



ARSET

Applied Remote Sensing Training

<http://arset.gsfc.nasa.gov>

 @NASAARSET

Introduction to Satellite Remote Sensing for Air Quality Applications

Webinar Session 3 – July 20, 2016

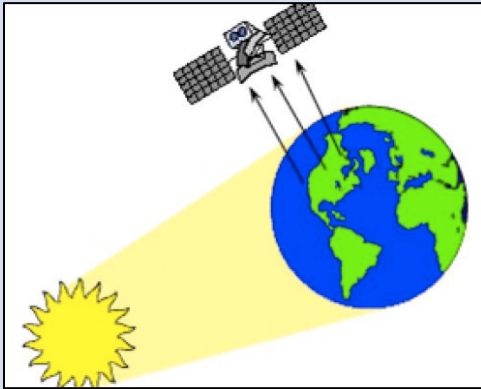
**NASA Aerosol Products for Particulate
Matter Air Quality**

Session 3 - Outline

- **Aerosol Optical Depth**
- **Satellite vs Surface Observations**
- **Key NASA Satellites and Aerosol Product**
- **Data Access and Download tools**

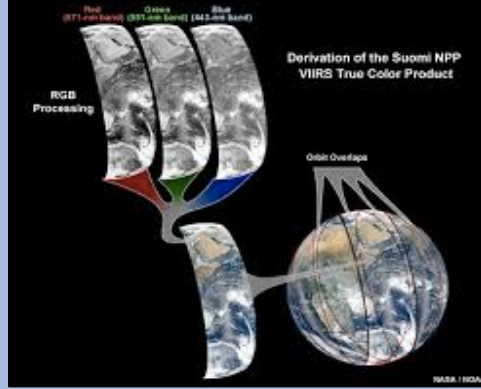
Today's Instructor: **Pawan Gupta**
GESTAR/USRA, Code 614
NASA Goddard Space Flight Center
Greenbelt, MD 20771, USA
pawan.gupta@nasa.gov
<http://arset.gsfc.nasa.gov/people/pawan-gupta-0>

5 Weeks Webinar Series: Agenda



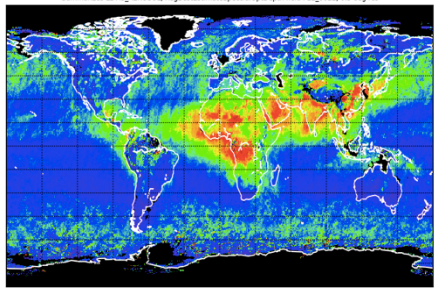
A diagram illustrating the fundamental concept of remote sensing. A yellow sun on the left emits a beam of light towards a satellite in orbit above a globe. The satellite has three arrows pointing towards the Earth's surface, representing the collection of data from a distance.

Week 1: Fundamental of Remote Sensing



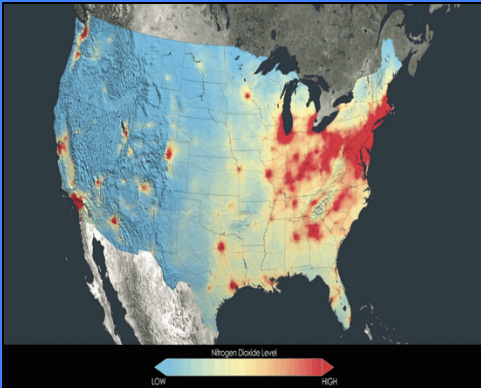
A diagram showing the derivation of the Suomi NPP VIIRS True Color Product. It features three satellite images labeled 'Red (413 nm band)', 'Green (555 nm band)', and 'Blue (443 nm band)'. These are processed into 'RGB Processing'. A 'Orbit Overlap' diagram shows a satellite's path over the Earth, with overlapping swaths. The final product is a 'True Color Product' of the Earth. Text includes 'Derivation of the Suomi NPP VIIRS True Color Product' and 'NASA / NOAA'.

Week 2: Satellite Imagery



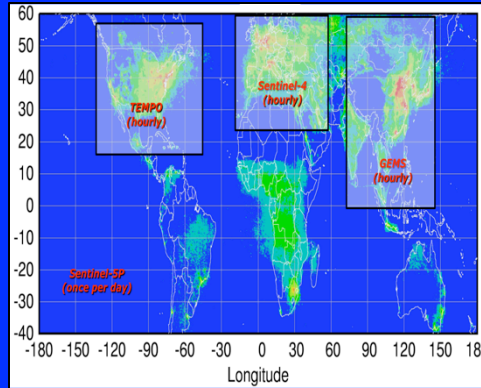
A global map showing aerosol optical depth. The map uses a color scale from blue (low) to red (high). A color bar at the bottom is labeled 'Optical Depth' and ranges from 0.00 to 1.00 in increments of 0.10. Text at the top reads: 'Optical depth average ANN 2013 F15_0031 All, Blue, All Summarizes L2_AS_AEROSOL_#regBestEstimateSpectralOptDepth field F12_0022, 0.5 deg res'.

Week 3: Aerosol Data



A map of the United States showing Nitrogen Dioxide (NO2) levels. The map uses a color scale from blue (low) to red (high). A color bar at the bottom is labeled 'Nitrogen Dioxide Level' and ranges from 'LOW' to 'HIGH'.

Week 4: Trace Gas Data



A world map showing the future capabilities of satellite sensors. The map is plotted on a grid with Latitude from -40 to 60 and Longitude from -180 to 180. Three regions are highlighted with boxes: 'TEMPO (hourly)' in North America, 'Sentinel-4 (hourly)' in Europe, and 'GEMS (hourly)' in East Asia. A label 'Sentinel-5P (once per day)' is also present in the lower left.

Week 5: Future Capabilities

Visibility and PM_{2.5}

Pittsburgh

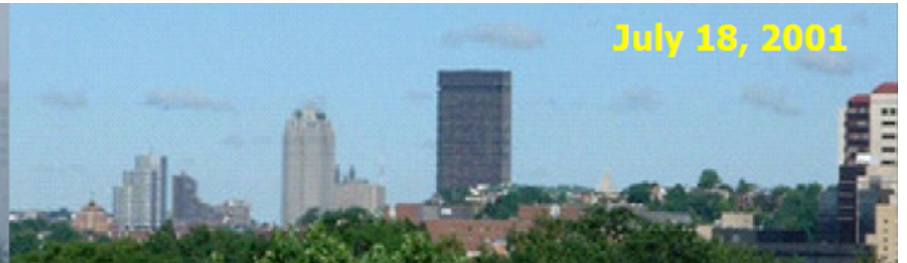
PM_{2.5}=45 μgm⁻³

July 2, 2001



PM_{2.5}=4 μgm⁻³

July 18, 2001



Pictures taken from the same location at the same time of day, on two different days

<http://caice.ucsd.edu/index.php/education/clear/learning-with-clear/introduction-to-aerosols/>

Singapore



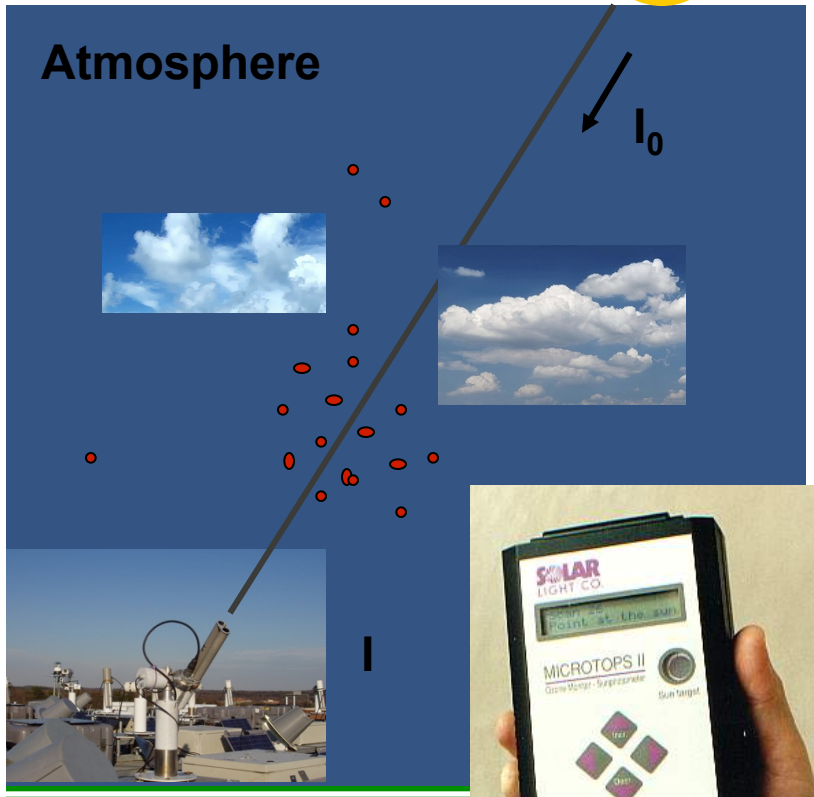
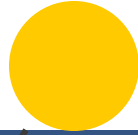
Roslan Rahman/AFP/Getty Images

Aerosol Optical Depth

- AOD – Aerosol **Optical** Depth
- AOT – Aerosol **Optical** Thickness
- These **optical measurements** of light extinction are used to represent aerosol amount in the entire column of the atmosphere

Optical Depth

Sun



Surface

The optical depth expresses the quantity of light removed from a beam by **scattering** or **absorption** during its path through a **medium**.

