



ARSET

Applied Remote Sensing Training

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# Aerosol Observations from Satellites: Brief Theory & Existing Products

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## The Practical Use of Satellite Observations for Visibility and Air Quality Analysis

Monday, September 26, 2016

Atmospheric Optics: Aerosols, Visibility, and the Radiative Balance

Jackson Hole, Wyoming, USA

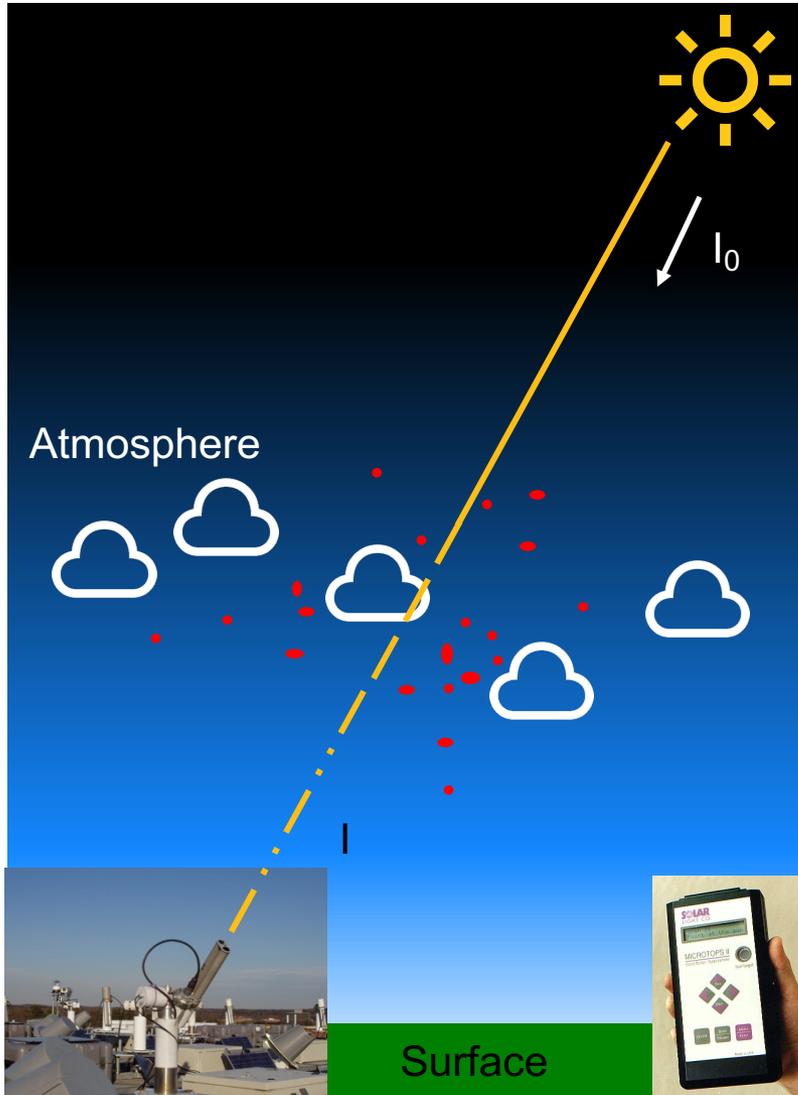
# Objectives

1. Gain a basic understanding of aerosol optical depth
2. Gain knowledge of and ability to access available aerosol products from NASA sensors

# Aerosol Optical Depth

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

# Optical Depth



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

optical depth  $\tau$  as

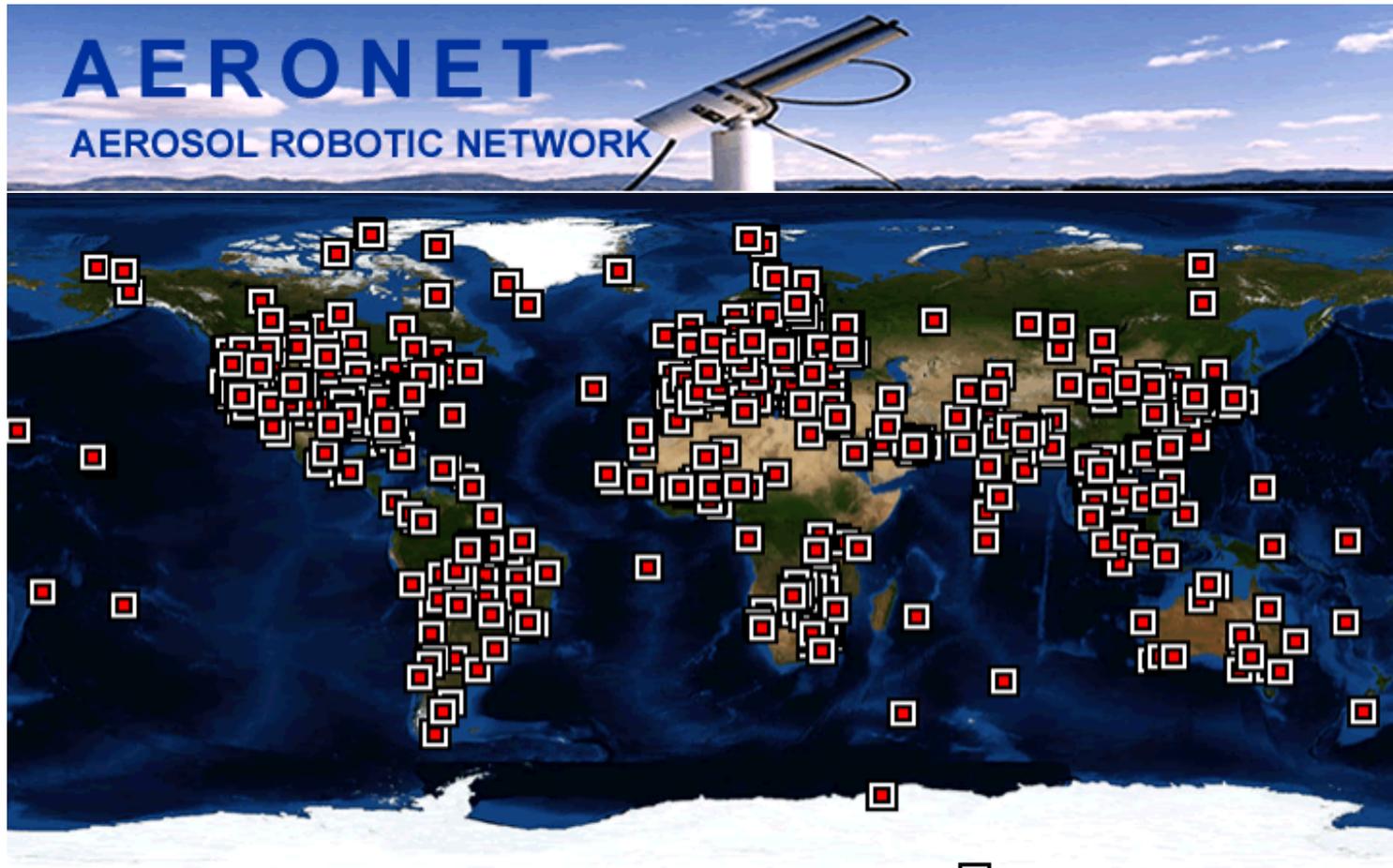
$$I = I_0 e^{-m\tau}$$

$$m = \sec \theta_0$$

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

# AERONET

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



**Serves as a validation tool for satellite aerosol products**

# Satellites for Air Quality Data

- MODIS (Terra and Aqua)
  - AOD: columnar aerosol loading – can be used to get PM2.5 or PM10
- 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

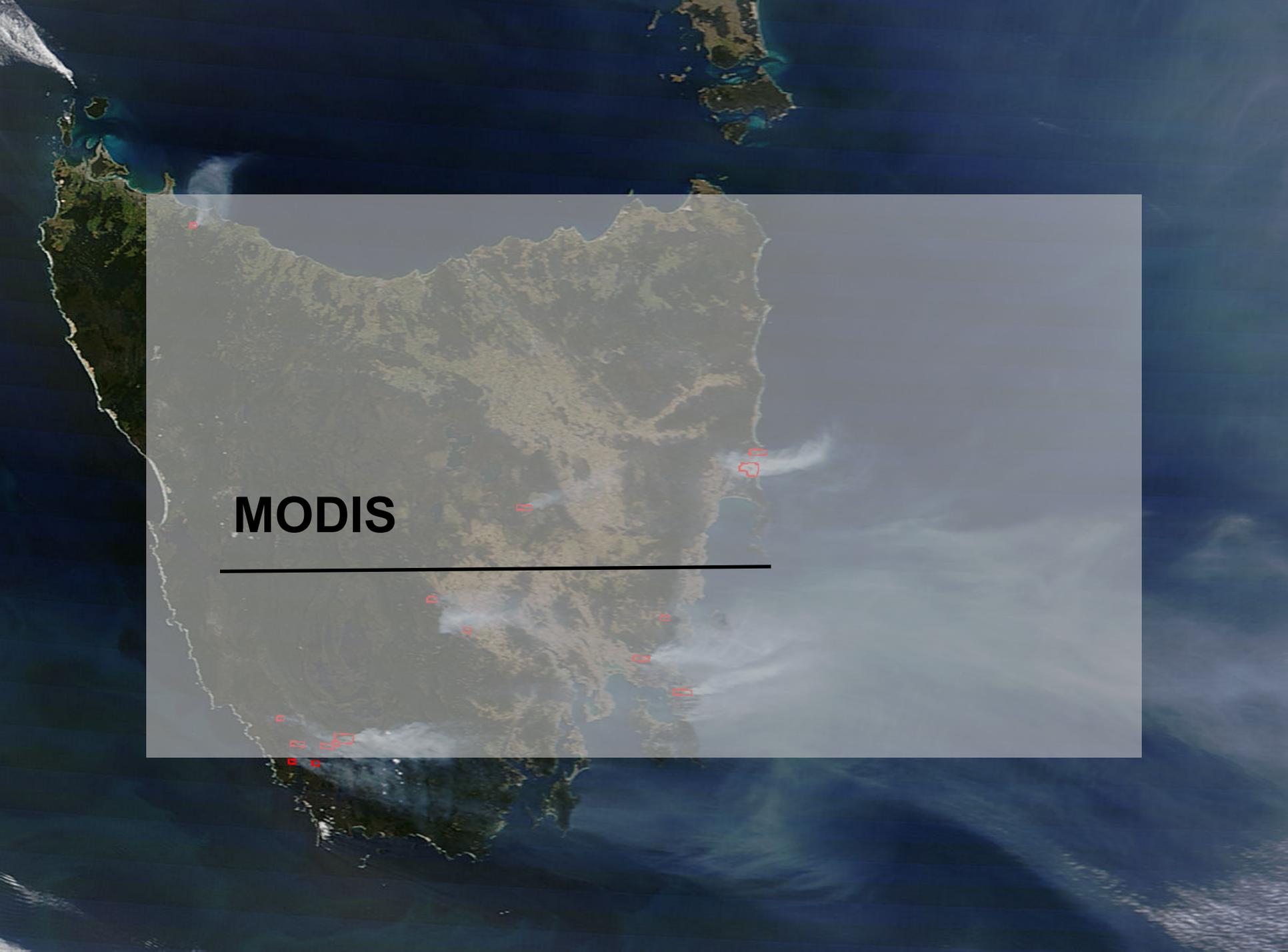
# Instrument Capabilities for Air Quality

