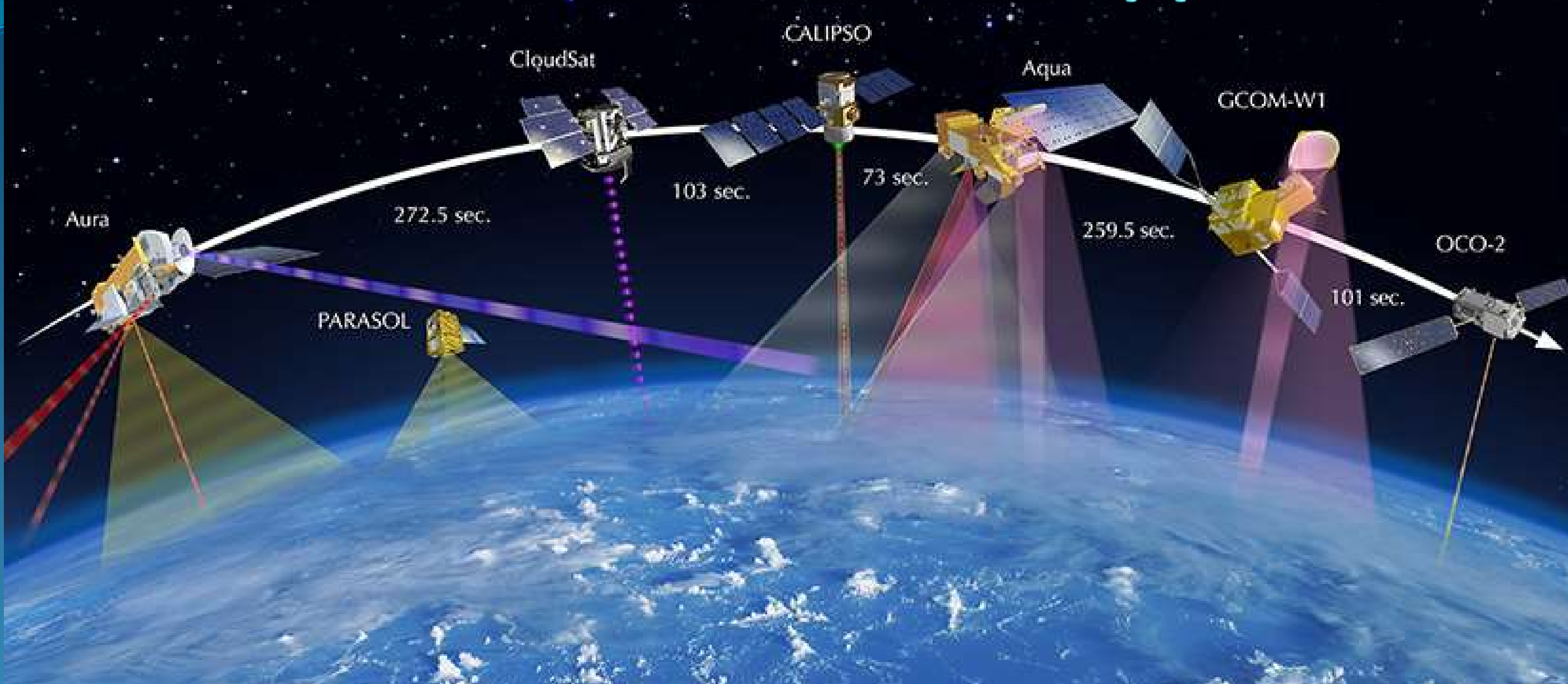
MET 611 – Satellite Data Applications



TOMS and OMI Aerosol

Jennifer D. S. Griswold

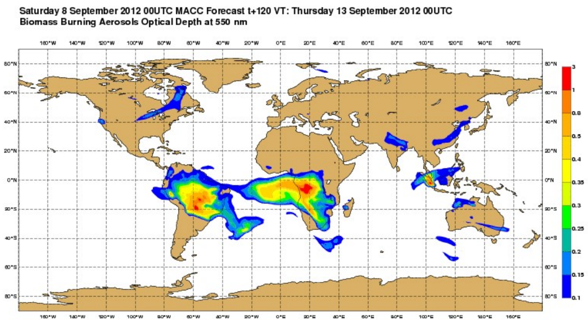
Introduction to TOMS and OMI

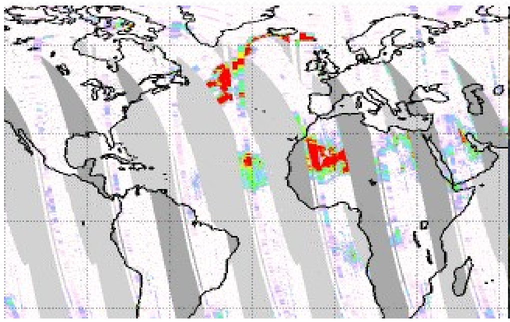
- **Smoke from biomass burning**, and **dust particles from desert storms** are among the main atmospheric constituents that affect the air quality and the Earth's climate system.

- Monitoring of these atmospheric constituents is only possible through **satellite measurements** because ground based measurements are very limited in space and time and these constituents get transported over long distance from their source region.

- For more than two decades, **Total Ozone Mapping Spectrometer (TOMS)** instruments (**McPeters et al, 1996**) have been providing useful global data on the long range transport of smoke and dust plumes.

- **TOMS measures back scattered radiances in the near UltraViolet (UV)** region of the spectrum and from these measurements, the TOMS ozone retrieval algorithm computes an absorbing **Aerosol Index (AI)**, which is a qualitative measure of the presence of UV absorbing aerosols such as mineral dust and smoke.





Introduction to TOMS and OMI

- At the present time, the long-term data record of the aerosol information from the TOMS instrument is continued by **the Ozone Monitoring Instrument (OMI) flown on the EOS Aura spacecraft (launched July 2004).**

- The key objectives (Levelt et al., 2000) of the OMI measurements (Ahmad et al., 2003) include:
  - **monitoring of aerosols and smokes from biomass burning**
  - SO_2 from volcanic eruptions
  - key tropospheric pollutants
  - surface UV radiation

- In general, threats to **human health**.

- Because of better measurement accuracy and better spatial resolution (13x24 km) **OMI provides better estimates of atmospheric pollutants and their transport through the Earth's atmosphere than TOMS.**

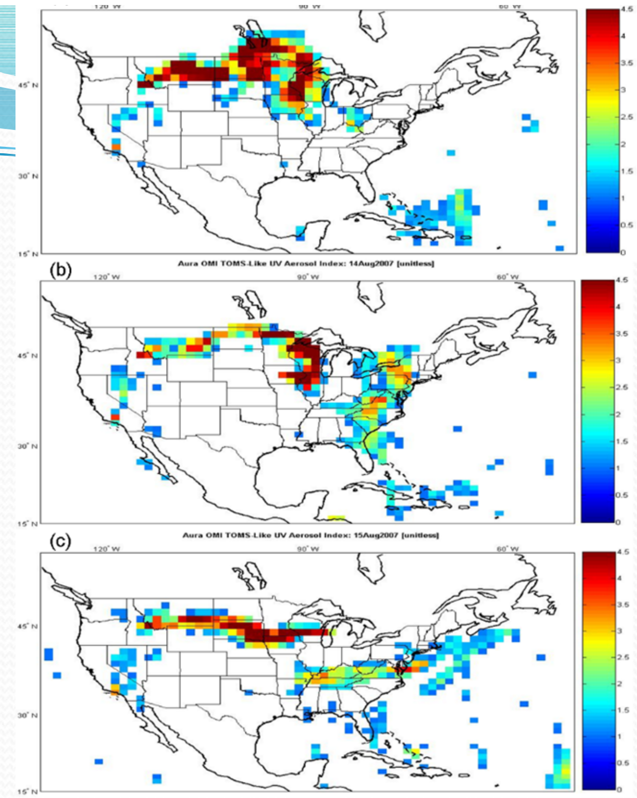
https://disc.gsfc.nasa.gov/datasets?page=1&keywords=TOMS
https://disc.gsfc.nasa.gov/datasets?page=1&keywords=OMI

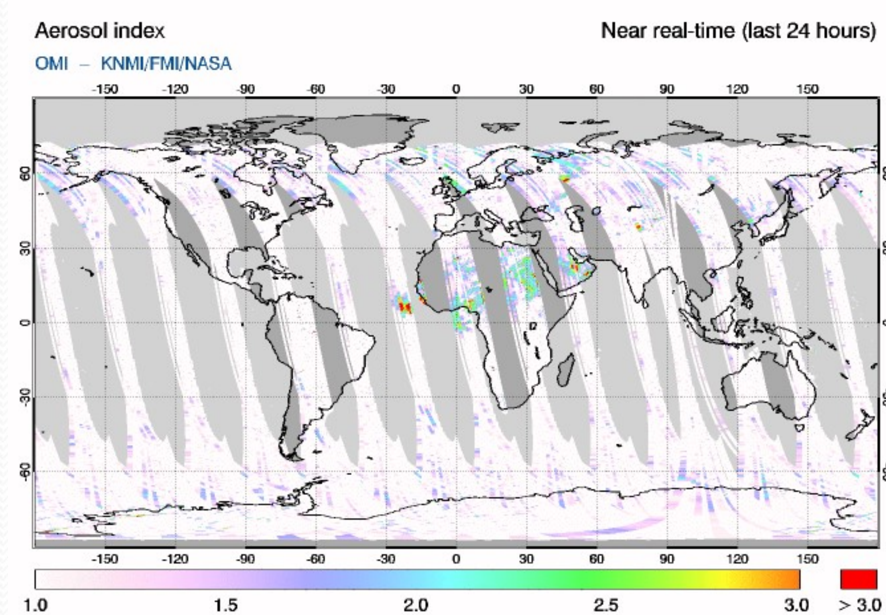
Aerosol Index

- In spite of the fact that the **Aerosol Index is a qualitative indicator of the presence of the absorbing aerosols**, many scientists have used it in variety of applications with the encouraging results.

- For example, AI has been used in identifying the sources of air pollution over the globe, understanding the transport of air pollution across the oceans and continents, air quality forecast models, and radiation energy balance, and climate forcing studies.

- We'll use data from three satellites and two instrument types in this course:
  - **NIMBUS 7 - TOMS**
  - **Earth Probe -TOMS**
  - **Aura - OMI**





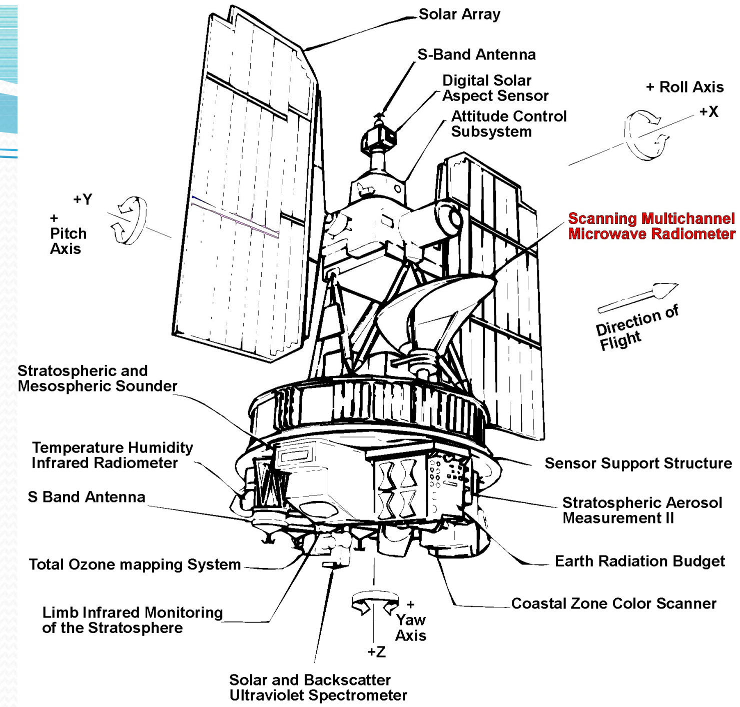
Nimbus 7

- Earth-oriented platform for the testing of advanced systems for sensing and collecting data in the pollution, oceanographic and meteorological disciplines (Launched 1978).

- **The polar-orbiting spacecraft consisted of three major structures:**
  - a hollow torus-shaped sensor mount
  - solar paddles
  - a control housing unit that was connected to the sensor mount by a tripod truss structure.

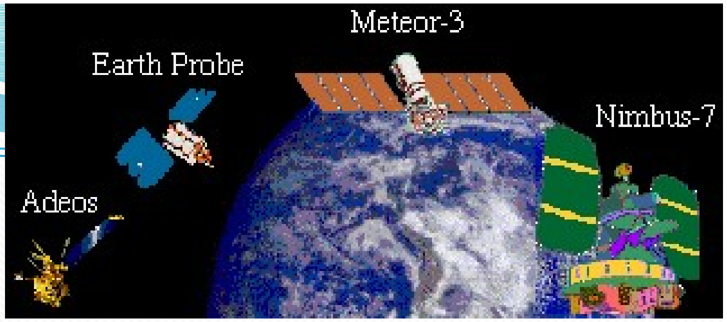
- **The spacecraft spin axis was pointed at the earth.** An advanced attitude-control system permitted the spacecraft's orientation to be controlled to within plus or minus 1 deg in all three axes (pitch, roll, and yaw).

- Eight experiments were selected:
  - (1) limb infrared monitoring of the stratosphere (LIMS)
  - (2) stratospheric and mesopheric sounder (SAMS)
  - (3) coastal-zone color scanner (CZCS)
  - (4) stratospheric aerosol measurement II (SAM II)
  - (5) earth radiation budget (ERB)
  - (6) scanning multichannel microwave radiometer (SMMR)
  - **(7) solar backscatter UV and total ozone mapping spectrometer (SBUV/TOMS)**
  - (8) temperature-humidity infrared radiometer (THIR).

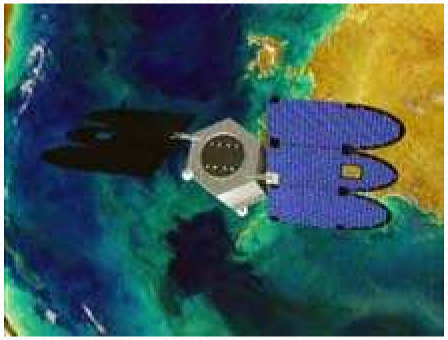


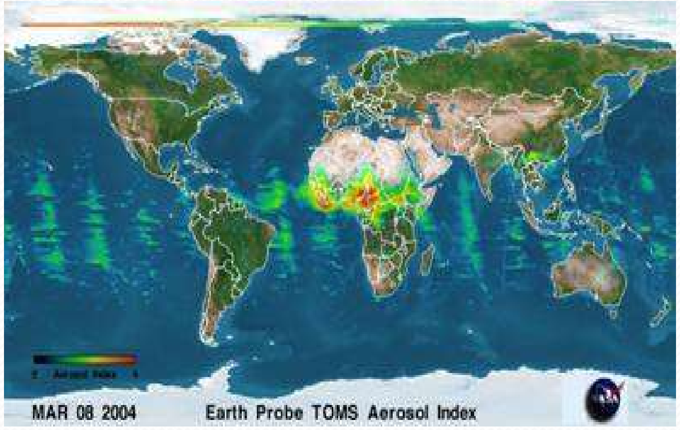
Nimbus 7 Observatory

Earth Probe



- **The Total Ozone Mapping Spectrometer, launched in July 1996 onboard an Earth Probe Satellite (TOMS/EP)**
- Continued NASA's long-term daily mapping of the global distribution of the Earth's atmospheric ozone and absorbing aerosol.
- EP/TOMS made 35 measurements every 8 seconds, each covering 30 to 125 miles (50 to 200 kilometers) wide on the ground, strung along a line perpendicular to the motion of the satellite.
- Almost 200,000 daily measurements cover every single spot on the Earth except areas near one of the poles, where the Sun remains close to or below the horizon during the entire 24-hour period.
- **AEROSOL INDEX** - The data are an aerosol index formed directly from the measured radiances in two TOMS channels. **Positive values generally represent absorbing aerosols (dust and smoke) while negative values represent nonabsorbing aerosols. The identification is not perfect because of geophysical reasons (e.g., aerosol too low to the ground).**





N7 and EP TOMS Summary

- TOMS provides measurements of ozone, tropospheric aerosols, volcanic SO_2, ultraviolet irradiance, erythemal UV exposure, and effective reflectivity from the Earth's surface and clouds.

