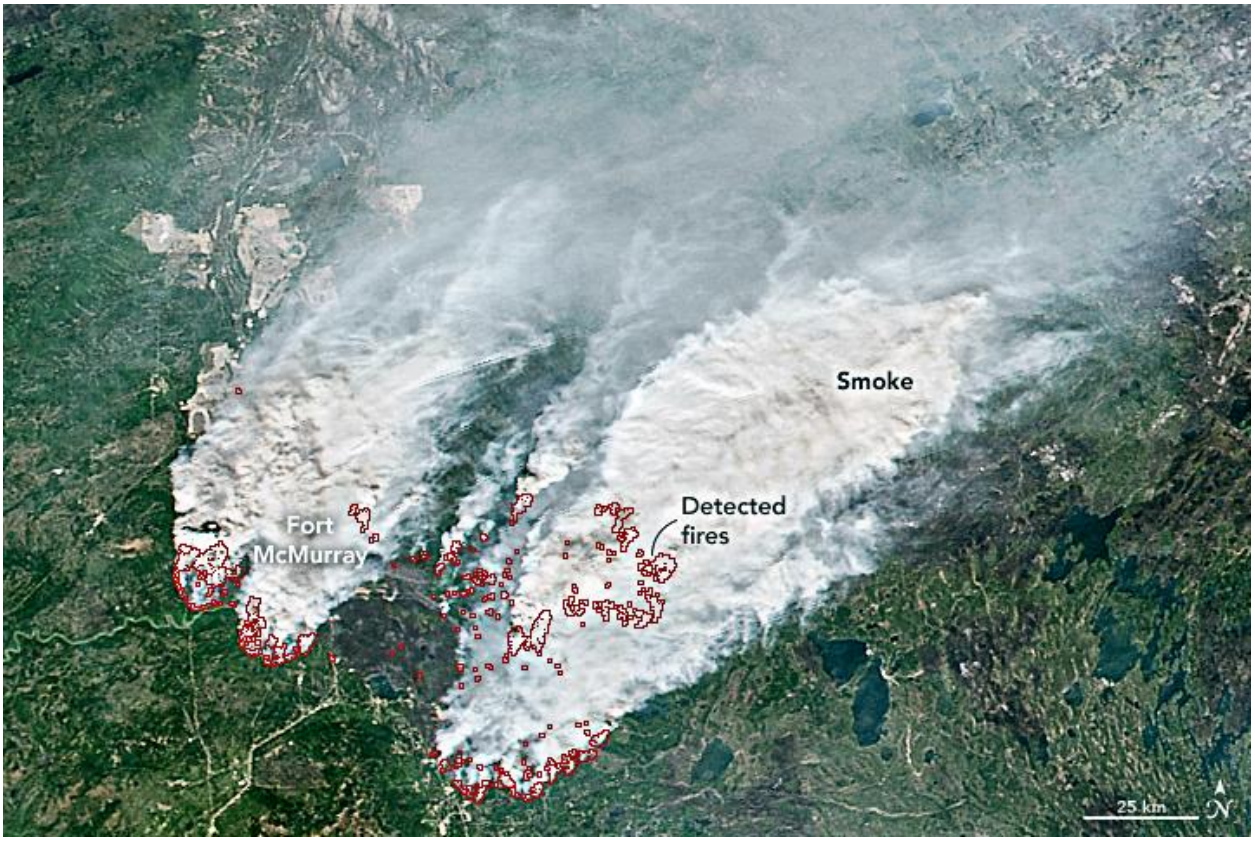
Connecticut Department of
ENERGY &
ENVIRONMENTAL
PROTECTION

May 2016 Ozone Exceptional Event Analysis
Technical Support Document



DRAFT FOR PUBLIC REVIEW

Connecticut Department of Energy and Environmental Protection

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1. OVERVIEW

1.1 Introduction

Early in the day on May 25th, 2016, an unusual area of elevated ozone concentrations over the upper Midwest and New York State moved into New England. Widespread, highly elevated ozone levels early in the season occur infrequently. Rarely do ozone events occur under the meteorological conditions observed.

It became quickly evident, initially through discrepancies with the forecast model results, and later through analyses of satellite and other data, that the elevated ozone was likely due to the Fort McMurray wildfire smoke plume that had been moving toward New England for several days. The National Oceanic and Atmospheric Administration (NOAA) operational ozone model, which was not configured to include effects from wildfires, had been predicting good to moderate ozone concentrations throughout the area; nevertheless, air quality reached unhealthy levels in many areas of the State by noon on May 25th.

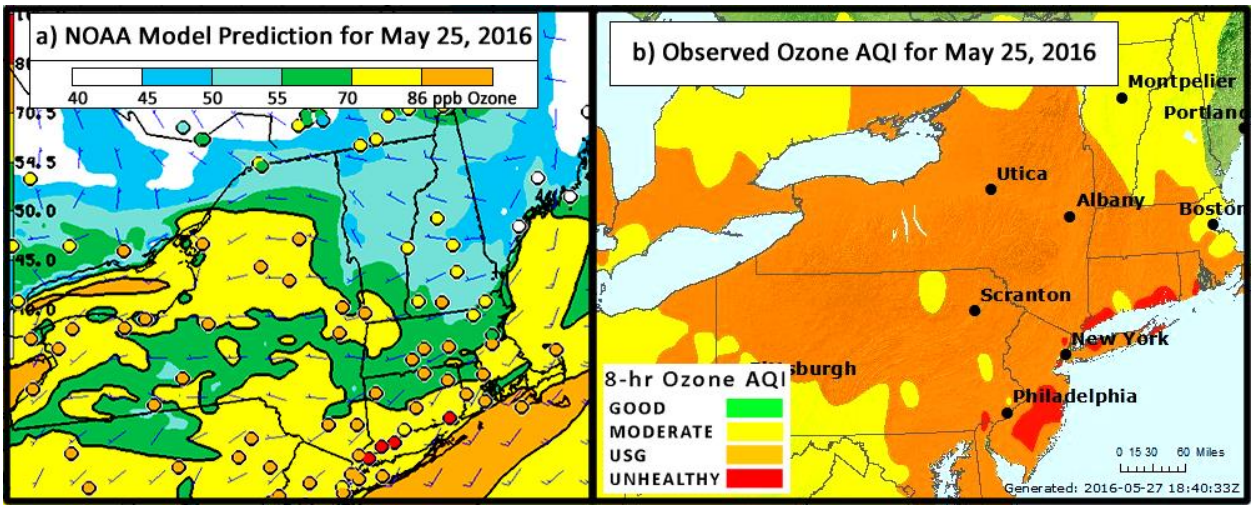


Figure 1. Model Forecasted Air Quality versus Observed. NOAA model forecasted AQI values for May 25th, 2016 (a) and the observed ozone AQI values (b). Figure 1a shows the early morning forecast (isopleths) for the day of May 25th including wind fields and actual observed ozone AQI levels at monitoring sites (circles) in the northeast. Figure 1b shows the extent of the observed ozone levels. Note that Figure 1a color scheme for monitors match the color scheme in figure 1b.

The unusual air quality continued as Connecticut air quality monitors and those in nearby states reported daily maximum 8-hour average ozone levels over the 70 ppb National Ambient Air Quality Standard (NAAQS) from May 25th through the 28th.

In August of 2016, having conducted a preliminary review of the event, the Connecticut Department of Energy and Environmental Protection (DEEP) placed an informational flag on all

the monitored ozone data for that entire four-day event indicating that the data had been influenced by the Canadian wildfire. As required by the Exceptional Events Rule (Title 40 of the Code of Federal Regulations Part 50.14) DEEP notified the Environmental Protection Agency (EPA) by letter dated September 28th, 2016, that we intended to submit an exceptional events' data exclusion demonstration for the event.

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;
- Visible satellite plumes and back trajectory analyses for the time period before the event showed wildfire smoke transported southeast into the Midwestern States before arriving over Connecticut on May 25th, 2016; 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.

Although all four days of the regional 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. This document, in accordance with the exceptional events rule, provides the evidence for 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 Exceptional Events Rule, contained in Title 40 of the Code of Federal Regulations Part 50.14 (40CFR50.14), was revised by EPA in October of 2016[1]. The revised rule describes the procedures for treating data which has been influenced by an exceptional event. Accordingly, 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;

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

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;

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.

Wildfires are defined at 40 CFR 50.1(n) 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." EPA has prepared guidance specific to analyzing the influence of wildfires on ozone events[2].

Furthermore, 40CFR50.14(b)(4) states that the EPA " … Administrator shall exclude data from use in determinations of exceedances and violations where a State demonstrates to the Administrator's satisfaction that emissions from wildfires caused a specific air pollution concentration in excess of one or more national ambient air quality standard at a particular air quality monitoring location and otherwise satisfies the requirements of this section. Provided the Administrator determines that there is no compelling evidence to the contrary in the record, the Administrator will determine every wildfire occurring predominantly on wildland to have met the requirements identified in paragraph (c)(3)(iv)(D) [item (4) above] of this section regarding the not reasonably controllable or preventable criterion."

We address each of the necessary elements above in the subsequent sections of this document, generally relying on the EPA guidance for wildfires. EPA guidance offers suggestions for appropriate analyses to demonstrate the clear causal relationship between the wildfire and excessive ozone levels and recognizes that appropriate levels of analysis will vary for particular locations and conditions. EPA does not intend for the guidance to constrain the analysis and we include some of the suggested analytics, and variations on those methods to support our conclusion that the ozone exceedances throughout the State were caused or worsened by the wildfire plume from the Fort McMurray in May of 2016.

1.3 Regulatory Significance

The exceptional events rule applies to data showing an exceedance of a standard which may affect regulatory determinations regarding attainment designation status or other action by the Administrator. While the wildfire plume was regional in nature and was observable over the State during the four day event, it did not cause all monitors to exceed the standard throughout

[2] Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentrations, Final, US EPA OAQPS, Research Triangle Park, North Carolina, September 2016.

the event. Nor were all the exceedances such that they would likely affect attainment designation status or other EPA actions.

Attainment designation status is determined by design values derived from monitored values. For ozone the design value is determined by taking the three-year average of the fourth highest 8-hour maximum daily average monitored ozone level.

Table 1 shows the maximum 8-hour ozone averages observed at the Connecticut ozone monitors during the event from May 25th through May 28th. There were monitored exceedances of the 70 ppb ozone NAAQS on all 4 days. However, the more severe exceedances occurred on the first two days of the event and those values are most significant with respect to computation of design values.

Table 1. Event Maximum 8-hour Ozone Concentrations. The maximum 8-hour average ozone concentration in parts per billion (ppb) for each ozone monitoring site in Connecticut during the four day May 2016 ozone event. Data for Connecticut's Greenwich monitor has been invalidated.

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
Groton	87	80	54	60
Madison	89	86	56	63
Middletown	80	91	67	79
New Haven	63	84	65	73
Stafford	74	82	70	73
Stratford	89	76	59	70
Westport	87	90	61	81

The levels which occurred on May 27-28 are consistent with values which occur later in the ozone season and are less likely to affect current or future design values.

Table 2 compares current 2016 design values (based on 2014-2016 data), calculated with and without the inclusion of all data from the first two days of the event. The table also shows the 2017 critical 4th-high value, which is the fourth highest annual 8-hour average value that would produce a 2017 design value that violates the NAAQS indicated beside it in parenthesis. The difference in critical values is shown in the final column. Where there is no difference in critical value, there can be no regulatory significance to excluding data from the event. Based on the severity of the difference in critical value, and the expectation that those sites with the largest differences will be controlling in any assessment of attainment status, DEEP has decided to focus this demonstration on the four sites with the greatest difference in critical value. If future assessments of attainment status based on inclusion of sites with lower critical differences prove to be controlling, then DEEP will revisit this analysis.

Table 2. Comparison of 2016 Design Values with and without May 25 and May 26, 2016 Data, and Corresponding 2017 Critical 4th High Values.

Current Values						Excluding May 25-26, 2016			Difference in Critical Value
Site Name	4th high 2014	4th high 2015	4th high 2016	2014-2016 DV	2017 Critical 4th High Value (NAAQS Standard)	4th high 2016	2014-2016 DV	2017 Critical 4th High Value (NAAQS Standard)	
Abington	67	70	**74**	70	69 (70)	67	68	76 (70)	7
Westport	**81**	**87**	**87**	**85**	81 (84)	**81**	**83**	87 (84)	6
Cornwall	68	**76**	**78**	**74**	74 (75)	**74**	**72**	78 (75)	4
East Hartford	**77**	**75**	**75**	**75**	78 (75)	**72**	**74**	81 (75)	3
Madison	69	**81**	**80**	**76**	94 (84)	**78**	**76**	96 (84)	2
Stafford	**77**	**72**	**72**	**73**	84 (75)	70	**73**	86 (75)	2
Danbury	**74**	**79**	**81**	**78**	95 (84)	**80**	**77**	96 (84)	1
Middletown	**80**	**78**	**80**	**79**	97 (84)	**79**	**79**	98 (84)	1
Stratford	**74**	**86**	**83**	**81**	86 (84)	**82**	**80**	87 (84)	1
New Haven	**72**	**81**	**75**	**76**	99 (84)	**75**	**76**	99 (84)	0
Groton	65	**77**	**75**	**72**	76 (75)	**75**	**72**	76 (75)	0

Table 3 shows the four sites that DEEP has concluded are affected by the event in a significant regulatory way and to which this data exclusion request is limited. Excluding the two days

significantly lowers the fourth highest value for 2016 at each of these sites, which then results in a lower design value.

Table 3.Comparison of 2016 Design Values with and without May 25 and 26, 2016 Data, and Corresponfding 2017 Critical 4th High Values at the Four Sites Proposed for 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 4th High Value (NAAQS Standard)**	**4th high 2016**	**2014-2016 DV**	**2017Critical 4th High Value (NAAQS Standard)**
Abington	67	70	**74**	70	69 (70)	67	68	76 (70)
Westport	**81**	**87**	**87**	**85**	81 (84)	**81**	**83**	87 (84)
Cornwall	68	**76**	**78**	**74**	74 (75)	**74**	**72**	78 (75)
East Hartford	**77**	**75**	**75**	**75**	78 (75)	**72**	**74**	81 (75)

The Abington site, which currently measures attainment for all the ozone NAAQS, could easily measure non-compliance in future years if this data is not excluded. Table 3 shows that (including the May 25th and 26th data) a 4th-high value in 2017 of 69 ppb or higher could push Abington into measured nonattainment for the 2015 NAAQS of 70 ppb. Also, the 4th high value in 2016 for Abington is clearly aberrant when the event data is included. This site is a Clean Air Status and Trends Network (CASTNET) site run by EPA. Therefore, on March 23, 2017, in cooperation with EPA, DEEP requested the CASTNET administrator to apply data flags for May 25-26, 2016 to Abington.

The Westport monitor's 2016 design value decreases by 2 ppb if the event is excluded. This decrease is sufficient to bring the site, and the Southwest Connecticut portion of the NY-NJ-CT nonattainment area, back into attainment with the 1997 ozone NAAQS of 84 ppb.

Both the Cornwall and East Hartford monitors currently measure nonattainment for the 2015 NAAQS of 70 ppb. While there is concern that the event data could impede attainment of the 2015 NAAQS, the more immediate concern for these two sites is that the wildfire influenced data could produce 2017 (or 2018) design values that violate the 2008 NAAQS of 75 ppb. This would jeopardize the determination of timely attainment for the Greater Connecticut nonattainment area.

2. CONCEPTUAL MODEL

2.1 Typical Exceedance Day 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, meteorological variation is still an important factor. Figure 2 shows the historical trends for Connecticut's ozone exceedance days with separate lines for each of the 8-hour ozone NAAQS established since 1997. Vertical lines indicate the year the standard was established.

