MANE - VU

Mid-Atlantic/Northeast Visibility Union

Trajectory Clustering Techniques

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NESCAUM

Air and Waste Management Association
Visibility Specialty Conference
October 27, 2004

Acadia 1997

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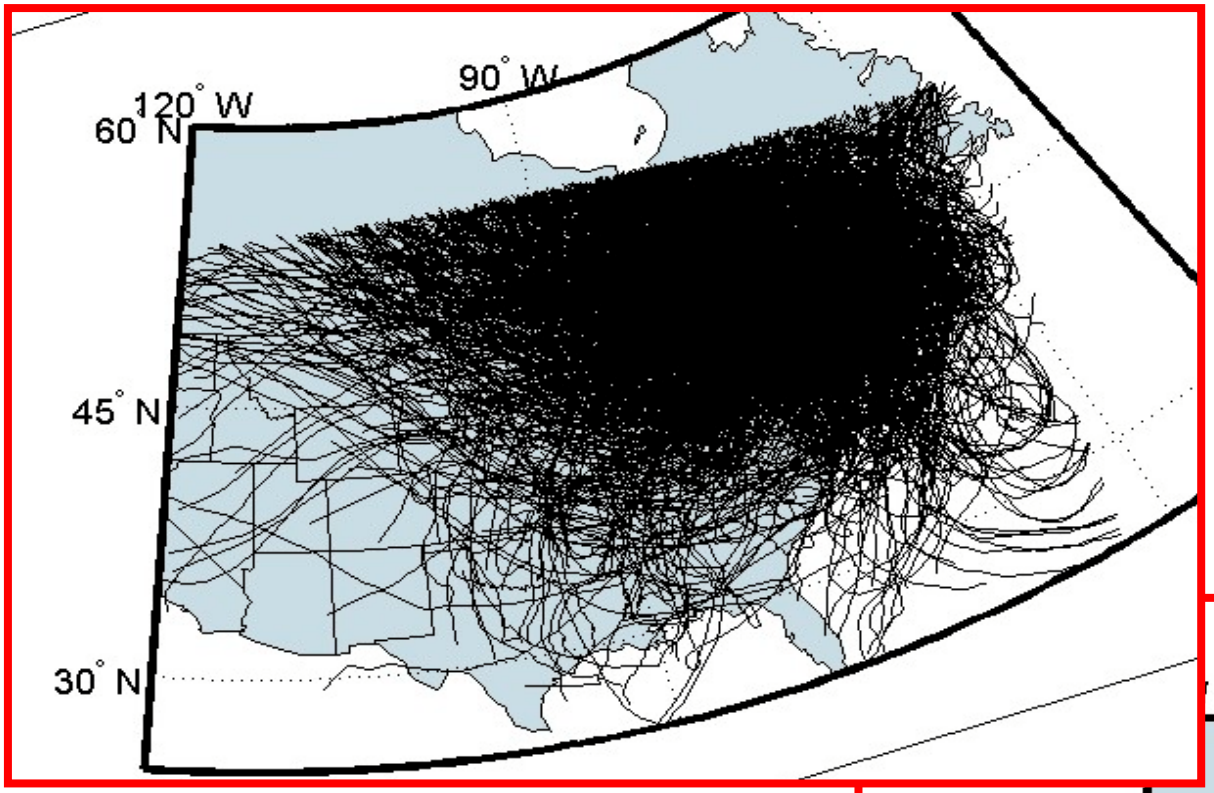
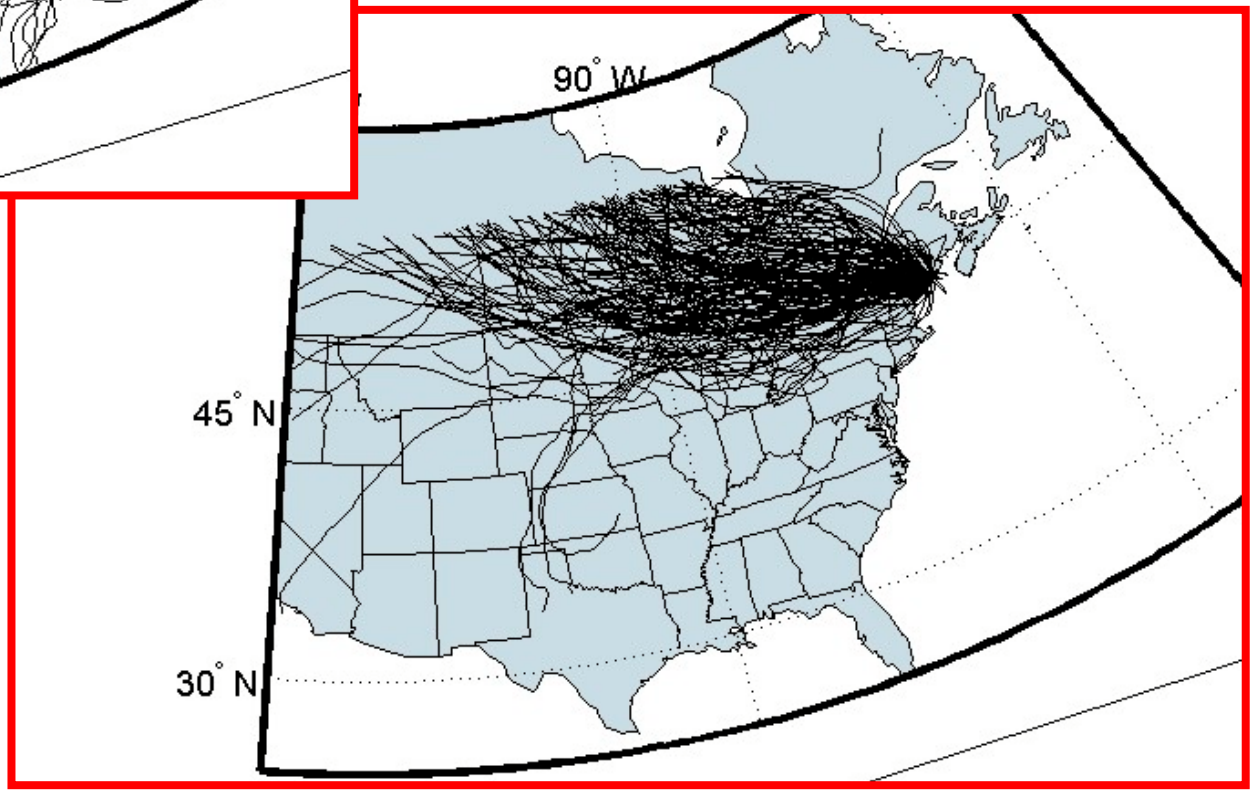
ALL TRAJECTORIES



CLUSTER 3 TRAJECTORIES



PATH Analysis

- Patterns in Atmospheric Transport History
- Based on prior work by Jenny Moody (UVA) at Harvard Forest in Central MA
- Groups similar trajectories in 3-dimensions

PATH Algorithm

- Similarity quantified as distance between trajectories:

$$D_{ij} = \sqrt{\sum_{k=1}^{n} (Z_{ik}^{lat} - Z_{jk}^{lat})^2 + (Z_{ik}^{lon} - Z_{jk}^{lon})^2 + (Z_{ik}^{press} - Z_{jk}^{press})^2}$$

(Z represent **normalized** coordinates with 0 mean and standard deviation of 1)

Cluster Definition

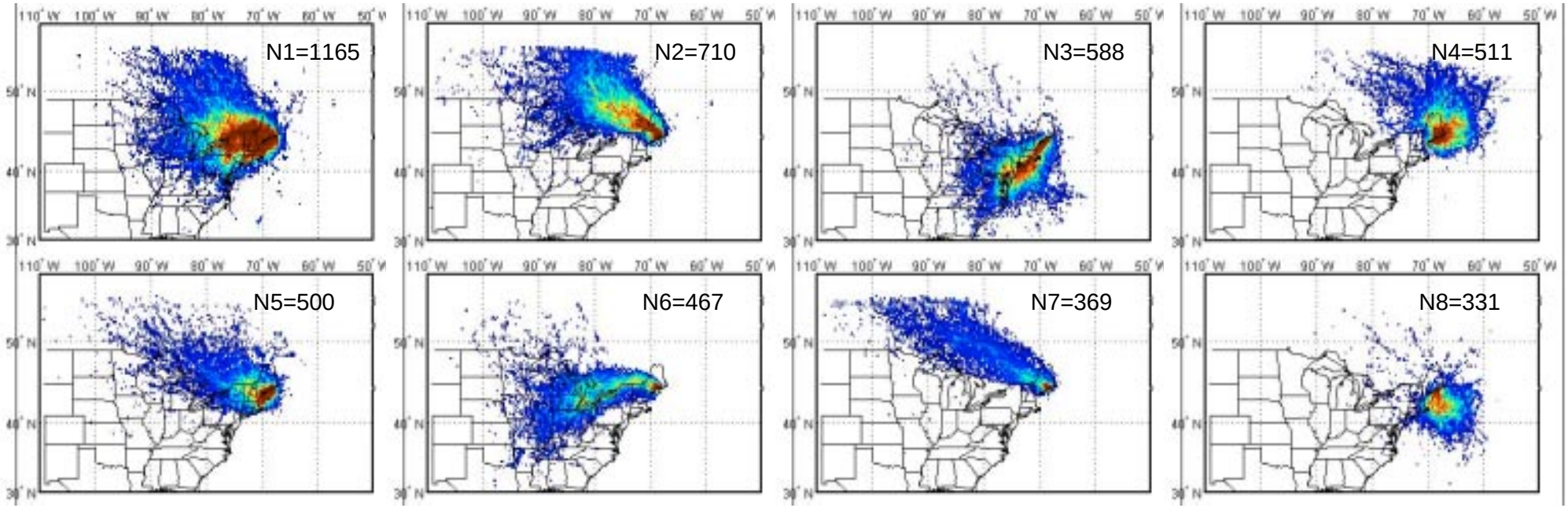
- Clusters are defined by establishing a radius of proximity R:

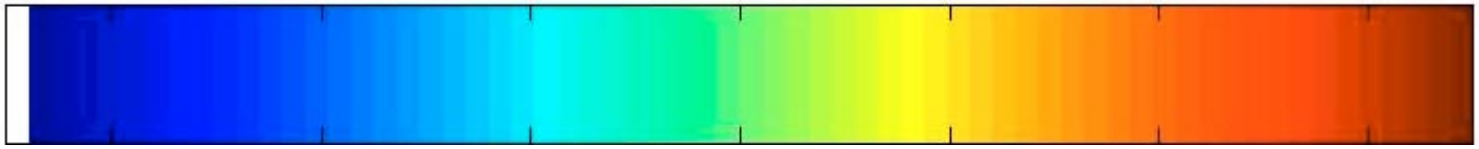
$$C(T_i) = \{ T_j \} \ni D_{ij} \leq R$$

