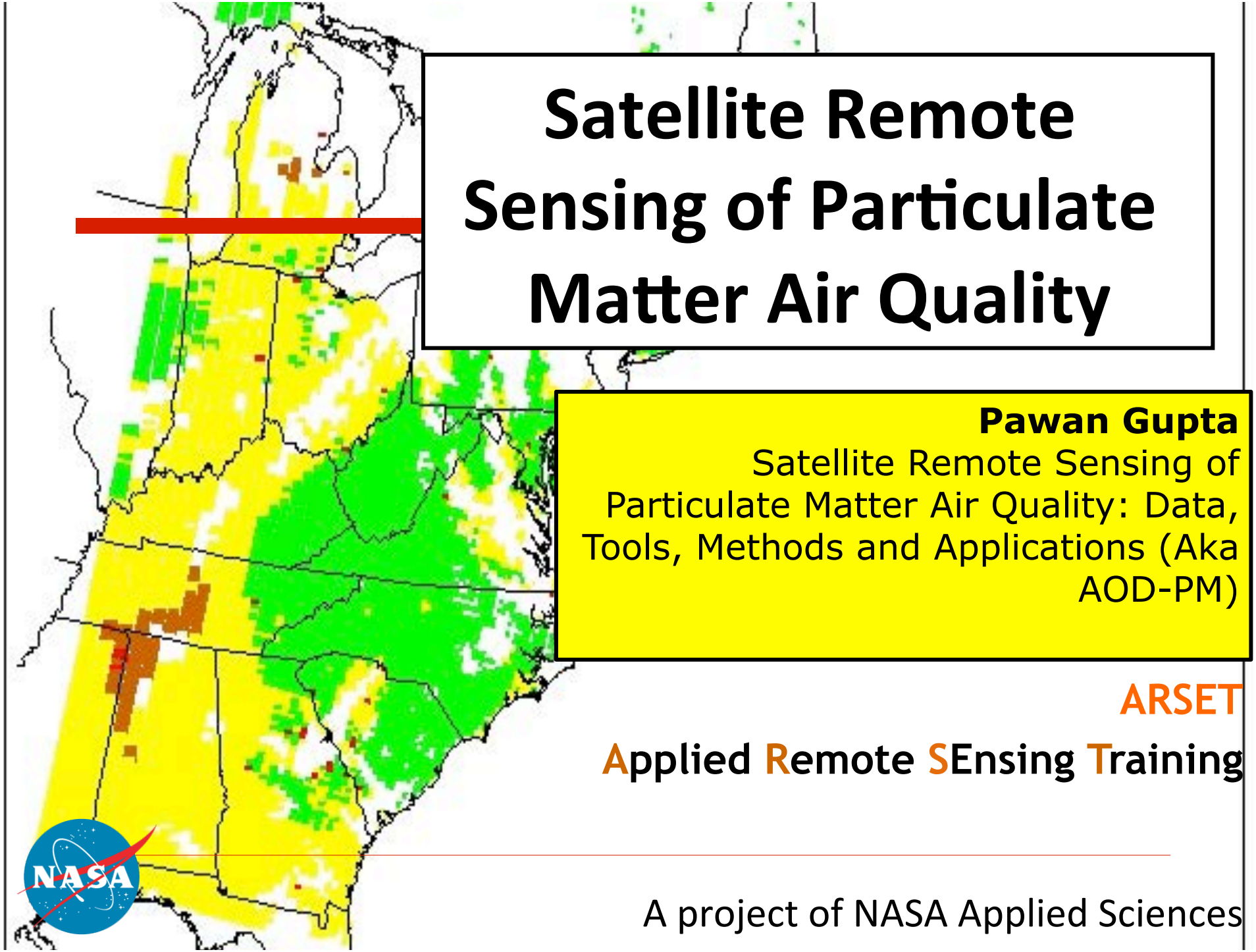


Satellite Remote Sensing of Particulate Matter Air Quality

Pawan Gupta

Satellite Remote Sensing of Particulate Matter Air Quality: Data, Tools, Methods and Applications (Aka AOD-PM)

ARSET

Applied Remote SEnsing Training

A project of NASA Applied Sciences

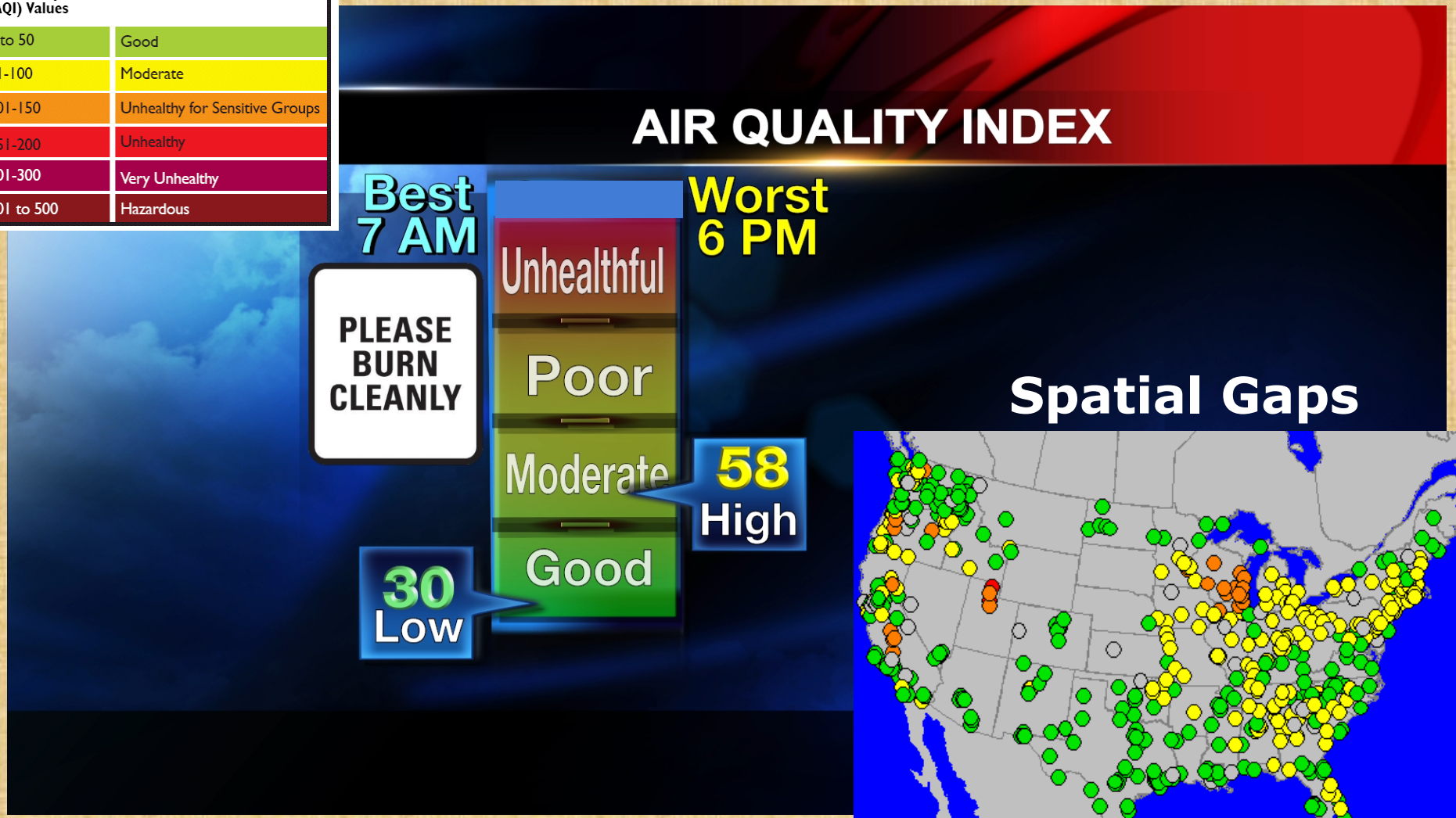
OBJECTIVE

Estimation of PM2.5 mass concentration at surface (μgm^{-3}) while utilizing satellite derived Aerosol Optical Depth (AOD – unitless quantity) at visible wavelength

