Evaluation of near-UV/blue Aerosol Optical Thickness Retrieval from Airborne Hyperspectral Imagery

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Abstract— **An aerosol retrieval algorithm is currently under development in scope of the upcoming APEX hyperspectral imager. It will be able to close the gap between global remote sensing and one-dimensional in situ measurements of atmospheric particles. This paper presents a feasibility study of the proposed APEX aerosol retrieval approach for hyperspectral imagery with high spatial resolution. The extraction of a sample aerosol optical thickness is done by fitting radiation transfer model results to measured at-sensor radiances at two near-UV/blue bands (394 and 404 nm) from the PHILLS imager. The PHILLS hyperspectral data are used to simulate the APEX Visible Near-Infrared detector and comprehend a dark surface reference target to avoid most uncertainties from the surface reflection contribution.**

I. INTRODUCTION

It is unquestioned that atmospheric particles affect the global radiation budget and climate. Numerous satellites measurements have been conducted during the last decade to study the distribution and effect of aerosols. But optical space based instruments are limited in spatial and/or spectral resolution and have to deal with relatively large uncertainties in the surface reflectance component. The information about local particle distribution, including sources and sinks, is hidden in the insufficient resolution of the global measurements. Especially the aerosol research in urban and industrial areas can benefit from airborne remote sensing techniques. Aerosol products from airborne hyperspectral imagers are expected to close the gap between the global and the in-situ measurements.

The presented aerosol retrieval algorithm is optimized for the use with hyperspectral sensors with high spatial resolution, foremost airborne imagers. It is currently under development for the Airborne Prism EXperiment (APEX) [1] sensor system, which itself is under development by the scientific lead of the Remote Sensing Laboratories (RSL) in Switzerland. This paper assesses the potential of this algorithm for the aerosol optical depth retrieval and the resulting surface reflectance information. A dataset from the Portable Hyperspectral Imager for Low Light Spectroscopy (PHILLS) from the Naval Research Laboratory (NRL) was found to ideal simulate the expected APEX imagery. The spectral range of PHILLS, corresponds to the Visible Near-Infrared (VNIR) detector of APEX. The spatial resolution is also in the same range of a few meters, depending on the flight altitude and spatial binning.

II. AEROSOL RETRIEVAL APPROACH

The proposed aerosol retrieval procedure for APEX is outlined here. The further analysis focus on its initial iteration, the aerosol retrieval over a reference target.

The procedure combines the classic two-channel approach with the assets of the aerosol information extraction in the near-UV/blue spectral region between 380 nm and 420 nm [2]. This allows the retrieval of AOT, aerosol size distribution and Ångstrøm wavelength exponent without being strongly disturbed by the surface reflectance [3]. The procedure works iteratively, as shown in Fig. 1. A reference aerosol optical thickness (AOT) is retrieved above a reference surface target by inversion of a radiation transfer model (RTM) (e.g. MODTRAN4 [4]). The sample AOT and aerosol model is then used to determine the apparent surface reflectance by atmospheric compensation. The resulting Level-2 APEX data provide corrected surface reflectance information to exploit aerosol parameters over the whole imagery.

In order to minimize the retrieval error, it is planned to run individual scene-specific RTM calculations with all available atmospheric, solar, elevation and viewing geometry inputs. The AOT and the aerosol model with its vertical distribution are the remaining variables to be determined. The RTM calculation yields the relation between radiance and AOT for the given observation parameters. This information is further used to invert the measured radiance to a corresponding AOT and single scattering albedo value, while the vertical distribution cannot be retrieved with this methodology.

The implementation of further aerosol models and basic consideration of BRDF and polarization effects of the Rayleigh

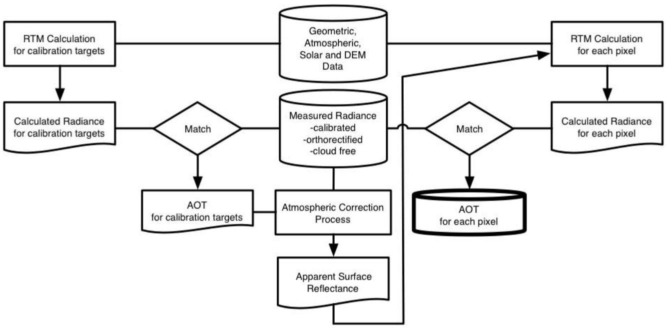

Fig. 1. The suggested APEX aerosol retrieval procedure. It starts with a first iteration of RTM calculation over reference or black targets to calculate an expected radiance for various AOT. Where the calculated and the measured radiance match, the corresponding AOT will be retrieved. This AOT enables the atmospheric correction process to determine the apparent surface reflectance. The following iterations over all pixels rely on that apparent surface reflectance information. The AOT for each pixel is now retrieved and finally it is possible to achieve an accurate surface reflectance by feeding a second atmospheric correction run.

atmosphere has the potential to increase the retrieval accuracy in the future.

