Regional Ozone Transport: The State of the Science

Presented to

The Ozone Transport Commission

by

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Supported by MDE

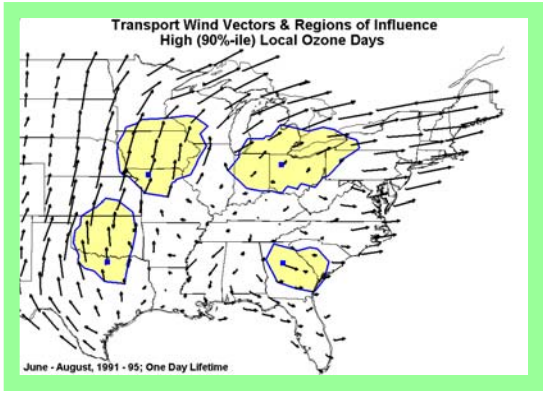
NASA, NOAA, and DNR

November 15, 2012

UMD/URF Cessna
Photo by J. Stehr

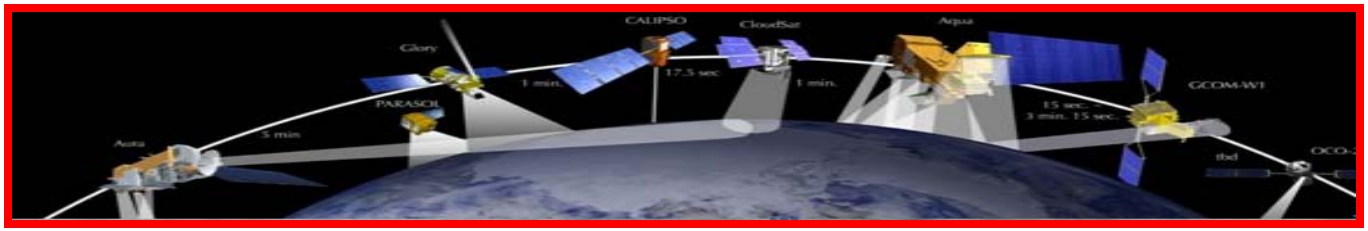
What Jeff Underhill already said:

- Ozone has improved.
- Regional controls are cost effective and successful.
- Transport is critical:
  - Synoptic scale transport from the West
  - Nocturnal Low Level Jet (and other)transport from south.
- To understand transport you must understand the elevated reservoir of ozone and precursors.



What I will cover:

- The Regional Atmospheric Measurement, Modeling, and Prediction Program: RAMMPP
  - A collaborative research effort
  - Policy Relevant Science
- Revisiting the "**Black-Out**" study
- NASA's Air Quality Applications Science Team (AQAST)
- New findings from NASA's DISCOVER-AQ
- How does ozone respond to NOx reductions?
- Collaboration with EPA/ORD and modeling for transport.
- The Bottom Line (spoiler warning)
  - **The science leads inexorably to the conclusion that the most critical effort to reduce ozone in the OTR is NOx controls across a large part of the East.**



Good Questions

Do super-regional NOx reductions really work?

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Is there substantial ozone produced and transported aloft and upwind as well as at surface?

*****

Do NASA's measurements help confirm the observations and help improve the modeling?

*****

Will additional regional controls be necessary?

RAMMPP: Policy Relevant Air Quality Science

The MDE/UMD RAMMPP Team

Including NASA, NOAA, PSU, UMBC, DNR.

MDE

Partners

- NASA
  - Goddard
  - Langley
  - AQAST
  - OMI
- EPA
  - ORD CMAQ modeling
  - Observations (with PSU)
- NOAA
  - ARL (AQ Forecast)
  - NESDIS Satellite Applications and Research

NASA, NOAA, EPA
Harvard, PSU, U Wisconsin
Columbia, GIT, U Iowa
St Louis U, NRL, Argonne, Emory
Rice, UMD, U Colo, U AL, NCAR.
A NASA project dedicated to YOU.
http://acmg.seas.harvard.edu/aqast/

Partners, Continued

- NIST for Calibration
- UMBC
  - LIDAR
  - Modeling
- Penn State Univ.
  - Edgewood observations
  - O_3 Sondes
  - analysis
- Howard Univ.
  - Beltsville Site
- Last but not least
  - MDE

MDE

RAMMPP

(Regional Atmospheric Measurement Modeling & Prediction Program)

Balanced Theory & Observations

WRF

Dynamical Model

12-0.5 km Resolution

Forecasting

Input

Emissions Inventories

SMOKE

(Chem Engineering)

Chemical Transport Models

CMAQ

Modular
Open Code
Collaborative
w/EPA
and
WRF-CHEM
Interactive
Photochem.
Aerosols
Transport
Deposition

Observations

Surface:
- Beltsville
- Greenbelt
- Piney Run

Aloft
- Cessna Aircraft
- NASA P3
- Profiler
- Sondes

Remote (NASA & NOAA)
- AERONET
- GASP (AOD)
- MOPITT (CO)
- MODIS (particles)
- OMI (NO_2, SO_2)
- PANDORA (NO_2, SO_2)
- SCIAMACHY (SO_2, NO_2, H_2CO…)

UMD Research Aircraft

GPS Position (° Lat, ° Long)

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

Carbon Monoxide (CO)

Nitrogen Dioxide (NO_2)

Ozone (O_3)

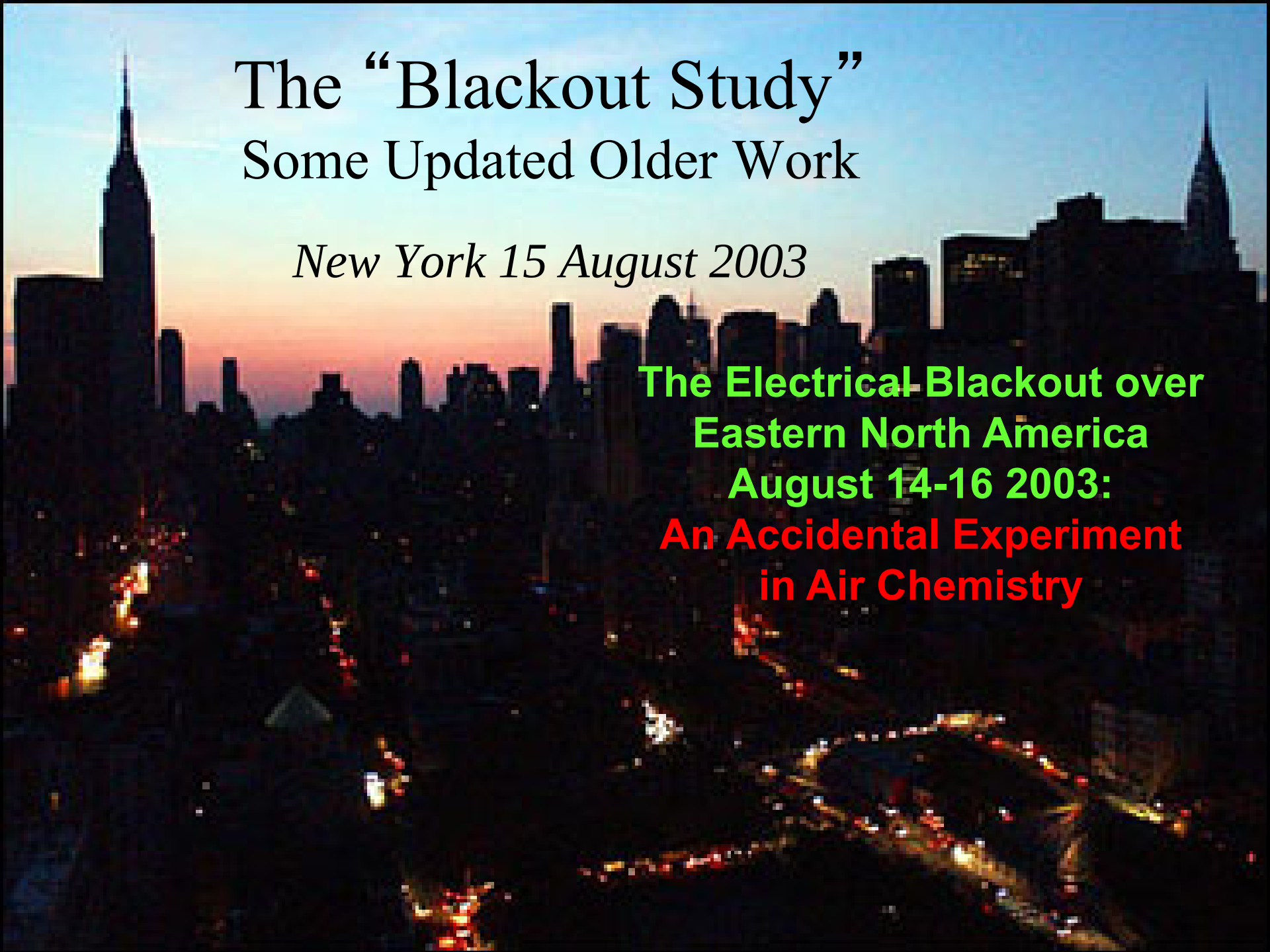
Sulfur Dioxide (SO_2)

Aerosol Optical Properties:

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

Aerosol Particle Size (MetOne)

