U.S. Environmental Protection Agency - future use of GOES-R in air quality assessments

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5th GOES-R User Conference AMS
88th Annual Meeting
New Orleans, LA
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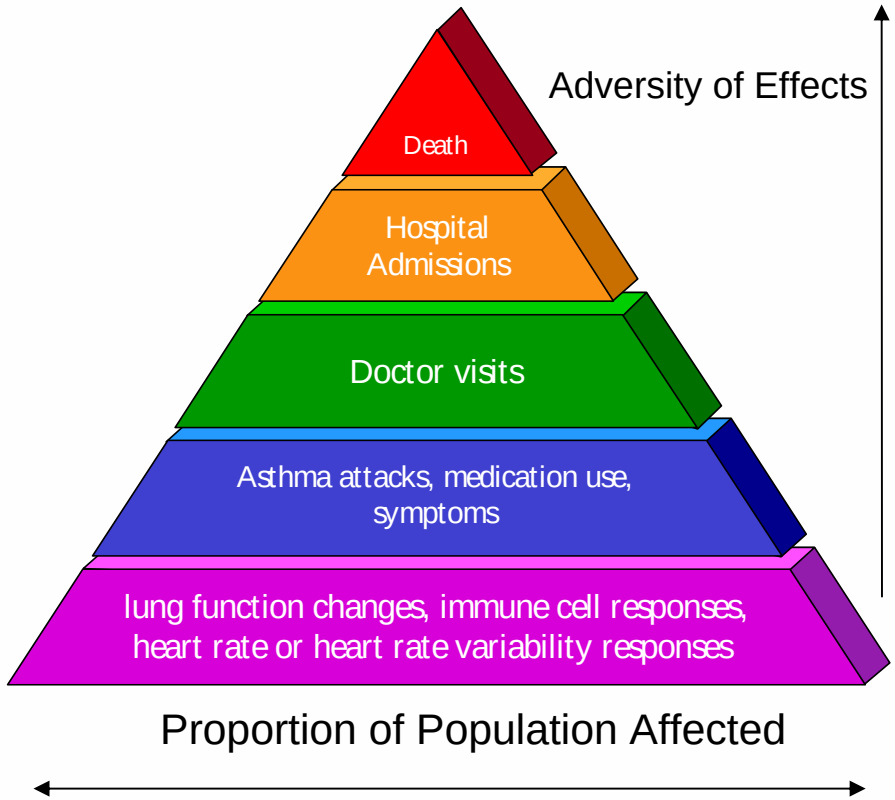
U.S. Environmental Protection Agency - future use of GOES-R in air quality assessments

Outline Talk

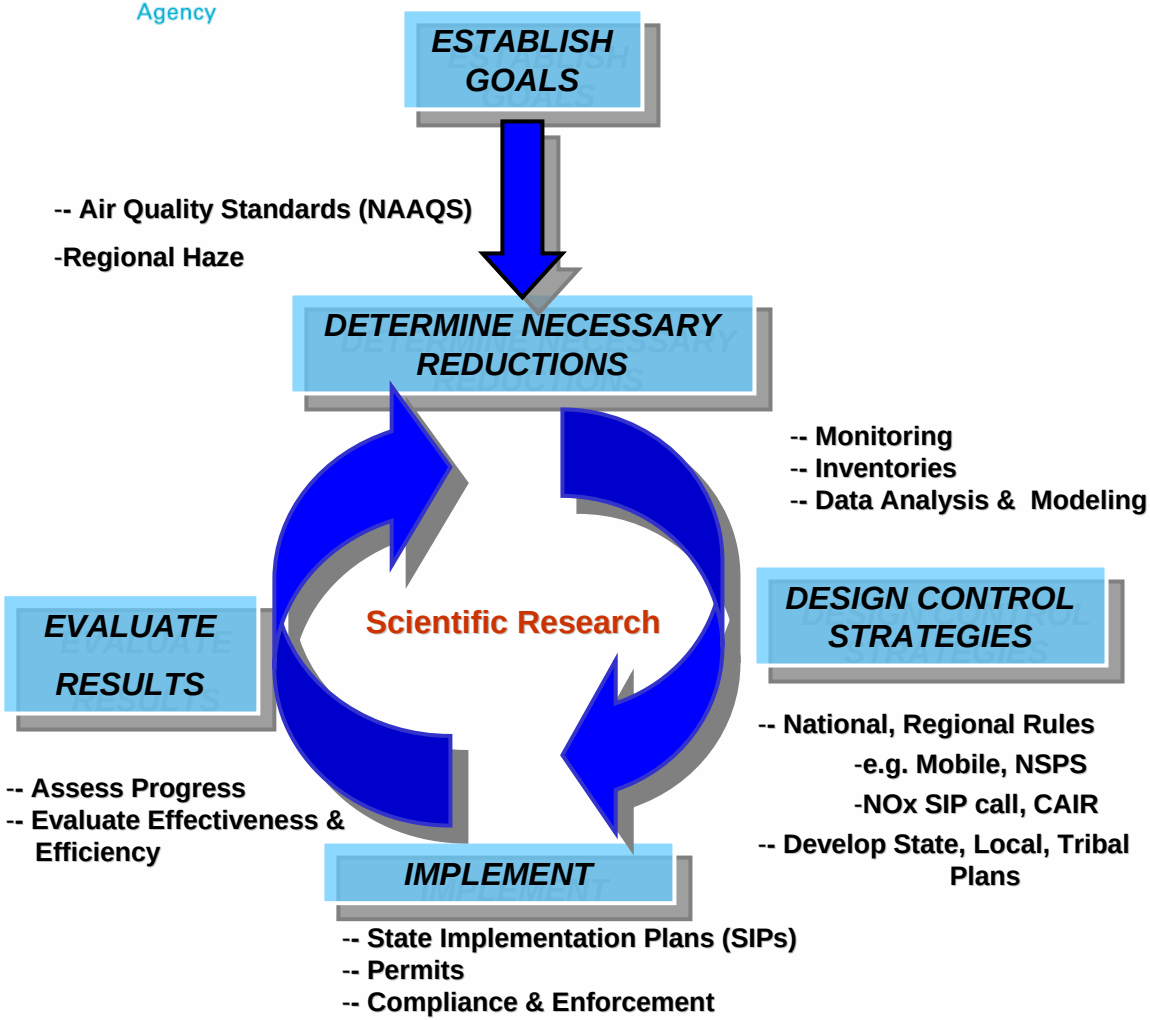
- Air Quality Standards/Societal Impact
- Planned uses of GOES-R data (MODIS used at primary proxy dataset)
  - Fire Characterization
    - Detection and Biomass Burning Emission Estimates
  - Aerosol Optical Depth
    - $PM_{2.5}$ forecasting
    - $PM_{2.5}$ monitoring/trends
    - Aerosol assimilation into CMAQ

Science Driver for Ozone and Aerosols are the Health Based Standards

- Annual PM2.5 (1997)
  - Form: Annual Arithmetic Mean
  - Level: 15.0 ug/m3
- 24-hr PM2.5 (2006)
  - Form: 98th percentile
  - Level= 35 ug/m3
- 8-hr O3 (1997)
  - Form: 4th daily max
  - Level =0.08 ppm
- (proposed 2007)
  - Considering level as low 0.06 ppm



The Air Quality Management Process



- **Impacts of Poor Air Quality on Society**
  - 106 million+ people in the US live in areas with poor air quality[+]
  - $143 Billion Cost per annual (mean)**
- **Aerosols ($PM_{2.5}$): Human Health Impacts**
    - cardiovascular disease,
    - respiratory diseases, and
    - cancer
  - Reduce visibility
  - Impacts Climate
- **Ozone: Human Health Impacts**
    - irritate to respiratory system
    - reduce lung function
    - inflammation and damage cells that line lungs
    - aggravate asthma and chronic lung diseases

[+] USEPA 2006; **American Lung Assoc. 2001

U.S. EPA Participating in GOES-R Program as a User

- GOES-R will provide improved operational AQ related products.
  - MODIS like aerosol and fire products.
  - Traces gas –Total column O3, limited applicability for air quality.
- GOES-R will help with temporal resolution for air quality aerosol needs, but no sounder will limit use of any trace gas products.