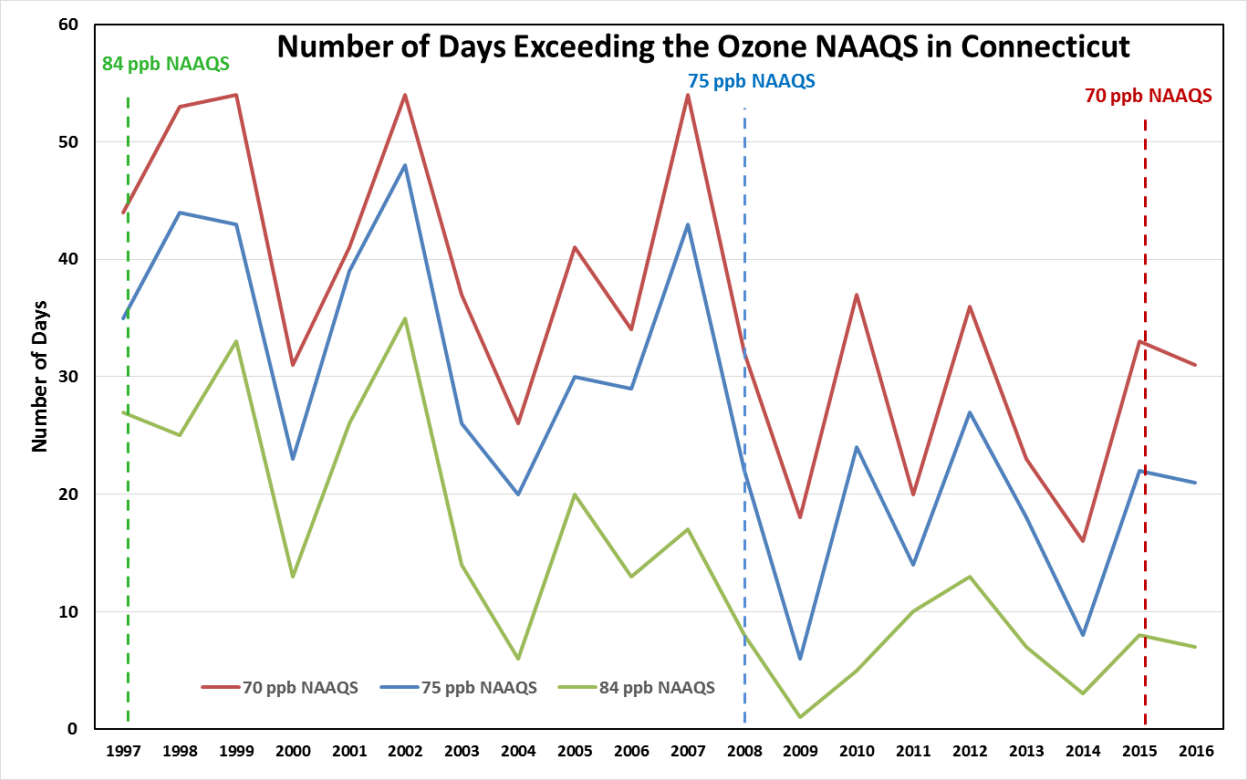


Figure 2. Number of Ozone Exceedance Days. The number of days exceeding the respective ozone standards in Connecticut since 1997. Dashed vertical lines indicate the respective dates the standards were established.

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 occur overnight 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 across 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 localized sea breeze with a southerly component, resulting in ozone exceedances along the coast. Inland winds from the west carry cleaner air to inland areas and also prevent sea breeze penetration, sometimes contributing 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

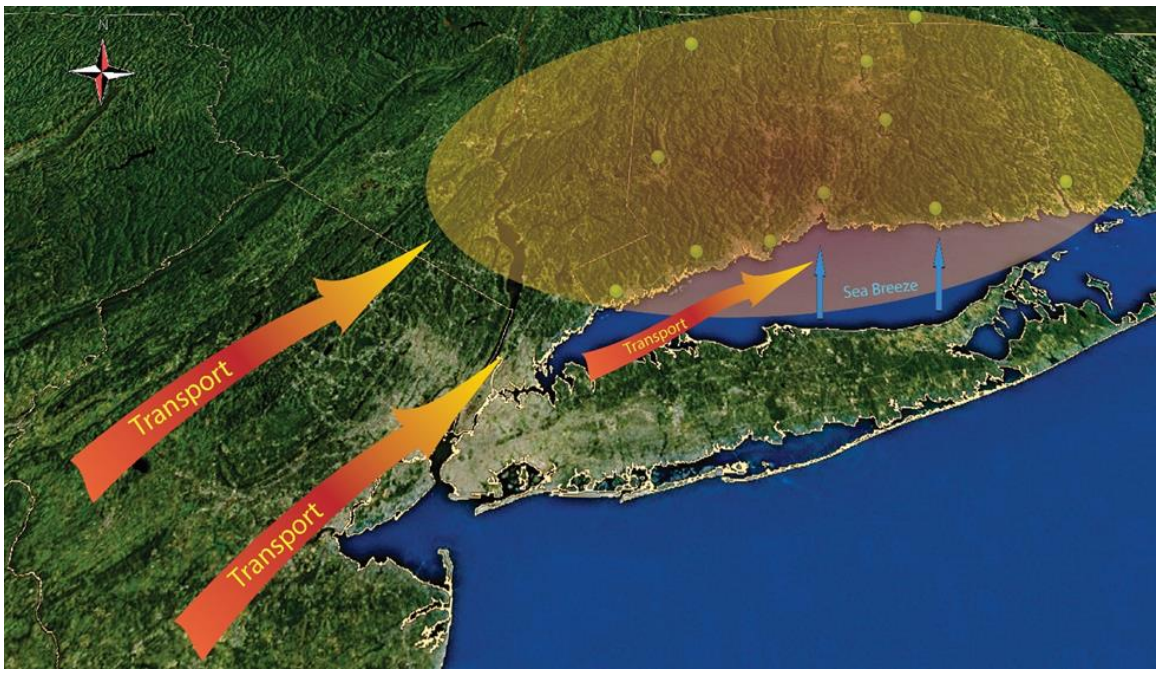


Figure 3. State-wide Ozone Exceedance Scenario

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 typically be caused by the State-wide Exceedances scenario (Figure 3); however, the necessary meteorological conditions were not present. In fact, the event started with winds originating from the northwest, which would typically result in low ozone levels in Connecticut. Therefore, the event did not fit any of the scenarios which cause widespread multiday ozone exceedance events in Connecticut.

2.2 Regional Emissions

The scenarios described above occur because winds transport ozone precursors, nitrogen oxides (NOx) and volatile organic compounds (VOC), from regional emission sources into Connecticut on sunny days which are conducive to ozone formation. When there is insufficient sunlight or insufficient emissions, ozone episodes do not occur.

The maps below show the location of regional NOx and VOC emissions. Note that winds from the northwest, as occurred as the event initiated, would travel over the cleanest areas of the region and could not typically have transported sufficient precursors from regional sources to instigate such a widespread multiday ozone event of the magnitude that occurred.

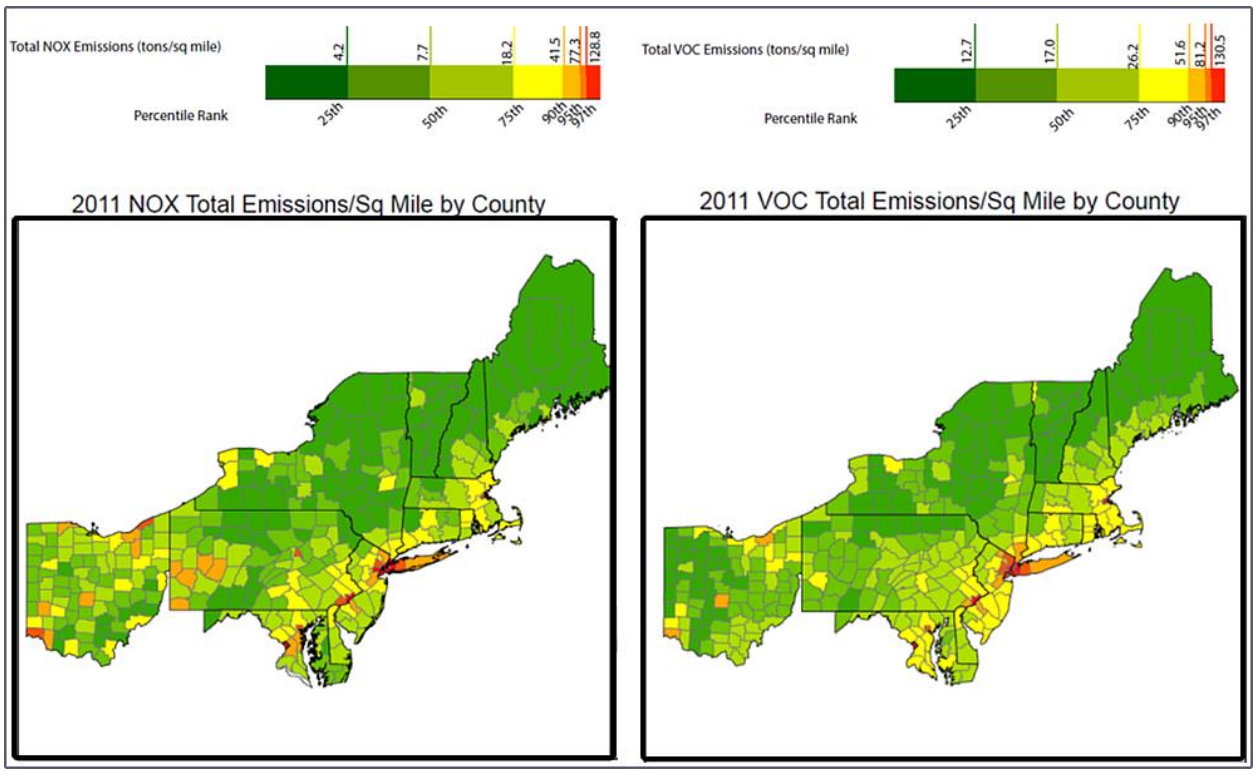


Figure 4. 2011 NEI County Percentile Map of (a) Total NOx Emissions per square mile and (b) Total VOC Emissions per square Mile

2.3 CSAPR NOx Source Emissions

Power facilities, or electric generating units (EGUs), have traditionally played a major role during ozone events on the East Coast. EGUs are capable of producing a large amount of emissions over a short duration and generally emit at elevations conducive to transport. Therefore, during hot days many of the less frequently used high emitting EGUs come online to supply the high electric demand of air conditioning and refrigeration along with base load units operating at full capacity.

Recognizing the ability of these sources to affect cross state air pollution, EPA monitors the real-time emissions from these facilities and regulates them as under the Cross-State Air Pollution Rule (CSAPR). The following figures show the actual total daily NOx emissions from these CSAPR sources for our closest upwind States -- New York, New Jersey and Pennsylvania – for the 2016 ozone season. Plotted on the right hand axis, as yellow bars, are the number of Connecticut monitors that exceeded the 70 ppb NAAQS each day. Clearly, the May 25-26th ozone event had the most monitored daily exceedances of the summer, while peak NOx emissions from these facilities did not occur until later in the season.

Therefore, the exceedances of May 25 -26th cannot be attributed to EGUs operating on high electric demand days as is more typically the case later in the ozone season.

