# 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*

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## LONG-TERM GOAL

The long-term goals of this project are:

- To provide an aid for tactical decisions through a user-friendly web-based interface. Specifically, the tool will provide an assessment of the visibility conditions as seen by different types of detectors in a given region of the world. This is a tactical aid where speed of computation is emphasized over precision in the computation.

- To investigate quantitatively the radiative forcing and climatic effects of aerosols by analyzing and modeling data obtained from various ONR/NASA field campaigns.

- To construct and utilize computationally efficient radiation post-processors for running on US Navy Aerosol Analysis and Prediction System (NAAPS) to estimate aerosol radiative flux (e.g., Fu and Liou 1993) perturbations and general visibility conditions from visible to thermal IR wavelengths.

## OBJECTIVES

Target detection and visibility tactical decision aid products used by the United States Navy are based on the Target Acquisition Weather Software (TAWS). The objective of this project consists to design a radiative transfer model that computes the EO radiation (radiance) measured by an airborne detector at various types of viewing geometry defined by the user. Because radiance is modulated by the presence of gases and aerosols present in the line of view, the computation is performed using the aerosol data predicted at each grid point within the domain of the Naval Research Laboratory Aerosol Analysis and Prediction System (NAAPS) model. The result is presented in a graphical form and implemented in a

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web-based interface. The output must consist of simple parameters that will convey to the user the visibility conditions in a selected region.

## APPROACH

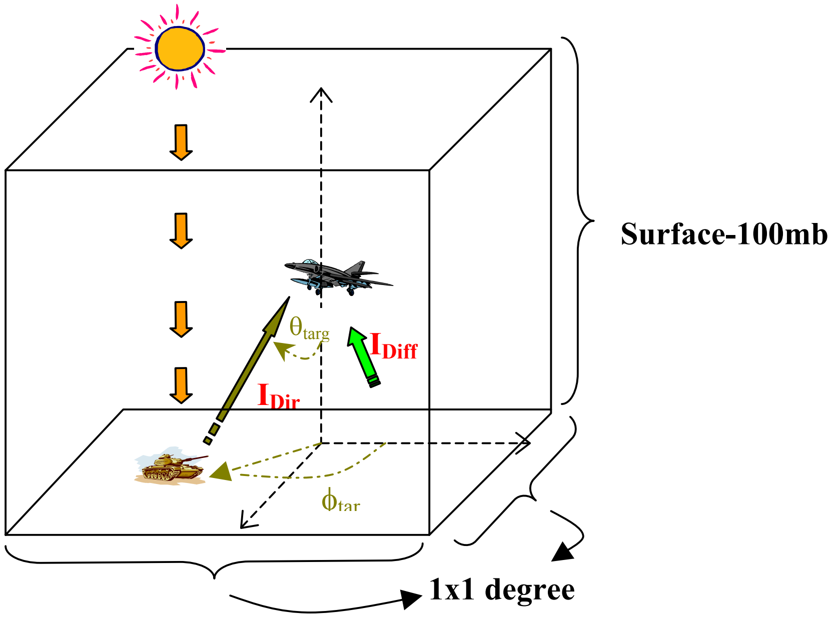

***Figure 1. Scheme of one of the possible user defined viewing geometry at grid point (size 1 x 1 degree), where $I_{direct}$ is the measured radiance scattered and emitted by the target and the $I_{diff}$ is the measured radiance scattered and emitted by the medium.***

During FY03, we have studied the effects of aerosol properties on atmospheric energetics and radiative transfer by (1) analyzing satellite (e.g., TOMS, SeaWiFS, etc.) and ground-based (e.g., SMART, http://smart-commit.gsfc.nasa.gov/) remote sensing observations, and (2) modeling efforts to implement current state-of-the-art atmospheric radiative transfer codes into Navy TAWS. The first part of the work has been completed (*cf.* sec. 4 & 10). For the second part of the work, the measured electromagnetic signals are simulated by computing the radiation reaching the sensor. This requires an information of the optical properties of the medium. The standard output of NOGAPS (Navy Operational Global Atmospheric Prediction System) and NAAPS in each grid point provides profiles of ambient temperature and moisture and aerosol mass for three aerosol species (dust, smoke and sulfates). Because NAAPS does not compute the aerosol size distribution explicitly (essential for the derivation of optical parameters such as visibility), a parameterization is used to derive the inputs needed for the radiative transfer computations. Values of mass extinction efficiency, single scattering albedo and asymmetry factor from literature (OPAC table, Hess *et al.* 1998) are used to generate the optical parameters needed for radiative transfer computations. The radiative transfer scheme must be fast enough to provide an output in almost real-time. Figure 1 displays the relative position and geometry used in the simulations. The user defines the position of the target with respect to the airborne sensor. The code simulates two signals measured by the sensor: the radiance scattered and emitted by the target and the diffuse radiance from the environment in the target sensor view path (i.e., background noise). The ratio of these two radiances (i.e., contrast) conveys to the user how much of the signal reaching the sensor originated in the target.

