Characterization of Dust Aerosols and Atmospheric Parameters from Space-borne and Surface-based Remote Sensing: Application of Community Radiative Transfer Algorithms to Navy Electro-Optical Models

Dr. Si-Chee Tsay
NASA Goddard Space Flight Center, Greenbelt, MD 20771
301-614-6188 (voice), 614-6307 (fax), e-mail: tsay@climate.gsfc.nasa.gov

Dr. Q. Jack Ji
SSAI/ and NASA Goddard Space Flight Center, Greenbelt, MD 20771
301-614-6231 (voice), 614-6307 (fax), e-mail: ji@climate.gsfc.nasa.gov

Dr. Santiago Gassó
NASA Goddard Space Flight Center, Greenbelt, MD 20771
301-614-6244 (voice), 614-6307 (fax), e-mail: santiago@climate.gsfc.nasa.gov

Dr. Jeffrey S. Reid
Atmospheric Propagation Branch, SPAWAR Systems Center, San Diego, CA 92152-5001
619-553-1419 (voice), 553-1417 (fax), e-mail: jreid@spawar.navy.mil

Document Number: N00014-01-F-0182 (March 2001-March 2003)

LONG-TERM GOAL

The long-term goal for this project is threefold: (i) to characterize dust aerosols (i.e., Saharan and Asian dusts) and atmospheric parameters (e.g., column water vapor) from space-borne and surface-based remote sensing, (ii) to investigate quantitatively their radiative forcing and climatic effects by analyzing and modeling data obtained from various ONR/NASA field campaigns, and (iii) to construct and utilize computationally efficient radiation post-processors for running on US Navy Aerosol Analysis and Prediction System to estimate aerosol radiative flux (e.g., Fu and Liou 1993) perturbations and general visibility conditions from visible to thermal IR wavelengths (e.g., Tsay *et al*. 1990).

OBJECTIVES

Target detection and visibility tactical decision aid products used by the United States Navy are based on the Target Acquisition Weather Software (TAWS). As part of the Naval Research Laboratory Aerosol Analysis and Prediction System (NAAPS) development, aerosol microphysics codes are for the first time being implemented. The objectives of this project are to validate the regional transport and visibility aspects of the US Navy NAAPS by using observational data combining with current state-of-the-art atmospheric radiative transfer simulations.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**

4. TITLE AND SUBTITLE
Characterization of Dust Aerosols and Atmospheric Parameters from Space-borne and Surface-based Remote Sensing:Application of Community Radiative Transfer Algorithms to Navy Electro-Optical Models

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Goddard Space Flight Center,,Greenbelt,,MD, 20771

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The long-term goal for this project is threefold: (i) to characterize dust aerosols (i.e., Saharan and Asian dusts) and atmospheric parameters (e.g., column water vapor) from space-borne and surface-based remote sensing, (ii) to investigate quantitatively their radiative forcing and climatic effects by analyzing and modeling data obtained from various ONR/NASA field campaigns, and (iii) to construct and utilize computationally efficient radiation post-processors for running on US Navy Aerosol Analy-sis and Prediction System to estimate aerosol radiative flux (e.g., Fu and Liou 1993) perturbations and general visibility conditions from visible to thermal IR wavelengths (e.g., Tsay et al. 1990).

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

APPROACH

Figure 1. The latest version of SMART system shown in center panel: (a_1) an array of broadband-total radiometers in ultraviolet, shortwave and longwave regions, (a_2) broadband-diffuse radiometers, (b) shadow-band radiometer, (c) sun photometers, (d) meteorological probes for atmospheric pressure, temperature, humidity, wind speed/direction, (e) interferometer, (f) solar spectrometer, (g) whole-sky imager, (h) microwave radiometer, (k) surface moisture probes, (m_1) physical rain gauge, (m_2) optical rain gauge, and (n) micro-pulse lidar.