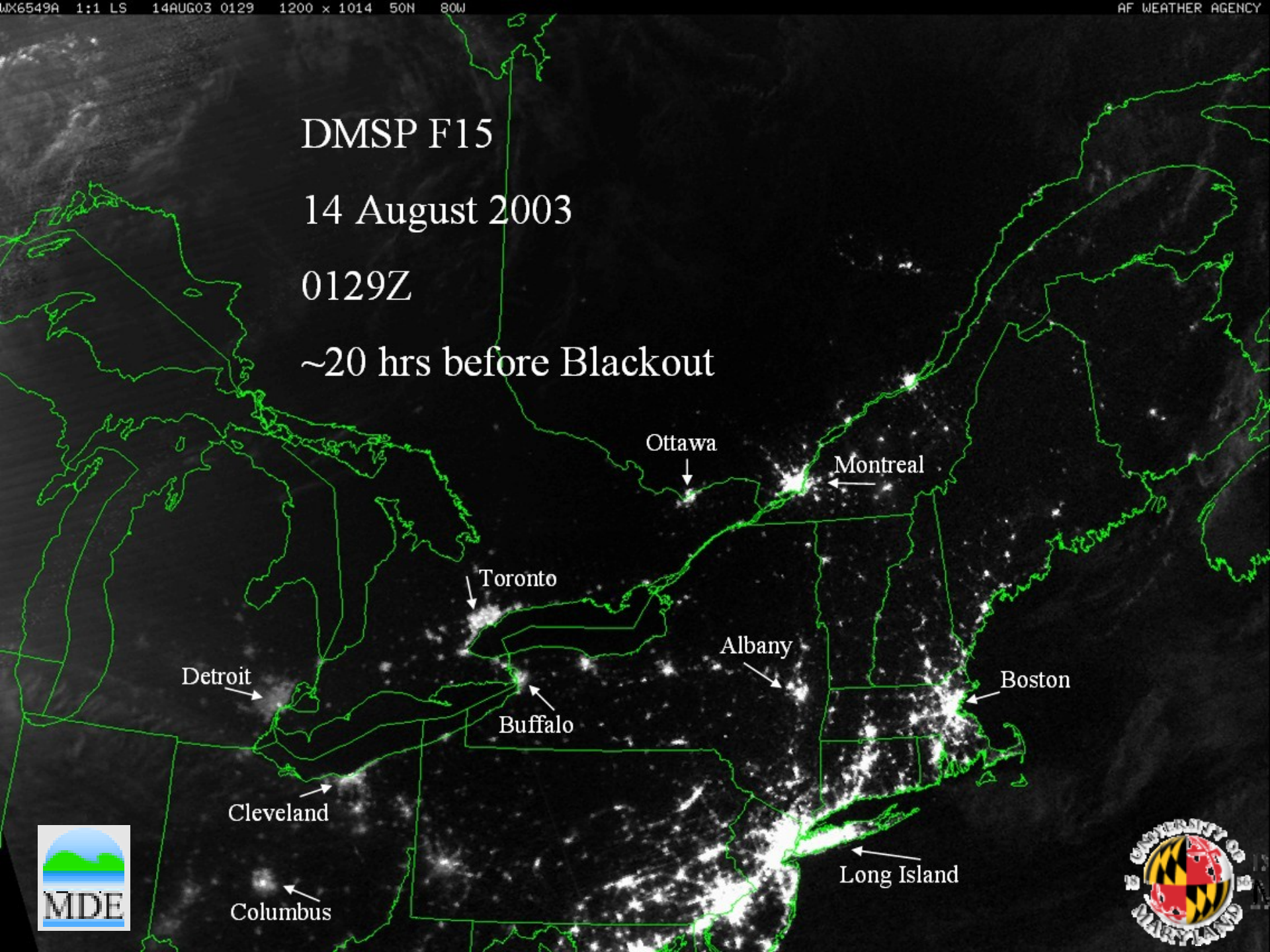
- **6 cuts – Range 0.3-1.0 µm**

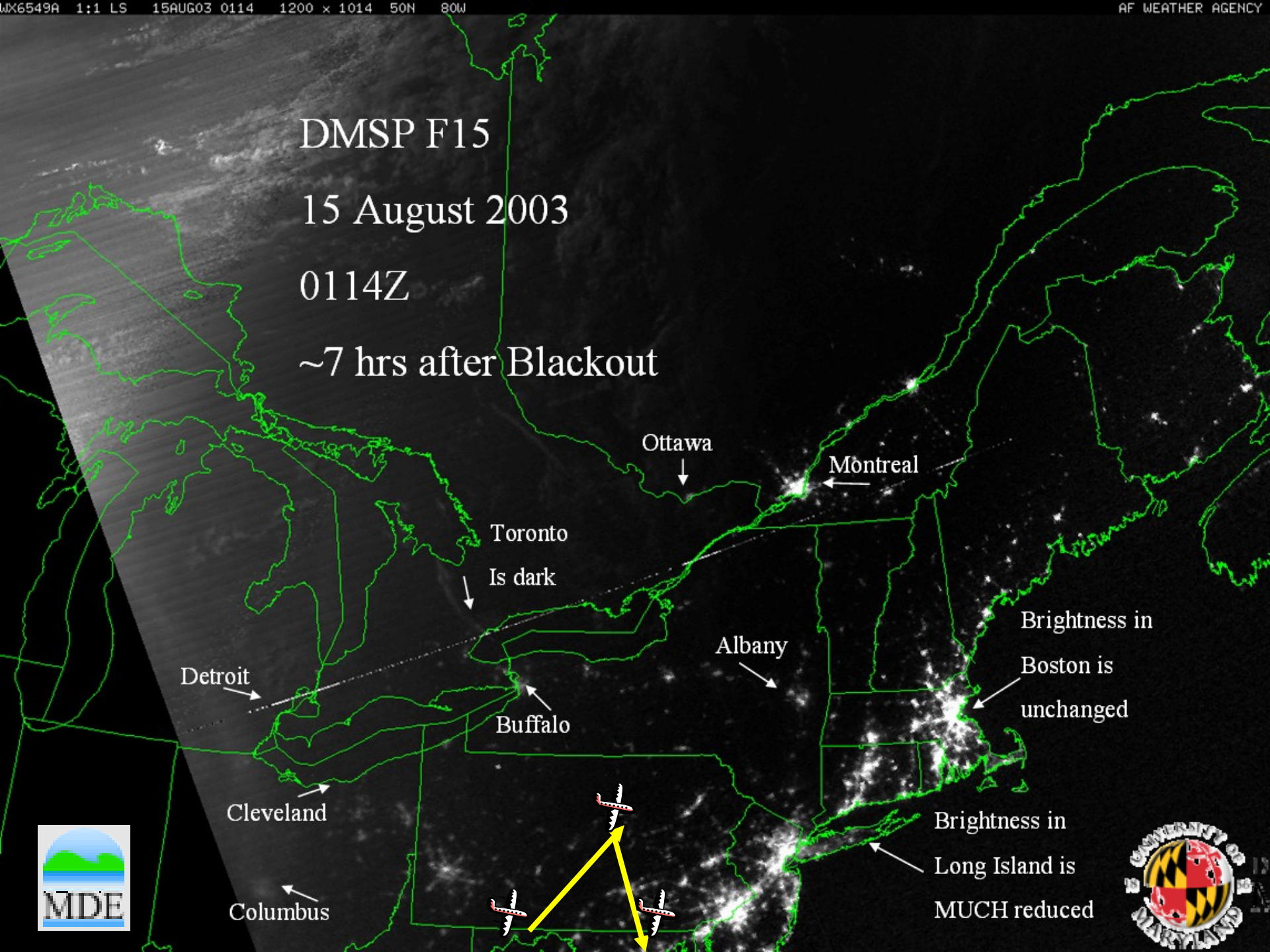


The "Blackout Study"
Some Updated Older Work

New York 15 August 2003

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

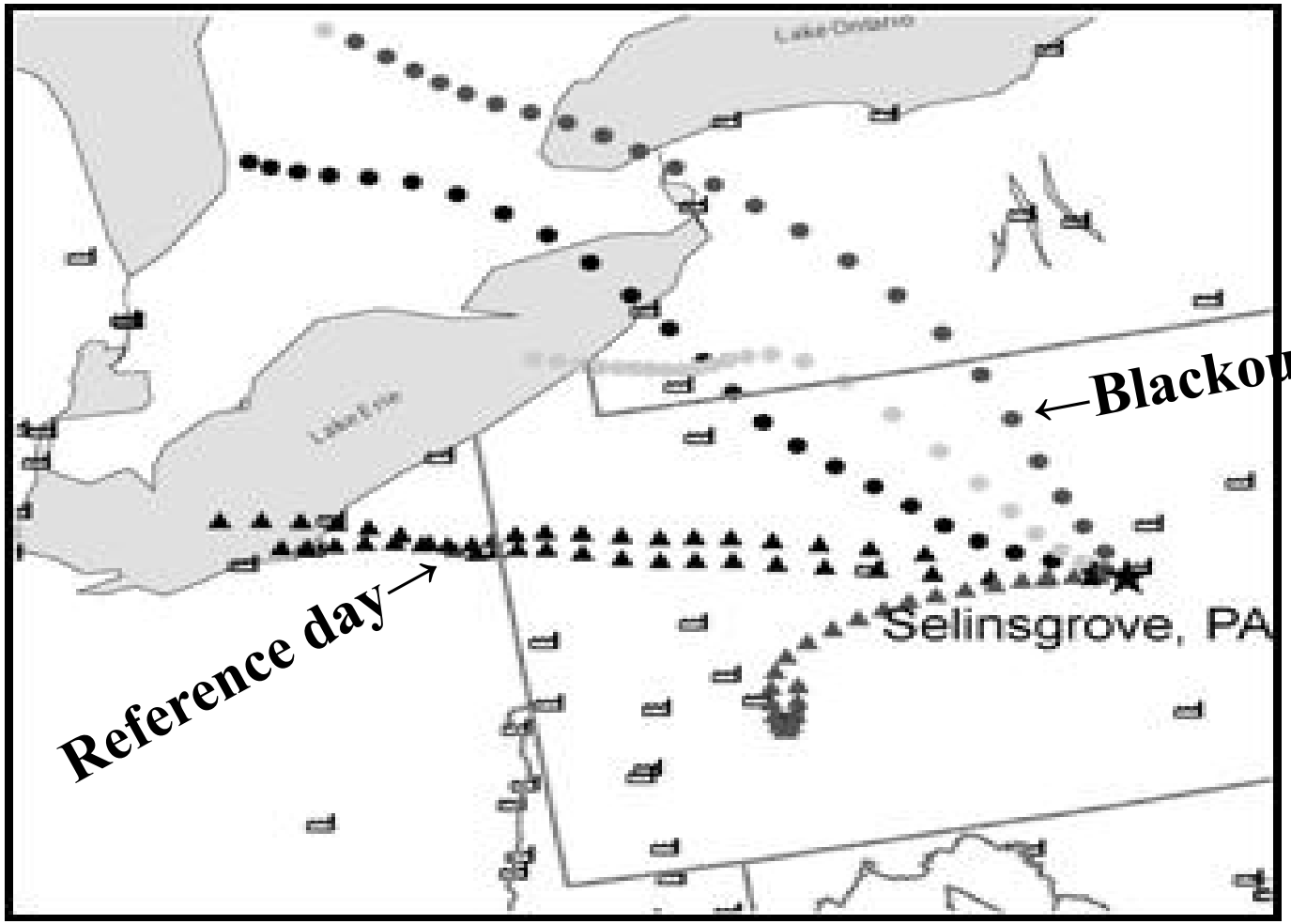

DMSP F15
14 August 2003
0129Z
~20 hrs before Blackout
Ottawa
Montreal
Toronto
Albany
Boston
Detroit
Buffalo
Cleveland
Columbus
Long Island
MDE


WX6549A 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

Where was the wind coming from?

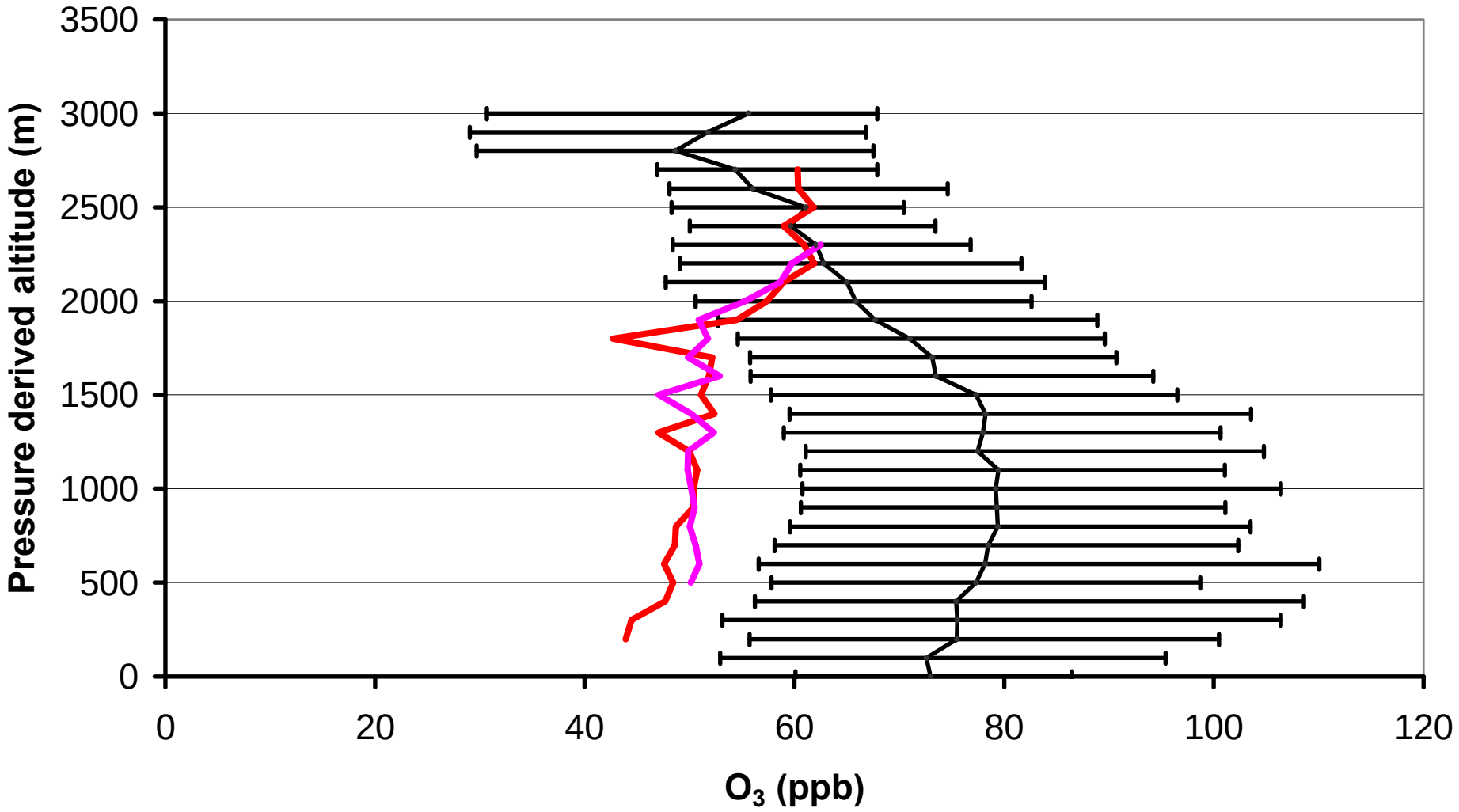
Back Trajectories

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

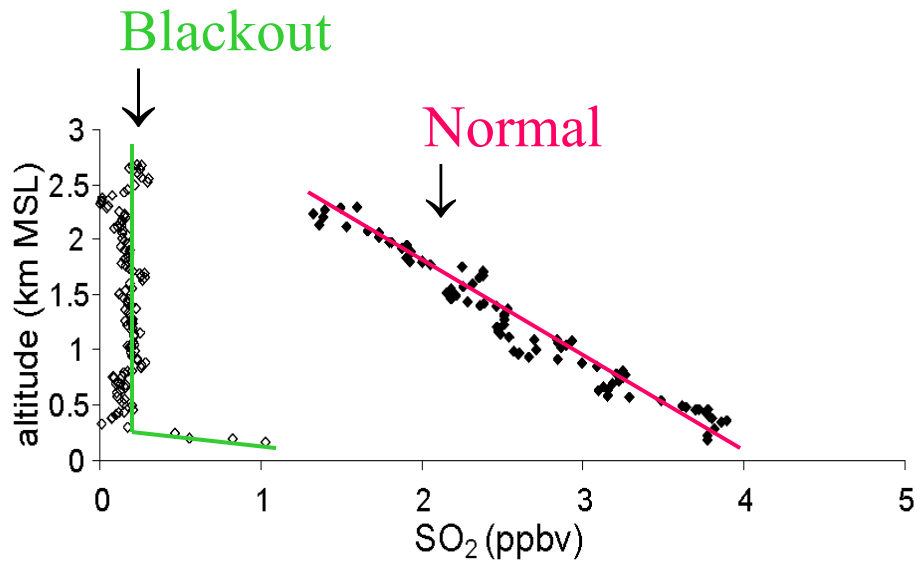


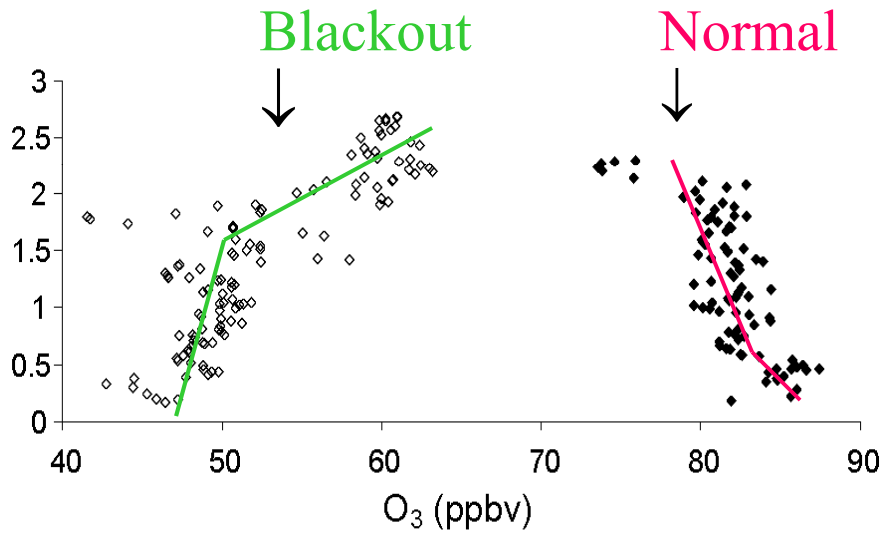
Much Lower Ozone Aloft During the Blackout

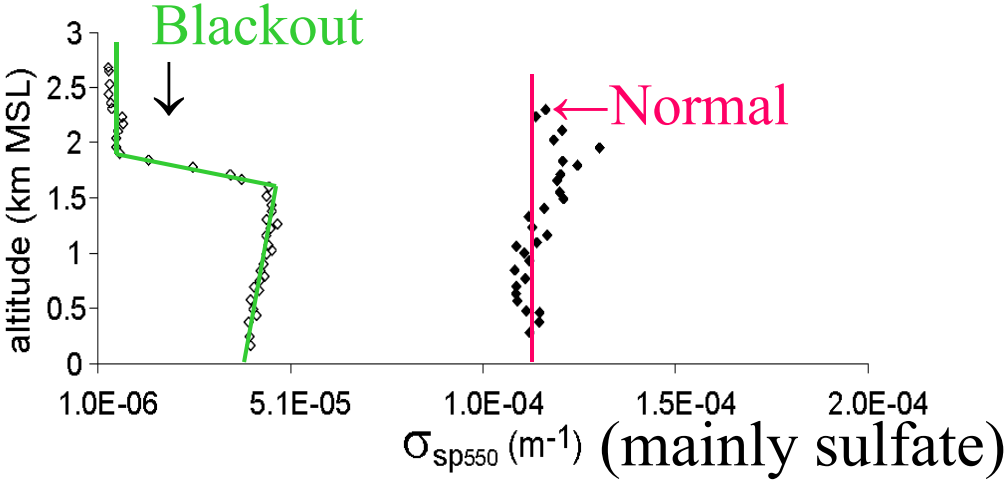
O_3 Median (10% & 90%) for afternoon Cluster 1 (62 profiles)
Flights during Blackout in color.

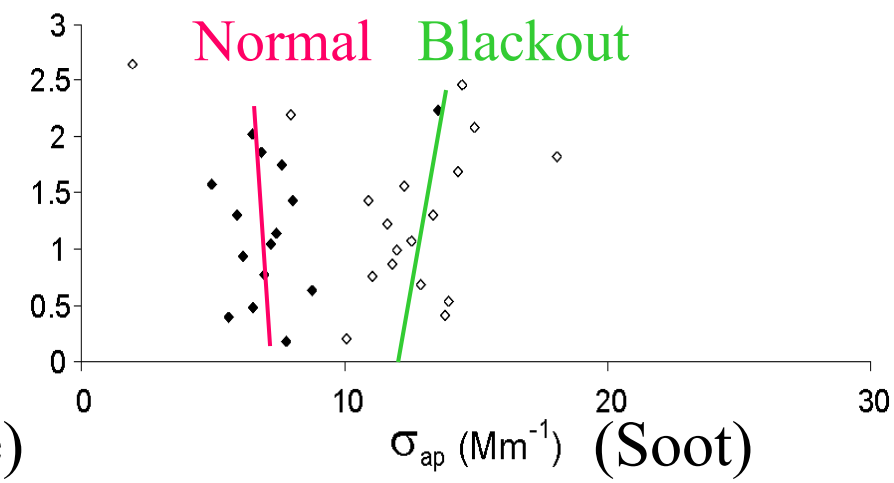


Idled power plants means improved air quality









Observations over central Pennsylvania.

