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

Presented at the OTC Fall Meeting
Nov. 9 & 10, 2004

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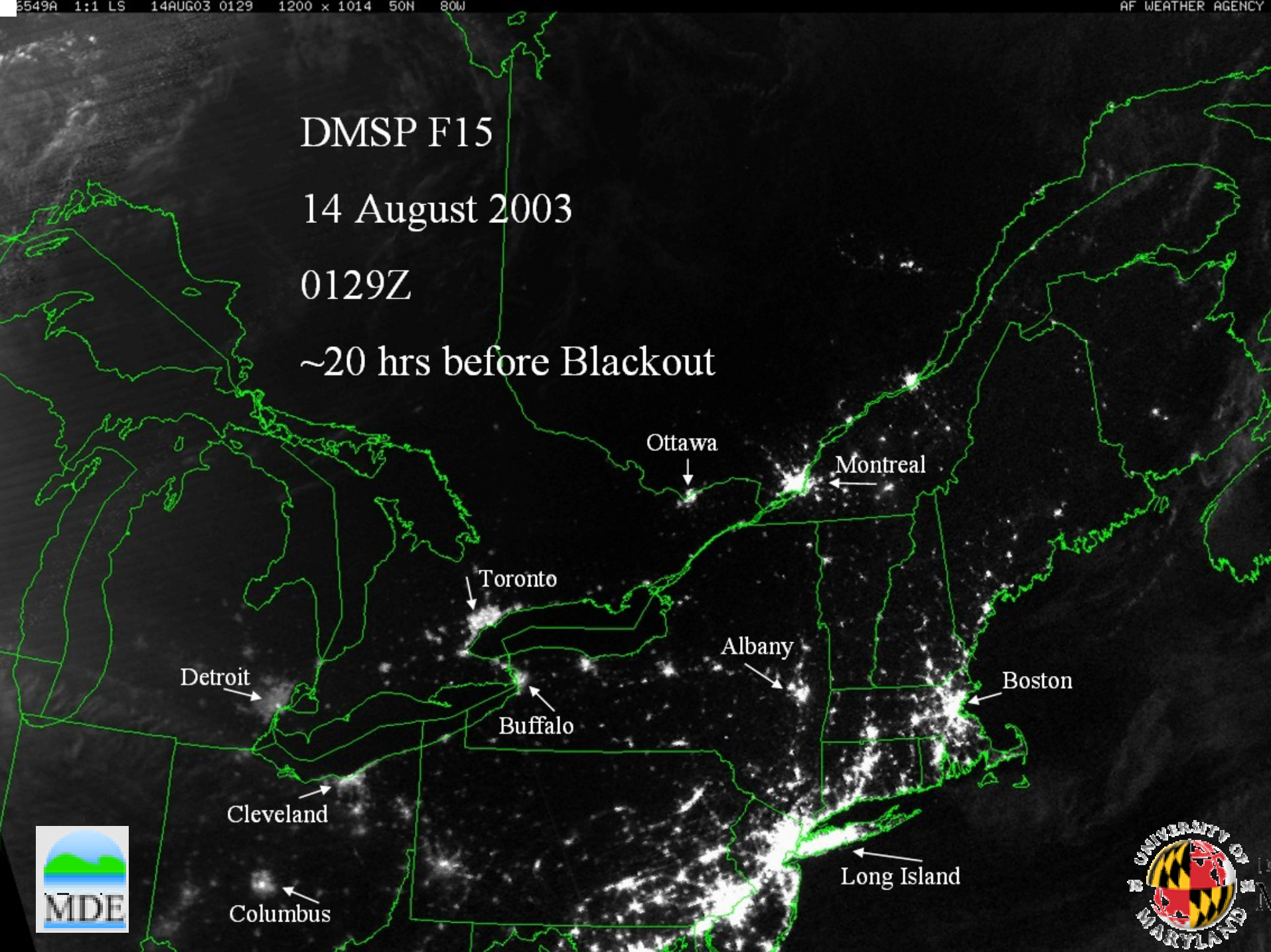
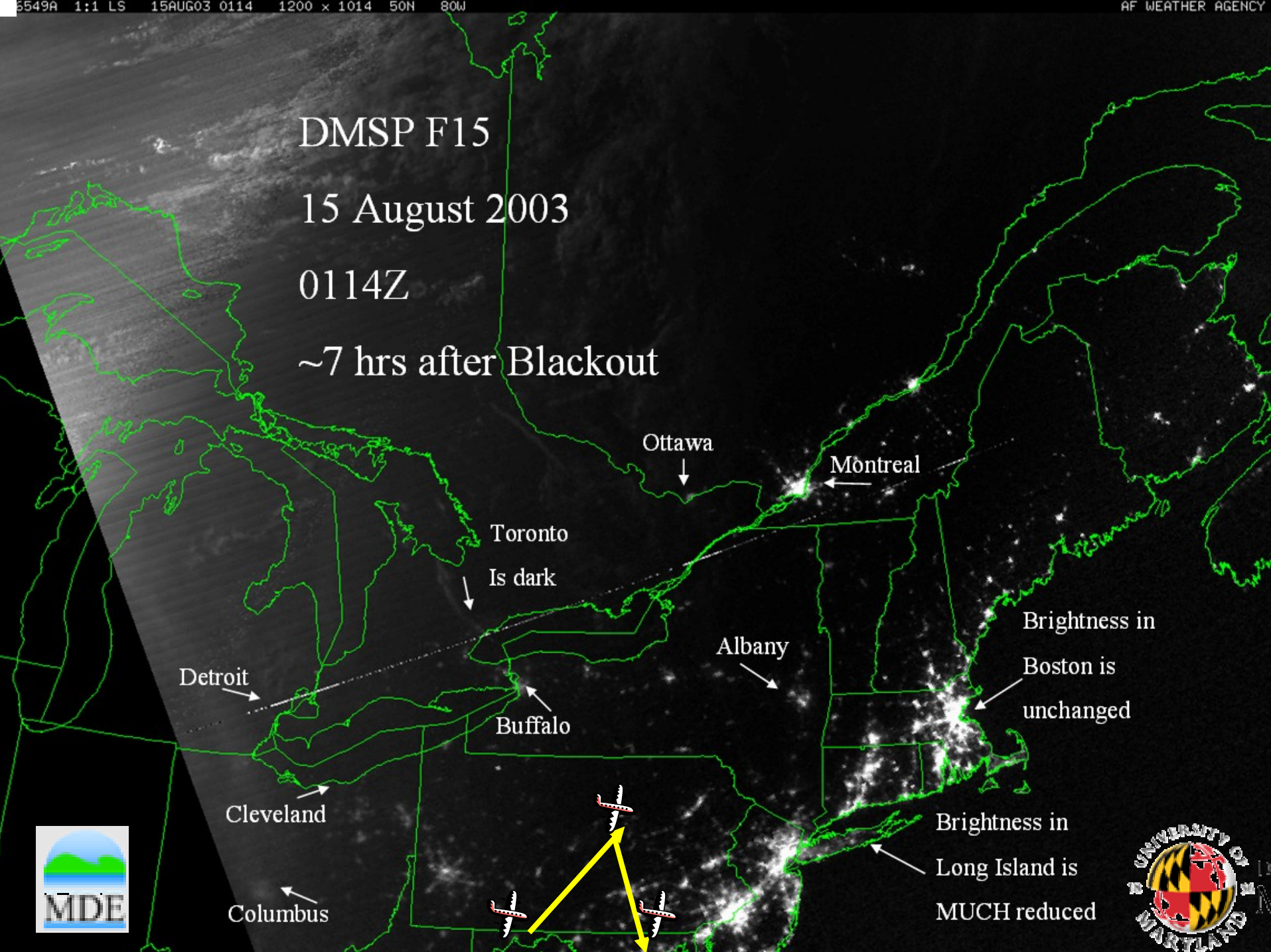
The University of Maryland

