Remote Sensing Tools for Air Quality Forecasting

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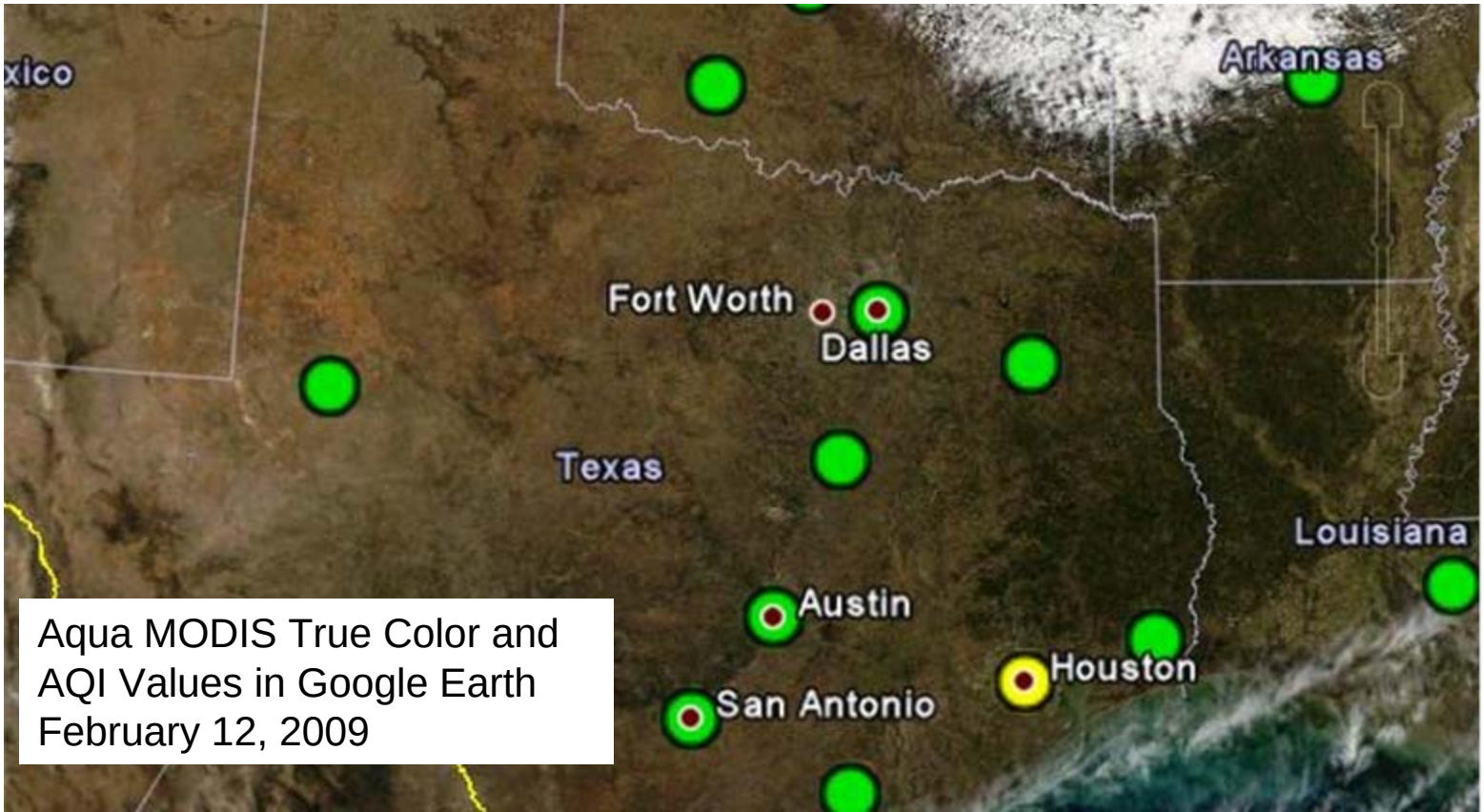
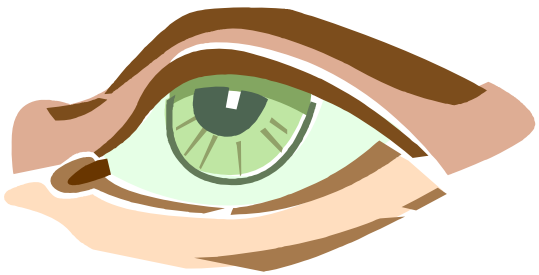


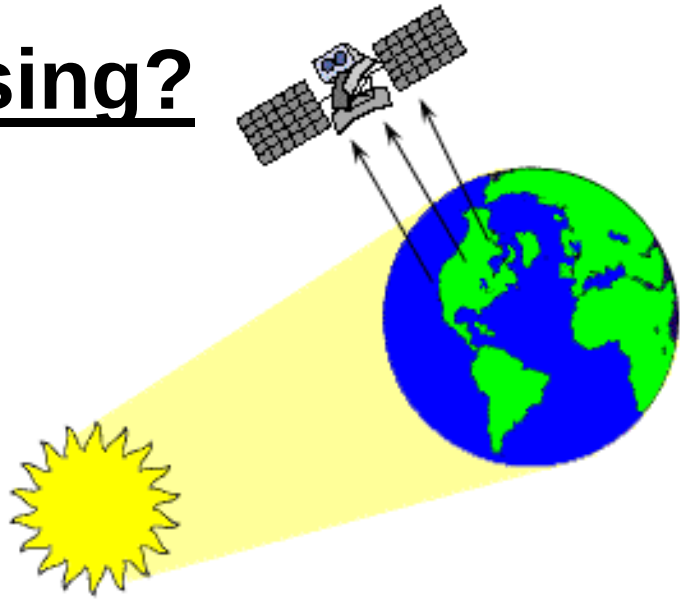
Aqua MODIS True Color and AQI Values in Google Earth February 12, 2009

Today's Agenda

12:30 – 1:00	Overview of Satellite Tools
1:00 – 1:45	Activity 1: Air Quality Case Studies
1:45 – 2:00	Review of Air Quality Case Studies
2:00 – 2:30	Using Giovanni for Retrospective Event Analysis
2:30 – 2:45	Break
2:45 – 3:30	Activity 2: Giovanni
3:30 – 3:50	Visualizing NRT Air Quality Data Sets in Google Earth
3:50 – 4:50	Activity 3: Google Earth
4:50 – 5:00	Course Evaluations

What is Remote Sensing?

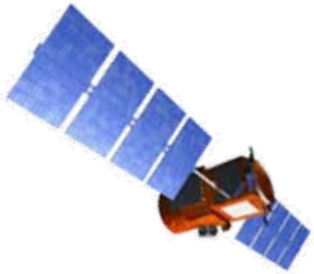




Remote sensing is a method of obtaining information about the properties of an object without coming into physical contact with it.

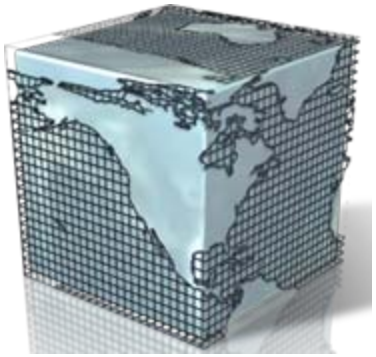
Why use Satellites to Study Air Quality?

- Information about the atmosphere on the regional, national, and local scales – the “big picture”
- Pollutant measurements in areas where there are no ground-based monitors
- Advance warning of impending air quality events, especially fires
- Visual appeal for the public and decision-makers: a picture is worth a thousand words



Important Satellite Characteristics: Spatial Resolution

- **Spatial resolution** is the smallest area on Earth that a satellite can observe.
  - Depends on the type of instrument
  - **Low spatial resolution** (*e.g.*, 10 km): can see large regional features (cities, forests, lakes)
  - **High spatial resolution** (*e.g.*, 10 m): can see detailed features (buildings, roads, trees)



