

# Introduction to Remote Sensing of Air Quality

Data Analysis Tools for High Resolution Air Quality Satellite Datasets

Pawan Gupta & Melanie Follette-Cook, January 17-22, 2018



# Learning Objectives

By the end of this presentation, you will be able to:

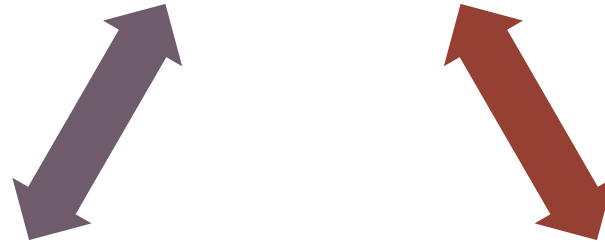
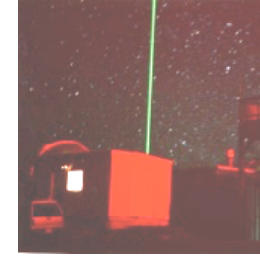
- outline aerosol and trace gas products
- identify potential applications for air quality monitoring
- describe tools to read and map datasets



# Air Pollution Monitoring



Ground  
Measurements

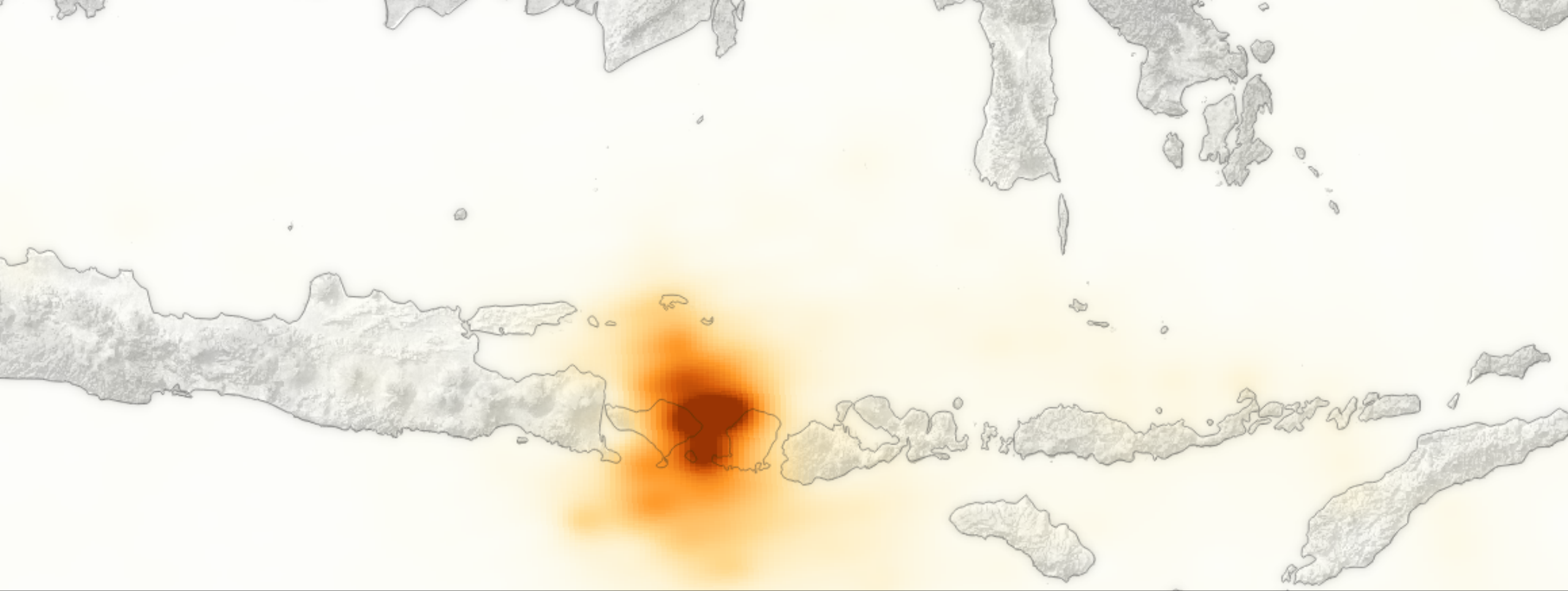


Air & Space  
Observations



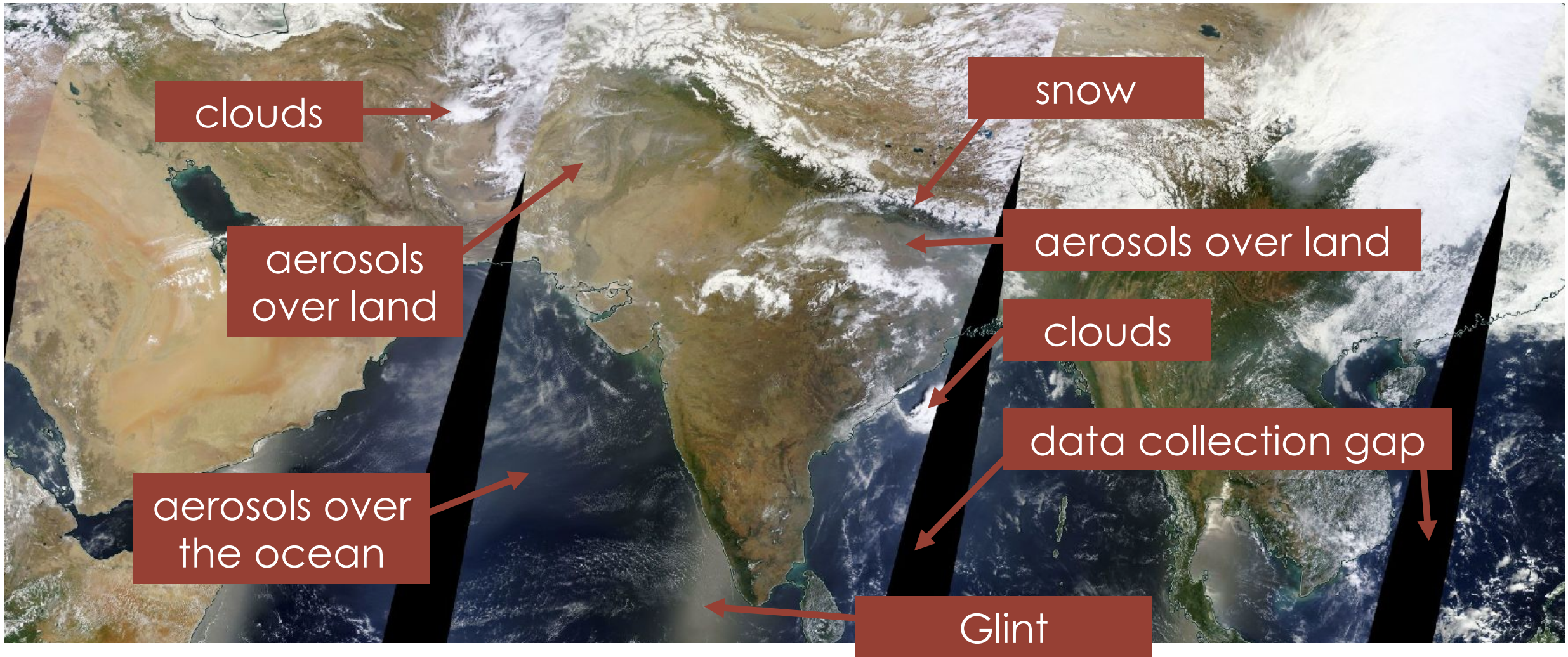
Models





Why use satellite data?

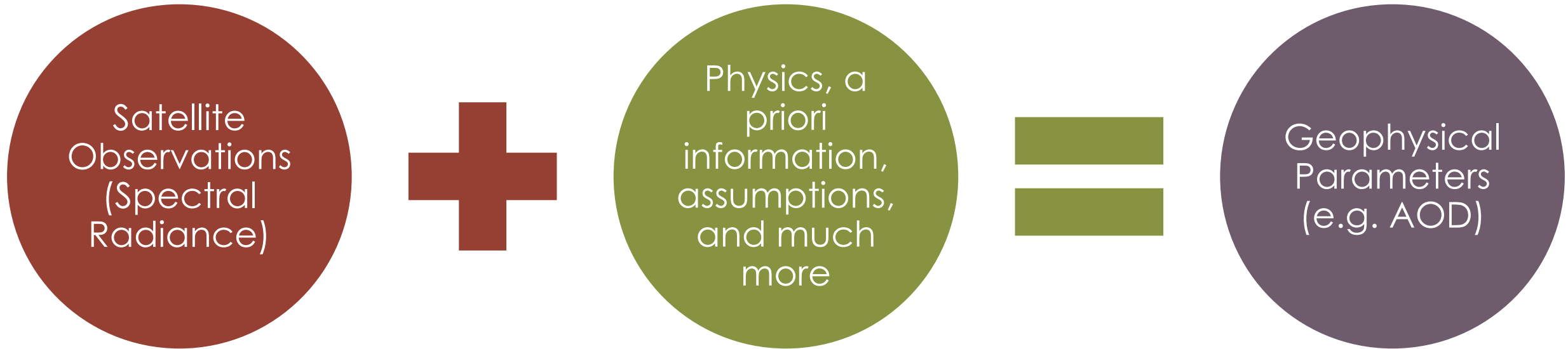
# What can we learn from true color imagery?



Terra (MODIS) image, April 19, 2013



# Radiance to Geophysical Parameter



# Aerosols from Satellites

- Several satellites provide state-of-the-art aerosol measurements globally, on a daily basis

## Aerosol Optical Thickness (Aqua MODIS)

Winter

Spring

Summer

Fall

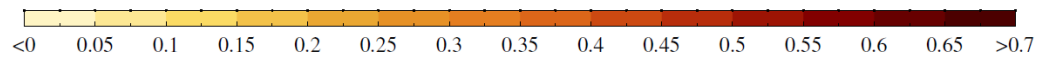
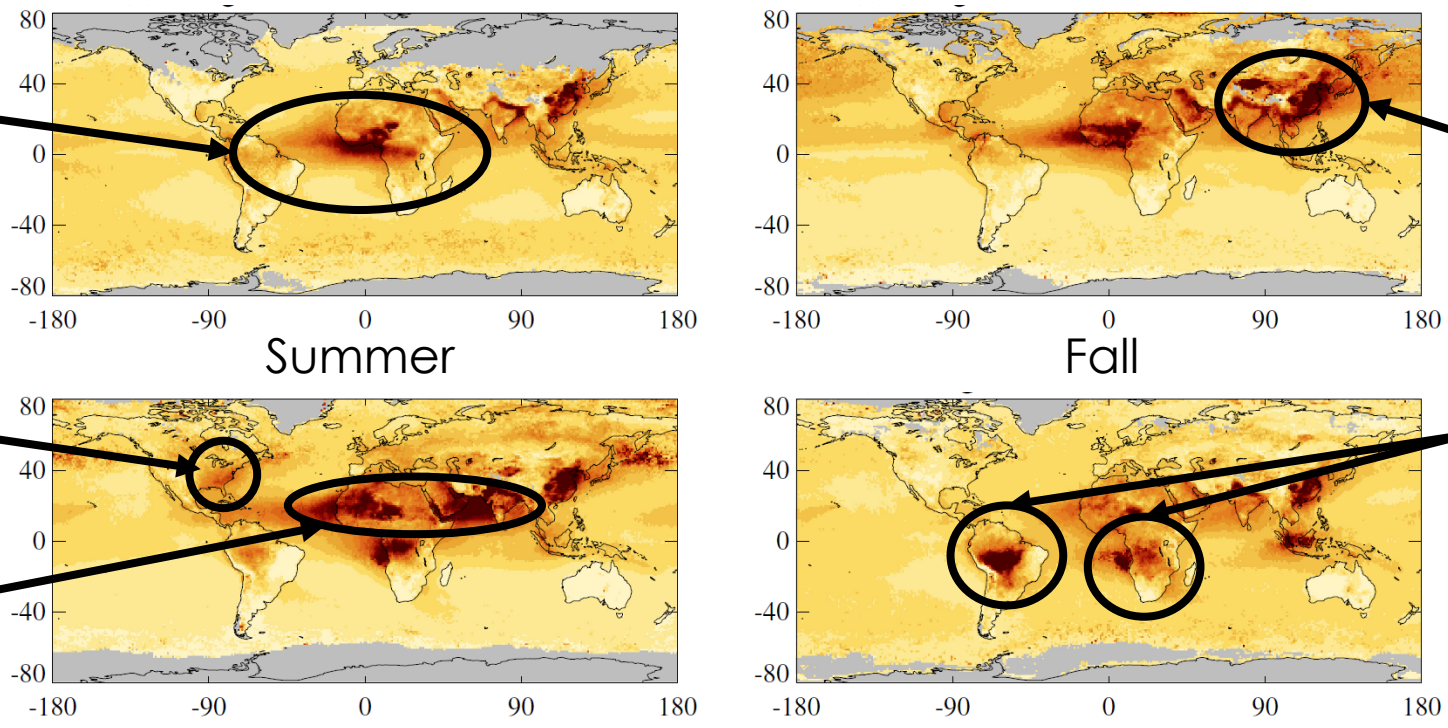
biomass burning

