3D Air Quality and the Clean Air Interstate Rule:

Air Quality Event Case Studies for Baltimore, MD and Development of Metrics of Source Attribution

Stephanie Weber

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Battelle
The Business of Innovation

National Air Quality Conference

Portland, Oregon

9 April 2008

Outline

- Introduction
- Datasets and Methodology
- Results
  - Event Summaries
    - August 24/25, 2004
    - July 22, 2004
  - Proposed Metrics using Source Region Analysis and Simplified ΔAOD Method
- Conclusions and Recommendations

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Background

- 2003-2004: Assessment of source apportionment methods and recognition of a gap in determining source areas of PM

TECHNICAL PAPER

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Compilation and Assessment of Recent Positive Matrix Factorization and UNMIX Receptor Model Studies on Fine Particulate Matter Source Apportionment for the Eastern United States

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"The weakness of back trajectories is difficulty identifying where the modeled packet of air encountered the pollutants…"

ods is now an important component of the information available to decision makers when evaluating the new standards. This literature compilation summarizes a subset of the source apportionment research and general findings on fine particulate matter in the eastern half of the United States using Positive Matrix Factorization. The results between studies are generally comparable when comparable datasets are used; however, methodologies vary considerably. Commonly identified source categories include: secondary sulfate/coal burning (sometimes over 50% of total mass), secondary organic carbon/mobile sources, crustal sources, biomass burning, nitrate, various industrial processes, and sea salt. The source apportionment tools and methodologies have passed the proof-of-concept stage and are now being used to understand the ambient composition of particulate matter for sites across the United States and the spatial relationship of sources to the receptor. Recommendations are made for further and standardized method development for source apportionment studies, and specific research areas of interest for the eastern United States are proposed.

IMPLICATIONS
This literature compilation and analysis demonstrates that the source apportionment methods presented can be used with consistency in similar locations and are valuable tools for compiling relevant data. The apportionment results can be used in conjunction with back-trajectory tools by regulatory state and local agencies to attribute $PM_{2.5}$ to various local sources and upwind locations during attainment evaluations.

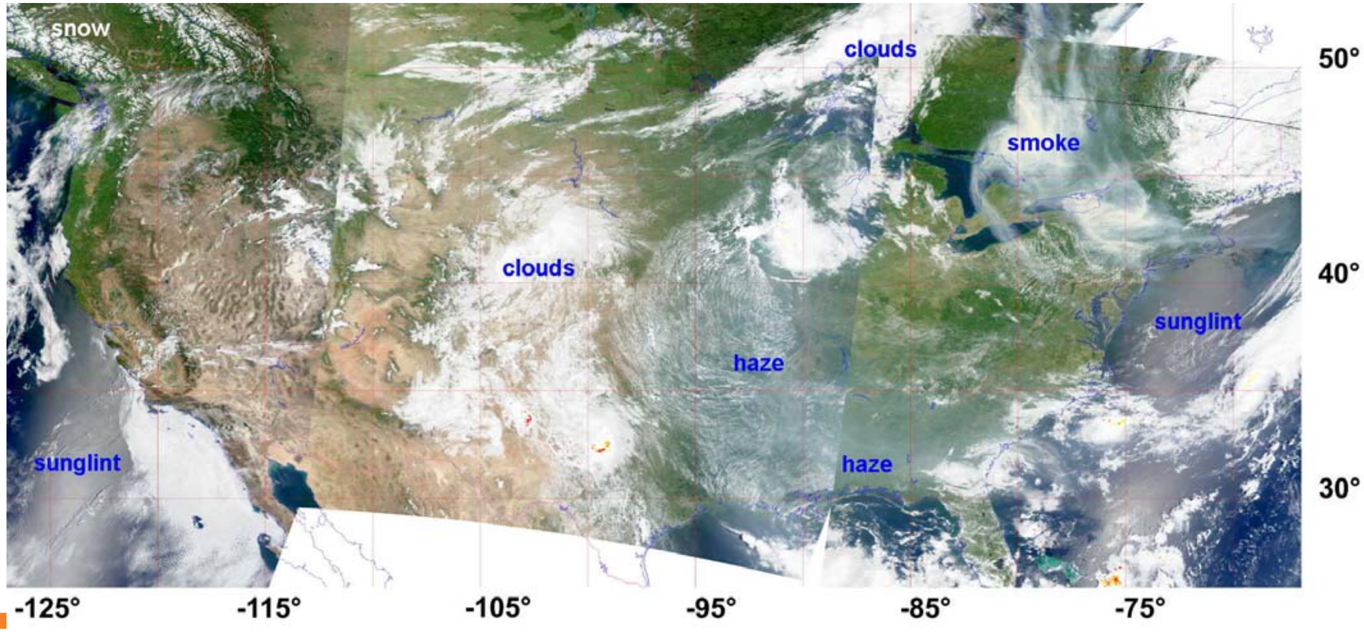
protection against health effects associated with short term fine particulate exposure.[2] EPA also issued rules related to an expanded monitoring network for $PM_{2.5}$ so that cities could evaluate their compliance with the new standards.[3] Challenges to the regulations, resolved by the Supreme Court in 1999, delayed implementation, but many cities now face compliance requirements within the next few years. Requirements are not restricted to urban areas; large national parks and wilderness areas (Class I areas) also have visibility requirements, which are directly linked to particulate matter levels.

In any particular urban or Class I area, determining the sources of ambient particulate matter has become increasingly important as the regulations tighten and become more focused on $PM_{2.5}$. Although local sources can be monitored and are subject to local control regulations, particulate matter that has been transported into the region cannot easily be monitored or controlled. Research in the late 1990s began to indicate that transport could be a major source of $PM_{2.5}$ in some areas. Quantifying the sources of particulate matter in a particular region (source apportionment) is important for decision makers when evaluating compliance with the new standards, particularly the Clean Air Interstate Rule (CAIR) (70 FR 25162). CAIR caps the generation of pollutants likely to be transported across state boundaries—sulfur dioxide (SO_2) and nitrogen oxides (NO_x)—in 28 eastern U.S. states and the District of Columbia. Reductions from CAIR will begin in 2010 and are expected to be fully realized by 2015.

This literature compilation is designed to summarize a subset of source apportionment research and its general findings. The literature in this compilation is representative of the key source apportionment research, focusing

Background

- 2003-2004: Assessment of source apportionment methods and recognition of a gap in determining source areas of PM
- 2003-2004: Application of satellite data semi-quantitatively to document air pollution transport in support of development of CAIR



Background

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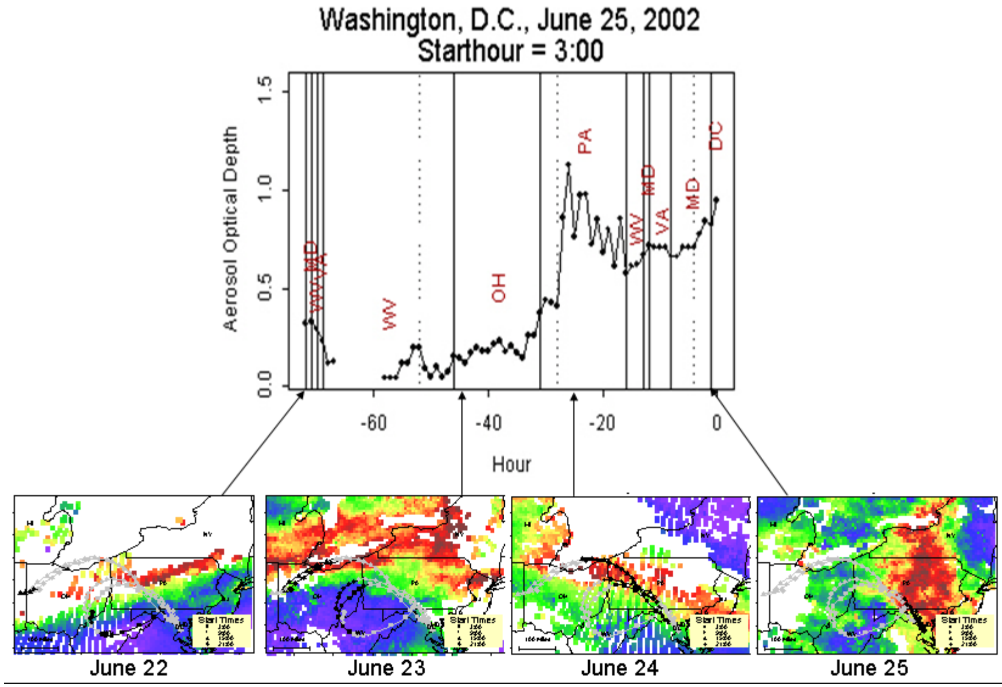
- 2004-2005: Development of integrated satellite data source analysis methodology and improved understanding of quantitative relationships between dataset



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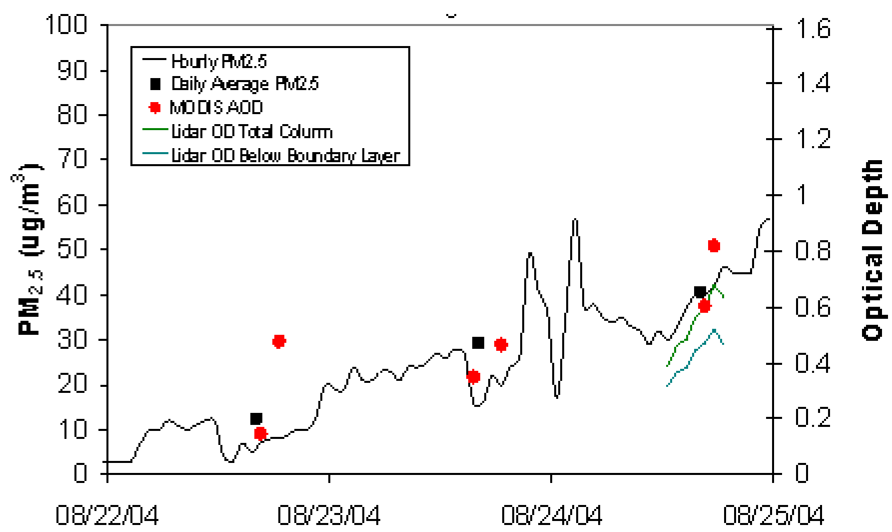
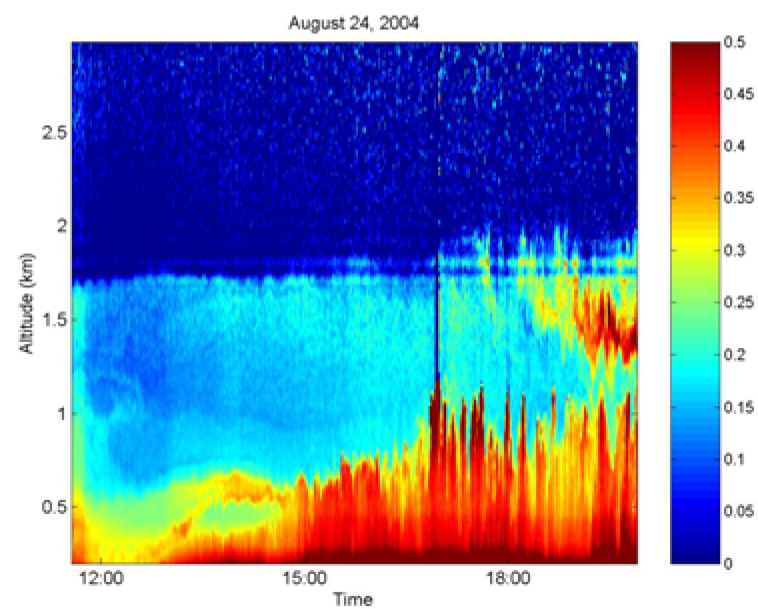
- 2004-2005: Development of integrated satellite data source analysis methodology and improved understanding of quantitative relationships between dataset
- 2005-2006: Integration of lidar and 3-dimensional data in satellite and ground-based air quality data





Purpose of CAIR Accountability Assessment

- Demonstrate an integrated monitoring network of ground-based and satellite sensors that can enhance understanding of air pollution transport.
  - Quantify fine particle and sulfate contributions from identified source regions
  - Provide new information about source characteristics of particulate air pollution events
- Develop metrics for measuring accountability of the CAIR in reducing pollutant transport across state borders

