June 11, 2015 Maryland Smoke & 8-Hour Ozone Exceedance Event

Joel Dreessen
Meteorologist, Maryland Department of the Environment

9/3/2015

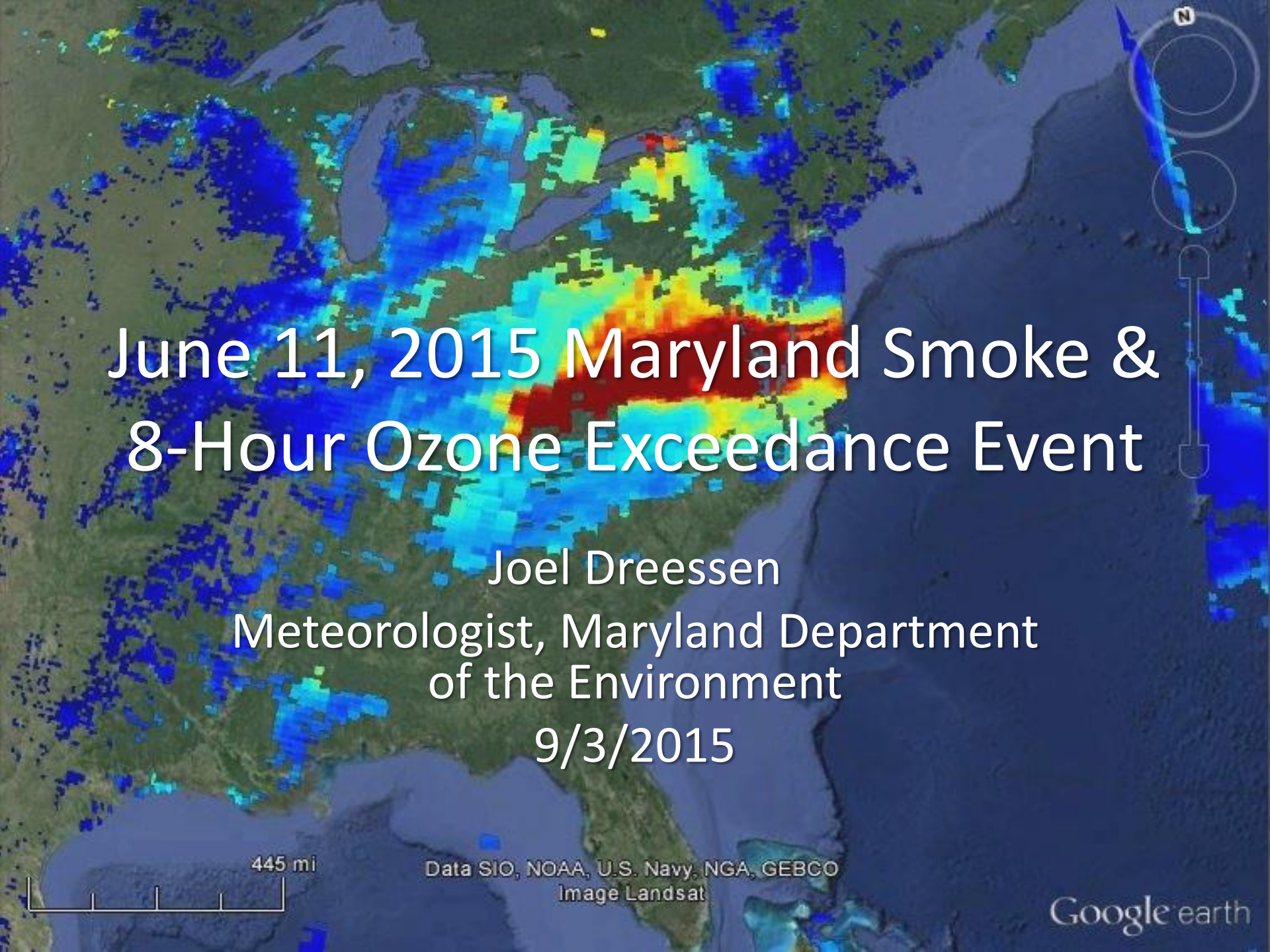
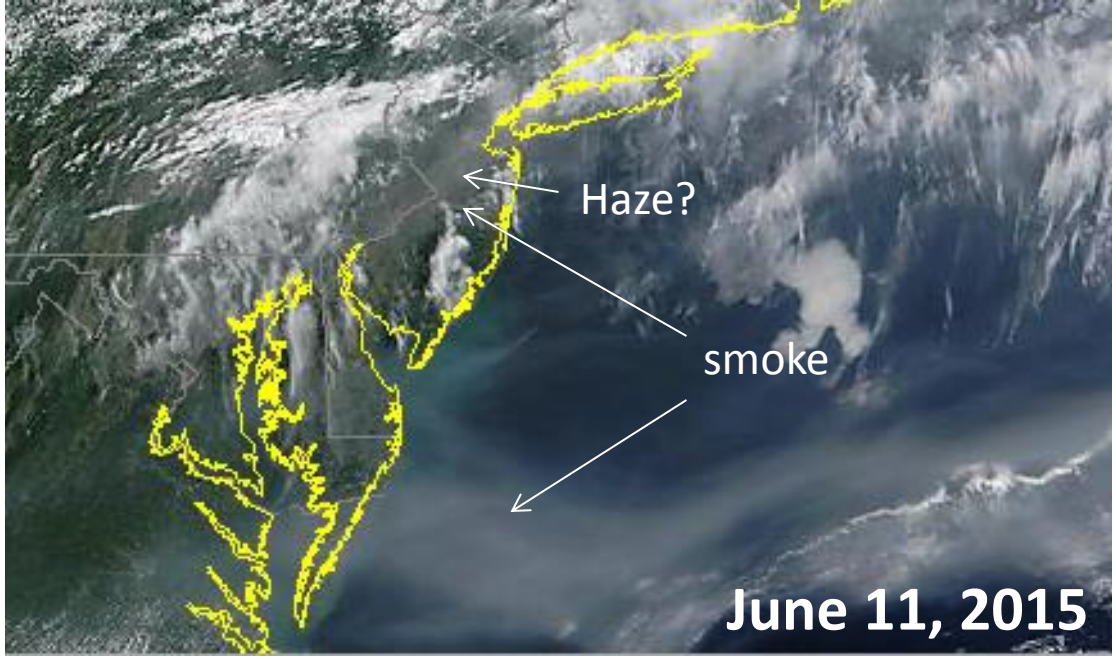
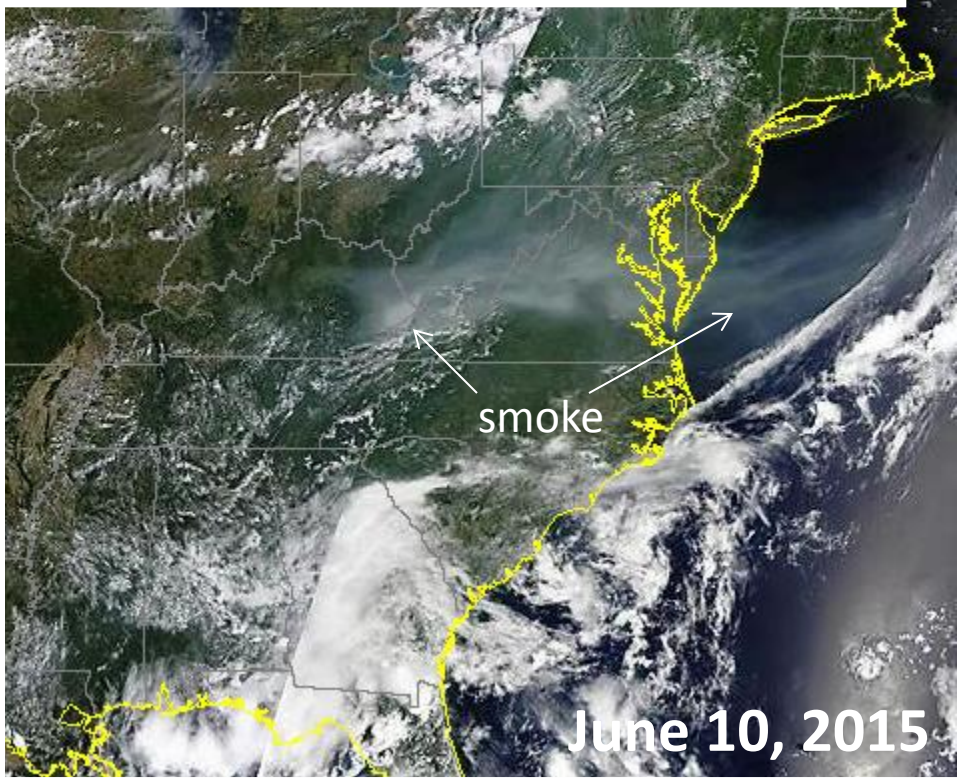
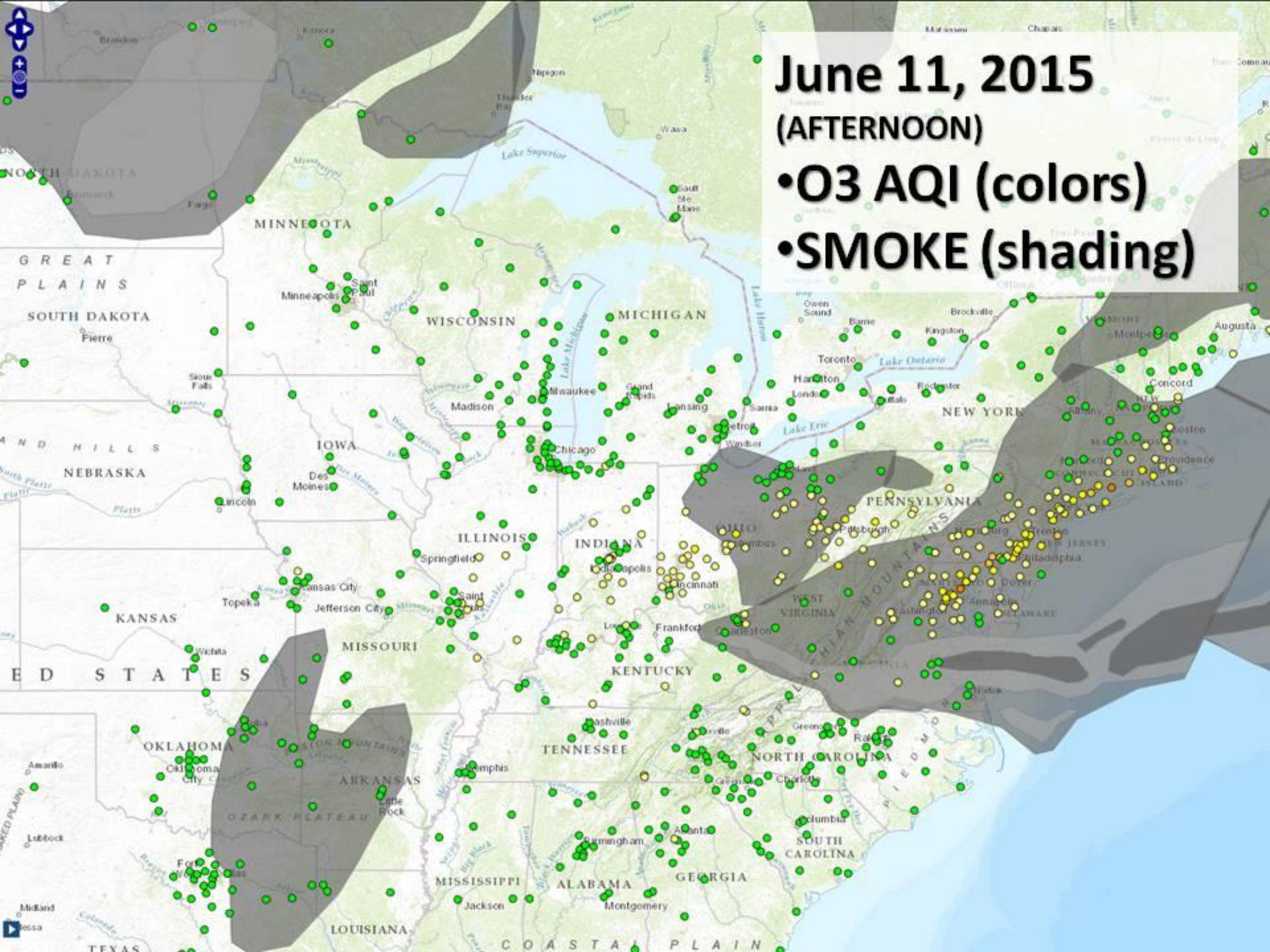
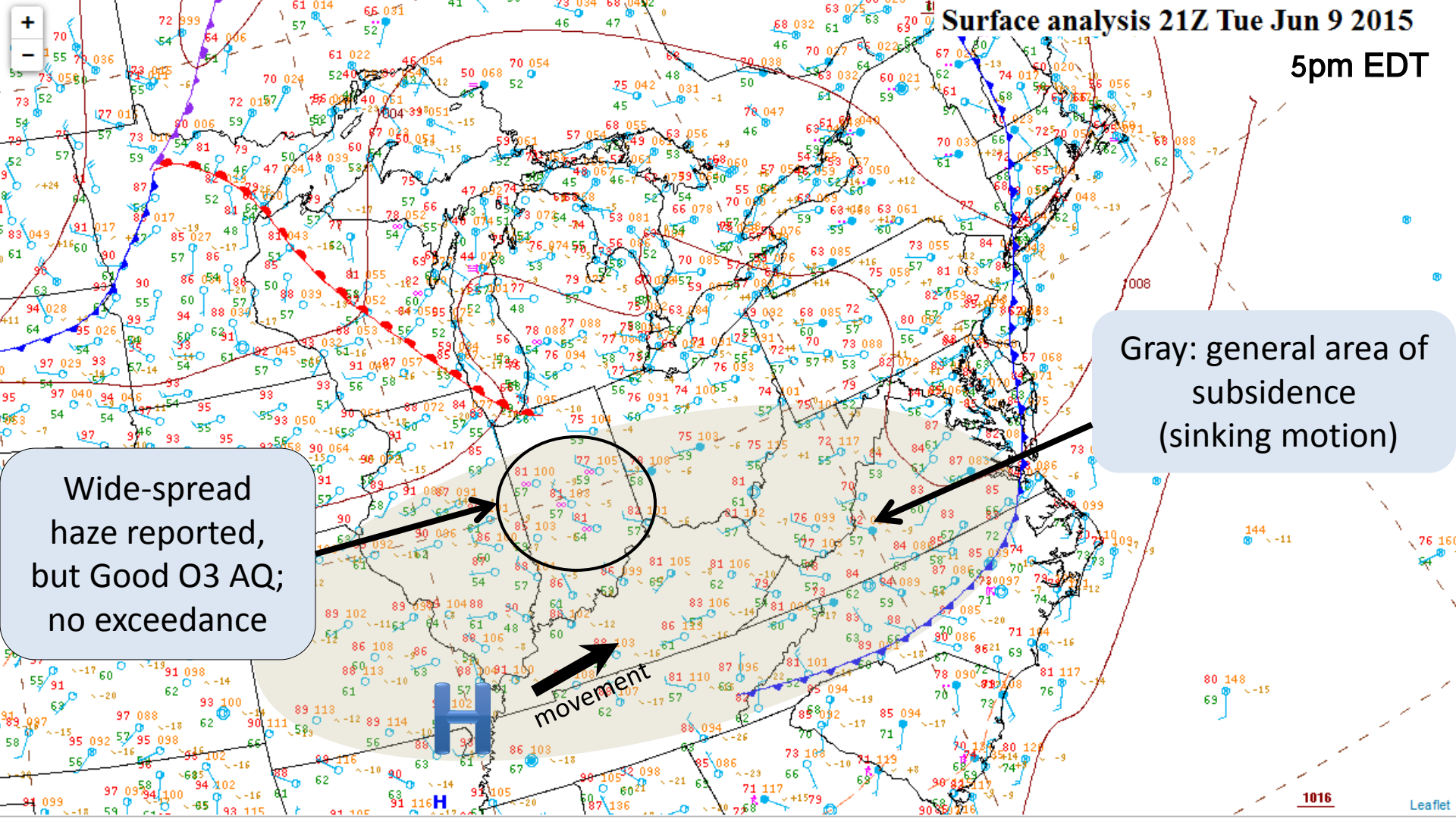


Image Source:
SSEC of UWM, MODIS






June 11, 2015
(AFTERNOON)
•O3 AQI (colors)
•SMOKE (shading)
MINNESOTA
WISCONSIN
MICHIGAN
SOUTH DAKOTA
NEBRASKA
IOWA
ILLINOIS
INDIANA
OHIO
PENNSYLVANIA
NEW YORK
KANSAS
MISSOURI
KENTUCKY
WEST VIRGINIA
OKLAHOMA
ARKANSAS
TENNESSEE
NORTH CAROLINA
SOUTH CAROLINA
MISSISSIPPI
ALABAMA
GEORGIA
LOUISIANA
TEXAS
GREAT PLAINS
COASTAL PLAIN
Lake Superior
Lake Michigan
Lake Huron
Lake Ontario
Lake Erie
Minneapolis
Saint Paul
Madison
Milwaukee
Chicago
Lansing
Detroit
Toronto
Des Moines
Lincoln
Springfield
Indianapolis
Cincinnati
Frankfort
Topeka
Jefferson City
Wichita
Oklahoma City
Little Rock
Nashville
Memphis
Birmingham
Montgomery
Jackson
Columbia
Charlotte
Raleigh
Pittsburgh
Philadelphia
Boston
Concord
Augusta
Providence
Pierre
Fargo
Sioux Falls
Amarillo
Lubbock
Midland
Fort Worth
Dallas



- Subsidence behind the cold front and associated with high pressure allowed smoke to subside to the surface
- Indiana, as early as 6/9, reported haze yet ended the day with Good Ozone AQ, but <u>UPPER</u> Moderate AQ for PM 2.5 and Moderate AQ for PM 10
- Smoke was reaching the surface but did not create an immediate Ozone response

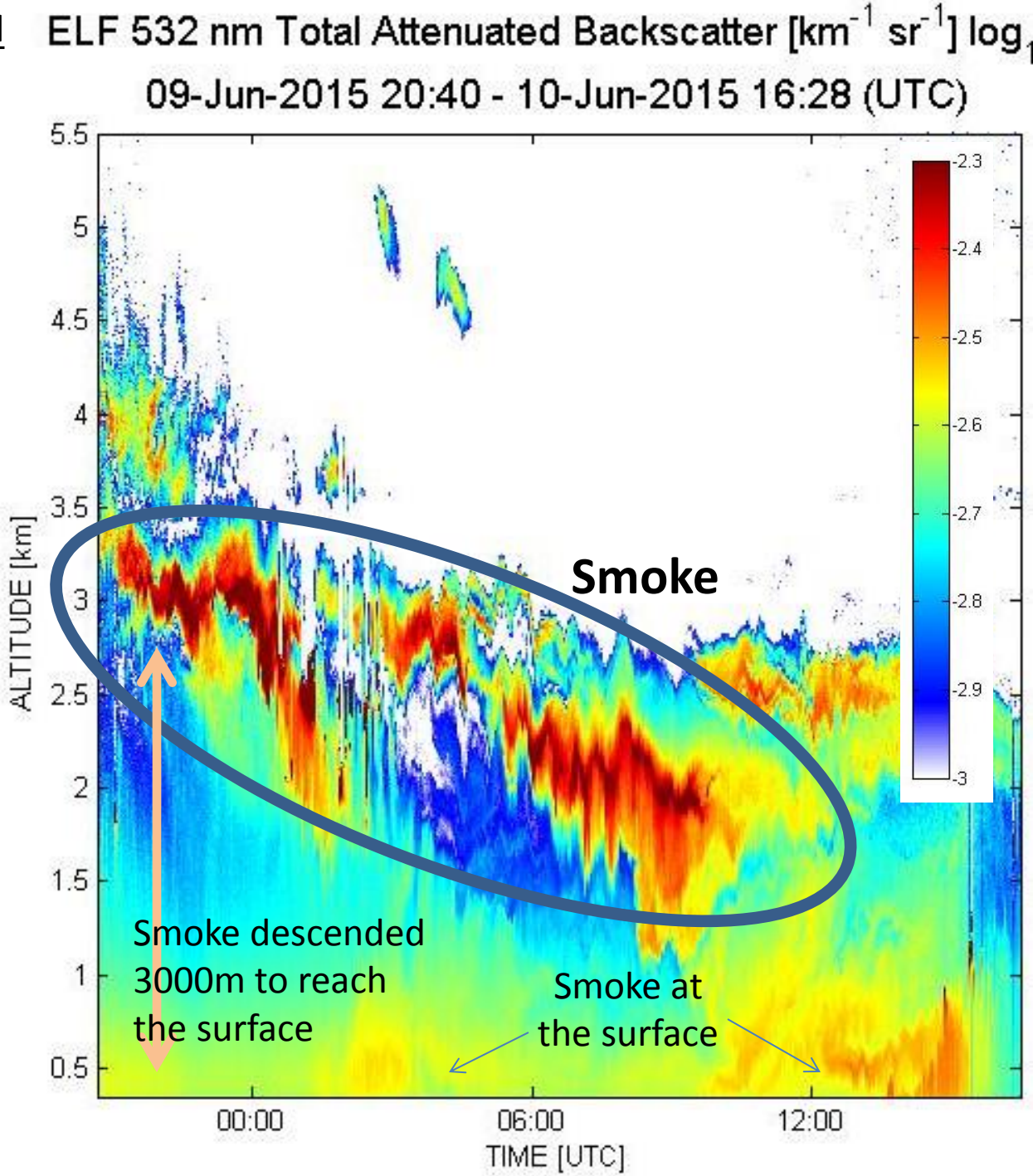
How do we know smoke reached the surface?

