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Approximating Landsat Surface Reflectance

Previous White Papers have described the concept of Top of Atmosphere (TOA) Reflectance. TOA reflectance is a unitless number that can be computed from satellite spectral radiance, the earth-sun distance in astronomical units, the mean solar exoatmospheric irradiance and the solar zenith angle. The spectral radiance is in turn converted from the satellite band digital numbers (DNs) using satellite sensor gain and bias constants.

The significance of the TOA reflectance is it represents the solar radiation incident on the instrument in standard unit less terms, independent of the position of the sun with respect to the earth. The main advantage of TOA reflectance is that it can be more easily compared to reflectance spectra archived by the USGS and others. Although TOA reflectance is more useful than the archived DNs for many purposes, what we really need is surface reflectance. Surface reflectance is the TOA reflectance corrected for atmospheric effects. This is the value that would be recorded by a hand-held spectrophotometer by someone standing on the ground. This is often the way archived reflectance spectra are actually collected.

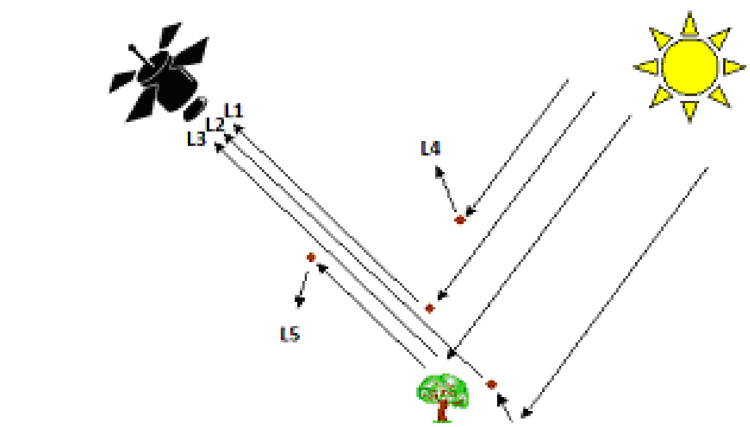
The earth's atmosphere can significantly distort the light incident on the satellite sensor, both on the way down through the atmosphere to the earth's surface, and then again on the way back up to the sensor by interaction with aerosols and gases in the earth's atmosphere.

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. One of the key properties of aerosols is their effect on electromagnetic radiation (EMR). As light traverses the atmosphere it is scattered. One type of scattering is called Rayleigh scattering. In this type of scattering, electromagnetic radiation interacts with matter whose size is much smaller than the wavelength of the EMR. Since the interaction is inversely proportional to the fourth power of the wavelength, longer wavelengths (red, near infrared (NIR), infrared (IR) etc.) are less affected and pass through the atmosphere without interacting at a molecular level, while shorter (blue/violet) wavelengths are more affected.

Another type, called Mie scattering, does affect longer wavelengths of light. In this type of scattering, electromagnetic radiation interacts with much larger aerosol particles. The wavelengths affected depend on the size, shape and texture of the particles encountered by the radiation. The result of both types of scattering is less of the incident light reaching the surface and more radiation from the atmosphere reflected back toward the sensor.

In addition, gases in the earth's atmosphere (for example ozone, methane, etc.) have their own absorption spectra that can cause differences between TOA and surface reflectances. Atmospheric absorption and Rayleigh scattering are predominantly responsible for changes in the shape of the spectrum at the surface relative to the top of atmosphere. The effect of Mie scattering on the shape of the spectrum is in comparison with these processes rather weak.

TOA reflectance 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 below where L1 is the atmospheric radiation, L2 is the reflected radiation and L3 is adjacency radiation. L4 and L5 are 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 L2.



If TOA reflectance is not corrected for the effects of the earth's atmosphere it may lead to inaccuracies when comparing the light incident on satellite sensors with spectra collected on the ground. This is of particular concern for spectral signature matching. A rough analogy would be trying to match human fingerprint data where one of the fingerprint images is smudged.

The situation can be improved by applying certain corrections to the TOA data in order to make it more closely match the surface data. This is what the USGS does for their archived Landsat Reflectance data. This data set is of very high quality and should be strongly considered for use in multispectral analysis.

For other satellite platforms, or when Landsat Reflectance data is not suitable, the alternatives are to convert DNs to TOA reflectance, or to further process the TOA reflectances to surface reflectances. There are two ways to accomplish the latter: absolute correction and relative correction.

Absolute correction modifies the TOA reflectance from an atmospheric physics approach. This requires an understanding of atmospheric physics, a mathematical model and the requisite characteristics of the local atmosphere. The problems with this approach are many, but the two most significant are obtaining the local atmospheric characteristics and then solving the mathematical model for each pixel in the scene. Since the computational expense of direct solution of the model is high, a common approach is to solve a sparse representation of the solution space and then interpolate among the solved points. This is the so-called Lookup Table (LUT) method. Although this can address the computational issue, availability of the necessary atmospheric data is still a problem. This data must come from somewhere other than the Landsat scene, and the availability of relevant atmospheric data remains the biggest problem with the absolute method

The alternative is the relative method. Relative correction takes one band and/or image as a baseline and transforms the other bands and/or images to match. An example is the dark pixel method, a histogram method used by **PANCROMA**™. In this method, any radiance associated with dark pixels such as deep shadows is assumed to be the result of atmospheric scattering. If such pixels are assumed to have a DN of zero, any difference is assumed to constitute a standard brightness bias in all pixels in the image. This bias is determined and then subtracted from all DNs.

An alternative relative method is the Haze Optimized Transform (HOT) method. This is done as follows. 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 of 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.

$$HOT = DN_{blue} \sin\theta - DN_{red} \cos\theta$$

The concept is shown graphically in the diagram below.

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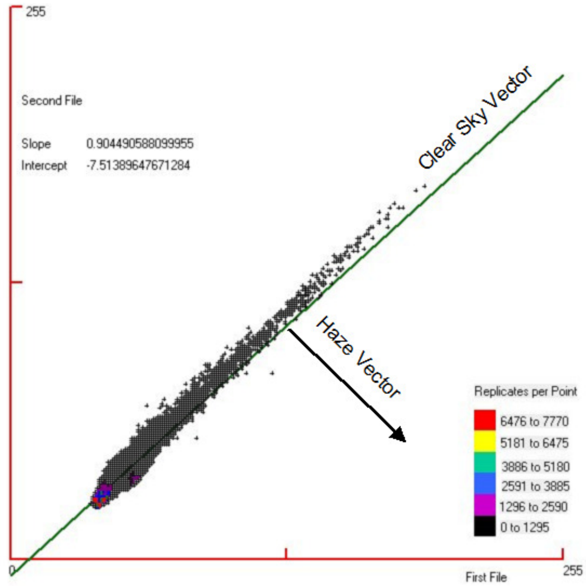

Haze reductions are commonly applied to only the visible multispectral bands, as the infrared (IR) bands are less susceptible to haze. Both the Dark Area and HOT algorithms are offered as three-f ile methods. **PANCROMA**™ also offers the HOT algorithm in a six file and seven-file implementation. It 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.