5.2 AEROSOL OPTICAL DEPTH RETRIEVAL OVER LAND FROM THE AVHRR PATHFINDER ATMOSPHERE DATA SET

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1. INTRODUCTION

Given the current emphasis to retrieve aerosol information from newer satellite instruments (e.g., MODIS, ATSR), it is beneficial to understand what previous satellite datasets can provide. The 1980-2000 period was observed by AVHRR, TOMS and SAGE. The SAGE experiment is most sensitive to stratospheric aerosols, and thus misses tropospheric events. The TOMS instrument is most sensitive to absorbing aerosol in the UV region and is less sensitive to aerosol near the surface. This leaves the AVHRR which already has provided a 20-year climatology of aerosol over ocean. It has been established that AVHRR can sense aerosol over ocean, so this work looks toward retrieving aerosol over land.

The AVHRR Pathfinder Atmosphere (PATMOS) dataset (Jacobowitz et al., 2002) provides cloud-free radiance statistics for each day on a global 110 km grid for all five channels of AVHRR from 1981 through 2001. Ocean grid cell data have already been processed with the NOAA operational aerosol retrieval algorithm to create an extensive record of aerosol optical depth (τ) (available in PATMOS-2 data). However, as theoretical climate model studies indicate, the most significant concentrations and radiative effects of aerosols occur over land. To assist these climate studies, as well as the Global Aerosol Climatology Project, we are developing a τ retrieval algorithm over land comparable to the one over oceans when and where an aerosol signal is present in the 0.63µm reflectance channel of AVHRR.

Since visible reflectances of land are a convolution of atmosphere (i.e., aerosol) and surface contributions, the first step of this research was to determine the underlying surface reflectance properties. This research retrieved the temporally-varying surface Bidirectional Reflectance Distribution Function (BRDF) for each grid cell. This work produced a 20-year climatology of BRDF values as well as estimates of NDVI and broadband albedo which are atmospherically-corrected. Description of the BRDF retrieval method as well as the estimation of NDVI and albedo is described in paper P3.13 of these proceedings. This paper focuses primarily on the retrieval results of aerosol over land.

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2. DATA

Two data sources are used in this study: the PATMOS data set provides cloud-free TOA reflectance observations and the Aerosol Robotic Network (AERONET) data provide ground-truth aerosol optical depths.

2.1 PATMOS Data

This vast amount of AVHRR data is condensed into a useable format in the PATMOS data set (Stowe et al., 2002). The volume of the Global Area Coverage (GAC) AVHRR data has been significantly reduced from terabytes to gigabytes by statistically decreasing the spatial resolution. The GAC data are binned into 110×110 km^2 quasi-equal area grid cells where statistics are calculated for each AVHRR channel for each grid cell.

The PATMOS daily-radiance data set (PATMOS-1) includes 71 parameters for each grid cell. 54 parameters are direct variables of AVHRR measurements. Four statistical categories are used for each channel: All pixels, clear sky, aerosol burden and cloudy. Statistics for each category (generally, the mean and standard deviation) are recorded for each channel. The parameter used in this study is the channel 1 (0.63µm) reflectance (R_{sat}) deemed cloud-free by the CLAVR-1 algorithm (Stowe et al., 1999).

For this study, the PATMOS-1 data from 1993 through 1999 are used to compare with AERONET observations of τ.

2.2 AERONET Data

The AERONET provides the ground truth validation for this research. AERONET is a federation of sun-sky radiometers independently owned with centrally archived data, which can measure aerosol optical depth to an accuracy of ±0.02 (Holben et al., 1998). Data used in this study utilizes only those sites where the data have been cloud filtered as well as post-calibrated (i.e., level 2 data).

3. AEROSOL RETRIEVAL METHOD

The retrieval of aerosol information from PATMOS data over land is a three-step process. First, reflectances for numerous conditions are calculated from a radiative transfer model and stored in look-up tables (LUT). Second, these tables are then used to retrieve the surface BRDF from the PATMOS data. Third, the surface BRDF data are then used to retrieve τ from the PATMOS data using LUT information for that BRDF. This method is developed and further test by (Knapp and Stowe, 2002). While the BRDF retrieval is detailed in paper P3.13 (this proceeding), a summary is provided here.