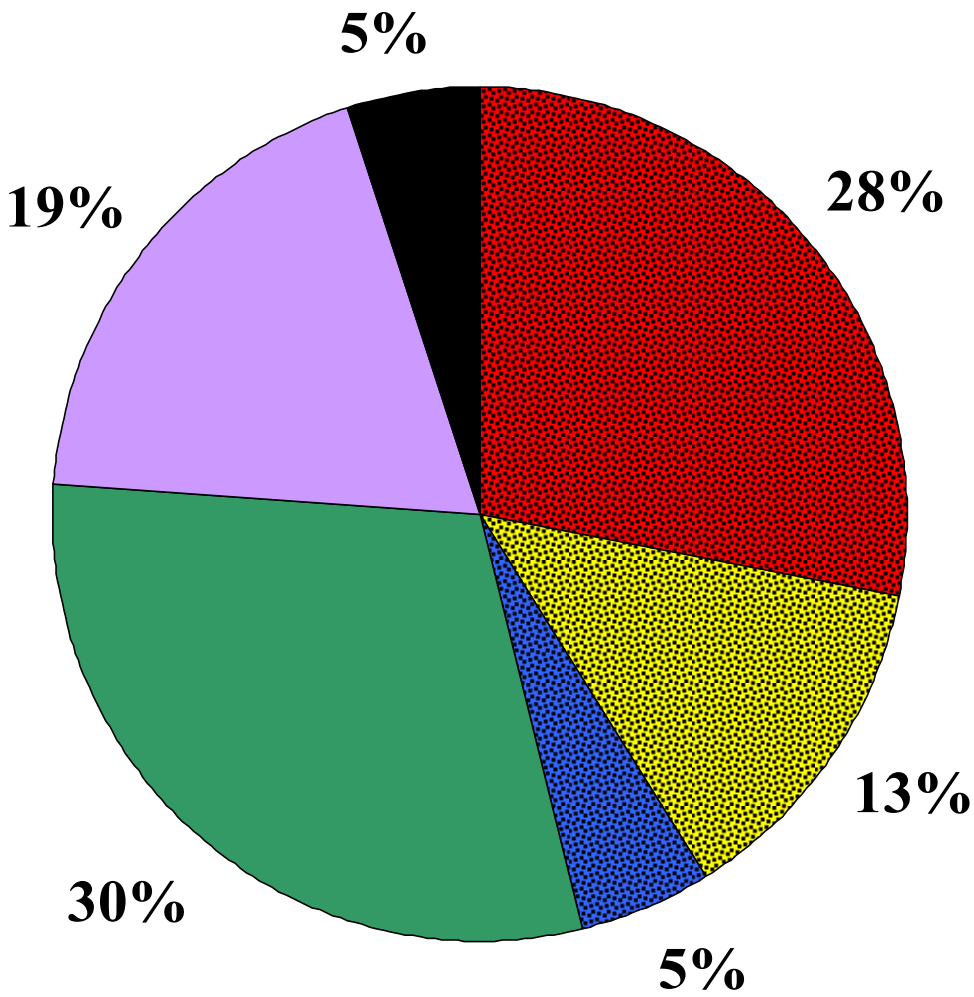
Question: What would happen to air quality if emissions from power plants were suddenly eliminated?

(For the impatient: ozone down by almost factor of 2; SO_2 down by factor of 5; visual range increased 25 miles.)


5549A 1:1 LS 14AUG03 0129 1200 x 1014 50N 80W
AF WEATHER AGENCY
DMSP F15
14 August 2003
0129Z
~20 hrs before Blackout
Ottawa
Montreal
Toronto
Albany
Detroit
Boston
Buffalo
Cleveland
Long Island
Columbus
MDE


5549A 1:1 LS 15AUG03 0114 1200 x 1014 50N 80W
AF WEATHER AGENCY
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
UNIVERSITY OF MARYLAND

US Nitrogen Oxide Emissions



- Fuel Combustion - Electric Utility
- Fuel Combustion - Industrial
- Fuel Combustion - Other
- On-Road Vehicles
- Non-Road Vehicles
- All Other

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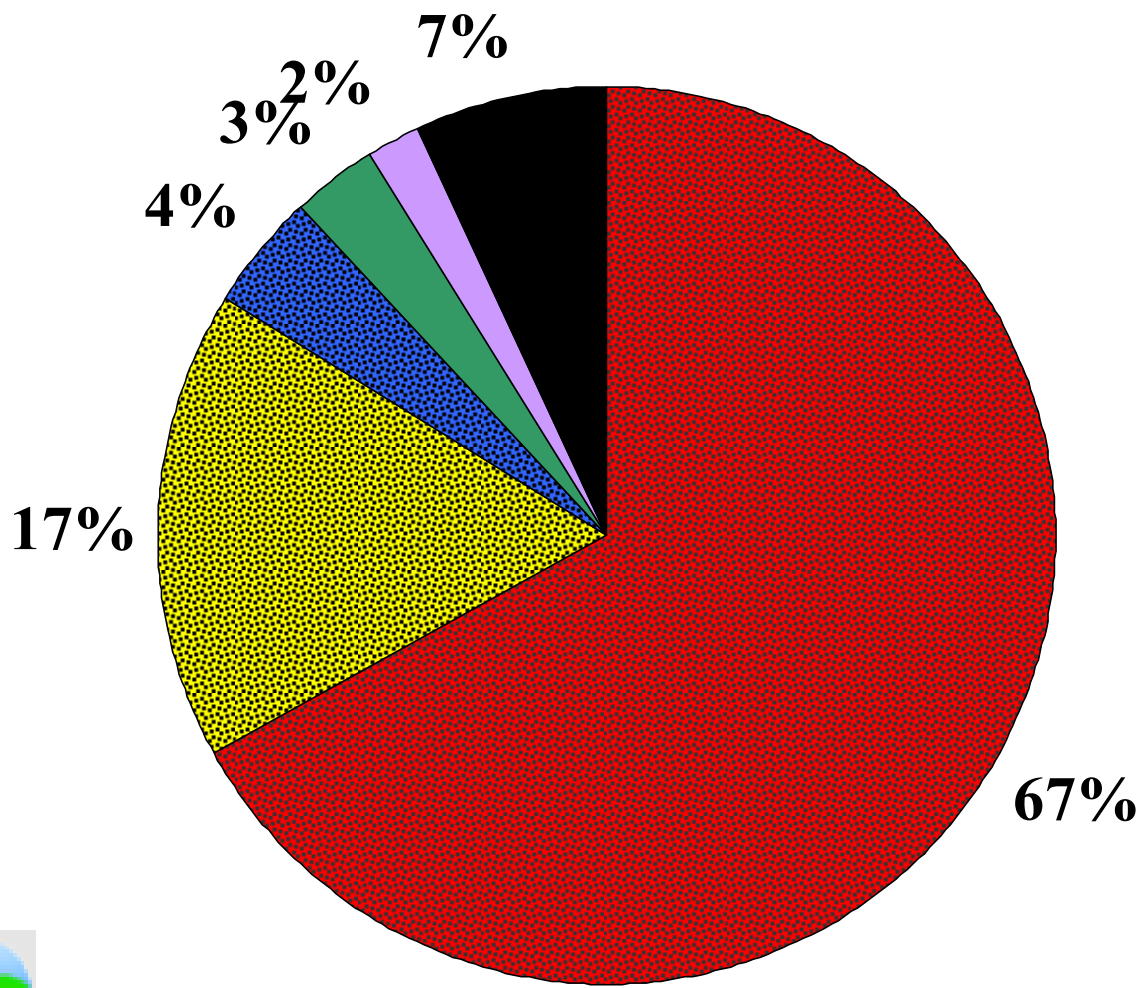
US Sulfur Dioxide Emissions



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(Regional Atmospheric Measurement Modeling & Prediction Program)

Balanced Theory & Observations

MM5

Dynamical Model

4-km Resolution

Forecasting

Input

Emissions Inventories

Emissions Models

(Chem Engineering)

CTM

CMAQ

Modular

Open Code

Collaborative w/EPA

Photochem.

Aerosols

Transport

Deposition

Observations

Surface:

- Shenandoah National Park, VA
- Fort Meade, MD
- Philadelphia, PA
- Greenbelt, MD

Aloft

- Aztec Aircraft
- Profiler
- Sondes

Remote (NASA)

- TES/OMI etc.
- MOPITT (CO)
- TOMS (O_3)
- MODIS (particles)
- GOME (SO_2, NO_2…)
- SCIAMACHY