optical depth τ as

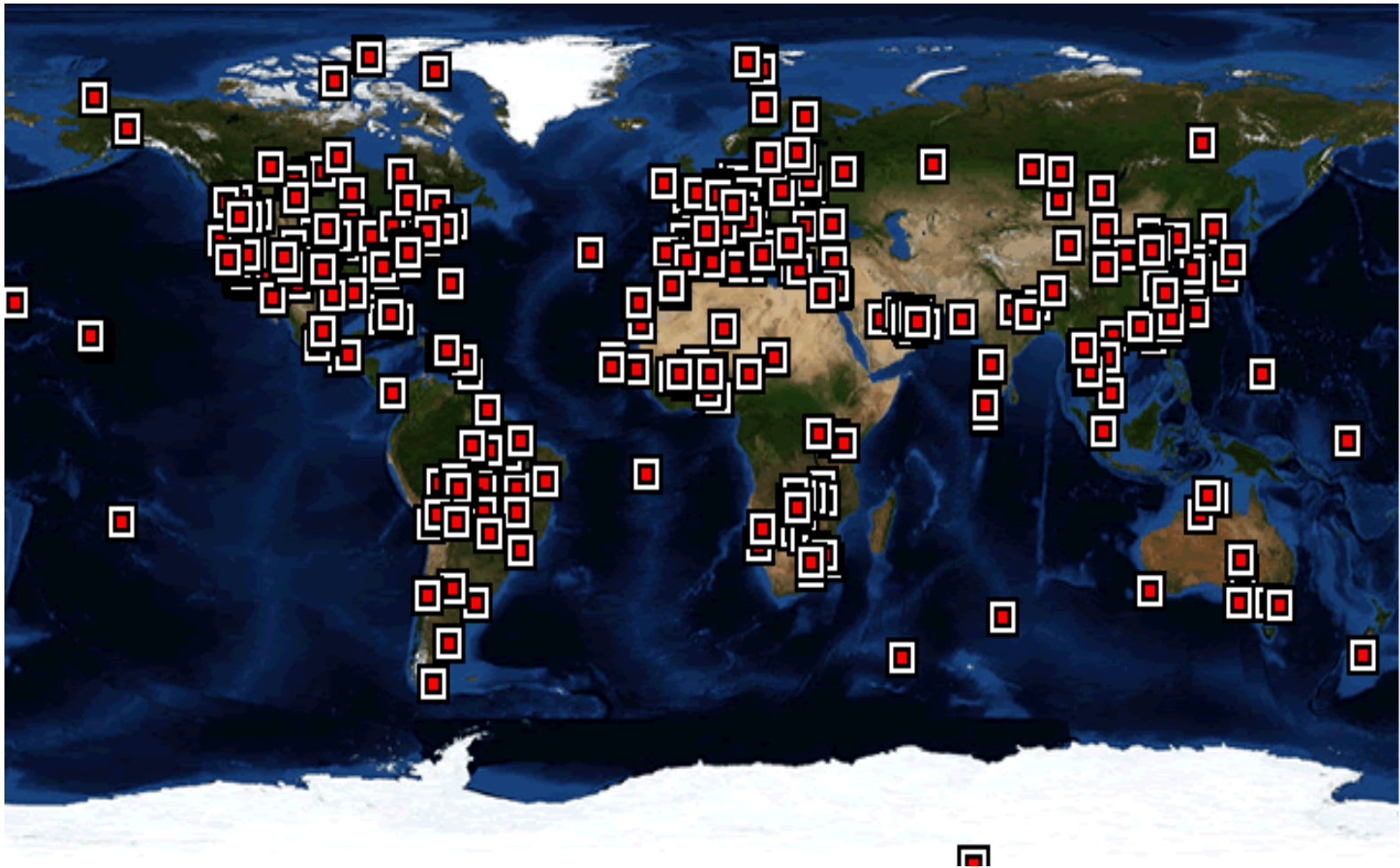
$$I = I_0 e^{-m\tau}$$

$$m = \sec \theta_0$$

$$\tau = \tau_{Rayl} + \tau_{aer} + \tau_{gas}$$



AERONET



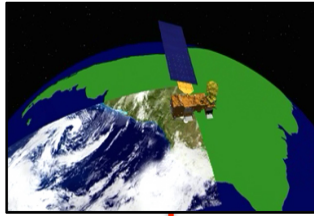
Aerosol Robotic Network
<http://aeronet.gsfc.nas.gov>

AERONET serves as a validation tool for satellite aerosol products

A satellite-style map of the Middle East and surrounding regions, including parts of North Africa, the Red Sea, and the Persian Gulf. The map is overlaid with a semi-transparent grey rectangle containing the title. The map shows various geographical features like coastlines, rivers, and landmasses. There are several red rectangular markers scattered across the landmasses, likely indicating specific locations of interest. The title 'AOD-PM2.5 Relationships' is centered within the grey rectangle, underlined.

AOD-PM2.5 Relationships

Column vs Surface Measurement



To of the Atmosphere

10 km² Vertical Column

Aerosol Optical Depth

Surface Layer

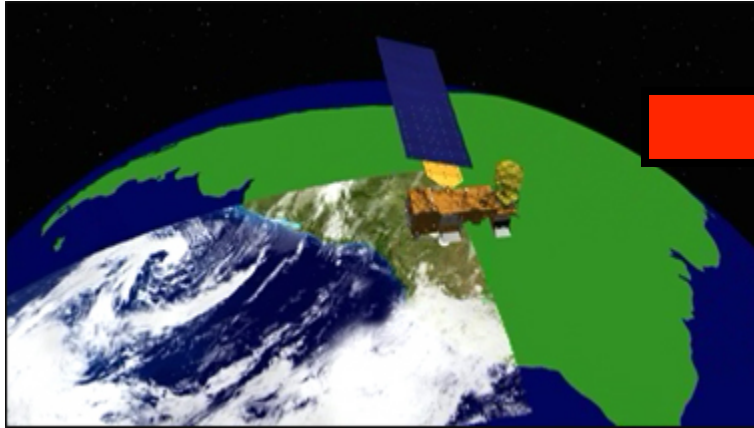
Earth Surface

PM2.5 mass concentration (μgm^{-3})
-- Dry Mass



Measurement Technique

Satellite



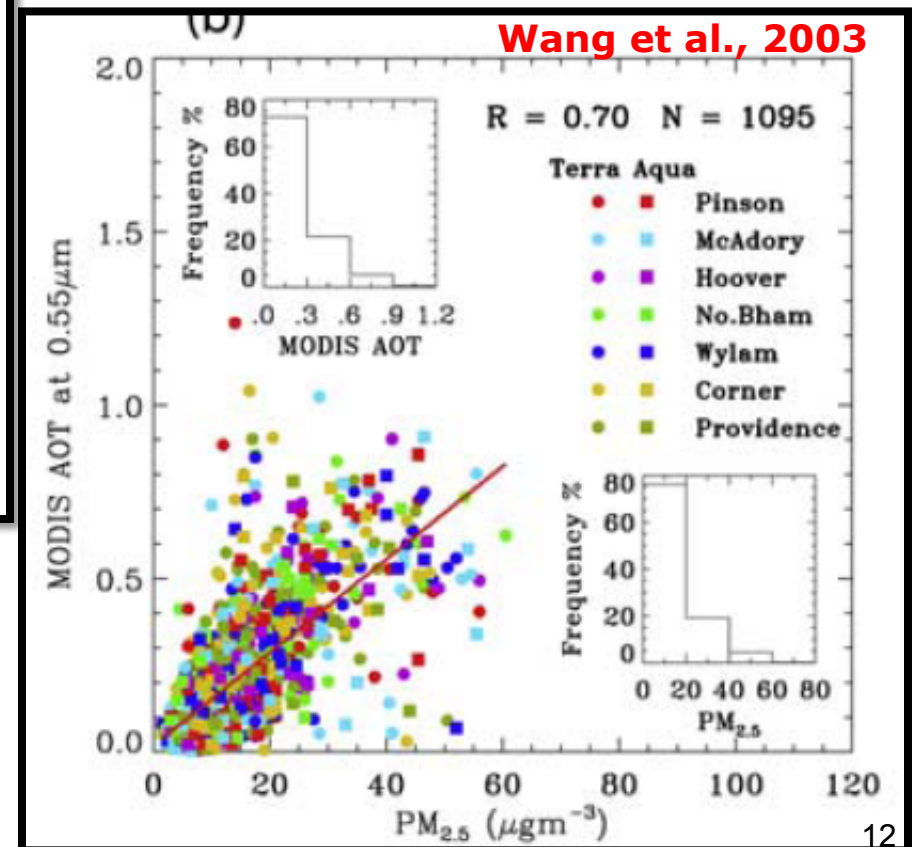
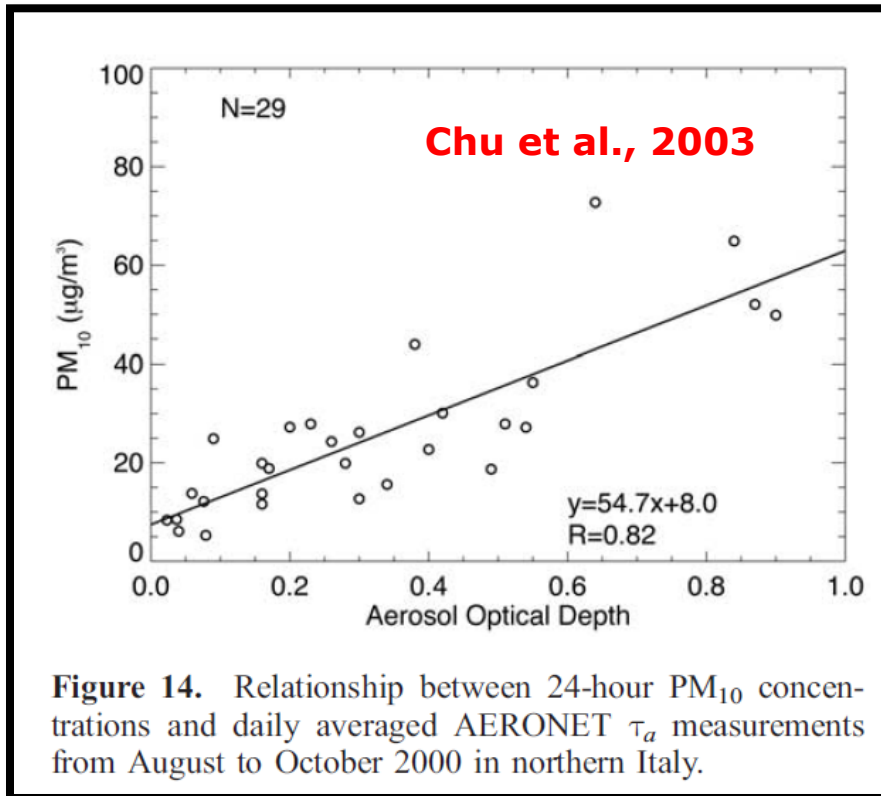
AOD – Column integrated value (top of the atmosphere to surface) - Optical measurement of aerosol loading – unitless. AOD is function of shape, size, type, and number concentration of aerosols