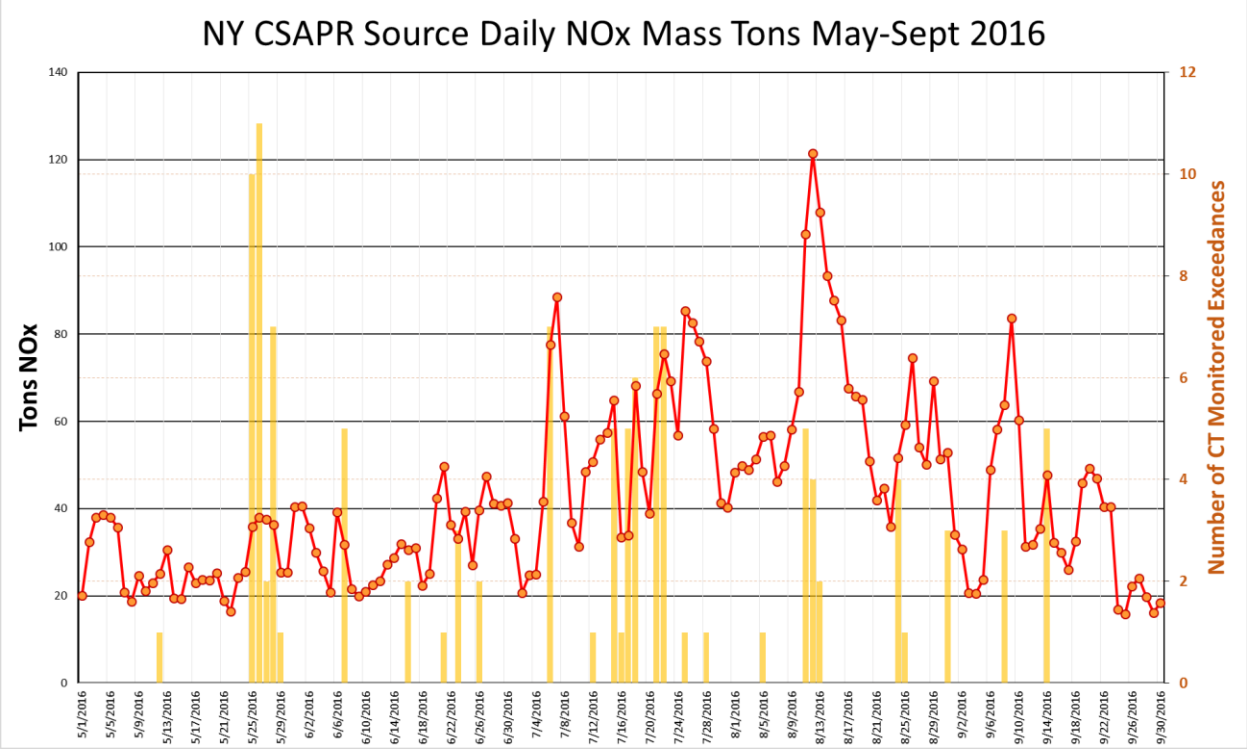


Figure 5. New York CSAPR Source 2016 Daily NOx Emissions

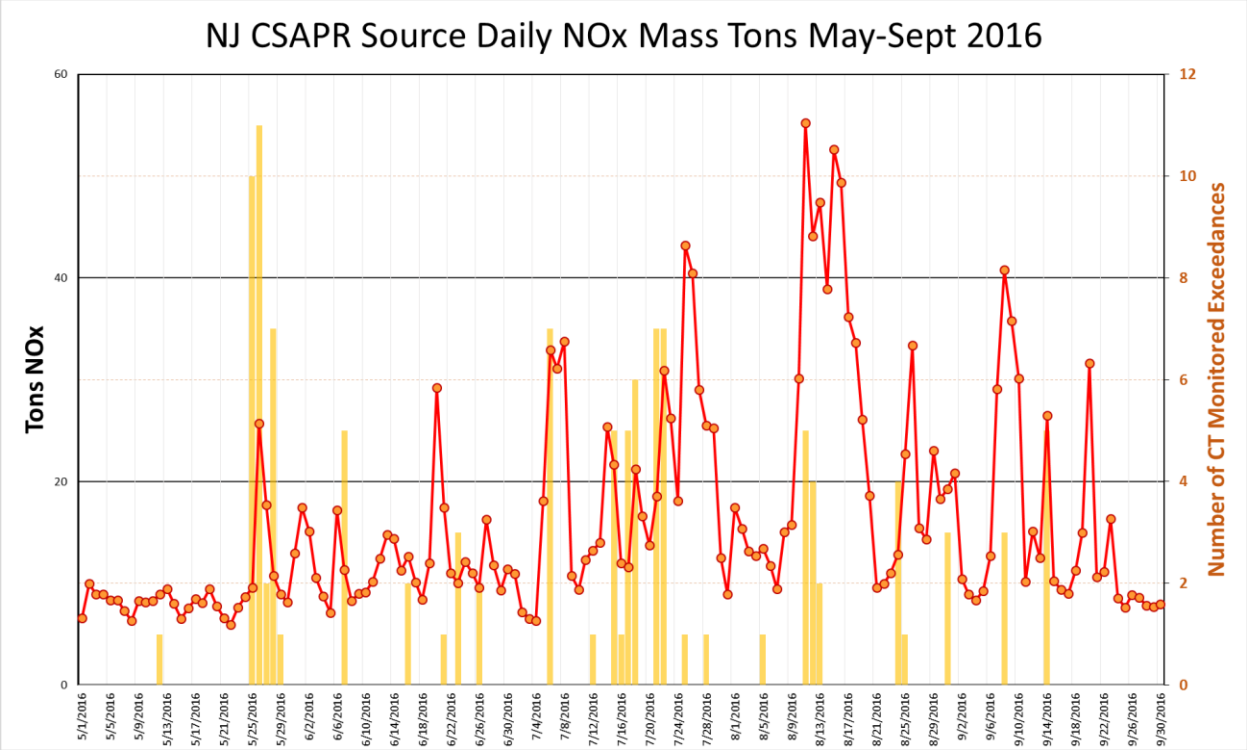


Figure 6. New Jersey CSAPR Source 2016 Daily NOx Emissions

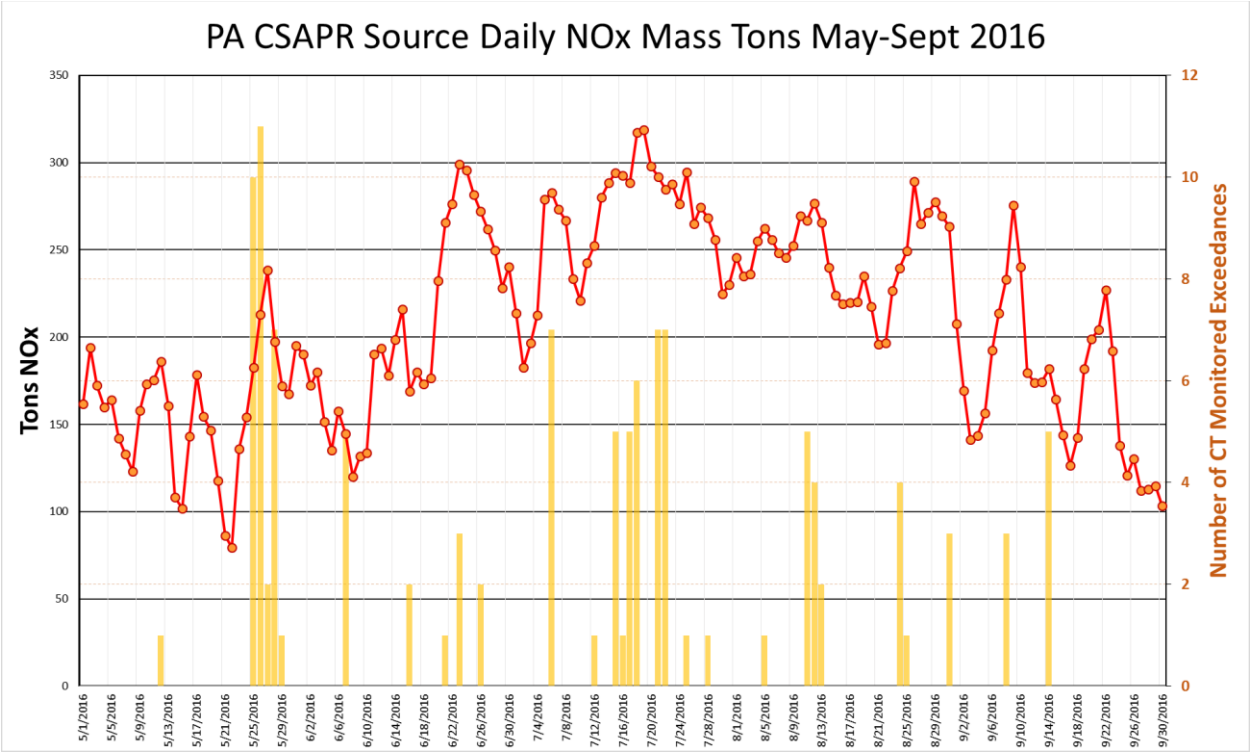


Figure 7. Pensylvania CSAPR Source 2016 Daily NOx Emissions

2.4 The Fort McMurray Fire

On May 1, 2016, a wildfire began southwest of Fort McMurray, Alberta, Canada. Within days, it swept through the community, destroying approximately 2,400 homes and buildings and forcing the largest wildfire evacuation in Albertan history. By May 11, The Guardian Newspaper was reporting on the wildfire that was now nicknamed "the beast" and stated that it was "… an extremely intense fire…so intense the soil is likely scorched, tree roots burned… [and] will likely smoulder and have hotspots for months mainly because of thick peat." [3]

Figure 8. Wildfire as it approaches Fort McMurray. This photo taken, Wednesday, May 4, 2016 shows the plume rising into the atmosphere forming pyro-cumulus clouds. (photo by Jeff McIntosh/CP).

Similarly, the Edmonton Journal was reporting that "firefighters started to realize the uniquely destructive nature of the Fort McMurray wildfire when they saw aspen poplar trees instantaneously and loudly explode into fire." The article continued the fire was so intense it was generating its own weather producing pyro cumulonimbus clouds and thunder and lightning storms.[4]

[3] Leahy, Stephen, *Canada Wildfire – what are the environmental impacts*, The Guardian, May 11, 2016.
[4] Staples, David, *Alberta battles The Beast, a fire that creates its own weather and causes green trees to explode*, Edmonton Journal, May 7, 2016.

Additional news articles describe a massive plume of global proportions resulting from the Fort McMurray fire:

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.

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."

The fire, most likely the result of human activity[5], spread across approximately 590,000 hectares (1,500,000 acres) and became the costliest natural disaster in Canadian history[6] before it was declared to be under control on July 5, 2016.

[5] Canadian Broadcasting Corporation, *Someone likely sparked the Fort McMurray wildfire, but was it a crime? RCMP ask.* June 14, 2016

[6] Insurance Bureau of Canada, *Northern Alberta Wildfire Costliest Insured Natural Disaster in Canadian History – Estimate of insured losses:$3.58 billion*. July 7, 2016.

2.5 Long Range Transport of Ozone and Precursors from Biomass Burning

Winds during the ozone event of May 2016 originated from the direction of the Fort McMurray fire. 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 seldom occur to see greater enrichment of ozone, as much as 25 ppb in the northeastern United States, than areas where wildfires more frequently occur.[7]

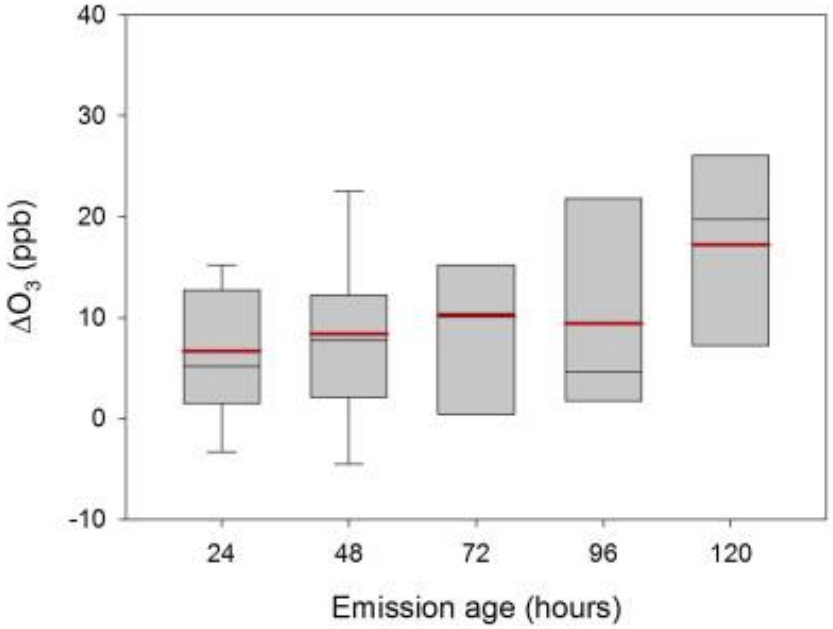


Figure 9. Ozone Enrichment by Age of Plume. This figure, taken from Putero et al[8] shows the results of their study on the influence of biomass burning on ozone concentrations. Ozone enhancement increases as the plume ages. Here we see increases on the order of 20 ppb from a five day old plume.

Many variables, such as type of fuel or forest burned, plume path and distance burned, affect the intensity of the fire and ability of a plume to enhance downwind ozone production. Emissions from boreal forests such as in the area of the Fort McMurray fire can be much higher than from typical forests in the U.S. due to the high available biomass (on the order of 100 tons per acre) that may be stored in the forest floor as lichens, moss, peat and duff.[9] The Fort McMurray fire occurred following an unusually hot dry spring season. Under these conditions the fire can burn and smolder deeper into the forest floor to add considerable emissions to the plume.

[7] Brey, Steven J. and Emily V. Fischer, Smoke in the City: How Often and Where Does Smoke Impact Summertime Ozone in the United States?, Environmental Science and Technology, vol. 50, pp1288-1294, 2016.
[8] 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.
[9] 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.

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.[10]

Jaffe and Wigder[11] and others have confirmed that the maximum ozone 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 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 smoke plume due to ultra violet (UV) light attenuation, lower temperatures, and non-optimal surface layer composition.

2.6 Fort McMurray Wildfire Emissions Impact on Connecticut using a Q/d Analysis

EPA guidance[12] recommends conducting a fire emissions – transport distance ration (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 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. 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. This method is intended to be a simple and conservative approach to establishing clear causality. Failure to meet the 100 ton per day per kilometer threshold does not preclude a finding clear causality. EPA developed this value based on limited 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:

[10] Jaffe, Daniel A. and Nicole L. Wigder, Ozone production from wildfires: A critical review, Atmospheric Environment, 2012, vol 51, pp1-10.
[11] Jaffe, D.; Wigder, N. Ozone production from wildfires: A critical review. Atmos. Environ. 2012, 51, 1−10
[12] Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events that May Influence Ozone Concentrations, Final, EPA, September 2016

$F_i = P_i * L$ (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.[13] The chart below (Figure 10) indicates the total area covered by the fire as reported by the Alberta government[14]. 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

[13] Any large area estimate can only be considered comprehensible if compared to the State of Rhode Island.
[14] 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]

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

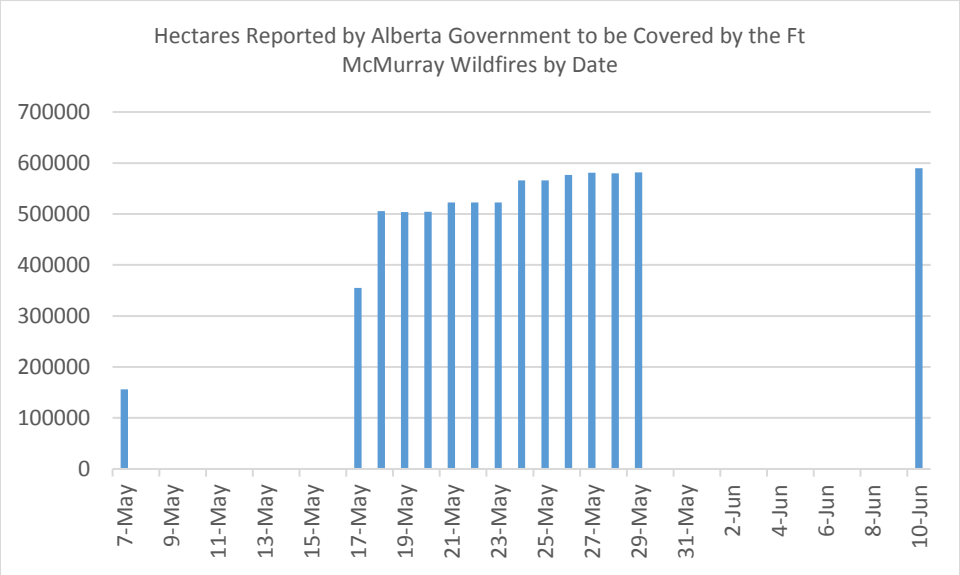


Figure 10. Chart of Hectares Burned. Reported by the Alberta Goverment from May 7-June 10, 2016.

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.

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. This is 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 can 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.[15] 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.

[15] 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.

3. SATELLITE PHOTOS, PLUME ANALYSIS AND WEBCAMS

3.1 Satellite Images

During the month of May, a large smoke plume, fed by the Fort McMurray 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 also observed on the satellite images, but we do not believe that these had a major influence on the ozone observed by the Connecticut monitors.

Figure 11 shows the presence of the smoke plume over the Upper Midwest states on May 18th and May 19th. A satellite animation of this plume that shows the movement of the plume across the upper Midwest into upstate New York and then southeast into New England can be viewed on our web site[16]. The presence of a surface high pressure center allowed pollutants to become trapped near the surface while conditions became conducive for ozone formation on May 23-24th. Figure 12 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 13 shows the progression of the smoke plumes over North America, as analyzed by the Hazard Mapping System (HMS) staff at NOAA, using the satellite images. This series of maps shows the movement of the Fort McMurray smoke plume as it tracks over the Connecticut region on May 25-26, 2016. Figure 13d shows the plume over Michigan, where every monitor in lower Michigan exceeded the 8-hour ozone NAAQS of 70 ppb.

