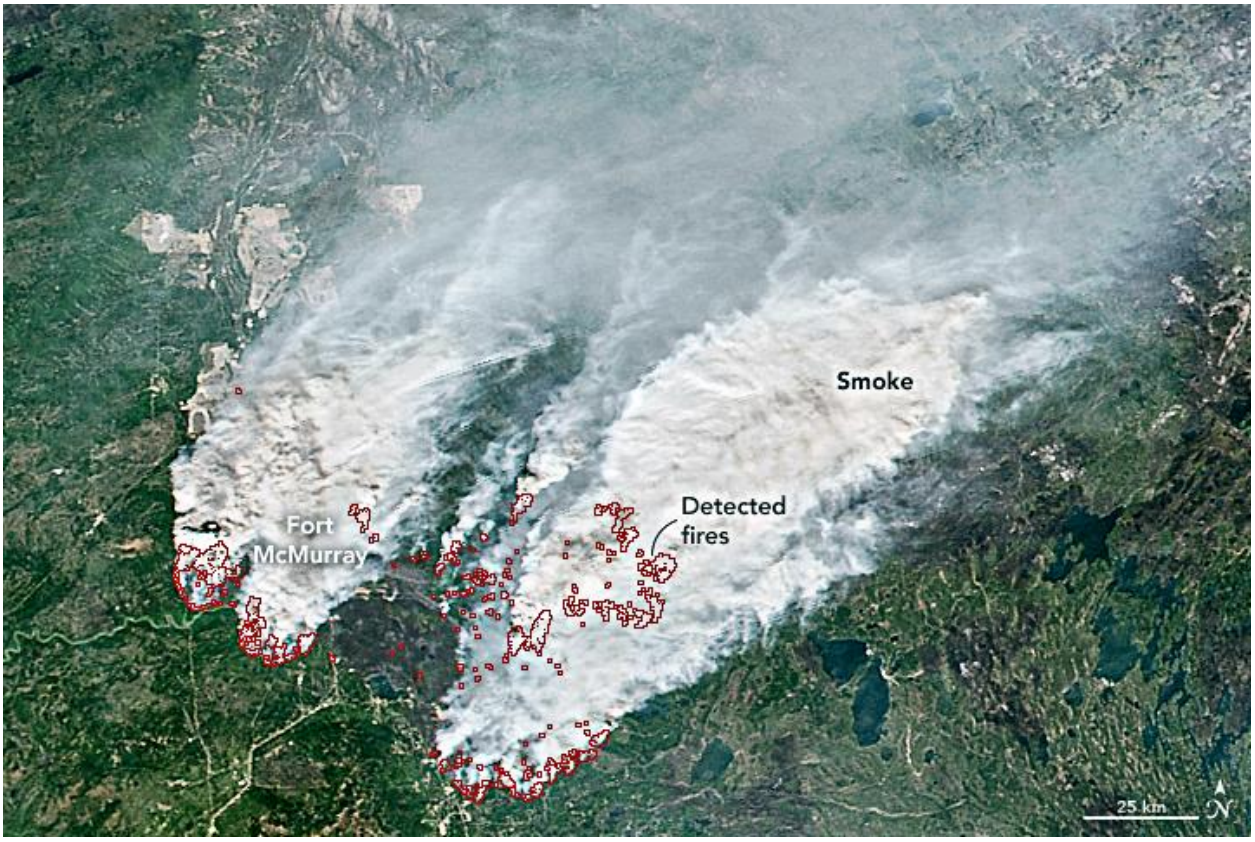
Connecticut Department of
ENERGY &
ENVIRONMENTAL
PROTECTION

May 2016 Ozone Exceptional Event Analysis
Technical Support Document



Connecticut Department of Energy and Environmental Protection

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1. OVERVIEW

1.1 Introduction

On May 25th, 2016, Connecticut's air quality forecasters noted an unusual area of elevated ozone concentrations over the upper Midwest and New York State moving into New England. This was unusual for this early in the season with the meteorological conditions that were observed. It became apparent that the elevated ozone was likely due to the interaction with the persistent Fort McMurray wildfire smoke plume that had been moving toward New England for several days. Although the National Oceanic and Atmospheric Administration (NOAA) operational ozone model had been predicting good to moderate ozone concentrations throughout the area, air quality reached unhealthy levels in many areas of the State. Figure 1 shows the NOAA air quality index forecast (a) for May 25th compared to the actual air quality index values (b) for that day.

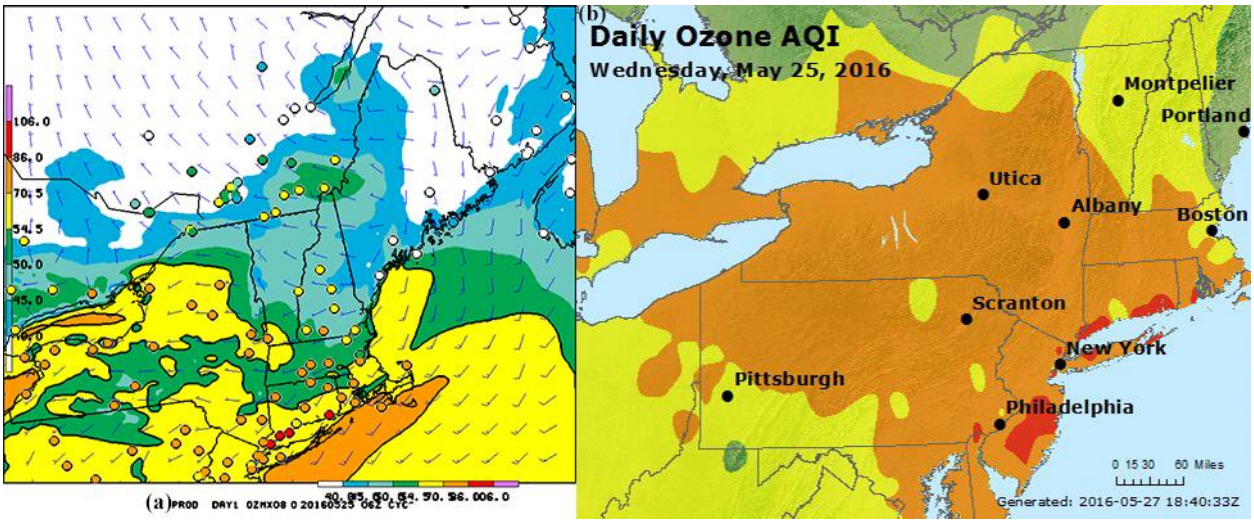

Figure 1. NOAA model forecasted AQI values for May 25th, 2016 (a) and the observed ozone AQI values (b) on that day.

Connecticut air quality monitors reported daily maximum 8-hour average ozone levels over the 70 ppb National Ambient Air Quality Standard (NAAQS) during the May 25-28, 2016 time period. In August of 2016, Connecticut placed an informational flag on all the monitored ozone data for that entire 4-day period. An Agency is required to notify EPA of its intent to exclude one or more measured exceedances of an NAAQS as being due to an exceptional event by placing an informational flag in the appropriate field for the data record of concern that has been submitted to the federal air quality system (AQS) database. By letter, dated September 28th, 2016, Connecticut officially notified the EPA Region 1 Office of our intent to submit an exceptional events' data exclusion demonstration for that time period.

The letter cited the factors indicating that the Fort McMurray wildfire influenced the flagged data as follows:

- Weather patterns were initially not favorable for ozone formation over Connecticut. High pressure trapped pollutants from the wildfire over the upper Great Lakes for several days before normally clean northwest winds transported 'unhealthy' levels of ozone to the east and southeast across New York State and then to Connecticut (See section 2.6 Meteorological Conditions);
- Visible satellite plumes and back trajectory analysis before the event showed wildfire smoke transport southeast into the Midwestern States before arriving over Connecticut on May 25th, 2016 (See Section 3.1 Satellite Photos, Webcams and Plume Analysis); and
- The NOAA operational ozone forecast model under-predicted ozone by more than 20 ppb during the period. The under prediction is likely due to the inability of the model to account for the effect of real-time gas-phase smoke emissions from the fire (See section 3.6 NOAA CMAQ Model Prediction).

Although all four days of the ozone event were likely influenced by the smoke plume chemistry, Connecticut believes that the days of May 25-26, 2016 unequivocally qualify for an exceptional event data exclusion and request this exclusion for the four monitors that would have the most regulatory impact. Connecticut is requesting the exclusion of ozone data for the entire 48 hour period of May 25-26, 2016 for the following four monitors: Cornwall, East Hartford, Westport, and Abington.

1.2 EPA Exceptional Event Guidance

The Environmental Protection Agency (EPA) revised the Exceptional Events Rule (EER) in October of 2016[1], based on implementation experiences with the exceptional events data exclusion process. The revised EER states that an exceptional events demonstration must include the following elements:

1) A narrative conceptual model that describes the event(s) causing the exceedance or violation and a discussion of how emissions from the event(s) led to the exceedance or violation at the affected monitor(s);

2) A demonstration that the event affected air quality in such a way that there exists a clear causal relationship between the specific event and the monitored exceedance or violation;

3) Analyses comparing the claimed event-influenced concentration(s) to concentrations at the same monitoring site at other times. The Administrator shall not require a State to prove a specific percentile point in the distribution of data;

4) A demonstration that the event was both not reasonably controllable and not reasonably preventable;

[1] **Federal Register** / Vol. 81, No. 191 / Monday, October 3, 2016: **Treatment of Data Influenced by Exceptional Events**

5) A demonstration that the event was caused by human activity that is unlikely to recur at a particular location or was a natural event; and

6) Documentation that the submitting air agency followed the public comment process.

The guidance document introduced the concept of a 3-tier analysis: "Tier 1 clear causal analyses should be used for wildfire events that cause clear O_3 impacts in areas or during times of year that typically experience lower O_3 concentrations, and are thus simpler and less resource intensive than analyses for other events. Tier 2 clear causal analyses are likely appropriate when the impacts of the wildfire on O_3 levels are less clear and require more supportive documentation than Tier 1 analyses. Tier 3 clear causal analyses should be used for events in which the relationship between the wildfire and the O_3 exceedance or violation is more complicated than the relationship in a Tier 2 analysis, and thus would require more supportive documentation than Tier 2 analyses".

Though ozone exceedances of this magnitude do not generally occur this early in the ozone season, after consulting with our Regional EPA Office, it was determined that a Tier 1 analysis would not be appropriate; because of the remote distance of the fire from Connecticut (~3200 km). To qualify for a Tier 2 analysis, a comparison of the ratio of Q, the daily tons of VOC and NOx emitted from the fire, to d, the distance in kilometers from the fire to the point of concern, a "Q/d" analysis, resulting in a value in excess of 100 tons per day per kilometer (tpd/km) can be considered to have a clear causal impact on ozone. EPA developed this value based on analyses of four fires which occurred in 2011. We present a summary of our analysis here in Appendix A. The Q/d method does not generally satisfy the expectation of a clear causal impact for Connecticut, therefore, we present other evidence demonstrating that the plume from the Fort McMurray fire caused elevated ozone levels in Connecticut.

1.3 Description of the Fort McMurray Fire

On May 1, 2016, a wildfire began southwest of Fort McMurray, Alberta, Canada. On May 3, it swept through the community, destroying approximately 2,400 homes and buildings and forcing the largest wildfire evacuation in Albertan history. The fire spread across approximately 590,000 hectares (1,500,000 acres) before it was declared to be under control on July 5, 2016. Figure 2 shows an image of the fire as it approached Fort McMurray and Figure 3 shows its extent on May 8th, 2016.

Press Releases

In a Canadian Broadcasting Corporation (CBC) June 14th, 2016 article:
"The Fort McMurray wildfire MWF-009, which came to be known across Canada as "The Beast," was not ignited by a lightning strike, and police are now asking for the public's help to determine whether it was the result of a criminal offence.

Provincial wildfire investigators have established that the fire was most likely the result of "human activity."

The fire was first sighted about 15 kilometres southwest of Fort McMurray by an airborne forestry crew on May 1.

Over the next two days, the wildfire grew rapidly. On May 3, pushed by high winds and fuelled by tinder-dry conditions, the fire raged into the city itself and forced more than 80,000 residents to flee."

Fort McMurray wildfire ash reaches all the way to Spain

By Wallis Snowdon, CBC News Posted: May 25, 2016 2:02 PM MT|

…"The massive plume of particulates from the fire would have travelled more than 12,000 metres into the atmosphere, before the haze was carried east along the jet stream.

When that column started to build over a couple of those really key days, it got the smoke way, way up into the atmosphere and it basically gets stuck in the jet stream, Gray said.

The jet stream will grab it, and like a river it will carry it down and take it as far as the volume goes. It could circumnavigate the globe if there's enough of it.

…Before the plume travelled east across the Atlantic Ocean, Gray said, it also travelled south, hitting large swaths of the southern United States."

Wildfires in western Canada send haze to New England

PORTLAND, Maine (May 12, 2016)—

"If you thought the sky didn't seem quite as brilliantly blue on Thursday, you were right, and you can blame wildfires in western Canada.

Smoke continues to billow from fires in western Canada, fanned eastward by winds in the middle and upper atmosphere.

The smoke is just potent enough to cause the sky over much of New England to appear a bit hazy or "milky" in appearance.

…Wildfires have been burning in parts of Alberta and British Columbia, including the large Fort McMurray fire that led to the evacuations of tens of thousands of people from the northern Alberta province."

Description of the Plume

During the month of May, a large smoke plume, fed by this massive, long lasting wildfire, meandered through southern Canada and the Upper Great Lakes to New England. From about May 18- May 24th, surface high pressure settles over the upper Mid-Western United States, trapping residual pollutants from the wildfire in the lower boundary layer of the atmosphere. Coincident with this, wildfire plumes from extensive agricultural fires in the Yucatan Peninsula in Mexico were being transported northward by winds higher in the boundary layer. Satellite

imagery suggests that the two plumes began merging together in the Upper Mid-West States as early as May 13th

On May 24th, surface temperatures rose to produce conditions suitable for ozone formation around the Great Lakes States, especially in Michigan. On that date, every monitor in Michigan exceeded the 8-hour ozone NAAQS of 70 ppb. On May 25th, the wildfire plume, enhanced by the plumes' interaction with urban NOx plumes in the Midwest States, was transported to the east and southeast to the Mid-Atlantic States and New England, resulting in some of the highest

Figure 2. Photo of Wildfire as it approaches Fort McMurray on Wednesday, May 4, 2016. (Jeff McIntosh/CP). Note that the plume ejects far into the atmosphere, forming pyro-cumulus clouds.

ozone concentrations for the 2016 summer. Weather conditions in the northeastern United States were originally not conducive for ozone formation during May 24-25th and although conditions became more favorable for ozone formation after May 25th, it is evident from our analysis that that the wildfire plumes had a significant effect on the ozone levels for several days. Though more conducive to an exceedance, the wildfire plume likely increased ozone levels by as much as 20 ppb and therefore qualifies as an exceptional event. Figure 4 shows the movement of the unhealthy for sensitive groups (USG) ozone levels from the great lakes to the east coast from May 24-25, 2016

Figure 3. Photo of the Fort Murray Wildfire Plume on May 8, 2016

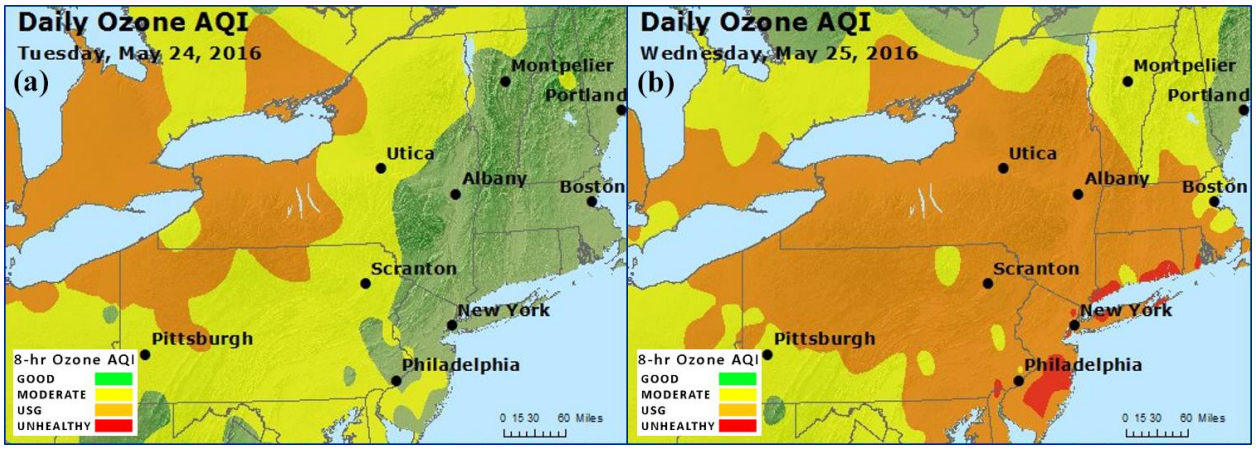

Figure 4. Ozone AQI Map for (a) May 24th and (b) May 25th, 2016.

2. CONCEPTUAL MODEL OF EVENT

2.1 Monitoring Network

Network Overview: DEEP currently operates 14 air monitoring stations in its state-wide network. These include two National Core (NCore) multi-pollutant sites: Criscuolo Park in New Haven, and Mohawk Mountain in Cornwall. In addition, EPA operates an ozone site in

Abington, in the town of Pomfret, as part of the Clean Air Status and Trends Network (CASTNET). Table 1 provides a summary of pollutant and meteorological parameters currently monitored in the network.

Ozone is monitored in Connecticut at 12 sites, 11 DEEP State and Local Air Monitoring Stations (SLAMS) and 1 CASTNET, as shown in Figure 5. As of 2017, the ozone monitoring season is March 1 through September 30; previously it was April 1 through September 30.

The DEEP air monitoring network meets the minimum monitoring requirements for criteria pollutants as put forth in Title 40 Part 58 of the Code of Federal Regulations (CFR), Appendix D. More detailed descriptions of the monitoring network are provided in the Connecticut 2016 Annual Air Monitoring Network Plan and the Connecticut 2015 Air Monitoring Network Assessment.

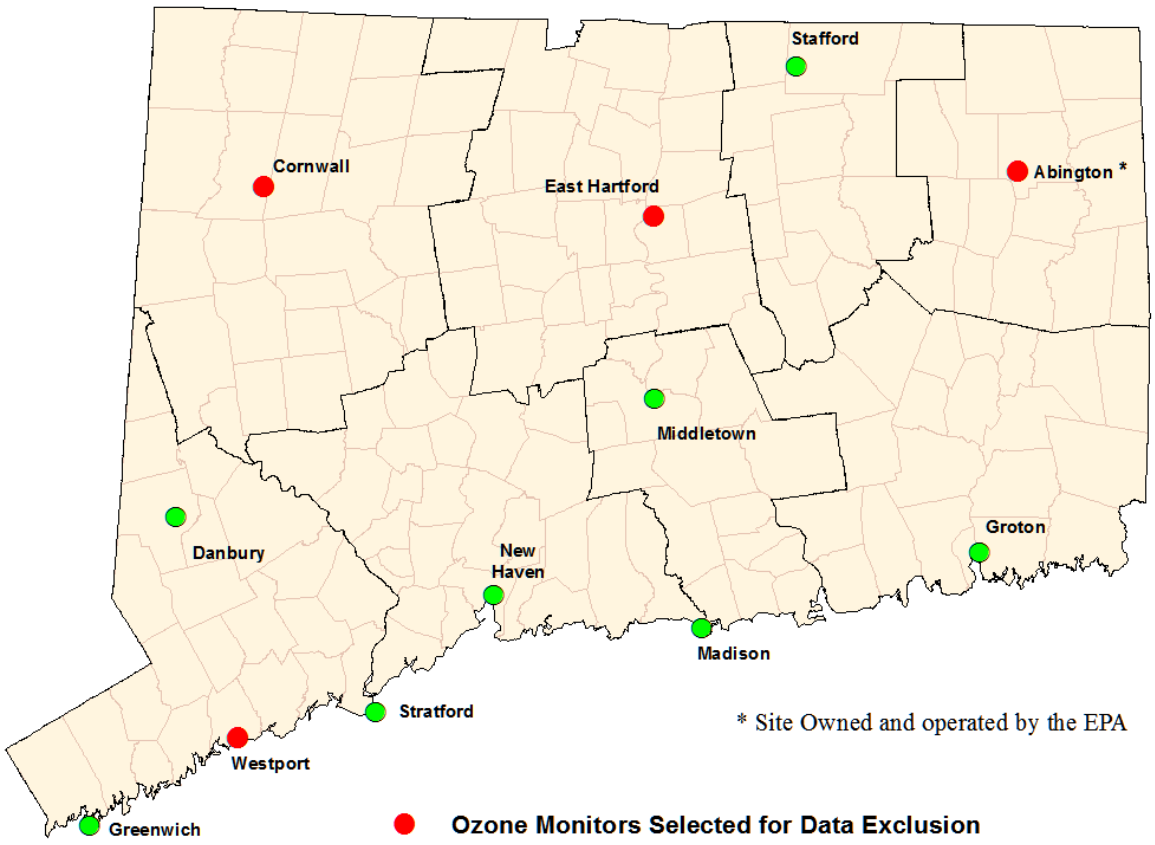

Figure 5. Connecticut Ozone Monitors. Ozone Monitors Selected for Data Exclusion are Highlighted.

Site Descriptions: This exceptional event demonstration is focused on the impacts of the event on 4 monitoring sites that are key in Connecticut's ozone attainment planning efforts. These are:

Westport (Sherwood Island State Park), Cornwall (Mohawk Mountain), East Hartford (McAuliffe Park) and Pomfret (Abington).

Pomfret (Abington): AQS ID 09-015-9991; Lat: 41.84046°, Lon: -72.010368°.
The Abington site is a regional-scale site located in a rural/agricultural area in northeast Connecticut in the town of Pomfret. This site is operated by the National Park Service under the direction of EPA as part of their Clean Air Status and Trends Network (CASTNET). It is located on a hilltop approximately 2.3 km south of State Route (SR) 44 and 0.6 km east of SR 97. The site includes a portable shed located in the center of an agricultural field that is surrounded by forest.

Cornwall (Mohawk Mountain): AQS ID: 09-005-0005; Lat: 41.82140°, Lon: -73.29733°.
The Mohawk Mountain site is a regional-scale site located in northwestern Connecticut in the town of Cornwall. The site is located at the summit of Mohawk Mountain with an elevation of 505 m (1656 ft), and is approximately 17 km to the east of the New York border and 25 km to the south of the Massachusetts border.

East Hartford (McAuliffe Park): AQS ID: 09-003-1003; Lat: 42.78471°; Lon: -72.63158°.
The McAuliffe Park site is neighborhood-scale site located in central Connecticut in the town of East Hartford. The site is located approximately 120 m to the east of Rte 5, 2.0 km to the east of I-91 and 2.5 km to the south of I-291. This site is located 3.7 km to the northeast of the city of Hartford. Residential neighborhoods are located in all directions of this site.

Westport (Sherwood Island State Park). AQS ID: 09-001-9003; Lat: 41.11822°; Lon: -73.33681°.
The Westport Sherwood Island State Park site is a regional-scale site located in southwestern Connecticut. This is a coastal site that is approximately 0.5 km to the south of I-95 on the Long Island Sound. This site is ideally situated to measure impacts from transported pollution from New York City and the I-95 corridor.

Table 1. List of Connecticut Ambient Air Monitoring Sites and Parameters. Shaded rows are the monitors being requested for exclusion.

Town	Site	PM2.5 (FRM)	PM2.5 (FRM, Collocated)	PM2.5 (Continuous - FEM)	PM10/PM-Coarse (FRM)	PM10/PM-Coarse (FRM, Collocated)	PM10/PM-Coarse (Continuous)	PM Speciation (CSN)	PM Speciation (IMPROVE)	PM2.5 Carbon (BC/UVC, Continuous)	Ozone	SO2	CO	Direct NO_2	NO/NOy	Traffic Count	Wind Speed	Wind Direction	Temperature	Dew Point / Rel. Humidity	Barometric Pressure	Solar Radiation	Mixing Height
Bridgeport	Roosevelt School		1/6†	X	1/6							X	X						X				
Cornwall	**Mohawk Mountain**	**1/3 ***		**X**			**X**		**1/3**	**X**	**X**	**X**	**X**		**X**		**X**	**X**	**X**	**X**	**X**		
Danbury	Western Connecticut State University	1/6		X						X	X						X	X	X		X		
East Hartford	**McAuliffe Park**	**1/6**		**X**	**1/6**					**X**	**X**	**X**	**X**	**X**			**X**	**X**	**X**	**X**	**X**	**X**	
Greenwich	Point Park										X						X	X	X				
Groton	Fort Griswold	1/6		X							X								X				
Hartford	Huntley Place	1/3		X			X			X			X	X		X	X	X	X		X		
Madison	Hammonasset State Park										X						X	X	X				
Middletown	Connecticut Valley Hospital										X						X	X	X				
New Haven	Criscuolo Park	1/3	1/6	X	1/3	1/6	X	1/3		X	X	X	X	X	X		X	X	X	X	X	X	X
Pomfret	**Abington (EPA)**										**X**												
Stafford	Shenipsit State Forest										X						X	X	X				
Stratford	Stratford Lighthouse										X								X				
Waterbury	Meadow & Bank Street	1/6		X													X	X	X				
Westport	**Sherwood Island State Park**										**X**						**X**	**X**	**X**				

*1 in 3 day sampling schedule †1 in 6 day sampling schedule

2.2 Monitored Maximum 8-hour Average Ozone for May 25-28, 2016

Table 2 shows the maximum 8-hour ozone averages observed at the Connecticut monitors during this ozone event that occurred during the May 25-28th period. There were monitored exceedances of the 70 ppb ozone NAAQS on all 4 days between May 25-28th, 2016. The overwhelming influence of the wildfire smoke is most readily observed on May 25-26, which is the period that this demonstration focuses on..

Table 2. Monitored Maximum 8-hour Ozone for Connecticut Sites

Site Name	5/25/2016	5/26/2016	5/27/2016	5/28/2016
Abington	76	83	68	67
Cornwall	81	91	78	65
Danbury	82	99	81	81
East Hartford	75	93	70	81
Greenwich	89	91	63	82
Groton Fort Griswold	87	80	54	60
Madison-Beach Road	89	86	56	63
Middletown	80	91	67	79
New Haven - Criscuolo Park	63	84	65	73
Stafford	74	82	70	73
Stratford	89	76	59	70
Westport	87	90	61	81

2.3 Regulatory Significance

According to the EER guidance document, an exceptional event can be requested when *"…The assignment or re-assignment of a classification category (marginal, moderate, serious, etc.) to a nonattainment area to the extent this is based on a comparison of its "design value" to the established framework for such classifications; ..."* For this ozone event, the Westport monitor design value would no longer be in violation of the 1997 ozone NAAQS, if this wildfire event had not occurred.

We are also requesting data exclusions for our Abington, Cornwall and East Hartford sites. East Hartford and Cornwall are currently in non-attainment for the 2015- 70 ppb NAAQS, but there is concern that the wildfire influenced data could cause exceedances of the 2008 NAAQS or impede attainment of the 2015 NAAQS these sites could exceed the 2008- 75 ppb NAAQS, if future years produce high ozone events.

Our Abington site, which is currently in attainment for all the ozone NAAQS, could easily become non-attainment in future years, if this data is not excluded. Table 3 shows how this data exclusion would affect the 2016 design values. On March 23, 2016, DEEP requested to CASTNET to apply the data flags for May 25-26, 2016.

Though the plume remained over the region during the entire 4-day period, excluding May 27-28 would not have any significant effect on design values. The other sites were not clear outliers nor would rank as high for regulatory significance, since the 4th high values for those days would not be as critical in the design value calculations. Therefore, we have limited out data exclusion request to the four above-mentioned monitors.

Table 3. Preliminary 2016 Design Values with Critical 4th High 8-hour Ozone Average vs. Revised Design Values with Data Exclusion

Current Values						Revised Values Excluding May 25-26, 2016		
Site Name	**4th high 2014**	**4th high 2015**	**4th high 2016**	**2014-2016 DV**	**2017 Critical Value (NAAQS Standard)**	**4th high 2016**	**2014-2016 DV**	**2017 Critical Value (NAAQS Standard)**
Abington	67	70	**74**	70	69 (70)	67	68	76 (70)
Cornwall	68	**76**	**78**	**74**	74 (75)	**74**	**72**	78 (75)
East Hartford	**77**	**75**	**75**	**75**	78 (75)	**72**	**74**	81 (75)
Westport	**81**	**87**	**87**	**85**	81 (84)	**81**	**83**	87 (84)
DV Violations Classification	**70 ppb NAAQS**			**75 ppb NAAQS**		**84 ppb NAAQS**		

2.4 Monitored Concentrations

Figure 6 shows the hourly ozone concentrations for the four monitors from May 24-30, 2016 for the above mentioned monitored. It can be noted that May 24th showed very low ozone levels before spiking up on May 25th and May 26th. Although very high hourly concentrations were reported again at our East Hartford and Westport sites on May 28th, ozone transport from the I-95 corridor became a major factor and it would be difficult to estimate any lingering effects from the wildfire plume. Figure 7 shows the hourly ozone plots for the remaining seven monitors in Connecticut (Greenwich ozone data was invalidated). Though these sites show similar hourly ozone trends, the regulatory impact of the design values was not great enough to warrant a data exclusion request. It should be noted, however, that it may be possible that future ozone trends may increase the importance of the 4th high maximum 8-hour ozone values that this event generated.

Fine Particulate Matter (PM2.5) likewise showed an upward trend during the May 25-28, 2016 time period. This trend would be expected when a smoke plume interacts with the surface, although concentrations are generally much higher when a wildfire plume is nearby. Figure 8 shows the hourly PM2.5 concentrations for Connecticut monitors during this period. Higher order polynomial trend lines were inserted for the New Haven and Bridgeport monitors to show the upward shift from the pre-event baseline. Connecticut has a aerosol backscatter ceilometer

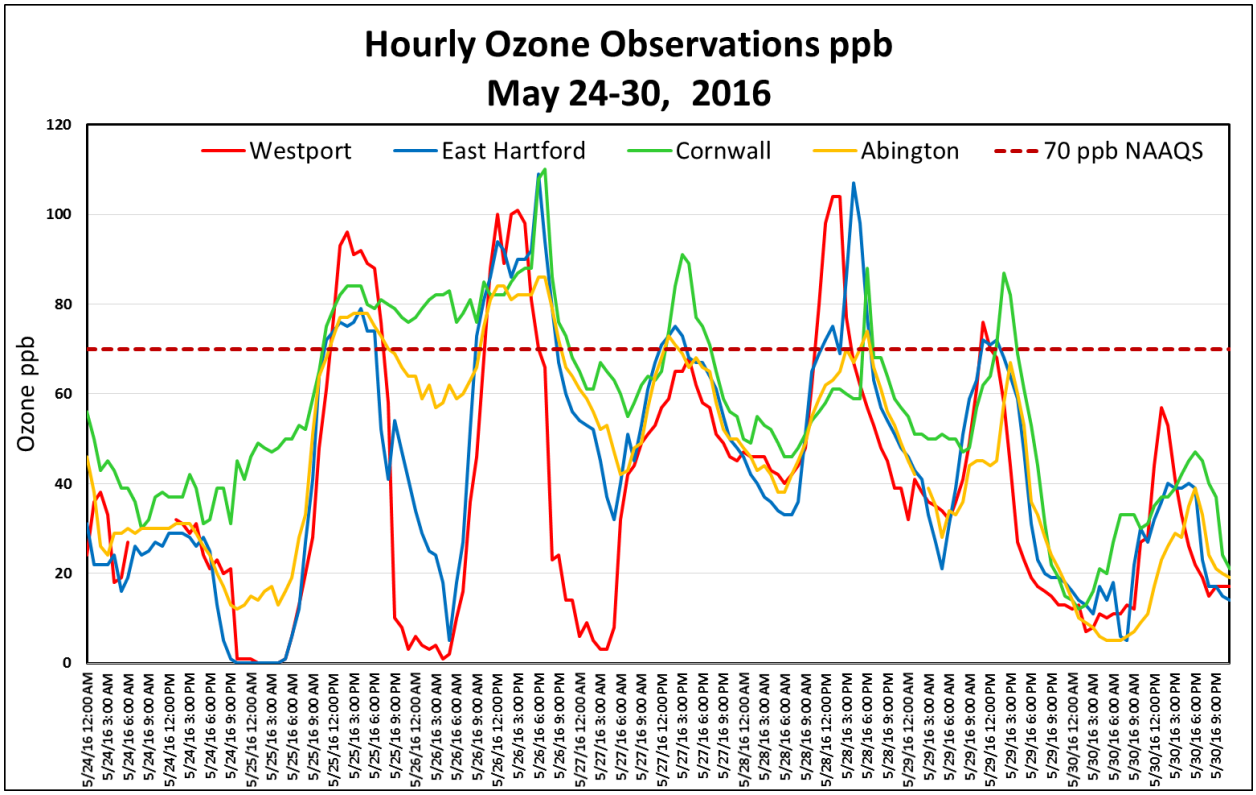

Figure 6. Hourly Ozone Concentrations for May 24-30, 2016 for Data Exclusion Sites

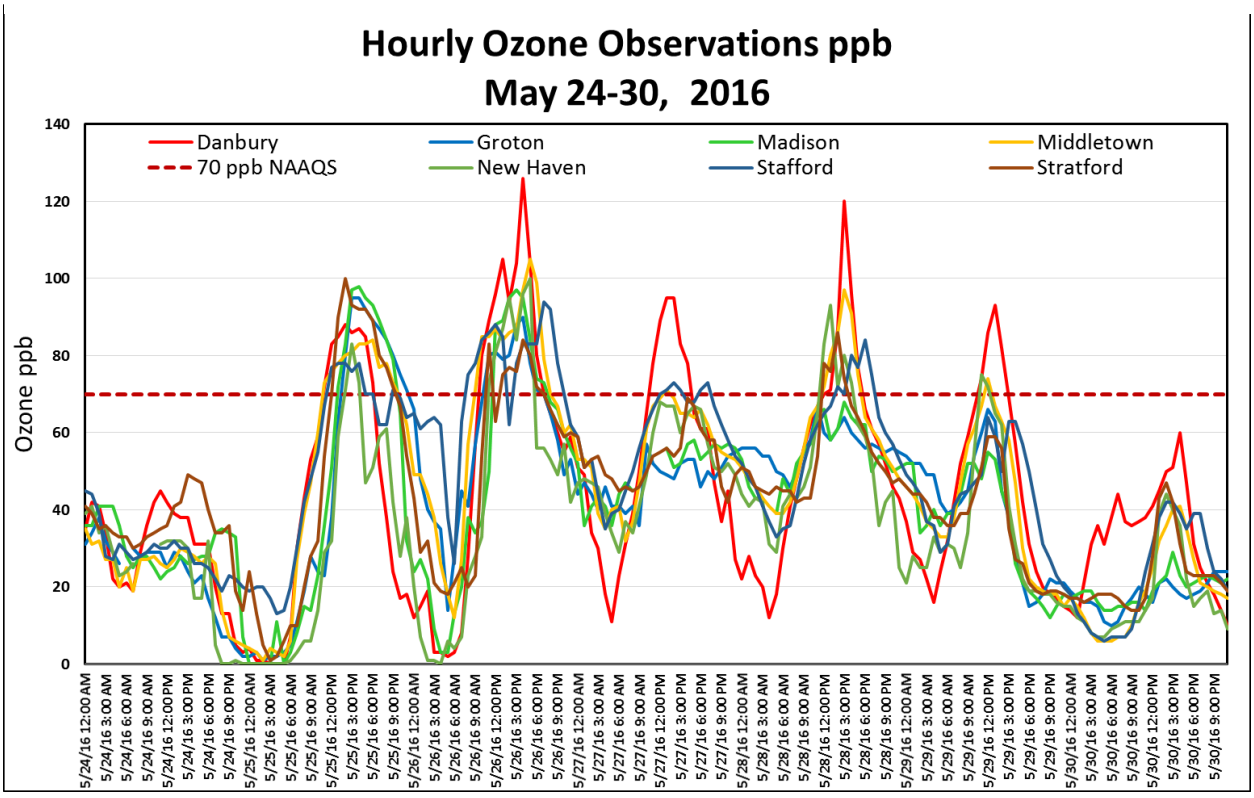

Figure 7. Hourly Ozone Concentrations for May 24-30, 2016 for remaining seven Connecticut Ozone Monitors.

operating at our New Haven monitoring site, from which can be produced, graphical aerosol

backscatter image over the New Haven monitoring site. The CL-51 ceilometer is manufactured by Vaisala and provides lidar backscatter plots up to a height of 4000 meters. This instruments runs continuously and the BLVIEW software calculates the height of the maximum aerosol gradients, which are typically the height of the boundary layer(s). The time series of the aerosol backscatter is presented in Figure 9, along with the hourly monitored surface PM2.5 concentrations from the nearby New Haven monitor. The time series shows an unusually dense region of aerosols reaching a height of 3 kilometers. This coincides exactly with the increase in monitored surface PM2.5 and the arrival of the smoke plume over Connecticut on May 25th.

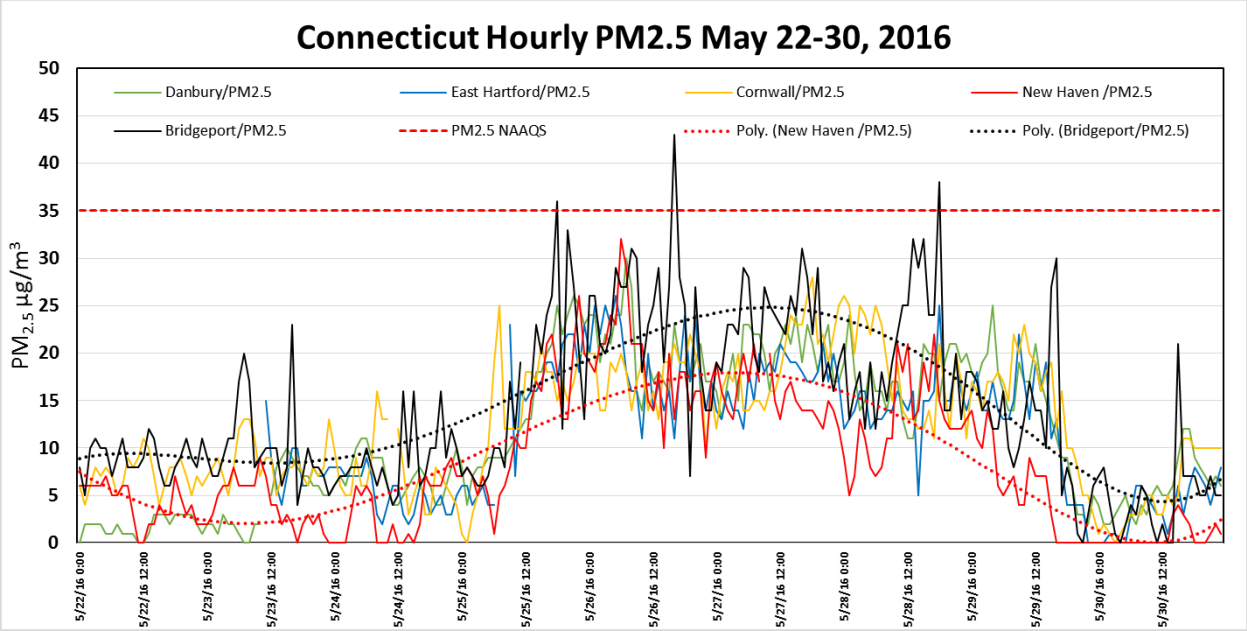

Figure 8. Hourly PM2.5 Concentrations Recorded at Connecticut Monitors from May 22-30, 2016

Other monitored parameters that show the likely presence of a smoke plume include black carbon (BC), deltaC, and carbon monoxide (CO). The Aethalometer measures the attenuation of light thru a filter spot at multiple wavelengths, usually at least at near-IR (880 nm, or BC) and near-UV (370 nm, "UVC"). DeltaC is the different between the 370 and 880 Aethalometer measurements, in ug/m3. It is a semi-quantitative indicator of biomass combustion. At rural summertime sites, DC is very specific to woodsmoke. Woodsmoke has a BC component to it, ~ 10% of woodsmoke PM2.5 is BC. We have plotted the DeltaC PM2.5 parameter which is calculated by multiplying the DeltaC by 10, although multipliers up to 15 have been used.[2]

Our Cornwall monitor, in the northwest corner of the State, was one of the first sites to encounter evidence of smoke related pollutants. The trends are consistent with what would be expected from a distant smoke plume. Figure 10 plots these pollutant trend with the hourly ozone

[2] Allen GA, Babich P, Poirot RL (2004) Evaluation of a new approach for real time assessment of woodsmoke PM. In "Proceedings of the Regional and Global Perspectives on Haze: Causes, Consequences and Controversies", Paper #16, Air and Waste Management Association Visibility Specialty Conference, Asheville, NC

concentrations. DeltaC, indicative of wood (figure 10c) smoke shows large upward spikes starting on May 25th and BC (figure 10d) shows an increase in base levels together with increased hourly deviations. CO base levels (figure 10b) also trend upward and increases on the order of 50% from the previous four days. Figure 10 (e) shows that the PM2.5 levels suddenly spike on the morning of May 25th and soon after, the other parameters begin to rise. Figures 11 and 12, East Hartford and New Haven respectively, show similar trends as the Cornwall monitor and Figure 13 shows the Danbury monitor without the CO parameter. Additional monitoring data from upwind sites will be presented later that will further confirm these pollutant trends.

