8.5 THE CONTINUOUS MONITORING OF DESERT DUST USING AN INFRARED-BASED DUST DETECTION AND RETRIEVAL METHOD

David P. Duda*
National Institute of Aerospace, Hampton, VA 23666

Patrick Minnis
Atmospheric Sciences, NASA Langley Research Center, Hampton, VA 23681

Qing Trepte
Science Applications International Corporation, Hampton, VA 23666

Sunny Sun-Mack
Analytical Services and Materials, Inc., Hampton, VA 23666

1. INTRODUCTION

Airborne dust and sand are significant aerosol sources that can impact the atmospheric and surface radiation budgets. Because airborne dust affects visibility and air quality, it is desirable to monitor the location and concentrations of this aerosol for transportation and public health. Although aerosol retrievals have been derived for many years using visible and near-infrared reflectance measurements from satellites, the detection and quantification of dust from these channels is problematic over bright surfaces, or when dust concentrations are large. In addition, aerosol retrievals from polar orbiting satellites lack the ability to monitor the progression and sources of dust storms. As a complement to current aerosol dust retrieval algorithms, multi-spectral thermal infrared (8-12 micron) data from the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Meteosat-8 Spinning Enhanced Visible and Infrared Imager (SEVIRI) are used in the development of a prototype dust detection method and dust property retrieval that can monitor the progress of Saharan dust fields continuously, both night and day. The dust detection method is incorporated into the processing of CERES (Clouds and the Earth's Radiant Energy System) aerosol retrievals to produce dust property retrievals. Both MODIS (from *Terra* and *Aqua*) and SEVERI data are used to develop the method.

**Corresponding author address:* David P. Duda, NASA Langley Research Center, MS 420, Hampton, VA 23681-2199. Email: dduda@nianet.org

2. DATA

2.1 *MODIS*

Multi-spectral data from the MODIS instruments are used in the CERES aerosol detection method. Radiance data from visible, near-infrared and thermal infrared channels are used to distinguish between clear and cloudy skies, and to detect dust.

MODIS data are analyzed at 1-km resolution. The *Terra* and *Aqua* satellites are in sun-synchronous orbits, with an equatorial crossing time at 1030 and 1330 local time, respectively. For each MODIS pixel, the CERES processing system assigns a scene classification of clear or cloudy (Trepte et al., 1999) by using several sets of threshold trees. The clear and cloudy pixels are further categorized as being weak or strong depending on how much the radiances diverge from the expected cloud-free radiances. The clear radiances are estimated using empirical clear-sky albedo maps (Sun-Mack et al., 1999, 2004) for the visible and near-infrared data and the GEOS (Goddard Earth Observing System) skin temperatures and soundings with surface emissivities (Chen et al., 2004) for the thermal infrared data. Over oceans, the clear pixels are further screened to eliminate cloud contamination and the method of Ignatov and Stowe (2002) is then applied to the remaining pixels using the visible and near-infrared channels (Ignatov et al. 2005) to derive the aerosol optical depth (AOD) and the Angstrom exponent. Thus, the current dust detection method is limited to clear ocean during the daytime and often misses the largest dust outbreaks because the large optical depths cause the current cloud mask to classify the dusty scene off the African coast as cloudy.

2.2 *SEVERI*

Nine-km resolution images of northern Africa at 3.9, 8.7, 10.8 and 12.0 μm have been collected from the SEVERI instrument at 1-hour intervals since May 2004. Although the SEVERI data have a coarser resolution than the MODIS data, they provide continuous monitoring of Saharan dust storms.

3. PROTOTYPE DUST DETECTION ALGORITHM

A simple dust detection method was developed to begin the analysis process. Empirical thresholds for the 3.7 minus 11 micron, 8.5 minus 11 micron, and 11 minus 12 micron brightness temperature differences (BTD) were created to classify a satellite pixel as dusty or not dusty. During the night, dust tends to produce a negative 3.7-11 BTD so different thresholds are required. Figure 1 shows an example of the prototype dust detection method.