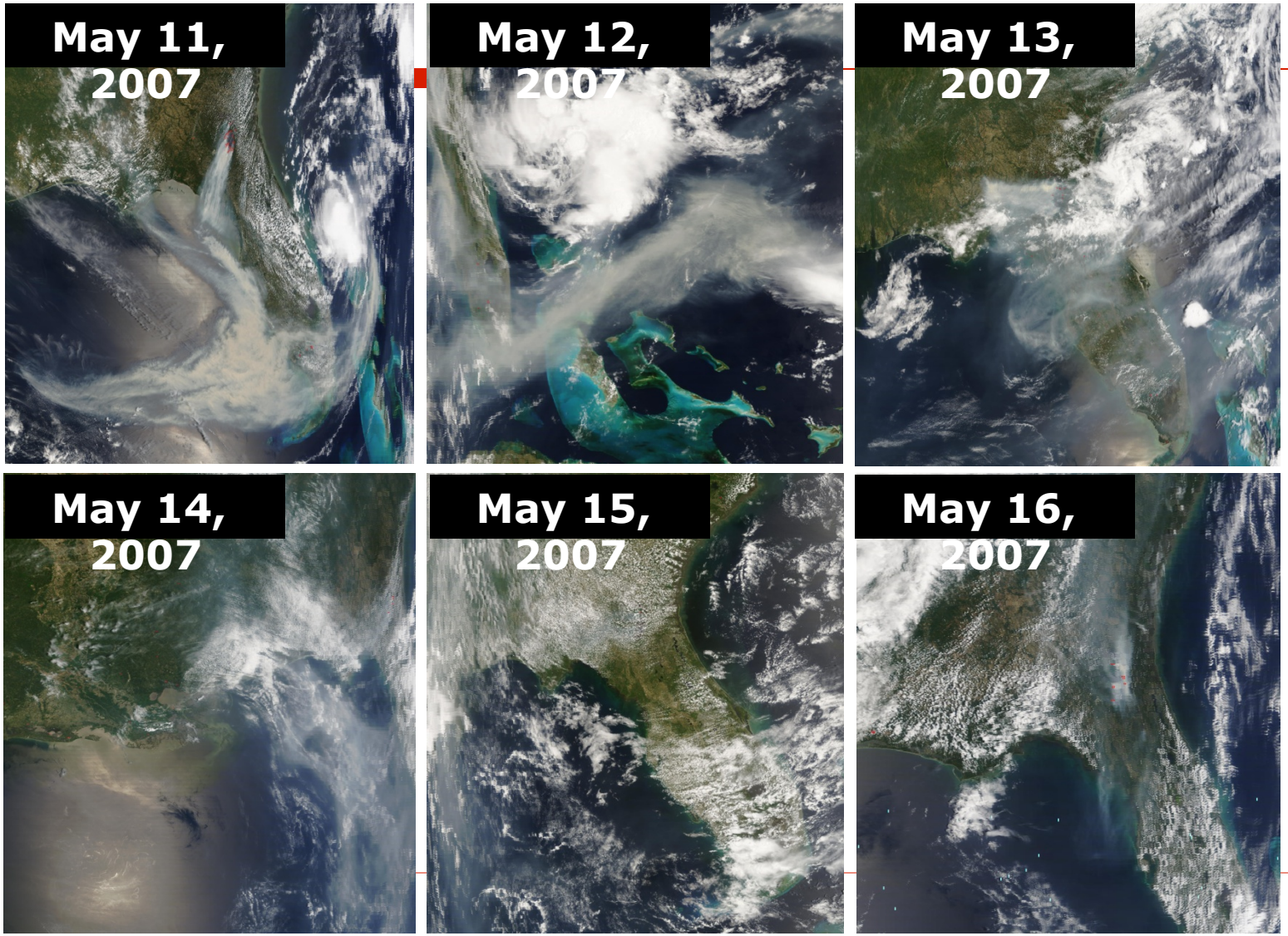
What are we looking for ? & Why ?

AIR QUALITY INDEX

Air Quality Index (AQI) Values	Levels of Health Concern
0 to 50	Good
51-100	Moderate
101-150	Unhealthy for Sensitive Groups
151-200	Unhealthy
201-300	Very Unhealthy
301 to 500	Hazardous

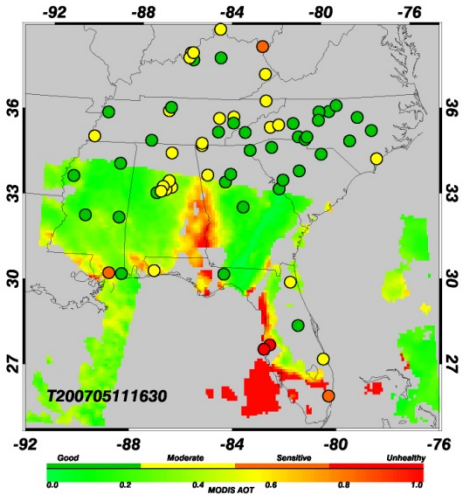


MODIS-Terra True Color Images

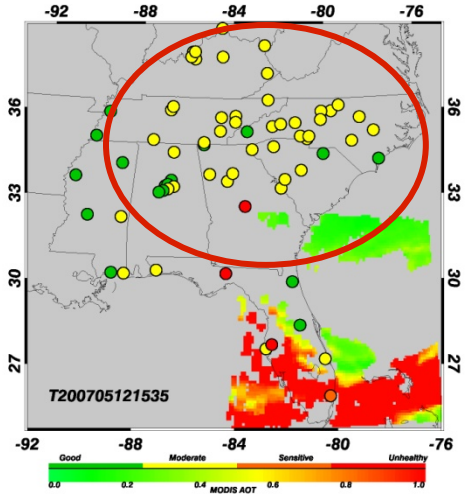


MODIS-Terra Aerosol Optical Thickness

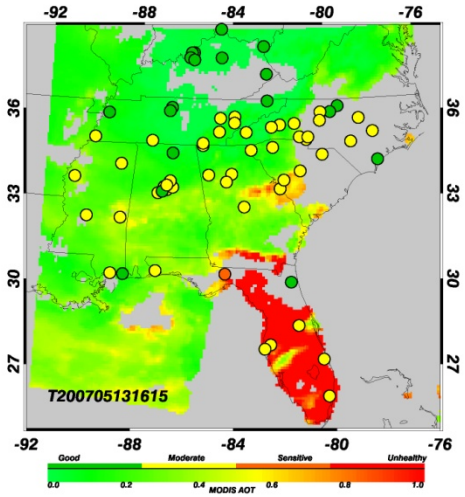
May 11, 2007



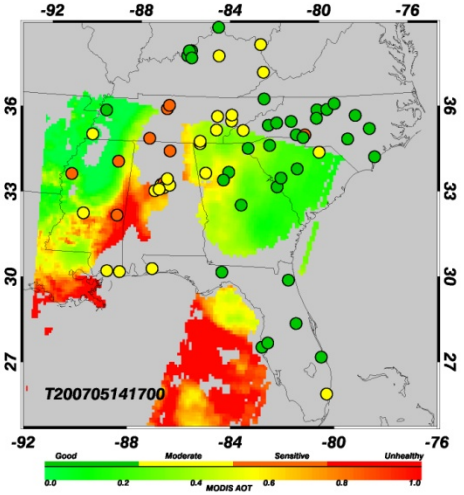
May 12, 2007



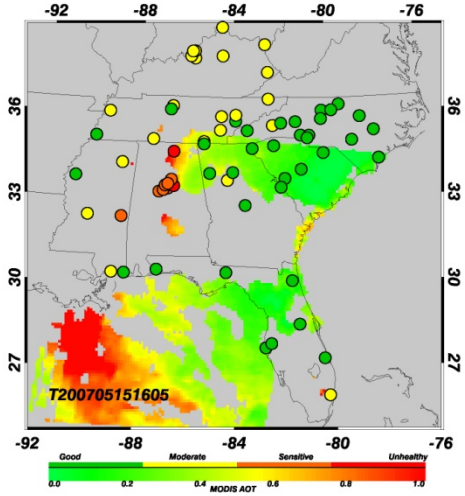
May 13, 2007



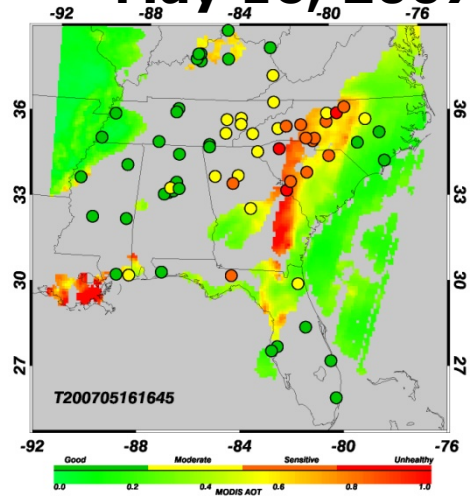
May 14, 2007

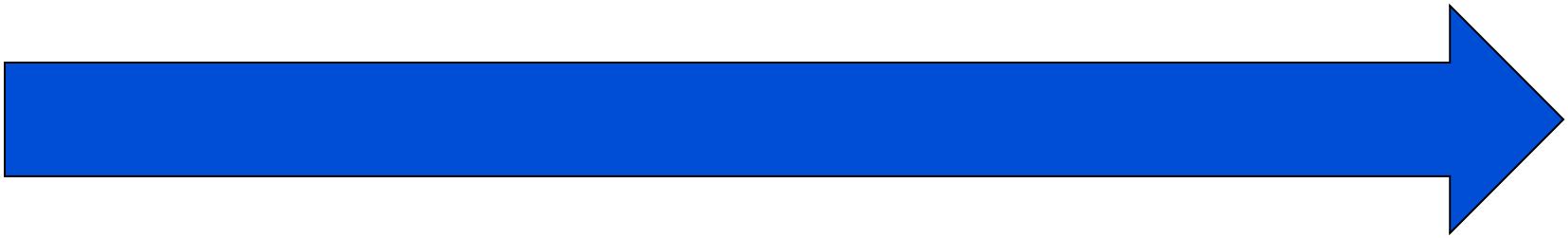


May 15, 2007



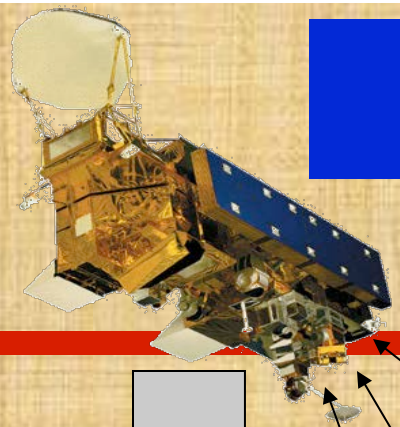
May 16, 2007





AOD (or AOT) to PM

What Satellite Provides?