pollution & dust

haze & pollution

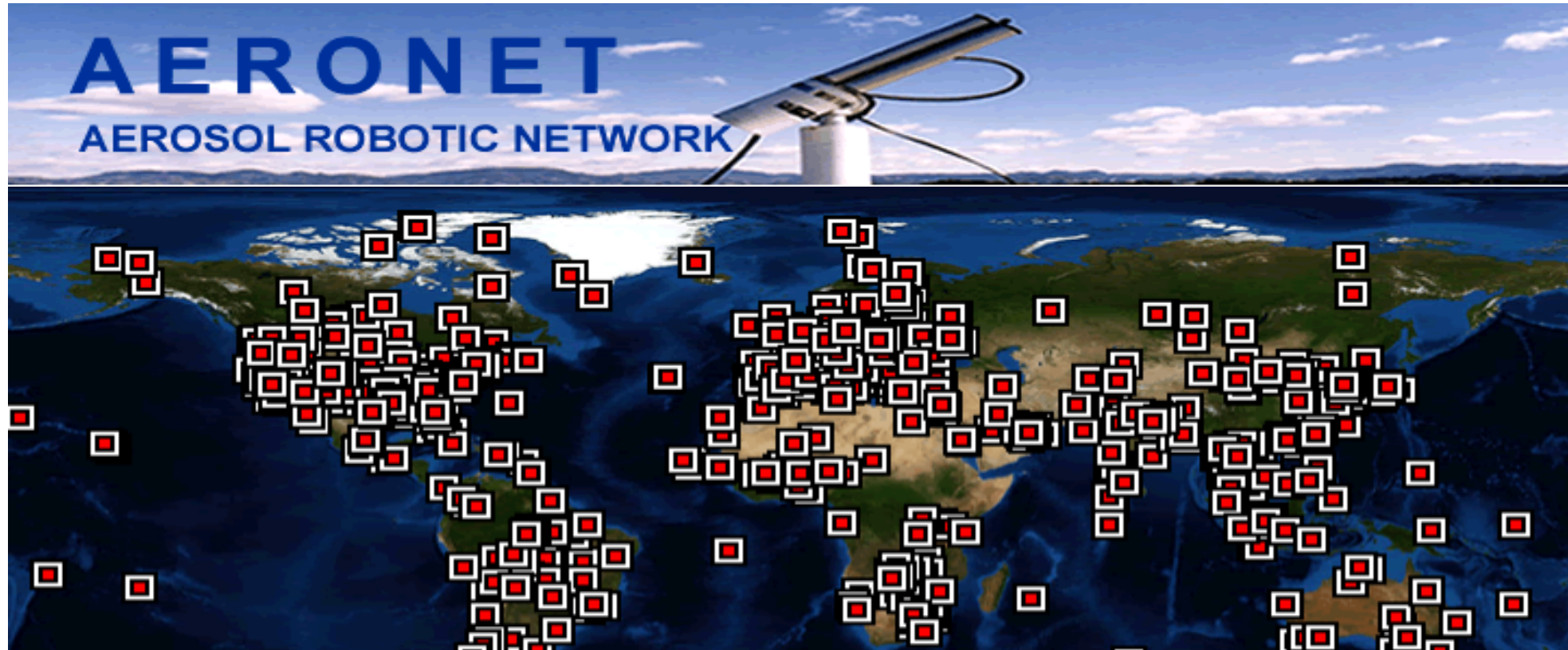
biomass burning

dust



# AERONET

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

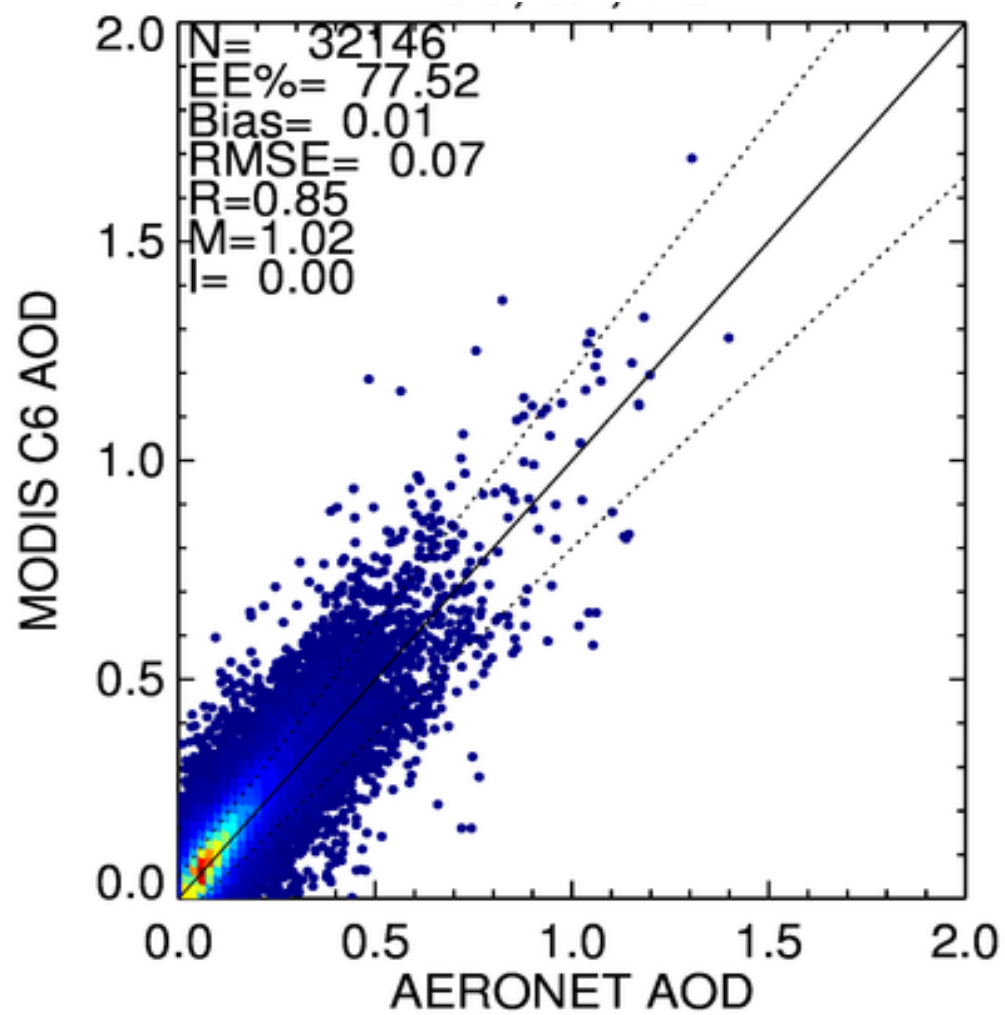


**AERONET measurements of aerosol optical depth are considered ground truth and are used to validate satellite aerosol retrievals**

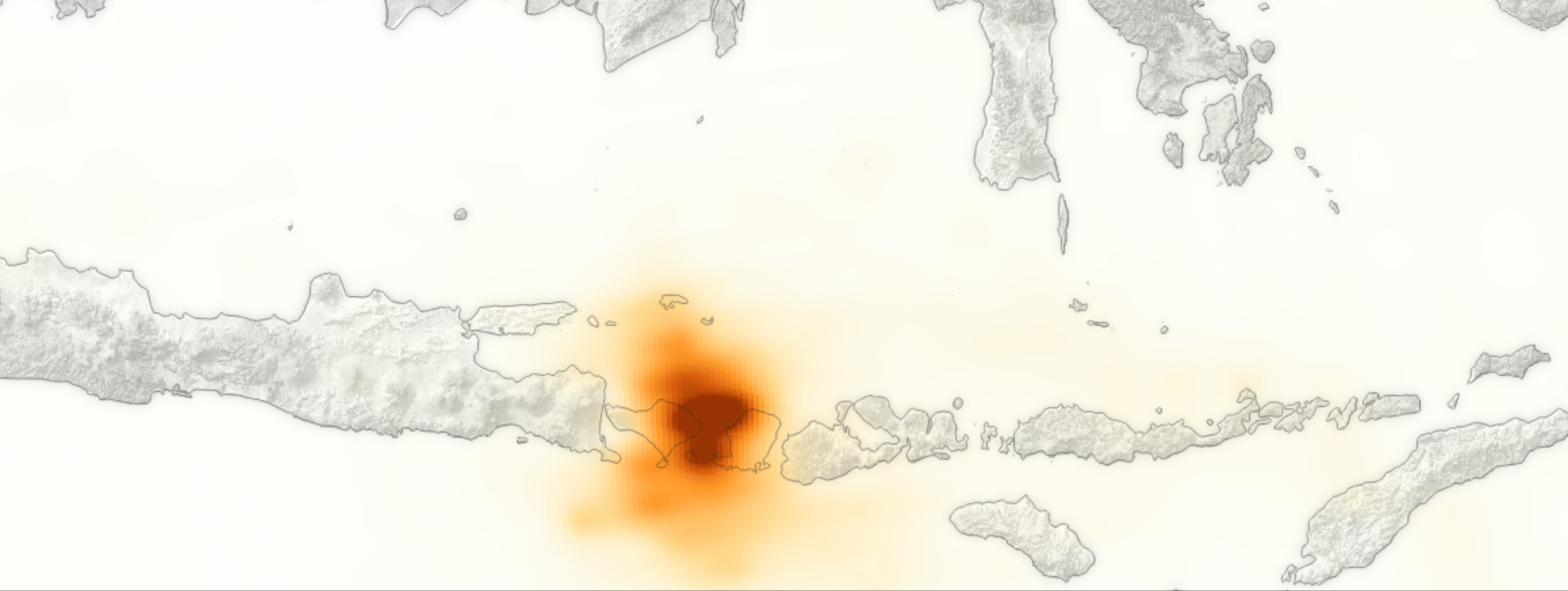




# MODIS Aerosol Validation

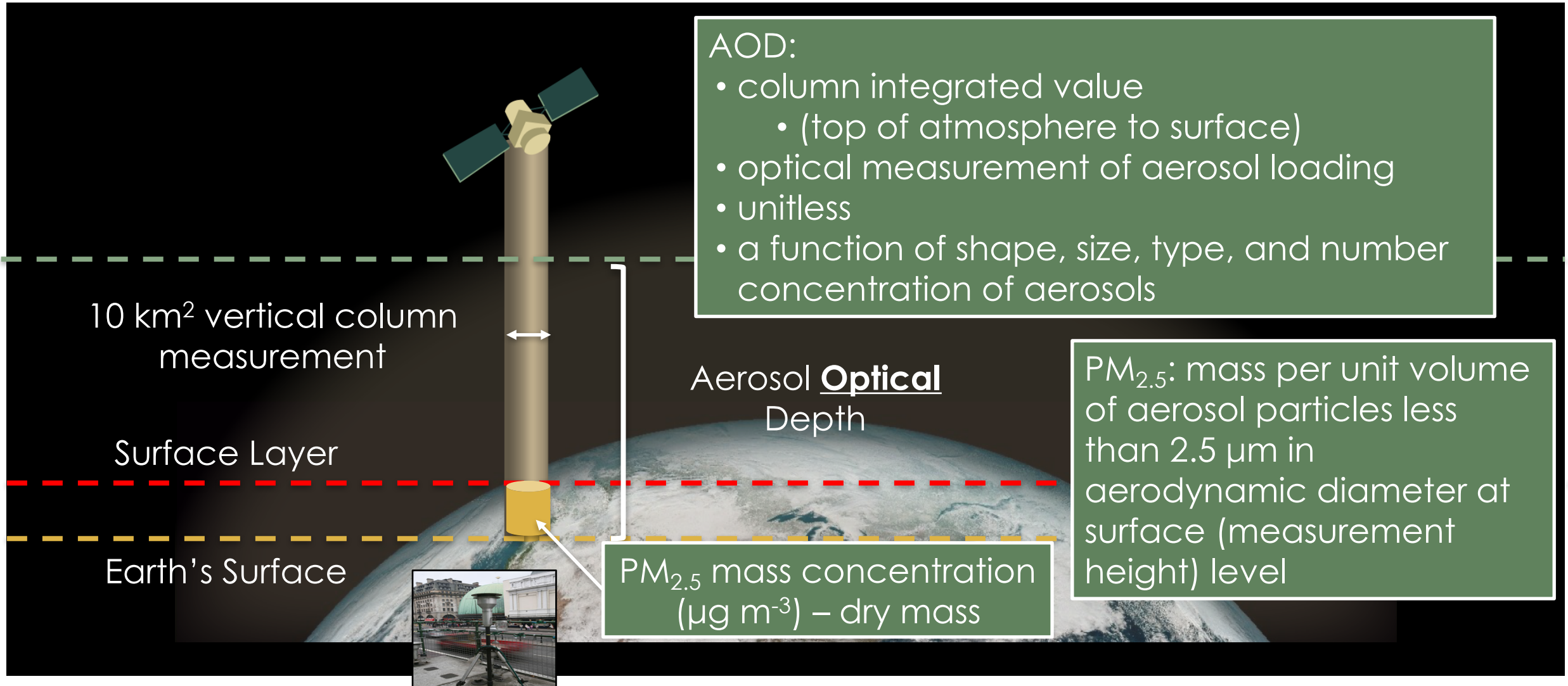


Credit: Gupta



Applications

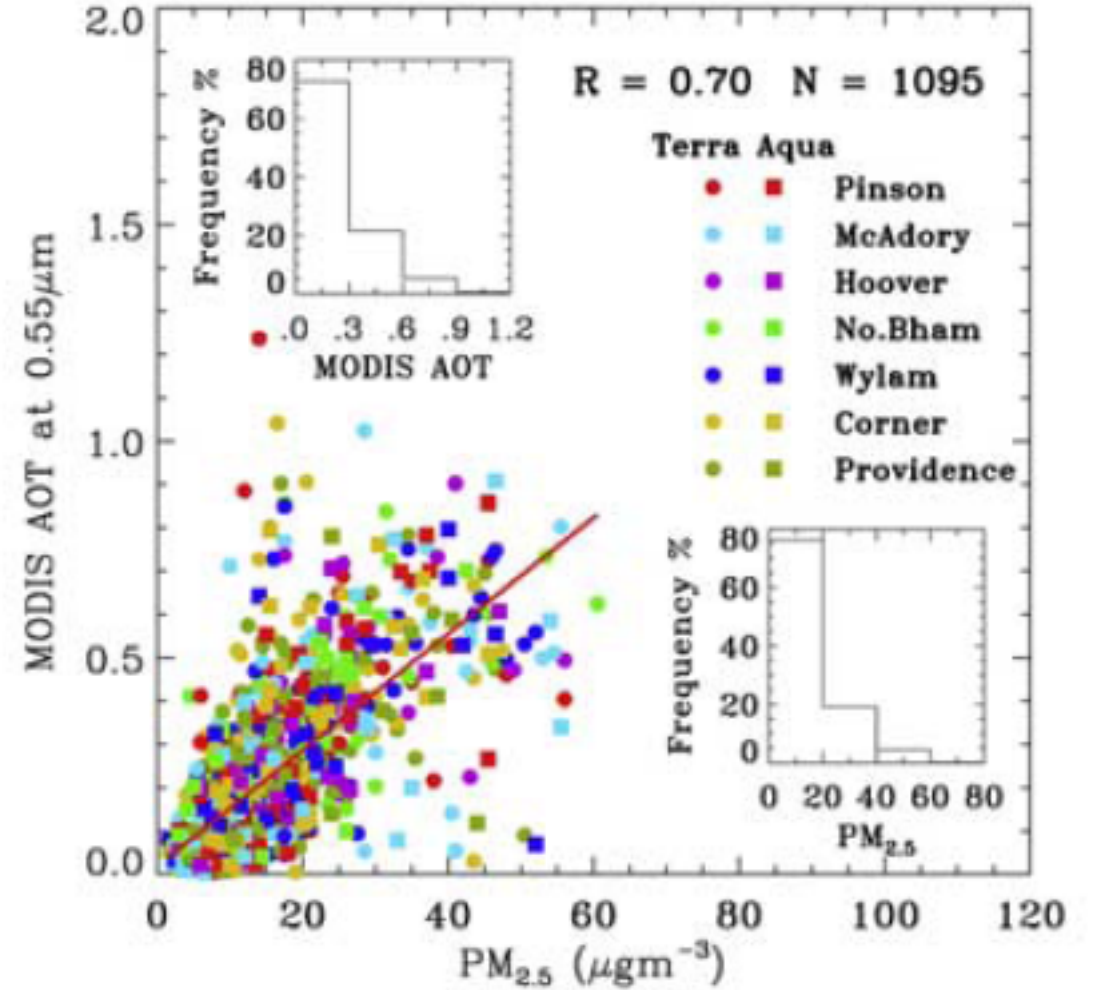
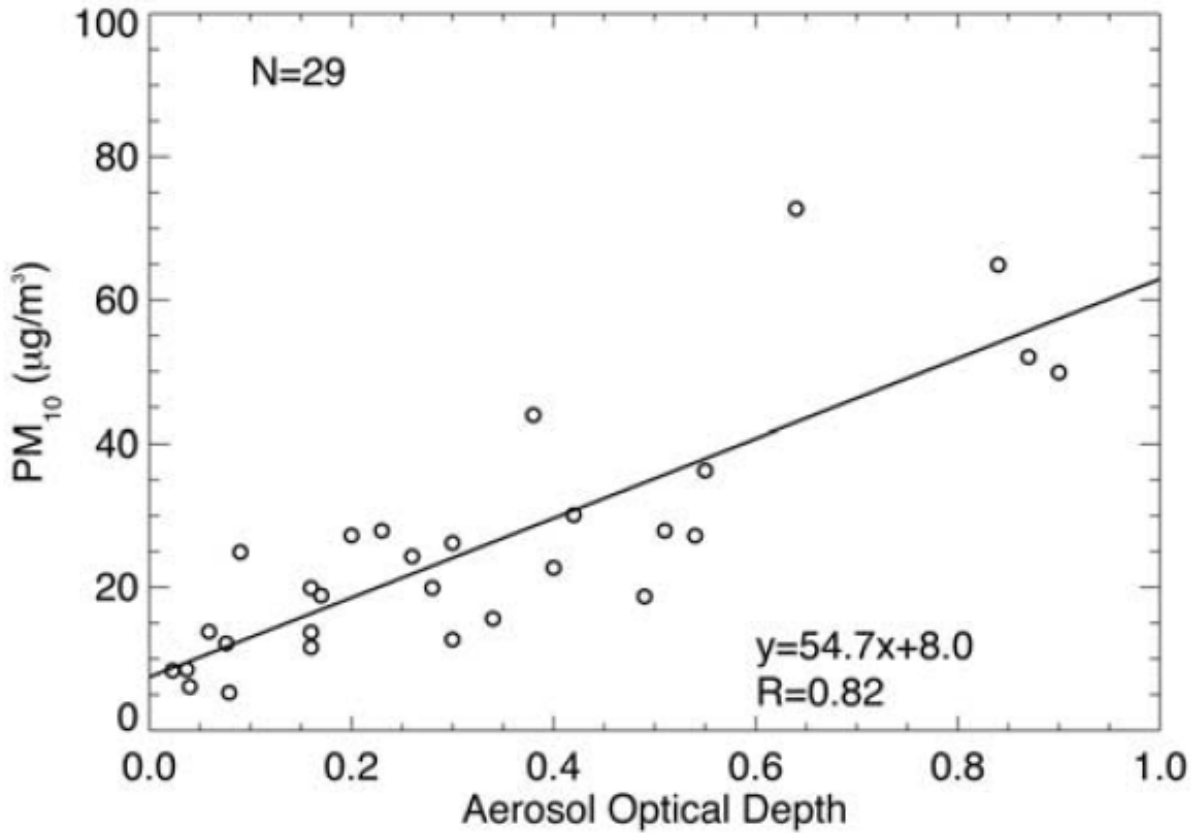
# Satellite vs. Ground Observation



