Improving Aerosol and Visibility Forecasting Capabilities Using Current and Future Generations of Satellite Observations

Jianglong Zhang
Department of Atmospheric Sciences
University of North Dakota
phone: (701) 777-6342 fax: (701) 777-5032 email: jzhang@atmos.und.edu

Grant Number: N00014-10-0816

LONG-TERM GOALS

The study of atmospheric aerosols is important because of their effects on air quality, climate change and atmospheric circulation. Aerosols reflect and absorb light which can severely reduce visibility during episodes of heavy loading, and thus, aerosols directly impact air, sea, and land operations for the DOD. Additionally, the widespread use of advanced electro-optical (EO) systems requires the accurate characterization and prediction of aerosol optical properties on both regional and global scales. The long-term goal of this study is to improve the Navy's aerosol and EO propagation forecast capability through the use of multi-channel, multi-sensor, and multi-task aerosol data assimilation.

OBJECTIVES (abstract from proposal)

Critical to both military and civilian applications, the Navy Aerosol Analysis and Prediction System (NAAPS) is the only truly operational global aerosol and visibility forecasting model. Recent studies indicate that the utilization of satellite observations significantly improves NAAPS aerosol forecasting capability and reliability. To fully utilize the wide breadth and depth of various current satellite observations and to prepare for future reductions in aerosol sensing satellites over the next decade, we propose to construct a multi-channel, multi-sensor, and multi-task assimilation system to improve NAAPS forecasts for both current and future applications. The specific objectives of this study are to:

1. Finalize over-land and over-ocean aerosol assimilation methods using operational data assimilation quality *Moderate Resolution Imaging Spectroradiometer* (MODIS) and *Multiangle Imaging SpectroRadiometer* (MISR) aerosol products, and develop a framework for considering current and future satellite aerosol products.
2. Develop forward models to enable a radiance assimilation capability by: 1) improving forecast performance over cloudy regions using the *Ozone Monitoring Instrument* (OMI) Aerosol Index; and 2) preparing for the post-MODIS/MISR era using the *Geostationary Operational Environmental Satellite* (GOES).
3. Improve model representations of aerosol vertical profiles and the accuracy of aerosol speciation in NAAPS through the use of a 3-D aerosol assimilation method and a generalized Angstrom exponent assimilation scheme.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **30 SEP 2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**
4. TITLE AND SUBTITLE **Improving Aerosol and Visibility Forecasting Capabilities Using Current and Future Generations of Satellite Observations**		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) **University of North Dakota,Department of Atmospheric Sciences,Grand Forks,ND,58202**		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		
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)**	**10**	

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

4. Develop an improved 3-D parameterization for satellite observation and model forecasting error matrices using ground observations from the *Aerosol Robotic Network* (AERONET) and the *Micropulse Lidar Network* (MPLNET).

APPROACH

This proposed effort focuses on two main areas: 1) studying uncertainties in existing and future (e.g., VIIRS) satellite aerosol products and developing algorithms for constructing data-assimilation-quality (DA-quality) satellite aerosol products; and 2) developing a multi-sensor, multi-channel, and multitasking satellite data assimilation capability. This includes the development of an optimized strategy for multi-sensor aerosol optical depth assimilation, algorithms to improve aerosol speciation and the vertical representation of aerosol plumes, schemes for utilizing aerosol retrievals above clouds, and the capability for GOES radiance assimilation in preparation for the post-MODIS/MISR era.

Large uncertainties exist in most of the current satellite aerosol products (Figure 1). Extensive efforts are needed to understand the sources of uncertainties for aerosol modeling and aerosol assimilation. With support from the ONR, uncertainties in the operational MODIS over-ocean and over-land aerosol products have been studied with respect to surface boundary conditions, aerosol microphysics, and cloud contamination through multi-sensor intercomparison and cross validation against ground based observations. New DA-quality MODIS over-water aerosol products were developed and are currently in operation at FNMOC. New improvements include the development of quality assured over-land MODIS aerosol products. Similar efforts are being conducted and planned for current and future sensors such as MODIS DeepBlue, MISR, and NPP VIIRS.