UMBC LIDAR

- Smoke descended from 3km in height to the surface, as evident by higher fine particle counts and lidar observations, by **June 10, 2015**

- Smoke plume initially heaviest around the DC metro (red sunsets publicized) based on PM2.5 counts

- Surface winds on Thursday, June 11, 2015, blew DC polluted air back along I-95; cleaner air was to the south



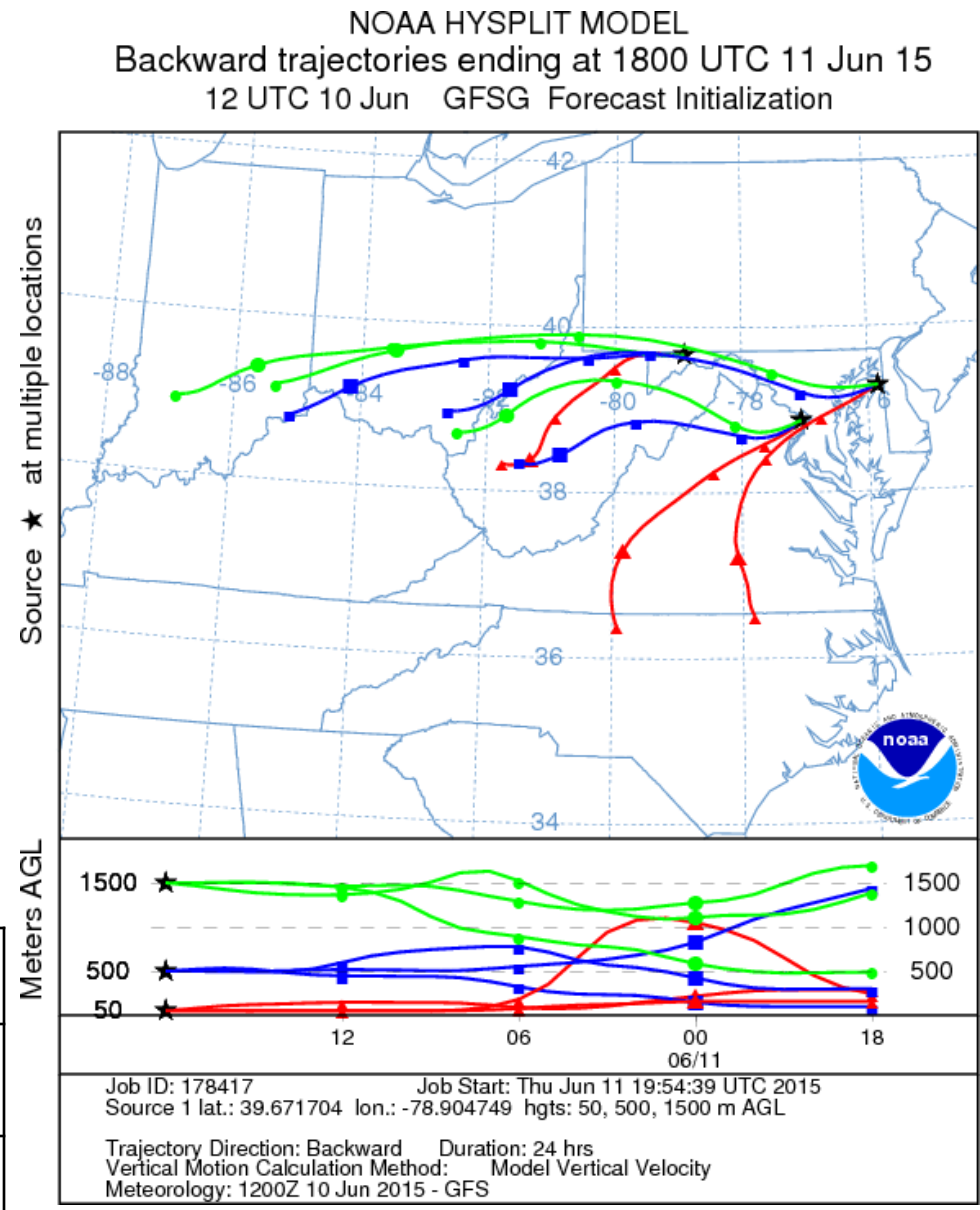
LIDAR images courtesy Dr. Ruben Delgado, UMBC

June 11, 2015 Maryland Meteorology

- Westerly 500m trajectories
- Southwest surface transport along I-95 corridor
- Weak Appalachian Lee Trough along I-95 corridor
- Bay Breeze at Essex and Edgewood (did not exceed)
- BWI airport:

	6/9	6/10	6/11	6/12
T_{max} (°F)	84	84	93	94
Avg WS (kts)	9.4	3.5	3.9	6.2

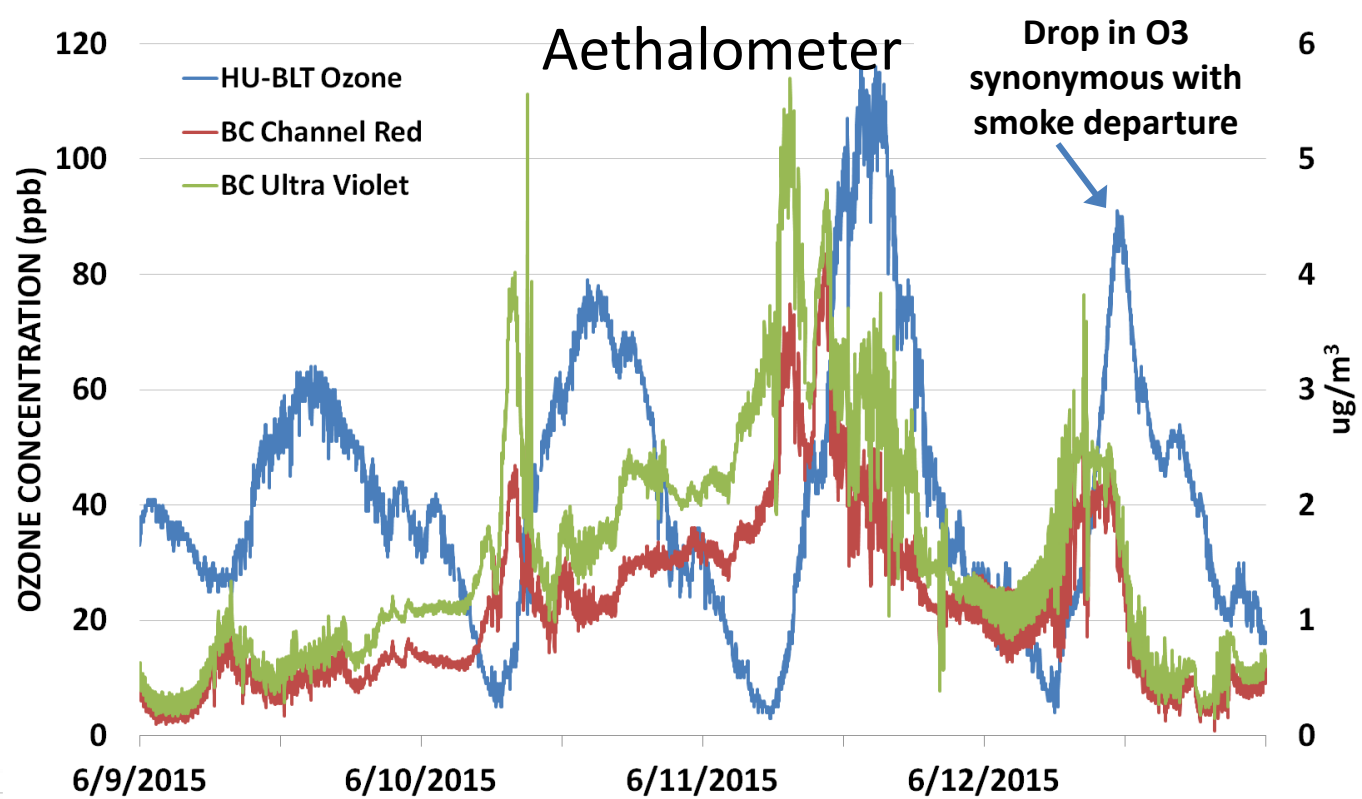
Source: NOAA NWS, ARL

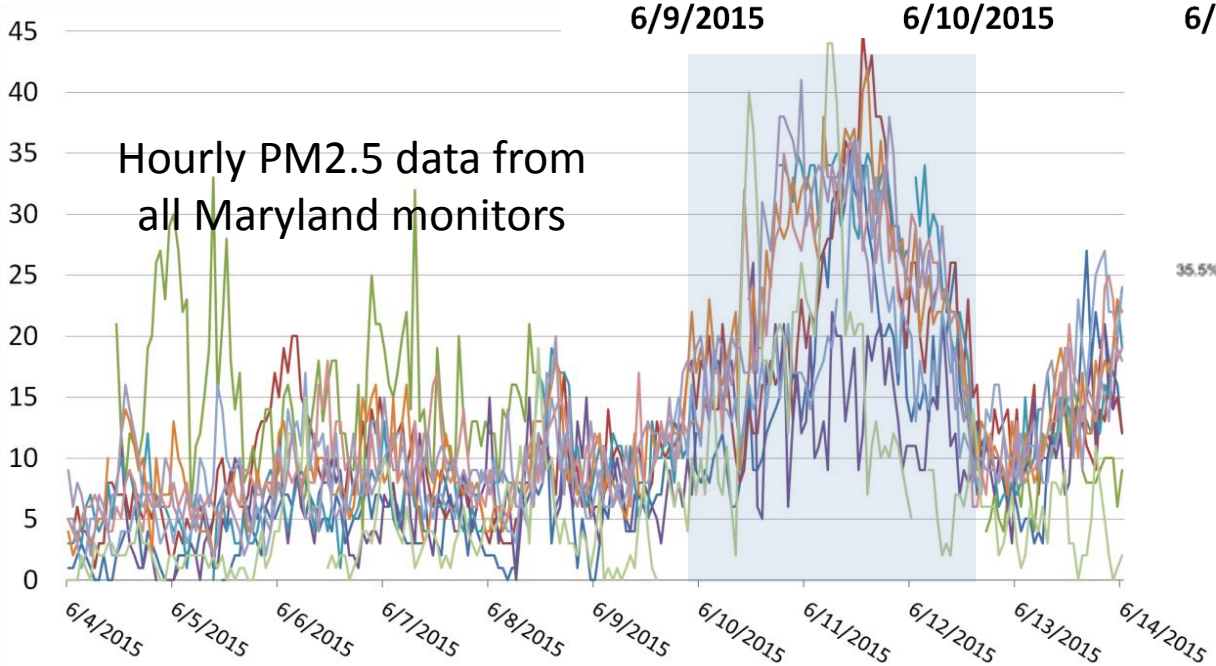


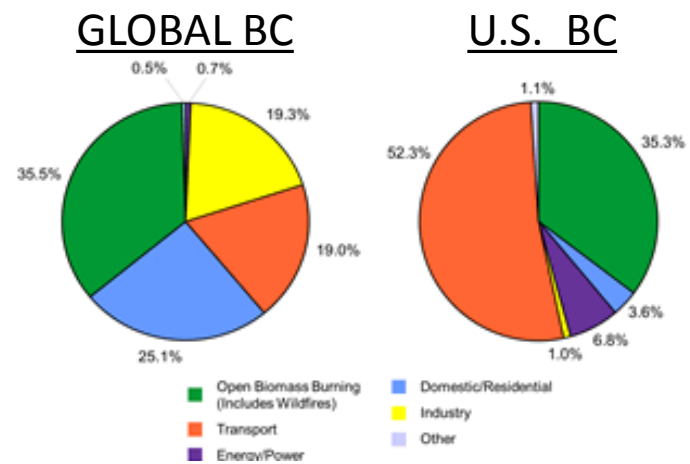
Significant Temperature Difference

Evidence of Smoke

Black carbon and PM2.5 increase synonymous with LIDAR detected smoke gives conclusive evidence of smoke presence at surface

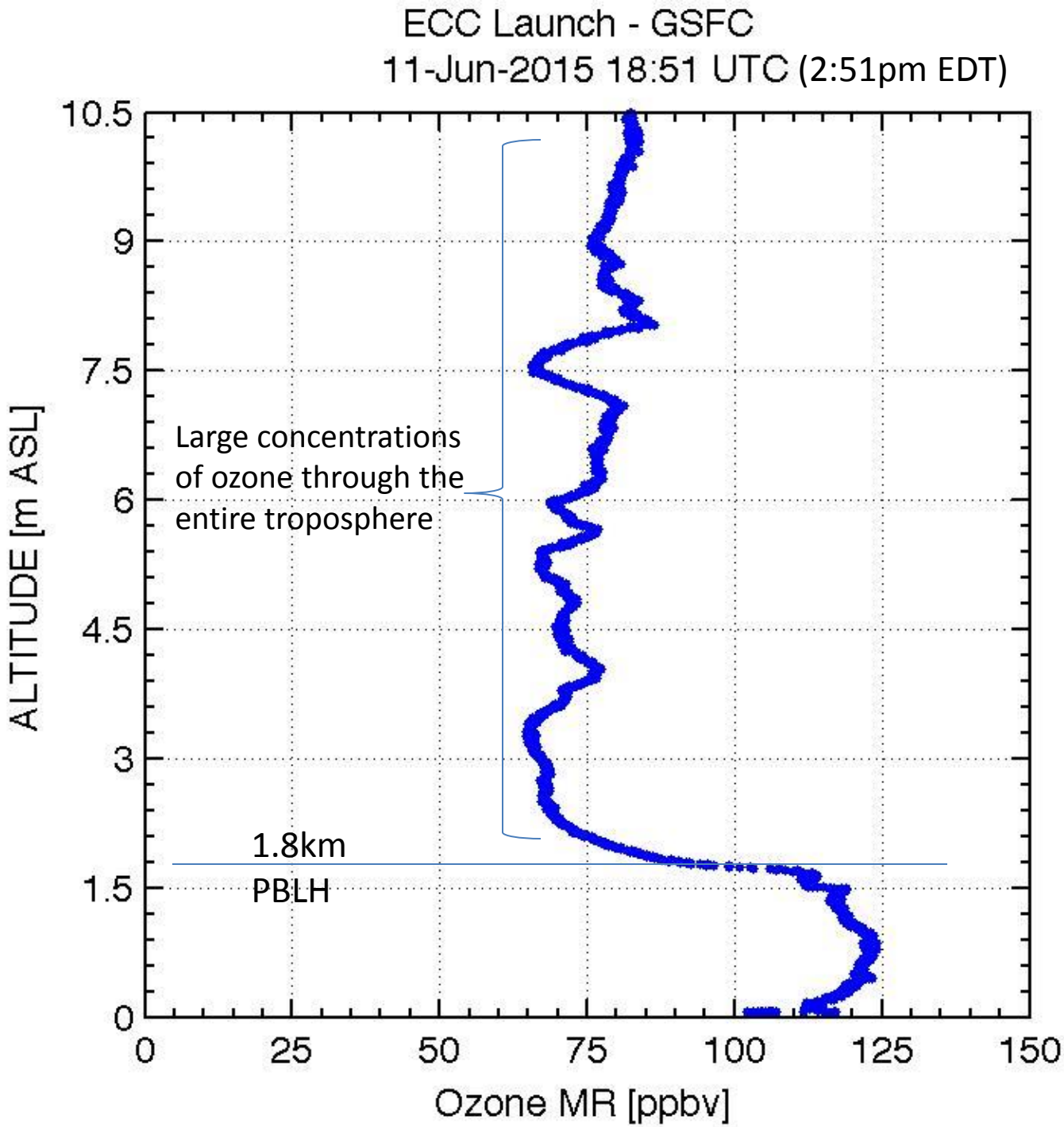






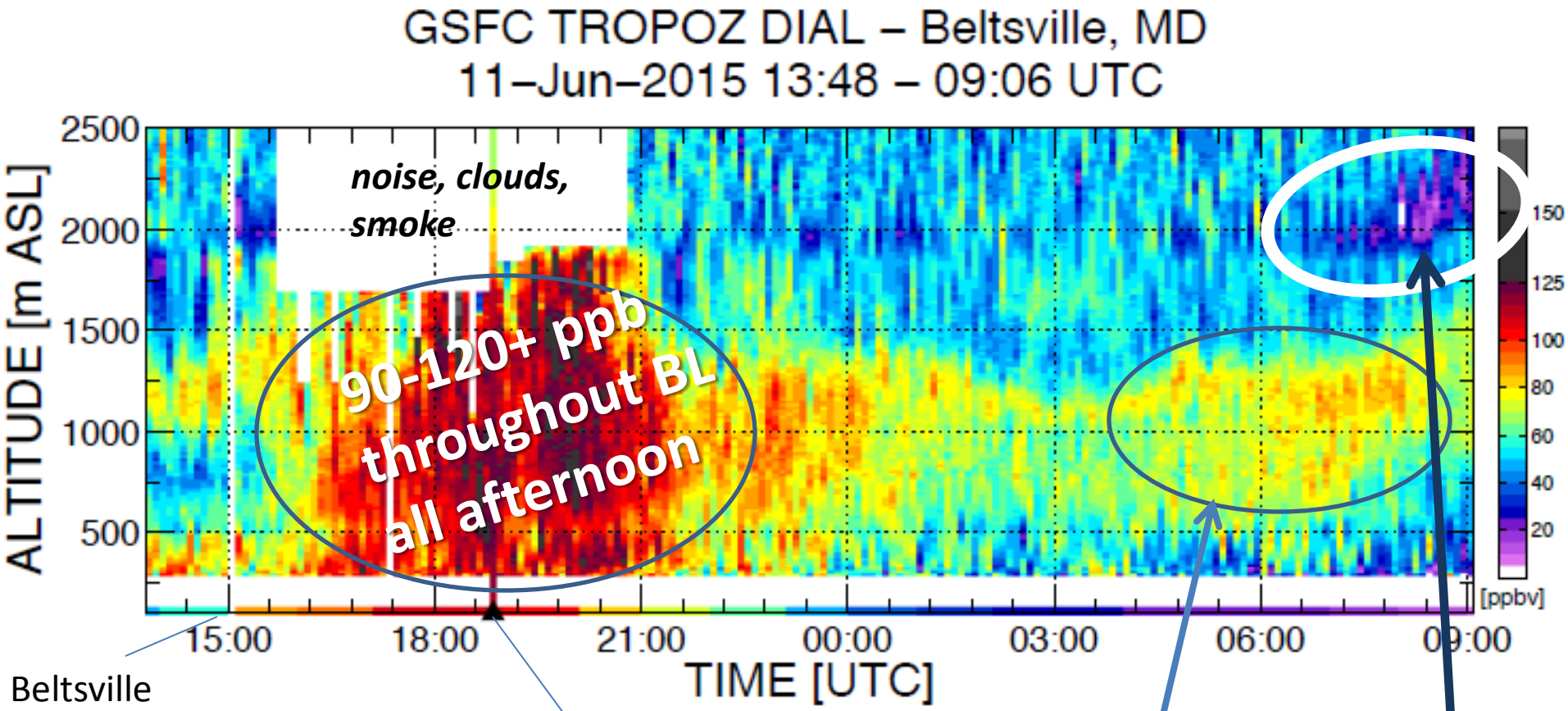
BC Emissions by Major Source Category
(Source: Lamarque et al., 2010 and US EPA)
http://epa.gov/blackcarbon/basic.html