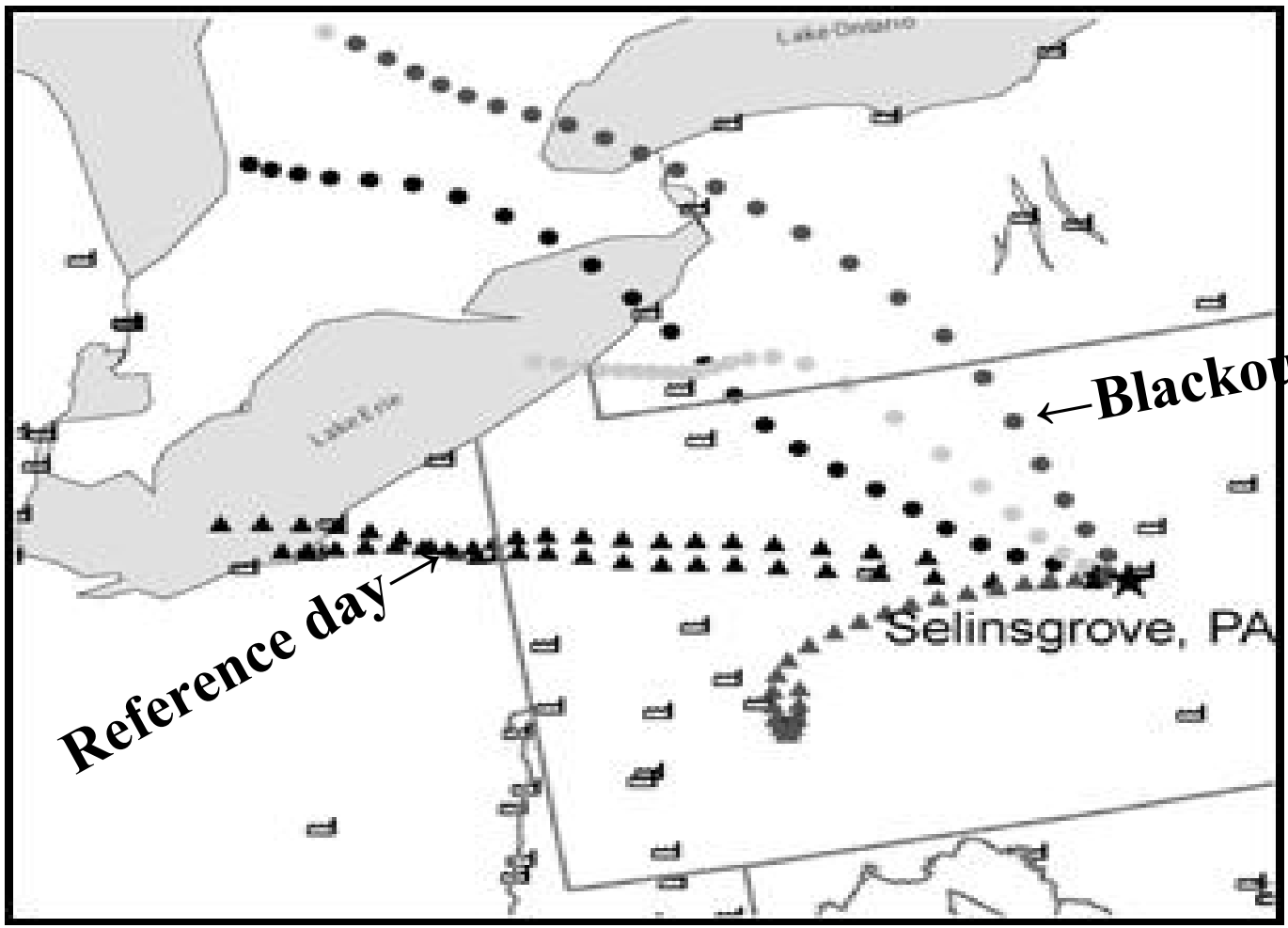
Experimental Control

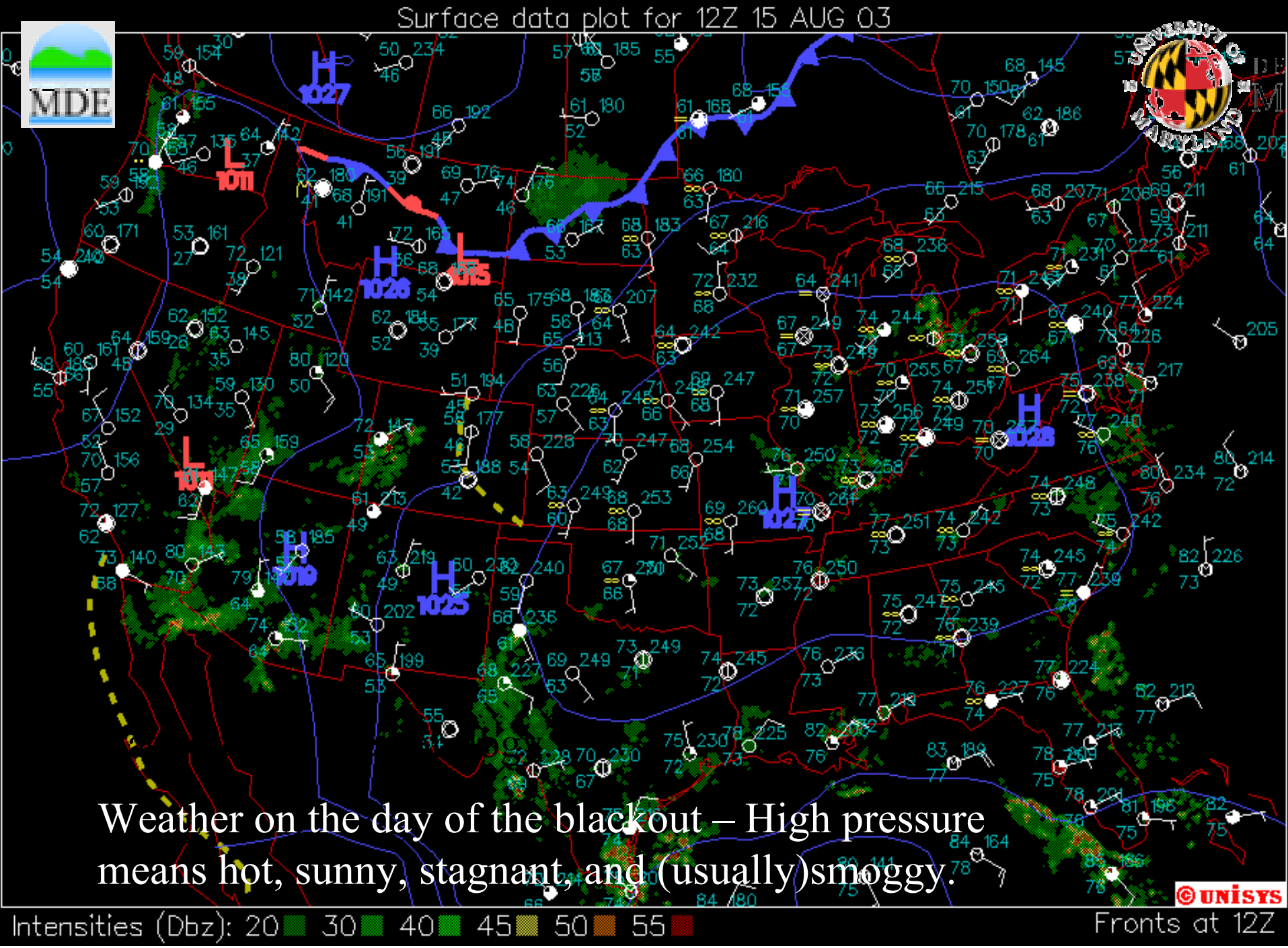
Compare pollutant concentrations in the blackout region to those of:

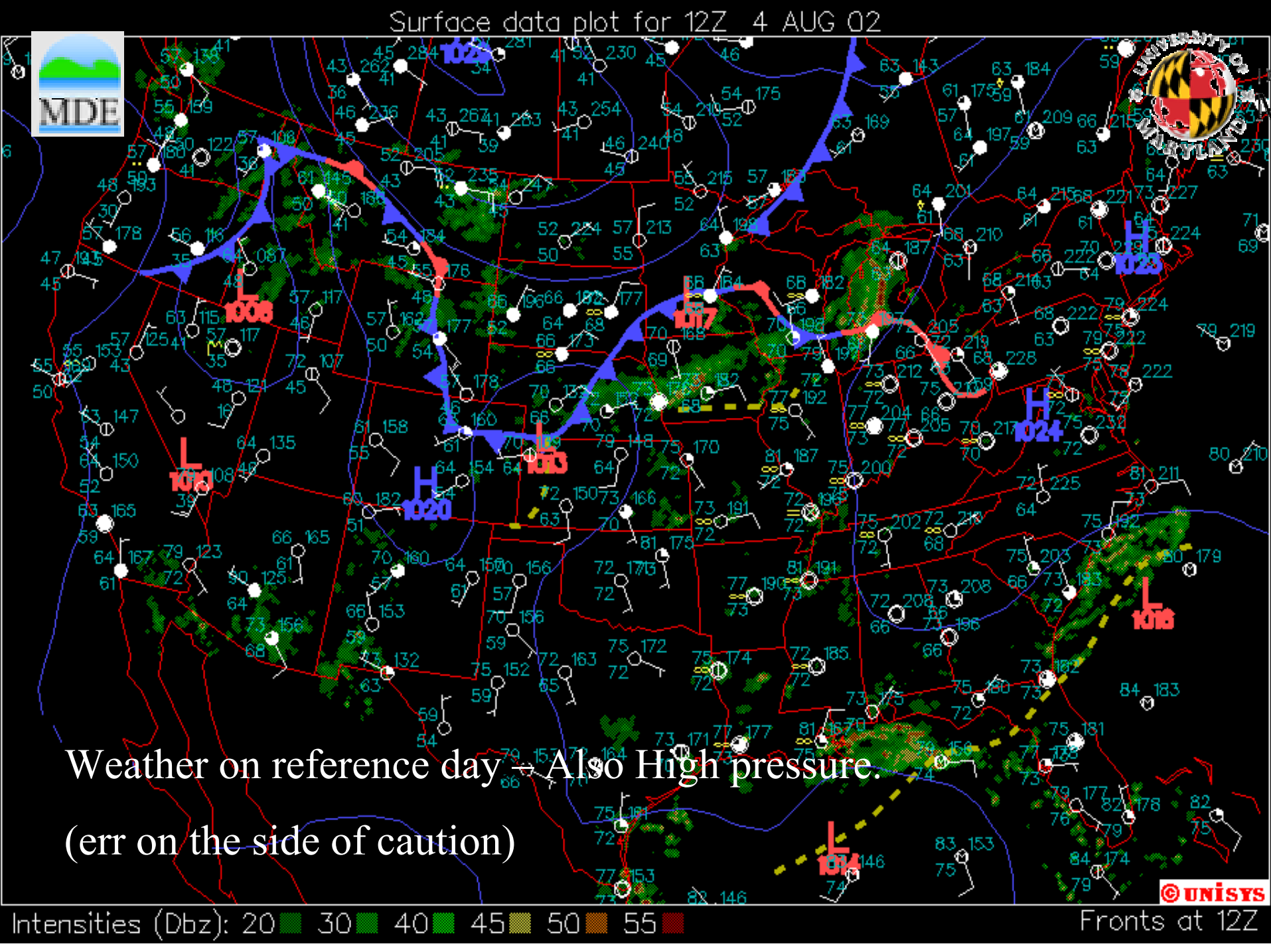
- August 4, 2002, a meteorologically similar, non-blackout day.
- Blackout day, south of the blackout area.

