The Launch of TEMPO

(Tropospheric Emissions: Measurement of Pollution; April 7, 2023):

NASA's First Mission Primarily Devoted to the Improvement of U.S. Air Quality

Jack Fishman
Department of Earth and Atmospheric Sciences
Saint Louis University
St. Louis, MO 63108

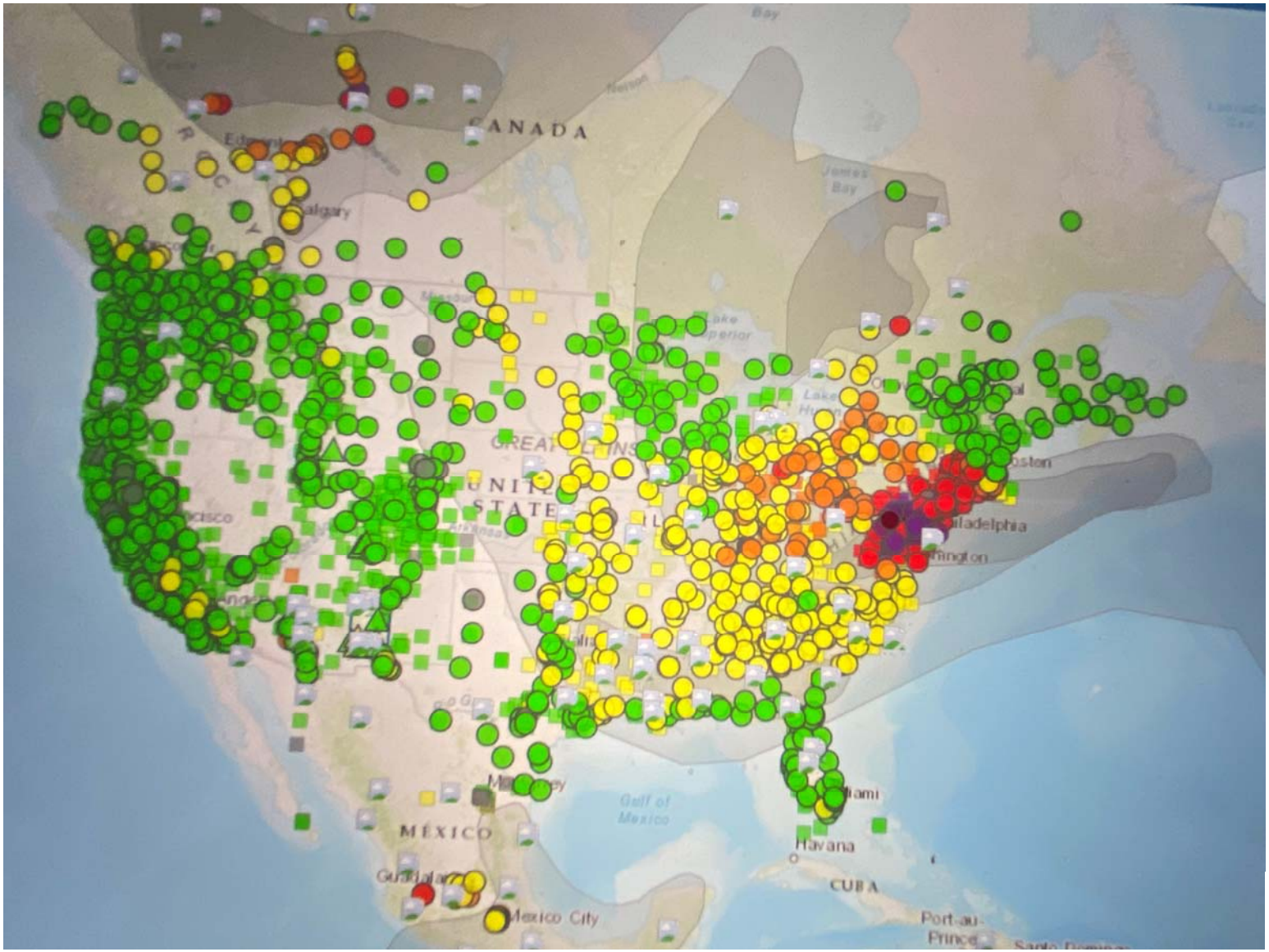
Air Quality Advisory Committee
East-West Gateway Council of Governments
St. Louis, MO
June 27, 2023

Images of New York City

(June 2023)

Air Quality Forecast Map from Airnow.epa.gov

(June 8, 2023)



IDEA Infusing satellite Data into Environmental Applications

A Good IDEA

(Infusing satellite Data into Environmental Applications): The Use of Measurements Derived from Satellites for Tropospheric Chemistry Studies

Doreen O. Neil[1], James J. Szykman[1,2], **Jack Fishman[1]**, R. Bradley Pierce[1], Jassim Al-Saadi[1], Chieko Kittaka[1,3] and John K. Creilson[1,3]

[1] NASA Langley Research Center, Hampton, Virginia USA 23681
[2] U.S. EPA, Research Triangle Park, North Carolina USA 27709
[3] SAIC, Hampton, Virginia USA 23666

13th Conference on Satellite Meteorology
Norfolk, Virginia
21 September 2004

IDEA Infusing satellite Data into Environmental Applications

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Emphasis on Air Quality by Responsible Federal Agencies:

Earth Observations:
Global Collaboration for Local Benefits

Consistent with Reorganization of NASA Earth Sciences Division (~2002)

Michael O. Leavitt
Administrator
U.S. Environmental Protection Agency

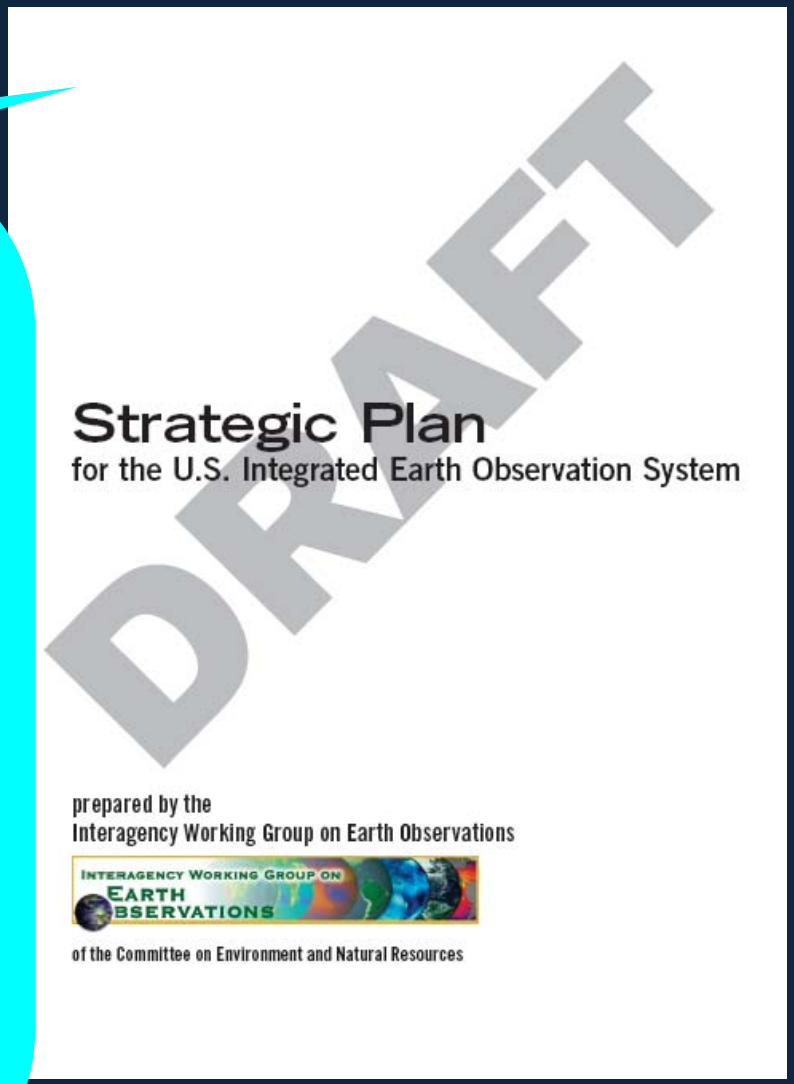
Vice Admiral (Ret) Conrad C. Lautenbacher
Under Secretary of Commerce for Oceans and Atmosphere and Administrator of NOAA

National Press Club August 17, 2004

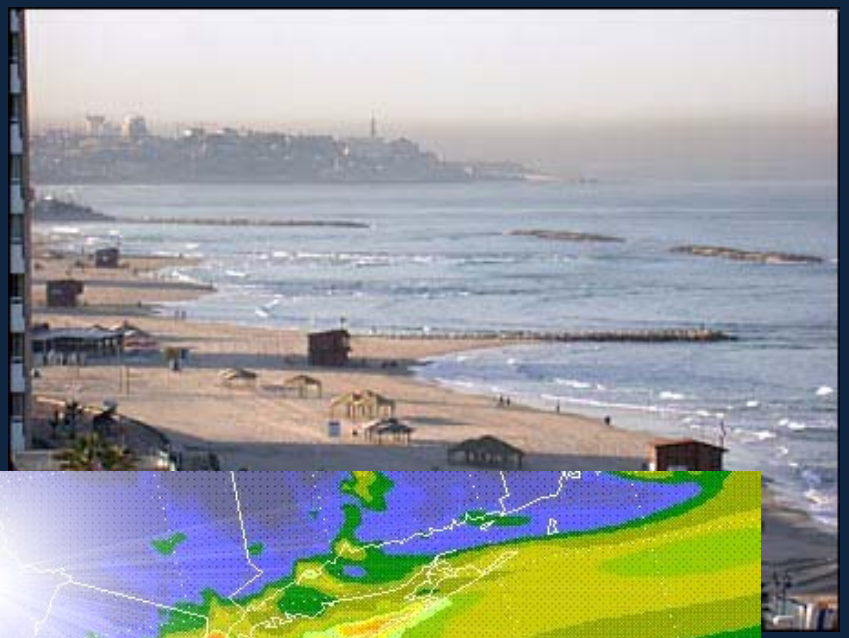
Emphasis on Air Quality in the Integrated Earth Observing System Agencies:

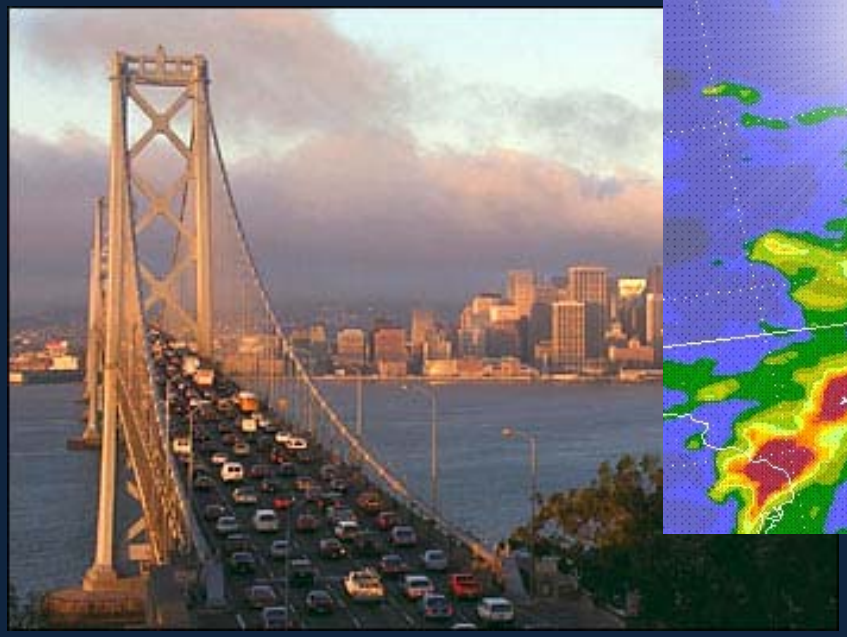
F. Air Quality Assessment and Forecast System

- *Future System integrated with modeling and decision support tools will:*
- *Improve the ability to forecast air quality across large parts of the country (and in other parts of the world) for which forecasts are not currently available*
- *Provide better information about emissions and transport mechanisms on regional to international scales.*
- *Provide important information to help the public avoid harmful exposures and to help air quality management better manage air pollution essential Outcome: An enhanced observational network to identify episodes over the short and long terms.*



IDEA: NASA-EPA-NOAA partnership to improve air quality assessment, management, and prediction by infusing (NASA) satellite measurements into (EPA, NOAA) analyses for public benefit.



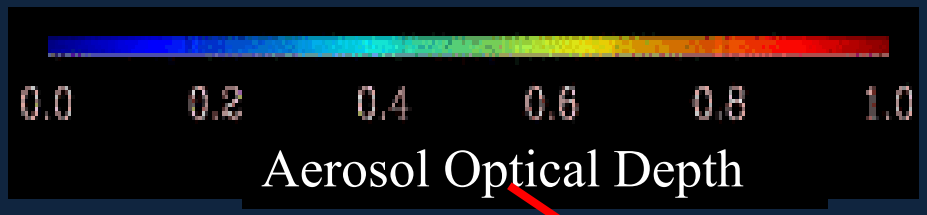


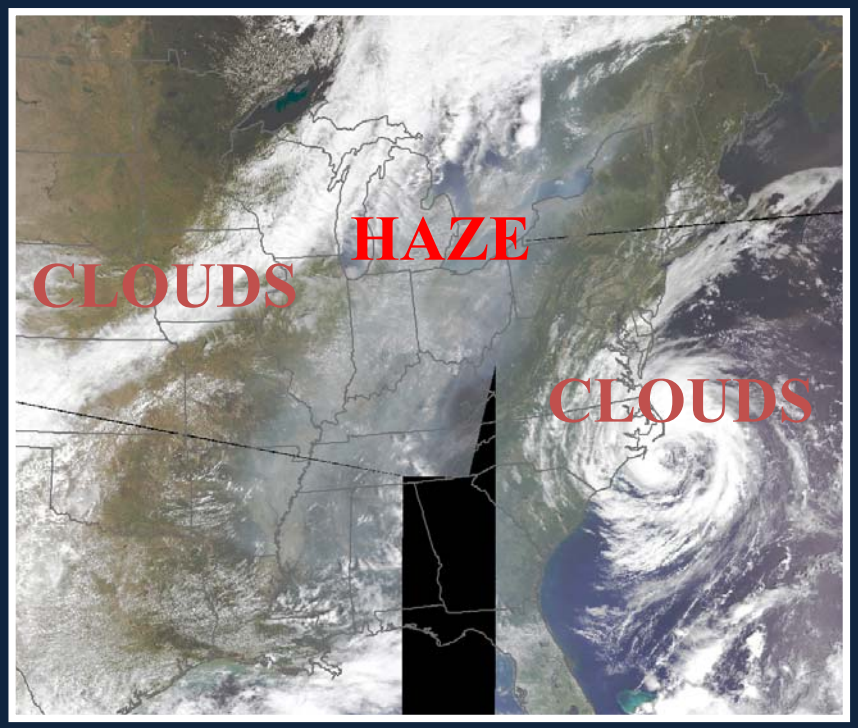
IDEA (Infusing satellite data into environmental air quality applications)

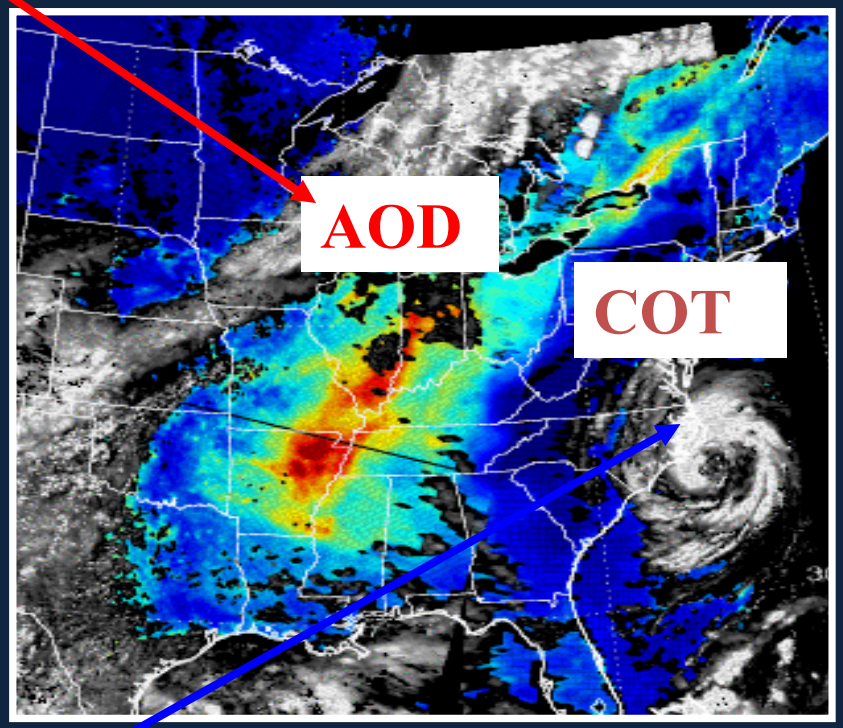
Part of NASA Earth Science Enterprise (ESE) Applications Program strategy to demonstrate practical uses of NASA sponsored observations from remote sensing systems and predictions from scientific research.