- Four TOMS instruments have been successfully flown in orbit – aboard the:
  - **Nimbus-7 (Nov. 1978 - May 1993)** → **Aerosol Index available**
  - Meteor-3 (Aug. 1991 - Dec. 1994)
  - **Earth Probe (July 1996 – December 2006)** → **Aerosol Index available**
  - ADEOS (Sep. 1996 - June 1997)

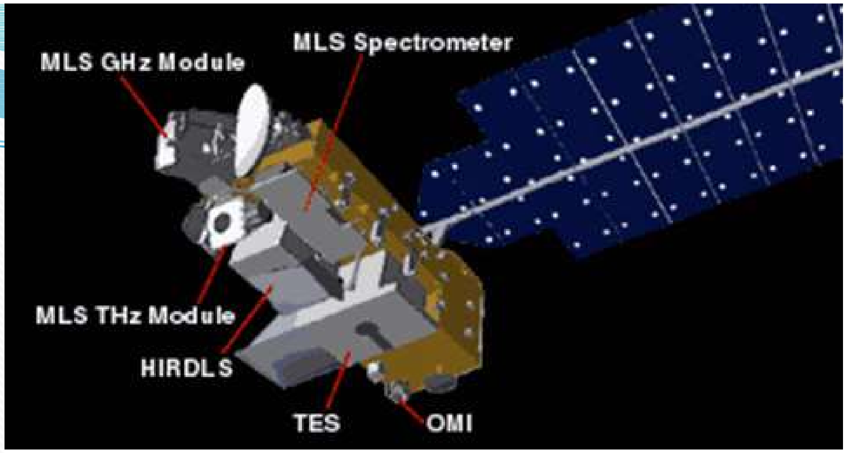
- Version 8 TOMS data products are available from the Goddard Earth Sciences Distributed Information and Services Center (GES DISC).
  - **Level 3 gridded data (1.0° x 1.25°)**
  - Level 2 instrument resolution data (between 50x50 km and 26x26 km pixel at nadir).
  - At this time, the data are from the Nimbus-7 and Earth Probe TOMS instruments.

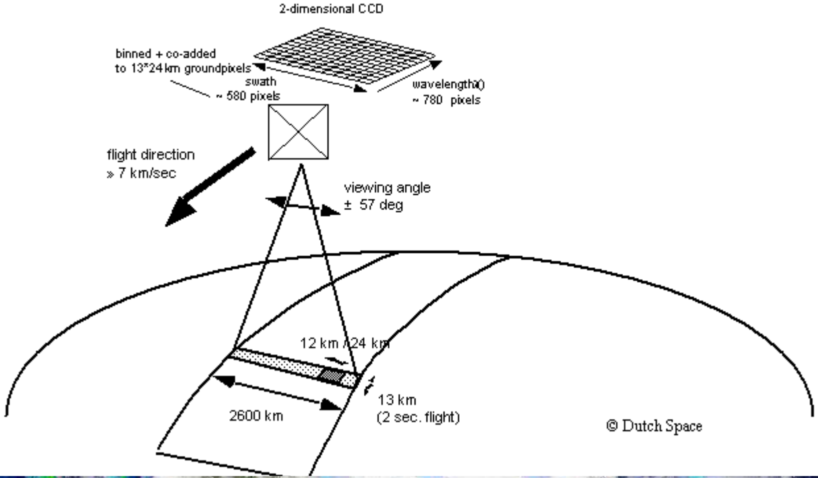
- WARNING: EP TOMS started experiencing calibration problems a few years after launch.
  - Data beginning in year 2000, the calibration had been stabilized relative to NOAA-16 SBUV/2 in the equatorial zone.
  - **Because of this error, data since 2002 had been recommended NOT be used for trend analysis.**

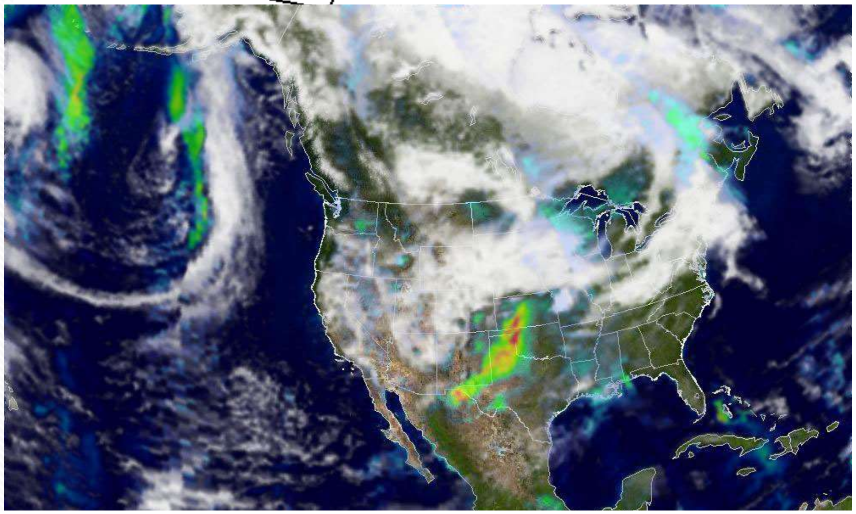
- **The principle investigator for TOMS is Dr. Richard McPeters (Richard.D.McPeters@nasa.gov). For more information about TOMS, please see the official TOMS web site (http://ozoneaq.gsfc.nasa.gov).**

OMI

- **Launched in 2004 on Aura -** hyperspectral imaging in a push-broom mode to observe solar backscatter radiation in the visible and ultraviolet.
- **The Earth will be viewed in 740 wavelength bands along the satellite track with a swath large enough to provide global coverage in 14 orbits (1 day).**
- The nominal 13 x 24 km spatial resolution can be zoomed to 13 x 13 km for detecting and tracking urban-scale pollution sources.
- **Distinguish between aerosol types, such as smoke, dust, and sulfates.**
- Measure cloud pressure and coverage, which provide data to derive tropospheric ozone.
- It is a wide-field-imaging spectrometer with a **114° across-track viewing angle range that provides a 2600 km wide swath, enabling measurements with a daily global coverage**





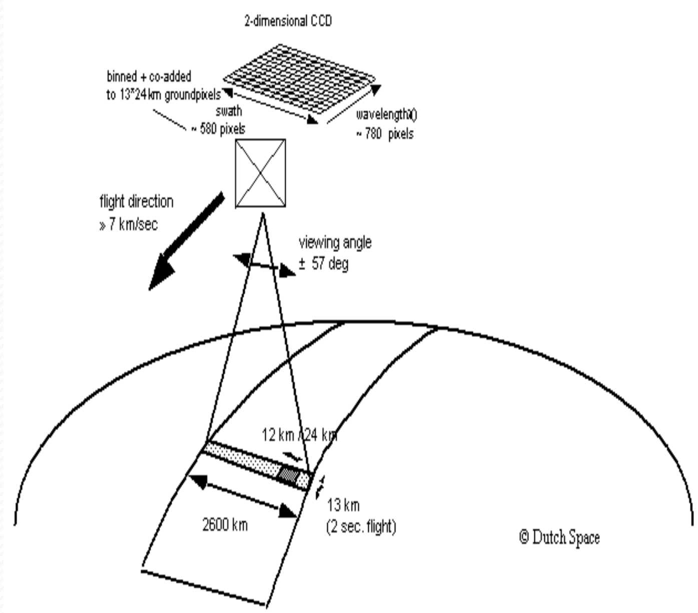


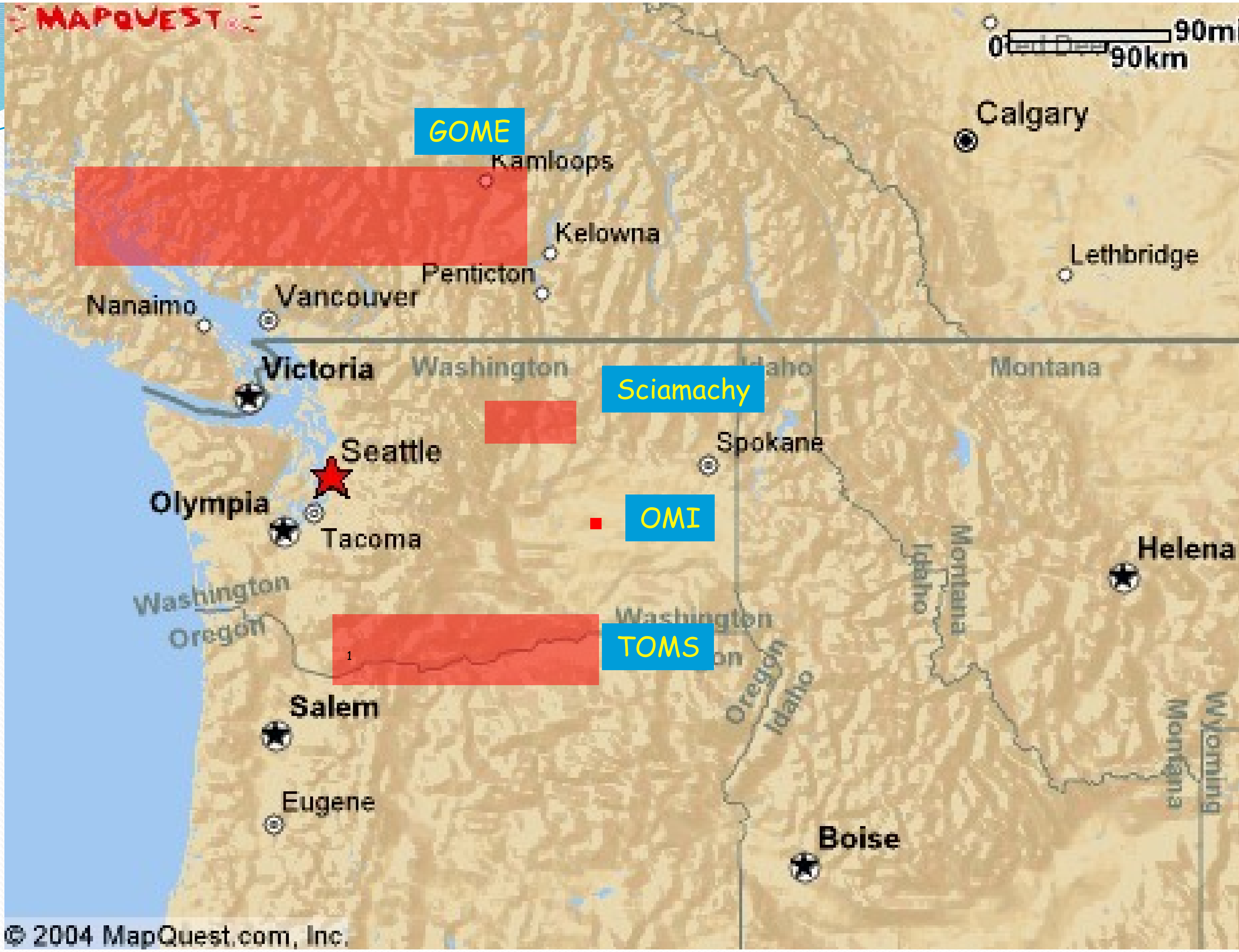
Aura OMI

- **double channel** spectrograph covering 270 - 510 nm at 0.7 nm resolution

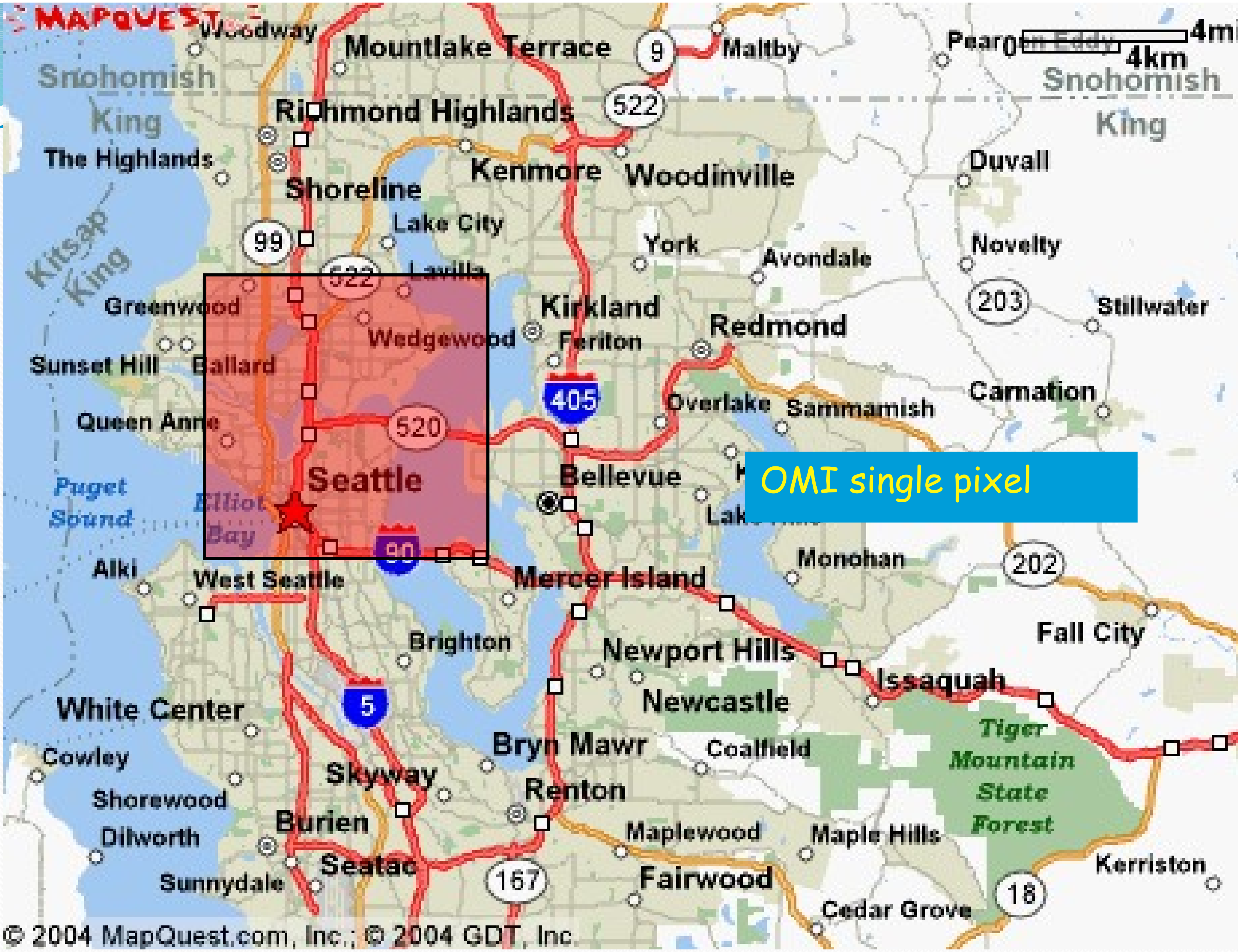
- measures column O_3, NO_2, BrO, OClO, CH_2O, SO_2, **aerosol indices**

- data products:
  - atmospheric column of above gases
  - trop NO_2
  - trop O_3
  - aerosol data





single pixel size for four satellite instruments



OMI pixel 12 km x 13 km superposed onto the Seattle airshed (zoom mode)

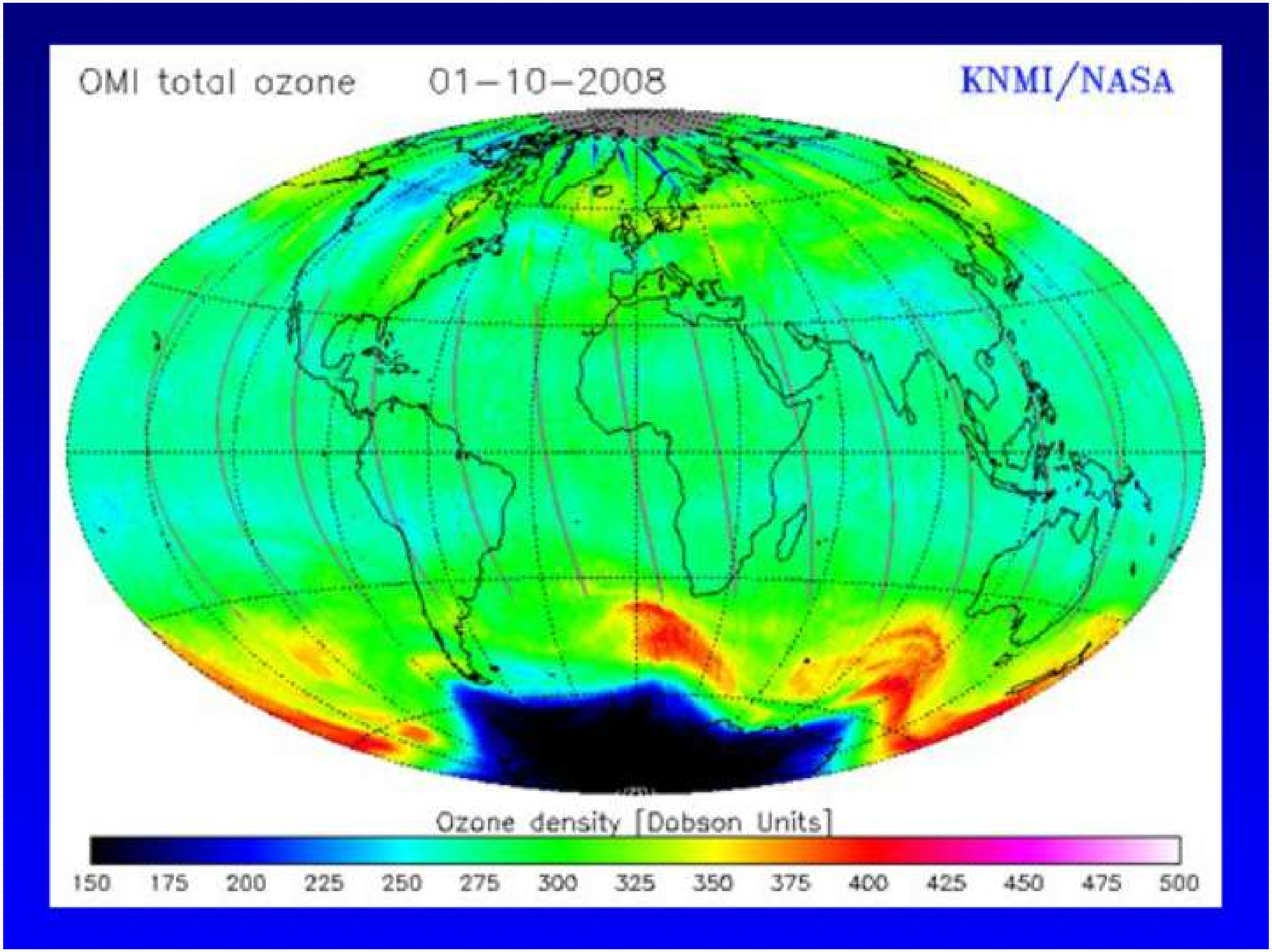
OMI aerosol products

	Near-UV method	Multi-wavelength method
Maintainer:	Omar Torres (GSFC)	Pepijn Veefkind (KNMI)
Heritage:	TOMS	none (new)
Status:	Provisionally released	Ready for provisional release
λ's employed:	342.5 and 388 nm	~8 λ's between 340 and 500 nm
Main retrievals:	Absorption optical thickness, UV aerosol absorbing index	Extinction optical thickness, Aerosol type
Principle:	1) Determine *aerosol index*	1) Fit spectrum to find AOT for ~50 aerosol models
	2) Determine aerosol type from aerosol index and aerosol climatology	2) Choose best aerosol model based on RMS error (χ^2)
	3) Determine AOT and SSA from lookup tables for the aerosol type	3) Spread in AOTs for different models gives indication for accuracy