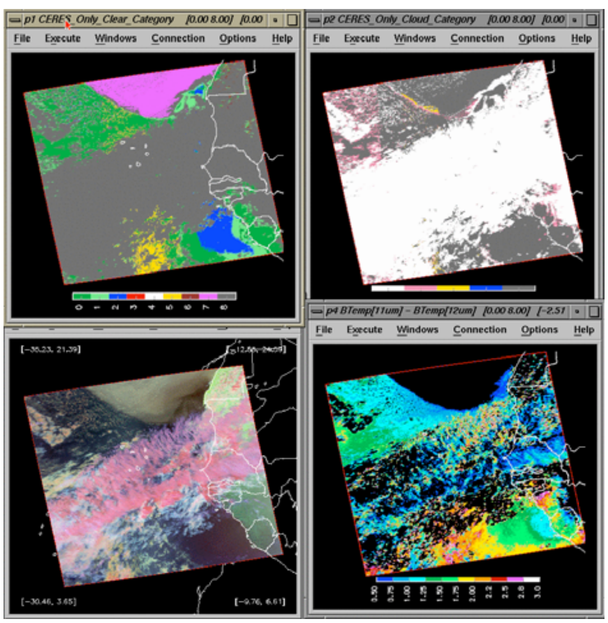

Figure 1. CERES prototype dust detection from MODIS imagery on 12 February 2005. Top left hand figure is clear sky mask showing dust (magenta). The top right figure is the corresponding cloud mask. The bottom left image is a 3-channel RGB composite highlighting the dust near the top of the image, and the bottom right image shows the 11 minus 12 micron BTD.

The detected dust (magenta color in top left figure) is generally consistent with the visual outline of the dust shown in the bottom left figure, but some exceptions are apparent near the edges of the dusty region.

The dust detection method relies on assumptions about the optical properties of dust in the thermal infrared region to distinguish the dust from land surfaces and clouds. Dust can include many constituents such as quartz, various clays, calcite, gypsum, hematite and others (Sokolik et al., 2001) that have absorption bands at thermal infrared wavelengths. In contrast to liquid and ice water clouds, the 11-12 micron BTD for dust is generally negative. Over deserts, this BTD can become smaller than -5 K during the day due to high surface temperatures. During the day, the 3.7-11 micron BTD for dust can have a (positive) magnitude similar to water and ice clouds, but is generally larger than the corresponding BTD for land surfaces. The 8.5-11 micron BTD for dust is also usually negative, and also is affected by the surface temperature, especially over deserts. The 8.5-11 micron BTD of the Sahara is much more negative than many other land surfaces (and most dust clouds), and can help in the detection of dust in this region.

Figure 2 presents a time series of 3-channel enhanced images from SEVERI data on 27 March 2006. The images use the 11-12 micron and 8.7-11 micron BTDs, and the 11-micron brightness temperature in an RGB pseudo-color composite. The dust appears as magenta in the images. Although the dust can be easily detected in the first image made when the desert surface is hot, the dust is harder to detect at night as the surface cools and the magnitude of the 11-12 micron BTD decreases.

4. DISCUSSION

The continuous monitoring of airborne dust by satellite can provide many benefits including information on dust climatology, estimates of dust emission and transport with high time and space resolution. Because of the short lifetime of dust in the atmosphere, high temporal and spatial resolution data are needed to estimate atmospheric dust emission. Thus, MODIS and SEVERI measurements are potentially valuable sources of dust information. Much work is needed, however, to improve the quality of dust estimates from infrared measurements. Many current infrared-based satellite detection methods still do not account for variations in fundamental atmospheric variables including surface emissivity, surface temperature, and the atmospheric temperature and moisture profiles. Also, diurnal changes in these properties and regional changes in dust properties must be explored. With the launch of the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation satellite (CALIPSO), a new source of space-borne validation data will help in the discrimination between cloud and aerosols and the retrieval of dust and cloud properties in the presence of dust clouds. Furthermore, the CALIPSO aerosol layering and optical depth information can be used to empirically simplify the complexities of regional and temporal variability in dust properties, and to help in the improvement of passive retrieval techniques. Although satellite data are limited in the information they can provide about dust, satellite data can complement dust modeling and in situ measurements to allow for a better understanding of how the processes controlling the evolution of dust relate to dust emissions in the atmosphere.