The core of the assimilation efforts is the NRL Atmospheric Variational Data Assimilation System (NAVDAS) Aerosol Optical Depth (NAVDAS-AOD) system. Upon the development of the DA-quality aerosol products, a framework for optimally utilizing the current (e.g., MODIS, MODIS DeepBlue, MISR) and future (e.g., VIIRS) satellite aerosol optical depth products will be developed with the use of NAVDAS-AOD.

Realistic aerosol vertical distribution is also critical to the forecasting of the longer range transport of aerosol plumes. To improve the representation of aerosol vertical distributions in an aerosol forecast model, a 2D/3DVAR Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) aerosol assimilation package is needed. The first version of such a scheme has been developed with the support of this project (Figure 2).

Improving aerosol speciation is critical to aerosol forecasts. Aerosol size and type information could be interpreted from parameters such as the aerosol fine mode fraction and angstrom exponents that are derived from simultaneous measurements made from multiple ancillary aerosol-sensitive channels. Currently, a prototype assimilation model that uses the MODIS over-water fine mode fraction has been built and is under evaluation. This effort will be extended to include angstrom exponents.

Although not included in this year’s research efforts, we will be looking into methods that use OMI observations for determining the presence of aerosols above clouds. Most remote sensing algorithms limit aerosol detection over cloud-contaminated regions. However, the OMI AI product is sensitive to the presence of absorbing aerosols over cloudy scenes, and thus, this product could help aerosol prediction and modeling studies over cloudy regions.

Lastly, we must prepare for the coming period when most advanced aerosol satellites such as MODIS and MISR are decommissioned, yet replacement satellites such as NPP will either not be in orbit or will not have reached operational specifications to ensure sufficient data quality. However, there is no single geostationary satellite aerosol product that is widely accepted by the community and provides DA-quality data over both land and ocean regions. To resolve this situation, a radiance assimilation method will be built by using over-water GOES satellite observations. Currently, a GOES radiance simulator is being constructed by using NAAPS and the *Community Radiative Transfer Model*.

WORK COMPLETED

In this first year of the project, successful progress has been made in research areas as listed below, and several new research areas have also been initiated.

With the joint support from an ONR YIP project (N00014-08-1-0935) and by collaborating with Dr. Jeff Reid and Dr. James Campbell from NRL, a coupled 2D/3DVAR scheme that uses aerosol vertical profiles from CALIPSO and AOD observations from standard aerosol products has been developed. This coupled 2D/3DVAR assimilation scheme improves the vertical representation of the aerosol analysis state in NAAPS, which is evidenced through improved globally-averaged AOD that is solved throughout the 48-hr model forecast. The CALISPO aerosol assimilation system has been delivered to NRL for further evaluation, and a journal paper has been published for this research effort.

Along with the CALIPSO assimilation system, an own analysis system has also been developed and delivered to NRL for further testing. The own analysis system was developed for assessing model performance and for highlighting further system development needs by evaluating NAAPS analyses and forecasts with three methods: comparison with ground-based AERONET observations, comparison with satellite AOD data, and comparison with NAAPS analyses with the inclusion of aerosol assimilation (own analysis).

A prototype of the scheme that assimilates aerosol fine mode to total aerosol optical depth (η) from MODIS has also been developed. The η value represents aerosol particle size and is associated with aerosol types. Small η values relate to dust and sea salt aerosol types while large η values indicate pollutant and smoke aerosols. This effort is jointly supported by N00014-08-1-0935.

To improve understanding of uncertainties in existing satellite aerosol optical depth products, a study was conducted to examine the spatial biases among MODIS Dark-Target, MODIS DeepBlue, and MISR aerosol products. This study reveals regions where large discrepancies are found among current satellite aerosol products, yet some of these discrepancies are missed by the conventional AERONET–based analysis. This is important not only to satellite aerosol assimilation efforts, but also to the satellite aerosol community in general. A manuscript has been submitted to AMT for publication.

Continuing from the ONR YIP project, the DA-quality MODIS DeepBlue aerosol product (new version) and the over-water MISR aerosol product are in the final stage of their development. Manuscripts for publication are being prepared for these two subjects.