Ozonesonde launched from Beltsville, MD 2:51pm, June 11, 2015



Courtesy Dr. John Sullivan, UMBC/NASA; Do not redistribute without permission

Ozone Lidar at Beltsville, MD



Beltsville surface O3 (bottom)

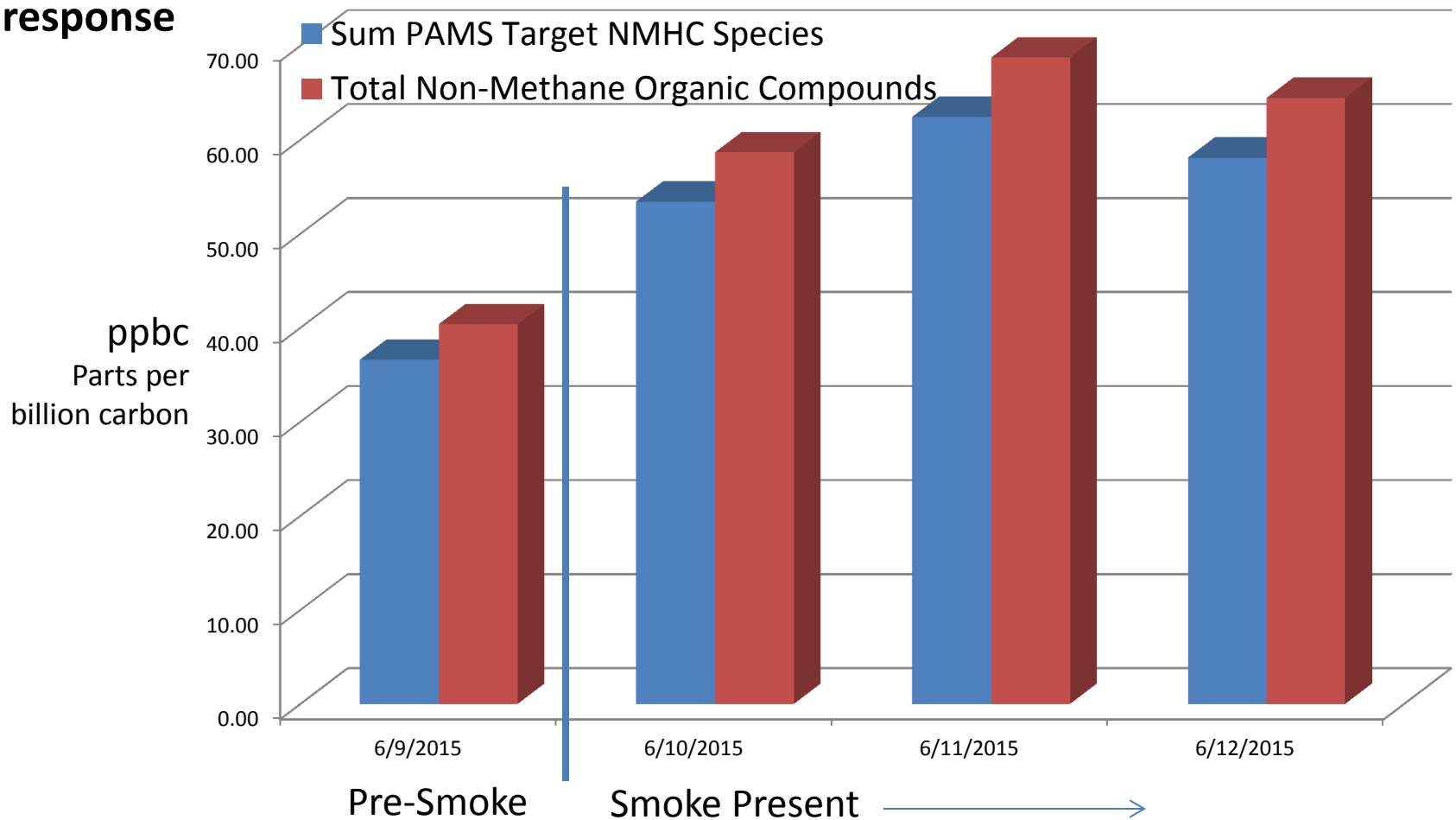
Ozonesonde

Residual layer of ~80ppb at 1km. Notice the very clean air at 2km associated with a southwesterly Nocturnal LLJ

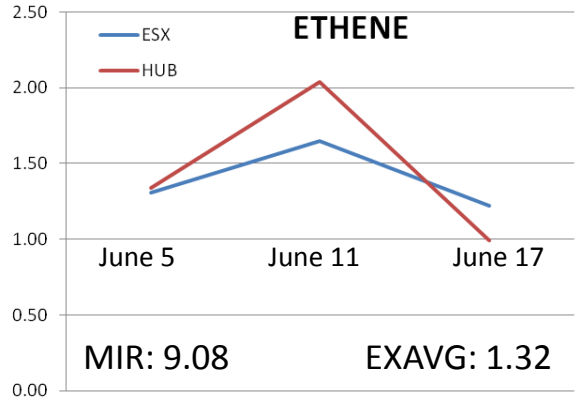
Courtesy Dr. John Sullivan, NASA/UMBC; Do not redistribute without permission

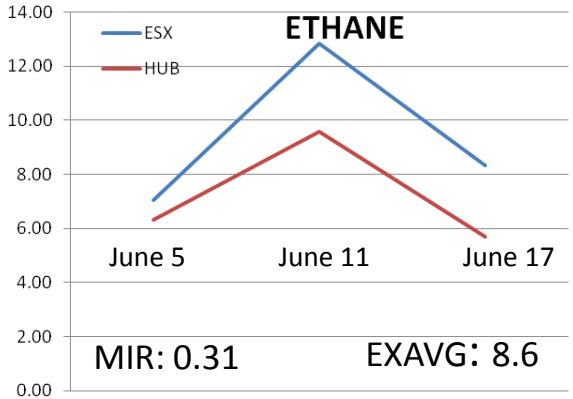
The Role of the Smoke

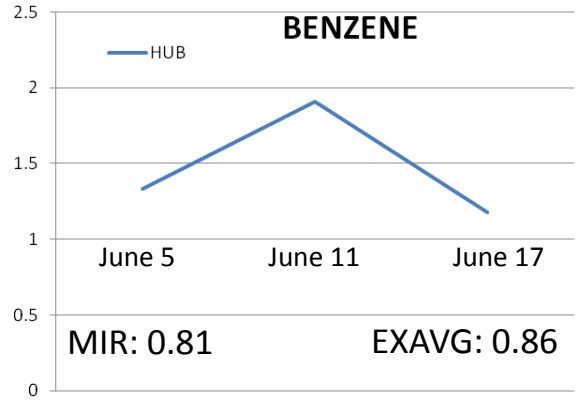
- **The leading hypothesis for the role of the smoke, first proposed by Pius Lee, is that greater concentrations of reactive VOCs within the smoke amplified ozone reactions.**
- **The NOx saturated I-95 corridor (mobile emissions) could then utilize the VOCs in ozone production – *<u>but all areas north of DC show ozone increases.</u>***
- **VOC data from MDE supports this hypothesis but with a significant delay in ozone response**

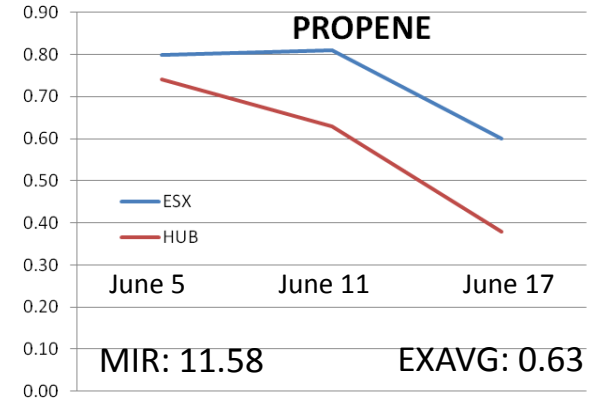


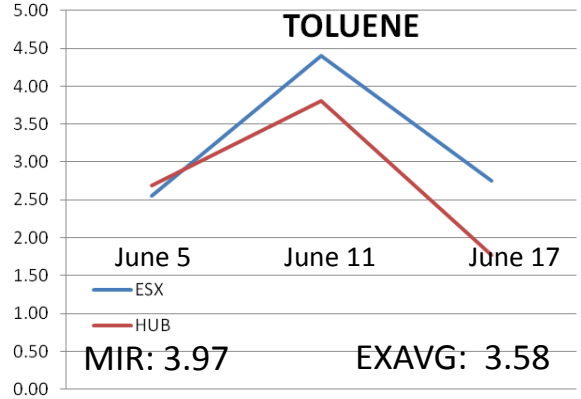
Wildfire VOC species

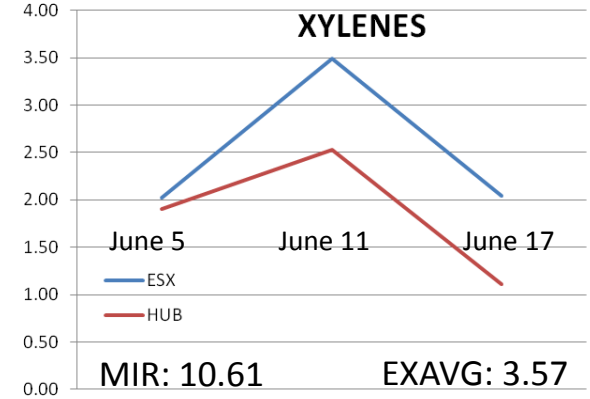




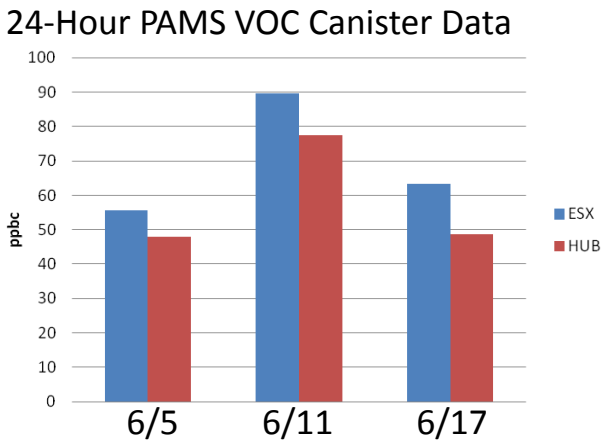








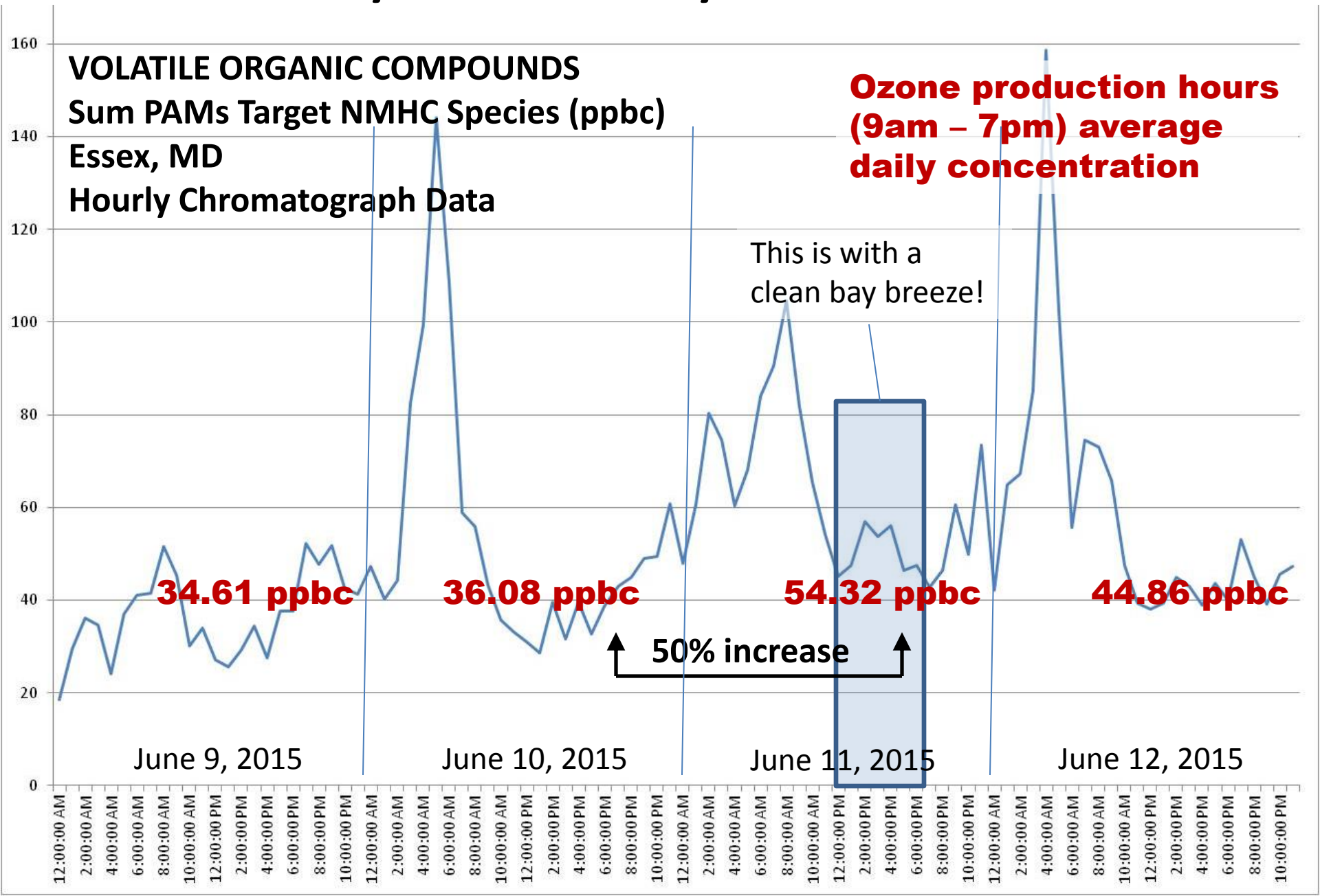
Besides Propene, all VOC species identified as potential emissions from wildfires and available in canisters showed a 33-50% (61% total PAMs) increase from 6 days before the wild fires on June 5 with a similar (38-60%) drop 6 days later on June 17.



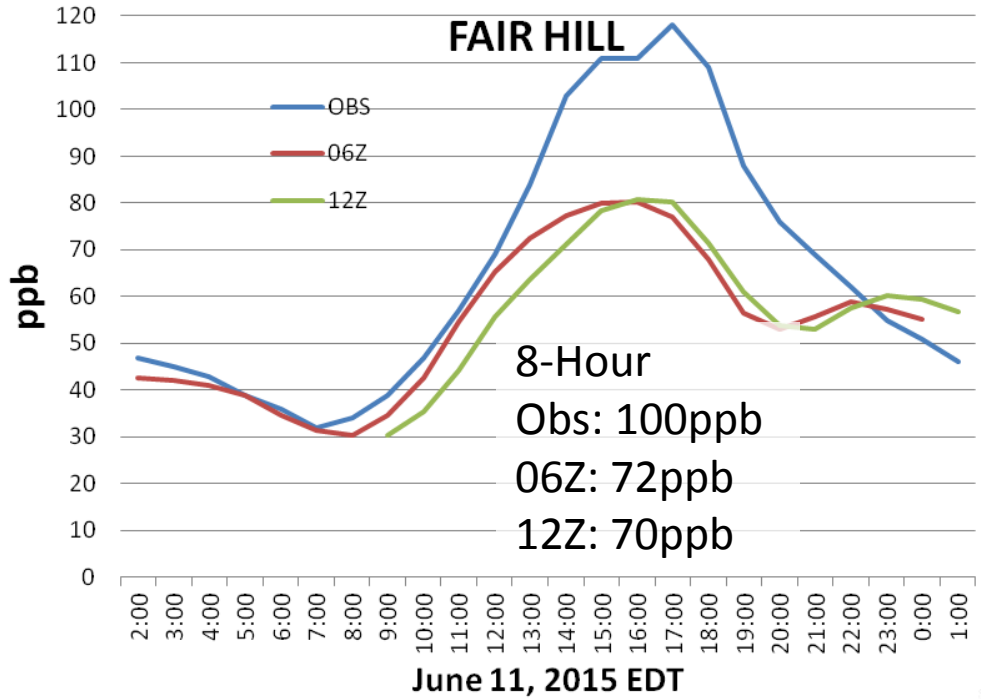
EXAVG: Average concentration during exceedance days (2010-2012)

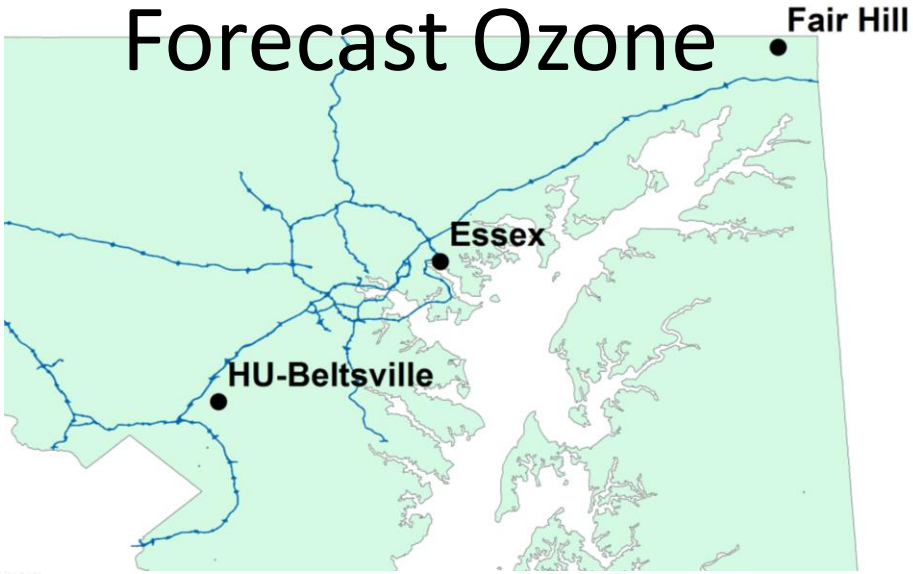
MIR: Maximum Incremental Reactivity
Source: Acefaw Belay, MDE Lab

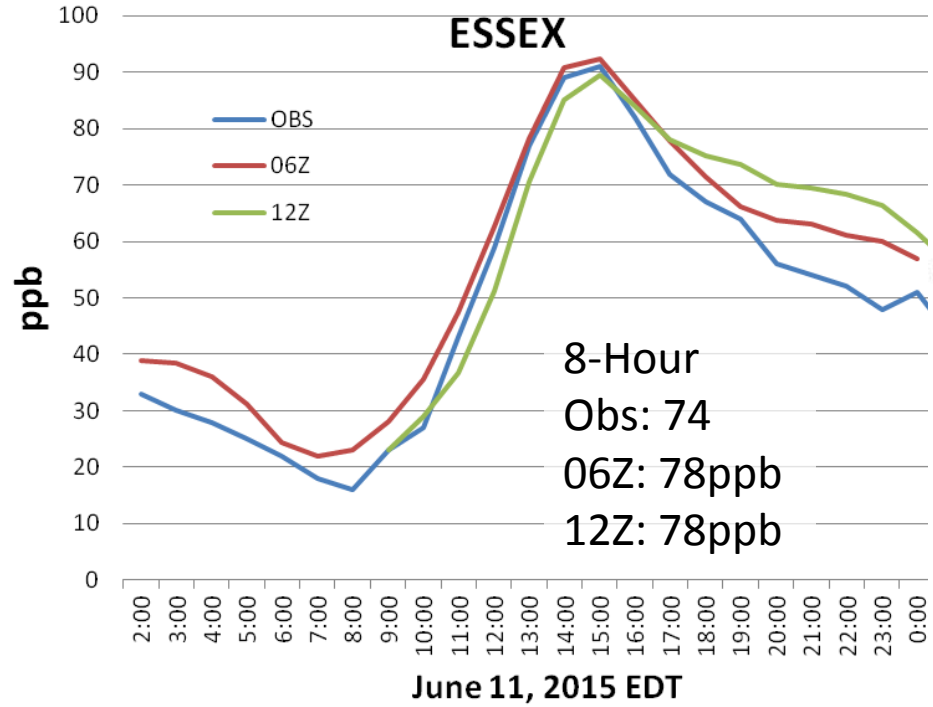
Why the Delay in Ozone?