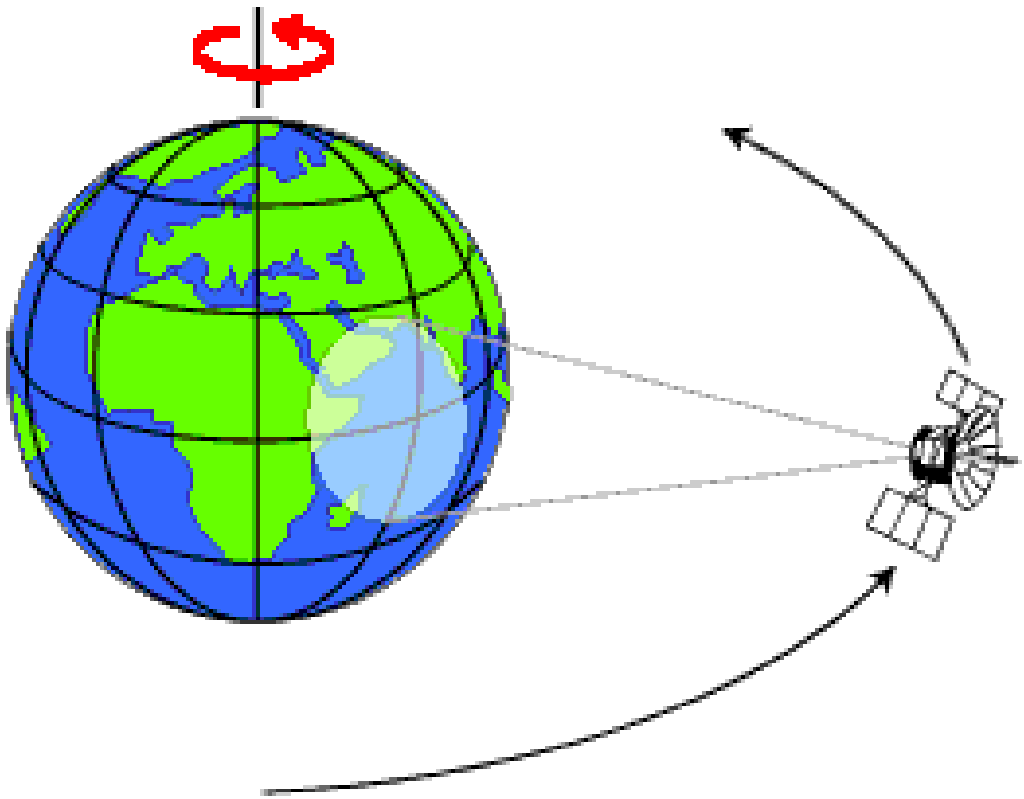
- **Low spatial resolution (1 km):**
  - Major regional features are visible (rivers, lakes, urban areas)
  - Detailed features are NOT visible!

- **High spatial resolution (10 m):**
  - Detailed features are visible!
  - Usually high spatial resolution images are *expensive*!!

Important Satellite Characteristics: Temporal Resolution

- **Temporal resolution** is how frequently a satellite observes the same area on Earth.
  - Depends primarily on the *orbit* of the satellite
  - **High temporal resolution** (e.g., 30 minutes): nearly continuous observations
  - **Low temporal resolution** (e.g., 1 day): only one observation per day

High-Altitude Orbit: Geostationary Satellites

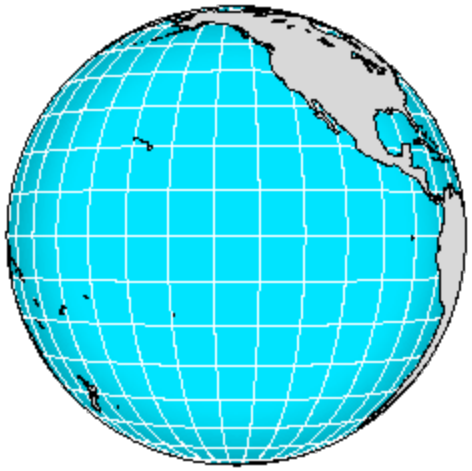


- High altitude orbit: ~35,800 km
- Orbital period of satellite matches rotational speed of Earth
- Continuously observe same area on Earth
- *Very high temporal resolution (min – hours)*
- Usually used to monitor meteorological conditions

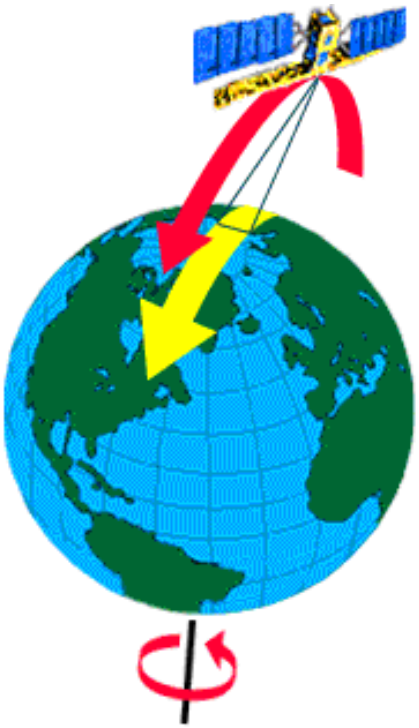
Geostationary Environmental Operational Satellites (GOES)

- U.S. weather satellites
- Temporal resolution: 30 min – 3 hr
- Spatial resolution: 1 km, 4 km, 8 km

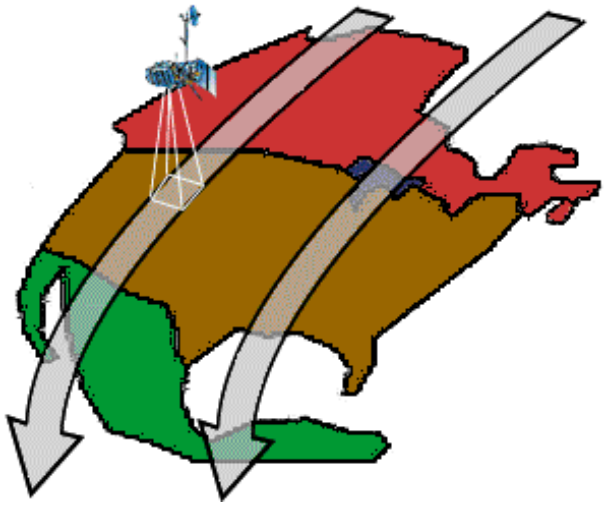
GOES-East



GOES-West

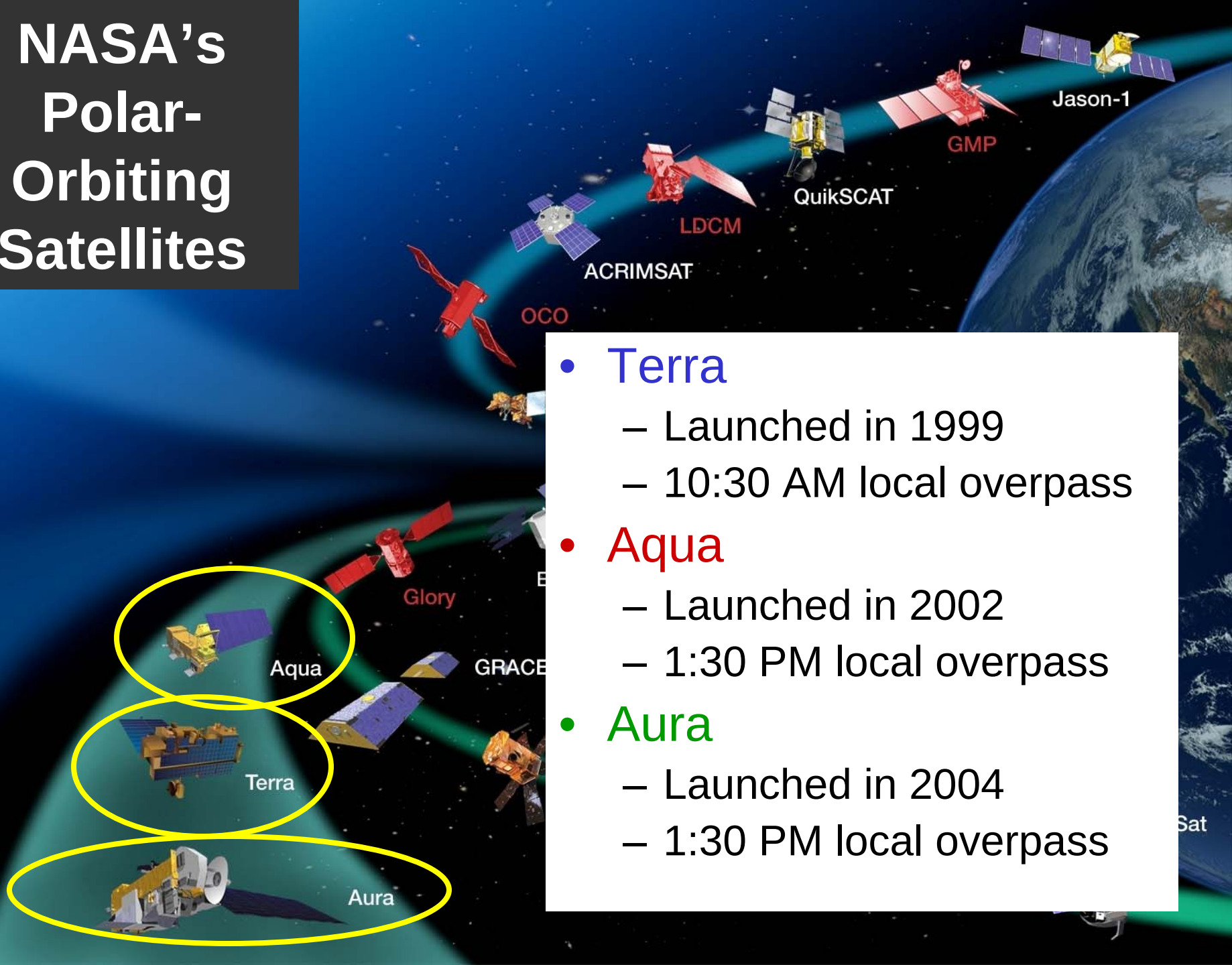


Low Altitude Orbit: Polar-Orbiting Satellites



- Low altitude orbit: ~700-800 km
- Earth rotates under satellite as it orbits around N and S poles, so each time satellite makes a pass over Earth, it observes a new area
- Polar-orbiting satellites observe the same area on Earth 1-2 times per day (or less)
- *Low temporal resolution*, but global coverage (trade-off)
- Many application: air, land, water