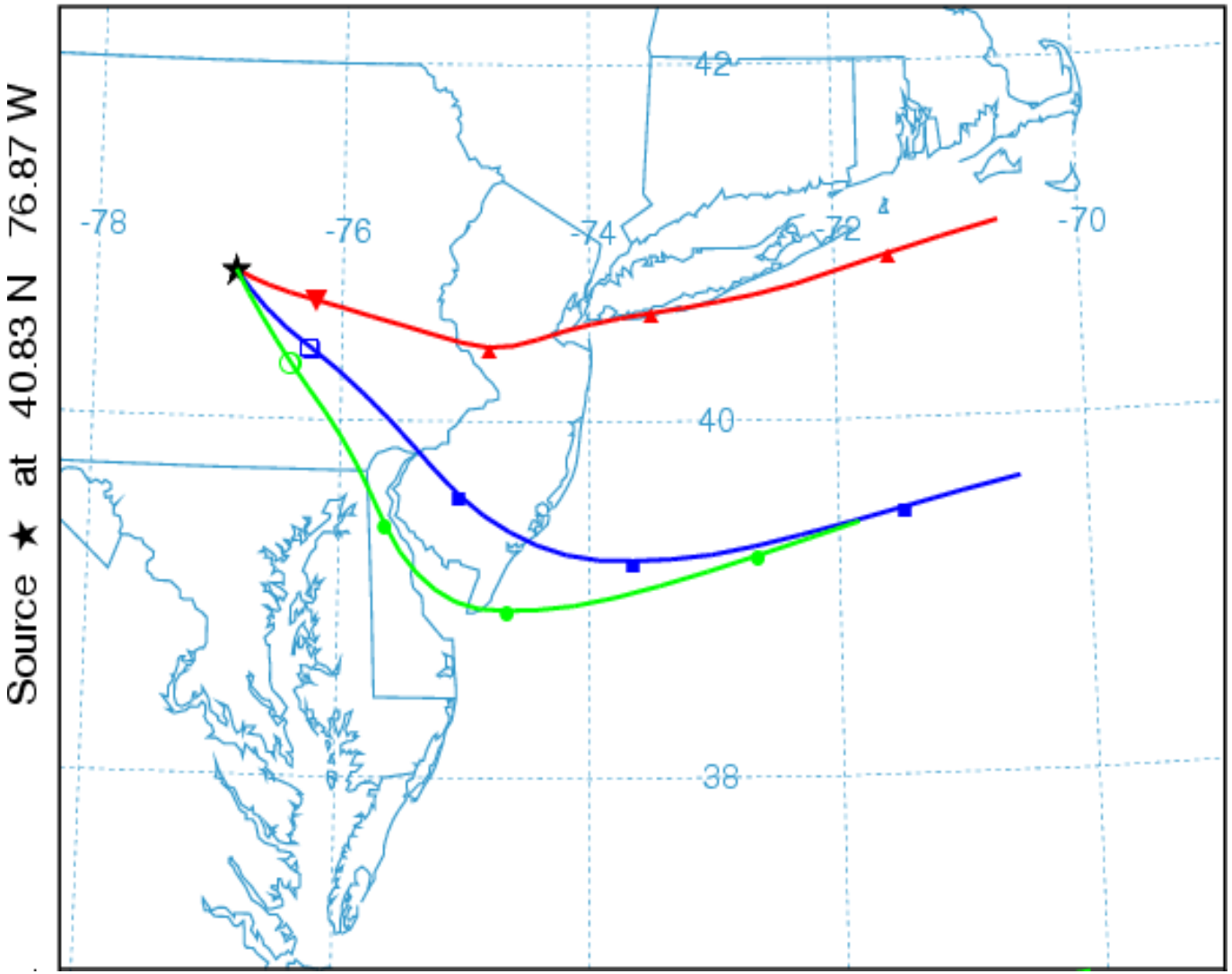
Blackout: Where did the clean air go?

Forward Trajectories

1500 m

1000 m

500 m



Take home message #1

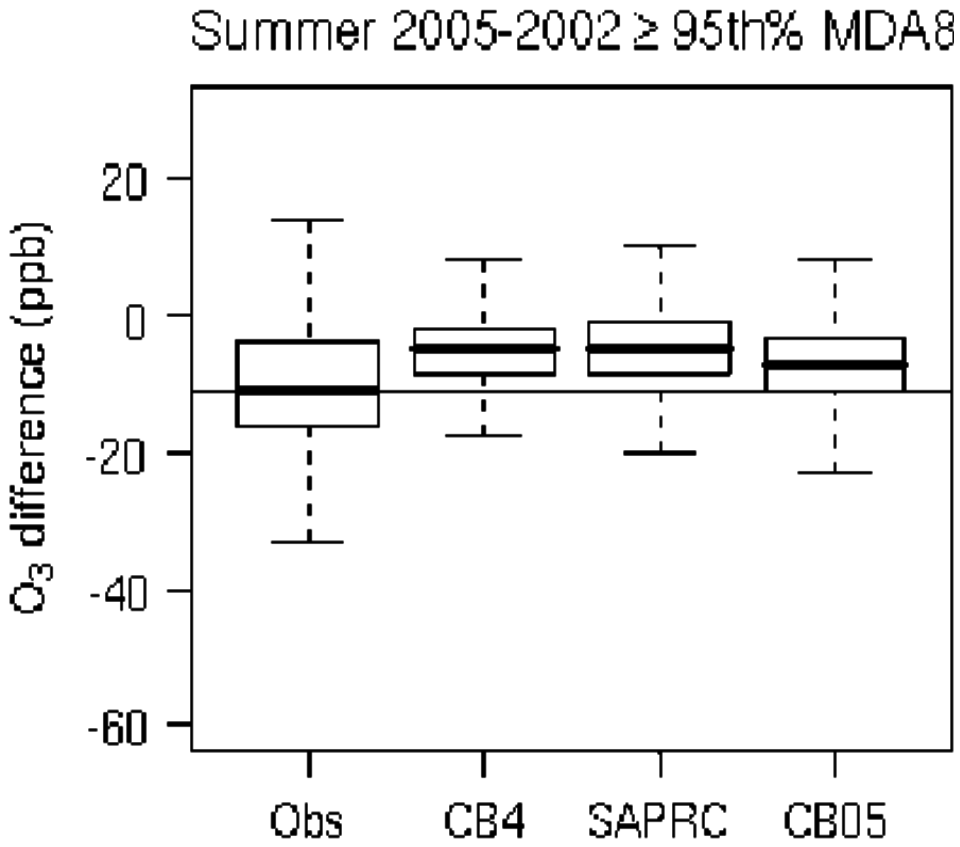
Reductions in NO_x and SO_2 emissions can lead to rapid, dramatic reductions in ozone, aerosols, and fine particle pollution.

*****

Lead to questions about whether the models capture transport & chemistry correctly.

Gilliland (now at EPA) et al., *Atmos. Environ.* (2008)
"The evaluation results presented in this study suggest that the air quality model predictions underestimate the O_3 reductions observed after the NOx SIP Call was implemented. The spatial correlation analysis and comparison with observations aloft suggest that the model underestimates the contribution of long-range transport of O_3 and precursors…."

How do the partnerships with EPA and NASA inform our modeling?



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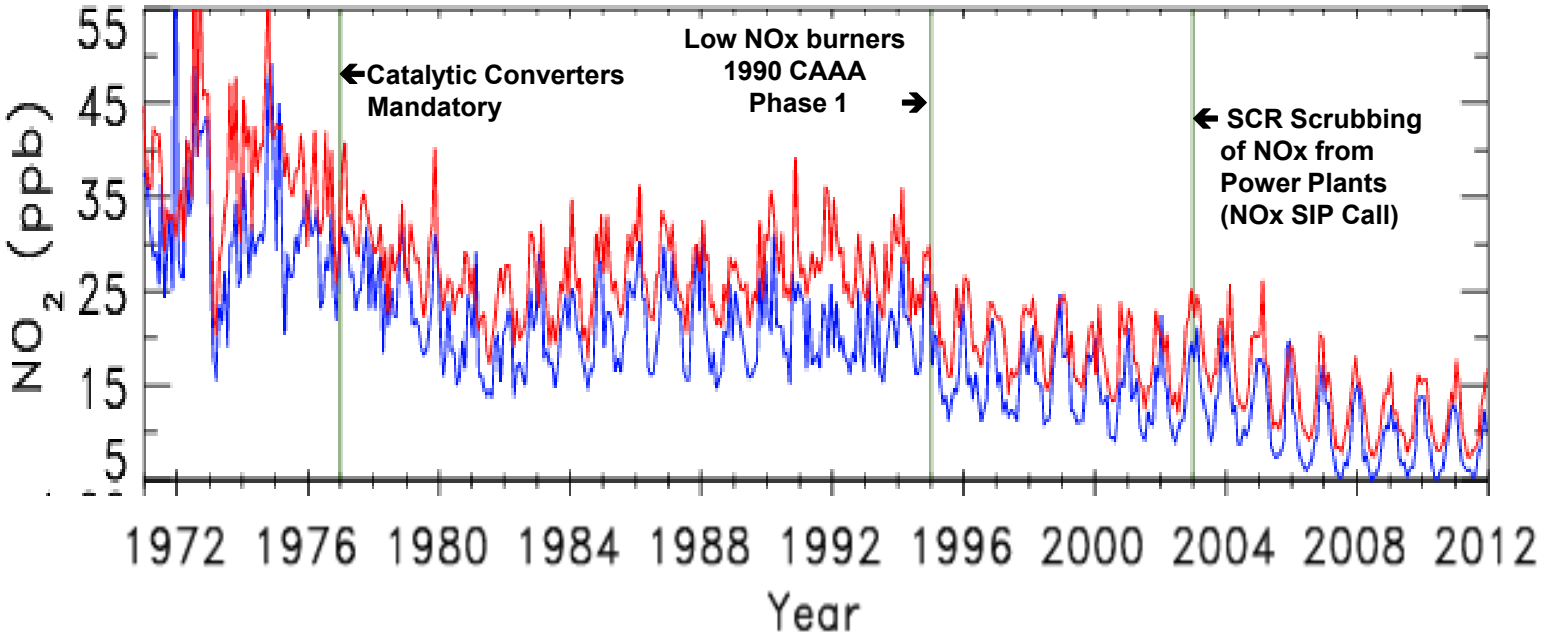
Recent UMD Analysis

Tracking NO_X Reductions and Ozone Improvements

Ambient NO_2 concentration trends: DC, MD and Northern VA



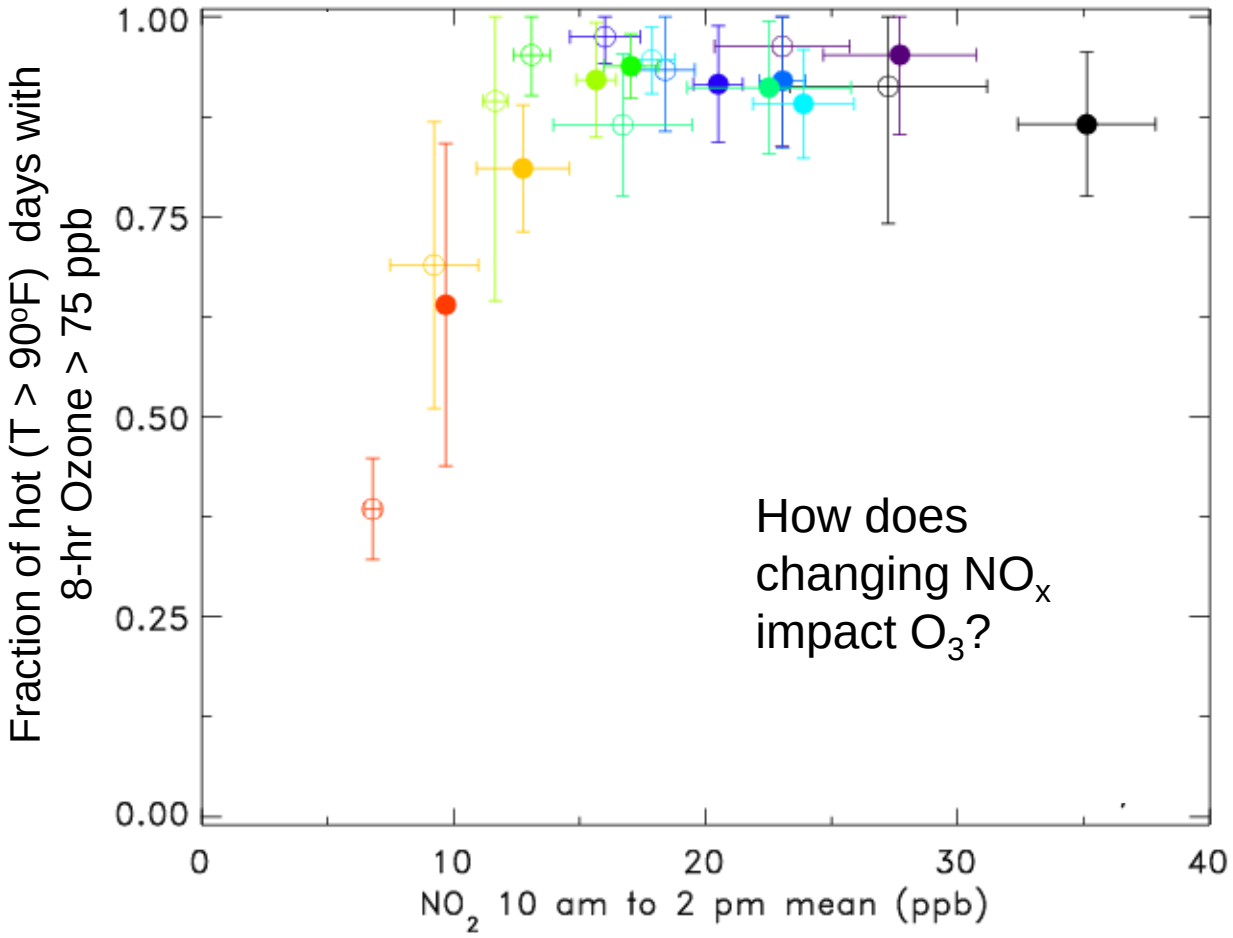
Red - Weekdays

Blue - Weekends

From Hosley, Salawitch, Canty, et al. in preparation, 2012; Preliminary Data. Do not cite!

As measured NO_x levels have gone down …

… *So have ambient ozone levels*



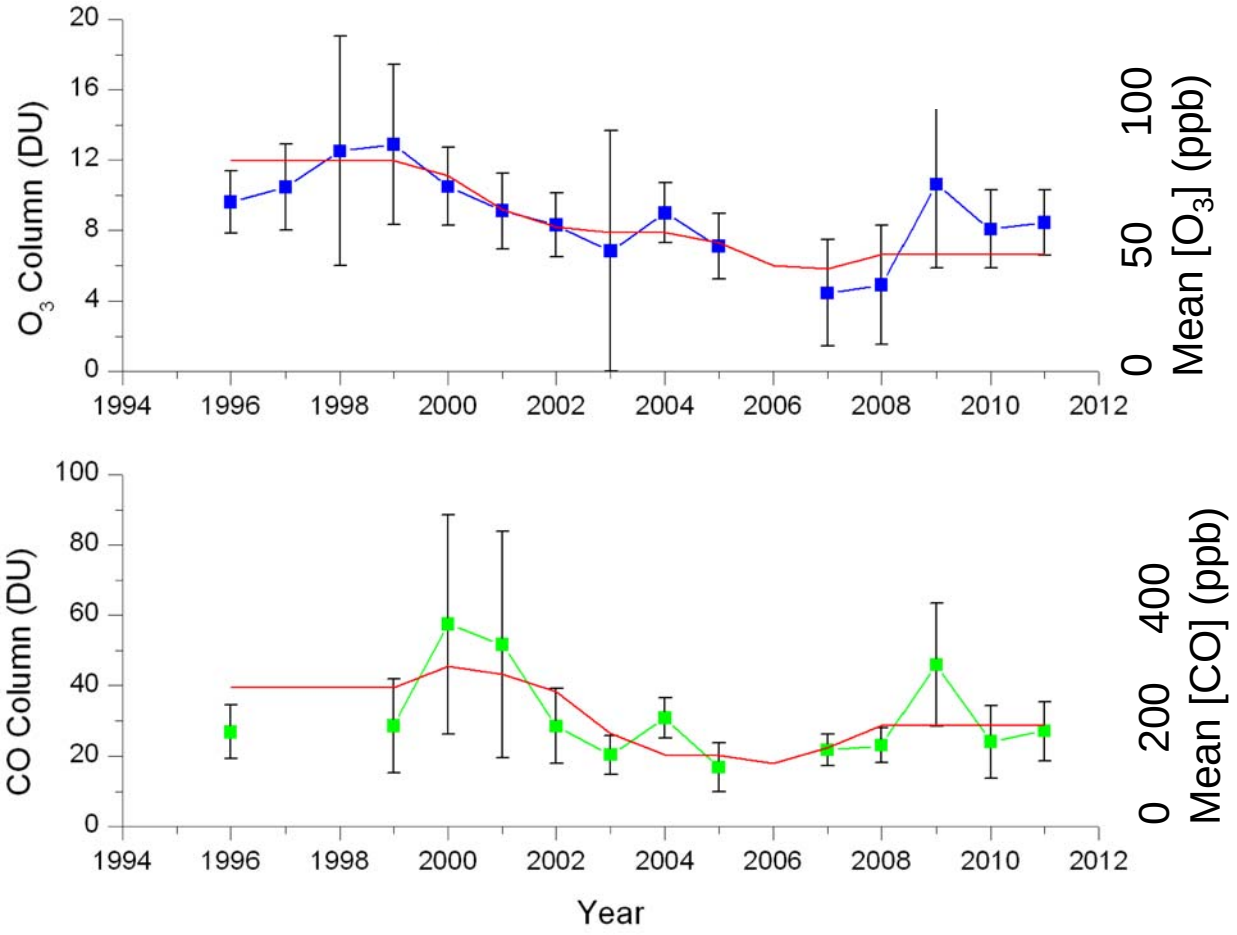
Observations show:
NOx reductions worked, but we had to get over the hump.