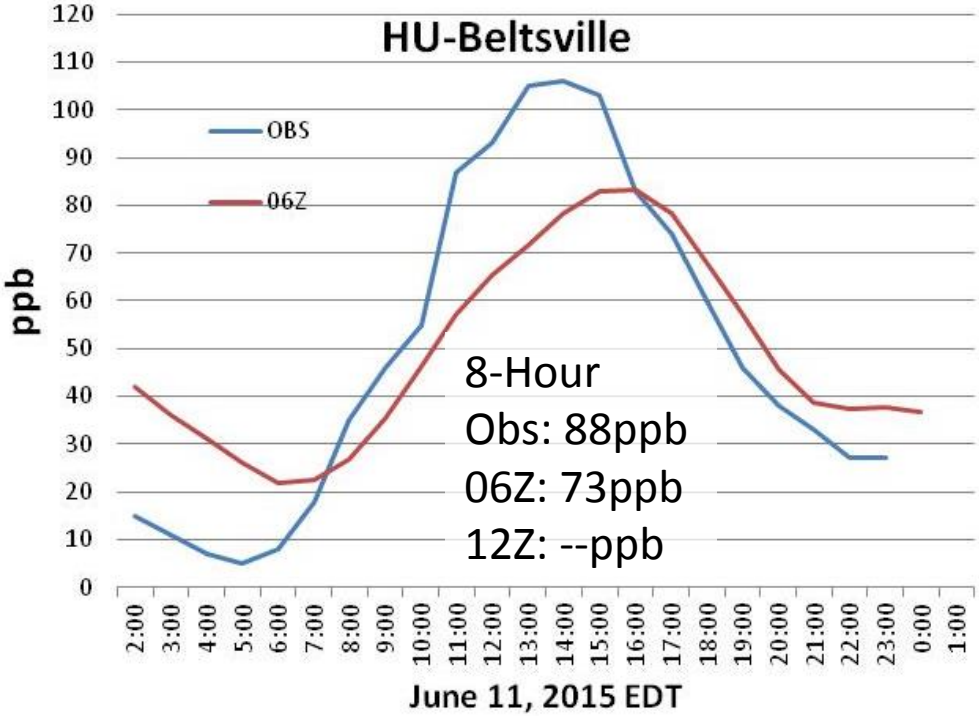


NOAA: Hourly Forecast Ozone





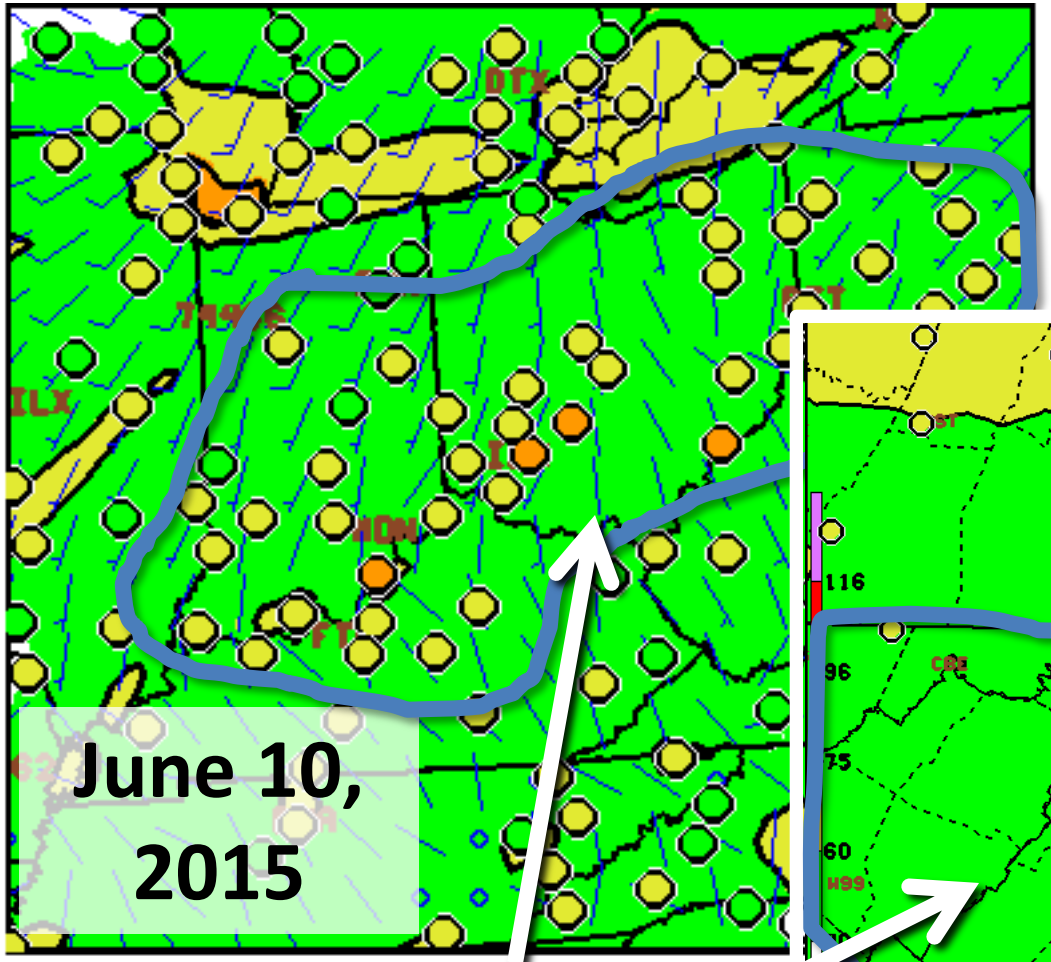


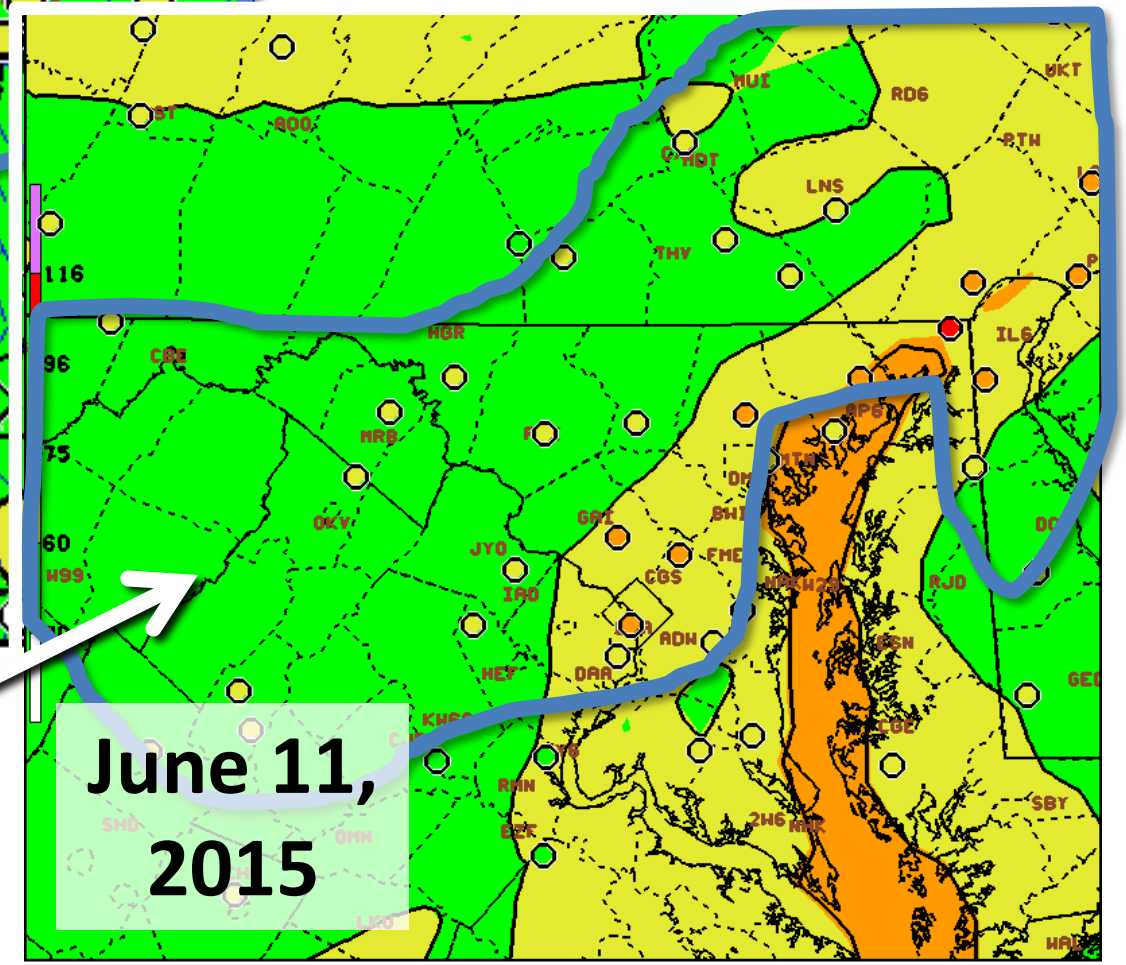


How Much Ozone from Smoke?

NOAA AQ MODEL SERVES AS A **"WHAT IF"** GUIDE

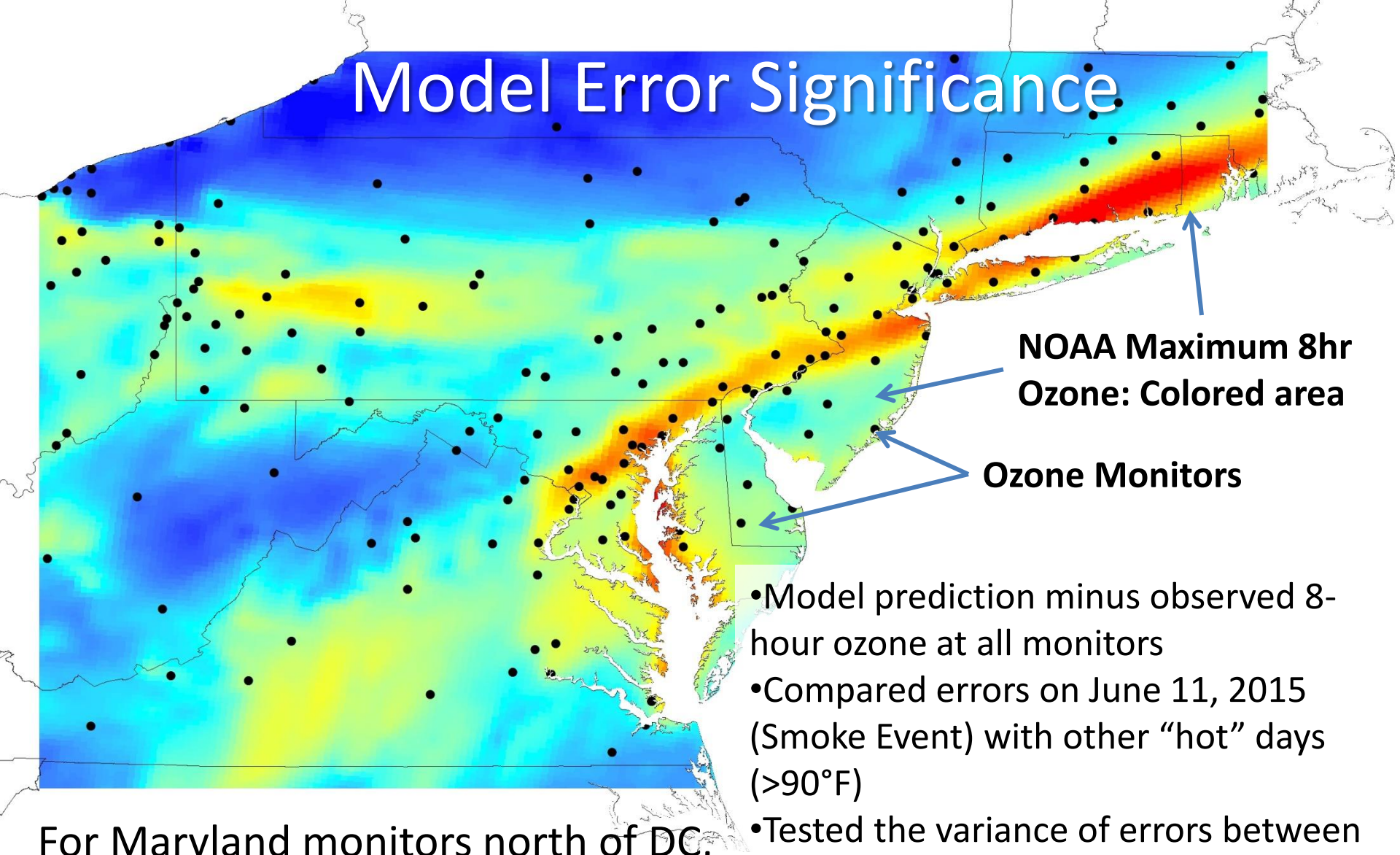
- Smoke not captured in model





Large **<u>under-</u>** <u>prediction</u> by the NOAA model

Model Error Significance



- Model prediction minus observed 8-hour ozone at all monitors
- Compared errors on June 11, 2015 (Smoke Event) with other "hot" days (>90°F)
- Tested the variance of errors between smoke day and non-smoke day
- F-test shows the variances are different with statistical significance at the 95% confidence level

For Maryland monitors north of DC, ozone contribution from smoke is approximately **<u>14ppb</u>**.
Range: 7.6ppb – 30ppb

Ohio Error: 18-21ppb

Conclusions

- Smoke from Canadian wildfires was transported to Maryland on June 11, 2015 and caused Maryland's worst air quality event since June 29, 2012
- Enhanced concentrations of VOCs within the smoke promoted ozone creation
- Preliminary analysis using operational model guidance that did not capture the smoke transport suggests the smoke contributed on average 14ppb of ozone to the 8-hour average

Appendix

Contacts

- Joel Dreessen – MDE Air Quality forecaster, meteorologist

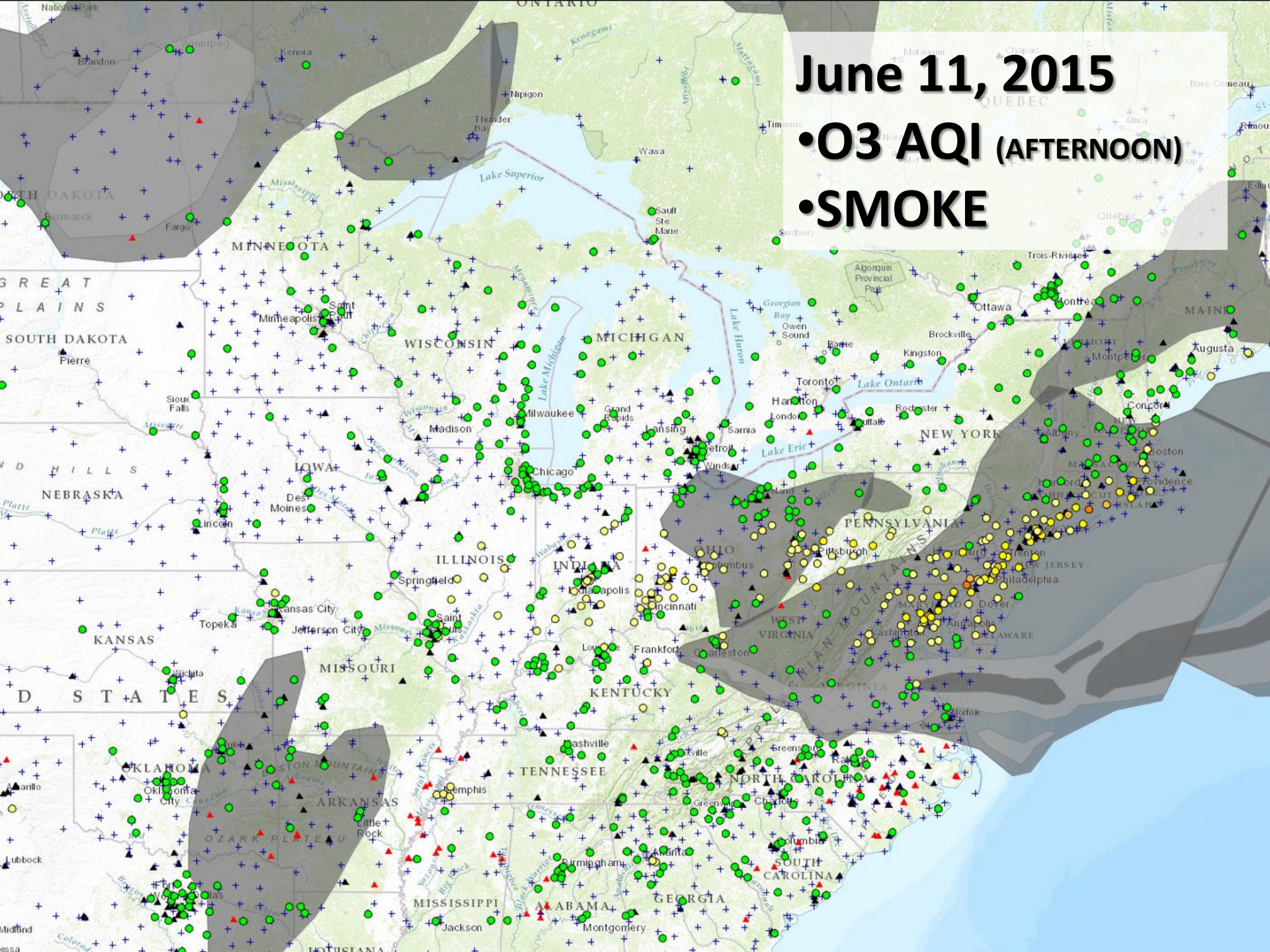
  Joel.dreessen@maryland.gov
- Ruben Delgado – Professor, UMBC