NASA's Polar-Orbiting Satellites



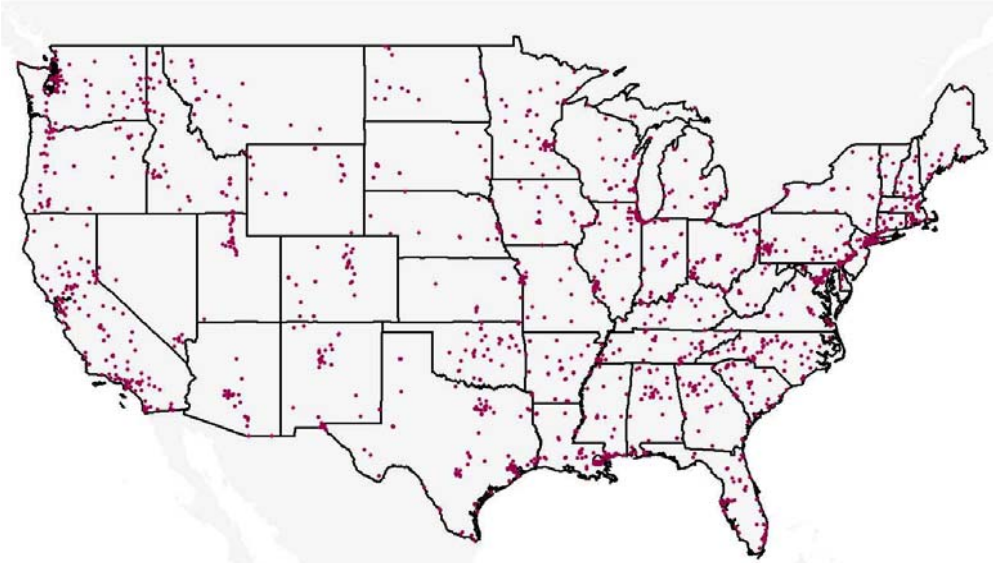
- Terra
  - Launched in 1999
  - 10:30 AM local overpass
- Aqua
  - Launched in 2002
  - 1:30 PM local overpass
- Aura
  - Launched in 2004
  - 1:30 PM local overpass

How Do Satellites Measure Pollutants and Detect Air Quality Features?

- Satellites do not make *direct* measurements of atmospheric pollutants, like monitors do.
- Instead, satellites measure solar and/or terrestrial *radiance* in a *vertical column* of the atmosphere.
- Radiance data are converted into geophysical parameters using science-based algorithms (*e.g*., aerosol optical depth)

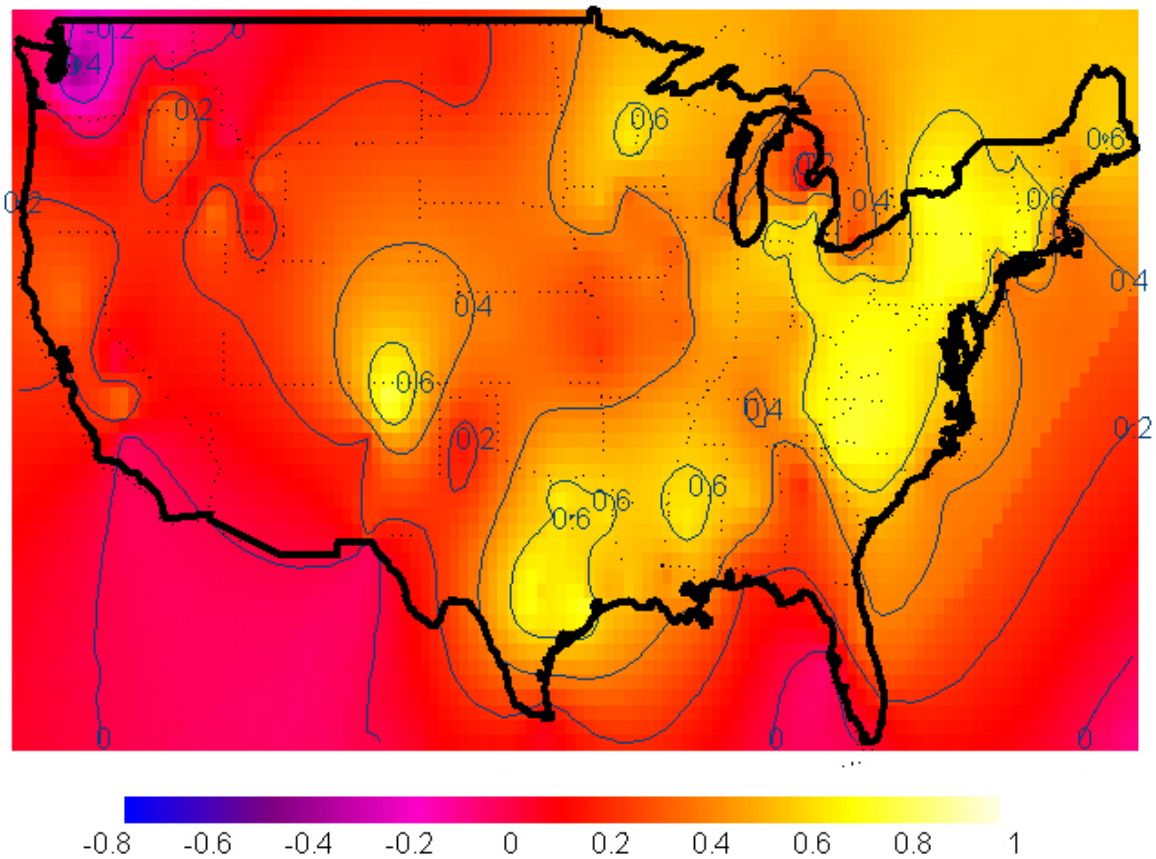
Correlations between Satellite and Ground-Based Monitor Measurements

- We care about air quality at the *surface*, where people live.
- Satellites measure parameters over a *vertical column* in the atmosphere.
- So we need to know how satellite and ground-based monitor measurements are correlated.



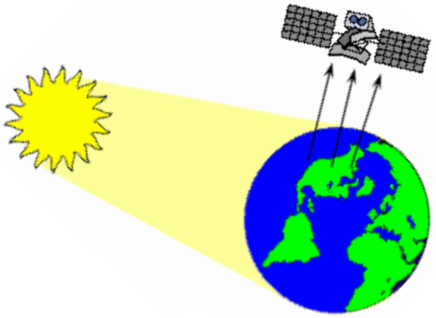
$PM_{2.5}$ Ground-Based Monitor Network

Example: Correlations between MODIS AOD and $PM_{2.5}$ for 2002



- Correlations vary by season and location
- Highest in East during summer and fall
- AOD is less accurate over bright surfaces, like snow and desert
- AOD measurements of sulfate and smoke particles are more accurate than nitrate

Interpretation of Satellite Images

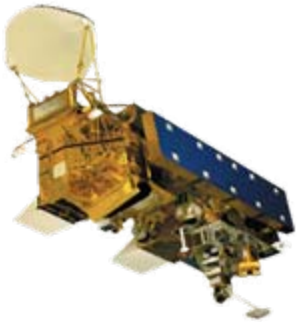


- *Quantitative* for $PM_{2.5}$
- *Qualitative* for NO_2, SO_2, CO
- Bottom line: use satellite images for information about the distribution and transport of pollutants, but not about the exact concentrations of pollutants.
- Caveat: just because satellites indicate the presence of pollutants, it doesn't mean concentrations are high at the surface!!

