Aerosol Microphysics and Radiation Integration

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LONG-TERM GOALS

This project works toward the development and support of real time global prognostic aerosol and visibility models for the benefit of the Department of Defense and civilian research communities. The Aerosol Microphysics and Radiation program was established to lend support to these models through the development of physical to optical transfer functions to bridge the gap between observables (in situ and satellites) and models as well as lay the foundations for aerosol data assimilation. Fundamental to this program is the development of consistent aerosol microphysical and radiation parameterizations for the Navy's two primary operational aerosol models, the NRL Aerosol Analysis and Predictions System (NAAPS) and the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®).

This work included generation of Navy relevant satellite products, source/sink functions, creation of bulk and theoretical optical parameterizations, investigation of microphysical transformations, and the primary validation of model electro-optical products. Goals ranged in intricacy from the creation of simple thermodynamic and microphysical parameterizations for use in models to the development of error matrices and products for use in aerosol data assimilation. FY07 was the last year for this program and met its long term goals.

OBJECTIVES

In FY07 the Aerosol and Radiation Integration Program had several diverse objectives. These included in order of effort:

a) Over Ocean Data Assimilation and Satellite Products: Develop the satellite products and algorithms necessary for transition of over ocean aerosol optical depth to 6.4 for quasi-operational implementation.

b) Southwest Asia: Finish comprehensive assessment of aerosol particle properties and vertical distribution in Southwest Asia. Begin analysis of the effects of aerosol particle properties and vertical distribution on the radiative budget in Southwest Asia.

c) Over Land Data Assimilation and Satellite Products: Perform strategic assessment of potential for over-land aerosol optical depth data assimilation

d) Tools development: Develop semi-automated methods for data validation and distribution

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14. ABSTRACT
This project works toward the development and support of real time global prognostic aerosol and visibility models for the benefit of the Department of Defense and civilian research communities. The Aerosol Microphysics and Radiation program was established to lend support to these models through the development of physical to optical transfer functions to bridge the gap between observables (in situ and satellites) and models as well as lay the foundations for aerosol data assimilation. Fundamental to this program is the development of consistent aerosol microphysical and radiation parameterizations for the Navy?s two primary operational aerosol models, the NRL Aerosol Analysis and Predictions System (NAAPS) and the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS?).

15. SUBJECT TERMS

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e) Analysis of severe sea salt conditions (Reid): perform meteorological analysis of sea salt conditions in extra-tropical cyclones.

f) Biomass Burning (Curtis, Hyer) Transition of real time satellite source function to 6.4.

APPROACH

Team members supported by this project include Jeffrey S. Reid (analysis), Anthony Bucholtz (radiative measurements), Cynthia Curtis (data systems), Edward Hyer (biomass burning, ASEE Fellow), and Jianglong Zhang (data assimilation, UCAR Fellow). To complete project goals, this work requires the simultaneous study of model, remote sensing, and field data. Effort on all project objectives utilized all three of these product types.

To a large degree, work focuses on the development of aerosol data assimilation of MODIS optical depth data. Data is downloaded daily from the NOAA Near Real Time Rapid Processing effort (“bent pipe”) data feed where MODIS level 2 and degraded level 1b is made available to NRL with only a few hours latency. This includes optical depth data for assimilation, land surface data for data screening, and fire products for real time source functions.

The first step is in the development of products suitable for data assimilation. For over ocean these were outlined in a Jianglong Zhang et al. [*Zhang et al.*, 2007]. Additional checks and corrections are now being made based on field data. For the over land problem, the utility of satellite derived surface products are now being investigated. Bias corrections suitable for real-time application were developed based on the Navy Operational Global Atmospheric Prediction System (NOGAPS) and retrieved fine/coarse partition. Corrected and thinned data were aggregated into a new gridded product suitable for data assimilation.

Based on the improved product, the new products are assimilated in the global NRL Aerosol Analysis and Prediction System (NAAPS) via the Atmospheric Variational Data Assimilation System (NAVDAS) aerosol optical depth package (NAVDAS-AOD). Then through cross comparison with other remote sensing and field data derived in this work unit as well as other funded by ONR 32, specified applied science projects are conducted.