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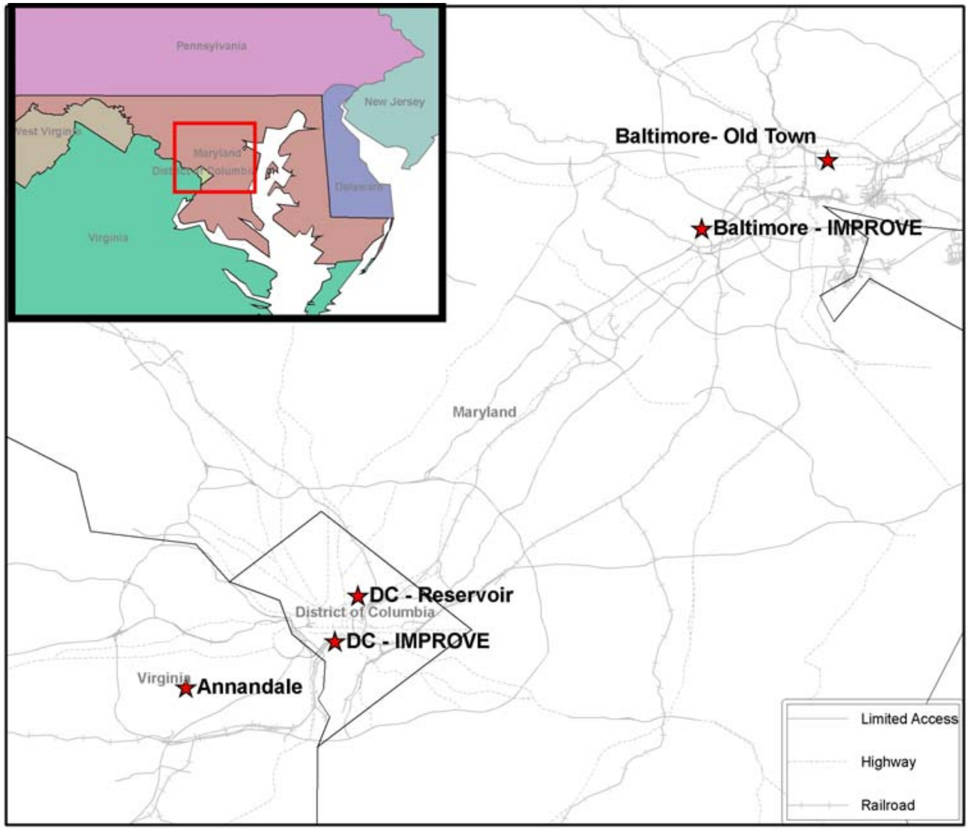
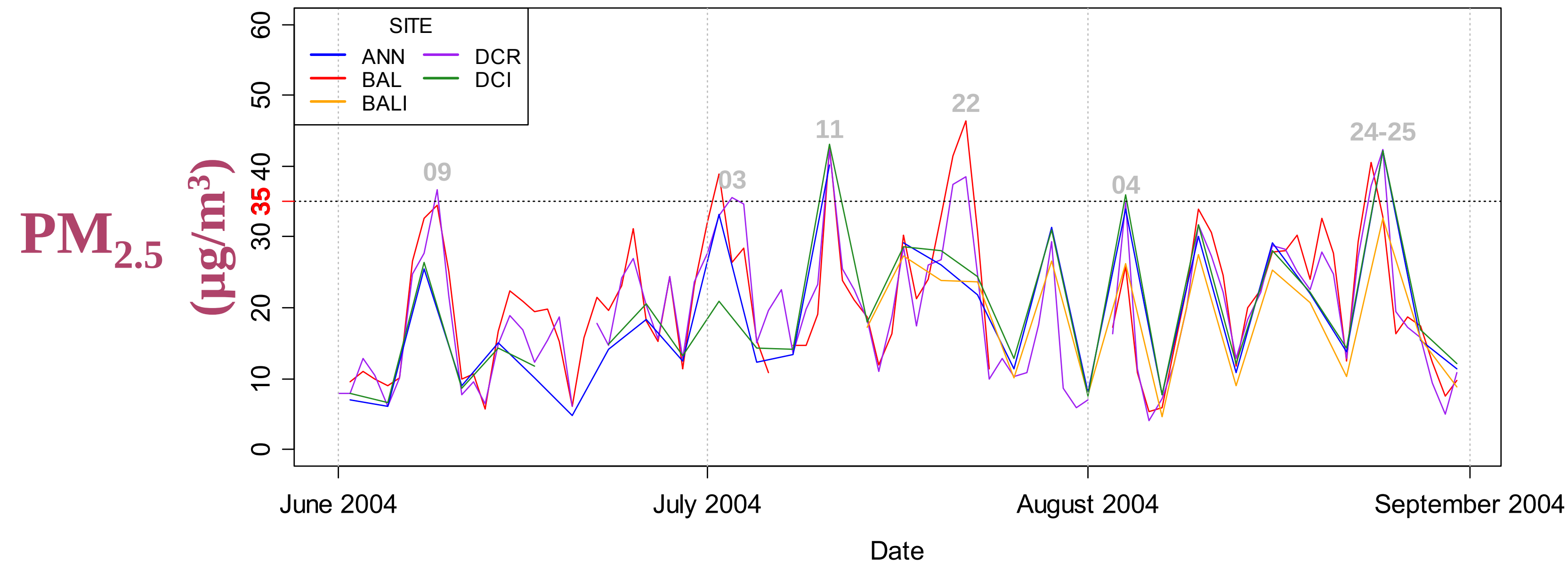
Surface Monitor Sites

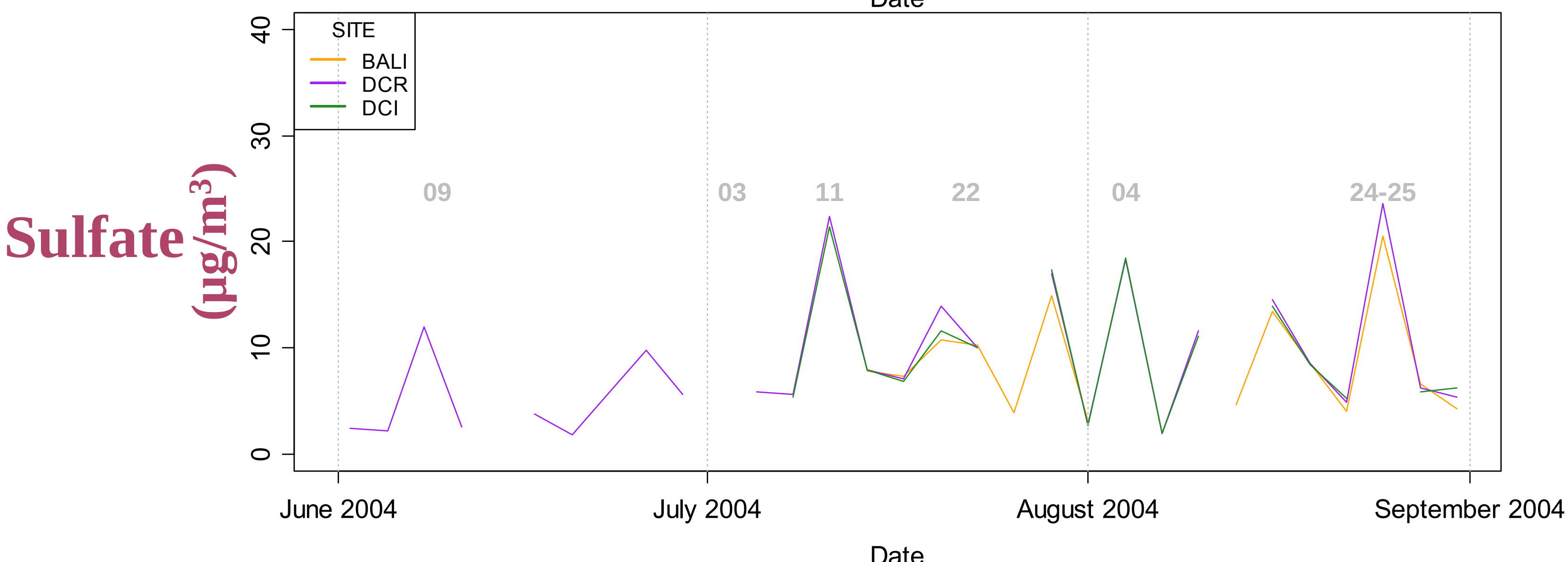
- **24 hour average $_{2.5}$ concentrations recorded using the filter-based Federal Reference Method (FRM)**
- **Continuous Tapered Element Oscillating Microbalance (TOEM) instruments provide hourly averaged $PM_{2.5}$ concentrations**



- **Annandale (ANN)**
  - *24 hour $PM_{2.5}$*
  - *1 hour $PM_{2.5}$*
- **Baltimore (BAL)**
  - *24 hour $PM_{2.5}$*
  - *1 hour $PM_{2.5}$*
- **Baltimore- IMPROVE (BALI)**
  - *24 hour $PM_{2.5}$*
  - *Sulfate*
- **Washington, DC (DCR)**
  - *24 hour $PM_{2.5}$*
  - *1 hour $PM_{2.5}$*
  - *Sulfate*
- **Washington, DC- IMPROVE (DCI)**
  - *24 hour $PM_{2.5}$*
  - *Sulfate*

Summer 2004


$PM_{2.5}$
(µg/m³)
60
50
40
35
30
20
10
0
SITE
ANN
BAL
BALI
DCR
DCI
09
03
11
22
04
24-25
June 2004
July 2004
August 2004
September 2004
Date


Sulfate
(µg/m³)
40
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SITE
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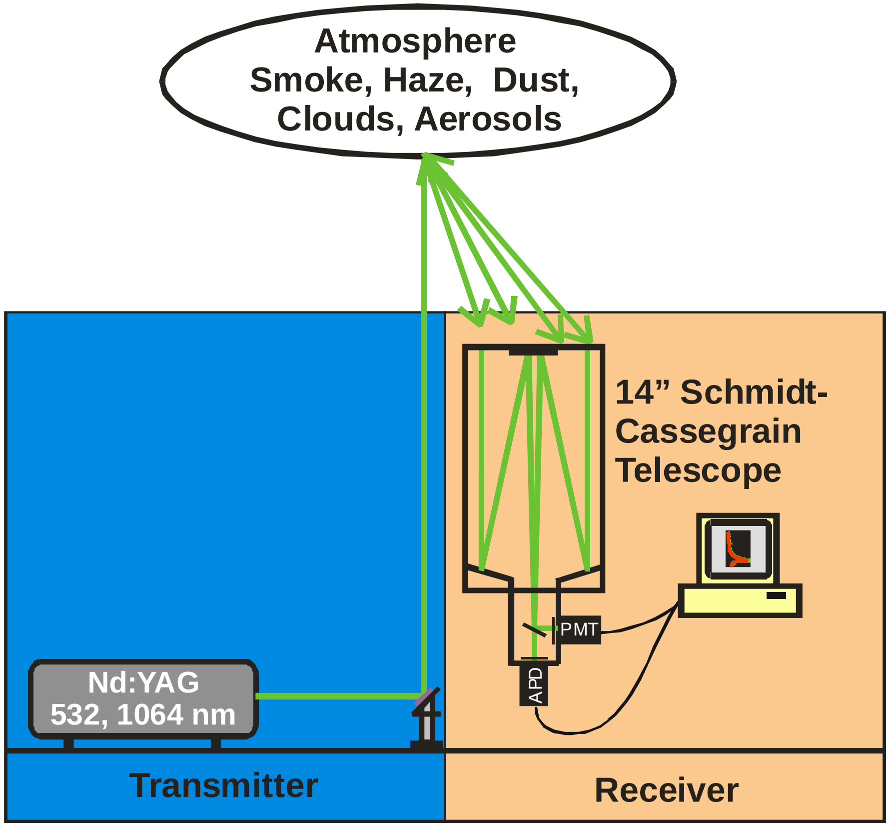
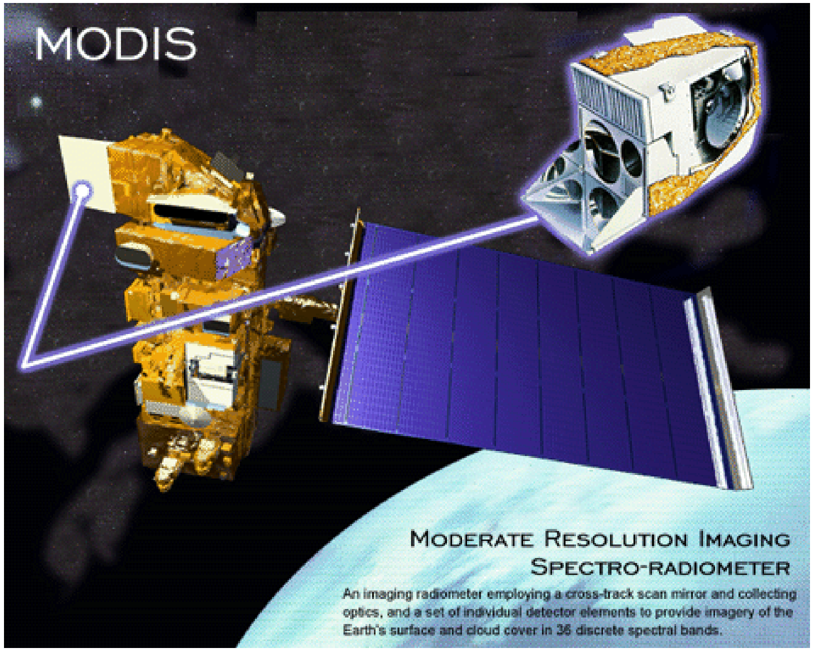
Surface-based remote sensing



- **LIDAR AOD**
  - *Provided by Ray Hoff and Ana Prados*
  - UMBC Polar Elf
    - Upward pointing laser used to measure aerosol scattering in the atmosphere as a function of altitude
  - Aerosol Optical Depth
    - Calculated by vertically integrating the extinction coefficient over the total atmospheric column
    - Data also provided for AOD above and below the Planetary Boundary Layer
  - Co-located with BALI monitoring site

Satellite-based remote sensing

- **SATELLITE AOD**
  - MODIS Terra and Aqua Level 2 Aerosol Product *(Version 5.2.6 from LAADS)*
  - Total column AOD
    - A measure of how much light airborne particles prevent from passing through a column of atmosphere
    - Wavelength: 550 nm
    - Horizontal Resolution: 10km x 10km
  - Reviewed true color (RGB) imagery from MODIS Rapid Response System
  - Observations converted to Voronoi polygons for mapping



http://modis-sr.ltdri.org/

Relationship between MODIS AOD and Surface $PM_{2.5}$

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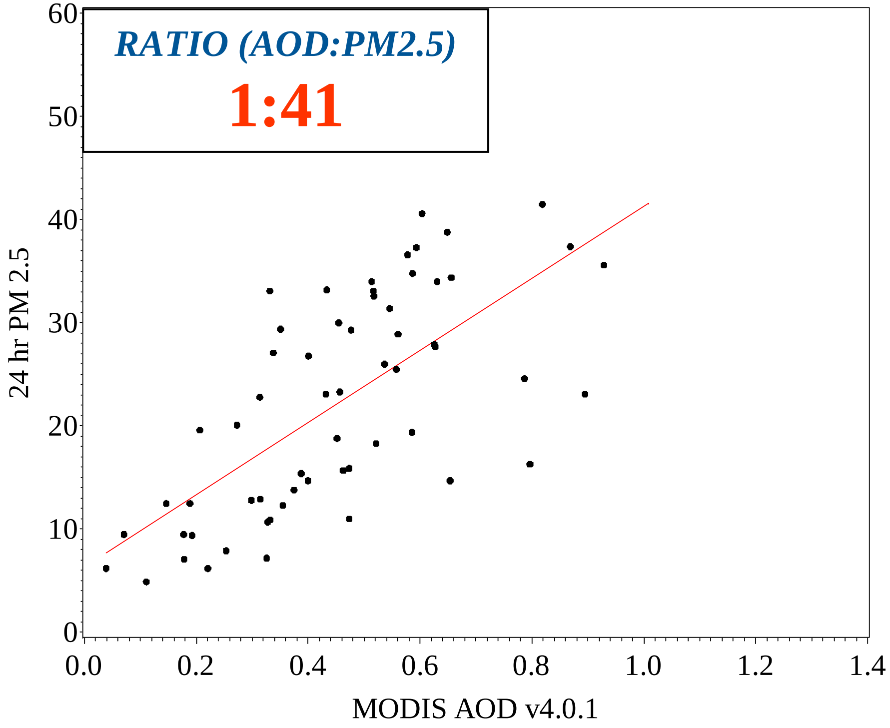
MODIS v4.0.1

