

The GOES-R Aerosol Optical Depth Product

Istvan Laszlo

Center for Satellite Applications and Research
National Environmental Satellite, Data and Information Service
National Oceanic and Atmospheric Administration



Outline

- The nature of atmospheric aerosols
- Why do we care about them?
- Aerosol retrieval from space
- The GOES-R ABI aerosol retrieval
- Examples
- Quality of ABI aerosol data



Aerosols



Atmospheric aerosols are liquid or solid particles suspended in air.

- dust, smoke, haze
- size from a few nanometers to a few tens of micrometers



Stay aloft for about a week.

Heterogeneous distribution in space and time.

Natural and anthropogenic sources.





sea spray



Sources

emission from vegetation



volcanic eruptions



windblown dust



vehicle exhaust

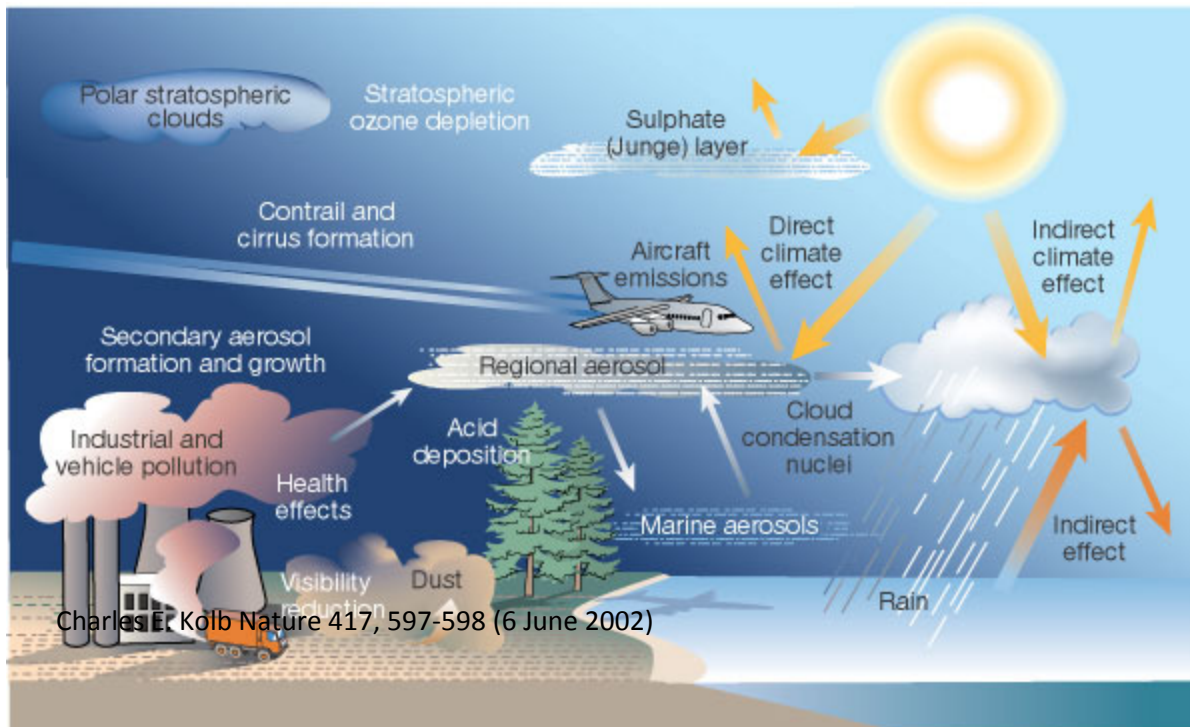


wildfires



industrial emission

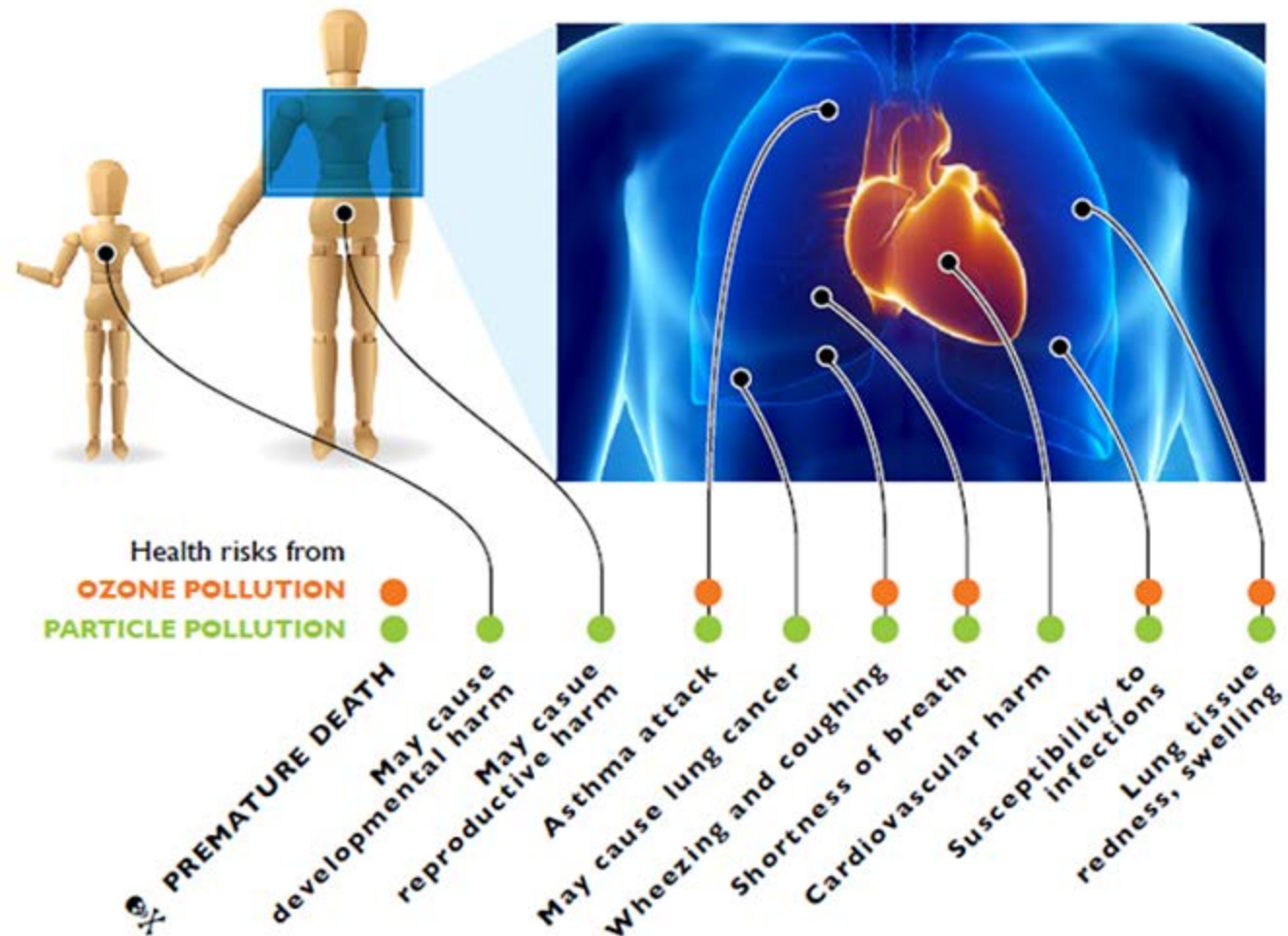
Aerosol effects



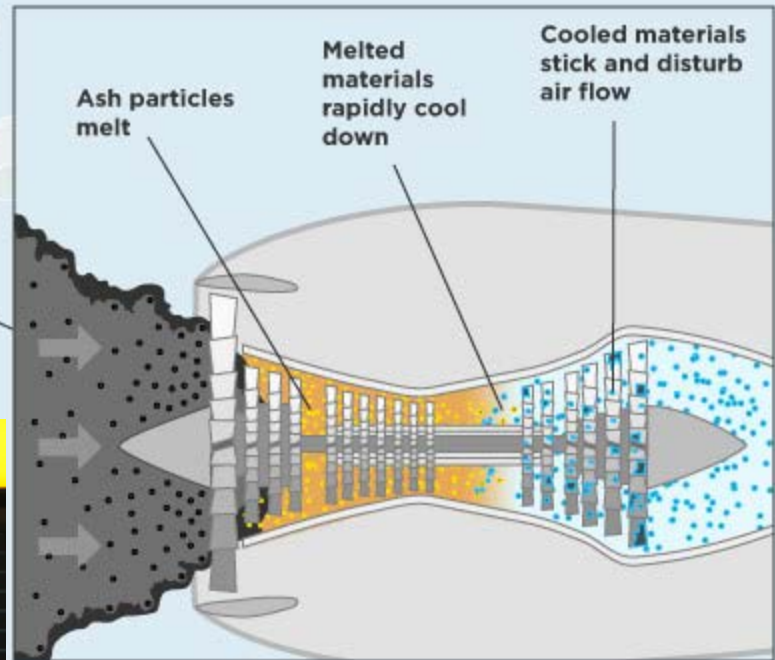
- ☐ radiation budget
- ☐ hydrologic cycle
- ☐ chemistry of atmosphere
- ☐ climate
- ☐ health
- ☐ aviation

Aerosol effects - Health

- PM10:
diameter $>$
 $10\ \mu\text{m}$;
eliminated
through
coughing.
- PM2.5:
diameter $<$
 $2.5\ \mu\text{m}$;
penetrates
deep into the
lungs.