Beside the research activities mentioned above, new research efforts are being rigorously pursued. Research areas that are currently in progress include the development of a forward model for radiance assimilation, the development of a nighttime aerosol retrieving scheme, and the study of aerosol optical depth anomalies over southern oceans.

RESULTS

The results obtained over the past year can be summarized with the abstracts of papers and presentations that have been submitted and new results that could lead to future publications.

Where do we need additional in situ aerosol and sun photometer data?: A critical examination of spatial biases between MODIS and MISR aerosol products (abstract from the AMT paper, Shi et al., 2011)
AERONET data are the primary benchmark for evaluating satellite retrieved aerosol properties. However, despite its extensive coverage, the representativeness of the AERONET data is rarely discussed. Indeed, many studies have shown that satellite retrieval biases have a significant degree of spatial correlation that may be problematic for higher-level process or inverse emissions modeling studies. To consider these issues and evaluate relative performance in regions of few surface observations, cross-comparisons between the aerosol optical Depth (AOD) products of MODIS collection 5 and MODIS Deep Blue with MISR version 22 were conducted. Through such comparisons, we can observe coherent spatial features of AOD bias while sidestepping the full analysis required for determining when or where either retrieval is more correct. We identify regions where MODIS to MISR AOD ratios were found to be above 1.3 or below 0.75. Regions where lower boundary condition uncertainty is likely to be a dominant factor include portions of western North America, the Andes Mountains, Saharan Africa, the Arabian Peninsula, and Central Asia. Similarly, microphysical biases may be an issue in greater South America and specific parts of southern Africa, India Asia, East Asia, and Indonesia. These results help identify high-priority locations for possible future deployments of both *in situ* and ground based remote sensing measurements.

Evaluating the Impact of Assimilating CALIOP-derived Aerosol Extinction Profiles on a Global Mass Transport Model (abstract from the GRL paper, Zhang et al., 2011)
Coupled 2D/3DVAR assimilation of aerosol physical properties retrieved from the MODIS, MISR, and CALIOP satellite-borne instruments is described for the U.S. NAAPS global aerosol mass transport model. Coupled 2D/3DVAR assimilation for NAAPS is evaluated for 48-hr forecast cycles, computed four times daily in six-hour intervals, versus stand-alone 2DVAR assimilation of MODIS and MISR aerosol optical depths (AOD). Both systems are validated against AERONET ground-based sun photometer measurements of AOD. Despite a narrow nadir viewing swath and more than 2700 km of equatorial separation between orbits, satellite lidar data assimilation elicits a positive model response. Improvements in analysis and forecast AOD absolute errors are found over both land and maritime AERONET sites. The primary impact to the model from 3DVAR assimilation is the redistribution of aerosol mass into the boundary layer, though the process is sensitive to parameterization of vertical error correlation lengths.

Own analysis (partly from the abstract from Johnson et al., 2011, fall AGU; Johnson et al., ICAP III, 2011)
With recent advancements in satellite aerosol technology, such as high spatial and spectral resolution measurements from multi-sensor, multi-channel, multi-angle, and polarized satellite platforms, the aerosol modeling community has started tapping into these observations to improve the accuracy of model forecasts. Remaining to be addressed is the identification of the benefits each of these sensors has on model performance and the determination of the ability of current observational platforms to

provide adequate amounts of data for aerosol data assimilation. To allay these concerns a series of analyses and forecasts are evaluated through a newly developed own analysis system. This analysis system evaluates the performance of NAAPS with three methods: an analysis where model forecasts are compared to analyses at the same valid time, a comparison to AERONET data for point validation, and a comparison to MODIS and MISR satellite AOD data. The system is used to monitor improved performance of the NAAPS model with each instrument that is added to the data assimilation process, from a natural run with no assimilated observations, to 2DVAR with MODIS, then MISR, and then Deep Blue observations, to coupled 2D/3DVAR with the addition of CALIOP observations. Preliminary studies from this analysis suggest the importance of including nighttime observations for future aerosol modeling applications.