A good example of this method is the analyses of the aerosol properties of Southwest Asia complete in this fiscal year (Figure 1). Here, we wished to explain dust vertical profiles and microphysics in a Shamal dust event. This was done through the combination of model, remote sensing and field data to yield a complete picture of the environment.

A secondary example is the analyses performed in cooperation with NOAA on the meteorological conditions leading to the near loss of a NOAA WP-3D aircraft due to sea salt accretion on the airframe and eventually leading to engine compressor stalls in hurricane like conditions. Through the above processes we brought together meso-scale (COAMPS-on Scene®) and global (NOGAPS/NAAPS) together with space based lidar (CALIPSO) and imagery (MODIS, GOES, and MSG) to do a post analyses of the event. Further, we laid the ground-work for applying this post analyses paradigm to the forecasting problem. Through similar processes we developed functional tools for the validation and dissemination of Navy aerosol products. This year, data was integrated through the Google Earth® client-server via the development of KML scripting tools.

WORK COMPLETED

Work completed under this program can be summarized as follows:

(a) Over Ocean Data Assimilation and Satellite Product (Zhang; Reid; Curtis):

(1) Developed aerosol optical depth data assimilation system for NAAPS based on NAVDAS suitable for 6.4 transition

(2) Performed 6 month data assimilation baseline test to determine model improvement and submitted results for peer reviewed publication.

(b) Southwest Asia(Reid, Bucholtz):

(1) Finalized analysis of dust micropshysical properteis and submitted paper for peer reviewed publication.

(2) Determined factors controlling aerosol vertical structure in SW Asia and submitted paper for peer reviewed publciation.

(3) Calibrations of the solar and infrared radiometers used in the Study of Aerosol Meteorology Interaction-Arabian Gulf (SAMI-A) field study were carried out and an initial quality check of the SAMI-A radiometer data was completed.

(c) Over Land Data Assimilation (Hyer; Zhang; Reid)

(1) Developed nighttime aerosol optical depth algorithm utilizing DMSP city light data and submitted paper for peer reviewed publication.

(2) Complied comprehensive land surface database for use in quality assurance applications.

(3) Performed preliminary analysis of MODIS optical depth product fidelity over-land using new database.

(d) Tools development (Curtis):

(1) Created Google Earth® web products for enhanced distribution of NAAPS and EO products.

(2) Developed semi-automated system for validating long period NAAPS model simulations.

(e) Analysis of severe sea salt conditions (Reid)

(1) Performed comprehensive analysis of meteorological conditions leading to the near loss of a NOAA WP-3D aircraft due to sea salt accretion. Developed meteorological guidance for future operations.

(2) Composed memorandum report on findings for ONR and NOAA.

(f) Biomass Burning (Hyer; Curtis; Reid)

(1) Finshed transition of real time satellit source function to 6.4 and aided in transition to FNMOC.

RESULTS

Using the 2-D variational assimilation components of NAVDAS-AOD, Zhang et al. implemented the new level 3 product in NAVDAS-AOD. Corrections to aerosol mass concentration were made in a straightforward and traceable fashion in NAAPS by changing the amplitude of the preexisting aerosol profile. In cases of very large innovations, vertical profiles fall to a seasonal NAAPS climatology. The impact of this new system during a 5 month test run is presented in Figure 2. Given is a scatter plot of the NAAPS/NAVDAS-AOD analysis versus AERONET sun photometer data, which shows good general agreement (Figure 2 a) and a 40% reduction in AOD error. Even after 48 hours of integration (Figure 2b), assimilation improved the forecast by 25%.

Preliminary work on over-land data assimilation suggests that while the MODIS product is promising, there are still errors that need characterization. Much of the difficulty of retrieving aerosol properties over land is related to the lower boundary conditions. Figure 3a shows the mean (black line) and standard deviation (blue) of the bias, and also the fraction of MODIS retrievals (in red) that fit within our target error for data assimilation. Even for dark targets (albedo <0.10), only 60-75% of data points pass. At albedos >14%, suitable data falls off precipitously. Errors in AOD also relate to surface type (Figure 3b), indicating a source of contextual bias. We have also found regional biases on the order of 20% due to microphysics simplifications in the retrieval. Over land, correlations may exist between different types of error (e.g. aerosol models, optical depths and surface properties), and the spatial scales over which sources of error vary are fine, often finer than the grain of the MODIS AOD retrieval itself.