Satellite Remote Sensing: Challenges

- Satellites are expensive to build and launch, and they have finite lifetimes.
- Satellite radiance measurements must be converted to geophysical values, such as temperature or pollutant concentration.
- Tradeoffs between spatial and temporal resolution – can't always get want you want.

Advantages outweigh the challenges!



Satellite Data Products for Air Quality

- MODIS true color images
- MODIS aerosol optical depth (AOD)
- GASP (GOES AOD)
- OMI tropospheric nitrogen dioxide (NO_2)
- Hazard Mapping System Fire and Smoke Product
- 48-Hour Aerosol Trajectory Forecast

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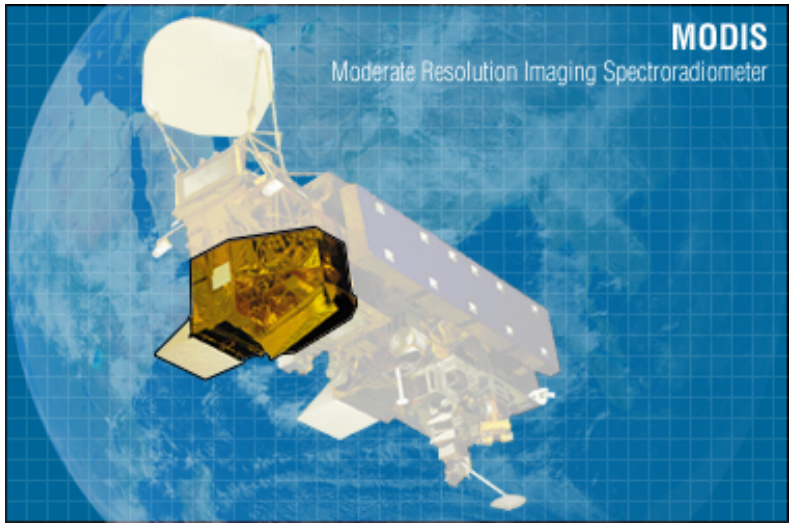
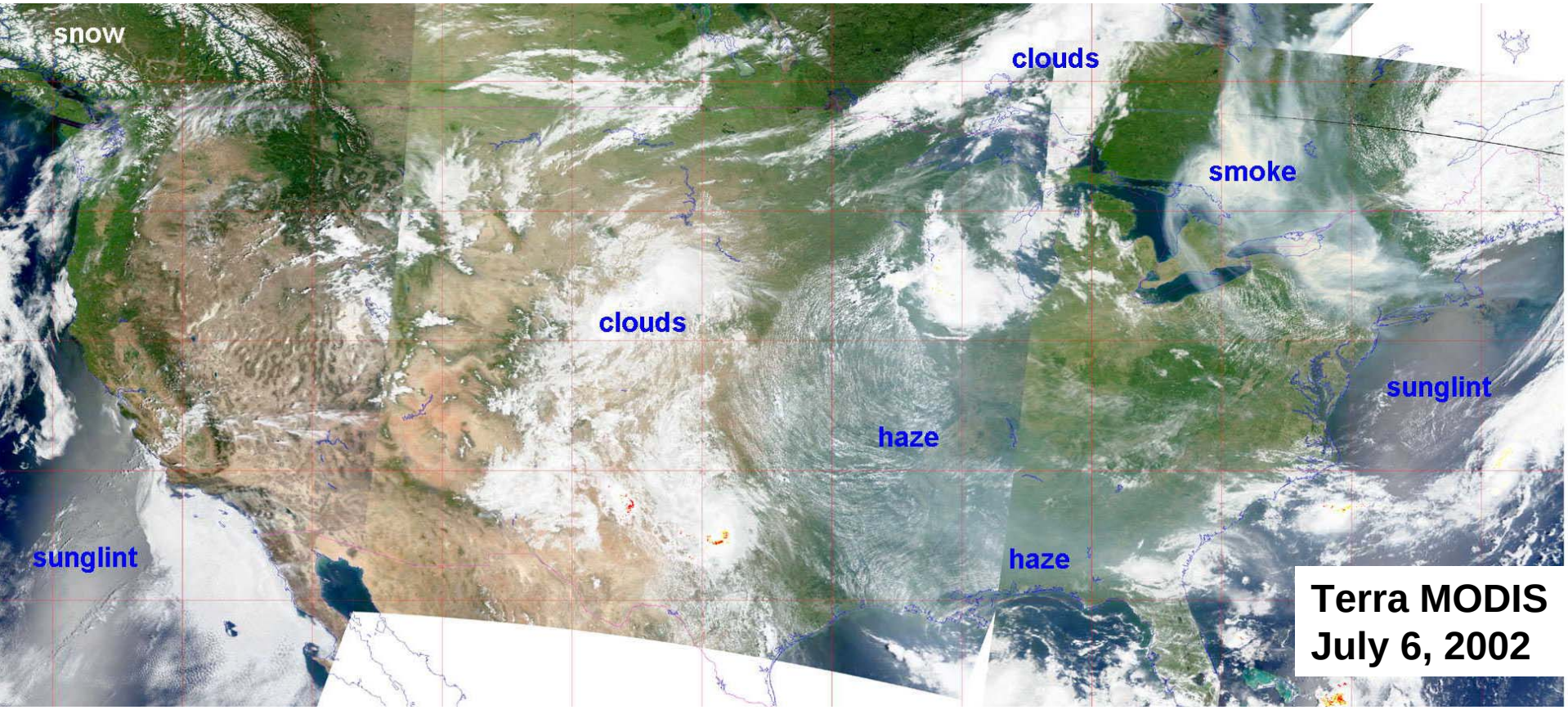
MODerate Resolution Imaging Spectroradiometer (MODIS)

- MODIS is on NASA's Terra and Aqua satellites
- Temporal resolution: 2 measurements per day (10:30 AM and 1:30 PM local time)
- Spatial resolution: 1 km, 500 m, and 250 m

