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Atmospheric correction of optical imagery from MODIS and Reanalysis atmospheric products

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ABSTRACT

In this paper we analyze the differences obtained in the atmospheric correction of optical imagery covering bands located in the Visible and Near Infra-Red (VNIR), Short-Wave Infra-Red (SWIR) and Themal-Infrared (TIR) spectral regions when atmospheric profiles extracted from different sources are used. In particular, three sensors were used, Compact High Resolution Imaging Spectrometer (CHRIS), Advanced Spaceborne Thermal Emission and Reflection radiometer (ASTER) and Landsat5 Thematic Mapper (TM), whereas four atmospheric profiles sources were considered: i) local soundings launched near the sensor overpass time, ii) Moderate Resolution Radiometer (MODIS) atmospheric profiles product (MOD07), iii) Atmospheric Correction Parameter Calculator (ACPC) generated by the National Center for Environmental Prediction (NCEP) and iv) Modified Atmospheric Profiles from Reanalysis Information (MAPRI), which includes data from NCEP and National Center of Atmospheric Research (NCAR) Reanalysis project but interpolated to 34 atmospheric levels and resampled to $0.5°\times0.5°$. MODIS aerosol product (MOD04) was also used to extract Aerosol Optical Thickness (AOT) values at 550 nm. Analysis was performed for three test dates (12th July 2003, 18th July 2004 and 13th July 2005) over an agricultural area in Spain. Results showed that air temperature vertical profiles were similar for the four sources, whereas dew point temperature profiles showed significant differences at some particular levels. Atmospheric profiles were used as input to MODTRAN4 radiative transfer code in order to compute atmospheric parameters involved in atmospheric correction, with the aim of retrieving surface reflectances in the case of VNIR and SWIR regions, and Land Surface Temperature (LST) in the case of the TIR region. For the VNIR and SWIR region, significant differences depending on the atmospheric profile used were not found, particularly in the Visible region in which the AOT content is the main parameter involved in the atmospheric correction. In the case of TIR, differences depending on the atmospheric profile used were appreciable, since in this case the main parameter involved in the atmospheric correction is the water vapor content, which depends on the vertical profile. In terms of LST retrieval from ASTER data (2004 test case), all profiles provided satisfactory results compared to the ones obtained when using a local sounding, with errors of 0.3 K for ACPC and MAPRI cases and 0.7 K for MOD07. When retrieving LST from TM data (2005 test case), errors for MOD07 and MAPRI were 0.6 and 0.9 K respectively, whereas ACPC provided an error of 2 K. The results presented in this paper show that the different atmospheric profile sources are useful for accurate atmospheric correction when local soundings are not available. In particular, MOD07 product provides atmospheric information at the highest spatial resolution, 5 km, although its use is limited from 2000 to present, whereas MAPRI provides historical information from 1970 to present, but at lower spatial resolution.

1. Introduction

The removal of the atmospheric perturbation introduced in the signal registered by remote sensing sensors is one of the key elements in order to obtain accurate geo/biophysical products for Earth observation purposes. The relationship between Top of Atmosphere (TOA) signal and Top of Canopy (TOC) or ground-level signal is given by the Radiative Transfer Equation (RTE), written in different forms depending on the spectral range considered. Hence, when working in the Visible and Near Infra-Red (VNIR) and Short-Wave Infra-Red (SWIR) spectral ranges, both absorption and scattering processes should be accounted for, whereas when working in the Thermal Infra-Red (TIR) range scattering processes are commonly neglected and only atmospheric absorption is considered.

In general terms, conversion from TOA to TOC (or ground-level) signal is referred as Atmospheric Correction or Atmospheric

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Compensation (AC). This conversion is not totally direct in the case of TIR data, since once the radiance at ground-level (or land-leaving radiances) is obtained, there is still an atmospheric contribution in it, due to the coupling between atmospheric down-welling radiance and surface emissivity. In the case of the VNIR/SWIR range, it is possible to obtain a TOC signal free of atmospheric effects, both in radiance units as well as reflectance units. In any case, when this conversion is achieved directly from inversion of the RTE, one needs to compute the different atmospheric parameters involved. This requires the knowledge of vertical distribution for some meteorological variables, i.e., requires the availability of an atmospheric profile, which could be achieved by launching an atmospheric sounding. This information can be introduced into a Radiative Transfer Code (RTC) and then, after band averaging according to the system spectral response of a certain sensor band, retrieve the atmospheric parameters required for AC.

In this paper MODTRAN4 RTC code (Berk et al., 1999) has been used, since it represents the state of the art in realistic computing of absorption and scattering in the terrestrial atmosphere at high spectral solution (1 cm^{-1}) over the VNIR, SWIR and TIR spectral ranges, providing accurate simulations of atmospheric radiative transfer (Guanter et al., 2009; Verhoef & Bach, 2003). MODTRAN includes the Discrete Ordinates Radiative Transfer code for a Multi-Layered Plane-Parallel Medium (DISORT) algorithm (Stamnes et al., 1988), which can be used for accurate multiple scattering calculations.

