INCORPORATION OF CLOUD RADIANCE EFFECTS INTO HYPERSPECTRAL TARGET DETECTION

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INTRODUCTION

Clouds create uneven scattering and absorption in the atmosphere making calculations of sky radiance for spectral measurements or image simulation difficult. MODTRAN [1] is capable of modeling transmission through a single overcast cloud layer [2] but does not consider a partly cloudy sky or phase changes with in a cloud. These conditions are prevalent in the real atmosphere and it is necessary to study the radiometric properties of varying cloud cover to further understand the phenomenology necessary for modeling more realistic sky environments. The study characterizes the variation and differences in global and diffuse irradiance and radiance measurements under varying sky conditions.

BACKGROUND

Clouds can be modeled as objects using in-water transfer models, but the addition of scattering over large areas makes the simulation of cloudy skies computationally expensive. The scattering effect, however, cannot be disregarded, since the geometry of a cloud can cause uneven scattering that can affect the appearance of targets on the ground. The total sky and solar irradiance incident onto a target flat to the ground is given by

$$E_{total}(\lambda) = \tau_1(\lambda) E_{sun}(\lambda) cos\theta_{sun} + E_{sky}(\lambda) \tag{1}$$

where E_{sun} is the exoatmospheric solar irradiance, t_1 is the solar path transmission, q_{sun} is the solar zenith angle, and E_{sky} is the hemispherically integrated sky irradiance given by

$$E_{sky} = \int_0^{\pi/2} \int_0^{2\pi} L_{sky}(\lambda, \theta, \phi) cos\theta sin\theta d\phi d\theta \quad . \tag{2}$$

In some cases, a portion of the hemisphere may be blocked by other objects in the scene, such as a building, resulting in a reduced irradiance load from the sky.

Hyperspectral target detection [3] and atmospheric compensation algorithms traditionally model the sky as clear, absent of optically thick clouds. Although realistic sky conditions may have un-obscured sun to target and sensor to target lines of sight, a significant level of cloud cover may be present in the sky dome altering the total sky irradiance E_{sky} incident onto a target surface. The resulting entrance aperture radiance (EAR) is given by

$$L_{EAR}(\lambda) = \tau_2(\lambda)\left(\tau_1(\lambda)E_{sun}(\lambda)cos\theta_{sun} + E_{sky}(\lambda)\right)\frac{r}{\pi} + L_{path}(\lambda) \qquad (3)$$

where the line of sight path radiance is given by L_{path}(l). The target reflectance r may be retrieved given a good estimate of the total sky irradiance (which may contain clouds), path radiance, solar irradiance, and path transmissions t_1 and t_2.

APPROACH

We measured the total sky irradiance and directional sky radiance with two radiometrically calibrated Ocean Optics spectrometers over the wavelength range of 400 to 1100 nm. For clear sky conditions, we expect measured sky radiance and total sky irradiance to closely follow simulated values generated from appropriately configured MODTRAN runs. Skies containing significant cloud cover (ie. greater than about 10%) will have directional radiance and total irradiance values deviating from the clear sky predictions of MODTRAN. MODTRAN is capable of modeling cloud radiance reaching a sensor above the clouds, but is not currently capable of modeling clouds as viewed from the ground due to the one dimensional nature of the atmospheric model. We will compare our up-looking measured cloud radiance spectrum against downlooking MODTRAN predictions.

The radiometric deviations of clouds from clear sky conditions will manifest themselves as error in the retrieved reflectance of pixels within a hyperspectral image making target detection more difficult and prone to higher false alarm rates. We intend to leverage our spectral measurements of various cloud types to mitigate this error in the retrieved reflectance [4] given some ground truth about the partial cloud cover and cloud types present at the time of imaging. To demonstrate the improvement, we will simulate a hyperspectral image cube over a complex urban environment with embedded targets of interest using the DIRSIG [5] software. One version of the simulated scene will generate a hyperspectral image cube assuming a clear sky based on MODTRAN runs, while another version of the synthetic scene will be generated using measured cloud radiance values for portions of the simulated sky dome. The accuracy of the retrieved target reflectance values will be assessed using both the clear sky and partially cloudy sky assumptions within the reflectance retrieval algorithm against both versions of the simulated image cubes permitting evaluation of the potential value added of a more rigorous treatment of partially cloudy sky conditions.