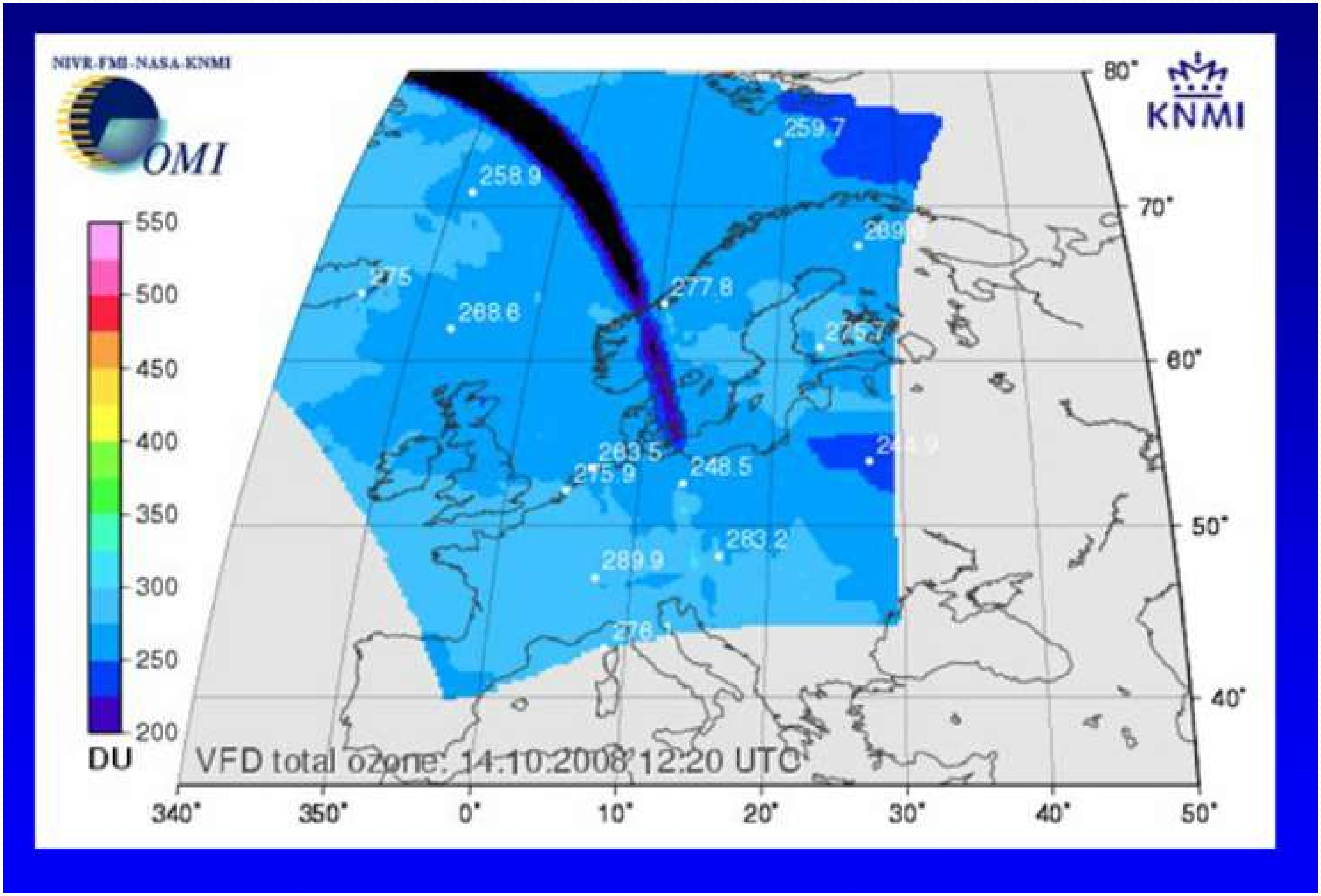
OMI Row Anomaly - 2007

- A row anomaly was discovered in September 2007. This anomaly has persisted since then.
- On May 19th 2008, a new row anomaly was discovered.
- Both row anomalies impact specific CCD rows (is specific part of the OMI field of view).
  - 2007 anomaly: 2 rows affected for complete illuminated orbit
  - 2008 anomaly: 4 rows affected for only northern part of illuminated orbit
- Data users must carefully read the L1b readme file on how to treat the affected CCD rows in their retrieval algorithms.

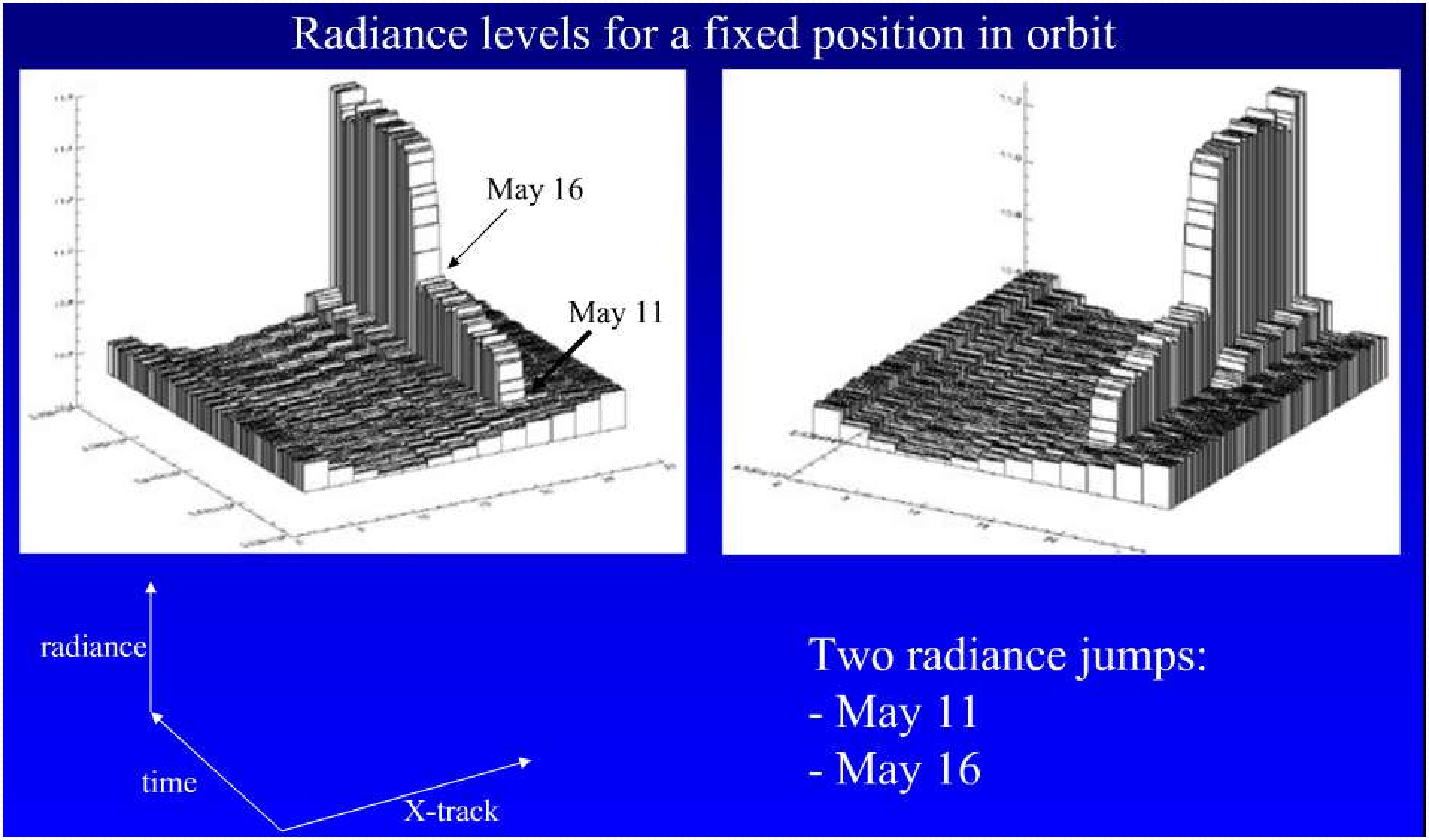
Row Anomaly Impact on L2



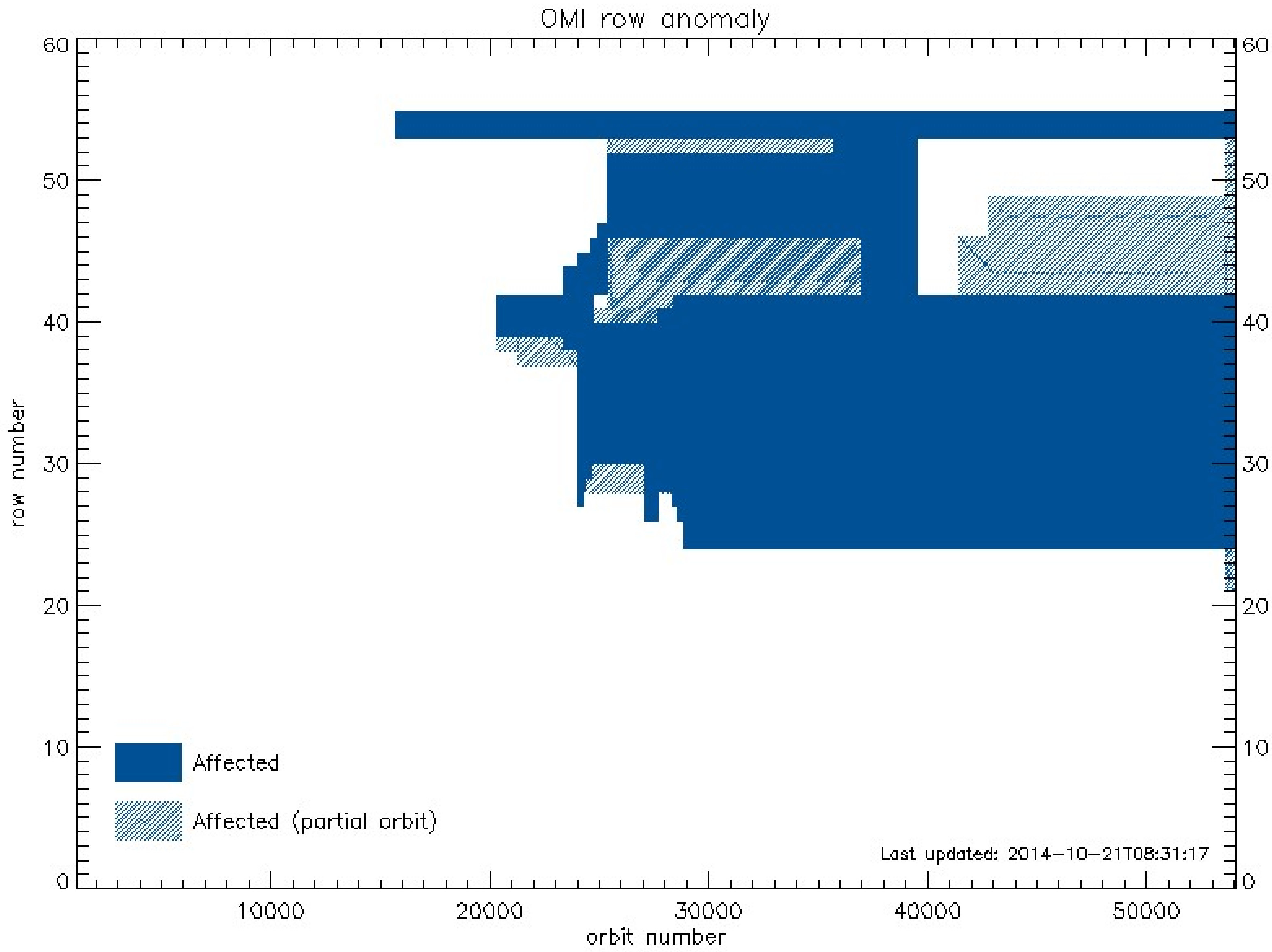
Row Anomaly Impact on L2



Row Anomaly: When did it start?



Row Anomaly up to 2014



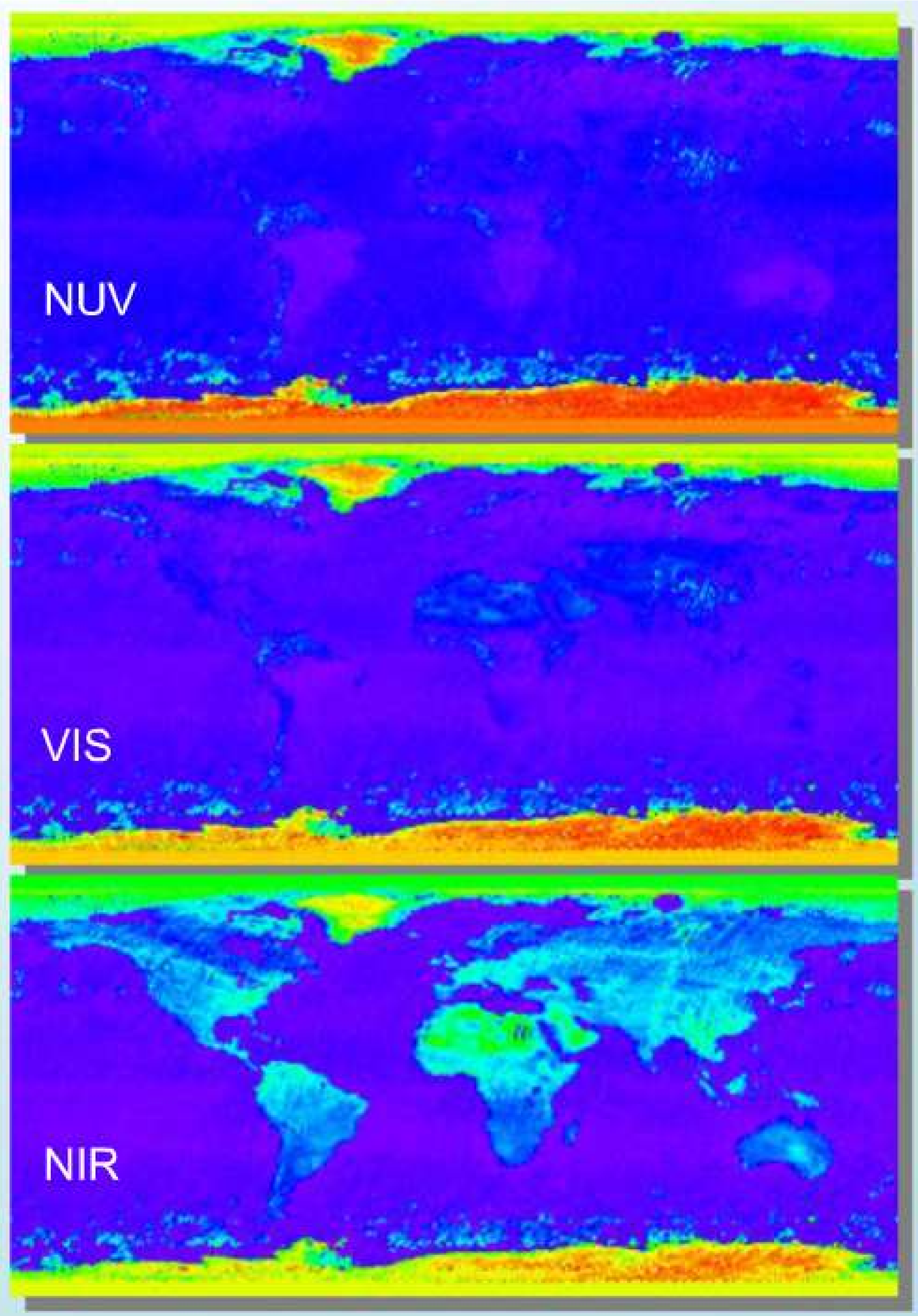
OMI Row Anomaly - Summary

- A small piece of MLI close to the nadir and solar aperture has moved into the field of view of the nadir port.
- The anomaly causes a partial blocking of the field of view of the UV2 and VIS channels
- The anomaly causes a reflection of sunlight into the field of view of the UV1 channel.
- Constant timing of the anomaly indicates that the blockage / reflection is located close (a few centimeters) to the nadir and solar aperture.
- Correcting for the anomaly is complicated because it is dependent on:
  - orbit position
  - solar beta angle
  - channel
  - wavelength

Advantages of Near UV

- Aerosol types can be distinguished from surface spectral absorption characteristics

- Low surface albedo over land.