ANN, BAL, DCR

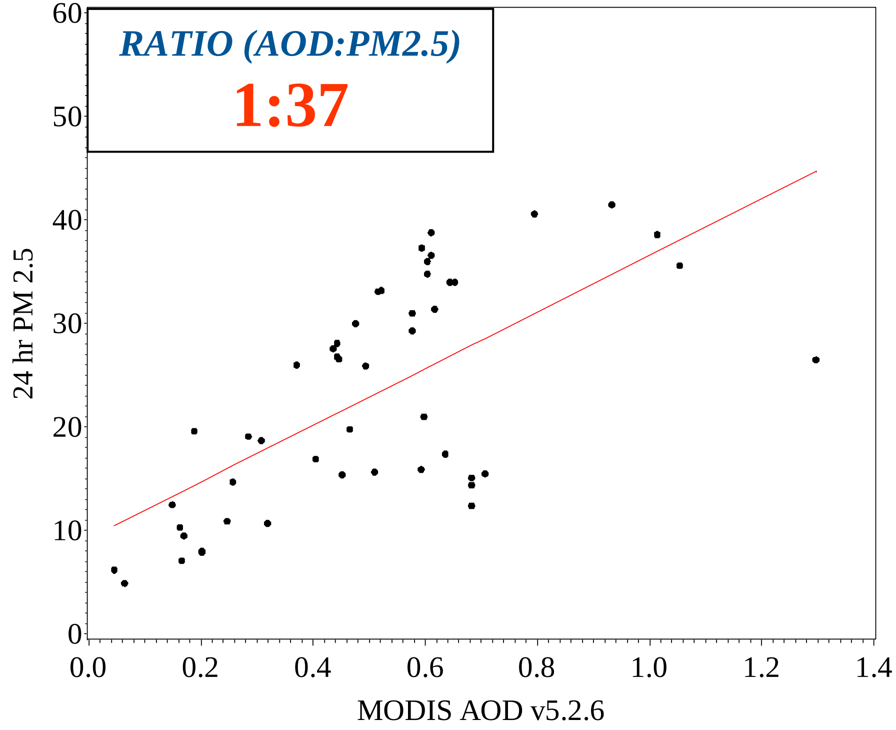


$PM_{2.5} = 6.3 + 34.9 * AOD$

$r = 0.68$

MODIS v5.2.6

All Sites



$PM_{2.5} = 9.2 + 27.4 * AOD$

$r = 0.66$

LaTM Back Trajectories and CMAQ

- **BACK TRAJECTORIES**
  - *Provided by Duncan Fairlie (NASA LaRC)*
  - NASA Langley Trajectory Model (LaTM)
  - Initialized daily at 0 and **18Z**
  - 20, 100, **500**, 1000m initialization heights
  - 72 hour back trajectories
  - Clusters of 49 trajectories used to compute ensemble mean trajectory path for each day
- **EPA's Models 3/Community Multi-scale Air Quality (CMAQ) Model**
  - *Provided by Alice Gilliland (US EPA)*
  - Version 4.5
  - 12 km horizontal resolution, 14 sigma levels in the vertical
  - Driven by Meteorology-Chemistry Interface Processor (MCIP) meteorological fields
  - Sampled in three-dimensional space and time along each of the LaTM back trajectories

Sampling Satellite AOD

- While the CMAQ model was sampled in three dimensions, the total column MODIS AOD values were sampled along each ensemble mean trajectory in horizontal space and time.
- Consistent with previous methodologies:
  - The closest AOD observation within 40km was selected for each location.
  - For the hours of 0-16Z, the data were matched to MODIS-Terra observations, while for 16-24Z, data were matched to MODIS-Aqua.

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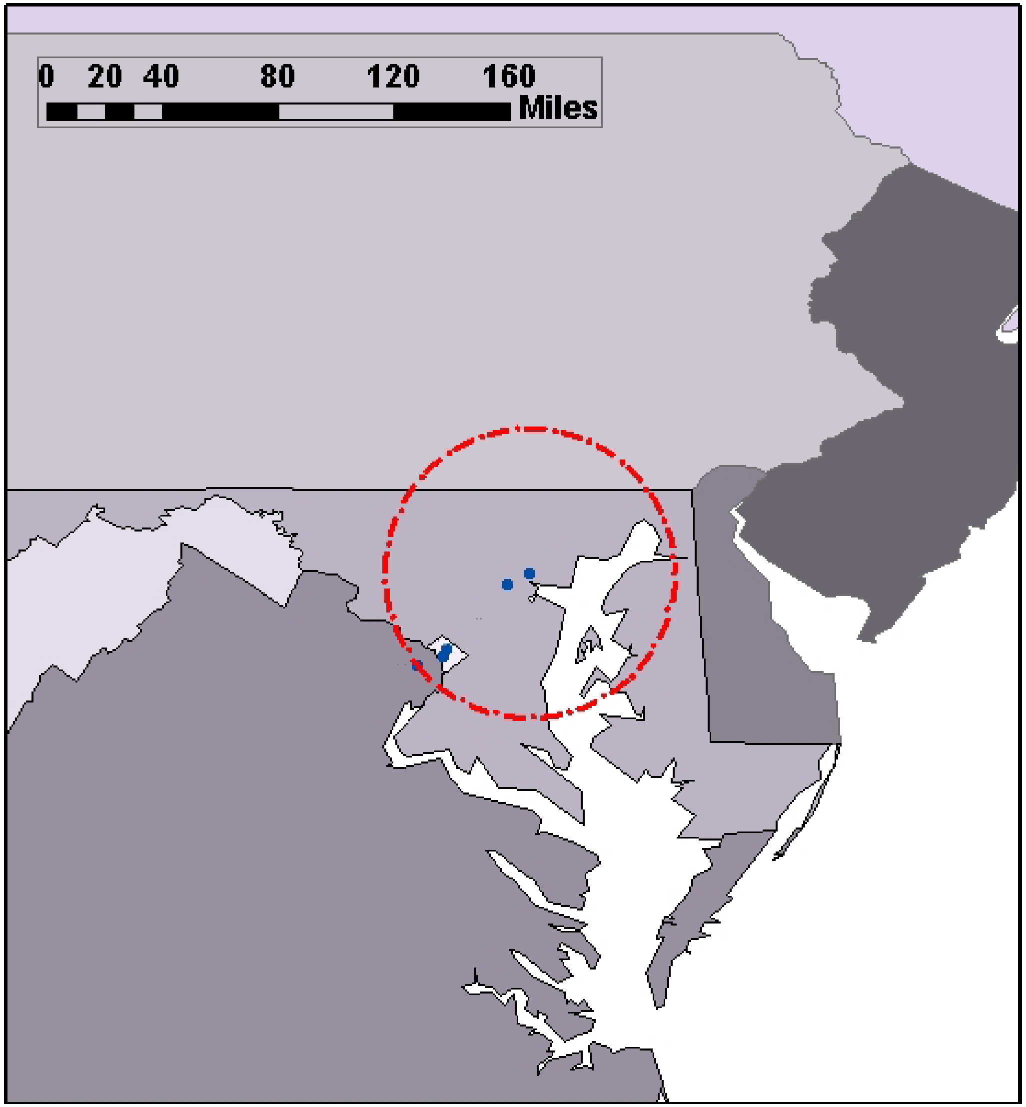
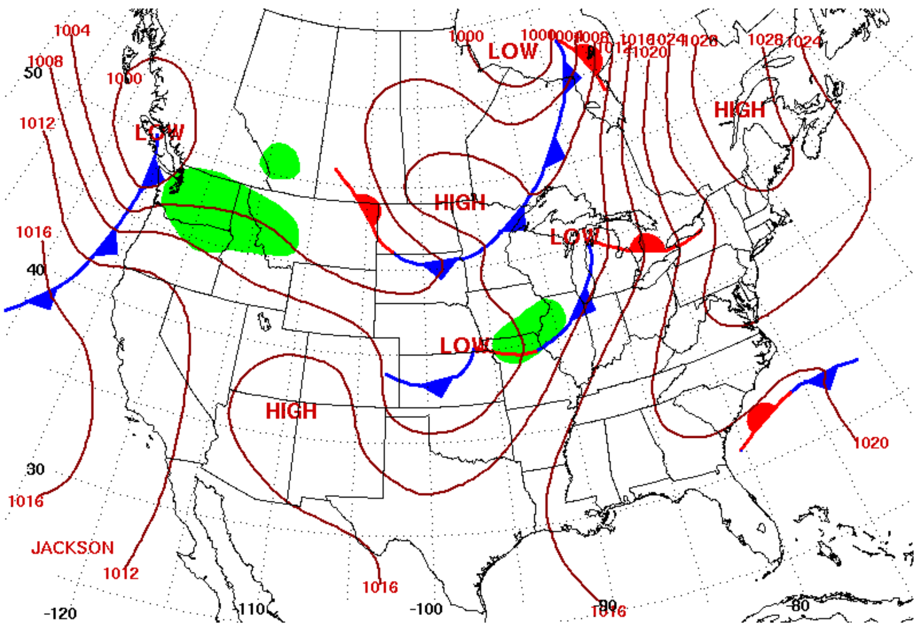
Definition of Baltimore Local Domain



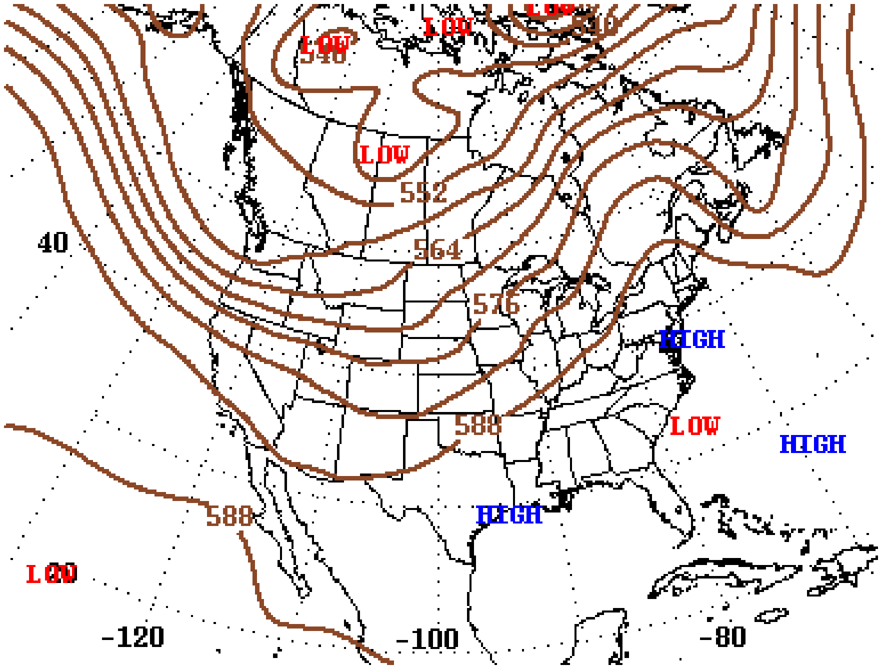
- Radius around Baltimore considered to be the local boundary (red dashed line):
  - **80 km (50 mi)**
- Agreed upon by MDE and NASA
- *Blue dots represent the five monitoring sites*

