CURRENT AND FUTURE PERSPECTIVES OF AEROSOL RESEARCH AT NASA GODDARD SPACE FLIGHT CENTER

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Aerosols are tiny atmospheric particles that are emitted from various natural and anthropogenic sources. They affect climate through direct and indirect interactions with solar and thermal radiation, clouds, and atmospheric circulation (Solomon et al. 2007). The launch of a variety of sophisticated satellite-based observing systems aboard the *Terra*, *Aqua*, *Aura*, SeaWiFS (see appendix for all acronym expansions), *CALIPSO*, and other satellites in the late 1990s to mid-2000s through the NASA EOS and other U.S. and non-U.S. programs ushered in a golden era in aerosol research. NASA has been a leader in providing global aerosol characterizations through observations from satellites, ground networks, and field campaigns, as well as from global and regional modeling. AeroCenter (http://aerocenter.gsfc.nasa.gov/), which was formed in 2002 to address the many facets of aerosol research in a collaborative manner, is an interdisciplinary union of researchers (~200 members) at NASA GSFC and other nearby institutions, including NOAA, several universities,

NASA GSFC AEROCENTER ANNUAL MEETING 2013

WHAT: More than 100 participants (scientists, professors, and students) from the NASA Goddard Space Flight Center and other organizations in the Washington, D.C., metropolitan area (NOAA, universities, and other institutions) who are engaged in various research activities on atmospheric aerosols and related science met to discuss current and future measurement and modeling capabilities to advance aerosol science.
WHEN: 31 May 2013
WHERE: NASA Goddard Space Flight Center Visitor Center, Greenbelt, Maryland

AFFILIATIONS: MATSUI—NASA Goddard Space Flight Center, Greenbelt, and Earth System Science Interdisciplinary Center, University of Maryland, College Park, College Park, Maryland; ICHOKU, DA SILVA, COLARCO, LEVY, CHIN, HOLBEN, AND WELTON—NASA Goddard Space Flight Center, Greenbelt, Maryland; RANDLES—NASA Goddard Space Flight Center, Greenbelt, and Morgan State University, Baltimore, Maryland; YUAN—NASA Goddard Space Flight Center, Greenbelt, and University of Maryland, Baltimore County, Baltimore, Maryland; KIM, SAYER, and ECK—NASA Goddard Space Flight Center, Greenbelt, and Universities Space Research Association, Columbia, Maryland; GILES—NASA Goddard Space Flight Center, Greenbelt, and Sigma Space Corporation, Lanham, Maryland; REMER—University of Maryland, Baltimore County, Baltimore, Maryland
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and research laboratories. AeroCenter hosts a web-accessible regular seminar series and an annual meeting to present up-to-date aerosol research, including measurement techniques; remote sensing algorithms; modeling development; field campaigns; and aerosol interactions with radiation, clouds, precipitation, climate, biosphere, atmospheric chemistry, air quality, and human health. The 2013 annual meeting was held at the NASA GSFC Visitor Center on 31 May 2013, which coincided with the seventh anniversary of the passing of Yoram Kaufman, a modern pioneer in satellite-based aerosol science and the founder of AeroCenter. The central theme of this year's meeting was "current and future perspectives" of NASA's aerosol science and satellite missions.

FUTURE SATELLITE MISSIONS AND AEROSOL SCIENCE. Building on the success of the A-Train constellation of satellites from NASA and international partners in providing multisensor views of aerosol distributions and aerosol–cloud interactions, NASA plans to launch the ACE mission in 2023, as part of the NASA Earth Science Tier-2 Decadal Survey missions. ACE aims to improve our understanding of aerosol forcing, particularly the highly uncertain aerosol indirect effects, with a multiangle, multispectral polarimeter, a high-spectral-resolution lidar, a dual-frequency (Ka–W bands) Doppler radar, and an ocean ecosystem spectroradiometer. ACE science lead, David Starr, emphasized that ACE represents a substantial step forward, beyond the A-Train and EarthCare (Earth-observing satellites), in remote sensing capability, for aerosols, clouds *and* ocean ecosystems, enabling critical science progress, especially with regard to physical processes. He also presented a summary of the recent field campaign designed to define the ACE polarimeter instrument (www.srl.caltech.edu/ACE/).