Aerosol effects - Aviation



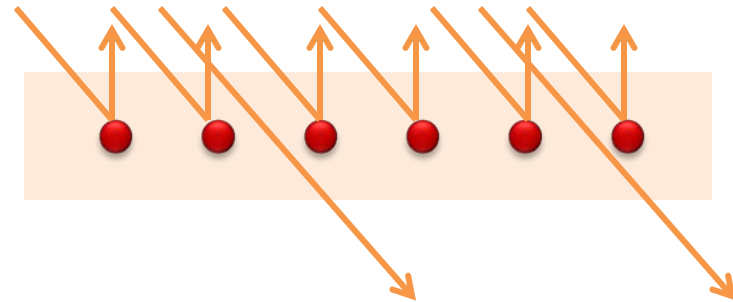
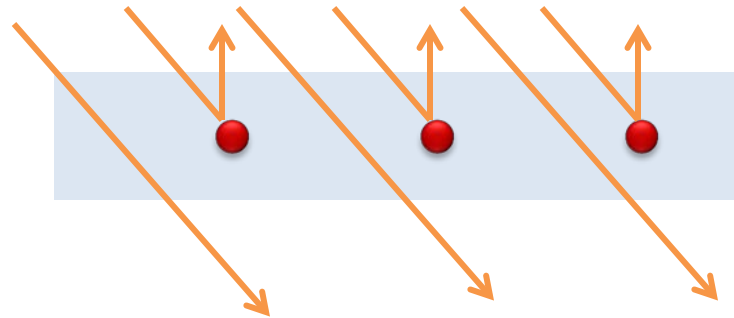
Arrivals								
09:45 Chicago	BA296	Cancelled	18:00 Zurich	BA717	Cancelled	19:35 Paris CdG	BA325	Cancelled
12:10 Denver	BA218	Cancelled	18:05 Lusaka	BA254	Cancelled	19:35 Istanbul	BA677	Cancelled
13:40 Vancouver	87612	Cancelled	18:05 Geneva	BA733	Cancelled	19:40 Larnaca	BA663	Cancelled
13:55 Mexico City	BA242	Cancelled	18:05 Paris CdG	QF3623	Cancelled	19:40 Boston	BA238	Cancelled
15:10 Beijing	BA038	Cancelled	18:05 Tripoli	8A899	Cancelled	19:40 Edinburgh	BA1459	Cancelled
16:05 Istanbul	BA679	Cancelled	18:05 Aberdeen	QF3354	Cancelled	19:45 Newcastle	QF3586	Cancelled
16:25 Manchester	BA1399	Cancelled	18:15 Mumbai	BA198	Cancelled	19:50 Stuttgart	CX7172	Cancelled
16:25 Algiers	BA895	Cancelled	18:15 Manchester	BA1403	Cancelled	19:50 Munich	BA961	Cancelled
16:25 Shanghai	BA168	Cancelled	18:15 Oslo	BA767	Cancelled	19:50 Prague	8A857	Cancelled
16:30 Nice	BA345	Cancelled	18:20 Moscow	8A873	Cancelled	19:50 Glasgow	BA1495	Cancelled
16:40 Amsterdam	BA439	Cancelled	18:30 Munich	BA955	Cancelled	19:55 Milan-Malpensa	BA567	Cancelled
16:40 Athens	BA641	Cancelled	18:30 Bucharest	BA887	Cancelled	19:55 Warsaw	BA851	Cancelled
7:00 Paris CdG	BA319	Cancelled	18:30 Dusseldorf	QF3452	Cancelled	20:00 Lyon	QF3530	Cancelled
7:25 Dusseldorf	CK7144	Cancelled	18:40 Mauritius	BA122	Cancelled	20:00 Aberdeen	BA1315	Cancelled
7:25 Milan-Linate	BA563	Cancelled	18:40 Edinburgh	QF3455	Cancelled	20:05 Milan-Linate	BA569	Cancelled
7:15 Munich	BA953	Cancelled	18:55 Basel	BA755	Cancelled	20:15 Zurich	QF3385	Cancelled
7:15 Stockholm	BA779	Cancelled	18:55 Toulouse	BA375	Cancelled	20:15 Stockholm	BA781	Cancelled
7:15 Edinburgh	BA1453	Cancelled	19:00 Rome	BA559	Cancelled	20:20 Tel Aviv	BA164	Cancelled
7:25 St Petersburg	BA879	Cancelled	19:05 Copenhagen	BA819	Cancelled	20:25 Dusseldorf	BA945	Cancelled
7:25 Copenhagen	BA817	Cancelled	19:15 Nice	BA355	Cancelled	20:25 Manchester	BA1407	Cancelled
7:25 Kiev	BA883	Cancelled	19:15 Hamburg	QF3522	Cancelled	20:25 Rome	BA557	Cancelled
7:25 Brussels	BA397	Cancelled	19:25 Geneva	BA735	Cancelled	20:30 Paris CdG	BA327	Cancelled
7:25 Berlin	BA985	Cancelled	19:25 Amsterdam	BA441	Cancelled	20:35 New York	BA178	Cancelled

- reduces visibility
- volcanic ash can damage components (engine)

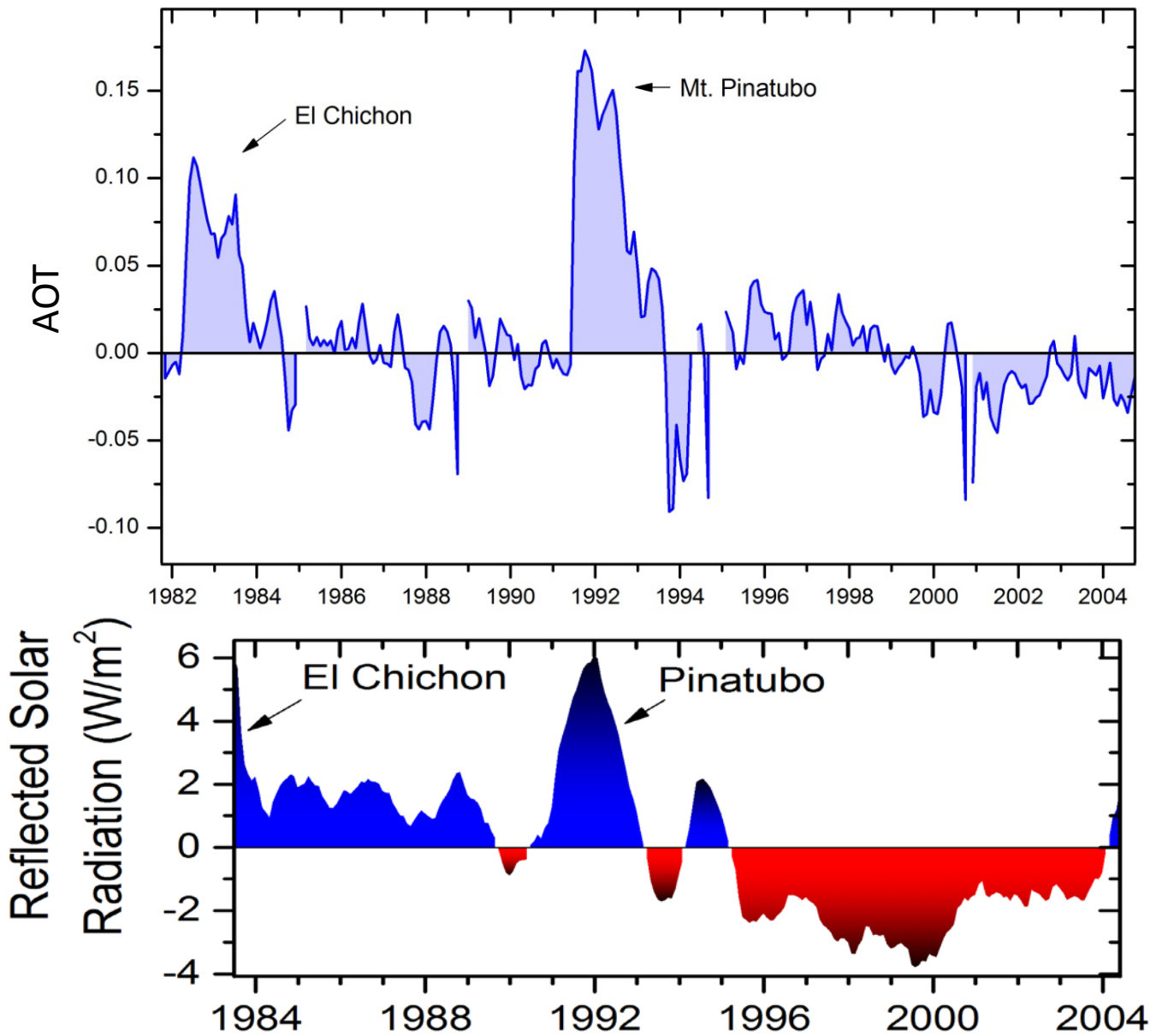
Aerosol effects – Radiation Budget

Direct effects:

- Aerosols mainly reflect solar radiation back to space → *increase the planetary albedo* → *net cooling at the surface*
- Some aerosols also absorb solar radiation → *warming of the atmosphere* → *net cooling at the surface*



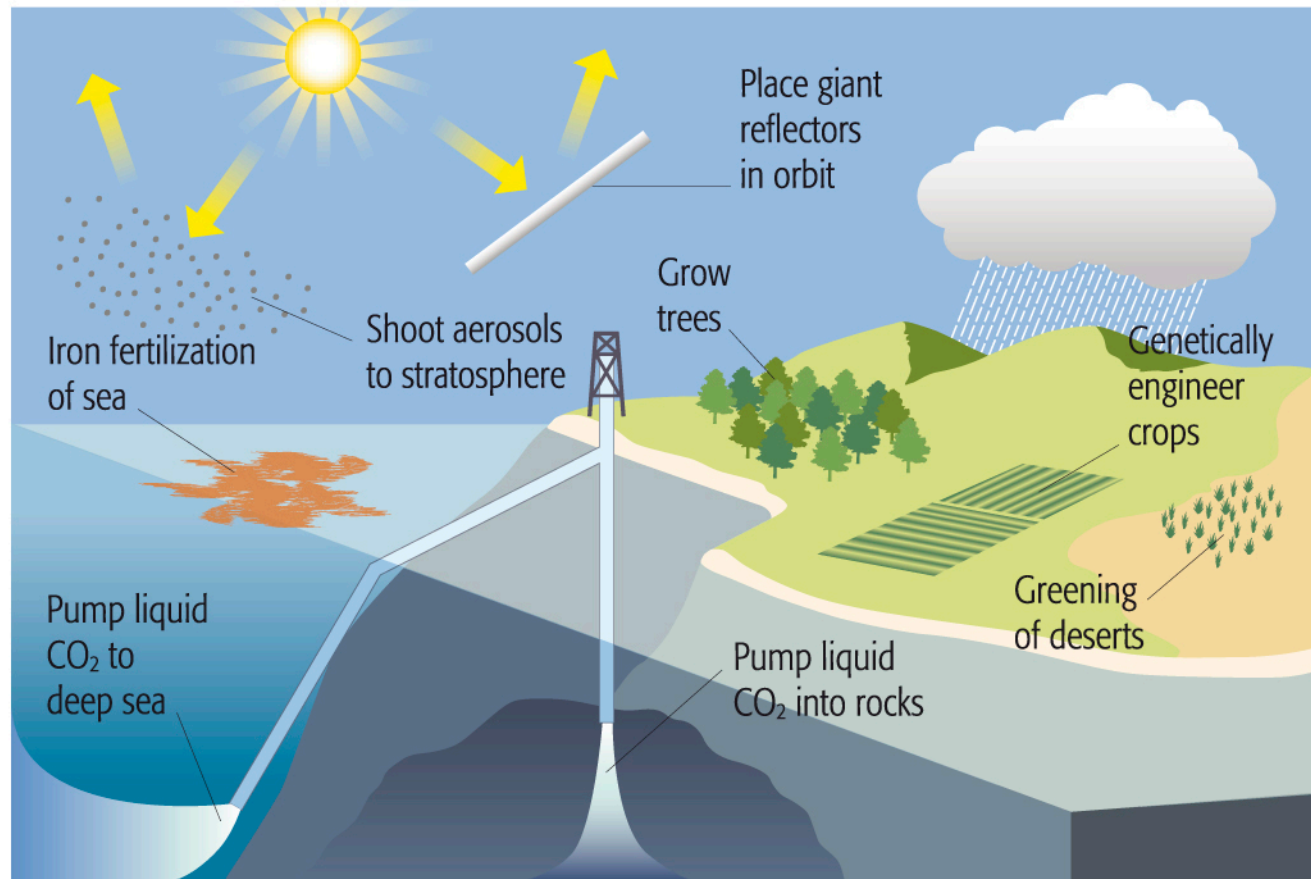
Solar radiation budget



Solar Radiation Management

Aerosol pumped high into the atmosphere reflects solar radiation back to space, thus reducing warming of lower atmosphere and surface.