# Satellite vs. Ground Observation



# Simple Models from Early Days



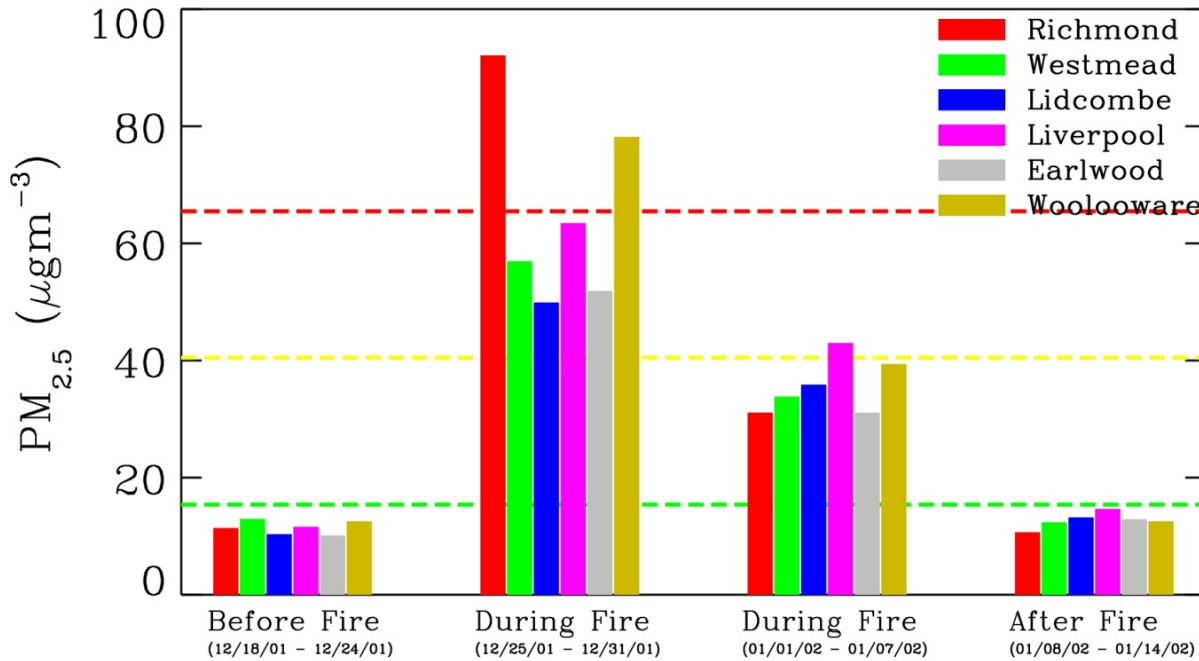
Source (right): Wang et al., 2003 and Chu et al., 2003 (left)



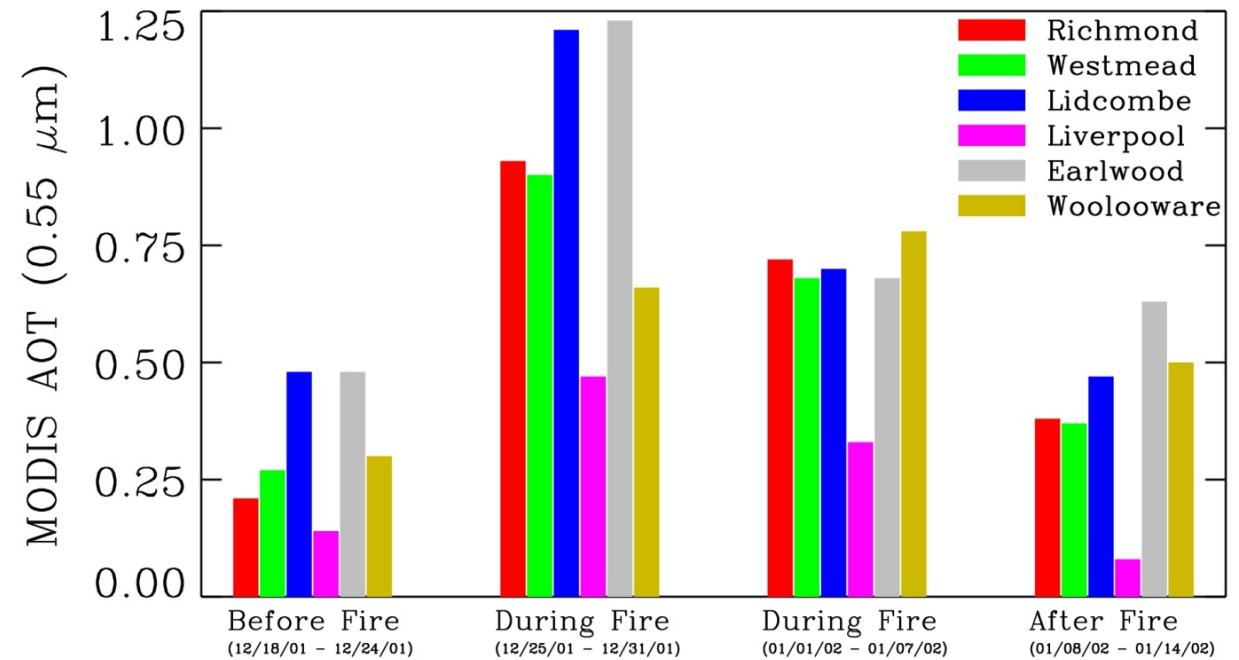
# Application of Satellite Observations

## Bushfires in Sydney, Australia

Surface PM<sub>2.5</sub>



AOD from Satellites



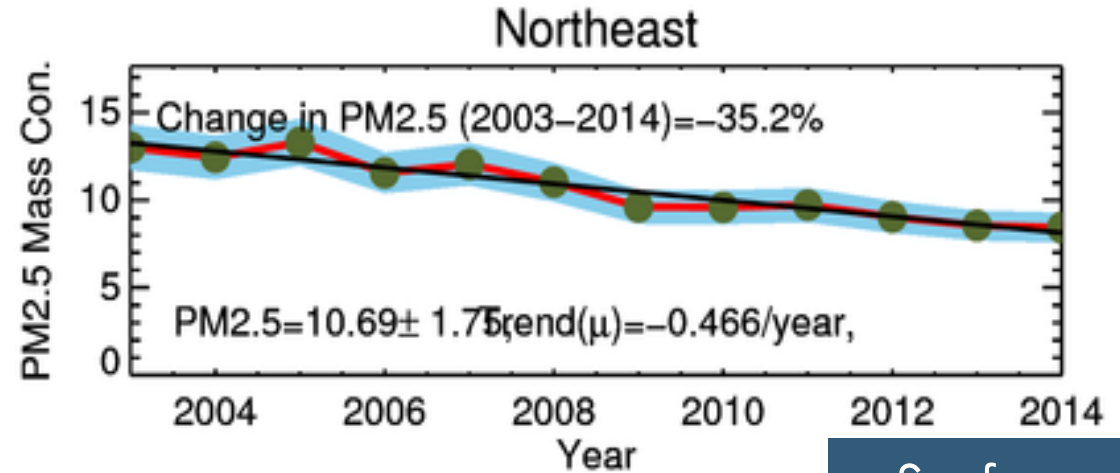
Credit: Gupta and Christopher, 2007



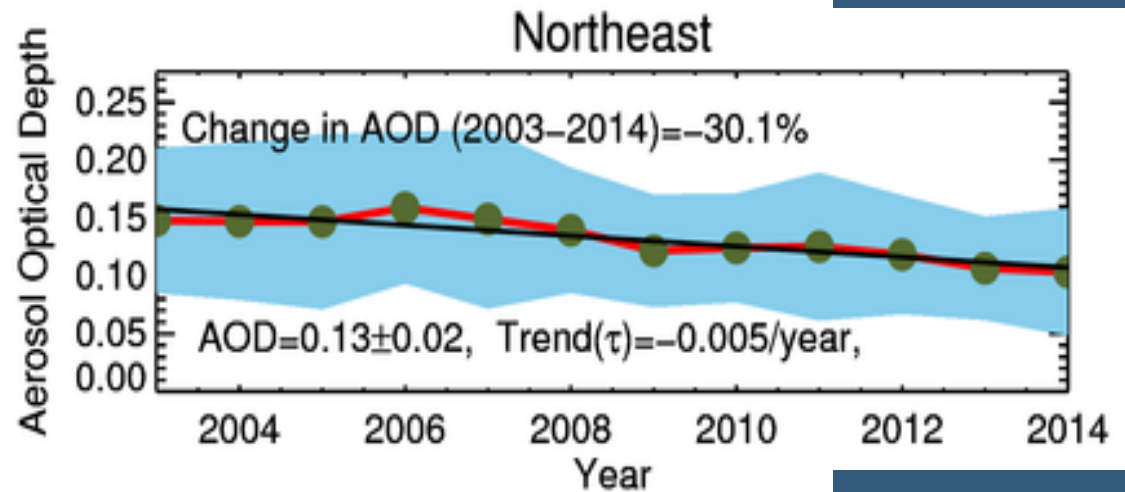
# Measurements: Surface vs. Satellite



Map Credit: U.S. Climate Regions, NOAA; Time Series Credit: Gupta



Surface

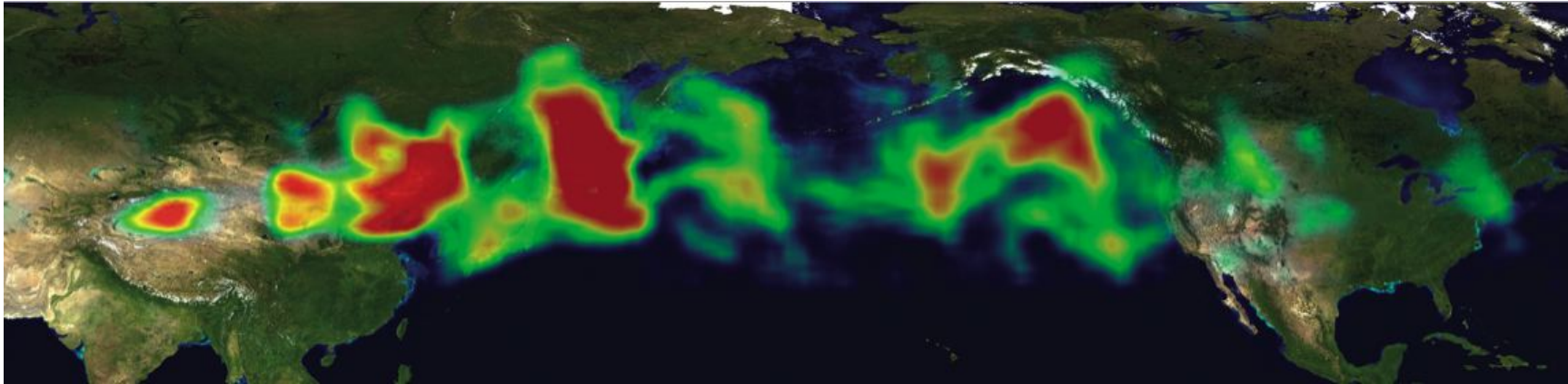


Satellite

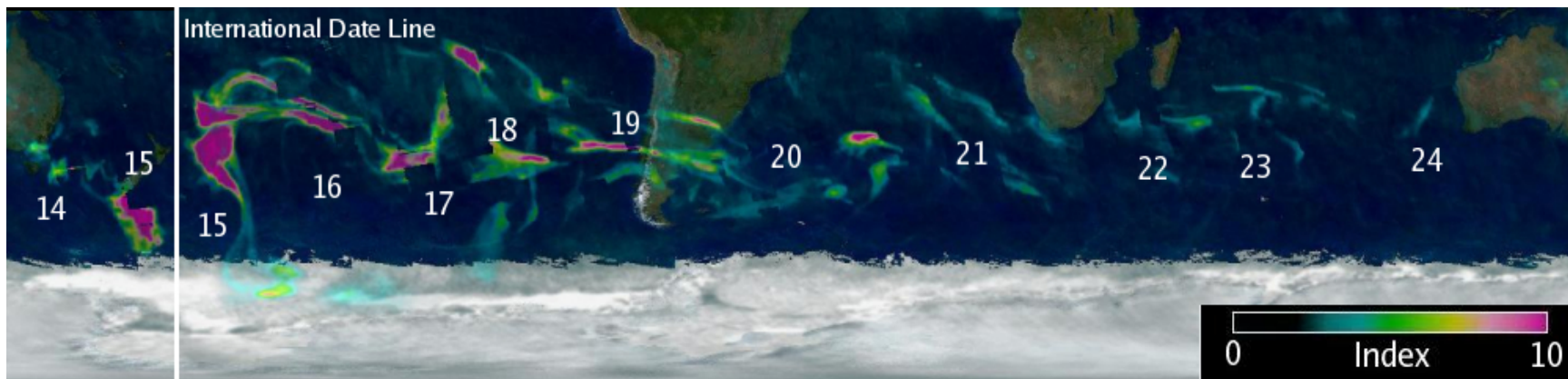


# Long Range Transport

Dust from Mongolian Deserts Reaches the U.S.



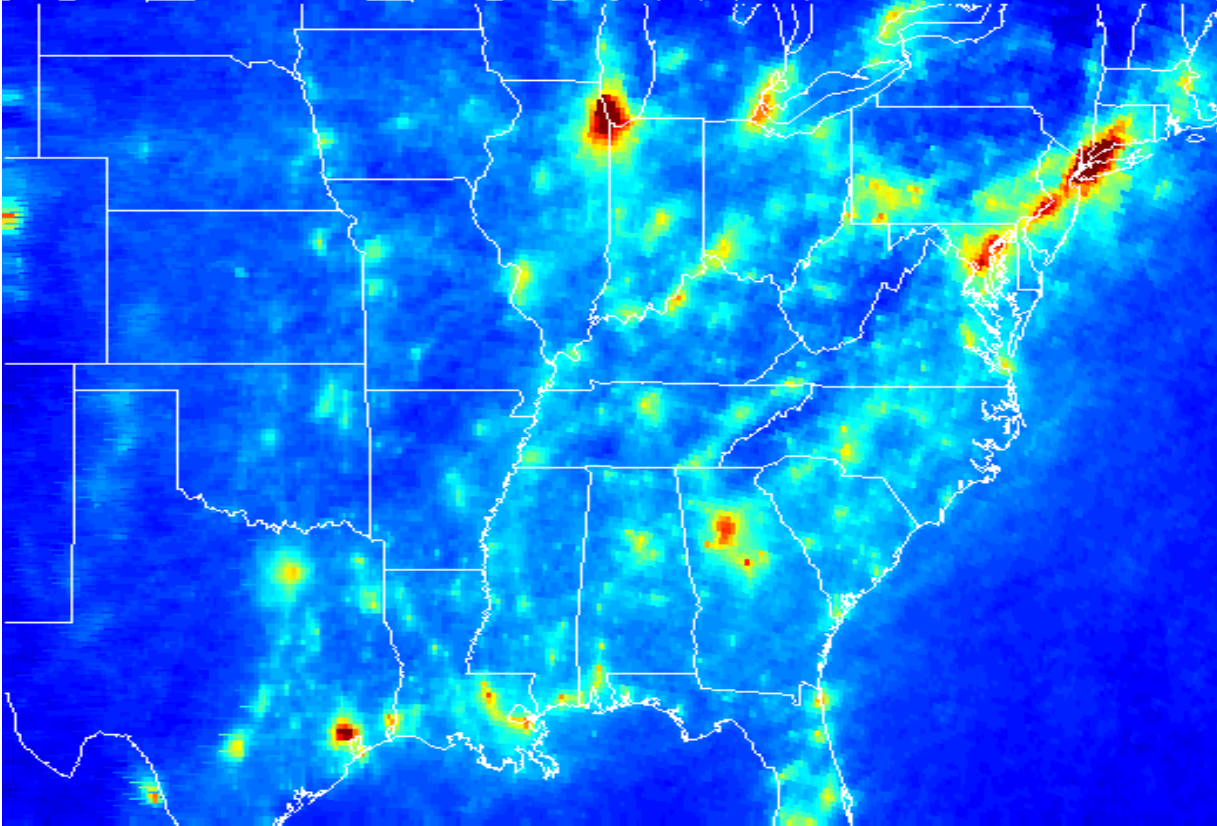
Smoke Travels Around the World in 11 Days