III. Sensor and Data Description

The NRL built a series of PHILLS imaging spectrometers over the past twelve years. Typically, the VNIR spectrometer is operated on an Antonov An-2 biplane. The pushbroom-scanning instrument uses a thinned, backside-illuminated detector array with great sensitivity, particular in the blue spectral region. A comprehensive description of the instrument and calibration is given by Bowles et al. [5], Davis et al. [6], and Kohler et al. [7].

The PHILLS flight data were acquired on July 15. 2004 on the eastern coast of Florida. Fig. 2 shows the subset used for this study at Stuart/Witham Field. The flight campaign was proposed and used to demonstrate the characteristics of water properties, bathymetry and bottom types in hyperspectral imagery. The approximate 3050 m altitude of the aircraft results in a GSD of about 2.3 m by 2.3 m. The hyperspectral data ranges from 385 nm to 1000 nm, resolving 128 spectral bands with continuous spectral bins ($\Delta\lambda$) of 4.8 nm. The spectral radiances were computed using the calibration coefficients from the PHILLS calibration site in the NRL Remote Sensing Division's Radiometric Calibration Laboratory.

IV. Results

The described PHILLS data were used to test the ability of the AOT retrieval from hyperspectral imagery by using a surface reference target. This corresponds to the initial iteration of the proposed aerosol retrieval algorithm for APEX. An atmospheric compensation over the whole scene and a spatial AOT retrieval is subject to ongoing studies.

A. Radiation transfer model calculation

RTM calculations were carried out with MODTRAN4 to simulate at sensor radiances for a range of visibilities and different aerosol models. The result with the best fit to the image data is assumed to represent the actual AOT. In this paper, the given AOT's refer to the total vertical AOT between the surface and the sensor at 3050 m. The AOT in higher levels is considered to be small. Meteorological elements for the Stuart/Witham Field on July 15. 2004, were taken from the US National Climate Data Center [9] in order to adapt the modeled atmosphere as realistic as possible.

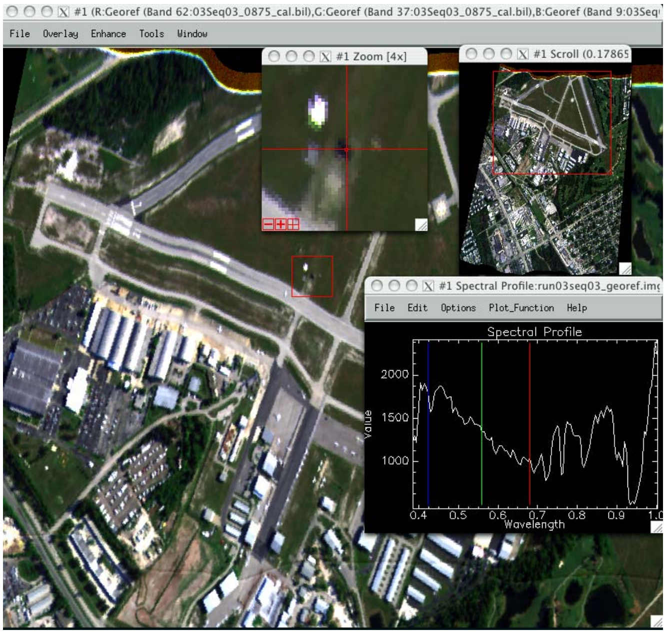

Fig. 2. Sample of the PHILLS spectral calibrated data at Stuart/Witham Field, Florida. Shown is a red, green, blue composite of the 0.68, 0.56 and 0.42 μm bands. The red crosshair in the *Zoom* window identifies the 2% reference target. The plot in the *Spectral Profile* window corresponds to the sampled pixel of the reference target.

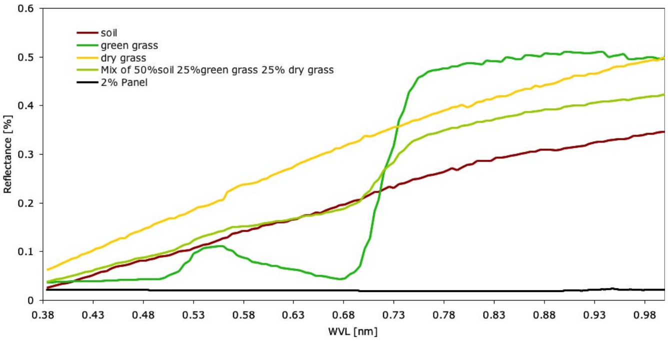

Fig. 3. Plot of the surface reflectance used for the radiation transfer model calculations. The soil, green and dry grass spectra are derived from the ENVI spectral libraries [8].