Sun

Column Satellite Measurement

Seven MODIS bands are utilized to derive aerosol properties 0.47, 0.55, 0.65, 0.86, 1.24, 1.64, and 2.13 μm

10km

Ozone

Rayleigh Scattering

Water vapor + other gases (absorption)

Aerosol

Surface

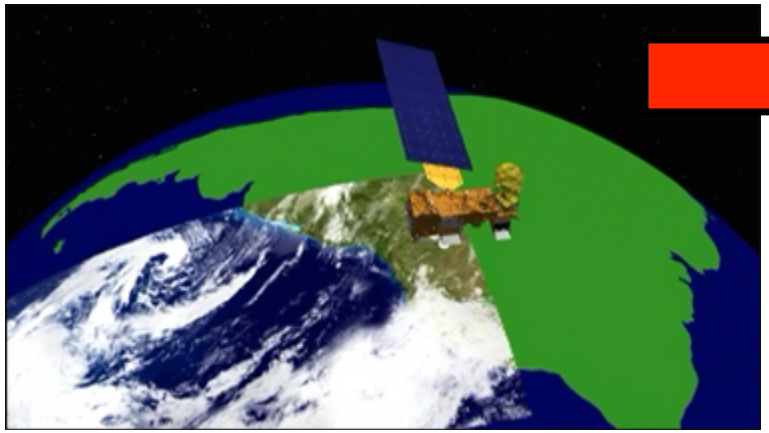
$$AOT(\tau) = \int \beta_{ext}\, dz$$

Particle size
Composition
Water uptake
Vertical Distribution

10X10 km^2 Res.

Satellite retrieval issues - inversion (e.g. aerosol model, background).

Measurement Technique



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

PM2.5 – Mass per unit volume of aerosol particles less than 2.5 µm in aerodynamic diameter at surface (measurement height) level

AOD – PM Relation

$$AOD(\lambda) = \int_{0}^{Top} \beta_{ext,p}(\lambda, z)\,dz$$

Top-of-Atmosphere

surface

$$C = \frac{4\rho r_e}{3Q} \times \frac{f_{PBL}}{H_{PBL}} \times AOD$$

- ρ – particle density
- Q – extinction coefficient

} **Composition**

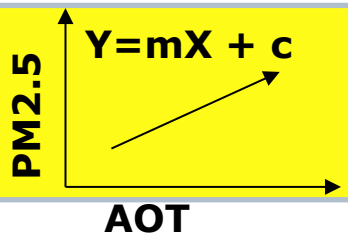
- r_e – effective radius ⟹ **Size distribution**
- f_{PBL} – % AOD in PBL
- H_{PBL} – mixing height

} **Vertical profile**

PM2.5 Estimation: Popular Methods

Difficulty Level

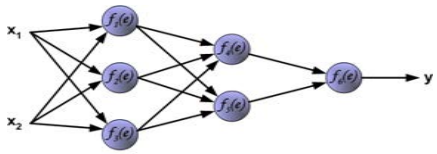
Two Variable Method



Multi-Variable Method

$$PM2.5 = \beta_0 + \alpha * \tau + \sum_{n=1}^{m} (\beta_n * M_n)$$

Artificial Intelligence



MSC

$$\text{Estimated } PM_{2.5} = \frac{\text{Model surface aerosol concentration}}{\text{Model AOD}} \times \text{Retrieved AOD}$$

and **Empirical Methods, Data Assimilation etc. are under utilized**

Simple Models from Early Days

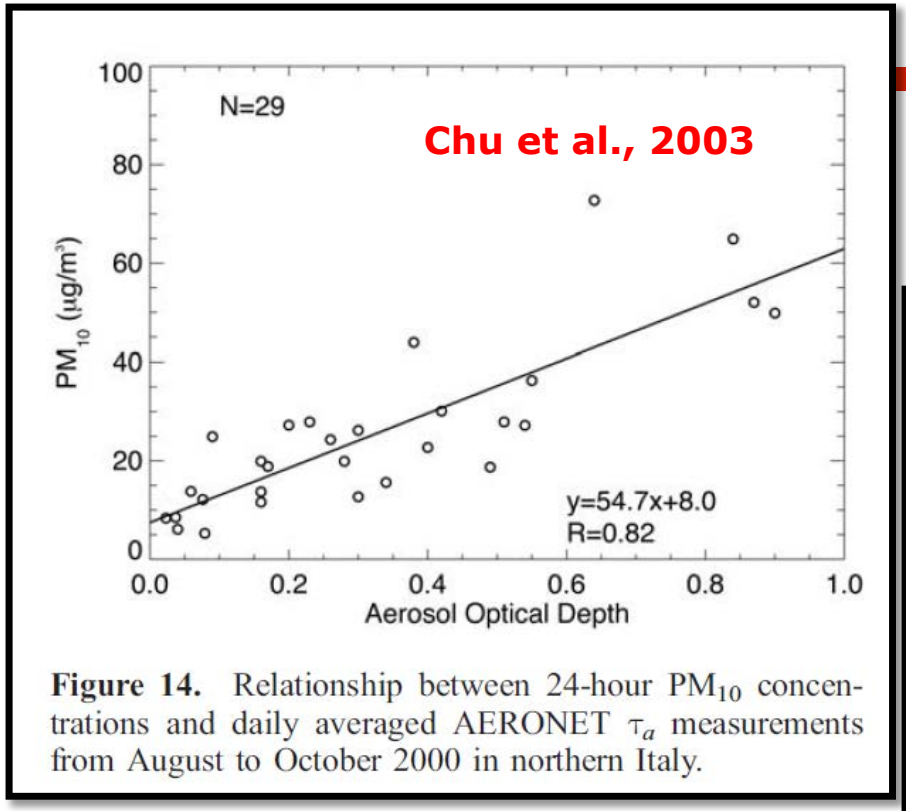
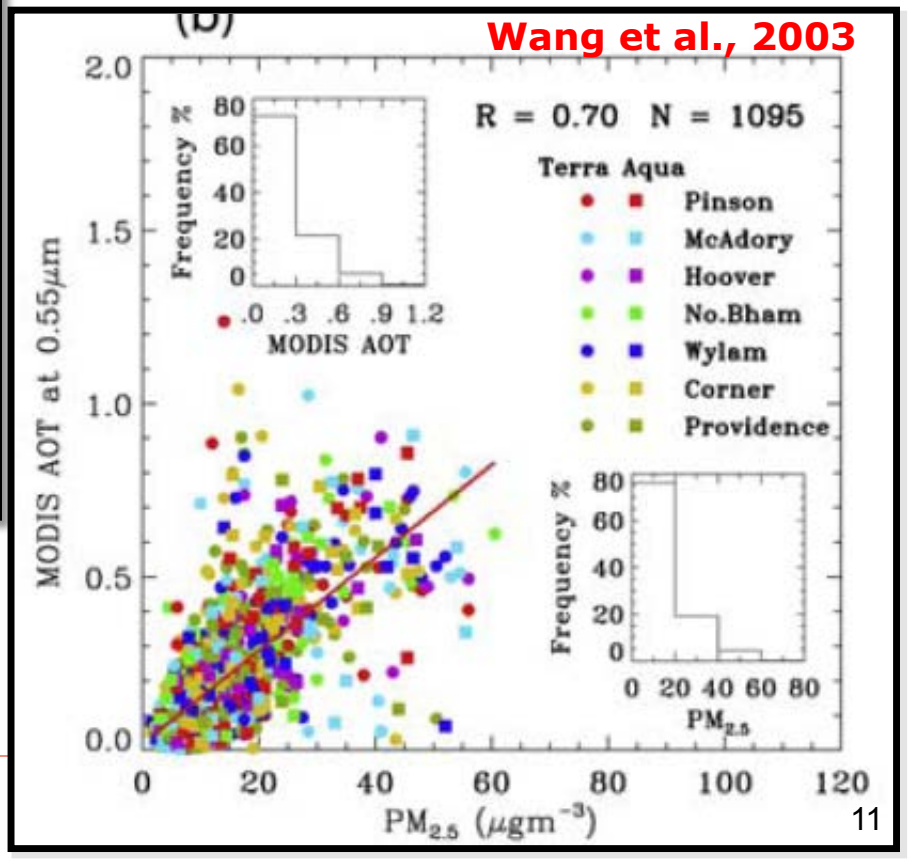
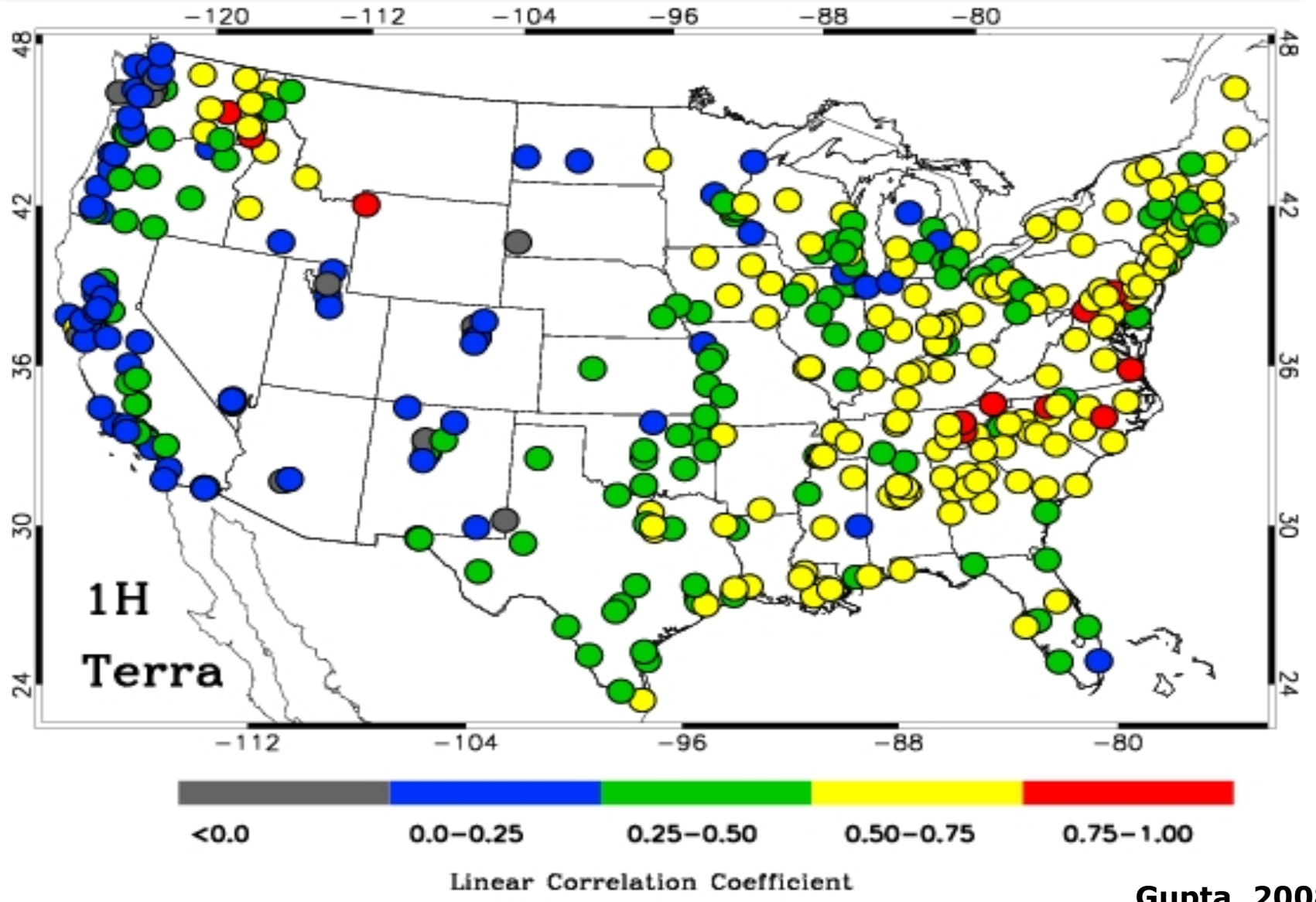