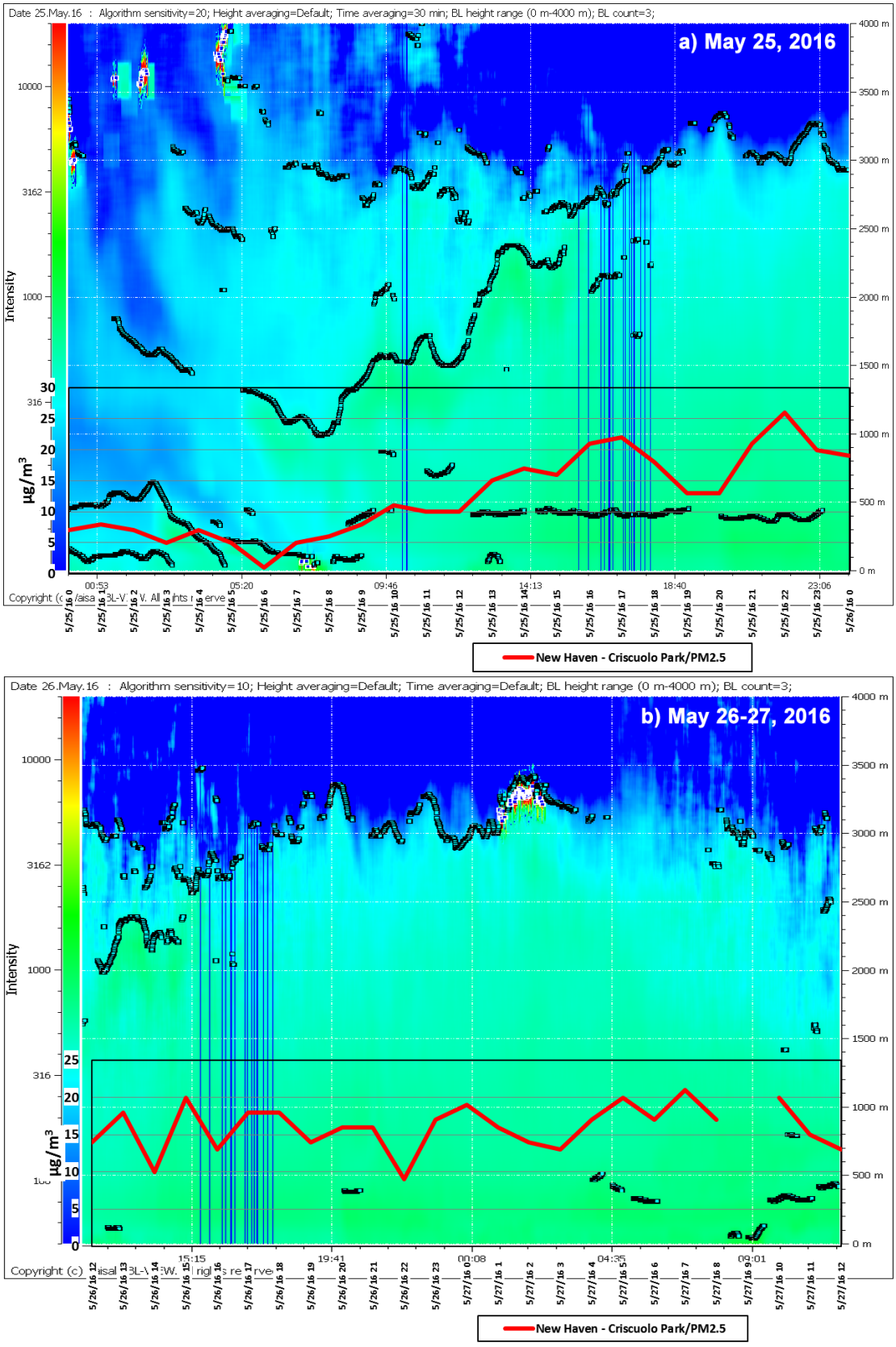

Figure 9. Aerosol Backscatter Intensity over New Haven with PM2.5 Levels

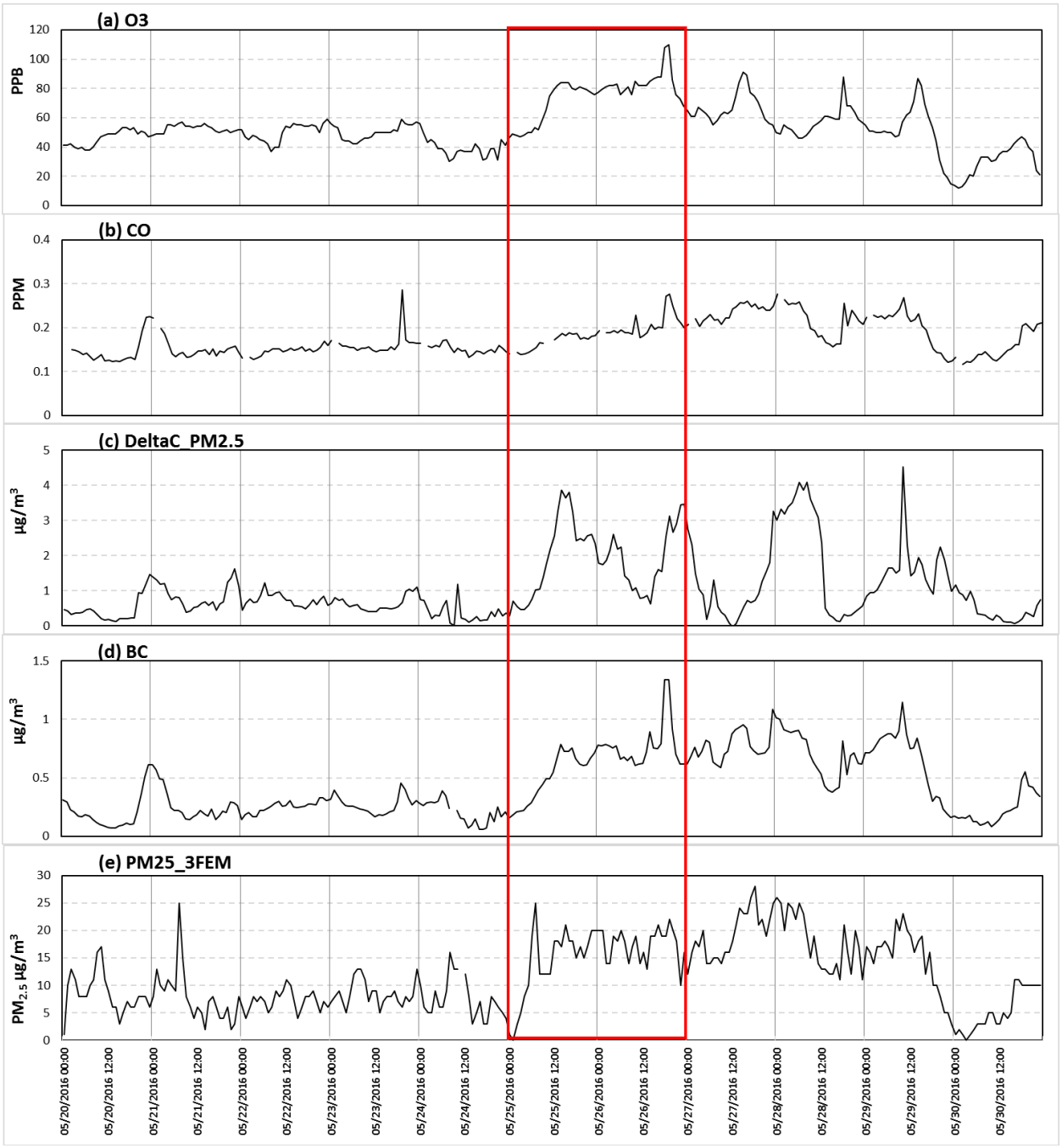

Figure 10. Monitored (a) Ozone, (b) Carbon Monoxide (CO) (c) DeltaC PM2.5 (d) Black Carbon (BC), and (e) PM2.5 at the Cornwall CT Monitor

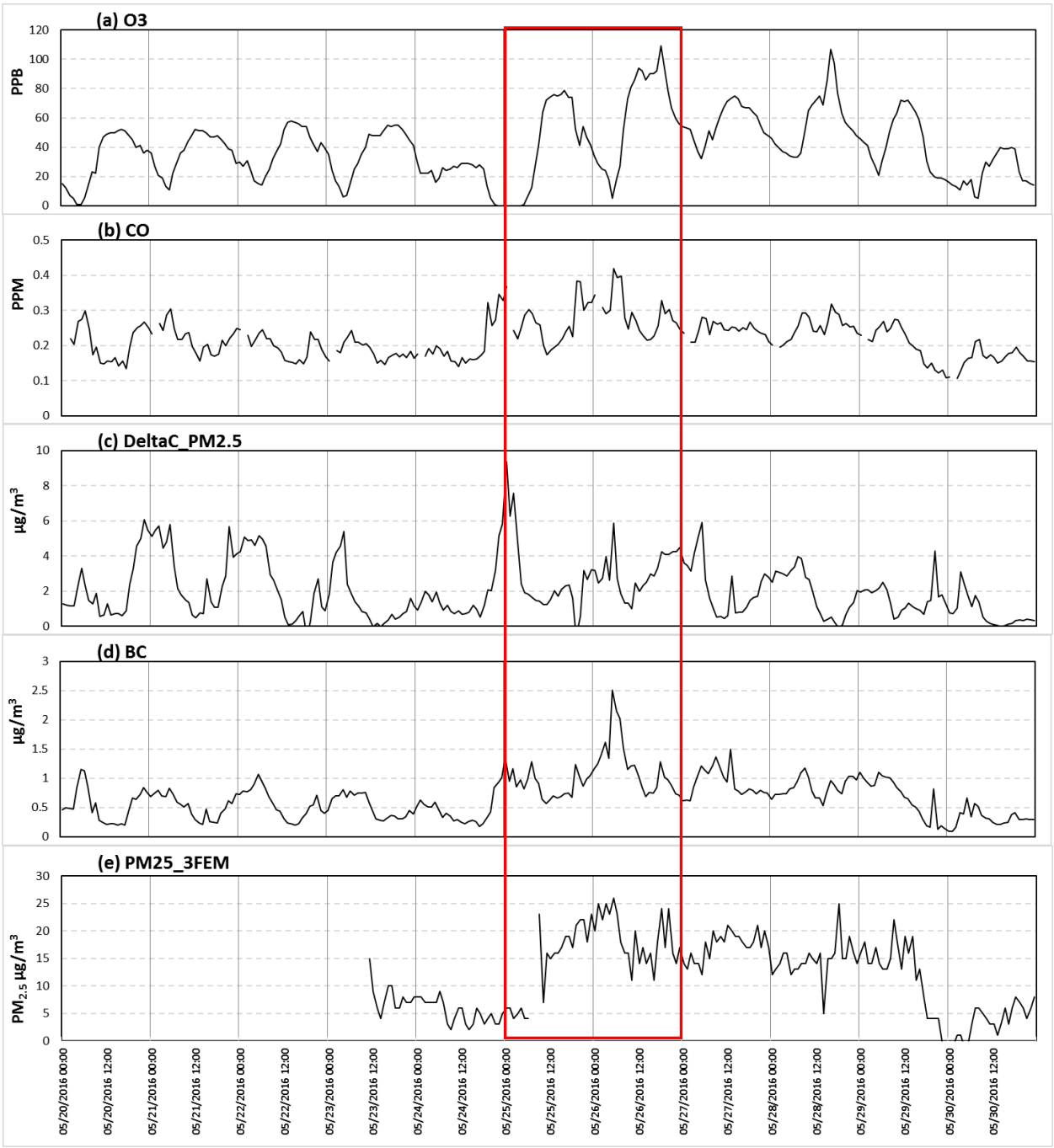

Figure 11. Monitored (a) Ozone, (b) Carbon Monoxide (CO) (c) DeltaC PM2.5 (d) Black Carbon (BC), and (e) PM2.5 at the East Hartford CT Monitor

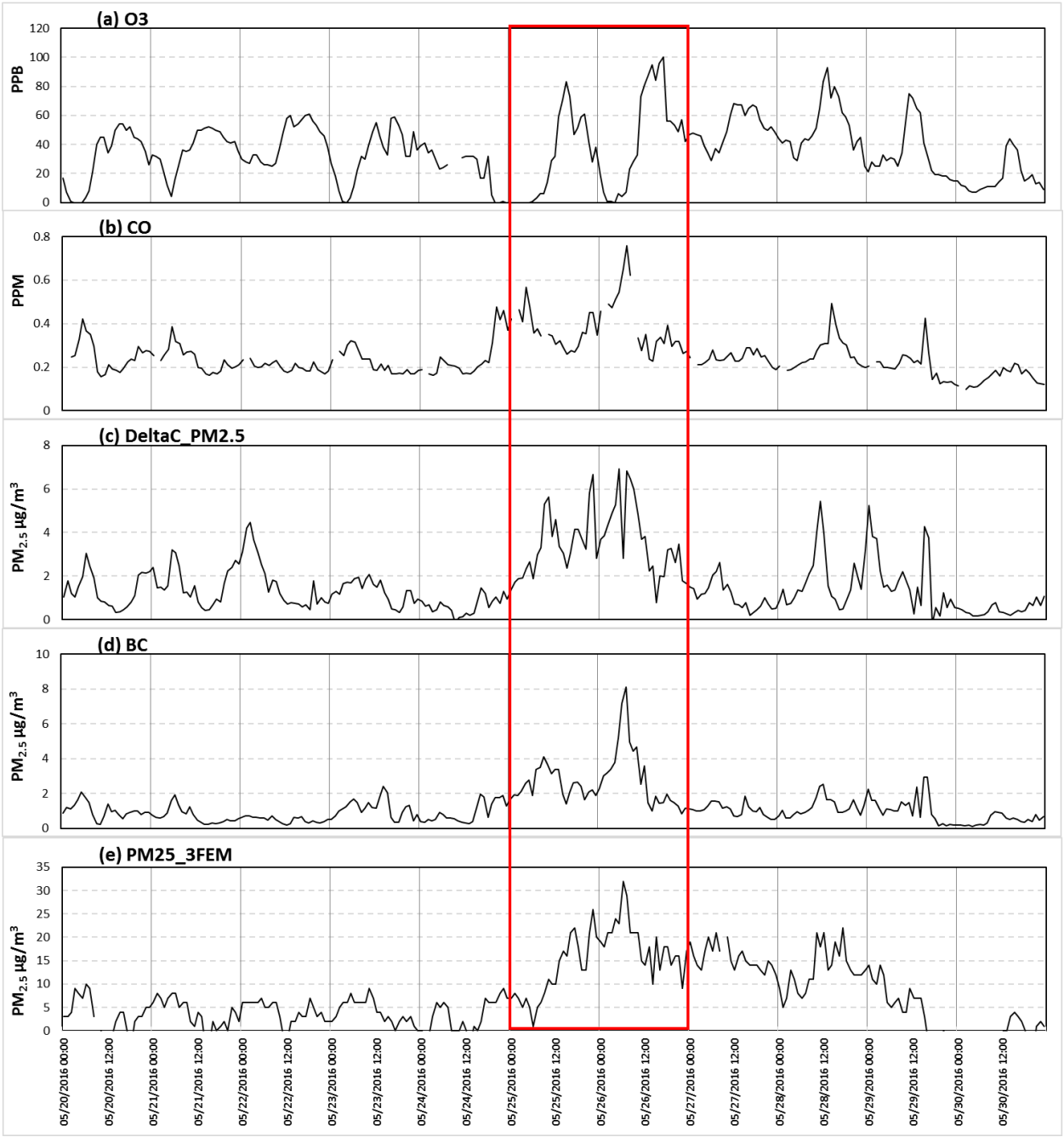

Figure 12. Monitored (a) Ozone, (b) Carbon Monoxide (CO) (c) DeltaC PM2.5 (d) Black Carbon (BC), and (e) PM2.5 at the New Haven CT Monitor

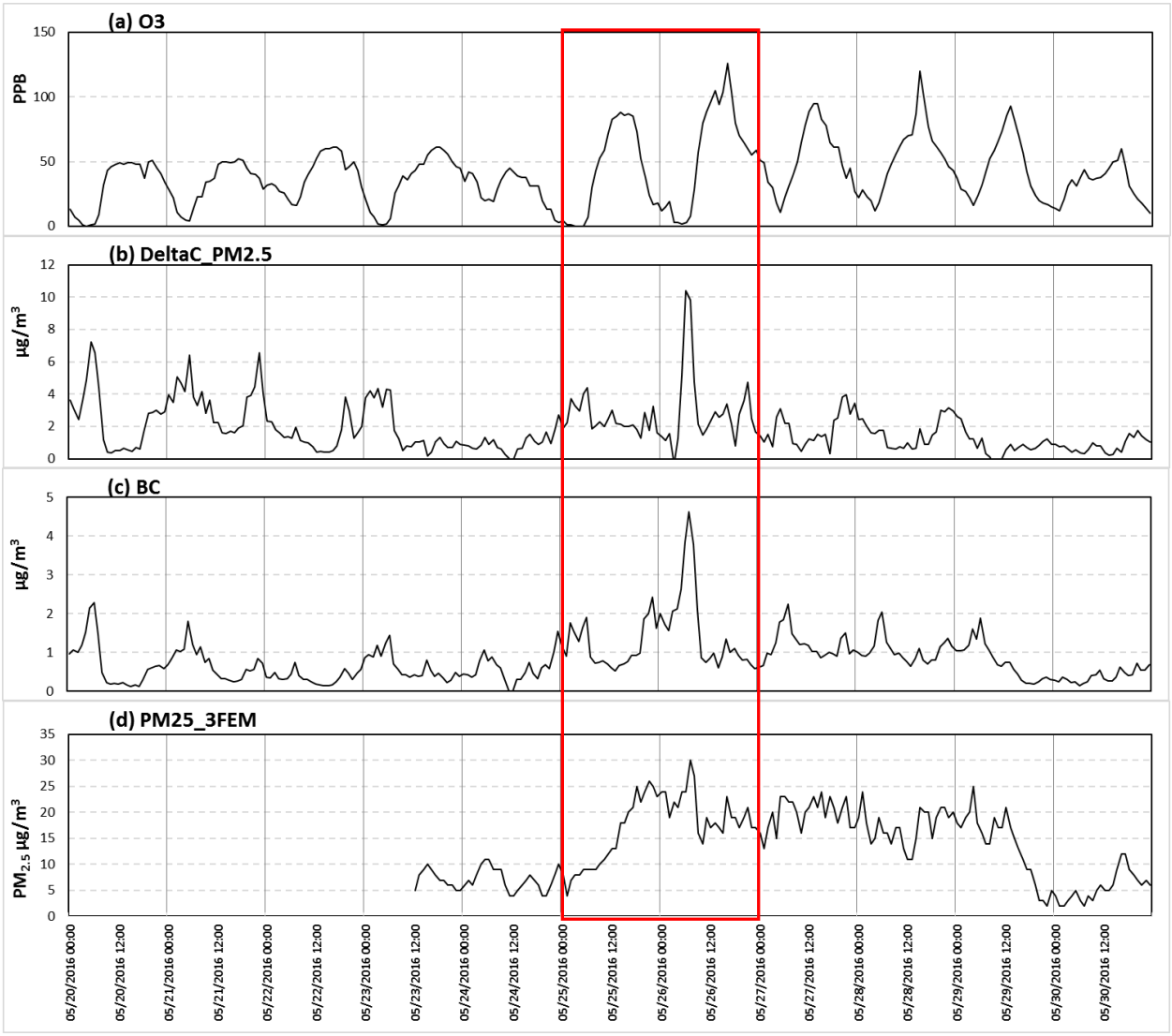

Figure 13. Monitored (a) Ozone, (b) DeltaC PM2.5, (c) Black Carbon (BC), and (d) PM2.5 at the Danbury CT Monitor

2.5 Regional Monitored Data

Fort Lee/ Leonia New Jersey

To observe similar monitored parameters as those in Connecticut, Fort Lee New Jersey was chosen for PM2.5, CO and the aethalometer carbon species and the nearby Leonia NJ monitor for hourly ozone. These sites are approximately 40 miles to the southwest of our Westport monitor and serve as a good comparison for the May 25-26, 2016 period. Figure 14 is a map

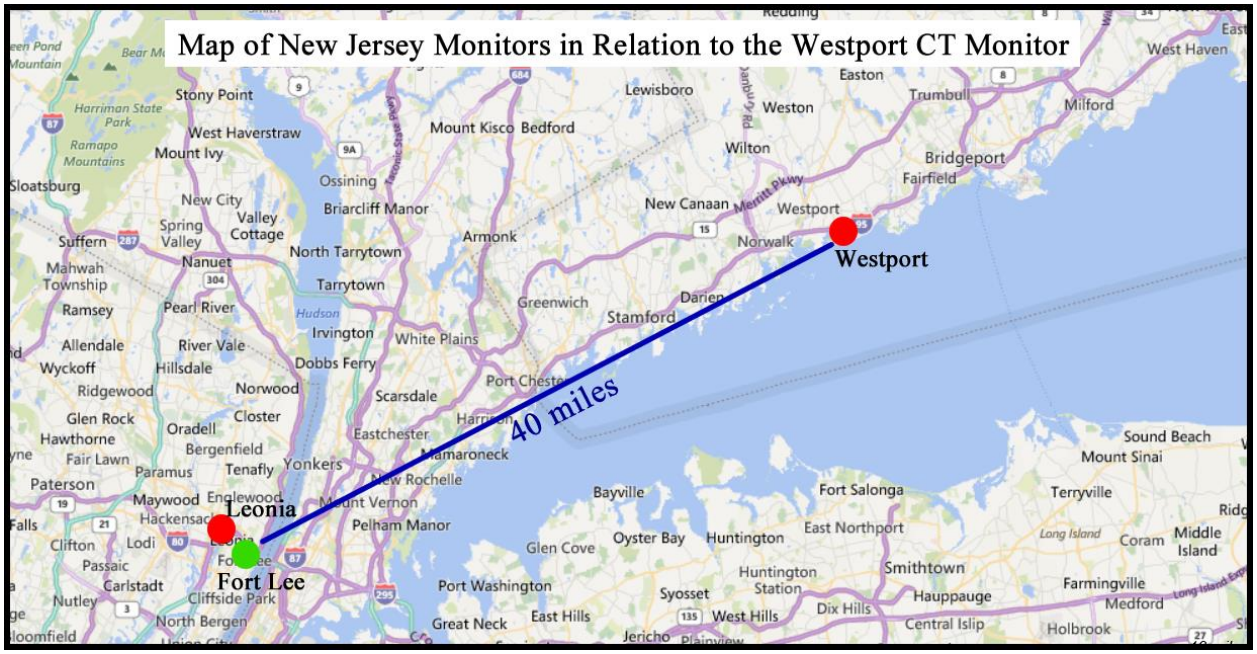

Figure 14. Map of Nearby New Jersey Monitors.

showing the locations of those monitors and figure 15 are charts of the monitored pollutants that shows similar trends as those observed at the New Haven CT monitor with peaks in BC, DeltaC and PM2.5. The Fort Lee NJ monitor did stop reporting during May 27th as the PM2.5 parameters appeared to be peaking. These monitors are 12 miles from the Haze Cam location, whose images are presented later and show the presence of smoke over New York City.

Connecticut Hill New York

Since ozone exceedances are so common in Connecticut, our EPA Region 1 Office commented that "*Although meeting these criteria may be difficult for all of the ozone monitors in Connecticut, you may be able to show that the high ozone concentrations measured directly upwind during episode in western Massachusetts, southern Vermont and upstate New York were truly unique over the last 5-8 years."* We present the case for the New York Connecticut Hill monitor, where this event was indeed much more of an outlier on May 25th, 2016. The following chart (Figure 16) shows daily 8-hour maximum monitored ozone for the years of 2011-2016 at the Connecticut Hill monitor in New York. The 77 ppb 8-hour maximum ozone noted for May 25th, 2016, was the highest ozone reported during those 6 years. 2012 stands out as having consistently higher monitored ozone data over this period.

Upwind Chemical Speciation Network (CSN) Sites

The U.S. EPA initiated the national $PM_{2.5}$ Chemical Speciation Monitoring Network (CSN) in 2000 to support evaluation of long-term trends and to better quantify source impacts of particulate matter (PM) in the size range below 2.5 μm aerodynamic diameter ($PM_{2.5}$; fine particles). EPA also administers the long standing Interagency Monitoring of Protected Visual Environments (IMPROVE) visibility monitoring network in rural Class 1 Areas across the country. Both networks measure the major chemical components of PM2.5 using historically accepted filter-based methods.

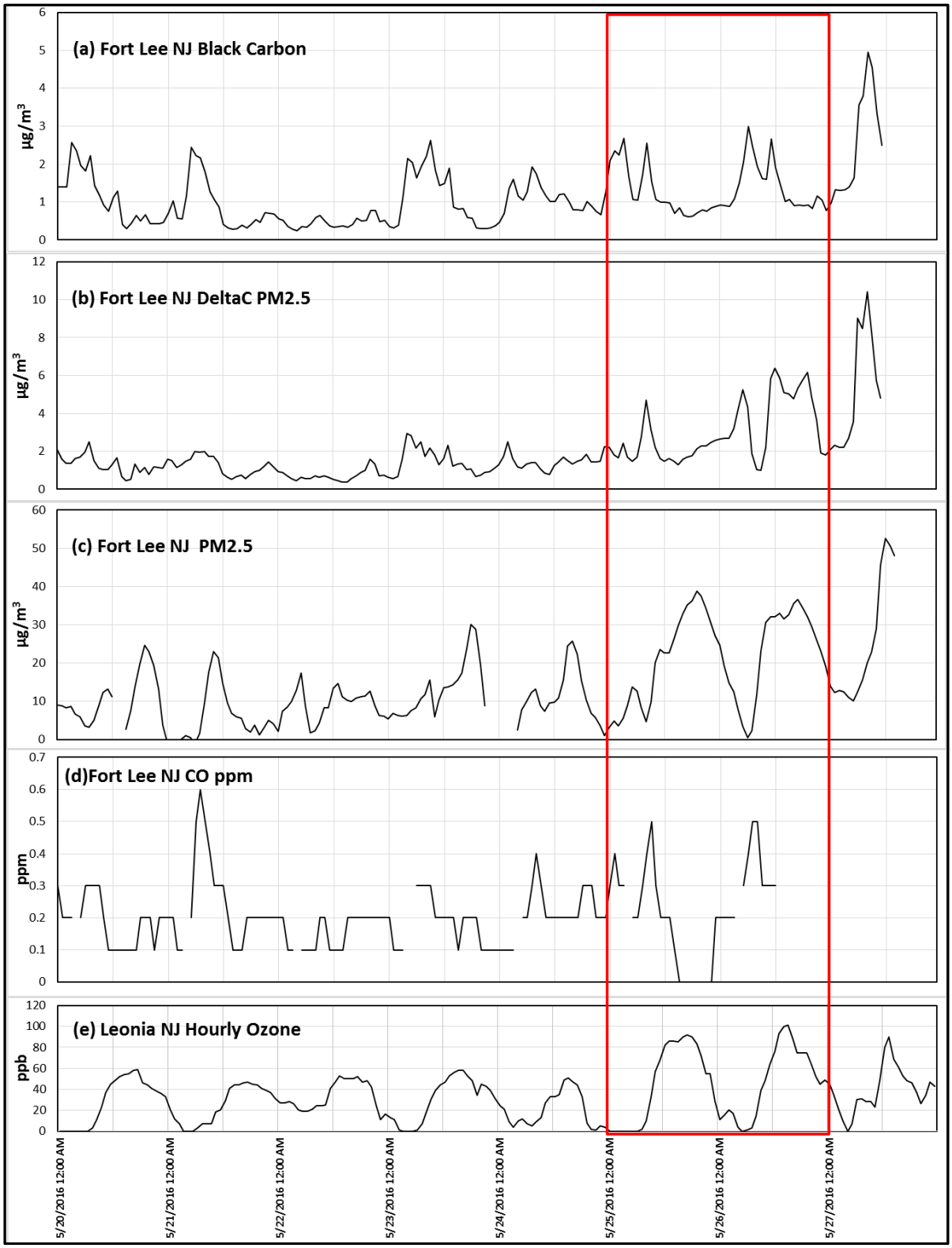

Figure 15. Monitored (a) Black Carbon, (b) DeltaC PM2.5, (c) PM2.5 (d) CO at the Fort Lee NJ monitor and (e) Ozone at the Leonia NJ Monitor.

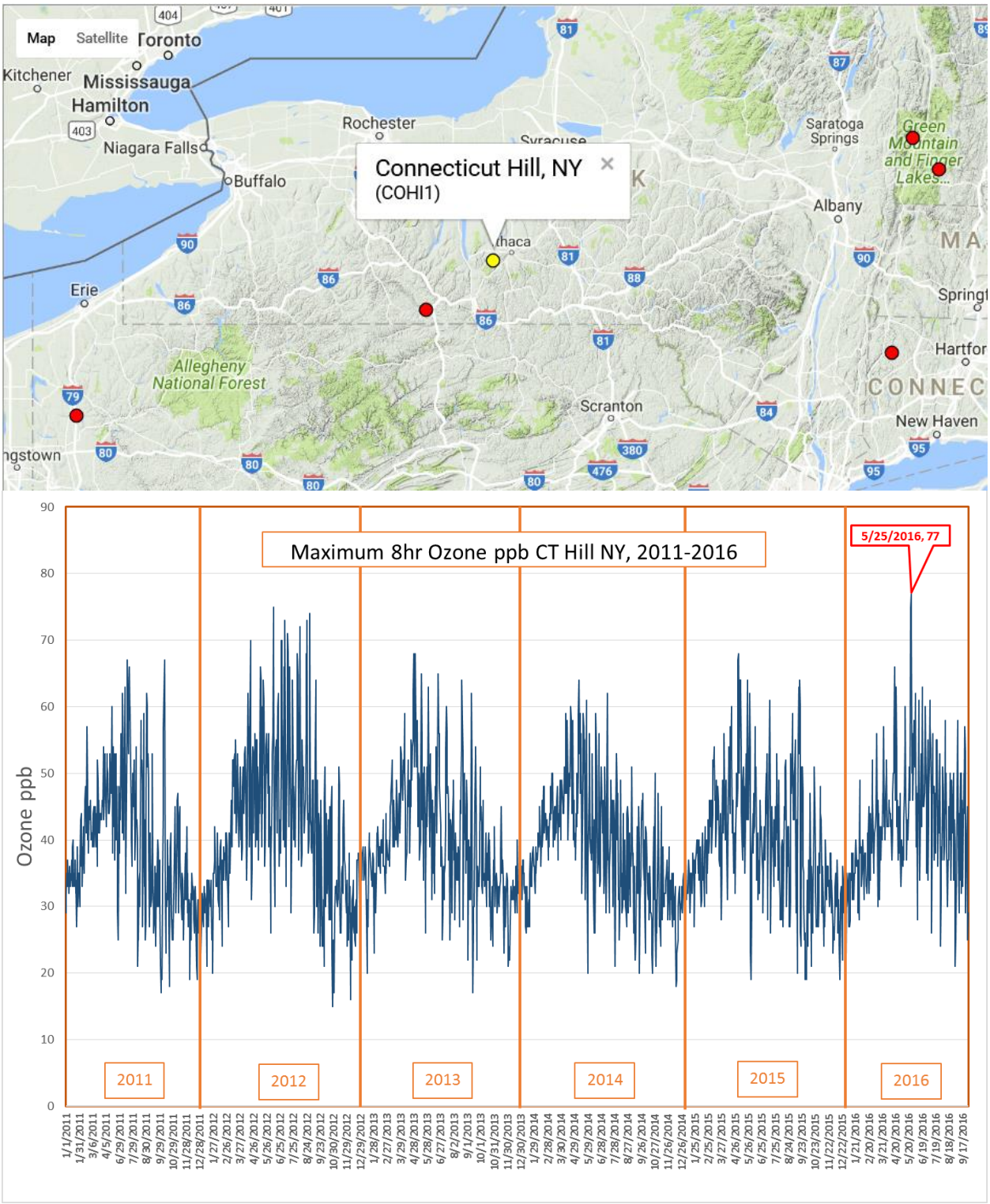

Figure 16. Monitored Daily Maximum 8-hour Ozone for 2011-2016 at Connecticut Hill, NY

Target Species:

- PM2.5 Mass by gravimetry,
- 33 trace elements (such as Al and Pb by X-ray fluorescence),
- Anions (nitrate and sulfate by ion chromatography),
- Cations (ammonium, sodium, and potassium by ion chromatography), and
- Organic Carbon (OC) and Elemental Carbon (EC

Organic Carbon (OC) and Potassium (K) species are most closely associated with wildfire emissions, so we have selected the sites in Figure 17 to plot these chemical compounds against the monitored 8-hour ozone maximums for these days. Samples are only available at three or six day intervals at these sites. Figures 18-24 generally show that K and/or K+ and OC exhibited upward trends, coinciding with elevated ozone levels. This is particularly evident on May 24th, 2016. This concurs with the presence of a wildfire smoke plume over the area on that day. Seney, Michigan, an IMPROVE wilderness background site, and Grand Rapids show distinct double peaks, which is no doubt due to the meandering nature of the smoke plume over several weeks .

