MEASURING URBAN AIR QUALITY USING WORLDVIEW2 MULTIANGLE MULTISPECTRAL BAND DATA

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ABSTRACT

This paper proposes using multi-angular, multispectral satellite data to monitor urban air pollution, in particular airborne aerosols and smoke. The approach suggests comparing WorldView-2 top-of-atmospheric (TOA) radiance measurements with a library of atmospheric radiances for key urban pollutants, calibrated to existing ground measurement data. This might allow techniques currently applied on a global scale, using instruments such as the Multiangle Imaging Spectro-Radiometer (MISR), to be applied to much more localized areas. The paper also suggests using parallax data to derive above ground elevations of opaque atmospheric layers to separate clouds from haze and air pollution as a further enhancement of WorldView-2 capabilities.

1. INTRODUCTION

The WorldView-2 instrument is a multispectral sensor sampling electromagnetic frequencies that range from 400 to 1040 nanometers across eight multispectral bands. The WorldView-2 instrument has the ability to acquire multiple images of a ground scene within a relatively short period of time as it traverses the target. This allows the satellite to acquire images close to its nadir (directly overhead) and also at both forward looking and backward looking off-nadir angles. The contest sample data set targeted downtown Rio de Janeiro and acquired images with the following angular characteristics:

Scene Identifier	Mean In-Track View Angle
10JAN19130923	39.2
10JAN19130954	29.8
10JAN19131046	7.5
10JAN19131200	-26.7
10JAN19131241	-39.4

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. Scientists are interested in the effect of aerosols on global climate; their effect on weather; as indicators of global weather patterns; and because of their possible effects on human health. 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. As a result, the short wavelengths of visible light (mainly violet and blue) interact with gas molecules in the atmosphere. Since the interaction 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. 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. Key atmospheric parameters related to aerosol-induced scattering include optical depth, the single scattering albedo, scattering phase function, and the angstrom exponent. Remote sensing of aerosols requires inferring particle properties from observed top-of-atmosphere (TOA) radiances.

TOA radiance 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 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 .

In simplified terms TOA radiation can be described by the following equation:

(1) $L_{TOA} = L_{atmospheric} + L_{reflected} + L_{adjacency}$

Where: $L_{atmospheric}$ is scattered into the satellite's sensor without ever reaching the ground target; $L_{reflected}$ is reflected off the target into the satellite sensor; $L_{adjacency}$ is reflected into the satellite sensor from objects adjacent to the target; and L_{TOA} is the top-of-atmosphere spectral radiance, measured directly by the WorldView2 sensor. This is shown in Figure 1.

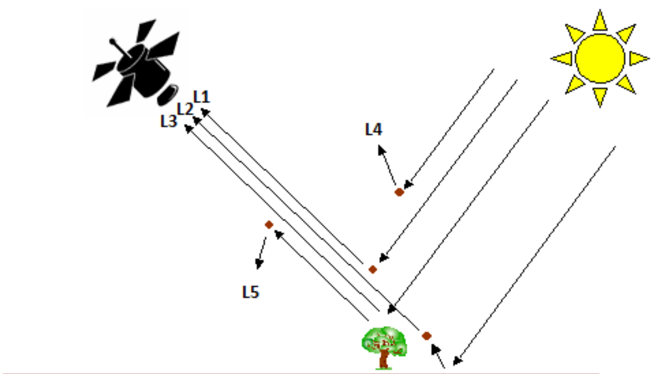

Figure 1

Liu, et al, proposed the atmospheric component of TOA radiance:

(2) $L_{atmospheric} = R_a + R_r$

Where R_a is the particle reflectance and R_r is the molecular reflectance. The molecular atmospheric reflectance component, R_r,

(3) $R_r = \tau_r P_r (\Theta) / 4 \mu_s \mu_v$,

Where:

τ_r is the molecular optical thickness
$P_r (\Theta)$ is the Rayleigh scattering phase function
μ_s is the cosine of the viewing angle
μ_v is the cosine of the solar zenith angle

The Rayliegh scattering phase function can be determined analytically and is given by:

(4) $P_r (\Theta) = (3/16 \text{ PI}) (1/(\cos^2(\Theta))$

The molecular optical thickness can also be computed and is given by:

(5) $\tau_r = \exp(-0.1188 * h - 0.00116 * h2) \{0.00859 * \lambda\text{-}4 (1 + 0.0013 * \lambda\text{–}2 + 0.00013 * \lambda\text{-}4)\}$

where h is the height above the surface and λ is the wavelength. Similarly the aerosol atmospheric reflectance, R_a is given by:

(6) $R_a = \tau_a P_a (\Theta) / 4 \mu_s \mu_v$, where

τ_a is the aerosol optical thickness, and
$P_a (\Theta)$ is the aerosol scattering phase function.