[16] http://www.ct.gov/deep/lib/deep/air/ozone/2016_exceptional_event_request/fort_mcmurray_2016.wmv

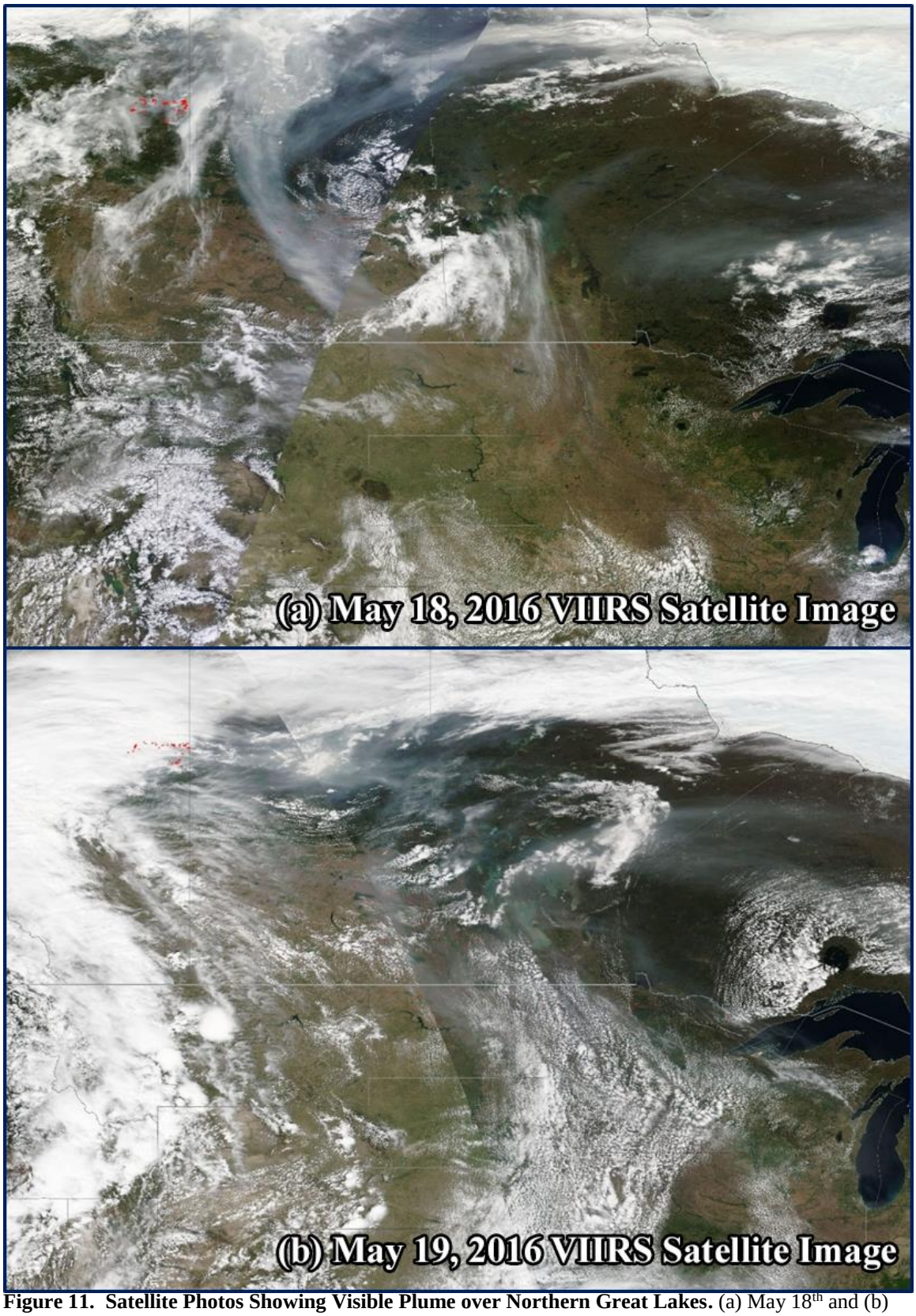


Figure 11. Satellite Photos Showing Visible Plume over Northern Great Lakes. (a) May 18th and (b) May 19th, 2016

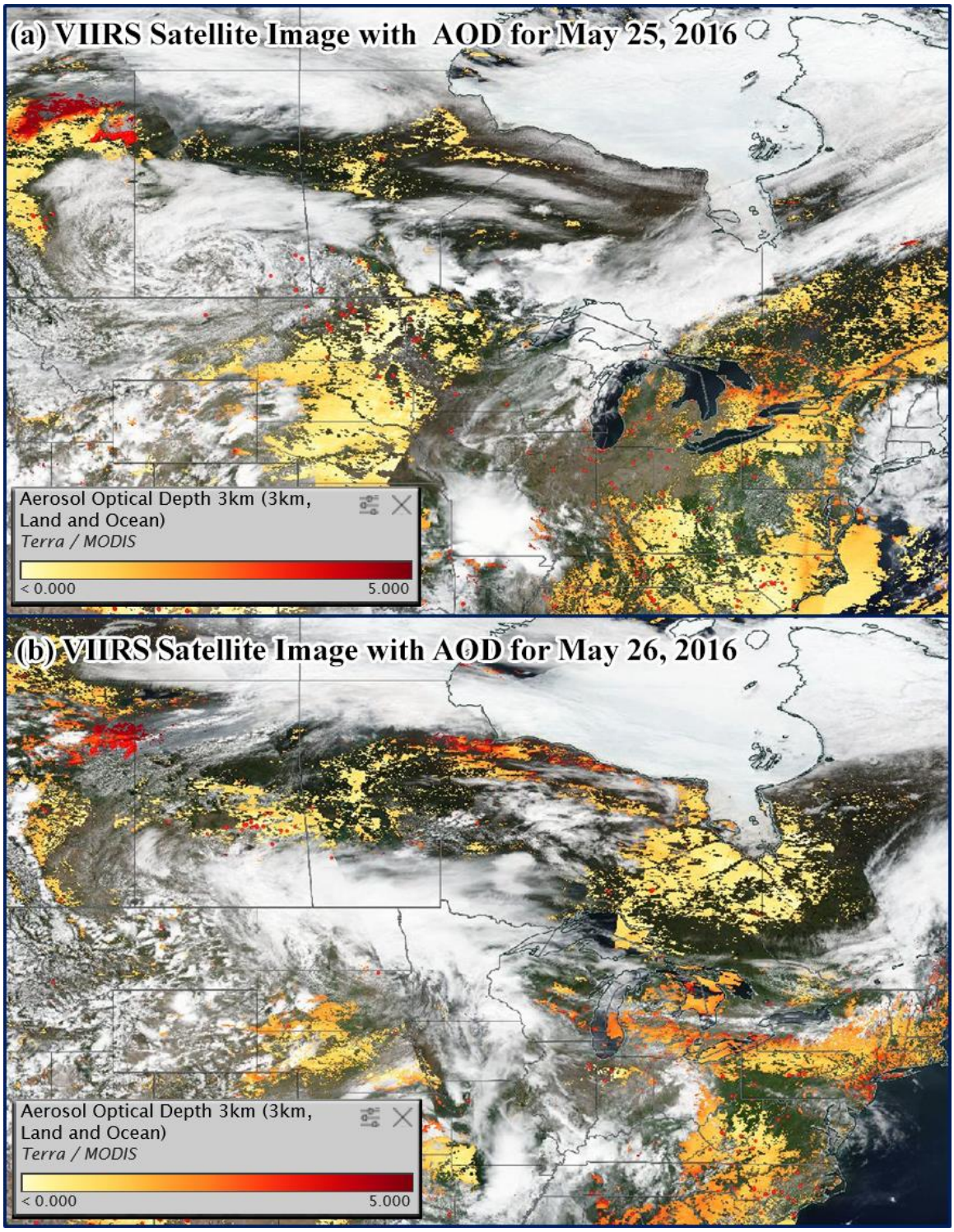


Figure 12. VIIRS Satellite Images. (a)May 25th and (b) May 26th, 2016 showing the Analyzed Aerosol Optical Depth (AOD) Associated with the Smoke Plume.

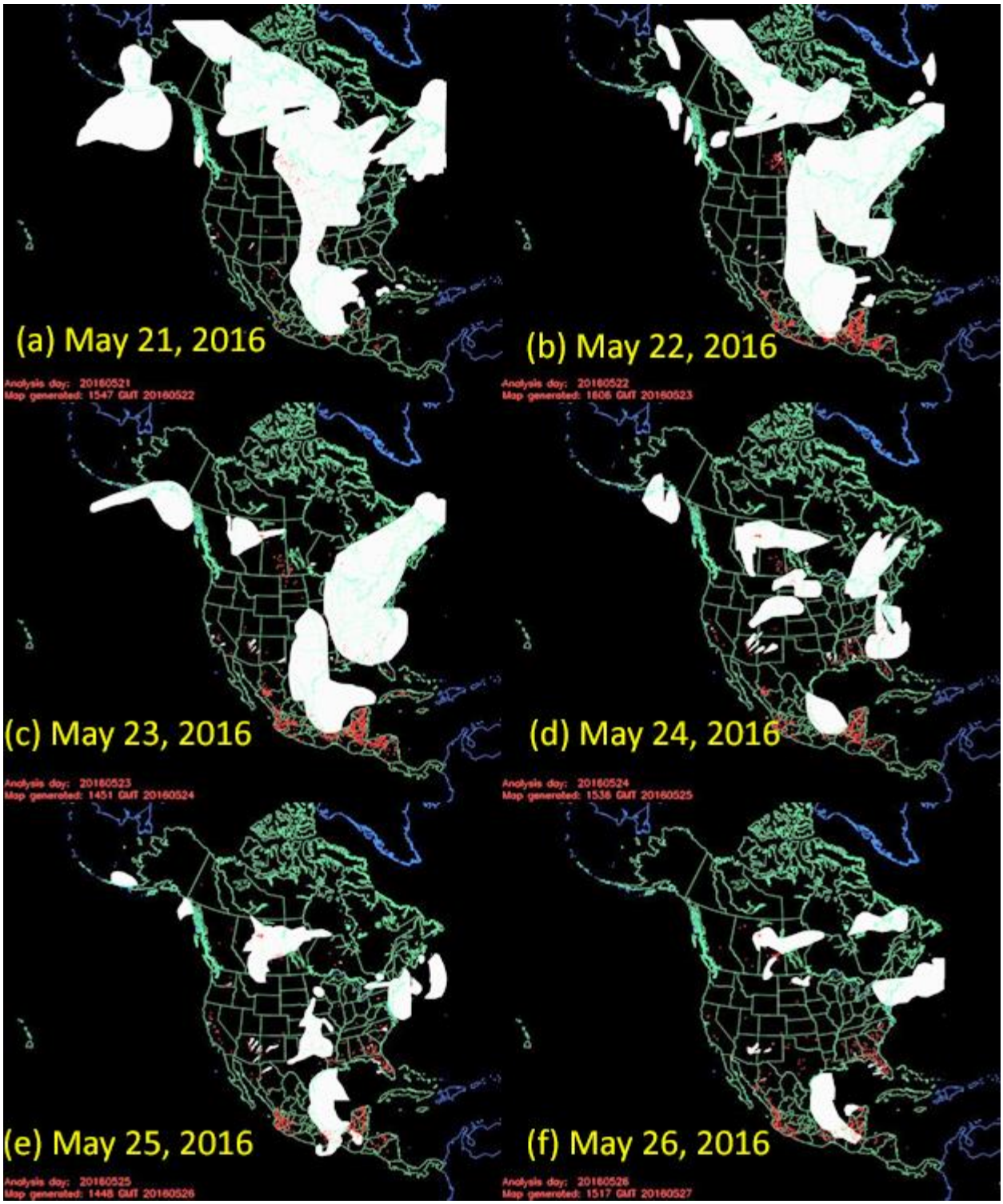


Figure 13. HMS Smoke Analysis from May 21-26(a-f), 2016.

3.2 Satellite Observed Carbon Monoxide Plumes

Further evidence of smoke plumes travelling in to Connecticut 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 in Figure 14, as darker red pixels, as it meanders across eastern North America. The plume 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 15 shows the CO plume dispersing over the Midwestern States and then moving east into Connecticut. The May 20th satellite image in Figure 16 is consistent with the CO plume location over Connecticut. Figure 17 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. Click link to view an animation[17] 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.

[17] http://www.ct.gov/deep/lib/deep/air/ozone/2016_exceptional_event_request/may_co_animation.gif

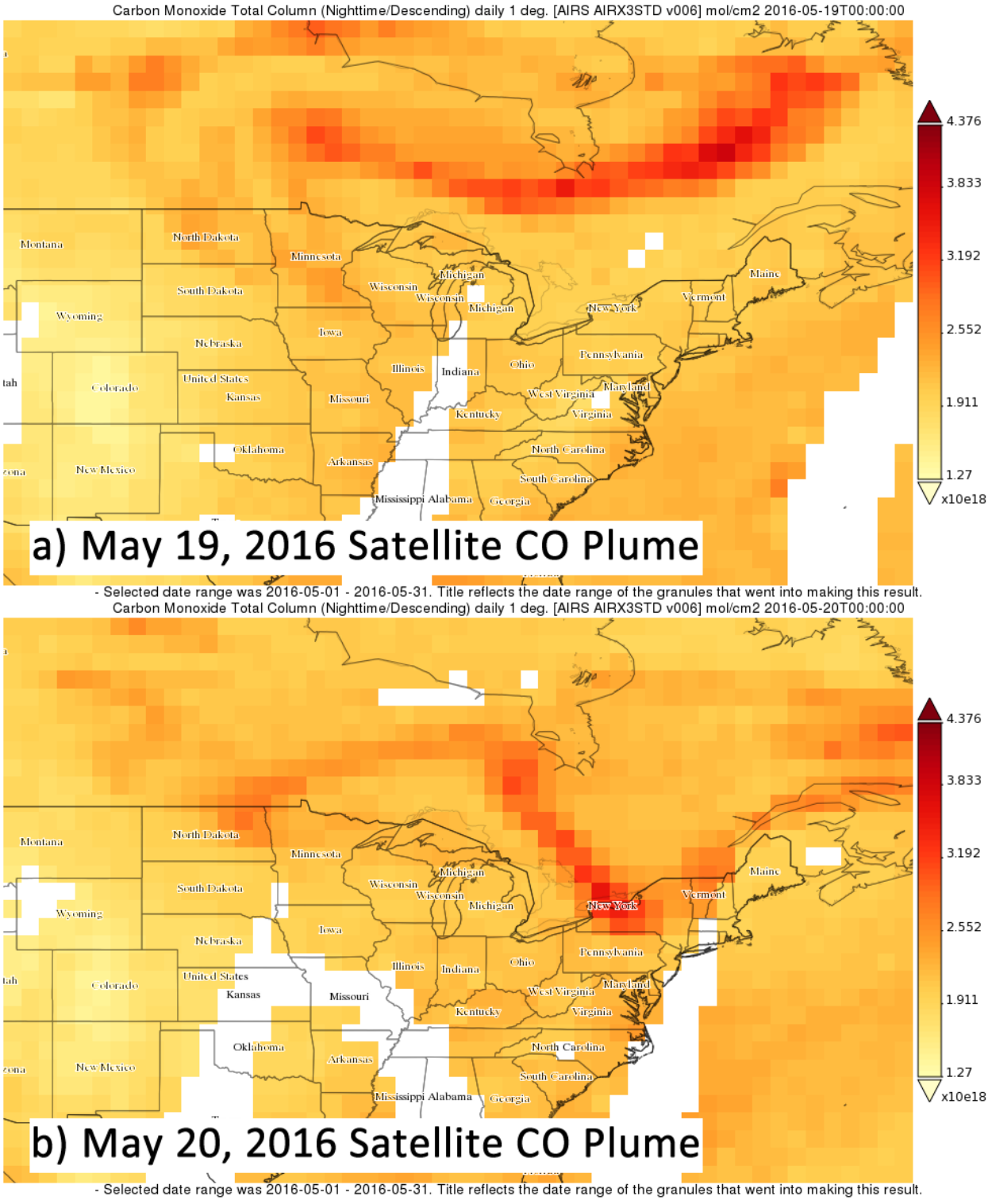


Figure 14. Satellite CO Plume from May 19 (a) and May 20 (b) , 2016. The plume meanders across southern Canada into the U.S. Midwest and across Connecticut.

