Development of an Operational Data Assimilation Package using NAAPS and NAVDAS

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LONG-TERM GOALS

One of the strategies to improve the Navy Aerosol Analysis and Prediction System (NAAPS) electro-optical propagation forecast capability is through operational aerosol data assimilation. This process of combining the strength of both near real time aerosol observations and aerosol model predictions has only becomes feasible in the past few years. The assimilation of satellite observations into numerical models is now commonplace. However, only a few attempts have been made to assimilate satellite aerosol products into numerical models. Methods include using an Optimal Interpolation (OI) technique, mainly through retrospective studies or limited regional studies and most recently through radiance assimilation. Based on a previous NRL award, a first of its kind aerosol optical depth data assimilation system was developed. Our long term goals are to improve the long term stability of the system, and to allow for the easy application of data from multiple satellite sensors.

OBJECTIVES

Scientific objectives of this project are tightly aligned with the long term development of the Navy's atmospheric constituent's data assimilation system - Navy Variational Analysis Data Assimilation System-Aerosol Optical Depth (NAVDAS AOD). Now that an initial prototype system has been developed, incremental enhancements can be performed. In this one year grant, we had the following objectives.

1) The original NAVDAS-AOD system was developed with the MODIS data collection 4 optical depth data. Now obsolete, the system must be adapted and new quality assurance coefficients must be derived for the new data collection 5.

2) With the new data collect 5 data stream, we wished to perform a multi-year aerosol data assimilation test analysis to gauge model improvement. Included is not only the collection 5 over ocean, but also the NRL provided over land aerosol products generated by Edward Hyer under J. Reid program. Lastly, we wished to test the improvement of satellite data sets of opportunity, such as the Multi-Angle Imaging Spectroradiometer (MISR).

3) Recently we gained access to global space-based lidar data. To aid in the vertical placement problem in aerosol optical depth data assimilation, we wished to develop a 3-D aerosol climatology using multi-year Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) data.

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14. ABSTRACT
One of the strategies to improve the Navy Aerosol Analysis and Prediction System (NAAPS) electrooptical propagation forecast capability is through operational aerosol data assimilation. This process of combining the strength of both near real time aerosol observations and aerosol model predictions has only becomes feasible in the past few years. The assimilation of satellite observations into numerical models is now commonplace. However, only a few attempts have been made to assimilate satellite aerosol products into numerical models. Methods include using an Optimal Interpolation (OI) technique, mainly through retrospective studies or limited regional studies and most recently through radiance assimilation. Based on a previous NRL award, a first of its kind aerosol optical depth data assimilation system was developed. Our long term goals are to improve the long term stability of the system, and to allow for the easy application of data from multiple satellite sensors.

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APPROACH

The first goal is to develop a data set for assimilation with known uncertainties and easy to apply empirical corrections. For the upgrade from MODIS data collection 4 to 5, we utilize a similar methodology as in the original research.

Once a suitable product is available, it can be assimilated into the model. An aerosol optical depth data assimilation system has been developed at NRL that incorporates aerosol optical depth retrievals into the NRL Atmospheric Variation Data Assimilation System (NAVDAS). NAVDAS has been operational since October 1, 2003 for NOGAPS, and will become operational for COAMPS® in the near future. NAVDAS is capable of assimilating conventional observations, univariate observations (such as moisture and ozone), and observations with complex nonlinear observation operators (such as satellite radiances and the Special Sensor Microwave Imager wind speed). The NRL Aerosol and Radiation Section has completed the use of the univariate two-dimensional capabilities of NAVDAS for MODIS level 2 optical depth assimilation into NAAPS. When more products become available, through geostationary satellite imagers or other polar orbiters such as the European MetOP, they too can be added to the analysis.

After each new sensor or data set is added to NAVDAS-AOD, we need to conduct an Observing System Simulation Experiment (OSSE) to assess model impact. This is conducted though a series of multi-year model simulations that include differing amounts of data. After the simulations, the optimum method is derived and sent on for transition.

WORK COMPLETED

Because NASA MODIS standard optical depth data was undergone a new version release, a rapid analysis of product efficacy was undertaken. Validation of the collection 5 MODIS over water aerosol product was performed using three years of MODIS and AERONET data. Revised QA and QC procedures and empirical correction schemes were constructed for use in a data assimilation quality product. This work is currently being formed into a peer reviewed publication.

We began the study of multi-sensor data fusion over both land and ocean using the operational MODIS, MODIS DeepBlue and MISR aerosol product. Because Quality assurance procedures are still under development, these overland products were taken “as is” with static error fields.

To improve the vertical distribution of assimilated optical depth, we developed an observational aerosol climatology using one year of CALIPSO data. This was sent to NRL Monterey for inclusion in the latest version of NAVDAS-AOD.

As part of a future effort on scaling effects, we also began a study in conjunction with NRL Monterey of sample and contextual biases in the over water MODIS aerosol product. A manuscript is in preparation.