GOES-R Sensor	Bands	Product
ABI	0.47µm, 0.68µm, 2.1µm	Aerosol optical depth, type (dust vs non dust), and particle size (effective radius) Fraction of fine mode vs coarse mode
ABI	9.6µm	Total column ozone
ABI	3.9µm, 11µm	Fire location, size and intensity Carbon consumption Aerosol and trace gas emissions
ABI	11µm, 12µm	Dust detection

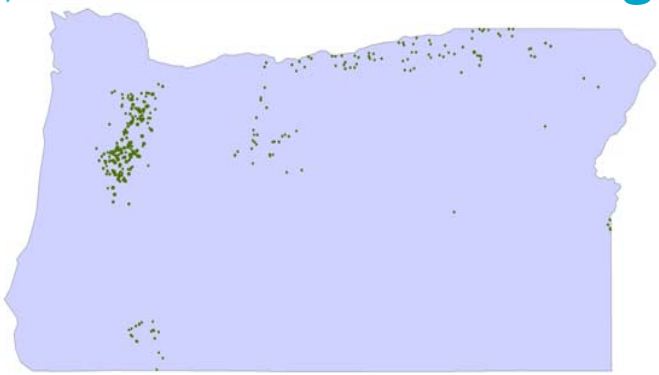
USEPA Program Needs for Biomass Burning Emissions

- **AQ Management of PM2.5, Ozone & HAPs**
  - PM & O_3 NAAQS ~ 24 hr (or less) averaging time
  - Some HAPS (e.g., acrolein) associated with short term exposures
- **Forecasting**
  - Fire impacts ~ consideration in AirNow forecasts
- **Fire emissions needed for both**
  - 20% of PM2.5 in 48-State EI
  - VOC, NOx important to Ozone formation
  - Selected HAPs also important

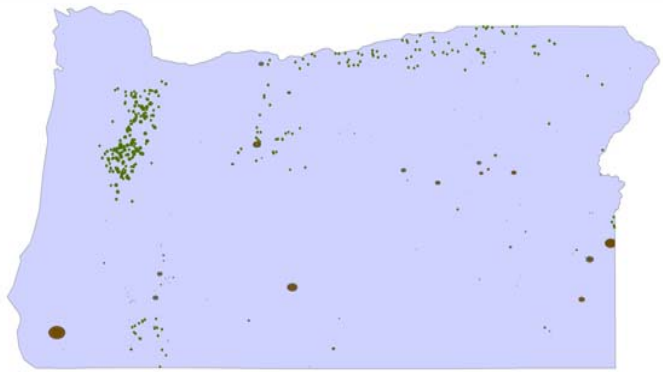
A Brief History of Fire Emissions Tracking by EPA

- Prior to 2002 fire year, fire emissions relied on rudimentary allocation of USFS/DOI ground-based report of fires (many fires missing or mis-characterized)
- 2002 ~ QA & gap-filling was done on a 1-time basis at cost > $1M
- Daily, spatially resolved fire emissions data is a continuing need – not just for 2002
  - Cost effective method needed
- 2003-2006 Fire Emission Inventories being prepared now using NOAA-HMS fire activity data to generate emissions in SmartFire.

Spatial coincidence in satellite- and ground-based fire data

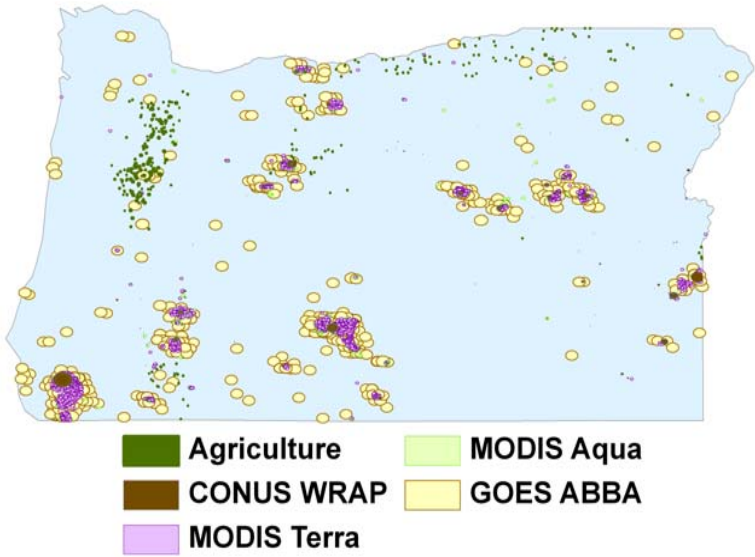


Agriculture Only



Agricultural, State, Federal and Private Ground-based Fire Data

Satellite- and Ground-based Fire Data



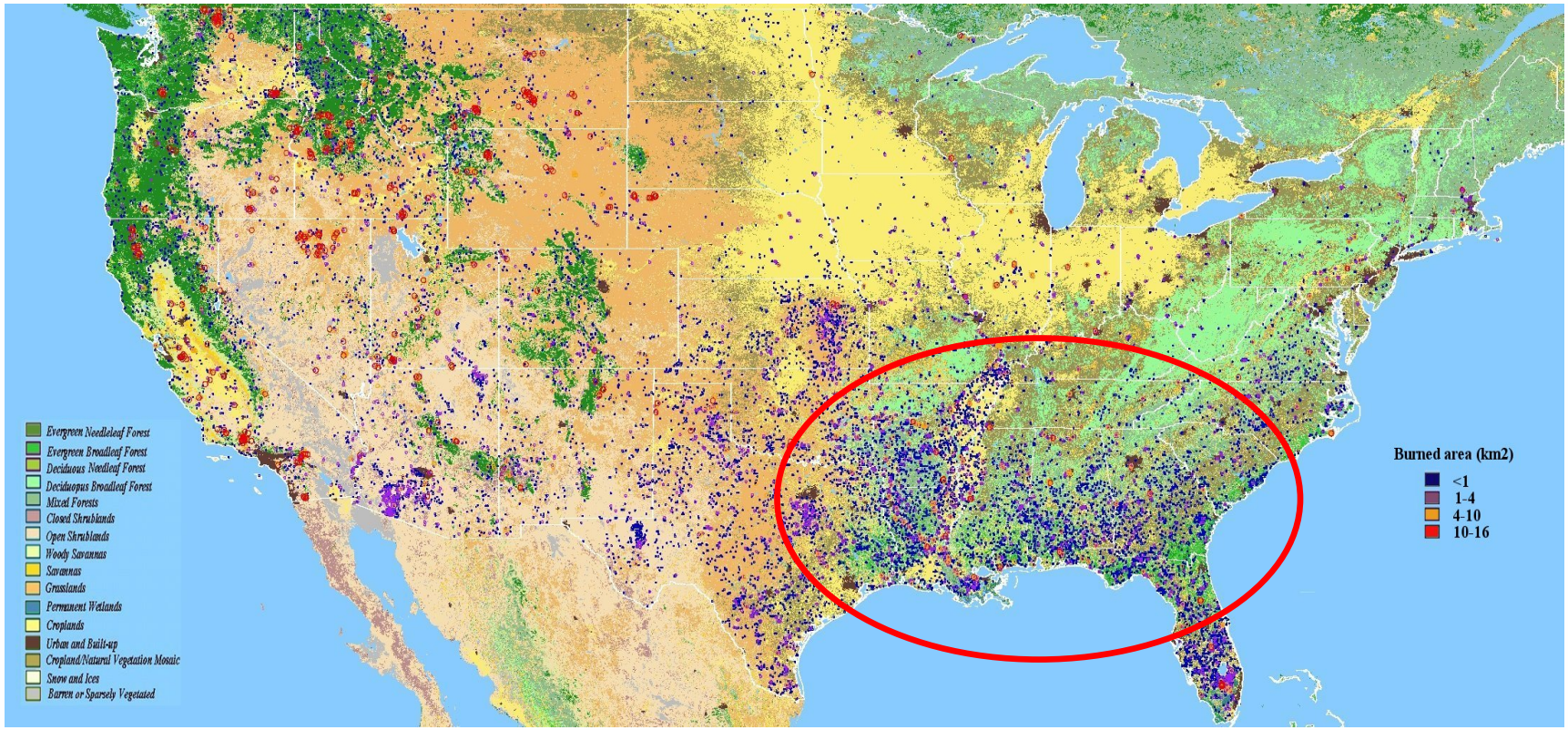
GOES WF-ABBA fire detections appear to capture smaller agriculture fires. Oregon, July 2002

Soja et. al., 2007 16th EPA Emission Inventory Conference

Data source	Number of records	Non – Ag acres burned (range)	% area burned all grnd. data, % area non-ag % area ag	% # all fires coincident % # non-ag % # ag
GOES ABBA [Agric. Fires]	1996	197,655 (1.16 – 806.66)	37%, 32% (Instantaneous) [20% Ag area]	34 % 34 % [34 %]
MODIS Terra [Agric. Fires]	2761	682,268 (from detections)	126%, 131% (detect = 1km^2) [10% Ag area]	10 % 37 % [< 2 %]
MODIS Aqua [Agric. Fires]	1984	350,643 (from detections)	94%, 98% (detect = 1km^2) [10% Ag area]	12 % 43 % [< 2 %]
Oregon ground, 101 fires, mean 1691 acres [Agric. Fires] mean 69 acres	296 [312]	500,555 (1.98 – 54400.5) [21,570 Agric. acres]	All satellites, all area 181% Combined representative satellite area 97%	Combined satellite, all fires 53 % [41 %]

Soja et. al., 2007 16th EPA Emission Inventory Conference

GOES-derived Burn Area over MODIS Land Cover Map



While wildfires dominate total biomass burning emissions significant agricultural burning in the South East US will likely require use of sub-pixel characterization to get accurate emission estimates.