Another NASA Tier-2 Decadal Survey mission discussed at the meeting is GEO-CAPE, a geostationary satellite mission with ultraviolet to infrared spectral sensors that will enable high-spatiotemporal-resolution measurement of trace gases and aerosols for studying coastal ocean biophysics and air quality. Mian Chin presented some key points of progress from the GEO-CAPE aerosol working group and an assessment of the potential synergy between multiple geostationary satellites, including NASA's recently selected TEMPO Earth Venture mission and NOAA's GOES-R mission (http://geo-cape.larc.nasa.gov/).

The most recently launched aerosol-measuring observatory, *Suomi–NPP* VIIRS, is starting to provide good-quality aerosol products, which within two years have reached uncertainty levels that took MODIS several years to attain, as noted by Lorraine Remer. VIIRS provides measurements at a finer spatial resolution and with a wider swath than MODIS, allowing for full daily global coverage (www.class.noaa.gov), thereby showing promise to bridge the gap between NASA EOS and future NOAA JPSS missions.

William K. Lau reviewed various field campaigns, satellite observations, and recent modeling studies that helped reveal the impact of aerosol radiative forcing on the monsoon circulation, although factors that control climate feedback are still not very well known. These issues must be investigated further through the continuous improvement and synergistic use of aerosol–climate modeling, satellite data, ground-based networks, and advanced data from future missions (Kaufman et al. 2002).

AEROSOL MODELING. The GOCART aerosol (http://acd-ext.gsfc.nasa.gov/People/Chin/gocartinfo.html) and GMI chemistry (http://gmi.gsfc.nasa.gov/index.php?section=14) models have been developed over the past decades at NASA. Dongchul Kim reported recent results from the offline versions of GOCART and GMI. Emission inventories are updated for key aerosols, including anthropogenic and volcano aerosols. Seasonal variations of dust emission have been significantly improved using a satellite-derived vegetation index, and MODIS-derived smoke AOT can constrain uncertainties in modeling biomass-burning emissions. GOCART offline modeling has been recently applied to i) study the multidecadal trend of regional and global aerosol distributions from 1980 to 2010, and ii) identify the important source–receptor relationships for aerosol long-range transport. Extensive intercomparisons between multiple global models and satellite observations have revealed that models need further improvement, especially at regional scales, where mesoscale dynamics dominate aerosol emission and transport processes.

Arlindo da Silva and Peter Colarco presented updates on global aerosol modeling and data assimilation in GEOS-5 (www.geos5.org/wiki/), which can provide integrated Earth system analyses and coupled online simulations of atmospheric aerosols at weather, seasonal, and decadal time scales (including 7-km mesh simulation; http://gmao.gsfc.nasa.gov/research/aerosol/modeling/). Such aerosol simulations within the integrated Earth system modeling environment have a number of applications, including forecasting support for NASA aircraft missions (e.g., ARCTAS, HS3, DISCOVER-AQ, SEAC4RS), OSSEs to support future NASA satellite missions (e.g., GEO-CAPE), and studies of aerosol impacts on chemistry and climate. GEOS-5 includes the QFED, providing daily biomass-burning emissions of aerosol and trace gases in near–real time. Assimilation of MODIS-derived AOT measurements has enabled an aerosol reanalysis (called MERRAero, covering the period of mid-2002 to the present) that shows improved agreement with AERONET relative to the standard hindcast of the model. The MERRAero fields are now being exploited for simulating observations, including the OMI UV aerosol index and the CALIOP lidar signal and feature mask.