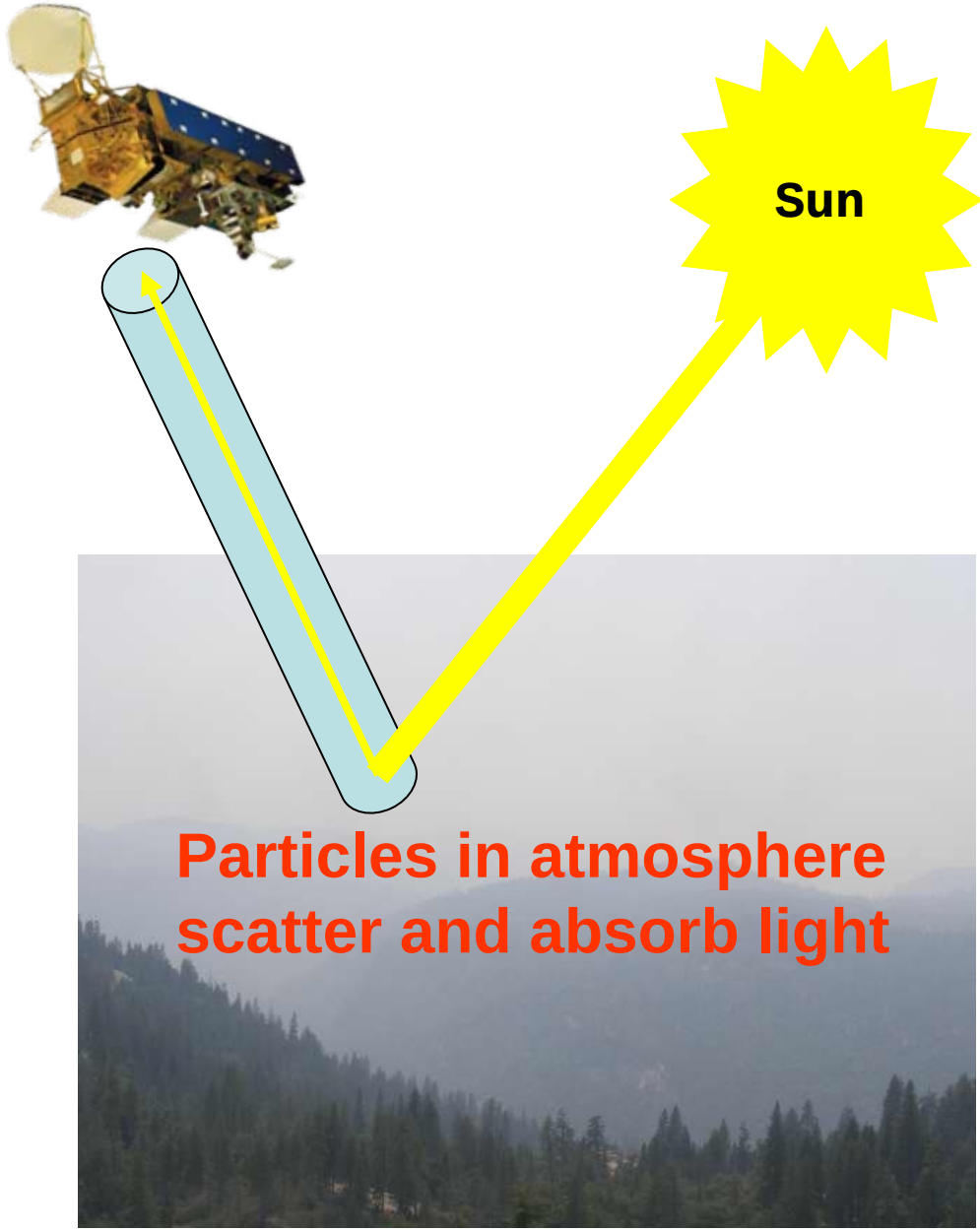


MODIS True Color Image



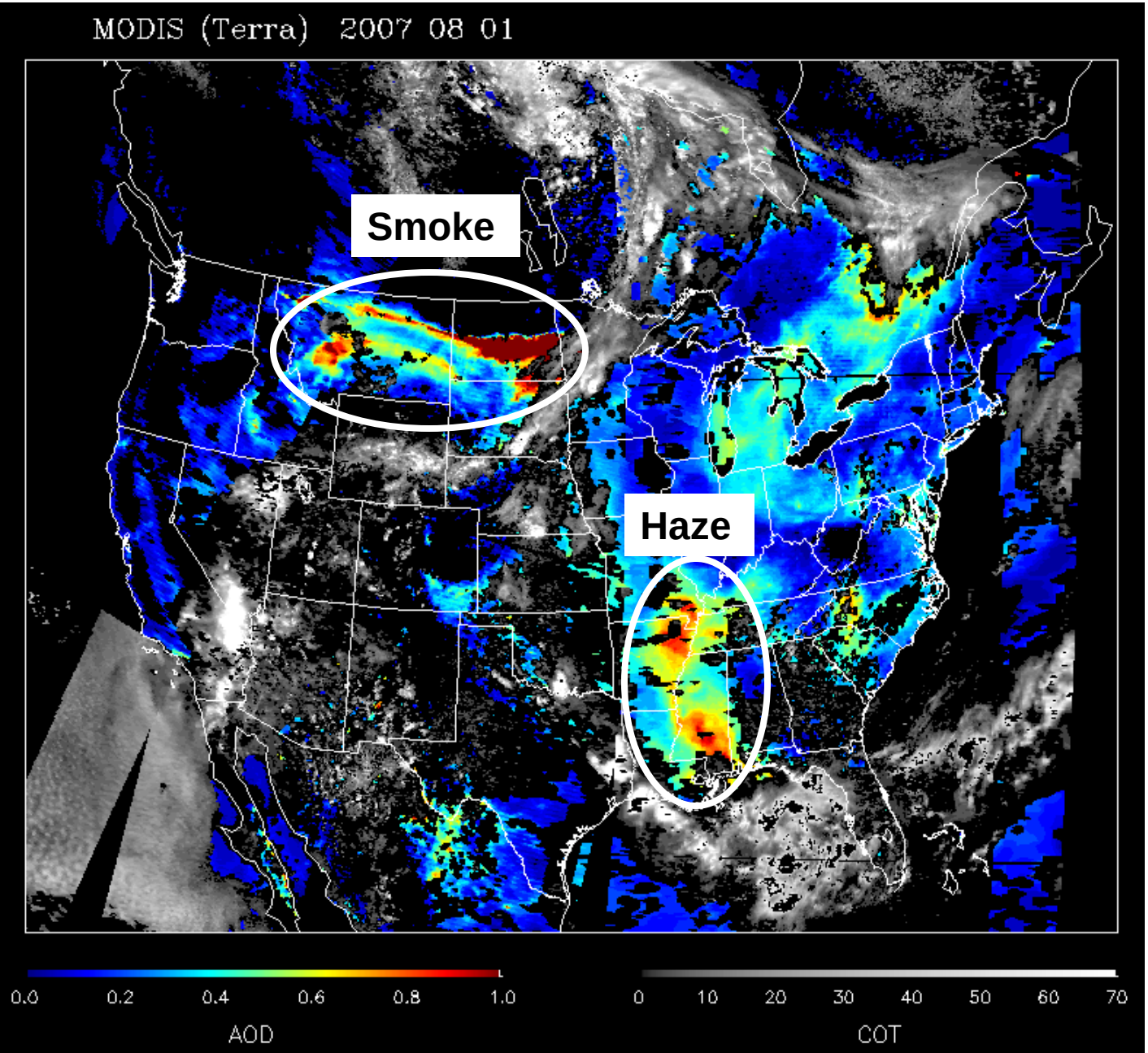
- A true color image is NOT a picture!

Aerosol Optical Depth (AOD)



- AOD is a measure of the scattering and absorption of light by particles in a *vertical column* of the atmosphere.
- AOD is proportional to particulate concentration.
- AOD is dimensionless; higher values correspond to high particulate concentrations.

MODIS Aerosol Optical Depth (AOD) Image



Red = high AOD

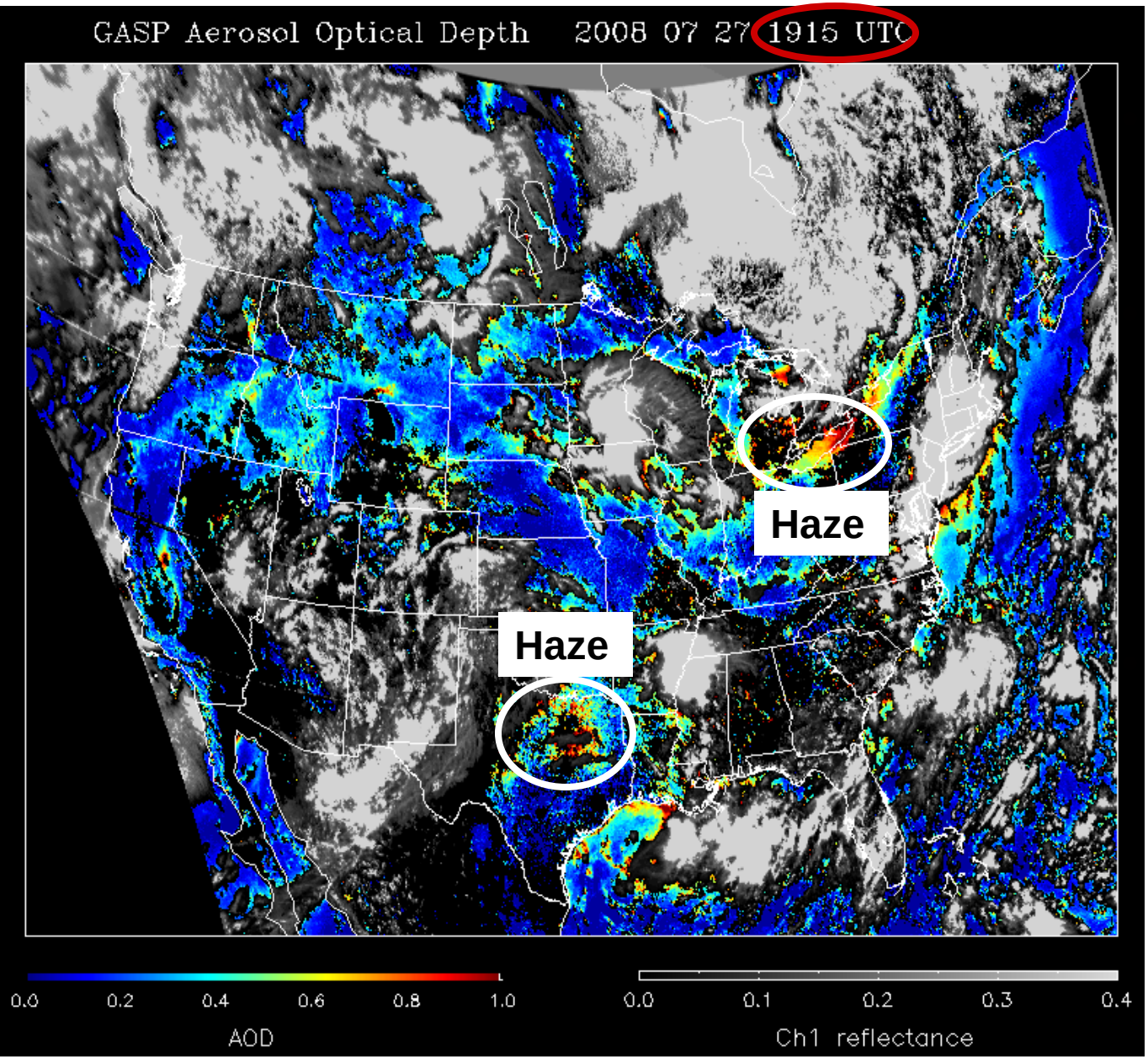
Blue = low AOD

MODIS has 2 images per day:

Terra: 10:30 AM
Aqua: 1:30 PM

Clouds block measurement of AOD!

