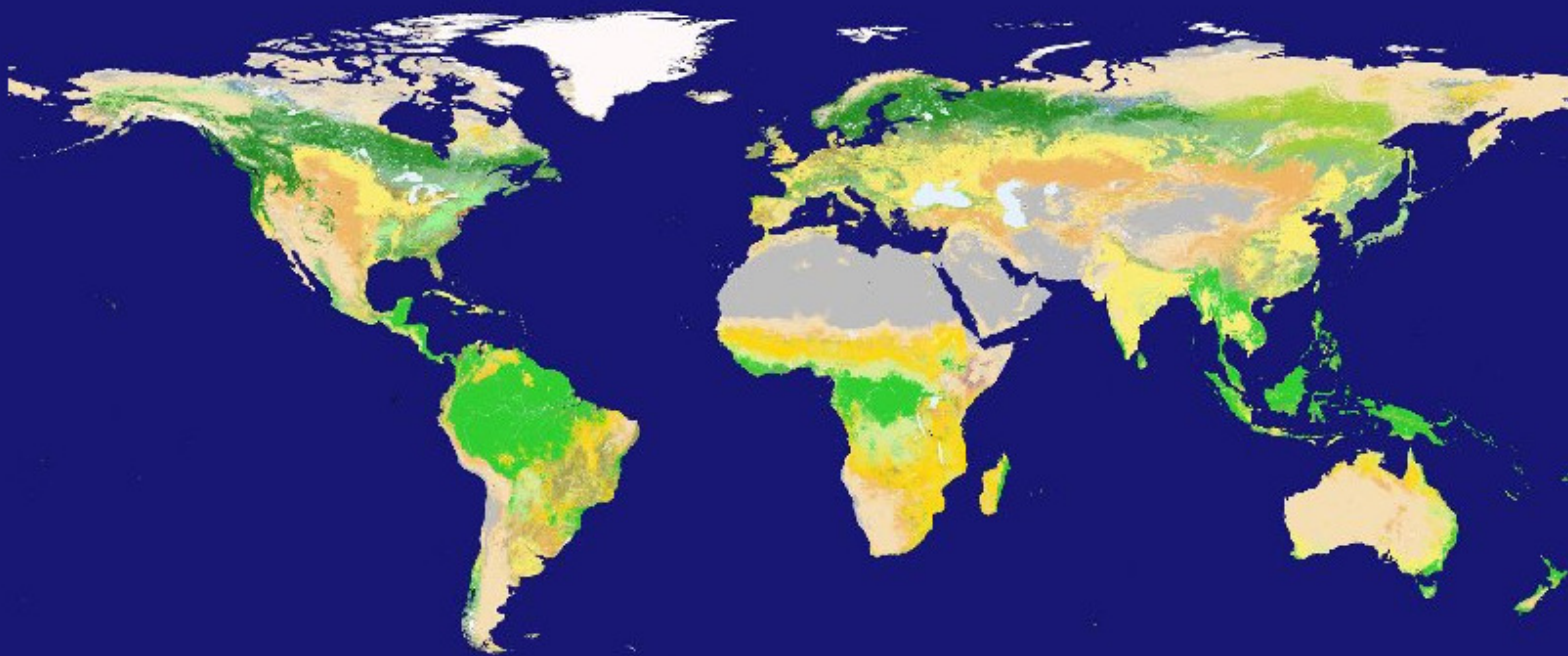




PANCROMATM

Satellite Image Processing
Making Satellite Images BetterTM



Instruction Manual

www.PANCROMA.com

John Childs
jchilds@terrainmap.com

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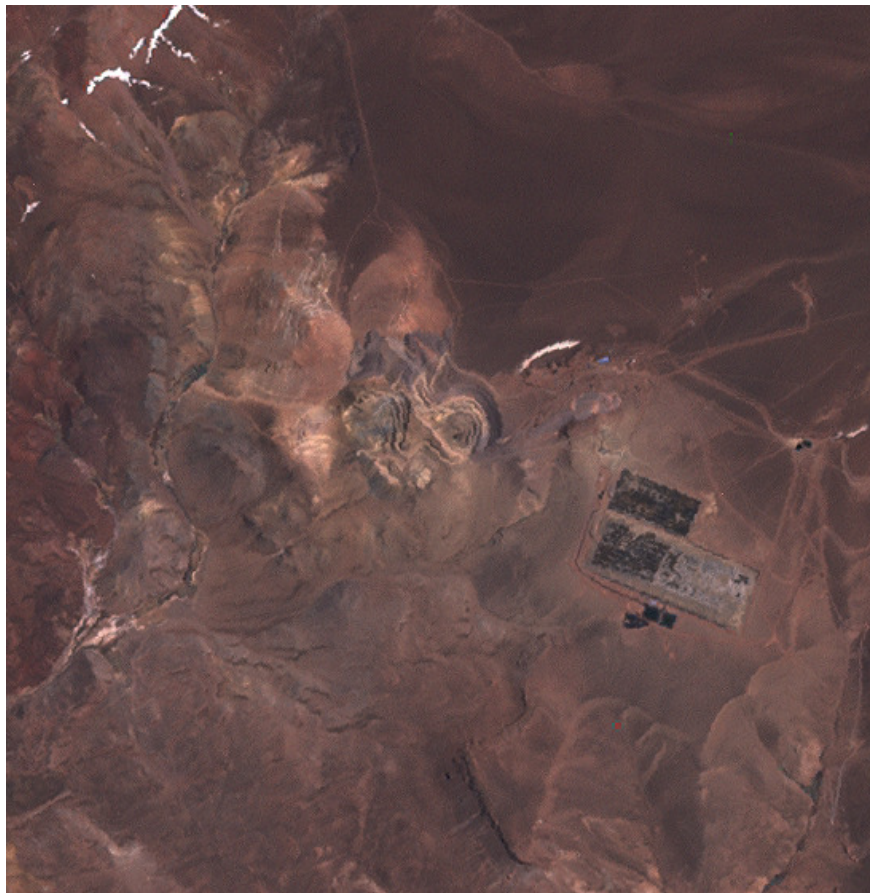
Version 101

Cover Land Use Image Credit NASA

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1. What Is PANCROMA™?

PANCROMA™ is a powerful software application for improving images and extracting information from Landsat, SPOT®, Digital Globe®, GeoEye®, Formosat®, IKONOS®, EO-1 ALI and ASTER satellite multispectral bands. For example it can create color RGB images and color pan sharpened images from such data. The program can pan sharpen any file set where the panchromatic band has 2X, 3X, 4X or 6X the resolution of the multispectral bands and that is in a file format that **PANCROMA™** can read. The program is designed to complement archives such as the free USGS GLOVIS and Earth Explorer Landsat databases and the free Canadian GeoBase archive of SPOT® data. Free Landsat data is available from other sources as well, and **PANCROMA™** can handle most of the formats that you will encounter. **PANCROMA™** is also recognized for its powerful Landsat gap filling capabilities, multispectral analysis and image deconvolution.



Detail from 15m Pan Sharpened Landsat Image – Chilean Copper Mine

2. What Useful Things Can PANCROMA™ Do?

PANCROMA™ uses a technique called *pan sharpening* to produce a high-resolution color image from three or four low-resolution multispectral bands plus a high-resolution panchromatic band:

Low Res Color Bands + High Res Grayscale Band = Hi Res Color Image

Such band combinations are commonly bundled in satellite data sets, for example Landsat, SPOT®, GeoEye® and Digital Globe® commercial packages as well. Pan sharpening transforms the high-resolution grayscale band into a high-resolution color image, doubling or quadrupling the resolution of the color information in the data set.

Pan sharpening techniques can result in spectral distortions when pan sharpening Landsat images as a result of the nature of the panchromatic band. That is, the raw pan sharpened color image may not exactly match the color tones of the corresponding low resolution RGB image. **PANCROMA™** provides proprietary algorithms and utilities to reduce this spectral distortion and to produce visually pleasing images.

In addition, **PANCROMA™** fills gaps in post-2003 Landsat 7 data. That is, it allows SLC-Off Landsat band files with 22% missing data to be recovered by filling the missing gaps with either corresponding pre-2003 legacy band data or post-2003 data (where the gaps are offset). The program also produces synthetic natural color composites from SPOT® and ASTER band files and can produce pan sharpened SPOT®, and WorldView® images.

PANCROMA™ also offers a variety of unique multispectral image analysis tools, including the Point Spectrum Generator™ for generating spectra from multispectral data sets, and the Spectral Analyzer™, for interrogating data sets to match input spectra.

PANCROMA™ can remove blur from satellite images caused by camera vibration, atmospheric turbulence, and other factors using FFT-based deconvolution algorithms.

PANCROMA™ also offers a variety of image preprocessing and post processing utilities to help you create high quality images from satellite data. These include haze reduction, vegetation indices, and much more.

3. Why PANCROMA™?

- For most of the world, Landsat is the only unrestricted license, no-cost, full-coverage satellite imagery available¹. **PANCROMA™** increases the value of this data by doubling the resolution of Landsat color imagery, calibrating and deblurring. (**PANCROMA™** can pan sharpen images from other satellite platforms as well).
- Landsat data is multispectral. Landsat provides the only widely available free source of valuable multispectral data for land use, mineral prospecting, and other applications. **PANCROMA™** image processing utilities increase the usefulness of this data.
- All of the Landsat data collected after 2003 contains missing data in the form of unsightly stripes across the images. **PANCROMA™** can recover these images and synthesize useful images from this data.
- **PANCROMA™** can also pan sharpen and process data from other popular sources, for example EO-1, SPOT, Digital Globe, ASTER and GeoEye.
- **PANCROMA™** offers a selection of valuable utilities for pre and post processing satellite images.

¹Note: Google and Microsoft provide satellite data coverage for most of the world. However, use of this data is restricted subject to the terms and conditions of the provider. Google for example allows free use of their imagery as long as the data is continuously available via Internet access and as long as no access fee is charged. Google uses image watermarks to help enforce their ownership rights. Landsat data on the other hand is copyright-free.



4. PANCROMA™ Features

- Input and output image files in JPEG, BMP, PNG, GeoTiff and Landsat L1G (raw binary) format.
- Display individual grayscale band files at full resolution
- Create 30m resolution true-color RGB images from Landsat multispectral band files 3, 2 and 1.
- Create 20m false color images from SPOT and ASTER multispectral bands.
- Create SPOT® and ASTER true color images from bands 3, 2 and 1 using a synthetic band recombination utility.
- Create 30m resolution false-color images from any combination of Landsat band files
- Create 15m resolution pan sharpened images from Landsat ETM+ multispectral band files and panchromatic band data using HSI, XIONG, AJISANE or Brovey Transform methods.
- Subset one, three, four or six file data sets.
- Automatically subset to the maximum overlap area (Maximum Common Extents) between two Landsat data sets.
- Create 10m resolution SPOT pan sharpened images.
- Create 10m resolution EO-1 pan sharpened images.
- Pan sharpen Landsat images using 10m SPOT or EO-1 panchromatic bands.
- Interpolate using Nearest-Neighbor, Laplacian or Iterative methods. (Iterative is also available as a stand-alone utility.)
- Create up to 0.5m pan sharpened images from Digital Globe WorldView or QuickBird bundles. **PANCROMA™** can read both the 8-bit and 11-bit Digital Globe files or bundles.
- Correct WorldView2 band files to top-of-atmosphere spectral radiance.
- Preprocess images using an extensive set of custom image processing tools and utilities.
- Post process images using an extensive set of image processing tools.
- Automatically subset satellite image file sets to a matched, co-registered set of band and panchromatic files for subsequent pan sharpening.
- Resize groups of three, four or five band files to a matched, co-registered set of band and panchromatic files
- Resample large Landsat files to lower resolution
- Batch process RGB files
- Batch process pan sharpened files
- Gap fill ETM+ SLC-Off images using Transfer, Hayes and TERAS methods in two-file or six file batch mode
- Automatically co-register two sets of three Landsat band files.
- Batch process by Hayes method two sets of three Landsat band files
- General image registration using linear transform

- Automatically histogram adjust for better pan chromatic color tones
- Correct image artifacts produced by histogram matching
- Correct for blue spectral distortion in pan sharpened images using the EHNG and XIONG algorithms, either manually or automatically
- Pan sharpen using the AJISANE algorithm
- Pan sharpen using SPECTRAL algorithm
- Pan sharpen using ELIN Local Optimization algorithm
- Decompose SPOT and ASTER RGB composites into their corresponding band files.
- Decompose RapidEye data
- Spectrally transform Landsat GEOCOVER 732 images to natural RGB
- Create color and grayscale anaglyphs from stereo views
- Create Landsat cloud masks
- Dark Image haze reduction utility
- HOT haze reduction utility
- Register arbitrary images
- Create image tiles
- Compute Landsat SPOT and ASTER Top of Atmosphere Reflectances and Radiances
- Compute Surface Temperatures from Landsat TIR band
- Spectral Analyzer™ for Landsat, SPOT, ASTER and EO-1 ALI/Hyperion and WorldView2 data (8-bit or 16-bit format)
- Point Spectrum Generator™ for Landsat, SPOT, ASTER and EO-1 ALI/Hyperion and WorldView 2 data (8-bit or 16-bit format)
- Multispectral Unsupervised Classification
- Euclidean Distance Analysis
- Distance Fraction™ analysis for precise land use coverage estimates
- Spectral Angle analysis
- Landsat Spectral Unmixing
- Landsat Change Detection
- Object Oriented Classification
- Compute vegetation indices
- Compute Tasseled Cap Transformation
- Display X-Y Scatter Plots
- Compute Multiple Linear Band Regressions
- Correct WorldWind IEEE FP32 DEM TIFF data
- Georeferencing
- Display an online Help file
- Automatically import spectral data from USGS ASCII files
- Compute FFT of an image and display image spectrum
- Compute FFT Image Deconvolutions
- Export Reflectance and Radiance Data in Landsat USGS I16 Format

More details on these and other capabilities are given in the subsequent sections of this manual.

5. System Requirements

PANCROMA™ runs on all popular  Windows® operating systems, including Windows 8, Windows 7, Windows Vista, Windows XP and Windows NT.

Landsat and SPOT data files are very large. Each of the three Landsat band files needed for pan-sharpening is about 60MB in size. The panchromatic file is even larger: about 250MB. Several temporary files of similar size are required to perform the necessary transformations. As a result, pan-sharpening software uses a lot of computer resources and a more powerful computer will perform the computations faster than an older and slower machine. Computer requirements are as follows.

Minimum system requirements¹:

- 1.6 GHz Pentium Processor
- 256MB SDRAM
- 32MB Graphics Card
- Windows XP/NT Operating System

Recommended system configuration²:

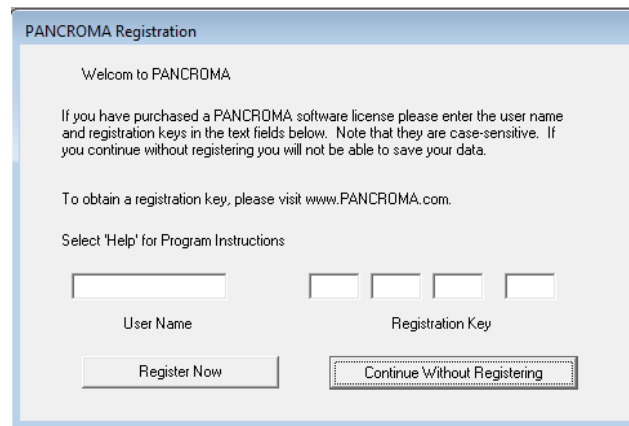
- 2.66 GHz Intel Core™ Quad CPU
- 4.0GB SDRAM
- 512MB Graphics Card
- Windows Vista or higher Operating System

¹ Note: this configuration can run the program but will produce long wait times during processing. Certain other features may be limited.

² Note: this configuration will allow the full range of **PANCROMA™** subsetting and pan-sharpening and batch-processing capabilities at reasonably fast speeds.

6. Installation

Installation of the program is accomplished by downloading the program from www.PANCROMA.com and then running the installation file. The file can be obtained by clicking on the 'Downloads' menu selection. A trial version is available that is identical to the production version except that the save utilities have been disabled. When you successfully download and install the file and run it for the first time you will be presented with a software registration screen.



The screenshot shows a window titled "PANCROMA Registration". Inside, it says "Welcom to PANCROMA" (note the typo). Below that, a paragraph explains that users with a license should enter their username and registration key, noting that they are case-sensitive and that saving data is disabled without registration. It also provides the website www.PANCROMA.com for obtaining a key and a link to 'Help' for instructions. There are two input fields: one for the "User Name" and another for the "Registration Key" (which is divided into four small boxes). At the bottom, there are two buttons: "Register Now" and "Continue Without Registering".

You may purchase the program or use it in trial mode by selecting 'Continue Without Registering'. All program features will be fully operational and you will be able to process full-size Landsat files. However the 'Save' features will be disabled.

In order to activate the 'Save' features, enter the user name and Registration Key in the text fields provided. This information will be emailed to you when you purchase the program.

Keep the registration key in a safe place. If you lose it, you may obtain it by contacting us through www.PANCROMA.com.

Upgrading is simple: the latest PANCROMA version is always posted on the 'Downloads' page of the website. Download the new version and install. You will not have to re-enter your registration information. The new version will not install over the old one so you may keep both if you wish or uninstall the old version after making sure the new one works OK.

7. Getting Started

PANCROMA™ The recommended progression for learning to use the program is as follows:

1. Understand the satellite data sets that you will be working with by reading the introductory section of this manual.
2. Download Landsat bands 1, 2, 3 and the panchromatic band from one of the free archives listed in the **PANCROMA™** Help menu.
3. Load and display a single grayscale band image.
4. Load bands 1, 2 and 3 and display them as a color RGB image.
5. Subset the band file set into a small matched set of band and panchromatic subset files using the four file subset utility provided by **PANCROMA™**.
6. Pan sharpen the subsetted images.
7. Pan sharpen a full Landsat scene.
8. Read the Manual and use other **PANCROMA™** image processing features.

Scan the relevant section of the manual and refer to the appropriate tutorials when trying out a new capability for the first time. When reading a section, look ahead to the next section as often both a manual and automatic method are available for a utility. The description for the manual method is generally given first and you can save yourself some time if you do not want to make custom adjustments or are not interested in what is going on “under the hood”. The instructional videos posted at www.PANCROMA.com/videos should also be helpful in understanding the necessary steps. **PANCROMA™** has many other useful utilities but these exercises will cover the core capabilities of the program.

IMPORTANT NOTE: **PANCROMA™** will issue information on the band file input types that it expects in the form of message boxes. If you wish to turn these messages off, select ‘System’ | ‘File Size Messages’ | ‘Off’ from the main menu.

IMPORTANT NOTE: Certain menu selections will initially be disabled. They will become enabled as you open input files and process them. For example if you open a single band file, then all the menu selections appropriate to processing a single file will become enabled, and all those that require two or more input bands will be disabled. When you open a second band file, the menu selections appropriate for processing a single file will become disabled and those that require two input files will become enabled, etc. When you are done processing a data set, select ‘Close Graphics Windows and Reset’ to start over again processing a new data set.

8. Landsat 7 Data Sets

The primary purpose of the Landsat earth survey satellites is to provide scientists with data to assess the earth's vegetation, crop and mineral resources. It was not necessarily intended to produce true color images of the earth's surface. However, Landsat bands 3, 2, and 1 are close to the red, green and blue (respectively) wavelengths that the human eye is sensitive too. These bands can be inserted into an RGB color model and will produce images that are very satisfactory for visualization. Of course **PANCROMA™** can also combine other sets of Landsat bands in order to produce false-color images for scientific purposes. For example, bands 4, 3, 2 are commonly used to highlight vegetation. Many other combinations of bands are used for different purposes. A good reference describing Landsat band characteristics can be found at <http://web.pdx.edu/~emch/ip1/bandcombinations.html>.

The Landsat 7 platform is the Enhanced Thematic Mapper (plus) (ETM+). The specifications for its sensors are given below. (The bands highlighted in blue are the most useful for producing natural color images.)

Band	Wavelength (μ)	Resolution (m)
1	0.450-0.515 (blue)	30
2	0.525-0.605 (green)	30
3	0.630-0.690 (red)	30
4	0.750-0.900 (near-IR)	30
5	1.55-1.75 (mid-IR)	30
6	10.4-12.5 (thermal-IR)	60
7	2.08-2.35 (long-IR)	30
Panchromatic	0.52-0.90 (green-near IR)	15

Among other improvements, ETM+ included for the first time a 15m resolution panchromatic band. Rather than detecting radiation in a narrow range of frequencies, a *panchromatic* sensor collects radiated energy across a broader spectrum. In the case of Landsat, this spans the green, red and near infrared (NIR) frequencies. And it does so at increased resolution compared to previous sensors, i.e. 15m/pixel as opposed to the 30m/pixel resolution of the band sensors.

The panchromatic data is recorded in a single channel. So despite having greatly increased resolution compared to bands 1-7, the panchromatic band can still only be displayed as a black and white image. The useful visible RGB color data is stored separately in channels 3, 2, and 1, but of course at the lower (30m) resolution.

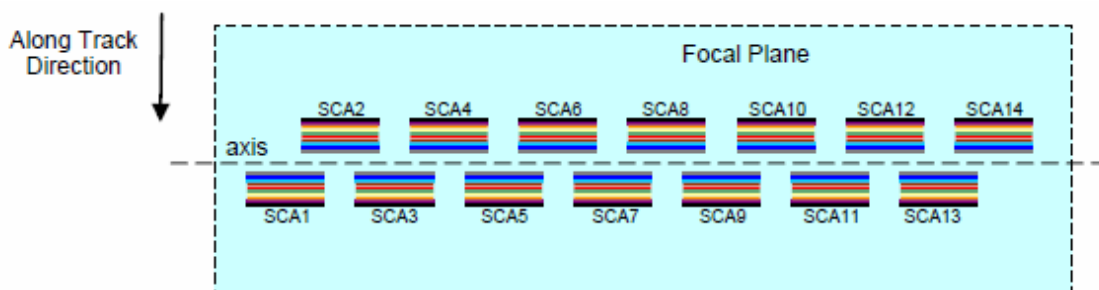
Each color and NIR band channel contains only 25% of the pixels and visual information as compared to the panchromatic channel. If there were a way to combine the color information in these channels with the higher resolution image information in the panchromatic channel then it would be possible to produce color images at the higher (15m) resolution. There is a way, and it is what the **PANCROMA™** algorithms do: produce a color 15m resolution RGB image by combining RGB color information in ETM+ bands 1, 2, 3 and image information in the panchromatic channel using appropriate image fusion techniques. The result is a 15m color image with colors that can closely approach those of the lower resolution images produced by combining the band data. Because Landsat covers virtually the entire earth, you can produce such images for any area that interests you. And unlike image data extracted from sources such as Google Earth™, Landsat is copyright free.

9. Landsat 8 Data Sets

Landsat 8 was successfully launched on February 11, 2013 from Vandenberg Air Force Base in California. It initially achieved stable orbit with its sensors turned off. It was gradually maneuvered into its final orbit with its sensors completely powered up in May, 2013.

There are many similarities between Landsat 8 and its predecessor, Landsat 7 and significant differences as well. The biggest difference is that Landsat 8 works. Landsat 7 has a so-called whiskbroom sensor, meaning that it has a mechanical scanning mirror that sweeps from one side of the forward path to the other, successively directing points along the swept path to the sensor. As owners of computer hard drives know, mechanical elements of electronic systems are always the weak link and are prone to early failure. That is what happened to the scanning mirror (actually the scanning mirror corrector called the SLC) in 2003. Since that time Landsat images have black stripes of missing data that must be patched in order to create useful images.

Landsat 8 in contrast has what is sometimes called a push broom sensor. It consists of an array of sensors called a Sensor Chip Assembly (SCA) that each collect data for part of the swath. As a result there are no mechanical parts and this sensor should be much more reliable. The main Landsat 8 SCA is shown schematically below.



The most obvious specification difference to the user between Landsat 8 and Landsat 7 is the dynamic range of the digital number (DN) output from the sensors. Landsat 7 has 8 bits of dynamic range while Landsat 8 has 12. This does not mean that Landsat 8 is more accurate than Landsat 7, or that it can report back a larger number (since any number can be scaled infinitely large). It means that the numbers it returns are known more precisely. Landsat 7 can report 256 discrete levels of sensed electromagnetic radiation ($2^8=256$) while Landsat 8 can report $2^{12}=4096$ levels. Essentially, Landsat 7 measures things with a ruler that has 256 gradients on it while Landsat 8 measures things with 4096 gradients on its ruler. This can theoretically be very useful when trying to

determine if one number is different from another, in multispectral signature matching for example. The signal to noise ratio is expected to be much better for Landsat 8 as well.

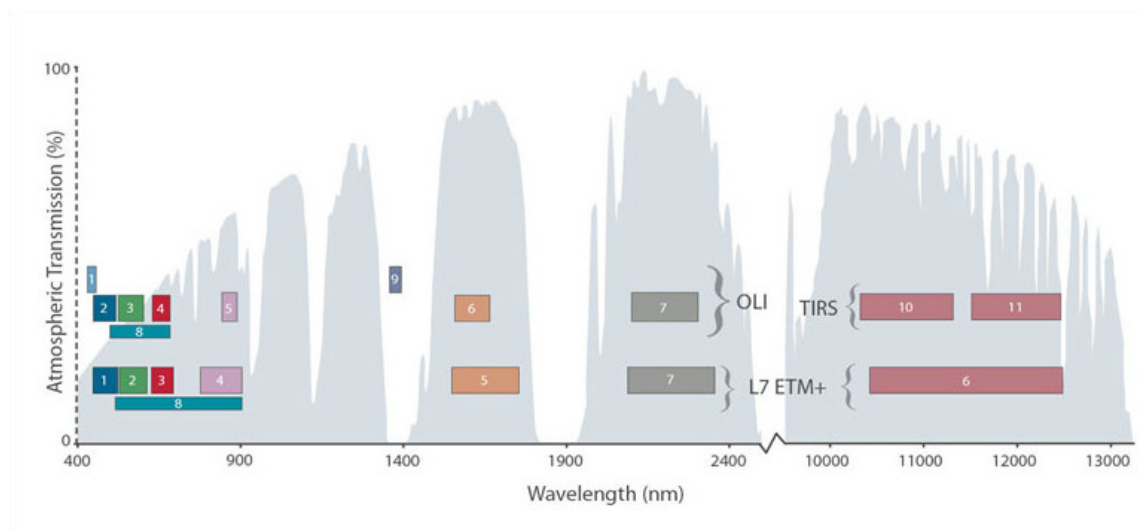
This increased resolving power comes with a price. Landsat 8 scenes are considerably larger than Landsat 7 scenes. Landsat 8 scenes on the other hand will be in the neighborhood of 1.5GB (unzipped), more than twice as large as Landsat 7 scenes.

Another reason for the large difference in size between Landsat 8 and Landsat 7 scenes is the number of spectral bands. Landsat 7 has 8 or 9, depending on whether the scene contains one or two versions of the thermal infrared (TIR) band (high gain/low gain). Landsat 8 has two additional multispectral bands, two narrower TIR bands in place of the single Landsat 7 TIR band and a panchromatic band for a total of 11 bands. The two additional bands are a narrow Coastal Aerosol band at a slightly shorter wavelength than the blue band and a Cirrus band sensitive to radiation wavelengths between 1.36 and 1.38 microns.

Another difference between Landsat 8 and its predecessor is the character of the panchromatic band. The Landsat 7 panchromatic band is sensitive to electromagnetic radiation between wavelengths 0.52 to 0.90 microns. This range excludes visible blue but includes the NIR band. It was probably chosen in order to produce a clearer image, since the blue band is most susceptible to Rayleigh scattering than any other. The result however is severe color distortion when the band was used for pan sharpening. It takes a lot of computational effort to correct this and few do it very well. (The PANCROMA™ ELIN algorithm is one of the best for removing such distortions).

The Landsat 8 panchromatic band covers a range of 0.50 to 0.68 microns. This still excludes the blue band but also excludes the NIR band, spanning the visible green and red bands. As a result we can still expect color distortions resulting from pan sharpening, but perhaps not quite so severe as Landsat 7. The band specifications are shown in the table and graphic below.

Finally, the passbands for Landsat 8 bands 5, 6 and 7 are narrower (more discriminating) than the corresponding Landsat 7 bands. This will benefit spectral signature matching and other target discrimination techniques.



Landsat Data Continuity Mission (LDCM) Launch February 11, 2013	Bands	Wavelength (micrometers)	Resolution (meters)
	Band 1 - Coastal aerosol	0.43 - 0.45	30
	Band 2 - Blue	0.45 - 0.51	30
	Band 3 - Green	0.53 - 0.59	30
	Band 4 - Red	0.64 - 0.67	30
	Band 5 - Near Infrared (NIR)	0.85 - 0.88	30
	Band 6 - SWIR 1	1.57 - 1.65	30
	Band 7 - SWIR 2	2.11 - 2.29	30
	Band 8 - Panchromatic	0.50 - 0.68	15
	Band 9 - Cirrus	1.36 - 1.38	30
	Band 10 - Thermal Infrared (TIRS) 1	10.60 - 11.19	100
	Band 11 - Thermal Infrared (TIRS) 2	11.50 - 12.51	100

10. Downloading Data

The recommended first step in creating images is to get some Landsat data. Free Landsat data is available from several sites. Look at <http://www.pancroma.com/data.html> for a complete listing of free sources. One good source is the USGS Glovis website at <http://glovis.usgs.gov/>. This website will permit you to download, free of charge, the necessary Landsat 7 or Landsat 8 bands to create useful medium resolution color images. Such data is available from other sources as well, for example the University of Maryland GLCF site at <http://glcf.umd.edu/>.

Unlike photographic data, satellite data is temporarily recorded digitally at the satellite. As the satellite orbits the earth in a generally north-south direction, its sensors sweep an east-west path. This, combined with the rotation of the earth allows the satellite to record north-south strips of the earth's surface. These strips are segmented into rectangular sections and stored (after relaying to earth base stations using a data downlink) as files of raster information. Once the raw data is recorded at the earth station, it is processed and formatted into an appropriate file structure and metadata is associated with the file sets.

Because the earth's surface is large, a lot of data is recorded. As a result, Landsat files are large. Landsat data files are the largest that most people will ever encounter in any context. ETM+ band files are approximately 60MB each, and you will need three of them. The ETM+ panchromatic (PAN) file is around 250MB. Fortunately you only need one of these at a time. The size of these files introduces challenges for the user and even greater challenges for the programmer, challenges that will become apparent as you begin to work with these files.

The first step in acquiring your own Landsat data files is to navigate one of the free data archives such as GLOVIS, Earth Explorer or one of several others. There is a video explaining how to use the GLOVIS site at the PANCROMA Video web page at <http://www.pancroma.com/videos.html>. The following instructions are for the Landsat 7 GLCF site.

The GLCF user interface, like most of those that you will encounter on satellite data download sites can take a bit of effort to master. One possible method is as follows: Right click on the area of interest on the map display. Repeat the clicks until you zoom in to the maximum magnification. Now select ETM+ by checking the box to the left of the screen. Then click on the Select Arrow icon (The arrow with the +). Next click on a point at the area of interest on the map. A new image will form surrounded by a yellow border. The number of images in the display

will be shown at the bottom of the map display. To view the area selected click on a magnification block closer to the negative side to zoom out.

You may see a message that there are more than 600 images in the selection or else that there are no images in the selection, even though the screen may show only a few images. This can usually be remedied by repeatedly clicking on the rubber band or arrow icon, which will keep redrawing the image. Eventually, you will see a notification that informs you that there are something like 44 images in the selection.

Once your images are available, you can select the 'Preview and Download' icon. This will display a page with a list of Landsat data files. Under the 'Type' column you will see the file type indicated, either GeoTiff or L1G. Either format is OK. Clicking on the 'ID' heading will select the file and display a thumbnail image of the area of coverage. When you find the image you want, click on the 'Download' button.

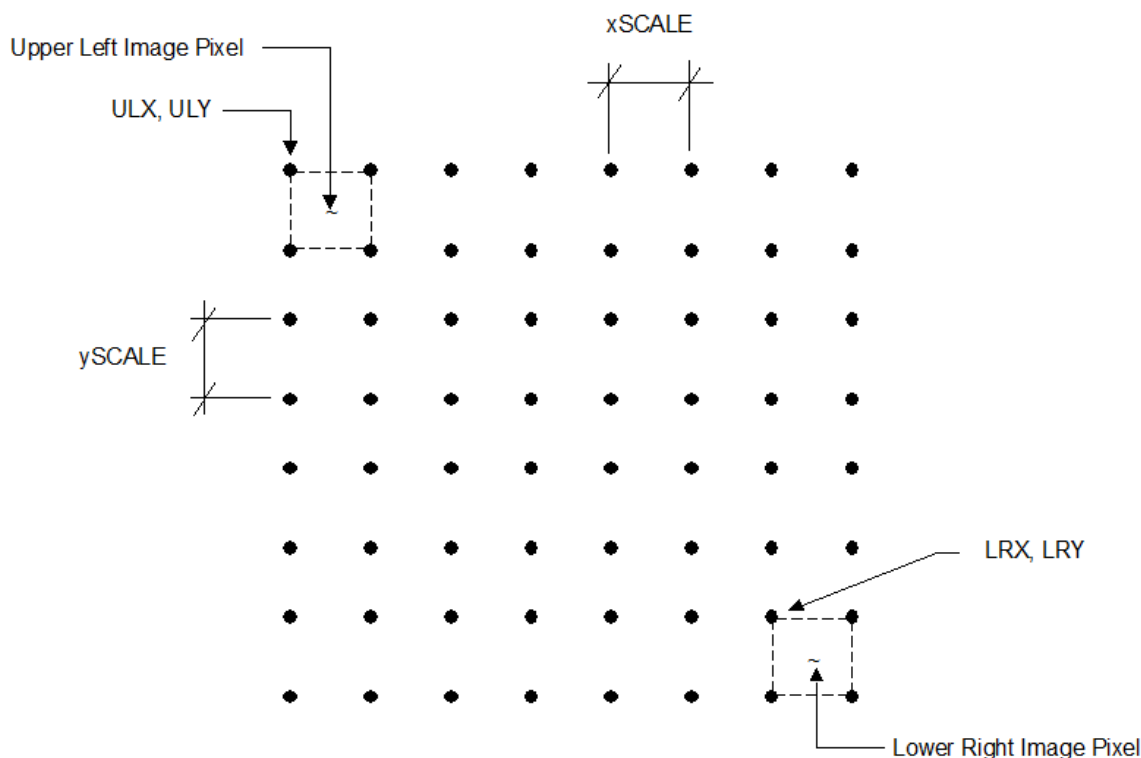
A page containing a listing of the band, image and metadata files will then be presented. The file name will look something like 'p174r084_7t20010711_z34_nn10.tif.gz'. You will need to download the files that contain the ...nn10...; ...nn20...; ...nn30...; and ...nn80... (for GeoTiff) or ...'_B10...'; ...'_B20...' ...'_B30...' and ...'_B80...' (for L1G) suffixes. (Landsat files are usually archived in either GeoTiff or L1G (which is actually a flat binary format. **PANCROMA**TM can read both.) These are the band1, band2, band3 and panchromatic bands, respectively.

The files are zipped to save storage space. If you are downloading an L1G file, you will also need the metadata file. (Because the format is flat binary, the format has no ability to contain any metadata. This is stored in a separate ASCII file). The file has the suffix '.mht'. You will need this file as **PANCROMA**TM extracts important metadata from it during processing. It contains lots of additional useful information about your dataset that you can inspect in any word processor or text editor.

You should download these files into any convenient directory on your computer. After downloading the files, extract the band data using an unzipping utility like 'Winzip' or the free GNU utility called 'jZip' available at <http://www.jzip.com/>.

11. Coordinate Display

PANCROMA™ will read metadata from the GeoTiff tags or L1G (flat binary) metadata file (if provided). The program will echo the upper left X (ULX longitude) and upper left Y (ULY latitude) UTM coordinates to the screen exactly as reported by the metadata. **PANCROMA™** will report the latitude and longitude to the main window coordinate boxes, and use these coordinates for subsetting and other purposes. The convention used to report to the screen is the GeoTiff PixelsPoint, meaning that the pixel coordinate location in 2D space is equal to the upper left corner of the pixel. The program will compute the lower right (and indeed all other) coordinates based on this assumption, using the xScale and yScale values from the metadata file. As a result, the computed lower right coordinate corresponds to the upper left corner of the last pixel in the image. This convention is shown in the diagram below.



PANCROMA™ will preserve metadata throughout the image processing sequence.

12. File I/O

PANCROMA™ can input and output files in several formats. The most common input formats are TIFF (GeoTiff), and raw binary (.L1G suffix) format - most Landsat and SPOT image data is archived in these formats. ASTER data is often archived in compressed HDF format, which **PANCROMA™** will also read. **PANCROMA™** can also import data in JPEG, BMP and PNG format. Although these are not typical satellite data archival formats, it is often convenient to use these as output formats, particularly JPEG and PNG as they are compressed and therefore take up a lot less storage space. PANCROMA can also read DTED and write elevation index files and read/write and IEEE FP32 TIFF DEM data.

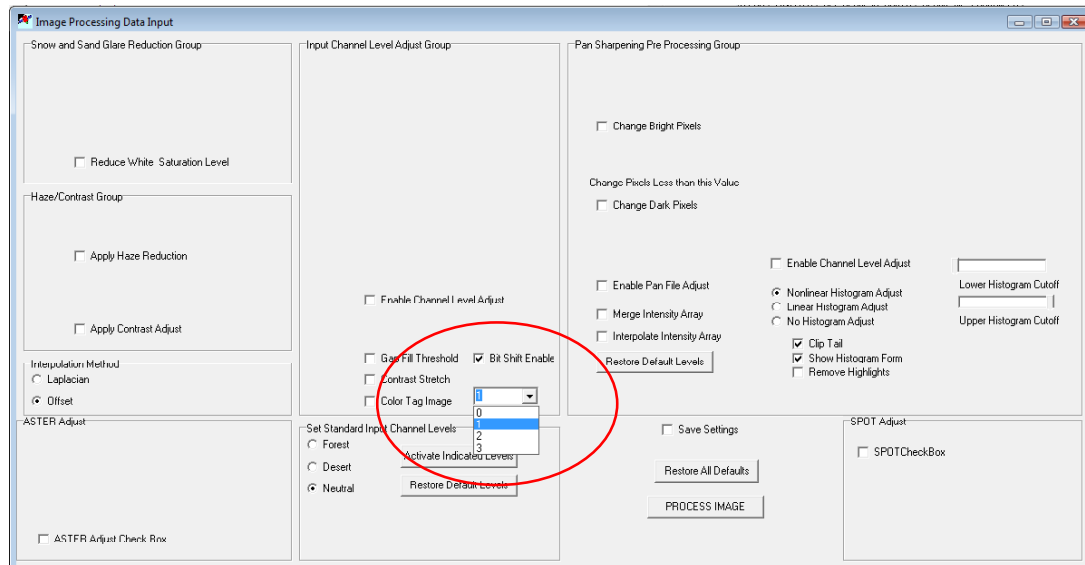
The GeoTiff reader has certain limitations. It cannot read compressed GeoTiff format at the present time. Compressed GeoTiff is indicated by a Compression code other than '1'. (PANCROMA reports the GeoTiff tag codes to the dialog screen as it opens data files.) The file reader will recognize WGS84, WGS 72, NAD 83 and NAD 27 geodetic datum codes only. Although the reader is generally robust, you may be able to cause a fault by discovering and illegal file condition that the programmer did not consider. Please file a bug report if you encounter such a condition.

Standard Landsat images contain 8 bits of grayscale information per raster pixel. The number of bits per pixel is called the image quantization or dynamic range. The analog incident light is digitized into $2^8=256$ levels per channel. **PANCROMA™** can also read Digital Globe WorldView®, Landsat Reflectance, GeoEye® EO-1 ALI and other data with greater dynamic range. This data is formally 16-bit format. Often the useful dynamic range is only 11 bits however. These grayscale and RGB images are archived as either TIFF PlanarConfiguration=1 or PlanarConfiguration=2 files.

All common computer grayscale and color display models are based on 8-bit quantization. The reason is that 8 bits are more than sufficient to produce visually pleasing grayscale or color images, and the human eye cannot discriminate finer color detail anyway. This means that **PANCROMA™** must convert or rationalize 11 or 16 bits into 8 bit quantization in order to usefully display it, using one of two methods. The default method scales the 11-bit integer by a ratio of 255 divided by the maximum pixel value. Some Digital Globe data files have a small percentage of pixels displaying the maximum pixel value of 2047 while the vast majority are clustered much closer to 255. The result can be a very dark image when scaling from the maximum value. **PANCROMA™** offers an alternative algorithm: it will read all 11 bits into a SHORT, shift right by 'shiftBits=1' bits, and truncates if greater than 255. If the result is too bright, you can successively bit shift by 0 (-1 from the default) 1

(default), 2 (default +1) or 3 (default +2). Shifting right (dividing the channel value by two) will darken the image while the opposite will occur with a left shift. This algorithm is enabled by checking the 'Bit Shift Enable' check box on the Image Processing Data Input screen. The bit shift combo box can also be found on the image processing input box in the Input Channel Adjust Group.

See the individual sections on Digital Globe, GeoEye, Landsat Reflectance and EO-1 ALI data for further information.



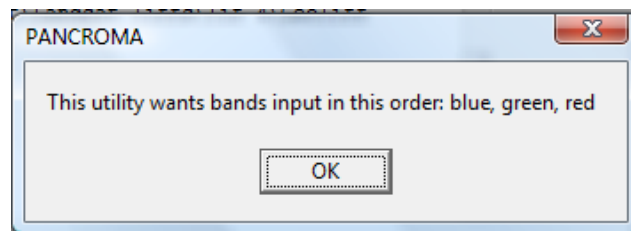
The GeoTiff writer capabilities pretty much mirror the reader. However its GeoKey output is limited to two values: GTModelTypeGeoKey and a projectedTypeCSGeoKey. The output has been successfully tested against some common GIS applications.

IMPORTANT NOTE: Operations that require you to process satellite data for other than display purposes (like multispectral analysis) will not convert the data to 8-bit format but will instead maintain the full dynamic range of the data. This preserves the full precision of the information during processing. At the end of the processing cycle, the result may be converted to 8-bit format for display purposes. Some utilities allow you to save the result in 16-bit format however.

13. System Variables

Information Messages

PANCROMA™ will normally provide system information messages designed to help the user understand what kind of input the selected utility is expecting. For example, when you select 'Band Combination' | 'Generate RGB True Color Composite' **PANCROMA™** generates an information message box informing you that it expects the band files input in the order blue, green and red.



Other utilities have their own message boxes that confirm the order of entry, file type, file number and file size details. If you do not wish to have these message boxes presented, you can turn them off by selecting 'System' | 'Information Messages' | 'Off' from the Main Menu screen.

File Size Verification

PANCROMA™ has several input file size and type sentinels. These are designed to prevent operating system access violations by over writing or over reading internal array boundaries. In general, **PANCROMA™** has three levels of file sentinels, plus a fourth menu enabling check. When there is more than one input file, the first level checks to see if all the input files are the same size. The second level checks that the file characteristics are correct, for example, that the file is uncompressed, the bits per sample is 8, the planar configuration is either 1 or 2, etc. The third level checks to make sure if the row and column counts all match up.

The fourth level is controlled by the menu enabling logic. **PANCROMA™** tries to present only those menu selections that are consistent with the characteristics of the opened files. If the files are not consistent, it can cause an untrapped error. These are usually caught by the operating system but at best they would cause **PANCROMA™** to crash by over writing an array or some similar misbehavior.

Cases may arise where multiple input files do not have the same byte count but are still legitimate input files. For example, if one GeoTiff band file is processed by an application other than **PANCROMA™**, it is possible that the application might write to the GeoTiff ASCII fields and causing one of the bands to be larger or smaller by a few bytes. PANCROMA provides a switch to turn the file size verification sentinel off. Select 'System' | 'File Verification' | 'Off' to disable it.

14. Display

Zoom Out

Satellite band images are large. Often it is convenient to zoom out in order to better inspect input band files. **PANCROMA™** allows you to zoom out and then back in to your color or grayscale input and processed images. In order to demonstrate with a grayscale image, open a file by selecting 'File' | 'Open'. Select 'Display Files' | 'Display One Grayscale Band Image'. When the file displays in the graphics window, the zoom menu selections are enabled. Select 'Display' | 'Zoom Out'. Your grayscale image will zoom to half its original size. Successively selecting the 'Zoom Out Grayscale' feature will increase the zoom factor by 2. In order to return to the original zoom factor, select 'Display' | 'Zoom In'. The Zoom Factor is displayed at the top of the Main Window when zooming is enabled.

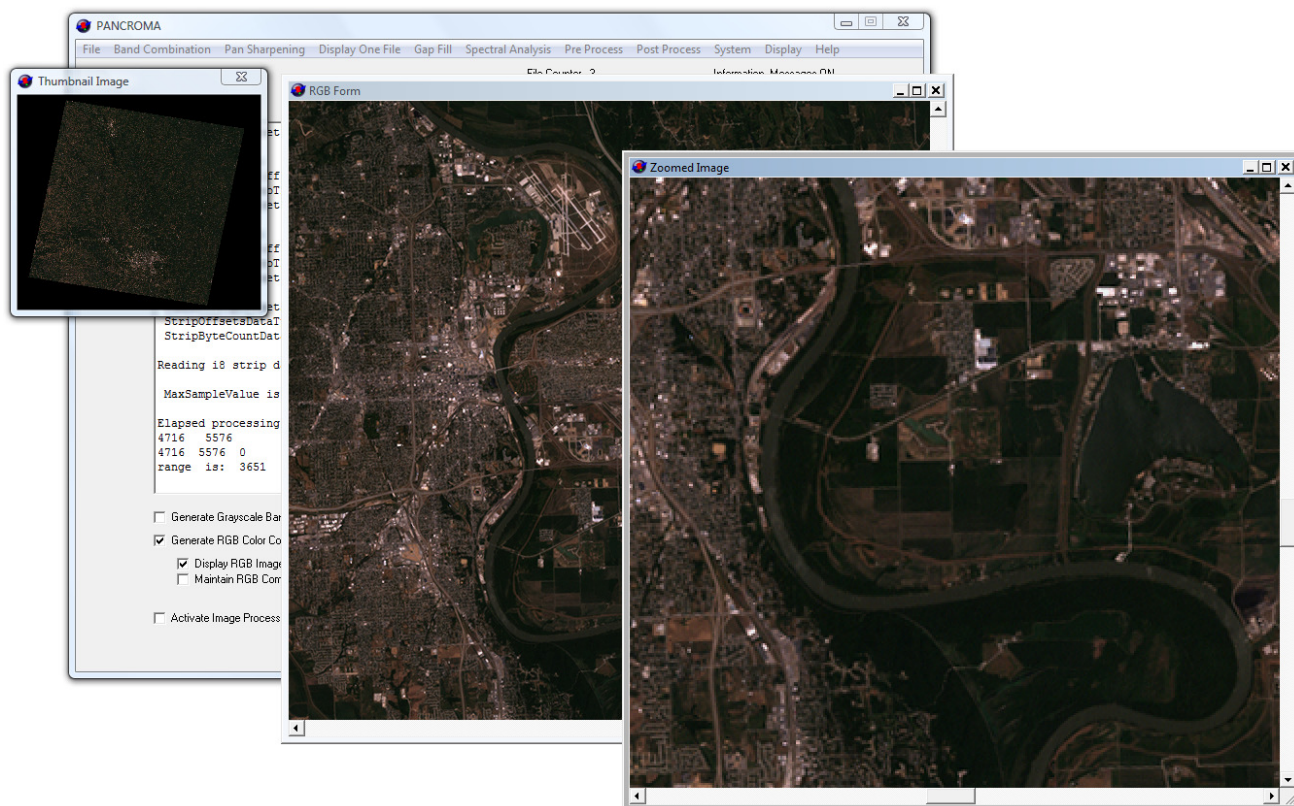
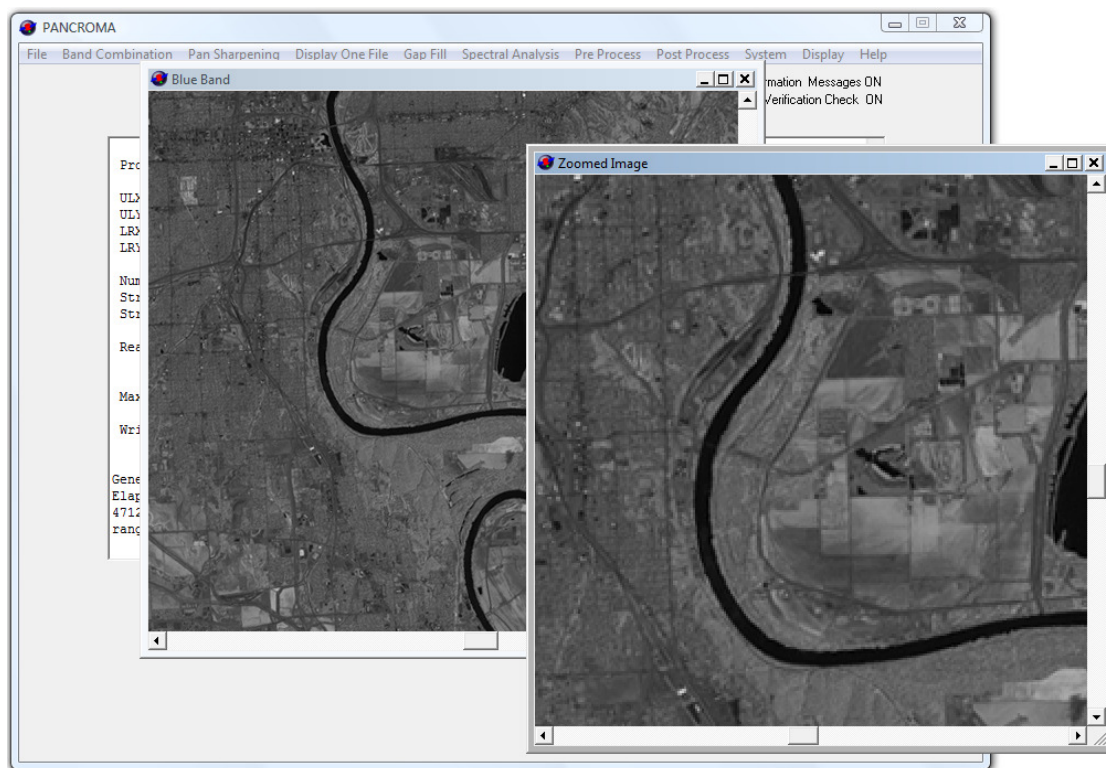
Note that if you save your image at other than full scale (Zoom Factor=0) **PANCROMA™** will zoom back to the original scale so that the image will match the metadata.

Note also that zooming is relatively fast, except for images that exceed 100 million pixels (like Landsat panchromatic bands for example). In order to avoid running out of memory resources, the initial zoom out or the last zoom in will take considerably longer as a result of the memory management technique used.

Zoom In

You can also zoom into a color or grayscale image. To demonstrate this with a grayscale image, create a grayscale image by opening a band file by selecting 'File' | 'Open' and 'Display Files' | 'Display One Grayscale Band Image'. When the file displays in the graphics window, select the zoom center by clicking on a pixel. When you select a pixel, the zoom menu selection will be enabled. (You can click on the image as many times as you want. The zoom center will refresh to the new location after each click. Now Select 'Display' | 'Zoom In'. A new graphics window with your zoomed image will appear with a zoom ratio of two. If you wish to zoom in further, click on the *new* (Zoomed) window and select 'Display' | 'Zoom In' again. The image will zoom in by a factor of four. Successive clicking and zooming will allow you to create as many zoom levels as desired.

Note that the coordinates of the zoom image map back to the source image. This is important for spectral analysis where selected individual pixels need to be identified and selected for processing. When you are done zooming, you can close the Zoom Window by clicking the 'X' in the upper right corner of the image.



Flip Image

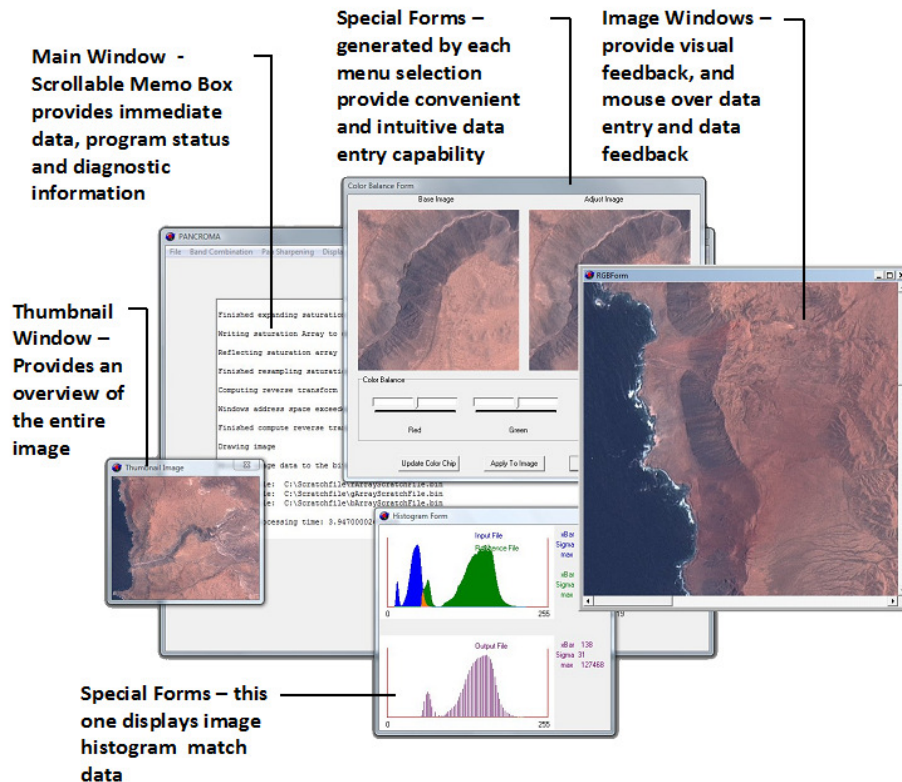
This utility mirror flips an image across the east-west center latitude line. The coordinate system is unchanged.

Rotate Image 180 Degrees

This utility rotates image 180 degrees. The coordinate system is unchanged.

15. The PANCROMA User Interface

The **PANCROMA™** user interface is shown below.



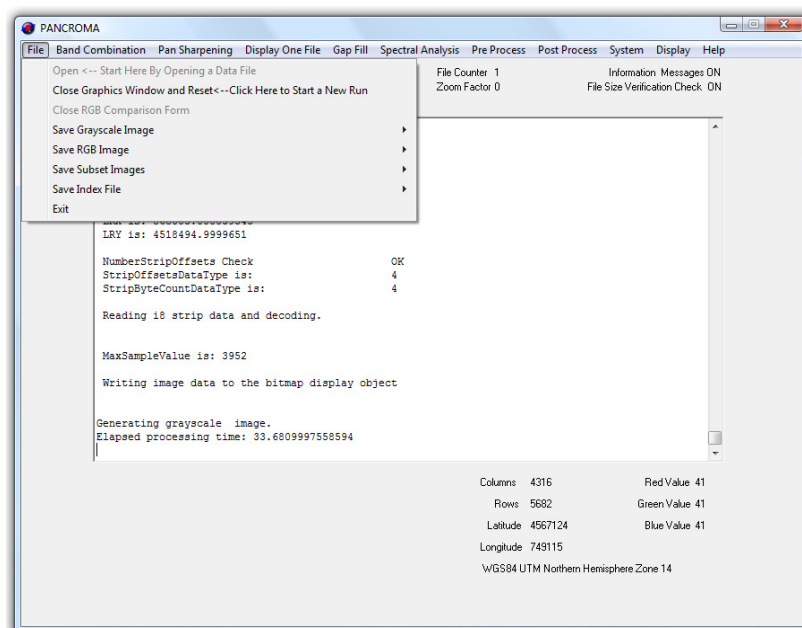
The principal components of the user interface are:

- Main Window – This will always be displayed as long as **PANCROMA™** is running.
- Menu Area – This is the menu location for the system.
- Data Area – System information is echoed to this screen. This information informs you of **PANCROMA™** state and progress executing the selected task. The information displayed here is also useful for diagnosing problems if you need customer support.
- System Information Area – Displays the status of certain system information that is selected by the 'System' menu bar selection.
- Image – One or more of these will be displayed during processing or at the end of processing.
- Image Information Area – Shows data for one or more images, for example coordinates and pixel grayscale or color channel levels.
- Data Entry Form – This is how user-supplied information is entered into the system. These will be displayed as needed during the course of processing after you make your menu selection.

16. Quick Start-Display a Single Grayscale Image

Once you have unzipped the data files, you are ready to begin processing. (Note: if you have done this correctly your files will have the suffix '.tif' or '.L1G'. Although **PANCROMA**TM can import .jpg and .bmp format, Landsat images are not normally archived in this format. You may find .jpg and .bmp useful for storing your **PANCROMA**TM processed file.)

The simplest **PANCROMA**TM task is to display and examine a single Landsat grayscale band file. It is a good idea to do this before trying more complicated image processing tasks just to make sure that you have acquired your data correctly and understand how to manipulate images in **PANCROMA**TM. This is done by selecting 'File' | 'Open' as shown in the image below and then opening any single GeoTiff ('.tif') or L1G file from the sets you downloaded (i.e. any ...10; ...20; or ...30 type file). (You can likewise open the panchromatic (...80) band. This file is larger and takes a bit longer to display.) The menu selection necessary to open a file is shown in the figure below.



IMPORTANT NOTE: if you are processing Landsat .L1G images, it is necessary to download the metadata file into the same directory as the band and panchromatic files. This is because the L1G flat binary format is not capable of including image metadata itself. The companion metadata file has the suffix '..._MTL.L1G.htm'. Note: the metadata file is available in different formats. Be sure to select the HTML version with the file suffix '.mht'. (If **PANCROMA**TM does

not find this file , you will be prompted to enter the row and column count data manually.) These values will always be labeled 'lines' and 'samples' and will look something like this in the metadata files:

```
PRODUCT_SAMPLES_PAN = 15781
PRODUCT_LINES_PAN = 13961
PRODUCT_SAMPLES_REF = 7891
PRODUCT_LINES_REF = 6981
```

IMPORTANT NOTE: Some browsers may add control characters when saving the .mht file. These characters may prevent **PANCROMA™** from successfully reading the metadata. It is usually safest to save the .mht file as a text file (.txt) and then rename it as an .mht file.

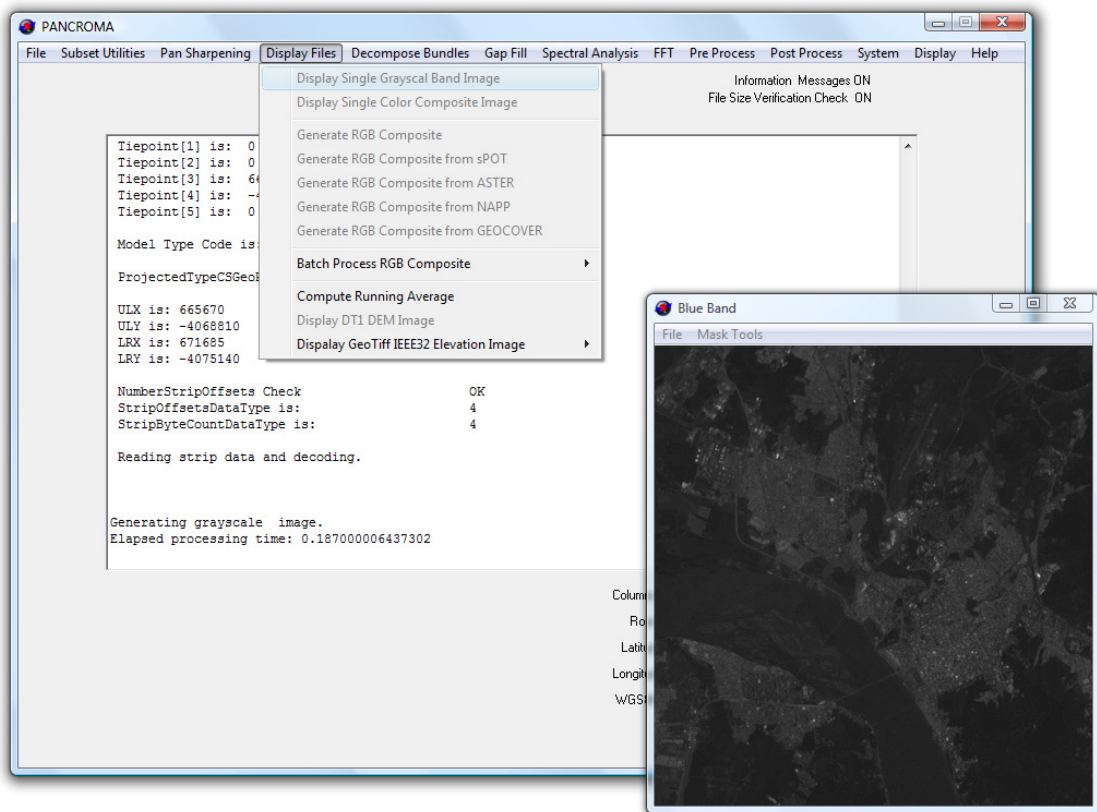
The exact number of SAMPLES and LINES will vary somewhat from one Landsat file to the next. The first two entries describe the PAN file and the latter two are for the band files. You will not care about this at all for GeoTiff format as the metadata is embedded in the GeoTiff band and PAN files.

Select 'Display Files' and then 'Display Single Grayscale Image'. The single grayscale image will be loaded and rendered in a separate window and will look something like the image below. These images are quite interesting and useful by themselves. Open the various band files successively and note the differences. Various features of the earth's surface record in the different sensor bands differently, for example water, vegetation, urban areas, and even surface mineral deposits. This is what makes Landsat data so useful for so many purposes. If you wish to save the grayscale image, select 'File' | 'Save' and then either .jpg .bmp, .tif or .png format. You can also display the grayscale panchromatic image in exactly the same fashion.

IMPORTANT NOTE: A common error after displaying a single grayscale image or any other image is to think that the process failed because only a black field is visible in the graphics viewing window. This is because Landsat images are somewhat rotated on a black background, and the viewing window defaults to the upper left corner. Make sure you scroll down and across using the slider bars before you conclude that the operation failed.

Once you are done with an operation such as displaying and/or saving an image, you can start again by selecting "Close Graphic Image and Reset" from the "File" menu.

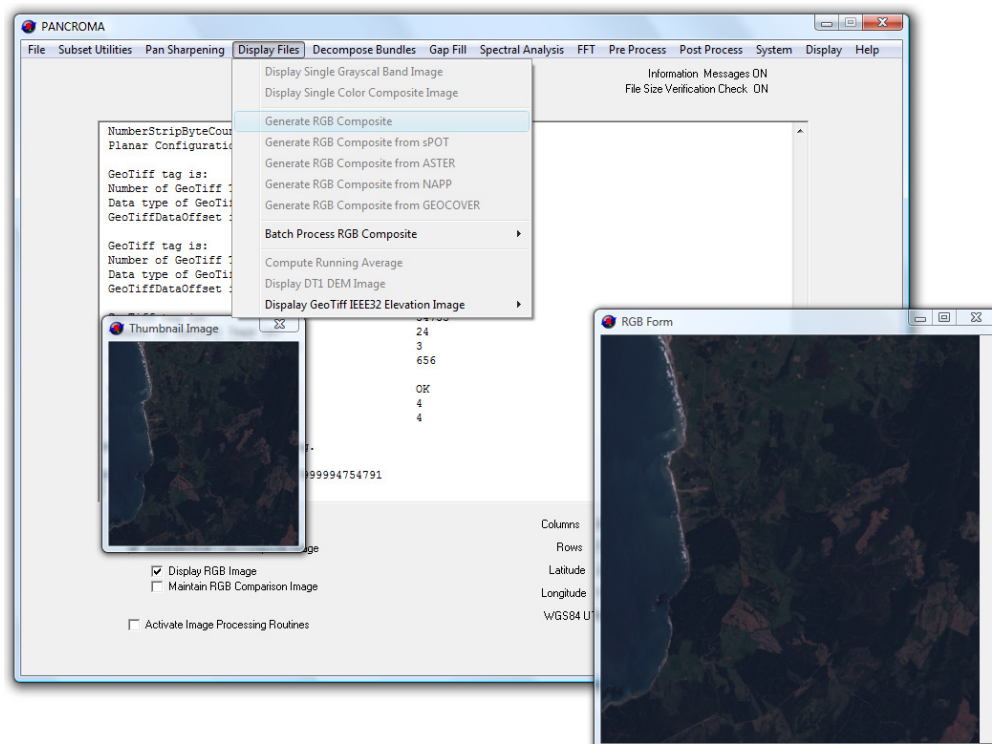
IMPORTANT NOTE: The "Close Graphic Image and Reset" menu selection must usually be selected when finishing one operation and starting another. This menu selection resets the program variables to their starting conditions, makes sure unused memory is freed and carries out other important functions.



17. Quick Start - RGB Color Image from Band files

Producing RGB true color images is straightforward. You start by opening three input files, one each containing the blue, green and red channel color information. Start **PANCROMA™** by clicking on the desktop icon. Select 'File' | 'Open'. You will be presented with a standard file open dialog window. Select your desired file type, either '.tif' or '.L1G'. Successively select and open the Blue, Green and Red bands in this order. These will be the files that have ...nn10...; ...nn20...; ...nn30...; or ...B10, ...B20, ...B30 in their file names as explained above. As you add the files, their names will be echoed on the diagnostics/dialog box. Failure to open the files in the proscribed order will result in the red data going into the green channel, the blue into the red, etc. producing an interesting but unrealistic color image.

Once all three files are opened, the appropriate menu selections and check boxes will be activated on the main screen. The simplest way to proceed is to select 'Display Files | Generate RGB Composite' from the menu. **PANCROMA™** will immediately begin combining the channels to produce a 30m resolution RGB image. After a bit of time, the image will be displayed. You can save the image by selecting 'File' | 'Save' and then selecting either .jpg or .bmp format.



If you check the 'Generate Grayscale Band Images' check box, the grayscale band file images will be displayed in addition to the RGB composite image. Save the RGB image by selecting 'File' | 'Save' | 'Save RGB' and selecting your desired file format. To save the grayscale images, select 'File' | 'Save' | 'Save Subset Image'. You will be prompted for a base file name. When you enter it and select 'OK' all three files will be saved as the base file plus an appended band file number.

18. Display RGB Color Composite Image

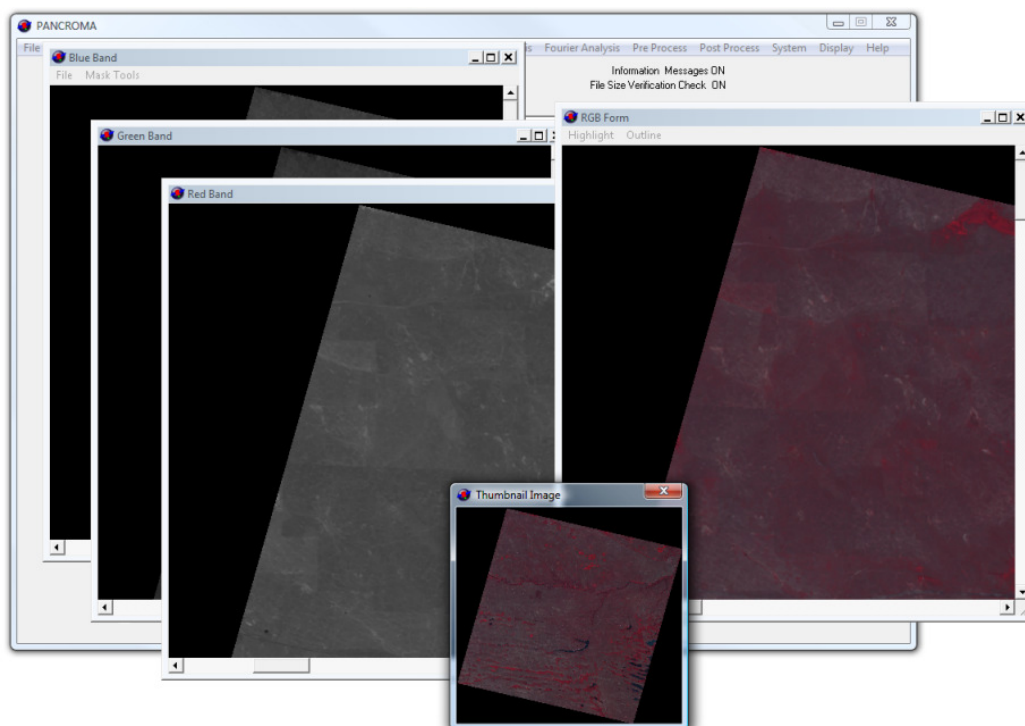
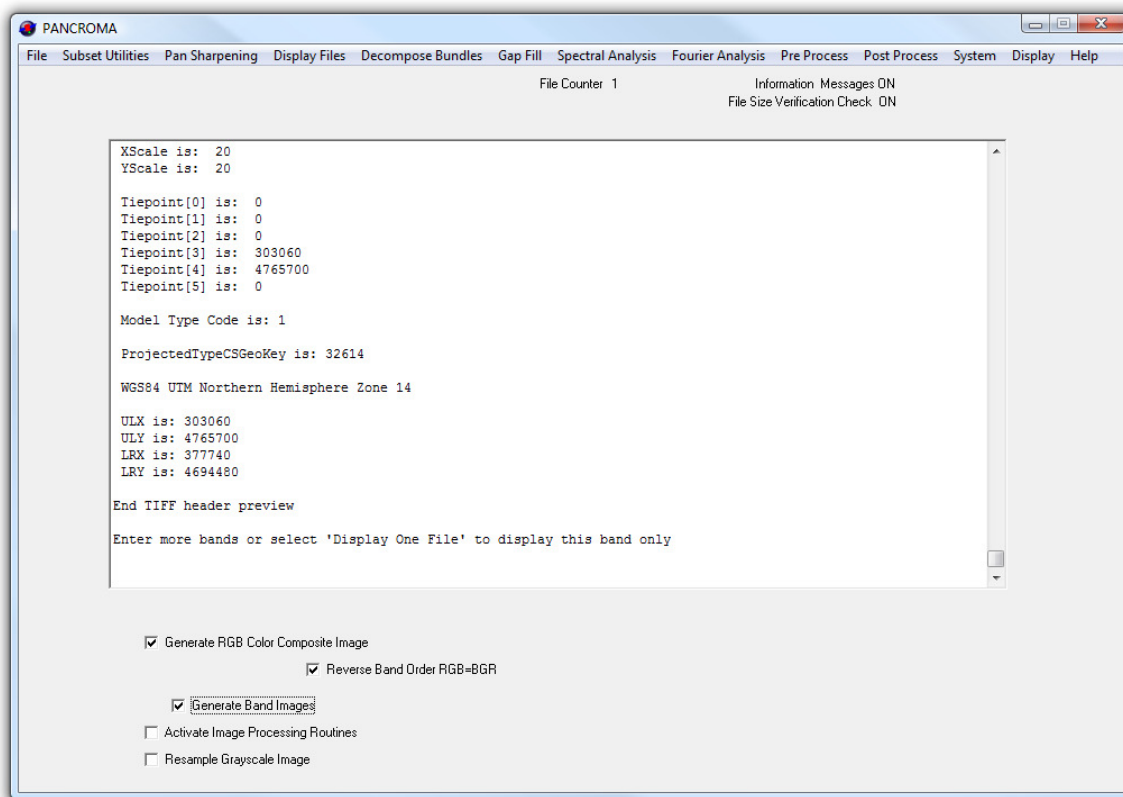
Once you have saved an RGB color image you may wish to display it for analysis or subsequent post processing. To display an already created color image, select 'File' | 'Open' and select your input image. Note that check boxes become visible at the lower left hand side of the Main Menu. If you check 'Activate Image Processing Routines', you will be presented with the Image Processing Input Box if you are processing a GeoTiff format RGB image. (This check box will not work for other file formats as a result of the way that JPEG and PNG files are read and processed).

The 'Resample Grayscale Image' check box is only operational for grayscale images. If you check the 'Generate Band Images' check box, the 'Generate RGB Composite Image' check box will appear. If both are checked, an RGB color composite image plus the corresponding three grayscale blue, green and red grayscale band files will be generated. If just the 'Generate RGB Composite Image' is checked, only the RGB image will be displayed. Finally, if only the 'Generate Band Images' check box is checked, the three band images will be displayed but the RGB image will not.

Sometimes it is desirable to reverse the blue, green and red channels in the displayed image, for example when processing USGS North American SPOT data available at the Earth Explorer website. To do this, check the 'Reverse Band Order' check box. This will reverse the band order for both the RGB display and the grayscale bands, if generated. Currently, this check box is only active for processing GeoTiff files.

Once you have generated and/or processed the images, you can save the RGB image by selecting 'File' | 'Save RGB Image' from the main menu. You can save the grayscale band images (if you choose to display them) by selecting 'File' | 'Save Grayscale Image'. In the latter case you will be prompted for a base file name, and PANCROMA will append either 'band1', 'band2' or 'band3' to the end of the base file name.

PANCROMA™ offers other ways to generate color composite images, for example synthesizing pseudo true color composites from SPOT and ASTER data. See subsequent sections for an explanation of these utilities.



19. Image Subsetting

Many users will wish to process and pan sharpen entire scenes. However there are many reasons to process image subsets, that is, part of a satellite image file. Often only a portion of a large image is of interest. Even when the entire image is needed, it is much more convenient to determine the optimum image processing parameters (see sections below) iteratively while experimenting with subset data, and then afterwards apply those settings to the larger file, thus saving a lot of computing time. One problem is that the pan sharpening and gap filling processes require *precisely matched* sets of images: for example three or four band files plus the panchromatic image with row and column sizes in the correct proportion. **PANCROMA™** is able to produce such matched sets using its subsetting algorithms.

You can subset four band data sets in any supported file format for 2X file sets (where panchromatic band rows and columns are 2 times (or 2X-1) the corresponding band row and column sizes). You can also subset four file subsets created by the Digital Globe file extraction utility in GeoTiff format (since this is the only output format supported by the utility.)

To begin the subsetting process, Select 'File' | 'Open' as above. Successively select the input band images in the order: blue; green; red. In addition, open one additional file: the associated panchromatic image. This will have an ...nn80... (GeoTiff) or '..._B80.L1G' (L1G) suffix if it is a Landsat file or a .._p10_.. suffix if it is a SPOT file.

IMPORTANT NOTE: if you are processing Landsat L1G images, it is necessary to download the metadata file into the same directory as the band and panchromatic files. This is because the L1G flat binary format is not capable of including image metadata itself. The companion metadata file has the suffix '..._MTL.L1G.htm'. Note: the metadata file is available in different formats. Be sure to select the HTML version with the file suffix .mht'. (If **PANCROMA™** does not find this file, you will be prompted to enter the row and column count data manually.) These values will always be labeled 'lines' and 'samples' and will look something like this in the metadata files:

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PRODUCT_SAMPLES_PAN = 15781
PRODUCT_LINES_PAN = 13961
PRODUCT_SAMPLES_REF = 7891
PRODUCT_LINES_REF = 6981
```

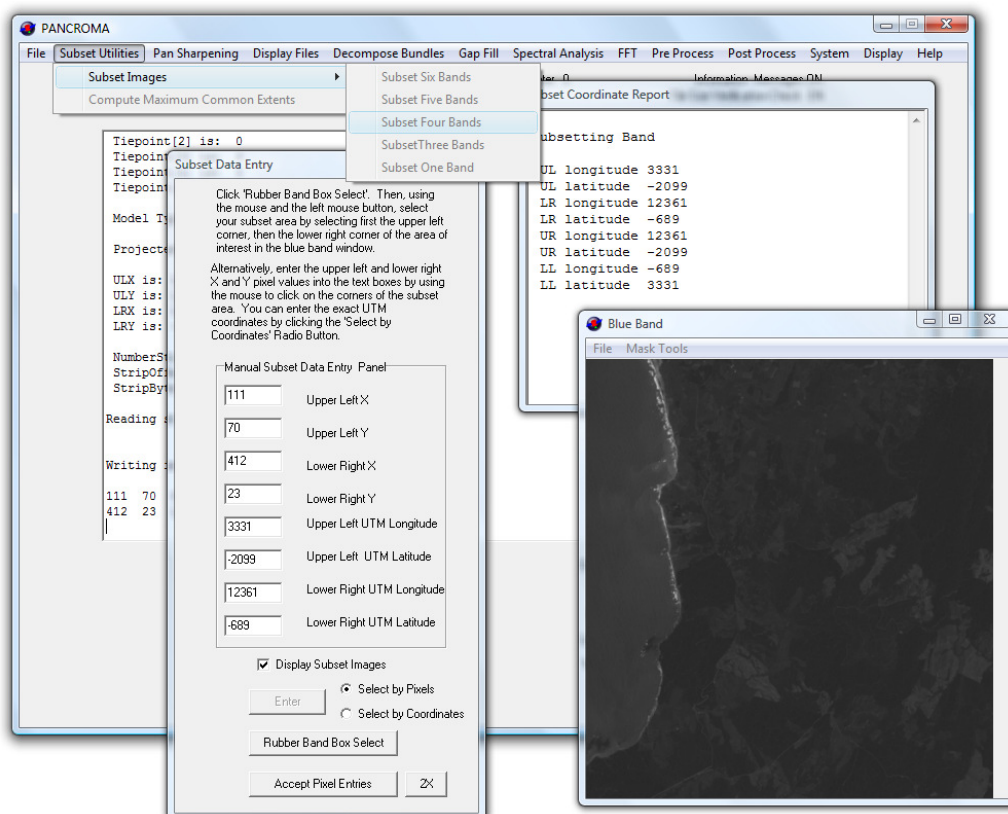
IMPORTANT NOTE: Some browsers may add control characters when saving the .mht file. These characters may prevent **PANCROMA™** from successfully

reading the metadata. It is usually safest to save the .mht file as a text file (.txt) and then rename it as an .mht file.

The exact number of SAMPLES and LINES will vary somewhat from one Landsat file to the next. The first two entries describe the PAN file and the latter two are for the band files. You will not care about this at all for GeoTiff format as the metadata is embedded in the GeoTiff band and PAN files.

Next, select 'Subset Utilities | 'Subset Images' | 'Subset Four Bands'. **PANCROMA™** will successively read in the data from the four files. When the program is done decoding the input files, you will be prompted to indicate a subset area of the image by a dialog box. You have the choice of several ways to enter the corner coordinates:

- using a rubber band box
- entering pixel values using the mouse
- entering UTM coordinate values using the mouse
- entering UTM coordinate values manually



IMPORTANT NOTE: There is a check box option on the dialog box that allows the user to display the subsetted band and panchromatic files or not. If your subset area is a relatively large percentage of the base image size, and/or your computing power is not great, you should uncheck this box. This will allow the processing of larger files before a possible 'out of memory' error occurs.

PANCROMA will automatically detect the corner coordinates for GeoTiff Landsat, SPOT and ASTER files and Landsat L1G input files. The UTM latitude and longitude coordinates, as well as the row and column values will be reported to the Main Window as the cursor tracks across the image. Knowing the corner coordinates of your subsetted images is often necessary for subsequent uses of the cropped Landsat images. Note that the UTM zone and hemisphere designation is reported at the bottom of the Main Window.

If you want to enter the pixel coordinates of the upper left and lower right corners of the subset area, click the 'Select by Pixel' radio button. Then use your mouse to locate these numbers on the Landsat image that is presented to you. Just click on the corners and the corresponding pixel coordinates will be entered into the text fields in the dialog box. If you make a mistake, just keep clicking. **PANCROMA™** will allow you as many tries as you need. When you are satisfied that you have entered the correct coordinates, select the 'Accept Pixel Entries' and then select the 'Enter' button on the dialog box. (As you click on the corners, the latitude and longitude will also be entered into the text box fields automatically.) The subset band images will be computed and displayed upon clicking 'Enter'.

If you want to key in the coordinates, select the 'Select by Coordinates' radio button. The coordinate data entry boxes will be enabled, allowing you to enter your desired upper left and lower right coordinates. If you make a mistake and enter a coordinate value outside the image extents, the offending latitude or longitude will default to the closest boundary coordinate.

IMPORTANT NOTE: The UTM coordinates for the Southern Hemisphere are reported using Landsat convention, which is different from the UTM standard. The UTM standard assigns a false northing of 10,000,000 meters at the equator, decreasing the latitude value as one moves toward the South Pole. Landsat convention assigns zero meters at the equator (the same as for the Northern Hemisphere). Southern Hemisphere latitudes are all negative, decreasing in value (becoming more negative) as one moves south towards the pole. In order to convert from one convention to the other, add the Landsat latitude to 10,000,000.

IMPORTANT NOTE: if you have left the 'Display Subset Images' box checked, the images will be displayed when you save the file.

Alternatively, you can enter the coordinates using the rubber band box. Click on the 'Rubber Band Box Select' button and then use the mouse and the left mouse button to identify the subset box. Finally, you can input latitude and longitude manually. In order to switch from automatic coordinate entry to manual entry of coordinates into the text boxes, switch the radio button from 'Select by Pixels' to 'Select by Coordinates'. Automatic reporting will stop and the boxes will be enabled for manual entry.

PANCROMA also provides a Subset Coordinate Report form that records the file names, projection, datum and the corner coordinates. You can cut and paste this information if you need to save it for subsequent image processing applications.

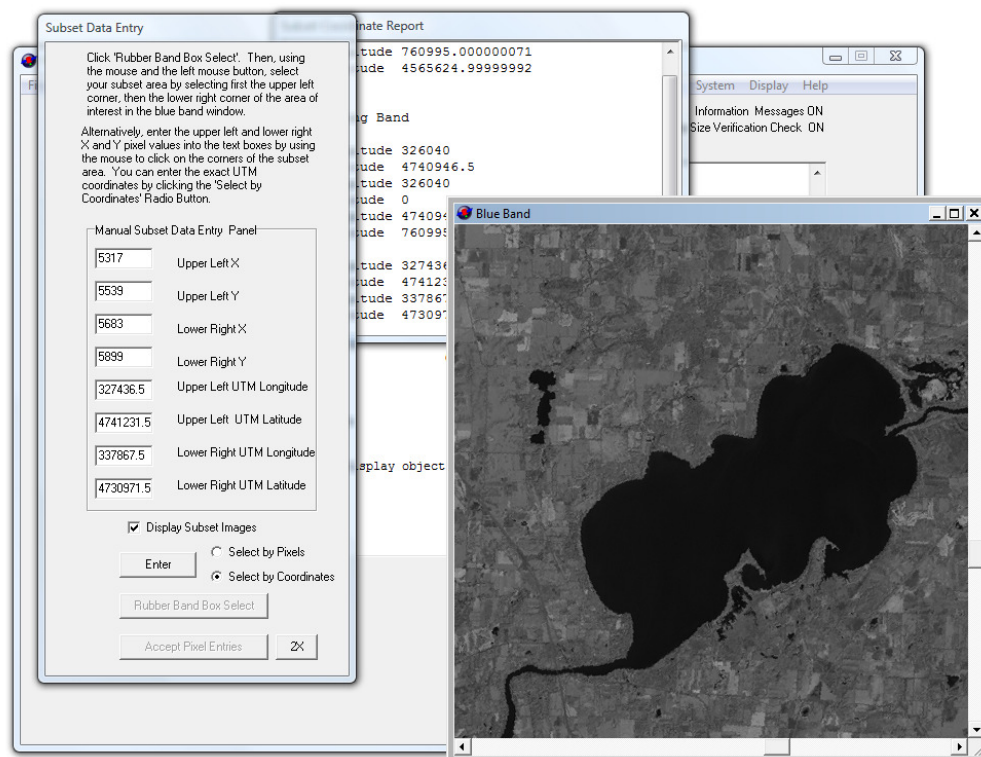
Although no subset images are yet displayed (or computed, for that matter), the program has recorded the key data to produce four subset images: one for each of the band files and one for the PAN file. These images will be precisely matched to each other, that is they will describe the exact same area of the earth's surface. (The panchromatic image will of course have twice the length and width of the band images.)

IMPORTANT NOTE: Clicking the 'Enter' button will not start the computations. These start when you save your images. When your selection is complete, you can save the subset images to disk by selecting 'File' | 'Save Subset Images' and selecting .jpg, .bmp or .png format.

The computations are done in this manner in order to conserve system RAM resources. This is necessary when your subset is almost the same size as the parent image. If computed immediately, both the image and the array data would consume a lot of memory resources. By computing on 'Save', each band file is computed, written to disk, and the memory resources immediately freed. If the 'Display Subset Images' box checked (default), the images will be displayed as the image is saved as well.

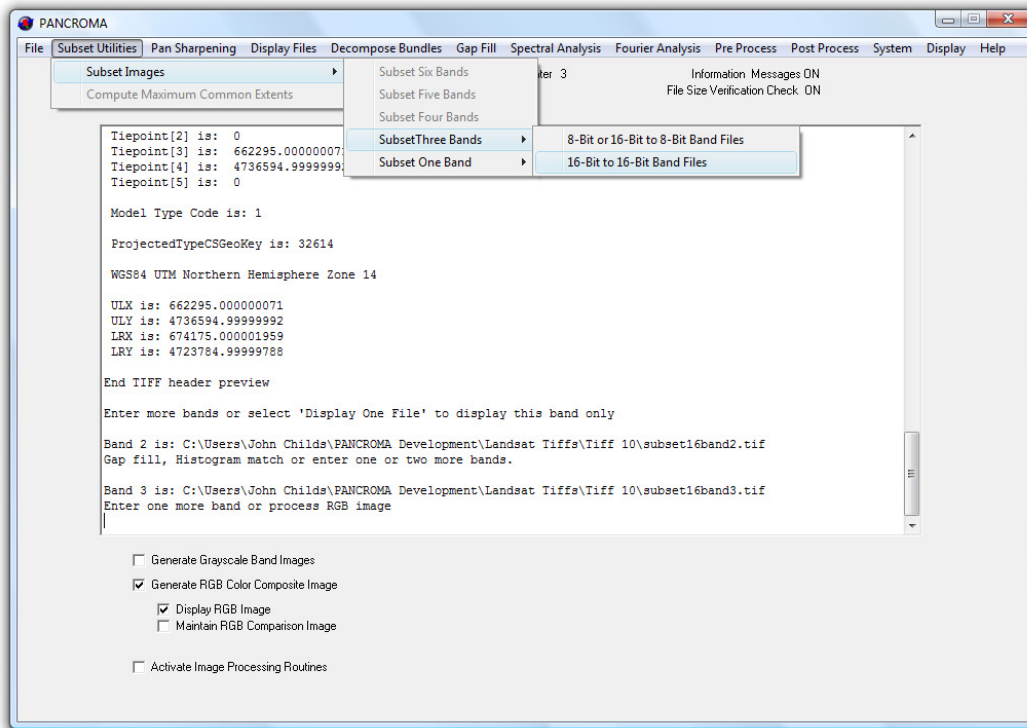
Since the resulting files are exactly matched, they can now be pan sharpened exactly as described in the previous section for full Landsat images, only more quickly since they are of course smaller than the parent images.

IMPORTANT NOTE: Even if you intend to pan sharpen the full Landsat image, it is generally a good idea to subset the image first in order to determine the best image processing settings. These settings of course can be retained after the subset images are unloaded and the full band and panchromatic images are opened.



IMPORTANT NOTE: Saving and opening large .jpg files can be a problem due to the nature of JPEG file writing algorithms, especially if your computer has less than 1GB RAM. For example, you may not be able to successfully save very large subset file sets in .jpg format. Although **PANCROMA™** is written to minimize internal storage expense, the file native JPEG file compression routines require significant storage and processing resources. The maximum size of the subset files that you can store will depend on the RAM resources of your computer. In general, .jpg format requires more processing resources than .bmp or .png.

PANCROMA™ is also capable of subsetting *three* band files of the same size. This utility is useful for gap filling images and for other purposes and is described in subsequent sections. In order to subset three files, load three Landsat or SPOT images and select 'Band Combination | 'Subset Images' | 'Subset Three Bands'. You will then have two menu options: '8-Bit or 16-bit to 8-Bit Band Files' or alternatively 16-Bit to 16-Bit Band Files'. The first selection will accept either 8-Bit or 16-Bit band files and process them so that 8-Bit GeoTiff band files can be saved. The other option will accept 16-Bit input files and process them so that 16-Bit Band files will be saved. The subset selection process is identical to that used to subset four bands. However when you select 'Enter' the subset images will be presented immediately rather than upon saving.



You can subset *five* band data sets in any supported file format for 2X file sets (where panchromatic band rows and columns are 2 times (or 2X-1) the corresponding band row and column sizes). You can also subset five file subsets created by the Digital Globe file extraction utility in GeoTiff format (since this is the only output format supported by the utility.) This capability is useful when using an additional near infrared (NIR) band for ENHG enhanced green channel or XIONG processing. The techniques for gap filling, ENHG and XIONG processing are described in detail in later sections.

IMPORTANT NOTE: When subsetting non-Landsat scenes for pan sharpening, the procedure is a little different. First subset the three or four band files as described above. Afterwards, subset the panchromatic band using the 'Select by Coordinates' option, using the coordinates that are automatically saved during the band file subsetting operation.

Another useful option is the 'Subset Six Bands' menu selection. This utility automatically resizes six input bands to maximum common extents. The utility will rationalize unequal row and column counts and also unequal image xScale and yScale values. As long as there is an overlap between the two sets of band files, **PANCROMA™** will co-register the images.

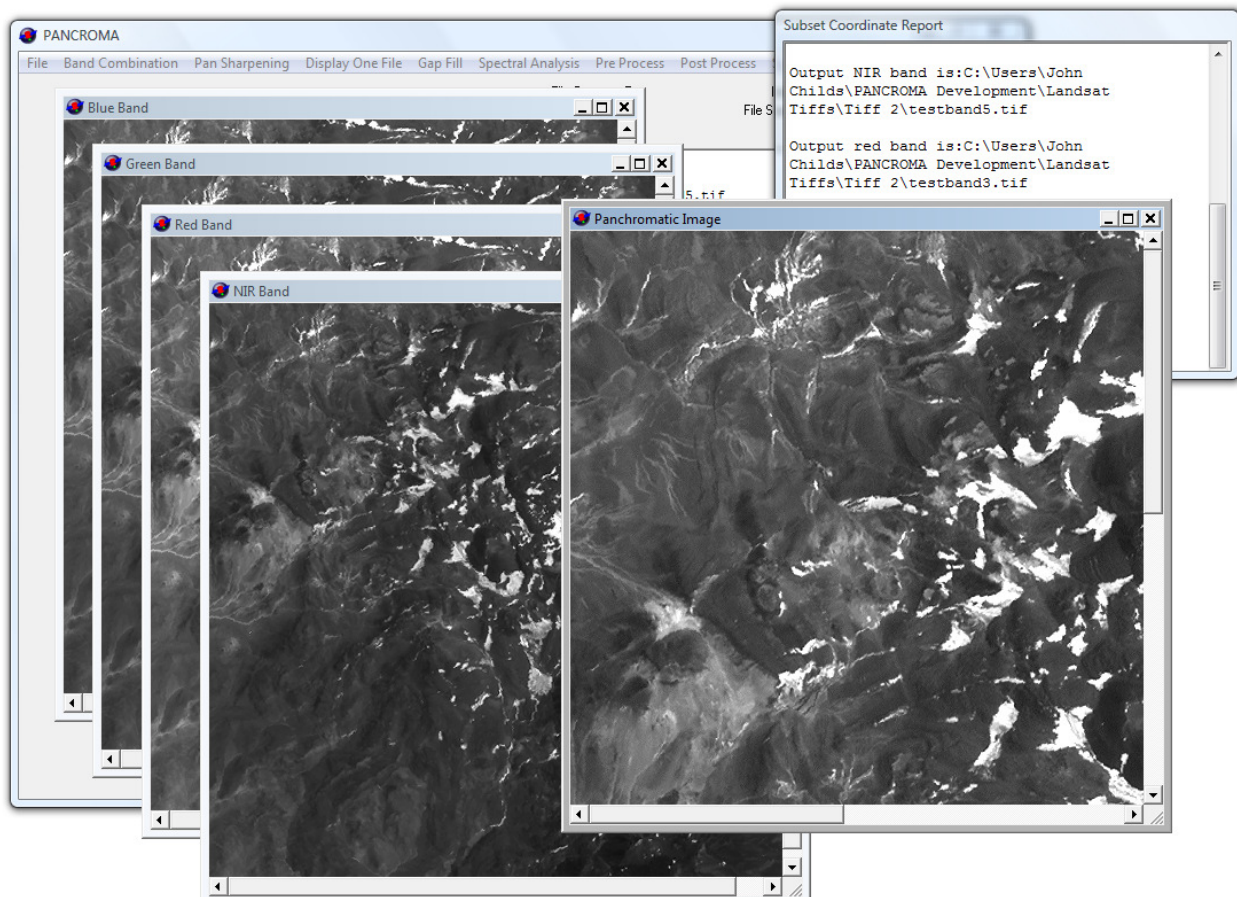
To use it, select 'File' | 'Open' and open six input band files, three from the first Landsat or SPOT scene followed by three from the second Landsat or SPOT scene. Then select 'Subset Utilities' | 'Subset Images' | 'Subset Six Bands'.

When the Input Box becomes visible, just click 'Enter'. **PANCROMA™** will automatically register the band files. This utility is useful for gap filling, cloud mask and other operations requiring two sets of registered images.

Finally you can subset a single multispectral or panchromatic band by selecting select 'Band Combination' | 'Subset Images' | 'Subset One Band'. You will be presented with two menu options, similar to those for the three file method. Selecting the '8-Bit or 16-bit to 8-Bit Band File' will save the subset image in 8-Bit GeoTiff format. The '16-Bit to 16-Bit Band File' selection accepts a 16-Bit file as input and saves it in 16-Bit GeoTiff Format.

IMPORTANT NOTE: When subsetting four or five band data sets that include the panchromatic band, it may be necessary on some computers to uncheck the 'Display Subset Images' check box. This will prevent the images from being displayed and is useful if displaying all the images uses excessive memory resources.

PANCROMA™ also has a utility for determining the Maximum Common Extents coordinates of any two files with overlapping areas. Open the two files and select 'Subset Utilities' | 'Subset Images' | 'Compute Maximum Common Extents'



IMPORTANT NOTE: The 'Compute Common Extents' utility determines the UTM coordinates of the overlap area for two images. Once it does this it copies the coordinates to the coordinate text boxes in the Subset Data Entry form. In order to subset single images to those coordinates, you need to follow that operation by (without exiting the program):

- 1) Selecting 'Close Graphics Coordinates and Reset'. This closes both files but retains the coordinate information in the text boxes.
- 2) Then select 'File' | 'Open' and re-open one of your two files.
- 3) Select 'Band Combination' | 'Subset Images' | 'Subset One Band'. When the Subset Data Entry form becomes visible you should see the corner coordinates already entered. I attached a picture of what the form should look like at this point.
- 4) Select the 'Select by Coordinates' radio button.
- 5) When you select 'Enter' the subset will be computed and displayed.
- 6) Now select 'Close Graphics Window and Reset'.

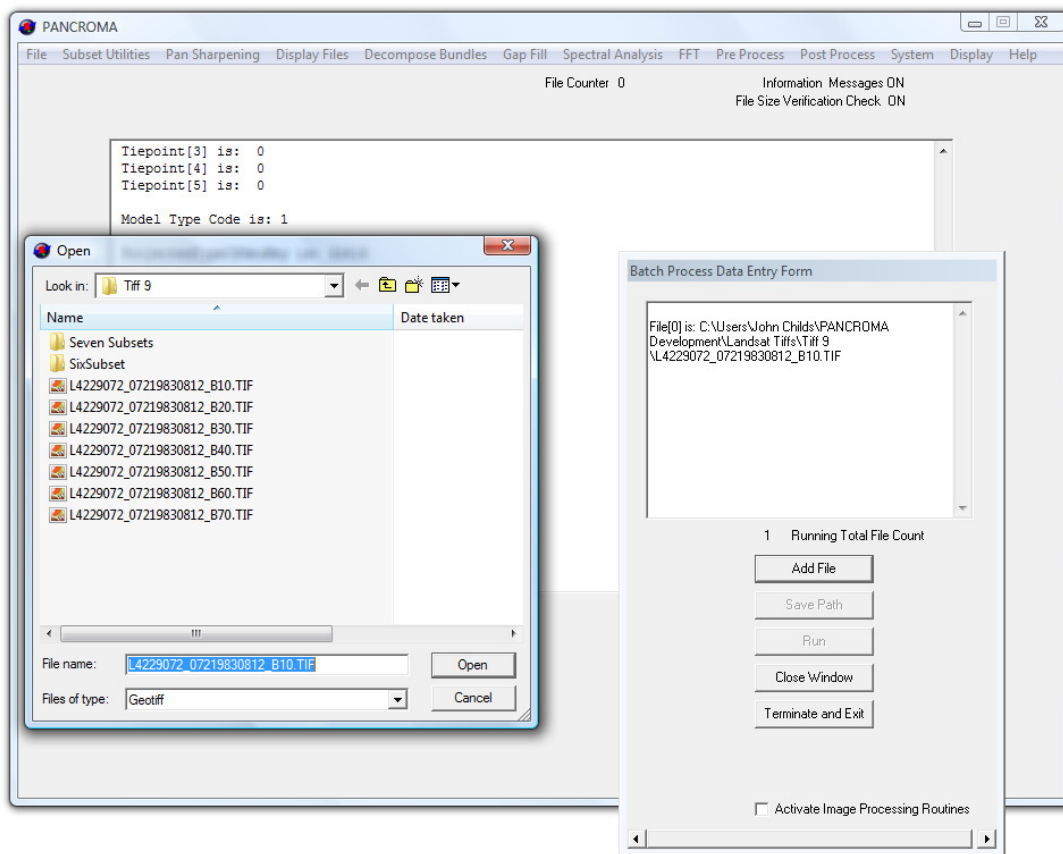
Repeat steps (2) through (5) for the second image. The UTM coordinates will persist in the text boxes for as many images as you wish to subset.

20. Batch Subsetting

PANCROMA™ provides a utility for subsetting Landsat multispectral GeoTiff files batch-wise in groups of six. That is, you can queue up as many six-band Landsat band file sets as you want and then instruct **PANCROMA™** to subset them to a common set of corner coordinates.

In order to subset multiple scenes batch wise, select 'Subset Utilities' | 'Subset Images' | 'Batch Subset' | 'Subset Six Bands'. You will be prompted to enter your data using a dialog box. Two of the buttons will be enabled. Choose 'Add File' to add band files to the queue and 'Cancel' to interrupt the operation.

When you select the 'Add File' button a familiar Windows open dialog box will appear that will allow you to browse to the directory where your files are stored. After doing so, select the first multispectral band and select 'Open'. The first band file will be added to the queue and its name will appear in the text box of the data entry dialog box.



Add multispectral band2, band3, band4, band5 and band7 the same way. Now you are ready to add the band data for the second scene. Just repeat the above operation, choosing six bands from the second scene in the order shown above. Repeat as many times as desired. You will notice that after every sixth band file the 'Save Path' button will become enabled. Saving the path tells **PANCROMA™** where to store the processed graphics files. In order to do so you must provide a root file name.

Each processed file will be given a unique name equal to the base name plus an index. Note that you only click the 'Save Path' button one time after you are finished adding all of your band files to the queue. Activating the 'Save Path' button disables the 'Add File' button so you will be unable to add more files and will have to start over again.

Once you have saved the path you can click the 'Run' button. After the first band is read, you will be prompted to enter your corner coordinates into a dialog box using your mouse or by keying them in as shown in the previous section. When you are done Accept and click 'Enter'.

Run progress will be displayed on the diagnostic screens and you will be notified of a successful run. If there is a problem with an input file it will be logged on the data screen. The Data Entry Form will stay open throughout the run. You can close it by clicking on the 'Close Window' button at the completion of the run.

21. Quick Start – Pan Sharpening an Image

You can produce a pan sharpened image almost as easily as producing an RGB image. To begin the process, Select 'File' | 'Open' as described in the 'Image Subsetting' section above. Successively select the band images in the order: blue; green; red. In addition, open one additional file, namely the associated panchromatic image with the ...nn80... (GeoTiff) or '..._B80.L1G' suffix as well.

It is recommended that you run your first panchromatic computation with a subsetting Landsat image set, prepared as described above. This will save a lot of computing time while you learn the method and iterate the process in order to achieve the best results.

IMPORTANT NOTE: if you are processing Landsat images with the suffix 'L1G' (raw binary format), it is necessary to obtain the metadata file and to have it in the same directory as the band and panchromatic files. This file has the suffix '..._MTL_L1G.mht', for example: 'L71002073_07319991106_MTL_L1G.mht'. Note: the metadata file is available in different formats. Be sure to select the HTML version with the file suffix .mht'. If the file is named something different, rename it to match the format above. If **PANCROMA™** does not find this file, you will be prompted to enter the row and column count data manually. These will always be labeled 'lines' and 'samples' and will look something like this in the metadata files:

IMPORTANT NOTE: Some browsers may add control characters when saving the .mht file. These characters may prevent **PANCROMA™** from successfully reading the metadata. It is usually safest to save the .mht file as a text file (.txt) and then rename it as an .mht file.

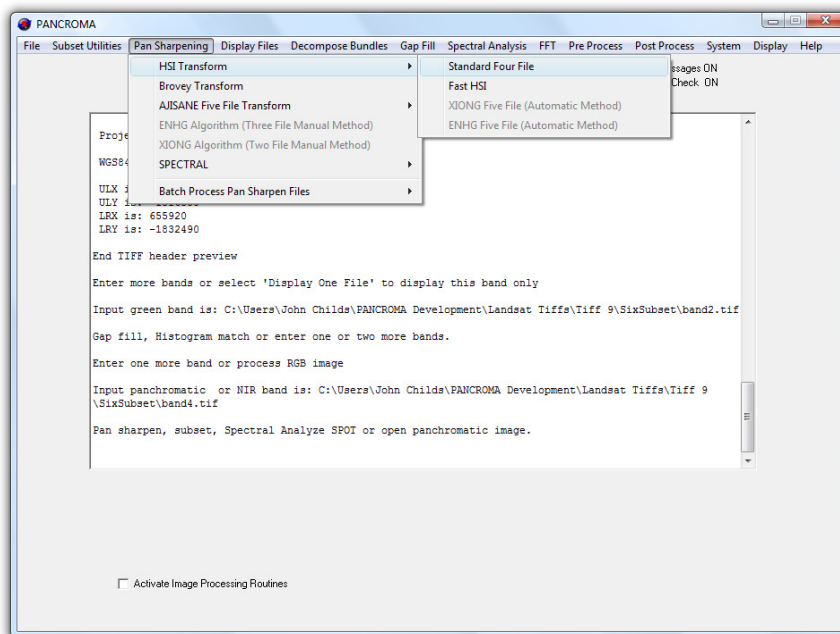
```
PRODUCT_SAMPLES_PAN = 15781
PRODUCT_LINES_PAN = 13961
PRODUCT_SAMPLES_REF = 7891
PRODUCT_LINES_REF = 6981
```

IMPORTANT NOTE: The exact number of SAMPLES and LINES varies somewhat from one Landsat file to the next. The first two entries are for the PAN file and the latter two are for the band files. You will not care about this at all for GeoTiff format as the metadata is embedded in the GeoTiff band and PAN files themselves. For L1G you will not care either as long as you download the metadata file into the same directory as the band and panchromatic file data as described.

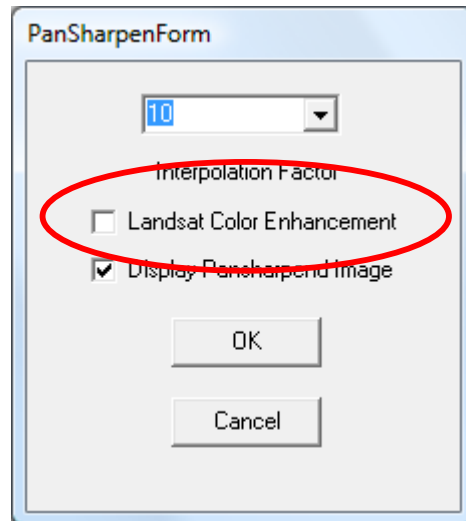
When all four files are opened successfully, the relevant menu selections and check boxes will be enabled. If you do not wish to set any pre or post image processing parameters, select 'Pan Sharpen' from the menu bar. You will be

presented with a choice of several pan sharpening methods, for example: 'HSI Transform' or 'Brovey Transform'. **PANCROMA™** provides several different algorithms for producing panchromatic images. Different algorithms are necessary in order to best compensate for spectral distortions inherent with different satellite data sets.

The HSI transform is a good one to start with. However for many data sets XIONG and ENHG variants yield better results. The AJISANE algorithm uses a completely different computational approach. You may wish to experiment with all of them. (Technical details regarding these algorithms are given in Section 15). If you select 'HSI Transform' you will be presented with submenu selections of 'Standard Four File', 'XIONG Five File' or 'ENHG Five File' choices. Select 'Standard Four File'. The other options can produce improved color tones and they will be described in subsequent sections.



After opening your files and selecting the HSI processing option, you will be presented with a dialog box prompting you to select the number of HSI iterations. If you selected HSI processing you will also have the option of checking the 'Landsat Color Enhancement' check box. Checking this box invokes special image processing algorithms to help compensate for spectral distortion introduced by the Landsat panchromatic band and may result in better color tones. This option will not appear on the Pan Sharpen Form if HSI processing is not selected. (This option is also enabled for AJISANE processing).



During the internal processing of the band files, color information is extracted and placed in intermediate scratch files that match the panchromatic file in size. Since Landsat band files are only $\frac{1}{4}$ the size of the panchromatic file, these sparse files are interpolated to fill in the empty spaces in the data arrays. Increasing the number of interpolation iterations does not usually improve the quality of the results appreciably. Accept the default for the first run.

After selecting the number of iterations, the program will begin computing your pan-sharpened image.

IMPORTANT NOTE: If you are submitting a full Landsat data set, computation time can vary: around 200 seconds on a powerful computer under the best conditions and as much as three hours on a slow computer. This is because the sheer volume of input and process data will exceed the application address space segment allowed by the Windows operating system. This is true no matter how much RAM your system has installed. When the input file size exceeds a practical cutoff, the program will make scratch files on your hard disk for storing temporary data, and disk access is slow compared to RAM access. When the process is complete, **PANCROMA™** will display the panchromatic image.

IMPORTANT NOTE: Without special automatic image processing techniques, some spectral distortion may occur during the four file HSI pan sharpening process when processing Landsat data. This may cause green colors of the pan sharpened image to look unnatural. Sometimes the default settings will produce very acceptable results. This is especially true of Landsat data sets due to the spectral characteristics of the panchromatic band. **PANCROMA™** can employ several automatic techniques to deal with this problem. These will be discussed in the following sections. **PANCROMA™** also offers an extensive set of manual image preprocessing and post processing utilities.

22. Pan Sharpening Transformation Methods

PANCROMA™ provides four transformation algorithms for pan sharpening: HSI, AJISANE, Brovey and SPECTRAL. These are offered as choices when you select the 'Pan Sharpening' menu item. The HSI algorithm is considered a standard. This method works best for Landsat 8 data. **PANCROMA™** can pan sharpen three multispectral bands with the panchromatic band. Alternatively by selecting 'Pan Sharpening' | 'HSI Based Transforms' | 'Pan Sharpen from RGB Composite' you can sharpen an RGB color composite image with the panchromatic band.

The basic HSI is improved by the XIONG and ENHG five file algorithms, which use the near infrared (NIR) band in addition to the blue, green and red bands to create the pan sharpened image. These, especially XIONG generally produce superior results when pan sharpening with the Landsat 7 panchromatic band. ENHG can also provide improved results but can often over compensate and create an image with overstated green tones.

The AJISANE method also works well with Landsat 7 as it uses the NIR band to correct spectral distortions introduced by the nature of the Landsat panchromatic band. It is especially useful for images where the XIONG method produces unwanted artifacts as described in Section 14.

The Fast HSI algorithm is also included. The Fast HSI algorithm has been described by Giannini and others³. This algorithm generally produces results very similar to that of the standard HSI algorithm. Unfortunately the algorithm does not live up to its name. While it may arguably be faster in theory, it is slower and takes up more RAM than the standard HSI algorithm in practice. It can sometimes produce less noisy results especially on ocean surfaces than the standard HSI so it is included for that reason.

PANCROMA™ also includes a 16-bit version of the Fast HSI algorithm. This option uses the full 16-bit dynamic range when pan sharpening Landsat 8 scenes. After pan sharpening you can choose to save the color RGB image in the standard 8-bit formats. In addition you can save the band files in 16-bit GeoTiff format by selecting 'File | 'Save Subset Images' | 'GeoTiff'.

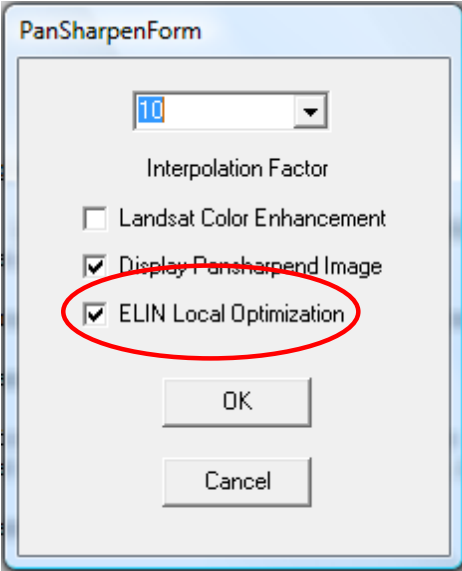
The Brovey method is a bit less expensive with respect to computational time and memory resources. It often produces a darker image that needs brightening and often contrast improvement to produce acceptable images. Experiment with all to see which gives the better result for your image. (Note that some of the default image processing settings will be altered when processing with Brovey. It

³ APPLICATION OF IHS PAN-SHARPENING TECHNIQUES TO IKONOS IMAGES, *Massimiliano Basile Giannini Pasquale Maglione, Claudio Parente*, CNR - Institute of Atmospheric Pollution Research Monterotondo (Rome)

is unlikely that the settings will be optimal for any particular image but they should be better than the default in any case. The settings are restored to the default when Brovey processing is done.)

The SPECTRAL algorithm was originally conceived as a method for pan sharpening single multispectral or hyperspectral bands. It introduces very low spectral distortion into the pan sharpening process, and can also be used to produce virtually spectral distortion-free color composite images as well.

The most recent algorithm is the ELIN Local Optimization addition to the basic HSI transformation. This method produces a synthetic panchromatic band with virtually zero spectral distortion regardless of the condition of the original panchromatic band. It usually produces the best results of all, especially for Landsat scenes where the panchromatic band sensitivity is shifted toward longer wavelengths. However, processing times can be considerably longer as the algorithm requires a lot of computation for each synthesized pixel. ELIN Local Optimization is the default setting for HSI pan sharpening. It can be switched off if not needed by un-checking the box on the pan sharpening data entry screen.



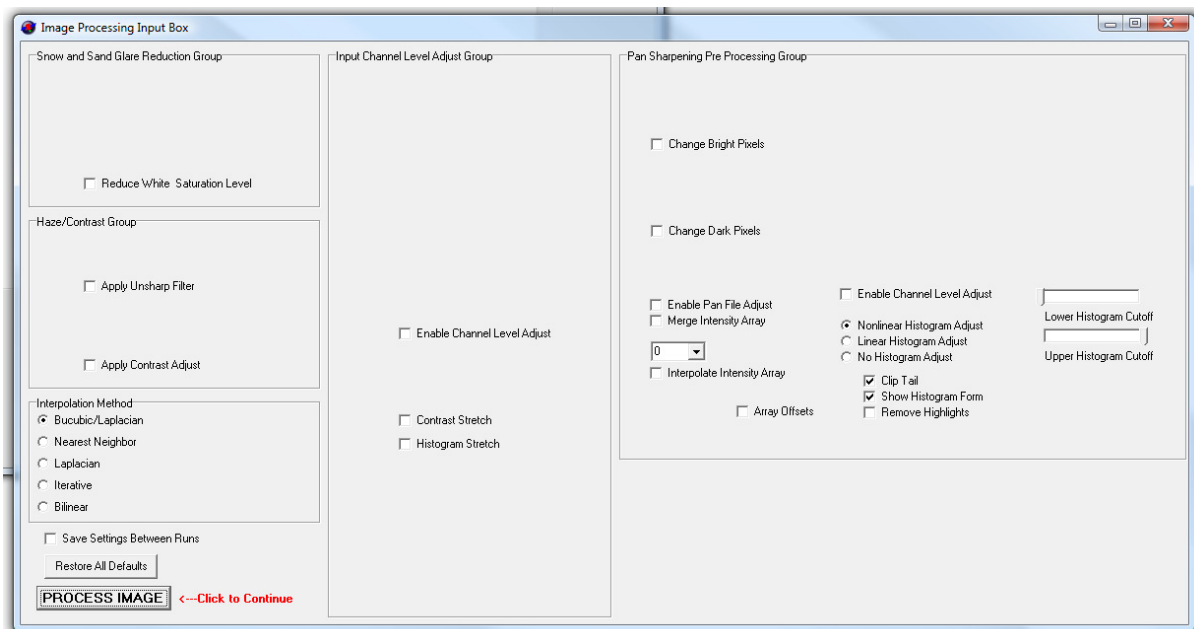
The image shows a software dialog box titled "PanSharpenForm". It contains a dropdown menu at the top with the value "10" selected. Below the dropdown is the label "Interpolation Factor". There are three checkboxes: "Landsat Color Enhancement" (unchecked), "Display Pansharpened Image" (checked), and "ELIN Local Optimization" (checked). The "ELIN Local Optimization" checkbox is circled in red. At the bottom of the dialog are "OK" and "Cancel" buttons.

23. Pan Sharpening Interpolation Methods

Interpolation is a key part of the pan sharpening process. Regardless of the method, at some point the row and column counts of the multispectral band files (or transformed multispectral band files) must be forced to match that of the panchromatic band. This is typically done in a two-step process. In the first step, the multispectral band files are resampled, i.e. expanded to create a sparse image. In the case of Landsat, for example, the rows are expanded so that there is an original band pixel at every other pixel location along the rows, with a 'no data' (actually zero value) pixel in between. Moreover, these rows exist at only every other row location. The result is a sparse data file containing 25% original band file data and 75% missing data. The missing data is replaced with color information interpolated from the original data in the second step.

PANCROMA™ normally uses a proprietary bicubic/Laplacian non-iterative interpolation algorithm for pan sharpening as its default method. This method is specially designed for data sets where the size of the panchromatic file is 2X the size of the multispectral bands.

PANCROMA™ offers alternative interpolation methods as well. Checking the 'Activate Image Processing Routines' checkbox on the main menu will display the Image Processing Data Box during processing. The lower left had corner contains the Interpolation Group.



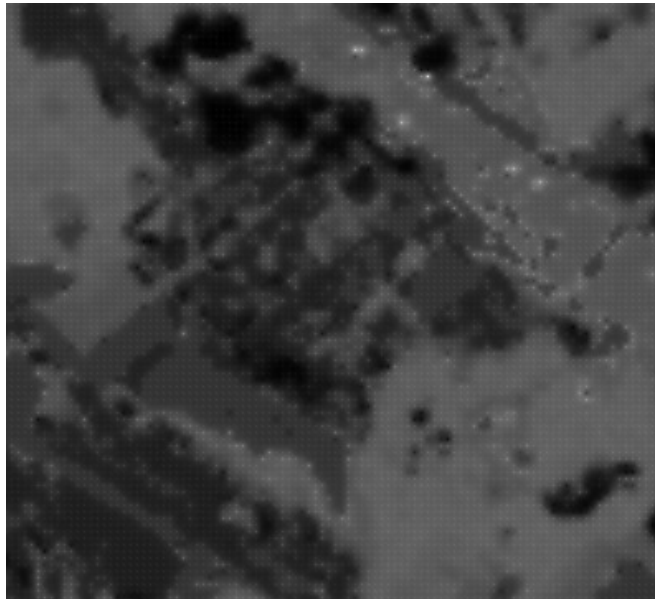
The default method is checked. The Nearest Neighbor method is a fast and simple interpolation method that can work well in many cases. However it can result in ragged edges in areas of abrupt color change.

An iterative Laplacian method can alternatively be used. It is the default method for data sets where the panchromatic band is more than 2X the multispectral bands, for example pan sharpening Landsat with the SPOT panchromatic band where the ratio is 3X. The Laplacian is relatively fast and it converges reliably. When you check this radio button, a text box will become visible so that you can specify the number of iterations. The larger the number, the more likely the interpolation will converge. However this is at the expense of greater processing time.

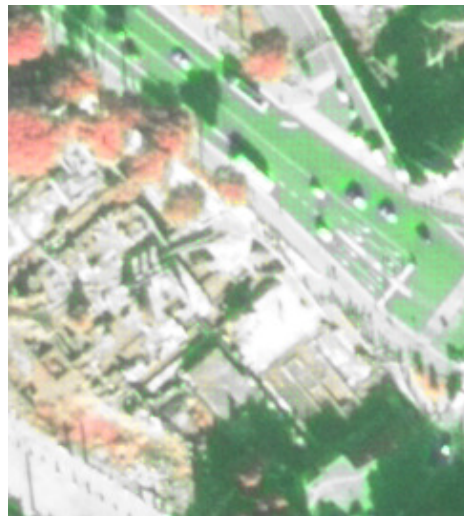
A problem with the Laplacian however is that it is not very efficient at extracting information from beyond its nearest neighbor pixels. This can start to affect the RGB image color quality for 4X data like WorldView2. To remedy this, **PANCROMA™** can run a Thin Plate preprocessing interpolation algorithm if you instruct it to. The Thin Plate algorithm is also fast and it reaches out beyond nearest neighbor pixels to interpolate. One disadvantage is that it can be noisy. That is why it may work better as a preprocessing step using relatively few iterations than as a primary interpolation method.

In order to select the Laplacian (or any other than the default Nearest Neighbor method) check the 'Activate Image Processing Routines' check box on the main window. When the image processing data input box becomes available, select the 'Laplacian' radio button in the 'Interpolation Method' data group. Once this is selected, two 'Laplacian' combo boxes and a 'Thin Plate' combo box will become visible. Select either standard Laplacian or modified Laplacian (Laplacian2). The Laplacian2 interpolation is a modified Laplacian algorithm that reaches out further beyond the target pixel in performing its interpolation. It improves pan sharpening results for difficult 4X and 6X interpolations. You can add the desired number of Laplacian iterations from the drop down menu. To add Thin Plate iterations, check the 'Thin Plate Check Box' and select your desired iterations from its drop down combo box. These will be added to the Laplacian iterations that you specified in the pan sharpening data input box. The location of the Interpolation Method data group is shown in the figure below.

Some 4X and 6X interpolations can be troublesome. The problem is that neither the Laplacian nor Thin Plate algorithms can be absolutely relied upon to produce smooth interpolations. In an interpolation algorithm, the source image pixels are typically frozen and not modified by the interpolation in order to preserve the data integrity the relatively few known values. Rather than interpolating smoothly, the known pixels may remain standing somewhat proud of the surrounding interpolated pixels. This can occur under certain arrangements of source image pixel values. The problem is shown below in an example interpolated hue file.



This can result in artifacts in the pan sharpened image, as shown below.



PANCROMA™ offers a third interpolation method based on an implementation of the Franklin Approximation algorithm implemented with an iterative linear equation solver. The Franklin Approximation algorithm can produce very good results. However, unlike the Laplacian and Thin Plate methods it cannot be implemented as a convolution mask but instead requires solving a large number of linear equations simultaneously in a sparse matrix configuration. As a result, it requires too much RAM storage to interpolate full size Landsat or even SPOT data sets. However it can be useful for smaller sets with panchromatic files up to

around 4000 rows by 4000 columns. It may require long processing times however.

This algorithm is normally used in combination with the Laplacian or Thin Plate interpolation methods (or both). The Iterative solver converges on a solution (assuming it does converge) much faster when it starts with a good estimate of the solution vector. Such a solution can be obtained by first running the Laplacian solver for example, and using the solution to this interpolation as the starting point for the Iterative solver.

When pan sharpening, access the Iterative selection check box by checking the 'Activate Image Processing Routines' check box on the Main Window. When the Image Processing Data Input screen becomes visible, check the 'Iterative' radio button. Also check the Laplacian and/or Thin Plate check boxes as well. Enter the desired number of iterations. It is best to start with a 10X ratio between Laplacian/Thin Plate iterations and Iterative iterations, as Laplacian and Thin Plate are much more computationally expensive than the Iterative solver. When you press 'Process Image' your pan sharpened image will be computed using Iterative interpolation.

A fourth interpolation method is the bilinear algorithm. This algorithm is also efficient at reaching beyond adjacent pixels for interpolation information. It is much faster and uses less RAM resources than the Iterative solver. In order to use this algorithm, check the 'Bilinear' radio button on the Image Processing Data Input screen. Since this is not an iterative method, no iterations need be input. This algorithm is often more effective than either of the Laplacian algorithms for 4X and 6X interpolations.

IMPORTANT NOTE: When interpolating using the bilinear method and XIONG pan sharpening, the Laplacian check box will be checked and you will have the option to input Laplacian iterations. This is for the NIR band interpolation that is used for XIONG. The default number is 40, which you can increase or decrease to get a better NIR band interpolation. See Section 25 on the XIONG method for more information.

24. Histogram Matching

PANCROMA™ creates a pan sharpened image by combining three lower resolution multispectral (RGB) bands with the higher resolution panchromatic band. It does this by transforming the RGB bands to the corresponding hue, saturation and intensity bands. The (computed) intensity band is discarded and The H and S bands are doubled and interpolated. The panchromatic band is then substituted in its place and a reverse transformation back to RGB color space is performed (HSI method). Although this often yields good results, some pan sharpened images may not look very pleasing and may need extra preprocessing to create an acceptable image.

One of the reasons that the pan sharpened image may not look the same as the corresponding RGB color composite image is that the panchromatic band fundamentally differs from the 'I' or computed intensity band. The Intensity band can be computed from the low resolution band files, along with the Hue and Saturation bands. Reverse transforming the Intensity band would yield the original RGB image. In pan sharpening, the Intensity band is discarded and is replaced with the panchromatic band.

Problems can arise because the panchromatic image is acquired using its own dedicated sensor sensitive to a sometimes translated (toward the IR wavelengths for Landsat) spectrum of radiated light, and is in no way related mathematically to the Intensity band that it replaces. The result of the replacement, necessary for pan sharpening to work, can be a pan sharpened image that has more pronounced blue color tones in green vegetated areas. A technique called histogram matching can be used to mitigate the problem by adjusting the panchromatic image histogram to more closely match that of the computed Intensity histogram.

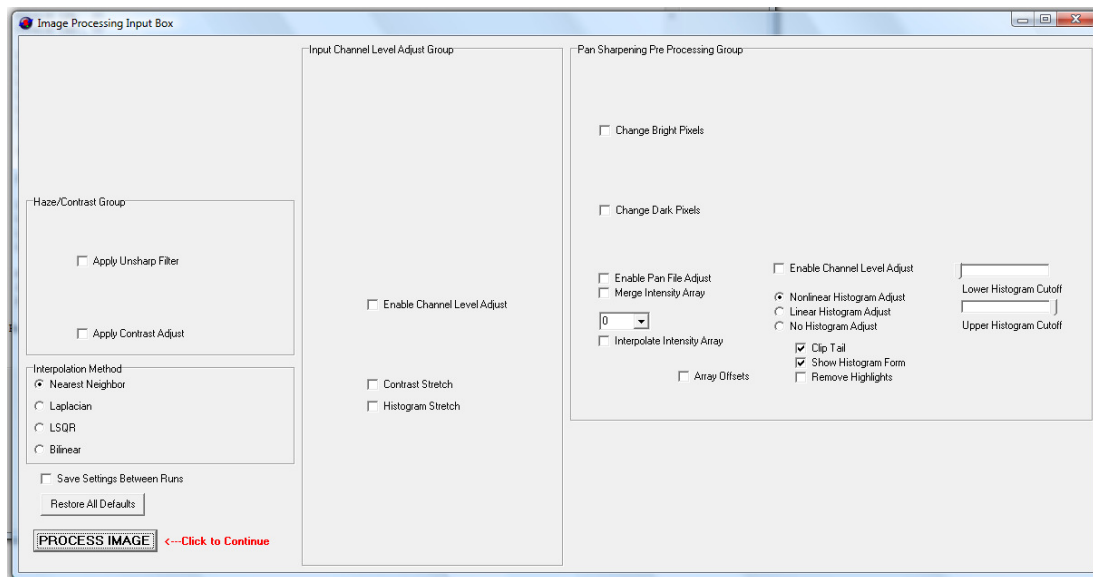
In order to histogram match one image to another, a discrete transformation function is computed that when applied to the panchromatic band, adjusts each pixel to a more appropriate grayscale level (more appropriate meaning a closer match to the computed Intensity band.) Better color tones often result when the transformed (i.e. histogram matched) panchromatic band is fused in a pan sharpening algorithm. **PANCROMA™** provides two histogram methods: non-linear and linear. The non linear transform usually produces better results, although this is not always true.

Non linear histogram matching is enabled as the default condition when pan sharpening images with **PANCROMA™**. You can select between the two methods, and disable histogram matching entirely using the radio buttons 'Non Linear Histogram Adjust'; 'Linear Histogram Adjust' and 'No Histogram Adjust' in

the 'Pan Sharpening Pre Processing Group' on the 'Image Processing Data Input' form.

IMPORTANT NOTE: Histogram matching is automatically disabled if ELIN local optimization is enabled as it is unnecessary.

In addition, you can clip the histogram tails. Clipping the histogram can prevent a skewed transformation as a result of a lot of purely black pixels in the collar area of the image. It is sometimes beneficial to also clip the high tail (pure white) if there are a lot of saturated clouds or snow that may similarly skew the transform. The default is for a single histogram channel (histogram[0] all black pixels) to be clipped. If you wish to clip additional channels from the high and/or low tails of the histogram, you can adjust the sliders provided. The following figure shows the location of the histogram match settings on the image processing data input form.



Unfortunately, histogram matching can sometimes itself create undesirable artifacts in the pan sharpened image. This is because the adjusted histogram differs from the reference histogram in small but important ways, and is purely a result of the nature of the discrete transform function. In most cases this transform function, when applied to the input histogram will yield an acceptable result. Occasionally the transform function will produce artifacts. One of the more common artifacts is an unnatural light blue image highlight. This is common and can be pronounced in images where green foliage and ocean are both present in the image. The following image shows an example of these artifacts.



PANCROMA™ has an image processing algorithm for removing them. It is disabled as the default condition. (This algorithm is not needed for all images, and there is a possibility that the correction algorithm itself could introduce other unwanted side effects.) The algorithm can be enabled by checking the 'Remove Highlights' check box in the Histogram data group within the Image Processing Data Input box. When you do so, two Combo Boxes will become visible. These are used to set the lower and upper limits of the transformation function levels to which the correction will be applied.

The levels are defined in terms of fractions and multiples of sigma, the standard deviation of the output histogram. The lower level is equal to the histogram mean plus sigma plus the standard deviation divided by the lower level integer. The upper level is defined by the histogram mean plus sigma multiplied by the upper level multiple. (The algorithm will decrease the value of all channels within its span in its attempt to correct the highlights, so it is important to exclude bright cloud, snow and surf pixels on the upper end and vegetation and ocean pixels on the lower end.)

$$\begin{aligned}\text{lowerLevel} &= \text{xBar} + (\text{sigma}/\text{lower Integer}) \\ \text{upperLevel} &= \text{xBar} + (\text{sigma} * \text{upper Integer})\end{aligned}$$

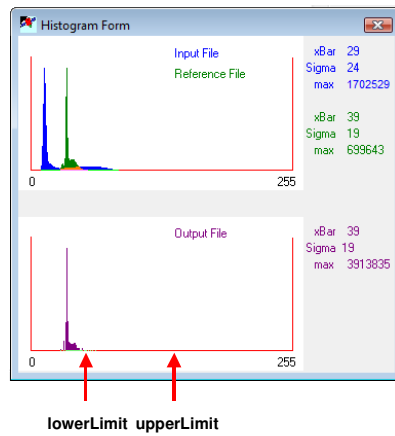


Image Processing Input Box

Haze/Contrast Group

☐ Apply Unsharp Filter

☐ Apply Contrast Adjust

Interpolation Method

☒ Nearest Neighbor

☐ Laplacian

☐ LSQR

☐ Bilinear

☐ Save Settings Between Runs

Restore All Defaults

PROCESS IMAGE <---Click to Continue

Input Channel Level Adjust Group

☐ Enable Channel Level Adjust

☐ Contrast Stretch

☐ Histogram Stretch

Pan Sharpening Pre Processing Group

☐ Change Bright Pixels

☐ Change Dark Pixels

☐ Enable Pan File Adjust

☐ Merge Intensity Array

☐ Interpolate Intensity Array

☐ Array Offsets

☐ Enable Channel Level Adjust

☒ Nonlinear Histogram Adjust

☐ Linear Histogram Adjust

☐ No Histogram Adjust

☒ Clip Tail

☒ Show Histogram Form

☒ Remove Highlights

Lower Histogram Cutoff

Upper Histogram Cutoff

Lower 1 Upper 1

1

2

3

4

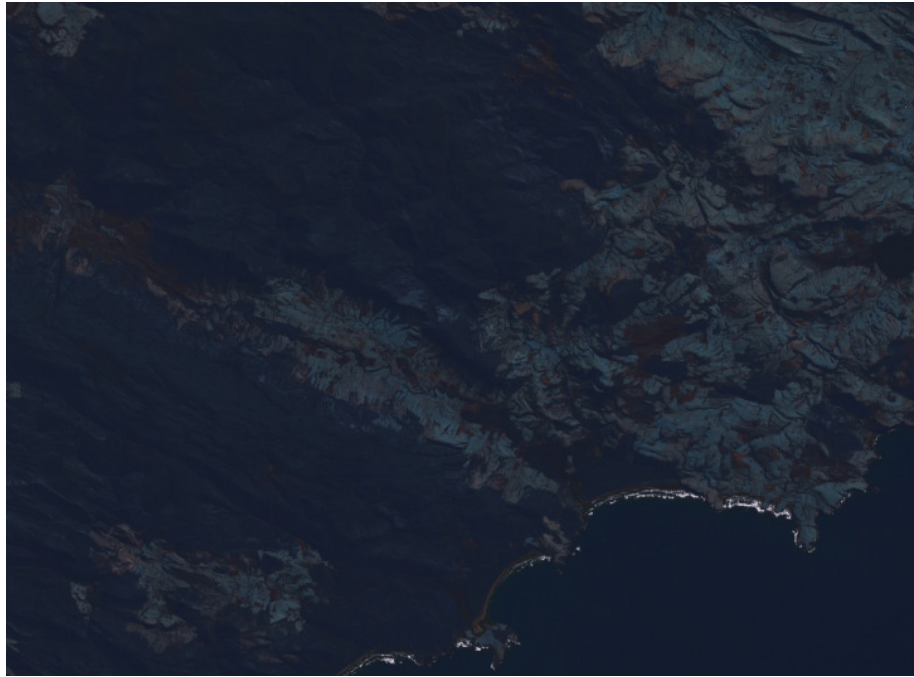
5

6

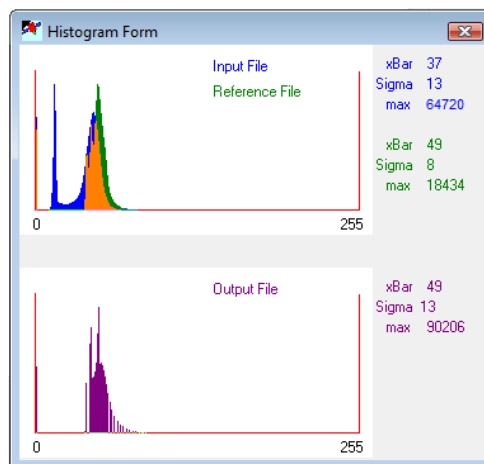
7

8

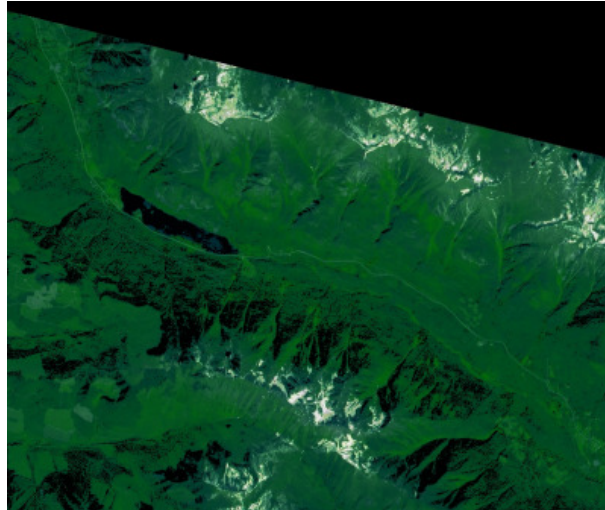
The following image shows the result of this using the setting on an otherwise problematic image.



PANCROMA™ displays the input, reference, and output image histograms when histogram matching is enabled. The objective is for the output histogram to match the reference histogram as closely as possible. The histograms are displayed on the Histogram Form during computation as the default condition as shown in the figure below. (The input and reference histograms are superimposed so that input is blue, reference is green, and overlap is orange.) Image statistics are also displayed. If you do not wish to view the image histograms, uncheck the ‘Show Histogram Form’ check box.



Another type of unwanted artifact is the “black spot” anomaly. In this case the image suffers from black blobs seemingly randomly scattered across the image. For example, if the SPOT image in the Video 7 tutorial listed on the www.PANCROMA.com website is pan sharpened with the default settings, the result in the image below will be computed.

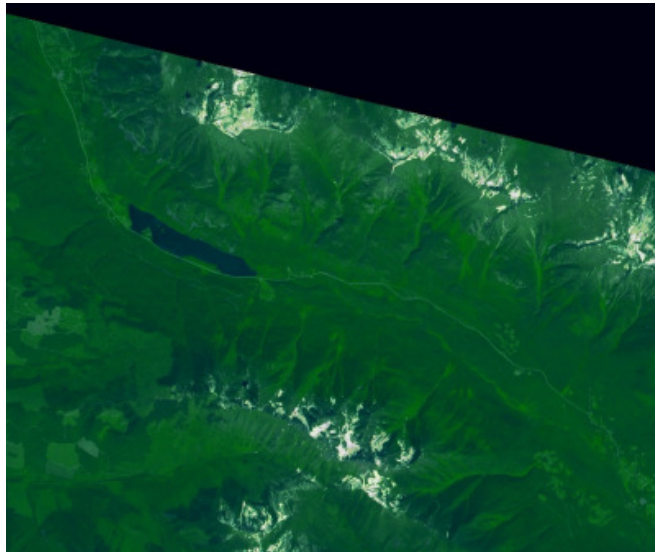


This is an artifact of the algorithm for computing cumulative histograms for the panchromatic and computed intensity images. The problem is unfortunately also common when gap filling. It is sometimes associated with a lot of black pixels in the image pairs.

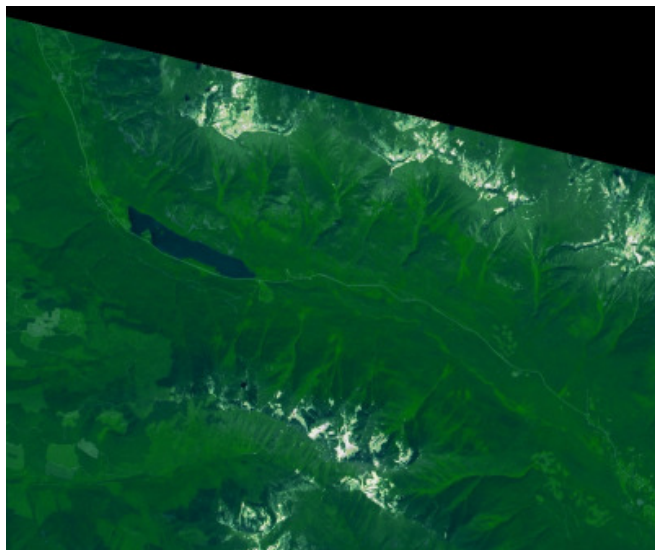
There are several remedies to this problem. The simplest is to disable histogram matching. To do so check the 'Activate Image Processing Routines' check box on the main form before pan sharpening. When the image processing box appears, click on the 'No Histogram Adjust' radio button. Then select 'Process Image'. This will cause the image to be pan sharpened without histogram matching.

Of course by disabling histogram matching you will forgo the benefits of the process. If you have a problematic image but still want to histogram match, there are a few more possibilities. If you encounter the problem during gap filling, try checking the 'Activate Image Processing Routines' check box at the bottom of the main window. When the Image Processing Data Input box becomes visible, check the 'Enable Channel Level Adjust' in the Input Channel Level Adjust Group. Modify the grayscale intensity by adjusting the 'gap adjustment level' slider bar. Often brightening the image a bit can address this problem satisfactorily.

Sometimes merely unchecking the 'Clip Tail'. The following image resulted after this adjustment.

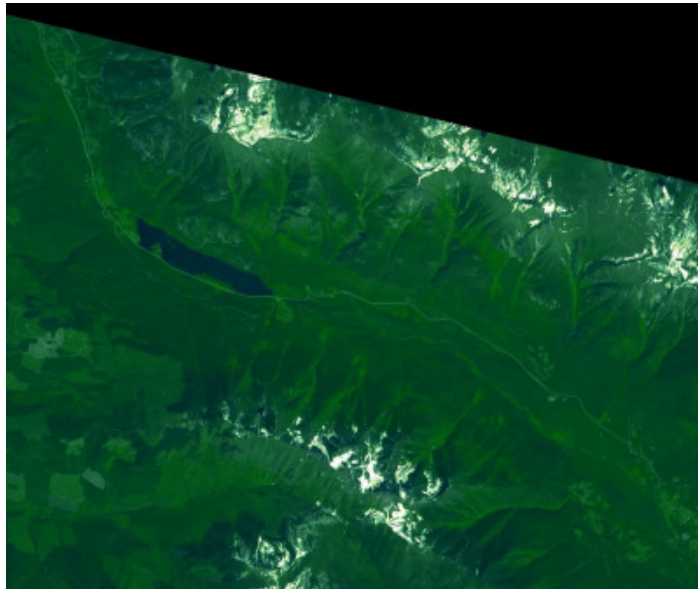


Another possibility is to clip more of the lower histogram tail. In this case, leave the 'Clip Tail' check box checked but increase the number of channels clipped. Clipping the bottom 20 channels also removed the black spots.



Yet another possibility is to use Linear Histogram Matching instead of Non Linear matching. To enable this, check the 'Linear Histogram Match' radio button on the 'Image Processing Data Input' box. This will cause a different histogram

matching algorithm to be applied. The following image shows the result of applying this option.



This produced the best result of all for this particular image, which is a synthetic natural color image created from SPOT bands. Histogram matching can be a very powerful aid but it can also cause unwanted side effects. Settings that work well for one image may not work for another. The defaults I set up work well for most Landsat pan sharpening tasks. SPOT images may benefit from different settings.

Histogram Match two Images

PANCROMA™ also has the ability to perform a linear or nonlinear histogram match on two input bands. The histogram adjusted output image can then be exported for other purposes. In order to perform the match, input first the reference band and the adjust band, in this order. Check the 'Activate Image Processing Routines' check box. The image processing data entry box will appear as usual. Adjust the histogram parameters as usual. Now select 'Pre Process' | 'Histogram Match'. **PANCROMA™** will match the 'adjust' band to the 'reference' band and display the 'adjust' band. You can save it as a JPEG or BMP file.

Histogram matching is currently enabled for pan sharpening (HSI and Brovey transform methods) for image gap filling and for individual file adjustment. See the relevant manual sections for additional information.

IMPORTANT NOTE: The two images do not have to be the same size for matching, just the same image format. This is true except for L1G. At present both L1G bands must have identical row and column sizes.

25. ENHG Algorithm – Manual Method

The Enhanced Green (ENHG) Channel method is designed to correct a spectral distortion problem that is characteristic of the pan sharpening process when using panchromatic images that are shifted from the blue wavelengths toward the IR spectrum (for example the Landsat panchromatic band.) This can cause a shift of green hues toward blue in the pan sharpened image, especially for vegetated areas. The ENHG method can correct this somewhat. It uses the NDVI index to identify probable vegetation areas, and then increases the value of the green channel pixels in these areas. The NDVI index uses a fourth low resolution near infrared (NIR) band to help identify vegetation. The NDVI index is given by:

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED})$$

Where NIR is the near infrared band (0.76 – 0.9 micrometers) and RED is the visible red band. For Landsat NIR is band 4 and RED is band 3. The idea is to compute an enhanced green band (ENHG) and then substitute the ENHG for band 2 (green band) in the pan sharpening process.

ENHG can be computed manually as a pre-processing step saving the ENHG file for subsequent processing. In this case the pan sharpening process is conducted as a separate step, substituting ENHG for the *green* band. The only real advantage of the manual method is additional control as the ENHG file can be image processed separately if desired. Automatic ENHG processing is described in the next section. This example of the manual process will assume that a Landsat image is being processed.

The first step is to download five band files: bands 1, 2, 3 and panchromatic as usual for pan sharpening plus an extra band: band 5 (NIR). The easiest way to proceed is to subset the band files first. This allows you to experiment with the ENHG scale factor in order to iteratively produce the optimal ENHG file without taking up a lot of computing time. **PANCROMA™** provides a special five-file subset utility for this purpose.

After loading your five files in the order: band1; band2; band3; panchromatic and NIR band select 'Band Combination' | 'Subset Images' | 'Subset Five Bands'. The subsetting procedure is exactly as described for subsetting four bands as described previously except that an additional subsetted file will be produced corresponding to the NIR band. The usual subsetting techniques can be used and of course the subset files will be the same size and co-registered.

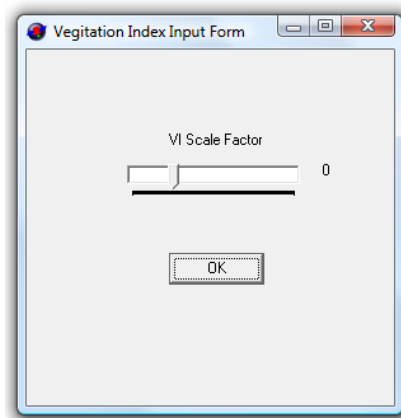
Next, compute the ENHG file. Open three files: NIR, band 2 (green) and band 3 (red), in this order. (For the first pass, use the default scale factor setting.) Do

this by selecting 'Pan Sharpening' | 'ENHG Algorithm'. In a few moments a single grayscale file will be displayed. This is the ENHG image. Save it in your desired format, naming it 'enhg.tif' or the like.

IMPORTANT NOTE: You must open the files in the specified order or unexpected color tones will result.

Now HSI pan sharpen as usual (four file method) by opening band1 (blue), ENHG, band3 (red), band4 (panchromatic) in this exact order. The resulting pan sharpened file should have greener vegetation than the corresponding pan sharpened image using bands 1, 2, 3 and panchromatic.

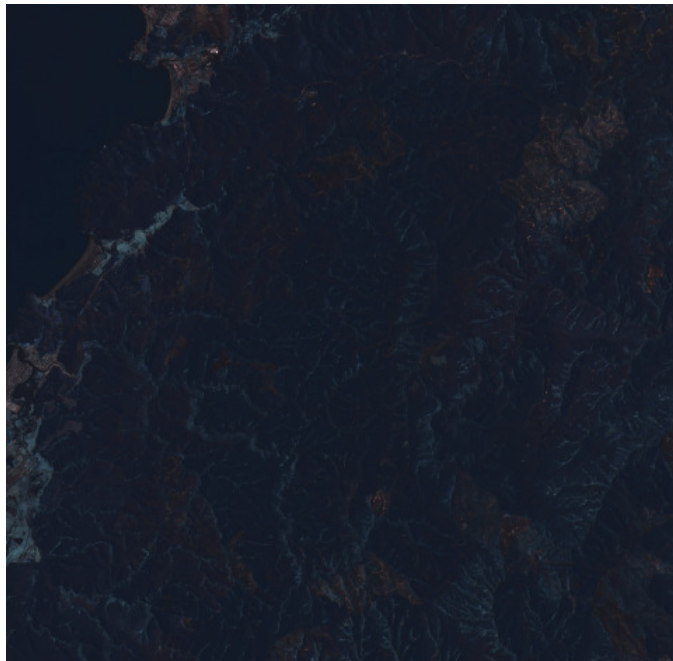
If the vegetation is too green or not green enough, run another iteration except this time check the 'Activate Image Processing Routines'. Adjust the NDVI scale factor using the slider bar at the lower right of the image Vegetation Index Input Form. The default value is 0.05.



The following files illustrate a problem pan sharpened image and the result of using the NDVI method. The first image is the RGB composite reference image.



The next image is the result of pan sharpening bands 1, 2, 3 and panchromatic. It suffers a pronounced green-to-blue color distortion common to many pan sharpened images.



The final image is the result of the ENHG process using a scale factor of 0.25.
(The color quality could be further improved by combining ENHG with other **PANCROMA™** image processing techniques.



26. ENHG Algorithm – Automatic Method

The same ENHG process that is described above can be performed in a single automatic step that both computes the ENHG image and then uses it to pan sharpen the band files. In order to do this simply open the three RGB band files, the NIR file and the panchromatic file in this order:

- band1 (blue)
- band2 (green)
- band3 (red)
- band 4 (panchromatic)
- band 5 (NIR)

IMPORTANT NOTE: You must open the files in the specified order or an error message will result.

Now select 'Pan Sharpening' | 'HSI Transform' | 'ENHG Five File (Automatic Method)'. **PANCROMA™** will automatically compute the ENHG file and then use it to pan sharpen the band files. You can use the full array of image processing utilities, the same as if you were processing the standard four files.

27. XIONG Algorithm – Manual Method

The XIONG algorithm offers another alternative to correct the blue spectral distortion inherent in Landsat panchromatic bands⁴. This algorithm often produces better results than the ENHG algorithm described above.

Like the ENHG, both manual and automatic processing is available. If computed as a pre-processing step, the output file is saved for subsequent processing. In this case the pan sharpening process is conducted as usual, this time substituting XIONG file for the *panchromatic* band. This example will again assume that a Landsat image is being processed although it can be applied to any image set.

The first step is to download five band files as before: bands 1, 2, 3 and panchromatic as usual for pan sharpening plus the extra (NIR) band: band 5. The easiest way to proceed is to subset the band files first. This allows you to experiment with the XIONG scale factor in order to iteratively produce the optimal color tones without taking up a lot of computing time. **PANCROMA™** provides a special five-file subset utility for this purpose. After loading your five files in the order: band1; band2; band3; panchromatic; and NIR band select 'Band Combination' | 'Subset Images' | 'Subset Five Bands'.

The subsetting procedure is exactly as described for subsetting four bands as described previously except that an additional subsetting file will be produced corresponding to the NIR band. The usual subsetting techniques can be used and of course the subset files will be the same size and co-registered.

IMPORTANT NOTE: You must open the files in the specified order or an error message will result.

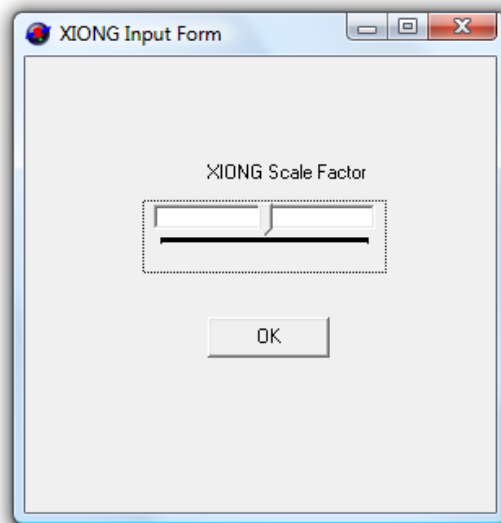
⁴ The XIONG algorithm is particularly useful when pan sharpening using the Landsat panchromatic band. The reason is that the Landsat panchromatic band spans wavelengths of 0.52 to 0.90 microns. This covers the green, red and NIR bands. This means that a Landsat panchromatic band contains no blue color information. Pan sharpening using this band can lead to spectral distortion. You can easily notice this when pan sharpening scenes with a high blue spectral component, i.e. forested scenes. Desert scenes in contrast that lack a lot of blue are not so much affected. The PANCROMA™ XIONG and AJISANE algorithms are designed to help correct this.

On the other hand the SPOT panchromatic band spans a spectrum of 0.48 to 0.71 microns. This almost exactly covers the blue, green and red spectral bands. Pan sharpening with the SPOT panchromatic band does not produce the kind of spectral distortions common with Landsat, and the XIONG algorithm may actually produce poorer results than the four-file HSI algorithm. It is generally helpful to check the specifications of the panchromatic band in whatever data set you are using in order to select the most appropriate pan sharpening algorithm.

Next, compute the XIONG file. Open NIR band 5 and band 4 (panchromatic) in this order. (For the first pass, use the default scale factor setting.) Do this by selecting 'Pan Sharpening' | 'XIONG Algorithm'. In a few moments a single grayscale file will be displayed. This is the XIONG image. Save it in any format, naming it 'xiong.tif' or the like.

Now HSI pan sharpen as usual (four file method) by opening band1 (blue), band2 (green), band3 (red), XIONG (processed panchromatic). The resulting pan sharpened file should have more natural vegetation tones than the corresponding pan sharpened image-using bands 1, 2, 3 and panchromatic.

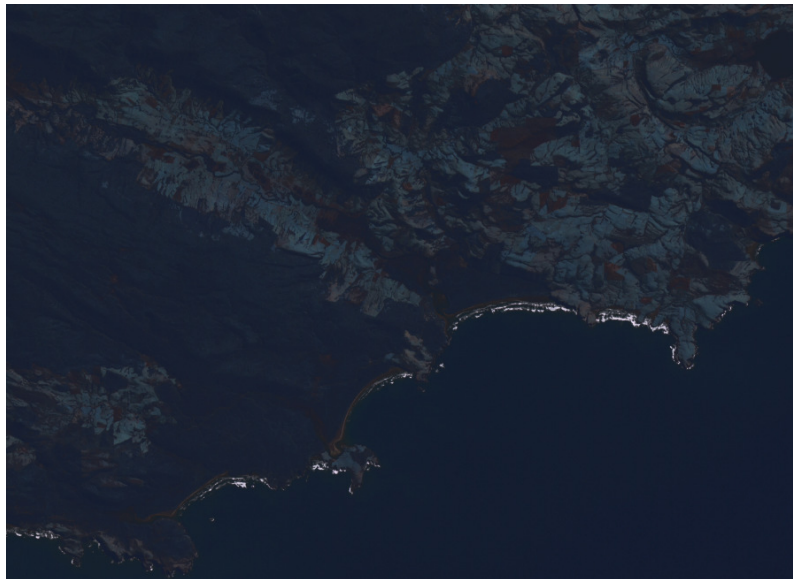
If the vegetation is too green or not green enough, run another iteration except this time check the 'Activate Image Processing Routines'. Adjust the XIONG scale factor using the slider bar on the XIONG Input Form. The default value is 50%.



The following files show the results of using the XIONG algorithm on a troublesome file with lots of vegetation. The first image shows the low resolution RGB composite image that forms the color standard.



The next image shows the pan sharpened image with histogram matching. Note there is still a lot of unnatural blue tint to the vegetated areas.



Finally, the XIONG image. Note that the color tones match the RGB standard almost exactly (of course this image has twice the resolution of the RGB image.)



The XIONG algorithm is one of the most powerful for overcoming the spectral distortion inherently present in the Landsat panchromatic band. It requires a bit more processing time, but for many images the result will be worth the effort.

28. XIONG Algorithm – Automatic Method

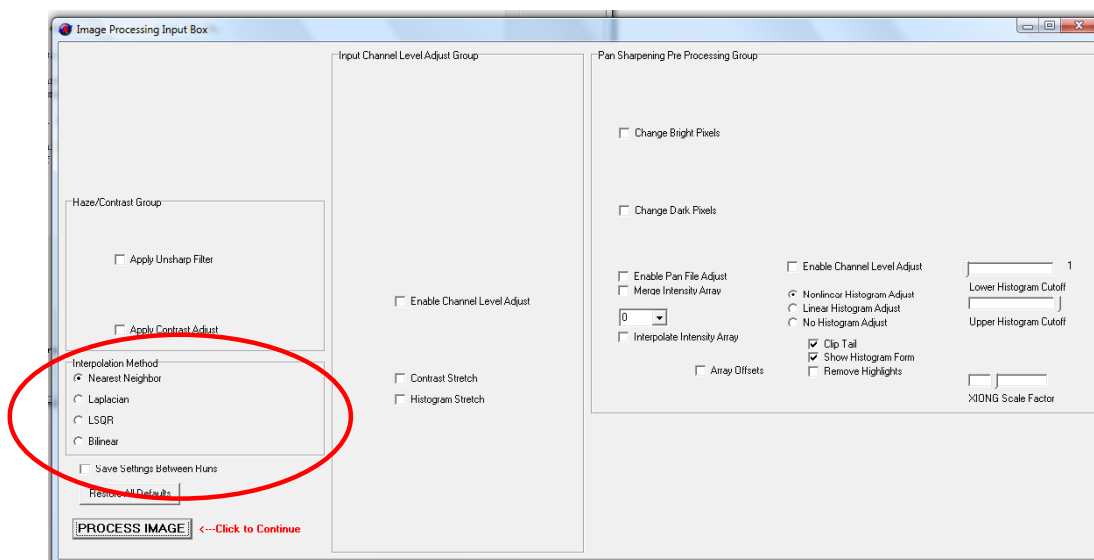
As with ENHG processing, the same XIONG process that is described above can be performed in a single automatic step that both computes the XIONG image and then uses it to pan sharpen the band files. In order to do this simply open the three RGB band files, the NIR file and the panchromatic file in this order:

- band1 (blue)
- band2 (green)
- band3 (red)
- band 4 (panchromatic)
- band 5 (NIR)

IMPORTANT NOTE: You must open the files in the specified order or an error message will result.

Now select 'Pan Sharpening' | 'HSI Transform' | 'XIONG Five File (Automatic Method)'. **PANCROMA™** will automatically compute the XIONG file and then use it to pan sharpen the band files. You can use the full array of image processing utilities, the same as if you were processing the standard four files.

IMPORTANT NOTE: When interpolating using the bilinear method and XIONG pan sharpening, the Laplacian check box will be checked and you will have the option to input Laplacian iterations. This is for the NIR band interpolation that is used for XIONG. The default number is 40, which you can increase or decrease to get a better NIR band interpolation. See Section 25 on the XIONG method for more information.



29. AJISANE Algorithm

PANCROMA™ contains an implementation of the AJISANE transform. This algorithm is similar in some ways to the HSI algorithm. It is capable of transforming any number of spectral channels into an orthogonal color space qualified by an intensity vector. As a result, it is possible to transform the blue, green, red, and near infrared (NIR) bands into the AJISANE space, substitute the panchromatic band for the intensity band, and then reverse transform back to RGB space.

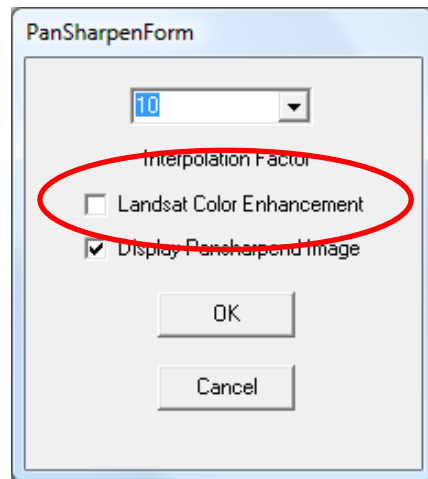
The advantage of such a four-dimensional transform is that some panchromatic bands (notably Landsat) overlap into the NIR band. As a result, substitution of the panchromatic band for the intensity band in the HSI algorithm can result in spectral distortions, as described previously. Because the AJISANE space can contain NIR information as well as RGB information, this type of spectral distortion can be reduced. AJISANE is more memory expensive than XIONG, the other **PANCROMA™** five-file pan sharpening method. However, it can offer an alternative for those cases where the use of XIONG results in unwanted artifacts as described in a previous article.

To use the AJISANE transform, open five band files by selecting 'File' | 'Open', opening the blue, green, red, panchromatic, and near infrared bands in this exact order. As always, the band files must all be of exactly the same dimensions and the panchromatic band must be a 2X, 3X, 4X or 6X multiple of the band file sizes. When the files are open, select 'Pan Sharpening' | 'AJISANE Transform'. You can select either the 'Simple' or the 'Enhanced' computation methods. The two differ in how they compute the adjusted intensity array from the panchromatic array. The Enhanced computation takes a bit longer but may offer better color fidelity in some files than the Simple computation. The trade off is a slight loss of pan sharpened image resolution.

After choosing the computation method, the Pan Sharpening Input box will become visible. You must input the number of interpolation iterations using the drop-down combo box. **PANCROMA™** will automatically select Laplacian interpolation for any panchromatic file size greater than 2X and will assign a default interpolation factor of 10.

If you wish to assign more Laplacian iterations, if you wish to add Thin Plate iterations or if you wish to conduct an Iterative interpolation, you must check the 'Activate Image Processing Routines' check box on the Main Window. When you do so, you can check the 'Thin Plate Check Box' and assign Thin Plate iterations. You will also have the option of checking the 'Landsat Color Enhancement' check box. Checking this box invokes special image processing algorithms to help

compensate for spectral distortion introduced by the Landsat panchromatic band and may result in better color tones.



When you are finished, click on the 'Process Image' check box. After some processing time, your pan sharpened image will be computed. If you have left the 'Display Pan Sharpened Image' check box checked, your image will be displayed. This method of pan sharpening, like the Brovey, can result in images that are a bit dark. If this is the case, you can brighten the image by checking the 'Enable Channel Level Adjust' on the Image Processing Data Input box.



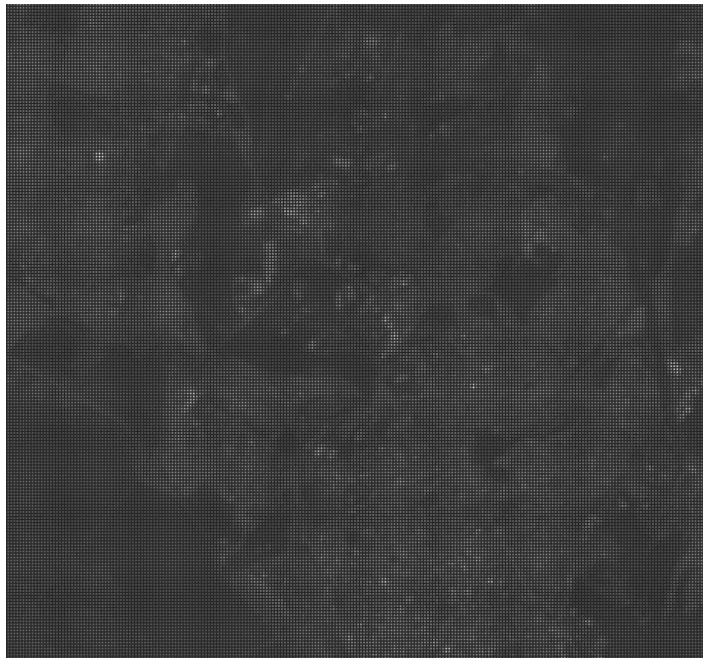
An example of a pan sharpened image using this method is shown below. In addition to adding ten units of brightness to each channel as described above, I also used the sharpening and contrast adjustment utilities on the Image Processing Data Input box. The color quality is fairly good, as can be seen by comparing the pan sharpened image with the RGB color composite from the three band files



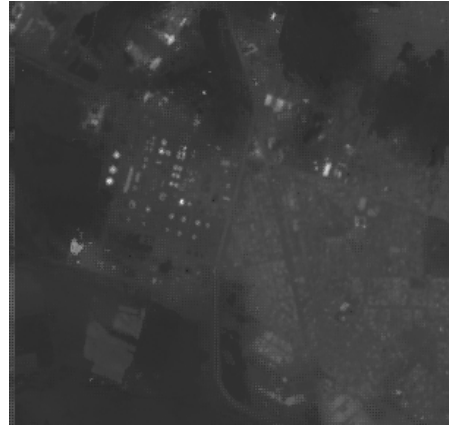
30. SPECTRAL Pan Sharpening Algorithm

All of the methods previously described are designed for pan sharpening color composite images. It may be desirable for to increase the resolution of a single multispectral or hyperspectral band if a single band rather than a band combination contains the more useful information. This can be done for Landsat and SPOT data using **PANCROMA™** SPECTRAL pan sharpening algorithm.

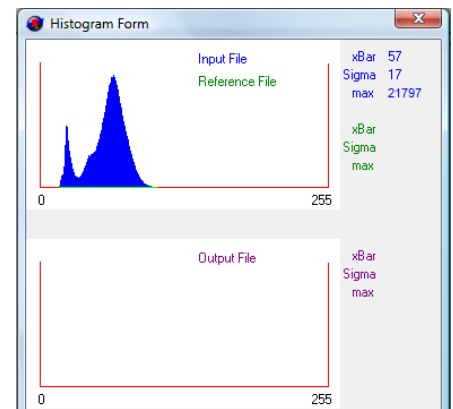
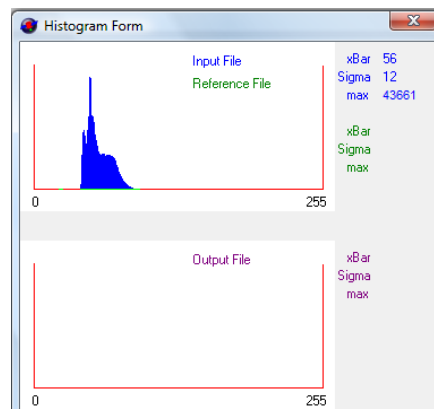
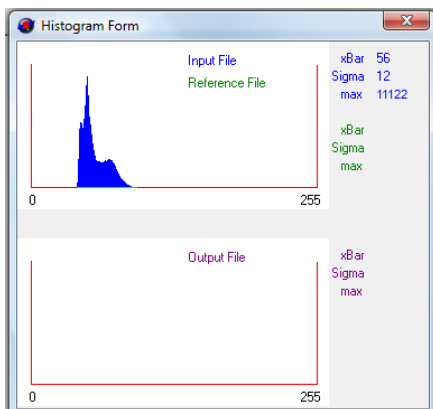
The SPECTRAL algorithm does this in two steps. In the first step, the multispectral or hyperspectral band is expanded to match the size of the panchromatic image. This creates a sparse image with only 25% of the digital numbers (DNs) as the panchromatic image. An example of such an image is shown below.



In the next step, the missing information is synthesized using both the DNs from the multispectral or hyperspectral band and the DNs from the panchromatic band. This is done in a way such that very little spectral distortion is introduced. A comparison between the original Landsat multispectral band image, the pan sharpened multispectral band and the panchromatic band is shown in the three images below.



The spectral match is indicated by the three image histograms below. The first histogram is the multispectral band. The second is the pan sharpened band, and the third is the panchromatic band that was used to compute the pan sharpened image.



It is apparent that the histograms for the multispectral and pan sharpened multispectral images match very closely, while that of the panchromatic image is significantly different. Very little of the spectral characteristics of the panchromatic band have been transferred to the pan sharpened band.

To pan sharpen a single multispectral band, you must first open your two input files in this order: multispectral band; panchromatic band. The multispectral band should have half the row and column count of the panchromatic band. Now select 'Pan Sharpen' | 'SPECTRAL' | 'Single Landsat Multispectral Band'. (Currently this utility is only implemented for Landsat and SPOT bands that have a 1:2 row and column ratio to the panchromatic band.) The SPECTRAL pan sharpening data form will become visible. You can select the Search Extents, Threshold and the Comparison Radius.

SPECTRAL Pan Sharpening Data Form

Search Extents: 8

Threshold: 1

Comparison Radius: 6

OK

Cancel

The default values are 8, 1 and 4, respectively. The Search Extents defines the size of the sliding window within which **PANCROMA™** will use DNs from panchromatic and multispectral bands to synthesize a single DN. **PANCROMA™** will search the target +/- the Search Extents, so the size of the window is twice the Search Extents value.

The Threshold determines what constitutes missing data. Normally this would be a zero value. If the Threshold is set equal to one, all values less than 1 (i.e. zero) will be considered missing data and any value higher (1 or greater) is considered valid data and will not be interpolated. The Threshold can be set higher if necessary. (It is advisable to leave it at 1 unless there is a good reason to change it.)

The Comparison Radius value determines how closely a searched pixel must be to the target pixel in order to be considered 'similar'. The default value is 4, meaning that pixels within 4 levels of the target will be considered similar. For example, if the target has value 83 and the Threshold is 4, then coordinates of pixels with values 79, 80, 81, 82, 83, 84, 85, 86 and 87 will be considered as similar for purposes of the computation.

You must be careful when selecting the input parameters, as your choice will have affect both the quality of the computed image and the processing time (the higher the quality, the greater the time). For example, increasing the size of the Search Extents increases the number of candidate pixels for the synthesis computation. In general, the larger the value of the Search Extents, the better the result. However, choosing a large Search Extents value will rapidly bog down computational speeds, as the extents must be searched for each missing DN in the expanded multispectral image.

Choosing too small of a window will result in a poor result. (The optimum combination of Search Extents and Threshold cannot be computed and must be determined empirically.) Although the algorithm has been streamlined for computational speed, whatever the size of the Search Extents, the SPECTRAL method will be slower to process than other pan sharpening methods. In addition, the SPECTRAL method will leave a collar of unprocessed pixels around the border of the image where the edge of the sliding window bumps up against the image extents.

The SPECTRAL method can also be used to produce RGB color composite or false color composite pan sharpened images. This can be done by separately computing each pan sharpened band file and then combining them using the 'Band Combination' menu selection. This produces an image with very little spectral distortion. An example is shown below, comparing the RGB color composite from the multispectral bands to the pan sharpened SPECTRAL image.





The SPECTRAL algorithm allows single multispectral and hyperspectral bands to be pan sharpened without loss of spectral fidelity and achieving low levels of spectral distortion in color pan sharpened images. See the White Paper at <http://www.pancroma.com/Pan%20Sharpen%20Single%20Multispectral%20Band.html> for further information on SPECTRAL.

The single band SPECTRAL utility will use 16-bit math for Landsat 8 data.

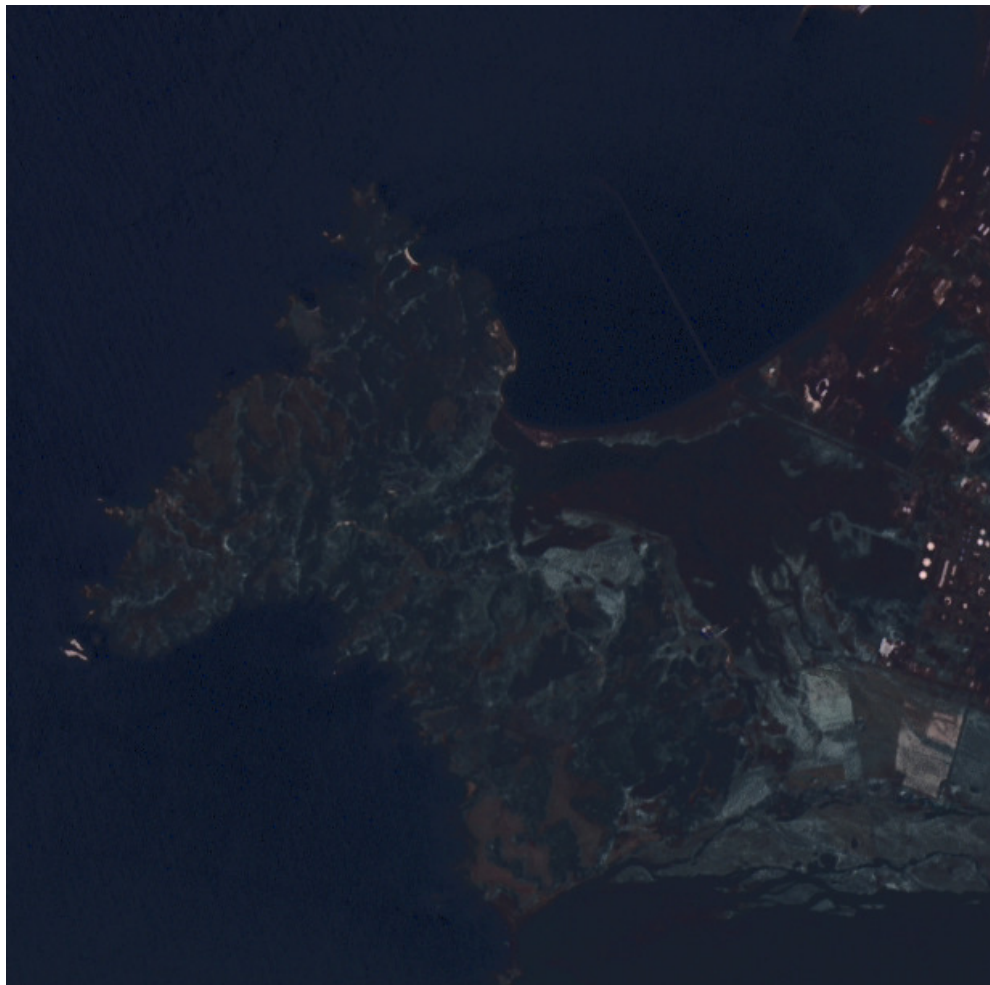
31. ELIN Local Optimization Algorithm

The ELIN algorithm is the latest **PANCROMA™** technology designed at overcoming the problem of spectral distortions introduced by the nature of the panchromatic bands that represent the high-resolution information in satellite data scenes. As explained elsewhere in this manual, the Hue, Saturation, Intensity (HSI) transformation method provides a convenient way to inject high resolution spatial information into the lower resolution spectral information in order to fuse the spatial and the spectral to produce a high resolution color image. The problem with the naive approach is that the process only works if the spectral characteristics of the panchromatic band closely match those of the discarded Intensity band. Unfortunately, this may not be true. Landsat provides the most common example of this type of panchromatic band.

The Landsat panchromatic band is sensitive to light in the 0.52μ to 0.92μ wavelength range. Visible light spans the 0.45μ to 0.69μ wavelength range. As a result, substituting the panchromatic band for the Intensity band before reverse-transforming back to red-green-blue (RGB) color space can cause noticeable and often severe spectral distortions in the resulting pan sharpened image, especially in areas of high Near Infrared (NIR) reflectivity like grasslands and other narrow-leaf vegetation for example. The methods described in the previous sections address this problem by using the NIR band 5 to adjust the panchromatic band before substituting. These methods can produce very acceptable results. However, none of them is perfect because while NIR adjustment can correct for panchromatic NIR sensitivity, it cannot provide the missing blue band (0.45μ - 0.515μ) information.

ELIN takes a different approach. This algorithm replaces the panchromatic band with a synthesized panchromatic (SPAN) band that has virtually zero spectral distortion. When the SPAN band is substituted for the Intensity band, the reverse transformation from HSI color space to RGB color space occurs with a similar lack of spectral distortion. The result is often a pan sharpened image that matches the low resolution RGB image color tones almost exactly.

The following set of images demonstrates the advantages of ELIN. The first image is a subset from a Landsat scene L71001086_08620051201_BXX.TIF RGB color composite image from band1, band2 and band 3. Immediately after it is the corresponding pan sharpened image using the HSI transform method.



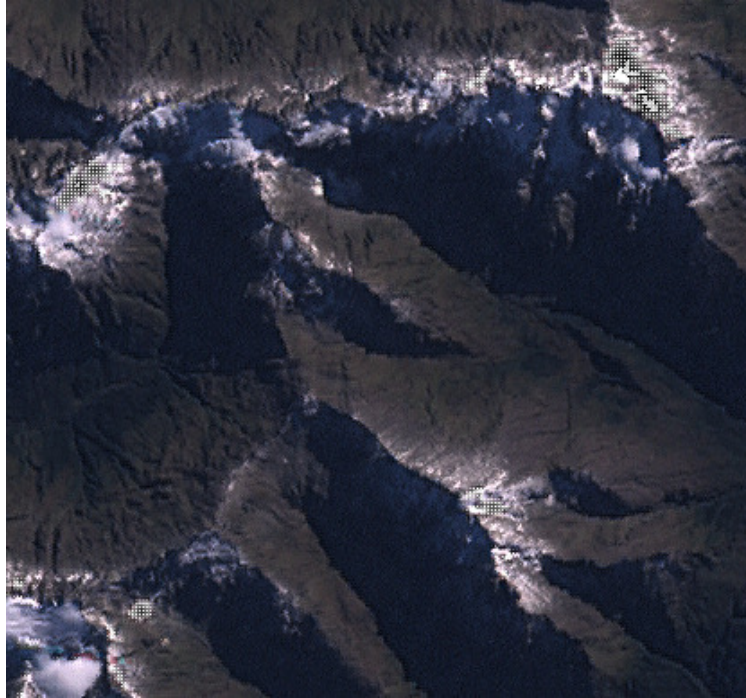
This image is very sharp but shows some severe color distortions in the vegetated areas (other than dense forest). The final image is one made using the HSI transform method with ELIN local optimization activated.



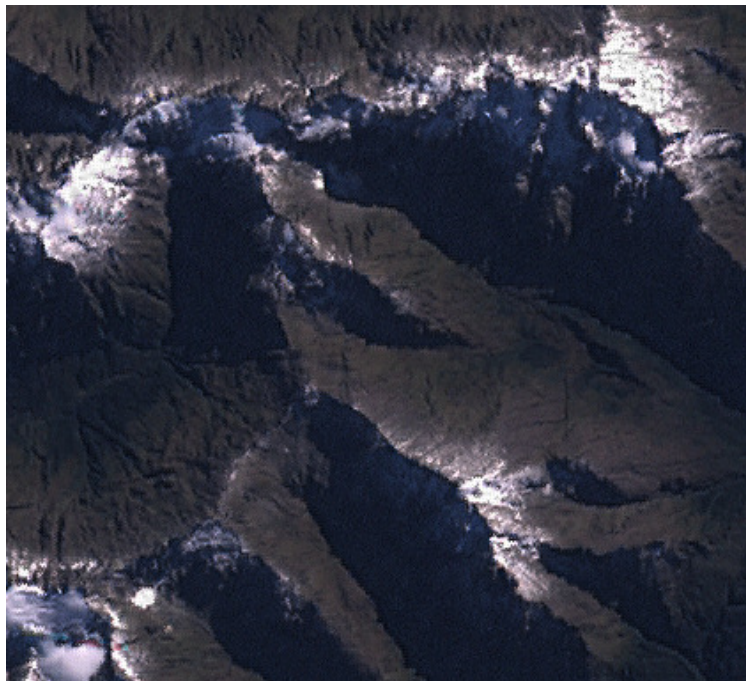
The color tones of this image match those of the reference low resolution RGB color composite almost exactly. The vegetation tones in particular match very well.

Because creating the SPAN is very computation intensive, ELIN runs can require significantly more processing time than the transformation methods discussed in previous sections. However the excellent results, especially for Landsat may be well worth the extra processing time.

IMPORTANT NOTE: Regions of high contrast can cause ringing effects with the ELIN algorithm, for example, areas with snow cover. An example of such an effect is shown in the image below.



The effect can be mitigated by using the Snow and Glare Reduction Group on the Image Processing Input Box to selectively cut down the glare. Doing so with the test image resulted in a mitigation of the effect as shown in the processed image below.



32. RGB Color Image Batch File Processing

PANCROMA™ provides a utility for processing GeoTiff or L1G files batch-wise. That is, you can queue up as many Landsat (or SPOT) band file sets as you want and then instruct **PANCROMA™** to construct the RGB color composite images. In order to do this, you must of course download the sets of band data necessary for constructing the images. It is not necessary that the files be all GeoTiff type or all L1G type. (Of course each band file for a particular image must match.) So for example, you could download the following six files into a directory:

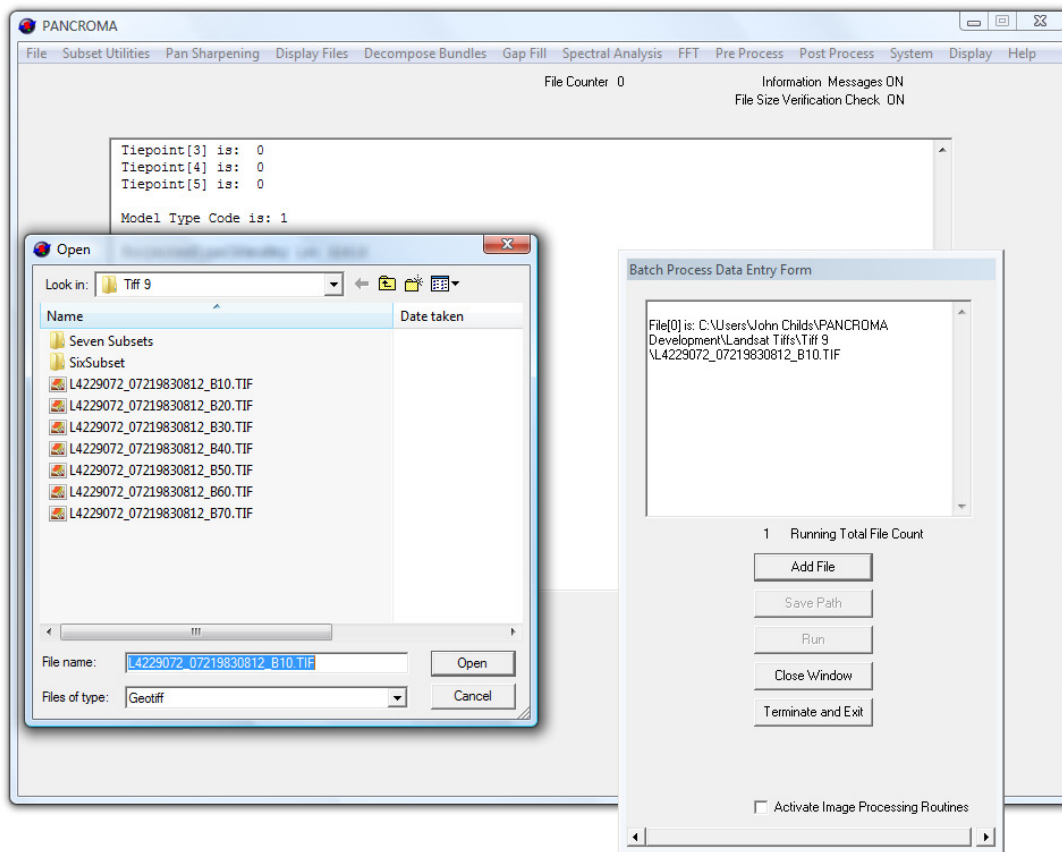
p001r051_7t20011104_z20_nn10.tif
p001r051_7t20011104_z20_nn20.tif
p001r051_7t20011104_z20_nn30.tif

and

L71004071_07120000412_B10.L1G
L71004071_07120000412_B20.L1G
L71004071_07120000412_B30.L1G

Each set of L1G files must have the accompanying metadata file and the metadata file must reside in the same directory as the associated band files. In order to process the two groups batch wise, select 'Display Files' | 'Batch Process RGB True Color Composite ETM+' | 'Batch Process'. You will be prompted to enter some data by the appearance of a dialog box. Two of the buttons will be enabled. Choose 'Add File' to add band files to the queue and 'Cancel' to interrupt the operation.

When you select the 'Add File' button a familiar Windows open dialog box will appear that will allow you to browse to the directory where your files are stored. After doing so, select the first blue band and select 'Open'. The first band file will be added to the queue and its name will appear in the text box of the data entry dialog box.



Add the green band and the red band the same way. Now you are ready to add the band data for the second file. Just repeat the above operation, choosing the second group in the order shown above. You will notice that after every third band file the 'Save Path' button will become enabled. Saving the path tells **PANCROMA™** where to store the processed graphics files. In order to do so you must provide a root file name.

Each processed file will be given a unique name equal to the base name plus an index. Note that you only click the 'Save Path' button one time after you are finished adding all of your band files to the queue. Activating the 'Save Path' button disables the 'Add File' button so you will be unable to add more files and will have to start over again. You can choose JPEG, TIF or PNG format. If you wish to set the image processing parameters, check the 'Activate Image Processing Routines' check box.

Once you have saved the path you can click the 'Run' button. If you have checked the 'Activate Image Processing Routines' check box the data input box will appear on the screen. Make any adjustments that you wish, for example setting haze reduction. Keep in mind that any settings that you select will apply to all of the images in the batch queue. Select the 'Process Image' button if the image processing data input box is visible. Run progress will be displayed on the diagnostic screens and you will be notified of a successful run. If there is a

problem with an input file it will be logged on the data screen. The Batch Process RGB Data Entry Form will stay open throughout the run. You can close it by clicking on the 'Close Window' button.

33. Pan Sharpen Batch File Processing

PANCROMA™ also offers the ability to pan sharpen GeoTiff or L1G files in a batch-wise mode. This can be very useful if you need to pan sharpen a large number of files especially on a slower computer. In this case you can queue up the input Landsat (or SPOT) files and let the program run unattended or overnight.

You can process either Landsat or SPOT (2X) band ratios in any of the standard **PANCROMA™** input file formats. Alternatively you can process standard Digital Globe (4X) band ratios as long as the input files are GeoTiff format.

The procedure is very similar to the process described in the previous section for batch processing RGB color composite files. Start by selecting 'Pan Sharpen' | 'Batch Process Pan Sharpen Files' | 'Batch Process' and then select either 'Batch Process Four Files Standard Method', 'Batch Process Five Files XIONG Algorithm' or 'Batch Process Five Files AJISANE Algorithm'. The first pan sharpens the three visible band files plus the panchromatic file while the latter two pan sharpen visible band files, the panchromatic file plus the NIR band using the XIONG or AJISANE algorithms. If you are pan sharpening four files, input them in the normal order: blue, green, red, and panchromatic. If you are pan sharpening five files, input blue, green, red, panchromatic and NIR.

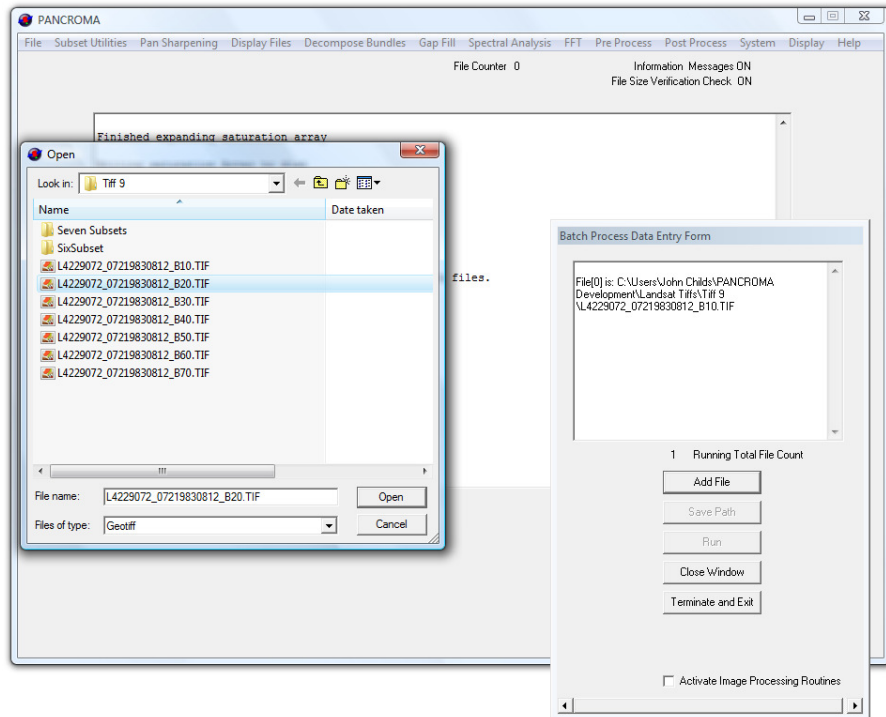
IMPORTANT NOTE: You must open the files in the specified order or an error message will result.

Select the 'Add File' button. A familiar Windows open dialog box will appear that will allow you to browse to the directory where your files are stored. After doing so, select the first (blue) band and select 'Open'. The first band file will be added to the queue and its name will appear in the text box of the data entry dialog box.

Successively add groups of four band files, i.e. the three color bands plus the panchromatic band. When you have added all of your groups, select 'Save' from the batch entry form. (The 'Save' button will only be enabled after every fourth file entry.) When the save dialog appears, enter or select a root output file name. This name will again be the root name to which a run number will be appended after each run.

You can choose either JPEG, TIF or PNG format. As mentioned in previous sections, beware of JPEG format as computers with lesser memory resources will throw an 'out of memory' exception when processing full size Landsat files. Use PNG format instead if this occurs. If you wish to set the image processing parameters, check the 'Activate Image Processing Routines' check box.

Once you have saved the path you can click the 'Run' button. If you have checked the 'Activate Image Processing Routines' check box the data input box will appear on the screen. Make any adjustments that you wish, for example setting the XIONG scale factor. Keep in mind that any settings that you select will apply to all of the images in the batch queue. Select the 'Process Image' button if the image processing data input box is visible. Run progress will be displayed on the diagnostic screens and you will be notified of a successful run. If there is a problem with an input file it will be logged on the data screen.



When your run has finished, close the session by selecting the 'Close Window' button. After selecting the 'Close Graphics Window and Reset' menu selection you will be ready for another processing operation. Selecting the 'Terminate and Exit' button will exit the program.

34. Working with SPOT® Data

In general, SPOT medium resolution images can be processed exactly as Landsat images are. The band files can be combined to produce color images and the panchromatic image can be combined with the band files to produce pan sharpened images. The major difference between SPOT and Landsat are the sensors. SPOT bands 1, 2, 3 and 4 are approximately equivalent to Landsat bands 2, 3, 4 and 5. As a result, you will not get a true color RGB image using SPOT bands by directly combining the first three bands as in Landsat.

SPOT-5 SATELLITE SENSOR CHARACTERISTICS

Launch Date	May 3, 2002
Launch Vehicle	Ariane 4
Launch Location	Guiana Space Centre, Kourou, French Guyana
Orbital Altitude	822 kilometers
Orbital Inclination	98.7°, sun-synchronous
Speed	7.4 Km/second (26,640 Km/hour)
Equator Crossing Time	10:30 AM (descending node)
Orbit Time	101.4 minutes
Revisit Time	2-3 days, depending on latitude
Swath Width	60 Km x 60 Km to 80 Km at nadir
Metric Accuracy	< 50m horizontal position accuracy (CE90%)
Digitization	8 bits
	Pan: 2.5m from 2 x 5m scenes
	Pan: 5m (nadir)
Resolution	MS: 10m (nadir)
	SWI: 20m (nadir)
	Pan: 480-710 nm
	Green: 500-590 nm
Image Bands	Red: 610-680 nm
	Near IR: 780-890 nm
	Shortwave IR: 1,580-1,750 nm

However it is possible to produce reasonable natural color images using a **PANCROMA™** utility to synthesize the natural color bands from the false color bands. This utility is described in the manual section on image processing SPOT data.

Another difference is file format. The most recent SPOT data is archived in DIMAP format, which is SPOT Imaging Corporation's designation for GeoTiff 1.0. Orthorectified SPOT images obtained from Canada's GeoBase repository are also formatted in GeoTiff, although the source or raw imagery is archived in the older CAP format. At this time **PANCROMA™** is not capable of reading CAP although it can read all of the SPOT GeoTiff data just like Landsat. SPOT images are also available from the USGS Earth Explorer website. These images are archived in false color RGB format. However SPOT bands 1, 2 and 3 can be extracted by decomposing these files using a **PANCROMA™** utility. Once extracted and saved, the band file can be used exactly as those downloaded directly from the GeoBase website. To extract the band files from SPOT data see the section on decomposing SPOT data below.

Creating SPOT Band File Images

In order to combine SPOT band images directly, process the data exactly as described in the 'Processing Data - RGB True Color Image' section in this manual. That is, Select 'File' | 'Open'. Select your desired file type (SPOT is not archived in .jpeg or .L1G format). Successively select and open the desired bands. GeoBase SPOT files will have the suffix have ... m20_1_utm10.tif', ... m20_2_utm10.tif', ... m20_3_utm10.tif', ... m20_4_utm10.tif'. A full file name in the UTM coordinate system will look like 'S4_11930_5531_20060629_m20_4_utm10.tif'. As you add the files, their names will be echoed on the diagnostics/dialog box.

Once all three files are opened, the appropriate menu selections and check boxes will be activated on the main screen as before. Select 'Display Files' | 'Generate RGB Composite'

IMPORTANT NOTE: The 'Generate RGB Composite' will produce true *color* images when Landsat data is input and *false color* images when SPOT band files are input. This menu selection would be better named 'Direct Band Combination'.

After the file is processed, the image will be displayed and you can save it to disk as described previously.

Creating SPOT Natural Color Images

Although SPOT band files are very useful, you may need SPOT images that have more natural color, for example for overlaying to create terrain models. To obtain such images, open SPOT bands 1, 2 and 3 in order as usual. Then select 'Display Files | Generate RGB True Color Composite from SPOT'. This menu selection invokes an algorithm that processes the band data to produce more natural looking images. See Section 47 in this manual for instructions for using

the special image processing utilities in order to produce acceptable synthetic true color images from SPOT data.

Creating SPOT Pan Sharpened Images

SPOT sensors also produce a 10m-resolution panchromatic band file. This can be combined with the four 20m band files in order to produce pan sharpened pseudo color images. The process for doing this is exactly the same as that described previously for Landsat images, except of course that you must open the appropriate SPOT bands instead of Landsat bands. You can use any three of the four 20m bands plus the 10m panchromatic band. The data set for my example file would look like this:

```
S4_11930_5531_20060629_m20_1_utm10.tif  
S4_11930_5531_20060629_m20_2_utm10.tif  
S4_11930_5531_20060629_m20_3_utm10.tif  
S4_11930_5531_20060629_p10_1_utm10.tif
```

the latter band being the panchromatic. The main difference in pan sharpening SPOT data is that the files are smaller so that they process faster. The GeoBase SPOT data is of exceptionally high quality and produces very impressive pan sharpened images.

Decomposing Earth Explorer SPOT RGB Images

It is possible to download 20m RGB SPOT composited images from the Earth Explorer website. These images cover all of the United States. Unfortunately, the panchromatic data is not available from this source, nor is the band 4 data. However the band 1, 2 and 3 files can be easily extracted from the color RGB file. **PANCROMA™** provides a utility for doing this. Once extracted and saved to disk, the bands can be recombined to produce true color composites using the utility described above, or recombined in other ways or with data obtained from other sources.

To decompose an RGB file, open the file and select 'Display Files' | 'Display One Color Composite Image' from the menu. Doing so will automatically generate both the false color image (as downloaded from Earth Explorer) and the three grayscale band files. Save the data in either .jpg or .bmp format.

IMPORTANT NOTE: The color image and the grayscale band files must be saved in separate operations. To save the color image, select 'File' | 'Save RGB Image' and then choose either .jpg, .bmp or .png format. To save the band files, select 'Save Grayscale Image' and select either .jpg or .bmp format. All three band files will be saved in a single operation. Suffixes '1', '2'. And '3' will be appended to the file name that you assign.

Now you can reload the images singly and recombine the bands in any order you wish. Alternatively, you can create a true color image by selecting the 'Band Combination | Generate RGB True Color Composite from SPOT' menu selection as described above.

Pan Sharpening Landsat with SPOT

It is possible to pan sharpen Landsat multispectral band files using the SPOT panchromatic band. The advantage is that Landsat; unlike SPOT has a blue band, so natural RGB color images are easy to produce. The SPOT panchromatic band has 50% higher resolution than Landsat, so combining the two allows you to produce excellent quality 10m RGB color images. A complete tutorial on this technique is shown on the www.PANCROMA.com/Pan%20Sharpen%20Landsat%20with%20Spot.html webpage.

35. Working with ASTER Data

ASTER L1B data for all of the United States can be downloaded at no cost from the LP DAAC Data Pool at https://lpdaac.usgs.gov/lpdaac/get_data/data_pool.

Vgroup Data Fields/ Spectral Range (μm)	Units	Data Type	Valid Range	Telescope Pointing Capability
VNIR (15 Meters)				
Band 1 (0.52 - 0.60)	w/m ² /sr/microns	8-bit unsigned integer	0 - 255	+/- 24°
Band 2 (0.63 - 0.69)	w/m ² /sr/microns	8-bit unsigned integer	0 - 255	+/- 24°
Band 3N (0.78 - 0.86)	w/m ² /sr/microns	8-bit unsigned integer	0 - 255	+/- 24°
Band 3B (0.78 - 0.86)	w/m ² /sr/microns	8-bit unsigned integer	0 - 255	+/- 24°
SWIR (30 Meters)				
Band 4 (1.600 - 1.700)	w/m ² /sr/microns	8-bit unsigned integer	0 - 255	+/- 8.55°
Band 5 (2.145 - 2.185)	w/m ² /sr/microns	8-bit unsigned integer	0 - 255	+/- 8.55°
Band 6 (2.185 - 2.225)	w/m ² /sr/microns	8-bit unsigned integer	0 - 255	+/- 8.55°
Band 7 (2.235 - 2.285)	w/m ² /sr/microns	8-bit unsigned integer	0 - 255	+/- 8.55°
Band 8 (2.295 - 2.365)	w/m ² /sr/microns	8-bit unsigned integer	0 - 255	+/- 8.55°
Band 9 (2.360 - 2.430)	w/m ² /sr/microns	8-bit unsigned integer	0 - 255	+/- 8.55°
TIR (90 Meters)				
Band 10 (8.125 - 8.475)	w/m ² /sr/microns	16-bit unsigned integer	0 - 65535	+/- 8.55°
Band 11 (8.475 - 8.825))	w/m ² /sr/microns	16-bit unsigned integer	0 - 65535	+/- 8.55°
Band 12 (8.925 - 9.275)	w/m ² /sr/microns	16-bit unsigned integer	0 - 65535	+/- 8.55°
Band 13 (10.25 - 10.95)	w/m ² /sr/microns	16-bit unsigned integer	0 - 65535	+/- 8.55°
Band 14 (10.95 - 11.65)	w/m ² /sr/microns	16-bit unsigned integer	0 - 65535	+/- 8.55°

ASTER L1B images are archived in HDF format. All bands are contained in a single HDF format file. To access the data, open your ASTER HDF data file one band at a time. Do this by selecting 'ASTER L1B, SPOT VEG HDF, MODIS' from the File Type drop down box and clicking on your ASTER scene. Then select 'Display Files' | 'Display Single Grayscale Band Image'. When the ASTER Band Selection Form becomes visible, select your desired band. Clicking 'OK' will render the band, which you can save in GeoTiff, JPEG or other format.

Once your bands are converted, the bands can be recombined and processed to produce other interesting images. Like SPOT, ASTER sensor lacks the visible spectrum bands necessary for the direct production of true color RGB images. However **PANCROMA™** offers a utility for creating natural color RGB images from ASTER bands 1, 2 and 3N. These are the bands that are composited in the 15m-resolution VNIR ASTER image in the Data Pool data set. To create a

natural color image, first load the VNIR image by selecting select 'File' | 'Open'. Check the 'Generate Band Images' check box. The select 'Display Files' | 'Display One Color Composite Image' from the menu.

Doing so will automatically generate both the false color image (as downloaded from the Data Pool) and the three grayscale band files. Save the band files by selecting 'File' | 'Save Grayscale Image'. Now you can create a natural color image by selecting the 'Band Combination | Generate RGB True Color Composite from ASTER' menu selection. See Section 48 of this Manual for further instructions in using the special image processing utilities needed to produce acceptable synthetic RGB color composite images from ASTER.

ASTER L1B data is also available for most of the earth for a modest fee. You can download the data from the NASA WIST website. At the time of this writing, the cost for an ASTER multispectral scene is \$80 USD.

36. Working with Formosat-2 Data

FORMOSAT-2 is an Earth observation satellite operated by the National Space Organization (NSPO) of the Republic of China (Taiwan). It is a high-resolution photographic surveillance satellite with a daily revisit capability. Images are commercially available from Spot Image.

Products	B&W: 2 m Color: 2 m (merge) Multispectral (R, G, B, NIR): 8 m Bundle (separate Pan and MS images)
Spectral bands	P : 0,45 – 0,90 μm B3 : 0,45 – 0,52 μm (Blue) B2 : 0,52 – 0,60 μm (Green) B1 : 0,63 – 0,69 μm (Red) B4 : 0,76 – 0,90 μm (Near-infrared)
Sensor footprint	24 km x 24 km
Revisit rate	Daily
Viewing angles	Cross-track and along-track (forward/aft): +/- 45°
Pre-processing levels	Level 1A, 2A and Ortho
Delivery	Data are posted on an FTP site within 48 hours of acquisition

[Note that some sources mistakenly state the blue, green and red bands in the wrong order].

Formosat-2 multispectral data is offered in the form of a single GeoTiff file containing four multispectral bands in a multiple bit-plane, Little Endian configuration. Resolution is 8 meters/pixel for the multispectral bands and 2m/pixel for the panchromatic band. The multispectral data must be unbundled into separate band files for processing. (The panchromatic band is offered in a separate file.

In order to perform the extraction, select 'File'-'Open'. Then select 'Decompose Bundles'. Select 'Decompose Four File Digital Globe/GeoEye/Formosat-2 Bundle' menu selection. You will be prompted via a Save Dialog box to enter an output file name. A numerical suffix will be added to whatever name you select, for example 'outputfile1.tif', 'outputfile2.tif', etc. When you accept the file name, **PANCROMA™** will decode the bundle file and write individual band files to the

directory that you designated. Band3 will be the (blue) band, band2 the (green), band 1 the red band and band 4 the NIR band.

An example Formosat-2 RGB image is shown below.



The panchromatic band is archived in a separate GeoTiff image. An example pan sharpened image using the three visible multispectral bands and the panchromatic band is shown below.



37. Working with EO-1 ALI Data

The NASA EO-1 (Earth Observing-1) satellite was launched on November 21, 2000 from Vandenberg Air Force Base, California. The satellite was designed as a prototype for testing new multispectral and hyperspectral hardware concepts for the next generation Landsat platform. EO-1 carries two sensors. The Advanced Land Imager (ALI) is a multispectral sensor sampling a spectrum that ranges from 0.43 to 2.40 microns. Its bands resemble those of Landsat in many respects. Hyperion is a hyperspectral sensor, meaning that its bands continuously span the same spectrum from 0.43 to 2.40 microns. The characteristics of the two sensor suites are summarized in the following table:

Mode:	Hyperion	ALI	
		Multispectral	Panchromatic
Spectral bands (mkm):	0.43-2.40 (220 bands)	0.433-0.453 0.450-0.515 0.525-0.605 0.630-0.690 0.775-0.805 0.845-0.890 1.200-1.300 1.550-1.750 2.080-2.350	0.480-0.690
Spatial resolution:	30 m	30 m	10 m
Swatch Width:	7.7 km		
Data transmission rate:	105 Mbits/sec		
Radiometric resolution:	16 bits per pixel		
Revisit time:	16 days (depending on altitude)		

EO-1 ALI data is offered free of charge at the USGS Earth Explorer and GLOVIS websites. The data may be accessed by selecting the EO-1 ALI check box and searching the UI map. Although about 60,000 ALI images have been captured and archived, global coverage is far from complete. Some regions (for example populated areas of North America and Europe) are fairly well covered with multiple scenes of the same location. Other areas are covered very sparsely. This is a major and serious drawback for this data set.

ALI data is similar to Landsat with a few differences. The first major difference is the dynamic range of the ALI data: 16 bits versus 8 bits for Landsat. In order to be displayed as an image by standard desktop computing equipment, the 16 bit data must be scaled to accommodate an 8-bit grayscale or RGB color model. **PANCROMA™** handles this the same way it handles 11 bit Digital Globe data, by scaling by a ratio of $255/\text{MAX_VALUE}$ where MAX_VALUE is the largest DN value in the image.

Alternatively every DN can be divided by successive multiples of two (bit shift). The former is the **PANCROMA™** default while the latter can be accomplished by checking the 'Bit Shift Enable' check box on the **PANCROMA™** Image Processing Data Input screen. In either case, after extracting all of the band files from the .tar.gz file, each band must be loaded ('File' | 'Open' | 'Display Files' | 'Display Single Grayscale Image'), scaled ('Activate Image Processing Routines' check box or alternatively accept default method), and then saved to disk after scaling.

The second difference is the number and arrangement of the band files. Landsat has 8 30m multispectral bands plus a 15m panchromatic band. ALI has 9 30m multispectral bands plus a 10m panchromatic band. As a result, bands 3, 4 and 5 correspond to Landsat bands 1, 2 and 3 while ALI band 1 (panchromatic) corresponds to Landsat band 8.

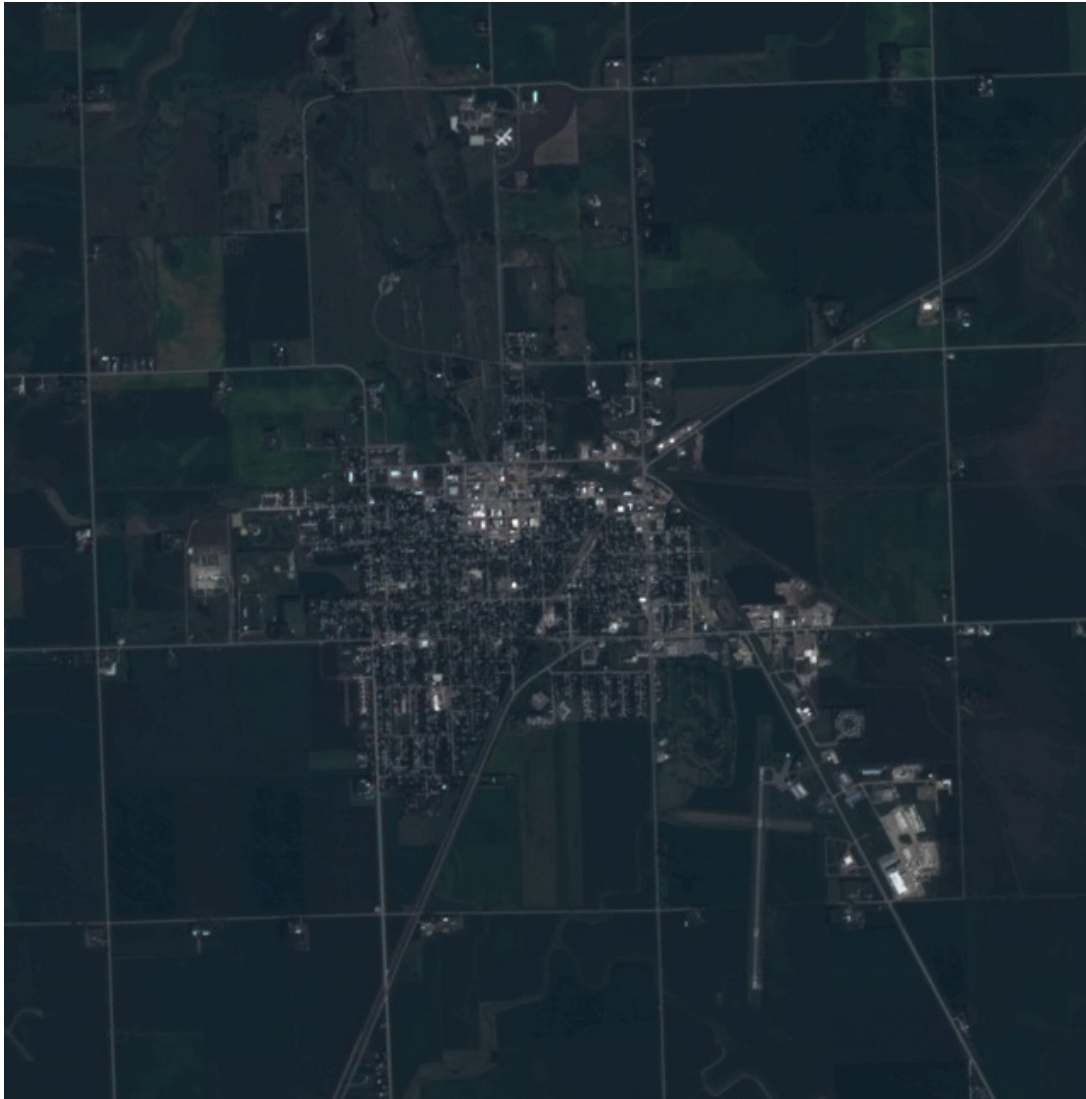
The ALI multispectral bands are not even multiples of the panchromatic band. As a result, all of the band files (both multispectral and panchromatic) must be decreased by exactly one row and one column. You can accomplish this using the **PANCROMA™** 'Pre Process' | 'Rescale' | 'Rescale Three Images' and 'Pre Process' | 'Rescale' | 'Rescale Single Image' selections.

After resizing, you can pan sharpen the multispectral band files as usual. Since the panchromatic band is three times the resolution of the multispectral bands, the Laplacian interpolation will be the default and it will be necessary to use the appropriate number of iterations (at least 40) to process the hue and saturation images. Note that since the panchromatic band spectral range exactly matches the combined range of the RGB bands, NIR processing techniques such as XIONG and ENHG are not generally helpful.

IMPORTANT NOTE: EO-1 files must be individually converted from 16-bit to 8-bit format before subsequent processing. It is not possible to open multiple EO-1 files and directly create a RGB color composite, for example.

IMPORTANT NOTE: The simple nearest neighbor interpolation that is the default for Landsat processing will not work for the 3:1 size ration of EO-1 ALI. Laplacian interpolation is the default with 40 iterations. If you wish to increase or decrease the iterations you should check the 'Activate Image Processing Routines' and modify the 'Interpolation Method' data entry panel.

The image below is a 10m pan sharpened subset using bands EO-1 ALI bands 3, 4, 5 and the panchromatic band and the standard HSI pan sharpening algorithm with non-linear histogram matching. Forty Laplacian interpolation iterations were used. The band files were pre-processed using the **PANCROMA™** HOT haze reduction algorithm.



A few words about this impressive image. At 10m resolution it is 50% better than the corresponding Landsat image as the EO-1 platform has a 10m panchromatic band. In addition, the spectral fidelity is excellent because the spectral range of the EO-1 panchromatic sensor more closely matches the visible spectrum than the Landsat panchromatic band. This is what Landsat 8 should have been. Unfortunately, its panchromatic band, after ten years of development, will be no better than that of Landsat 7 launched in the 1990s.

38. Working with Digital Globe® Data

Digital Globe is a leading commercial provider of satellite imagery. Their products are offered in a variety of resolutions and GeoTiff file format variants. Sample files are offered for download at the Digital Globe pages at <http://www.digitalglobe.com/product-samples>. These products include the WorldView 1, WorldView2, and Quickbird brand names. The various products are offered in both 8-bits and 11-bits per pixel images; unbundled and 3, 4 and 8 file bundles using separate planar configurations in Big Endian byte order. **PANCROMA™** can read all of the files offered for download on the Digital Globe sample image download site. There may be additional configurations not offered on the download page that **PANCROMA™** cannot read. If you happen to encounter one, please contact us and we will try to accommodate your needs.

Digital Globe offers multispectral VNIR band data and panchromatic files suitable for pan sharpening. These are offered as two GeoTiff file sets. One file contains only the panchromatic band with a resolution typically four times that of the multispectral bands. The multispectral bands are all in a single file, either written as separate bit planes or interleaved. In order to use the multispectral bands, you must first extract them from the bundled GeoTiff file and save them as individual band files. Once they are extracted they can be handled exactly as Landsat or SPOT® files.

Spectral Characteristics (nanometers)									
	Coastal	Blue	Green	Yellow	Red	Red Edge	Near-IR1	Near-IR2	Pan (B&W)
QuickBird		430-545	466-620		590-710		715-918		405-1053
WorldView-1									397-905
WorldView-2	396-458	442-515	506-586	584-632	624-694	699-749	765-901	856-1043	447-808

WorldView2 Imagery

In order to perform the extraction, select 'File'|'Open'. Then select 'Decompose Bundles'. **PANCROMA™** will detect whether the input file contains either a four file or an eight file bundle. If four file, the 'Decompose Four File Digital Globe Bundle' menu selection will be enabled. If eight file, the 'Decompose Eight File Digital Globe Bundle' menu selection will be enabled. Once you select one or the other, you will be prompted via a Save Dialog box to enter an output file name. A numerical suffix will be added to whatever name you select, for

example 'outputfile1.tif', outputfile2.tif, etc. When you accept the file name, **PANCROMA™** will decode the bundle file and write individual band files to the directory that you designated. The numbering convention will be consistent with that for Landsat band data, to an extent practical. That is, band1 will be the shortest wavelength (blue) band, band2 the next longer, band 3 the next longer, etc. Make sure to consult the Digital Globe web site for band file specifications as the 8 band WorldView2 files do not match the 8 Landsat bands at all. The blue, green and red bands are band2, band3 and band5, respectively.

Another difference is the dynamic range. Some products are offered with a dynamic range of 11 bits-per-pixel. Since the GeoTiff file format only allows numerical data types that are multiples of 8-bit bytes, 11 bit files are actually recorded as SHORT (16-bit) integers. **PANCROMA™** will resolve the 11 bits into the 8-bit color channels by scaling by $255/\text{maxValue}$, where maxValue is the largest magnitude 11-bit integer in the data file. Quite often most of the pixel values in an 11-bit file are less than 255.

This has the effect of producing a dark image when scaled. As an alternative, **PANCROMA™** allows you to bit-shift the pixel data. (Each bit shift is equivalent to dividing the pixel value by 2). This allows more flexibility in creating images with reasonable overall brightness. To bit shift, check the 'Activate Image Processing Routines' check box on the Main Window. When the image processing data entry window becomes visible, select the 'Bit Shift Enable' check box in the 'Input Channel Adjust Group' and select either 1, 2 or 3 pixels from the Combo Box. Another alternative is to Histogram Stretch the band files after decoding using the 'Pre Process'|'HistogramStretch' menu selection.

IMPORTANT NOTE: WorldView 2 files must be individually converted from 16-bit to 8-bit format before subsequent processing. It is not possible to open multiple WorldView2 11-bit files and directly create a RGB color composite, for example.

Calibrating WorldView2 Imagery

in contrast to Landsat WorldView2, QuickBird and other very high-resolution satellites can acquire images at high off nadir angles. This presents a much longer atmospheric path to the satellite sensors, and can produce a blue-green coloring when RGB images are produced from the band files. Calibrating the images often produces better color results.

The calibration procedure is described in the Digital Globe publication entitled Radiometric Use of WorldView-2 Imagery available at the Digital Globe website. Quoting from this publication: "WorldView-2 products are delivered to the customer as radiometrically corrected image pixels. Their values are a function of how much spectral radiance enters the telescope aperture and the instrument conversion of that radiation into a digital signal. That signal depends on the

spectral transmission of the telescope and MS filters, the throughput of the telescope, the spectral quantum efficiency of the detectors, and the analog to digital conversion. Therefore, image pixel data are unique to WorldView-2 and should not be directly compared to imagery from other sensors in a radiometric/spectral sense. Instead, image pixels should be converted to top-of-atmosphere spectral radiance at a minimum."

Calibration requires multiplication of each grayscale image digital number (DN) by the Absolute Calibration Factor and then dividing it by the Effective Bandwidth. After calibration, each of the grayscale bands must be rescaled to reasonable brightness levels using the same scale factor for each image. The code required for the calibration and scaling and incorporated it into the latest version of **PANCROMA**TM. To calibrate an image you must first obtain the Absolute Calibration Factor (absCalFactor) and Effective Bandwidth (effectiveBandwidth) from the .IMI file that accompanies each WorldView2 data set. Note that each of the eight bands has its own calibration coefficients. Each band must be calibrated using its own calibration coefficients but scaled using a common scale factor.

To calibrate, open a single grayscale image using the 'File|Open' menu selection. After opening the file, select 'Pre Process'|'Calibrate WorldView2 Band'. A data input form will be displayed. Insert the calibration coefficients for the band you are calibrating into the text boxes on the data input form. You can use the default scale factor, or input one of your own. The optimum scale factor can be computed as:

$$\text{Scale Factor} = \text{SUM}(\text{absScaleFactor}) / \text{SUM}(\text{effectiveBandwidth})$$

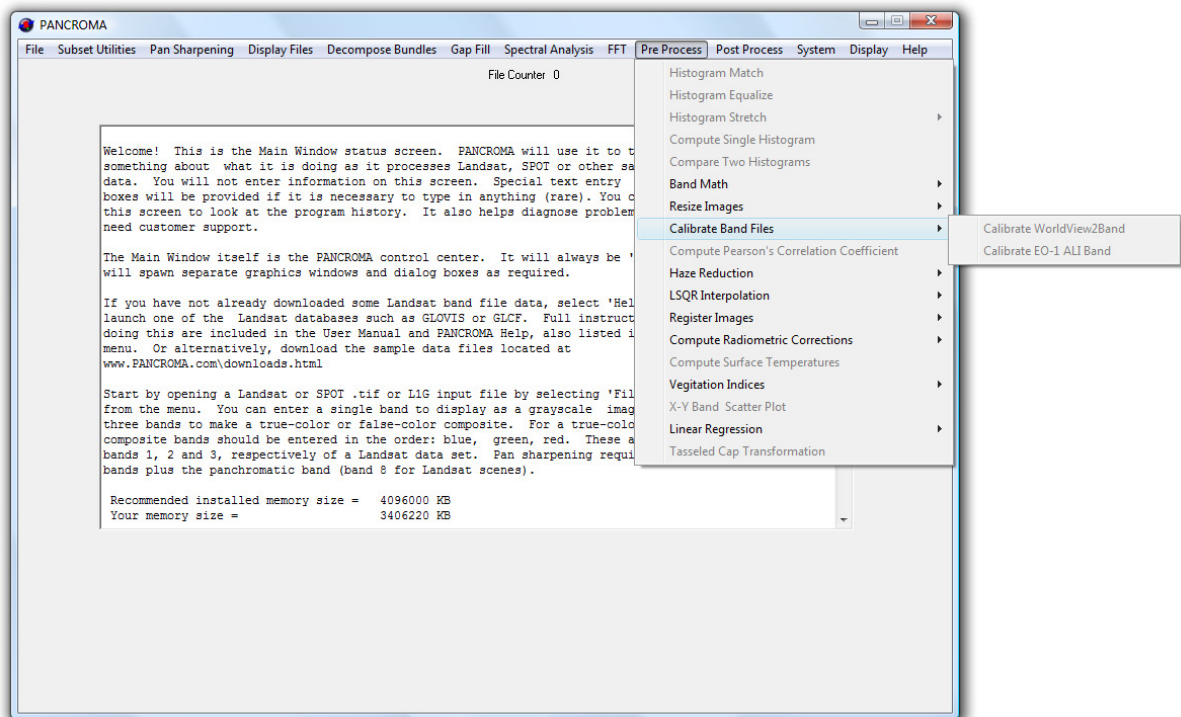
Where

$$\text{SUM}(\text{absScaleFactor}) = (\text{absCalFactor1} + \text{absCalFactor2} + \text{absCalFactor3})$$

And

$$\text{SUM}(\text{effectiveBandwidth}) = (\text{effectiveBandwidth1} + \text{effectiveBandwidth2} + \text{effectiveBandwidth3})$$

After calibrating the band and panchromatic images it is often beneficial to apply a histogram stretch to each of the bands for better contrast. (Note: it is not necessary to stretch the panchromatic band as it will be automatically histogram matched during the pan sharpening operation.)



QuickBird Imagery

Like WorldView2 data, QuickBird multispectral data is offered in the form of a single GeoTiff file containing all the bands in a multiple bit-plane, Little Endian configuration. Resolution is 2.4 meters/pixel for the multispectral bands and 0.6m/pixel for the panchromatic band. The multispectral data must be unbundled into separate band files for processing. (The panchromatic band is offered in a separate file.

In order to perform the extraction, select 'File'/'Open'. Then select 'Decompose Bundles'. Select 'Decompose Four QuickBird Bundle' menu selection. You will be prompted via a Save Dialog box to enter an output file name. A numerical suffix will be added to whatever name you select, for example 'outputfile1.tif', 'outputfile2.tif', etc. When you accept the file name, **PANCROMA™** will decode the bundle file and write individual band files to the directory that you designated. Band1 will be the shortest wavelength (blue) band, band2 the next longer, band 3 the next longer, etc. Consult the Digital Globe web site for band file specifications.

Pan Sharpening WorldView2 and QuickBird Imagery

WorldView2 imagery can be pan sharpened in a manner similar to Landsat. There are a few important differences, however. WorldView2 multispectral band files may not be even multiples of the panchromatic band, but may be off by one

row. Make sure you check this before attempting to pan sharpen. If this is the case you will have to resize the multispectral images to force a match. It is also possible that the multispectral bands are offset by one or two pixels. This can be adjusted using a utility accessed from the Image Processing Data box. The multispectral files are one quarter the scale of the panchromatic image. Laplacian interpolation with more iterations will be necessary than are commonly used for Landsat images. An example WorldView2 pan sharpened image is shown below. More information on pan sharpening WorldView2 data is available in the article entitled "IEEE GRSS Digital Globe Data Fusion Contest" at www.pancroma.com/whitePapers.html

39. Working with GeoEye® Data

GeoEye® is another commercial satellite data source. Data is typically offered in 8-bit and 11-bit per sample images, similar to the Digital Globe® data described in the preceding section. GeoEye® is handled by **PANCROMA™** in the same fashion as described above. Sample data is available from the GeoEye® web site at www.geoeye.com. You are supposed to register your contact information in order to access the sample data but you may be able to get at it directly at http://www.geoeye.com/CorpSite/resource/sample_imagery_response.aspx. PANCROMA is able to handle both the grayscale bundles and the RGB images offered at this site.

The sample data is offered in GeoTiff 8-bit grayscale, 24-bit RGB, 11-bit grayscale (tiled) and 11-bit grayscale with samples-per-pixel=4 (tiled). (The latter means that there are four multispectral band files, R; G; B; and NIR bundled into a single file.) **PANCROMA™** can handle all of these file formats. Although some of the data is tiled rather than stripped, this will make little difference to the user. However the bundled multispectral data must be decomposed into individual band files exactly as described for the Digital Globe data above. You will be prompted for a base file name upon opening this type of file. As before, a suffix will be appended to each band file once they are extracted from the bundled file.

40. Working with Landsat Surface Reflectance Data

As explained in other sections of this Manual, remotely sensed data is used in several different forms. The raw data from satellites is stored as integer Digital Numbers (DNs) with varying formats of quantization. Typical quantization formats are 8-bit, 11-bit and 16-bit. Although an efficient way to store data, these numbers do not correspond directly to any physical parameter.

TOA Radiance is the total amount of electromagnetic energy that the satellite sensor intercepts, usually expressed in terms of watts per steradian per square meter ($W \cdot sr^{-1} \cdot m^{-2}$). TOA Reflectance is the Radiance, corrected for the solar elevation angle and distance from the sun. Such a correction allows for better comparison between images and to archived reflectance spectra.

Surface Reflectance is TOA Reflectance corrected for atmospheric effects. It is the fraction of incoming solar radiation that is reflected from Earth's surface. Surface reflectance approximates what would be measured by a sensor held just above the Earth's surface, without any artifacts from the atmosphere or illumination and viewing geometry. Surface reflectance is the highest quality remotely sensed surface parameter in the solar reflective wavelengths (i.e., visible and infrared), providing the best possible input for virtually all higher-level surface geophysical parameters, for example vegetation indices, albedo, burned area, land cover, prospecting, and land cover change. Removing atmospheric artifacts also increases the comparability between images of Earth's surface taken at different times, making it the most useful parameter for studying change effects.

Landsat surface reflectance data is archived at the GLCF and USGS GLOVIS. **PANCROMA™** supports both formats. The GLCF data is presented as six standard multispectral band files (bands 1, 2, 3, 4, 5 and 7) plus a seventh TIR band. The data is archived in 16-bit integer format. **PANCROMA™** will read the 16-bit data and convert it to 8-bit unsigned integer format (i.e. 256 discrete quantization levels). This is done in order to facilitate memory management and to display the data using a standard 8-bit color model. In order to use surface reflectance data, just open the archived TIFF format files as usual. The surface reflectances can be combined and manipulated in the same way as standard Landsat.

Note that this data often contains anomalously high reflectance values. These can darken the image and also cause the majority of the reflectance values to lose precision (often to two significant decimal figures.)

GLOVIS archives Landsat reflectance data a six-file (Planar Configuration=2) 8-bit bundle format. **PANCROMA™** will decompose this file into six individual 8-bit

band files. To do this you must open the file by selecting 'File' | 'Open'. You will be prompted for an output file base name. PANCROMA will append the band number to the base file name. Now select Display Files' | 'Display Single Grayscale Image' | 'Display Six File Landsat Reflectance Bundle'. **PANCROMA™** will open the file and extract the six multispectral reflectance bands, saving them as described above.

Characteristics of Landsat Reflectance data are shown in the following tables.

Science Data Sets	Units	Bit Type	Fill	Valid Range	Scale factor
Band1 Surface Reflectance	Reflectance	16-bit signed integer	-9999	-2000,16000	0.0001
Band2 Surface Reflectance	Reflectance	16-bit signed integer	-9999	-2000,16000	0.0001
Band3 Surface Reflectance	Reflectance	16-bit signed integer	-9999	-2000,16000	0.0001
Band4 Surface Reflectance	Reflectance	16-bit signed integer	-9999	-2000,16000	0.0001
Band5 Surface Reflectance	Reflectance	16-bit signed integer	-9999	-2000,16000	0.0001
Band7 Surface Reflectance	Reflectance	16-bit signed integer	-9999	-2000,16000	0.0001
Band6 TOA Temperature	Celsius	16-bit signed integer	-9999	-7000, 7000	0.01
Atmospheric Opacity of band1		16-bit signed integer	-9999	-2000,16000	0.0001
Landsat SR QA		16-bit signed integer	-1	0, 32767	N/A

Quality Flags	Description
Bit 0	Unused
Bit 1	Data Quality flag (0=Valid data, 1=Invalid data)
Bit 2	Cloud mask (0=clear, 1=cloudy)
Bit 3	Cloud shadow mask
Bit 4	Snow mask
Bit 5	Land mask (0= water, 1=land)
Bit 6-15	Unused

41. Working with Landsat GEOCOVER Data

In August of 1998, NASA first produced positionally accurate GEOCOVER orthorectified Landsat imagery covering the majority of the Earth's land mass. The Landsat scenes used to create the GEOCOVER-Ortho products were hand selected to provide the lowest cloud cover and highest quality data possible. GEOCOVER combined the best available horizontal and vertical control with detailed manually measured tie points between adjacent imagery to create a highly accurate spatial relationship between the raw Landsat imagery and the surface of the Earth resulting in a positional accuracy of 50 meters root mean square (RMS).

The GEOCOVER 2000 worldwide set of satellite imagery from the Landsat 7 Enhanced Thematic Mapper (ETM+) represents NASA's latest effort. The ETM+ 30m multi-spectral bands 2, 4, and 7 were pan sharpened with the 15m panchromatic band. These Landsat images were then ortho-rectified, georeferenced, and projected in UTM WGS84.

The GEOCOVER data set has several attractive features:

- The images were selected to have exceptionally low cloud cover in most cases
- The orthorectification and georeferencing are of exceptionally high quality, making them very suitable for mapping work
- The images are already pan sharpened to 15m resolution
- Landsat band 2 (green) band 4 (near infrared) and band 7 (medium infrared) are less susceptible to atmospheric scattering than the visible light bands 1, 2 and 3 (blue, green, red) resulting in virtually haze-free images
- The images are stretched so that their dynamic range fully spans the 256 available digital number (DN) levels.

One possible drawback for some applications is the image color. GEOCOVER images display with unnatural vegetation, water and earth tones because of the selected bands as shown in the image below. Modifying these tones to make them appear more natural preserves all of the benefits of GEOCOVER while mitigating this drawback. **PANCROMA™** has utilities for making such spectral transformations.



Orthorectified, pan-sharpened ETM+7/4/2 individual scenes are available from two sources: the NASA 'ZULU' site at <http://zulu.ssc.nasa.gov/mrsid/> and also the USGS Global Visualization Viewer (GLOVIS) at <http://glovis.usgs.gov/>. The ZULU tiles are edge matched and would be ideal for creating natural color mosaics. Unfortunately, when inflated each tile is in excess of 4GB in size, exceeding the limits of the GeoTiff and even JPEG formats. The GLOVIS site archives tiles that are a more manageable size, but they are not edge matched. However, this data can be downloaded directly in GeoTiff format. In order to do so, select 'Collection | Landsat Legacy Collections | ETM+ Pan Mosaics". In order to do so, select 'Collection | Landsat Legacy Collections | ETM+ Pan Mosaics". Select the scene of interest (the north shore of Long Island, NY in the example above. Add it to the list for downloading and then download it to your computer.

Note that GEOCOVER images are considerably larger than pan sharpened Landsat ETM+ scenes. Typical image sizes are around 21,500 by 19,600 pixels equal to around 1.2GB, making processing of these files using the Windows operating system a bit of a challenge. You will need to shut down other

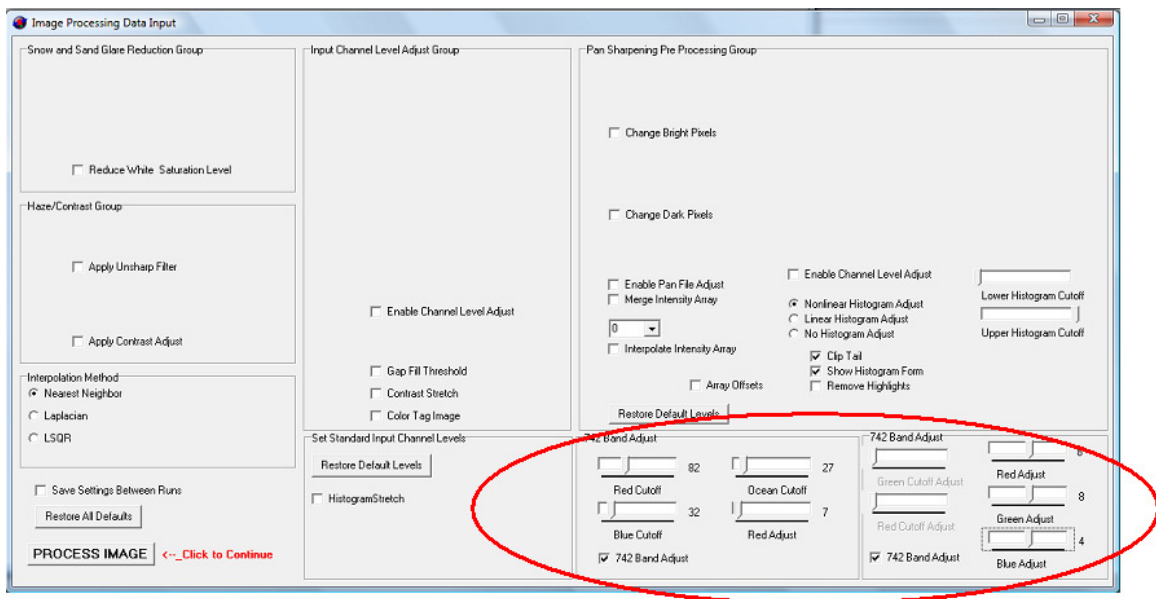
foreground and background applications to process them successfully. After downloading and unzipping your file, you should have a single RGB GeoTiff format image. You can open it and inspect it by selecting 'File' | 'Open' to select your file and then selecting 'Display Files' | 'Display One Color Composite Image'. After inspecting, select 'Close Graphics Window and Reset'. The first step in transforming a GEOCOVER image is to decompose the RGB false color image into its corresponding band files.

To do this select 'File' | 'Open' to select your file. Select 'Decompose Bundles' | 'Decompose Landsat Geocover – Spectral Transformer'. When the color image displays, select 'File' | 'Save Grayscale Image' | 'GeoTiff'. When prompted, supply a root file name. **PANCROMA™** will save the three band files with a '2', '4' and '7' suffix, indicating the Landsat band designation.

You can also do the decomposition manually by selecting 'Display Files' | 'Display Single Composite Image'. Check the 'Generate Band Images' check box and un check the 'Generate RGB Color Composite Image' check box. No images will be displayed in this case. When the processing stops, select 'File' | 'Save Grayscale Image' | 'GeoTiff'. When prompted, supply a root file name. **PANCROMA™** will save the three band files with a '2', '4' and '7' suffix, indicating the Landsat band designation.

The next step is to transform the band2, band4 and band7 files into a synthetic natural color RGB image. To do this, open the three band files, in the above order (i.e. band 2 first) by selecting 'File' | 'Open' in succession. Now select 'Landsat GEOCOVER 742/321 Spectral Transformer'. **PANCROMA™** will read in the three bands, process them, and then display the transformed RGB image. This image can be saved in the standard **PANCROMA™** formats as usual.

The standard image processing settings should work adequately in most cases. However, **PANCROMA™** offers image processing utilities to improve the outcome if this is needed. To access these utilities, check the 'Activate Image Processing Routines' check box on the main menu after selecting your three band files. When the Image Processing Data Input Box appears, check the two '742 Band Adjust' check boxes.



The Red Cutoff, Blue Cutoff and Red Adjust track bars appear in the left data group. This set addresses the inherent lack of red tone in the non-vegetated areas. **PANCROMA™** will increase the red DN value by the amount indicated on the Red Adjust track bar. This amount will be added only to pixels with red DNs *above* the Red Cutoff value and *below* the Blue Cutoff value.

The second adjustment in the left data group is the Ocean Cutoff track bar. **PANCROMA™** will zero the red and green DN values for all pixels with a red DN less than the Ocean Cutoff value. This serves to mask the ocean areas that would otherwise have a green tone if these pixels were not thus processed.

The right data group simply has Red, Green and Blue adjust track bars. The DNs of these channels will be incremented or decremented according to the values on the track bars. The default settings are 8, 8, and 0 for Red, Green and Blue, respectively. A processed section of the above GEOCOVER file is shown below.



GEOCOVER can offer a very attractive option to standard pan sharpened Landsat scenes, and can provide an ideal data set for preparing maps or earth mosaics.

42. Working with WorldWind Elevation Data

The NASA WorldWind SDK site is designed to allow access to the WorldWind database of geospatial information to developers interested in using the information in their applications. It is also possible to download co registered image and elevation data at <http://worldwind.arc.nasa.gov/java/1.2.0/demos/> using one of the demonstration applets posted on the site. After navigating to the page you can access WorldWind data using the 'Exporting Surface Imagery and Elevations' utility. You will need to check some of the relevant data layers in order to best navigate the virtual globe. I found that checking the following layers was helpful:

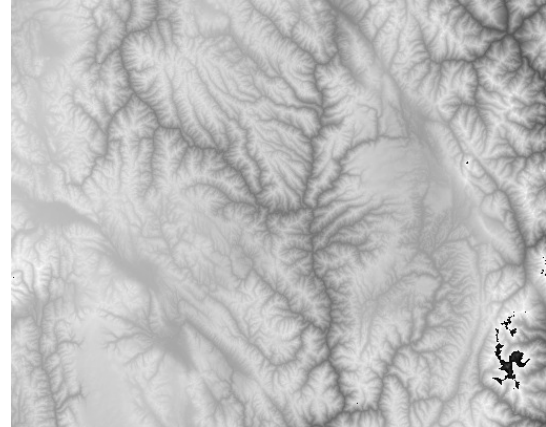
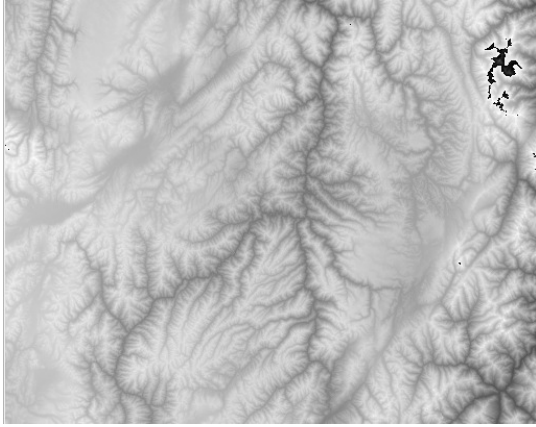
- NASA Blue Marble Image
- Blue Marble (WMS) 2004
- i-cubed Landsat
- MSVirtual Earth Aerial
- USDA NAIP
- USDA NAIP USGS

Note that only the first four data layers are relevant for areas outside of the United States. The USDA NAIP and USGS NAIP USGS data layers seem to have the highest resolution, apparently around 2m. As far as I can tell, the Urban Ortho Image layer and the USGS topographic map data layers have not been implemented in the demonstration applet. An example USGS NAIP image is shown below.



After navigation and selecting your area of interest, you can save both the image file and the elevation files separately. These can be used by other applications like the excellent 3DEM for preparing terrain models by draping the image over the elevation model.

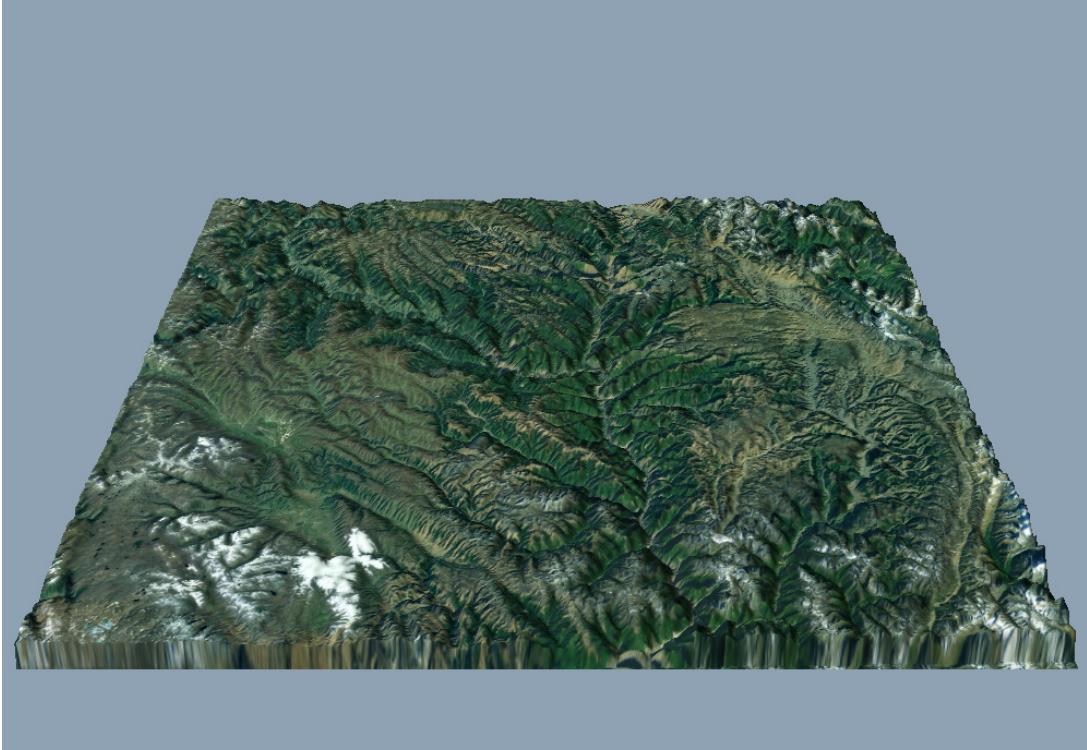
A major issue with this data is that the elevation files are saved mirror flipped around the center latitude line. **PANCROMA™** has a utility for correcting this problem. The elevation data is saved in GeoTiff format using IEEE floating point 32 bit representations for the elevation postings. To produce a corrected file, select 'File' | 'Open' and open the elevation file. Then select 'Display Files' | 'Display GeoTiff IEEE FP 32 Elevation Image' | 'Flipped'. A rendering of the processed file will appear. You can save the file by selecting 'File' | 'Save Grayscale Image' | 'GeoTiff'. The file will be saved as a GeoTiff DEM (not a raster image). Examples of a file as downloaded from WorldWind and a corrected file are shown below.



The satellite image that I downloaded is also shown (this does not have to be flipped):



I draped the satellite image over the flipped DEM using the free 3DEM utility. The results are shown in the following image.



Although not designed as a data source, the NASA WorldWind SDK demonstration applet can provide useful data for many applications.

43. Working with NAIP Data

The National Agriculture Imagery Program (NAIP) acquires aerial imagery during the agricultural growing seasons in the continental United States. The primary goal of the NAIP program is to make digital ortho photography available to governmental agencies and the public.

NAIP image acquisitions are contracted each year for different regions of the country, with the entire country currently being covered during a three-year cycle. The acquisition is timed to result in "leaf-on" imagery. The images are one-meter resolution, orthorectified with a 6-meter ground accuracy. Prior to 2007, three bands corresponding to the visible blue, green and red spectra were collected. After that year, a fourth near infrared (NIR) band was added. Google Earth uses NAIP data extensively as its high resolution layer in the continental USA.

The four band data can be downloaded from the USGS The National Map Viewer and Download Platform. The four bands are bundled into a single file offered in GeoTiff and JPEG2000 format. Instructions for downloading this data are offered at the USGS website. Limited metadata is offered with the images. Sensor data does not seem to be readily available, for example the band sensitivities.

To access NAIP four band data, download your area of interest from the USGS National Map Viewer. The USGS offers a lot of data from this site, but you will want the Orthoimagery product, NAIP 4 Band. Once you download the data according to the instructions on the website, you must unbundle the single file into four separate band files as described in previous sections. To do so select 'Decompose Bundles' | 'Four File NAIP Data' from the Main Menu. When the file opens, you will be prompted for a base file name. Input and save as GeoTiff. The band number designations will be atomically appended to your selected base file name.

The main disadvantage of NAIP data is that it consists of only four bands. The advantage is its coverage and resolution (1 meter). And it is free. For information regarding use of NAIP data for multispectral analysis, see the subsequent sections describing the **PANCROMA™** Point Spectrum Generator™ and Spectral Analyzer™.

44. Working with USGS DOQQ and NAPP Data

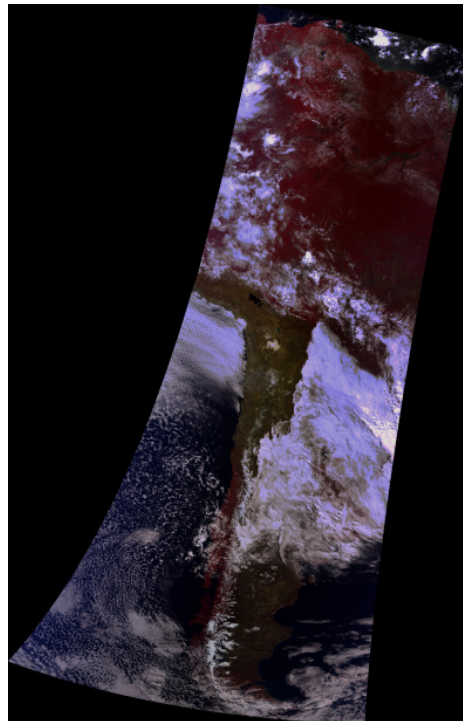
PANCROMA™ also offers an image synthesis utility for converting USGS DOQQ and National Aerial Photography Program (NAPP) to natural color RGB images. Follow the same procedure as described above for processing ASTER images. Load the NAPP image by selecting select 'File' | 'Open'. Check the 'Generate Band Images' check box. The select 'Display Files' | 'Display One Color Composite Image' from the menu. Doing so will automatically generate both the false color image (as downloaded from the Data Pool) and the three grayscale band files. Save the band files by selecting 'File' | 'Save Grayscale Image'. Now you can create a synthetic natural color image by selecting the 'Band Combination | Generate RGB True Color Composite from ASTER' menu selection.

45. Working with VITO SPOT Vegetation Data

The Flemish Institute for Technological Research (VITO) recently has launched a distribution portal for accessing SPOT vegetation data, which offers free access to all vegetation data (P-, global S1 and S10 data) older than three months. You can access the portal at <http://www.vito-eodata.be/>

PANCROMA™ can import SPOT Vegetation data in HDF format. You can open you SPOT HDF data file one at a time. Do this by selecting 'ASTER L1B, SPOT VEG HDF' from the File Type drop down box and clicking on your SPOT scene. Next select 'Display Files' | 'Display Single Grayscale Image' from the **PANCROMA™** menu. Band spectral characteristics are given in the table below.

Spectral Band	Wavelength
B0 (Blue)	0.43-0.47
B2 (Red)	0.61-0.68
B3 (NIR)	0.78-0.89
MIR (SWIR)	1.58-1.75



46. Working with MODIS Surface Reflectance Data

PANCROMA™ can import MODIS surface reflectance data designated MOD09/MYD09 - Surface Reflectance; Atmospheric Correction Algorithm Products from both the Terra or Aqua satellites. The MODIS surface reflectance products are generated from the first two, or seven, bands of the corresponding full 36 band scenes. These provide estimated “at surface” spectral reflectance values. Algorithms are applied to the MODIS bands to remove the effects of cirrus clouds, water vapor, aerosols and atmospheric gases. Global surface reflectance products can be obtained at either 250 m or 500 m spatial resolution, and as daily or 8-day composite images. The seven multispectral bands are centered at 648 nm, 858 nm, 470 nm, 555 nm, 1240 nm, 1640 nm, and 2130 nm, respectively, red, NIR, blue, green, NIR, NIR, NIR). Details of the surface reflectance products are as follows:

MOD09GQ/MYD09GQ - MODIS Surface Reflectance Daily L2G Global 250m

This product has a spatial resolution of 250 m and contains two bands of spectral data centered at 645 nm and 858 nm.

MOD09GA/MYD09GA - MODIS Surface Reflectance Daily L2G Global 500m

This product has a spatial resolution of 500 m and contains seven bands of spectral data

MOD09Q1/MYD09Q1 - MODIS Surface Reflectance 8-Day L3 Global 250m

This product is a composite using eight consecutive daily 250m images. The best observation during each eight day period, for every cell in the image, is retained. This helps reduce or eliminate clouds from a scene. The file contains the same spectral information as the daily file listed above, centered at 645 nm and 858 nm. There is one additional band of data for quality control.

MOD09A1/MYD09A1 - MODIS Surface Reflectance 8-Day L3 Global 500m

This file is a composite using eight consecutive daily 500 m images. Again, the best observation during each eight day period, for every cell in the image, is retained. This helps reduce or eliminate clouds from a scene. The file contains the same seven spectral bands of data as the daily file listed above.

To access the data, open your MODIS HDF data file. Do this by selecting ‘ASTER L1B, SPOT VEG HDF, MODIS 250m, MODIS 500m’ from the File Type drop down box and then clicking on your MODIS scene. Then select ‘Display Files’ | ‘Display Single Grayscale Band Image’. When the MODIS Band Selection Form becomes visible, select your desired band. Clicking ‘OK’ will render the band, which you can save in GeoTiff, JPEG or other format.

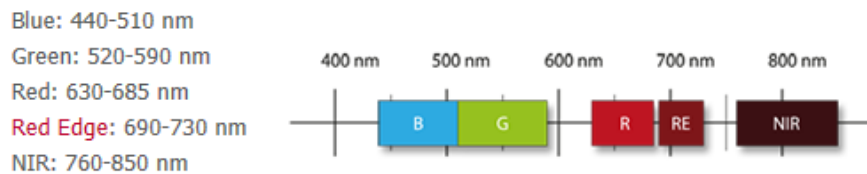
A MODIS band 3, 4, 1 (BGR) color composite image is shown below.



47. Working with RapidEye Data

PANCROMA™ can import RapidEye L3A orthorectified data in GeoTiff format. The RapidEye product has five multispectral bands at 5m resolution available at <http://www.blackbridge.com/rapideye/products/ortho.htm>. The bands are bundled together into a single GeoTiff file and can be decomposed into individual 8-bit or 16-bit multispectral band files using the utility.

In order to perform the extraction, select 'File' | 'Open'. Then select 'Decompose Bundles' | 'Five File L3A RapidEye/Ortho'. You will be prompted via a Save Dialog box to enter an output file name. A numerical suffix will be added to whatever name you select, for example 'outputfile1.tif', 'outputfile2.tif', etc. When you accept the file name, **PANCROMA™** will decode the bundle file and write individual band files to the directory that you designated. The numbering convention will be consistent with that for Landsat band data, to an extent practical. That is, band1 will be the shortest wavelength (blue) band, band2 the next longer, band 3 the next longer, etc. The band specifications are as follows:



PRODUCT ATTRIBUTE	DESCRIPTION
Product Components and Format	RapidEye Ortho image product consists of the following file components: Image File – GeoTIFF file that contains image data and geolocation information Metadata File – XML format metadata file Browse Image File – GeoTIFF format Unusable Data Mask (UDM) file – GeoTIFF format
Product Orientation	Map North up
Product Framing	Image Tile (image tiles are based on a worldwide, 24km by 24km fixed grid system (see Appendix B for full tile grid definition). To each 24km by 24km grid square, a 500m overlap is added to produce a 25km by 25km image tile. Image tiles are black-filled 1km beyond the order polygon used during order placement. Tiles only partially covered by an image take will be also be black-filled in areas containing no valid image data.
Pixel spacing	5m
Bit Depth	16-bit unsigned integers.
Product Size	Tile size is 25km (5000 lines) by 25km (5000 columns). 250 Mbytes per Tile for 5 bands at 5m pixel spacing.
Geometric Corrections	Sensor-related effects are corrected using sensor telemetry and a sensor model, bands are co-registered, and spacecraft-related effects are corrected using attitude telemetry and best available ephemeris data. Orthorectified using GCPs and fine DEMs (30m to 90m posting)
Horizontal Datum	WGS84
Map Projection	Universal Transverse Mercator (UTM)
Resampling Kernel	Cubic Convolution (default), MTF, or Nearest Neighbor

48. Gap Filling a Landsat 7 ETM+ Image

It is possible to use **PANCROMA**TM utilities to fill the gaps in Landsat ETM+ SLC-off (post 2003) imagery. The gap filling procedure requires a *Target* image (the one you are trying to correct, i.e. with gaps) and at least one *Adjust* image (the one you will extract data from to fill the gaps in the Reference image). The Adjust image is often gap-free, but it does not have to be. Because the gaps in two images may not coincide exactly, at least some useful data may be transferred from the Adjust image to the Target image despite possible gaps in both. You will need three Reference bands and three Adjust bands (blue green and red) for each image.

IMPORTANT NOTE: If you decide to use two gapped images rather than one gapped and one gap-free, there are two ways you can fuse the images. It is often useful to experiment to see which substitution direction gives better results.

PANCROMATM currently provides three methods for gap filling a Landsat image. The Transfer method conducts a histogram match between the Adjust and Reference images and then transfers the missing pixels of pixels from the Adjust image to the Reference image. The Hayes method uses an approximation algorithm to reconstruct each missing pixel in the Reference using a comparison between a sliding window sample of Adjust image pixels. The TERAS method uses a local optimization algorithm and a proprietary sliding window algorithm that results in fast processing times.

The Hayes method is a sliding-window method, meaning a small but significant number of computations is required for each pixel in the image. As a result, the Hayes method can be time consuming. In order to help with this, a batch-processing mode is available for Hayes processing. Select 'Gap Fill' | 'Gap Fill Hayes Interpolation Method' | 'Six File Set' to use this utility. When you do so a batch processing data input screen will become available. Add six files in the order: band1 gap, band1 no gap; band2 gap, band2 no gap; band3 gap, band3 no gap by successively clicking on the 'Add File' button and selecting your files from the dialog box.

When all six band files are entered, select 'Save Path'. Select the save file format and the base file name. Then select 'Run'. Processing will take place as in the two file Hayes processing method. As PANCROMA processes each file, it will save the result, appending the band number to the base file name. See the Tutorial section for more information on this utility.

The TERAS method is also a sliding-window routine that uses a proprietary local optimization algorithm. Processing times are similar to the Hayes algorithm and should produce similar results.

The Transfer method processes the fastest of the three. However it is based on a global histogram matching algorithm and usually may not produce as good a match as the Hayes or TERAS. The TERAS often produces the best match.

Gap filling an image is a multi step process requiring first that two sets of exactly matched images be prepared.

IMPORTANT NOTE: Input files must be pre-processed before gap filling so that they are co-registered, have the same corner UTM coordinates, and have the same row and column count. Please see Section 59 for an explanation of how to easily accomplish this in one easy step.

IMPORTANT NOTE: Detailed procedures for gap filling are described in the Tutorials at the end of this Manual. White Papers and instructional videos on gap filling are also available at www.PANCROMA.com.

IMPORTANT NOTE: The 'Compute Common Extents' utility determines the UTM coordinates of the overlap area for two images. Once it does this it copies the coordinates to the coordinate text boxes in the Subset Data Entry form. In order to subset single images to those coordinates, you need to follow that operation by (without exiting the program):

- 1) Selecting 'Close Graphics Coordinates and Reset'. This closes both files but retains the coordinate information in the text boxes.
- 2) Then select 'File' | 'Open' and re-open one of your two files.
- 3) Select 'Band Combination' | 'Subset Images' | 'Subset One Band'. When the Subset Data Entry form becomes visible you should see the corner coordinates already entered. I attached a picture of what the form should look like at this point.
- 4) Select the 'Select by Coordinates' radio button.
- 5) When you select 'Enter' the subset will be computed and displayed.
- 6) Now select 'Close Graphics Window and Reset'.

Repeat steps (2) through (5) for the second image. The UTM coordinates will persist in the text boxes for as many images as you wish to subset.

49. Gap Filling Cloud Masks for Landsat ETM+ Images

Although it is often possible to find a cloud free Landsat scene for a given area, a completely cloud-free image may not be available for your Landsat location of interest and acquisition time. In this case masking the clouds and replacing the masked areas with pixels from a corresponding cloud-free image may be of interest.

PANCROMA™ has two utilities for detecting clouds and for masking the obscured areas. They are included under the 'Gap Fill' menu selection as the filling of the masked areas is done using the Transfer gap fill method described in the previous section and in the following Tutorial.

The first method for creating cloud masks is called the 'Three Band Method'. This technique, as its name implies, requires that three band files be input, and uses information in two of those Landsat bands, the blue band 1 and the thermal band 6 to create a mask directly onto the input band. Clouds are both highly reflective in the short wavelength band 1 and also cold, meaning they will appear darker in the thermal band.

The **PANCROMA™** three-band algorithm is loosely based on the method of Martinuzzi, Gould and Gonzales. It compares the band 1 (blue band) and band 6 (thermal infrared or TIR band) digital numbers (DNs) against user-defined thresholds and classifies each pixel as either cloud or non-cloud. The cloud pixels are set equal to zero and the non-cloud pixels are left alone. The result is a band file with the cloud areas blacked out.

To use the utility, you must input the band file to be masked, then the band 1 file (blue band), and finally the band 6 (TIR) file *in that order, exactly*.

IMPORTANT NOTE: There are typically two band 6 files in an ETM+ data set. If so they will be designated 61 and 62. They differ in the gain setting of the sensor, 61 being the high gain image and 62 the low gain. Higher gain yields greater dynamic range. Lower gain means greater sensitivity (resolution). In this case the resolution of the thermal infrared (TIR) bands 61 and 62 are nominally 60m per pixel, half that of the other multispectral band. In order to perform the mask, the TIR band must be expanded and interpolated to match the size of band 1. **PANCROMA** will expand and interpolate the lower resolution TIR band to match the multispectral bands automatically.

IMPORTANT NOTE: If **PANCROMA™** automatic utility fails to handle the automatic resizing due to an off-by-one condition that it did not anticipate, you may have to manually resize the images so that the band 1 rows and column sizes are exactly twice as large as the TIR row and columns. This can be done

using the **PANCROMA™** 'Preprocess' | 'Resize Images' | 'Resize One Image' utility. Note that in order to get an exact match, you may have to resize *all* of your images downward. The TIR band of the scene used in this example had a row count of 4783 and a column count of 4503. Band 1 had a row count 9566 of and a column count of 9005. In order to get the correct ratio, it was necessary to resize the TIR band to 4783 by 4502 and band 1 (and other masked bands) to 9566 by 9004.

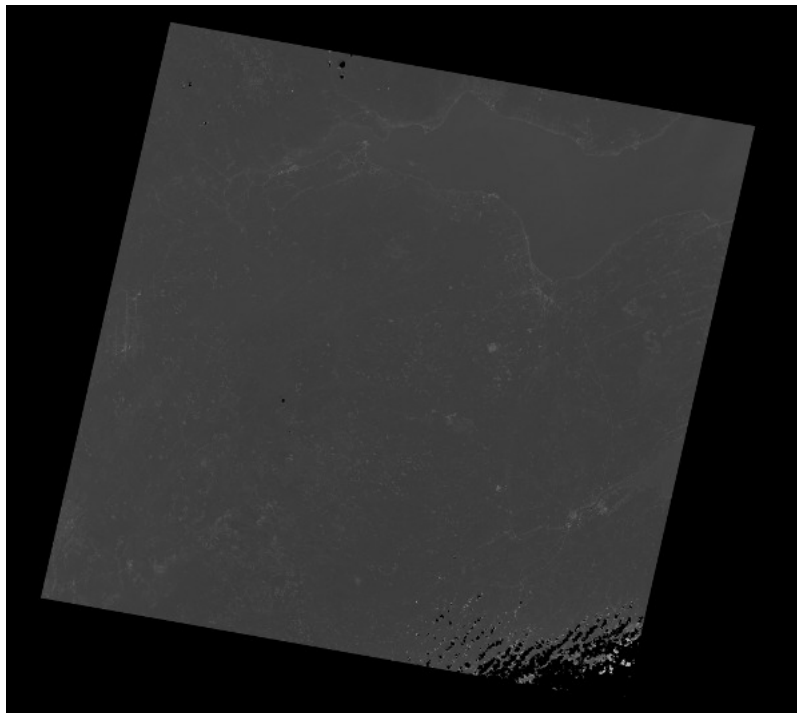
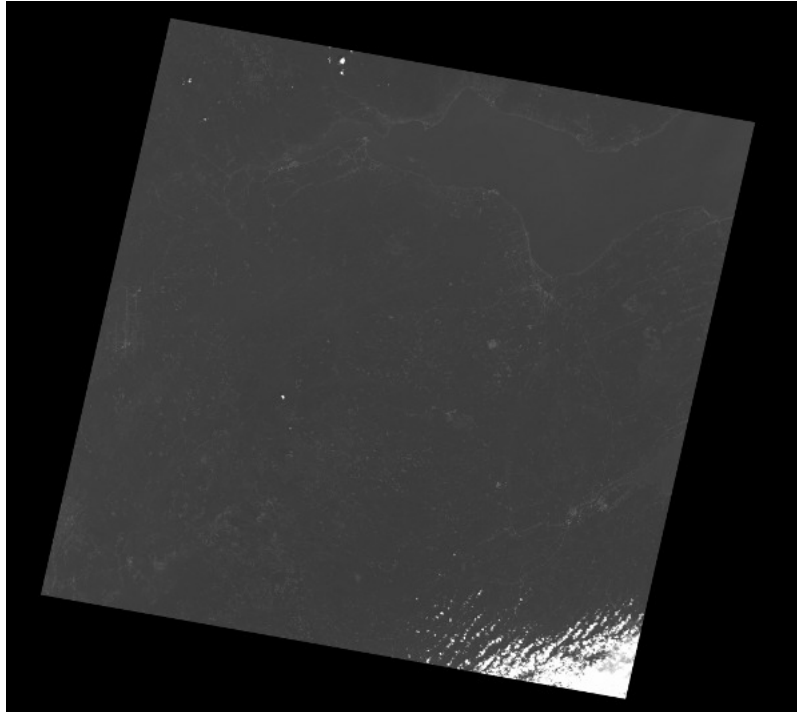
IMPORTANT NOTE: If there is only one TIR band, its resolution will match that of the other multispectral bands exactly.

After adjusting the row and column sizes (if necessary) open the files by selecting the 'Gap Fill' | 'Mask Clouds' | 'Three File Method' menu selection. After reading the three files, you will be presented with a data input box. This box will let you set the two comparison thresholds and the cloud buffer radius. The algorithm will select all pixels with DNs *below* the band1 threshold and above the band6 threshold. You can also set the Cloud Mask Buffer Width. Because the edges of clouds tend to be diffuse, the algorithm will add all pixels within a radius of the Cloud Mask Buffer Width of each selected pixel to the mask.

The thresholds must be determined empirically. This can best be done by inspecting the band 1 image and the TIR image and interrogating it using the cursor to determine the DNs of the cloud areas. Once this is done, the correct thresholds can be estimated. However, it may take some trial-and-error to get acceptable results.

Note that if you wish to mask band 1, you must select the file twice, i.e. 'File' | 'Open' | band1; 'File' | 'Open' | band1; 'File' | 'Open' | band6.

The images below show an input image with clouds followed by the masked image.



The second method is called the Five Band Method. In addition to the band to be masked, it requires that Landsat band 1 (blue), band 3 (red), band 4 (NIR)

and band 5 (MIR) also be input. This algorithm is based on the method of Luo and requires the band DNs be converted to top of atmosphere (TOA) reflectance at the sensor in order to make the computation. The relationship is given by:

$$\text{TOA Reflectance} = (\pi * L_{\lambda} * d^2) / (\text{ESUN}_{\lambda} * \cos \theta)$$

Where

L_{λ} = TOA radiance

d = earth-sun distance in astronomical units

ESUN_{λ} = mean solar exoatmospheric irradiances

θ = solar zenith angle

In order to use this method, select 'File' | 'Open' and input, *in this order*:

band file to be masked;

band 1 file

band 3 file

band 4 file

band 5 file

Select 'Gap Fill' | 'Mask Clouds' | 'Five File Method' from the menu. After the files are opened, you will be prompted to enter the acquisition date of the Landsat image in ordinal days (number of days elapsed into the acquisition year) and the solar elevation angle. This information can be found in the Landsat metadata file, as shown below:

```

GROUP = METADATA_FILE
PRODUCT_CREATION_TIME = 2004-02-12T17:18:09Z
PRODUCT_FILE_SIZE = 863.2
STATION_ID = "EDC"
GROUND_STATION = "SGS"
GROUP = ORTHO_PRODUCT_METADATA
SPACECRAFT_ID = "Landsat7"
SENSOR_ID = "ETM+"
ACQUISITION_DATE = 2002-08-25
WRS_PATH = 196
WRS_ROW = 013
SCENE_CENTER_LAT = +66.5410307
SCENE_CENTER_LON = +18.4119673
SCENE_UL_CORNER_LAT = +67.9989470
SCENE_UL_CORNER_LON = +17.1907324

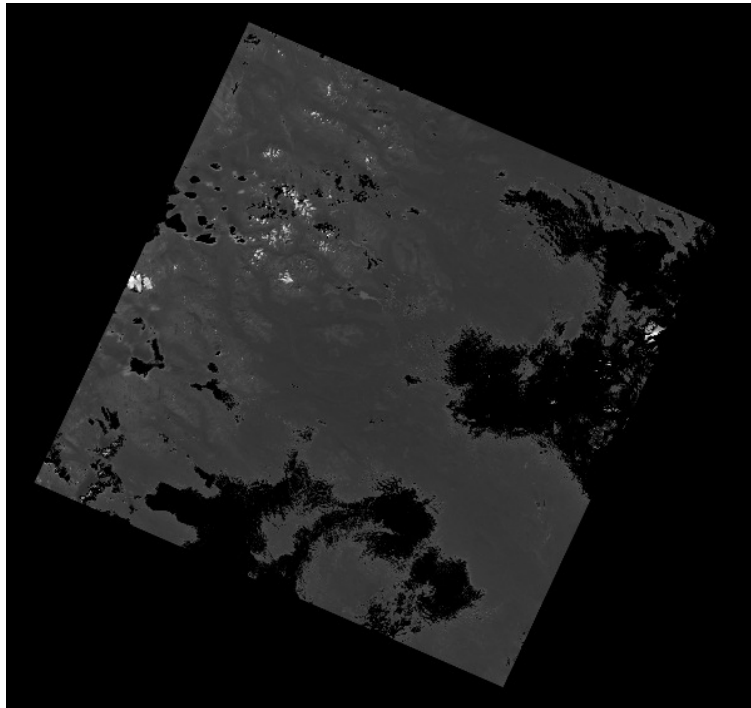
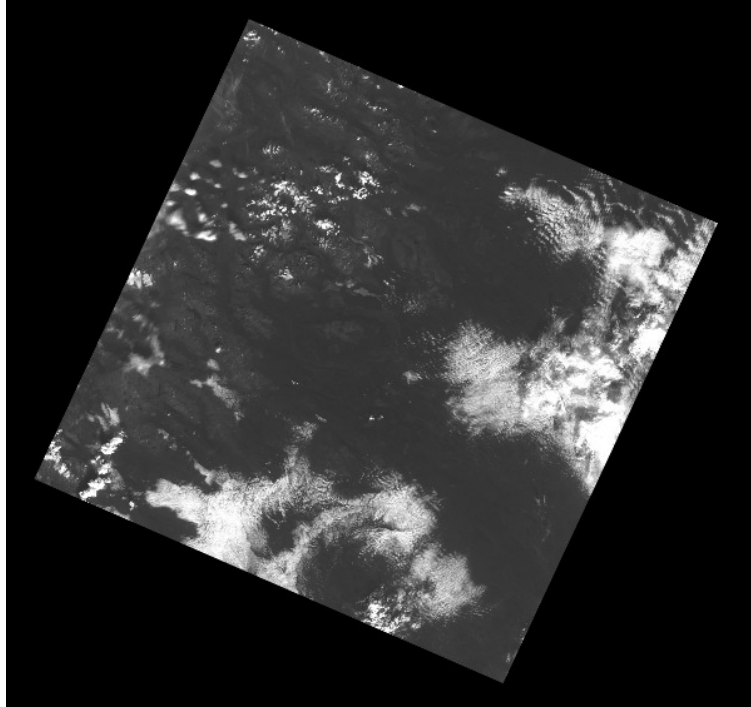
RESAMPLING_OPTION = NN
MAP_PROJECTION = "UTM"
END_GROUP = PROJECTION_PARAMETERS
GROUP = UTM_PARAMETERS
ZONE_NUMBER = +34
END_GROUP = UTM_PARAMETERS
SUN_AZIMUTH = 167.1665033
SUN_ELEVATION = 33.3279271
QA_PERCENT_MISSING_DATA = 0
CLOUD_COVER = 20
PRODUCT_SAMPLES_PAN = 19132
PRODUCT_LINES_PAN = 18010
PRODUCT_SAMPLES_REF = 9566
PRODUCT_LINES_REF = 9005
PRODUCT_SAMPLES_THM = 4783
PRODUCT_LINES_THM = 4503
OUTPUT_FORMAT = "GEOTIFF"
END_GROUP = ORTHO_PRODUCT_METADATA