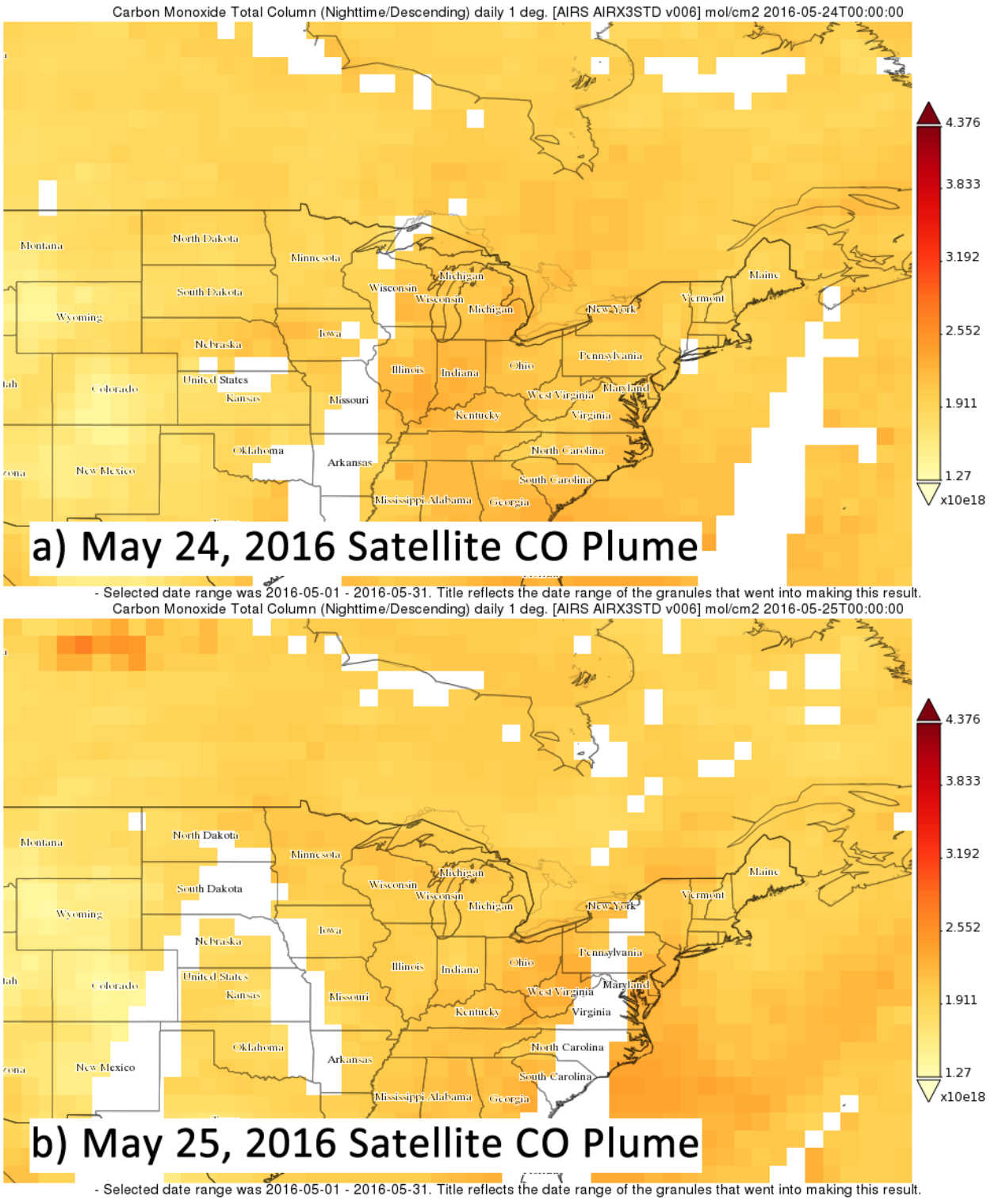


Figure 15. Satellite CO Plume from May 24 (a) and May 25 (b) , 2016. The elevated CO plume settles over the Midwest States and moves east into Connecticut.

Figure 16. May 20, 2016 VIIRS Satellite Images: Visible on left; AOD on right

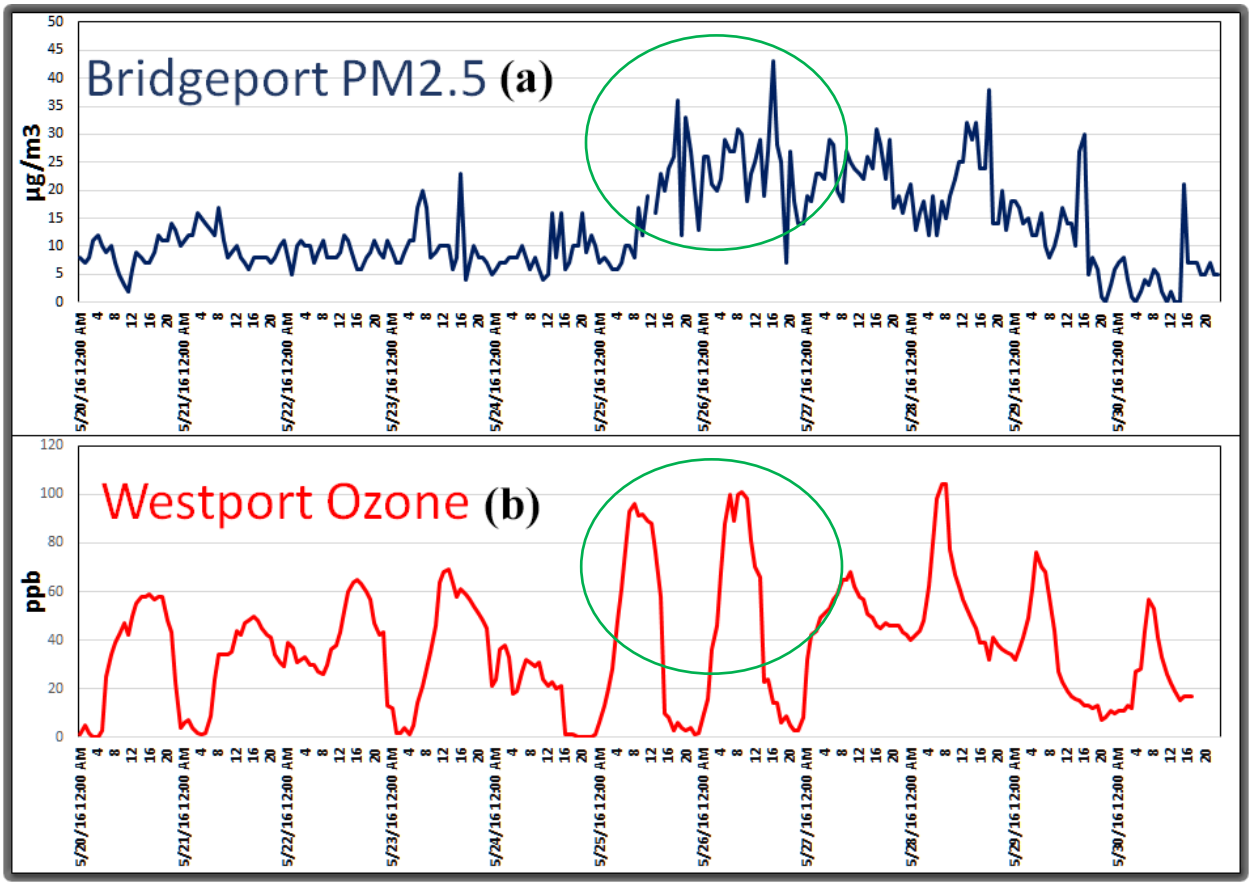


Figure 17. May 20-30, 2016 plots of (a) Bridgeport CT PM2.5 and (b) Westport Ozone Hourly Concentrations. The ozone peaks at Westport on May 25-26 coincide with the PM2.5 peaks at the Bridgeport monitor.

3.3 Webcams

Figure 18(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 18a) but can be seen increasing on May 25th (18b,c) and continues on May 26th (18d).

Figure 19(a-d) shows images from our Talcott Mountain webcam pointing east toward Hartford. Showing a similar sequence of smoke progression as Cornwall, May 24th (Figure 19a) shows a clean air mass with good visibility while the smoke obscures the sky on May 25-26th (Figure 19b,c,d).

Figure 20 shows images from the Newark New Jersey HazeCam[18] showing the progression of smoke over the May 24-27 period. An animation of these images is available from our web site[19].

The visible satellite photographs over Connecticut on May 25th (Figure 21a) and May 26th (Figure 21b) confirm evidence of a smoke plume.

[18] http://www.hazecam.net/camsite.aspx?site=newark
[19] http://www.ct.gov/deep/lib/deep/air/ozone/2016_exceptional_event_request/newark_hazecam_animation.gif

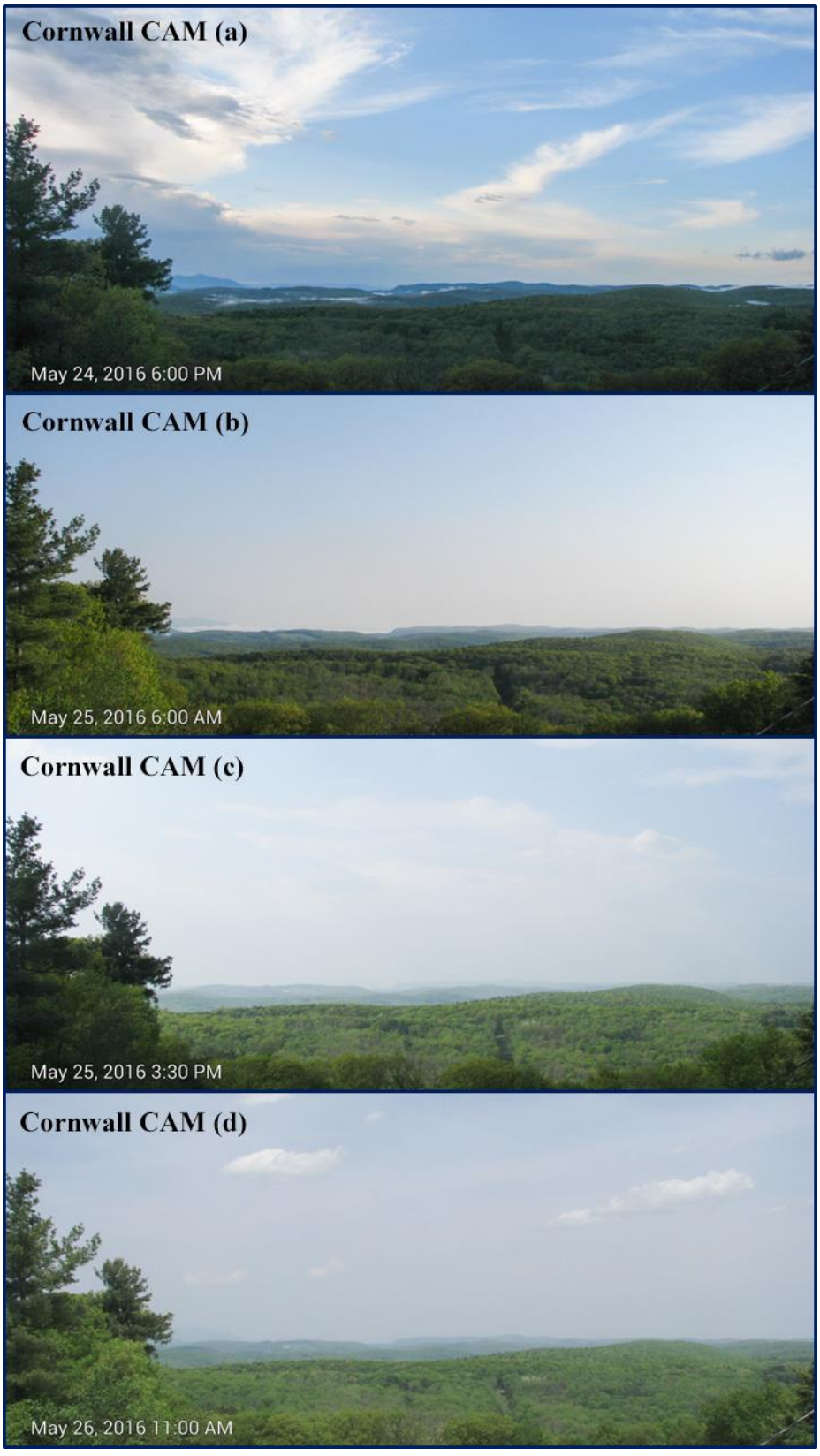


Figure 18. Cornwall Connecticut Webcam. (a)May 24-6:00pm, (b)May 25-6:00am), (c)May 25- 3:30pm and (d)May 26-11:00am, 2016.

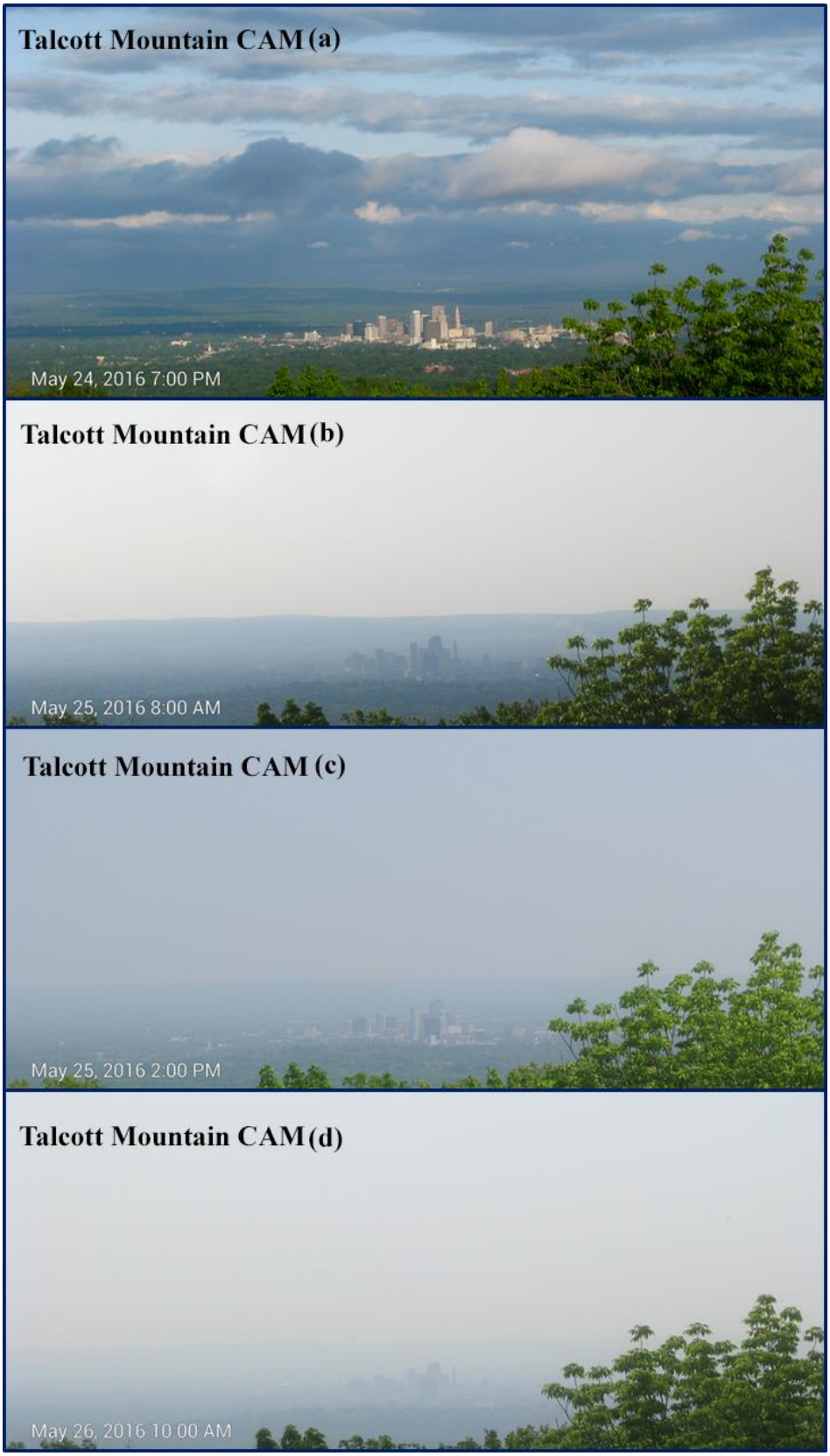


Figure 19. Talcott Mountain Connecticut Webcam. (a)May 24-7:00pm, (b)May 25-8:00am), (c)May 25- 2:00pm and (d)May 26-10:00am, 2016.

