INTERNATIONAL OPERATIONAL AEROSOL OBSERVABILITY WORKSHOP

BY JEFFREY S. REID, ANGELA BENEDETTI, PETER R. COLARCO, AND JAMES A. HANSEN

While the last three years have seen rapid operational implementation of aerosol and pollution models around the world, the key to further development of aerosol forecasting systems is aerosol observational data from satellites for model evaluation and data assimilation. However, although the dynamical meteorology community has a well-developed, near-real-time observing system to support forecasting, the aerosol community is only beginning to address its needs. This meeting was the first ever to combine the lead aerosol model developers and remote sensing data providers from around the globe in discussing state-of-the-art technologies and operational requirements for aerosol forecasting. Participants included representatives from the operational centers of ECMWF, FNMOC, JMA, NCEP, and the Met Office; remote sensing data providers from EUMETSAT, ESA, JAXA, NASA, and NOAA NESDIS; and additional developers from NASA GMAO, NGST, NOAA, NRL, and several universities.[1] Overviews were given by operational participants as to their centers' current forecasting status and projected data needs. Remote sensing agencies described current and planned relevant space missions. Last, developers provided an overview of future directions in aerosol data assimilation.

Much of the development of operational aerosol systems has relied on climate satellite datasets, predominantly from the MODIS instrument on the NASA *Terra* and *Aqua* spacecraft. With near-real time data available from the joint NASA–NOAA NRTPE (aka "bent pipe") beginning in 2002 and the recent implementation of the NASA LANCE data server, operational centers have developed a near-total reliance on MODIS aerosol, fire, and albedo products for model initialization and assimilation.

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WHAT: Approximately 15 developers for many of the world's operational numerical weather prediction centers with aerosol forecasting mandates met with an equal number of representatives for the satellite data providers to discuss the aerosol observability issues facing the next generation of aerosol forecast systems.
WHEN: 27–29 April 2010
WHERE: Monterey, California

AFFILIATIONS: REID AND HANSEN—Naval Research Laboratory, Monterey, California; BENEDETTI—European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom; COLARCO—NASA Goddard Space Flight Center, Greenbelt, Maryland
CORRESPONDING AUTHOR: Jeffrey S. Reid, Marine Meteorology Division, Naval Research Laboratory, Monterey, CA 93943
E-mail: jeffrey.reid@nrlmry.navy.mil

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[1] See the appendix for the definitions of acronyms.

However, like all EOS satellite products, there has been some expectation for operational transition—predominately through NPP/JPSS. At the same time, the newest generation of products, such as profiles from CALIOP lidar on the CALIPSO spacecraft, has only a research instrument follow-on (ATLID on the ESA–JAXA EarthCARE mission). Given the growing sophistication of aerosol systems and the sometimes multidecadal turnover time from research idea to operational satellite technology, there has been some concern that satellite data product efficacy, timeliness, and delivery demands generated by the availability of research-grade data will exceed what is available operationally.

The purpose of this meeting was not to generate a long list of new variables needed by models, but rather to investigate the continuation and further characterization as to what is available now. The key issues brought up in presentations and discussion were those of observational requirements and available data streams as the field develops from research endeavors, which were supported by research satellites, to fully operational entities with rigid system and operational satellite counterparts. Operational centers are now more willing to make use of short-term observation sets, operational or otherwise, if the data are provided quickly, reliably, and consistently. Simultaneously, model (e.g., NASA GMAO) and multisensor product (such as on the ESA–JAXA EarthCARE) research systems are migrating toward quasi-operational architectures. The proliferation of the global constellation of operational geostationary data products for fire and aerosol monitoring has also garnered interest from the climate science community, which previously had focused on polar-orbiting satellites. Clearly, the development of aerosol forecasting capabilities in an environment mostly independent of operational entities has resulted in significant blurring of the lines between what is considered "research" and "operational."

The smooth transition from the NASA EOS A-Train to the constellation of multimodel, multisensor products that satisfy both research and operational communities will require coordination and emphasis on areas of mutual interest. Much of the meeting was devoted to communication of the research and operations cohorts' points of view on key issues. Presentations and discussions included the following subject areas:

- *Data availability.* Currently, the wide swath and the AM/PM orbits of *Terra*/*Aqua* give good global coverage several times per day. While the NPP/JPSS VIIRS will have a wide swath and will have much of the current MODIS instruments' capabilities, its effective once-a-day overpass schedule will limit data assimilation efforts, particularly at the mesoscale. VIIRS also lacks key infrared channels imperative for some cloud applications. However, the ESA–JAXA EarthCARE and Sentinal series and the JAXA GCOM series do have large spectral suites but with narrower spatial coverage. Consequently, if proposed data liberalization policies at ESA and JAXA come to fruition, then multiple polar overpasses for each point over the globe will be possible; however, utilization will require a constellation approach. A clear need for satellite-based lidar was expressed (such as from CALIOP, or eventually from EarthCARE ATLID), even at decreased latency. Finally, current geostationary systems (GOES, MSG, MTSAT) now have aerosol algorithm development programs. The next generation of geostationary satellites (e.g., GOES-R, MTG) will have much improved sensor and navigation characteristics for aerosol particles and fires, and will likely greatly enhance global aerosol observability.
- *Timing and latency.* Delivery requirements were clearly specified. These differ slightly among the various centers. However, on average, to make the typical model run, data need to be delivered within 3 hours of overpass—but preferably faster. At 5 hours, data may be used in sweep up/postrun; at 8 hours, roughly half of the data are typically assimilated; after 11 hours, data are only used in verification.
- *Data product evaluation, validation, and verification.* Reliable and timely delivery of satellite aerosol and fire products is only half the challenge. If products are to be integrated, then biases need to be removed through careful product evaluation and verification. Contextual/sampling biases need to be understood. Because of possible degradation in model performance through data assimilation, aerosol product error characterization has been emphasized more in the operations than climate communities. Indeed, despite popular misconceptions, operational data characterization requirements are often more strict than what is commonly used in the climate research community. Even so, some centers would trade product efficacy for timeliness, provided uncertainties were well defined. A clear need for renewed effort in collaborative product verification and error characterization enterprises was also expressed.
- *NASA LANCE.* The goals of the original joint NASA–NOAA NRTPE ("Bent Pipe") program was to deliver a standard subset of MODIS products to operational centers within three hours of overpass.

This later grew to include other sensors, such as AIRS and AMSR-E. However, there was a need for a NASA-run system to ensure availability of NASA products to those partners who rely upon them, as well as to test new products of potential operational utility. The new LANCE system provides a host of near-real-time products via FTP from MODIS, AIRS, AMSR-E, and MLS. OMI products are available as well, with permission of product PI.

- *Ground data.* The advantage of satellite data is that the data know no political boundaries, and that their global coverage allows assimilation into numerical models. While surface data are required for model verification and, in some cases, assimilation, variability in sources and formats makes its application to operational and climate efforts a challenge. The surface network having the closest alignment with operational needs is the Japanese NIES network and its affiliated stations over East Asia. For the East Asian problem, lidar data timeliness and spacing allow for data assimilation and detailed model validation. An effort is underway at NASA MPLNET to extend consistency in data processing and output products to some LEOSPHERE commercial lidar systems over the globe. This is being coordinated with the global GALION effort. The NASA AERONET sun photometer data have long been used for satellite and model users alike. Although strides have been made to unify some of the data products from GAW sites, their scattered locations coupled with the typically low-correlation lengths for surface constituents makes their application time consuming. However, they are a unique resource that should be utilized.
- *Multisensor use.* Even the use of both MODIS instruments and *Terra* and *Aqua* presents some challenges in regard to bias removal. A true constellation approach must account for differences in sampling strategy and error budgets among sensors, which poses a greater challenge. Much discussion occurred regarding the potential of moving from product assimilation to shortwave radiance assimilation, although all current systems at operational centers use derived products for data assimilation.
- *Specialized product development.* Based on all of the considerations just mentioned, it is clear that special "operational grade" products need to be developed and subsequently generated. Emphasis should be placed on speed and error characterization. Standard level 3 products, such as daily means, are not deemed useful for assimilation. Operations-grade MODIS products already exist. Lidar and AERONET products are under development. Level 2 radiance products are being considered.
- *Customer outreach and research product delivery.* Unlike traditional meteorology products, aerosol products require additional outreach and education before the potential customer base can apply them. In cases of extreme events and natural hazards, the Internet is flooded with "one off" products from researchers. While there are well-defined pathways for most hazard assessments, and many of these products have uncharacterized uncertain-