Surface

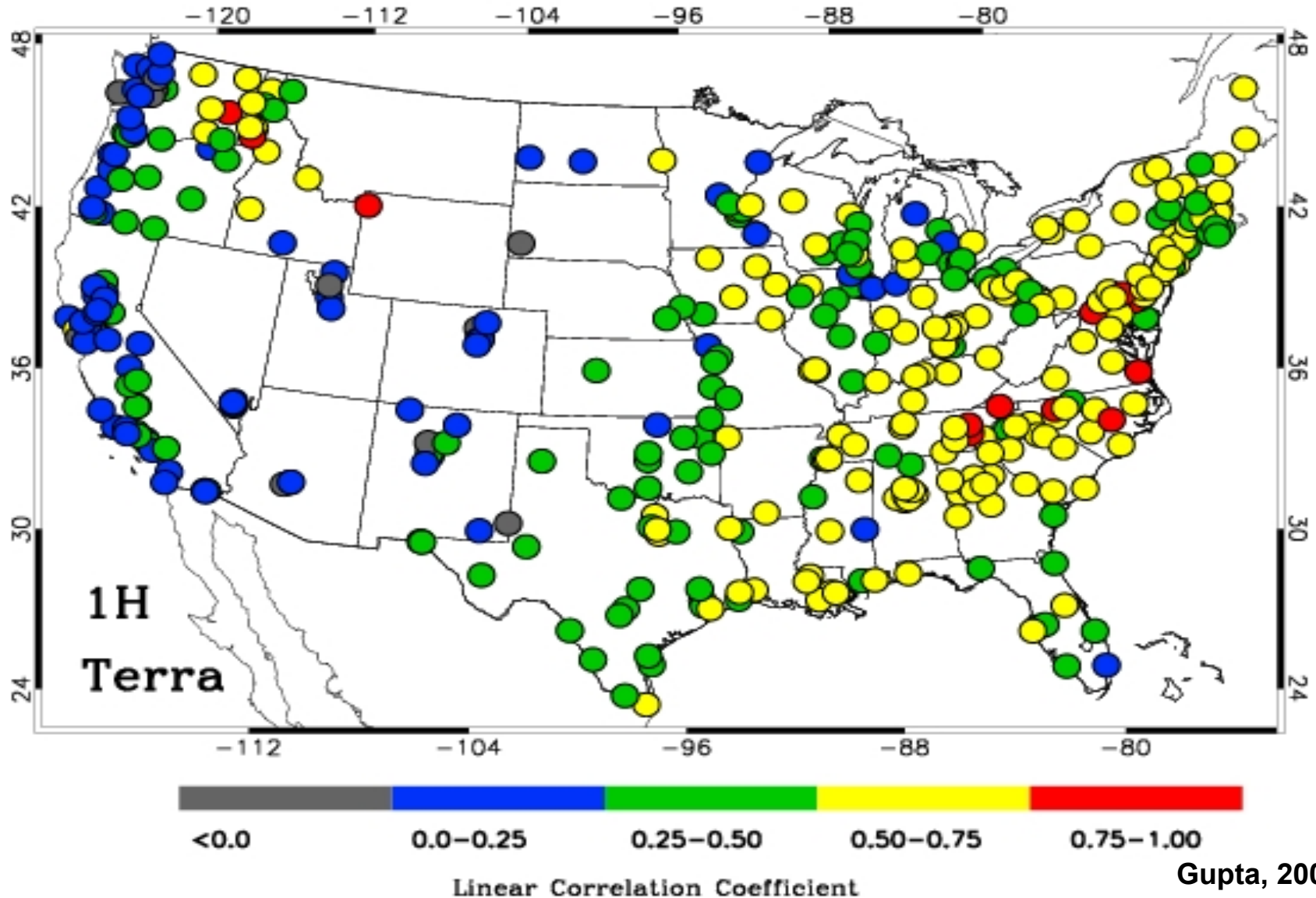


PM_{2.5} – Mass per unit volume of aerosol particles less than 2.5 μm in aerodynamic diameter at surface (measurement height) level

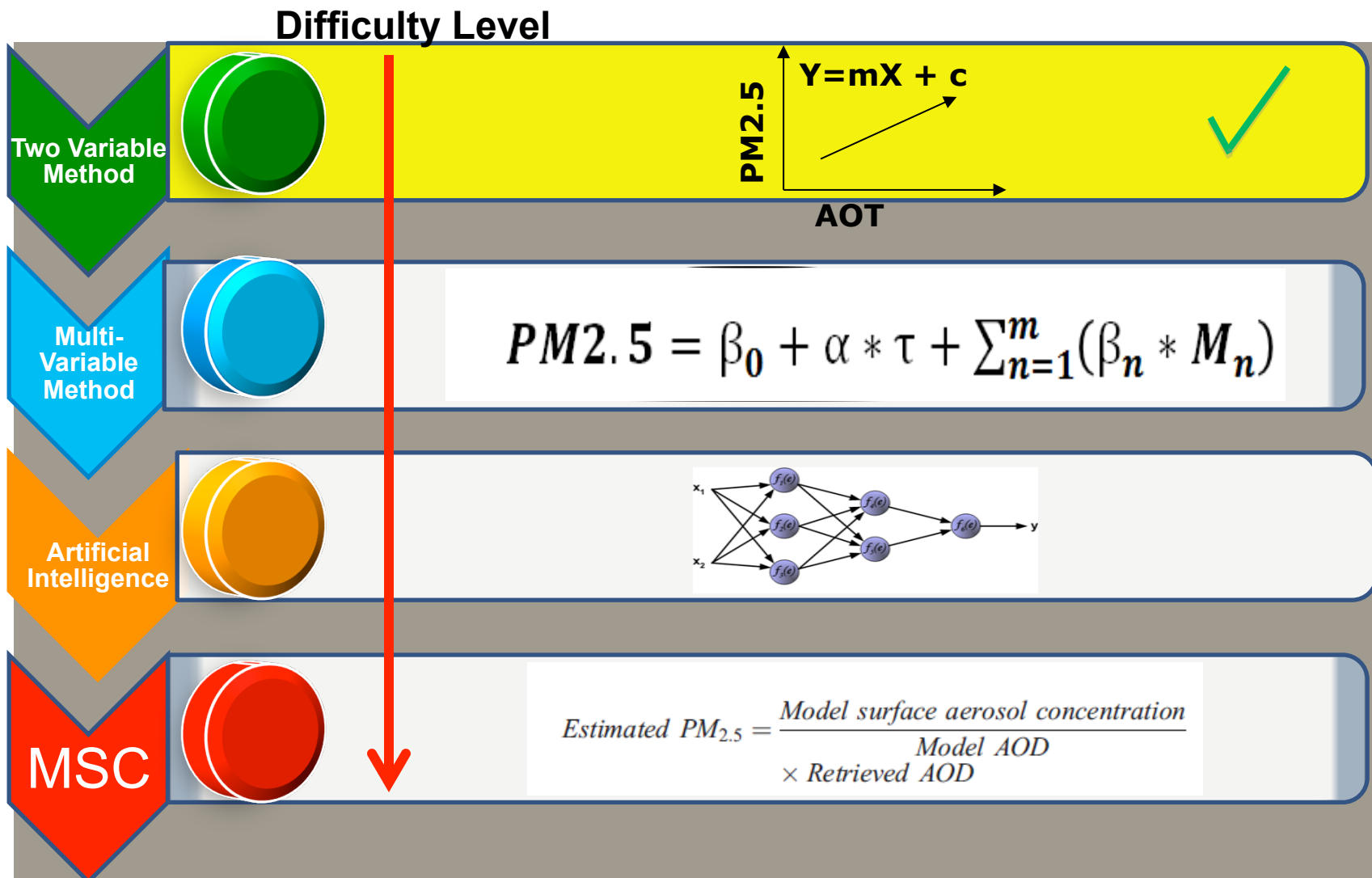
AOD-PM2.5 Relationship



Spatial Patterns in AOD-PM2.5 Relationships



PM2.5 Estimation: Popular Methods



Data Assimilation etc. is under utilized

Annual Mean Satellite Derived PM2.5 Data

Atmospheric Composition Analysis Group

http://fizz.phys.dal.ca/~atmos/martin/?page_id=140

Research

Publications &
Presentations

GEOS-Chem

Satellites

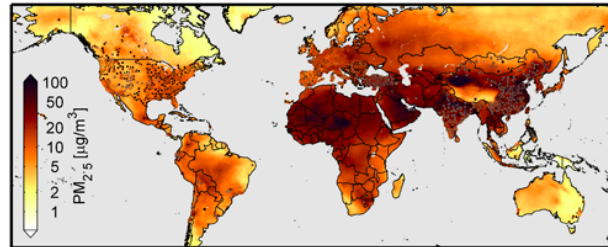
Datasets

SPARTAN

Group Info

Surface PM2.5

Global Estimates:



We estimate ground-level fine particulate matter (PM2.5) by combining Aerosol Optical Depth (AOD) retrievals from the NASA MODIS, MISR, and SeaWiFS instruments with the GEOS-Chem chemical transport model, and subsequently calibrated to global ground-based observations of PM2.5 using Geographically Weighted Regression (GWR) as detailed in the below reference.

References:

van Donkelaar, A., R.V Martin, M.Brauer, N. C. Hsu, R. A. Kahn, R. C Levy, A. Lyapustin, A. M. Sayer, and D. M Winker, **Global Estimates of Fine Particulate Matter using a Combined Geophysical-Statistical Method with Information from Satellites, Models, and Monitors**, *Environ. Sci. Technol*, doi: 10.1021/acs.est.5b05833, 2016. [\[Link\]](#)

Scientific Datasets:

Global resolved datasets are provided in ArcGIS-compatible NetCDF [.nc] or zipped ASCII [.asc.zip] file. Note that the unzipped ASCII files can be cumbersome. Gridded files use the WGS84 projection. The $0.01^\circ \times 0.01^\circ$ grid contains 12500 latitude coordinates, with centres from 54.995°S to 69.995°N , and 36000 longitude coordinates, with centres from 179.995°W to 179.995°E . The $0.1^\circ \times 0.1^\circ$ grid contains 1250 latitude coordinates, with centres from 54.95°S to 69.95°N , and 3600 longitude coordinates, with centres from 179.95°W to 179.95°E . Corresponding files for Google Earth are also provided [.kmz]. Country means are also provided in a comma separated ascii (.csv) format. Dust and Sea-Salt Removed PM2.5 estimates apply simulated compositional information to our full-composition values, following van Donkelaar et al., EHP, 2015. Other extractions can often be produced upon request. Please contact Aaron van Donkelaar (Aaron.van.Donkelaar@dal.ca) for further information.


All Composition PM2.5:

Satellite-Derived PM2.5, 1998, at 35% RH [$\mu\text{g}/\text{m}^3$]

$0.1^\circ \times 0.1^\circ$ [.nc] [.asc.zip] [.kmz] [.csv]

$0.1^\circ \times 0.1^\circ$ w GWR adjustment [.nc] [.asc.zip] [.kmz] [.csv]

$0.01^\circ \times 0.01^\circ$ w GWR adjustment [.nc] [.asc.zip] [.kmz] [.csv]

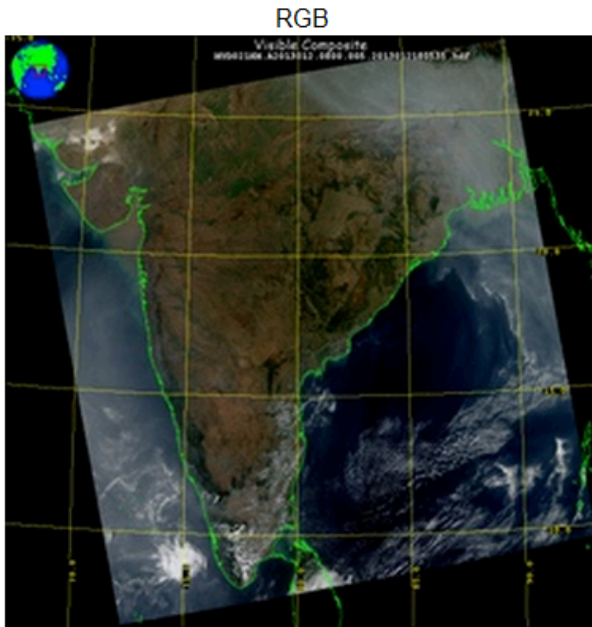
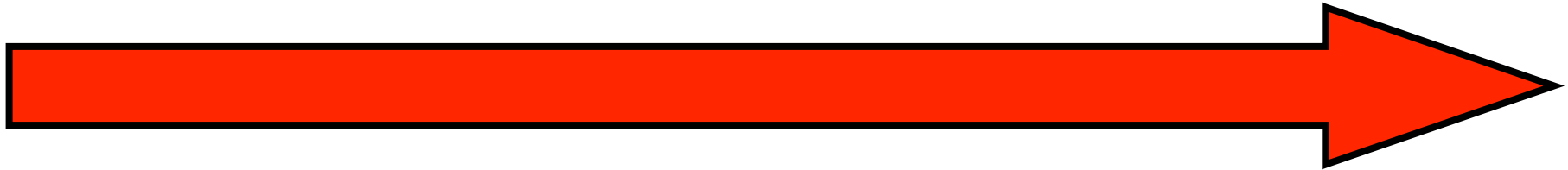
A satellite image of the Earth, showing the Indian subcontinent and surrounding oceans. The land is brown and tan, and the oceans are dark blue. There are some red and green markings on the land, possibly indicating specific locations or data points. The text is overlaid on a white rectangular background.