The maximal cluster (largest number of elements) is removed from the analysis and the process is repeated

Top 8 Clusters for Acadia

Acadia, 1997-2002, 48hr, 500m, R=6



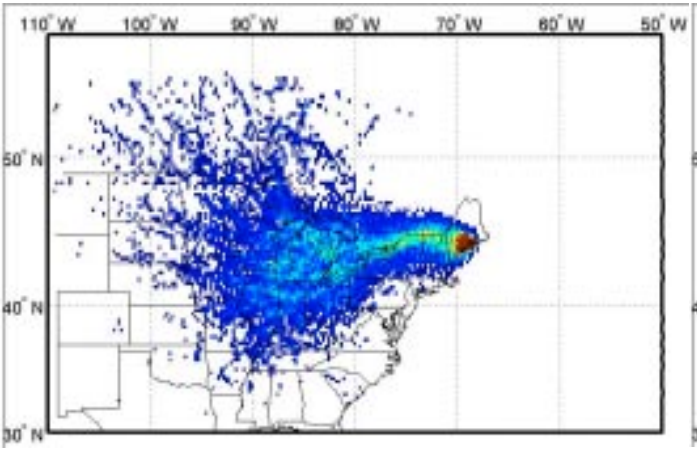


Free Parameters

- Radius of proximity
- Height of starting point
- Length of cluster calculation (e.g. 24 hr, 48 hr, 120hr)
- Temporal range (e.g. 97 vs. 97-02)
- Receptor site
- Resolution/completeness of met data

Starting height

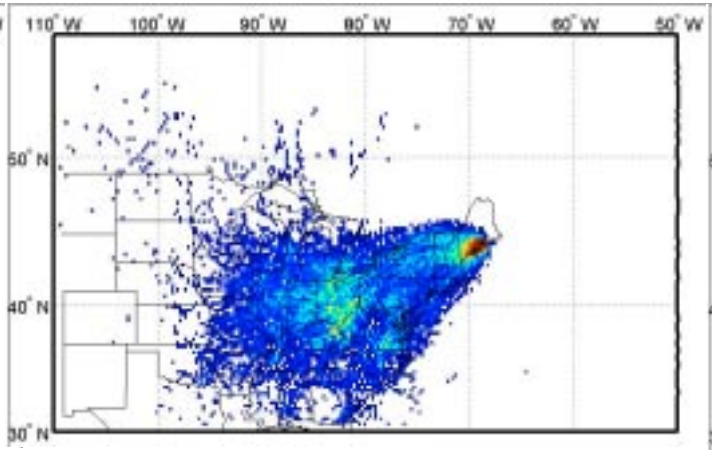
Acadia, 1997-2002, 48hr, 200/500/1000m, R=10



Cluster 5

Receptor Level= 200m

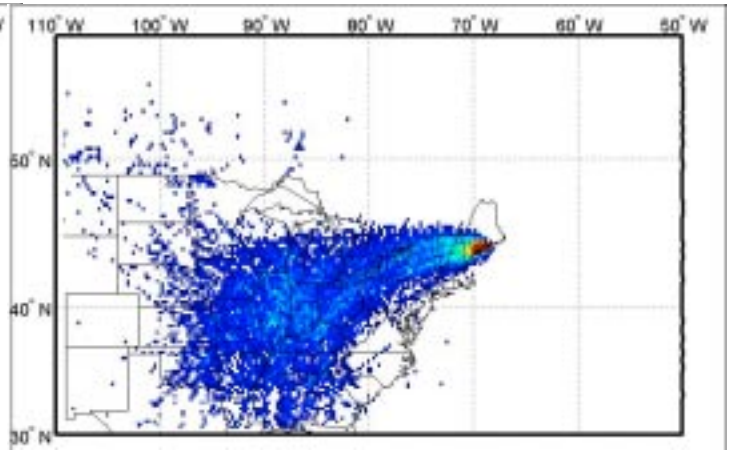
Mean Height= 892 m



Cluster 4

Receptor Level= 500m

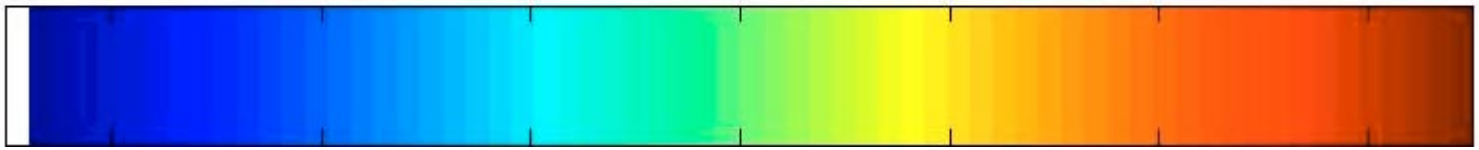
Mean Height= 867 m



Cluster 5

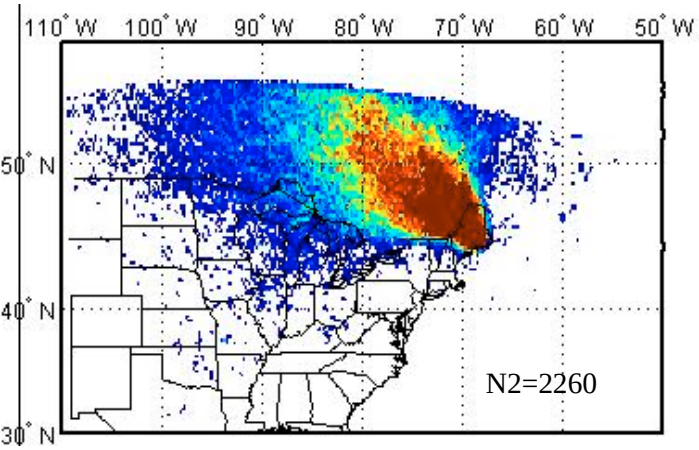
Receptor Level= 1000m

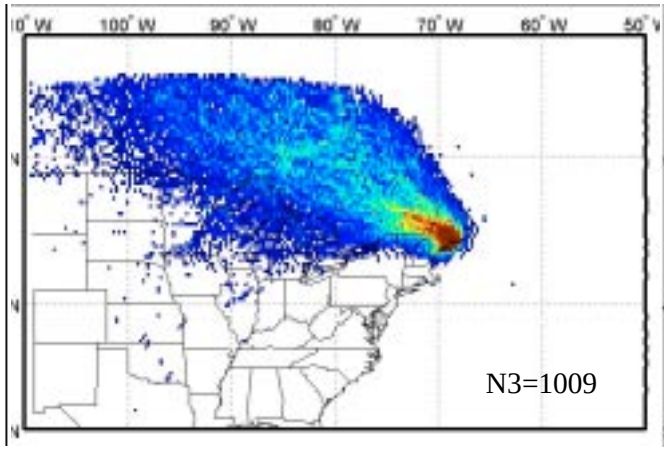
Mean Height= 1247 m

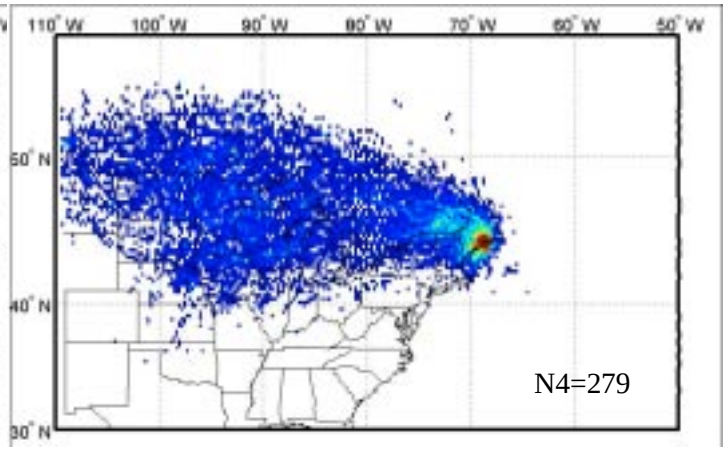


Length of cluster

Acadia, 1997-2002, 24/48/120hr, 500m, R=6,10,16







Total Trajectories in 24 hr
Analysis = 14235 (99-02)

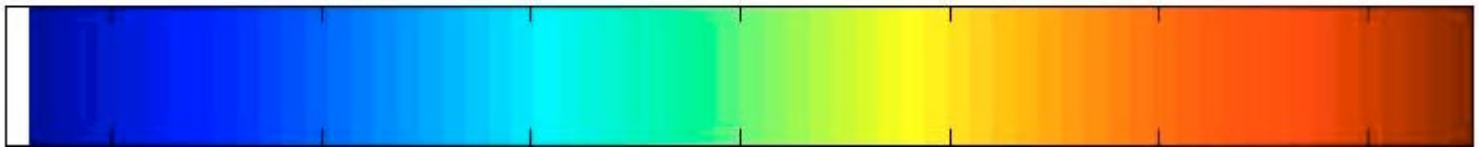
Mean Height= 1286 m

Total Trajectories in 48 hr
Analysis = 10592

Mean Height= 1916 m

Total Trajectories in 120 hr
Analysis = 4429

Mean Height= 1692 m



Temporal range

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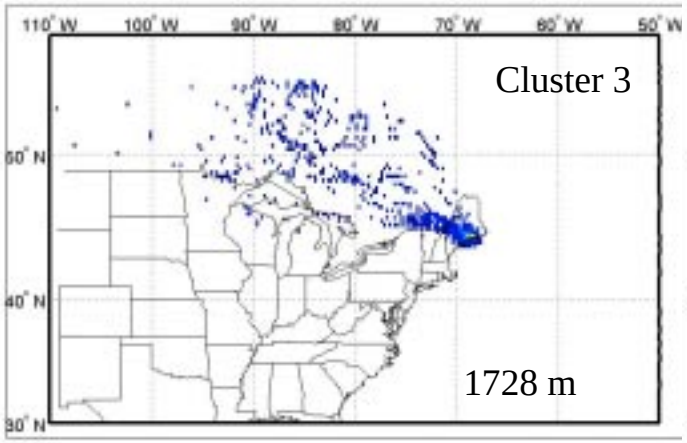
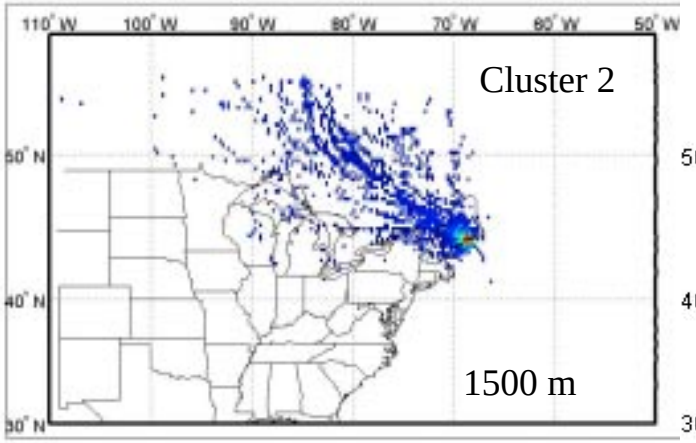
Acadia, 97/98/99/00/01/02/97-02, 48hr, 500m, R=10