August 24-25, 2004

- High pressure at the surface and aloft

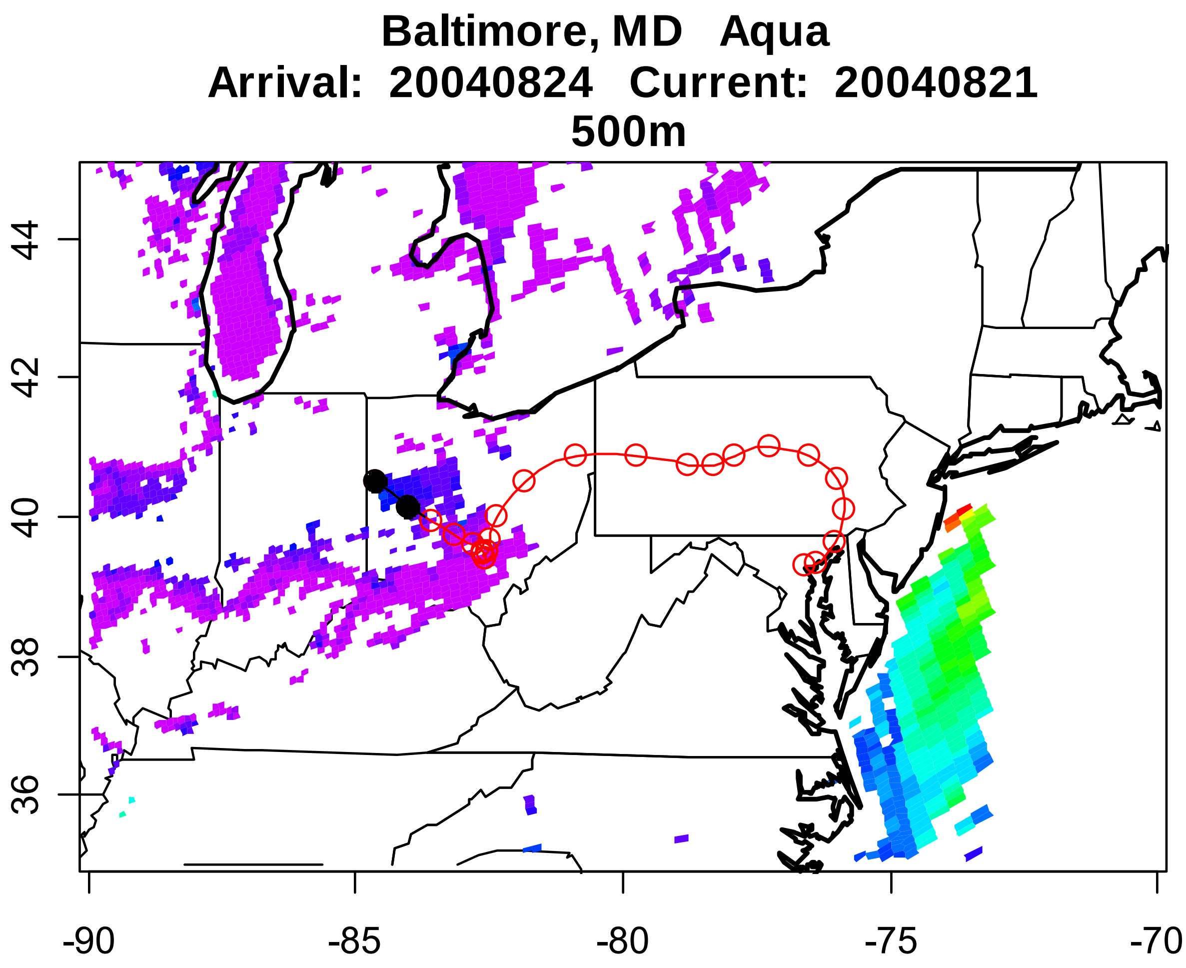


Surface Analysis



500 mb Height Contours

August 24-25, 2004



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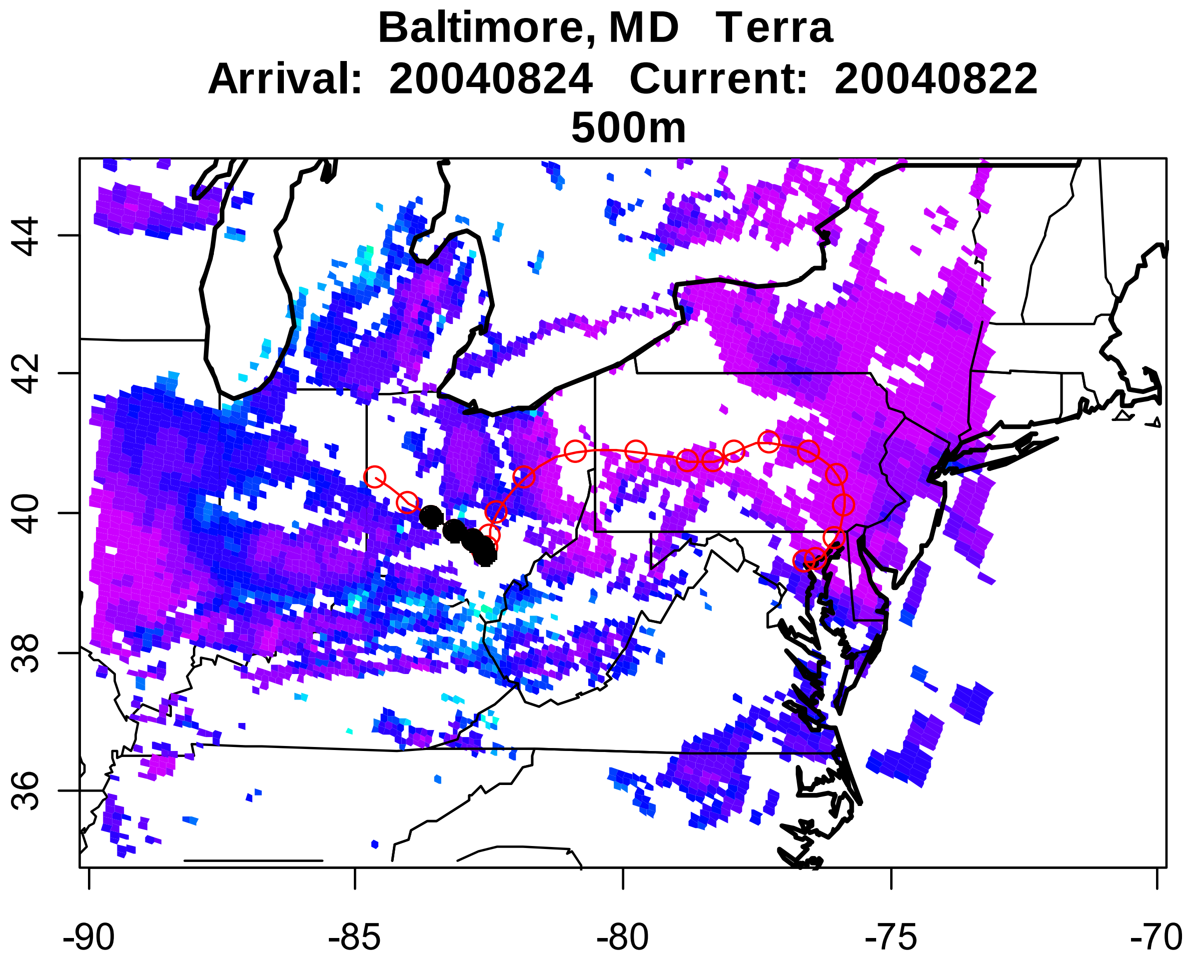

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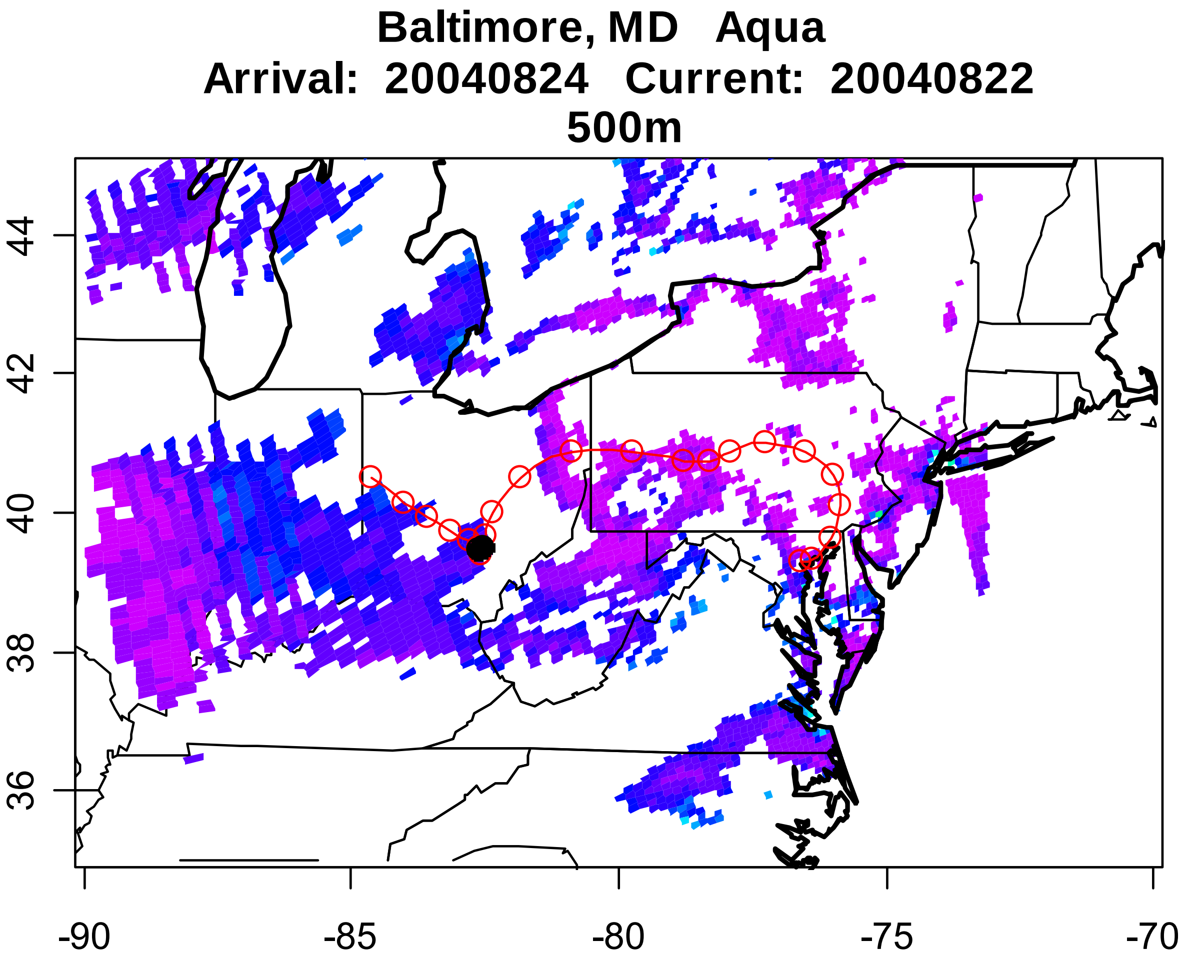

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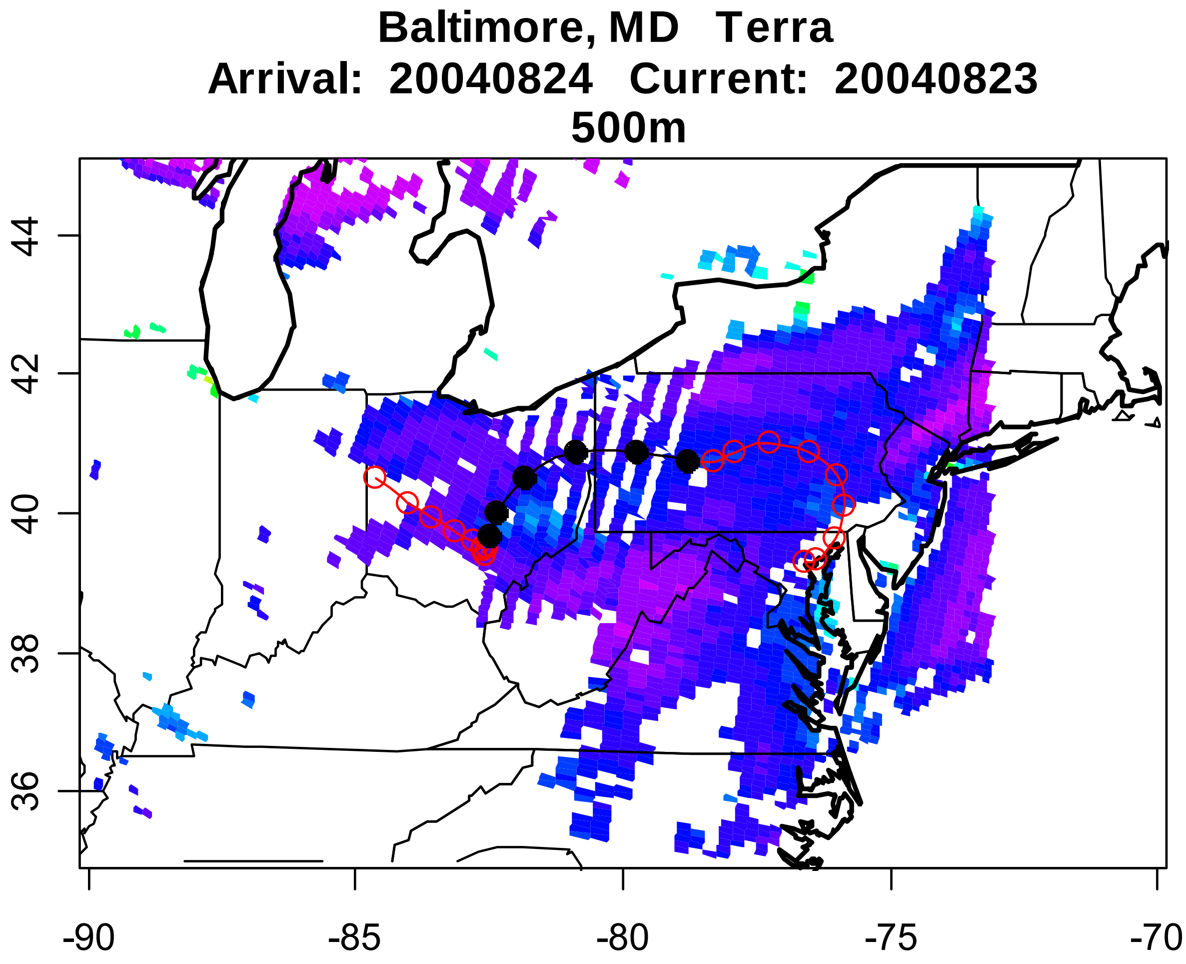

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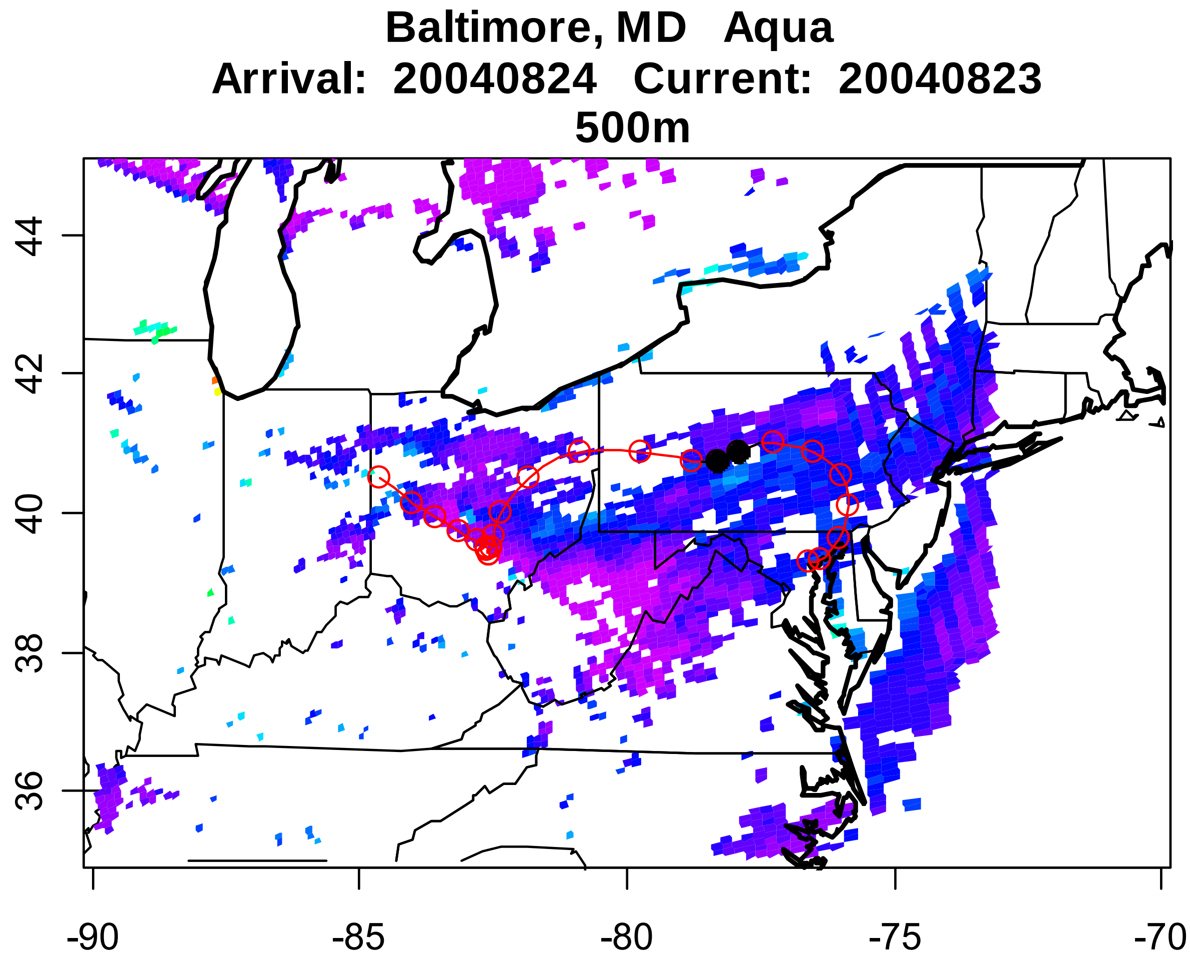