Stay tuned to the ARSET website for the upcoming advanced webinar series (January 2017) on satellite derived PM2.5 data, tools, and analysis to address the sustainable development goals (SDGs) of the United Nations

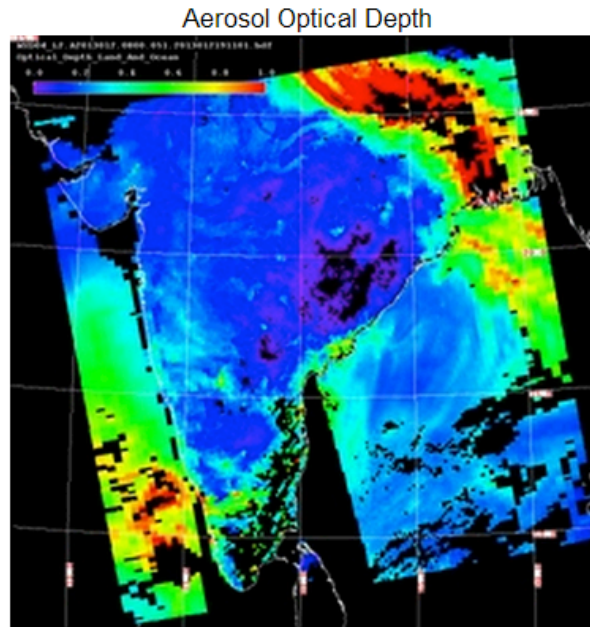
A satellite image of Earth showing aerosols over the Indian Ocean and Africa. The image is a composite of satellite data, with a central semi-transparent white box containing the title. The background shows the Indian Ocean to the west and south of Africa, with various shades of blue and green representing different aerosol concentrations. The African continent is visible in the lower half, with brown and tan colors representing land. The title "Aerosols Data from Satellite" is written in bold black text, underlined.

Aerosols Data from Satellite

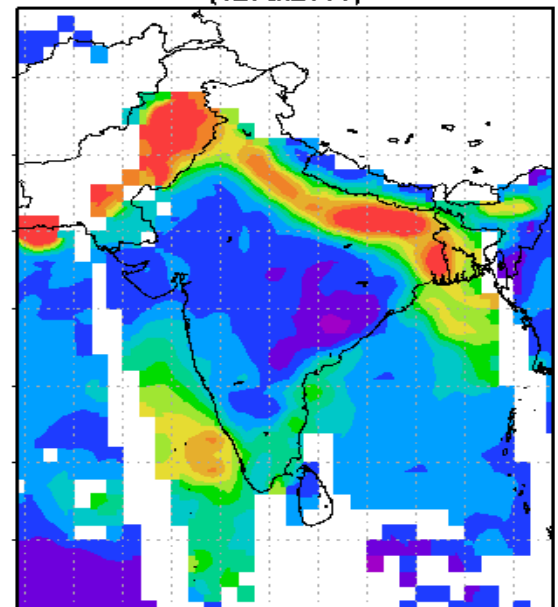
Levels of Data



Level 1B



Level 2



Level 3

**Calibration to
Radiance**

**Aerosol Retrieval
Algorithm**

**Spatial & Temporal
Averaging**

Data Product Hierarchy

- **Level 1 Products**

- Raw data with and without applied calibration
- No aerosol data



- **Level 2 Products**

- Geophysical products
- Aerosol data



- **Level 3 Products**

- Globally gridded geophysical products
- Aerosol data

Satellites for Air Quality Data

- **MODIS (Terra and Aqua)**
 - AOD: columnar aerosol loading – can be used to get particulate matter mass concentration
- **MISR (Terra)**
 - Columnar aerosol loading in different particle size bins
 - In some cases aerosol heights
- **OMI (Aura)**
 - Absorbing aerosols, Total Aerosols
 - Trace gases
- **VIIRS (NPP)**
 - Aerosol optical depth
 - Aerosol type

Instrument Capabilities for Air Quality

Sensor Measurement Resolution

- MODIS:** 250 m – 1km
- MISR:** 275 m – 1.1km
- OMI:** 13x24 km
- VIIRS:** 750 m

Satellite Aerosol Products

	MODIS	MISR	OMI	VIIRS
Strengths	Coverage Resolution Calibration Accuracy	Calibration Accuracy Particle shape Aerosol height for thick layer or plume	Indication of absorbing or scattering particles	Coverage Resolution Calibration Smaller bow-tie effect
Weaknesses	Bright Surfaces* Ocean glint Non-spherical particles	Coverage	Resolution Cloud contamination	Bright Surfaces* Ocean glint
Main Products	AOD Ocean–5 wavelengths Land–3 wavelengths Fine Fraction (Ocean only)	AOD 4 wavelengths Spherical/Non-spherical ratio Particle Size (3 Bins)	AOD AAOD Aerosol Index	AOD Aerosol Type
Product Resolution (level 2 and at Nadir)	10 Km 3 Km	17.6 Km	13 X 24 Km	0.75 km 6 km
Product Levels	2	2	2	2
Global Level 3 Aggregates	Daily 8 Day 30 Day	Monthly 3 Month Annual	Daily Monthly	Daily Monthly

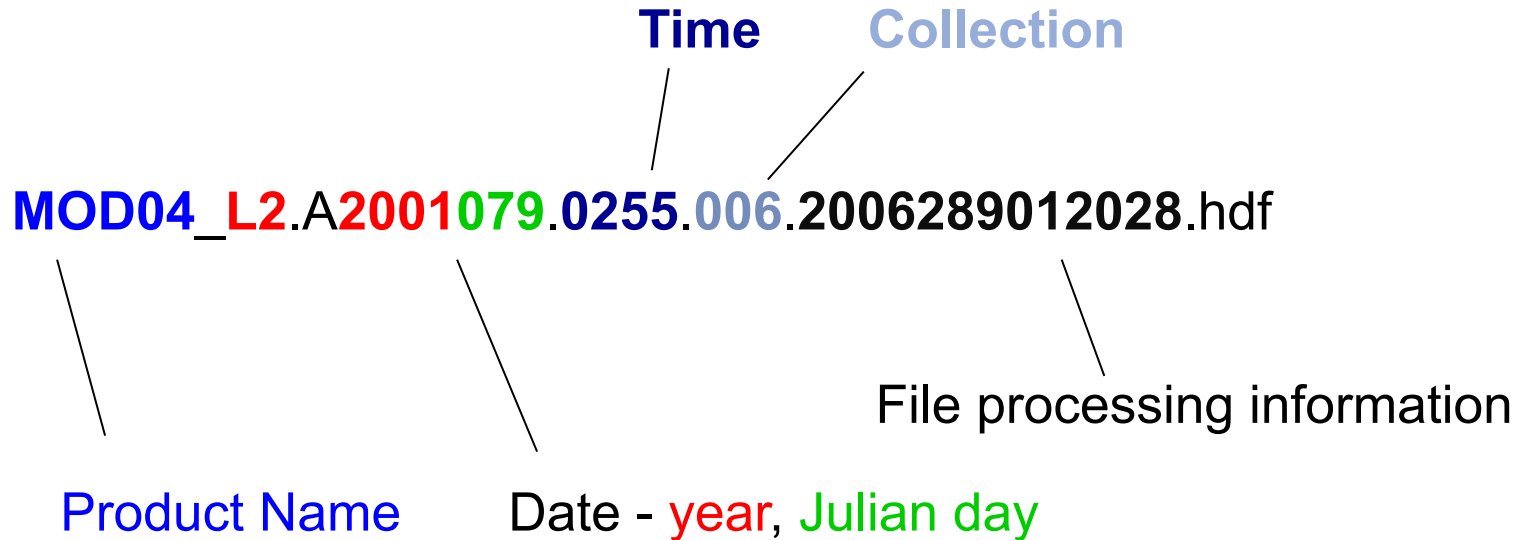
A satellite image of a coastal region, likely the Gulf of Mexico, showing a semi-transparent overlay box. The box contains the text 'MODIS' in a bold, black, sans-serif font. Below the text is a horizontal black line. The background image shows a coastline with brownish land and blue-green water. There are some red and white markings on the land, possibly indicating specific locations or features. The overall image has a high-resolution, detailed appearance.

MODIS

Understanding a MODIS File Name

Level 2, 10km, Aerosol Product

- Terra: MOD04
- Aqua: MYD04

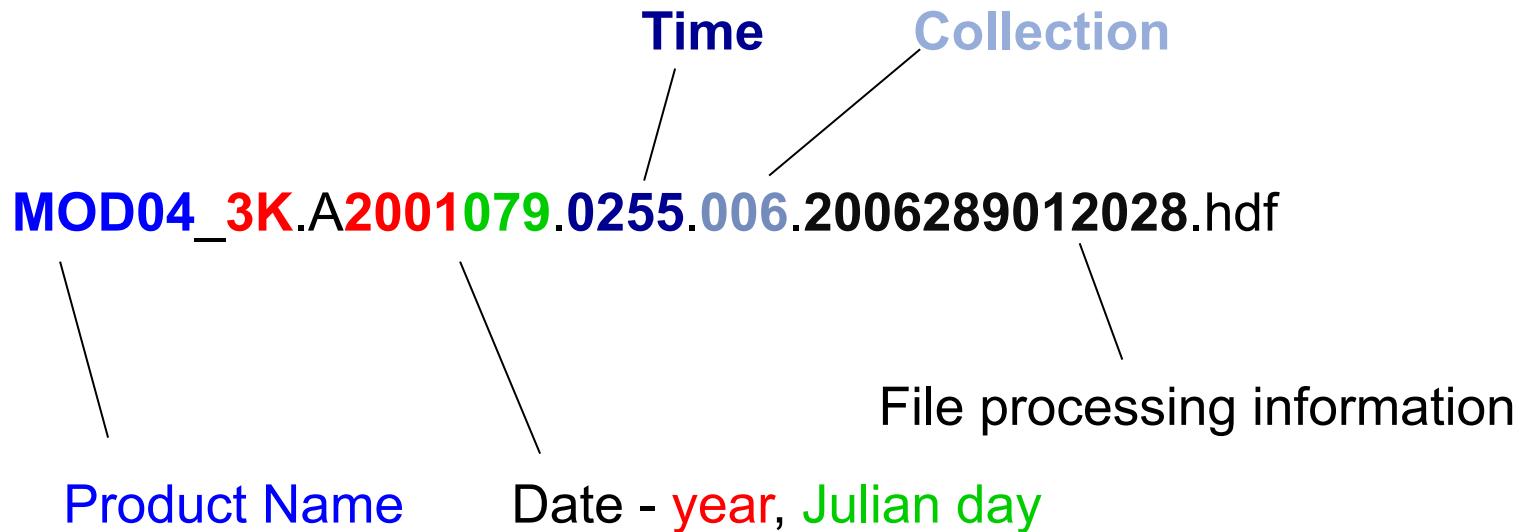


HDFLook, Panoply, IDL, Python, Fortran, MatLab etc. can be used to read the data

Understanding a MODIS File Name

Level 2, 3km, Aerosol Product

- Terra: MOD04
- Aqua: MYD04



HDFLook, Panoply, IDL, Python, Fortran, MatLab etc. can be used to read the data

MODIS Aerosol Parameters (SDS)