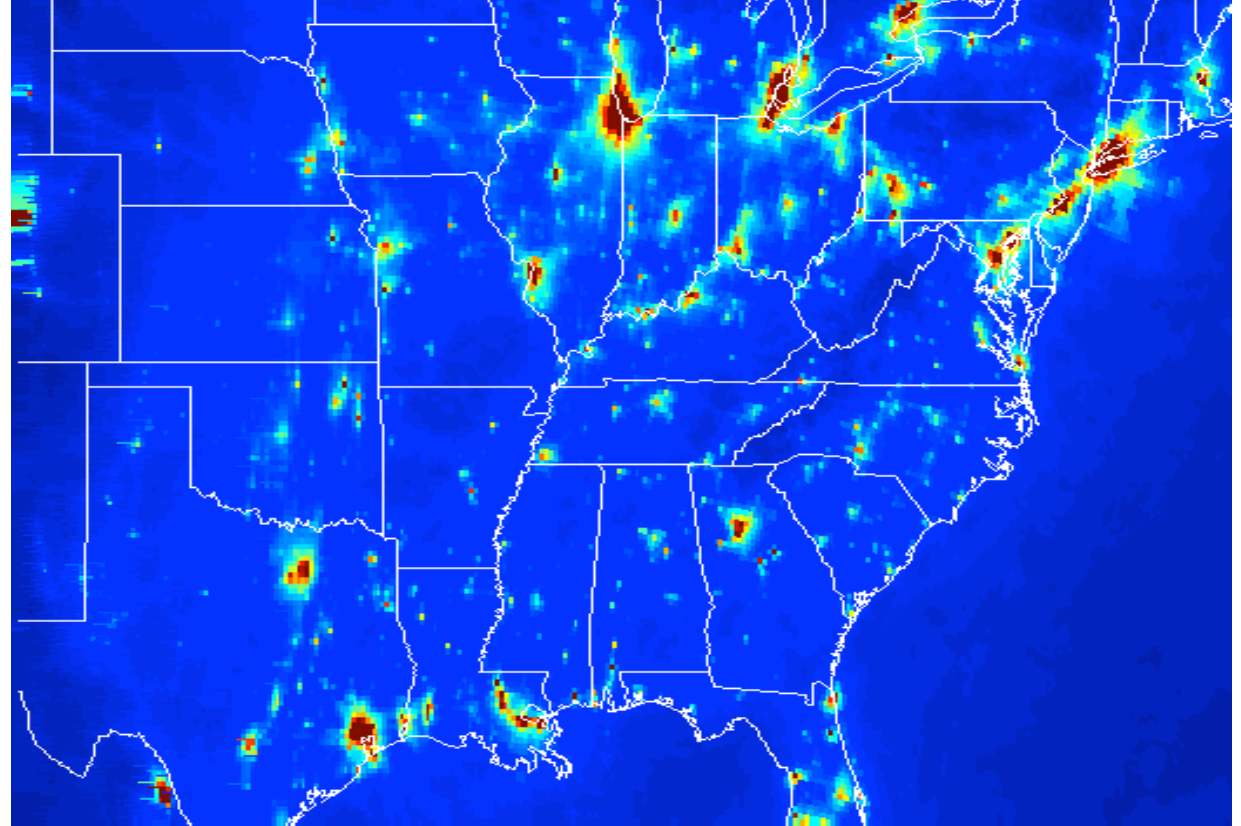


# Model-Satellite Inter-Comparison

CMAQ Model NO<sub>2</sub>

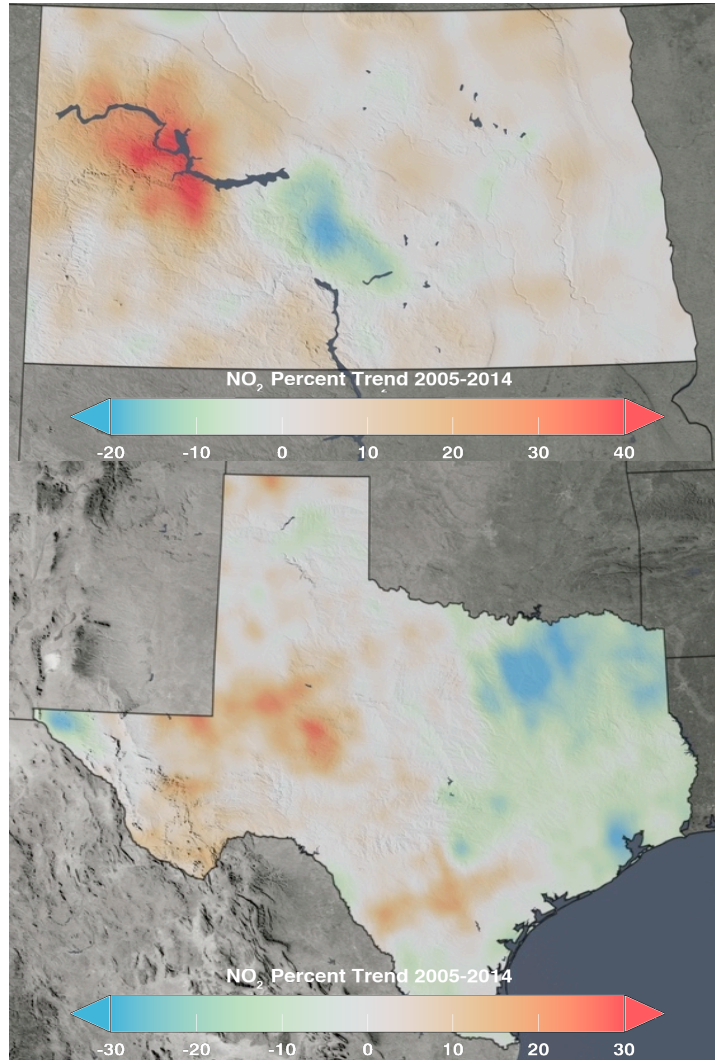


OMI NO<sub>2</sub>

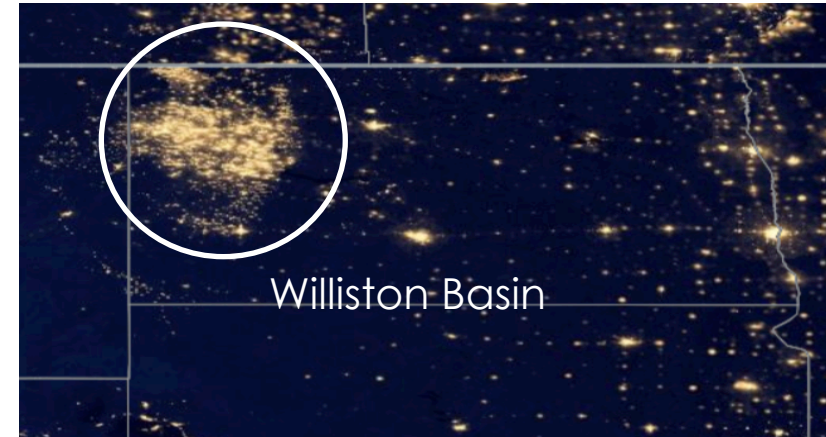


# OMI Detects NO<sub>2</sub> Increases from ONG Activities

2005-2014

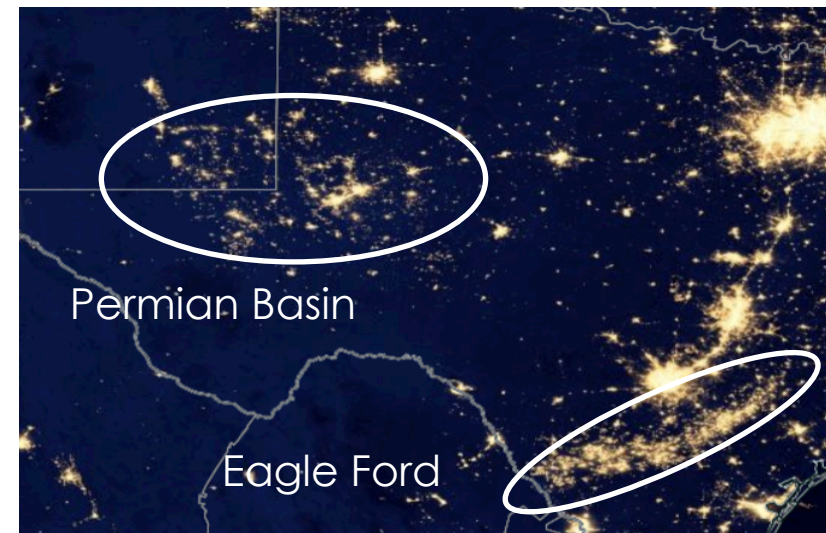


North  
Dakota

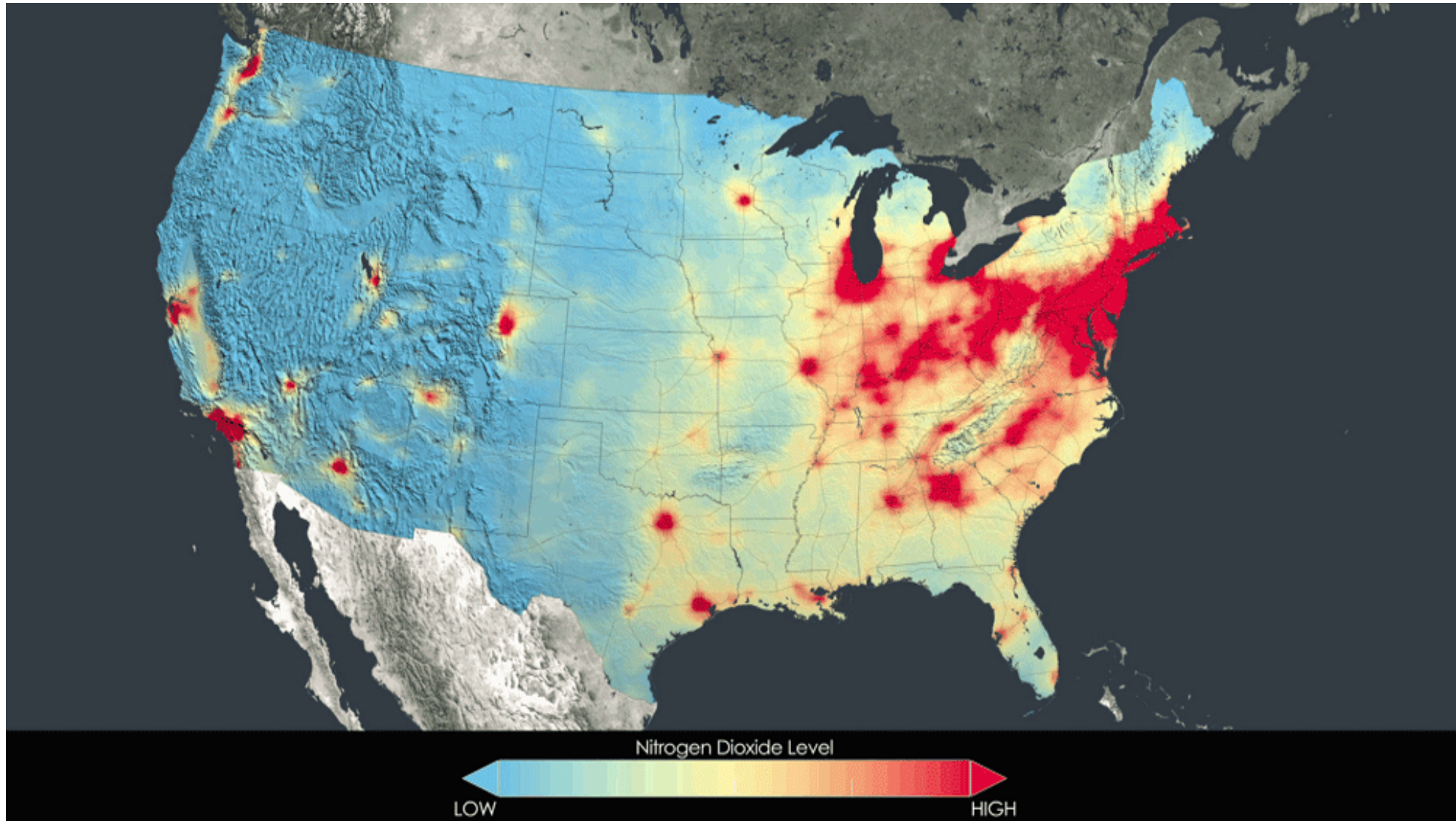


Suomi NPP VIIRS Lights at Night

Texas

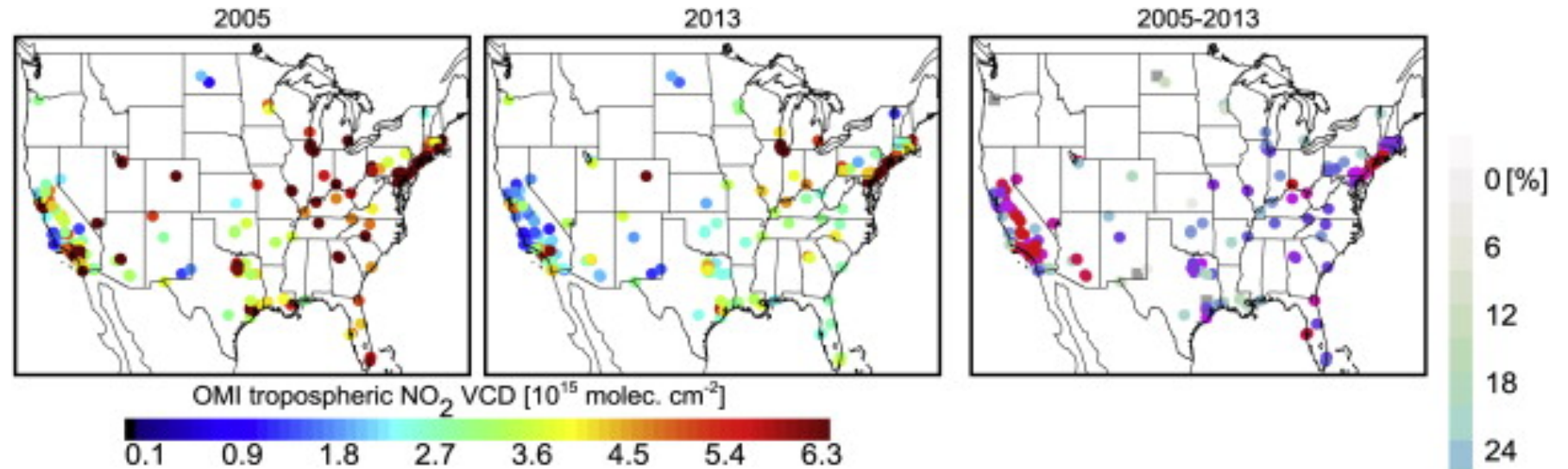


# NO<sub>2</sub> Trends Over the United States

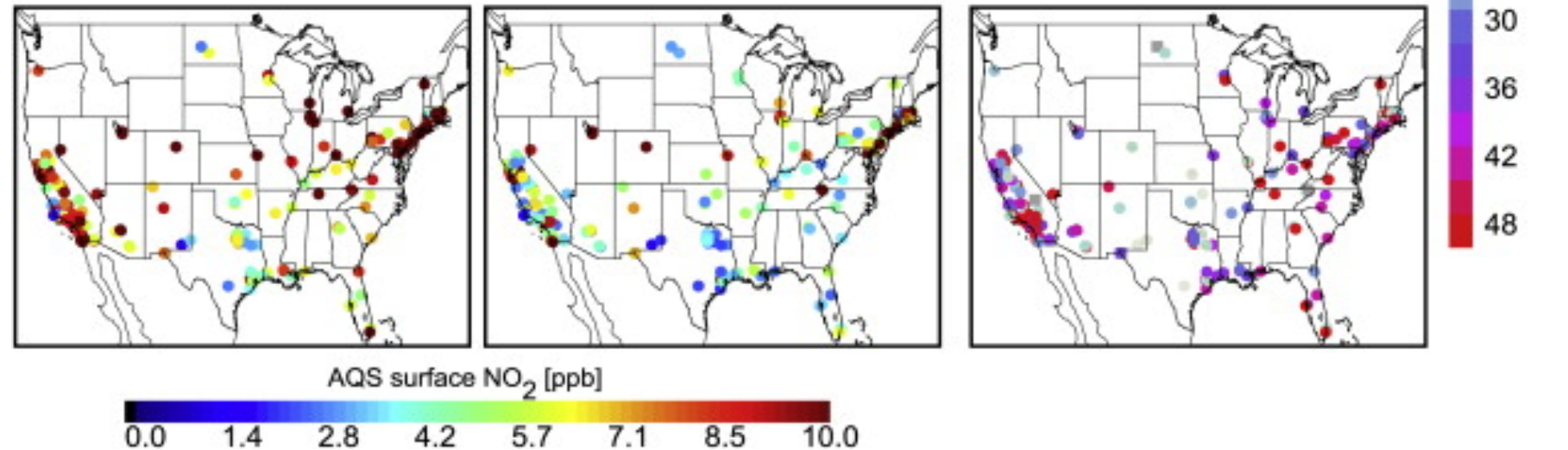


# OMI Trends in NO<sub>2</sub> Correlate Well With Surface Trends

OMI (Satellite)

