Atmospheric Correction of Satellite Signal in Solar Domain: Impact of Improved Molecular Spectroscopy

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Introduction

Atmospheric correction of satellite measurements is a major step in the retrieval of surface reflective properties. It involves removing the effect of gaseous absorption as well as correcting for the effect of an atmospheric molecular and particulate scattering. In the past few years, there has been significant advancement in our knowledge of the absorbing properties of various atmospheric radiatively active gases. In particular, Giver et al. (2000) reported important updates to the parameters of line and continuum absorption by water vapor. These and other updates have been incorporated into HIRTRAN spectroscopic database and implemented in Moderate-Resolution Atmospheric Radiance and Transmittance Model-4 (MODTRAN-4) radiative transfer model (Berk et al. 2001). We used the latest version of MODTRAN-4 combined with updated high-resolution transmission (HITRAN) 2001 database (Rothman et. al. 2001) to estimate the impact of these improvements on atmospheric correction of the signal in solar domain for various satellite sensors. The objectives of our study are to (1) develop fast, but accurate semi-analytical atmospheric correction scheme suitable for implementation in operational data processing of satellite narrowband observations, (2) estimate the impact of improved molecular spectroscopy on a atmospheric correction and surface reflectance retrievals, and (3) derive the sensor specific model parameters for narrowband satellite sensors, such as Advanced Very High Resolution Radiometers (AVHRR/2 and AVHRR/3), aboard National Oceanic and Atmospheric Administration (NOAA) spacecrafts, VEGETATION (VGT) sensor aboard SPOT, geostationary operational environmental satellite (GOES) imager, Landsat thematic mapper (TM), and enhanced thematic mapper plus (ETM+), and selected moderate-resolution imaging spectroradiometer (MODIS) channels using comprehensive radiative transfer modeling employing MODTRAN-4.

Atmospheric Correction Scheme

In the case of a uniform Lambertian target with reflectance ρ_s, the reflectance at the top of the atmosphere (TOA), ρ_{TOA} could be written as (e.g., Vermote et al. 1997; Rahman and Dedieu 1994).

$$\rho_{TOA} = T_g \left[\rho_{R+A} + T(\theta_s)\, T(\theta_v)\, \rho_s / (1 - S\,\rho_s)\right] \qquad (1)$$

where T_g is the two-way gases transmittance function, $T(\theta s)$ and $T(\theta v)$ are total atmospheric scattering transmission (atmospheric transmission normalized by T_g), S is the atmospheric spherical albedo. The term ρ_{R+A} denotes contribution from Rayleigh and aerosol scattering over non-reflecting surface. Following the approach proposed by Rahman and Dedieu (1994), we employ a single-scattering approximation for Rayleigh scattering. Aerosol scattering is described according to Sobolev (1975). The difference between accurate numerical results from MODTRAN-4 and above approximations was minimized by introducing the residual correction as a function of scattering angle ξ, $\rho_{res}(\xi)$. Surface reflectance corrected for the atmospheric attenuation effects can be derived by inverting Eq. (1) as

$$\rho_s = \left(\rho'_{TOA} - \rho_{R+A} - \rho_{res}(\xi)\right) / T(\theta_s)\, T(\theta_v) + S\left(\rho'_{TOA} - \rho_{R+A} - \rho_{res}(\xi)\right), \qquad (2)$$

where $\rho'_{TOA} = \rho_{TOA}/T_g$ and $\rho_{res}(\xi)$ is a residual correction.

Required coefficients of the model (Eqs. 1 to 2) were obtained by fitting approximations to the results of MODTRAN runs for wide range of atmospheric (set of four standard atmospheres) and geometric conditions (sun zenith angle [SZA]: 5° to 70°, viewing zenith angle [VZA]: 0° to 65°, variable altitude). The fitting errors of the empirical functions were in general quite small, though the simplified atmospheric scattering approximation was less accurate for high aerosol optical depth and small scattering angles.

An example of comparison of developed model against MODTRAN-4 results is shown in Figure 1 for a variety of realistic observational conditions: SZA 5° to 70°; VZA 0° to 65°, variable aerosol and gaseous contents. Figure 1 shows the results for AVHRR ch. 1 (red), 2 (NIR), 3A (SWIR) and SPOT4 VGT sensor for surface pressure of 1000 mb and sub-arctic summer atmosphere. The bias in TOA reflectance is mostly within 0.01. Few larger differences correspond to extreme geometry and large aerosol amounts.