- ❑ **Optical_Depth_Land_And_Ocean**
 - ❑ Retrieved using Dark Target Algorithm
 - ❑ Only high quality data
 - ❑ Over land QA = 3, Over ocean QA = 1, 2, 3
 - ❑ 10 km and 3 km

- ❑ **Dark_Target_Deep_Blue_Optical_Depth_550_Combined**
 - ❑ Deep Blue & Dark Target Algorithm Merged Product
 - ❑ 10 km only

- ❑ **Dark_Target_Deep_Blue_Optical_Depth_550_Combined_QA**
 - ❑ Quality Flag associated with DD product

Reference: <http://www.atmos-meas-tech.net/6/2989/2013/amt-6-2989-2013.html>

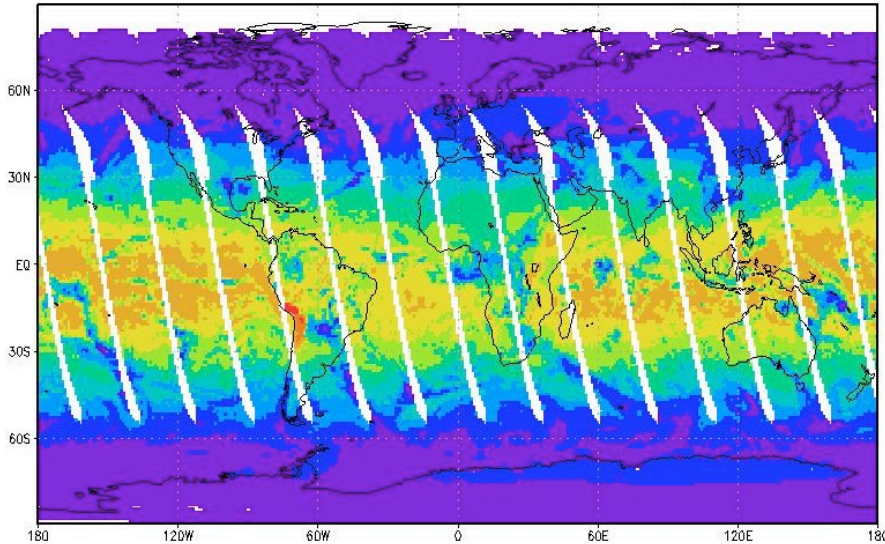
Access to MODIS Aerosol Products

- **NASA LAADSWeb**
 - Searchable database, FTP access
 - <http://ladsweb.nascom.nasa.gov/index.html>
- **MODIS-Atmos Site**
 - Complete RGB archive with Level 3 product imagery
 - <http://modis-atmos.gsfc.nasa.gov/>
- **Giovanni for Level 3 data sets**
 - Web tool for imagery visualization and analysis
 - http://disc.gsfc.nasa.gov/gesNews/giovanni_3_end_of_service?instance_id=MODIS_DAILY_L3
- **Dark Target Algorithm Site**
 - <http://darktarget.gsfc.nasa.gov/>
- **Deep Blue Algorithm Site**
 - <http://deepblue.gsfc.nasa.gov/>

A satellite image of the Amazon basin, showing the dense green forest and surrounding brownish terrain. The image is overlaid with a semi-transparent grey rectangle. Inside this rectangle, the text "OMI" is displayed in a bold, black, sans-serif font. Below the text, a solid black horizontal line extends across the width of the rectangle. The background image shows various geographical features, including rivers, lakes, and forest patterns, with some red and white markers scattered across the landscape.

OMI

Ozone Monitoring Instrument (OMI)



Instrument Characteristics

- Nadir solar backscatter spectrometer
- Spectral Range: 270-500nm (resolution ~1nm)
- Spatial Resolution: 13x24km footprint
- Swath Width: 2,600km (global daily coverage)

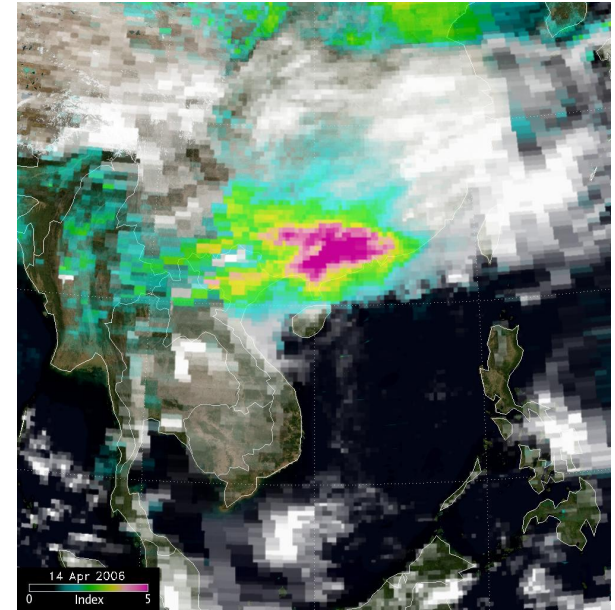
- One of four sensors on the EOS-Aura platform
 - OMI, MLS, TES, HIRDLS
- An international project:
 - Holland, USA, Finland
- Launched on 07/15/2004

Retrieval Products

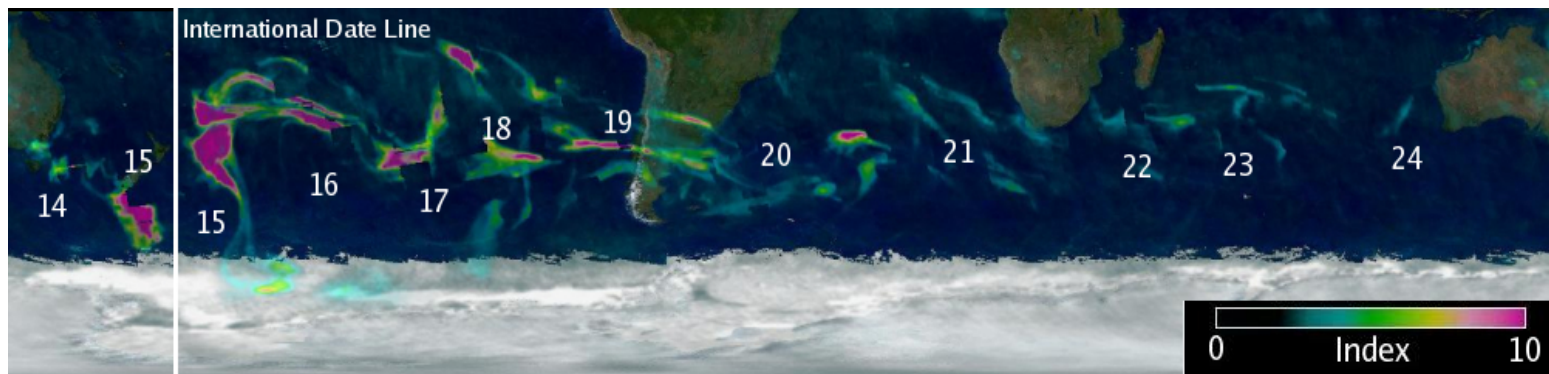
- Column Amounts
 - Ozone (O_3)
 - Nitrogen Dioxide (NO_2)
 - Sulfur Dioxide (SO_2)
 - Others
- Aerosols

Applications of the Aerosol Index

- Validation tool for transport models
- Separation of carbonaceous from sulfate aerosols
- Tracking of aerosol plumes above clouds and over ice/snow



(Right) Aerosols over clouds:
April 14, 2006



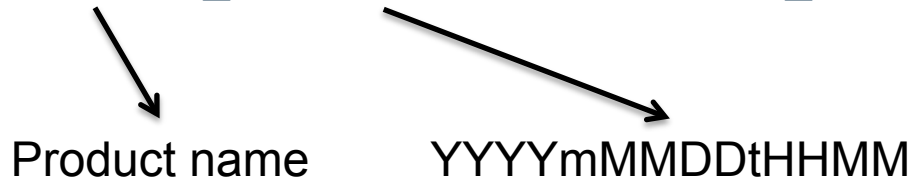
Transport around the globe of a high altitude smoke layer generated by the December 2006 Australian fires. Numbers indicate the day of the month.

OMI Data Site

<http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI>

Version 003 OMI Level 2, Level 2G, Level-3 and Climatology Products			
Short Name & Data Access			Product Description
Level-2 Orbital Swath (Nadir pixels 13x24 km)	Level-2G Global Binned (0.25x0.25 or 0.125x0.125 deg)	Level-3 Global Gridded (0.25x0.25 or 1x1 deg)	
Aerosols			
OMAERUV	OMAERUVG	OMAERUVd	OMI/Aura Near-UV Aerosol Optical Depth and single Scattering Albedo
OMAERO	OMAEROG	OMAEROe	OMI/Aura Multi-Wavelength Aerosol Optical Depth and single Scattering Albedo

OMI-Aura_L2-OMAERUV_2011m1024t0521-o38692_v003-2011m1024t115317.he5

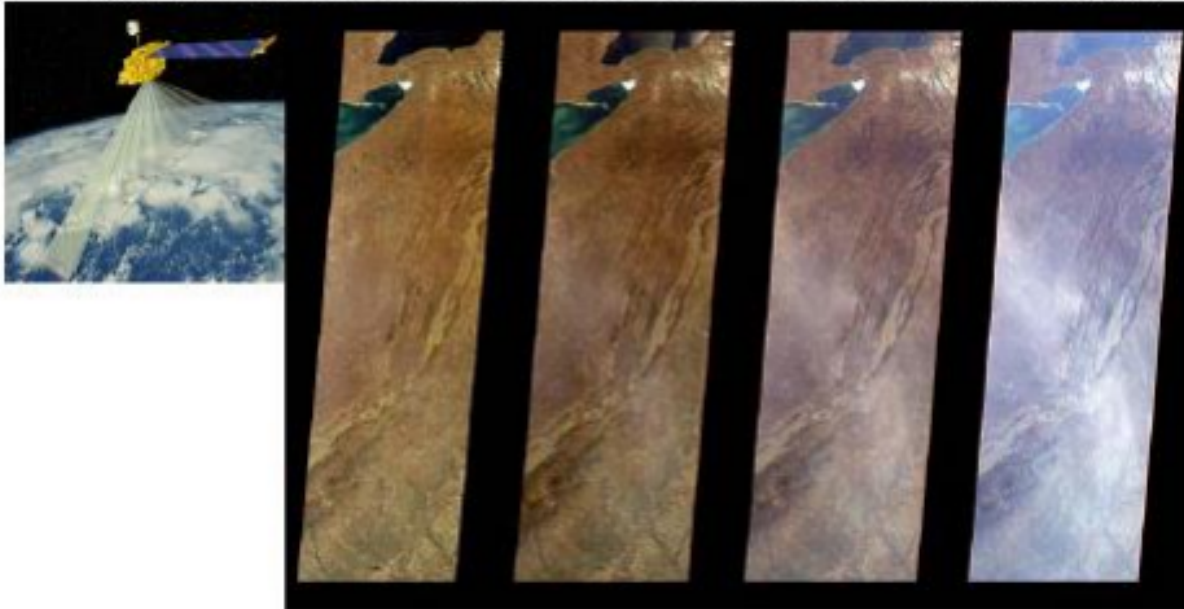


A satellite-style map of the Mediterranean region, including parts of Europe, North Africa, and the Middle East. A semi-transparent grey rectangular overlay covers the central part of the map. The word "MISR" is printed in bold black text on the left side of this overlay. A horizontal black line is positioned below the text. Several small red rectangular markers are scattered across the map, primarily in the eastern Mediterranean and the Middle East. The map shows various geographical features like coastlines, rivers, and terrain. The sea is depicted in shades of blue and green, while land is in shades of brown and tan.