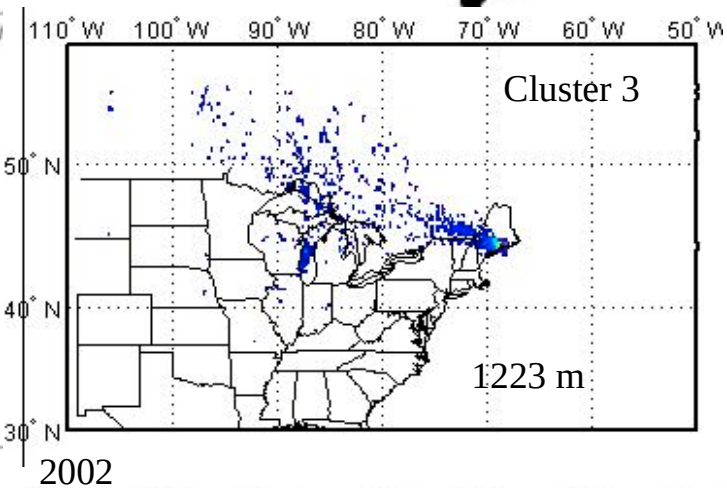
1997



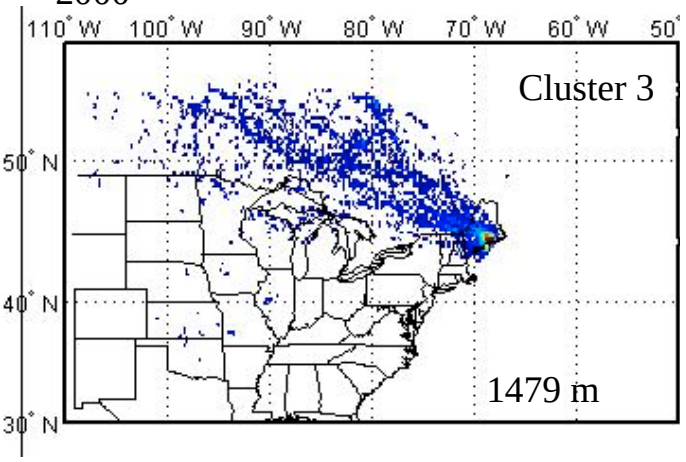
1998



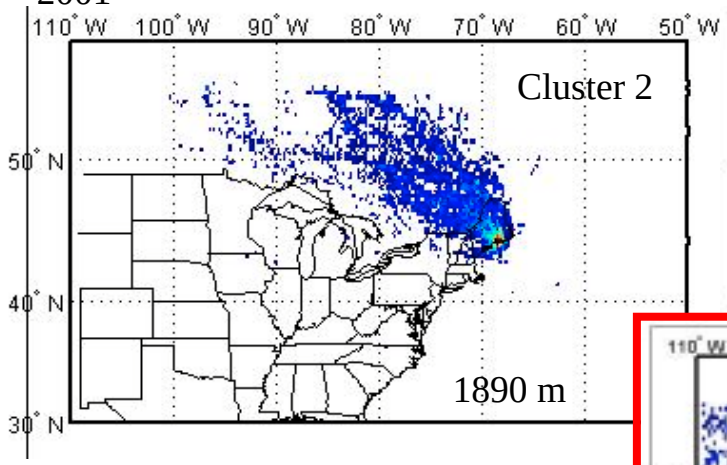
1999



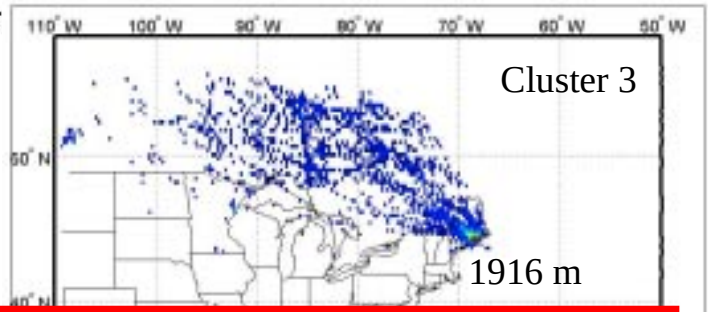
2000



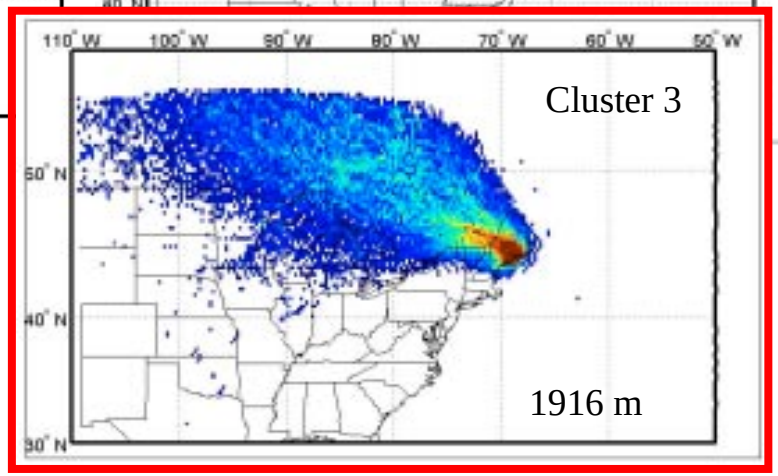
2001



2002



1997-2002

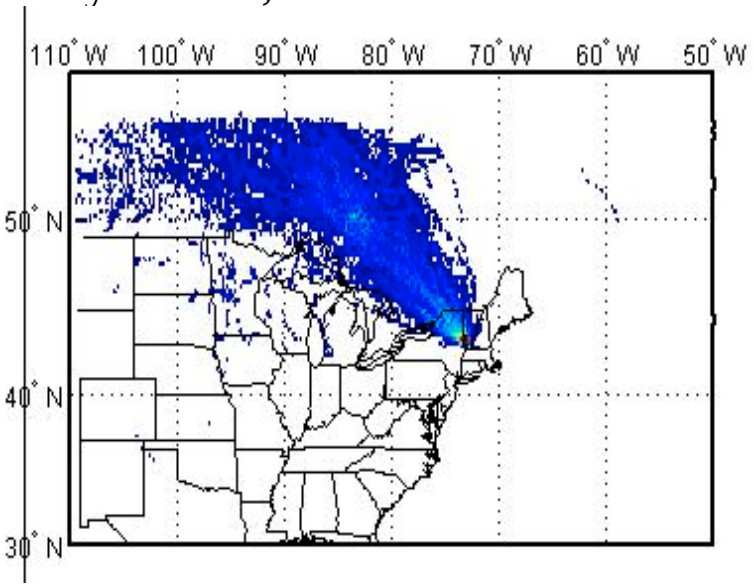


Atmospheric Modes vs. Clusters

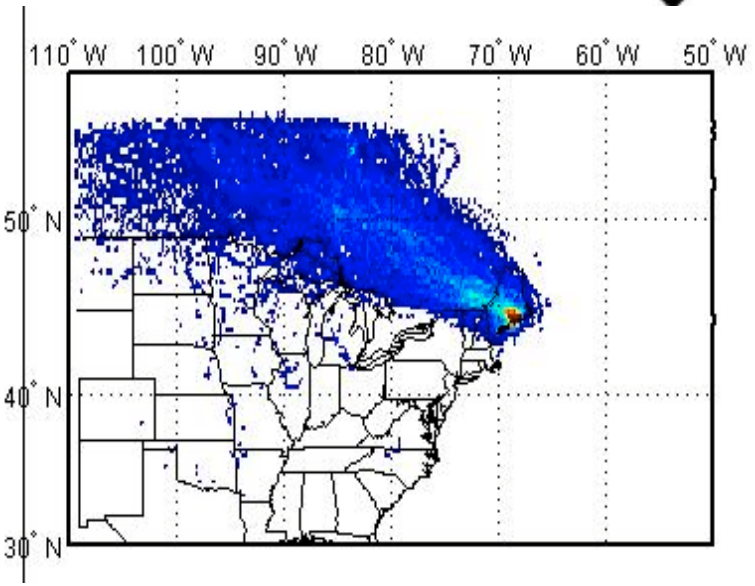
- *Clusters* are defined as groupings of similar trajectories during a specific time period
- *Atmospheric modes* describes the underlying meteorological phenomena that explain the observed clusters

Northwest Fast (NWF)