## Sensor Measurement Resolution

- MODIS: 250 m – 1 km
- MISR: 275 m – 1.1 km
- OMI: 13 x 24 km
- VIIRS: 750 m

# Satellite Aerosol Products

	MODIS	MISR	OMI	VIIRS
<b>Strengths</b>	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
<b>Weaknesses</b>	Bright Surfaces* Ocean glint Non-spherical particles	Coverage	Resolution Cloud contamination	Bright Surfaces* Ocean glint
<b>Main Products</b>	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
<b>Product Resolution (level 2 and at Nadir)</b>	10 Km 3 Km	17.6 Km	13 X 24 Km	0.75 km 6 km
<b>Product Levels</b>	2	2	2	2
<b>Global Level 3 Aggregates</b>	Daily 8 Day 30 Day	Monthly 3 Month Annual	Daily Monthly	Daily Monthly

A satellite image showing a coastal region with a semi-transparent overlay. The overlay contains the text 'MODIS' and a horizontal line. Several red markers are placed on the image, indicating specific locations. The background shows a coastline with a bay and surrounding land. The overlay is semi-transparent, allowing the underlying satellite imagery to be visible.

**MODIS**

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# Moderate Resolution Imaging Spectroradiometer

## MODIS

- **Spatial Resolution**

- 250m, 500m, 1km

- **Platform**

- Terra & Aqua

- **Temporal Resolution**

- 2000-present

- Daily, 8-day, 16-day, monthly, quarterly, yearly

- **Data Format**

- Hierarchical Data Format – Earth Observing System Format (HDF-EOS)

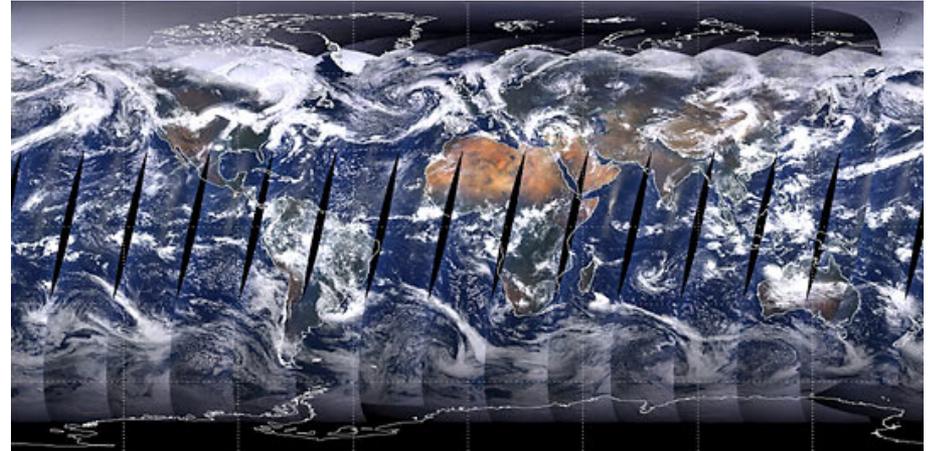
- **Spectral Coverage**

- 36 bands (major bands include red, blue, IR, NIR, MIR)

- Bands 1-2: 250m

- Bands 3-7: 500m

- Bands 8-36: 1,000m

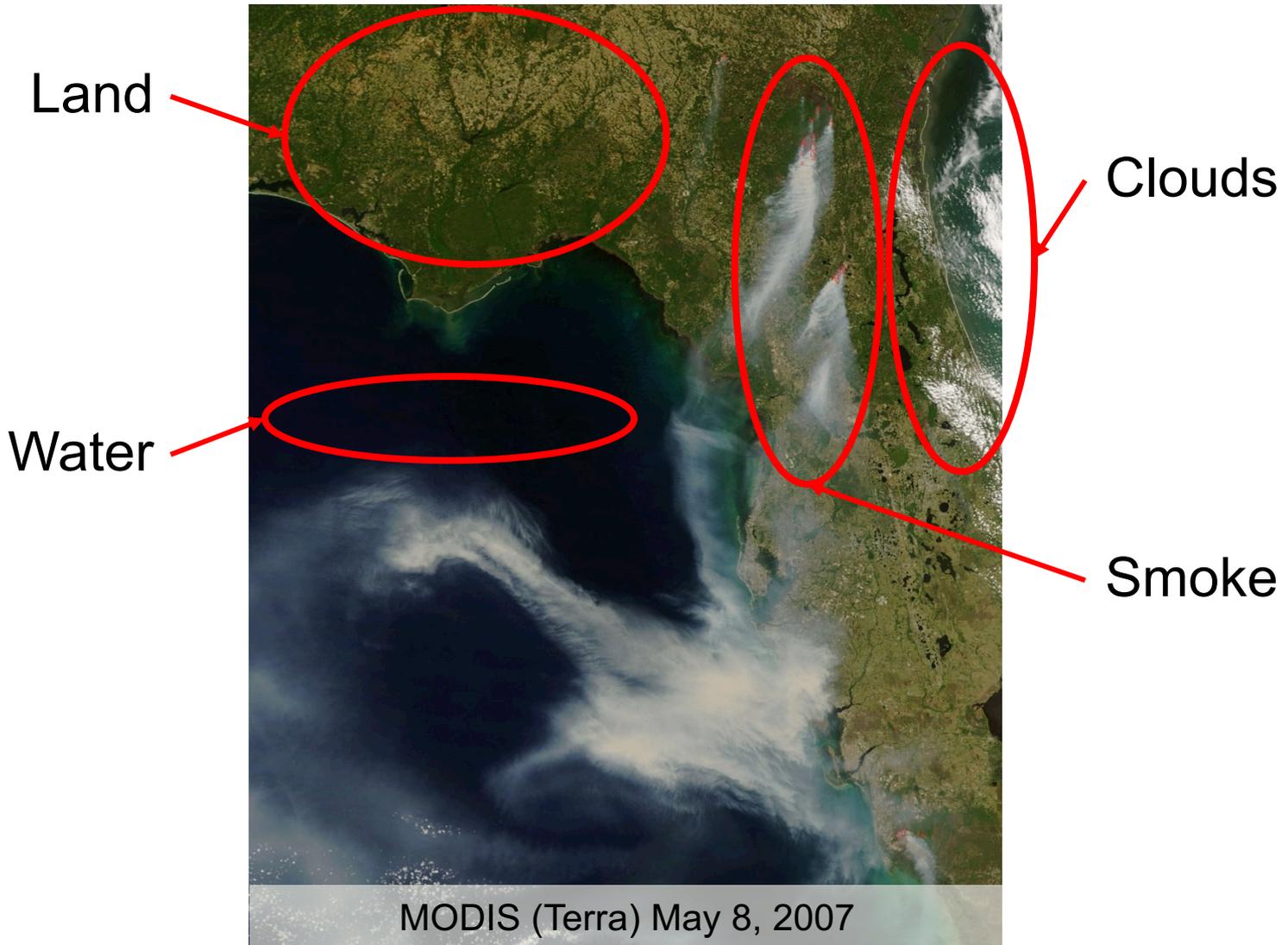


A satellite image of Taiwan and the surrounding waters. A semi-transparent grey rectangular box is overlaid on the island. Inside this box, the text "Aerosol Retrieval" is written in a bold, black, sans-serif font. Below the text is a horizontal black line. The background within the box shows a topographic map of Taiwan with red markers and white plume-like shapes indicating aerosol retrieval data. The markers are scattered across the island, with a notable concentration in the southern and eastern coastal regions. The white shapes appear to be plumes or clouds originating from the coast and moving inland or offshore.