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Aerosol effects - Cloud

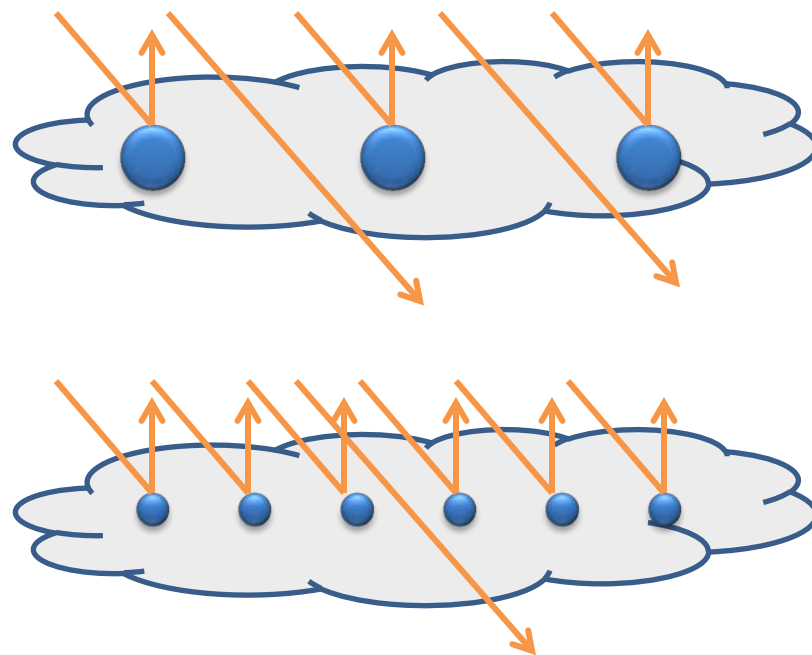
Indirect effects:

More aerosol provides an increase in the number of cloud condensation nuclei

→ *reduces cloud droplet size*

→ *increases cloud albedo*

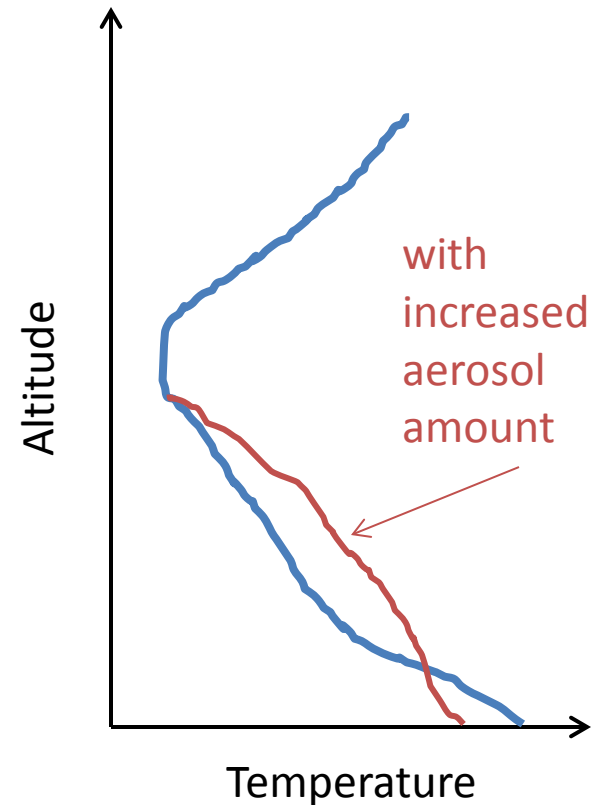
→ *cools surface*



Aerosol effects - Hydrology

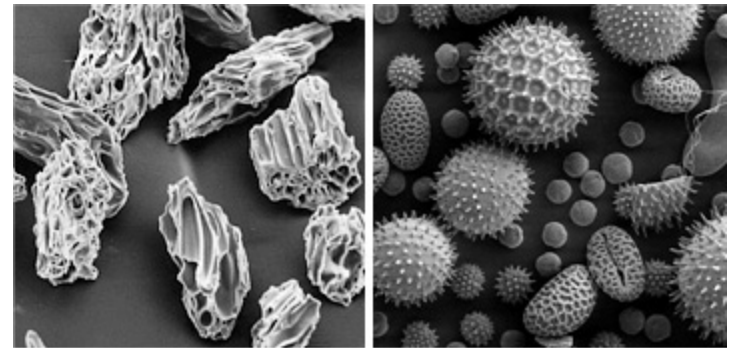
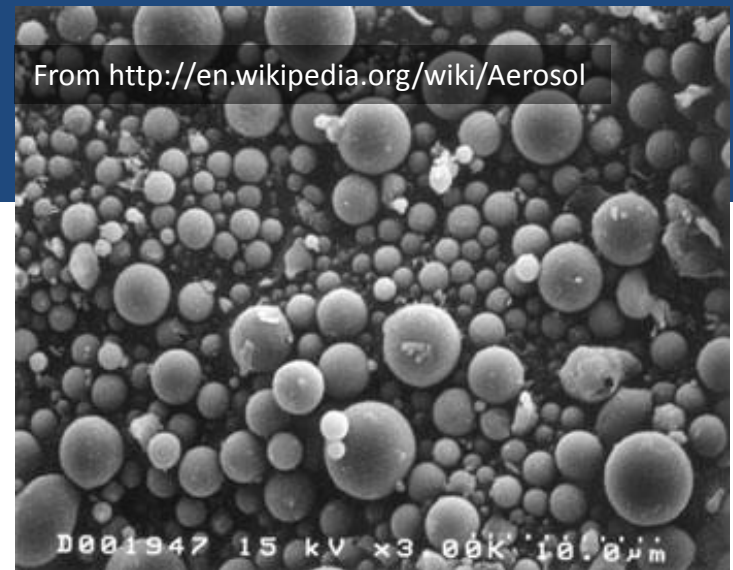
Indirect effects:

- Aerosol induced reduction in cloud droplet size may lead to *less precipitation*
- Increased solar absorption in “dirty” cloud droplets “dries” the cloud → *less precipitation*
- Heating the atmosphere and cooling the surface reduces the temperature gradient → *decline in evaporation and cloud formation*



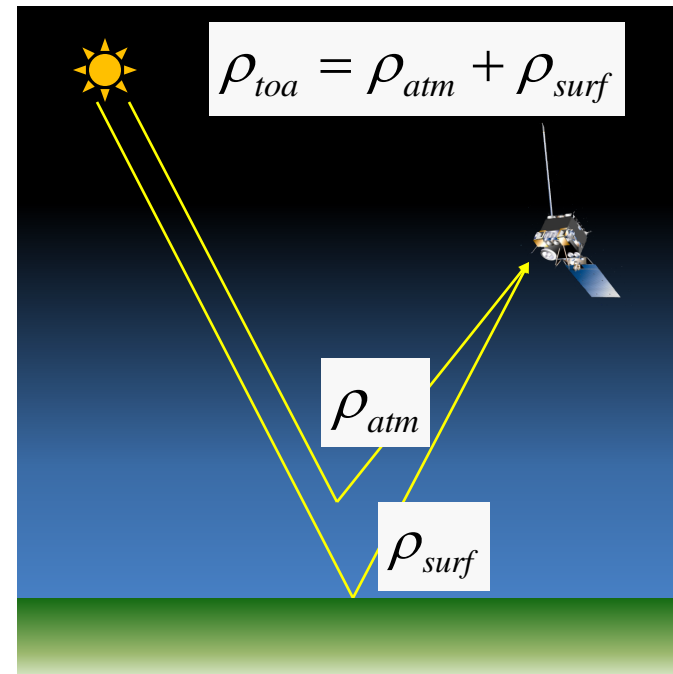
Aerosols

- Size, shape and chemical composition of aerosols vary significantly both in time and space (horizontal and vertical).
- In remote sensing, aerosol amount is expressed in **aerosol optical depth (AOD)** or **aerosol optical thickness (AOT)**.



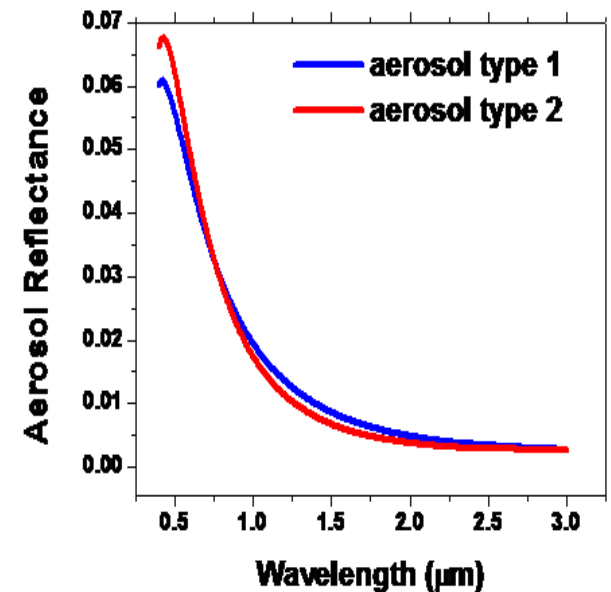
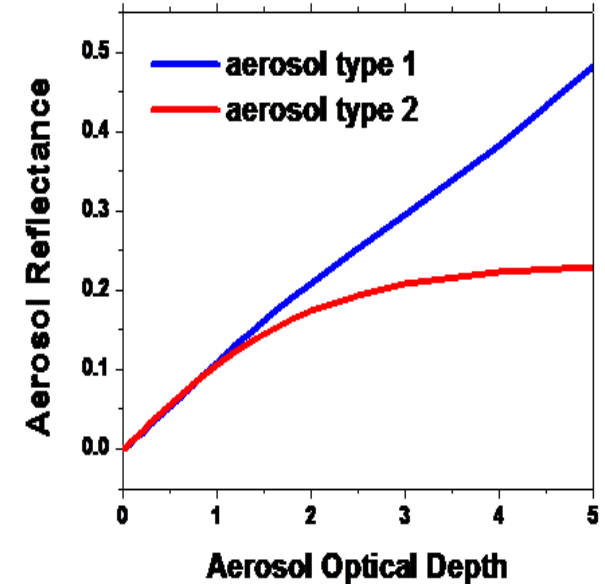
AOD Retrieval - Physical Basis (1)

- The satellite-observed reflectance (ρ_{toa}) is the sum of atmospheric (ρ_{atm}) and surface components (ρ_{surf}).
- These components are the result of reflection, scattering by molecules and aerosols and absorption by aerosols and gases.
- The atmospheric component carries information about aerosol.
- The aerosol portion of the atmospheric component (*aerosol reflectance*) is determined by the amount and type (size, shape and chemical composition) of aerosol.