Prototype scheme for the aerosol fine mode to total optical depth assimilation
The η assimilation scheme was developed for improving the model representation of aerosol speciation. Although not directly representing aerosol type, η could be used as an indirect indicator for aerosol species. Using the quality-assured MODIS over-water η product, a prototype of an η assimilation scheme was developed. Preliminary results from comparison with the fine mode AOD from AERONET data (O'Neill, 2003) suggest that the over-water fine mode AOD values are underestimated in NAAPS and that the new scheme improves the accuracy of fine mode AOD over water. Encouraged by preliminary results, an improved algorithm is under development.

Development of a data assimilation quality MODIS DeepBlue aerosol product
Using eight years (2000-2007) of Terra and eight years (2002-2009) of Aqua MODIS DeepBlue products, we studied the uncertainties of the products with respect to surface characteristics, cloud conditions, viewing geometry, and aerosol microphysical properties provided by the products. A quality assurance scheme has been developed for aerosol retrievals over the Saharan desert and Middle East regions. This is particularly important as the regular MODIS Dark-target product does not provide retrievals over bright surfaces such as deserts. Quality check and quality assurance steps were applied to remove noisy data, and an empirical correction scheme was also developed to correct for biases related to aerosol microphysical properties and surface characteristics. When compared with the AERONET data, a 10-40% reduction in RMSE was observed. The quality assurance procedures were further validated using the AERONET data from 2010.

IMPACT/APPLICATIONS

The CALIPSO data assimilation improves NAAPS forecasting performance up to 48h (48h is the longest forecasting time that has been evaluated). An improvement in vertical representation of the NAAPS model, especially through redistribution of aerosol plumes to the boundary layer is also observed.

TRANSITIONS

Two software systems have been delivered to NRL Monterey that include the coupled 2D/3DVAR scheme for CALIPSO data assimilation and the own analysis for the evaluation of NAAPS analysis and forecasts.

RELATED PROJECTS

This project is tightly coupled to a number of ONR 32 programs at the Marine Meteorology Division Aerosol and Radiation Section associated with the further development of the Navy's aerosol forecasting capabilities. This includes an integrated effort with the Earth Sciences Applications project of J.S. Reid for developing NAVDAS-AOD, model integration with the Large Scale Aerosol Modeling Development project of D. L. Westphal, and an ONR YIP project (N00014-08-1-0935) of Dr. Jianglong Zhang. Yingxi Shi is supported by the NASA Earth and Space Science Fellowship. 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).

REFERENCES

Johnson, R. S., J. Zhang, Reid, J. Campbell, E. Hyer, D. Westphal, N. Baker, P. Xian, Methods of NAAPS Evaluation, International Cooperative for Aerosol Prediction, Ensemble Forecasts and Data Assimilation (ICAP III), Boulder, CO, May 11-13, 2011.

O'Neill, N. T., Eck, T. F., Smirnov, A., Holben, B. N., and Thulasiraman, S.: Spectral Discrimination of Coarse and Fine Mode Optical Depth, JGR, Vol. 108, No.D17, 4559, 2003.

Shi Y., J. Zhang, J. S. Reid, E. J. Hyer, T. F. Eck, and B. N. Holben, Where do we need additional in situ aerosol and sun photometer data?: A critical examination of spatial biases between MODIS and MISR aerosol products, *Atmospheric Measurement Techniques,* submitted, 2011.

Zhang, J., J. R. Campbell, J. S. Reid, D. L. Westphal, N. L. Baker, W. F. Campbell, and E. J. Hyer, Evaluating the impact of assimilating CALIOP-derived aerosol extinction profiles on a global mass transport model, *Geophys. Res. Lett.*, 38, L14801, doi:10.1029/2011GL047737, 2011.

PUBLICATIONS

Zhang, J., J. R. Campbell, J. S. Reid, D. L. Westphal, N. L. Baker, W. F. Campbell, and E. J. Hyer, Evaluating the impact of assimilating CALIOP-derived aerosol extinction profiles on a global mass transport model, *Geophys. Res. Lett.,* 38, L14801, doi:10.1029/2011GL047737, 2011 [published, refereed].