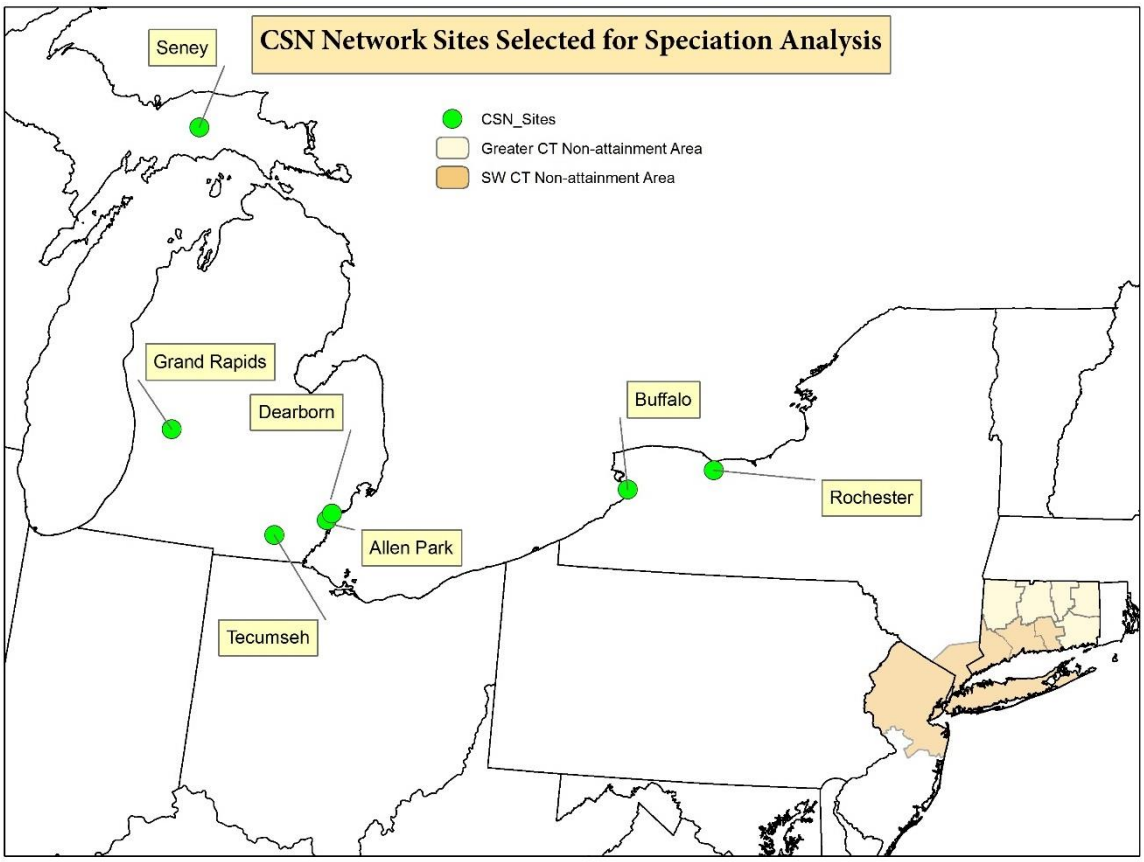

Figure 17. CSN Sites Selected for Speciation Analysis

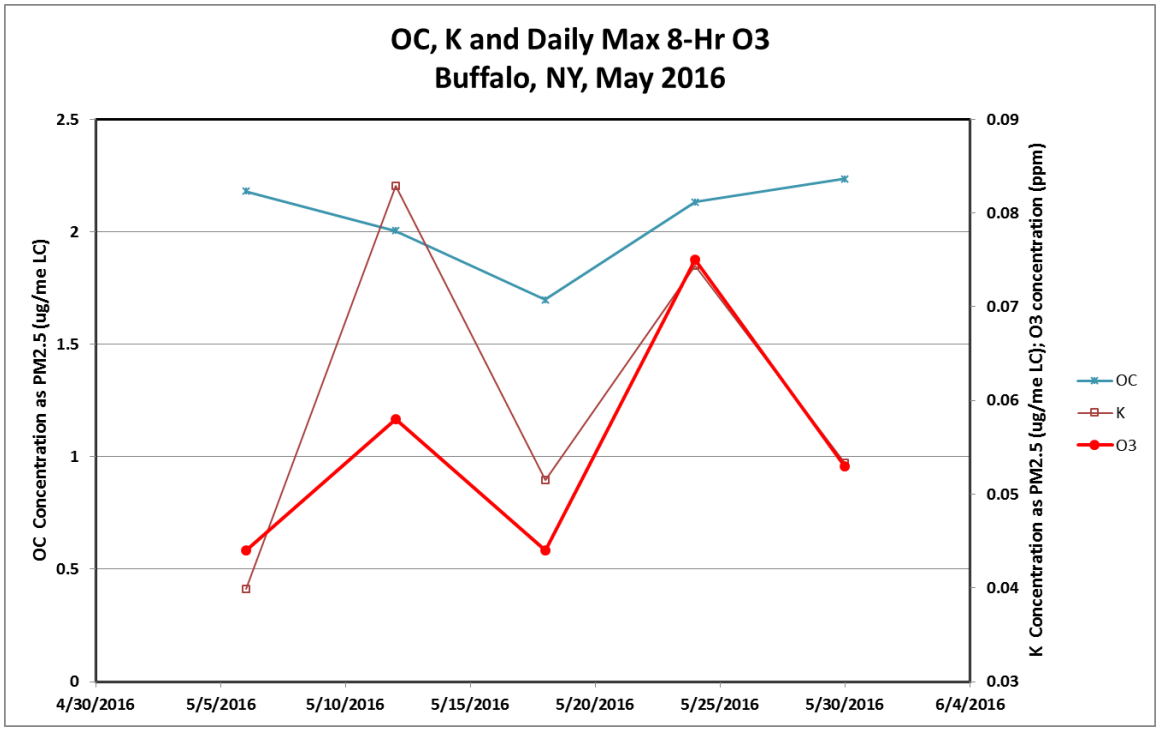

Figure 18. Buffalo New York CSN Data

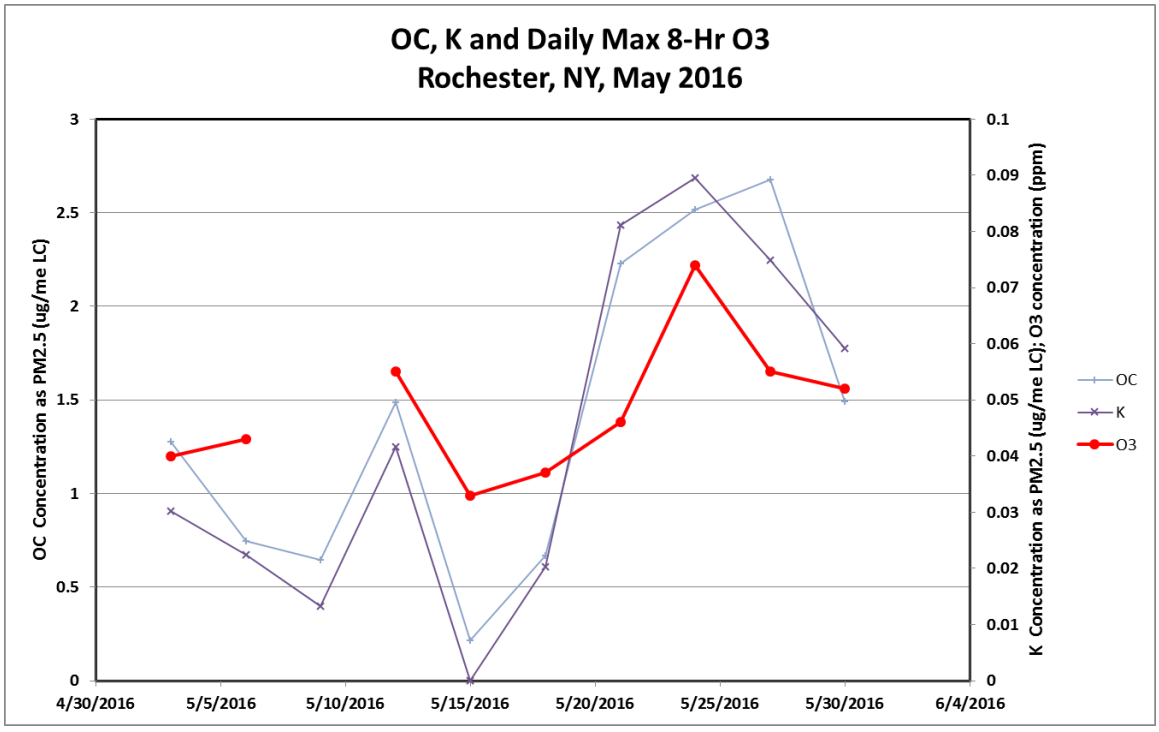

Figure 19. Rochester New York CSN Data

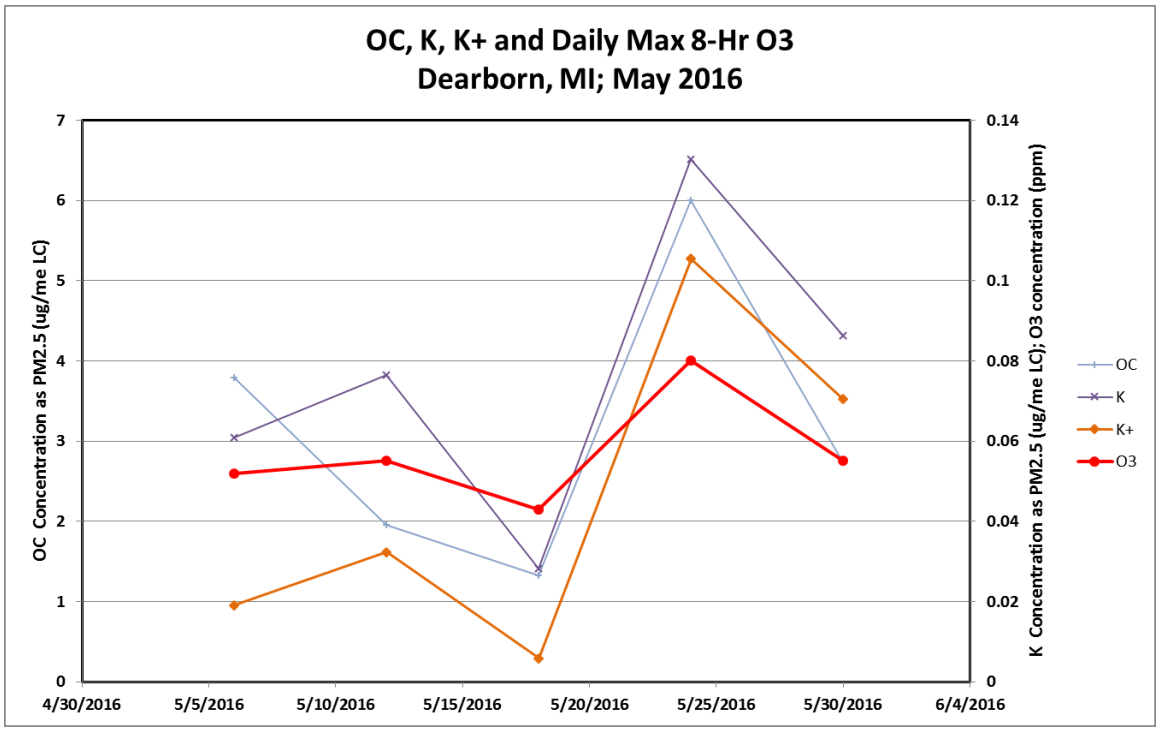

Figure 20. Dearborn Michigan CSN Data

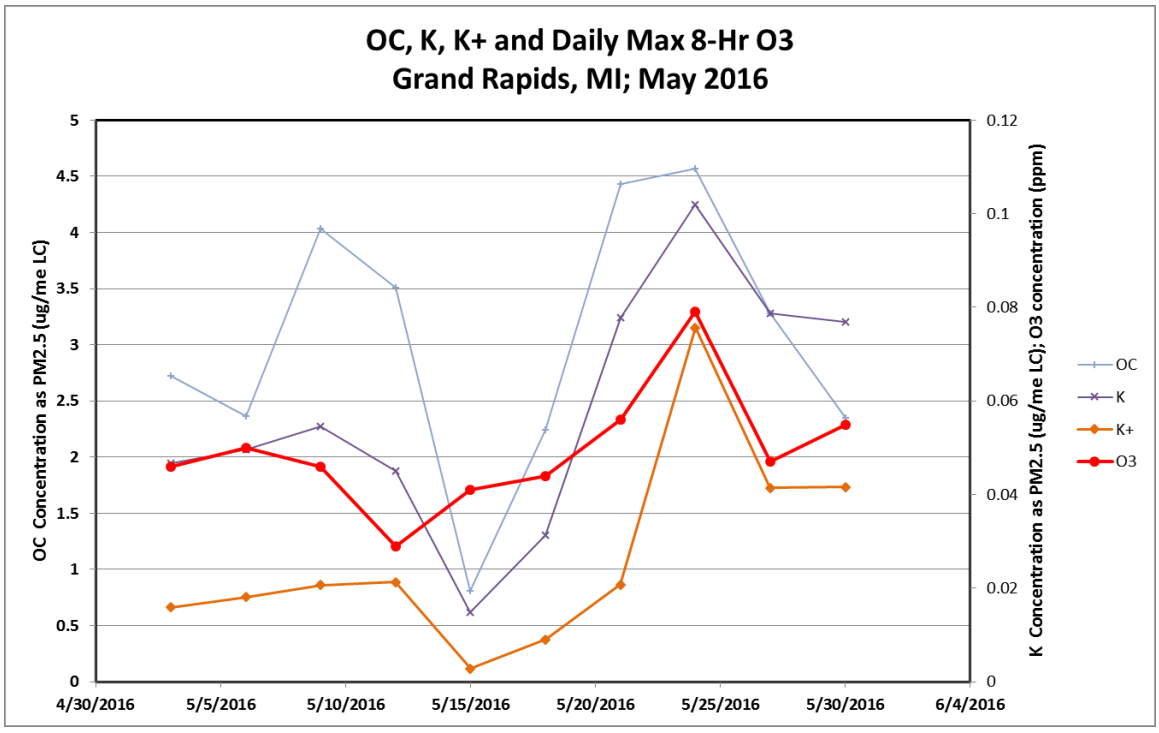

Figure 21. Grand Rapids Michigan CSN Data

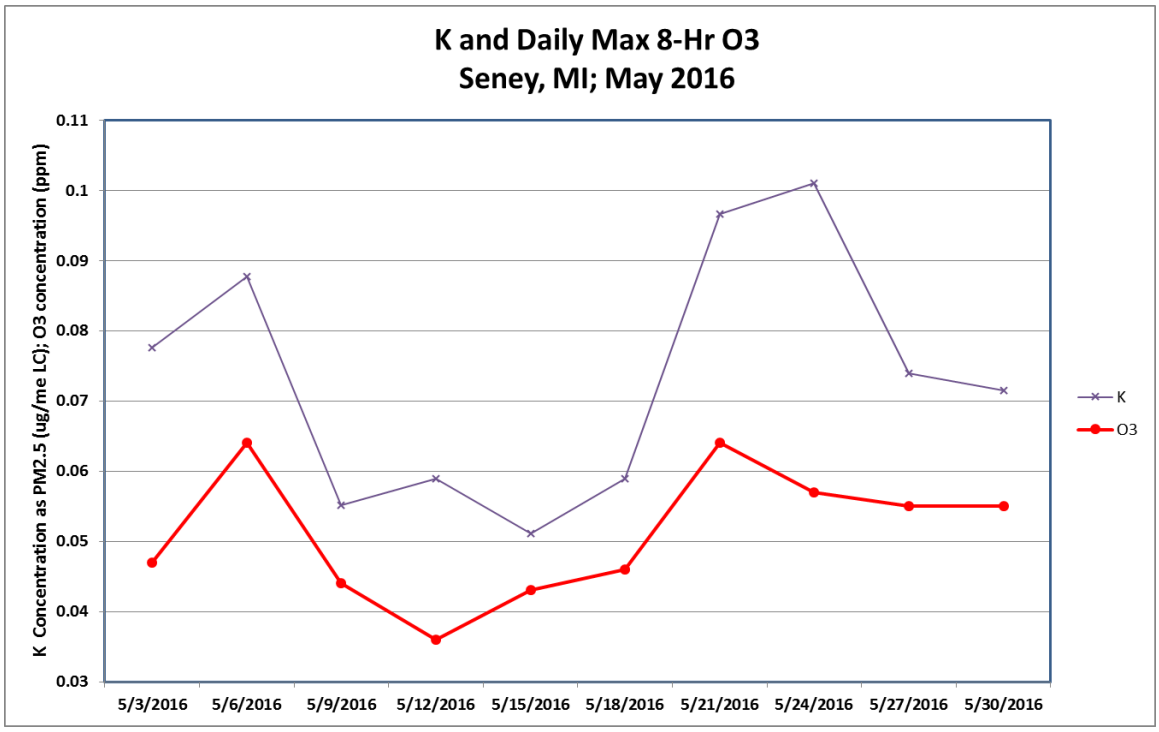

Figure 22. Seney Michigan IMPROVE Data

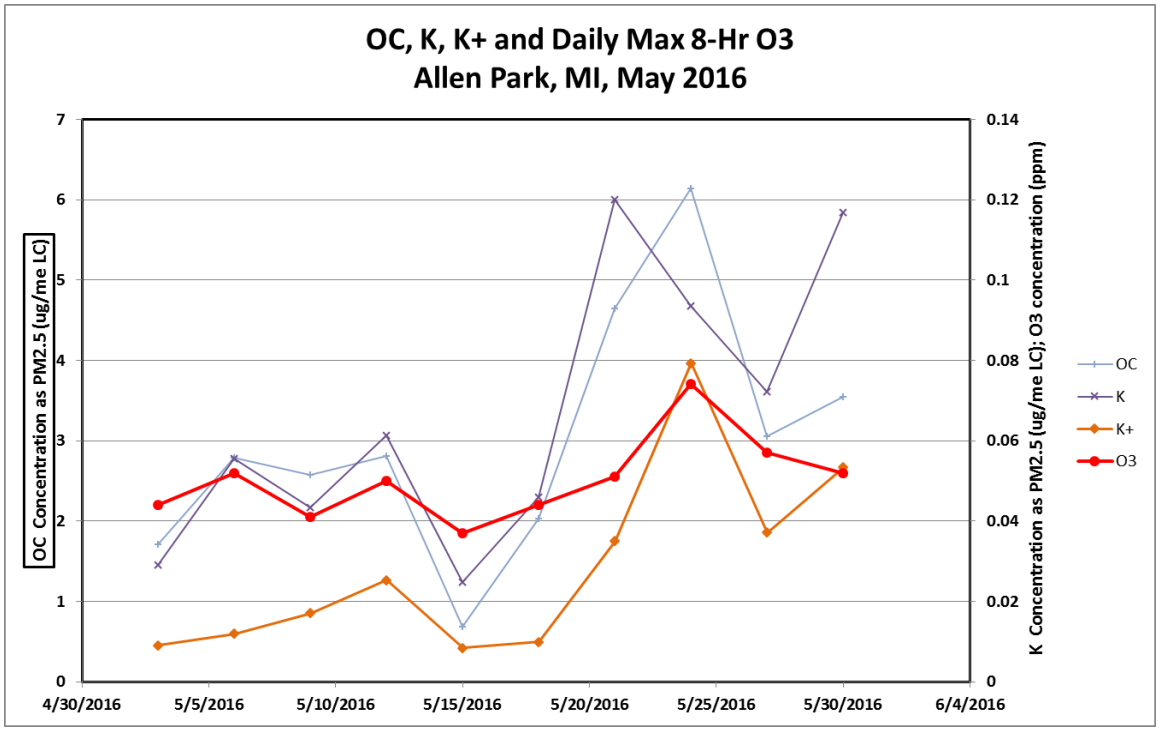

Figure 23. Allen Park Michigan CSN Data

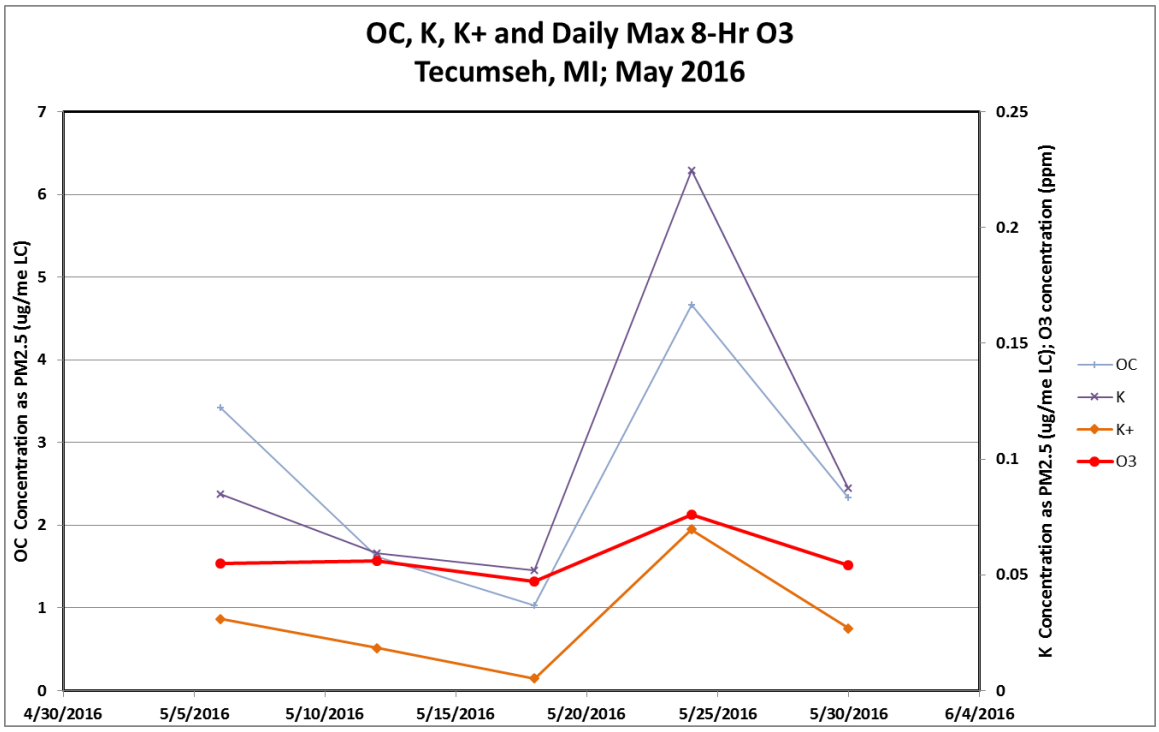

Figure 24. Tecumseh Michigan CSN Data

2.6 Meteorological Scenarios

Although Connecticut experiences frequent ozone exceedance days during the summer, these vary from year to year, due to the prevailing meteorology. While ongoing reductions in emissions of ozone forming pollutants have lowered the absolute number of exceedance days, the meteorological variation is still an important factor. Figure 25 shows the historical trends for Connecticut's ozone exceedance days with separate lines for each of the 8-hour ozone NAAQS since 1997

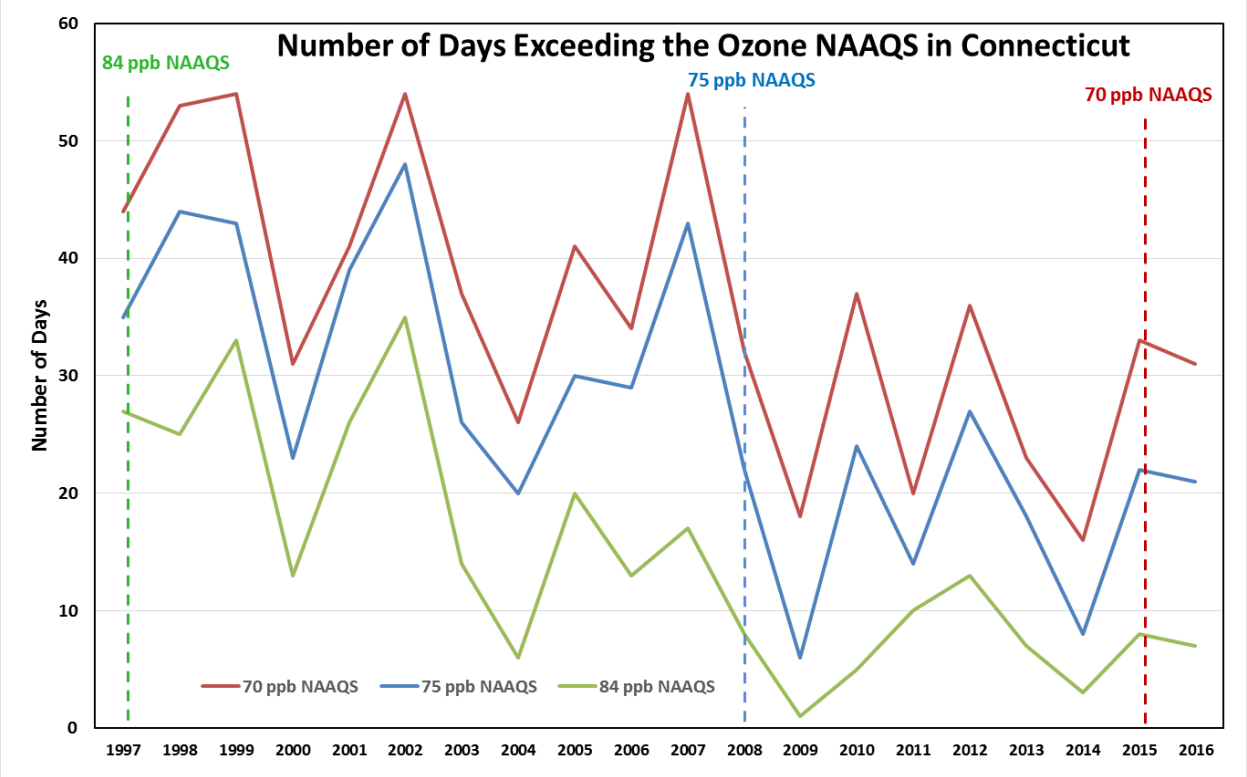

Figure 25. Number of Ozone Exceedance Days in Connecticut Ozone Monitors Since 1997

Typically, the bulk of the ozone exceedance days occur during the June-August timeframe, with fewer exceedances during May and September. Exceedances have occurred during April, but only rarely.

Ozone exceedances in Connecticut can be classified into four categories based on spatial patterns of measured ozone and the contributing meteorological conditions. Typically, most exceedances occur on sunny summer days with inland maximum surface temperatures approaching or above 90°F, surface winds from the south and southwest (favorable for transport of pollutants from the I-95 corridor) and aloft winds from the west to southwest (favorable for transport of pollutants from Midwest power plants).

Inland-only Exceedances: Ozone is transported aloft from the west and mixed down to the surface as daytime heating occurs. At times, transport from the southwest can also occurovernight at lower levels aloft due to the formation of a nocturnal jet. Strong southerly surface winds during the day bring in clean maritime air from the Atlantic Ocean, resulting in

relatively low ozone levels along the coast. The maritime front may not penetrate very far inland, and therefore does not mitigate transported and local pollutants' contribution to inland exceedances.

Coastal-only Exceedances: Strong westerly surface winds transport dirty air down Long Island Sound from source regions to the west (e.g., New York and New Jersey). The relatively cool waters of Long Island Sound confine the pollutants in the shallow marine boundary layer. Afternoon heating over coastal land creates a sea breeze with a southerly component, resulting in ozone exceedances along the coast. Inland winds from the west prevent sea breeze penetration and can sometimes contribute to the formation of a convergence zone that can further concentrate ozone along the coast.

Western Boundary-only Exceedances: Southerly maritime surface flow invades the eastern two-thirds of Connecticut, keeping ozone levels in that portion of the state low. The south-southwest urban winds out of New York City result in exceedances along Connecticut's western boundary. Winds aloft are often weak for this scenario.

State-wide Exceedances: This is the classical worst-case pattern, with flow at the surface in the Northeast up the Interstate-95 corridor, transport at mid-levels also from the southwest via the low level jet and flow at upper levels from the west. All of these flows are from emission-rich upwind areas, serving to transport ozone precursors and previously formed ozone into Connecticut. A weak sea breeze may also develop, which would transport ozone pooling over Long Island Sound into the State. The magnitude of the May 25-26, 2016 ozone event over Connecticut would have been representative of this type of scenario (figure 26), however these

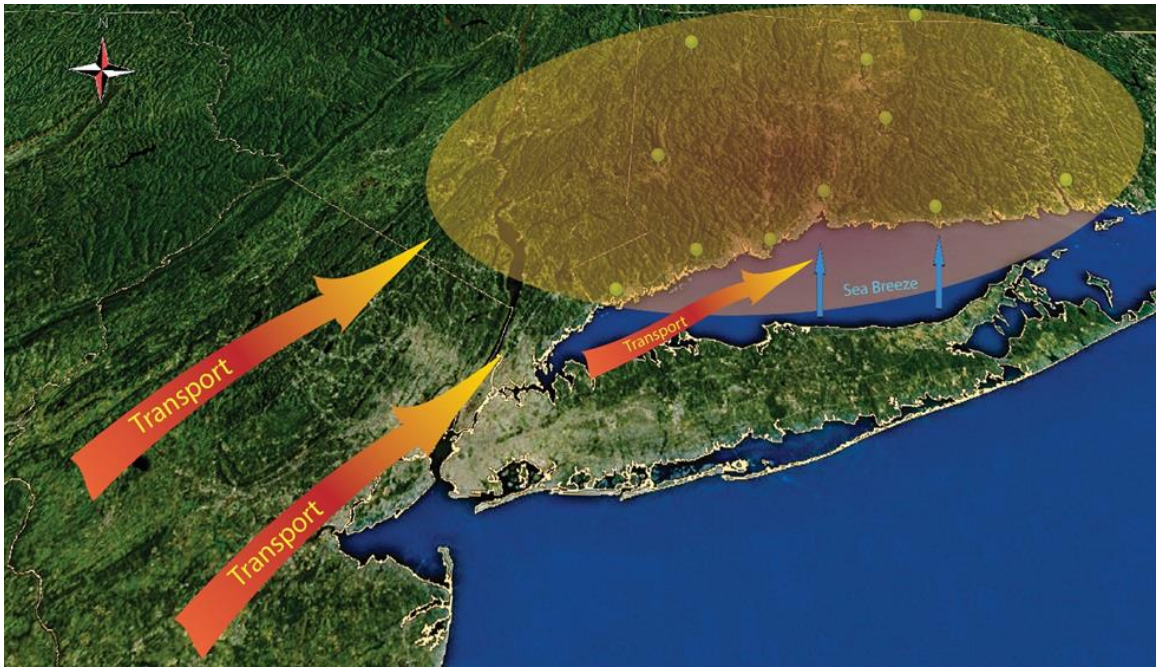

Figure 26. State-wide Ozone Exceedance Scenario

meteorological conditions were not present, as will be described later.

2.7 Meteorological Conditions

Weather conditions were dominated by strong high pressure over the Great Lakes early in the period, with weak low pressure passing off the New England coast (Figure 27a,b). The high pressure center over the Great Lakes was responsible for trapping pollutants from the wild fire plumes in the boundary layer while surface temperature began to heat up. Low pressure off the New England coast produced numerous showers over southern New England on May 24th with northeast winds and mild temperatures. By May 25th (figure 28a,b), the skies cleared over New England and winds were mostly from the northwest throughout the boundary layer.

Of special interest are the 850 mb height maps, since this is high enough in the boundary layer (~1500m) that long range transport can occur. In Figure 10 we observed that the aerosol plume extended up to 3000 meters, so the 850mb winds would be a good indicator for long range transport. In Figure 29(a,b), it is observed that there is an 850mb low pressure trough off the U.S. east coast. The airshed for western New York and western New England originates in Quebec and Ontario on May 23- 24th, which is typically a clean air mass, absent of wild fires.

By May 25th (figure 30a) the air flow loops around from Michigan, before turning southeast into New York and Connecticut. On May 26th (figure 30b), the transported boundary layer air flows from the Ohio River Valley before turning east-southeast into Connecticut. After this, the upper level flow becomes more indicative of what is expected for an 'I-95' corridor ozone event from May 27th onward. Therefore, May 25-26th , 2016, did not fit any previous scenario, and absent the wildfire plume, one would expect cleaner air coming into the region. The weather pattern, by May 27th, was more typical for an ozone exceedance scenario, but it obscures the effect of the smoke plume, which is dissipating, in favor the I-95 corridor influence on ozone production.

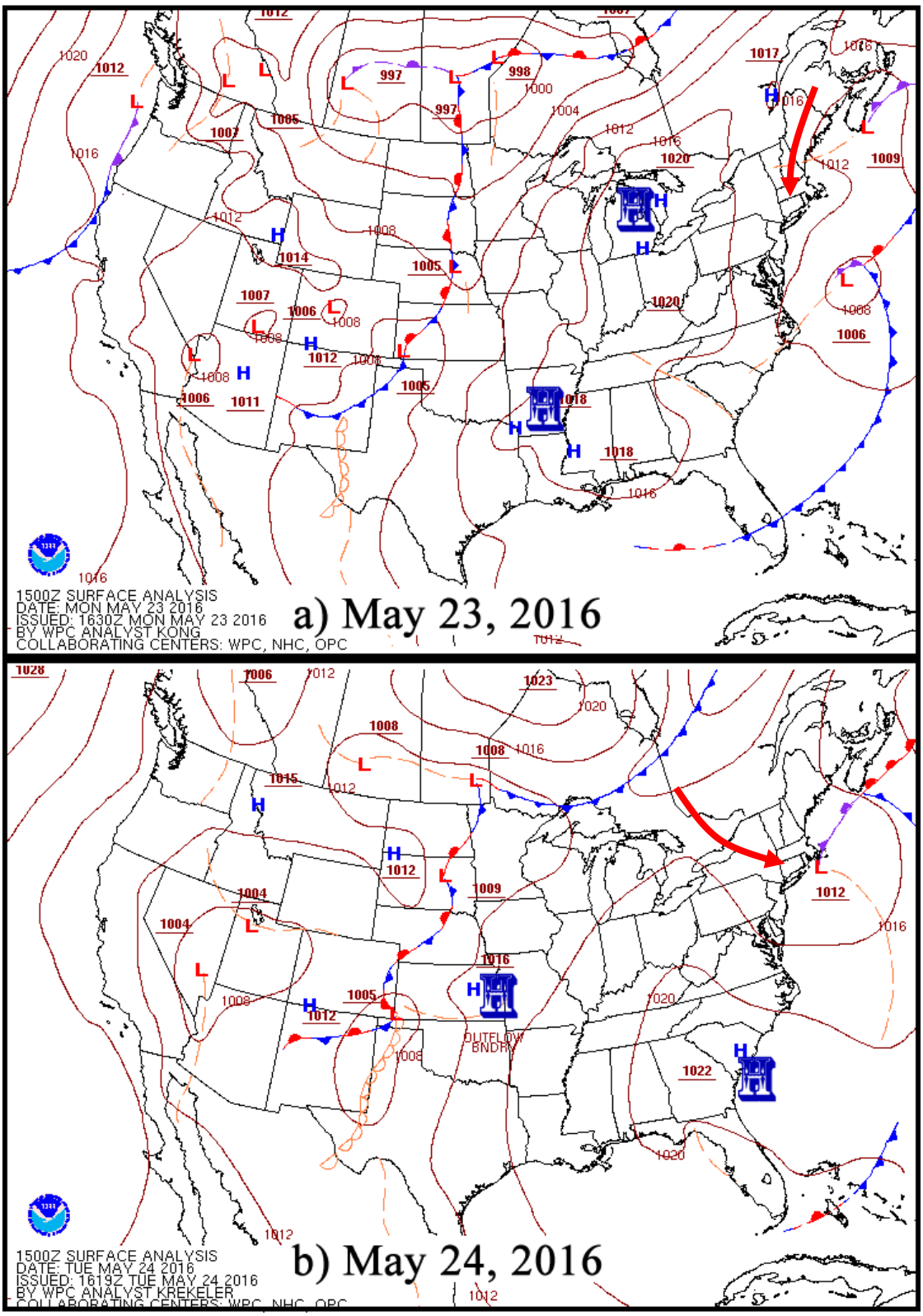

Figure 27. Surface Fronts for May 23-24 (a,b), 2016. Note the high pressure area over the Midwest on May 23-24th, creating subsidence and trapping the smoke plume pollutants over the Midwest.

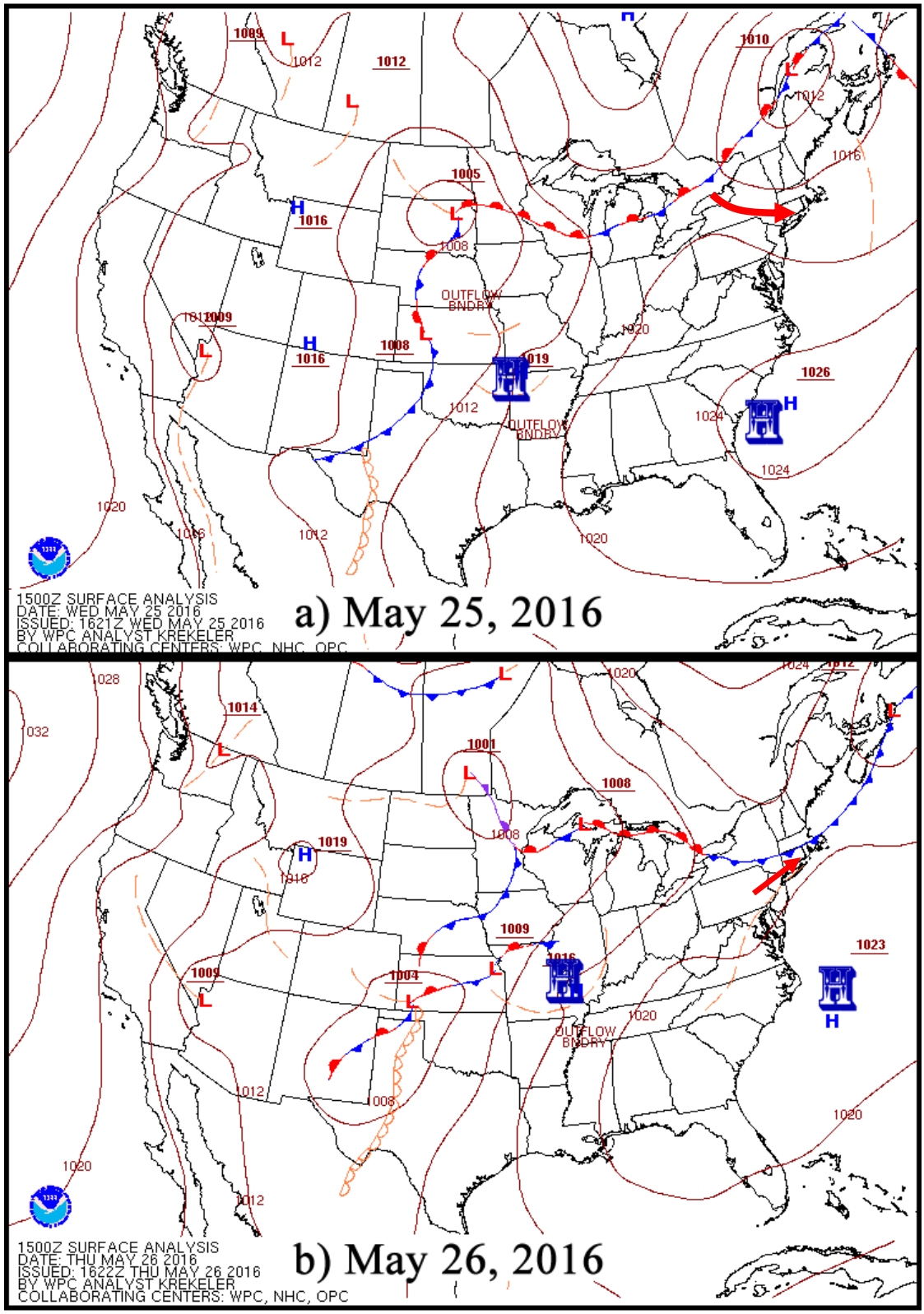

Figure 28. Surface Maps for May 25-26 (a,b), 2016. This shows northwest winds at the surface with approaching coldfront (a) turning the winds to the southwest(b) on May 26th.

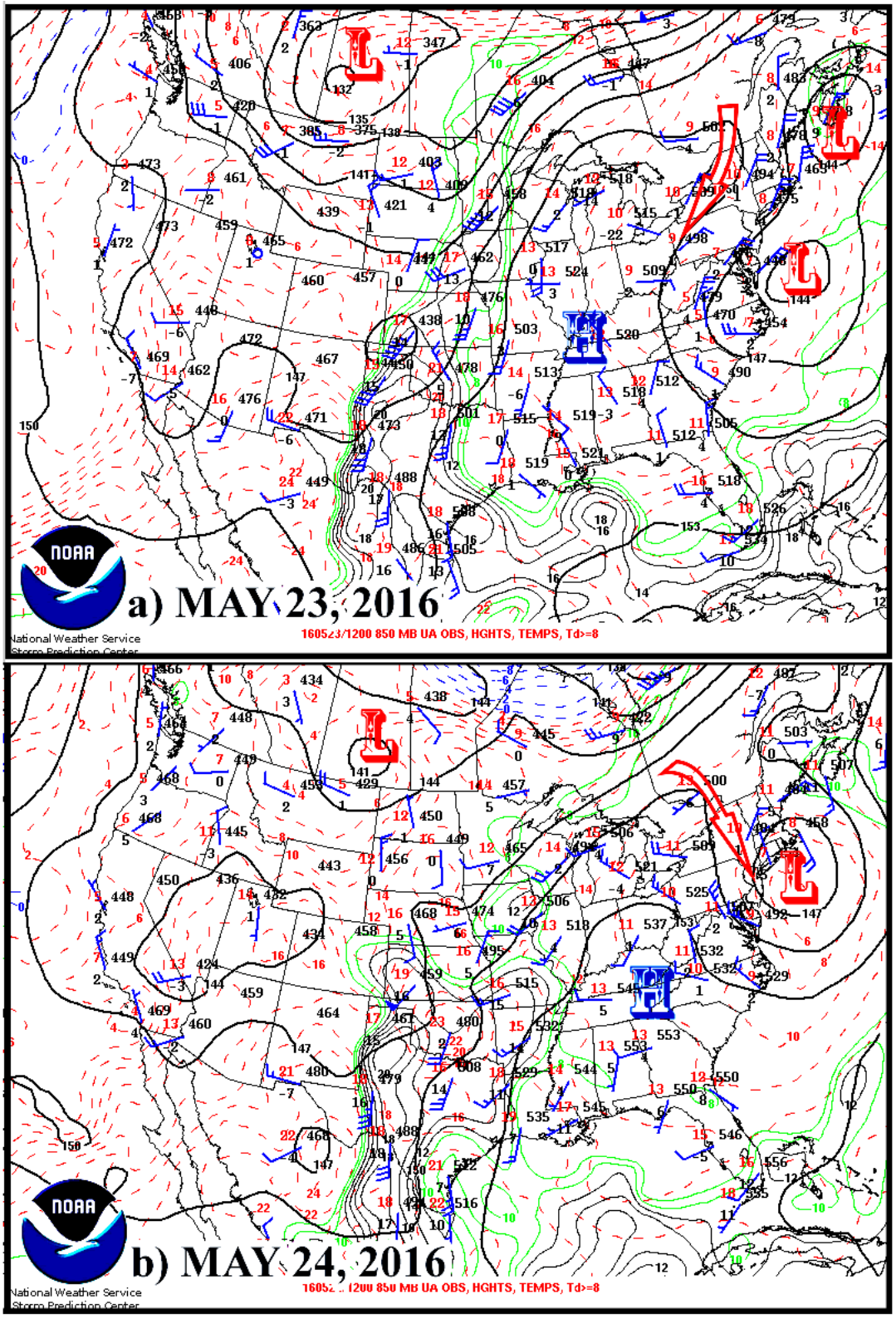

Figure 29. 850 mb Pressure Pattern with Winds for May 23-24 (a,b), 2016. Low pressure center off the New England coast creates a northerly wind at 850 mb.

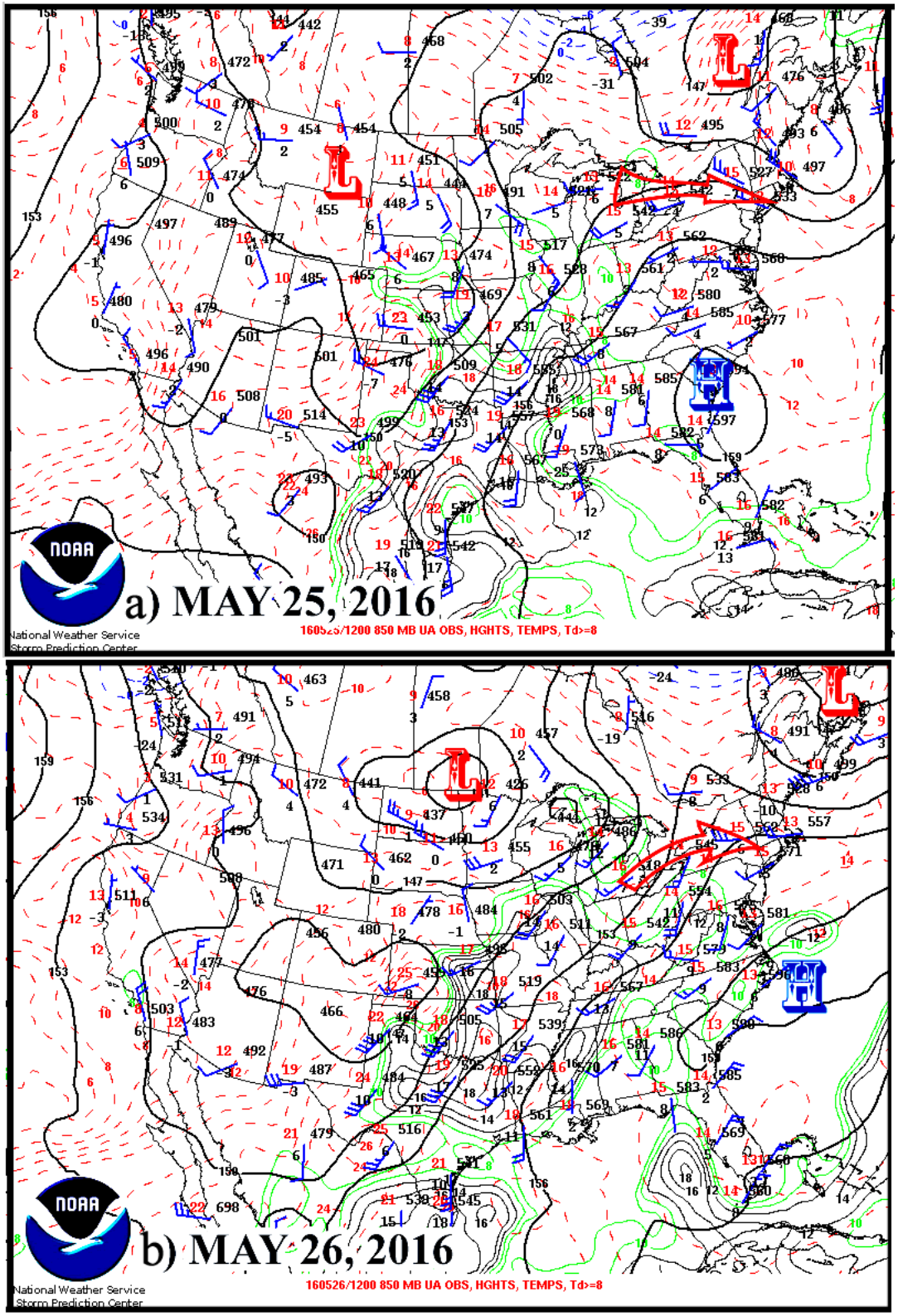

Figure 30. 850 mb Pressure Pattern with Winds for May 25-26 (a,b), 2016. High pressure center moves off the east coast causing the 850 mb transport winds to turn more westerly from Michigan.

3. CLEAR CAUSAL EFFECT AND WEIGHT OF EVIDENCE

3.1 Q/d Analysis

EPA guidance [Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentrations, Final, EPA, September 2016] recommends conducting a Q/d analysis as a rough assessment of the ability of a wildfire to cause increased ozone concentrations. The Q/d analysis is simply a comparison of the ration of Q, the daily tons of VOC and NOx emitted from the fire, to d, the distance in kilometers from the fire to the point of concern. If the Q/d value compares favorably to analytical data from other fires, then the fire can be presumed to have had a causal effect on ozone concentrations at the point of concern.

EPA guidance indicates that a fire should have a Q/d in excess of 100 tons per day per kilometer (tpd/km) in order to be considered to have a clear causal impact on ozone. EPA developed this value based on analyses of four fires which occurred in 2011.

Estimate of Q

The emissions from the fire can be estimated using information from EPA's AP-42 Compilation of Air Emission Factors Section 13.1 Wildfires and Prescribed Burning. The equations given are as follows:

$F_i = P_i * L$ (Equation 1)
$E_i = F_i * A$ (Equation 2)

F_i = emission factor (mass of pollutant/unit area of forest consumed)
P_i = yield for pollutant "i" (mass of pollutant/unit mass of forest fuel consumed)
= 12 kg/Mg (24 lb/ton) for total hydrocarbon (as CH_4)
= 2 kg/Mg (4 lb/ton) for nitrogen oxides (NO_x)
L = fuel loading consumed (mass of forest fuel/unit land area burned)
A = land area burned
E_i = total emissions of pollutant "i" (mass pollutant)

Combining equations 1 and 2, we have:

$E_i = P_i * L * A$

Pi is given above for total hydrocarbons and for nitrogen oxides. The fuel loading is given in AP-42 for different regions of the United States and ranges from 9 to 60 tons per acre. Conservatively, we will estimate a low end emission rate using 10 tons per acre which is associated with North Central US conifer forests. Note that our results could increase by a factor of 6 were we to expect the high end of emissions.