During FY02, we have pursued two tasks on studying aerosol properties: one is the analysis of ground-based remote sensing observations to characterize dust aerosol properties over desert regions, and the other is the modeling efforts to implement current state-of-the-art atmospheric radiative transfer codes into Navy TAWS. We employ data collected by the SMART system (*cf*. Fig. 1) to develop and compare US Navy visibility and transport models, as well as to achieve NASA's EOS validation. In particular, by placing the SMART system in the vicinity of Asian (Gobi and Taklamakan during ACE-Asia) and Saharan (during PRIDE) deserts, we got a first order estimate of aerosol particle variability in these regions. Current Navy visibility products do not adequately account for the radiative and meteorological impacts of aerosol particles. In particular, these products reveal great difficulty in predicting EO system performance in coastal environments, such as the Middle East, Balkans, and Korea, due to uncertainties in aerosol types, environmental parameters and limitations in current radiative transfer algorithms. EO system performance models could be improved by (1) making use of data from weather and aerosol prediction models, such as the NAAPS, and (2) upgrading the radiative transfer models. It is essential to develop radiative transfer post-processors that will take diagnostic and prognostic output fields from the NAAPS and generate EO products suitable for visibility prediction. For computational efficiency, two algorithms will be created. The low-resolution algorithm will run on each of the NAAPS grid points for each forecast period. Based on the NAAPS output variables (e.g., aerosol mass, type and vertical distribution), it give rough estimates of boundary layer visibility for the visible, near-IR, shortwave IR, and longwave IR window regions. Next, the high-resolution radiative post processor can be run on specific NAAPS grid-points when additional detail is needed. Based on a full 3-dimensional radiative transfer scheme, this processor has the ability to give atmospheric visibility estimates as a function of user specified variables such as altitude, look angle, target effective temperature contrast, and specific spectral ranges.

WORK COMPLETED

The Navy/NASA collaboration on PRIDE, SAFARI, and ACE-Asia missions was to study the radiative environment in the source and downwind regions. Special emphasis is being placed on deducing surface flux measurements and spectral observations collected from many ground-based and spaceborne sensors. These field deployments were successfully accomplished and quality control, calibration, and preliminary analysis were conducted to all remotely sensed and *in-situ* data for studying the radiation budget, as well as the physical and radiative processes of natural/anthropogenic aerosols. Results from analysis of observational data and modeling have, or will be, produced many conference papers or potential refereed papers (submitted, *cf*. sec. 10) and more in the preparation.

A simple parameterization of aerosol optical properties as a function of aerosol mass concentration has been implemented. The aerosol concentrations and meteorological parameters are standard outputs of the NRL operational model NOGAPS and NAAP. As a result, we are able to obtain global maps of aerosol spectral properties (e.g., optical depth and single scattering albedo). Comparisons of model predictions with ground-based sun photometer measurements of optical depth indicate that they are within reasonable agreements. In addition, a module that derives the visibility conditions (at visible and infrared wavelengths) for user-defined target-detector geometry was designed. The main focus of the design was on a fast and simple tool to forecast atmospheric conditions that will help to assess target detection conditions globally. Such algorithm (referred as Low Resolution Forecast of Atmospheric Radiative and Optical Properties, LR-FAROP) is based on the single scattering approximation and uses a standard parameterization of water vapor absorption along with aerosol optical properties derived earlier. LR-FAROP is a very fast computer code: it takes about 10 minutes to run globally. The design allows the user to define detector and target features as well as viewing geometry such as ground radar-airborne target, airborne-to-ground and to-airborne detection.

RESULTS

Since many observational data, preliminary results and radiative flux analysis of the project have been either reported in FY01 or submitted for publication, we focus here on the presentations of deriving atmospheric water vapor/liquid and their effects on aerosol optical depth simulations globally.