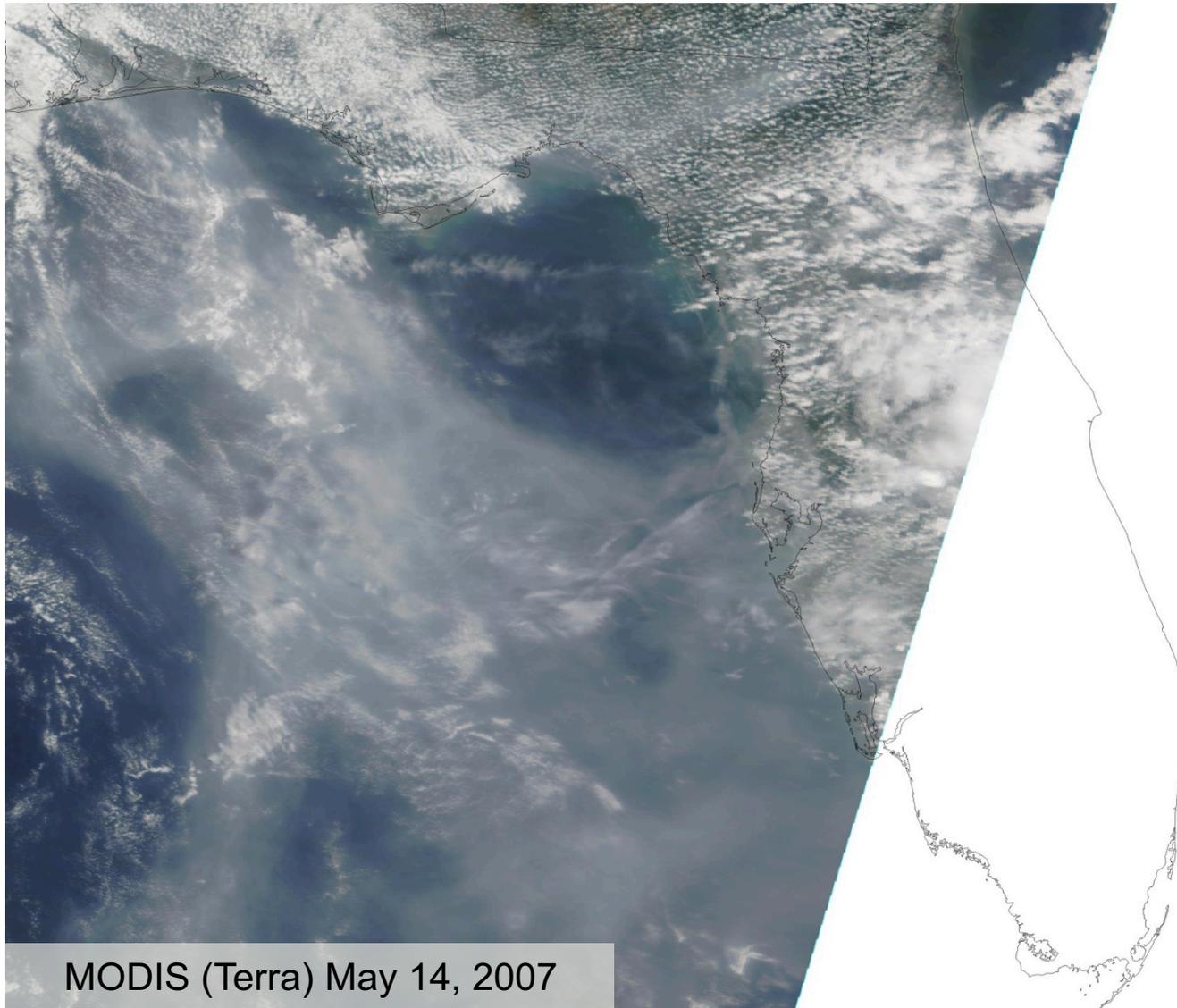
# Aerosol Retrieval

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# Aerosol Detection



# Complex Image: Smoke & Clouds

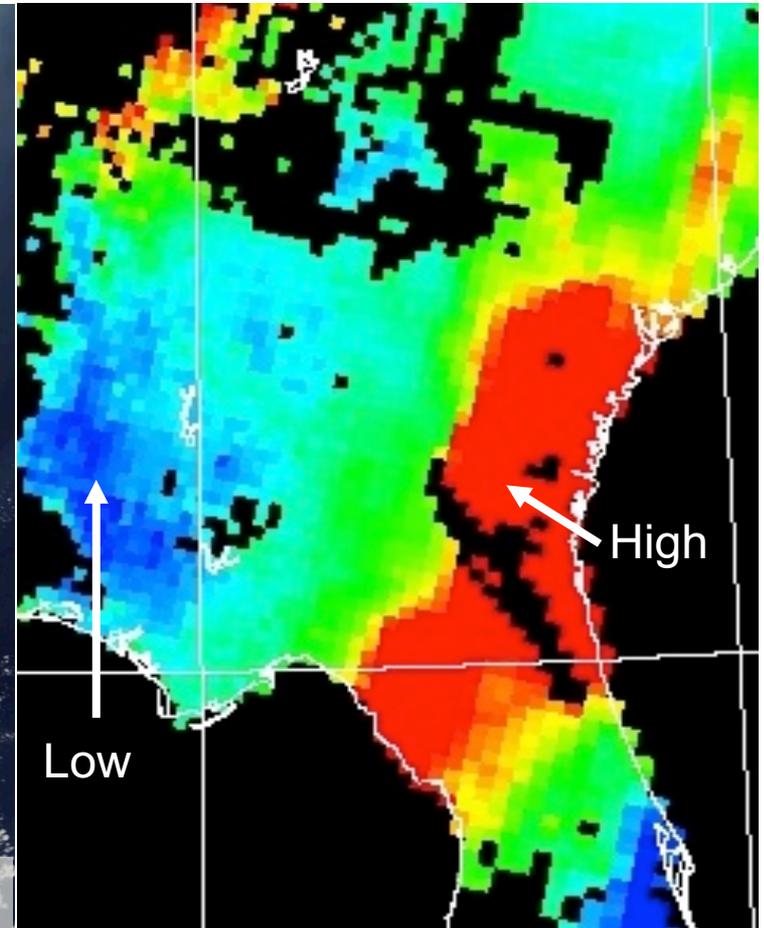


MODIS (Terra) May 14, 2007

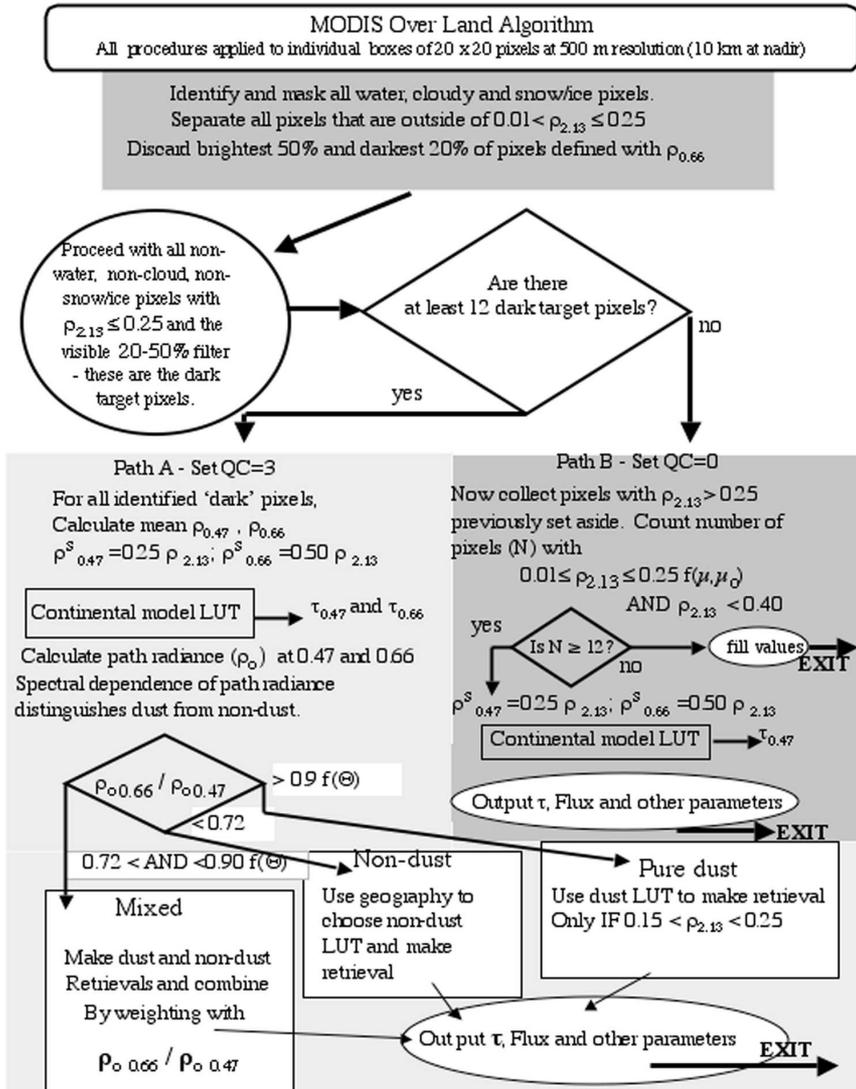
# Radiance to Aerosol Products



MODIS (Terra) May 2, 2007



# Aerosol Retrieval Algorithm



Aerosol retrieval algorithm is a complex inversion scheme where assumptions are made in simulating satellite observations with advance radiative transfer calculations to retrieve atmospheric aerosol properties

Sources: Remer et al., 2005, Levy et al., 2013

# 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**



# MODIS Products

**MOD01 Level-1A Radiance Counts**

**MOD02 Level-1B Calibrated Geolocated Radiances – also Level 1B”subsampled” 5kmx5km pro**

**MOD03 Geolocation Data Set**

**MOD04 Aerosol Product**

**MOD05 Total Precipitable Water**

**MOD06 Cloud Products**

**MOD07 Atmospheric Profiles**

**MOD08 Gridded Atmospheric Product (Level 3)**

**MOD09 Atmospherically-corrected Surface Reflectance**

**MOD10 Snow Cover**

**MOD11 Land Surface Temperature & Emissivity**

**MOD12 Land Cover/Land Cover Change**

**MOD13 Vegetation Indices**

**MOD14 Thermal Anomalies, Fires & Biomass Burning**

**MOD15 Leaf Area Index & FPAR**

**MOD16 Surface Resistance & Evapotranspiration**

**MOD17 Vegetation Production, Net Primary Productivity**

**MOD18 \*Normalized Water-leaving Radiance**

**MOD19 Pigment Concentration**

**MOD20 Chlorophyll Fluorescence**

**MOD21 \*Chlorophyll\_a Pigment Concentration**

**MOD22 Photosynthetically Active Radiation (PAR)**

**MOD23 Suspended-Solids, Conc, Ocean Water**

**MOD24 Organic Matter Concentration**

**MOD25 Coccolith Concentration**

**MOD26 \*Ocean Water Attenuation Coefficient**

**MOD27 Ocean Primary Productivity**

**MOD28 \*Sea Surface Temperature**

**MOD29 Sea Ice Cover**

**MOD32 Processing Framework & Match-up Database**

**MOD33 Gridded Snow Cover**

**MOD34 Gridded Vegetation Indices**

**MOD35 Cloud Mask**

**MOD36 Total Absorption Coefficient**

**\*MOD37 Ocean Aerosol Optical Thickness**

**MOD39 Clear Water Epsilon**

**MOD43 Albedo 16-day L3**

**MOD44 Vegetation Cover Conversion**

**MYD – MODIS Aqua**

**MOD – MODIS Terra**

# A Few More Things About MODIS Data...

- MOD: Terra product
- MYD: Aqua product
  
- All MODIS products come in **HDF** format
  
- In HDF format each file contains both data and metadata
  
- **Scientific Data Set (SDS)**: each parameter within a MODIS HDF file is referred to as an SDS
  - SDS must be referenced precisely according to name when analyzing the data within your own computer code