Zhang, J. and Reid, J. S.: A decadal regional and global trend analysis of the aerosol optical depth using a data-assimilation grade over-water MODIS and Level 2 MISR aerosol products, Atmos. Chem. Phys. Discuss., 10, 18879-18917, doi:10.5194/acpd-10-18879-2010, 2010 [published, refereed].

Shi Y., *J. Zhang*, J. S. Reid, E. J. Hyer, T. F. Eck, and B. N. Holben, Where do we need additional in situ aerosol and sun photometer data?: A critical examination of spatial biases between MODIS and MISR aerosol products, *Atmospheric Measurement Techniques,* submitted, 2011 [Submitted, refereed].

Shi, Y., *J. Zhang*, J. S. Reid, B. N. Holben, E. J. Hyer, and C. Curtis.: An analysis of the collection 5 MODIS over-ocean aerosol optical depth product for its implication in aerosol assimilation, Atmos. Chem. Phys., 11, 557-565, doi:10.5194/acp-11-557-2011, 2011 [published, refereed].

Hyer, E. J., J. S. Reid, and *J. Zhang*, An over-land aerosol optical depth data set for data assimilation by filtering, correction, and aggregation of MODIS Collection 5 optical depth retrievals, Atmos. Meas. Tech., 4, 379-408, doi:10.5194/amt-4-379-2011, 2011 [published, refereed].

Smirnov, A., B. N. Holben, D. M. Giles, I. Slutsker, N. T. O'Neill, T. F. Eck, A. Macke, P. Croot, Y. Courcoux, S. M. Sakerin, T. J., Smyth, T. Zielinski, G. Zibordi, J. I. Goes, M. J. Harvey, P. K. Quinn, N. B. Nelson, V. F. Radionov, C. M. Duarte, R. Losno, J. Sciare, K. J. Voss, S. Kinne, N. R. Nalli, E. Joseph, K. Krishna Moorthy, D. S. Covert, S. K. Gulev, G. Milinevsky, P. Larouche, S. Belanger, E. Horne, M. Chin, L. A. Remer, R. A. Kahn, J. S. Reid, M. Schulz, C. L. Heald, *J. Zhang*, K. Lapina, R. G. Kleidman, J. Griesfeller, B. J. Gaitley, Q. Tan, and T. L. Diehl, Maritime Aerosol Network as a component of AERONET – first results and comparison with global aerosol models and satellite retrievals, Atmos. Meas. Tech. Discuss., 4, 1-32, doi:10.5194/amtd-4-1-2011, 2011 [published, refereed].

Patadia F., S. A Christopher, *J. Zhang*, Development of Empirical Angular Distribution Models for Smoke Aerosols - Part 1. Methods, *J. Geophys. Res.*, D14203, doi:10.1029/2010JD015033, 2011 [published, refereed].

Sayer, M. A., N. C. Hsu, C. Bettenhausen, *J. Zhang* and coauthors, SeaWiFS Ocean Aerosol Retrieval (SOAR): algorithm, validation, and comparison with other datasets, submitted to JGR, 2011 [Submitted, refereed].

Reid J., E. J. Hyer, *R. Johnson*, B. N. Holben, *J. Zhang*, J. R. Campbell, S. A. Christopher, L. Di Girolamo, L. Giglio, R. E. Holz, C. Kearney, J. Miettinen, E. A. Reid, F. J. Turk, J. Wang, P. Xian, R. J. Yokelson, G. Zhao, R. Balasubramanian, B. N. Chew, S. Janai[1], N. Lagrosas, P. Lestari, N. Lin, M. Mahmud, B. Norris, A. X. Nguyen, N. T. K. Oahn, M. Oo, S. Salinas, and S. C. Liew, Observing the Southeast Asian aerosol system by remote sensing: A critical review for the Seven Southeast Asian Studies (7SEAS) program, *Atmospheric Research*, submitted, 2011 [Submitted, refereed].