Figure 14. Relationship between 24-hour PM_{10} concentrations and daily averaged AERONET τ_a measurements from August to October 2000 in northern Italy.



AOT-PM2.5 Relationship

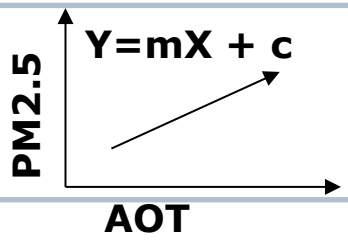


Gupta, 2008

PM2.5 Estimation: Popular Methods

Difficulty Level

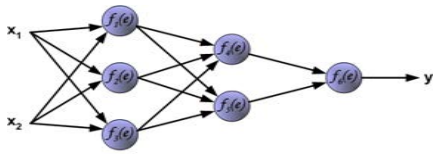
Two Variable Method



Multi-Variable Method

$$PM2.5 = \beta_0 + \alpha * \tau + \sum_{n=1}^{m} (\beta_n * M_n)$$

Artificial Neural Network



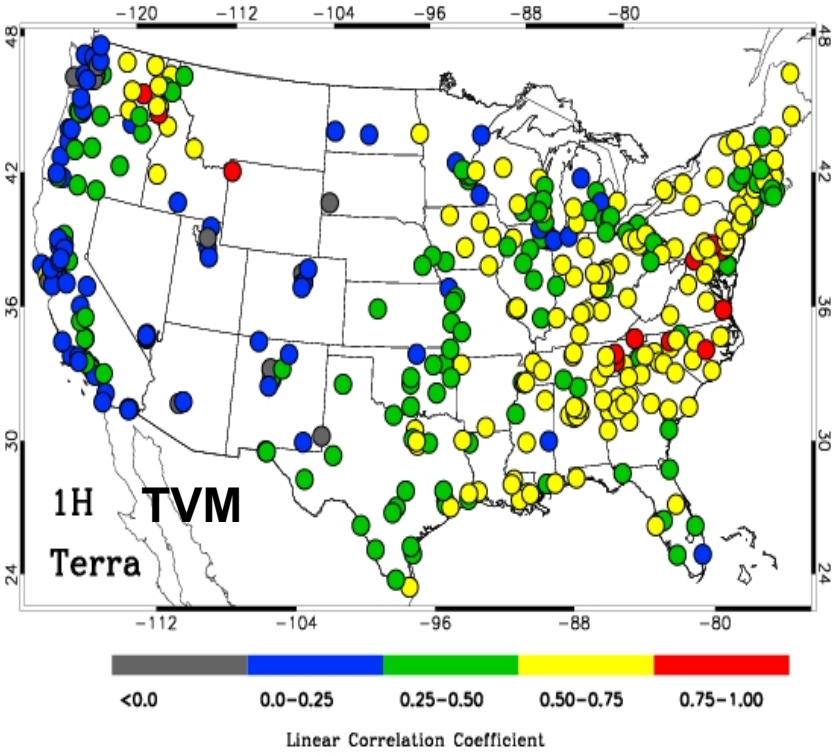
MSC

$$Estimated\ PM_{2.5} = \frac{Model\ surface\ aerosol\ concentration}{Model\ AOD} \times Retrieved\ AOD$$

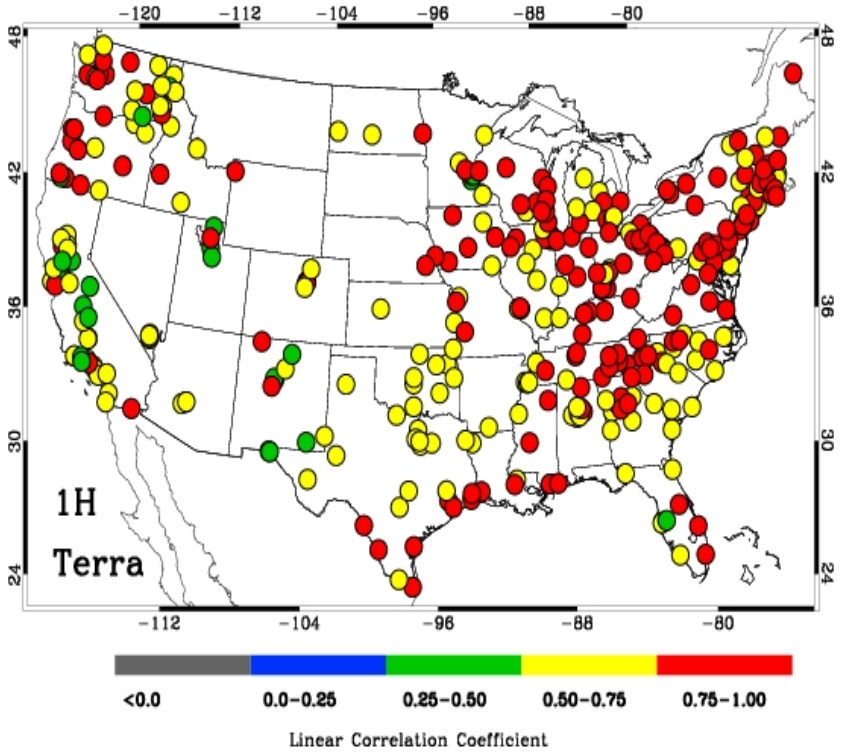
and Empirical Methods, Data Assimilation etc. are underutilized

Multi Variable Method

Predictor: AOD



Predictor: AOD + Meteorology

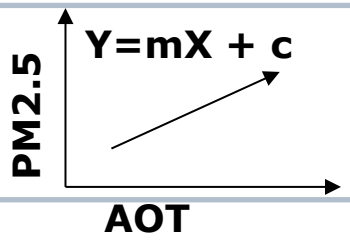


Linear Correlation Coefficient between observed and estimated PM2.5 Gupta, 2008

PM2.5 Estimation: Popular Methods

Difficulty Level

Two Variable Method



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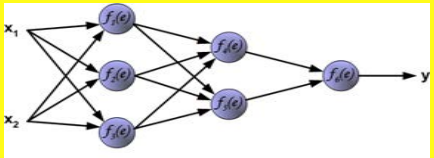
Artificial Neural Network