Impact of Improved Molecular Spectroscopy on Retrievals

An example of AVHRR/3 spectral bands and atmospheric transmission is given in Figure 2. Atmospheric transmission computed by MODTRAN-4 was compared to other models. Generally, we found more atmospheric absorption with MODTRAN-4 than estimated with earlier MODTRAN models, as well as 5S and 6S models. This is especially evident for narrowband channels located in the near-infrared (NIR) part of the solar spectrum in the vicinity of the water vapor absorption band located around 0.94 μm (Figure 3b). For example, the correction to atmospheric transmittance in AVHRR NIR

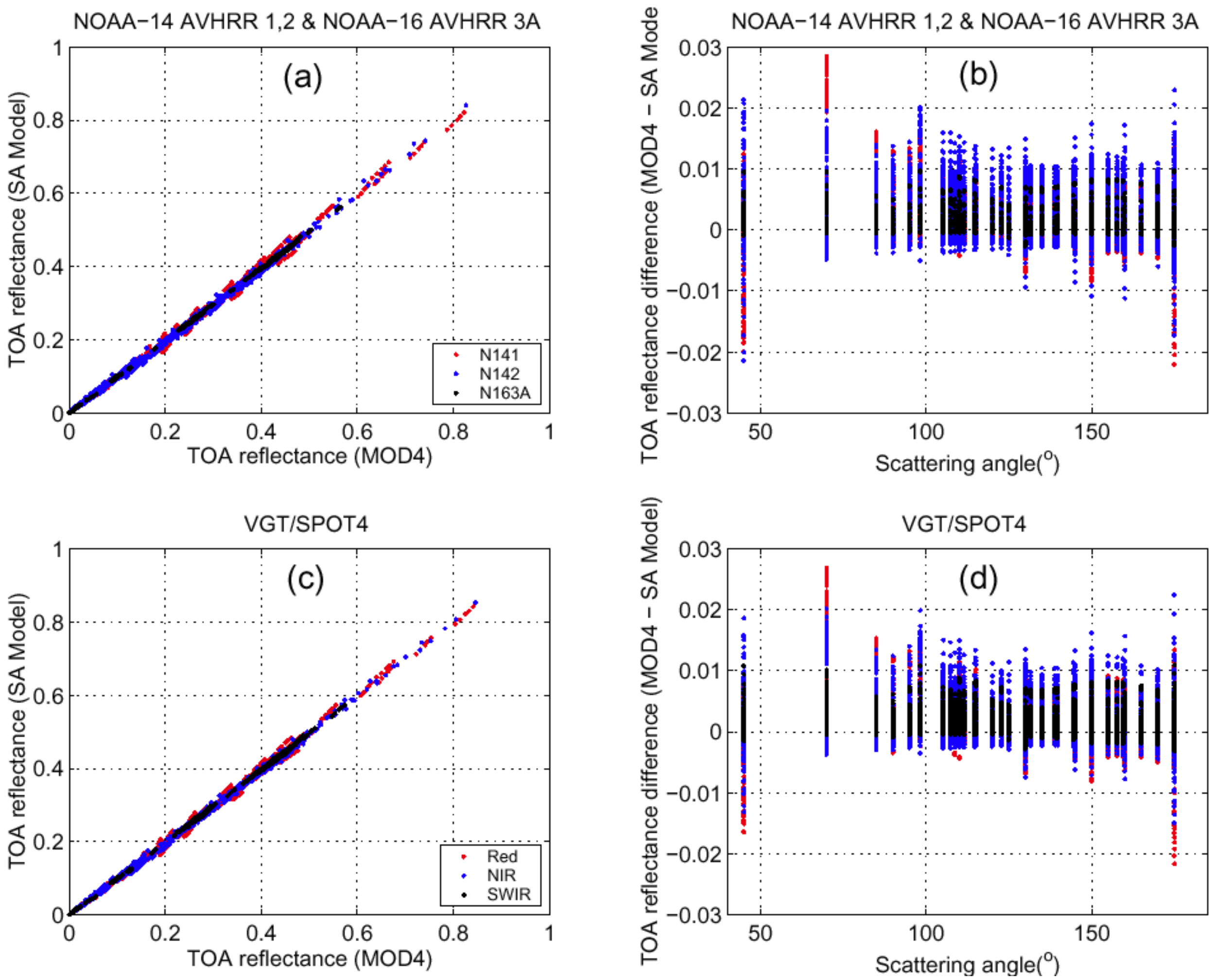

Figure 1. Scatter plot of the TOA reflectance simulated with MODTRAN-4 and developed atmospheric correction model Eqs. (1 to 2) for AVHRR (a) and (c) VGT. The difference in TOA reflectance between MODTRAN-4 and developed model as function of the scattering angle for (b) AVHRR and (d) SPOT4 VGT.

ch.2 reached 12% depending on observational condition, relative to the one computed with 6S model (version 4) (Figure 3c). This deviation could cause biases in the retrieved surface reflectance 0.01 to 0.04 (Figure 3d), which leads to underestimation of the normalized difference vegetation index (NDVI) up to 10% or more in terms of relative bias (Figure 4). The instrument spectral response function effects also need to be taken into account when comparing results between different sensors (Trishchenko et al. 2002).