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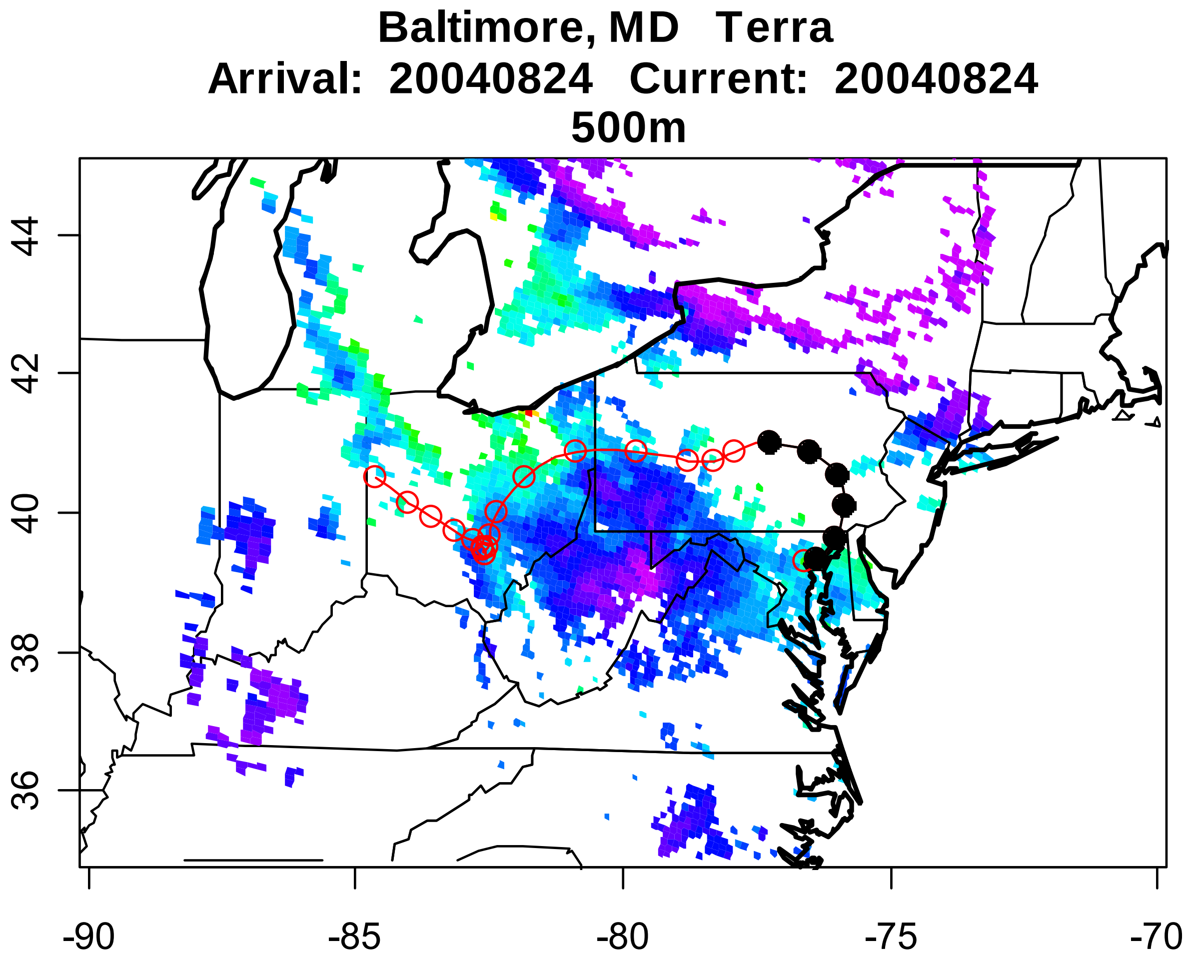

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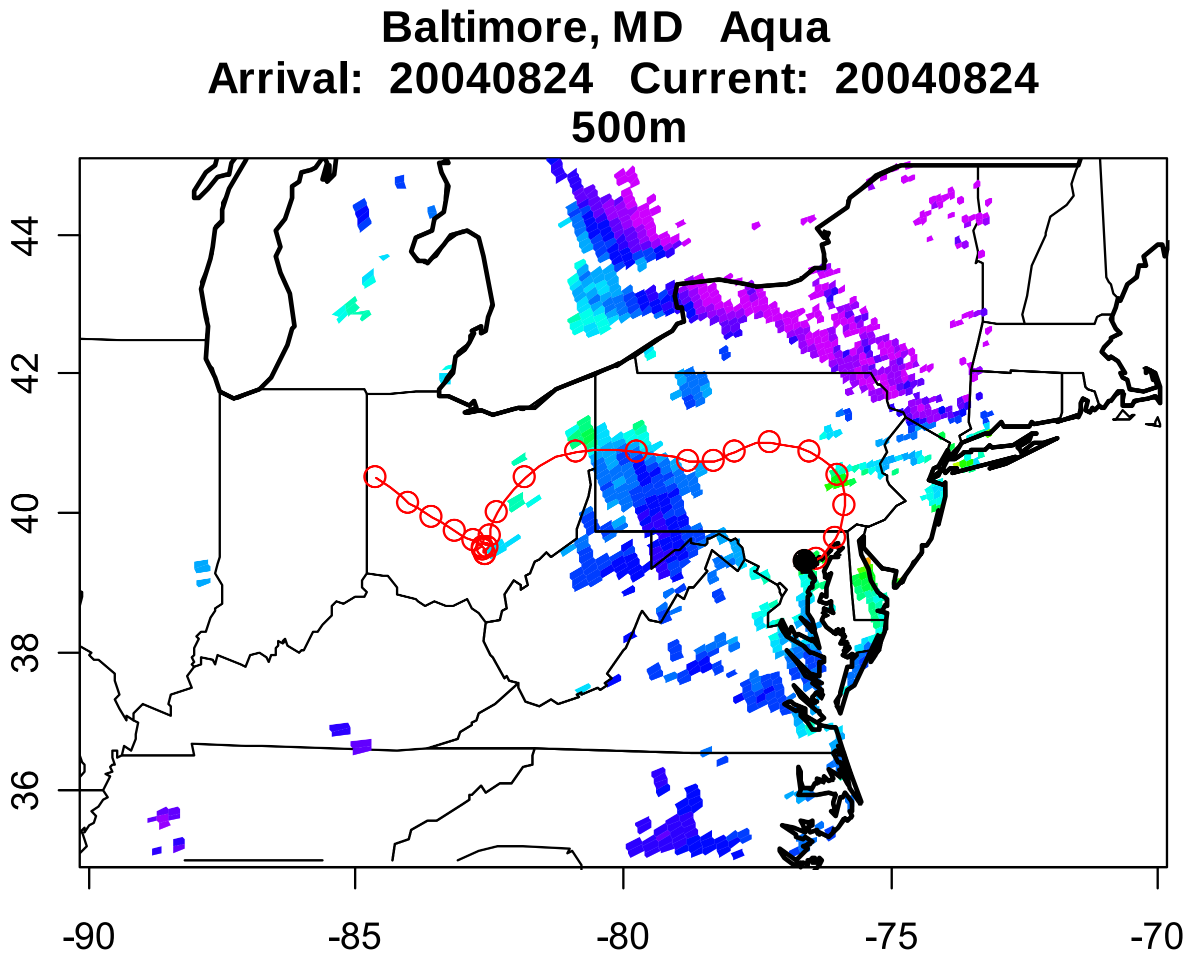

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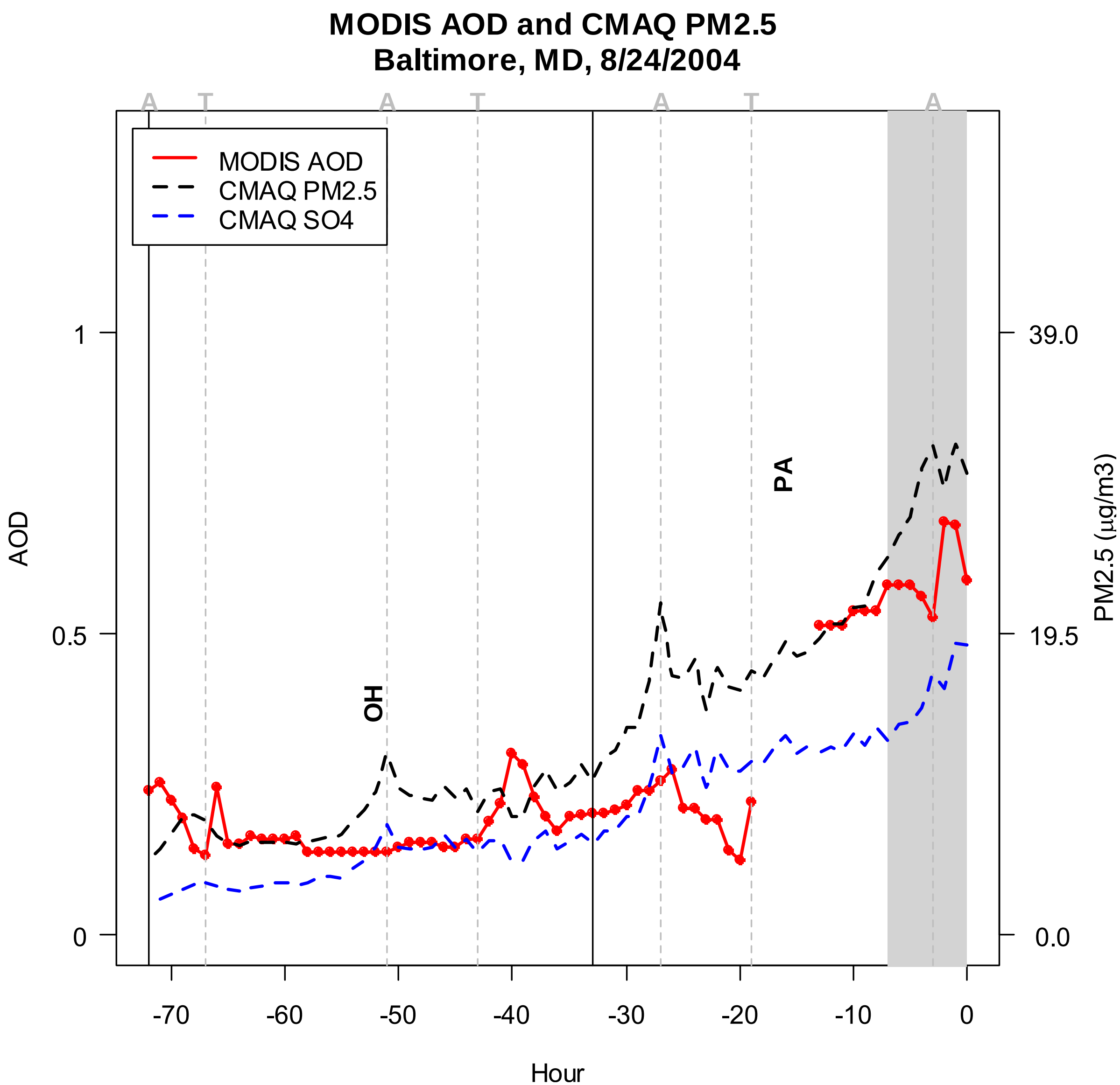
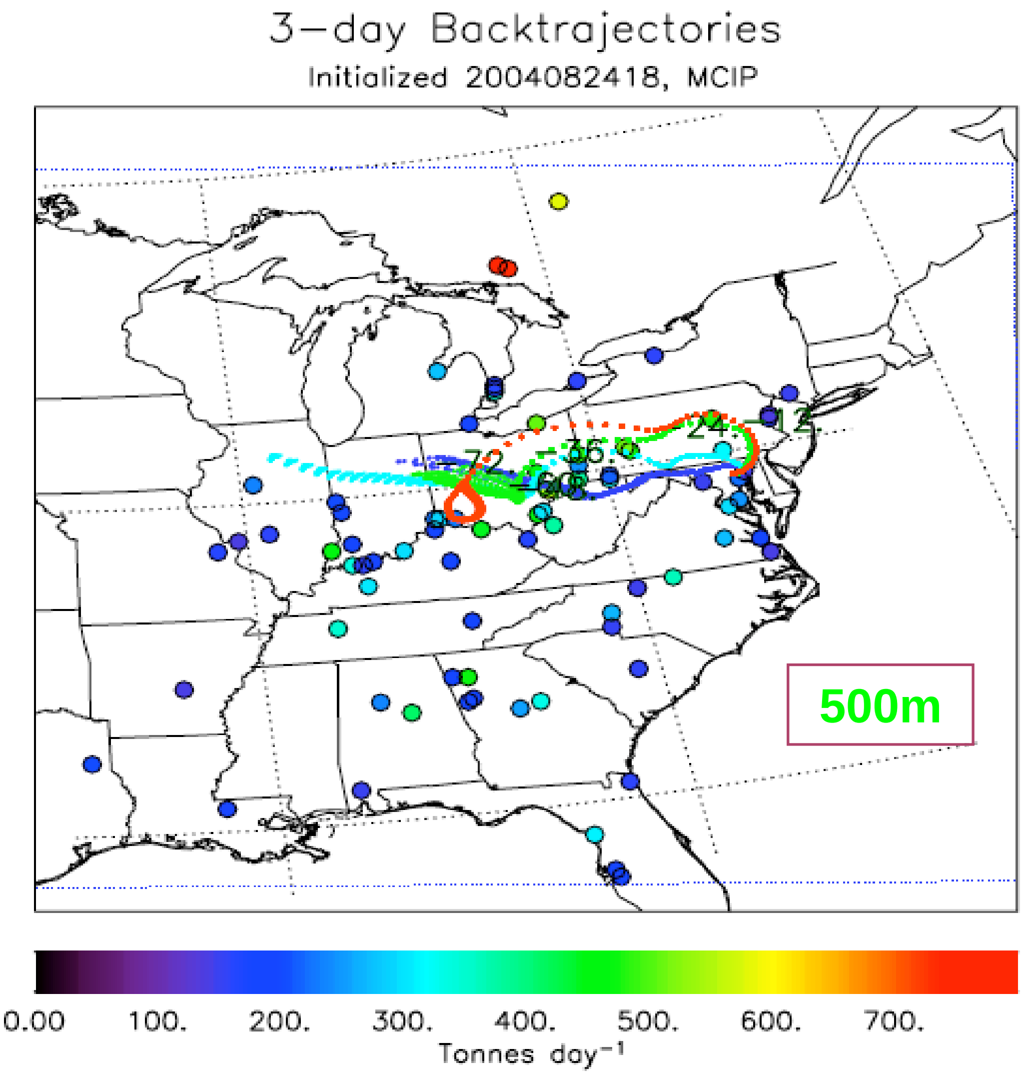


