The Electrical Blackout over Eastern North America August 14-16 2003: An Accidental Experiment in Air Chemistry

Presented at the LFEE MIT-NESCAUM Endicott House Clean Air Symposium on Air Emissions from Large Industrial Sources on August 17, 2006.

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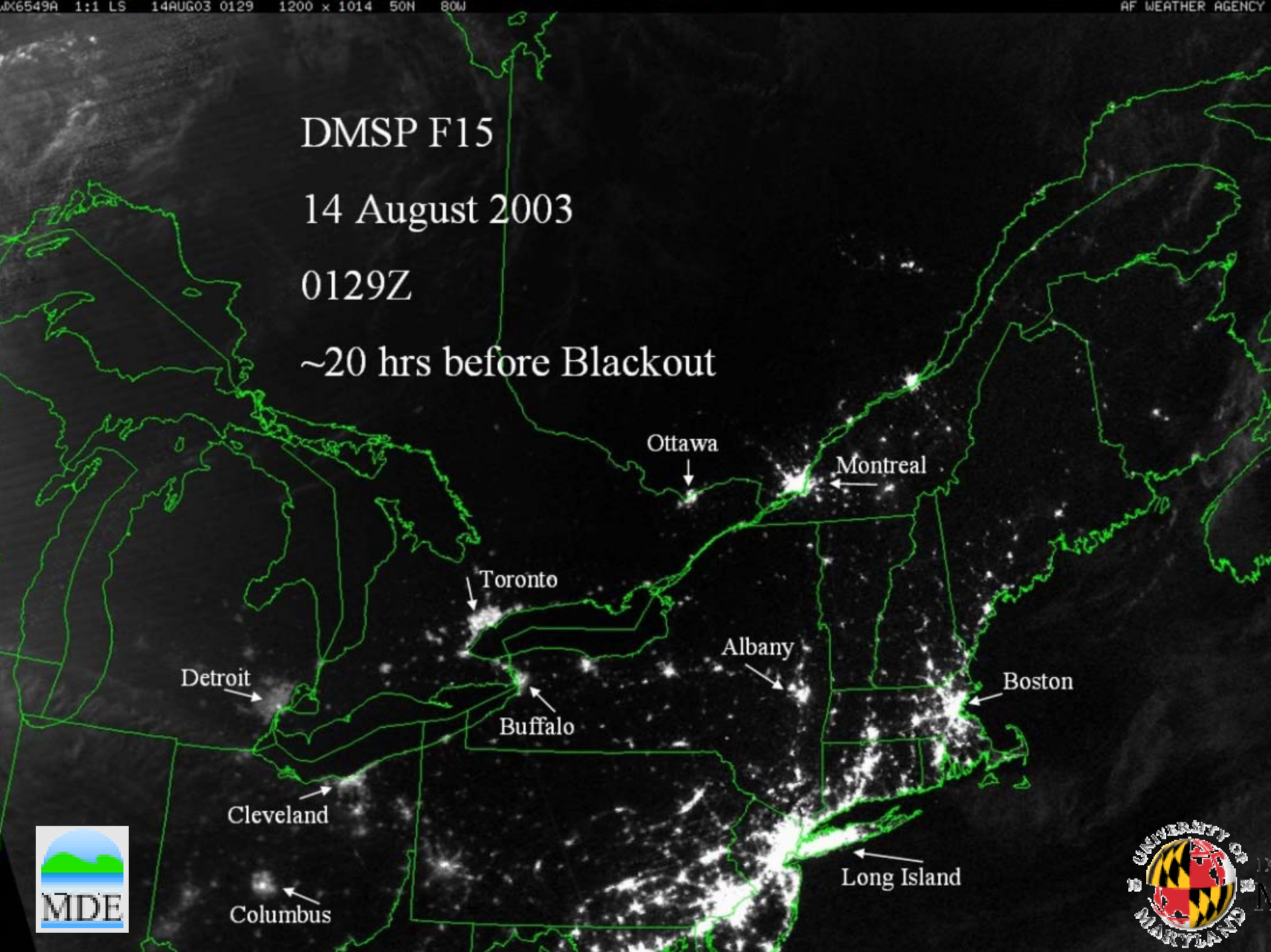
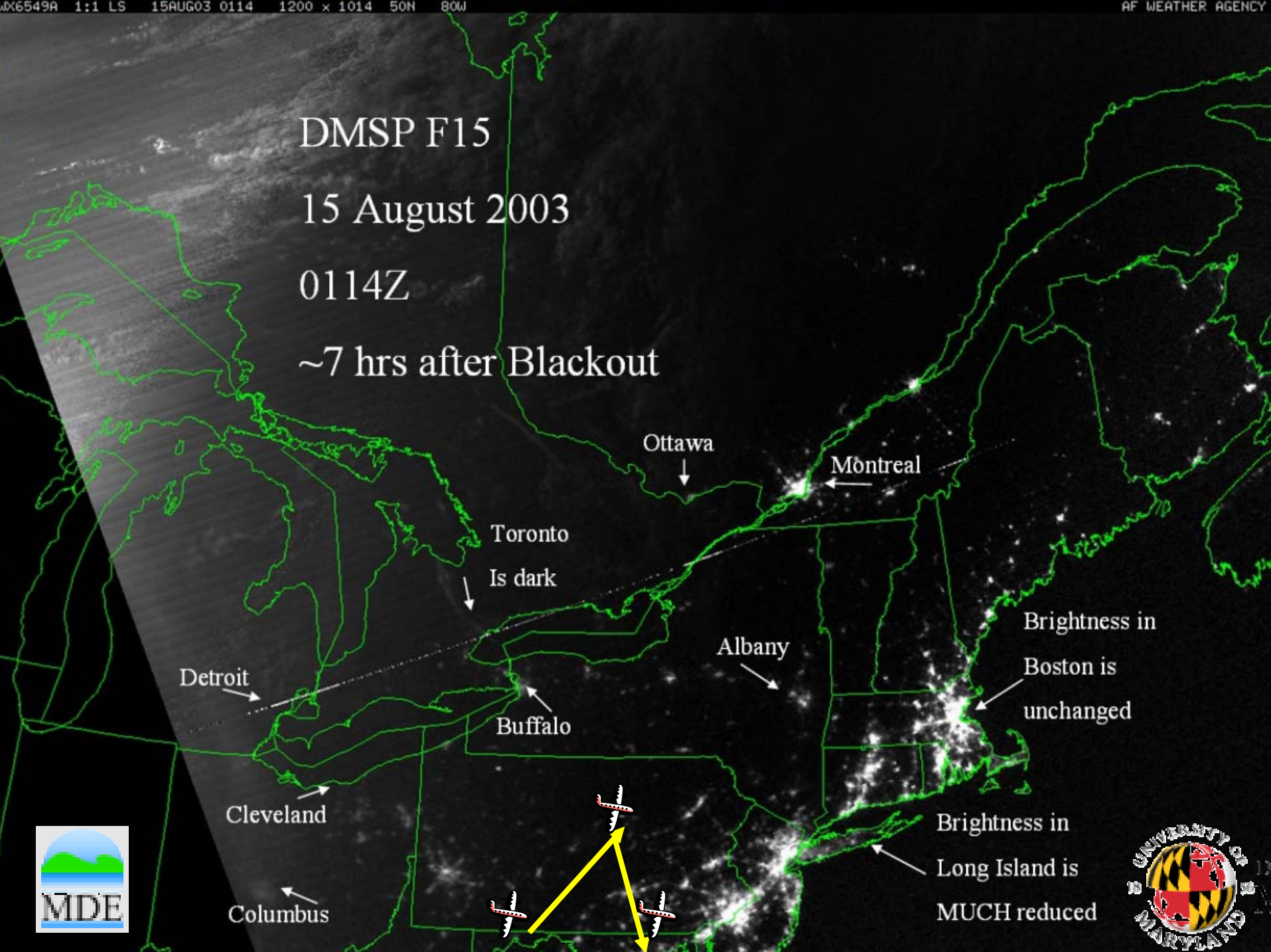
The University of Maryland


DMSP F15
14 August 2003
0129Z
~20 hrs before Blackout
Ottawa
Montreal
Toronto
Albany
Boston
Detroit
Buffalo
Cleveland
Columbus
Long Island
MDE


DMSP F15
15 August 2003
0114Z
~7 hrs after Blackout
Ottawa
Montreal
Toronto
Is dark
Albany
Brightness in
Boston is
unchanged
Detroit
Buffalo
Cleveland
Brightness in
Long Island is
MUCH reduced
Columbus
MDE

Question: What would happen to air quality if emissions from power plants were suddenly eliminated?

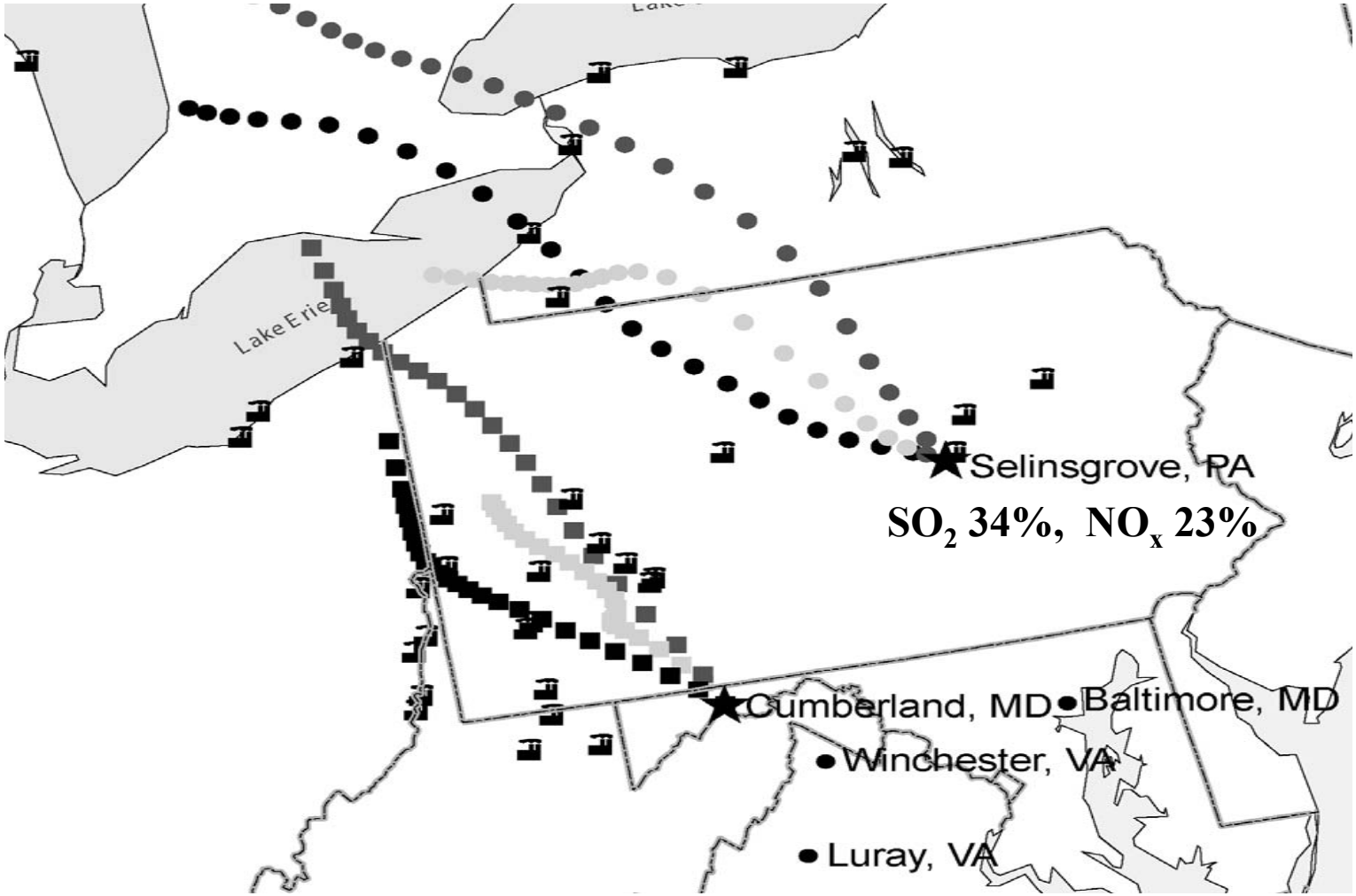
Problem: Many of the pollution monitors were without power.

