Atmospheric aerosol measurements from satellites

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The Afternoon Constellation satellites - their joint measurements provide an unprecedented sensor system for Earth Observations.

**Aura** (OMI - Ozone Monitoring Instrument)

**CloudSat** (CPR - Cloud Profiling Radar)

**CALIPSO** (CALIOP - Cloud-Aerosol Lidar with Orthogonal Polarization)

**Aqua** (AIRS - Atmospheric Infrared Sounder, CERES - Clouds and Earth's Radiant Energy System, MODIS - Moderate-Resolution Imaging Spectroradiometer)

**GCOM-W1** (AMSR2 - Advanced Microwave Scanning Radiometer 2) …..
Aerosol Optical Depth (AOD)

- AOD is a measure of the scattering and absorption of light by aerosols in a vertical column of the atmosphere.
- AOD is proportional to particulate concentration.
- AOD is dimensionless; higher values correspond to high particulate concentrations.
- Clouds block the measurement of AOD!
Methods of AOD measurements from satellites

- **Passive imagers** – sensors that measure the amount of radiation reflected and emitted by the Earth. So, solar radiation backscattered by the Earth's atmosphere and surface is measured by spectrometers aboard the satellites (OMI (Aura), MODIS (Aqua/Terra));

- **An active remote sensing technique**: the lidar sends pulses of light from the satellite toward the surface and a fraction of this light is reflected, or scattered back to the spacecraft from thin vertical segments of the atmosphere (CALIOP (CALIPSO), CATS (ISS)).
Aura satellite

Researches the composition, chemistry, and dynamics of the Earth’s atmosphere as well as study the ozone, air quality, and climate.

**Instruments:**

- **HIRDLS: High Resolution Dynamics Limb Sounder** – Observes global distribution of temperature and composition of the upper troposphere, stratosphere, and mesosphere
- **MLS: Microwave Limb Sounder** – Uses microwave emission to measure stratospheric temperature and upper tropospheric constituents
- **OMI: Ozone Monitoring Instrument** – Distinguishes between aerosol types, such as smoke, dust, and sulfates. Measure cloud pressure and coverage, which provide data to derive tropospheric ozone.
- **TES: Tropospheric Emission Spectrometer** – High-resolution infrared-imaging Fourier transform spectrometer that offers a line-width-limited discrimination of essentially all radiatively active molecular species in the Earth's lower atmosphere.
Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)

Three instruments:
- **Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP):** Two wavelength polarization-sensitive Lidar that provides high-resolution vertical profiles of aerosols and clouds
- **Wide Field Camera (WFC):** Fixed, nadir-viewing imager with a single spectral channel covering the 620-670 nm region
- **Imaging Infrared Radiometer (IIR):** Nadir-viewing, non-scanning imager

- Using pulses of laser light from a lidar instrument CALIOP, CALIPSO takes global measurements of the atmosphere, studying aerosols, and multilayered clouds to better understand Earth’s weather, climate and air quality.
Ozone Monitoring Instrument (OMI) on the Aura Satellite

One of four sensors on NASA’s EOS Aura platform

Aerosol Data possible to retrieve:
- Extinction Aerosol Optical Depth (AOD);
- Absorption Aerosol Optical Depth;
- Aerosol types;
- Single scattering albedo ...

Nadir solar backscatter spectrometer:
- Launched on July 15, 2004 and collected data since August 9, 2004;
- Covers wavelengths 264-504 nm with a spectral resolution 0.42-0.63 nm;
- 13x24 km² footprint (pixel);
- Telescope FOV: 115° => 2600 km swath width.

The Aura satellite orbit is:
- at an altitude 705 km;
- a sun-synchronous polar orbit with an 16-day repeat cycle.

Time of the measurements over the Pierre Auger Observatory is usually evening time: 17.00-19.00 UTC.
OMI aerosol optical depth measurements

One day measurements made by Aura (OMI) satellite over the PAO

Two algorithms:

- Near UV aerosol retrieval algorithm (OMAERUV) used to retrieve the AOD values over land. It uses as input OMI measured reflectances at 354 and 388 nm to retrieve column atmosphere values of AOD, using a set of 21 aerosol models. The algorithm differentiate the types of aerosols: desert dust, biomass burning carbonaceous particles, sulfate-based aerosols. For sulfate-based aerosols AOD equals to the aerosol optical thickness (the aerosol extinction coefficient integrated vertically from the surface to the top of the atmosphere).

