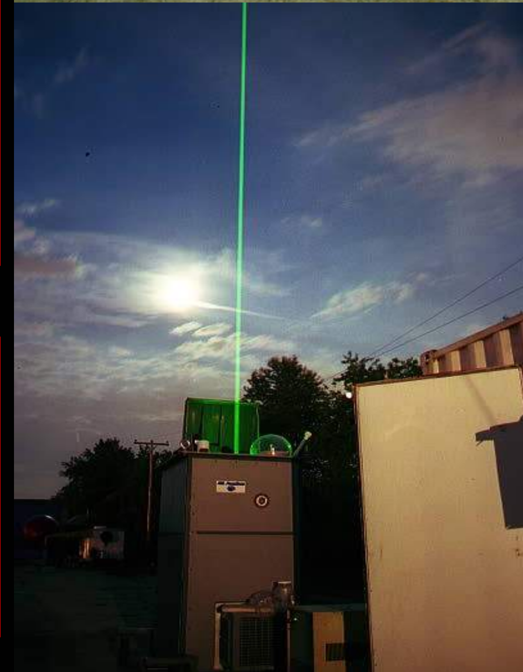
Science is as science does: Authentic learning by engaging students in research

By

Richard D. Clark

Richard.Clark@millersville.edu

2009 Unidata Users Workshop Using Operational and Experimental Observations in Geoscience Education June 8 - 12, 2009 in Boulder, CO



NARSTO - NE-OPS

North American Research Strategy for Tropospheric Ozone – Northeast Oxidant and Particle Study

Research Consortium Members

Penn State University - C.R. Philbrick (PI)
Lidar remote sensing, atmospheric structure and dynamics

Millersville University - R. D. Clark
Boundary layer meteorology, air chemistry, tethered balloon measurements

Harvard University
School of Public Health - P. Koutrakis
Atmospheric gas and aerosol chemistry
Engineering and Applied Science - J. W. Munger
NO_y measurements

University of Maryland - R. Dickerson, B. Doddridge
Instrumentation and use of small aircraft

Philadelphia Air Services Management Laboratory - W. C. Miller
Philadelphia PAMS, PM monitor at prime site

State University of New York - S. T. Rao,
Analysis and model calculations of air masses

Rutgers University, Envir. and Occupational Health - P. Georgopoulos
Emissions inventories and chemistry modeling

Brookhaven National Laboratory - L. Newman, P. Daum
Highly instrumented aircraft (G-1) chemistry and aerosol properties

View of Baxter Water Treatment Plant from over Delaware River looking northwest toward Northeast Philadelphia Airport

View of Baxter Water Treatment Plant from over Delaware River looking south-southwest toward downtown Philadelphia

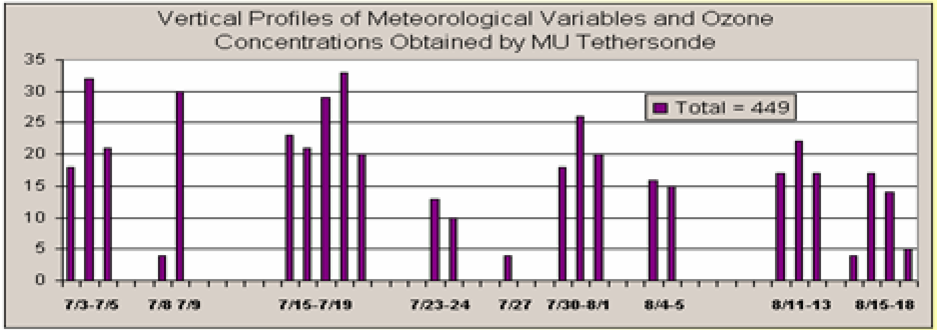
Instrument Platforms


N500Z
NO SMOKING
Battelle

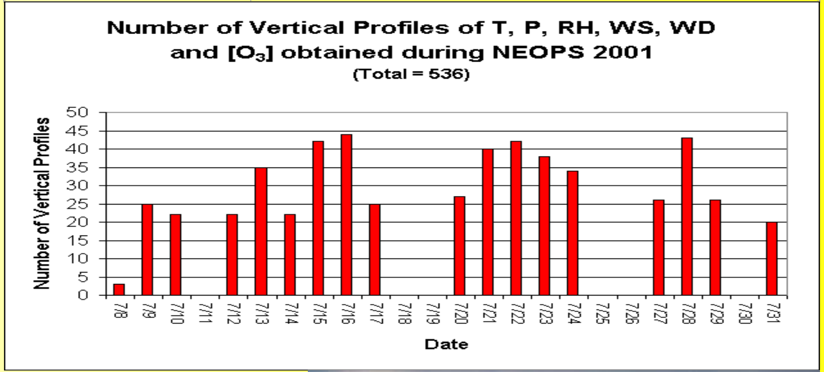
Undergraduate Research

1999- 2001 Episodes

Date	Description of 1999 Episodes
Jul 3-5	Warm sector, high temps (37.2 C), strong low level wind, Code Orange O_3
Jul 8-10	Frontal passage 7/8, warm sector 7/9 with strong 850 hPa advection. Moderate wind, Code Yellow O_3 with Code Orange west of site.
Jul 15-20	Strongest O_3 episode of season. Ramp-up and recirculation event followed by stagnation. Weak W to SW wind with strong Bermuda High. 17 1-hour exceedances on 7/19. Ramp-up [$PM_{2.5}$].
Jul 23-24	Recirculation late 7/22 followed by SW wind and Code Orange O_3. Upper level ridge brings warm 850 hPa temps. TRWs end the episode on 7/24.
Jul28-Aug 1	Lower O_3 levels 7/28-7/30 with W wind followed by lee trough on 7/31, SW wind, spike of 165 ppbv O_3 and passage of sea breeze front. Mobile trough on 8/1 ends the episode. High [$PM_{2.5}$] correlate with low [O_3].
Aug 4-5	High O_3 levels disturbed by frontal passage, NW winds and low T_d keep O_3 in Code Orange. Reduced temps.
Aug 11-13	Warm sector, recirculation of high O_3 before passage of bay breeze, strong bay breeze on 8/12 cleanses.
Aug 16-17	Similar meteorology to Aug 11-13 with spike in O_3 on 8/17.



Date	Description of 2001 Episodes
July 10	Recirculation brings WSW wind, temps > 30 C, leading to single-day spike in O_3, followed by strong afternoon convection.
July 17	Highest O_3 (120 ppbv) in July at site, convergence between backdoor front in NY and disturbance in the midwest.
July 21-25	Intermittent high O_3 associated with northward movement of Bermuda High.



<u>MU Measurements</u>

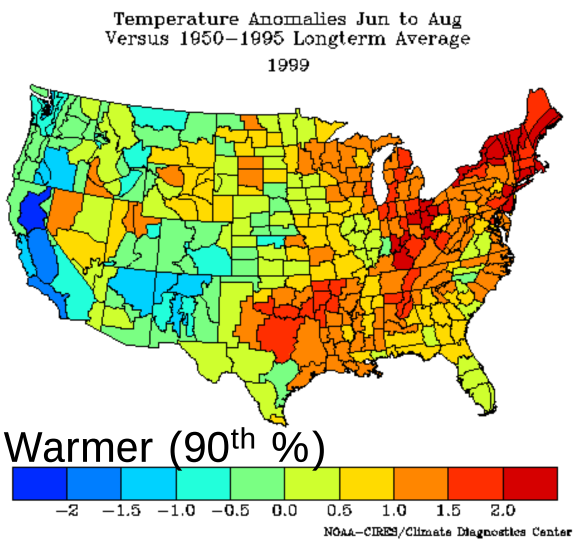
T, p, RH, wind speed and direction, O_3

Date	Description of 2002 Episodes
July 1-3	"Cut-off low; High O_3, particle, and haze event, strong nocturnal jet; many one-hour exceedances.
July 6-7	Canadian wildfires; highest particulate matter event in four years, priming conditions for high O_3 on July 8-9.
July 8-9	Recirculation event; highest O_3 on July 8th, 150 ppbv; Haze and high O_3 on July 9th.
July 17-19	High O_3 and haze event; Code Orange spread northerly along I-95 corridor from Philadelphia to New York
July 22-23	Hot and humid conditions but strong winds kept O_3 in moderate range in PA; CT and MA reported Code Red
July 28-29	Convergence along leeside trough brings moderate O_3 levels into PA; Temperatures in 80 F keep O_3 from reaching Code Red; Haze present due to high (70 F) dewpoints
July 31-Aug 5	Highest O_3 from IAD to NYC along I-95 corridor; Stagnation event and large areas of Code Red and Code Orange.

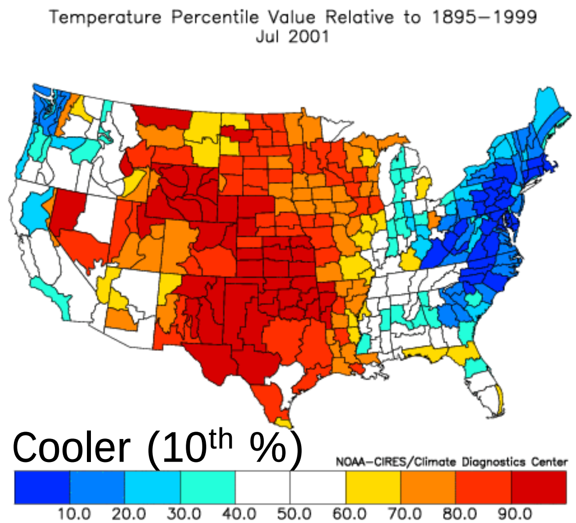
Courtesy NCEP CDC

Seasonal Comparison

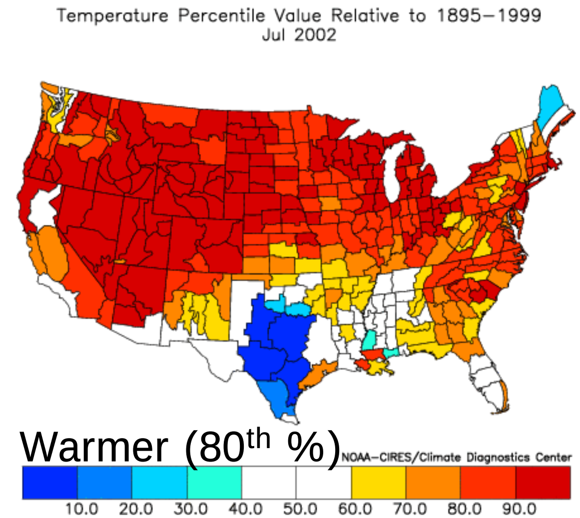
Summer 1999	Summer 2001	Summer 2002



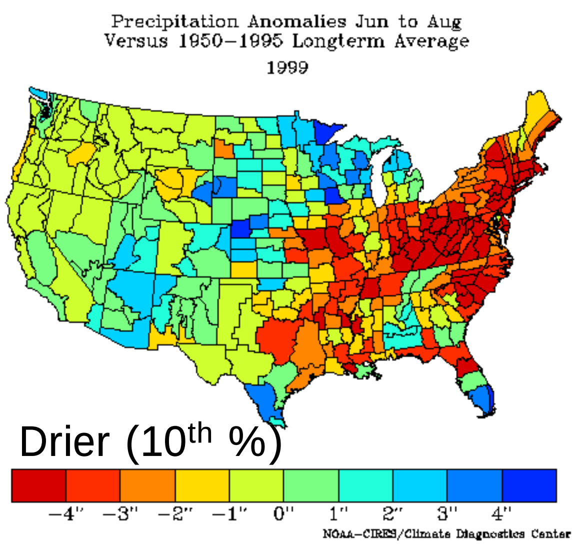
Warmer (90th %)



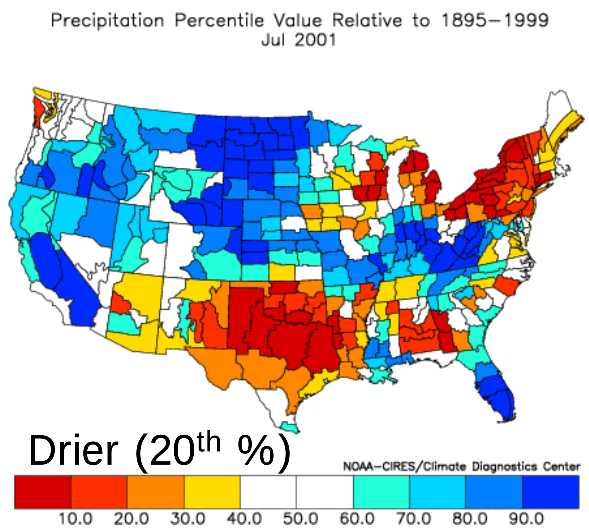
Cooler (10th %)



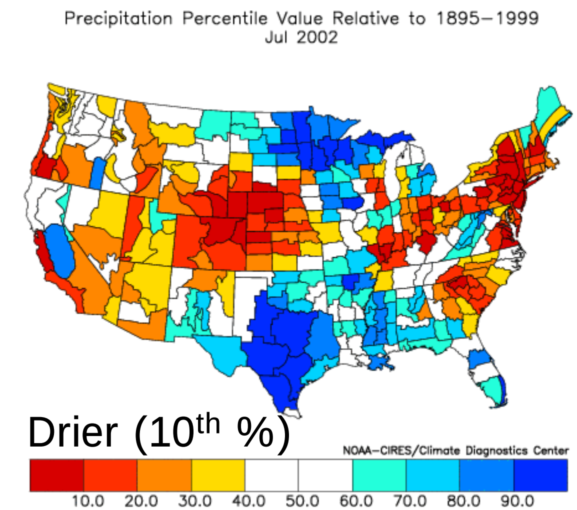
Warmer (80th %)



Drier (10th %)



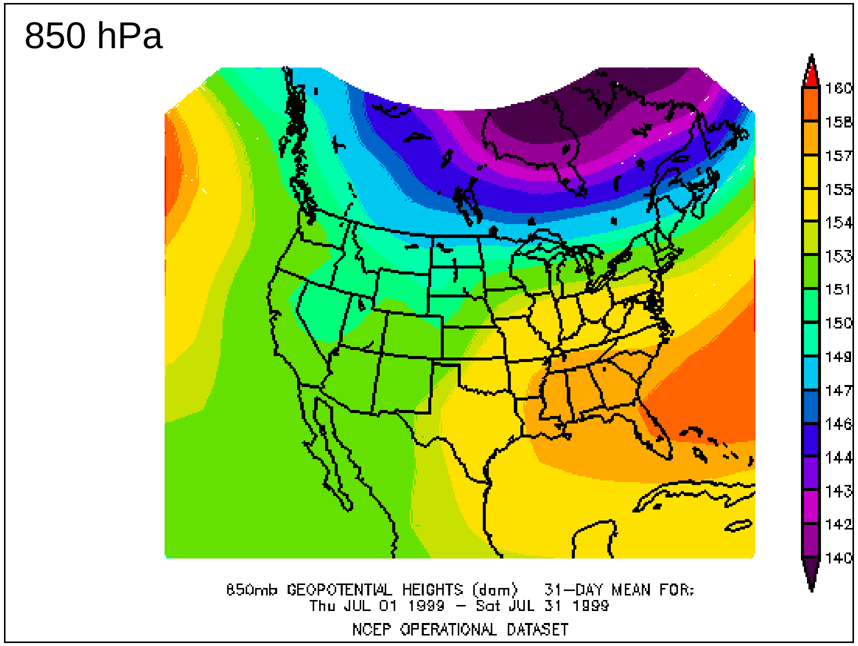
Drier (20th %)



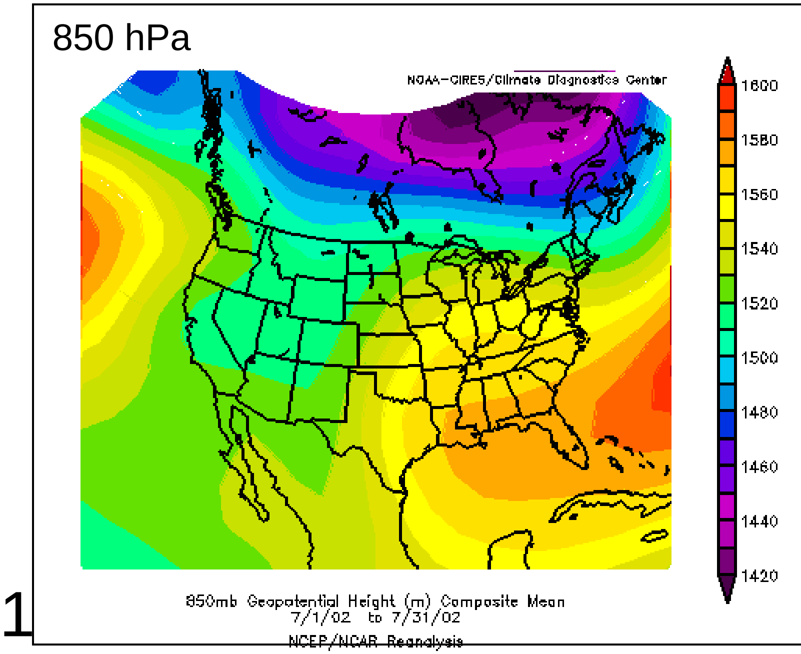
Drier (10th %)

Mean Geopotential Height

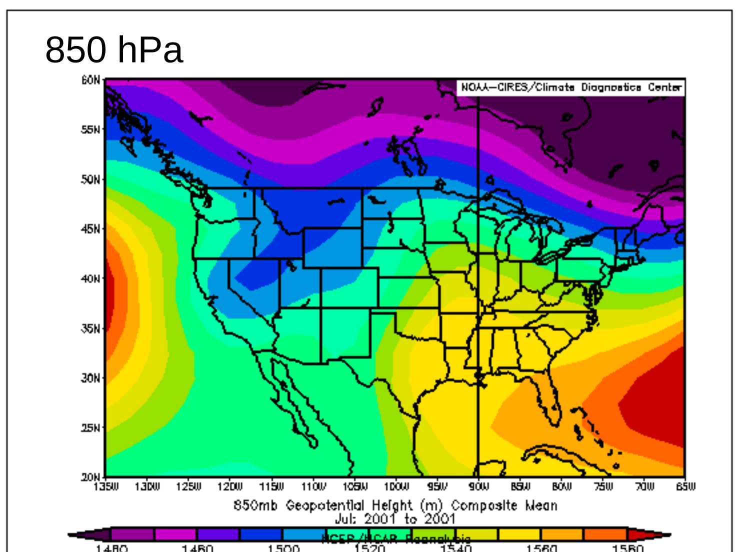
1999



2002



2001

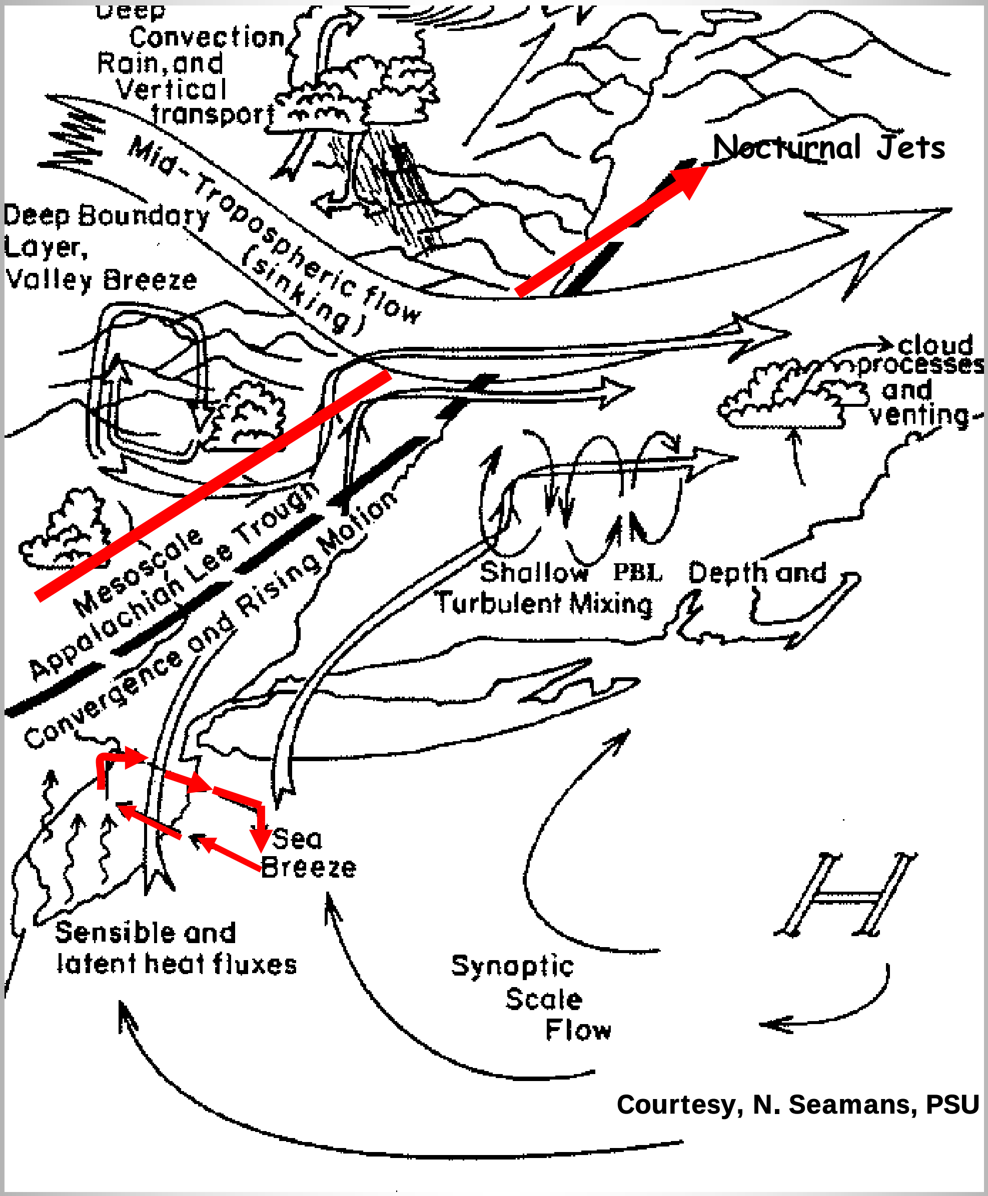


Mean geopotential height (m) for the period

July 1-31, 1999 (LEFT),
July 1-31, 2001 (CENTER),
July 1-31, 2002 (RIGHT).