MODTRAN4 comprehends only a few basic aerosol models (i.e. urban, rural, marine, troposphere, desert) for the lowest 2 km. The aerosol model for the free troposphere is assumed by an invariant mixing of 70% water-soluble (organic compounds, ammonium and calcium sulfate) and 30% dust-like aerosols in the small particle fraction. The background aerosols in the stratosphere consider sulfur and small amounts of volcanic particle compounds. The vertical gas, temperature and hu-

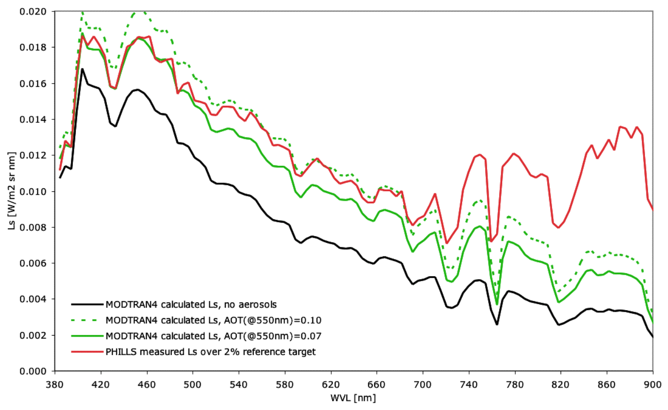

Fig. 4. Plot of the modeled and measured at sensor radiances (L_s). The L_s contribution by atmospheric particles is obvious by comparing the black to the other curves.

midity distribution represent an average mid-latitude summer atmosphere. For simplicity, the standard MODTRAN4 atmospheric profiles and aerosol models have been used for this study. The solar spectral irradiance is adapted from Thuillier [10]. Molecule and aerosol multiple scattering is computed by the DISORT algorithm implemented in MODTRAN4 [4]. The effect of the atmospheric water vapor on the particle growth is approximated by increased particle diameters [11].

The lambertian spectral surface reflectance of pixels surrounding the target is taken into account to consider adjacency effects. The special asset of the PHILLS image (Fig. 2) is the availability of a reference surface for a sampled AOT retrieval. It is a 10 m square sized black target, which reflects spectral constant at 2% (Fig. 3). There are no in situ spectral reflectance information available of the surrounding surface to account for the adjacency radiance contribution. The surface constituents are therefore assumed by visual image interpretation as: 50% soil, 25% green grass and 25% dry grass (Fig. 3). The corresponding spectral behaviors are taken from the ENVI spectral libraries [8].

B. *Transmittance and Aerosol optical thickness*

Numerous RTM calculations were performed to find a spectral at sensor radiance (L_s), which represents the measured PHILLS radiances at the 2% reference target. The best fit was found for the rural aerosol model with an AOT between 0.07 and 0.1 at 550 nm (Fig. 5). The weaker aerosol loading fits better in the near-UV and blue, while an AOT of 0.1 approximate better between 540 nm and 720 nm, as shown in Fig. 4 and 5. A change in the aerosol model alters mainly the slope of the spectral plot, while a change in AOT shifts the L_s. None of the standard aerosol models in MODTRAN4 could reproduce the measured L_s throughout the PHILLS spectrum. Especially L_s at wavelenghts above 700 nm are difficult to fit due to the remaining uncertainty in the adjacency effect. But the proposed aerosol retrieval is not so strongly influenced by the surface radiance contribution because the atmospheric scattering dominates in the near-UV and blue.

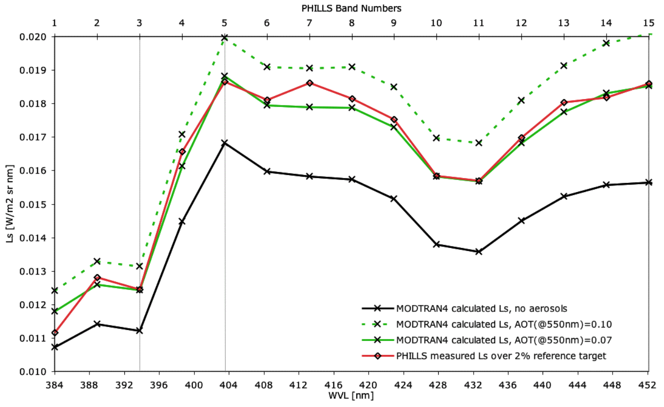

Fig. 5. Zoom of Fig. 4. The modeled L_s with AOT=0.07 fits well to the measured L_s at PHILLS band 3 and 5.