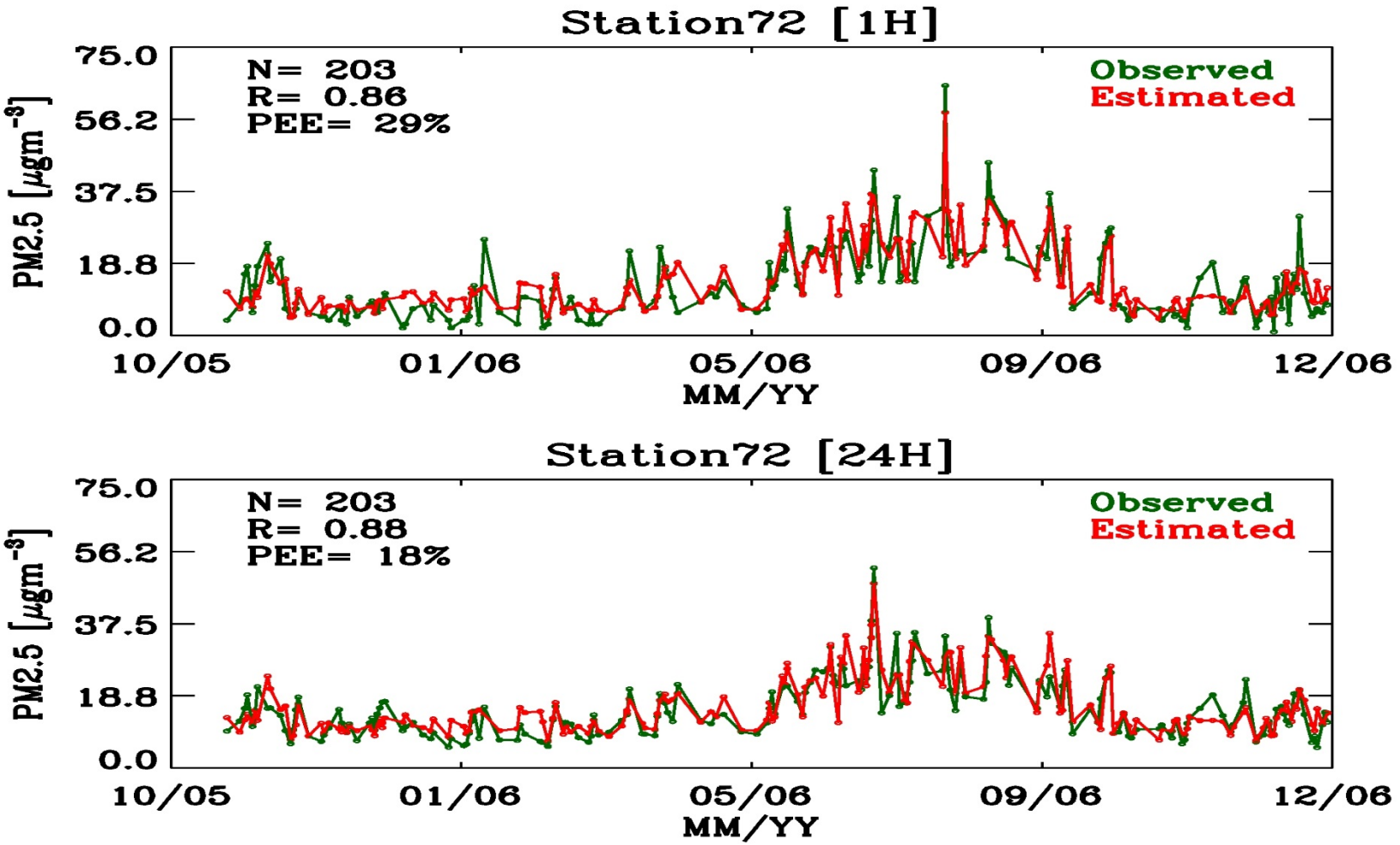


MSC

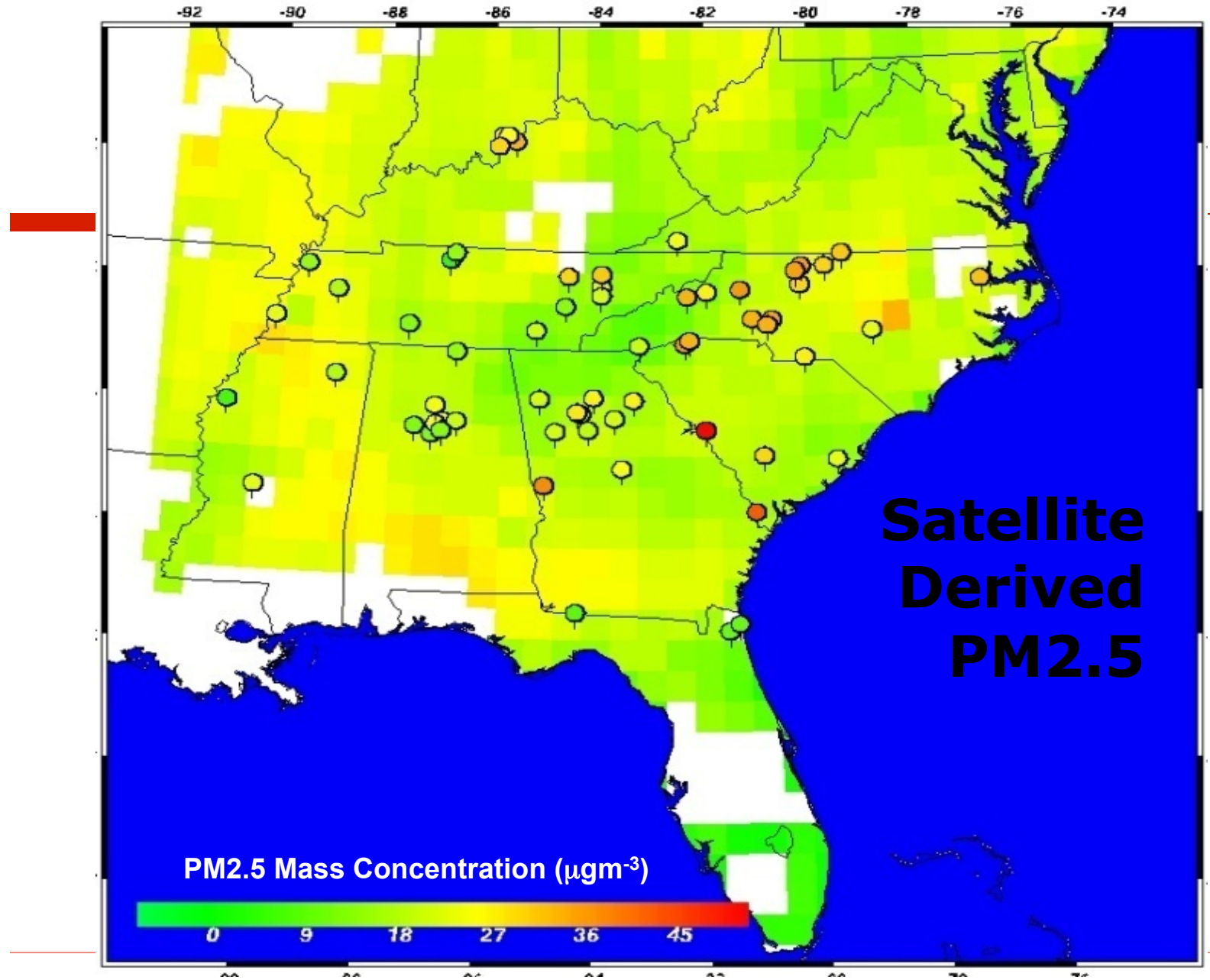
$$Estimated\ PM_{2.5} = \frac{Model\ surface\ aerosol\ concentration}{Model\ AOD} \times Retrieved\ AOD$$

and Empirical Methods, Data Assimilation etc. are underutilized

Time Series Examples of Results from ANN



Gupta et al., 2009



Gupta et al., 2009

PM2.5 Estimation: Popular Methods

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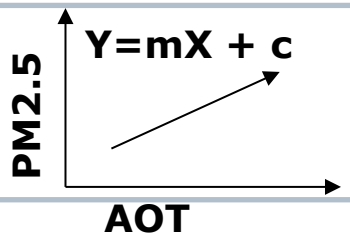

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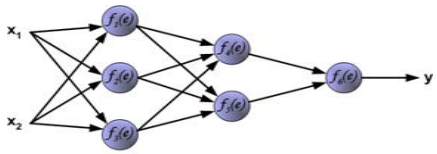
Artificial Neural Network



MSC

$$\text{Estimated } PM_{2.5} = \frac{\text{Model surface aerosol concentration}}{\text{Model AOD}} \times \text{Retrieved AOD}$$

and Empirical Methods, Data Assimilation etc. are underutilized

Questions to Ask: Issues

- ✓How accurate are these estimates?
- ✓Is the PM2.5-AOD relationship always linear?
- ✓How does AOD retrieval uncertainty affect estimation of air quality?
- ✓Does this relationship change in space and time?
- ✓Does this relationship change with aerosol type?
- ✓How does meteorology drive this relationship?
- ✓How does the vertical distribution of aerosols in the atmosphere affect these estimates?