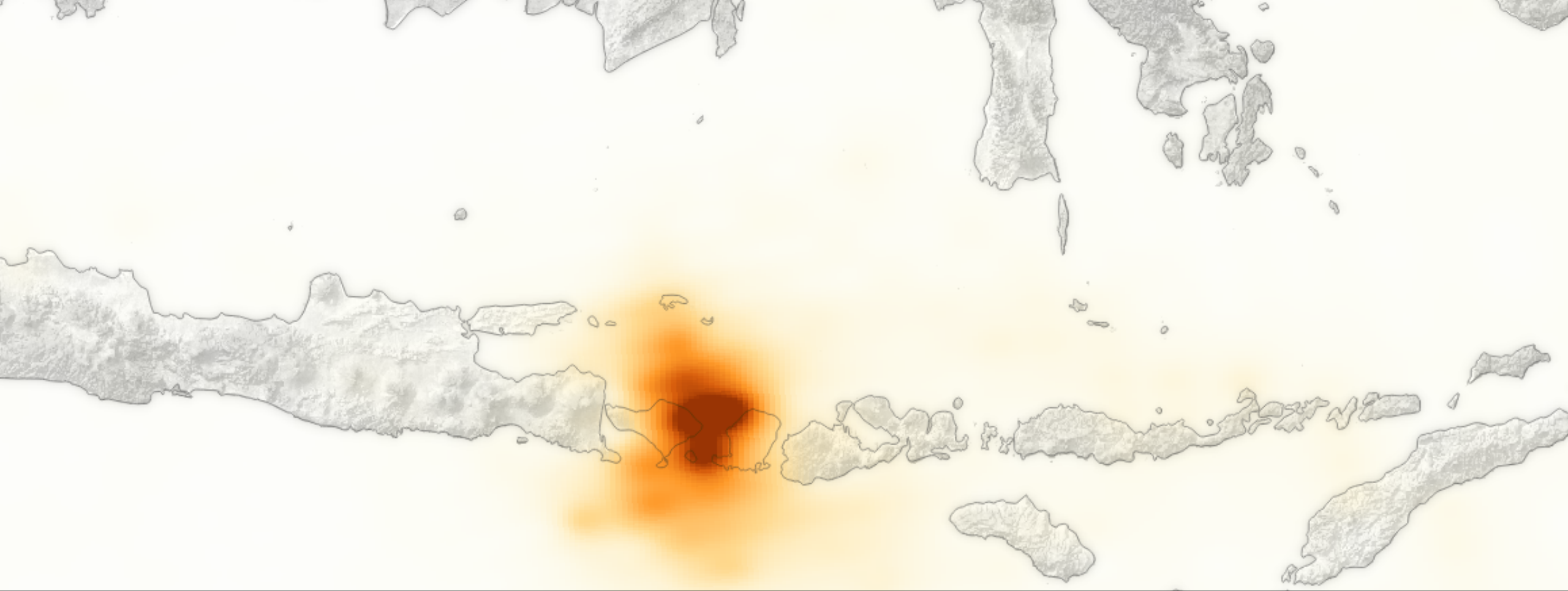


AQS (Surface)



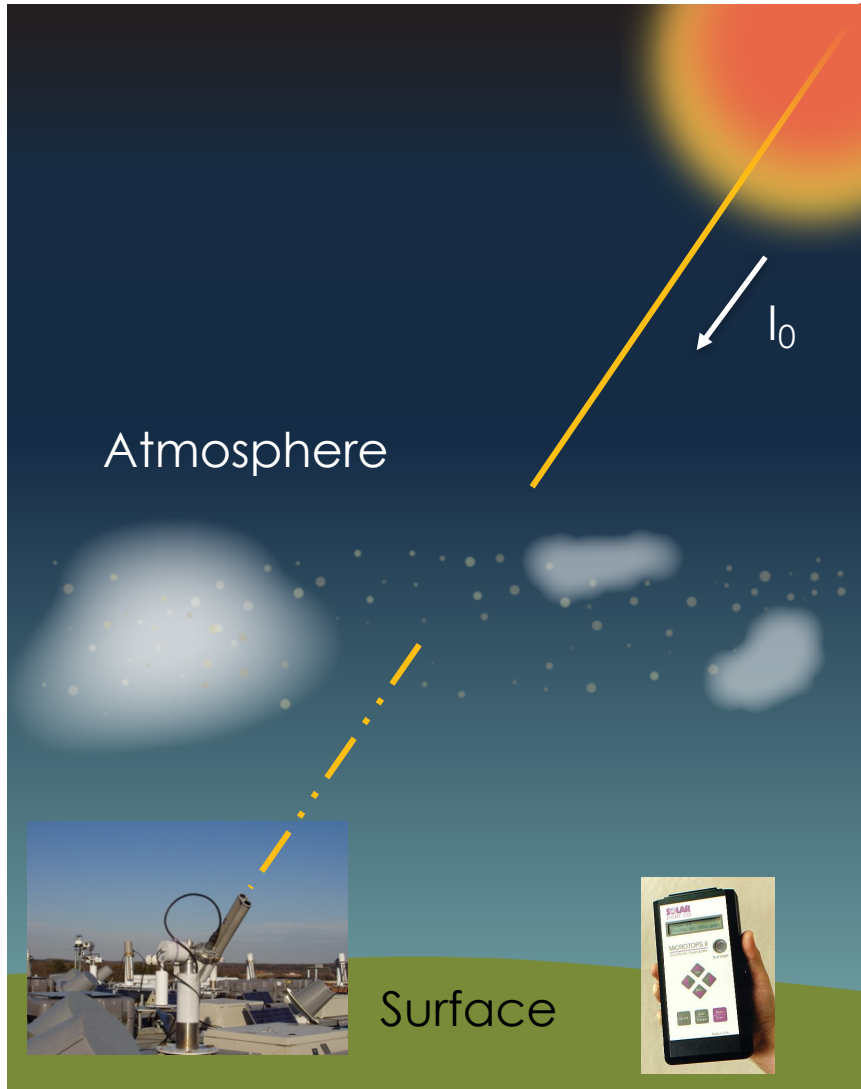
Source: Lamsal, L.N. et al. (2016)





MODIS Aerosol Product

# Optical Depth



The optical depth expresses the quantity of light removed from a beam by **scattering** or/and **absorption** during its path through a medium  
optical depth  $\tau$  as:

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

$$m = \sec \theta_0$$

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



# MODerate resolution Imaging Spectroradiometer

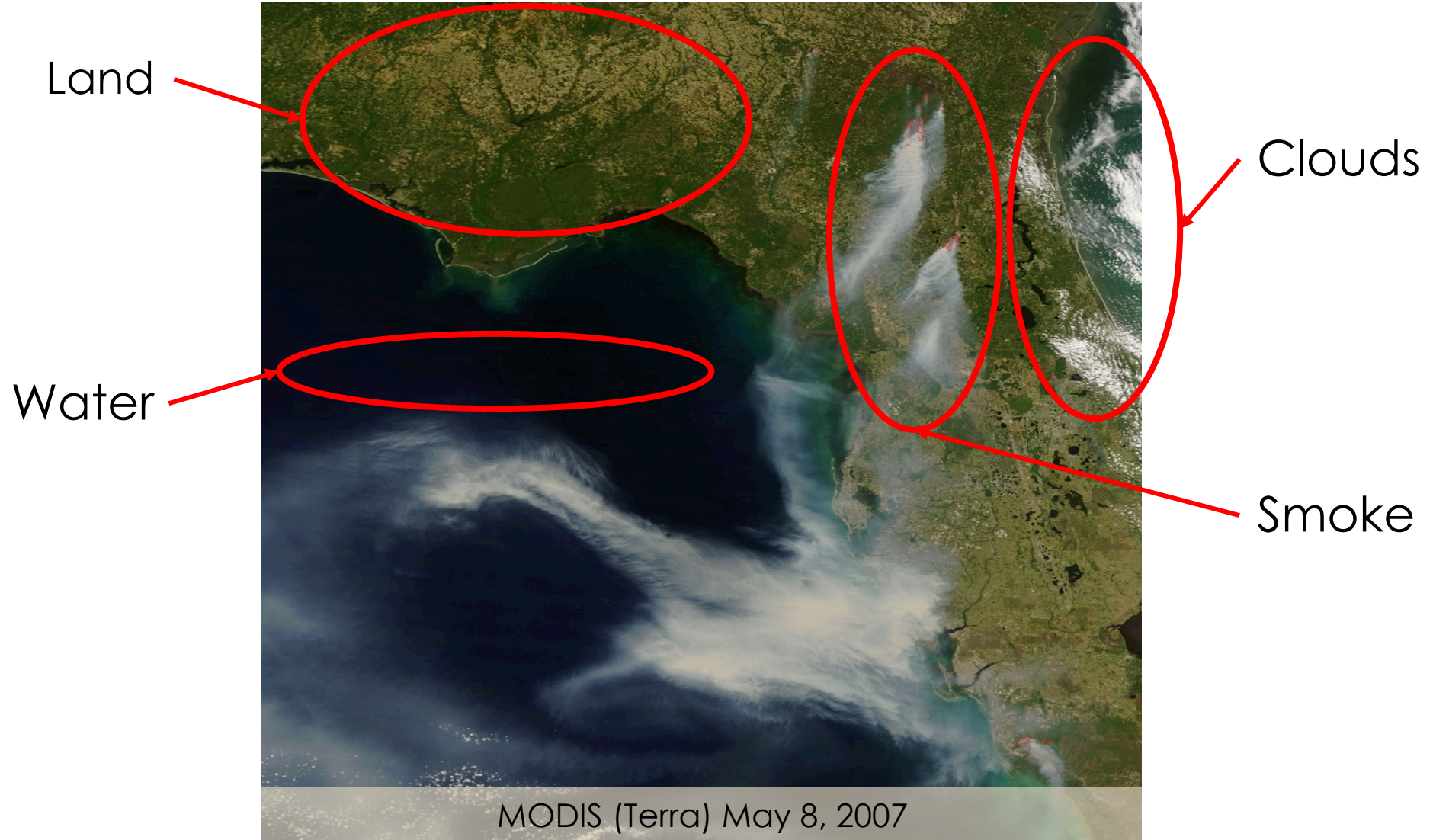
- 2000 - present
- Spatial Resolution
  - 250 m, 500 m, 1 km
- Platform
  - Terra & Aqua
- Temporal Resolution
  - Daily, 8-day, 16-day, monthly, quarterly, yearly
- Data Format
  - Hierarchical Data Format – Earth Observing System Format (HDF-EOS)



- Spectral Coverage
  - 36 bands (major bands include red, blue, IR, NIR, MIR)
    - Bands 1-2: 250 m
    - Bands 3-7: 500 m
    - Bands 8-36: 1,000 m