From Hosley, Salawitch, Canty, et al. in preparation, 2012; Preliminary Data. Do not cite!

Transported Ozone Aloft Has Also Improved

15 year aircraft record shows that aloft ozone (throughout the lowest 4500' of the atmosphere) has improved.

Carbon monoxide has also cleaned up - NASA satellite confirmation.

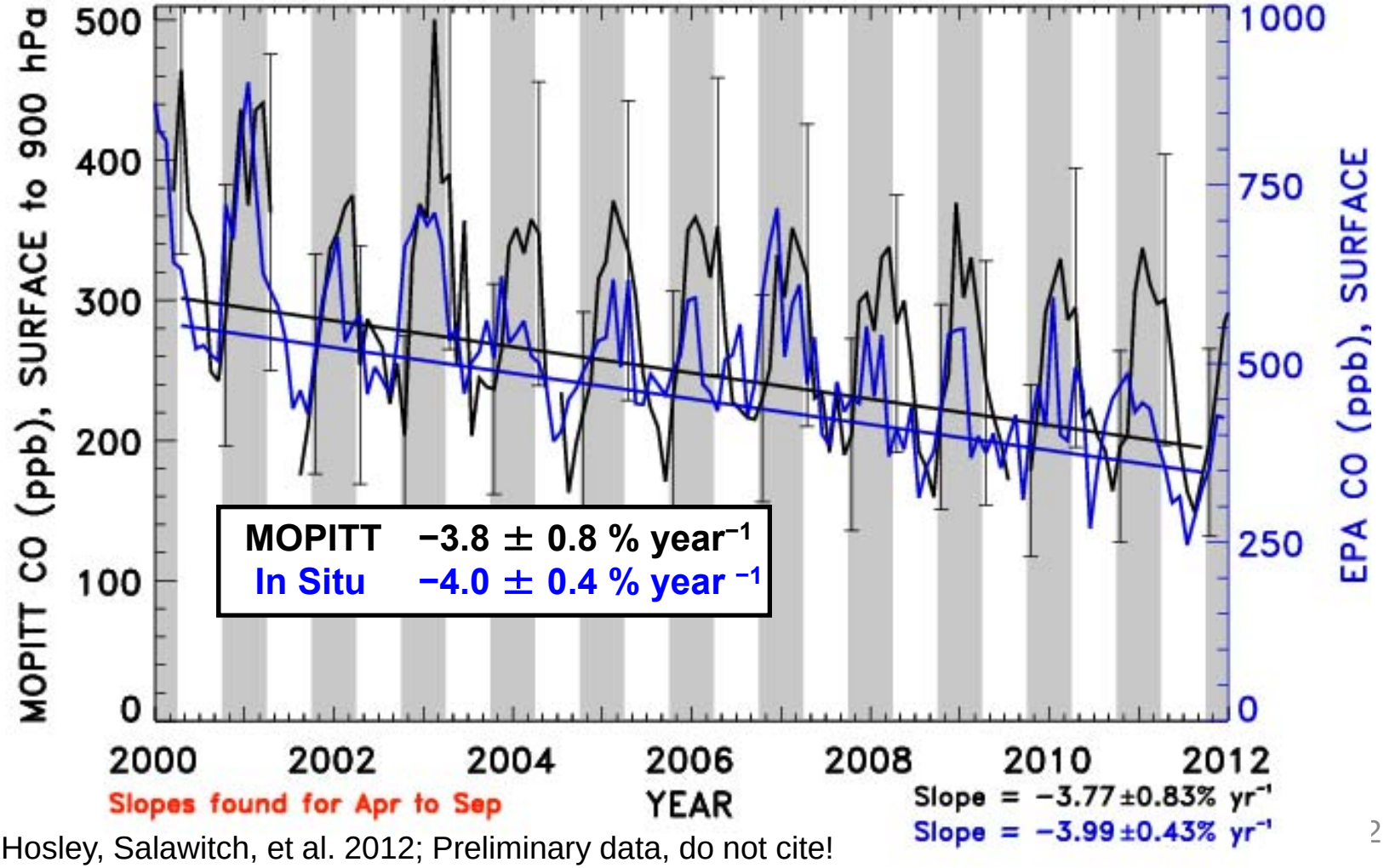


Hao He, Ph.D. Dissertation 2012.

Satellites and Air Quality

An emerging tool

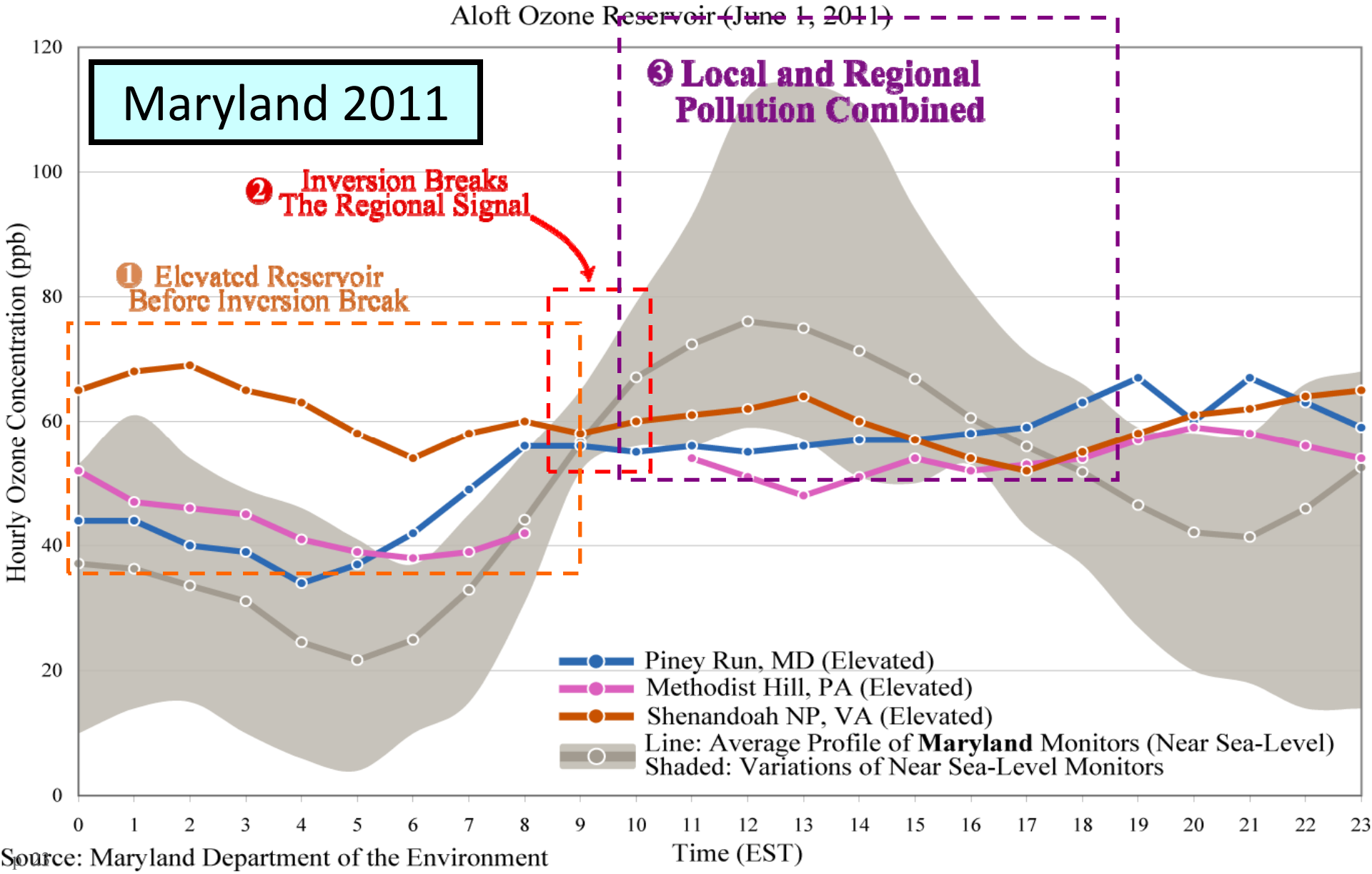
NASA Satellite (MOPITT) CO over Greenbelt, MD
Confirms wide spread improvements in CO



Canty, Hosley, Salawitch, et al. 2012; Preliminary data, do not cite!

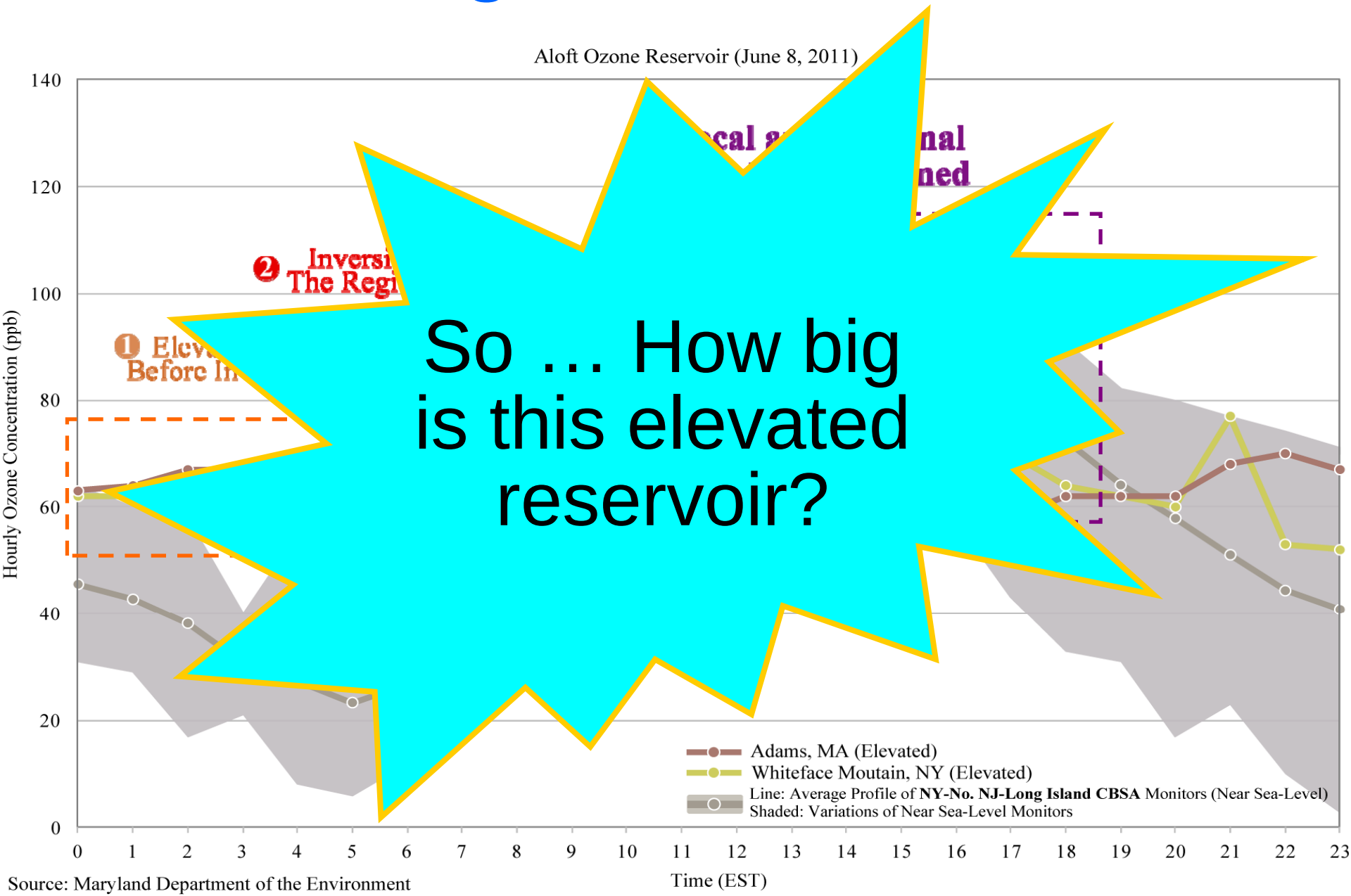
Understanding Transport

The Key Role of the "Elevated Reservoir"



Source: Maryland Department of the Environment

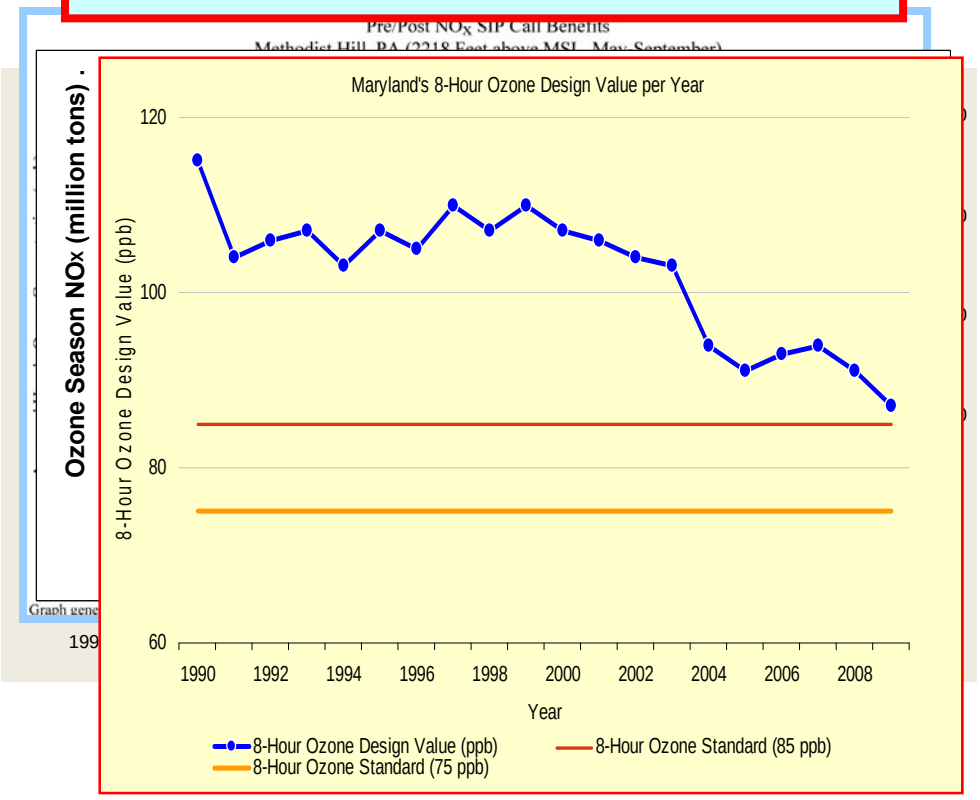
Same Signal – New York 2011



Source: Maryland Department of the Environment

Will Cleaning Up the Reservoir Help?

Ground Level Ozone Drops Dramatically in the Same Time Frame

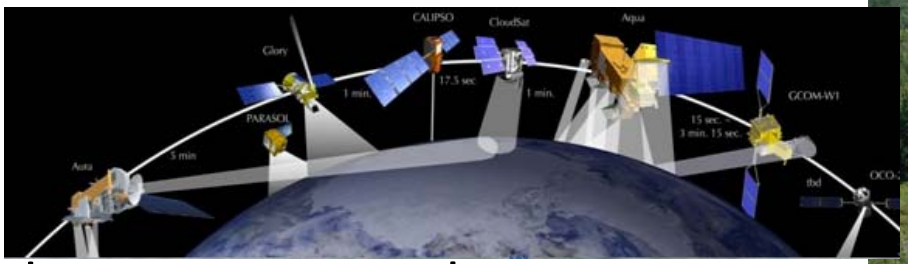


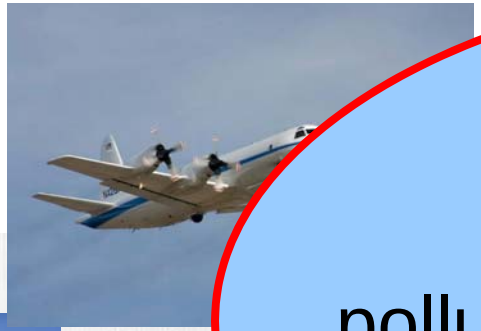
- Real world programs like the NO_X SIP call have shown as ozone in the reservoir drops, ground level ozone also drops
  - Adding regional controls …
  - Results in regional NOx emission reductions …
  - Which lead to reduced ozone in the elevated reservoir …
  - Which lead to lower ozone at ground level and public health protection !!!
- More of the same should work. Right?