  delgado@umbc.edu
- John Sullivan – Post-doc, NASA

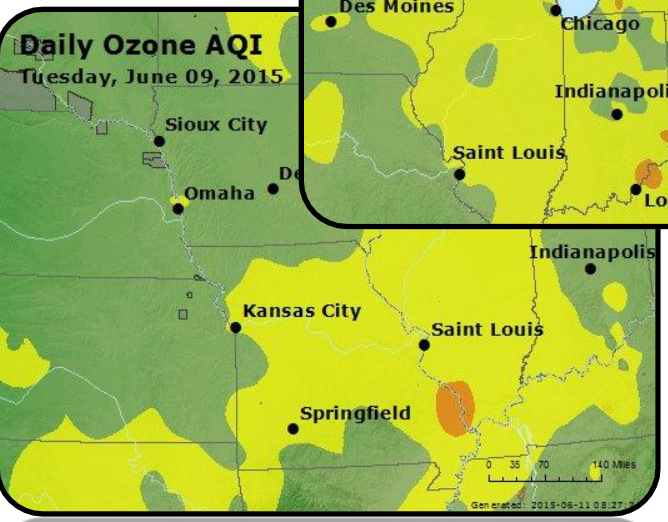
  jsull1@umbc.edu

June 11, 2015

- O3 AQI (AFTERNOON)
- SMOKE

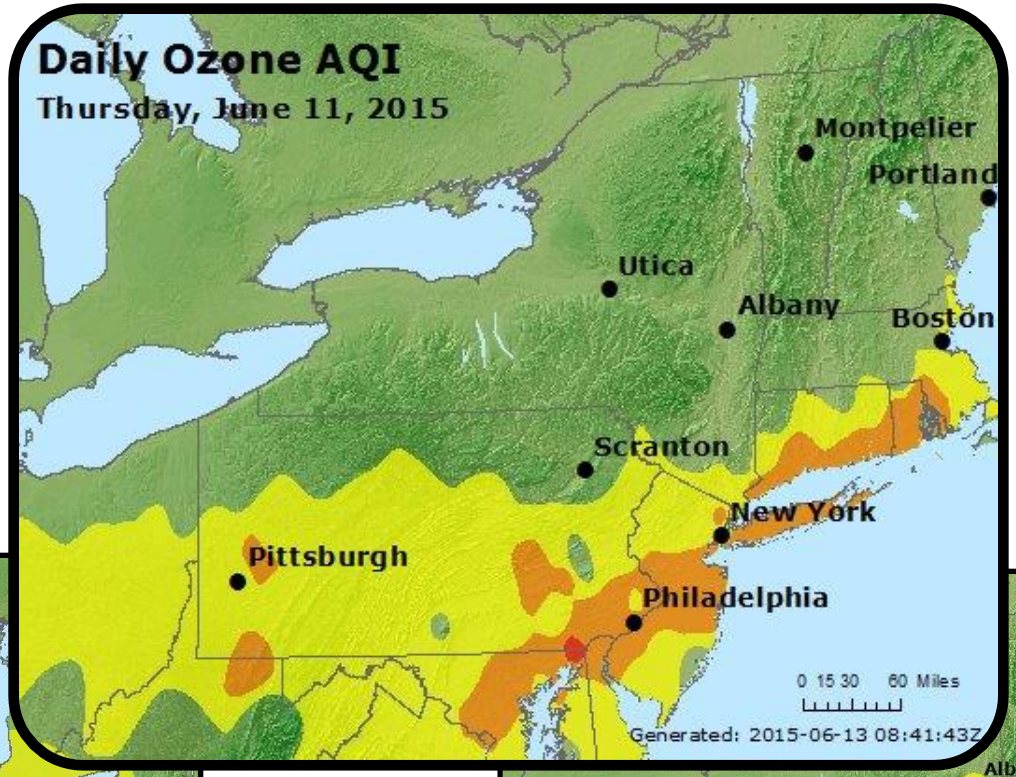

Lake Superior
Lake Michigan
Lake Huron
Lake Ontario
Lake Erie
MINNESOTA
WISCONSIN
MICHIGAN
SOUTH DAKOTA
NEBRASKA
IOWA
ILLINOIS
INDIANA
OHIO
PENNSYLVANIA
NEW YORK
KANSAS
MISSOURI
KENTUCKY
TENNESSEE
ARKANSAS
OKLAHOMA
MISSISSIPPI
ALABAMA
GEORGIA
SOUTH CAROLINA
NORTH CAROLINA
WEST VIRGINIA
Minneapolis
Saint Paul
Milwaukee
Madison
Chicago
Des Moines
Lincoln
Sioux Falls
Pierre
Bismarck
Fargo
Winnipeg
Kenora
Thunder Bay
Nipigon
Wawa
Sault Ste. Marie
Sudbury
Timmins
Toronto
Hamilton
London
Sarnia
Detroit
Windsor
Cleveland
Buffalo
Rochester
Ottawa
Montréal
Trois-Rivières
Quebec
Kingston
Brockville
Barrie
Owen Sound
Augusta
Concord
Boston
Providence
Albany
Philadelphia
Pittsburgh
Columbus
Cincinnati
Indianapolis
Springfield
Saint Louis
Kansas City
Topeka
Jefferson City
Wichita
Frankfort
Louisville
Charleston
Nashville
Memphis
Little Rock
Birmingham
Atlanta
Jackson
Montgomery
Columbia
Charlotte
Greensboro
Raleigh
Norfolk
Dover
Annapolis
Washington
Oklahoma City
Amarillo
Lubbock
Midland
Dallas
Fort Worth
Austin
Houston
Denver
Colorado Springs
Cheyenne
Lincoln
Omaha
Des Moines
Minneapolis
Saint Paul
Milwaukee
Madison
Chicago
Detroit
Cleveland
Pittsburgh
Philadelphia
Boston
Providence
Concord
Augusta
Montréal
Ottawa
Toronto
Buffalo
Rochester
Albany
Kansas City
Saint Louis
Memphis
Nashville
Atlanta
Birmingham
Jackson
Montgomery
Charlotte
Raleigh
Norfolk
Washington
Philadelphia
Boston
Providence
Concord
Augusta

Summary: June 9-12, 2015



June 9, 2015

June 10, 2015



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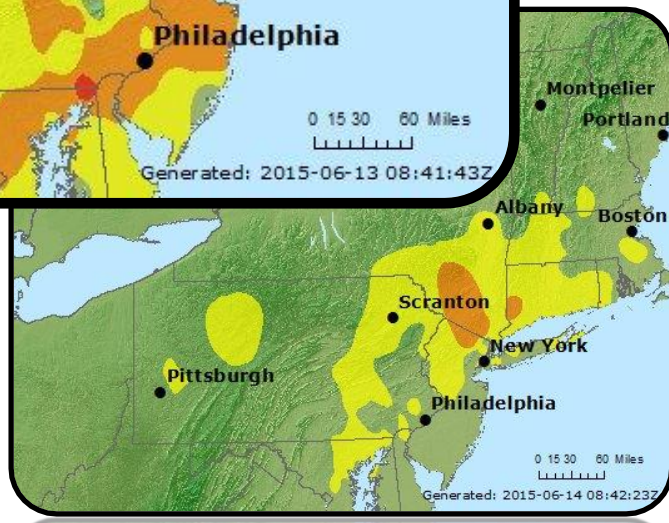
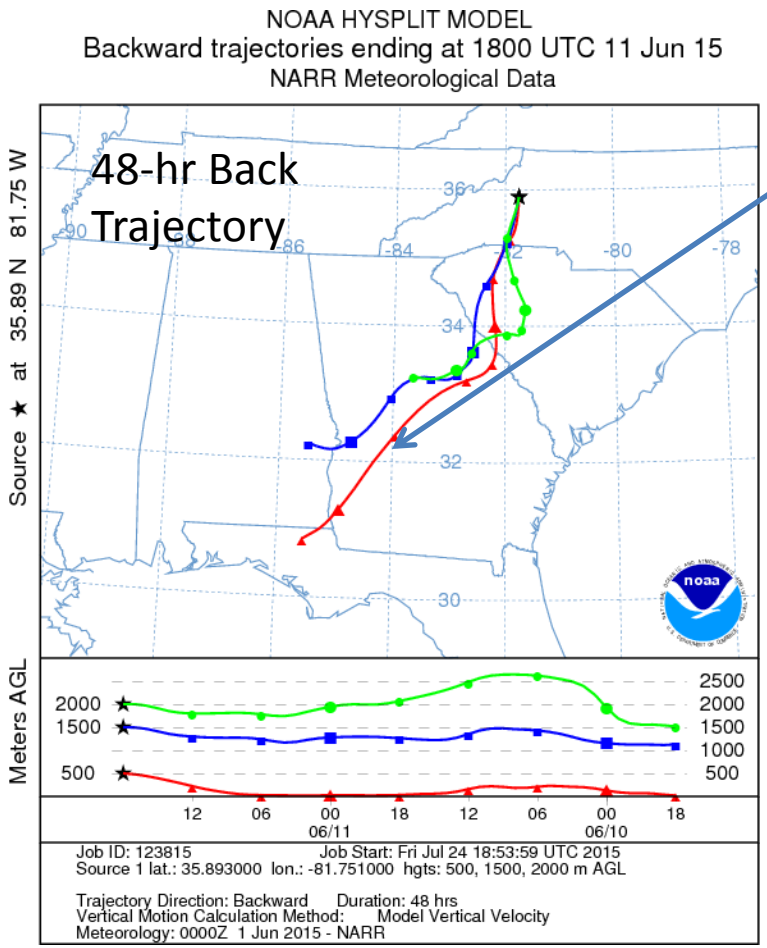


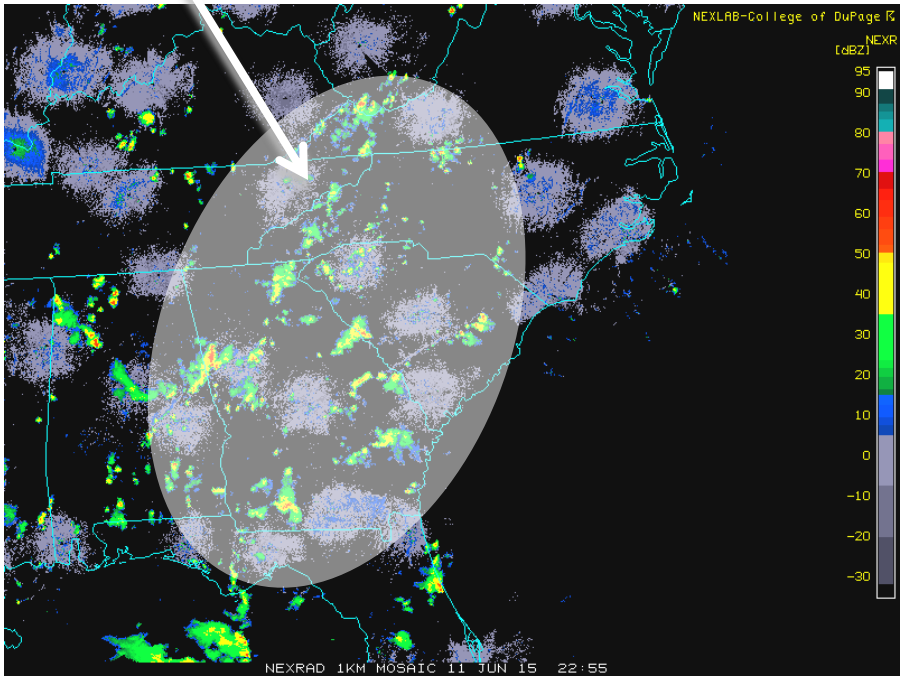
June 12, 2015

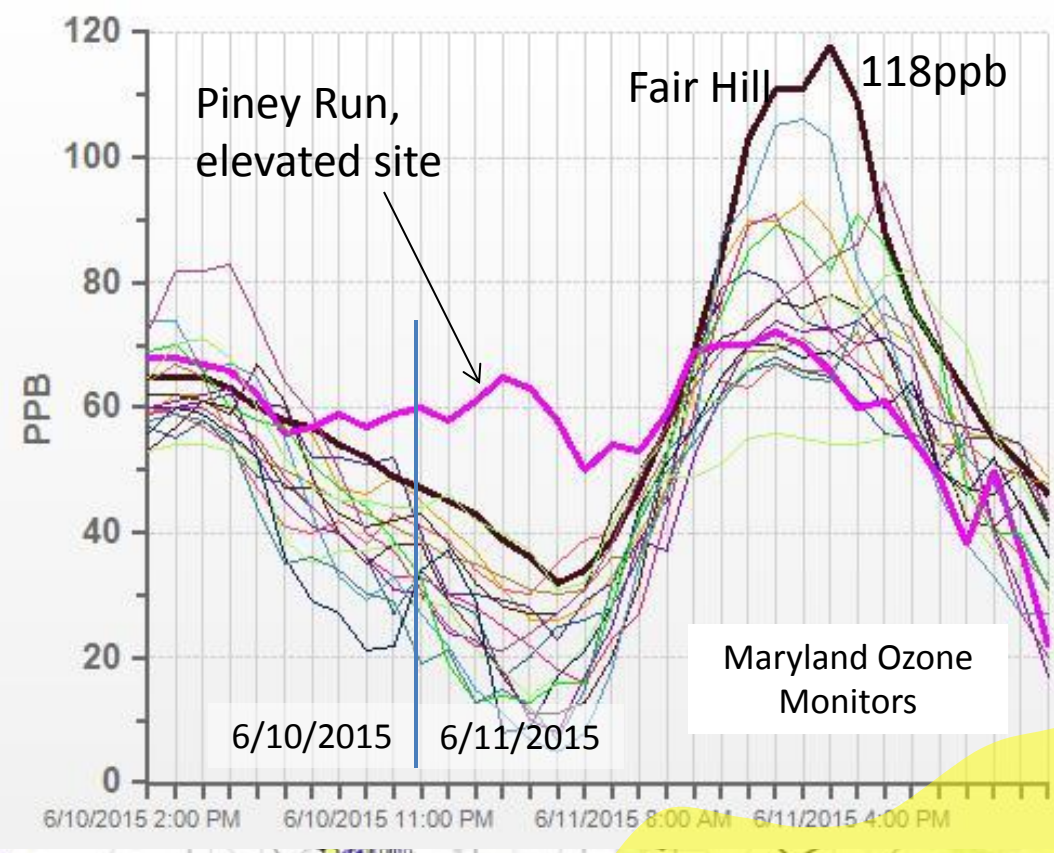
Why was the Low Level Jet clean?

- Based on Lidar observations, the air associated with the nocturnal low-level jet was quite clean. <u>Why</u>?
- Source region for the clean air was SW VA and NC Piedmont



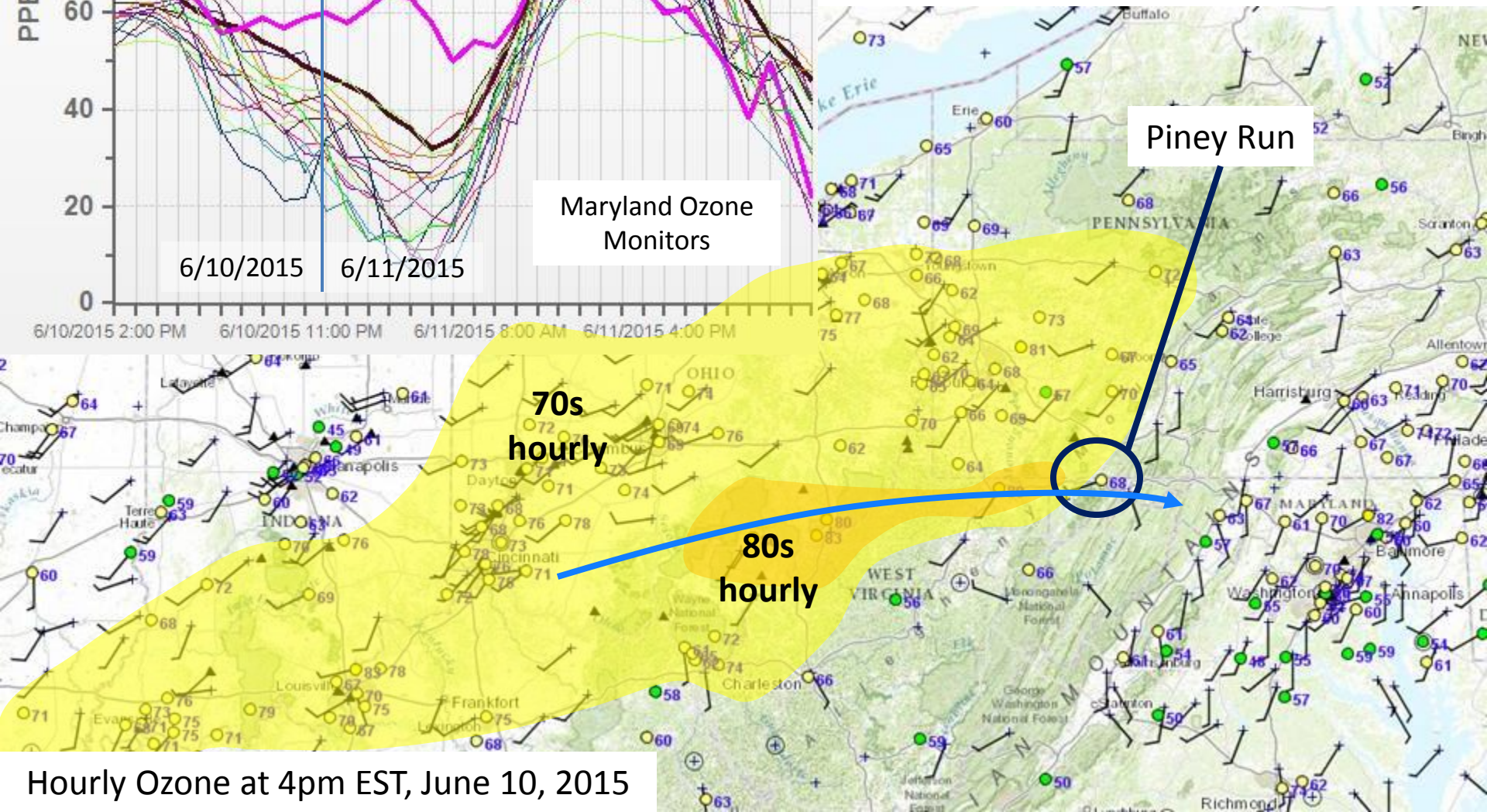
- Strong near-surface winds from the south (no large sources in area)
- Widespread over-turned air mass on June 11





•Piney Run had elevated ozone of ~60ppb through the early morning of 6/11 under westerly transport.

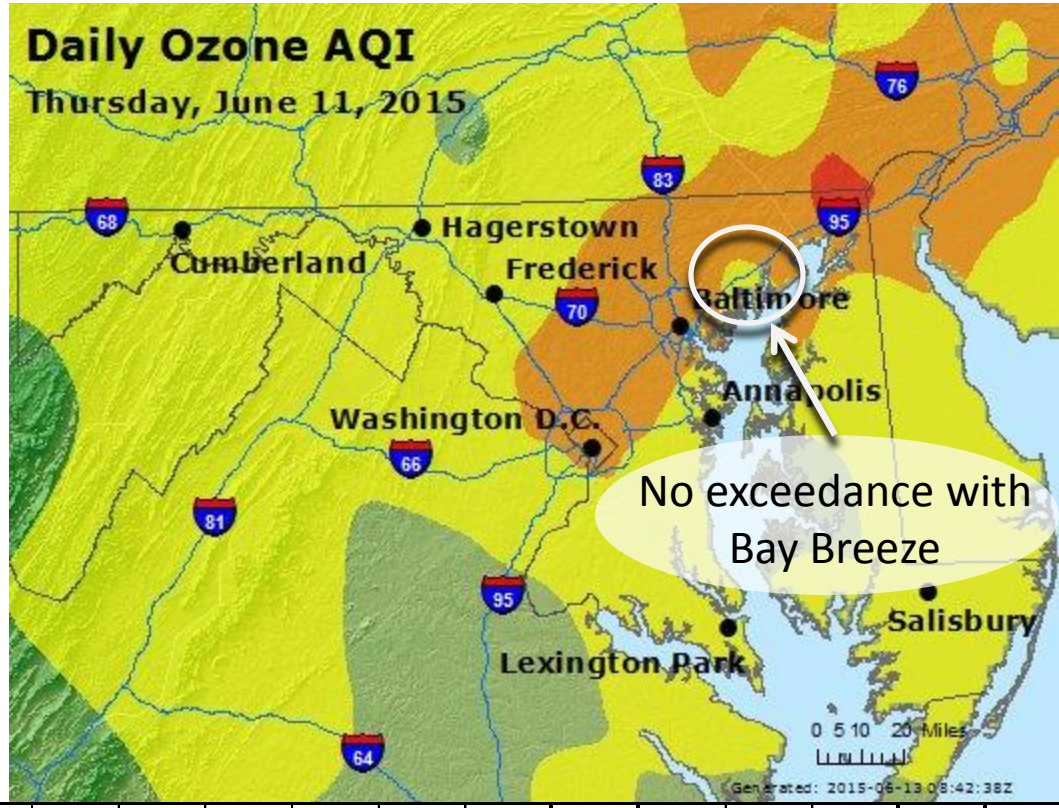
•The next day Fair Hill had a maximum 1-hr average of 118ppb!