GOES Aerosol/Smoke Product (GASP)

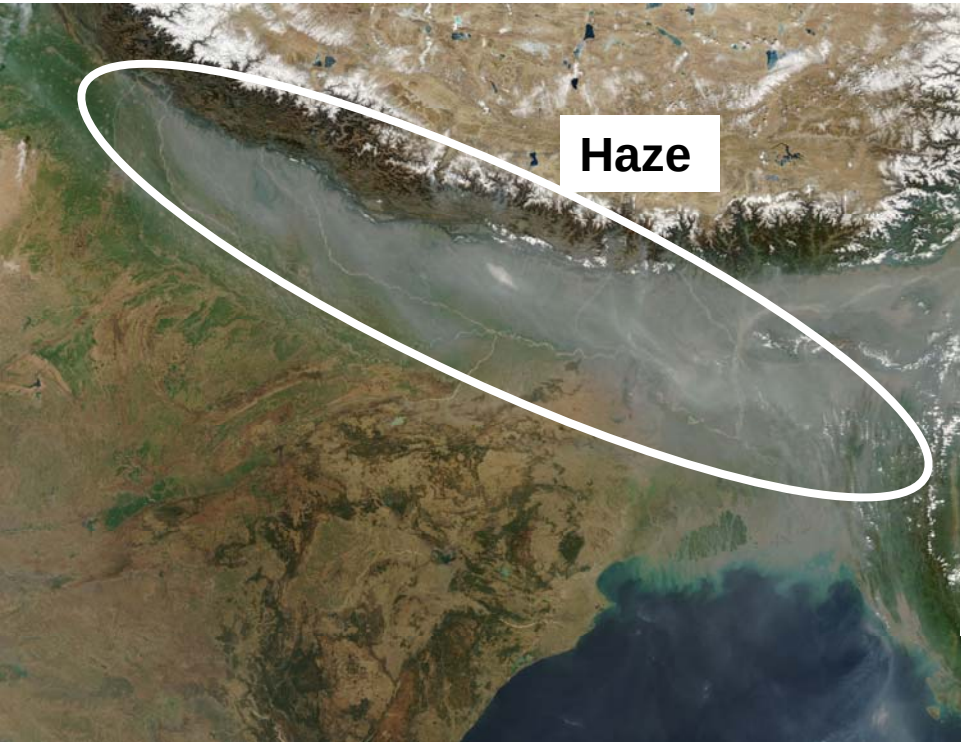


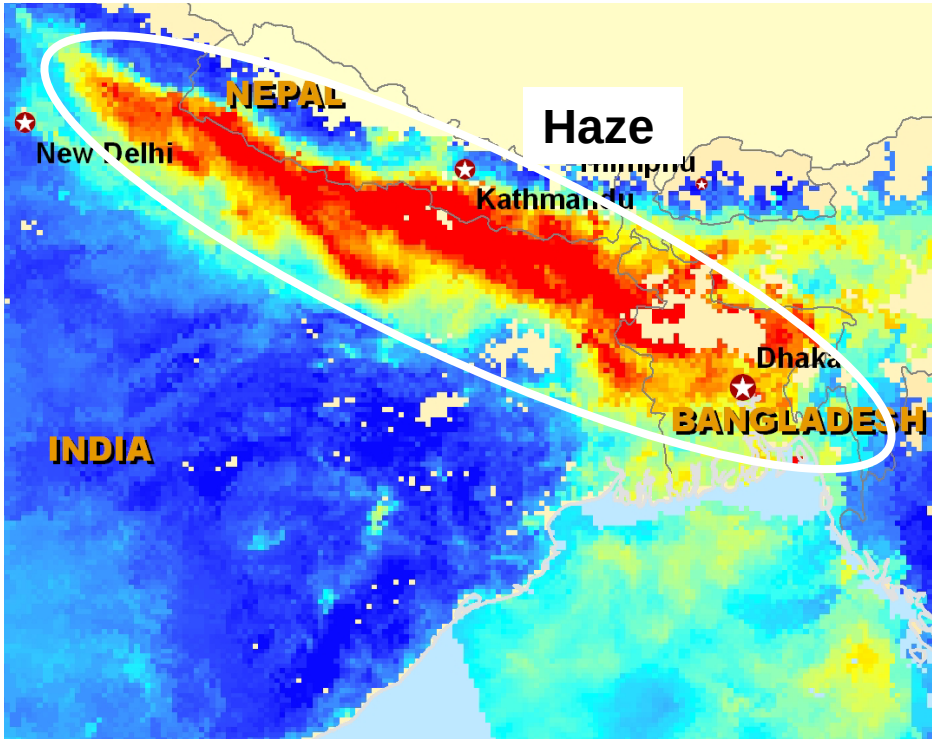
GASP is AOD derived from GOES

Color scale is similar to MODIS AOD:
red is high AOD
blue is low AOD
white is clouds

GASP has *high temporal resolution* (available every 30 minutes)

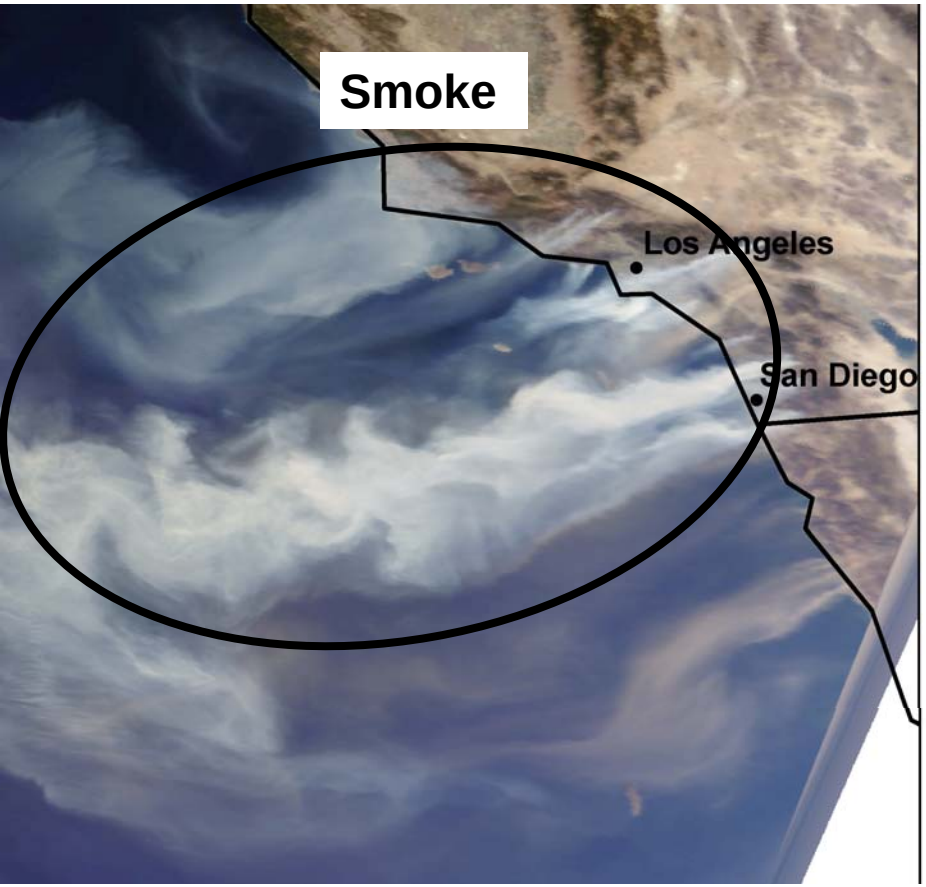
Northern India, Nepal, and Bangladesh MODIS True Color and AOD Images