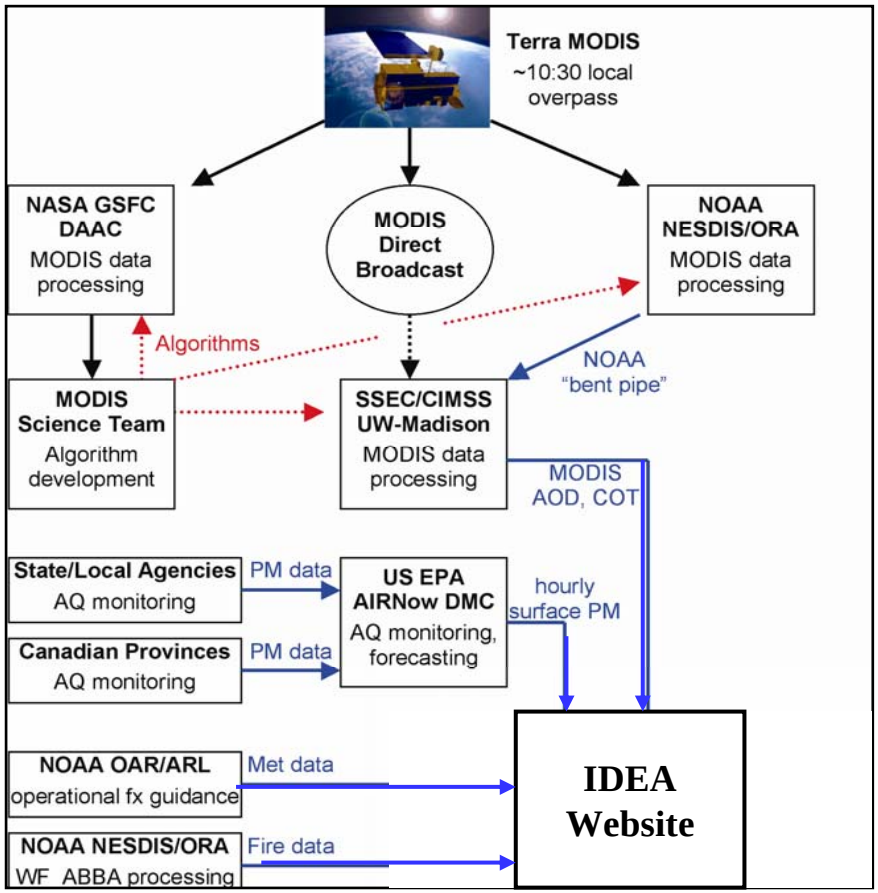
Zhang and Kondragunta, RSE, 2008, (in review)

US EPA Program Needs for GOES-R

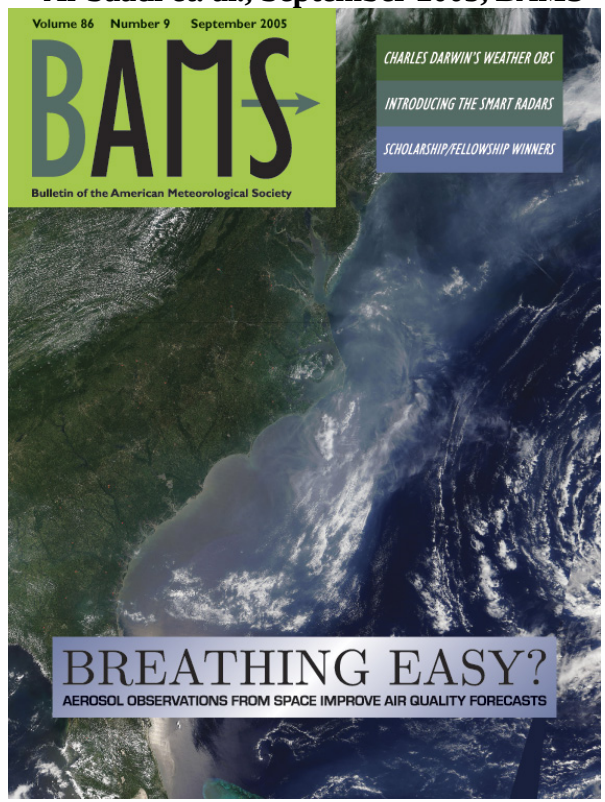
- US EPA is now using satellite fire detection within the Fire Emission Inventory.
- US EPA looks for the GOES-R Program to continued support of improved fire characterization capabilities:
  - Characterization of fire size (sub-pixel) and temperature
  - Fire radiated power (FRP)

Infusing satellite Data into Environmental Applications (IDEA)

A joint NASA-NOAA-EPA initiative: - Prototype a near-real-time MODIS trajectory forecast product using MODIS direct broadcast aerosol optical depth over CONUS.



Al-Saadi et. al., September 2005, *BAMS*



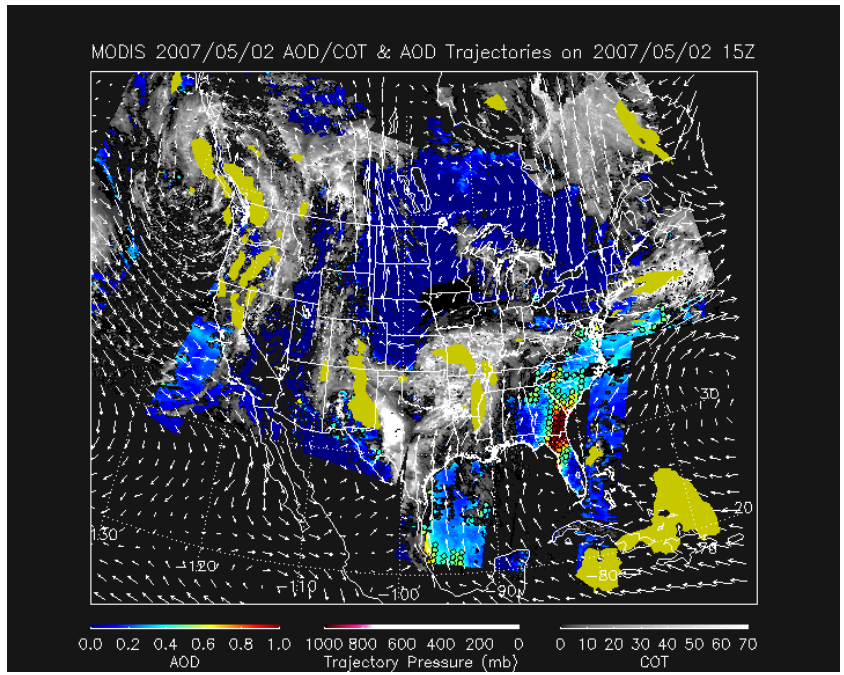
MODIS AOD shows strong correlations with PM2.5 mass concentrations during large scale aerosol events (US EPA, 2003 and Al-Saadi, J. et.al., 2005). MODIS AOD estimate correct AQI level >90% (regional AL study) (Wang, J., S. Christopher, 2003). Plus many other studies since

Infusing satellite Data into Environmental Applications (IDEA)

United States Environmental Protection Agency

- **A joint NASA-NOAA-EPA initiative that is GEOSS relevant.**
- **Provides forecast guidance for surface air quality (PM2.5)**
  - Dust storms
  - Smoke from forest fires
  - Urban/industrial haze
- **Trajectories are initialized at locations with aerosol optical depth > 0.4 at 50, 100, 150, and 200mb and run using 12Z NOAA/NCEP NAM forecast data providing 48 hr forecast**
- **System requirements**
  - Direct broadcast receiving station for satellite data
  - Trajectory model
  - Regional meteorological forecast model output
  - Algorithms to derive aerosol optical depth or related parameters
  - Surface mass aerosol monitors
- **System flexibility**
  - Easily adaptable to other regions of the globe
  - Easy to modify to input other satellite data