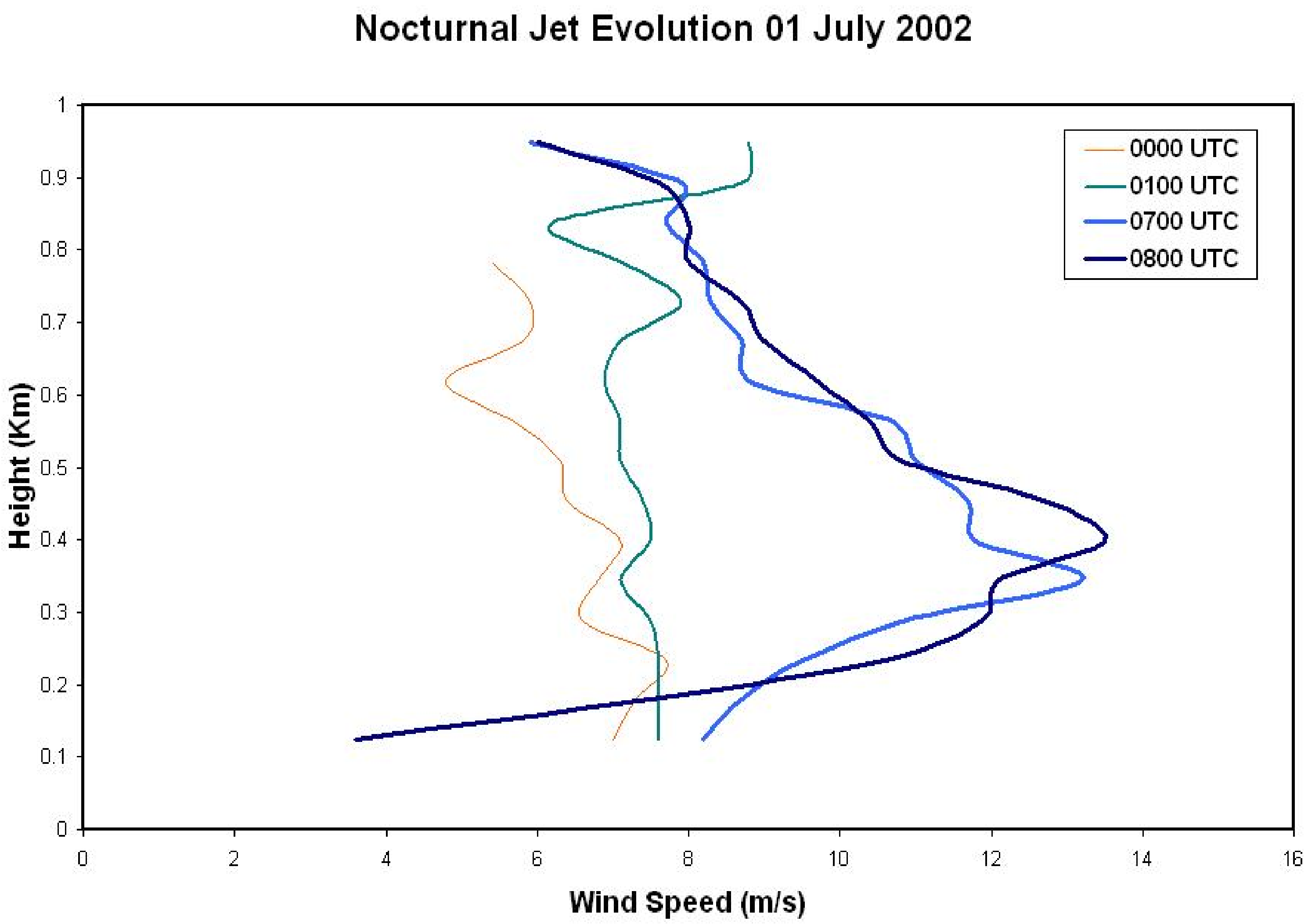
Figure courtesy of NCEP Climate Diagnostics Center (CDC)

Local and Regional Circulations



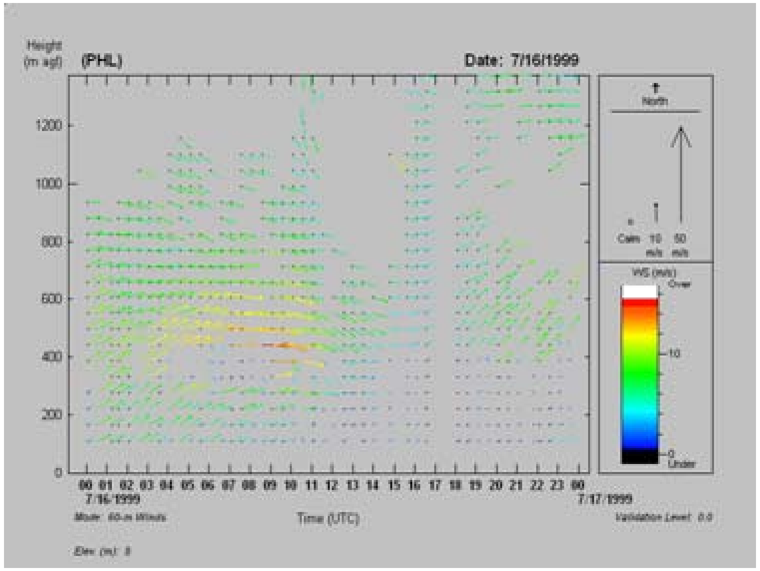
Characteristics of Mid-Atlantic LLJs

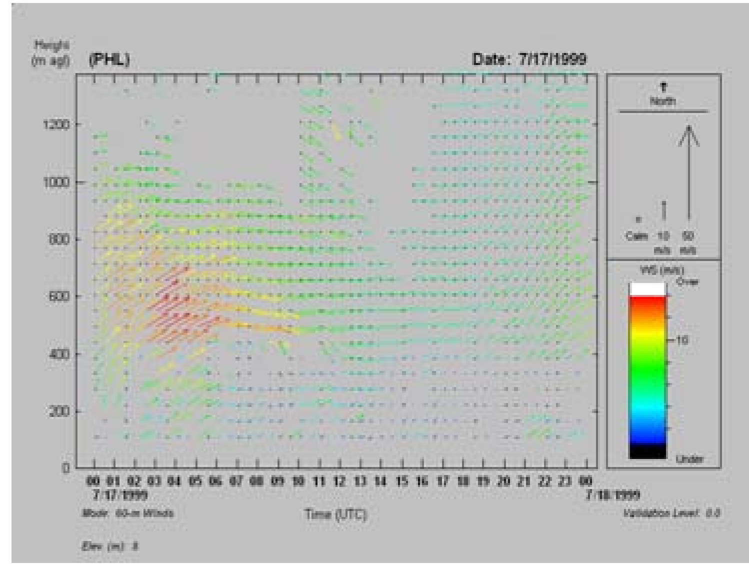
- Common under clear sky, high pressure conditions, which allows for maximum differential heating/cooling
- Typically a southerly component (SE, S, SW) depending on the orientation of the average BL PGF
- Generally confined to a shallow layer 300-800 m AGL
- Observed wind speeds 10-15 m/s
- Distinctly boundary layer forced dynamics
- Characteristic inertial oscillation (observed)
- Displays considerable variability in reaching maximum wind speed
- Significant influence on the air chemistry of the mid-Atlantic region