3.1 Summary of BRDF Retrival

The retrieval is based on radiative transfer. The DISORT radiative transfer model (Stamnes and Swanson, 1981) version 2 is used to produce theoretical TOA reflectances as a look up table (LUT) at numerous viewing and illumination geometries and BRDF parameter values. Atmospheric effects were held constant during the calculations, with ozone absorption and Rayleigh scattering characteristic of a tropical atmosphere.

The (Rahman et al., 1993) was used in this research to model the surface; it uses three terms to describe the surface: the magnitude of the surface reflectance, ρ; the Henyey-Greenstein function parameter, Θ; and the level of anisotropy, k.

Aerosol scattering and absorption are included in these calculations via the continental aerosol described by Kaufman et al (1997). One look-up table is computed with τ = 0.05. This is the assumed to be the minimum τ observed during the composite time period. LUTs area also calculated at other τ values, the interpolation between which allows the τ retrieval.

The surface BRDF is estimated by compositing PATMOS reflectances. For example, over the course of 24 days it is possible to composite 3 observations from each look angle given cloud-free observations. The LUT with τ = 0.05 is used to determine the surface BRDF. First, the LUT is interpolated for the viewing geometry of each of the points, then a cost function is used to retrieve the best-fit BRDF parameters.

3.2 Aerosol Optical Depth Retrieval

Once the BRDF parameters have been determined, the τ retrieval is straightforward. The LUT is interpolated for geometry and BRDF parameters. The remaining free variable is aerosol optical depth, which is retrieved using the PATMOS reflectances. Before discussing the retrieval results, the uncertainty in these comparisons should be considered.

4. UNCERTAINTIES AND LIMITATIONS

Uncertainty in aerosol retrievals are prevalent in all algorithms. Uncertainties in aerosol optical properties, instrument calibration and cloud contamination all affect aerosol retrievals from satellite. In addition to these uncertainties, there are some which are specific to this retrieval method.

Perhaps the most significant uncertainty is the sampling of cloud-free pixels in the PATMOS grid cell. The portion of the grid-cell surface viewed each day varies with the spatial distribution of cloud. So for spatially inhomogeneous regions, the day-to-day variation in the observed surface can be large.

Also, the temporal variability of the grid-cell surface affects the retrieval performance. Since the surface properties are determined from numerous observations, any changes during that time could cause significant biases or noise in the ensuing aerosol retrievals. This is most important in regions with seasonal vegetation change, such as the Midwest US.

The presence of stagnant aerosol masses can also bias the aerosol retrieval. The retrieval method assumes that by compositing observations, there will be some observations made when the aerosol optical depth is at a “background” condition, since most aerosol events are transient in time (with time scales less than a week). However, in certain areas, aerosol are more prevailing. For example, the biomass burning plume in South America can be very persistent throughout August and September. In these cases, the persistent aerosol is interpreted by the algorithm as a surface signal, thus biasing the aerosol retrievals.

Last, there is a lack of sensitivity to aerosols over bright surfaces, however this is not unique to this algorithm. The aerosol generally increase the TOA reflectance. However, in the presence of significant aerosol absorption or bright surfaces, the aerosol effect goes to zero or possibly becomes negative (thus decreasing the

TOA reflectance). Thus, most aerosol retrievals algorithms, including this one, will likely not work over snow, ice, desert and other surfaces with large reflectance.

Other uncertainties result from departure of the actual conditions from those assumed in the LUT, which include variations in:

- aerosol optical properties (spatially and temporally)
- column ozone amount
- Rayleigh scattering optical depth
- cloud contamination in the PATMOS cloud-free reflectances
- the discrepancy between the modeled BRDF and the actual BRDF

5. RESULTS

First, retrievals are applied to PATMOS land grid cells nearest to 84 of the AERONET sites around the world to estimate regions where the algorithm will work. Then, the algorithm is applied to all PATMOS land reflectances.

5.1 AERONET validation

An example of the retrieval validation is provided in Figure 1. The Cuiaba site is located in Brazil and is primarily affected by seasonal biomass burning. Thus it has a strong aerosol signal and its surface is generally constant (being near the rainforest). The correlation is large (0.88) with an RMS difference of 0.15. There is a negative bias, however, (i.e., slope of 0.78) likely due to the larger absorption of typical biomass-burning aerosol than the continental aerosol used in the LUT.

Grouping all the AERONET sites in South America provides more insight to the retrieval performance (figure 3). A similar low bias (with a slope of 0.63) and correlation (r = 0.87) is found. However, the retrieval shows significant errors during August and September (the burning season) when the assumed background τ (0.05) is likely wrong. Error analysis, together with independent observations and models of the surface and atmosphere, will allow us to analyze error sources and increase the accuracy of the retrieval method.