The Alberta government reported that by June 10, 2016 the fire ultimately covered 589,995 hectares (1,457,909 acres) with a perimeter of 996 kilometers (618 miles). For reference, the

total land area of Rhode Island is approximately 270,000 hectares.[3] The chart below (figure 31) indicates the total area covered by the fire as reported by the Alberta government[4]. During the week prior to the exceptional event in Connecticut the fire grew by approximately 60,000 hectares (148,263 acres).

Therefore, ignoring the smoldering of approximately 500,000 hectares we estimate the total hydrocarbon emissions from the week to be:

Ehc = 24 lbs of HC / ton of forest fuel consumed * 10 tons fuel / acre * 148,263 acres

Ehc = 35,583,120 pounds of HC

Ehc = 17,791 tons of HC emitted during the period from May 19 to May 24

Similarly for NOx:

Enox = 4 lbs of NOx / ton of forest fuel consumed * 10 tons fuel / acre * 148,263 acres

Enox = 5,930,520 pounds of NOx

Enox = 2,965 tons of NOx emitted during the period from May 19 to May 24

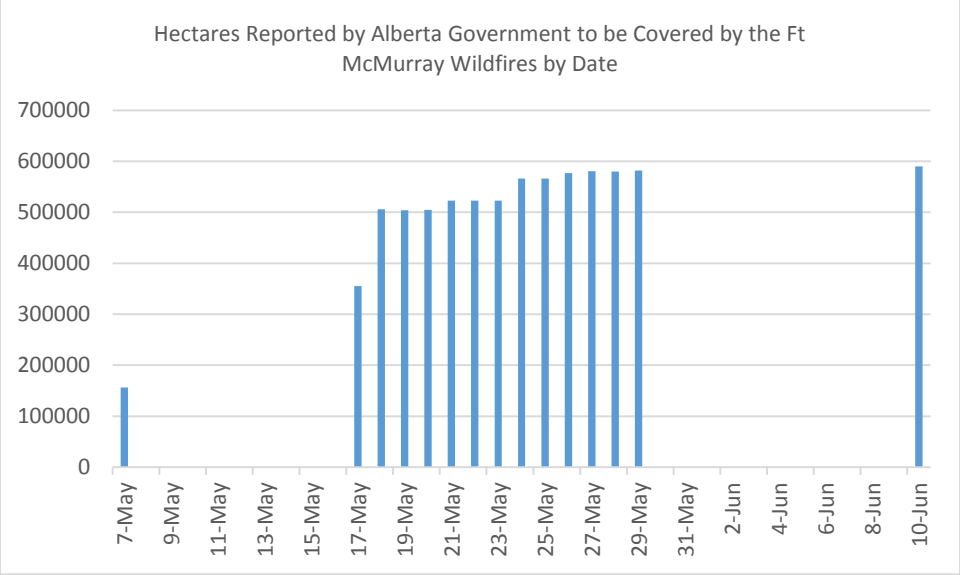

Figure 31. Chart of Hectares Burned Reported by the Alberta Goverment from May 7-June 10, 2016

[3] Any large area estimate can only be considered comprehensible if compared to the State of Rhode Island.
[4] https://www.alberta.ca/release.cfm?xID=41701E7ECBE35-AD48-5793-1642C499FF0DE4CF [Final Update 39: 2016 Wildfires (June 10 at 4:30 p.m.), Alberta Government]

Q is the total daily emission rate in tons per day of reactive hydrocarbons and nitrogen oxides. EPA recommends, in the exceptional events guidance, that only 60% of the hydrocarbons should be considered reactive. Therefore the reactive hydrocarbon emissions become rHC = 0.6 * Ehc or 0.6 * 17,991 = 10,794 tons of reactive HC emitted during the period of interest. No adjustments are suggested for the NOx emissions. Therefore the total rHC and NOx emissions over the period are 10794 + 2965, or 13,759 tons over the six days. On average this results in a daily emission rate, or Q, of 2293 tons per day.

Estimate of d

Based on the large distance, we will not present individual analyses for each monitor in Connecticut but estimate the distance from the Fort McMurray fire to the most distant point in Connecticut. We will therefore use a value of d of 3286 kilometers, the flight distance from Fort McMurray to Stonington, CT.

Q/d Estimate

Using the values determined above, Q/d then becomes 2293 tpd divided by 3286 km or 0.69 tpd/km. This value is well below the EPA recommended level of 100 tpd/km indicating clear causality (table 4).

{this table may be used to calculate Q/d – and will not appear in this form in the final}

Table 4. Table of Q/d calculation using a conservative approach.

acres	Ehc	Enox	Q	d	q/d	q/d per day	
148263	17791.56	2965.26	13640.2	3286	4.151003	0.691834	as explained above
1457909	174949.1	29158.18	134127.6	3286	40.8179		if the entire area burned in
	0	0	0	3286	0		
	0	0	0	3286	0		
	0	0	0	3286	0		
	0	0	0	3286	0		
	0	0	0	3286	0		

Taking a less conservative approach and using the maximum extent of the burn area over the life of the fire, the result would be a Q/d of 40.8 tpd/km. Still sufficiently below the EPA recommended threshold for establishing clear causality. Recalling that a worst case fuel loading would increase our results by a factor of six, Q/d would in this case result in 240 tpd/km and would indicate clear causality. While this approach might be justified by the ongoing smoldering of the peat, the intensity of the Fort McMurray fire, variability in the burn rate and other factors, it is difficult to justify without further details that may only be obtained through estimates which introduce their own error.

Taking a slightly different approach we consider the basis for the EPA guidance and look at emissions from one of the four fires EPA relied on in developing their guidance. Appendix A2 of the EPA guidance indicates that EPA based their conclusions on 12 km grid CMAQ modeling of four 2011 multiday fires: Wallow, Waterhole, Big Hill and Flint Hills. Emissions from the fires were based on a program called SMARTFIRE. Using information available on the Wallow Fire, we approximate the emissions that might be calculated for the Fort McMurray fire.

The Wallow Fire burned in eastern Arizona and western New Mexico from May 29, 2011 through July 8, 2011 and burned 841 square miles (538,240 acres) by June 26th. The maximum daily emissions from that fire were reported as approximately 15,000 tons of rVOC and 1,000 tons of NOx. [Simulating Fire Event Impacts on Regional O3 and PM2.5 and Looking Forward Toward Evaluation, Kirk Baker, EPA October 5, 2015 and Using SOAS and related field study data for scientific and regulatory modeling, Kirk Baker, EPA, undated; both are slide presentations] If we scale this fire up by a factor of three to approximate the acreage burned in the Fort McMurray fire, then we have daily emissions as high as 45,000 tons for rVOC and 3,000 tons for NOx. These emissions produce a Q of 48,000 tpd and Q/d becomes 14.6 – still well below EPA expectation for causality.

Noting the wide variability in emissions estimates from different approaches, and as the Q/d method does not generally satisfy the expectation of a clear causal impact, we present other evidence demonstrating that the plume from the Fort McMurray fire caused elevated ozone levels in Connecticut.

3.2 Long Range Transport of Ozone and Precursors from Biomass Burning

While the EPA Q/d screening method does not establish a clear causal connection between the Fort McMurray fire and elevated ozone levels in Connecticut, neither does it preclude a connection. Wildfire smoke plumes contain gases including non-methane hydrocarbons (NMHCs), carbon monoxide (CO), nitrogen oxides (NOx), and aerosols, which are all important precursors to photochemical production of tropospheric ozone (O_3), and can travel thousands of kilometers. This may cause urban areas where forest fires seldomly occur to see greater

enrichment of ozone, as much as 25 ppb in the northeastern United States (figure 32), than areas where wildfires more frequently occur.[5]

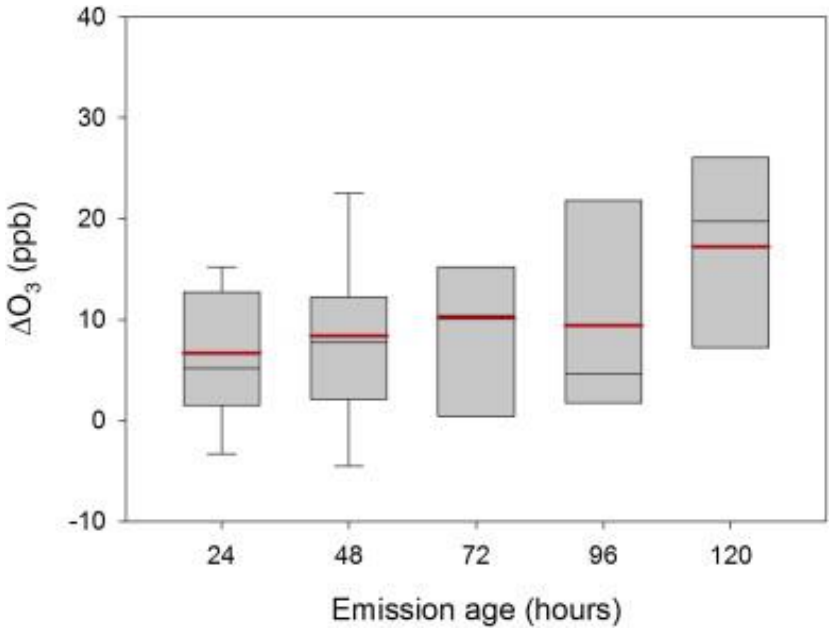

Figure 32. Ozone Enrichment by Age of Plume. This figure, taken from Putero et al[6] shows the results of their study on the influence of biomass burning on ozone concentrations. Ozone enhancement increases as the plume ages. Here we see increases on the order of 20 ppb from a five day old plume.

Many variables can affect the ability of a plume to affect downwind ozone production. Emissions from boreal forests such as the Fort McMurray fire result not just from the consumption of the standing mass and litter, but as much as 80% of the available biomass (on the order of 100 tons per acre) may be stored in the forest floor as lichens, moss, peat and duff.[7] The Fort McMurray fire occurred following an unusually hot dry Spring. Under these conditions the fire can burn and smolder deeper into the forest floor to add considerable emissions to the plume.

Typically, NOx emissions react within a few days and are no longer available to participate in ozone reactions. However, at high latitudes cooler ambient temperatures are conducive to the sequestering of NOx emissions as Peroxyacetyl Nitrates (PAN), aerosols which can decompose back to NOx far downwind. Study of boreal wildfires indicate that as much as 40% of the NOx emitted from the fire can be converted to PAN and transported downwind for six to fifteen days before returning to NOx.[8]

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[5] Brey, Steven J. and Emily V. Fischer, Smoke in the City: How Oftern and Where Does Smoke Impact Summertime Ozone in the United States?, Environmental Science and Technology, vol. 50, pp1288-1294, 2016.
[6] Putero, D. et. al., Influence of open vegetation fires on black carbon and ozone variability in the southern Himilayas, Environmental Pollution, vol 184, pp 597-604, 2014.
[7] Ottmar, Roger D. and Stephen P. Baker, Forest Floor Consumption and Smoke Characterization in Boreal Forested Fuelbed Types of Alaska, Final Report JFSP Project #03-1-3-08, May 25, 2007.
[8] Jaffe, Daniel A. and Nicole L. Wigder, Ozone production from wildfires: A critical rReview, Atmospheric Environment, 2012, vol 51, pp1-10.

The impact of wildfires on O_3 level on downwind regions can vary significantly with the magnitude of aged plumes, the amount of biomass consumed and the emissions produced, fuel type, burning area, and combustion conditions (Jaffe et al., 2003, 2008; Martin et al., 2006). Jaffe and Wigder[9] and others have confirmed that the maximum O3 production is often observed substantially downwind of the fire, after the smoke plumes have aged for several days. Dreesen et al (2016) have noted in their analysis of a June 2015 wildfire ozone enhancement in Maryland that at peak smoke concentrations in Maryland, wildfire-attributable Volatile Organic Compounds (VOCs) more than doubled, while non-NOx oxides of nitrogen (NOz) tripled, suggesting long range transport of NOx within the smoke plume. They also noted that ozone peaks a few days after the maximum plume due to ultra violet (UV) light attenuation, lower temperatures, and non-optimal surface layer composition.

3.2 Satellite Photos, Webcams and Plume Analysis

Figure 33 shows the presence of the smoke plume over the Upper Midwest states several days before arriving in Connecticut. A satellite animation of this plume can be viewed on our web site[10]. The presence of a surface high pressure center allowed these pollutants to become trapped near the surface while conditions became conducive for ozone formation by May 23-24th. Figure 34 shows the 3km aerosol optical depth (AOD) image overlaid with the Visible Infrared Imaging Radiometer Suite (VIIRS) satellite image on May 24-25th, 2016. The AOD is indicative of particulate matter transported with the smoke plume over the Northeast States.

Figure 35 shows the progression of the smoke plumes over North America as analyzed by the Hazard Mapping System (HMS) staff using the satellite images. This series of maps shows the merging of the Fort McMurray smoke plume with that from the southern States and Mexico, prior to passing over the Connecticut region on May 25-26, 2016.

Figure 36(a-d) shows webcam images from our Cornwall CT monitoring site. These show that haze from the smoke is not visible on May 24th (figure 36a) but can be seen increasing on May 25th 36b,c) and continues on May 26th (36d). Figure 37(a-d) shows images from our Talcott Mountain webcam pointing east toward Hartford. Likewise, May 24th (figure 37a) shows a clean air mass with good visibility while the smoke obscures the sky on May 25-26th (37b,c,d). Figure 38 are images from the Newark New Jersey HazeCam showing the progression of smoke over the May 24-27 period. An animation of images from those days is available from this link[11]. The visible satellite photographs over Connecticut on May 25th (Figure 39a) and May 26th (Figure 39b) confirm evidence of a smoke plume.

[9] Jaffe, D.; Wigder, N. Ozone production from wildfires: A critical review. Atmos. Environ. 2012, 51, 1−10
[10] ftp://ftp.state.ct.us/dep/air/public/2016_Exceptional_Event/Animations/Fort%20McMurray%202016.wmv
[11] ftp://ftp.state.ct.us/dep/air/public/2016_Exceptional_Event/Animations/Newark HazeCam.WMV

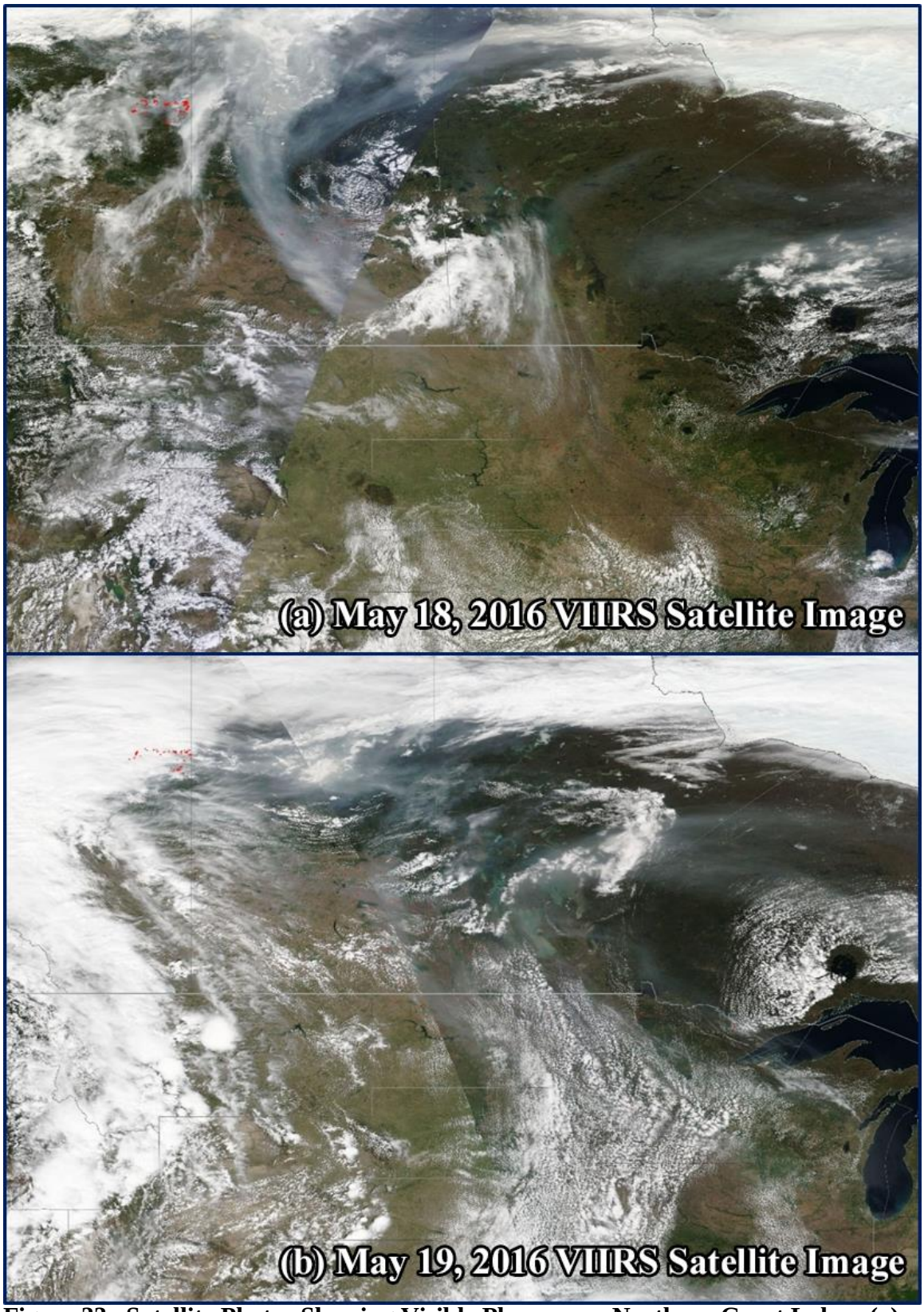


Figure 33. Satellite Photos Showing Visible Plume over Northern Great Lakes, (a) May 18th and (b) May 19th, 2016

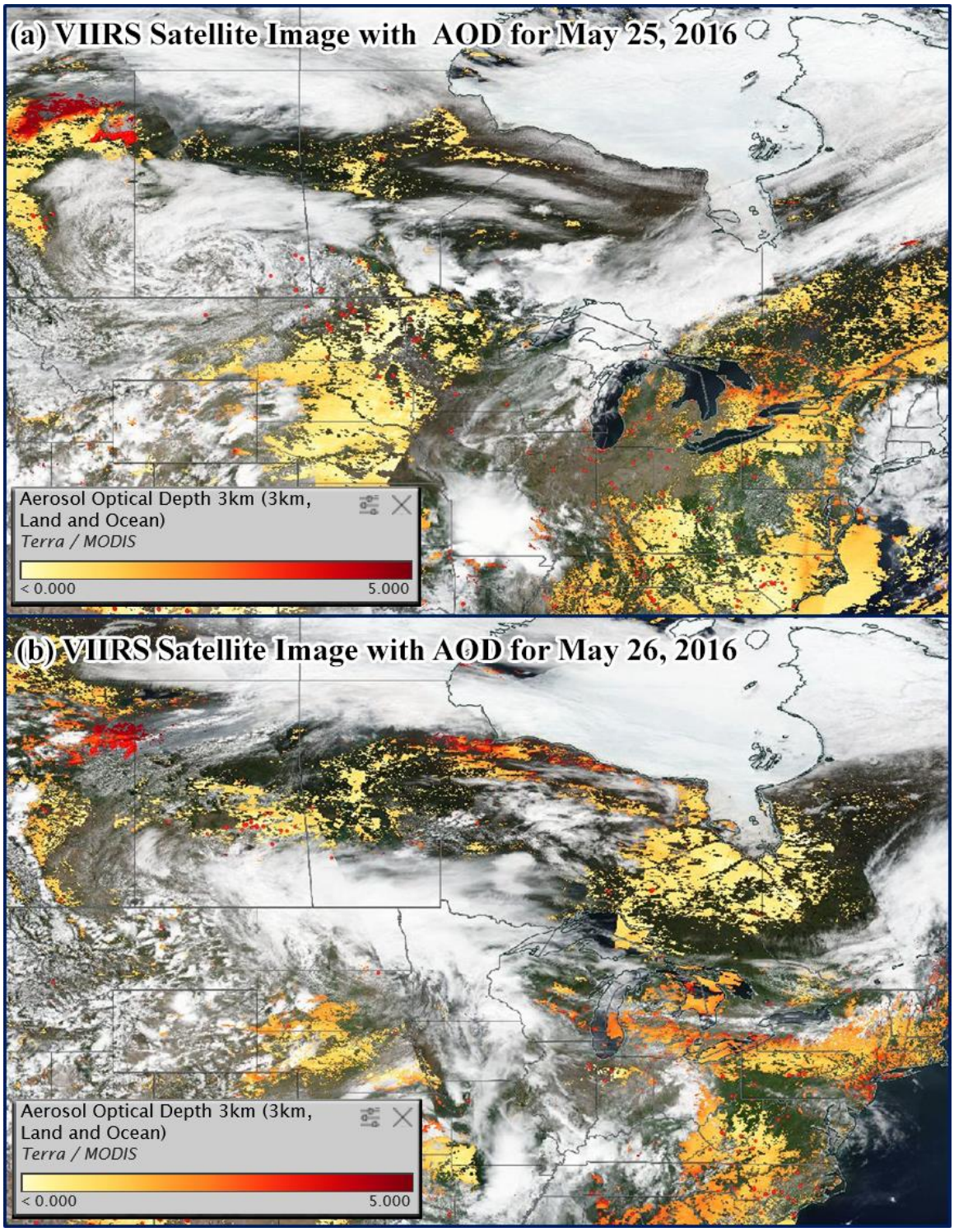


Figure 34. VIIRS Satellite Images for (a)May 25th and (b) May 26th, 2016, showing the Analyzed Aerosol Optical Depth (AOD) Associated with the Smoke Plume.

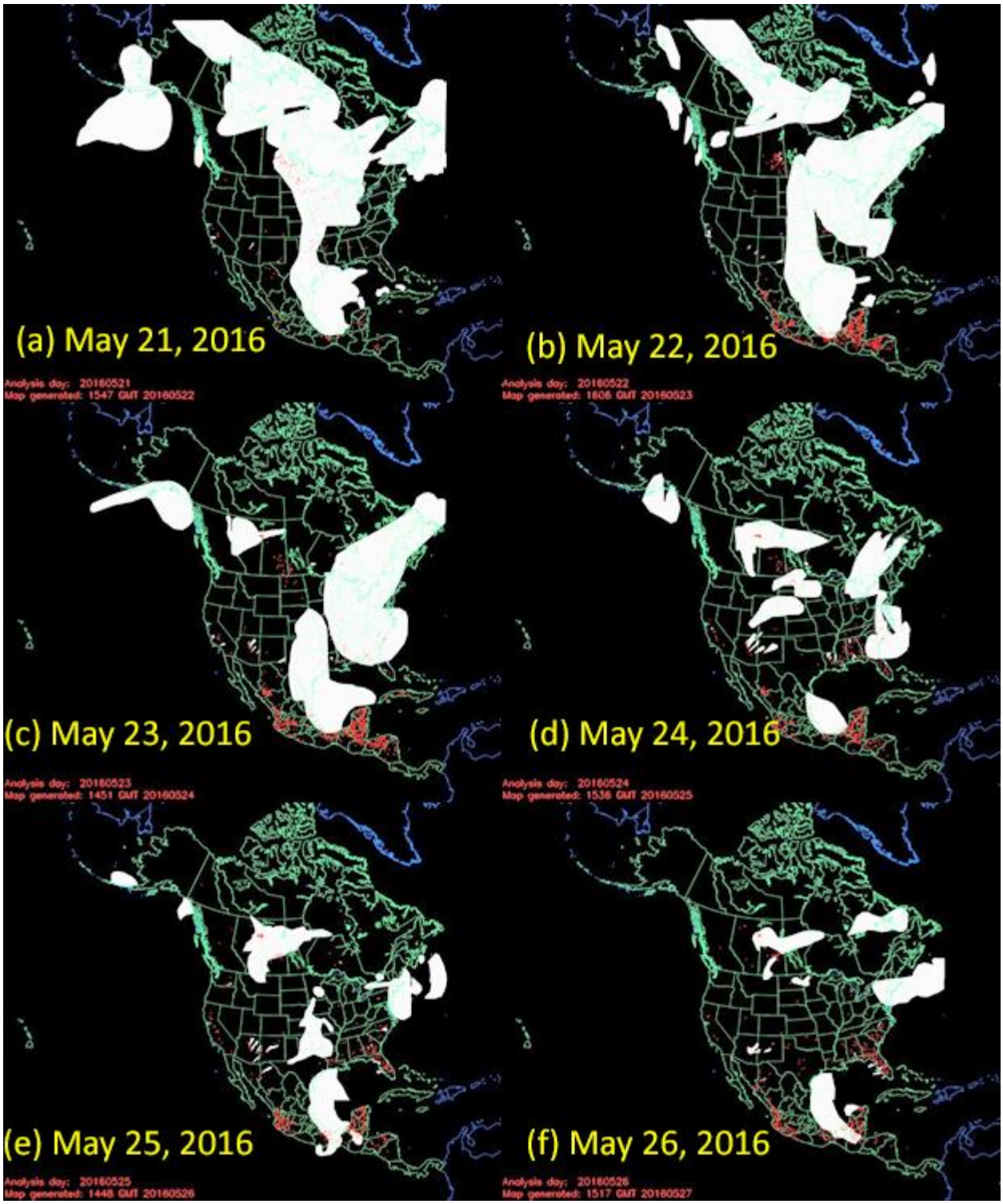


Figure 35. HMS Smoke Analysis from May 21-26(a-f), 2016.

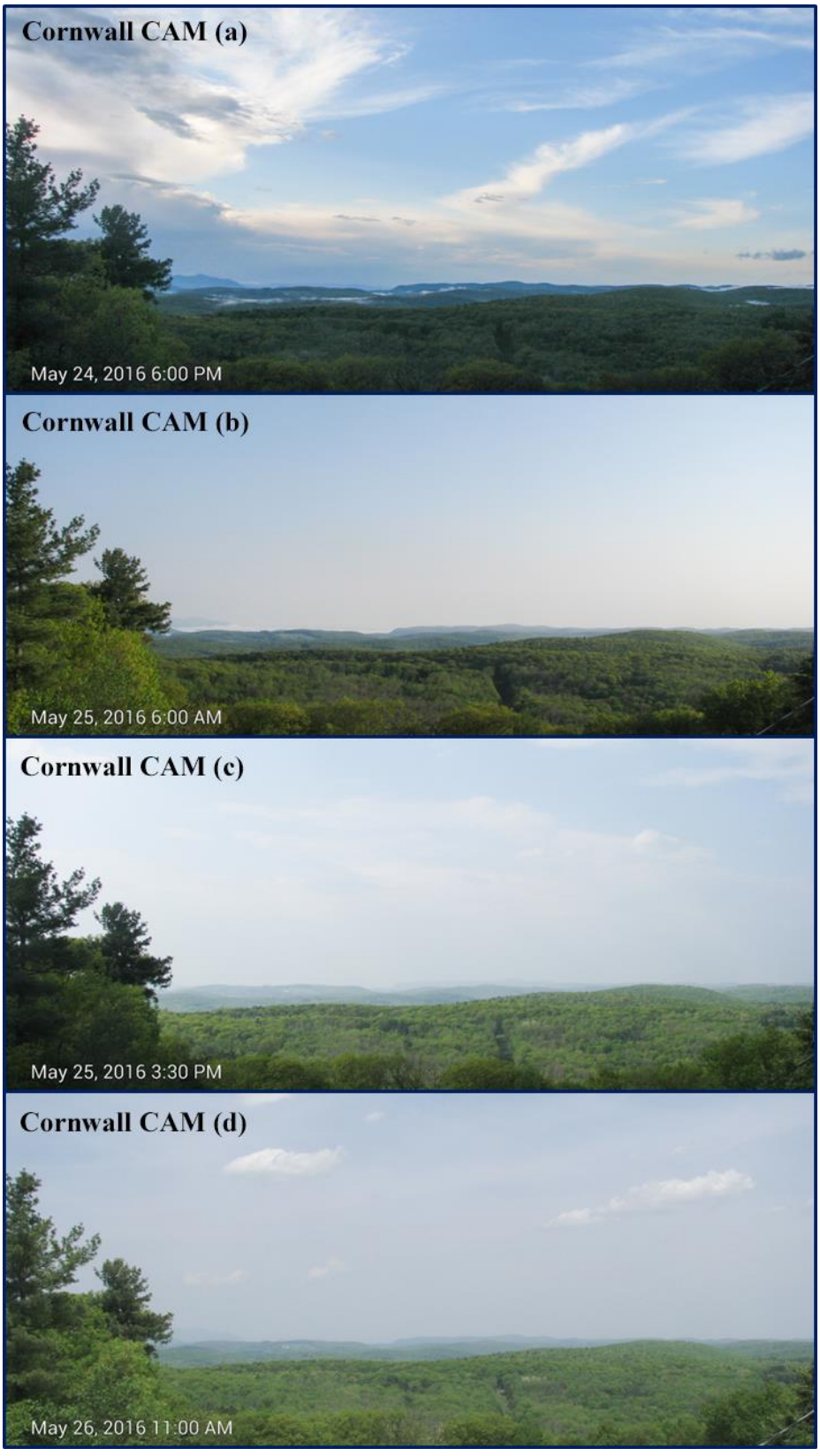


Figure 36. Cornwall Connecticut Webcam (a)May 24-6:00pm, (b)May 25- 6:00am), (c)May 25- 3:30pm and (d)May 26-11:00am, 2016.

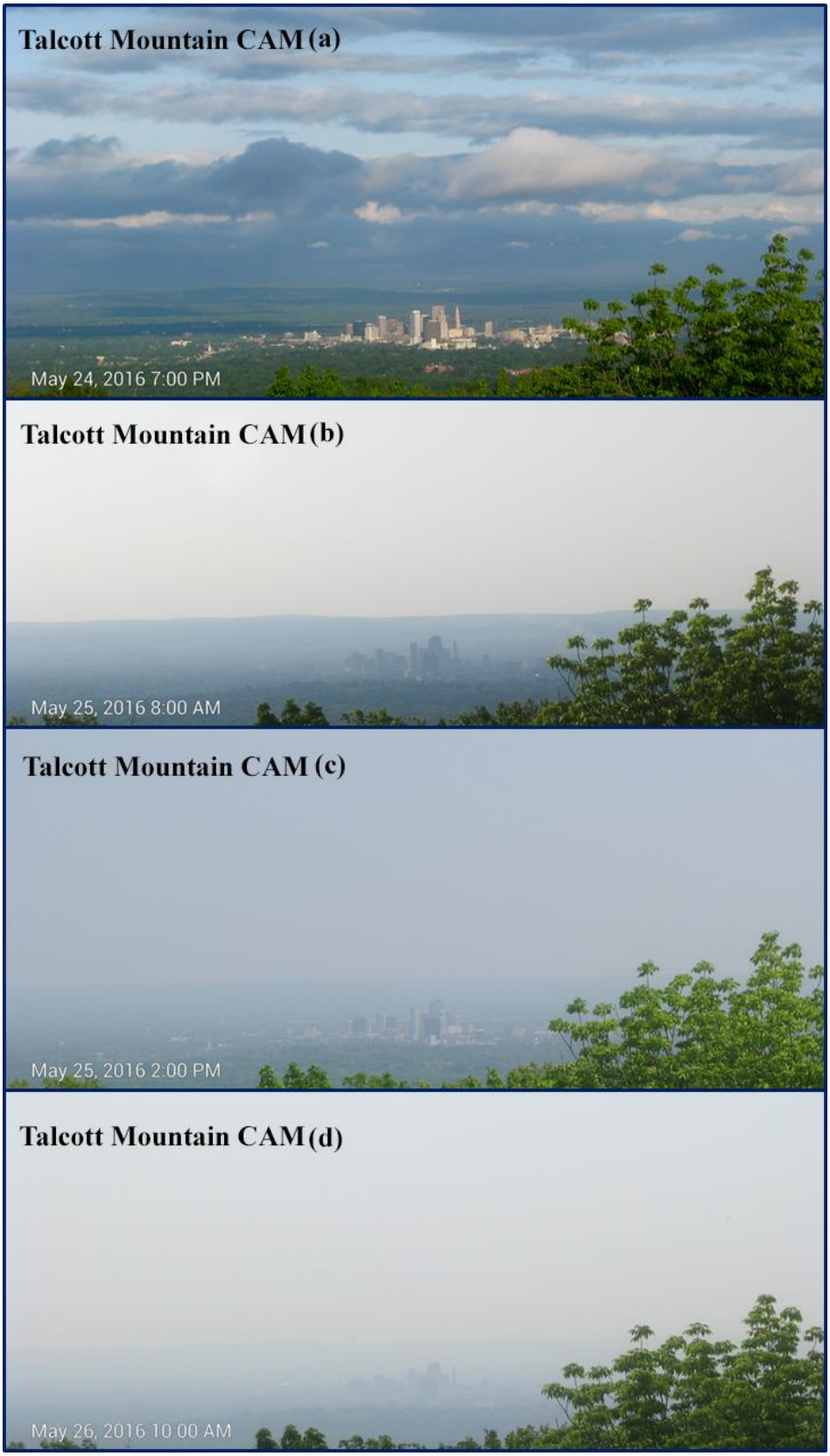


Figure 37. Talcott Mountain Connecticut Webcam (a)May 24- 7:00pm, (b)May 25- 8:00am), (c)May 25- 2:00pm and (d)May 26- 10:00am, 2016.

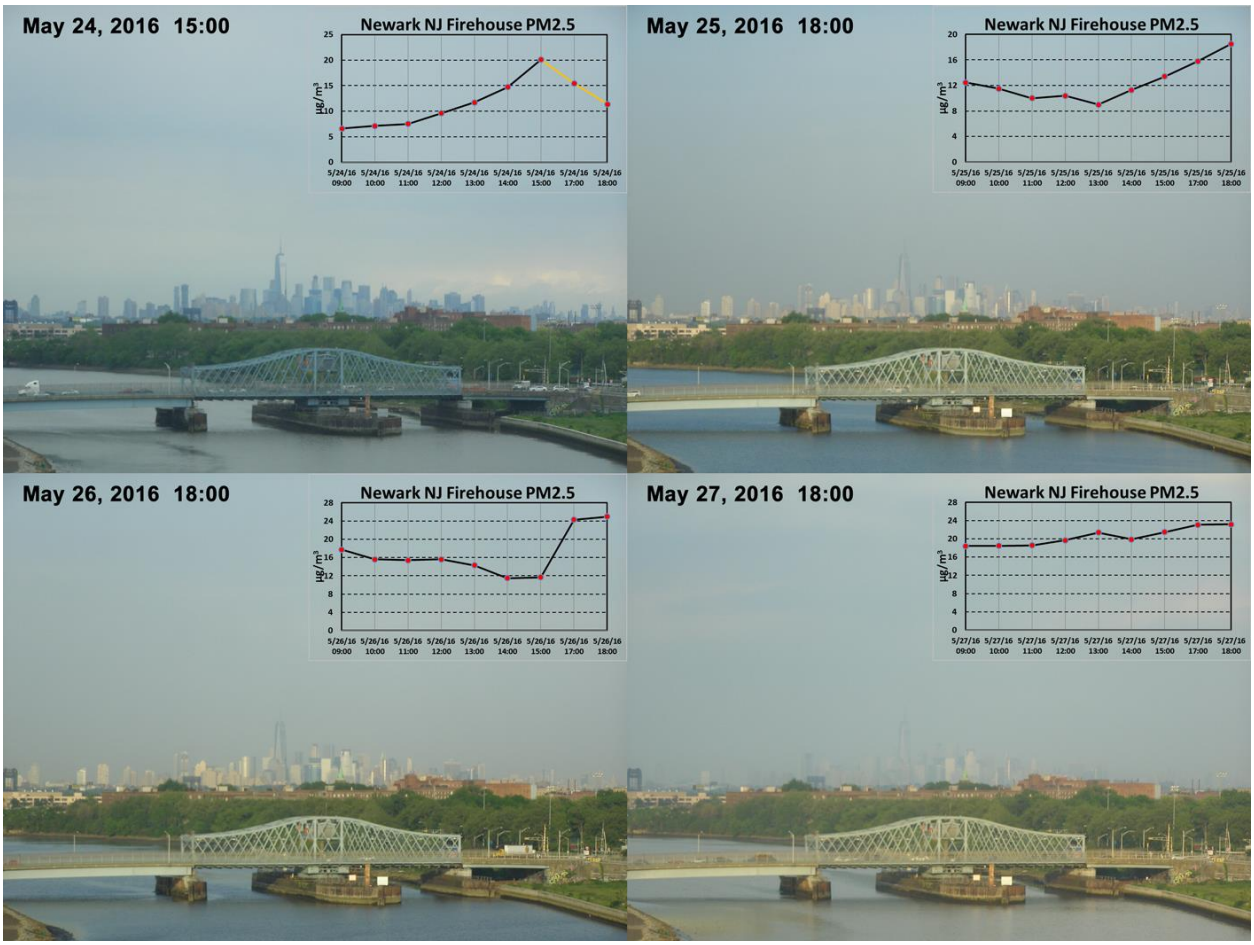


Figure 38. Haze Cam image from Newark NJ to New York City with PM2.5 concentration plots from the Newark Firehouse monitor from May 24-27, 2016.

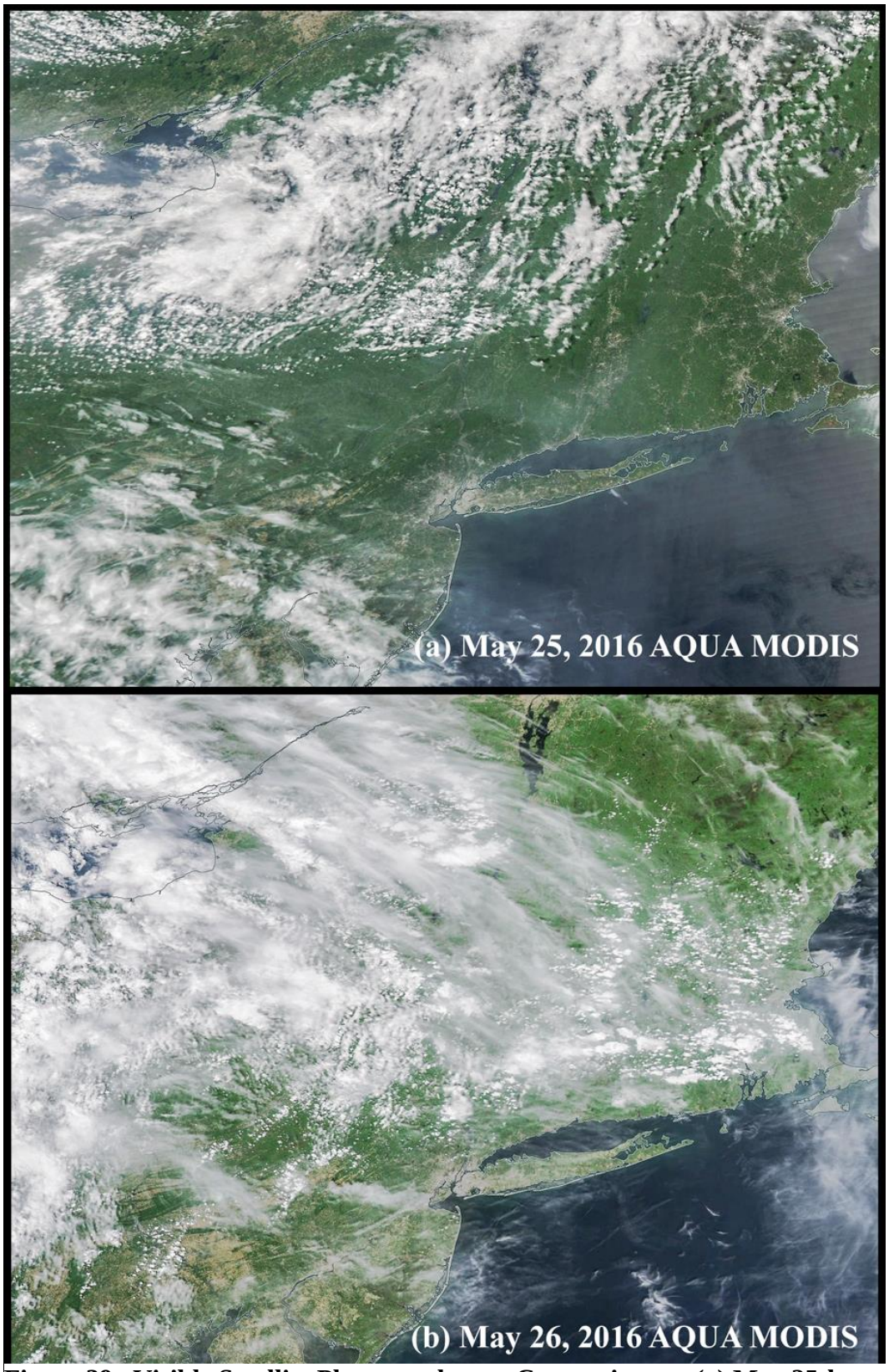


Figure 39. Visible Satellite Photograph over Connecticut on (a) May 25th and (b) May 26th, 2016, showing visible smoke plume.