## 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 space-borne 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 produced many conference papers and refereed papers (*cf*. sec. 10) and will not be presented here.

A fast computer code (FAROP version 1.2, Forecast of Atmospheric Radiative and Optical Properties) that fulfills the required specifications depicted in Fig. 1 was developed. The code computes radiance fields measured by a hypothetical detector with 3 bands (visible, near IR and IR) for several viewing geometry. The detector is assumed to be mounted on an aircraft flying at 20,000 feet and looking at a target located in five different locations with respect to the plane. In two positions the target is 10 km ahead and behind in the same layer as the sensor. In the other three the target is on the ground, straight down, ahead 60 degrees down with respect to the direction of motion of aircraft and away from the sun behind the aircraft. The typical run time is in the order of 10 seconds for a region the size of North America. High speed computation is accomplished through the use of the single scattering approximation, a simple parameterization of the water vapor absorption and the use of the Henyey-Greenstein phase function. Version 1.2 of FAROP was finalized at the beginning of the funding period an it outputs a fixed number of viewing geometry. Version 1.3 was developed throughout the funding period and it incorporates a number of improvements such as more user-defined options (e.g., customized viewing geometry) and improvements in the parameterizations used. In addition, an alternative module was created for application in climate studies. Specifically, a radiative transfer module for computation of top-of-the-atmosphere (TOA) and surface aerosol fluxes and aerosol radiative forcing. It is based on the Fu-Liou radiative transfer code (Fu and Liou, 1993) and it can be ran in parallel with FAROP.

## RESULTS

Figure 2 shows an example of FAROP for a case of a dust + pollution plume coming off Asia towards the North Pacific Ocean. Band 1 refers to a visible wavelength sensor and Case 1 to a case where the target and sensor are in the same layer. The magnitude of the contrast is highly dependent on the presence of aerosols (visible and near-IR) and water vapor (near-IR and IR) in the line of sight. In the case shown, the contrast is most sensitive to the presence of aerosols and it correlates with the location of the plume. For each case, FAROP computes the contrast at three bands (visible, near IR and IR), optical depth (visible) and visibility at the surface and at the layer where the sensor is located.

An application suitable for climatic studies is shown in Figures 3a,b and c. Aerosol optical depth is computed from the same parameterization used to generate the inputs for FAROP. The top-of-the-Atmosphere (TOA) aerosol radiative forcing provides information on how much energy is stored or emitted by the presence of an aerosol layer in clear skies conditions. Aerosol forcing is computed as the flux difference of clear sky with aerosol conditions and without aerosols (no aerosol minus with aerosols). It is directly related to the heating rate in the column. Figure 3 displays the aerosol optical depth and it indicates areas of heavy aerosol loading. Figures 4a and 4b show the TOA and surface aerosol forcing. As expected the forcing is the highest in those places where the high aerosol concentrations are present, indicating that more energy is reflected back to space, thus the input of energy is diminished by the presence of aerosols. Note that because the three aerosol types were assumed to be low in absorbing material, the forcing resulted in negative values. In the case of more absorbing aerosol (e.g. smoke of heavy pollution) the forcing would be positive, implying that the systems is retaining energy implying warming conditions.

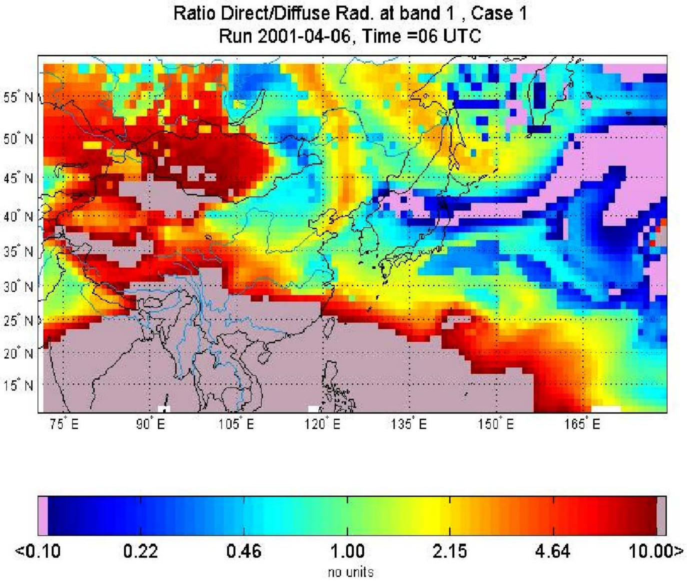

***Figure 2. Example of FAROP output, displaying the contrast (ratio of radiance) for Case 1 (target and sensor in same layer separated at 20 km distance from each other) at band 1 (visible wavelengths). The contrast varies with the presence of aerosol mass in the line of view target-sensor.***