Back Trajectories

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




Surface data plot for 12Z 15 AUG 03
MDE
UNIVERSITY OF MARYLAND
Weather on the day of the blackout – High pressure means hot, sunny, stagnant, and (usually)smoggy.
©UNISYS
Intensities (Dbz): 20 30 40 45 50 55
Fronts at 12Z


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

Aztec-F Research Aircraft N500Z

GPS Position (°Lat, °Long)

Meteorology (T, RH, Pr, P_{alt}, WS, WD)

Carbon Monoxide (CO)

Ozone (O_3)

Sulfur Dioxide (SO_2)

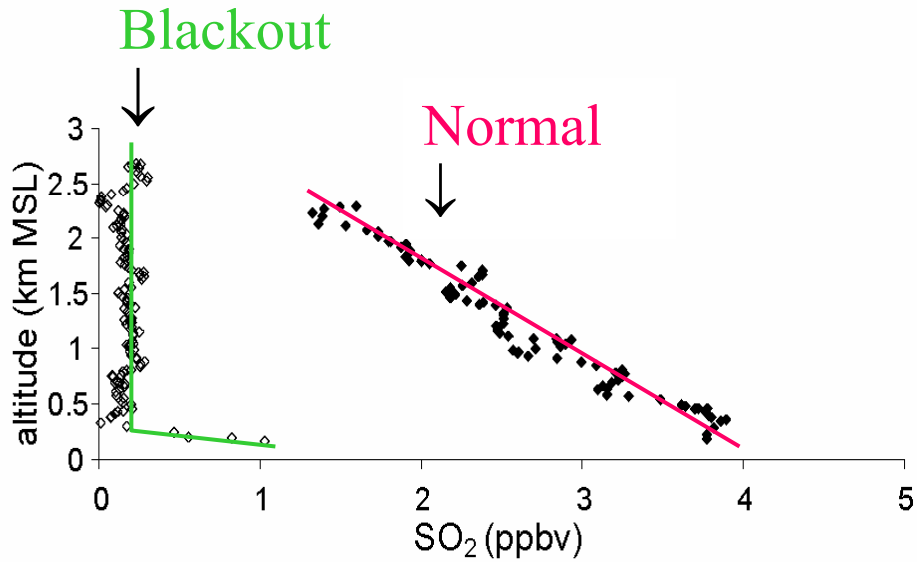
Aerosol Optical Properties:

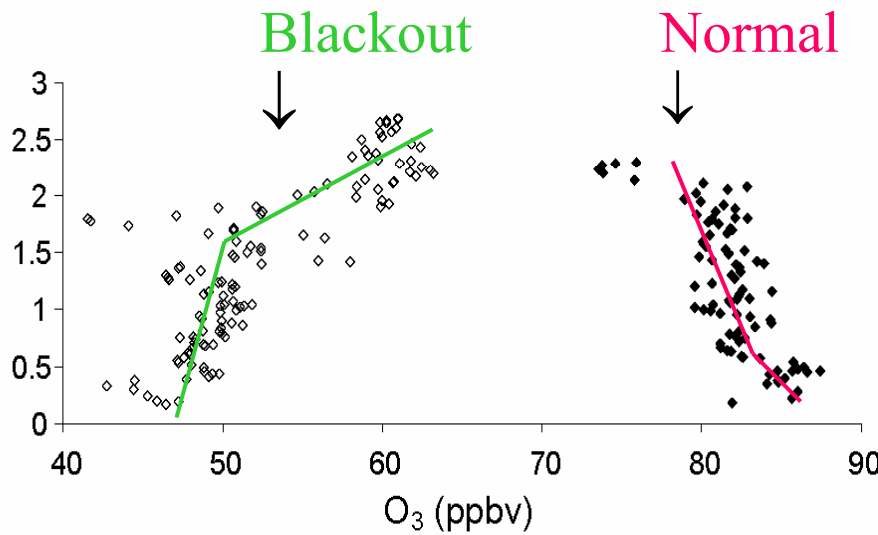
- **Absorption, b_{ap}** (565 nm)
- **Scattering, b_{scat}** (450,550,700 nm)

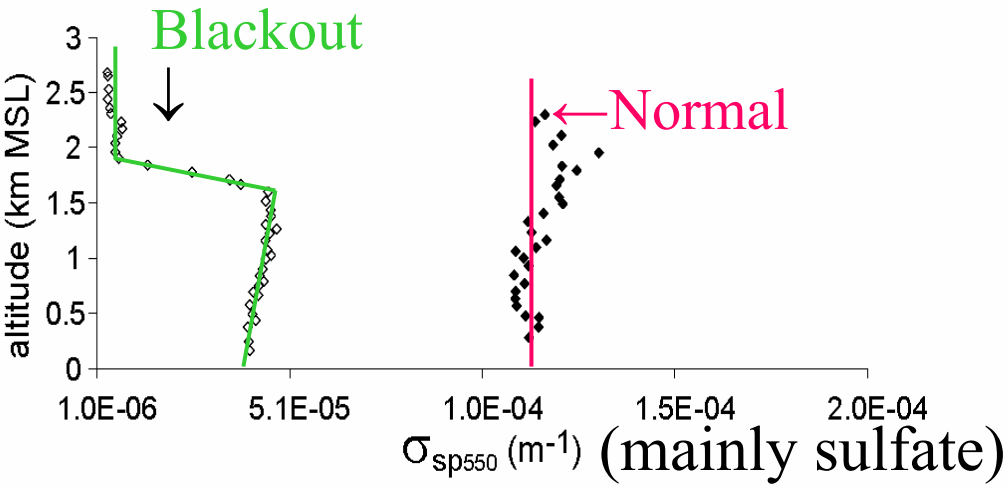
Aerosol Particle Size (MetOne)

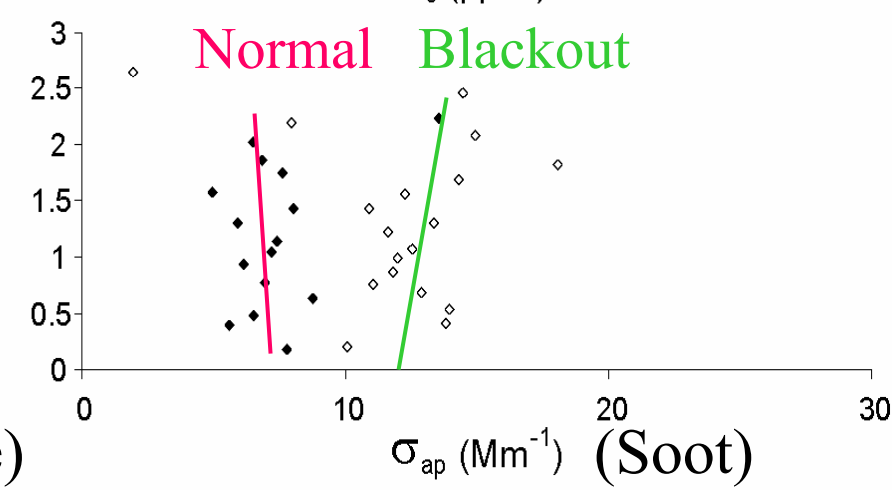
- **6 cuts – Range 0.3-1.0 µm**

Idled power plants means improved air quality.









Observations over central Pennsylvania.

Compared to a normal day when power generation was typical, which pollutants were affected?

- Ozone was reduced to ~55% of normal.
- SO_2 was virtually eliminated.
- Light scattering (causes haze & limits visibility) was substantially reduced. Implies reduced sulfate aerosol.
- Light absorption, primarily caused by soot, was not reduced. Diesel engines emit soot, power plants do not. Story for CO is the same.