Carbon Monoxide Plumes

Further evidence of smoke plumes can be found in the satellite detection of carbon monoxide (CO), which is a by-product of combustion. The Fort McMurray plume can be seen very distinctly, as darker red pixels, as it meanders across eastern North America (figure 40a,b). The plumes disperses over the Great Lakes by May 19-20 and a visible smoke plume was seen over Connecticut on May 20th, but did not reach the ground. Figure 41(a,b) shows that CO plume dispersing over the Midwestern States and then moving east into Connecticut. The May 20th satellite image in Figure 42 is consistent with the CO plume location over Connecticut. Figure 43(a,b) shows a plot of ozone at Westport vs. PM2.5 from our Bridgeport monitor. These sites are about 14 kilometers from each other and one can distinctly observe when the PM2.5 levels rose dramatically on May 25th, with the onset of the ozone episode. Prior to this on May 20th, both PM2.5 and ozone levels remained relatively low, despite the presence of the smoke plume aloft. View an animation of the mapped twice/day CO concentrations for May 2016 that shows the Fort McMurray fire erupting on May 4th and a dense plume crossing Connecticut on May 20th and the plume settling over the Great Lakes On May 23-24th.

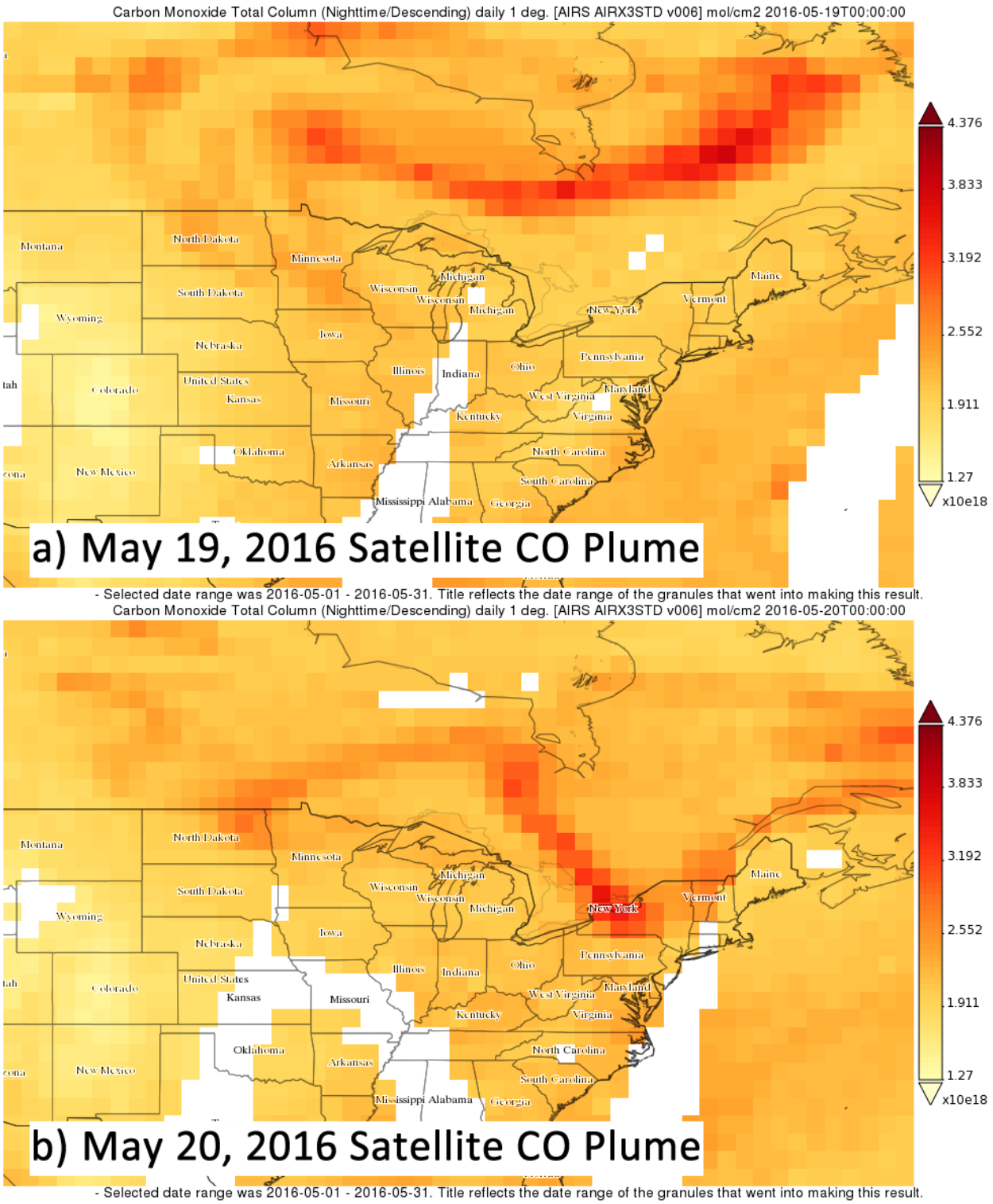


Figure 40. Satellite CO Plume from May 19 (a) and May 20 (b) , 2016 as the plume meanders across southern Canada into the U.S. Midwest and across Connecticut.

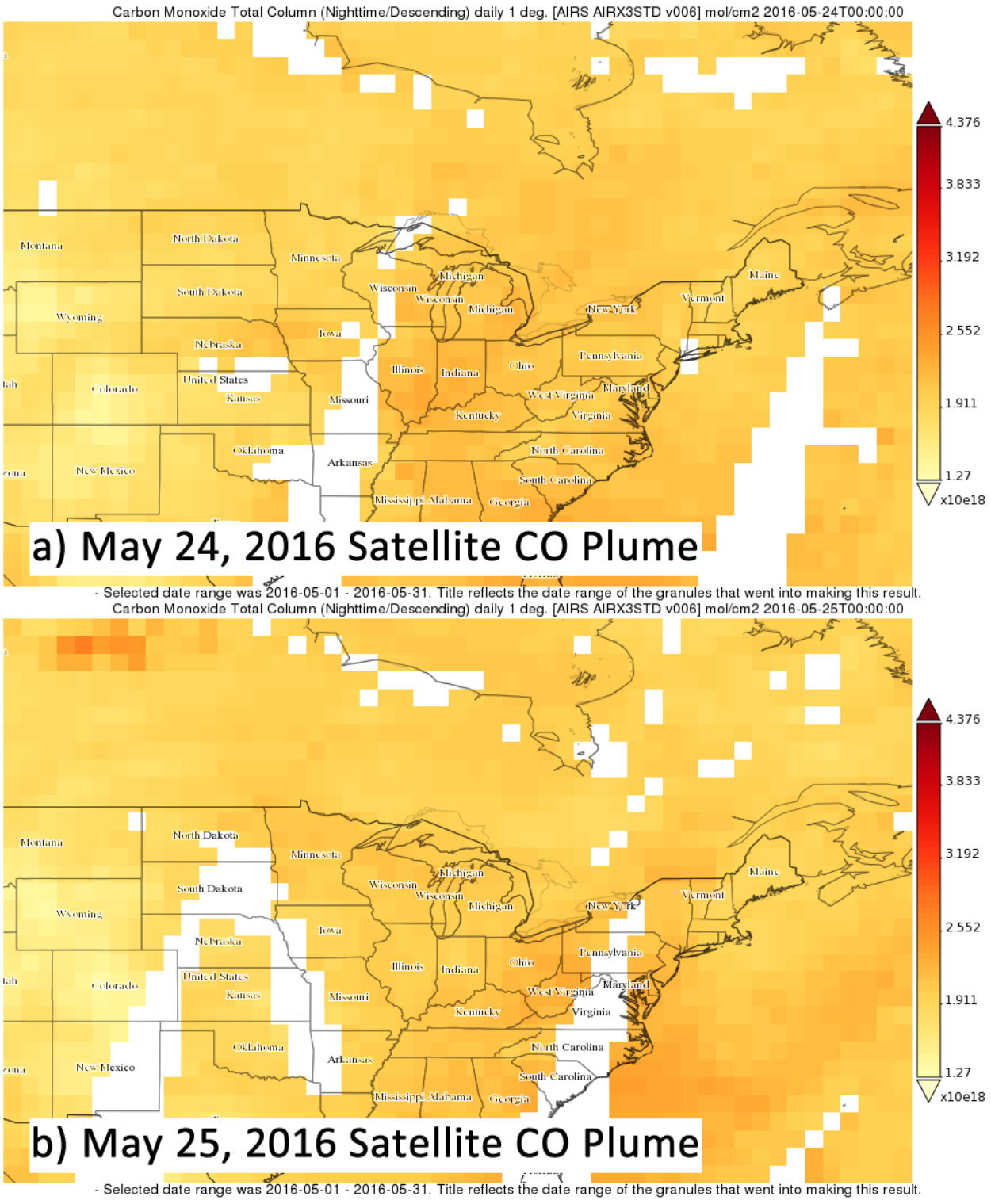


Figure 41. Satellite CO Plume from May 24 (a) and May 25 (b) , 2016 as the elevated CO plume settles over the Midwest States and moves east into Connecticut

Figure 42. May 20, 2016 VIIRS Satellite Images: Visible on left; AOD on right

3.3 Percentile Rankings

EPA guidance suggests that for each monitor requested for data exclusion, a 5-year percentile of the data on a per monitor basis be determined. If the flagged data is above the 99th or higher percentile of the 5-year distribution of ozone monitoring data, or is one of the four highest ozone concentrations within 1 year, these data can be considered outliers and would provide strong evidence for the event.

The following table shows the maximum 8-hour daily ozone levels observed at four sites on May 25-26, 2016, compared with the 99th percentile ranked 8-hour ozone levels observed during the last five years. All four sites had a 99th percentile ranking for one or more of these two days.

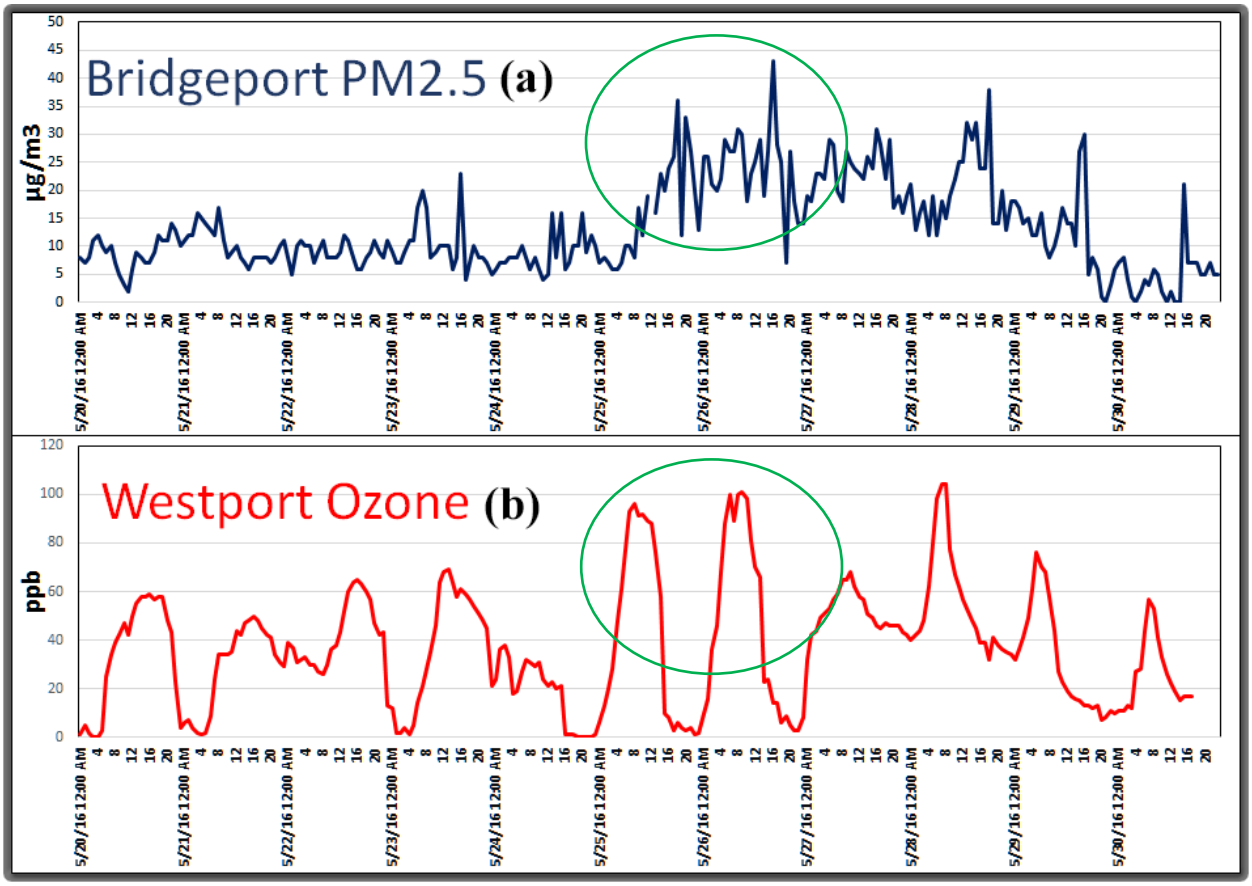


Figure 43. May 20-30, 2016 plots of (a) Bridgeport CT PM2.5 and (b) Westport Ozone Hourly Concentrations. The ozone peaks at Westport on May 25-26 coincide with the PM2.5 peaks at the Bridgeport monitor.

Table 5. 99th Percentile Rankings for May 25-26th, 2016

Maximum Daily 8-hour Ozone ppb			
Site	May 25 ppb	May 26 ppb	99th Percentile
Abington CT	76	83	74
Cornwall CT	81	91	79
East Hartford CT	75	93	78
Westport CT	87	90	90

The following figures (44-47) are plots of the ranked percentile 8-hour ozone observations at each site to further illustrate the outlier status of the May 25-26, 2016 event.

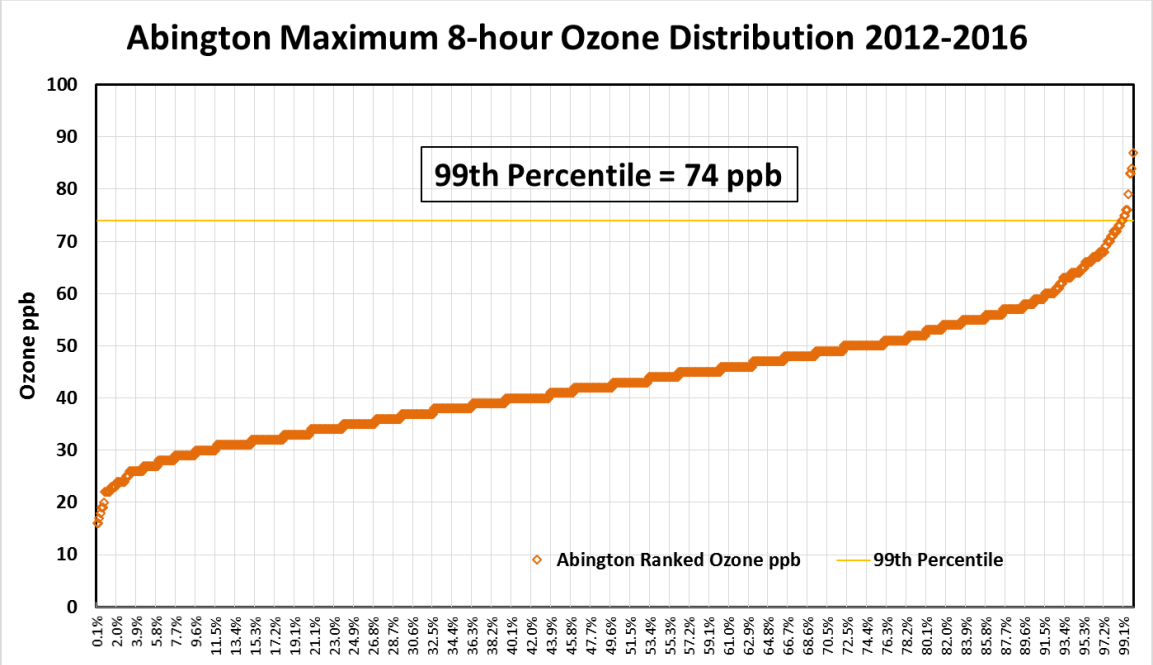


Figure 44. Ranked 8-hour Ozone Distribution for Abington CT 2012-2016

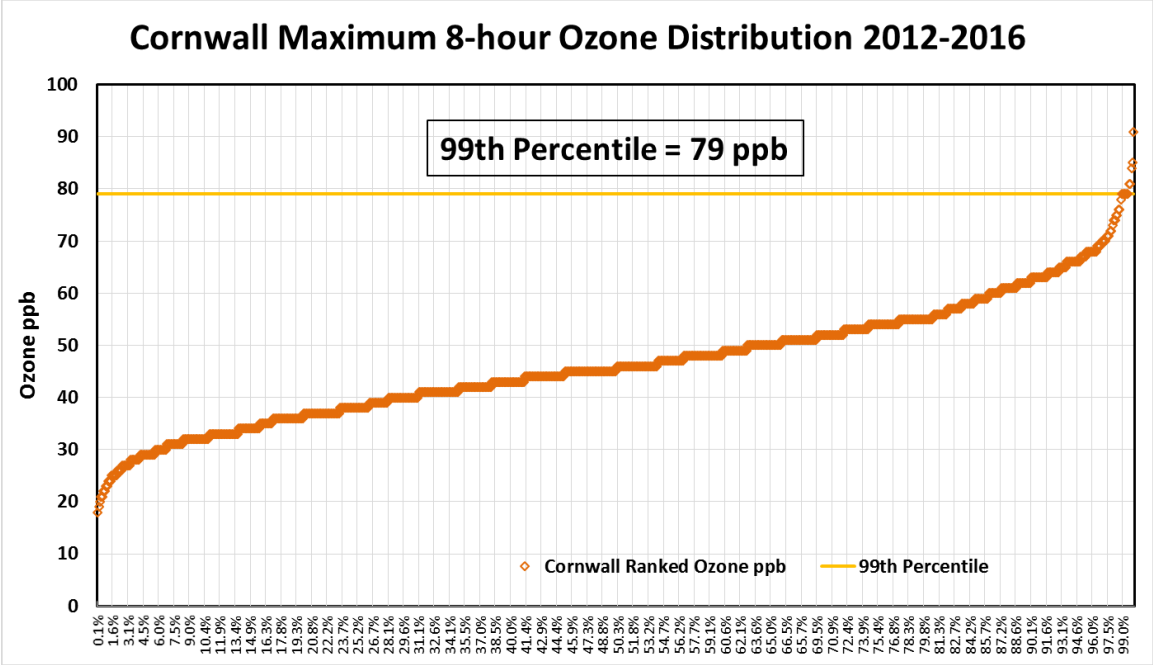


Figure 45. Ranked 8-hour Ozone Distribution for Cornwall CT 2012-2016

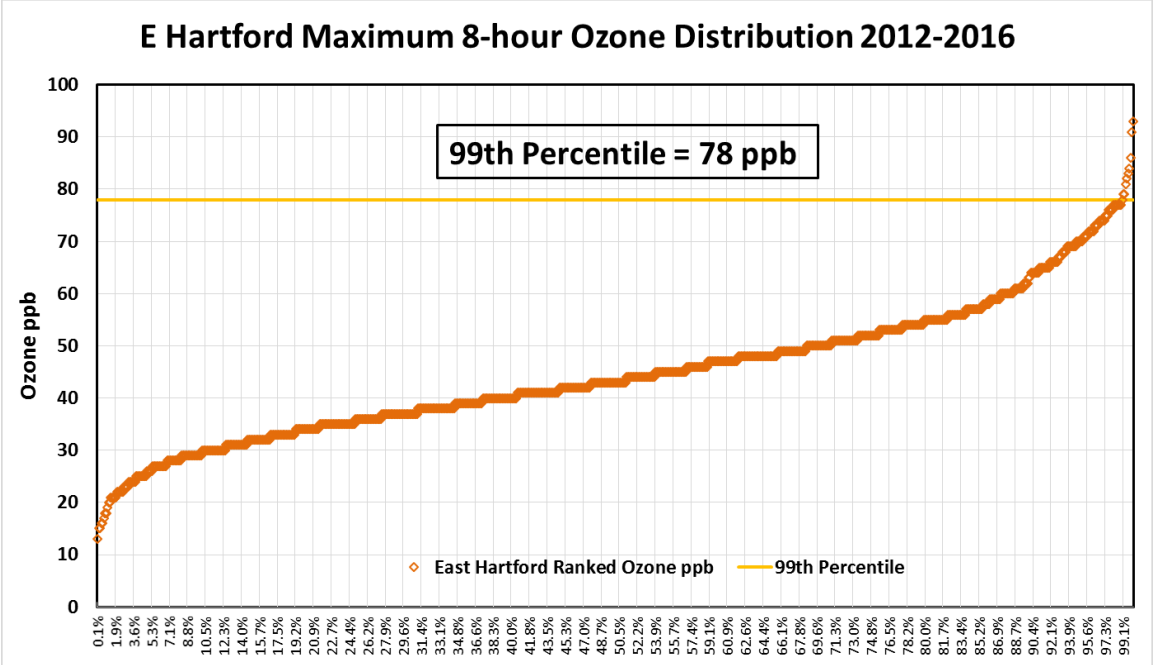


Figure 46. Ranked 8-hour Ozone Distribution for E Hartford CT 2012-2016

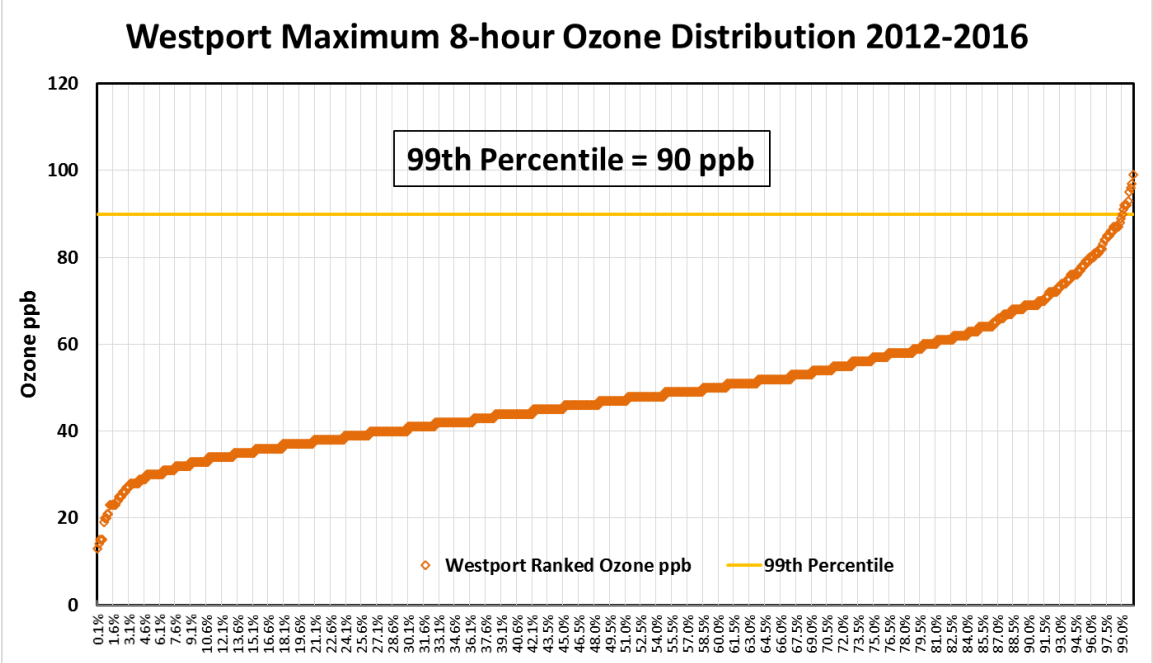


Figure 47. Ranked 8-hour Ozone Distribution for Westport CT 2012-2016

The following figures (48-51) are the 5-year plots of the four monitors of interest in Connecticut. The 8-hour ozone concentrations for the May 25-26, 2016 event have been circled and the percentile rankings have been labeled next to those data points. To illustrate the frequency of high ozone days (i.e. > 70 ppb) with a northwest wind flow, we obtained sounding wind data from the nearest upwind site, Albany NY (ALY), for the 2010-2016 May-September time period.

The National Weather Service (NWS) dispatches weather balloons with sounding instrumentation twice a day from numerous sites across the United States. There are specific 'mandatory' pressure levels that are reported for input into weather models as well as for plotting the pressure height maps. The mandatory sounding height of 925mb (~800m) was chosen, because it represents winds in the middle of the boundary layer and should be relatively free of surface drag effects. On May 25th, 2016, the 925 mb wind direction at ALY was from 305° at 32 knots. We selected a wind direction (WD) compass range between 295°-335° to filter the days with similar wind patterns, which also included May 26th. This range was broad enough to ensure that an ample number of days would be selected.

It is observed that most of the over 70 ppb days disappear over our Greater Connecticut monitors (figures 48-51) when the filter is applied, but the percentile rankings do not always increase since there are generally 75% less data points. At our Cornwall monitor, nearly all of the high ozone days are eliminated on days when the 925 mb wind is from this northwest direction. Not surprisingly, our coastal Westport monitor still displays numerous days above 70 ppb when applying this filter. The sea breeze effect plays an important role in ozone transport to our coastal monitors, and this effect is frequently observed when the ozone levels are far below 70 ppb at our inland monitors. These charts also show an abundance of high ozone days during 2012. This is not sufficiently explained by the emission reductions that may have occurred since then, but it is more likely due to multiple smoke events for that summer that likely had an influence on ozone concentrations in Connecticut. Transport from the northwest generally travels over a region with reduced NOx sources, as is evidenced in figure 52. Back trajectories over New York State would pass over a region with NOx emissions generally below the 50th percentile of the total.

Cornwall Connecticut

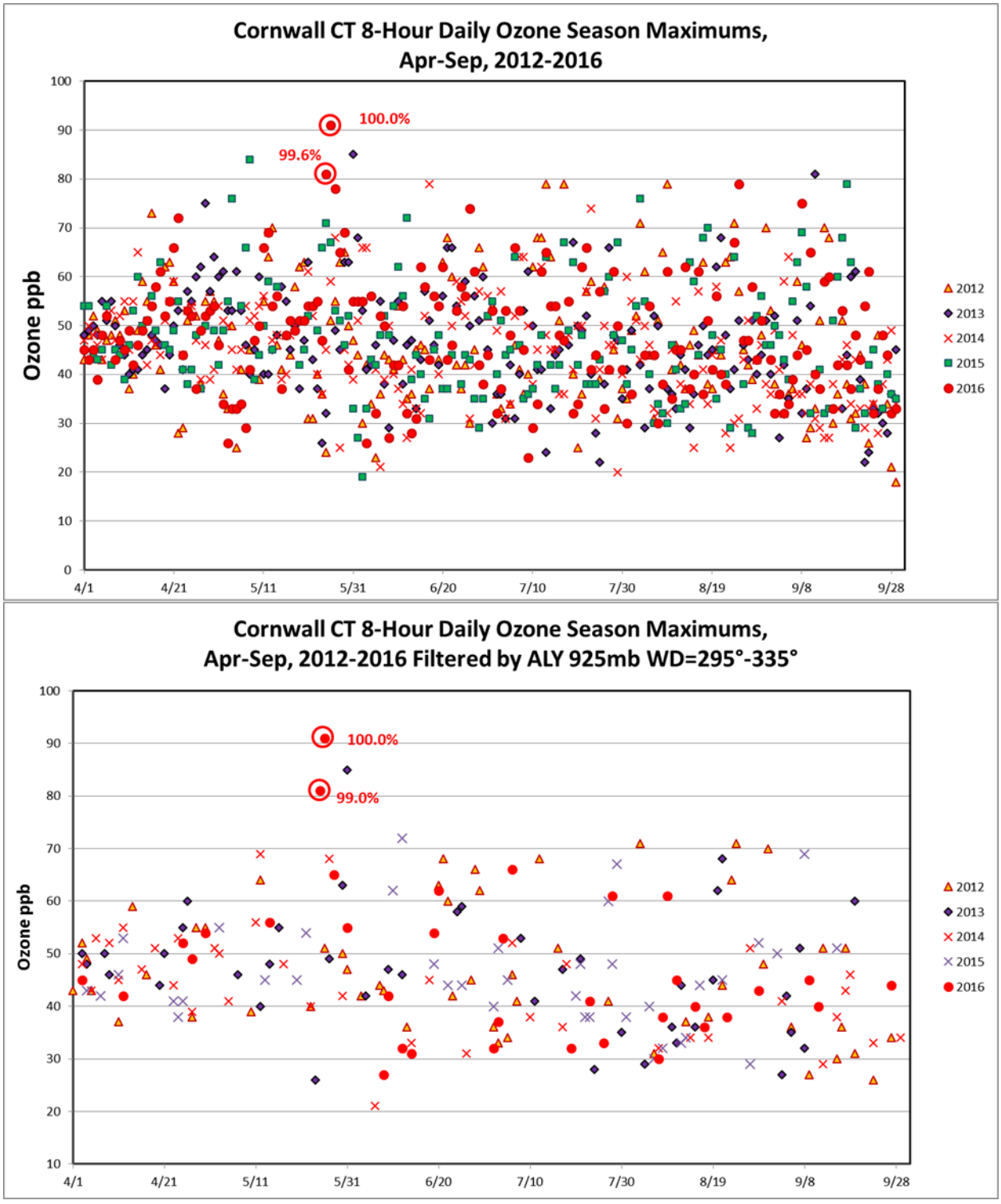


Figure 48. Cornwall CT Daily Ozone Season Maximums 2012-2016

East Hartford Connecticut

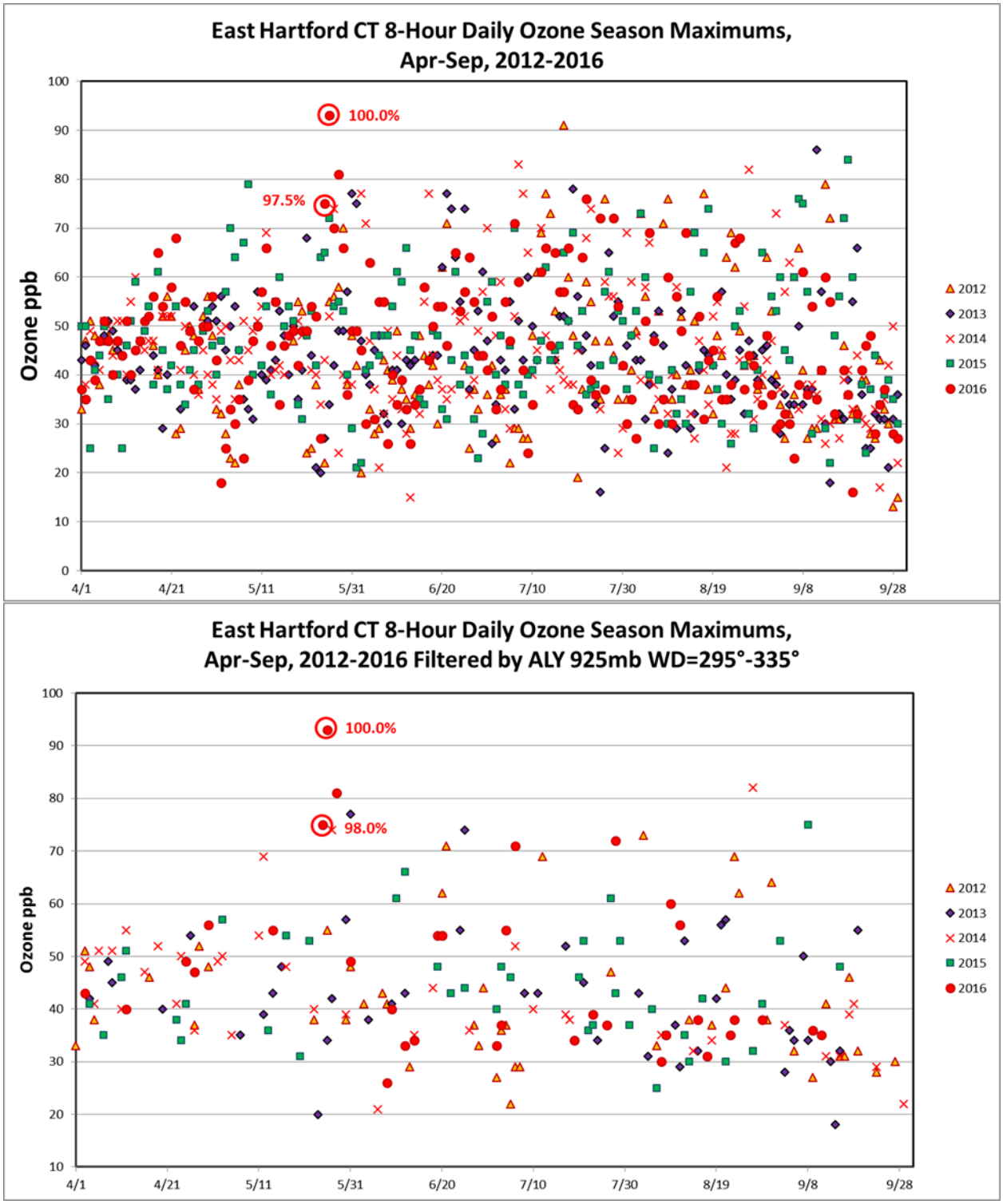


Figure 49. East Hartford CT Daily Ozone Season Maximums 2012-2016

Abington Connecticut

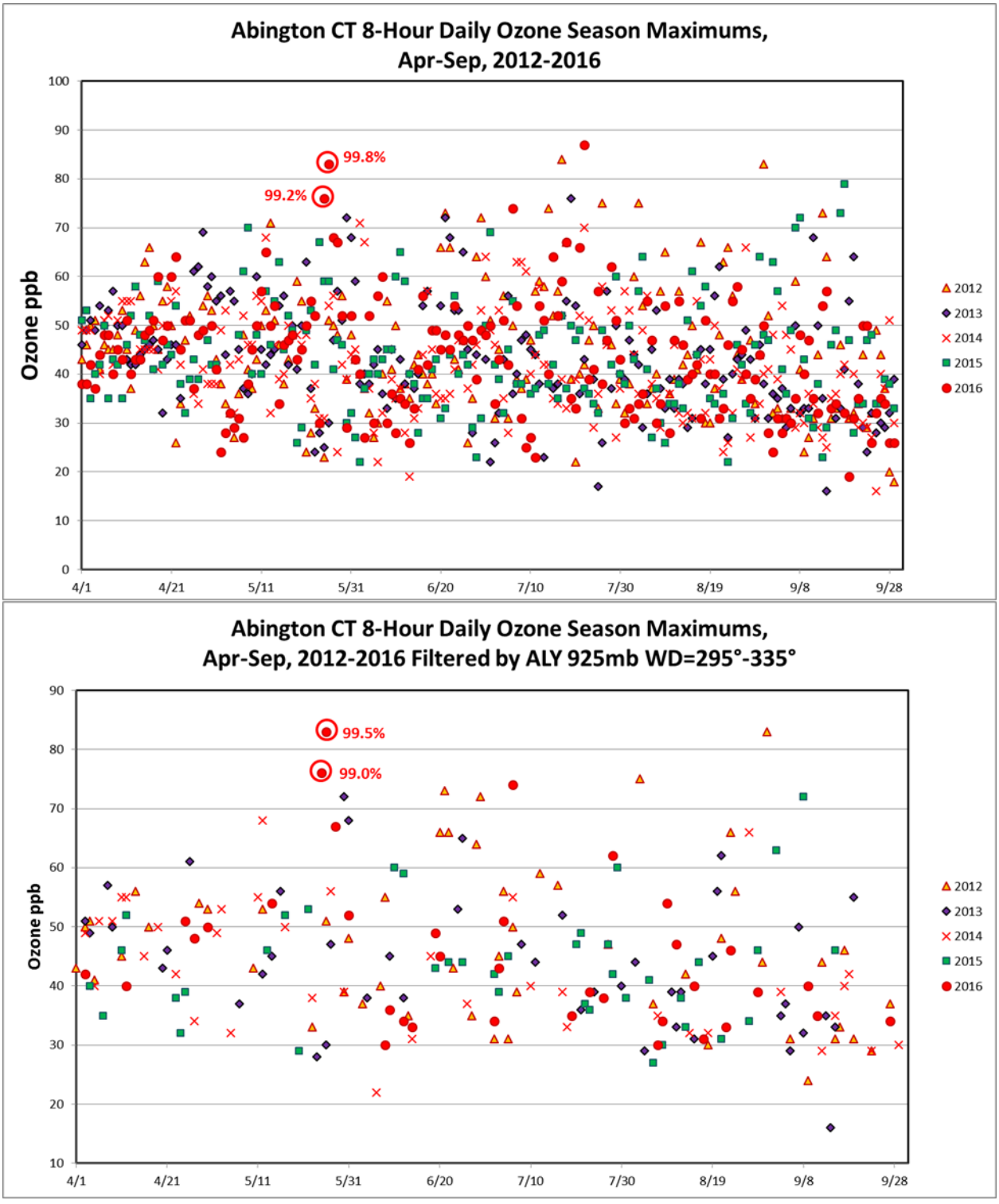
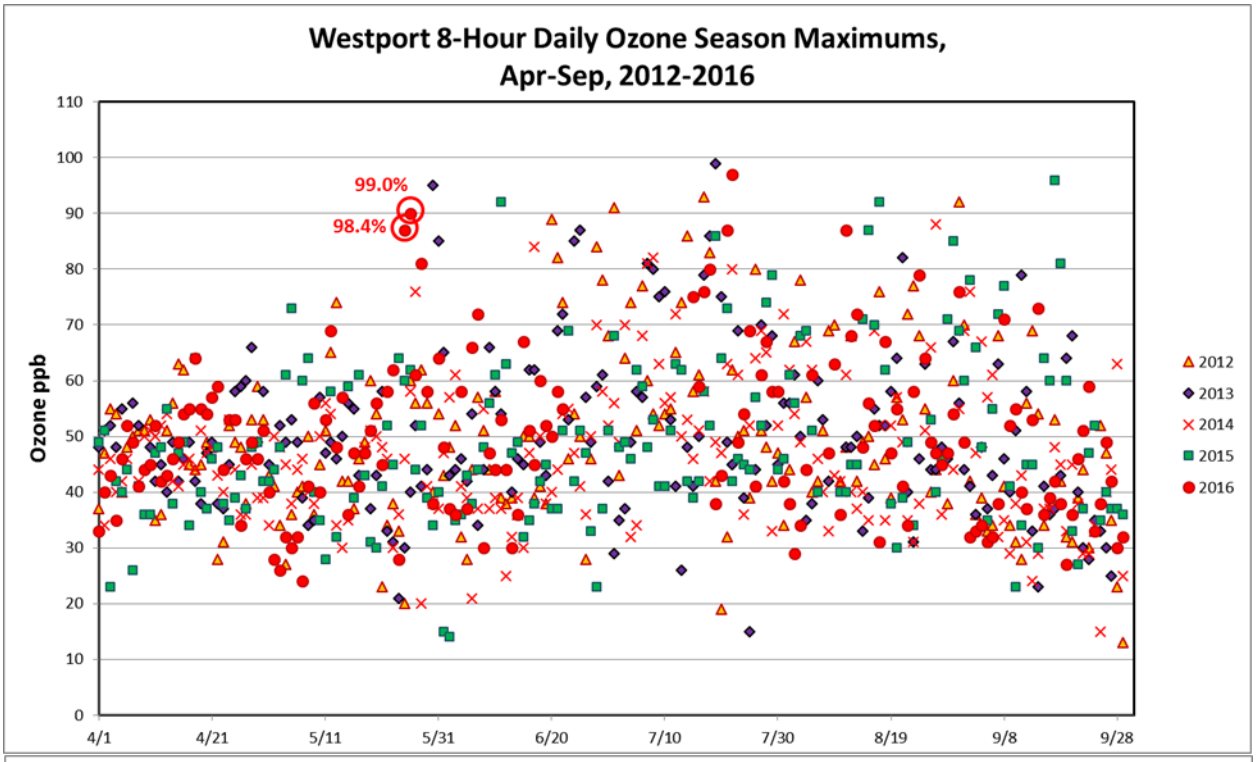


Figure 50. Abington CT Daily Ozone Season Maximums 2012-2016

Westport Connecticut



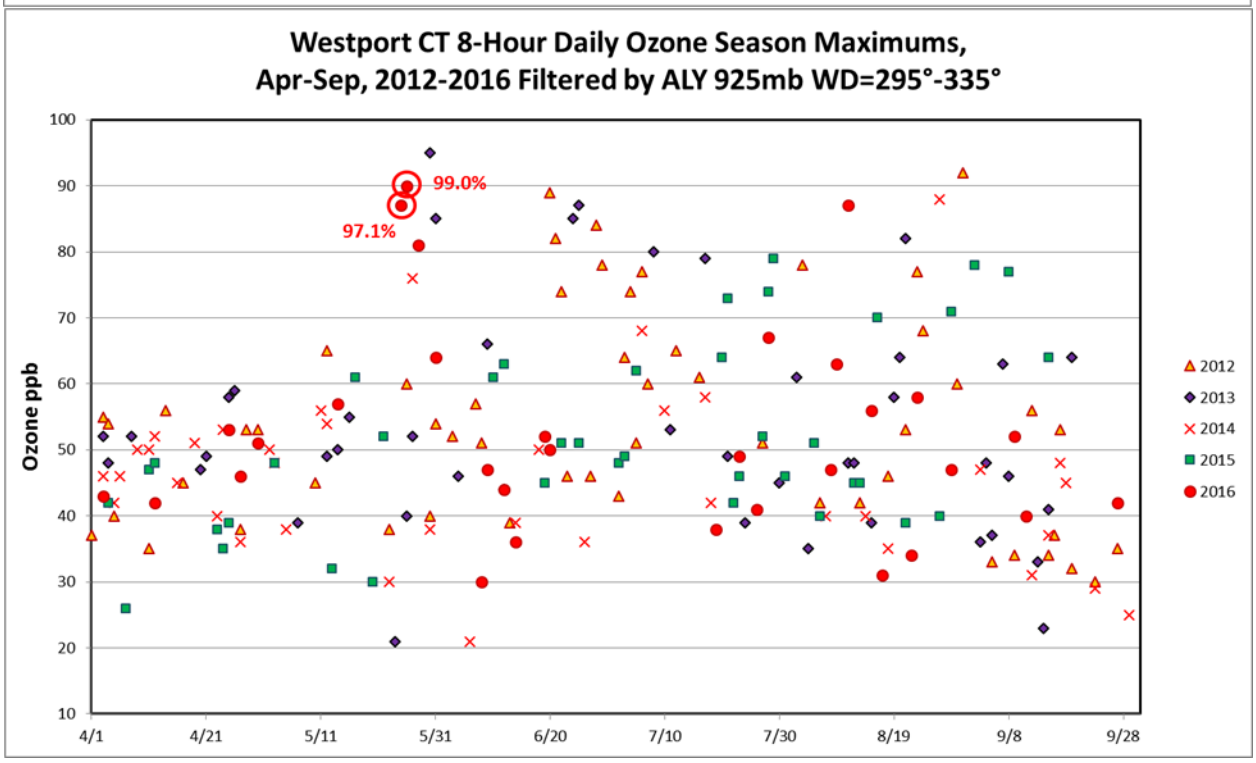


Figure 51. Westport CT Daily Ozone Season Maximums 2012-2016

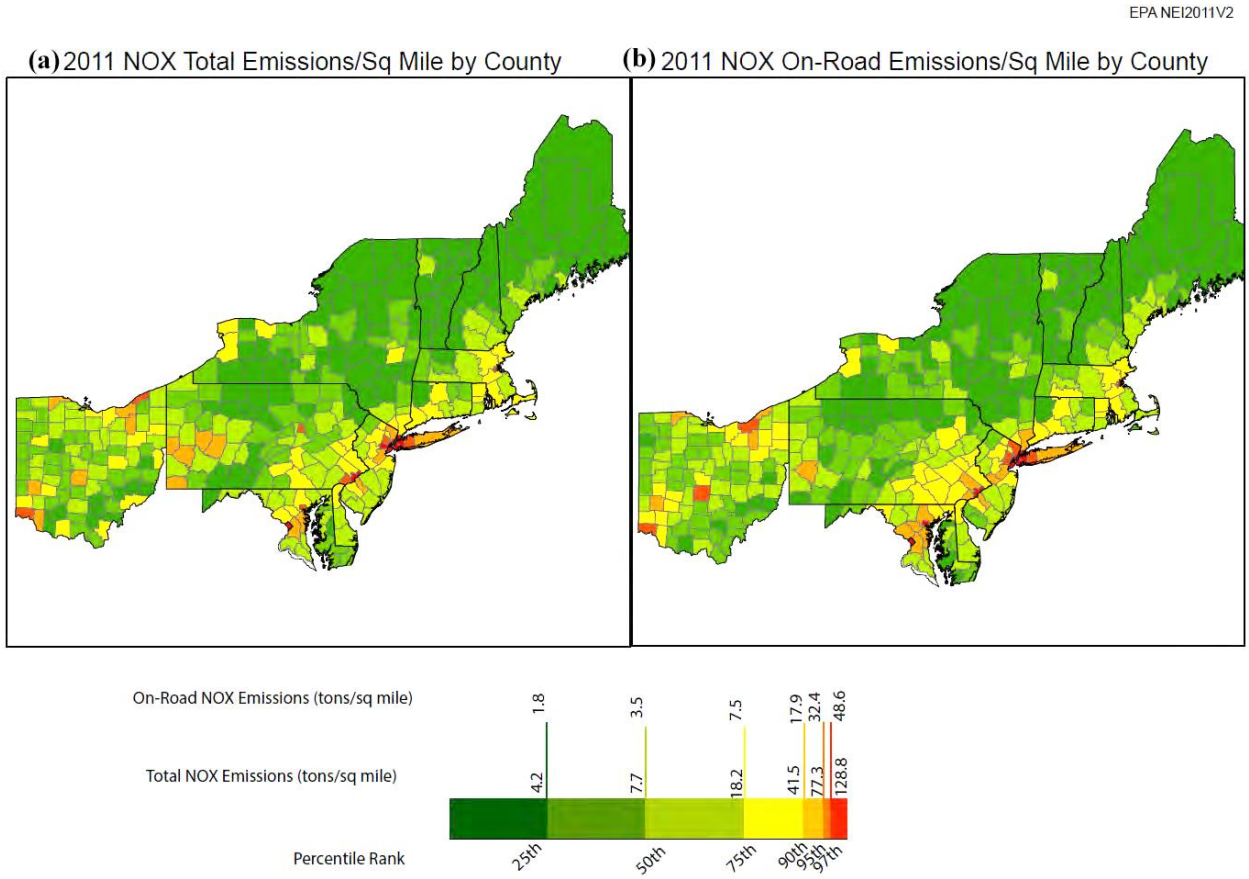


Figure 52. 2011 NEI County Percentile Map of (a) Total NOx Emissions per square mile and (b) On-road NOx Emissions per square Mile.

