

Coastal Aerosol Distribution by Data Assimilation

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LONG-TERM GOALS

The long-term goal of this research is to develop a practical predictive capability for visibility and weather effects of aerosol particles for the entire globe for timely use in planning and executing DoD operations and activities. The fundamental predicted variables are the concentrations of atmospheric aerosol particles responsible for degradation of EO propagation in regions of DoD interest. Post-processors calculate the parameters useful in strategic and tactical planning, training, and operational activities. This forecast and simulation capability also is used in theoretical studies of the Earth's atmosphere and has operational usefulness in scientific field campaigns.

OBJECTIVES

The objective of this program is to investigate, develop, and test aerosol initialization, source, and prediction schemes. These will be incorporated into an aerosol data assimilation and prediction system based on observations, aerosol process models, and meteorological models.

APPROACH

The approach to the problem of aerosol and Electro-Optical (EO) extinction prediction follows that used in numerical weather prediction, namely real-time assessment for initialization of first-principles models. The Naval Research Laboratory has developed a new capability for forecasting the global and regional concentration of atmospheric particulate matter and the subsequent effects on visibility. The regional model (COAMPS/Aerosol) became operational during OIF. The global model (NAAPS) became operational in October 2005. These models allow the prediction of the concentration of the dominant visibility reducing aerosol species up to six days in advance anywhere on the globe. NAAPS and COAMPS are particularly useful for forecasts of dust storms in areas downwind of the large deserts of the world: Arabian Gulf, Sea of Japan, China Sea, Mediterranean Sea, and the Tropical Atlantic Ocean. NAAPS also accurately predicts the fate of large-scale smoke and pollution plumes. With its global and continuous coverage, the Navy Aerosol Analysis and Prediction System (NAAPS) is invaluable in filling the gaps in observations of aerosol particles and visibility and in satellite observations and extends our understanding of aerosol particles and their impact on Navy operations. However, validation studies indicate that the forecasts would benefit from increasing the resolution and the number of species and the implementation of aerosol data assimilation.

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WORK COMPLETED

The collaboration with Scripps Institute of Oceanography and the University of Warsaw has led to the addition of a sea salt component to NAAPS. The single-bin implementation provides improved estimates of visibility and optical depth over the oceans, particularly over open-ocean under strong wind conditions. The physics include emission from the water's surface, vertical and horizontal advection and diffusion, dry and wet deposition, and gravitational sedimentation. This version of the code is running in research mode on NRL machines, has been validated, and is being used for research. Transition to operations is expected in FY08.

In collaboration with NASA/GSFC, new SO₂ source databases have been identified and used in NAAPS. These are the AeroCom (Aerosol Model Comparison) and ACACIA (A Consortium for the Application of Climate Impact Assessments) SO₂ databases. These two databases were developed within the past 5 years and reflect changes in the emission rates in East Asia brought about by the rapid industrialization of that region. The evaluation of the upgrades to the dust and SO₂ source databases is underway. Comparisons are being made between the original simulations, the new simulation, and the available data, which include AERONET sun photometers, IMPROVE network data, surface concentrations, visibility, and satellite retrievals. Final results and conclusions are not yet available. A preliminary SO₄ validation shows improvement with the new databases particularly in Europe, and Asia.

NRL's participation in the Dust Model Intercomparison Project (DMIP), along with six other dust-modeling groups from China, Korea, Japan, U.S.A., Canada and Malta, is completed and an article has been published. The program compared various aspects of model simulations of Asian dust storms for two two-week periods during 2002. The program compared mobilization, mixing, transport and removal processes. Participation in the program included access to validation data. NAAPS forecasts of CONUS dust storms and long-range dust transport to CONUS are being further evaluated in collaboration with CSU. These results have been reported in an M.S. thesis and a paper in preparation.

NRL researchers continue to interact and collaborate with outside researchers through the use of NAAPS data for explaining various aerosol transport phenomena around the world, both in real time and in the research mode. These collaborations result in a better understanding of the atmosphere, an improved NAAPS model, peer-reviewed publications and conference proceedings.

RESULTS

The validity of the sea salt parameterizations has been tested and shown to produce concentrations in good agreement with shipboard measurements. Correlation coefficient for all data points was 0.76, and varied from 0.55 to 0.84 for different experiments. The average sea salt mass concentration was 4.61 $\mu\text{g}/\text{m}^3$ from measurements and 7.21 $\mu\text{g}/\text{m}^3$ from the model, for all considered experiments. It was found that model-measurements discrepancies were mostly affected by wet deposition uncertainties, but also suggested was the influence of source uncertainties in strong wind speed regime, lack of a wind speed threshold for emission onset, and lack of size differentiation for deposition velocity. In addition, a global sea salt simulation for 7 years was conducted. Average annual sea salt emission is estimated to be about 3×10^{12} [kg], which is in agreement with previous estimates.