GENERAL CONCLUSIONS AND OUTCOMES OF THE MEETING

1) An inventory was made of operational aerosol forecasting data needs and was coupled with best estimates of future satellite product time lines. Simultaneously, lead developers provided ideas and forecasts for the future direction of aerosol observability research and requirements. Meeting presentation and summary slides can be found online (http://bobcat.aero.und.edu/jzhang/ICAP/).
2) The once-clear lines between research and operational satellite and model products have become blurred. Many satellite systems intended for pure research, including those from NASA, are now used operationally for data assimilation and model verification. Simultaneously, research-oriented organizations (e.g., NASA) are moving toward quasioperational modeling and the utilization of operational geostationary and polar-orbiter data.
3) A constellation approach for satellite aerosol products will likely be needed to meet operational aerosol needs. Operational centers are now much more willing to utilize nonoperational satellite aerosol products as long as they are provided in near–real time, even at the expense of some product efficacy (relative to postprocessed "research grade" data). Research data providers are speeding up processes in their own right to meet demand for multisensor satellite products and to show the general utility of their data. With likely data liberalization policies at ESA and JAXA for Sentinel-3, EarthCARE, and GCOM-C1, a constellation approach is a distinct possibility.
4) The keys to the operational utilization of any product, however, are low latency, efficient delivery pathway, and accurate error characterization. Specialized products used to meet these key requirements are now under development.
5) This meeting has formed a basis for subsequent gatherings of global aerosol forecasting system developers to exchange ideas on pressing issues facing the community. Such topics for consideration include model verification, multimodel ensembles, and research-grade product dissemination.

ties and limited efficacy. Participants agreed that methods need to be investigated for harnessing such products and effectively pumping them into the data stream used by advisory centers.

- *Research requirements.* Areas of research emphasized by developers included consistency in optical models in the visible to infrared, feedback of aerosol forcing into NWP models, aerosol impacts on SST retrievals, surface reflectance characterization, and aerosol forward modeling.

The meeting concluded with a discussion of other issues facing the global aerosol forecasting community. Participants agreed that communication between system developers should continue as needed. Selected topic workshops could include verification, multimodel ensembles, data assimilation, model variable requirements, product development and delivery, and source functions. Since this first meeting, subsequent meetings were held in September 2010 in Oxford UK on verification, and May 2011 in Boulder, CO on ensemble forecasts and data assimilation. These repeated meetings have lead to the formation of the ICAP, where operational developers and centers can discuss cooperation and community needs. The next meeting was agreed to be on model source and sink functions.

This simple grassroots-style organization is a fairly direct and efficacious way to move global aerosol forecasting forward. The findings of this workshop were presented as part the EarthCARE system JMAG meeting in June 2010 in Tokyo Japan. This played an important role in the discussion on data latency requirements for EarthCARE, which resulted in a recommendation of the JMAG to implement "NRT for EarthCARE data products (level 1b and selected level 2 data) with a data latency maximum of 3 hours for at least 60%–70 % of global data and a data latency maximum of 12 hours for the data products of all sensed data."

APPENDIX: LIST OF ACRONYMS

AERONET	Aerosol Robotic Network
AIRS	Atmospheric Infrared Sounder
AMSR-E	Atmospheric Microwave Scanning Radiometer for EOS
ATLID	Atmospheric Lidar
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol lidar and Infrared Pathfinder Satellite Observations
EarthCARE	Earth Clouds, Aerosols, and Radiation Explorer
ECMWF	European Centre for Medium-Range Weather Forecasts
EOS	Earth Observing System
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FNMOC	Fleet Numerical Meteorology and Oceanography Center
FTP	File transfer protocol
GAW	Global Atmospheric Watch
GCOM-C1	First satellite of the Global Change Observation Mission-Climate series
GMAO	Global Modeling and Assimilation Office
GOES	Geostationary Operational Environmental Satellite
ICAP	International Cooperative for Aerosol Prediction
JAXA	Japanese Aerospace Exploration Agency
JMA	Japan Meteorological Agency
JMAG	Joint Mission Advisory Group
JPSS	Joint Polar Satellite System
LANCE	Land, Atmosphere Near-Real-Time Capability for EOS
MLS	Microwave Limb Sounder
MODIS	Moderate Resolution Imaging Spectroradiometer
MPLNET	Micro-Pulse Lidar Network
MSG	Meteosat Second Generation
MTG	Meteosat Third Generation
MTSAT	Multifunctional Transport Satellite
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Prediction
NGST	Northrop Grumman Space Technology
NESDIS	National Environmental Satellite, Data, and Information Service
NIES	National Institute for Environmental Studies
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOESS Preparatory Project
NRL	Naval Research Laboratory
NRT	Near–real time
NRTPE	Near Real Time Processing Effort
NWP	Numerical weather prediction
OMI	Ozone Monitoring Instrument
PI	Principal investigator
SST	Sea surface temperature
VIIRS	Visible/Infrared Imager Radiometer Suite