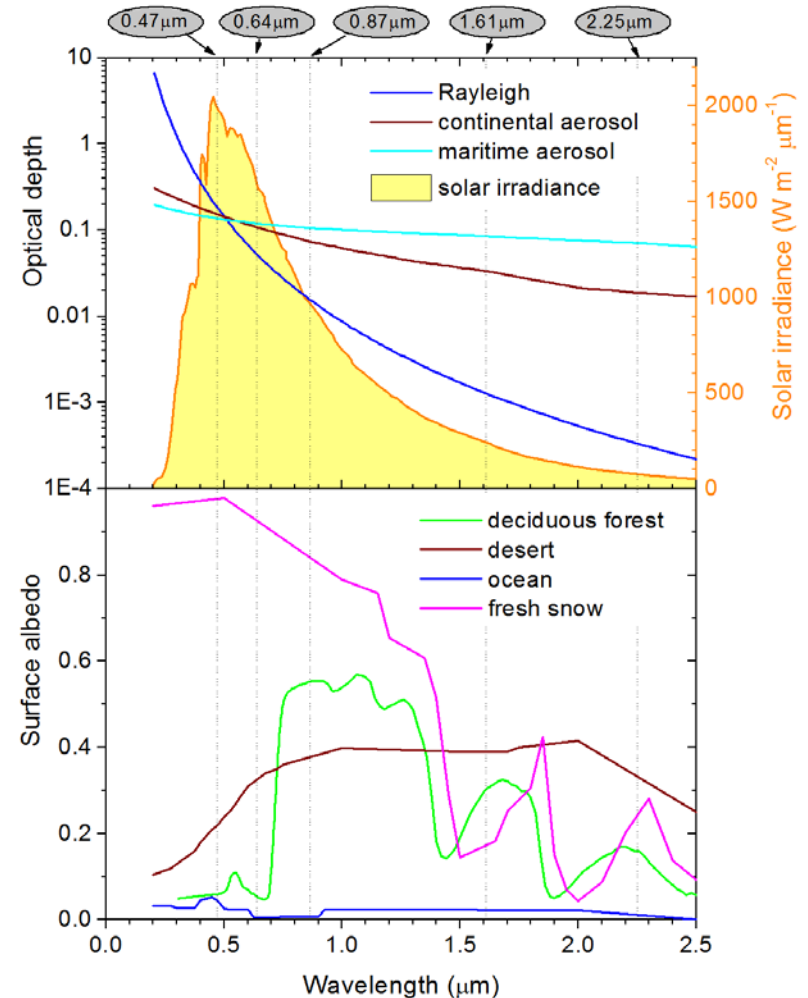
AOD Retrieval Physical Basis (2)

- Aerosol reflectance (ρ_A) increases with increasing amount of aerosol (as measured by AOD)
 - for estimating AOD
- The spectral dependence of aerosol reflectance is a function of aerosol type.
 - for estimating aerosol type

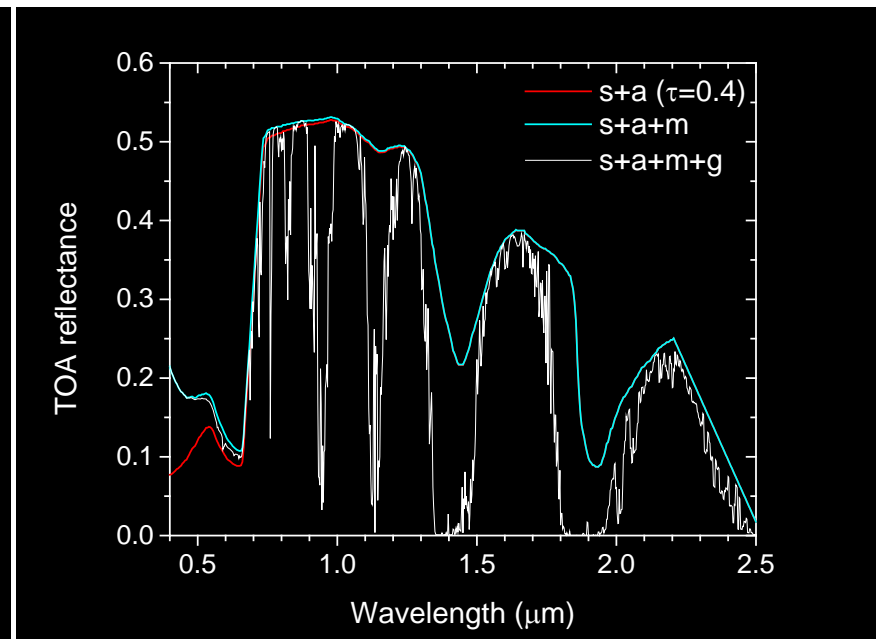
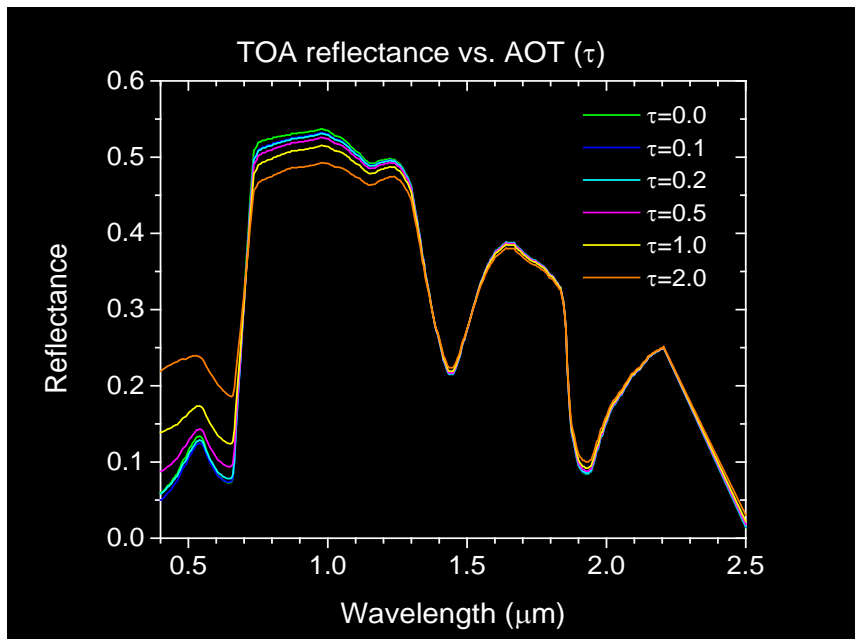


Aerosol Remote Sensing

- Done from clear radiances → *need good cloud screening*
- Aerosol signal is relatively low → *need good calibration*
- Surface contribution can be overwhelming → *need good description of surface*
- Aerosols have complex, spatially and temporally varying structure/composition
- Five unknowns (amount, real and imaginary refractive index, mean radius, and effective variance) even in the simplest case.