North American dust production has been investigated and compared with that from East Asia. The latter dominates large areas of the U.S. in the spring, but North American sources produce the highest concentrations in other seasons, though over more localized regions. These local sources are readily apparent at the head of thin plumes in satellite imagery for any desert during mobilization. Over N. America, these might be as small as individual agricultural fields. The point sources and sharp gradients of the plumes make comparison with surface data, such as that from IMPROVE, problematic. Nevertheless, further studies will lead to an improvement in the dust source database for N. America.

NAAPS is being used to investigate long-range transport processes and pathways. NAAPS was used in support of study of the transatlantic transport of dust-borne microorganisms from the arid lands of northwest Africa to the Caribbean and Americas. Between the dates of 22 May and 30 June 2003, daily air samples were collected and evaluated for the presence of culturable bacterial and fungal colony forming units (CFU). This study found for the first time a statistically significant correlation between daily atmospheric CFU counts at a mid-ocean research site (~15N, 45W) and NAAPS daily desert dust concentrations (Figure 1.) This study presents evidence of early summer survival and transport of microorganisms from North Africa to a mid-Atlantic research site. Additionally, the statistical correlation between the NAAPS model dust concentrations and microbial CFU counts observed demonstrates the potential for using models to address the global dispersion of microorganisms (nonpathogenic and pathogenic) and other soil associated constituents as they pertain to ecological evolution and ecosystem and human health.

The second Ice Nuclei SPECTroscopy (INSPECT-II) campaign was conducted at Storm Peak Laboratory (SPL) in northwestern Colorado in April and May 2004. The physical and chemical characteristics of springtime atmospheric aerosol particles, including those which act as heterogeneous ice nuclei (IN), were investigated. Based on the NAAPS analysis, it appears that dust layers from long-range transport having a measurable impact on surface aerosol soil concentrations typically arrive first in the upper atmosphere, then at lower altitudes, and finally at the surface after several days. These layers are associated with troughs and surface dust concentrations tend to reach their peak values immediately preceding any precipitation associated with these troughs. Elevated IN concentrations were observed as these dust layers reached SPL. This is consistent with laboratory observations that mineral dust particles are well suited to serve as IN. Based on modeled dust vertical profiles, dust concentrations aloft can be significantly higher than those observed at an elevated surface site, which implies stronger impacts of dust on IN concentrations might be expected at the higher altitudes of cold clouds.

A case of long range transport of Saharan dust over a pathway spanning Asia and the Pacific to Western North America has been documented for the first time. A combination of NAAPS output, lidar, sunphotometer and high altitude surface monitoring observations confirmed the presence of a dust layer over western North America on 13-14 March 2005. NAAPS simulations, together with an analysis of surface and satellite observations of dust storm activity in North Africa and Eurasia, strongly suggest that this layer originated from significant dust storm activity in northwestern Algeria approximately 14 days earlier. (The model and surface observations showed no major dust emission in Taklimakan and Gobi Deserts during the observation period.) The mineral dust followed a mid tropospheric pathway that crossed central and East Asia and the Pacific and then gradually subsided in a ridge along the west coast of North America. Dust layers in the free troposphere were observed with the lidars in Suwon, Gosan, and Tsukuba in March 7-9, 2005. On the basis of sunphotometer data and surface observations in British Columbia it appears that this event had a weak but detectable impact on

near surface particulate concentrations and aerosol optical depths. However, the significance of the observations rests in identifying a case of very long range transport of dust (~19,000 km) over an intercontinental pathway not previously documented.

IMPACT/APPLICATIONS

NAAPS helps to satisfy the Navy's long-term goal of a predictive capability for aerosol particles and EO propagation. The forecasts of aerosol concentration are distributed via NIPRNET and SIPRNET for use by DoD forecasters, operators, planners, and aviators (<http://www.nrlmry.navy.mil/aerosol/>). The model output is processed by FNMOC and converted into the fundamental optical properties required to calculate EO propagation. These properties are used to populate the Tactical Environmental Data Server (TEDS) and subsequently used by the Target Acquisition Weapons Software (TAWS) to calculate slant-path visibility. The forecasts are used to correct satellite retrievals of sea surface temperature (SST) by NAVO, thus improving tropical forecasts.