OMI near UV Products 388 nm

-Aerosol Index (AI)
Qualitative Indicator of the presence of absorbing aerosols:
smoke, desert dust, volcanic ash. It is calculated using observations at two wavelengths in the range 330-390 nm.

-Extinction Optical Depth, AOD
A measure of the aerosol capacity to extinguish radiation by scattering and absorption.
It is related to the total column amount of aerosol particles in the atmosphere.

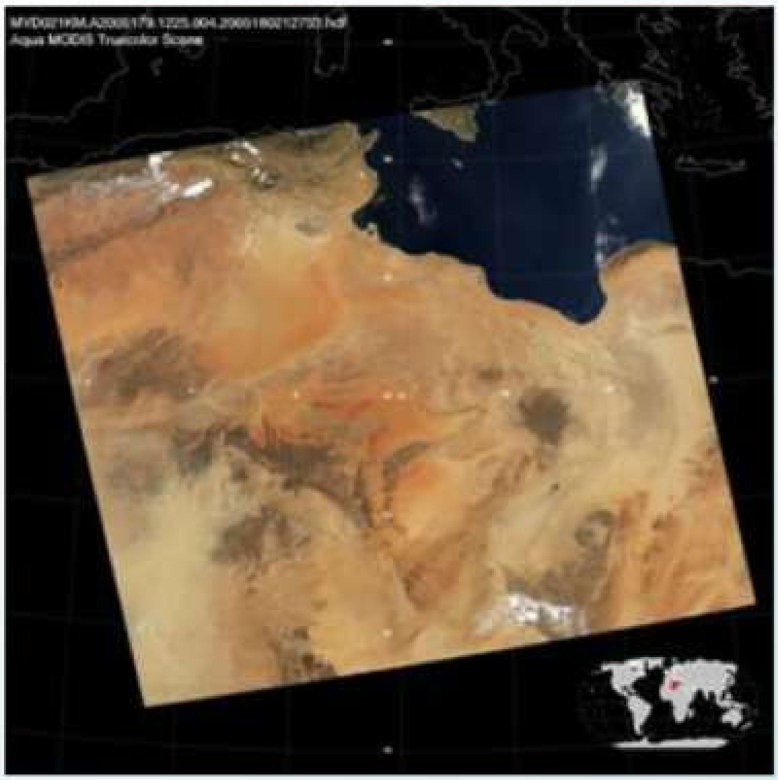
-Single Scattering Albedo, SSA
A measure of the fractional extinction due to scattering of incident solar radiation.
Varies between 0 (all absorption, no scattering) and 1 (all scattering, no absorption)
Typical variability range (0.6 to 1.0)

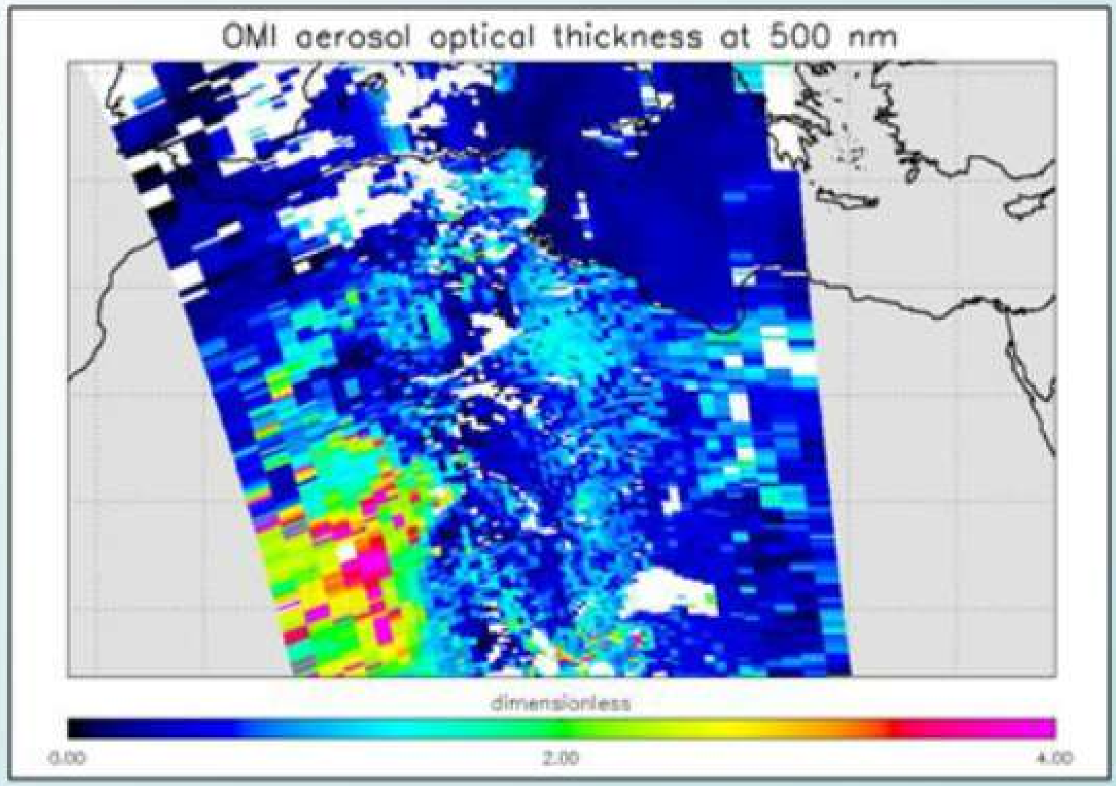
-Absorption Optical Depth, AAOD
The actual optical depth resulting from the absorption process. It is easily calculated as

$$AAOD = AOD \times (1.0 - SSA)$$

Multi-Wavelength Aerosol Product Example

Case study: Sahara, 28 June 2006

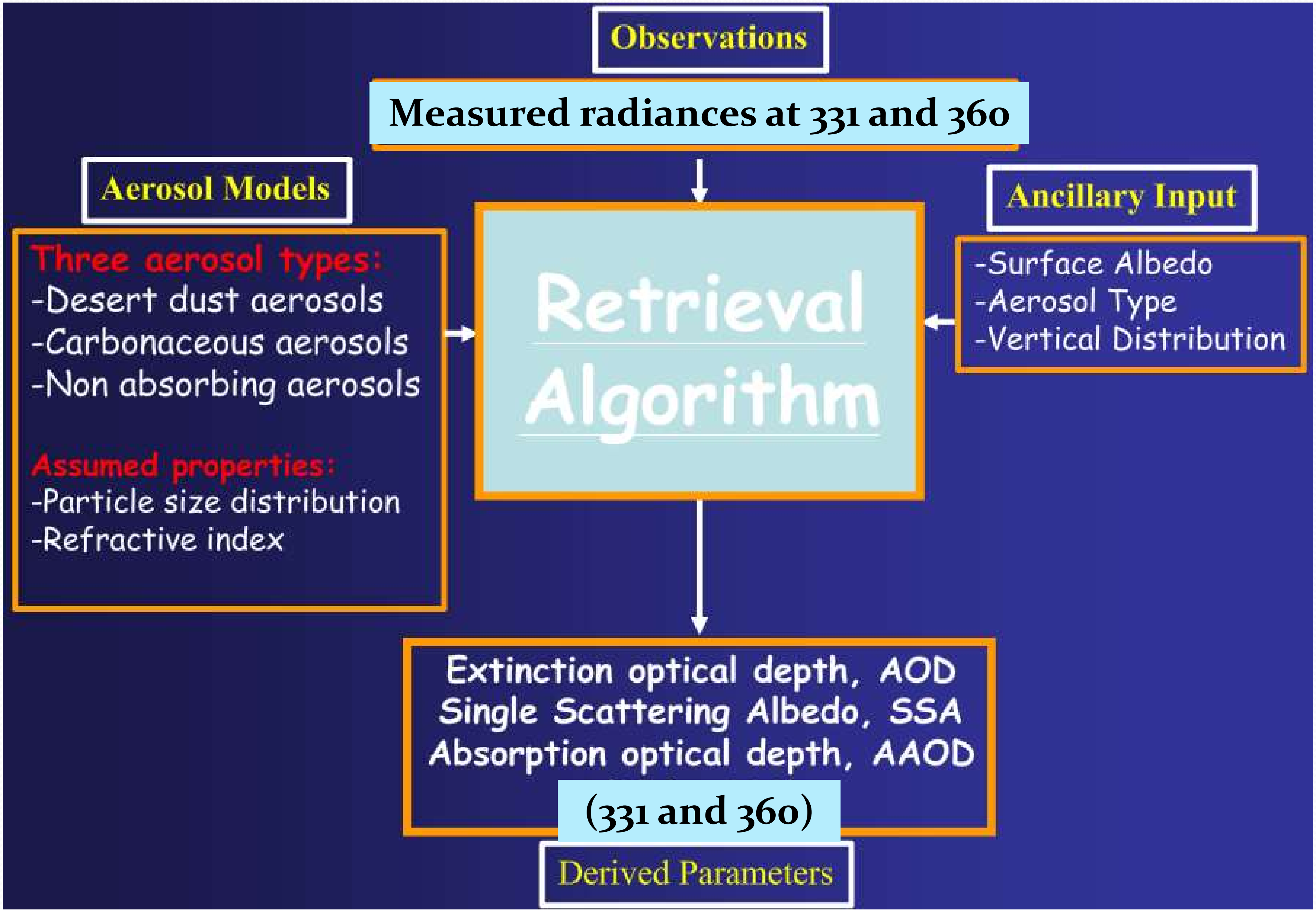




MODIS image

OMI multi-wavelength AOT

Inversion Proceedure



Absorbing Aerosol Index

- The absorbing aerosol **index** (AI) from the difference between the measured (includes aerosols effects) **spectral contrast of the 360 and 331 nm wavelength radiances** and the contrast calculated from the radiative transfer theory for a pure molecular (Rayleigh particles) atmosphere.

- In the current version 8 Nimbus 7 TOMS (1979-1993) and Earth Probe TOMS (1996-2006) and version 2 Aura OMI (2004-present) algorithms, it is mathematically defined as:

$$AI = 100 \{ \log_{10}[(I_{360}/I_{331})_{meas}] - \log_{10}[(I_{360}/I_{331})_{calc}] \}$$

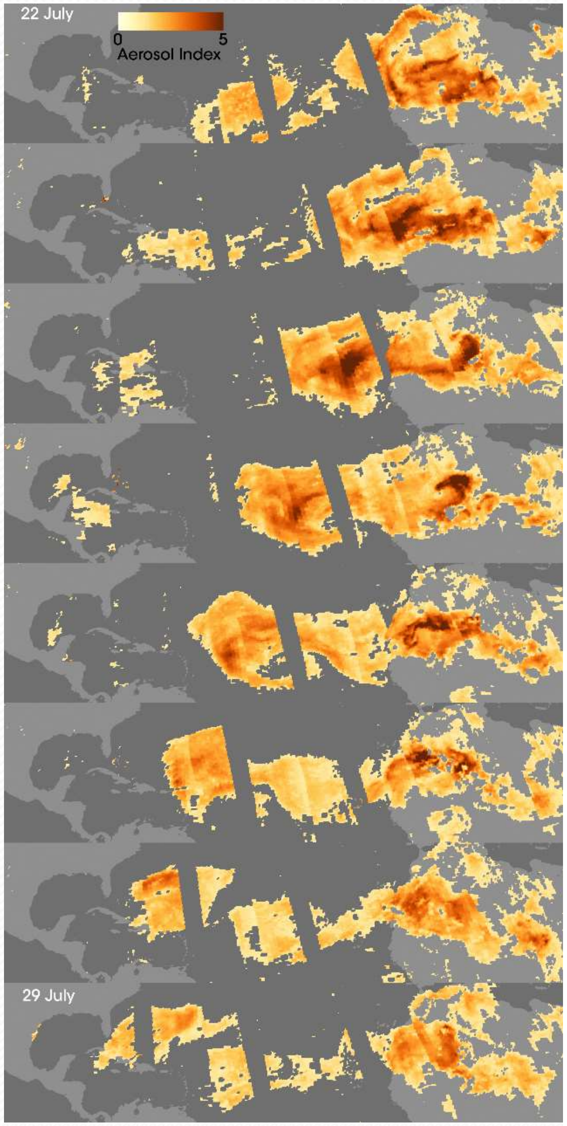
  - Since $I_{360\ calc}$ calculation uses reflectivity derived from the 331 nm measurements, the Aerosol Index definition essentially simplifies to:

$$AI = 100 \log_{10} (I_{360\_meas} / I_{360\_calc})$$

Aerosol Index

- The Aerosol Index **detects dust, smoke and volcanic ash over all terrestrial surfaces including deserts and snow-ice covered surfaces. These aerosol types are also detected intermingled with clouds and above cloud decks**.

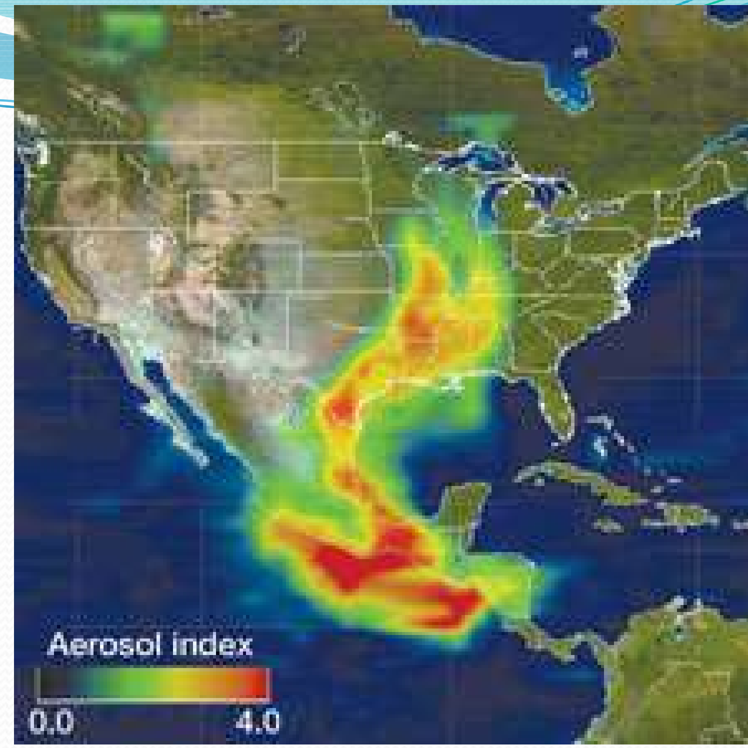
- The **AI can differentiate very well between absorbing and non absorbing aerosols**, because it provides a measure of **absorption of UV radiation by smoke and desert dust**.

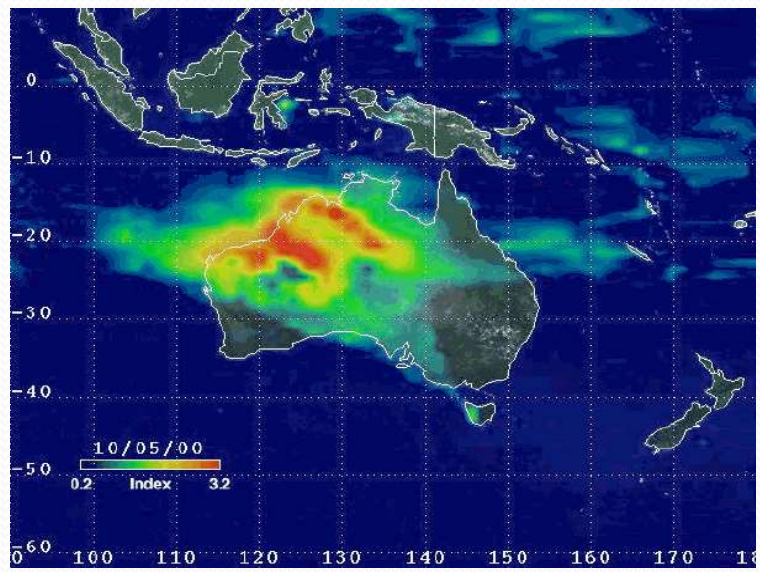


Properties of AI

- AI **positive** values are associated with **UV-absorbing aerosols**, mainly mineral dust, smoke and volcanic aerosols.