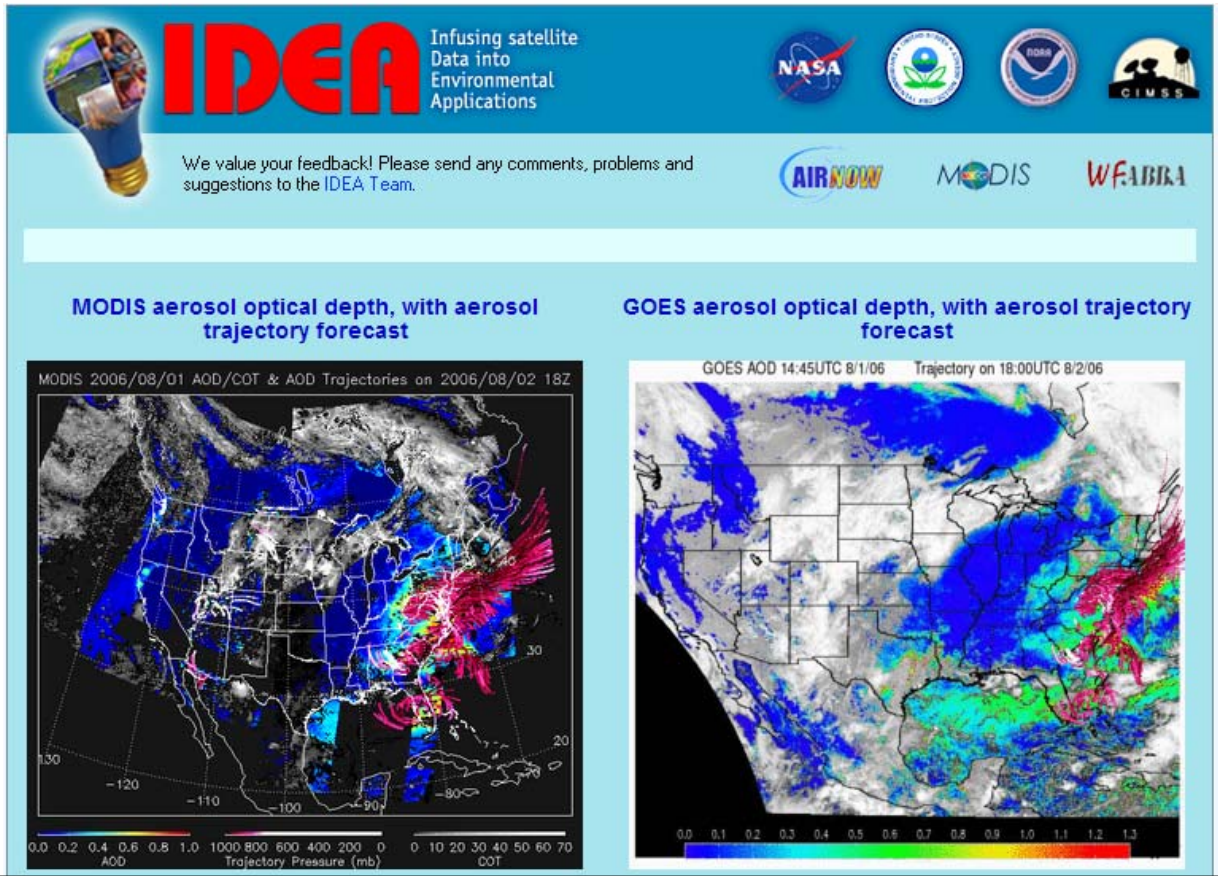
Forecast Product for May 2, 2007



48-hr trajectory forecast initialized with satellite (MODIS) observations of Aerosol Optical Depth. Pink color in the forecast trajectories indicates pollution will be closer to the ground

IDEA Enhancements

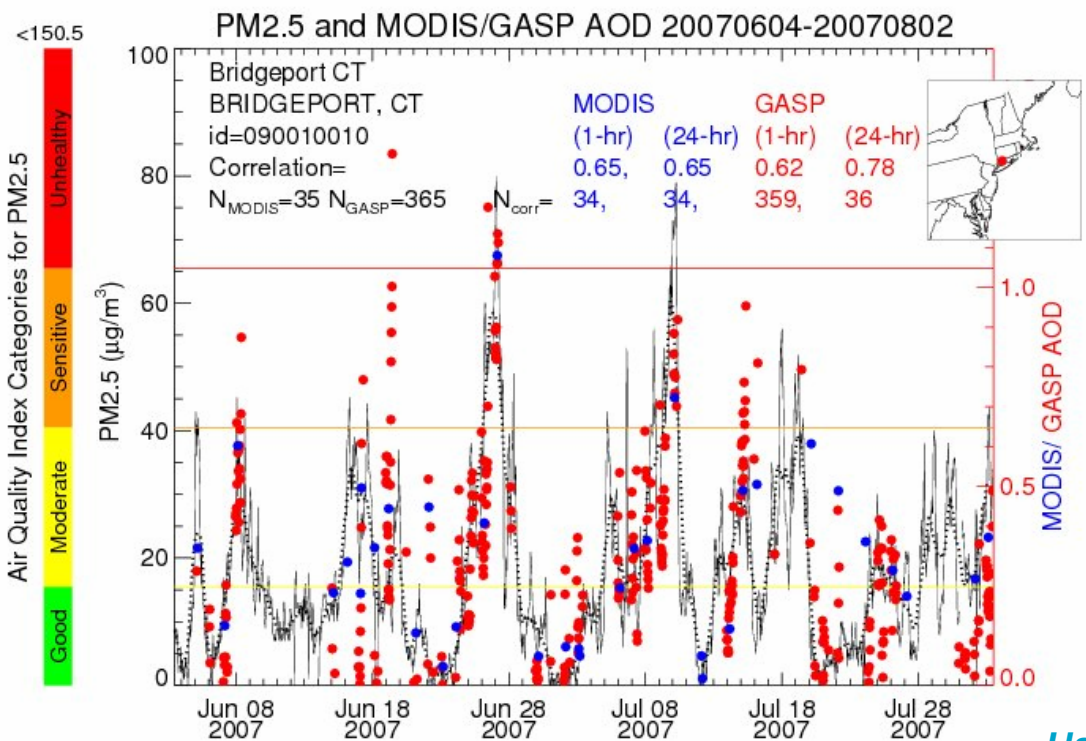
- Transition IDEA from CIMSS to NOAA/NESDIS.
- Add half-hourly geostationary aerosol optical depth retrievals to provide better time resolution of aerosols.



Joint NOAA-UMBC effort to enhance IDEA with GOES AOD. Figure above compares IDEA with MODIS AOD (left panel) to IDEA with GOES AOD (right panel)

IDEA Product Enhancement in the GOES-R Era

Time-series and correlations of MODIS/GASP aerosol optical depth and surface PM2.5



- 60-day time-series for each site including:
  - GASP AOD
  - MODIS AOD
  - Hourly PM2.5
  - 24-hour average PM2.5

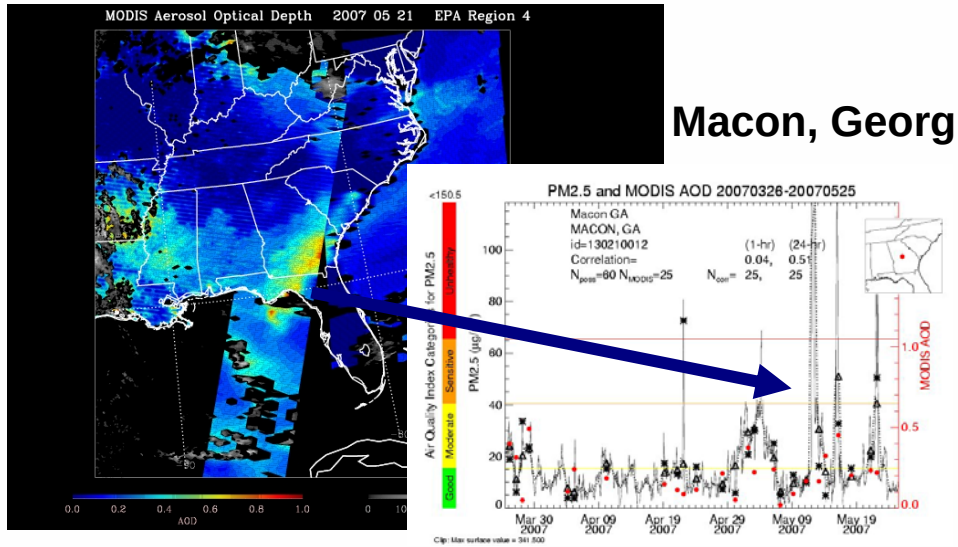
Hai Zhang,et. al. JCET/UMBC
5th GOES Users' Conference, P1.80
An enhanced IDEA product with GOES AOD

Use of AOD to help define Ground Measurements Influenced by Exceptional Events, 2007 Georgia Fires

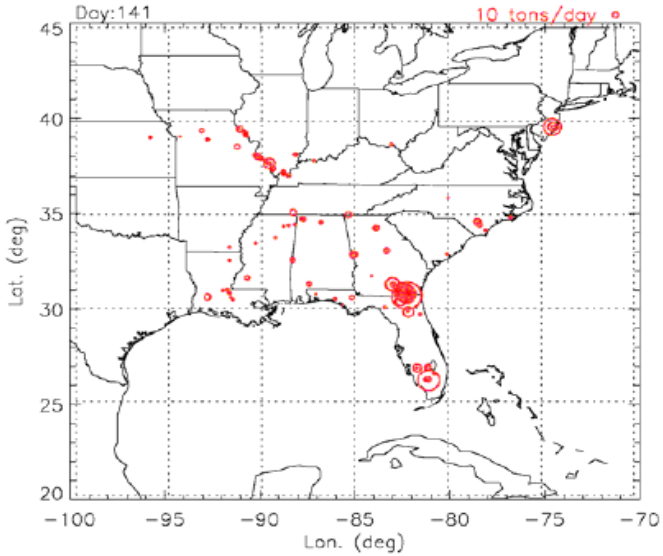
- Anthropogenic (urban/industrial) emissions are the main source of poor air quality.