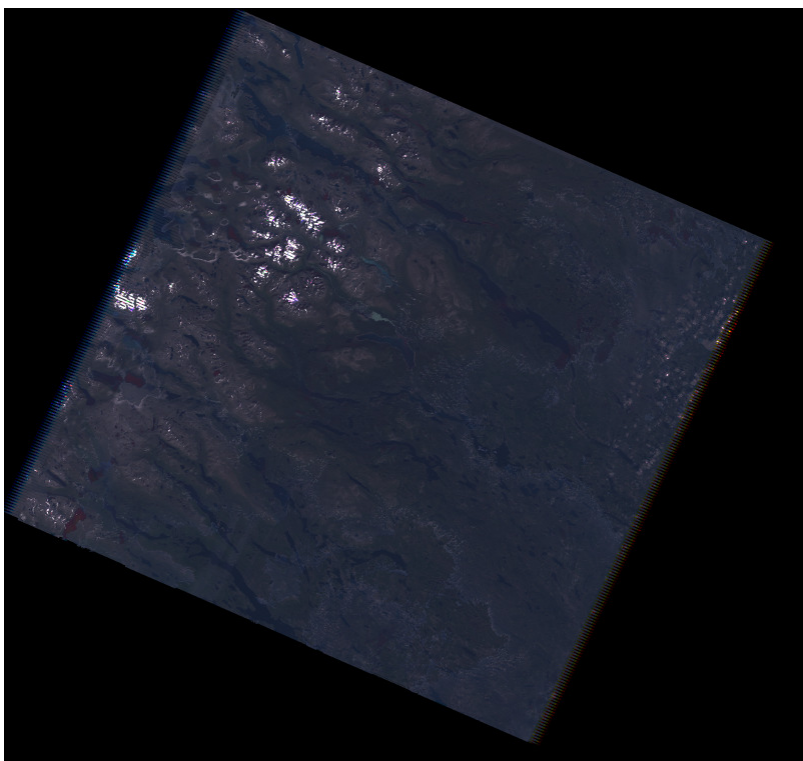
```

Note that you must convert the calendar date into Ordinal date manually. The **PANCROMA™** help file includes a link to the NASA calculator for converting calendar days to ordinal days. Also note that although the computation wants the solar zenith angle, you must input the solar *elevation* angle. This is intended as a slight convenience as the elevation angle is listed in the metadata file, not the zenith angle. In this example the ordinal days are 237 and the solar elevation angle is 33.33 degrees.

IMPORTANT NOTE: Be sure to input the solar *elevation* angle NOT the solar azimuth angle, which is also listed in the metadata file.

The images below show a band file both before and after mask processing by the Five File Method. (Note that the image has both snow and clouds. The algorithm has successfully discriminated between the two.) An RGB rendering of the cloud mask gaps filled with a





50. Automatic Image Registration of Six Band Files

In order to use the **PANCROMA**TM Landsat gap-filling and cloud mask utilities you must provide two image sets. The first set, which I call the Reference set, typically has some feature that needs to be corrected using data from a second data set, that I call the Adjust set. For example, the Reference set may have gaps, that is, missing data as a result of the failure of the Landsat Scan Line Corrector (SLC) in 2003. **PANCROMA**TM gap filling utilities use the data in an image set collected prior to the failure of the SLC to fill in or to compute the image information that should go into the gaps. Likewise the Reference image may not suffer SLC-off gaps but may have considerable cloud cover. In this case **PANCROMA**TM cloud mask utilities can detect and replace the clouds with black pixels, so that they can be subsequently filled in from a suitable Adjust data set without clouds.

In either case, the Reference and the Adjust data sets must be perfectly co-registered or matched so that the data can be transferred from the Adjust set to the Reference set seamlessly, producing a natural looking image. **PANCROMA**TM provides a collection of utilities to produce this registration. These utilities often contain the following elements:

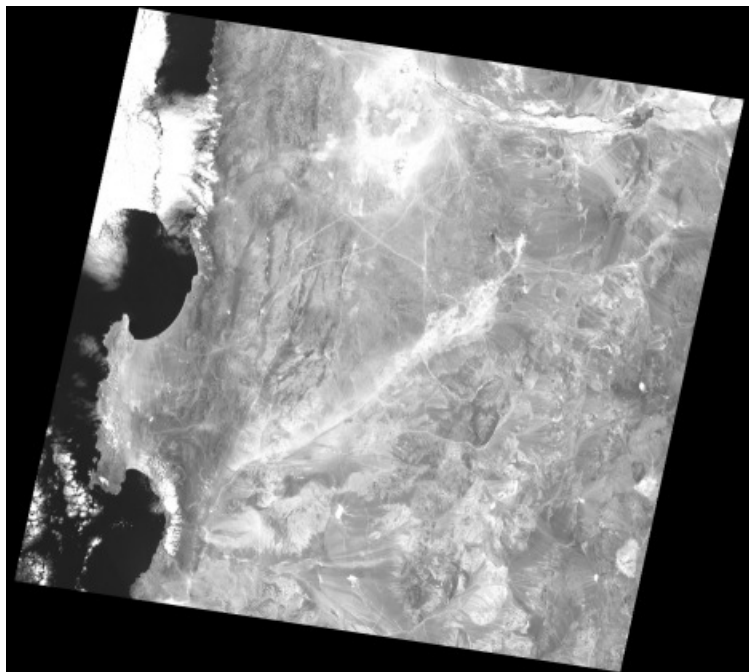
- Compute Maximum Extents – this utility determines the maximum overlap between the Reference and Adjust data sets and specifies this overlap by computing the corner coordinates that define the overlap
- Image Rescale. Sometimes the Reference and Adjust images do not have the same scale factor. Landsat band images for example can have either 30m or 28.5m resolution. In this case the images must be rescaled so that the two match, i.e. the 28.5m image must be rescaled to 30m resolution
- Image Subsetting. Next the two images must be cropped according to the Maximum Extents corner coordinates so that both images have the same latitude and longitude boundaries
- Row and Column Count Rationalization. The images get a final check to correct any off-by-one row or column discrepancies resulting from rounding errors when recomputing row and column counts during any rescaling and when mapping the corner latitude and longitude values to their corresponding row and column values.

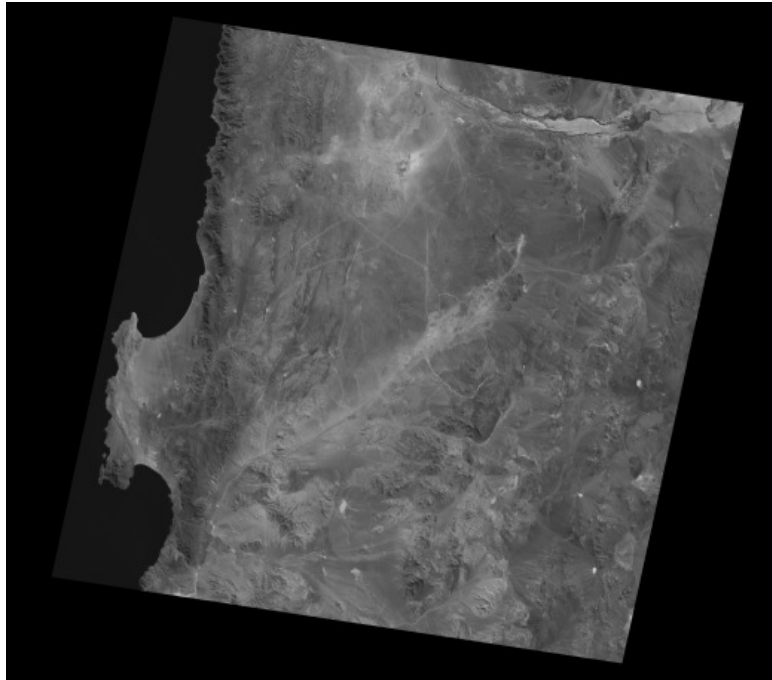
Formerly, this process was done using four separate, semi-manual utilities. A new **PANCROMA**TM utility conducts these operations automatically, saving time and reducing the probability of making an error in the process. In order to use

the utility, you must start with two three-file data sets, for example a Landsat band1, band2 and band3 Reference file and a band1, band2 and band3 Adjust file. There must be at least some common area shared between the two data sets. The band files must also be in GeoTiff format. To get started, open three band files (either the Reference or Adjust group) by selecting 'File' | 'Open' and opening three files from the same data set in series. Continue opening three more files, for example the files from the Adjust data set if you opened the Reference set first.

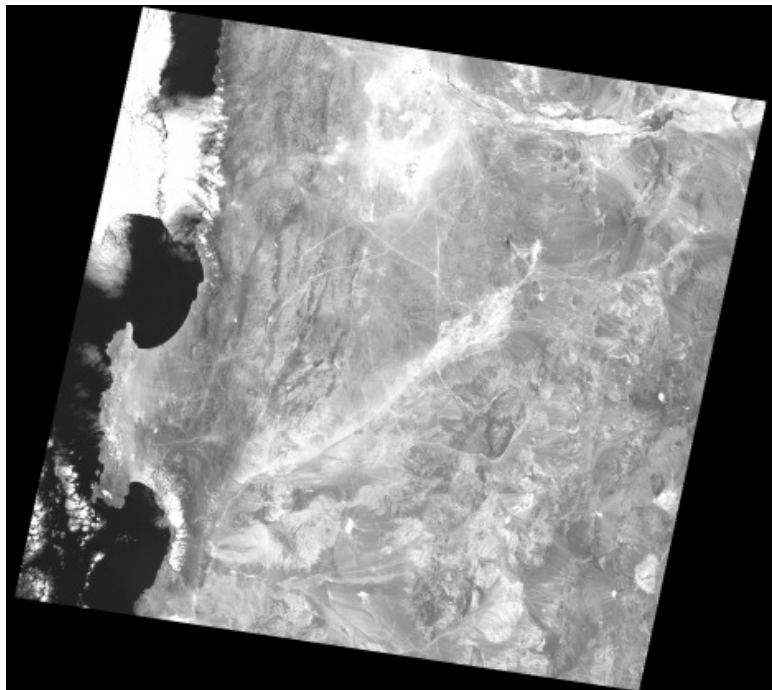
You should now have six band files opened. Now select 'Band Combination' | 'Subset Images' | 'Subset Six Bands'. When the subset data entry box appears, just click on 'Enter'. **PANCROMA™** does the rest after that. If all goes well, you should see your six registered images appear after a bit of computation. You can save all six files by selecting 'File' | 'Save' and typing in a base file name. **PANCROMA™** will add a numerical suffix to the base file name, numbering the output files in the same order that you input them. You are now ready to gap fill, cloud mask, or otherwise process the registered images.

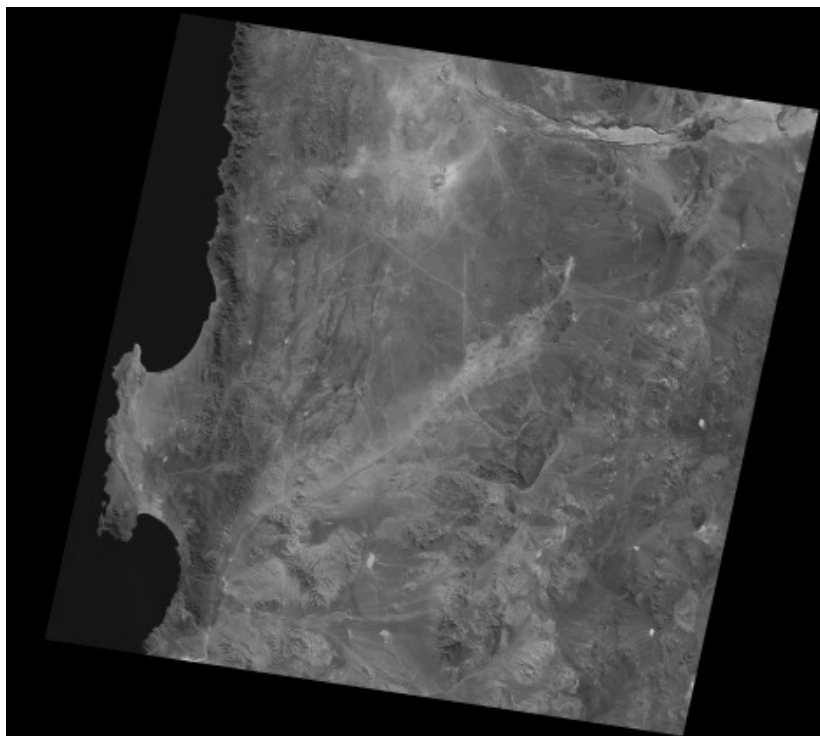
The example files below illustrate how the utility works. The first image is Landsat file L71001076_07619991115_B30.TIF, Row 76 Path 1 acquired over Anotfagasta, Chile. The second image is Landsat p001r076_7t20000525_z19_nn30.tif, Row 76 Path 1 of the same area. The first image has 6991 rows and 7851 columns and is a 30m per pixel image. The second image has 7641 rows and 8704 columns and is a 28.5m per pixel image.



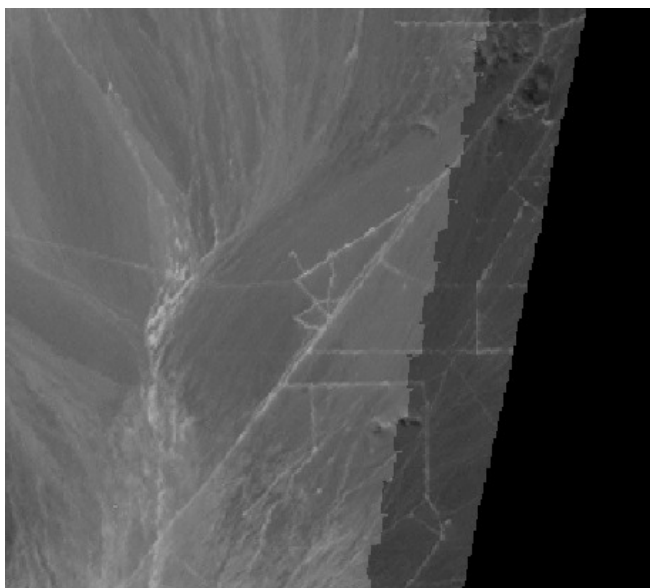


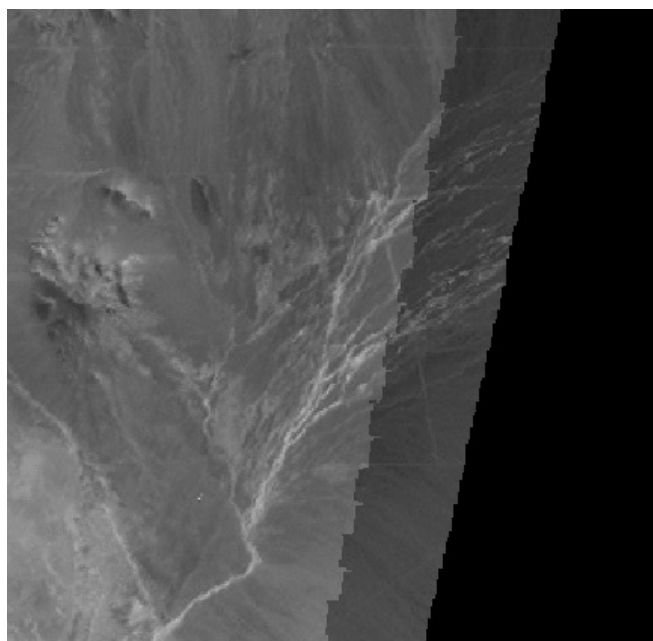
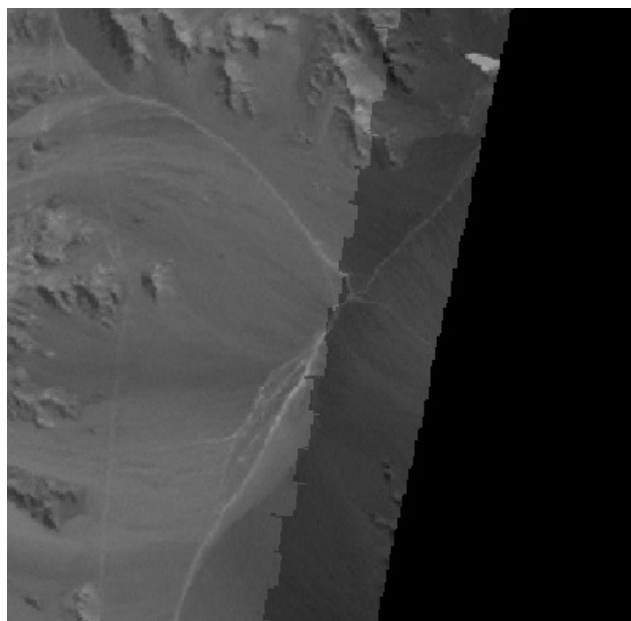
The next two images are the registered versions of the two images, having the same corner coordinates, same scale, and same row and column counts.





When superimposed one over the other the features match very closely. The details to the below show the boundary area between the two image edges, one fully opaque and one semi-transparent. (The image edges do not match perfectly because **PANCROMA™** matches the collared area corners, not the exposed image within). As you can see, the road and dry watercourse features align almost perfectly along the western edge of the image.





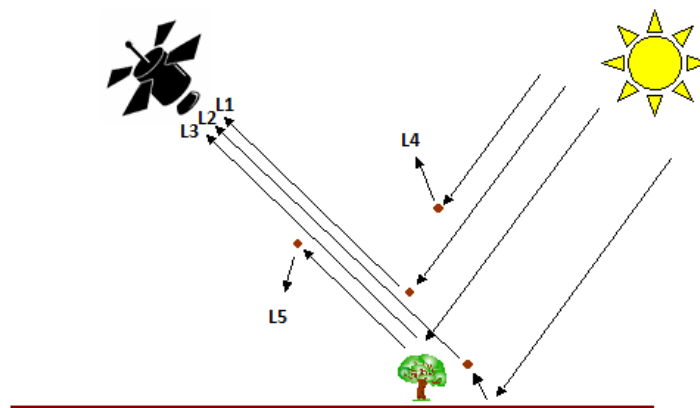
At the present time, **PANCROMA™** can only match three-file data sets using the automatic utility, and data must be in GeoTiff format. Subsetting is to Maximum Common Extents only. I will probably expand the utility to handle BMP and JPEG format and also four-file data sets for pan sharpening. However I believe that three-file sets represent the majority of maximum.

51. Haze Reduction – Dark Area Method

As solar light traverses the atmosphere it is scattered. One type of scattering is called Rayleigh scattering. In this type of scattering, electromagnetic radiation (EMR) interacts with matter whose size is much smaller than the wavelength of the EMR. Haze can also be caused by atmospheric aerosols. An aerosol is a suspension of fine particles or liquid droplets in a gas. Examples are smoke, oceanic haze, air pollution, clouds, soot and photochemical smog.

Short wavelengths of visible light (mainly violet and blue) are most affected by Rayleigh scattering, which is inversely proportional to the fourth power of the wavelength. Longer wavelengths (red, near infrared (NIR), infrared (IR) etc. are relatively unaffected and pass through the atmosphere without interacting at a molecular level. A second type of scattering called Mie scattering affects longer wavelengths of light. In this type of scattering, electromagnetic radiation interacts with much larger aerosol particles and can be scattered in the same way that shorter wavelengths are scattered by gas molecules. The wavelengths affected depend on the size, shape and texture of the particles encountered by the radiation.

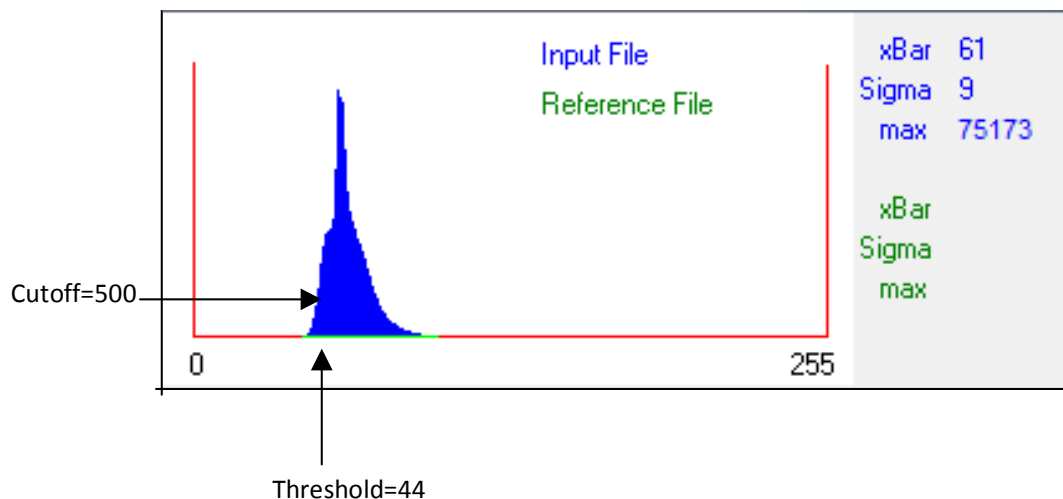
The top of atmospheric (TOA) radiance sensed by orbiting satellites is the result of a complicated series of interactions between the EMR, the atmosphere and the ground both downward toward the earth from the sun and from the earth to the satellite sensor. This is shown in the Figure 1 where L1 is the atmospheric radiation, L2 is the reflected radiation and L3 is adjacency radiation. L4 and L5 represent backscattered radiation that represents a net loss of available sensed radiation. Only radiation component 2 contains information from the currently viewed pixel. Normally, the task of atmospheric correction is the removal of components 1 and 3 and the retrieval of component 2.



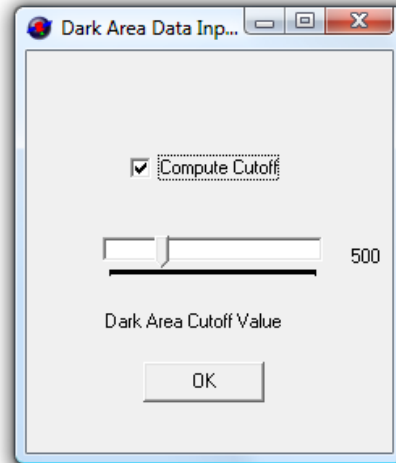
Since only a portion of EMR reaching the satellite sensor is actually reflected from objects on the surface under observation, the result is a blurring effect, often significantly limiting the view of surface features. The result of both types of scattering is less of the incident light reaching the surface and more radiation received at the satellite sensor from the atmosphere.

There are a few widely-used techniques used to reduce the effect of molecular and aerosol scattering. One technique is called the Dark Image Adjustment. This is a histogram-based method that determines the onset of the lower edge of the band histograms. The Dark Image algorithm then subtracts this value from each digital number (DN) of the image. If the subtraction causes the DN to be less than zero, it sets it equal to zero. In addition to reducing the haze component of a band file, it of course decreases most of the DNs of the image, thus the name.

PANCROMA™ has a preprocessing utility for haze reduction of an RGB image using the Dark Image method. To use it, open your three band files in the order blue, green and red by selecting 'File' | 'Open' from the menu. When the three files are open, select 'Pre Process' | 'Haze Reduction' | "Dark Image Technique'. After the files are opened, you will be prompted to input a cutoff value. The cutoff is the minimum number of DNs in a channel that determines the location of the threshold. For example, if the cutoff is 500, and channel 44 of the histogram is the first one to have at least 500 DNs in it, then the threshold and therefore the onset of the lower edge of the histogram will be determined to be 44. The figure below illustrates the idea.

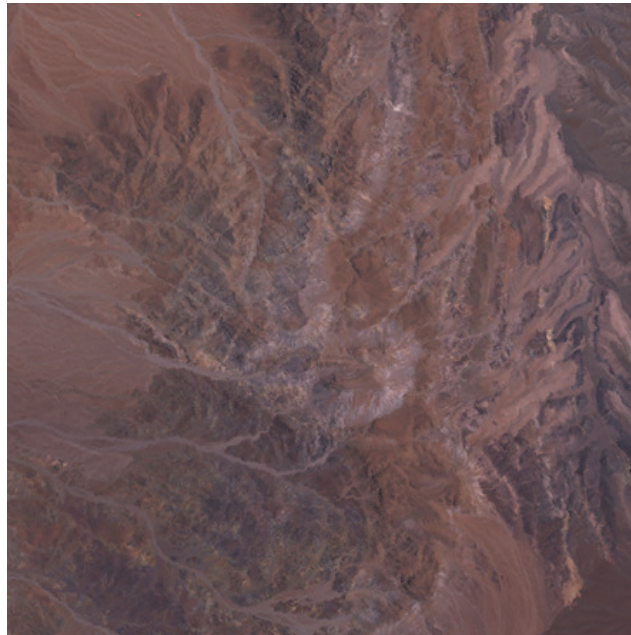


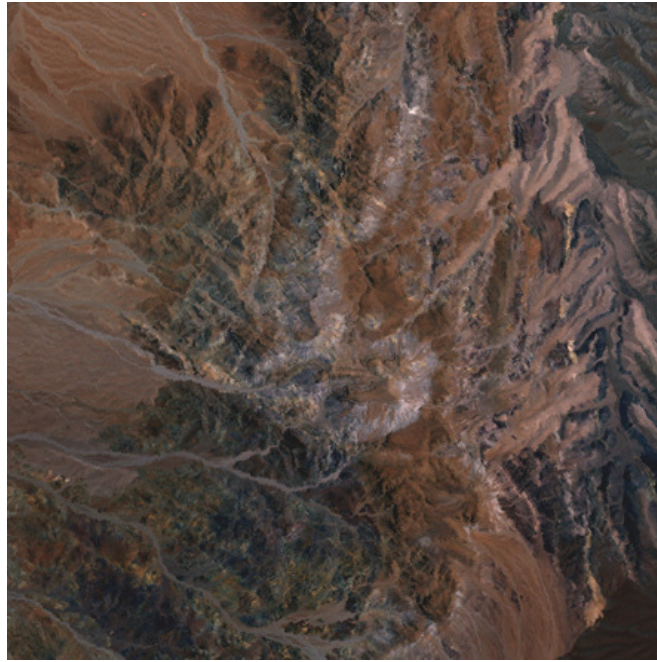
You must specify the cutoff value using the 'Dark Area Data Input' form that will appear after you specify your band files. The form is shown below.



The default cutoff is 500. You can adjust it from zero to 2000 using the slider bar. If you check the 'Compute Cutoff' check box, **PANCROMA™** will compute the cutoff value automatically. You also have the option of letting estimate the optimal cutoff value automatically. If you check the 'Compute Cutoff' check box, the cutoff histogram channel will be that channel corresponding to a DN count of 10% of the histogram maximum

The images below show the results of applying the Dark Image haze reduction algorithm. The first image is the unprocessed image. The second has had the haze reduction applied.





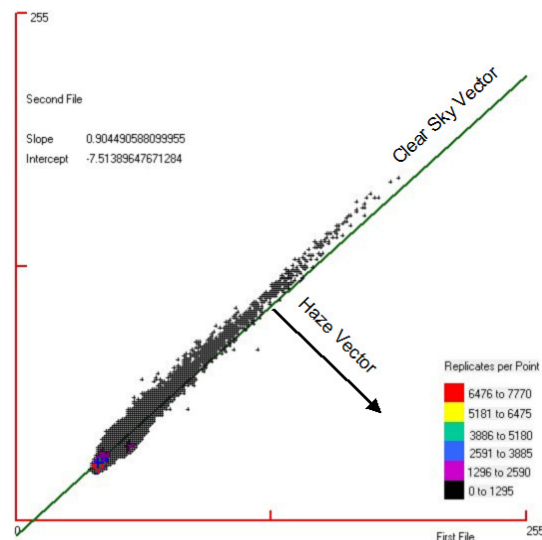
52. Haze Reduction – Haze Optimized Transform Method

The previous section discussed atmospheric physics and the Dark Area method for haze reduction. This Section discusses an alternative method called the Haze Optimization Transform (HOT). The HOT method was developed by Zhang and others from the Canadian Center for Remote Sensing. It is based on the premise that in clear images, the digital numbers (DNs) of the pixels in all the band files are different but highly correlated. As explained in the previous article, the blue band generally exhibits more scattering due to atmospheric haze than the other bands. The presence of haze decreases the correlation between the blue band and the red band, which is much less affected by haze.

Zhang proposed the following: First, prepare a scatter plot of the DNs of the blue band and the DNs of the red band. Determine the best-fit line through the scatter plot using linear regression. Highly correlated pixels will tend to fall on the line. Those altered by light scattering will tend to be less correlated and will fall off the line. Zhang proposed determining the HOT number for each pixel as the perpendicular (or orthogonal) distance from the HOT line. The HOT number can then be used to remove the haze component of each band.

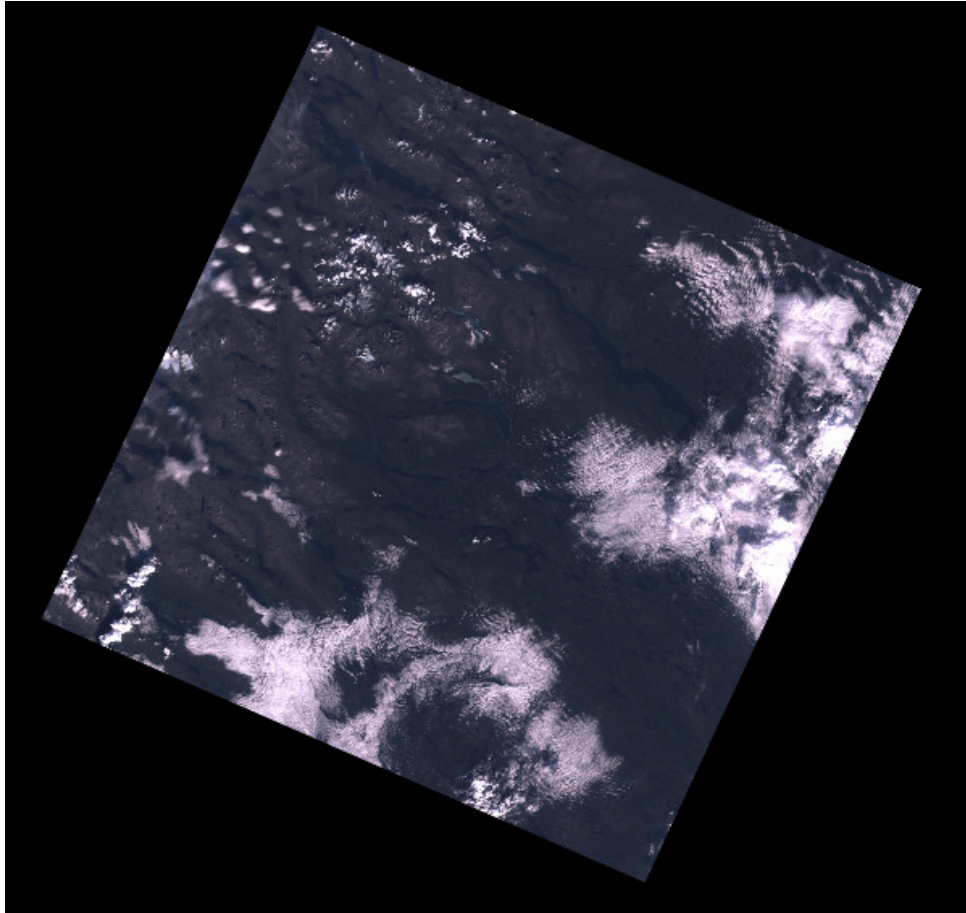
$$\text{HOT} = \text{DN}_{\text{blue}} \sin\theta - \text{DN}_{\text{red}} \cos\theta$$

The concept is depicted in the diagram below.

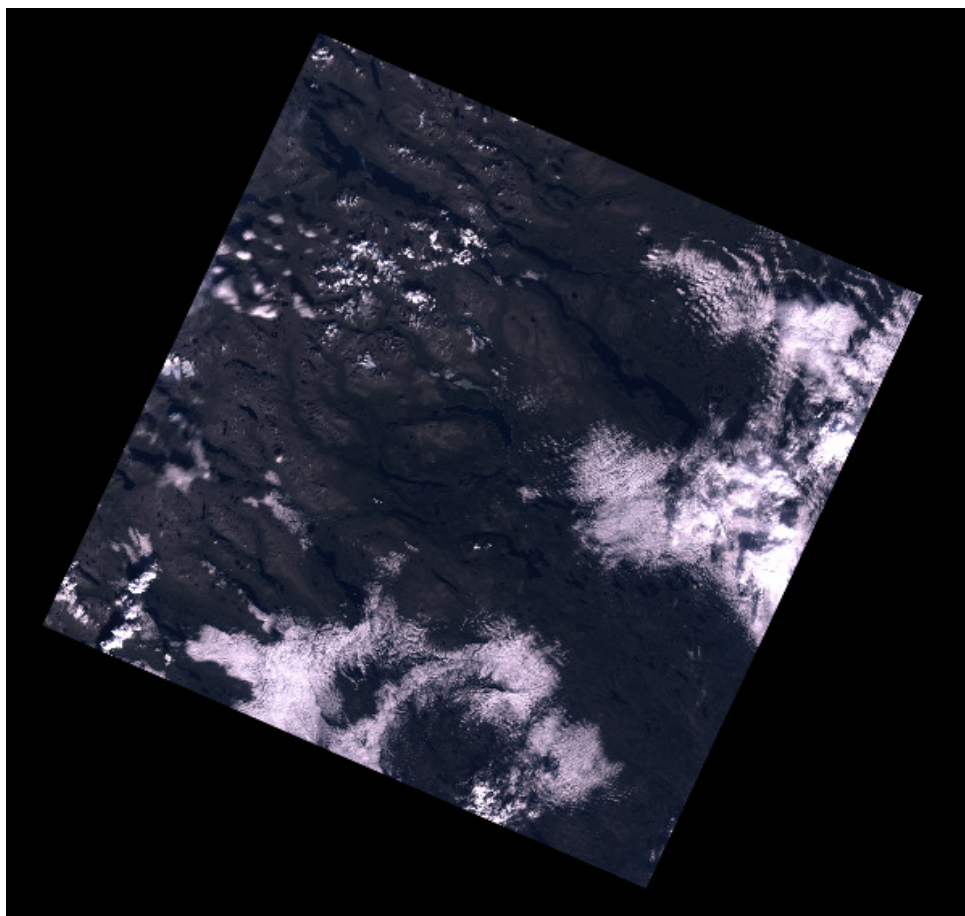


The **PANCROMA™** HOT utility is a three-file method like the Dark Area method. To use it, open your three band files in the order blue, green and red by selecting

'File' | 'Open'. After your files have loaded, select 'Preprocess' | 'Haze Reduction' | 'Haze Optimized Transform' | 'Three Band'. After a few moments, the haze reduced RGB image will be displayed. Unprocessed and processed images are shown below



The second image shows significantly improved contrast and detail compared to the unprocessed image. The overall image brightness is better, and the color tones of the unprocessed image have been retained better than in the Dark Areas method shown previously.



Haze reduction may be used as a preprocessing step for computing TOA reflectances. This combination can yield the cleanest multispectral band data as the effects of solar irradiation variables and atmospheric variables are removed from the data set. See Section 47 for more information on TOA Reflectance.

Haze reductions are commonly applied to only the visible multispectral bands, as the infrared (IR) bands are less susceptible to haze. Both the Dark Area and HOT algorithms are offered as three file methods. **PANCROMA™** also offers the HOT algorithm in a six file and seven-file implementation. Select 'File' | 'Open'. After your files have loaded, select 'Preprocess' | 'Haze Reduction' | 'Haze Optimized Transform' | 'Six Band' or 'Preprocess' | 'Haze Reduction' | 'Haze Optimized Transform' | 'Seven Band'. It is doubtful whether applying a haze reduction method to the thermal infrared (TIR) band 6 makes much sense in most cases. However both are offered. It is possible to perform a haze reduction on all seven Landsat bands for example and then select as many as judged necessary for further processing.

Haze reduction may be useful in converting Landsat DN band files to surface reflectance approximations. In this case you would first perform a haze reduction to reduce scattering of solar and upwelling radiation. Then compute Top of Atmosphere (TOA) reflectance on the haze-reduced images. The result should more closely approximate surface reflectances, although further correction is still necessary, for example for gas absorption and for aerosols that might absorb in the non-visible regions.

Future improvements will include a consolidation of the haze reduction and TOA Reflectance computations and provisions to include atmospheric optical thickness parameters.

53. Haze Reduction – DEM Method

A third method for reducing image haze uses a digital elevation model (DEM) plus a RGB color image. The method uses the DEM to determine how much atmosphere is between the earth's surface and the satellite sensor. The higher the ground elevation, the less atmosphere there is to scatter light. The algorithm then corrects each pixel in the RGB color image in order to compensate for the atmospheric effects. This algorithm is not suitable for multispectral analysis but may be useful for improving RGB color composites for other purposes.

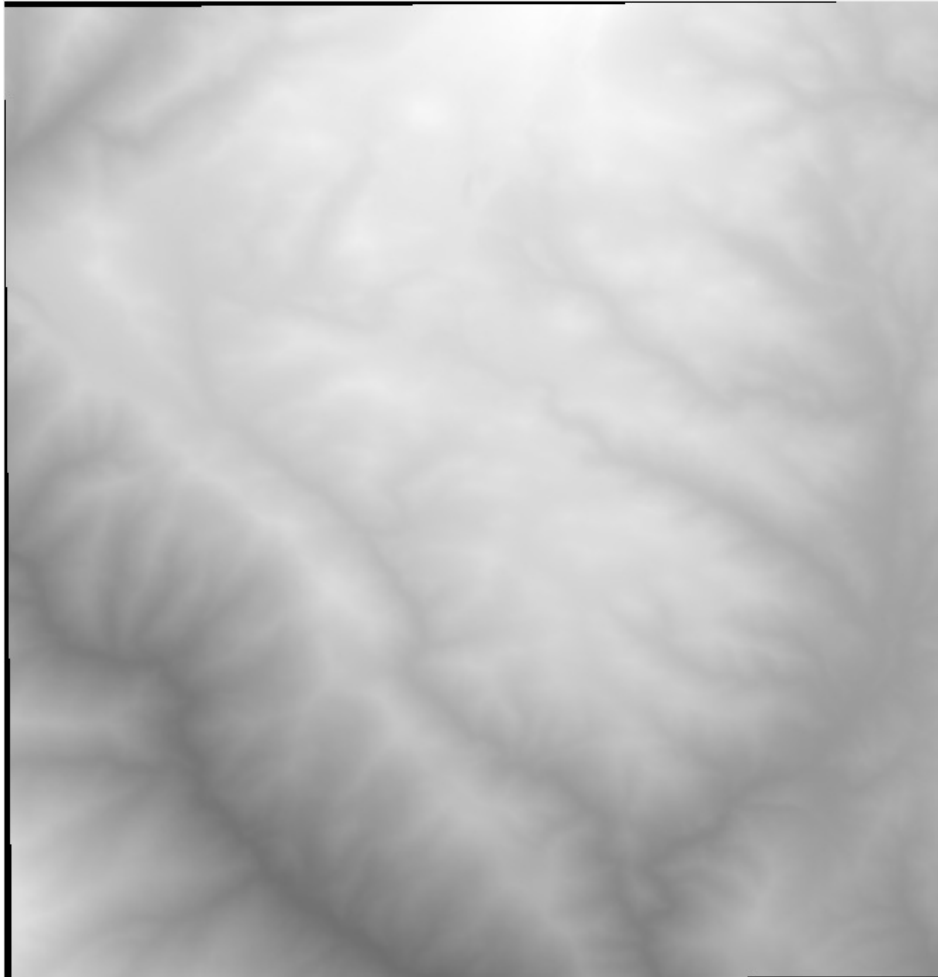
You will need a matched image/DEM pair in order to use the image. A good combination is an RGB color image prepared from Landsat bands 1, 2 and 3 and ASTER DEM data. Both have pixel resolutions of 30m. ASTER DEMs can be obtained free of charge for most of the world from the USGS/NASA LP DAAC Global Data Explorer website at <http://gdex.cr.usgs.gov/gdex/>. Select your area of interest by coordinates. It is important to download your ASTER DEM first, and then subset the Landsat data to the corner coordinates of the ASTER DEM. This is because the Global Data Explorer selection tool rounds the coordinates, making it more difficult to get a match. Use UTM coordinates to make your selection, and make sure the datums match (should be WGS 84). Your selection criteria should look something like those in the image below.

The screenshot shows the 'Output' window of the Global Data Explorer (GDEX) application. The window has two tabs: 'Data Preview' and 'Data Information', with 'Data Information' currently selected. The 'Data Information' tab displays the following details:

- URL:** A text box containing the URL: `http://gdex.cr.usgs.gov/geoportal_data_cache/20130614090355_1770219417`
- Size:** Two text boxes showing 'Columns: 670' and 'Rows: 697'.
- Bounding Box:** A section with a 'Projection' dropdown set to 'WGS 84 / UTM zone 19N'. Below it are four text boxes for the bounding box coordinates: 'West: 418498.929', 'East: 437791.554', 'South: -3403313.032', and 'North: -3383236.752'.
- Elevation:** A section with five text boxes: 'Min: 2286', 'Max: 5230', 'Mean: 3929.471', 'StdDev: 631.567', and 'NoData: -32768'.

At the bottom of the window, there are two buttons: 'Download' and 'Close'.

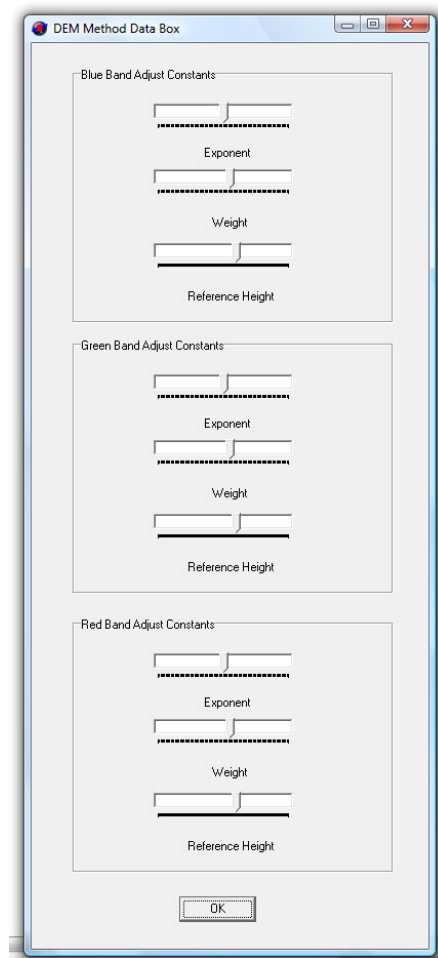
Save your image using GeoTiff file format. You can inspect your DEM by selecting 'File' | 'Open' and then 'Display Files' | 'Display GeoTiff II16 Elevation Image'



The next step is to open your Landsat scene and subset it to match the corner coordinates of the DEM. Create an RGB color composite from the band files. An example of such a matching image is shown below.



Now the DEM can be used to conduct a haze reduction on the image. Open your two data files, opening the RGB color composite image first and the DEM image second. Select 'Pre Process | 'Haze Reduction' | 'DEM Method'. A data entry box will be come visible as shown below.



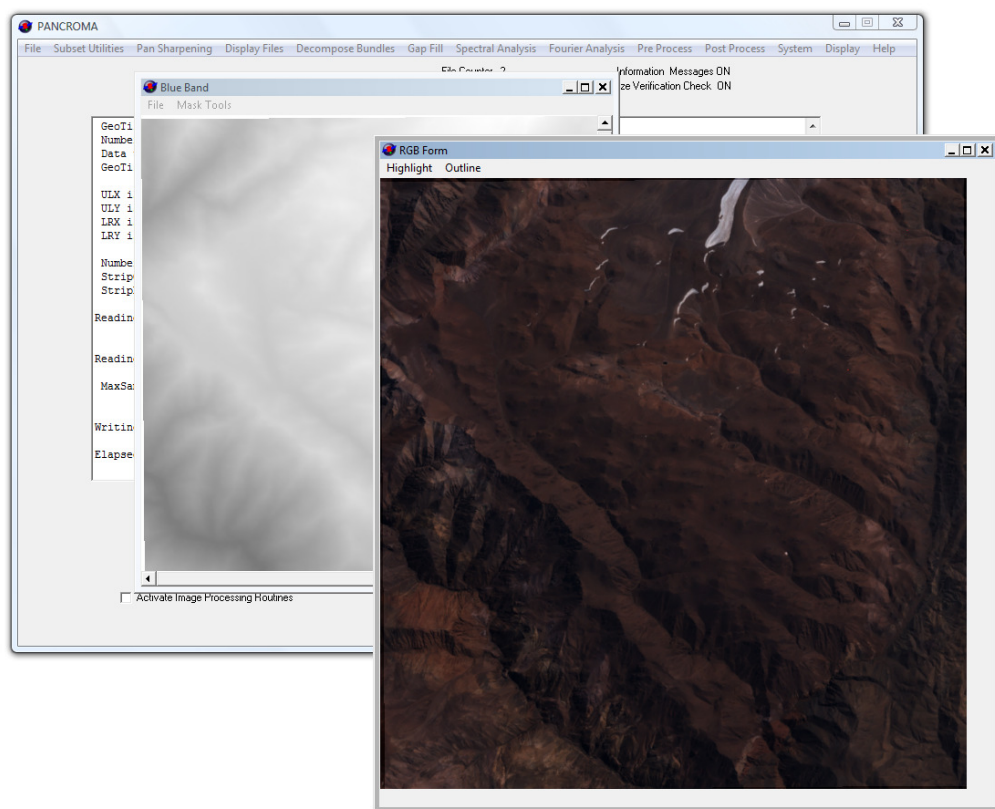
The correction is made according to the equation suggested by Hormann:

$$\text{Adjusted Pixel}(x,y) = \text{Pixel}(x,y) - \text{pow}(\text{Pixel}(x,y), \text{Exponent}) * \text{Weight} * \text{HRel}(x,y)$$

Where

$$\text{HRel}(x,y) = (\text{HRef} - \text{Height}(x,y)) / \text{HRef}$$

Where HRef is the elevation at which no correction is necessary. An example of a corrected image is shown below.

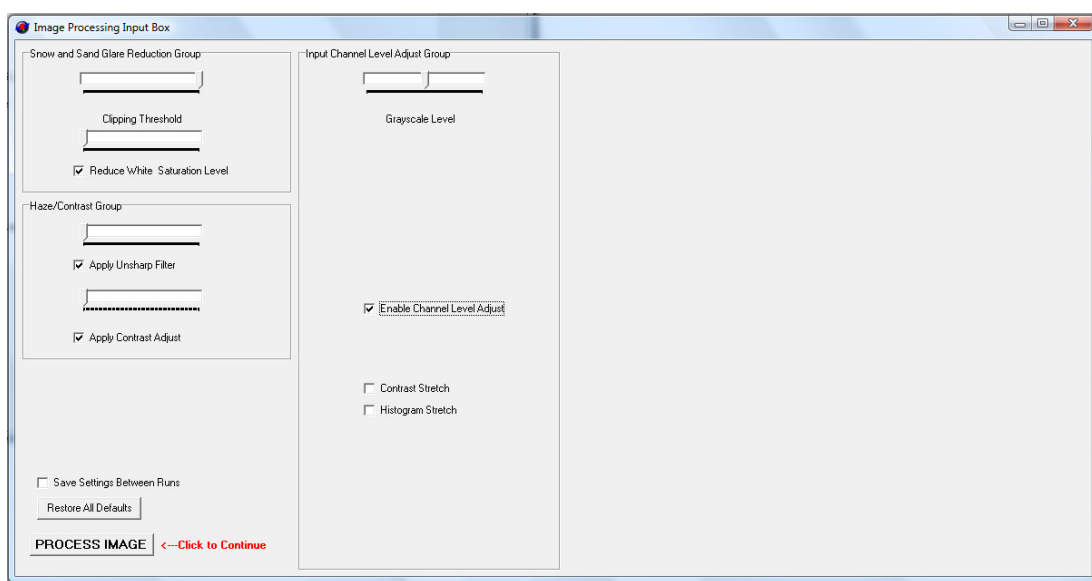


54. Image Processing Utilities – Grayscale and RGB

PANCROMA™ provides image preprocessing techniques to improve the quality of simple RGB band combinations. When bands 3, 2 and 1 are combined to create an RGB image, the result is very close to what the satellite sensor “sees” and theoretically no image processing is necessary. However atmospheric water vapor will scatter both incident and reflected light, especially in the blue band. The result can be a hazy image. Although this is a natural phenomenon, the appearance of RGB images can often be improved by the use of **PANCROMA™** haze reduction and contrast enhancement algorithms. These and all image processing utilities are accessed using the Image Processing Data Input dialog box, which in turn is presented when the ‘Activate Image Processing Routines’ check box is checked on the main screen. The image processing routines can be used during any image display routines, including the production of grayscale, RGB and pan sharpened images.

The figure below shows the Image Processing Data Input box, with all the check boxes checked. Not all of the image processing features apply to all operations. For example, the routines on the right side of the screen, in the ‘Pan Sharpening Post Processing Group’ apply only to the pan sharpening process. All of the routines in the other data group boxes also apply to the pan sharpening process, but not the other way around. When you are processing a single grayscale image, for example, only one channel in the ‘Input Channel Adjust Group’ will be active (as there is only one channel, namely the single grayscale band, to adjust.)

IMPORTANT NOTE: PANCROMA™ will automatically enable and disable image processing menu selections based on the operation that you are currently performing. This is to prevent executing inappropriate image processing actions. For example, it would not make sense to adjust the three-color channels when you are processing a single image.



The image processing utilities are explained below.

Snow and Sand Glare Reduction Group Utility (Grayscale; RGB; Pan)

Sometimes areas of an image are close to saturation as a result of intense reflection from snow, sand or clouds. This utility uses a combination of two sliders (which is a common format for many **PANCROMA™** image processing utilities). The upper slider selects the clipping threshold. That is all pixels above the setting on the slider bar will be affected by the clipping operation. For example if the slider is set at 245, then all pixel values of 245 and above will be adjusted.

IMPORTANT NOTE: Since all Landsat files have 8 bits of color information, the color level can range from 0 – 255 i.e. 256 total levels.

The lower slider bar sets the adjustment value, in this case the number by which all the values above the clipping threshold will be decremented. The result is that pixel values that are so “overexposed” so that detail is lost can be made less intense so that detail can be recovered.

Haze/Contrast Group Utility (Grayscale; RGB; Pan)

This utility allows images that are excessively hazy to be sharpened. The degree of haze reduction is proportional to the slider position. The lower slider adjusts contrast. Its purpose is to add definition to images lacking contrast.

IMPORTANT NOTE: The haze reduction and contrast adjust algorithms can have unwanted side effects, so attempt small adjustments at first.

Input Channel Adjust Group Utility (Grayscale; RGB; Pan)

This useful utility allows you to add intensity to either a single channel (grayscale) or to individual blue, green and red channels (rgb and pan). A common example is if an image has a blue or green cast or tint. By decreasing the blue channel, the level of “blueness” of the image will decrease in proportion to the slider setting. You can also increase any or all of the channels either independently or in equal proportion (when the ‘Lock RGB Ratios’ check box is checked).

Set Standard Input Channel Levels Group Utility (Grayscale; RGB; Pan)

This utility is closely related to the ‘*Input Channel Adjust Group*’. The radio buttons are essentially adjustment ‘presets’ that will set the input channels for forest and desert images.

IMPORTANT NOTE: After selecting a preset, the individual channels can still be adjusted independently, although they cannot be saved.

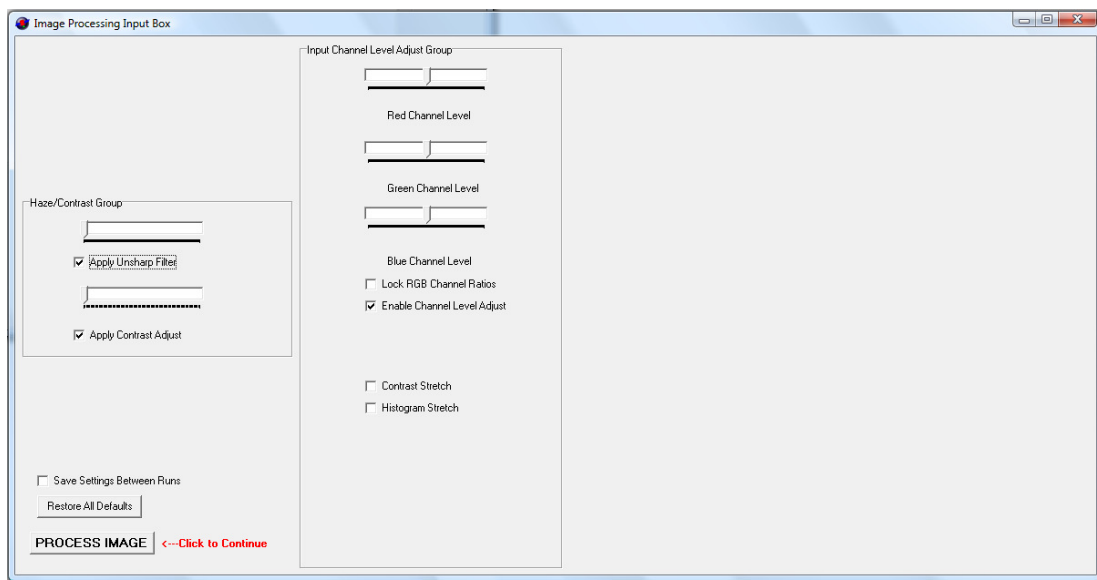
As an example, open a single grayscale band as in the previous section. Make sure that the ‘Activate Image Processing Routines’ check box is checked and then select ‘Display Files’ and then ‘Display Single Grayscale Image’. Instead of the image being immediately generated, the Image Processing Data Input dialog box will appear. The box is full of blank areas separated by a series of check boxes. Check the box labeled ‘Apply Contrast Adjust’.

When you do so a slider will appear on the screen. The rest of the image processing utilities work similarly: they are inactive and invisible until activated by the user. When the check boxes are activated, the user interface functionality is presented. In this case, moving the slider to the right increase the contrast of the image and moving it to the left decreases it. The same is true for the haze reduction function. Experiment with both of these. When a single band is loaded, the processing of course applies only to that band. When multiple bands are loaded, the changes apply equally to all three input bands.

Another useful processing utility is the ‘Input Channel Level Adjust Group’. Enabling this check box presents a single slider when a grayscale image is loaded. Moving the slider from the neutral position adds or subtracts from each pixel value in the image. There are 256 possible values for an 8-bit pixel value, and the increase or reduction of the channel level is displayed in to the right of the slider. Adding or subtracting values uniformly from a single grayscale image is not very useful, except for making the image appear lighter or darker. Its real utility is in the adjustment of RGB and PAN images. Selective reduction of the blue channel level uniformly will result in the RGB or PAN image being “less blue” and “more red and green”. While it is possible to adjust the bands singly, it is usually easier to adjust them all at once.

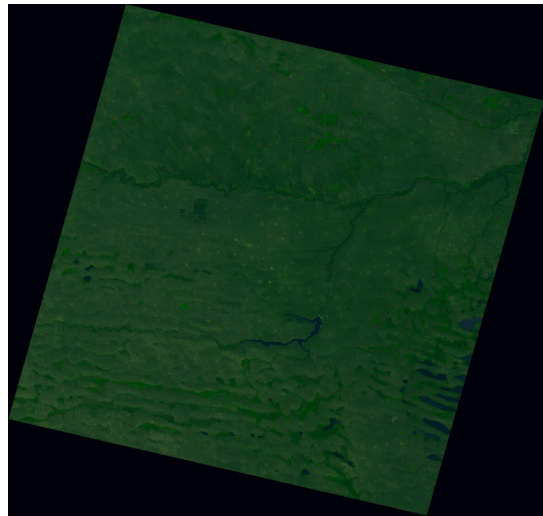
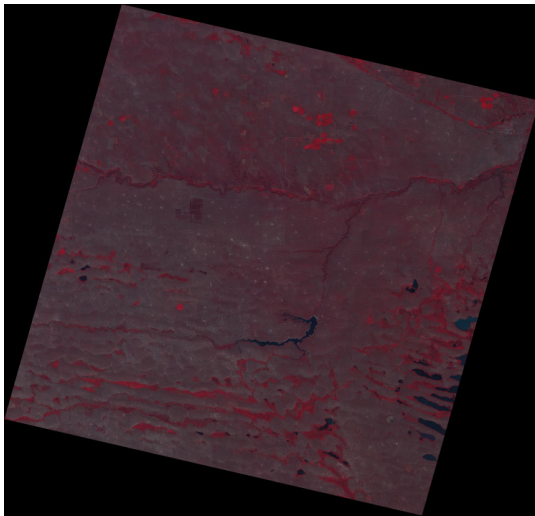
In order to adjust the color balance of an RGB image, load three band files as described in the section entitled “Processing Data - RGB Pseudo True Color Image”. Select the ‘Activate Image Processing Routines’ check box. Now select ‘Band Combination | Generate RGB True Color Composite from ETM+’. The Image Processing Data Input dialog box will appear.

Now enable the ‘Enable Channel Level Adjust’ check box. When you do three sliders will appear, one for each of the Red, Green and Blue channels. Another check box will also appear allowing you to lock the sliders together if you wish. You can add or subtract the indicated values from each channel or from all channels, thereby adjusting the color balance of the processed image. The radio buttons are channel presets, one for neutral, one to enhance desert images and another to improve forested images. Once selecting a preset you can fine tune by moving the sliders if you wish.

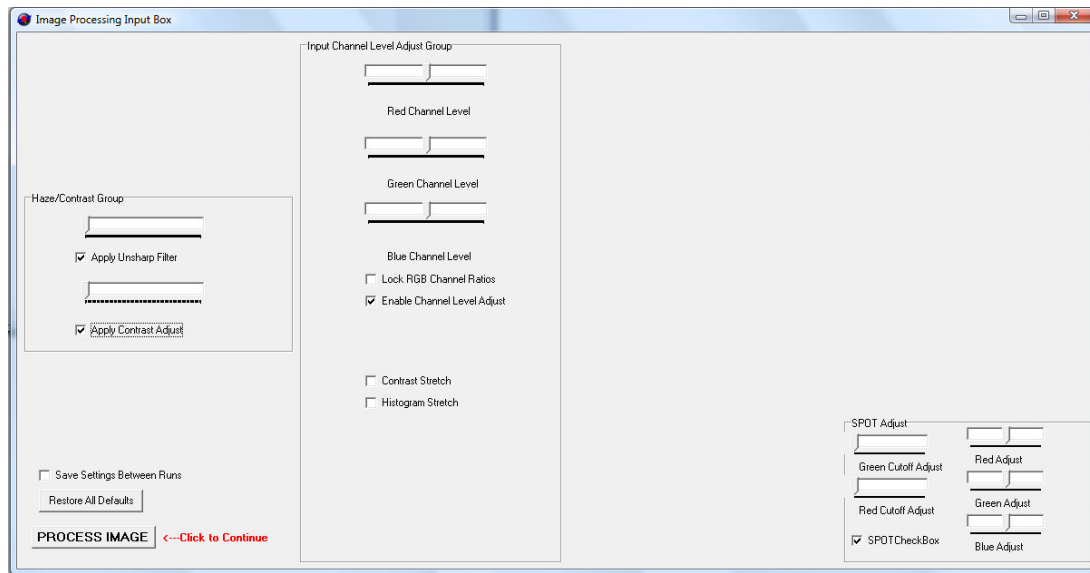


55. Image Processing Utilities – SPOT Images

Image processing of SPOT false color composites proceeds exactly like processing true color RGB images, except that the sliders designated 'Red', 'Green', and 'Blue' will adjust the intensities of the green, red and near-infrared bands, respectively. **PANCROMA™** also offers the option of synthesizing natural color images from the false color bands. To generate a pseudo true color image from SPOT green, red and NIR bands, first open the three bands in the stated order. Then select 'Display Files' | 'Generate RGB Composite from SPOT'. Often the color using the default settings is acceptable. Examples of a SPOT false color composite (as received from the USGS) and a pseudo true color composite generated using the utility are shown below.



To adjust the color of these images, you may check the 'Activate Image Processing Routines' check box and use the 'SPOT Adjust' group at the lower right of the control panel.

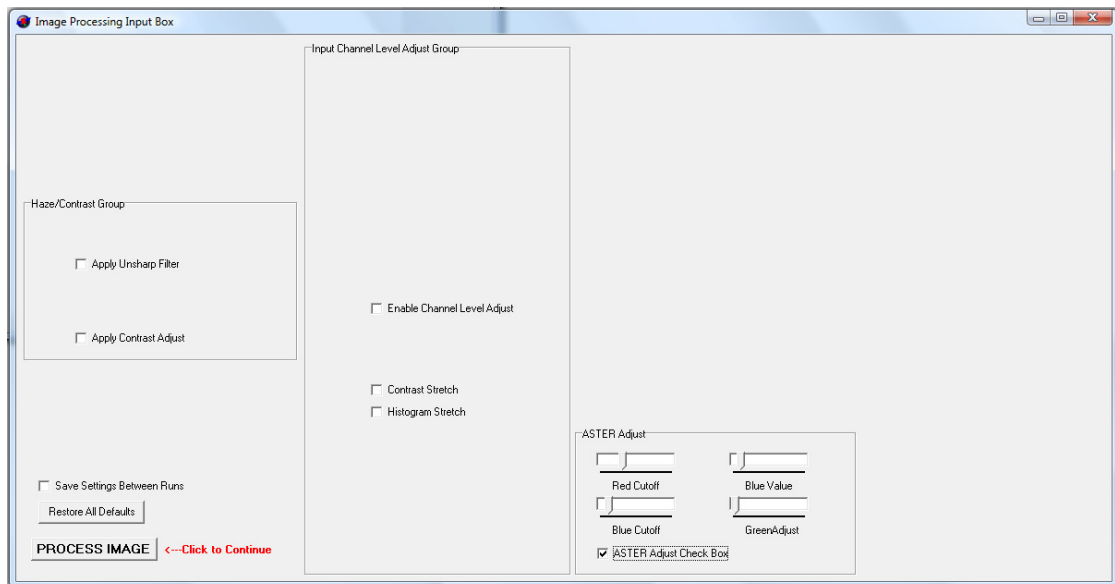


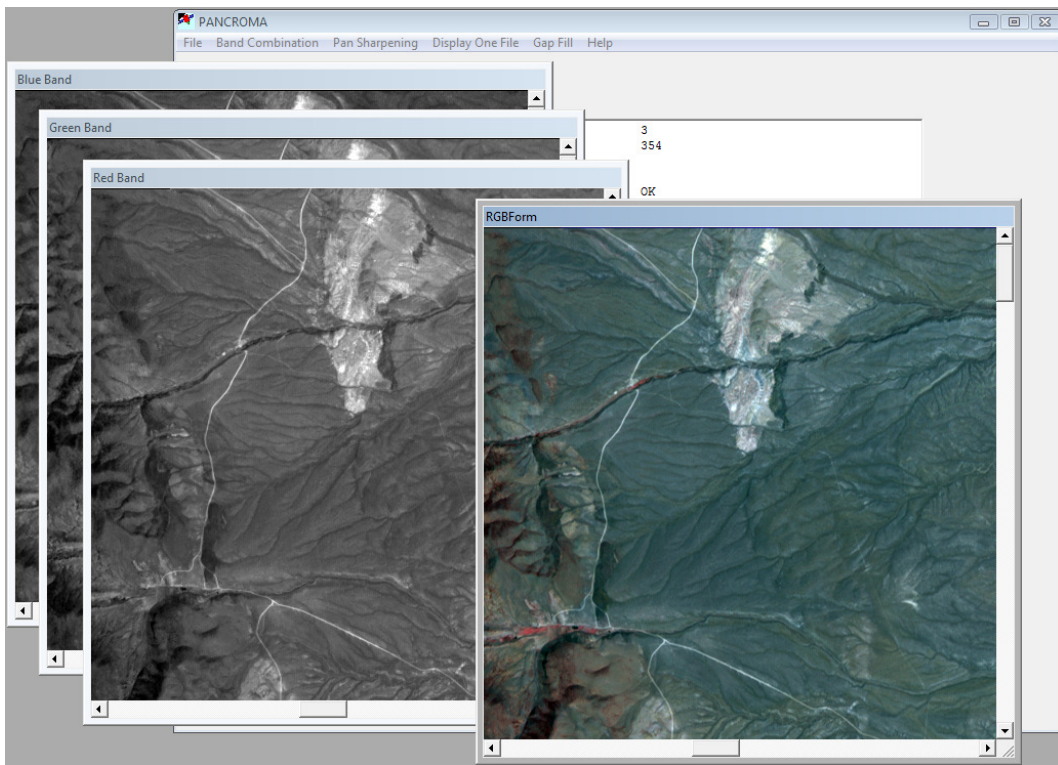
The 'Red Adjust', 'Green Adjust' and 'Blue Adjust' sliders will alter the intensity of the synthesized red, green and blue SPOT bands, respectively. An additional pair of sliders is provided for selective adjustment of green cover in the image. It has the familiar 'Cutoff' and 'Adjust' sliders. The 'Cutoff' slider allows you to specify the green pixel threshold *above* which *red* pixels will be *decremented* by the value set on the 'Adjust' slider.

56. Image Processing Utilities - ASTER Images

Synthesizing pseudo true color images from ASTER green, red and NIR bands, proceeds similarly to the process described in the previous section for SPOT. First open the three bands in the stated order. Then select 'Display Files' | 'Generate RGB Composite from ASTER'.

As before, if you check the 'Activate Image Processing' check box, you can adjust the parameters of the algorithms that create the natural color image. In particular, changing the 'Red Cutoff' value slightly from its default is sometimes helpful. Increasing it will help remove blue artifacts and convert them to green. The intensity of the green color can be modified by slight variations of the 'Green Adjust' slider bar.





57. Image Processing Utilities – Panchromatic Images

Before the advent of **PANCROMA™** automatic image processing algorithms, intensive image processing efforts were often necessary to achieve accurate and pleasing pan sharpened images. **PANCROMA™** automatic preprocessing algorithms are often sufficient to produce excellent results without any manual intervention. However all of the manual utilities are still available if needed. **PANCROMA™** provides a toolkit of image processing utilities that allows manual production of high fidelity of the pan-sharpened images.

The following utilities are enabled when pan sharpening images. Note: several of these utilities have been overcome by development of the histogram match, ENHG and XIONG algorithms. They remain available for manual processing or for adjusting automatically corrected images if desired.

Snow and Sand Glare Reduction Group Utility (Grayscale; RGB; Pan)

Sometimes areas of an image are close to saturation as a result of intense reflection from snow, sand or clouds. This utility uses a combination of two sliders (which is a common format for many **PANCROMA™** image processing utilities). The upper slider selects the clipping threshold. That is all pixels above the setting on the slider bar will be affected by the clipping operation. For example if the slider is set at 245, then all pixel values of 245 and above will be adjusted.

IMPORTANT NOTE: Since all Landsat files have 8 bits of color information, the color level can range from 0 – 255 i.e. 256 total levels.

The lower slider bar sets the adjustment value, in this case the number by which all the values above the clipping threshold will be decremented. The result is that pixel values that are so “overexposed” so that detail is lost can be made less intense so that detail can be recovered.

This utility can be useful when processing snow capped peaks using the ELIN processor as abrupt changes in brightness can cause ringing with this algorithm.

Change Dark Pixels

As previously described, one of the problems inherent to the unenhanced HSI and Brovey algorithms used by **PANCROMA** is that the blue ocean color can be lost. This often results in ocean areas turning out with a dark greenish cast or even just black. In order to correct this, **PANCROMA™** has a simple and effective algorithm that adds a specified value to the ‘blue’ channel of all RGB pixels with values below the selected threshold. Thus if your test panchromatic

image shows an unnaturally dark ocean, you can increase the blue channel of all pixels whose blue AND red AND green channel values are all less than the cutoff value. The 'Enable Ocean Adjust' check box attempts to remedy this. It applies the PAN channel increase to only the darkest pixels, which are typically the ones corresponding to the ocean. The lower slider adjusts the cutoff value while the upper slider controls the increase to the pixels below the cutoff. This feature works pretty well to address this problem for files containing oceans, lakes or rivers.

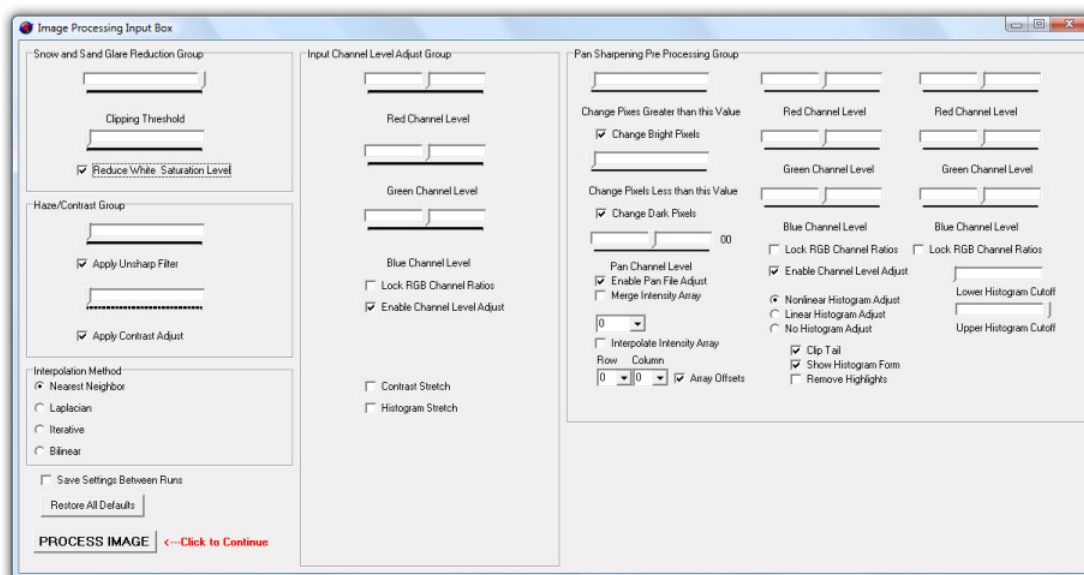
Change Light Pixels

This utility is something of the opposite of Enable Ocean Adjust. Its associated cutoff slider will likewise select all the pixels darker than the threshold level. However, instead of applying the RGB color adjustment to the dark pixels, it applies the adjustment to all *other* pixels. This allows independent adjustment of the ocean pixels by the *Change Dark Pixels* utility and the land pixels using the *Block Ocean Pixels* utility.

Enable Channel Level Adjust

This utility allows each of the *output* red, green and blue channels to be adjusted by a specified value, either incremented or decremented. The adjustment values can be locked as in the input adjustment described above so that each channel is adjusted by the same value if desired.

IMPORTANT NOTE: It is not possible to use the *Enable Channel Level Adjust* at the same time as *Change Light Pixels* as they use the same sliders. If it is necessary to use both, use the *Enable Channel Level Adjust* utility in the 'Input Channel Adjust Group' instead.



Channel Level Adjust

PANCROMA™ provides two types of channel adjustment. Modifying the color balance by adjusting the band files as described in the previous section affects the color of the input bands. A second set of channel adjustments is provided for balancing the channels of the output bands after the reverse transformation. Since the fidelity of the transformation and reverse transformation is good, these adjustments are equivalent for the most part. Post processing adjustments are exact but more computationally expensive while pre processing is computationally cheaper but may suffer a slight loss of fidelity due to transformation rounding errors. The adjustment can be made by checking the 'Enable Channel Level Adjust' check box and adjusting the red, green and blue slider bars.

Pan Channel Level

This utility allows the panchromatic image to be adjusted by adding or subtracting a specified value from each of the pixels in the panchromatic image. The 'Enable Pan File Adjust' check box activates a slider that allows the PAN file pixels to be adjusted up or down. This is sometimes useful to increase the 'blueness' of water coverage since the PAN sensor does not detect radiation reflected from water very well. Although increasing all panchromatic values will often make the ocean bluer, it will unfortunately make forested areas too blue as well.

Merge Intensity Array

This utility attempts to use the color information in the computed intensity array rather than to ignore or discard it. This color information in the computed intensity array is arithmetically combined with that in the panchromatic array to produce a higher fidelity panchromatic image. The 'Merge Intensity Array' feature replaces panchromatic file pixels with the corresponding pixels from the intensity array computed from the RGB bands. Since there are only $\frac{1}{4}$ as many intensity pixels than panchromatic pixels, the result is a kind of gridded image where 25% of the pixels are "true" color (as if from the RGB image) and the remaining 75% are uncorrected panchromatic pixels.

PANCROMA™ provides a utility for interpolating between the intensity pixels and the panchromatic pixels, and is accomplished by selecting the 'Interpolate Intensity Array' check box. (Note: if you intend to select this feature you must set the number of interpolation iterations in the dialog box that is presented immediately after loading the band and panchromatic images. If you do not it will use the default 10 iterations.

This approach is only marginally beneficial. Interpolating color information works well but interpolating image information works much less so as the latter diffuses

the image resolution to a point whereby it is not much better than the input band resolution.

Interpolate Intensity Array

The problem with merging the computed intensity array with the pan array is that the file sizes are mismatched. As a result, only 25% of the pan pixels are adjusted by the merge and others are left unadjusted. This will result in a regular “grain” being introduced to the processed image. In order to correct this, there is an option to interpolate the adjusted image in order to smooth out the grain. Checking the ‘Interpolate Intensity Array’ check box does this.

Save Settings Check Box

When this box is checked, your image processing settings will be retained from one run to the next. This is a very useful feature as getting good panchromatic color can be an iterative process. You will often want to change one setting at a time, making smaller and smaller adjustments as you approach a pleasing color balance.

Histogram Data Group

These utilities at the lower right hand corner of the Pan Sharpening Pre Processing group allow you to select between non linear and linear matching and turn the histogram match algorithm on and off. In general the non-linear produces better results but in some cases linear histogram matching performs better. (See subsequent section on histogram matching.) Besides enabling and disabling histogram matching, you can also clip the tails of the histograms using the enable check box and the slider bars. A better histogram match can sometimes result if you remove the first channel (zero or all black pixels) from the histogram match computation.

This does not remove the black pixels from the image, only from the matching computation. You can also clip bright pixels resulting from clouds or snow from the upper end of the histogram. The ‘Remove Highlights’ check box enables an algorithm to clean unwanted blue highlights that often result when histogram matching images with both green vegetation and water present. When it is enabled, you can select the range of application (on the transformation function) by selecting the upper and lower divisor and multiplier integers in the drop down Combo Boxes. Remove Highlights is described in more detail in the Manual section on Histogram Matching.

ENHG Scale Factor

The ENHG slider bar is enabled during ENHG pan sharpening or two file processing. Increasing the scale factor results in more intense green vegetation tones.

XIONG Scale Factor

The XIONG slider bar is enabled during XIONG pan sharpening or two file processing. Increasing the scale factor results in less blue and greener vegetation tones. However, increasing the scale factor beyond a certain point will result in an unacceptably noisy image.

Array Offsets

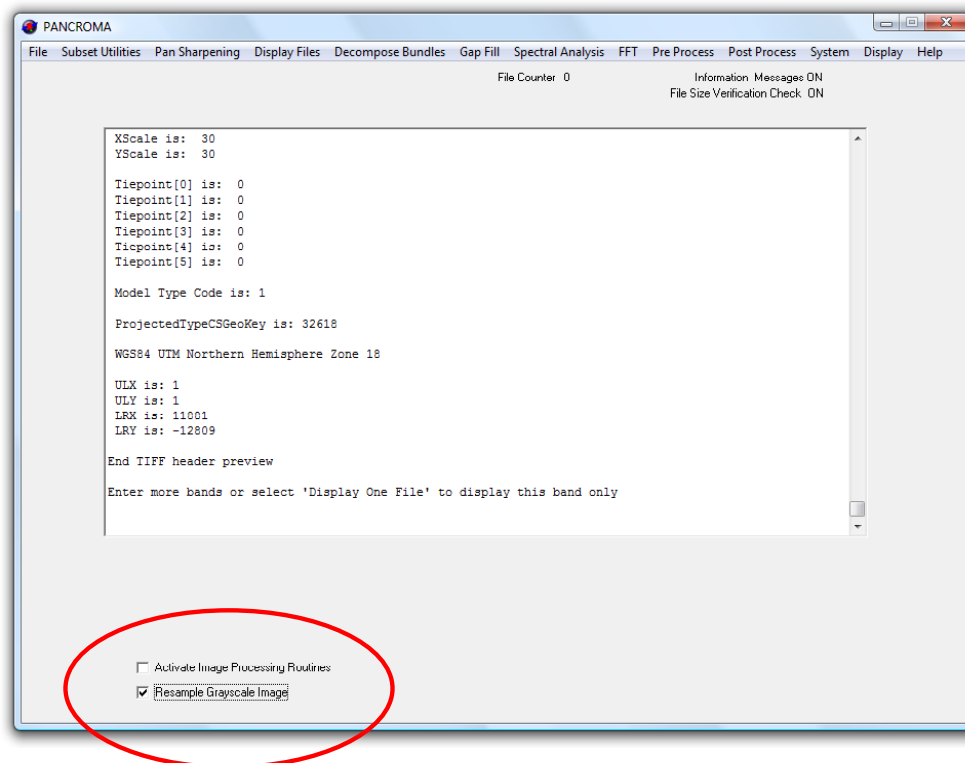
When this check box is checked, it allows shifting of the panchromatic image with respect to the hue and saturation images. This is useful if the images are not perfectly registered. The 'row' Combo Box shifts the panchromatic image North by the indicated (positive) number of pixels while the 'columns' shifts the image west.

IMPORTANT NOTE: The Save Settings Check Box can be used to advantage with the Maintain RGB Comparison Image check box in the Main Window. This allows you to iterate your panchromatic image while maintaining an RGB image prepared from bands 1-3 for reference.

58. Resizing an Image by an Integer Multiple

Sometimes it is beneficial to reduce the size of a grayscale image. For example, it is not practical to include a 250MB pan sharpened image into a presentation slide or a report. **PANCROMA™** provides a utility to reduce the file size (and correspondingly the resolution) of an input grayscale image. This is sometimes called 'resampling' because the algorithm samples every other pixel, or every fourth pixel, etc. and then recombines the sampled pixels into a new image.

In order to use this utility, load a single grayscale band or pan file image as described in the previous section. Check the 'Resample Grayscale Image' check box and then select 'Display Files' and then 'Display Single Grayscale Image' as in the previous section. You will be presented with a dialog box asking you to specify the resampling factor. A factor of '2' reduces the row and column count by $\frac{1}{2}$; a factor of '4' by $\frac{1}{4}$, etc. After producing the reduced image, you can save it by selecting 'File' | 'Save' and then either .jpg or .bmp format as described previously.



59. Image Preprocessing

PANCROMA™ provides a selection of useful image preprocessing utilities. Some of these can be used as part of other PANCROMA image processing operations. Others are offered as stand-alone utilities for general application. The current suite of preprocessing utilities is described below.

Arbitrary Image Resizing

PANCROMA™ provides a utility for resizing either a single or else three images simultaneously. The first utility is useful for pan sharpening Landsat with SPOT whereby you need to match the SPOT panchromatic image to the Landsat subset images. Alternatively, you can resize the three or four Landsat subset images. This utility is also used for gap filling images and will be described in more detail in the subsequent Gap Filling sections.

In order to use this method, load either a single grayscale file or else three identically sized files. Then select 'Pre Process' | 'Resize Images'. Select 'Resize One Image' to resize a single grayscale image or else 'Resize Three Images' to resize three or else 'Resize Four Images' to resize four. You will be prompted to enter the number of rows and columns for the new image in the Resize Data Input box. You can only scale an image down, not up, so make sure that both the new Rows and new Columns are less than the originals. When you have entered the values, click 'OK' and the new image will be displayed. Save it by selecting 'File' | 'Save' as usual and save it in one of the standard output formats. Note that the 'Resize Four Images' menu selection allows you to either rescale the image or to truncate it. Truncating may be more convenient in some cases where a band image needs to be altered by only one row or column.

PANCROMA™ also provides a utility to resize 28.5m resolution Landsat bands to 30m resolution. This is often useful when gap filling. Select 'PreProcess' | 'Resize Images' | 'Scale Landsat 28.5m to 30m'. The utility multiplies the rows and columns by a factor of 28.5/30 and multiplies xScale and yScale by the inverse ratio.

Histogram Matching

If you wish to match the histograms of two images, you must first open the files by selecting 'File' | 'Open' and select first the Reference image and then the Adjust image.

IMPORTANT NOTE: Make sure that you open the files in this order.

Now select 'Pre Process' | 'Histogram Match'. The image histogram of the Adjust image will be matched to the Reference image. The Adjust image will be displayed and can be saved as usual for subsequent processing by PANCROMA or using another program if desired.

Histogram Equalization

Histogram equalization improves the contrast of an image by mapping a narrow distribution of grayscale values to one that spans the entire grayscale color space. (This is also known as linear contrast stretch). This operation is conducted on a single image. Select 'File' | 'Open' and open your file. Now select 'Pre Process' | 'Histogram Equalization'. The input image will be adjusted and displayed and can be saved as usual. Histogram equalization can often improve the detail of a dark or muddy image. However it will have a powerful effect on the color balance of the image if used for subsequent processing and may produce unwanted effects. Histogram equalization is frequently needed for processing Digital Globe imagery.

Histogram Stretching

Often equalizing the histogram over the entire span of grayscale pixel levels has a very disruptive effect on image color balance. This is especially true if you are aiming to produce natural color RGB or pan sharpened images. In this case, it is often useful to stretch the histogram in a non-linear manner so that the pixels closest to the mean are displaced less than those further from the mean. The overall effect is heightened contrast without the disruptive effect on color balance. To histogram stretch an image, Select 'File' | 'Open' and open your file. Now select 'Pre Process' | 'Histogram Stretch'. A Histogram Form will be displayed that lets you input the Histogram Scale Factor using a track bar. The greater the Scale Factor, the greater the degree of stretch. The stretched image will be computed as with equalization and the stretched image displayed. Works for grayscale and color images.

Gamma Correction

Gamma correction originated in computer graphics in compensating for the non-linear response of cathode ray tube (CRT) terminals to power inputs. Since the CRT response was a power function rather than a linear response, an inverse power function was used to correct it. Gamma correction controls the overall brightness of an image. Images, which are not properly corrected, can look either bleached out, or too dark. Trying to reproduce colors accurately also requires some knowledge of gamma. Varying the amount of gamma correction changes not only the brightness, but also the ratios of red to green to blue

PANCROMA™ can apply an inverse gamma function (gamma correction) to either a single grayscale band or alternatively a color RGB image. To do so

select 'File' | 'Open' and open your file. Now select 'Pre Process' | 'Gamma Correction' and either 'Grayscale Image' or 'Color Image'. When you do so a thumbnail version of your input image will be come visible. Using the slider, adjust the gamma coefficient until the image has the brightness and contrast characteristics you desire.

Band Math - Image Subtraction

As its name implies, this utility subtracts one grayscale image from another on a pixel-by-pixel basis. Select 'File' | 'Open' and open two files. **PANCROMA™** will subtract the second file from the first. If you wish to scale how much of the second file gets subtracted, select the 'Activate Image Processing Routines' check box. When the image processing box appears, use the 'Subtraction Scale Factor' slider bar to adjust the percentage of the second file to be subtracted from the first. This utility will use 16-bit math for Landsat 8 data.

Band Math - Band Ratios

Band ratios are often very helpful for highlighting different features on the earth's surface. The technique is especially useful for Landsat bands and there is quite a bit of information available regarding this technique. (See the 'Band Combinations' link in the **PANCROMA™** 'Help' menu for some useful ratios.)

As its name implies, ratioing two Landsat bands just means dividing each pixel value in the numerator image by its corresponding pixel in the denominator image. There are some complications in practice however. The first problem is that corresponding pixels tend to be not very different in magnitude. So although pixel values can theoretically range from 0 to 255 (disallowing division by zero), most of the values will be less than 6. Such a division would result in a very dark, low contrast image that would not be useful. As a result, **PANCROMA™** uses the following algorithm to compute band ratios:

- Convert each pixel value to type FLOAT
- If the numerator and denominator are both zero, set the ratio equal to zero
- (Or else) if the denominator is zero, set the ratio equal to 254
- (Or else) f the denominator is greater than zero, compute the ratio as a FLOAT
- Multiply the computed ratio by scaleFactor
- Remove all values greater than the Upper Clipping Percent*Max Value
- If the Histogram Stretch check box is checked, stretch the image so that the max DN is 254 and the min DN is 0
- If the Histogram Equalize check box is checked, equalize the image
- Convert the ratio to type BYTE

It is often necessary to clip the ratio histogram significantly if there are high flyers in the band ratio array. The portion of the histogram that is clipped is determined

by the position Upper Clipping Percent track bar. High-end flyers can also be mitigated by scaling.

To compute a band ratio, select 'File' | 'Open' and open two input files. The first file opened will be the numerator file and the second file will be the denominator. Select 'PreProcess' | 'Band Math' | 'Band Ratio'. A dialog box will become visible. You can set the scale factor and select histogram equalization or histogram stretching by checking the boxes. You can also clip pixels as well. This utility will use 16-bit math for Landsat 8 data.

Band Math - Band Linear Combinations

You can create linear combinations of one, two, three and four bands using the Band Linear Combination feature. Select 'PreProcess' | 'Band Math' and then either 'One Band', 'Two Bands', 'Three Bands' or 'Four Bands'. A data entry box will become visible that will prompt you to input your intercept and slope coefficients. (These coefficients are automatically populated by the Multiple Linear Regression utilities.) After processing, the transformed image will be displayed and can be saved as usual. This utility will use 16-bit math for Landsat 8 data.

Band Math – Boolean AND two Images

This utility conducts a Boolean operation on two files. FOR each pixel in the two images, IF(the pixel in the first image is greater than zero) AND (the corresponding pixel in the second image is greater than zero) THEN leave the pixel in the first image alone or ELSE (set the pixel in the first image equal to zero). Note that none of the pixels in the second image are modified.

This utility is intended to be used with masks created by the PANCROMA Spectral Analysis tools or masks from other sources.

Resize Images

Resize Images is a set of utilities for modifying the row and column count and/or modifying the scale factor of one or more images. Truncating an image will delete the specified number of rows and/or columns from the target band file or files. Resizing will also change the row and column count to be consistent with the specified new scale factor. The metadata will be updated to reflect the new values when saved in GeoTiff format. There are also two utilities for rescaling multispectral band data from 28.5m to 30m resolution and for rescaling panchromatic band files from 14.2m to 15.0m resolution.

The Resize group has a special utility for doubling the size of the Landsat thermal infrared (TIR) band. Doubling the TIR band is necessary in order to include it in Landsat multispectral analysis, i.e. the Landsat Point Spectrum GeneratorTM, Landsat Spectral AnalyzerTM, or Landsat Euclidean Distance

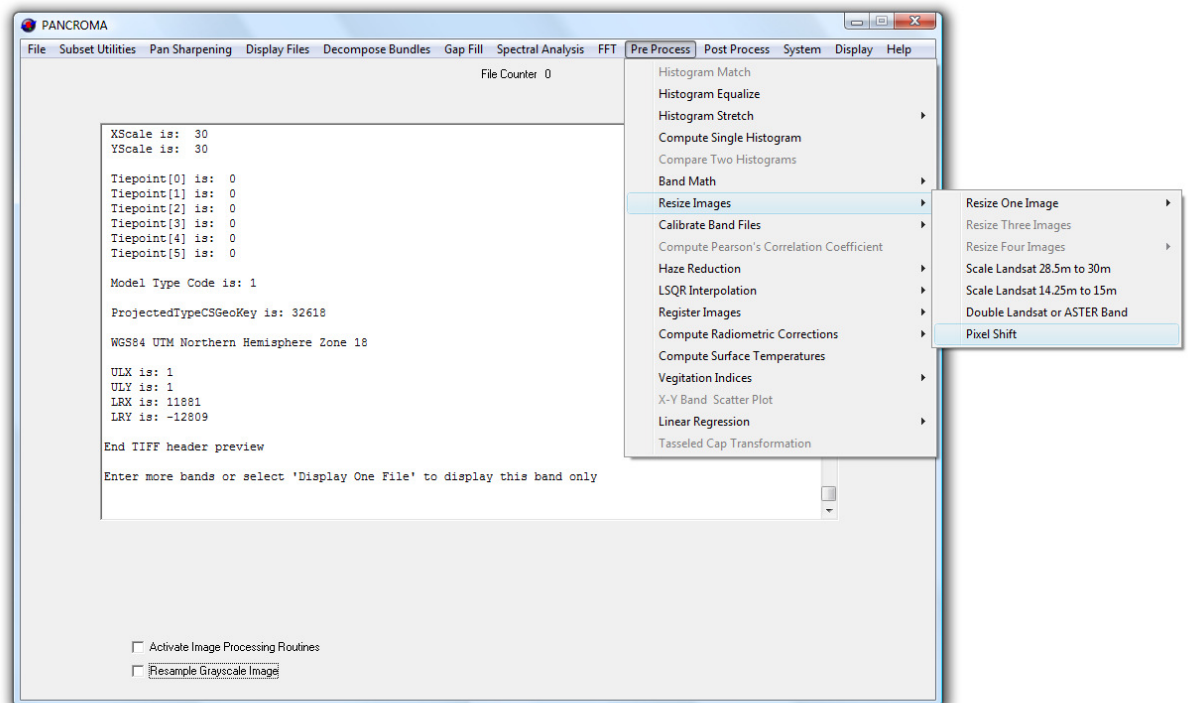
Analyzer. Doubling is done by first expanding the image and then interpolating it. The effective resolution of course does not change but the row and column count will match those of the multispectral bands.

To double a TIR (or any other) image, select 'File' | 'Open' and then 'Preprocess' | 'Resize Images' | 'Scale Landsat Thermal Image'. The file will be doubled and displayed. Save the grayscale image in GeoTiff format if you plan to use it for multispectral analysis. Gamma correction can be useful in converting Landsat 8 data to pleasing RGB color images.

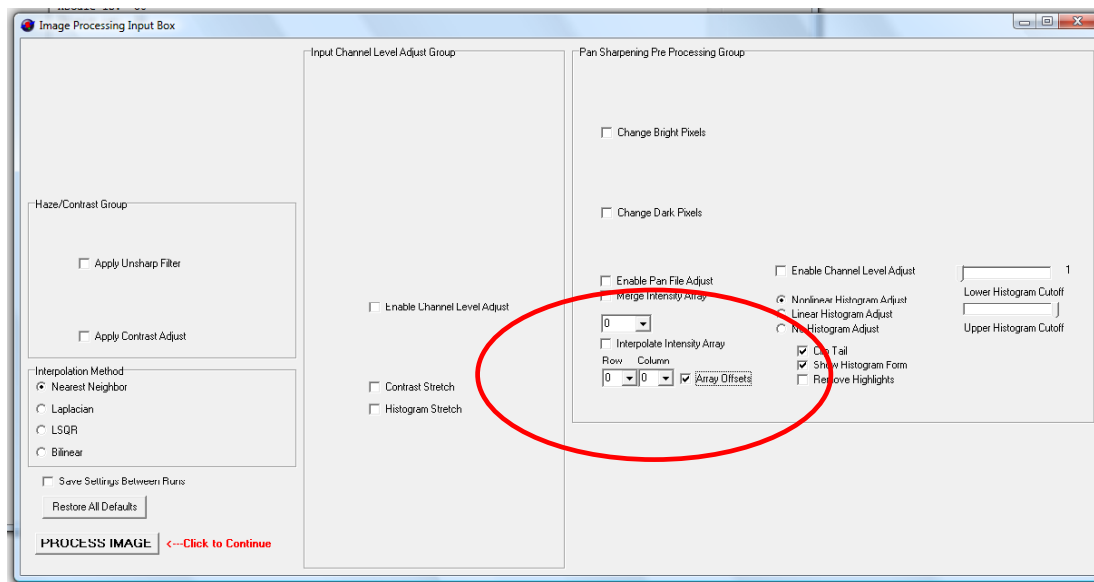
Pixel Shift

The Pixel Shift utility is a submenu selection under the 'Resize Images' menu selection. It allows you to shift your image North, South, East and/or West by a specified number of pixels (from -6 to +6). This utility may be useful if you feel that the PANCROMA automatic registration utilities need a little help, or if there is an underlying mismatch between multispectral bands and the panchromatic band, as can sometimes occur

To access this utility, select 'File' | 'Open' and then 'Preprocess' | 'Resize Images' | 'Pixel Shift'.



The Image Processing Input Form will become visible. Select the row and column offsets from the drop-down Combo Boxes as shown below



Positive row and column values are South and East. Select 'Process Image' and your shifted image will be computed.

Compute Single and Double Histograms

This feature allows the user to display the histogram of a single grayscale image or alternatively display the histograms of two grayscale images for comparison.

Compute Single Histogram

This menu selection will compute the image histogram for a single input image, along with image statistics. The histogram will be displayed graphically.

Compare Two Histograms

This menu selection will compute the image histograms for two input images, along with image statistics for both of them. The histograms will be displayed graphically

Compute Pearson's Correlation Coefficient

This menu selection will compute the Pearson's coefficient for two input images. The Pearson's coefficient is a standard measurement of the degree of difference between two images. Two images with a Pearson's coefficient of exactly 1 are identical. A coefficient of -1 indicates that the images are opposite, whereby

high pixel brightness in one image corresponds perfectly to low pixel brightness in the other. A coefficient of zero means that there is no correspondence at all between the two images.

Iterative Interpolation

PANCROMA™ offers an implementation of the Franklin Approximation interpolation algorithm as a stand-alone utility. The Franklin Approximation, implemented using the Iterative solver (with an initial estimate computed using the Laplacian convolution mask) has many advantages over other interpolation methods. The algorithm may be used for general interpolation tasks, for example the interpolation of elevation contour lines into digital elevation models (DEMs).

To use the utility, open a JPEG or BMP input file by selecting 'File' | 'Open'. Then select 'Pre Process' | 'Iterative Interpolation' | 'JPEG/BMP'. The image processing data input box will automatically open. Default values for Laplacian, Iterative and Thin Plate interpolation counts will be entered. Accept these or input your own values. The interpolation will be computed when you click 'Process Image'.

Input file size is limited to 3000 X 3000 rows and columns or equivalent due to the large amount of RAM required for the Iterative solver data structures. At present, the utility is only implemented for JPEG and BMP input files. Contact us if you wish to input alternative formats.

Landsat 7 Image Registration

Previous sections have discussed the **PANCROMA™** image registration utilities designed specifically for subsetting and co-registering sets of Landsat band files for gap-filling and cloud masking. These utilities, although powerful, have certain limitations. They always are combined with subsetting and row and column rationalizing steps. They automatically select ground reference points using common UTM latitude and longitude coordinates. When rescaling, they always rescale the larger scale image down to the size of the smaller scale image.

Sometimes you may need a general image registration utility that merely aligns two images without cropping or subsetting either of them. You may wish to use ground control points rather than latitude and longitude, and you may wish to interpolate the smaller image to that of the larger scale. **PANCROMA™** preprocessing image registration utility can do this.

Image registration is the process of aligning two images of the same area of the earth such that they correspond to each other on an exact pixel-by-pixel basis. This can be thought of as holding two image transparencies up to the light – if properly registered the land and water features will overlap exactly. It is rarely possible to produce a perfectly exact match. However, it is generally possible to produce very close matches for certain classes of images. One example is

Landsat scenes. Different Landsat images taken of the same scene possess a high degree of commonality. However they can also differ in the following ways:

- Corner coordinates generally will not match exactly
- Row and column counts will usually be different
- Obvious transnational differences will exist with respect to the upper left corner of the image (which is commonly taken as the 0,0 row and column coordinate)
- Scales may differ - some Landsat scenes have a resolution of 30m per pixel while earlier images have a slightly higher resolution of 28.5m/pixel

Sometimes it is necessary to adjust two similar images so that these and other differences are minimized and the two images align, for example in gap-filling, cloud masking and creating image mosaics.

Image registration is accomplished by conducting one or more image transformations to one of the images so that it matches the other. There are many types of transformations, for example linear, affine, approximations, piecewise methods, etc. They all work by building transformation functions using reference points (called ground control points or GCPs) on both images that are known to describe the same point on the earth's surface. The transformation functions contain parameters or coefficients that are constructed using mathematical models describing the expected differences between the two images. **PANCROMA™** uses a relatively simple linear transformation in its general registration function. Although simple in principle, its implementation in code is of course be less than simple. Linear transformations are generally appropriate for images that are acquired far from the earth's surface, and for data sets like Landsat are projected to a common datum and are oriented 'north is up'.

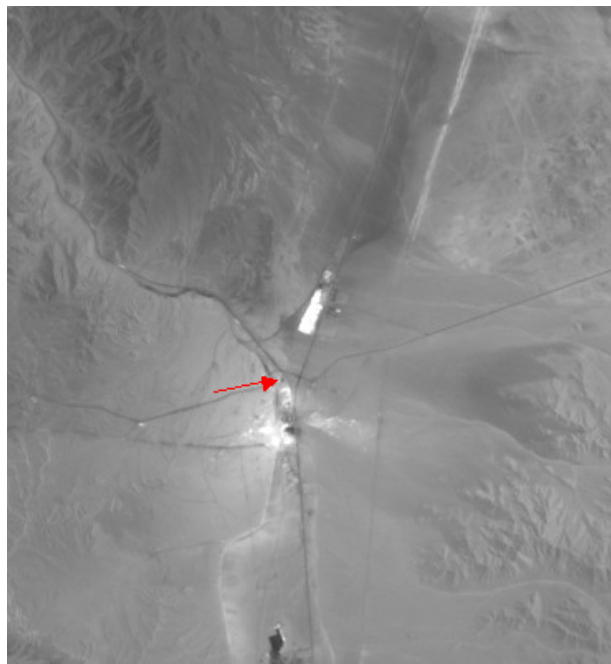
To use the utility, you must have two images that have at least some common area, and preferably a high percentage of overlap. Start by Selecting 'File' | 'Open' and opening two GeoTiff band files that you wish to register. The files should use the UTM projection and have the same datum and be oriented so that north is up. The first file that you open will be the 'base' file. The second file (adjust image) will be the 'adjust' file, i.e. the one that is transformed to match the base image. Now select 'PreProcess' | 'Register Images' | 'Linear Transformation Two Images'.

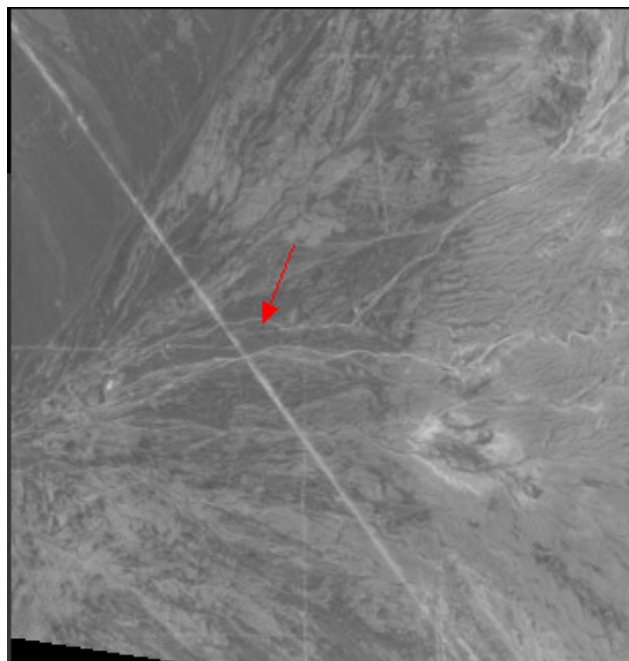
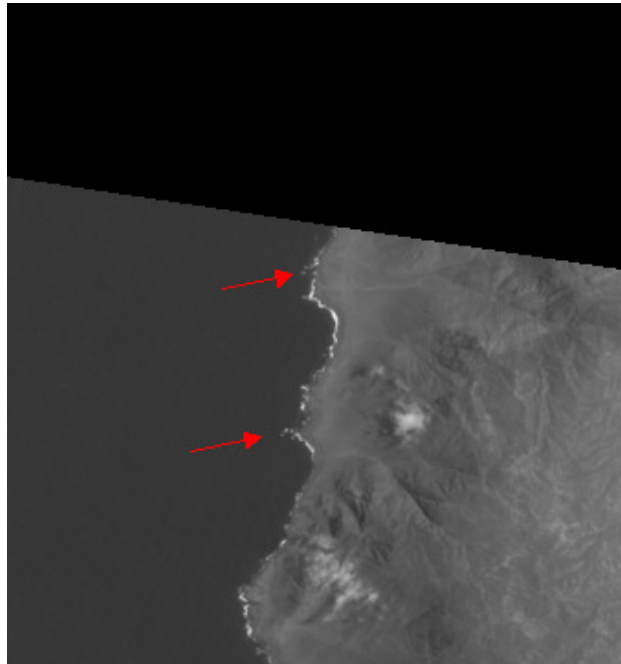
A data entry box will become visible. The next step is to select the ground control points (GCPs). GCPs are points on the base and adjust image that you can clearly identify as having precisely the same location. The easiest way to select such points is to select those with the same latitude and longitude coordinates. The UTM coordinates for both the base and adjust images are displayed in the Main Window as you scroll over the base and adjust images. You can also select ground features for GCPs.

There are a few rules of thumb regarding selection of such points. They should be clear, precise and preferably man-made. (Some natural features are clear and precise. However there is a possibility that they may shift position over time. Features such as river bends, edges of snow fields and the like may migrate over time and yield errors. Features such as crossroads, buildings and bridges are generally more reliable.)

IMPORTANT NOTE: Make sure that your points are NOT co-linear. This will lead to a singular matrix and a bad result. The points should be spaced as far as possible apart as possible (for example two upper corners and the middle of the bottom edge) and preferably close to the edges of the image.

Some control points that I used for an example registration are shown below. The first image shows a distinct crossroads. (The corner of the white lot or a small building could have been used as well.) The second image shows some small islands that could serve as suitable control points. The third image shows the intersection of a road and a dry wash. Although using the wash could be dangerous, inspection of the two images showed the signatures to be exactly equal so I suspected that the location had not moved between the images.





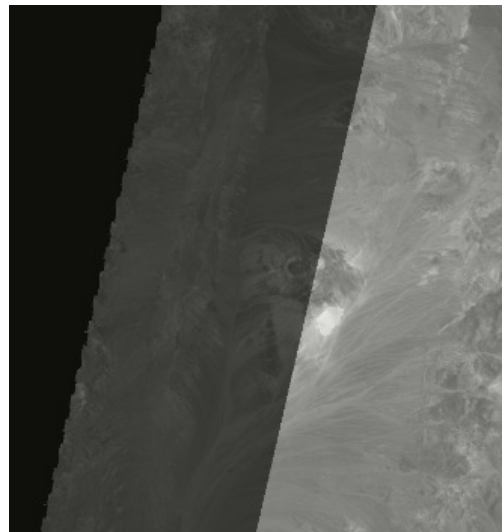
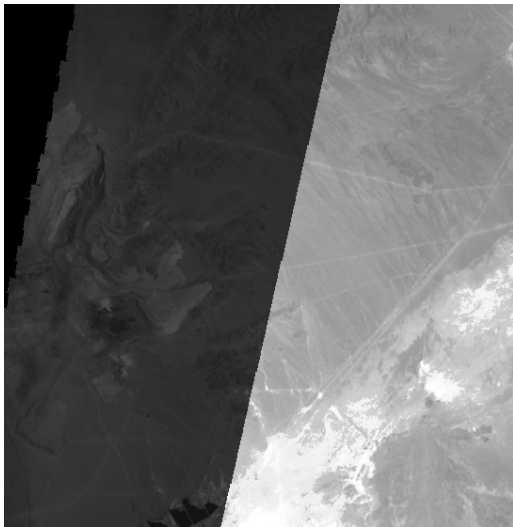
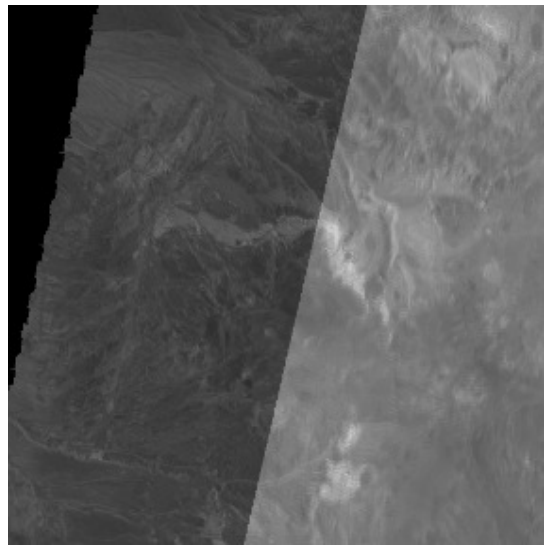
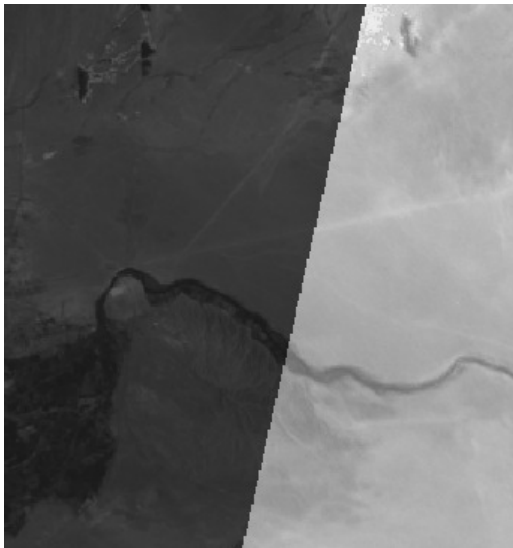
You will need three control points for the registration. Select the first one by moving your cursor over it on the base image and clicking on it. Now locate the corresponding point on the adjust image and click on it. *The second image will be adjusted during the registration process while the base image will remain unchanged.* Return to the base image and click on the second point. Find its corresponding point on the adjust image and click on it. Repeat for the third point. (Note that an internal toggle enforces the correct point entry order.)

Each time you click on a point, its row and column coordinates will be displayed on the Image Registration form. If you make a mistake you can clear the text boxes or else just keep clicking, as the algorithm will just keep cycling until you stop. Once you have your three pairs of points recorded, select 'Enter' to start the computation.

PANCROMA™ will first compute the transformation coordinates based on the control point data that you have input. It will then apply the transformation to the adjust image. Since the transformation will not generally be a one-to-one mapping, narrow gaps will occur after the transformation. **PANCROMA™** will fill these gaps using a Laplacian transformation interpolation.

Although the adjust image is generally mapped to the base image, there is a common case where the base image must also be adjusted. The transformation may compute negative adjust image row and column coordinates if the adjust image must be moved west and north. This cannot be, so the necessary offset is applied to both the base and adjust images to prevent this from happening. The result is extra padding pixels added to the base image such that its row and column counts are increased by the offset amount. The UTM corner coordinates are then corrected to keep everything in order. If the base image adjustment goes the other way, the offset is not needed.

After the registration is computed, the graphics windows will display the base image, adjusted if necessary as explained above and the transformed adjust image. The images can be saved in GeoTiff format by selecting 'File' | 'Save' | 'Save Grayscale Image' | 'GeoTiff'. You will be asked to supply a base file name. When you do so and select 'Save', both images will be saved. They can be used for other purposes, or can be processed using future **PANCROMA™** utilities, like image merge. The straightforward linear transformation can yield excellent results for Landsat images. Some examples of the quality of the registration can be seen in the images below.



Landsat 7 Top of Atmosphere Reflectance

Raw Landsat data is designed 'Level 0' by NASA and the USGS. Level 0 data is the raw telemetry from the satellite. In order to be usable, this data must be corrected and processed. All commonly available Landsat data has been radiometrically corrected to Level 1 standard. According to the *Landsat 7 Data Users Handbook*, Level 1 processing algorithms include:

- Payload Correction Data (PCD) processing
- Mirror Scan Correction Data (MSCD) processing
- ETM+/Landsat 7 sensor/platform geometric model creation
- sensor line of sight generation and projection
- output space/input space correction grid generation

- image resampling
- geometric model precision correction using ground control
- terrain correction

The terrain (T) and geometric (G) corrections are as described at http://landsathandbook.gsfc.nasa.gov/data_prod/prog_sect11_3.html. This reference also states that during 1G product rendering image pixels are converted to units of absolute radiance using 32 bit floating point calculations. Pixel values are then scaled to byte values prior to media output. The following equation is used to convert DN's in a 1G product back to radiance units:

$$L_{\lambda} = \text{Grescale} * \text{QCAL} + \text{Brescale}$$

Published Landsat data is corrected using algorithms 1-8, listed above. The terrain correction using a DEM is only applied for L1T, and not L1G. It is possible to convert from DN's to radiances using the band gain and bias parameters in the Landsat metadata. (DN's or Digital Numbers are sensed radiation quantized to discrete levels, for example 0-255 for Landsat data.)

Conducting analyses using Landsat data (for example NDVI analysis) may or may not require further processing. NDVI or other image parameters can be computed using uncorrected DN's from L1T data and the index can be successfully used to highlight vegetative areas in an L1T color composite image. However, problems could be introduced when comparing derived image characteristics or statistics using DN's between one Landsat scene and another, or between two Landsat scenes acquired at different dates.

The problem is that the parameter that you are interested will probably be related to ground reflectance, i.e. the light reflected off the earth's surface if you were standing next to the plant and aiming a spectrophotometer at it. You could collect data during different seasons or during different years and draw conclusions from the readings if you took into account the differences in the incident solar radiation as a function of solar zenith angle, atmospheric characteristics and other factors.

Comparing DN's acquired by a satellite in a similar fashion can lead to problems because even though the Landsat DN's have been calibrated and processed, they have been acquired under different lighting and atmospheric conditions. This can be partially corrected by working with Top of Atmosphere (TOA) reflectance's rather than DN's. There are of course a great many other factors that could influence the validity of such comparisons. The USGS tutorial posted at <http://www.pancroma.com/data> that you can download has a lot more information on atmospheric physics and corrections. Also see the paper entitled "Measuring Urban Air Quality Using Worldview2 Multiangle Multispectral Band Data" published at <http://www.pancromap.com/whitePapers.html>.

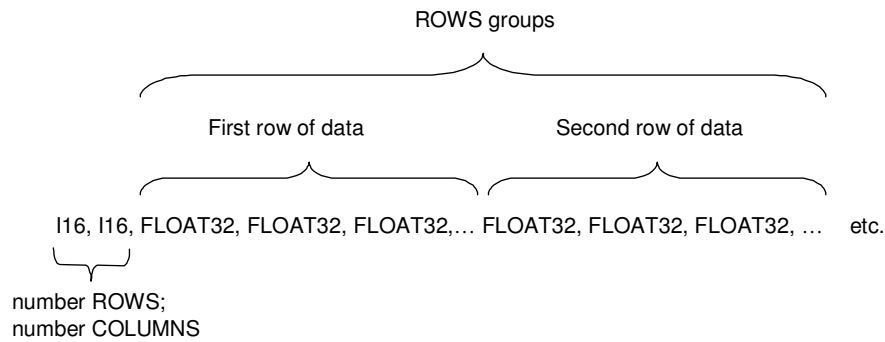
PANCROMA™ has a utility for converting Landsat 7 band file DN's to TOA reflectances. The procedure for carrying out such a conversion is as follows:

Conversions must be made one Landsat 7 band file at a time. Open a band file by selecting 'File' | 'Open'. (**PANCROMA™** can input Landsat TIFF and L1G format files) Then select 'PreProcess' | 'Compute Radiometric Corrections' | 'Compute Landsat 7 TOA Reflectance'. The TOA Reflectance Data Form will become visible. This form will ask you to input certain parameters from the metadata file that accompanies each Landsat 7 scene. These parameters are needed to compute and render (if desired) the TOA data. The required parameters are the band number, the solar elevation angle, the acquisition date and a scale factor (to make the image display properly.)

Note that the Landsat 7 algorithm actually wants the solar zenith angle, which is 90° minus the solar elevation angle. However the solar elevation angle, not the zenith angle is archived in the metadata file so input the solar elevation angle and PANCROMA will take care of the conversion. **PANCROMA™** will not convert the acquisition date from the Gregorian calendar to Julian days. You must do this yourself by either counting on your fingers or alternatively using the NASA link on the **PANCROMA™** Help menu (<http://www-air.larc.nasa.gov/tools/jday.htm>) labeled "Launch NASA Ordinal Date Converter".

TOA reflectance is also used for cloud masking and an explanation of the Solar Elevation Angle and Acquisition Date is given in the Cloud Masking section of this manual. Additional required parameters include the Landsat band number (this is needed because the sensor gain and offset values are not the same for all Landsat bands) and a graphics image scale factor. In addition, the form has check boxes for writing the TOA reflectance data to file and for rendering it as an image.

PANCROMA™ gives you two options for saving your reflectance or radiance data: flat binary file or GeoTiff. You can elect to save your file to disk in flat binary format by checking the check box on the TOA Reflectance form when it becomes visible. Afterward, you will be prompted for an output file name, with the suffix 'bin', denoting a binary data file. **PANCROMA™** will output the data in flat binary form using IEEE 32-bit FLOAT (little endian) format. The output file will be $((\text{ROWS by COLUMNS} * 4) + 8)$ bytes in size. The extra 8 bytes result from the number of rows and number of columns that precede the FLOAT data. These are output as 4 byte integers, again in little endian format. The file structure is shown schematically below.



Contact us if you need more information regarding the file structure or the C++ algorithms for reading it.

Another option is to save your reflectance data in GeoTiff format. If you check this box on the TOA reflectance form (shown below) you will be prompted for a TIFF file name.

TOA Reflectance Data Form

45

Solar Elevation Angle

175

Acquisition Date in Ordinal Days

1

Landsat Band Number

500

Graphics Image Scale Factor

☒ Write 16-Bit GeoTiff File

☐ Output Float to File

☒ Render Grayscale Image

Landsat Type

☒ Landsat ETM+

☐ Landsat TM

OK

Cancel

When this option is enabled, a GeoTiff reflectance file is written immediately after the TOA Reflectance array is computed. The file is in the same format that USGS Landsat Reflectance data is archived in, namely sixteen bit integer (I16) format. A scaling factor of 100000 is applied to the data. This is ten times greater than the USGS convention but I found it was necessary in order for the output files to display adequately in other applications. You will have to take this into consideration if you import this format into another application.

You can also elect to display the TOA reflectances as an image file. Since the TOA reflectances are small numbers compared to the DNs, they will need to be scaled in order to display properly. The default scale factor is 500. If the images are too dark, try increasing the scale factor. Black splotches on the image mean that the scaled values exceed 255, the maximum grayscale image quantization value so you may want to decrease the scale factor a bit. As long as you use the same scale factor between images, the TOA reflectance values can still be valid since they are scaled absolute numbers. If you decide to create such images, you can output them in any of the standard **PANCROMA™** output formats. A TOA reflectance image, with scaleFactor=500 is shown below.



Landsat 7 Top of Atmosphere Radiance

PANCROMA™ can compute TOA radiance in a fashion similar to TOA reflectance. TOA radiance is given by:

$$L_{\lambda} = \text{Grescale} * \text{QCAL} + \text{Brescale}$$

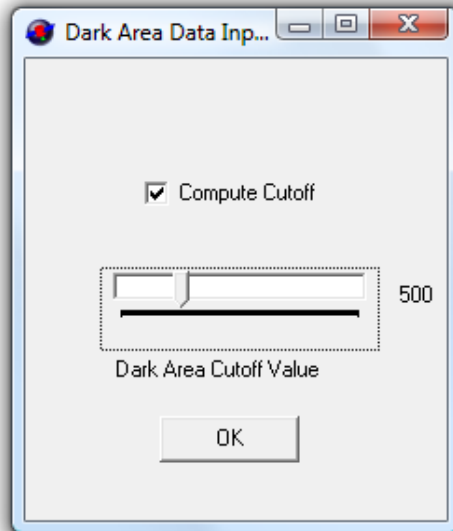
Where QCAL are the calibrated image DNs, and Grescale and Brescale are the sensor gain and offset, respectively.

Open a band file by selecting 'File' | 'Open'. (**PANCROMA™** can input Landsat TIFF and L1G format files) Then select 'PreProcess' | 'Compute Radiometric Corrections' | 'Compute Landsat 7 TOA Radiance'. The TOA Radiance Data Form will become visible. This form will ask you to input certain parameters that are needed to compute and render (if desired) the TOA data. The Solar Elevation Angle and Acquisition Date are not required. A scale factor can be input to scale the image rendering. Additional parameters include the Landsat band number (this is needed because the sensor gain and offset values are not the same for all Landsat bands). As for TOA reflectance, the form has check boxes for writing the TOA reflectance data to file and for rendering it as an image.

Landsat 7 Approximate Surface Reflectance

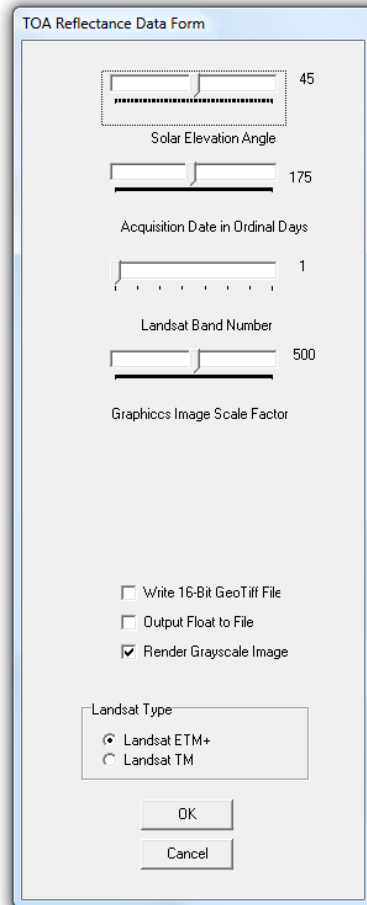
PANCROMA™ now has the ability to conduct haze reduction and then TOA reflectance computations with a single menu selection. Currently Landsat, SPOT, ASTER and EO-1 ALI are supported. The method pairs the Dark Area haze reduction algorithm with the TOA reflectance calculations specified by the Data Handbooks for each sensor platform. (I will probably add at least some HOT capability in the future.)

The utility currently handle a single band file at a time. To use it, first open your input band file by selecting 'File' | 'Open' as usual. Then select 'Preprocess' | 'Compute Radiometric Corrections' | 'Landsat Approximate Surface Reflectance' for Landsat data or the corresponding menu selection for SPOT, ASTER or EO-1 ALI. After the file is read in, the Dark Area Data Input form will become visible.



This allows you to select the onset of the band histogram edge as explained in previous articles describing the Dark Area method. It is generally best to leave the 'Compute Cutoff' check box checked and let **PANCROMA™** find the cutoff automatically. Alternatively, you can set the value manually using the slider bar as explained in the Instruction Manual. When you click 'OK', the histogram, cutoff and threshold will be computed. The histogram values and cutoff data will be echoed to the diagnostic screen.

Next the TOA Reflectance Data Entry form will become visible. You must enter the appropriate data that you can obtain from the metadata file from your data set.



The image shows a software dialog box titled "TOA Reflectance Data Form". It contains several input fields and checkboxes. At the top, there is a slider for "Solar Elevation Angle" with a value of 45. Below it is a slider for "Acquisition Date in Ordinal Days" with a value of 175. Next is a slider for "Landsat Band Number" with a value of 1. Below that is a slider for "Graphics Image Scale Factor" with a value of 500. There are three checkboxes: "Write 16-Bit GeoTiff File" (unchecked), "Output Float to File" (unchecked), and "Render Grayscale Image" (checked). At the bottom, there is a "Landsat Type" section with two radio buttons: "Landsat ETM+" (selected) and "Landsat TM" (unselected). At the very bottom are "OK" and "Cancel" buttons.

TOA Reflectance Data Form

Solar Elevation Angle 45

Acquisition Date in Ordinal Days 175

Landsat Band Number 1

Graphics Image Scale Factor 500

☐ Write 16-Bit GeoTiff File

☐ Output Float to File

☒ Render Grayscale Image

Landsat Type

☒ Landsat ETM+

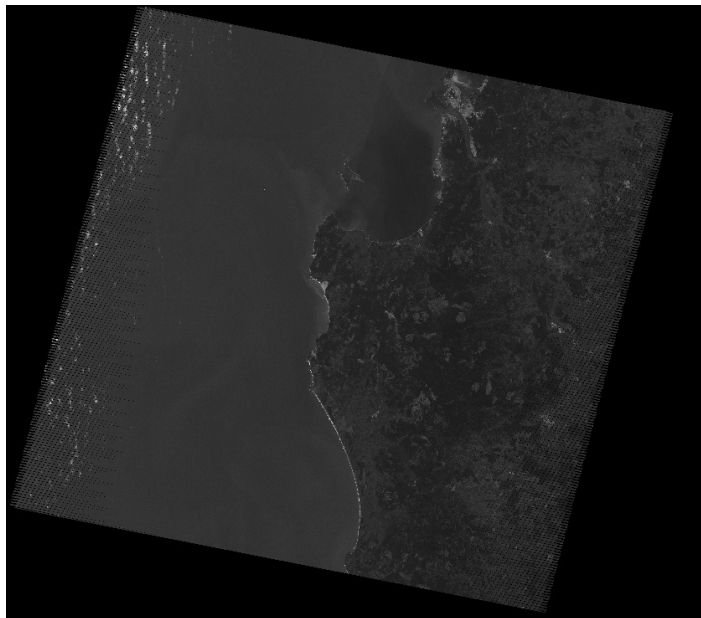
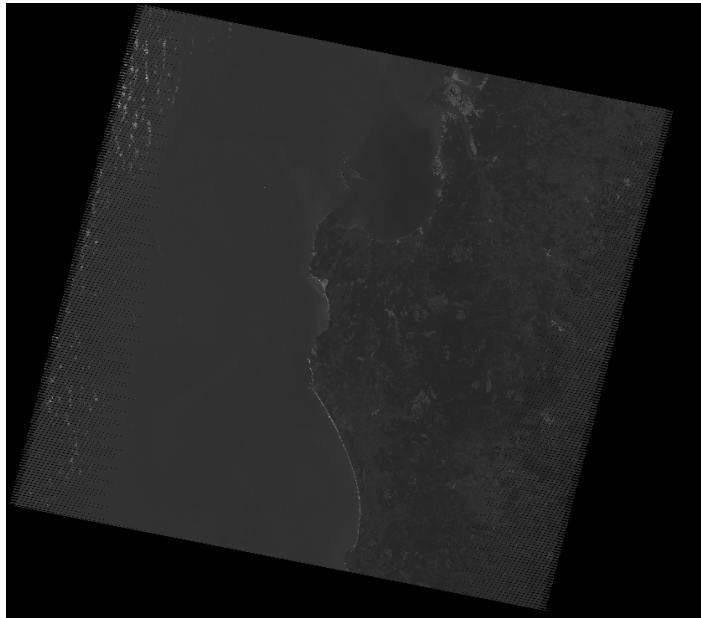
☐ Landsat TM

OK

Cancel

When you select 'OK' the surface reflectance file will be computed. Note that there are two check boxes on the form that allow you to save your file in flat binary IEEEFP32 format or in GeoTiff I16 format.

The following two images show a band1 DN image and a scaled reflectance image after correction.



Landsat 7 Surface Temperature

The Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors acquire temperature data and store this information as a digital number (DN) between 0 and 255 inclusive in the Thermal Infrared (TIR) bands. It is possible to convert these DNs to degrees Kelvin using **PANCROMA™** Surface Temperature utility. **PANCROMA™** uses the method specified in the *Landsat 7 Science Data Users Handbook*, first converting the DNs to radiance using the bias and gain values specific to the Landsat band 6, 6a or 6b TM or ETM bands. It then uses the Thermal Band Constants specified in the handbook. The temperatures can be written as FLOAT types to file, displayed as a scaled grayscale image or as a color contour plot.

$$T = K_2 / \ln((K_1/L_\lambda) + 1)$$

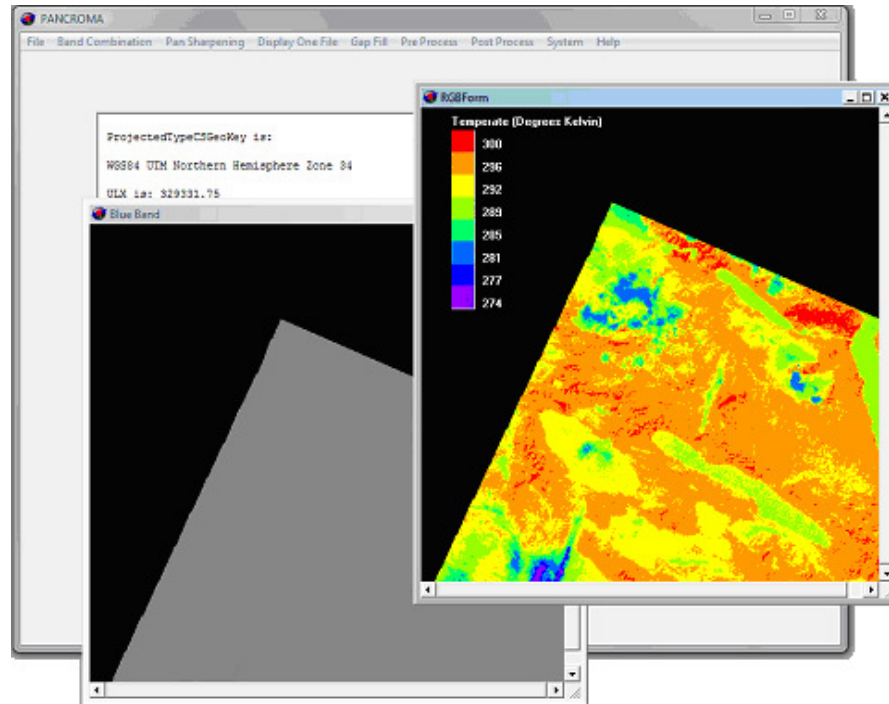
Where:

- T = Effective at-satellite temperature in Kelvin
- K2 = Calibration constant 2 from Table 11.5
- K1 = Calibration constant 1 from Table 11.5
- L = Spectral radiance in watts/(meter squared * ster * μm)

Table 11.5 ETM+ and TM Thermal Band Calibration Constants		
	Constant 1- K1 watts/(meter squared * ster * μm)	Constant 2 - K2 Kelvin
Landsat 7	666.09	1282.71
Landsat 5	607.76	1260.56

To use the utility, open a Landsat TIR band by selecting 'File' | 'Open'. Then select 'PreProcess' | 'Compute Surface Temperatures' | 'Landsat 7'. (Note that only TIFF and L1G format is accepted by this utility.) A data entry screen will be displayed. You will be prompted to select how the data will be output. You can check boxes to direct **PANCROMA™** to save a data file, display a grayscale image or display a color contour plot. The band number track bar is visible but is not adjustable as the temperature computation is only valid for band 6 input files. However the Graphics Image Scale Factor can be used to attenuate the grayscale image output, since the temperature is reported in degrees Kelvin and will typically exceed the maximum allowable grayscale channel value (255) if not. The default setting is 0.5. Note that you must check either the 'Landsat ETM+' or 'Landsat TM' radio button as the band 6 gains are different for the two Landsat types. If your input file is a Landsat ETM+ type, **PANCROMA™** will automatically detect whether the input file is a high gain (suffix 61) or low gain (suffix 62) type so that the correct gain and bias coefficients will be used.

The rendering below shows a color thermal contour plot and a grayscale image scaled by a factor of 0.5.



Landsat 8 Top of Atmosphere Reflectance

Landsat 8 OLI band data can also be converted to TOA planetary reflectance using reflectance rescaling coefficients provided in the product metadata file (MTL file). The following equation is used to convert DN values to TOA reflectance for OLI data:

$$\rho\lambda' = M_p Q_{cal} + A_p$$

where:

$\rho\lambda'$ = TOA planetary reflectance, without correction for solar angle.

M_p = Band-specific multiplicative rescaling factor from the metadata (REFLECTANCE_MULT_BAND_x, where x is the band number)

A_p = Band-specific additive rescaling factor from the metadata (REFLECTANCE_ADD_BAND_x, where x is the band number)

Q_{cal} = Quantized and calibrated standard product pixel values (DN)

TOA reflectance with a correction for the sun angle is:

$\rho\lambda = \rho\lambda' / \cos(\theta_{sz})$, where:

$\rho\lambda$ = TOA planetary reflectance

θ_{SE} = Local sun elevation angle. The scene center sun elevation angle in degrees is provided in the metadata (SUN_ELEVATION).

θ_{SZ} = Local solar zenith angle; $\theta_{SZ} = 90^\circ - \theta_{SE}$

PANCROMA™ has a utility for converting Landsat 8, 16-bit band file DNs to TOA reflectances. The procedure for carrying out such a conversion is similar to that described for converting Landsat 7 bands as described above.

Conversions must be made one Landsat 8 band file at a time. Open a band file by selecting 'File' | 'Open'. Then select 'PreProcess' | 'Compute Radiometric Corrections' | 'Compute Landsat 8 TOA Reflectance'. The TOA Reflectance Data Form will become visible. This form will ask you to input the Solar Elevation Angle from the metadata file that accompanies each Landsat 8 scene.

Note that unlike Landsat 7, the conversion coefficients are the same for each Landsat 8 band so it is not necessary to enter the band number. In addition, the conversion does not use the sun-earth distance (although this parameter is listed in the metadata).

Landsat 8 Top of Atmosphere Radiance

OLI and TIRS band data can be converted to TOA spectral radiance using the radiance rescaling factors provided in the metadata file:

$L_\lambda = M_L Q_{cal} + A_L$ where:

L_λ = TOA spectral radiance (Watts/(m² * srad * μm))

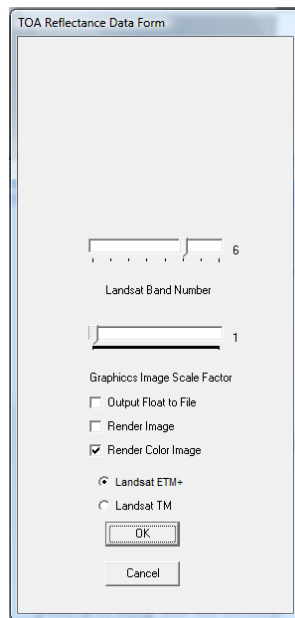
M_L = Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number)

A_L = Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number)

Q_{cal} = Quantized and calibrated standard product pixel values (DN)

Open a band file by selecting 'File' | 'Open'. Then select 'PreProcess' | 'Compute Radiometric Corrections' | 'Compute Landsat 8 TOA Radiance'. The TOA Radiance Data Form will become visible. This form will ask you to input certain parameters that are needed to compute and render (if desired) the TOA data. The required parameters are the Additive and Multiplicative band constants (the bias and gain) and a graphics scale factor if generating an image.

Note that the Solar Elevation Angle and Acquisition Date are not required to compute Atmospheric Radiance for Landsat 8. However the band constants will differ from scene-to-scene so it is necessary to input them explicitly for each Landsat 8 band.



Landsat 8 Surface Temperature

PANCROMA™ can also compute Landsat 8 surface temperatures. TIRS band data is converted from spectral radiance to brightness temperature using the thermal constants provided in the Landsat 8 metadata according to the equation:

$$T = K_2 / \ln((K_1/L_\lambda) + 1)$$

where:

T = At-satellite brightness temperature (K)

L_λ = TOA spectral radiance (Watts/(m² * srad * μm))

K_1 = Band-specific thermal conversion constant from the metadata
(K1_CONSTANT_BAND_x, where x is the band number, 10 or 11)

K_2 = Band-specific thermal conversion constant from the metadata
(K2_CONSTANT_BAND_x, where x is the band number, 10 or 11)

To use the utility, open a Landsat TIR band by selecting 'File' | 'Open'. Then select 'PreProcess' | 'Compute Surface Temperatures' | 'Landsat 8'. (Only TIFF and L1G format is accepted by this utility.) A data entry screen will be displayed. You will be prompted to select how the data will be output. You can check boxes to direct **PANCROMA™** to save a data file, display a grayscale image or display a color contour plot. The band number track bar is visible but is not adjustable as the temperature computation is only valid for band 6 input files. However the Graphics Image Scale Factor can be used to attenuate the grayscale image output, since the temperature is reported in degrees Kelvin and will typically exceed the maximum allowable grayscale channel value (255) if not. The default setting is 0.5. Note that you must check either the 'Landsat 8 Band 10' or 'Landsat 8 Band 11' radio buttons as the band gain and offset are different for the two Landsat thermal bands.

SPOT Top of Atmosphere Reflectance

PANCROMA™ can also compute TOA Reflectance for SPOT band files. The procedure is nearly the same as for Landsat band files. Conversions must be made one SPOT band file at a time. Open a band file by selecting 'File' | 'Open'. Then select 'PreProcess' | 'Compute Radiometric Corrections' | 'Compute SPOT TOA Reflectance'. The TOA Reflectance Data Form will become visible. This form will ask you to input the parameters that are needed to compute and render (if desired) the TOA data. The Solar Elevation Angle and Acquisition Date are required.

Additional parameters include the SPOT band number and a graphics image scale factor. In addition, the form has check boxes for writing the TOA reflectance data to file and for rendering it as an image. You must also input the appropriate Absolute Calibration Gain coefficient from the SPOT metadata file. Unlike Landsat, these coefficients are not constant but vary somewhat from scene to scene. The coefficient can be input using the SPOT Absolute Calibration Gain Track Bar on the TOA Reflectance Data Form.

TOA Reflectance Data Form

Solar Elevation Angle: 45

Acquisition Date in Ordinal Days: 175

SPOT Band Number: 1

Graphics Image Scale Factor: 500

SPOT Absolute Calibration Gain: ☒

Output Float to File: ☐

Render Grayscale Image: ☒

OK Cancel

A section of a SPOT metadata file showing the Absolute Calibration Gain coefficients is shown below. After inputting the data, click 'OK' and the reflectance values will be computed.

Scene ID	4 022-092 10-09-07 20:36:55 2 I			
K-J identification	022-092			
Date	2010-09-07 20:36:56			
Instrument	HRVIR 2			
Shift Along Track	1 300			
Preprocessing level	1A			
Spectral mode	XI			
Number of spectral bands	4			
Spectral band indicator	XS1	XS2	XS3	XS4
Gain number	6	6	6	5
Absolute calibration gains (1/W*m2*sr*µm)	2.89755	3.98208	4.50901	18.09397
Orientation angle	31.5 degree			
Incidence angle	L2.8 degree			
Sun angles (degree)	Azimut: -175.8 Elevation: 23.7			
Number of lines	3000			
Number of pixels per line	3000			

SPOT Top of Atmosphere Radiance

PANCROMA™ can also compute atmospheric radiance values for SPOT. The procedure is similar to Landsat radiance calculation. Open a single input file and then input the band number, the image scale factor, and the Absolute Calibration Gain from the metadata. Click 'OK' and the band radiances will be computed.

ASTER Top of Atmosphere Reflectance

PANCROMA™ can also compute TOA Reflectance for ASTER band files using ASTER L1B data in either GeoTiff or HDF file format. The procedure is nearly the same as for Landsat band files. Conversions must be made one ASTER band file at a time. Open a band file by selecting 'File' | 'Open'. Then select 'PreProcess' | 'Compute Radiometric Corrections' | 'Compute ASTER TOA Reflectance'. The TOA Reflectance Data Form will become visible. This form will ask you to input the parameters that are needed to compute and render (if desired) the TOA data. The Solar Elevation Angle and Acquisition Date are required. Additional parameters include the ASTER band number and a graphics image scale factor. It is necessary to check the ASTER metadata for the correct Gain setting. There are four: High, Normal, Low1 and Low2. The default setting is Normal. There are six ASTER multispectral bands, similar to Landsat. These bands are numbered 4 through 9. Band data for ASTER is given in Section 30 of this manual. The form has check boxes for writing the TOA reflectance data to file and for rendering it as an image.

ASTER Top of Atmosphere Radiance

PANCROMA™ can also compute atmospheric radiance values using ASTER L1B data in either GeoTiff or HDF file format. The procedure is similar to Landsat radiance calculation. Open a single input file and then input the band number, and the image scale factor. It is necessary to check the ASTER metadata for the correct Gain setting. There are four: High, Normal, Low1 and Low2. The default setting is Normal. Click 'OK' and the band radiances will be computed.

ASTER L1B Surface Temperature HDF File Format

PANCROMA™ can also compute atmospheric radiance values for ASTER L1B HDF format files. ASTER surface temperatures, like Landsat surface temperatures are computed from spectral radiance, so **PANCROMA™** begins by converting DNs to radiance. The equation relating the two is given by:

$$L_{\lambda} = (DN - 1) \times UCC$$

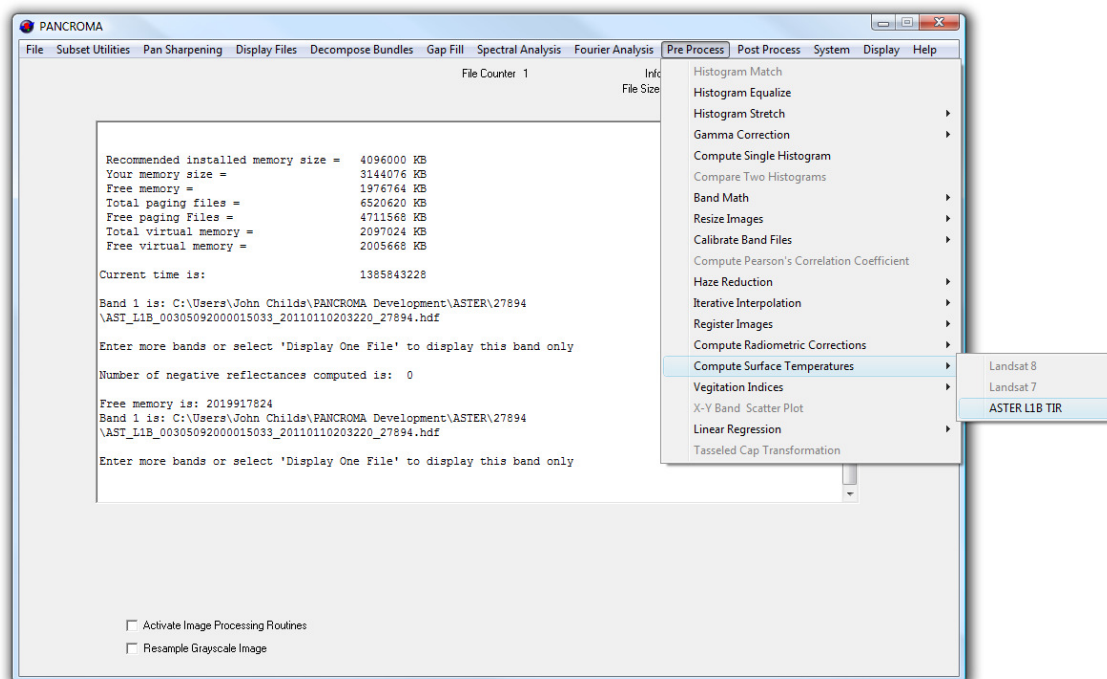
Where L_{λ} is the spectral radiance, DN are the TIR band digital numbers, and UCC are the published Unit Conversion Coefficients.

Temperature (measured in degrees Kelvin) is then given by:

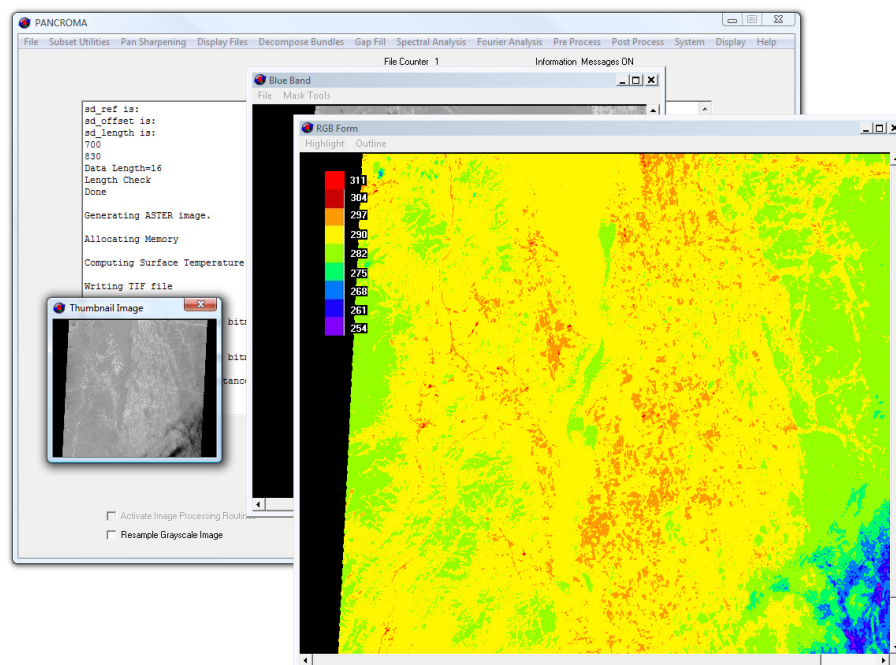
$$T = K2 / (\ln(K1 / L_{\lambda} + 1))$$

Where K1 and K2 are constants derived from Planck's radiance function.

The technique for computing surface temperatures is as follows. First, open your ASTER L1B HDF data file. (Note that ASTER L1A HDF data is implemented differently from L1B data, and currently PANCROMA will not handle L1A data successfully). Do this by selecting 'ASTER L1B HDF' from the File Type drop down box and clicking on your ASTER scene. Next select 'PreProcess' | 'Compute Surface Temperatures' | 'ASTER L1B TIR' from the **PANCROMA™** menu.



The TOA Reflectance Data Form will become visible. Set the TIR band number that you wish to process. Acceptable band numbers are 10, 11, 12, 13 or 14. You can also select various display and file output options. You can display the surface temperatures as a grayscale image or as a color contour image. These two, along with the thumbnail are shown in the figure below. The surface temperatures are indicated by the color scale bar at the upper left hand corner of the image. For the grayscale image, the darker the pixel, the cooler the temperature.



Note that the ASTER TIR bands are I16 format with a 14 bit dynamic range. **PANCROMA™** uses the full available dynamic range in converting the DN's to degrees Kelvin. As with Landsat surface temperature computations, you can also save your color and grayscale image files, and also save the computed temperatures in GeoTiff or flat binary format.

WorldView 2 Top of Atmosphere Reflectance

PANCROMA™ can compute WorldView2 TOA reflectances. Digital Globe calls this procedure 'calibration'.

The calibration procedure is described in the Digital Globe publication entitled Radiometric Use of WorldView-2 Imagery available at the Digital Globe website. Quoting from this publication: "WorldView-2 products are delivered to the customer as radiometrically corrected image pixels. Their values are a function of how much spectral radiance enters the telescope aperture and the instrument conversion of that radiation into a digital signal. That signal depends on the spectral transmission of the telescope and MS filters, the throughput of the telescope, the spectral quantum efficiency of the detectors, and the analog to digital conversion. Therefore, image pixel data are unique to WorldView-2 and should not be directly compared to imagery from other sensors in a radiometric/spectral sense. Instead, image pixels should be converted to top-of-atmosphere spectral radiance at a minimum."

Calibration requires multiplication of each grayscale image digital number (DN) by the Absolute Calibration Factor and then dividing it by the Effective Bandwidth. After calibration, each of the grayscale bands must be rescaled to reasonable brightness levels using the same scale factor for each image. I wrote the code required for the calibration and scaling and incorporated it into the latest version of PANCROMA. To calibrate an image you must first obtain the Absolute Calibration Factor (absCalFactor) and Effective Bandwidth (effectiveBandwidth) from the .IMI file that accompanies each data set. Note that each of the eight bands has its own calibration coefficients. Each band must be calibrated using its own calibration coefficients but scaled using a common scale factor.

To calibrate, open a single grayscale image using the 'File|Open' menu selection. After opening the file, select 'Pre Process'|'Calibrate WorldView2 Band'. A data input form will be displayed. Insert the calibration coefficients for the band you are calibrating into the text boxes on the data input form. You can use the default scale factor, or input one of your own. The optimum scale factor can be computed as:

$$\text{Scale Factor} = \text{SUM}(\text{absScaleFactor}) / \text{SUM}(\text{effectiveBandwidth})$$

Where

$$\text{SUM}(\text{absScaleFactor}) = (\text{absCalFactor1} + \text{absCalFactor2} + \text{absCalFactor3})$$

And

$$\text{SUM}(\text{effectiveBandwidth}) = (\text{effectiveBandwidth1} + \text{effectiveBandwidth2} + \text{effectiveBandwidth3})$$

After calibrating the band and panchromatic images using the default scale factor of '4', I saved them to disk. I then applied a proportional histogram stretch to each of the bands in turn and saved them again. (Note: it is not necessary to stretch the panchromatic band as it will be automatically histogram matched during the pan sharpening operation.)

RapidEye Top of Atmosphere Reflectance

PANCROMA™ can compute TOA Reflectance for RapidEye band files. The procedure is nearly the same as for Landsat band files. Conversions must be made one RapidEye band file at a time. First, decompose the bundled RapidEye five-band TIFF file into individual 16-bit bandfiles. Next, open a band file by selecting 'File' | 'Open'. Then select 'PreProcess' | 'Compute Radiometric Corrections' | 'Compute RapidEyeTOA Reflectance'. The TOA Reflectance Data Form will become visible. This form will ask you to input the parameters that are needed to compute and render (if desired) the TOA data. The Solar Elevation Angle and Acquisition Date are required.

Additional parameters include the RapidEye band number and a graphics image scale factor. You must scale the reflectance data in order for it to display properly since reflectance values are typically between zero and two. In addition, the form has check boxes for writing the TOA reflectance data to file and for rendering it as an image.

RapidEye Top of Atmosphere Radiance

PANCROMA™ can also compute atmospheric radiance values for RapidEye bands. The procedure is similar to the reflectance calculation. Open a single input file and then input the band number. RapidEye radiance values are typically between 0-1000 so they may have to be scaled to display properly. Click 'OK' and the band radiances will be computed.

Landsat Vegetation Indices

Vegetation Indices (VIs) are combinations of DN's or surface reflectances at two or more wavelengths designed to highlight a particular property of vegetation. Each of the VIs is designed to accentuate a particular vegetation property. Analyzing vegetation using remotely sensed data requires knowledge of the structure and function of vegetation and its reflectance properties. This knowledge enables the linking of vegetative structures and their condition to their reflectance behavior in an ecological system of interest.

The solar-reflected optical spectrum spans a wavelength range of 400 nm to 3000 nm. Of this range, the 400 nm to 2500 nm region is routinely measured using a variety of optical sensors, including Landsat. Vegetation interacts with solar radiation differently from other natural materials, such as soils and water bodies. The absorption and reflection of solar radiation varies depending on the characteristics of the vegetation and the incident wavelength. Water, pigments, nitrogen, and carbon are each expressed in the reflected optical spectrum from 400 nm to 2500 nm, with often overlapping, but spectrally distinct, reflectance behaviors. The known signatures allow scientists to combine reflectance measurements at different wavelengths to enhance specific vegetation characteristics.

PANCROMA™ currently provides seven VIs: Vegetation Index (VI), Normalized Difference Vegetation Index (NDVI), the Modified Soil Adjusted Vegetation Index (msavi2), the Enhanced Green (ENHG) index, the Moisture Stress Index (MSI), Normalized Burn Ratio (NBR) and the Normalized Difference Water Index (NDWI). This reference http://geol.hu/data/online_help/Vegetation_Indices.html provides a good introduction to VIs, as does <http://www.yale.edu/ceo/Documentation/rsveqfaq.html>.