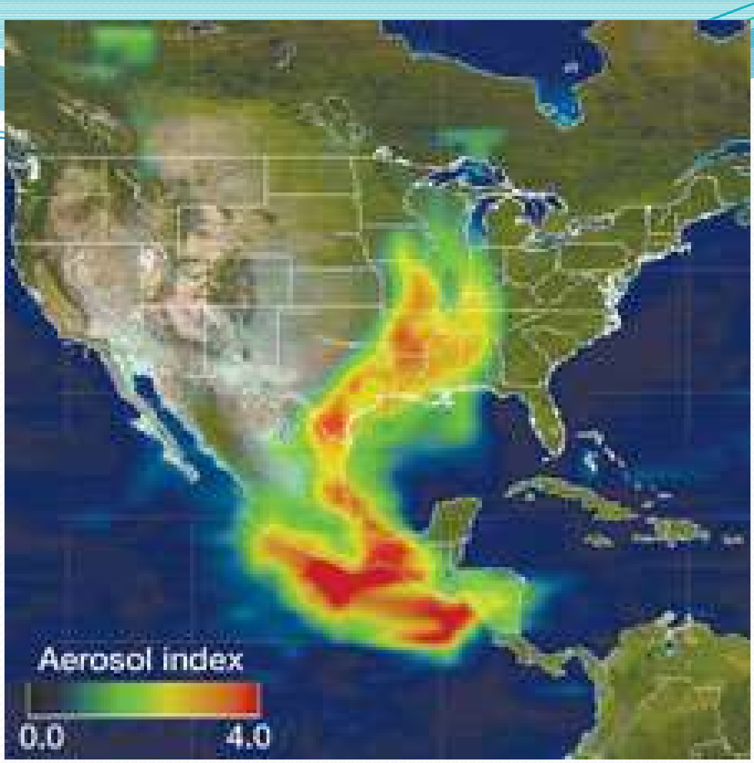
- However, **negative** values are associated with **non-absorbing aerosols** (for example, sulfate and sea salt particles) from both natural and anthropogenic sources (**Torres et al, 1998**) with sizes less than 0.2 microns. In practice, it is difficult to separate aerosol effects from other non-aerosol effects that also produce negative AI values



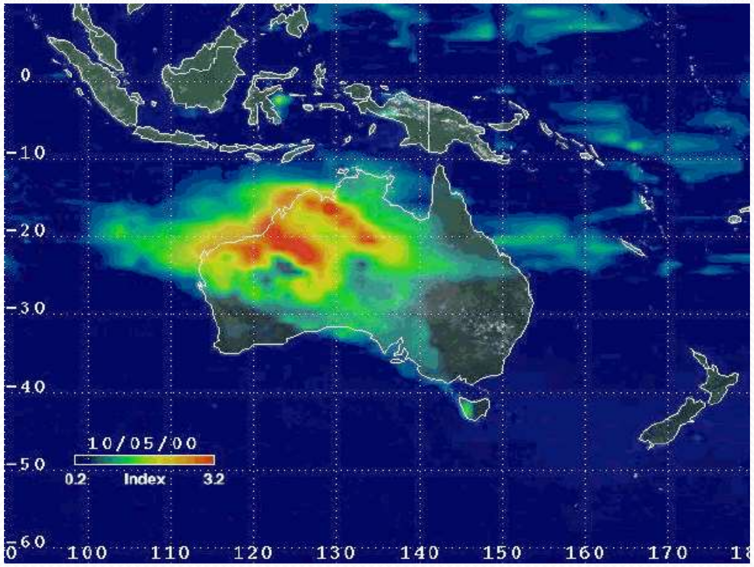


Properties of AI

- **Near zero values indicate cloud presence.** In interpreting the results care has to be taken that some surface effects, such as sea-glint and ocean color, can also enhance the AI.

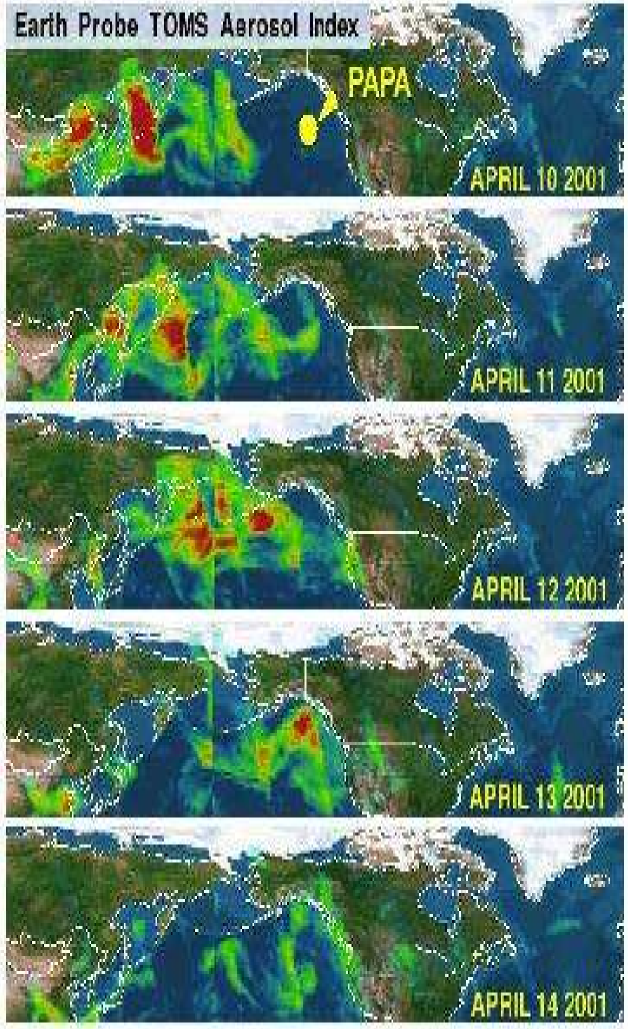


- **Magnitude of positive AI** depends mainly on **aerosol absorption optical depth** and height of aerosol layer and also depends on **aerosol microphysical properties**.



Properties of Aerosol Index

- **Detects absorbing aerosols over all surface types**: ocean, vegetated surfaces, deserts, snow/ice, etc.
- Detects absorbing aerosols under partial cloudiness conditions and above clouds
- Aerosol Index is **insensitive to carbonaceous aerosols** (smoke) below **~2 km**
- Large sensitivity to low altitude desert aerosols (~ 0.5 km)
- **Aerosol Index** signal meaningful for values larger than 0.5
- **Direct conversion of AI** to any physically meaningful parameter is not possible because of multiple dependencies (AOD, SSA, height, etc).



Applications

- The Aerosol Index, though initially computed for the correction of aerosol induced errors in the retrieval of total ozone (Torres and Bhartia, 1999), has been extensively used in a variety of other applications.

- In particular, NASA and other scientists have used AI in:
  - Mapping and analyzing the global distribution of UV-absorbing aerosols (*Herman et al.*, 1997)
  - studying the aerosol properties (*Torres et al.*,1998, 2001)
  - estimating UV reduction at the earth's surface (Herman et al. 1999; Krotkov et al. 1998)
  - estimating the radiative forcing effects of mineral aerosols and the smoke layer above the cloud deck, in conjunction with Earth Radiation Budget Experiment (ERBE) data (Hsu et al. 2000).

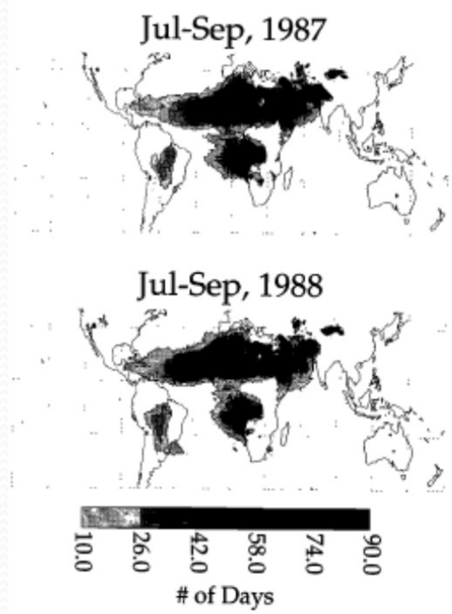
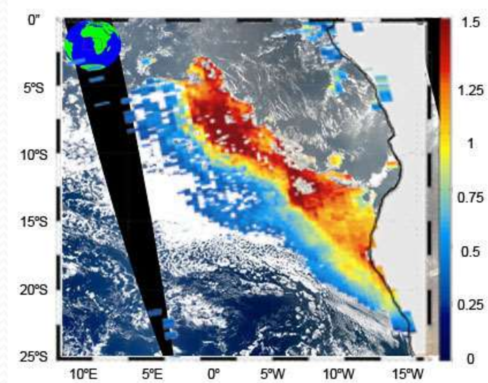


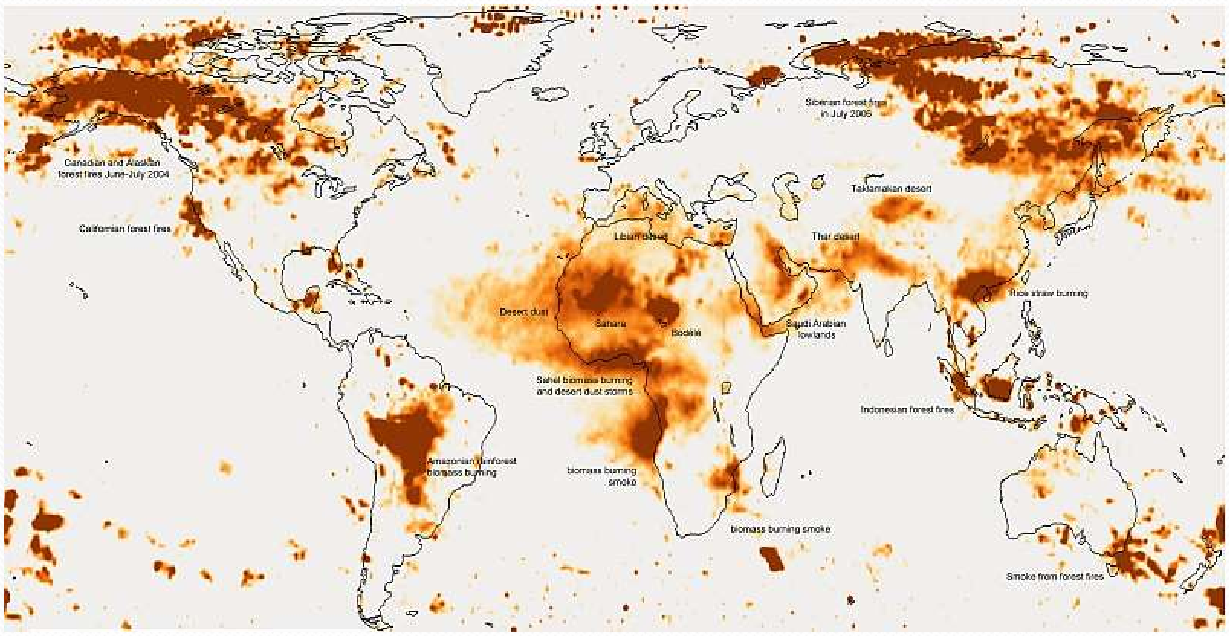
Figure 4. Maps of UV-absorbing aerosol occurrence during northern hemisphere summer months (July, August, September 1987 and 1988).



Applications – Soil Dust Sources

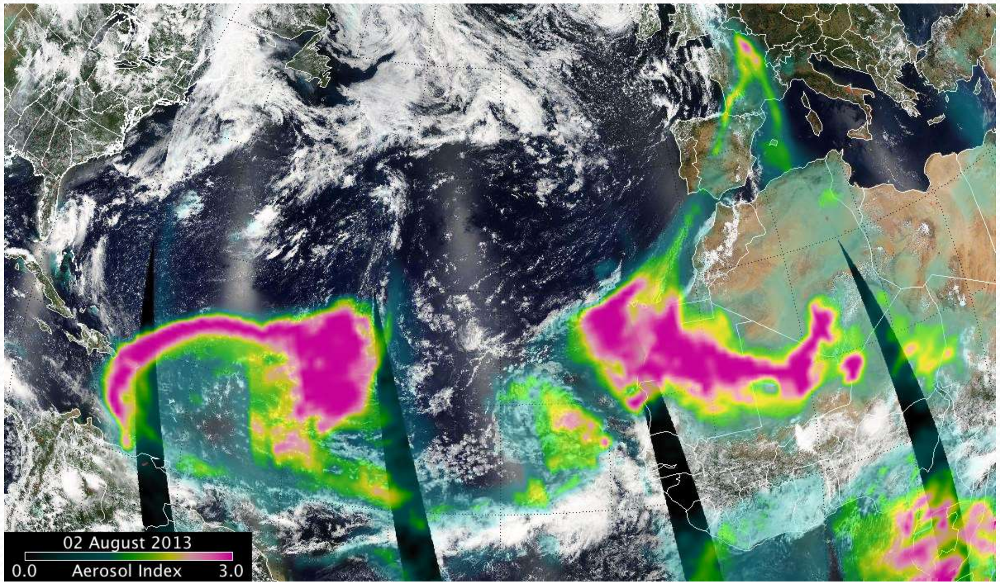
- studying the inter-annual variability of soil dust aerosols in conjunction with Advanced Very High Resolution Radiometer (AVHRR) data (Cakmur et al. 2001)

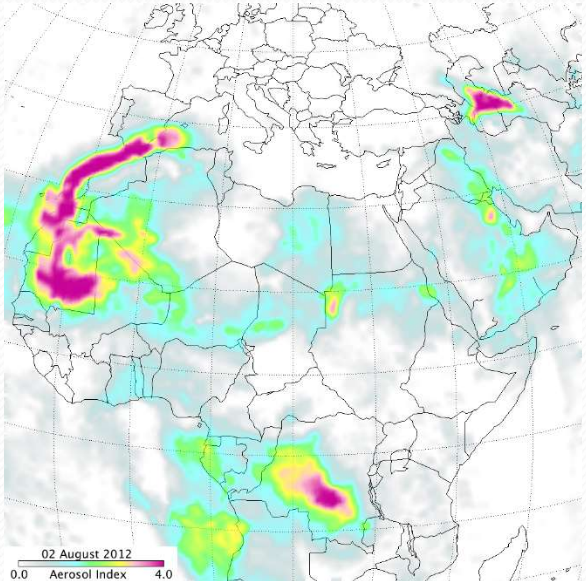
- environmental characterization of soil dust sources (Prospero et al. 2002)



Applications – Dust Impacts

- monitoring of health hazard microorganisms transported by African dust across the Atlantic Ocean) and identifying microbes and pollutants in the African soil dust(Prospero, 2004)
- monitoring of the ecosystems, for example the decline of coral reefs caused by the dust from Saharan desert dumping into the North Atlantic Ocean(Shinn, et al.,2000)



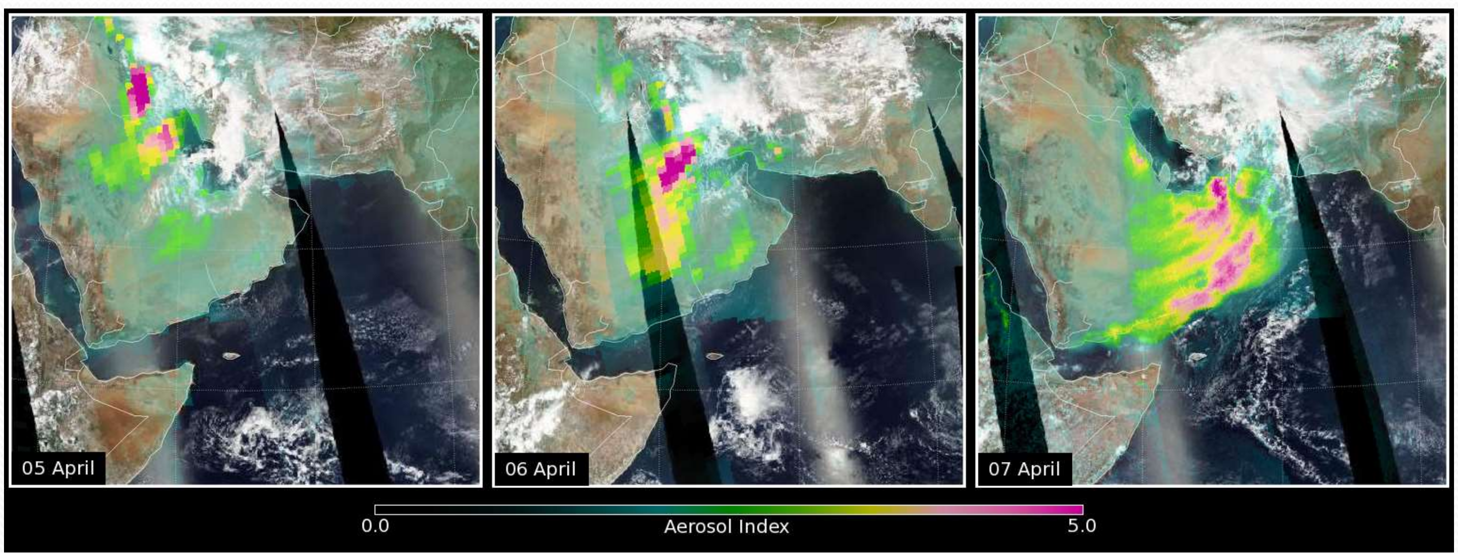


Applications - DUST

- identifying the dust aerosol induced biases in retrieved sea surface temperature and devising a correction based on the relationship between errors in AVHRR-derived SST and the TOMS AI.(Diaz et al. 2001)

- initializing forecasting model of dust aerosol (*Alpert et al.*, 2002)

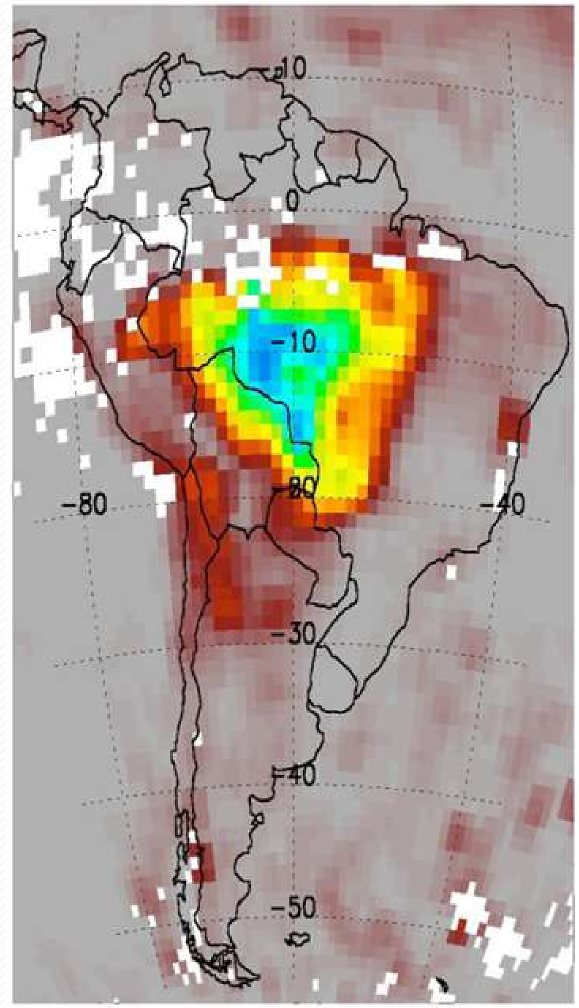
- developing a global dust source function for aerosol transport model (*Ginoux et al.*, 2001), and validating dust distribution at the regional and global scale.