- However, episodic events of large forest fires and prescribed fires to clear agricultural land lead to deteriorated air quality
  - Adjacent plots show MODIS aerosol optical depth and time series of AOD & continuous $PM_{2.5}$ concentration (top panel) and NESDIS-GOES $PM_{2.5}$ emissions (bottom panel) from the May 2007 Georgia wildfires. Throughout May, smoke from these fires blankets part of Georgia and Florida and affected others states in the SE, leading to numerous air quality health alerts.

- **Satellite data, such AOD, fire activity, and emissions can be used under 40 CFR Part 50 to demonstrate ground monitoring data was influenced by exceptional events, such as wildfires and dust storm.**

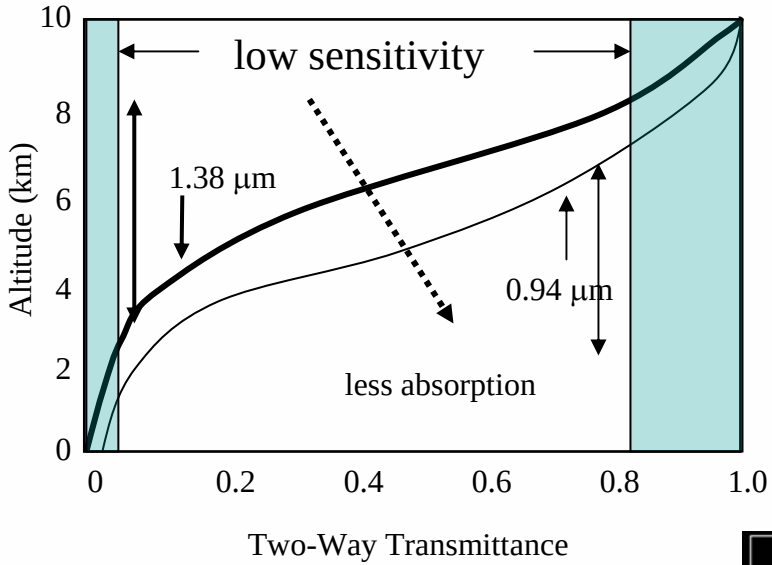


Macon, Georgia



Future Directions relevant to GEOS-R

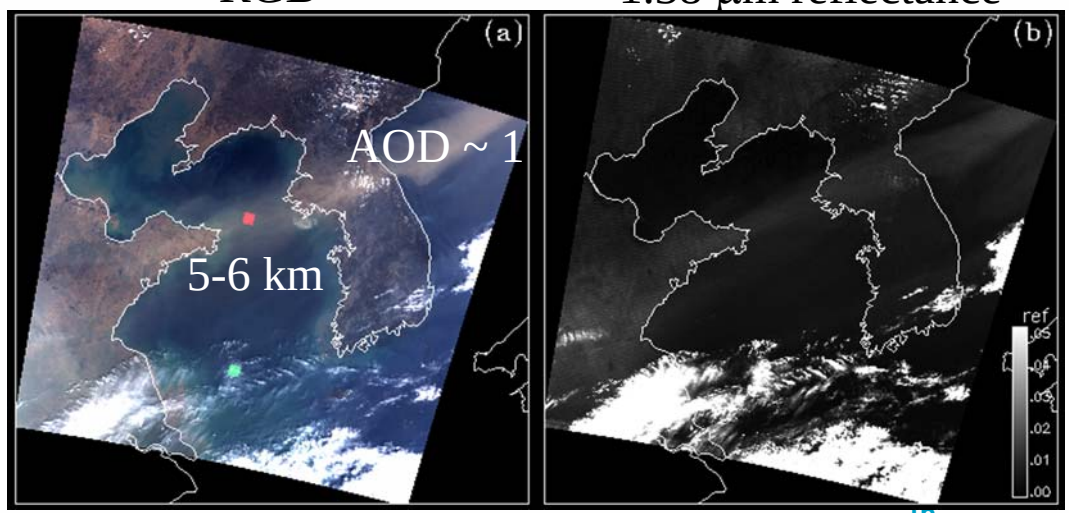
• Develop Aerosol Height Index



- 1.38 µm is the most strong water vapor absorption channel; sensitive to altitudes between 3-8 km.
- 0.94 µm is not as strong as 1.38 µm; sensitive to lower altitude (2 km).
- Instead of deriving total column water vapor, we can derive the AHI.

•When combined with CALIPSO lidar measurements (nadir) (part of A-Train several minutes behind Aqua), we can verify and extend to a full range of viewing angles (55° ~ 2330 km).

RGB 1.38 µm reflectance

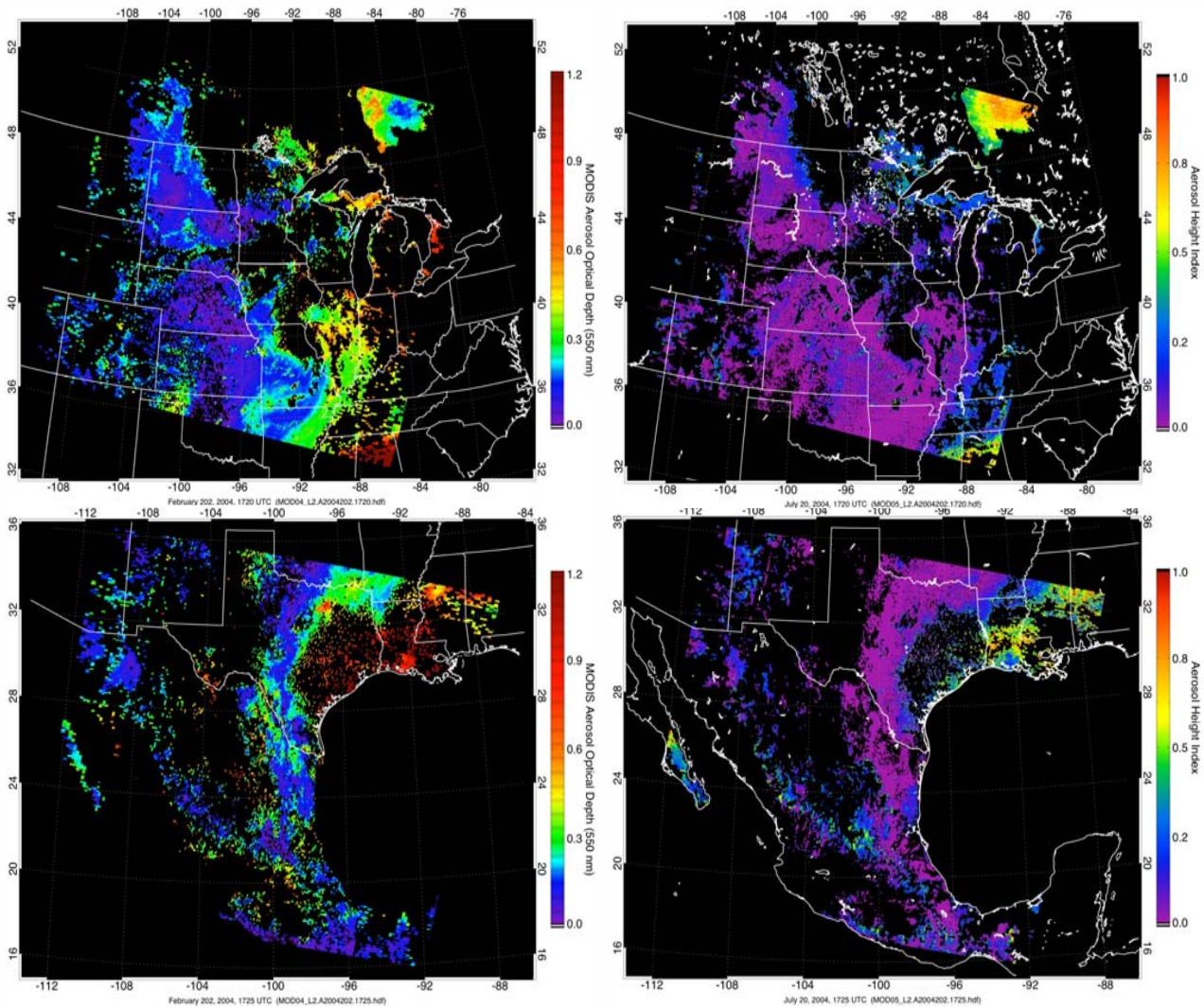


Chu, A.,et.al., Winter AGU 2007

Potential AOD Aerosol Height Index improves use of satellite products for Air Quality Applications

- Ability to determine if aerosol loading is within the boundary layer increases the usability of GOES-R AOD for air quality applications.