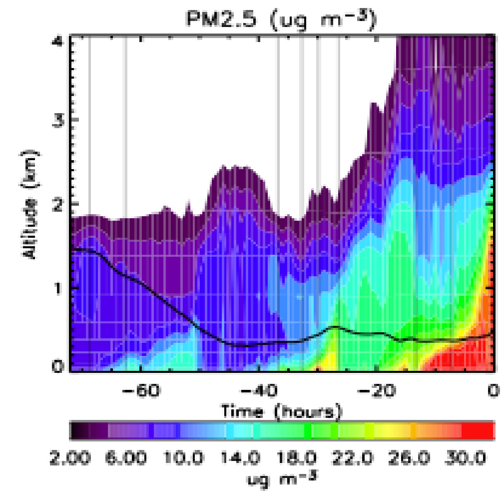
- **Black** Vertical Lines: State Boundaries
- **Gray** Vertical Lines: Satellite Boundaries
  - *satellite indicator [A/T] at top of plot*

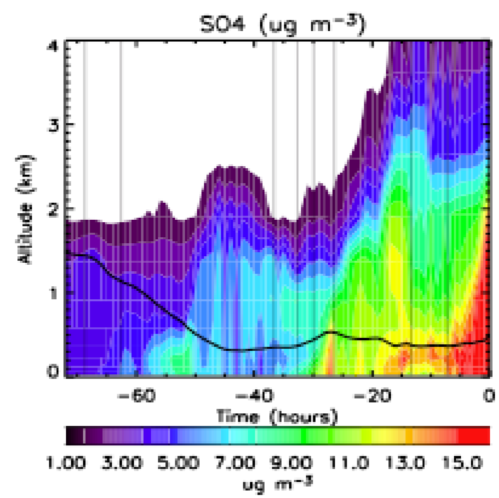
- Similar pattern of MODIS AOD and CMAQ $PM_{2.5}$ observed along the back trajectory
- AOD values do not increase until air parcel approaches local domain in PA
- CMAQ $PM_{2.5}$ values rapidly increase upon entry into local domain
- CMAQ Sulfate rises steadily before increasing in the local domain

August 24-25, 2004



Lagrangian Curtains

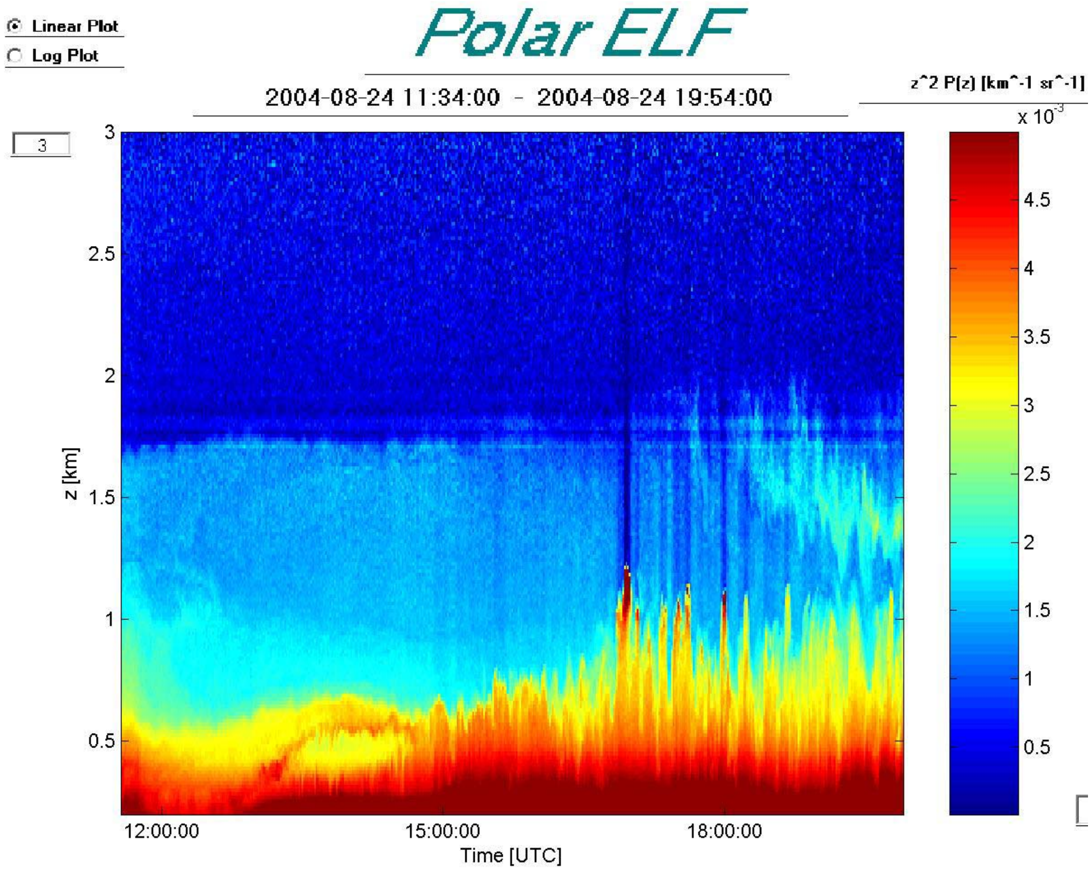




Figures courtesy of: D. Fairlie, NASA LaRC

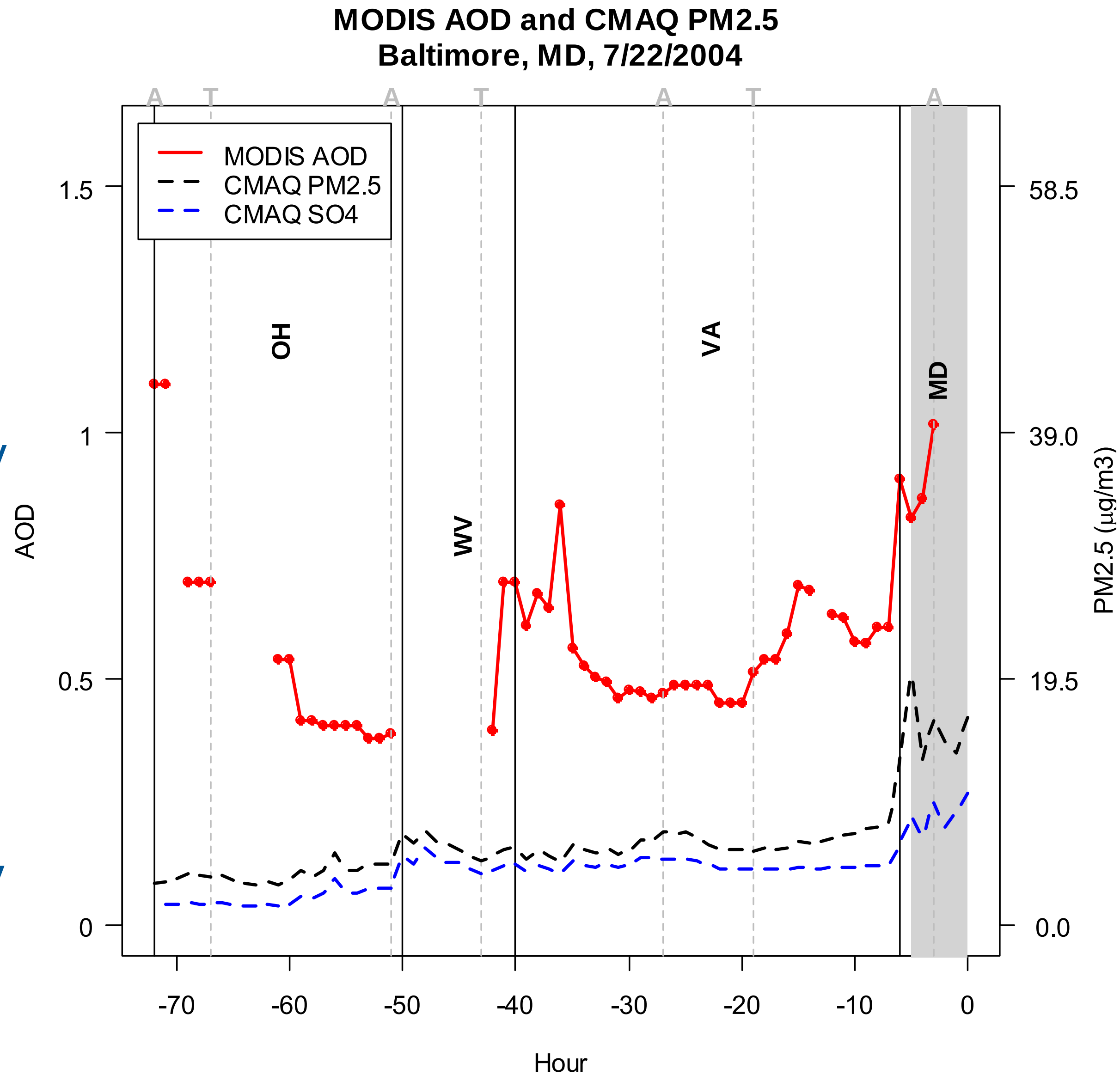
August 24-25, 2004

- UMBC Lidar profile



July 22, 2004

- While the air parcel is in the up-trajectory states, increases in MODIS AOD are observed
- CMAQ $PM_{2.5}$ along the back trajectory is steadily increasing before rising rapidly just inside of the local boundary
  - *Maybe some local contribution*
- The AOD remains relatively high upon entry into Baltimore



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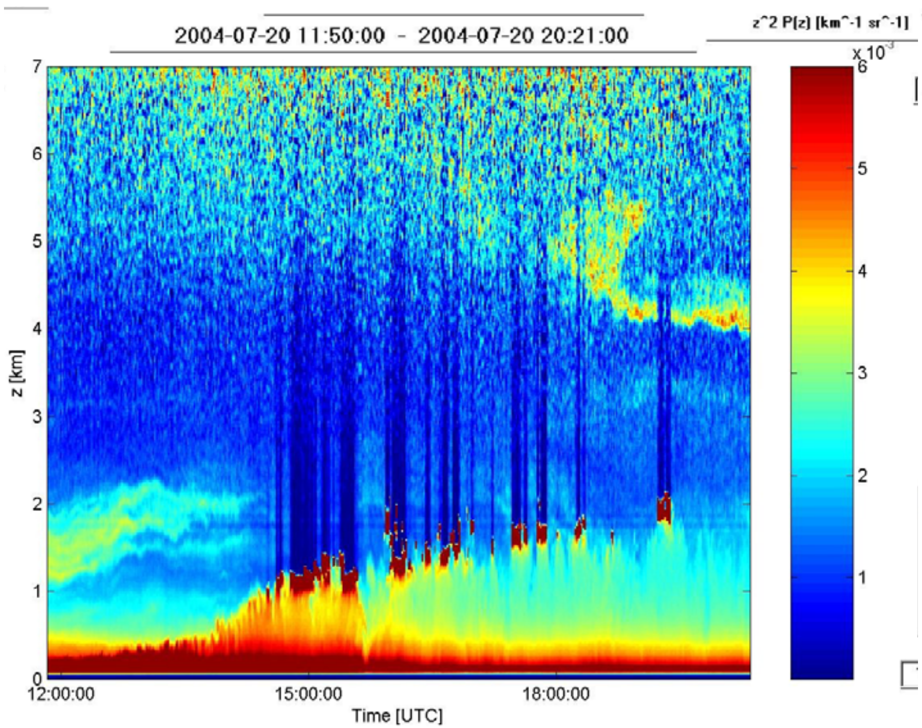
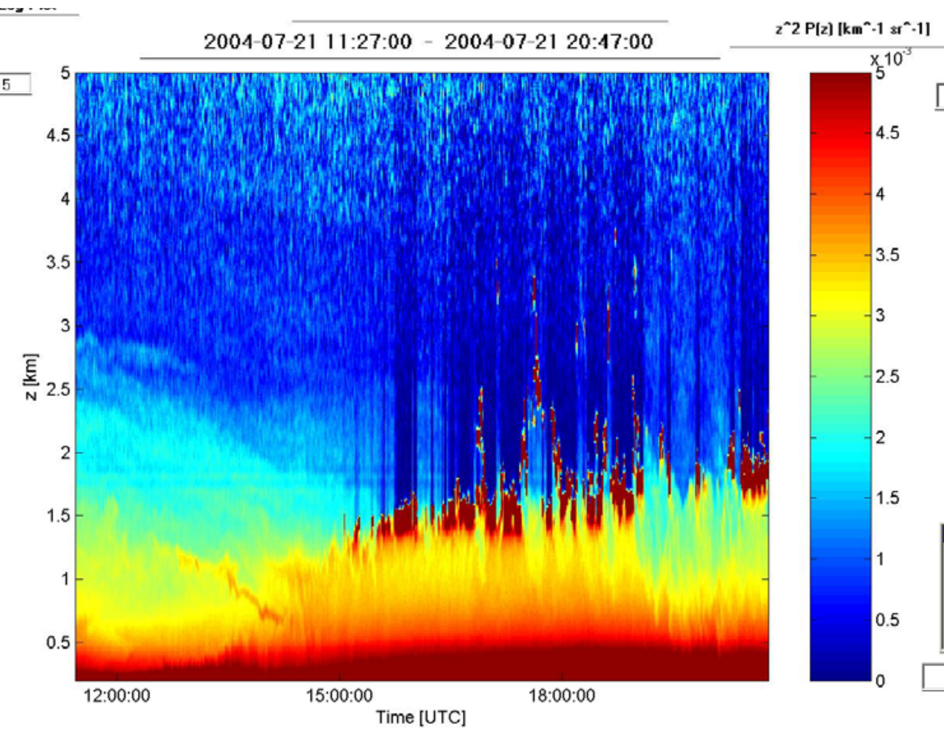


July 20



July 21

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Metric 1

- Number and/or percent of pollution events classified as having predominantly regional sources.

Source	Component
Surface Monitors	PM2.5 (µg/m3)
	Sulfate (µg/m3)
	% sulfate
CMAQ	PM2.5 (µg/m3)
	Sulfate (µg/m3)
	% sulfate
	PM2.5 increases outside local boundary
MODIS	AOD Coverage
	AOD increases outside local boundary
Lidar	% Lidar AOD Above Planetary Boundary Layer
Meteorology	Trajectory Path
	Pressure Systems
	Frontal Systems

- Pollution event defined when one or more of the surface monitors report a 24 hour average $PM_{2.5}$ concentration greater than 35 µg/m^3.
- **SIX** pollution events for Summer 2004
  - 2 days classified as regional
  - 1 day classified as local
  - 1 day classified as regional/smoke
  - 2 day with combined local/regional sources

Metric 2

- Total number and/or percentage of days where the changes in AOD, $PM_{2.5}$ or sulfate in the regional domain along the ensemble mean trajectory are greater than a given threshold.