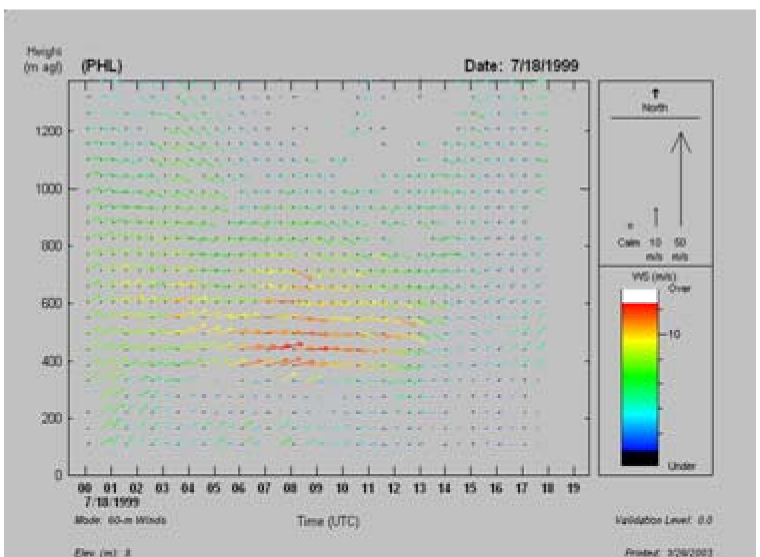


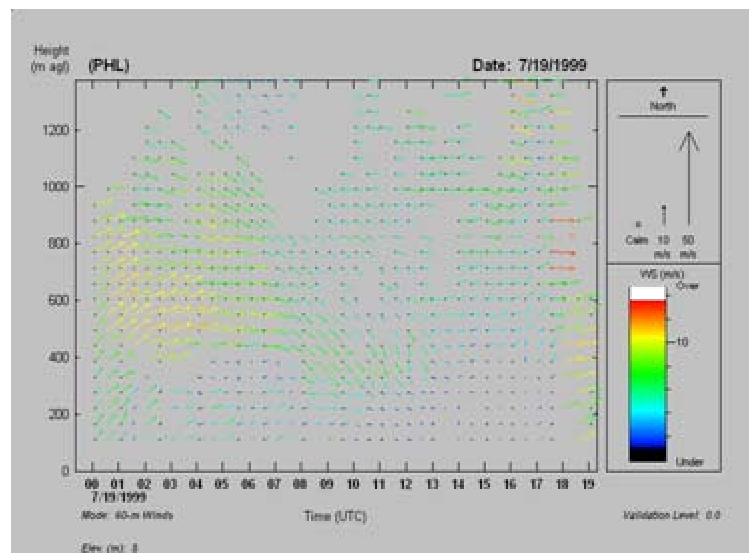
Courtesy, Sachin Verghese, PSU

Boundary Layer LLJs of 1999

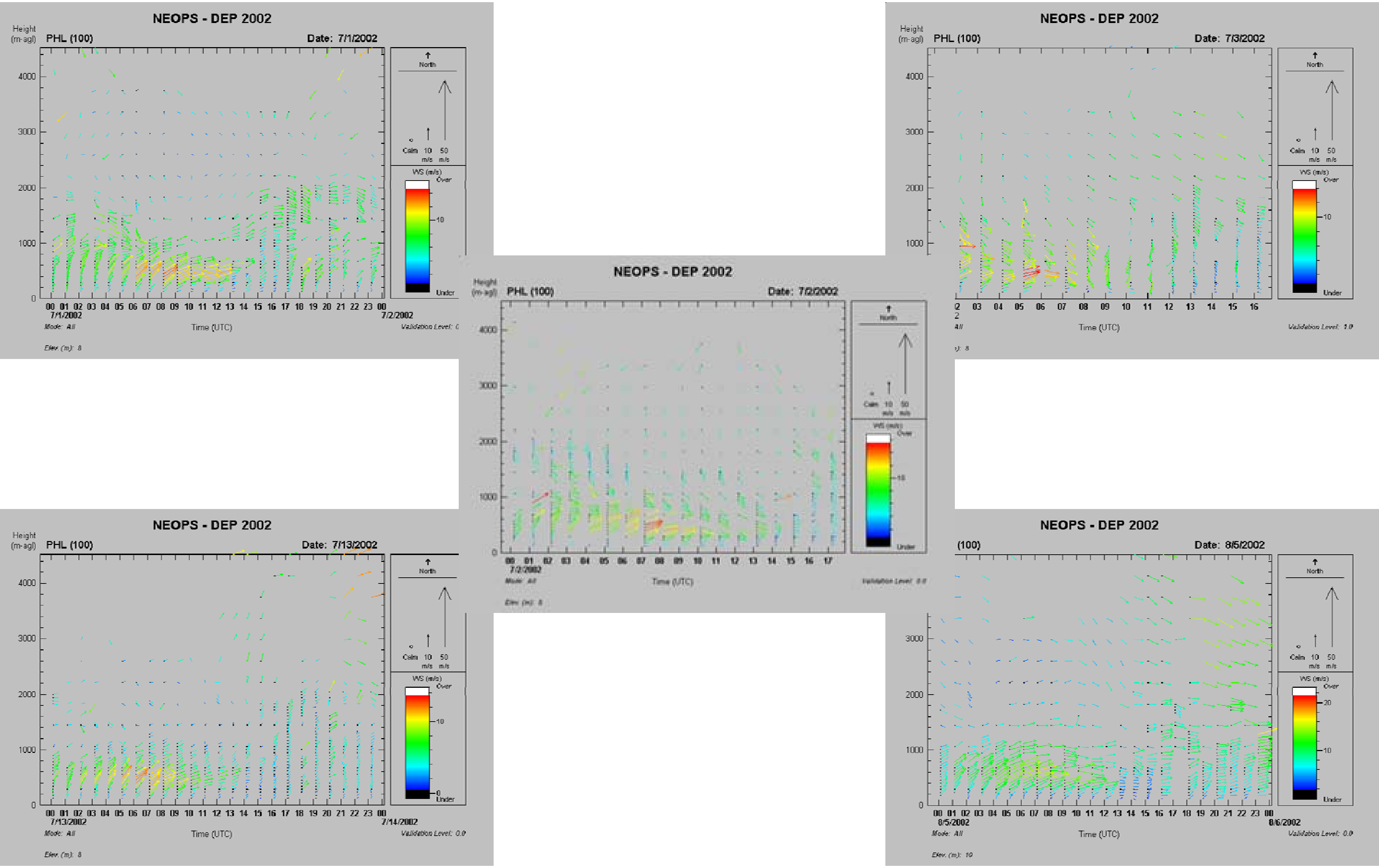




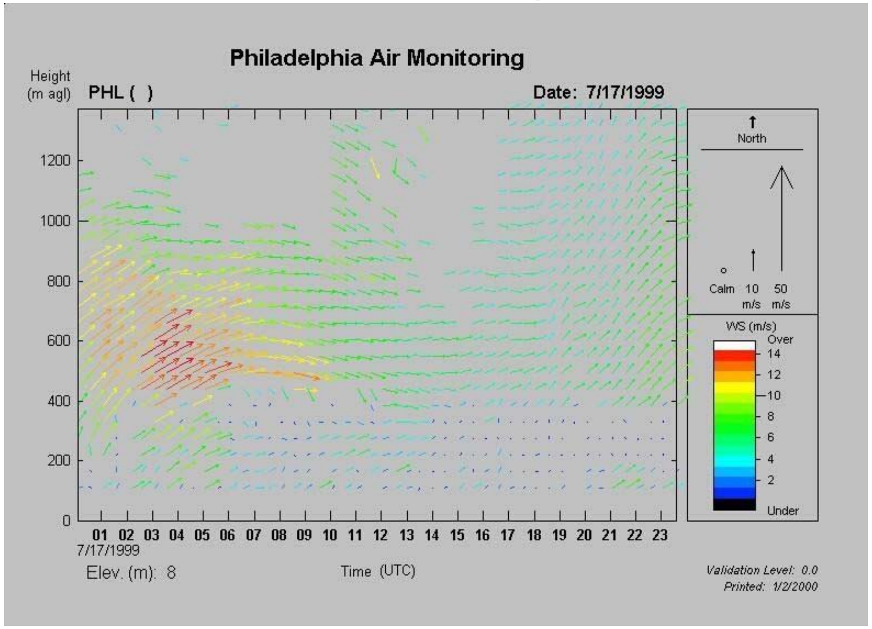


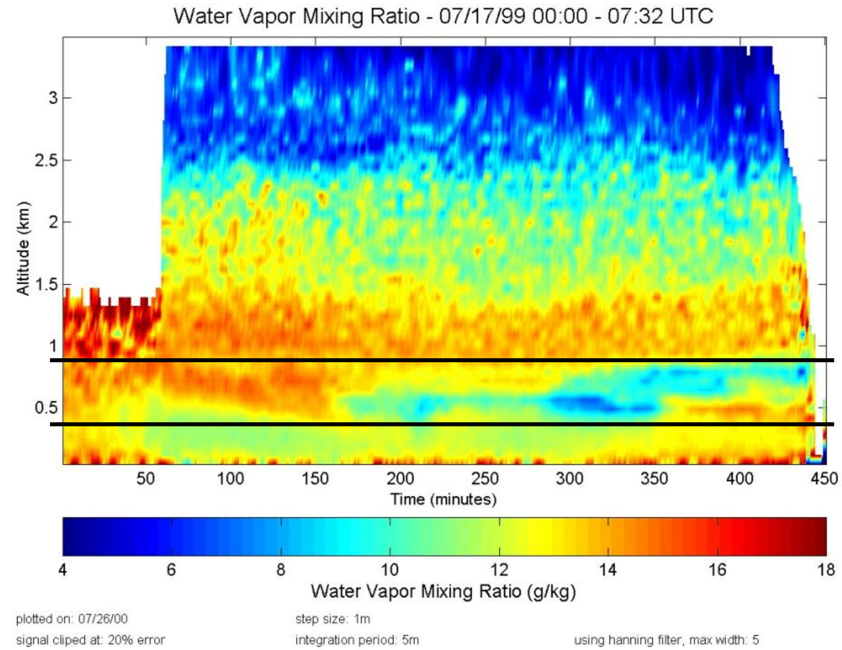


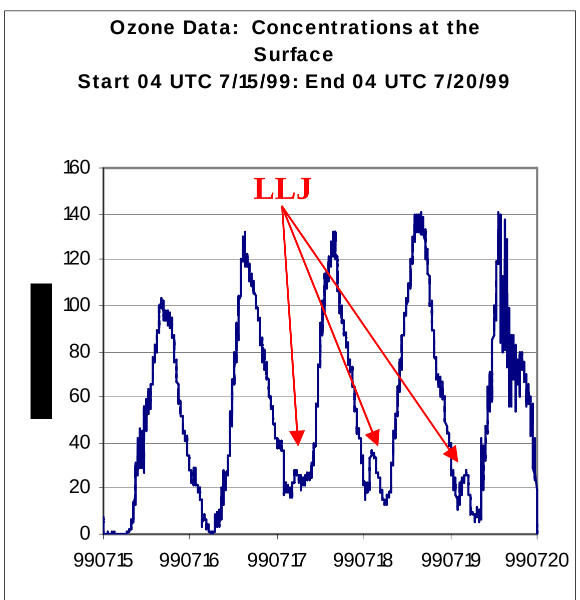
Boundary Layer LLJs of 2002

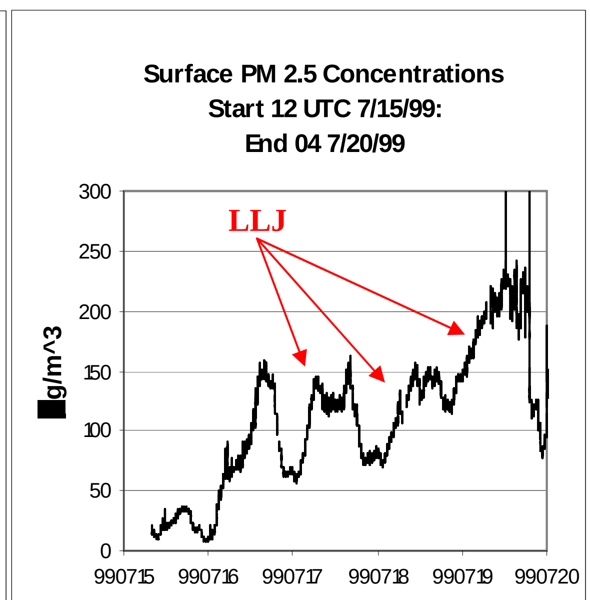


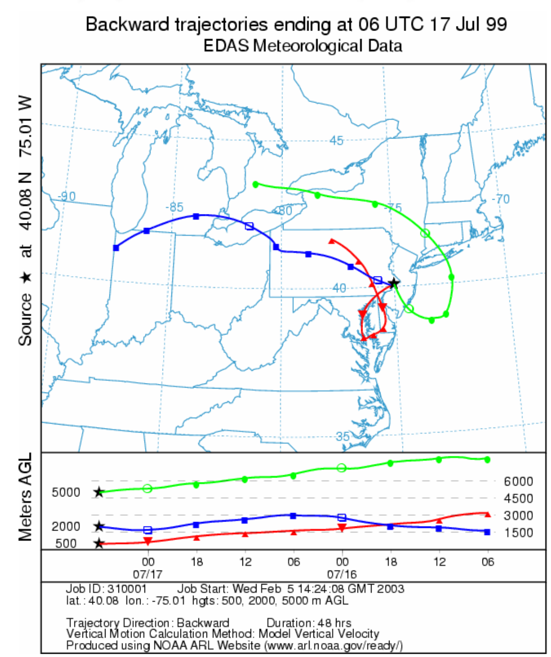
Observational Signatures

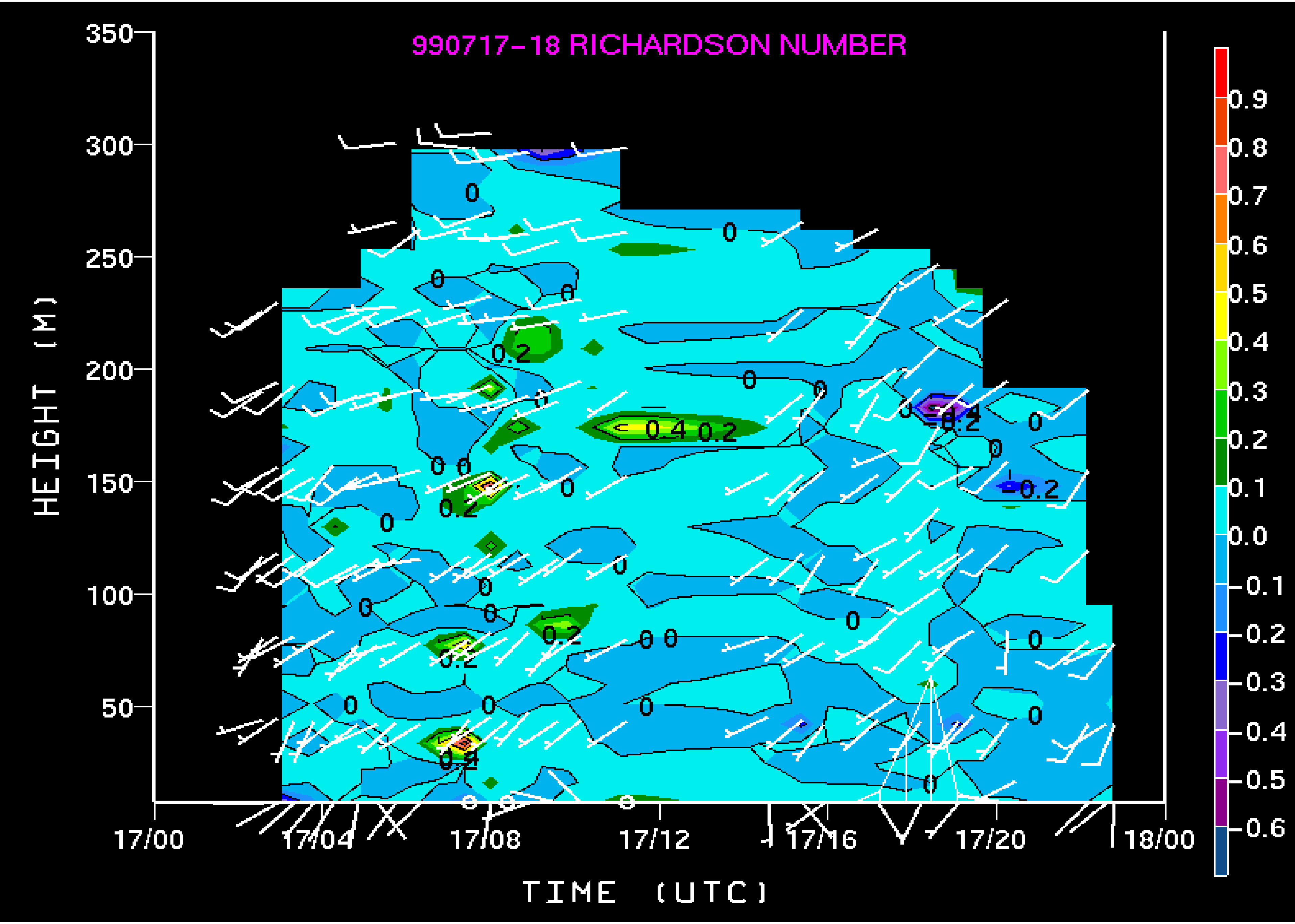


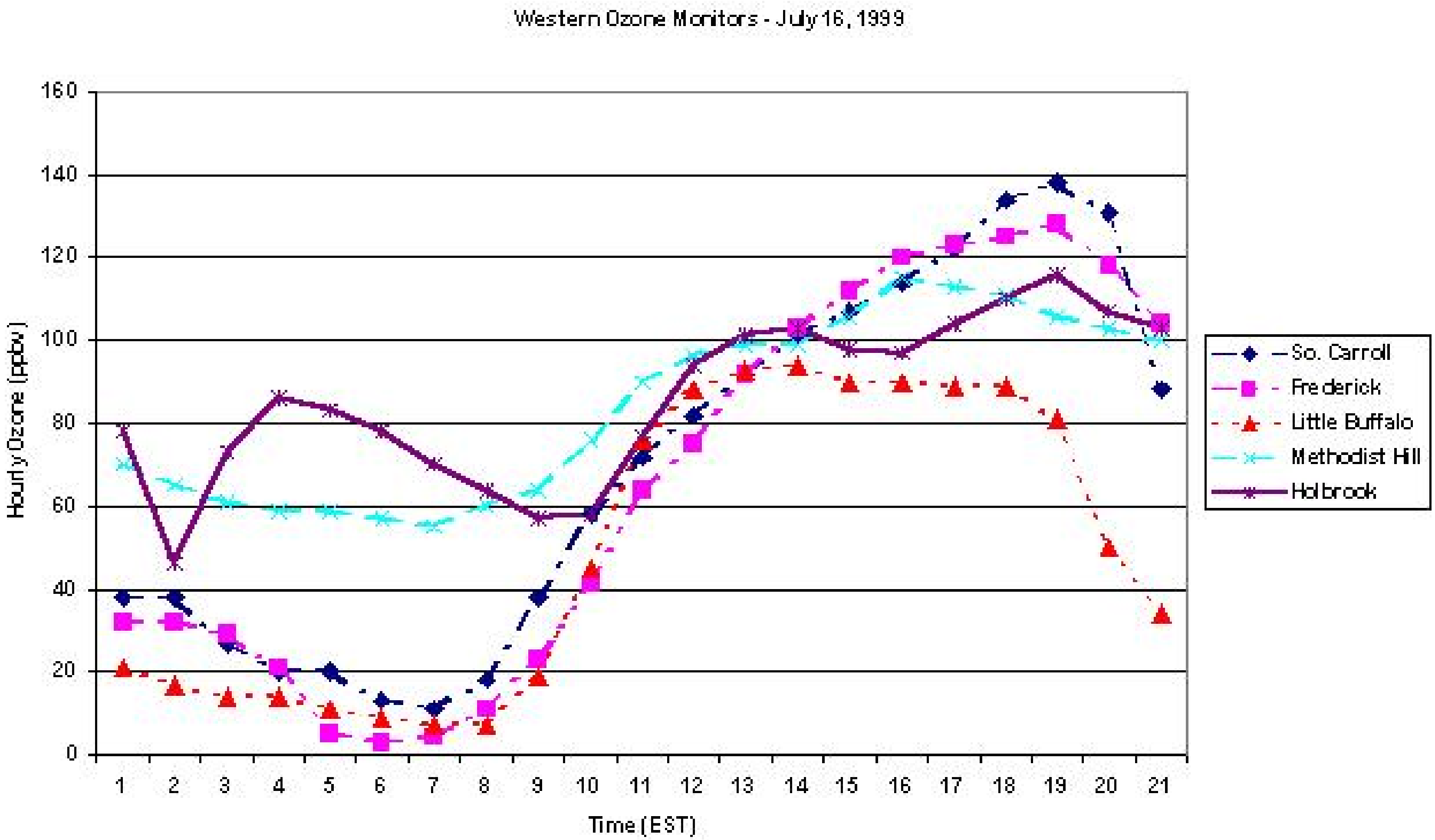




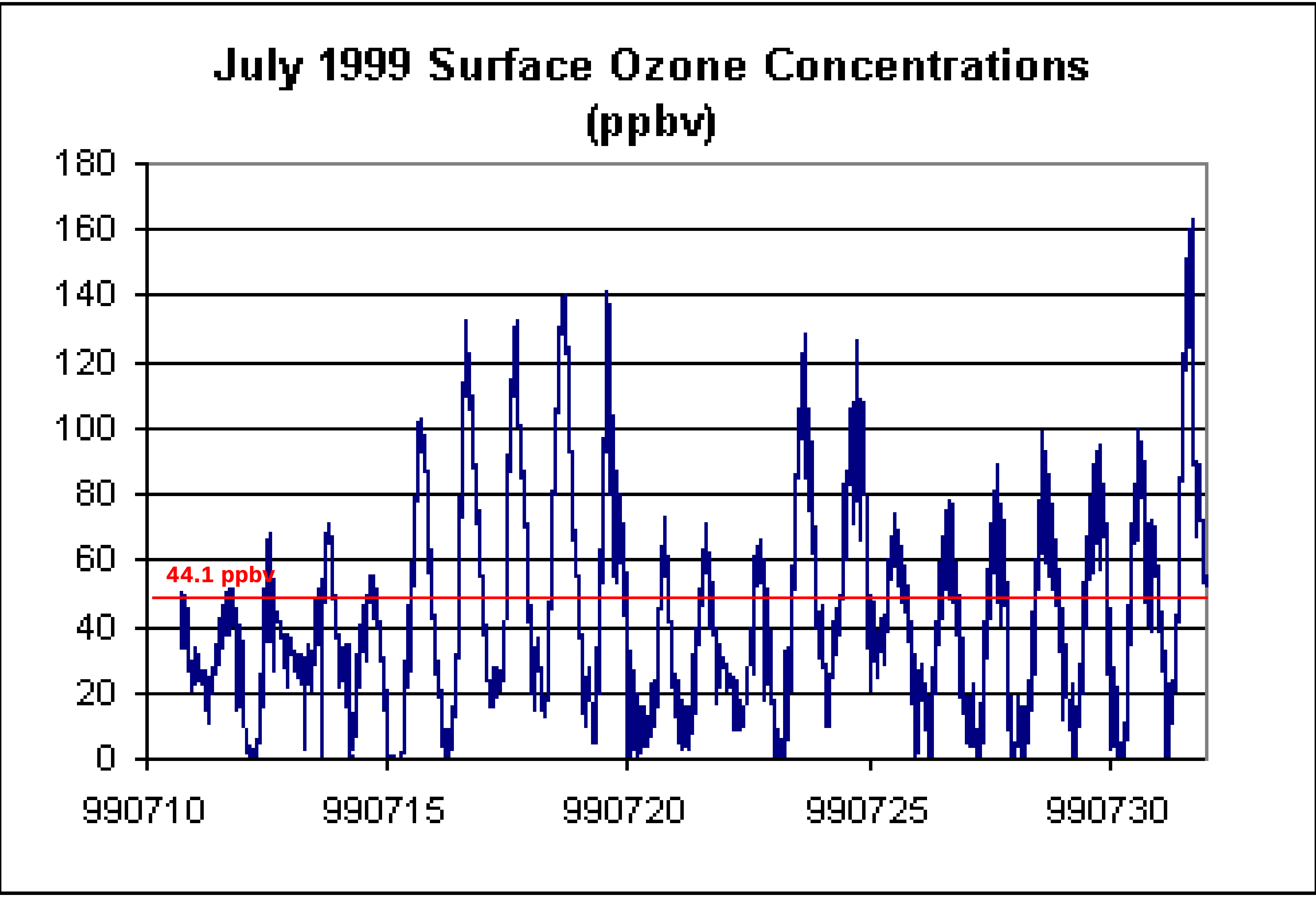




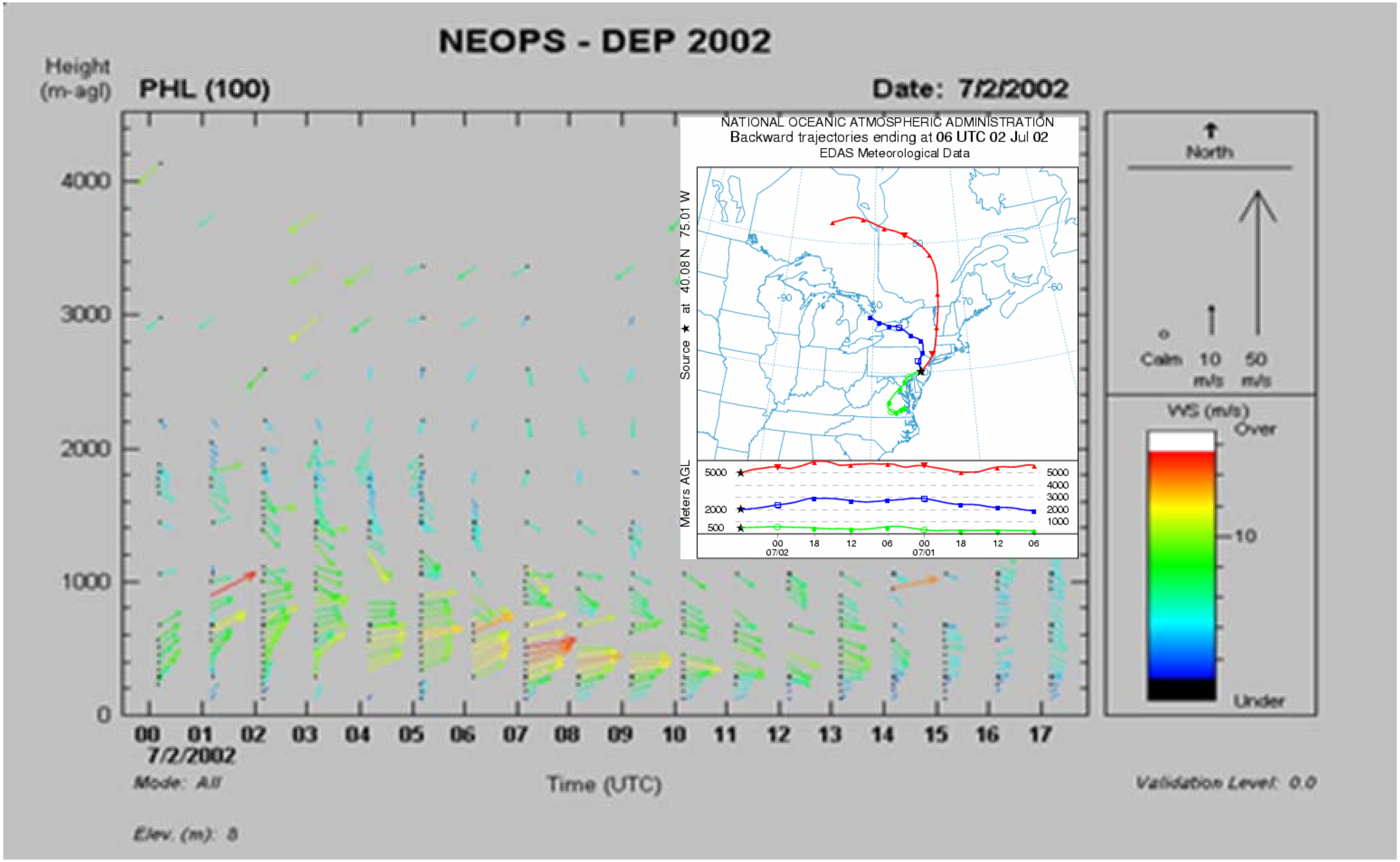

990717-18 RICHARDSON NUMBER
HEIGHT (M)
TIME (UTC)
350
300
250
200
150
100
50
17/00
17/04
17/08
17/12
17/16
17/20
18/00
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6



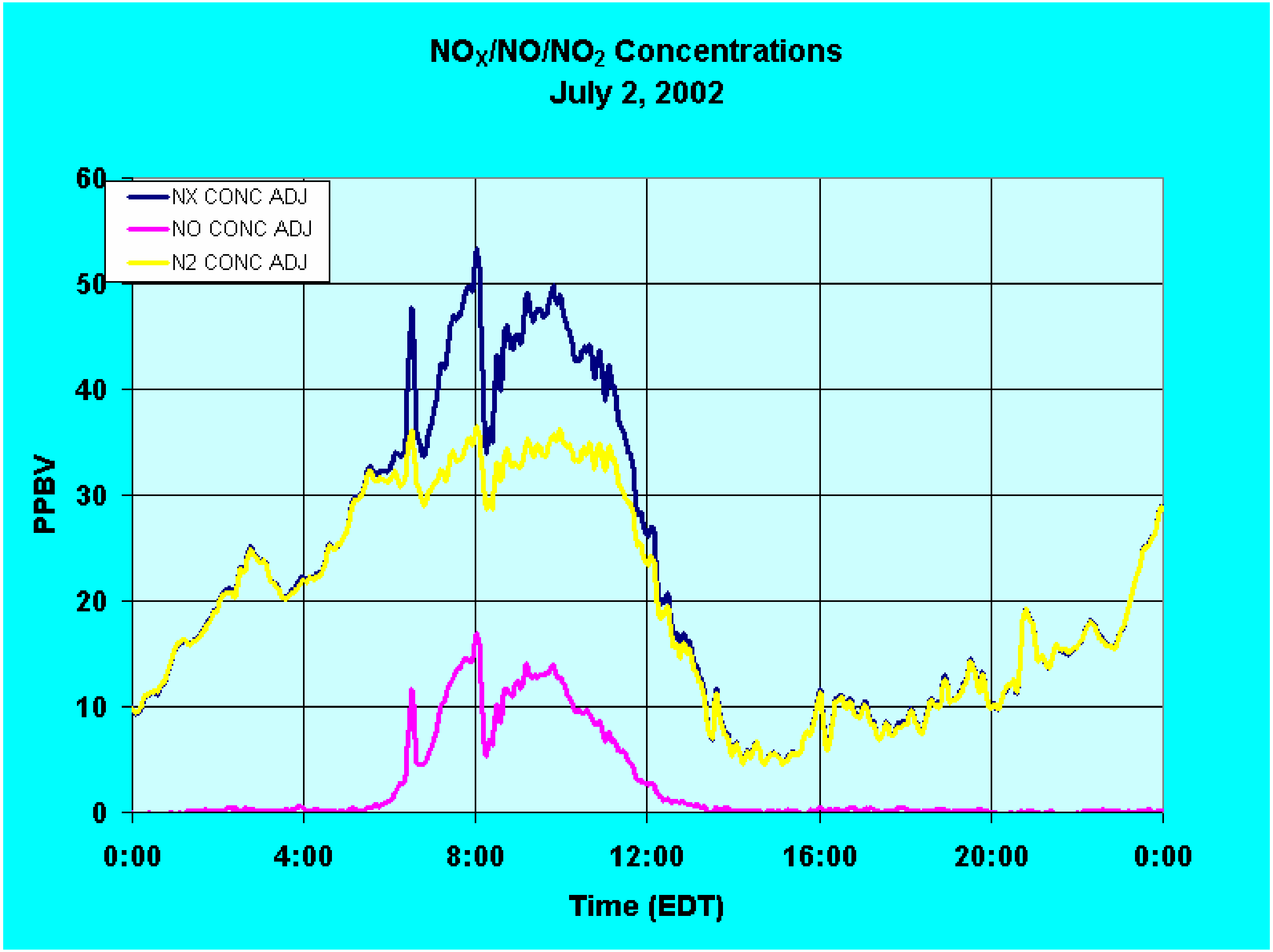
Western Ozone Monitors - July 16, 1999
Hourly Ozone (ppbv)
0
20
40
60
80
100
120
140
160
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
Time (EST)
So. Carroll
Frederick
Little Buffalo
Methodist Hill
Holbrook


July 1999 Surface Ozone Concentrations
(ppbv)
180
160
140
120
100
80
60
40
20
0
44.1 ppbv
990710
990715
990720
990725
990730