Figure 2 shows the dry-extreme, column water vapor/liquid retrievals from surface scanning microwave radiometer during ACE-Asia, which is focused on the regional to global impact of Asian dust. The wet-extreme column water vapor/liquid retrievals, such as PRIDE which is designed to measure the properties of Saharan dust transported across the Atlantic Ocean to the Caribbean, are still being analyzed due to difficult cloud screening and fewer cloud-free conditions for accurate calibration. First, the brightness temperatures (at 23.0, 23.8 and 36.5 GHz frequencies) reveal clear and sufficient signals. Thus, time series retrievals of water vapor/liquid from two pair channels are overlapped each other to assure the accuracy of retrievals. These values are compared to the satellite Terra/MODIS retrievals, using shortwave-IR and thermal-IR techniques. It is clear that results from microwave and shortwave-IR retrievals agree very well for cloud-free conditions, including heavy dust cases based on micro-pulse lidar profiling and whole-sky imager observations. When clouds exist, it is expected that the shortwave-IR retrievals of water vapor amount are smaller than those from microwave retrievals due to cloud boundary. Since the optical properties of dust at shortwave-IR channels (0.87, 0.94, and 1.24 μm) are nearly linear, the dust effect can be removed and results compared well with microwave retrievals which frequencies are transparent to dust aerosols. The agreement between thermal-IR (6.72, 7.33, 11.03, and 12.02 μm) and microwave retrievals is not acceptable. Improvement for the thermal-IR technique is currently undergoing for better spatial resolution and accurate emittance of desert surface.

Any radiative transfer computation necessitates the microphysical and optical properties of the medium as inputs. In the case of aerosols, the optical properties are dependent on the aerosol size distribution and the aerosol type, as well as the degree of mixture the different aerosol types. One of the major strengths of the NAAPS and NAAPS models is that they operate almost in real time, globally and regionally with a relatively low grid resolution (1^o x 1^o). NAAPS handles three basic aerosol types (dust, smoke and sulfate) and uses simple microphysics parameterizations to derive mass concentrations. Since NAAPS does not derive the aerosol size distribution explicitly, the approach used there is based on using standard aerosol distributions from the literature (OPAC model, Hess *et al.* 1998). The table of spectral optical properties (optical depth, τ; single scattering albedo, ω_o; and phase function, $P(\Theta)$) are computed from these distributions for each aerosol type at a reference aerosol concentration. Then, the optical properties in each grid cell are derived by scaling with the aerosol mixture of mass concentration computed by NAAPS. In addition, NOGAPS predicts global water vapor distributions. The knowledge of both aerosols and water vapor distributions are essential for prediction of impairment conditions on any detector at IR, near-IR and visible conditions. Since tabulated values are computed at reference (dry) humidity, the computed dry optical properties are corrected to ambient conditions by a using standard parameterization (Hanel 1976, Gassó *et al.* 2000). This correction provides an interesting tool to assess the influence of ambient humidity in visibility impairment according to the aerosol type. An example of such computation is shown in Figs. 3a, and 3b. Both figures show a global map of aerosol optical depth in the visible band without (dry) and with (ambient) relative humidity correction (Fig. 3a and Fig. 3b, respectively). The differences between both figures illustrate the importance of considering humidity in hydrophilic aerosols such as sulfates from pollution and DMS (East US and mid-South Atlantic) whereas in other areas this correction is not as important (Saharan dust or South

American smoke). The approximate time to generate each figure from NAAPS outputs is of the order 5-10 seconds.