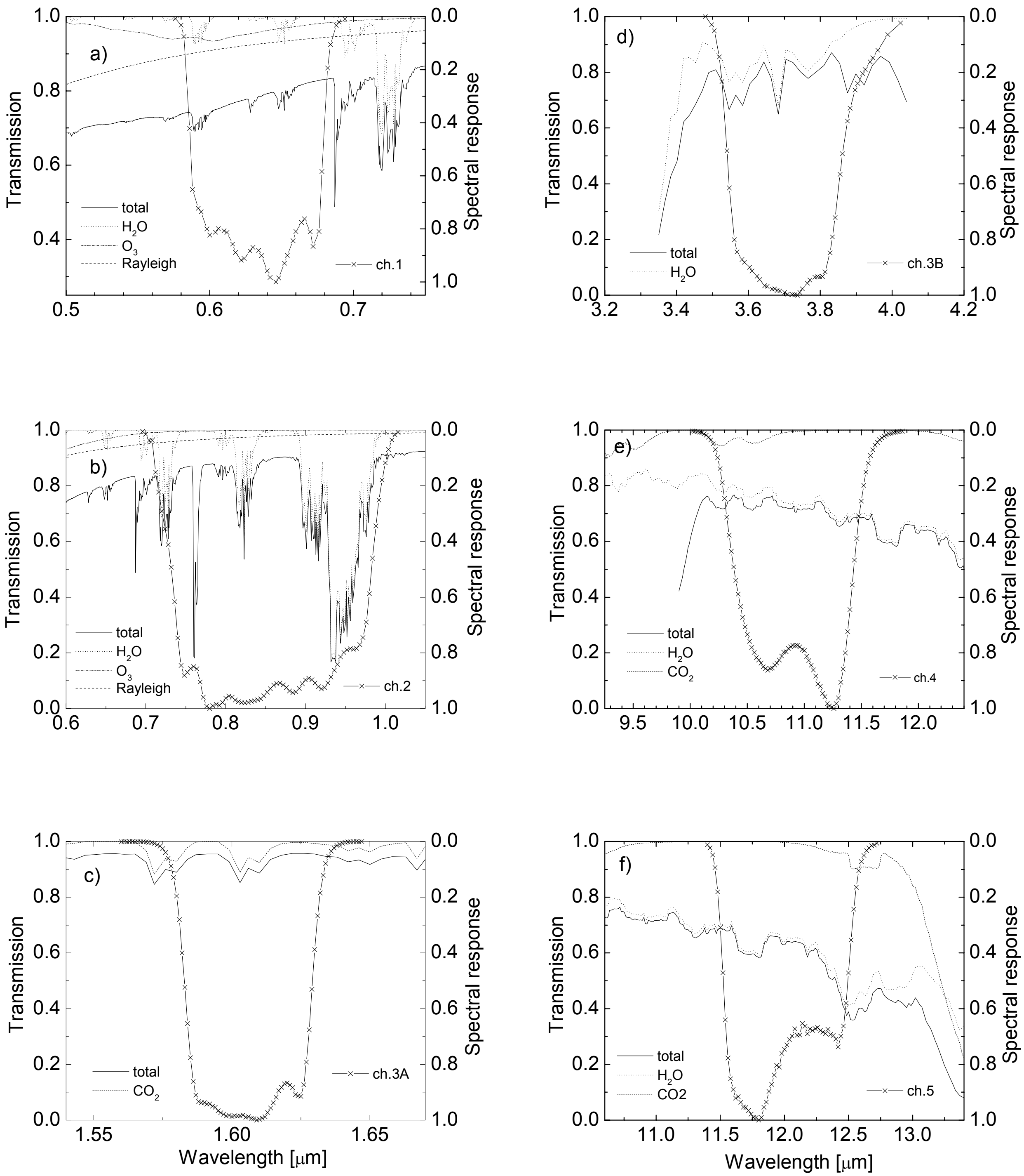

Figure 2. NOAA-16 AVHRR/3 spectral response functions and atmospheric transmission computed with MODTRAN-4.