The Use of Satellite Data

- Currently for research
  - Spatial trends of $PM_{2.5}$ at regional to national level
  - Interannual variability of $PM_{2.5}$
  - Model calibration / validation
  - Exposure assessment for health effect studies
- In the near future for research
  - Spatial trends at urban scale
  - Improved coverage and accuracy
  - Fused statistical – deterministic models
- For regulation?

Tradeoffs and Limitations

- Spatial resolution – varies from sensor to sensor and parameter to parameter
- Temporal resolution – depends on satellite orbits (polar vs geostationary), swath width etc.
- Retrieval accuracies – varies with sensors and regions
- Calibration
- Data Format, Data version
- Etc.

No textbook solution!

2009 CRITICAL REVIEW

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DOI:10.3155/1047-3289.59.6.
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R.M. Hoff S.A. Christopher

Remote Sensing of Particulate Pollution from Space: Ha Promised Land

Raymond M. Hoff
Department of Physics and the Joint Center for Earth Systems Tec and Technology Center, University of Maryland
th Sciences

Sundar A.

IMPLICATIONS

Satellite measurements are going to be an integral part of the Global Earth Observing System of Systems. Satellite measurements by themselves have a role in air quality studies but cannot stand alone as an observing system. Data assimilation of satellite and ground-based measurements into forecast models has synergy that aids all of these air quality tools.

The use of the AOD as a measure for mass concentration has skill in some regions but less in others and does not provide a uniform way to measure aerosols across the United States. We discussed in Table 4 the range of mea-

dards (NAAQS).[142] The 39-yr history of those standards parallels the time period that satellite meteorology and observations have developed and yet, to date, no satellite measurements have been used to quantitatively address the NAAQS. From the review conducted here, only one congres-

EPA has taken a satellite observations role for itself in the Exceptional Events Rule.[144] If a region can show conclusively that they are being impacted by an event (a fire, a dust storm, etc.) that is outside of their jurisdiction to regulate, the event can be flagged as a nonexceedance event. This provides a significant motivation for regional

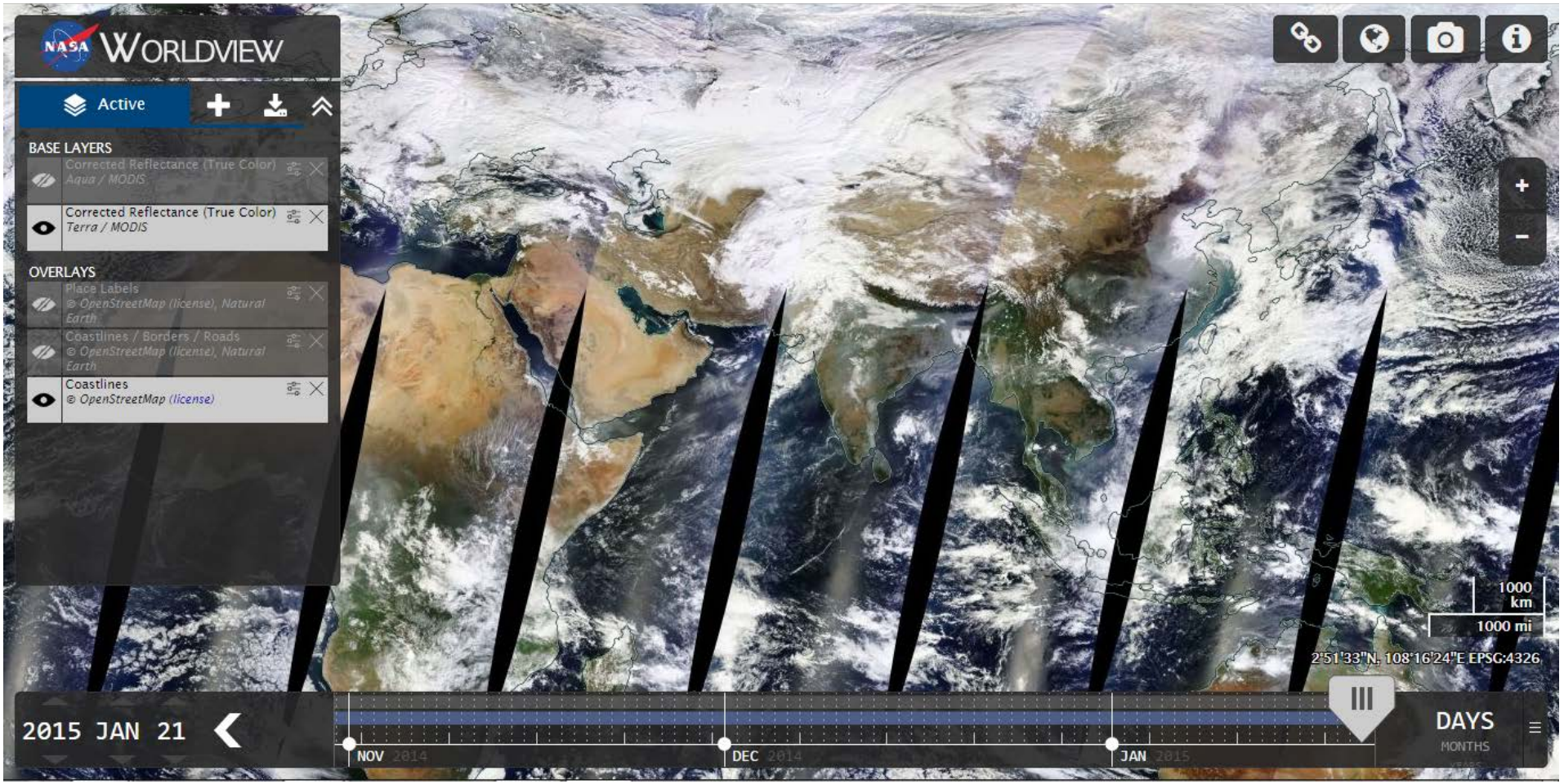
ellite data possible in significant exceedances only. Applications such as event identification, transport, and atmospheric composition determination are strengths of satellite measurements. Where high precision is required (compliance monitoring, the "but for" test, and quantitative measurement of visibility effects on Class I areas), satellite data are presently of limited utility.

Although the desire for the use of satellite data for air quality purposes is widely stated, the reality is that many of the measurements have not yet met the promise that they can be operationally used for today's air quality monitoring requirements. Precision in measuring AOD is

Suggested Reading

NASA's Worldview

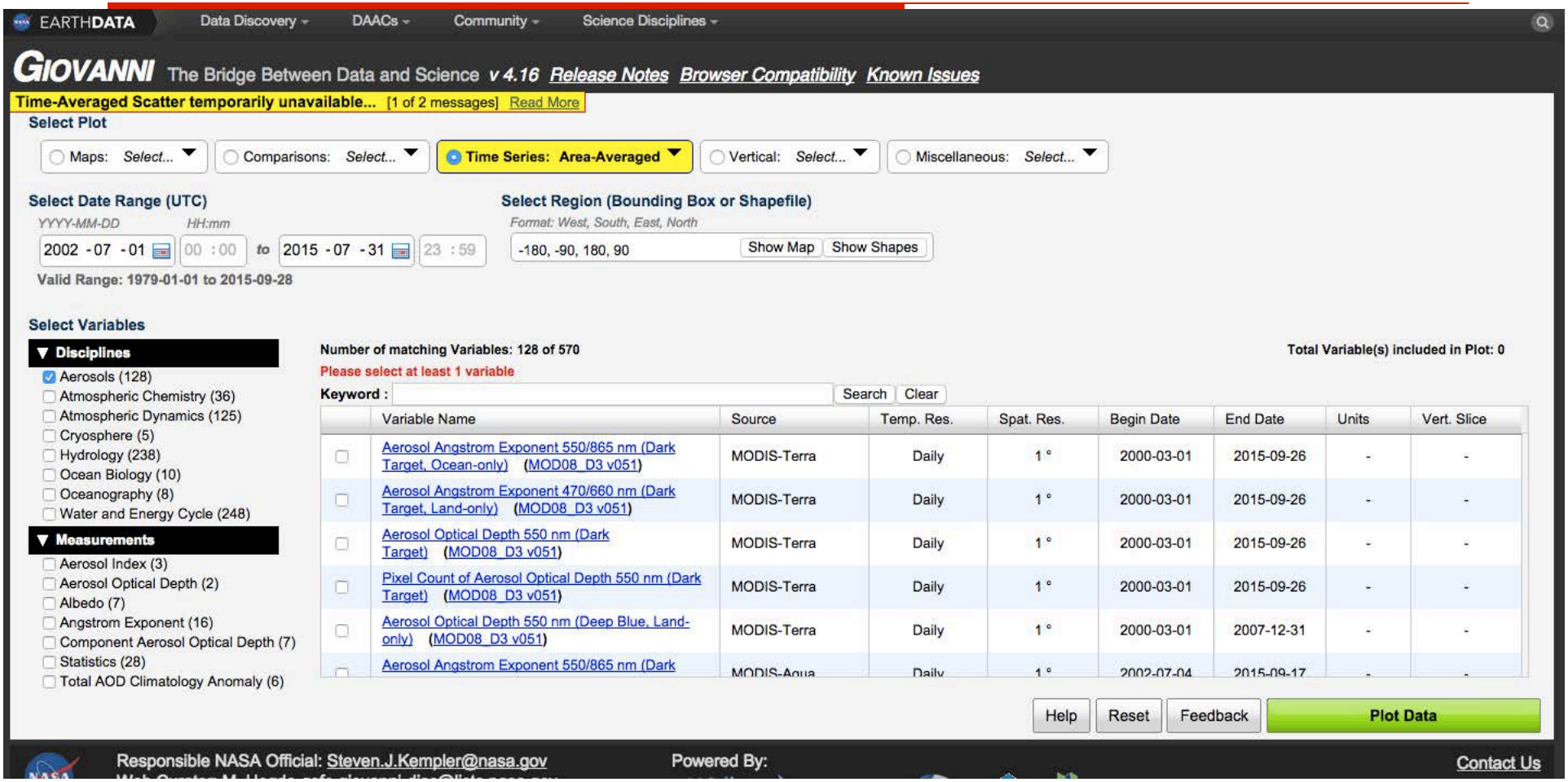
(https://earthdata.nasa.gov/labs/worldview/)