NAAPS also provides tools for the 6.1 and 6.2 aerosol research communities and the academic community. NAAPS data continues to be used in interactions with research community appearing in peer-reviewed and conference papers. Over the year, collaborations have occurred between NRL and the University of Warsaw, Scripps Institute of Oceanography, Colorado State University, USGS, Université de Sherbrooke (Quebec), U. British Columbia, Environment Canada, University of Washington, Harvard University, and others. NAAPS forecasts and NRL's continued participation in field programs will give us further opportunities for collaboration and access to important validation data.

TRANSITIONS

NAAPS has been operational at FNMOC since September 2005. Subsequent improvements to NAAPS (as developed in this work unit) are transitioned to FNMOC via 6.4 funding provided by PMW-180.

RELATED PROJECTS

The NRL 6.1 Atmospheric Physics and the NRL 6.2 Advanced Moist Physics Modeling programs use NAAPS data and products for initialization, investigations and validation. ONR 6.2 Aerosol Microphysics and Radiation supports improvements in NAAPS physics and model initialization. The improvements to NAAPS and the implementation of NAAPS and FAROP at FNMOC are supported by PMW 180 6.4 Large-scale and Mesoscale Aerosol Forecasting. This funding also supports development and generation products for use by the fleet.

PUBLICATIONS

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HONORS/AWARDS/PRIZES

Douglas L. Westphal: NRL Technology Transfer Award for transitioning the Navy Aerosol Analysis and Prediction System (NAAPS) to FNMOC.

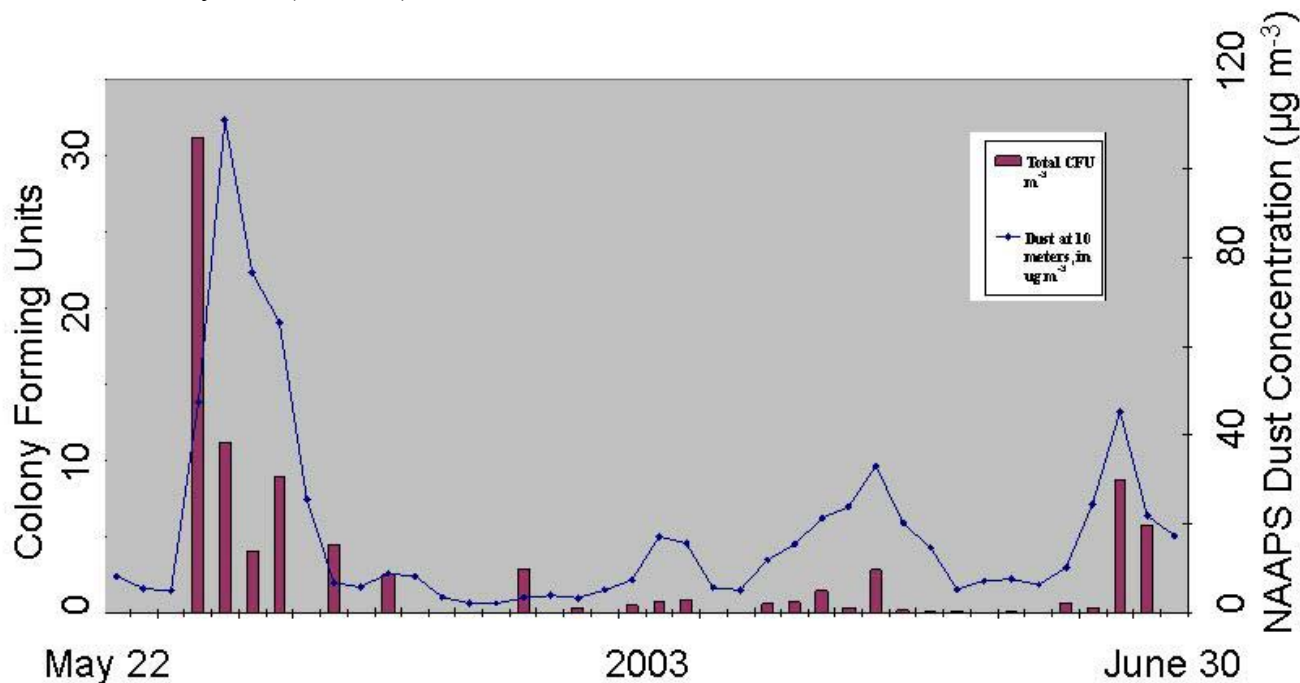


Figure 1. Mid-Atlantic airborne dust (from NAAPS, blue line, $\mu\text{g m}^{-3}$) and total bacterial and fungal-colony-forming unit concentrations (normalized data for concentrations m^{-3} air, red bars) for each sample date, 22 May through 30 June, 2003 showing strong correlation between the two quantities, especially for four multi-day events centered at May 26 and June 12, 19, and 28 (Griffin et al., 2006).