Further grouping of results into ten regions provides analysis for sites over the globe. These results are preliminary; yet still suggest where this approach is appropriate. Statistics for the ten regions are presented in Table 1. It is clear that the best results are in South America where the surface reflectance has small temporal and spatial variations and the aerosol is relatively

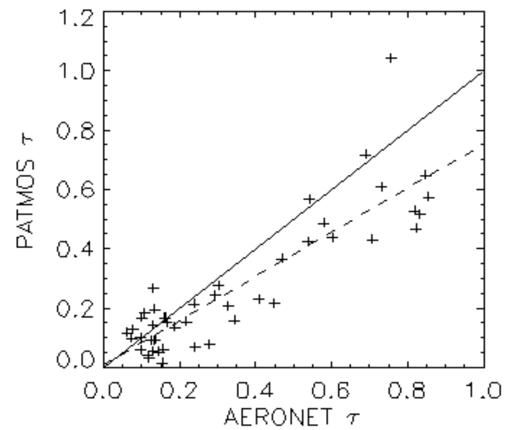

Figure 1 – Validation of filtered PATMOS AOD with AERONET AOD at Cuiaba. The linear regression best fit (dashed line) is: y=0.78x + 0.01 with r = 0.88 (for 47 points)

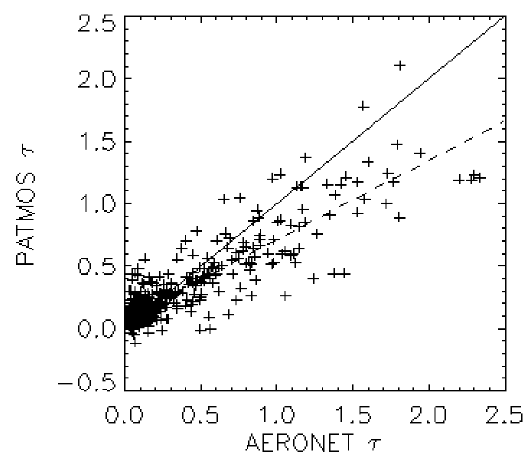

Figure 2 – Validation of filtered PATMOS AOD with AERONET AOD for South America. The linear regression best fit (dashed line) is: y=0.63x + 0.08 with r = 0.87 (for 396 points)

Table 1 – Statistics of the filtered validation of AOD estimation for different regions of the world.

Region	n	r	Slope	Offset
South America	**396**	**0.87**	**0.63**	**0.08**
Northwestern U.S.	101	0.33	0.81	0.11
Southwestern U.S.	293	0.16	0.75	0.27
Midwestern U.S.	**216**	**0.55**	**0.75**	**0.11**
Eastern U.S.	431	0.49	0.47	0.14
Central Canada	**240**	**0.87**	**0.75**	**0.06**
Europe	208	0.49	0.53	0.13
Western Africa	374	0.29	0.71	0.44
Southern Africa	**249**	**0.66**	**0.55**	**0.09**
Other*	468	0.15	0.80	0.60

* All other sites outside the defined regions

constant (aerosol here are primarily from biomass burning). Other regions with high correlations include southern Africa, Central Canada and parts of the U.S.

5. SUMMARY

The surface BRDF is retrieved from PATMOS channel 1 cloud-free reflectance data and used to retrieve the aerosol optical depth. Comparisons of retrieved τ to ground-truth show positive correlation for most regions of the globe. However, the correlations are weak in some areas, likely due to:

- Desert areas have a brighter reflectance than used in the LUT BRDF calculations
- TOA reflectances are less sensitive to aerosols over brighter areas.
- Other uncertainty sources as described in section 4.

Further research will include:

- More error analysis to determine error sources.
- Inclusion of multiple aerosol types in the LUTs to remove regional biases.

The addition of this information should increase the accuracy (and thus, value) of the retrieval of AOD from the PATMOS data set.

The current results are encouraging. The retrieval of aerosol optical depth over land has been very limited and these results suggest the possibility of quantifying spatial and temporal variation of aerosol optical depth over some land areas within the 20-year record of the PATMOS data set.

APPENDIX

This work is further described at:
http://orbit-net.nesdis.noaa.gov/crad/sat/atm/aerosol/kknapp/

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