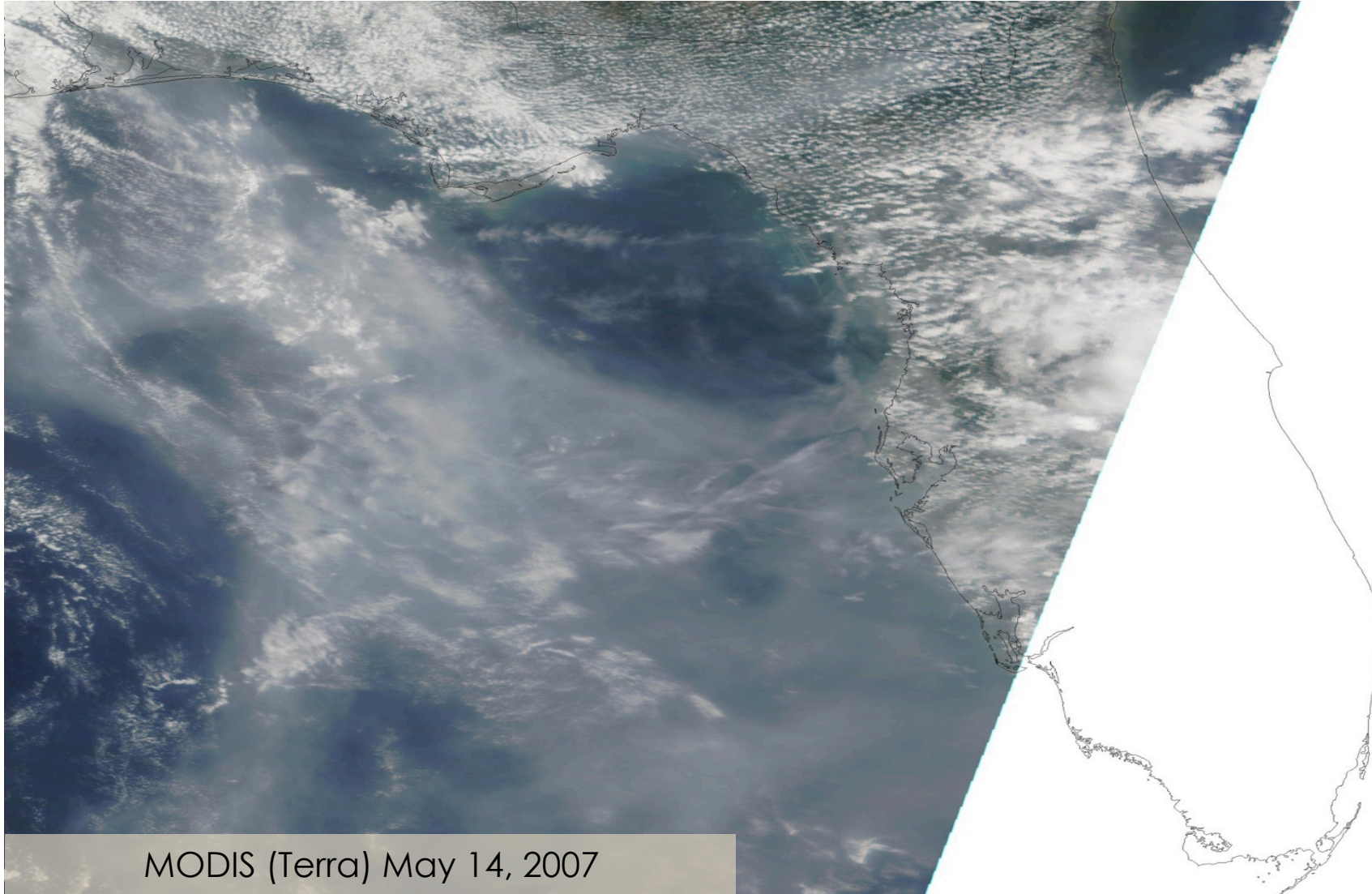


# Aerosol Detection





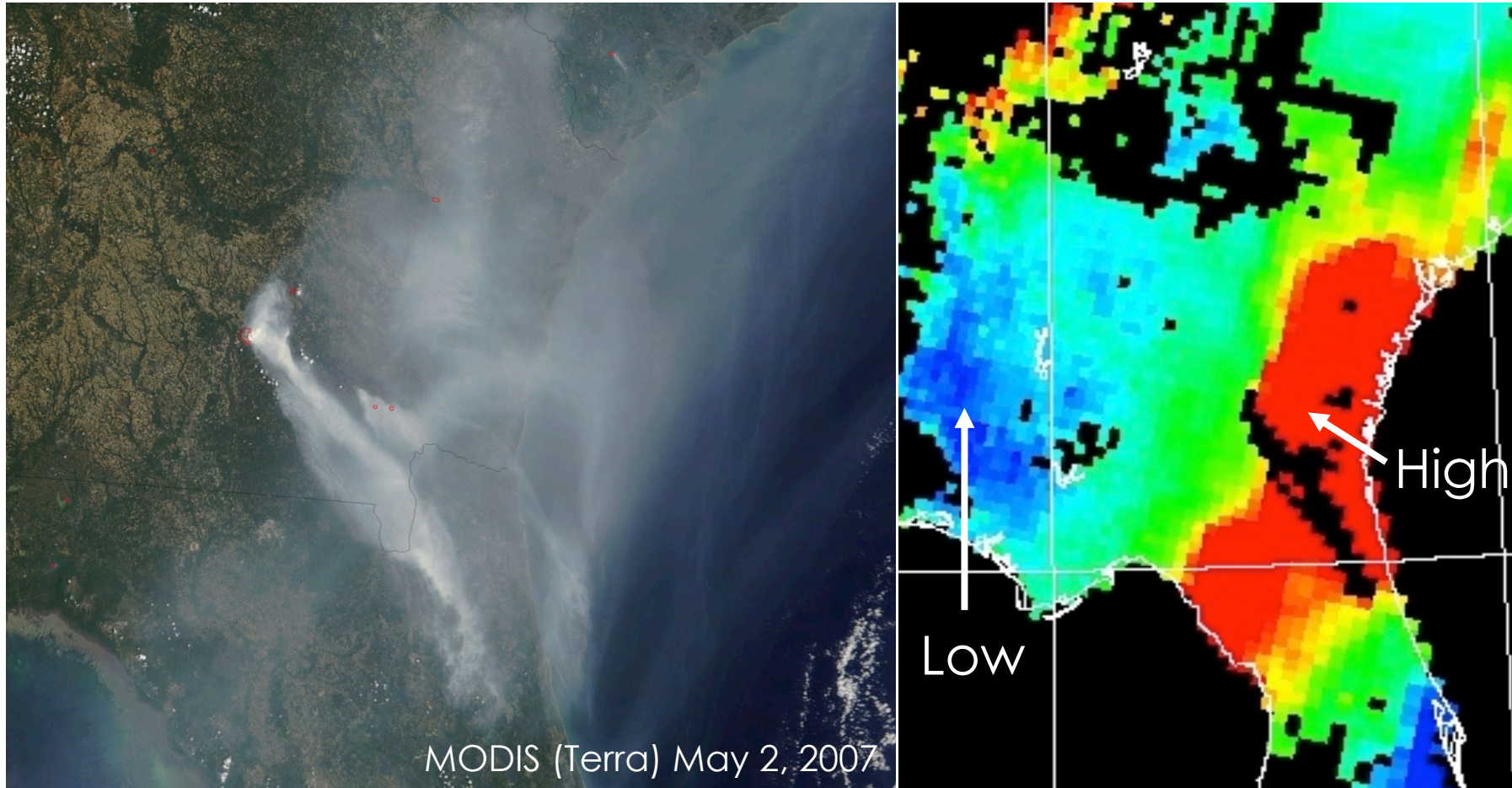
# Complex Image: Smoke & Clouds



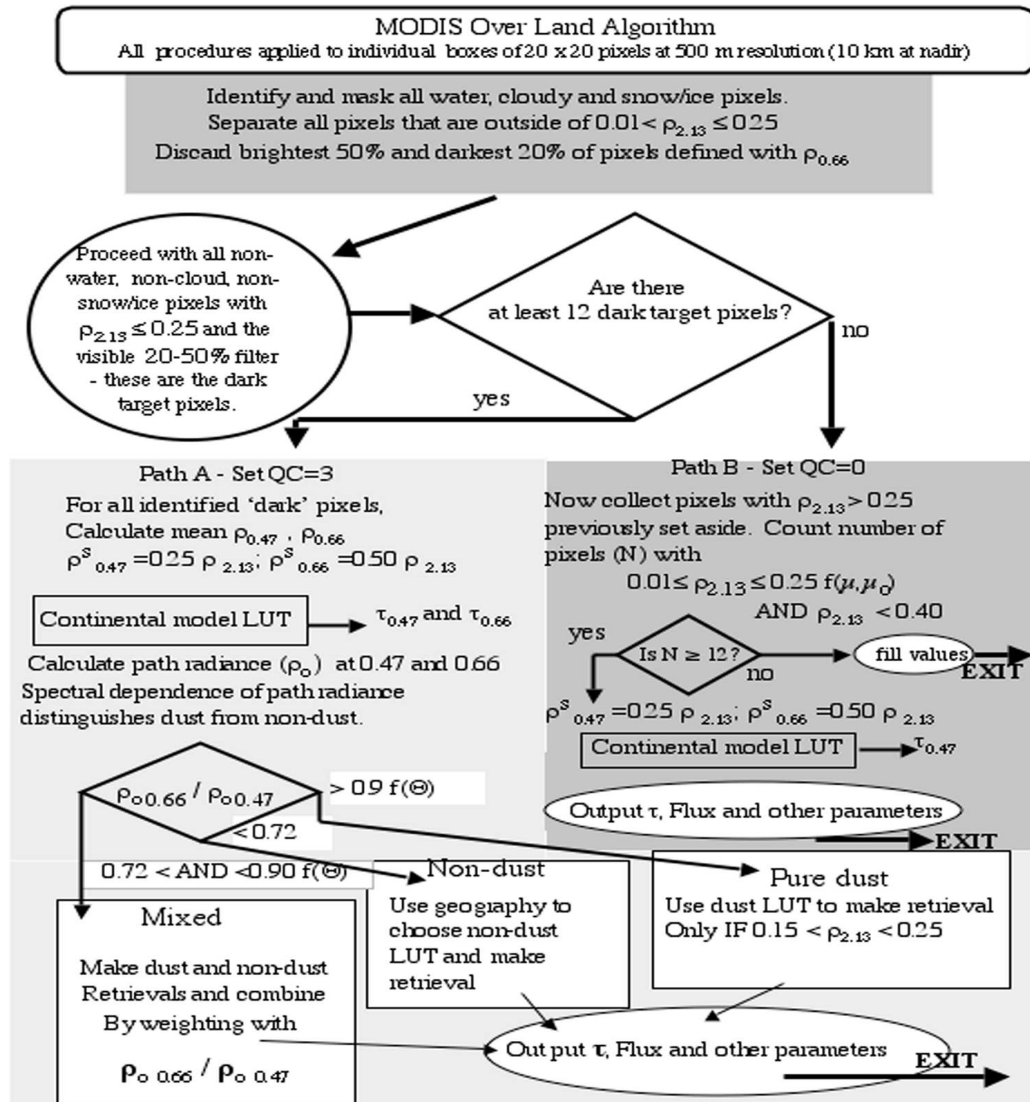
MODIS (Terra) May 14, 2007



# Radiance to Aerosol Products



# Aerosol Retrieval Algorithm



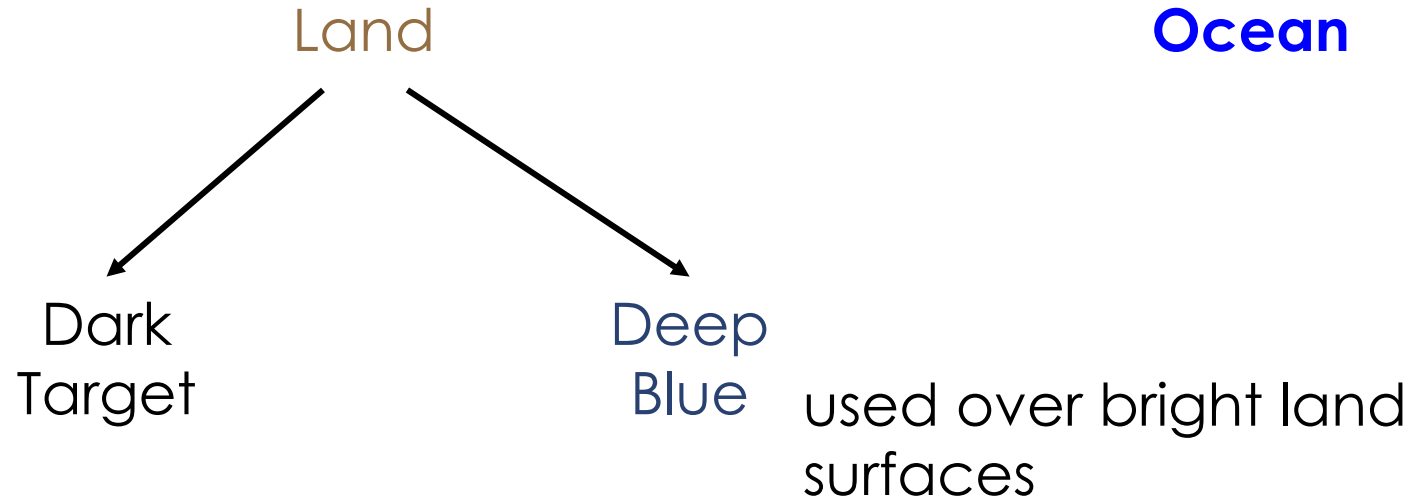
Aerosol retrieval algorithm is a complex inversion scheme where assumptions are made in simulating satellite observations with advance radiative transfer calculations to retrieve atmospheric aerosol properties

Sources: Remer et al., 2005, Levy et al., 2010



# MODIS Aerosol Products

## Three Separate Algorithms

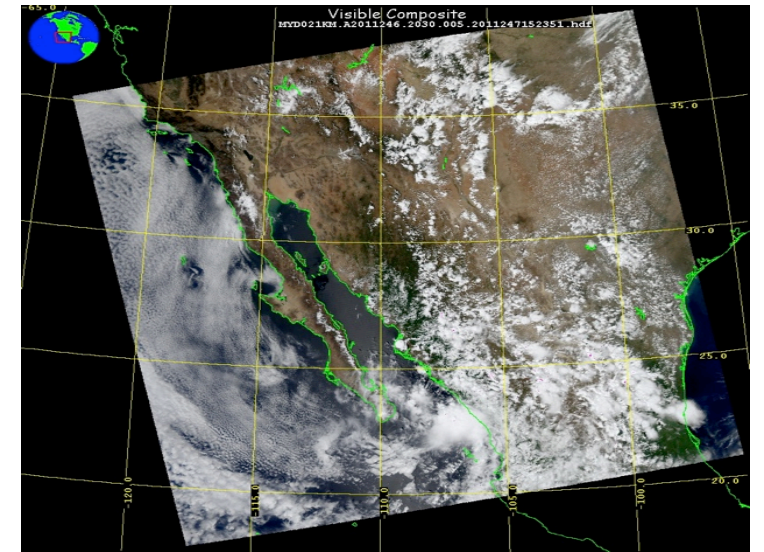


- The dark target and deep blue products are separate and when both are available, the user must select which to use
- In collection 6 (and 6.1), there is a joint product that uses an automated procedure to select the appropriate product