TABLE I

RETRIEVED OPTICAL THICKNESSES FOR PHILLS BAND 3 AND 5 AND AT THE 550 NM REFERENCE.

	$\lambda = 394$ nm	$\lambda = 404$ nm	$\lambda = 550$ nm
τ_{aer}	0.093	0.091	0.069
τ_{mol}	0.110	0.099	0.028
τ_{tot}	0.192	0.182	0.095

The rural aerosol model is composed by the same constituents as the mentioned troposphere model. There are no soot particles included, thus the absorbing effects on the transmittance can be neglected ($T_{aer,scat} \cdot T_{aer,abs} \approx T_{aer,scat} \equiv T_{aer}$). Fig. 6 plots the MODTRAN4 retrieved transmittance for aerosol scattering ($T_{aer,scat}$), aerosol absorption ($T_{aer,abs}$), Rayleigh (molecular) scattering (T_{mol}) and the total atmospheric transmittance (T_{tot}) between the sensor and the surface. The conversion to the optical thickness ($\tau = 1 - T$) is given in Table I. for the wavelengths, which corresponds to PHILLS band 3 and 5. The standard value at 550 nm is also provided as a reference.

The Ångstrøm wavelength exponent can be computed from the given values by the following equation:

$$\alpha = \frac{\log\left(\frac{\tau_{aer_1}}{\tau_{aer_2}}\right)}{-\log\left(\frac{\lambda_1}{\lambda_2}\right)}. \tag{1}$$

With $\lambda_1 = 394$ nm and $\lambda_1 = 550$ nm α is equal to 0.895.

V. SUMMARY AND CONCLUSION

The described aerosol retrieval approach is designed to benefit from the high spectral and spatial resolution of the upcoming APEX hyperspectral imager. It works iteratively. It starts in the near-UV spectral region over a reference or dark target, in order to determine the apparent surface reflectance. And it ends with the retrieval of aerosol parameters from a whole scene. The feasibility of the RTM inversion with surface reference targets was successfully studied with PHILLS hyperspectral data and presented in this paper. It was found that the rural aerosol model with an AOT of 0.07 at 550

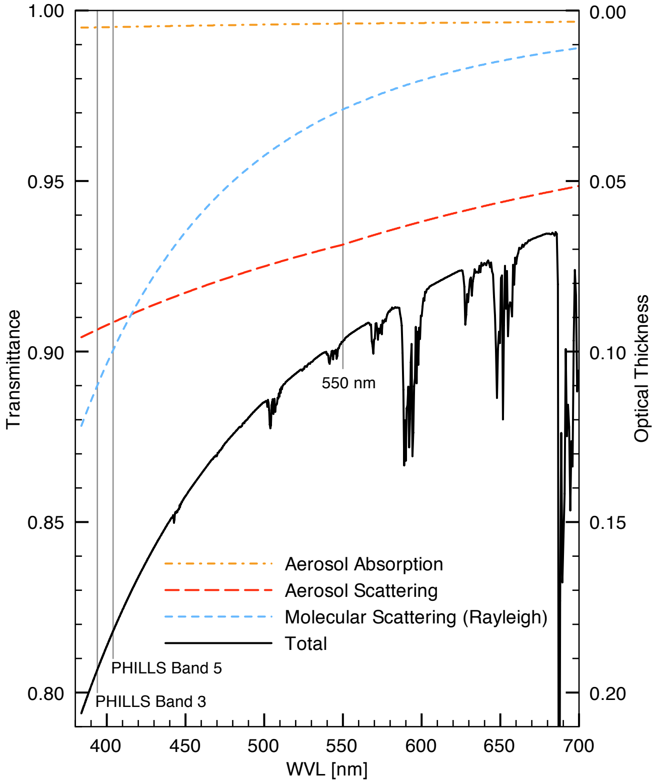

Fig. 6. Transmittance and optical thickness of the atmosphere, the aerosols and the Rayleigh scattering between aircraft and surface, where the modeled L_s fits the measured L_s in the near-UV.

nm reproduces the L_s of PHILLS in the near-UV and blue. Nevertheless, the rural MODTRAN4 aerosol model, cannot model the measured image radiance for the complete imager spectrum. Further efforts are therefore planed to improve the retrieval accuracy by the implementation of refined aerosol models and by taking basic considerations of BRDF and polarization effects of the Rayleigh atmosphere into account.

The proposed algorithm has the potential to advance the knowledge in the small-scaled spatial dispersion structures of atmospheric particles. Beside the enhanced atmospheric compensation of airborne hyperspectral data, further applications in aerosol related climate and environmental research are possible.

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