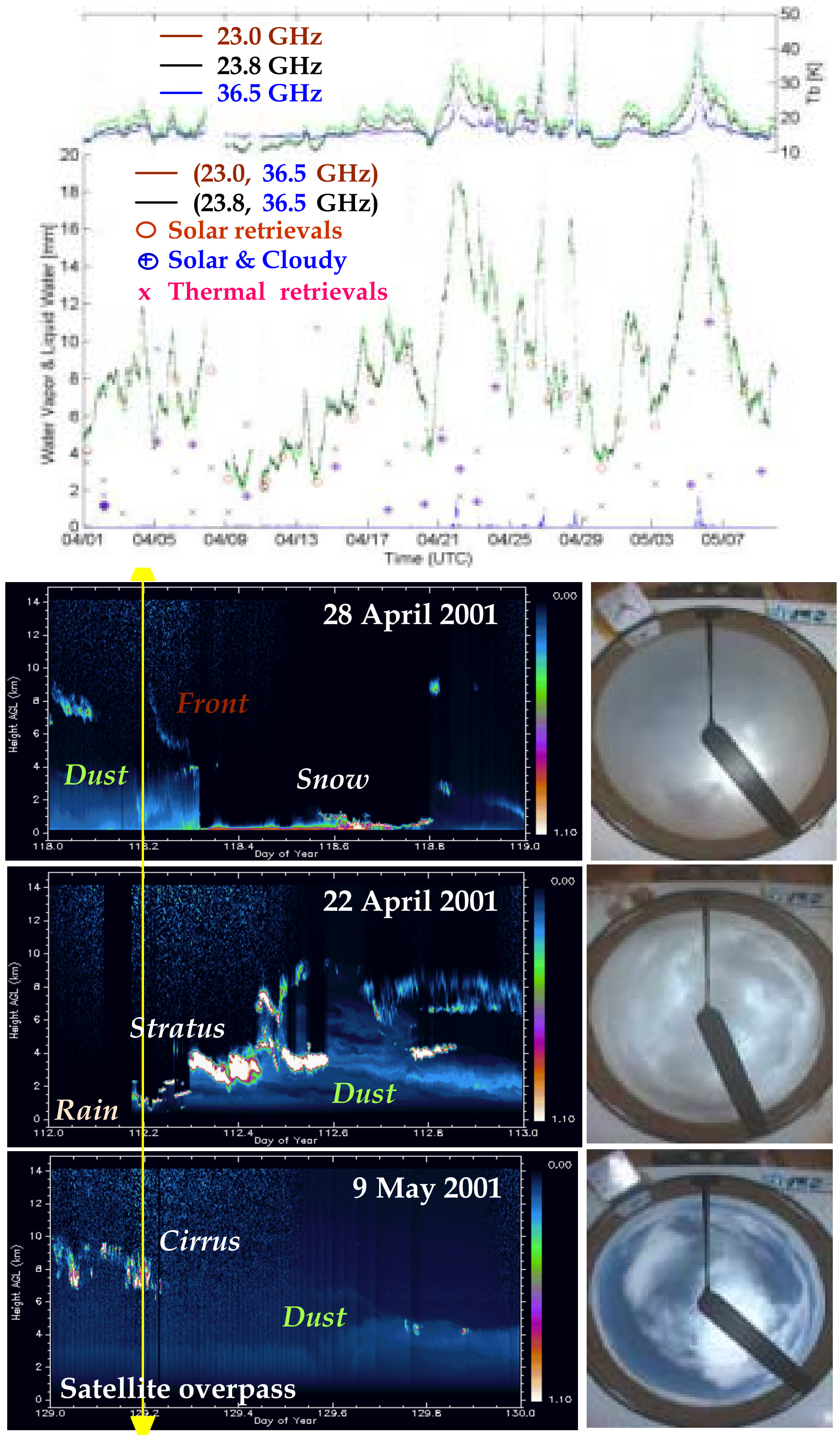

Figure 2. Observations during ACE-Asia of microwave brightness temperatures (top-most panel), water vapor/liquid retrievals from surface and satellite measurements (second panel from the top), and represent three groups of atmospheric cloud-free, low-level cloud, and high-level cloud conditions (three panels below), based on micro-pulse lidar and whole-sky imager observations.