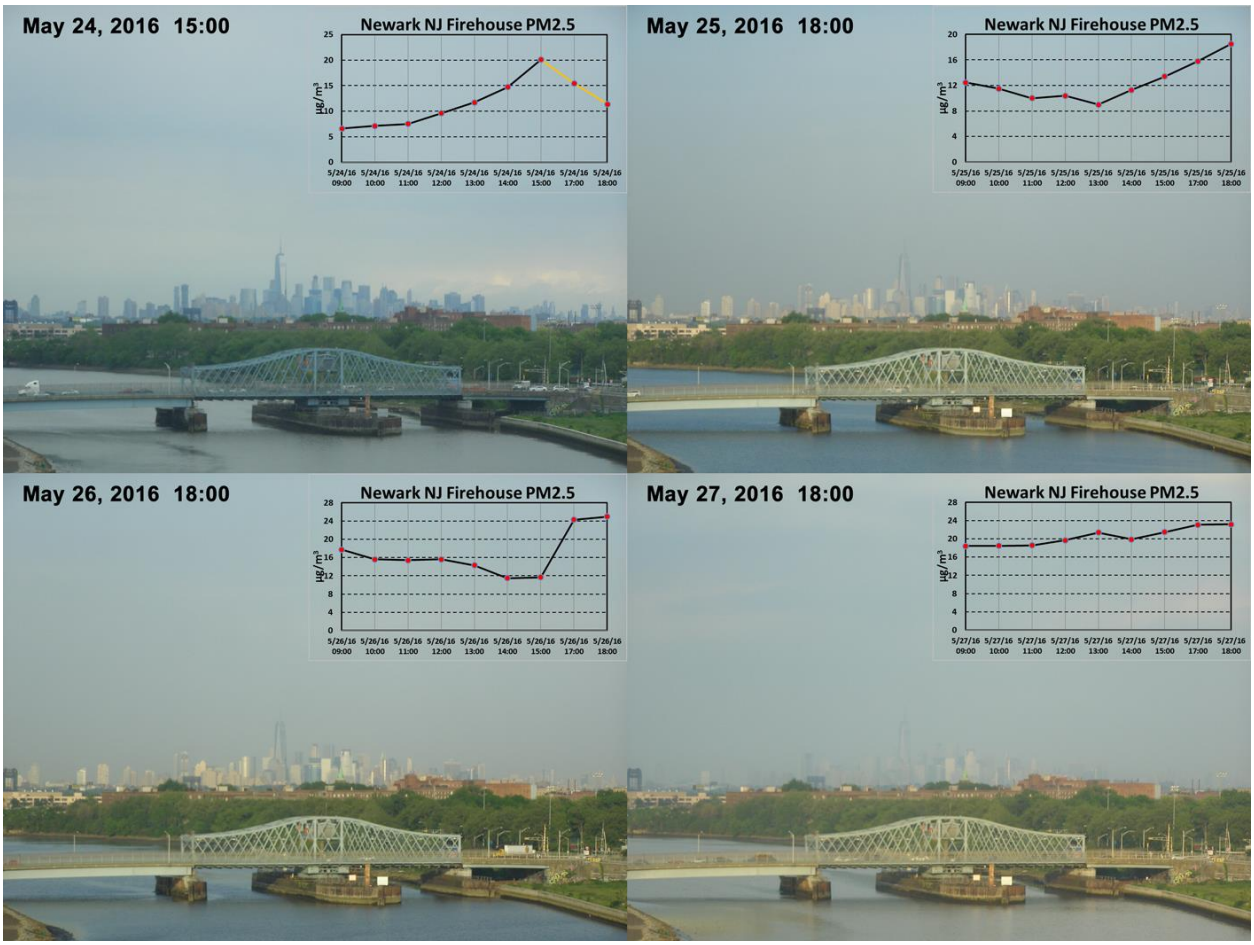


Figure 20. Haze Cam image looking from Newark, NJ to New York City. Images from May 24-27, 2016 with inset of hourly PM2.5 concentration plots of each day from the Newark Firehouse monitor.

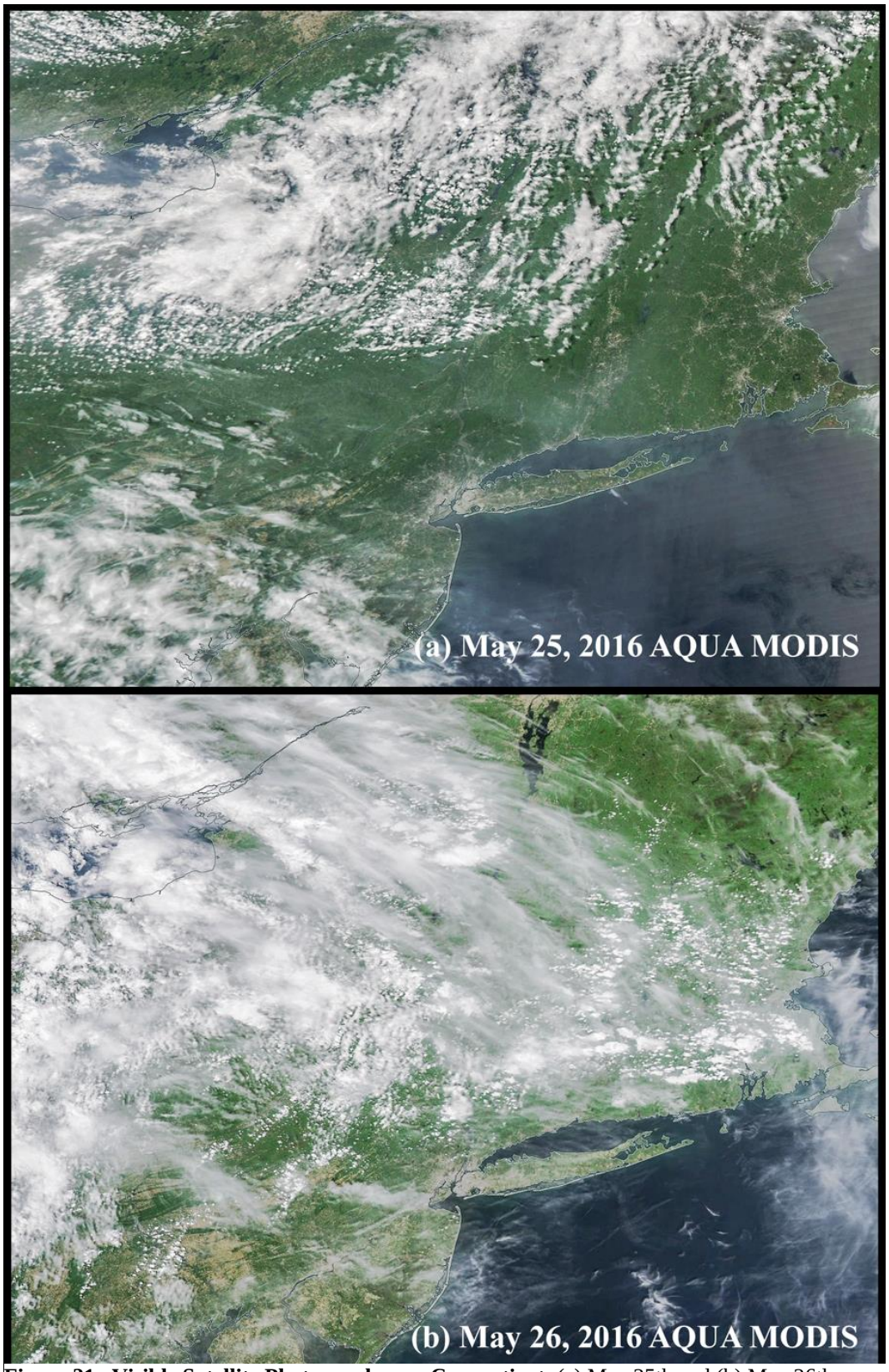


Figure 21. Visible Satellite Photograph over Connecticut. (a) May 25th and (b) May 26th, 2016, showing visible smoke plume.

4. MONITORING DATA

4.1 Monitoring Network

There are currently fourteen air monitoring stations operating in Connecticut's state-wide network, including 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 4 provides a summary of pollutant and meteorological parameters currently monitored in the network.

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.

Table 4. List of Connecticut Ambient Air Monitoring Sites and Parameters. Shaded rows indicate the monitors being requested for exclusion as a result of the Fort McMurray wildfire.

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

Ozone is monitored throughout the ozone season in Connecticut at the twelve sites shown in Figure 22. As of 2017, the ozone monitoring season is March 1 through September 30; previously it was April 1 through September 30. Cornwall has historically measured ozone throughout the year, and as of late 2016 two more sites, East Hartford and New Haven, also began monitoring throughout the year.

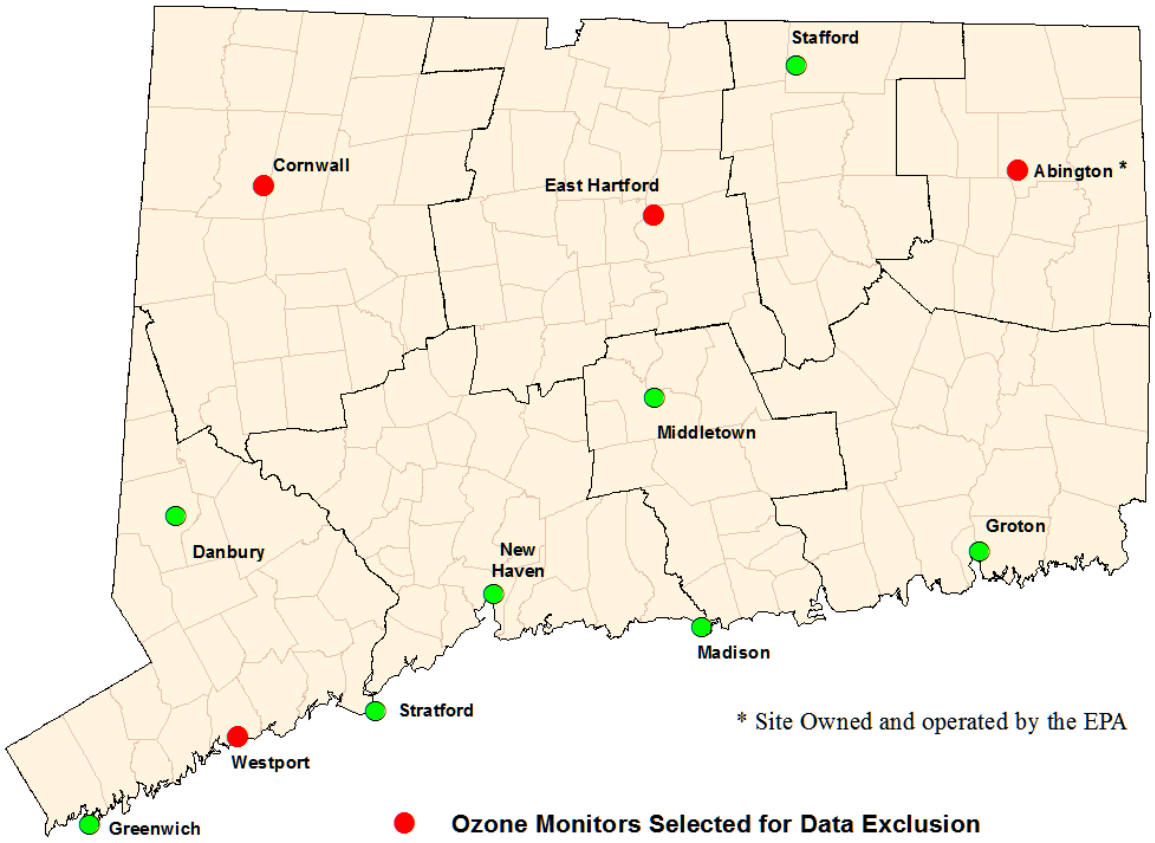


Figure 22. Connecticut Ozone Monitors. Ozone Monitors Selected for Data Exclusion are Highlighted in Red.

Site Descriptions

This exceptional event demonstration is focused on the four monitoring sites described below that were selected for data exclusion. These are: Westport (Sherwood Island State Park), Cornwall (Mohawk Mountain), East Hartford (McAuliffe Park) and Pomfret (Abington).

To help characterize the sites, ozone wind roses were constructed for the period of April 1, 2012 through September 30, 2016. The Cornwall measured ozone year-round, while the other three sites were operating from April 1- September 30th consistently during the five year period. These ozone wind roses are constructed from matching hourly averaged wind vector direction vectors and the hourly monitored ozone concentrations (ppb). Hours with average winds speeds less than 0.25 m/s or with missing ozone data were not plotted. Since the Abington monitoring site is not operated by CT DEEP and does not have wind data, we used wind data from our Mansfield site, which is located about 14 miles to the southwest of Abington. These ozone wind roses show the prevailing wind directions divided into 16 sectors around the compass with due

north at the top. The longer 'petals' of the rose represent sectors where the wind direction is more prominent. Overlaid on these petals are color bars representing specific ranges of ozone concentrations for each wind direction sector. The unique surrounding geography of each site will be reflected in the surface wind patterns. Therefore, the five year wind roses will appear much different for each site and only limited conclusions can be obtained in relation to ozone concentrations.

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 and sits at an elevation of 683 feet and generally has the lowest monitored ozone of all the sites. The wind data was obtained from our nearby Mansfield site (250 feet elevation), which is situated in a shallow valley that is oriented west to east. Because of this, the dominant wind direction is from the west-northwest to northwest (Figure 23). The highest ozone concentrations originate from the south-southwest wind direction.

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. Figure 24 shows the dominant wind direction from the north-northwest, which includes the winter months. The highest ozone concentrations of 70-85 ppb (magenta color bar) are shown to occur when the wind is blowing from the south and south-southwest, which is to be expected when there is transport from the I-95 corridor and New York City area. Moderate levels of ozone (55-70 ppb) are also shown to occur in the northwest quadrant, but are most prevalent from the southwest quadrant. The dominant direction for good air quality (<55 ppb) occurs when the wind blows from the north-northwest.

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 from this site. Since the East Hartford site is located in the Connecticut River Valley and the valley is oriented north-south, the dominant wind direction reflects this in Figure 25. Since this ozone wind rose does not cover the winter months, winds from the south become more dominant. The highest ozone concentrations represented in the magenta and brown color bars are plainly visible in the south and south-southwest wind directions. The lowest ozone concentrations occur when the wind blows from the north.

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. Because Westport is coastal site, its winds are often subject to a daily sea breeze that develops during the summer. A prominent spike of high ozone can be seen from the south-southwest wind direction (Figure 26), which is indicative of transport from the I-95 corridor and New York City. Even when the dominant wind is from the northwest over inland areas of the State, the surface wind will turn southwest along the coast. This fact makes it more difficult to correlate surface winds with ozone transport as it is also observed that the highest proportion of good air quality winds (<55 ppb) also come when surface winds originate from the southwest for this site.

Generally, the worst ozone at each site is monitored when the surface winds are from the south-southwest while the winds from the northwest, the dominant wind direction during the May 2016 Fort McMurray wildfire event, are cleaner.