Campbell J.R., J. S. Reid, D. L. Westphal, *J. Zhang*, B. N. Chew, E. J. Welton, A. Shimizu and N. Sugimoto, Characterizing Aerosol Particle Composition and the Vertical Profile of Extinction and LinearDepolarization over Southeast Asia and the Maritime Continent: The 2007-2009 View from CALIOP, *Atmospheric Research*, submitted, 2011 [Submitted, refereed].

Zhang J., J. Reid, D. Westphal, J. Campbell, E. Hyer, and N. Baker, Multi-sensor Data Assimilation Using MODIS MISR and CALIPSO Aerosol Products, the 9th Joint Center for Satellite Data Assimilation Science Workshop, Greenbelt, MD, May 24-25 11, 2011.

Johnson, R. S., *J. Zhang*, Reid, J. Campbell, E. Hyer, D. Westphal, N. Baker, P. Xian, Methods of NAAPS Evaluation, International Cooperative for Aerosol Prediction, Ensemble Forecasts and Data Assimilation, Boulder, CO, May 11-13, 2011.

Reid, J. S., *J. Zhang*, B. Sampson, J. Hansen, and W. Sessions, Climatological-Persistence Models (CLIPERs), International Cooperative for Aerosol Prediction, Ensemble Forecasts and Data Assimilation, Boulder, CO, May 11-13, 2011.

Zhang J., J. Reid, E. Hyer, J. Campbell, and D. Westphal, Critical analysis of ten years of AOD trends over global oceans from MODIS, MISR, and NAAPS (*Invited*), Abstract A14C-08 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec, 2010.

Westphal, D., J. Campbell, J. Reid, E. Hyer, *J. Zhang*, D. M. Winker, Fulfilling Operational Requirements for Operational Aerosol Data Assimilation (*Invited*), Abstract A33G-02 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec, 2010.

Zhang J., E. Hyer, J. Campbell, Y. Shi, J. Reid, D. Westphal, Overview of the data assimilation quality satellite aerosol products, Abstract A31A-0024 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec, 2010.

Campbell J., J. S. Reid, J. L. Tackett, D. Westphal, D. M. Winker, *J. Zhang*, Satellite Lidar Data Assimilation For Improved Global Aerosol Forecasting: Lessons Learned From CALIOP, With an Eye Toward EarthCARE, Abstract A31A-0021 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec, 2010.

Shi, Y, J. *Zhang*, *J*. Reid, and C. Hsu, Evaluation of the MODIS Deep Blue aerosol product over the North Africa Regions for aerosol forecasts related applications, Abstract A31A-0025 presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec, 2010.

HONORS/AWARDS/PRIZES

(1) Jianglong Zhang, North Dakota Spirit Faculty Achievement Award, 2011

(2) Jianglong Zhang, University of Alabama in Huntsville Alumni of Achievement Award, 2011

(3) Travis Toth, 1st place in the Environmental Science division at the Department of Energy's 2010 Science and Energy Research Challenge, 2010.

(4) Yingxi Shi, Outstanding Student Paper Award, the 2010 Fall AGU Meeting in San Francisco, California, 2011.