Applications – Biomass Burning Smoke

- monitoring of transport of biomass burning emissions deeply injected into the lower stratosphere, followed by the phenomenon of pyrocumulonimbus events (Fromm et al, 2005).

- Although the AI is a very useful qualitative indicator of aerosol presence, an **actual inversion procedure is needed to interpret the measured radiance departures from a Rayleigh atmosphere model, in terms of traditional aerosol parameters such as optical depth, τ, and single scattering albedo, ωo** (Torres et al. 1998).



Applications

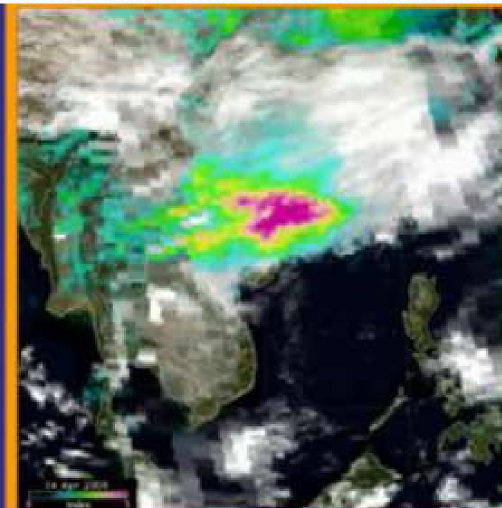
-Validation tool for transport models

-Separation of carbonaceous from sulfate aerosols

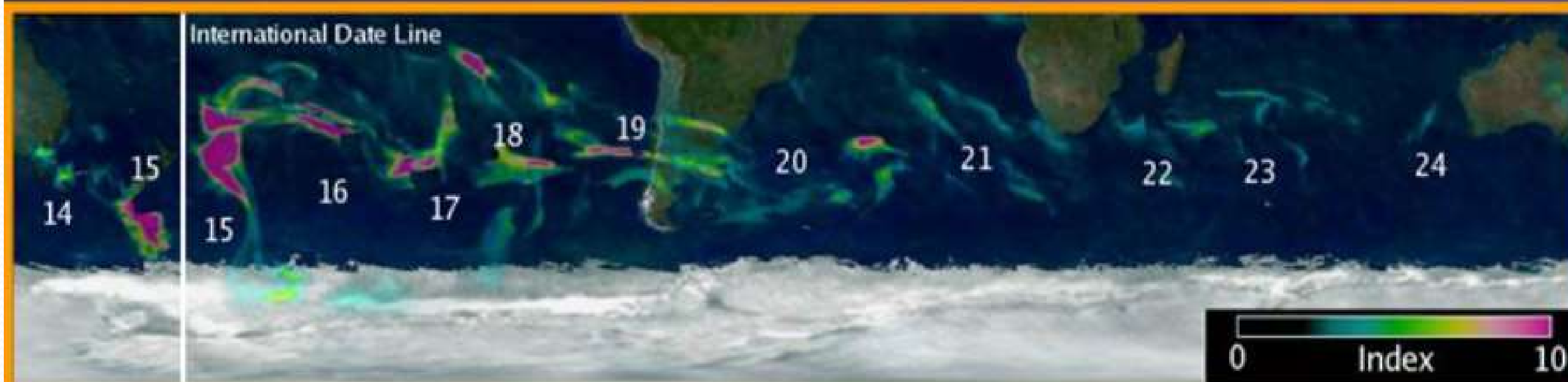
-Identification of aerosols above PBL (i.e., PBL aerosols are not detectable by AI)

-Tracking of aerosol plumes above clouds and over ice/snow

-Detection of UTLS (upper troposphere/lower stratosphere aerosols)

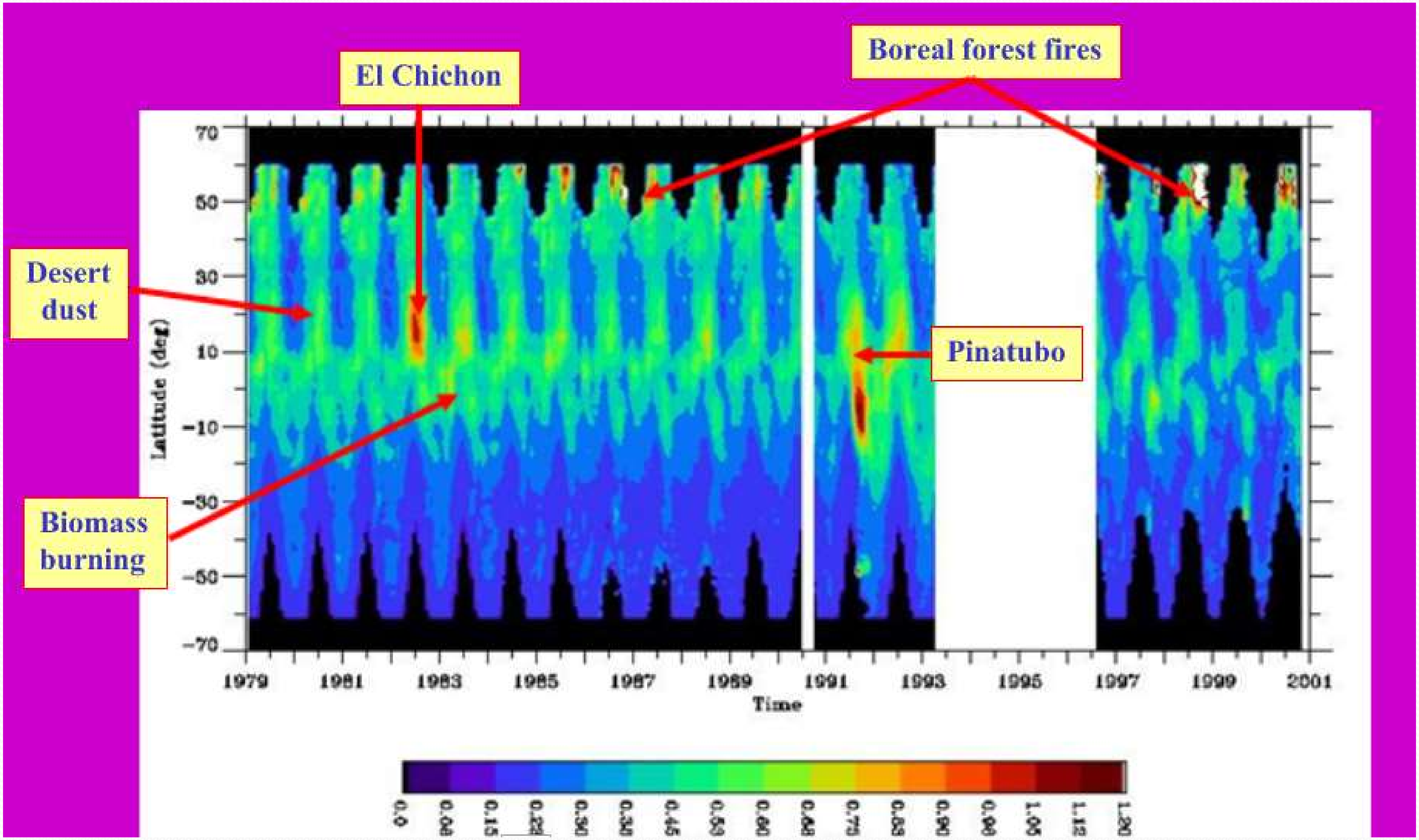


Aerosol s over clouds: April 14, 2006

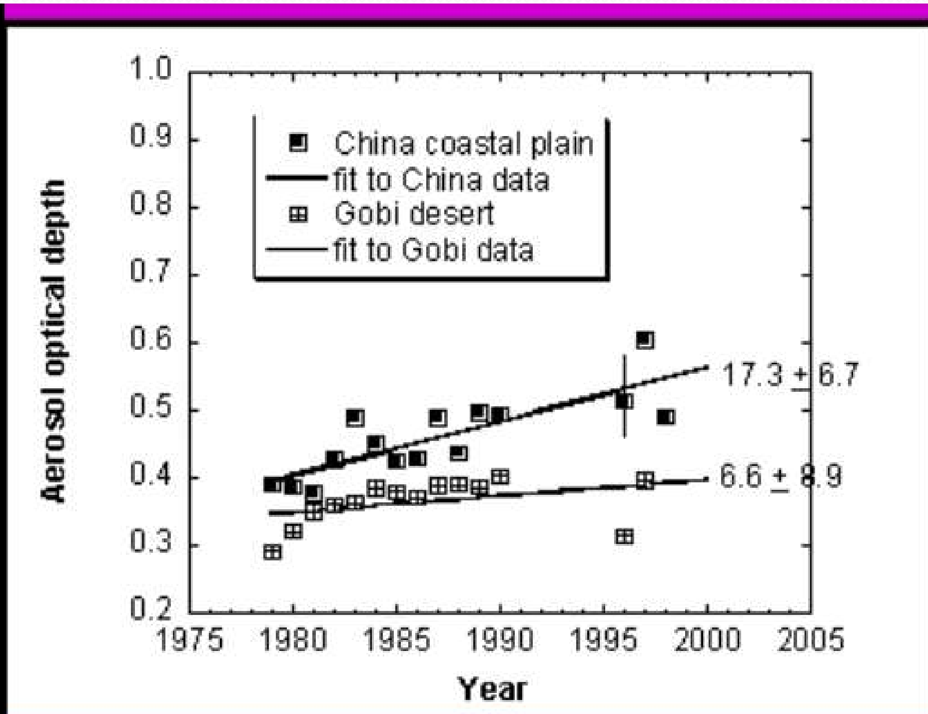


Transport around the globe of a high altitude smoke layer generated by the Australian fires in December 2006. Numbers indicate the day of the month.

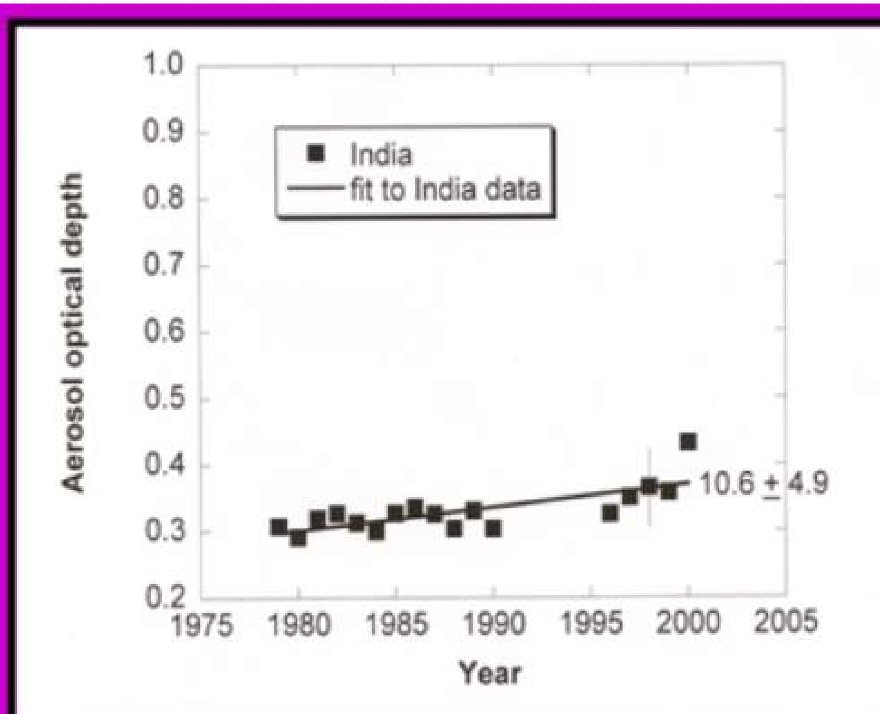
Long Term History



Trends in Aerosol Optical Depth from TOMS



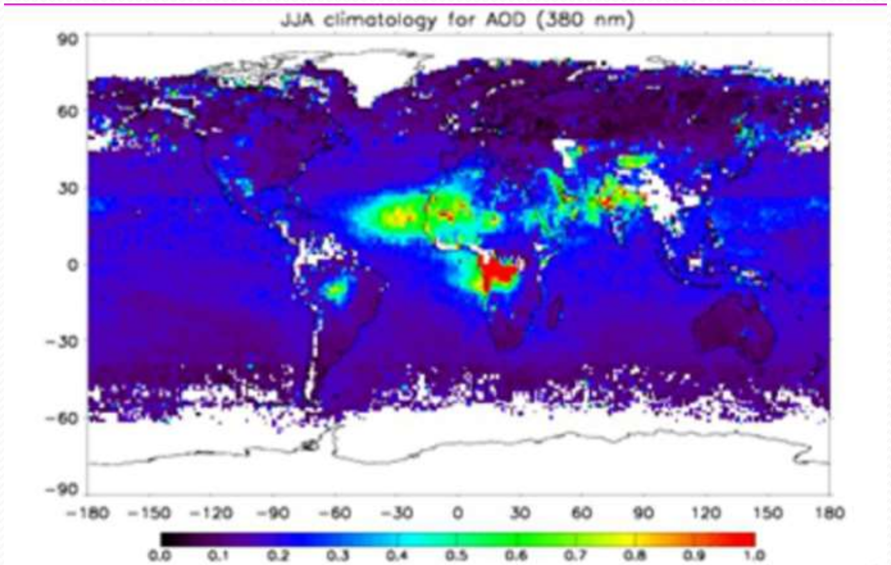
Winter aerosol load increase in China : 17.3%/decade



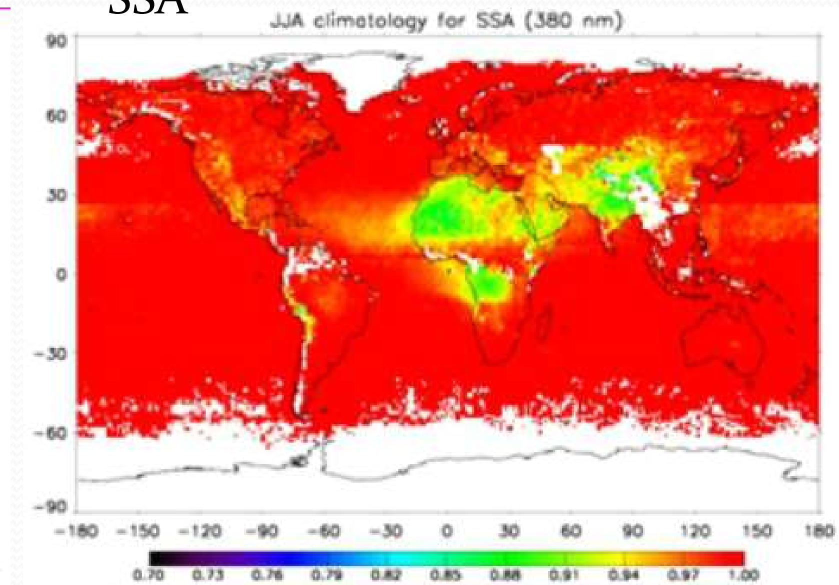
Winter aerosol load increase in India: 10.6%/decade