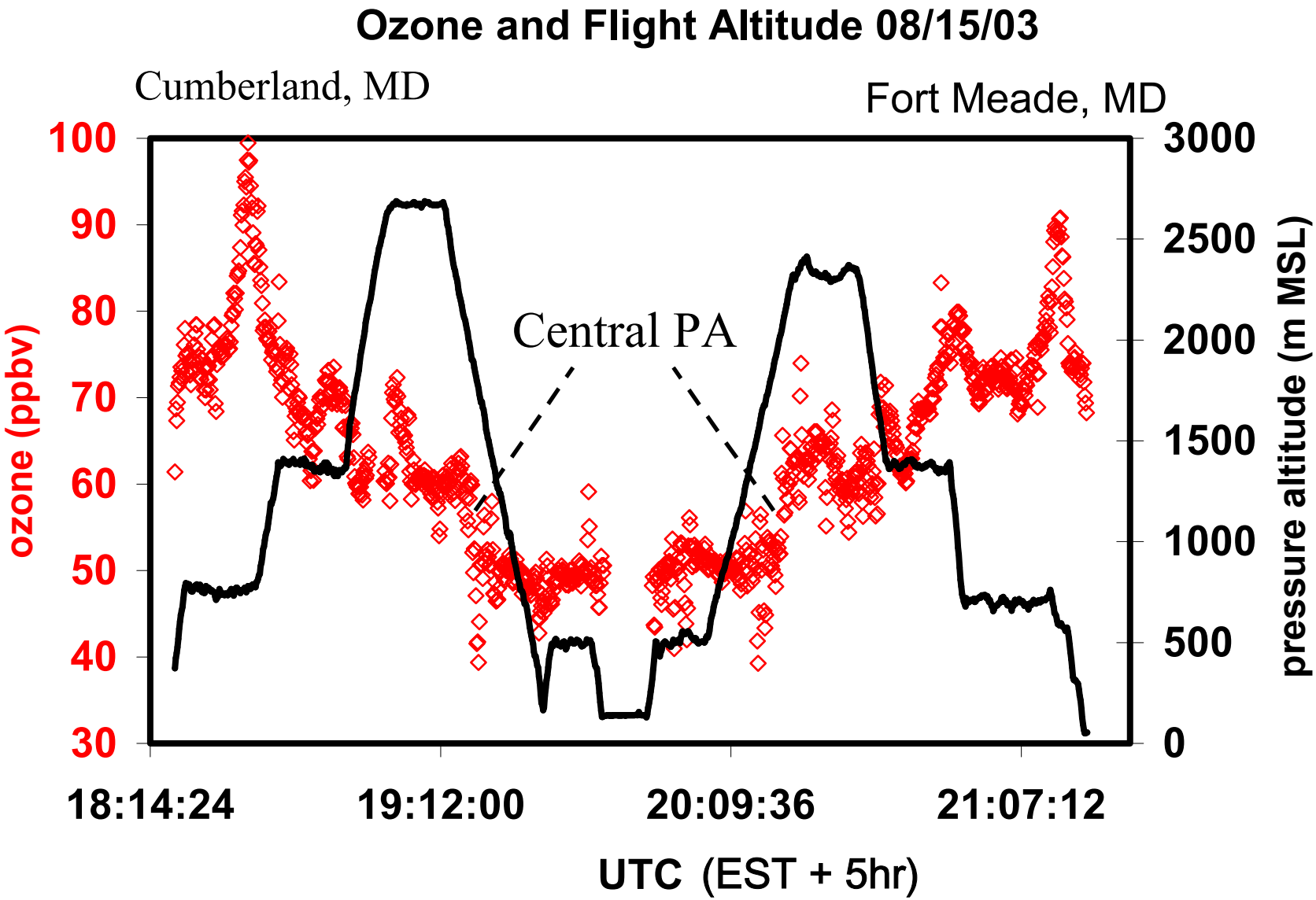
Experimental Control

Compare pollutant concentrations in the blackout region to those of:

- Blackout day, south of the blackout area.
- Meteorologically similar, non-blackout day in same location.
- All flights (1997-2003) with similar meteorology selected by an objective back trajectory clustering technique.

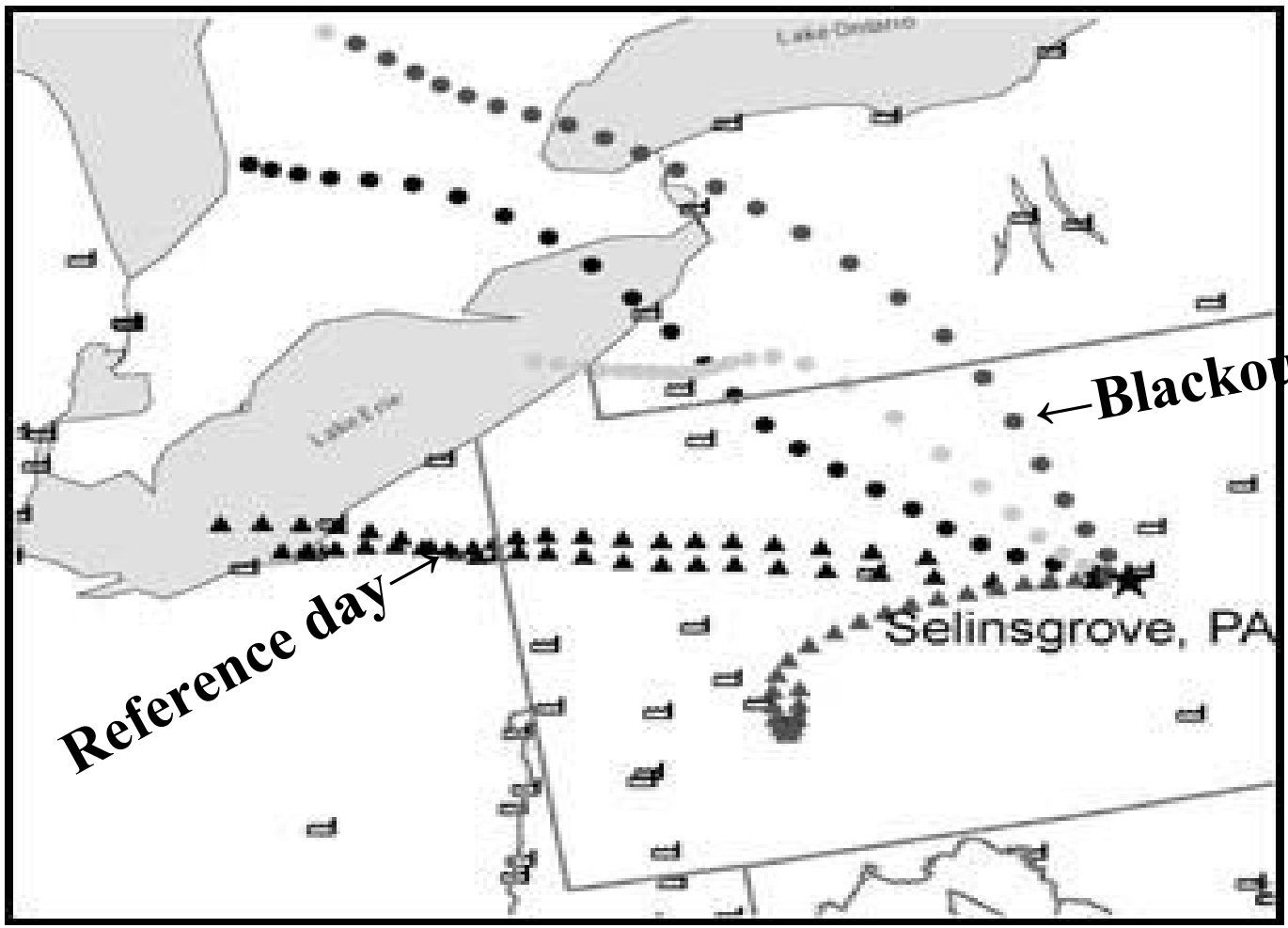
Power plants upwind of Cumberland were operating normally.

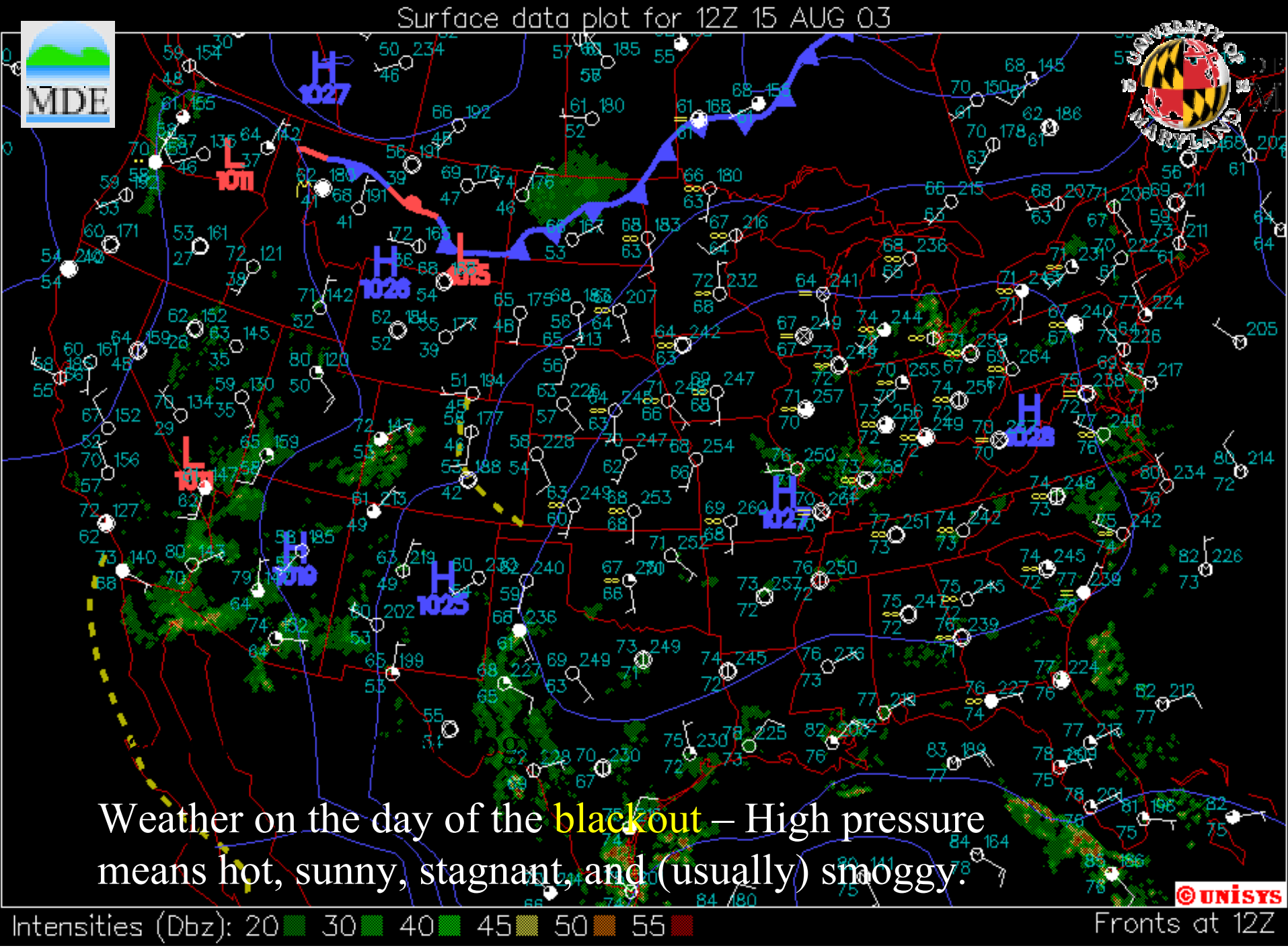



Ozone and Flight Altitude 08/15/03
Cumberland, MD
Fort Meade, MD
Central PA
ozone (ppbv)
100
90
80
70
60
50
40
30
pressure altitude (m MSL)
3000
2500
2000
1500
1000
500
0
18:14:24
19:12:00
20:09:36
21:07:12
UTC (EST + 5hr)

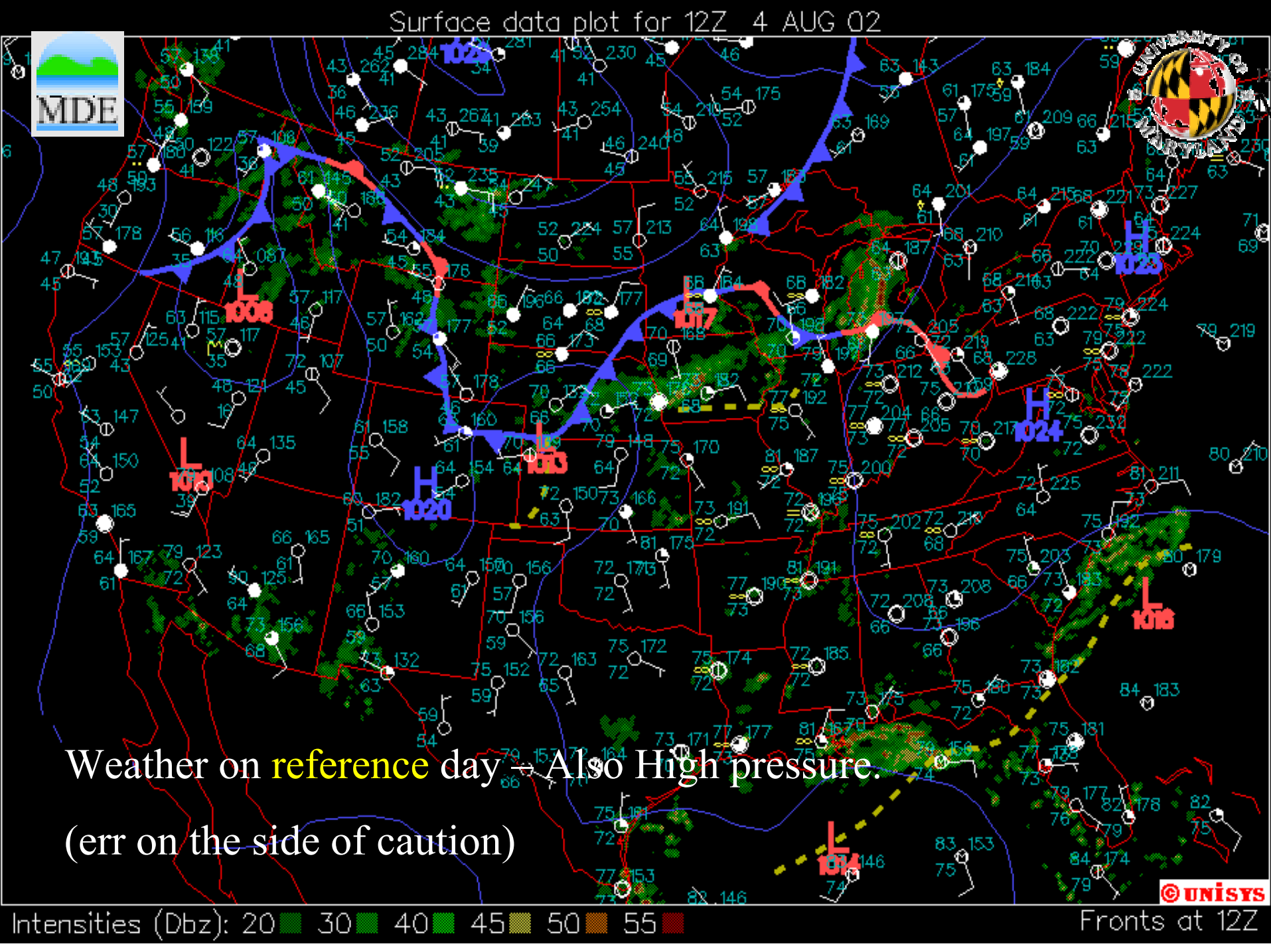
Back Trajectories

(24 hr @ 500, 1000, and 1500 m)