DISCOVER-AQ

July 2011

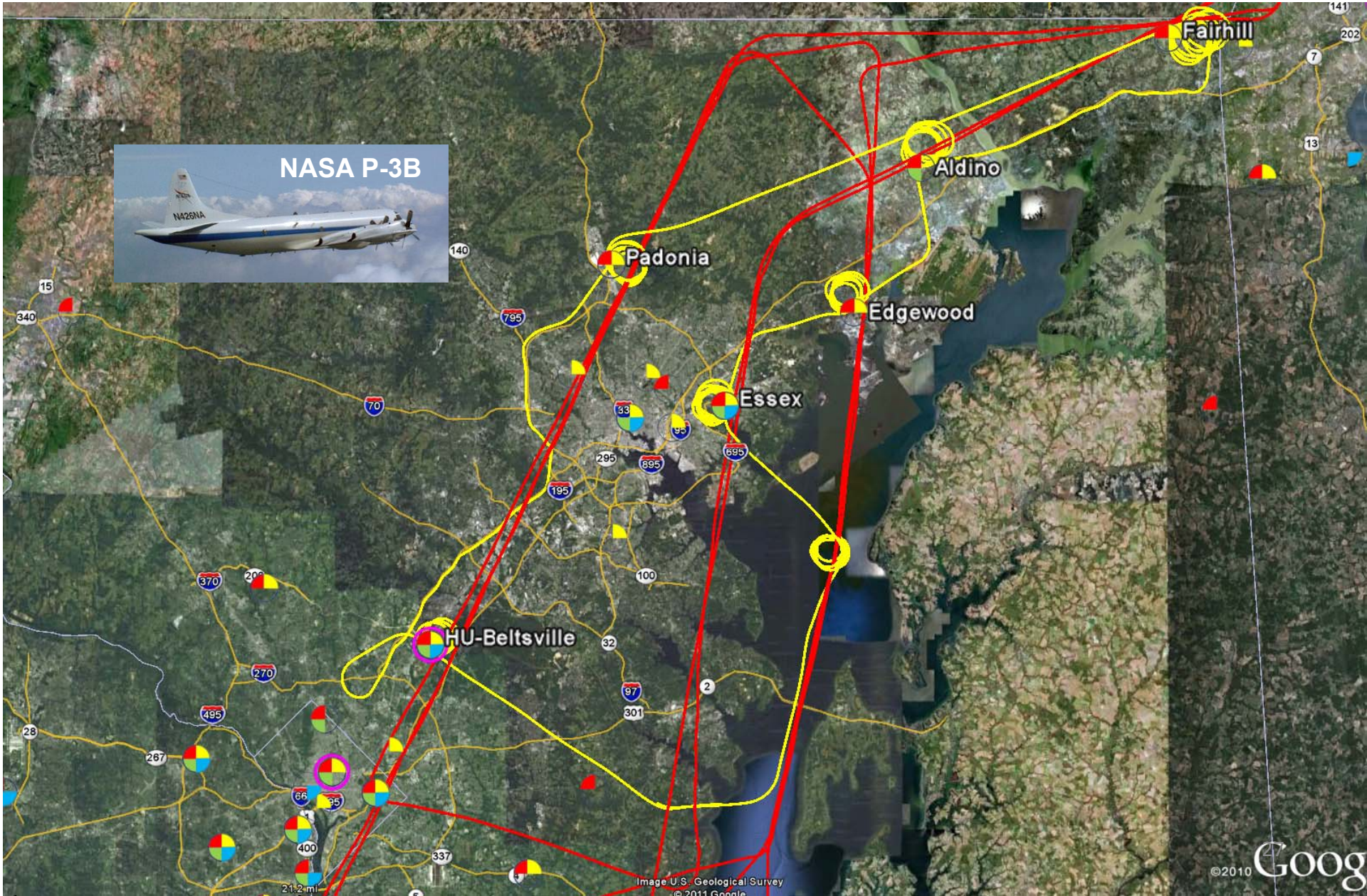
- 3 Aircraft
- 1 Ship
- 2 satellites
- 2 ground-based remote networks
- Many Ground stations
- $ 30M





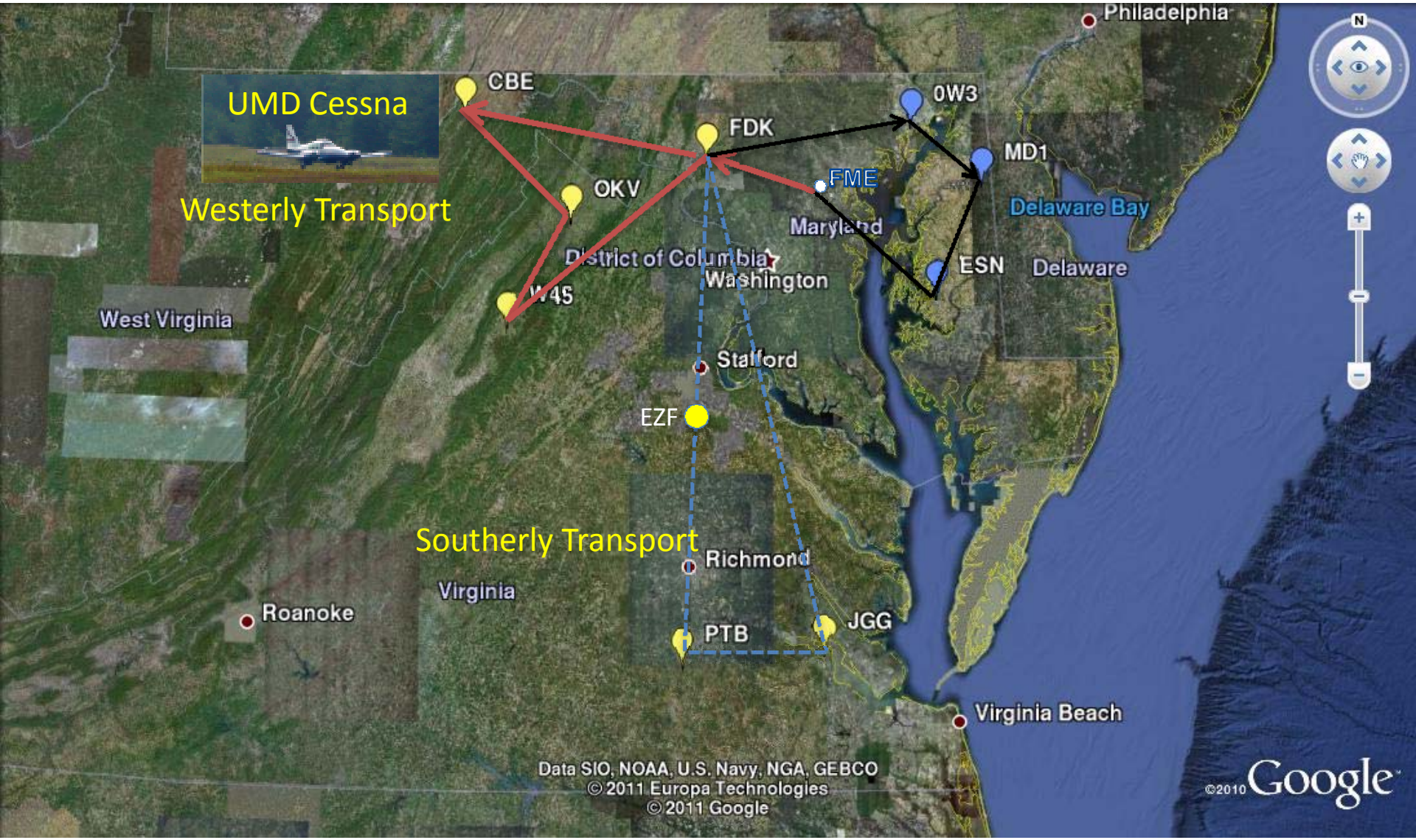
Foremost air pollution field study in the Mid-Atlantic region ever.

NASA Aircraft flew spirals over ground sites all day.



UMD Cessna in RAMMPP during DISCOVER-AQ flew spirals over a larger area.

AM → PM



The Regional Nature of Ozone Formation.

Results from the RAMMPP Aircraft in DISCOVER-AQ show that NOx is already high upwind of Baltimore.

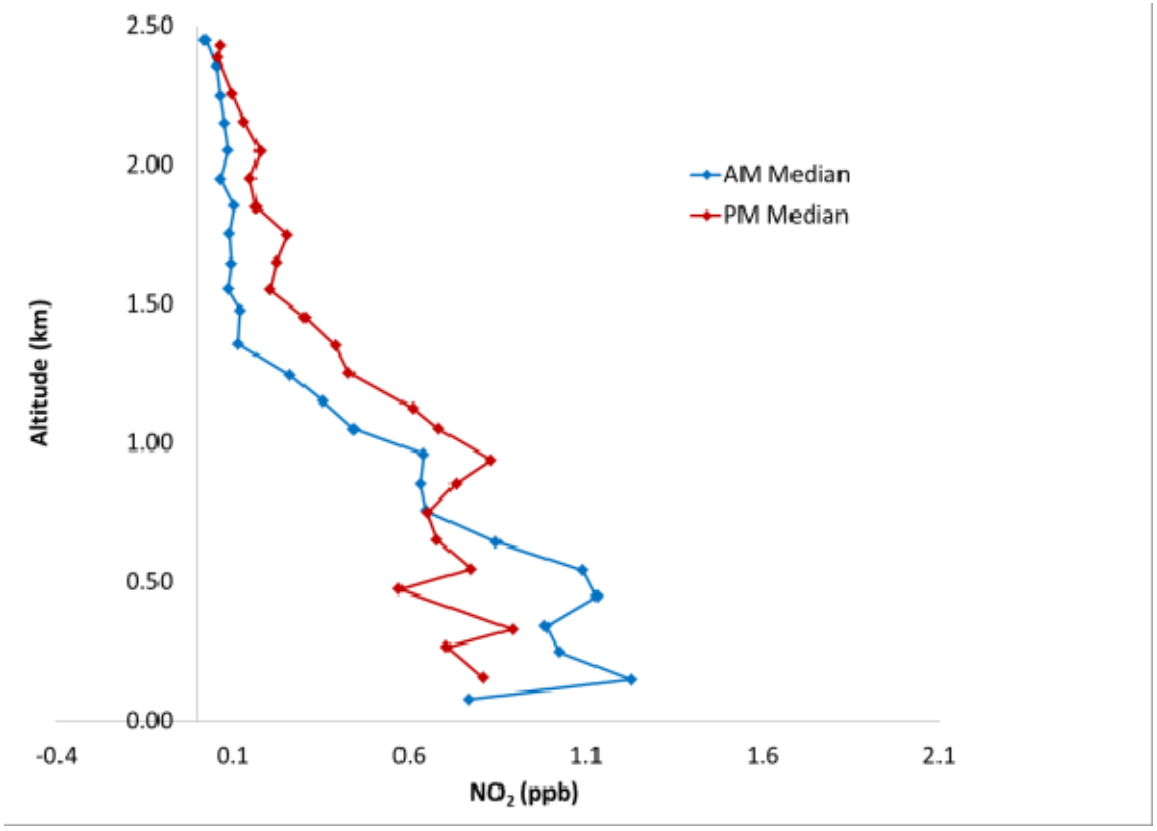
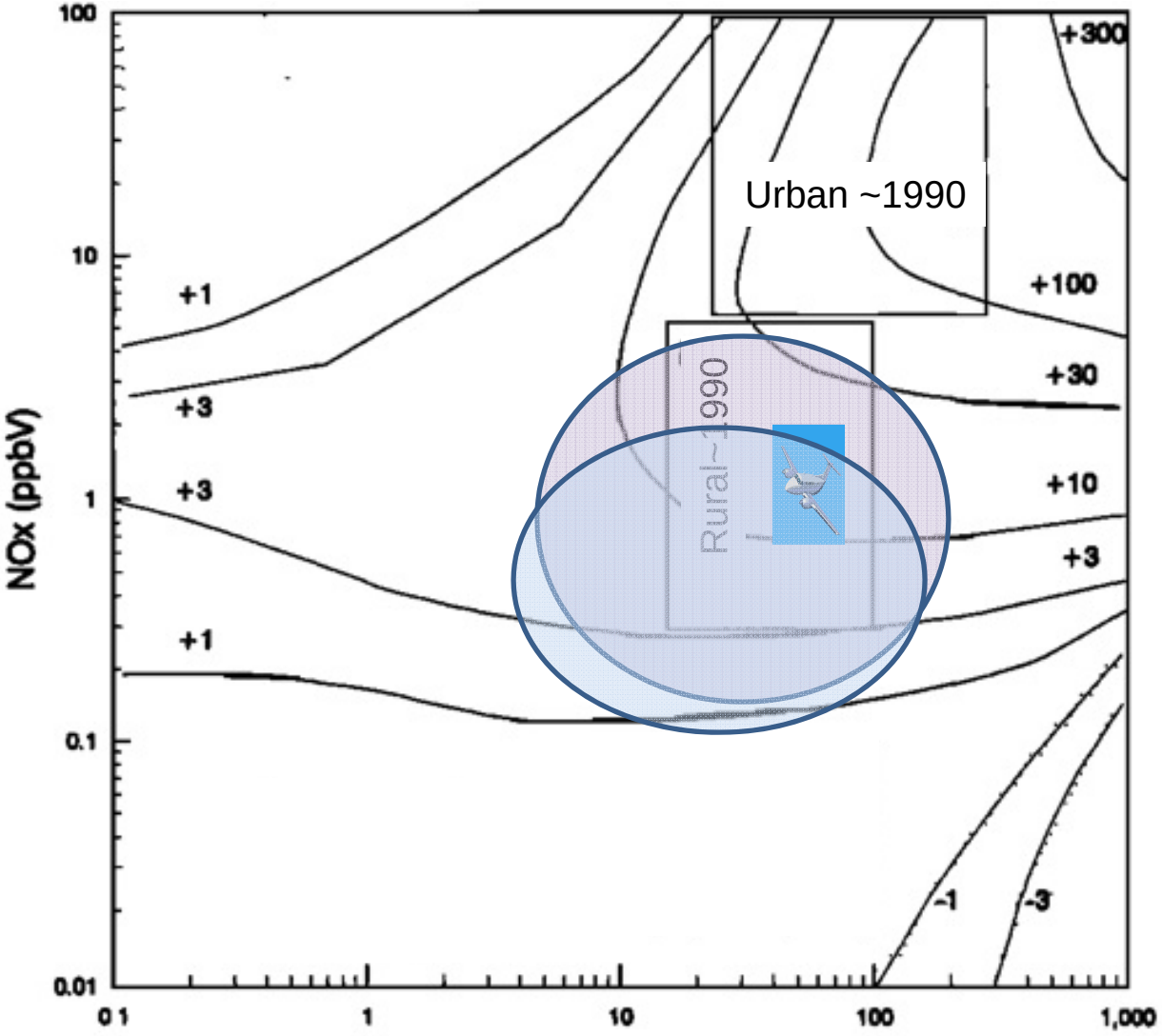


Figure 4.8.3. Morning (upwind of the Baltimore/Washington area) vs. afternoon (downwind) NO_2 profiles from DISCOVER-AQ as measured from the UMD Cessna. Little difference is observed in the observed column content (altitude integral) indicating the regional nature of pollutants [L. Brent et al., manuscript in preparation; 2012].

How fast do precursor pollutants make ozone (ppb/hr)?