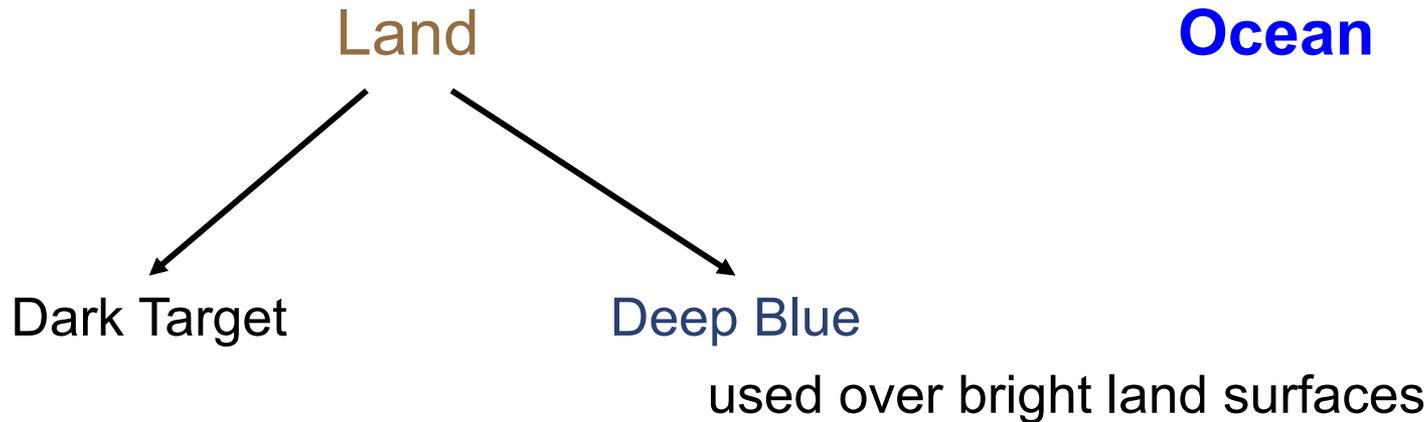
# Things That Change with Each Instrument

(So you need to learn them!)

- Calibration Accuracy
- Quality Assurance – quality of the data
- Data Formats
- Product Resolutions
- Creating Level 3 products from Level 2  
–temporally and spatially averaging
- Current data release and data history

# MODIS Aerosol Products

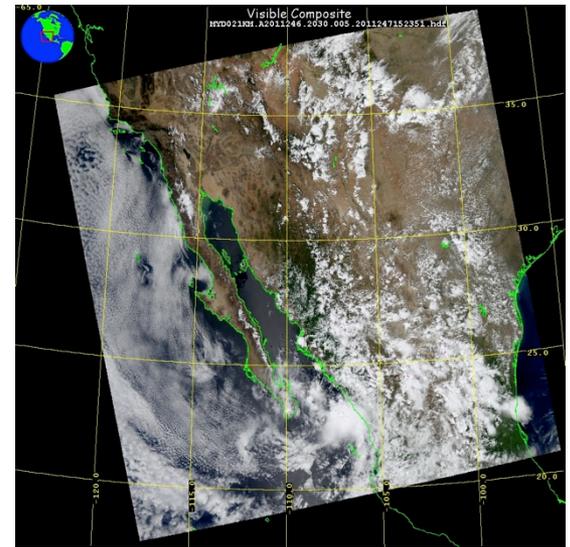
## Three Separate Algorithms



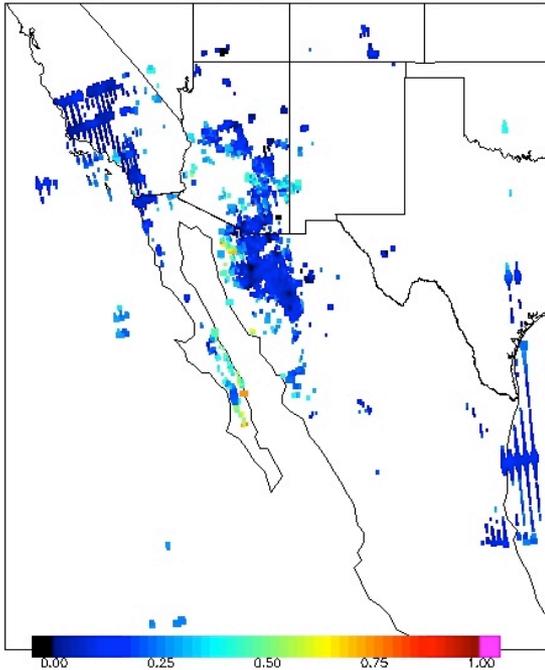
- The dark target and deep blue products are separate and when both are available, the user must select which to use
- In collection 6, there is a joint product that uses an automated procedure to select the appropriate product