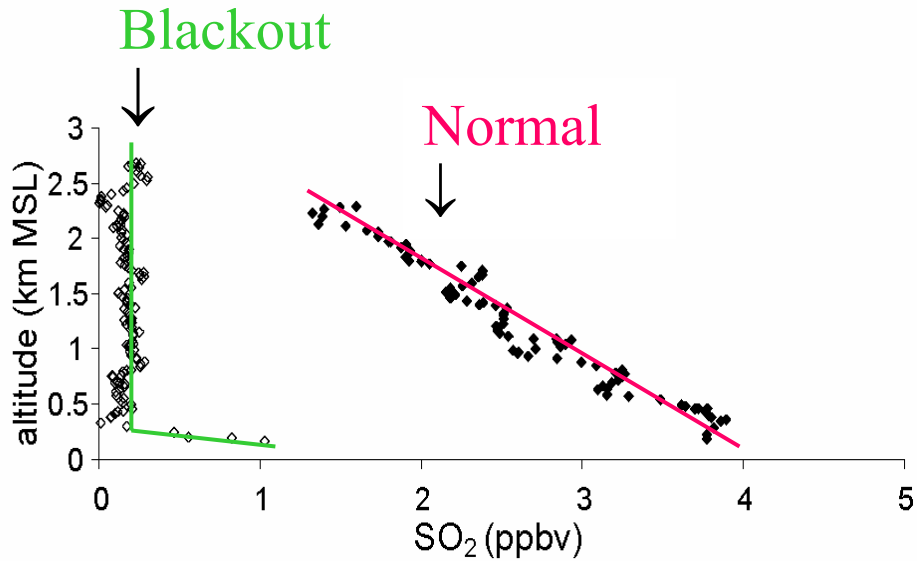


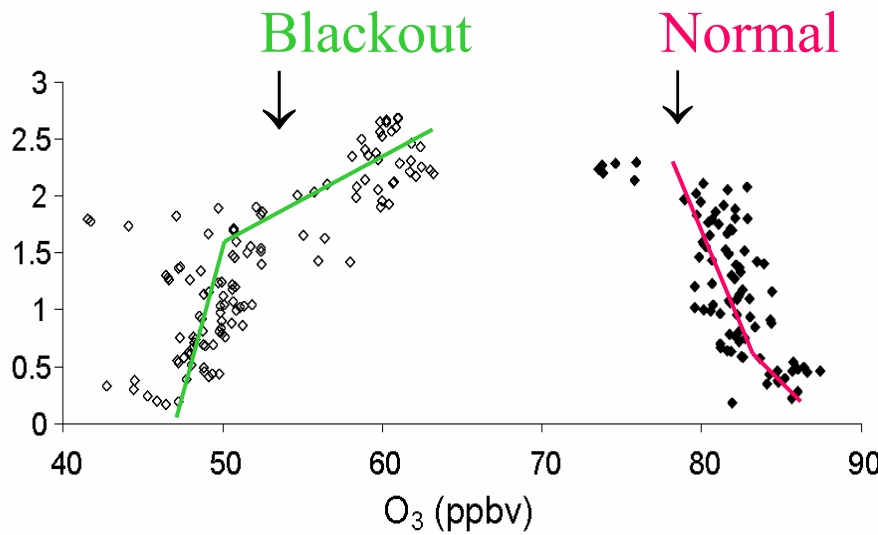


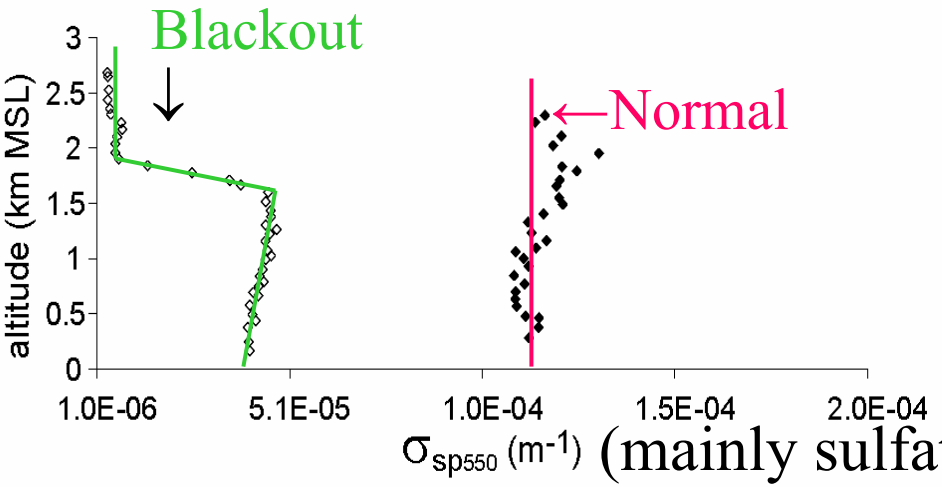
Weather on the day of the blackout – High pressure means hot, sunny, stagnant, and (usually) smoggy.

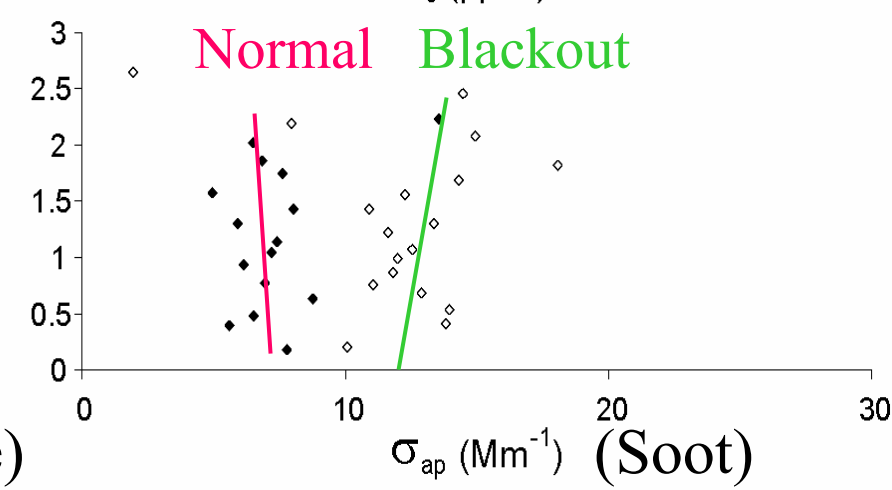

Surface data plot for 12Z 4 AUG 02
MDE
Weather on reference day – Also High pressure.
(err on the side of caution)
Intensities (Dbz): 20 30 40 45 50 55
Fronts at 12Z
©UNISYS

Idled power plants means improved air quality.







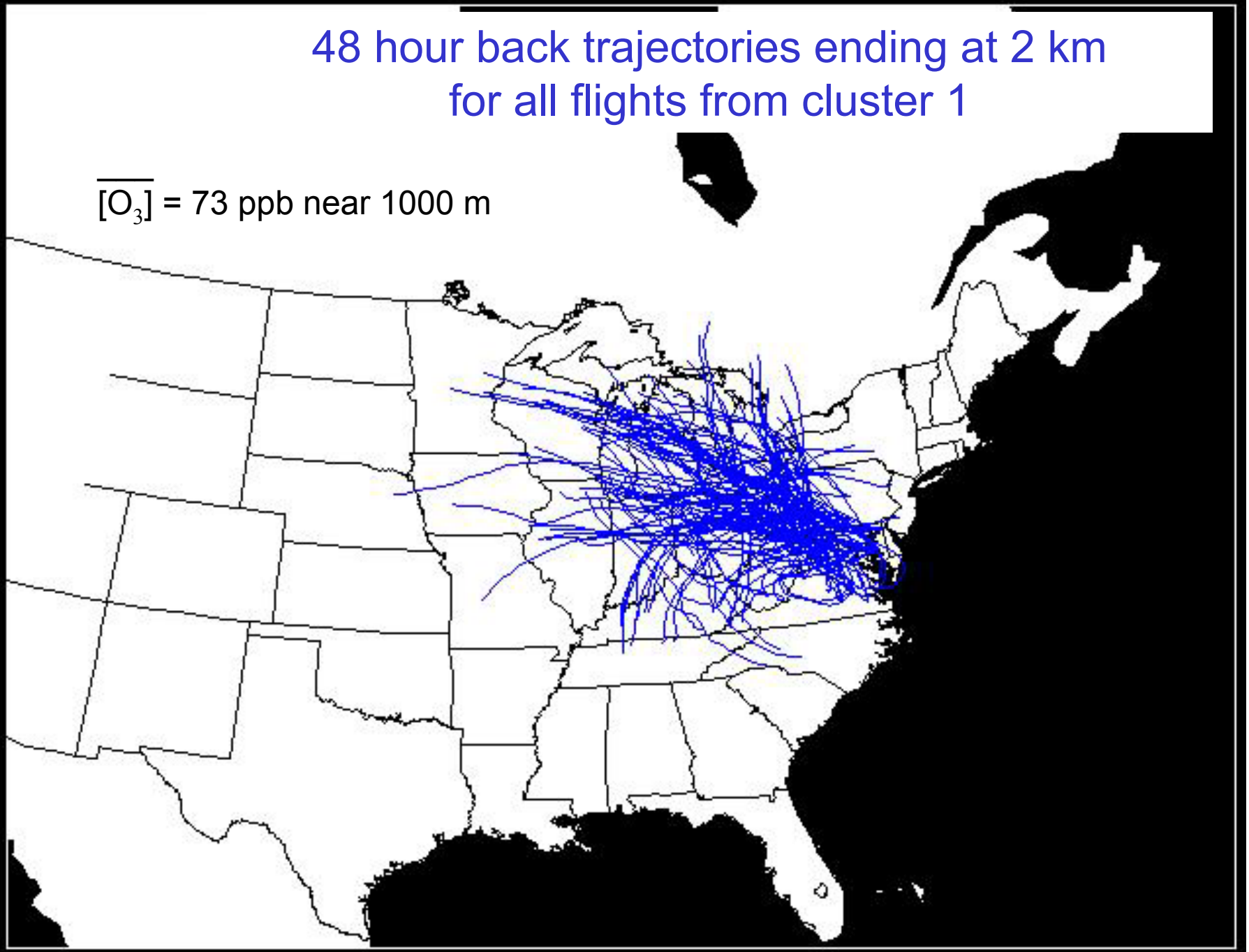


Observations over central Pennsylvania.

New point of reference: Clustered all profiles (hundreds) by meteorological condition based on back trajectories. See Taubman et al. *JGR, 2006.*

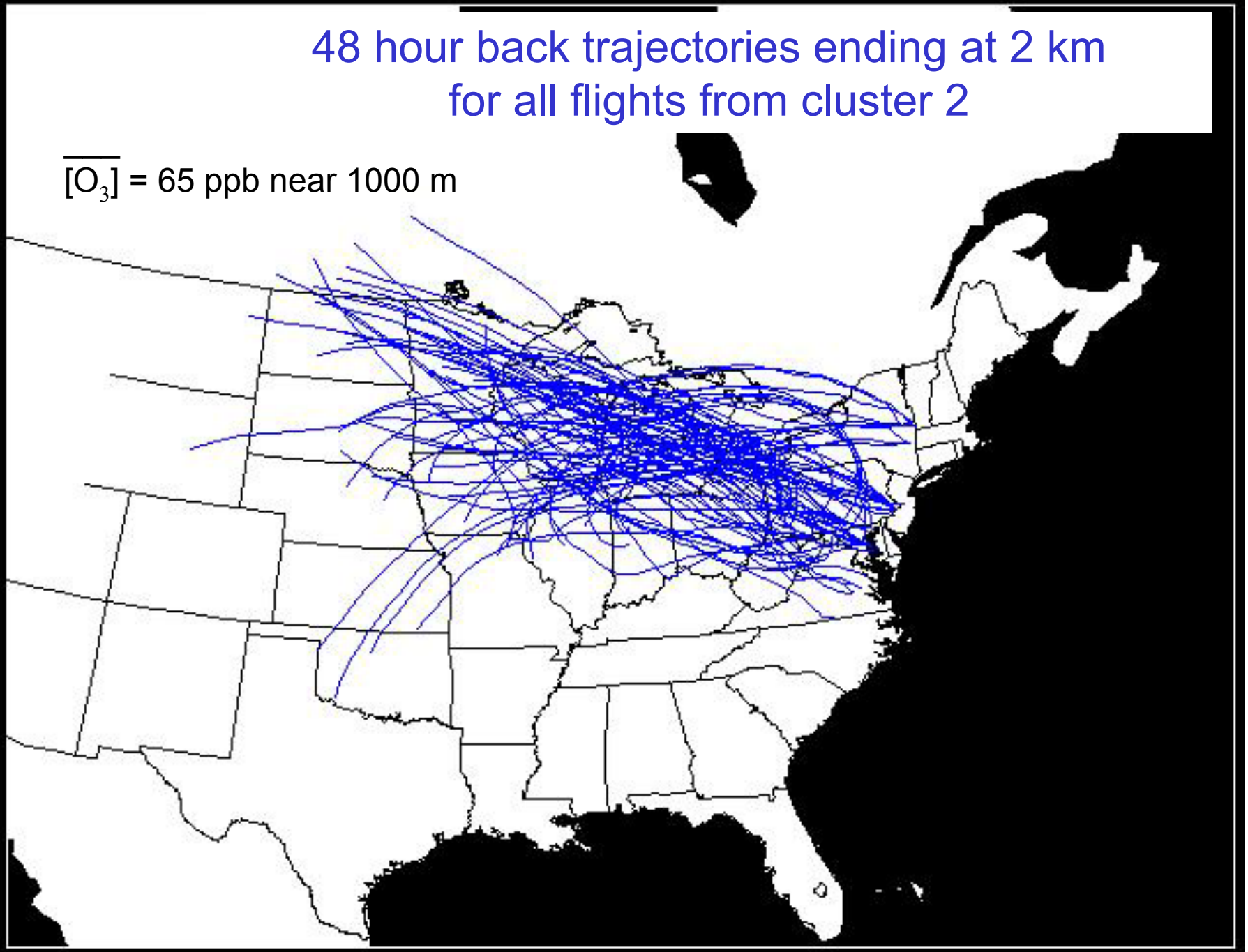
48 hour back trajectories ending at 2 km for all flights from cluster 1