Visualization tool for near real time satellite observations

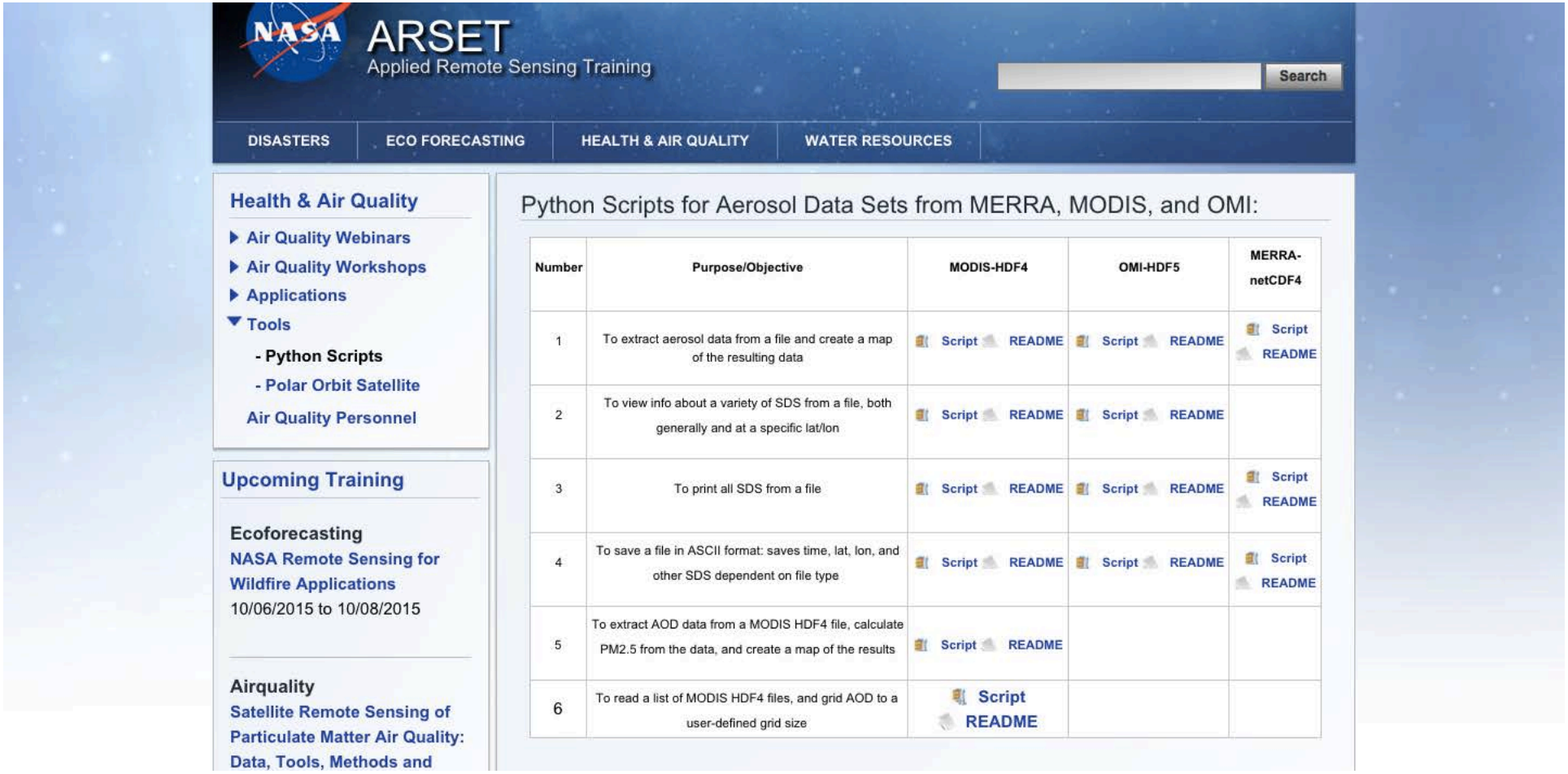
GIOVANNI

(Visualization and Analysis of Level 3 Satellite Products)



http://giovanni.sci.gsfc.nasa.gov/

Python Tools



ARSET
Applied Remote Sensing Training

Search

DISASTERS | ECO FORECASTING | HEALTH & AIR QUALITY | WATER RESOURCES

Health & Air Quality

- Air Quality Webinars
- Air Quality Workshops
- Applications
- Tools
  - **- Python Scripts**
  - - Polar Orbit Satellite
- Air Quality Personnel

Upcoming Training

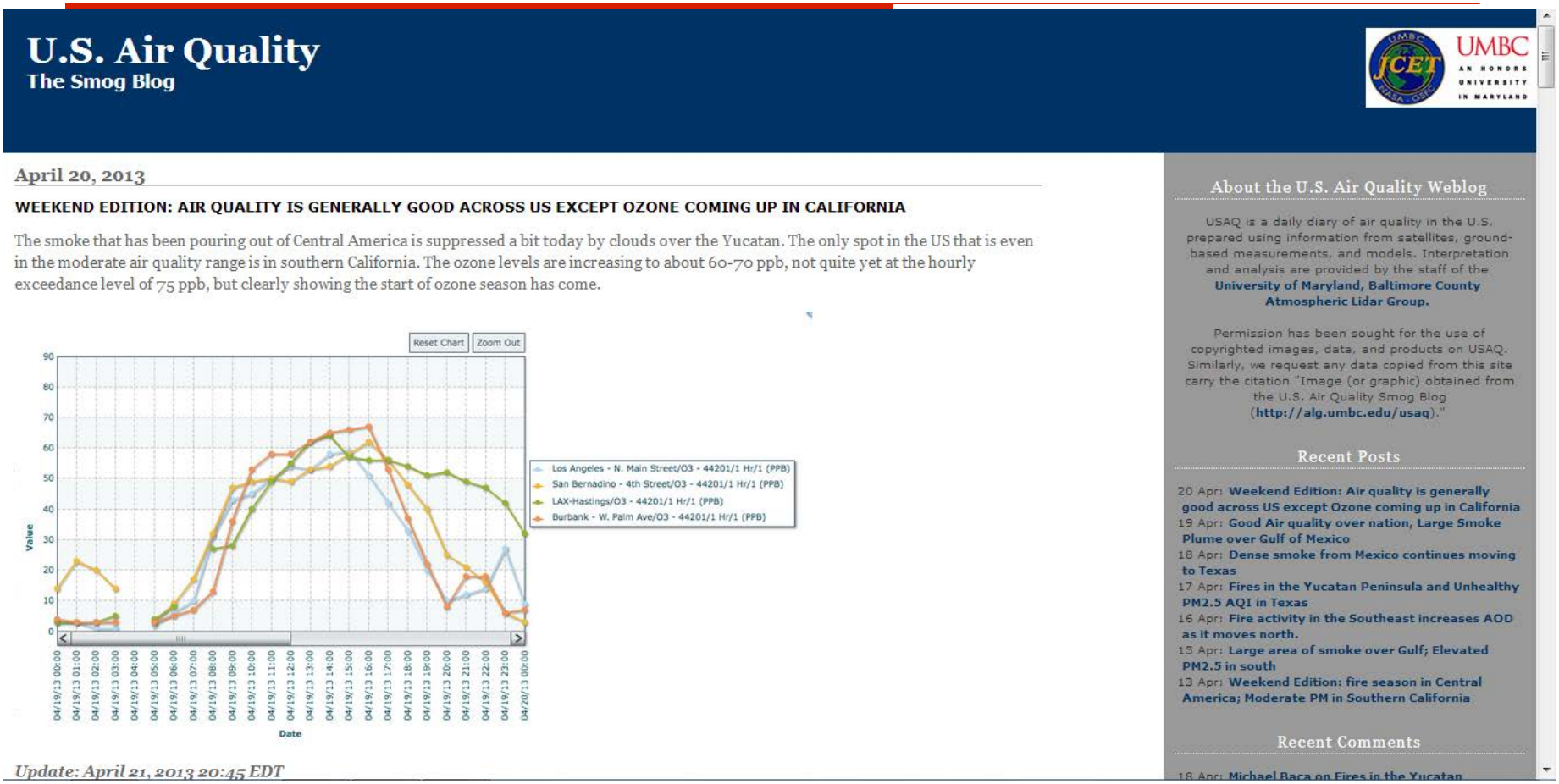
Ecoforecasting
NASA Remote Sensing for Wildfire Applications
10/06/2015 to 10/08/2015