# MODIS Aerosol Products

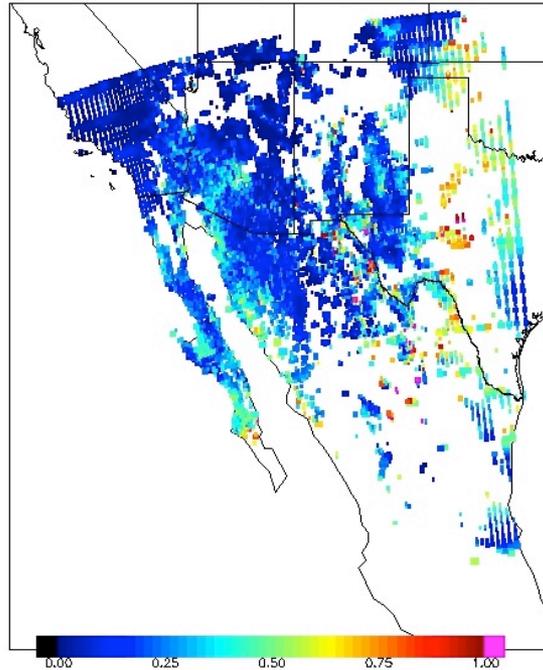
## Two Algorithms



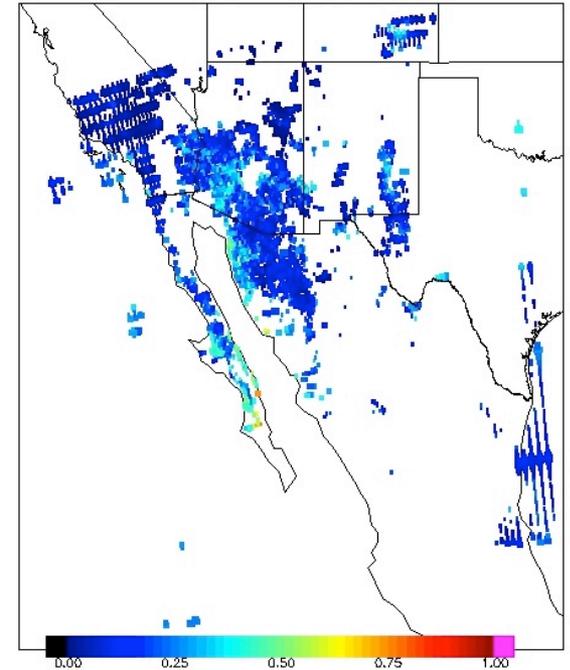
### Dark Target



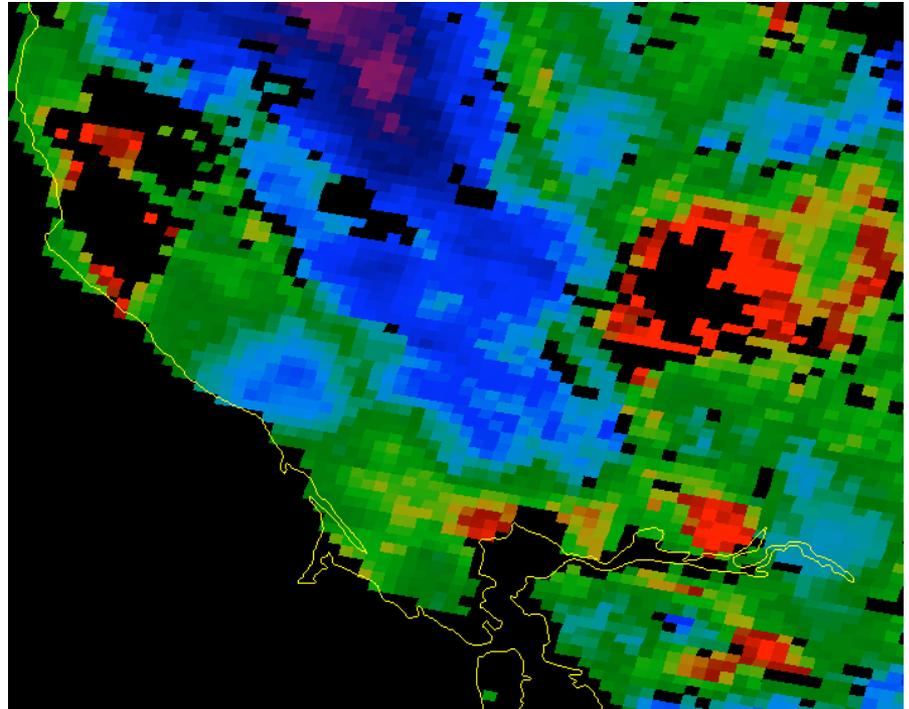
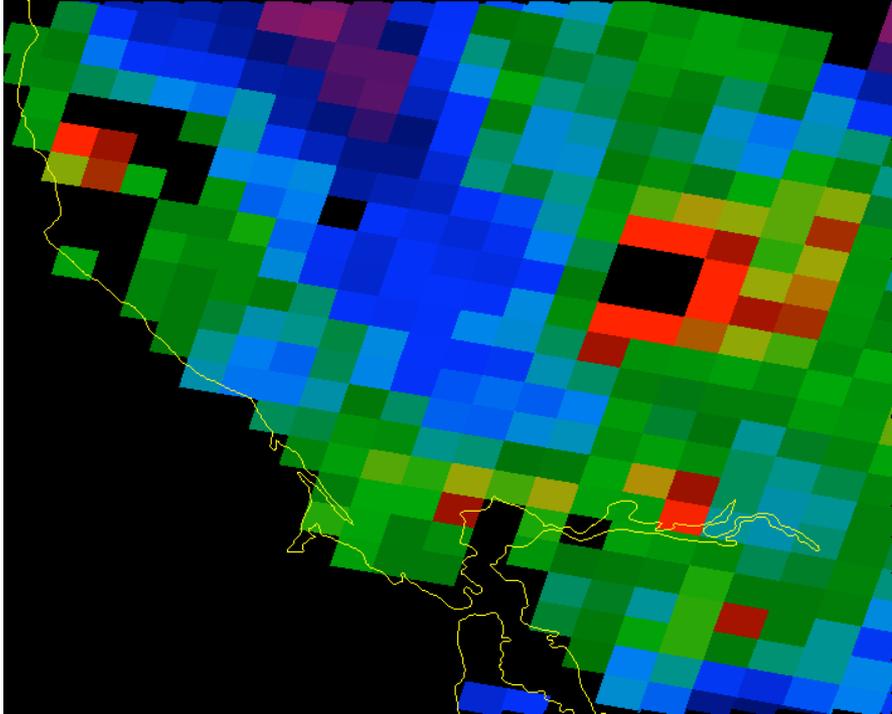
### Deep Blue



### Deep\_Dark\_Combined



# MODIS 10km vs. 3km Products



# Quality Assurance is Extremely Important

QA indicates confidence in the quality of the retrieval

## Quality\_Assurance\_Ocean

- Scale is 0-3
- Recommended Ocean QA above 1, 2, 3
- Factors:
  - Number of pixels
  - Error fitting
  - **How close to glint**

## Quality\_Assurance\_Land

- Scale is 0-3
- Recommended Land QA of 3
- Factors:
  - Number of pixels
  - Error fitting
  - **Surface reflectance**

# Understanding a MODIS File Name

Level 2, 10km, Aerosol Product

## Product Name

- Terra: MOD04
- Aqua: MYD04



HDFLook, Panoply, IDL, Python, Fortran, MatLab, and more can be used to read the data

# Understanding a MODIS File Name

Level 2, 3km, Aerosol Product

## Product Name

- Terra: MOD04
- Aqua: MYD04

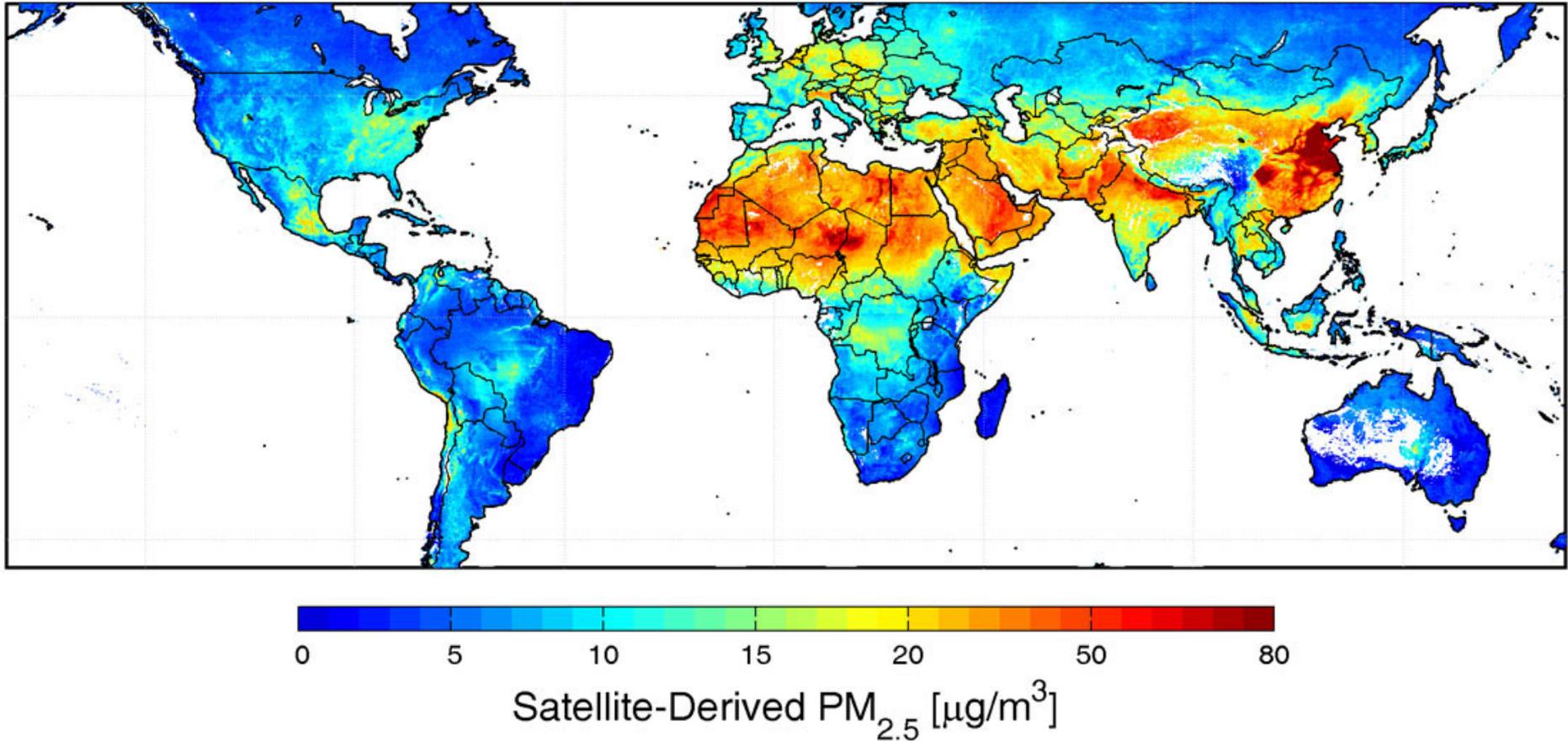


HDFLook, Panoply, IDL, Python, Fortran, MatLab, and more can be used to read the data

# 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 3km
- **Dark\_Target\_Deep\_Blue\_Optical\_Depth\_550\_Combined**
  - Deep Blue & Dark Target Algorithm Merged Product
  - 10km only
- **Dark\_Target\_Deep\_Blue\_Optical\_Depth\_550\_Combined\_QA**
  - Quality flag associated with DD product

# Application of MODIS Aerosol Product



Source: van Donkelaar et al., 2006, 2009



# Application of MODIS Aerosol Product - Fusion

- AirNow Satellite Data Processor  
– <https://youtu.be/ALPBWkBAxf4>

## Daily Estimated PM<sub>2.5</sub> Concentrations ( $\mu\text{g}/\text{m}^3$ ) and Weights

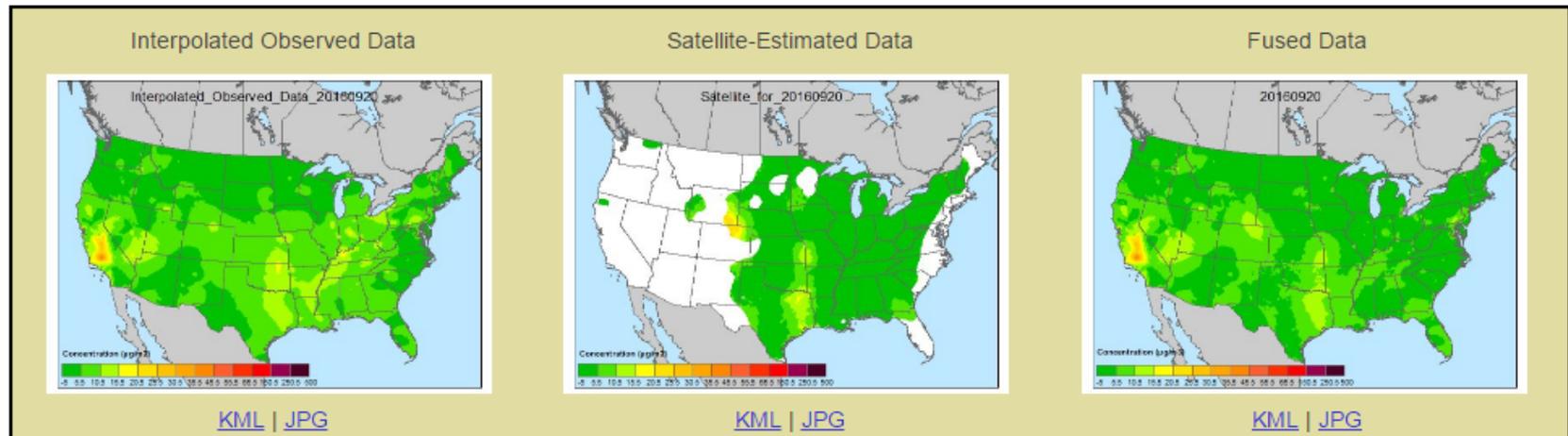
Fusion Method

Date



[Test KMZ for 20160920](#)