$\overline{[O_3]}$ = 73 ppb near 1000 m



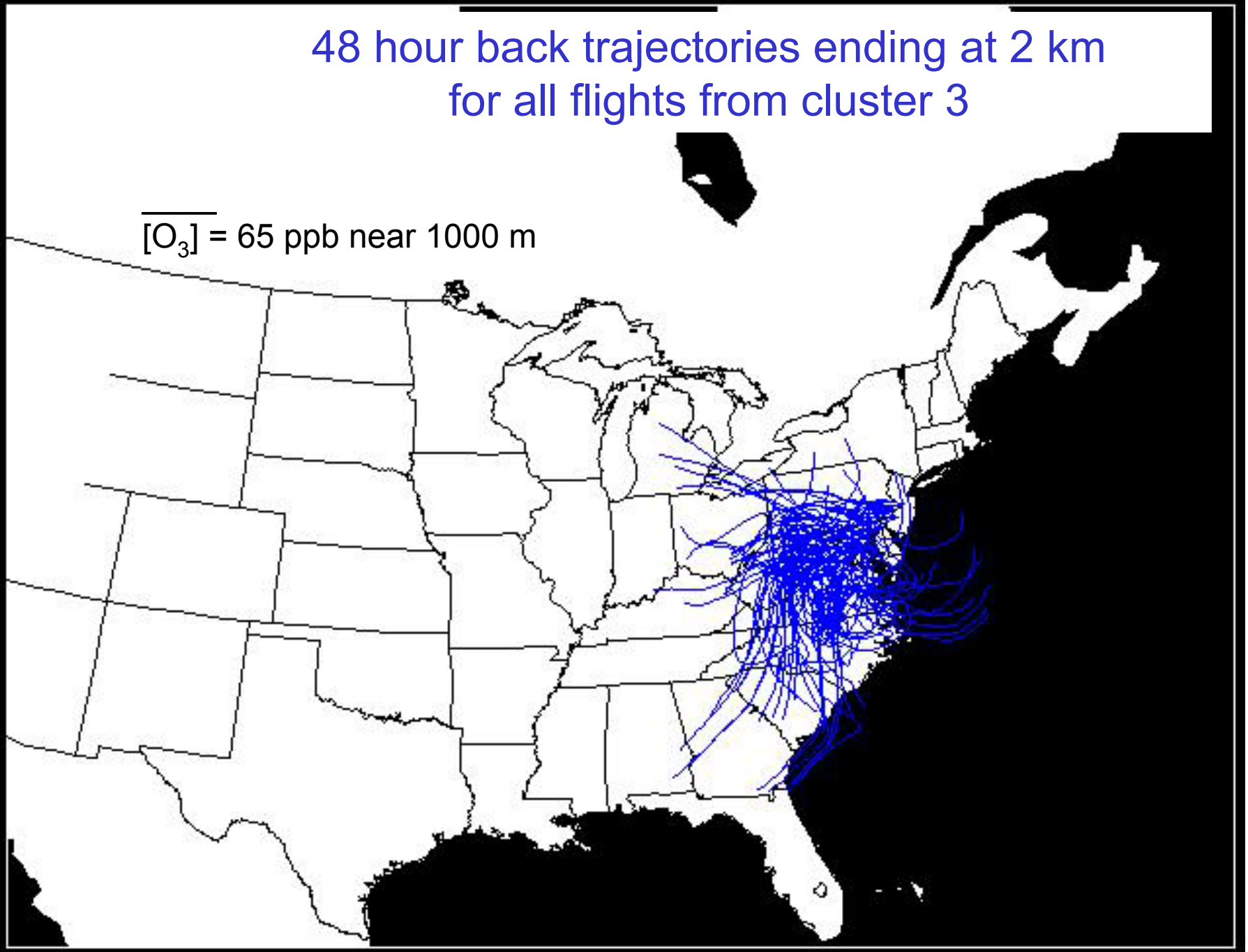
48 hour back trajectories ending at 2 km for all flights from cluster 2

$\overline{[O_3]}$ = 65 ppb near 1000 m



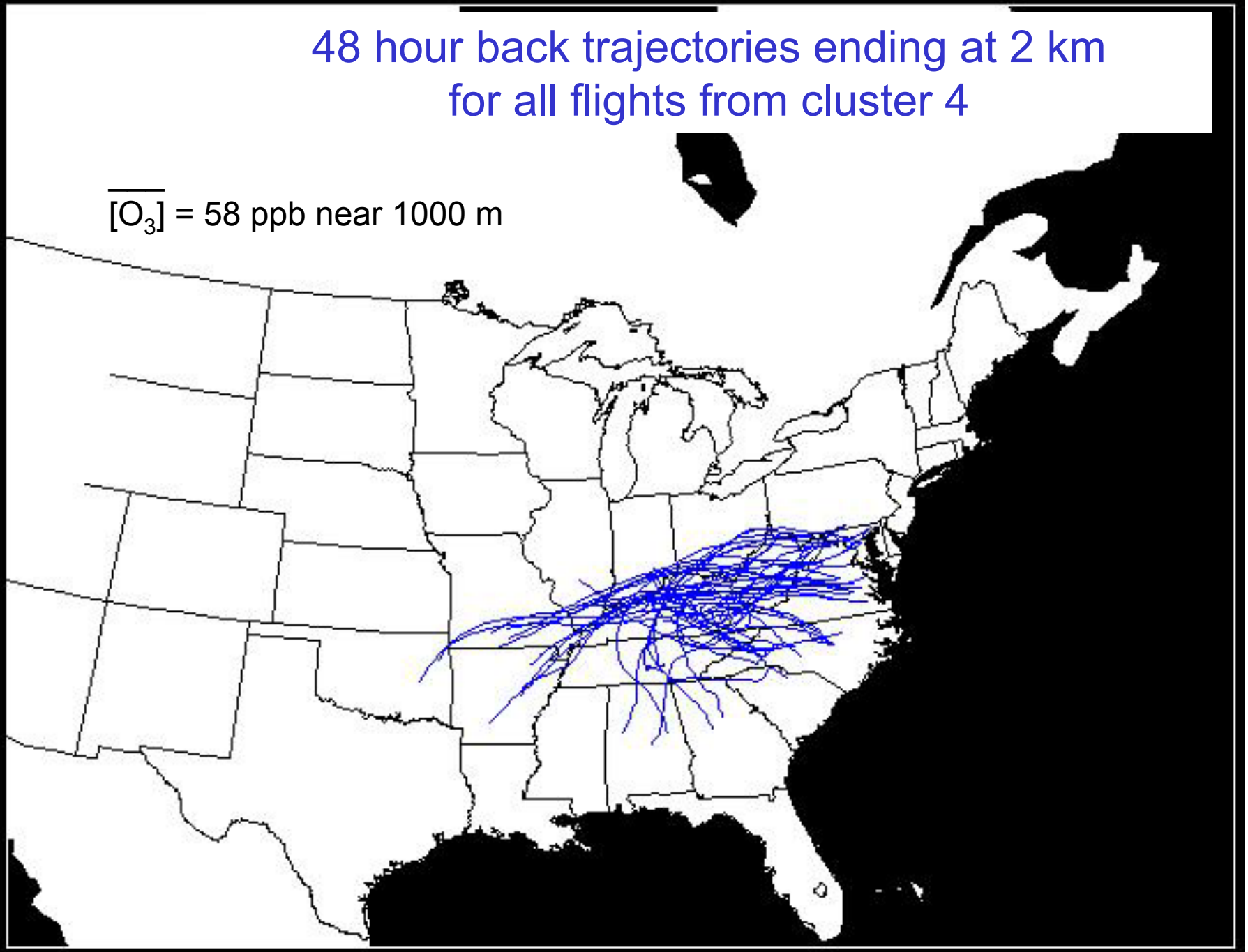
48 hour back trajectories ending at 2 km for all flights from cluster 3