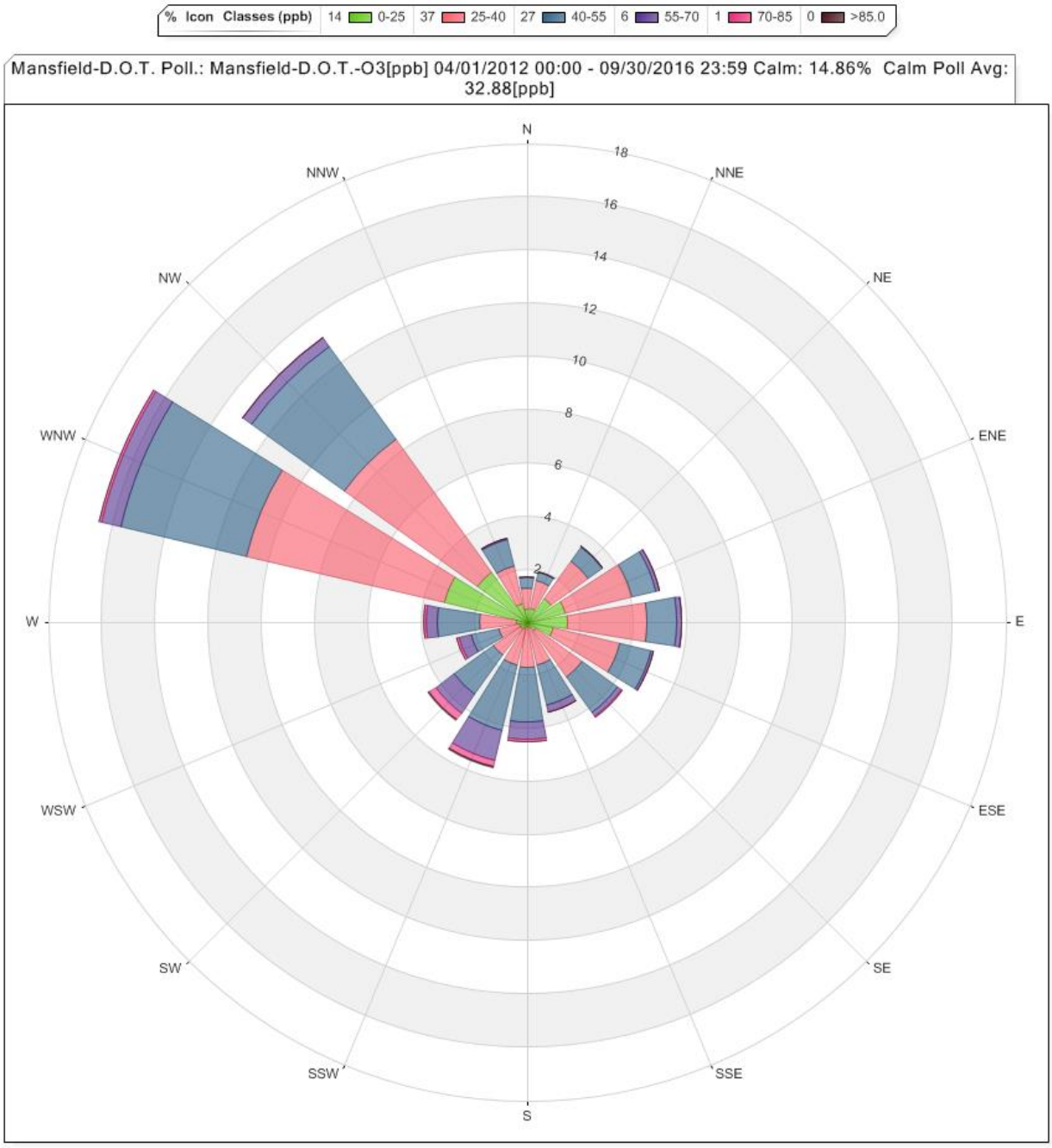


Figure 23. Ozone Wind Rose from Abington Connecticut.

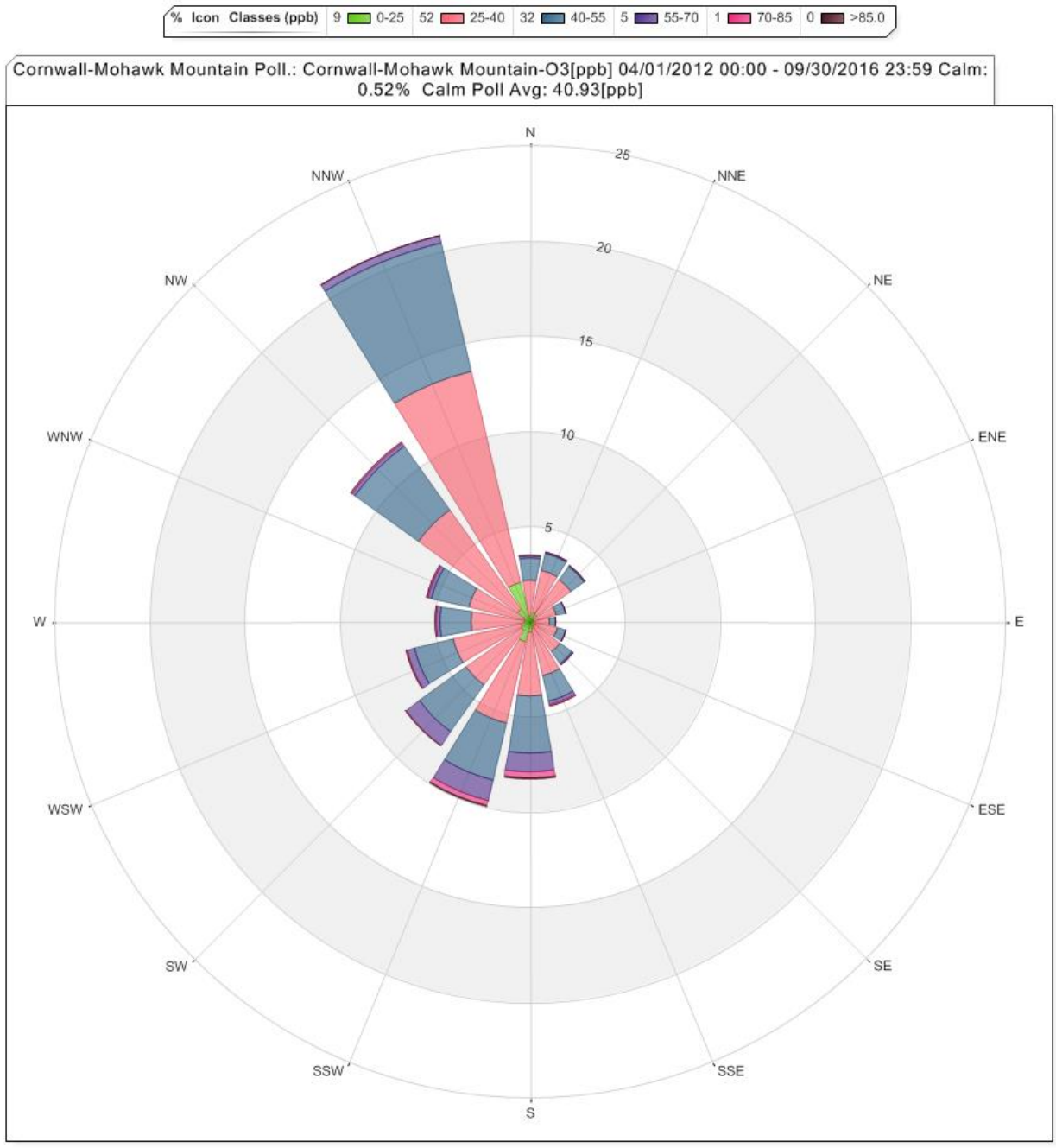


Figure 24. Ozone Wind Rose from Cornwall Connecticut.

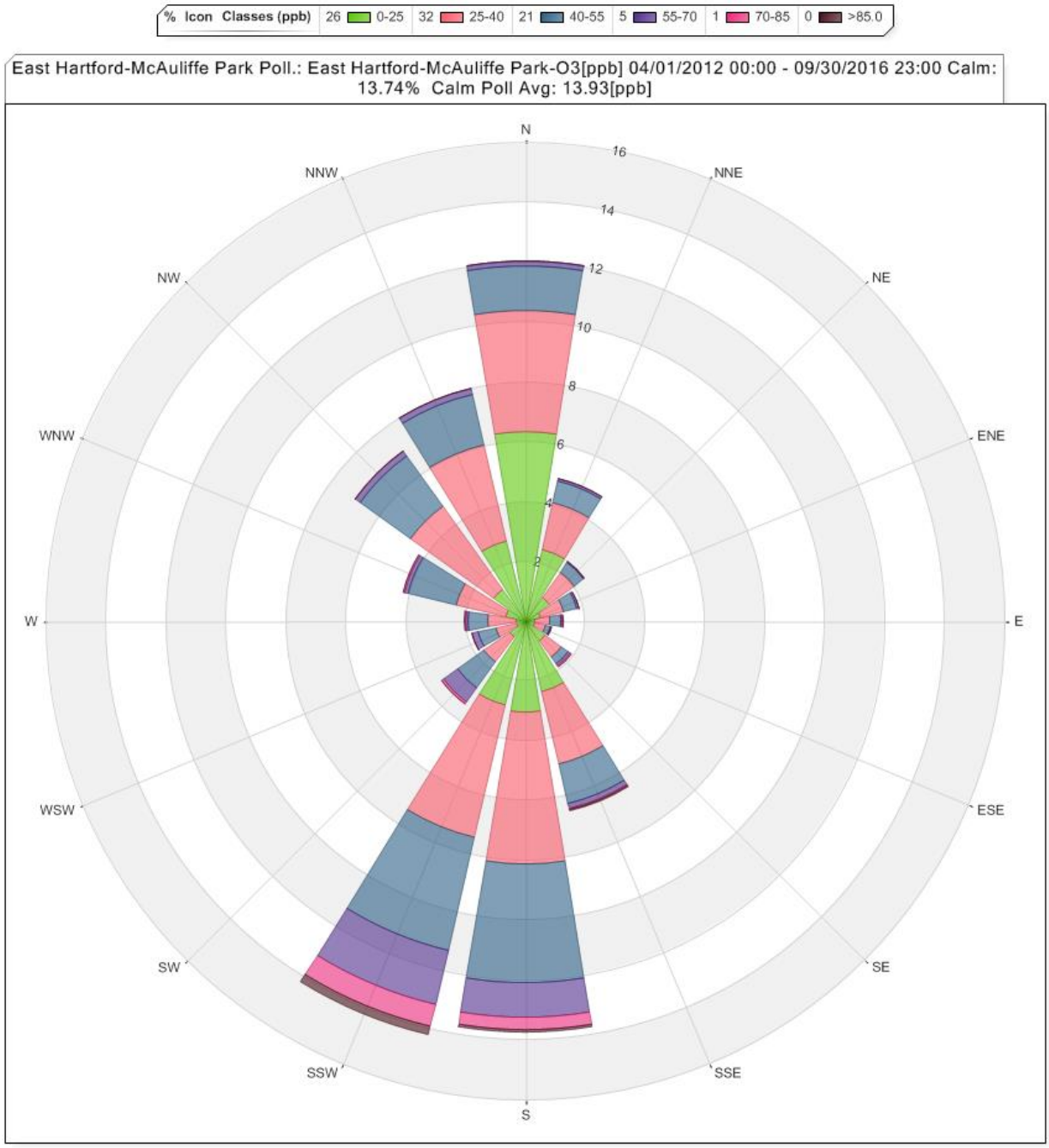


Figure 25. Ozone Wind Rose from East Hartford Connecticut.

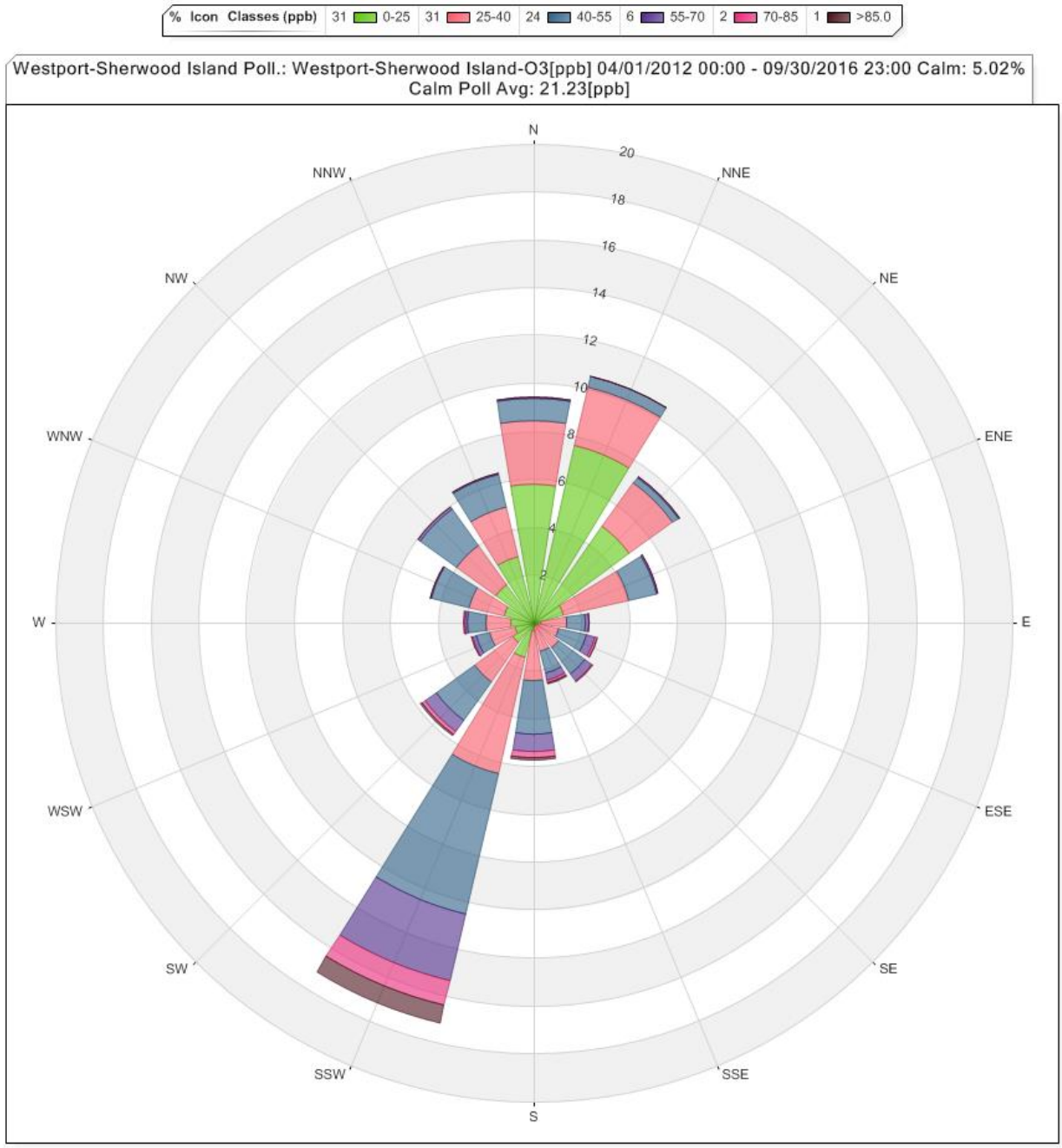


Figure 26. Ozone Wind Rose from Westport Connecticut.

4.2 Ozone Monitored Data

Figure 27 shows the hourly ozone concentrations for the four monitors from May 24-30, 2016. Ozone levels on the 24th are typical of May with a northerly wind direction. Levels spike on the

25th and remain high with a slight decrease on the 27th as cleaner maritime air pushes the ozone northward to Cornwall. Ozone levels increase again on the 28th at Westport and East Hartford before decreasing again by the 30th with a brisk influx of clean maritime air. The decrease at Abington, from the 27th through the 28th was likely due to the persistent mixing with the cleaner maritime air. The increases at the East Hartford and Westport sites on May 28th were likely due to the maritime having less impact on western Connecticut. Transport from the I-95 corridor was occurring during May 27-28th, however it was not a typical setup for a major ozone event.