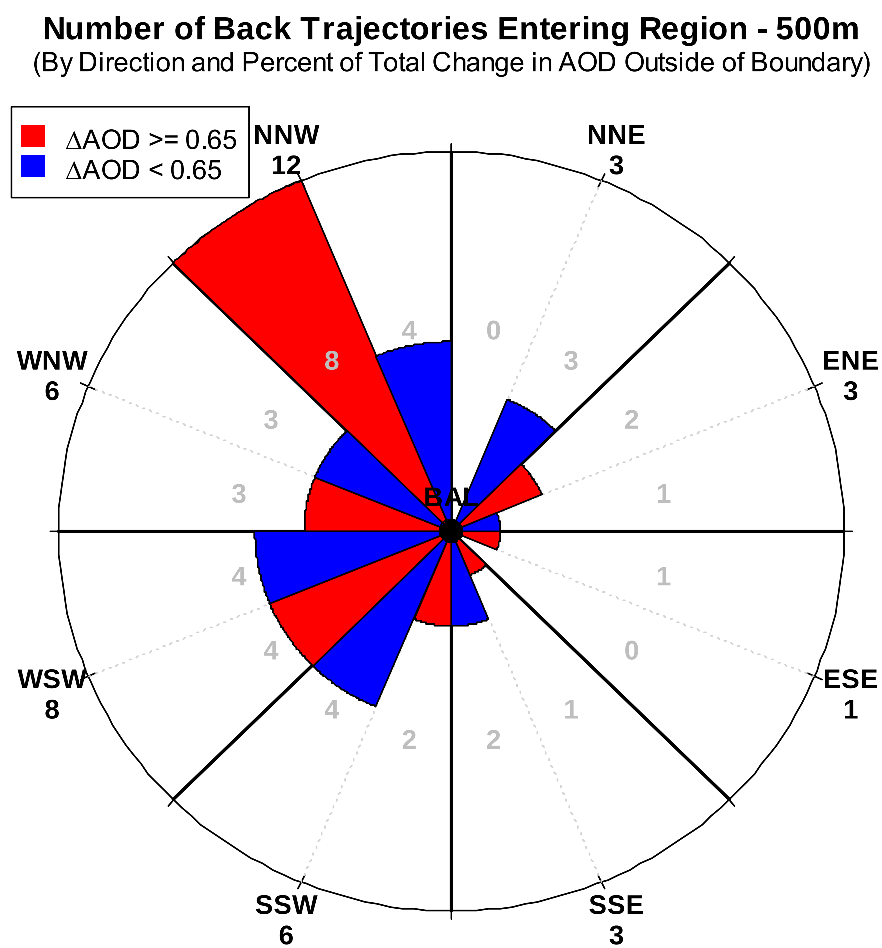
- Compute the percent of total change in MODIS AOD along the ensemble mean trajectory that occurs from the point along the back trajectory closest to the boundary of the local domain to the initialization location (Baltimore).
- 50% of the days during Summer 2004 had local contributions less than 35%, indicating that regional sources are typical for the local domain.

$$AOD_{local}(\%) = \frac{\Delta\, AOD_{BAL-BOUND}}{\Delta\, AOD_{BAL-MIN}}$$

	AOD_{local} (%)			
	< 35%	35 – 65%	> 65%	Total
# Days	21	14	7	42
% Days	50%	33%	17%	100%

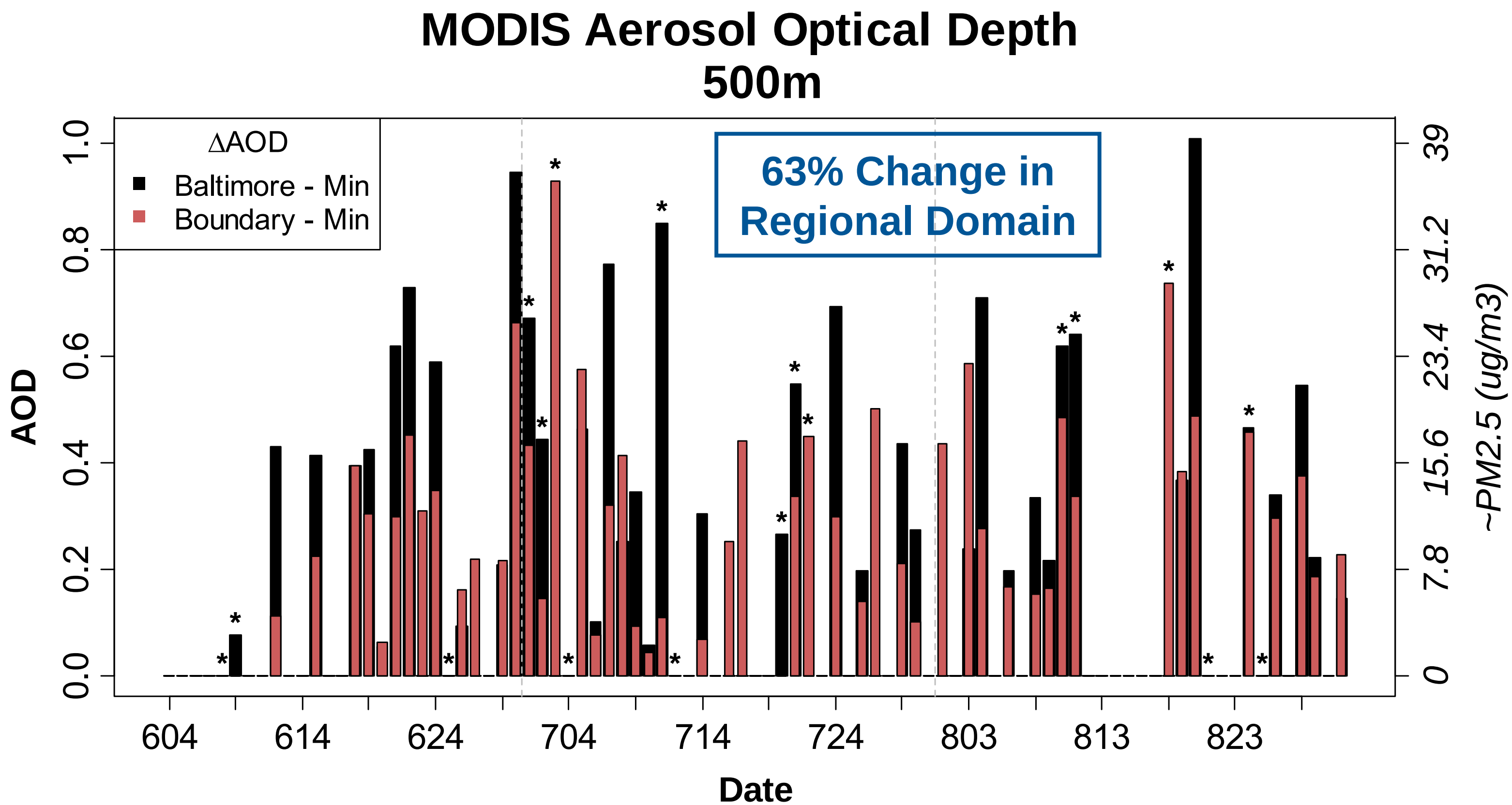
Estimate Regional Contribution to AOD

- Estimate regional contribution
  - $\Delta AOD_{BOUND\text{-}MIN}$
- Direction indicates location where the air parcel last enters the local domain
  - i.e., if the air parcel enters the local domain, exits and then enters again, it is the time and location of the second entry that is considered when the parcel enters the local domain.
- Most trajectories with large regional components entered the local domain from the NNW.



Metric 3

- Overall comparison of the changes occurring in the regional domain relative to the total changes along the trajectory.



- Black bars represent the total change along the ensemble mean trajectory, while the red bars represent the change outside of the 80km local boundary.
- Asterisks (*) indicate the top 20% of days for $PM_{2.5}$ from the Baltimore FRM monitor

Metric 3

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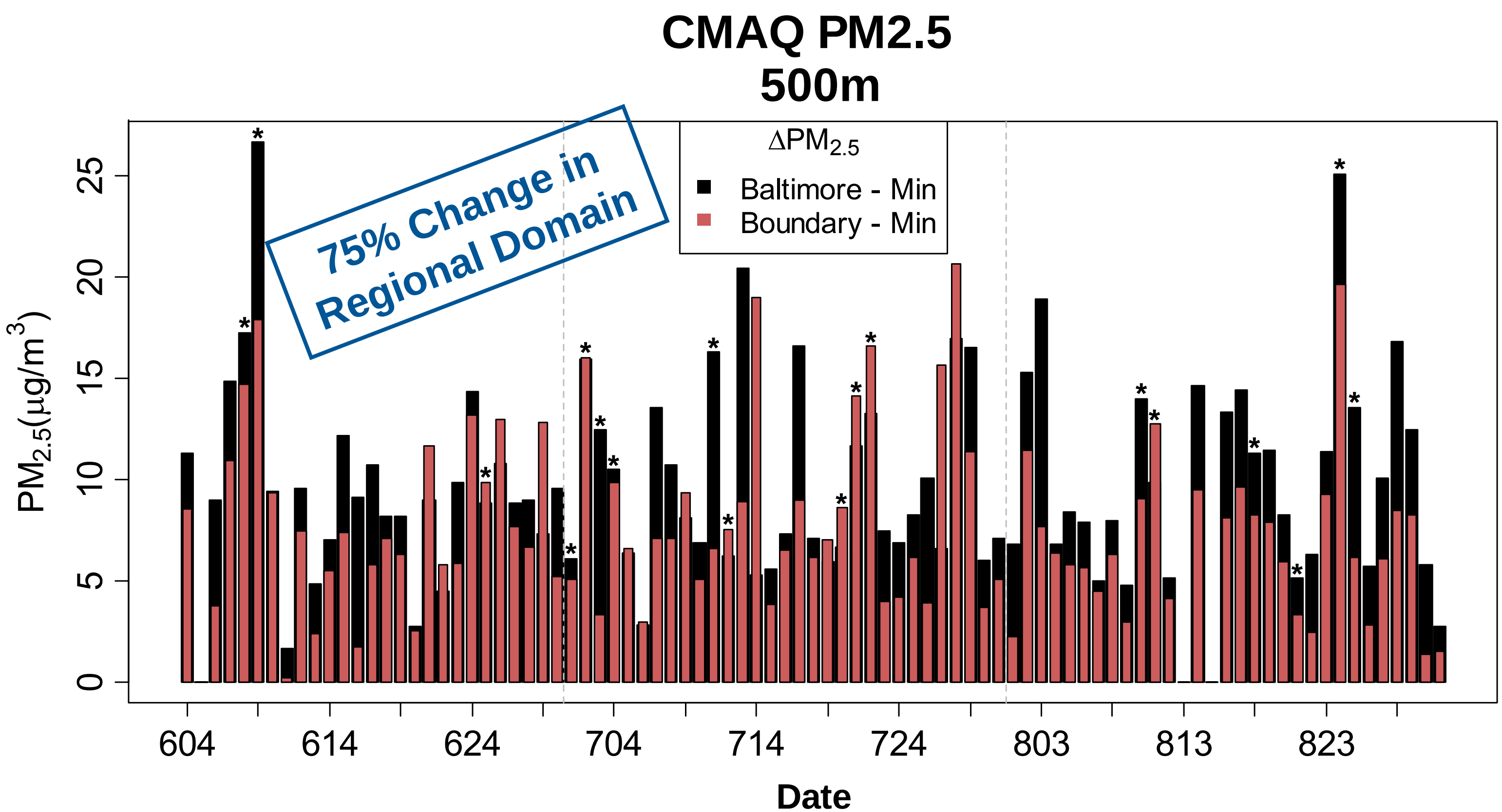