Hourly Ozone at 4pm EST, June 10, 2015

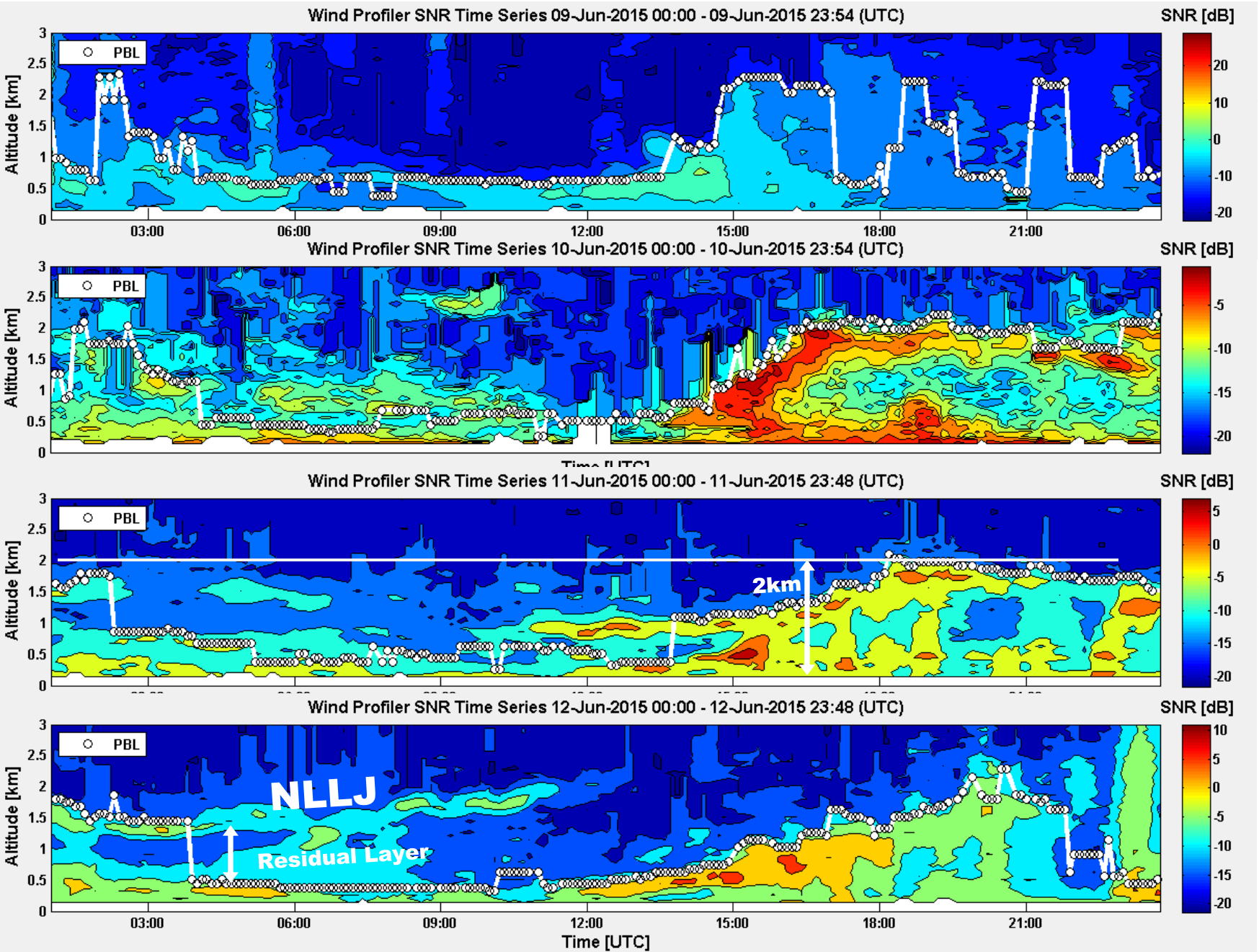
Maryland Summary

- **UNHEALTHY** AQI at Fairhill (northeast MD)
- **USG** at
  - All 3 DC monitors
  - 6 Maryland monitors
- Event centered along I-95 corridor
- Smoke aided
- Worst air quality since 6/29/2012 (Derecho)

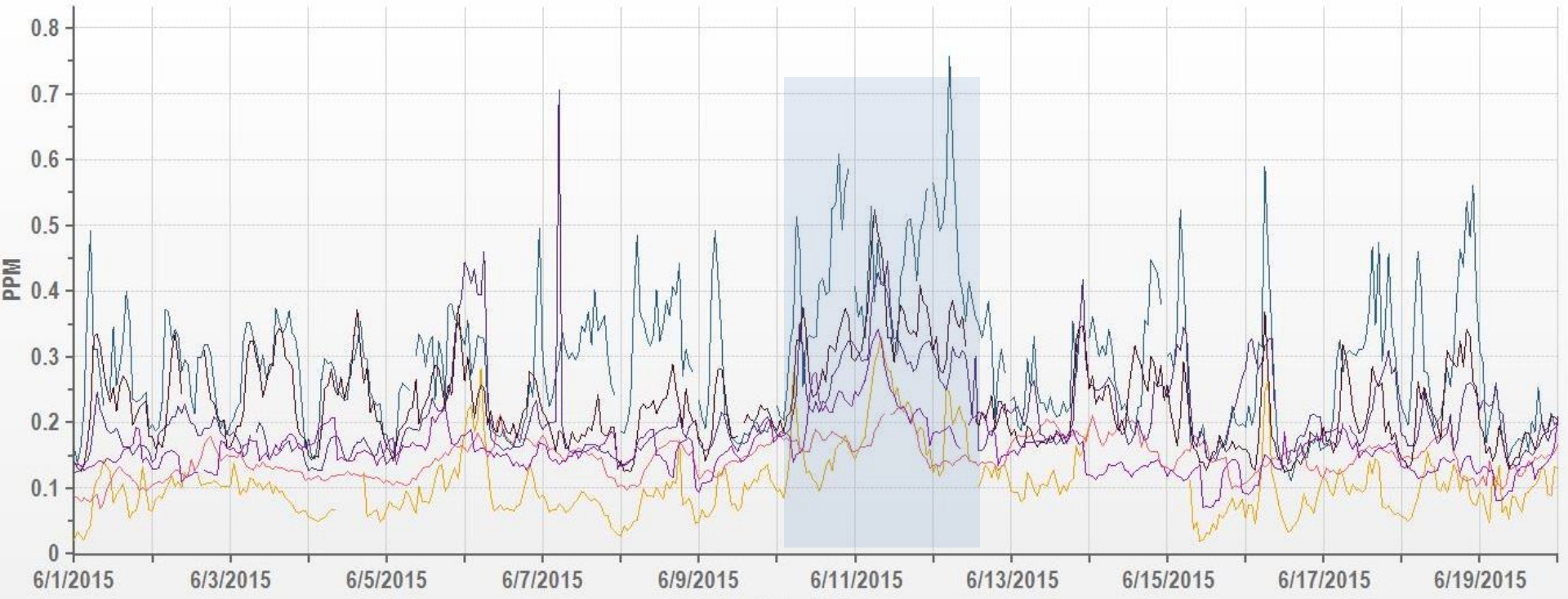


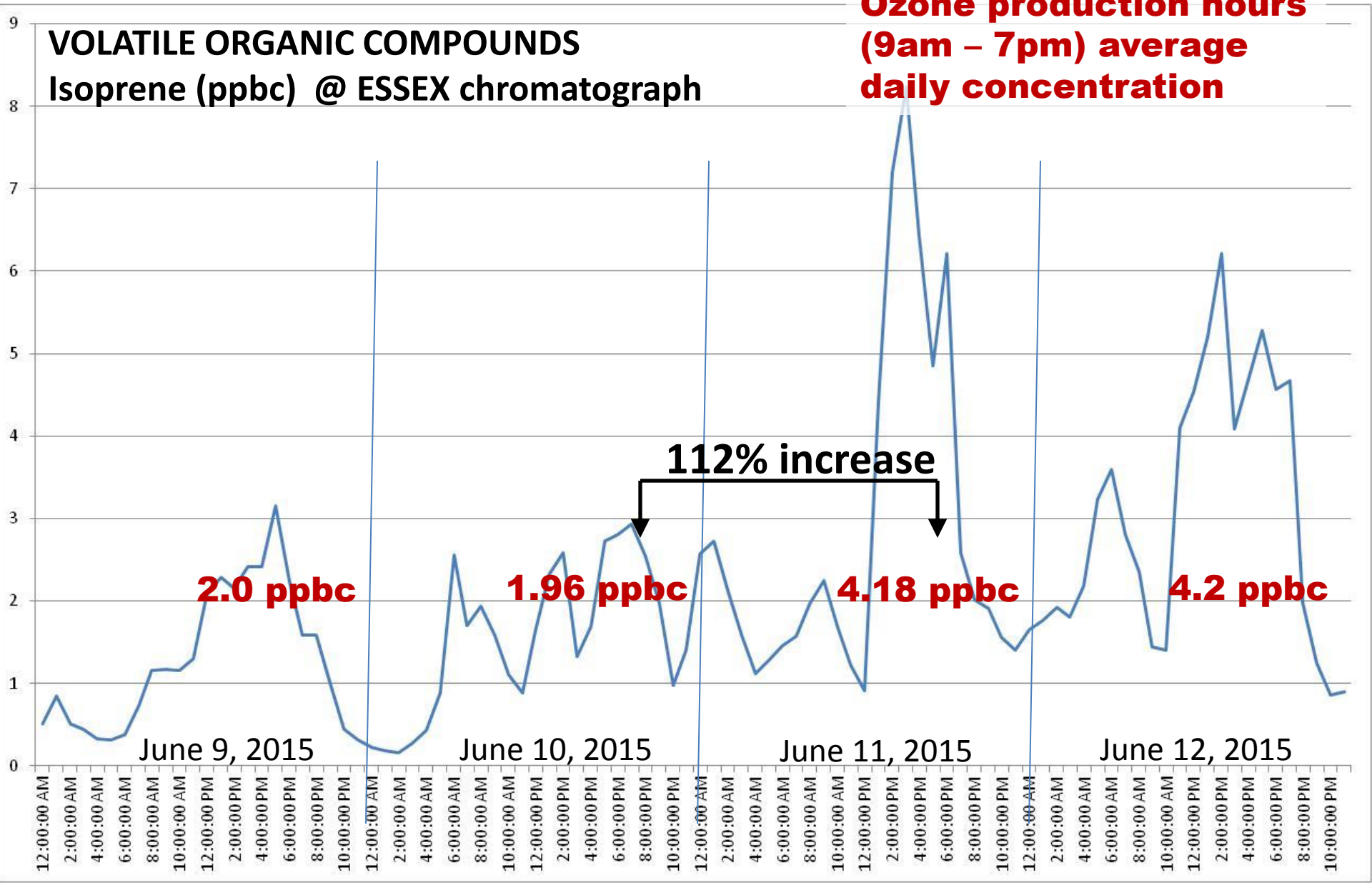
	Aldino	Davidsonville	Edgewood	Essex	Furley	Padonia	South Carroll	Calvert	PG Equest. Ctr.	Frederick Airport	Howard U.	Beltsville*	Rockville	So. Maryland	Fair Hill	Blackwater NWR *	Millington	Horn Point	Hagerstown	Piney Run
2014 Design Value	73	74	75	72	64	72	69	73	76	70	70	75	68	71	77	70	74	73	67	68
06/11/2015	**83**					**81**					**88**	**86**	**83**		**100**					

Boundary Layer Height



Influence/Proof of Smoke: Carbon Monoxide

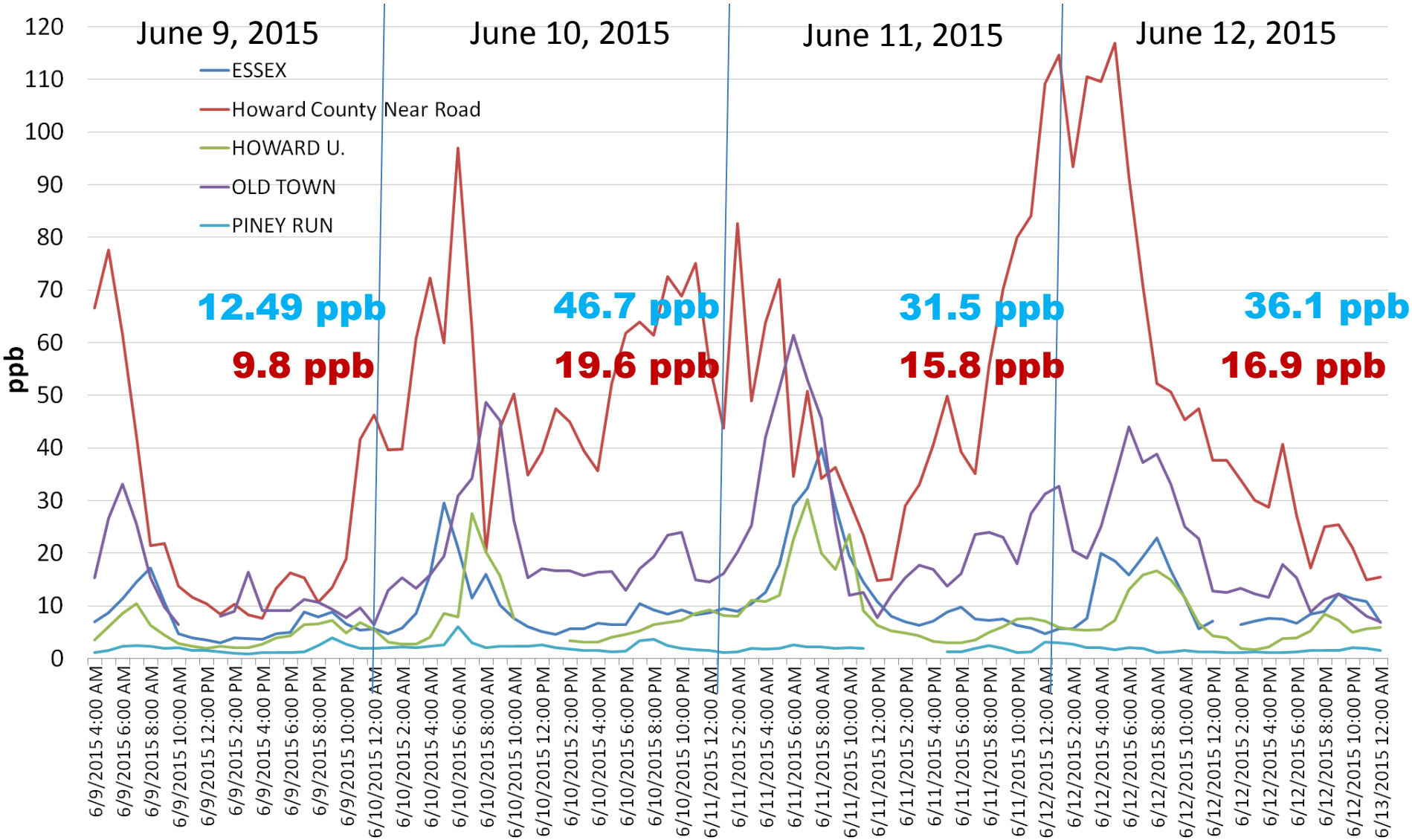



VOLATILE ORGANIC COMPOUNDS
Isoprene (ppbc) @ ESSEX chromatograph
Ozone production hours (9am – 7pm) average daily concentration
112% increase
2.0 ppbc
1.96 ppbc
4.18 ppbc
4.2 ppbc
June 9, 2015
June 10, 2015
June 11, 2015
June 12, 2015
0
1
2
3
4
5
6
7
8
9
12:00:00 AM
2:00:00 AM
4:00:00 AM
6:00:00 AM
8:00:00 AM
10:00:00 AM
12:00:00 PM
2:00:00 PM
4:00:00 PM
6:00:00 PM
8:00:00 PM
10:00:00 PM

Nitrogen Oxides (ppb) - Show a DECREASE on 6/11 compared to 6/10 and 6/12.

Old Town: Ozone production hours (9am – 7pm) average daily concentration

HCNR: Ozone production hours (9am – 7pm) average daily concentration



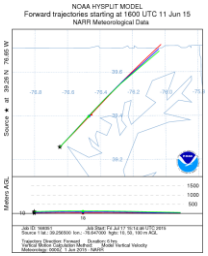
Leading VOC Changes

Since ozone did not increase with the immediate arrival of the smoke, it is good to compare VOC species between 6/10 (first full day of smoke) and 6/11 (day of ozone increase).

<u>Essex Hourly:</u>

<u>Molecule (ppbc % change 6/10 to 6/11)</u>

2-Methylheptane (500%)
n-Decane (331.8%)
n-Nonane (264.5%)
Methylcyclopentane (249%)
Methylcyclohexane (168.6%)
3-Methylheptane (152%)
3-Methylpentane (151%)
Cyclopentane (122.4%)
2-Methylhexane (116.2%)
n-Octane (110%)
Isoprene (112%)



SW Baltimore Fire

Other leading wildfire smoke indicators: After CO_2, CO and CH_4, the largest emission factors are:

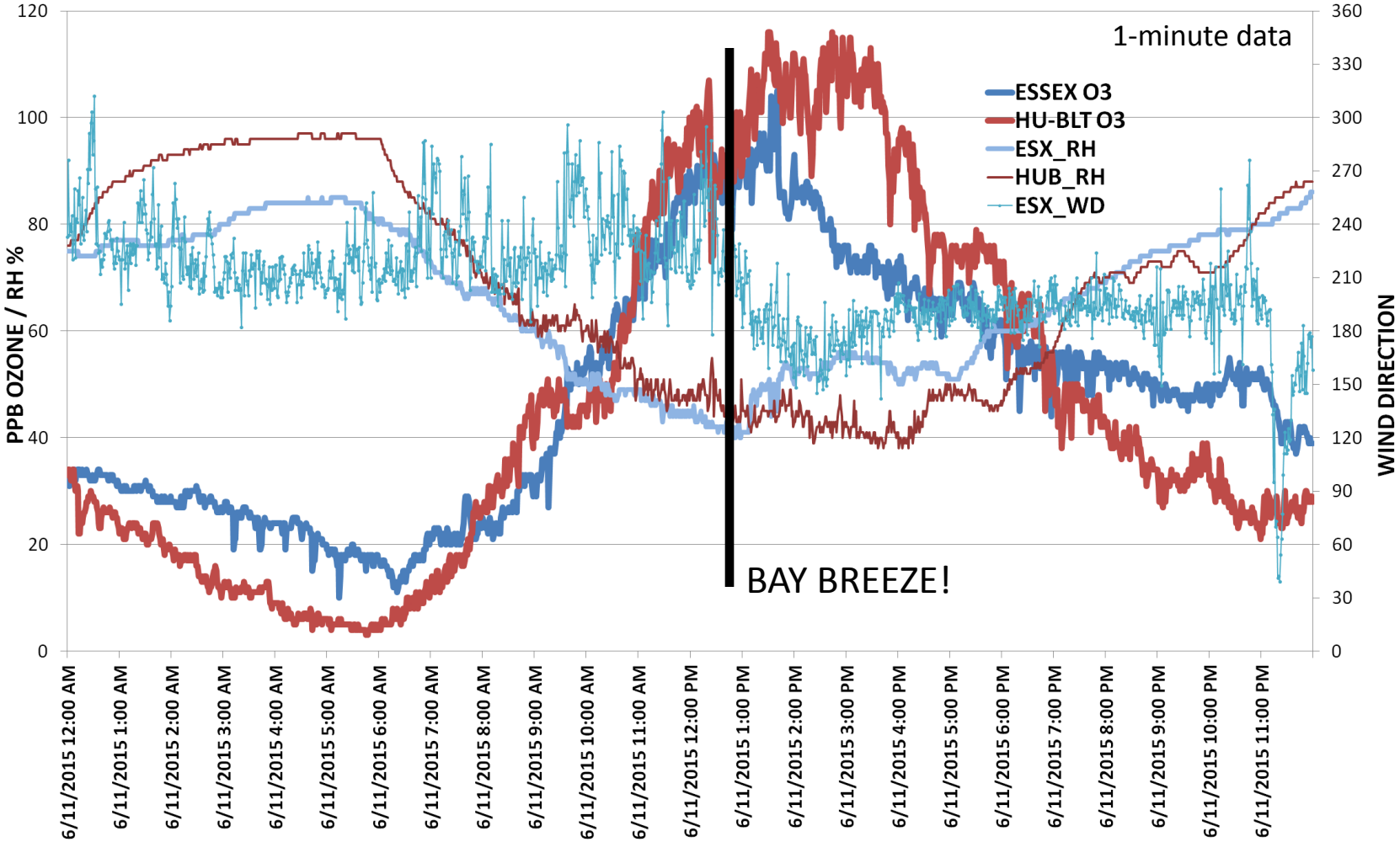
Formaldehyde (not <u>yet</u> available)
methanol, (not available)
pinenes(not <u>yet</u> available)
Ethene (yes)
NO_2 (yes)
HCN (cyanide) (not available)
Ethane (yes)
Benzene (yes)
propene (yes)
Toluene (yes)
Xylene (yes)
acetone and CH_3CN (not available)

By absolute concentration increase, isoprene and isopentane (96% increase) dominate all others at 2.22 and 2.06 ppbc change, respectfully, between 6/10 and 6/11.