Also aiding the over land-effort, a night time city light algorithm to estimate aerosol optical depth was developed using Operational Linescan System (OLS) data on Defense Meteorological Satellite Program (DMSP) platforms. Since the OLS instruments have no on-board calibration, only qualitative retrievals are possible with uncertainties in aerosol optical depth being on the order of 0.3. While this is considered coarse for daytime algorithms, this method shows great potential for the early detection of major aerosol plumes such as for dust and smoke. The technique was demonstrated using China and India as testing regions. This study sets the frame work for future nighttime aerosol optical property studies using the Visible/Infrared Imager/Radiometer Suite (VIIRS) instrument on National Polar-Orbiting Operational Environmental Satellite System (NPOESS) in the coming decade.

Through the combination of satellite, model and observational data, an analysis of how the vertical distribution of aerosol particles in Southwest Asia is impacted by flow meteorology was conducted. For offshore flow conditions, classic over desert characteristics were found with deep well-mixed boundary layers. Over the Arabian Gulf, stable marine boundary layers topped by strong inversions rapidly formed offshore (typically between ~400-800 m). Dust and pollution vertical profiles were consequently complex and highly dependant on mesoscale circulations, such as the sea/land breeze. In the case of pollution, the ability of flaring plumes to penetrate the inversion may also in part determine if pollution is layered above or below the inversion. An example of a particularly strong pollution event over the Arabian Gulf is presented in Figure 1. This event resulted in near surface visibilities of less than 1 km, the lowest experienced by this investigator. This event was formed during a synoptic scale flow reversal from southwesterly to northwesterly winds. A result was that the air-mass had prolonged exposure to the warm Arabian Gulf waters with a subsequent intensification of the marine boundary layer inversion. This in turn trapped pollution emitted from the regions oil industry. Our preliminary findings are that half of the visibility reduction found over the Arabian Gulf is due to pollution.

Also studied under this grant was microphysical variability of airborne dust in Southwest Asia. A key finding was that observed dust particle size distributions appear to be fairly static from individual sources, regardless of production and transport phenomenology. Thus, this study provides direct experimental evidence that on regional scales common mode dust is not impacted by production wind speed but rather influenced by soil properties such as geomorphology or roughness length. This allows a major simplification for models. It also implies that transport processes of at least the mesoscale do not significantly impact common mode dust size. Lastly, evidence for a strong submicron dust mode, as has been suggested in previous studies, was inconclusive.

The last scientific study undertaken this year is with regards to the near loss of a WP-3D aircraft in the winter of 2007 when it lost power to three of its four engines while flying in hurricane like conditions in the North Atlantic Ocean. Preliminary engineering and meteorological analysis performed by the National Atmospheric and Oceanic Administration (NOAA) pointed to sea salt fouling when the aircraft encountered a super concentrations of sea salt aerosol particles in the atmosphere at altitude above 1 km.. To our knowledge this type of sea salt event is previously unrecorded in the peer reviewed literature and required investigation. Utilizing a combination of model, satellite, and in situ data we tracked the flight environment for three research flights as part of the 2007 Ocean Winds Winter Experiment (OWWE) out of St. John's, Newfoundland, where the aircraft experienced hurricane force winds. In the case in question the aircraft track took it into the dry slot behind the bent back warm-type occluded front of a North Atlantic explosive cyclogenesis event. In this environment, dry air polar was advected at high wind speeds over the relatively warm waters of the Gulf Stream. This lead to an environment of high winds, high seas and massive atmospheric instability and turbulence along a 400 km fetch without precipitation. This allowed giant sized sea salt particles to be well mixed in the marine boundary layer. By our estimations, marine boundary layer heights for this flight were on the order of 1200 to 1500 m, well above the flight level of the aircraft. In comparison, other OWWE flights may have experienced high winds, but did not the other causal factors determined for February 9th. Lastly, since the WP-3D was intersecting warm moist and sea salt laden updrafts in between longer periods of drier environments, it is possible that increased sea salt accretion developed through the oscillating wet-dry cycle.