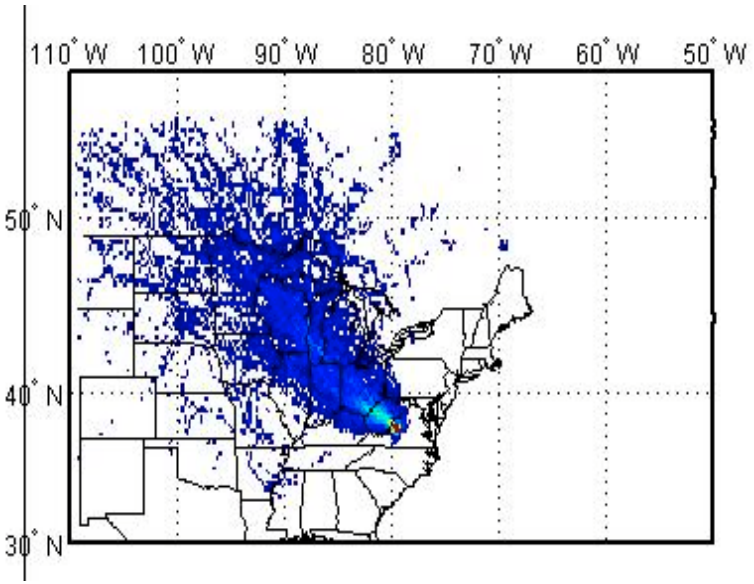
Lye Brook, VT



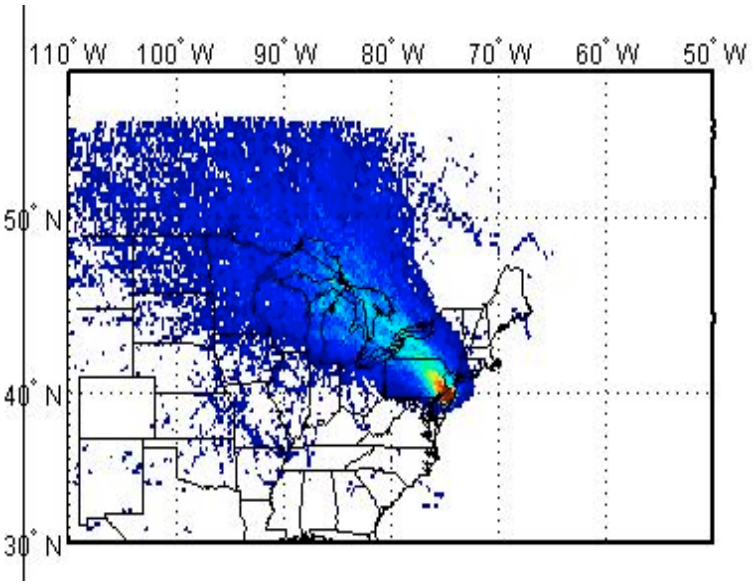
Acadia, ME



Jefferson/James River Face, VA

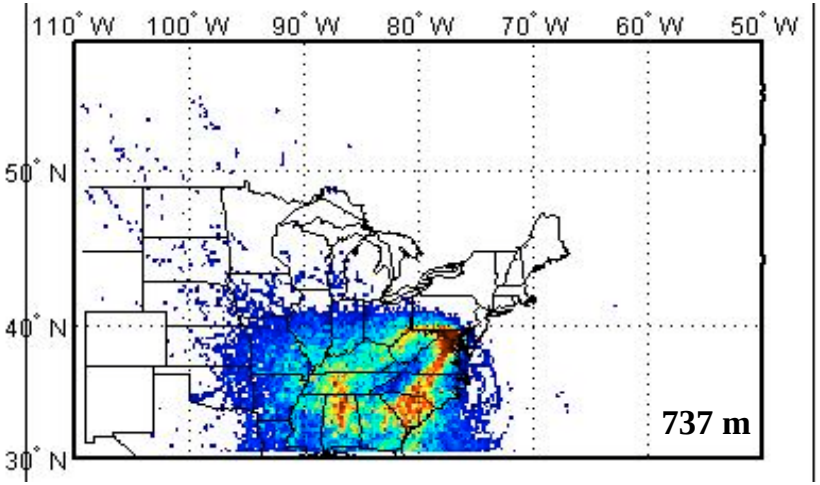


Brigantine, NJ

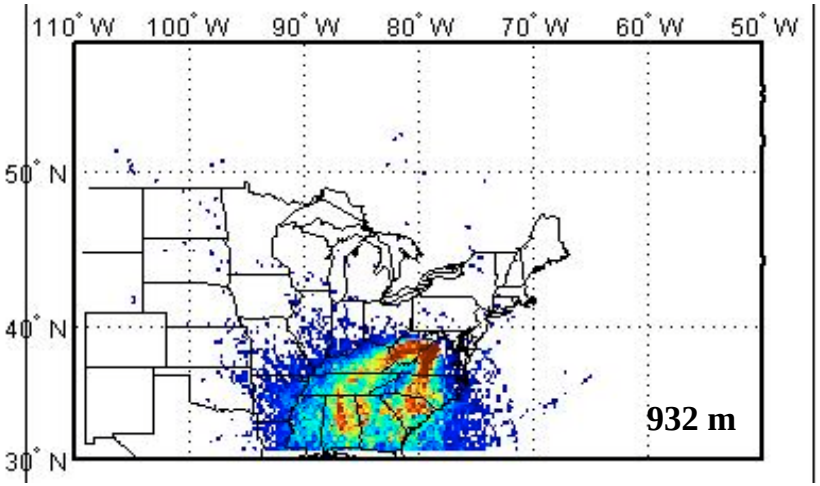


Southwest Bi-modal (SWB)

Baltimore



Shenandoah



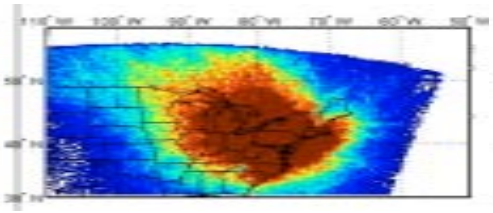
- Represents a mix of southwest coastal and southwest inland

Predominant Meteorological Pathways and Influence on Air Quality

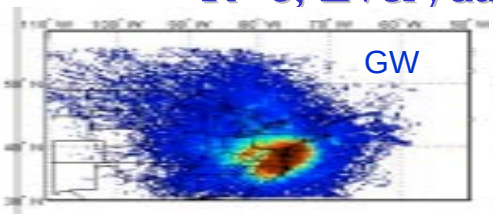
- Back-trajectory Clusters
- Pollution-Date Database
- Correlate dates to establish relationships between atmospheric modes and pollution tendencies

Brigantine 97-02 EDAS- 48 hrs

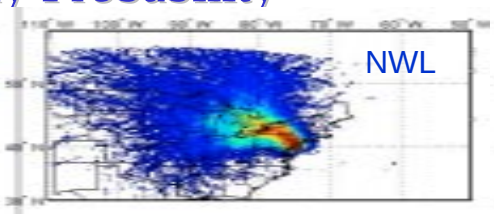
R=6, Everyday Probability



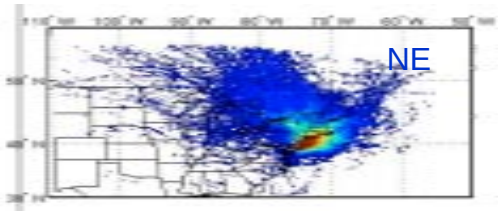
Cluster 0
N=12993 , H=1042 m



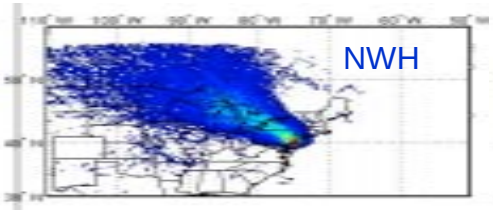
Cluster 1
N=1830 , H=479 m
15.41, 6.29, 107.92



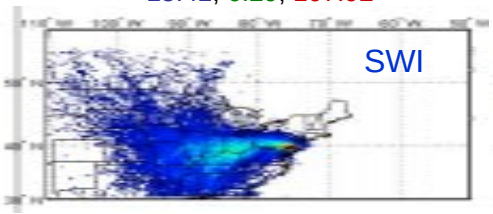
Cluster 2
N=1101, H=923.0 m
13.57, 6.10, 95.51



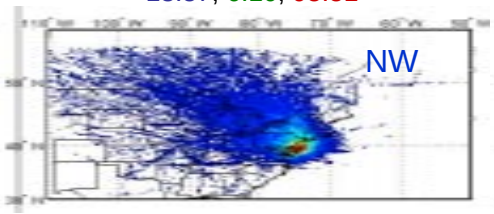
Cluster 3
N=708, H=512.1 m
8.63, 3.17, 63.58



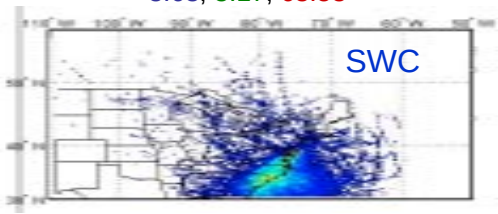
Cluster 4
N=692, H=1586.6 m
11.55, 4.10, 81.23



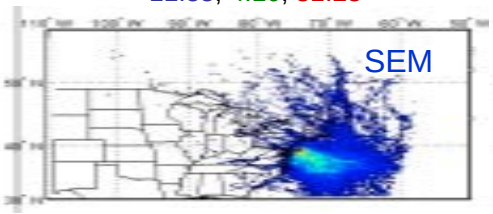
Cluster 5
N=655, H=871.2 m
14.48, 5.32, 103.44



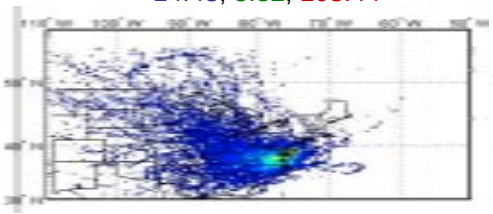
Cluster 6
N=624, H=1308.5 m
11.63, 4.01, 79.55



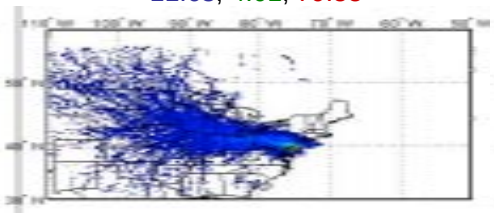
Cluster 7
N=619, H=479.9 m
10.67, 3.94, 73.66



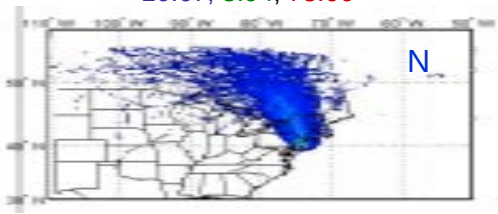
Cluster 8
N=402, H=441.8 m
7.42, 3.33, 59.62



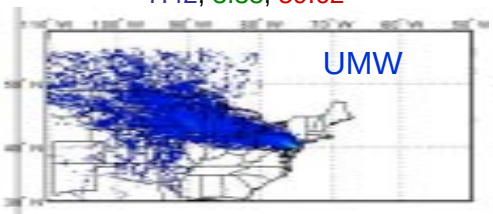
Cluster 9
N=375 , H=1319.7 m
14.99, 5.90, 107.12



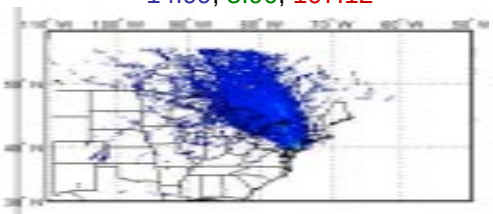
Cluster 10
N=357 , H=1800.2 m
15.49, 6.48, 114.24