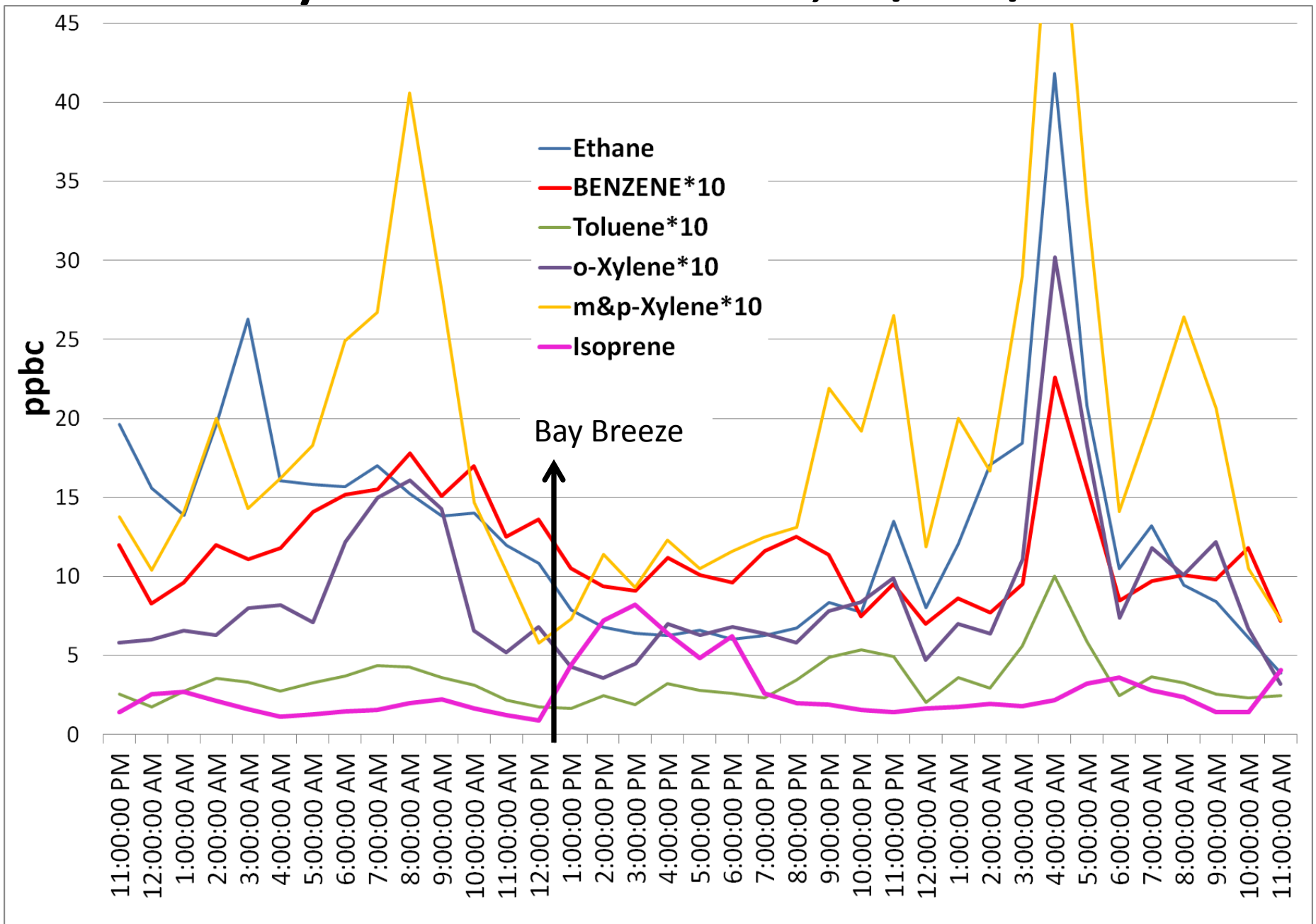
Essex and Howard University Beltsville

June 11	Max 8hr O3	24hr PAMs (ppbc)	24hr Avg NOX
Essex	75 (74)	89.6	13.5
HU-BLT	88	77.4	10.1

Why did Essex (and Edgewood) not exceed the 76ppb ozone NAAQS standard?



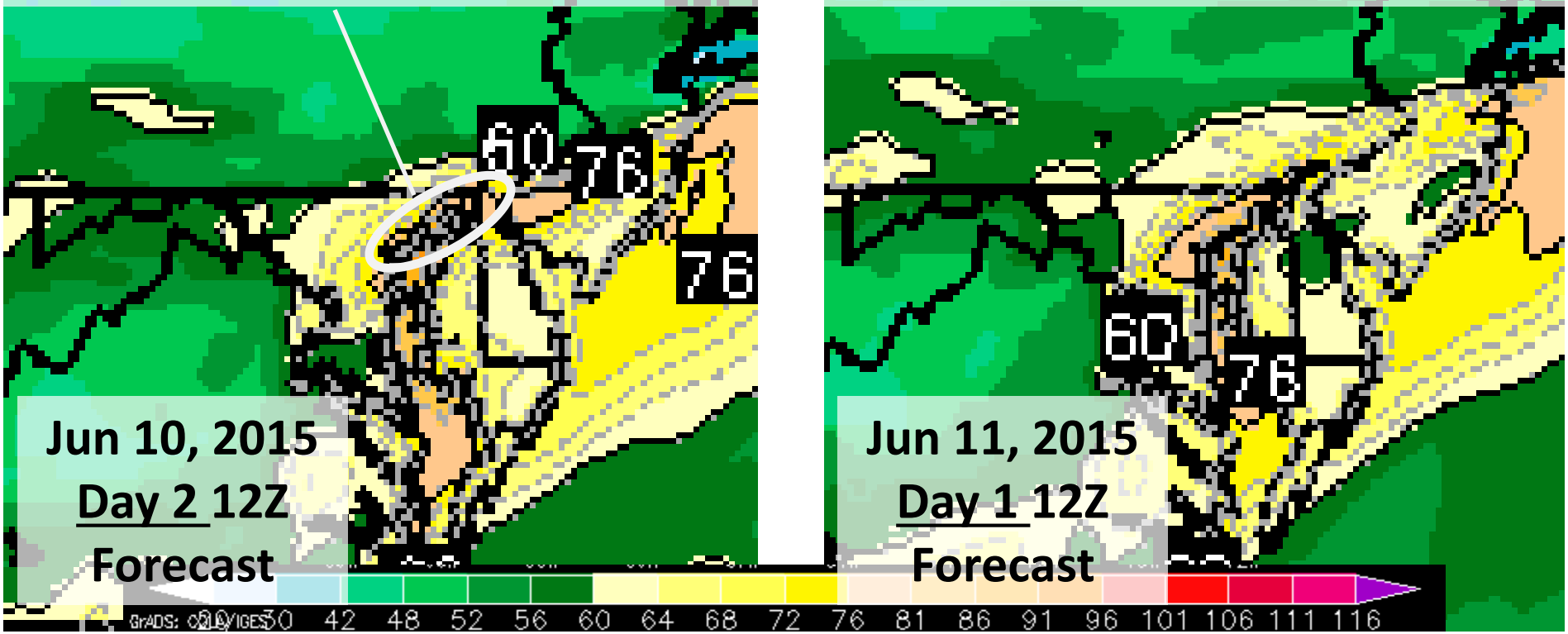
Hourly VOCs at Essex, 6/11/2015



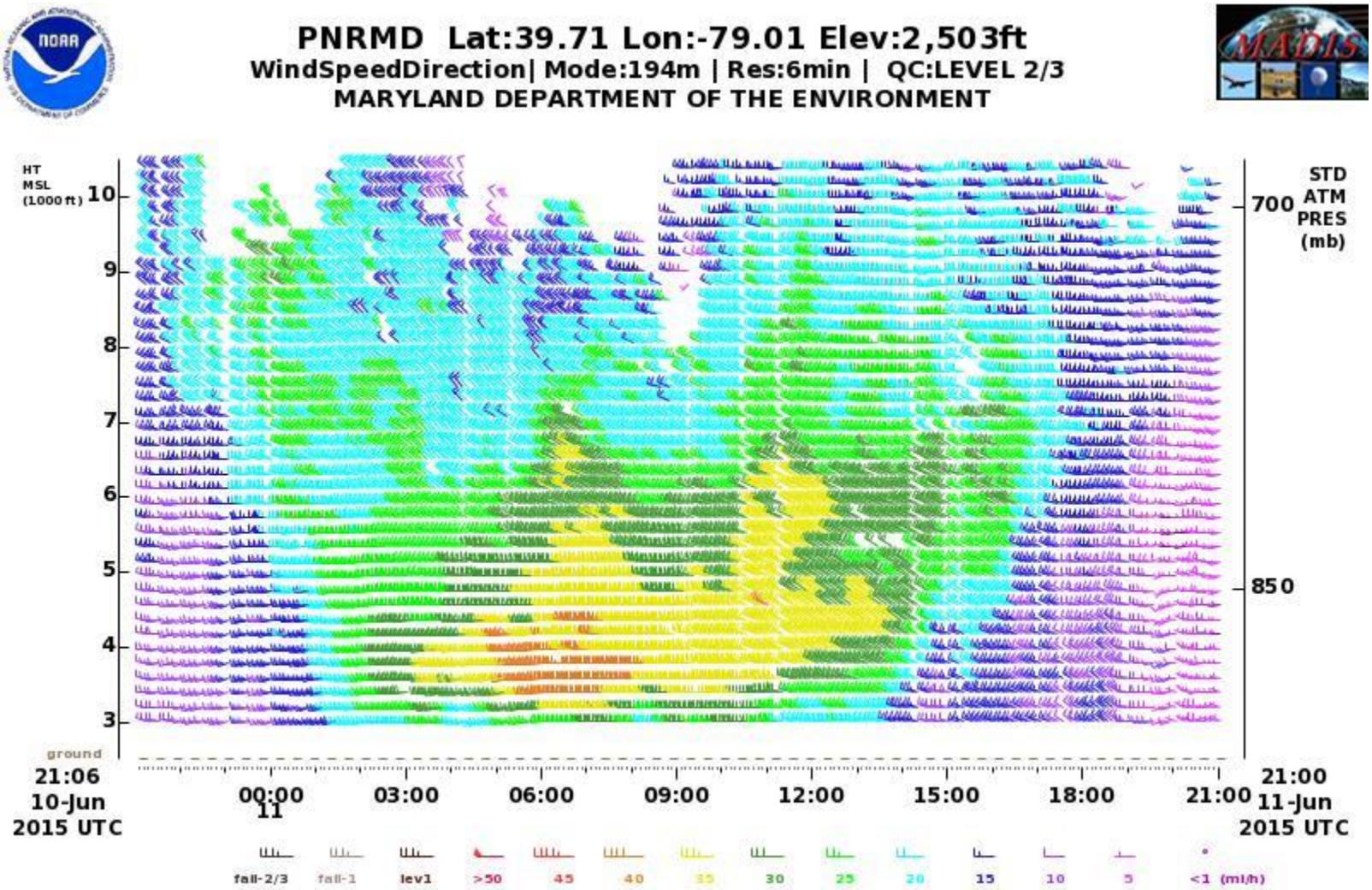
Exceptional Event – North Carolina Model

Neither the NOAA or North Carolina Model predicted an exceedance and/or the event magnitude, supporting the aid of smoke in ozone concentrations (since smoke was unaccounted for) and an exceptional event in Maryland.

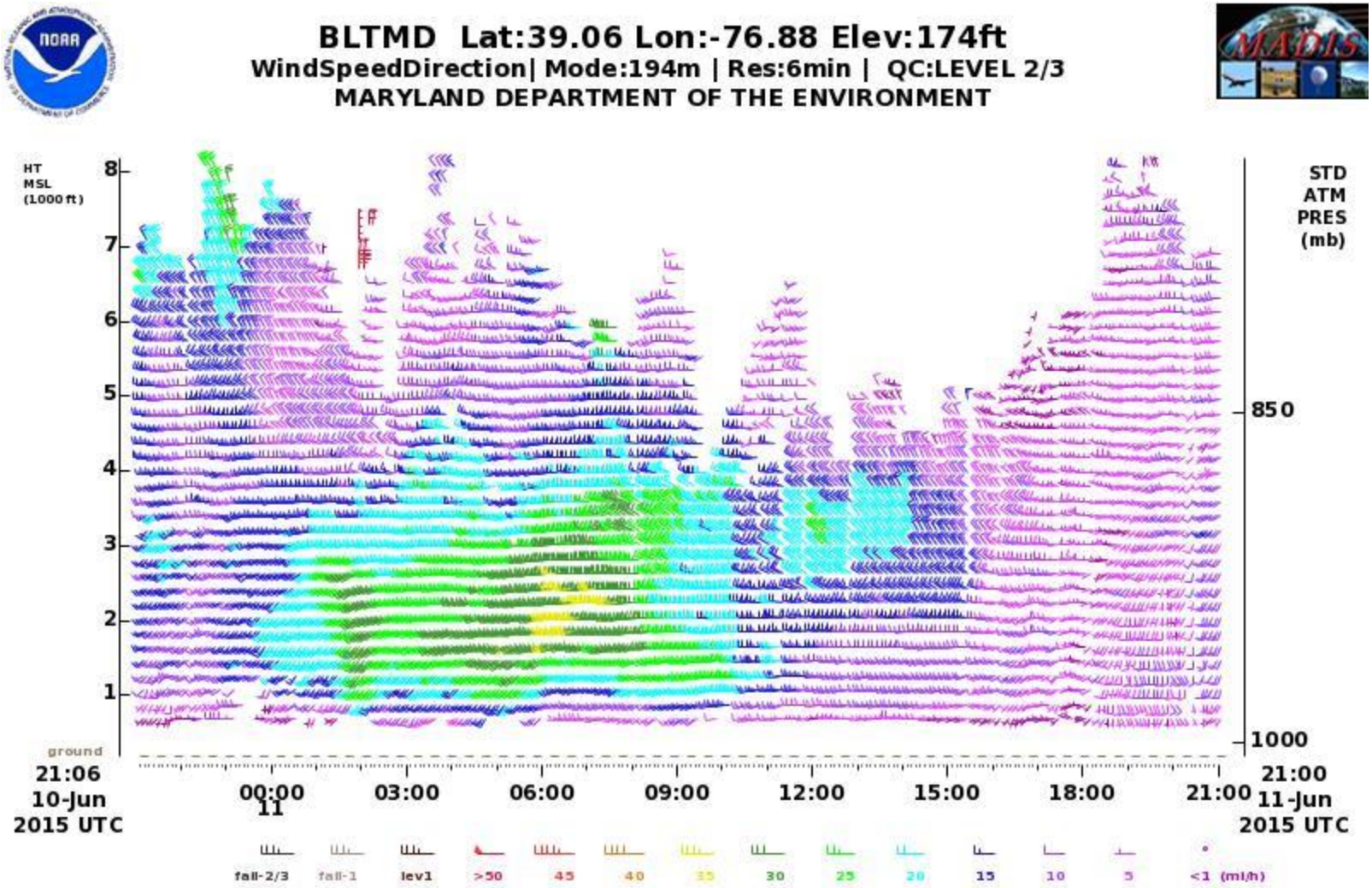
Neither Edgewood, Essex, or Furley exceeded as forecast in the AQ model. The event was NOT Bay related as indicated by the over-prediction of Bay ozone in the NOAA model. It should therefore NOT be concluded the orange AQ in the model was indicative of real conditions along I-95 and an exceedance would not have occurred except for the smoke.



Piney Run NLLJ 6/11



Beltsville NLLJ 6/11

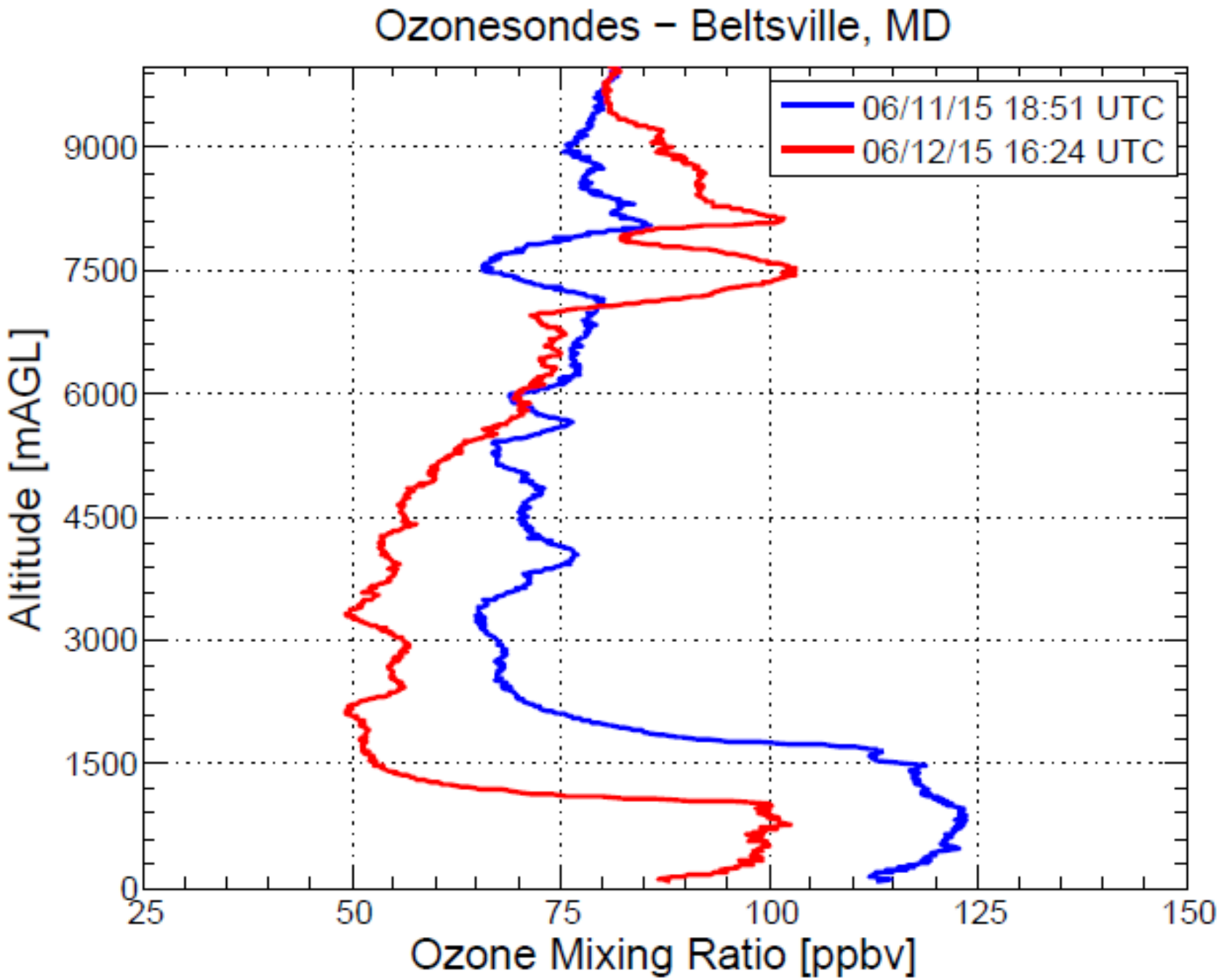


June 12, 2015 Non-Exceedance Post-Smoke Cleanout

Maryland

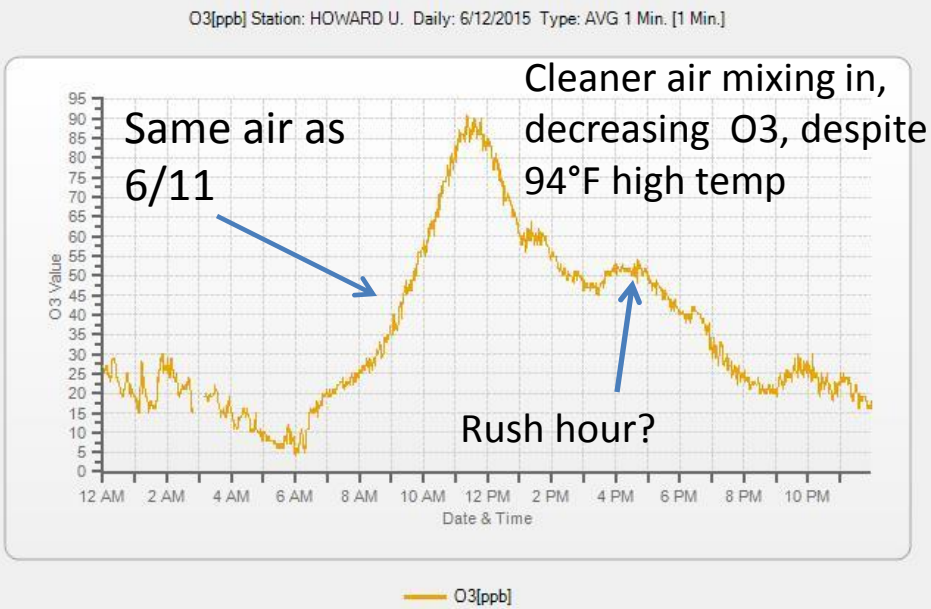
Summary

- Very quick clean-out from the south
- Strong vertical mixing and wind speeds resulted in:
  - Fairhill from 100ppb (6/11) to 60ppb (6/12)
  - Padonia, highest Maryland monitor: 71ppb
- Greater DC forecast region verified in the Good range (exception of HU-Beltsville at 60ppb)