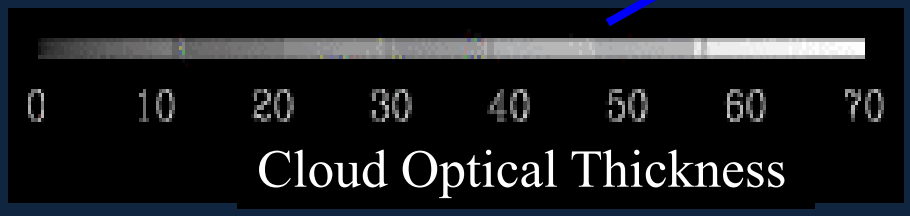
Visible Image vs. Atmospheric Retrievals
MODIS Sensor - Sept. 10, 2002

« Turning the Image into a Chemical Weather Map for Aerosols »









< Back

Air Quality Index for Particles

Index Values	Category	Cautionary Statements	$PM_{2.5}$ (ug/m^3)	PM_{10} (ug/m^3)
0-50	Good	None	0-15.4	0-54
51-100	Moderate	Unusually sensitive people should consider reducing prolonged or heavy exertion	15.5-40.4	55-154
101-150	Unhealthy for Sensitive Groups	Sensitive groups should reduce prolonged or heavy exertion	40.5-65.4	155-254
151-200	Unhealthy	Sensitive groups should avoid prolonged or heavy exertion; everyone else should reduce prolonged or heavy exertion	65.5-150.4	255-354
201-300	Very Unhealthy	Sensitive groups should avoid all physical activity outdoors; everyone else should avoid prolonged or heavy exertion	150.5-250.4	355-424

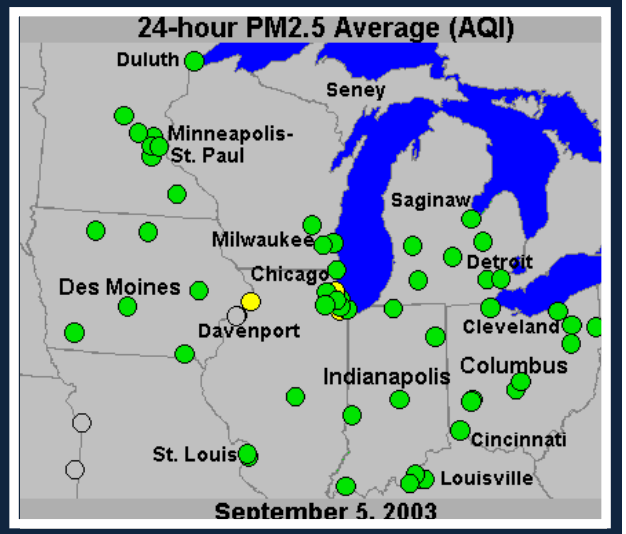
Source: US EPA, 1997

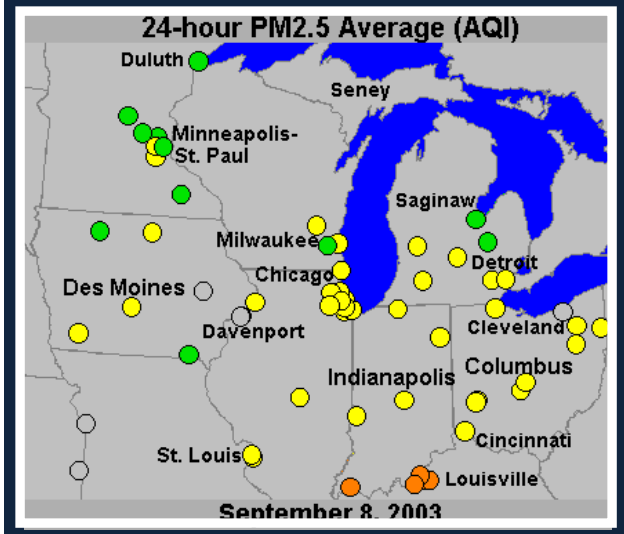
Operational Use of Satellite Data for Air Quality

- Can Satellites be Used to Improve Near-real Time Air Quality Forecasts?

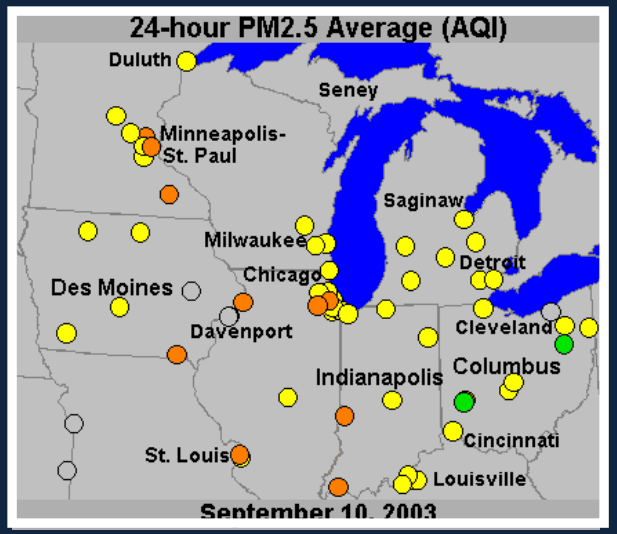
- PM2.5 Levels in Models Predicted **Unhealthy air Quality for Sensitive Groups on 8-12 September 2003 in the Midwest**

September 5, 2003

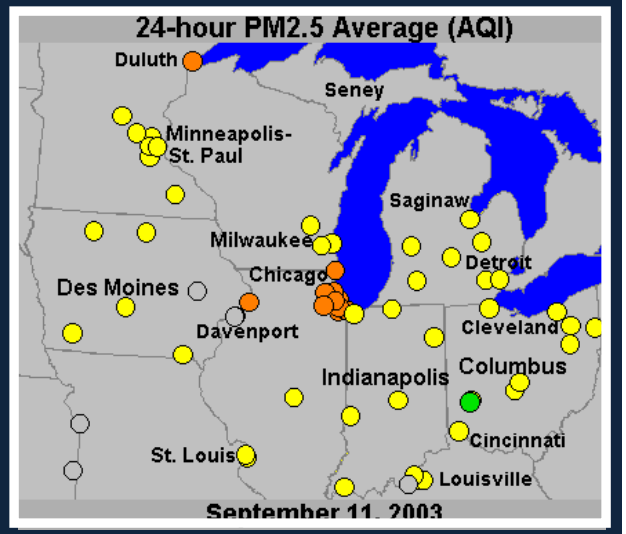




September 8



September 10



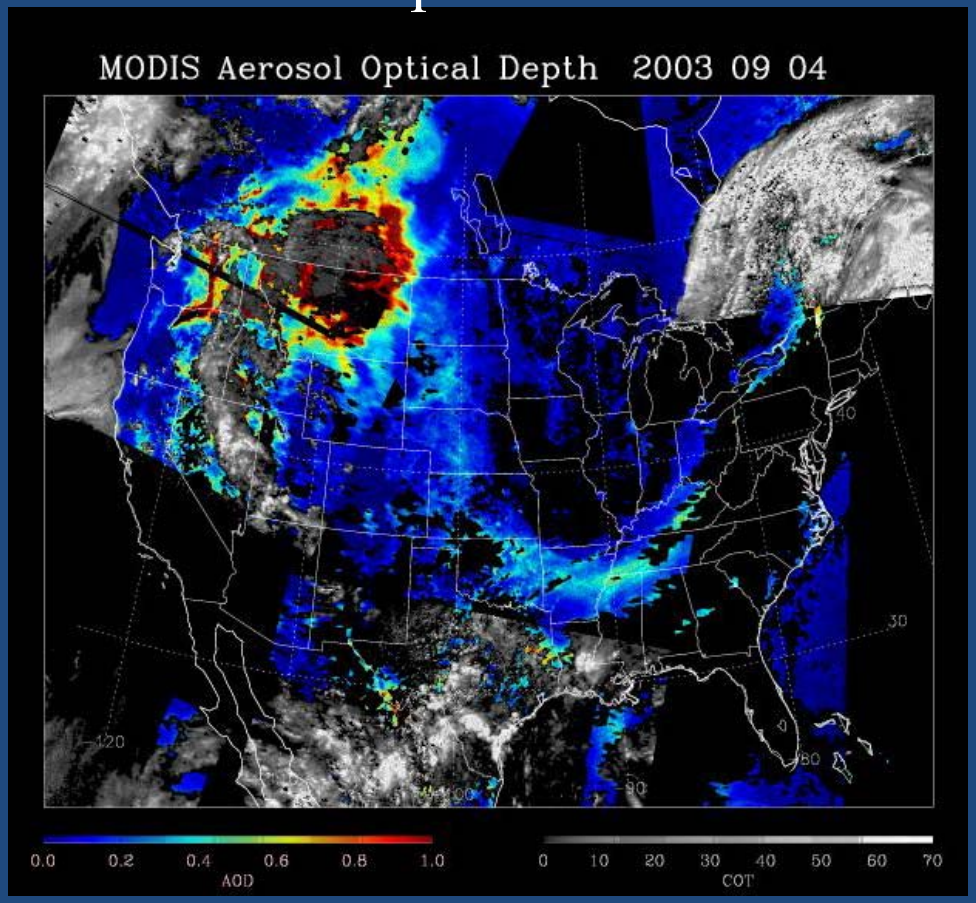
September 11

How Near-Real Time MODIS τ_a Aids Forecast

Provides a once daily, pseudo-synoptic view of aerosol loading across North America at a 10 km x 10 km spatial scale

- Regional transport influences
- Natural event influences
- Re-circulation influences

04 September 2003



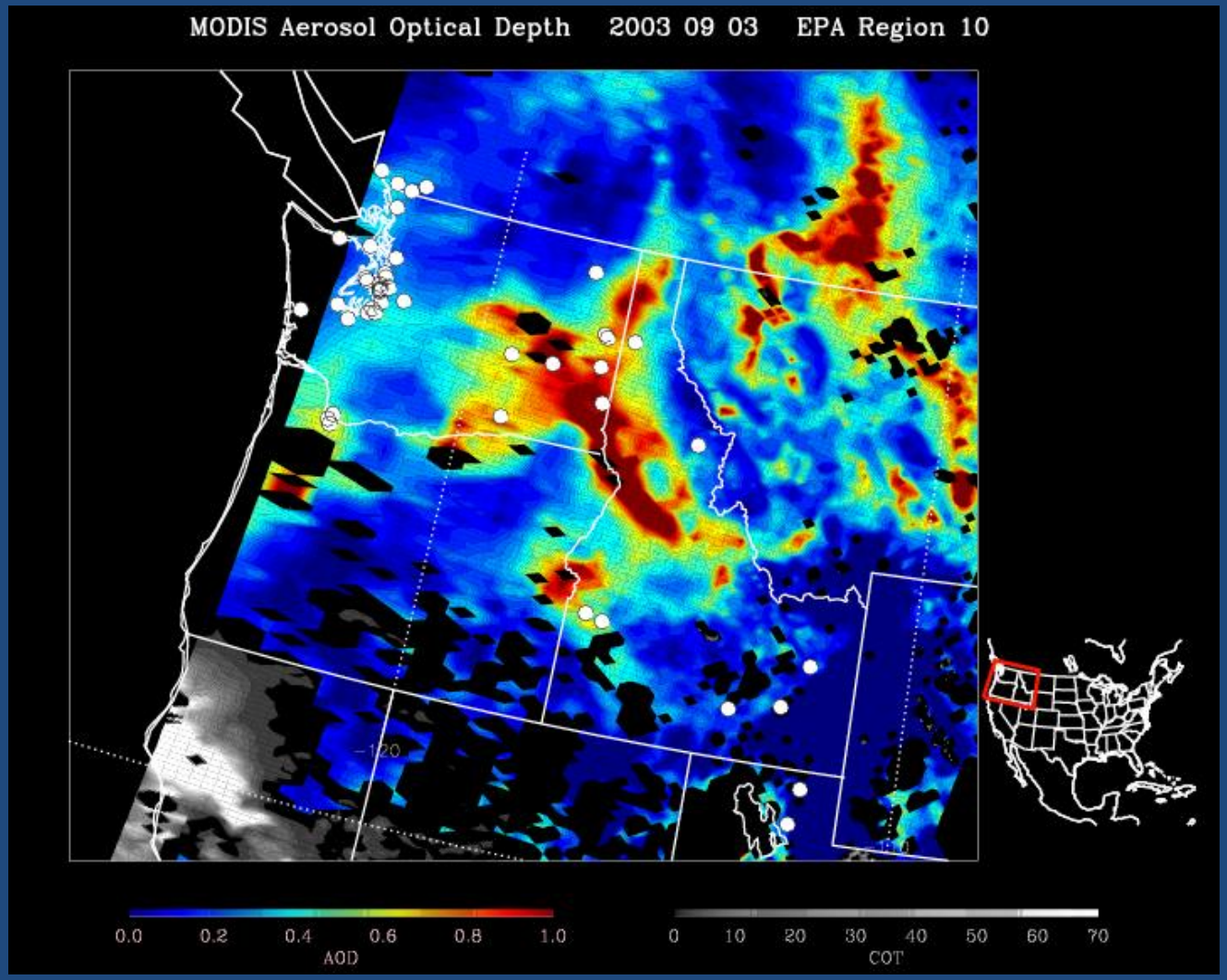
< Back

MODIS/AIRNow Forecast Tool Products

- Regional Summary Plots of MODIS Aerosol Optical Depth and Cloud Optical Thickness
- MODIS Aerosol Optical Depth 48 hour Air Parcel Forecast Trajectories Forecast
- Composite PM2.5/MODIS Aerosol Optical Depth Data Fusion 3-day Animation
- Time-series between MODIS Aerosol Optical Depth and PM2.5 (1hr and 24hr) Mass Concentration
- National Correlation Map between PM2.5 and MODIS Aerosol Optical Depth

< Back

Regional Summary Plots of MODIS Aerosol Optical Depth and Cloud Optical Thickness 03 September 2003



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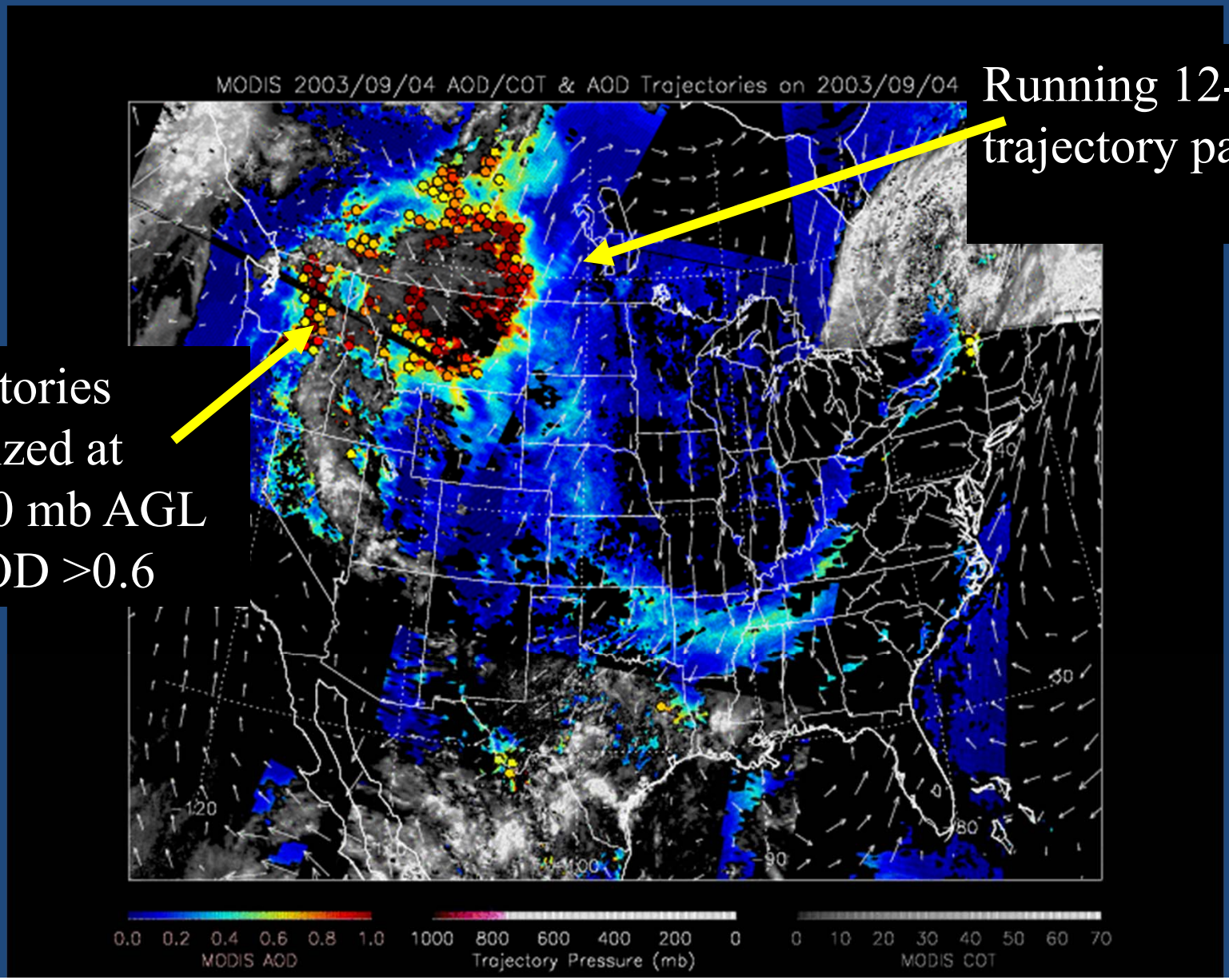
MODIS Aerosol Optical Depth 48 hour Air Parcel Forecast Trajectories (04 September 2003)