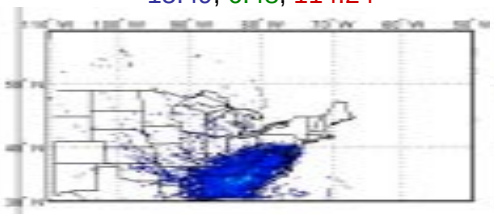
Cluster 11
N=329, H=1688.2 m
9.91, 2.07, 61.94



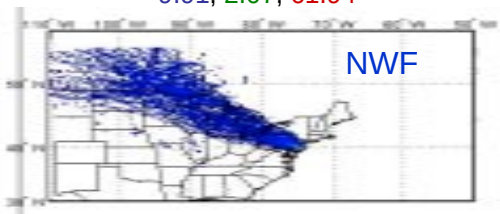
Cluster 12
N=282, H=1226.0 m
10.86, 3.32, 79.65



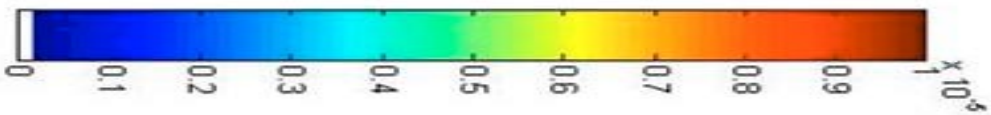
Cluster 13
N=267, H=762.4 m
7.00, 2.39, 53.80



Cluster 14
N=223, H=693.6 m
12.61, 4.26, 82.92



Cluster 15
N=215, H=1948.6 m
9.61, 3.27, 71.54



1997-2002 IMPROVE Averages:
Total $PM_{2.5}$ (µg/m^3)
$PM_{2.5}$ SO_4 (µg/m^3)
Reconstructed Extinction (Mm^{-1})

Trajectory Analysis: Multiple Metrics

Everyday Residence-time Probability

$$EP = \left(n_{ij} / N \right)$$

n_{ij} = total endpoints passing through grid cell i, j

N = total endpoints passing through all grid cells from all trajectories

High Day Residence-time Probability

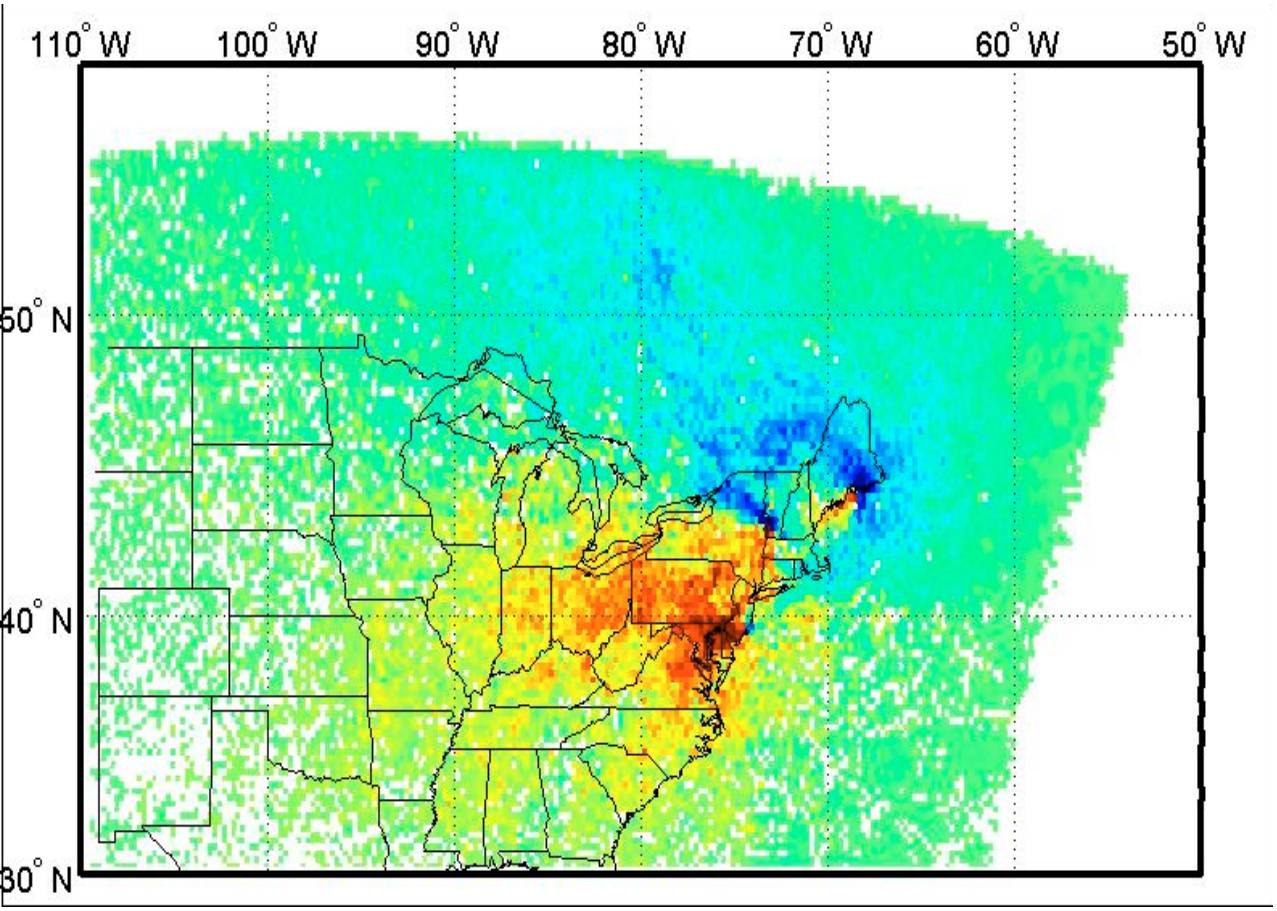
$$HP = \left(m_{ij} / M \right)$$

m_{ij} = total high day endpoints passing through grid cell i, j

M = total high day endpoints passing through all grid cells from high day trajectories