MISR

MISR Background

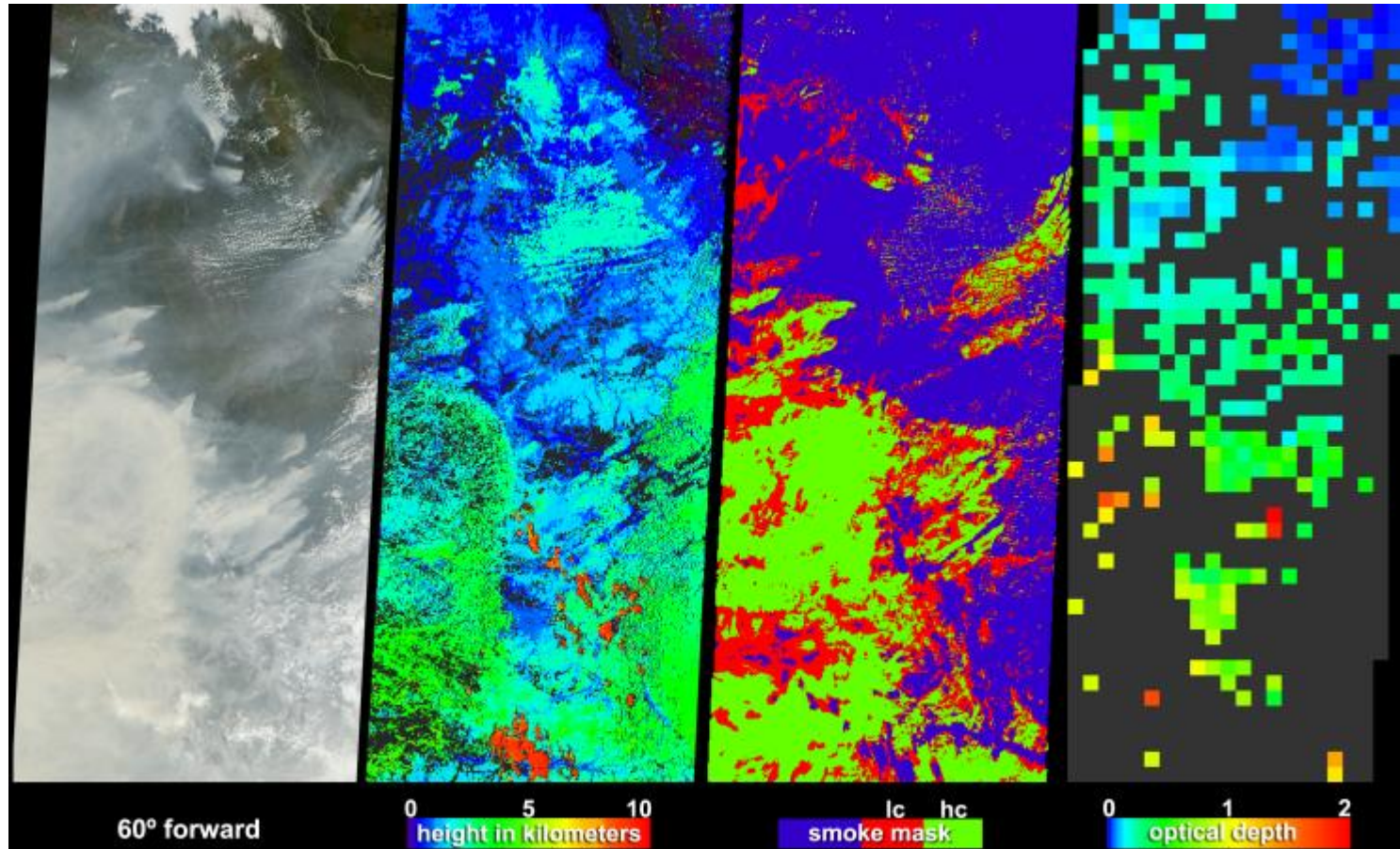
Figure A-1 Artist's Rendition of MISR aboard Terra and sample MISR images.



Four MISR images over Appalachian Mountains
Nadir, 45.6 deg, 60.0 deg, 70.5 deg forward viewing cameras

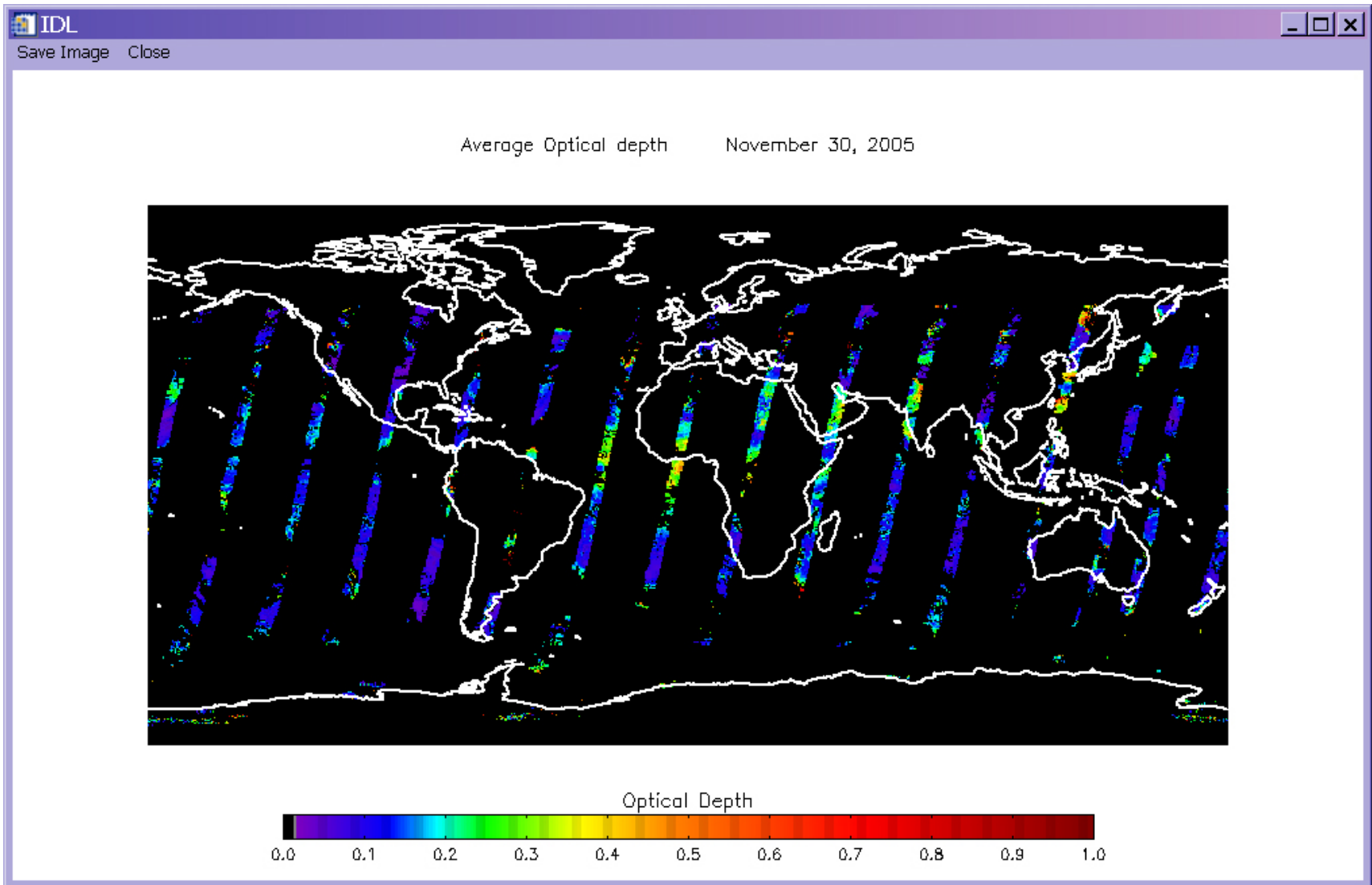
Angular observations (which are not available in MODIS) makes MISR capable of providing additional information on particle size, shape and aerosol height under specific cases

Aerosol Heights from MISR



Smoke Signals from the July 2004 Alaska and Yukon Fires

MISR Level 3 Tool



Level 2 & 3 Aerosol

1 file = one orbit – about 98 min data

17.6x17.6km², 0.5x0.5, and 1x1 deg daily, monthly, seasonal

MISR_AM1_AS_AEROSOL_P028_O002510_F12_0022.hdf

- RegBestEstimateSpectralOptDepth
 - AOD – 4 wavelengths
- RegBestEstimateSpectralOptDepthFraction
 - AOD fraction for small, medium, large, spherical, and non-spherical particles
- Data access and handling tutorial
 - http://eosweb.larc.nasa.gov/PRODOCS/misr/workshop/ppt/2010_lcluc/misr_tutorial.pdf