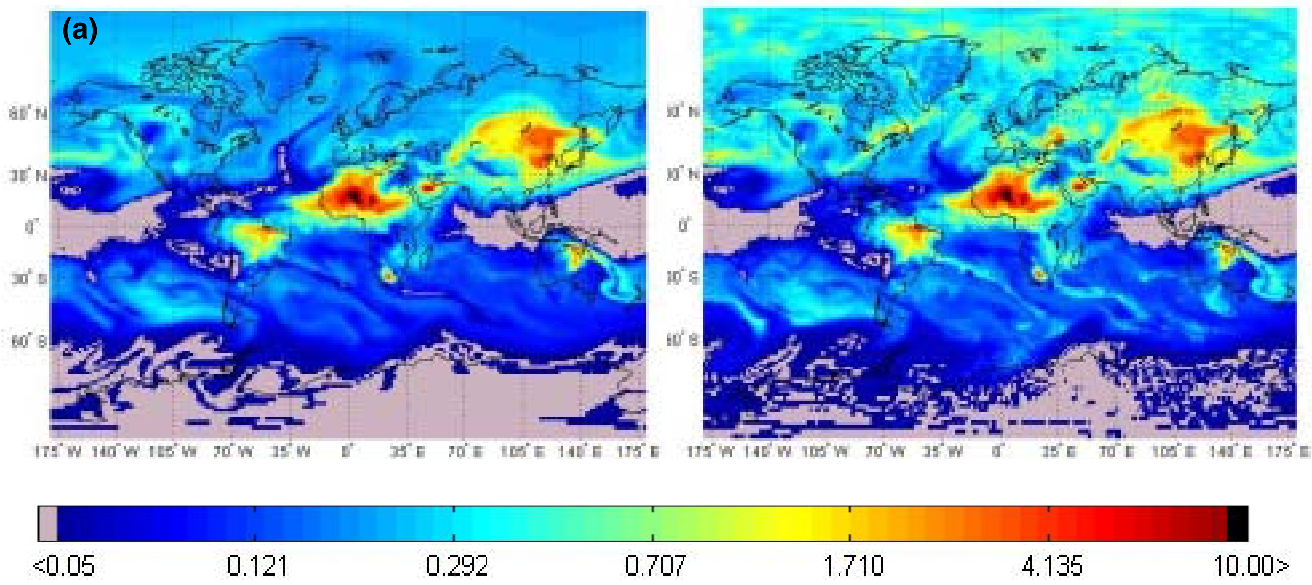

Figure 3. Simulations of global aerosol optical depth at visible band (0.2-0.7 µm) on 20 November 2001, 00UTC for (a) dry condition, and (b) ambient relative humidity condition.

IMPACT/APPLICATIONS

Spectral observations of aerosol properties from the space and from the ground create a powerful tool for determining the extinction of solar radiation by aerosols. Revisiting the aerosol properties and generating remote sensing procedures of aerosol are the first step for an attempt for visibility monitoring in affected regions, as well as their effects on climate.

TRANSITIONS

We have developed a technique, using both remotely sensed observations and model simulations, to derive the microphysical and radiative properties of aerosols. During Navy/NASA collaboration, atmospheric visibility/radiation models and aerosol models will be transferred to scientists at NRL and other Navy research institutes.

RELATED PROJECTS

This work is related to the NASA/EOS effort of remote sensing and validation of aerosols and their effect on climate.

REFERENCES

Fu, Q., and K. N. Liou, 1993: Parameterization of the radiative properties of cirrus clouds. *J. Atmos. Sci.*, **50**, 2008-2025.

Gassó, S., D. A. Hegg, D. S. Covert, D. Collins, and K. J. Noone, 2000: Influence of humidity on the aerosol scattering coefficient and its effect on the upwelling radiance during ACE-2. *Tellus*, **52B(2)**, 546-567.

Hänel, G., 1976: The properties of atmospheric aerosols as functions of the relative humidity at thermodynamic equilibrium with surrounding air. *Adv. Geophys.*, **19**, 73-188.

Hess, M., P. Koepke, and I. Schult, 1998: Optical properties of aerosols and clouds: The software package OPAC. *Bull. Am. Met. Soc.*, **79**, 831-844.

Tsay, S. C., K. Stamnes, and K. Jayaweera 1990: Radiative transfer in planetary atmospheres: Development and verification of a unified model. *J. Quant. Spectrosc. Radiat. Transfer*, **43**, 133-148.

PUBLICATIONS

Campbell, J. R., E. J. Welton, J. D. Spinhirne, Q. Ji, S.-C. Tsay, S. J. Piketh, M. Barenbrug, and B. N. Holben, 2002: Micropulse lidar observations of tropospheric aerosols over northeastern South Africa during the ARREX and SAFARI-2000 dry season experiments, *J. Geophys. Res*., submitted.

Christopher, S. A., J. Wang, Q. Ji, and S.-C. Tsay, 2002: Estimation of diurnal shortwave dust aerosol radiative forcing during PRIDE, *J. Geophys. Res*., submitted.

Tsay, S.-C., J. Reid, Q. Ji, M. D. King, N. C. Hsu and E. J. Welton, 2002: Dust aerosols in PRIDE and ACE-Asia: A column satellite-surface perspective, *Bull. Amer. Met. Soc*., in preparation.

Ji, Q. and S.-C. Tsay, 2002: Surface direct radiative forcing by Saharan and Asian dust aerosols in PRIDE and ACE-Asia, *J. Climate*, in preparation.