$\overline{[O_3]}$ = 65 ppb near 1000 m

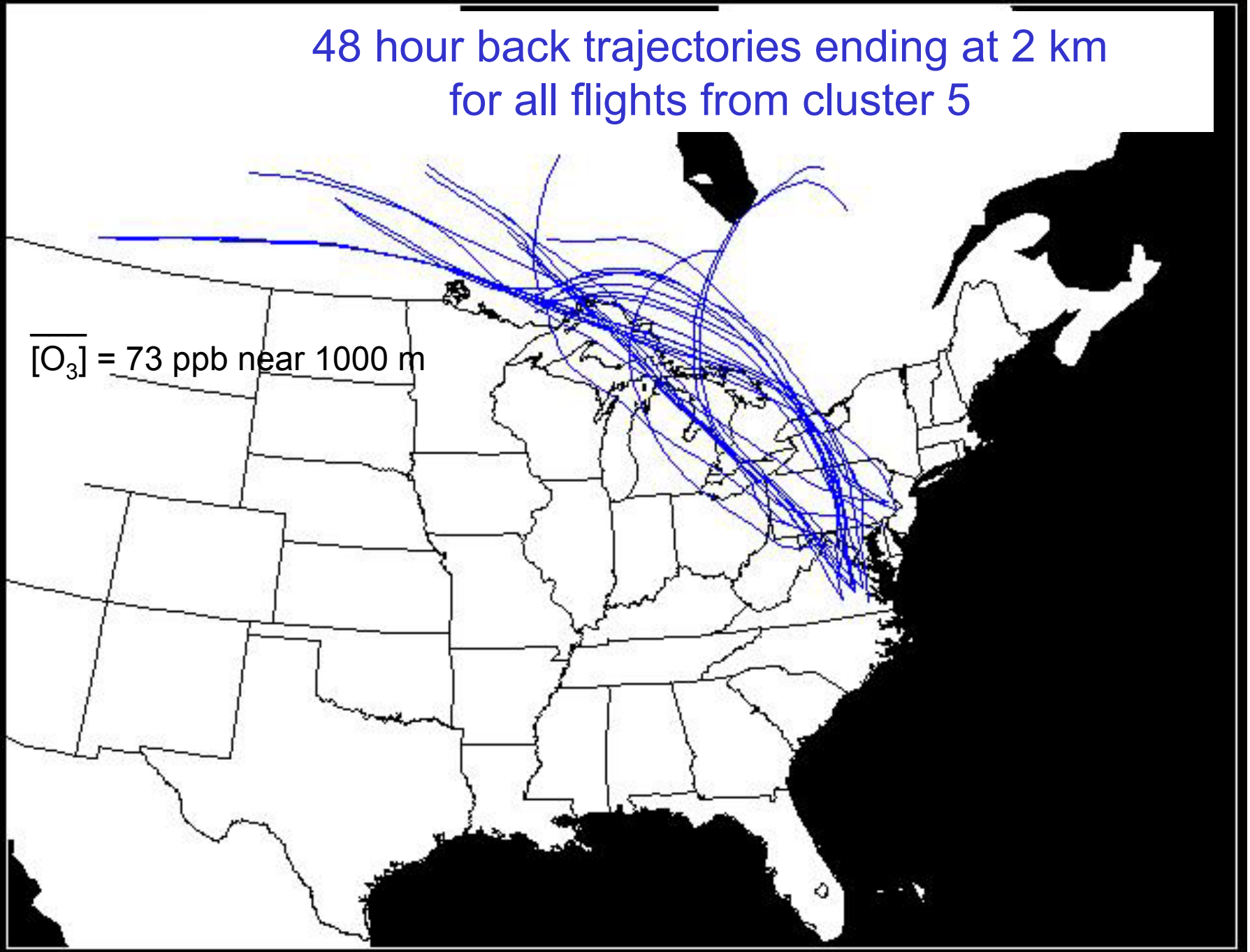


48 hour back trajectories ending at 2 km for all flights from cluster 4

$\overline{[O_3]}$ = 58 ppb near 1000 m

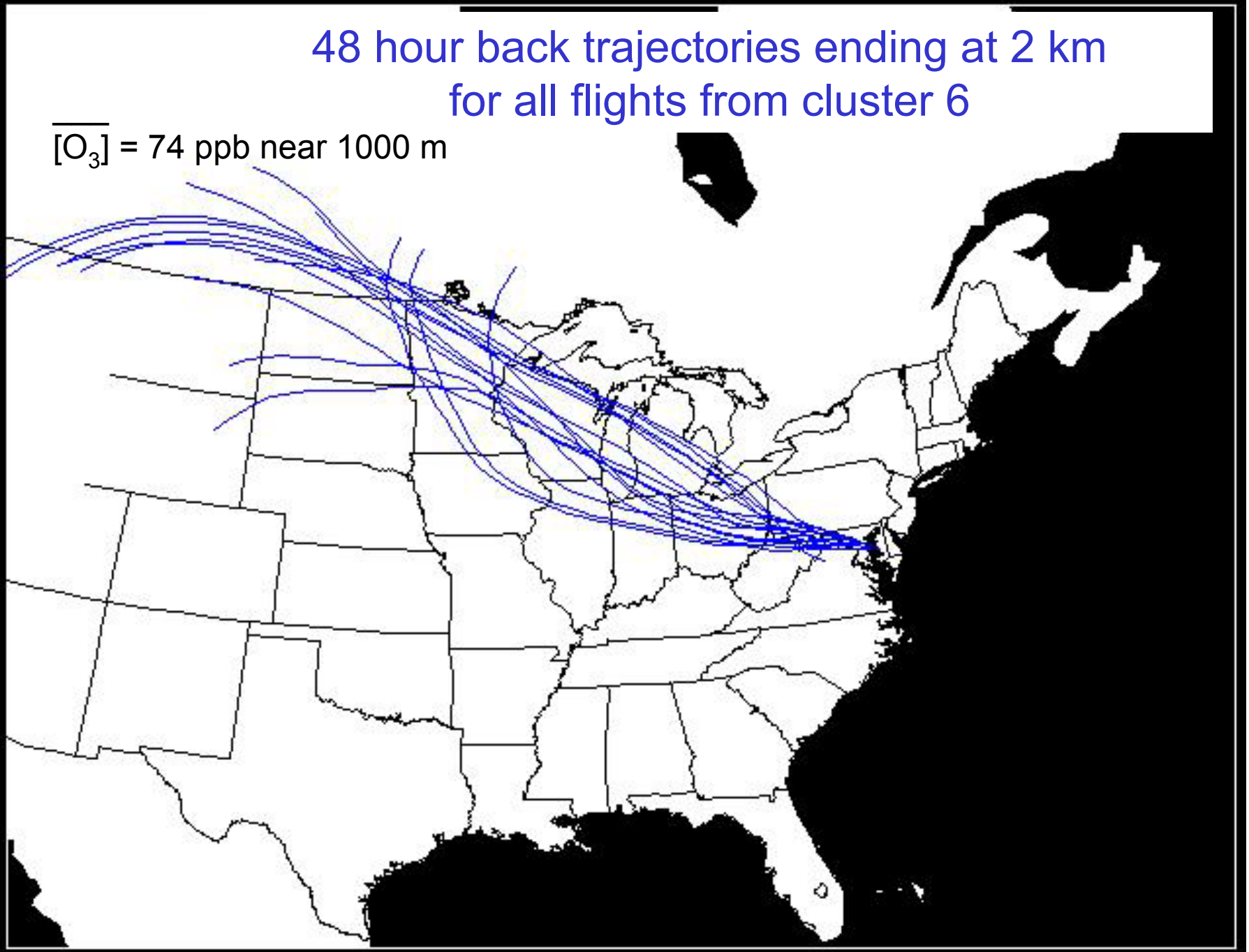


48 hour back trajectories ending at 2 km for all flights from cluster 5



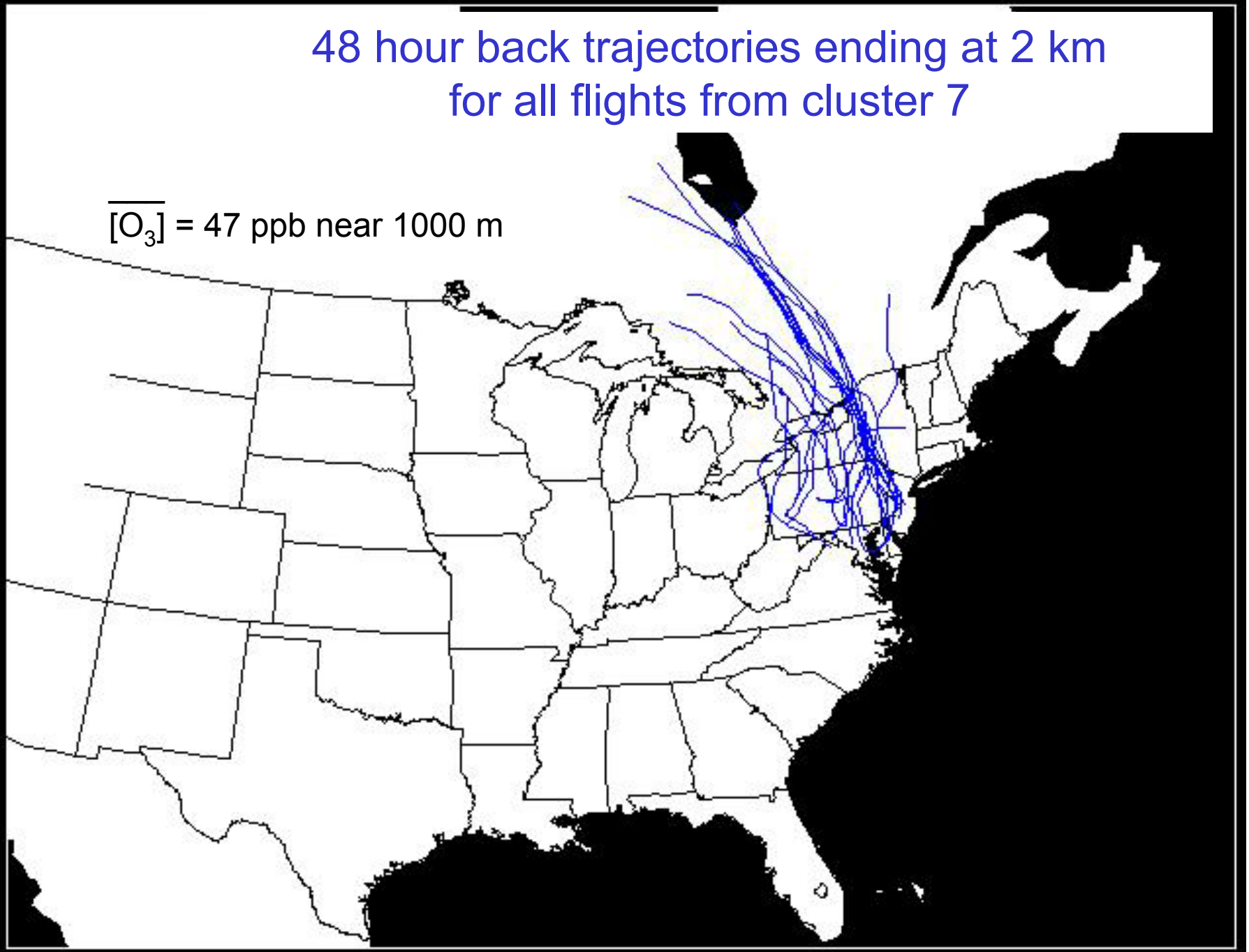
48 hour back trajectories ending at 2 km for all flights from cluster 6

$\overline{[O_3]}$ = 74 ppb near 1000 m



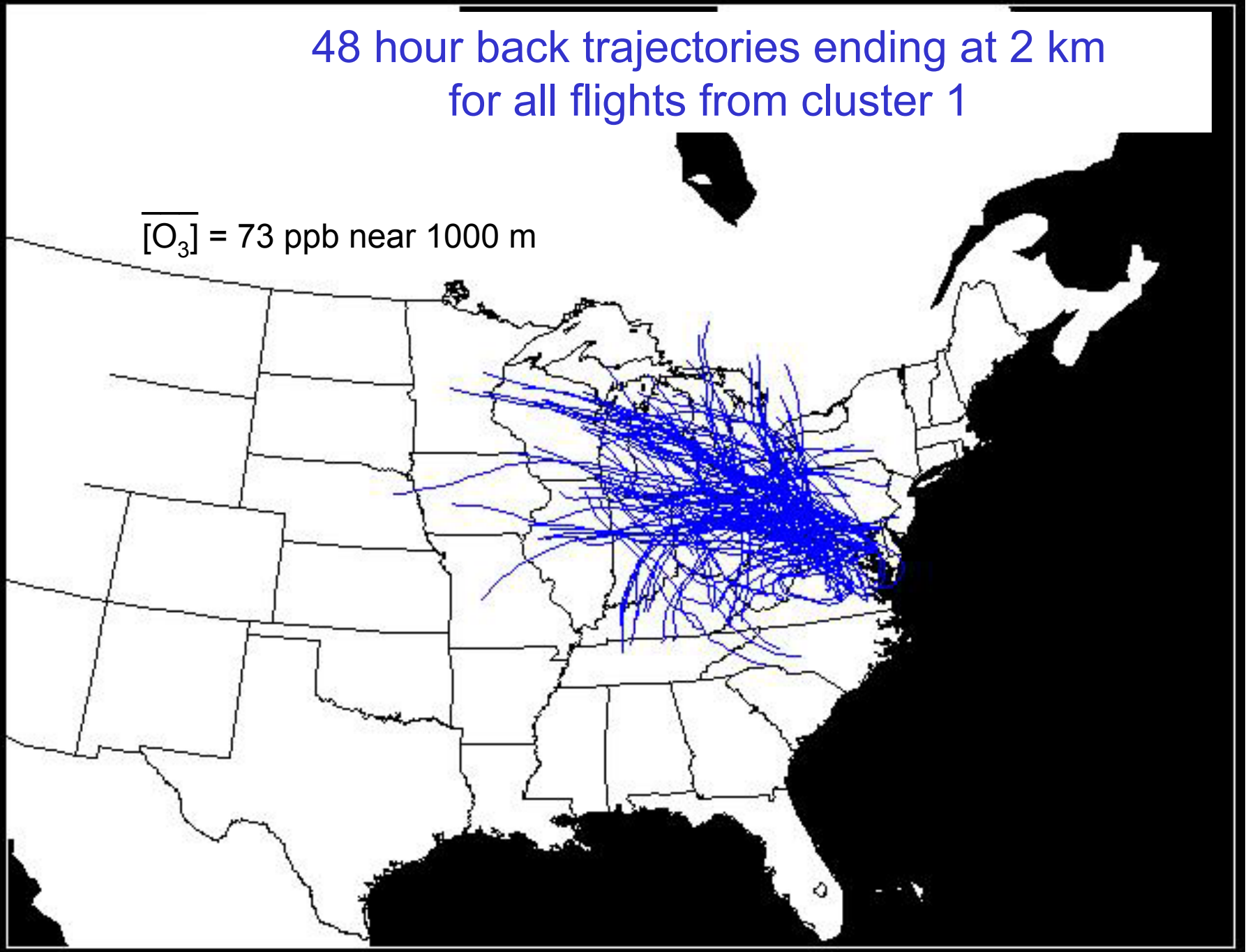
48 hour back trajectories ending at 2 km for all flights from cluster 7

$\overline{[O_3]}$ = 47 ppb near 1000 m



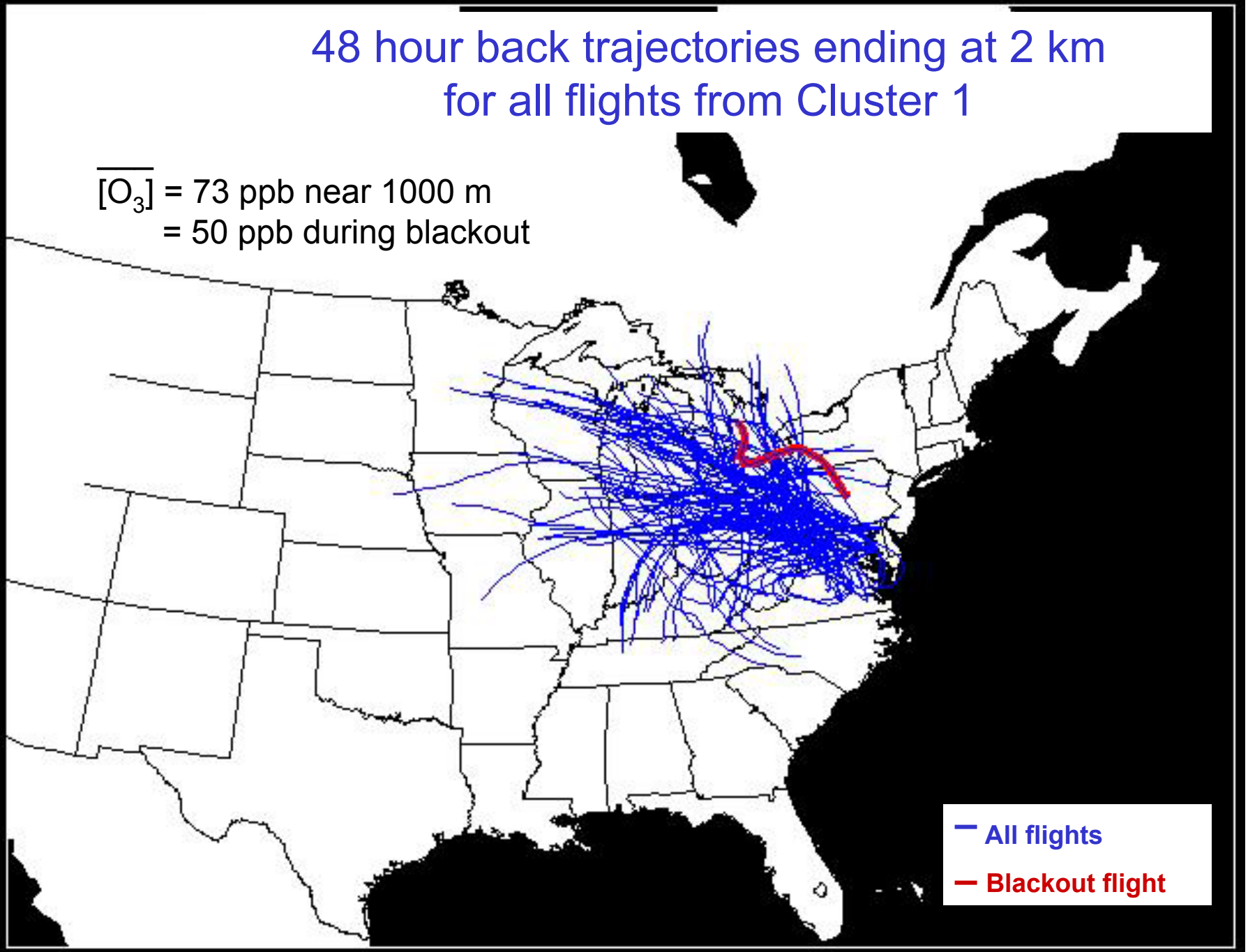
48 hour back trajectories ending at 2 km for all flights from cluster 1