3.4 Similar Day Analysis

"Comparison of O_3 Concentrations on Meteorologically Similar Days (Matching Day Analysis). O_3 formation and transport are highly dependent upon meteorology. Therefore, a comparison between O_3 on meteorologically similar days with and without fire impacts could support a clear causal relationship between the fire and the monitored concentration. Both O_3 concentrations and diurnal behaviors on days with similar meteorological conditions can be useful to compare with days believed to have been influenced by fire. Since similar meteorological days are likely to have similar O_3 concentrations, significant differences in O_3 concentrations among days with similar meteorology may indicate influences from non-typical sources."

-EPA guidance: Treatment of Data Influenced by Exceptional Events

Methodology

Simply using surface winds and/or temperatures at our Connecticut monitors as a predictor for ozone can be problematic because of the land/sea interface. Inland ozone monitoring sites can observe northwest winds and very warm temperatures while the coastal sites will experience a southwest sea breeze and much cooler temperatures. Historically, temperatures over 90 ° F have been a good indicator for ozone production, but with NOx emissions on the decline, one must

look at other factors.

For example, the highest temperature recorded at Bradley Airport, 102° F, occurred on July 6, 2010. Figure 53 shows that there was a northwest wind flow for most of the State, except for the immediate coast. Back trajectory analysis generally does not have sufficient spatial resolution to show that there was southwest surface wind transport from the New York City area to the Connecticut coast, aided by the sea-breeze, where an ozone exceedance occurred. While July 6, 2010 was not a similar day to the event in question, it is an illustration how extreme heat is no longer the main factor for an ozone exceedance in Connecticut. This is a good example that shows that high surface temperatures are not always correlated with high ozone concentrations. The path of the wind and the pollutants that are carried to the monitor is often the better indicator for whether there will be elevated ozone on that day. Surface wind trajectories often will not coincide with those trajectories from higher in the atmosphere. The upper level winds have the ability to transport pollutants from great distances, even across oceans and continents, while the surface winds are more indicative of more localized transport.

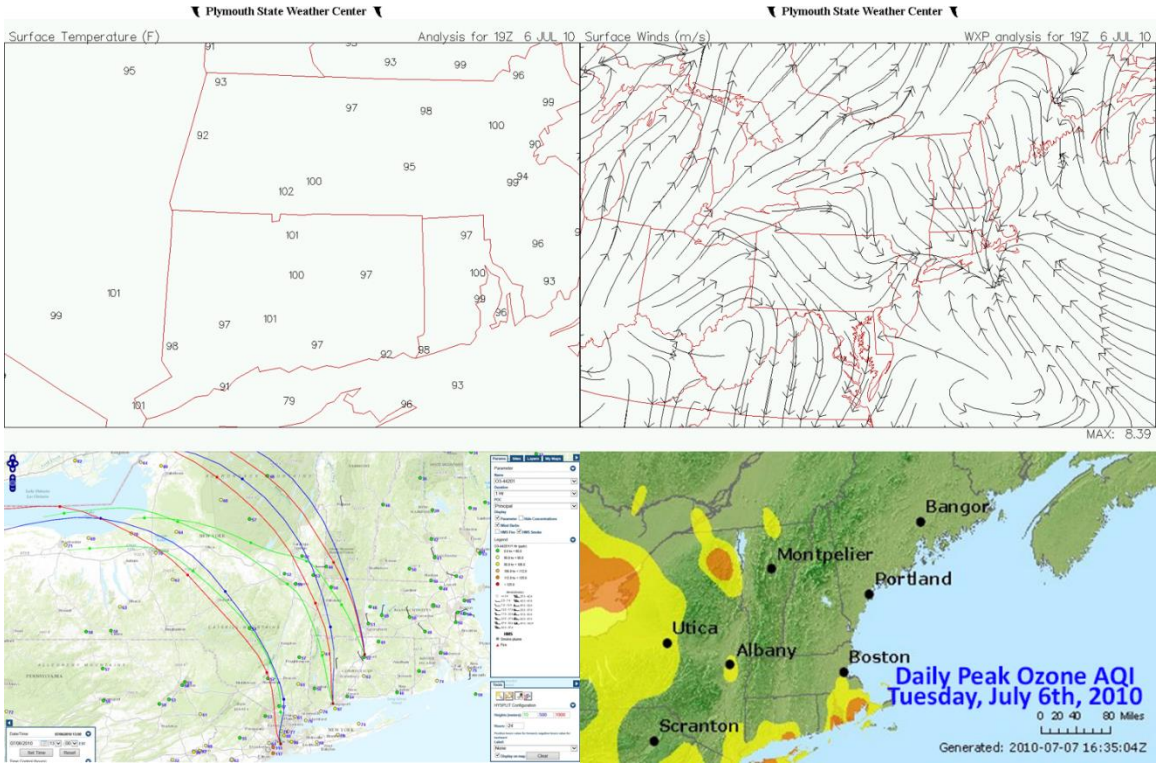


Figure 53. Temperatures and Winds around Connecticut on July 6, 2010

A more reliable variable for identifying similar days from past years is to look for similar 850mb pressure and wind patterns. The following method was used for this analysis:

- 12z (12:00 UTC= 8:00 EDT)sounding data from Albany (ALY) was analyzed from May 25th, 2016 to determine 850 mb winds;

- Obtained all ALY sounding data from April- September 2012-2016;
- Filtered wind direction for 310-330 degrees and greater than or equal to 20 knots;
- Ran 24 hour HYSPLIT back trajectories from 16z (noon) for those days that fit this criteria;
- Chose several days from each year that most closely matched 500m/1500m back-trajectories to Lake Huron region.
- Plotted 850 mb North American Regional Reanalysis (NARR) maps (if available) for those dates, to examine similarity of pressure height patterns.

We used May 25th 12z sounding data from ALY because it was the beginning of the event at our Cornwall monitor and was the closest location for sounding data. It was determined that the 850mb from ALY was from 320 degrees at 23 knots from the 12z sounding. Figure 54 is a graphic of the 12z sounding from that day. The windspeed/ wind direction flags on the right vertical bar shows northwest wind flow from all levels above the surface.

An 850 mb height map (Figure 55) was generated for May 25th to create a reference pattern for comparison. This figure shows that an 850 mb ridgeline extended north to just west of Hudson's Bay in Canada. Wit this pattern, source winds to Connecticut would be expected to originate in eastern Canada, which is generally air that is low in ozone precursors, barring any wildfires in the region. Figure 56 are the HYSPLIT trajectories for that day that show the 500 and 1500 meter back trajectories originating near lake Huron. Figures 57-61 represent closely matching 850 mb examples from 2012-2016 with the accompanying AQI maps for those days. In every one of those cases, the ozone levels were in the good to moderate range.

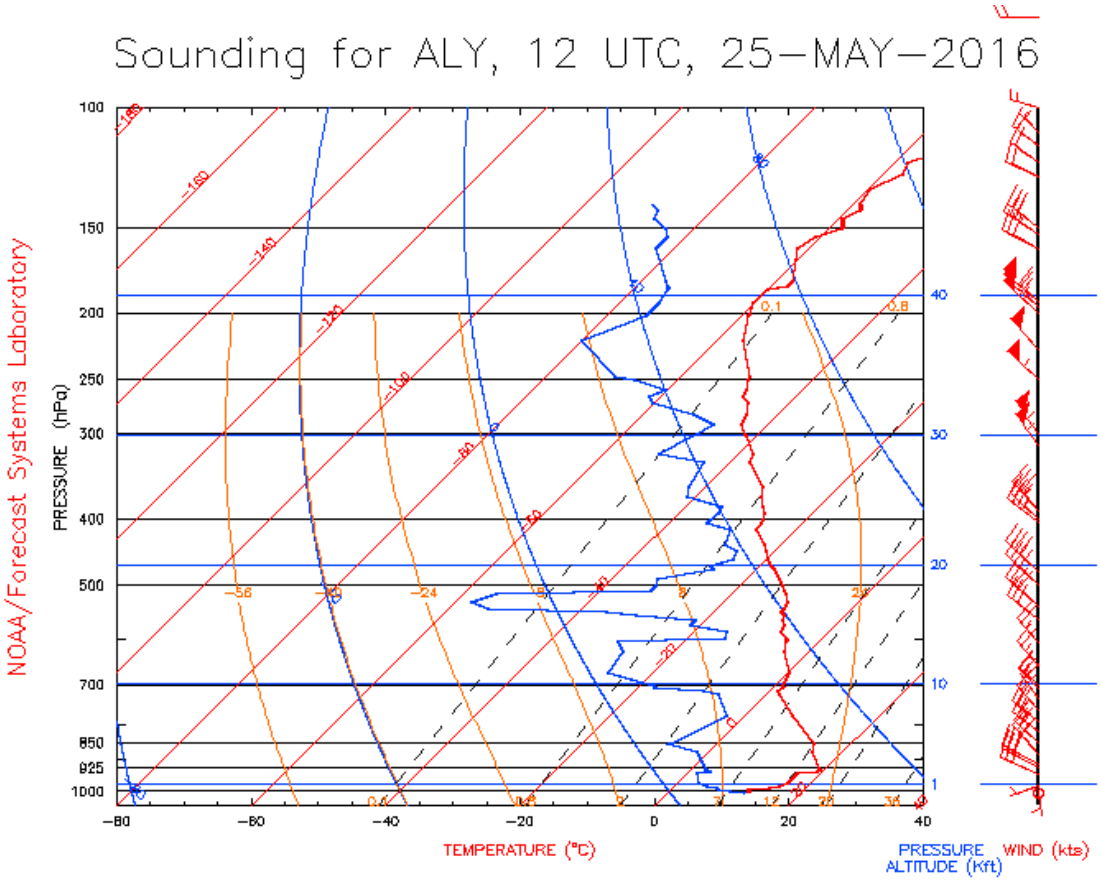


Figure 54. 12z ALY Sounding from May 25th, 2016

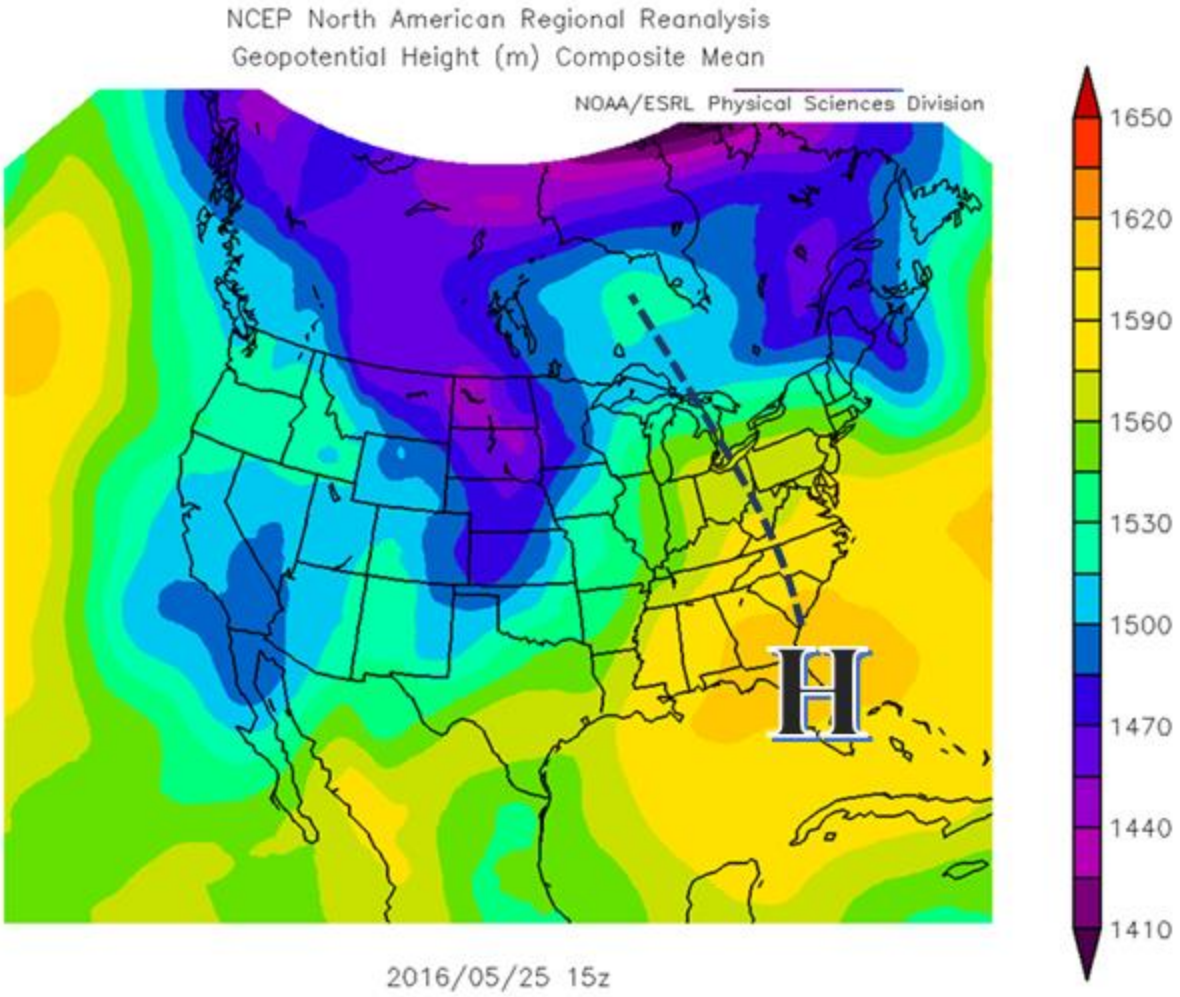


Figure 55. 850 mb Reference Pressure Pattern for May 25th, 2016

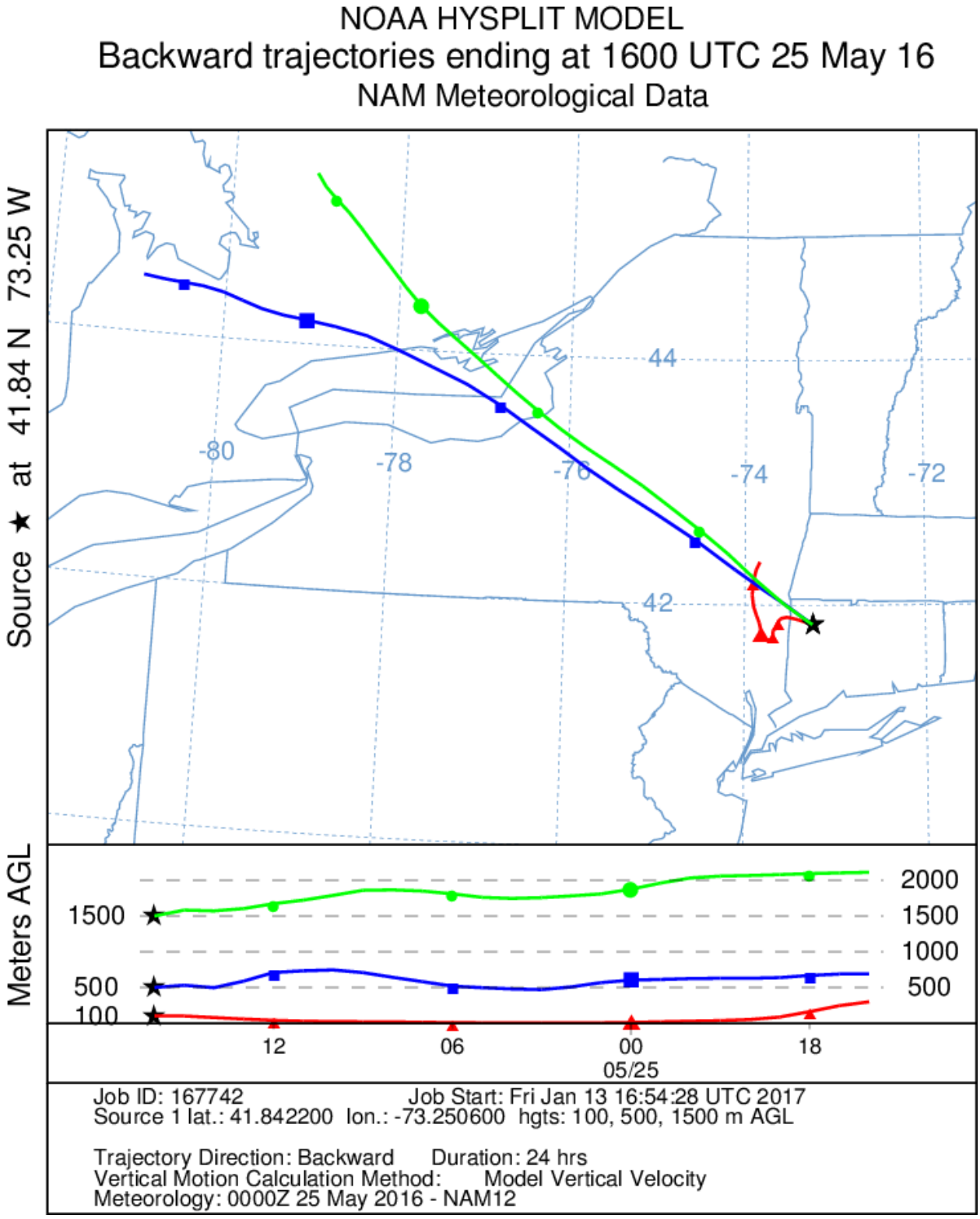


Figure 56. HYSPLIT Reference Trajectories from May 25th, 2016

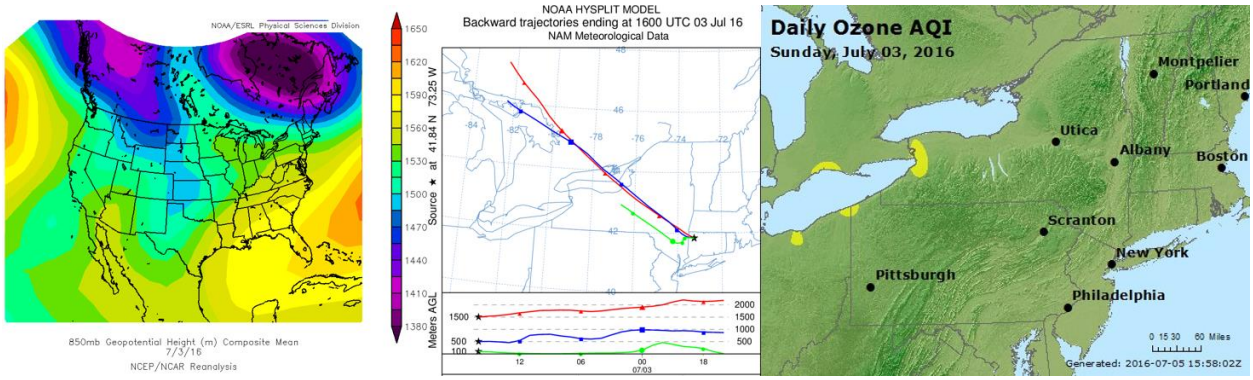


Figure 57. Matching 850 mb Pressure Pattern with Back Trajectories July 3, 2016

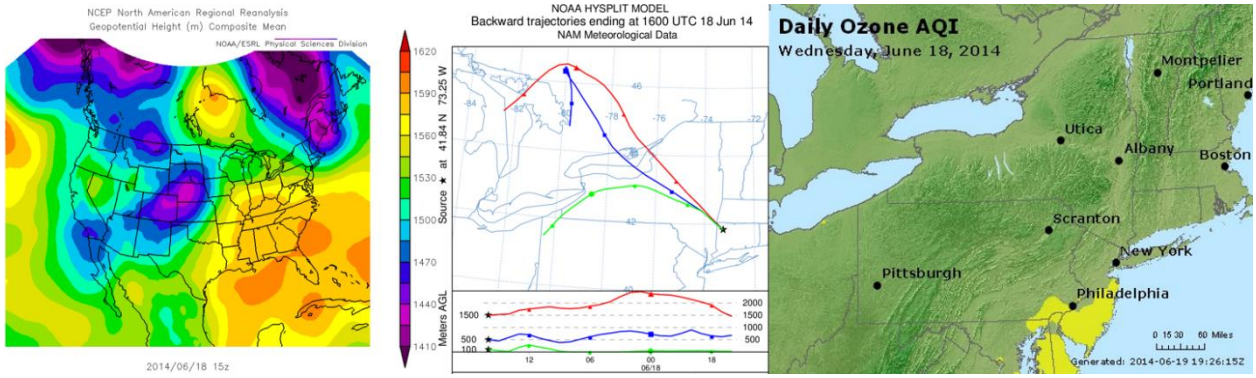


Figure 58. Matching 850 mb Pressure Pattern with Back Trajectories June 18, 2014.

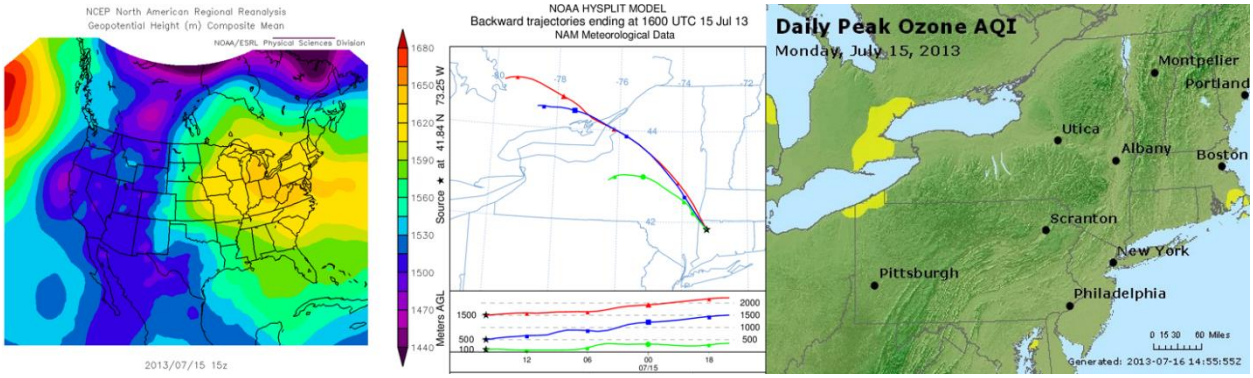


Figure 59. Matching 850 mb Pressure Pattern with Back Trajectories July 15, 2013.

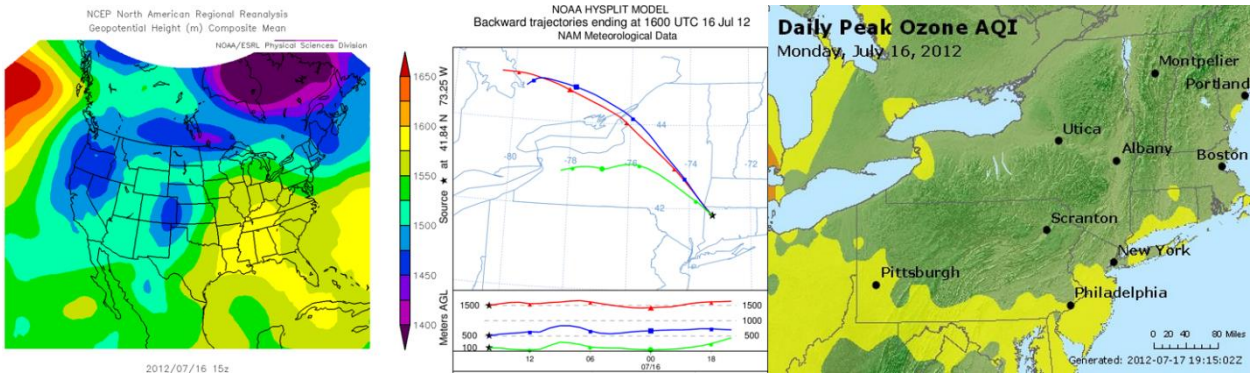


Figure 60. Matching 850 mb Pressure Pattern with Back Trajectories July 16, 2012.

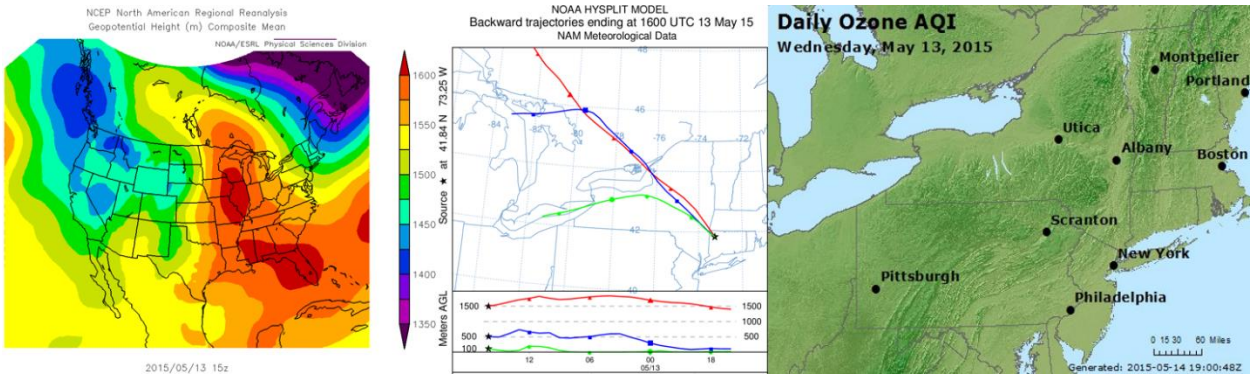


Figure 61. Matching 850 mb Pressure Pattern with Back Trajectories May 13, 2015

3.5 HYSPLIT Trajectory Analysis

"Air agencies can produce HYSPLIT trajectories for various combinations of time, locations and plume rise. HYSPLIT back-trajectories generated for specific monitor locations for days of high O_3 concentrations illustrate the potential source region for the air parcel that affected the monitor on the day of the high concentration and provide a useful tool for identifying meteorological patterns associated with monitored exceedances. Forward-trajectories from specific wildfire events to specific monitors can also be used to indicate potential receptors."

-EPA guidance: Treatment of Data Influenced by Exceptional Events

<u>Forward Trajectory Example</u>

Although the actual ozone event over Connecticut occurred after May 24th, 2016, the conditions producing the ozone were taking place several days before over the Mid-western States. Satellite images showed that the wildfire plume had been traversing Great Lakes' States several days after the fire had started, on May 4th. It wasn't until after May 20th that the weather condition began trapping the plume in the boundary layer over that region. Because of this, it is most useful to begin a forward trajectory analysis from Fort McMurray beginning on May 18th , 2016.

The model of choice was the North American Regional Reanalysis (NARR) model, which uses the very high resolution NCEP Eta Model (32km/45 layer), together with the Regional Data Assimilation System (RDAS) which, significantly, assimilates precipitation along with other variables. The 120-hour May 18th forward trajectory was chosen as a scenario where particles and VOCs released at 1000-2000 meters above ground level could theoretically travel from the Fort McMurray, Alberta plume and pass over Michigan after May 21st (figure 62). The VIIRS satellite image on May 18th (figure 63) shows the parts of the plume heading east over Hudson's

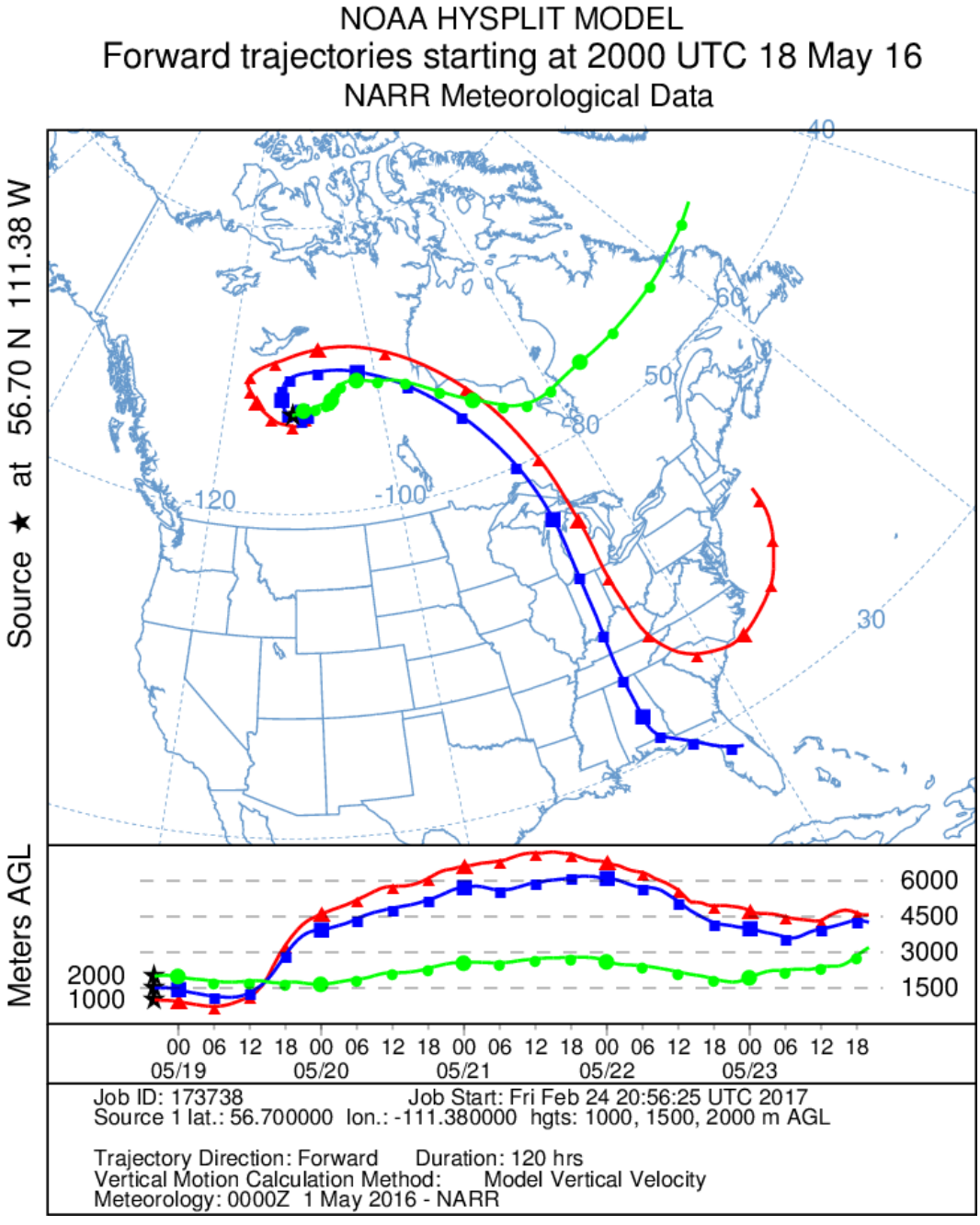


Figure 62. 120-hour HYSPLIT Forward Trajectories from Fort McMurray May 18-23, 2016

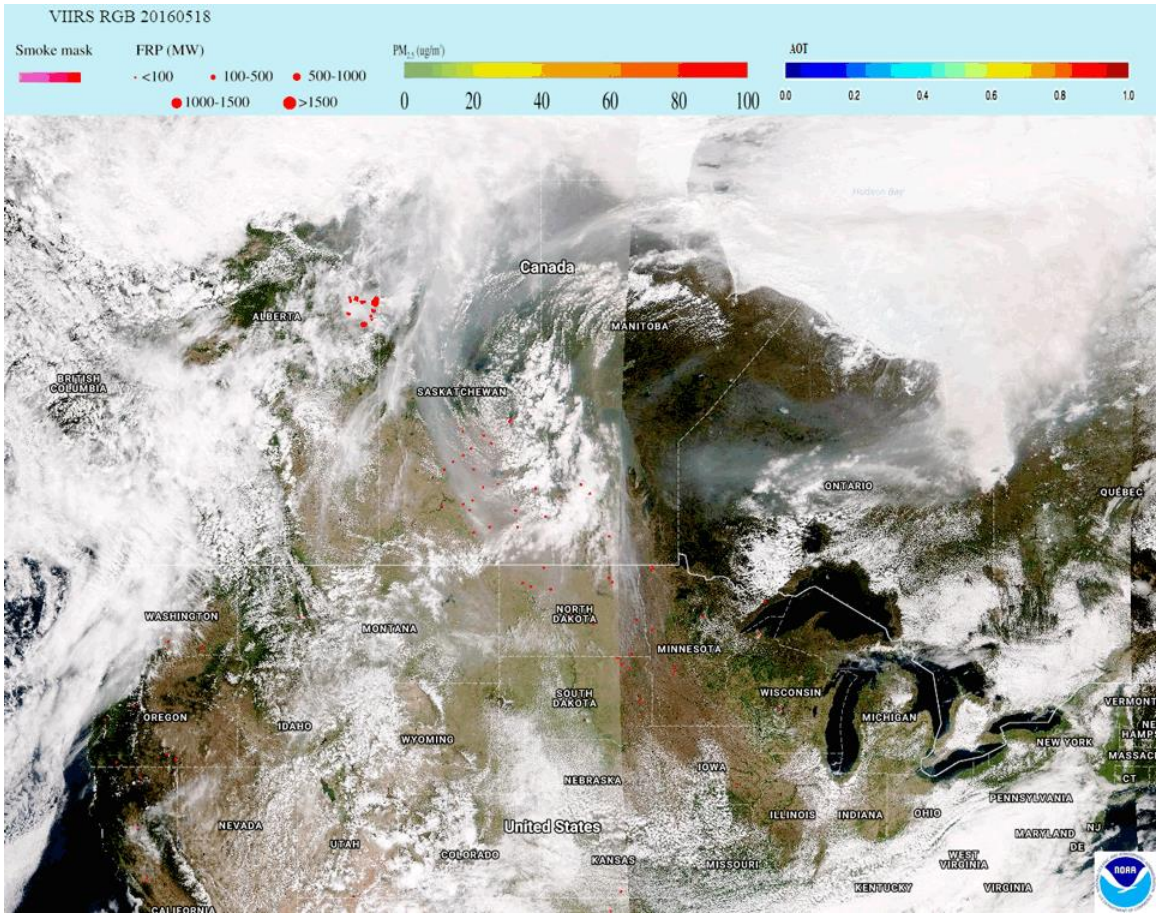


Figure 63. VIIRS Satellite Image from May 18, 2016

Bay, on its way to Michigan a few days later. This is significant, since on May 21st, a high pressure system was camped over the Mid-western States (Figure 64), which would trap the pollutants and later lead to the production of ozone over the Great Lakes' States.

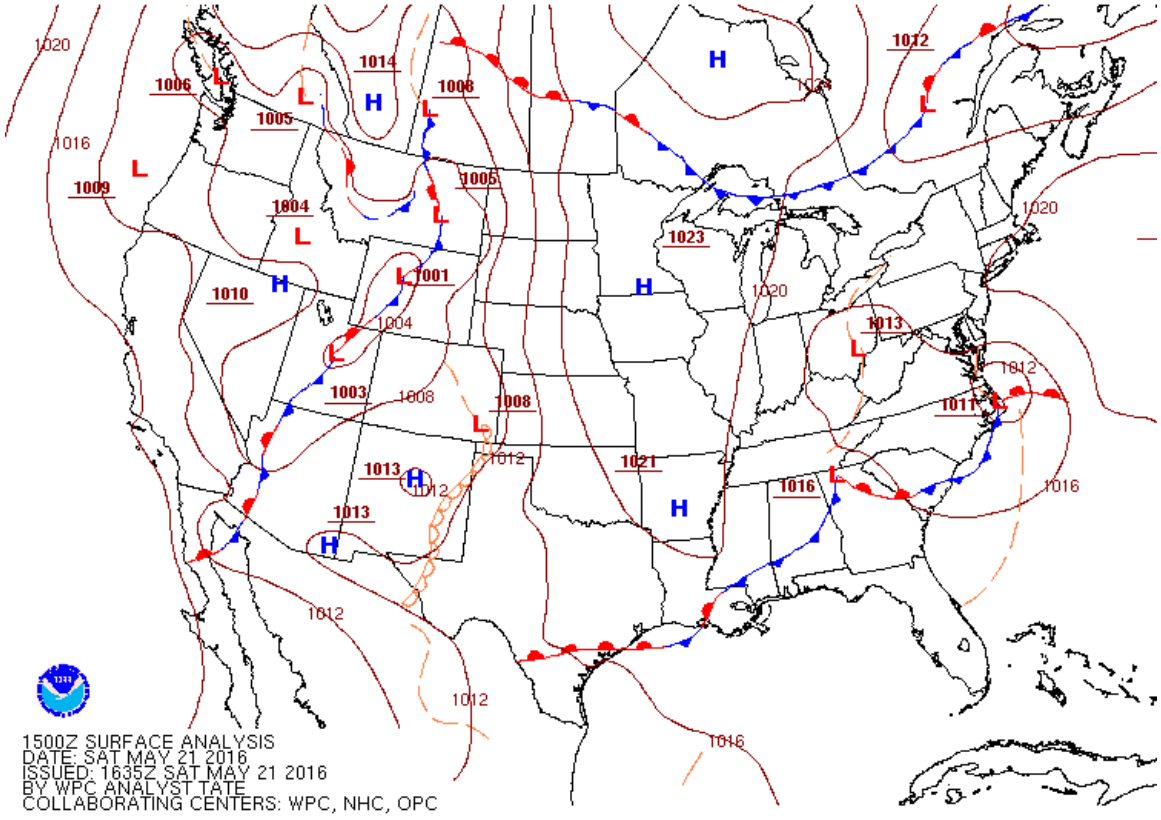


Figure 64. Surface Weather Analysis from May 21, 2016

Back Trajectory Analysis

Ozone began building up around the Great Lakes' on May 23rd and peaked on May 24th (Figure 65) before moving east to Connecticut. The forward trajectories and plume analysis clearly showed that the smoke plume settled over this area for several days. Back trajectory analysis for this area confirms the source of the ozone precursors (Figure 66). By May 24th, the wind had turned to the southwest, which allowed the VOC's from the smoke to mix with the Urban NOx sources to the south and rapidly produce ozone on that day. Figure 67 shows a matrix of back trajectories ending at 1000m over western New England for both May 25th and May 26th. The source region is clearly the Michigan area on both days, but they shift southward on May 26th. The winds also turned southwestward over Long Island Sound (LIS) on May 26th, which provides some enhancement from the New York City area.