Summing these two equations, for a given multispectral band:

(7) $R_{atm} = [\tau_a P_a (\Theta) / 4 \mu_s \mu_v] + [\tau_r P_r (\Theta) / 4 \mu_s \mu_v]$

Substituting into equation (1), the expected angular functionality can be given by:

(8) $L_{TOA} = [\tau_a P_a (\Theta) / 4 \mu_s \mu_v] + [\tau_r P_r (\Theta) / 4 \mu_s \mu_v] + L_{reflected}$

2. PROPOSED METHOD

Special techniques can be used to estimate τ_a and $P_a(\Theta)$, allowing the radiance due to scattering to be isolated from Rayleigh scattering and surface reflectance according to equation (7). As a result, it should be possible to use WorldView-2 multi angular data to determine atmospheric radiance and to derive detailed information on urban air quality in a similar way that MISR collects data on a global basis. The MISR instrument is complex, but in simplified terms, it acquires data at nine view angles and four wavelengths providing 36 channels of information. From the observed radiances the instrument computes optical depths. It compares the radiance and optical depth data to an aerosol library of mixtures of up to three aerosol components chosen from ten pure aerosol types. The instrument is periodically calibrated against the AERONET network of ground stations. The statistical comparison yields predicted air quality based on the selected aerosols.

Many urban municipalities collect atmospheric ground data routinely. These ground observations could be used to create similar atmospheric models for WorldView-2. The five angles and eight wavelengths of the sample imagery provide 40 channels of information. Use of WorldView-2 data could allow the benefits of ground observations to be extended over much larger areas, especially those where routine air quality measurements are not made. Since such ground data is typically collected close to ground level, the air quality above the surface is often not monitored at all. Multi-angular satellite observations aggregate data across

the full depth of the atmosphere, potentially providing information about higher-level atmospheric conditions created by temperature inversions, high altitude smoke, haze and clouds. The nature of the multi-angular data could potentially facilitate the collection of such height dependent data as higher angle images would be more sensitive to thin haze and smog layers than near nadir images.

The variation of atmospheric properties as a function of acquisition angle can be seen by examining the five C-band images in the sample WorldView-2 data set. The C-band is the shortest wavelength band in the set, and is expected to be most sensitive to scattering. In order to examine this, the digital numbers (DNs) of each C-band image from the data set were calibrated to TOA radiance as recommended in the Digital Globe Technical Note entitled *Radiometric Use of WorldView-2 Imagery*, using the absolute radiometric calibration factor and effective bandwidth values included in the associated band IMD files. Haze and scattering can be measured in a variety of ways. For this test, image contrast was used as an indication of scattering. It was expected that images closer to the nadir would exhibit less scattering and thus have higher contrast values than oblique images. The standard deviation of the processed images was used as a measure of image contrast. (Higher contrast images generally exhibit a broader distribution of pixel brightness levels and therefore a larger standard deviation.) A plot of standard deviation as a function of acquisition angle for the five C-bands is shown in Figure 2 below. As expected, the nadir image showed the highest contrast. Image contrast decreased as the off-nadir angle increased in absolute value.

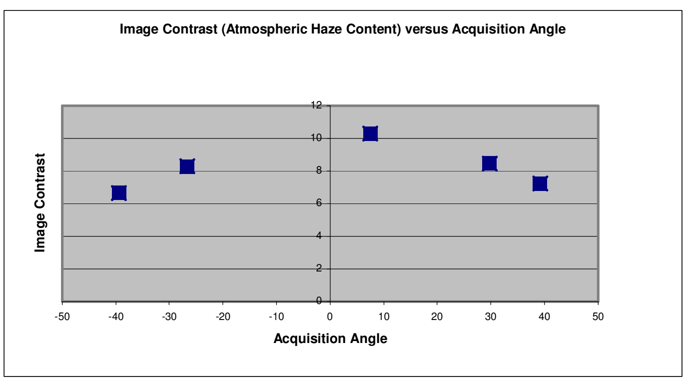

Figure 2

3. STEREOSCOPIC CAPABILITIES

WorldView-2 observations can potentially provide additional indications of aerosol quantity and quality as a result of parallax effects created by the multi angular data acquisition. Two images taken at different perspectives can be used to measure height above the ground, for example the elevation of clouds above the surface. This allows ground-level smoke and smog to be better separated from clouds than is possible with single images taken at nadir. An example of the stereoscopic information that can be derived from WorldView-2 is shown below. This anaglyph was created from two true color composites (bands B, G and R) taken at acquisition angles 7.5 degrees and 29.8 degrees. Although the sample imagery is cloud-free, the (relative) heights of the downtown Rio buildings can be clearly seen if the image is viewed with red/blue glasses. This type of stereoscopic capability to classify atmospheric aerosols by type should provide a useful complement to the direct

Figure 3

measurement of angle-dependent atmospheric radiances.

4. CONCLUSION

This paper proposed using multi-angular, multispectral satellite data to monitor urban air pollution. The approach infers air quality from WorldView-2 top-of-atmospheric (TOA) radiance measurements. It suggests comparing such measurements with a library of atmospheric radiances for key urban pollutants, calibrated to existing ground measurement data. This might allow techniques currently applied on a global scale using MISR to be applied to much more localized areas. The paper also suggests using parallax data to derive above ground elevations of opaque atmospheric layers to separate clouds from haze and air pollution to provide additional air quality information. The author feels that with additional work, these two aspects of WorldView-2 data could be used to the benefit of public health officials to monitor air quality. This additional work might include establishing the most appropriate indicators of aerosol content for the most appropriate WorldView-2 bands and correlating these indicators to actual ground air quality measurements. It should also include the creation of stereoscopic image templates that would aid in the qualitative separation of clouds from surface haze layers.

5. REFERENCES

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