Summary of Session 5

Integration of models and remote sensing observations for 3D characterization of spatiotemporal distribution of dust
Chairs: Ina Tegen and David Winker

Summary of oral presentations:

Dave Winker presented a summary of the capabilities and limitations of CALIPSO for observing dust and a summary of initial studies integrating CALIPSO with models. The CALIPSO satellite carries CALIOP, a two-wavelength polarization lidar. CALIOP provides aerosol profiles, both day and night, with a vertical resolution up to 30-60 meters. The assumptions and biases in the CALIOP aerosol retrieval are different from those of passive sensors. Comparisons of CALIOP AOD with passive retrievals can be used to identify weaknesses in both retrievals.
Polarization has been found to be a reliable indicator of mineral dust. Initial studies have analyzed the global, 3D distribution of mineral dust and used CALIOP observations to study a Sahara dust transport event across the Atlantic Ocean. Aerosol transport can be studied by using CALIOP observations to initialize trajectory models. CALIOP observations have been used to initialize a large ensemble of HYSPLIT forward trajectories to identify the primary transport pathways for dust originating in the Takla Makan and Thar deserts. The zonal distribution of aerosol predicted by global aerosol models shows large discrepancies. The vertical distribution of aerosol observed by CALIOP is now being used to evaluate predictions from several models.

Albert Ansmann presented a summary of how measurements from ground-based lidars complement the global observations available from satellite lidars. Since space lidars fly in low earth orbit, they can only observe a given location twice per day, at most. Ground-based lidars can make continuous measurements and observe the temporal variation of aerosol. Networks of ground-based lidars can provide regional spatial coverage. An example was shown where the Earlinet network of ground-based lidars was used to observe the spatial and temporal evolution of a Sahara dust outbreak event over Europe. Lidar signal strength is inversely proportional to the square of the range to the target. Therefore, ground-based lidars can have much higher signal-to-noise-ratios than satellite lidars and can resolve weak aerosol layers and fine structure that cannot be observed from space.
Whereas satellite sensors have limited lifetimes and intercalibration of satellite sensors can be problematic, ground-based lidars can provide long-term measurements (decadal scales). Ground-based lidars can be used to harmonize observations from satellite lidars with disparate sensing characteristics (532 nm vs. 355 nm for example).
Ground-based lidars can be more sophisticated than satellite instruments, using the latest technology, and provide measurements not possible from space. Some techniques common in ground-based systems, such as Raman detection, cannot be used from orbit due to signal-to-noise-ratio limitations.
Final comment on dust-cloud interactions: looking up is better than looking down when the interest is dust interacting with dense clouds at the top of the mixed layer.

Omar Torres pointed out that the A-train constellation of satellites provides observations of dust from a number of passive sensors: currently MODIS, OMI, PARASOL, and soon to be joined by OCO and Glory. Each of these sensors has different capabilities and limitations for observing dust. This talk focused on capabilities of the OMI instrument (on the Aura satellite) to characterize dust absorption optical depth. OMI makes high spectral resolution measurements from 270 - 500 nm with a footprint of 13 x 24 km across a 2600 km swath. The standard algorithm, similar to the one developed for TOMS, retrieves aerosol index (AI), aerosol optical depth (AOD), and absorption aerosol optical depth (AAOD). The optical depth retrievals are sensitive to the vertical distribution of aerosol, so AOD and AAOD are retrieved using 5 different assumptions on the vertical distribution of aerosol and the best solution is selected based on climatology. CALIPSO measures aerosol profiles near the center of the OMI swath and using these observed profiles can improve the OMI retrieval. An example was shown where use of CALIPSO aerosol profiles increased the AOD retrieved by OMI by 30-50%. Another example was shown where MODIS AOD at 440 nm was used as a constraint and OMI measurements were used to retrieve aerosol height and AAOD.

Keiya Yumimoto pointed out that even considering great progress in large scale modeling of mineral dust large uncertainties in determining atmospheric dust contents from models remain. While observations are used to validate models, particularly modeled dust emissions show a large variability. Data assimilation for dust by 4DVar is done in the model system developed at Kyushu University minimize the differences between forecasts and observations of dust, and thus helps to provide an improved dust forecast for East Asia. In addition, an adjoint model uses observations to obtain information on dust emissions by running the model backward in time. It was pointed out that assimilation and inverse modeling of dust transport are very powerful for unification of observations and numerical models, and provide better forecasting and estimation capabilities. In fact, assimilation results were already used for hindcast analyses of Asian dust outflows.