RESULTS

Collection 5 over ocean data quality study: The quality of collection 5 (C5) MODIS over water product was studied for its use in aerosol data assimilation. Three years of MODIS C5 over water aerosol data were collocated and inter-compared with ground based observations as functions of low boundary condition, aerosol optical properties, and cloud contaminations. Uncertainties in the MODIS data were examined, and the procedures in constructing a data-assimilation quality product were developed, which include quality assurance procedures and empirical correction steps. One of the major finding of this study is that despite assurances from original developers, large discrepancies are found between the collection 5 aerosol fine mode fraction (η) and both collection 4 and AERONET derived aerosol fine mode fractions. This large discrepancy in η, if not carefully categorized, could have adverse impact our data assimilation studies, and will significantly hamper research efforts that use the MODIS aerosol fine mode fraction for anthropogenic aerosol climate studies. Using multi-channel aerosol optical depth (AOD) retrievals from MODIS, we reconstructed η based on a spectral-deconvolution methods. We expect to transition this new data assimilation quality MODIS correction 5 over water product to a 6.4 prototype assimilation system by the coming fiscal year.

Multi sensor data fusion: Advanced satellite aerosol optical depth retrievals and datasets now allow the scientific community an unprecedented volume of observations of the global aerosol distribution. Each algorithm has advantages and disadvantages, and no single dataset can boast top performance everywhere over the globe. We developed a multi-sensor aerosol optical depth analysis over Saharan regions by assimilating MODIS operational, MODIS deep blue, and MISR aerosol products into NAAPS via NAVDAS-AOD for June to August, 2005. Our study suggested that aerosol data assimilation can be a very efficient technique for multi-sensor aerosol data fusion. Our study also suggested that aerosol and aerosol modeling could in turn greatly benefit from the multi-sensor aerosol observations. A more than 50% increase was found for the correlation between NAAPS and AERONET aerosol optical depth (including both land and ocean) after assimilating data from multi-sensor measurements into NAAPS (Figure 1).

Contextual and clear sky bias: The spatial distribution of aerosol optical properties derived from satellite observations are limited by various sampling biases including biases introduced by sampling methods, clear sky biases, and retrieval method introduced sampling biases. Using one year of NAAPS Aerosol Optical Depth (AOD) product with assimilation, we estimated the sampling biases in the operational MODIS level 2 collection 5 over water aerosol products. Our main conclusions were that although global mean AOD over global oceans show a small sampling bias, large regional biases (both negative and positive) are found even for three month averages. The averaged negative and positive sampling biases are found to be on the order of 10%, and should be considered for any regional studies.

This study suggests that at least two weeks of MODIS data are required for a reasonable coverage of aerosol field over global oceans. Adding two sensors (Both Terra and Aqua) would not significantly improve sampling biases.

This study also suggests that the Indo-China region has consistent positive sampling bias for all seasons. And other major areas with positive sampling biases are ITCZ, and high latitude regions over both Northern and Southern hemisphere that are associated with high cloud fractions. Major areas with negative sampling biases are found over the coast of South America and west coast of Africa that could associated with contextual biases.

CALIPSO climatology: One of the limitations in the 2-D var version of aerosol assimilation is that NAAPS aerosol climatology was used in redistributing the analysis increments from 2-D aerosol optical depth fields to 3-D aerosol mass concentrations. A new CALIPSO climatology is included in the NAVDAS-AOD for a better representation of the aerosol vertical distributions in NAAPS. The CALIPSO climatology is constructed for four seasons, four aerosol types (smoke, dust, sulfate, and sea salt), with spatial and vertical resolution of 5°Lat/Lon, and 250m-2km (varies with altitude) respectively. However, insignificant improvements were found in the NAAPS analysis (mostly over small AOD values), and a 3-D var data assimilation package may be necessary for NAAPS to fully benefit from the CALIPSO measurements.

IMPACT/APPLICATIONS

Current OSSE's suggest that the inclusion of over water MODS AOD data improves the initial root mean square analysis by more than 40%. Further, this improvement is shown to hold out through 48 hrs - the longest the OSSE has been performed. We expect however that improvements will continue up though 96 hours. This OSSE is expected to take place in the next fiscal year. Further, the"as is" assimilation of over land data improves the model (e.g. increase the correlation between NAAPS and AERONET AOD by 50%) in areas of Navy interest, such as Africa and SW Asia. After a proper QC and QA procedure for over land data is completed (ongoing at NRL MRY), we expect performance to further increase.

TRANSITIONS

Code for optical depth data assimilation and NAVDAS-AOD has been delivered to NRL Monterey for future implementation to FNMOC. The algorithm for constructing a data assimilation quality MODIS collection 4 over water product has been delivered as well.