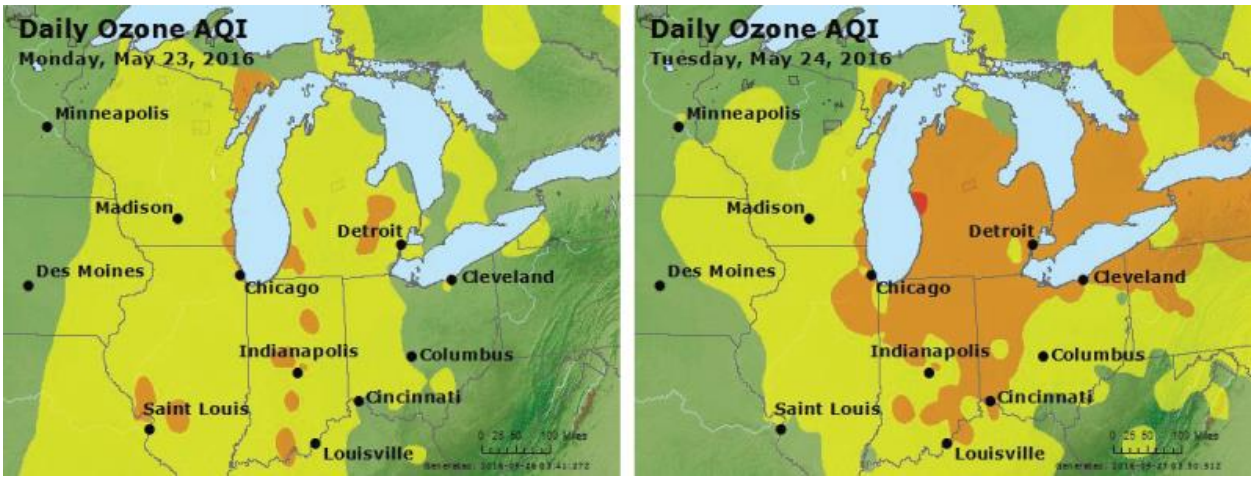


Figure 65. Ozone AQI Maps for May 23-24, 2016.

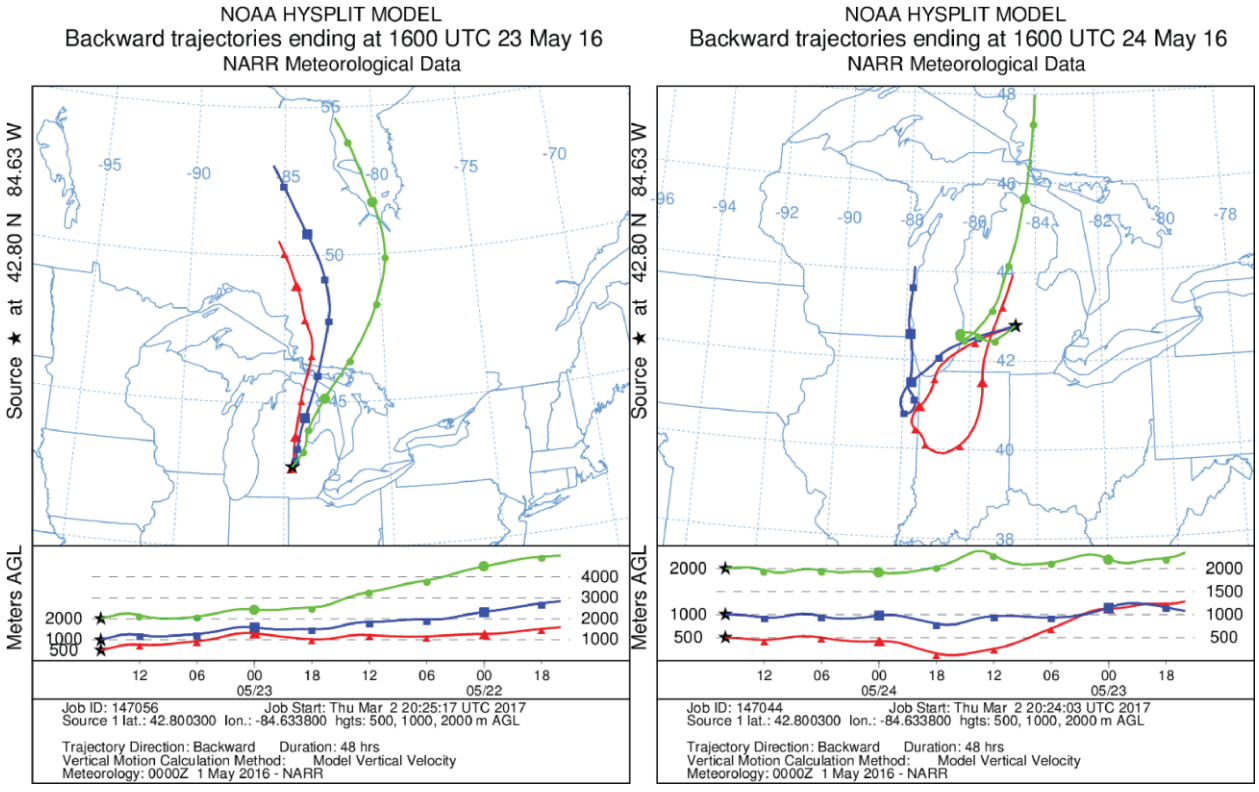


Figure 66. HYSPLIT Back Trajectories from Michigan, May 23- 24, 2016

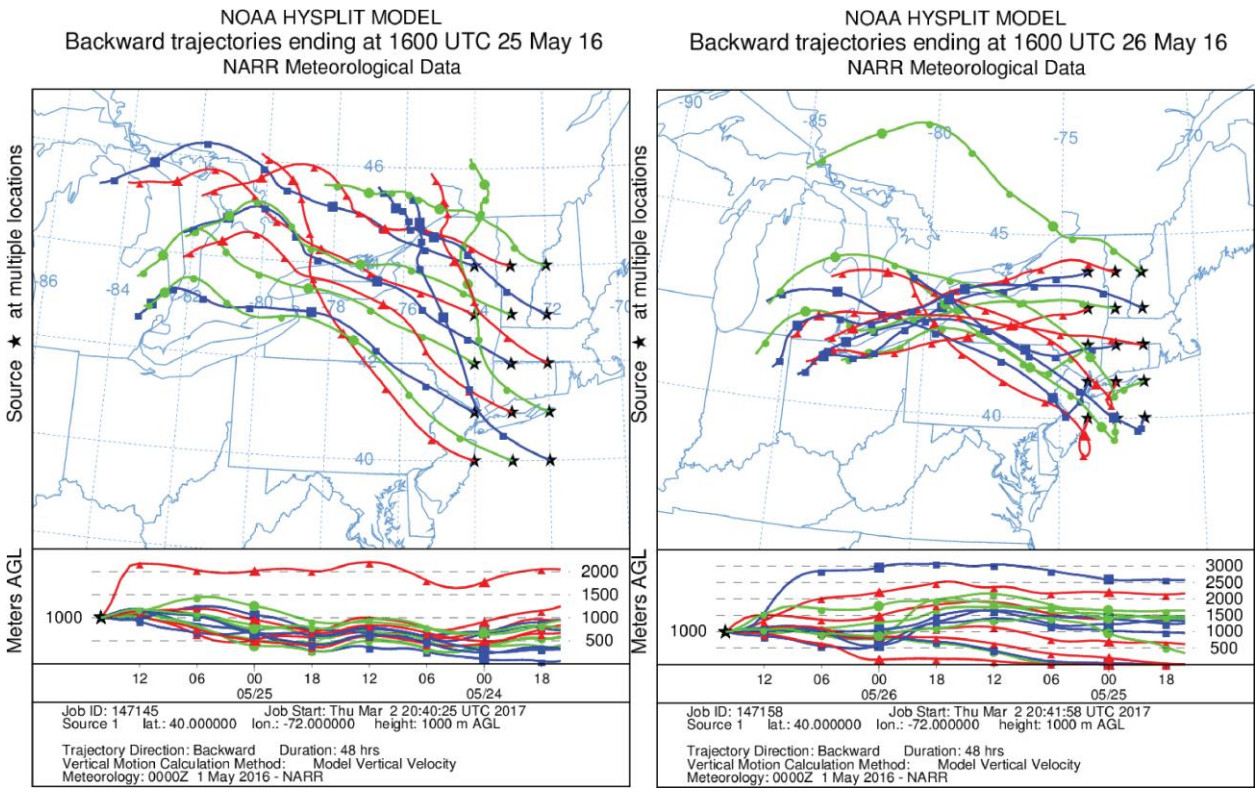


Figure 67. HYSPLIT Back Trajectories from New England

Westport Connecticut surface winds often blow from the southwest during the summer due to the sea breeze that develops during the late morning and afternoon. Because of this, it is important to show that even with clean air being transported aloft from the northwest, the surface winds can turn southwest during the afternoon. Southwest winds are often associated with polluted air being transported northeastward from the I-95 corridor into Connecticut. The previous figure of the New Haven Ceilometer backscatter aerosol levels showed the smoke plume arriving during the early morning on May 25, 2016. The aerosol level reached a height of 3000 meters and a layer of high concentrations was evident at about 500 meters. Accordingly, the ending elevations for the Westport back trajectories were set at 500 and 3000 meters to determine if the paths crossed the Fort McMurray wildfire plume during its journey.

Figure 68 shows the 168-hour back trajectories ending at 8:00 am LDT on May 25, 2016. The 3000 meter trajectory has its start in far northern Canada, and the 500 meter level begins over hudson's Bay. These trajectories would likely pass through a very clean air mass, in the absence of wildfires. Two hours later (10:00am LDT), these back trajectories have already shifted westward (figure 69). It is observed that both trajectories are approaching the Fort McMurray wildfire area (yellow star) and could have easily traveled through the plume on these paths. Figure 70 shows the noon LDT 3000 meter back trajectory passing right over the wildfire area. This direct path would bring the pollutants from the wildfire right over Westport Connecticut over the course of six days. Finally, Figure 71 shows the fire locations with the aerosol plume on May 20th with the HYSPLIT trajectory paths from May 19-25th. This clearly shows that the plume was present and the the 3000 meter trajectory would have brought its plume to Westport.

It is also important to look at the low level trajectory, ending at 100 meters above Westport, to determine whether local sources would have had much effect on the air quality that day. Initially, the low level winds started out from the northwest, but as the day progressed, the winds turned southwest, likely due to the sea breeze. At 6:00 am LDT, figure 72 shows the winds coming from the northeast, which is normally a source of clean air at the surface. Figure 73 shows the winds coming from a more northerly direction ending at 10:00 am LDT and by 4:00 pm LDT (figure 74), the ending trajectory does shows the wind traveling along the coast, however by this time, there would have been little time for the I-95 corridor to provide significant ozone enhancement.

On May 26th, the synoptic weather pattern was changing, as a cold front was moving south over New England, turning the surface winds to the southwest. Figure 75 reflects this in the low level trajectory turning to the southest, however it is still not a classic I-95 corridor set up providing a long fetch of pollutants along the corridor into Connecticut. This patterns appears short-lived, however, as the 4:00 pm LDT ending trajectory (figure 76) already has the wind turning southerly and mixing with maritime air. Westport monitored it's highest ozone concentration of the event on May 26th, but the weather pattern and limited transport over the I-95 corridor does not explain the concentration monitored there or at the other monitors in Connecticut. Back trajectory analysis strongly suggests that the Fort McMurray wildfire was the main driver behind these ozone exceedances.

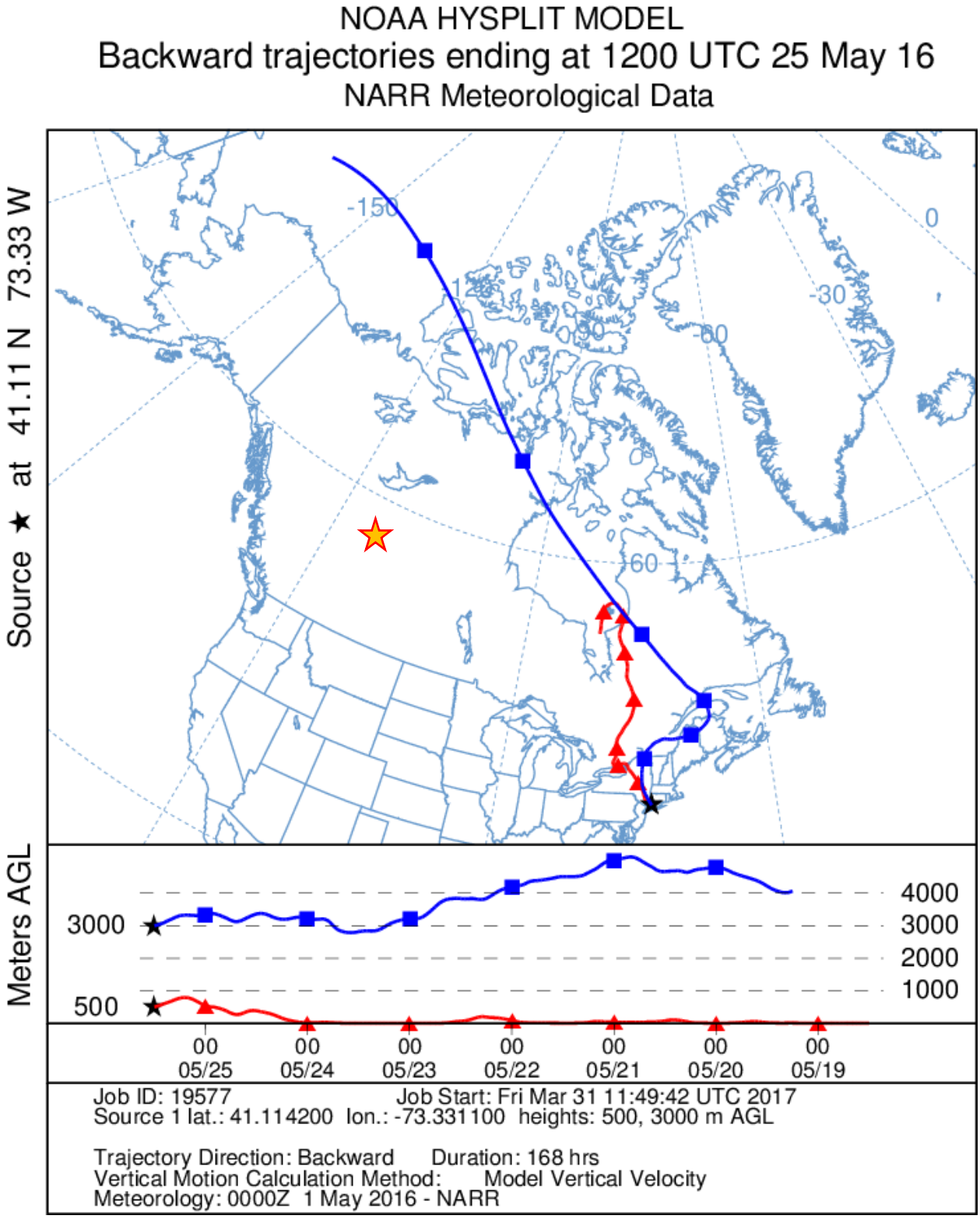


Figure 68. May 25, 2016 12 UTC Back Trajectories from Westport CT.

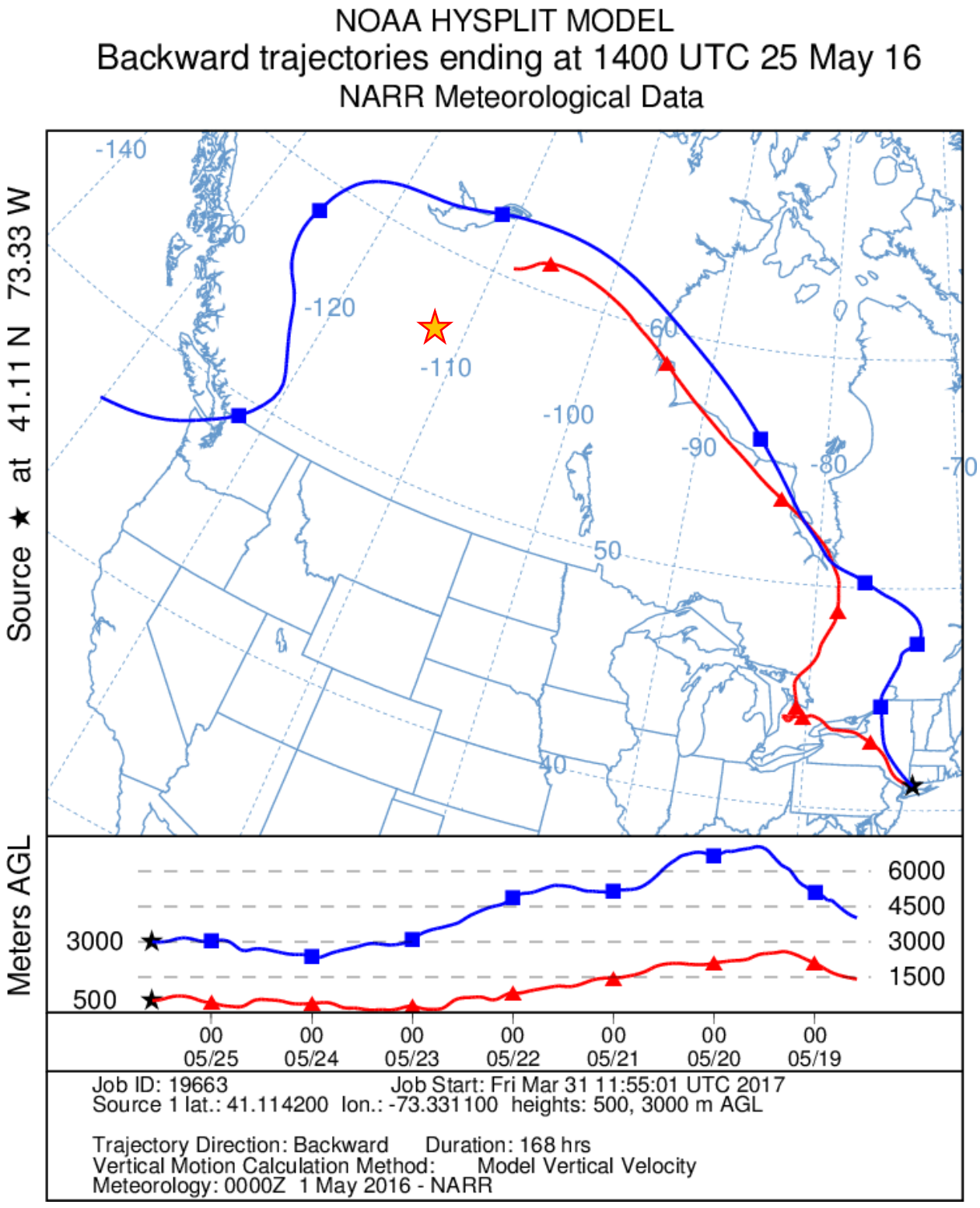


Figure 69. May 25, 2016 14UTC Back Trajectories from Westport CT.

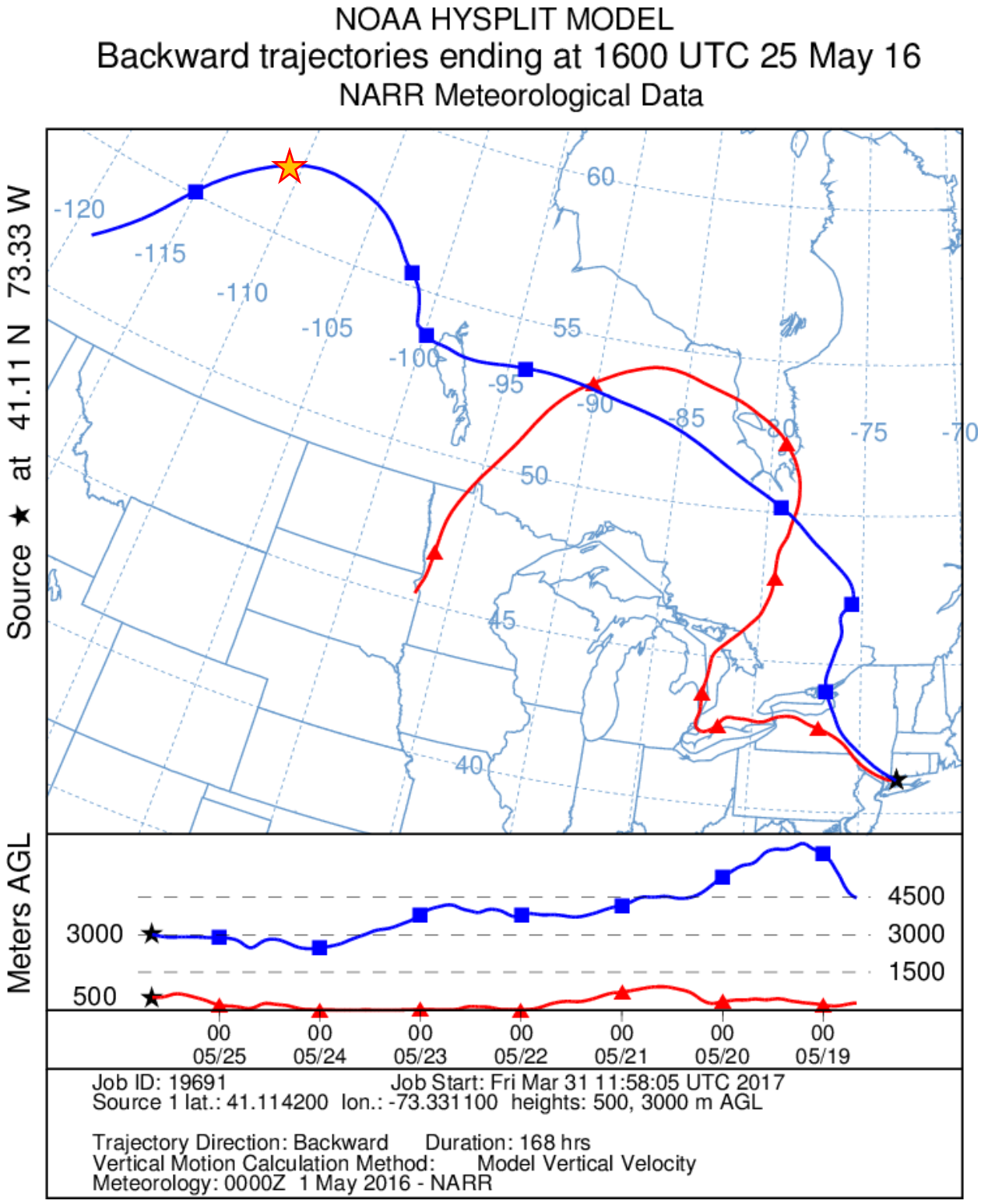


Figure 70. May 25, 2016 16UTC Back Trajectories from Westport CT.

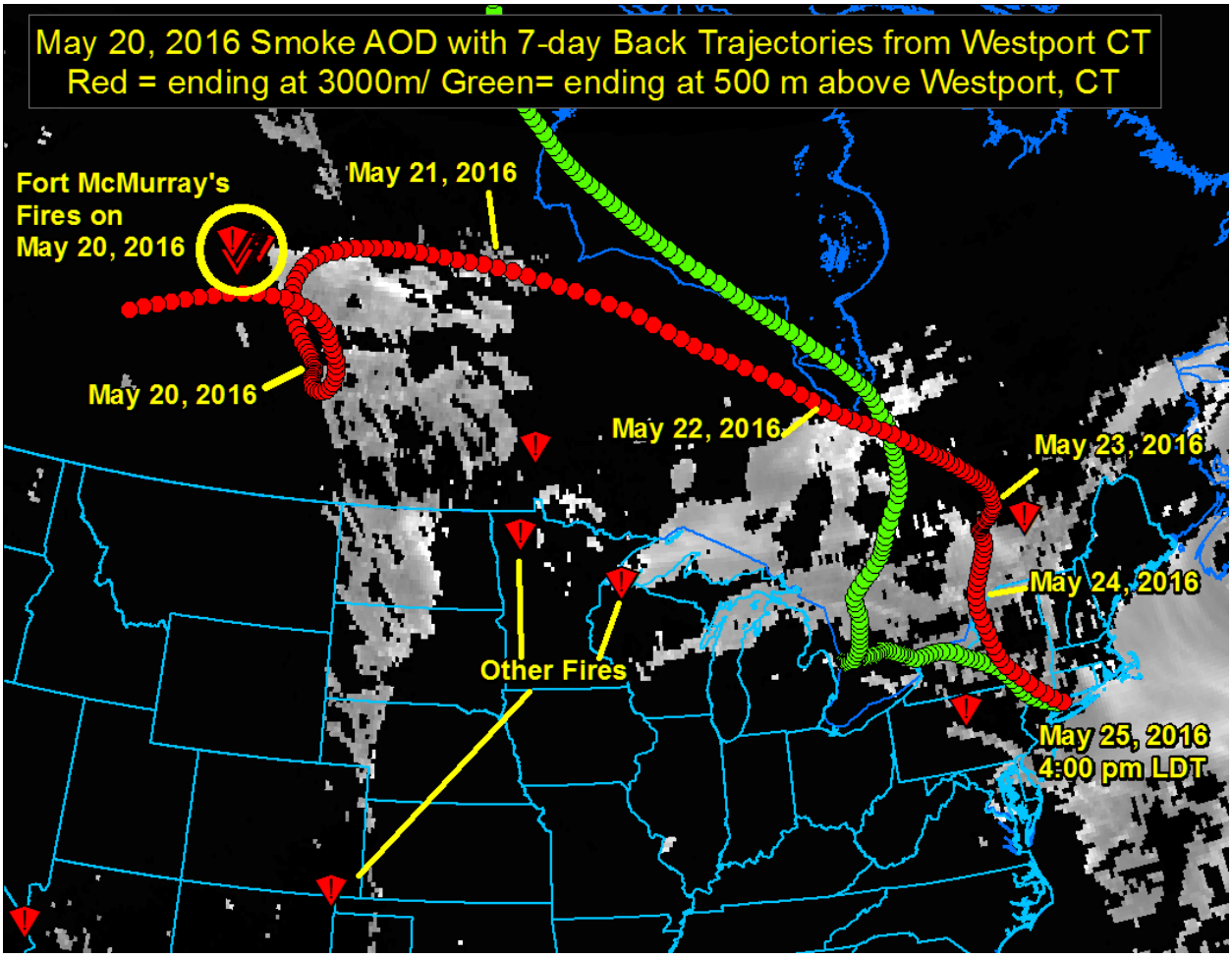


Figure 71. Hourly Back Trajectories ending at 4:00 pm LDT on May 25th with Fire Locations and Satellite AOD from May 20th, showing Path of Transport of Smoke Plume Pollutanst to Westport CT.

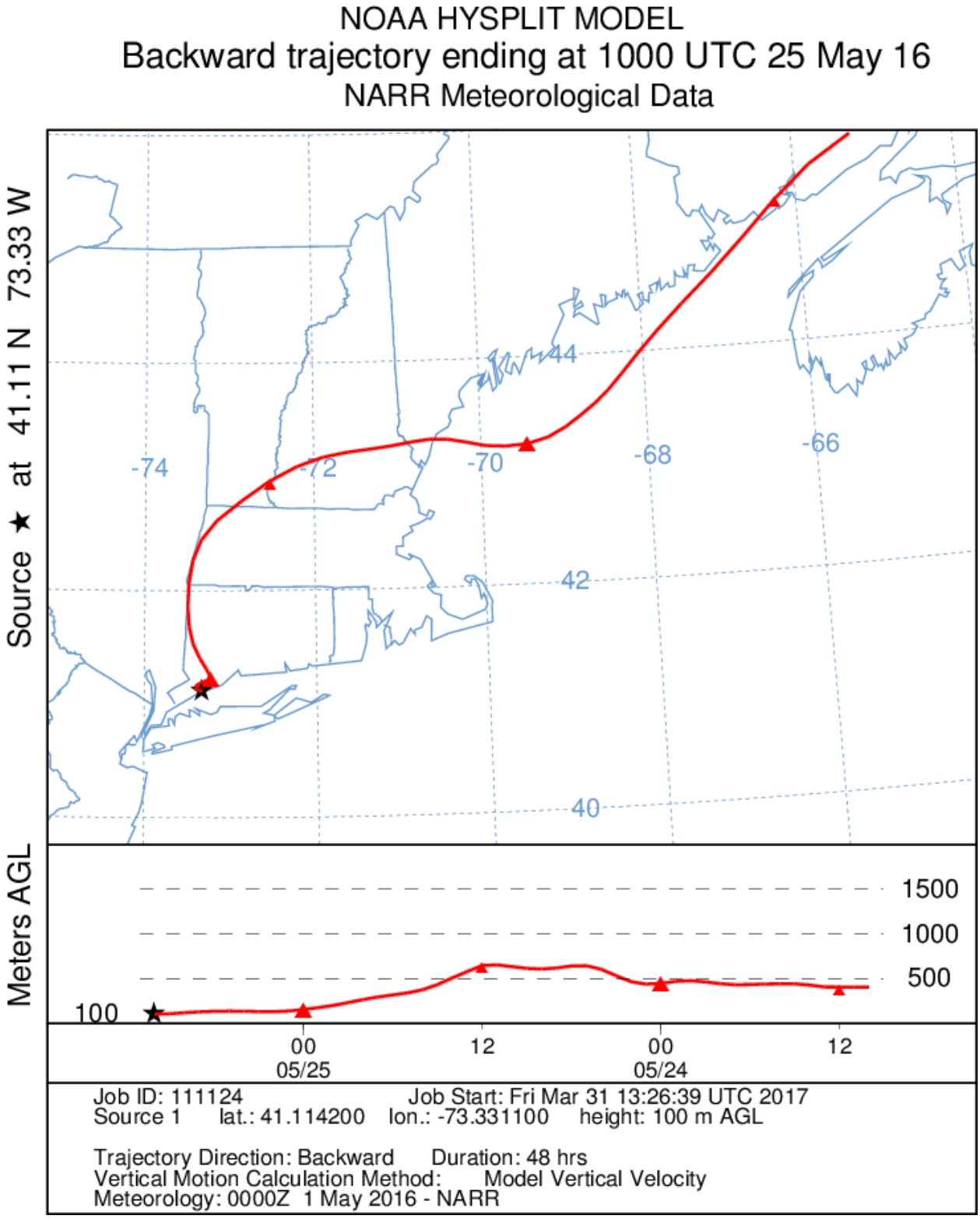


Figure 72. 100 meter Back Trajectory from Westport Connecticut ending at 6:00 am LDT May 25, 2016.

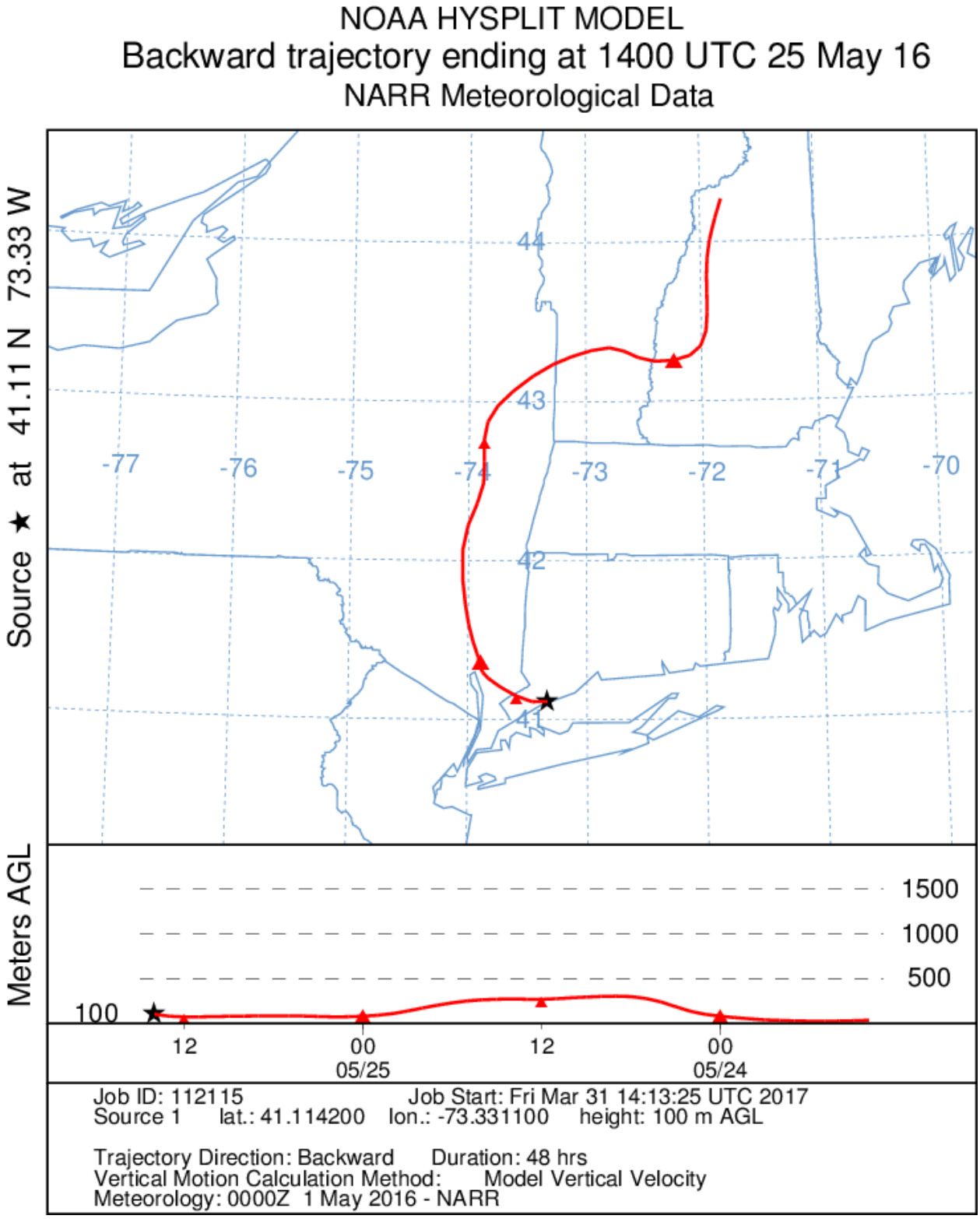


Figure 73. 100 meter Back Trajectory from Westport Connecticut ending at 10:00 am LDT May 25, 2016.

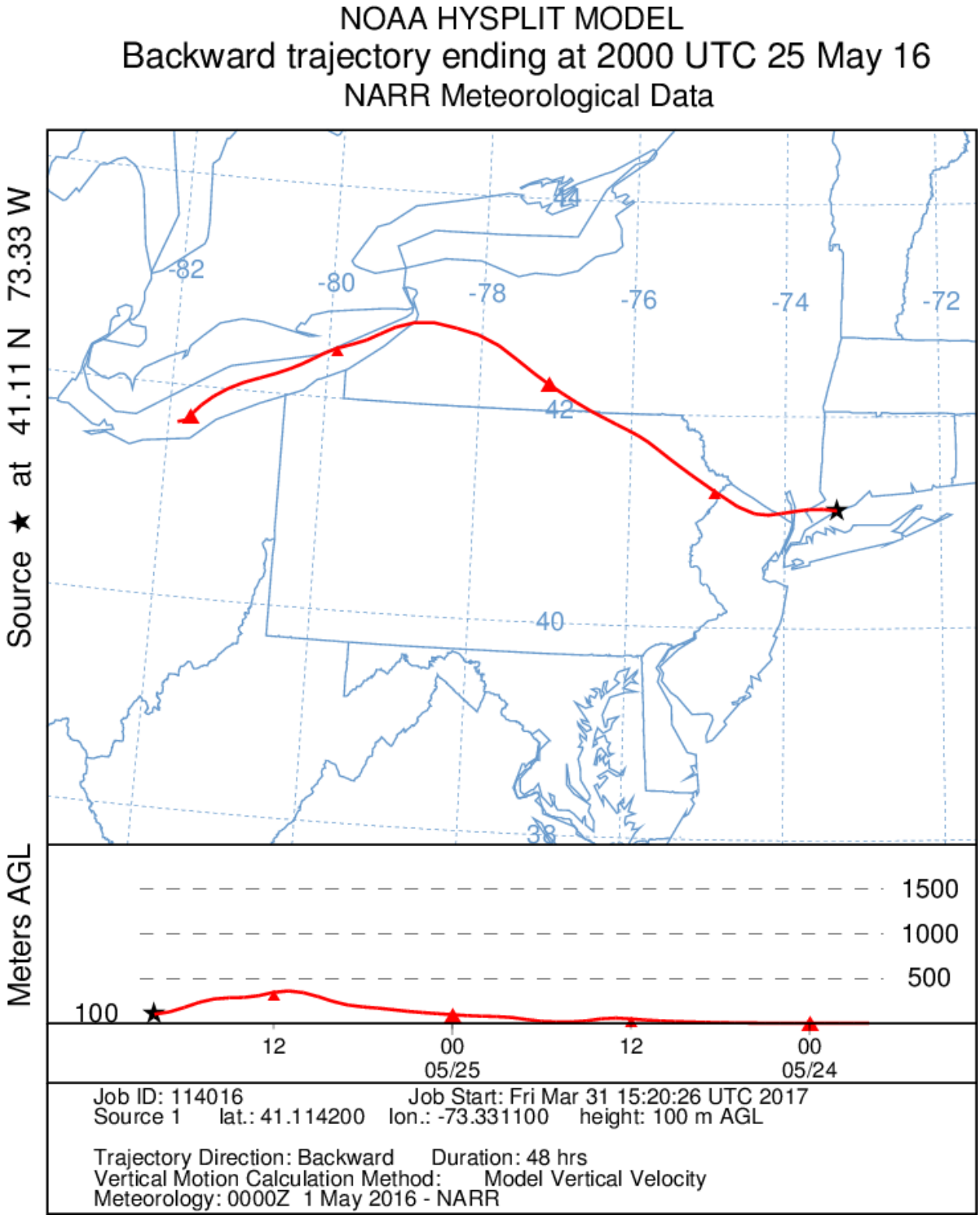


Figure 74. 100 meter Back Trajectory from Westport Connecticut ending at 4:00pm LDT, May 25, 2016.

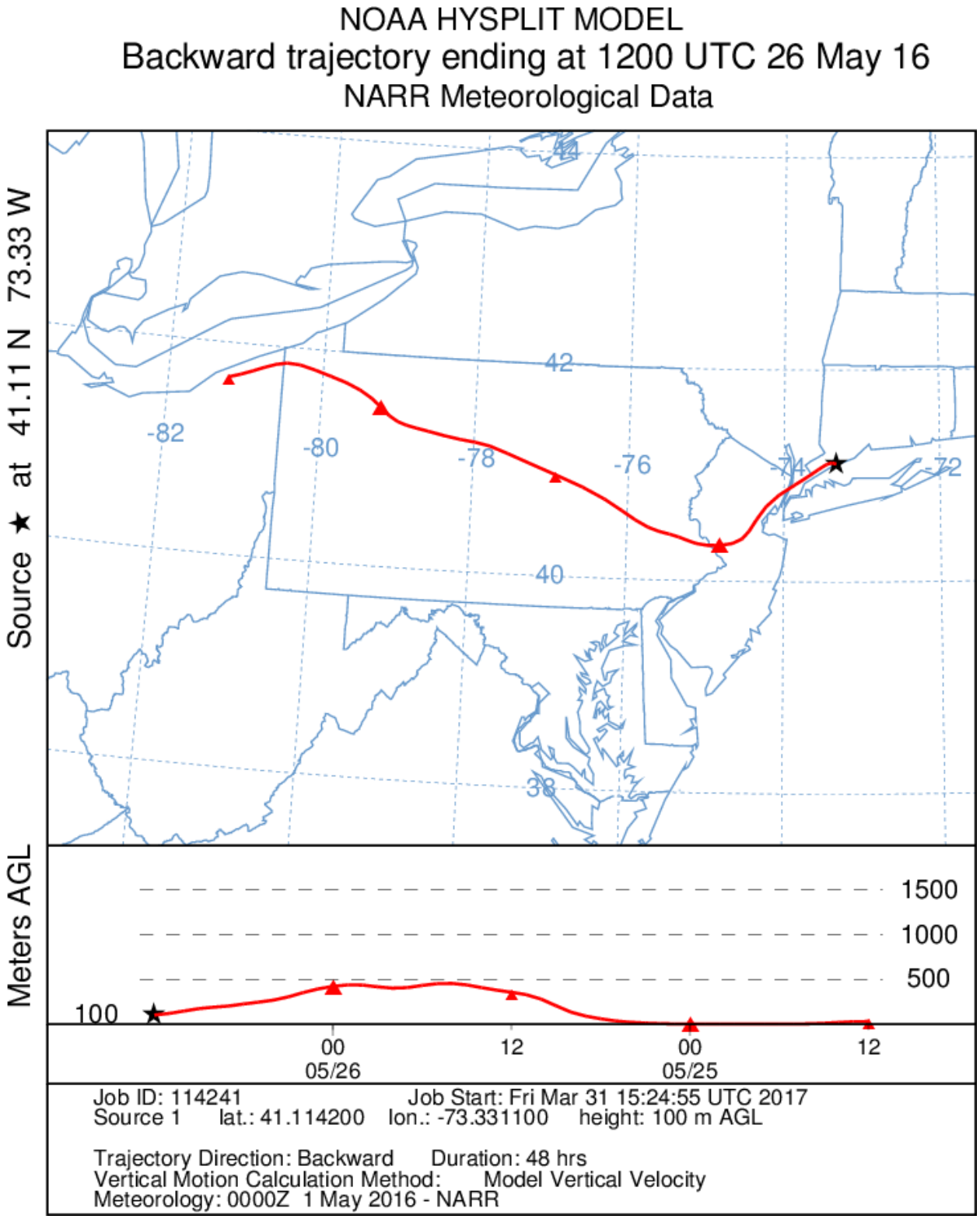


Figure 75. 100 meter Back Trajectory from Westport Connecticut ending at 8:00 am LDT, May 26, 2016.