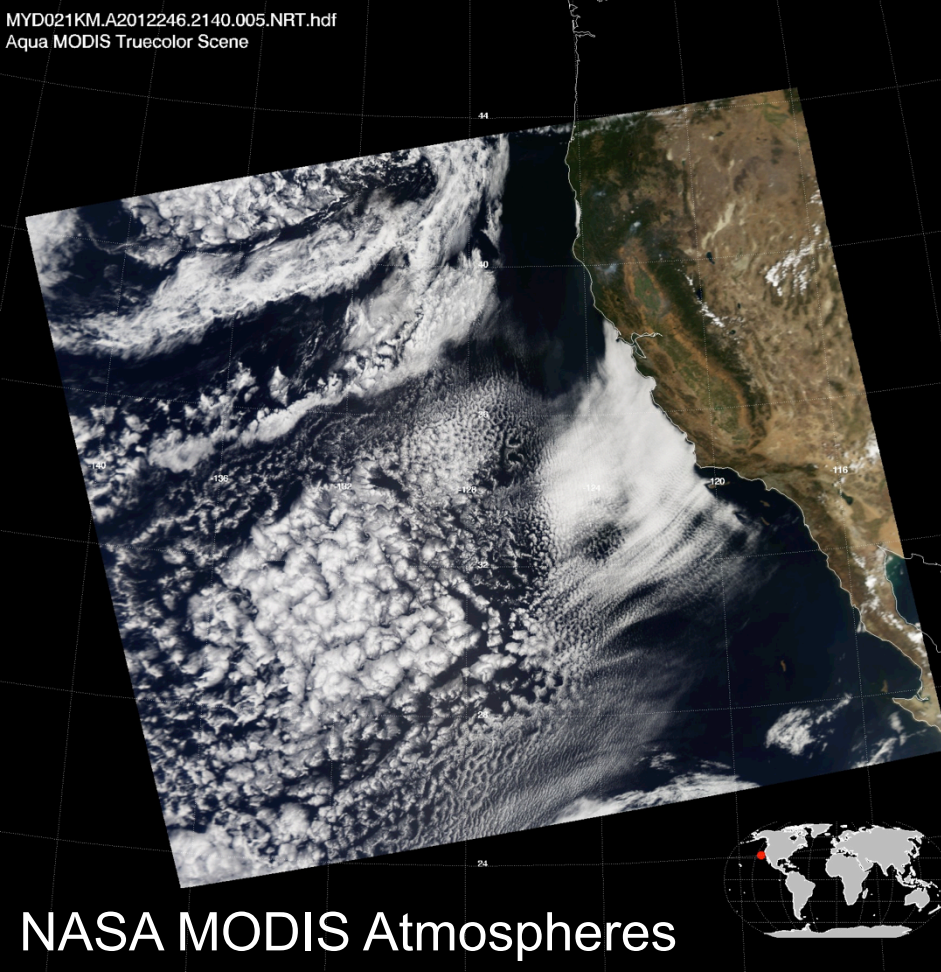
A satellite image of a coastal region, likely the Gulf of Mexico, showing a semi-transparent overlay box. The box contains the text "VIIRS" in a bold, black, sans-serif font, positioned above a solid black horizontal line. The background image shows a mix of brownish land, blue-green water, and white clouds. Several red rectangular markers are scattered across the land area, indicating specific locations of interest. The text "VIIRS" is centered within the box.

VIIRS

Visible Infrared Imaging Radiometer (VIIRS)

- A multi-wavelength imager, like MODIS with similar wavelength bands

	MODIS	VIIRS
Orbit altitude	690 km	824 km
Equator crossing time	13:30 LT	13:30 LT
Granule size	5 minutes	86 seconds
Swath	2330 km	3000 km
Pixel nadir	0.5 km	0.75 km
Pixel edge	2 km	1.5 km



NASA MODIS Atmospheres

MODIS

0.66 – 0.55 – 0.47 μm

2 Sep 2012

21:40 UTC



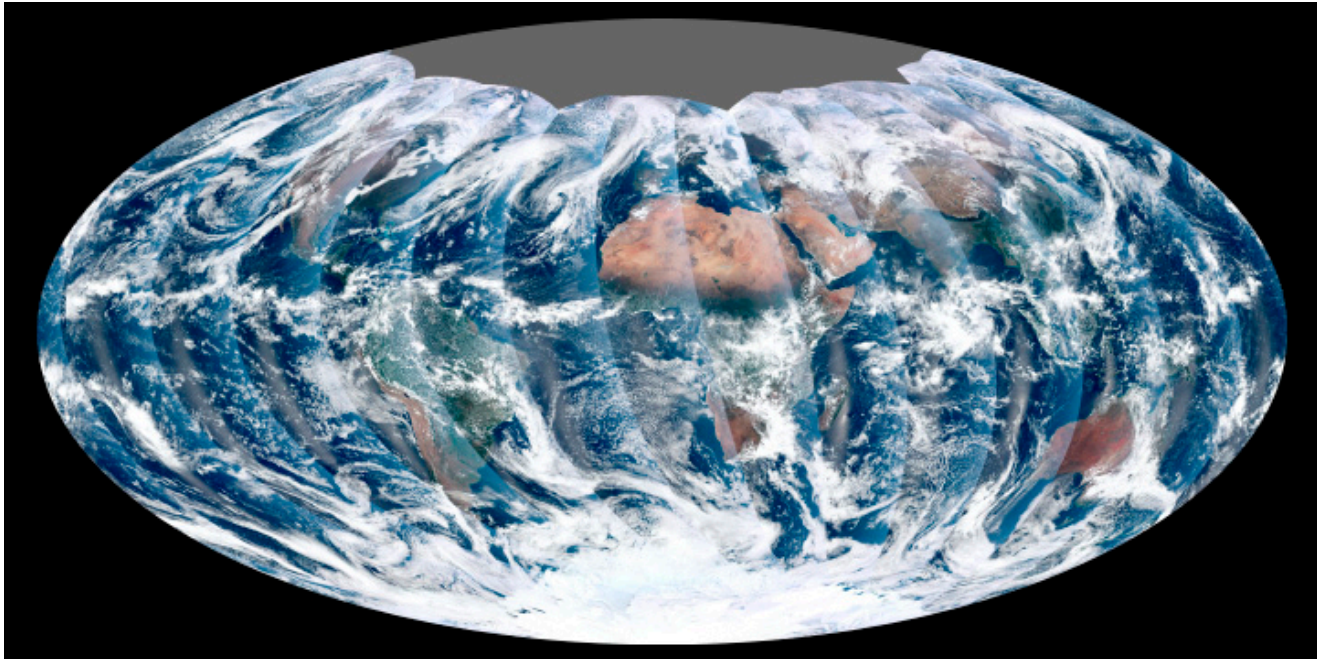
SSEC PEATE

VIIRS

0.67 – 0.55 – 0.49 μm

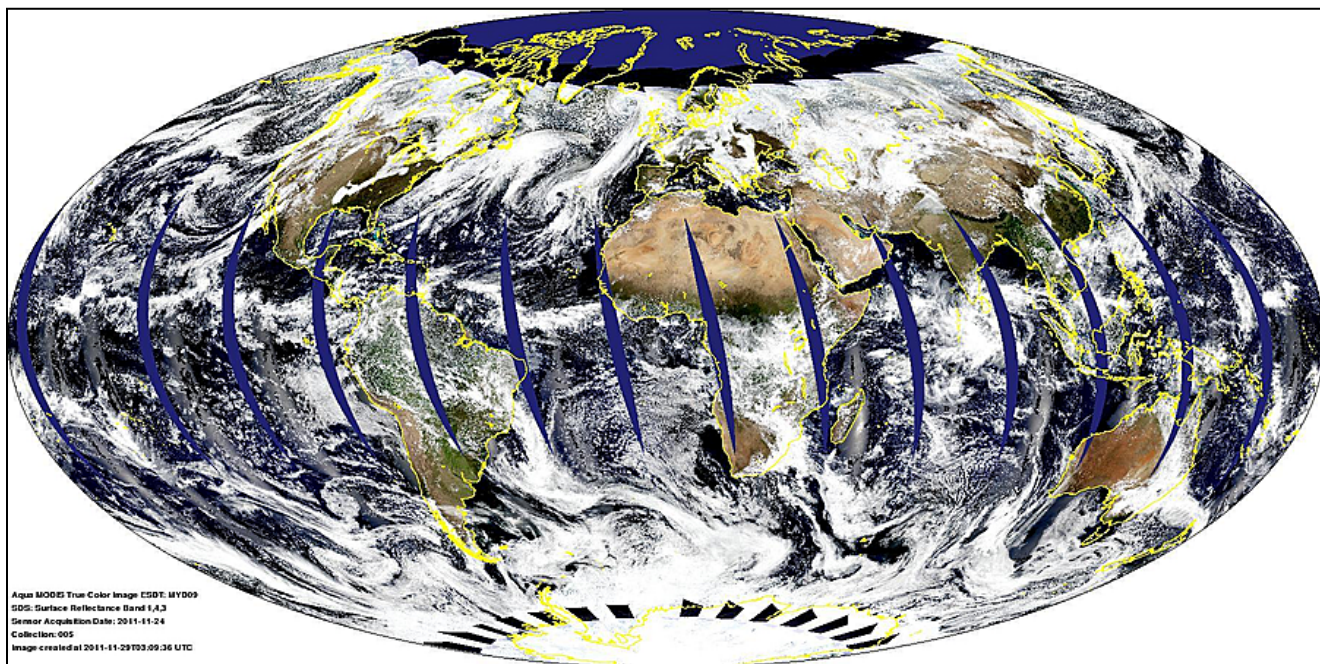
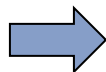
2 Sep 2012

20:24:27.8 UTC



← **VIIRS**
Nov 24, 2011

MODIS - AQUA
Nov 24, 2011



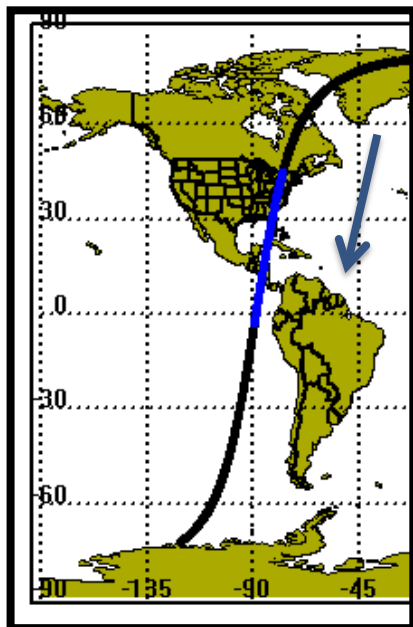
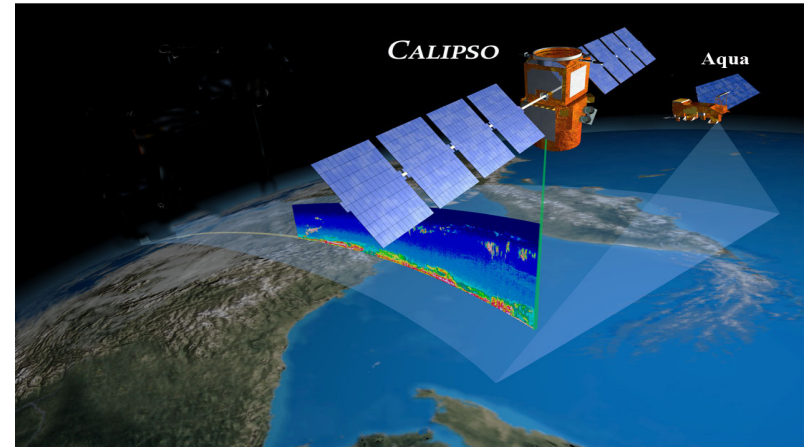
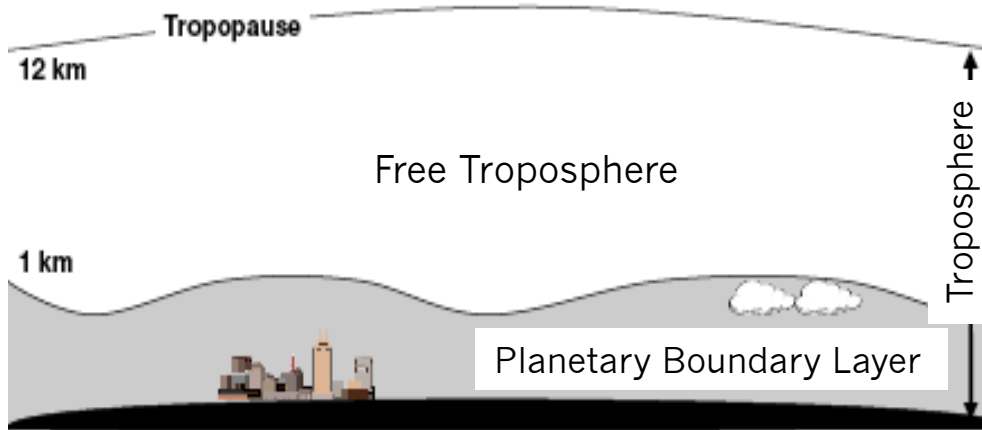
Aqua MODIS True Color Image: ESDT: MY009
SOS: Surface Reflectance Band 1, A, 3
Sensor Acquisition Date: 2011-11-24
Collection: 005
Image created at 2011-11-29T03:09:36 UTC