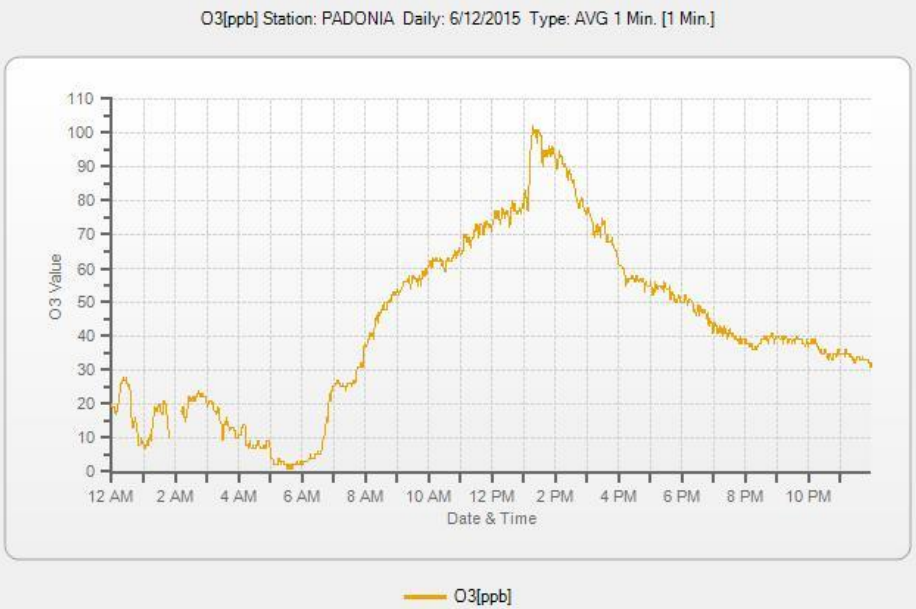

Ozonesondes – Beltsville, MD
06/11/15 18:51 UTC
06/12/15 16:24 UTC
Altitude [mAGL]
0
1500
3000
4500
6000
7500
9000
25
50
75
100
125
150
Ozone Mixing Ratio [ppbv]

1-Minute Ozone

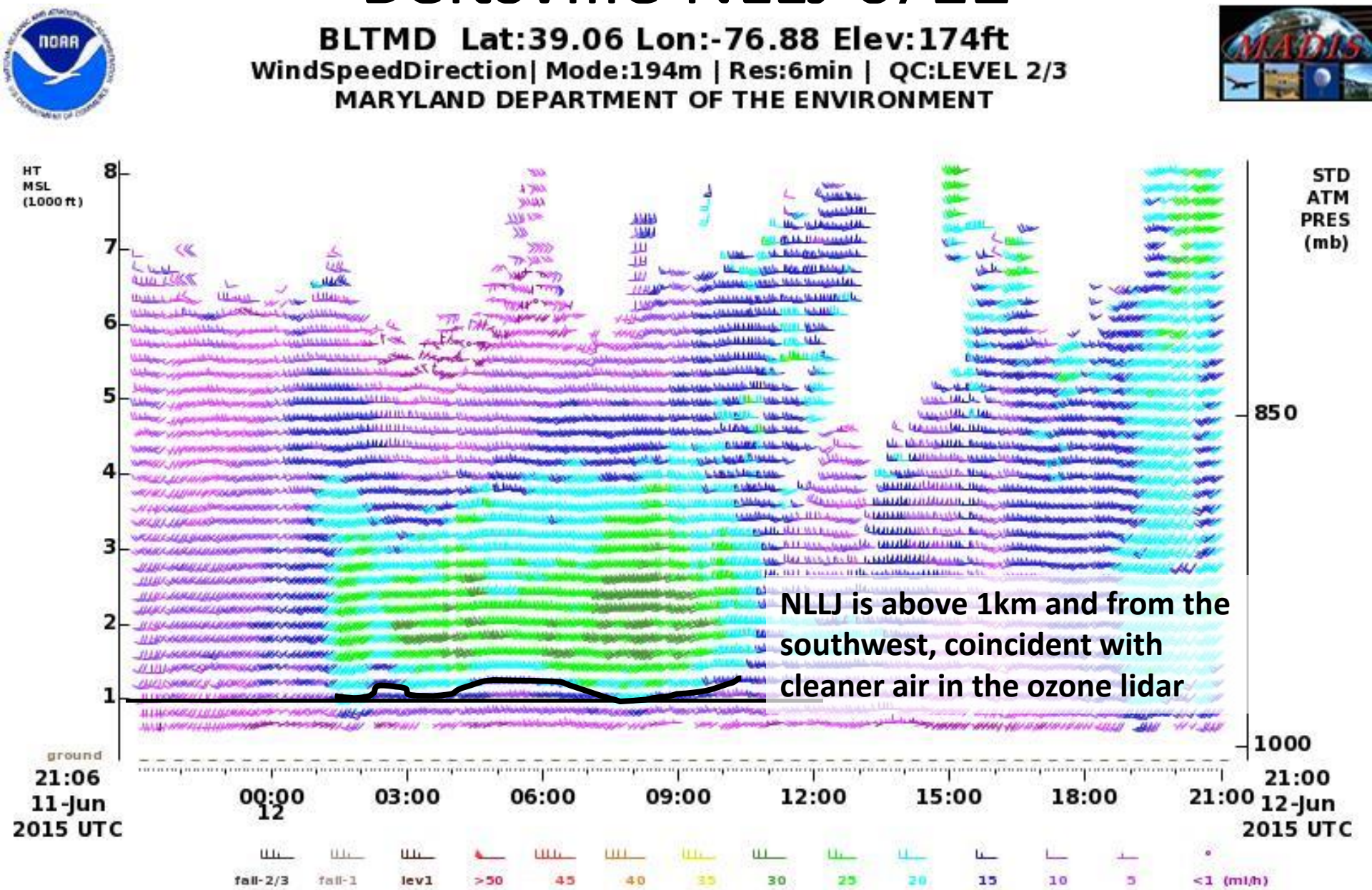
Beltsville



Padonia



Beltsville NLLJ 6/12



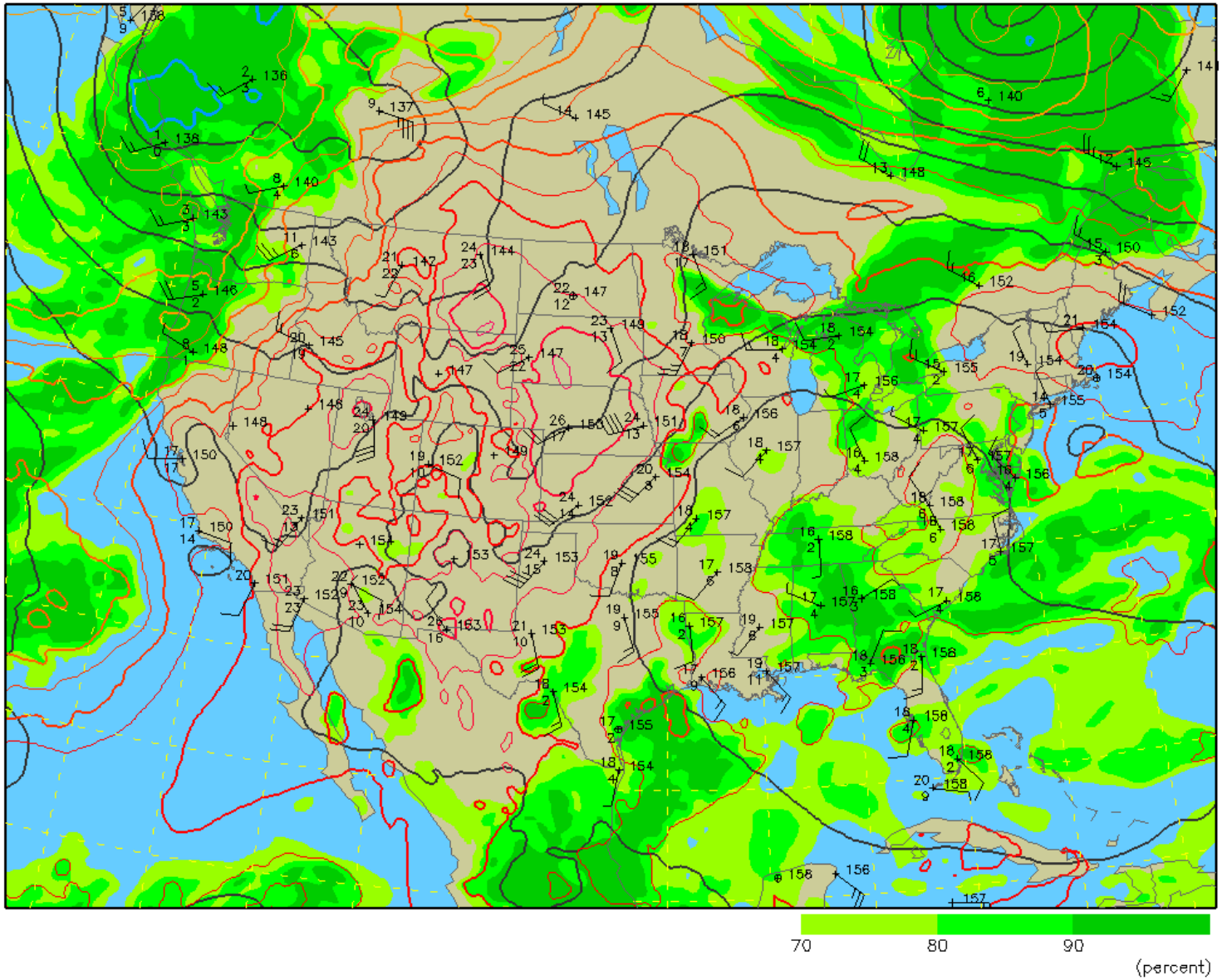
NLLJ is above 1km and from the southwest, coincident with cleaner air in the ozone lidar

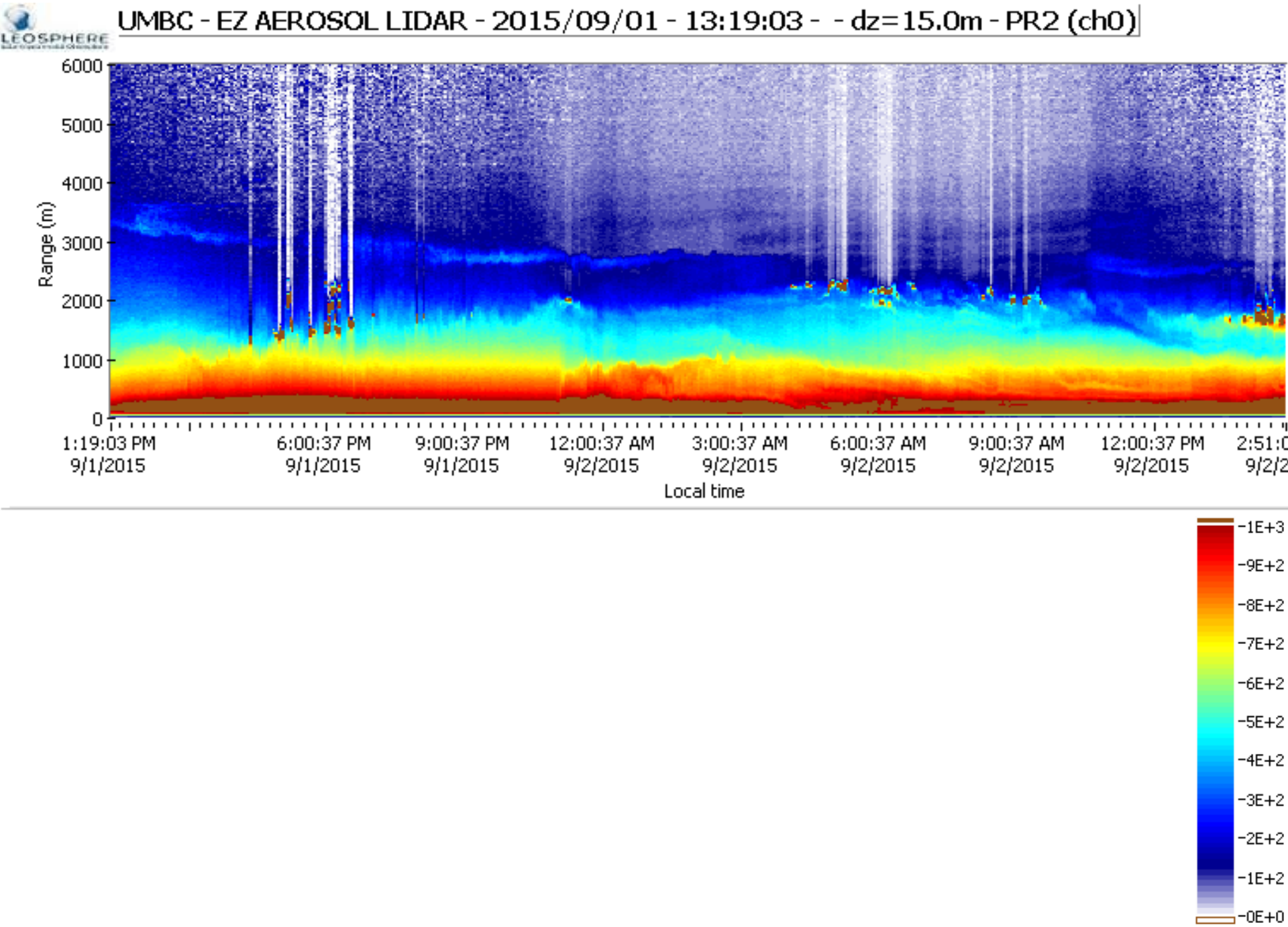
850 mb rawinsonde data 12z Wed 02 Sep 2015

850 mb Heights (dm) / Temperature (°C) / Humidity (%)

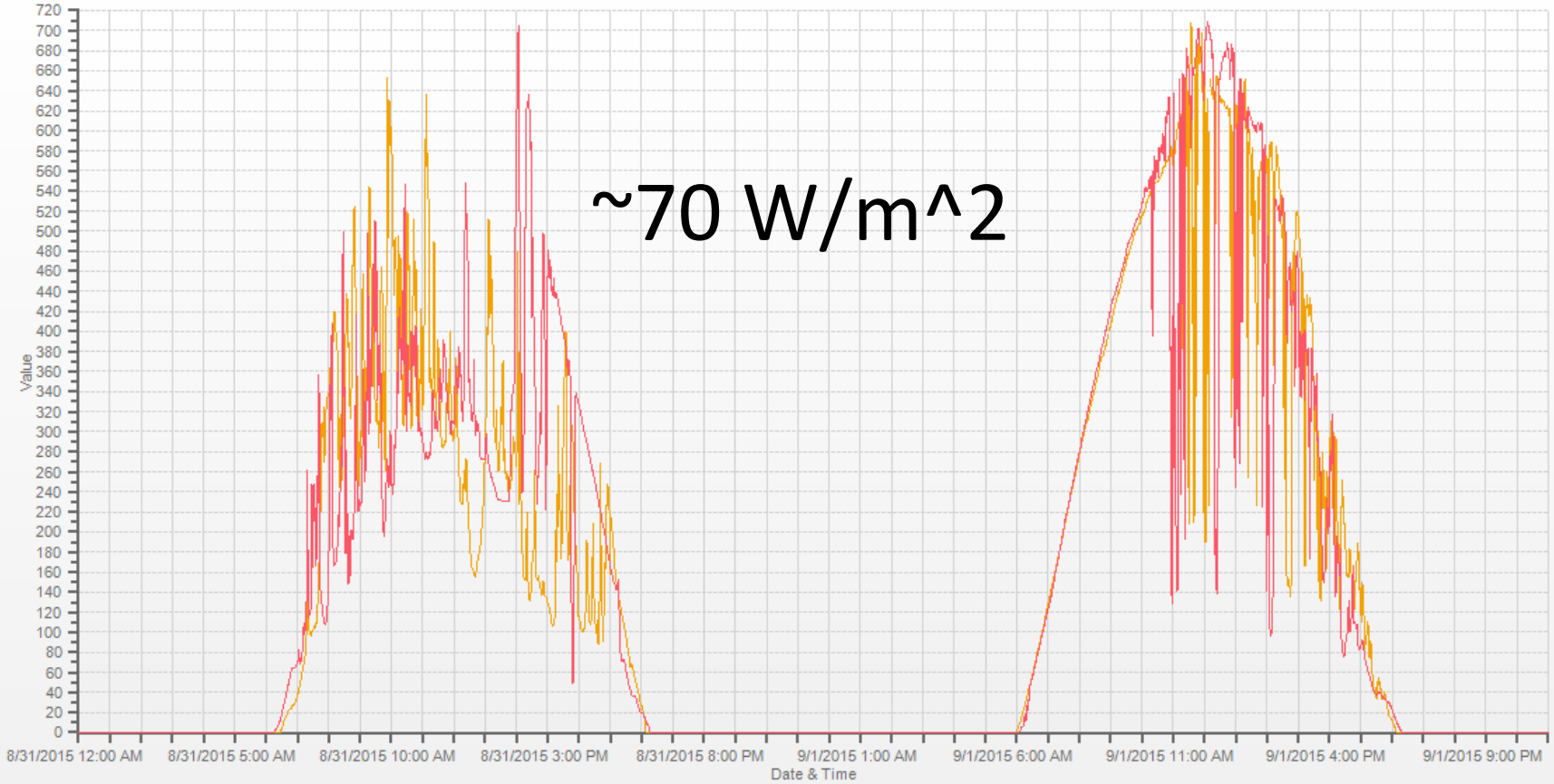
0-hour analysis valid 1200 UTC Wed 02 Sep 2015

RAP (12z 02 Sep)




UMBC - EZ AEROSOL LIDAR - 2015/09/01 - 13:19:03 - - dz=15.0m - PR2 (ch0)
LEOSPHERE
Range (m)
6000
5000
4000
3000
2000
1000
0
1:19:03 PM 9/1/2015
6:00:37 PM 9/1/2015
9:00:37 PM 9/1/2015
12:00:37 AM 9/2/2015
3:00:37 AM 9/2/2015
6:00:37 AM 9/2/2015
9:00:37 AM 9/2/2015
12:00:37 PM 9/2/2015
Local time
-1E+3
-9E+2
-8E+2
-7E+2
-6E+2
-5E+2
-4E+2
-3E+2
-2E+2
-1E+2
-0E+0

MultiStation: Periodically: 8/31/2015 12:00 AM-9/1/2015 11:00 PM Type: AVG 1 Min.



ESSEX(Solar Rad[W/M2]) HOWARD U.(Solar Rad[W/M2])

Analysis day: 20150901
Map generated: 1806 GMT 20150902
AVAILABLE
Analysis day: 20150902
Map generated: 0112 GMT 20150903