- Engle-Cox, J., et. al, 2006, Atmos. Env. and Al-Saadi, J. et. al., 2008 AMS, 10th Conference on Atmos. Chem. show boundary layer AOD improves predictions of $PM_{2.5}$.

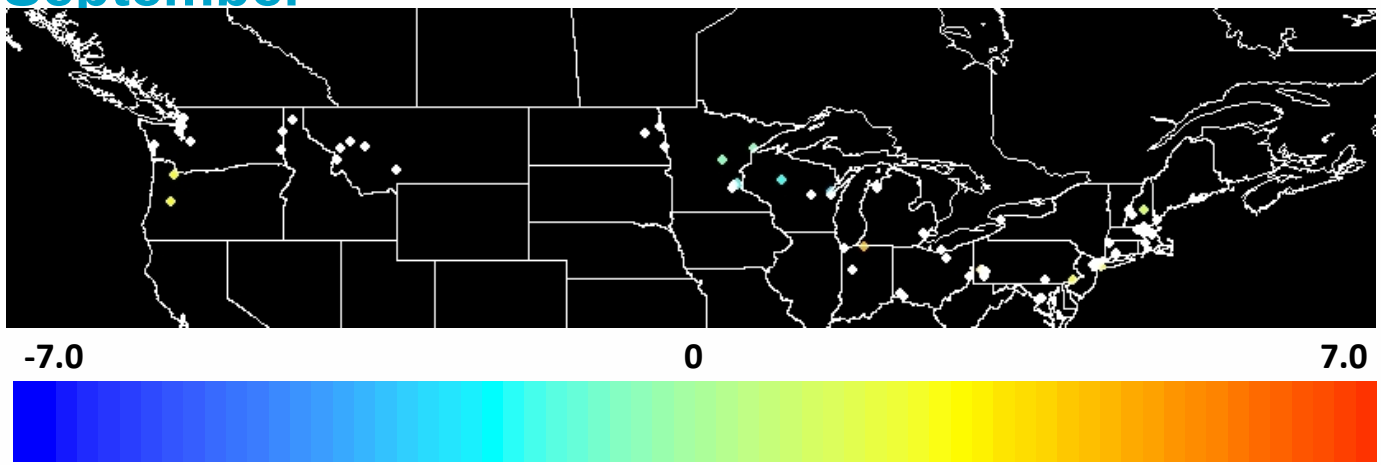


Chu, A.,et.al., Winter AGU 2007

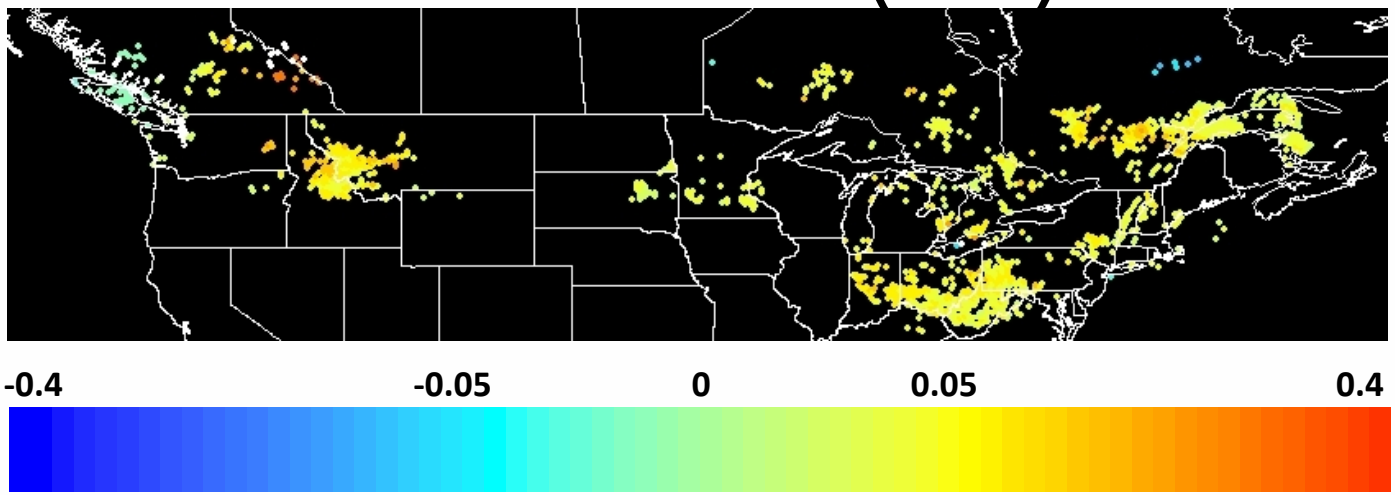
AOD to assess aerosol trends over large domains and relationship to $PM_{2.5}$

September

EPA PM2.5 2000 - 2006

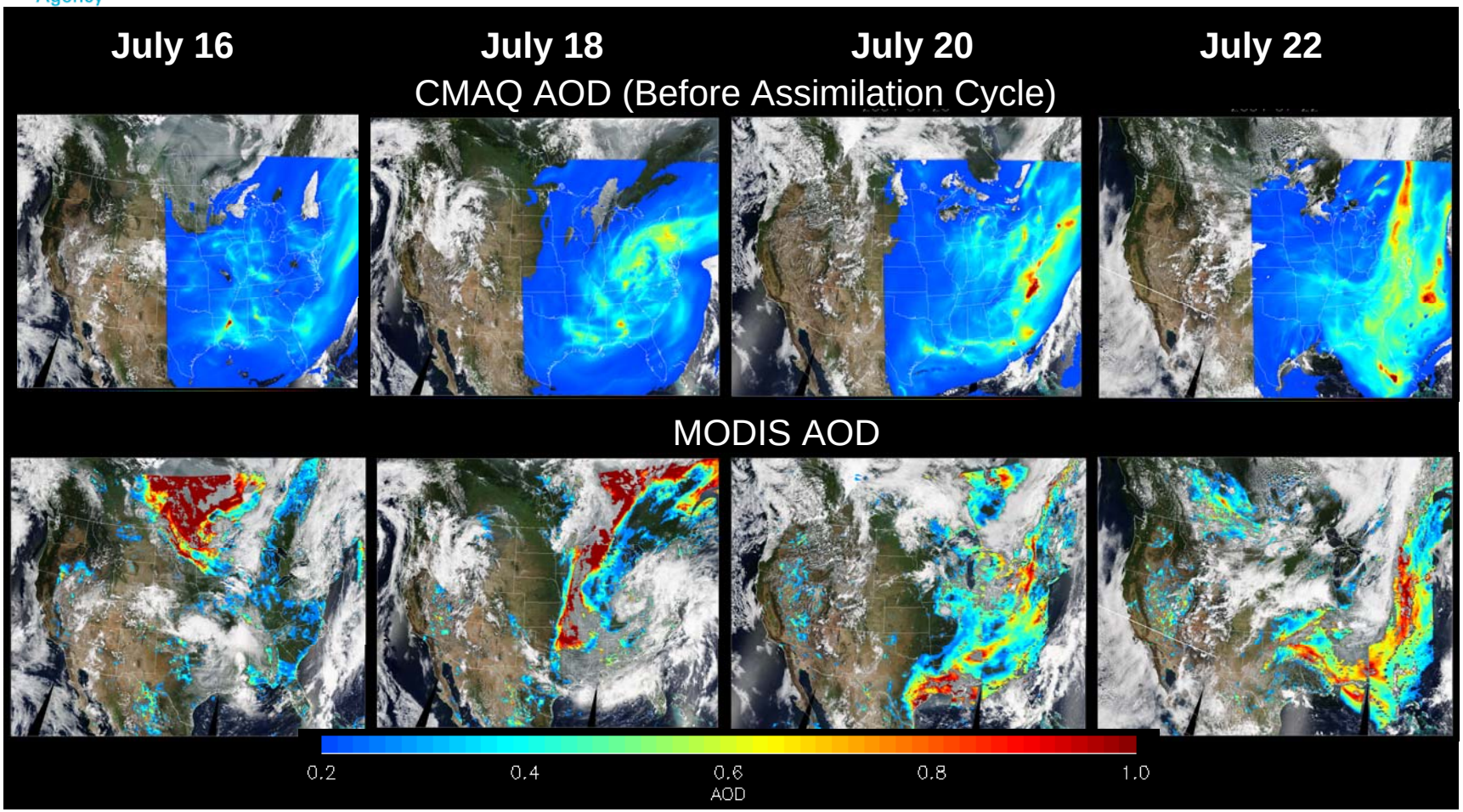


MODIS AOD (Terra) 2000 - 2006



DeWinter J., et. al, AGU Winter 2007

Assimilation of MODIS AOD to Improve Surface PM2.5 impacts for 2004 Alaskan Fires