VIIRS Level 2 & 3 Aerosol Data

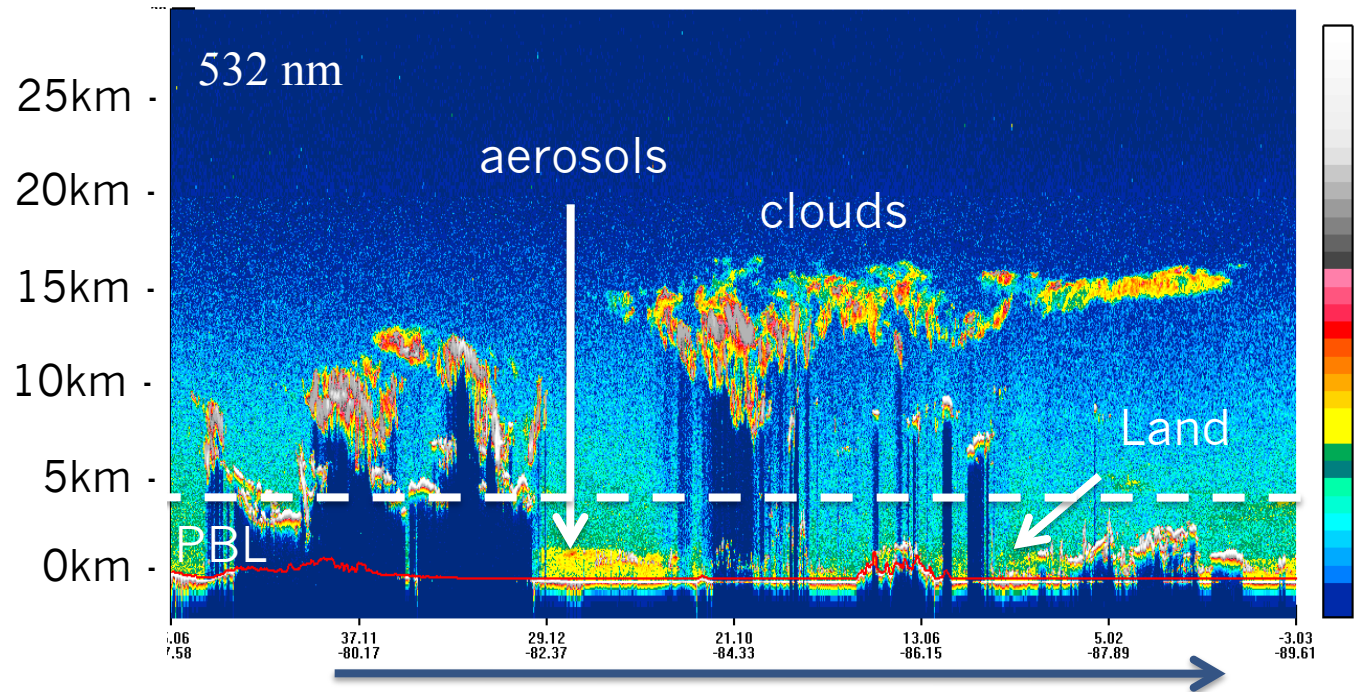
- Level 2, VIIRS Data:
 - http://www.class.ngdc.noaa.gov/saa/products/search?sub_id=0&datatype_family=VIIRS&submit.x=26&submit.y=6
- Level 3, Quarter Degree Gridded VIIRS Data
 - http://www.star.nesdis.noaa.gov/smcd/emb/viirs_aerosol/products_gridded.php

CALIPSO – Vertical Profiles

Slide from Meloë Kacenenbogen



National Aeronautics and Space Administration



References & Links

- ARSET air quality webpage
 - <http://arset.gsfc.nasa.gov/airquality/>
- NASA Air Quality
 - <http://airquality.gsfc.nasa.gov/>
- MODIS Atmos
 - http://modis-atmos.gsfc.nasa.gov/mod04_12/
- MISR Data
 - http://eosweb.larc.nasa.gov/PRODOCS/misr/Quality_Summaries/L2_AS_Products.html
- OMI Data
 - <http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI>
- IDEA
 - <http://www.star.nesdis.noaa.gov/smcd/spb/aq/>
- Smog Blog
 - <http://alg.umbc.edu/usaq/>

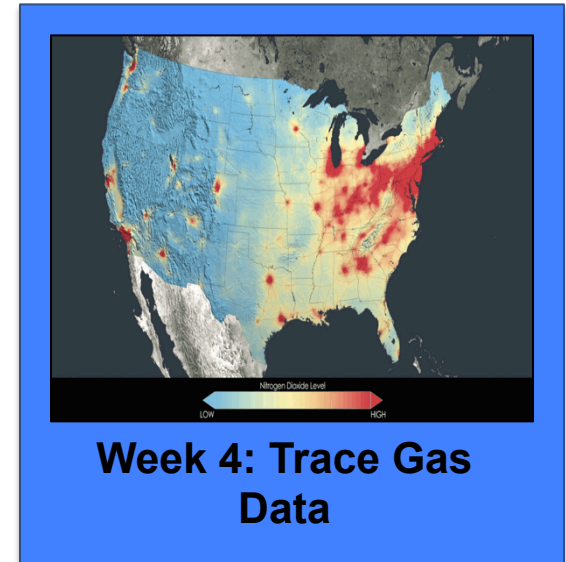
A satellite-style map of the Pacific Northwest coast of the United States, showing the coastline, the ocean, and inland terrain. A semi-transparent grey rectangular overlay covers the central portion of the map. The text "NO ASSIGNMENTS" is centered within this overlay in a large, bold, black, sans-serif font. A thin black horizontal line is positioned directly below the text.

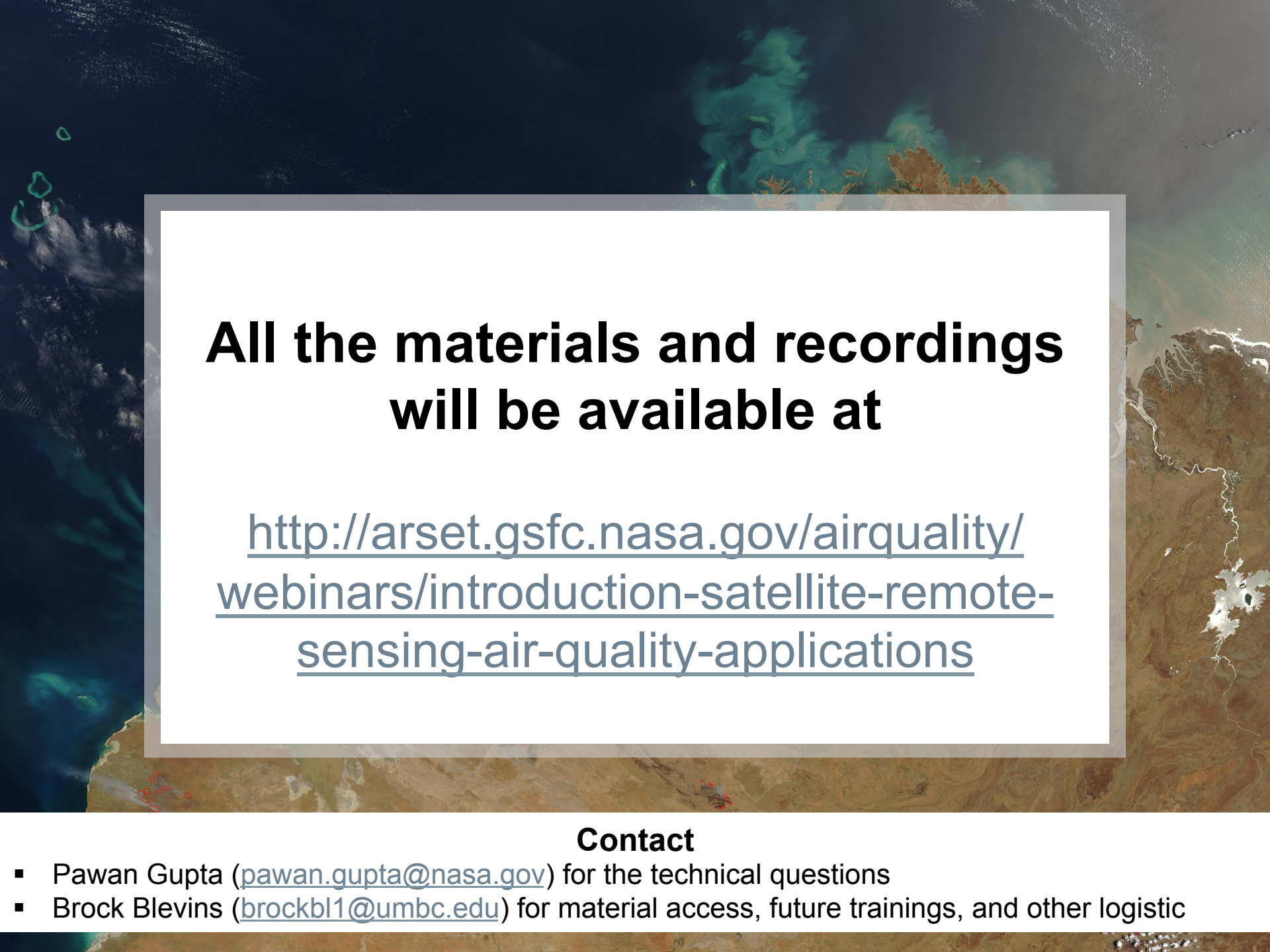
NO ASSIGNMENTS

Next Week

NASA Trace Gas Products

- Background information on trace gas detection and products
- Applications of trace gases products
- Downloading and analyzing Level 3 NO₂, SO₂ and CO products.





**All the materials and recordings
will be available at**

[http://arset.gsfc.nasa.gov/airquality/
webinars/introduction-satellite-remote-
sensing-air-quality-applications](http://arset.gsfc.nasa.gov/airquality/webinars/introduction-satellite-remote-sensing-air-quality-applications)

Contact

- Pawan Gupta (pawan.gupta@nasa.gov) for the technical questions
- Brock Blevins (brockbl1@umbc.edu) for material access, future trainings, and other logistic