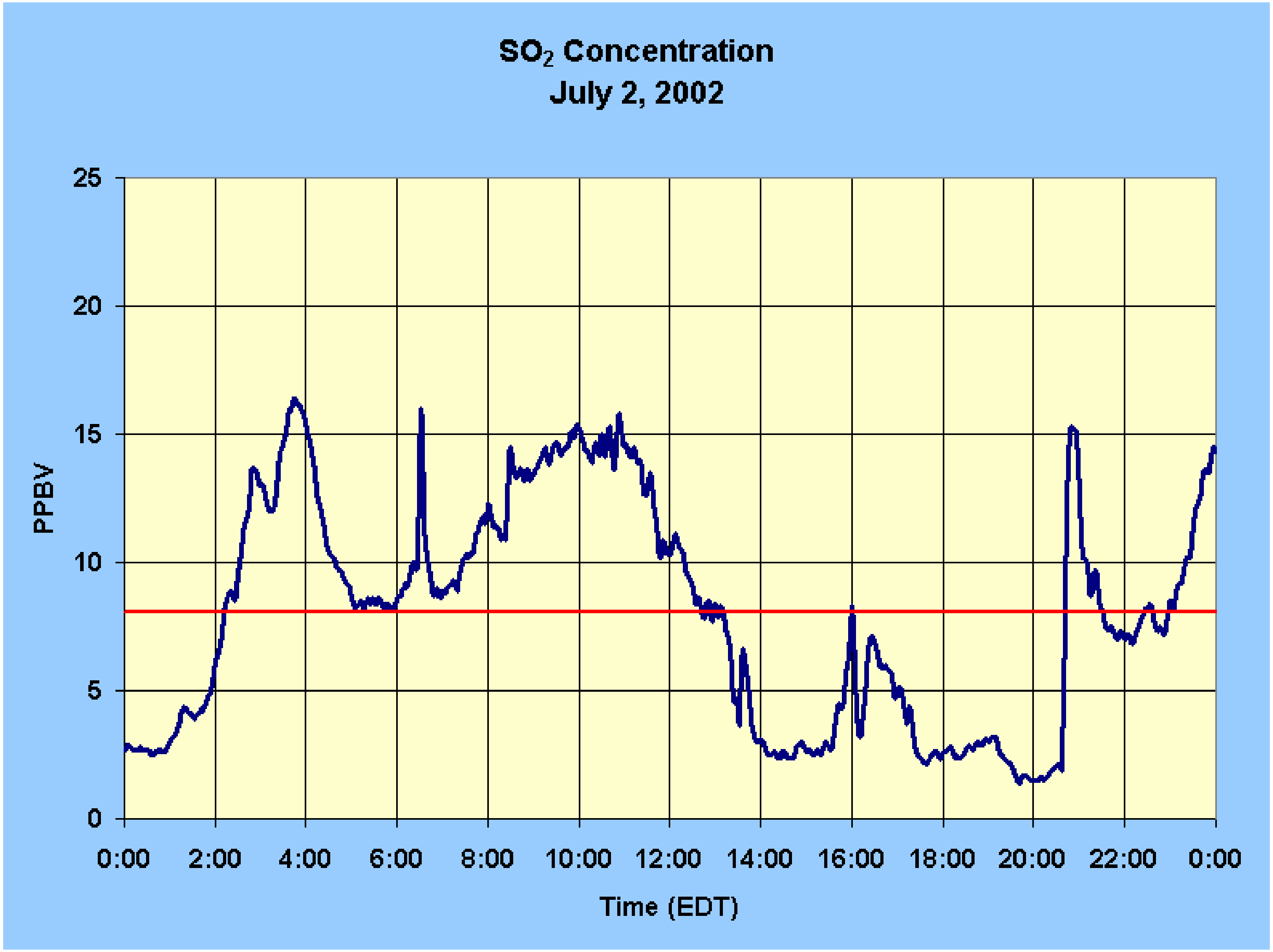
A closer look at the 07-02-02 LLJ



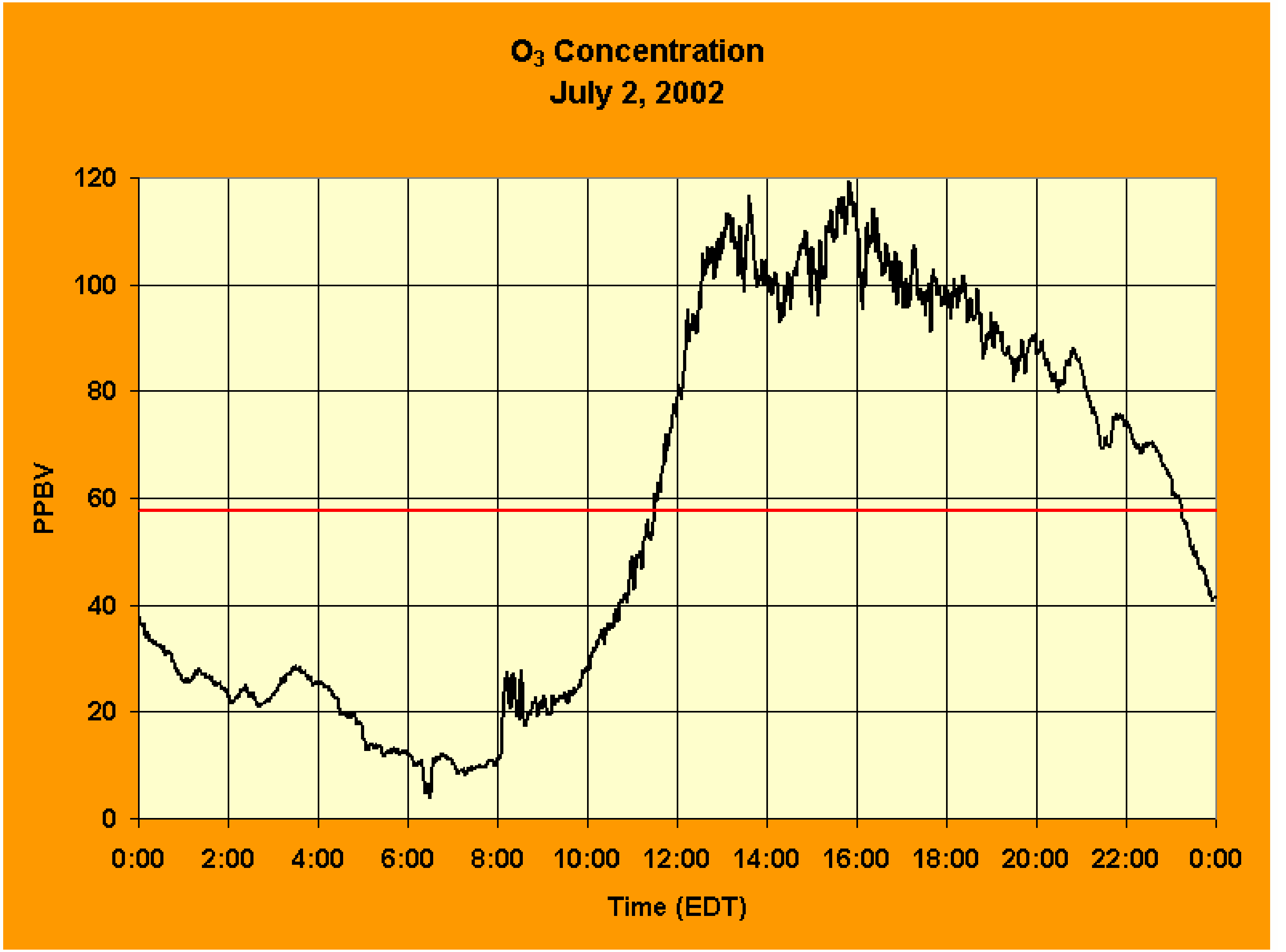
NO_X Signature 07-02-02



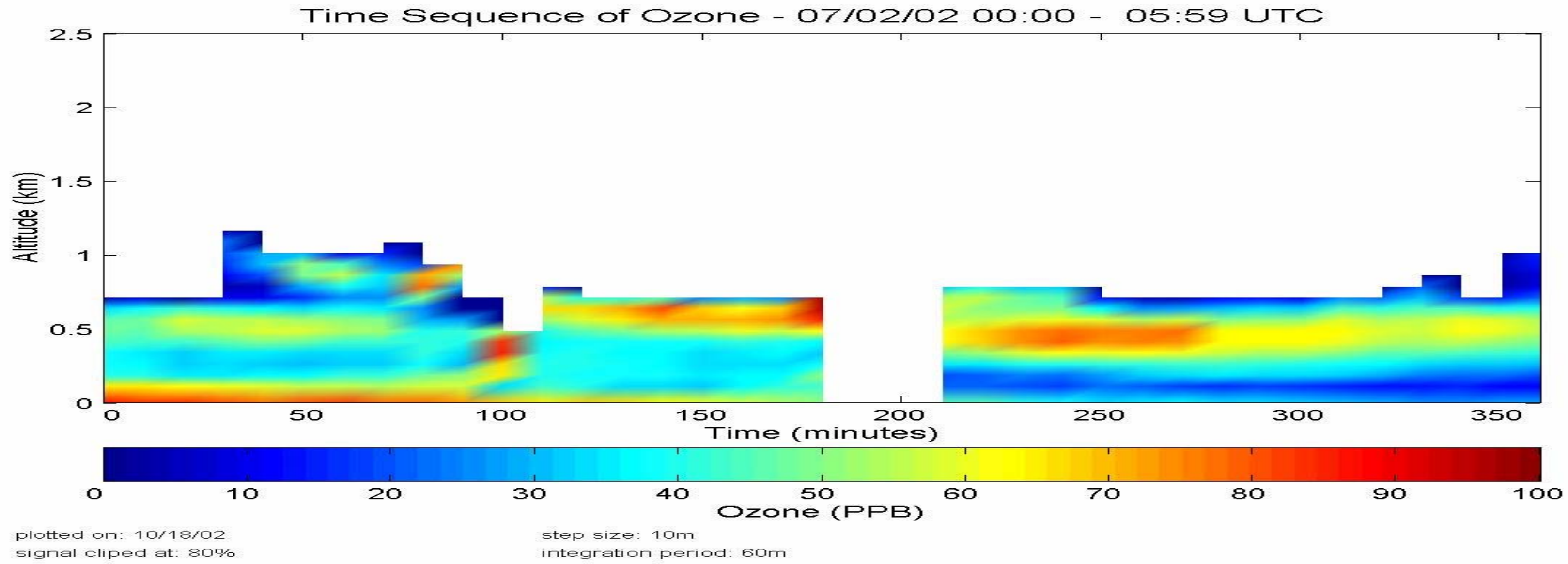
SO_2 Signature 07-02-02

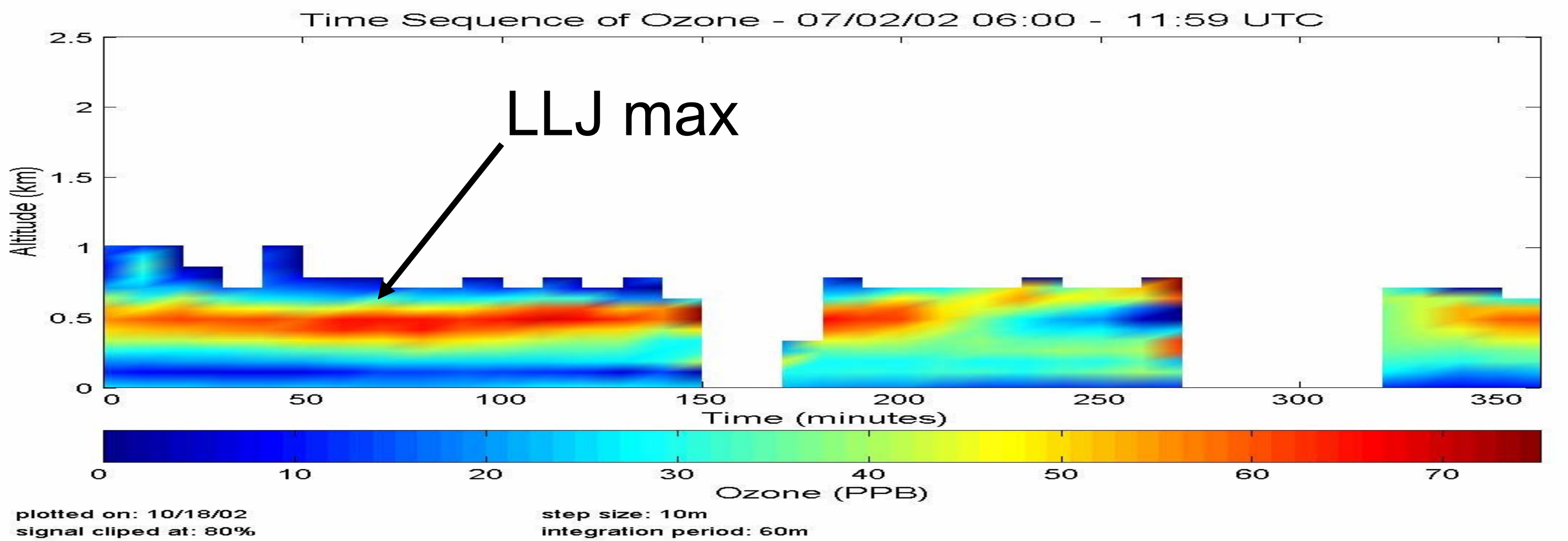


O_3 Signature 07-02-02

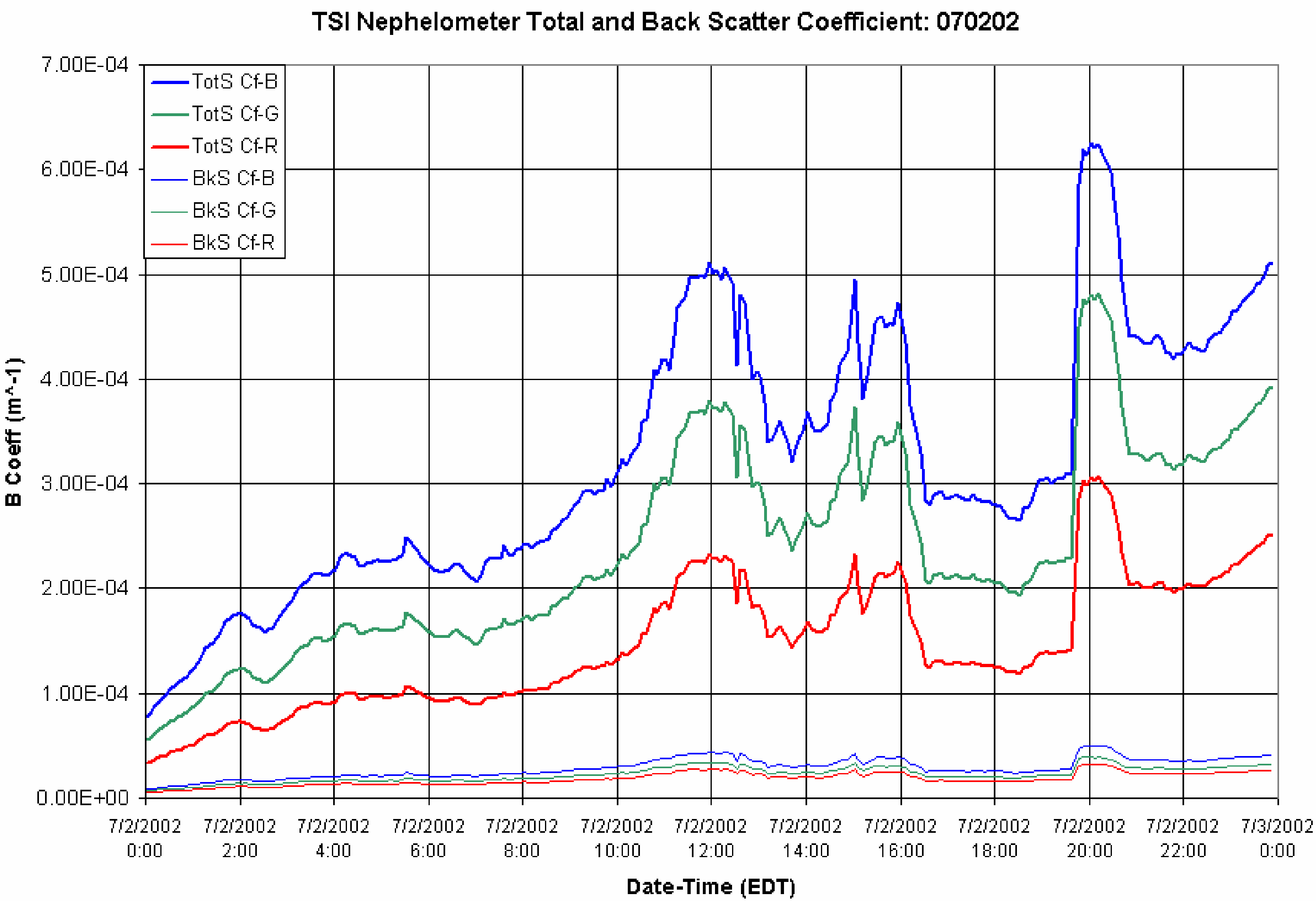


Aloft O_3 Transport 07-02-02 from PSU Raman Lidar

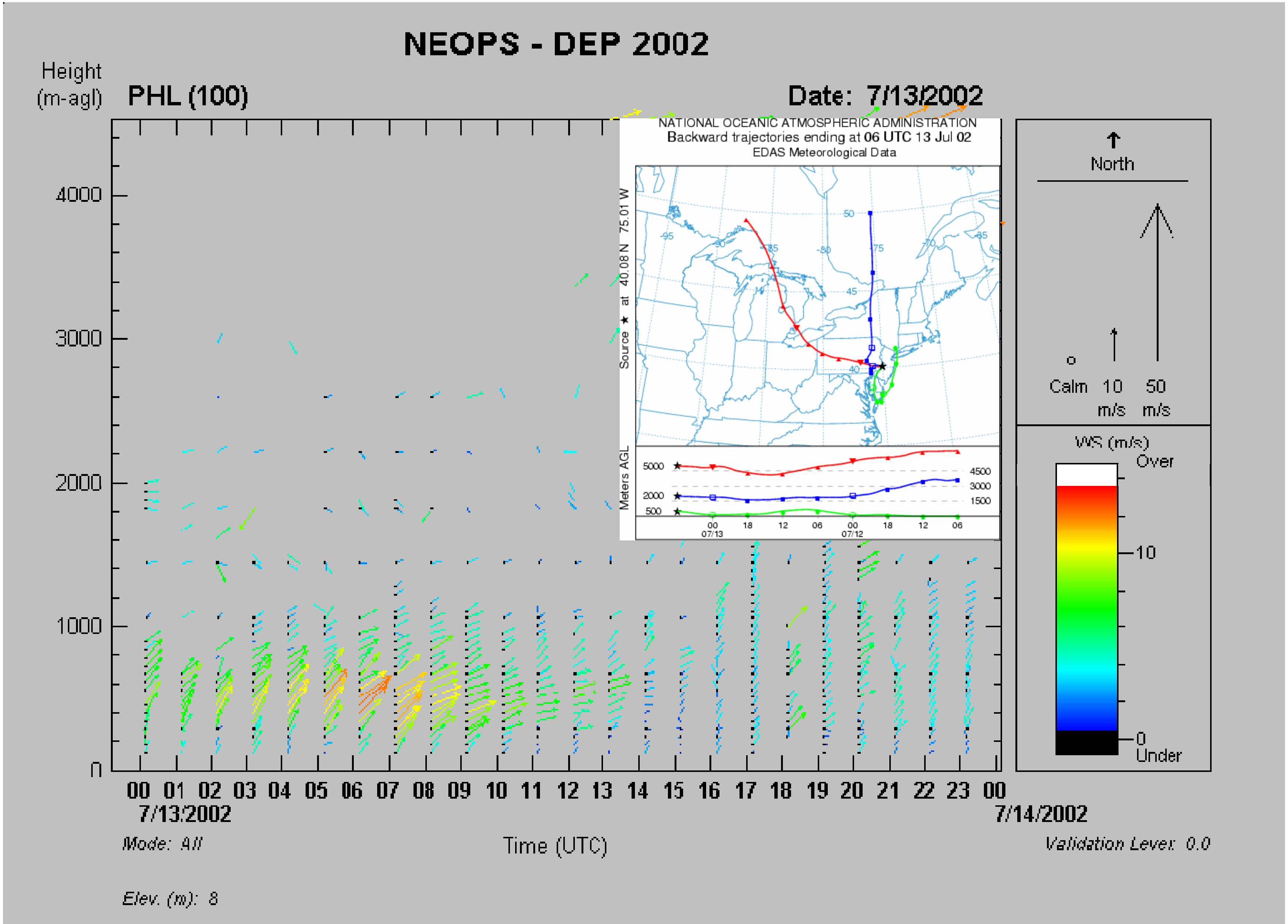




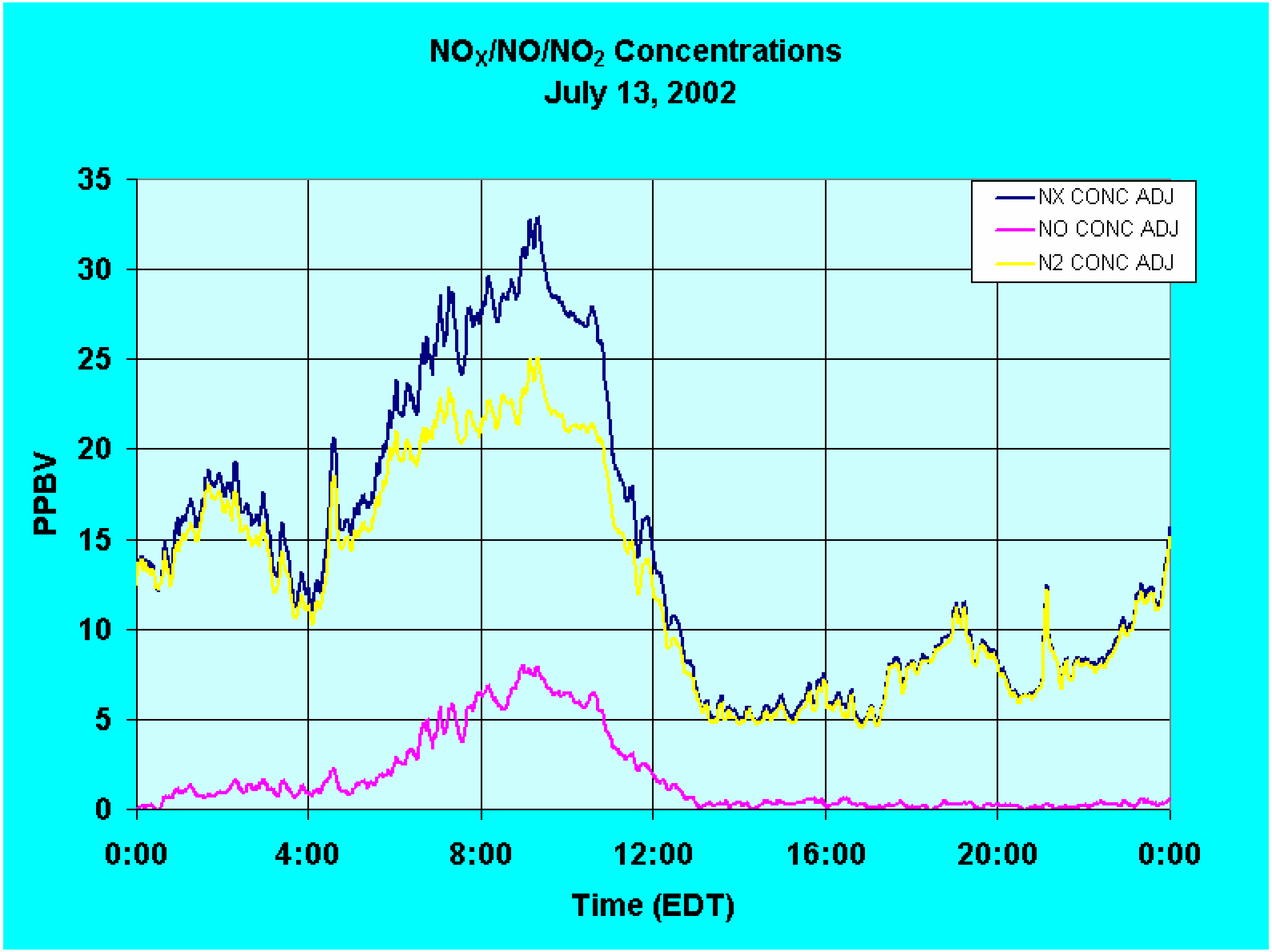
Scattering Signature 07-02-02



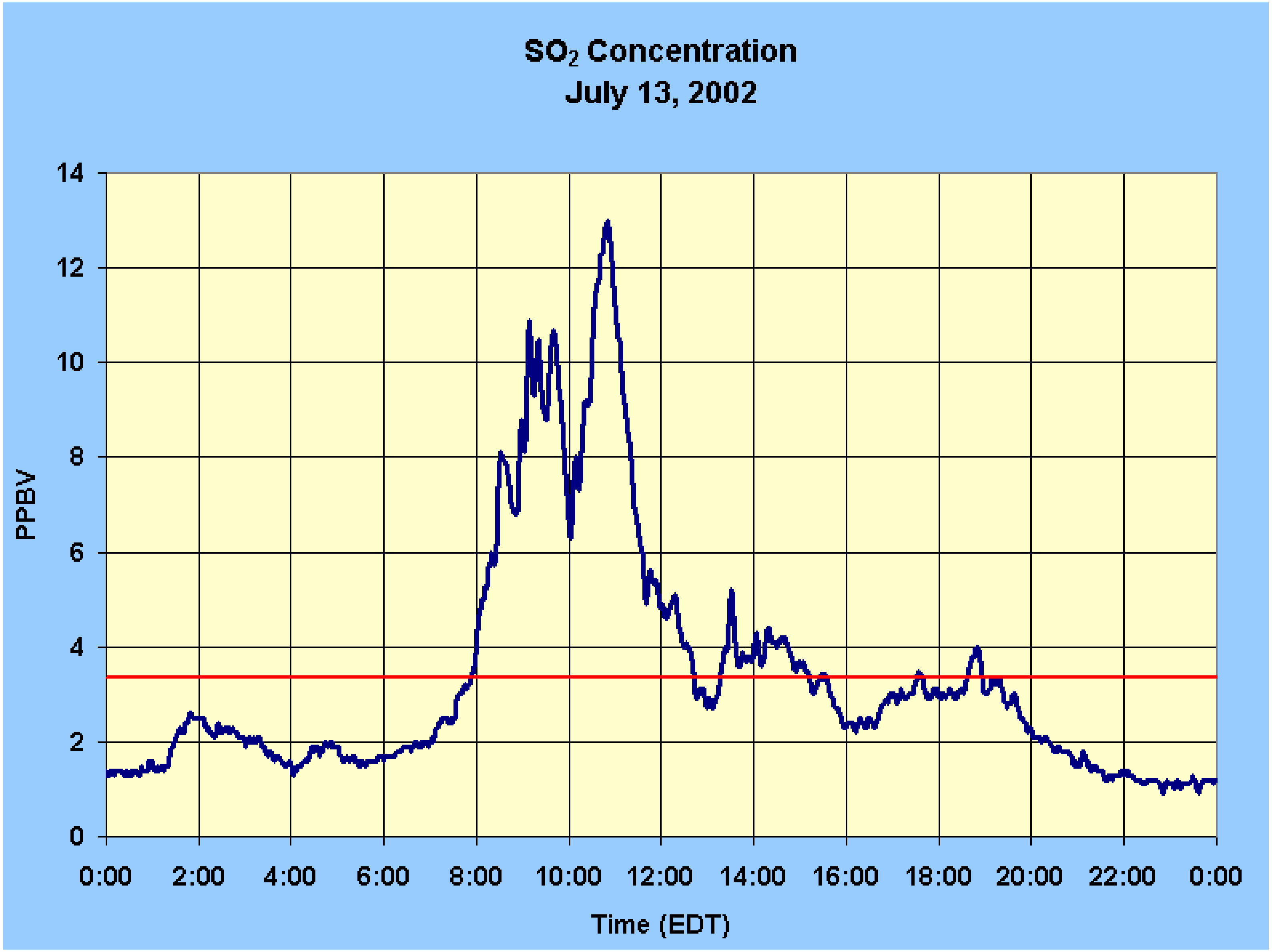
A closer look at the 07-13-02 LLJ



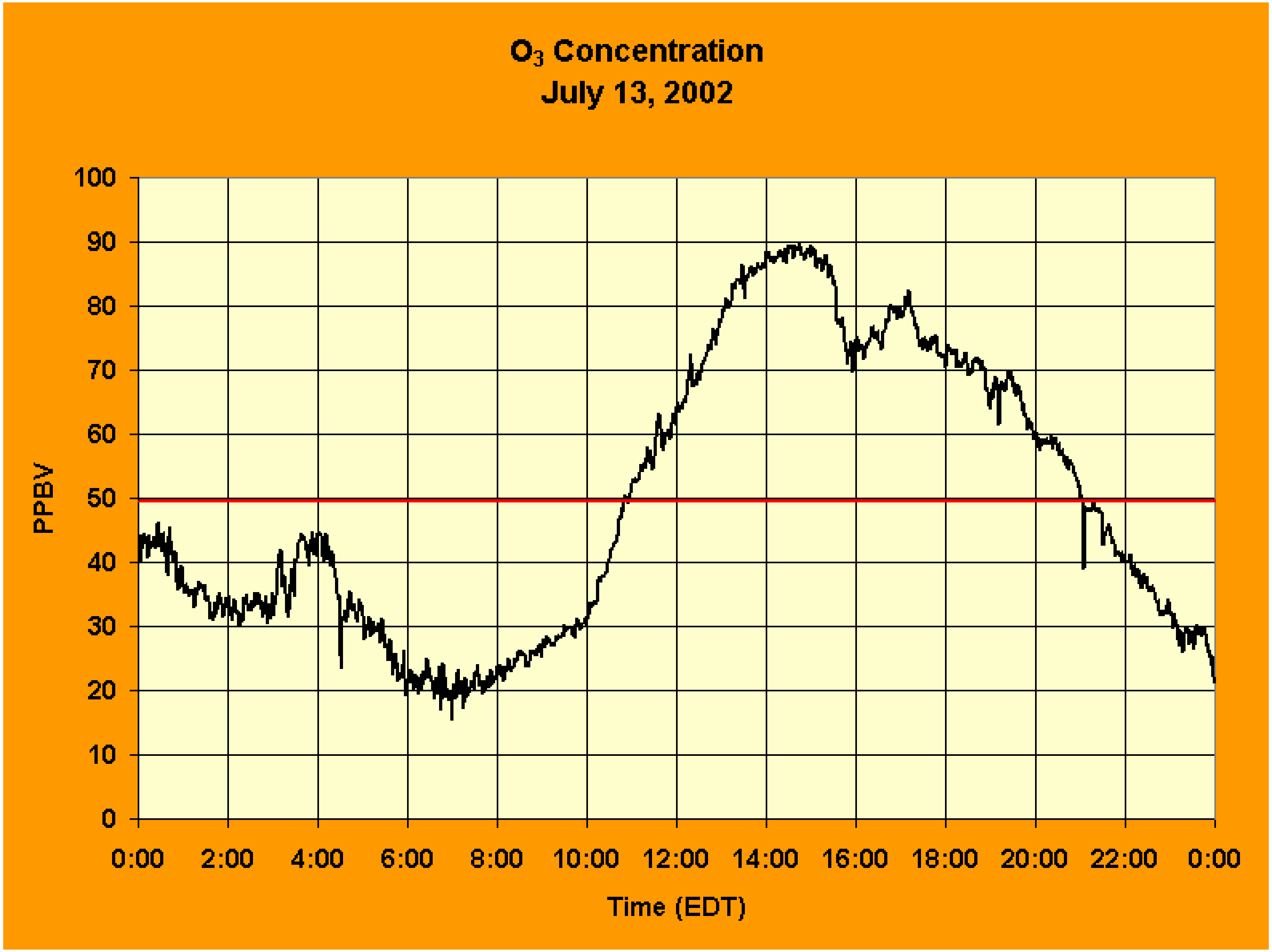
NO_X Signature 07-13-02



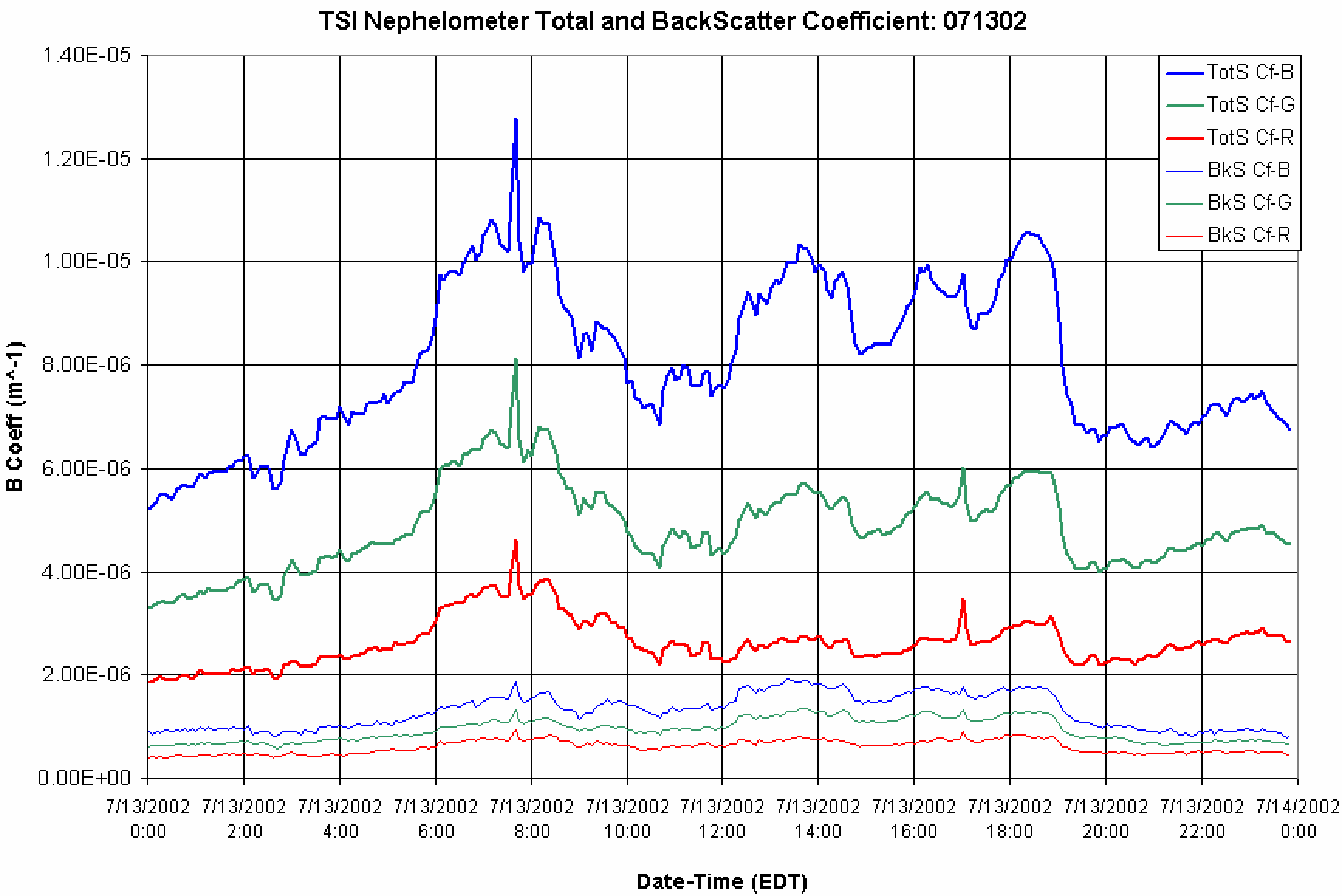
SO_2 Signature 07-13-02



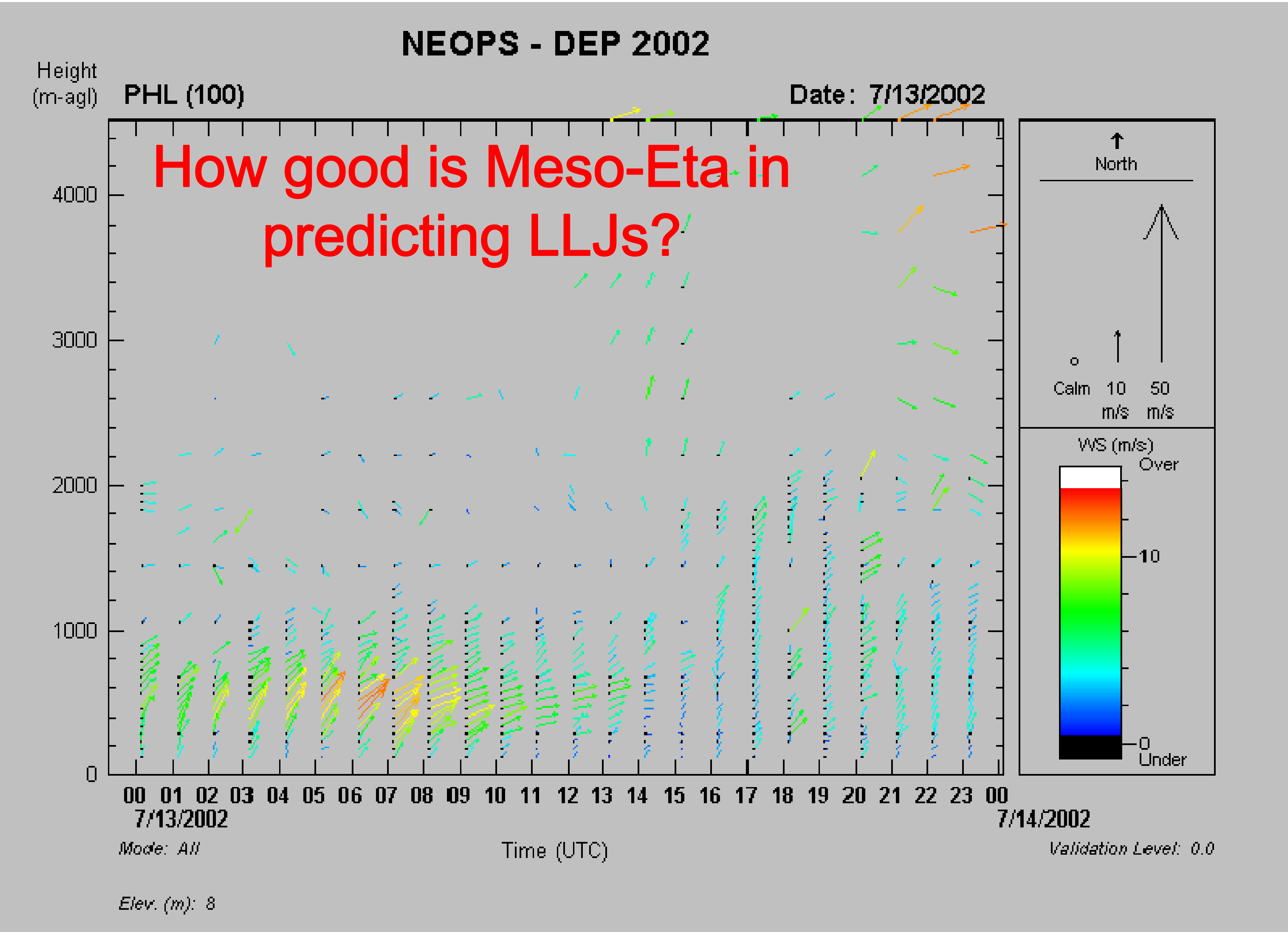
O_3 Signature 07-13-02



Scattering Signature 07-13-02



How good is Meso-Eta in predicting LLJs?



LLJ Summary

- Mid-Atlantic LLJs can transport significant quantities of pollutants and pollutant precursors; surface analyzers reveal characteristic signatures of this transport and downward mixing
- LLJ are often associated with high ozone events since both LLJs and high ozone episodes occur under the same meteorological conditions
- Operation mesoscale models (Meso-eta) can be used to forecast the occurrence of mid-Atlantic LLJs, and display reasonable skill in estimating wind velocity
- The spatial extent of the LLJ and the surface scalar flux have not been adequately documented and will become the focus of future studies