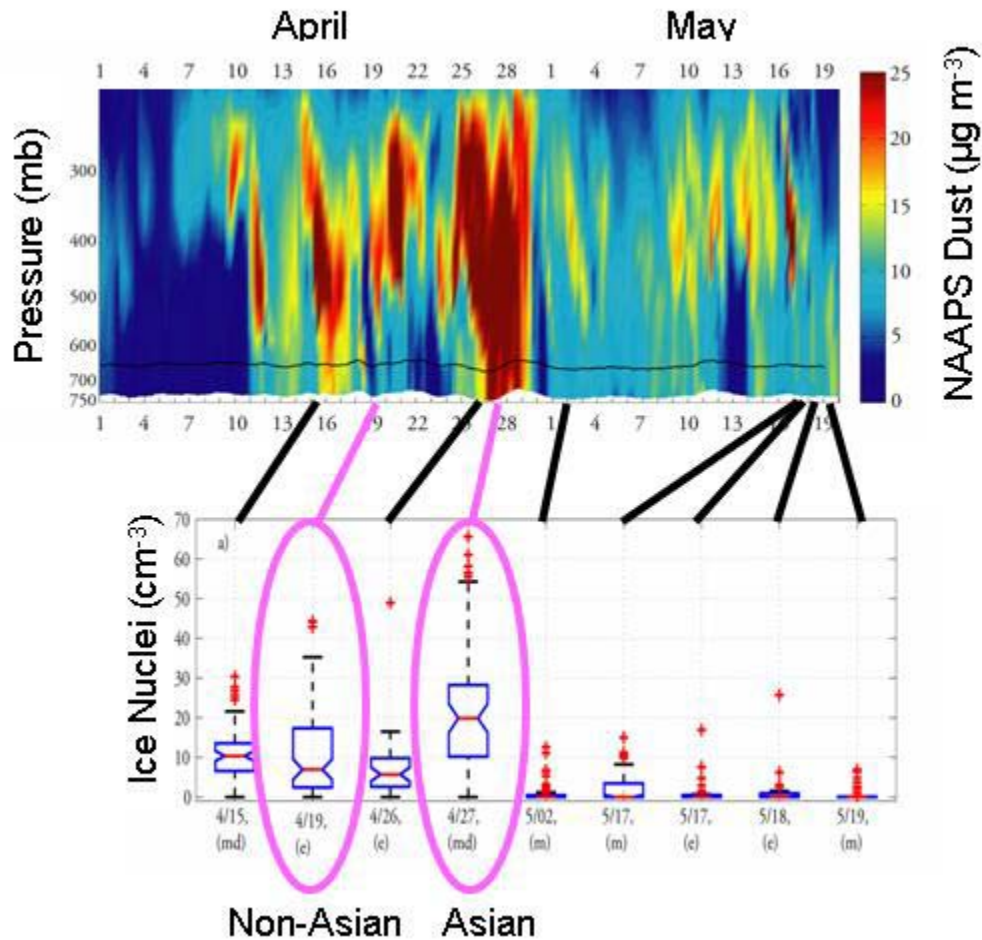


Figure 2. Top: NAAPS predictions of dust concentrations ($\mu\text{g m}^{-3}$) at a grid box centered at 106.5°W , 40.5°N as a function of height; the thin black line indicates the surface pressure recorded at the Storm Peak Laboratory. Bottom: Box and whisker plot of heterogeneous nucleation data for nine sampling periods. The identifiers 'm', 'md', and 'e' stand for morning, midday, and evening, respectively. Horizontal box lines represent lower quartile, median and upper quartile values while the notches represent a robust estimate of the uncertainty about the medians in a box-to-box comparison. Boxes of which the notches do not overlap have medians that differ at the $\alpha = 5\%$ level. The whiskers show the extent of the data while the red crosses represent outliers in the data. Experimental periods shown in this plot are those for which at least 40 min of data were obtained. For each Asian dust event, NAAPS shows dust appearing first in the mid troposphere and then at lower levels. The highest concentrations occur on April 27 and 28. NAAPS shows little surface dust on April 19. The nuclei data also show high concentrations in April with the highest on April 27, as in NAAPS, but also high values on the 19th, leading to the conclusion that the April 19 event was not of Asian origin (Richardson et al., 2006).