Running 12-hour trajectory path

Trajectories initialized at 50-200 mb AGL for AOD >0.6

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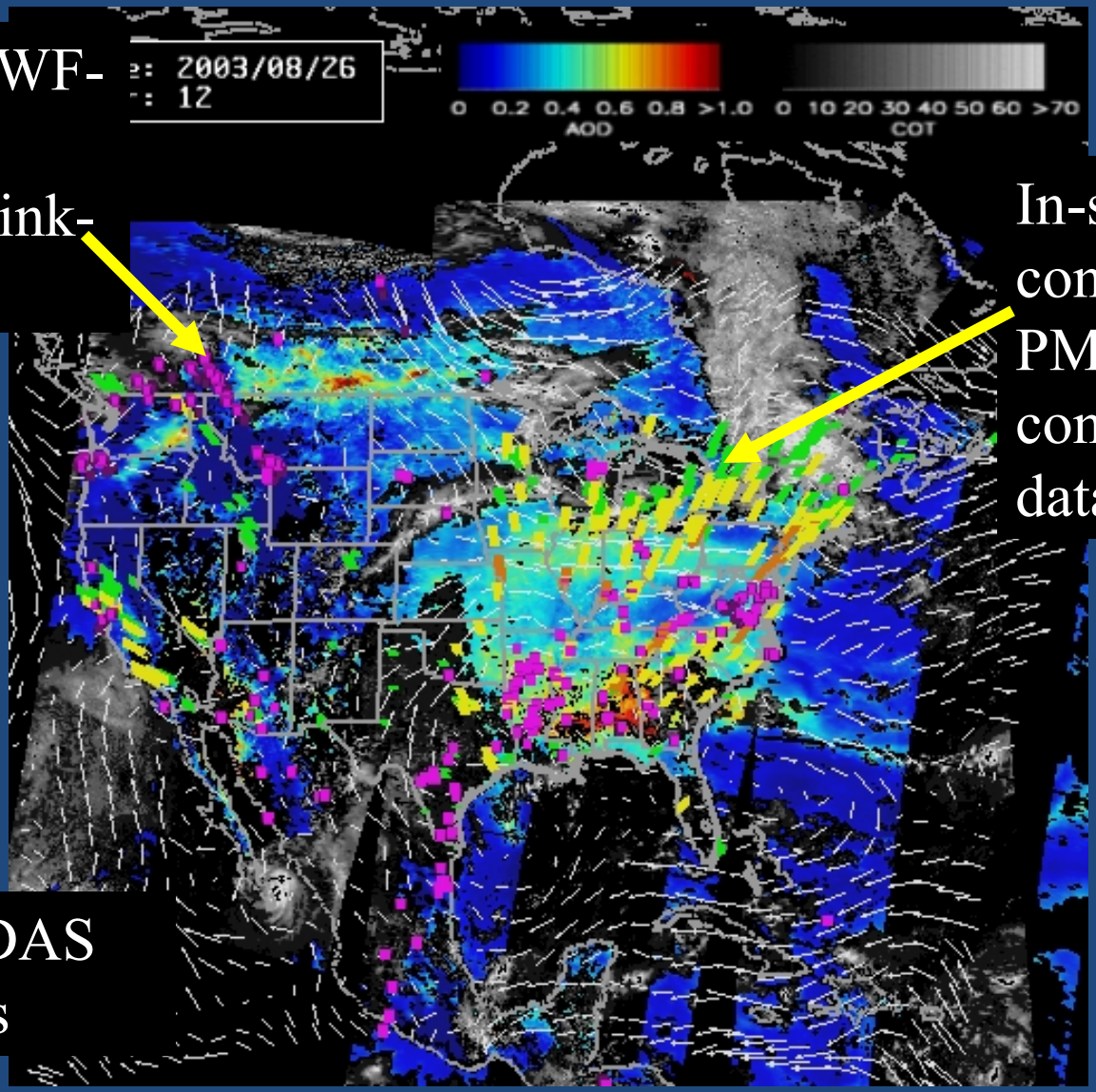
Composite PM2.5/MODIS Aerosol Optical Depth Data Fusion 3-day Animation



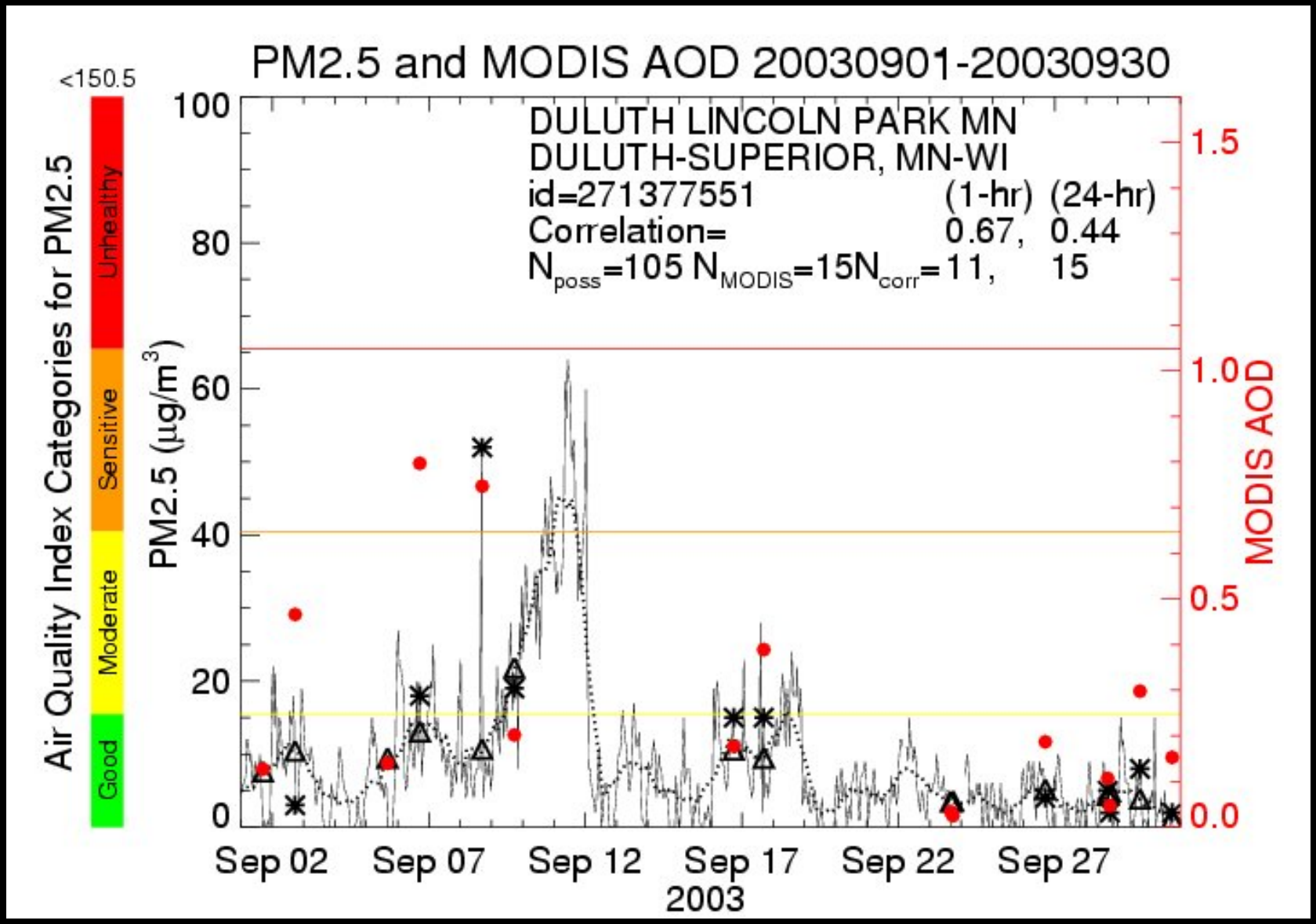
Half-hourly WF-ABBA Fire Locations (pink-purple)

In-situ continuous $PM_{2.5}$ mass concentration data

850 mb EDAS wind fields

< Back

Time-series between MODIS Aerosol Optical Depth and PM2.5 (1hr and 24hr) Concentrations



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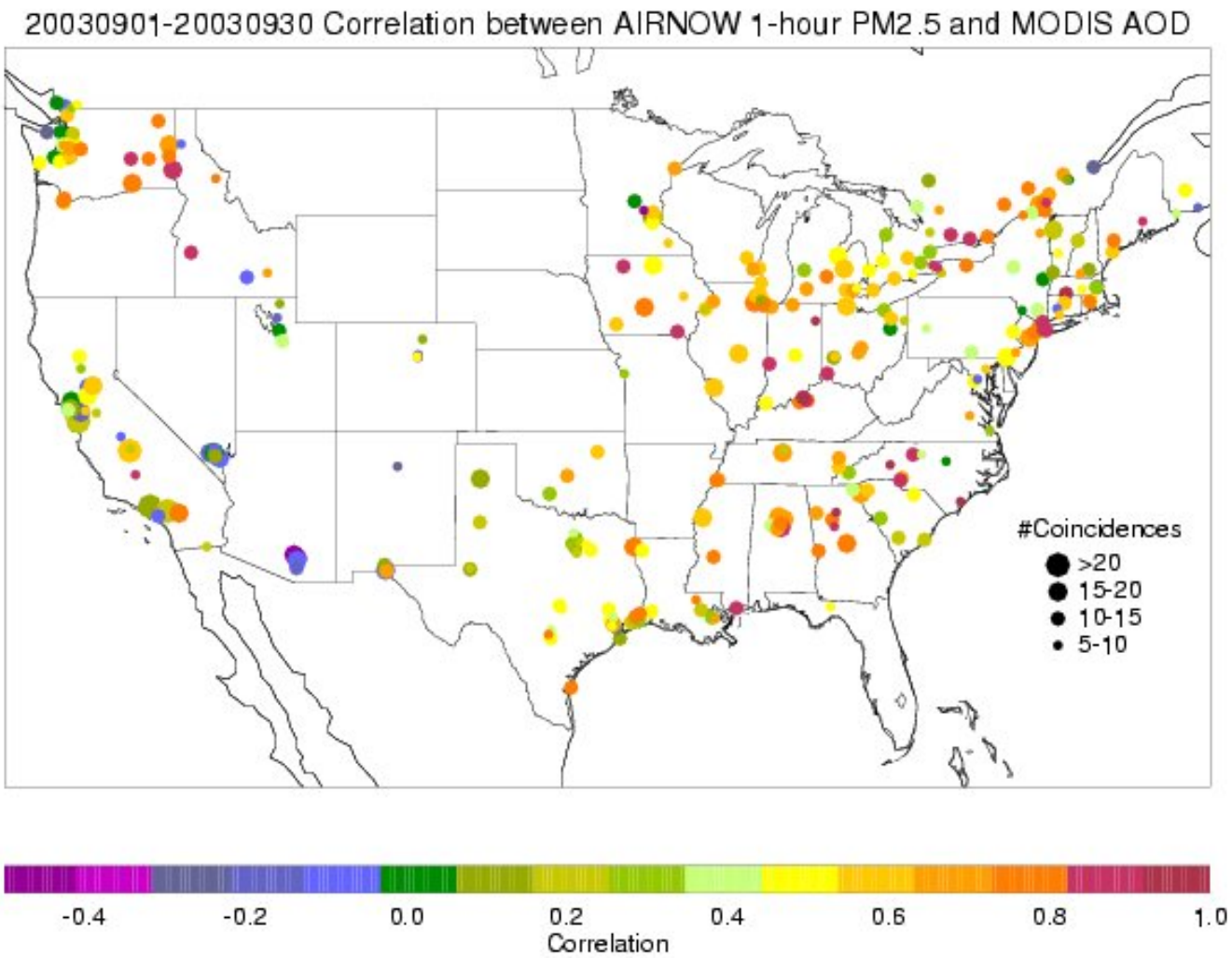
National Correlation Map between PM2.5 Mass Concentration and MODIS Aerosol Optical Depth



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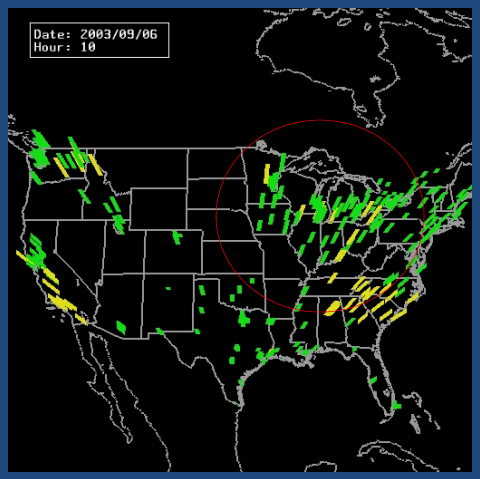
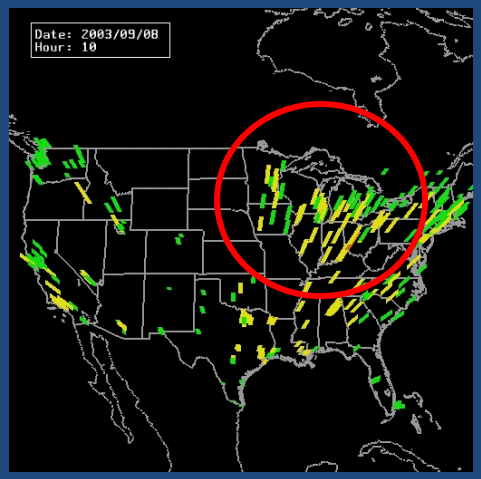
Case Study - September 4-10, 2003

10Z Sep. 6



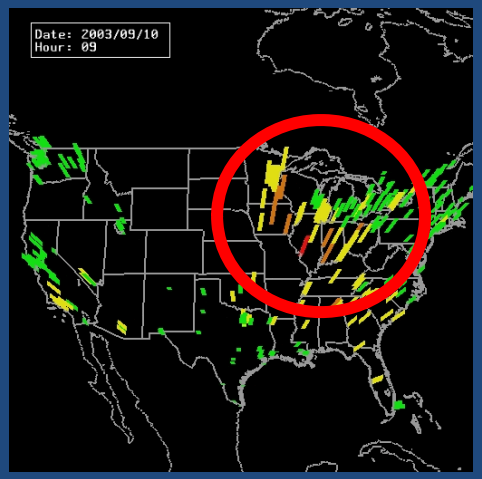
AQI :
Good
Moderate

10Z Sep. 8



AQI :
Moderate
Sensitive

9Z Sep. 10



AQI :
Sensitive
Unhealthy

Question : ***What is responsible for the poor air quality in Midwest for this time period?***

Approach : ***Utilize satellite and surface observations in combination with trajectory analysis***

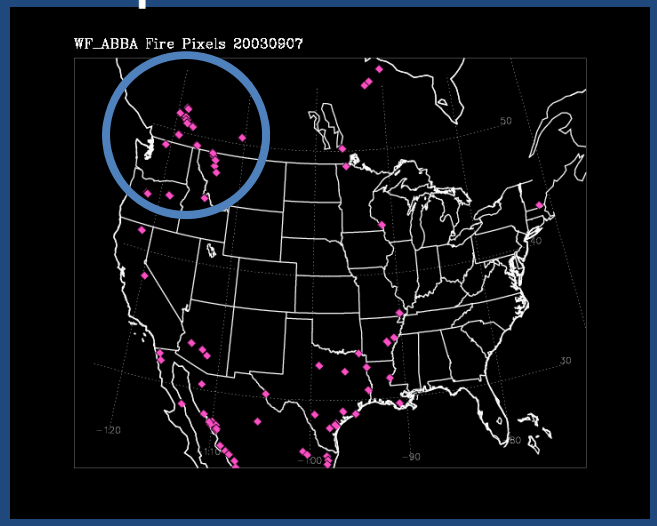
Historic wildfire events in Pacific NW and British Columbia during 2003