Trajectory Analysis: Multiple Metrics

Incremental Probability

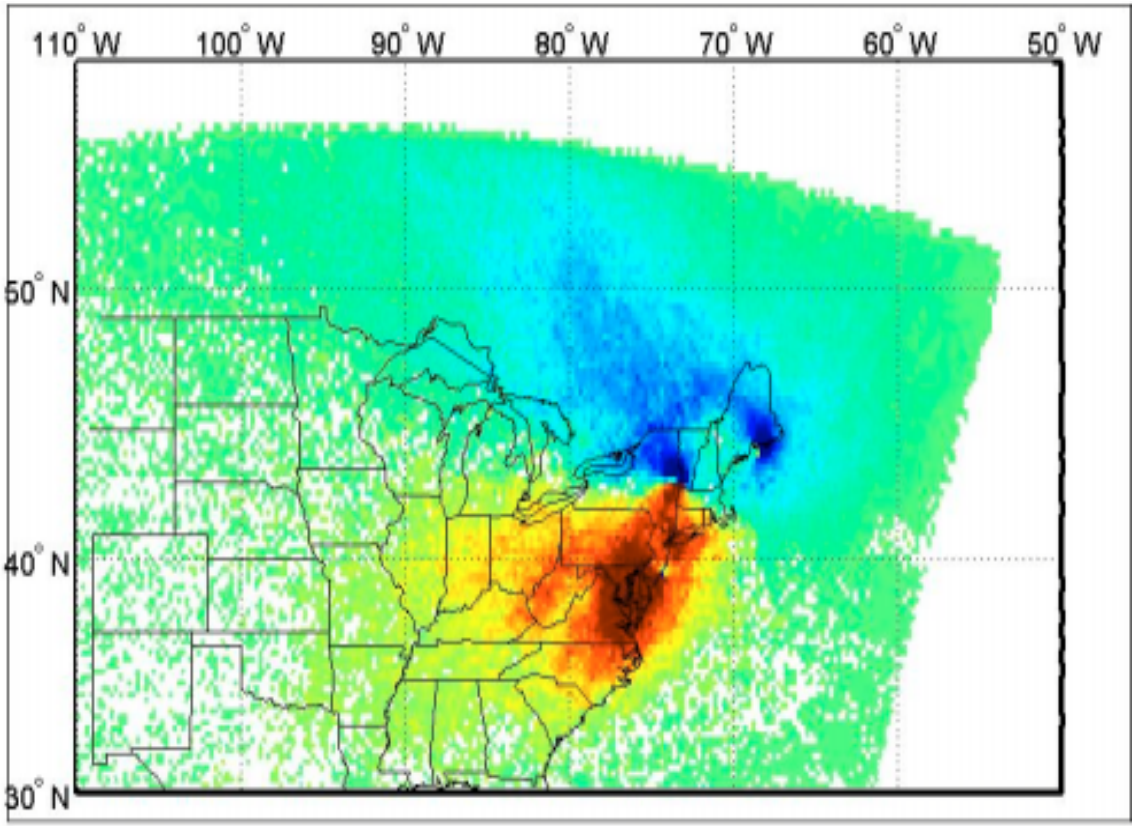


$$IP = HP - EP$$

3-site average:
Acadia, Lye Brook, and Brigantine

Trajectory Analysis: Multiple Metrics

Clustered Incremental Probability



$$CIP = \sum_{k \in K} RP_k - EP$$

K = Subset of clusters, 20% worst pollution days

RP_k = Residence - time probability for cluster k

3-site average:
Acadia, Lye Brook, and Brigantine

Trajectory Analysis: Multiple Metrics

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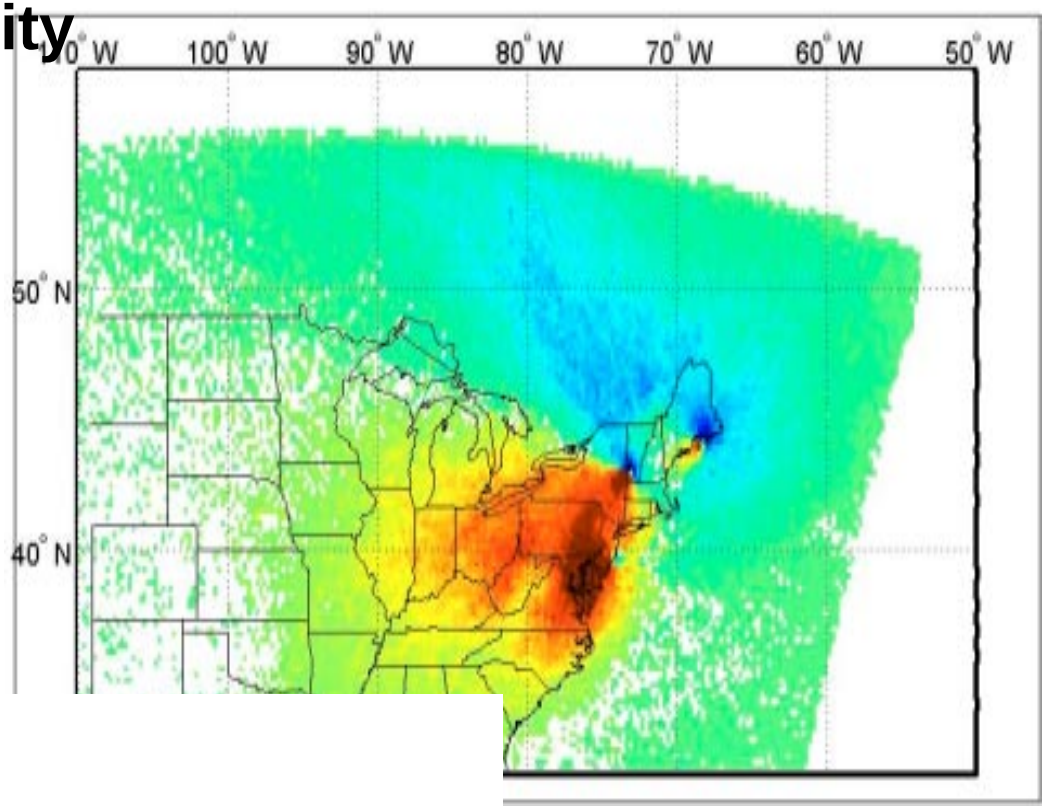
Cluster-Weighted Probability



$$CWP = \frac{1}{\overline{C}}\left(\sum_{i=1}^{L}(\overline{C})_i \cdot RP_i - \overline{C} \cdot EP\right)$$

$L = \text{total number of clusters calculated}$

$(\overline{C})_i = \text{Average concentration (obs associated with cluster i)}$

$\overline{C} = \text{Average concentration (all days)}$

3-site average:
Acadia, Lye Brook, and Brigantine

Distribution of CIP for Sulfate Transport

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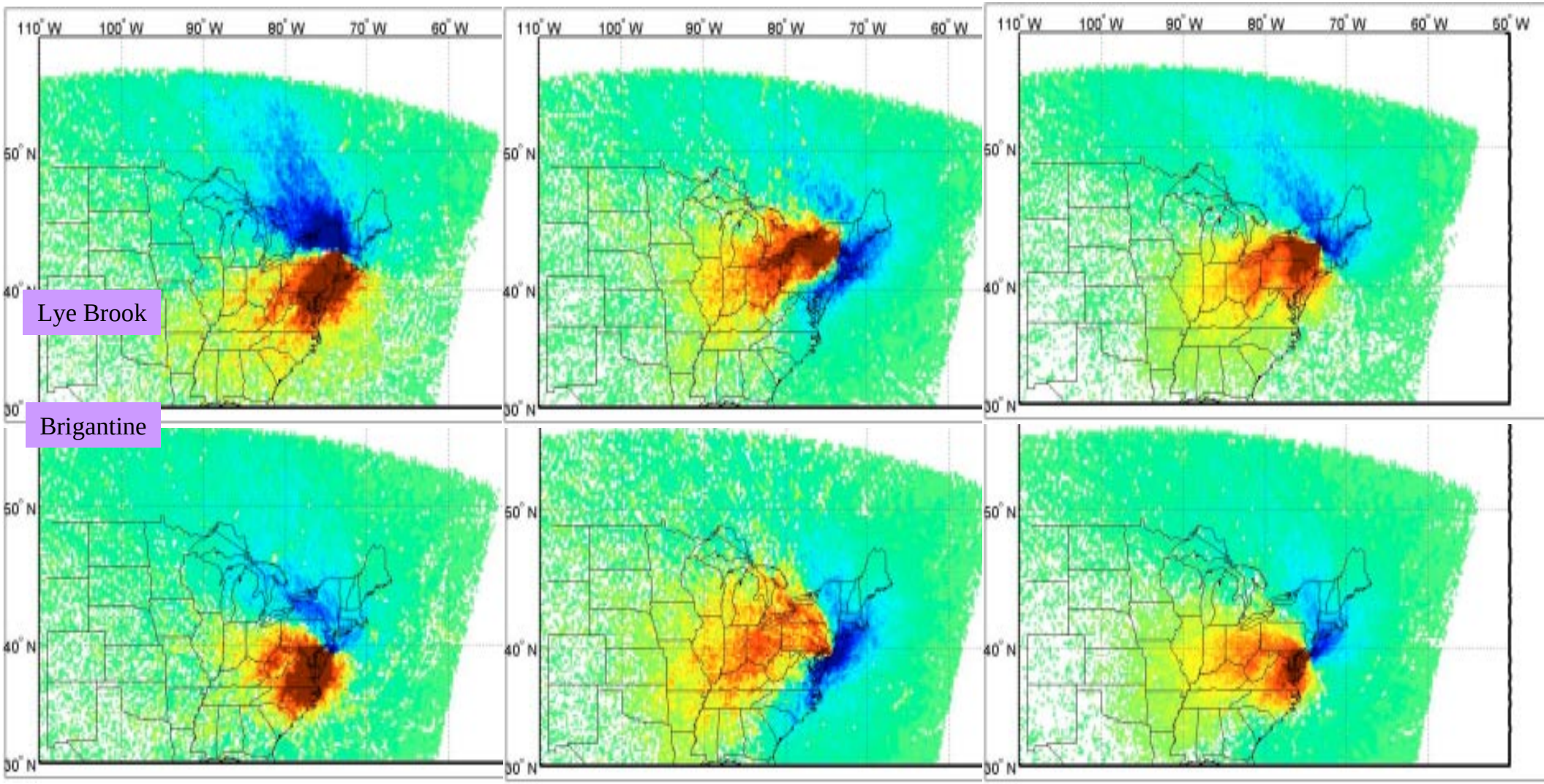
Worst 20% days

Second worst 20% days

Worst 40% days



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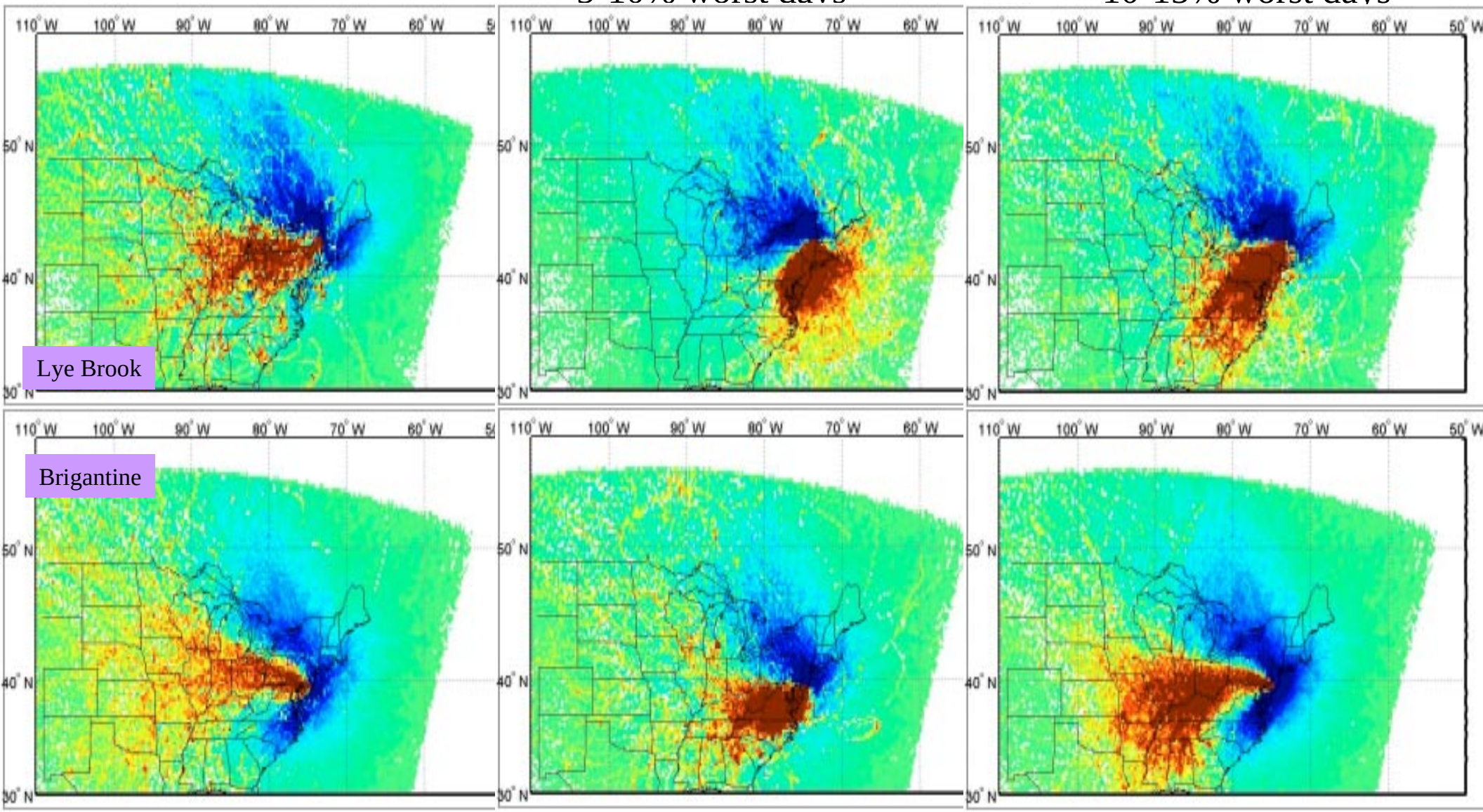
20 Percent is a lot of days…