Ongoing work includes incorporating other satellite data sources (e.g., MISR, AVHRR) into the aerosol assimilation, and the extension of QFED to include fire radiative power from geostationary satellites under a collaboration between NASA and NOAA. Future developments will include the coupling of the MAM-7 aerosol microphysics to a two-moment cloud microphysical scheme for aerosol indirect effects, continued development of the sectional aerosol microphysics model, introduction of nitrates and secondary organic aerosols, and sea salt emissions linked to the WaveWatch III model.

GROUND-BASED NETWORKS. AERONET (http://aeronet.gsfc.nasa.gov) measurements have provided AOT and retrieved aerosol microphysical and radiative characteristics for over 20 years. Ground sites established by NASA and the University of Lille in 1993 formed the basis of AERONET. Collaboration with universities, government agencies, and individual scientists expanded the AERONET federation to support approximately 500 instruments at more than 400 sites in over 80 countries and territories. In the 1990s, AERONET pioneered NASA's open data policy with free public data access to encourage widespread use of this scientific resource. Subsequently, principal AERONET publications were cited over 7,000 times in peer-reviewed literature by 2013. David Giles highlighted that AERONET established a first-of-its-kind mesoscale gridded network of 40 instruments near Washington, D.C., called DRAGON (http://aeronet.gsfc.nasa.gov/new_web/dragon.html), for a field campaign in 2011. This distributed regional aerosol network concept, applied successfully to field campaigns elsewhere in the United States and Asia in 2012 and 2013, allows for optimization of high-resolution satellite retrievals (e.g., MODIS, MISR, and VIIRS) and fine-resolution models (e.g., 7-km mesh GEOS-5). AERONET coverage increased in the Southeast United States in June/July 2013 and is expected to increase globally over the next several years.

The MPLNET (http://mplnet.gsfc.nasa.gov) is a federated network of MPL systems designed to measure aerosol and cloud vertical structure continuously day and night over long periods to provide essential information for aerosol validation, modeling, and analysis. NASA's partnership with research groups worldwide has promoted the growth of MPLNET to 16 active instruments, with additions in Asia supporting the 7-SEAS mission (http://7-seas.gsfc.nasa.gov). Recently, MPLNET accepted and approved the new depolarization MPL, allowing for discrimination of ice and liquid clouds and aerosol types (e.g., urban pollution and dust).

Both networks plan product changes and updates. AERONET will release a version 3 product including updates to cloud screening, NO_2 and O_3 climatology, and instrument temperature characterization. Furthermore, AERONET sky retrievals will incorporate vector radiative transfer code, and estimate lidar depolarization ratios and uncertainty for each retrieval product. MPLNET will provide updates in a version 3 release including new PBL height and depolarization ratio products, improved detection of high clouds and cirrus, and enhanced day/night aerosol retrievals. These instrument and product updates will continue to advance aerosol scientific understanding and improve satellite and model retrievals.

SATELLITE AEROSOL MEASUREMENTS. The final session addressed recent updates to algorithms and results from NASA's current and heritage satellite-based aerosol missions. In addition to providing updates about the datasets most heavily used by the community, all speakers provided perspective on the short-term and medium-term outlook for new missions and datasets.

Three presentations focused on the upcoming version, "Collection 6," MODIS data products; Robert Levy outlined the major changes to the ocean and Dark Target overland aerosol algorithms and products, while Andrew Sayer provided the same for the Deep Blue aerosol remote sensing technique. Both presentations discussed the expected improvements as compared to the current Collection 5 datasets, including lower uncertainties, expanded spatial coverage, and more comprehensive diagnostics. Levy introduced the high-resolution (3 km) Dark Target product and evaluation against DRAGON, while Sayer introduced the new version (4) of Deep Blue plus ocean aerosol retrieval as applied to SeaWiFS, and plans to apply the same to *Suomi–NPP* VIIRS.