Sep. 04

Sep. 05

Sep. 06

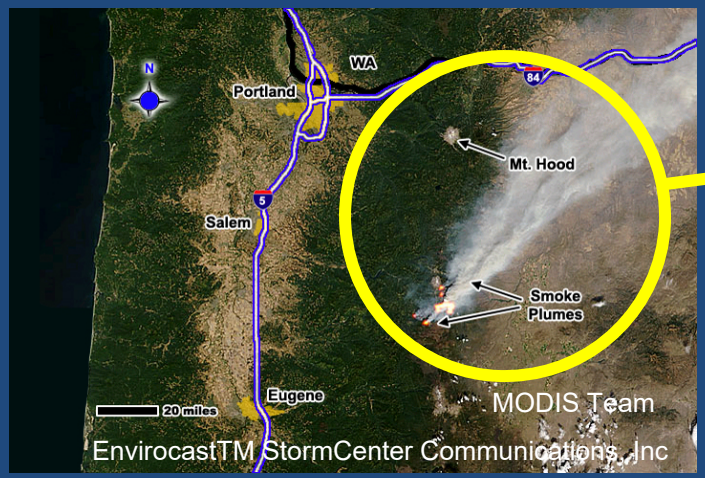
Sep. 07



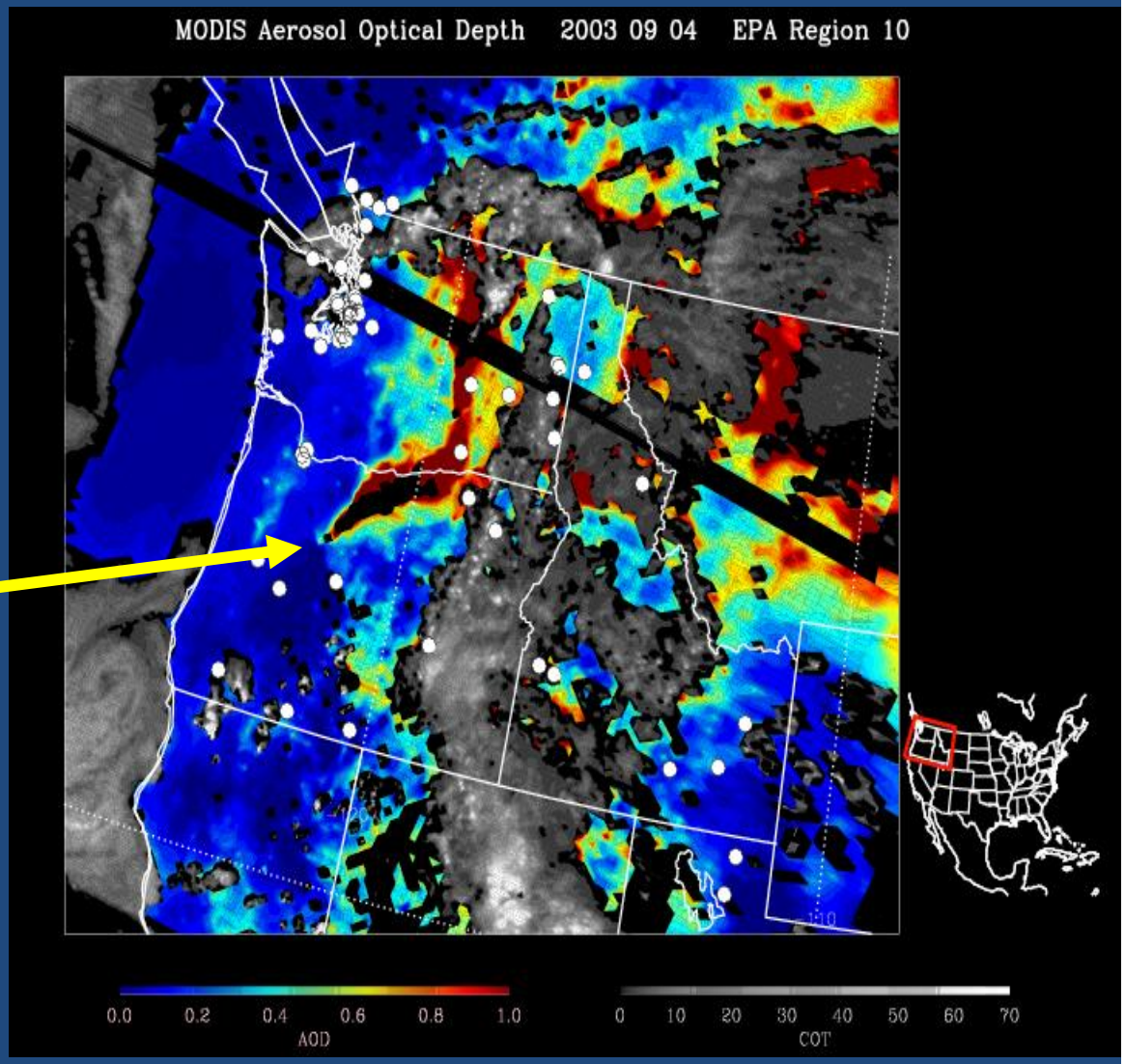
WF_ABBA Fire Pixels, Elaine Prinns (NOAA/NESDIS)

MODIS observations of Pacific NW wildfires on Sep. 4, 2003

Bear Butte Fire & Booth Fire wildfire complex
Northwest Oregon on September 4, 2003