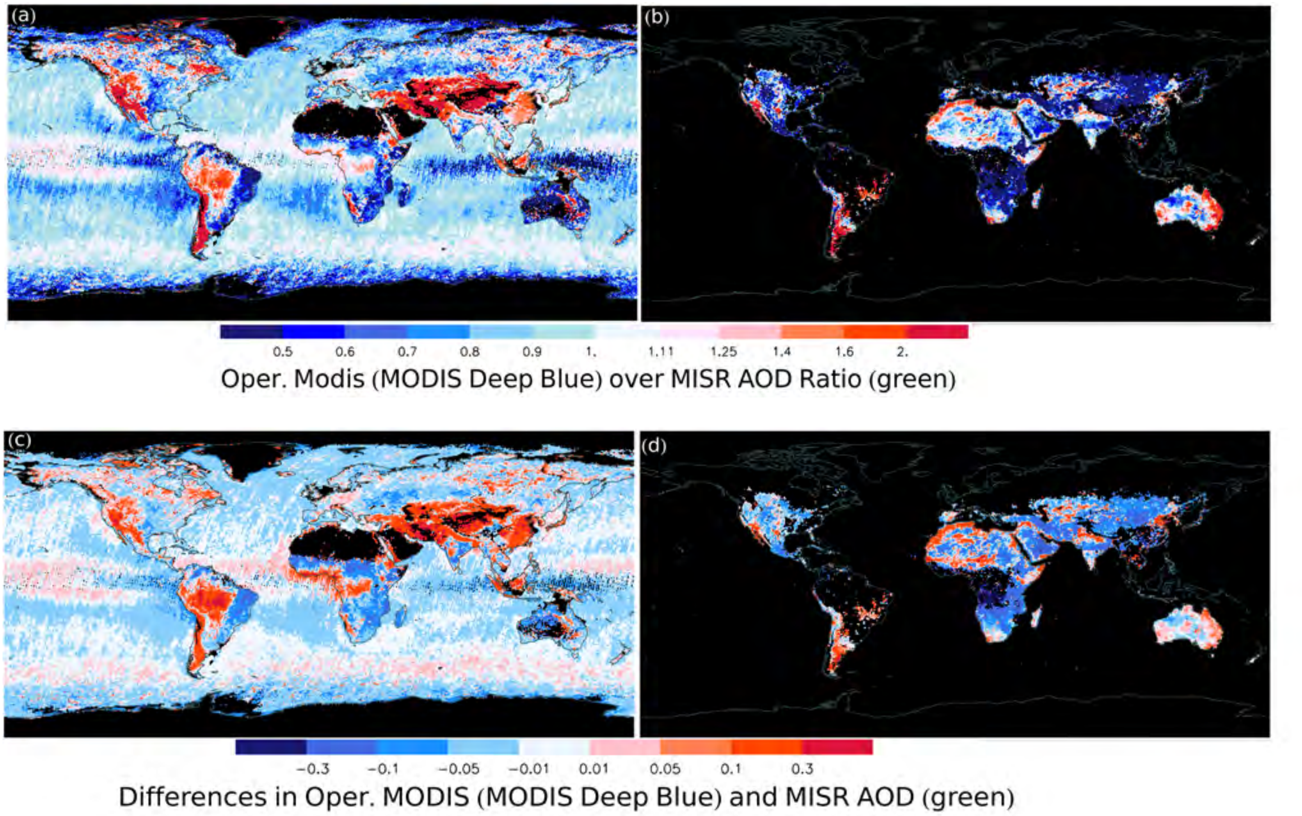

Figure 1) The ratio of operational MODIS over MISR (0.558 µm) AOD in the green channel for the years 2005-2007. The MISR and the operational MODIS / MODIS Deep Blue AOD data were first collocated both in space and time, and only collocated MISR retrievals were used in generating this plot. Data were gridded every 0.5°×0.5° (Lat/Lon). Red represents regions where the three year averaged AOD values from the two most widely used satellite aerosol products differ by more than 50%. 1b) Similar to 1a) but for MODIS Deep Blue. 1c) The differences between operational MODIS and MISR AOD in the green channel for the years 2005-2007. 3d) Similar to 3c) but for MODIS Deep Blue. Figure 1 shows that larger uncertainties exist in the most of the current aerosol products. Careful data quality check and quality assurance procedures are critical to aerosol data assimilation.