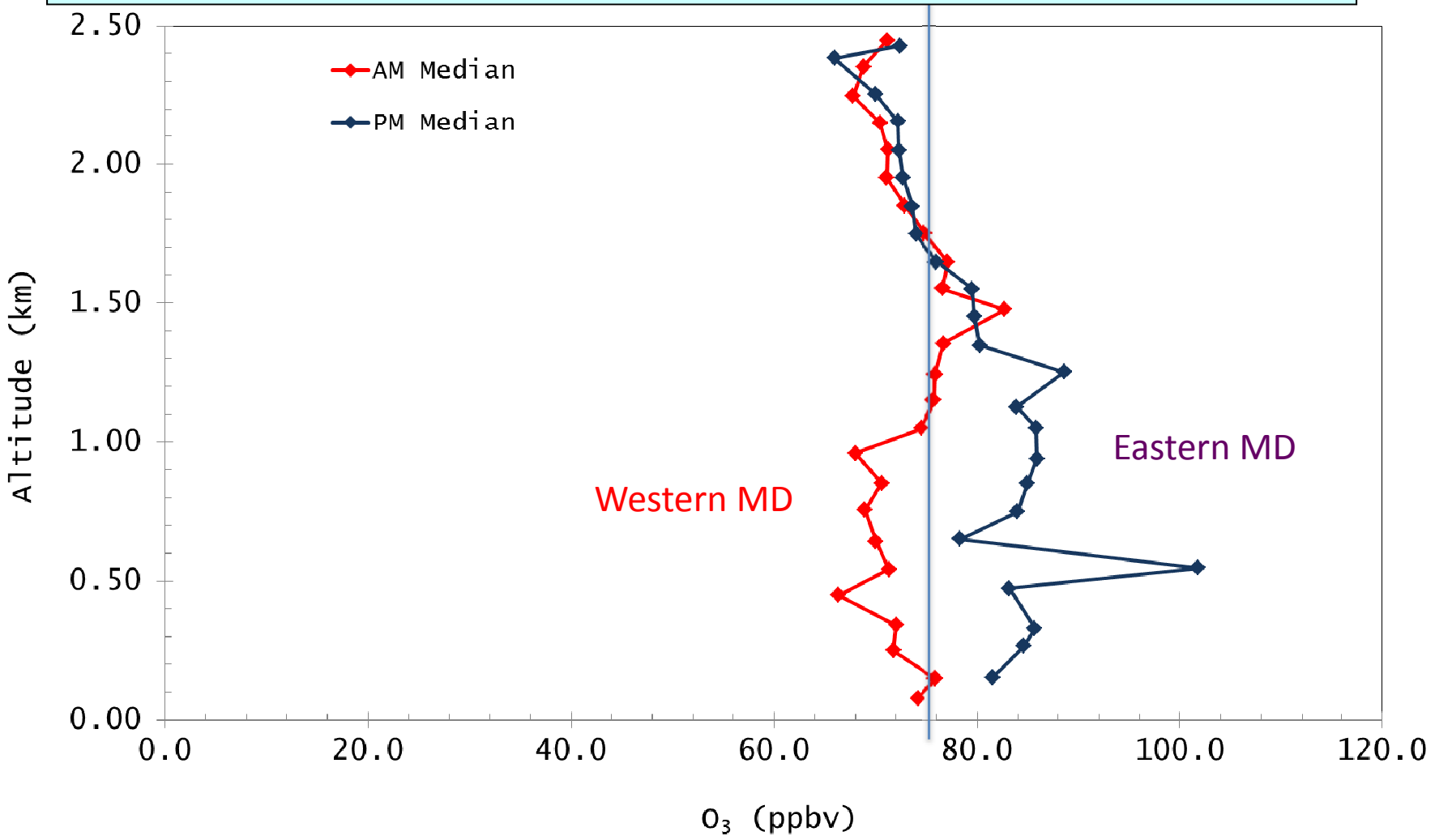


Where is the Balt/Wash area? (boundary layer)

Where is Western MD?

Smog chamber and modeling results on O_3 formation rates.

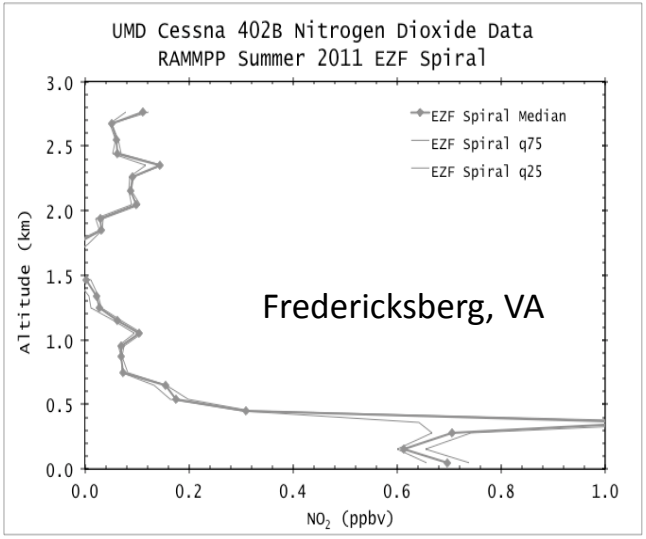
Ozone observed over western Maryland in the morning and over eastern Maryland (downwind of Baltimore and Washington) in the afternoon during DISCOVER-AQ, July 2011

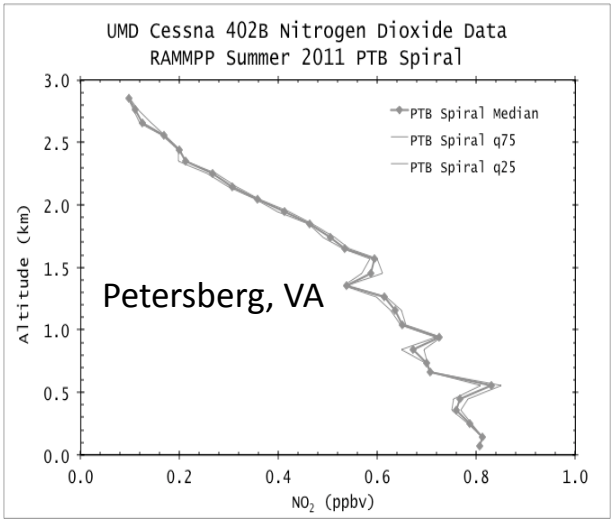


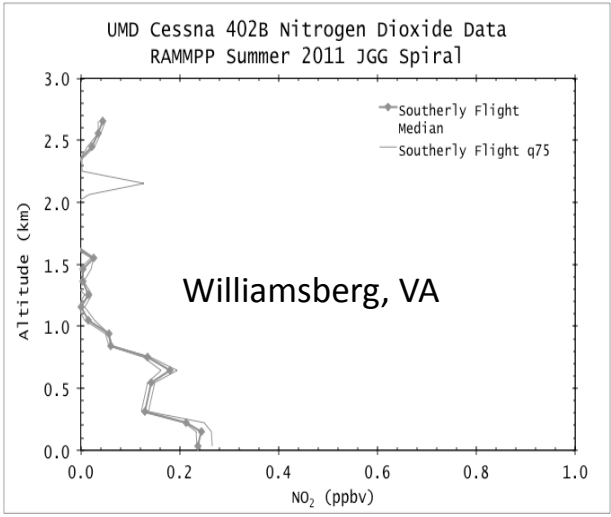
Take Home Message #2

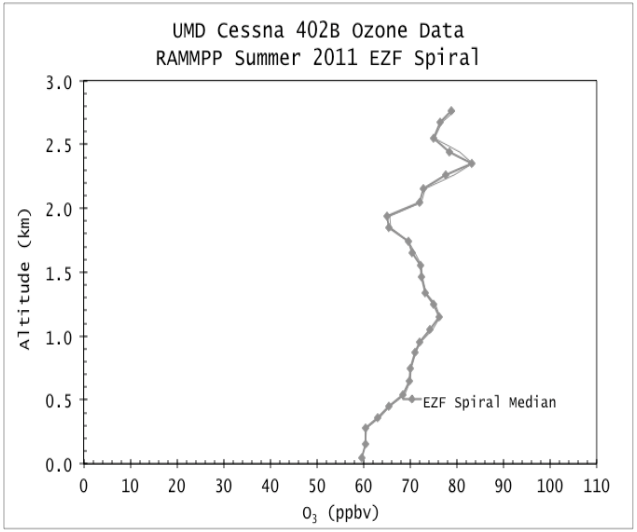
- Westerly transport certainly brings the eastern seaboard ozone and ozone precursors (NOx).
- What about Southerly transport such as in the Nocturnal Low Level Jet?

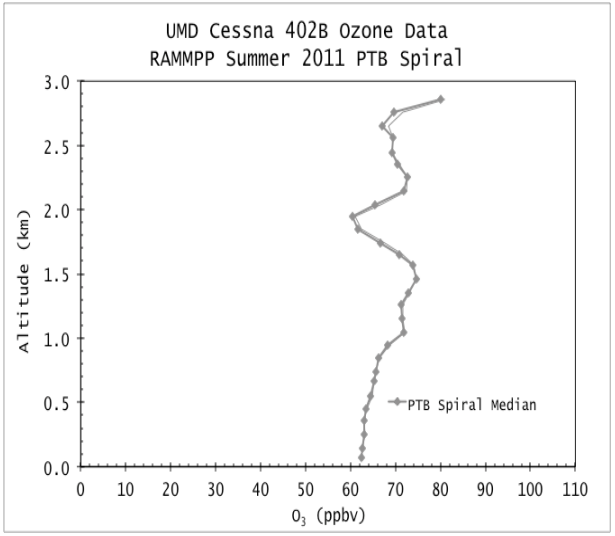
Transport from the south can also bring O_3 and precursors

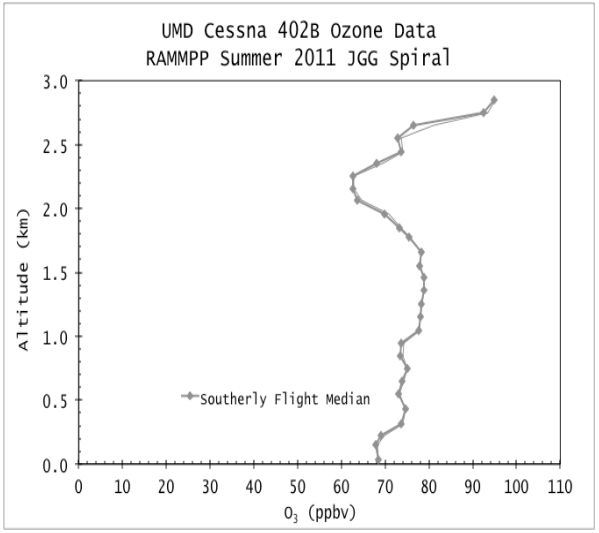




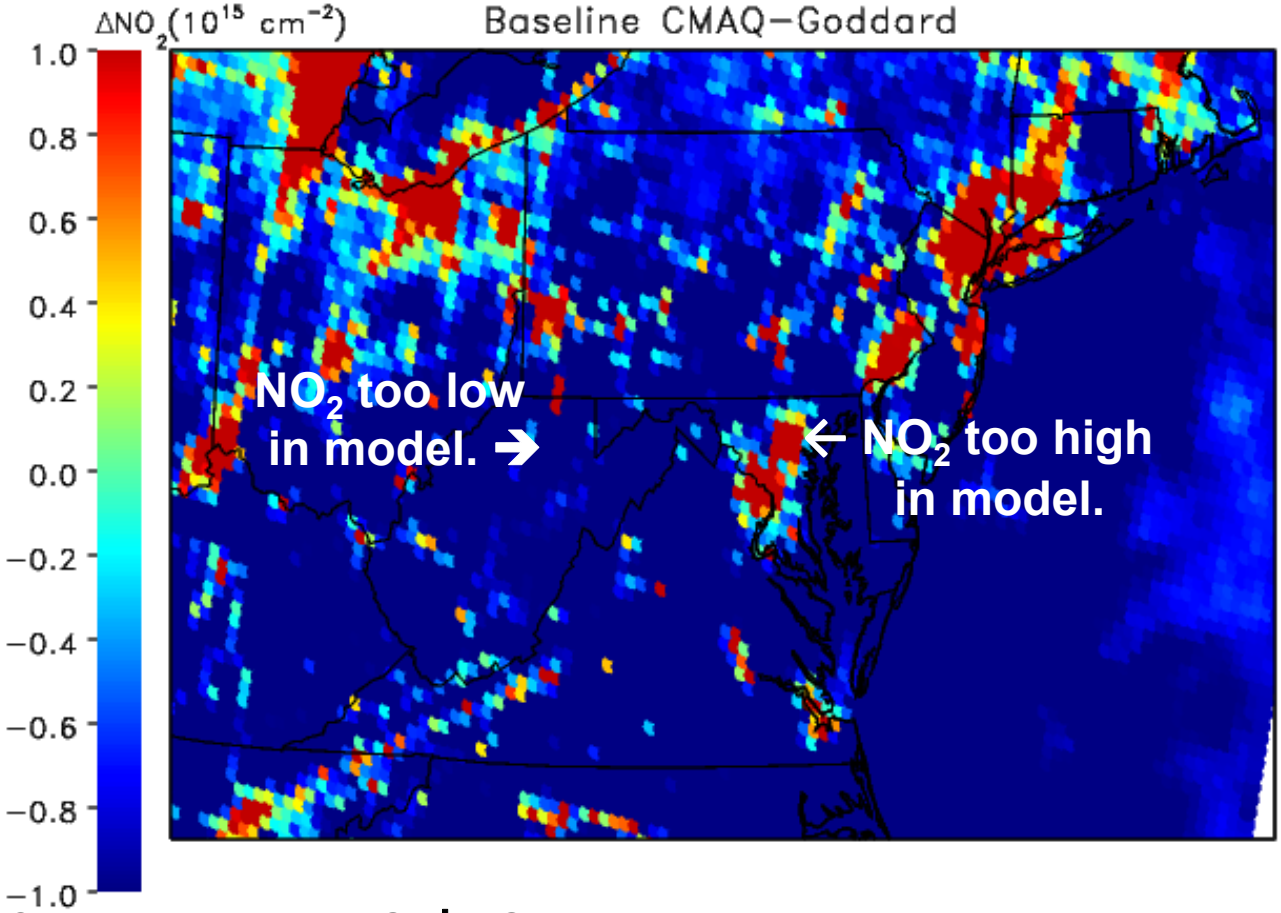








NASA Satellite observations suggest enhancements in CMAQ/CB05 chemistry. The models have improved and we will make them even better.

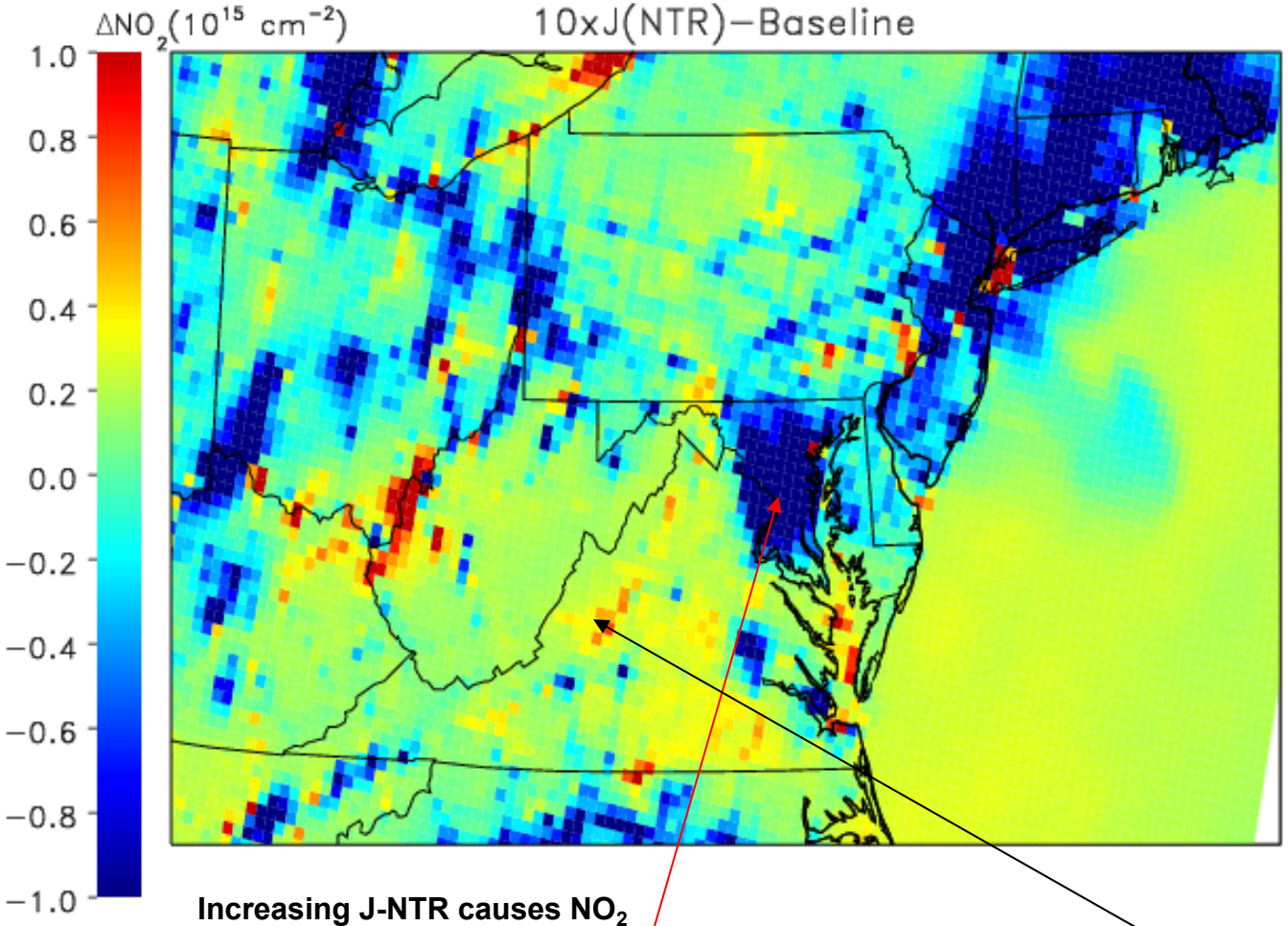


Comparison to NASA's OMI satellite data indicates that the ratio of urban/rural NO_2 is too high in the model simulation.