Dedicated calibration and validation activities are periodically carried out in the framework of different field campaigns organized by different agencies or institutions. These activities commonly include the launch of an atmospheric sounding near the overpass time of a certain sensor in order to perform accurate ACs. Since in most cases local soundings are not available, it is important to assess the feasibility of using other external sources of atmospheric profiles for accurate AC of optical imagery. This is the main purpose of this paper. In particular, the study focuses on profiles extracted from Moderate Resolution Radiometer (MODIS) Atmospheric profiles product (MOD07) and on profiles extracted from Reanalysis information, whose resolutions have been vertically and spatially improved in relation to other existing Reanalysis-based profiles. MOD07 products provide daily atmospheric profiles at 5 km spatial resolution and at world-wide scale since year 2000, thus providing a powerful information for AC of any kind of imagery, from high to low resolution ones. As far as we know, MOD07 is the existing atmospheric profiles product with the highest spatial resolution. Results will be analyzed for three test dates in the framework of different field campaigns carried out over an agricultural area, in which local atmospheric soundings were launched. MOD07 and Reanalysis-based vertical profiles were compared to local soundings, considered as the "ground-truth", and differences on the AC depending on the atmospheric profile used were analyzed. Satellite sensors included in this study were the Compact High Resolution Imaging Spectrometer (CHRIS) on-board the Project for On-Board Autonomy (PROBA) platform, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on-board the TERRA platform, and Thematic Mapper (TM) on-board the Landsat-5 satellite.

The paper is organized as follows: Section 2 provides the theoretical basis for radiative transfer in the VNIR and SWIR spectral ranges, including description of methods for surface reflectance retrieval, whereas Section 3 provides the theoretical basis for radiative transfer in the TIR region, including description of methods for LST retrieval; Section 4 presents the test area and imagery used in the study, and Section 5 includes a description of the different atmospheric profiles sources considered in this paper; Section 6 shows the results obtained in the intercomparison of the different vertical profiles, and Section 7 shows the results obtained in the atmospheric correction in the VNIR/SWIR (reflectance retrievals) and TIR (LST retrievals) cases; finally, Section 8 summarizes and includes the main conclusions drawn from the study presented in this paper.

2. Theoretical basis for atmospheric correction in the VNIR and SWIR

Atmospheric correction in the VNIR and SWIR regions usually refers to the conversion of TOA radiances (or at-sensor radiances) into surface reflectances. In comparison to the TIR region (analyzed in the next section), the expression for the RTE in the VNIR/SWIR is probably subjected to more variations depending on the different assumptions considered. In this paper we will start from the RTE as presented in Verhoef and Bach (2003), which is based on a four-stream approximation and provides a complete description for the different contributions involved in the AC. Since this approach is not easy to implement for a non-experienced user, we will propose a simplified methodology based on MODDTRAN4 calculations which use MODTRAN outputs directly, and then a deep knowledge of radiative transfer issues is not required.

2.1. Four-stream land-atmosphere radiative transfer

The four-stream approach is described in detail in Verhoef and Bach (2003). According to this formulation, four terms are considered for describing the radiative transfer into the atmosphere in the VNIR and SWIR: i) the photons reflected by the atmosphere before reaching the surface, ii) the photons transmitted directly to the target and directly reflected to the sensor, iii) the photons that are scattered by the atmosphere before reaching the target and directly reflected to the sensor and finally iv) the photons that have at least two interactions with the atmosphere and one with the target. Taking these different contributions into account and considering the surface as uniform and Lambertian the Radiative Transfer Equations for the atmosphere can be written as:

$$E_s(b) = \tau_{ss} E_s(t) \tag{1}$$

$$E^-(b) = \tau_{sd} E_s(t) + \rho_{dd} E^+(b) \tag{2}$$

$$E_o(t) = \rho_{so} E_s(t) + \tau_{do} E^+(b) + \tau_{oo} E_o(b) \tag{3}$$

$$E^+(b) = \rho_{surf}[E_s(b) + E^-(b)] \tag{4}$$

where $E(b)$ and $E(t)$ indicate the bottom and the top of the atmosphere irradiance respectively, $E_s(b)$ is the direct solar flux, $E_0(t)$ is the top of atmosphere irradiance in the direction of viewing, $E^-(b)$ is the downward radiation from the sky, $E^+(b)$ is the diffuse upward flux, ρ_{so} is the bi-directional reflectance of the atmospheric layer, τ_{ss} is the down-welling direct transmittance, τ_{sd} is the diffuse transmittance in the solar direction, τ_{do} is the diffuse transmittance in the viewing direction, ρ_{dd} is the atmospheric spherical albedo, τ_{oo} is the up-welling direct transmittance and ρ_{surf} is the surface reflectance. Taking into account the Lambertian assumption for the surface, it implies that $E_o(b) = E^+(b)$, and using radiance units, $L_{TOA}(t) = E_o(t)/\pi$, the final RTE can be written as

$$L_{TOA} = \left(\rho_{so} + \frac{(\tau_{ss} + \tau_{sd})(\tau_{oo} + \tau_{do})}{1 - \rho_{surf}\rho_{dd}} \rho_{surf}\right) \frac{E_s}{\pi} \tag{5}$$

where L_{TOA} is the radiance measured at the top of the atmosphere that must be corrected atmospherically. E_s is the extraterrestrial solar irradiance. Using reflectance terms and by inversion of Eq. (5), we can finally obtain an expression for the surface reflectance ρ_{surf}:

$$\rho_{surf} = \frac{\rho_{TOA} - \rho_{so}}{(\tau_{do} + \tau_{oo})(\tau_{ss} + \tau_{sd}) + \rho_{dd}(\rho_{TOA} - \rho_{so})} \tag{6}$$

Application of Eq. (6) requires the computation of six atmospheric parameters τ_{do}, τ_{oo}, τ_{ss}, τ_{sd}, ρ_{dd} and ρ_{so}, which can be achieved from three MODTRAN4 runs for a uniform Lambertian surface reflectance