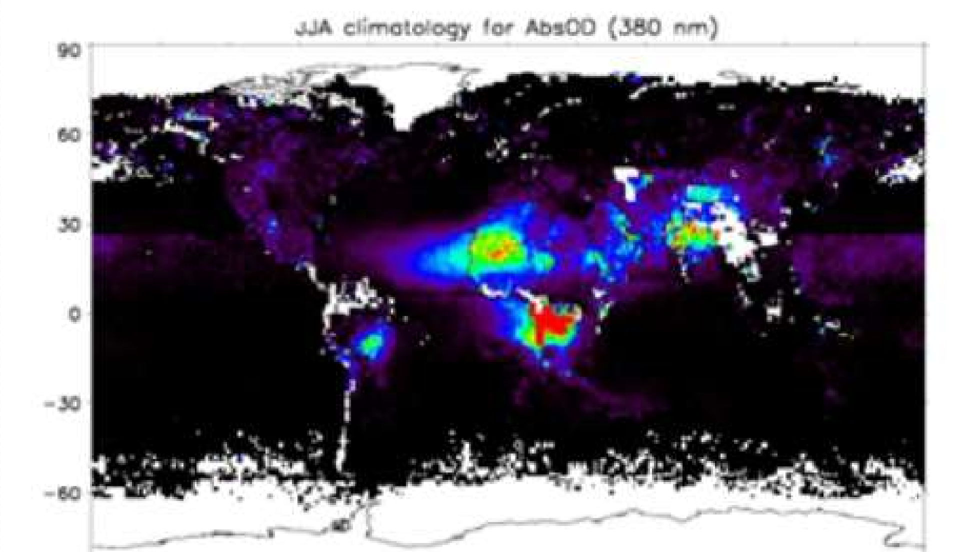
EP-TOMS Climatology (1996-2001)

AOD



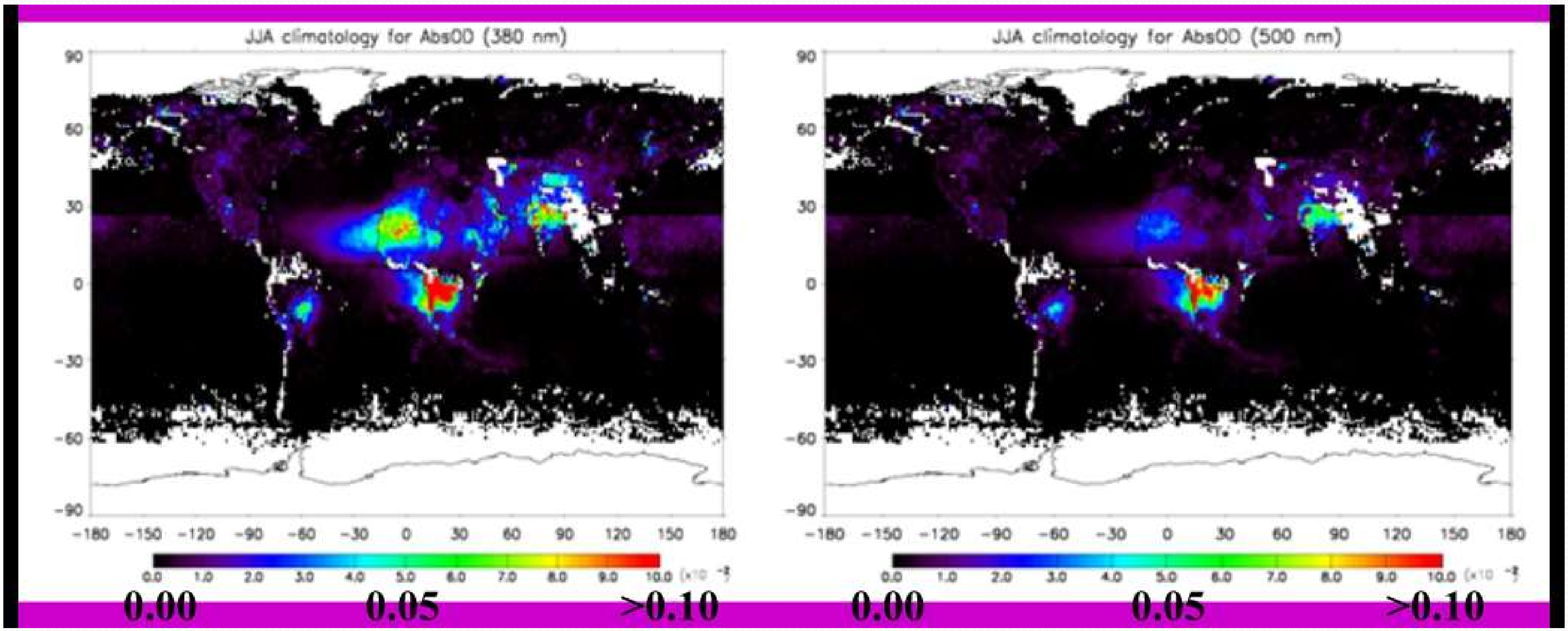
SSA



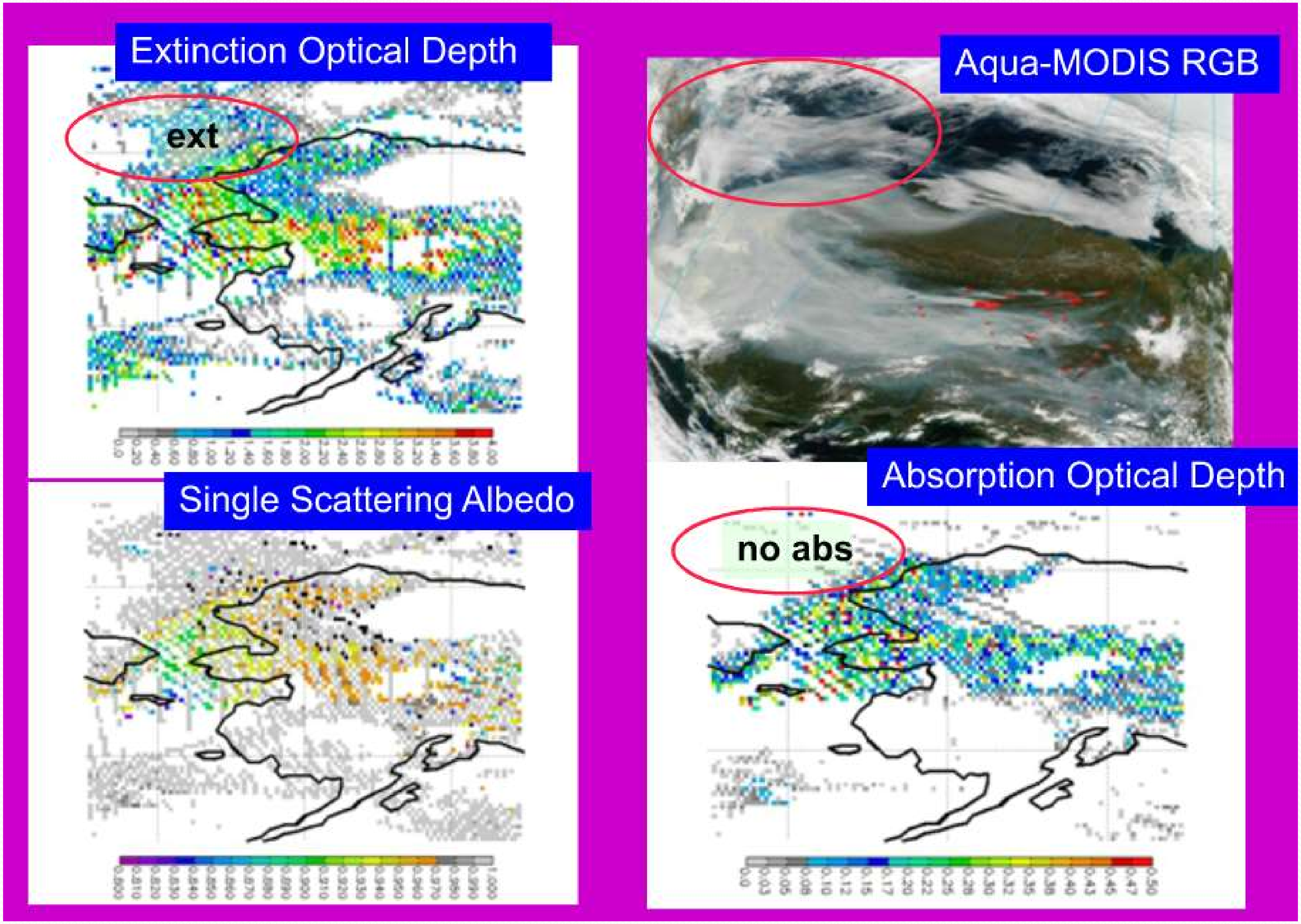


Absorption AOD –
Vertical column integral of spectral aerosol absorption coefficient: AAOD = exp(-K. Δz) where K is the absorption coefficient [km^{-1}] and Δz the vertical path [km]

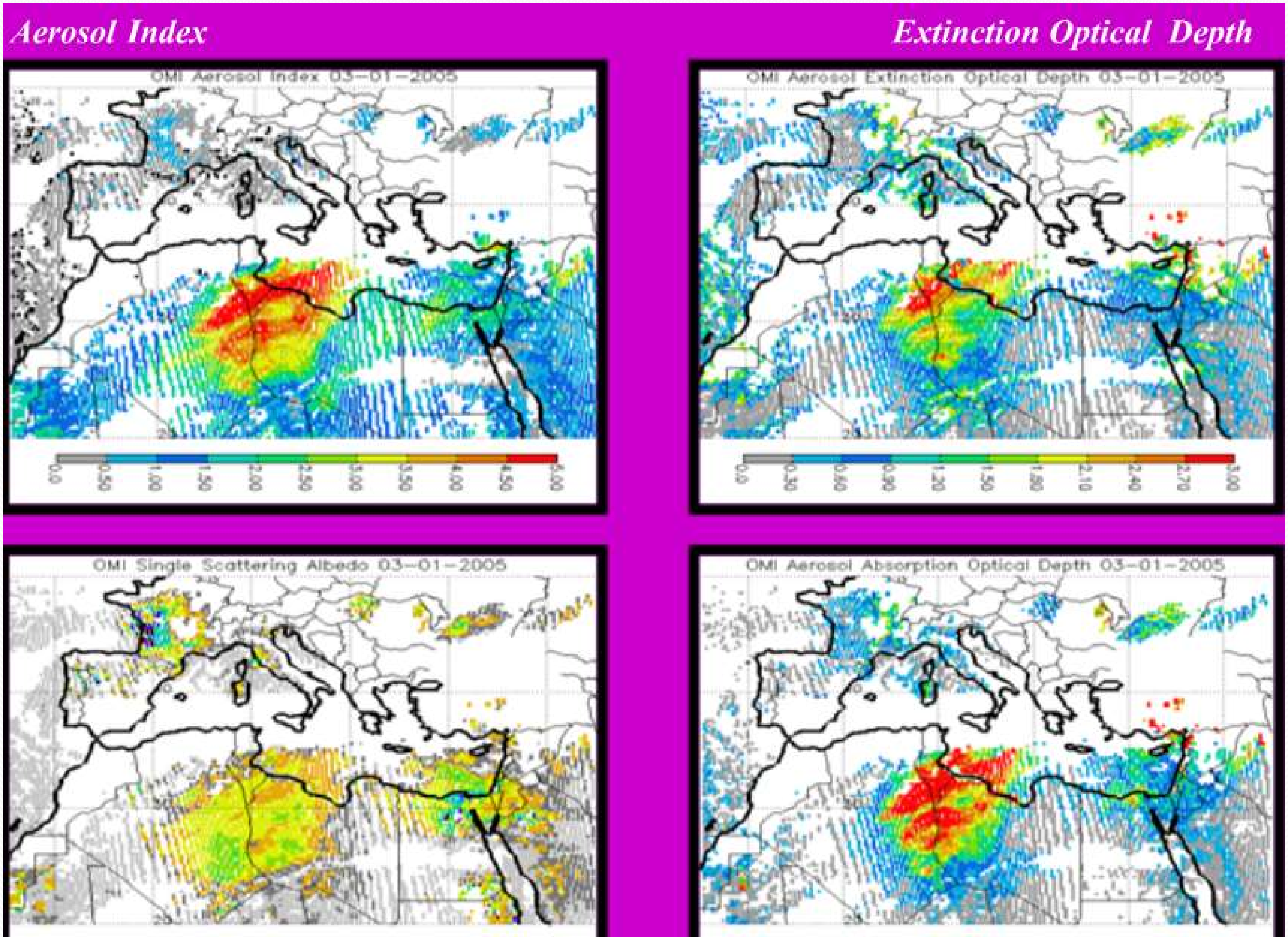
Seasonal Climatology at 380 nm and 500 nm



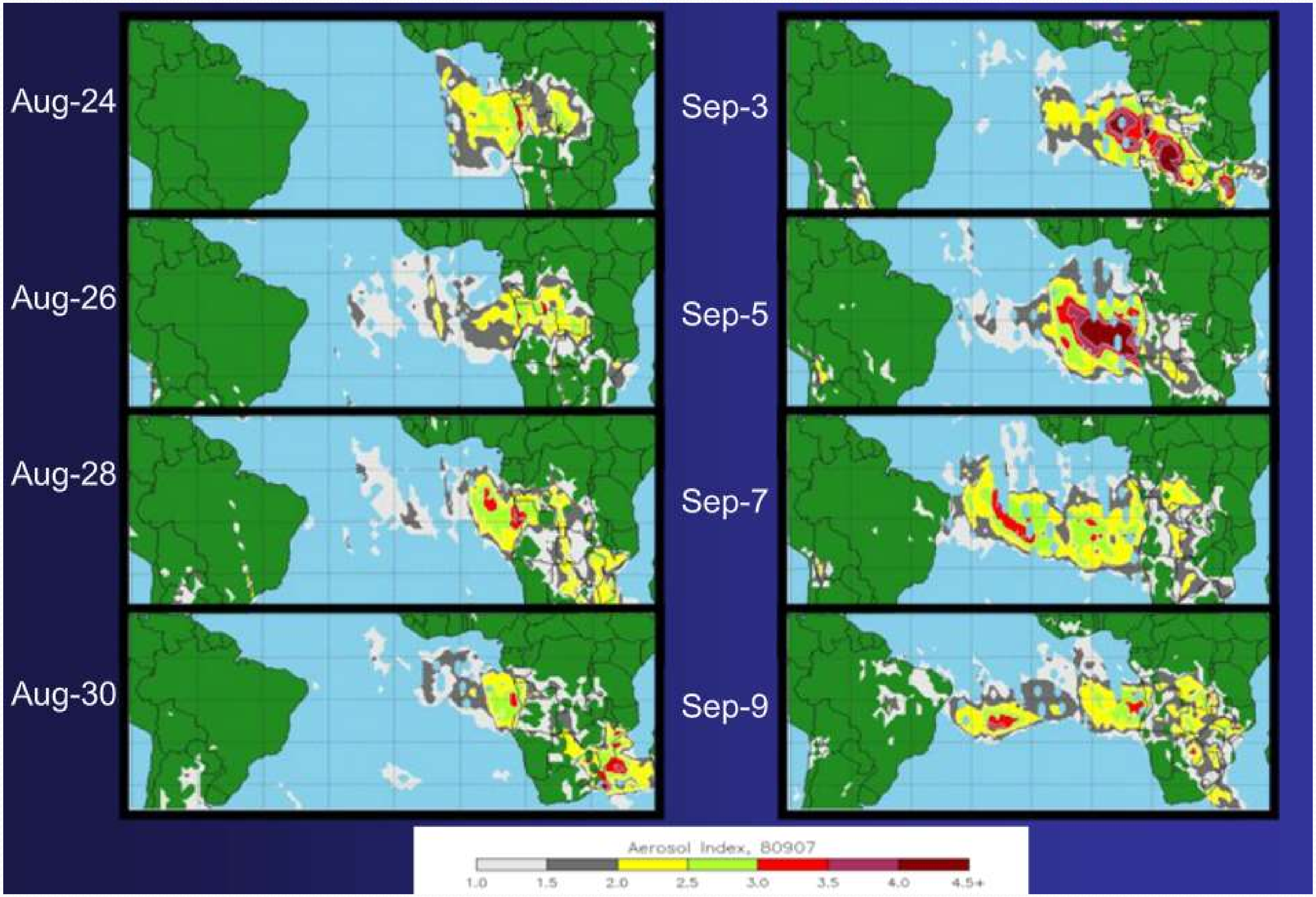
Example OMI Results - SMOKE



Dust Over Mediterranean

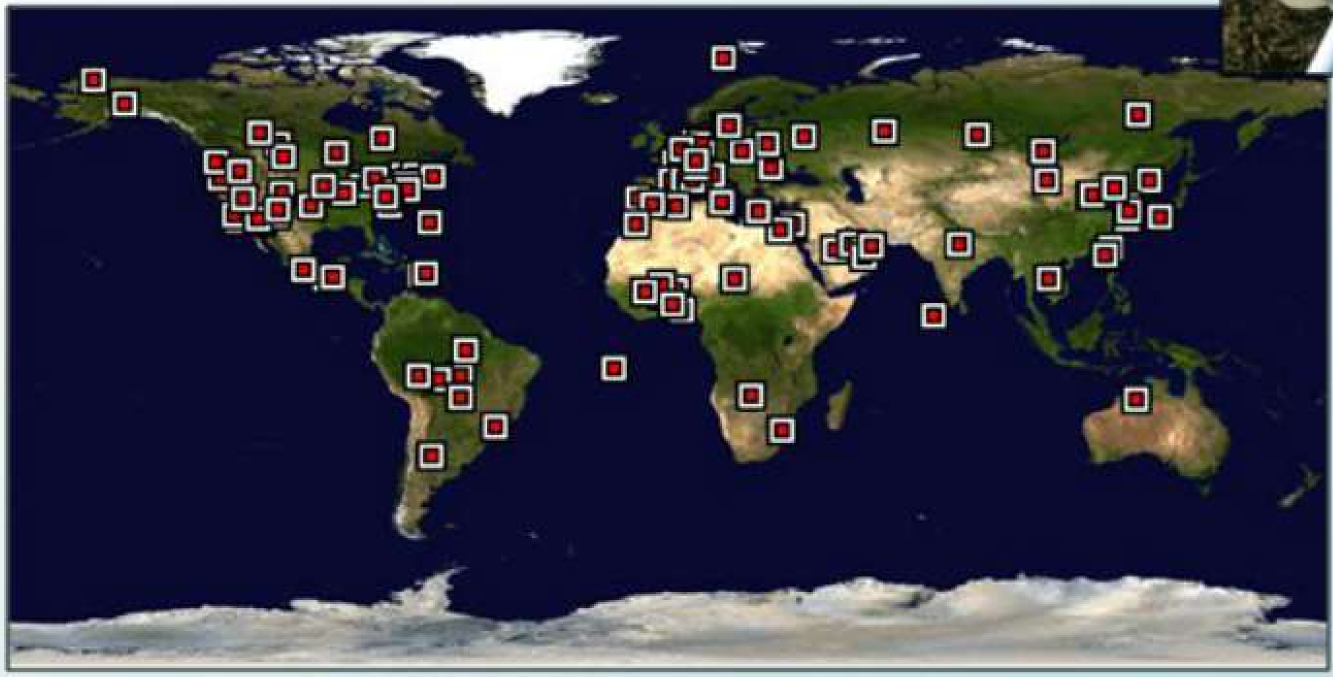


A case study: 2008 Trans-Atlantic aerosol transport in the SH.