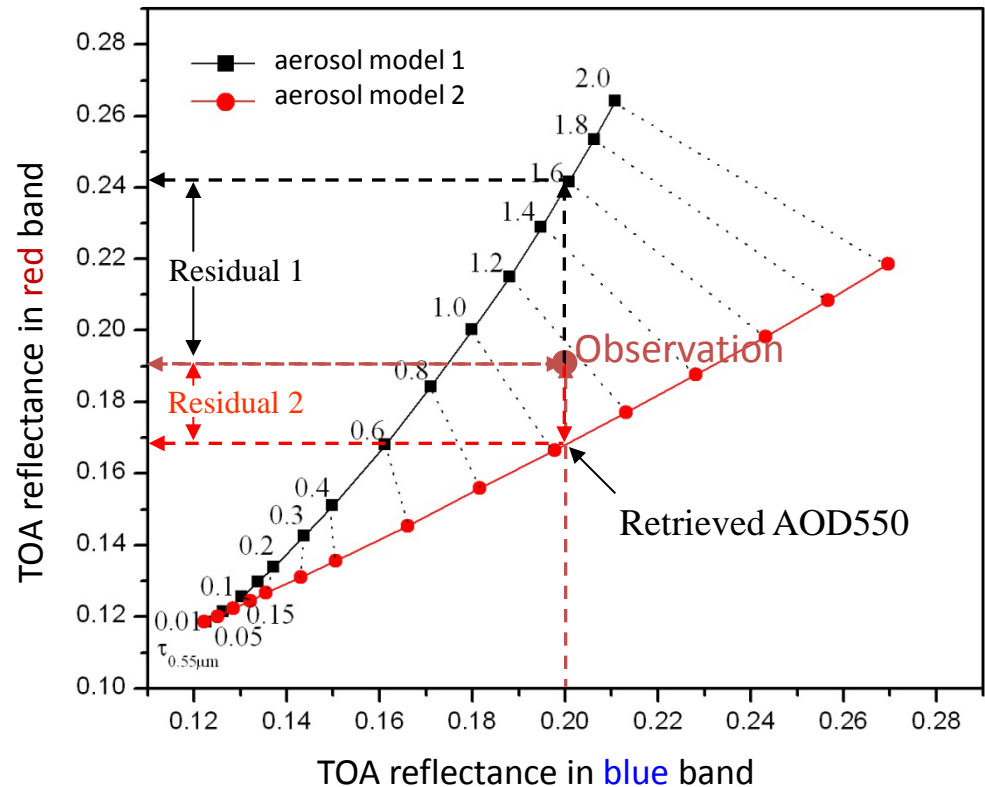
The Aerosol Signal



ABI Aerosol Algorithm

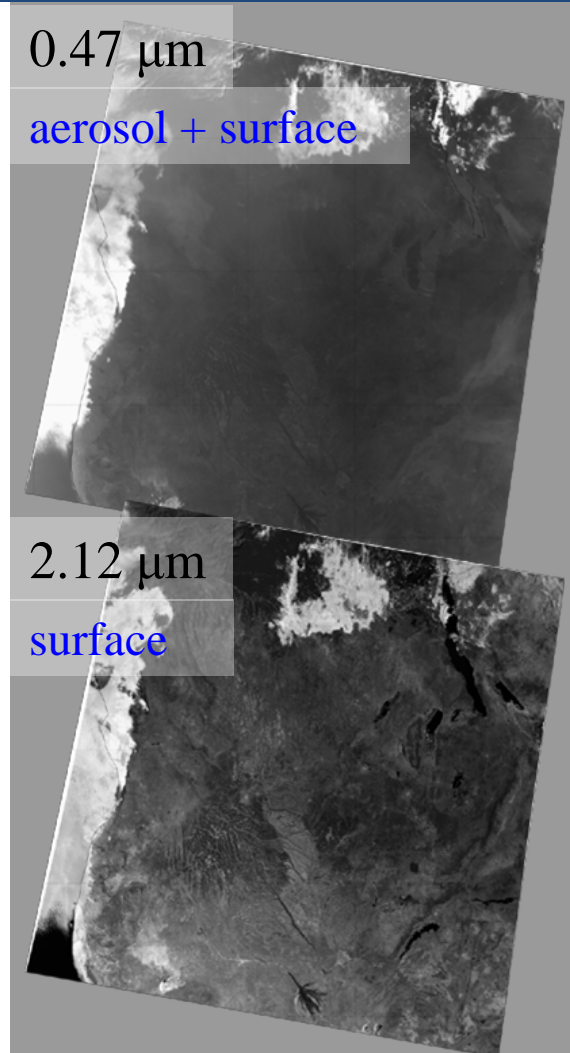
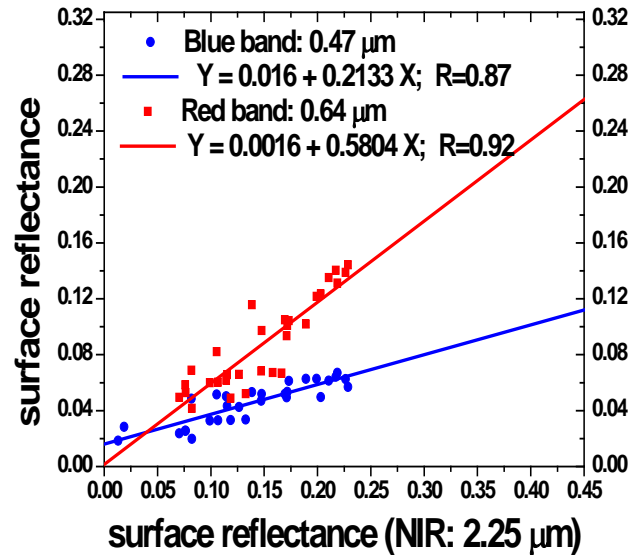
General features:

- Separates aerosol and surface signals by estimating surface reflectance in “blue” and “red” channels from that in SWIR for land.
- Models surface contribution for water.
- Uses multi-channel information.



Land Surface Reflectance

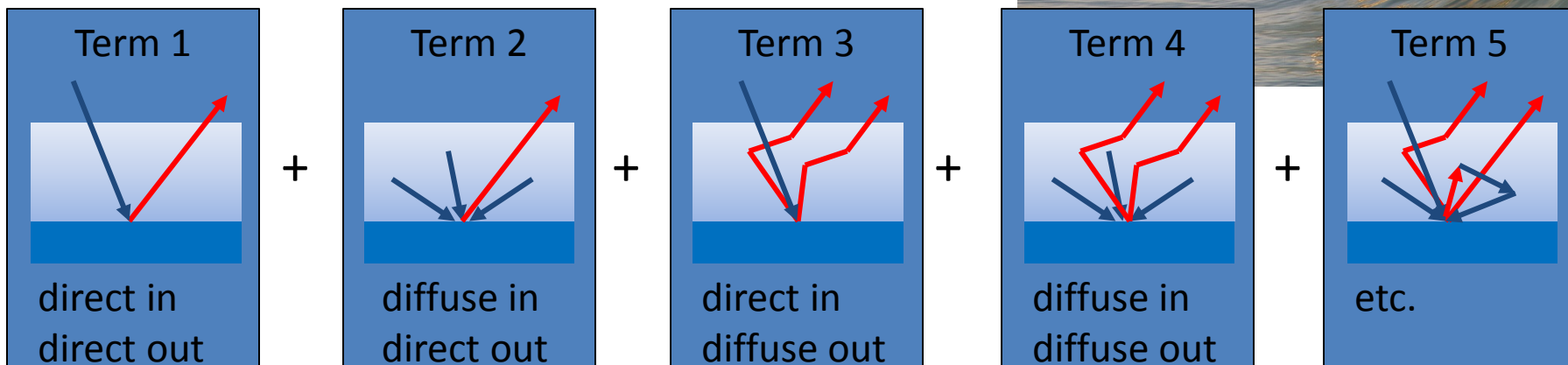
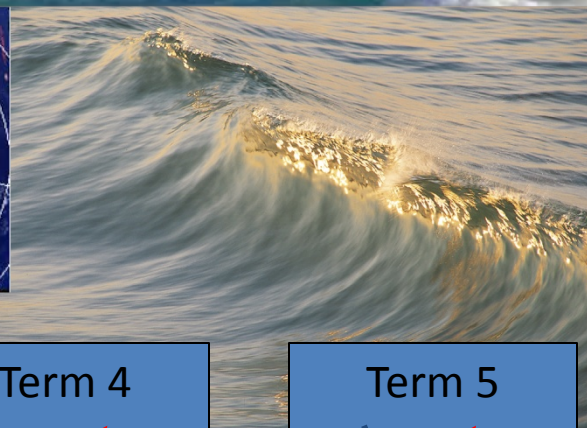
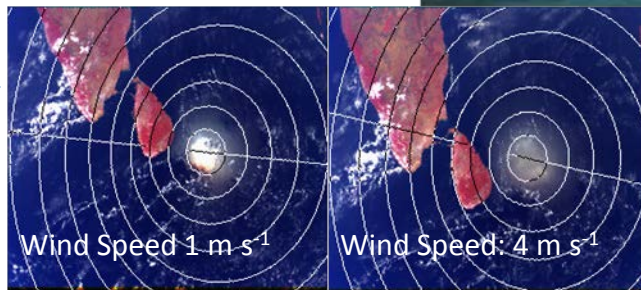
- AOD at 2.2 μm is generally small; allows seeing the surface.
- Over dark targets and dense dark vegetation surface reflectance across the solar spectrum is well correlated.
- Vegetation has low reflectivity in the visible (0.47 and 0.64 μm) region due to chlorophyll absorption and in the 2.2 μm region due to absorption by liquid water.



Ocean Surface Reflectance

Modeled as sum of three components:

- Whitecap
- Sunglint
- Radiation coming from under water

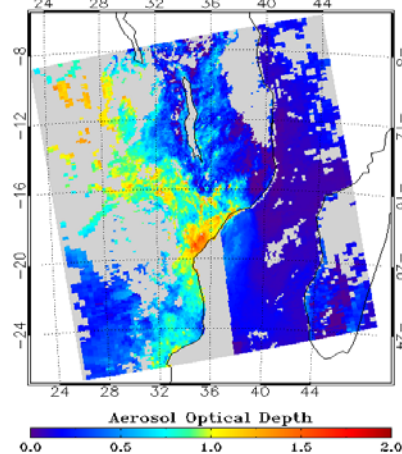


Example Output

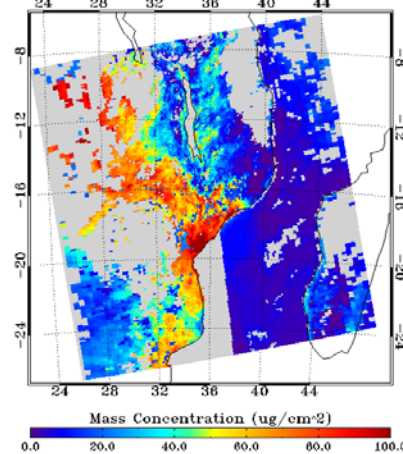
MODIS Granule: Aqua, Sep 23, 2007, 11:20 UTC



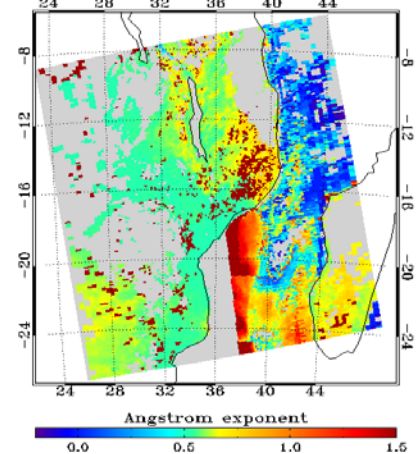
Aerosol Optical Depth (550nm)



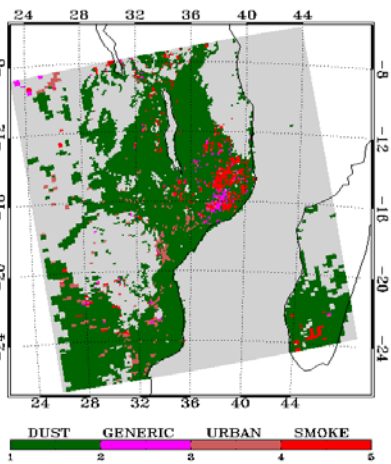
Suspended Matter



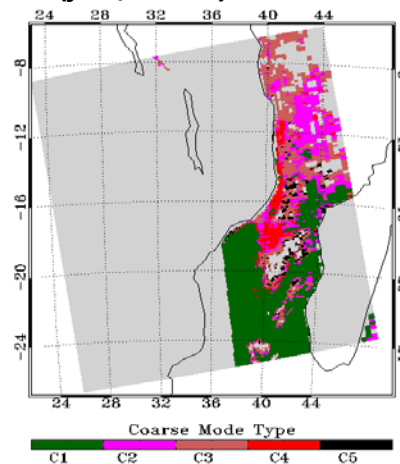
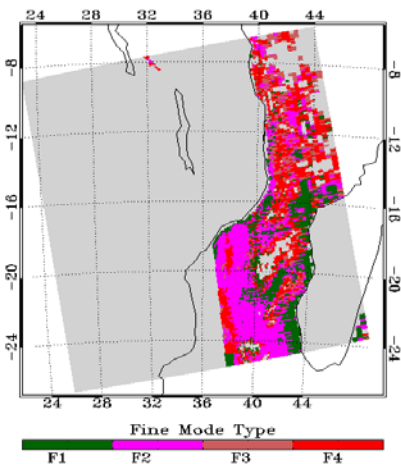
Ångström Exponent (470/860)