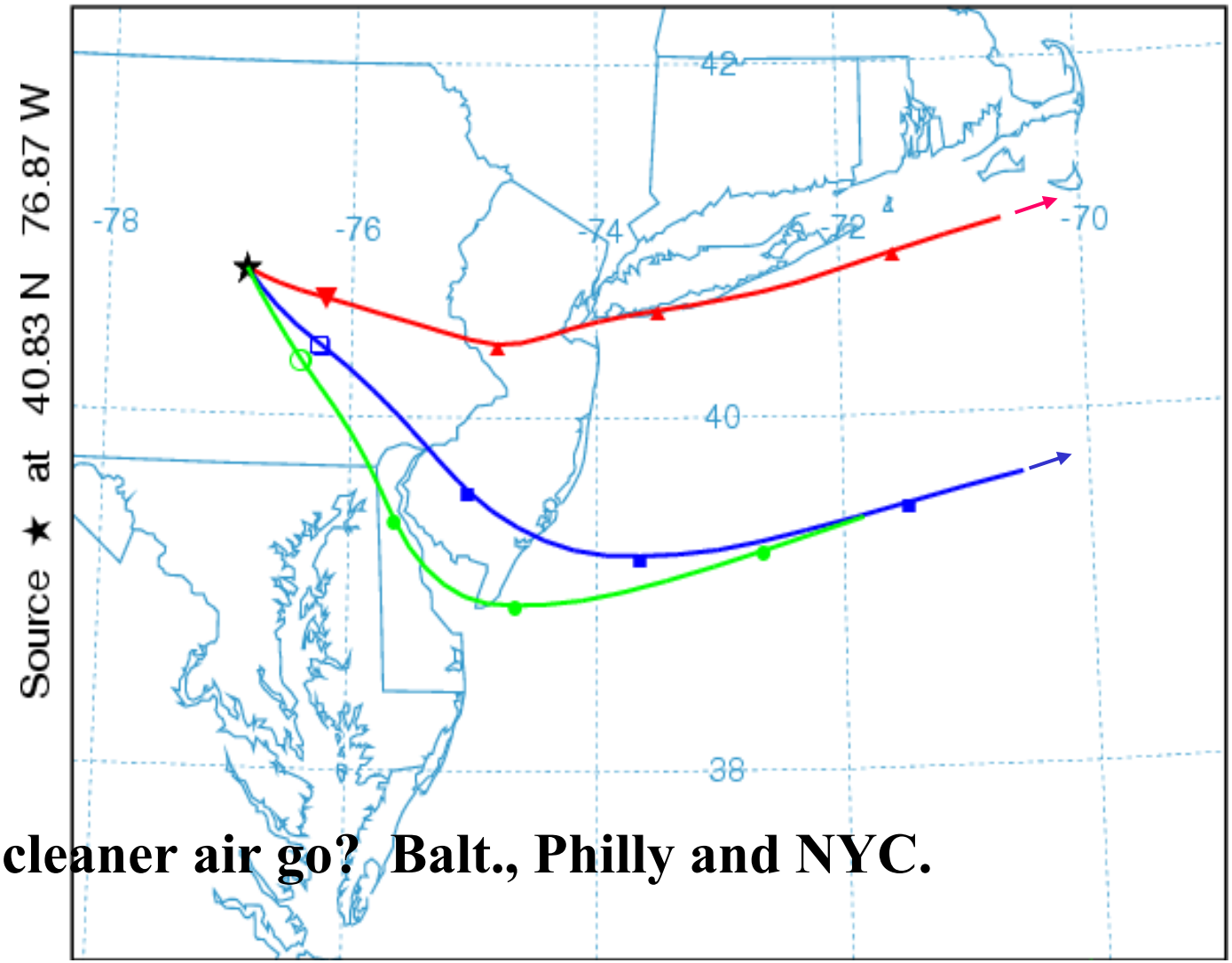
Who benefited from cleaner air:

Forward Trajectories

1500 m

1000 m

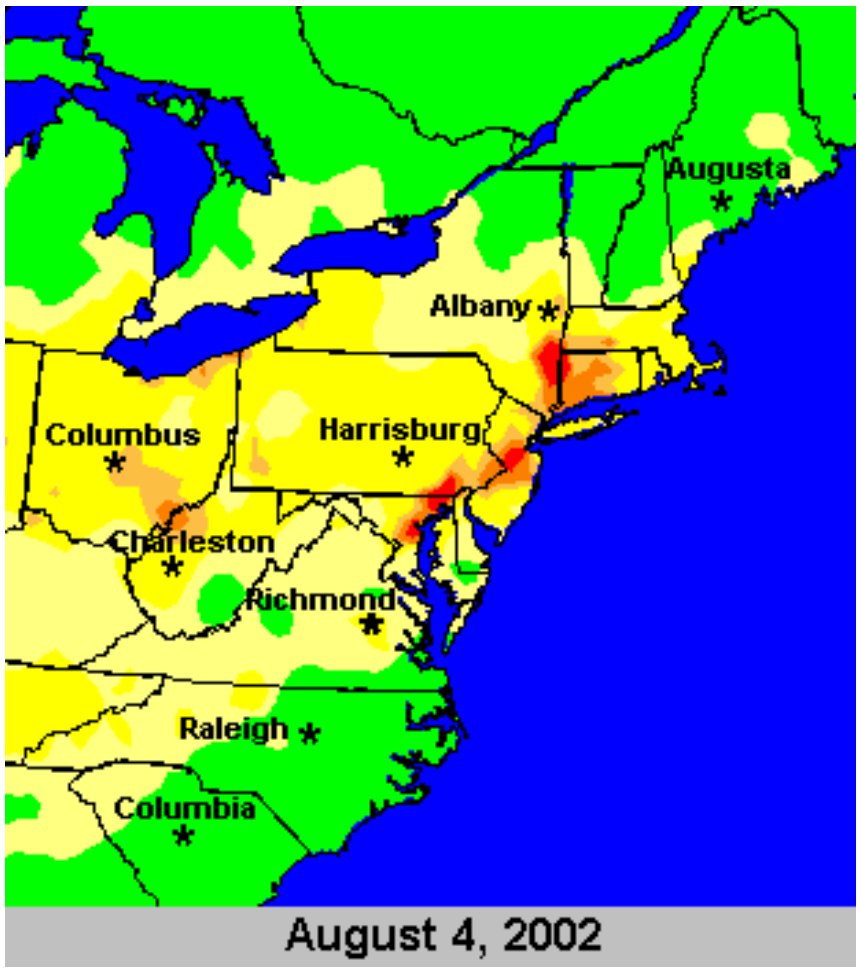
500 m



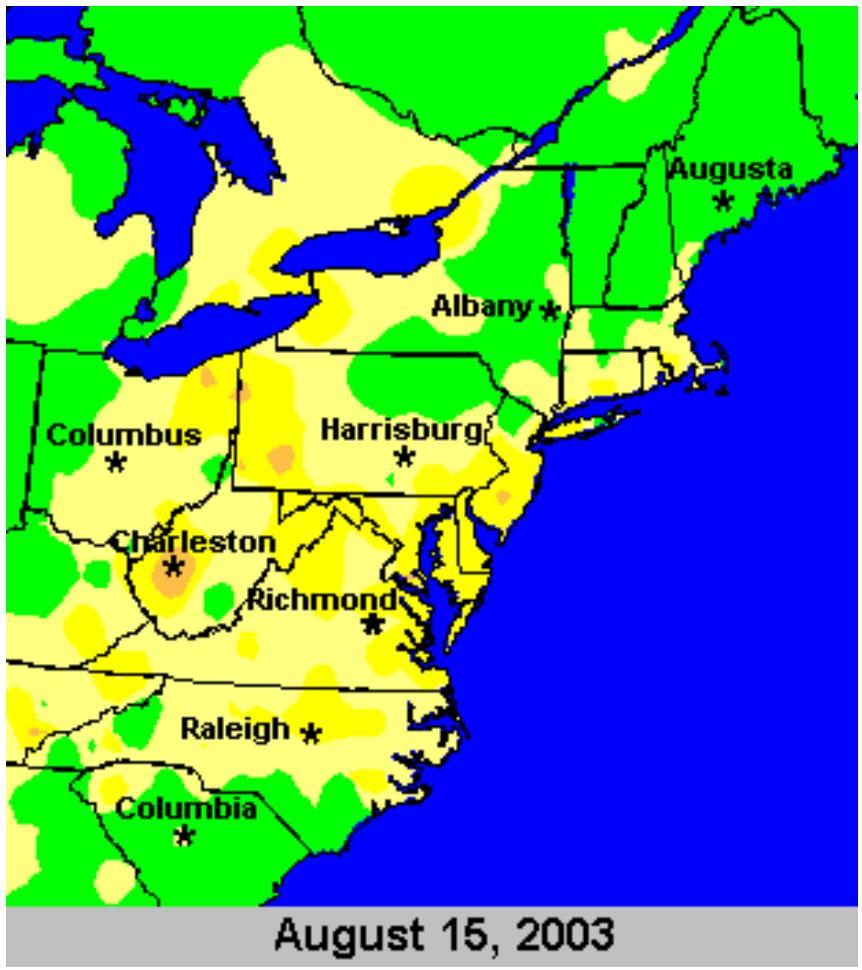
Where did the cleaner air go? Balt., Philly and NYC.

AIRNow surface ozone, 1 hr max [O_3]