- Multi-wavelength Algorithm (OMAERO) used to retrieve the AOD values preferably over ocean. It uses the measurements from the 15 wavelengths in the range from 342.5 to 483.5 nm.

Green points represent pixels centers, numbers - the sequence of measurements (every 2 sec). Pixel size is 13x24km2.
AOD measurements for years 2004 to 2016 over the Pierre Auger Observatory

Cuts on data:
1. OMAERUV algorithm AOD values;
2. Wavelength = 354nm;
3. Use of satellite data quality flags: Row anomaly correction flag, Pixel Quality Flags, Measurement Quality Flags, Algorithm Flag.

4. For AOD estimation only Sulfate-based aerosols were chosen as their distribution decreases exponentially with height. According to OMI models other aerosol types have distributions with maximum at some altitude.
<AOD> map for the years 2004 to 2016

Aerosols are inhomogeneous over the Pierre Auger Observatory!
\textbf{<AOD> values at different longitudes}

\textbf{<AOD> over years}

\textbf{<AOD> for LA \sim 0.24}

\textbf{<AOD> for LM \sim 0.43}
• Can the higher values of <AOD> be connected with the water reservoirs situated near the Pierre Auger Observatory?
Seasonal <AOD> maps for years 2004 to 2016

<AOD> map for summer months (12,1,2)

<AOD> map for autumn months (3,4,5)

<AOD> map for winter months (6,7,8)

<AOD> map for spring months (9,10,11)
Possible explanations of large AOD values

- From OMI Data User’s Guide:
  Because of the relatively large footprint of the OMI observations (13x24 km² at nadir), the major factor affecting the quality of aerosol products is sub-pixel cloud contamination. So, the mean AOD can be significantly overestimated. However, experience with Total Ozone Mapping Spectrometer (TOMS) suggests that monthly mean AODs do reliably capture variation in the AOD with time.

- OMI cloud identification procedure is not good enough. Using the OMI data with cloud data from other sources may exclude many partly clouded OMI scenes that are not recognized as being cloudy by the OMI. So, other methods for cloud estimation should be used to reselect more clear data.

- Sulfate aerosol emissions are higher than expected because of volcanoes, other sources (NASA release 16-055, June 1, 2016, “NASA Satellite Finds Unreported Sources of Toxic Air Pollution”): “... Reported emissions from known sources in these regions were -- in some cases -- two to three times lower than satellite-based estimates”.
Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) on the CALIPSO satellite

Elastic backscatter lidar that transmits linearly polarized laser light at 532 nm and 1064 nm.

Spatial Resolution: 5 km
Temporal Resolution: 5.92 seconds
Day & Night measurements
Data Available from CALIPSO

- Profile observations of aerosols and thin clouds
- The layers of aerosols and clouds
- Backscatter Coefficients
- Extinction Coefficients
- Column Optical Depth of Aerosols
- Column Optical Depth of Clouds
- Aerosol height information
- Aerosol particle type
- Qualitative classification of aerosol size

Profile data from CALIPSO can be used to improve information from OMI.
Example of CALIPSO measurements (over the Pierre Auger Observatory)

The signal strength has been color coded such that blues correspond to molecular scattering and weak aerosol scattering, aerosols generally show up as yellow/red/orange. Stronger cloud signals are plotted in gray scales, while weaker cloud returns are similar in strength to strong aerosol returns and coded in yellows and reds.
Example of CALIPSO measurements (over the Pierre Auger Observatory)

Plot shows the vertical and horizontal locations of all layers, or features.
Example of CALIPSO measurements (over the Pierre Auger Observatory)

Ice/water phase of all cloud layers

The aerosol type for all aerosol layers (output from the aerosol classification algorithm)
CONCLUSION

- Satellite databases for study of aerosols are available.
- The OMI aerosol measurements over the Pierre Auger Observatory indicate inhomogeneity of aerosol distribution.
- Aerosol concentration for different locations of the fluorescence detectors differs very much. The largest values are observed for LM (almost factor 2 larger than for LA).
- Seasonal dependence is observed.
- To improve our measurements:
  - reduce influence of clouds on satellite data by using the cloud information from other satellites (CALIPSO);
  - analyze aerosol data from other satellites (CALIPSO) to make cross-check of the results obtained from OMI data.