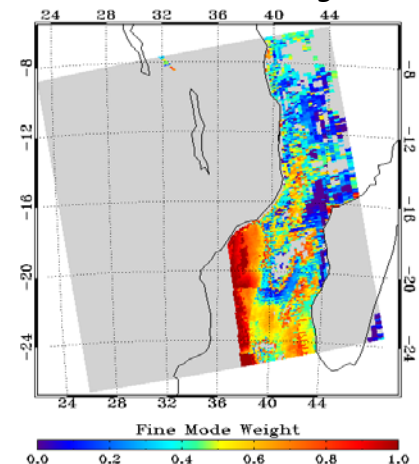
Land Aerosol Model



Ocean Aerosol Model (fine/coarse)

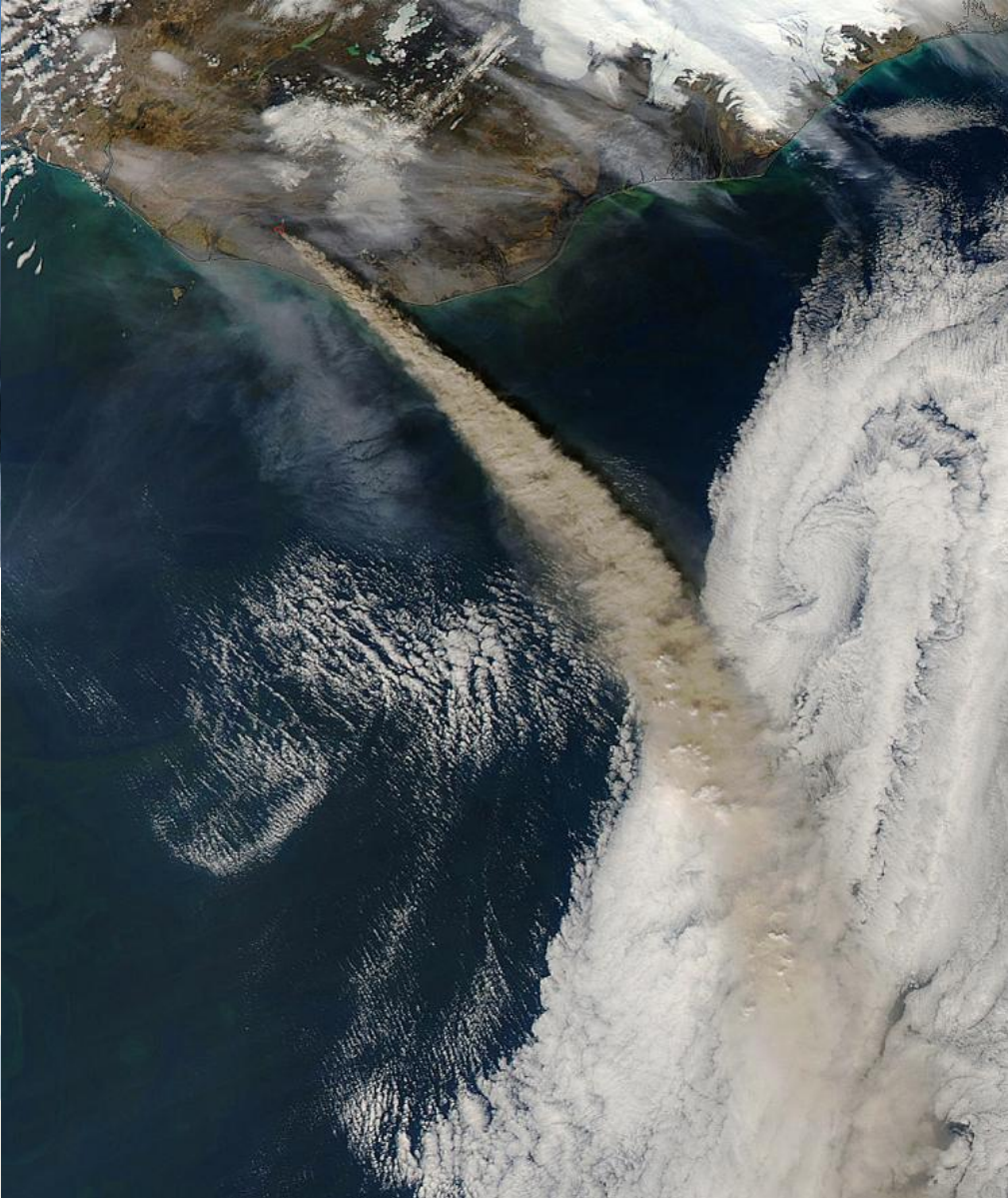


Ocean Fine-mode Weight

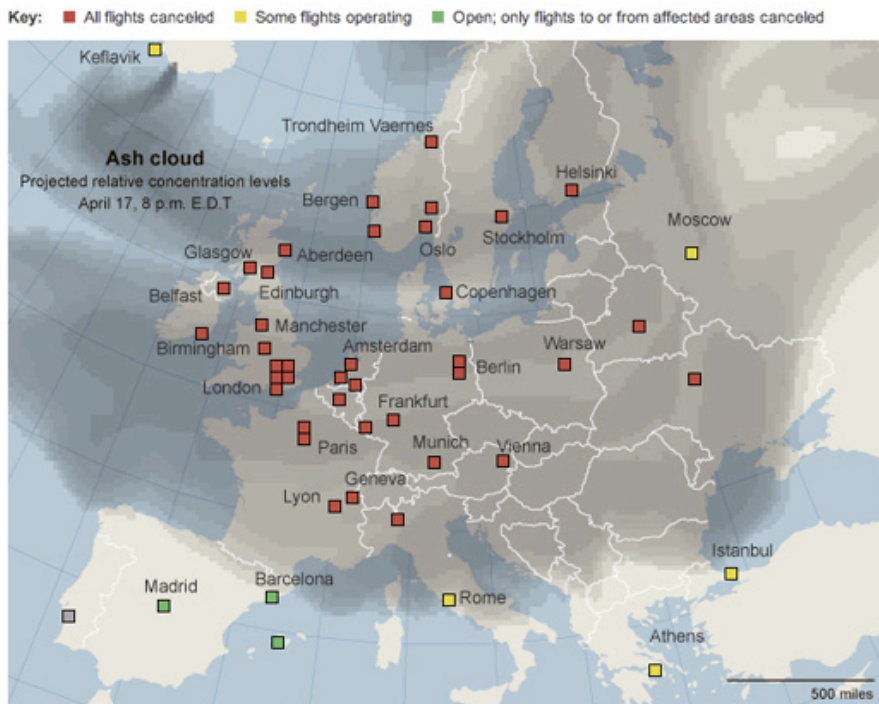




Eyjafjallajökull volcano April 17, 2010



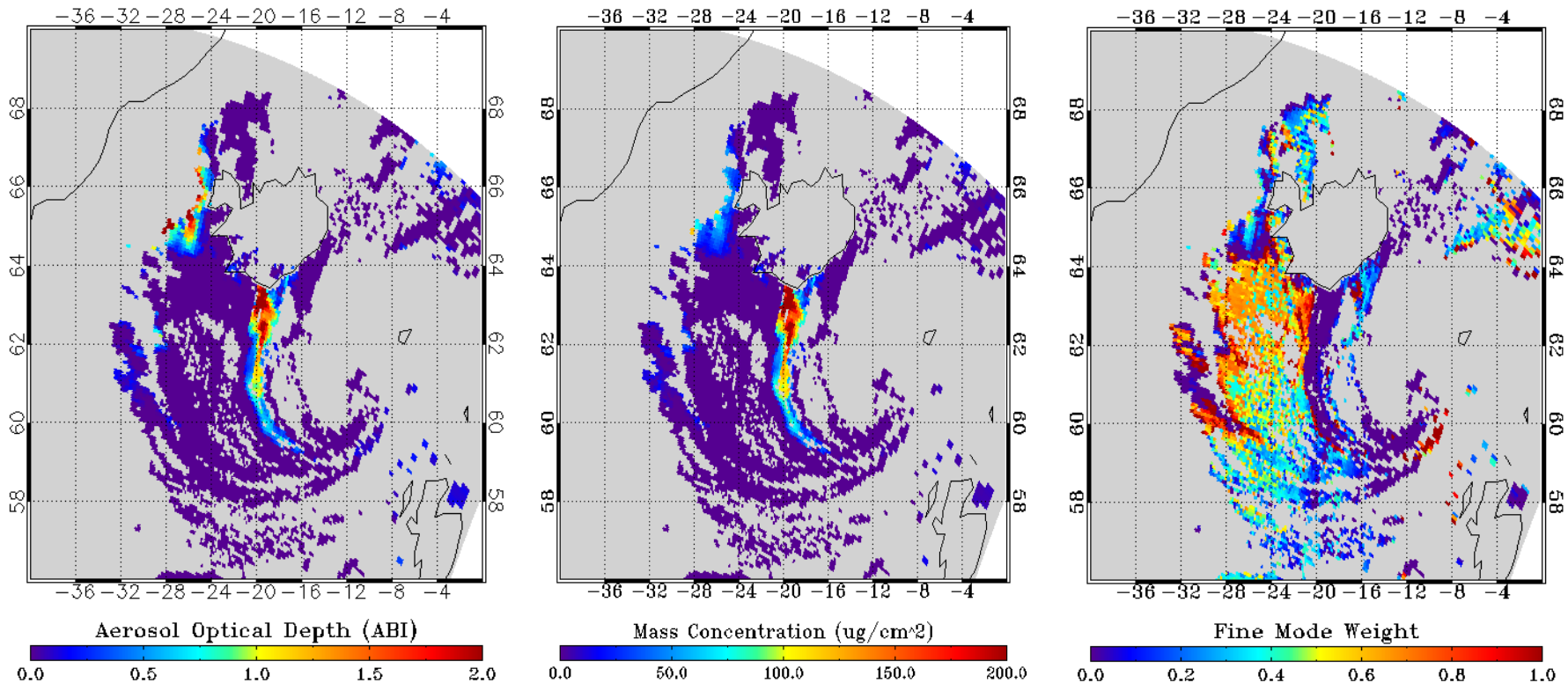
AQUA/MODIS image on May 8, 2010



Eyjafjallajökull Volcano

ABI Aerosol Retrieval Results

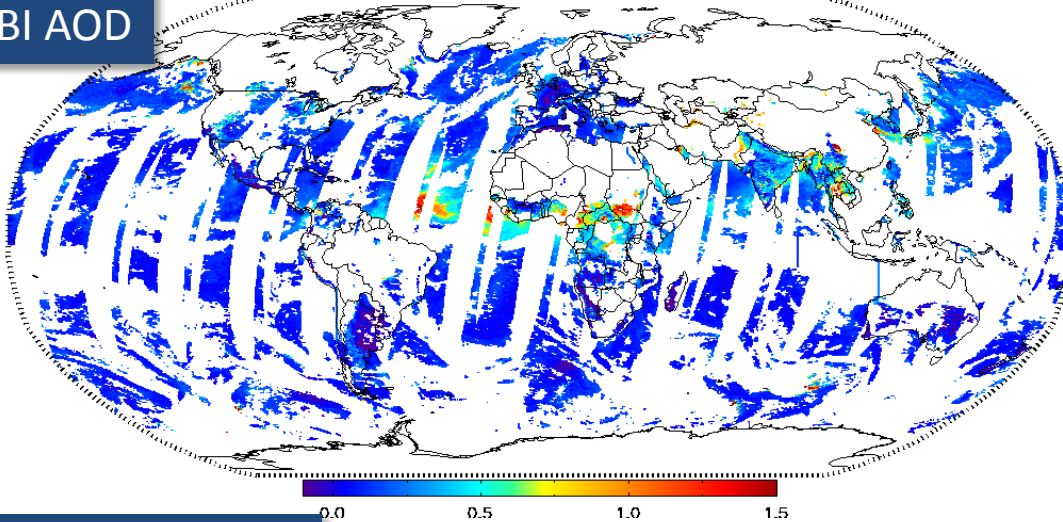
Terra/MODIS, 12:50 UTC



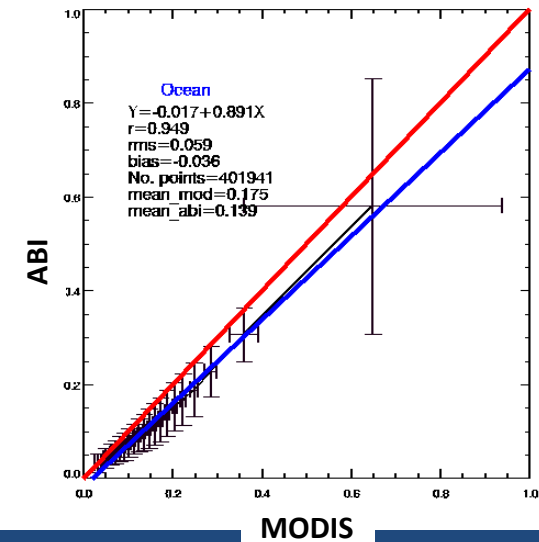
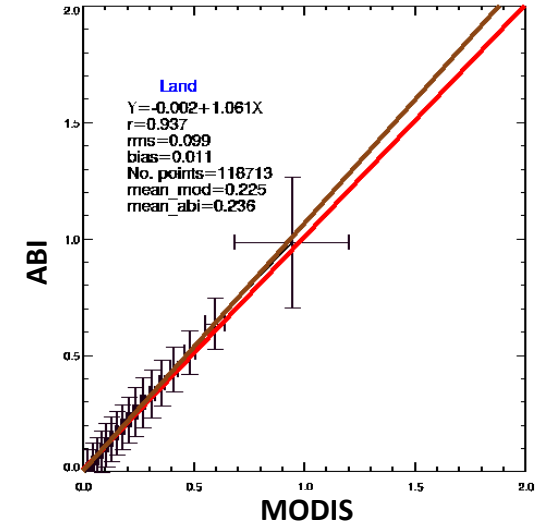
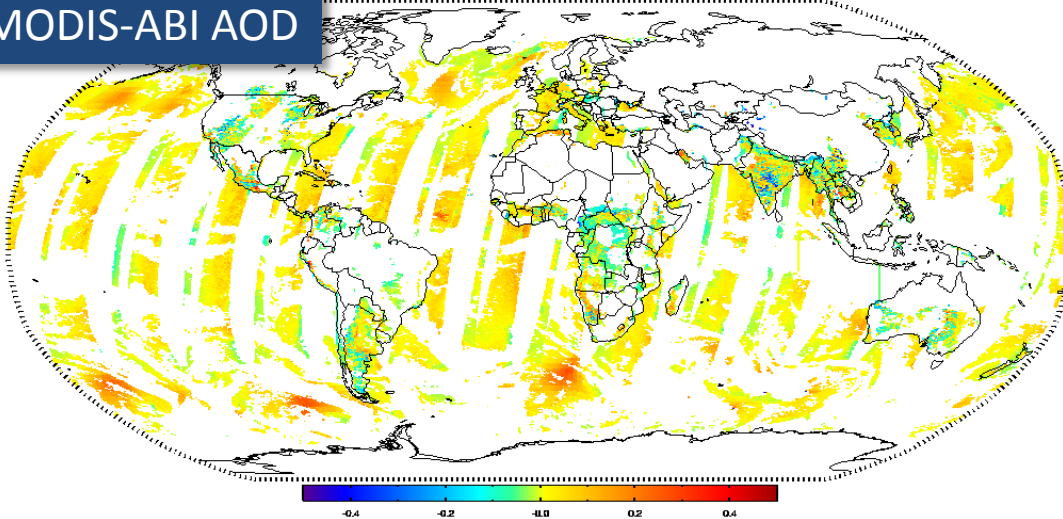
Comparison with MODIS