0-5% worst days

5-10% worst days

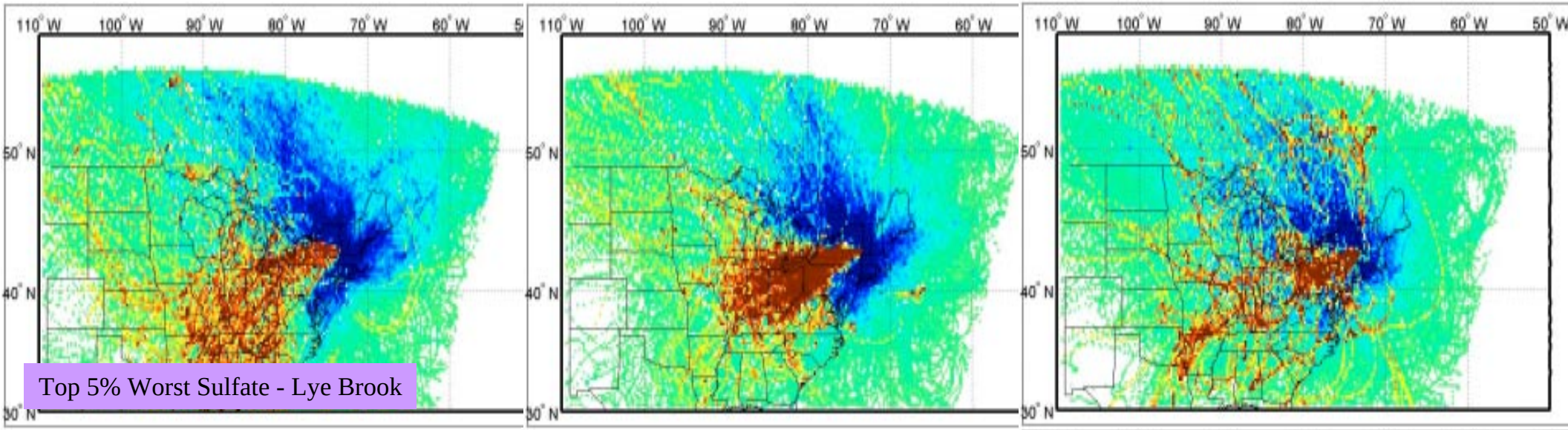
10-15% worst days



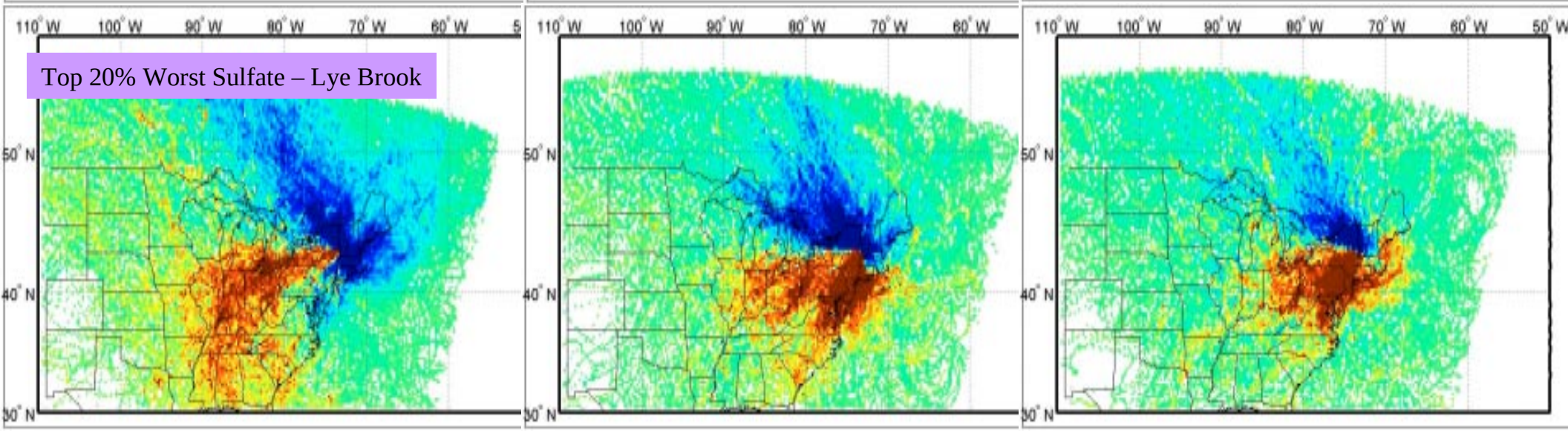
20 Percent covers a lot of seasons…

NESCAUM
Northeast States for Coordinated Air Use Management

Spring | Summer | Fall

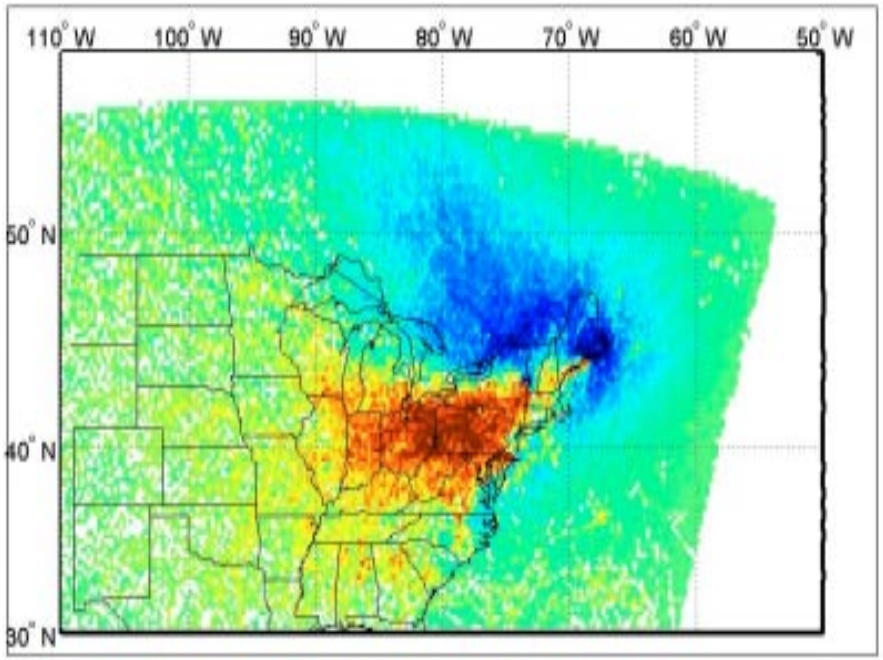


Top 5% Worst Sulfate - Lye Brook

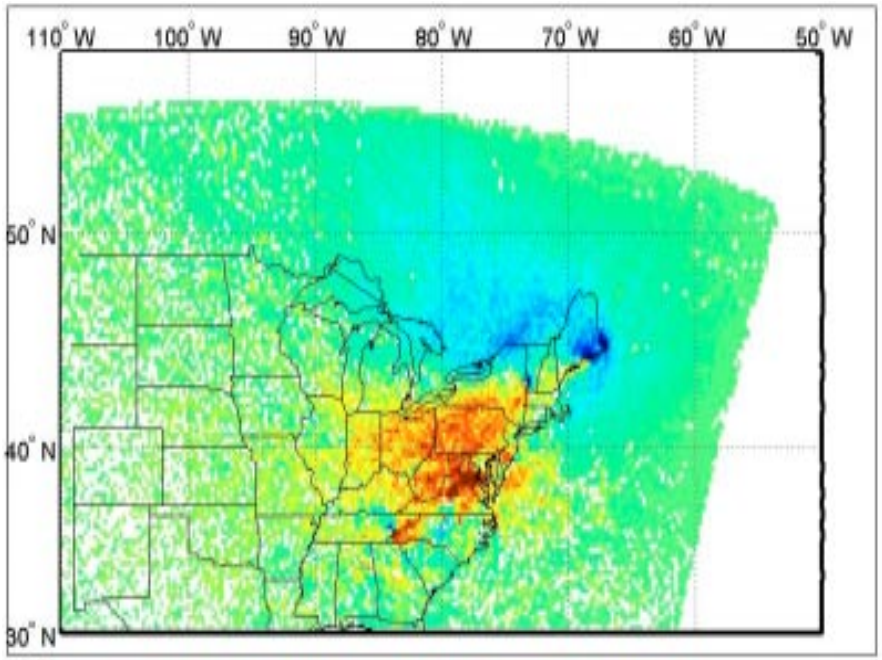


Top 20% Worst Sulfate – Lye Brook

5% worst days from the perspective of multiple sites



Acad, Brig, Lybr, Moos



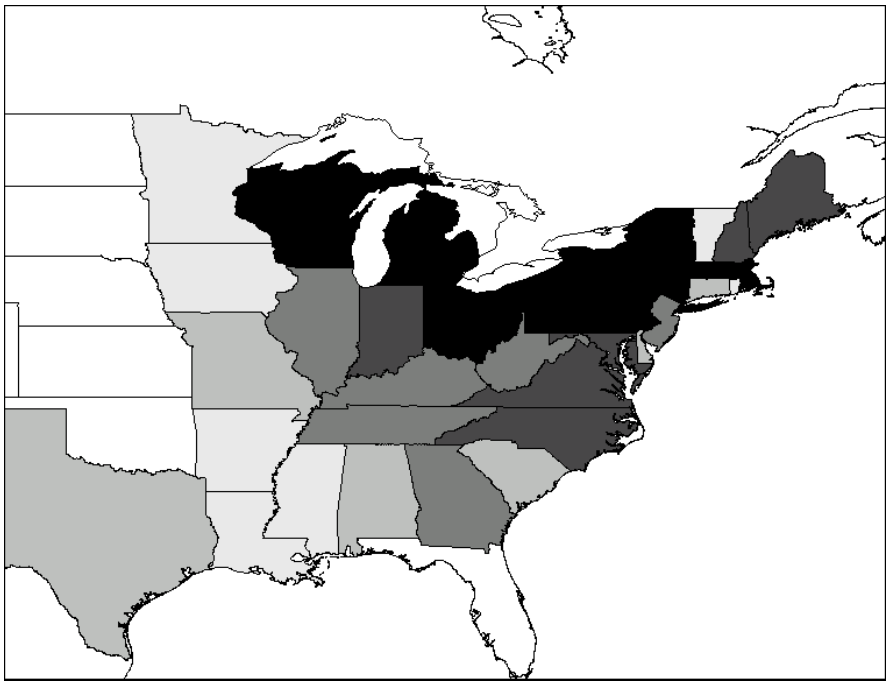
Acad, Brig, Lybr, Grsm, Moos, Shen, Wash, Jeff