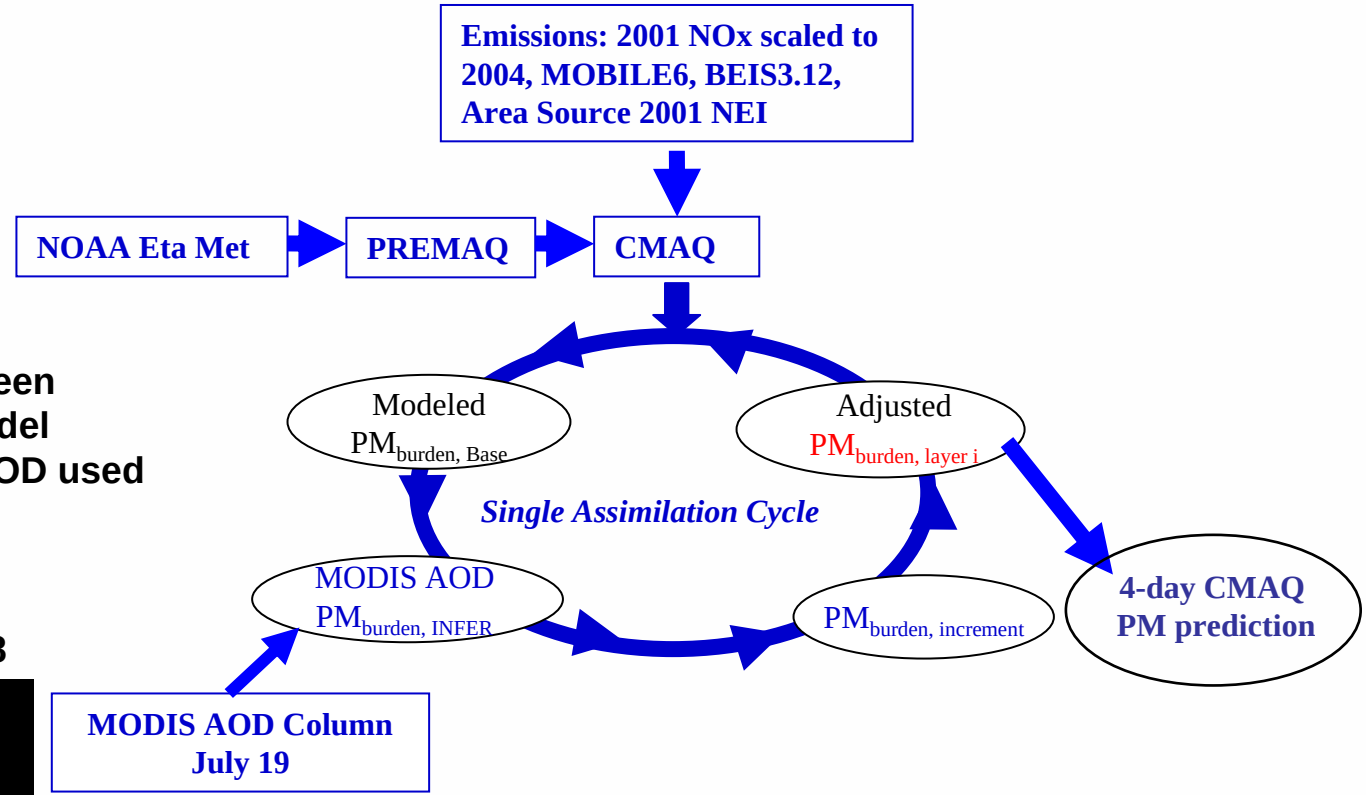


Transport from outside the domain influences observed PM concentrations causing under-prediction:

- Model picks up spatial signatures ahead of the front
- Under predictions behind the front (due to LBCs)

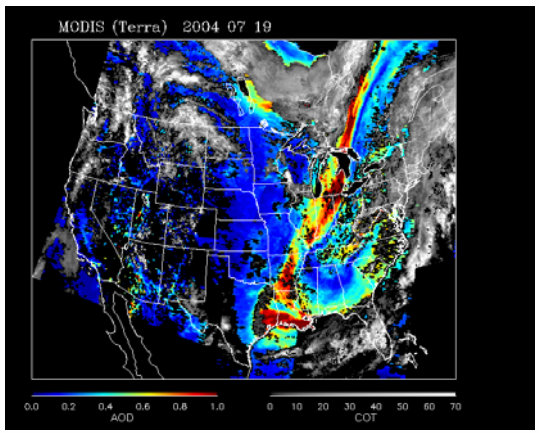
Mathur, R. submitted JGR Dec 2007

Assimilation of MODIS AOD to Improve Surface PM2.5 impacts for 2004 Alaskan Fires



Empirical relationship between model derived AOD and model column –average PM and AOD used to derive PM adjustment for assimilation:

PM_{burden} = 9.065 x AOD =0.18



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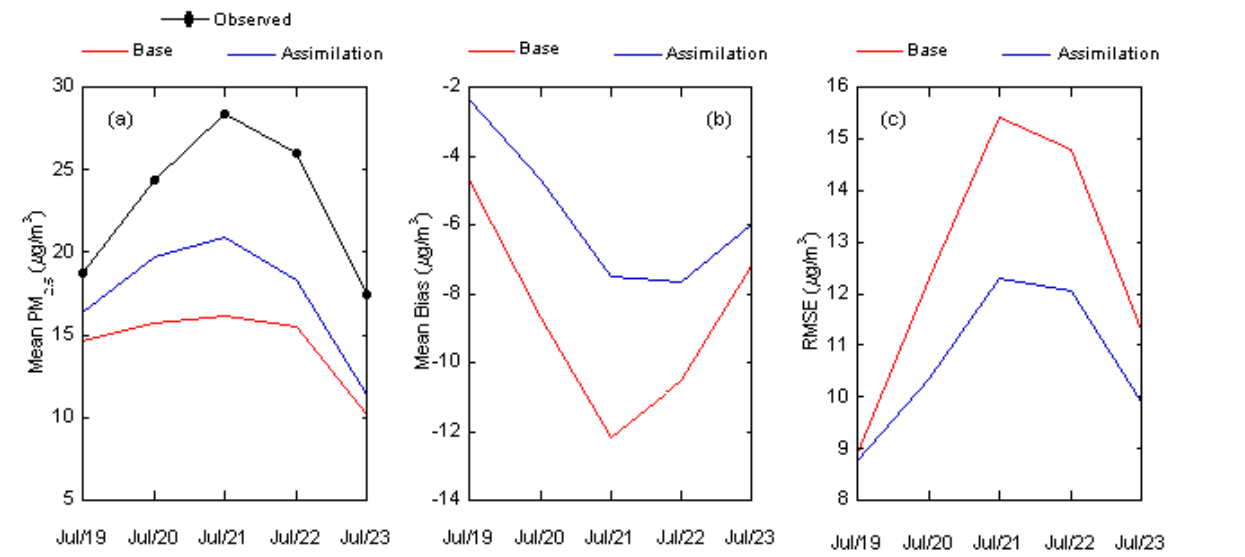


<u>July 19, 2004 Model Estimates on PM2.5 mass loading</u>

Base Model Run $PM_{2.5}$ burden: 0.18 Tg

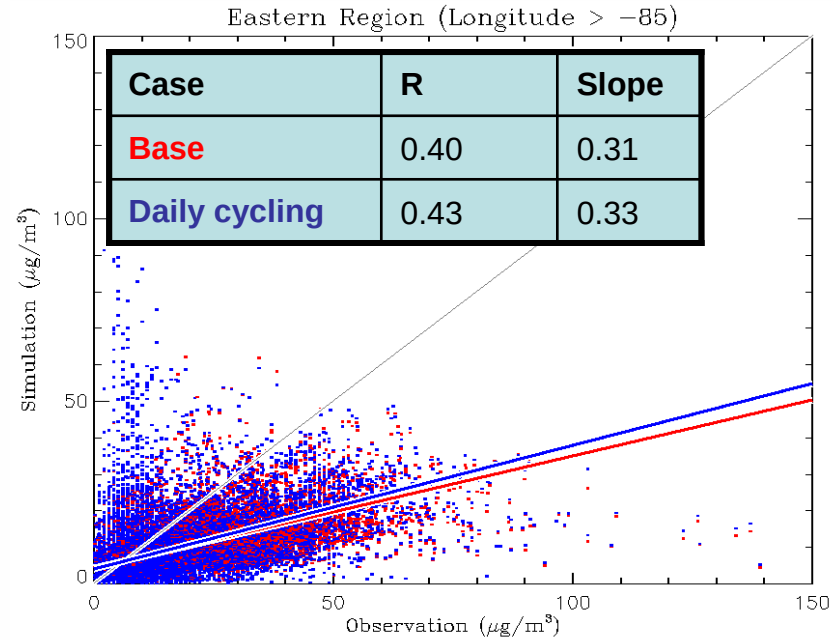
Assimilation Model Run PM2.5 burden: 0.30 Tg

Assimilation results in 0.12 Tg (55%) increase in PM2.5 burden
~8 fold increase over total daily anthropogenic emissions (0.0089 Tg)