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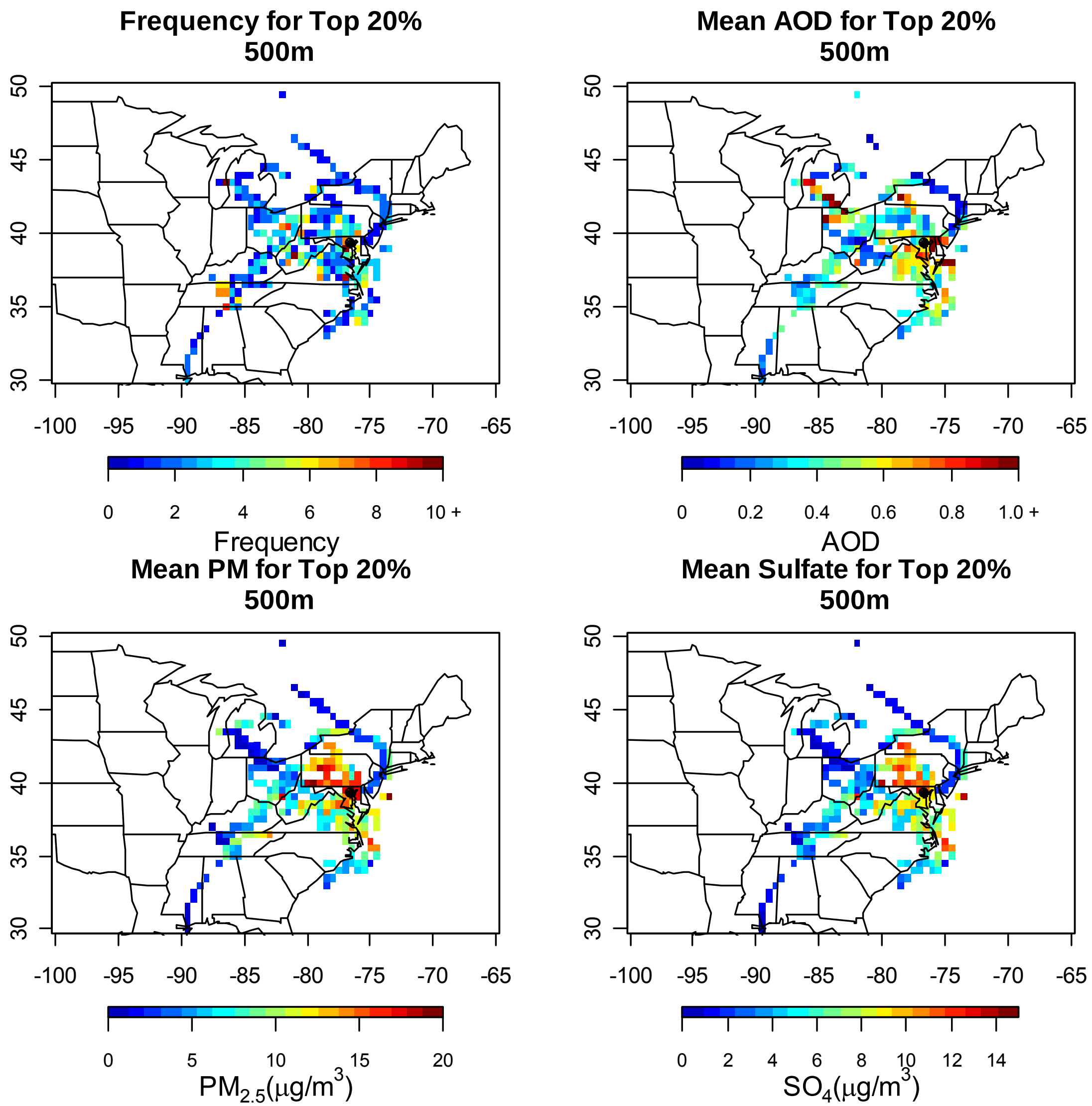
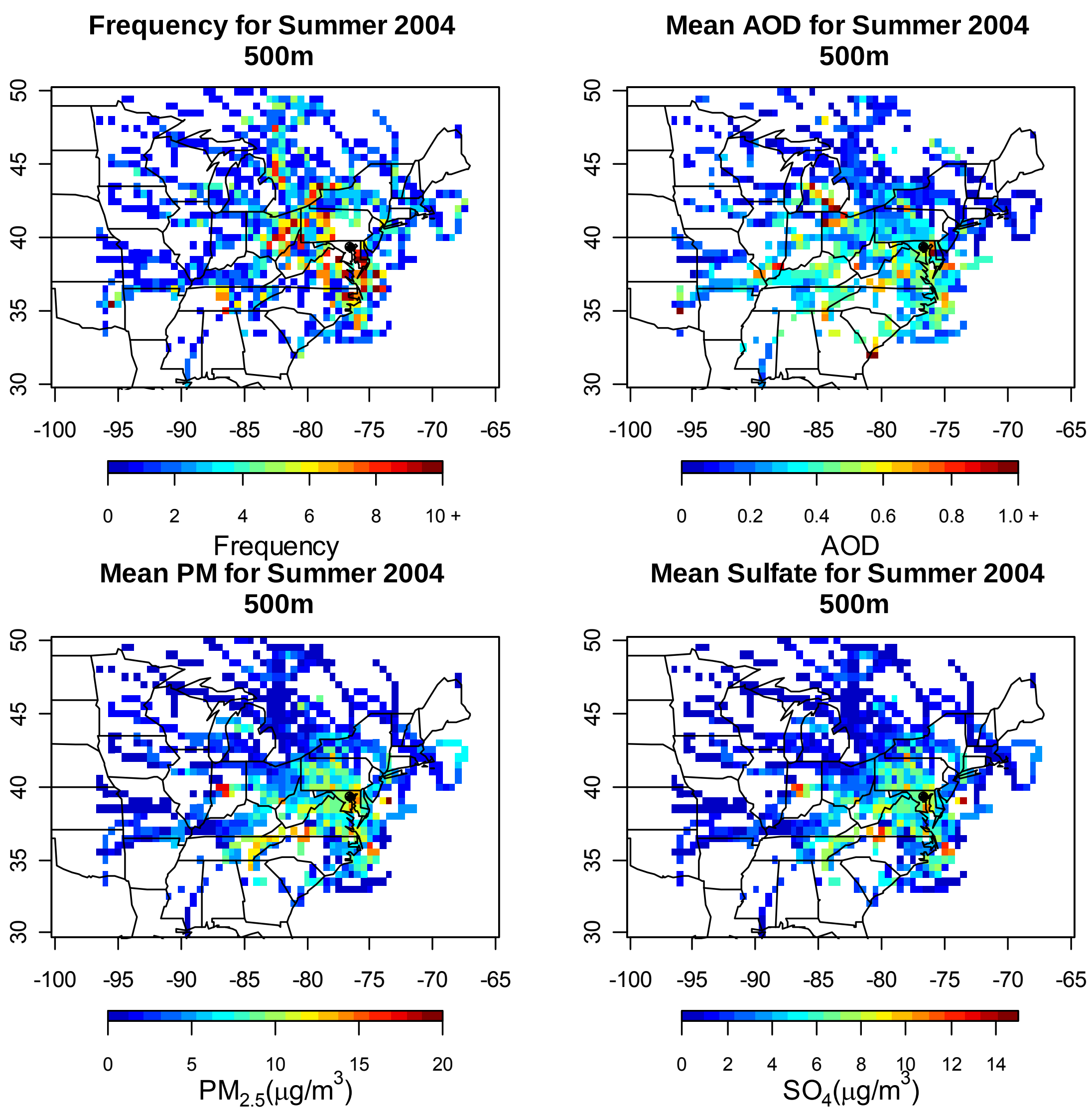
Mean Trajectory Characteristics



Mean Trajectory Characteristics



Simplified ΔAOD Method

- Sum of the **CHANGE** in MODIS AOD over time for a given grid cell *(lat, lon)* over all back trajectories
- Grid cells are 0.5° x 0.5°
- Changes in AOD are only computed if AOD observations are present and there are less than three hours between AOD observations
- The *lat* and *lon* represent the location of the air parcel after the time step (t_f)

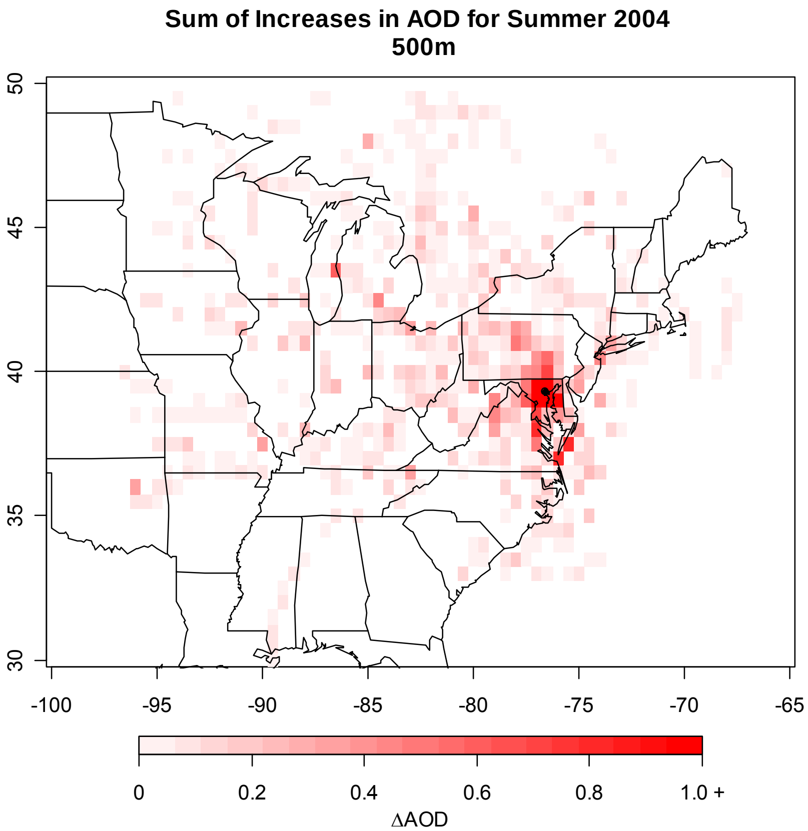
$$\sum_{traj} [AOD_{lat,lon}(t_f) - AOD_{lat,lon}(t_i)],$$

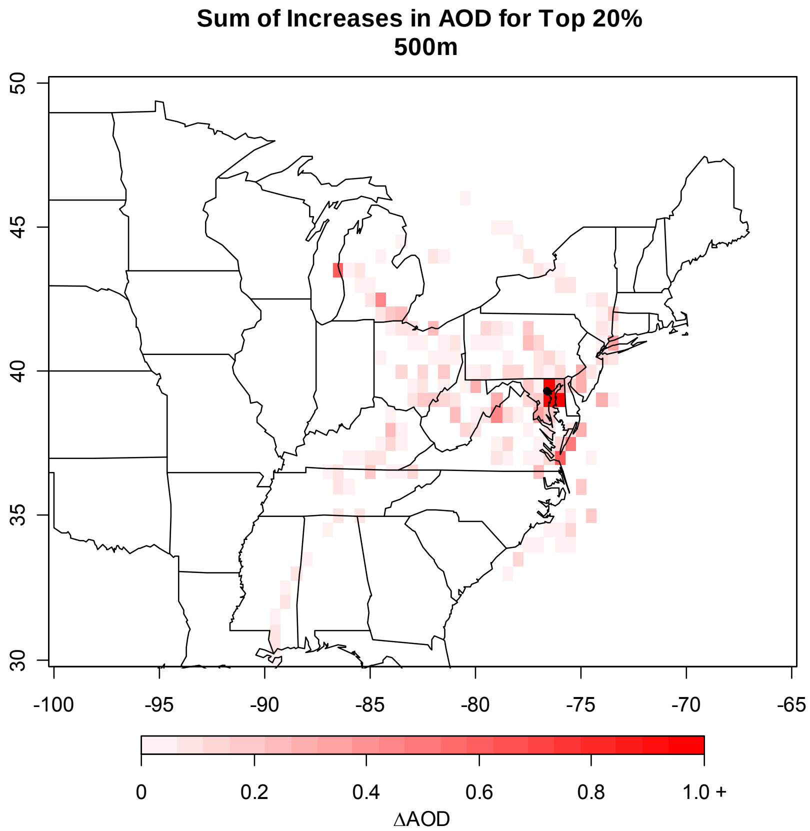
$$where\ (t_f - t_i) < 3h$$

Metric 4

- Map of the sum of the increases per time period for a single site *[or for multiple sites]*

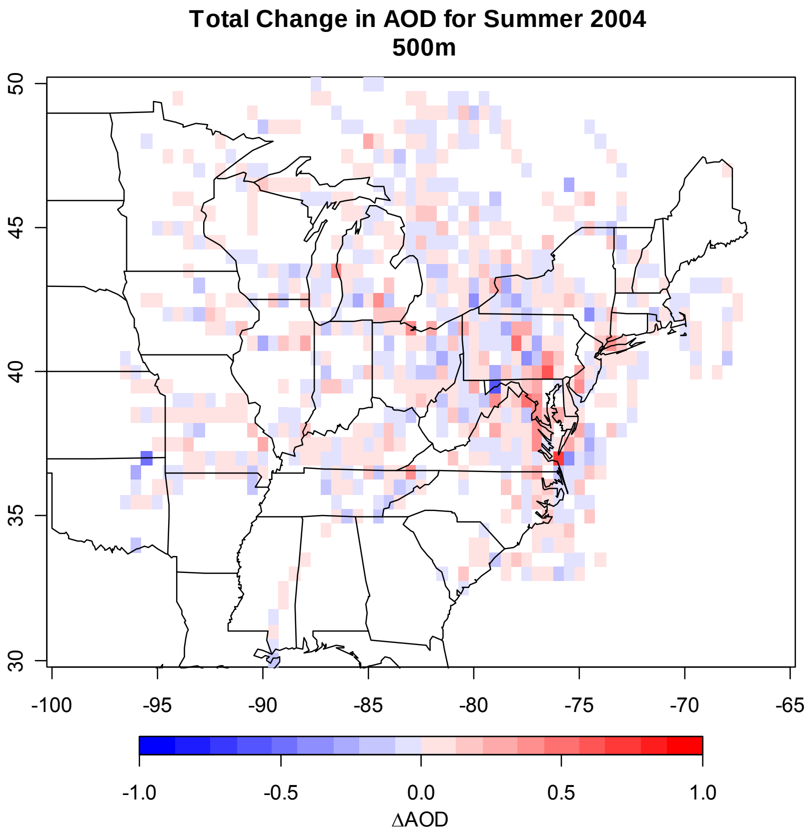
$$[AOD_{lat,lon}(t_f) - AOD_{lat,lon}(t_i)] > 0$$

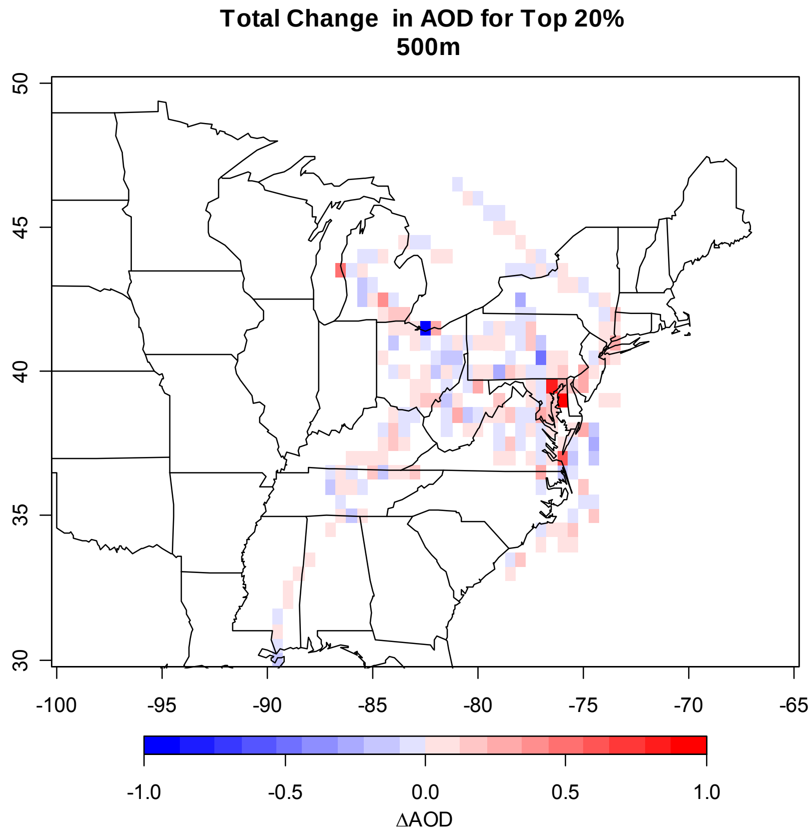




Metric 4

- Sum of the **TOTAL CHANGE** in AOD over time for a given grid cell *(lat, lon)* over all trajectories





Outline

- Introduction
- Datasets and Methodology
- Results
  - Event Summaries
    - August 24/25, 2004
    - July 22, 2004
  - Proposed Metrics using Source Region Analysis and Simplified ΔAOD Method
- **Conclusions and Recommendations**

Conclusions and Recommendations

- **CAIR Accountability Assessment**
  - Methodology completed and validated
  - CAIR metrics proposed and evaluated for Baltimore, Maryland
  - Stakeholder consensus on overall approach
  - Related projects would support semi-automation
- **Recommendations**
  - Extend this application to the full year of 2005
  - Address additional major urban areas in the eastern U.S. that are expected to benefit from the CAIR rule
  - Refine and enhance metrics to improve their ability to quantify changes in air quality
  - Establish a “library” of metrics for a greater number of locations and longer time periods.
  - Integrate with AirQuest database and semi-automate with EPA tools (source apportionment, IDEA site, etc.)


Questions?