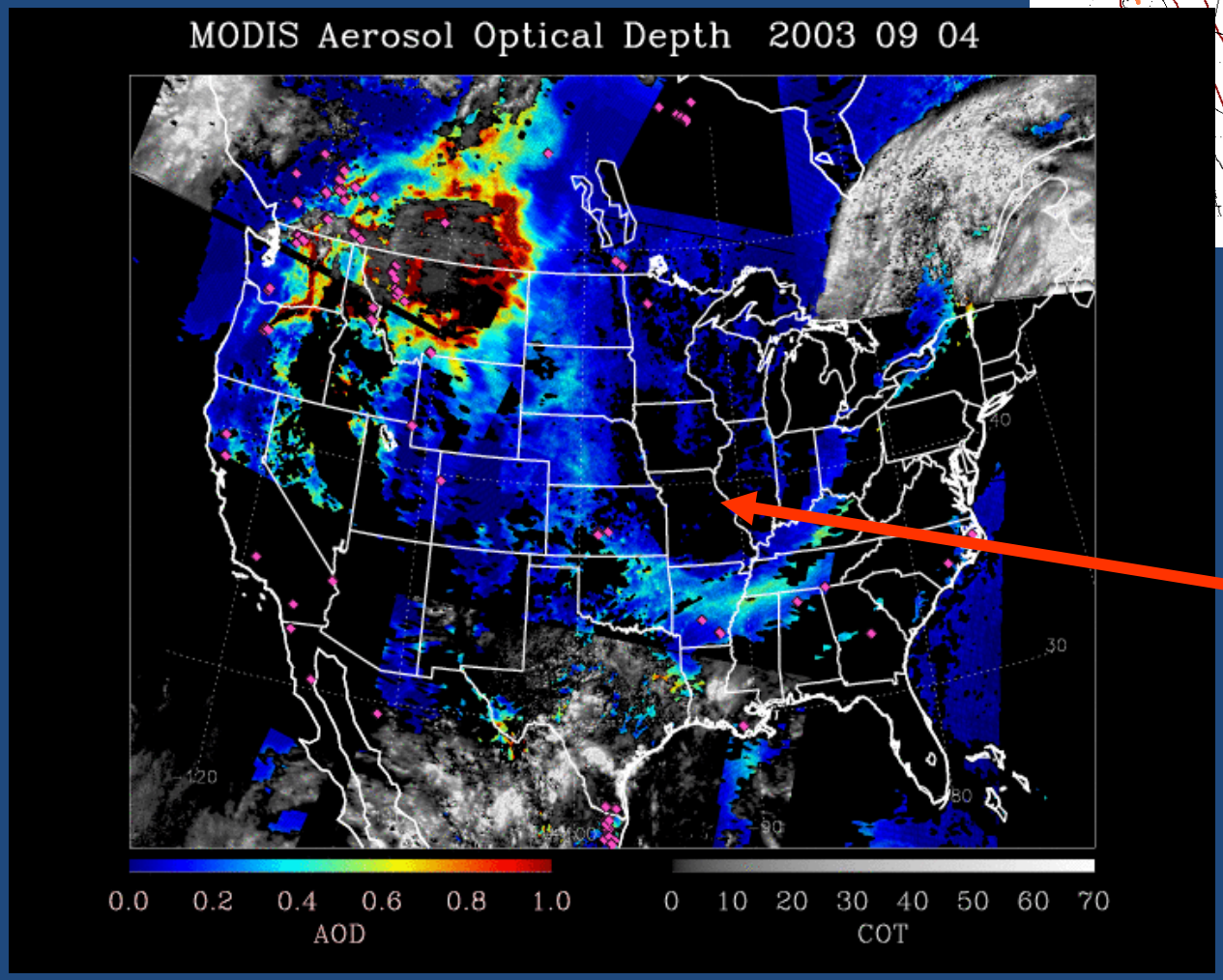


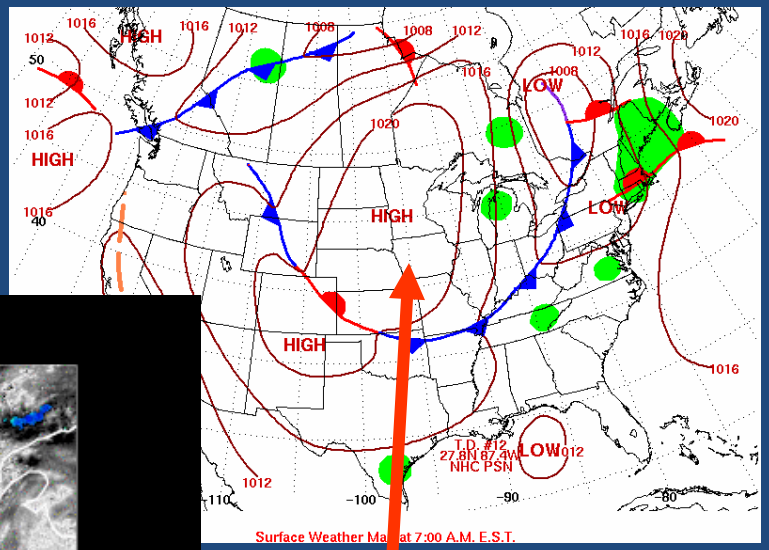
Visible image



Aerosol Optical Depth

September 4, 2003



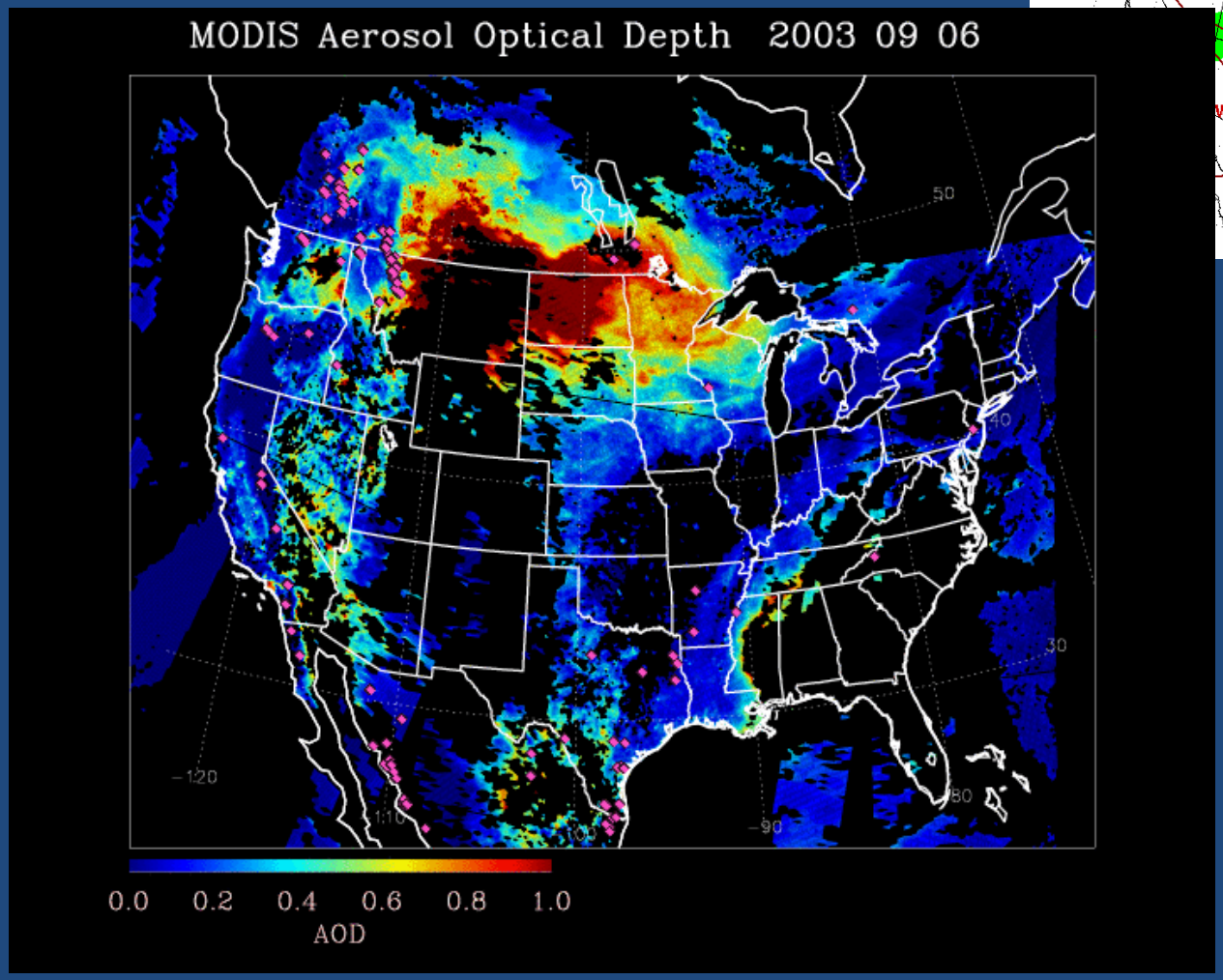


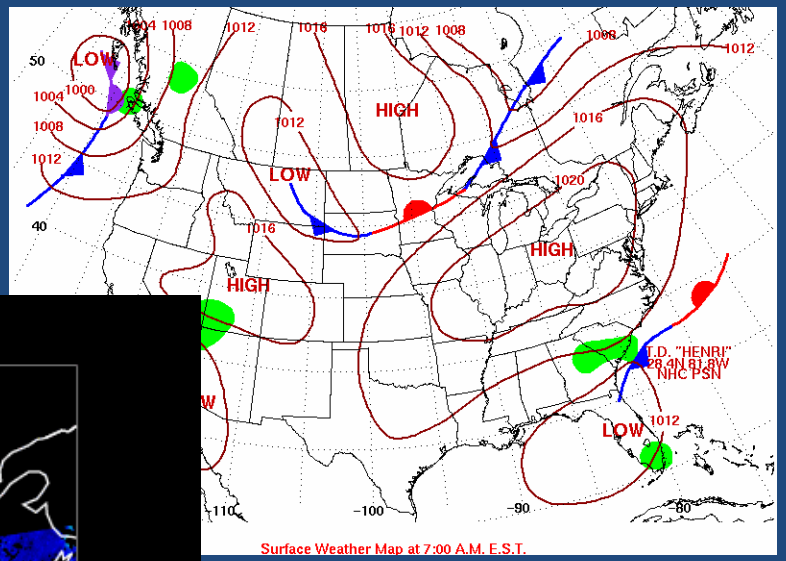
www.hpc.ncep.noaa.gov

Clean air advection behind cold front

MODIS AOD: color contours
WF_ABBA Fire pixels: purple dots

September 6, 2003

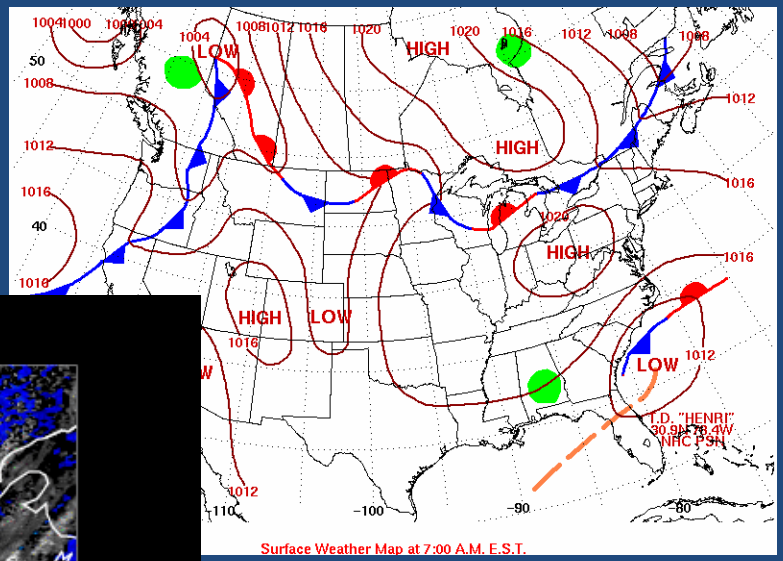




www.hpc.ncep.noaa.gov

MODIS AOD: color contours
WF_ABBA Fire pixels: purple dots

September 7, 2003



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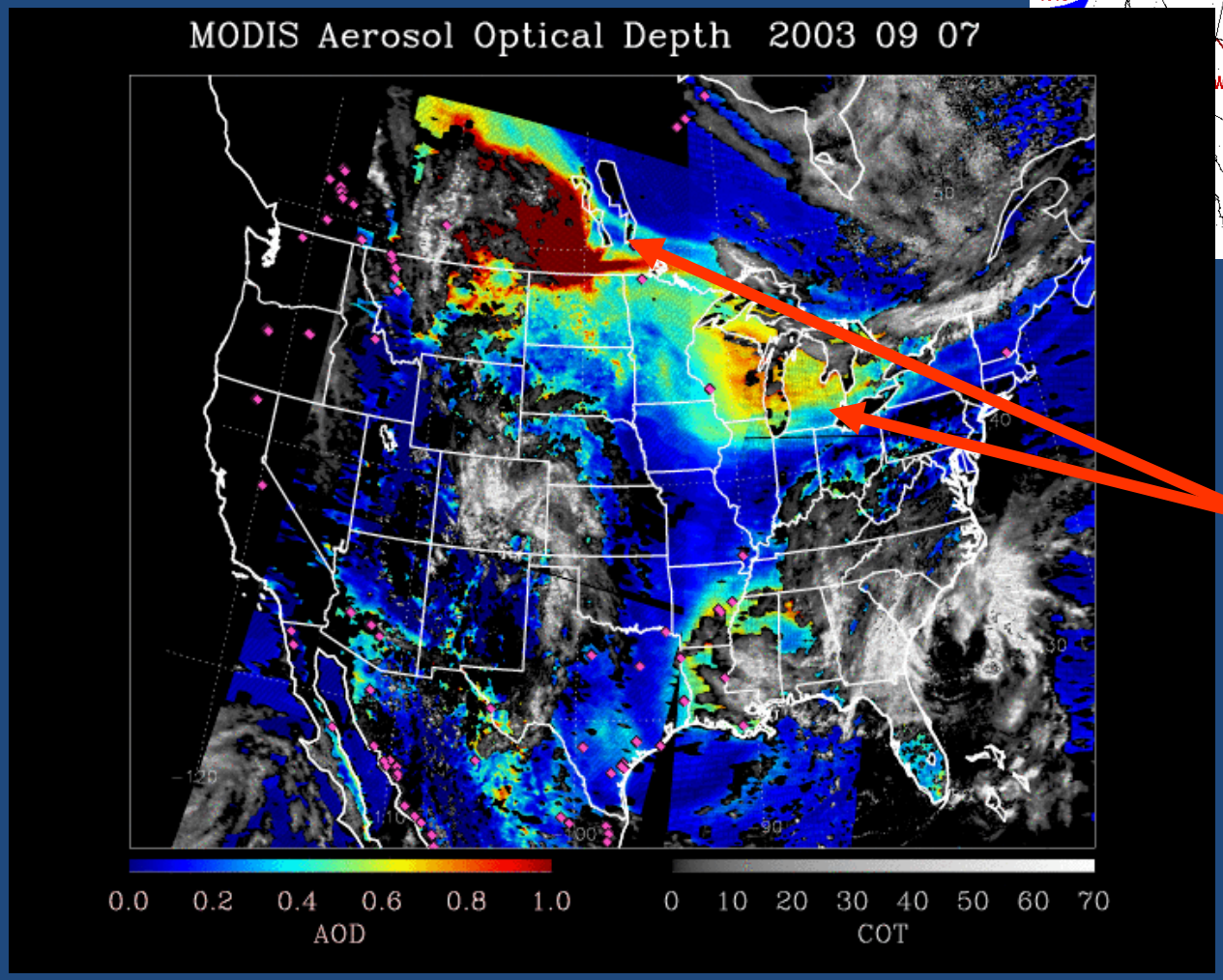
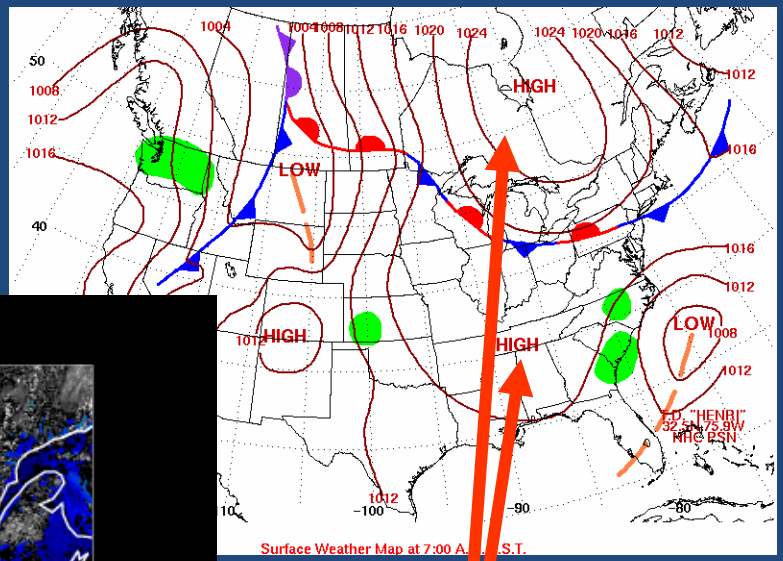


Elongation of high AOD along trough axis

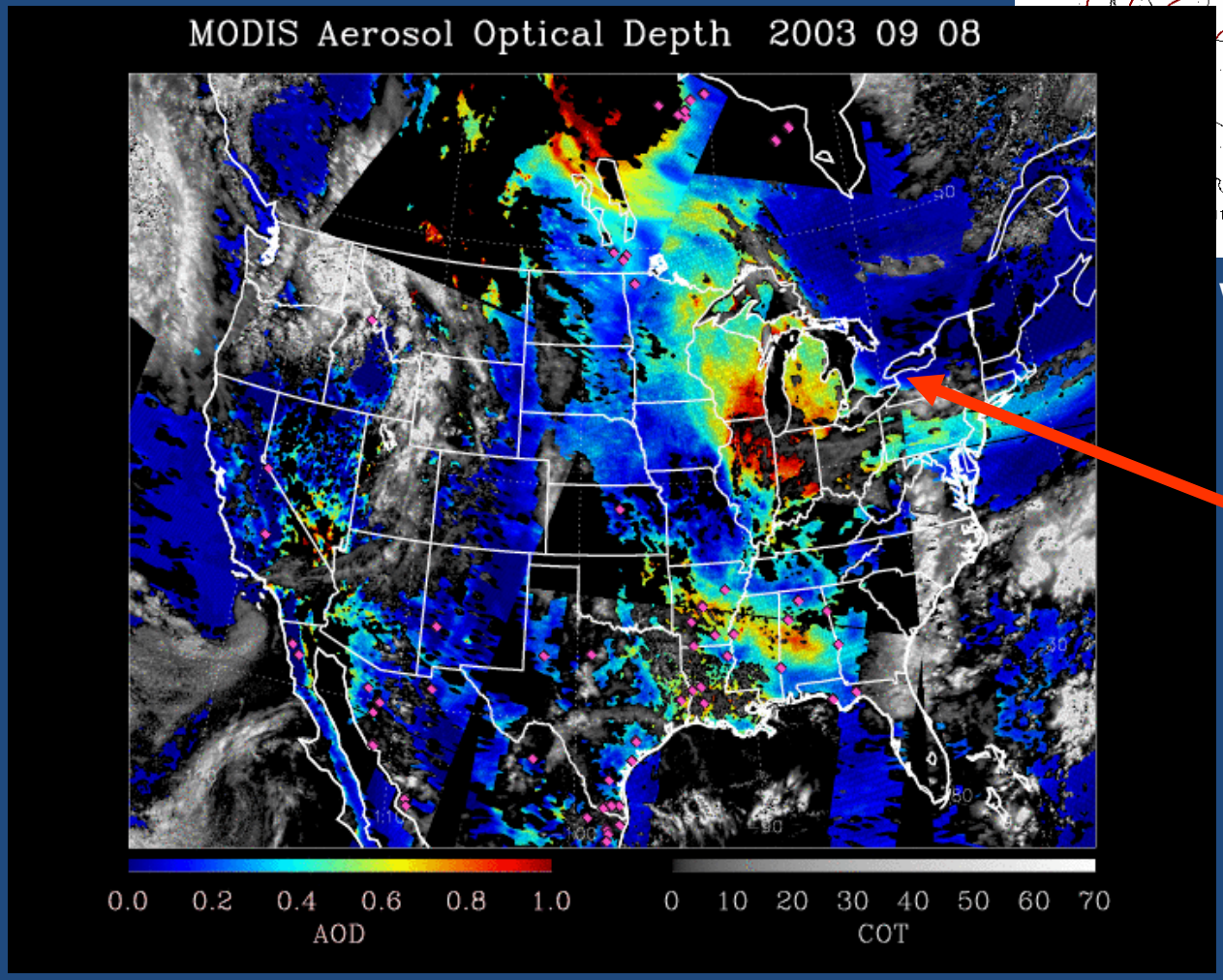
MODIS AOD: color contours

WF_ABBA Fire pixels: purple dots

September 8, 2003



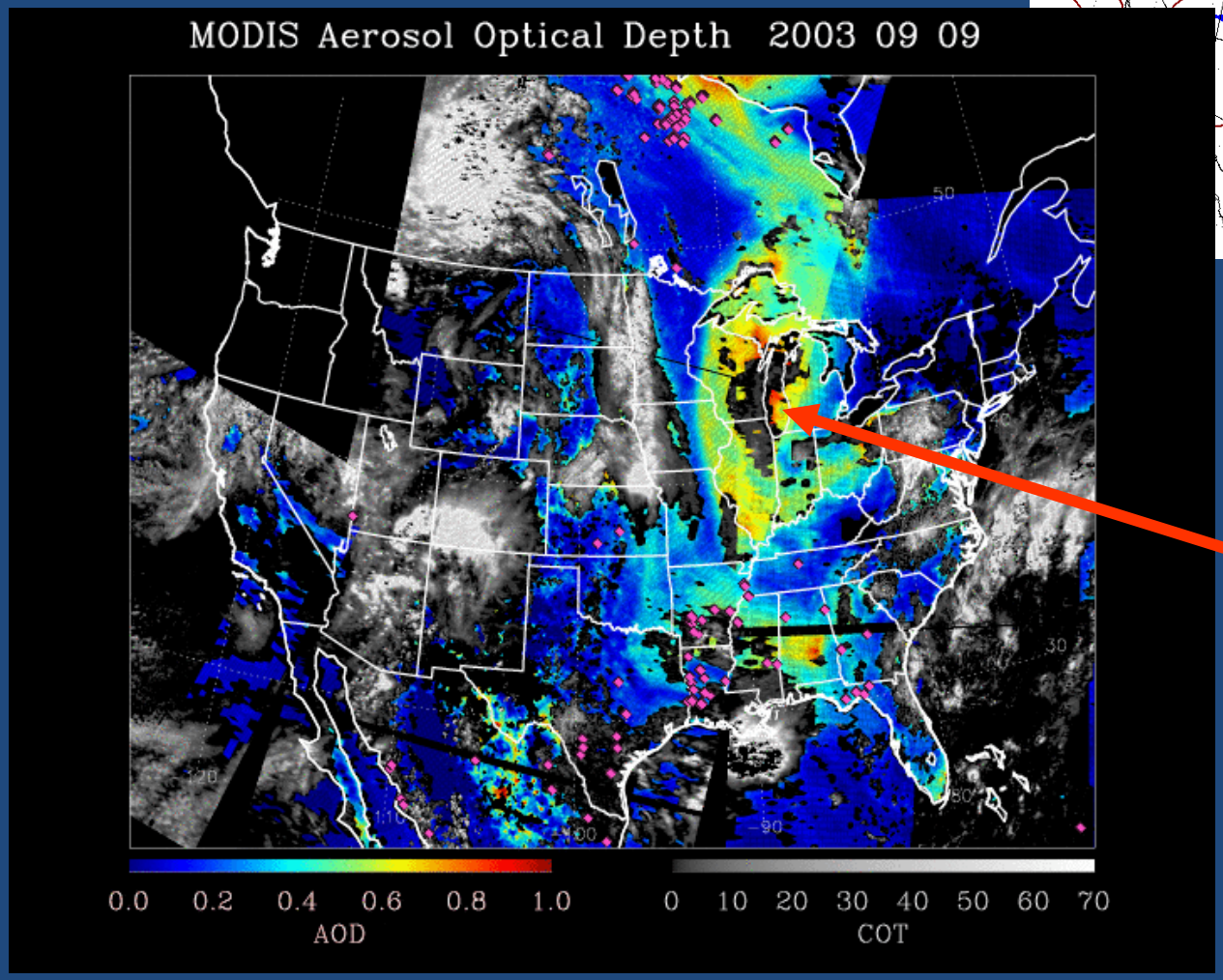
www.hpc.ncep.noaa.gov

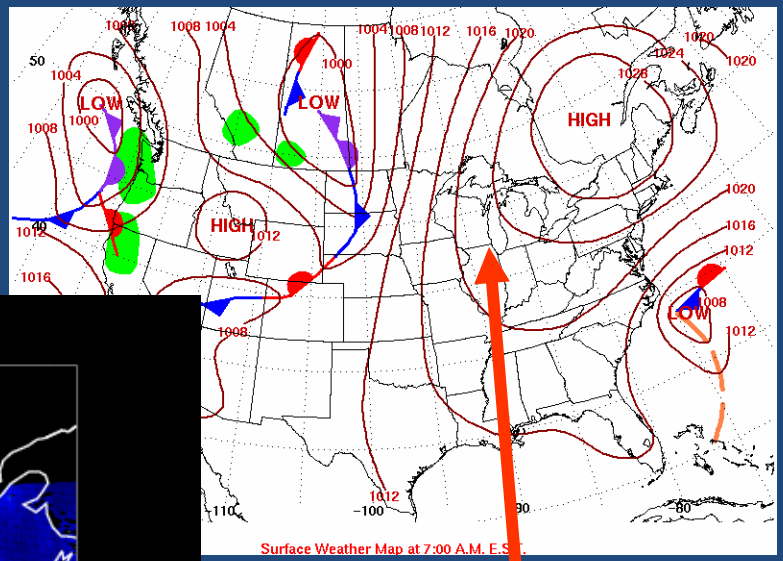


Development of high pressure systems over Canada and central US

MODIS AOD: color contours
WF_ABBA Fire pixels: purple dots

September 9, 2003





www.hpc.ncep.noaa.gov

Elevated AOD entrained into merging high pressure systems

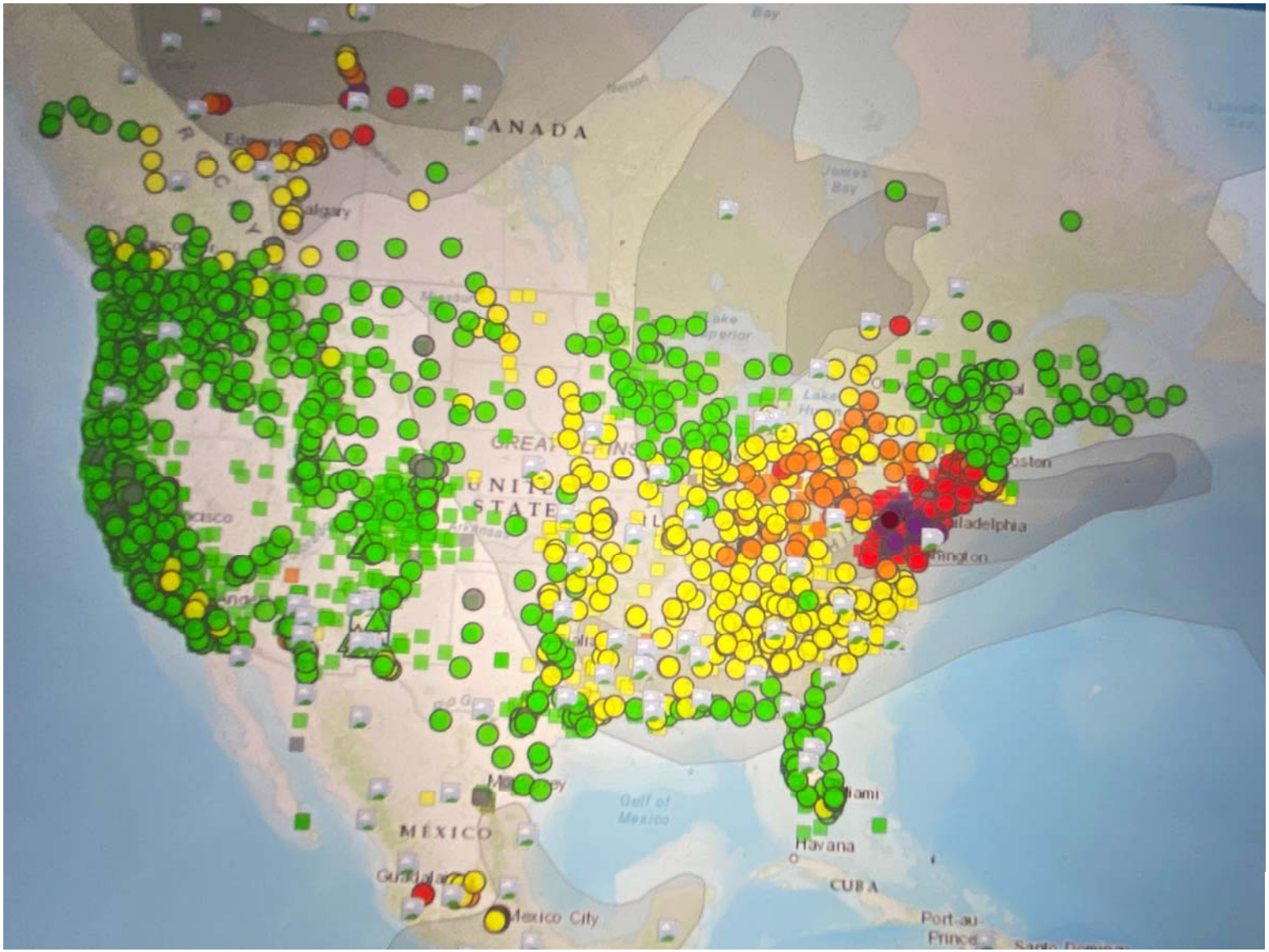
MODIS AOD: color contours
WF_ABBA Fire pixels: purple dots

Images of New York City

(June 2023)

Air Quality Forecast Map from Airnow.epa.gov

(June 8, 2023)



Primary Pollutant for St Louis is Ozone

AQI AIR QUALITY INDEX

Air Quality Index for Ozone

(Based on 8-hr average concentrations)

Index Values (Conc. Range)	Air Quality Descriptors	Who needs to be concerned	What should I do?
0 – 50 (0-54 ppb)	Good	It's a great day to be active outside.	
51 – 100 (55-70 ppb)	Moderate	Some people who may be unusually sensitive to ozone.	Unusually sensitive people: *Consider reducing* prolonged or heavy outdoor exertion. Watch for symptoms such as coughing or shortness of breath. These are signs to take it easier. Everyone else: It's a good day to be active outside.
101 – 150 (71-85 ppb)	Unhealthy for Sensitive Groups	Sensitive groups include people with lung disease such as asthma, older adults, children and teenagers, and people who are active out- doors.	Sensitive groups: *Reduce* prolonged or heavy outdoor exertion. Take more breaks, do less intense activities. Watch for symptoms such as coughing or shortness of breath. Schedule outdoor activities in the morning when ozone is lower. People with asthma should follow their asthma action plans and keep quick relief medicine
151 – 200 (86-105 ppb)	Unhealthy	Everyone	Sensitive groups: *Avoid* prolonged or heavy outdoor exertion. Schedule outdoor activities in the morning when ozone is lower. Consider moving activities indoors. People with asthma, keep quick-relief medicine handy. Everyone else: *Reduce* prolonged or heavy outdoor exertion. Take more breaks, do less intense activities. Schedule outdoor activities in the morning when ozone is lower.
201 – 300 (106- 200 ppb)	Very Unhealthy	Everyone	Sensitive groups: *Avoid all* physical activity outdoors. Move activities indoors or reschedule to a time when air quality is better. People with asthma, keep quick-relief medicine handy. Everyone else: *Avoid* prolonged or heavy outdoor exertion. Schedule outdoor activities in the morning when ozone is lower. Consider moving activities indoors.
301 – 500 (≥ 201 ppb)	Hazardous	Everyone	Everyone: *Avoid all* physical activity outdoors.