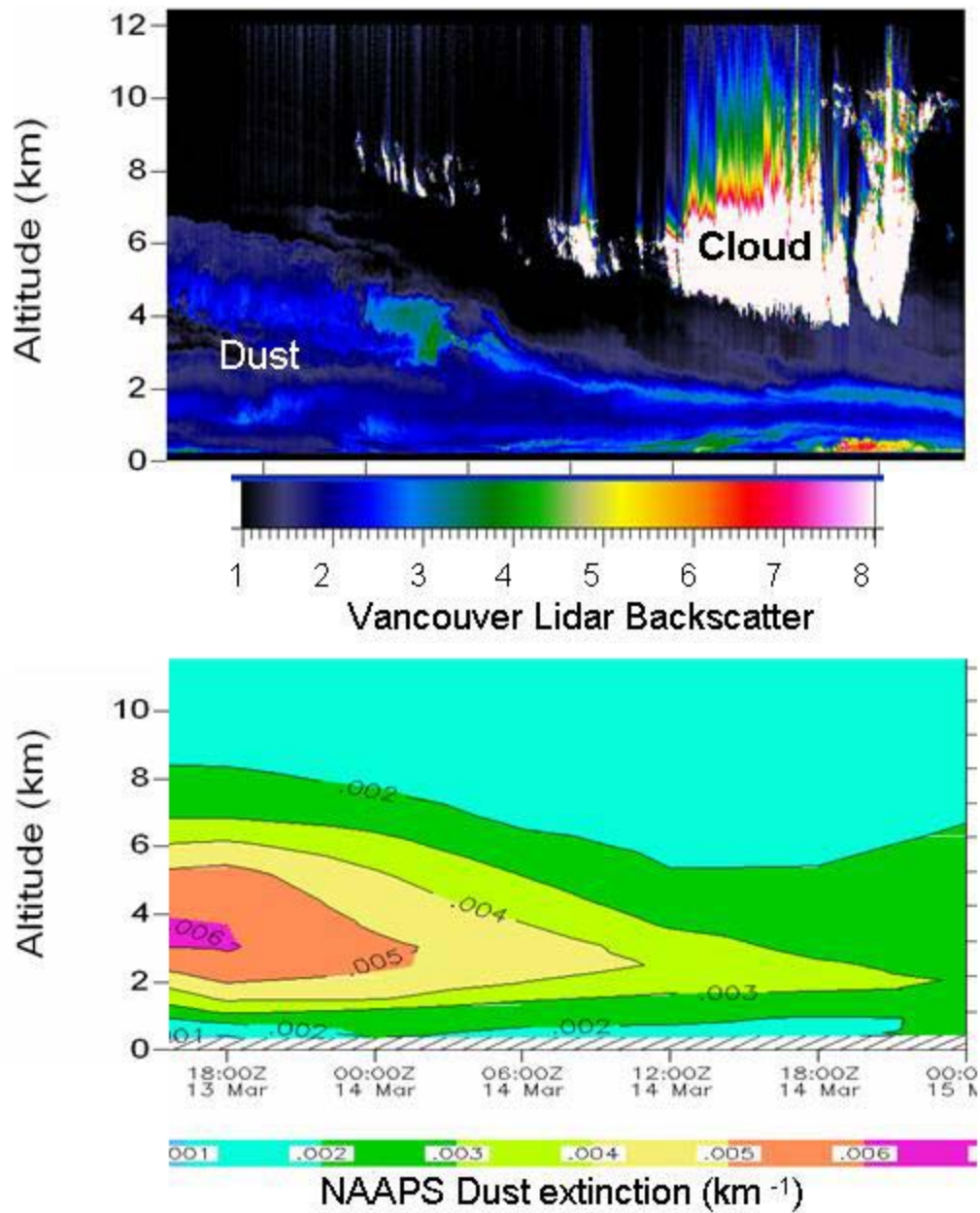


Figure 3. Top: Lidar backscatter for 12Z 13 March through 00Z 15 March, 2005 at Vancouver, BC showing an elevated dust layer between 1 and 6 km early in the period, then below 2 km by the end of the period. Bottom: NAAPS predictions of extinction (km^{-1}) for the grid point at Vancouver BC for the same period showing the same features (McKendry et al., 2006). NAAPS shows that this dust was of African origin.