MODIS/Terra aerosol reflectances are used; 03/15/2012

ABI AOD

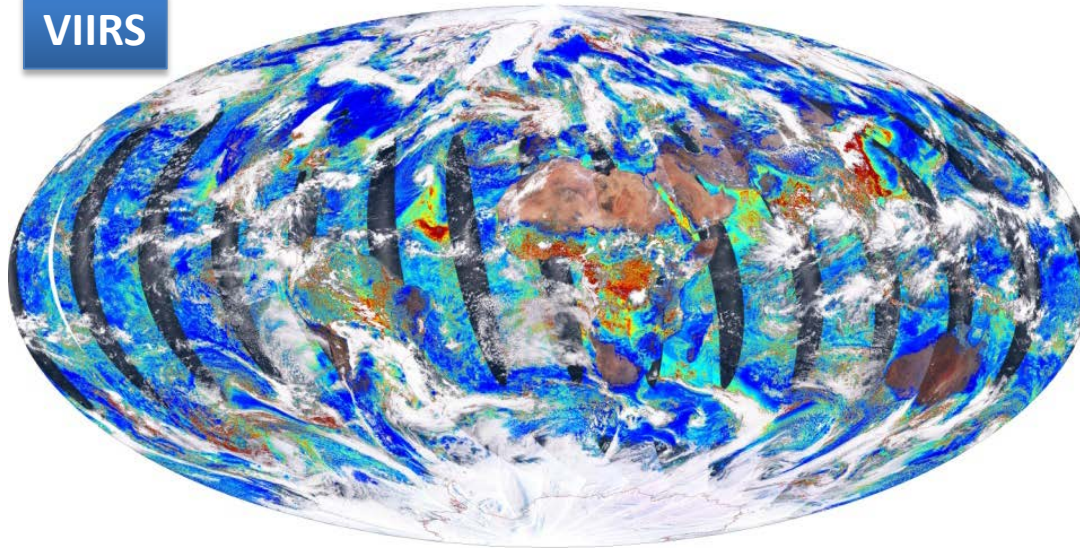


MODIS-ABI AOD



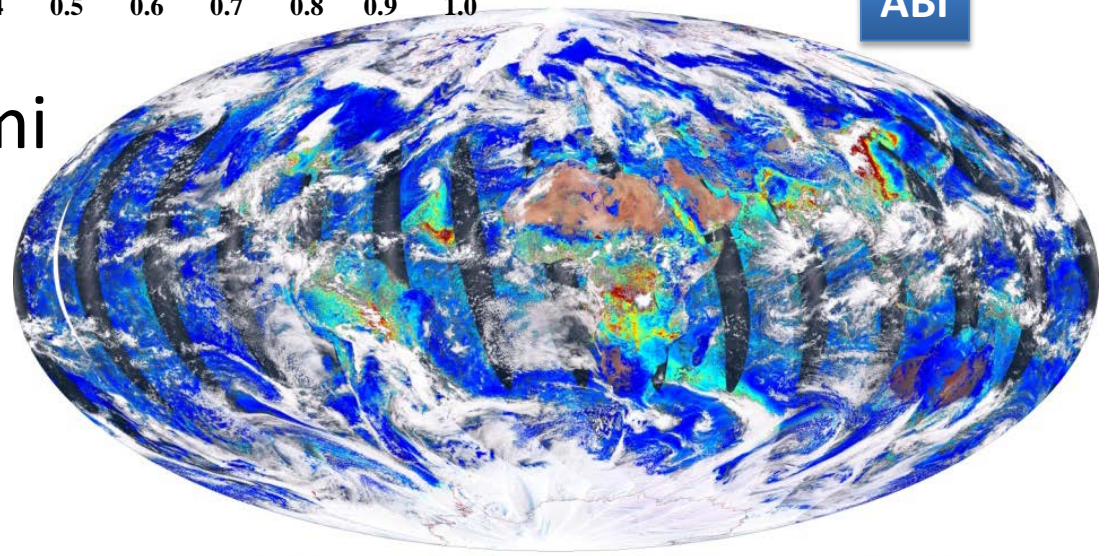
Comparison with AOD from
S-NPP/VIIRS

VIIRS

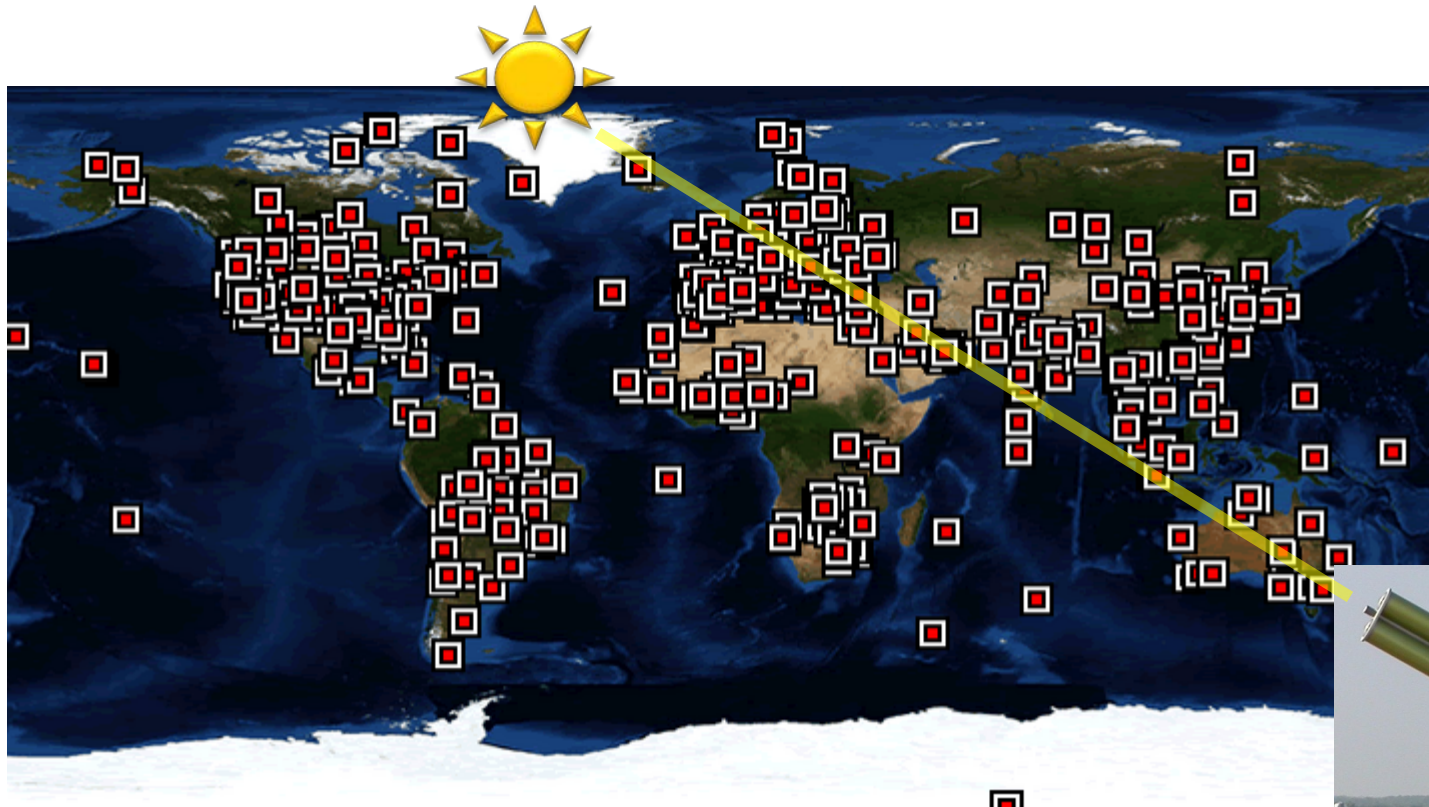


ABI

AOD from Suomi
NPP/VIIRS
input for
09/17/2013



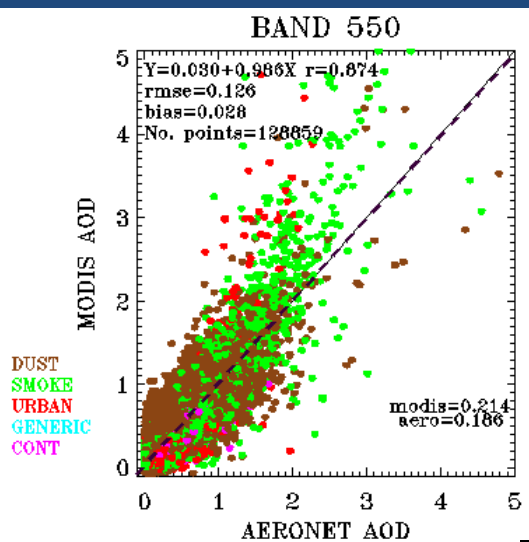
AERONET



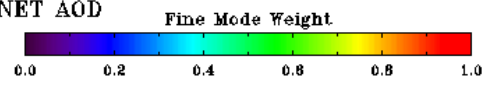
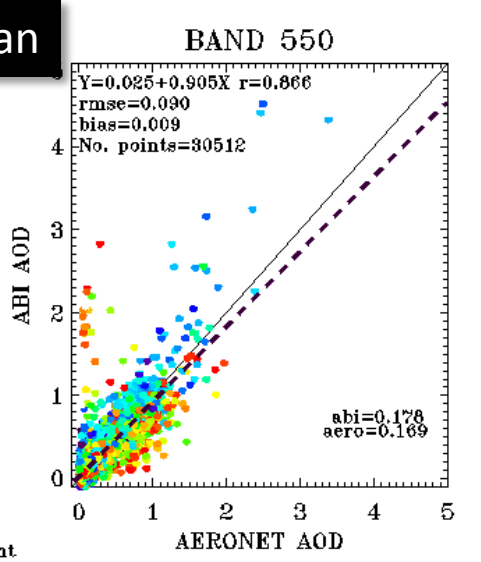
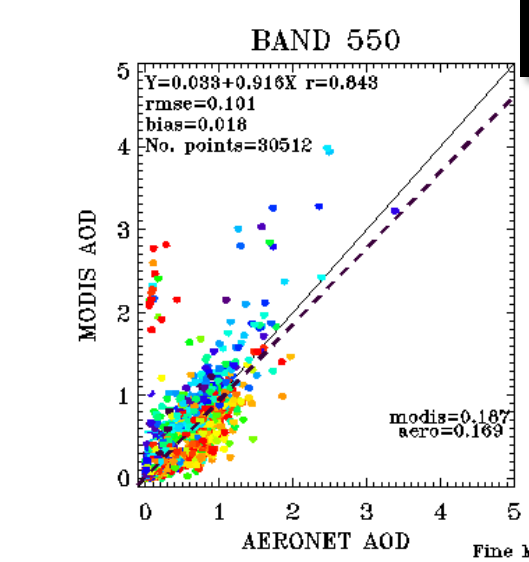
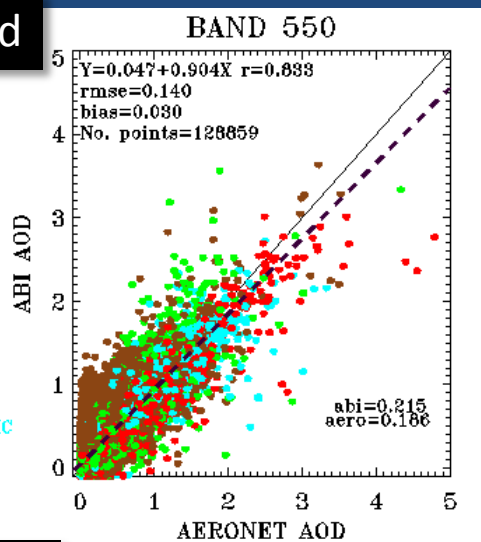
- AERONET: Aerosol Robotic Network (Holben et al., 1998)
- Error in AOD ~ 0.02 \rightarrow “ground truth” for aerosol

Comparison with AERONET

Land



Ocean



- Retrievals are from MODIS Terra and Aqua from 2000-2009
- AOD at 550 nm
- Same overall performance of MODIS and ABI over land
- Slightly smaller overall ABI bias over water



Summary

- Aerosols, although tiny particles, can have a big effect on radiation, clouds, and precipitation.
- The GOES-R/ABI aerosol algorithm retrieves aerosol optical depth (a measure of the amount of aerosol in a vertical column).
- The GOES-R/ABI aerosol products are expected to have a performance comparable to those of products derived globally from polar orbiters (MODIS and VIIRS).

References

- GOES- R Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document for Suspended Matter/ Aerosol Optical and Aerosol Size Parameter NOAA/NESDIS/STAR, Version 2.0, September 25, 2010.
- **Holben** et al., 1998: AERONET - A federated instrument network and data archive for aerosol characterization, *Rem. Sens. Environ.*, **66**, 1-16.
- **Kahn**, R. A., H. Yu, S. E. Schwartz, M. Chin, G. Feingold, L. A. Remer, D. Rind, R. Halthore, and P. DeCola, 2009: Introduction, in *Atmospheric Aerosol Properties and Climate Impacts, A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research*. [Mian Chin, Ralph A. Kahn, and Stephen E. Schwartz (eds.)]. National Aeronautics and Space Administration, Washington, D.C., USA.
- **King**, M., Y. Kaufman, D. Tanré, and T. Nakajima, 1999: Remote sensing of tropospheric aerosols: Past, present, and future. *Bulletin of the American Meteorological Society*, **80**, 2229-2259.