- The variability in the time of maximum wind speeds is not well understood, nor is it captured adequately by models

Sea Breeze Events during NARSTO-NE-OPS 1998-2002

- No sea breeze episodes during the 1998, 3 week pilot project
- Five cases observed during the 1999 and 2002 field intensives
  - Several more were observed by Ft Dix radar propagating over NJ, but only the most intense reached the NE-OPS Philadelphia site
  - Two cases studies described herein:

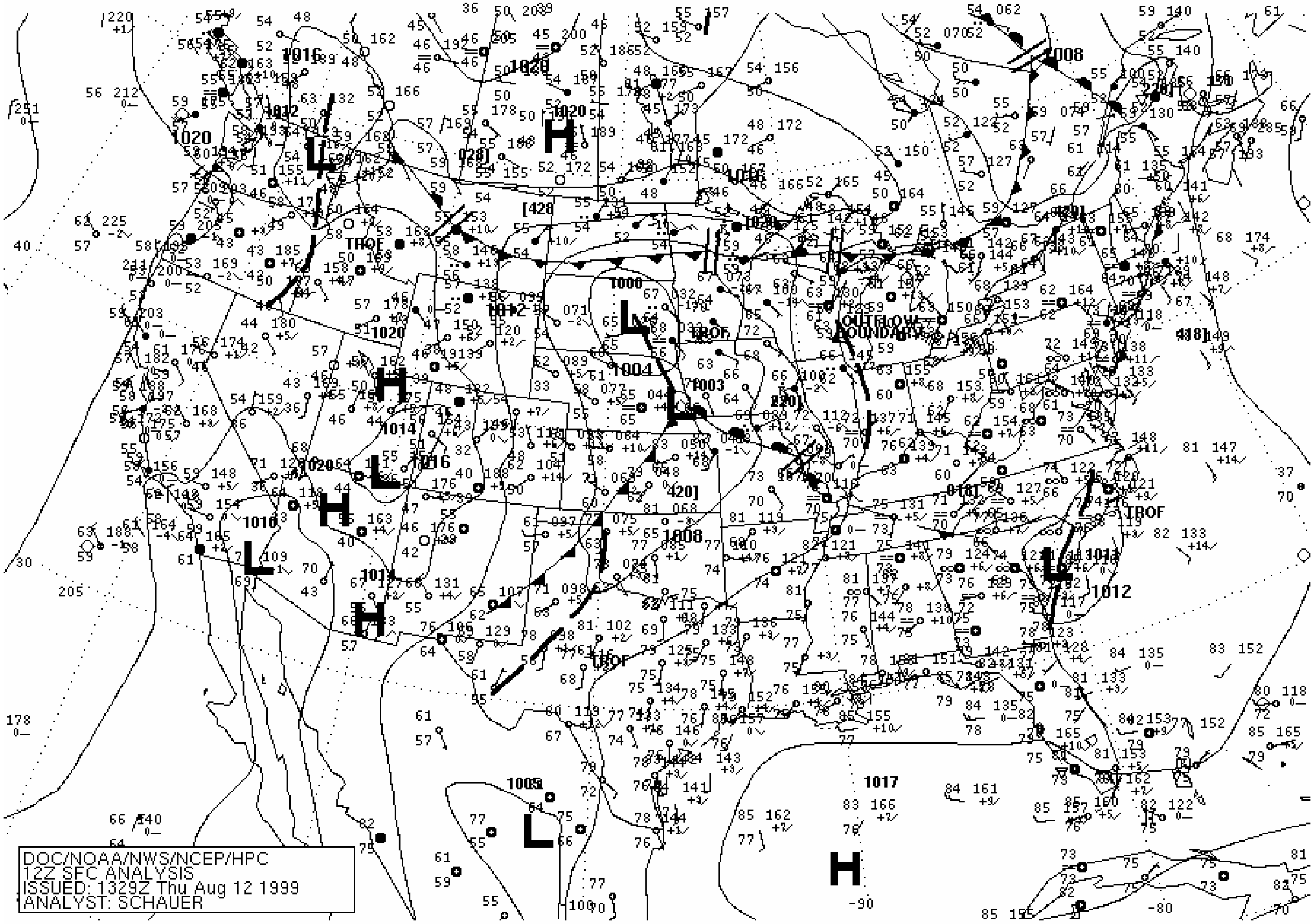
    12 August 1999 and 20 July 2002

Overview

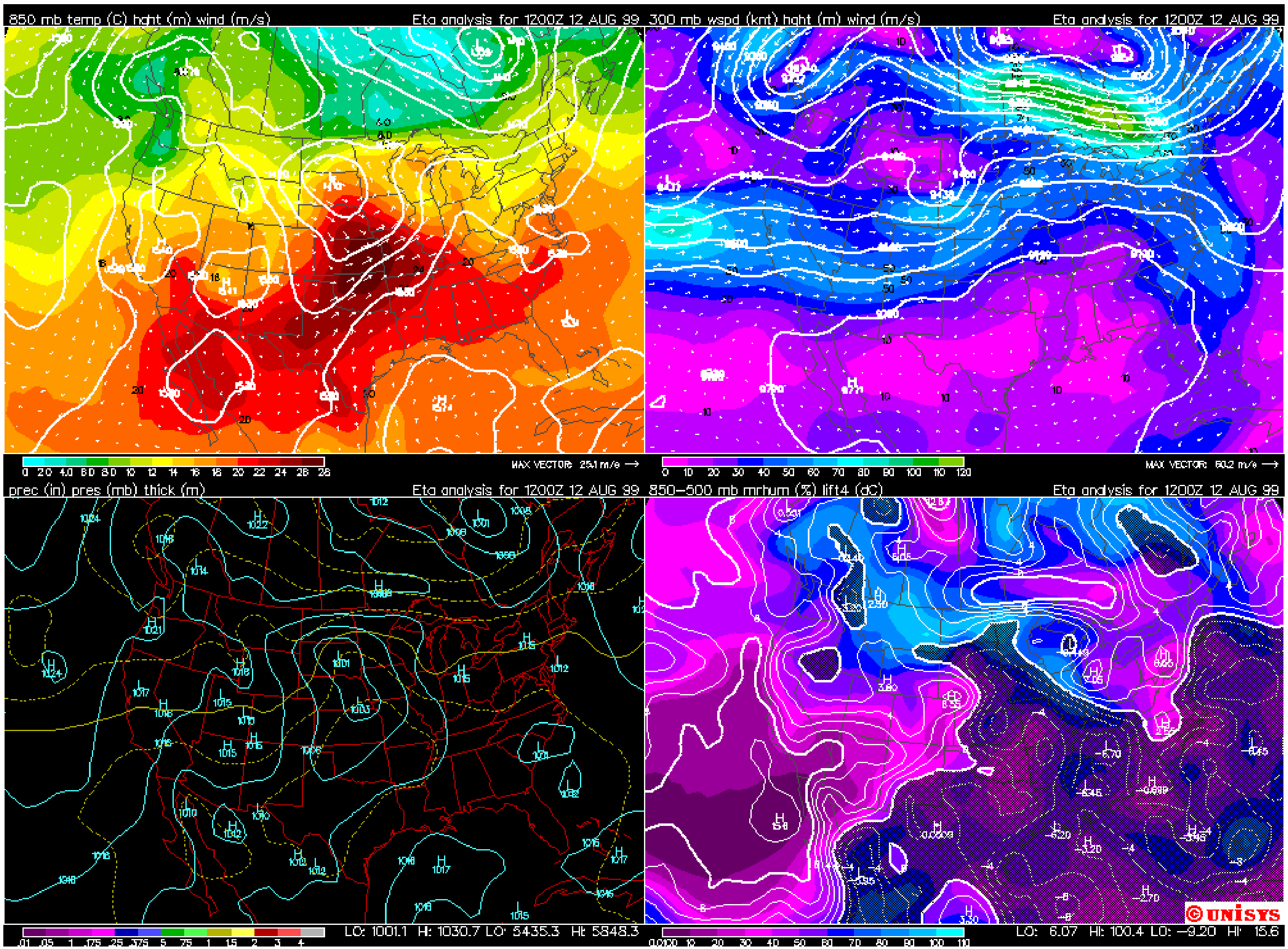
- Sea breeze circulations have the ability to significantly modify the atmospheric boundary layer
- Common to all sea breeze events is the sudden (~ 1-10 minutes) rise in relative humidity to saturation levels, and the concurrent increase in optical extinction with the formation of haze droplets on existing aerosols
- Sea breezes are typically shallow; 100 – 300 m
- As a sea breeze propagates westward, its length, intensity, and signature clear air Radar return diminishes as it dissipates in the surrounding air mass
- The effect on the air chemistry is very sensitive to the relative change in wind direction
- Operational models can simulate the sea breeze but fail to adequately capture the depth and timing of this shallow event
- Sea breezes can enhance upstream convergence and storm development and, in turn, be influenced by even moderate meso-dynamic forcings