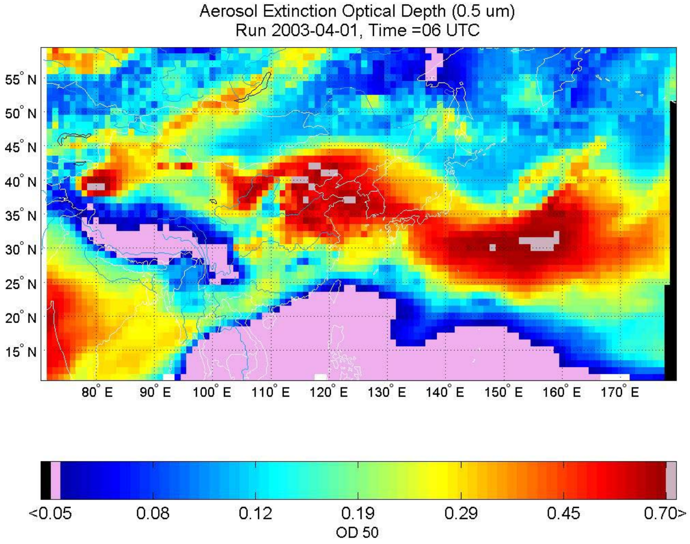

***Figure 3. Aerosol optical depth at 0.5 µm.***

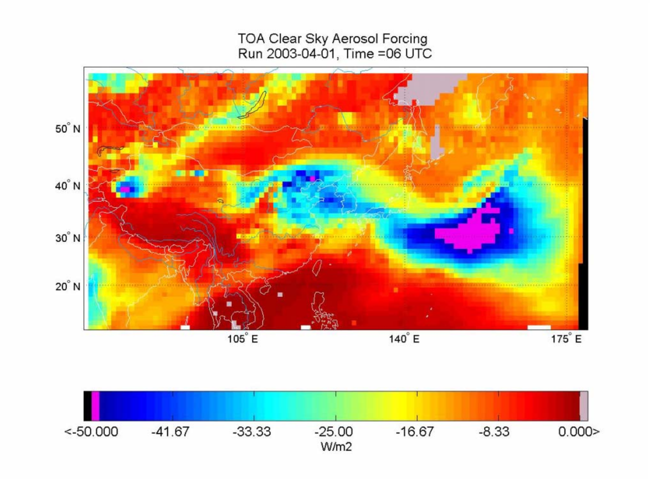

***Figure 4. Clear sky radiative forcing at the top of the atmosphere (left) and at the surface (right). Forcing at visible wavelengths correlates with aerosol mass concentration. The sign indicates whether the system is taking up energy (positive) or returning energy to the space (negative). Because the aerosols in this simulation are low in light absorbing black carbon, the areas under the aerosol plume tend to cool with respect to clear sky conditions.***

## IMPACT/APPLICATIONS

Spectral observations of aerosol properties from the space and from the ground create a powerful device for determining the extinction of solar radiation by aerosols. Prediction of the conditions for detection impairment of airborne detectors is a forceful tool for making tactical decisions. In addition, the assessment of the radiative impact of aerosols is important for understanding the energy balance in the Earth-atmosphere system and its implications to climate change.

## TRANSITIONS

We have developed a technique, using both remotely sensed observations and model simulations, to derive the microphysical and radiative properties of aerosols. As part of the much larger Electro-Optical Prediction Rapid Transition Plan (EORTP) we collaborate scientists from NRL, SPAWAR, and NASA. ONR 6.2 work done under this project including FAROP has been transitioned to NRL Monterey for further 6.4 development, will be subsequently transitioned to operations at Fleet Numerical Meteorological and Oceanographic Center Monterey.

## RELATED PROJECTS

This work is related to the NASA/EOS effort of remote sensing and validation of aerosols and their effect on climate, and is also related to ongoing projects at NRL Monterey (Aerosol Microphysics and Radiation Project by Dr. J. Reid and the Aerosol Coastal Assimilation Project by Dr. D. Westphal).

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