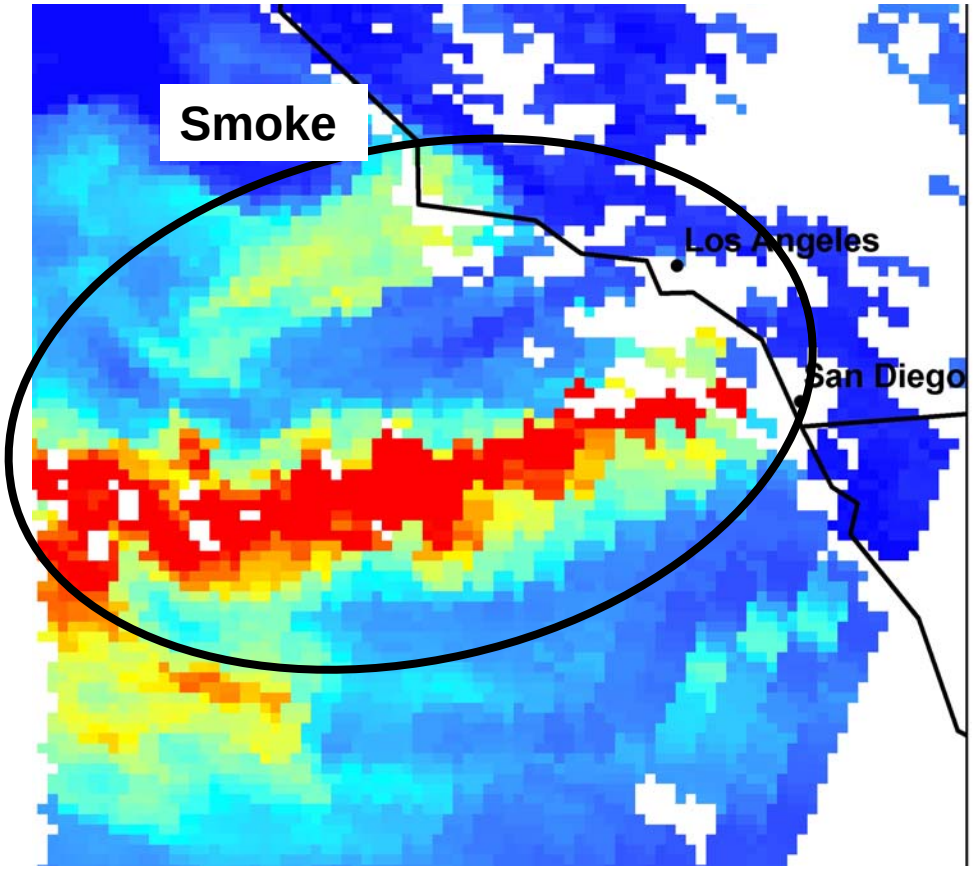




MODIS Terra
February 5, 2006

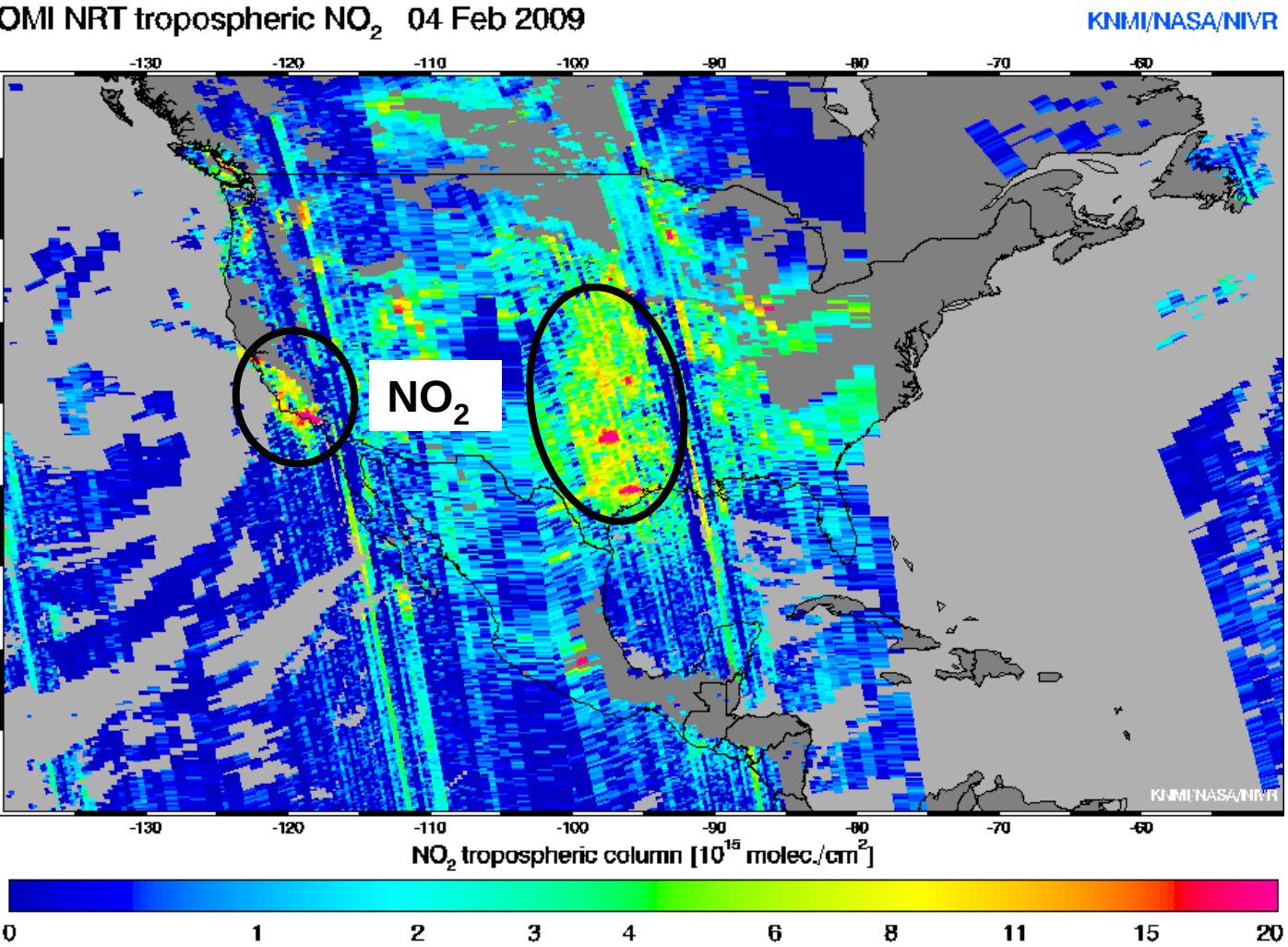
Southern California
MODIS True Color and AOD Images





MODIS Terra
October 22, 2007

Ozone Monitoring Instrument (OMI) Tropospheric Nitrogen Dioxide (NO_2)



OMI is on Aura (1 measurement per day, in the afternoon)

Red = high NO_2

Blue = low NO_2

Grey areas indicate missing data due to cloud cover

NOAA Hazard Mapping System
Fire and Smoke Product

DESCRIPTIVE TEXT NARRATIVE FOR SMOKE/DUST OBSERVED IN SATELLITE IMAGERY THROUGH 0215Z May 25, 2008

Western Gulf of Mexico/East Texas/Oklahoma:
Widespread thin to locally moderate smoke and haze covers much of the western Gulf of Mexico and extends into eastern Texas and Oklahoma. The smoke originated from large numbers of fires in the Yucatan Peninsula and Central America. Another patch of thin smoke was seen in the eastern Gulf off the southwest coast of Florida.

Southeast:
An area of haze or possible remnant smoke was seen over southern Georgia and Alabama. If smoke is included in this area it is likely from the Central American fires.

West Texas:
The fire in Brewster county has diminished compared to yesterday's smoke. The direction of the plume has shifted through the day and by evening a narrow plume of thin smoke extended to the north of the blaze reaching into western Pecos county.

Manitoba:
A fire that developed late this afternoon in southern Manitoba about 60 km northwest of Roseau Minnesota expanded rapidly and was producing a broad plume of thick smoke that extended to the north reaching southeast Lake Winnipeg.