Paul Ginoux gave an overview presentation on global-scale dust modeling and the use of remote sensing data to aid evaluation dust sources and atmospheric transport. He addressed major uncertainties in that need to be addressed in dust models, that include the determination of dust source areas, anthropogenic contribution on dust emissions and the difficulties in explaining the change in atmospheric dust over the past decades. He finds that modifying the usual prescription of topographic depressions as dust sources in global models by the location of ephemeral lakes would improve dust emissions. The TOMS and OMI absorbing aerosol indeed data as well as the different aerosol information obtained by the MODIS instrument provide valuable information for model evaluation, in particular when used in combination. Taken together, the instruments by now cover almost three decades of information to be used for analysis of dust changes. He suggests that implementing dust into a dynamic vegetation model as part of a global climate model will help to explain the decadal increase in Saharan dust export from the southern Saharan/Sahel region.

Jeff Reid gave the presentation for Doug Westphal, who could not attend the workshop. The topic was how to proceed from making use of remote sensing information in a qualitative way in regional and global models towards the quantitative use of such information. While many models attempt to model dust emissions from first principles, whereby they are limited to static inventories of geomorphological characteristics of the soils, a pragmatic approach is to only consider such dust source areas that are known to be eroding. To identify dust plumes from remote sensing to use for identification of eroding soils the author makes use of the thermal contrast of dust over deserts, using the IR split window technique (12-11 micron Brightness Temperature difference from MODIS data). For making use of remote sensing data in model assimilation for forecast purposes, model complexity should be matched to the fundamental observability of the system. New algorithms allowing dust retrievals over deserts are making a significant improvement to source functions, and enable realistic mesoscale simulations. Dynamic source functions are under development and will be operational in the near future.

Summary of Session 5 discussion

1) What is the "right" value for the lidar ratio of dust? SAMUM and Earlinet measure 55 +/- 5 sr for Sahara dust, whereas CALIPSO retrieves 40 +/- 5 sr. Could difference be due to multiple scattering effects?

   This discrepancy will be tried to resolve using coincident observations during SAMUM-II. An ESA study is comparing Earlinet observations with CALIOP.

   Earlinet measures a lidar ratio of 55 sr for elevated dust layers over northern Europe. Lower values are measured in southern Europe. Reasons for the difference are not understood yet. A possible explanation is mixing with marine aerosol mixing with low-altitude dust.

   Lidar ratio is sensitive to the size distribution and shape. Recent results show dust lidar ratio is related to particle depolarization. Thus particle depolarization may provide constraints on the lidar ratio.

It was also noted that Australia dust likely has unique optical properties and might have different lidar ratios compared to dust from other regions.

2) What are specific requirements for model assimilation or inversion?

For assimilation, modelers need measurement uncertainties and would prefer to have random and bias errors specified separately.

It was commented that assimilation can also be used to test and improve model parameterizations.

All observations are biased low near strong sources, where optical depths may be 10 or higher. Assimilation of this data may result in low biases unless the limited maximum observable optical depth is represented in the observational uncertainty estimates. Could inverse modeling be used to estimate the high optical depths in source regions, overcoming the limitations of the observations?

Biases may also arise from the limited temporal coverage of satellites in low earth orbit. (In Sahara, emissions seem to be greatest in morning, whereas MODIS Aqua observes in the afternoon) Geostationary satellite instruments could be used to observe temporal development and assess biases of polar orbiting sensors.

What is the sensitivity of satellite sensors? MISR is sensitive to AOD less than 0.2, but lose the ability to retrieve particle properties. OMI is sensitive to AOD greater than about 0.4. Retrieval of aerosol dense enough to obscure the surface looks like a cloud. A new algorithm is required to retrieve such dense aerosol layers.

The need to intercompare the various satellite dust retrievals was pointed out: E.g. Deep Blue retrievals vs. the MSG infrared dust index.

3) Discussion of a model intercomparison study:

Michael Schultz presented features of the global aerosol model intercomparison study AeroCom, and discussed the feasibility of a dedicated dust intercomparison study

It was pointed out that a model intercomparison can be very useful There is a large uncertainty in the amount of dust in the atmosphere: A factor of 2-3 at least, due to uncertainties in emissions, deposition fluxes and microphysical properties of dust particles.

Models develop quickly and the last comparison study was done some time ago, implicating the need of a new intercomparison project.

New observation data are now available to support such a project: Besides the CALIOP dataset, there is also a MISR data base on aerosol plume height.

AeroCom focused on global models, regional models also need validation. Field campaigns are appropriate for validating regional models and provide observations that may serve as basis for a regional dust model intercomparison.

The need for new strategies for intercomparing regional models to really learn something was adressed. Regional models can be developed primarily for forecasting or for process studies, and such different models may require different validation strategies.

There would be need emission/deposition data for model evaluation, not just atmospheric observations.