12 August 1999 Sea Breeze

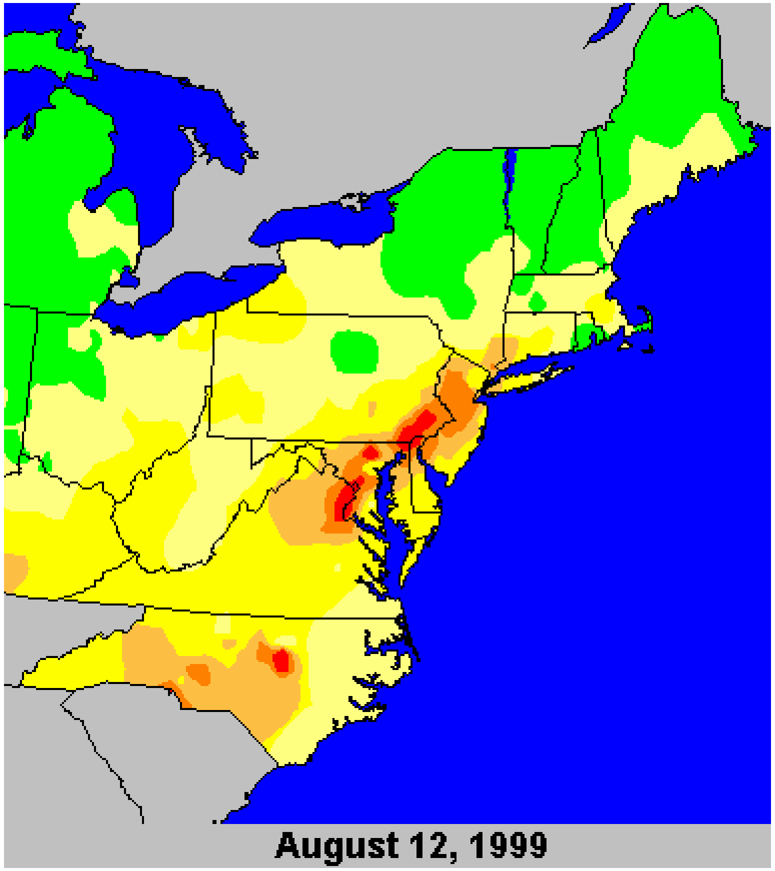
12Z Surface Analysis

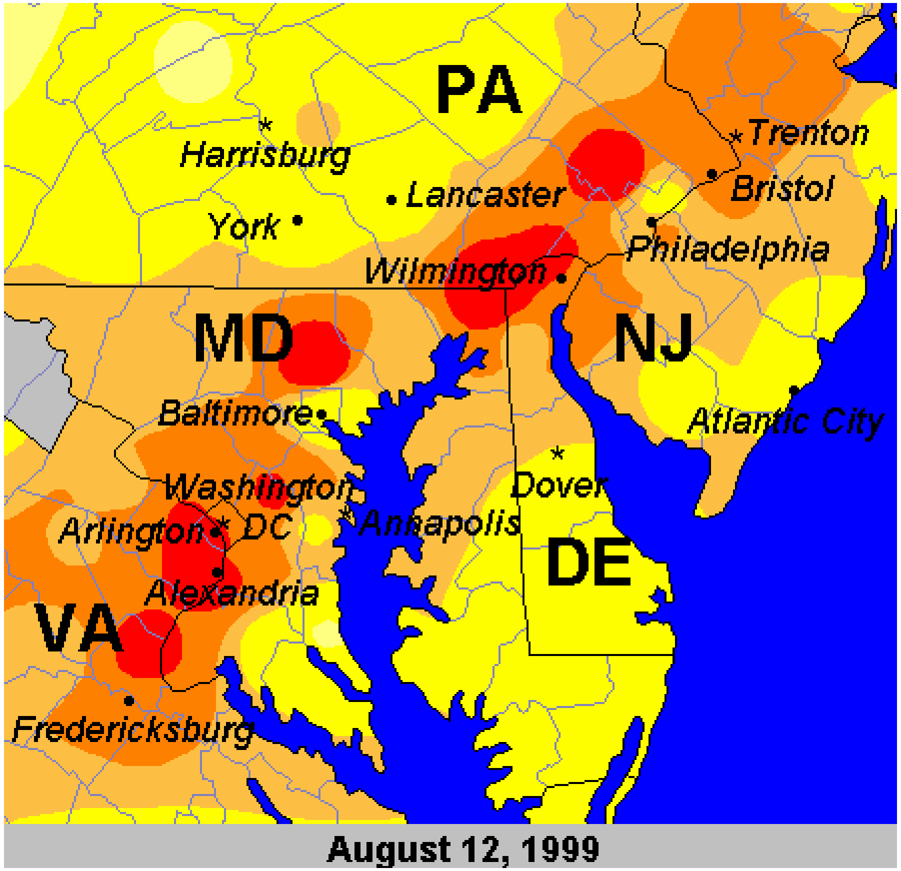


12 August 1999
Eta Upper Air Initialization



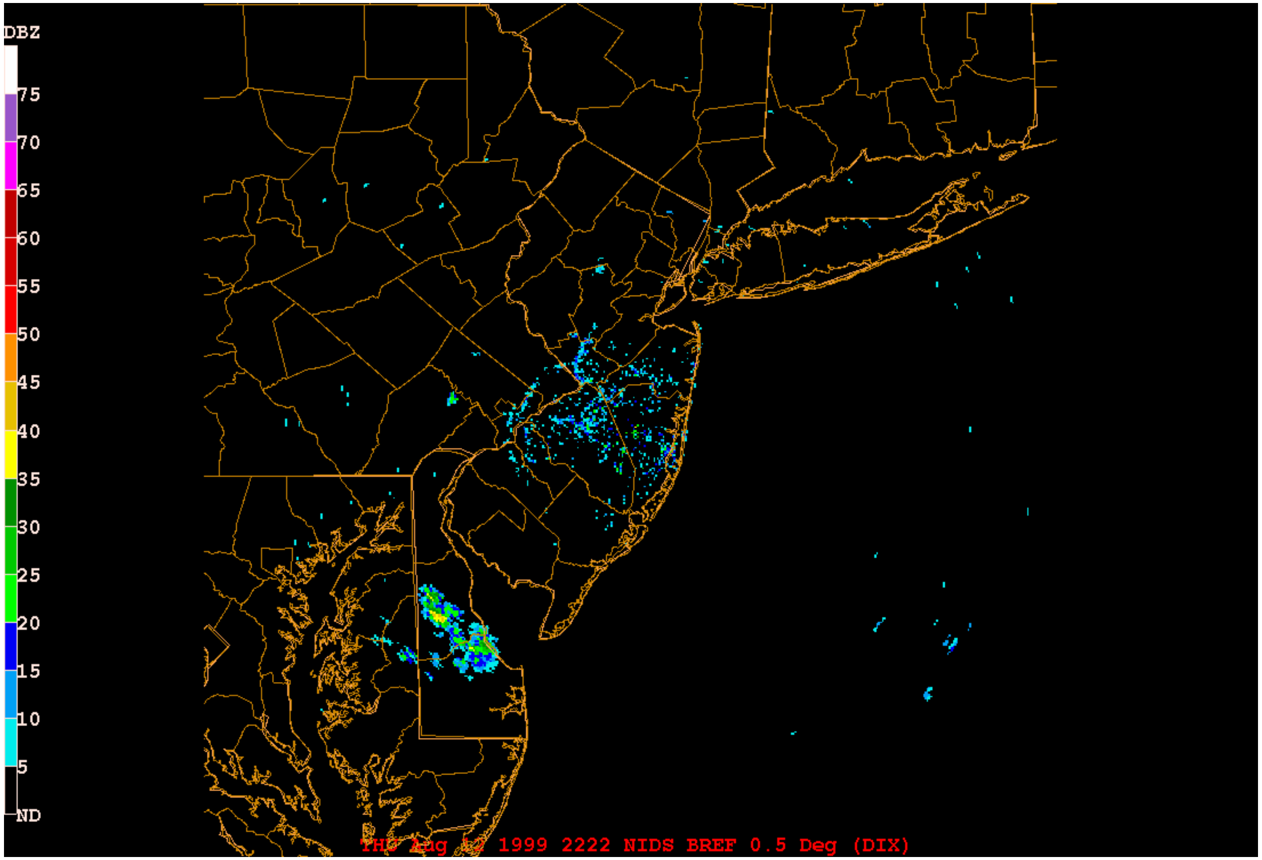
12 August 1999
Regional Ozone



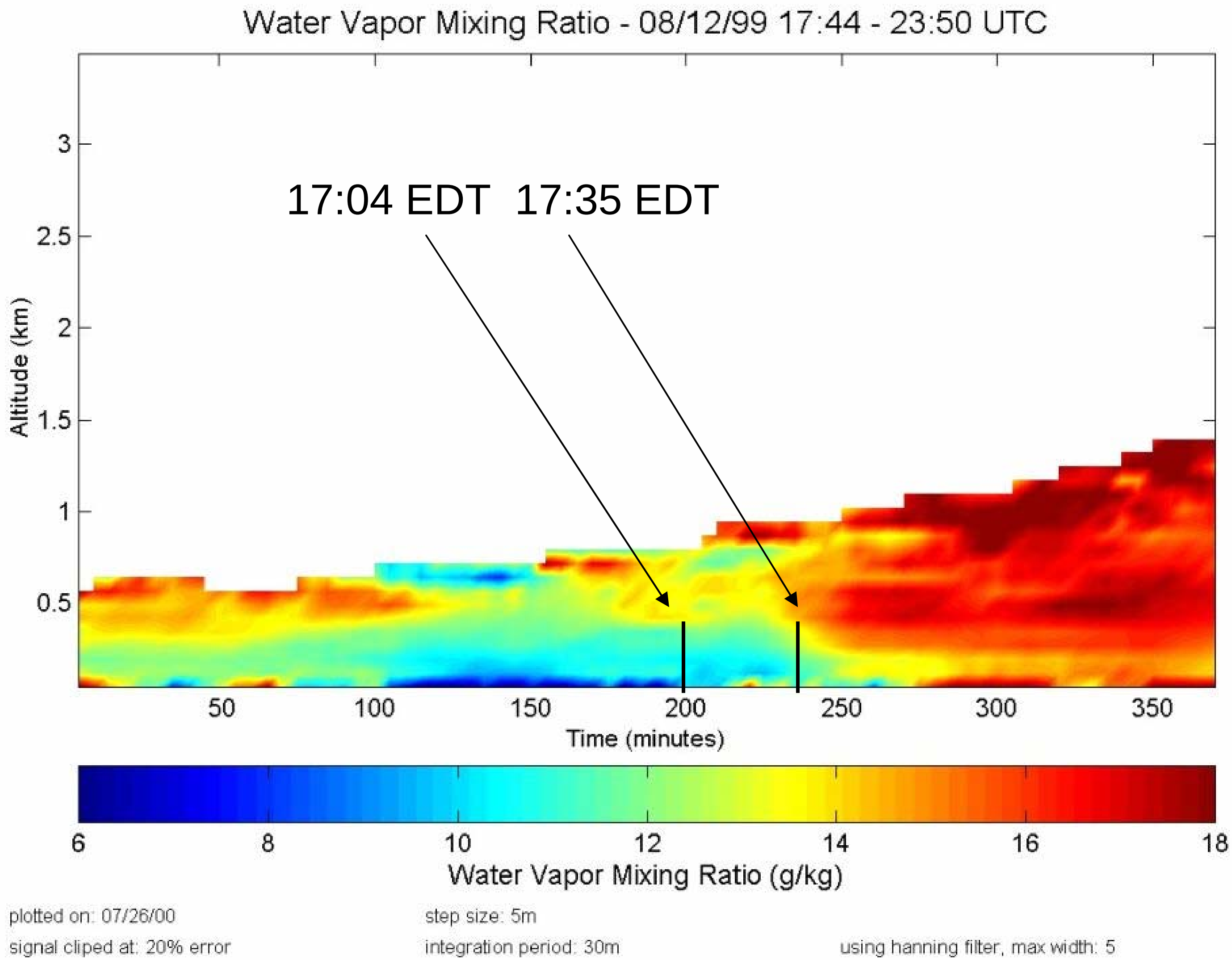


EPA AirNow

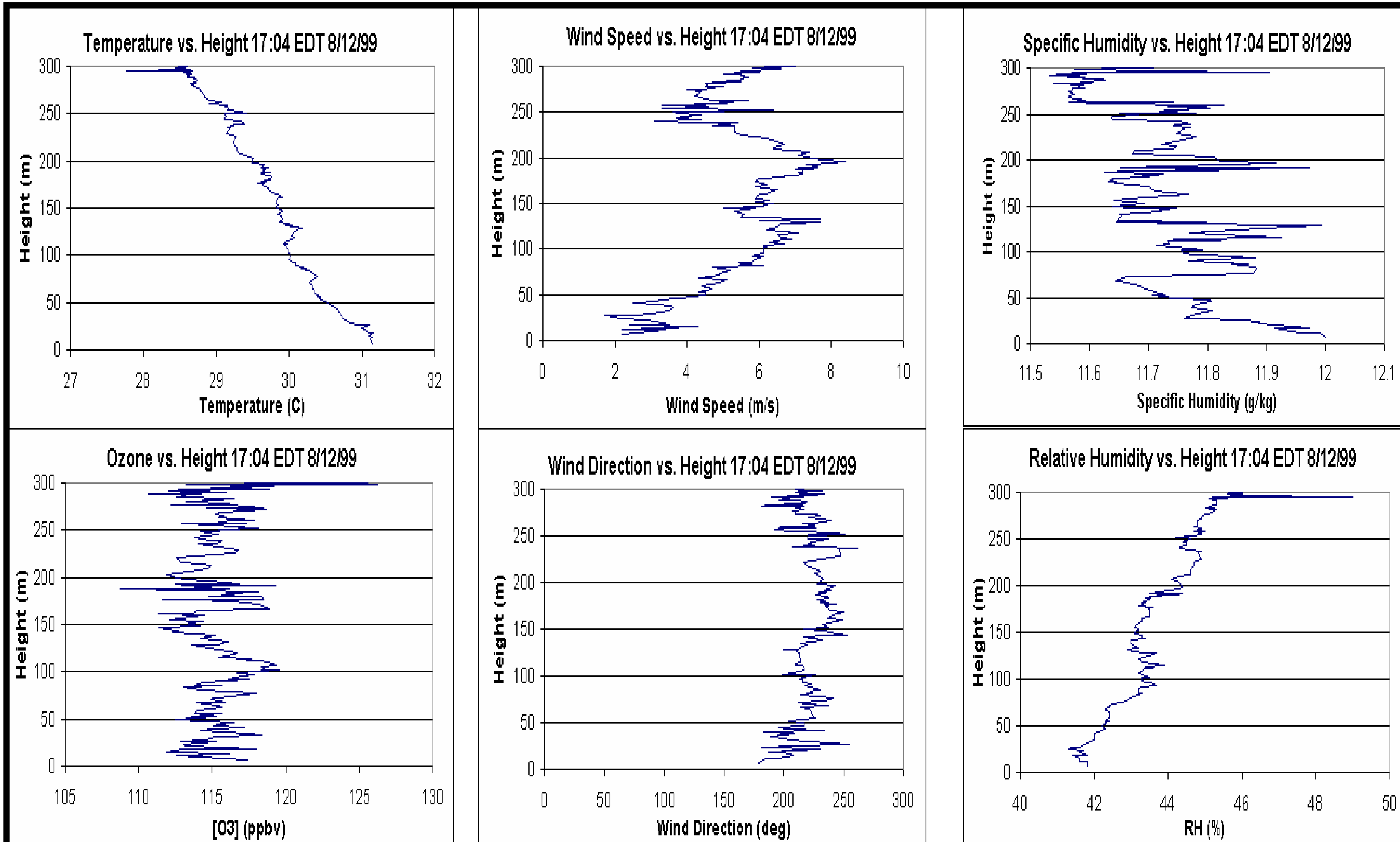
12 August 1999
Ft Dix Radar



12 August 1999
PSU Raman Lidar

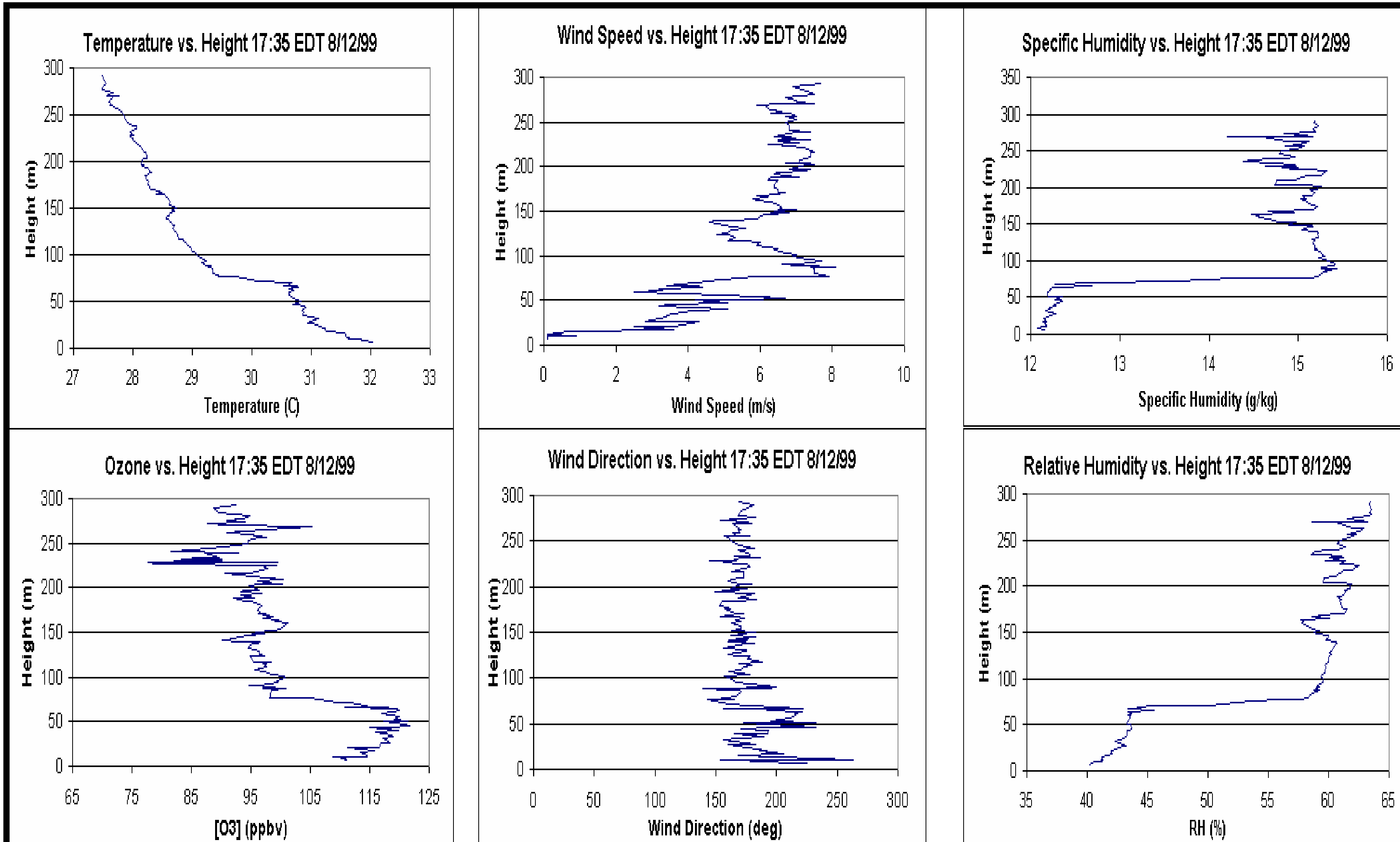


17:04 EDT 12 August 1999
MU - TASS

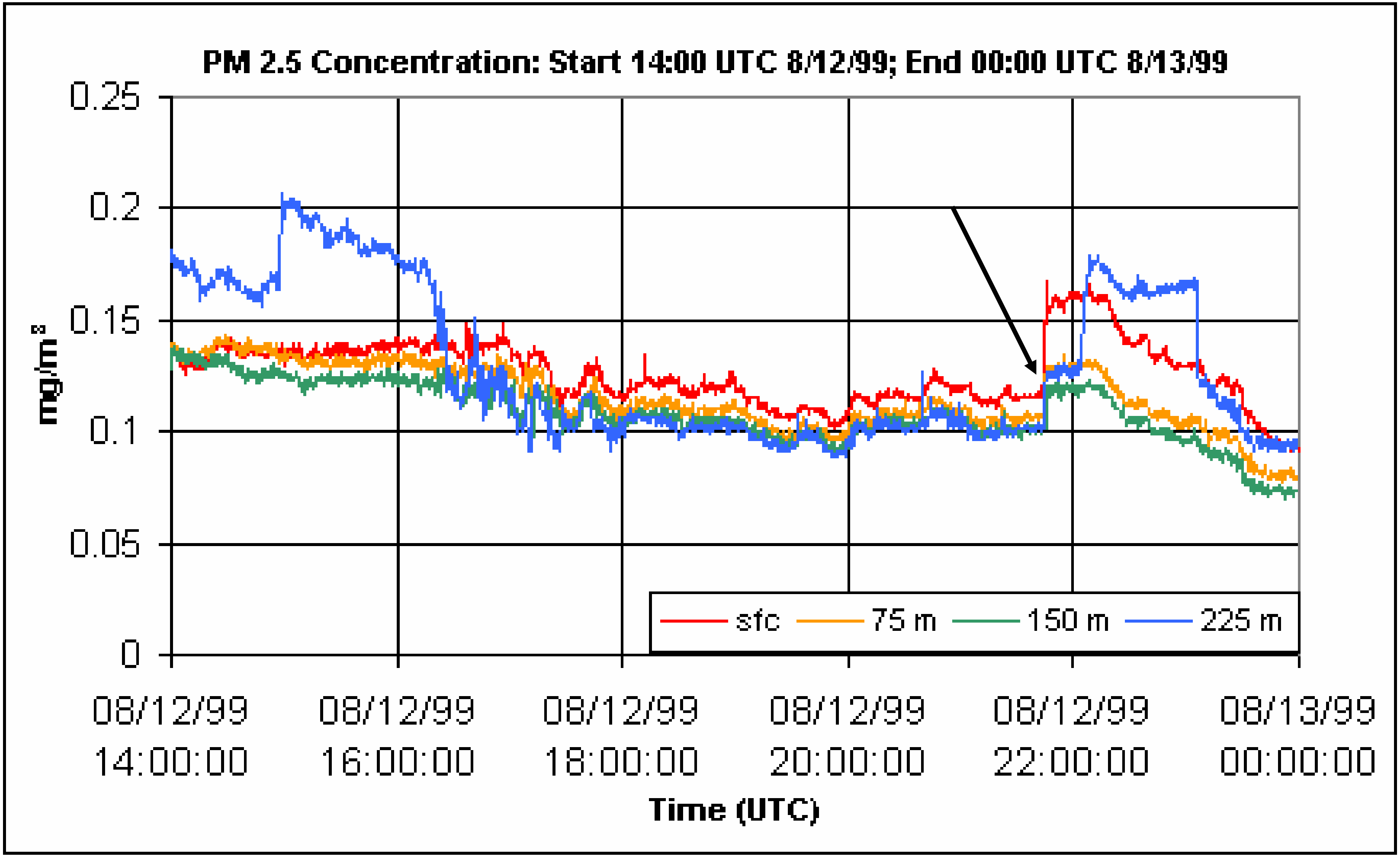


MILLERSVILLE UNIVERSITY Earth Sciences Department

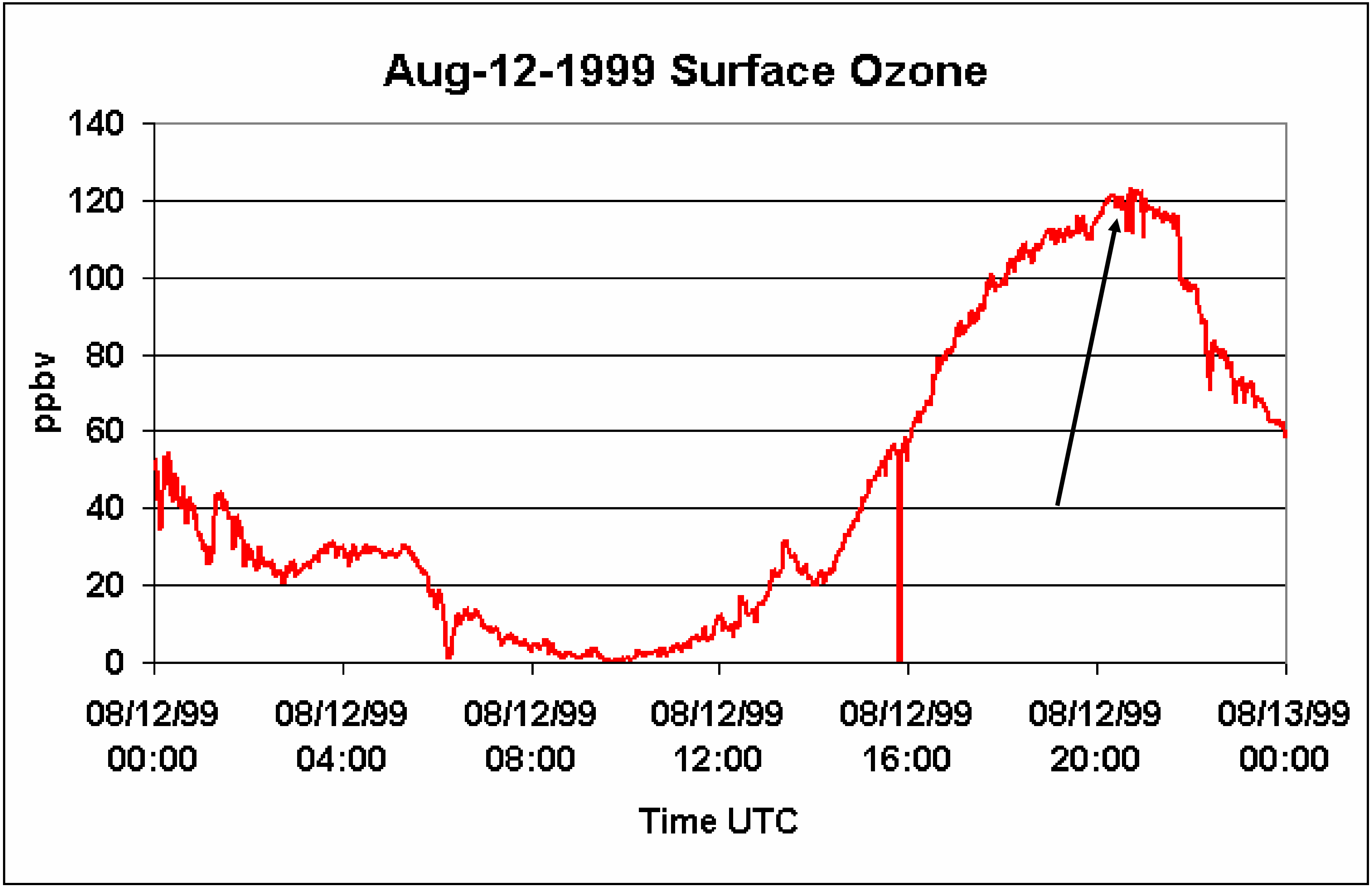
17:35 EDT 12 August 1999
MU-TASS



Aloft $PM_{2.5}$ 12 August 1999 Laser-diode nephelometer

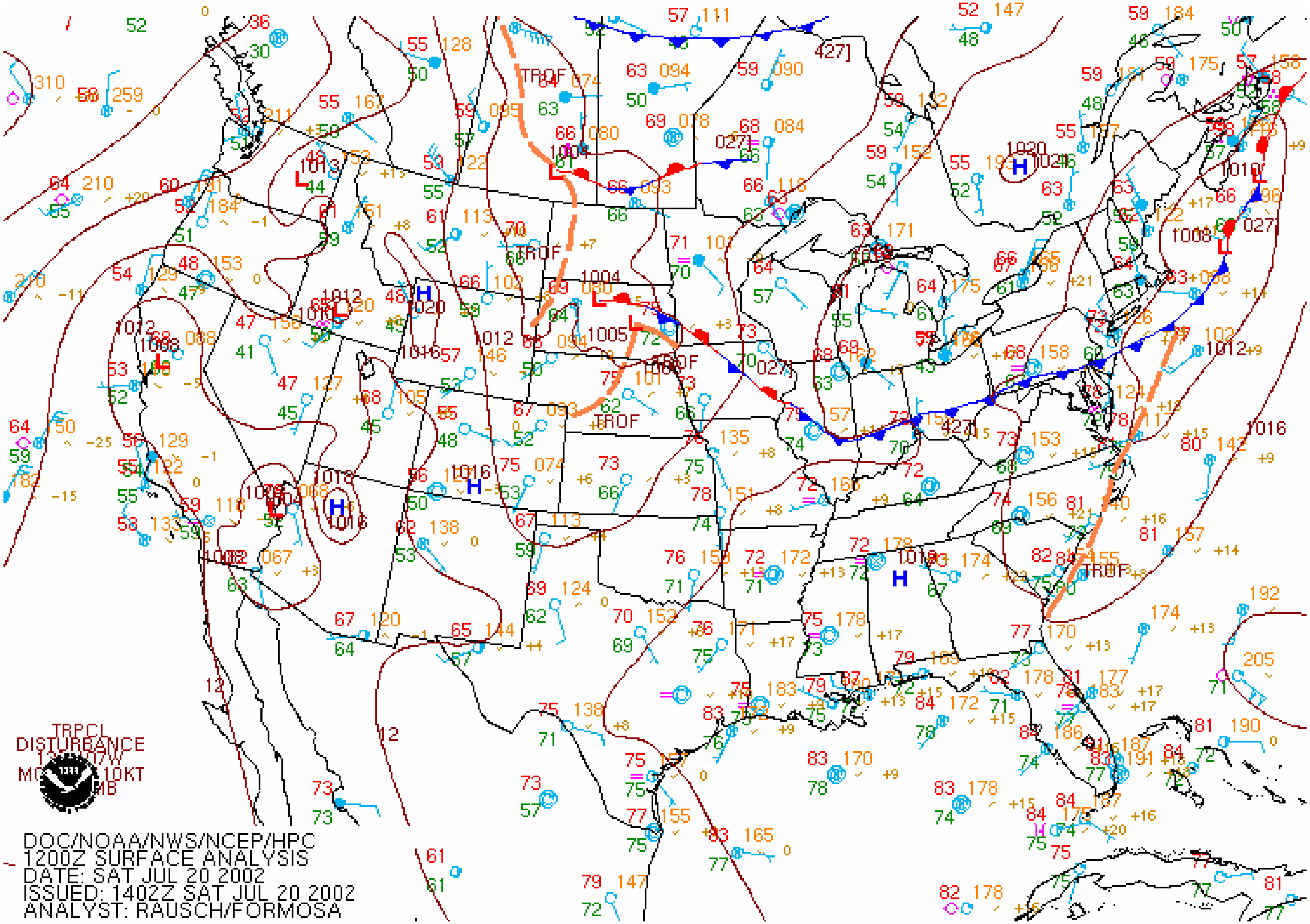


12 August 1999
Surface Ozone Concentration



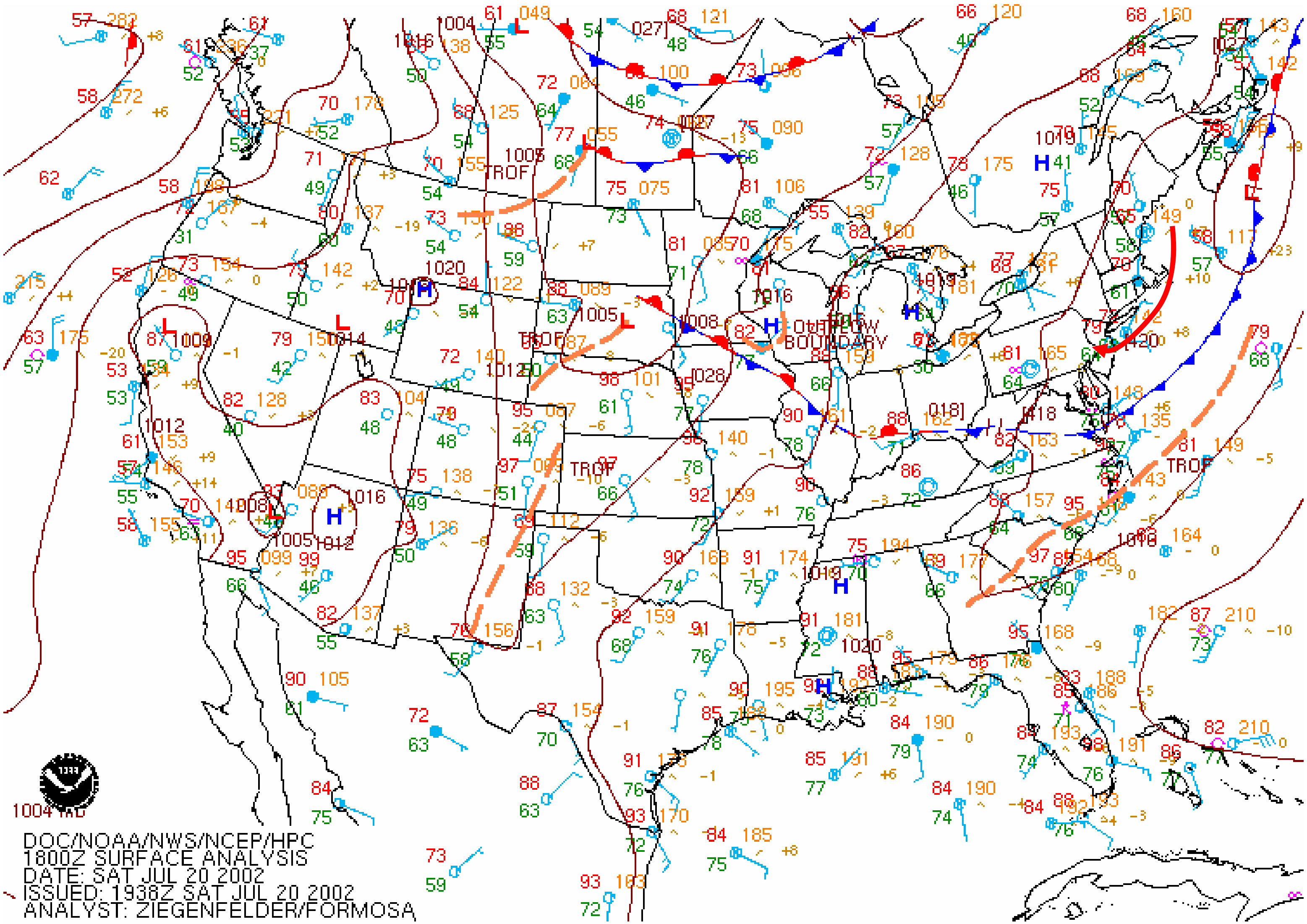
MILLERSVILLE UNIVERSITY Earth Sciences Department

