Atmospheric Correction of High-Spatial-Resolution Commercial Satellite Imagery Products Using MODIS Atmospheric Products

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Remotely sensed ground reflectance is the foundation of any interoperability or change detection technique. Satellite intercomparisons and accurate vegetation indices, such as the Normalized Difference Vegetation Index (NDVI), require the generation of accurate reflectance maps (NDVI is used to describe or infer a wide variety of biophysical parameters and is defined in terms of near-infrared (NIR) and red band reflectances). Accurate reflectance-map generation from satellite imagery relies on the removal of solar and satellite geometry and of atmospheric effects and is generally referred to as atmospheric correction. Atmospheric correction of remotely sensed imagery to ground reflectance has been widely applied to a few systems only. The ability to obtain atmospherically corrected imagery and products from various satellites is essential to enable wide-scale use of remotely sensed, multitemporal imagery for a variety of applications. An atmospheric correction approach derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) that can be applied to high-spatial-resolution satellite imagery under many conditions was evaluated to demonstrate a reliable, effective reflectance map generation method.

Currently the most extensively available reflectance-based products are from MODIS. Landsat and other systems' products are also atmospherically corrected by various groups, but reflectance-based products are not regularly provided from the systems' distribution centers. Atmospheric correction for these systems has generally used a radiative transfer approach in which solar and satellite geometry, as well as atmospheric aerosols and gases, are estimated and used to invert the top-of-the-atmosphere (TOA) radiance values to ground reflectance. High-spatial-resolution commercial systems, such as IKONOS, QuickBird, and OrbView-3, provide only four-band (blue, green, red, and NIR) radiance products as standard multispectral products. Consequently, interoperable NDVI products cannot be directly produced, and validation of coarser resolution results using high-spatial-resolution imagery, which requires atmospheric correction, is not possible. The literature contains many papers in which only solar geometry and Earth-sun distance are used to generate reflectance maps. This method–the planetary albedo method–is typically inaccurate. Generation of reflectance maps with accuracies approaching 0.01 reflectance units, as required by global climate change studies, is not achievable by the planetary albedo method.

The Empirical Line Method (ELM) was the first general approach used in this study. The ELM uses the fact that TOA radiance has a linear relationship with ground reflectance. By curve fitting TOA radiances against at least two known reflectance values, an empirical relationship between TOA radiance and reflectance can be found. Using the ELM, a highly accurate reflectance map can be generated for a scene. The ELM, however, is not a practical operational algorithm because it requires ground-truth data for every scene evaluated. In this study, the ELM was used to test and evaluate other methods.

In addition to the ELM, several different atmospheric correction methods employing radiative transfer techniques were applied to the IKONOS and QuickBird scenes. The simplest was the planetary albedo method, in which only the solar illumination (geometry and Earth-sun distance) was taken into account. This approach is easy to implement but does not include any atmospheric effects. The other radiative-transfer-based methods, based on a modified spherical albedo

approach, used a combination of ground-truth data and/or near-coincident satellite data to derive atmospheric gases and aerosols required to invert TOA radiance values into ground reflectance. Terra MODIS collects, nearly coincident with the high-spatial-resolution collects, provided atmospheric aerosols and water vapor data from MODIS MOD04 and MOD05 products, respectively. The near-coincident orbits of the sun-synchronous commercial satellite systems and the Terra satellite produce acquisitions typically found to be within an hour of each other. In cases where the atmosphere is not changing quickly, this approach allows virtual ground truthing from MODIS products, taking advantage of MODIS algorithms that have been tested and validated under a wide set of conditions and reducing the cost associated with acquiring ground-truth data. The spherical albedo method also incorporates adjacency effects, which were found to be much more significant with high-spatial-resolution systems than with coarser resolution systems.

To evaluate directly the accuracy of any atmospheric correction method, extensive measurement of ground reflectances and atmospheric conditions is necessary at the time of acquisition. The National Aeronautics and Space Administration (NASA), the National Geospatial-Intelligence Agency, and the U.S. Geological Survey have formed the Joint Agency Commercial Imagery Evaluation (JACIE) team, whose purpose is to characterize the geometric, spatial resolution, and radiometric properties of commercial imaging systems. NASA's Stennis Space Center has acquired extensive ground truth data for approximately a dozen IKONOS and QuickBird scenes over four years through its JACIE team characterization work. Most of the scenes were acquired under fairly clear skies with excellent visibility. For radiometric characterizations, 20-m uniform tarps with various reflectances were typically deployed and characterized near the time of acquisition. Reflectances of natural targets, such as concrete and grass, were also measured near the time of acquisition, and the atmosphere was characterized with sun photometers (aerosols) and radiosondes (water vapor, pressure, and temperature).

For baseline studies, high-spatial-resolution NDVI products generated by the various atmospheric correction methods were examined and then compared with MODIS 16-day MOD13 NDVI and daily MOD09 derived NDVI products. The atmospherically corrected product that showed the best agreement to the MODIS NDVI product, with less than 0.1 NDVI difference, was the ELM-derived NDVI. Very little difference was found between NDVI products generated using either MODIS atmospheric products or atmospheric ground truthing (sun photometers and radiosondes). For highly vegetative areas, the NDVI generated from MODIS-corrected, high-spatial-resolution products were 0.1-0.2 less than the NDVI generated from ELM-based products but were much more accurate than the NDVI generated from the planetary albedo method.

Because all the comparisons were made on days with excellent atmospheric conditions, a semi-analytical error model was created that takes into account the uncertainties in atmospheric properties, adjacency, and radiometric calibration coefficients. Comparison between the model and known conditions showed good agreement and should allow performance prediction under a wide set of conditions. Future work would benefit from having ground measurements and acquisitions under varying conditions. For highly heterogeneous atmospheres, other algorithms will be needed. In cases of homogeneous atmospheres, the MODIS-derived atmosphere approach produces excellent NDVI and reflectance maps.

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