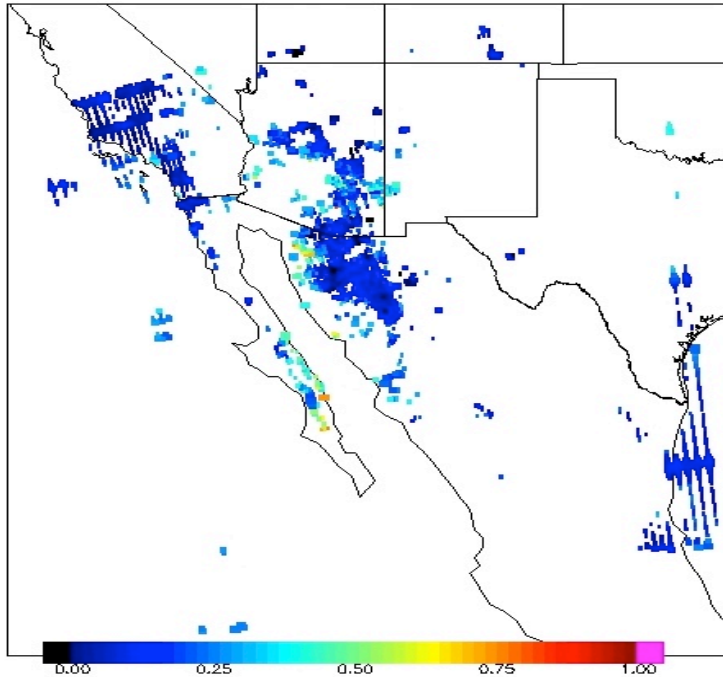


# MODIS Aerosol Products

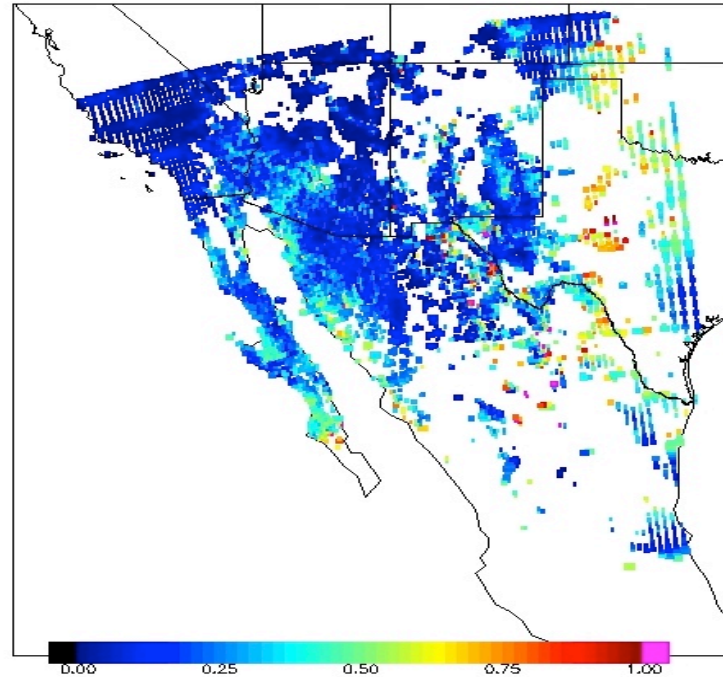
## Two Algorithms



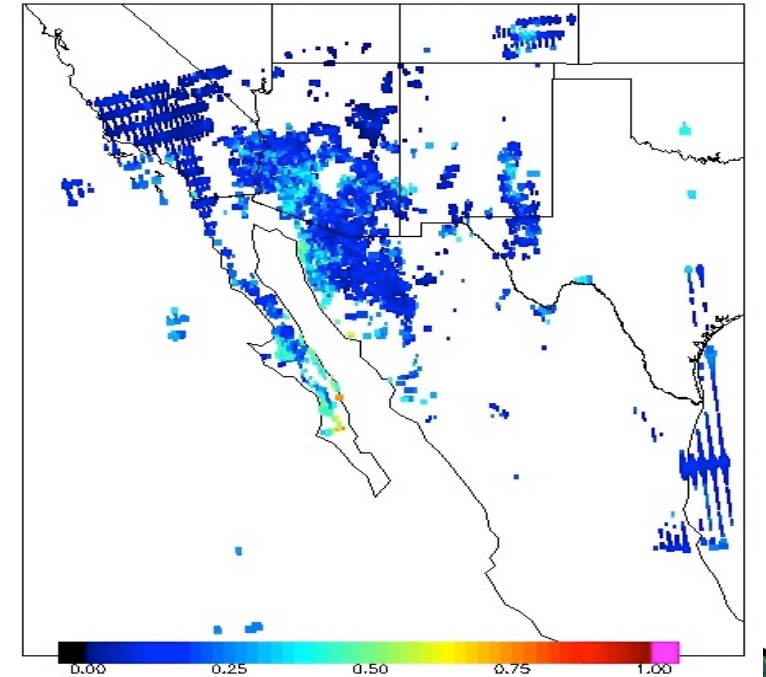
Dark Target



Deep Blue

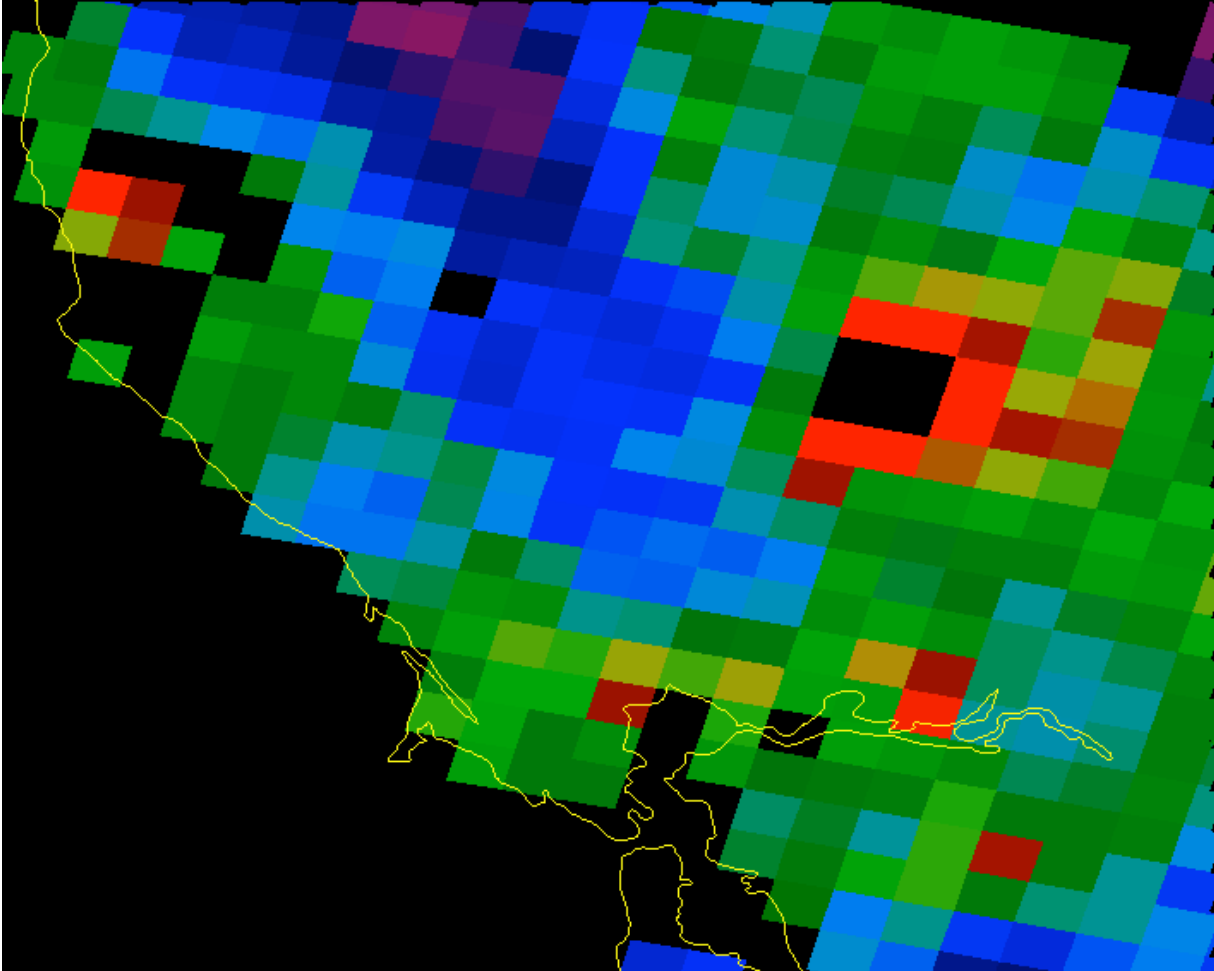


Deep\_Dark\_Combined

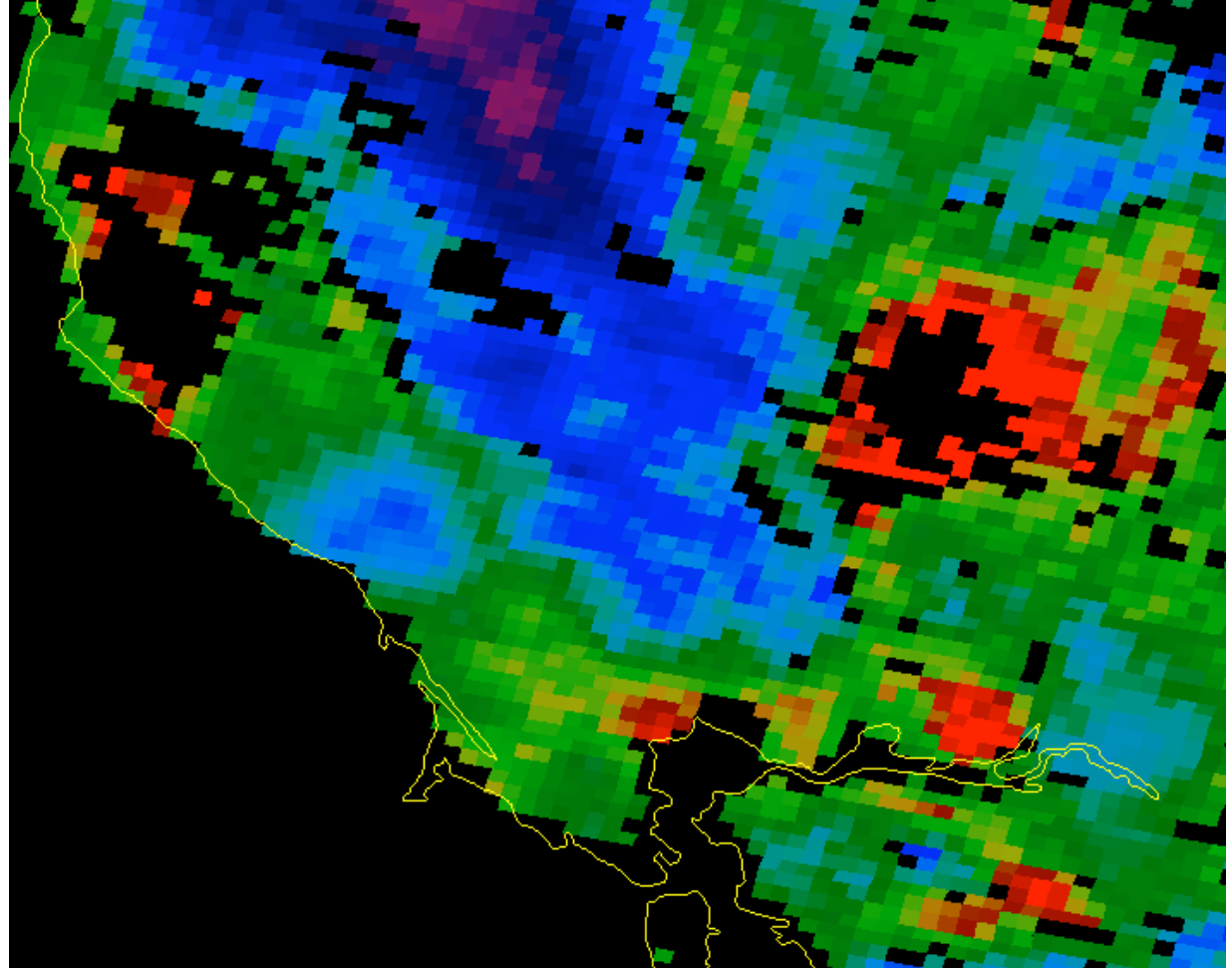


# MODIS 10 km vs. 3k m Products

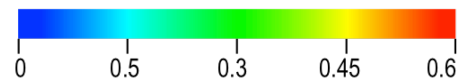
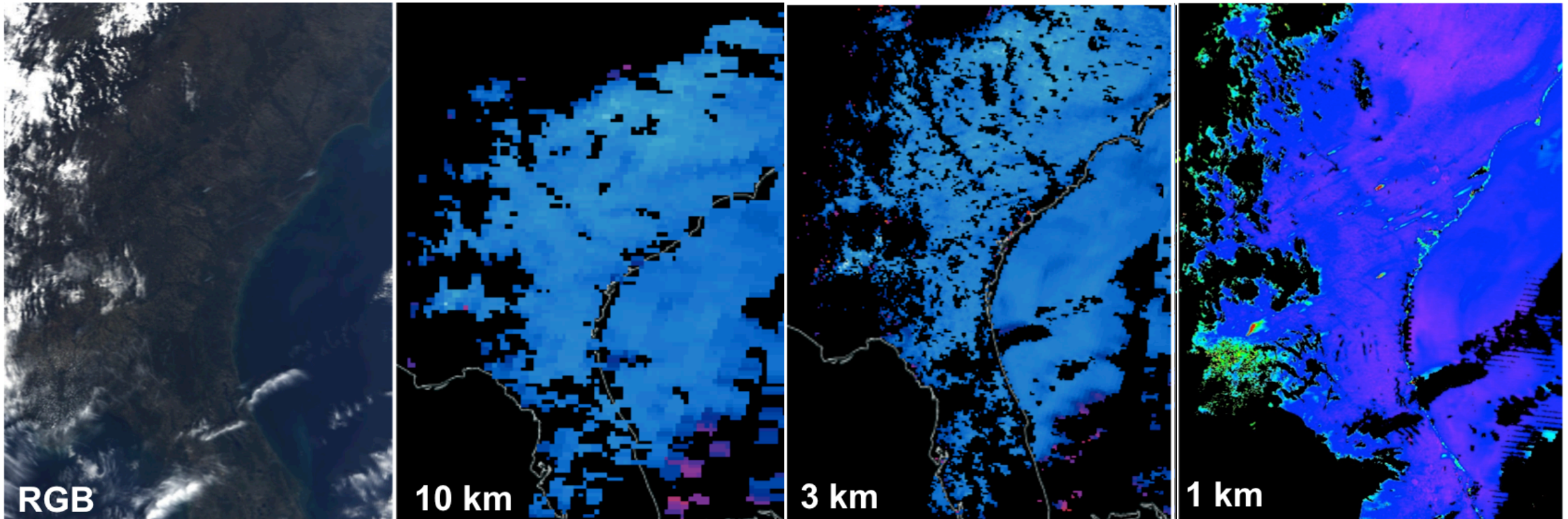
10km



3 km



# High Resolution Aerosol Product

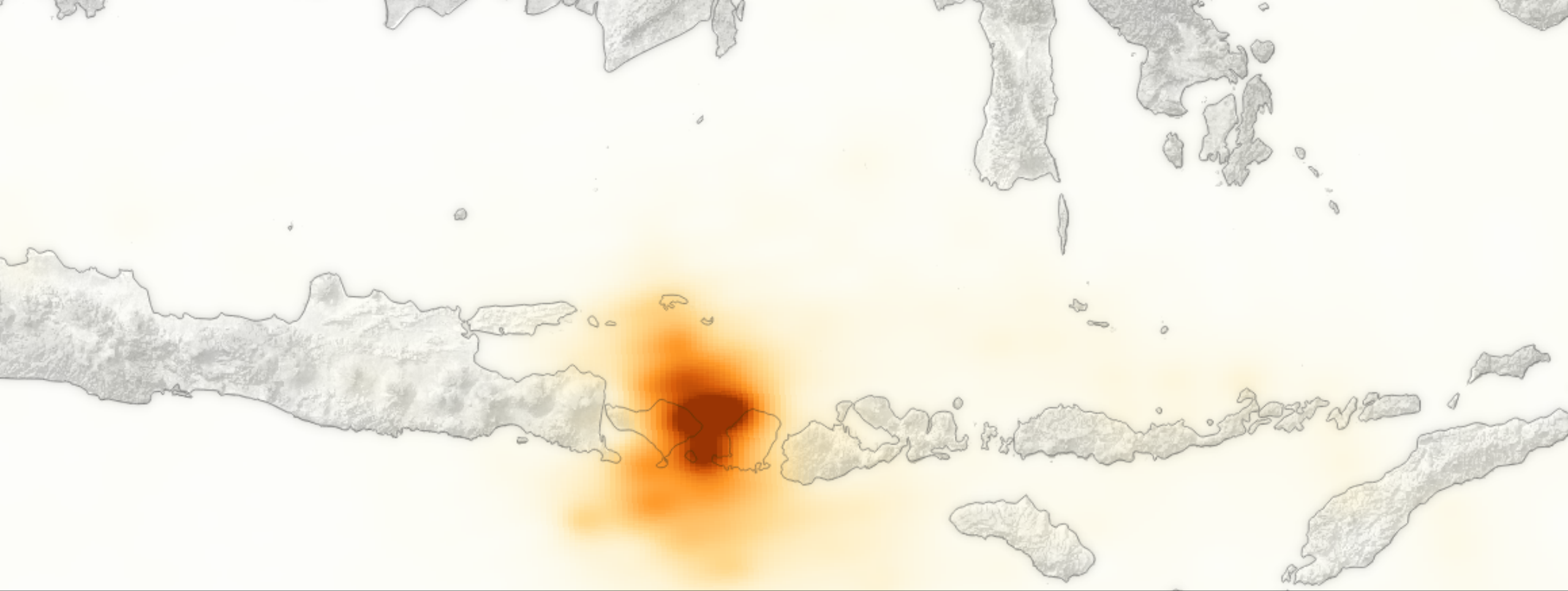


# Satellite Aerosol Products

	MODIS	MISR	OMI	VIIRS
Strengths	<ul style="list-style-type: none"> <li>• Coverage</li> <li>• Resolution</li> <li>• Calibration</li> <li>• Accuracy</li> </ul>	<ul style="list-style-type: none"> <li>• Calibration</li> <li>• Accuracy</li> <li>• Particle Shape</li> <li>• Aerosol height for thick layer or plume</li> </ul>	<ul style="list-style-type: none"> <li>• Indication of absorbing or scattering particles</li> </ul>	<ul style="list-style-type: none"> <li>• Coverage</li> <li>• Resolution</li> <li>• Calibration</li> <li>• Smaller bow-tie effect</li> </ul>
Weaknesses	<ul style="list-style-type: none"> <li>• Bright surfaces</li> <li>• Ocean glint</li> <li>• Non-spherical particles</li> </ul>	<ul style="list-style-type: none"> <li>• Coverage</li> </ul>	<ul style="list-style-type: none"> <li>• Resolution</li> <li>• Cloud contamination</li> </ul>	<ul style="list-style-type: none"> <li>• Bright surfaces*</li> <li>• Ocean glint</li> </ul>
Main Products	<ul style="list-style-type: none"> <li>• AOD</li> <li>• Ocean-5 wavelengths</li> <li>• Land-3 wavelengths</li> <li>• Fine Fraction (Ocean only)</li> </ul>	<ul style="list-style-type: none"> <li>• AOD</li> <li>• 4 wavelengths</li> <li>• Spherical/Non-Spherical Ratio</li> <li>• Particle Size (3 bins)</li> </ul>	<ul style="list-style-type: none"> <li>• AOD</li> <li>• AAOD</li> <li>• Aerosol Index</li> </ul>	<ul style="list-style-type: none"> <li>• AOD</li> <li>• Aerosol Type</li> </ul>
Product Resolution	<ul style="list-style-type: none"> <li>• 10 km</li> <li>• 3 km</li> </ul>	<ul style="list-style-type: none"> <li>• 17.6 km</li> </ul>	<ul style="list-style-type: none"> <li>• 13 x 24 km</li> </ul>	<ul style="list-style-type: none"> <li>• 0.75 km</li> <li>• 6 km</li> </ul>
Global L3 Aggregates	<ul style="list-style-type: none"> <li>• Daily</li> <li>• 8 day</li> <li>• 30 day</li> </ul>	<ul style="list-style-type: none"> <li>• Monthly</li> <li>• 3 month</li> <li>• Annual</li> </ul>	<ul style="list-style-type: none"> <li>• Daily</li> <li>• Monthly</li> </ul>	<ul style="list-style-type: none"> <li>• Daily</li> <li>• Monthly</li> </ul>





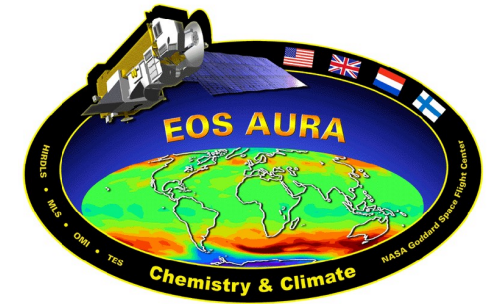


OMI

# Ozone Monitoring Instrument (OMI)

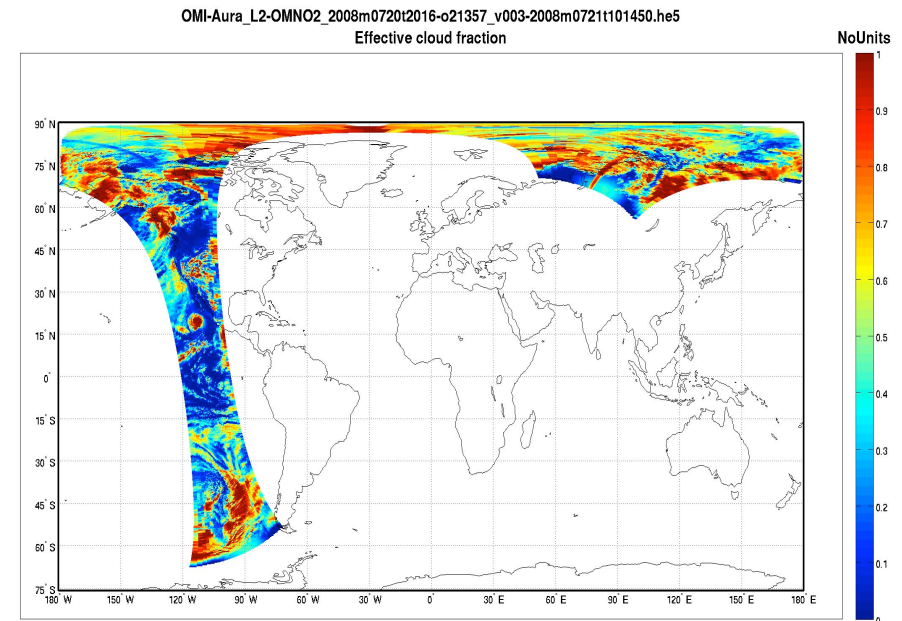
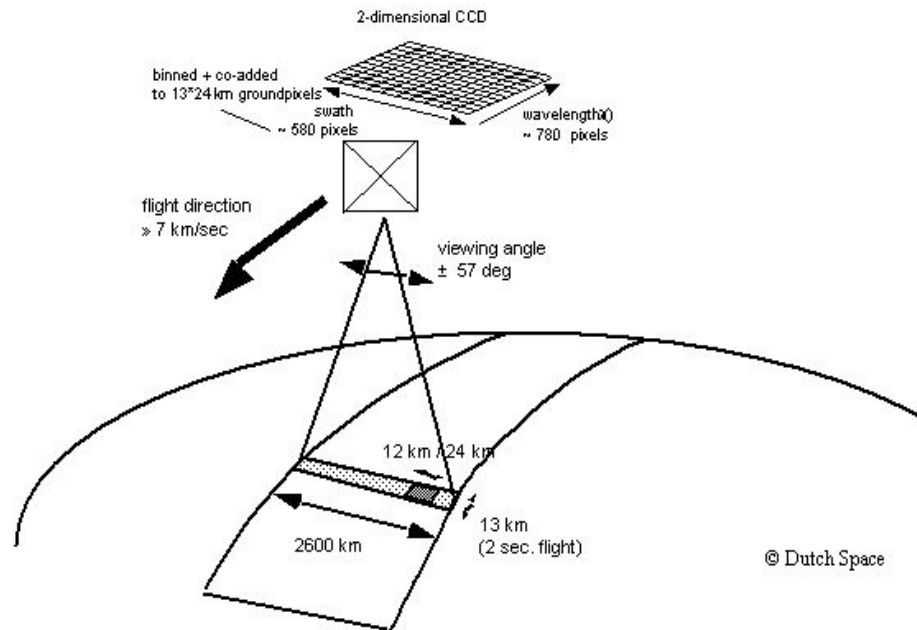
- Launched July 15, 2004
- NASA EOS Aura Satellite
- Nadir-viewing UV/Visible
  - 270 – 310 nm at 0.6 nm
  - 310 – 500 nm at 0.45 nm
- 1:45 p.m. equatorial crossing time
- 13x24 km<sup>2</sup> at nadir
- Daily global coverage

- Products
  - Total Column O<sub>3</sub>
  - Tropospheric Column O<sub>3</sub>
  - Aerosol optical depth (in UV)
  - Total Column Formaldehyde
  - Total Column NO<sub>2</sub>
  - Tropospheric column NO<sub>2</sub>
  - Total Column SO<sub>2</sub>