Updated on May 10, 2016

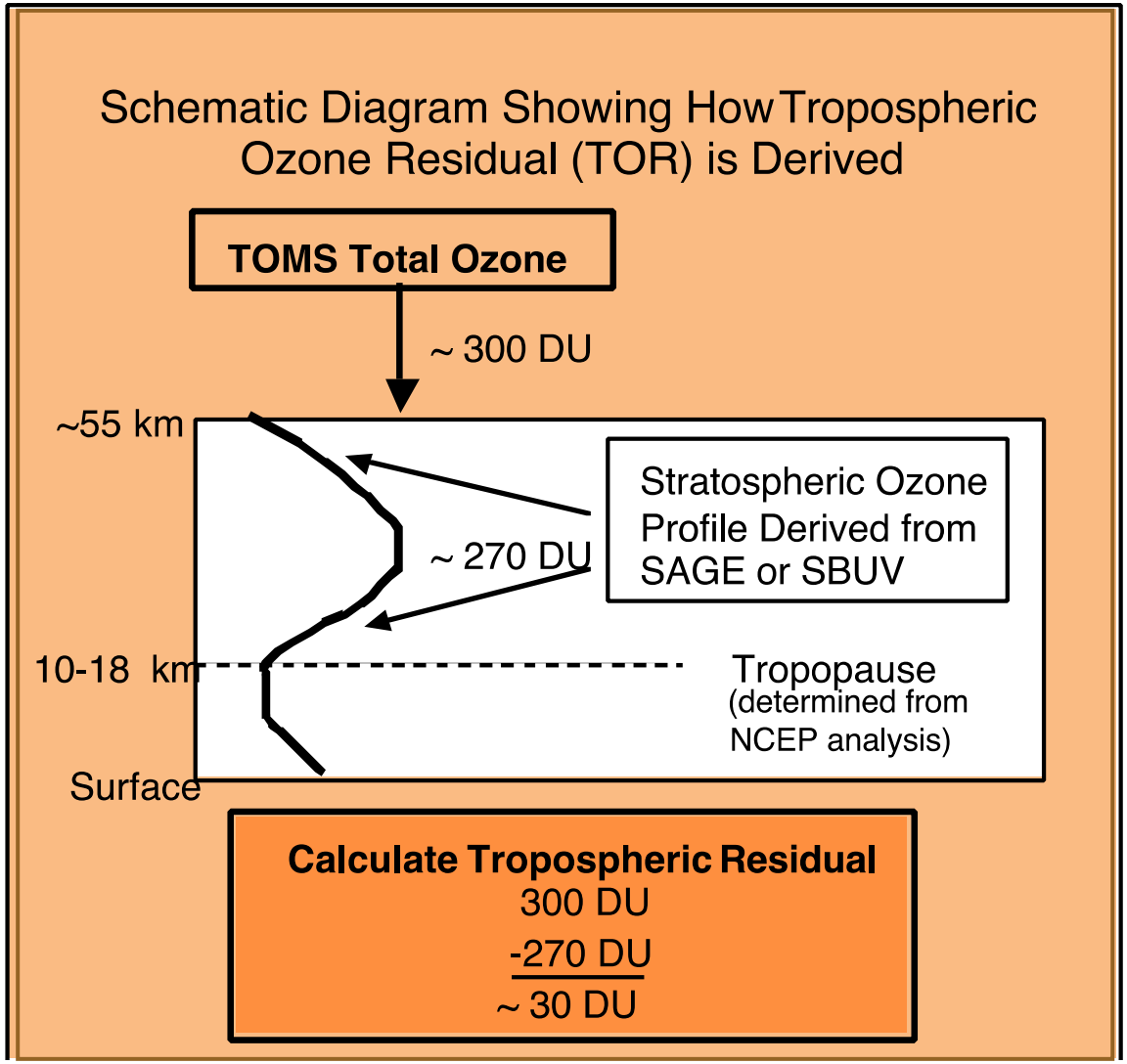
Primary Pollutant for St Louis is Ozone

AQI Category	Index Values	Breakpoints in the 2008 AQI (ppb, 8-hour average)	Updated Breakpoints (ppb, 8-hour average)
Good	0 - 50	0-59	0-54
Moderate	51 - 100	60-75	55-70
Unhealthy for Sensitive Groups	101 – 150	76-95	71-85
Unhealthy	151 – 200	96-115	86-105
Very Unhealthy	201 – 300	116-374	106-200
Hazardous	301 –500	375 to the Significant Harm Level*	201 to the Significant Harm Level*

**The Significant Harm Level for ozone is 600 ppb, two-hour average*

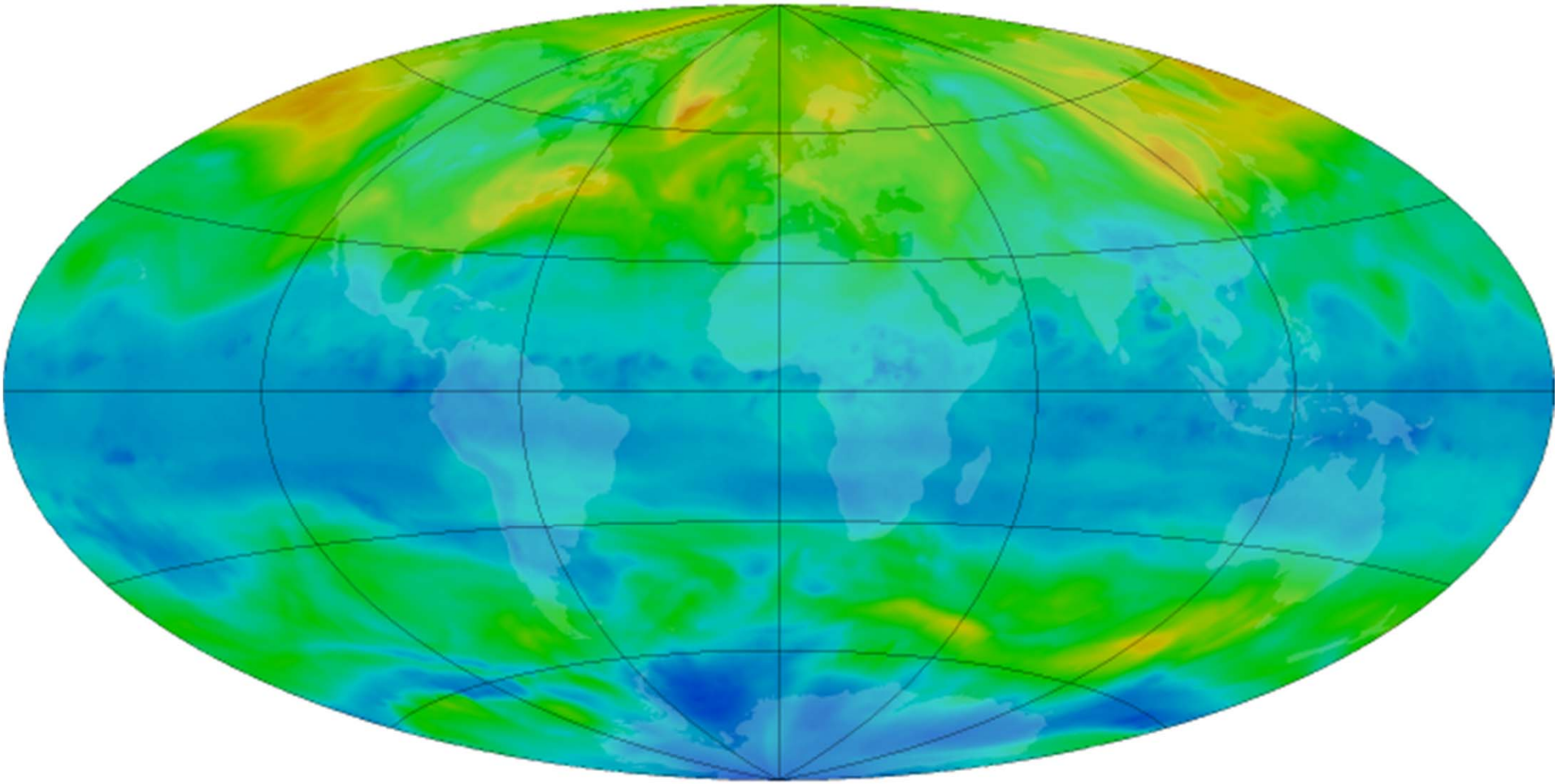
Used TOMS Satellite for Ozone Satellite Studies:

Only One Measurement per Day



Daily Total Ozone Map – June 8, 2023

Global Maps Generated from 1-day Coverage of the Entire Planet

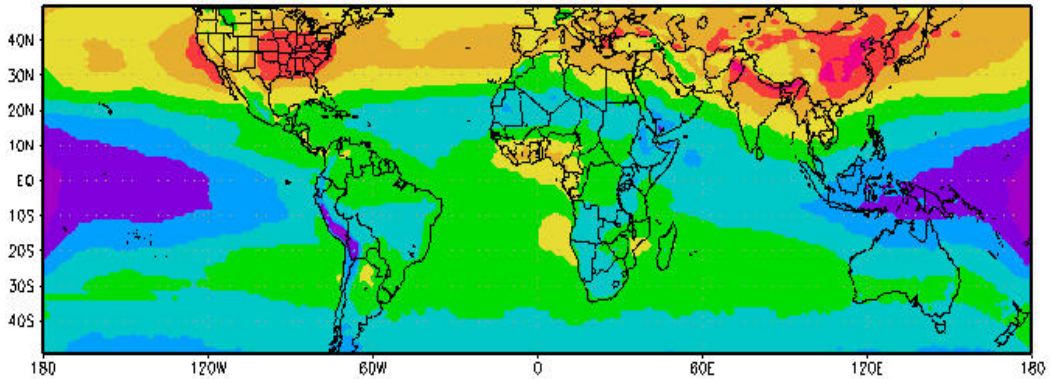


Satellites Provide Tools to See the Extent of Global Pollution:

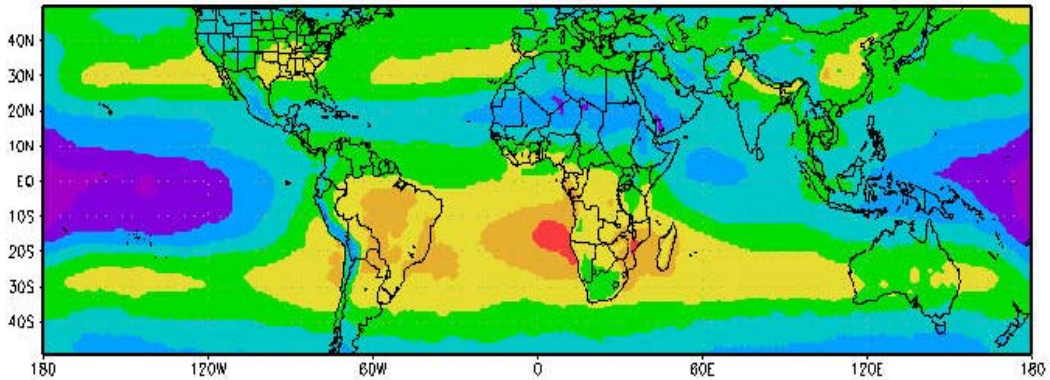
Source from Biomass Burning in Tropics Nearly as Large as Pollution from NH Industrial Emissions

- Summer smog dominant feature during NH summer

Pollution over Beijing

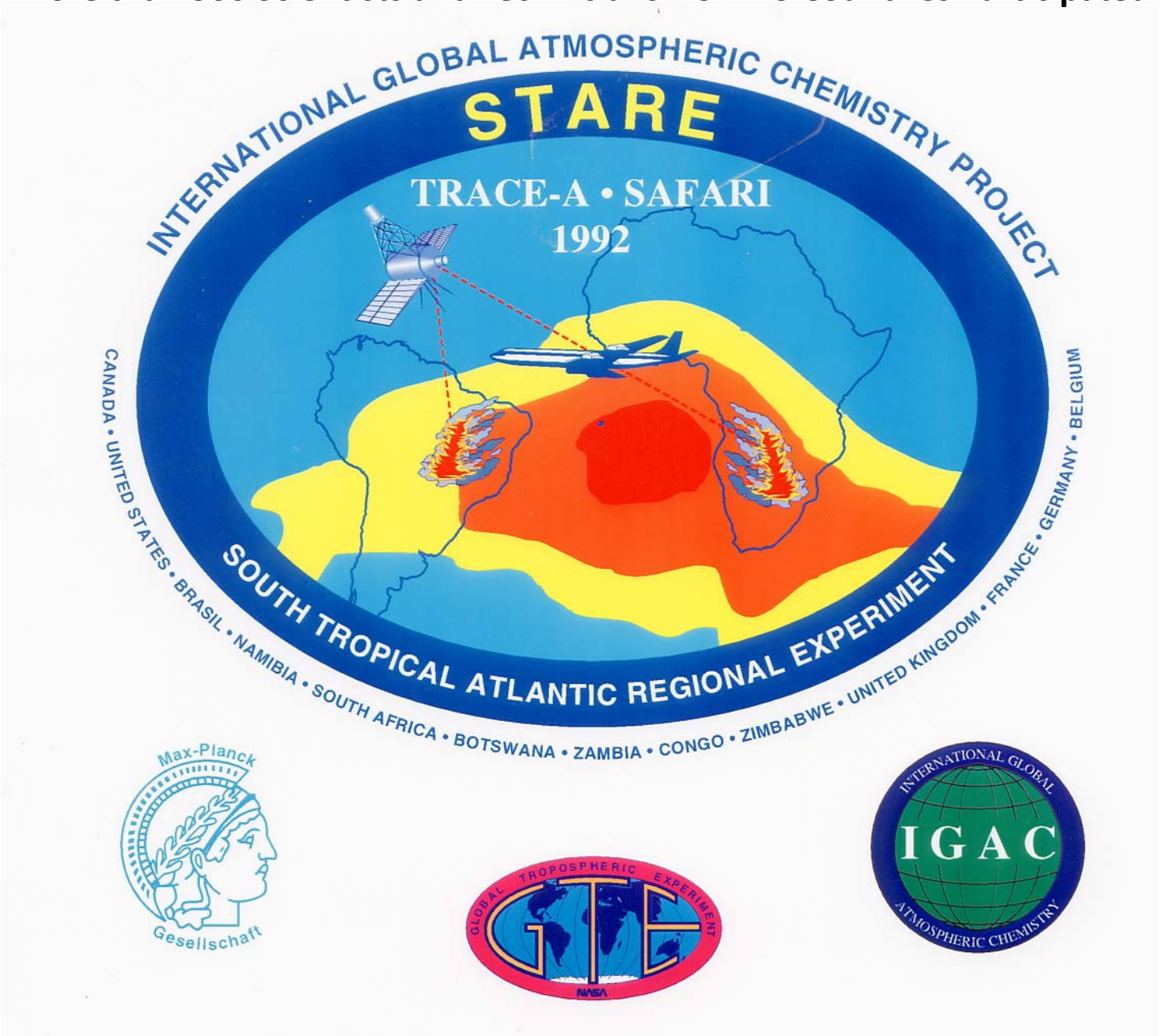


- African and South American biomass and savanna burning generate massive pollution plume during austral spring (Sep-Nov)



IGAC's STARE Mission:

More than 300 Scientists and Technicians from 13 Countries Participated



Satellite Finding led to Field Campaign to Study Origin of Pollution over South Atlantic

Key to Analysis was Ability to Derive "Synoptic" Scale Distribution from Surface Measurements