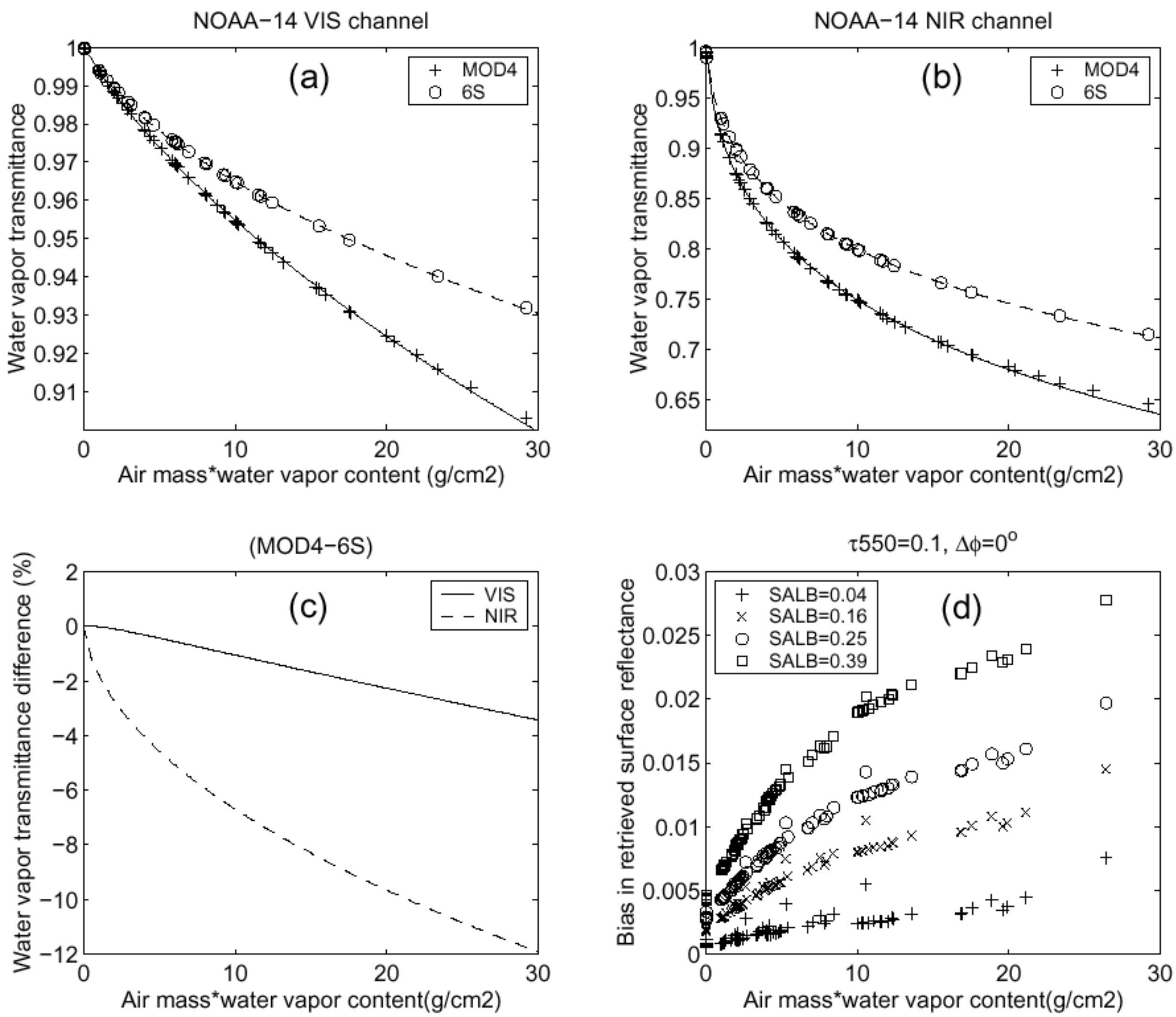

Figure 3. The water vapor transmittance computed by MODTRAN-4 (+) and 6S code (version 4) (o) for NOAA-14 AVHRR (a) visible and (b) NIR channels. The solid and dotted lines in (a) and (b) represent the corresponding calculation by the semi-analytical model. (c) Difference in the water vapor transmittance between MODTRAN-4 and 6S for the visible (solid line) and NIR channel (dotted line). (d) Estimated bias in the retrieved AVHRR NIR surface reflectance for different surface albedo.

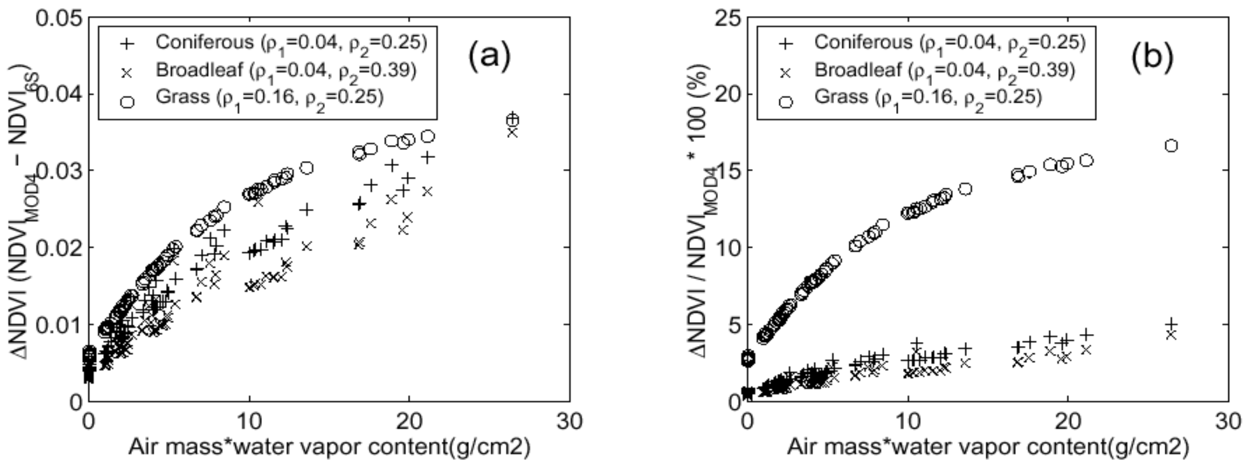

Figure 4. The (a) absolute and (b) relative difference in the NDVI due to the improved correction for the atmospheric absorption. The estimation was made for three surface types: coniferous (+), deciduous broadleaf forest (x), and grass (o) observed by NOAA-14 AVHRR/2 visible and NIR channels. The reflectance of the coniferous, broadleaf forest, and grass are 0.04 and 0.25, 0.04, and 0.39, and 0.16 and 0.25, and the corresponding NDVI values are 0.73, 0.81, and 0.22.

Conclusions

Use of the improved molecular spectroscopy database resulted in more atmospheric absorption, especially in the NIR region where the correction may reach 12% relative to the computations based on obsolete, but still popular spectroscopic data. This may lead to the biases in the NDVI of 10% or more. Similarly, this effect leads to a decrease of water vapor amounts retrieved from satellite observations in the NIR region, when improved spectroscopy is implemented.

Operational atmospheric correction model was developed and validated against MODTRAN-4 with the updated HITRAN 2001 molecular database. The reflectance calculated from this model is mostly within ±0.01 relative to MODTRAN-4. Coefficients of the model were produced for all narrowband shortwave channels of AVHHR/2-3, Landsat TM, VGT/SPOT, GOES, and selected MODIS channels.

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