RESULTS

Initial measurements of reflected radiance from a Fluorilon target (a 99% reflective spectrally flat, diffuse calibration target) under a clear blue sky were compared to two clear sky MODTRAN4 spectra, one with no aerosols and one with the Urban 23km visibility aerosol model (Fig.1)

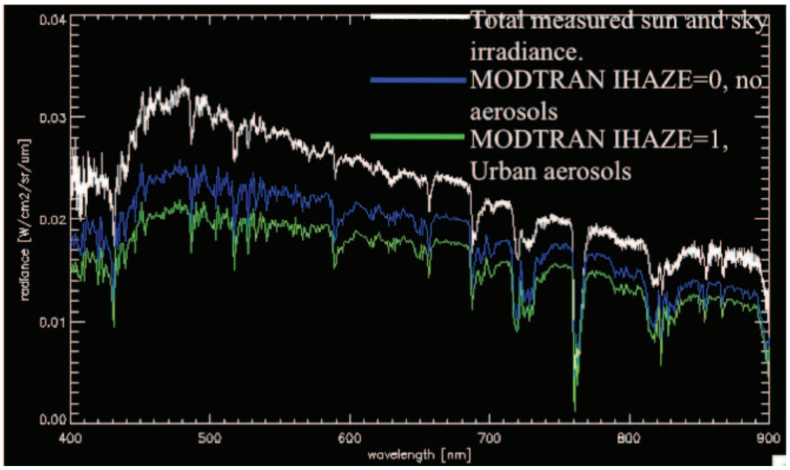

Figure 1: A comparison of the spectra of the Fluorilon full solar and sky irradiance to the MODTRAN full solar and sky irradiance no aerosols and urban aerosol models.

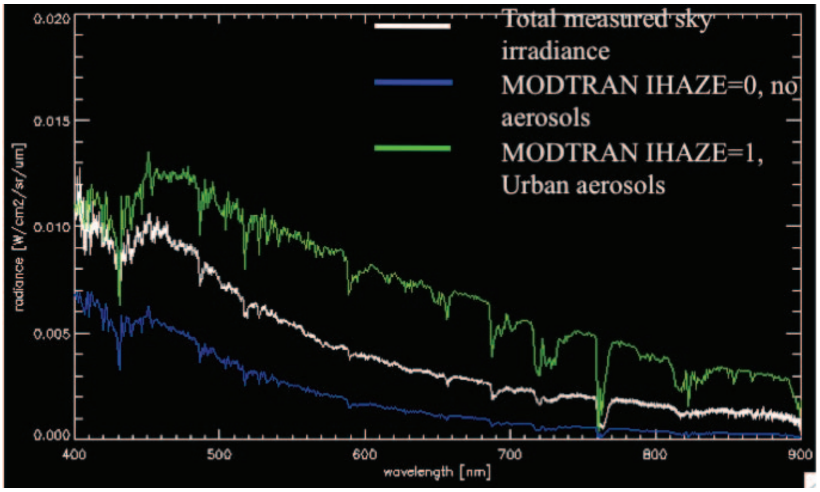

Figure 2: A comparison of the spectra of the Fluorilon skydome irradiance to the MODTRAN skydome irradiance no aerosols and urban aerosols models

Preliminary results show good correlation in spectral shape, but the MODTRAN spectra differ in the magnitude from the measured spectra. The magnitude difference is not surprising given that no initial effort was made to configure the MODTRAN runs beyond the standard mid-latitude summer 23km visibility atmosphere. The final work will utilize locally acquired radiosonde profiles to more appropriately configure the MODTRAN atmosphere for comparison to measured clear sky and cloud spectral radiance.

CONCLUSION

Preliminary measurements show discrepancy between the real sky radiance and the MODTRAN sky radiance under a blue sky. The addition of clouds to the hemisphere may increase the discrepancy and contribute uneven downwelling. Cumulus clouds, in particular, will intensify this effect due to their complex geometries (i.e. they have a greater number of ground-visible reflecting facets than stratus clouds). This has the potential to cause the light incident on a target surface to deviate from the amount predicted by MODTRAN and affect the ability of target detection and atmospheric compensation algorithms from reaching accurate results.

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