Lastly, regarding software engineering, it was found that Google Earth(R) is a rapidly evolving method of disseminating atmospheric science data to the scientific and warfighter community alike. Publicly available interfaces were developed showing MODIS satellite imagery, fires detected from the Geostationary Operational Environmental Satellite (GOES) and from MODIS, and data from the Navy Aerosol Analysis and Prediction System (NAAPS). Additional techniques were developed for building an animation from a set of images, displaying 3-D aircraft flight tracks, and the use of progressively higher resolution datasets when zooming.

IMPACT/APPLICATIONS

The development of an over ocean aerosol optical depth data assimilation system under this work unit will likely be the most significant single improvement to the Navy's aerosol forecasting capabilities in the last 5 years. Test runs have shown 40% improvements to global model aerosol analyses at coastal sites, and 25% improvements over 48 hour forecasts. Preliminary work on over-land data assimilation quality AOD product suggest that once implemented, equal improvement for over major landmasses are also possible in the near future. These developments are already leading to improvements in model source and sink function.

The development of a nighttime aerosol optical depth product from DMSP city light data changes the paradigm of how aerosol observations can be incorporated in models. With improved fidelity expected from NPOESS VIIRS, we expect the transition of this method to operations to be feasible.

The complete analysis of data collected in the UAE2 field program has significantly changed our understanding of the aerosol and EO/EM propagation environment in Southwest Asia. Our finding that common mode dust size distribution does not vary as a function of wind speed for any given source region results in a large simplification in model source functions.

The creation of a Google Earth® data server for NRL Code 7544 aerosol products will greatly enhance data availability to the warfighter and civilian scientific community. Preliminary products placed on-line are already heavily downloaded on the world wide web.

TRANSITIONS

All source functions and microphysics products feed directly into NAAPS, COAMPS® and now COAMPS On Scene® aerosol modules. As these models are updated at Fleet Numerical Oceanographic and Center (FNMOC) for Navy operational visibility forecasting, associated products from this work unit are being transitioned as well.

Aerosol optical depth data assimilation work under this 6.2 project was staged in FY07 for quasi-operational development (6.4) led by Douglas Westphal.

Fire products (including fluxes and transport data) from the joint ONR 32/NASA Fire Locating and Modeling of Burning Emissions (FLAMBE) project were transition to the Fleet Numerical Oceanographic Center (FNMOC) Monterey in FY07.

Meteorological guidance resulting from WP-3D compressor stall investigation was accepted by NOAA Aircraft Operations Center.

RELATED PROJECTS

This project is closely tied to other work units from ONR Code 35, NRL Base Program, NASA, and JCSDA. Products, data assimilation code, and validation work feed directly into the ONR 32 6.2 project Coastal Aerosol Distribution by Data Assimilation (Douglas L. Westphal, PI) for further development of NAAPS as well as 6.1 Base funding projects developing an aerosol component to COAMPS® (Ming Liu, Shouping Wang). Systems developed under this work unit are being immediately applied to the ONR 35 project on directed energy propagation. Field measurements collected in FY04 and 06 in the Arabian Gulf region and analyzed in under this work unit are being used in COAMPS® and NAAPS model assessment (Westphal, Holt). COMAPS-On Scene® is now also a customer for this work unit's products.

Outside the Navy, products and parameterizations receive heavy usage from NASA, JCSDA and the air quality communities as well as a broad base of researchers.