20 July 2002
12Z Surface Analysis

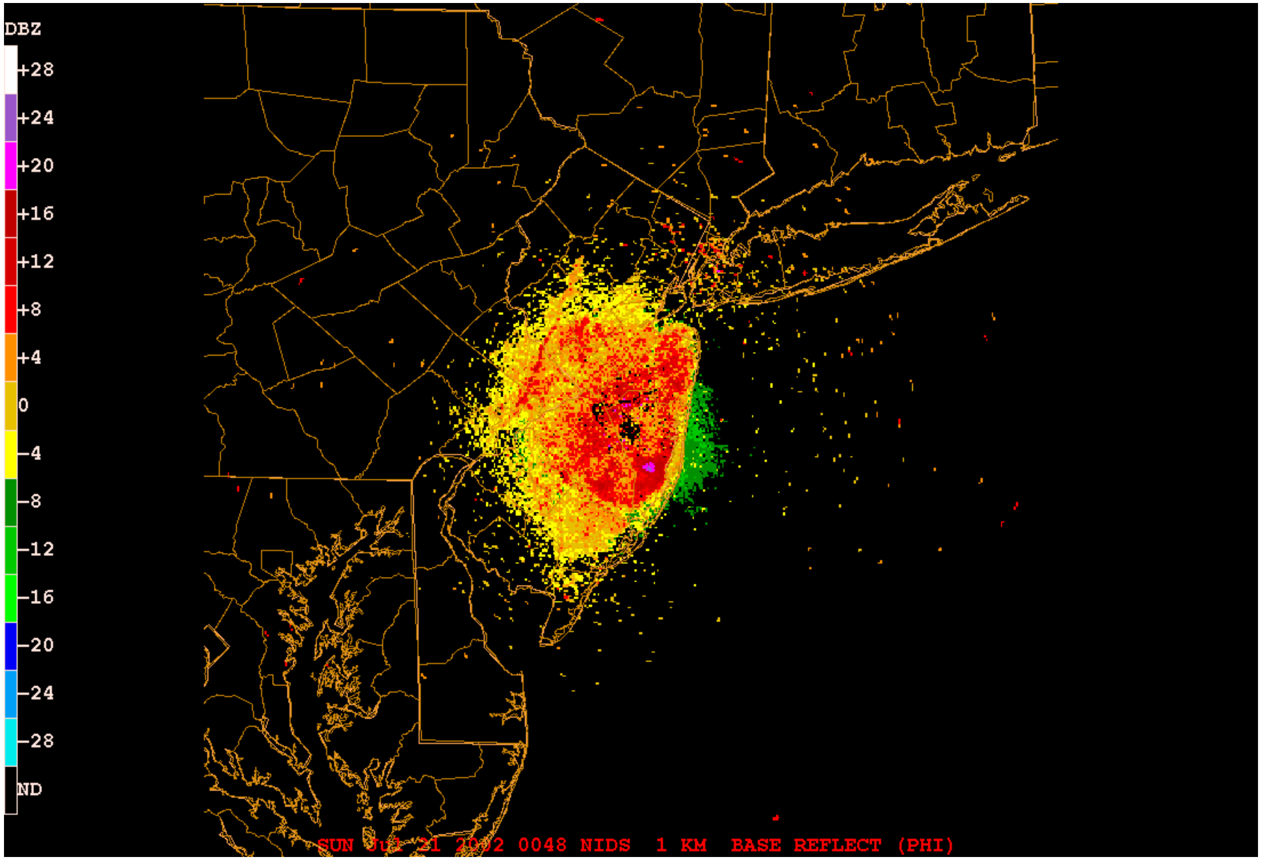


MILLERSVILLE UNIVERSITY Earth Sciences Department

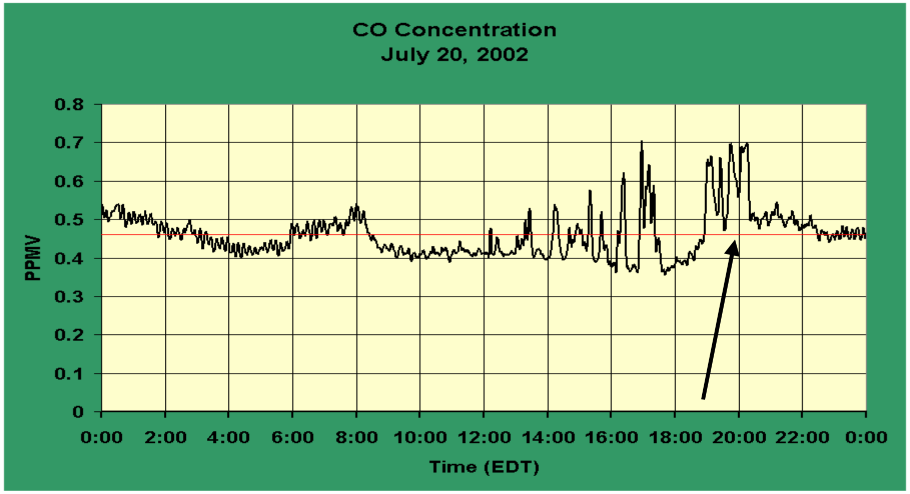
20 July 2002
18Z Surface Analysis

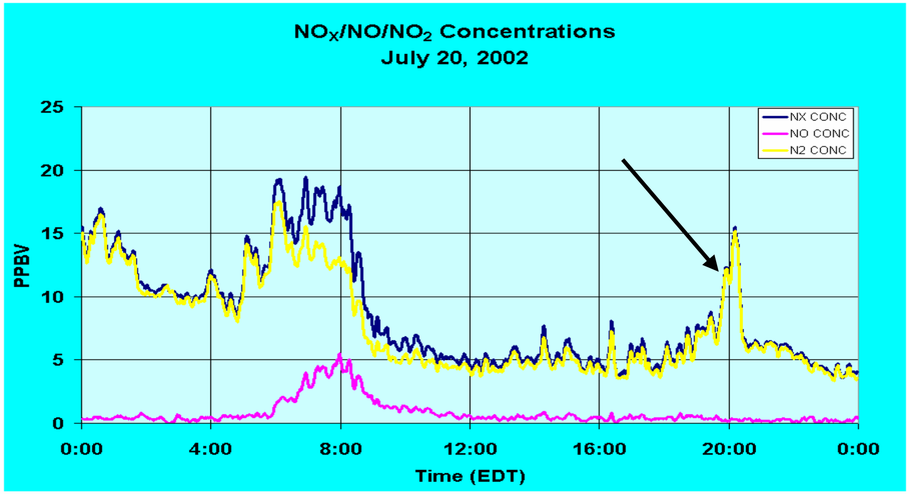


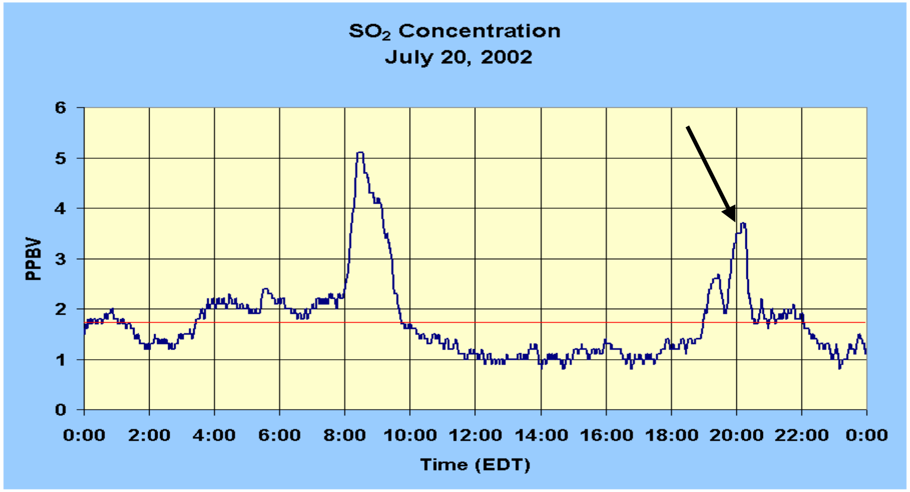
20 July 2002
Ft Dix Radar

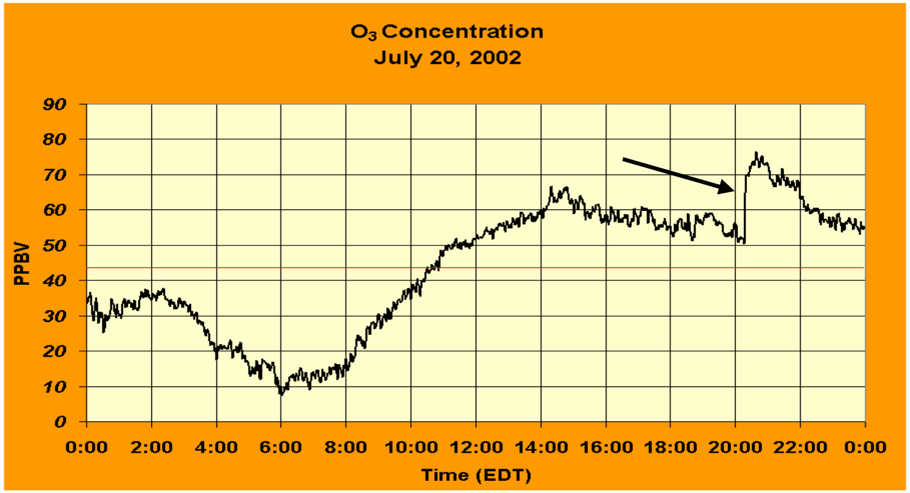


20 July 2002
Surface Trace Gases

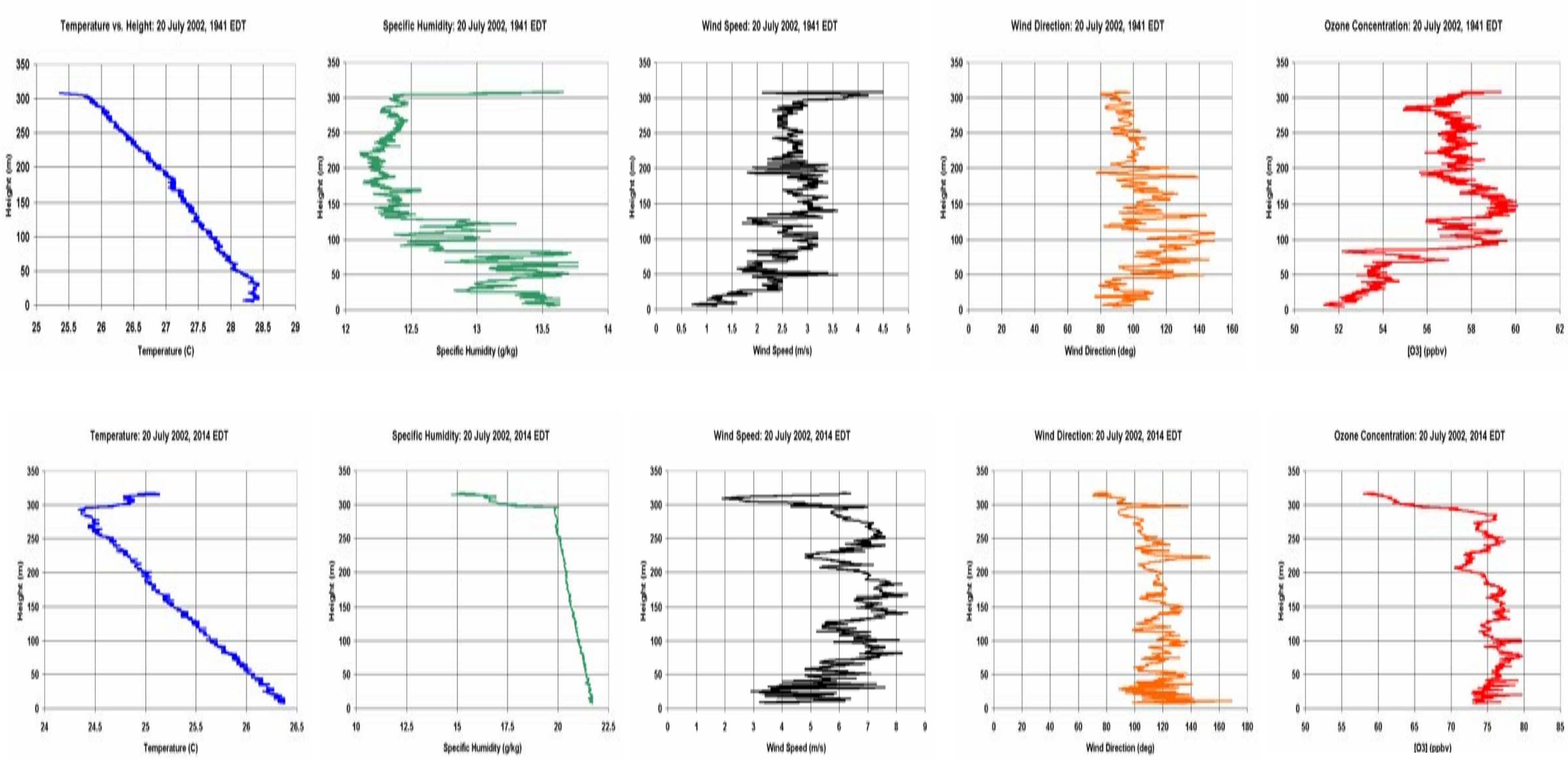






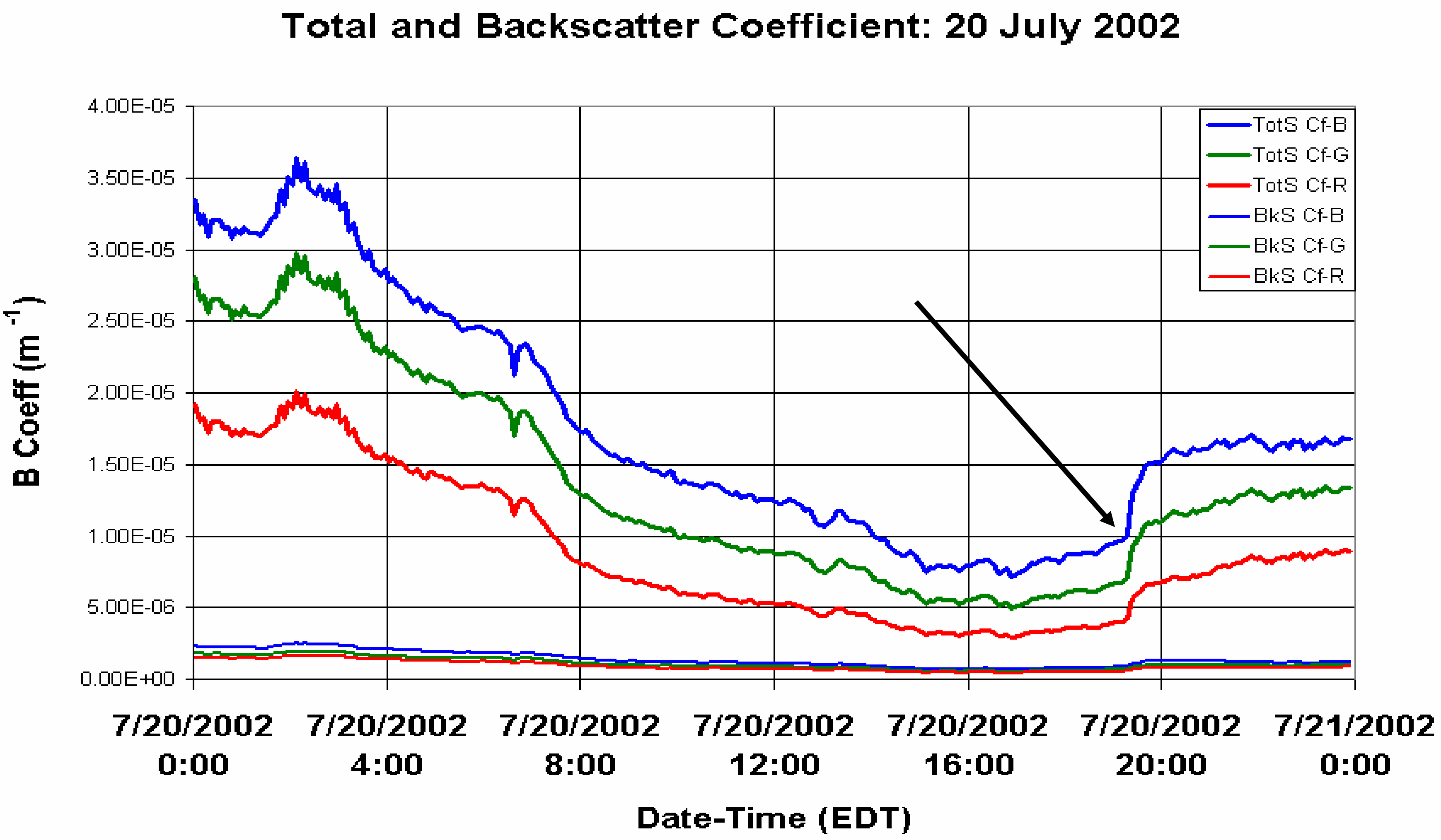


1941 – 2014 EDT 20 July 2002 MU- TASS



Saturday at the beach

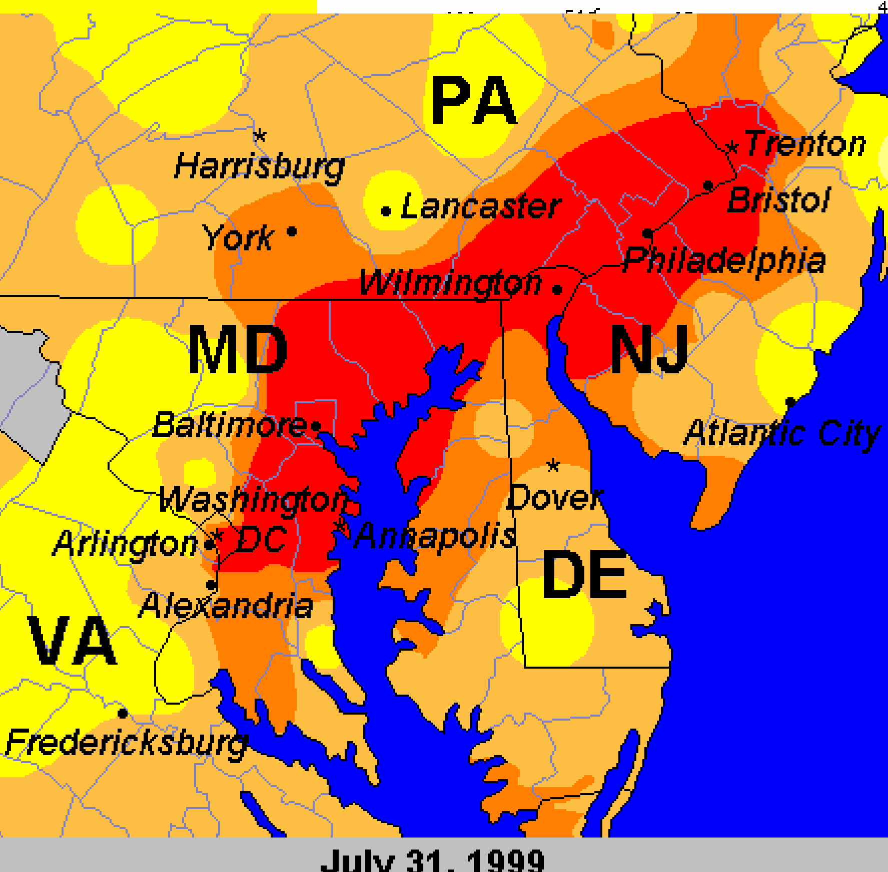
20 July 2002
Total and Back Scatter Coefficient

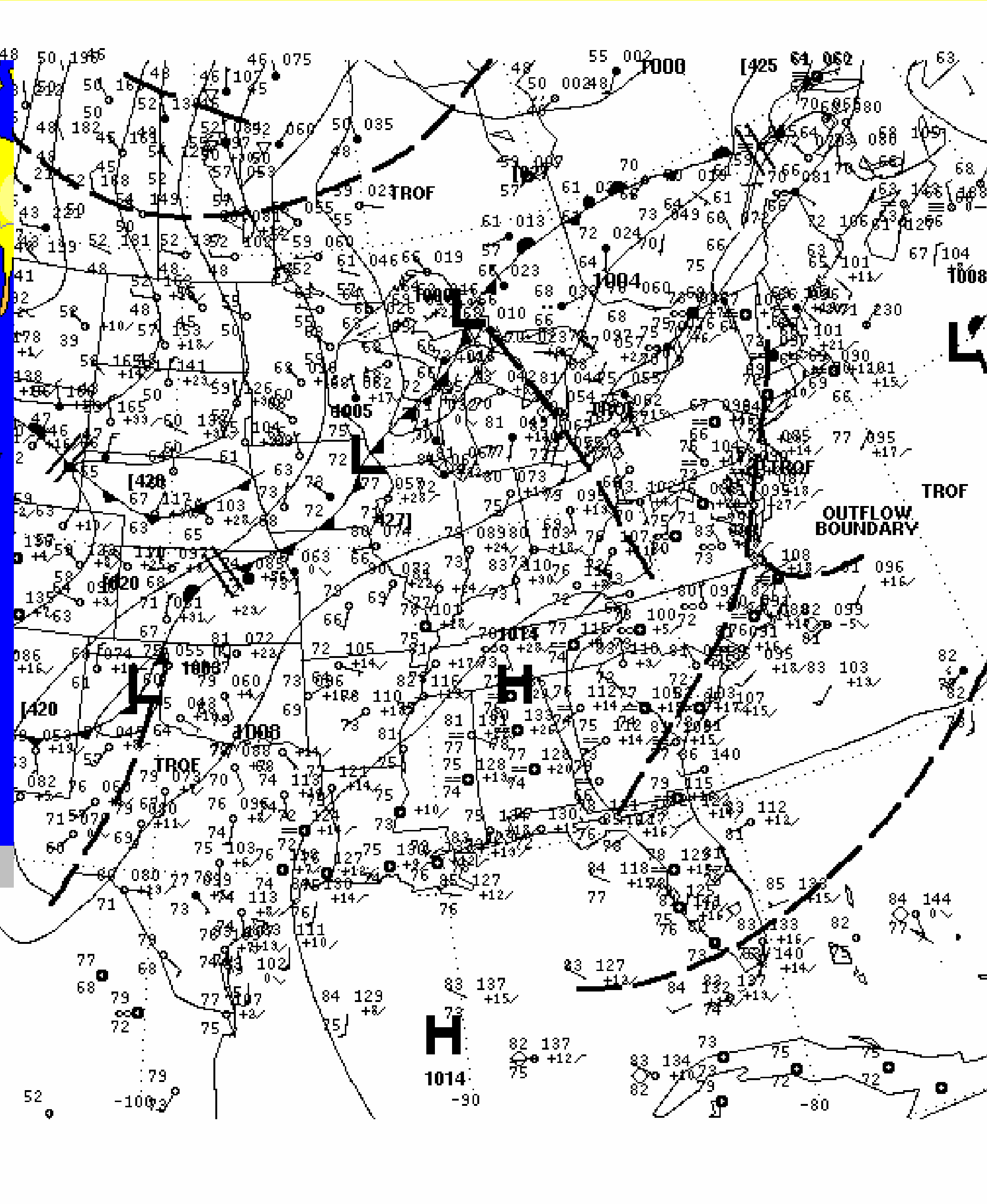


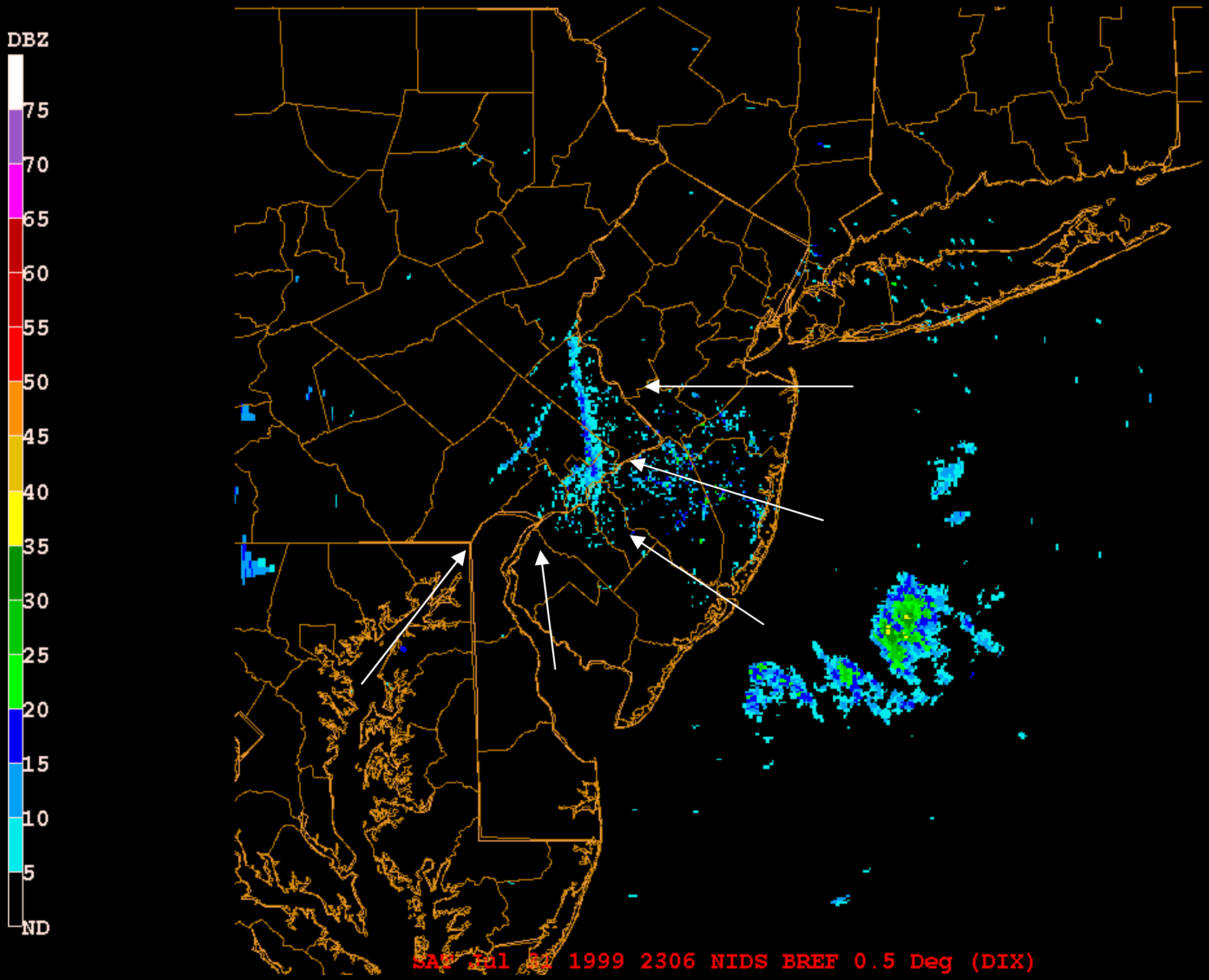
The Case Study of 31 July 1999
Sea/Bay Breeze Convergence
Highlights

- Highest O_3 levels (165 ppbv) in PHL in 11 years.
- Convergence along the I-95 corridor resulting from complex interaction between lee trough, sea breeze, and outflow boundary to the SE.
- Westerly transport aloft on 30 July.
- Surprising structure and variation within the lowest 100 meters, with dramatic changes in temperature, relative humidity, wind velocity, O_3, and total scattering due to PM fine.