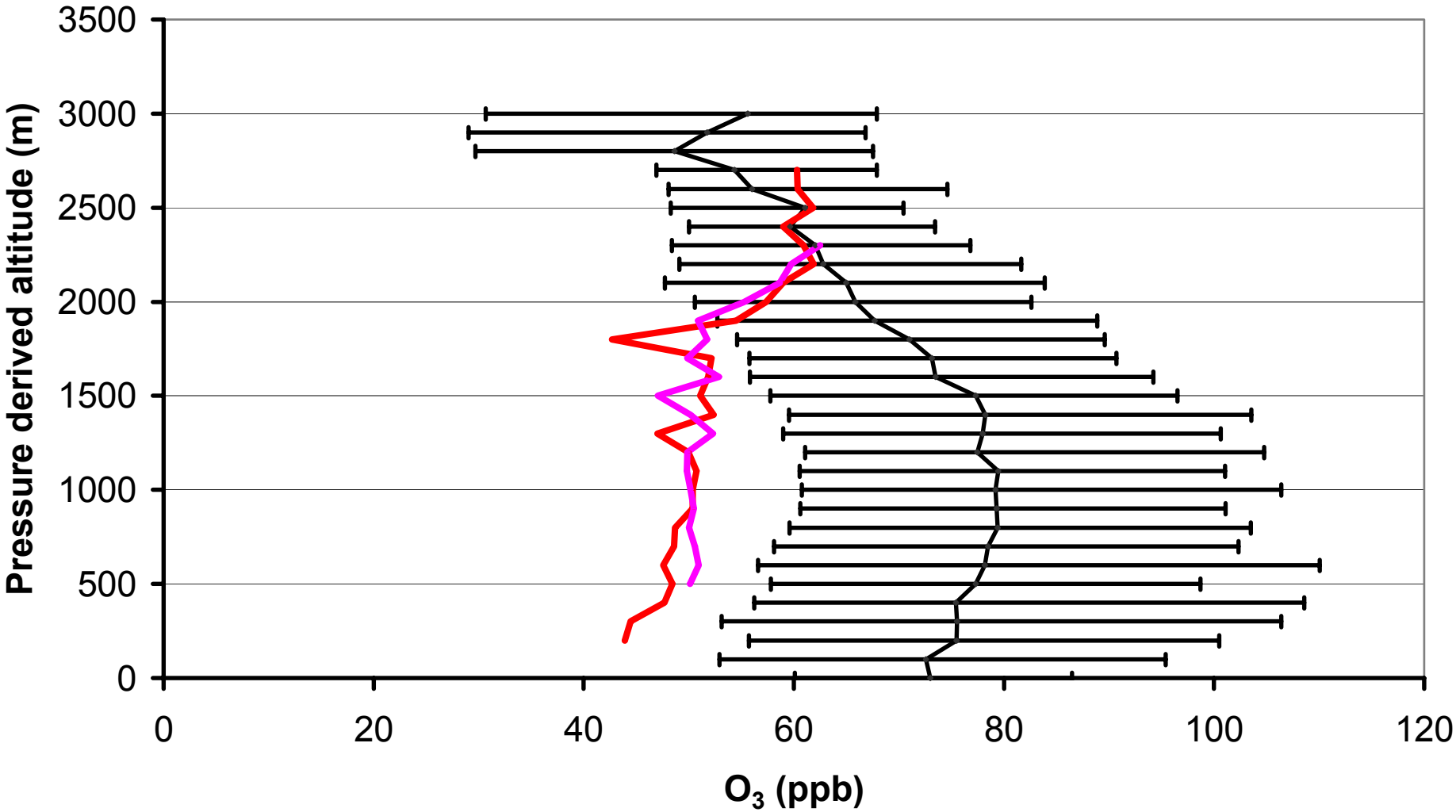
$\overline{[O_3]}$ = 73 ppb near 1000 m

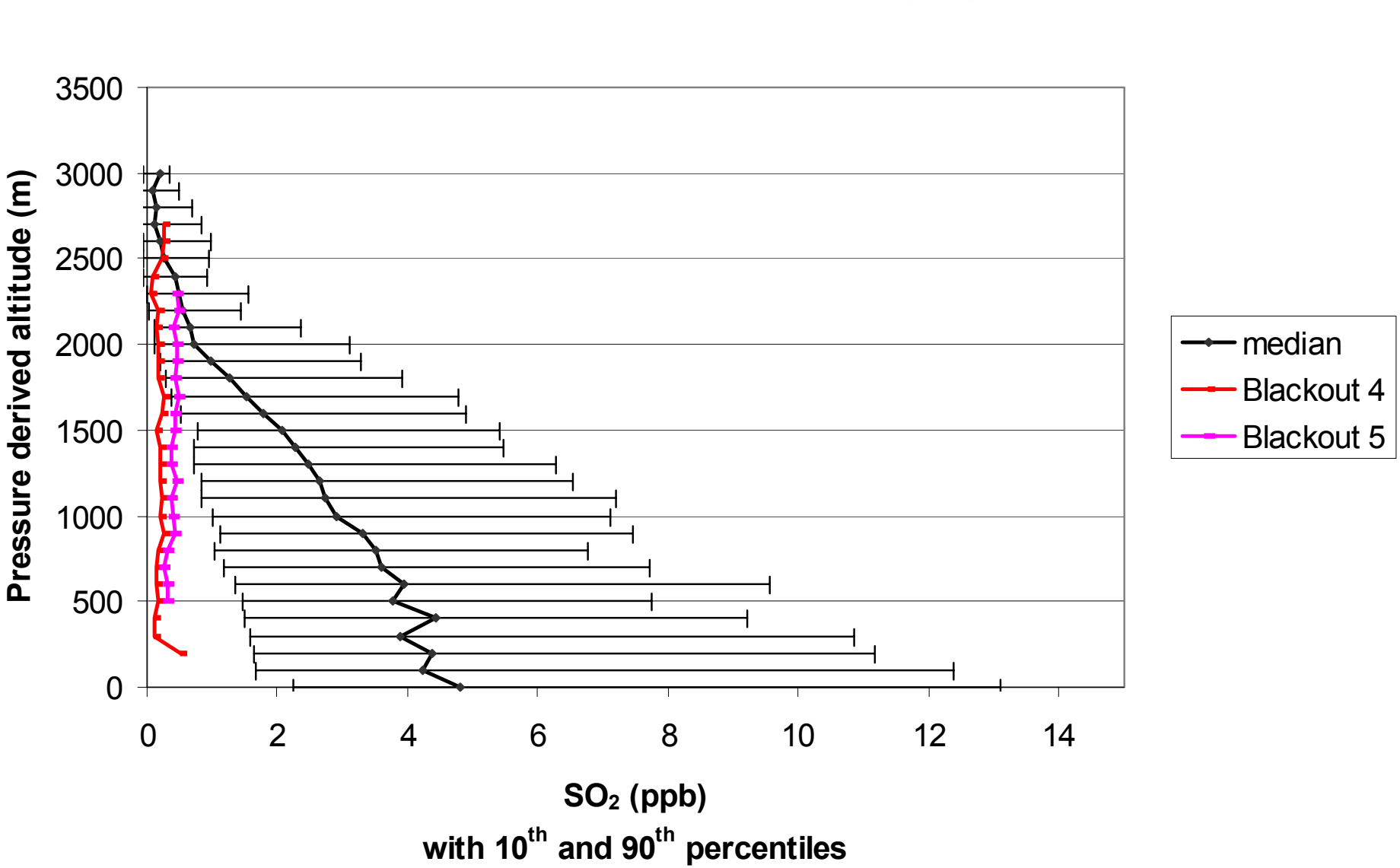


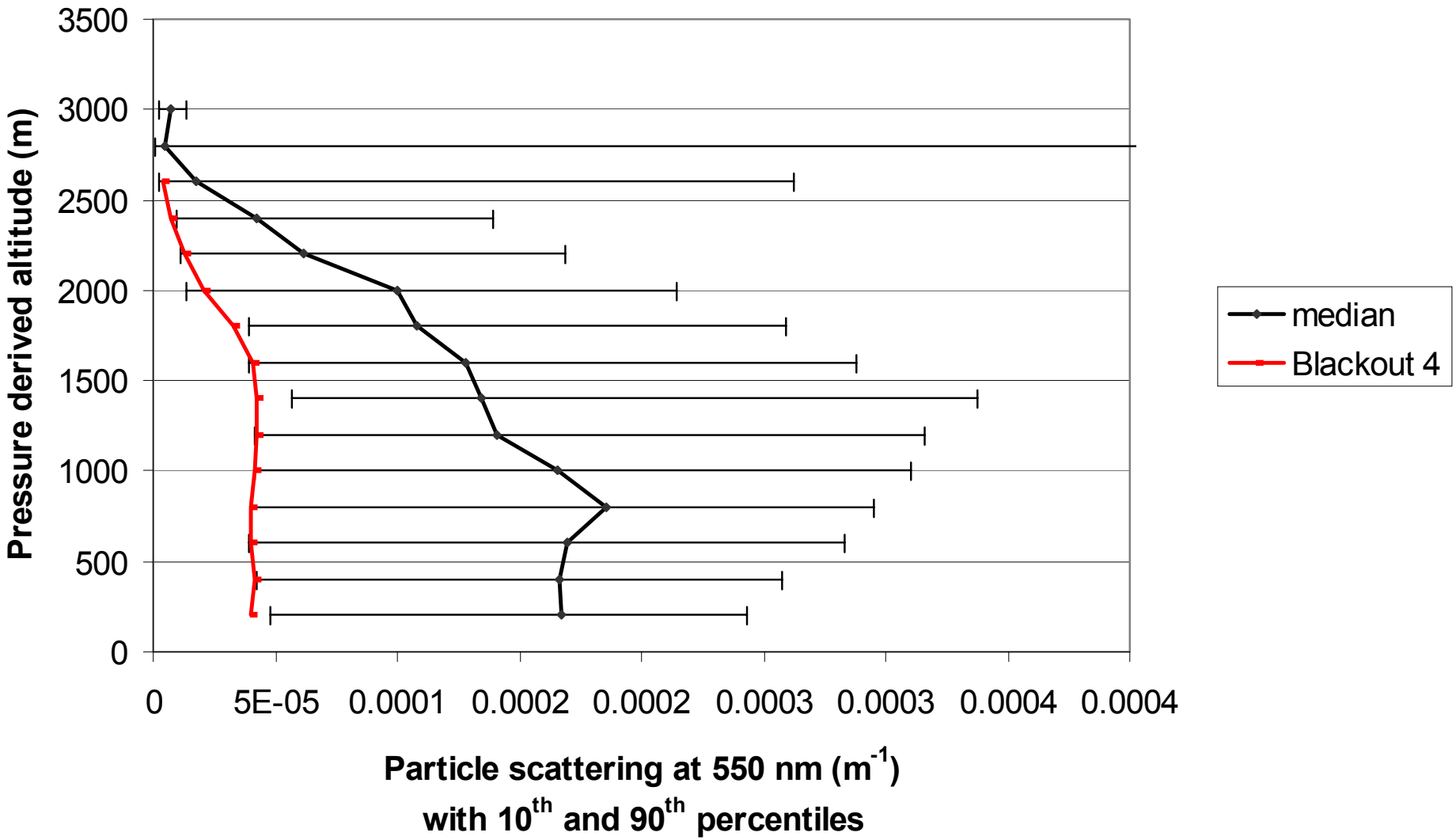
48 hour back trajectories ending at 2 km for all flights from Cluster 1

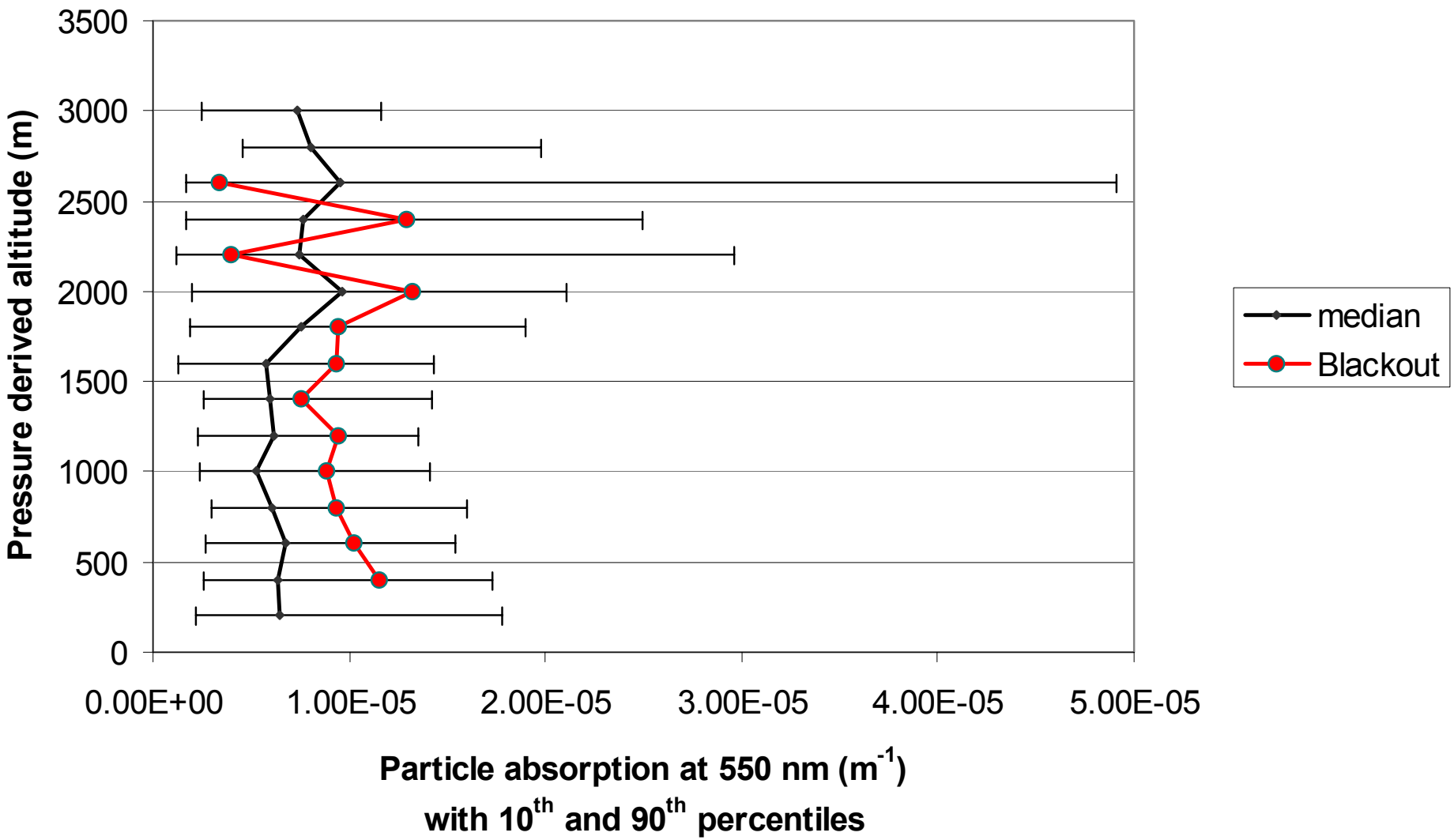
$\overline{[O_3]}$ = 73 ppb near 1000 m
= 50 ppb during blackout