Control



Blackout



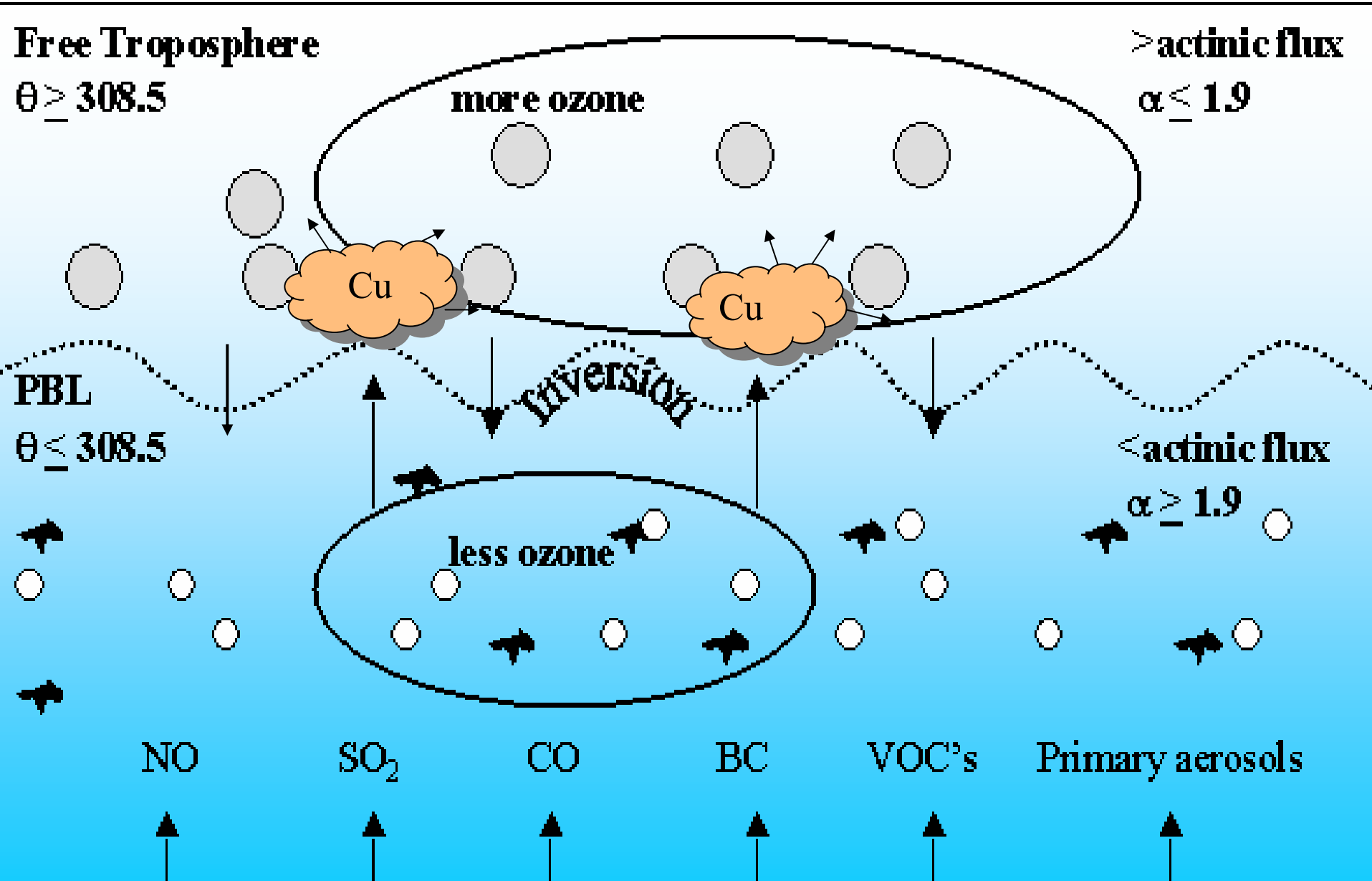
Both power plants and vehicles involved here.

During the Blackout:

- Rural SO_2 was reduced by a factor of 2 to 10.
- Aerosol loading fell from ~24 to 8 μg m^{-3}.
- Visual range increased by >40 km (25 mi).
- No significant change in CO or black carbon.
- Air is headed toward Balt, Philly, NYC.
- Rural ozone was reduced by nearly 40 ppb.
- Forecast (regression equation) 115 ppb, observed 90 ppb.

Why so much?

Two Reservoir Model (Taubman et al., *JAS*, 2004)



Major Findings:

- **Emissions from power plants dominated 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.**

Additional work to do.

- **Why was ozone reduced by so much?**

  Model episode with CMAQ.

  Investigate role of altitude of emissions.

- **Verify CEM data.**
- **Look for surface observations.**
- **Check for traffic & industry in additional upwind regions.**
- **What were Canadians doing?**
- **Satellite observations.**
- **Fly additional control days.**

Acknowledgements

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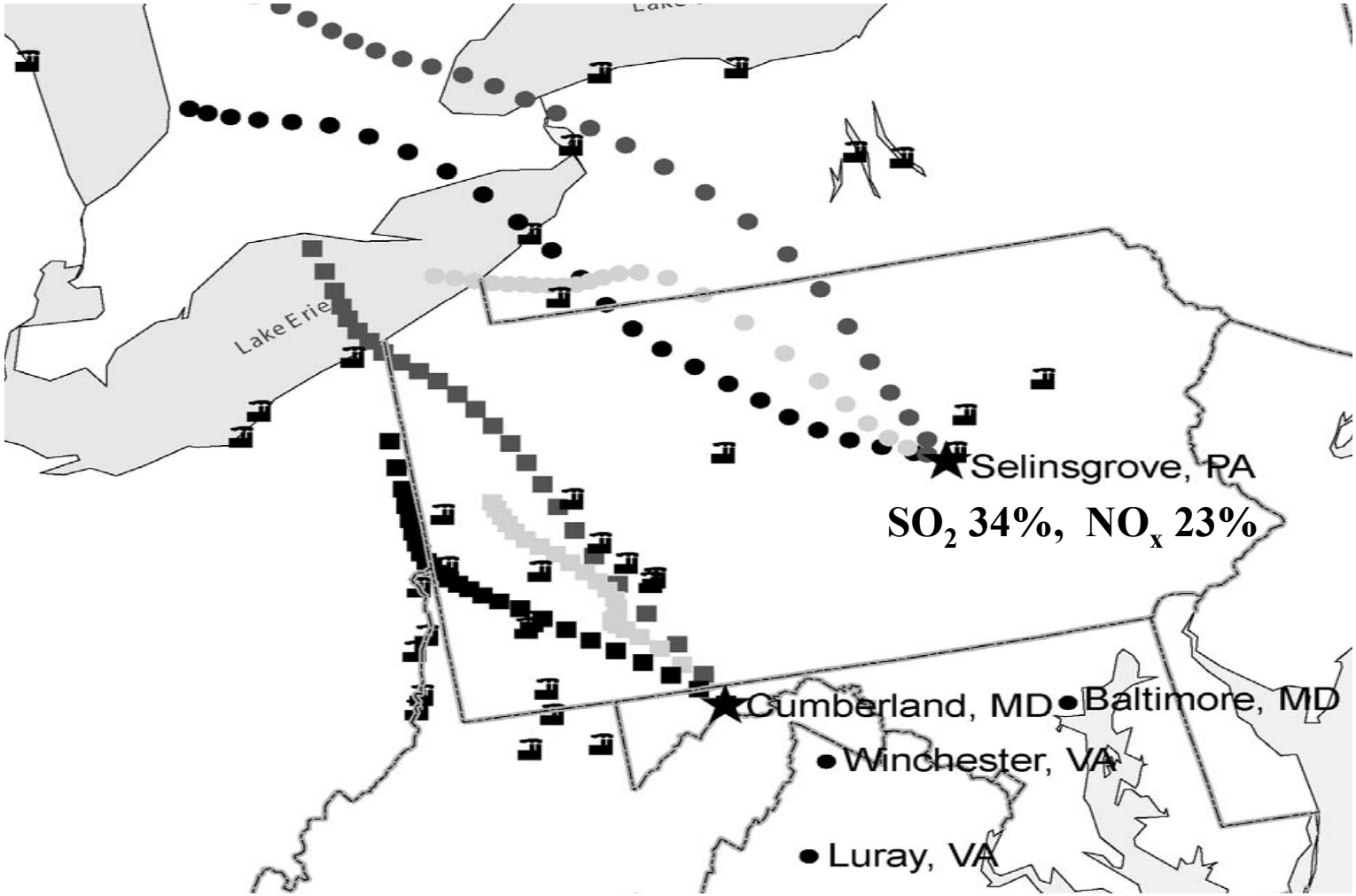
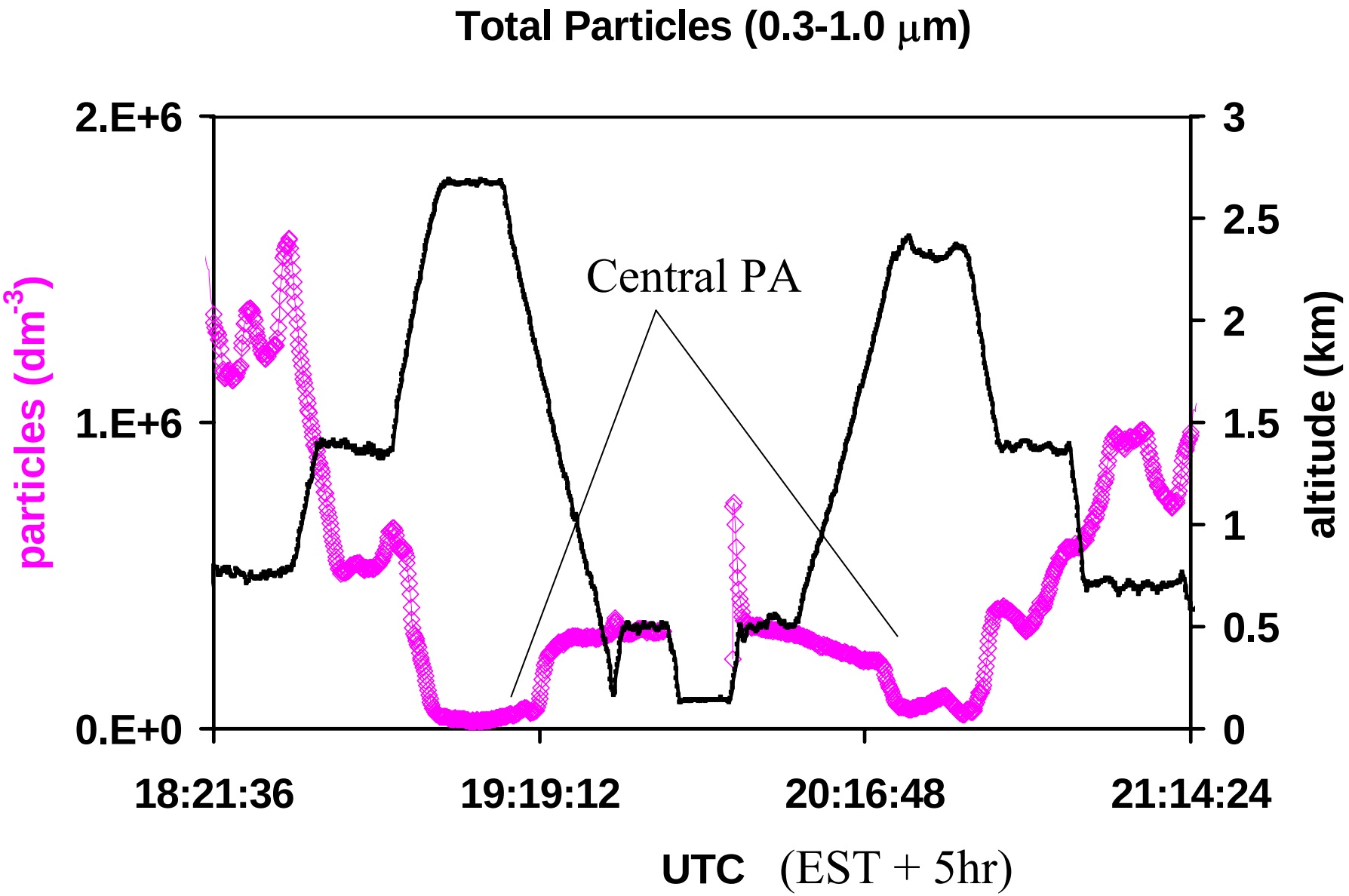
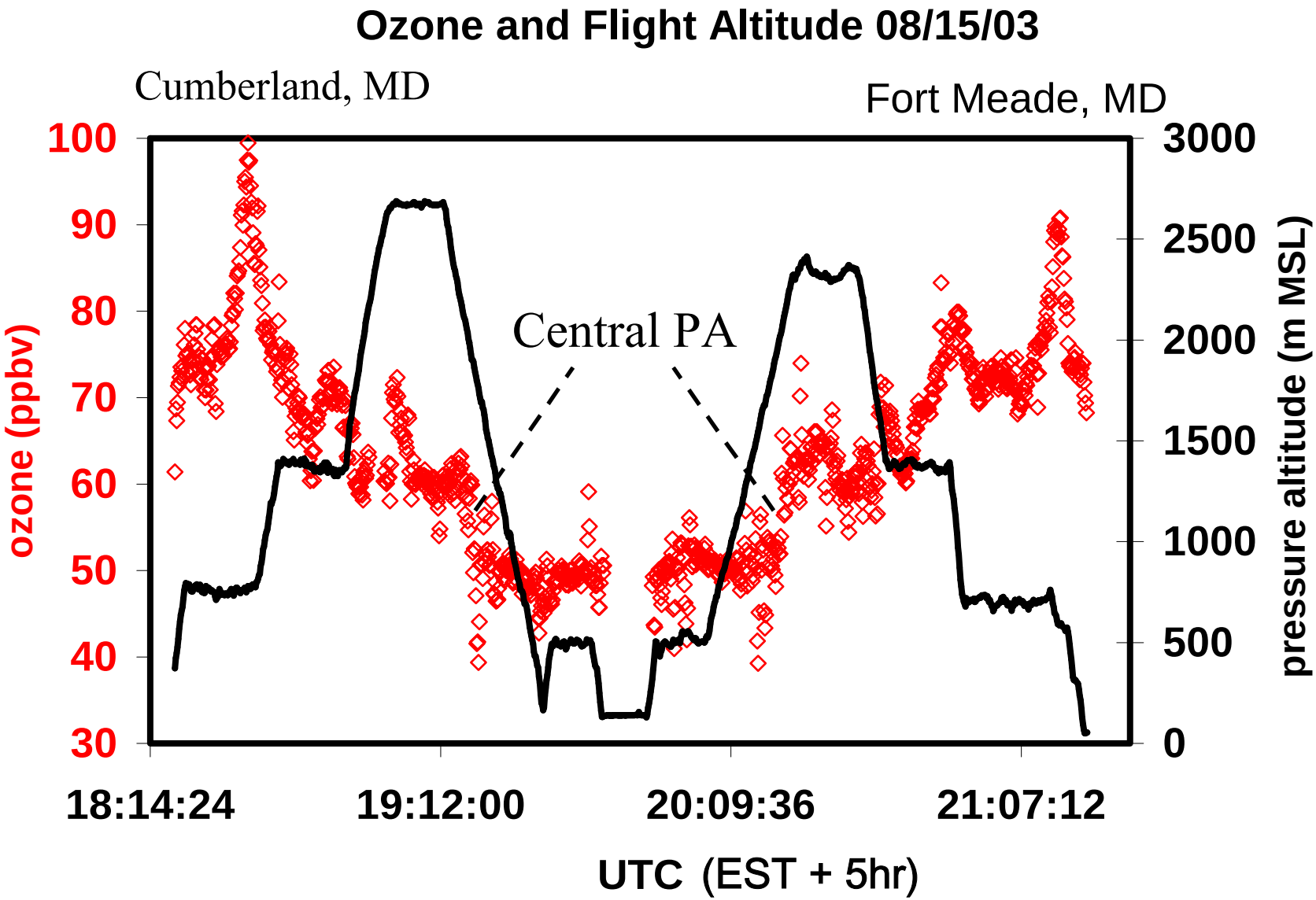
The End.