The VI, NDVI, MSAVI2 and ENHG all use the Landsat near infrared (NIR), green and red bands. The same procedure is used for all three. Open three band files:

NIR band, band 2 (green) and band 3 (red) in this order. Select 'Preprocessing' | 'Vegetation Index' and the desired VI from the menu. If you check the 'Activate Image Processing Routines' you can adjust the VI Scale Factor. This will decrease or enhance the effect. After you compute the index, a grayscale image will be displayed. This is the Vegetation Index image. It will be used to replace the green band for subsequent display as an RGB color composite. Save it in your desired format, naming it 'VI.tif' or the like.

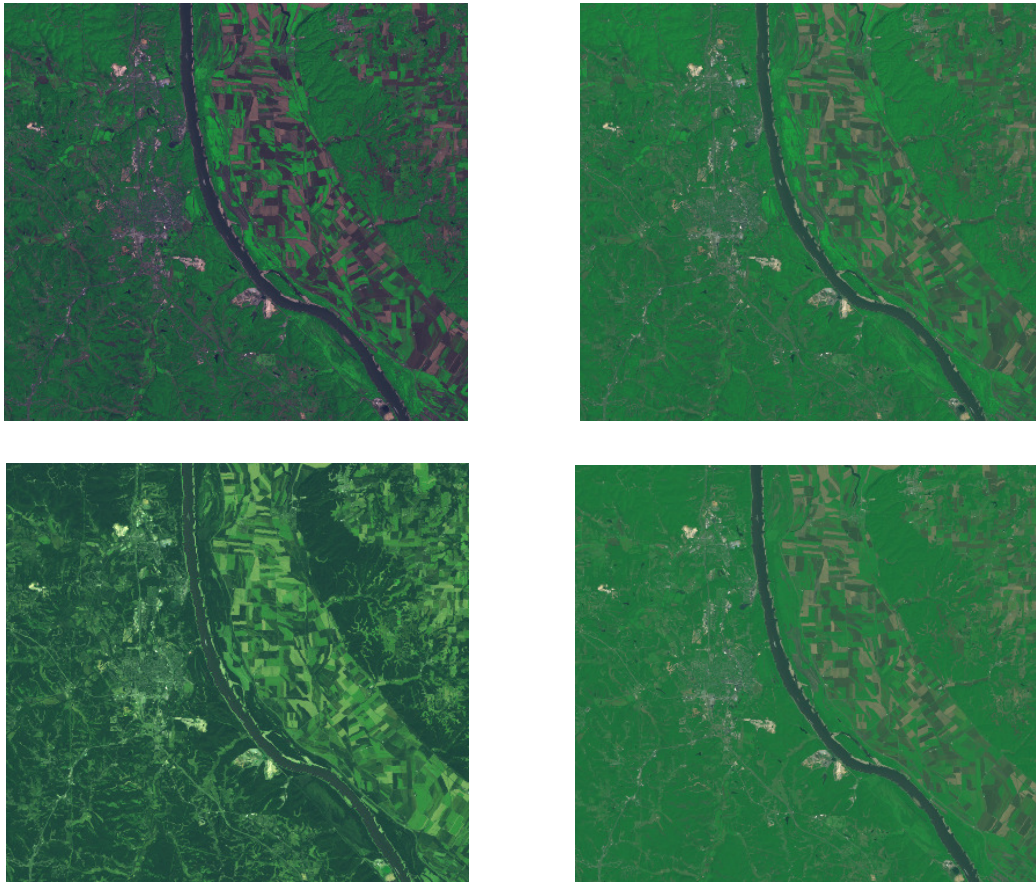
The Normalized Burn Ratio (NBR) uses the red, NIR and MIR bands. Open three band files: red band 3, band 4 (NIR) and band 7 (MIR) in this order. Select 'Preprocessing' | 'Vegetation Index' and 'NBR' from the menu. This utility modifies the red band so this must be substituted for the normal red band in order to create the color composite NBR image.

Now create an RGB color composite as usual by opening band1 (blue), the vegetation index band, and band3 (red), in this order. (Note: you can also use the NDVI as the red band for perhaps a better contrast. This appears to be the convention.) The resulting RGB image should have greener vegetation than the corresponding RGB color composite image using bands 1, 2, and 3.

If the vegetation is too green or not green enough, run another iteration except this time check the 'Activate Image Processing Routines'. Adjust the VI scale factor using the slider bar at the lower right of the image processing data form. The default value is 0.05. An example NDVI image is shown below.

The MSI and the NDWI use the mid infrared (MIR band 5) instead of the visible red band, in addition to near infrared (NIR band 4) and green (band 2) bands. To compute these indices, open the NIR, green and MIR bands in this order. Select 'Preprocessing' | 'Vegetation Index' and either 'NDWI' or 'MSI' from the menu. If you check the 'Activate Image Processing Routines' you can adjust the VI Scale Factor as before. This will decrease or enhance the effect. After you compute the index, a grayscale image will be displayed. This is the Vegetation Index image. It will be used to replace the green band for subsequent display as an RGB color composite. Save it in your desired format, naming it 'VI.tif' or the like. The list of available Vegetation Indices will increase. Example VI images are shown below. Clockwise from upper left: ENHG, VI, NDVI, MSI. Contact us if you need a specific index and we will look into adding it.

IMPORTANT NOTE: As usual, you must open the files in the specified order or unexpected color tones will result.



Tasseled Cap Transformation

The Tasseled Cap Transformation is the conversion of the readings in a set of channels into composite values; i.e., the weighted sums of separate channel readings. One of these weighted sums measures roughly the brightness of each pixel in the scene. One of these other composite values represents the degree of greenness of the pixels and another represents the degree of yellowness of vegetation and is commonly interpreted as the wetness of the soil. Usually there are just three composite variables. The Tasseled Cap Transformation was presented in 1976 by R.J. Kauth and G.S. Thomas of the Environmental Research Institute of Michigan in an article entitled "The Tasseled Cap -- A Graphic Description of the Spectral-Temporal Development of Agricultural Crops as Seen by LANDSAT." This paper was published in the *Proceedings of the Symposium on Machine Processing of Remotely Sensed Data*.

The Tasseled Cap transformation is commonly used for enhancing the spectral information content of Landsat ETM+ data. The Tasseled Cap indices are calculated from DN or reflectance data from six ETM+ bands, band 1, band 2, band 3, band 4 (NIR) band 5 and band 7. The six input bands are transformed into three output bands:

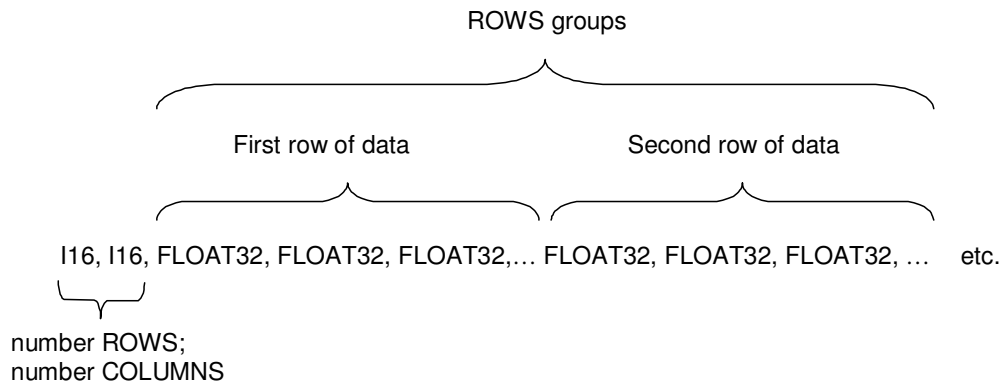
band 1 (Brightness, a measure of soil characteristics)
band 2 (Greenness, a measure of vegetation characteristics)
band 3 (Wetness, the interrelationship of soil and canopy moisture)

PANCROMA™ computes the Tasseled Cap Transformation from Landsat ETM+ satellite imagery using the following coefficients:

Tasseled cap coefficients for Landsat 7 ETM+ at-satellite reflectance

Index	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Brightness	0.3561	0.3972	0.3904	0.6966	0.2286	0.1596
Greenness	-0.3344	-0.3544	-0.4556	0.6966	-0.0242	-0.2630
Wetness	0.2626	0.2141	0.0926	0.0656	-0.7629	-0.5388

Tasseled Cap band values are not all positive, and can range from around –200 to +255 when computed from DNs. As a result the bands cannot be directly inserted into an 8-bit grayscale image model. **PANCROMA** automatically scales the each band based on the minimum and maximum values in that particular band so that they fall within the range of 0 to 255 so that a grayscale and/or false color composite image can be displayed. **PANCROMA** also offers the option of saving the raw band data as a file of type IEEE FP32 data. The file format is the same as that described in Section 46 of this manual. A diagram of the file format is repeated here.



To compute the Tasseled Cap transformation for a Landsat ETM+ scene, select 'File ' | 'Open' and open six Landsat band files: band1, band2, band3, band4, band5 and band 7. Note that the files must be opened in this order. Next select 'Pre Process' | 'Tasseled Cap Transformation' from the main menu. The Tasseled Cap Data Entry Form will be presented, as shown below.

Tasseled Cap Data Entry Form

Solar Elevation Angle 45

Acquisition Date in Ordinal Days 175

☐ Write Float Band 1
☐ Write Float Band 2
☐ Write Float Band 3

☒ Render Color Image
☐ Compute using DNs
☒ Compute using Reflectance

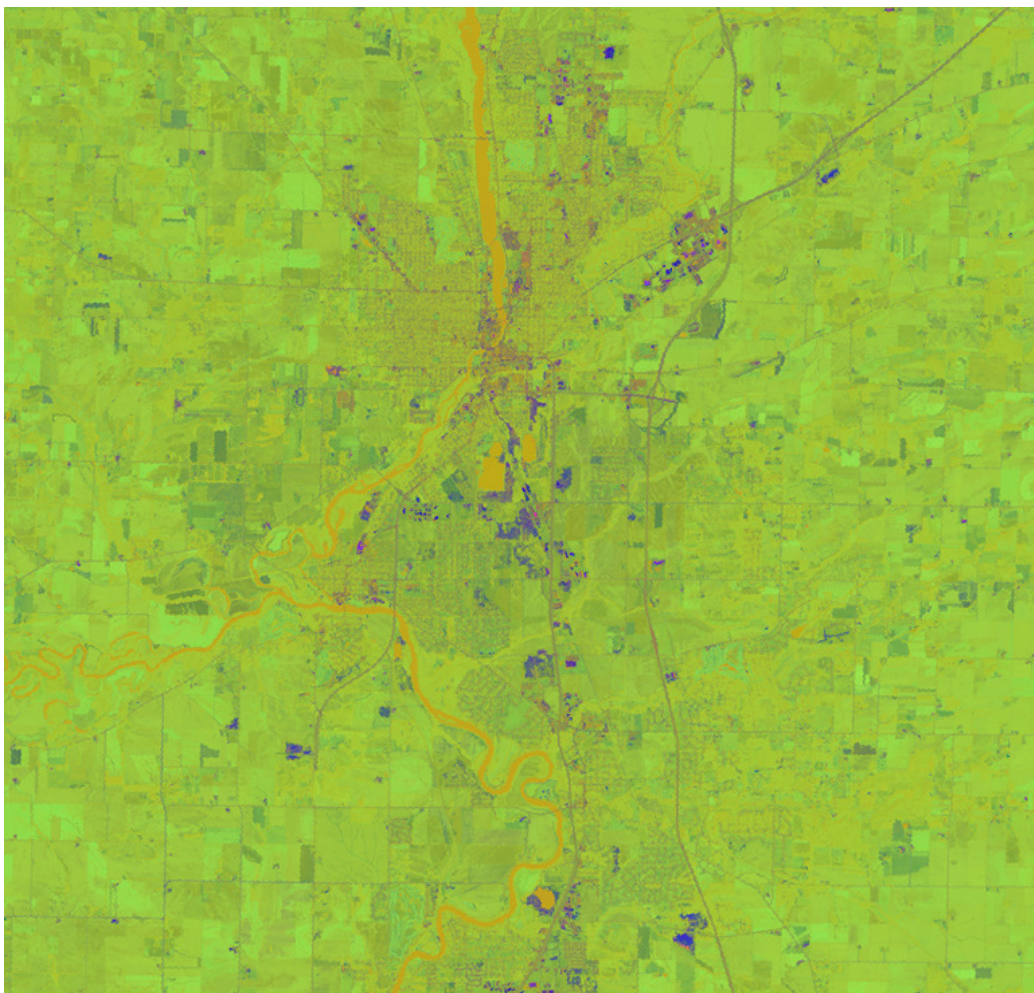
OK

Cancel

The Tasseled Cap transformation can be computed from band file digital numbers (DNs) or more correctly using Top of Atmosphere reflectance, which is the default condition. If you compute using reflectance values, you must obtain the Solar Elevation Angle and the Acquisition Date from the Landsat metadata files as described in the section above entitled 'Landsat Top of Atmosphere Reflectance'. If you wish to use DNs, check the 'Compute using DNs' radio button.

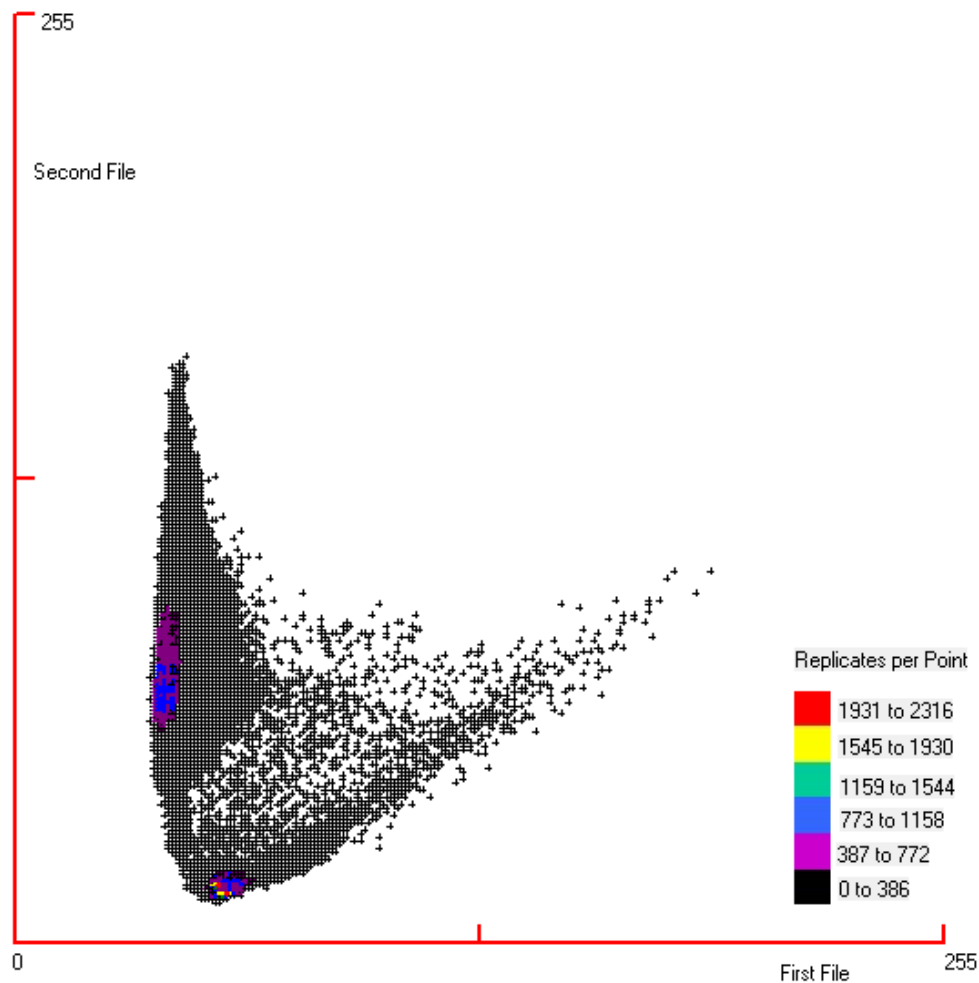
The 'Render Color Image' check box is also true by default. If you wish you can individually select the 'Write Float' check boxes. Checking these will cause **PANCROMA™** to write the raw Tasseled Cap values to disk file. You can output one, two, all three, or none of these files. Be advised that each one contains four times the bytes of the input band files as the values are 32 bits each rather than 8 like the input band files.

After processing, a composite color image will be displayed rendering the Tasseled Cap transformation. You can save this file to disk as usual by selecting 'File' | 'Save RGB Image'. An example of such an image is shown below.



X-Y Band Scatter Plots

A scatter plot can provide a graphical way to examine the correlation between two bands. **PANCROMA™** has the capability to compute scatter plots for comparing two band files to each other. The comparison is computed as follows: for each pixel with row and column count location $[i][j]$ in the each image, plot the DN of the first image pixel versus the DN of the second image pixel. Zero values are ignored. This latter provision is to prevent the plot from being skewed as a result of zero value collar pixels. To compute a scatter plot, select 'File' | 'Open' and open two input bands. Then select 'PreProcess' | 'X-Y Band Scatter Plot'. A data entry box will be presented. Select 'OK' and the plot will be generated. Such a plot is shown in the image below. (Note that there may be many superpositions in such a plot where multiple DNs in the first band plot to the same DNs in the second band.)



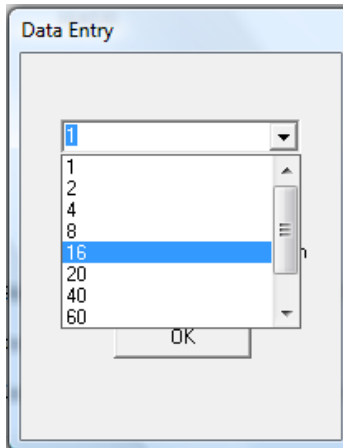
PANCROMA™ will color the data points based on the number of occurrences of identical replicates of that point. If you look closely at the lower left and center left of the data set you will see the red, blue and violet point coloring. The color bar key indicates the range of replicates that are associated with each point color.

The band sizes do not have to be identical to compute scatter plots. **PANCROMA™** will automatically resample the larger row and column sized image down to the smaller. {Note that the plot of a Landsat band 1 against a Landsat band 5 assumes the classic Tasseled Cap form.}

X-Y Band Linear Regression

PANCROMA™ can also compute linear regression parameters between two bands. To do so select 'File' | 'Open' and open two input bands. Then select 'PreProcess' | 'X-Y Band Scatter Plot' as before. A data entry box will be

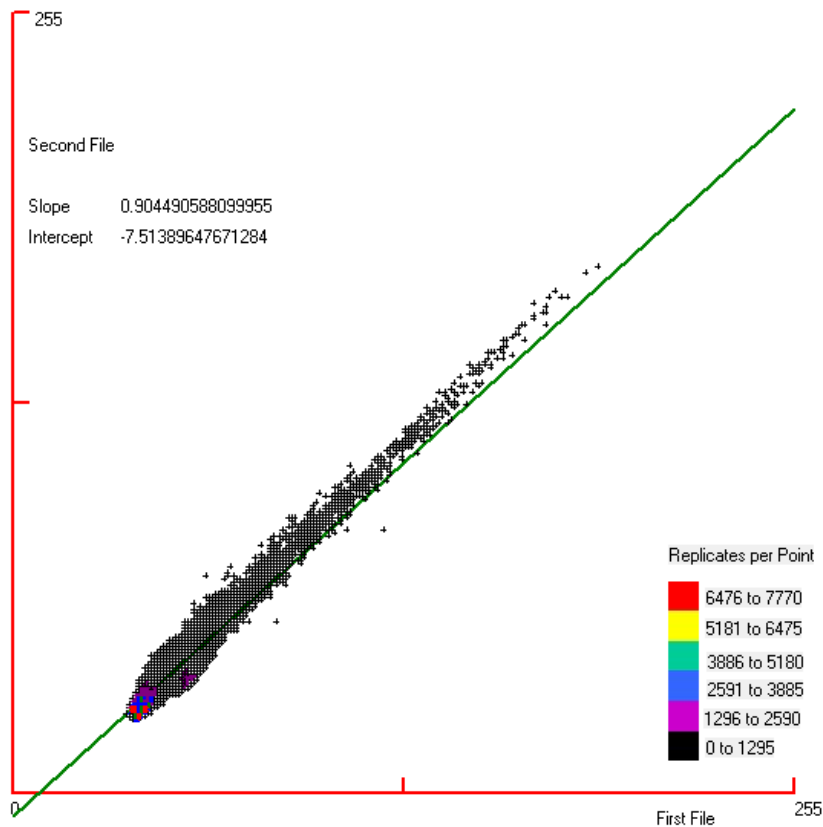
presented. Check the 'Compute Linear Regression' check box. A drop down Combo Box will become visible. You may select the sampling parameter. The default is 1, meaning that every pixel is included in the computation. If you select a higher resampling parameter the row and column counter will increment by the value selected, resulting in a lower number of pixels being included in the computation.



Select 'OK' and the plot will be generated. The regression statistics will be reported to the diagnostic screen and the slope and intercept values will appear on the plot. Note that zero values are ignored so that collar pixels do not skew the regression intercept.

IMPORTANT NOTE: Beware of running regression analysis on images with no data (black) collars. If the data areas do not match exactly **PANCROMA™** may have difficulty rationalizing the unequal data counts between the two images. It is best to use subset images or at least check your result against subset images.

This utility will use 16-bit math for Landsat 8 data.



Multiple Linear Regression

PANCROMA™ has a utility for regressing one independent variable (bands) against a second dependent variable band, i.e. solving the equation

$$Y = a + b_1X_1$$

Where **X₁** represents an independent multispectral or hyperspectral band file and **Y** represents the dependent band file. In order to compute the slope and intercept terms, select 'File' | 'Open' and open the dependent (**Y**) band first, and then the **X₁** band. (You must open the **Y** band first.) Then select 'PreProcess' | 'Multiple Regression' | 'One Independent Variable'. When the Data Entry box becomes visible, select the sampling interval. (If the sampling interval is one, every DN will be included in the computation and it will take longer. If the interval is 2, every other DN will be computed, etc.) The linear coefficient terms will be reported to the diagnostic screen on the Main Window. They will also automatically be inserted into the Data Entry Form for subsequent use for linear transformations. Note that zero values are ignored. This is to prevent the intercept from being skewed as a result of zero value collar pixels.

PANCROMA™ has a utility for regressing two independent variable (bands) against a third dependent variable band, i.e. solving the equation

$$Y = a + b_1X_1 + b_2X_2$$

Where **X1** and **X2** represent the independent multispectral or hyperspectral band files and **Y** represents the dependent band file. In order to compute the slope and intercept terms, select 'File' | 'Open' and open the dependent (**Y**) band first, and then the **X1** and **X2** bands. (You must open the **Y** band first.) Then select 'PreProcess' | 'Multiple Regression' | 'Two Independent Variables'. When the Data Entry box becomes visible, select the sampling interval as discussed above. The linear coefficient terms will be reported to the diagnostic screen on the Main Window. They will also automatically be inserted into the Data Entry Form for subsequent use for linear transformations. Note that zero values are ignored. This is to prevent the intercept from being skewed as a result of zero value collar pixels.

PANCROMA™ also has a utility for regressing three independent variable (bands) against a third dependent variable band, i.e. solving the equation

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3$$

Where **X1**, **X2** and **X3** represent the independent multispectral or hyperspectral band files and **Y** represents the dependent band file. In order to compute the slope and intercept terms, select 'File' | 'Open' and open the dependent (**Y**) band first, and then the **X1**, **X2** and **X3** bands. (You must open the **Y** band first.) Then select 'PreProcess' | 'Multiple Regression' | 'Three Independent Variables'. When the Data Entry box becomes visible, select the sampling interval as discussed above. The linear coefficient terms will be reported to the diagnostic screen on the Main Window. They will also automatically be inserted into the Data Entry Form for subsequent use for linear transformations. Note that zero values are NOT ignored for the three independent variable case. As a result it is necessary to subset the band files so that no-data collar pixels do not skew the regression intercept.

PANCROMA™ also has a utility for regressing four independent variable (bands) against a third dependent variable band, i.e. solving the equation

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4$$

Where **X1**, **X2**, **X3** and **X4** represent the independent multispectral or hyperspectral band files and **Y** represents the dependent band file. In order to compute the slope and intercept terms, select 'File' | 'Open' and open the dependent (**Y**) band first, and then the **X1**, **X2**, **X3** and **X4** bands. (You must open the **Y** band first.) Then select 'PreProcess' | 'Multiple Regression' | 'Four Independent Variables'. When the Data Entry box becomes visible, select the

sampling interval as before. The linear coefficient terms will be reported to the diagnostic screen on the Main Window. They will also automatically be inserted into the Data Entry Form for subsequent use for linear transformations. Note that zero values are NOT ignored for the three independent variable case. As a result it is necessary to subset the band files so that no-data collar pixels do not skew the regression intercept.

This utility will use 16-bit math for Landsat 8 data.

60. Image Post Processing

PANCROMA™ also offers a selection of image post processing utilities, as described below:

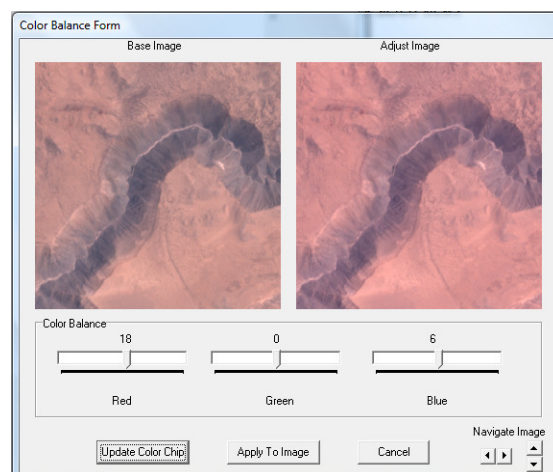
Color Adjustment

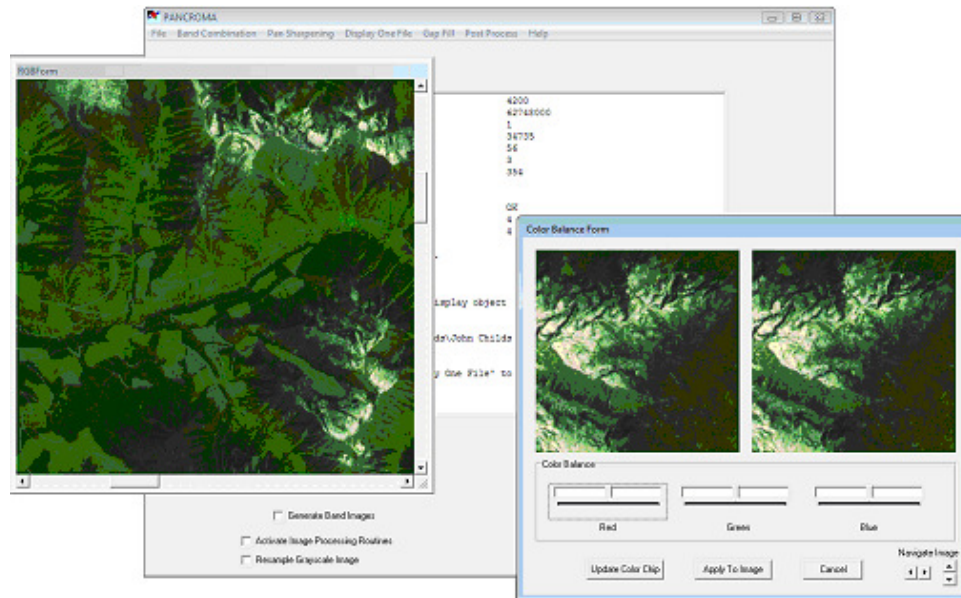
This utility allows fine-tuning the color image without recomputing the transforms. The utility may be used to adjust color images immediately after pan sharpening or compositing. Alternatively, images may be reloaded later for post processing.

To use the utility, either process or load a color image. If you are loading one, select 'File' | 'Open' and then 'Display Files' | 'Display One Color Composite Image' from the menu. When the image appears, select 'Post Process' | 'Color Adjust' from the menu. An image processing form will appear. The left hand image is the base image and the right hand image will preview your adjustments before applying the changes to the full image.

There are three sliders in the center of the form, one for each of the red, green and blue channels. They allow you to add or subtract up to 255 from each channel. Once you set the slider position, you can select 'Update Color Chip' to apply the changes to the adjust image on the right. You can modify the adjust image as many times as you like. Once you are satisfied with your settings, click the 'Apply to Image' button and the changes dictated by the slider positions and shown in the adjust image will be applied to the full image. Alternatively, select 'Cancel' to exit the form without making any changes to the image. If you make a mistake or don't like the result you must close or exit and start over.

There are navigation arrows at the lower right of the form. Use these to move the base and adjust windows up and down and across the image.





Shadow Reduction

This utility adjusts an RGB color composite image by lightening those pixels that are shaded by terrain features. The method, like the DEM Haze Reduction algorithm, uses the elevation information in a digital elevation model to correct the RGB color image. Start by obtaining a matching DEM/RGB image set. You can use an ASTER DEM/Landsat set as described in Section 47. Once you have created your matched set, open both files, first the RGB image and then the DEM. Select 'Post Process' | 'Brighten Shadow Areas' | 'DEM Method'. When you do the Shadow Adjust Data Entry Form will become visible.

You can adjust weighting factors for each band, and must enter the DEM resolution (30m per posting for ASTER DEM), and the Solar Elevation Angle and Solar Azimuth Angle from the metadata. When you click 'OK' the shadow reduced image will be produced. An example of before and after correction is shown below.



Unsupervised Classification

Unsupervised classification is a method for attempting to group similar pixels as a single hue with the intention of highlighting certain surface features, such as vegetation, water, urban areas, etc.

RGB images may be classified. To classify an image, open an RGB image. Display it by selecting 'Display Files'/'Display One Color Composite Image'. When the image is displayed, the 'Classify' menu selection under the 'Post Process' category will be enabled. Select it. A data entry box will be displayed that allows you to select from several algorithms and to set the classification parameters. The defaults will usually work fine. The utility is has the following limitations:

- Maximum input file size is limited to 16MB. This is because the classification algorithm requires floating point pixel value precision.
- The classification is computationally and memory intensive. It will take a while to process an image.
- It is not possible to easily predict how many iterations it will take the k-classification algorithm to converge on the solution. The progress bar indicates the status of a single loop but it generally takes many loops to converge.
- The algorithm clusters pixels around a mean or median pixel value. As a result the hues of the processed image will resemble those of the unprocessed image. It is not possible at this time to toggle the hues for higher contrast but this will be available in future versions.



The two images shown above illustrate unsupervised classification on an image. The image on the left is a SPOT® false color composite. The image uses 131,000 unique colors. The image on the right has classified those colors into

only six. The colors correspond to land usage, including water, vegetation, and several levels of urbanization. Now it is much easier to compute image characteristics, for example the percentage of area covered by vegetation or water. **PANCROMA™** will also compute the percent area occupied by each cluster and report the statistics to the Main Window log screen. The statistics for the sample are:

Pixel cluster centroids:

Cluster0

29
58
78

Cluster1

172
102
117

Cluster2

142
78
97

Cluster3

131
132
127

Cluster4

144
215
180

Cluster5

145
165
150

Fraction of total image area of cluster 0 is: 0.0627331584692001

Fraction of total image area of cluster 1 is: 0.153274908661842

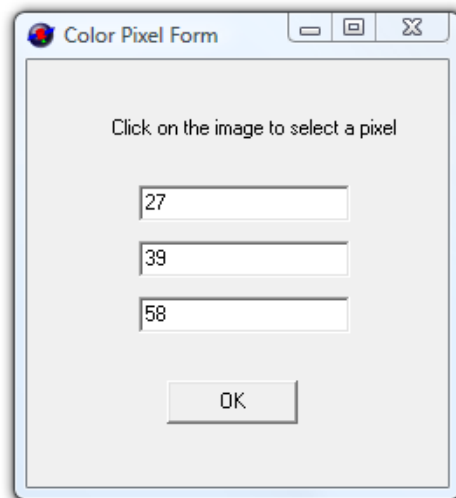
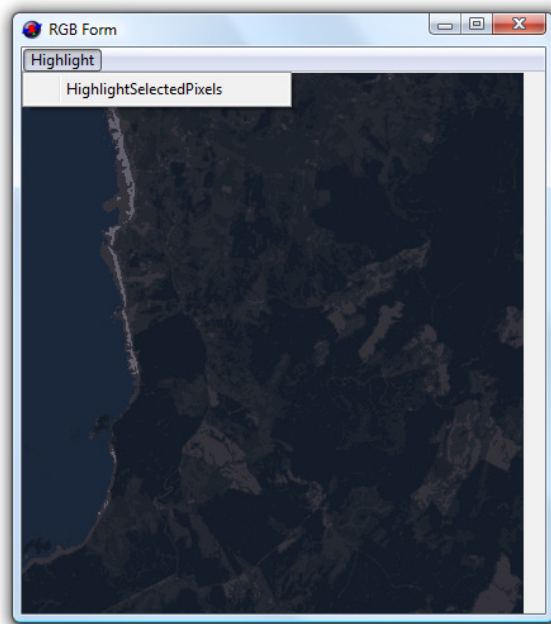
Fraction of total image area of cluster 2 is: 0.232252687215805

Fraction of total image area of cluster 3 is: 0.249773144721985

Fraction of total image area of cluster 4 is: 0.0691162198781967

Fraction of total image area of cluster 5 is: 0.232849881052971

PANCROMA™ will also allow you to highlight a selected cluster. When the RGB form appears, a drop down menu will become enabled. Selecting it causes the Pixel Color Form to become visible. Click on the classified image. The RGB pixel values that you clicked on will be entered into the text boxes on the Pixel Color Form. Click 'OK'. The RGB image will be repainted with all pixels of the selected class highlighted in orange. Repeating the process will add classes of pixels to the painted area.





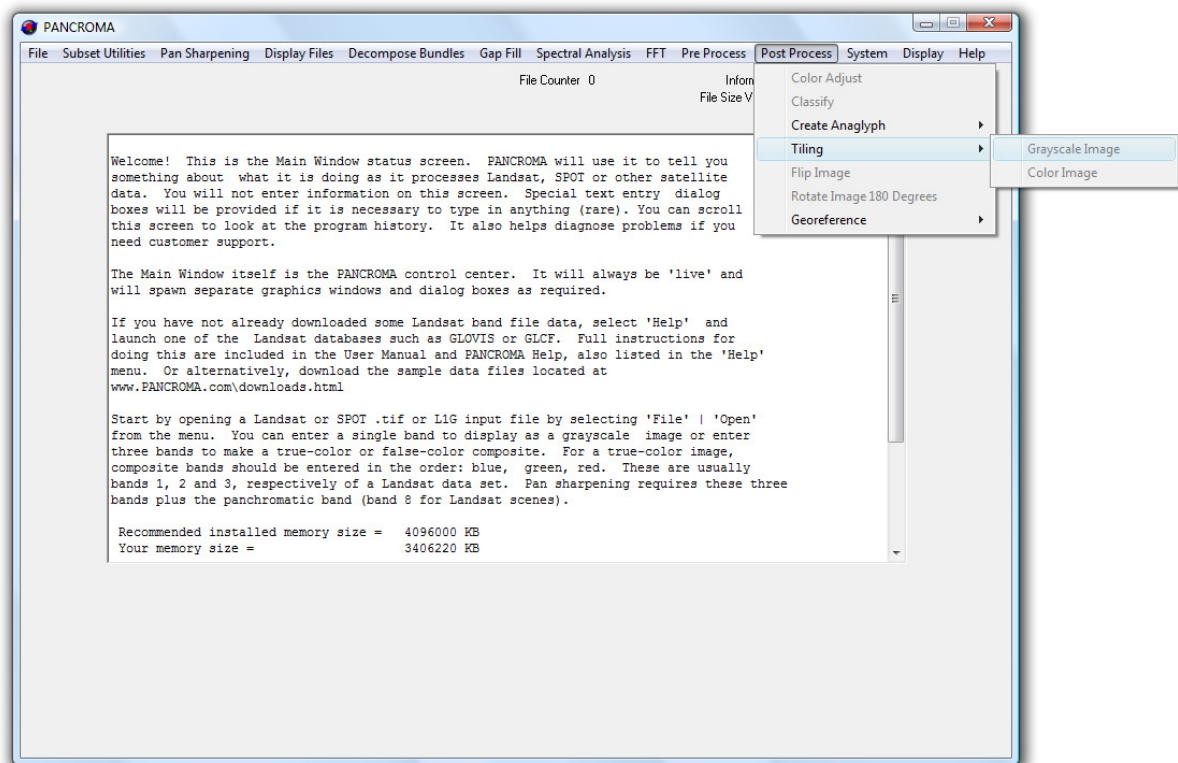
Red Blue Anaglyph Computation

Red/Blue anaglyphs are a simple and computationally inexpensive method for quickly evaluating the photogrammetric potential of stereo images. Such images are available as stereo pairs from ASTER, MISR, WorldView2 and other platforms that capture off-nadir images. Choose 'Post Process | 'Create Anaglyph' and then choose the type of anaglyph you want to compute. Note that both the left and right stereo images must be exactly the same size.

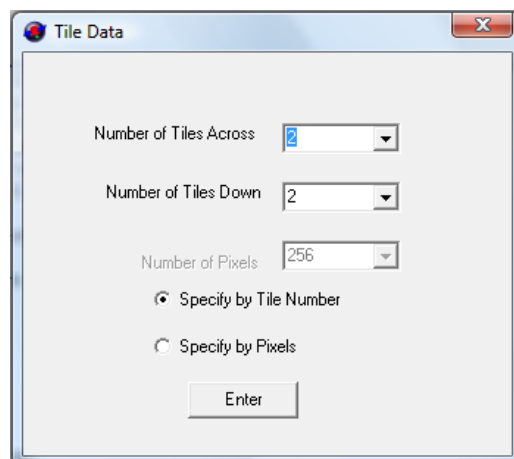


Grayscale and Color Image Tiling

It may sometimes be advantageous to save processed grayscale or color images as tiles rather than a single image. PANCROMA offers a post processing utility that decomposes a single image into a tile array. To use the utility, open a grayscale or RGB image by selecting 'File' | 'Open' as usual (currently, tiling is only implemented for TIFF images). Select 'Post Process' | 'Tiling' and either 'Grayscale Image' or 'Color Image', depending on your input file.



PANCROMA™ will read in your file and present a Tile Data entry box as shown below. By selecting between the two radio buttons you can either specify the tiling by the number of row and column tiles or by the number of pixels in the tile. (If you specify by pixels, **PANCROMA™** will generate square tiles with an equal number of row and column pixels in each tile.) When you have made your selection, click 'Enter'. **PANCROMA™** will then present you with a file save dialog box. You must specify the base file name for the tiles. **PANCROMA™** will append a row and column index code to each tile. For example, the first tile in the first row will be saved as basefilename0-0.jpg, the second tile in the first row will be saved as basefilename0-1.jpg, etc. At this time only JPEG is supported as an output format.



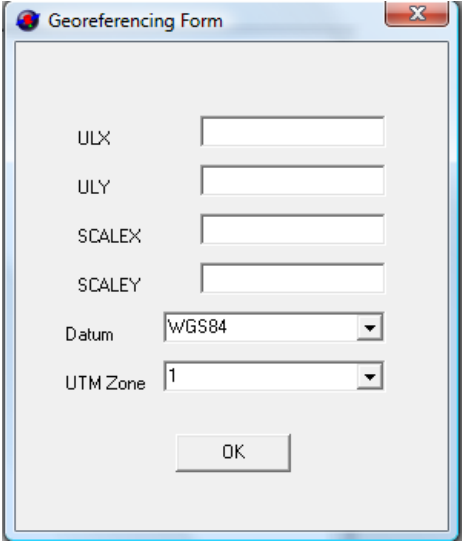
Note that you must be careful not to specify too small a tile size if you do not want a large number of tile files. PANCROMA will generate an error message if your tile size requires saving more than 2500 tiles. Also note that PANCROMA will not generate partial tiles at present so some image clipping may result, depending on the specified tile size.



Georeferencing

PANCROMA™ has a utility for simple georeferencing of an ungeoreferenced image when North is up. That is, if it is known that the edges of the ungeoreferenced image are aligned with true north, then the utility can be used to create a GeoTiff image with rudimentary georeferencing. The utility works for grayscale images only.

To use the utility, open a grayscale image by selecting 'File' | 'Open'. Then display the grayscale image by selecting 'DisplayOne File' and the submenu selection appropriate to your input image. After the image is displayed, select 'Post Process' | 'Georeference' | 'Enter Corner Coordinates and Scale'. The Georeferencing Form will become visible.

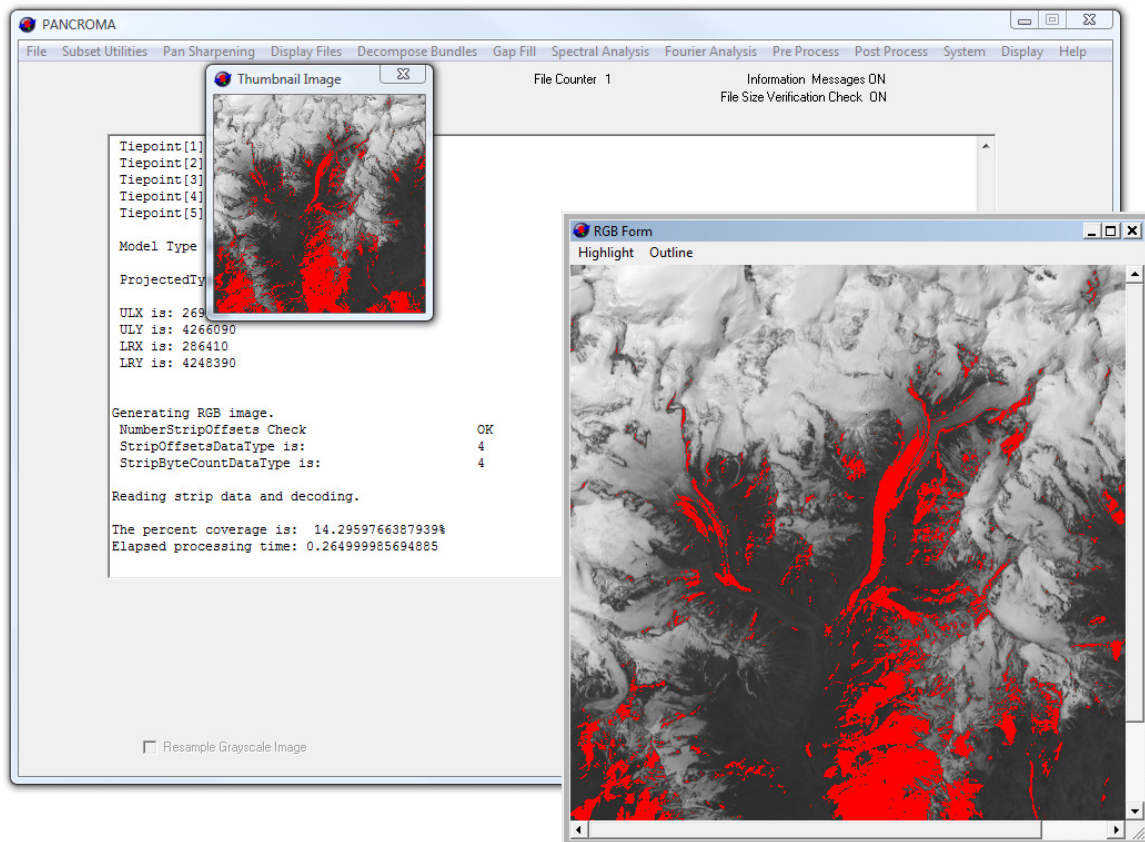
A screenshot of a Windows-style dialog box titled "Georeferencing Form". The dialog has a light gray background and a blue border. It contains several input fields and two dropdown menus. The fields are labeled "ULX", "ULY", "SCALEX", and "SCALEY", each followed by a text input box. Below these are two dropdown menus labeled "Datum" and "UTM Zone". The "Datum" dropdown currently shows "WGS84" and the "UTM Zone" dropdown shows "1". At the bottom center of the dialog is an "OK" button.

Enter the corner UTM coordinates. (Note enter a negative number for the Southern Hemisphere.) Enter the xScale and yScale values (these are the resolutions, i.e. the number of meters per pixel.) Select the datum and the UTM zone from the drop down menus. When you click 'OK' the corner coordinates will be computed. Save your file as a GeoTiff to preserve the computed metadata.

Compute Color Coverage

PANCROMA™ has a utility for computing how much of an image is grayscale and how much is colored. This may be useful in post processing your processed images from the Spectral Analyzer Euclidean Distance Fraction or Spectral Angle Fraction plots. The coverage is computed during processing, but you may need to run it again afterwards.

To use the utility, open a single RGB TIFF image and select 'Post Process' | 'Compute Color Coverage'. The percent coverage will be reported to the diagnostic screen.



61. Spectral Analysis

Landsat DN Point Spectrum Generator™

The Landsat Point Spectrum Generator™ is a utility that allows you to interrogate a satellite band data set and to generate a spectrum that corresponds to points that you select from the set. The generated spectrum can be automatically input into the Spectral Analysis™ (see following section) tool for classification of surface features. This can be a powerful tool for mineral exploration or land use analysis when combined with the Spectral Analyzer™ described below.

The use of the Landsat Point Spectrum Generator™ is best illustrated by an example. Consider the Landsat 7 data set represented by the band1 image below.



For Landsat 7 data sets, the NIR band4 will be displayed for point selection as the default. The NIR band often works better is because the excessive Rayleigh scattering exhibited by the blue band can obscure surface details to such an extent that pixel selection is difficult. Let's say that we are interested in measuring the snow pack coverage for the subsetted region in the image. Snow pack measurements are often needed in order to estimate the amount of runoff in the spring and to determine the water supply potential for down gradient areas. We can estimate the coverage using the PSG, followed by using the Landsat Spectral Analyzer™ (see following section).

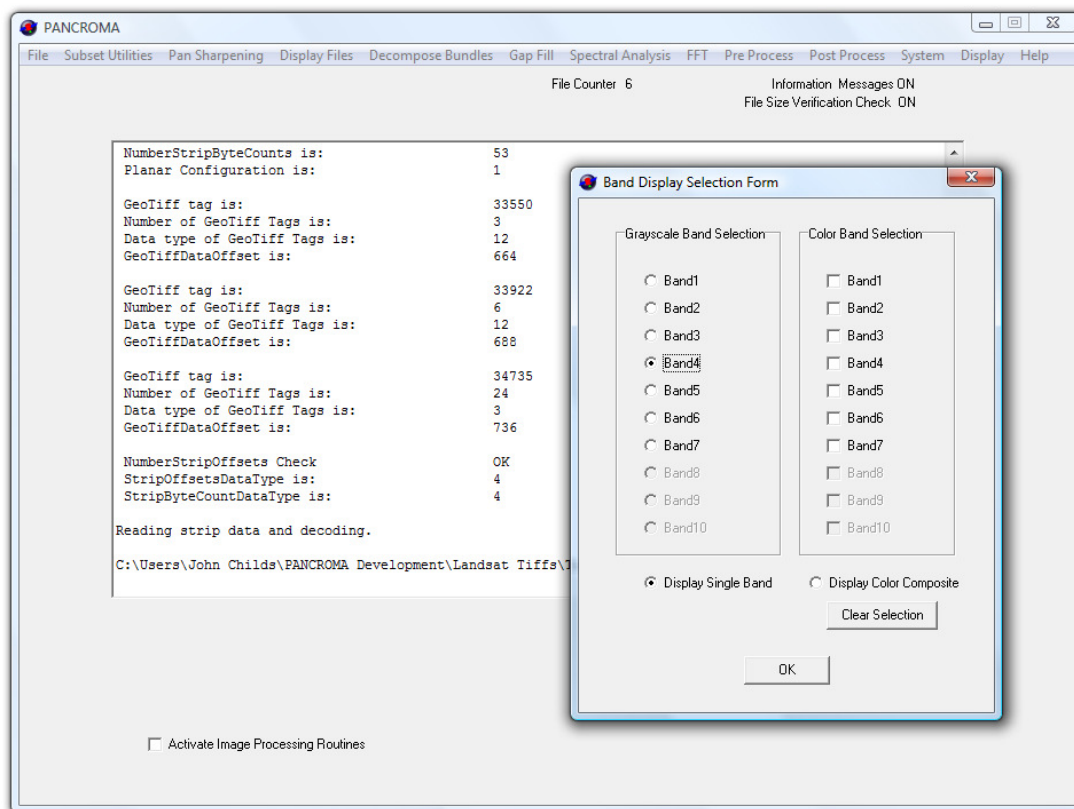
We first start by opening either six Landsat visible and infrared multispectral band files, or alternatively the six multispectral bands plus the thermal infrared (TIR) band 6. That is, either open bands 1,2,3,4,5 and 7 or alternatively bands 1, 2, 3, 4, 5, 6 and 7 by selecting 'File' | 'Open' as usual. Next select 'Spectral Analysis' | 'Landsat Point Spectrum Generator' | 'Six/Seven DN Bands'. When you do so a band selection screen will be displayed. Note that there are two radio buttons labeled 'Display Single Band' and 'Display Color Composite'. This allows the choice of using either a single multispectral band for point selection or a composite of three bands. For this exercise select 'Display Single Band'. The color composite option will be explained at the end of the section.

IMPORTANT NOTE: Using the TIR band may give additional discriminating power to your analysis. If you decide to use the TIR band, you may have to preprocess it before doing so. Some Landsat TIR files are archived the same size as the multispectral band files. However most are archived as 57 or 60m resolution files, i.e. half the resolution of the multispectral bands. In addition, there are usually two TIR band files with suffixes 61a and 61b. These are the high gain and low gain versions of the data. If you choose to use the TIR band, you will be prompted to tell PANCROMA which type of file you are processing by checking a radio button on the TOA Reflectance Form.

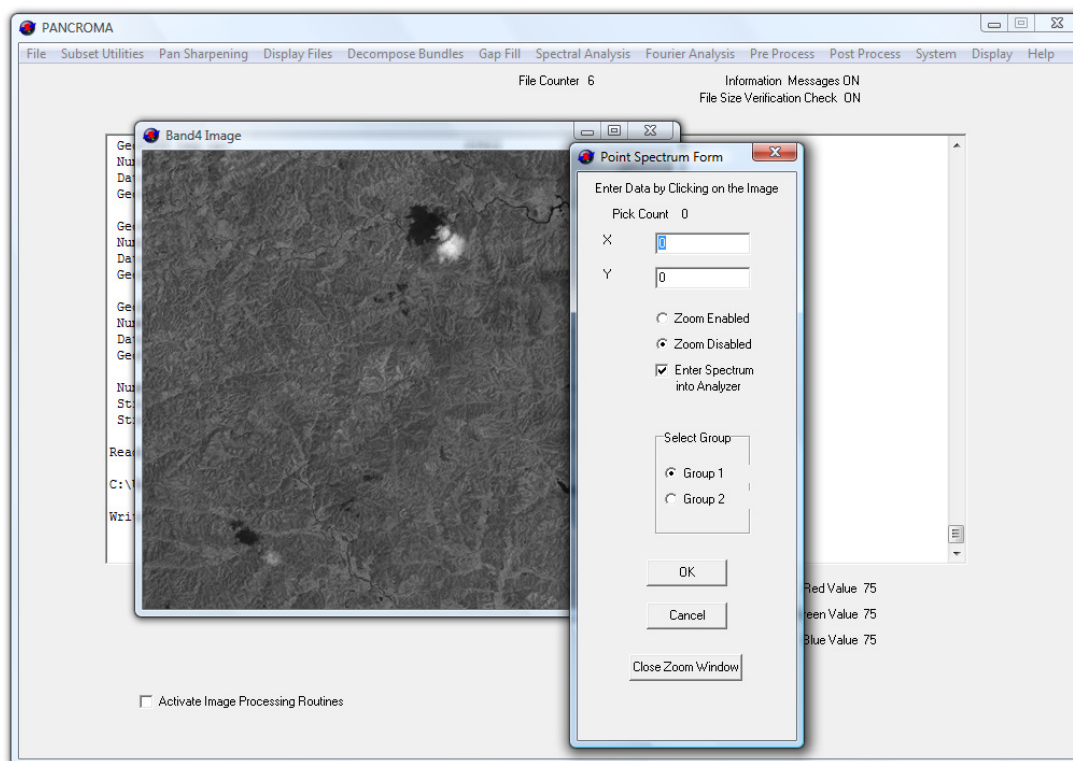
In order to use a TIR band at half resolution, you must first expand and interpolate it up to 27.5 or 30m resolution. This can be done using the utility described in the Preprocessing Section. Once the scale is adjusted, it can be used to generate a Point Spectrum.

When **PANCROMA™** processes the TIR band, it will divide the computed temperature in degrees Kelvin by a factor of 1000. This scales the temperature data so that it is of the same order of magnitude as the TOA reflectance data.

You can select the multispectral band that you want to be displayed for point selection by checking the appropriate radio button.

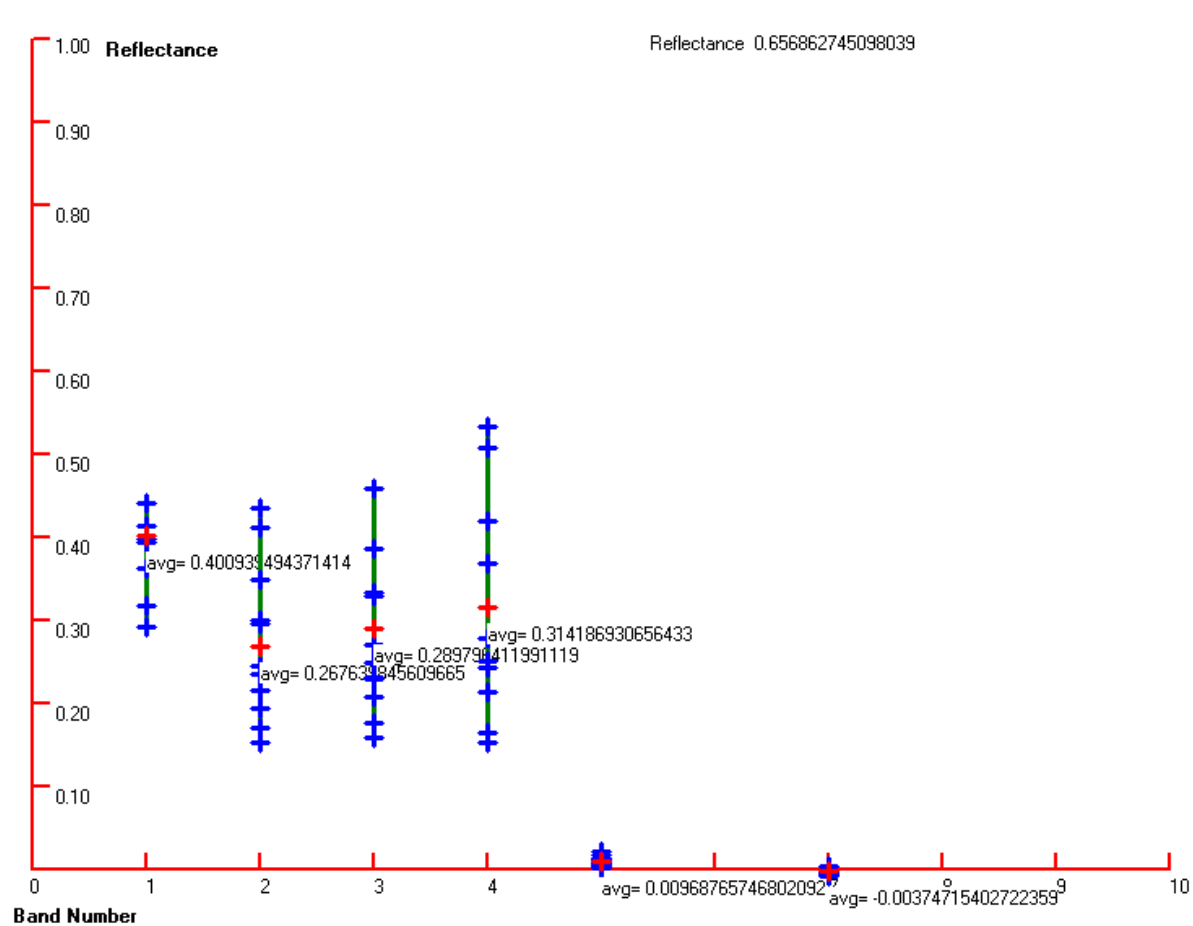


When you click 'OK', the selected band image will be displayed, along with the Point Spectrum Data Entry Form, as shown below.



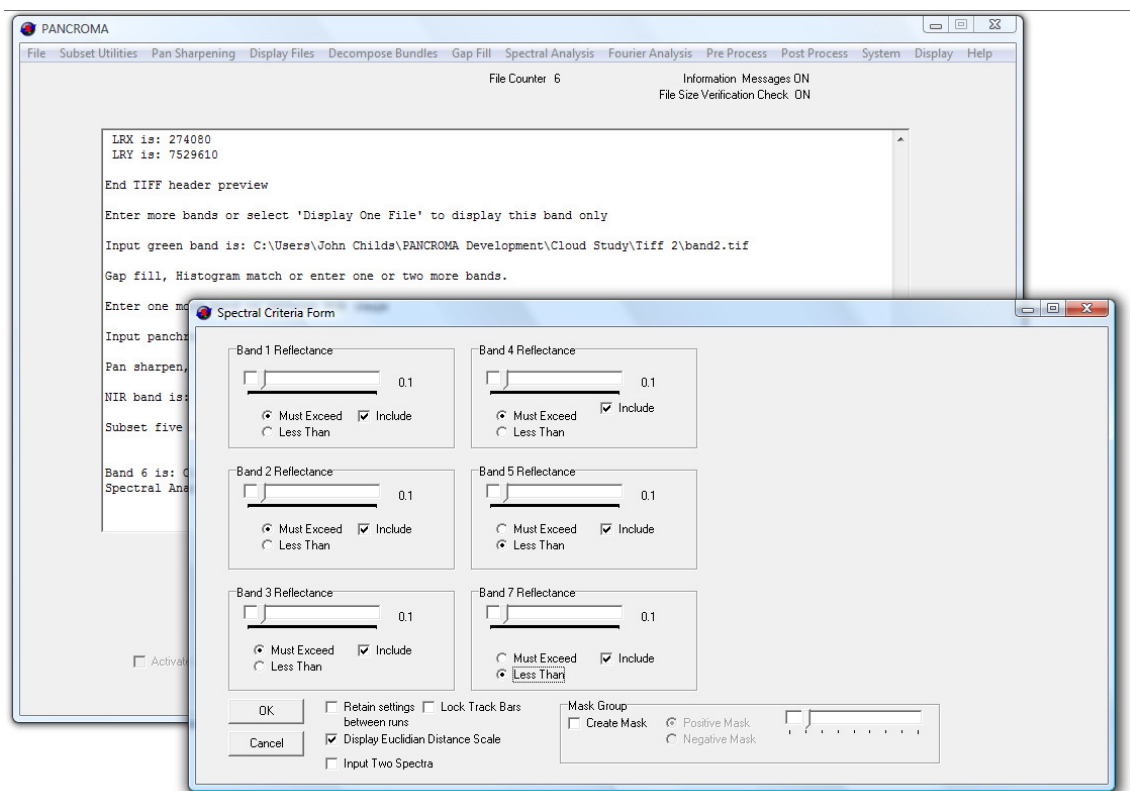
Since we want to measure the snow pack, we will start by generating its spectrum. We can do this by successively clicking the cursor on the snowy areas in the band file. Notice that there are areas of highly reflective snow and areas in shadow, as well as areas of thinner coverage. Click on all types that you are interested in measuring. You can sample as many as 50 points. Note that the coordinates of your selection appear in the text boxes and a running count is kept of your selections.

When you have collected your sample, click 'OK'. The TOA reflectance form will appear. This is the same form that is described in the previous Section. As before, you must enter the Acquisition Date and Solar Elevation Angle from the Landsat metadata so that TOA reflectances can be computed. When you click 'OK' on this form, the spectrum will be generated.

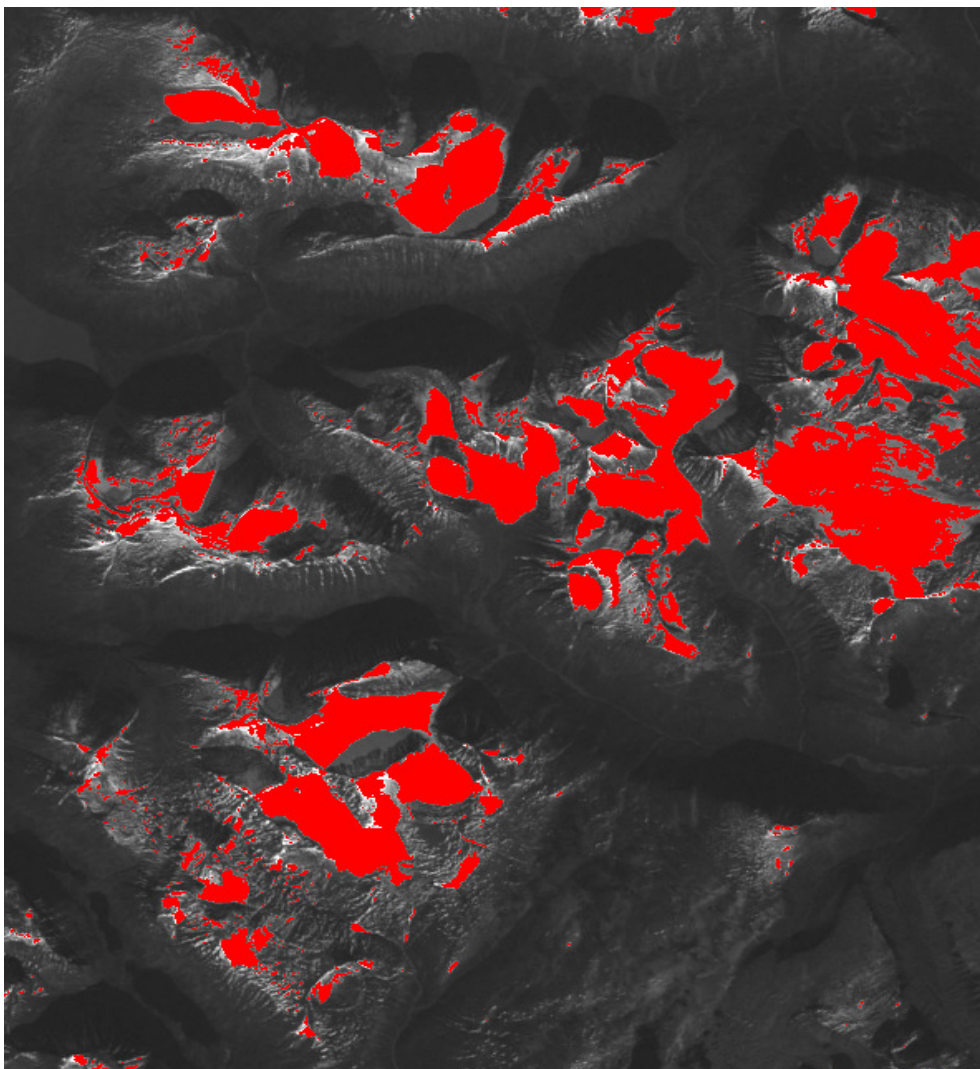


The plot shows all of the computed TOA reflectances versus band number. Now you must analyze the plot. Notice that the snow pack reflectances are uniformly low for bands 5 and 7 and higher for the other bands. Note also that the other bands do not show such uniformity as in bands 5 and 7. Our objective is to determine the appropriate settings for the Spectral Analyzer™ (see following section) by inspecting this plot. I decided that I would try specifying that bands 5 and 7 not exceed 0.10, while requiring that band1 be at least 0.20 and the rest of the bands at least 0.10.

So the next step is to select 'Close Graphics Windows and Reset'. Select 'File' | 'Open' again and then re-open the six band files as before, i.e. bands 1,2,3,4,5 and 7. Next select 'Spectral Analysis' | 'Landsat Spectral Analyzer' | 'Six DN Bands'. When the Spectral Criteria Form appears, enter the criteria from your analysis of the Point Spectrum. In this example the separation is very easy as every pixel reflectance in sample bands 1 through 4 are well above 0.1 while every reflectance in bands 5 and 7 is below 0.1. The settings are as shown in the figure below.



(Note the radio button selections on the six enabled bands.) Now select 'OK'. The TOA Reflectance Data Form will again appear. Re-enter the Solar Elevation Angle and Acquisition Date and click 'OK'. After a bit of computation a grayscale image will appear with the areas that match your specified criteria highlighted in red. It may take a bit of trial-and-error in order to dial in the settings that you feel best outline your areas of interest. The results for this example are shown in the image below.



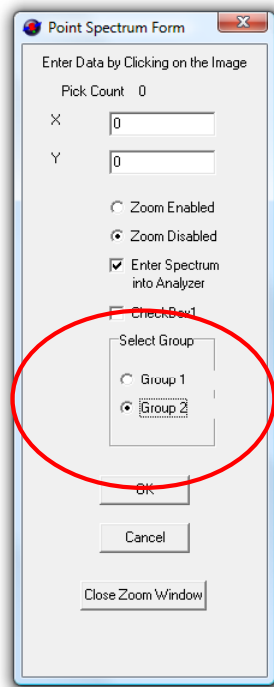
PANCROMA™ computed that the coverage was 11.355%. Comparison of the highlighted image with the band1 image indicates that the coverage is about right.

There are many other uses for the Point Spectrum Generator™ and the Spectral Analyzer™. These include crop coverage analyses and mineral exploration.

Generating Two Spectra

PANCROMA™ has a utility for generating two reflectance spectra and inputting both spectra into the Landsat Spectral Analyzer. (At this time only the first spectrum is plotted). To use the utility, proceed exactly as detailed in the

previous section. To generate the second spectrum, select the radio button labeled 'Group 2' as shown in the image below



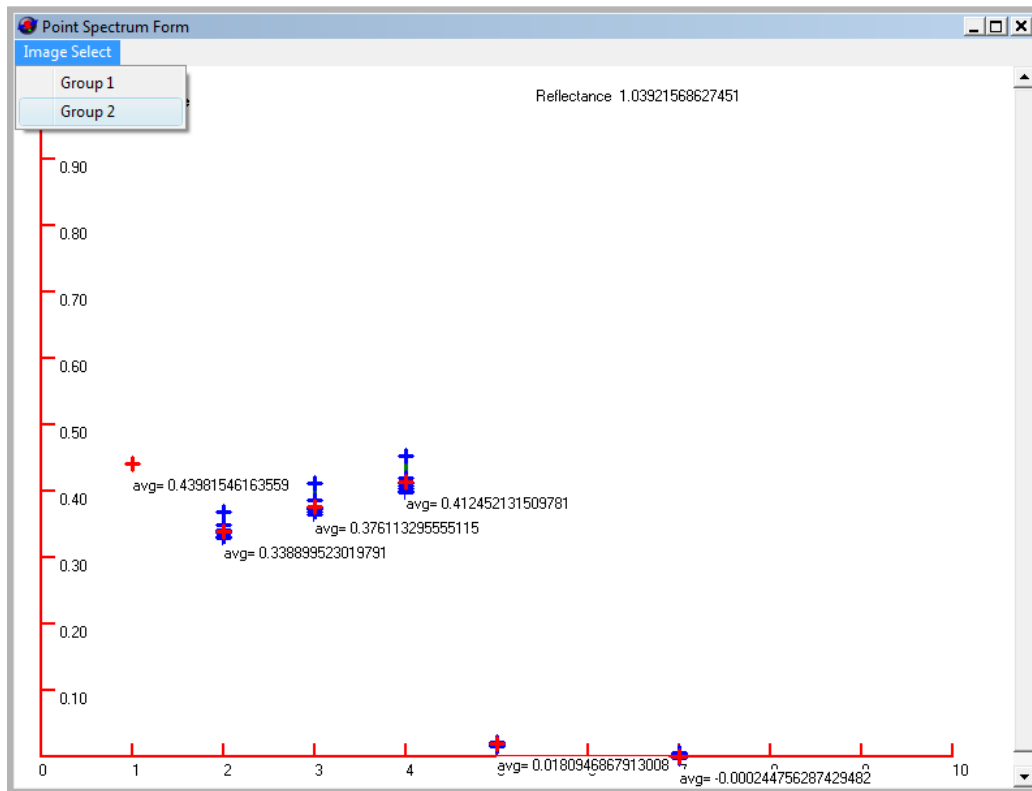
The image shows a 'Point Spectrum Form' dialog box. It has a title bar with a close button. The main area contains the following elements:

- Text: 'Enter Data by Clicking on the Image'
- Text: 'Pick Count 0'
- Input fields for 'X' and 'Y', both containing '0'.
- Radio buttons for 'Zoom Enabled' and 'Zoom Disabled'. 'Zoom Disabled' is selected.
- Checkboxes for 'Enter Spectrum into Analyzer' (checked) and 'Check Box 1' (unchecked).
- A 'Select Group' section with two radio buttons: 'Group 1' and 'Group 2'. 'Group 2' is selected.
- Buttons: 'OK', 'Cancel', and 'Close Zoom Window'.

A red circle is drawn around the 'Select Group' section, highlighting the 'Group 2' radio button.

After selecting this radio button, repeat the procedure for selecting target pixels by clicking on the image as described in the previous section. The selected pixel data will be stored and then automatically input into the Spectral Criteria form when conducting a Landsat Euclidean Distance analysis. Note that it is possible to switch between groups during the selection process by selecting the desired radio button.

When the spectra are computed, the Group 1 data will be displayed. To view the Group 2 spectrum, select it from the drop down menu at the top of the form.



Landsat Reflectance Point Spectrum Generator™

The Landsat Reflectance Point Spectrum Generator™ operates very much like the DN Point Spectrum Generator™ except it accepts 16-bit Landsat Reflectance band files instead of the 8-bit DN files described in the previous section. To use it, open six multispectral band files as described in the previous section. Then select 'Spectral Analysis' | 'Landsat Point Spectrum Generator' | 'Six Reflectance Bands'. The Point Spectrum Data Entry box and band1 image will be presented as described in the previous section. Unlike the DN PSG, it is not necessary to input the Solar Elevation Angle and Acquisition Date as the reflectance have of course already been computed and are stored in the input files. The Reflectance PSG is otherwise exactly as described above.

The NIR band is also used for point selection for Landsat reflectance data for the reason cited above.

Landsat Reflectance/TIR Band Point Spectrum Generator™

The Landsat Point Spectrum Generator™ accepts six 16-bit Landsat Reflectance band files (bands 1, 2, 3, 4, 5 and 7) plus the thermal infrared (TIR) band 6, for a total of seven bands. Using the thermal band adds an additional discriminator that can be useful for classifying certain types of targets. To use it, open six multispectral band files as described in the previous section, plus the thermal

band 6. The files should be opened in numerical order, i.e. band1, band2, band3, band4, band5, band6 and band7.

Then select 'Spectral Analysis' | 'Landsat Point Spectrum Generator' | 'Six/Seven Reflectance Bands'. The Point Spectrum Data Entry box and band1 image will be presented as described in the previous section. Unlike the DN PSG, it is not necessary to input the Solar Elevation Angle and Acquisition Date as the reflectance have of course already been computed and are stored in the input files. The Reflectance PSG is otherwise exactly as described above.

Please see the note on how the TIR band data is scaled in the Landsat Reflectance Spectral AnalyzerTM Section preceding this Section.

Landsat 8 Point Spectrum GeneratorTM

The Landsat Point Spectrum GeneratorTM can also accommodate Landsat 8 data. The procedure is exactly the same as described for Landsat 7 data except that 8 input bands are required, Landsat 8 bands 1, 2, 3, 4, 5, 6, 7, and 9.

ASTER Point Spectrum GeneratorTM

The ASTER Point Spectrum GeneratorTM (PSG) accepts ASTER DN bands 4,5,6,7,8 and 9 or alternatively, ASTER DN bands 1,2,3,4,5,6,7,8 and 9. These are DN bands so TOA reflectances will be computed. To use it, open six or nine ASTER multispectral band files as described in the previous section. Then select 'Spectral Analysis' | 'ASTER Point Spectrum Generator' | 'Six DN Bands' or 'Spectral Analysis' | 'ASTER Point Spectrum Generator' | 'Nine DN Bands'. The Point Spectrum Data Entry box and band1 image will be presented as described in the previous section. You must input the Solar Elevation Angle and Acquisition Date. In addition, you must select the Gain settings from among 'High', 'Medium', 'Low 1' and 'Low 2' settings. This information can be found in the ASTER metadata. The reflectances will be computed and the spectrum displayed.

IMPORTANT NOTE: If you decide to use the three ASTER Very Near Infrared (VNIR) bands in addition to the six Short Wave Infrared (SWIR) bands, you will have to rationalize the file sizes. The resolution of the VNIR bands is 15m/pixel while that of the SWIR bands is 30m/pixel. The file sizes can be rationalized either by resampling the VNIR bands down or interpolating the SWIR bands up using the PANCROMATM Resize utilities. Interpolating up is recommended in order to avoid loss of information from the ASTER scene.

IMPORTANT NOTE: PANCROMATM wants the ASTER data in GeoTiff format. You may have to convert your data using the free MultiSpec utility before processing.

SPOT[®] Point Spectrum Generator[™]

The SPOT Point Spectrum Generator[™] accepts SPOT DN bands 1,2,3 and 4. These are DN bands so TOA reflectances will be computed. To use it, open four SPOT multispectral band files as described in the previous section. The select 'Spectral Analysis' | 'SPOT Point Spectrum Generator' | 'Four DN Bands'. The Point Spectrum Data Entry box and band1 image will be presented as described in the previous section. Afterwards, data entry box will be displayed for entering the appropriate TOA Reflectance data. The data entry is similar to that described above.

You will have to enter the SPOT Absolute Calibration Gain for each band. These vary from image to image so they must be obtained from the metadata for each SPOT scene. In order to enter SPOT Absolute Calibration Data, enter the data for band1 and click 'OK'. The band slider will automatically advance to the band2 position. Now enter the band2 data and click 'OK'. Repeat for band3 and band4. When you click 'OK' for the fourth time, the reflectances will be computed and the spectrum displayed.

NAIP Point Spectrum Generator[™]

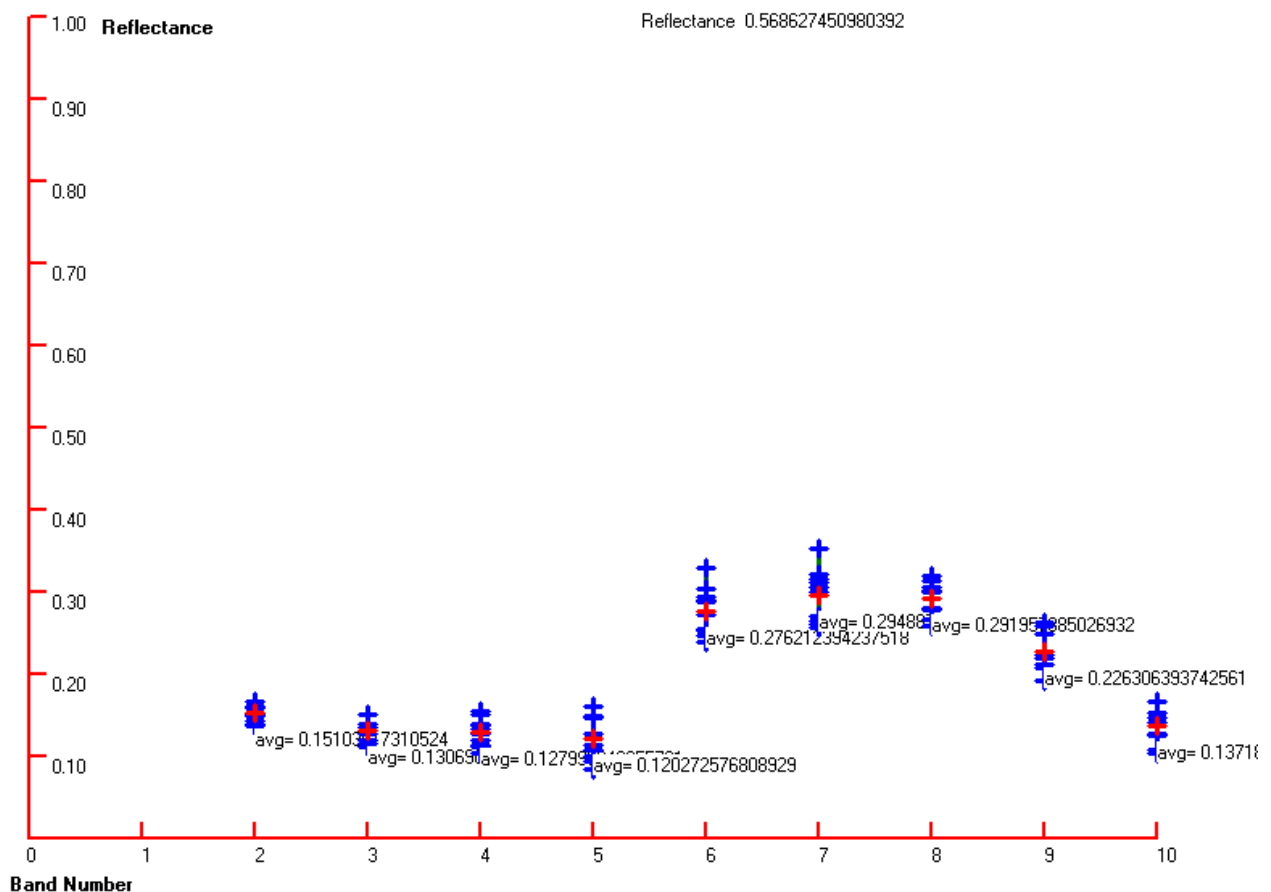
The NAIP Point Spectrum Generator[™] accepts NAIP DN bands 1,2,3 and 4. Calibration data is not provided with NAIP data, so false TOA reflectances are computed. To use it, open four NAIP multispectral band files as described in the Using NAIP Data section of this manual. The select 'Spectral Analysis' | 'NAIP Point Spectrum Generator' | 'Four 8-Bit DN Files'. The Point Spectrum Data Entry box and band 1 image will be presented as described in the previous section. Select your data points by clicking on the image. When you are finished selecting, Click 'OK' the false reflectances will be computed and the spectrum displayed.

EO1-ALI/Hyperion Point Spectrum Generator[™]

The EO1-ALI Point Spectrum Generator[™] accepts EO-1 ALI bands 2,3,4,5,6,7,8,9 and 10 or alternatively any nine Hyperion bands. These are I16 DN bands so TOA reflectances will be computed. To use it, open the nine EO-1 ALI DN multispectral band files as described in the previous section. The select 'Spectral Analysis' | 'EO-1 ALI Point Spectrum Generator' | 'Nine DN Bands'. The Point Spectrum Data Entry box and band1 image will be presented as described in the previous sections. You must input the Solar Elevation Angle and Acquisition Date. The reflectances will be computed and the spectrum displayed.

World View 2[®] Point Spectrum Generator[™]

The WorldView 2 Point Spectrum Generator™ accepts WorldView2 bands 1, 2,3,4,5,6,7,8 and 8 in either 8-bit or 16-bit format. To use the utility, unbundle the planarConfiguration=2 Digital Globe data file into eight 8-bit or 16-bit band files. Save using a base file name. Then open the eight unbundled multispectral DN band files. The select ‘Spectral Analysis’ | ‘WorldView2 Point Spectrum Generator’ | ‘Eight 16-bit Bands’ or ‘Spectral Analysis’ | ‘WorldView2 Point Spectrum Generator’ | ‘Eight 8-bit Bands’, depending on your file format. The Point Spectrum Data Entry box and band1 image will be presented as described in the previous sections. You must input the Solar Elevation Angle and Acquisition Date for each WV2 band as they will probably differ. The reflectances will be computed and the spectrum displayed.

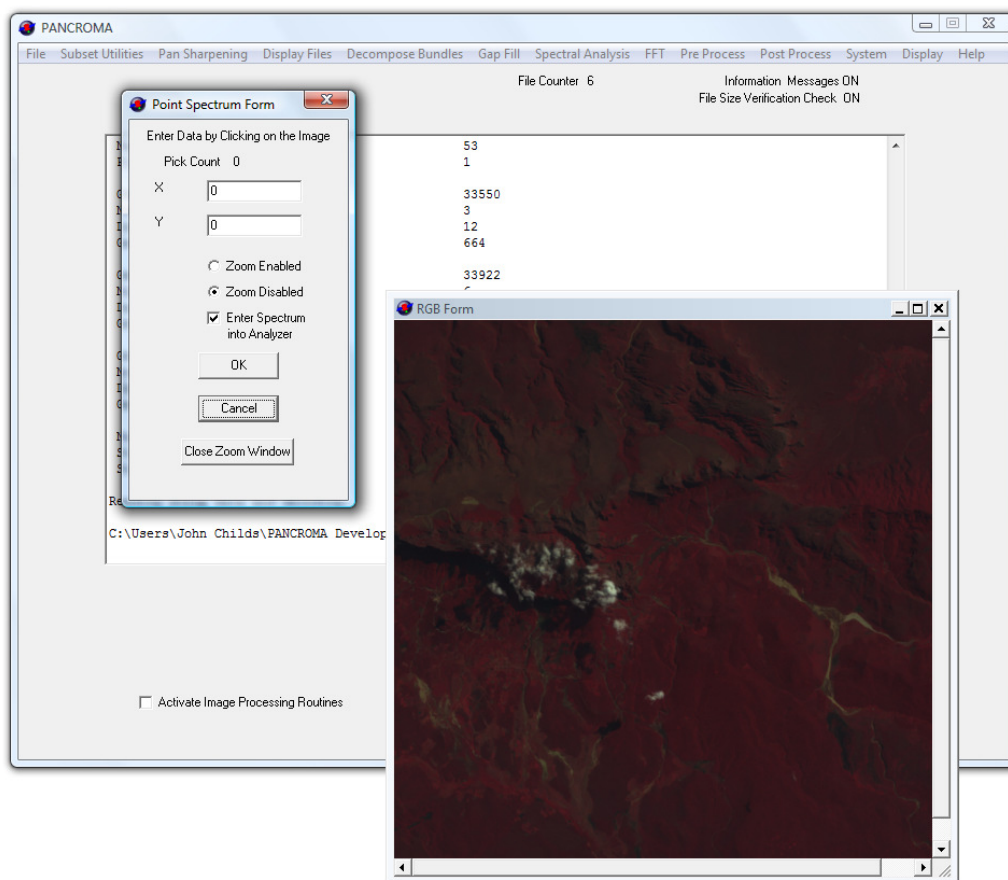


RGB Color Composite Point Selection

PANCROMA™ alternatively lets you use a color composite image for point selection. In order to use this option, check the ‘Display Color Composite’ radio button on the Band Display Selection Form instead of the ‘Display Single Band’ button. When you make this selection, the Grayscale Band Selection data group

will become disabled and the Color Band Selection data group will become enabled. Check the boxes for the bands that you want to composite, in the order: blue channel; green channel and red channel. For example, if you want to display a natural color composite image, check band1, band2 and band3, in that order. If you want band 2 in the blue channel, red in the green channel, and the NIR band in the red channel, check band2, band3 and band4, in that order. If you make a mistake or change your mind, select the 'Clear Selection' button and start over again. Note that you can only select three bands as there are only three color channels. If you select more you will get an error message.

Once you have made your channel selections, click 'OK'. After a moment an RGB color image will appear. You can make your point selections exactly as described above. You can also zoom into the color image during the selection process as described in the following section. When you are done with your point selection, click 'OK' on the Spectral Form and the spectrum will be computed as described above.



RapidEye® Point Spectrum Generator™

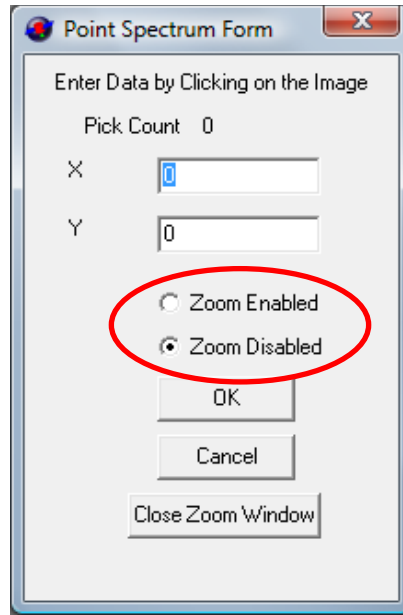
The Rapideye Point Spectrum Generator™ accepts RapidEye bands 1, 2,3,4, and 5 in bundled GeoTiff 16-bit format. To use the utility, select 'Spectral Analysis' | 'RapidEye Point Spectrum Generator' | 'Five 16-Bit (Bundled)GeoTiff File'. The Point Spectrum Data Entry box will be presented as described in the previous sections. Select the single band or composite bands that you wish to use to display for selecting your target points. You must also input the Solar Elevation Angle and Acquisition Date from the RapidEye metadata. The reflectances will be computed and the spectrum displayed. As is usual, the reflectances will be saved and automatically inserted into the Spectral Criteria form for subsequent use by the **PANCROMA™** Spectral Analyzer utility.

MODIS Point Spectrum Generator™

The MODIS Point Spectrum Generator™ accepts MODIS Surface Reflectance bands 1, 2,3,4,5, 6 and 7 in bundled HDF 16-bit format. These are the MODIS type 'A1' and 'GA' data products. To use the utility, first open the single bundled HDF file. The single data file will contain all seven MODIS bands. select 'Spectral Analysis' | 'MODIS Point Spectrum Generator' | 'Seven 16-Bit (Bundled) HDF File'. The Point Spectrum Data Entry box will be presented as described in the previous sections. Select the single band or composite bands that you wish to use to display for selecting your target points. No Solar Elevation Angle, Acquisition Date or other metadata is required since these files contain processed surface reflectance data. The spectrum will be computed and displayed. As is usual, the spectrum will be saved and automatically inserted into the Spectral Criteria form for subsequent use by the **PANCROMA™** Spectral Analyzer utility.

Point Spectrum Zoom Tool

The above sections have described the **PANCROMA™** Point Spectrum tool for generating spectral data from selected pixels in multispectral data sets. It is often helpful to be able to zoom into an image in order to identify and select pixels of interest to add to the Point Spectrum list. **PANCROMA™** has a utility for doing this. In order to use the zoom tool, open your multispectral images as described in the previous articles describing the Point Spectrum generator™. When the Point Spectrum Form becomes visible, you will see two radio buttons labeled 'Zoom Enabled' and 'Zoom Disabled', as shown below.



When the 'Zoom Disabled' radio button is checked, data entry works as described previously. That is, each time you click on the multispectral band image, a data point corresponding to that pixel location will be added to the list. However, when 'Zoom Enabled' is checked, data will no longer be added to the Point Spectrum list when you click on the grayscale band image. Instead, clicking on the image will identify the zoom center and enable the Zoom menu. When you select your zoom center by clicking on an area of interest in the image, select 'Display' | 'Zoom In'. A zoomed image will be created in a new graphics window, centered on the point that you clicked. (Note: in order to avoid attempting to compute zoom data for pixels off the edge of the image where no data exists, the zoom center will be automatically moved back from the image borders if necessary. In this case you may have to scroll the zoomed image a bit to locate your zoom center.)

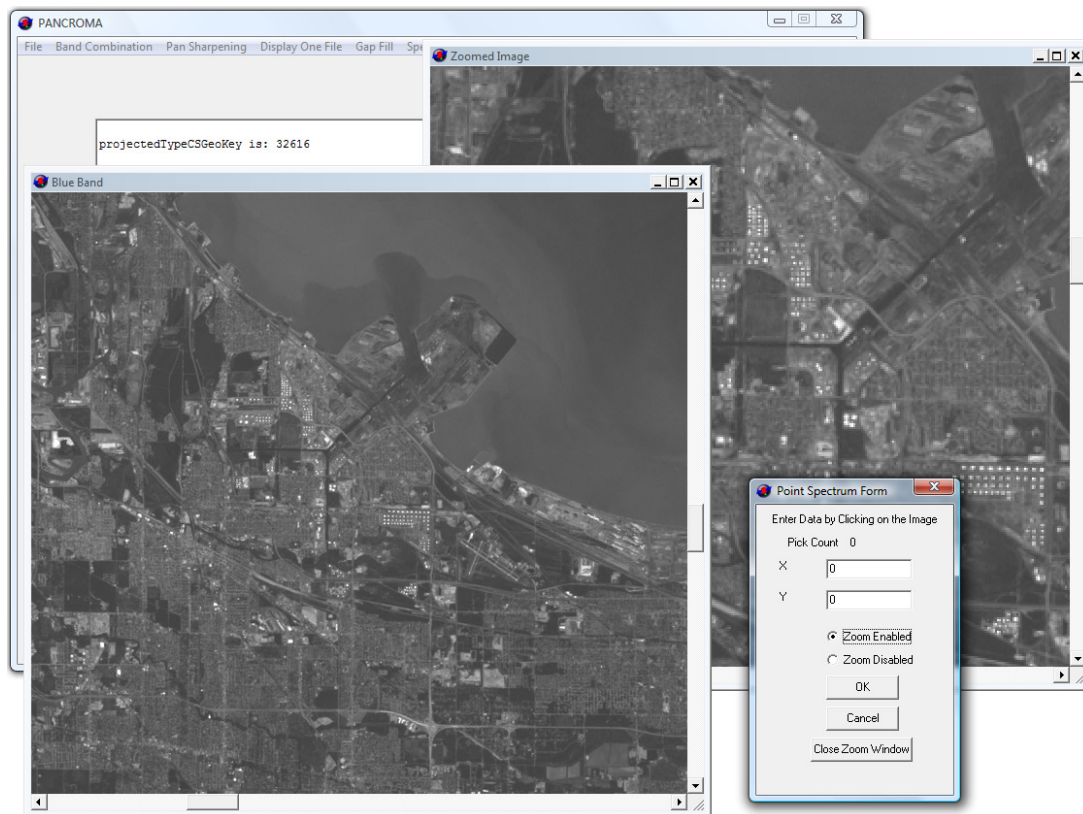
Note that the pixels in the zoom window track those of the source image as you move your cursor. In order to add points to the Point Spectrum list, select the 'Zoom Disabled' radio button. This will allow points that you select from *either* image to be added to the Point Spectrum list. You can go back and zoom more deeply into the image by re-checking the 'Zoom Enabled' button, which will suspend the addition of points to the Point Spectrum list again and allow the identification of new zoom centers on either image.

Note that it is possible to display an RGB true color or false color image to aid in the location of points of interest. To do this, open the three band files of interest by selecting 'File' | 'Open'.

Once all three files are opened, check the 'Maintain RGB Comparison Image' check box at the bottom of the Main Window. Then select 'Band Combination |

Generate RGB True Color Composite'. Two RGB images will be displayed select 'Close Graphics Window and Reset'. The RGB form will close, leaving the Comparison Image open. Now you can process your band file data as usual.

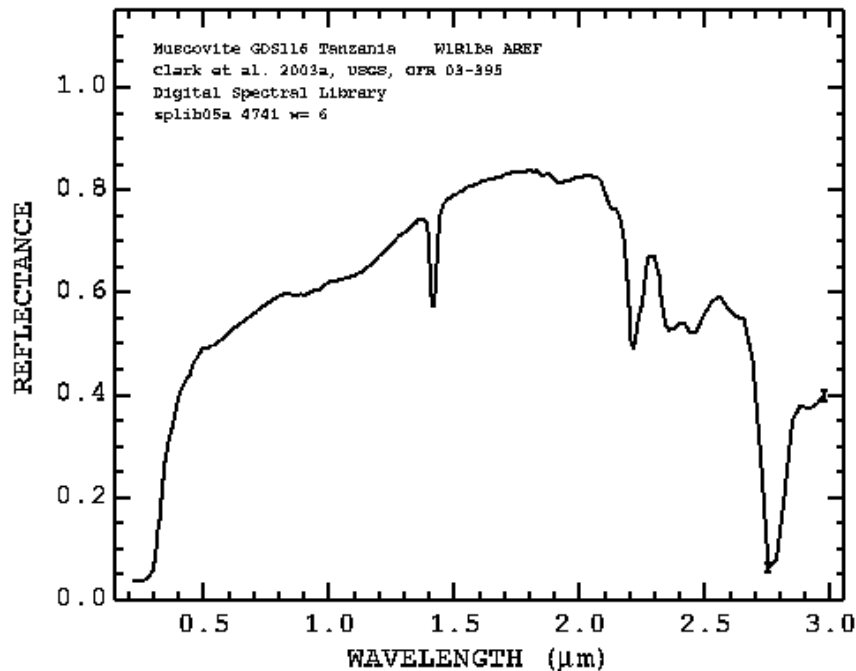
See the **PANCROMA™** Section 13 for more information on the zoom utilities.



Landsat Spectral Analyzer™

Spectral analysis using Landsat multispectral data is a powerful tool for exploring and characterizing many aspects of the earth's surface called the Landsat Spectral Analyzer™ (LSA). Applications of spectral analysis include mineral exploration, vegetation analysis, land use, forest health and many other applications. False color band combinations and vegetation indices are well-known methods for using multispectral data to extract information from the earth's surface. The **PANCROMA™** LSA uses all of the Landsat spectral bands for extracting such information. The LSA is used in conjunction with databases such as the USGS Digital Spectral Library (<http://pubs.usgs.gov/of/2003/ofr-03-395/datatable.html>). A Digital Spectrum (DS) is a plot of reflectance versus wavelength. Reflectance values typically vary between zero (complete absorption) and unity (complete reflectance). Instruments used to record such spectra are calibrated against special card standards to make sure that this is so.

Digital spectra are recorded for minerals, flora, and various man-made substances as well as snow and ice. The individual spectra contained in the databases constitute an electromagnetic “fingerprint”. Matching remotely sensed data to a DS can give indications of the presence of the target minerals or substances. The DS for the mineral Muscovite is shown below.

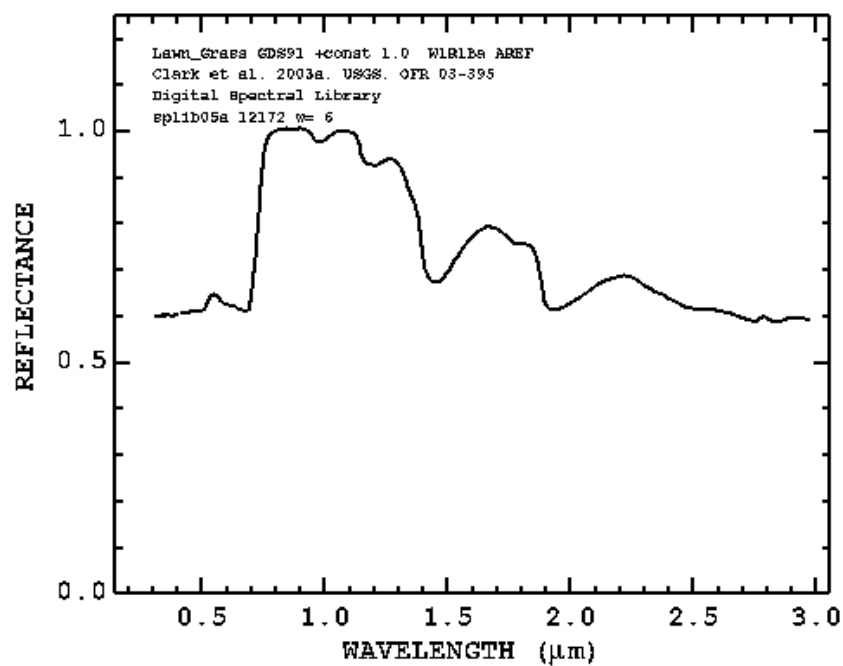


The **PANCROMA**TM LSA is a semi-automated utility for searching Landsat multispectral data for spectral fingerprints. The user sets the search criteria for each multispectral channel. The LSA then interrogates the six Landsat multispectral channels to determine which if any pixels match the fingerprint data. It then displays each “hit” as a red pixel on a gray band image. An example will make the use of this utility clearer. This example will look for something not very exotic – Lawn Grass. We will use a subset of a Row 23 Path 39 Landsat scene of Louisiana near the town of Abbeyville. Lake Peigneur is at the lower right.

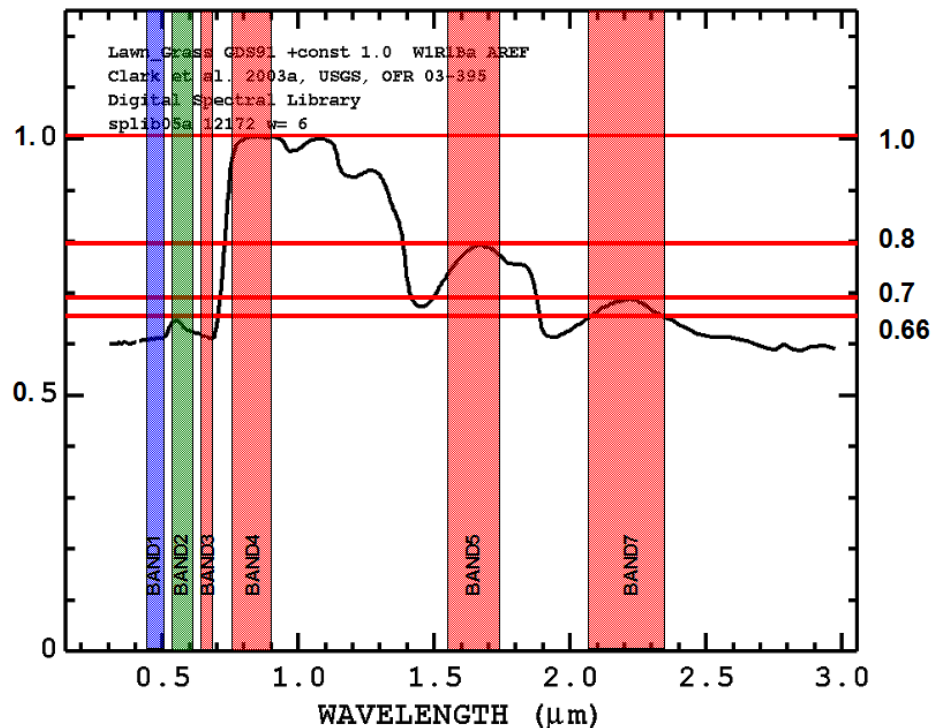
I subsetting the scene for faster processing, although you should have no problem processing full Landsat scenes with computers with more than 2GB of RAM. The band 123 (BGR) image is shown below.



I then pulled a spectrum for Lawn Grass from the USGS library. The spectrum is shown below.



The next step is to overlay the Landsat channels over the spectrum. I did this in Power Point although you can use any convenient graphics editor.



I then struck horizontal lines that marked the intersection of the Landsat bands with the spectral curve. My strategy was to require that the reflectance be “at least” as large as the peaks and “no more than” for the valleys. The next step will show how the LSA allows such discrimination.

A note of caution: there are five “Lawn Grass” spectra listed and six “Grass” spectra, none of them exactly the same. I chose one arbitrarily to see what I would get. In reality, library spectra may be useful but it is best not to place blind faith in them, as we shall soon see. The best spectra are the ones that come from a reliable source directly from your target area. You should at least read the Documentation that accompanies each USGS spectrum.

Now we are ready to scan our data. Select ‘File’ | ‘Open and open six or seven Landsat band files, band1 (Blue), band2 (Green), band3 (Red), band4 (NIR) band 5 (SWIR) and band 7 (LWIR), or alternatively use the Thermal Infrared (TIR) band. If you decide to use the TIR band, open the files in the order: band1, band2, band3, band4, band5, band6 (TIR) and band 7. Now select ‘Spectral Analysis’ | ‘Landsat Spectral Analyzer’ | ‘Six/Seven DN Bands’.

IMPORTANT NOTE: Using the TIR band may give additional discriminating power to your analysis. If you decide to use the TIR band, you may have to

preprocess it before doing so. Some Landsat TIR files are archived the same size as the multispectral band files. However most are archived as 57 or 60m resolution files, i.e. half the resolution of the multispectral bands. In addition, there are usually two TIR band files with suffixes 61a and 61b. These are the high gain and low gain versions of the data. If you choose to use the TIR band, you will be prompted to tell PANCROMA which type of file you are processing by checking a radio button on the TOA Reflectance Form.

In order to use a TIR band at half resolution, you must first expand and interpolate it up to 27.5 or 30m resolution. This can be done using the utility described in Section XX. Once the scale is adjusted, it can be used to generate a Point Spectrum.

When **PANCROMA™** processes the TIR band, it will divide the computed temperature in degrees Kelvin by a factor of 1000. This scales the temperature data so that it is of the same order of magnitude as the TOA reflectance data.

You can select the multispectral band that you want to be displayed for point selection by checking the appropriate radio button.

After opening your multispectral bands, the Spectral Criteria Form will be displayed as shown below.

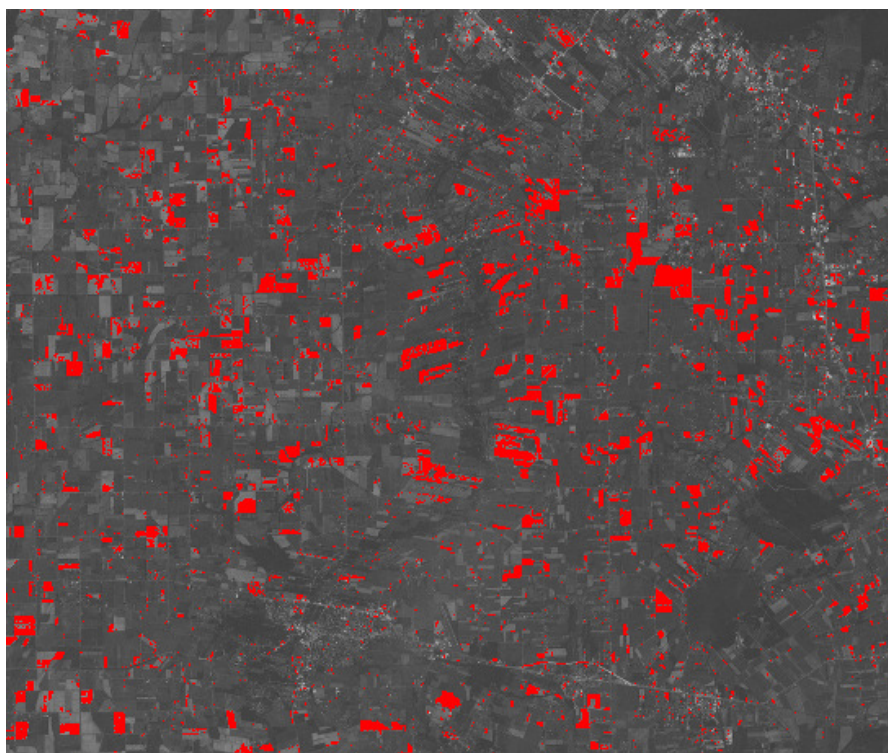
There are six (or seven if you use the TIR band) track bar sliders corresponding to the six input Landsat bands. Beneath each one is a radio button that lets you select between 'Must Exceed' and 'Less Than' as level qualifiers.

http://www.science.aster.ersdac.or.jp/en/documnts/users_guide/index.html. At the bottom of the screen is a check box that lets you lock all the sliders and another check box that allows you to save your settings between runs. Note that I have input the selection criteria from my channel plot.

When you click 'OK', the TOA Reflectance Data Form will appear. This contains the usual reflectance computation criteria. Since the spectra are given as reflectances, the band digital numbers (DNs) must be converted. This will be done in the same way as described in Section 49 Landsat Top of Atmosphere Reflectance. Make sure that the 'Render Color Image' check box is checked (this is the default). When you click "OK", the LSA will convert the DN's to TOA reflectances. It will report the maximum and minimum reflectance values to the Main Window data screen. Note that some reflectance values may be less than zero. This of course does not make sense. **PANCROMA™** uses the method proscribed in the Landsat Data Users Handbook directly without biasing the computed values to make them all positive or zero. Since the magnitude of any negative reflectances is usually very small, this is not a problem.

PANCROMA™ will mark each pixel that matches the comparison criteria by coloring it red, and displaying it on the band1 grayscale image. The results of my first run were exactly... nothing. No hits at all. I inspected the maximum reflectance value for the band4 channel and noticed that it was around 0.8. I concluded that there might be a standard error between the measured reflectances and the spectrum. I made a second run decreasing all channel values by 0.2 units and again got no hits. I then decreased all channels by another 0.1 unit. This yielded the image shown below. (The image is shown at half scale so that it fits on the page conveniently.)

Comparison of the marked plots with the RGB image shown that the scan has apparently marked the plowed fields, not the lawn grass. I "ground truthed" the image using a high resolution aerial photograph and this seemed to confirm my suspicion. I also included a band 145 false color composite, commonly used to discriminate vegetation for comparison. (Note that **PANCROMA™** will compute the percentage of red pixels on the active part of the image and display them in the Main Window dialog box.)



Note that you can flip back and forth between the base image and the classified image by selecting 'Switch Images' | 'Base Image' and 'Switch Images' | 'Spectral Images 1'



Although the run was not successful in discriminating Lawn Grass, a few conclusions can be drawn:

- The method did seem to be a fairly sensitive discriminator for the plowed fields
- More experimentation with the selection criteria might find the grassy fields as intended
- The technique appears to be more sensitive and more positive than either false color composites or classification
- It is clear why more multispectral bands are better, and why hyperspectral data is the best for this purpose. It is also clear why 11 bit or 16 bit data is better than 8 bit data, as the former yields more resolving power for applications like this

The **PANCROMA**TM LSA is a powerful tool for exploring and characterizing geological and agricultural aspects of the earth's surface with many possible useful applications. However like most tools, it still relies on the expertise and skill of the user to produce the best results. This example showed how it is possible to discriminate plowed fields in an image. Although this particular task was relatively simple, the method is equally applicable to cases where the discrimination is not so obvious, as in mineral exploration.

Landsat Reflectance Spectral AnalyzerTM

As described above, the **PANCROMA**TM Spectral AnalyzerTM can convert Landsat band file DNs to TOA reflectance and then compare the computed reflectance values to archived surface spectra. The USGS offers Landsat data surface reflectance data. This information is archived in at least two formats. The Global Land Cover Facility archives surface reflectance values in I16, Little Endian format. GLOVIS archives the six multispectral bands in a single Planar Configuration=2 file. PANCROMA can decode both of these formats but currently the Spectral AnalyzerTM can only process the individual bands archived at GLCF. It uses the data in these files directly instead of computing TOA reflectance values from Landsat DNs.

There are several advantages to using surface reflectance as an alternative to DNs or even computing TOA reflectances from DNs. Surface reflectance is basically TOA reflectance corrected for atmospheric effects. As a result, surface reflectance values are generally superior to TOA reflectance as removing the atmospheric effects makes them more similar to the archived spectra, as these values are usually measured directly at the surface. Another advantage is precision.

The surface reflectance values are archived as 16-bit integers with a valid range of -2000 to 16000. A value of -9999 represents 'no data' while 20000 is 'saturation'. **PANCROMA**TM sets 'no data' and 'saturation' values equal to zero and decodes the valid integers, scaling them by a factor of 0.000100 (in

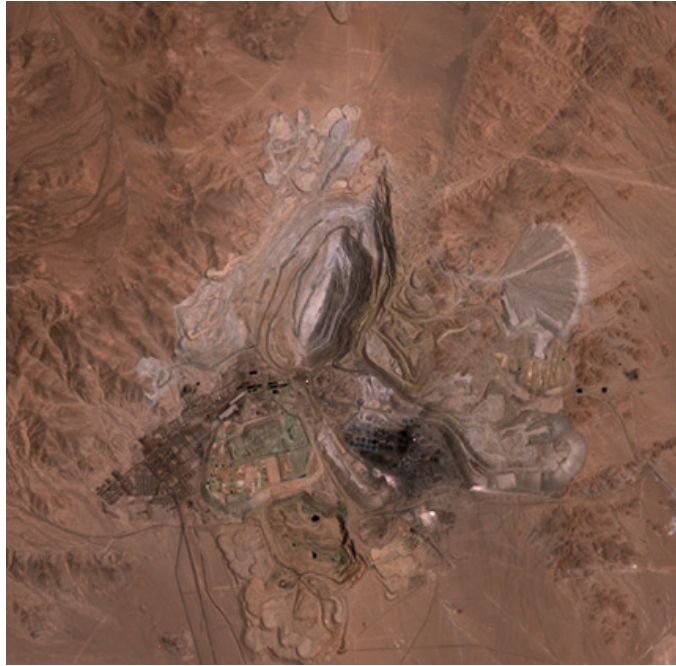
accordance with the accompanying Landsat metadata) without loss of precision. DNs have only 8 bits of dynamic range and this is of course limits the precision of the TOA reflectance values derived from them.

Using the LSA with surface reflectance data proceeds almost exactly as with the corresponding DN bands. Select 'File' | 'Open' and open either six Landsat surface reflectance band files, band1 (Blue), band2 (Green), band3 (Red), band4 (NIR) band 5 (SWIR) and band 7 (LWIR) or alternatively include the thermal IR (TIR) band by opening band1 (Blue), band2 (Green), band3 (Red), band4 (NIR) band 5 (SWIR) band6 (TIR) and band 7 (LWIR). Now select 'Spectral Analysis' | 'Landsat Spectral Analyzer' | 'Six/Seven Reflectance Bands' | 'Manual Method'. The Spectral Criteria Form will be displayed as described above. The settings are made the same as described previously. After accepting (clicking 'OK') the LSA will compute the image as before.

A couple of notes about the TIR band. Thermal data is archived in I16 format as scaled degrees Celsius. The integer values should normally be multiplied by a scaling factor of 0.01 to convert the I16 data to degrees Celsius. **PANCROMA™** instead multiplies the data by a factor of 0.0001, the same scale factor as is used to convert the I16 band data to surface reflectance. The advantage of doing this is that the data stored in the thermal band is of the same order of magnitude as the reflectance data, which simplifies data display. Since the band data can be considered as orthogonal vectors, it is not possible to combine them as scalar values anyway so it does not really matter how they are scaled from a processing standpoint. However, if thermal ground truthing data is used to calibrate or verify the results, the measured temperatures should be divided by 100.0 in order to match the values that PANCROMA™ computes.

Note that processing times for surface reflectance data will take somewhat longer than using DN band data. This is because the integer reflectance files are twice as large as the corresponding DN band files, and decoding the 16 bit data and converting it to float type takes longer for each file.

Another application for Landsat reflectance data is combining channels to make true color or false color RGB composite images and even pan sharpened images. Because atmospheric effects are removed, this data can make images of exceptional quality. Example RGB color composite and pan sharpened images of the massive Chuquicamata mine in northern Chile made with Landsat surface reflectance data are shown below.



The pan sharpened image was created by downloading a standard Landsat Path 1 Row 75 DN panchromatic band. The reflectance band files had to be converted from 16 bit to 8 bit format. Then the corner coordinates were rationalized using the 'Compute Maximum Common Extents' utility. The scales

were matched using the 'Rescale Landsat 14.25m to 15m' Preprocessing utility. Finally, the reflectance band files were pan sharpened using a standard HSI transformation. The ELIN local optimization was switched off since this desert scene did not need this utility.

SPOT Spectral Analyzer™

Spectral analysis using SPOT multispectral data proceeds the same as for Landsat, except that SPOT has only four multispectral bands as compared to the six Landsat multispectral bands. Select 'File' | 'Open and open four SPOT band files, band1 (Green), band2 (Red), band3 (NIR), band4 (SWIR). (SPOT spectral band data is given in Section 29). Now select 'Spectral Analysis' | 'SPOT Spectral Analyzer' | 'Four DN Bands' | 'Manual Method'. The Spectral Criteria Form will be displayed as described in the previous section except only four band file data groups will be active. Afterwards, a second data entry box will be displayed for entering the appropriate TOA Reflectance data. The data entry is similar to that described in Section 47 except that no binary float file option is offered and the a color image is displayed as a default. In addition, you will have to enter the SPOT Absolute Calibration Gain for each band. These vary from image to image so they must be obtained from the metadata for each SPOT scene. **PANCROMA™** will compute the percentage of red pixels on the active part of the image and display them in the Main Window dialog box as described above.

NAIP Spectral Analyzer™

Spectral analysis using SPOT multispectral data proceeds the same as for Landsat, except that SPOT has only four multispectral bands as compared to the six Landsat multispectral bands. Select 'File' | 'Open and open four SPOT band files, band1 (Green), band2 (Red), band3 (NIR), band4 (SWIR). (SPOT spectral band data is given in Section 29). Now select 'Spectral Analysis' | 'SPOT Spectral Analyzer' | 'Four DN Bands' | 'Manual Method' (or 'Euclidean Distance'). Follow the instructions for these two methods outlined in the previous sections. The Spectral Criteria Form will be displayed as described in the previous section except only four band file data groups will be active. **PANCROMA™** will compute the percentage of red pixels on the active part of the image and display them in the Main Window dialog box as described above.

ASTER Spectral Analyzer™

Spectral analysis using the six ASTER multispectral data proceeds the same as for Landsat. Select 'File' | 'Open and open the six ASTER SWIR band files, band4, band5, band6, band7, band8 and band9. (ASTER spectral band data is given in Section 30). Alternatively, you can also include the three Very Near Infrared (VNIR) bands (see note below).

Now select 'Spectral Analysis' | 'ASTER Spectral Analyzer' | 'Six DN Bands' | 'Manual Method' or alternatively 'Spectral Analysis' | 'ASTER Spectral Analyzer' | 'Nine DN Bands' | 'Manual Method'. The Spectral Criteria Form will be displayed as described in the previous Landsat section. Afterwards, a second data entry box will be displayed for entering the appropriate TOA Reflectance data. The data entry is the same as described in Section 47 except that no binary float file option is offered and the a color image is displayed as a default. **PANCROMA™** will compute the percentage of red pixels on the active part of the image and display them in the Main Window dialog box as described above.

IMPORTANT NOTE: If you decide to use the three ASTER Very Near Infrared (VNIR) bands in addition to the six Short Wave Infrared (SWIR) bands, you will have to rationalize the file sizes. The resolution of the VNIR bands is 15m/pixel while that of the SWIR bands is 30m/pixel. The file sizes can be rationalized either by resampling the VNIR bands down or interpolating the SWIR bands up using the PANCROMA™ Resize utilities. Interpolating up is recommended in order to avoid loss of information from the ASTER scene.

IMPORTANT NOTE: PANCROMA™ wants the ASTER data in GeoTiff format. You may have to convert your data using the free MultiSpec utility before processing.

EO-1 ALI/Hyperion Spectral Analyzer™

Spectral analysis using the nine EO-1 ALI multispectral or Hyperion hyperspectral data proceeds the same as for Landsat except that three more files must be input. Select 'File' | 'Open and open the nine EO-1 ALI band files, band2, band3, band4, band5, band6, band7, band8, band8 and band10. (EO-1 spectral band data is given in Section 31). Now select 'Spectral Analysis' | 'EO-1 ALI Spectral Analyzer' | 'Nine DN Bands' | 'Manual Method'. The Spectral Criteria Form will be displayed as described in the previous Landsat section. Afterwards, a second data entry box will be displayed for entering the appropriate TOA Reflectance data. The data entry is the same as described in Section 47 except that no binary float file option is offered and the a color image is displayed as a default. **PANCROMA™** will compute the percentage of red pixels on the active part of the image and display them in the Main Window dialog box as described above.

WorldView2 Spectral Analyzer™

Spectral analysis using the eight WorldView2 multispectral or data first requires that the eight WV2 multispectral bands be decomposed from the single PlanarConfiguration=2 (non-contiguous) GeoTiff file into eight individual band files. To do this, open the single bundled GeoTiff file as issued by DigitalGlobe® by selecting 'File | Open'. Then select 'Display Files' | 'Decompose Eight File

Digital Globe Bundle' | 'Save as 16-Bit' or alternatively, 'Display Files' | 'Decompose Eight File Digital Globe Bundle' | 'Save as 8-Bit'.

IMPORTANT NOTE: Digital Globe data is offered in both 8-bit and 16 bit formats. If you have 16-bit format, you can unbundle your Digital Globe data into either 8-bit or 16-bit format. It is advisable to save in 16-bit format to preserve the full precision of the dynamic range of the digital numbers in the band files. However, if your data is 8-bit format, or if you wish to use PANCROMA utilities that only handle 8-bit format, you will have to save the unbundled band file data in 8-bit format. When prompted, give the band files a root name and a numerical suffix will be attached designating the band numbers when the eight individual GeoTiff band files are saved.

Now it is possible to run the Spectral Analyzer™. This is done exactly as described in the preceding sections. Select 'File' | 'Open' and open the eight WorldView2 band files, band1, band2, band3, band4, band5, band6, band7 and band8. (WorldView2 spectral band data is given in Section 34). Now select 'Spectral Analysis' | 'WorldView2 Spectral Analyzer' | 'Eight 16-Bit Bands' | 'Manual Method' or 'Spectral Analysis' | 'WorldView2 Spectral Analyzer' | 'Eight 8-Bit Bands' | 'Manual Method' depending on the file format you selected when unbundling.

The Spectral Criteria Form will be displayed as described in the previous sections. Set your selection criteria using the track bar sliders. When you are finished, select 'OK'. Afterwards, a second data entry box will be displayed for entering the appropriate TOA Reflectance data. You will have to enter the metadata for each WV2 band file as it will probably be different for each one.

The computation of TOA reflectance for WorldView2 data is described in the Digital Globe publication entitled *Radiometric Use of WorldView-2 Imagery*. This publication is available at the Digital Globe website and on the www.PANCROMA.com/data web page. Additional information regarding IMD files and calibrating WorldView2 data is shown in Section 34.

Because the calibration factors and effective bandwidth values are typically different for each band, they have to be entered eight times. (Note that the solar elevation angle and Julian day data only has to be entered once. The appropriate data entry form will appear eight times to allow input of the values. (The data can be found in the .IMD file that accompanies each WorldView2 data set. When you select OK the final time, **PANCROMA™** will compute the percentage of red pixels on the active part of the image and display them in the Main Window dialog box as described above.

RapidEye® Spectral Analyzer™

Spectral analysis using the five bundled RapidEye multispectral bands in GeoTiff format can be done by selecting Select 'File' | 'Open and opening the single GeoTiff file that contains the five multispectral bands. Now select 'Spectral Analysis' | 'RapidEye Spectral Analyzer' | 'Five (Bundled) 16-Bit GeoTiff Bands'. Select either the 'Manual Method', Euclidean Distance or Spectral Angle methods, setting the selection criteria as described in previous sections.

MODIS Spectral Analyzer™

Spectral analysis using the seven bundled MODIS multispectral bands in HDF format can be done by selecting Select 'File' | 'Open and opening the single HDF file that contains the five multispectral bands. Now select 'Spectral Analysis' | 'MODIS Spectral Analyzer' | 'Seven (Bundled) 16-Bit HDF Bands'. Select either the 'Manual Method', Euclidean Distance or Spectral Angle methods, setting the selection criteria as described in previous sections.

Euclidean Distance Spectral Analyzer™

The previous methods require setting the spectral selection criteria manually in terms of the reflectance levels and “greater than” or “less than” slider settings. An alternative way to match spectral signatures is distance minimization. In this technique, the multispectral band data is considered an n-dimensional vector, with n being the number of available spectral bands. This is the so-called hypercube approach, i.e. three orthogonal vectors defining the edge of a standard cube and additional orthogonal vectors defining a hypercube.

The method computes the distance between each multispectral reflectance vector and the target vector defined by spectral signature you are trying to match. At this time, the target vector can be entered into the Spectral Criteria form automatically, using the Point Spectrum Generator™. In this case, you must click on representative target pixels as described above. When you compute your spectrum, the average reflectance values will be automatically entered into the Spectral Criteria sliders. You must select 'Close Graphics Window and Reset' and then re-open your multispectral band files.

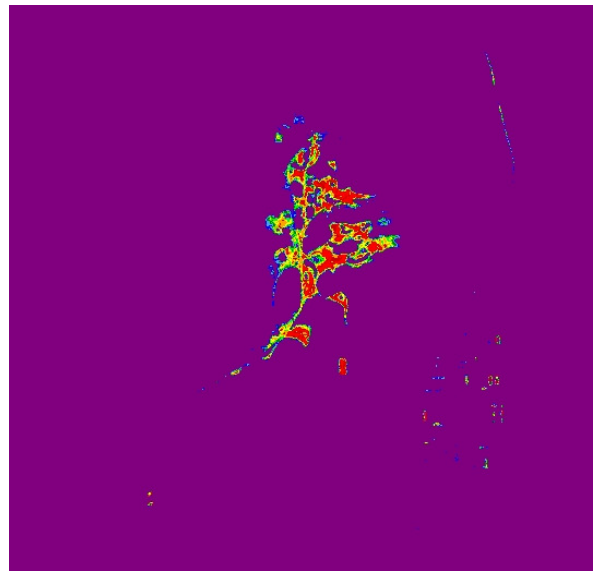
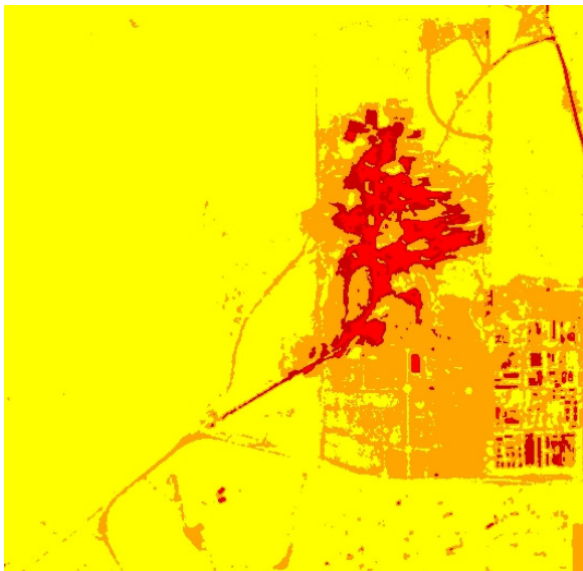
To conduct a distance match, first open either six or seven Landsat DN band files. Then select 'Spectral Analysis' | 'Landsat Spectral Analyzer' | 'Six/Seven DN Bands' | 'Euclidean Distance'. (See the subsection entitled Landsat DN Point Spectrum Generator™ for information on how to preprocess the TIR band if you decide to use it.

The Spectral Criteria Form will not become visible. If you are entering data manually, use the band sliders for bands 1,2,3,4,5 and 7, input the reflectance values for the target vector taken from the spectrum of interest. If you used the

Point Spectrum Generator™, the target vector will already be entered in the sliders.

Note that there is a check box at the bottom left side of the form entitled 'Input Two Spectra'. **PANCROMA**™ allows you to compute the Euclidean distance plot using one input spectrum or alternatively two spectral. If you want to analyze two spectra and compare them to the base image, check the box as is shown in the figure above. If you want to analyze only a single spectrum, keep it un checked. Note that if you input two target spectra using Point Spectrum Generator™, both sets of spectra will be automatically input into the Spectral Criteria form.

The 'Set Upper Cutoff' check box at the lower right side of the form is also very useful. Often there will be a small number of pixels with low reflectance values. These may not even be visible on a color contour plot, but will widen the reflectance range so that there is little color contrast in the plot. These can be clipped out using the 'Set Lower Cutoff' slider bar and can produce much better color plots. An example of two such plots, one unclipped, and the second one clipped are shown below.



Click 'OK'. The TOA Reflectance Data Form will become visible. Enter the Solar Elevation Angle and the Acquisition Date and click 'OK'.

TOA Reflectance Data Form

45

Solar Elevation Angle

175

☐ Retain Settings

☐ Write 8-Bit GeoTiff File

Landsat Type

☐ Landsat ETM+

☐ Landsat TM

OK

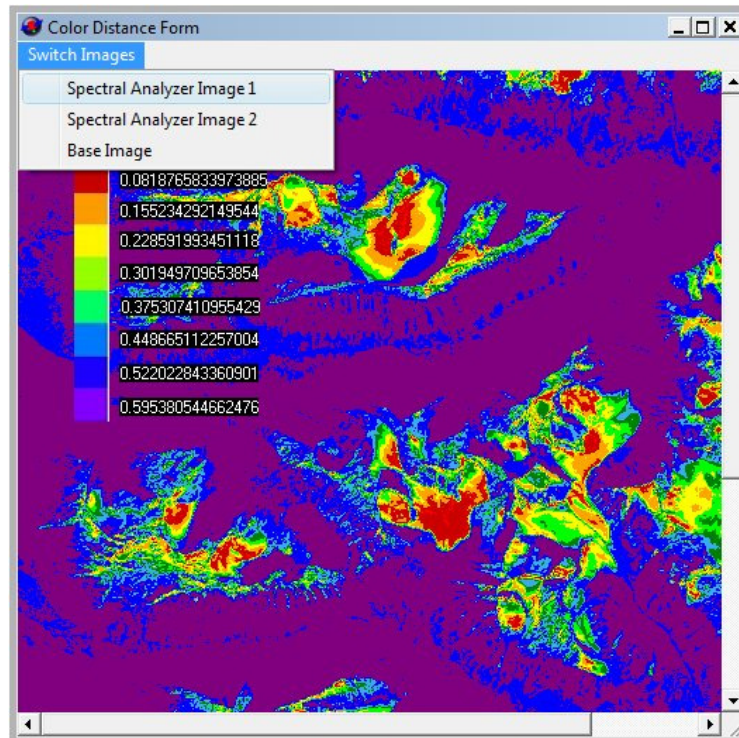
Cancel

Note that the TOA Reflectance Data Form contains a check box marked 'Write 8-Bit GeoTiff File'. If this box is checked, **PANCROMA™** will write the Euclidean Distance or Spectral Angle values to a GeoTiff file. The values will be scaled between 0-255 so that they can be viewed in other applications. Note that the darker the grayscale pixel value, the smaller the Euclidean Distance, so target areas will appear black.

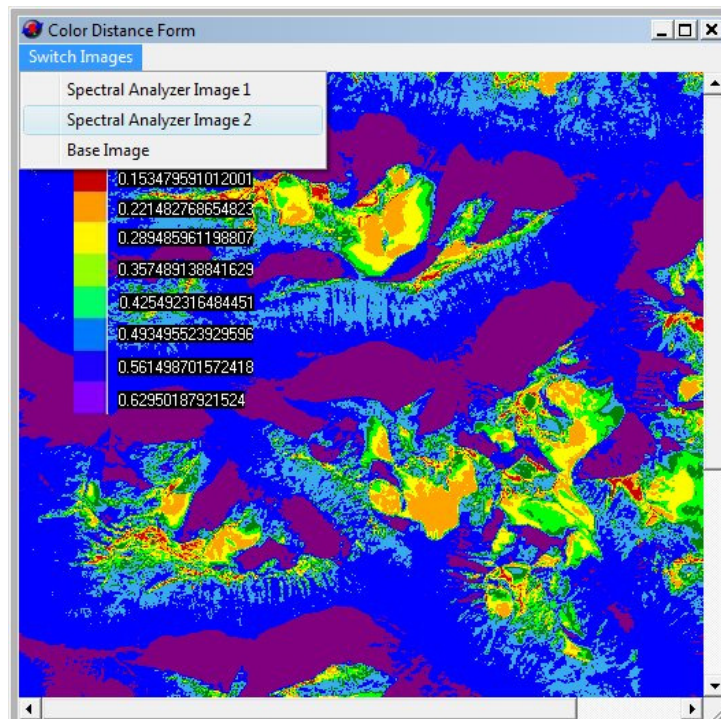
After a bit of computation, two images will become visible, a grayscale image and an RGB contour image. The grayscale image displays the Euclidean Distances, scaled to fall between 0 and 255. The RGB contour plot plots the actual Euclidean Distances with red being the shortest distance and violet being the greatest. Note that in the grayscale plot, black represents the closest match and pure white (DN=255) is the farthest distance. If you are running two spectra, the Spectral Criteria Form will appear a second time. This time enter the second spectrum.

The analysis shown below uses the Euclidean distance method, running the snow pack example with two input spectra. I generated target vectors using the Point Spectrum Generator™. After clicking on the targets in each image and selecting a dozen or so points, I checked the 'Enter Spectrum into Analyzer' check box. In addition to generating my spectrum, it automatically entered the first set of average reflectance values into the Spectral Criteria Form. (The second set has to be entered manually).

The following image shows the first Euclidean Distance plot. The bright red areas correspond to the minimum Euclidean Distance and therefore the best match with the target vector. The purple areas are the worst matches, i.e. the farthest Euclidean Distances. The red areas correspond to the obvious snow areas in the band images, with the orange and yellow areas being probable matches as well in this case. Note that you can turn off the color scale by unchecking the 'Display Euclidean Distance Scale' check box on the Spectral Criteria form.



The second plot is shown below, displayed by selecting the 'Switch Images' | 'Spectral Images 2' menu selection. Finally, the base image, accessed by selecting 'Switch Images' | 'Base Image'.





Note that if you are not running two spectra, the Spectral Analyzer Image 2 layer will contain an RGB image.

Euclidean Distance analysis is also implemented for Landsat DN, Landsat Reflectance, SPOT, EO-1, WorldView-2 and ASTER. You can input either the six Short Wave Infrared (SWIR) bands or else the six SWIR plus the three Very Near Infrared (VNIR) bands into the Euclidean Analyzer. Select either 'Spectral Analysis' | 'ASTER Spectral Analyzer' | 'Six DN Bands' | 'Euclidean Distance' or alternatively 'Spectral Analysis' | 'ASTER Spectral Analyzer' | 'Nine DN Bands' | 'Euclidean Distance'

IMPORTANT NOTE: Although it is possible to conduct multispectral analysis using entire Landsat scenes, be advised that the edges of the individual Landsat multispectral bands do not match exactly. This can produce border regions containing invalid Euclidean Distance values because some of the multispectral band values are zero and some are non-zero. This can also influence the min and max value computations that set the color range scale. It is better for most work to crop off these regions before conducting multispectral analyses.

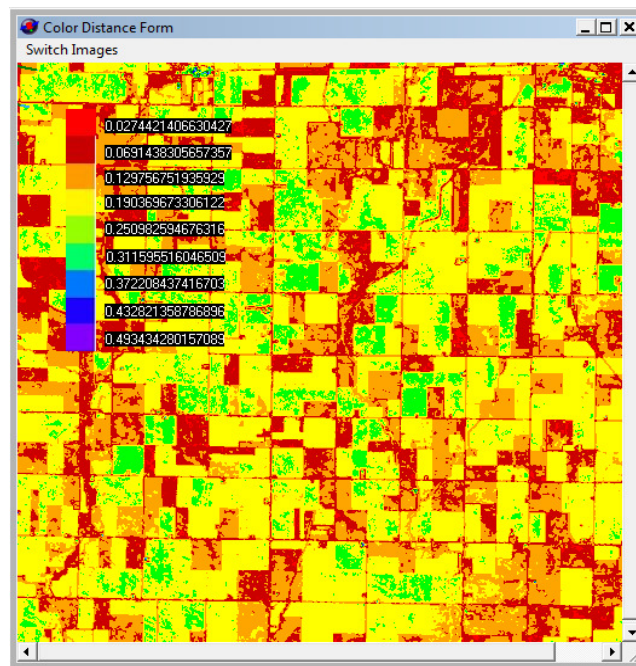
IMPORTANT NOTE: If you decide to use the three ASTER Very Near Infrared (VNIR) bands in addition to the six Short Wave Infrared (SWIR) bands, you will

have to rationalize the file sizes. The resolution of the VNIR bands is 15m/pixel while that of the SWIR bands is 30m/pixel. The file sizes can be rationalized either by resampling the VNIR bands down or interpolating the SWIR bands up using the PANCROMA™ Resize utilities. Interpolating up is recommended in order to avoid loss of information from the ASTER scene.

IMPORTANT NOTE: PANCROMA™ wants the ASTER data in GeoTiff format. You may have to convert your data using the free MultiSpec utility before processing.

IMPORTANT NOTE: PANCROMA™ can handle Digital Globe and World View2 data in either 8-bit or 16-bit format.

It may be desirable to adjust the data span for the Euclidean Distance display. Often a small number of “flyer” Euclidean Distance values can skew the plot so that there is not very much discrimination. An example of this situation is shown below.



The plot can be improved by lumping the larger Euclidean Distances together. To do so, check the ‘Set Upper Cutoff’ check box at the lower right hand corner of the Spectral Criteria Form.

Spectral Criteria Form

Band 1 Reflectance:
☐ Must Exceed ☒ Include
☐ Less Than

Band 2 Reflectance:
☐ Must Exceed ☒ Include
☐ Less Than

Band 3 Reflectance:
☐ Must Exceed ☒ Include
☐ Less Than

Band 4 Reflectance:
☐ Must Exceed ☒ Include
☐ Less Than

Band 5 Reflectance:
☐ Must Exceed ☒ Include
☐ Less Than

Band 6 Reflectance:
☐ Must Exceed ☒ Include
☐ Less Than

Band 7 Reflectance:
☒ Must Exceed ☒ Include
☐ Less Than

Band 8 Reflectance:
☒ Must Exceed ☒ Include
☐ Less Than

Band 9 Reflectance:
☒ Must Exceed ☒ Include
☐ Less Than

Distance Fraction Level:
☒ Include 11%
☐ Include 22%
☐ Include 33%
☐ Include 44%
☐ Include 55%
☐ Include 66%
☐ Include 77%
☐ Include 88%
☐ Include 100%
☐ Distance Fraction

OK Cancel
☐ Retain settings between runs ☐ Lock Track Bars
☒ Display Euclidian Distance Scale
☐ Input Two Spectra

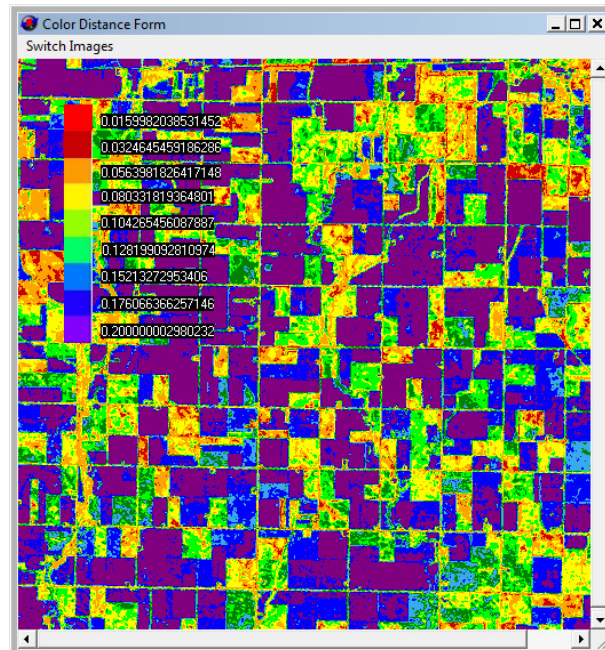
Mask Group
☐ Create Mask
☒ Positive Mask
☐ Negative Mask

Percent Mask Inclusion 11 22 33 44 55 66 77 88 100

Cutoff Group Box

Upper Level Cutoff Value
☒ Set Upper Cutoff

When you do so a track bar will become visible. All computed Euclidean Distances greater than the value set on the track bar will be set equal to this value. This will result in greater discrimination in the color plot, as shown in the image below.



Euclidean Distance Fraction™ Analysis

Another powerful technique for conducting land use studies is **PANCROMA™** Euclidean Distance Fraction™ analysis. Euclidean distance analysis considers the target spectrum as a multi dimensional vector. It also considers each pixel in the data set as a similar vector. It then computes the distance between each pixel and the target, in the vector sense. Rather than display the entire Euclidean distance plot, Distance Fraction™ analysis allows you to select all pixels within a selected fraction of the difference between the maximum and minimum Euclidean distance. This can result in very selective classifications of land features based on spectral signature matching.

Implementing this technique proceeds in a similar fashion to the Euclidean Distance method described in the previous section. For example, to conduct the analysis using Landsat data, start by opening your multispectral data files. Then select 'Spectral Analysis' | 'Landsat Spectral Analyzer' | 'Six/Seven DN Bands' | 'Euclidean Distance'. When the Spectral Criteria form appears, enter your target spectrum using the slider bars as before. If you have run Spectral Analyzer™, your values will of course already be entered. Check the 'Distance Fraction' check box at the lower right side of the form. This will enable the nine radio buttons on the Euclidean Distance Fraction panel as shown below.

The image shows a software window titled "Spectral Criteria Form". It contains nine sliders for Band 2 Reflectance through Band 10 Reflectance. Each slider has a value of 0 and two radio buttons: "Must Exceed" and "Less Than". Below each slider is a checked "Include" checkbox. At the bottom left are "OK" and "Cancel" buttons. Below them are checkboxes for "Retain settings between runs", "Lock Track Bars", "Display Euclidean Distance Scale", and "Input Two Spectra". In the bottom center is a "Mask Group" section with a "Create Mask" checkbox and "Positive Mask" and "Negative Mask" radio buttons. On the right side is a "Euclidean Distance Fraction" panel with a list of percentage options: "Include 11%", "Include 22%", "Include 33%", "Include 44%", "Include 55%", "Include 66%", "Include 77%", "Include 88%", and "Include 100%". Each option has a radio button. The "Distance Fraction" checkbox is checked and circled in red.

Now select one of the radio buttons. Choosing the top button will display only those pixels having the closest Euclidean distance (best match) with the target spectrum. These will be all pixels within 11% of the total span between the maximum and minimum Euclidean distance. For example, if the maximum

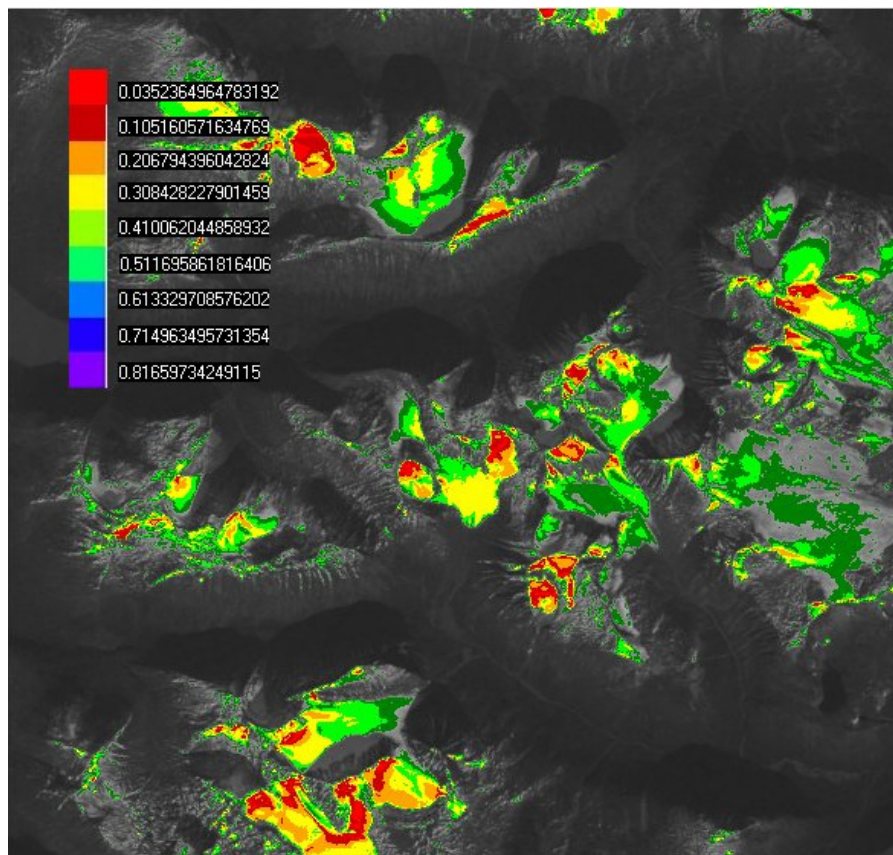
distance is 0.947 and the minimum distance is 0.155, checking the first button will display all pixels within a Euclidean distance D:

$$D = 0.11 * (0.155 + (0.947 - 0.155))$$

from the target spectrum. Checking the second button will display pixels with a distance D of

$$D = 0.22 * (0.155 + (0.947 - 0.155)).$$

and so on. These pixels will be overlayed onto the image. By moving the selection down the scale, more and more pixels are added to the overlay display. An example image from the snowpack example is shown below.



In this image, all pixels that are less than 0.5165 (dark green on the scale) from the target spectrum are overlayed onto the image. When the analysis is run, the area coverage as a percentage of the total image is displayed on the Main Window dialog box.

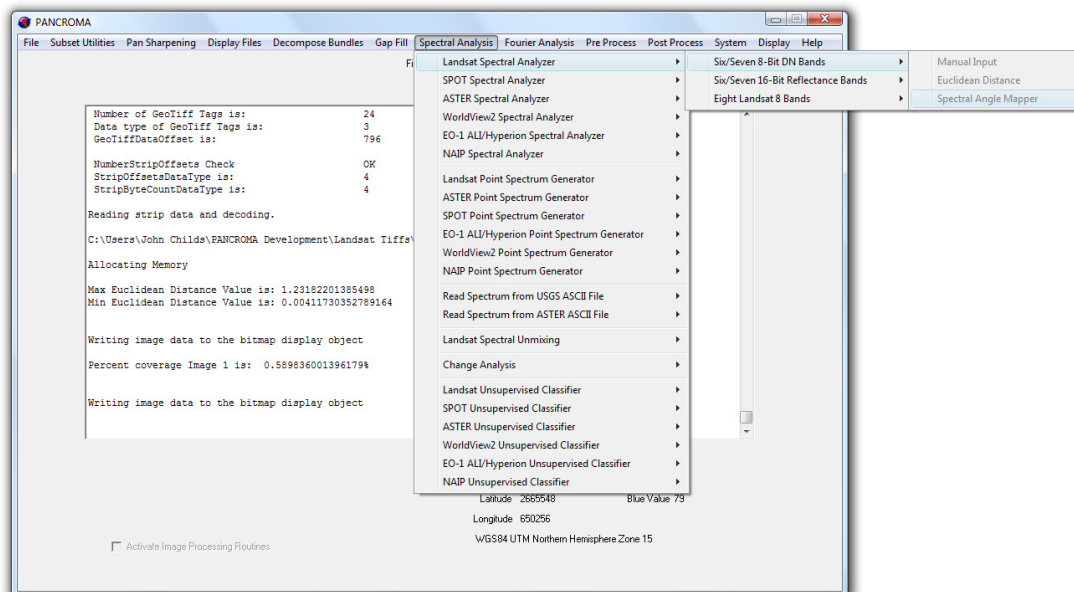
The idea is to adjust the included pixels to entirely cover ground features that are known by ground truthing or other means. When the match is close, it is likely that all other instances of that feature in the image will be closely identified. In the case of the snow pack exampleTM, the snow is easily identified visually. By adjusting the Distance FractionTM, an accurate snow pack coverage measurement can be taken.

Spectral Angle Analysis

SAA is an alternative method for matching image pixel reflectances with target spectra. As in Euclidean Distance analysis, SAA also considers each image reflectance value and the target spectrum as an n-dimensional vector, where n is the number of multispectral bands. The algorithm determines the spectral similarity between each image reflectance vector and the target vector by calculating the angle between each image reflectance and the target. As in Euclidean Distance comparisons, target spectra used by SAA can come from ASCII files or spectral libraries, or you can extract them directly from an image using the Point Spectrum GeneratorTM.

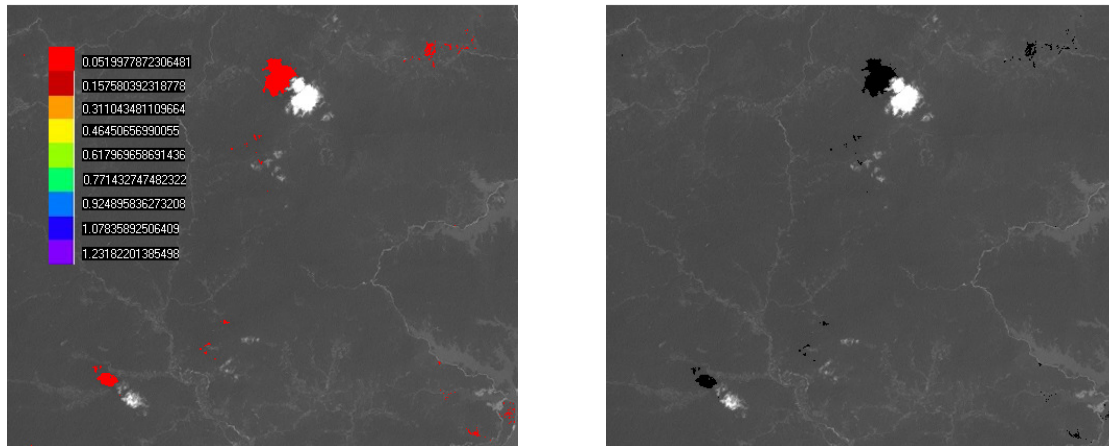
Spectral Angle comparisons can often be more discriminating and can yield more accurate matches than corresponding Euclidean Distance analyses. This is because, when used with calibrated reflectance data, Spectral Angle comparisons are relatively insensitive to illumination and albedo effects that can confound Euclidean Distance analyses.

In order to use the method for Landsat 7 data, open six or seven Landsat multispectral band files. Then select 'Spectral Analysis' | 'Landsat Spectral Analyzer' | 'Six/Seven 8-Bit DN Bands' | 'Spectral Angle'. (Or alternatively, if you are using Landsat 7 reflectance data choose the corresponding 'Six/Seven 16-Bit Reflectance Bands' submenu selection.

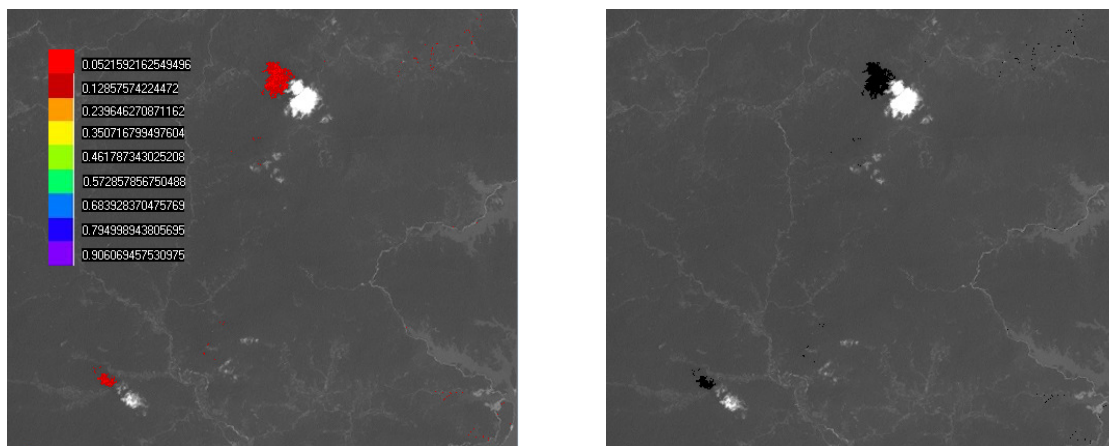


When you do, the same Spectral Criteria form used for Euclidean Distance analysis will become visible. The target spectrum can be entered in the same way as for Euclidean Distance analysis, either manually, by reading in ASCII spectra, or by using the Point Spectrum Generator™.

The following images show a comparison between cloud shadow masking results using the two methods. The first pair of images, a Euclidean Distance plot and a corresponding cloud mask (see next section) were generated using the Point Spectrum Generator™ and Euclidean Distance Analysis, with the mask track bar on setting zero.



The next pair of images were generated using the same target spectrum and Spectral Angle analysis



The SAA method resulted in a more discriminating match and it also excluded the false positives from the nearby water bodies that had similar reflectance spectra as the cloud shadows.

In addition to Landsat 7, Spectral Analysis is currently implemented for NAIC and SPOT data as well.

IMPORTANT NOTE: Although it is possible to conduct multispectral analysis using entire Landsat scenes, be advised that the edges of the individual Landsat multispectral bands do not match exactly. This can produce border regions containing invalid Euclidean Distance values because some of the multispectral band values are zero and some are non-zero. This can also influence the min and max value computations that set the color range scale. It is better for most work to crop off these regions before conducting multispectral analyses.

Creating Masks using Spectral Analysis

Various methods have been proposed for improving the appearance and usefulness of Landsat images that are obstructed by cloud layers. The **PANCROMA™** utilities for masking clouds use either three or five of the Landsat multispectral band files. These files are used in a non-linear combinatorial manner to predict which image pixels correspond to cloud cover and which do not. These methods, particularly the five-file utility based on Luo method can be highly effective.

An alternative approach to masking clouds is to use **PANCROMA™** multispectral analysis tools. In addition to being highly discriminating in identifying cloud cover, these tools can also identify cloud shadows, snow, and other features that you may wish to remove from your image by pixel substitution from another image. This section describes how this can be done. In the process, it will illustrate how a wide variety of surface features can be identified using **PANCROMA™** spectral analysis tools.

The first step in this procedure is to download all of the multispectral bands for both your target image, and for the image from which you will 'borrow' pixels. I will call this second image the Reference image. If you are processing Landsat data you will need all the bands 1,2,3,4,5,6 and 7 for each image. The described method also works for ASTER, EO-1 ALI, Landsat Reflectance and WorldView-2 data files.

Note that for many Landsat multispectral bundles, the thermal infrared (TIR) band6 image will be half resolution (approximately 60m/pixel) and half the size of the multispectral bands. Some band6 data has been processed by expanding the image and interpolating the gaps. If your data is archived as a 60m image, you can use the **PANCROMA™** TIR interpolation utility to expand and interpolate it to match the size and scale of the multispectral files.

You must first generate a spectral signature using the **PANCROMA™** Point Spectrum Generator™. You will then use the spectrum and the Euclidean Distance Analyzer to identify targets, in this case clouds, with the masking option switched on.

Begin by opening your seven Landsat reference bands in the order: band1, band2, band3, band4, band5, band6 and band7 by selecting 'File' | 'Open' from the main menu. Now select 'Spectral Analysis' | 'Landsat Point Spectrum Generator' | 'Six/Seven 8-Bit DN Bands'. The Band Display Selection Form will become visible. This form allows you to specify which band or band combination you want to use to identify your target pixels. If clouds are your target, band1 is a good choice, although other will work as well. Click 'OK' when you have selected your band.

Now the selected band image will appear, along with the Point Spectrum Form. The main purpose of the Point Spectrum Form is to keep a running tally of your selected points. It also controls the zoom feature in case you need to get in closer into your image to accurately identify your target pixels. Using your cursor, successively click on the cloudy areas of the image until you have collected a representative sample (You can choose as many as 50, but often you can get by with far fewer.) I chose 18. When you are finished, select 'OK'.

Now the TOA Reflectance Data Form will become visible. Enter the Solar Elevation Angle, Julian Day and TIR Gain Level corresponding to your image from the Landsat metadata file. Check the 'Retain Settings' box so that the entered values will be saved for subsequent runs. See the section on the PANCROMA Point Spectrum generator™ for details. Now select 'OK' and the Point Spectrum for your Reference image will be generated.

The next step is to generate the mask. Select 'Close Graphics Window and Reset' from the Main Menu. When you do so, the spectrum will close. However the average TOA reflectances will be stored for the next step.

Re-open your seven Target band files as before by selecting 'File' | 'Open' from the main menu. Select 'Spectral Analysis' | 'Landsat Spectral Analyzer' | 'Six/Seven 8-Bit DN Files' | 'Euclidean Distance'.

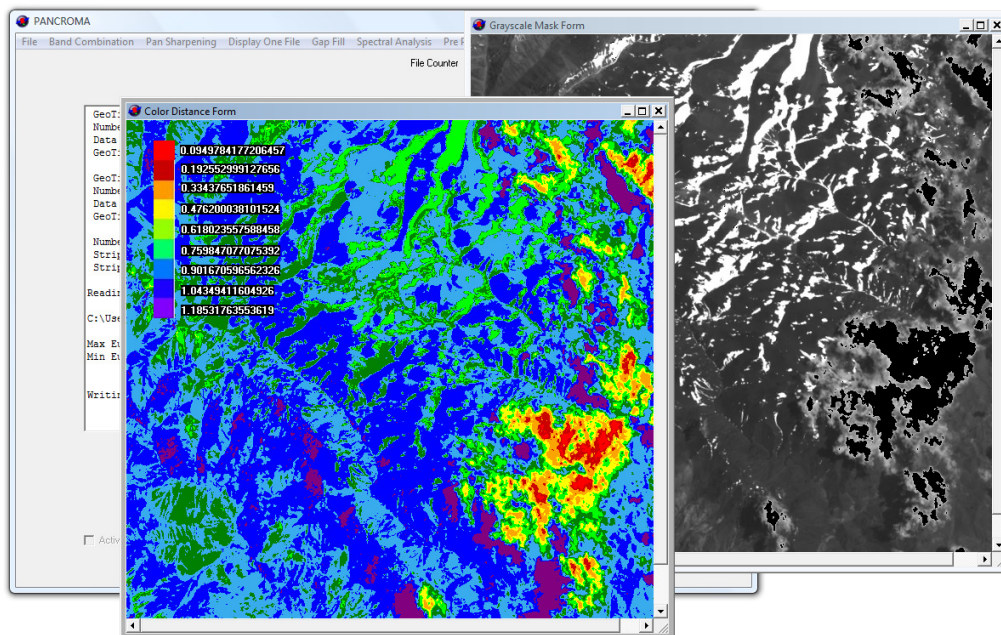
Note that there are seven track bars corresponding to the seven multispectral bands we have opened. The average reflectances are already set into these track bars so no adjustment is required (unless you feel some is necessary). Check the 'Retain Settings Between Runs' check box. This will hold our Spectral Criteria settings in case you will need multiple runs to make your mask.

Also check the 'Create Mask' check box in the Mask Group. When you do so, the Level Selection track bar in the will become enabled. You can generate either a positive mask or alternatively a negative mask, which will black out all of the non-target pixels and retain the targets. This selection can be made by using the 'Positive Mask' (default) and 'Negative Mask' radio buttons next to the 'Create Mask' check box.

This track bar lets you specify how far away the Euclidean Distance vector can be from the target and still be included in the mask. The higher the number from 0 to 8, the farther the distance and the more pixels will be included in the mask.

Low numbers mean high discrimination but possibly too narrow a specification. High number mean lower discrimination with the possibility of including unwanted pixels in your mask. I will use Level=3 for my first run. Select 'OK'.

When you do so, the TOA Reflectance Data form will again become visible. The values you used for the Point Spectrum Generator™ and click 'OK' and the mask will be generated as shown below.

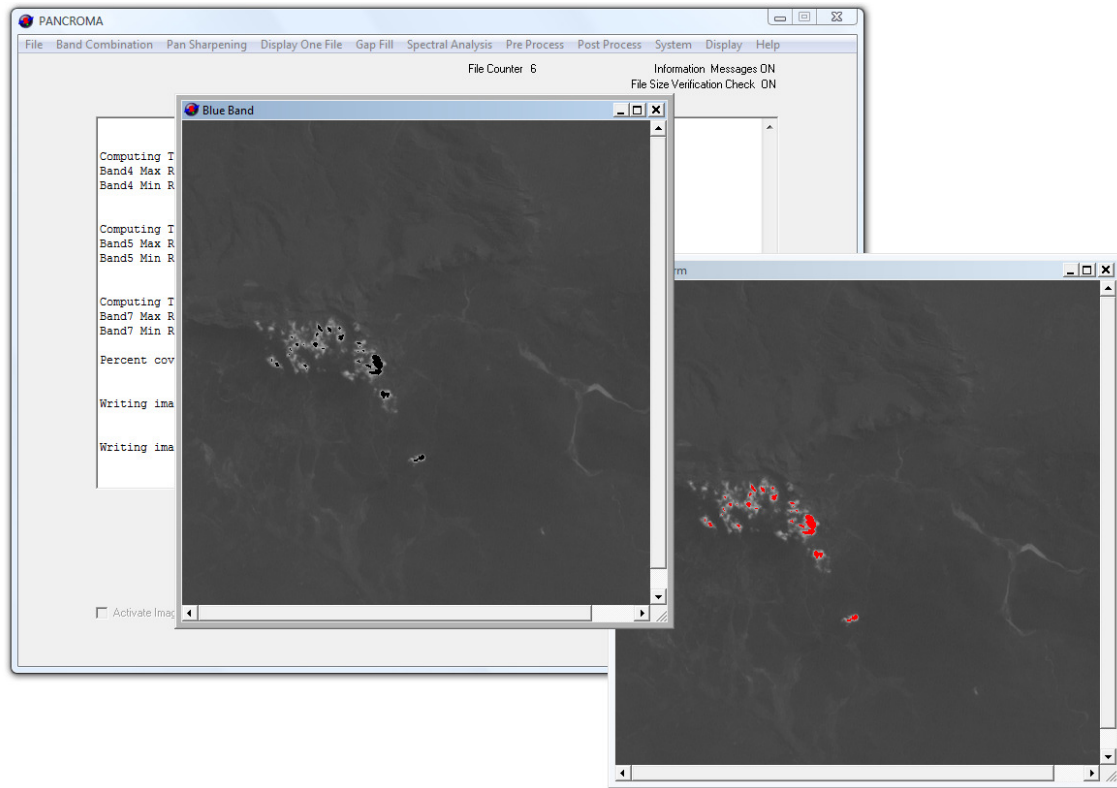


The color contour plot and the mask show the Euclidean distances between each pixel reflectance and the spectral signature target reflectance. The mask image has zeroed out image pixel values at locations corresponding to the cutoff you specified with the Level Selection track bar.

The analysis has been very successful at discriminating the clouds from everything else in the image. In particular, note how the bright cloudy areas are identified, while the bright snowy areas are not included. To the human eye, these areas are indistinguishable. To the multispectral “eye” of the Landsat sensors, they are quite different. Save the mask for further processing. Select 'File' | 'Save Grayscale Image' | 'GeoTiff' from the menu and give the file a name such as 'cloudMask.tif'.

Although this example used Landsat, you can make masks using ASTER, EO-1 ALI, Landsat Reflectance and WorldView-2 data. This example used the Euclidean Distance analyzer to identify the pixels to include in the mask.

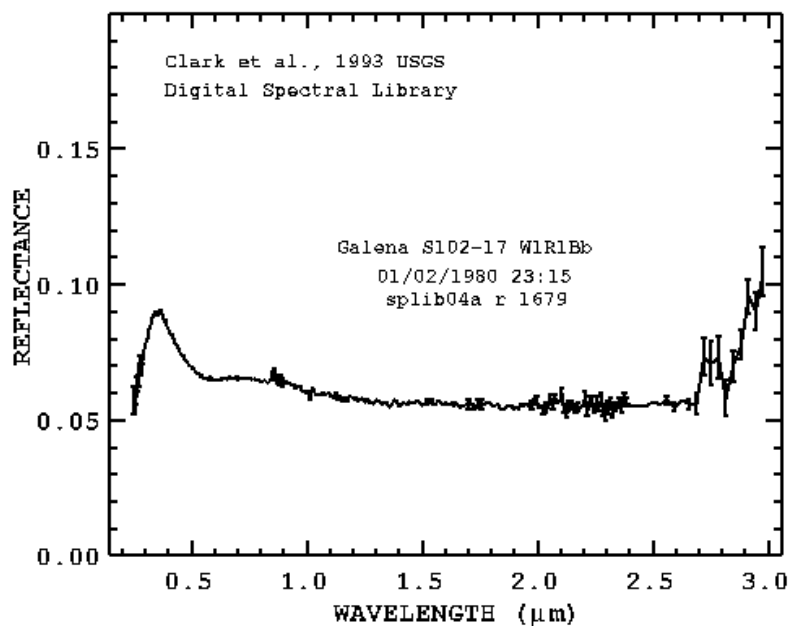
The Spectral Analyzer™ (menu selection 'Manual Method') to identify these pixels can also be used to generate masks for cloud and cloud shadow removal. When this option is selected, a second image is generated where the target pixels are black rather than red. This image can then be used with PANCROMA Gap Fill Transfer Method to substitute pixels from a similar cloud-free image into the mask.



'Band Math' | 'Boolean AND Two Images' utility described in Section 50. For additional information, see the White Paper available at <http://www.pancroma.com/Landsat%20Spectral%20Signature%20Mask.html>

Reading Data from USGS ASCII Spectra Files

The United States Geological Survey (USGS) publishes several spectral libraries for a wide variety of mineral and organic materials. These spectra can be accessed and downloaded from the USGS Spectroscopy Lab website at <http://speclab.cr.usgs.gov/>. An example of such a spectrum, for the mineral galena, is shown below.



Copyright USGS

Although this data is very useful in graphical form, it is also offered in ASCII file format. In this form, the wavelength, reflectance, and standard deviation of the reflectance values are listed as shown in the excerpt below.

USGS Digital Spectral Library splib05a
Clark et. al. 2003, USGS, Open File Report 03-395.

For further information on spectroscopy, see: <http://speclab.cr.usgs.gov>

ASCII Spectral Data file contents:
line 15 title
line 16 history
line 17 to end: 3-columns of data:
wavelength reflectance standard deviation

(standard deviation of 0.000000 means not measured)
(***** indicates a deleted number)