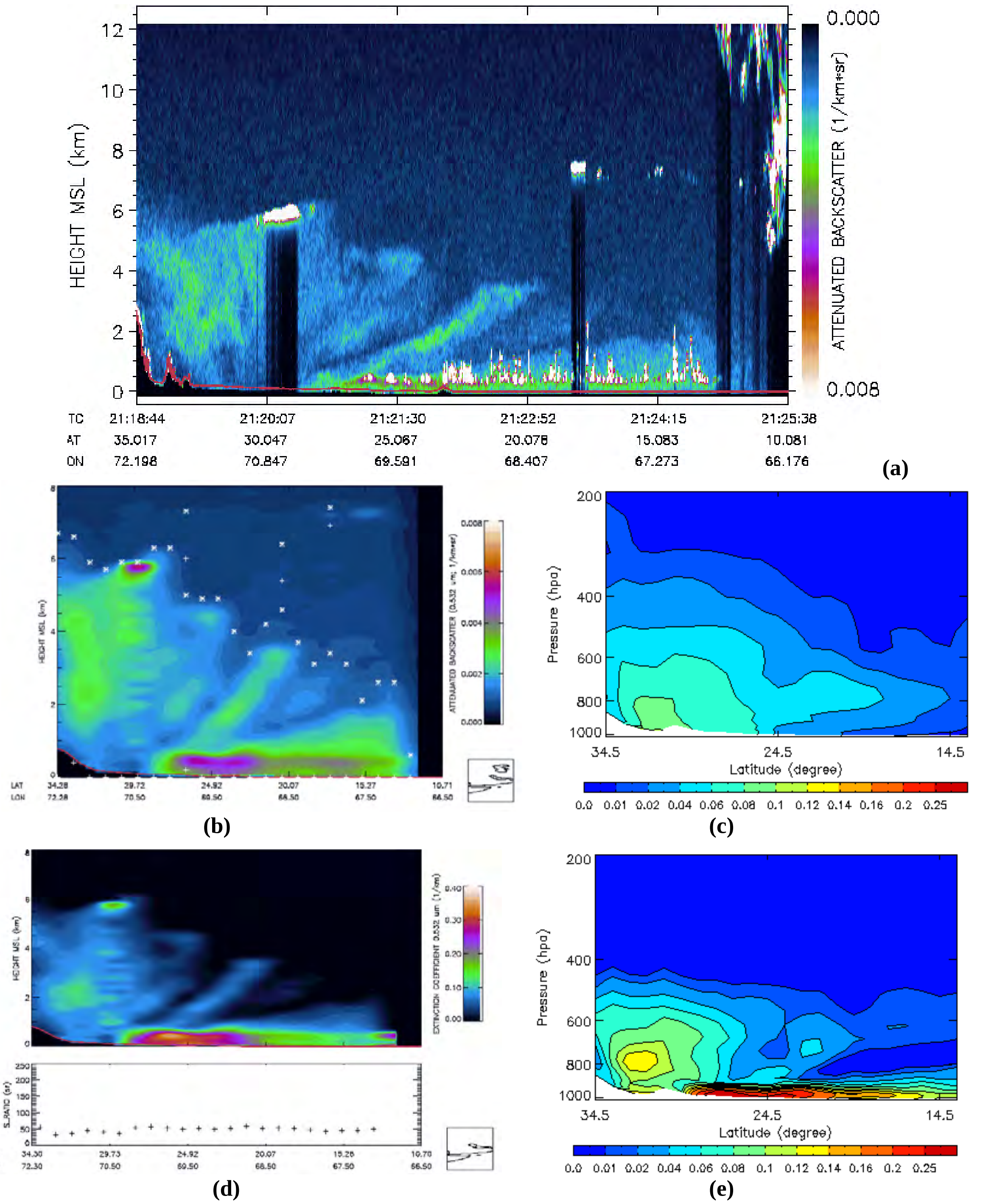

Figure 2. Example of CALIPSO assimilation. (a) CALIOP 0.532 µm attenuated backscatter (km^{-1} sr^{-1}) for 2122 UTC northeasterly orbital pass 17 May 2007, 35° to 10° N from 0.0 to 12.0 km MSL; (b) 1° along-track averaged and cloud-cleared attenuated backscatter profiles from 0.0 to 8.0 km MSL; (c) NAAPS analysis of extinction per model sigma level (level^{-1}) from 1000.0 to 100.0 hPa for this pass using only MODIS/MISR optical depth assimilation; (d) 0.532 µm extinction coefficient and extinction-to-backscatter ratios for inversion constrained by NAAPS optical depths in (c); (e) NAAPS analysis post-CALIOP assimilation. Derived aerosol layer tops and bottom heights for inversion step are shown in (b) using asterisks and plus symbols, respectively.