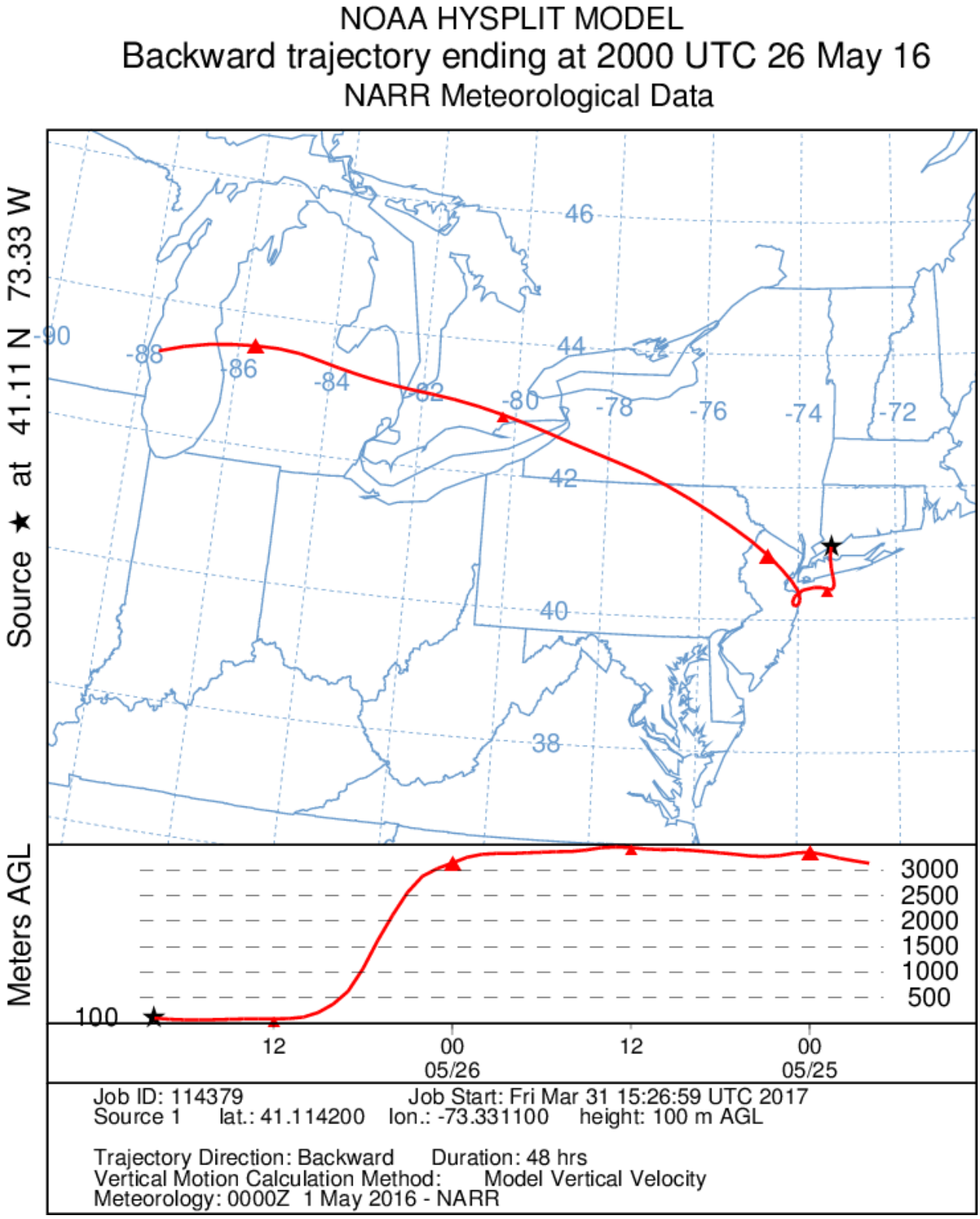


Figure 76. 100 meter Back Trajectory from Westport Connecticut ending at 4:00 pm LDT, May 26, 2016.

3.6 CSAPR NOx Source Emissions

Although point source EGUs have traditionally played a major role during ozone events on the East Coast, mobile source NOx emissions are becoming the major player as more EGUs adopt much needed controls. Neverless, it is still observed that during many summer events, more, and often dirtier, EGUs come online to fulfill the high electric demand days (HEDD). EPA monitors the real-time emissions from the CSAPR source facilities and the following figures (77-79) show the CSAPR 2016 daily NOx emissions for our closest upwind States; Pennsylvania, New York and New Jersey. Also plotted, on the right hand axis, are the number of Connecticut monitors that exceeded the 70 ppb NAAQS on that day. This gives a good indication of the extent of the ozone exceedances on any given day. Since the May 25-26th ozone event had the most monitored daily exceedances of the summer, it is worth noting that the NOx emission peaks that were recorded were well below the events later in the season. This lends creedence to the weight of evidence that the wildfire plume was the major contributor to the ozone levels for those days.

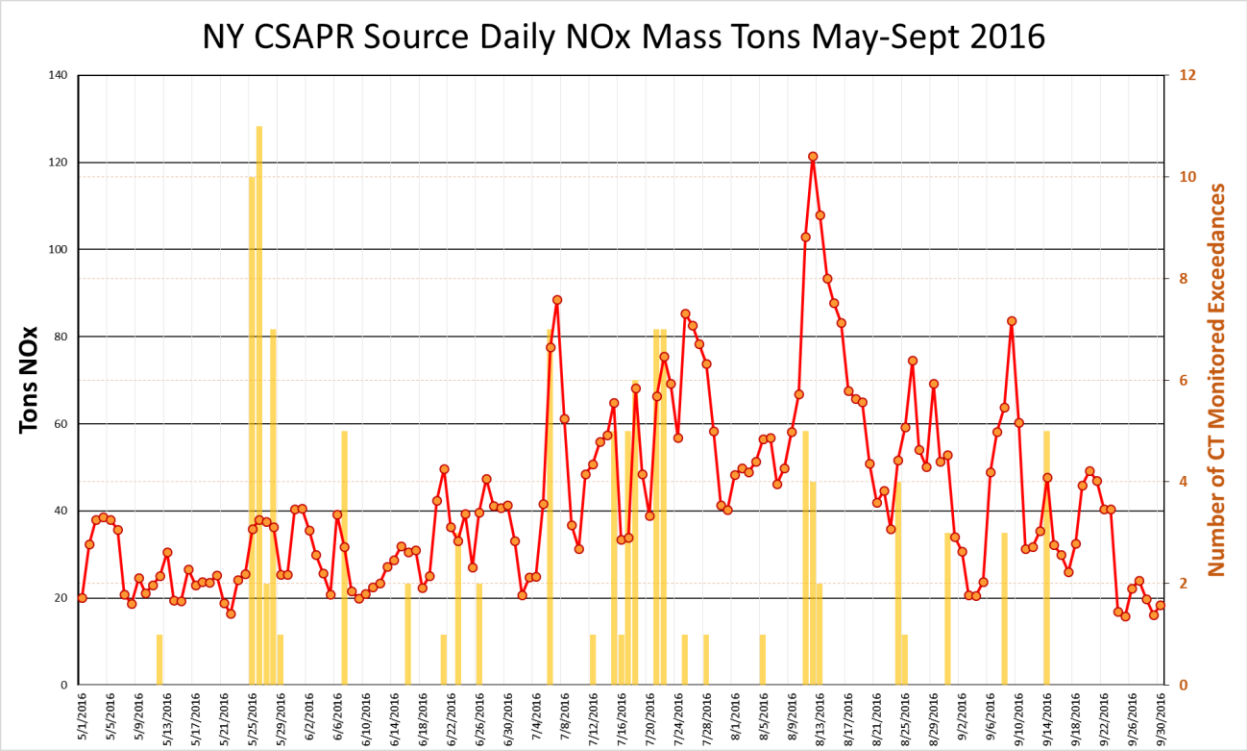


Figure 77. New York CSAPR Source 2016 Daily NOx Emissions

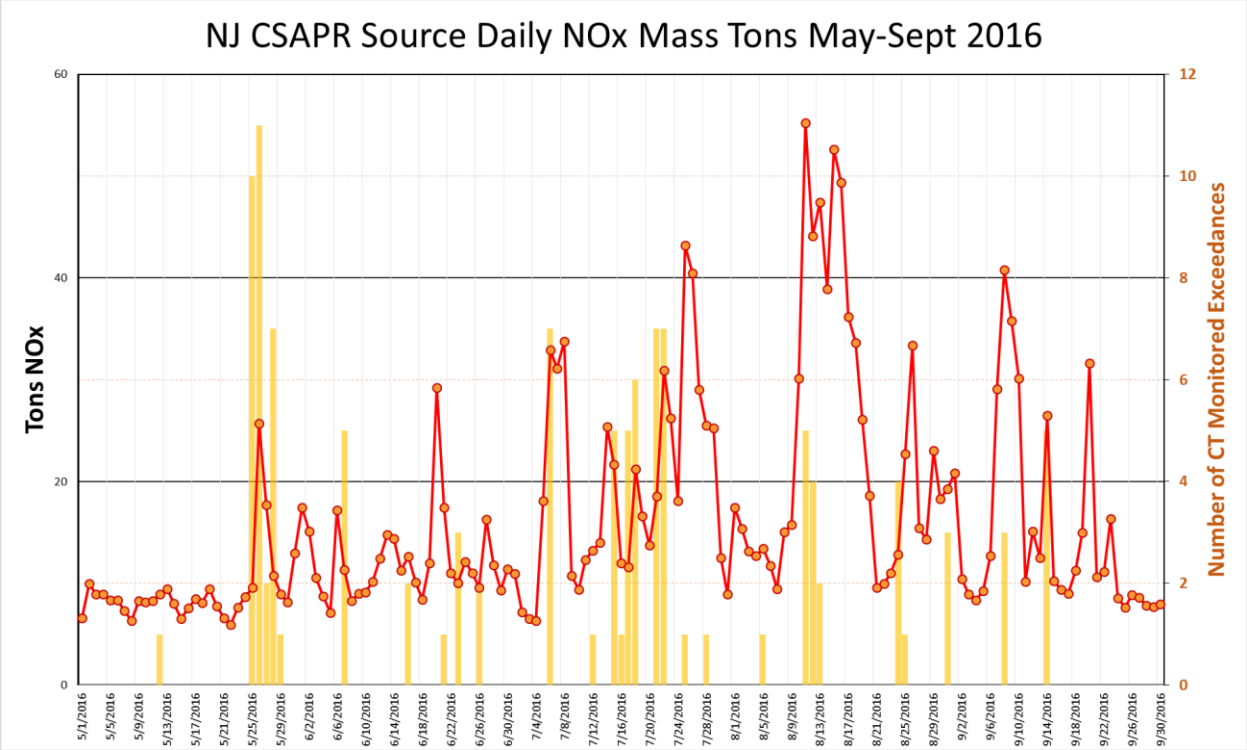


Figure 78. Pennsylvania CSAPR Source 2016 Daily NOx Emissions

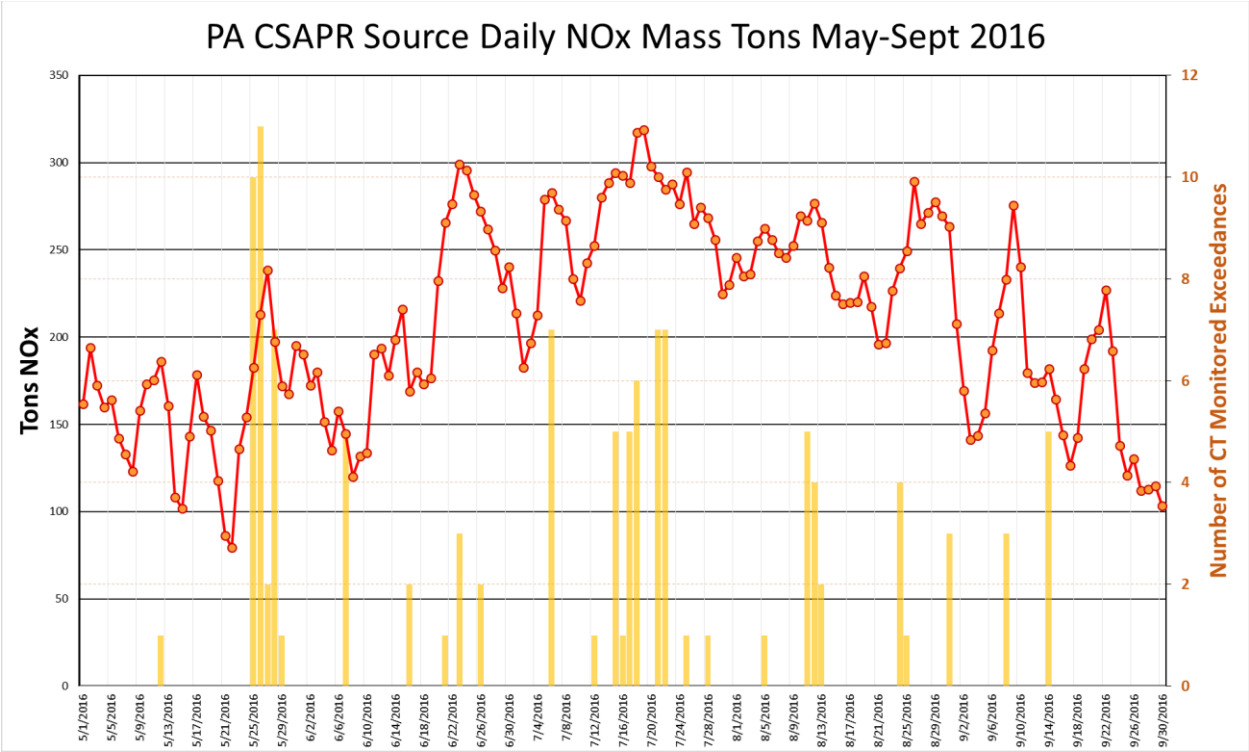


Figure 79. New Jersey CSAPR Source 2016 Daily NOx Emissions

3.7 NOAA CMAQ Model Predictions

CTDEEP air quality forecasters have relied upon the operational NOAA CMAQ ozone model for daily air quality forecasting. The NOAA CMAQ model v.4.6 ('the model') has used wildfire and dust emissions and suppression of soil emissions from snow/ice covered terrain since summer 2014, however, gaseous wildfire emissions have not been input into the ozone forecast. Although this model has issues about land/water interfaces and using the most up-to-date emissions inventory, it is generally a reliable tool for the air quality forecaster.

From the previous similar day analysis, August 29th 2016 was determined to have a similar weather pattern as May 25th of that year. Figure 80 shows the model output for that day as compared with the AQI levels observed. It is widely recognized that the model over-estimates ozone concentrations in the northeast U.S. during July and August, so this model output is more typical and shows the similarity with the May 25th forecast. In the May 25th case, however, the model is greatly under-predicting the observed ozone levels.

Maryland Department of the Environment air quality staff analyzed gridded model output for May 2016 over the eastern U.S. domain and have plotted the model bias from the observed daily maximum 8-hour ozone average as interpolated isopleths. Since the model does not assimilate the gaseous smoke emissions into the ozone calculations, the model shows a strong negative bias over the region of the smoke plume. Figure 81 shows the model bias for May 25th, 2016, with areas many areas in the northeast U.S. exceeding a negative 25 ppb model bias. This was plotted without using the observation from the New Haven CT monitor, since it suffers from the NOx titration phenomenon where ambient ozone levels are almost always much lower than surrounding areas due to its proximity to I-95 and the Port of New Haven.

Hourly plots of observed ozone vs. modeled ozone are also presented for the May 25-26th, 2016 period for three of the monitors that are being requested the data exclusion (Figures 82-84). In every case, it shows that strong negative model bias during the day time hours, under-predicting peak ozone concentrations by as much as 30 ppb.

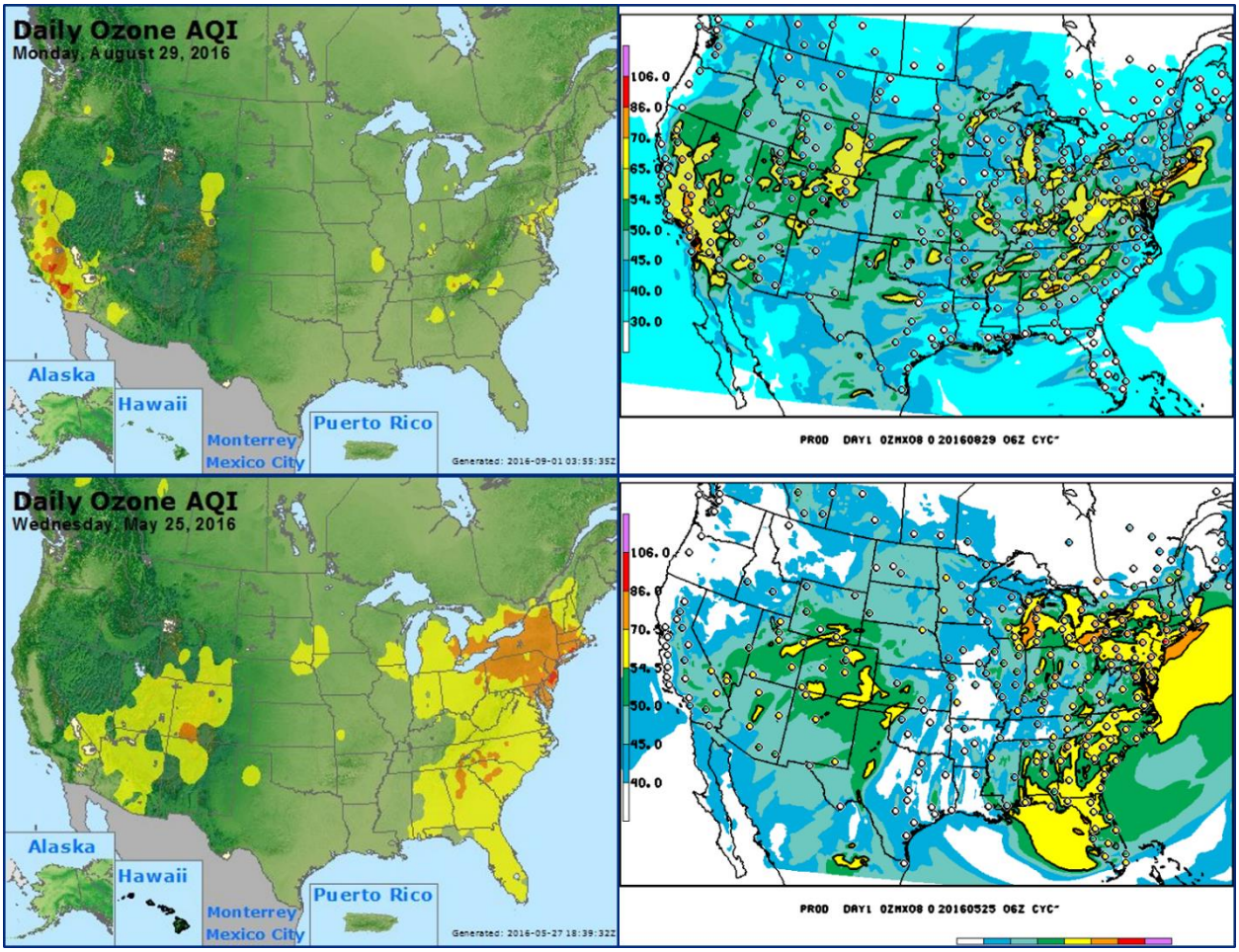


Figure 80. Comparing Similar Day Model Output from August 29th to May 25, 2016 with Observed AQI

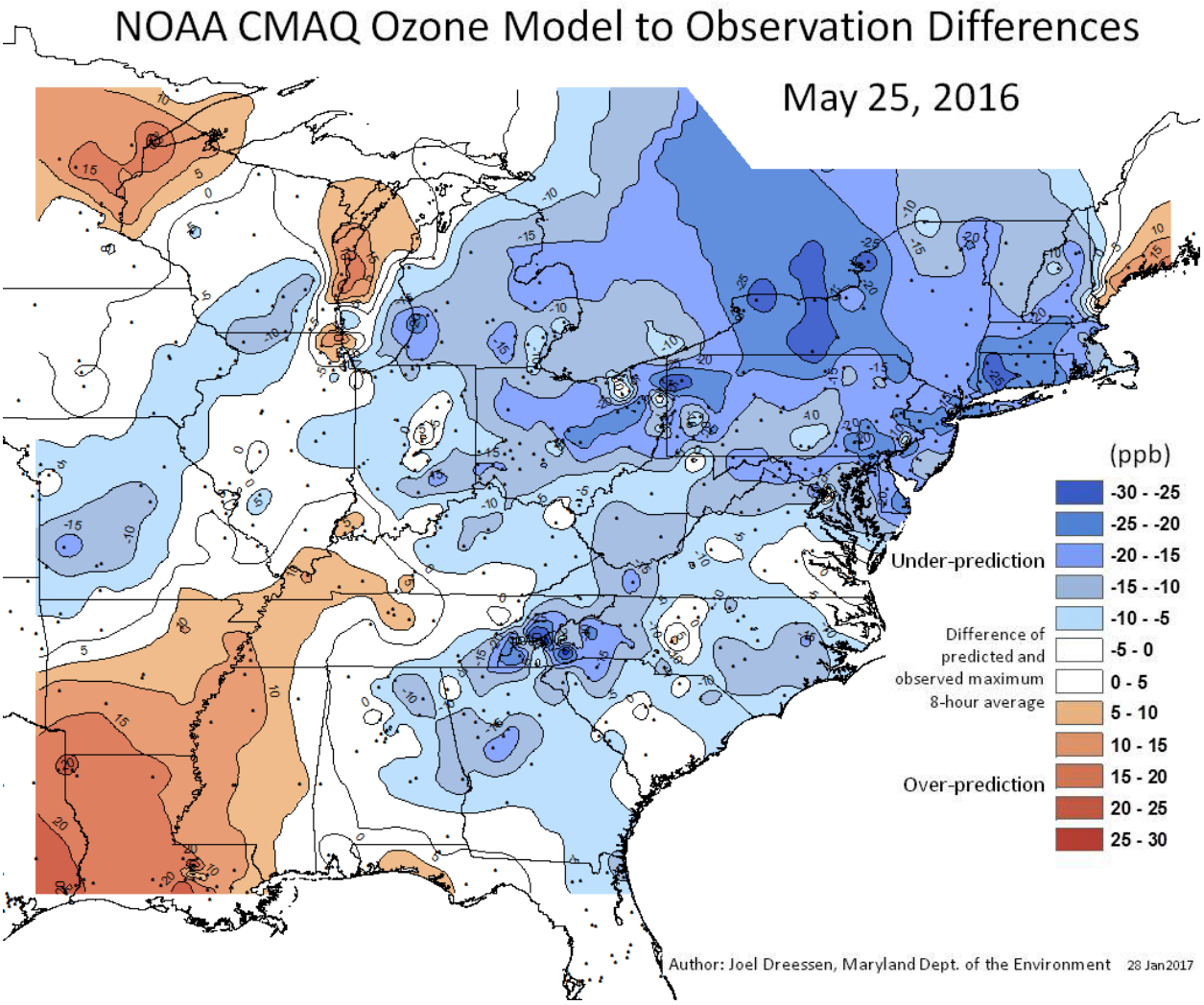


Figure 81. NOAA CMAQ Model Bias Isopleths for May 25, 2016

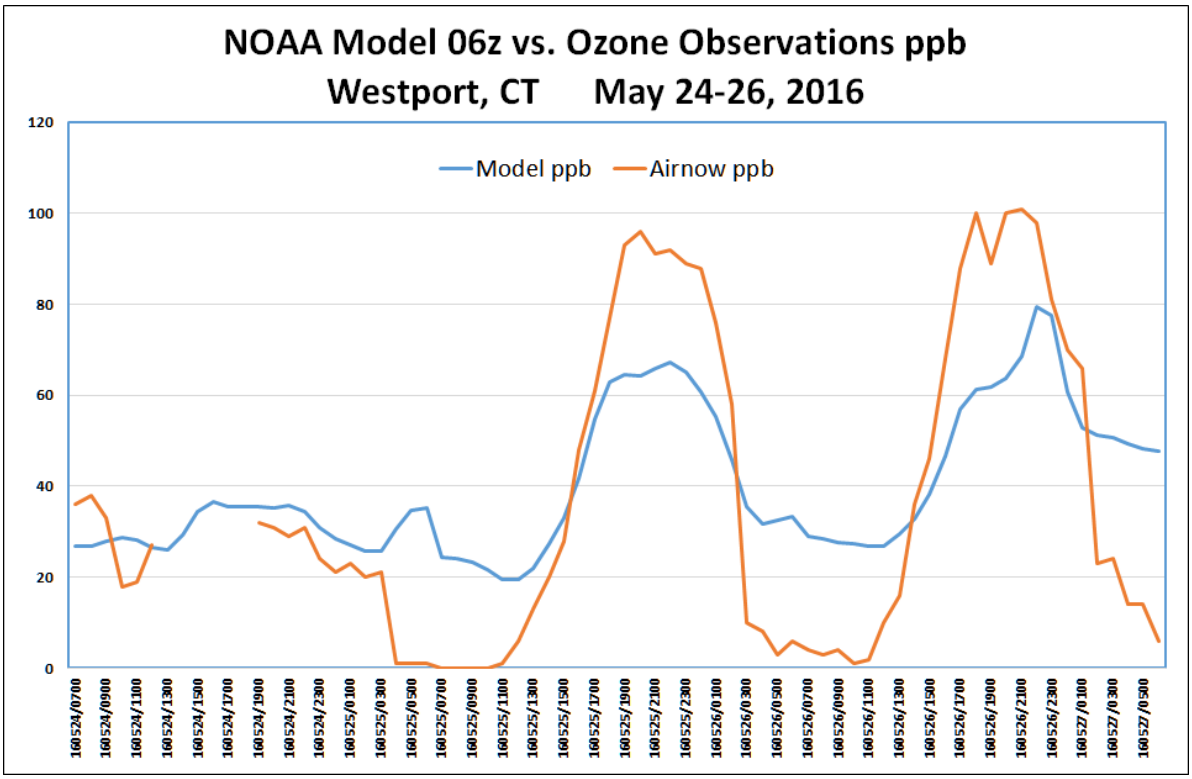


Figure 82. Westport CT NOAA Model vs. Observed Ozone, May 24-27, 2016

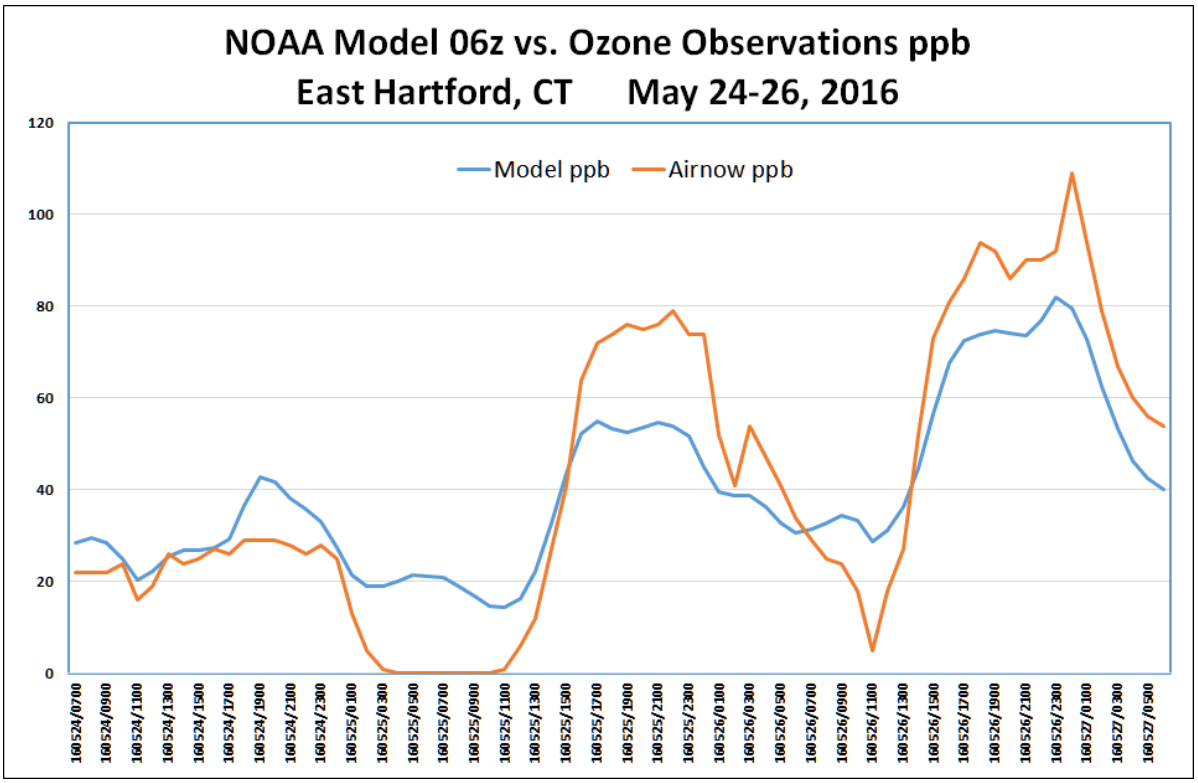


Figure 83. East Hartford NOAA Model vs. Observed Ozone, May 24-27, 2016

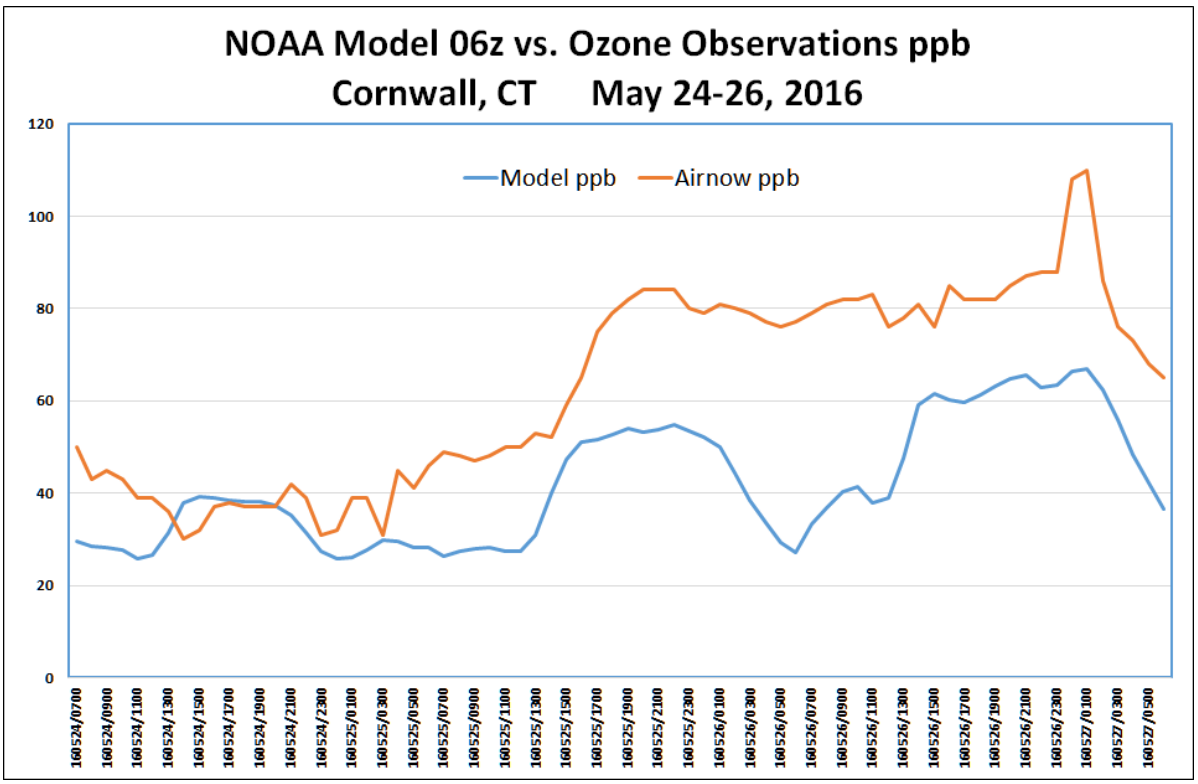


Figure 84. Cornwall CT NOAA Model vs. Observed Ozone, May 24-27, 2016

3.8 Causal Evidence Conclusion

During May of 2016, an historic wildfire occurred near Fort McMurray, Alberta Canada that generated a massive and lingering smoke plume into July 2016. The VOCs and NOx that were emitted from this fire were transported over the Great Lakes after May 20th, becoming trapped by a high pressure system, where these precursors contributed to elevated ozone concentrations at numerous monitors in the Upper Midwest States. This elevated ozone and plume was then transported southeast to Connecticut on May 25-26, where numerous ozone exceedances where observed. The monitored ozone concentrations of ozone were compared to historical concentrations during the April-September season since 2012. One or more of these days at each of these four monitors were in the 99th percentile rank over this seasonal basis. Meteorological conditions were not consistent with historically high concentrations, as the similar day analysis has shown of this demonstration supports CTDEEP's position that the wildfire event affected air quality in such a way that there exists a clear causal relationship between the specific event and the monitored exceedance or violation on May 25-26, 2016 of data requested for exclusion, or reference to summary table in demonstration and thus satisfies the clear causal relationship criterion.

Figure 85 is a map of the revised 2016 design values for Connecticut after the data exclusion is approved.

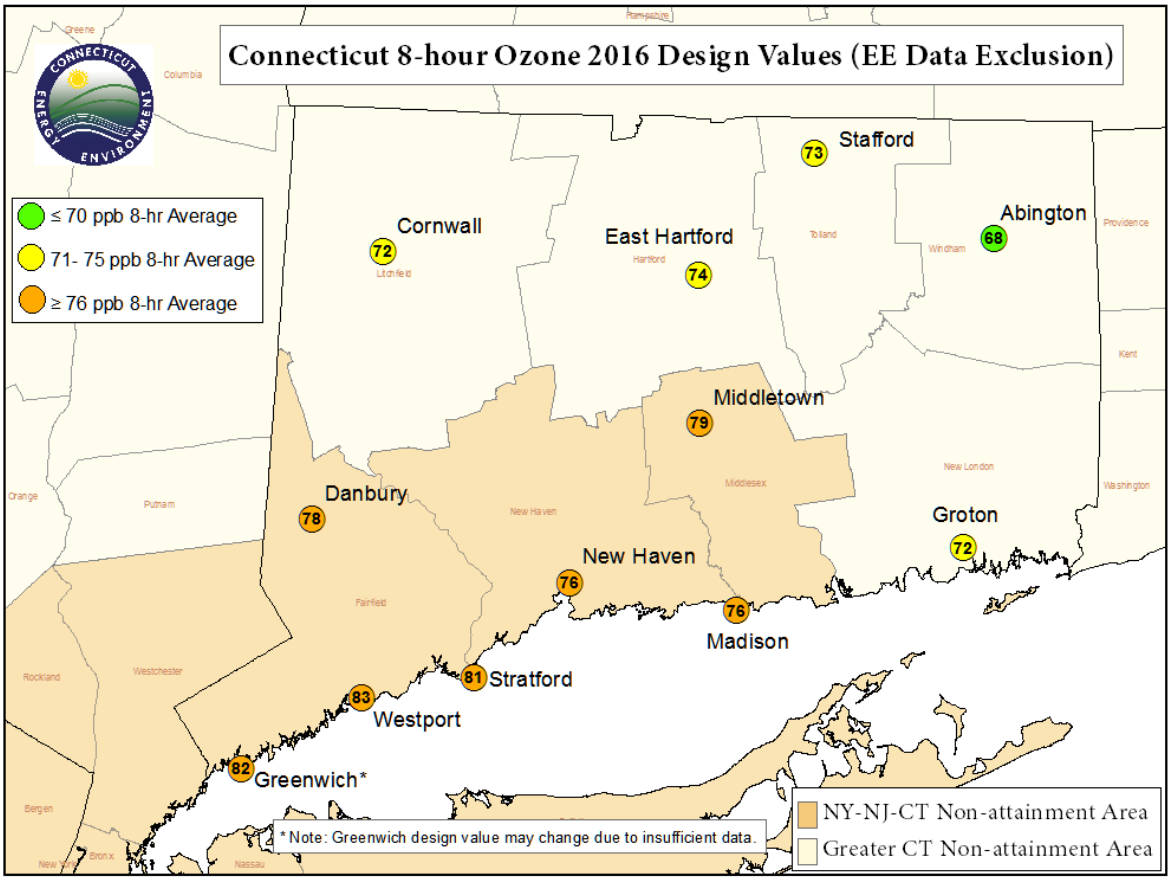


Figure 85. Map of 2016 Connecticut 8-hour Ozone design Values after Data Exclusion.

4. CAUSED BY A NATURAL EVENT

4.1 Definition of a Wildfire

The Exceptional Events Rule at 40 CFR 50.1(n) defines a wildfire as "…any fire started by an unplanned ignition caused by lightning; volcanoes; other acts of nature; unauthorized activity; or accidental, human-caused actions, or a prescribed fire that has developed into a wildfire. A wildfire that predominantly occurs on wildland is a natural event."

4.2 Conclusion

Based on the documentation provided in Section 3 of this submittal, the event qualifies as a wildfire, because, while it was not caused by lightning, it was nevertheless an unplanned wildfire event. The EPA generally considers the emissions of O3 precursors from wildfires on wildland to meet the regulatory definition of a natural event at 40 CFR 50.1(k), defined as one 'in which human activity plays little or no direct causal role.' This wildfire event occurred on wildland in

Alberta Canada as documented in the introduction, and accordingly, CTDEEP has shown that the event is a natural event and may be considered for treatment as an exceptional event.

5. NOT REASONABLY CONTROLLABLE OR PREVENTABLE

5.1 Exceptional Event Provisions

According to the CAA and the Exceptional Events Rule, an exceptional event must be "not reasonably controllable or preventable." The preamble to the Exceptional Events Rule clarifies that the EPA interprets this requirement to contain two factors: the event must be both not reasonably controllable and not reasonably preventable at the time the event occurred. This requirement applies to both natural events and events caused by human activities, however it is presumptively assumed that wildfires on wildland will satisfy both factors of the "not reasonably controllable or preventable" element unless evidence in the record clearly demonstrates otherwise.

5.2 Conclusion

Based on the documentation provided in the introduction of this submittal, human activity likely caused the wildfire event on wildland near Fort McMurray, Alberta. CTDEEP is not aware of any evidence clearly demonstrating that prevention or control efforts beyond those actually made would have been reasonable. Therefore, emissions from this wildfire were not reasonably controllable or preventable.

6. PUBLIC COMMENT (TO BE COMPLETED LATER)

6.1 Exceptional Events Rule Provisions

According to the provisions in 40 CFR 50.14(c)(1)(i), air agencies must "notify the public promptly whenever an event occurs or is reasonably anticipated to occur which may result in the exceedance of an applicable air quality standard." In addition, according to 40 CFR 50.14(c)(3)(v), air agencies must "document [in their exceptional events demonstration] that the [air agency] followed the public comment process and that the comment period was open for a minimum of 30 days…." Further, air agencies must submit any received public comments to the EPA and address in their submission those comments disputing or contradicting the factual evidence in the demonstration. Air agencies with recurring events may also be subject to the mitigation requirements at 40 CFR 51.930. Air agencies subject to these requirements have additional obligations regarding public notification and engagement.

6.2 Supporting Documentation

Air agencies should include in their exceptional events demonstration the details of the public comment process including newspaper listings, Web site postings, and/or places (library, agency office) where the hardcopy was available. As noted in Section 6.1, the agency should also include comments received and the agency's responses to those comments.

6.3 Conclusion Statement

The CTDEEP posted notice of this exceptional events demonstration on [date posted] in the following counties/locations: [list counties affected and locations posted]. [Number] public comments were received and have been included in Section 6 of the demonstration, along with CTDEEP's responses to these comments.