- **Remer**, L. A., M. Chin, P. DeCola, G. Feingold, R. Halthore, R. A. Kahn, P. K. Quinn, D. Rind, S. E. Schwartz, D. Streets, and H. Yu, 2009: Executive Summary, in *Atmospheric Aerosol Properties and Climate Impacts, A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research*. [Mian Chin, Ralph A. Kahn, and Stephen E. Schwartz (eds.)]. National Aeronautics and Space Administration, Washington, D.C., USA.



Image Credits

- [Atmospheric chemistry: Iodine's air of importance](#) Charles E. Kolb Nature 417, 597-598(6 June 2002) doi:10.1038/417597a
http://www.nature.com/nature/journal/v417/n6889/fig_tab/417597a_F1.html
- Scanning electron microscope images of atmospheric aerosol particles.
<http://en.wikipedia.org/wiki/Aerosol> and
http://www.redorbit.com/news/science/1579581/sahara_aerosol_discovery_useful_to_climate_change_studies/#y7duzOdQi1bwCgZZ.99
- Biomass burning aerosols over the Amazon during the 2005 dry season with embedded cumulus clouds. (From NASA Goddard)
- Bright yellow streamers of dust sweep off North Africa's Moroccan coast toward the Canary Islands; Terra MODIS image from February 17, 2004. Credit: Jacques Descloitres, MODIS Rapid Response Team, NASA/GSFC
- Smoke covers wide swaths of the Amazon. Photograph taken from an airplane in 2005. **Credit:** Ilan Koren, Weismann Institute.
- Fire burns near Cessnock, Australia, Friday, Jan. 18, 2013. (AP Photo/NSW Rural Fire Service, Kerry Lawrence.) The Huffington Post.
- NASA's Aqua satellite image of Iceland's Eyjafjallajokull volcano, May 8, 2010.
- Solar radiation management. <http://www.mediaglobal.org/2011/03/15/geo-engineering-should-the-world-have-a-plan-b/>
- Aviation and volcanoes.
<http://www.cnn.com/2011/WORLD/asiapcf/06/13/volcano.questions/index.html>



Example with SEVIRI data

- **SEVIRI**: imager instrument onboard the European geostationary satellite Meteosat.
- AOD retrieved for March 5, 2007 at 7:15, 10:15, 12:15 and 15:15 UTC.
 - single channel over land
 - three-channels over ocean
 - note the sun-glint region