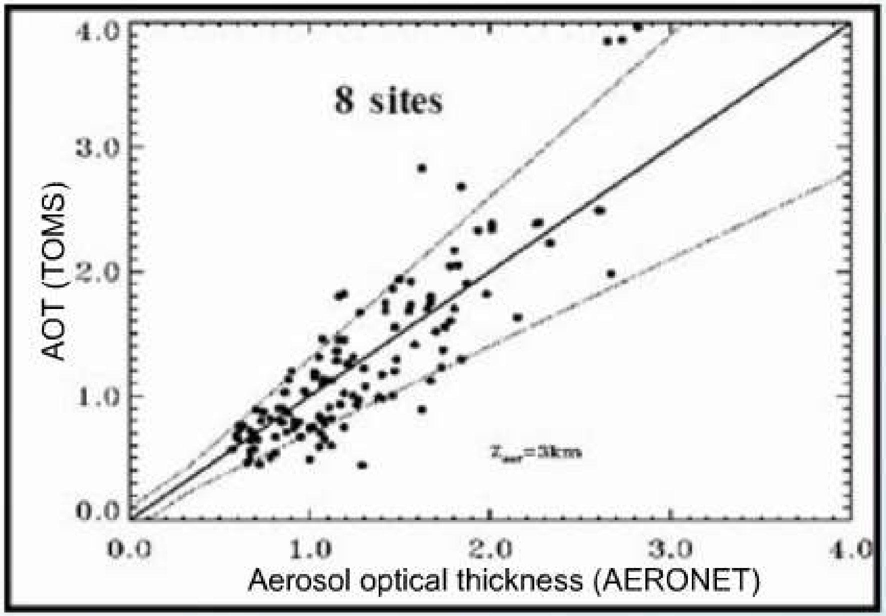
Validation: AERONET

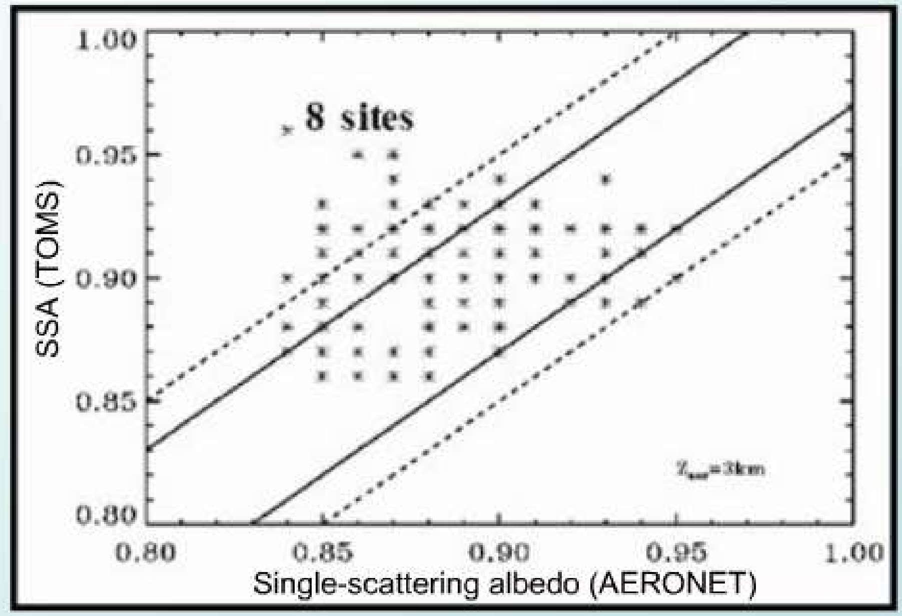
- Aerosol Robotic Network
- Sun photometers (CIMEL CE-318)
- Measure the AOT every 15 minutes (λ = 340 - 1020 nm)
- ~120 ground stations currently active



CIMEL λ = 340, 380, 412, 440, 443, 490, 500, 532, 551, 555, 667, 675, 870, 1020, 1640 nm

Near-UV Validation with TOMS



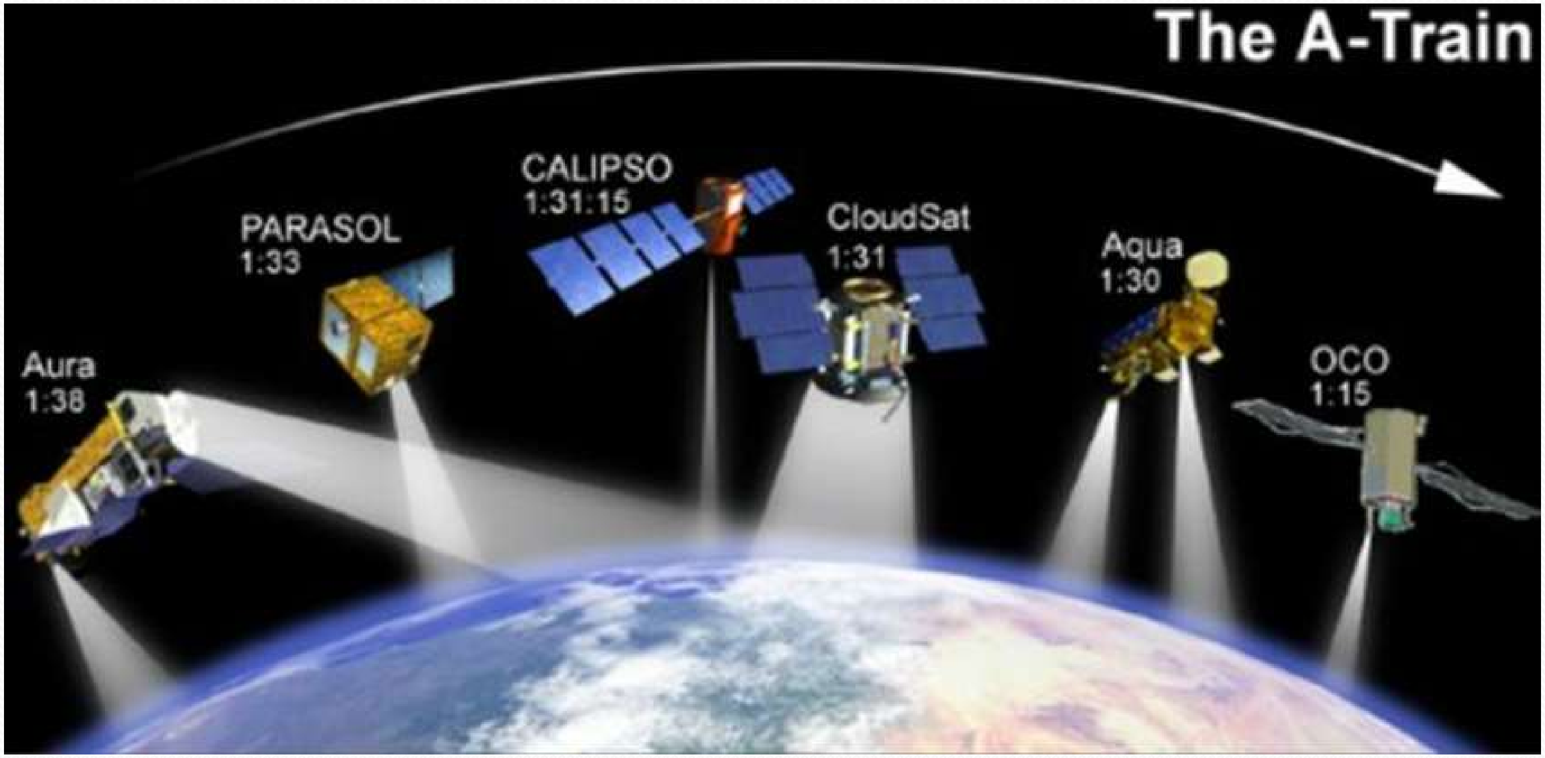


- 82% of points are within expected accuracy limits (0.1 or 30%)

- 63% within +/- 0.03
- 87% within +/- 0.05
- (Torres et al. 2005)

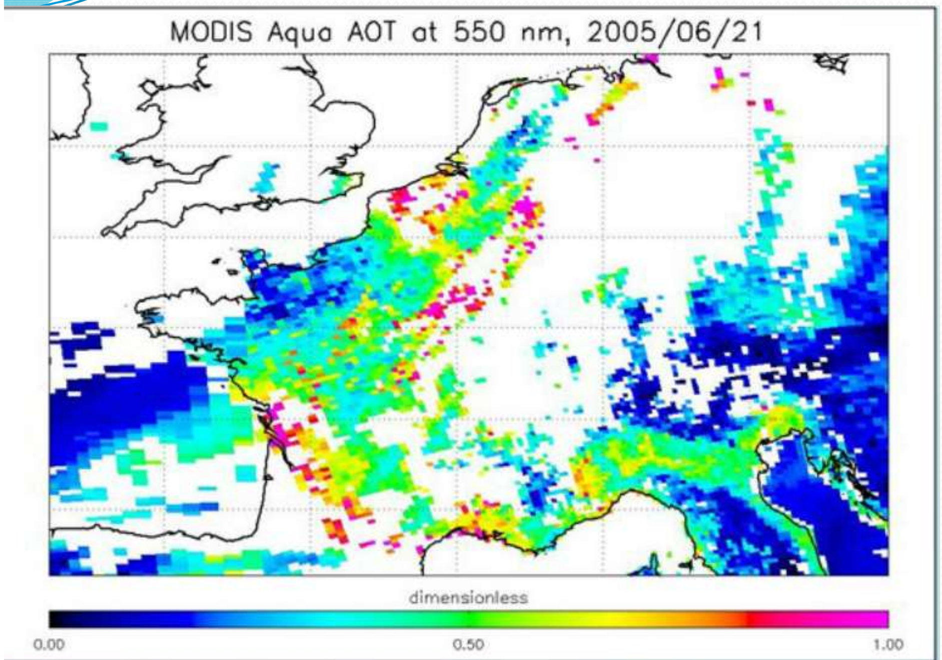
- Performance for OMI similar or better

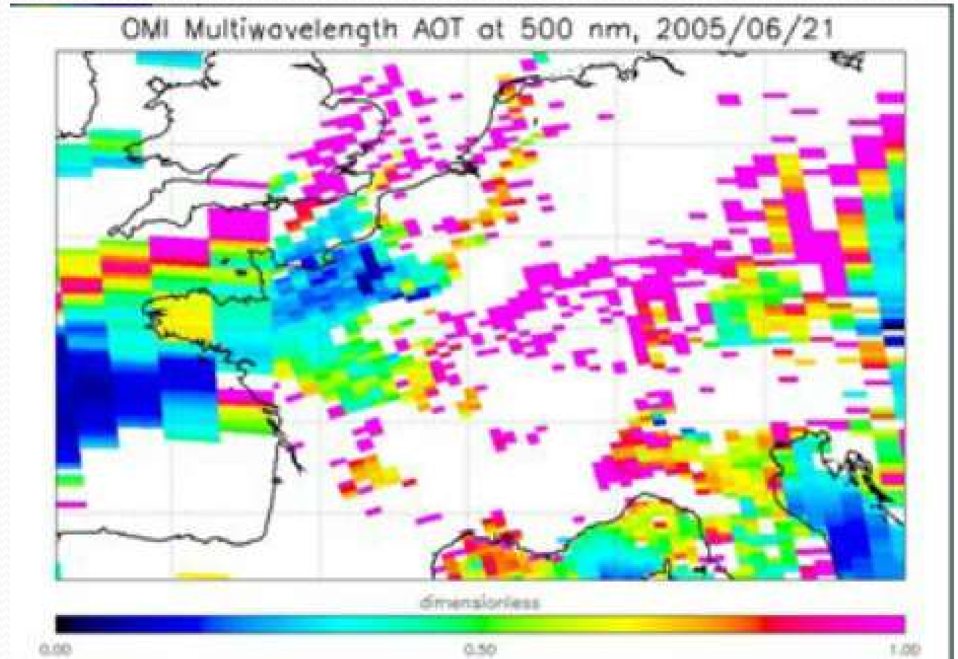
Potential A-Train Comparisons

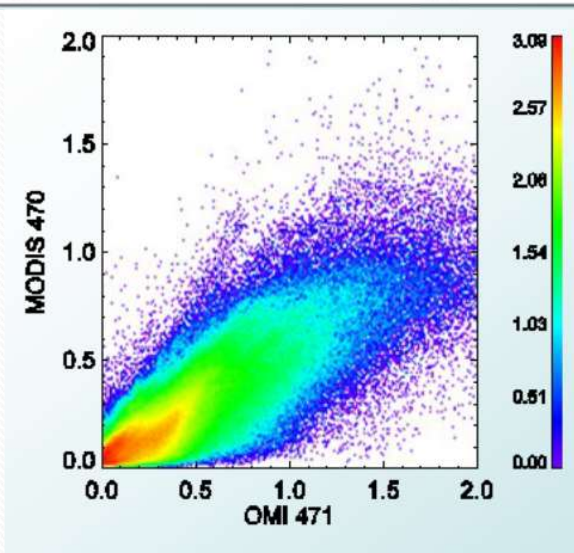


- Other instruments on the A-Train that observe aerosols:
  - on EOS-Aqua: MODIS and AIRS
  - on PARASOL: POLDER
  - on CALIPSO: CALIOP

Comparison with MODIS



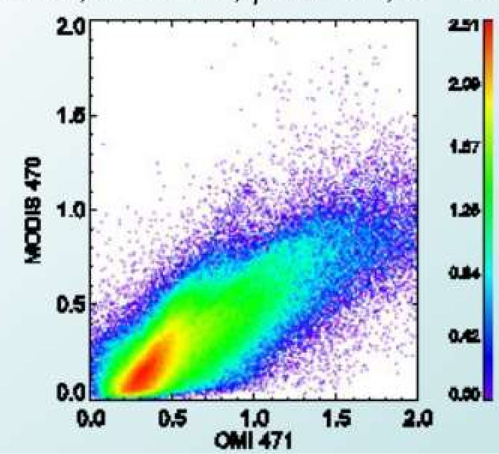




r = 0.833, α = 0.477, β = 0.053, N ~ 620,000

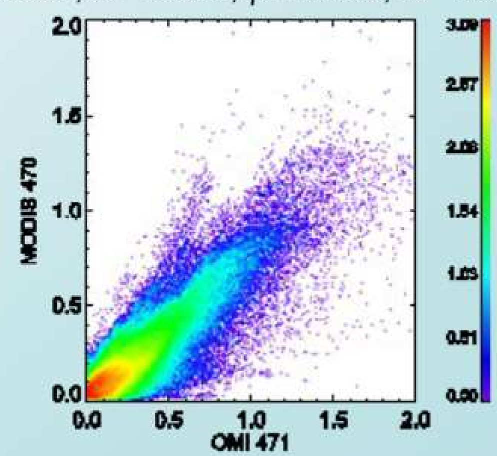
Land only

r = 0.814, α = 0.466, β = 0.033, N ~ 260,000



Ocean only

r = 0.862, α = 0.650, β = 0.032, N ~ 350,000



Summary

- TOMS and OMI Satellite measurements in the near UV produce valuable global information on aerosol absorption over the oceans and the continents.
- A global data set on **Aerosol Absorption Optical Depth** has been produced from TOMS observations.
- The **long term TOMS record** revels the existence of **trends in aerosol optical depth** in Chin and India.
- OMI observations of aerosol absorption will extend the TOMS **long-term record on aerosol absorption**.