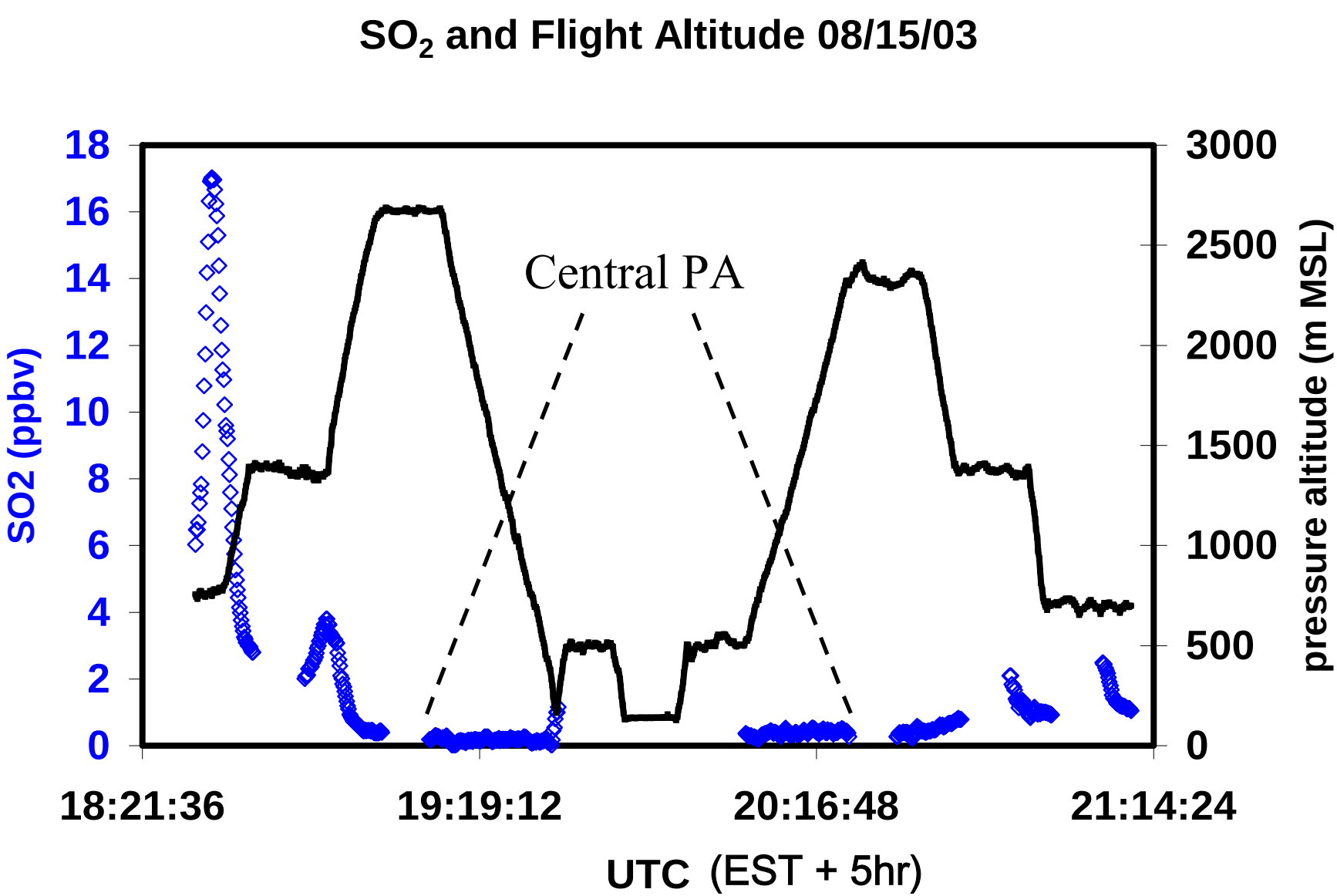
The 2003 North American Electrical Blackout: An Accidental Experiment in Atmospheric Chemistry, Lackson T. Marufu, B. F. Taubman, B. Bloomer, C. A. Piety, B. G. Doddridge, J. W. Stehr, and R. R. Dickerson, *Geophys. Res. Lett.*, 31, 2004.