Show/Hide 6 Panels



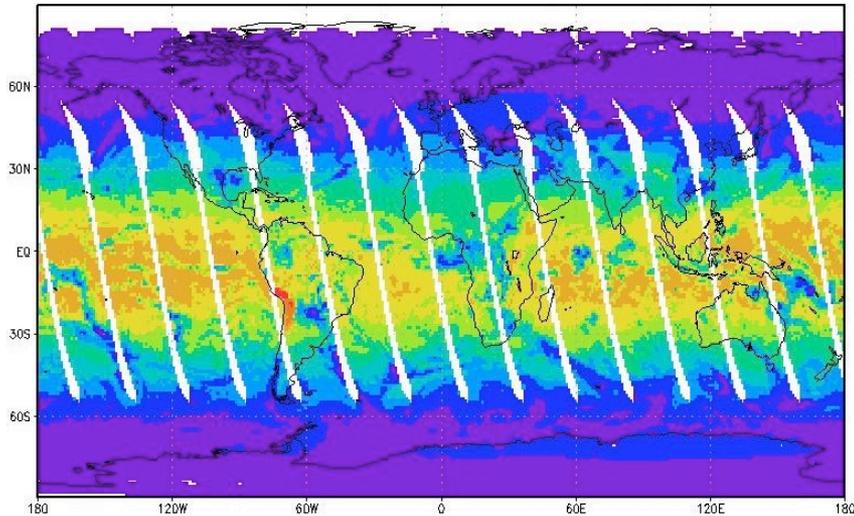
# Access to MODIS Aerosol Products

- 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](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/>



OMI

# Ozone Monitoring Instrument (OMI)



## Instrument Characteristics

- Nadir solar backscatter spectrometer
- Spectral Range: 270-500nm
  - Resolution ~1nm
- Swath Width: 2,600km
  - Global daily coverage with 13x24 km spatial resolution

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

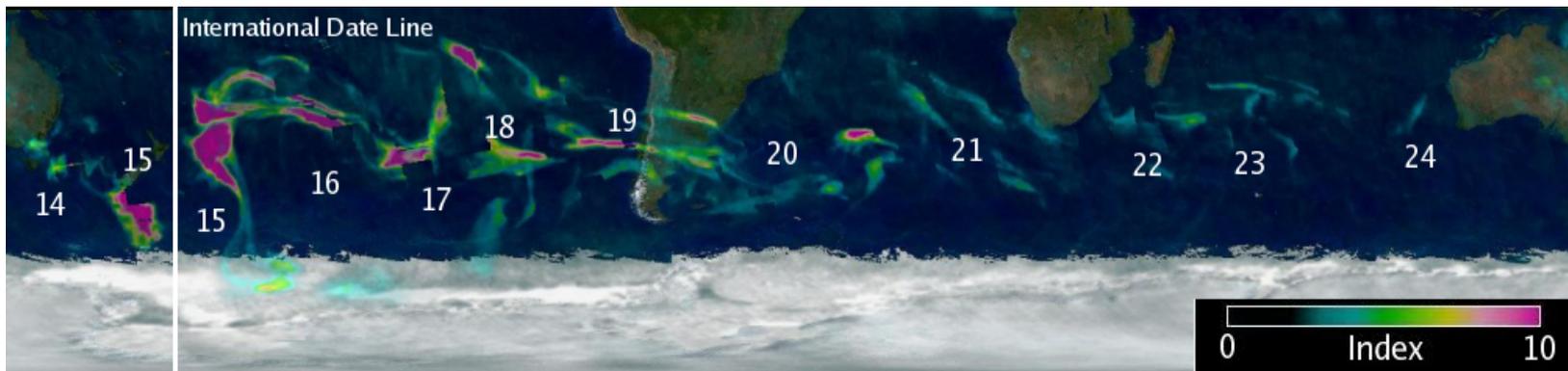
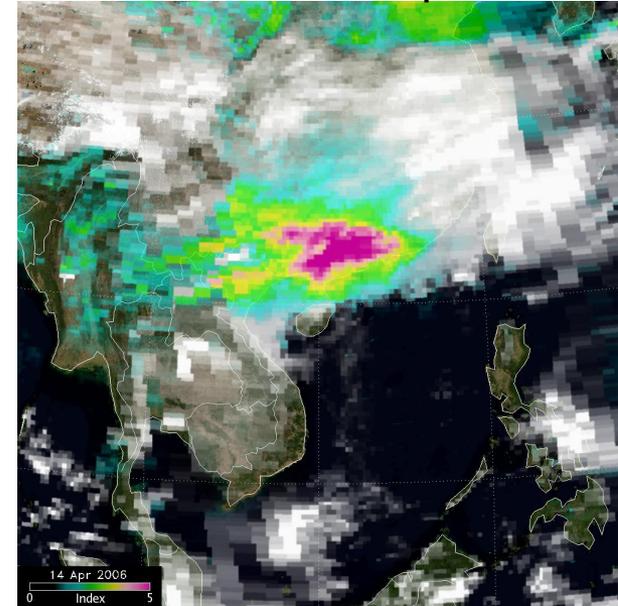
## Retrieval Products

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

# Applications of the Aerosol Index

Aerosols over clouds, April 14, 2006

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

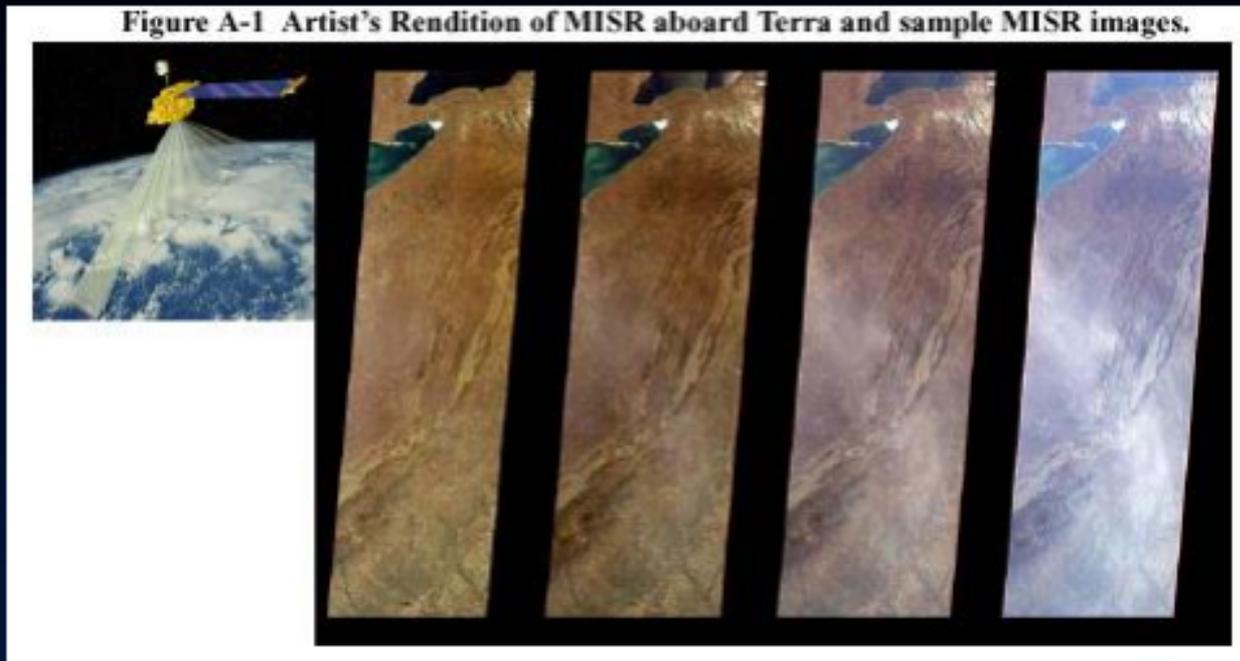


**Above: Transport around the globe of a high altitude smoke layer generated by the Dec 2006 Australian fires. Numbers indicate the day of the month.**