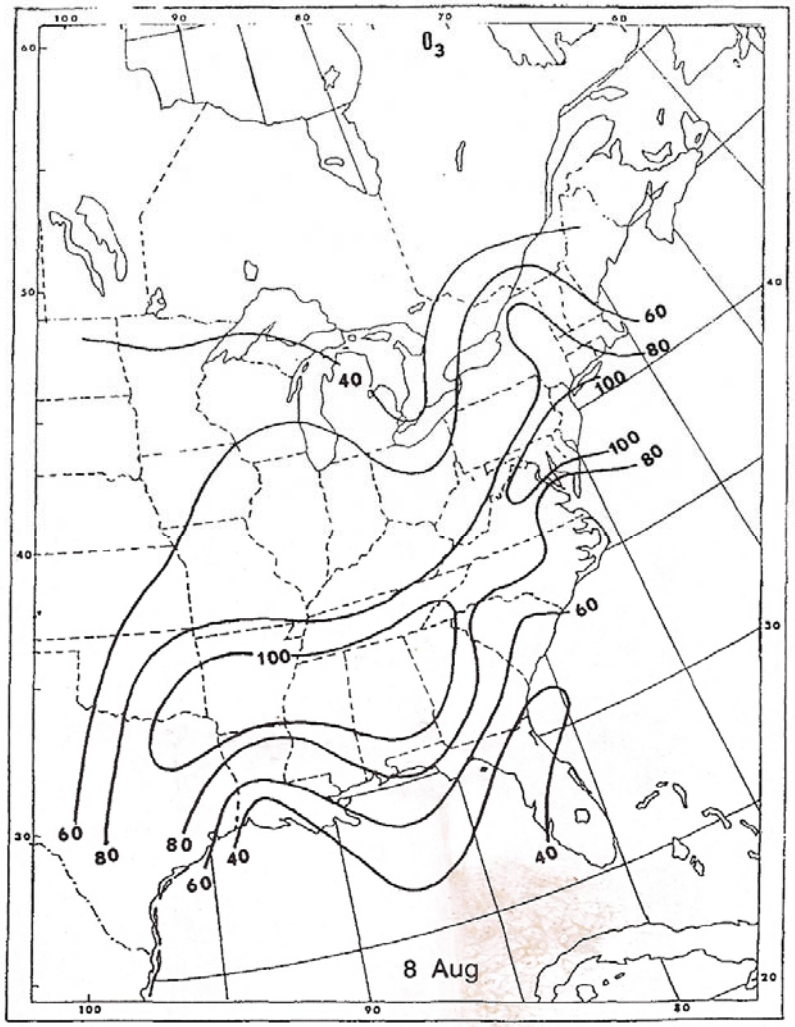
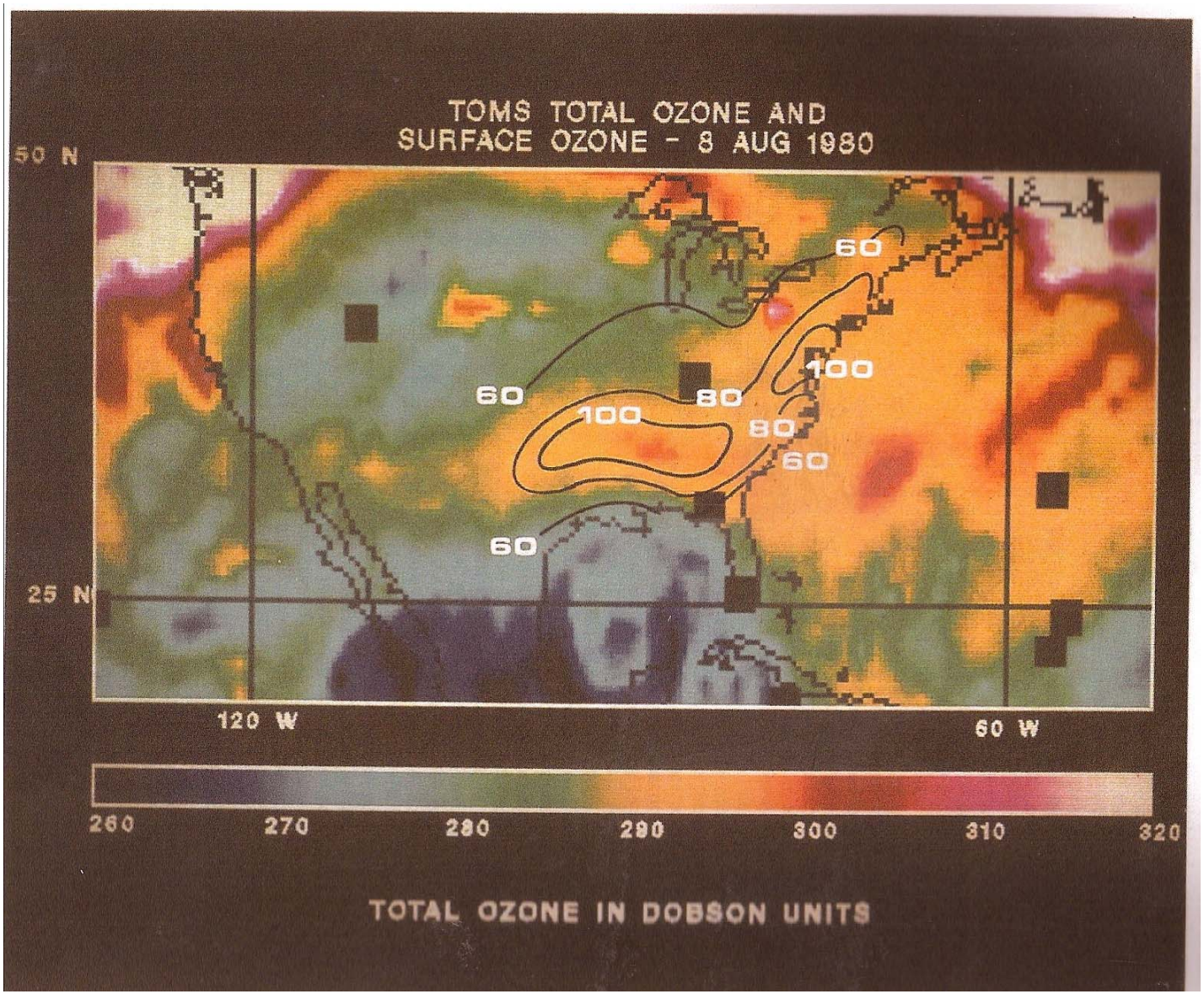


FIG. 3. (*Continued*)

Vukovich (in 1985 study) "…used data from individual sites that were carefully screened to avoid using measurements that might represent local pollution."

Total Ozone Distribution Influenced by What was Present at Surface



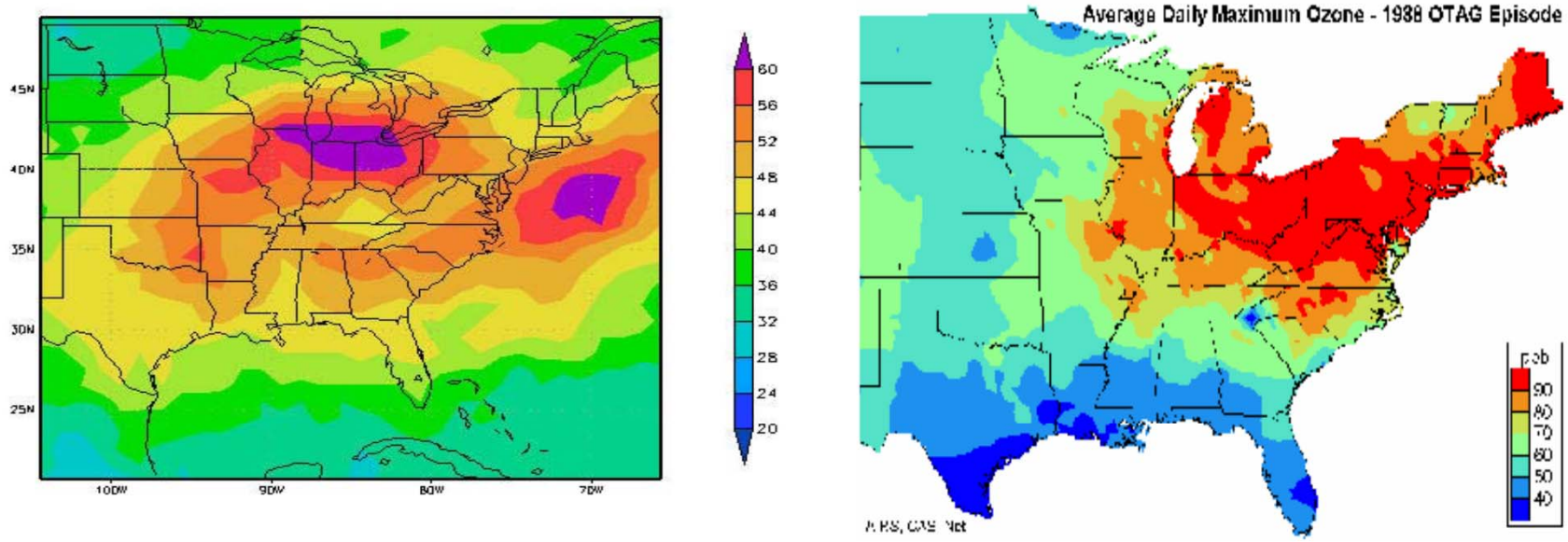


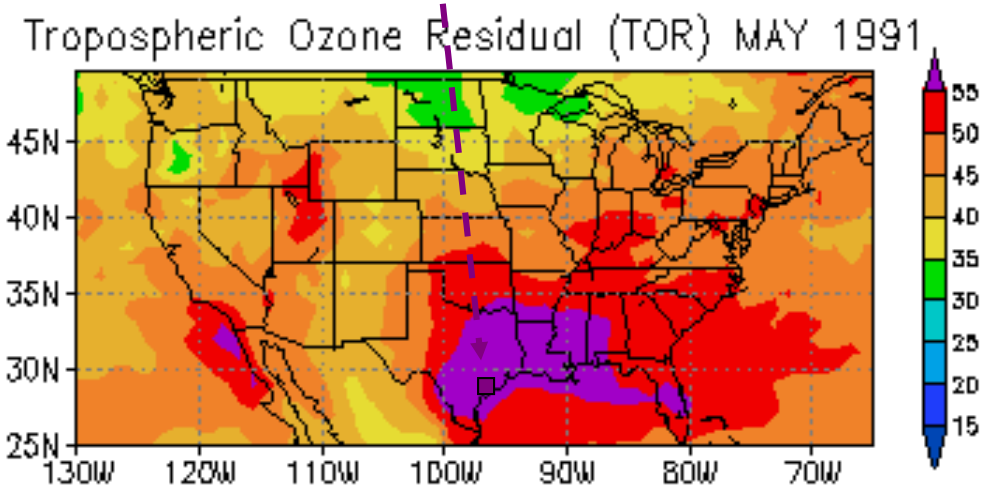
Fig. 4. Distribution of TOR during 2–13 July 1988, and analysis of average daily surface maximum ozone concentration during an air pollution episode over the eastern United States during the same days.

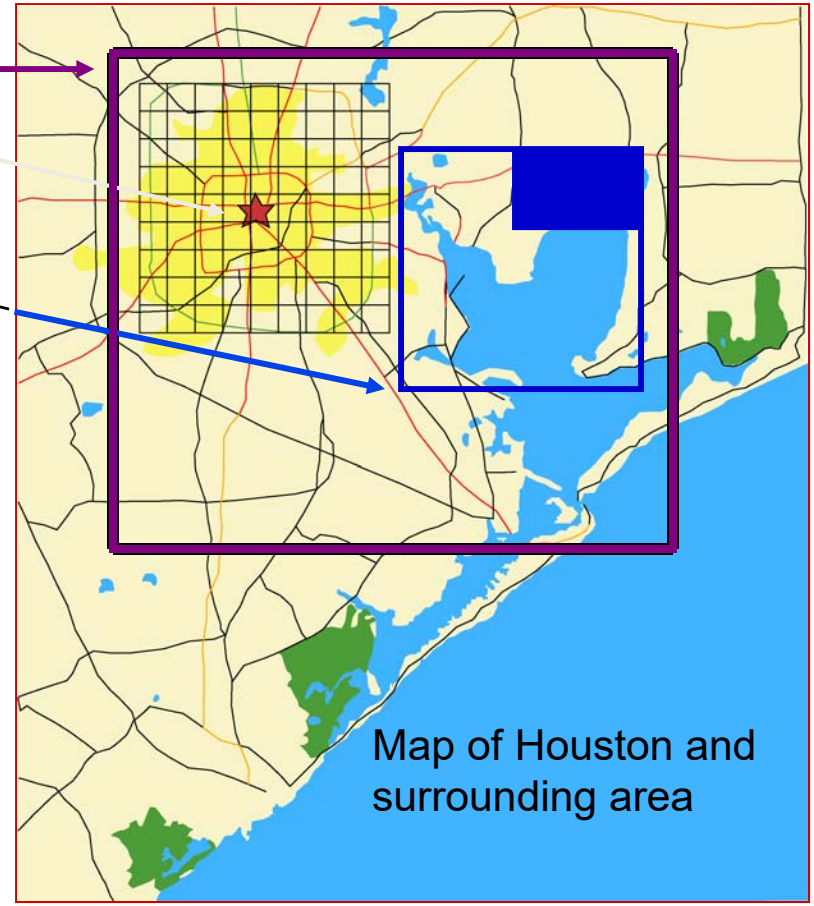
Best Method to Observe Pollution is from Geostationary Orbit

TOMS (Daily) 100-km res.

Geostationary (Hourly)

OMI (Daily)





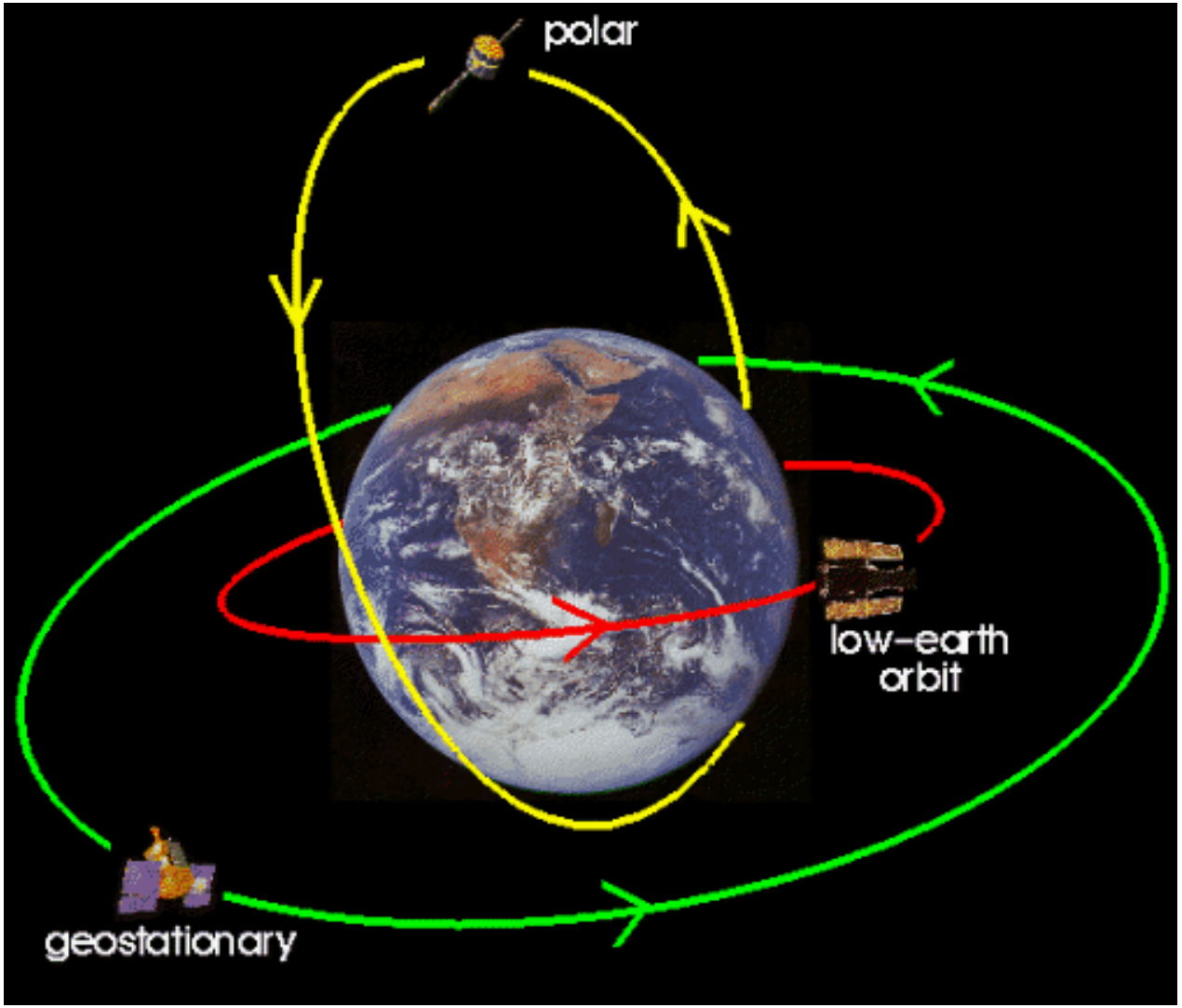
Technology Readily Available:

O_3, CO, NO_2, SO_2, CH_2O and aerosols

GEO-CAPE Recommended by NRC to be launched in 2013-2016 time frame

J. Fishman 09/2003

Sensors Must Be Launched into Geostationary Orbit to Obtain High Enough Resolution for Air Quality Studies



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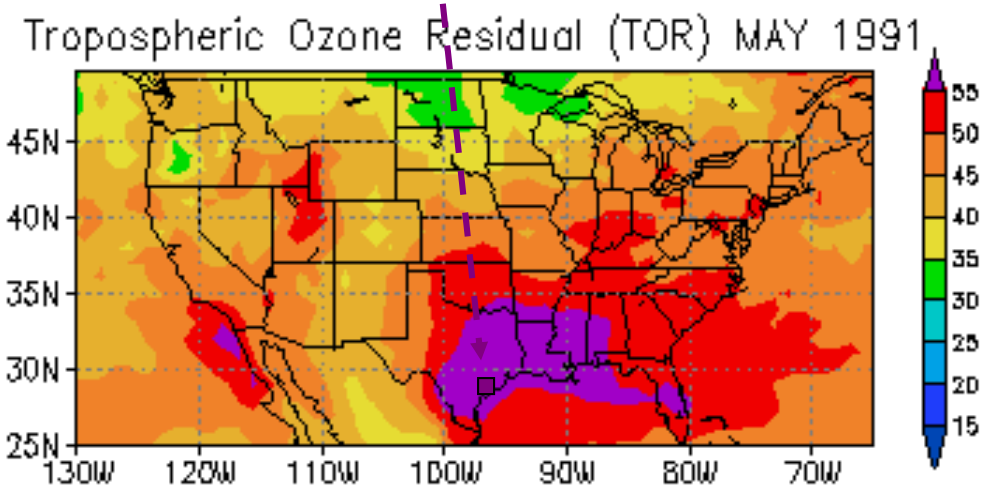