The third MODIS Collection 6 update, presented by Alexei Lyapustin, focused on the new MAIAC dataset, which uses temporal compositing to simultaneously retrieve aerosol properties and surface reflectance at 1-km spatial resolution on the regional scale. He discussed the algorithm, including its application to air quality monitoring and the potential for more robust approaches to aerosol type identification.

Ralph Kahn provided an overview of recent studies that took advantage of MISR's unique multiangle imaging capability to advance our understanding of global aerosol sources and composition. Some examples included observations of ash plumes from the Etna and Eyjafjallajökull volcanoes, derivations of plume height to constrain biomass-burning emissions in global chemistry transport models, and mapping of airmass aerosol types globally and in urban areas. Kahn also addressed the strengths and weaknesses of AOT and aerosol type–related data provided by MISR, and mentioned the need for utilizing aircraft measurements to better characterize aerosol types.

Omar Torres reported on aerosol research using the OMI sensor, from which measurements in the UV spectral region help to characterize aerosol absorption and aerosols above clouds. He presented comparisons of OMI-derived AOT and absorption against AERONET, and estimates of AOT for absorbing aerosols above clouds (using OMI, MODIS, and POLDER). He also presented new ideas for extending ground-based retrieval techniques into the UV, and mentioned the potential application of the UV aerosol retrievals technique to upcoming DSCOVR at Lagrange 1 and future TEMPO missions.

MORE INFORMATION. Annual meeting slides and detailed references are available online (http://aerocenter.gsfc.nasa.gov/index.php?section=19). Anyone can register for the AeroCenter mailing lists, and receive information of routine seminars, publications, jobs, meetings, and more (http://aerocenter.gsfc.nasa.gov/). Remote members can access the seminars via live webinars and telecons.

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APPENDIX: SUMMARY OF ACRONYMS.

ACE	Aerosol–Cloud–Ecosystem
AERONET	Aerosol Robotic Network
AOT	Aerosol optical thickness
ARCTAS	Arctic Research of the Composition of the Troposphere from Aircraft and Satellites
AVHRR	Advanced Very High Resolution Radiometer
CALIOP	Cloud–Aerosol Lidar with Orthogonal Polarization
CALIPSO	*Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations*
DISCOVER-AQ	Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality
DRAGON	Distributed Regional Aerosol Gridded Observation Networks
DSCOVR	Deep Space Climate Observatory
EOS	Earth Observing System
GEO-CAPE	Geostationary Coastal and Air Pollution Events
GEOS-5	Goddard Earth Observing System Model, version 5
GMI	Global Modeling Initiative
GOCART	Goddard Chemistry Aerosol Radiation and Transport
GOES-R	Geostationary Operational Environmental Satellite R series
GSFC	Goddard Space Flight Center
HS3	Hurricane and Severe Storm Sentinel
JPSS	Joint Polar Satellite System
MAIAC	Multiangle Implementation of Atmospheric Correction
MAM-7	Seven-mode version of the modal aerosol module
MERRAero	Modern-Era Retrospective Analysis for Research and Applications (MERRA) Aerosol Re-Analysis
MISR	Multiangle Imaging SpectroRadiometer
MODIS	Moderate Resolution Imaging Spectroradiometer

MPL	Micropulse lidar
MPLNET	Micropulse Lidar Network
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NPP	*National Polar-Orbiting Partnership*
OMI	Ozone Monitoring Instrument
OSSEs	Observing system simulation experiments
PBL	Planetary boundary layer
POLDER	Polarization and Directionality of the Earth's Reflectances
QFED	Quick Fire Emission Dataset
SEAC4RS	Southeast Asia Composition, Clouds, Climate Coupling Regional Study
SeaWiFS	Sea-Viewing Wide Field-of-View Sensor
7-SEAS	Seven Southeast Asian Seas
TEMPO	Tropospheric Emissions: Monitoring of Pollution
UV	Ultraviolet
VIIRS	Visible Infrared Imaging Radiometer Suite

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