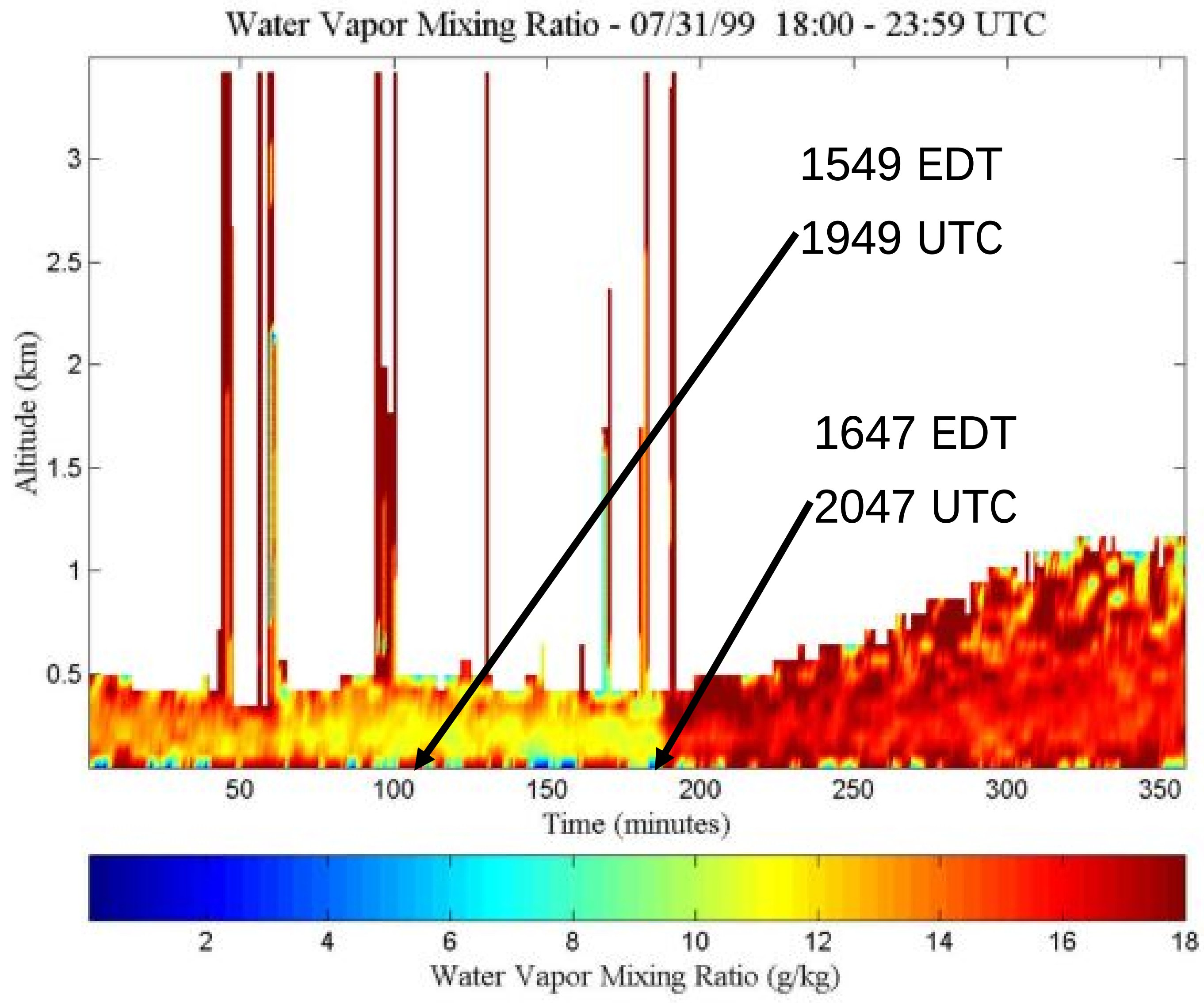
31 July 1999 continued...



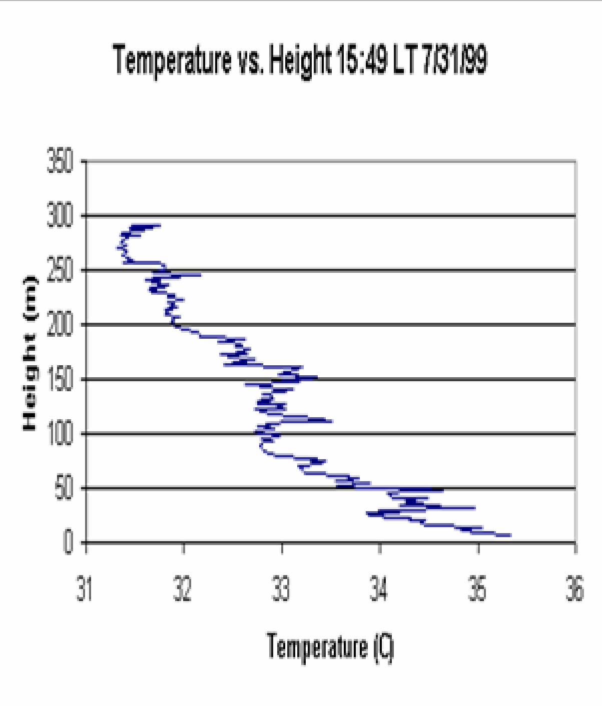


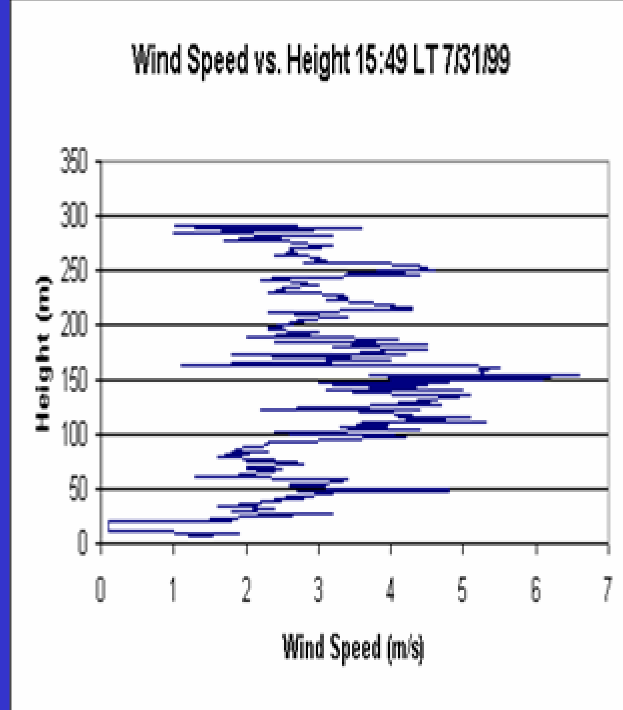


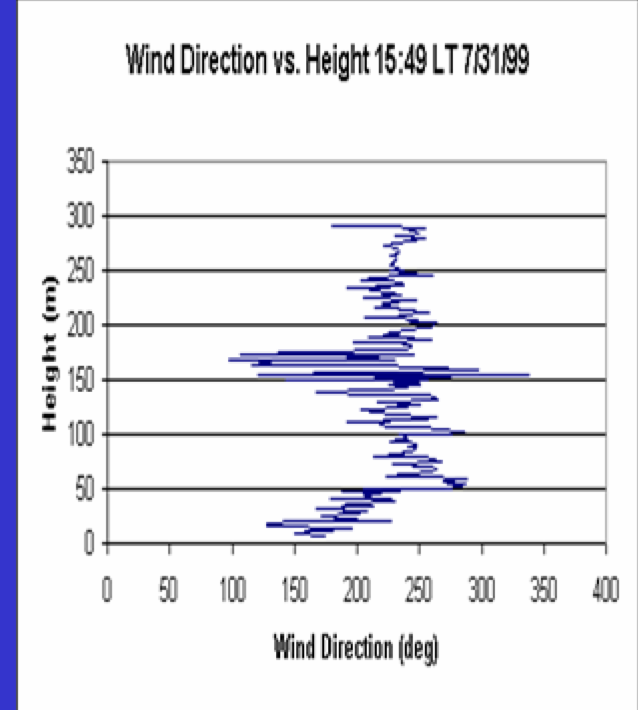
31 July 1999 1906 EDT



PSU Raman Lidar

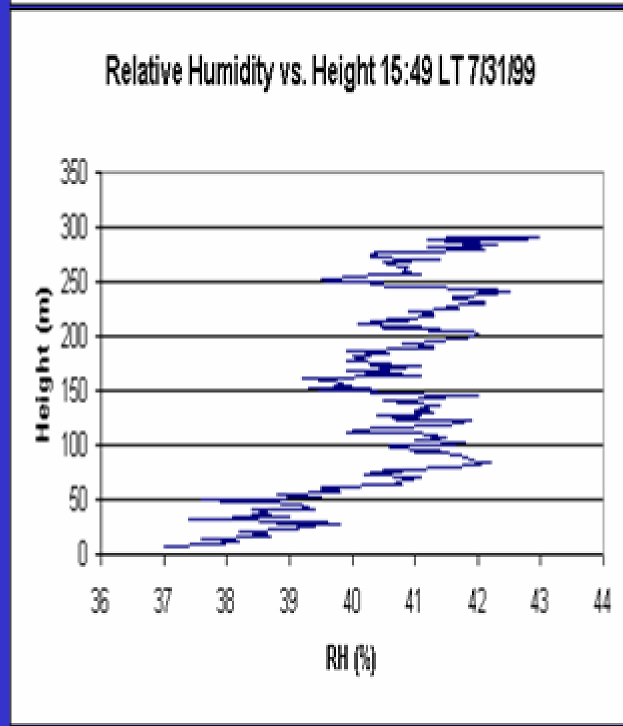


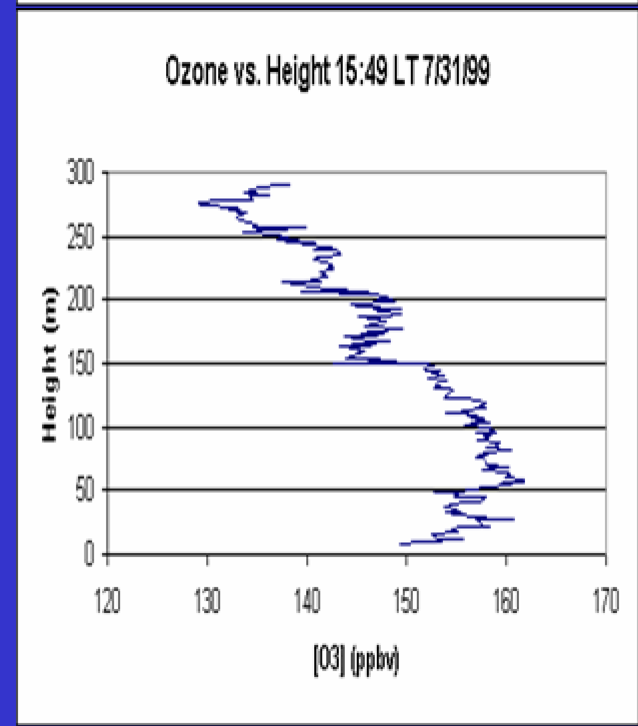


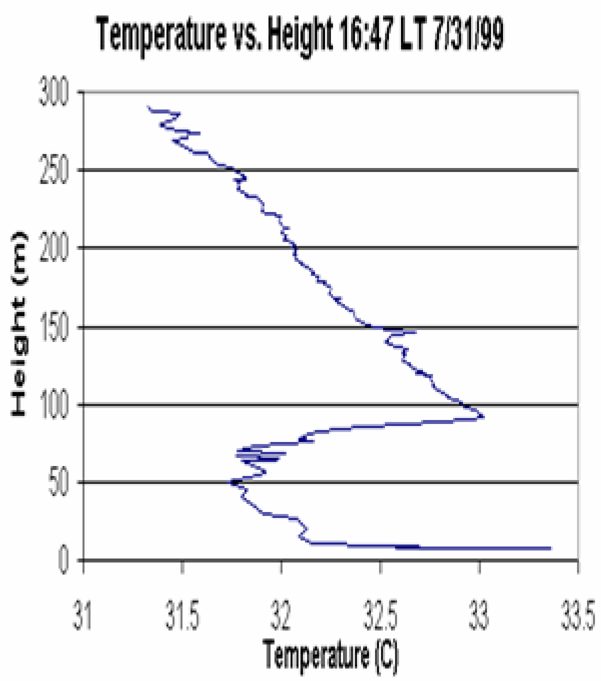


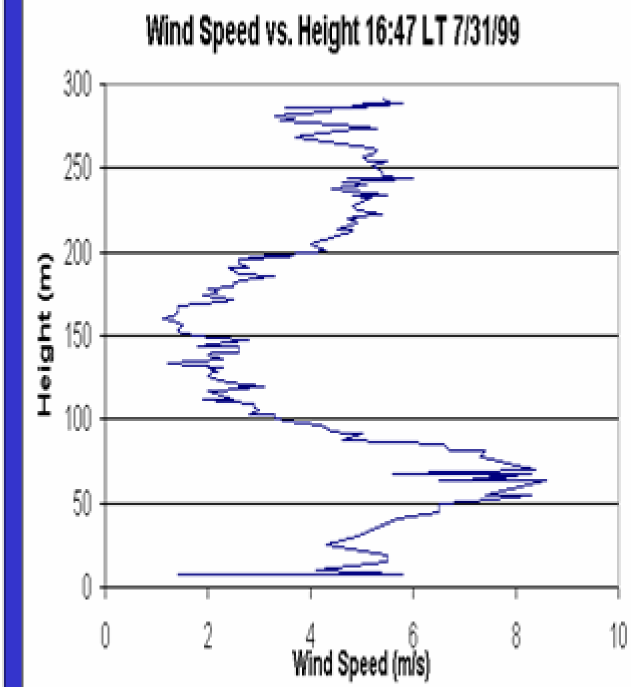
Vertical profiles prior to passage of sea/bay breeze convergence zone

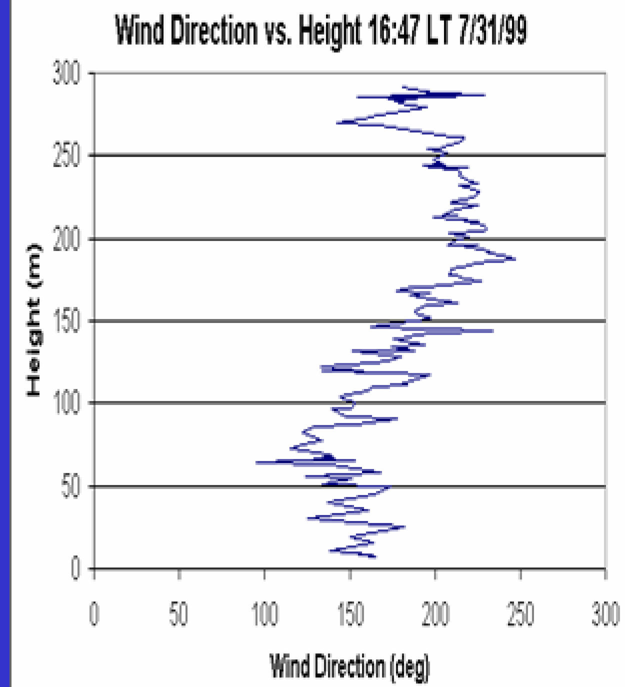
1549 EDT 31 July 1999





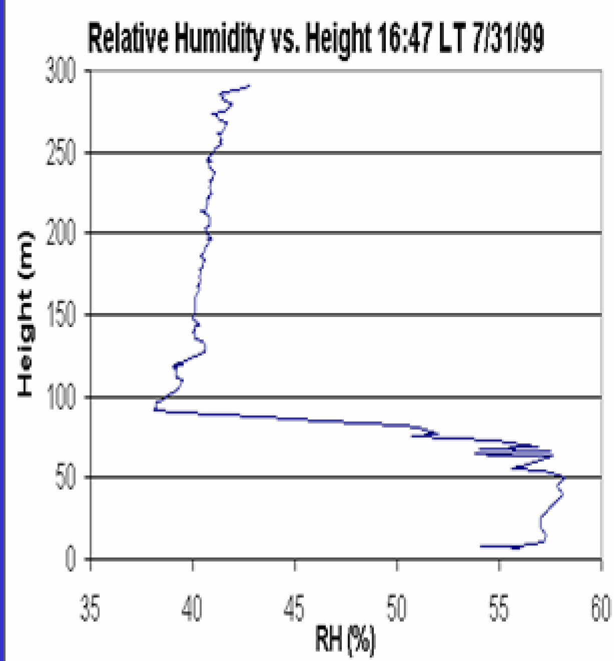


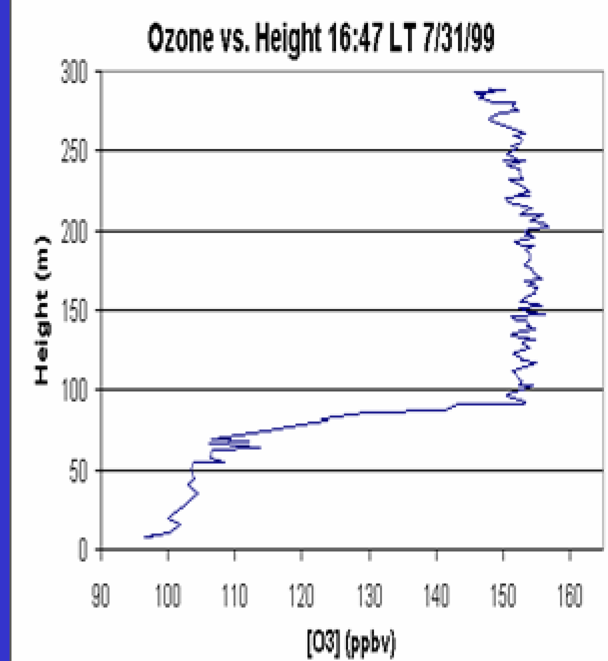




Vertical Profiles after the passage of the sea/bay breeze front

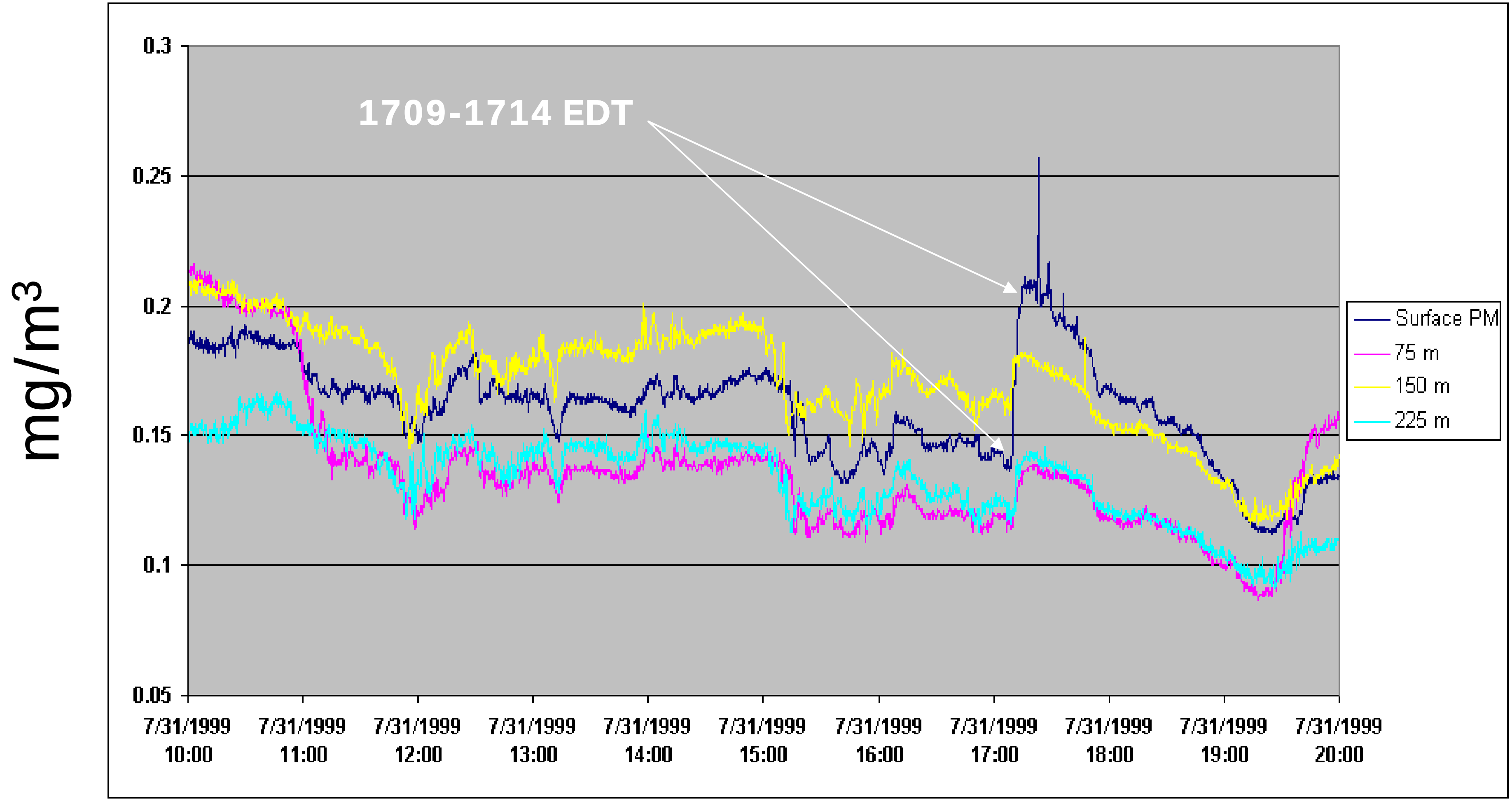
1647 EDT 31 July 1999

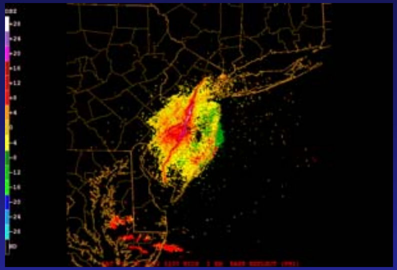




$PM_{2.5}$ obtained with laser-diode scatterometers at four levels

31 July 1999, 1000-2000 EDT





Summary and Conclusions

- Sea breeze circulations have the ability to significantly modify the atmospheric boundary layer in the Philadelphia area in time scales on the order of minutes
- Sea breezes are accompanied by a rapid rise in relative humidity to saturation levels, and the concurrent increase in optical extinction with the formation of haze droplets on existing aerosols, and the advection of maritime aerosols into the area
- Sea breezes are typically shallow; 100 – 300 m by the time they intrude as far inland as Philadelphia
- As a sea breeze propagates westward, its length, intensity, and signature clear air Radar return diminishes as it dissipates in the surrounding air mass
- The effect on the air chemistry is very sensitive to the relative change in wind direction
- Operational models can simulate the sea breeze but fail to adequately capture the depth and timing of this shallow event
- Sea breezes can enhance upstream convergence and storm development and, in turn, be influenced by even moderate meso-dynamic forcings

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