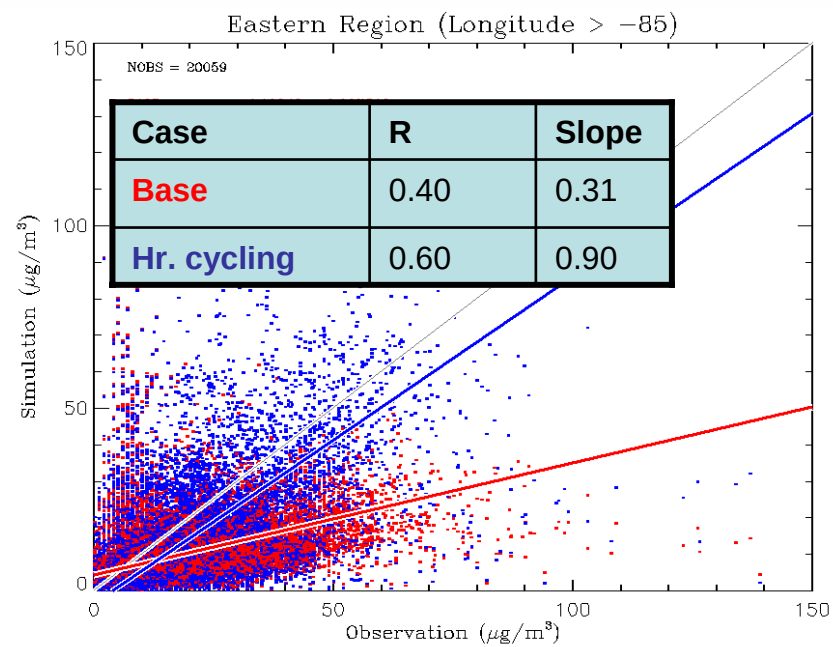
Annual $PM_{2.5}$ (particle) emissions (Continental US) 2001 NEI: 5Tg

GOES AOD Assimilation Experiments

- June 30 to August 4, 2007 regional scale sulfate episode was simulated using Community Multiscale Air Quality (CMAQ) model.
- Two assimilation experiments using GOES AODs were carried out. Top panel: Daily cycling of PM2.5 initial conditions. Bottom panel: Hourly cycling of PM2.5 initial conditions. Figures compare observed and predicted surface PM2.5 concentrations
- Correlation coefficient and slope higher for hourly cycling experiment compared to daily cycling. Assimilating hourly information helps tune the model for missing sources and sinks and improves predictions



Case	R	Slope
Base	0.40	0.31
Daily cycling	0.43	0.33

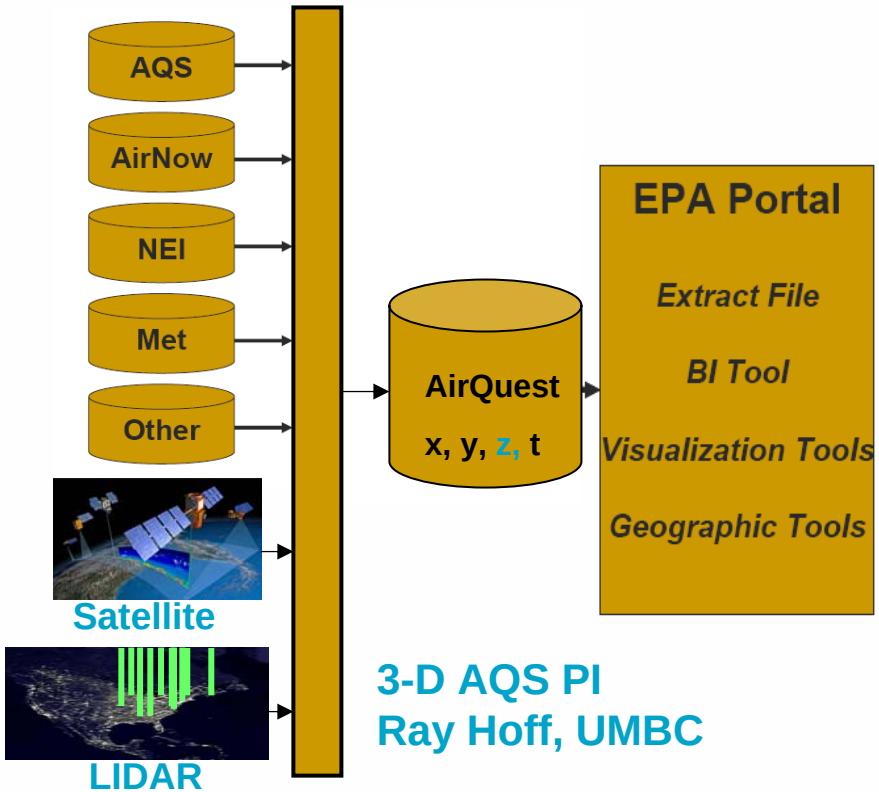


Case	R	Slope
Base	0.40	0.31
Hr. cycling	0.60	0.90

Kondragunta and Zhao, GOES-R risk reduction studies

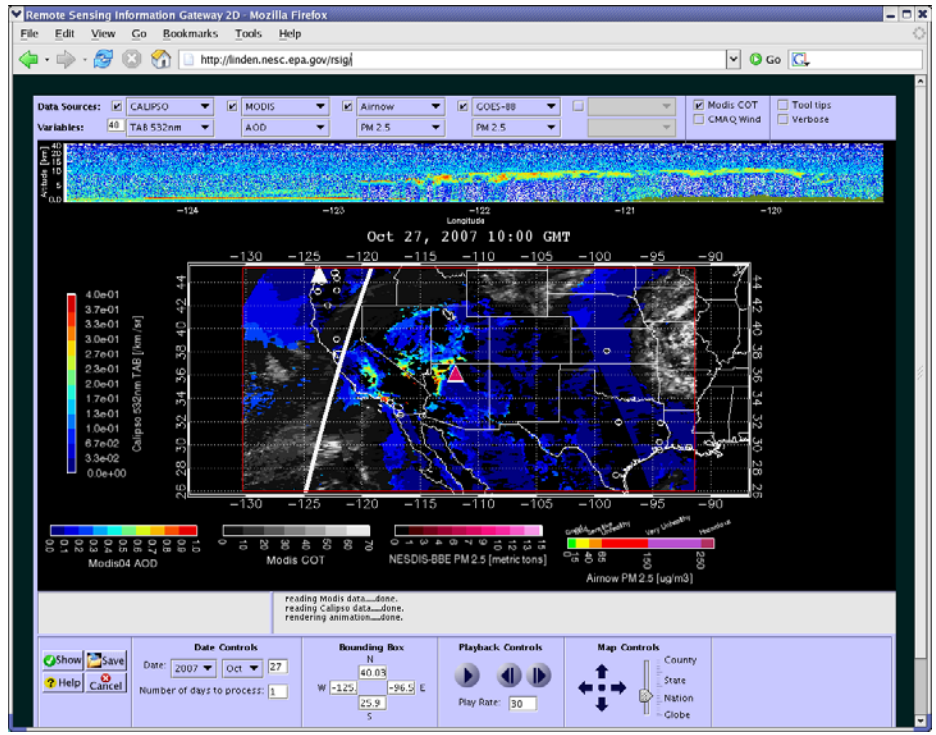
Examples of Data Systems in EPA to Increase Access and Use of Satellite Data

3D Air Quality System (3D-AQS): organizes satellite and lidar data with adequate metadata into coordinates matched to air ground stations and CMAQ model grid in EPA's AirQuest system.



3-D AQS PI
Ray Hoff, UMBC

Remote Sensing Information Gateway (RSIG): provides user the ability to subset a large number of files over a select geographic domain and time and provides sub-setted data set back to the user's workstation.



In Summary – Air Quality is more than Aerosol Optical Depth and Fire Characterization

- The Air Quality Community is a new community now embracing use of satellite observations. The maturity of the community is where the satellite meteorological community was decades ago.

- MODIS provided the first opportunity to EPA to conduct quantitative research and begin to build capacity, and GOES-R will allow that effort to continue in a operational environment.
  - For aerosols MISR and other instruments in the A-Train are demonstrating the ability to infer aerosol type and size, and provide vertical structure - what should be moved into an operational environment?

- What else is needed:
  - The most useful trace gas observations relevant to air quality in the boundary layer are O3, NO2, CO, SO2, H2CO.
  - The diurnal variability and meteorological processes that drive air quality will require high spatial and temporal resolution such as that achieved by geostationary satellites.
  - The NRC Earth Science and Applications from Space Decadal Survey commissioned by NASA, NOAA, and USGS recommended this suite of measurements in the GEOCAPE mission. GOES-R series spans 2013 to 2020, can these type of measurements fit within the future of GOES-R?

United States Environmental Protection Agency

Disclaimer

Although this work was reviewed by EPA and approved for publication, it may not necessarily reflect official Agency policy.