Thanks to NASA support through the AURA Science Team and AQAST.

From Canty, et al. in preparation, 2012

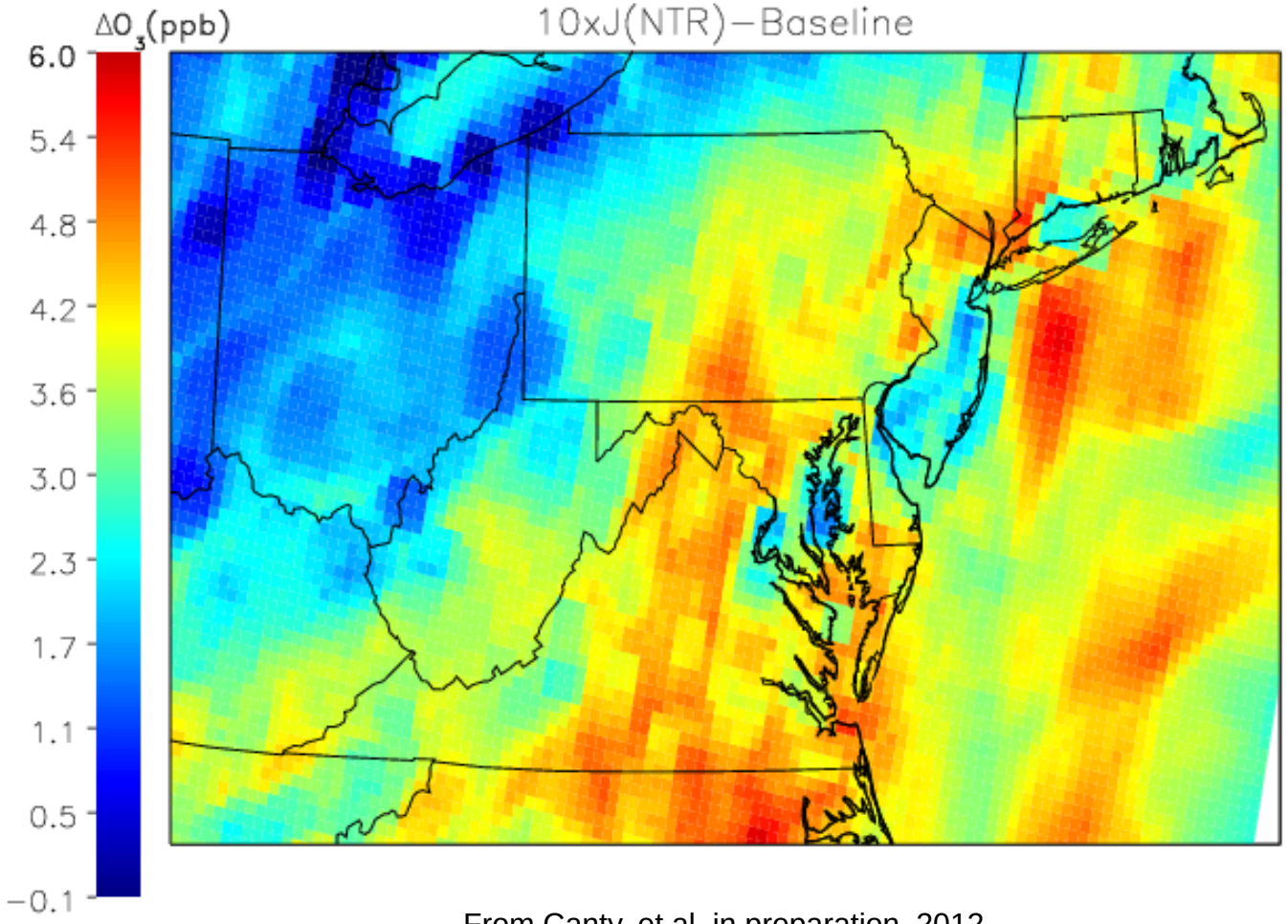
Improving the simulation of chemistry in CMAQ moves more NO_X to rural areas and brings the model closer to NO_2 observations



Increasing J-NTR causes NO_2 to fall where it is too high (urban) & to rise where it is too low (rural)

From Canty, et al. in preparation, 2012

Improving the simulation of chemistry in CMAQ moves more NOx to rural areas **and shows more ozone in rural areas in agreement with observations**.



From Canty, et al. in preparation, 2012

Using Measured Data to Check Emissions Models

- Recent analyses (Fujita et al. 2012) show mobile source emissions might be 25-50% too high in current emissions modeling (MOVES and MOBILE6)
- DISCOVER-AQ data also indicate that emissions inventories (NEI) of NOx and CO are too high. (Preliminary data - details if time allows.)

Before We Go:
Do you like the NOAA AQ Forecast?

A Public Notification Statement requesting comments by November 26, 2012 about proposed termination of ozone predictions and prototype predictions of fine particulate matter has been posted at:
http://www.nws.noaa.gov/om/notification/pns12ozone pm2.5removal.htm

Conclusions: Scientific evidence in support of regional measures to control ozone

- NO_x reductions really work!
- There is substantial ozone and its precursors aloft and upwind both west and south. NASA and UMD observations and put rural areas of the Mid Atlantic States squarely in regime of ozone formation rates of a few ppb/hr.
- NASA satellite measurements confirm the observations and help improve CMAQ/CB05. Emissions seem to be too high.
- Smog & haze are regional problems only amenable to region-wide solutions. As standards for O_3 and PM get tighter, the regional part of the solution becomes even more critical.

References, web sites and acknowledgments

http://www.atmos.umd.edu/~RAMMPP/archives/2011data.html

http://www-air.larc.nasa.gov/missions/discover-aq/discover-aq.html

http://airquality.weather.gov/sectors/conus.php

http://acmg.seas.harvard.edu/aqast/

Comparison of the MOVES2010a, MOBILE6.2, and EMFAC2007 mobile source emission models with on-road traffic tunnel and remote sensing measurements, E.M. Fujita, et al., ***J.*** *Air & Waste Manage. Assoc.*, 2012.

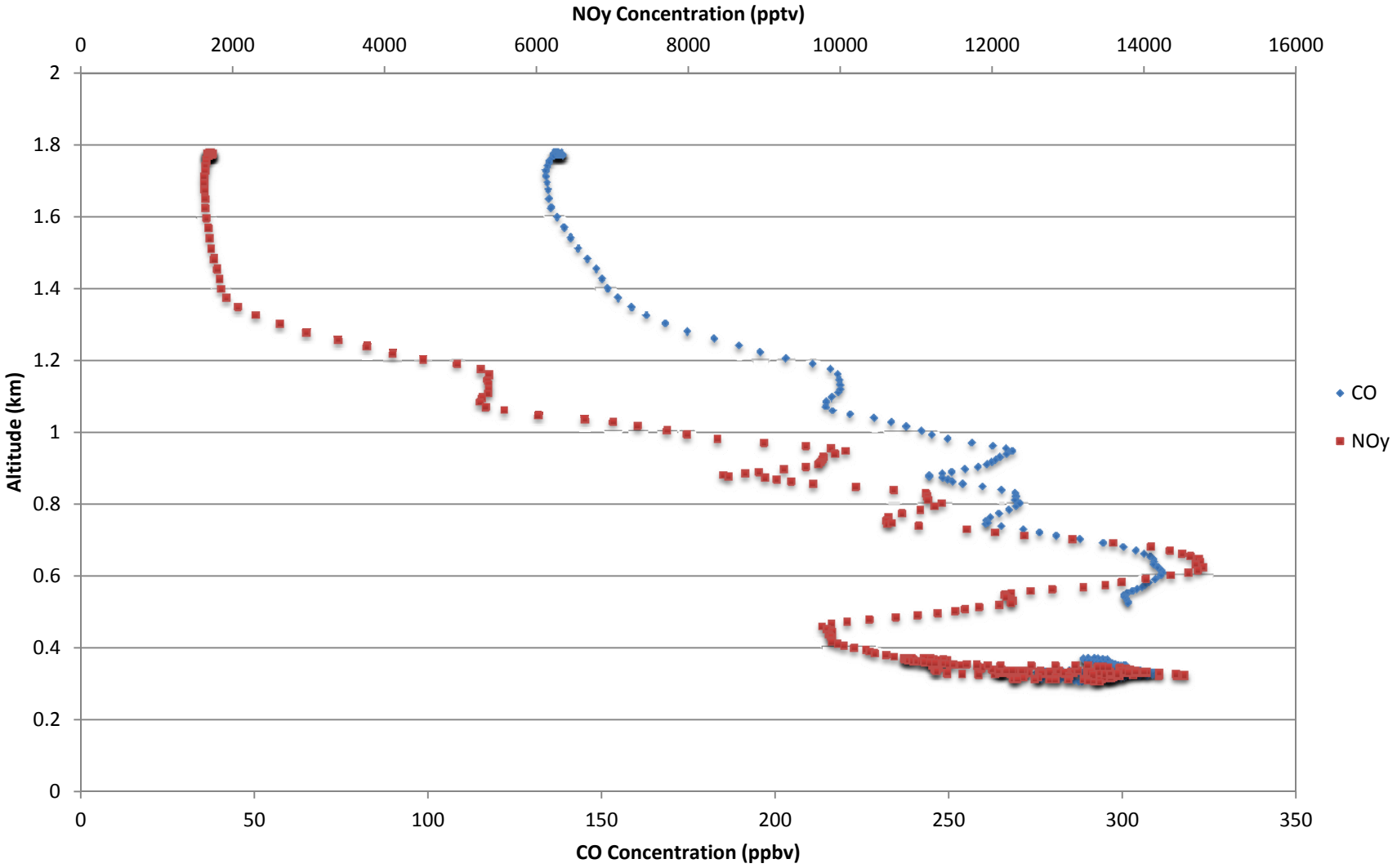
Characterization of eastern U.S. air pollution episode using WRF/Chem, E. A. Yegorova, D. J. Allen, C. P. Loughner, K. E. Pickering, R. R. Dickerson, *J. Geophys. Res.*, 116, D17306, doi:10.1029/2010JD015054 , 2011.

Gilliland, A. B., C. Hogrefe, R. W. Pinder, J. M. Godowitch, K. L. Foley, and S. T. Rao (2008), Dynamic evaluation of regional air quality models: Assessing changes in O_3 stemming from changes in emissions and meteorology, Atmos. Environ. 5110-5123.

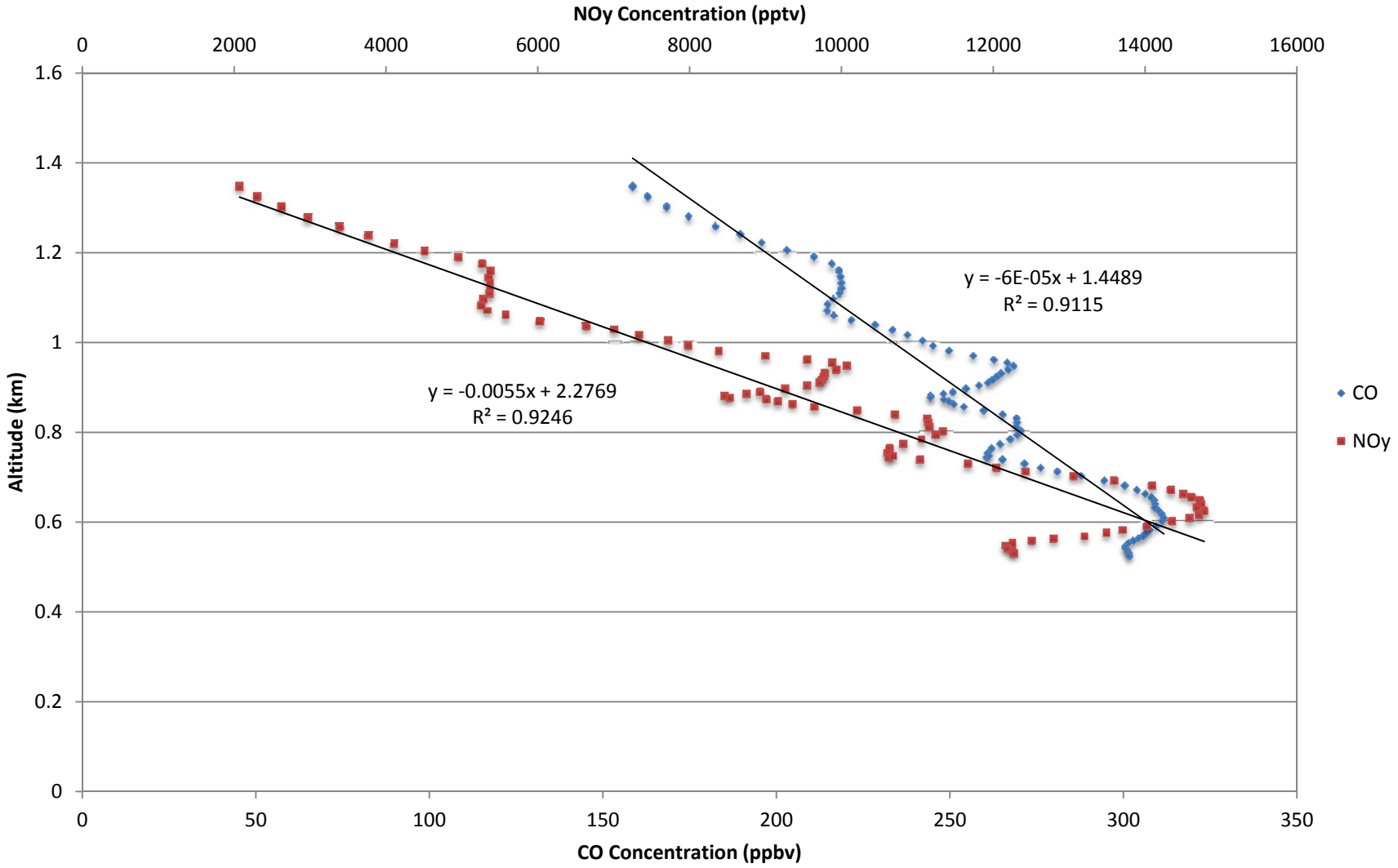
Thanks: D. Allen, D. Anderson, H. Arkinson, T. Canty, D. Goldberg, D. Krask, D. Baker, S. Ehrman, E. Yegorova, L. Hembeck, Hao He, K. Hosley, R. Hudson J. Hains, K. Vinnikov, Lacey Brent, L. Warren , C. Loughner, M. Woodman, K. Pickering, W. Ryan, R. Salawitch, L. Sparling, J. Stehr, J. Szykman, T. Vinciguerra, D. Willan, DL. Zhang.