REMSAD v.7.10

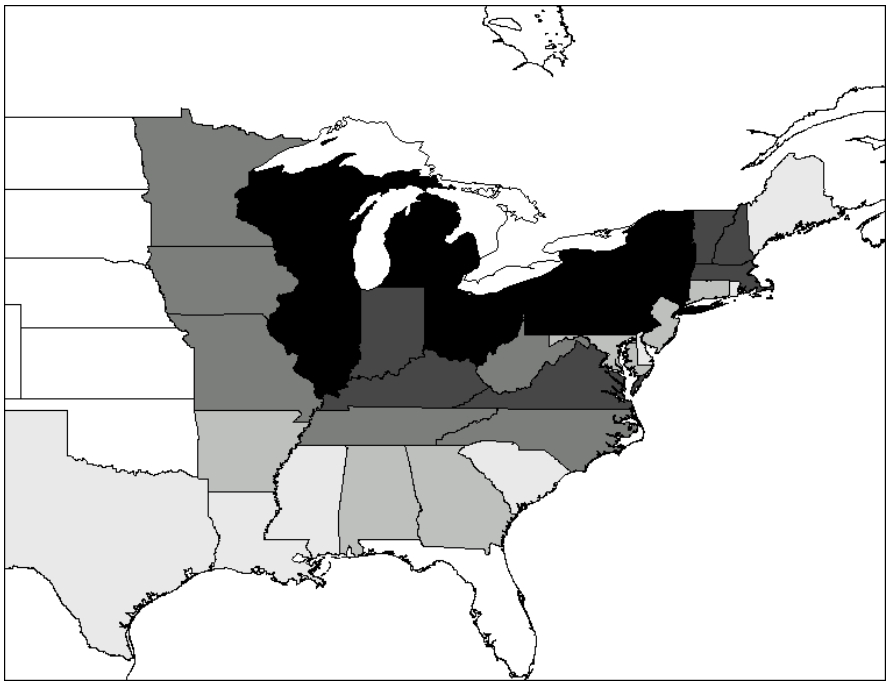
- Allows for source tagging (up to 11 tags per run)
- Meteorology and Emissions from EPA Clear Skies Act (2003) platform
- Tagged SO_2 emissions from elevated point sources in 33 Eastern U.S. states

Compare to REMSAD

REMSAD 7.10



Cluster-Weighted Probability



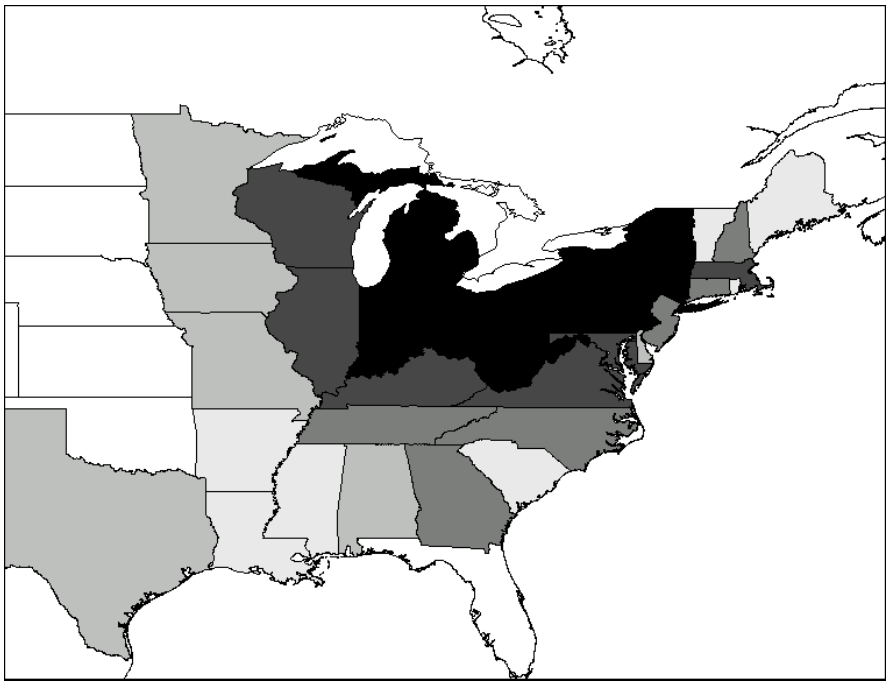
Top quintile contributor
2nd quintile contributor
3rd quintile contributor
4th quintile contributor
Bottom quintile contributor

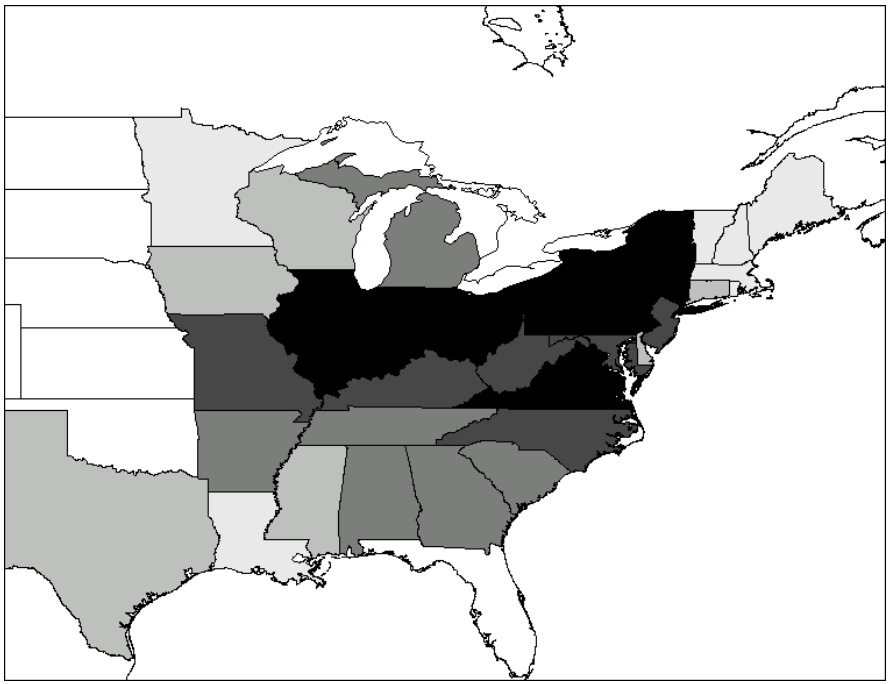
Acadia National Park, ME

Compare to REMSAD

REMSAD 7.10

Cluster-Weighted Probability





Top quintile contributor

2nd quintile contributor

3rd quintile contributor

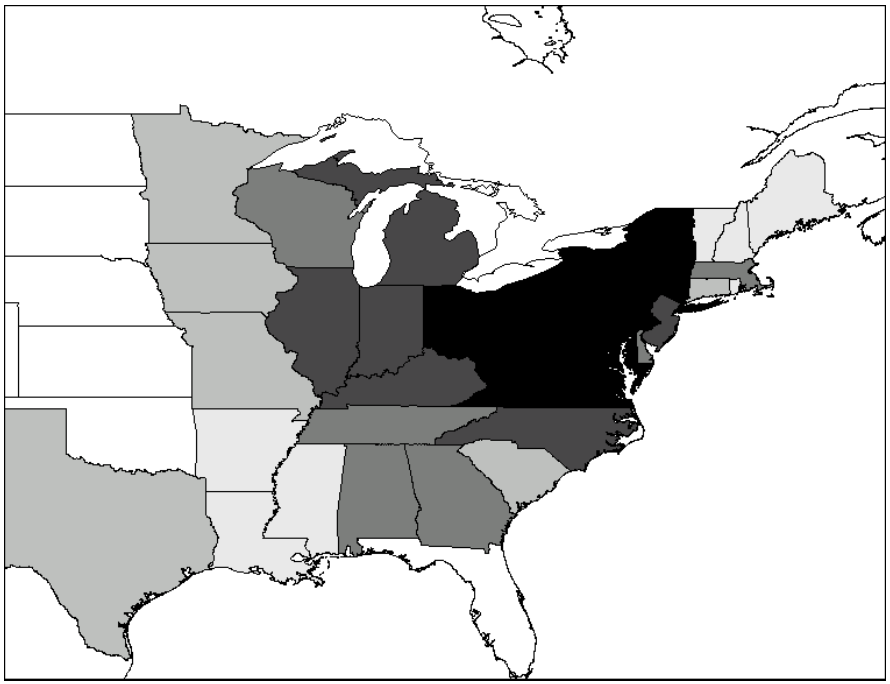
4th quintile contributor

Bottom quintile contributor

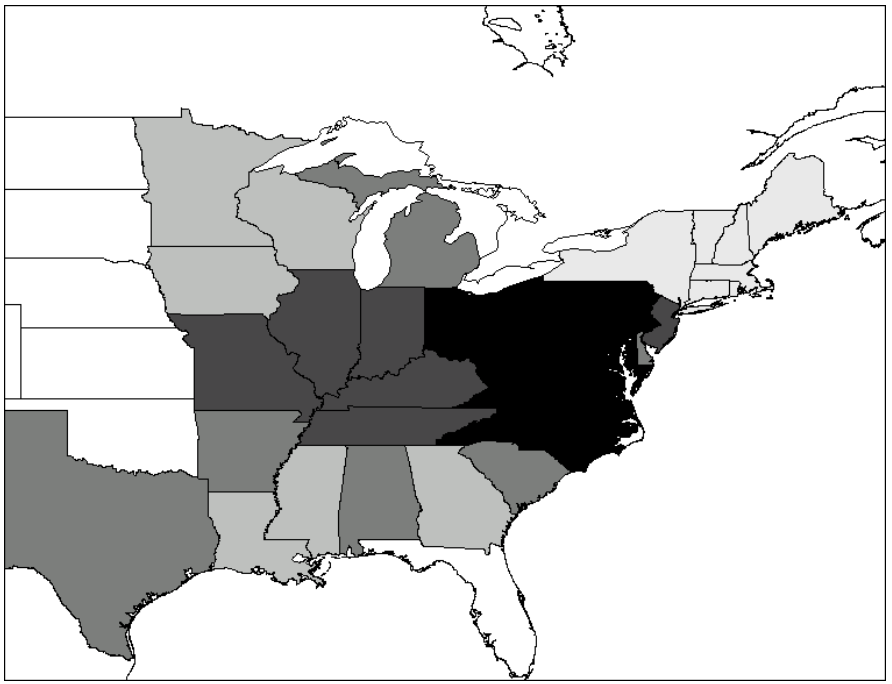
Lye Brook Wilderness, VT

Compare to REMSAD

REMSAD 7.10



Cluster-Weighted Probability



Top quintile contributor
2nd quintile contributor
3rd quintile contributor
4th quintile contributor
Bottom quintile contributor

Brigantine Wilderness, NJ