**MISR**

# MISR Instrument

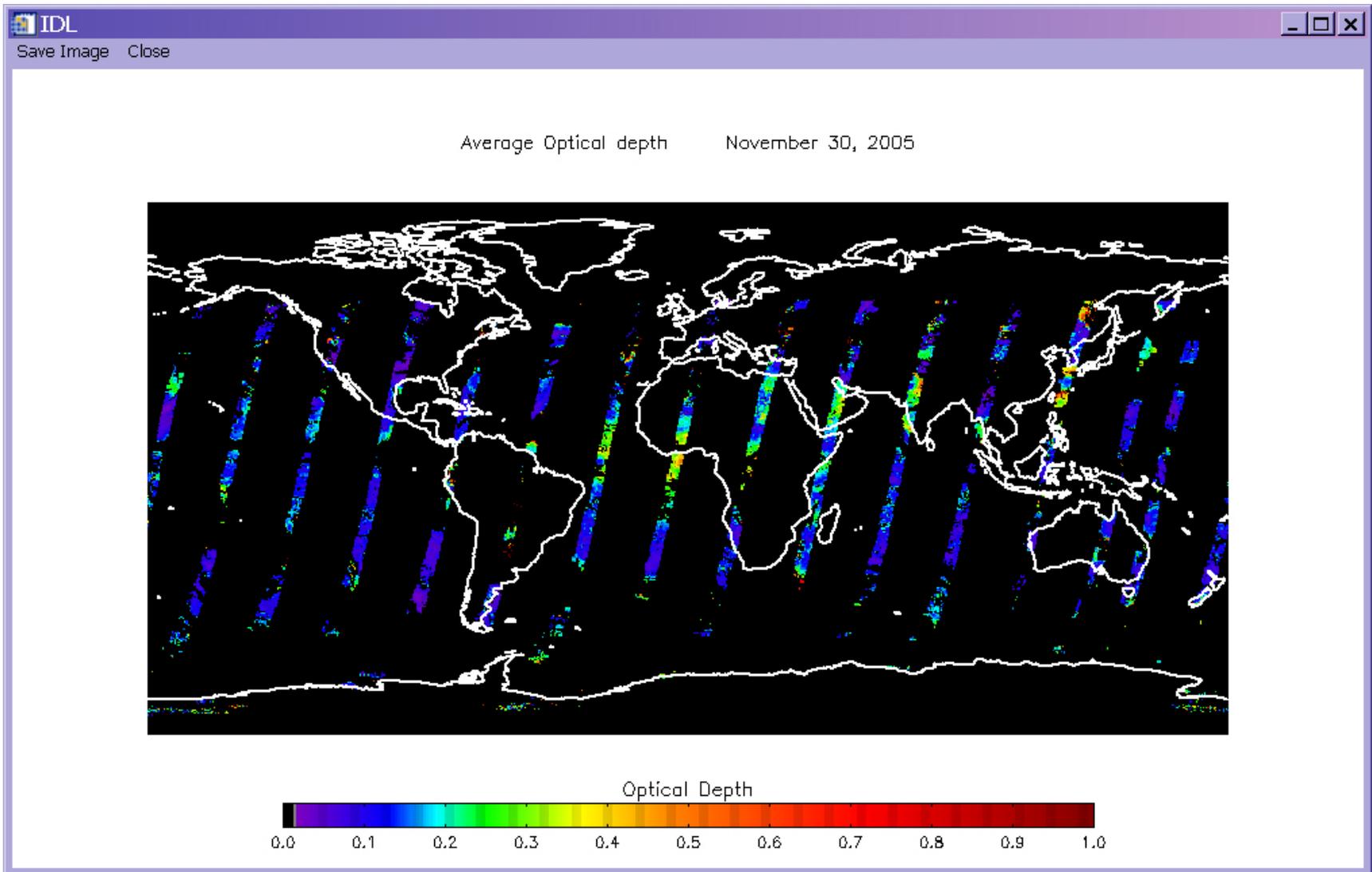


Source: Brian E. Rheingans, JPL

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

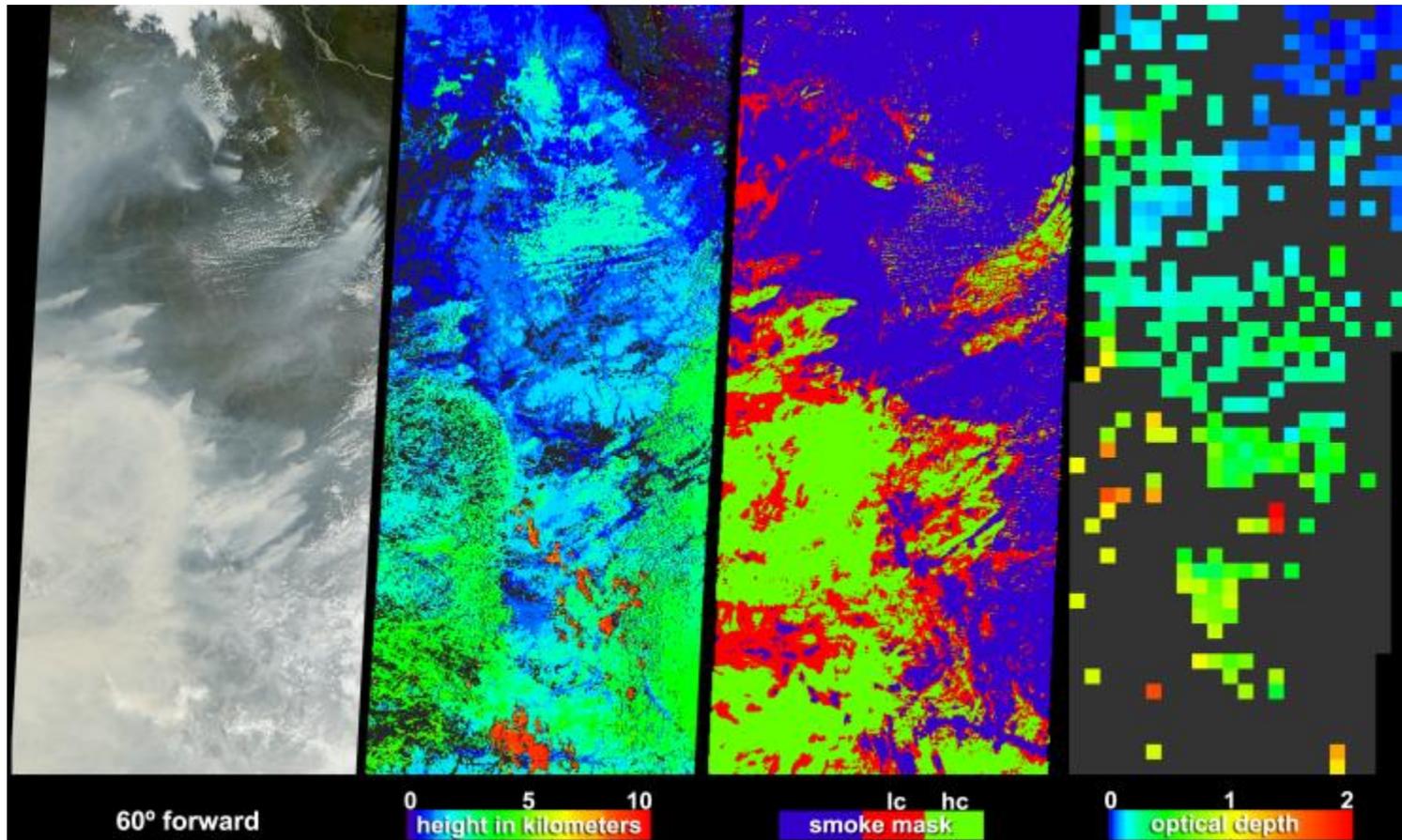
**Angular observations (which are not available in MODIS) makes MISR capable of providing additional information on particle size, shape and aerosol height under specific cases**

# MISR Global Daily Coverage



# Applications of MISR Data

## Smoke signals from the July 2004 Alaska and Yukon Fires



A satellite image of Taiwan is shown with a semi-transparent grey overlay. The overlay contains a map of the island with several red icons representing the locations of VIIRS sensors. The icons are distributed across the island, with a higher concentration in the southern and eastern coastal regions. The word "VIIRS" is printed in large, bold, black letters on the left side of the overlay, with a horizontal line underneath it.

**VIIRS**

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# Visible Infrared Imaging Radiometer (VIIRS)

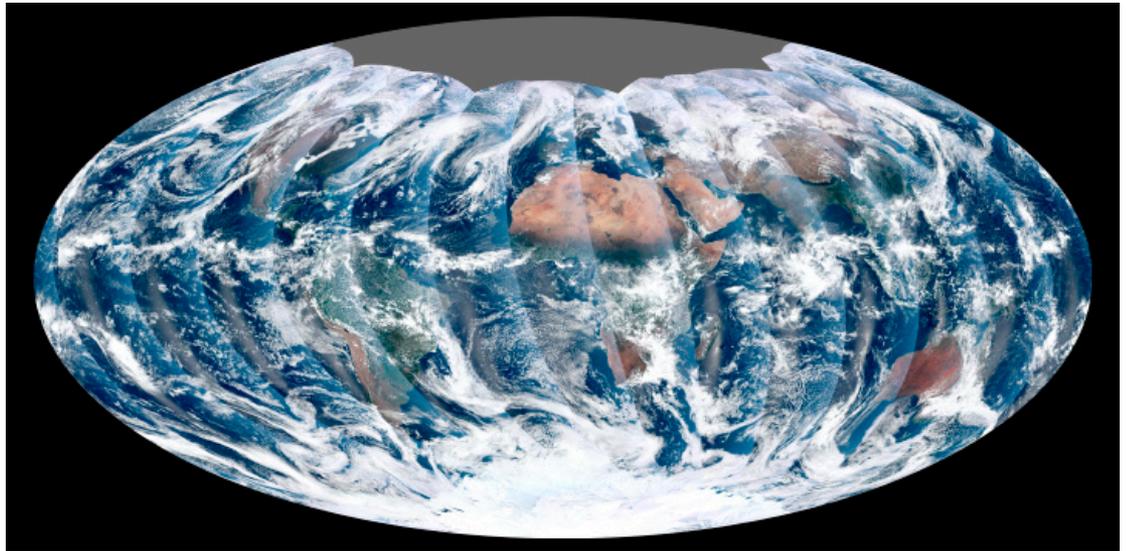
A multi-wavelength imager like MODIS with similar wavelength bands

	MODIS	VIIRS
Orbit Altitude	690 km	824 km
Equator Crossing Time	13:30 LT	13:30 LT
Granule Size	5 min	86 sec
Swath	2,330 km	3,000 km
Pixel Nadir	0.5 km	0.75 km
Pixel Edge	2 km	1.5 km