Extra slides

Beltsville CO and NOy Vertical Profiles (110721, 11:24-11:29 EST)



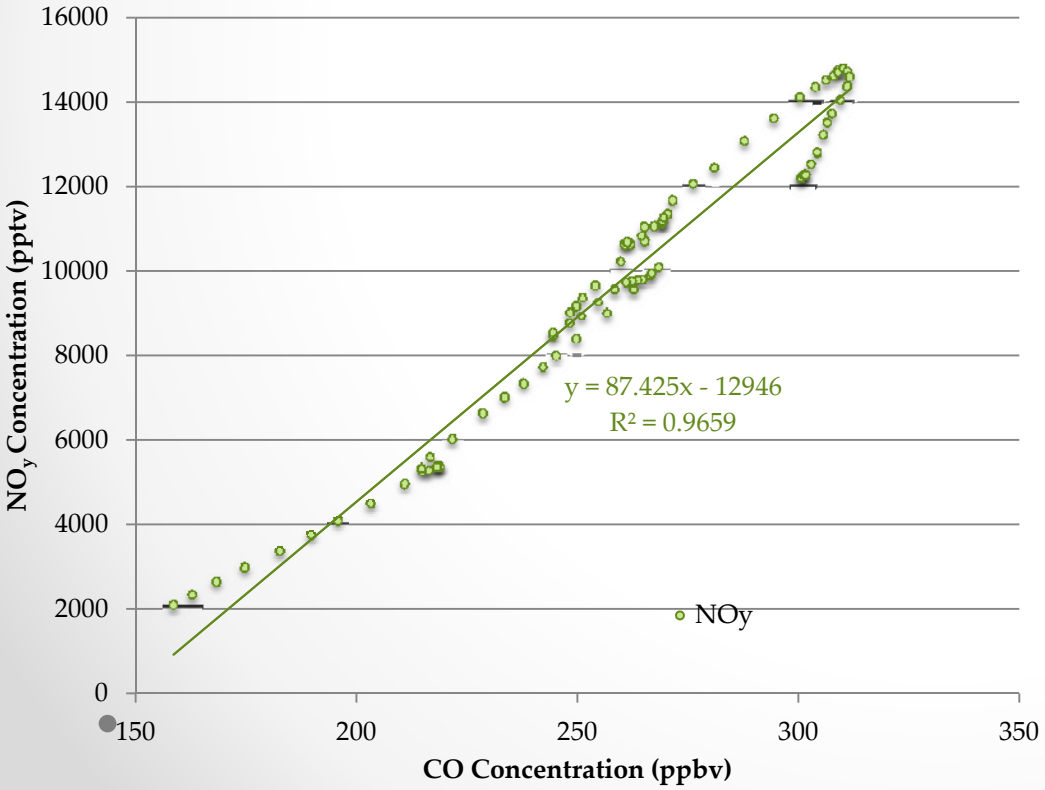
Beltsville CO and NOy Vertical Profiles (110721, 11:24 EST)

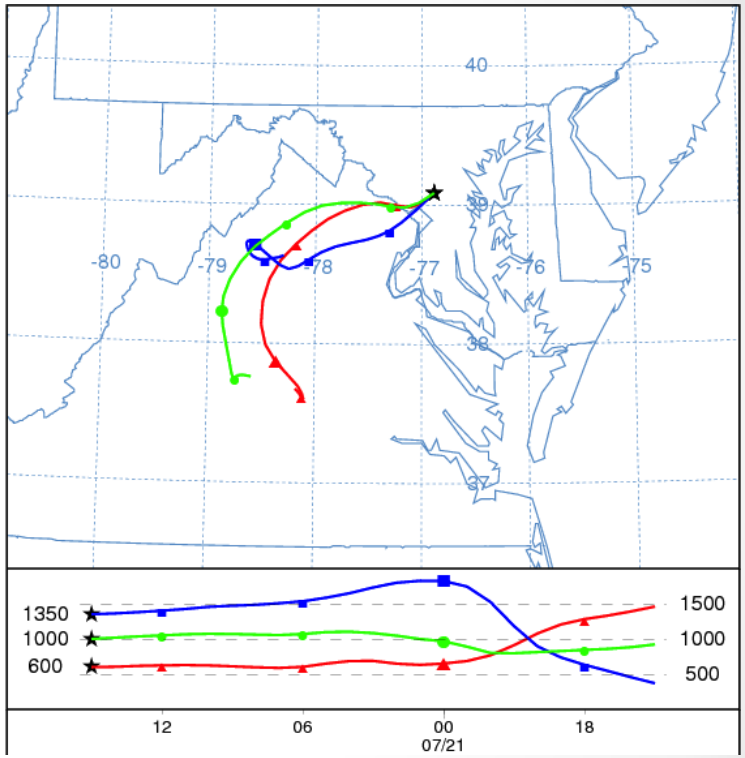


NASA Aircraft profile over Beltsville, 11:27 EST July 21,2011,

Air from DC and Virginia.

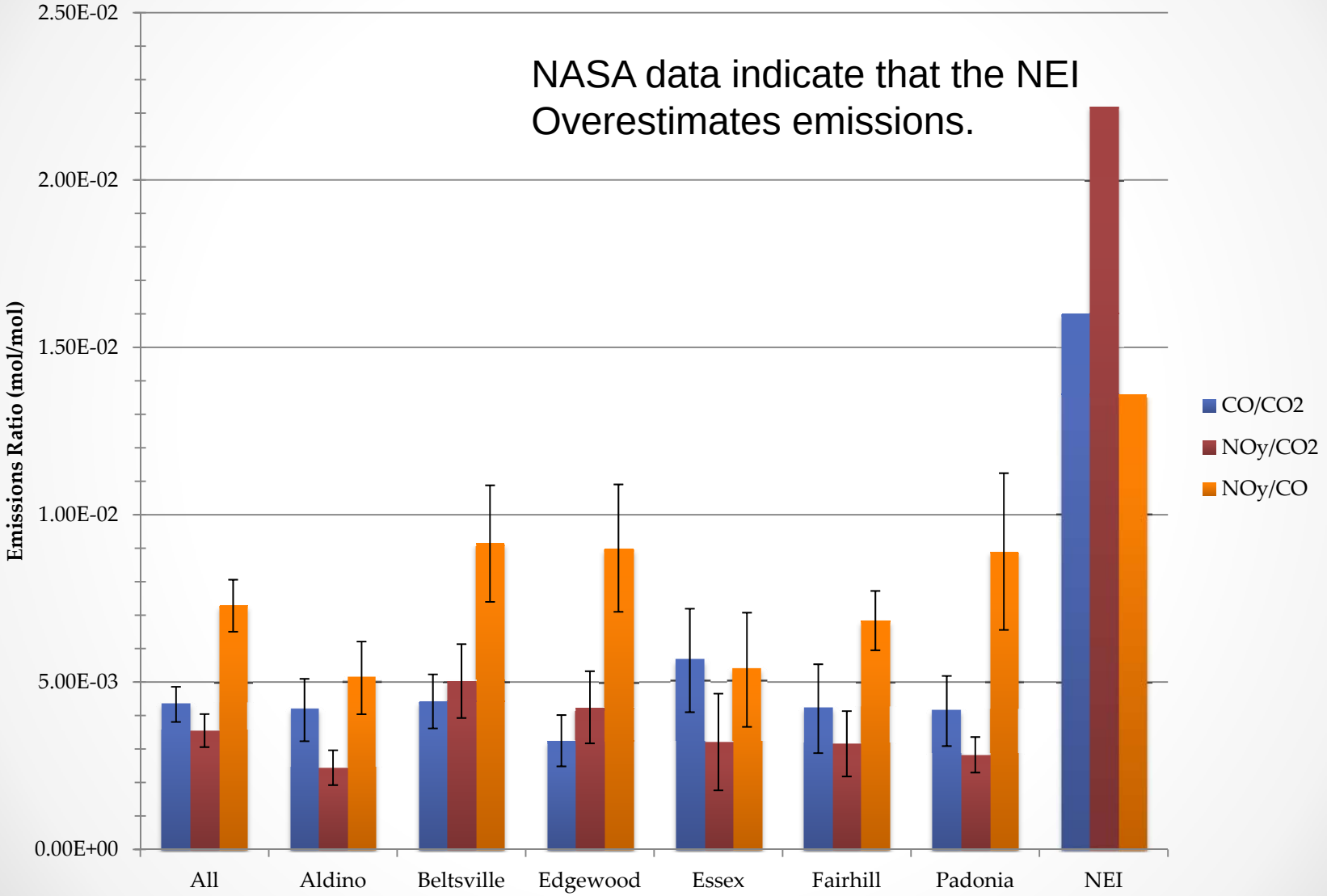
NO_y/CO ratio well below NO_X/CO in inventories.
(NO_y = NOx + PAN + HNO_3 + $RONO_2$ + …)





Preliminary Data. Do not cite!

Emissions Ratios by Location

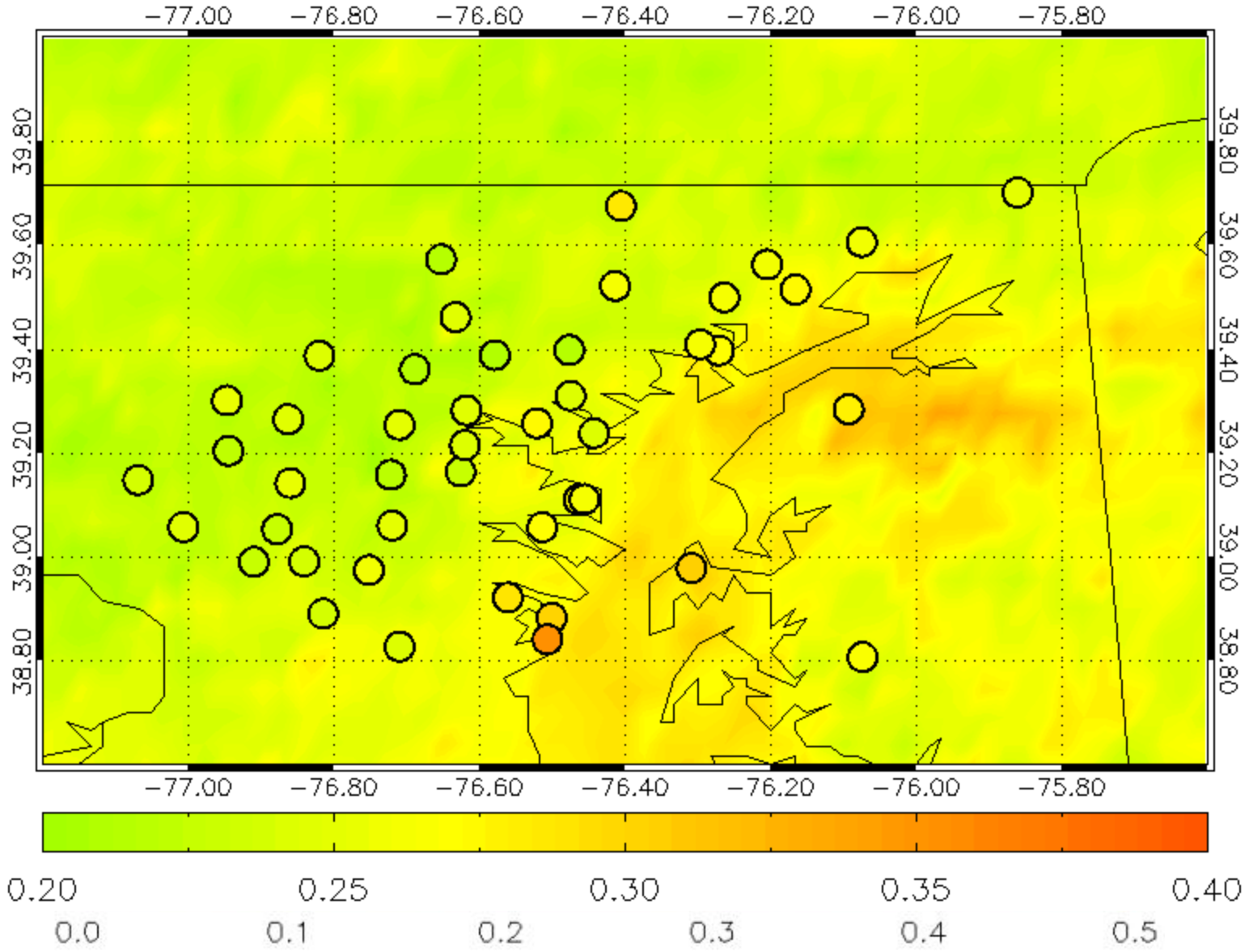


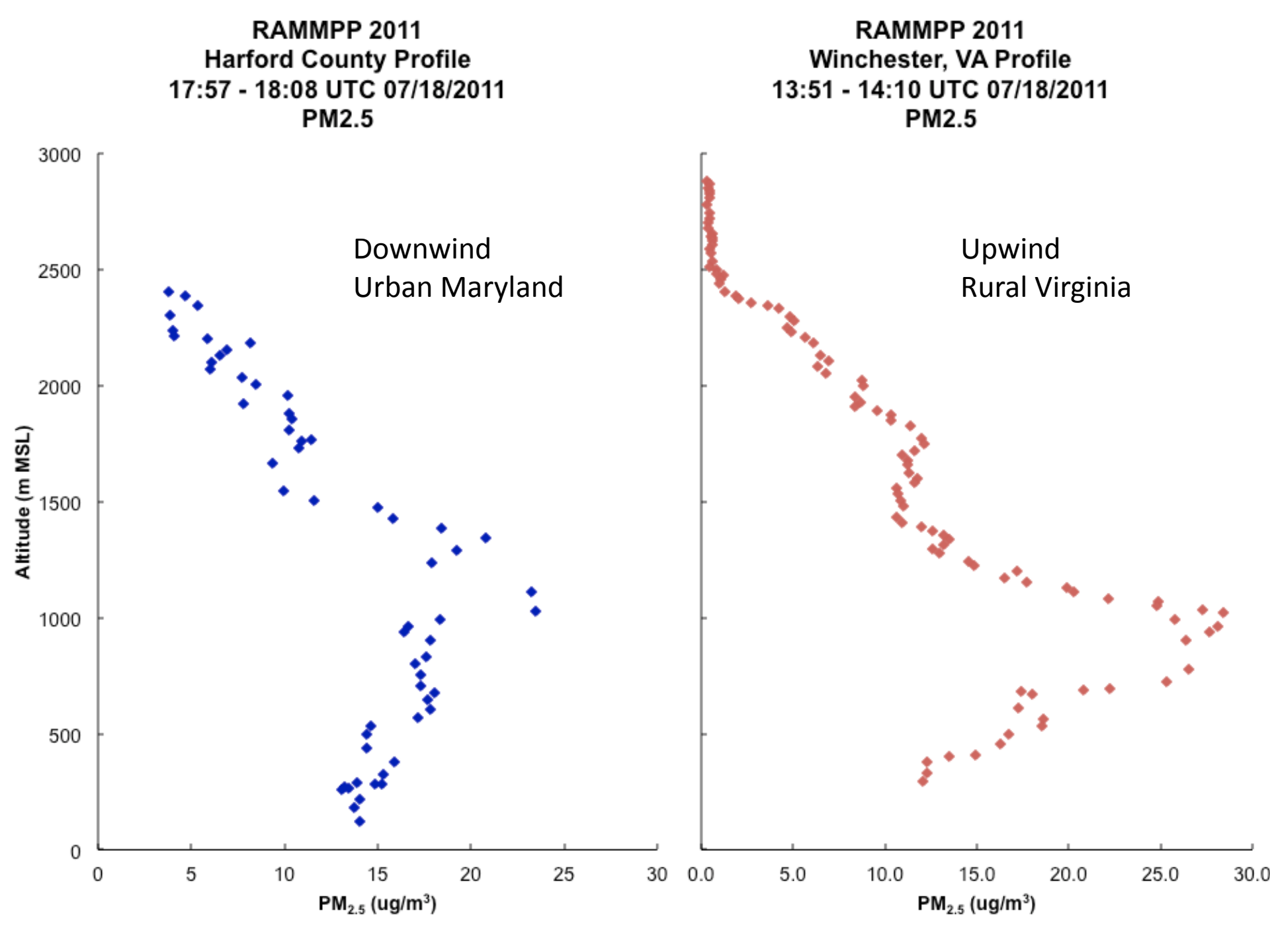
NO_y/CO_2 ratios multiplied by a factor of 10. NO_y/CO ratios divided by a factor of 10.

Preliminary Data. Do not cite.

Satellite and surface-based sun photometers measure haze

GOES and DRAGON Station AOD Data (June-July 2011)




RAMMPP 2011
Harford County Profile
17:57 - 18:08 UTC 07/18/2011
PM2.5
Downwind
Urban Maryland
Altitude (m MSL)
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
PM2.5 (ug/m3)
RAMMPP 2011
Winchester, VA Profile
13:51 - 14:10 UTC 07/18/2011
PM2.5
Upwind
Rural Virginia
0.0
5.0
10.0
15.0
20.0
25.0
30.0
PM2.5 (ug/m3)