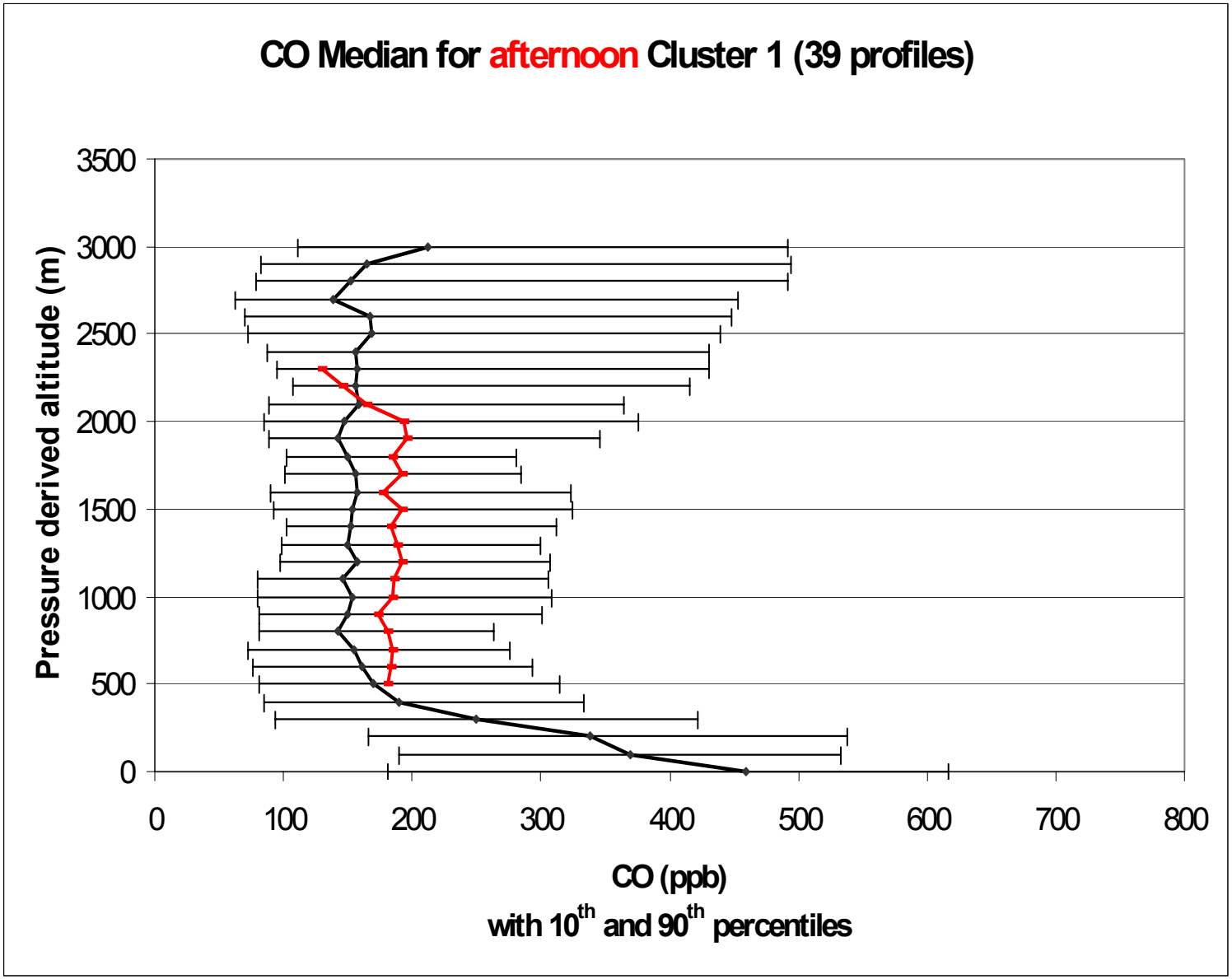



O_3 Median (10% & 90%) for afternoon Cluster 1 (62 profiles)
Flights during Blackout in color.
Pressure derived altitude (m)
3500
3000
2500
2000
1500
1000
500
0
0
20
40
60
80
100
120
O_3 (ppb)


SO2 Median for afternoon Cluster 1 (54 profiles)
Pressure derived altitude (m)
3500
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
12
14
SO2 (ppb)
with 10th and 90th percentiles
median
Blackout 4
Blackout 5


Particle scattering Median for afternoon Cluster 1 (42 profiles)
Pressure derived altitude (m)
3500
3000
2500
2000
1500
1000
500
0
0
5E-05
0.0001
0.0002
0.0002
0.0003
0.0003
0.0004
0.0004
Particle scattering at 550 nm (m-1)
with 10th and 90th percentiles
median
Blackout 4


Particle absorption Median for afternoon Cluster 1 (52 profiles)
Pressure derived altitude (m)
3500
3000
2500
2000
1500
1000
500
0
0.00E+00
1.00E-05
2.00E-05
3.00E-05
4.00E-05
5.00E-05
Particle absorption at 550 nm (m-1)
with 10th and 90th percentiles
median
Blackout


CO Median for afternoon Cluster 1 (39 profiles)
Pressure derived altitude (m)
3500
3000
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
700
800
CO (ppb)
with 10th and 90th percentiles
Median
Blackout

During the Blackout:

- Ozone was in the lowest 5th percentile of all observations; 25 ppb below median.
- SO_2 was below 5th percentile of all observations; a fraction of the median.
- Aerosol scattering in lowest 10th percentile; a factor of 3 below the median.
- Visual range increased by >40 km (25 mi).
- CO and b_{ap} (black carbon) were near the median.
- Forecast O_3 (regression equation) 115 ppb, observed 90 ppb.

Major Findings:

- **Emissions from power plants can dominate aerosol loading over eastern North America.**
- **Long range transport (100's of km) played a major role in haze and photochemical smog (O_3) formation over the East Coast.**
- **Reduction in ozone exceeded that expected.**

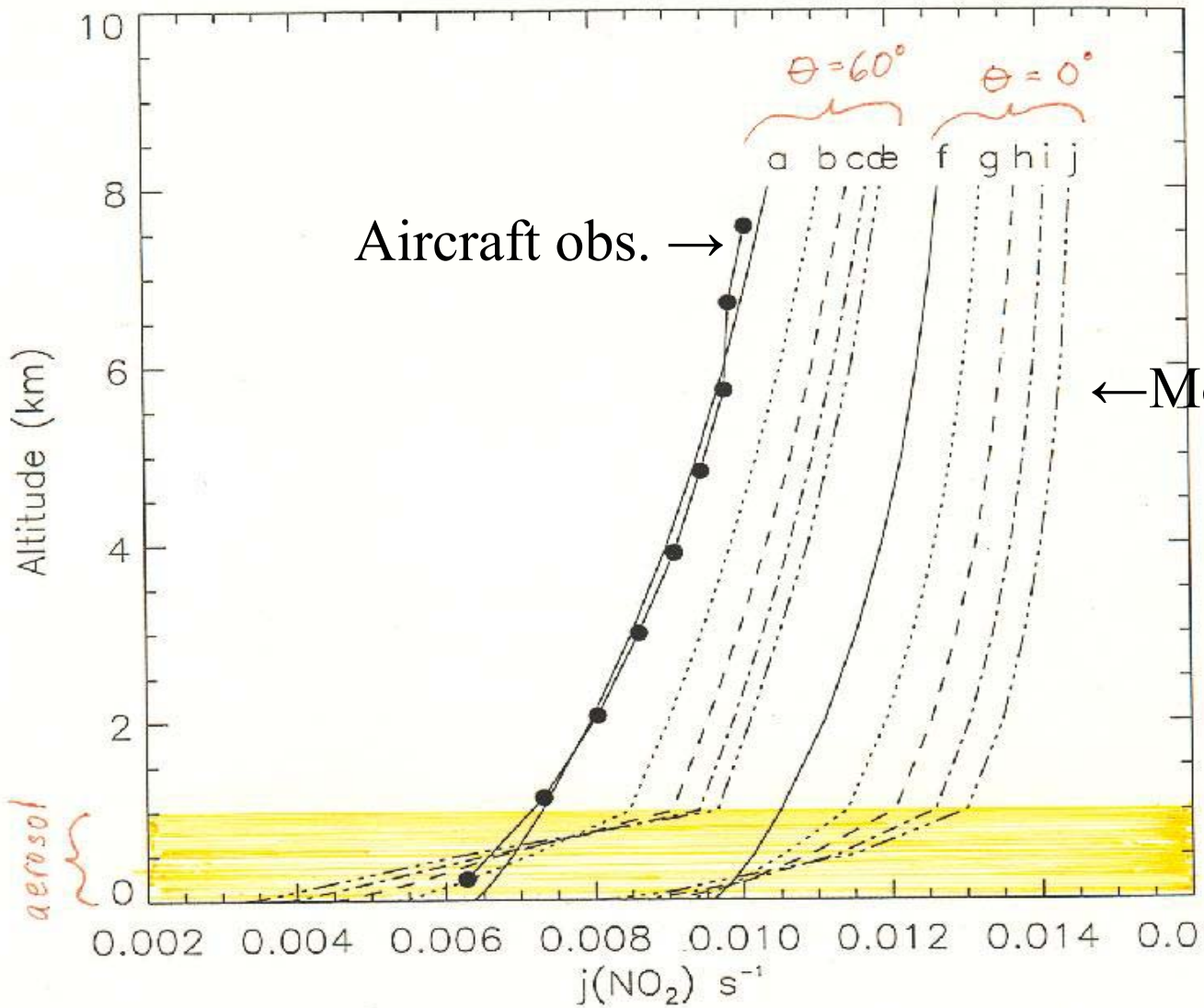
Why was the ozone so low?

Are there processes not well simulated by CMAQ?
Is the O_3 production efficiency higher aloft than in PBL?

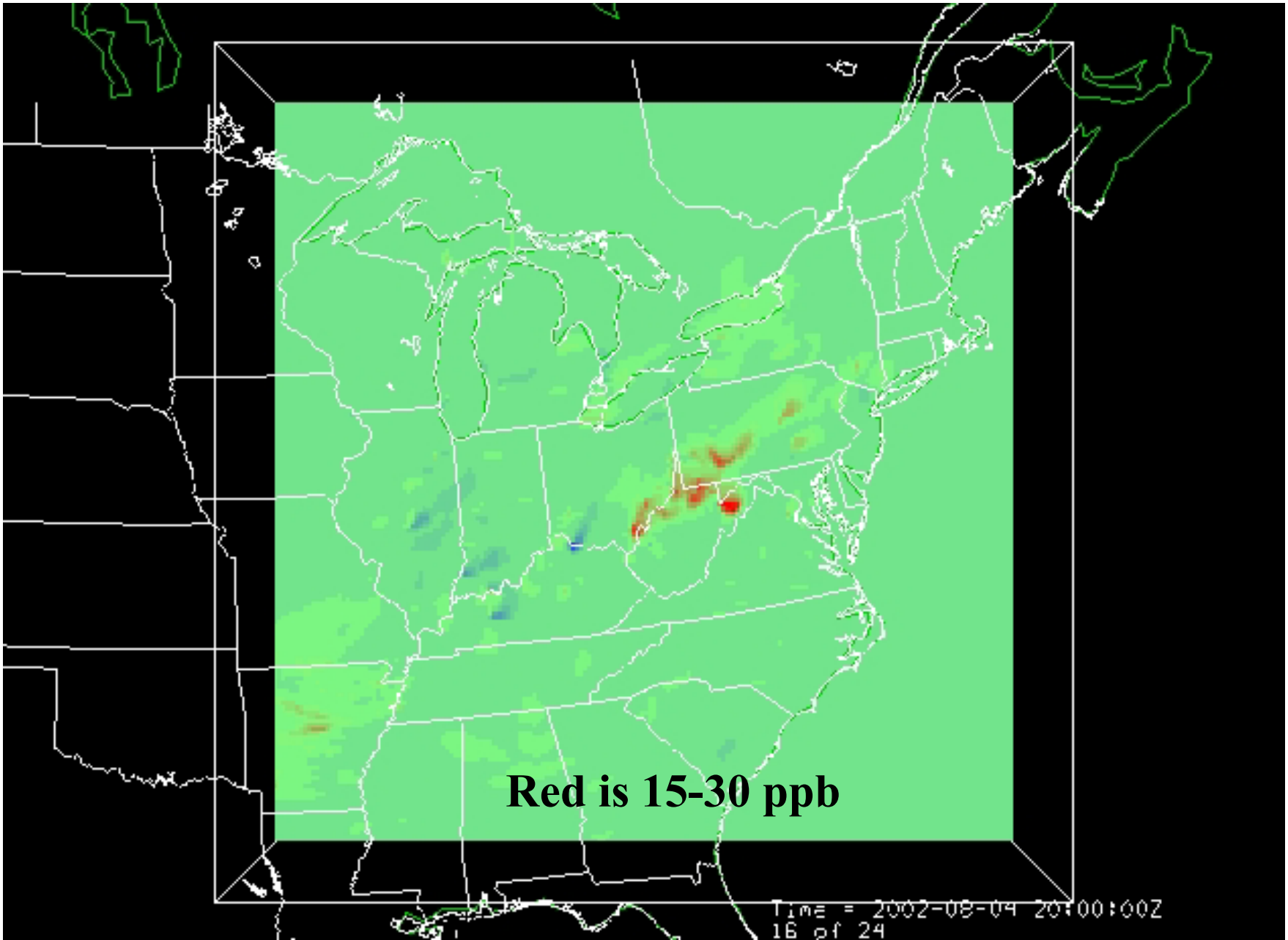
- **More UV radiation for NO_2 photolysis aloft (Science, 1997).**
- **Reactions of NO_3 and VOC's at night remove odd oxygen and NOx (Brown et al., *GRL*, 2006). Could make EGU NOx more efficient than urban NOx.**

$NO_2 + h\upsilon\ (+O_2) \rightarrow NO + O_3$

Altitude profiles of photolysis rate coefficients for solar zenith angles of 60° and 0° and aerosol optical depths of 0.0, 0.5., 1.0, 1.5, and 2.0.