```
-----
Augite WS588 Pyroxene          W1R1Ba AREF
copy of splib04a r 604
0.205100*****                0.043845
0.213100*****                0.006601
0.221100          0.025804      0.002118
0.229100          0.026781      0.001300
0.236100          0.025403      0.001186
0.242100          0.025548      0.001132
0.248100          0.025900      0.001083
0.253600          0.024198      0.001047
0.258600          0.024068      0.001023
```

0.263600	0.024684	0.001055
0.268600	0.026923	0.001052
0.273100	0.025821	0.001087
0.277100	0.025812	0.001107
0.281100	0.027588	0.001135

(Note that the asterisks mean missing data.)

PANCROMATM can read reflectance data from such files and insert that data automatically into the Spectral Criteria form for subsequent analysis. In order to do so, first download the ASCII spectrum for the material you are interested in. Save it in the default .txt text file format. Next start **PANCROMA**TM and select 'File' | 'Open' and open the file. Next, select 'Spectral Analysis' | 'Read Spectrum from USGS ASCII File'.

You must click the submenu selection for the type of data that you will be using for your subsequent analysis, for example Landsat ETM+. Note that there are two options for Landsat ETM+, depending on whether you intend to use the Thermal Infrared (TIR) band or not. If you decide to use the TIR band, you will have to input it manually into the Spectral Criteria form as the basic USGS spectral libraries do not include any TIR information.

When you click on the submenu, **PANCROMA**TM will search the file for the band wavelengths, and will extract the corresponding reflectances. It will place these reflectances into the Spectral Criteria form. They can then be conveniently used for either Manual or Euclidean Distance analysis.

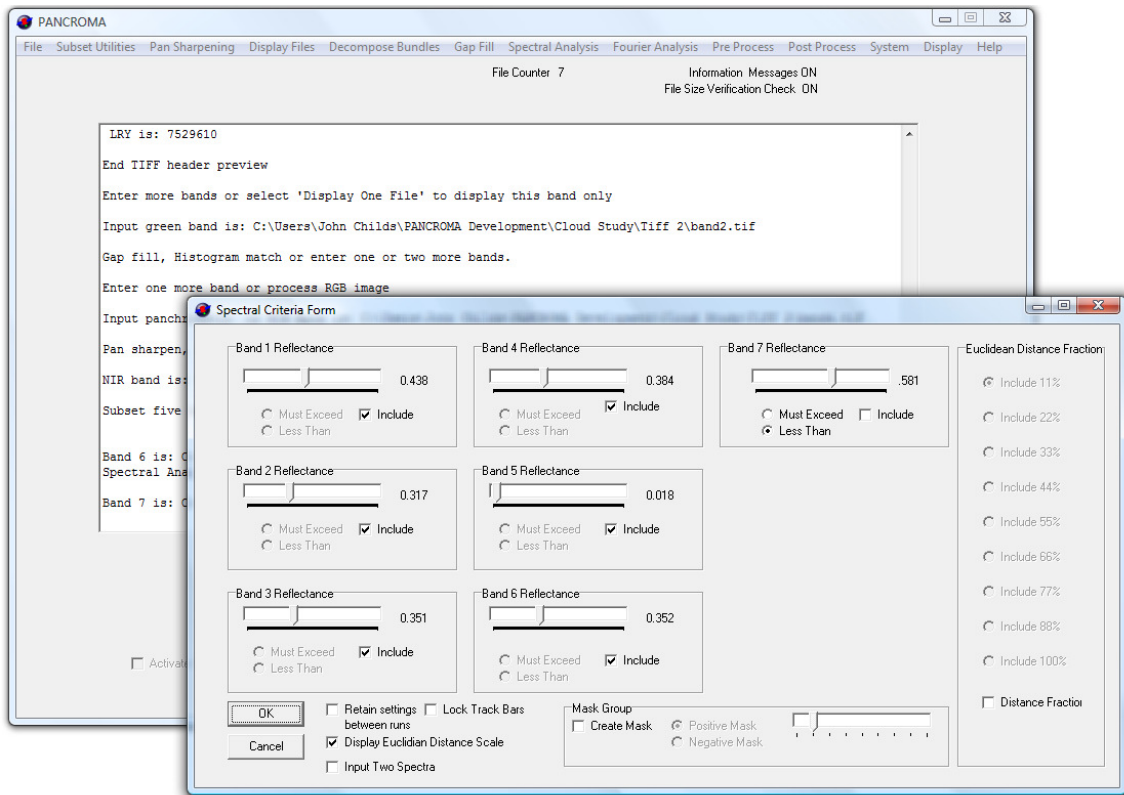
Note that the band sensors are sensitive across a narrow range of wavelengths. will look up the reflectance that corresponds to the midpoint of the band. For example, the Landsat band1 reflectance will correspond to a wavelength of 0.4825 microns. The band reflectances for the mineral augite are shown tabulated below as reported to the text screen.

File opened successfully

Wavelength:	0.483300	Reflectance:	0.154771
Wavelength:	0.565300	Reflectance:	0.175869
Wavelength:	0.661700	Reflectance:	0.153826
Wavelength:	0.828000	Reflectance:	0.133775
Wavelength:	1.654500	Reflectance:	0.254075
Wavelength:	2.215000	Reflectance:	0.381393

Spectral Criteria form is populated.

When you click 'Close Graphics Window and Reset' and then start a Landsat Euclidean Distance analysis, the reflectances will already be inserted into the reflectance value track bars, as shown in the image below.



Note that the band 6 (TIR) track bar is not set. This must be done manually.

Reading Data from NASA JPL ASCII Spectra Files

NASA/JPL also publishes ASCII spectral libraries, found at <http://speclib.jpl.nasa.gov/>. These are more comprehensive than the USGS libraries as they offer spectra for the visible, VNIR, SWIR and TIR spectral ranges. You must inspect the XStart and XStop limits carefully in order to determine the range of wavelengths included in a particular file. If the target wavelengths are not in the file you will obviously not get a match.

In order to read one of these ASCII files, select 'File' | 'Open' and open the file. Next, select 'Spectral Analysis' | 'Read Spectrum from ASTER ASCII File'. The submenus will specify your target wavelengths as described above for the USGS spectral files.

Landsat Linear Spectral Unmixing

Spectral unmixing represents an interesting approach to understanding and using multispectral data. The method starts with an assumption that the characteristics of observed image pixels constitute mixtures of the characteristics of a small number of basic cover types, called endmembers. If the mixtures are assumed to consist of linear combinations of the contributions of the individual

cover types, a linear mixing model can be formulated. This linear mixing model can be used to determine the fractions of each cover type present in the image. For example, consider the six Landsat visible plus NIR bands. A reflectance value can be computed for each pixel in the image, a different (usually) reflectance for each band corresponding to that pixel. Let's assume that these reflectances, measured by the satellite sensors are completely the result of reflectances from four cover types. As a result, each cover type will contribute a fraction F (referred to as endmember Abundance) of its individual reflectance X at that wavelength to the measured reflectance B for each multispectral Landsat band.

Let's further assume that we know the reflectances X in each multispectral wavelength for each of the four end members. These can be obtained from libraries as described in previous sections, or from actual ground measurements. F and B can be considered column vectors, F composed of the four unknown Abundances and B composed of the six reflectances (one for each multispectral band) measured by the satellite. We can write the linear relationship among X, F and B as an equation as follows:

$$X_{00} * F_0 + X_{01} * F_1 + X_{02} * F_2 + X_{03} * F_3 = B_0$$

This is just the standard linear mixing equation. We can formulate a set of linear equations that relate the reflectances in each wavelength of the end members to the measured reflectances Y. The relationship is shown in matrix form below.

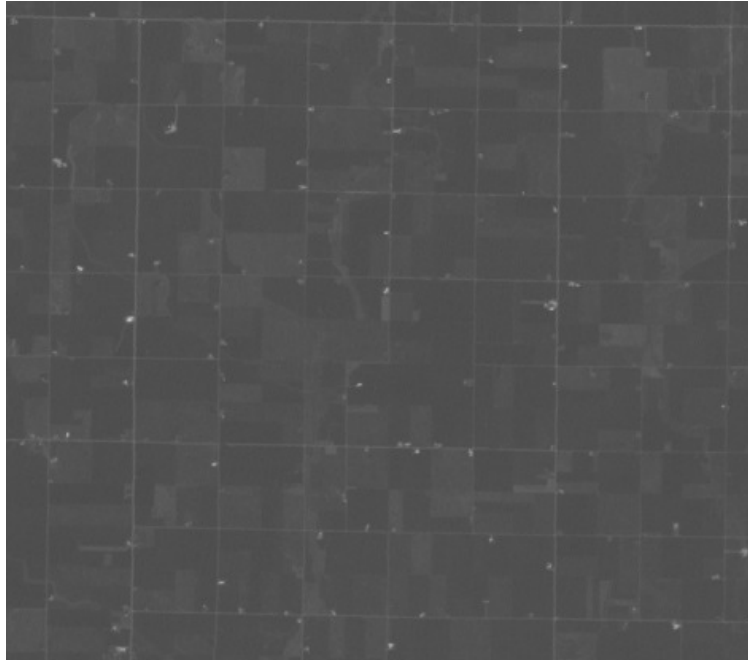
	Endmember X _i Library Spectra				Type Fraction		Image Reflectances
	X				F		B
	end1	end2	end3	end4			
reflectance at wavelength 0	X00	X01	X02	X03	*	F0	B0
reflectance at wavelength 1	X10	X11	X12	X13		F1	B1
reflectance at wavelength 2	X20	X21	X22	X23		F2	B2
reflectance at wavelength 3	X30	X31	X32	X33		F3	B3
reflectance at wavelength 4	X40	X41	X42	X43			B4
reflectance at wavelength 5	X50	X51	X52	X53			B5

Note that if we had only four equations we could solve for the fractions F exactly. We can get a better solution by including all of the multispectral data we have, and then solving the set of over determined equations using linear regression. Note that the system of equations that we have to solve applies to one pixel only. We will have to repeat the solution process for every pixel in the image. This is obviously a computationally expensive task but it can be accomplished by the **PANCROMA**TM regression solver.

The solution yields four sets of fractions F, one for each pixel in the image. These fractions are usually depicted graphically by scaling them so that the range from 0 to 255 and then rendering them as four grayscale images. The

higher (whiter) the grayscale pixel value, the greater the fraction of that particular end member in the pixel.

This process can be illustrated with an example. Consider the Landsat band1 image below.



For this example, let's assume that the reflectances measured by the satellite are the result of reflectances from just four end members: Cheatgrass, asphalt, dry grass and fresh oak leaves. We can obtain reflectance spectra for each of these from the USGS Spectral libraries.

Start by opening each of the six Landsat multispectral bands, that is bands 1,2,3,4,5 and 7 (recall that band 6 is the thermal infrared band) by selecting 'File' | 'Open' and selecting each of the six band files in succession.

Now select 'Spectral Analysis' | 'Landsat Spectral Unmixing' | 'Four End Members'. The files will be read and the TOA Reflectance Form will appear.

TOA Reflectance Data Form

Solar Elevation Angle 45

Acquisition Date in Ordinal Days 175

Landsat Type

☒ Landsat ETM+

☐ Landsat TM

OK

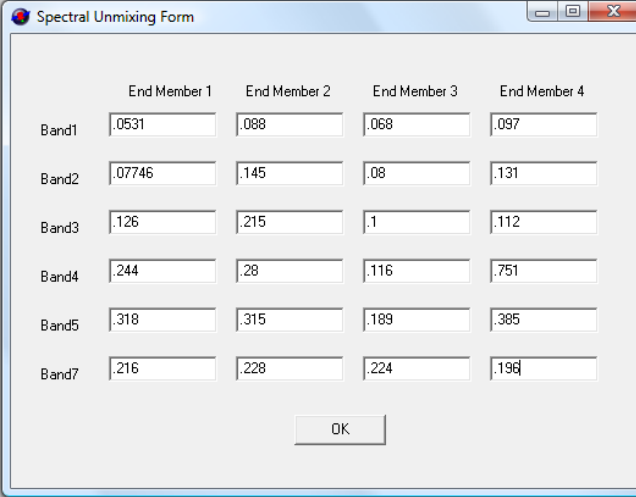
Cancel

Enter The Solar Elevation Angle and the Acquisition Date from the Landsat metadata. Afterwards the Spectral Unmixing form will appear.

Referring to the nominal multispectral band wavelengths and the USGS spectral data, enter the reflectances for each end member at each of the six Landsat wavelengths. The nominal wavelengths are shown in the table below.

Band	Wavelength (μ)	Resolution (m)
1	0.450-0.515 (blue)	30
2	0.525-0.605 (green)	30
3	0.630-0.690 (red)	30
4	0.750-0.900 (near-IR)	30
5	1.55-1.75 (mid-IR)	30
6	10.4-12.5 (thermal-IR)	60
7	2.08-2.35 (long-IR)	30
Panchromatic	0.52-0.90 (green-near IR)	15

The table with the manually input reflectance values for my selected endmembers is shown below.

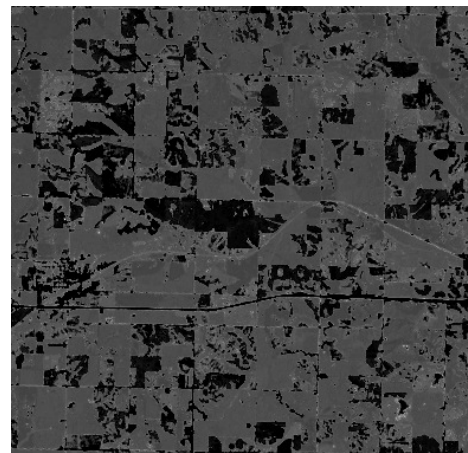
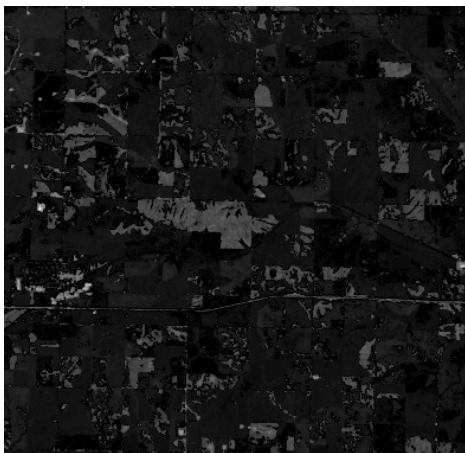
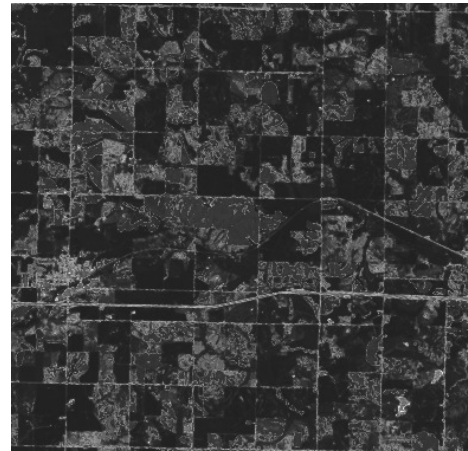
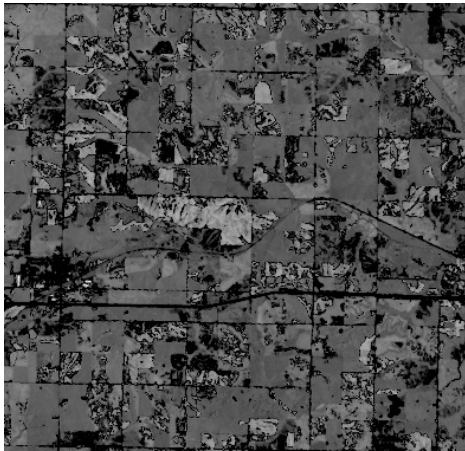


	End Member 1	End Member 2	End Member 3	End Member 4
Band1	.0531	.088	.068	.097
Band2	.07746	.145	.08	.131
Band3	.126	.215	.1	.112
Band4	.244	.28	.116	.751
Band5	.318	.315	.189	.385
Band7	.216	.228	.224	.196

OK

Select 'OK' and the computation will start. Because a linear regression computation must be run for each pixel in the image, run times may take some time, i.e. ten or fifteen minutes for a full Landsat scene. System RAM will be heavily used as well, so it is wise to shut down other applications during a four-endmember run.

The output images from my run are shown below. Theoretically, these show the relative abundances of each of the four cover types corresponding to the four spectra that were input to the model.



PANCROMA™ allows three, four and five endmember analyses for Landsat data. (Note that five-endmember analysis requires disk scratch files so certain parts of the computation may take considerably longer as stored data is recovered from disk). There may be more or less cover types in the image and all of the types may not be identified. Future releases will allow a greater range of endmember types but identification of the endmembers will still be an issue.

As with any multispectral analysis method the model may not always match reality and there are lots of provisos to consider for the method. The most obvious is how to determine the number and type of endmembers in the scene. Also, In order to get good results, the library spectra must be calibrated to the satellite sensor. This can be done by taking ground readings with a spectrophotometer or other means.

It is perfectly legitimate to compute negative abundances from a mathematical standpoint. This can sometimes occur for a variety of reasons. Unfortunately

this does not correspond to physical reality. If negative abundances are computed, **PANCROMA**TM will substitute a zero for the negative value in the endmember image. The number of substitutions is counted and reported to the dialog screen. A large number of negative abundances would cast doubt on the validity of the analysis.

Spectral unmixing provides another interesting approach to multispectral analysis. This is an area in need of more improvement but with a lot of potential. Watch for additional **PANCROMA**TM capabilities in this area.

Landsat Change DistanceTM Multispectral Change Detection

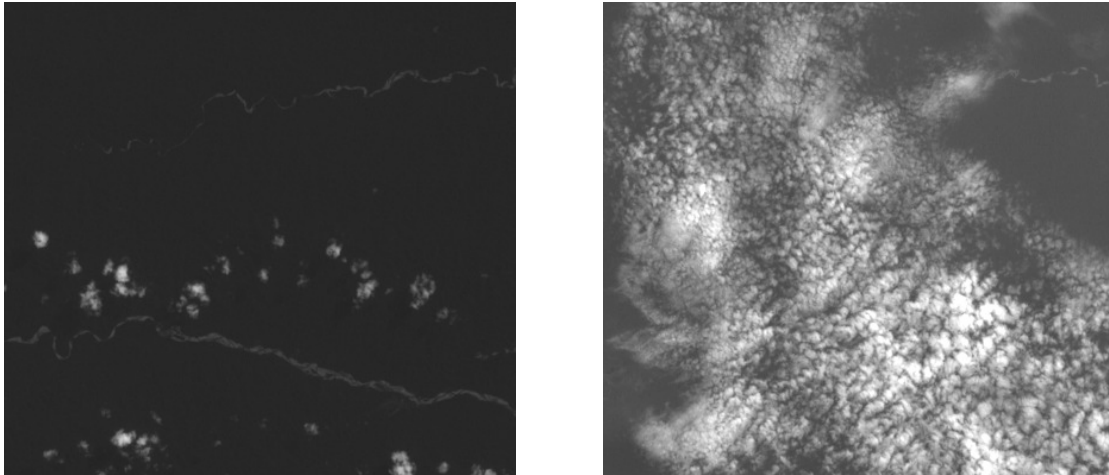
Many earth science disciplines required the detailed analysis of changes to the earth's surface over a period of time. Examples include studies of deforestation, urban growth, desertification, glacier and ice pack change, agricultural land use and many others. Satellite data can be very useful to such studies. Often these changes are made on the basis of visual comparison of individual band files, true color or false color images composited from such band file data. Another approach is to subtract one band image from another band image in order to obtain a quantitative measure for the degree of change.

PANCROMATM offers a powerful multispectral tool for assessing such changes. Rather than using a single multispectral band, the Change DistanceTM tool uses all available Landsat multispectral bands in order to determine the degree of change. This can often be more accurate than relying on a single band, because apriori knowledge of the most affected band is not necessary in order to detect the change. The utility considers each pixel in the scene as a vector in six-space, and computes the vector distance between the top of atmosphere (TOA) reflectance value of each pixel. Using the TOA reflectance provides a more accurate comparison between the two scenes than using raw digital numbers (DNs). Those pixels with near zero vector distances may be assumed to be unchanged, while those with larger vector distances are identified as changed.

Using the tool requires two multispectral Landsat data sets, one representing the base scene and one for the changed scene. Each set should include bands 1, 2, 3, 4, 5, and 7. Because a pixel-by-pixel comparison will be made between the two scenes, it is important that they are correctly co-registered. The registration requirements are exactly the same as those required for gap filling, and any and all of the **PANCROMA**TM tools that are used for preparing Landsat gap fill data can be used for change detection.

The first step in the process is to obtain two Landsat scenes with at least some overlapping area, i.e. two scenes with the same path and row number. Make sure that you download the metadata files with the Solar Elevation Angles and Acquisition Dates, as these will be needed in the process.

We are going to use a very obvious feature to demonstrate change detection in this example: cloud cover. The base image subset area has very little cloud cover, while the changed target has a lot. If change detection works properly, we should expect the cloud cover to be highlighted as a very measurable change.



The next step is to co-register the bands. There are several ways to do this but the easiest is probably to use the six file subsetting method. This method will crop the images to the Maximum Common Extents coordinates and rescale the images if necessary so that the row and column counts will match exactly. (The Maximum Common Extents are the corner coordinates of the common area between the two scenes). The main proviso with this technique is band file labeling. Since the utility was designed for gap filling, you have to be careful to get your file naming conventions set so that your registered band files do not get confused.

PANCROMA™ provides a file-naming tool in order to facilitate this if you choose to use it. To illustrate its use, suppose that we have two Landsat scenes as follows:

Group 1	Group 2
L71005068_06820030919_B10.TIF	L71005068_06820040804_B10.TIF
L71005068_06820030919_B20.TIF	L71005068_06820040804_B20.TIF
L71005068_06820030919_B30.TIF	L71005068_06820040804_B30.TIF
L71005068_06820030919_B40.TIF	L71005068_06820040804_B40.TIF
L71005068_06820030919_B50.TIF	L71005068_06820040804_B50.TIF
L71005068_06820030919_B70.TIF	L71005068_06820040804_B70.TIF

Start by opening the first three bands of Group 1 and the first three bands of Group 2, in order:

L71005068_06820030919_B10.TIF
L71005068_06820030919_B20.TIF
L71005068_06820030919_B30.TIF

L71005068_06820040804_B10.TIF
L71005068_06820040804_B20.TIF
L71005068_06820040804_B30.TIF

After the six band files are opened, select 'Subset Utilities' | 'Subset Images' | 'Subset Six Bands'. When the Subset Data Entry form becomes visible, check the 'Select Change Subset' check box and click on the 'First Group' radio button as shown in the image below.

Subset Data Entry

Click 'Rubber Band Box Select'. Then, using the mouse and the left mouse button, select your subset area by selecting first the upper left corner, then the lower right corner of the area of interest in the blue band window.

Alternatively, enter the upper left and lower right X and Y pixel values into the text boxes by using the mouse to click on the corners of the subset area. You can enter the exact UTM coordinates by clicking the 'Select by Coordinates' Radio Button.

Manual Subset Data Entry Panel

0	Upper Left X
0	Upper Left Y
0	Lower Right X
0	Lower Right Y
686370	Upper Left UTM Longitude
-1248840	Upper Left UTM Latitude
699300	Lower Right UTM Longitude
-1260810	Lower Right UTM Latitude

☒ Display Subset Images

Change Group Box

☒ First Group
☐ Second Group

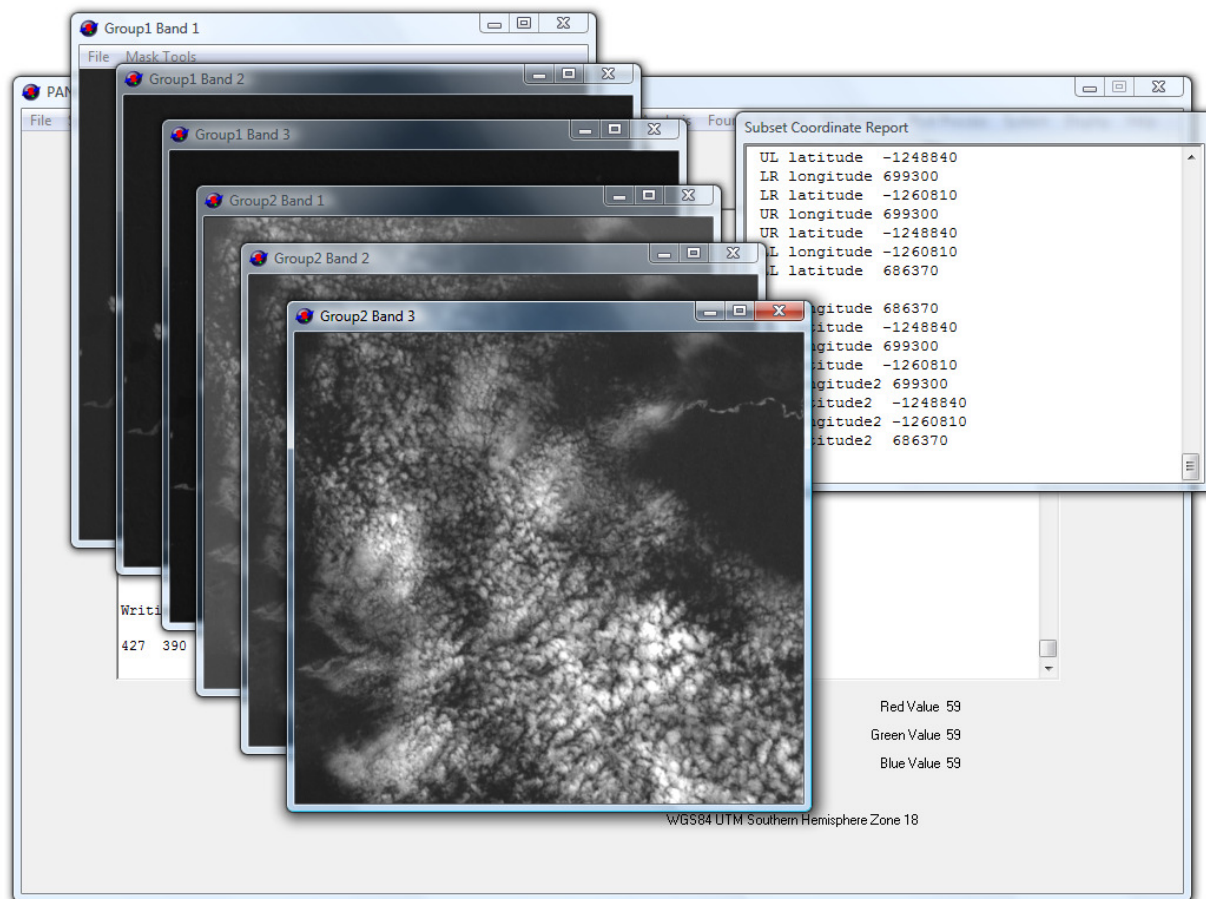
☒ Select Change Subset

Enter ☐ Select by Pixels ☒ Select by Coordinates

Rubber Band Box Select

Accept Pixel Entries 2X

Now select 'Enter'. The first six band files will be co-registered and displayed as shown in the following image.



Note that the captions in the image forms read: Group 1 Band 1, Group 1 Band2, etc. Now select 'File' | 'Save Subset Images' | 'Geotiff'. Select a base file name like 'changeTest' or the like. The first group of registered files will be saved. In this example, the file names will be:

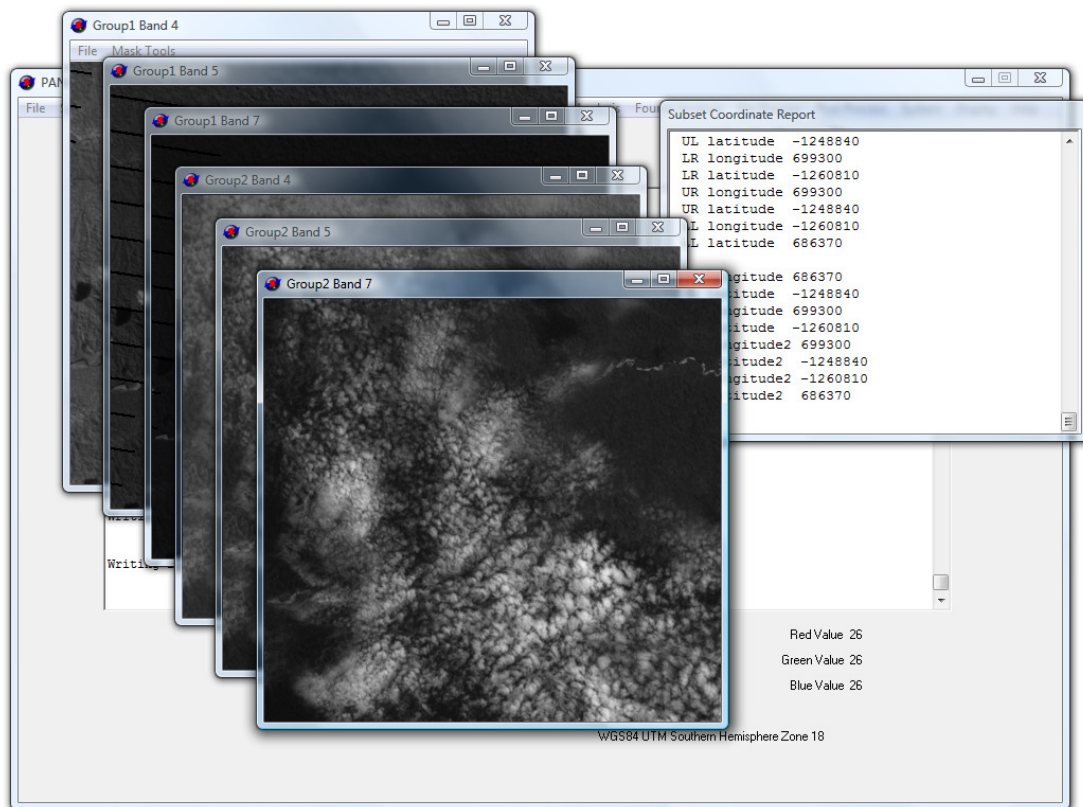
Group 1	Group 2
changeTestband 1-Group1.tif	changeTestband 1-Group2.tif
changeTestband 2-Group1.tif	changeTestband 2-Group2.tif
changeTestband 3-Group1.tif	changeTestband 3-Group2.tif

Now select 'Close Graphics Window and Reset'. Repeat the process outlined above for the second group of six band files, entering the files in this order:

L71005068_06820030919_B40.TIF
 L71005068_06820030919_B50.TIF
 L71005068_06820030919_B70.TIF
 L71005068_06820040804_B40.TIF

L71005068_06820040804_B50.TIF
L71005068_06820040804_B70.TIF

except this time when the Subset Data Entry form becomes visible, check the 'Select Change Subset' check box and click on the 'Second Group' radio button . Select 'Enter'. The next group of files will be displayed as shown below:



Select 'File' | 'Save Subset Images' | 'Geotiff' again. Select the same base file name as before ('changeTest' in this example). The second group of registered files will be saved. In this example, the file names will be:

Group 1	Group 2
changeTestband_1-Group1.tif	changeTestband_1-Group2.tif
changeTestband_2-Group1.tif	changeTestband_2-Group2.tif
changeTestband_3-Group1.tif	changeTestband_3-Group2.tif
changeTestband_4-Group1.tif	changeTestband_4-Group2.tif
changeTestband_5-Group1.tif	changeTestband_5-Group2.tif
changeTestband_7-Group1.tif	changeTestband_6-Group2.tif

You now have a set of 12 co-registered band files for your scenes. Select 'Close Graphics Windows and Reset' and move on to the next step: change detection. To start the change detection analysis, select 'File' | 'Open' and open your 12 band files in this order:

Group 1 bands 1-7

Group 2 bands 1-7

In this example the order would be:

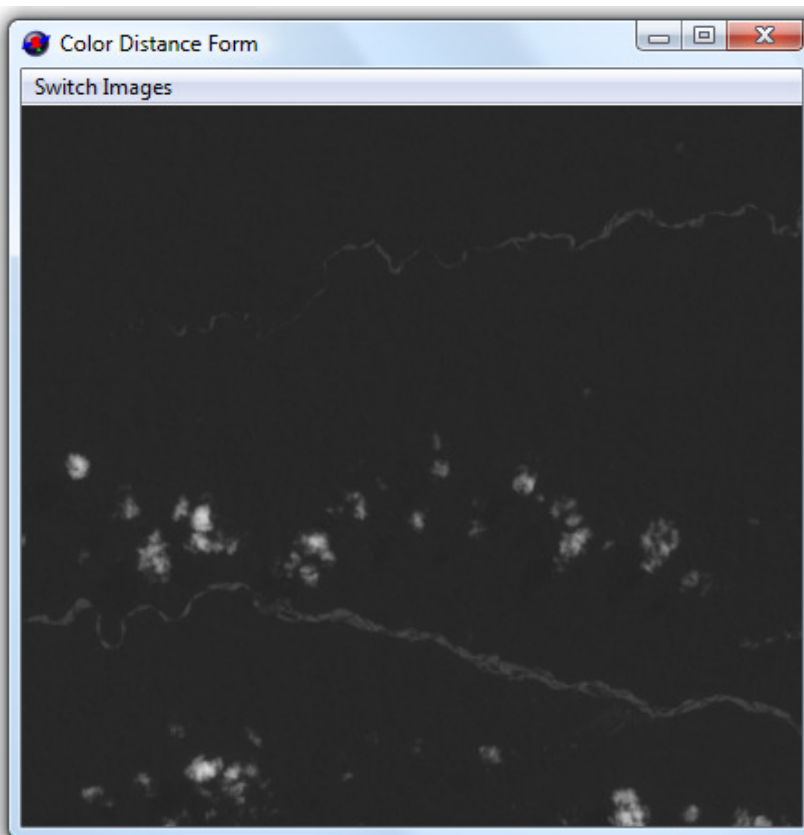
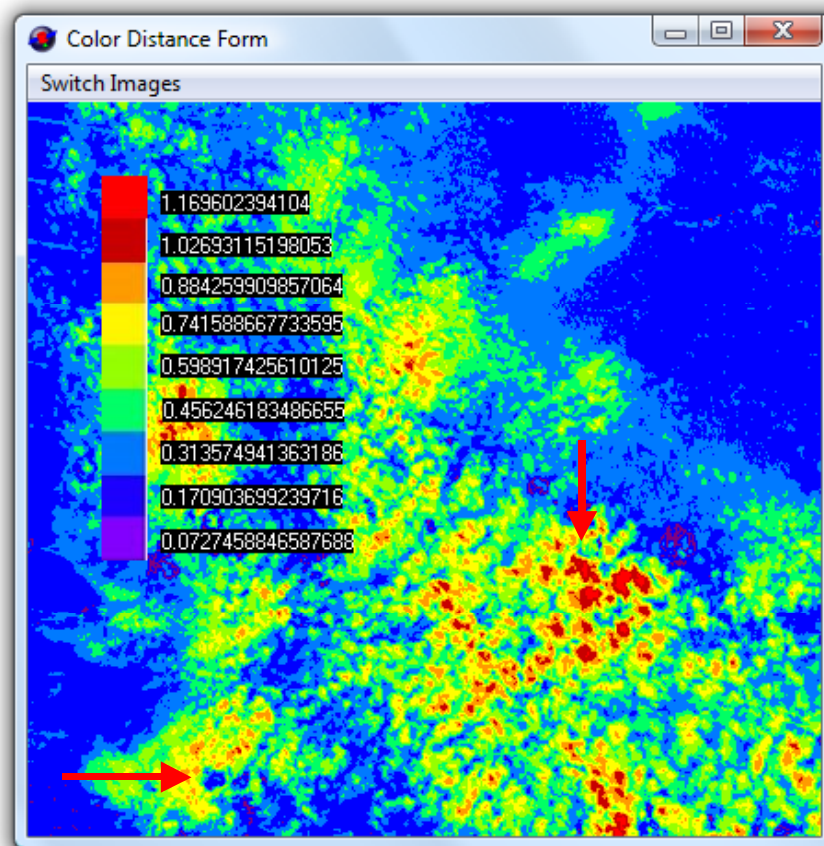
changeTestband_1-Group1.tif
changeTestband_2-Group1.tif
changeTestband_3-Group1.tif
changeTestband_4-Group1.tif
changeTestband_5-Group1.tif
changeTestband_7-Group1.tif

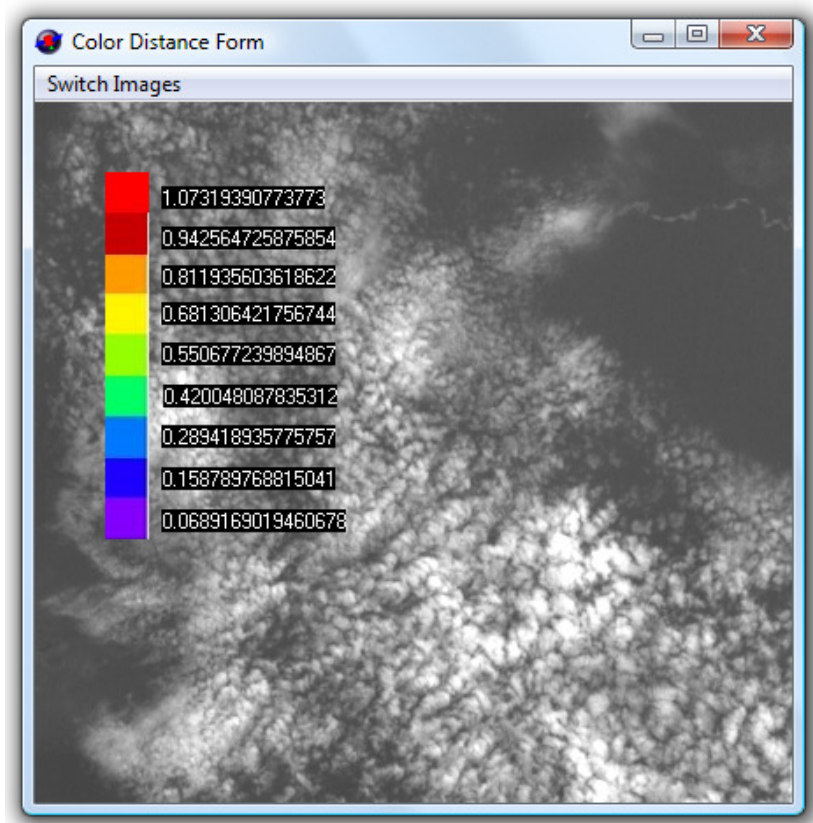
and then

changeTestband_1-Group2.tif
changeTestband_2-Group2.tif
changeTestband_3-Group2.tif
changeTestband_4-Group2.tif
changeTestband_5-Group2.tif
changeTestband_6-Group2.tif

Now select 'Spectral Analysis' | 'Change Analysis' | 'Landsat' | '12 File Vector Distance'. The TOA Reflectance Data Form will appear. Enter the values for the Solar Elevation Angle and Acquisition Date for the first Landsat Scene as described in Section 51 into the form and select 'OK'. All 12 of your band files will be read into memory. The TOA form will again appear. Enter the Solar Elevation Angle and Acquisition Date for the second Landsat Scene and select 'OK'.

IMPORTANT NOTE: The satellite metadata will typically not be the same for two Landsat scenes even if the path and row numbers are the same. It is important to enter the correct values for each scene when prompted so that the TOA reflectances are computed accurately. Select 'OK'. The change detection plot will be computed and displayed. The plot along with the base image is shown below. (Note that you can switch views between the distance plot and the base image using the 'Switch Images' menu on the Color Distance Form.



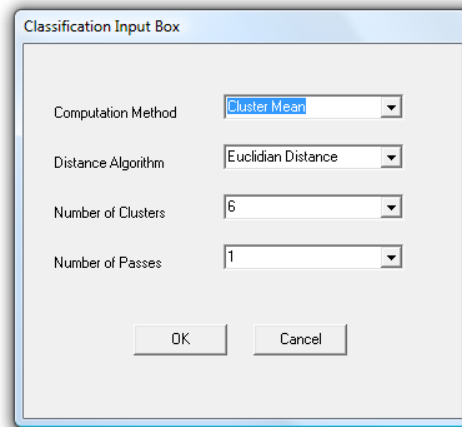


Notice that the areas of the most dense cloud coverage are colored red, indicating the most pronounced change from the base image. Note the small blue hole in the cloud coverage denoted by the lower arrow. This coincides with one of the few clouds in the base image. This has been correctly identified as a region of lesser change.

This example, although depicting a trivial change, illustrates how the Change Distance™ utility can be used to identify much more subtle changes in Landsat scenes with great sensitivity.

Multispectral Band Image Classification

PANCROMA™ provides utilities for image classification using multispectral image vectors. The procedure for conducting such classifications is similar to that described in the Post Processing section, except that Landsat 7, Landsat Reflectance, Landsat 8, SPOT, ASTER, EO-1 ALI and NAIO images can be classified using various numbers of bands. For example, you can classify using six Landsat 7 DN bands by selecting 'File' | 'Open' and opening your six multispectral band files. Then select 'Spectral Analysis' | 'Landsat Unsupervised Classifier' | 'Six Band DN'. The Classification Input Box will become visible.



The parameters are as follows:

Computation Method: Defines whether the arithmetic mean or the median is used to calculate the cluster center.

Distance Algorithm: Defines which distance measure is used, as given by the table:

- Euclidean distance
- City-block distance
- Correlation
- Absolute value of the correlation
- Uncentered correlation
- Absolute uncentered correlation

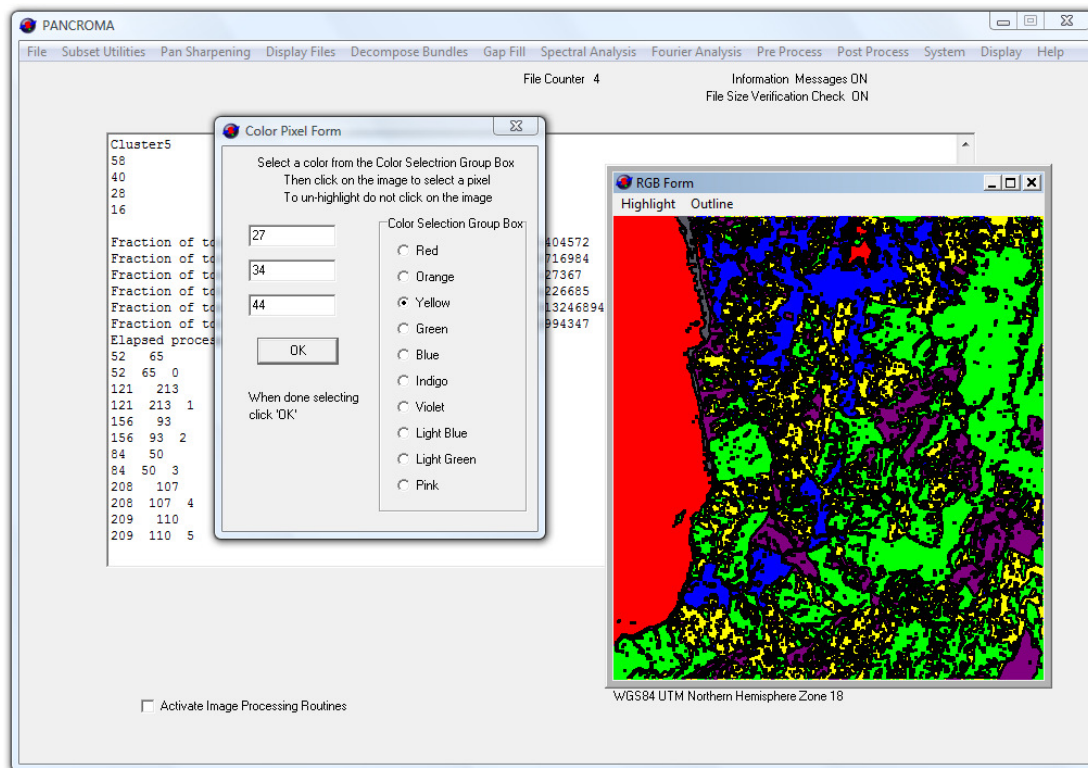
Number of Clusters: i.e. the number of classes computed

Number of Passes: The number of times clustering is performed. Clustering is performed the selected number of times, each time starting from a different (random) initial assignment of bands to clusters. The clustering solution with the lowest inside-cluster sum of distances is chosen.

IMPORTANT NOTE: Classification requires large internal fp32 data structures. Maximum input band sizes will be limited to less than full scenes. Maximum input band size 8MB-16MB depending on the number of input bands.

Select your run parameters and select 'OK'. Your specified number of best-fit classes will be statistically computed and displayed as an RGB image. In some cases the classified RGB image may look very similar to the input RGB image. However the classified image will be composed of one RGB color combination per class. You can highlight one or more of the classes by selecting the drop down menu on the RGB image and clicking on a target class. Clicking OK on the

Pixel Color form will paint your selected class the color that you specify using the radio buttons at the side of the form.



If you want to unhighlight the selection and highlight another cluster, select 'Un Highlight Selected Pixels' and then click 'OK' on the Color Pixel Form.

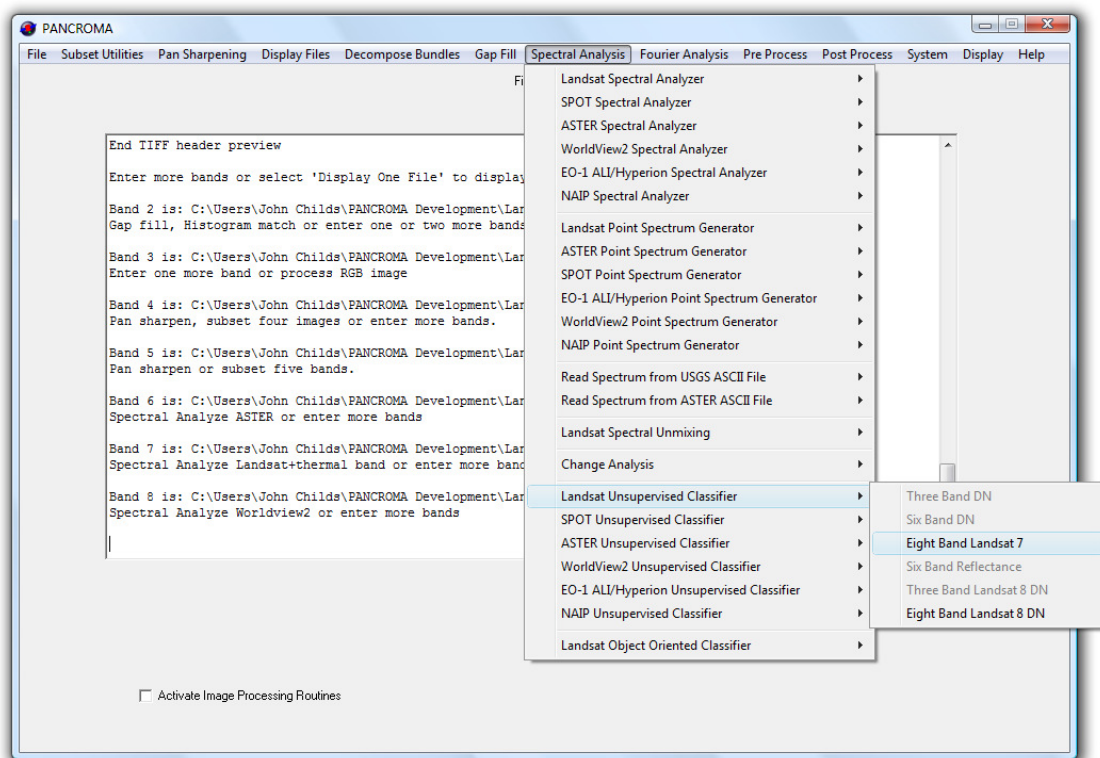
IMPORTANT NOTE: To unhighlight a region, do not click on the image as this will place the palette colors into the target text boxes instead of the cluster identifiers. If you make a mistake, you can obtain the correct values from the dialog screen and enter them manually.

You can also outline a selected region using a process similar to that described above, except for selecting the 'Outline' | 'Selected Region' | 'Outline' menu selection. You will be prompted to identify the target region as described above. Clicking 'OK' will outline the selected region with a black line. You can reverse the process by selecting the 'Outline' | 'Selected Region' | 'Un-Outline' menu selection. You can also outline all regions by selecting 'Outline' | 'Outline All Regions'. If you outline all regions, this process is not reversible.

The described process is similar for the other satellite data types.

Object Oriented Classification

PANCROMA™ allows you to use derived data in order to improve your classification. Selecting select 'Spectral Analysis' | 'Landsat Unsupervised Classifier' | 'Eight Band Landsat 7' allows the user to input the six Landsat 7 multispectral bands plus two additional derived bands. The derived bands are often vegetation indices, for example NDVI or VI. The classification will then be computed considering the two derived bands as well as the standard multispectral bands. You can even input dissimilar data, for example normalized elevation data, or slope gradient data or in fact, any type of data that you think might be useful, as long as the data is presented in a consistent GeoTiff format.



62. FFT Image Analysis

Introduction

Fourier Analysis has many applications to the field of satellite image processing. The idea behind Fourier analysis is as follows: a variable quantity, say a function of time, $f(t)$, can be approximated by a linear combination of harmonic functions (sines and cosines) of increasing frequencies, specifically, positive and negative multiples of the fundamental harmonic. If you know the right contributions of all frequencies (Fourier coefficients), that knowledge is equivalent to knowing the function. Put another way, a time dependent function $f(t)$ can be transformed and written equivalently as a frequency-dependent function $F(\omega)$. The Fourier Transform is a mathematical equation that computes the coefficients that, multiplied by cosine and sine functions expresses $f(t)$ in terms of $F(\omega)$.

The Fourier transformation has an inverse, which is very similar mathematically, except that it transforms $F(\omega)$ back into $f(t)$. Both transformations are linear, so that, if a and b are any constants, the transformations take $a f(t) + b g(t)$ into $a F(\omega) + b G(\omega)$ and back again.

Intuitively, it is best to think of the Fourier transformation as approximating a function by sines and cosines. However, the actual formulas become simpler if the transformation is re-cast as an approximation by a sum of complex exponentials according to Euler's equation:

$$\exp(ix) = \cos(x) + i \sin(x)$$

This notation is also essential for formulating the Fourier matrices used for computing the Fast Fourier Transform (FFT). In this new expression, which is called the complex Fourier transformation, the transformed function " f " can be complex, and its transformation " F " is generally a complex function as well. All the basic properties (the inverse, linearity, convolution etc.) remain the same, as expressing the Fourier transformation in complex notation is mathematically equivalent to the more cumbersome sine and cosine version.

IMPORTANT NOTE: In image processing, the image is considered to only have a real component, i.e. the imaginary component is always zero. However, the Fourier transform of an image resides in the complex plane and has both types of components.

One property of the Fourier transformation that is very useful in graphics and imaging is known as the convolution theorem. Technically, a convolution of two functions is an integral of their product, where one function is displaced relative

to the other. For example a filter is normally convoluted with an image in the neighborhood of a pixel. In order to filter the entire image, one must slide the filter around and convolve it with the image around every pixel.

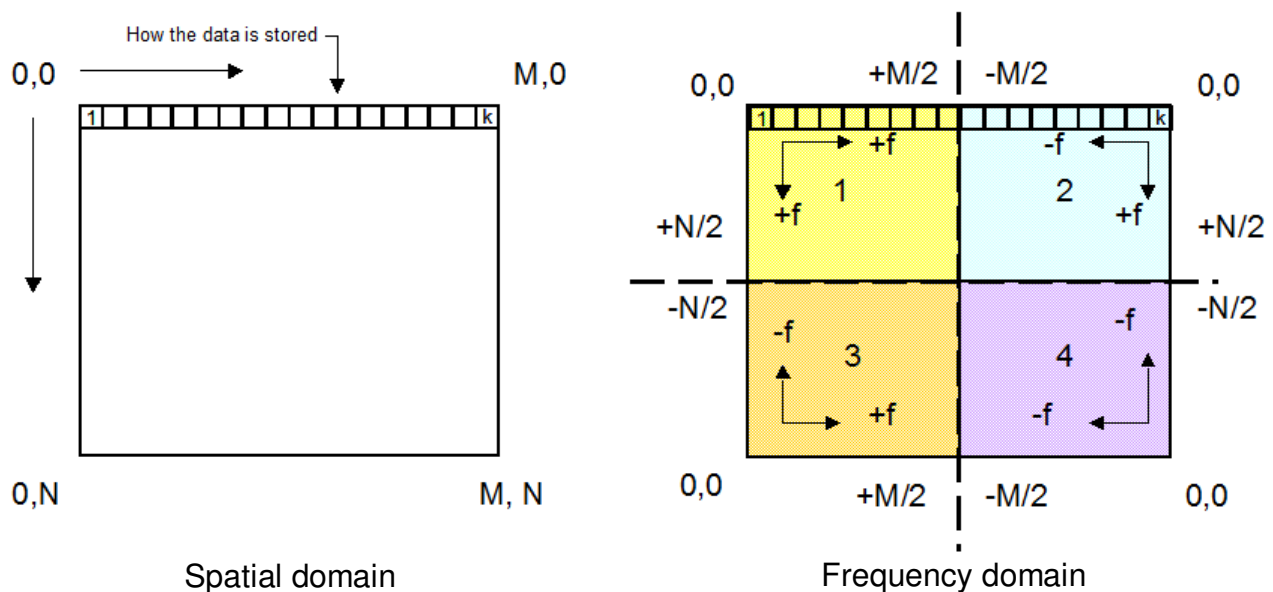
The convolution theorem states that the Fourier transformation of the convolution integral is the product of the transforms of the two functions. That means that we can separately transform the image and the filter, multiply the two, and inverse-transform the product. The result is the filtered image, without the need to multiply and sum around every pixel. The price that we pay for this simplification is the computational and memory expense of transforming the functions back and forth, but with a fast Fourier algorithm this technique can save a great deal of computational time, especially for large convolution kernels. There are many good descriptions of the Fourier transformation in the literature.

The method for calculating the Fourier transform of an image is to take the one-dimensional FFT of each of the rows, followed by the one-dimensional FFT of each of the columns. Specifically, start by taking the FFT of the N pixel values in row 0 of the real array. The real part of the FFT's output is placed back into row 0 of the real array, while the imaginary part of the FFT's output is placed into row 0 of the imaginary array. After repeating this procedure on rows 1 through $N-1$, both the real and imaginary arrays contain an intermediate image.

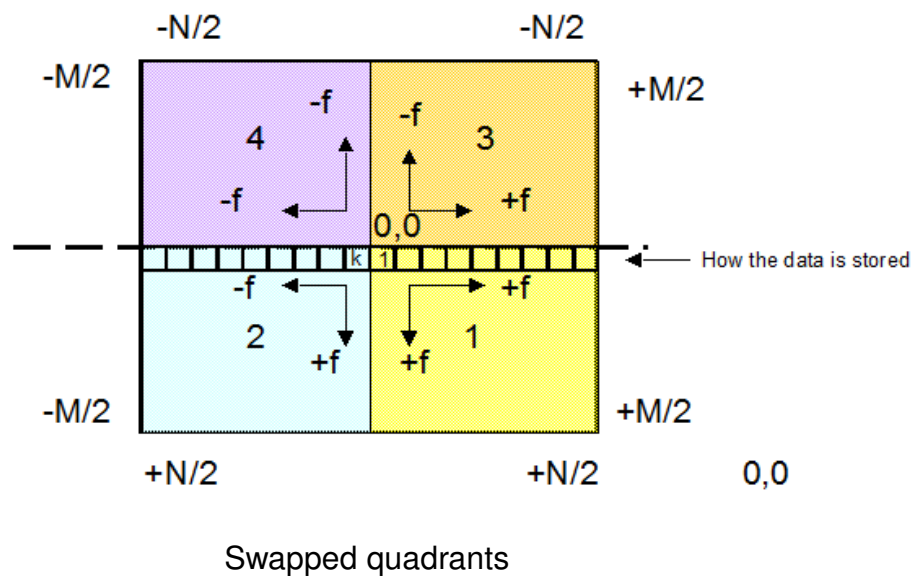
Next, the procedure is repeated on each of the columns of the intermediate data. Take the N pixel values from column 0 of the real array, and the N pixel values from column 0 of the imaginary array, and calculate the FFT. The real part of the FFT's output is placed back into column 0 of the real array, while the imaginary part of the FFT's output is placed back into column 0 of the imaginary array. After this is repeated on columns 1 through $N-1$, both arrays have been overwritten with the image's frequency spectrum.

Note that in this definition the row and column counts are the same. It is possible and in fact common to transform rectangular arrays using special processing provisions.

The image transform is usually expressed as the magnitude of the vector consisting of real and complex (orthogonal) components. The quadrants are quite commonly swapped so that zero frequency appears in the middle of the image, rather than at coordinate $\{0,0\}$. The following figures show graphically how the spatial data and frequency data are stored.



After the quadrants are swapped, the origin of the transformed image is at the center.



One Way FFT

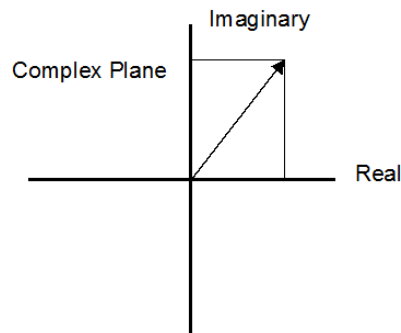
IMPORTANT NOTE: The FFT used by **PANCROMA™** is very fast computationally, but it does not utilize memory very efficiently. Moreover, it needs at least single precision (32 bit) FLOAT types to compute forward and reverse transforms. As a result, you must watch your memory resources

carefully. **PANCROMA**TM is able to process full-size Landsat multispectral bands on most modern systems, but is not able at this time to process the panchromatic band without subsetting it.

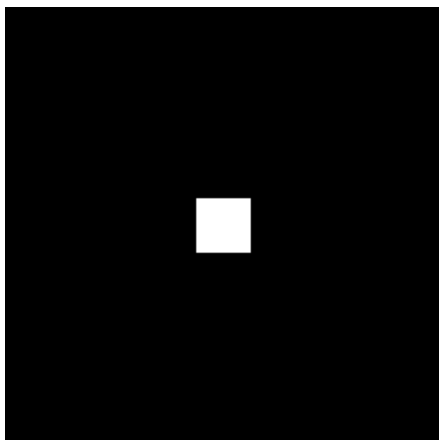
In order to compute the frequency spectrum of an image, first open a grayscale band file. Then select 'FFT' | 'Image Fourier Analysis' | 'Forward 2D Image Transform'. A dialog box will appear allowing you to input a scale factor. Because the spectra are often fractional values less than one, it is usually necessary to scale them for display. The default value is 1000.

The FFT output consists of a number real and an imaginary part. PANCROMATM will display the magnitude of the vector consisting of these parts, according to the equation:

$$\text{MAGNITUDE} = ((\text{REAL}^2 + \text{IMAGINARY}^2)^{1/2}) * \text{scaleFactor}$$



Some examples of the magnitude frequency spectra of some images are shown below:



Sharp square

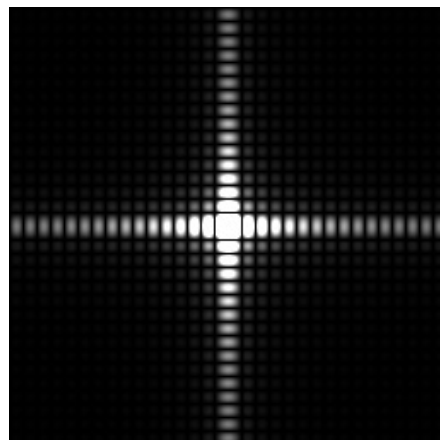
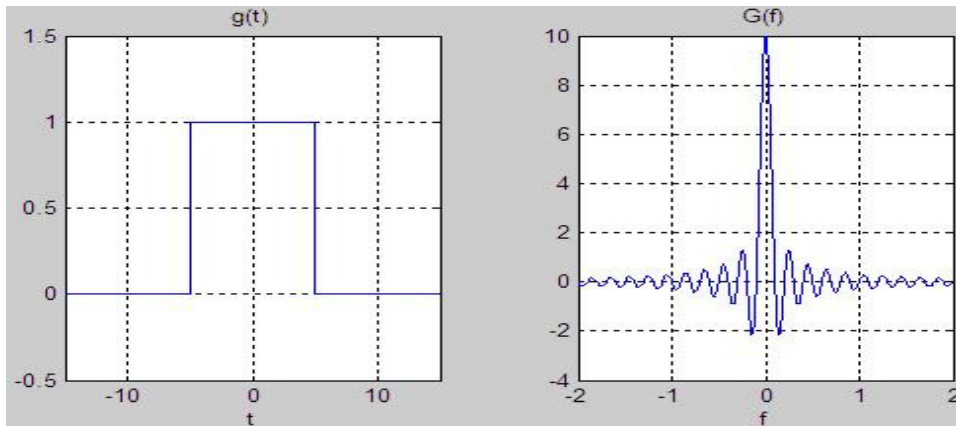
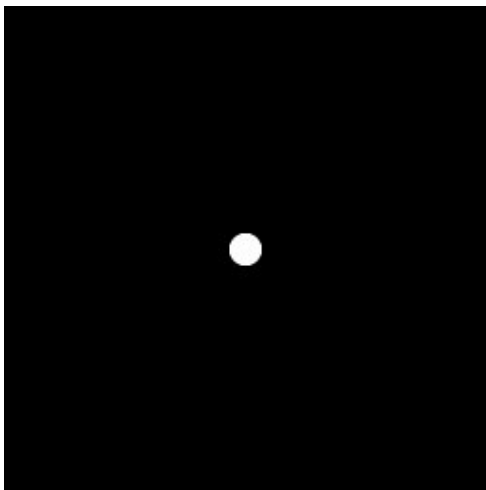


Image magnitude spectrum

Note that Fourier transform for the square is analogous to the corresponding transform for a square pulse shown below.



An important feature of the Fourier transform is that the maximum frequency is half of the discrete spatial dimensions. That is, if the column dimension is M , it is not possible for that dimension to support a frequency higher than $M/2$ (which would correspond to alternation in every other image pixel). The quantity $M/2$ is called the Nyquist frequency. Another important feature is that the Fourier transform, unlike the spatial function has both positive and negative components.



Sharp circle

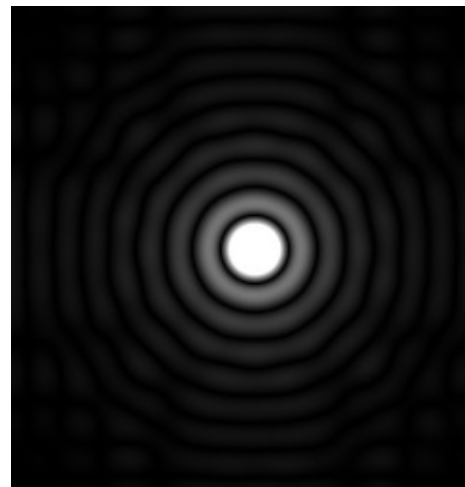
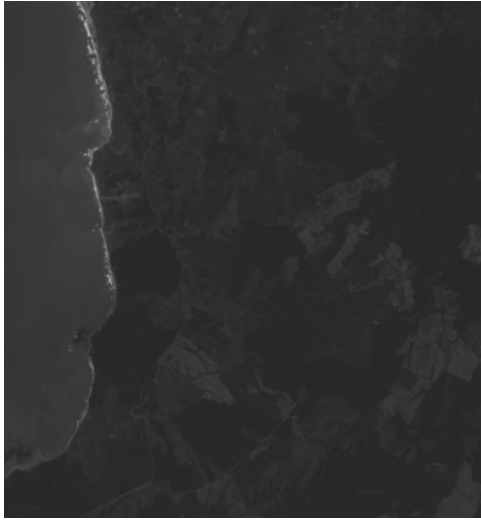


Image magnitude spectrum



Landsat image

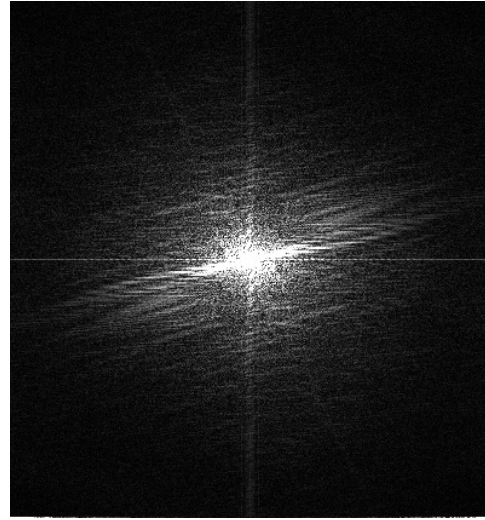
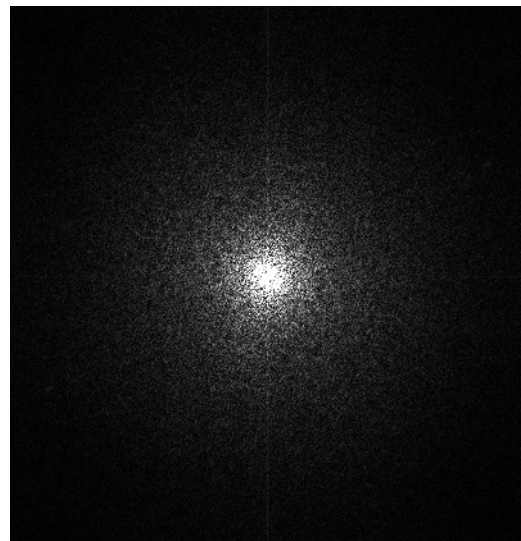


Image magnitude spectrum

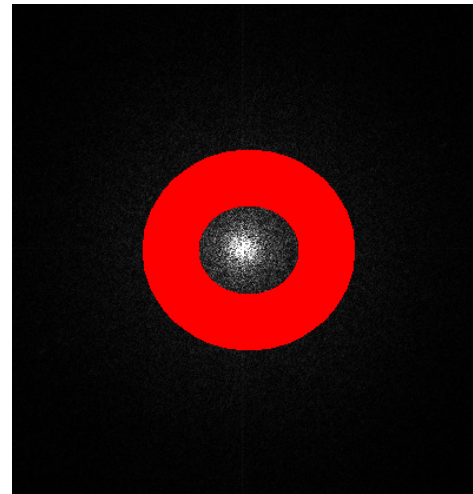
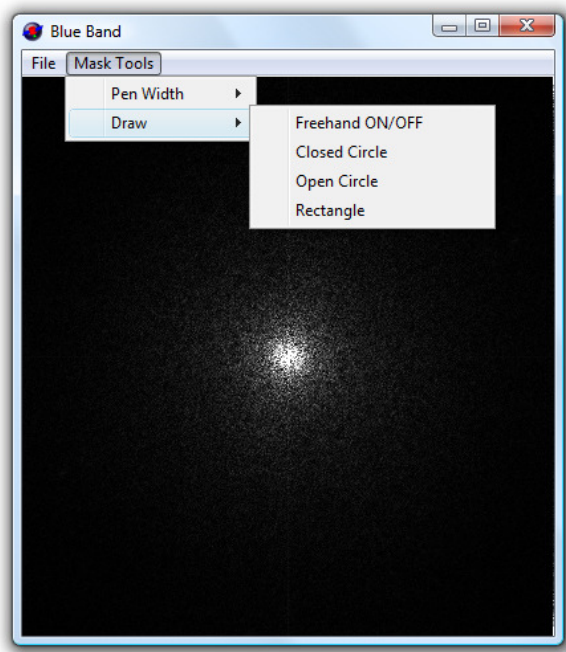
2D Graphical Magnitude Filter

PANCROMA has a utility that takes advantage of features of Fourier transformed images that let you to graphically design your own frequency spectrum filters. One of the great advantages of transforming images from the spatial domain to the frequency domain is the ease of designing filters.

In order to filter an image, select 'File' | 'Open' and open a single grayscale image. Now select 'FFT' | 'Image Fourier Analysis' | '2D Image Fourier Graphical Filter' | 'Magnitude Filter'. A dialog box will again appear allowing you to input a scale factor. Because the spectra are often fractional values less than one, it is usually necessary to scale them for display. The default value is 1000.



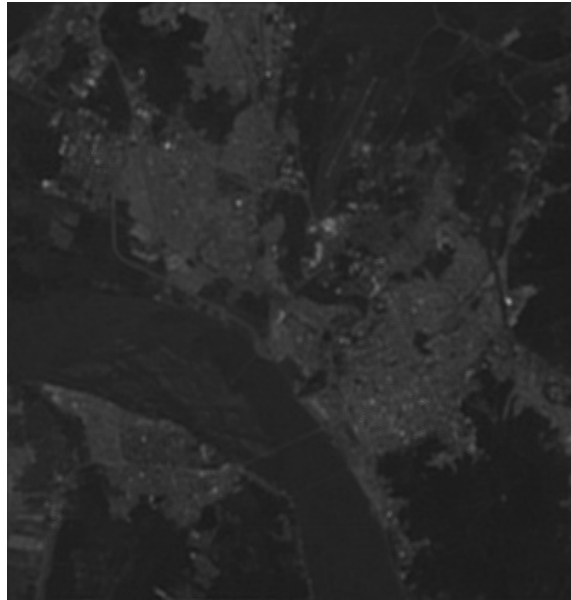
When the transformed image becomes visible you will be able to mark it using your cursor. The top menu allows you to select your pen width and select your masking shapes. Using your cursor, mark out any frequencies that you want to remove from your image. For example, if we wished to remove all high frequencies from the image, we would retain the center of the transformed image and remove the outside frequencies (low frequencies are in the middle).



The idea behind the mask tools is to remove frequencies from the image. Any frequency covered by red will be eliminated from the reverse transform back to the image, that is, both the real and imaginary components of the transformed image will be zeroed.

In order to use the mask shapes, click on the upper left and lower right corners, then choose the menu item. (This applies to all shapes: rectangle, closed circle (ellipse), open circle). When you are done defining your filter select 'Exit' from the menu. The designated frequencies will be removed from the transform and the result will be inverse transformed back to the spatial domain. The result of this example is shown below.

IMPORTANT NOTE: Because of the RAM constraints, no 'Undo' function is available. If you decide that you do not like your mask, you will have to start over.



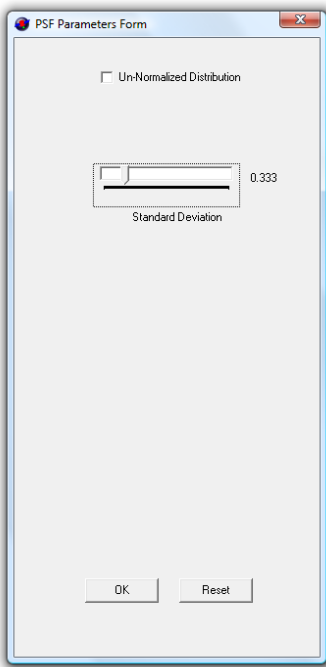
Considerable smoothing has occurred in the image as a lot of high frequency information has been removed. You can perform other useful filtering operations using this technique.

In order to filter the low frequencies and pass the high, use a solid circle centered on (0, 0). You can build many other useful and interesting frequency domain filters by studying your image spectra and experimenting with masks.

Gaussian Low Pass Filter

Low pass filters are essentially smoothing filters. This filter convolves a user sizable Gaussian kernel with the target image. The effect is to pass low frequencies and filter high frequencies. In order to use the utility, open a single band file by selecting 'File' | 'Open'. Then select 'FFT' | 'Image Fourier Analysis' | 'Gaussian Low Pass Filter'. A data entry box will become visible that allows you to input the Gaussian distribution parameters standard deviation and (if you wish) distribution amplitude.

If the 'Un-Normalized Distribution' check box is not checked (default) then the Gaussian distribution will be normalized so that pixel brightnesses of the processed image will remain approximately the same as in the source image. If the box is checked, the convolution kernel will not be normalized.



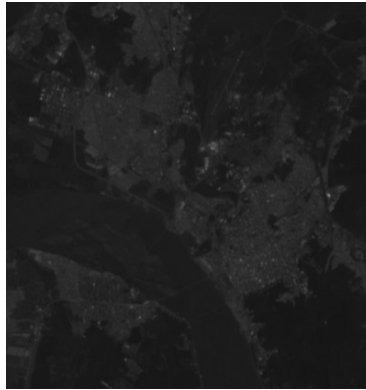
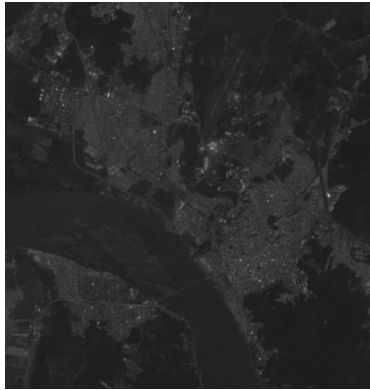
Set the standard deviation and if desired, the amplitude using the track bar sliders.

Gaussian Deconvolution

In general, low pass filters are not especially interesting for satellite image processing work except as an illustration of a more interesting topic, image deconvolution. The low pass filter will blur an image by convolving a Gaussian convolution kernel with the target image.

It is generally possible to recover the image by deconvolving the blurred image with the same convolution kernel. In particular, the Fourier transformed band image is divided by the Fourier Transform of the convolution kernel instead of multiplying. Theoretically, these images are inverse operations and the original image can be completely recovered.

This can be seen in the following three images. The first one is the target image. The second image has been blurred using the low pass filter. The third image has been recovered by deconvolving with the Gaussian convolution kernel.



IMPORTANT NOTE: *In reality, the convolution process may not be easily reversible. Inverting convolution operations has many potential issues*

- *The inversion process is usually very sensitive to small perturbations.*
- *The inversion process is always corrupted by rounding errors (noise).*
- *Instead of the desired solution we often see the amplified noise only.*
- *If the transformed convolution matrix is close to singular, we can easily lose important information.*

In addition, the FFT does not necessarily transform an image from the spatial domain to the frequency domain with complete fidelity. In particular, certain image features, combined with certain convolution kernel characteristics can cause the reverse FFT of the product array to "ring". If one attempts to reverse the convolution process (deconvolution), the convoluted array does not correspond to the input array, and the deconvoluted array will be corrupted. If sigma for example is too large, the deconvolution may "blow up" into an incomprehensible noisy mess. However, if sigma is not too large, the inversion generally works for most areas of the image. Image discontinuities like shorelines for example may still exhibit ringing effects.

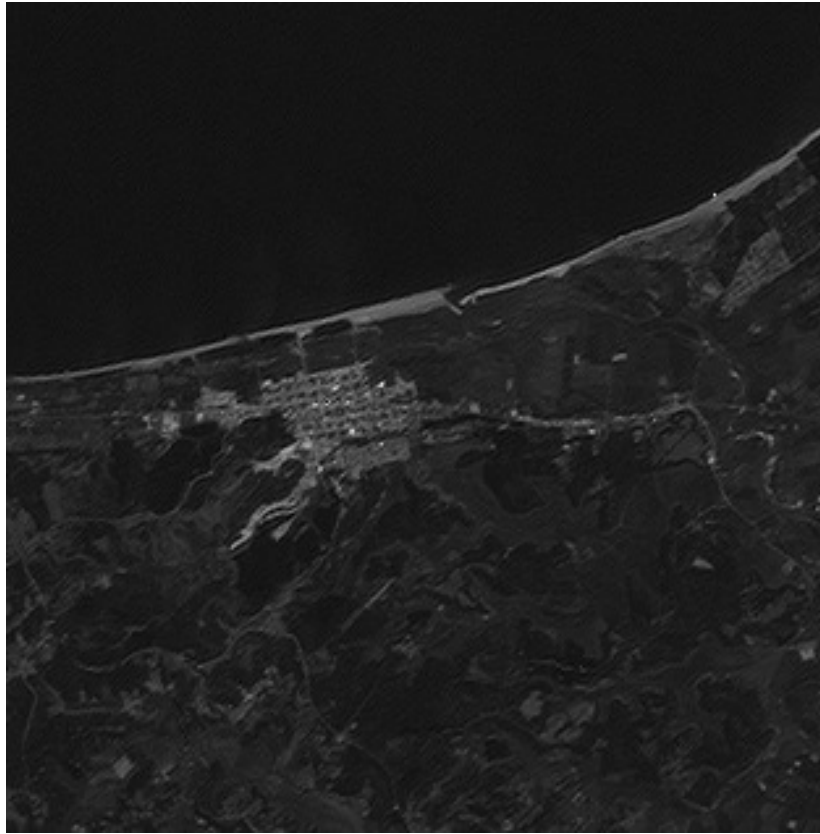
Taking the deconvolution idea a step further, what happens if we attempt to deconvolve an image that has not been blurred (by us)? Images can be blurry for a variety of reasons, including lens distortion, CCD sensor distortion, atmospheric turbulence, and many other reasons. If we knew the nature of the distortion we might recover the image using the same technique described above.

The distortion is described by the Point Spread Function (PSF), which as its name suggests describes how a point source of light actually ends up getting displayed in our image. Rather than a point mapping to a single pixel, it is actually spread among many pixels. Deconvolving with the Point Spread Function can recover the "true" image.

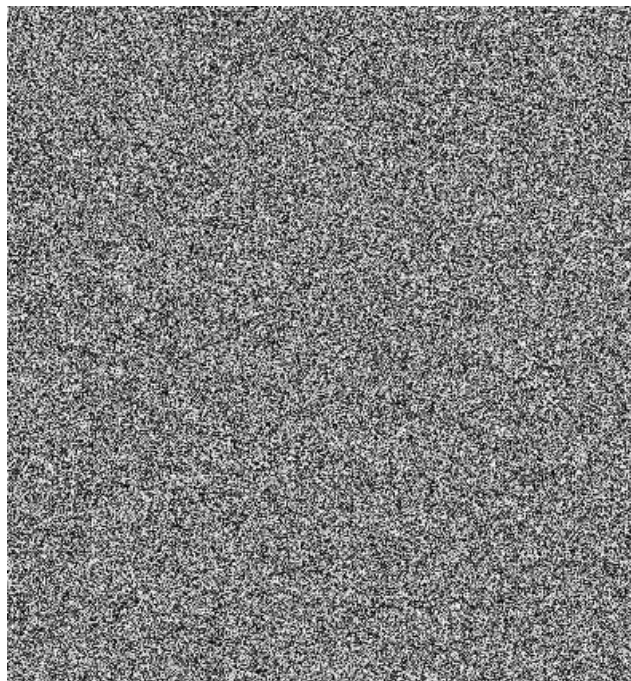
The problem is the Point Spread Function is often unknown. However the Gaussian and Moffat distributions offered by **PANCROMA**[™] can approximate it in many cases. Deconvolving with a reasonable PSF distribution with the right parameters can often improve an image. The “right” parameters being selected by trial and error.

The following two images illustrate the technique. The first image is uncorrected. The second image has been deconvolved with a normalized Gaussian distribution with $\sigma=0.5$. Generally, larger values for sigma result in a more pronounced sharpening effect, until the image is over-sharpened resulting in excessive image noise. In fact the onset of image noise is apparent in the sharpened image on the next page.



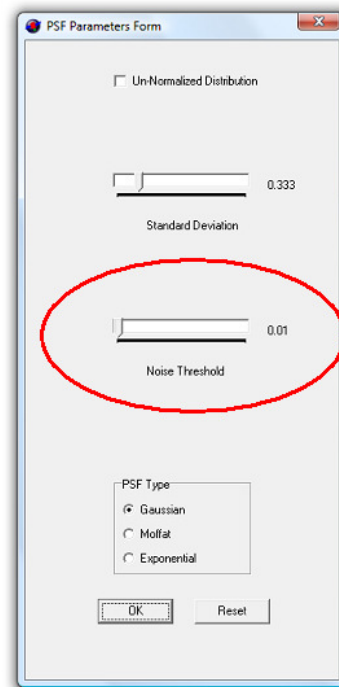


The following is an example of an image that has completely “blown up” due to excessive noise.



The problem lies in the division by the FFT of the deconvolution kernel. The kernel can have a lot of small values as a result of transformed noise. When a pixel in the transformed image is divided by one of these small values, an extremely large value results, resulting in an over-driven image.

This can be remedied by adjusting the thresholding value. The default value is 0.01. If you have a noisy image you can increase this value, increasing the effect of the noise filter.



PANCROMA™ offers two deconvolution utilities: Fixed Kernel Size and Variable Kernel Size, and three PSF distributions, Gaussian, Moffat and Exponential. The deconvolution kernel defines the extents of the selected distribution used to deconvolve the image. The fixed kernel size is five, meaning that the distribution is truncated at +/- 2 pixels from the pixel being operated on. Such a kernel for a normalized Gaussian distribution with sigma=1 is shown in the table below. (The kernel is centered on the (2, 2) position with the partitioning shown.)

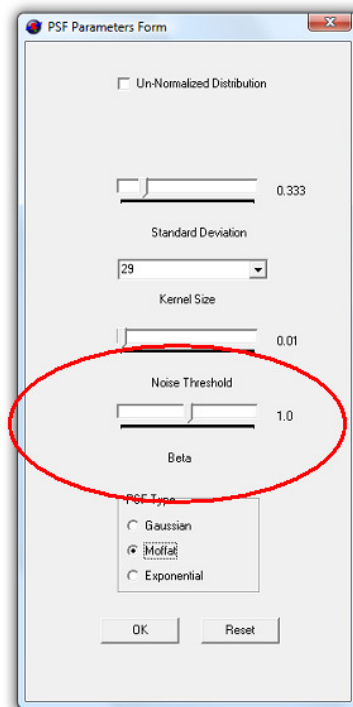
	0	1	2	3	4
0	0.002969	0.013306	0.021938	0.013306	0.002969
1	0.013306	0.059634	0.09832	0.059634	0.013306
2	0.021938	0.09832	0.162103	0.09832	0.021938
3	0.013306	0.059634	0.09832	0.059634	0.013306
4	0.002969	0.013306	0.021938	0.013306	0.002969

In order to deconvolve using fixed kernel size open a single grayscale band file and select: “FFT” | “Image Fourier Analysis” | “Gaussian Deconvolution” | “Fixed Kernel Size = 5”. You can also increase the kernel size in odd increments up to 29. In order to do so, select “FFT” | “Image Fourier Analysis” | “Gaussian Deconvolution” | “Variable Kernel Size”. The fixed kernel size runs faster than the variable size and takes less RAM.

In order to use the Moffat distribution, use the same procedure as outlined above except selecting the ‘Moffat’ PSF type on the Gaussian Parameters Form. When you do, the ‘Beta’ track bar will become visible.

The Moffat distribution has two use-adjustable parameters: the standard deviation (sigma) and the beta coefficient. Increasing sigma and decreasing beta will increase the deblurring effect, while possibly causing increasing noise. The thresholding track bar works as described above to filter noisy images.

The Moffat PSF often works better for many images as it allows more control of the shape of the PSF, allowing a closer match with the actual PSF and in turn better results.



IMPORTANT NOTE: The PSF parameters form setting will persist between runs. This makes it much easier to zero in on the correct deconvolution settings. To reset the form to the default settings, select the ‘Reset’ button.

In order to use the Exponential distribution, use the same procedure as outlined above except selecting the 'Exponential' PSF type on the Gaussian Parameters Form. When you do, the 'Beta' track bar will become visible.

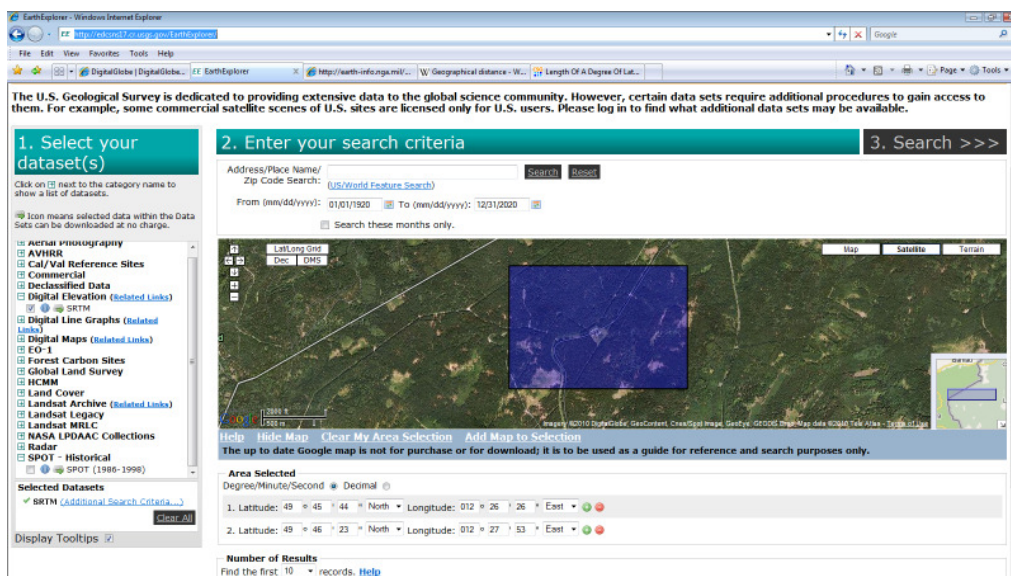
The Exponential distribution also has two use-adjustable parameters: the standard deviation (σ) and the beta coefficient. Increasing σ and decreasing beta will increase the deblurring effect, while possibly causing increasing noise. The thresholding track bar works as described above to filter noisy images.

IMPORTANT NOTE: Deconvolution requires forward and reverse transforms that are computationally expensive. When you conduct them on large images, for example entire Landsat multispectral bands, the process can take a long time, i.e. an hour or more. The fortunate thing is that your computer is doing this incredibly large amount of work, not you. However, processing large data sets will take some time.

63. Writing an Index File for an SRTM DTED1 DEM Image

Sometimes it is necessary to produce a formatted array of elevation data for a digital elevation model. That is, an ASCII file that lists the X and Y coordinates of the bitmap image, the latitude and longitude, and the elevation of each corresponding point. **PANCROMA**TM has a utility for creating such a file from SRTM DTED DEM images. These DEM images cover one degree of latitude and longitude for virtually the entire surface of the earth and are available for free from the USGS Earth Explorer site at <http://edcsns17.cr.usgs.gov/EarthExplorer/>.

Although SRTM DEM data is available in several formats, the DTED tiles are convenient because they are of fixed and manageable size. These files can currently be downloaded by selecting your area of interest using the rubber band box using the Earth Explorer interface



When you select 'Search' a list of DEM tiles, each containing either 1201 by 1201 postings (DTED1) or 3601 by 3601 postings (DTED2) will be listed.

USGS Home Contact USGS Search USGS

EarthExplorer

Home Profile Saved Criteria Saved Results Standing Requests Track Orders

Results

Your search results are now available in [KML](#). Click on the KML button below the search results list to download the KML file.

Show Map Pop-out of

The up to date Google map is not for purchase or for download; it is to be used as a guide for reference and search purposes only.

SRTM

3 of 3 metadata records retrieved. Showing 1-3

Preview Image	Show Footprint	Show All Fields	Exclude	Download BIL	Download DTED	Entity ID	Date Acquired	Resolution	NW Corner	NE Corner	SW Corner	SE Corner	Compressed File Size
	Show	Show	<input type="checkbox"/>	BIL Format	DTED Format	SRTM30N49E011	February 2002	3-ARC	50°00'00.00"N, 11° 00'00.00"E	50°00'00.00"N, 12° 00'00.00"E	49°00'00.00"N, 11° 00'00.00"E	49°00'00.00"N, 12° 00'00.00"E	1389250
	Show	Show	<input type="checkbox"/>	BIL Format	DTED Format	SRTM30N49E012	February 2002	3-ARC	50°00'00.00"N, 12° 00'00.00"E	50°00'00.00"N, 13° 00'00.00"E	49°00'00.00"N, 12° 00'00.00"E	49°00'00.00"N, 13° 00'00.00"E	1443218
	Show	Show	<input type="checkbox"/>	BIL Format	DTED Format	SRTM30N49E013	February 2002	3-ARC	50°00'00.00"N, 13° 00'00.00"E	50°00'00.00"N, 14° 00'00.00"E	49°00'00.00"N, 13° 00'00.00"E	49°00'00.00"N, 14° 00'00.00"E	1465443

[Redefine Criteria](#) [Result Summary](#)

[Hide Excluded Records](#)

[Restore All Excluded Records](#)

[Change Columns and Sort Order of Results](#)

[Show All Records](#) [Show All Records - Text Format](#)

Select the links entitled 'DTED Format' and save the tiles to disk. The tiles are named by the latitude of the southwest corner of the tile, for example 'n49.dt1'. Unfortunately, the DTED naming convention only includes the latitude and not the longitude so the file names are not unique and you will have to manage this issue when saving your files.

To create the elevation listing, open the DTED file in **PANCROMA™**. After choosing the file, select 'Display Files' | 'Display DTED Image'. After a moment a rendering of the DEM will be presented. In order to create the listing, select 'File' | 'Save Index File' | 'SRTM DTED File'. PANCROMA will present a data input box for inputting the row and column ranges to include in the index file output. The default is the entire image. If you wish to output only a portion of the DTED file, input the start and ending rows and columns in the text boxes provided. Then click 'OK'. It will take a minute or two to write out the rather large ASCII file.

Index File Limits

Start Rows

End Rows

Start Columns

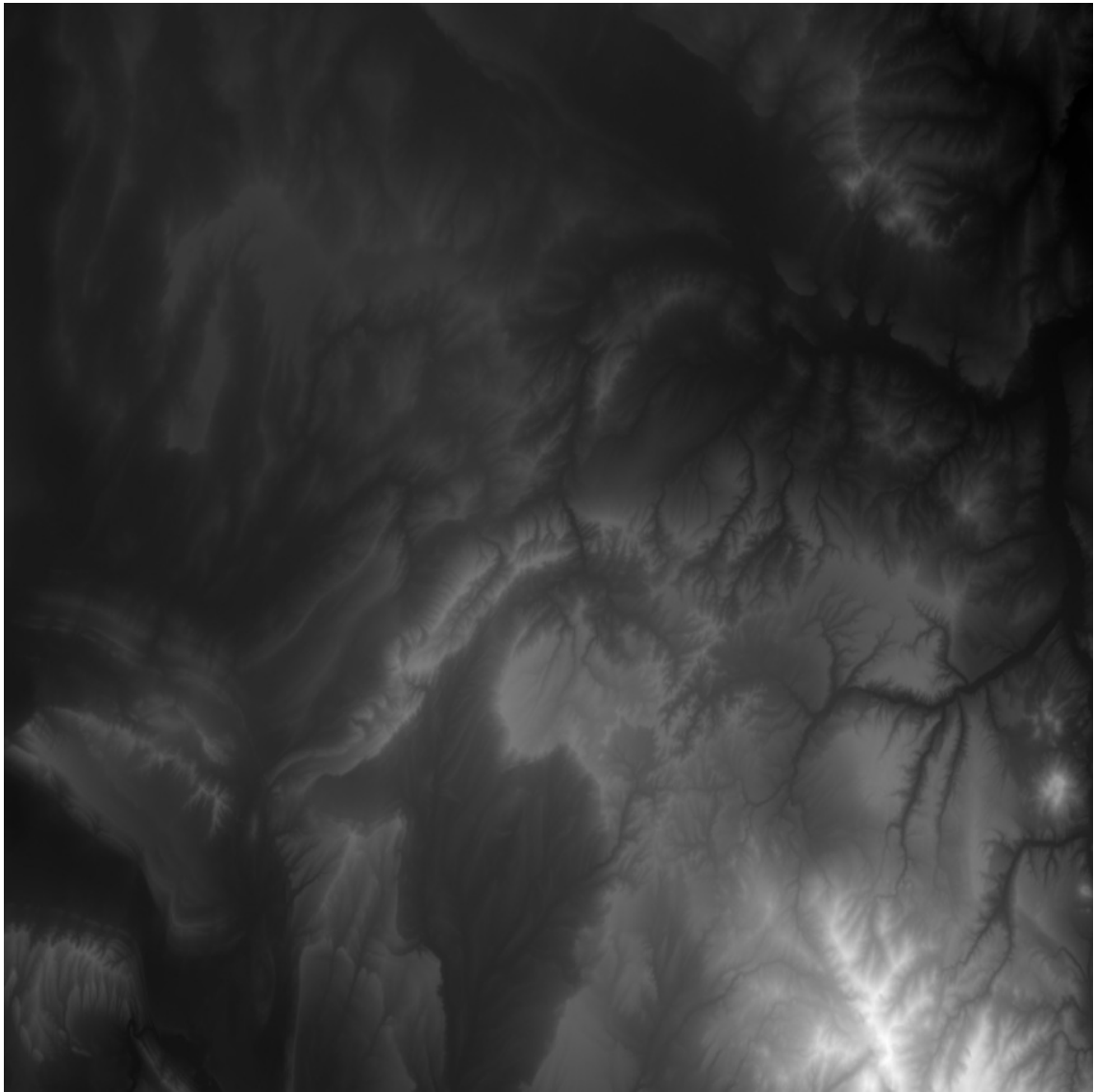
End Columns

It will be saved as a .dat file. A portion of a typical listing is shown below:

```
ASCII Data File for SRTM DTED1 Format 1-Degree Quadrangle
SW Corner Coordinates: 49 degrees Latitude 12 degrees Longitude
Horizontal Datum: World Geodetic System (WGS 84)
Vertical Datum: MSL
Distance Between Latitude Postings (m) at SW corner is: 92.6748
Distance Between Longitude Postings (m) at SW corner is: 60.9785
```

X Coordinate	Y Coordinate	Elevation (m)	Latitude	Longitude
0	0	777	50	12
0	1	767	50	12.0008
0	2	757	50	12.0017
0	3	750	50	12.0025
0	4	741	50	12.0033
0	5	734	50	12.0042
0	6	731	50	12.005
0	7	719	50	12.0058
0	8	712	50	12.0067
0	9	706	50	12.0075
0	10	698	50	12.0083
0	11	695	50	12.0092
0	12	687	50	12.01
0	13	678	50	12.0108
0	14	672	50	12.0117
0	15	664	50	12.0125
0	16	661	50	12.0133
0	17	652	50	12.0142
0	18	640	50	12.015
0	19	626	50	12.0158
0	20	616	50	12.0167
0	21	614	50	12.0175
0	22	612	50	12.0183
0	23	609	50	12.0192
0	24	616	50	12.02
0	25	621	50	12.0208
0	26	621	50	12.0217
0	27	629	50	12.0225
0	28	630	50	12.0233
0	29	637	50	12.0242
0	30	640	50	12.025
0	31	643	50	12.0258
0	32	647	50	12.0267
0	33	648	50	12.0275
0	34	654	50	12.0283
0	35	658	50	12.0292
0	36	663	50	12.03
0	37	666	50	12.0308
0	38	673	50	12.0317
0	39	673	50	12.0325
0	40	677	50	12.0333 ...etc.

PANCROMA™ can also output the file in JPEG, BMP or PNG format. Select 'File' | 'Save Grayscale Image' and the desired file format from the menu.



64. Processing Huge Files and File Size Limitations

PANCROMA™ was written and optimized to process standard Landsat multispectral image sets. The program manages system resources to effect an efficient balance between file size and processing speed for the size of data associated with Landsat multispectral and panchromatic band files. Files that are somewhat larger than standard Landsat can be successfully processed. The largest file that you will be able to process will be dependent on your computer resources, particularly your installed RAM. Since **PANCROMA™** requires internal storage that is proportional to the input file sizes, limitations exist that are imposed by the Windows operating system. These are described in a White Paper entitled “Pan Sharpening Huge Satellite Image Files” available at www.PANCROMA.com.






If your data set exceeds the capability of **PANCROMA™** and your computer, your only real recourse is to subset the input data. Since operations on a single grayscale image require only an 8-bit color model, quite large grayscale images can be displayed and subsetting. If “out of memory” processing errors occur, try subsetting your data one file at a time. This requires loading the first band file by selecting ‘File’ | ‘Open’ and then ‘Band Combination’ | ‘Subset Images’ | ‘Subset Single Image’.

Since **PANCROMA™** keeps track of your row and column coordinates in between subset runs, this is pretty easy. You just subset your first band and save it, then select ‘Close Graphics Windows and Reset’ and then repeat the subsetting process for the second band. The latitude and longitude coordinates and row and column coordinates from the first subsetting operation will be retained in the Subset Data Entry text boxes, so you just select ‘Accept Pixel Entries’ and then ‘Enter’ and the second band will be subsetting to the same coordinates as the first band. You can repeat this as often as desired.

Note that although the panchromatic band has the same latitude and longitude coordinates as the multispectral bands, it does not have the same row and column coordinates. These must be computed manually based on the size ratio between the multispectral bands and the panchromatic band. For Landsat, the ratio is 1:2. You can multiply the coordinates when subsetting Landsat data sets by clicking on the ‘2X’ button before clicking ‘Accept Pixel Entries’. In this case the row and column coordinates will be automatically updated for easier subsetting.

65. Tutorial – Pan Sharpened Image – Automated Method

This tutorial will walk you step-by-step through the recommended method for producing a panchromatic image from Landsat band files. For this example, I will start with Landsat files in .L1G format. This is a common format for Landsat data on the GLCF website. The other format is GeoTiff. Here is the set of files that I downloaded for this example:

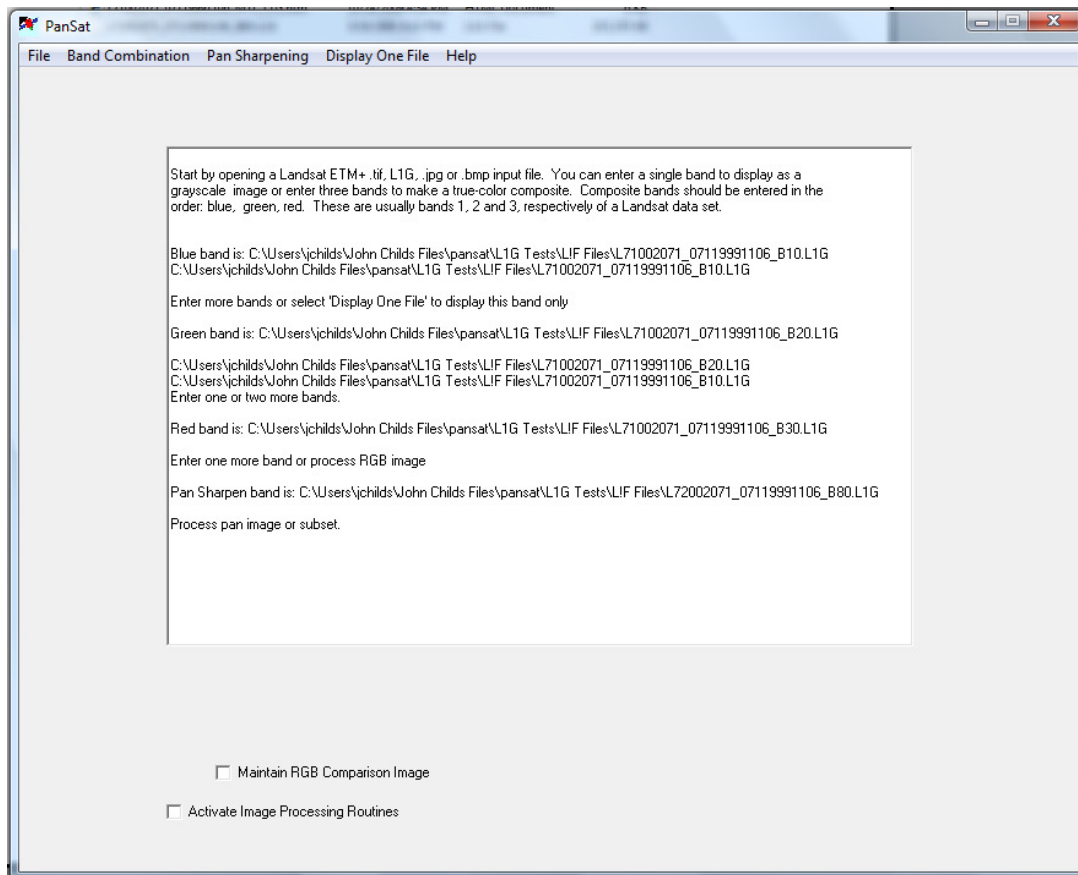
Name	Date modified	Type	Size
 L71002071_07119991106_B10.L1G	9/20/2009 12:36 PM	L1G File	53,796 KB
 L71002071_07119991106_B20.L1G	9/20/2009 12:38 PM	L1G File	53,796 KB
 L71002071_07119991106_B30.L1G	9/20/2009 12:39 PM	L1G File	53,796 KB
 L71002071_07119991106_MTL_L1G.htm	10/24/2009 4:34 PM	HTML Document	6 KB
 L72002071_07119991106_B80.L1G	3/14/2081 8:22 PM	L1G File	215,155 KB

Notice that there are three band files, i.e. the B10, B20 and B30 files for band1 (blue), band2 (green) and band3 (red), respectively. The B80 file is the panchromatic band. The three band files are about 53MB each and the panchromatic file is 215MB. I downloaded the metadata file in .htm format. This is the format that **PANCROMA™** reads.

The next step is to launch **PANCROMA™** and open the data files, in the order ...B10; ...B20; ...B30; and ...B80. (You do not have to open the .htm file explicitly as **PANCROMA™** will find it automatically if it is in the same directory as the band files.) (Make sure to select the '.L1G' file type from the drop down list in the file open dialog box.)

IMPORTANT NOTE: Make sure that all five files are in the same directory.

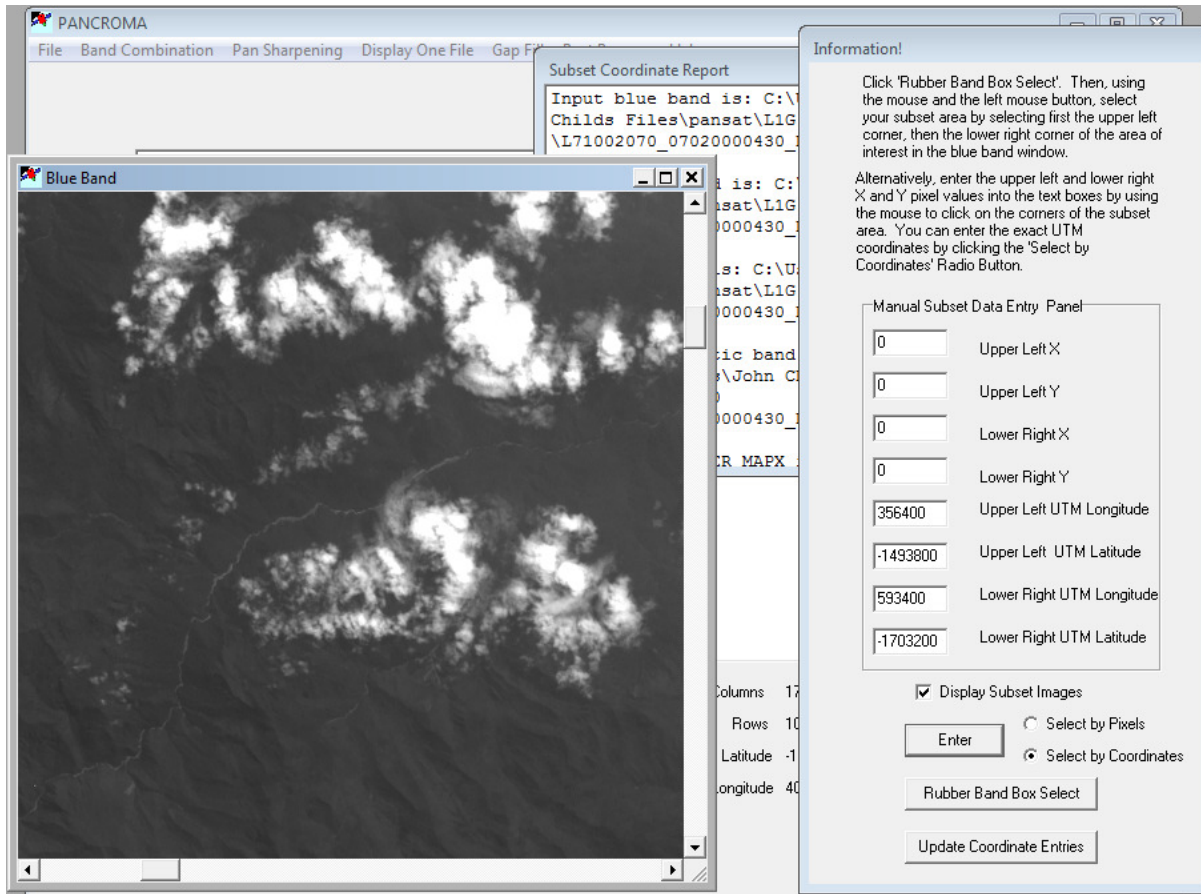
If you have opened your files correctly, your screen should look something like the figure below.



My area of interest for this image is on the eastern coast of South America (Argentina) around latitude -14.9467068 and longitude -70.6615959 (upper left corner of the image). So the next step is to select 'Band Combination' | 'Subset Images' | 'Subset Four Bands'. **PANCROMA™** will begin parsing and decoding the files. The progress bar and the text screen will inform you of progress. When **PANCROMA™** has successfully decoded the files you will be presented with an image window and a data entry screen as shown in the figure below.

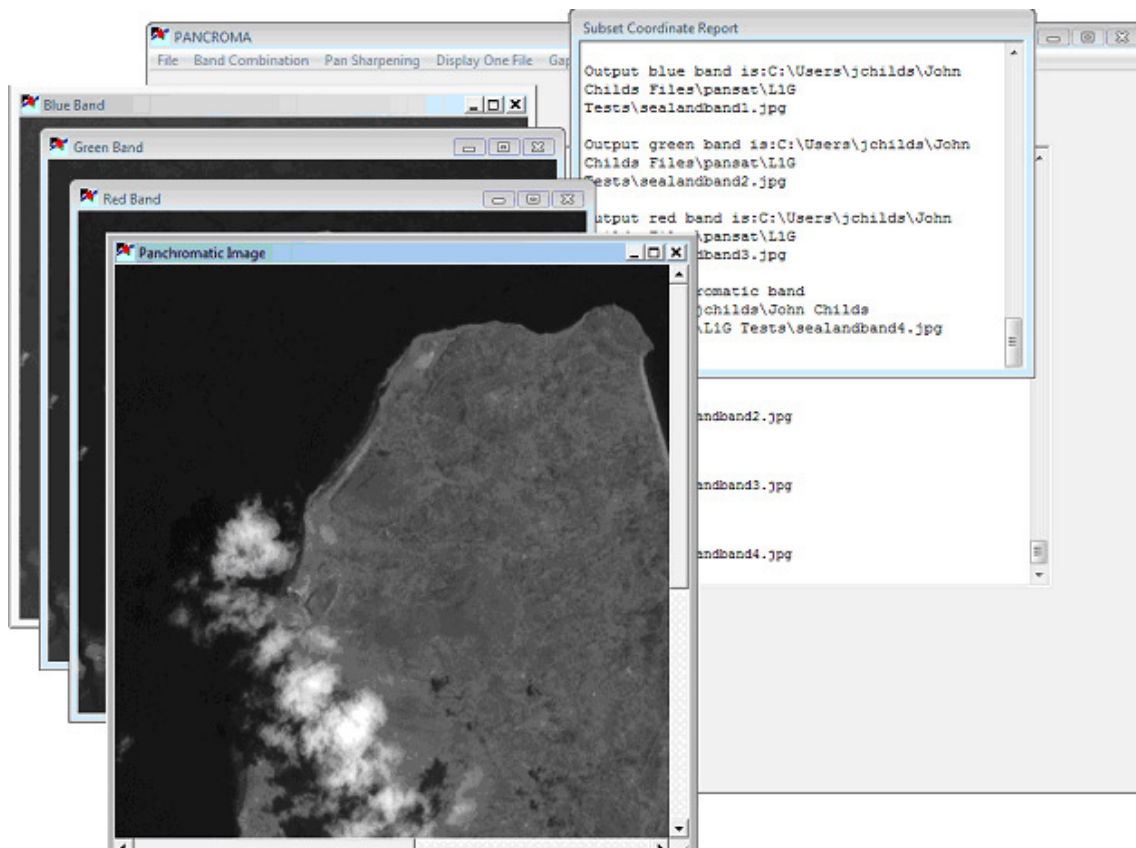
You can select your subset area either by clicking on the corners using the mouse (in which case the pixel coordinates will appear in the Manual Data Entry Panel), keying in latitude and longitude coordinates when available (all Landsat TIF and L1G format files as well as SPOT and ASTER TIF.) or else you can choose to enter the corners using the rubber band box. The pixel coordinate method allows you to select a point and then scroll using the slider bars to select the second point. When you use the rubber band box, your selection is confined to the visible screen. The pixel coordinate method also lets you make as many attempts as you like before selecting 'Enter'. If your subset area is not too large, it is OK to leave the 'Display Subset Images' check box checked. With larger subsets that approach the full size of the image it will be necessary to uncheck

this box to avoid out of memory errors. When you select 'Enter', nothing obvious happens. This is because the actual subsetting occurs when you save the file. This is necessary in order to minimize memory usage to allow larger subsets to be processed.



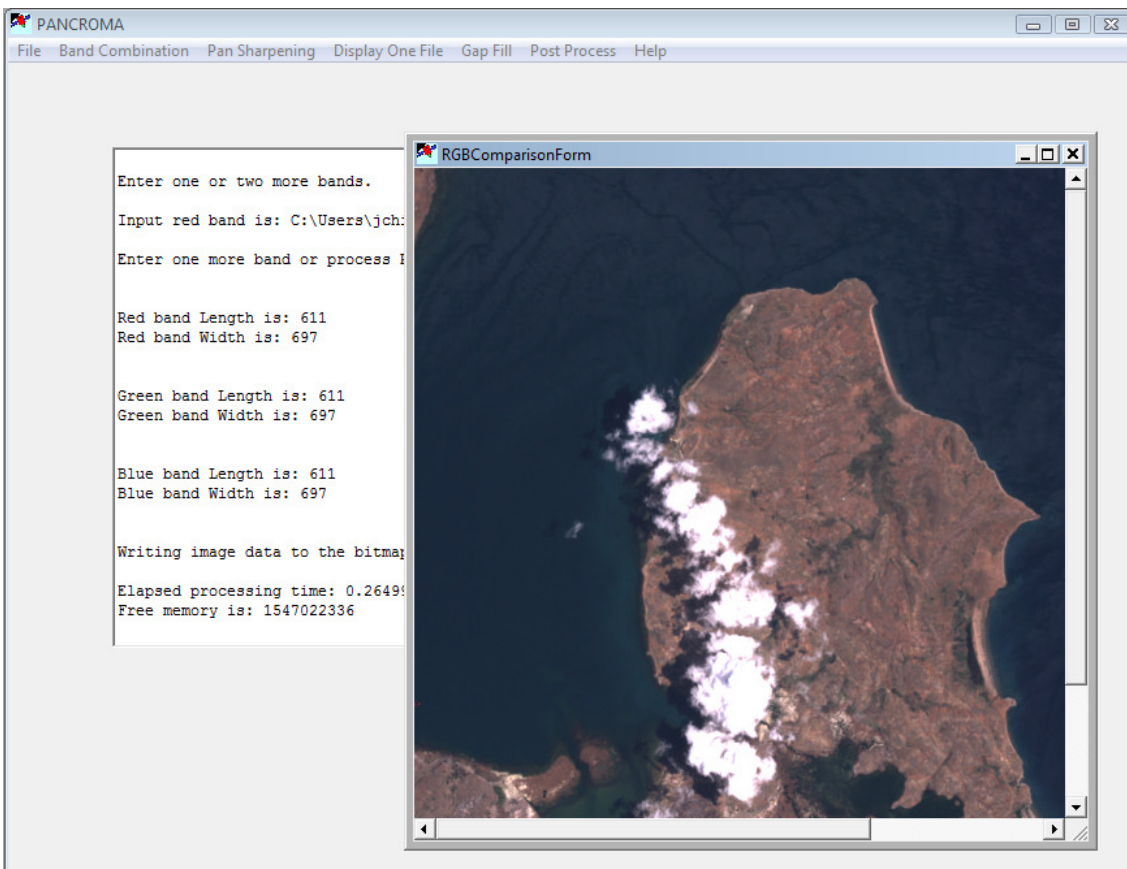
You save your file by selecting 'File'/'Save Subset Image' and choosing either 'jpg' or .bmp. I decided to use .jpg format for this example. When I did so, my subset images were presented as in the figure below. I called my files '1106Subset'. **PANCROMA™** appended the proper band identification onto the files when it saved them.

Note that the panchromatic image has twice as many rows and columns as compared to the three band images. PANCROMA has automatically subsetting the band files in the proportion 1:2 required for subsequent pan sharpening. The images are the correct size and also perfectly registered with each other, another requirement for pan sharpening.



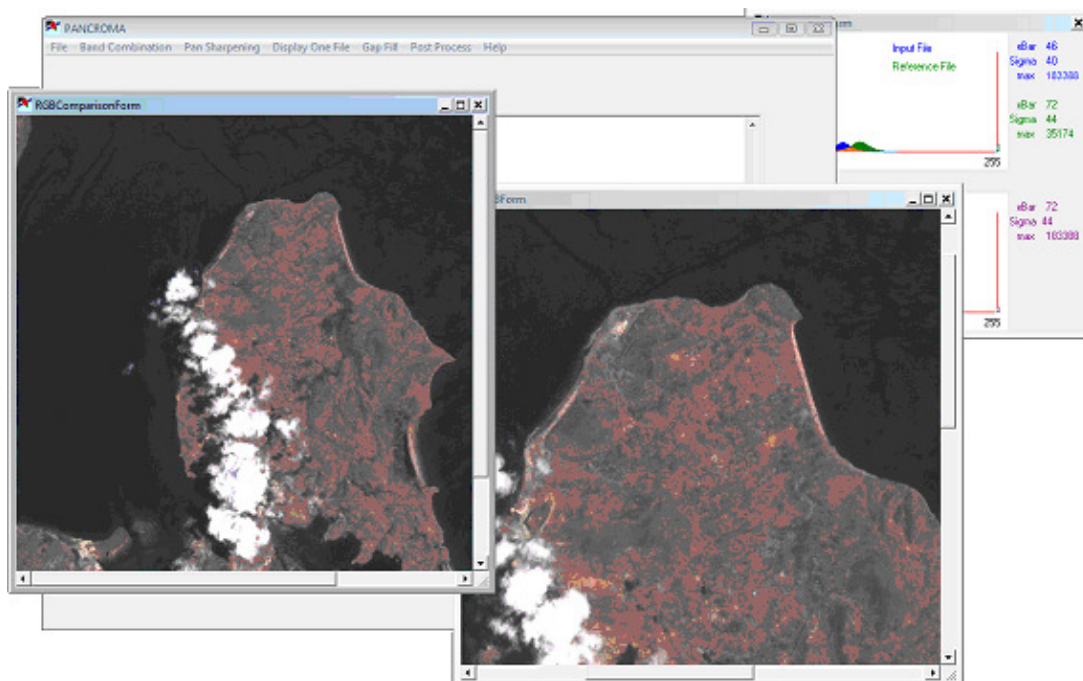
The next step will be to create an RGB color image reference image using the three band files only. This is a PANCROMA feature that allows you to readily compare the pan sharpened image to the image constructed from the three band files. This latter image represents the 'true' tonal image quality. Our objective is to match the RGB reference image as closely as possible with the pan sharpened image.

To create the reference, select 'File'|'Close Graphics Windows and Reset'. Now open your three subset band files, in my case the files '1106Subsetband1.jpg'; '1106Subsetband2.jpg'; and '1106Subsetband3.jpg'. Check the 'Maintain RGB Comparison Image' check box on the Main Window. This will allow the RGB image prepared from the three band files (the 'true color' image) to persist on the screen during the subsequent iterations of the panchromatic image creation. Now select 'Band Combination'|'Generate' RGB True Color Composite from ETM+' and the reference RGB image will quickly appear. Your screen should look like the image below.



Now we will start the pan sharpening. Select 'File' | 'Close Graphics Windows and Reset'. Now open your three subset band files, in my case the files '1106Subsetband1.jpg'; '1106Subsetband2.jpg'; '1106Subsetband3.jpg' plus the PAN file ; '1106Subsetband4.jpg' (i.e. open four files in total). Note that the reference image is still visible. We will compare the panchromatic image to this image in order to see how true our panchromatic colors are and to make adjustments if necessary.

For our first try, we will accept the default **PANCROMA**TM settings except for one small adjustment. Check the 'Activate Image Processing Routines' check box. Select 'Pan Sharpening' | 'HSI Transform'. When the iterations data entry box pops up, just click 'OK' to accept the default settings. When the image processing data entry box appears, uncheck the 'Clip Tail' check box in the histogram data group and then select the 'Process Image' button. After a bit of computation, the panchromatic image will be computed, and your screen should look something like the figure below:



The panchromatic image is the one in the form named 'RGB Form' and the comparison image is in the form named 'RGB Comparison Form'. The Histogram Form shows the results of the histogram match algorithm. This utility adjusts the panchromatic band pixels to match more closely the radiance of the

ideal computed Intensity band. The default condition is for the first channel of the histogram to be ignored when making the computation in order to avoid skewing the result if there are many black pixels in the image collar. Since this subset does not include the collar, it is more accurate to include the zero channel by unchecking the 'Clip Tails' box.

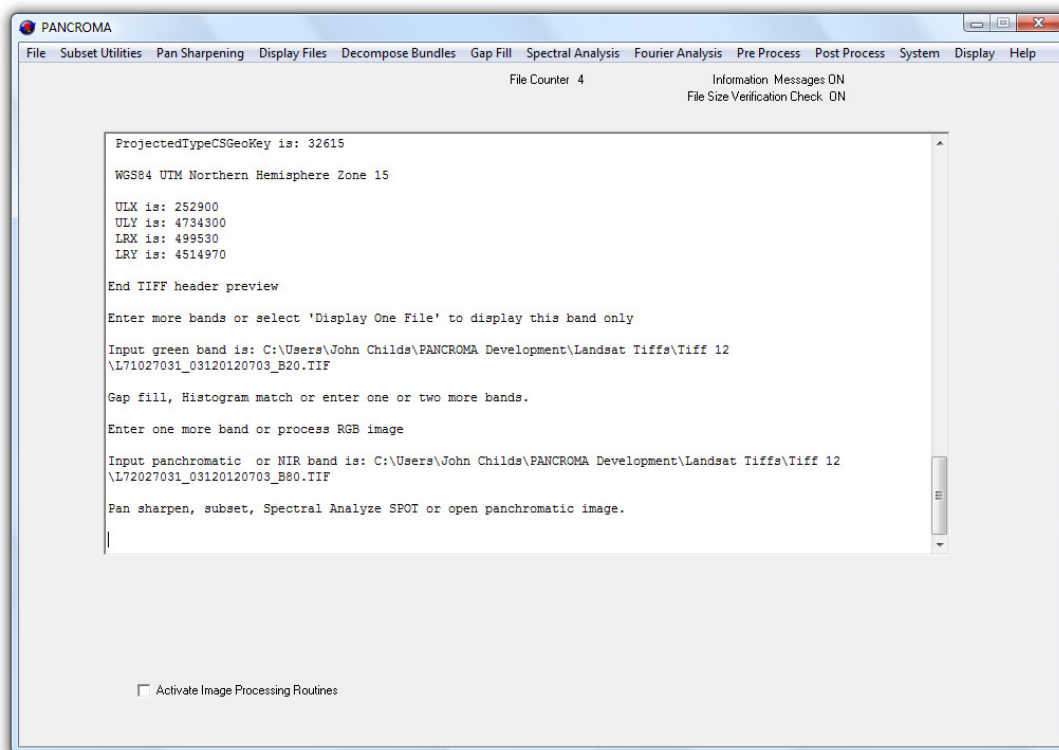
The procedure outlined above describes the automated method. Color tonal quality is automatically adjusted using this method. PANCROMA also provides a completely manual method for pan sharpening images. In this process you have much more direct control over the outcome, although it can require a bit more work. This manual process will be described in the balance of this section.

66. Tutorial – Pan Sharpened Image – Manual Method

This tutorial will walk you step-by-step through the manual method for producing a panchromatic image from Landsat band files. For this example, I will again start with Landsat files in .L1G format. This is a common format for Landsat data on the GLCF website.

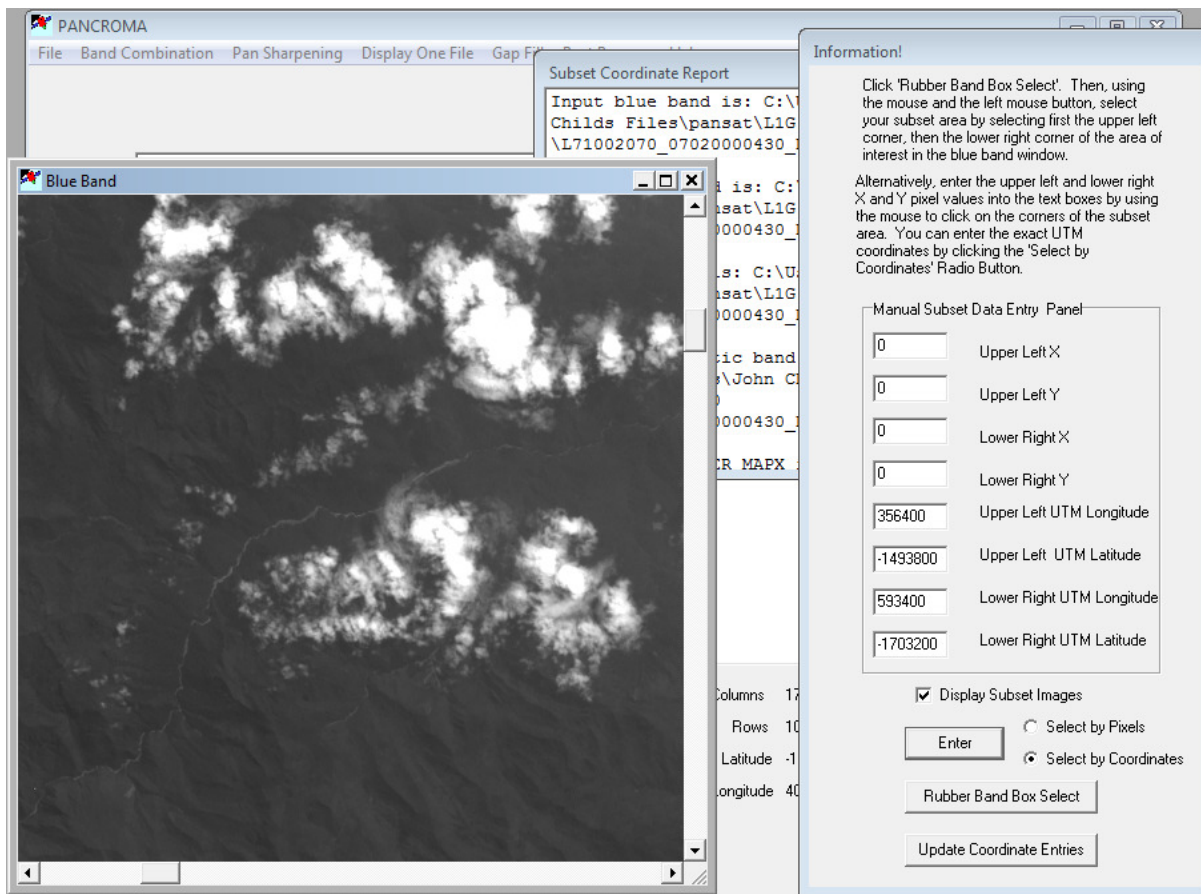
Launch **PANCROMA™** and open the data files, in the order ...B10; ...B20; ...B30; and ...B80.

If you have opened your files correctly, your screen should look something like the figure below.

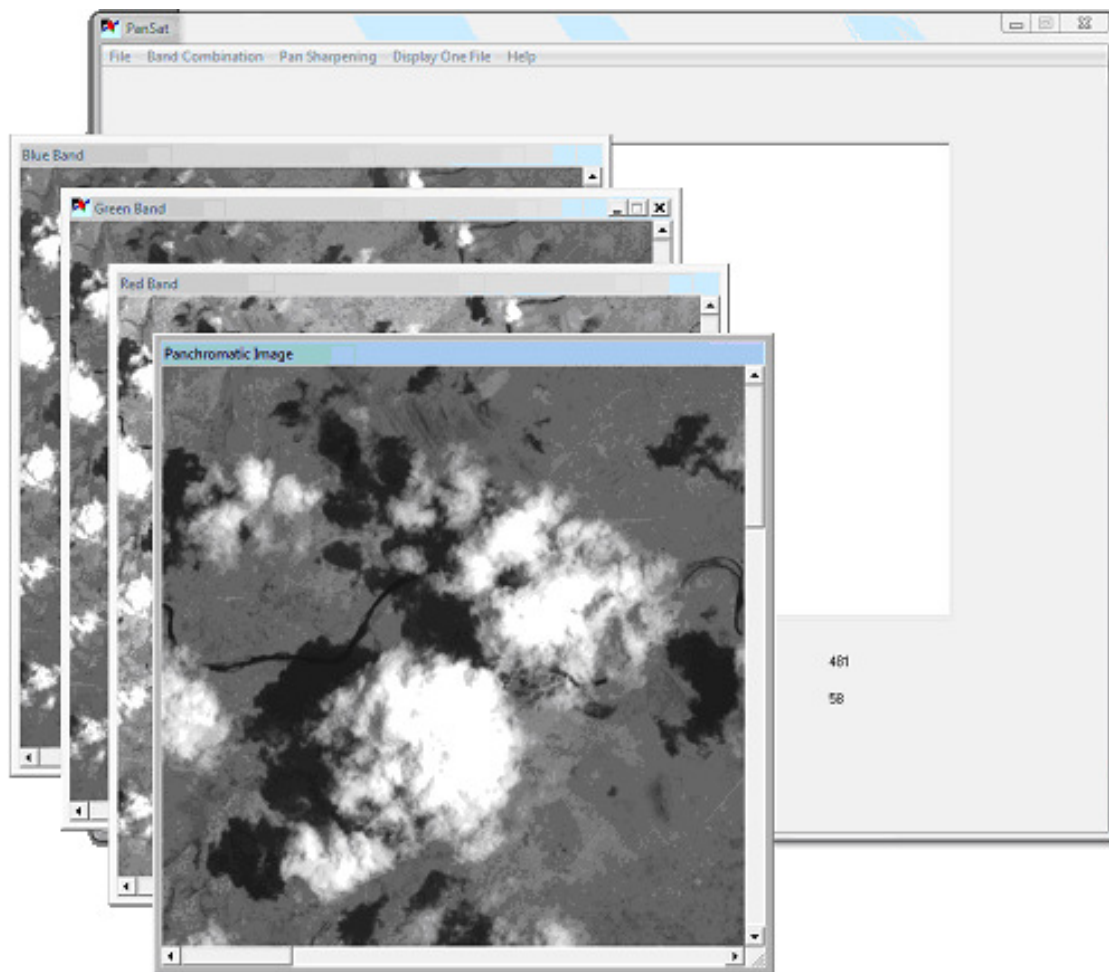


My area of interest for this image is again on the eastern coast of South America (Argentina) at latitude -14.9467068 and longitude -70.6615959. Again select 'Band Combination' | 'Subset Images'. **PANCROMA™** will begin parsing and decoding the files. The progress bar and the text screen inform you of progress. When **PANCROMA™** has successfully decoded the files you will be presented with an image window and a data entry screen as shown in the figure below.

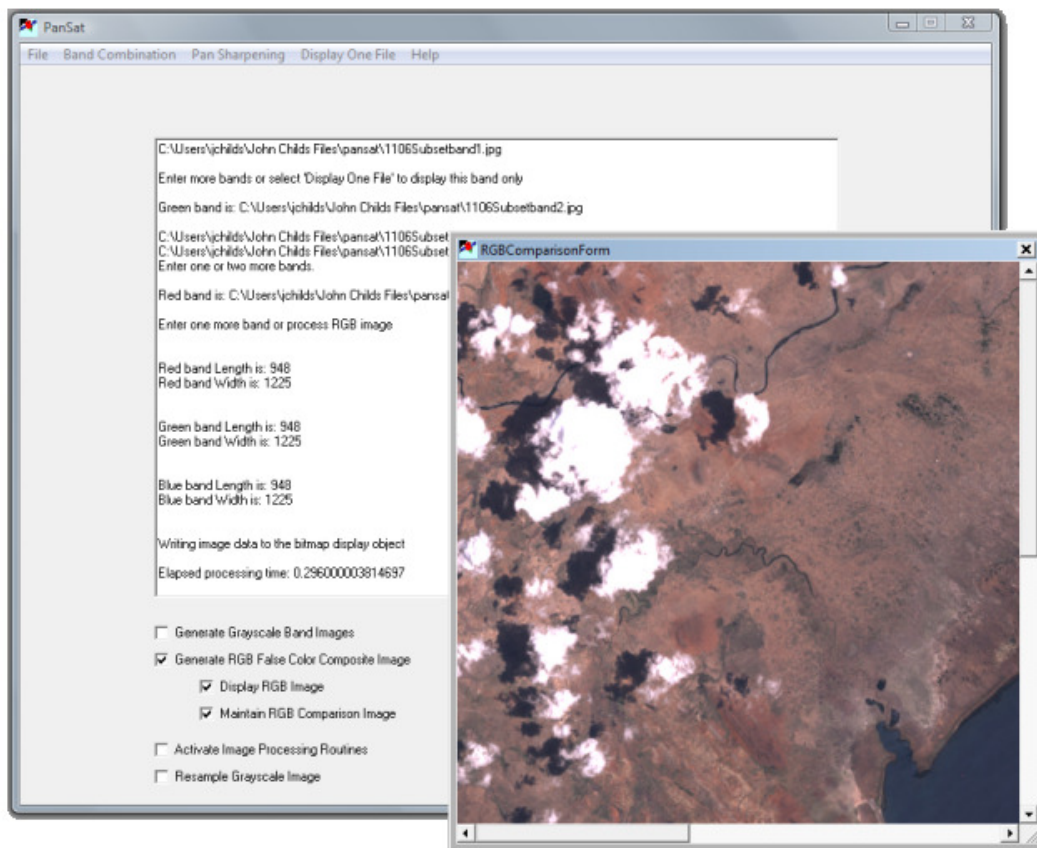
You can select your subset area either by clicking on the corners using the mouse (in which case the pixel coordinates will appear in the Manual Data Entry Panel), keying in latitude and longitude coordinates (when available) or else you can choose to enter the corners using the rubber band box. The pixel coordinate method allows you to select a point and then scroll using the slider bars to select the second point. When you use the rubber band box, your selection is confined to the visible screen. The pixel coordinate method also lets you make as many attempts as you like before selecting 'Enter'. If your subset area is not too large, it is OK to leave the 'Display Subset Images' check box checked. With larger subsets that approach the full size of the image it will be necessary to uncheck this box to avoid out of memory errors. When you select 'Enter', nothing obvious happens. This is because the actual subsetting occurs when you save the file. This is necessary in order to minimize memory usage to allow larger subsets to be processed.



You save your file by selecting 'File'/'Save Subset Image' and choosing either 'jpg' or .bmp. I decided to use .jpg format for this example. When I did so, my subset images were presented as in the figure below. I called my files '1106Subset'. **PANCROMA™** appended the proper band identification onto the files when it saved them.

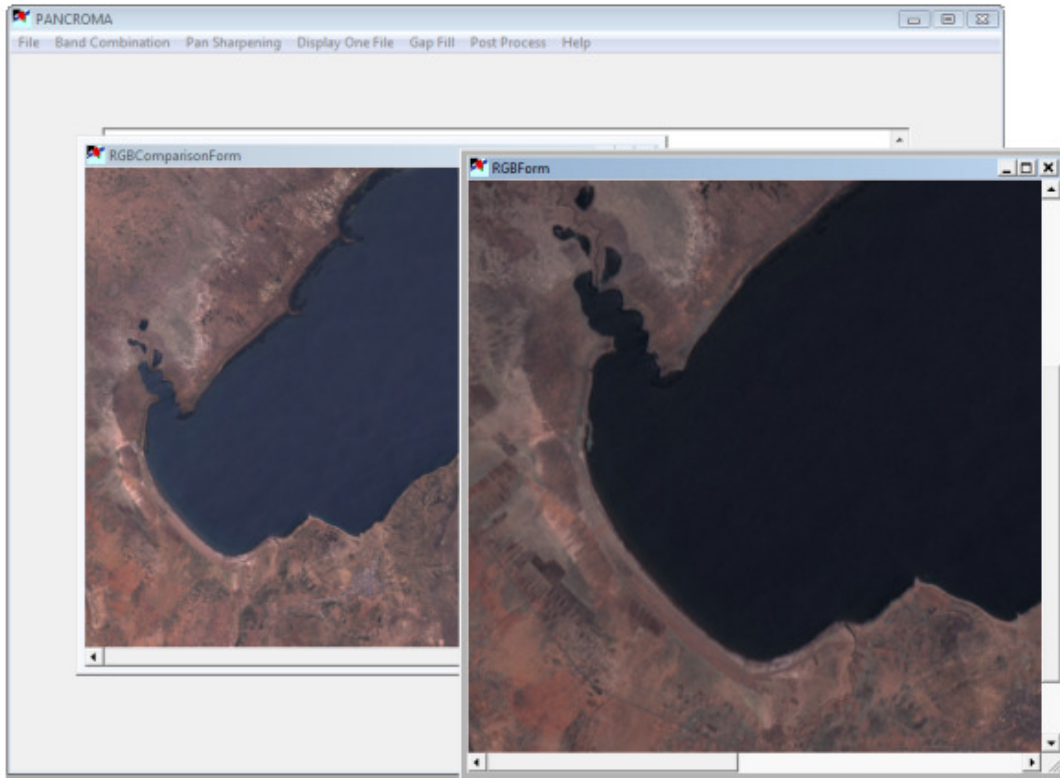


The next step will be to create an RGB Reference color image using the three band files only. To do this, select 'File'/'Close Graphics Windows and Reset'. Now open your three subset band files, in my case the files '1106Subsetband1.jpg'; '1106Subsetband2.jpg'; and '1106Subsetband3.jpg'. Check the 'Maintain RGB Comparison Image' check box on the Main Window. This will allow the RGB image prepared from the three band files (the 'true color' image) to remain on the screen during the iteration of the panchromatic image. Now select 'Band Combination'/'Generate' RGB True Color Composite from ETM+ and the reference RGB image will quickly appear. Your screen should look like the image below.



Now we will start the pan sharpening. Select 'File'-'Close Graphics Windows and Reset'. Now open your three subset band files, in my case the files '1106Subsetband1.jpg'; '1106Subsetband2.jpg'; '1106Subsetband3.jpg' plus the PAN file ; '1106Subsetband4.jpg'. Note that the reference image is still visible. We will compare the panchromatic image to this image in order to see how true our panchromatic colors are and to make adjustments if necessary.

For our first try, we will accept the default **PANCROMA**TM settings except for manual adjustment we will switch histogram matching off. Check the 'Activate Image Processing Routines' check box. Select 'Pan Sharpening'-'HSI Transform'. When the iterations data entry box pops up, just click 'OK' to accept the default settings. When the image processing data entry box appears, uncheck the 'Clip Tail' check box and then select 'Process Image'. After a bit of computation, the panchromatic image will be computed, and your screen should look something like the figure below:



The panchromatic image is the one in the form named 'RGB Form' and the comparison image is in the form named 'RGB Comparison Form'. The Histogram Form shows the results of the histogram match algorithm. This utility adjusts the panchromatic band pixels to match more closely the radiance of the ideal computed Intensity band. The default condition is for the first channel of the histogram to be ignored when making the computation in order to avoid skewing the result if there are many black pixels in the image collar. Since this subset does not include the collar, it is more accurate to include the zero channel.

Now let us compare the two images and see if we need any adjustments. The first thing we notice is that the panchromatic image is twice as big as the reference image. Of course this is the whole point of the panchromatic process. Looking at the color fidelity, we notice that in some respects the panchromatic image is perhaps better than the reference image. The clouds are less washed out, there is more green in the land mass (reflecting vegetation) and the image is less hazy. I decided that I liked these features.

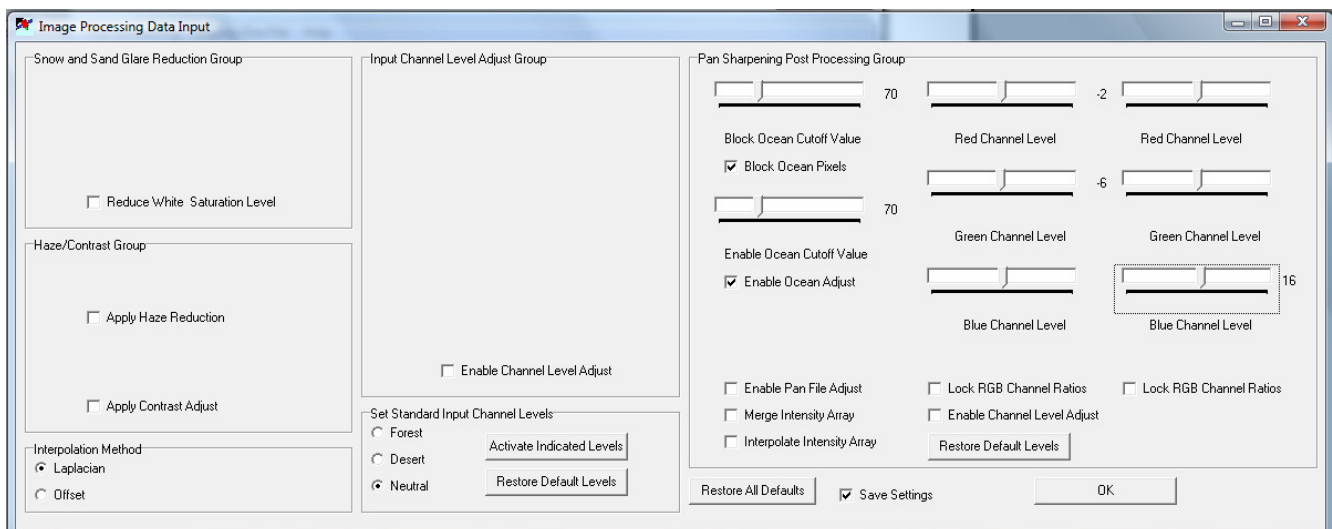
Other images may not be so cooperative and require adjustment of all these aspects. However, notice that the ocean is a different color in the panchromatic image. It is very dark and not as blue. This is a very common artifact of the HSI

algorithms. Although in this case the color is probably close enough, **PANCROMA™** has a feature to correct this if you wish. We will experiment with the ocean adjustment features to show how the image processing algorithms can be used to adjust the results ‘on the fly’.

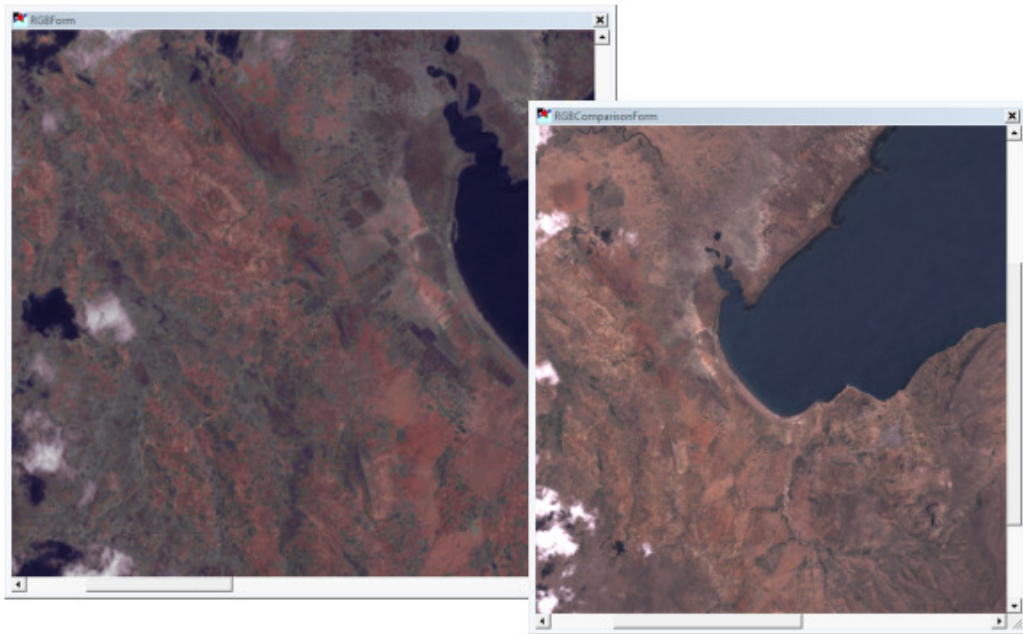
Check ‘Activate Image Processing Routines’ on the Main Window and without closing or exiting select ‘Pan Sharpening’|‘HSI Transform’ again. You will see the Image Processing Data Input’ form appear. Be sure to check the ‘Save Settings’ check box. This will (as indicated) save your image processing settings between iterations so that you can ‘tweak’ the next result from the previous each iteration without having to write down or remember your settings.

Since I want to adjust the ocean and the land *independently*, I check the ‘Enable Ocean Adjust’ check box and set the sliders to ‘70’ for the cutoff value and ‘16’ on the Blue slider, meaning I will add 16 to the Blue channel of all dark (<70) pixels. I am instructing **PANCROMA** to add 16 (out of 255) to every pixel whose red, green and blue values are less than 70 (out of 255). This means the darker pixels will be made somewhat “bluer”. I also check ‘Block Ocean Pixels’ I use the same cutoff value (70) and set those sliders to –2 for Red and –6 for Green. This means I am subtracting 2 from the Red channel of all pixels greater than 70 and subtracting 6 from the Green channel of all pixels likewise greater than 70.

Why did I select these particular values? No reason except previous experience and a little trial and error. Depending on the fidelity of the default image, and the characteristics of the image itself, you may wish to try many iterations in order to optimize the color in the panchromatic image. My ‘Image Processing Data Input’ box looked like this when I was done:



And my result looked like this:



As you can see, the ocean is much closer to the reference ocean. The land and vegetation are a pretty good match, and the clouds are better. Notice that the shadows under the clouds have not been turned blue. This is because I selected the ocean cutoff value so that it discriminated between the dark shadows and the even darker ocean. (Sometimes this will not work out so conveniently, depending on the characteristics of your image.)

At this point I am satisfied with my result and all that is left to do is to save it. To do this select: 'File'|'Save RGB Image'. I saved the image as a jpeg. The panchromatic image is shown in larger form in the Appendix. Other examples of **PANCROMA™** results are also listed in the Appendix.

PANCROMA™ of course offers many more Image processing and options as well as alternative interpolation options. It also offers the Brovey transform algorithms as an alternative to the HIS algorithm described. Experiment with these in order to produce the best quality panchromatic images possible.



67. Tutorial - Pan Sharpening Full Size Landsat Files

While many times you may only be interested in pan sharpening a portion of a Landsat image, some users will want to process full Landsat files. This is a sizeable task as it involves processing about 600MB of input files and producing an RGB output file of up to 850MB. Computers with over 3GB of SDRAM can typically process full sized Landsat files without any problem in as little as 225 seconds. Computers with less RAM, slower processors and less capable graphics cards may be challenged. The problem is not so much the processing speed as the RAM required to display the color pan sharpened image.

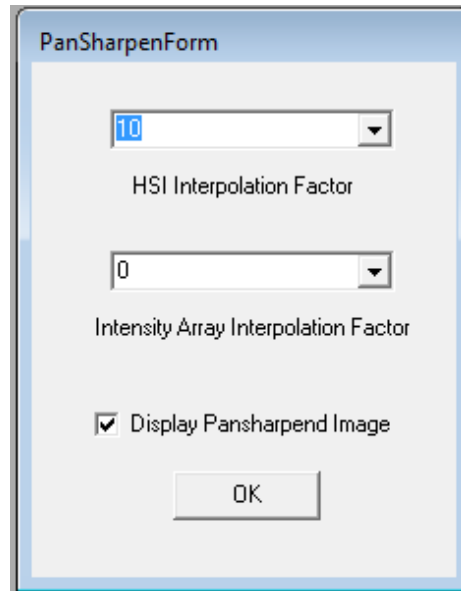
Large Landsat file sets can be processed the same as smaller files with a couple of important notes:

- It may not be possible to save full sized pan sharpened Landsat files in JPEG format. Currently the JPEG writer that **PANCROMA™** uses is not very memory efficient. Attempting to save pan sharpened Landsat files will result in an 'Out of System Resources' error message. Pan sharpened SPOT images can be saved in JPEG format without any problem.
- Files can be saved in BMP or PNG format. PNG format is recommended as it employs a lossless compression algorithm and results in files that are 25% of the size of BMP files. The PNG writer is very memory-use efficient.
- Processing the files can take a while. Processing speed is dependent on the amount of RAM on your computer and your processor speed and type.

In normal operation **PANCROMA™** computes a bitmap display object from which the screen display is computed. Normally the graphics file that is stored to disk when any of the 'Save' menu items are selected is also extracted from the bitmap object. However, a full sized color pan sharpened Landsat image can require 750MB of RAM itself. The JPEG save utility requires another 750MB. This combined with the executable, processing overhead, and other processes running on your computer can exceed the address space limitation imposed by the Windows operating system and may generate an 'Out of Memory' error message.

In order to avoid this, and to allow computers with fewer resources to process full size files, **PANCROMA™** offers the option to forego displaying the image. Do this by unchecking the 'Display Pan sharpened Image' checkbox on the Pan Sharpen Form that displays after you select the 'Pan Sharpening' menu item. This will prevent the program from attempting to display the image and will invoke lightweight .bmp, .jpg and .png writers. You will be able to save the image and then subsequently load it for viewing after the save.

IMPORTANT NOTE: The PNG writer is very efficient and can save even the largest files while displaying the full image.



The image shows a Windows-style dialog box titled "PanSharpenForm". It contains two spinners: the first is labeled "HSI Interpolation Factor" and has the value "10"; the second is labeled "Intensity Array Interpolation Factor" and has the value "0". Below these is a checked checkbox labeled "Display Pansharpend Image". At the bottom center is an "OK" button.

PanSharpenForm

10

HSI Interpolation Factor

0

Intensity Array Interpolation Factor

☒ Display Pansharpend Image

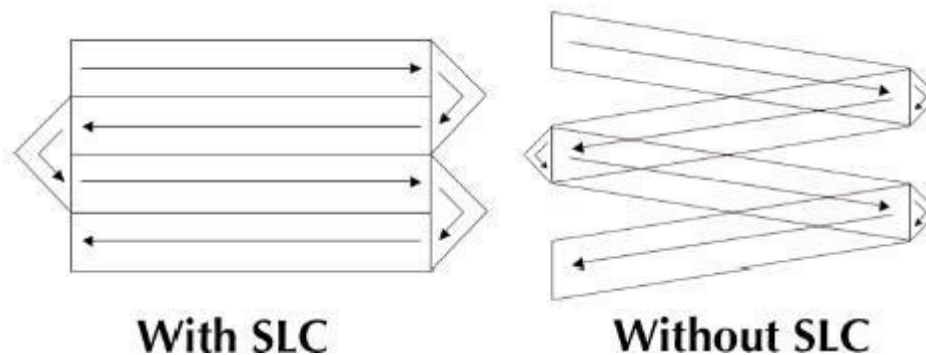
OK

68. Tutorial – Gap Filling using Transfer Method

IMPORTANT NOTE The semi-manual method for registering images in this tutorial has been superceded by the Six File method described in Section 32 of this manual. The semi-manual steps described in this tutorial work well but the automatic method is considerably easier.

The newest Landsat satellite (Landsat 7) was actually launched in 1999. Many Landsat users know that that this valuable earth science asset has been seriously broken since 2003 when its Scan Line Corrector (SLC), which compensates for its forward motion as it scans the earth's surface failed. This has resulted in systematic gaps in every Landsat image collected since that time.

To understand the problem, it is necessary to know a little about how the Landsat sensor works. As Landsat traverses an (approximate) north-to-south orbit, a mirror scans east-to-west collecting data across the orbital path. If uncorrected, a zigzag path would be described with wedge-shaped gaps in between the data. In order to make the transverse data rows parallel and remove these gaps, a mechanical corrector is attached to the mirror. This is the part that failed in 2003. All of NASA's attempts to fix the problem have been unsuccessful.



As a result, instead of nice parallel rows (like a well-mowed lawn) the uncorrected gapped pattern is transmitted to the ground station. This cannot be compensated by post-processing at the Landsat ground station because gap data is physically absent from the scan. Approximately 22% of the data is lost, with more lost information occurring at the edges of the image than at the center, where there is a vertical strip of complete data.

Although there is no way to recover the missing gaps, in many cases it is possible to make these images more useful by filling in the gaps with overlapping data or data collected before 2003. This is possible because various Landsat satellites have orbited the earth for so many years that there are multiple many

scans of the exact same patch of the earth's surface (these are called scenes). This legacy data can be used to fill in the gaps in more current scans. **PANCROMA™** has the necessary utilities to perform such gap-filling operations. Alternatively, current gapped Landsat data can be used to fill gaps if the gaps between the two images do not exactly coincide.

The gap filling procedure requires a Landsat Reference image (the one you are trying to correct and which has the gaps) and at least one corresponding Adjust image (the one you will extract data from to fill the gaps in the Reference image.) The Adjust image is usually gap-free, but it does not have to be. Because the gaps in two images may not coincide exactly, at least some useful data may be transferred from the Adjust image to the Reference image despite possible gaps in both.

There are some fundamental problems with a gap-filling strategy. The first is image registration. In order to transfer data from one image to the next, the two images must match exactly. The corner latitudes and longitudes must match and the number of rows and columns must be the same in the two images as a minimum. Constructing a set of such matched images is a vital part of the pre-processing work that must be done before the gap filling can begin.

Another problem is inconsistencies in lighting, season, snow cover and cloud cover between images. Two images of the same area, even when properly matched, may differ so significantly in these properties as to make them unattractive for gap fill. Of course great changes can occur over time in urban areas and deforestation may occur in remote areas. Other secondary factors such as radiance and color cast due to lighting and atmospheric effects are also important. However these can be somewhat corrected by **PANCROMA™**.

This procedure will describe the process for gap-filling a 30m resolution Landsat RGB image from three band files using **PANCROMA™**. I have chosen an image of southern New Zealand for this tutorial to illustrate the process for producing a useful gap filled image. Start the gap filling process by selecting and downloading your Reference (gapped) Landsat scene. Record the Reference image Path and Row numbers when you download the image. Download the blue, green and red bands of the Reference image.

The next step is to select your Adjust image. An easy way to do this is to use the GLOVIS website as it archives many Landsat scenes of the same Path and Row number. After navigating to the site, select 'Landsat Archive' and 'Landsat 7 SLC-on (1999-2003)' from the drop down menus. Click the 'View Images' button. When the Visualization Viewer screen appears, type the Path and Row numbers that you recorded earlier into the text boxes provided. Now click the 'Prev. Scene' and 'Next Scene' buttons to browse through all of the available scenes at your selected Path and Row numbers.

You can use the 'Max Cloud' drop down menu to eliminate scenes with excessive cloud cover. The ideal case is when both the Reference and Adjust images have 0% cloud cover. Selecting this will of course limit the number of scenes that you can select from. However for many parts of the earth there are multiple cloud-free scenes available. Once you have found an appropriate Adjust image, download the blue, green and red bands. It is recommended that you set up a file structure to keep everything straight during the subsequent operations.

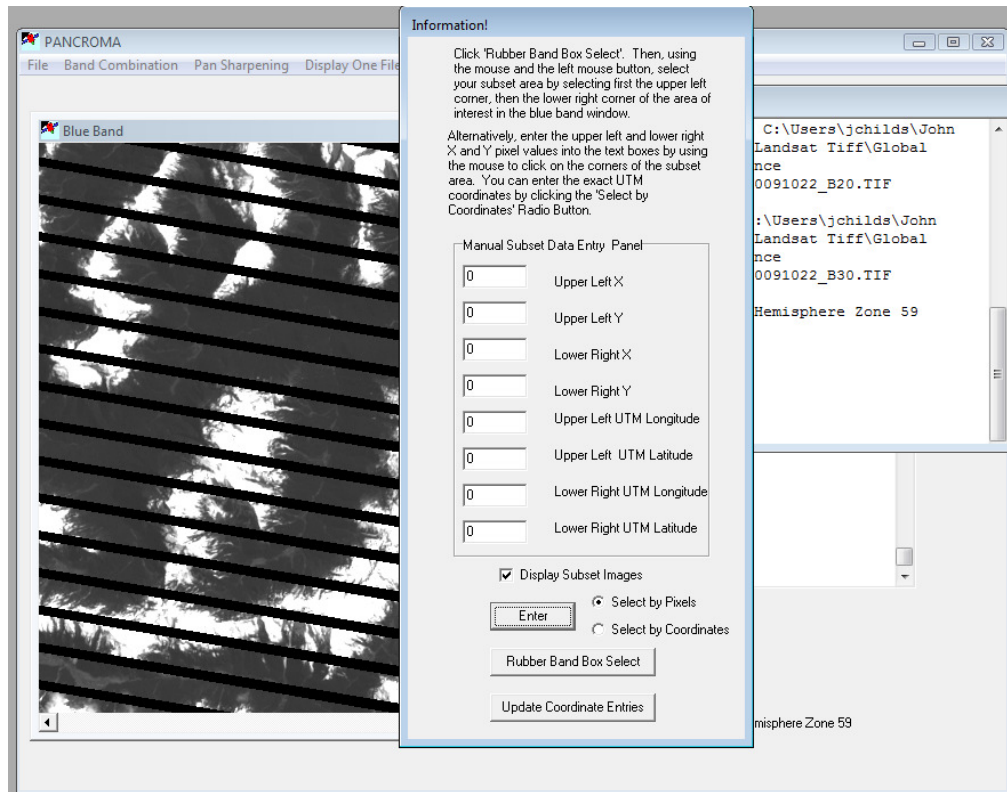
Landsat images are acquired at two different ground resolutions: 28.5m and 30.0m. Often the Reference and Adjust images do not match, and it is necessary to correct this. **PANCROMA™** provides a utility for converting 28.5m to 30.0m resolution. Open a single band file and then select 'Pre Process' | 'Resize Images' | 'Scale Landsat 28.5m to 30m'. After the file is rescaled, save it by selecting 'File' | 'Save' | 'Geotiff'. Repeat for the rest of the Adjust and Reference band files.

IMPORTANT NOTE: Landsat band files are archived in two resolutions: 28.5m and 30m. **PANCROMA™** has a utility for scaling a 28.5m to 30m scale. Select 'PreProcess' | 'Resize Images' | 'Scale Landsat 28.5m to 30m'. The utility multiplies the rows and columns by a factor of 28.5/30 and multiplies xScale and yScale by the inverse ratio.

The next step is to subset and register the images. Landsat scenes, even if they share the same path and row numbers usually will not match exactly. If you wish to produce the largest possible image then you must determine the extents of the area that is common to the two Landsat scenes. **PANCROMA** provides a utility for determining this common area. To do this, load a band file from the Reference scene, for example Reference band 1, by selecting 'File' | 'Open' and then selecting the band file. Then open the corresponding band from the Adjust scene. Now select 'Band Combination' | 'Subset Images' | 'Compute Maximum Common Extents'. After a moment the corner coordinates of the largest area that is common to both scenes will be displayed in the main text window. It is not necessary to record these coordinates as **PANCROMA™** will remember them automatically for the next steps.

Next you must subset both sets of band files to the computed corner coordinates. First load the three reference bands (blue, green and red). Select 'Band Combination' | 'Subset Images' | 'Subset Three Bands' from the main menu. After a moment a single grayscale image and subset form will appear. The corner coordinates computed by the 'Compute Maximum Common Extents' utility have been automatically inserted into the coordinates text boxes in the Subset Image Form. Check the 'Select by Coordinates' radio button and then select 'Enter'. The first set of subset images will be computed. Save the images by selecting 'File' | 'Save Subset Images' | 'Geotiff', saving the using an appropriate file name. (Suffixes will be automatically appended so you only need to specify the root name.)

Now select 'Close Graphics Windows and Reset' and repeat the process for the Adjust bands. The maximum common extents will be retained in the Subset Data Form as long as you do not exit the program. After subsetting, save the Adjust images as before.



If you do not wish to use the maximum common extents, but are interested in a smaller subset area, use the following procedure. Select the arbitrary subset area using any of the three methods provided (pixel coordinates, latitude/longitude, or rubber band box). Once you have selected the corner coordinates, select 'Enter'. The three band files will be subsetting and will be displayed on the screen. Save the images by selecting 'File' | 'Save Subset Images' and selecting either '.tif', '.jpg' or '.bmp'. Select 'Close Graphics Windows and Reset'.

Now open your three Adjust (non-gap) file bands. Select 'Band Combination' | 'Subset Images' | 'Subset Three Bands' as before. This time when the subset coordinate box appears, the corner latitude and longitude coordinates that you chose for the Reference image are already entered into the appropriate text boxes. Check the 'Select by Coordinates' radio button. You need only select

'Enter' and the Adjust file will be subsetted to the same latitude and longitude coordinates as the Reference subset images that you previously created. I named my subsetted files 'Reference' and 'Adjust'. (Band identification suffixes are automatically attached. The band1 Reference and Adjust images are shown on the right.

The Reference and Adjust subset images should be exactly the same size if you have matched the resolutions. It is necessary for the images to not only have corresponding latitude and longitude corner coordinates, but they must have the same number of pixels as well. **PANCROMA™** has a utility for resizing images if they do not match. The resize utility uses a simple x and y scaling algorithm to achieve the fit. In general it is more accurate to co-register both images using control points but since the images will be nearly the same size after subsetting the scaling approach will yield the same result for matching the images to each other.

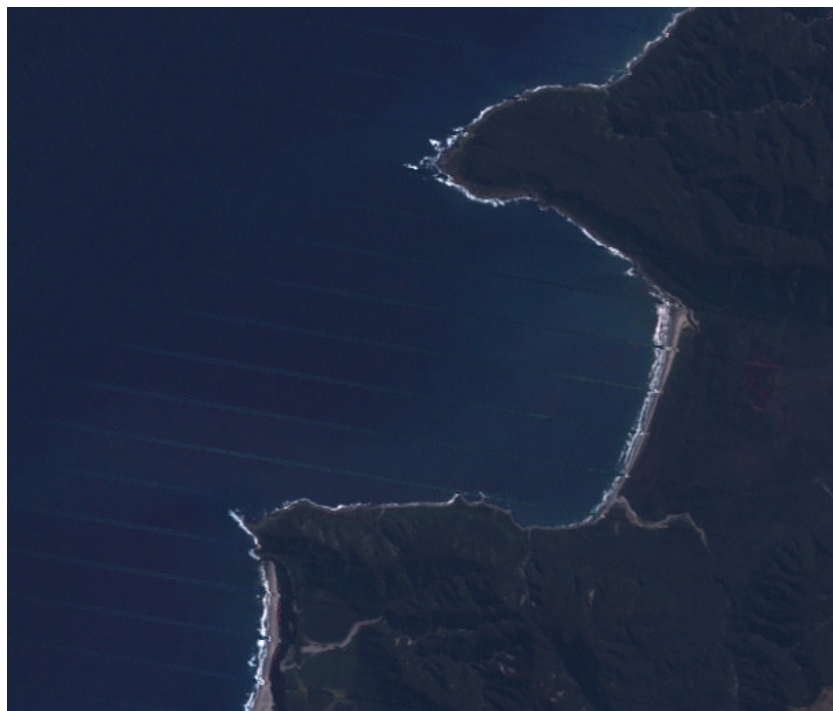
PANCROMA™ will decrease the size of the larger image to match the smaller one. As a result it is necessary for you to load the larger set by opening the three band files. Then select 'Band Combination' | 'Subset Images' | 'Resize Images'. The three images will appear on the screen along with the 'Resize Data Input Form'. Enter the row and column values for the smaller set into the text boxes and select 'OK'. The images will be scaled down. You can save the resized images when the process is complete.

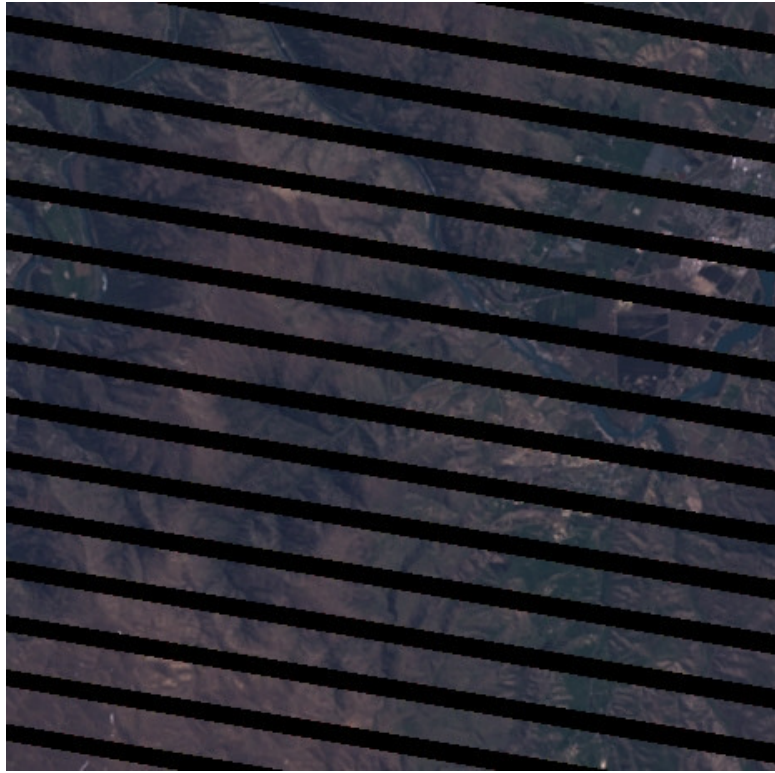
At the end of this operation, you should have six processed Landsat band files: two blue, green and red band files for the Reference image and two blue, green and red files for the Adjust image, all the same size and with the same corner coordinate in the same projection to the same datum. One set will have gaps and the other will be whole. You are now ready to gap fill and process the images using **PANCROMA™**.

The process is fairly straightforward. The six band files are loaded in pairs: first the two blue bands, then the two green bands, and finally the two red bands, *in the order*: Reference band (with gaps) then Adjust band (without gaps). Each pair is gap filled immediately after loading by selecting 'Gap Fill' | 'ETM+ Gap Fill' from the menu. Each gap-filled grayscale image must be successively saved, and then the next pair is loaded, repeating the process. **PANCROMA™** uses the non-linear histogram matching algorithm to automatically modify the 'Adjust' image in order to get a close match to the 'Reference' image. Without the histogram match, the radiance differences between the Reference and Adjust images would result in a severely striped image in most cases.

My example gap filled images are shown below. There is some faint striping visible but much of this is due to seasonal differences in vegetative covering. Both these image pairs show the benefit of gap filling and the satisfactory results that can be achieved.

The process outlined can also be used for pan sharpened images. In this case the images would be pan sharpened first., then the grayscale band files would be generated by loading a pan sharpened image while checking the 'Generate Band Images' check box. After the band files are thus obtained for the Reference and Adjust images, they can be gap-filled exactly as described above.





69. Tutorial – Six File Automatic Method

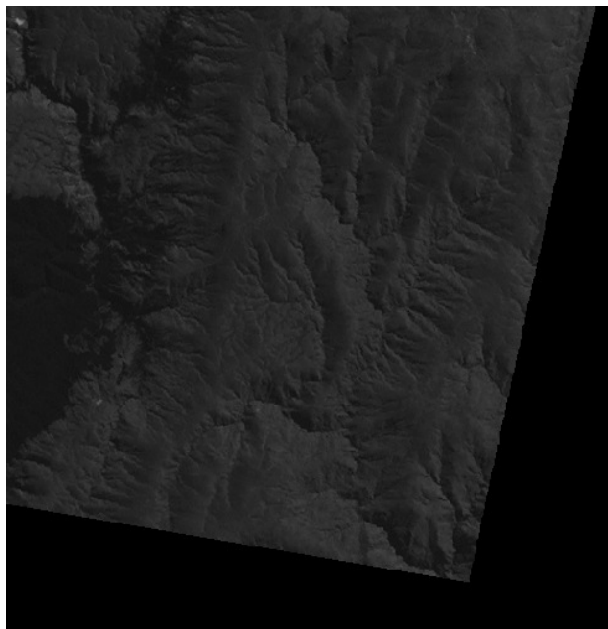
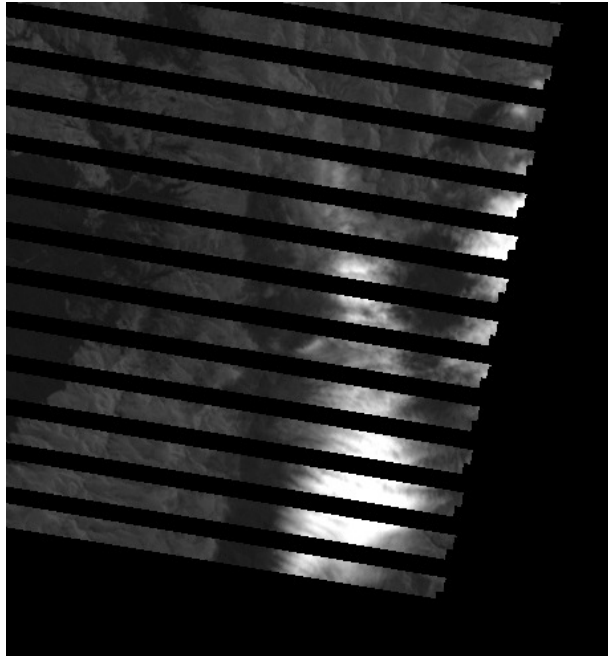
This tutorial describes the recommended method for co-registering the two sets of three each Landsat band files for gap filling. The gap filling process, identical to that described in Section 48 is also repeated.

The preceding section described the **PANCROMA**TM semi-manual process for co-registering Landsat band files. In general, the registration process contains the following elements:

- Compute Maximum Extents – this utility determines the maximum overlap between the Reference and Adjust data sets and specifies this overlap by computing the corner coordinates that define the overlap
- Image Rescale. Sometimes the Reference and Adjust images do not have the same scale factor. Landsat band images for example can have either 30m or 28.5m resolution. In this case the images must be rescaled so that the two match, i.e. the 28.5m image must be rescaled to 30m resolution
- Image Subsetting. Next the two images must be cropped according to the Maximum Extents corner coordinates so that both images have the same latitude and longitude boundaries
- Row and Column Count Rationalization. The images get a final check to correct any off-by-one row or column discrepancies resulting from rounding errors when recomputing row and column counts during any rescaling and when mapping the corner latitude and longitude values to their corresponding row and column values.

In the preceding Tutorial (Section 48) this process was done using four separate, semi-manual utilities. A new **PANCROMA**TM utility conducts these operations automatically, saving time and reducing the probability of making an error in the process. In order to use the utility, you start with two three-file data sets as before, for example a Landsat band1, band2 and band3 Reference file and a band1, band2 and band3 Adjust file. There must be at least some common area shared between the two data sets. The band files must also be in GeoTiff format. To get started, open three band files (either the Reference or Adjust group) by selecting 'File' | 'Open' and opening three files from the same data set in series. Continue opening three more files, for example the files from the Adjust data set if you opened the Reference set first. You should now have six band files opened. Now select 'Band Combination' | 'Subset Images' | 'Subset Six Bands'. When the subset data entry box appears, just click on 'Enter'.

PANCROMA™ does the rest after that. If all goes well, you should see your six registered images appear after a bit of computation. You can save all six files by selecting 'File' | 'Save' and typing in a base file name. **PANCROMA™** will add a numerical suffix to the base file name, numbering the output files in the same order that you input them. Two example subsets from such a pair of co-registered sets is shown below. You are now ready to gap fill the registered images.



When gap filling additional sets, you should just repeat the six file procedure after gap filling the first set. In this case you will have one set of three (partially) gap filled band files and the third set that you have not used yet. Just repeat the six file subsetting method with these two sets. This can be repeated for as many data sets as necessary.

70. Tutorial – Gap Filling using Hayes Method

The third **PANCROMA**TM method for filling gaps in Landsat ETM+ images is the Hayes Interpolation method. This procedure uses a computational approach to solving the gap filling problem. Instead of directly substituting the missing pixels from the Adjust image into the Reference image, it computes the brightness level of each missing pixel in the Reference image using information on corresponding pixels in the Adjust image.

Like the Transfer method, the Hayes method also requires exactly matched Reference and Adjust images. The procedure for producing them is exactly the same as described in the previous Tutorials, using either the semi-automatic or fully automatic methods for co-registering your two sets of three Landsat band files.

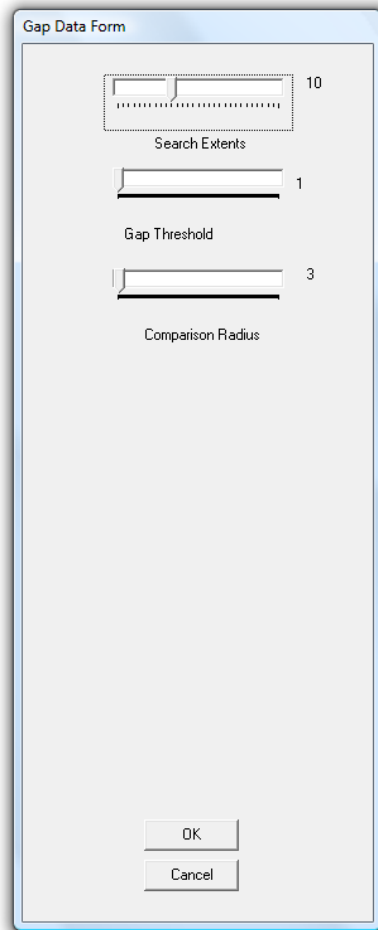
After you produce the matched images the gap filling procedure is similar with a few important differences. You start the filling procedure by opening first the Reference (grayscale) image (the one with the gaps), followed by the Adjust image.

When the images are loaded, select 'Gap Fill' | 'Gap Fill Hayes Method'. A Gap Fill Data Form will appear. You can select the algorithm parameters: Search Extents, the Gap Threshold and the Comparison Radius. The default values are 20, 4 and 4, respectively.

The Search Extents defines the size of the sliding window within which **PANCROMA**TM will look for similar pixels. **PANCROMA**TM will search the target +/- the Search Extents, so the size of the window is twice the Search Extents value.

The Comparison Radius value determines how closely a searched pixel must be to the target pixel in order to be considered 'similar'. The default value is 4, meaning that pixels within 4 levels of the target will be considered similar. For example, if the target has value 83 and the Threshold is 4, then coordinates of pixels with values 79, 80, 81, 82, 83, 84, 85, 86 and 87 will be considered as similar for purposes of the computation.

The Gap Threshold determines which pixels in the Reference image will be computed. Any pixel with a brightness value less than the Gap Threshold will be considered a missing pixel and **PANCROMA**TM will attempt to fill it. After you select your values, the program will compute the gap filled image. Note that a histogram match will not be computed for the Hayes method, as it does not generally benefit the result.

A screenshot of a software dialog box titled "Gap Data Form". It contains three horizontal sliders. The first slider is labeled "Search Extents" and has a value of 10. The second slider is labeled "Gap Threshold" and has a value of 1. The third slider is labeled "Comparison Radius" and has a value of 3. At the bottom of the dialog are two buttons: "OK" and "Cancel".

You must be careful when selecting the input parameters, as your choice will have affect both the quality of the computed image and the processing time (the higher the quality, the greater the time). For example, increasing the size of the Search Extents increases the number of candidate pixels for the comparison computation.

In general, the larger the value of the Search Extents, the better the pixel interpolation. However, choosing a large Search Extents value will rapidly bog down computational speeds, as the extents must be searched for each gap pixel in the image, plus the black collar pixels as there is no way to distinguish between a black gap pixel and a black collar pixel. Choosing too small of a window will result in failure to find any matching pixels. (The optimum combination of Search Extents and Threshold cannot be computed and must be determined empirically.)

Although the algorithm has been streamlined for computational speed, whatever the size of the Search Extents, the Hayes method will be slower to process than the Transfer method.

Another reason to keep the Search Extents as small as possible is that the edge of the window will eventually bump against the edge of the image. Since the target pixel is offset from the edge by the Search Extents, the result is that there will exist a band of uncomputed pixels on each side of the image. If you are processing a Landsat scene, this will not matter much because this band will be in the collar area. If you are computing a subset image, however, this will result in a “fringe” around the edges of the image.

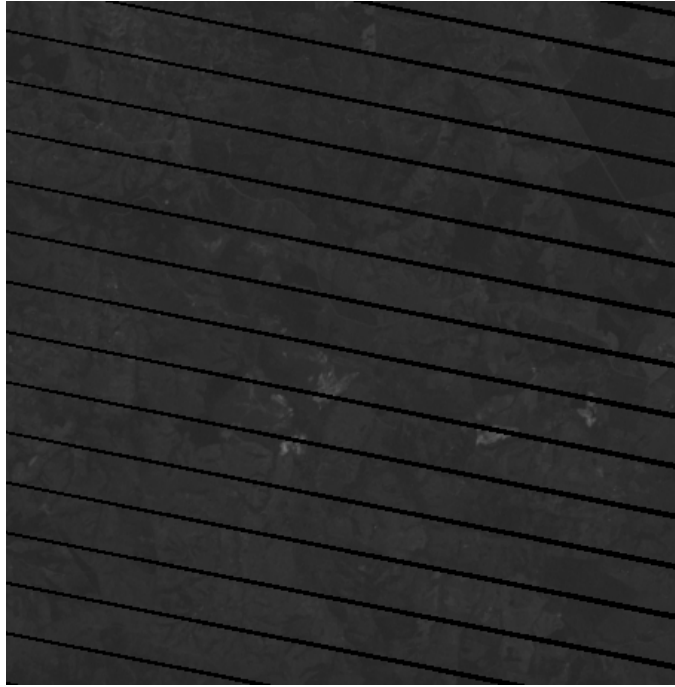
Your selection of a Comparison Radius value will also have an effect on the resulting image quality. Choosing a Comparison Radius of zero means that only pixels that exactly match the target pixel will be included in the computation. However, this may mean that no matching pixels will be discovered within the search window. In this case, **PANCROMA™** increases the size of the search window and repeats the process up to two more times.

Repeated failures to find any matching pixels will slow down the computation. If no match is found, then no gap fill is computed, resulting in a black pixel in the processed image. On the other hand, if the Comparison Radius is set too large, the computation will not be very discriminating. This will result in blurring within the filled gap and loss of detail.

It is generally a good idea to create a set of small subset Reference and Adjust images to be used for empirically determining the optimal settings before attempting to fill entire scenes. If you are able to crop out the image collars entirely the processing speed will be increased significantly. This is often difficult with Landsat scenes as the path direction is not aligned with true north so that a lot of the useful image may be lost if all collar area is cropped.

The main benefit of the Hayes method is potentially better results. Pixel brightness levels are computed from the Reference image itself, rather than copied from the Adjust image.

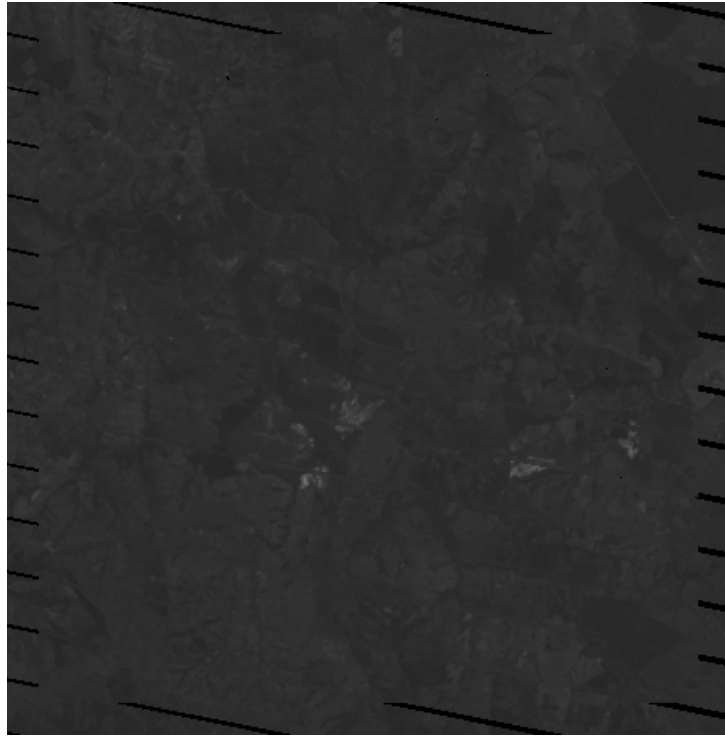
Of course the same issues discussed with the Transfer method, i.e. snow, clouds, seasonal changes to vegetative cover will affect images produced by the interpolation method, although the effect of the latter is greatly reduced. Some examples of results using this method are shown below.



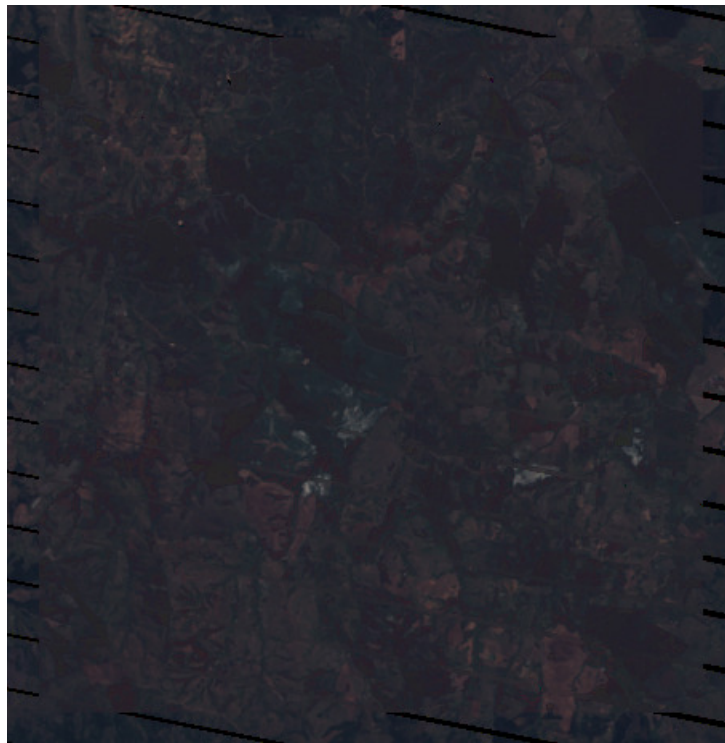
Reference Image



Adjust Image



Gap Filled Grayscale Image

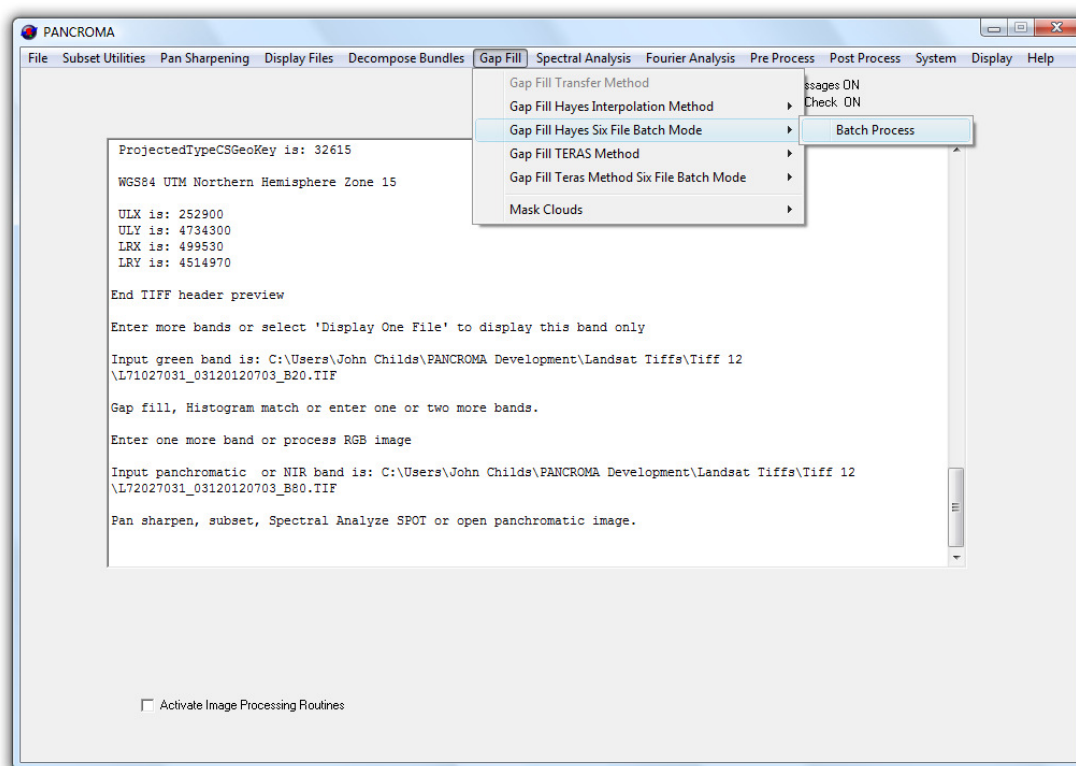


Gap Filled RGB Image

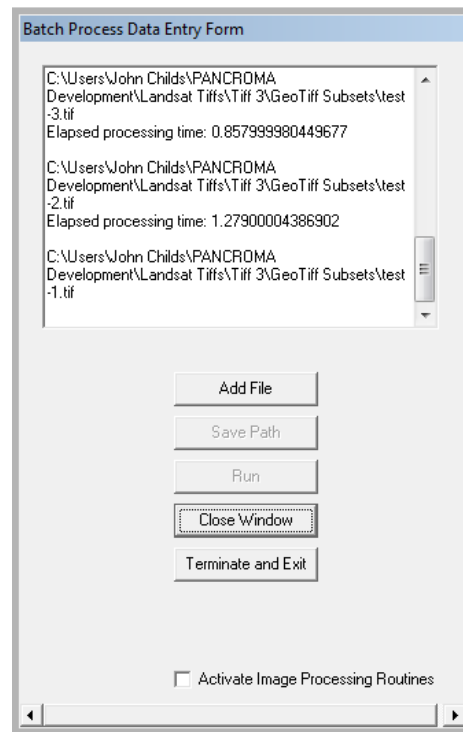
71. Tutorial – Six File Hayes Batch Processing

The Hayes method is a sliding-window method, meaning a small but significant number of computations are required for each pixel in the image. The number of computations is a geometric function of the size of the sliding window that you specify. As a result, the Hayes method can be time consuming. In order to help with this, a batch-processing mode is available for Hayes processing. This will allow you to start two sets of three registered band files (three gap and three no-gap) and run a complete set overnight or in the background.

To get started, you will need two sets of three co-registered band files. That is, the two sets of band files must have the same corner coordinates, the same scale and the same row and column count. Such a set of co-registered data can be prepared from Landsat input data using either the semi-automatic methods or the automatic method described in Section 48. Select 'Gap Fill' | 'Gap Fill Hayes Six File Batch Mode' | 'Batch Process' from the main menu.



When you do so a batch processing data input screen will become available, as shown below.



Add six band files in the order: band1 gap, band1 no gap; band2 gap, band2 no gap; band3 gap, band3 no gap by successively clicking on the 'Add File' button and selecting your files from the dialog box. When all six band files are entered, select 'Save Path'. Select the save file format and the base file name. Then select 'Run'. Processing will take place as in the two file Hayes processing method. As **PANCROMA**TM processes each file, it will save the result, appending the band number to the base file name.

When processing is finished, you will have three gap-filled band files. These files can be combined as usual to create an RGB color image.

72. Tutorial – Gap Filling using TERAS Method

The third **PANCROMA**TM method for filling gaps in Landsat ETM+ images is the TERAS method. TERAS is a modified sliding window, local optimization method. This means that a square frame is established so that the edges of the frame are twice the user-specified searchRadius in length and width. The frame is positioned over the first target Digital Number (DN). Computations are conducted to map the gap DNs to the reference image DNs, using only DNs within the frame. After filling the gaps, the frame is displaced and the process is repeated.

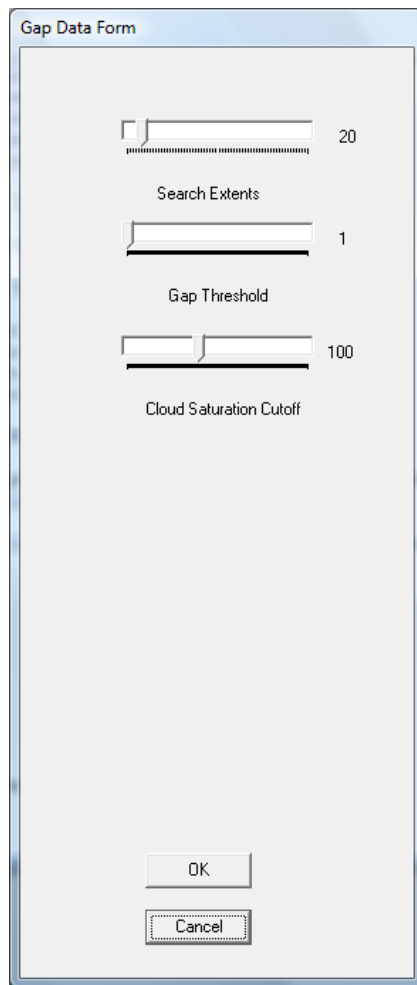
Because the mapping is very localized (for example within a frame of size 20 pixels) with respect to the size of the image, the match is only influenced by the DNs in the immediate vicinity of the center target DN. This can result in a high fidelity match between the filled DNs and the DNs adjacent to the gap.

Using the TERAS algorithm is similar to the Hayes described above. You start the filling procedure by opening first the Reference (grayscale) image (the one with the gaps), followed by the Adjust image. When the images are loaded, select 'Gap Fill' | 'Gap Fill TERAS Method'. A Gap Fill Data Form will appear.

You can select the algorithm parameters: Search Extents, the Gap Threshold and the Cloud Saturation Cutoff. The default values are 20, 1 and 100, respectively. The Search Extents defines the size of the sliding window within which **PANCROMA**TM will look for similar pixels. **PANCROMA**TM will search the target +/- the Search Extents, so the size of the window is twice the Search Extents value.

The Gap Threshold determines which pixels in the Reference image will be computed. Any pixel with a brightness value less than the Gap Threshold will be considered a missing pixel and **PANCROMA**TM will attempt to fill it.

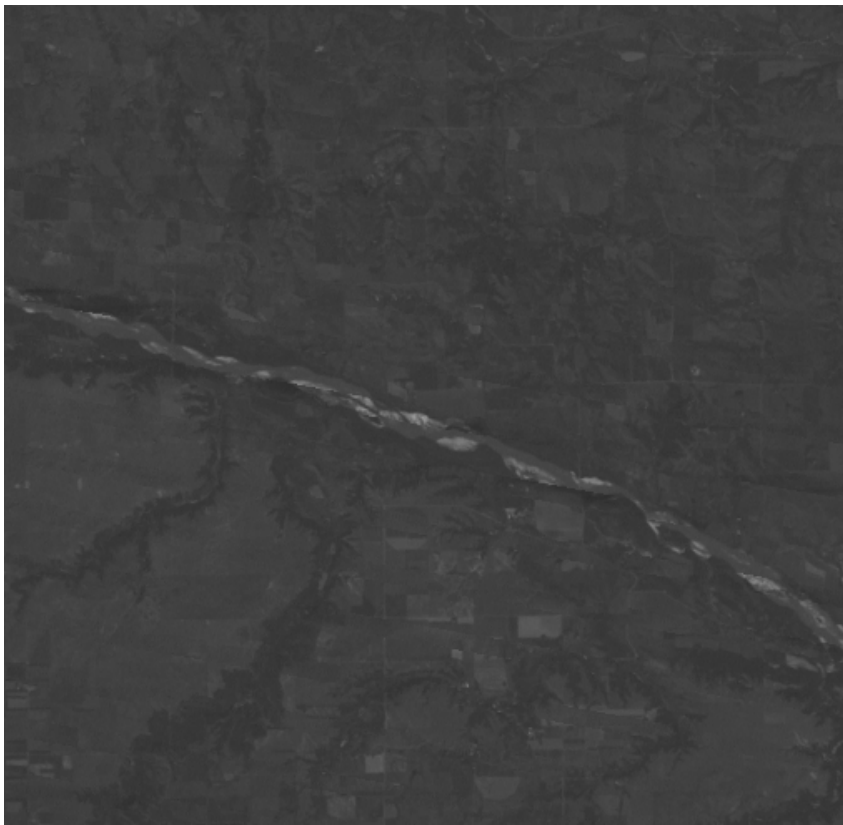
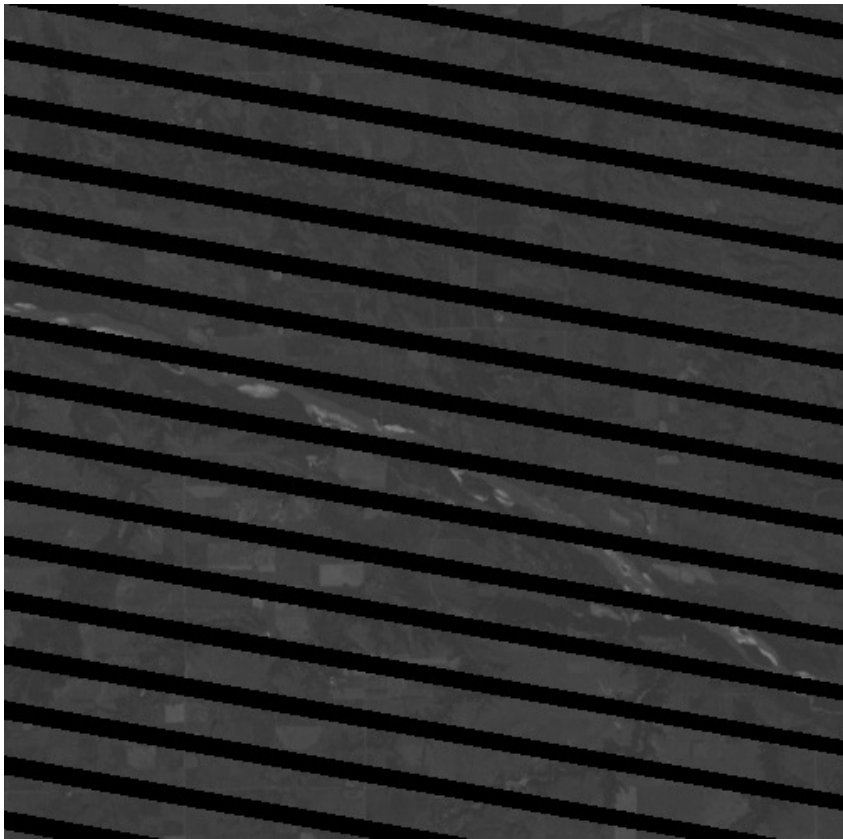
The Cloud Saturation Cutoff value is designed to minimize cloud pixel "blooming". This problem is caused when the Adjust (no gap) image has clouds that the Reference (gap) image does not. These highly saturated pixels can distort the matching computation and will propagate across the entire sliding window frame. In order to avoid this, the algorithm will ignore any pixel with a DN above the Cloud Saturation Cutoff value in its computations. Note that this will mitigate the phenomenon but may not completely eliminate it.

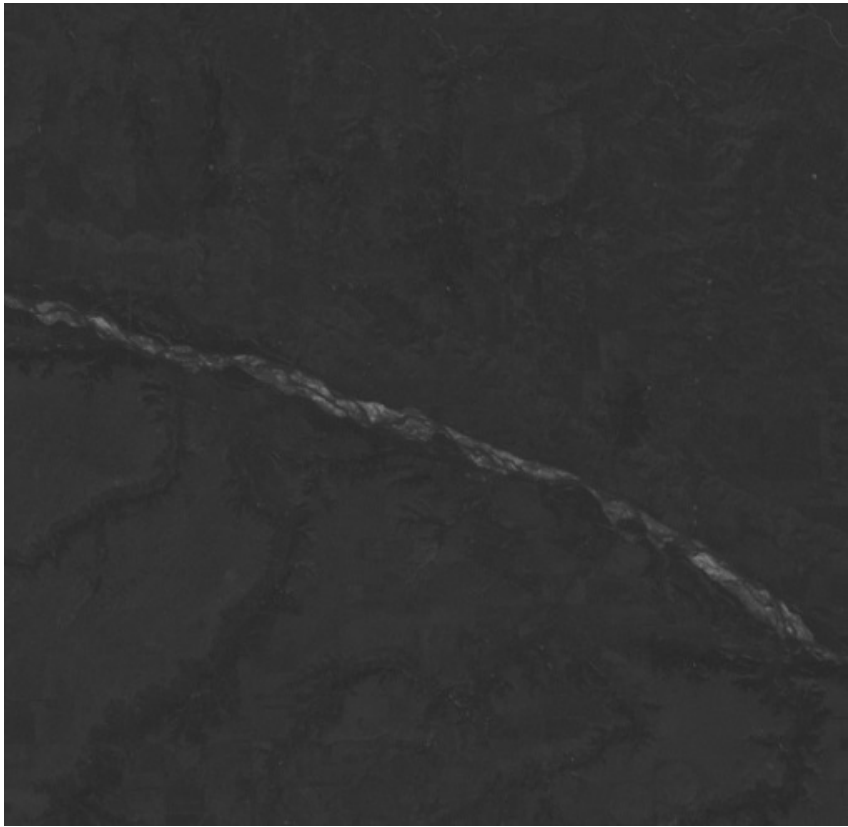


The image shows a 'Gap Data Form' dialog box with a light blue border. It contains four horizontal sliders, each with a label above it and a numerical value to its right. The first slider is labeled 'Search Extents' and has a value of 20. The second slider is labeled 'Gap Threshold' and has a value of 1. The third slider is labeled 'Cloud Saturation Cutoff' and has a value of 100. At the bottom of the dialog are two buttons: 'OK' and 'Cancel'.

Parameter	Value
Search Extents	20
Gap Threshold	1
Cloud Saturation Cutoff	100

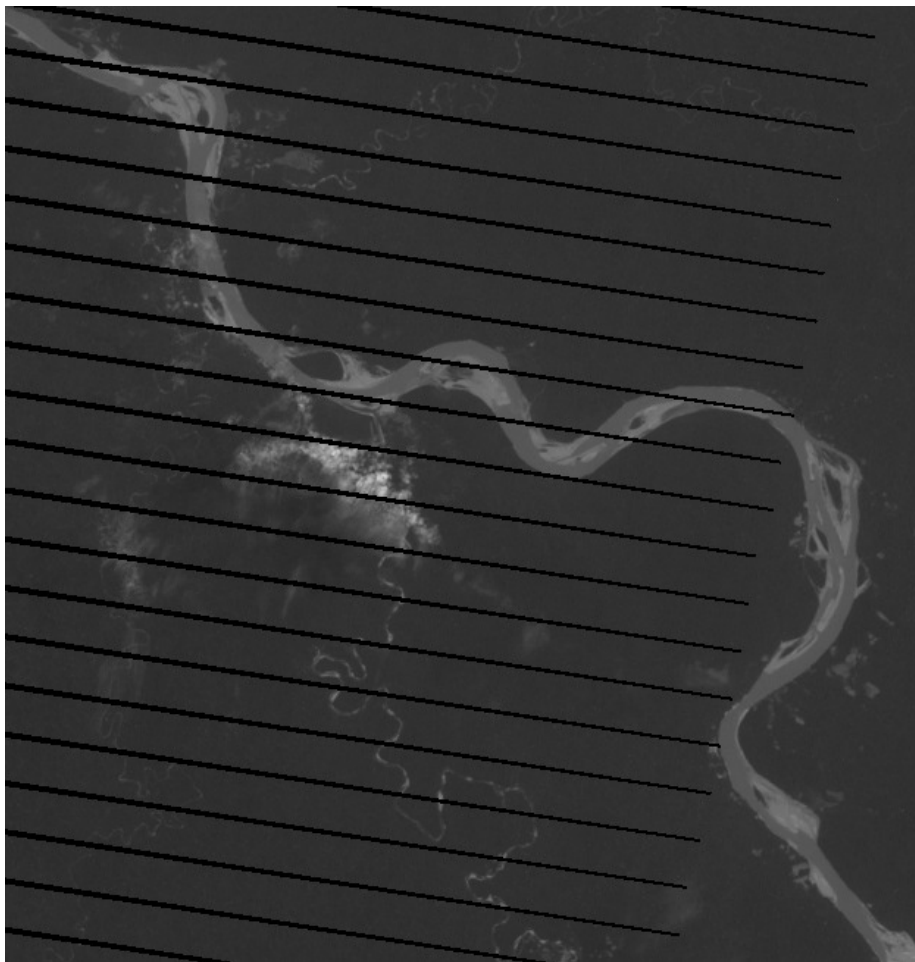
The images below show subsets taken from a Reference gap image, the corresponding filled image, and the Adjust image. The image match very good for this example. The corresponding RGB color composite made from the gap filled images is shown in the fourth image below.





Clouds in the Adjust image can bias the grayscale tone matching algorithm and to distort the gap filled image. The setting of the Cloud Saturation Cutoff will determine the extent of this problem to some degree. The optimal setting can be determined by opening the Adjust image and interrogating the cloud areas to determine the best Cloud Saturation Cutoff setting.

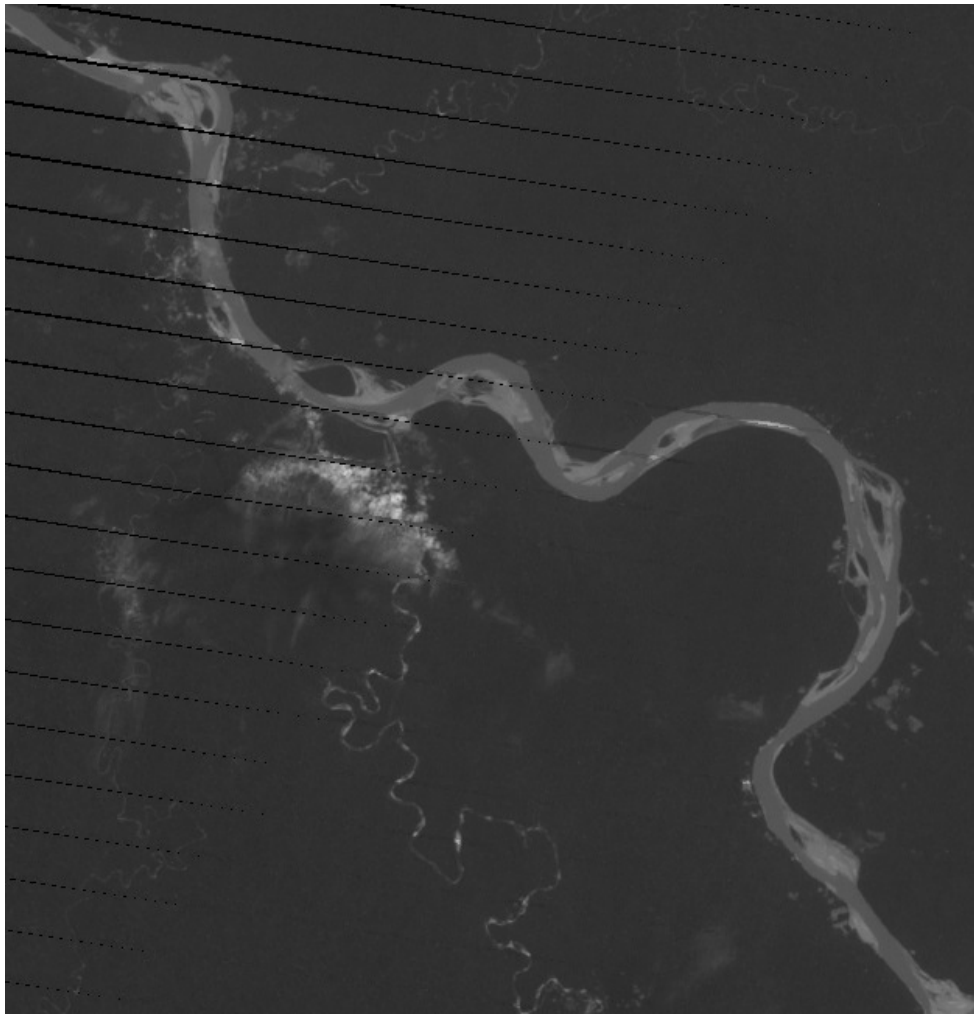
As mentioned in Section 37, it is not necessary to use an SLC-On image in the gap filling procedure. Since the gaps for a given scene will not match exactly, some good information can usually be obtained from a gapped image as well as an ungapped one. The two subset images below are from Landsat Row 5 Path 68 in South America. Both of them are gapped.





It is also apparent that the grayscale tones differ significantly between the two tones. I used the TERAS utility to synthesize data into the first image using information in the second. The result is shown below. Note that TERAS has matched the grayscale tones for the filled pixels very closely, despite the major differences between the two images. The gaps are not completely eliminated because there was some gap overlap between the two images. However the gaps are significantly smaller in the product image. Repeating this process perhaps one more time with a third SLC-Off Landsat scene would probably produce an acceptable image.

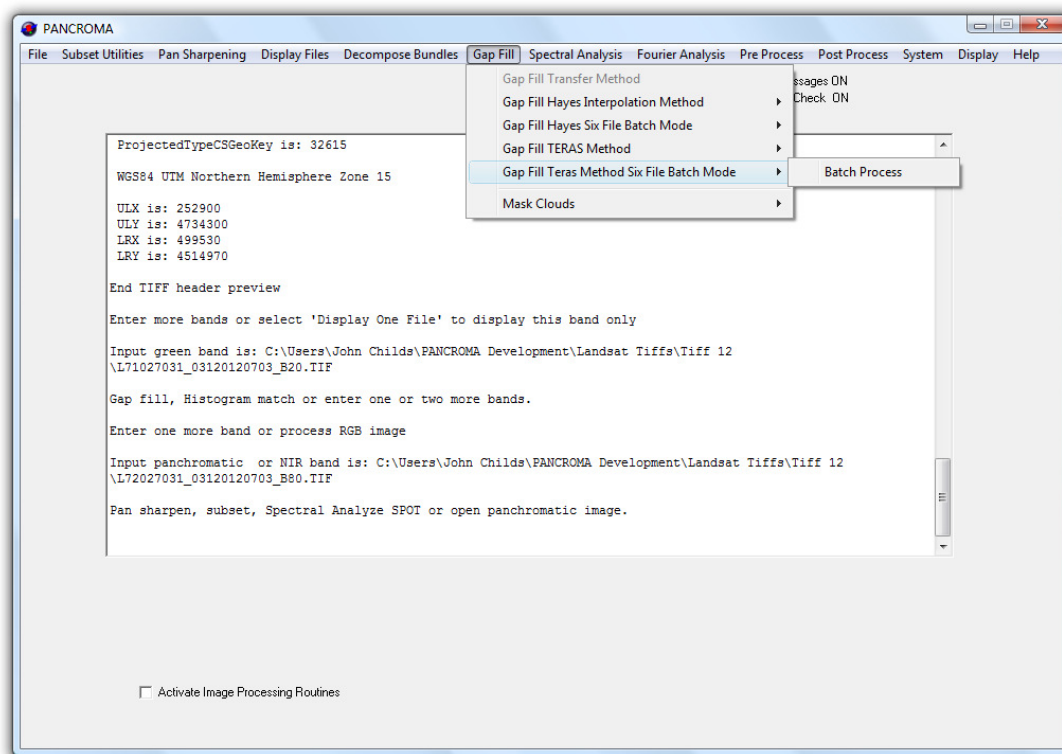
The advantage of using SLC-Off images for gap filling is temporal similarity, i.e. the images are typically acquired much closer together in time than pre-2003 SLC-On data. Although this result was produced with TERAS, the Transfer and Hayes can also be used similarly.



73. Tutorial – Six File TERAS Batch Processing

It is possible to gap fill six co-registered Landsat band files using the TERAS algorithm in exactly the same way that is described in Tutorial 56. Select 'Gap Fill' | 'Gap Fill TERAS Six File Batch Mode' | 'Batch Process' from the main menu.

Add six band files in the order: band1 gap, band1 no gap; band2 gap, band2 no gap; band3 gap, band3 no gap by successively clicking on the 'Add File' button and selecting your files from the dialog box. When all six band files are entered, select 'Save Path'. Select the save file format and the base file name. Then select 'Run'. Processing will take place as in the two file Hayes processing method. As **PANCROMA**TM processes each file, it will save the result, appending the band number to the base file name.



Similar file and data input screens will be presented as with the Hayes method.

74. Tutorial – Pan Sharpen Gap Filled Images

This tutorial describes the process for creating a natural color Landsat image by first gap filling and then pan sharpening the gap filled input files. The described procedure will create four matched multispectral bands and a matched panchromatic band for each of the two file sets: the Reference set (the one with gaps) and the Adjust set (the one without the gaps that will be used to correct the Reference set.) I used a pair of Landsat scenes from Row 91 and Path 76 in southern New Zealand for this example.

The first step is to assemble your five Reference images and five Adjust images: a set of four multispectral bands and a panchromatic band for each. The multispectral bands should include the blue, green, and red and near infrared (NIR) Landsat bands. You will need an exactly matched set of files. **PANCROMA™** provides the necessary subsetting and resizing utilities to produce these. The process will occur in four steps: subsetting, resizing, gap filling, and finally pan sharpening.

To start, select 'File' | 'Open' and open the first file set (you can use either the Reference or the Adjust set). You must open them in the precise order: blue (band1), green (band2), red (band3) panchromatic (band8) and NIR (band4) in your Landsat set. Now select 'Band Combination' | 'Subset Images' | 'Subset Five Bands'. After a bit of processing, the Subset Data Entry box will be presented. Subset the five bands simultaneously by any of the usual means for corner selection: rubber band box, pixel coordinates or latitude and longitude specification. Save the images by selecting 'File' | 'Save Subset Images' | 'GeoTiff' (or whatever format you like) and supplying a base file name like 'reference'. Select 'Close Graphics Window and Reset'. (Note: the images will not become visible until the 'Save' operation.

Now open the second set of five band files as described above. The Subset Data Entry box will again become visible. Notice that the pixel coordinates and the latitude and longitude values from subsetting the first set of images are still in the text boxes. This will allow you to select the same geographical area in the second set that you selected in the first set. Since the two Landsat scenes will differ somewhat in size and in area covered, you cannot select the second set by pixel coordinate value. Instead, select the 'Select by Coordinates radio button and then select 'Enter'.

Note that if you select a subset area in the second set that is outside of the geographic extents of the first set (something that is easy to do if you select an area near the image edges) then you will not get a matching subset. This is because **PANCROMA™** will truncate the selection in order to prevent inputting illegal coordinates. **PANCROMA™** has a feature to automatically select the full

common areas of both scenes. See the Instruction Manual for more information on this feature. When you have successfully subsetted the second set, you can save it as before by selecting 'File' | 'Save Subset Images' | 'GeoTiff and supplying a base file name like 'adjust'. Select 'Close Graphics Window and Reset'.

You now have two sets of subsetted images that have the same corner latitude and longitude coordinates but probably have different row and column sizes. Since the subsequent operations require consistent row and column values, you must resize the larger file set down to match the smaller one. To do this select 'File' | 'Open' and alternatively hover over your Reference and Adjust band files. The size of the tiff files will be reported at the tool tip. Note the row and column dimensions of the smaller set and open the larger four multispectral bands. Note: DO NOT open the panchromatic band at this time. Select 'Pre Process' | 'Resize Images' | 'Resize Four Images'. When the images and the Resize Image Data Entry box becomes visible, enter the row and column dimensions of the smaller file set and click 'OK'. After the images are resized, select 'File' | 'Save Subset Images' | 'GeoTiff and supply a base file name like 'resizedAdjust'. Select 'Close Graphics Window and Reset'.

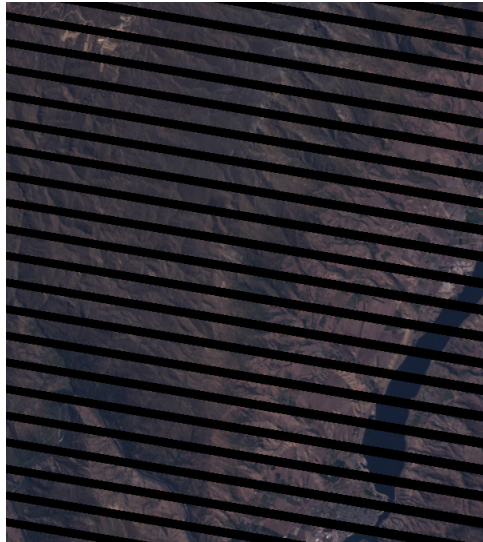
The final step before gap filling is to separately resize the larger of the two panchromatic bands to match the smaller. Again select 'File' | 'Open' and alternatively hover over your Reference and Adjust panchromatic band files to determine and record the row and column count of the smaller set. (Note: the row and column sizes for the two panchromatic bands must be consistent with both sets of multispectral bands, i.e. exactly double AND match each other. If this is not the case additional resizing may be necessary.) Open the larger of the two files and select 'Pre Process' | 'Resize Images' | 'Resize One Image'. When the images and the Resize Image Data Entry box becomes visible, enter the row and column dimensions of the smaller file set and click 'OK'. After the images are resized, select 'File' | 'Save Grayscale Image' | 'GeoTiff and supply an appropriate file name like 'resizedReferneceBand4'. Select 'Close Graphics Window and Reset'. Select 'Close Graphics Window and Reset'.

You should now have two matched sets of five file sets each, one with gaps (Reference set) and one without (Adjust set). The next step is to fill the gaps. This is done exactly as described in previous tutorials and in the Instruction Manual. Open the files pair-wise, first a Reference band (one with gaps) and then the corresponding Adjust band (one without gaps.) For example, start with referenceBand1 and resizedAdjustBand1 (or whatever you naming convention was.) Select 'Gap Fill' | 'Gap Fill Hayes Interpolation Method' or 'Gap Fill' | 'Gap Fill Transfer Method' If you choose the Hayes method, a Gap Fill Data Form will appear. You can then select the algorithm parameters: 'Search Extents', the 'Gap Threshold' and the 'Comparison Radius'. Select 'OK'. After the file is processed, save the gap filled band by selecting 'File' | 'Save Grayscale Image' | 'GeoTiff and supply an appropriate file name like 'gapBand1'. Repeat the process four more

times for the band 2, 3, 4 and 8 (panchromatic) file pairs. When you are done, select 'Close Graphics Window and Reset'.

Now you can pan sharpen you gap filled images as usual using the HSI or Brovey methods as described in previous articles and the Instruction Manual (I used the Hayes method for this example.). I posted results below. The first image is an RGB color composite of the Reference bands showing the extent of the gaps in the original image. The second image is an RGB color composite of the gap-filled bands. The third image is a pan sharpened image produced using XIONG processing and the NIR band.

Gap filling is very necessary and beneficial for SLC-Off Landsat RGB color composites. This article has shown how it can also be applied to pan sharpened images as well.





75. Tutorial - Manual Gap Fill Adjustment Procedure

Although the histogram matching method is very effective, it is possible to effect a match between the Reference and Adjust images using purely manual means. This method can also be used to adjust images that have been histogram matched, to hopefully produce better results. Manual methods can also be used to improve the automatic result. The first step in this process is to load a Reference and Adjust band. Check the 'Activate Image Processing Routines' check box in the **PANCROMA™** main window. Now select 'Gap Fill | Gap Fill ETM+' from the menu.

PANCROMA™ will present the 'Image Processing Data Input' box. Select the 'Enable Channel Level Adjust'; 'Gap Fill Threshold', 'Apply Haze Reduction', 'Apply Contrast Adjust' and 'Save Settings'

IMPORTANT NOTE: Because the image matching process is iterative you will want to save your settings between iterations so you can make changes incrementally.

The 'Channel Level Adjust' slider is the integer value to be added or subtracted from each pixel in the 'Adjust' image. **PANCROMA™** will transfer the value of each pixel in the 'Adjust' image to the corresponding pixel in the 'Reference' image if the pixel value in the 'Reference' image is equal to or below the Gap Fill Threshold value. For example, if the slider value is set at the default value of '30', then if any pixel value in the Reference image is 30 or less, it will be replaced by the corresponding pixel value in the Adjust image. An adjustable threshold is necessary because, unfortunately not all of the Reference image gap pixel values are zero as you would expect. As a result of the Reference image characteristics, gap values may be as high as 20 or 30.

IMPORTANT NOTE: You may wish to use the 'Compute Running Average' utility described below in order to aid in getting the best overall brightness match.

IMPORTANT NOTE: An added complication is that the brightness of each of the three Reference band files is not the same, so it may be necessary to adjust the 'Gap Fill Threshold' to different values for each of the three band images. You will know if the 'Gap Fill Threshold' value is not set high enough if you see dark "speckles" inside the gaps, indicating that, for example a dark pixel with a value of say, 24 did not get replaced because the 'Gap Fill Threshold' value was set at 20.

IMPORTANT NOTE: Setting the 'Gap Fill Threshold' value too high will cause unwanted substitution of valid pixels.

Use the checked image processing utilities to get the best match that you can between the Adjust image and the Reference image. After several iterations of trial and error, I ended up with the image shown below, which I saved as file PROCESS10.jpg:

The following settings are typical in achieving an acceptable manual match:

IMPORTANT NOTE: When you select 'Gap Fill | Gap Fill ETM+' from the menu the Image Processing Data Input box will again appear. **DO NOT ADJUST ANY OF THE SETTINGS.** The idea is to adjust each of the bands equally so not to upset the color balance in the processed image.

Compute Running Average

It is convenient to have an estimate of the average pixel values of the Adjust and Reference images in order to adjust the brightness of the Adjust image to better match that of the Reference image. Although **PANCROMA™** computes the average pixel values for the entire Adjust and Reference images, these are not very useful as the image includes many zero-value border pixels. Snow, clouds and ocean may further skew the average. As a result, it is more useful to interrogate the image at areas of interest only, compute the average for these regions, and then apply an brightness adjustment based on the difference between the two averages.

You can either interrogate the images one at a time or after they are filled. To interrogate them singly, select 'File | Open' and then open a single file, the Adjust image for example. Select 'Display Files'. When the grayscale image is displayed, select 'Display Files' | 'Compute Running Average'. Now place the cursor over the first area of interest and left click the mouse. The average value (current pixel value) will be displayed in the lower right corner of the main window. (You can reset the computation at any time by selecting the 'Reset Average' button.

Now move your cursor to a different location and click again. The average of the two pixels will be displayed. Continue in this fashion, querying as many pixels in as many different locations as you wish. When you are done, write down or remember the average value for the image. Now select 'File' | 'Close Graphics Windows and Reset'. Repeat the above procedure for the Reference image. Compute the difference between the two averages. This is the adjustment factor that you will use to increase or decrease the brightness of the Adjust image in the gap filling process. When you are finished, select 'File' | 'Close Graphics Windows and Reset'. You are now ready to start the gap filling process as described above.

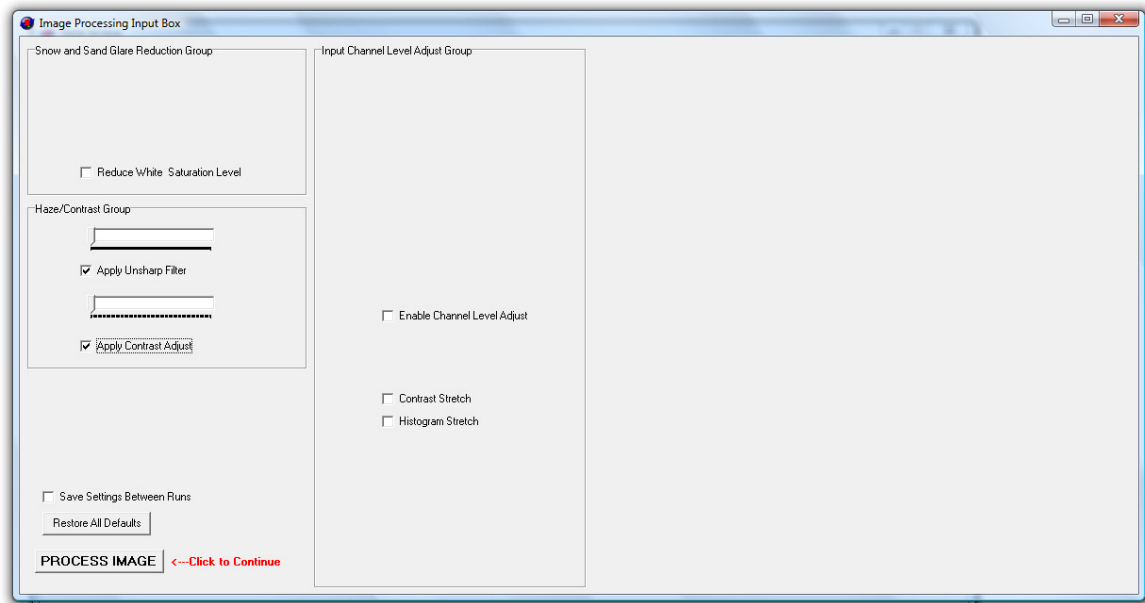
Alternatively, you can estimate the averages during the gap filling process itself. To do this, open the Reference and Adjust images as described in the gap filling

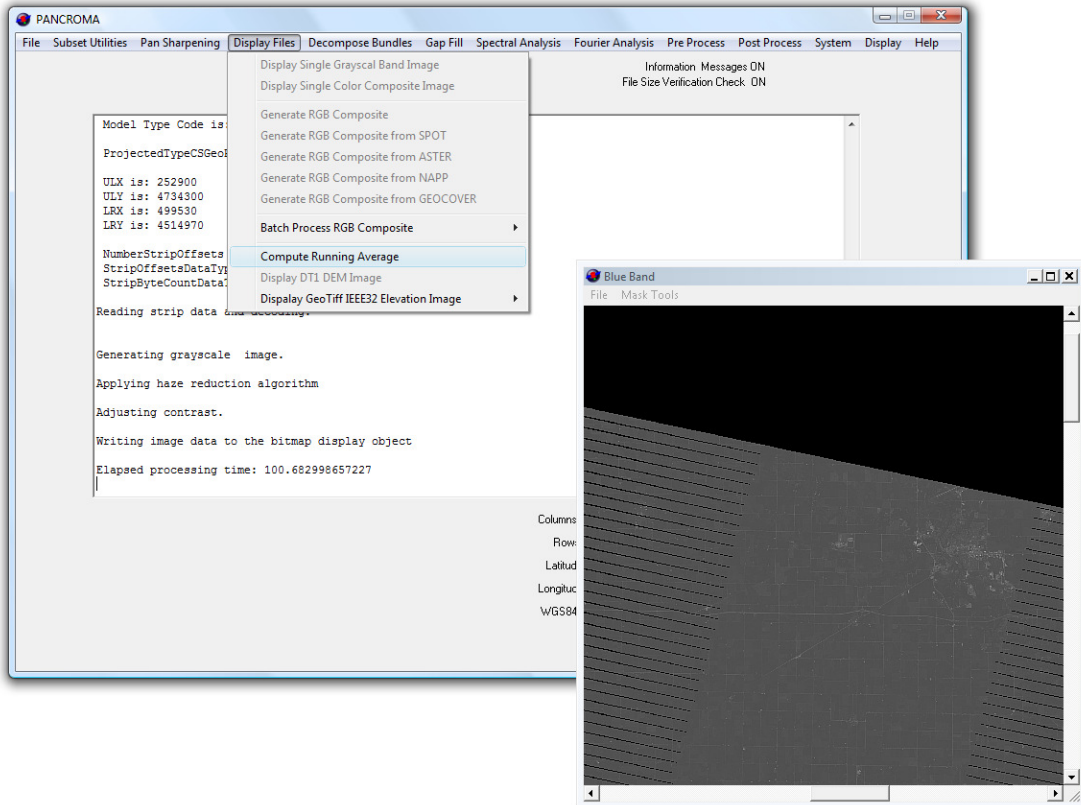
procedure described above. Do not apply any image processing adjustments, that is, leave the 'Adjust Image Processing Routines' check box unchecked.

When the image is displayed, select 'Display Files' | 'Compute Running Average' as before. Using your cursor, interrogate first one image, then the other. That is first query pixels outside the gaps. This will yield an average for the Reference image. Reset the average computation by depressing the 'Reset Average' button. The repeat the query, this time selecting pixels inside the gaps. This will yield an average for the Adjust image. Now subtract the Reference average from the Adjust average. This is the value that should be added to the Adjust image brightness in the next step. (Of course if the value is negative, the number is subtracted from the Adjust brightness).

When you are finished computing the two averages, select 'Gap Fill | Gap Fill ETM+' again, this time with the 'Adjust Image Processing Routines' check box checked. Using the 'Gap Adjustment Level' slider bar, adjust the brightness, adding or subtracting the average difference number computed above to every pixel in the image.

You may wish to combine this technique with contrast adjustment and haze reduction as described in the tutorial below in order to get the best results, but this technique provides a good starting point.

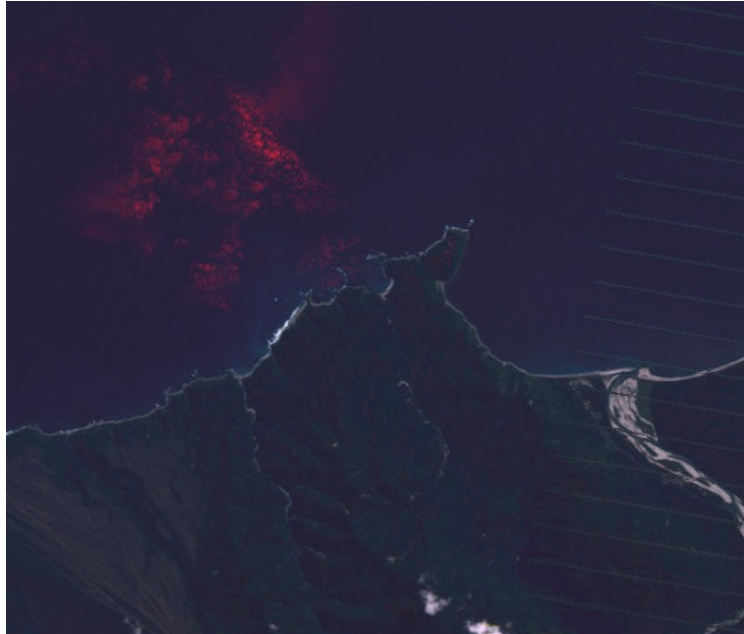




Issues

Although the gap filling process can transform an unusable image to a useful one, various difficulties can remain. The most obvious one is problems with snow and cloud covered areas. The if the Adjust image was acquired during a different season than the Reference, the foliate and snow cover could be very different.

Another interesting artifact is the 'red cloud' phenomenon.



This is the result of Adjust file pixels being transferred to the ocean in the red band. Since the ocean does not reflect too much red light, the ocean is especially dark in this band. The **PANCROMA™** gap fill algorithm interpreted the dark ocean pixels as gap pixels and copied the ocean area from the Adjust file. This did not happen in the blue and green bands as the ocean pixels were brighter in these bands. This may have been avoided by setting the 'Gap Fill Threshold' value lower. However this may have resulted in some real gap pixels not being filled.

Gap filling Landsat bands to produce good results is very challenging and time consuming. However, important images may well merit the time invested. Note that although I gap filled an RGB image, gap filling the RGB and PAN files would proceed in an analogous fashion.

76. Tutorial - Pan Sharpening Landsat with SPOT

One of the main advantages of the SPOT1 through SPOT4 over Landsat data is its slightly higher resolution. Landsat band files are approximately 30m resolution with a 15m panchromatic band. SPOT[®] on the other hand has 20m band files and a 10m panchromatic band. The disadvantage of SPOT[®] is that it does not have a visible blue band. As a result, if you want to create pan sharpened natural color RGB images from SPOT[®], you have to first synthesize the natural color bands from the three false color bands using a utility such as the one offered by PANCROMA. This can work reasonably well but even after a fair amount of effort the results will never be perfect. So one is left with either a true color pan sharpened RGB image at the lower 15m resolution or else a synthetic RGB image at the higher 10m resolution.

A third possibility is to use the SPOT[®] panchromatic band to pan sharpen the Landsat band files. **PANCROMA**[™] has the necessary utilities to do this, and the results can be quite satisfactory.

The first step is to locate your Landsat and SPOT[®] files. You will need three Landsat band files and a corresponding SPOT[®] panchromatic band. This procedure works best if the following conditions are met:

- Use ortho images if available.
- Both images should share the same projection and if possible the same datum.
- Both images should be relatively cloud free.
- It is OK if there is some mountain snow but it is better if there is none. If snow coverage exists, it should be similar in both images.

Select your SPOT[®] scene first. Select the Landsat scene so that it completely surrounds the SPOT scene. That is, the SPOT scene should be located completely within the bounds of the Landsat scene. This is not too hard to do because Landsat scenes cover an area approximately 185 km by 185 km while SPOT scenes cover an area of 60 km by 60 km.

Download the SPOT[®] panchromatic band. Record the latitude and longitudes of its upper left and lower right corner coordinates. Now select and download the three Landsat band files, i.e. band1, band2 and band3 (blue, green and red) according to the rules above. Subset the Landsat bands by opening the files as usual. In my case I subsetting the Landsat image to the SPOT[®] set of corner coordinates. Select 'Band Combination'|'Subset Images'|'Subset Three Bands'. When the Subset Input Box appears select the 'Select by Coordinates' radio button. Now enter the upper left and lower right corner coordinates that you recorded previously. These are the corner coordinates of the SPOT[®] scene. If

they do not occur within the Landsat image, you have made an error. Select the 'Enter' button. The data entry box will disappear and the subset images will be displayed. Now save the three subset images in GeoTiff format by selecting 'File'|'Save'|'Save Subset Images'|'GeoTiff'.

The next step is to compare your subset Landsat and SPOT[®] panchromatic images. They should cover exactly the same area. The SPOT[®] rows and columns should be exactly three times those of the Landsat Subset images. Often the rows or columns will be off by one. This must be corrected by resizing whichever is larger down to the smaller dimension. If the panchromatic band is larger, resize it by selecting 'Pre Process' | 'Resize Images'. Select 'Resize One Image' if the panchromatic band is larger or else 'Resize Three Images' if the Landsat bands are larger.

Once you have checked your images and resized if necessary, the Landsat band files can be pan sharpened using the SPOT[®] panchromatic band as usual.

If desired you can also use the five file XIONG algorithm **PANCROMA[™]** will subset a four file bundle of the three visible spectrum bands plus the NIR band. After subsetting, the pan sharpening proceeds as normal except of course that the SPOT panchromatic band is again used.

77. Tutorial – Image Processing Workflow

This tutorial walks you through a typical workflow for some of the more complicated combinations of image processing tasks. The example task for this exercise is as follows:

Given: two Landsat data sets for Row 74 Path 91 (Southeast New Zealand)

L71074091_09120050303_B10.TIF	Post 2003 SLC-Off (Gap)
L71074091_09120050303_B20.TIF	30m/pixel
L71074091_09120050303_B30.TIF	8421 Rows
L71074091_09120050303_B40.TIF	7421 Columns
L71074091_09120050303_B50.TIF	Standard Transformation
L71074091_09120050303_B80.TIF	

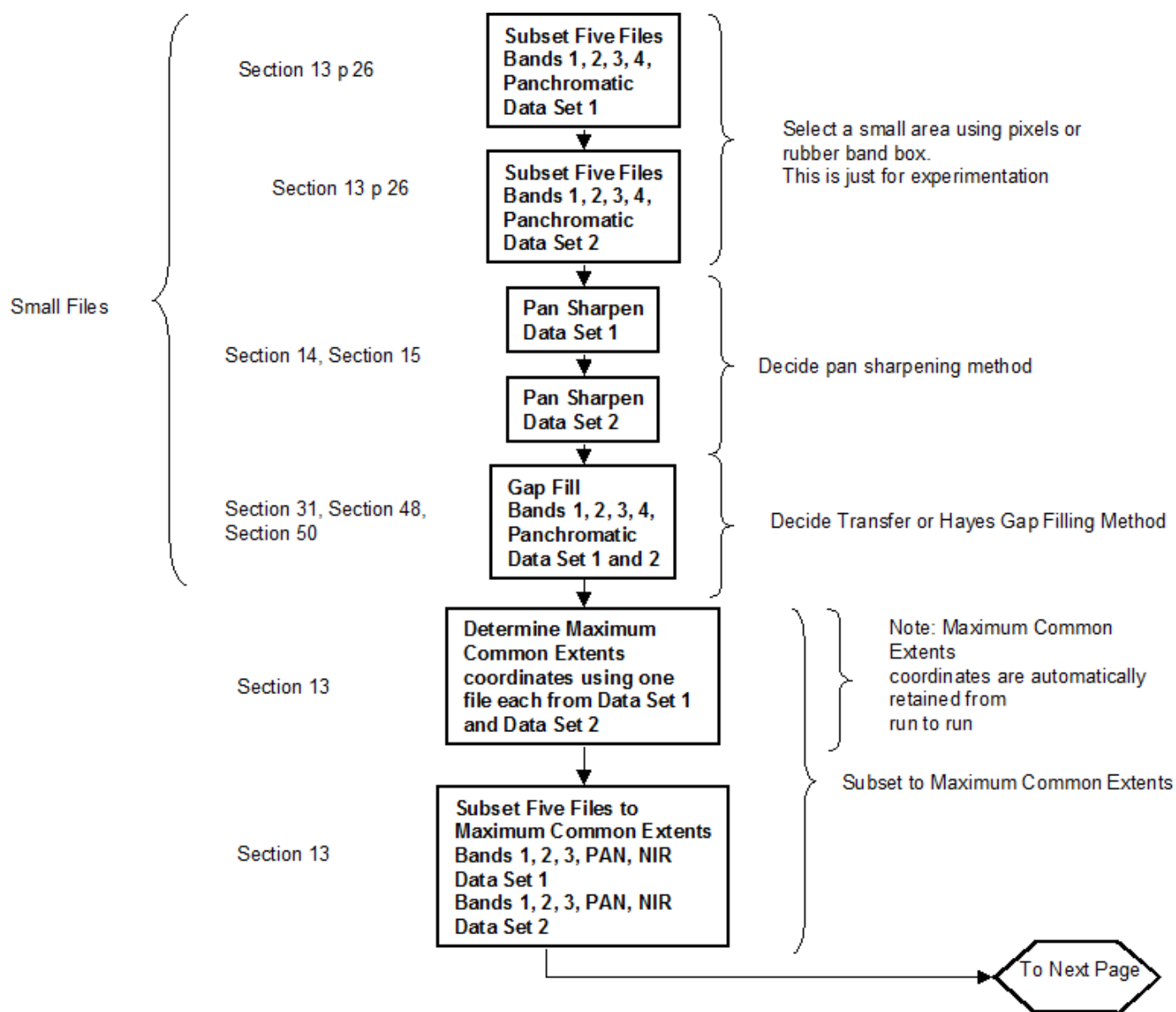
p074r091_7dt19991216_z59_10.tif	Pre 2003 SLC-On (No Gap)
p074r091_7dt19991216_z59_20.tif	30m/pixel
p074r091_7dt19991216_z59_30.tif	8596 Rows
p074r091_7dt19991216_z59_40.tif	7620 Columns
p074r091_7dt19991216_z59_50.tif	Affine transformation
p074r091_7dt19991216_z59_80.tif	

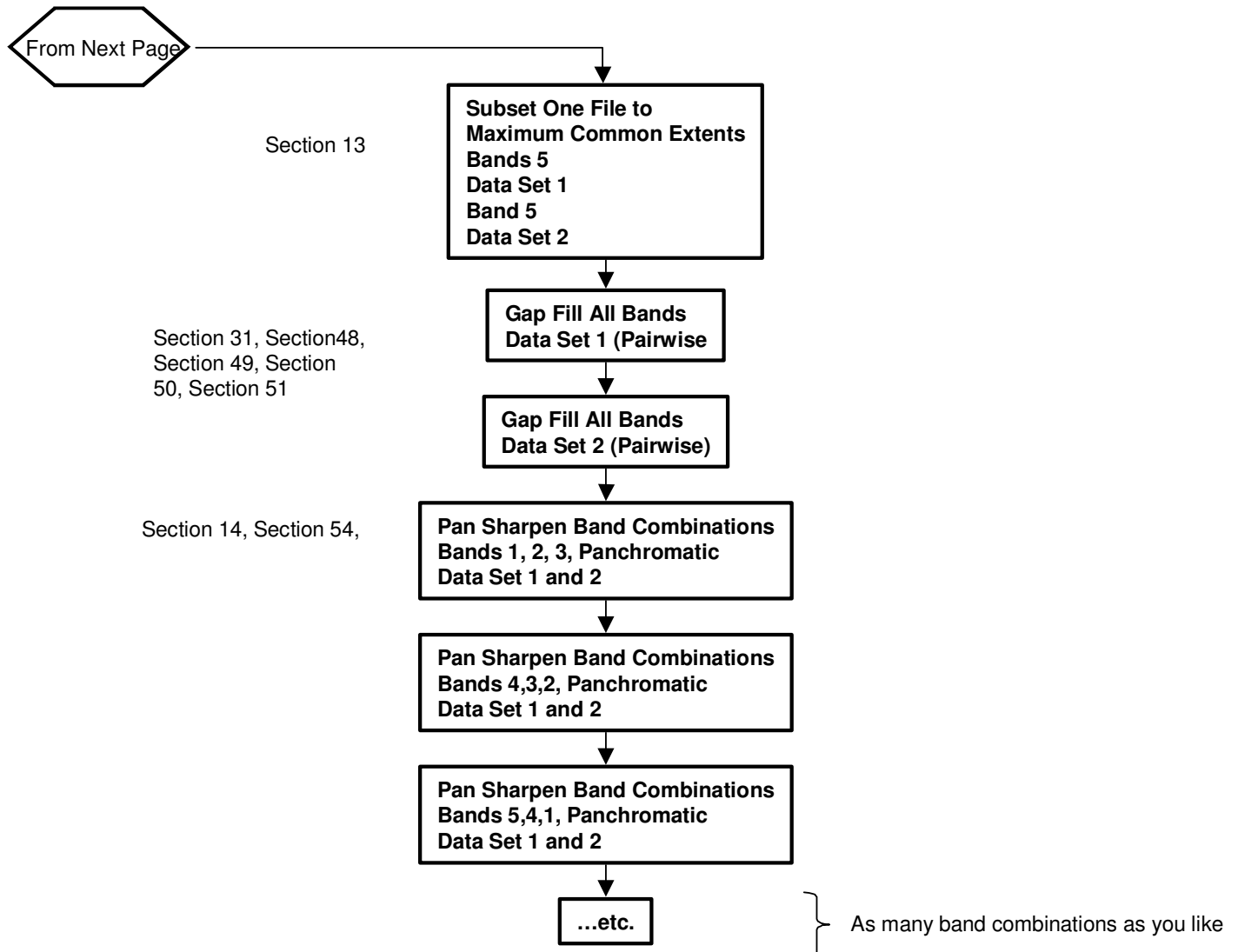
Task:

- Fill the gaps
- Pan Sharpen bands 1, 2, 3
- Pan Sharpen bands 2, 3, 5

The suggested workflow is shown below. The general process is as follows:

- Prepare small subsetting data bundles using bands 1, 2, 3 and the panchromatic band for each of the two Landsat scenes. The purpose of this set is to experiment to select the best algorithms and to identify the optimum parameters for these algorithms
- Subset the two scenes to their Maximum Common Extents (MCE) coordinates using automated **PANCROMA™** features. (Maximum Common Extents are the areas of maximum common overlap between the two Landsat scenes). During this process, the row and column counts will be rationalized
- Gap fill the MCE band and panchromatic files
- Pan sharpen the gap filled MCE band and panchromatic files





The first step is to subset the two Landsat scenes to an arbitrary subset size. The corner coordinates of the two subset scenes should be the same. This is relatively easy to do because PANCROMA will “remember” subset coordinates from a first subsetting operation so that you can apply them to a second subsetting operation. Lets see how this works.

I opened my first Landsat scene, files L71074091_09120050303_B10.TIF, L71074091_09120050303_B20.TIF, L71074091_09120050303_B30.TIF, L71074091_09120050303_B80.TIF and L71074091_09120050303_B50.TIF by selecting ‘File’ | ‘Open’ and opening them in that order. I then selected ‘Band Combination’ | ‘Subset Images’ | ‘Subset Five Images’. My subset coordinates were:

ULX is: 555990
ULY is: -4857180
LRX is: 573330
LRY is: -4878240

These coordinates were chosen to include some land and some water, since this scene includes both. I saved the files in TIFF format by selecting ‘File’ || ‘Save Subset Images’ | ‘GeoTiff’. **PANCROMA™** automatically saved them as:

minorBandAband1.tif
minorBandAband2.tif
minorBandAband3.tif
minorBandAband4.tif (this is the panchromatic band)
minorBandAband5.tif (this is the NIR band)

I then selected ‘Close Graphic Images and Reset’ to reset PANCROMA.

I then repeated the process for files p074r091_7dt19991216_z59_10.tif, p074r091_7dt19991216_z59_20.tif, p074r091_7dt19991216_z59_30.tif, p074r091_7dt19991216_z59_40.tif and p074r091_7dt19991216_z59_50.tif

To do this I opened the files as before and again selected ‘Band Combination’ | ‘Subset Images’ | ‘Subset Four Images’. When the Subset Data Entry Form appeared, the corner coordinates listed above were already entered into the coordinate text boxes. I checked the ‘Select By Coordinates’ radio button and clicked ‘Enter’. The subset bands for the second scene were computed. I saved these files as before in TIFF format as:

minorBandBband1.tif
minorBandBband2.tif
minorBandBband3.tif
minorBandBband4.tif (this is the panchromatic band)
minorBandBband5.tif (this is the NIR band)

I again selected 'Close Graphic Images and Reset'. Both subset scenes had 578 Rows and 702 columns with the same corner coordinates and of course the same scale so no further processing was necessary.

Since 78% of the 'A' scene would be output as compared to only 22% of the 'B' scene (no gap) I wanted to get the pan sharpening parameters correct for the 'A' scene. To do this I pan sharpened bands 1, 2 and 3 with the panchromatic band using the HSI algorithm. I first generated the 30m RGB rendering for reference by opening bands 1, 2 and 3. I checked the 'Maintain RGB Comparison Image' so that the 30m RGB band rendering would be maintained during subsequent pan sharpening. I then selected 'Band Combination' | 'Generate True RGB Color Composite'. Then I selected 'Close Graphic Images and Reset'.

Now for the pan sharpening. I opened bands 1, 2, 3 and the panchromatic subset bands. I then selected 'Pan Sharpening' | 'HSI Transform' | 'Standard Four File'. I accepted the default iterations. The pan sharpened image was computed. The 30m RGB color composite and the pan sharpened images are shown below. (The pan sharpened image is shown at half-scale).



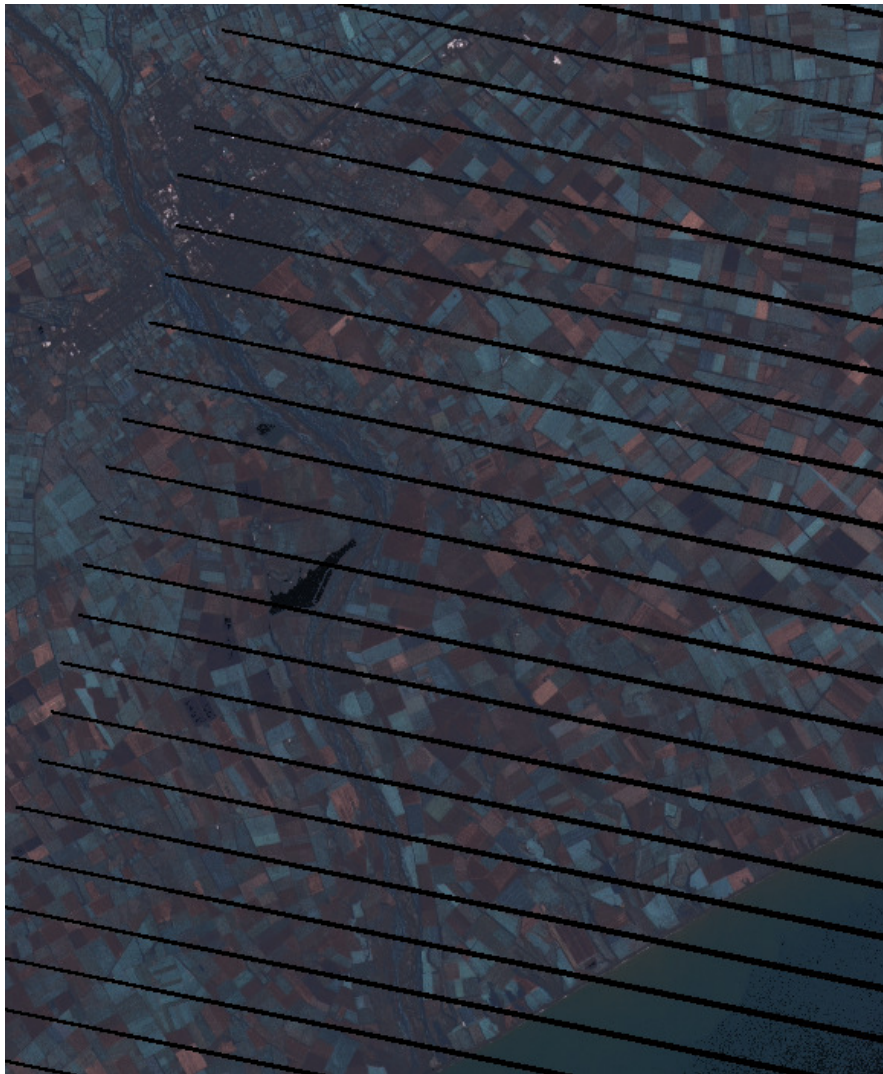


The vegetation color tones do not match very well as a result of spectral distortions introduced by the Landsat panchromatic band. To correct this I tried XIONG processing using the default values. XIONG processing requires the NIR band in addition to the four bands required for HSI processing. Since we already produced the subset NIR bands by using the five file subset utility, we are ready to go.

I selected 'Close Graphic Images and Reset' again and then opened five files in this order:

minorBandAband1.tif
minorBandAband2.tif
minorBandAband3.tif
minorBandAband4.tif
minorBandAband5.tif

I then selected 'Pan Sharpening' | 'HSI Transform' | XIONG Five File (Automatic Method)'. I accepted the default iterations. My resulting pan sharpened image is shown below.

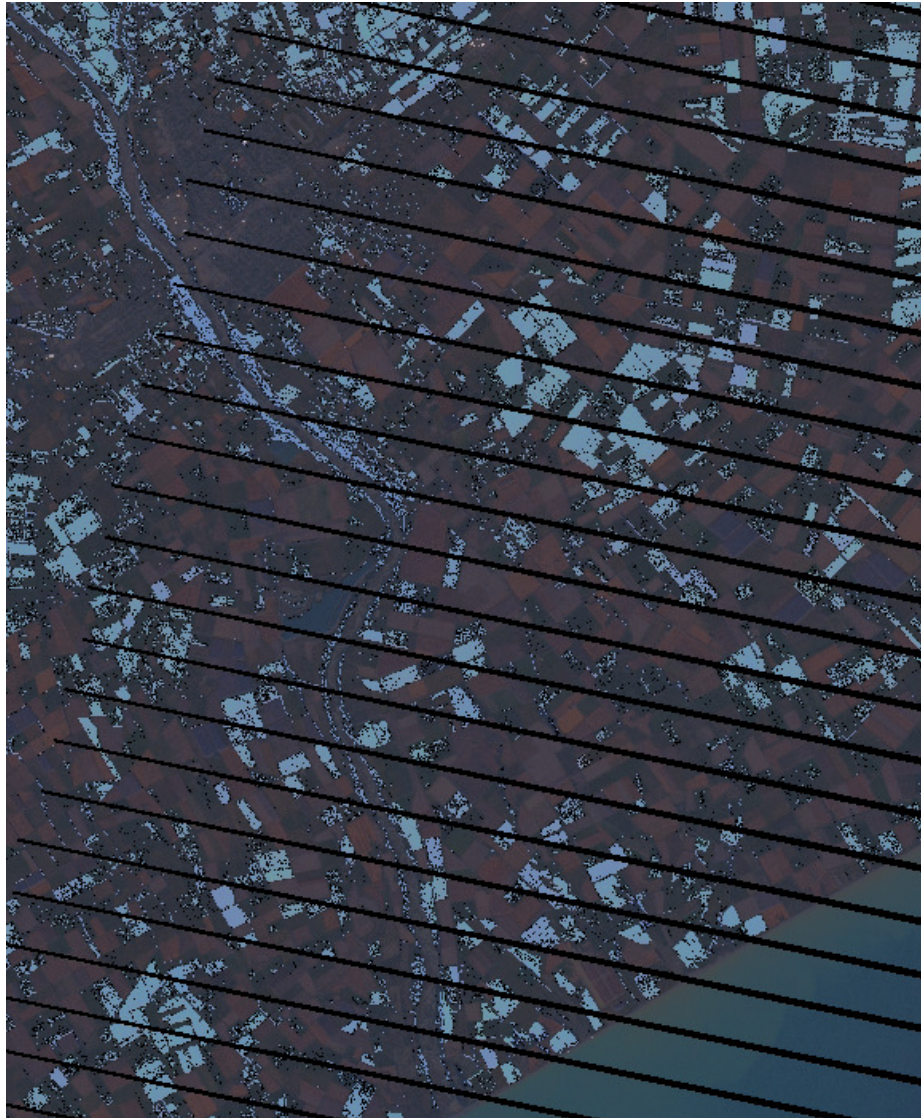


This is no improvement over the straight HSI result. I suspected that the 'alpha' multiplier that is applied to the NIR band before it is subtracted from the panchromatic band might be too small, resulting in not enough correction being applied. I made a second run with $\alpha=70\%$. To do this I selected I selected 'Close Graphic Images and Reset' again and then opened five files in this order:

minorBandAband1.tif
minorBandAband2.tif
minorBandAband3.tif
minorBandAband4.tif
minorBandAband5.tif

I checked the 'Activate Image Processing Routines' and I then selected 'Pan Sharpening' | 'HSI Transform' | XIONG Five File (Automatic Method)' as before. I again accepted the default iterations. When the image processing data entry box became visible, I moved the 'XIONG Scale Factor' slider bar to '70' and selected 'Process Image'

My resulting pan sharpened image is shown below.



OK, now we are getting somewhere. The vegetation tones are correct but most of these areas are saturated (light blue color). This is an indication that the subtraction has forced negative grayscale pixel values in the adjusted panchromatic band, which PANCROMA did not allow. Instead it inserted a default value equal to the average image pixel value in these instances. What we have to do is back off on the alpha factor until the saturation disappears while

the vegetation tones are still normal looking. I repeated the above operation using $\alpha = 65$. The result is shown below:



We are almost there. My last run was $\alpha = 50$. This result is shown below:



The color tones are acceptably close to the 30mRGB image generated earlier. However, there are some artifacts that are the result of the image processing required to get these tones. As a check, I also made an AJISANE run to see how this would compare. To do this, I reset PANCROMA by selecting 'Close Graphic Images and Reset'. I then opened the same five band files as for XIONG in the exact same order. I checked the 'Activate Image Processing Routines' and I then selected 'Pan Sharpening' | 'HSI Transform' | AJISANE Five File Transform' | 'Simple'. I added 22 units of blue, green and red pixel levels by checking 'Enable Channel Level Adjust' and also 'Lock RGB Color Ratio'. I grabbed one of the sliders and moved it to '22'. I checked 'Apply Haze

Reduction' and then 'Apply Contrast Adjust' and added 285 and 1017 units of each, respectively. My results are shown below:



Although this image does not suffer from the dark artifacts of the XIONG run the tones are not right. This is definitely a difficult image. I accepted the XIONG image as optimal.

The next step was to attempt a subset-level gap fill. Gap filling must currently be done on a pair wise basis, i.e. first the two band1 file pair, then the band2 file pair, etc. To get started, reset PANCROMA by selecting 'Close Graphic Images and Reset' as usual. Open the band1 subset file with the gaps first, then the

band 1 file without the gaps. In my case 'File' | 'Open', opening minorBandAband1.tif and then minorBandBband1.tif. Now select 'Gap Fill' and then 'Gap Fill Transfer Method'. Your first gap filled grayscale band1 file will be produced. Save it as band1Transfer.tif or the like. Select 'Close Graphic Images and Reset' and gap fill the band2 pair, then band3, band4 and finally the band5 pair using the same procedure.

As a check, I first created an RGB composite using the gap filled bands 1, 2 and 3. This image is shown below.



This does not portend well. The gaps are filled and the registration looks good but the cultivated fields are going to be a problem! It looks like the images were

acquired during different seasons or else the crop rotation is out of sync between the two images. Lets go ahead and pan sharpen it anyway to see what that looks like. To do so, proceed exactly as described above, except use the gap filled bands 1 through 5 instead of the gapped images. My result of XIONG sharpening, using the parameters from the experiment above (XIONG factor=50) yielded the following result:



This image is pretty rough. Part of the problem was that the band5 image pair was not very well behaved. The histogram match drove the ocean pixels in the non-gap band5 file to zero. I had to revive them by adding some brightness to the image. This had the effect of distorting the ocean region gaps and causing

other problems with the image. I decided to try Hayes method gap filling to see if this produced better results.

I gap-filled the first three pairs of band files using the Six File Hayes method. Before opening any files, select 'Gap Fill' | 'Gap Fill Hayes Interpolation Method' | 'Six File Set'. When the data entry box opens, select 'Add File'. When the dialog box opens, select the band1 gap file and click 'Open'. Repeat for the band1 no-gap file. Then repeat for two more successive pairs, i.e. the band2 pair and the band3 pair. Now click 'Save Path' and enter a root file name. As usual, PANCROMA will append a band number on the saved output file. Now select 'Run'. Another data entry box will open. This box lets you select the sliding window parameters, like the window size and pixel selection criteria. You can just accept the defaults. When PANCROMA is done processing, it will save your files. You must then process the remaining band4 and band 5 pairs one pair at a time. To do this select 'Close Graphic Images and Reset', then select 'File' | 'Open' and open the band4 gap and band4 no-gap files. Then select 'Gap Fill' | 'Gap Fill Hayes Interpolation Method' | 'Two Files'. Accept the default settings and save your file manually. Select 'Close Graphic Images and Reset' and then repeat for your band5 pair.

When I had my five Hayes gap filled files I pan sharpened again, using the same settings as before. My results are shown below. The first file is an RGB composite from bands 1, 2 and 3.



The next image is the pan sharpened scene at half scale.



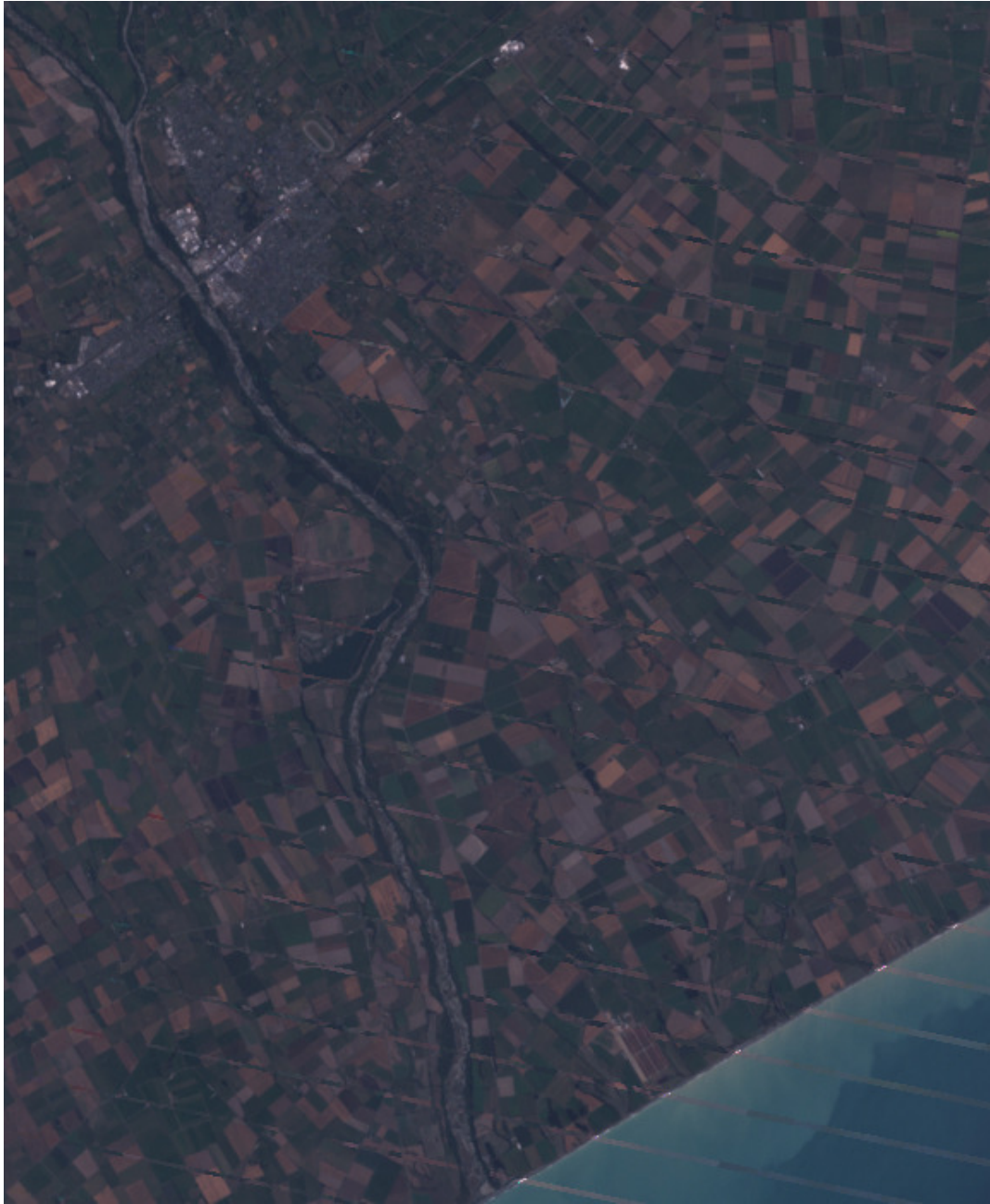
This image is better than the Transfer gap filled result but still has a lot of issues. As a result, I went back to the AJISANE method to see what this would produce. My result is shown in the next image.



This image looked a little muddy so I pushed the Haze Reduction and Contrast resulting in the following image. The color tones have been somewhat lost but the heightened contrast helps the image overall. The optimal images are probably the Hayes XIONG and the Hayes AJISANE enhanced contrast below.



I also prepared an image using the SPECTRAL algorithm, as described in Section 24 and in the article in the White Papers web page. This image is shown below. The color tones are an excellent match but the image resolution is not as good as for AJISANE or Hayes.



This turned out to be a difficult image. The main problem was the mismatch in the cultivated fields that I could never really rationalize. However, considerable image processing was able to produce a couple of promising pan sharpened subset images. The next step is to apply the subset results to the full size Landsat scenes.

Full sized Landsat scenes can be processed in a way that is similar to preparing smaller subsets. I used **PANCROMA™** five file utility to get started. This utility automatically subsets a set of five band files, typically band1, band2, band3, the panchromatic band, and the NIR band. to the maximum common area shared between them. However, I needed the Maximum Common Extents coordinates to do so I first selected 'File | 'Open' and opened L71074091_09120050303_B10.TIF and p074r091_7dt19991216_z59_10.tif. I then selected 'Band Combination' | 'Subset Images' | 'Compute Maximum Common Extents'. The coordinates of the maximum overlap area was computed as follows¹:

```
Maximum Extents Coordinates:
upperLeftX is: 406200
upperLeftY is: -4828800
lowerRightX is: 658830
lowerRightY is: -5050830
```

I then clicked 'Close Graphic Images and Reset', and selected 'File | 'Open' and opened five band files from the first scene:

```
L71074091_09120050303_B10.TIF
L71074091_09120050303_B20.TIF
L71074091_09120050303_B30.TIF
L71074091_09120050303_B80.TIF
L71074091_09120050303_B40.TIF (enter in this order!)
```

I then selected 'Band Combination' | 'Subset Images' | 'Subset Five Bands'

After a while, a data entry box was presented. **PANCROMA™** retained the Maximum Common Extents coordinates. After a few minutes the subsets were computed. I selected 'File' | 'Save Subset Images' | 'Geotiff' and gave the subsetted files the root name 'MCEA'. I clicked 'Close Graphic Images and Reset' and then repeated the process for the second set of five files from group B (no gap):

```
p074r091_7dt19991216_z59_10.tif
p074r091_7dt19991216_z59_20.tif
p074r091_7dt19991216_z59_30.tif
p074r091_7dt19991216_z59_80.tif
p074r091_7dt19991216_z59_40.tif
```

¹ Note: The panchromatic band for the gap set actually falls one pixel and 15m short of the band file MCE coordinates. The Five File subset utility will usually handle this off-by-one Landsat issue. However, other PANCROMA™ utilities may not. For example, if I had chosen the Six File method, it would have been necessary to manually adjust the computed MCE coordinates down by 30m (not 15m!) from the computed values.

The MCE coordinates were still retained. I saved these files as 'MCAB'. Finally, I subsetting the band 50 files singly, still using the retained MCE coordinates. I now have two sets of six band files each with the same corner coordinates, scales and row and column counts (the panchromatic rows and columns are double the band file counts and the scales are 15m per pixel rather than 30m per pixel of the band files.)

The next step is gap filling. This is done exactly as described for the small subset files, starting with the six file method selecting 'Gap Fill' | 'Gap Fill Hayes Interpolation Method' | 'Six File Set'. (This computation will take a while). At the completion of the run I saved the files, and then gap filled the panchromatic bands and bands 40 and 50 pair wise as before.

The final step was to compute the full sized RGB composite and pan sharpened images. This was done exactly as before, except using the full sized gap filled images instead of the small subset images. A complete set of the entire example files for this exercise, plus the output images are available for download from the PANCROMA™ customer ftp site. If you are interested in obtaining access to these files, please email me at jchilds@terrainmap.com.

This file set was not very well matched, and presented a lot of processing issues. The major take-away from the exercise is that it pays to spend more time up front obtaining as close a match of the gap and no-gap images as possible. The techniques I used for this example are not the only ones that could have been used. Hopefully however, this Tutorial gave you some ideas about PANCROMA™ satellite image processing capabilities.

78. Tutorial – Improving Image Quality with Regression

PANCROMA™ has utilities for conducting multiple linear regression on satellite band files. Such linear regressions can have many uses. One of the most interesting is to conduct image transformations in order to improve the color tones of processed images. The transformation equations used to approximate natural color composites from ASTER and SPOT multispectral composite images are one example. The equation coefficients for these transformations were determined by processing a large number of images and optimizing the coefficients for the general case. As a result, the transformations usually produce acceptable results for most cases but rarely yield ideal results for a particular case.

The procedure outlined in this article is designed to create image-specific transformation equations using multiple linear regression to compute the coefficients. The main advantage of this approach is that the transformation equation is optimized for the particular target image of interest, and can often yield improved results over a general transformation equation.

The objective of this example will be to improve the color tones of a pan sharpened image produced by the HSI pan sharpening process. However the technique outlined can be used to create a transformation equation for any image, as long as a suitable reference image is available, as will be shown below.

As discussed in previous articles and in the **PANCROMA™** Instruction Manual, pan sharpening Landsat multispectral band files using the Landsat panchromatic band can create spectral distortions. This is a result of the characteristics of the Landsat panchromatic sensor. Rather than being sensitive to the visible spectrum, its sensitivity is shifted to longer wavelength electromagnetic radiation, so that it excludes the blue band and includes the near infrared (NIR) band. As a result, pan sharpening with the Landsat panchromatic band yields an image that can show unnatural color tones. One remedy is to use the near infrared band to correct the panchromatic band. The **PANCROMA™** AJISANE and XIONG algorithms do this. Another possible approach is to create a transformation equation that can be used to post-process the image to correct spectral distortions. This is the technique that will be demonstrated in this article. The procedure to create the transformation will be as follows:

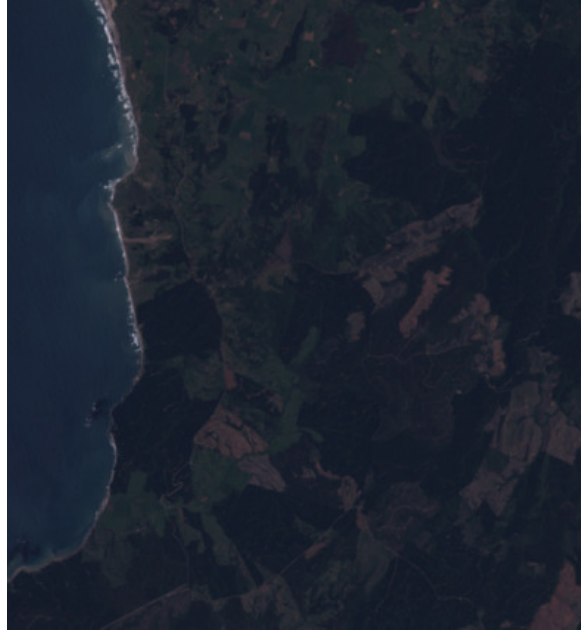
- Create a pan sharpened image using the HSI process
- Decompose the pan sharpened RGB image into its component blue, green and red band files
- Resize these band files to match the row and column counts of the original source band files

- Compute the coefficients of a linear equation that transforms the three resized bands to each of the source band files, individually
- Use the resulting three equations to transform the pan sharpened component bands to corrected component bands
- Recombine the transformed bands to create an improved RGB pan sharpened image

The first step is to pan sharpen an image. I used a subset of Landsat L71001086_08620051201_BXX.TIF. I pan sharpened it using the **PANCROMA™** HSI transform by successively opening the three multispectral band files and the panchromatic band, and then selecting 'Pan Sharpening' | 'HSI Transform' | 'Standard Four File' from the Main Menu. The results are shown in the image below.



The following image is the RGB color composite from the multispectral band files. This is the standard by which color tones will be evaluated.



The next step is to decompose the pan sharpened RGB image into its component band files. This can be done by opening the RGB image and checking the 'Generate Grayscale Band Images' check box at the bottom of the Main Window. (You can uncheck the 'Generate RGB Color Composite Image' if you want.) Then select 'Display Files' | 'Display One Color Composite Image'. When the grayscale band files are created, save them by selecting 'File' | 'Save Grayscale Image' | 'GeoTiff' and supplying a base file name, like 'rawImage'. **PANCROMA™** will automatically apply the correct band number suffix.

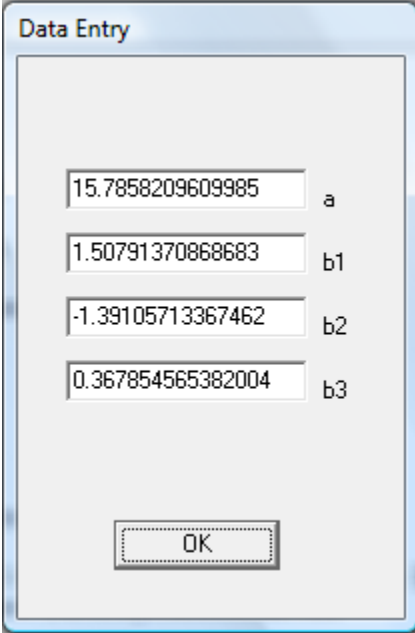
The next step is to compute the regression coefficients. But before we can do this, the raw images must be resized to match the row and column counts of the source multispectral images. This is necessary because the multiple regression utility wants all input files to match. You can resize the images by opening the three raw pan sharpened images and then selecting 'Pre Process' | 'Resize Images' | 'Resize Three Images'. You will be prompted for the row and column counts. Enter the row and column dimensions of the unprocessed Landsat band files. In this example, the size of the pan sharpened bands was 854 by 792 and the size of the multispectral bands was 427 by 396, i.e. the multispectral row and column counts were half those of the pan sharpened image. After resizing, save as GeoTiffs. My base file name was 'resizedPanSharpenedGrayscale'. Again, **PANCROMA™** will assign the appropriate band number suffixes.

Regression coefficients must be computed for each raw band file individually. Then the coefficients will be used to transform the raw band file into a corrected band file. **PANCROMA™** has a utility for regressing three independent variable (bands) against a third dependent variable band, i.e. solving the equation

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3$$

Where **X1**, **X2** and **X3** represent the independent multispectral or hyperspectral band files and **Y** represents the dependent band file. In order to compute the slope and intercept terms, select 'File' | 'Open' and open the dependent (**Y**) band first, and then the **X1**, **X2** and **X3** bands. Then select 'PreProcess' | 'Multiple Regression' | 'Three Independent Variables'. When the Data Entry box becomes visible, select the sampling interval. (If the sampling interval is one, every DN will be included in the computation and it will take longer. If the interval is 2, every other DN will be computed, etc. The linear coefficient terms will be reported to the diagnostic screen on the Main Window. They will also automatically be inserted into the Data Entry Form for subsequent use for linear transformations.

We will conduct the transformations in three steps as follows. Open the Landsat blue band file. Then open the three resized pan sharpened band files so that four files are opened. Now compute the regression coefficients as described above. I accepted all of the default conditions for this example. After the coefficients are computed, select 'Close Graphics Window and Reset'. Now select 'Pre Process' | 'Band Math' | 'Band Linear Combination' | 'Three Bands'. If you have done everything correctly, you should see the Data Entry form already populated with your regression coefficients, looking something like the form below.



The image shows a 'Data Entry' dialog box with a light blue border. Inside, there are four text input fields, each followed by a label. The first field contains '15.7858209609985' and is labeled 'a'. The second field contains '1.50791370868683' and is labeled 'b1'. The third field contains '-1.39105713367462' and is labeled 'b2'. The fourth field contains '0.367854565382004' and is labeled 'b3'. At the bottom of the dialog is an 'OK' button.

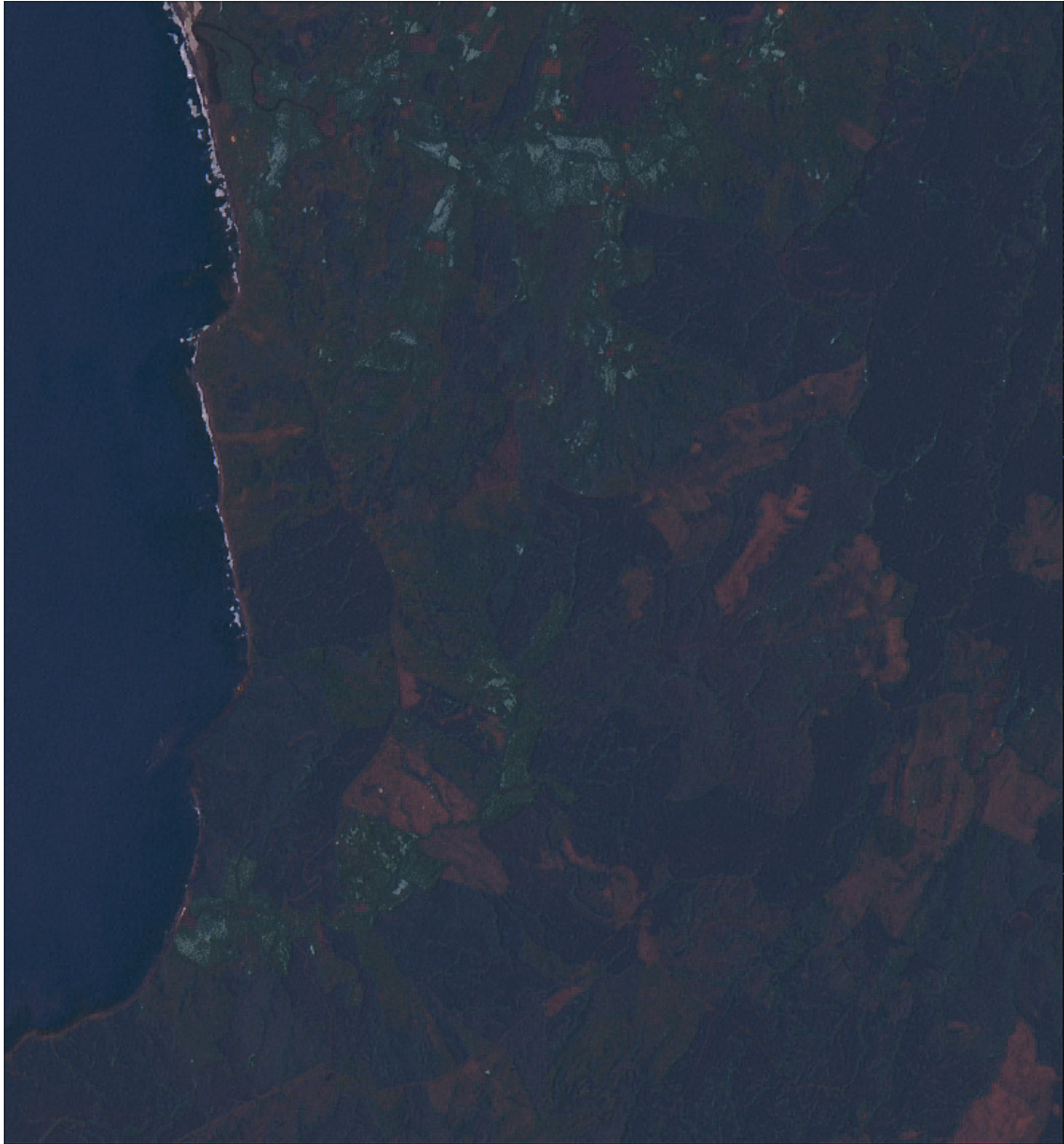
Parameter	Value
a	15.7858209609985
b1	1.50791370868683
b2	-1.39105713367462
b3	0.367854565382004

Press 'OK'. The transformed grayscale band will be computed and displayed. Save it as a GeoTiff file. I used the base file name 'processedImage1'.

What we have done is to create a linear equation that maps the three raw pan sharpened band to the source blue band. In other words, the equation defines how much of the raw blue, green and red bands must be combined in order to make the blue band. Because the coefficients are the result of a regression, the mapping will not be exact for each pixel. But hopefully the mapping will be close enough in order to produce an improved pan sharpened band, and thus an improved pan sharpened image.

Repeat the procedure above for the second Landsat multispectral band (i.e. the green band). That is, open the green band and the three resized raw pan sharpened bands. Compute the next set of coefficients and then transform the raw pan sharpened green band. Finally, repeat the procedure for the red band.

The only step left is to create an RGB color composite using the processed pan sharpened bands. Select 'Band Combination' | 'Generate RGB True Color Composite'. The result of my efforts is shown below.



Several features of the transformed image are apparent. The color tones appear to be more natural. In addition, the blue highlights caused by the NIR sensitivity of the panchromatic sensor to the high reflectivity of grassland areas is reduced. The processed image is somewhat less sharp than the unprocessed pan sharpened image. This might be improved by using the **PANCROMA™** image processing utilities.

I examined the residuals of the regression analysis. Residuals are the difference between the actual band DN and the DN computed by the regression equation. A visual inspection indicated that the fit was not a great one in this case.

However it is close enough to illustrate the technique and may even be close enough to be useful.

This article has demonstrated the possible advantages of creating image-specific transformation equations in improving RGB image quality. Although this demonstration was for a pan sharpened image, the technique has general application wherever a lower resolution reference image is available for creating transformation coefficients.

79. Tutorial – ENHG with AJISANE Processing

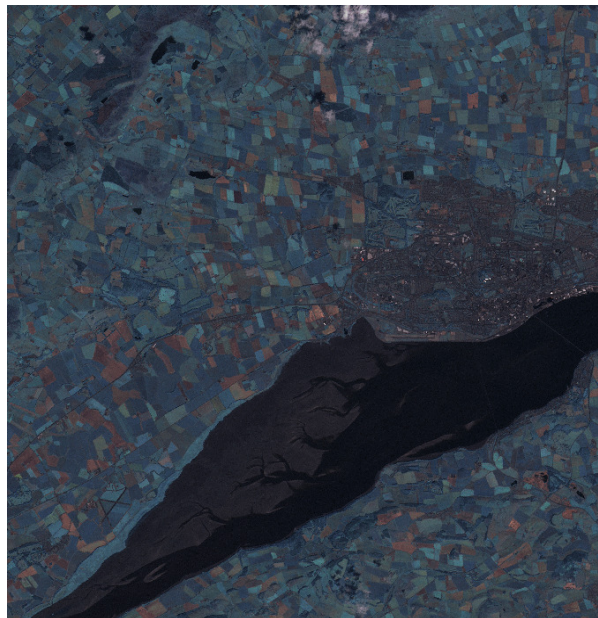
It can sometimes be very difficult to produce accurate color tones when pan sharpening Landsat images. As discussed in previous articles, the Landsat panchromatic band sensor is not sensitive to visible blue light. As a result, pan sharpened images can exhibit unnatural color tones when the panchromatic band is substituted for the Intensity or other color space band in the pan sharpening process. PANCROMA™ provides several algorithms to address this problem and these have been previously discussed. However, it may be difficult to achieve desired color tones using even these sophisticated algorithms. It is possible to combine the PANCROMA™ ENHG algorithm with other pan sharpening methods to help overcome such problematic images. The ENHG method uses the NDVI vegetation index to enhance the Landsat band 2 (green band). Although this method can produce improved results and works well by itself, it can also be combined with other methods. This paper outlines a technique for combining the ENHG with AJISANE.

As an introduction, I have compared the results of several PANCROMA™ pan sharpening methods using Landsat data set p205r021_7t20000717_z30_nnXX.tif, acquired over Scotland. This image is characterized by lots of vegetation in proximity to the ocean and other water bodies. This combination can prove troublesome as histogram matching algorithms can be influenced by such combinations.

The first image below is the RGB color composite. This is the standard to which we will compare the pan sharpened results.

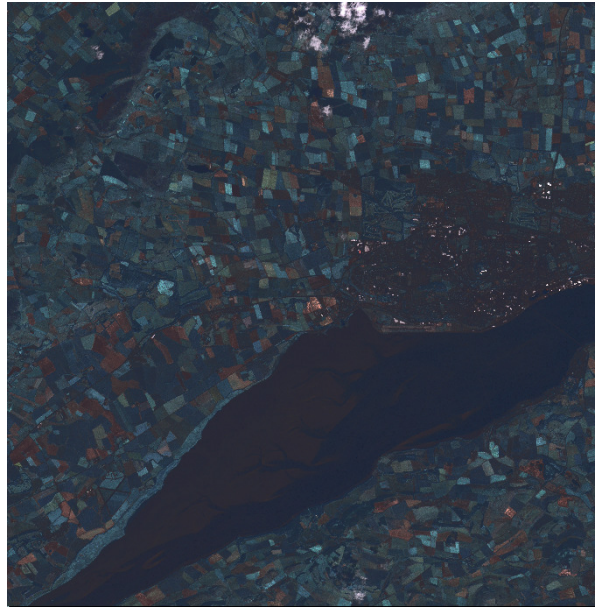


The second image is a straightforward application of four file HSI processing without histogram matching. This pan sharpened image exhibits the pronounced bluish cast that is characteristic of the Landsat panchromatic band.



The third image has been pan sharpened using the HSI algorithm and also using nonlinear histogram matching. As you can see, the histogram matching has

produced accurate color tones for some of the cultivated fields, but the ones with the darker vegetation tones are too blue.



PANCROMA™ offers several algorithms for improving the spectral fidelity of pan sharpened Landsat images. These include the ENHG, XIONG and AJISANE algorithms. Each of these use the information contained in a fifth band, the near infrared (NIR) in order to correct the spectral distortions. An example of the same image pan sharpened with the AJISANE method is shown below. The green tones are considerably closer to those in the RGB composite in this image.

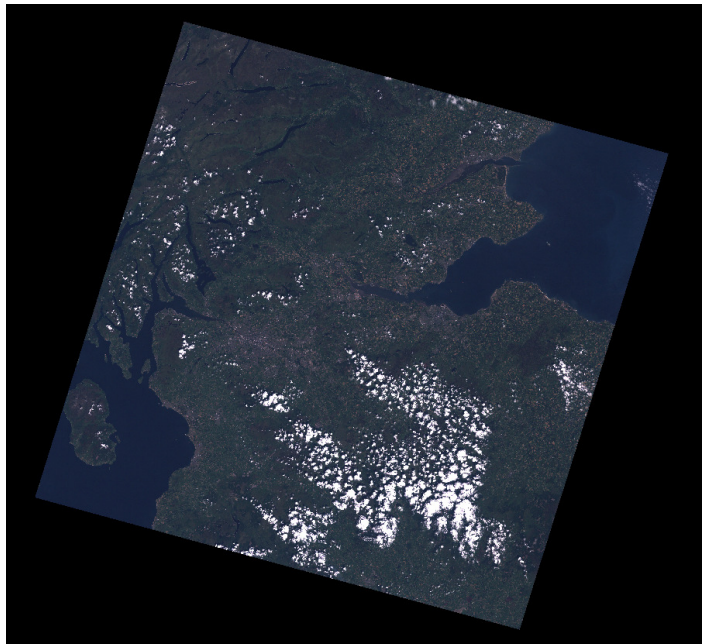
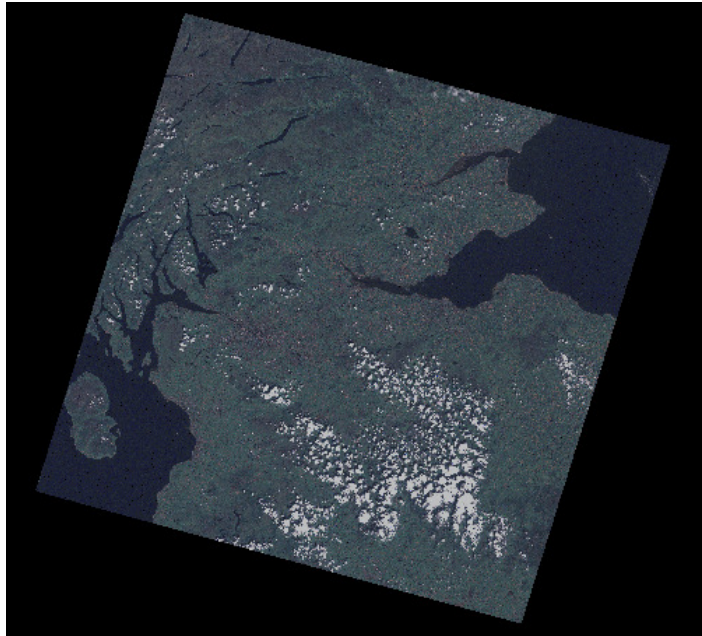


It is also possible to combine the ENHG and the other algorithms. ENHG uses the NIR band to modify the green band, increasing the pixel values of vegetated areas and creating a new ENHG band file. This file can be used in place of the green band. The ENHG file can be prepared manually or combined with the HSI method using the automatic utility. If prepared manually, it can be combined with the XIONG or AJISANE algorithms as well.

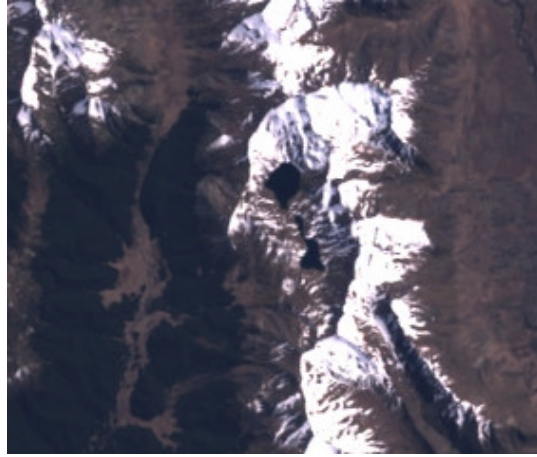
The final image shows the result of preprocessing the green band using the ENHG algorithm (using a factor of 0.07), then substituting the ENHG band for the green band in the AJISANE method. I also adjusted the water body tones using the 'Change Dark Pixels' utility on the Image Processing Data Input form using a cutoff of 42 and adding 20 to the blue channel. All three channels brightened by 20 and some contrast and sharpening applied. The green tones are a bit better and this image and the water looks OK. While not an exact match for the RGB image, is acceptably close.



This exercise has demonstrated how the spectra fidelity of pan sharpened Landsat images can be further improved by combining the PANCROMA™ ENHG and other pan sharpening methods, including the AJISANE, helping to achieve color tones in the pan sharpened image that approach those of the standard RGB composite. The final image is the entire scene, first the RGB composite and then the pan sharpened image using the ENHG and AJISANE methods in combination.



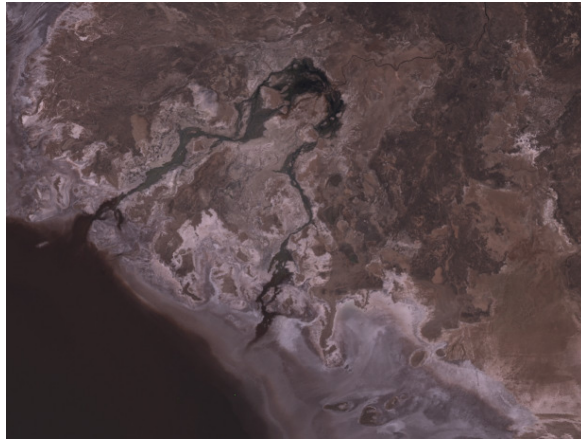
80. Pan Sharpened Image: Landsat Mountain Region



81. Pan Sharpened Image: Landsat 3, 4, 5 Composite



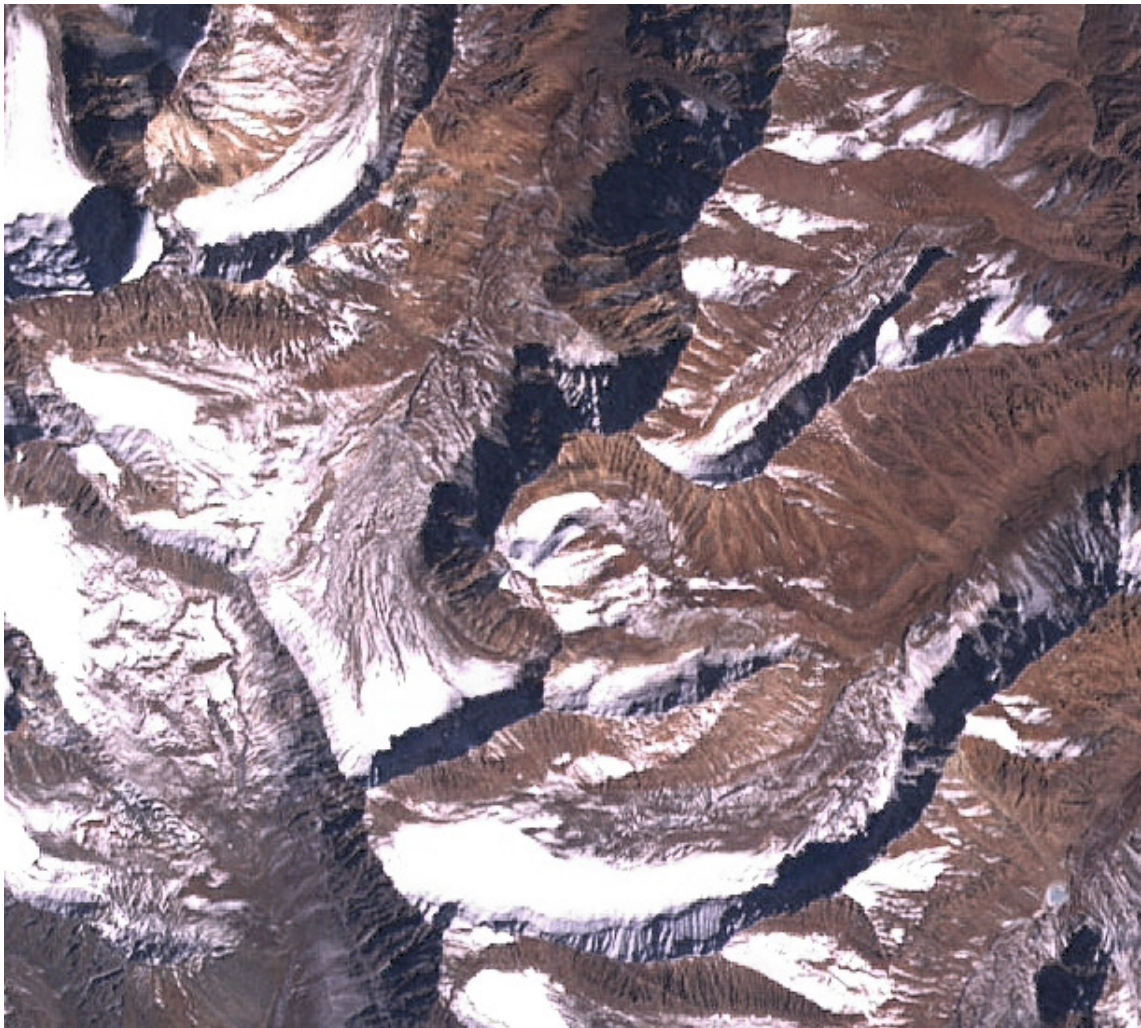
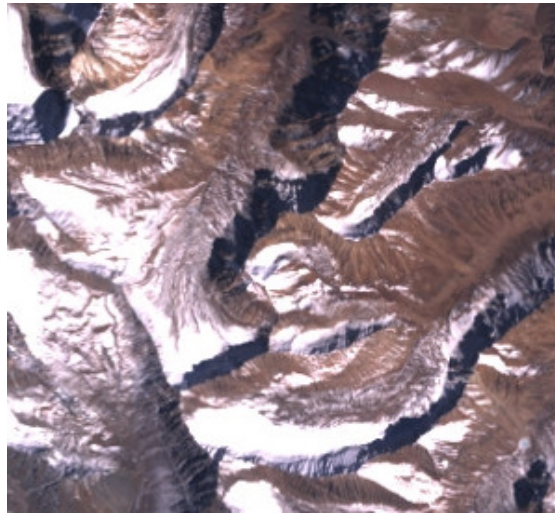
82. Pan Sharpened Image: Landsat Desert Region



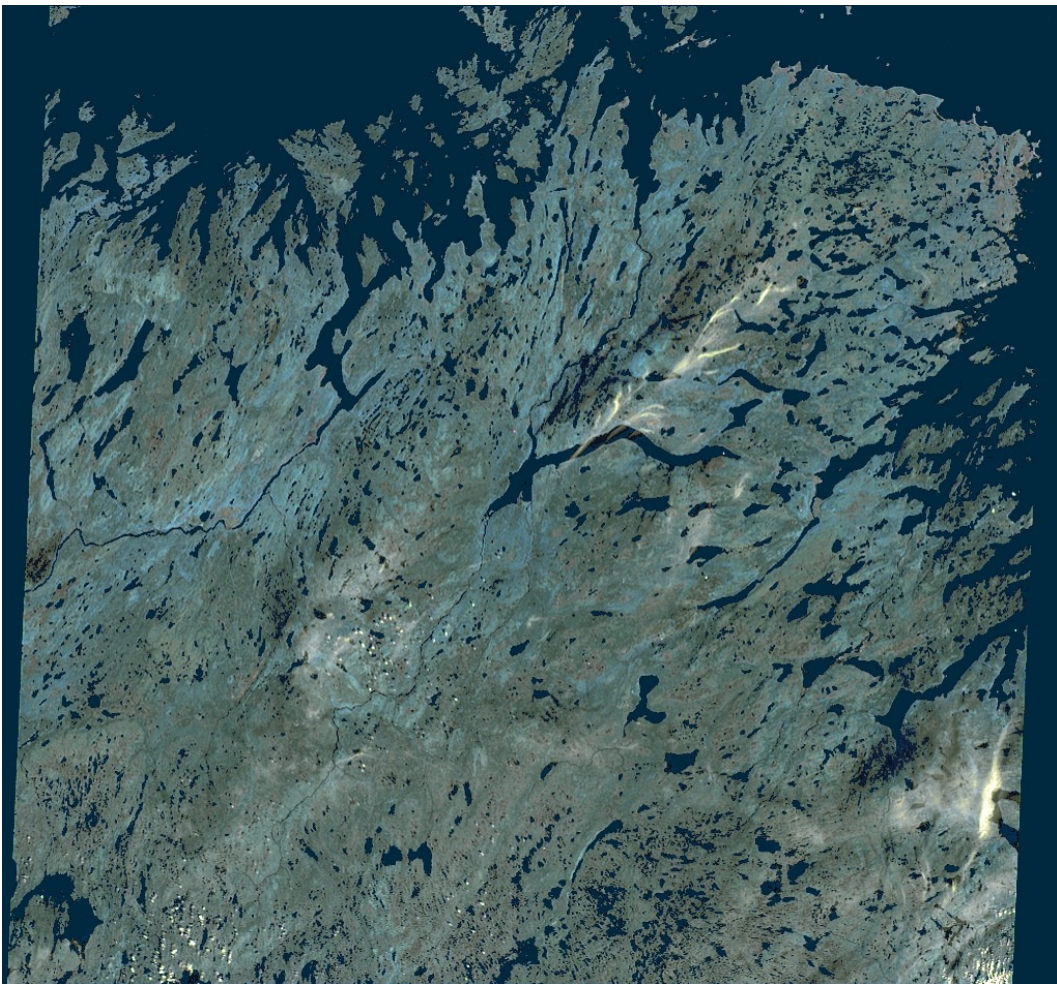
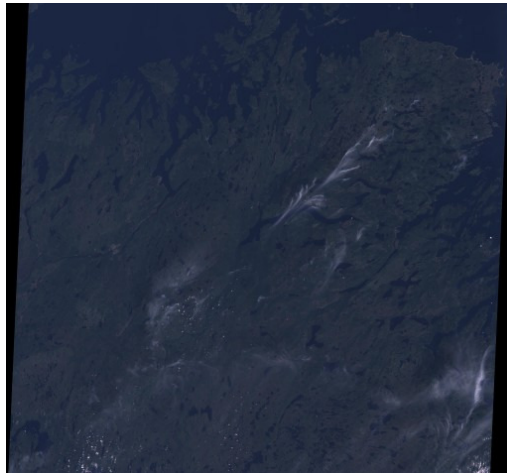
83. Pan Sharpened Image: Landsat Pacific Island Region



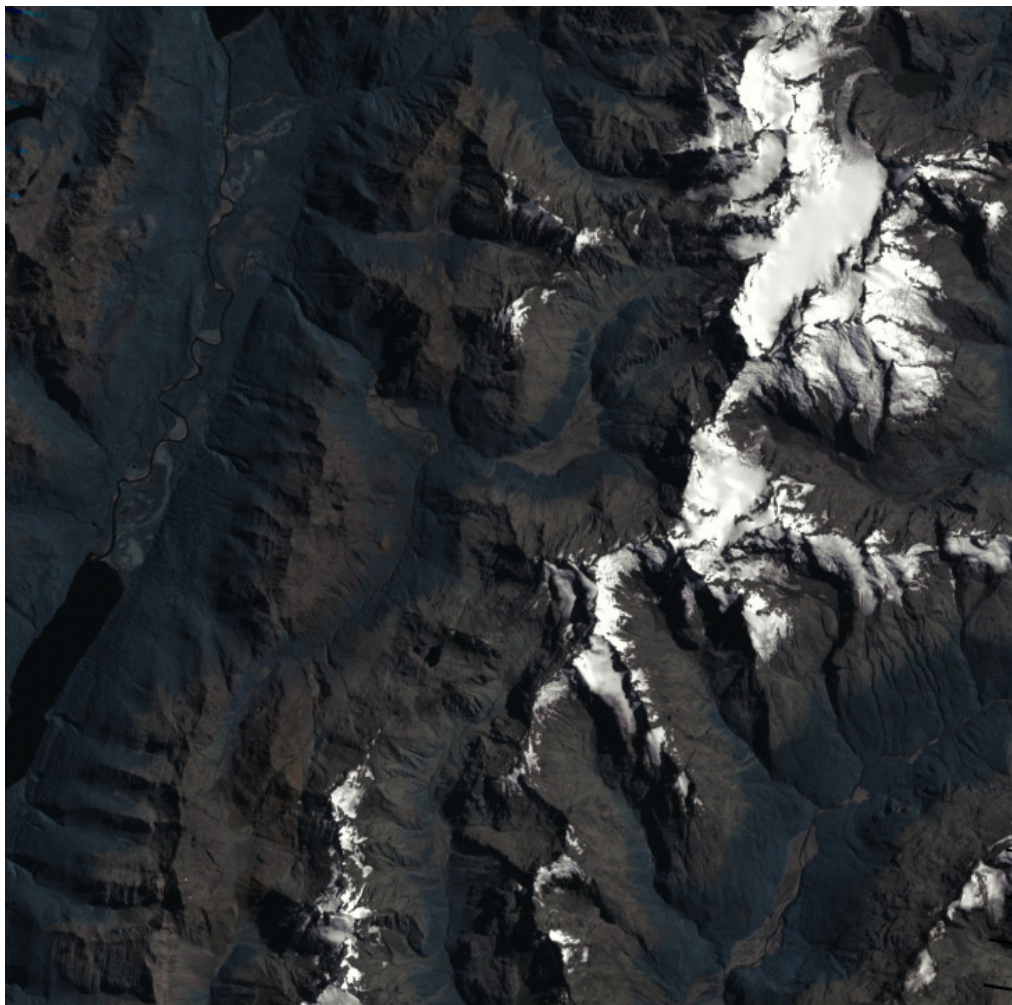
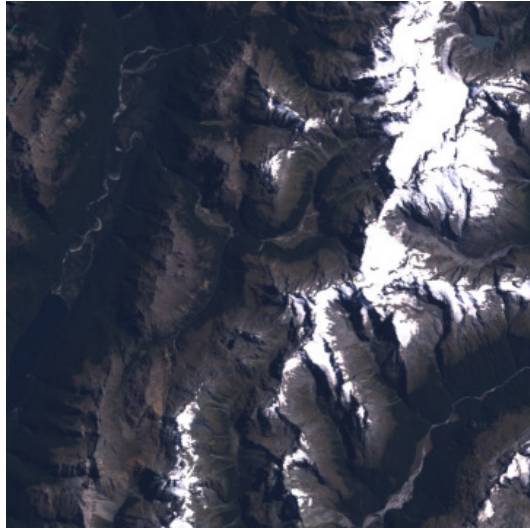
84. Pan Sharpened Image: Landsat Mountain Region



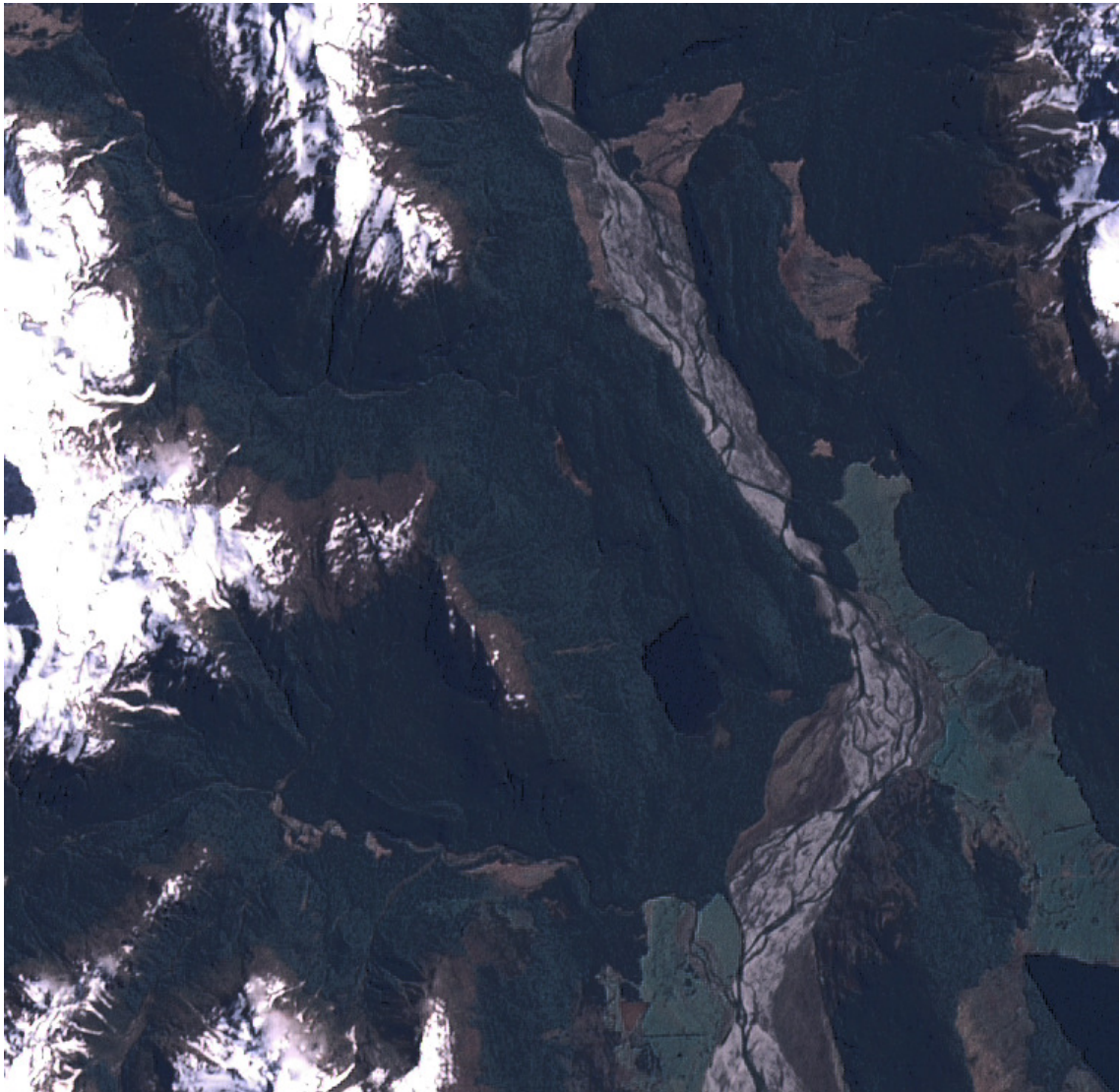
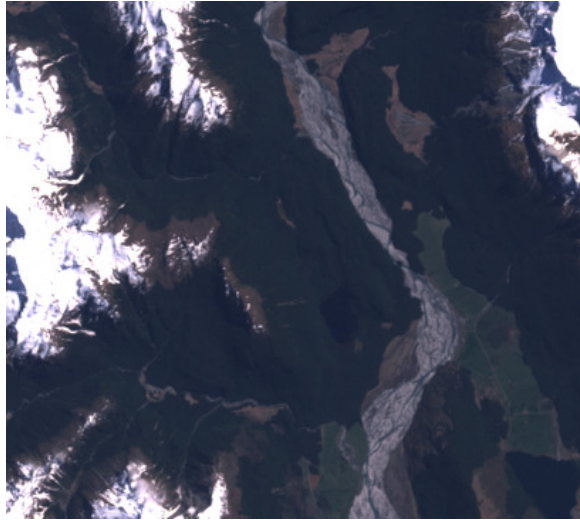
85. Pan Sharpened Image: Landsat Forest Region



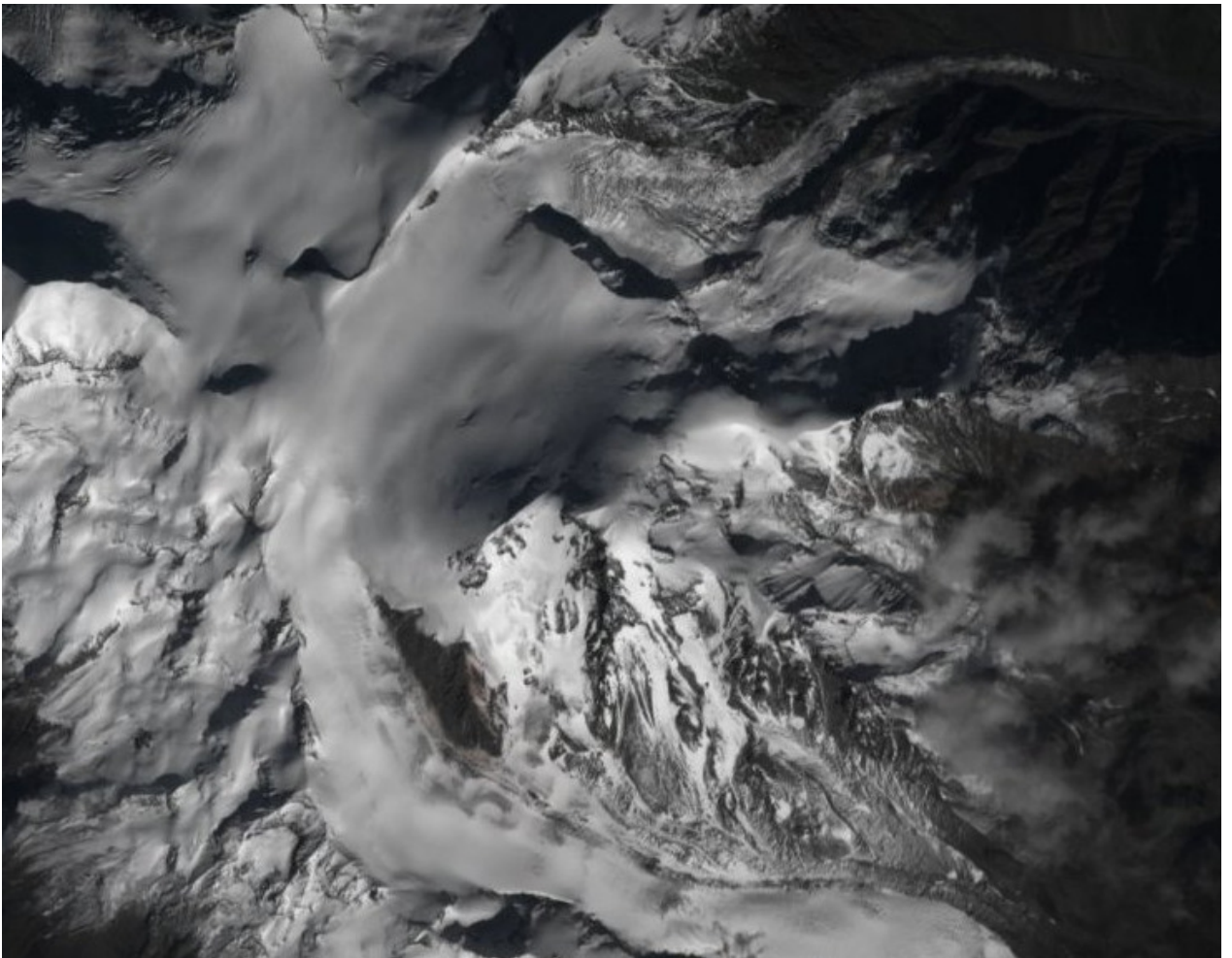
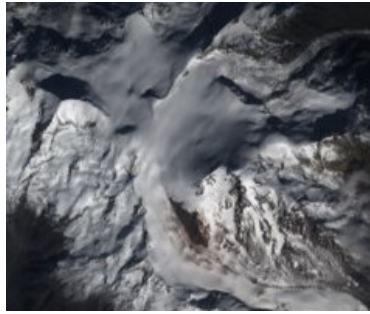
86. Pan Sharpened Image: Landsat Mountain Region



87. Pan Sharpened Image: Landsat Mountain Region



88. Pan Sharpened Image: EO-1 Mountain Region



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