PUBLICATIONS

Peer Reviewed Manuscripts Submitted In FY07

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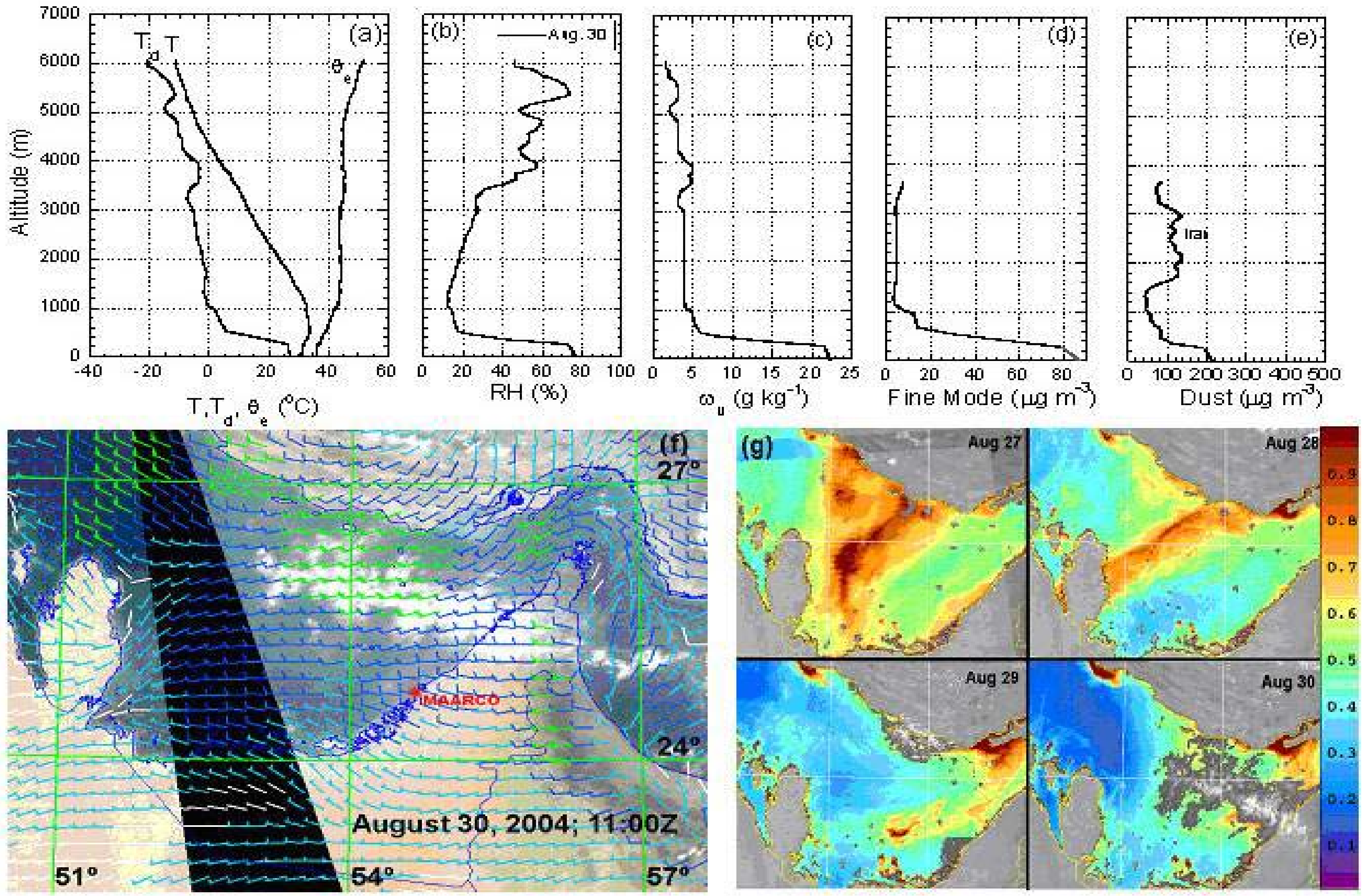

Figure 1. Analysis products of the extreme pollution event of Aug. 30, 2004. at the coastal MAARCO site. (a) Aircraft atmospheric state variables, (b) relative humidity, (c) water vapor mixing ratio, (d) estimated dry fine mode mass concentration, (e)estimated dust mass concentration, (f) MODIS Terra satellite RGB images with COAMPS® surface wind fields. (g) NRL high resolution aerosol optical depth [Kuciauskas personal communications]