Airquality
Satellite Remote Sensing of Particulate Matter Air Quality: Data, Tools, Methods and

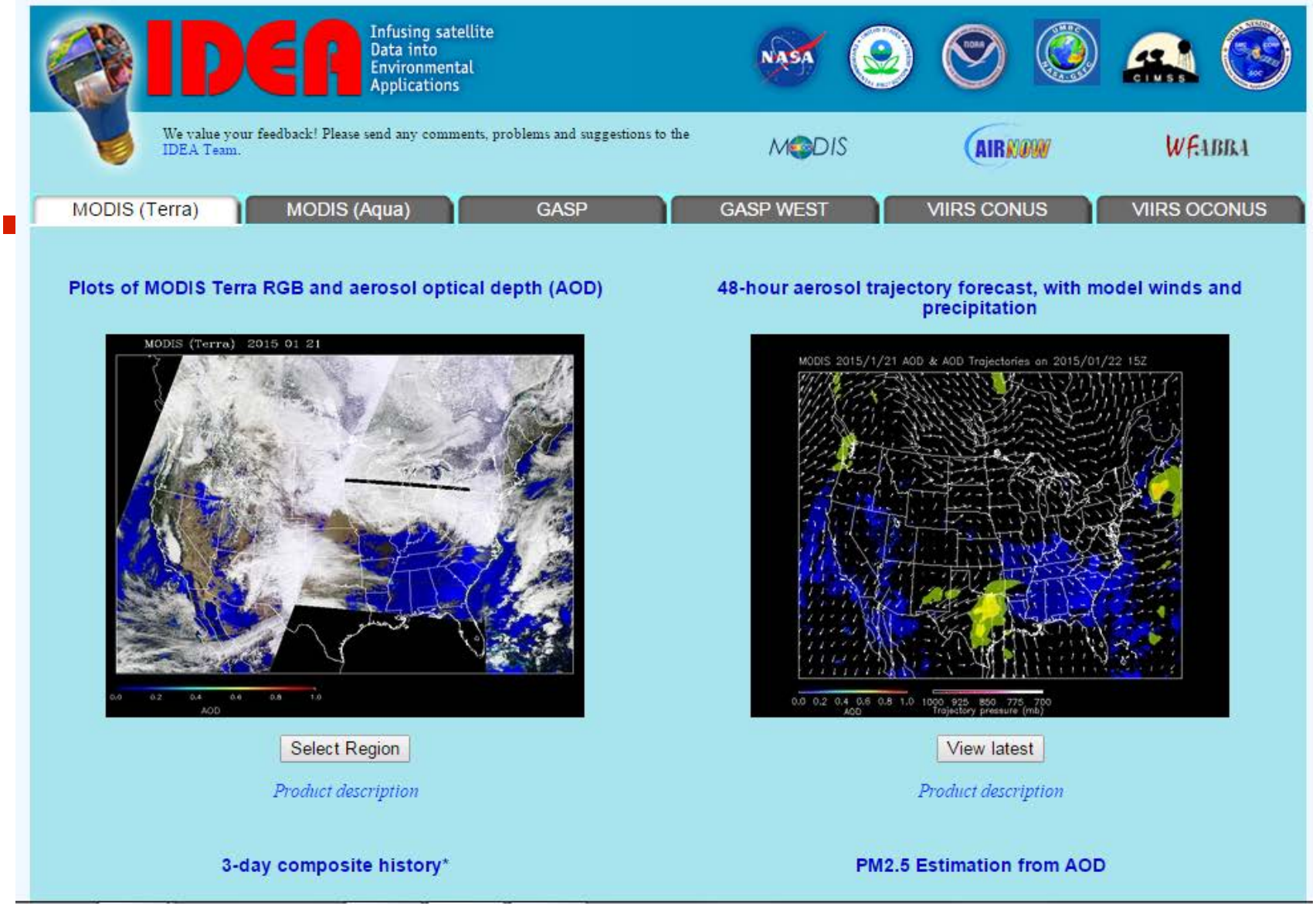
Python Scripts for Aerosol Data Sets from MERRA, MODIS, and OMI:

Number	Purpose/Objective	MODIS-HDF4	OMI-HDF5	MERRA-netCDF4
1	To extract aerosol data from a file and create a map of the resulting data	Script README	Script README	Script README
2	To view info about a variety of SDS from a file, both generally and at a specific lat/lon	Script README	Script README	
3	To print all SDS from a file	Script README	Script README	Script README
4	To save a file in ASCII format: saves time, lat, lon, and other SDS dependent on file type	Script README	Script README	Script README
5	To extract AOD data from a MODIS HDF4 file, calculate PM2.5 from the data, and create a map of the results	Script README		
6	To read a list of MODIS HDF4 files, and grid AOD to a user-defined grid size	Script README		

Some online tools



http://alg.umbc.edu/usaq/



Data are only available for US region

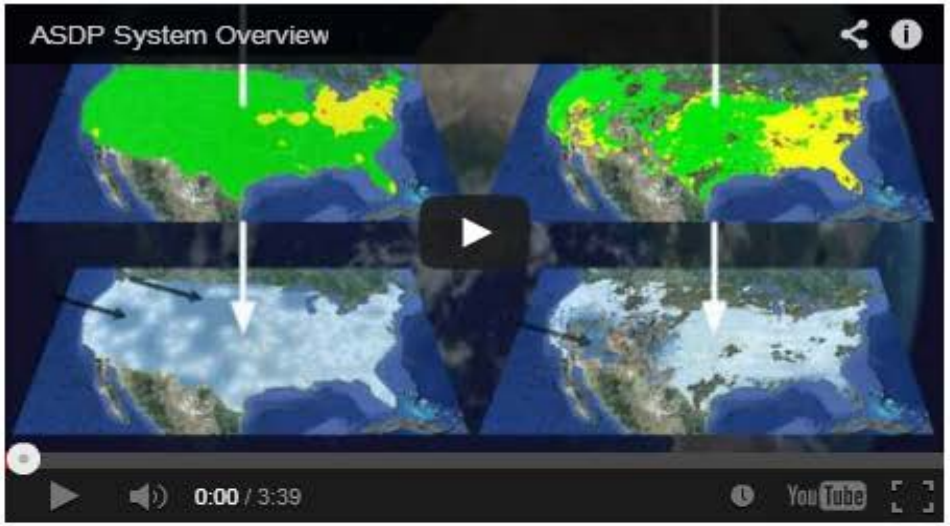
http://www.star.nesdis.noaa.gov/smcd/spb/aq/

AIRNow Satellite Data Processor

The AIRNow Satellite Data Processor (ASDP) is a system under development that enables blending (or fusing) of surface $PM_{2.5}$ measurements and satellite-estimated $PM_{2.5}$ concentrations to provide additional air quality information to AIRNow in regions without existing surface air quality monitoring networks.

The ASDP system builds the capacity and framework necessary to implement satellite data as these data become available to the air quality community. This project is being funded by the NASA Applied Sciences Program.

Log In to Learn More



airnowtech.org

Data are only available for US region

Air Quality Mini Project

(http://arset.gsfc.nasa.gov/sites/default/files/airquality/webinars/AOD_PM/Webinar_MiniProject_Guidelines_forwebpage.pdf)

Important Dates:

- **October 15, 2015: Project Title, Team Members, and other Details are Due. Enter Your Project Information** (Information can be entered before the deadline)
- **November 10, 2015: Project Presentation (not more than 5 slides) due.**
- **More information on the project submission will be available close to the deadline.**
- **November 20, 2015: Project Presentation – more details will follow soon.**

Air Quality Mini Project

- **Disclaimer: All projects suggested or completed as part of this webinar series are *exclusively for the purpose of learning* and may not be used for publications, reports or any kind of official document, presentation, or paper. NASA ARSET is not responsible for providing any kind of formal review of the research conducted as part of this webinar project.**

- **Participants are encouraged to work on this project as a team of 2-10 people but it is not mandatory and you can work individually as well. NASA-ARSET program will not assist in forming and managing project teams.**

Air Quality Mini Project

- **All projects must have a satellite component. Participants are highly encouraged to use data, tools, and methods covered during this webinar series. Previously done projects and research cannot be submitted.**

Air Quality Mini Project – Suggested Topics

- **PM2.5 Estimation using Satellite Data:** Estimate PM2.5 over a certain region or place using satellite, surface and model data sets. You can use any method (or methods) to make your estimations, and can use your own PM2.5 data or download some from SPARTAN/ AirNow networks or other sources. Please see the suggested resources and tools section for further details.

- **Long Term Trend Analysis:** Perform long-term air quality trend analysis over a certain region or place using satellite observations, while supporting results with surface measurements. Regional trends can be performed using level 3 satellite data sets as long as errors and uncertainties involved are known and discussed.

- **Transport of smoke, dust, and/or volcanic emissions:** Perform a case study analysis of certain air quality event in the region of interest. Analyze the impact of smoke or dust transport on the local and regional air quality using multiple data sets, tools and models.

- **Your own project:** This air quality project is not limited to topics suggested above. If you have other ideas, you are more than welcome to define your own project.

Home Work – Week 2

Perform time series analysis of aerosol optical depth using MODIS L3 monthly mean data over selected region of 5x5 degree. Analysis is performed using GIOVANNI and EXCEL.

http://goo.gl/forms/KUzkGollso