RELATED PROJECTS

This project is tightly coupled to a number of ONR 322 programs at the Marine Meteorology Division Aerosol and Radiation Section on the further development of the Navy's aerosol forecasting capabilities. This including integrated effort with the Earth Sciences Applications project of JS Reid on the development of NAVDAS-AOD, and the model integration with the Large Scale Aerosol Modeling Development project of D. L. Westphal. Lastly, we are beginning enhancements to 3-D and 4-D variational analysis in cooperation with the NRL data assimilation section (Bill Campbell and Nancy Baker).

PUBLICATIONS

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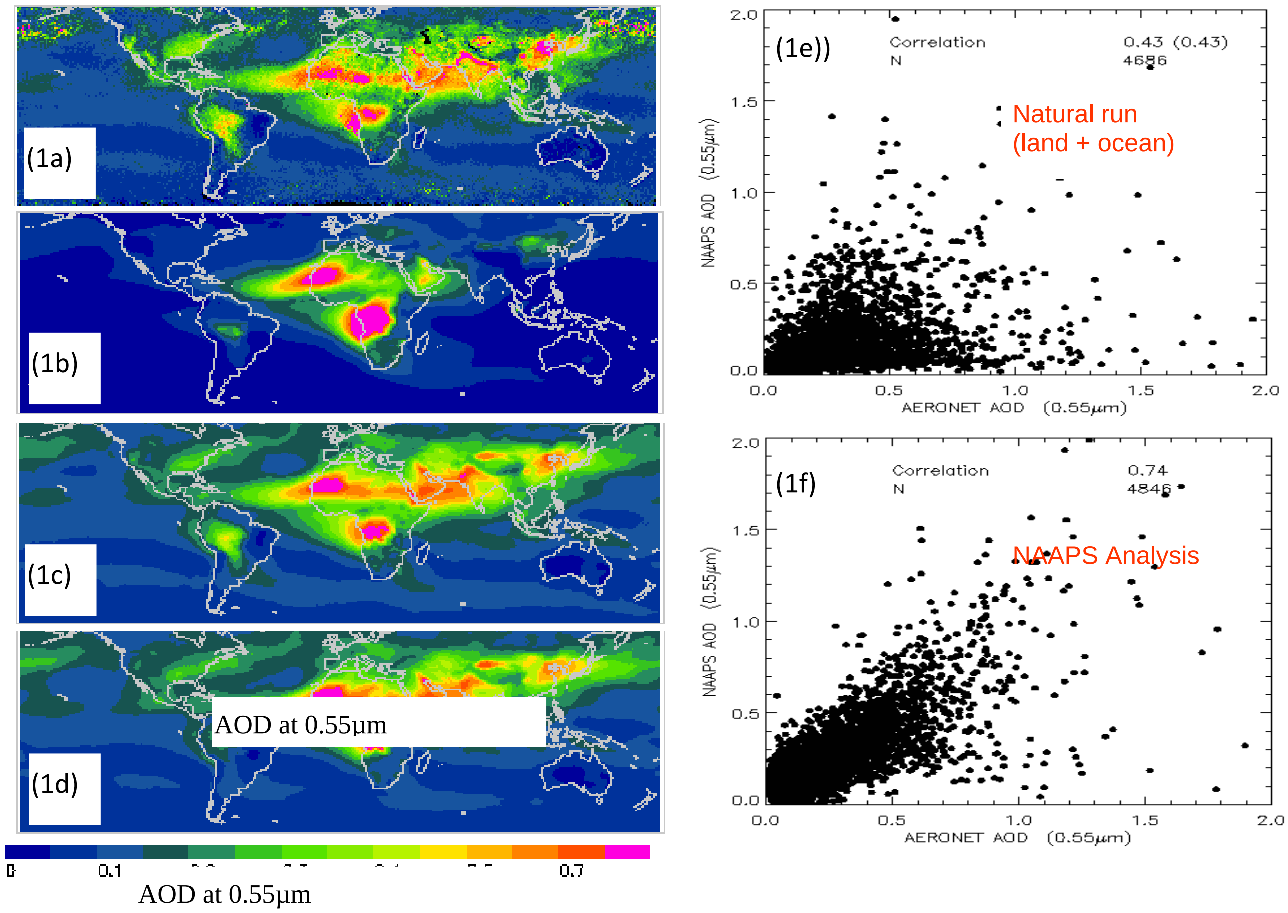

Figure 1a. Three month average of MODIS operational, MODIS DeepBlue and MISR aerosol products for June-August, 2005. 1b) NAAPS AOD forecast for the same study season as Figure 1a. 1c) NAAPS analysis with the inclusion of MODIS operational, MODIS DeepBlue and MISR aerosol products for the same study period as Figure 1a. 1d) Similar to Figure 1c, but for 6 hour forecast. 1e) Inter-comparison of NAAPS and AERONET AOD for NAAPS run without data assimilation for the same study period as Figure 1a. 1f) Similar to Figure 1e but for NAAPS runs with assimilation of the three satellite products as