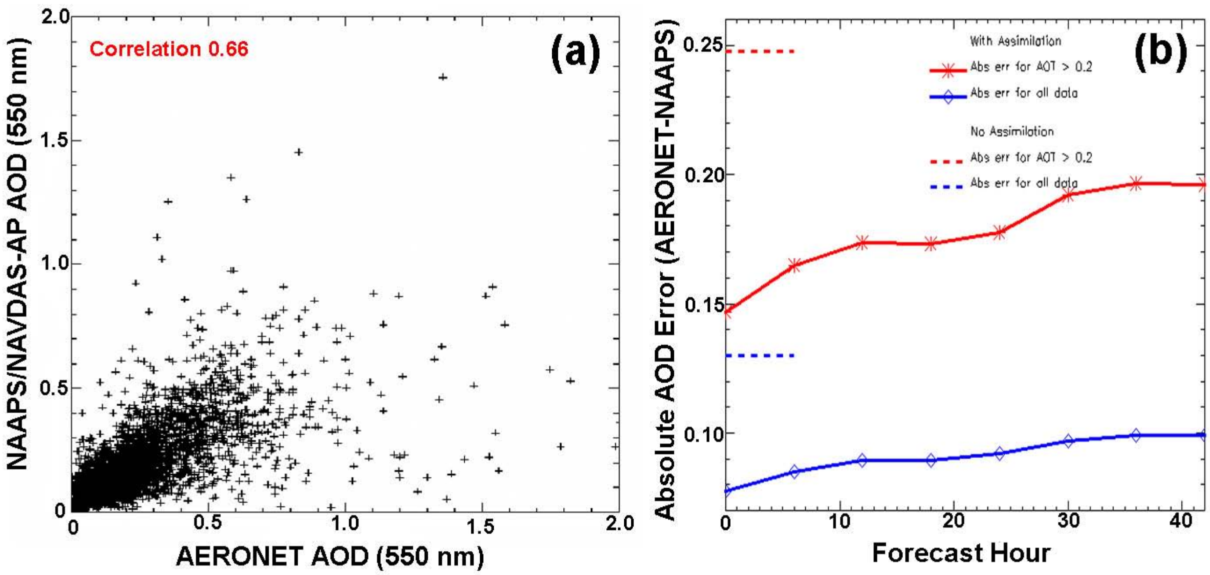

Figure 2. (a) NAAPS/NAVDAS-AOD 550 nm AOD versus coastal AERONET sun photometer sites for Jan-June 2005. (b) NAAPS AOD error as a function of forecast hour for the same period. Shown are curves for all data points (blue) and only those with significant optical depth (AOD>0.2; red). Dotted lines give the mean NAAPS errors without data .assimilation for t=0.

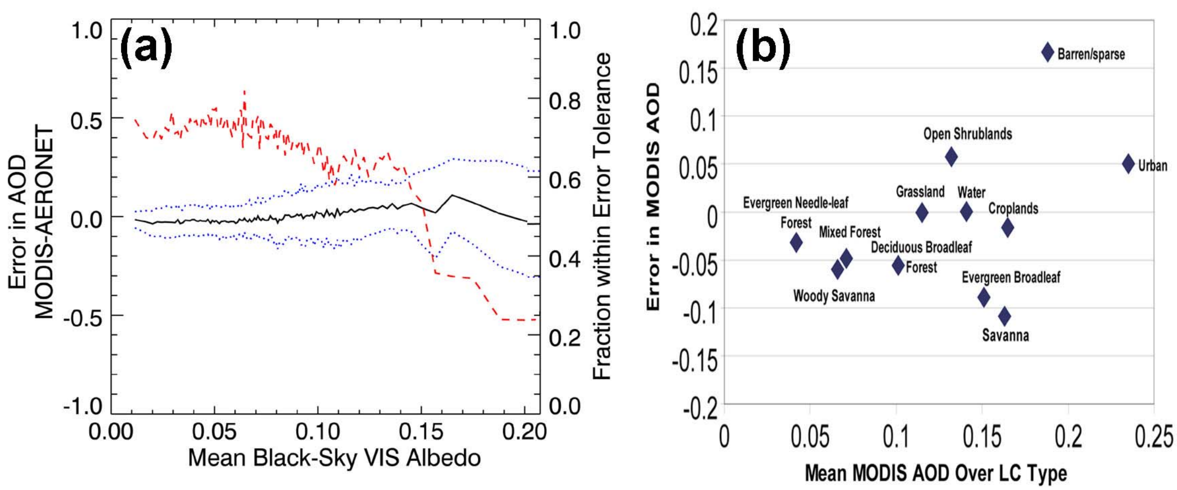

Figure 3. Comparison of over land MODIS V5.2 AOD to AERONET sun photometer AOD as a function of (a) mean surface albedo in the MODIS footprint. Given is AOD error (black) and the fraction of MODIS retrievals falling within the target error for optimal data assimilation (red, error < 0.1 for AOD < 1.0, error <0.2 for 1.0 < AOD < 2.0, error <0.5 for AOD > 2.0), and (b) Mean MODIS AOD by land cover type (MOD12 land cover).