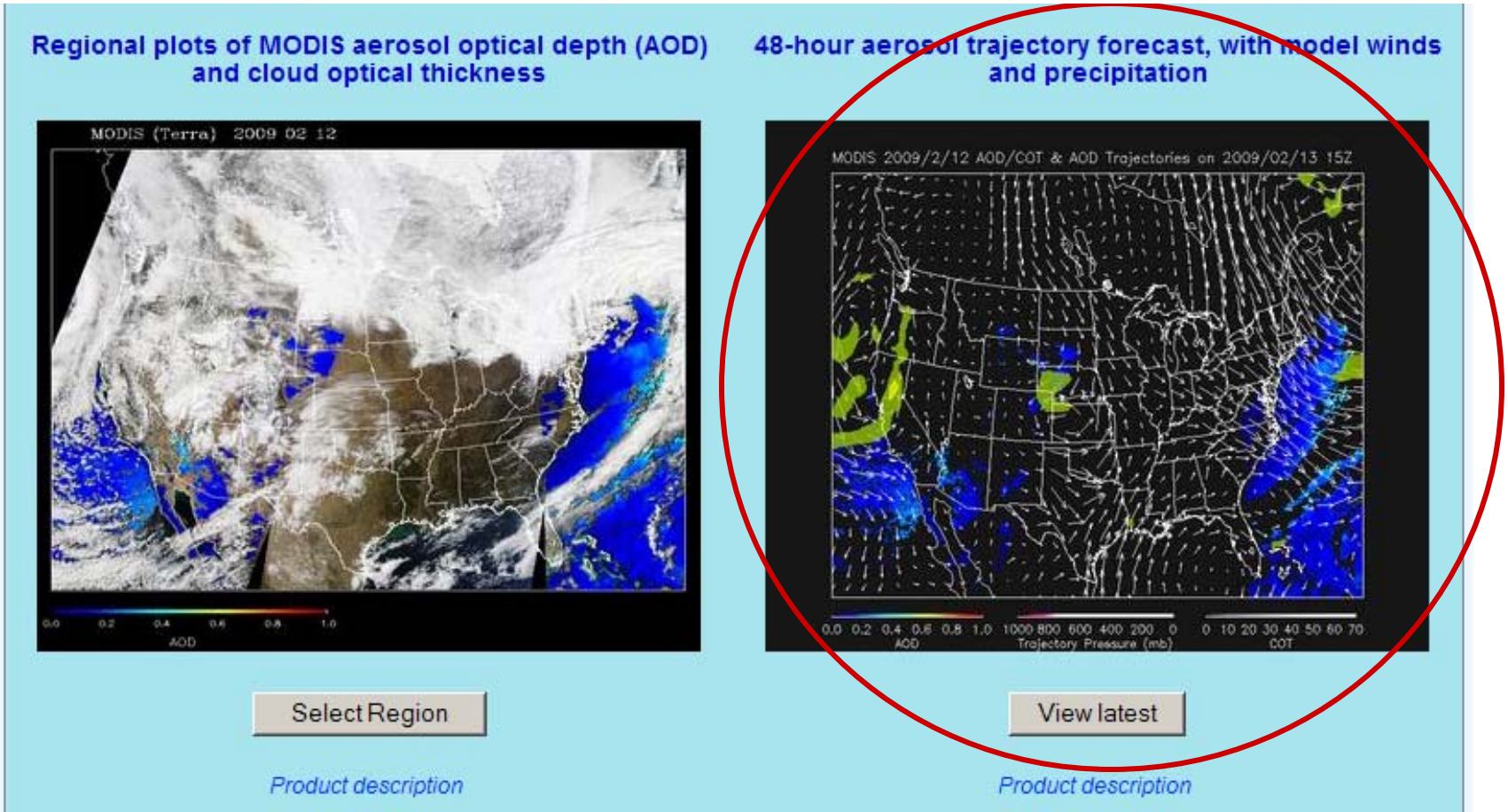
Northern Canada:
A broad area of smoke was seen covering much of the north central Canada, including northwest Alberta, much of eastern Northwest Territories and western Nunavut. The source of this smoke is likely large fires burning in eastern Russia.

Ruminski

- Analysis made 1 – 11 PM EST daily
- Red dots are “hotspots” identified by MODIS (fires)
- Smoke plumes are grey
- Countries outlined in green are the focus of the analysis

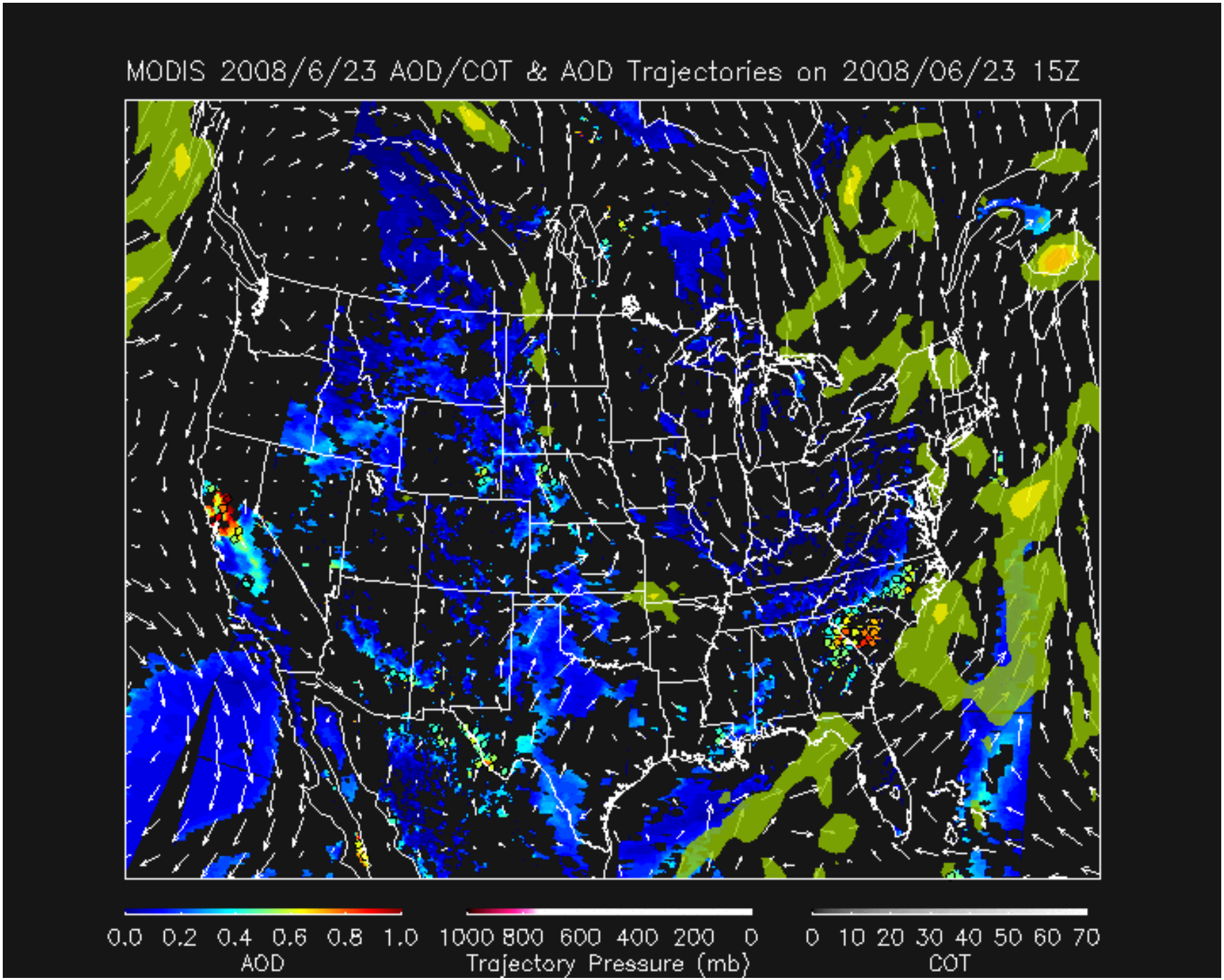
48-Hour Aerosol Trajectory Forecast

http://www.star.nesdis.noaa.gov/smcd/spb/aq/index.php



48-Hour Aerosol Trajectory Forecast

- Forward Air Parcel Trajectory Forecast:
  - Initialized at locations of AOD >0.4
  - Starting locations colored to AOD scale
  - Run using 12 UTC NAM
  - Pressure levels (mb) of trajectories color coded
  - 1000-850 mb level is magenta – parcel in boundary layer
  - White color indicates parcels aloft
- Map includes:
  - MODIS AOD and Cloud Optical Thickness (COT)
  - 850 mb forecasted wind field vectors
  - 3-hr accumulated precipitation forecast: yellow-shaded areas indicate potential for rain out or wet deposition


MODIS 2008/6/23 AOD/COT & AOD Trajectories on 2008/06/23 15Z
0.0 0.2 0.4 0.6 0.8 1.0
AOD
1000 800 600 400 200 0
Trajectory Pressure (mb)
0 10 20 30 40 50 60 70
COT

Acknowledgements

- Lawrence Friedl and NASA Applied Sciences
- Shobha Kondragunta, Hai Zhang, and NOAA NESDIS
- Ray Hoff and the entire 3D-AQS project team
- The Giovanni project team

3D-AQS

Three Dimensional Air Quality System

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