# VIIRS & MODIS

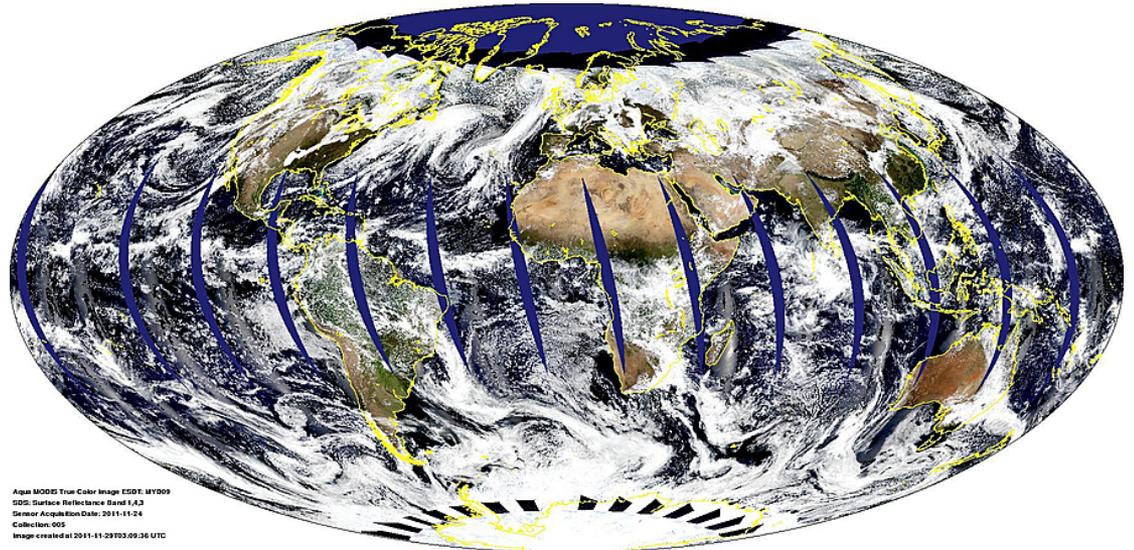
## VIIRS

Nov 24, 2011

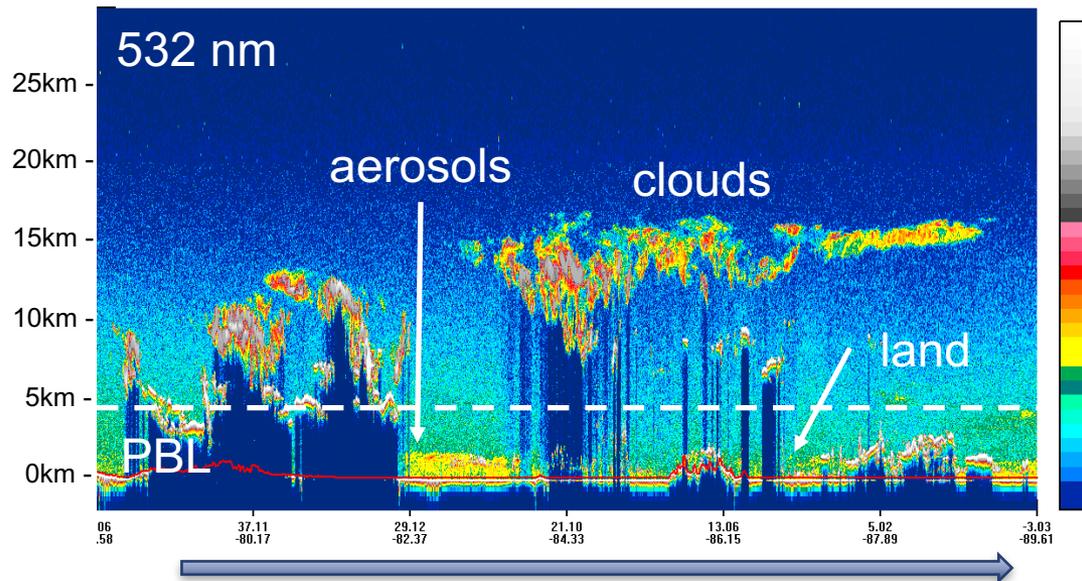
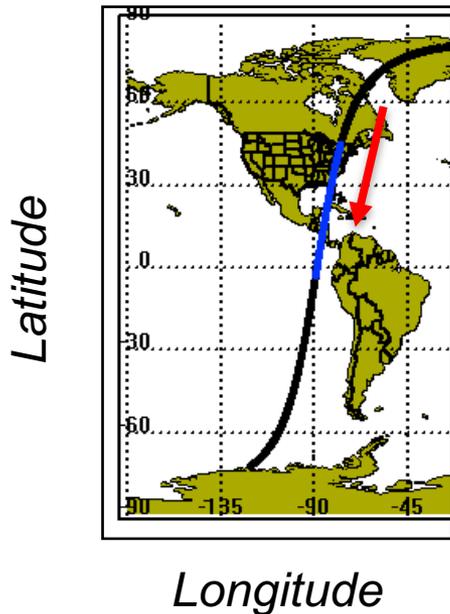
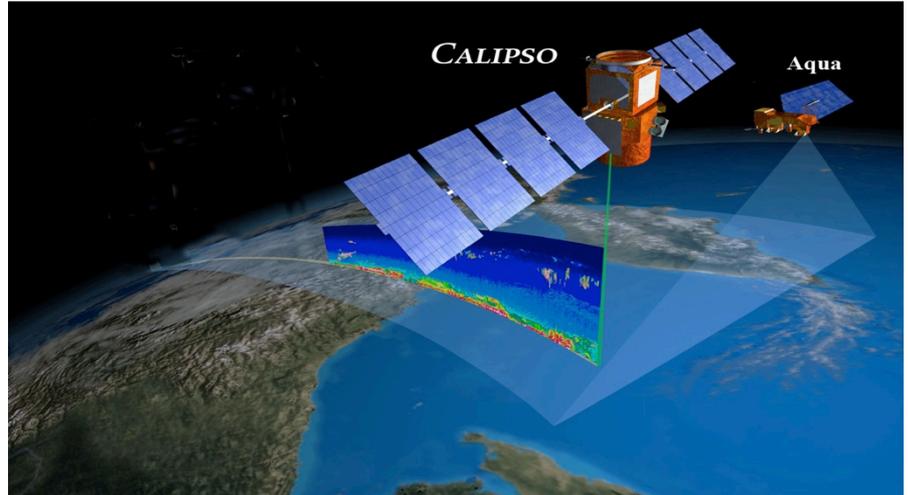
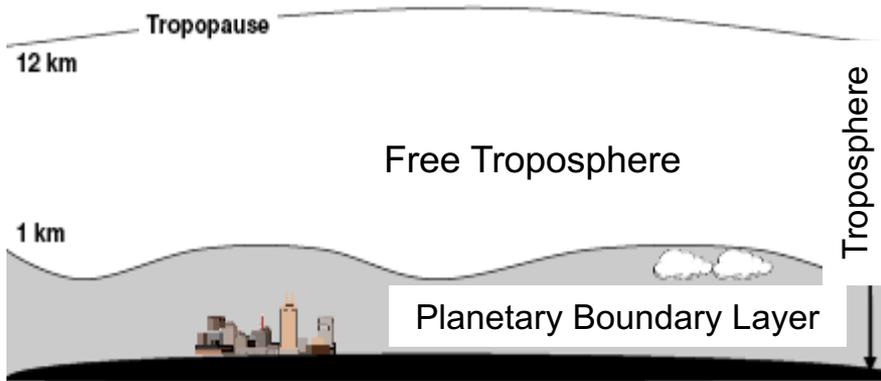


## MODIS (Aqua)

Nov 24, 2011



# CALIPSO: Vertical Profiles



Source: Meloë Kacenenbogen

# Available Satellites for Aerosol Monitoring

	Pros	Cons
MODIS	<ul style="list-style-type: none"> <li>• High spatial resolution (0.25-1km)</li> <li>• Fine vs. coarse</li> <li>• Twice daily near-global coverage</li> </ul>	<ul style="list-style-type: none"> <li>• No data under cloudy conditions</li> <li>• No vertical information</li> <li>• Larger uncertainties over bright targets</li> </ul>
MISR	<ul style="list-style-type: none"> <li>• Size/shape information</li> <li>• Higher accuracy</li> <li>• Multi-angle view</li> </ul>	<ul style="list-style-type: none"> <li>• Limited swath width (360km)</li> <li>• Limited vertical information</li> <li>• No daily observations for air quality</li> </ul>
OMI	<ul style="list-style-type: none"> <li>• Daily near-global coverage</li> <li>• Absorbing aerosols</li> <li>• Precursor measurements (sulfate, nox)</li> <li>• Available over bright targets</li> </ul>	<ul style="list-style-type: none"> <li>• Lack of information on scattering aerosols</li> <li>• Coarse resolution to separate clouds</li> <li>• Larger uncertainties</li> </ul>
POLDER	<ul style="list-style-type: none"> <li>• Daily near-global coverage</li> <li>• Sensitive to small mode aerosols</li> <li>• Available over bright targets</li> </ul>	<ul style="list-style-type: none"> <li>• No data under cloudy conditions</li> <li>• No vertical information</li> <li>• Larger uncertainties over bright targets</li> </ul>
CALIPSO	<ul style="list-style-type: none"> <li>• Vertical information available</li> <li>• Information on clouds</li> </ul>	<ul style="list-style-type: none"> <li>• Narrow swath (almost point measurement)</li> <li>• Very limited global coverage</li> <li>• Larger uncertainties in retrieved data sets</li> </ul>

**VIIRS, HIMAWARI, GOCI, and many more**

# Satellite Limitations

- **Optical measurements**
  - Only available in day time
  - Very limited in night time
- **Only available under**
  - Cloud free conditions
  - Snow/Ice free conditions
- **Accuracy - vary (AOD) – Depends on satellite/algorithm**
  - Very good over dark vegetated surfaces
  - Moderate over urban surfaces
  - Moderate to low over bright surface
  - Complex topography (i.e. mountains) – can be problematic
    - More uncertain for complex mixture of aerosols
- **Chemical Composition**
  - Very limited capabilities, only at research level
- **Temporal Coverage**
  - Usually once a day
  - But can use multiple satellite to get 2-3 a day
  - Geostationary will provide more frequent observations
- **Spatial Resolution**
  - 10 km (good)
  - 3 km (moderate)
  - 1km, 0.75 km etc.

A satellite-style map of Taiwan is shown, with a semi-transparent grey rectangular box overlaid on the central and eastern parts of the island. Inside this box, the text "Questions & Discussion" is written in a black, sans-serif font. A thin black horizontal line is positioned directly below the text. The background of the slide is a satellite image of the island, showing its topography and surrounding waters. Several red circular markers are scattered across the island, primarily along the coast and in the central mountainous regions.

# Questions & Discussion

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# References & Links

- ARSET air quality page
  - <http://arset.gsfc.nasa.gov/airquality>
- NASA air quality
  - <http://airquality.gsfc.nasa.gov>
- MODIS Atmos
  - <http://modis-atmos.gsfc.nasa.gov/>
- MISR data
  - [https://eosweb.larc.nasa.gov/PRODOCS/misr/Quality\\_Summaries/L2\\_AS\\_Products.html](https://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/>