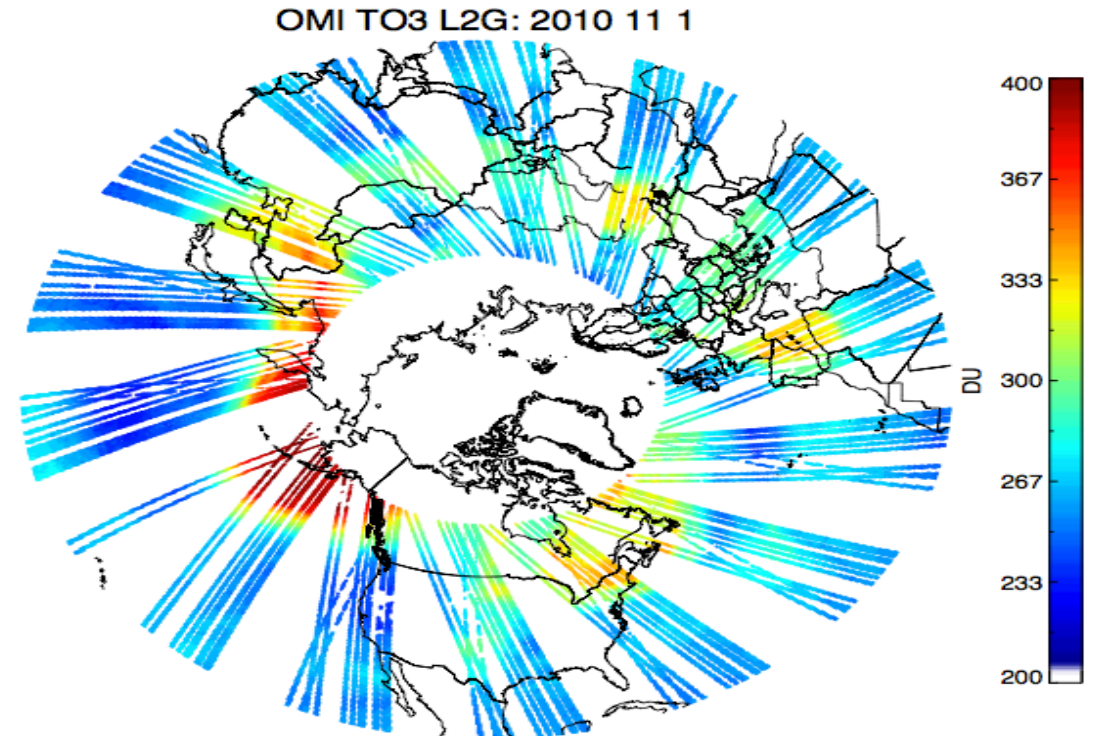
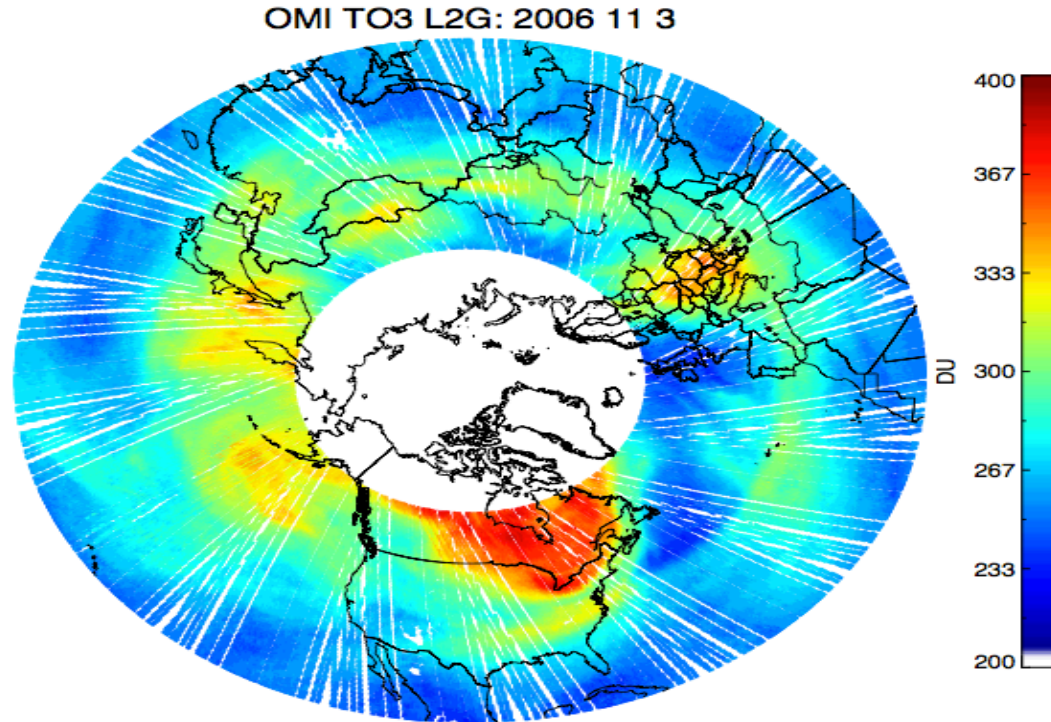
# Data Granule

- Product File
  - covers sunlit portion of the orbit with an approx. 2,600 km wide swath
  - contains 60 binned pixels or scenes per viewing line
- 14 or 15 granules are produced daily, providing fully contiguous coverage of the globe



# Important Information Regarding OMI

- Almost 50% data loss since 2008 (row anomaly effect)
- Affects all OMI products



# Quantification of Gas Abundances - Units

Satellite Tracer	Units
OMI O <sub>3</sub> , SO <sub>2</sub>	Dobson Units (DU)
OMI NO <sub>2</sub>	Molecules/cm <sup>2</sup>

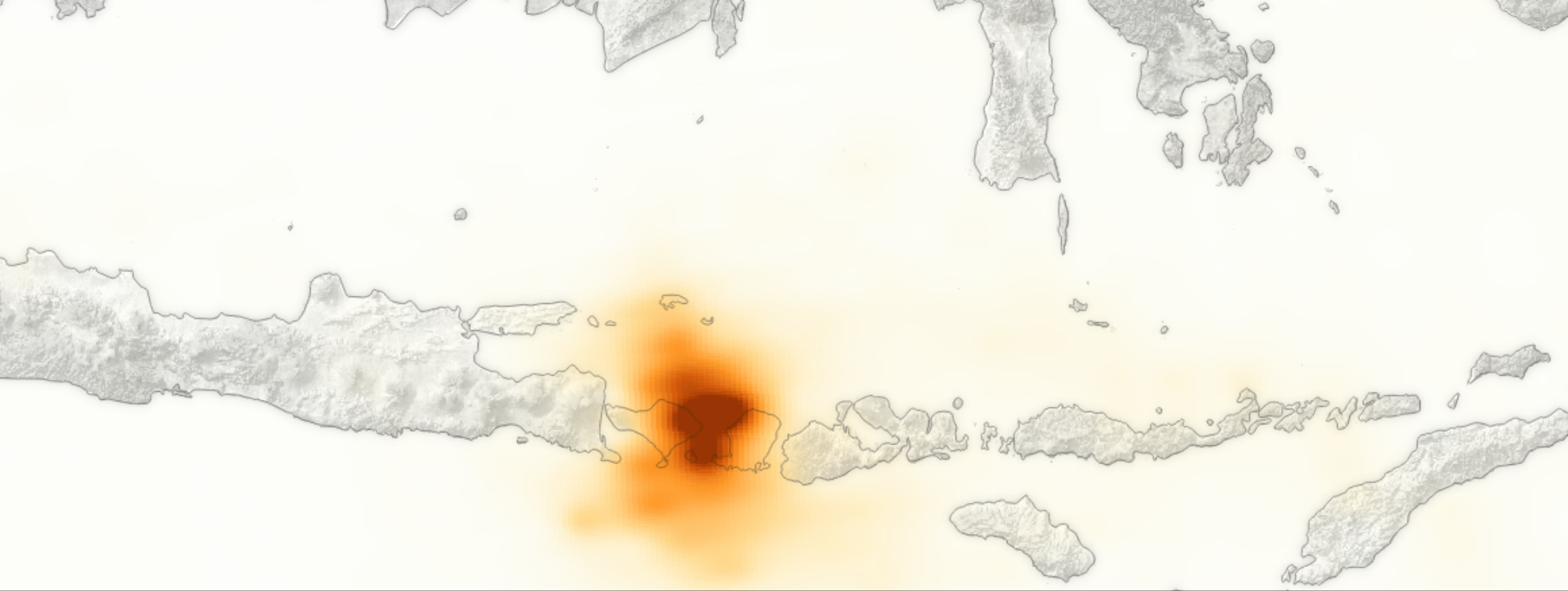
$$1 \text{ DU} = 2.69 \times 10^{16} \text{ molec/cm}^2$$



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

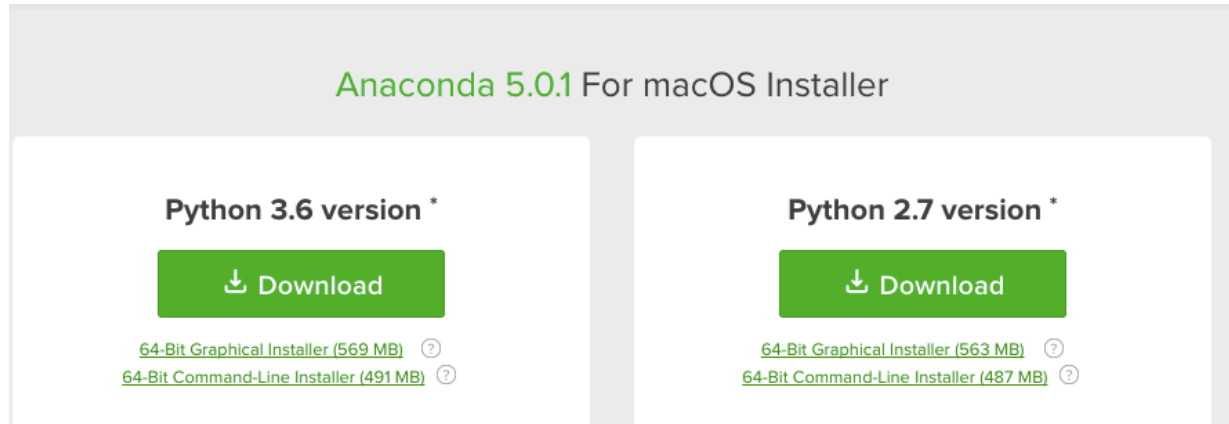




Things to do for Session 2

# Computer Requirements

- Install Python 2.7 using [Anaconda](#)
- Install all required python packages
  - Package List (right)
- Test python and package installations using following python test code
  - [test\\_python.py](#)
- Download MODIS Data and Python Codes on the training website
  - <https://arset.gsfc.nasa.gov/airquality/webinars/2018-hiresdatasets>
- For more detail on the code, visit:  
<https://arset.gsfc.nasa.gov/airquality/python-scripts-aerosol-data-sets-merra-modis-and-omi>



- Python package list:
  - pyhdf
  - numpy
  - sys
  - mpl\_toolkits.  
basemap
  - matplotlib
  - linearSegmented  
Colormap
  - h5py
  - time
  - calendar





# Python Test

- Open the spyder editor inside Anaconda
- Open **test\_python.py**
- Make sure the directory has the python code and HDF file
- Open the **ipython** console in the spider
- Run the code using the **green arrow** on the top
- Output should be an image as shown

The screenshot displays the Spyder Python IDE interface. The top toolbar features a green play button (run icon) circled in red. The editor window shows a Python script named `test_python.py` with the following code:

```
1 #!/usr/bin/python
2 '''
3 Module: read_and_map_mod_aerosol.py
4
5 Disclaimer: The code is for demonstration purposes only. Users are responsible to check for acc
6
7 Author: Justin Roberts-Pierel, 2015
8 Organization: NASA ARSET
9 Purpose: To extract AOD data from a MODIS HDF4 file (or series of files) and create a map of th
10
11 See the README associated with this module for more information.
12 '''
13
14
15 #import necessary modules
16 from pyhdf import SD
17 import numpy as np
18 from mpl_toolkits.basemap import Basemap, cm
19 import matplotlib.pyplot as plt
20 import sys
21 import h5py
22 import time
23 import calendar
24
25
26 FILE_NAME='MYD04_L2_A2017249.2105.006.2017250160535.hdf'
27
28 hdf=SD(FILE_NAME)
29 # Get lat and lon info
30 lat = hdf.select('Latitude')
31 latitude = lat[:]
32 min_lat=latitude.min()
33 max_lat=latitude.max()
34 lon = hdf.select('Longitude')
35 longitude = lon[:]
36 min_lon=longitude.min()
37 max_lon=longitude.max()
38 SDS_NAME='Image_Optical_Depth_Land_And_Ocean'
39 sds=hdf.select(SDS_NAME)
40 #get scale factor for AOD SDS
41 attributes=sds.attributes()
42 scale_factor=attributes['scale_factor']
43 #get valid range for AOD SDS
44 range=sds.get_range()
45 min_range=min(range)
46 max_range=max(range)
47
48 #get SDS data
49 data=sds.get()
50 #get data within valid range
51 valid_data=data.ravel()
52 valid_data=[x for x in valid_data if x>=min_range]
53 valid_data=[x for x in valid_data if x<=max_range]
```

The IPython console on the right shows the execution output, including a map plot titled "MYD04\_L2\_A2017249.2105.006.2017250160535 Image\_Optical\_Depth\_Land\_And\_Ocean". The plot displays a map of the Pacific Northwest region with a color scale for Aerosol Optical Depth (AOD) ranging from 0 to 5. A red arrow points to the plot area, labeled "output".



# Data Download

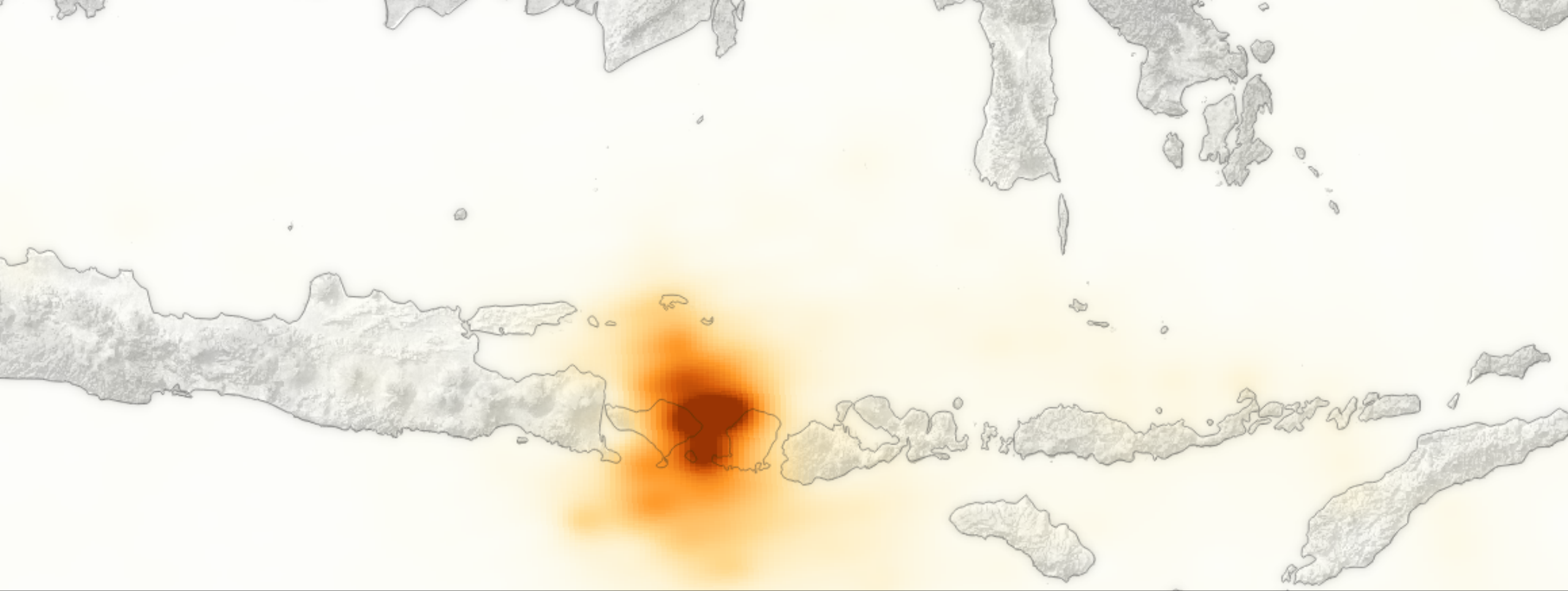
- MODIS 10 km, 3 km Aerosol Parameters
- Laadsweb – Earth Data Login
- Select and download data for suggested case studies:  
[https://arset.gsfc.nasa.gov/sites/default/files/airquality/webinars/18-hires/week2\\_code\\_data.zip](https://arset.gsfc.nasa.gov/sites/default/files/airquality/webinars/18-hires/week2_code_data.zip)



# Suggest Case MODIS Aerosol Data

- Follow the instructions as outlined in the exercise available on the training webpage: <https://arset.gsfc.nasa.gov/airquality/webinars/2018-hiresdatasets>
- Data Details:
  - Satellite: MODIS- Aqua
  - Product Names: MYD04\_L2 and MYD04\_3K
  - Date: 2017/10/08 to 2017/10/09
  - Region of interest: -123 E to -121 E & 36 N to 39 N





Questions & Discussion