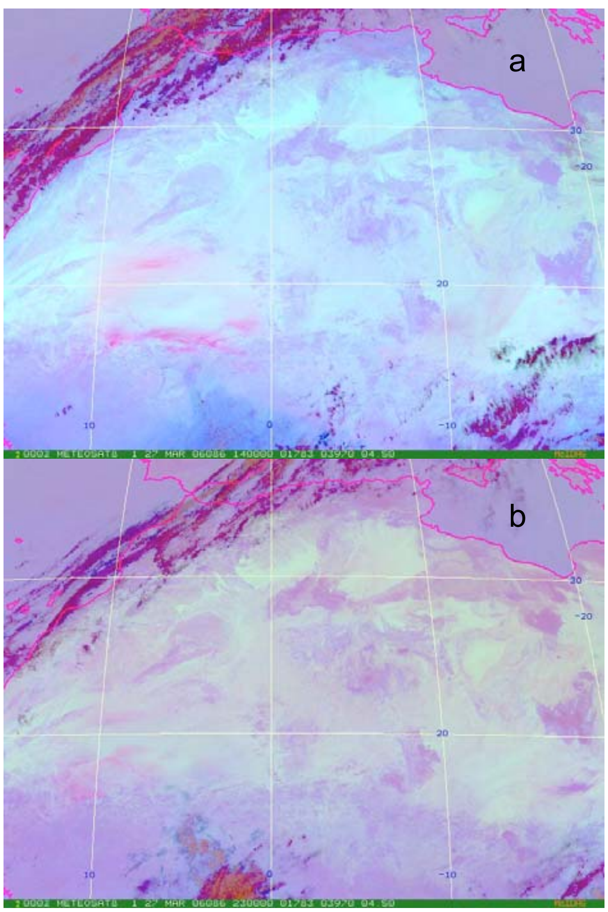

Figure 2. Meteosat-8 SEVERI RGB imagery of northern Africa on 27 March 2006. (a) 1400 UTC, dust appears as magenta over northwestern Africa near 17N and 22N. (b) same as (a), but for 2300 UTC.

References

Chen, Y., S. Sun-Mack, P. Minnis, D. F. Young, and W. L. Smith, Jr., 2004: Seasonal surface spectral emissivity derived from Terra MODIS data. Proc. 13^{th} AMS Conf. Satellite Oceanogr. and Meteorol., Norfolk, VA, Sept. 20-24, CD-ROM, P2.4.

Ignatov, A., P. Minnis, N. Loeb, B. Wielicki, W. Miller, S. Sun-Mack, D. Tanre, L. Remer, I. Laszlo, and E. Geier, 2005; Two MODIS aerosol products over ocean on the Terra and Aqua CERES SSF datasets. *J. Atmos. Sci.,* **62,** 1008-1031.

Ignatov, A., and L. L. Stowe, 2002: Aerosol retrievals from individual AVHRR channels. Part I: Retrieval algorithm and transition from Dave to 6S radiative transfer model. *J. Atmos. Sci.,* **59,** 313-334.

Sokolik, I. N., D. M. Winker, G. Bergametti, D. A. Gillette, G. Carmichael, Y. J. Kaufman, L. Gomes, L. Schuetz, and J. E. Penner, 2001: Introduction to special section: Outstanding problems in quantifying the radiative impacts of mineral dust. *J. Geophys. Res.,* **106(D16),** 18 015-18 027.

Sun-Mack, S., Y. Chen, R. F. Arduini, and P. Minnis, 2004: Clear-sky narrowband albedo variations from VIRS and MODIS data. Proc. 13^{th} AMS Conf. Satellite Oceanogr. and Meteorol., Norfolk, VA, Sept. 20-24, CD-ROM, P6.34.

Sun-Mack, S., Y. Chen, T. D. Murray, P. Minnis, and D. F. Young, 1999: Visible clear-sky and near-infrared surface albedos derived from VIRS for CERES. *Proc. AMS 10^{th} Conf. Atmos. Rad.,* Madison, WI, 28 June – 2 July, 422-425.

Trepte, Q., Y. Chen, S. Sun-Mack, P. Minnis, D. F. Young, B. A. Baum, and P. W. Heck, 1999: Scene identification for the CERES cloud analysis subsystem. *Proc. AMS 10^{th} Conf. Atmos. Rad.,* Madison, WI, 28 June – 2 July, 169-172.