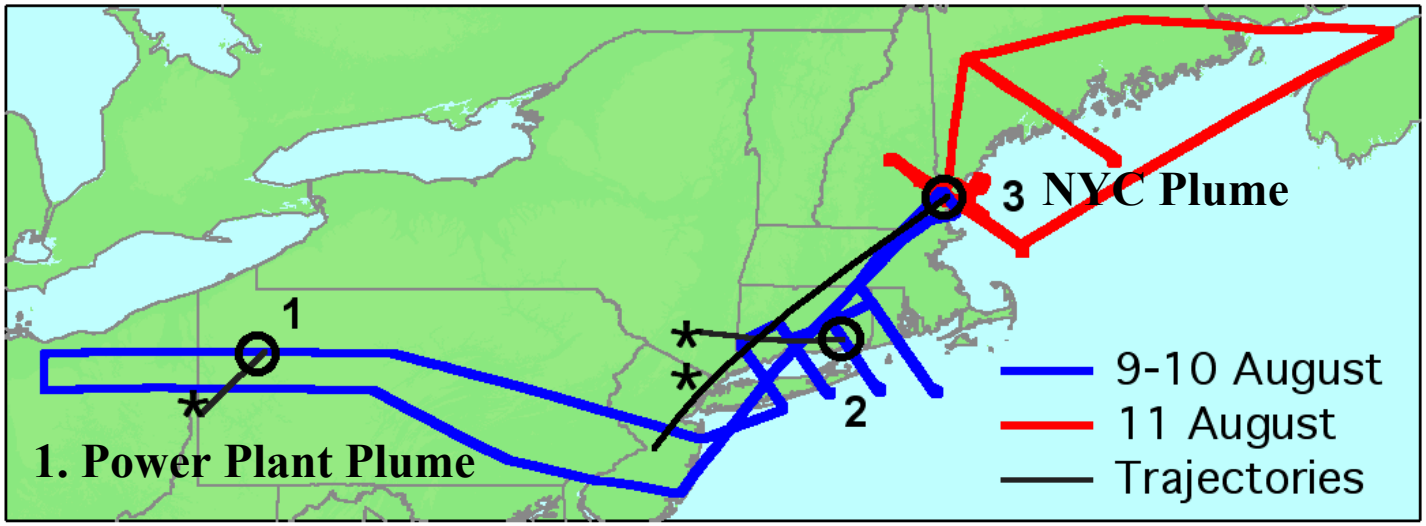


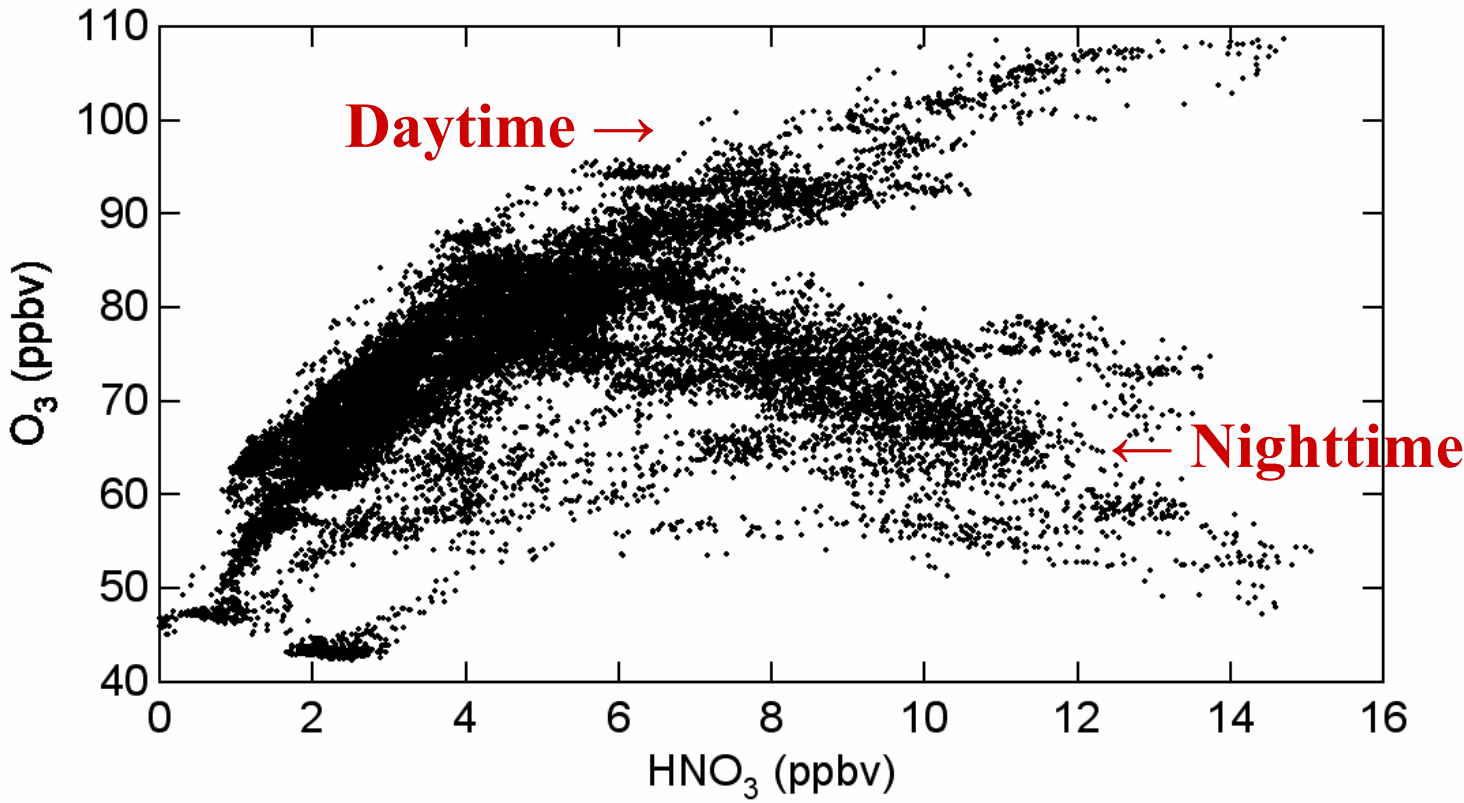
CMAQ Blackout run 4 August 2002



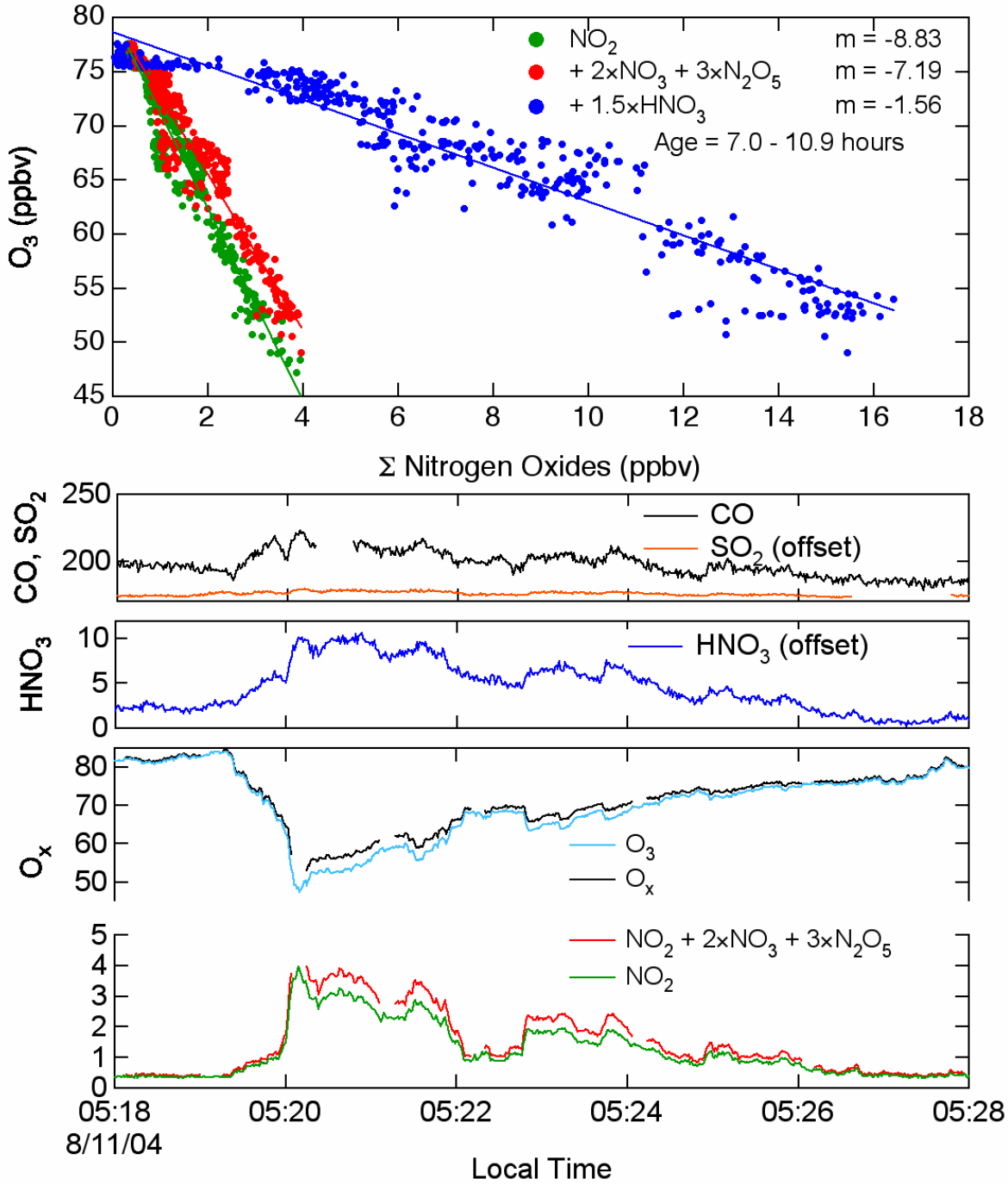
Flight track of NOAA P3 aircraft August 2004.

Brown et al., *GRL*, 2006.





Area 3. Plot of nighttime chemistry of an **urban plume** showing permanent ozone destruction at night (blue points) with ~1.6 O_3 destroyed for each molecule of NOy. **Faster than in a power plant plume.**



Mechanisms

$$2NO_2 + PM(H_2O) \rightarrow HNO_3 + HNO_2$$

or

$$NO + O_3 \rightarrow NO_2 + O_2$$

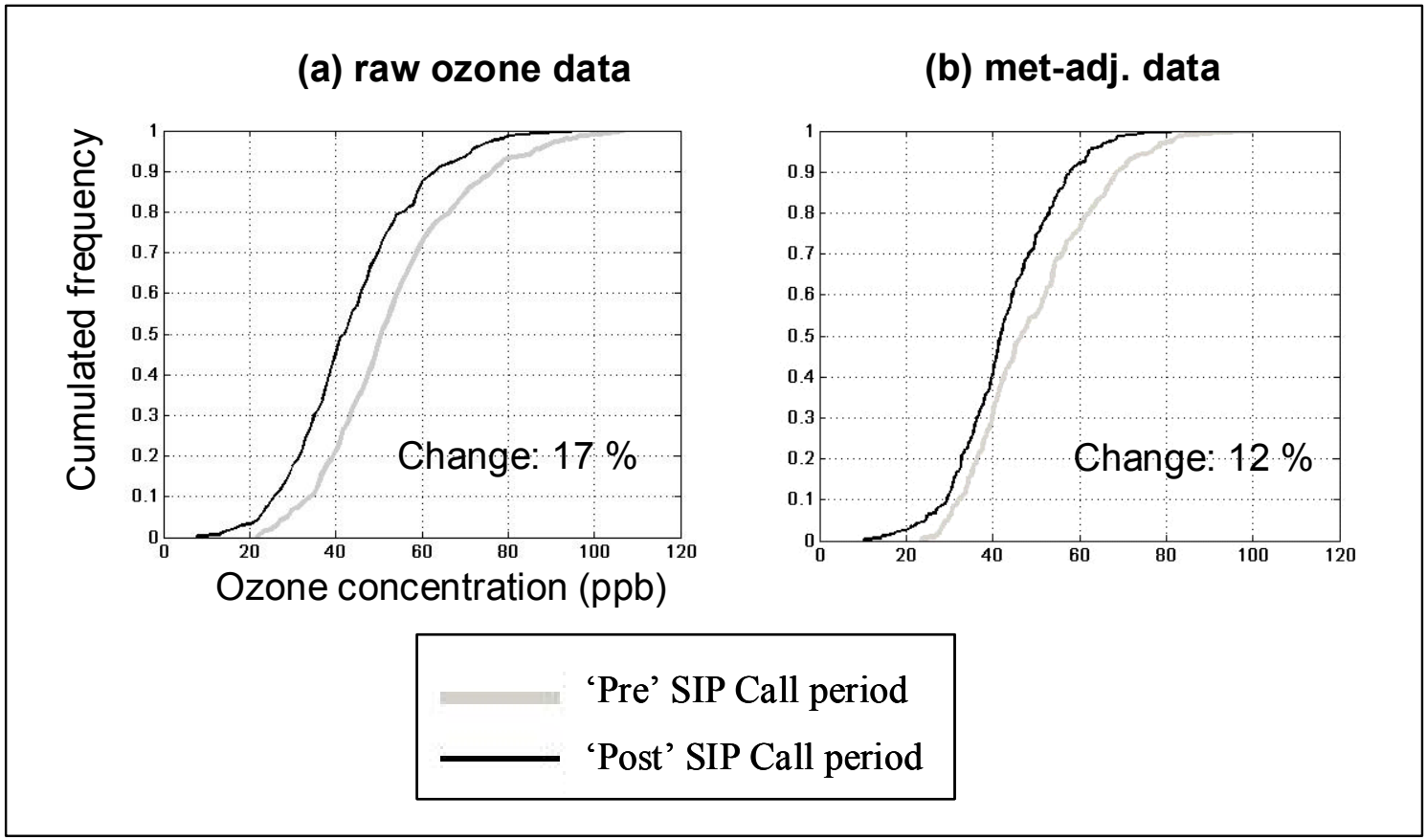
$$NO_2 + O_3 \rightarrow NO_3 + O_2$$

$$\underline{NO_3 + RCHO \rightarrow HNO_3 + RCH\cdot}$$

Net $NO + 2O_3 + RCHO \rightarrow HNO_3 + RCH\cdot$

Take home messages.

- Using three methods to control for weather, ozone was tens of ppb below normal during the blackout.
- CO and b_{ap} remained high suggesting that other (s.a. mobile) sources were emitting normally.
- Why was ozone low during the heat wave this (2006) summer?



Cumulative distribution functions of the daily maximum 8-hr ozone concentrations at site ABT147 during the 'pre' and the 'post' SIP Call periods, based on: (a) raw data, (b) met-adj. data. Gego et al. JAMC, in review 2006.

The End.

Acknowledgements

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Dave Krask (MDE)
Charles Piety
Brett Taubman
Da-Lin Zhang

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The 2003 North American Electrical Blackout: An Accidental Experiment in Atmospheric Chemistry, Lackson T. Marufu, B. F. Taubman, B. Bloomer, C. A. Piety, B. G. Doddridge, J. W. Stehr, and R. R. Dickerson, *Geophys. Res. Lett.*, 31, 2004.