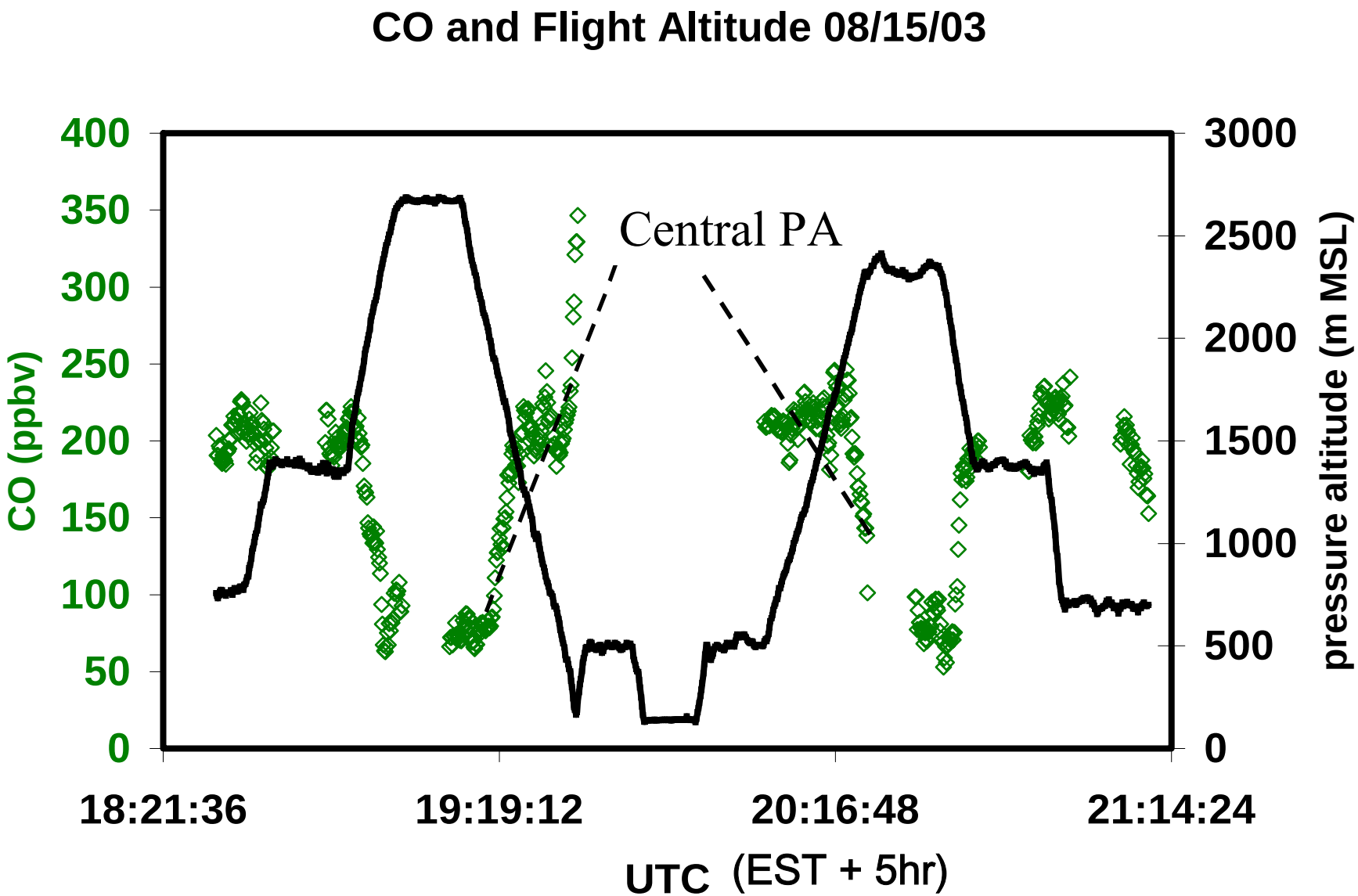
Power plants upwind of Cumberland were operating normally.



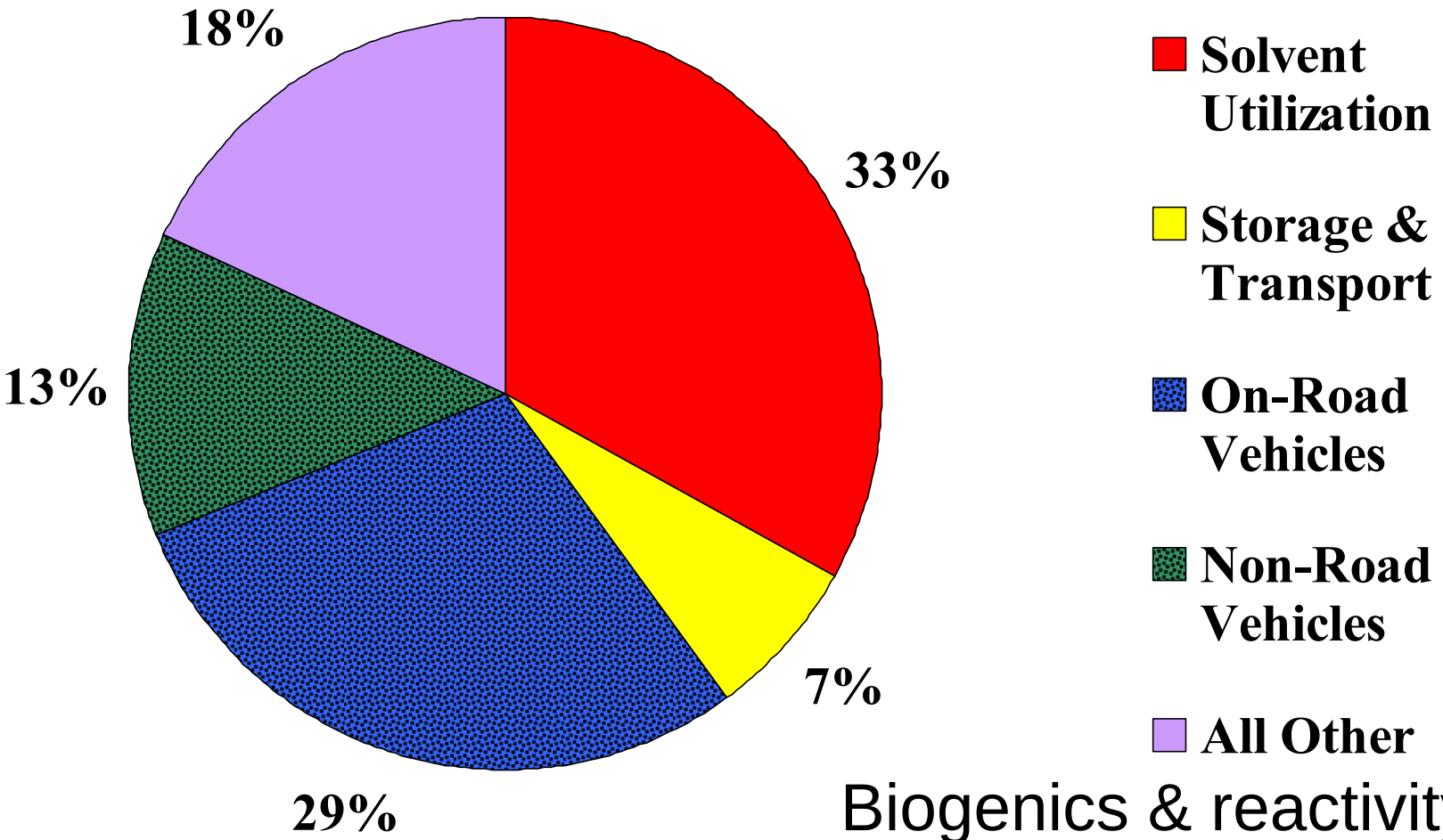

Total Particles (0.3-1.0 μm)
2.E+6
1.E+6
0.E+0
particles (dm-3)
3
2.5
2
1.5
1
0.5
0
altitude (km)
Central PA
18:21:36
19:19:12
20:16:48
21:14:24
UTC (EST + 5hr)


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)


SO2 and Flight Altitude 08/15/03
SO2 (ppbv)
18
16
14
12
10
8
6
4
2
0
pressure altitude (m MSL)
3000
2500
2000
1500
1000
500
0
Central PA
18:21:36
19:19:12
20:16:48
21:14:24
UTC (EST + 5hr)


CO and Flight Altitude 08/15/03
Central PA
CO (ppbv)
400
350
300
250
200
150
100
50
0
3000
2500
2000
1500
1000
500
0
pressure altitude (m MSL)
18:21:36
19:19:12
20:16:48
21:14:24
UTC (EST + 5hr)

Volatile Organic Compound Emissions (by mass)



1996 NEI

Biogenics & reactivity are very important!