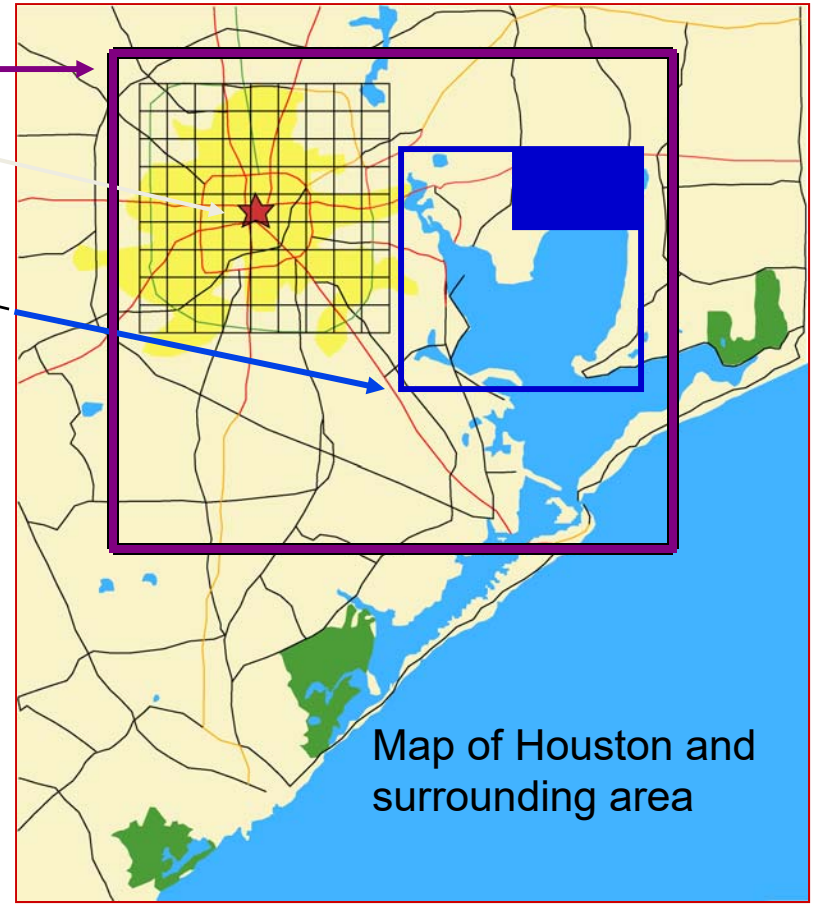

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J. Fishman 09/2003

Concept for Geostationary Air-Quality Measurements First Proposed in 1996 (GEO-TROPSAT)

Remote Sensing from Geostationary Orbit: GEO TROPSAT, A New Concept for Atmospheric Remote Sensing

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[b]NASA Goddard Space Flight Center

ABSTRACT

The Geostationary Tropospheric Pollution Satellite (GEO TROPSAT) mission is a new approach to measuring the critical constituents of tropospheric ozone chemistry: ozone, carbon monoxide, nitrogen dioxide, and aerosols. The GEO TROPSAT mission comprises a constellation of three instruments flying as secondary payloads on geostationary communications satellites around the world. This proposed approach can significantly reduce the cost of getting a science payload to geostationary orbit and also generates revenue for the satellite owners. The geostationary vantage point enables simultaneous high temporal and spatial resolution measurement of tropospheric trace gases, leading to greatly improved atmospheric ozone chemistry knowledge. The science data processing, conducted as a research (not operational) activity, will provide atmospheric trace gas data many times per day over the same region at better than 25 km ground footprint. The high temporal resolution identifies short time scale processes, diurnal variations, seasonal trends, and interannual variation.

Keywords: space mission design, atmospheric processes, geostationary, focal plane array applications, tropospheric pollution, secondary payload, communications satellite, GEO TROPSAT, Geo Express Pathfinder

Review:

Scientifically Excellent but No NASA had Never Flown on Commercial Satellite

GeoTRACE Proposed in 2001 and 2004

Submitted to
the NRC Decadal Study

Earth Science and Applications from Space

May 2005

Earth's First Time Resolved Mapping of Air Pollution Emissions and Transport from Space

Jack Fishman, Doreen Neil, James Crawford, R. Bradley Pierce
NASA

David Edwards
National Center for Atmospheric Research

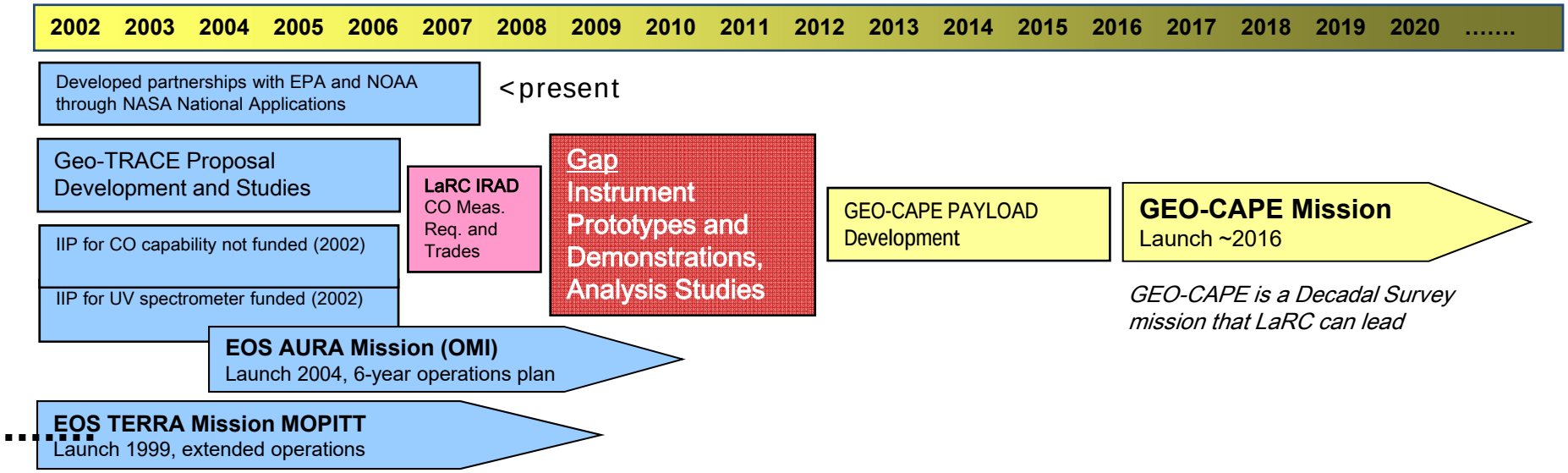
Kelly Chance, Thomas Kurosu
Harvard-Smithsonian Center for Astrophysics

W. Paul Menzel
NESDIS Senior Scientist
NOAA

Gary Foley
Director, National Exposure Research Laboratory
Rich Scheffe
Leader, Ambient Air Monitoring Group
US EPA

Langley Research Center

GEO-CAPE Mission



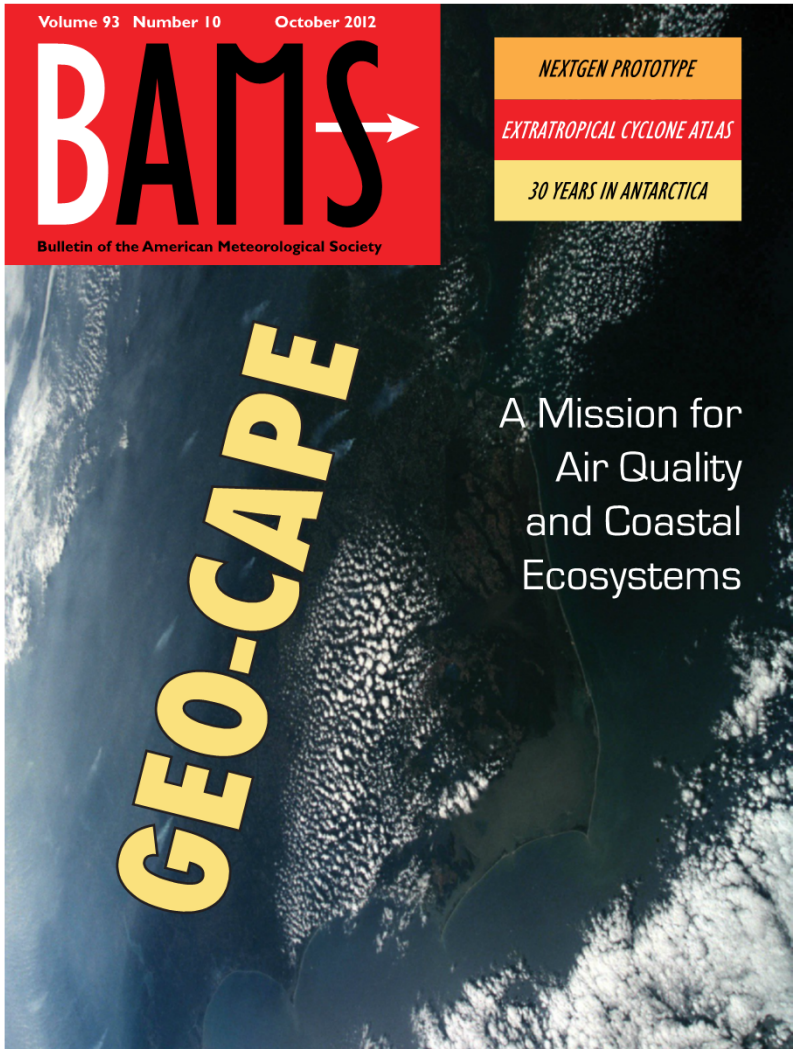
Status: * NASA LaRC developed the Geo-TRACE (Geostationary Observatory for Tropospheric Air Chemistry) mission concept and inter-Agency partnerships to use air quality measurements for societal benefit.
* We have a competitively selected partner to provide the payload and manage the mission.
* LaRC team demonstrated knowledge of EPA, NOAA data product requirements. LaRC created IDEA data fusion product for EPA, transitioned it to NOAA for operations, facilitated user request from EPA to NOAA for (unmet) trace gas measurements, supported EPA Remote Sensing Information Gateway, and formulated international science requirements (IGACO author).

NRC Study: **#1 Priority of Human Health Panel and #1 in Chemical Weather**
* Decadal Survey directs specific Aura and Terra heritage instruments: (1) Gas Filter Correlation Radiometry (GFCR, 2.3 and 4.7 um) for CO with MAPS (Shuttle) and MOPITT on Terra heritage (2) Backscatter UV-Visible Spectrometer (300-600 nm) for O3, NO2, HCHO, and aerosols with OMI on Aura heritage.

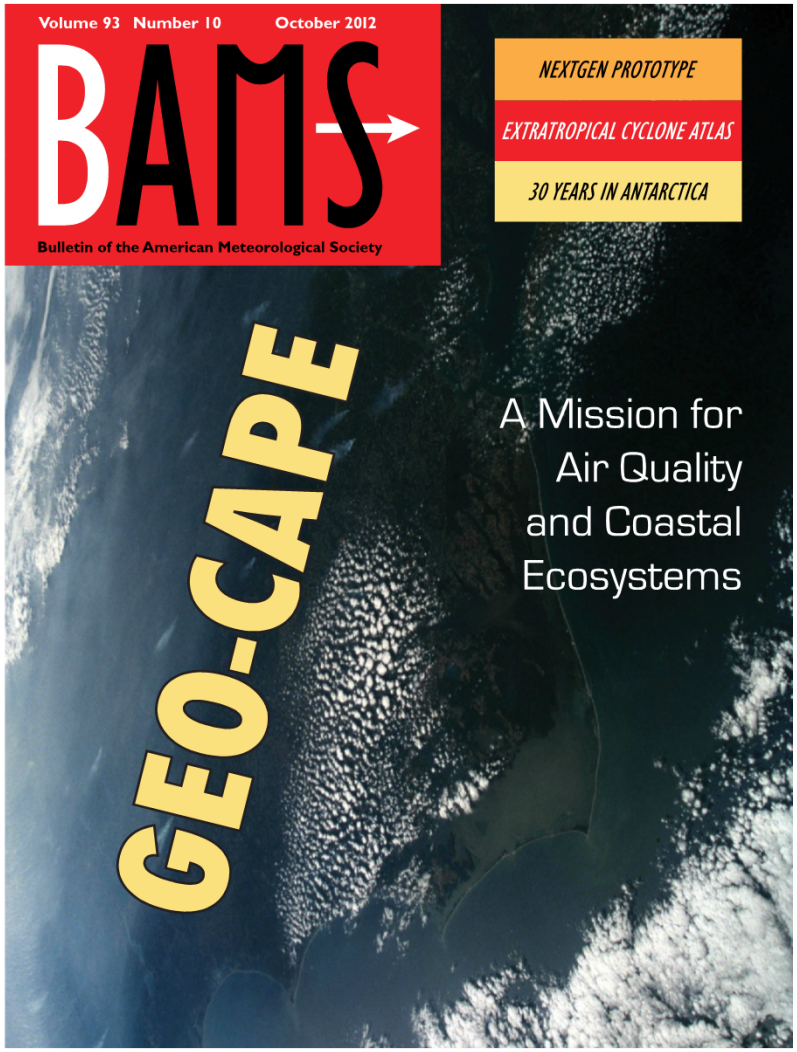
RFI White Paper cited in DS report: Earth's First Time Resolved Mapping of Air Pollution Emissions and Transport from Space, J. Fishman et al. (also submitted: Low-Earth-Orbit Global Mapping of Boundary Layer Carbon Monoxide, G. Sachse et al

Future Plan: * Perform mission analyses and formulation with partner.
* LaRC to demonstrate 2.3 um channel for the GFCR. Results relevant to ASCENDS, GACM.
* Seek HQ guidance for “Hitchhiker” to support affordable access to GEO orbit for GEO-CAPE, tech demos, GIFTS.

GEO-CAPE Recommended for Study as Future Mission by NRC's Decadal Study in 2007



GEO-CAPE Recommended for Study as Future Mission by NRC's Decadal Study in 2007



One Problem:

Cost of GEO-CAPE would be $1.5-2.0B

THE UNITED STATES' NEXT GENERATION OF ATMOSPHERIC COMPOSITION AND COASTAL ECOSYSTEM MEASUREMENTS

NASA's Geostationary Coastal and Air Pollution Events (GEO-CAPE) Mission

by J. Fishman, L. T. Iraci, J. Al-Saadi, K. Chance, F. Chavez, M. Chin, P. Coble, C. Davis, P. M. DiGiacomo, D. Edwards, A. Eldering, J. Goes, J. Herman, C. Hu, D. J. Jacob, C. Jordan, S. R. Kawa, R. Key, X. Liu, S. Lohrenz, A. Mannino, V. Natraj, D. Neil, J. Neu, M. Newchurch, K. Pickering, J. Salisbury, H. Sosik, A. Subramaniam, M. Tzortziou, J. Wang, and M. Wang

GEO-CAPE will measure tropospheric trace gases and aerosols and coastal ocean phytoplankton, water quality, and biogeochemistry from geostationary orbit to benefit air quality and coastal ecosystem management.

Proposed Solution: Launch GEO-CAPE in "Pieces"

PROGRESS TOWARD IMPLEMENTATION OF THE GEO-CAPE MISSION. The DS defined GEO-CAPE as a "tier 2" mission that could be implemented with mature instrumentation that had significant space heritage in LEO. The implied mission implementation would be similar to current Earth science missions such as *Terra*, *Aqua*, and *Aura* with multiple instruments on one large spacecraft. Although this implementation approach for GEO-CAPE was studied and found to be technically feasible, the total mission cost would be ~$2 billion.

Using Commercial Communication Satellites

The phased implementation concept being studied has instrumentation launched on separate satellites. The first launch would be a risk-reduction pathfinder mission in the 2017 time frame to demonstrate that a GEO-CAPE-hosted payload implementation approach is viable programmatically, technically, and scientifically. A significant goal of this mission is to demonstrate that GEO-CAPE science measurements are attainable using a COMSAT-hosted payload. Therefore, the risk-reduction payload must be capable of making GEO-CAPE science measurements, in addition to being low cost and low risk. One concept for this pathfinder payload is an instrument for measuring atmospheric CO. This first segment of a phased mission implementation could be accomplished for a total cost of ~$150 million and would allow NASA to assess the feasibility of using the hosted-payload approach for the remainder of the GEO-CAPE mission implementation.

The Launch of TEMPO

(Tropospheric Emissions: Measurement of Pollution; April 7, 2023):

NASA's First Mission Primarily Devoted to the Improvement of U.S. Air Quality

TEMPO is the First Phase of the Phased-Implementation Plan Described in Fishman et al. (2012)

https://video.search.yahoo.com/yhs/search?fr=yhs-infospace-050&ei=UTF-8&hsimp=yhs-050&hspart=infospace&param1=ccfumfwe0twkxv040lswdcyt&p=nasa+tempo+launch&type=ud-c-us--s-p-wgimboia--exp-none--subid-none -id=1&vid=337761b3bc22b4659ddb35633f1c7f0e&action=click

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