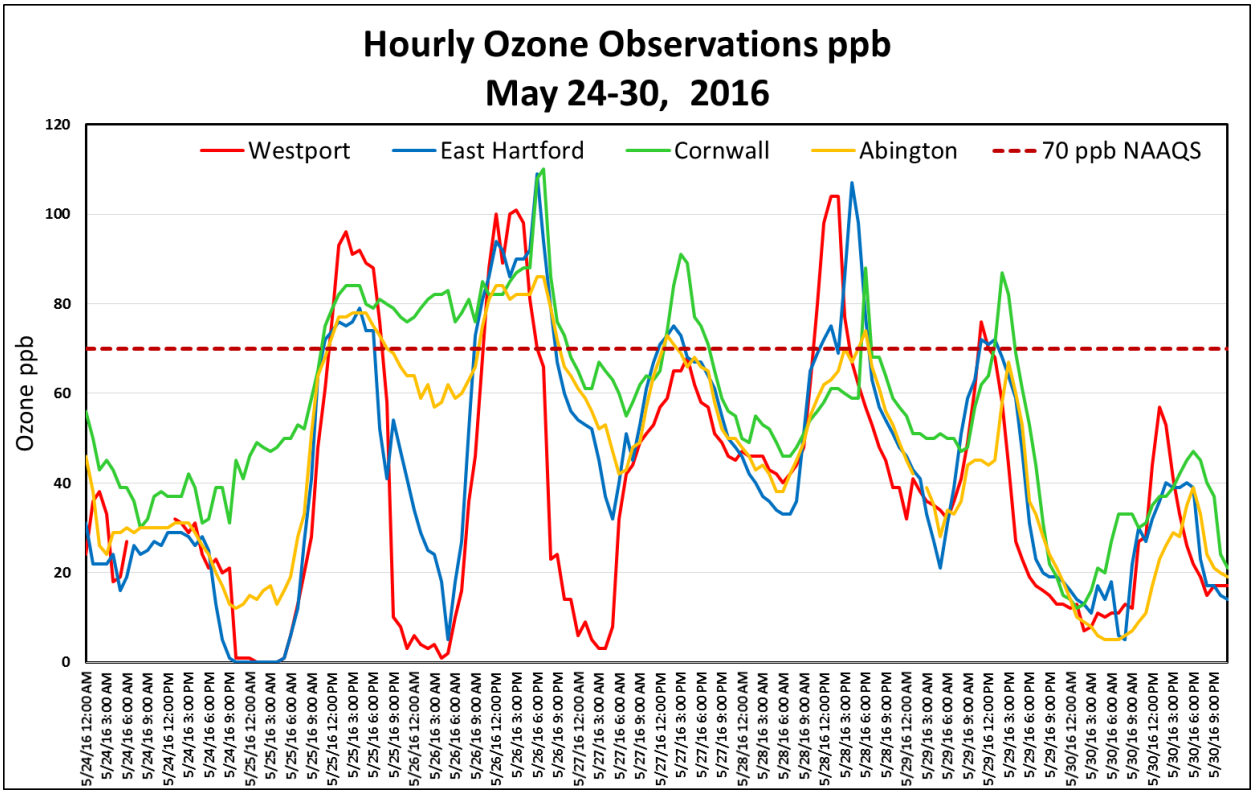


Figure 27. Hourly Ozone Concentrations for May 24-30, 2016 for Data Exclusion Sites.

Figure 28 shows the hourly ozone plots for the remaining seven monitors in Connecticut (Greenwich ozone data was invalidated). These sites show similar hourly ozone trends which may warrant data exclusions request in the future. Danbury showed the highest ozone values overall, likely experiencing the highest impact from the plume (see Figure 42), while Madison and Groton were similar to Abington, which would have had more mixing with maritime air.

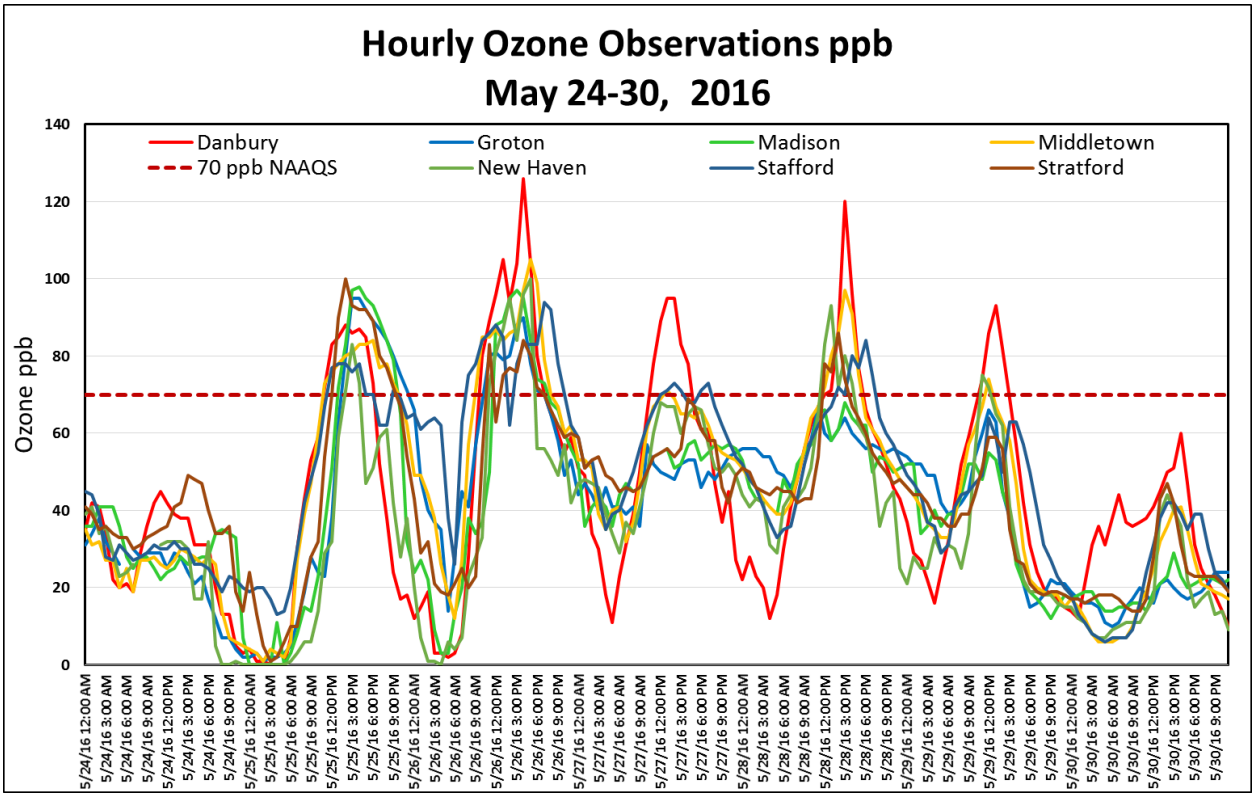


Figure 28. Hourly Ozone Concentrations for May 24-30, 2016 for remaining seven Connecticut Ozone Monitors.

4.3 Site Specific Outlier Analyses

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 provide strong evidence for the event.

The following table shows the maximum 8-hour daily ozone levels observed at the four sites on May 25th and 26th compared with the 99th percentile ranked 8-hour ozone levels observed during the last five years. The ozone levels at Abington and Cornwall exceeded the 99th percentile on both days and East Hartford and Westport approached the 99th percentile on the 25th and met or exceeded it on 26th.

Table 5. Five Year 99th Percentile Rankings for May 25th and 26th, 2016

Maximum Daily 8-hour Ozone (ppb) as measured by the monitors on the two days of interest and compared to the 99th percentile daily ozone value from the most recent five years of data.			
Site	May 25, 2016	May 26, 2016	99th Percentile of data from 2012 through 2016
Abington CT	76	83	74
Cornwall CT	81	91	79
East Hartford CT	75	93	78
Westport CT	87	90	90

To further illustrate the outlier status of the event, Figures 29 through 32 plot the ranked percentile 8-hour ozone observations at each site.

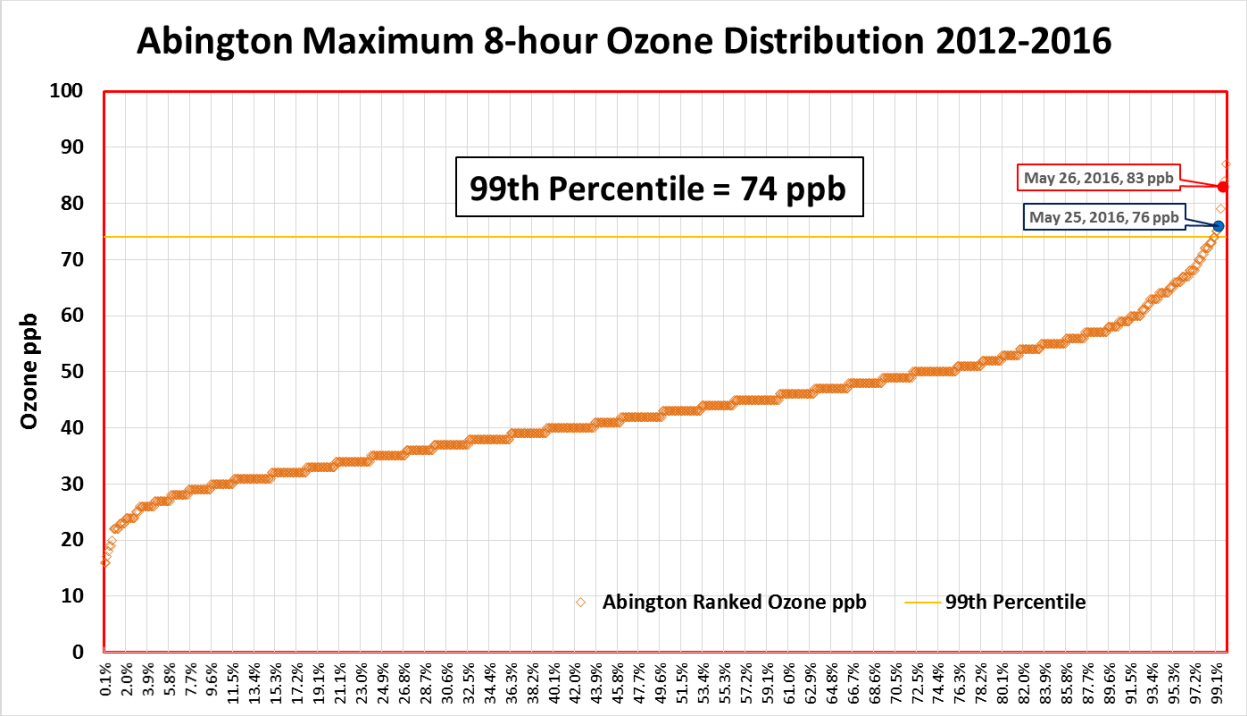


Figure 29. Ranked 8-hour Ozone Distribution for Abington CT 2012-2016

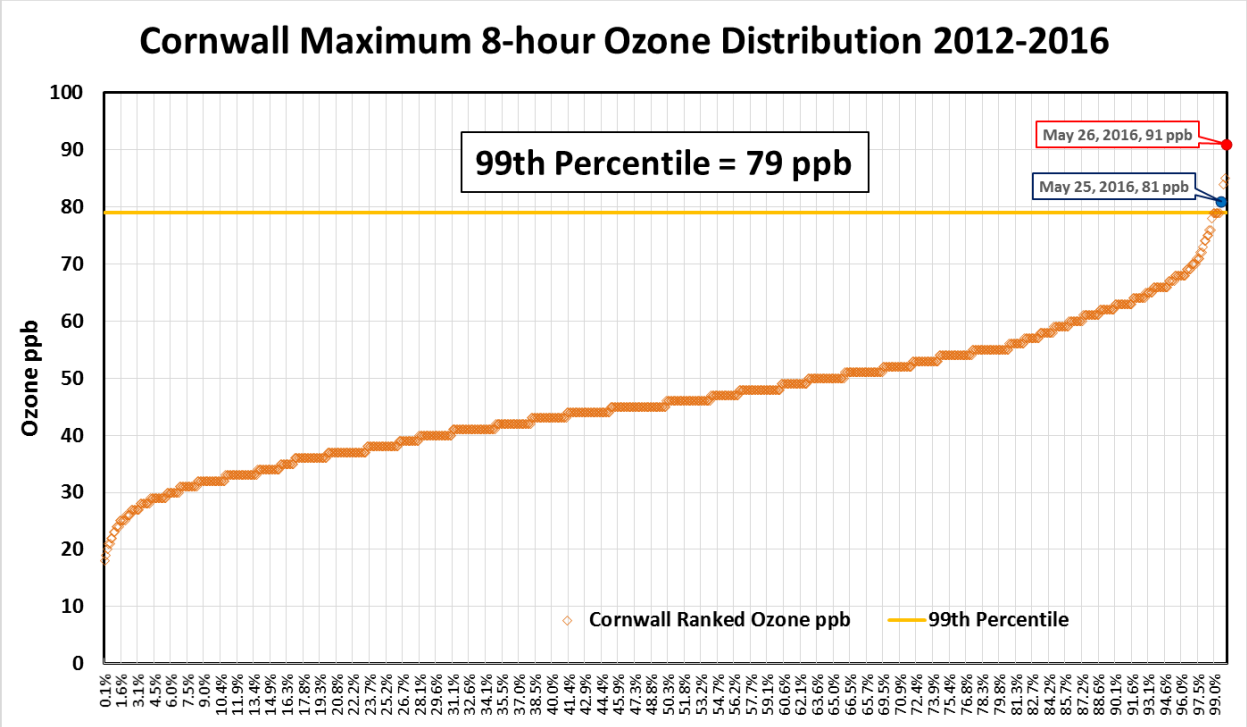


Figure 30. Ranked 8-hour Ozone Distribution for Cornwall CT 2012-2016

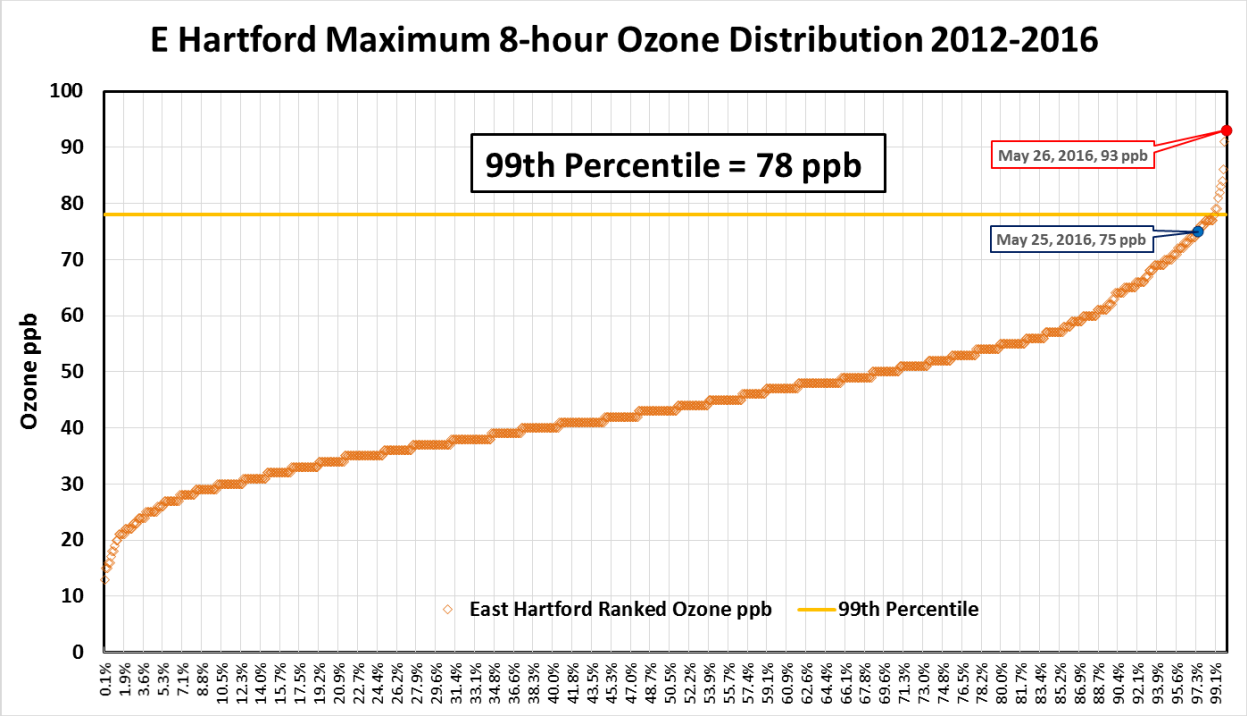


Figure 32. Ranked 8-hour Ozone Distribution for E Hartford CT 2012-2016

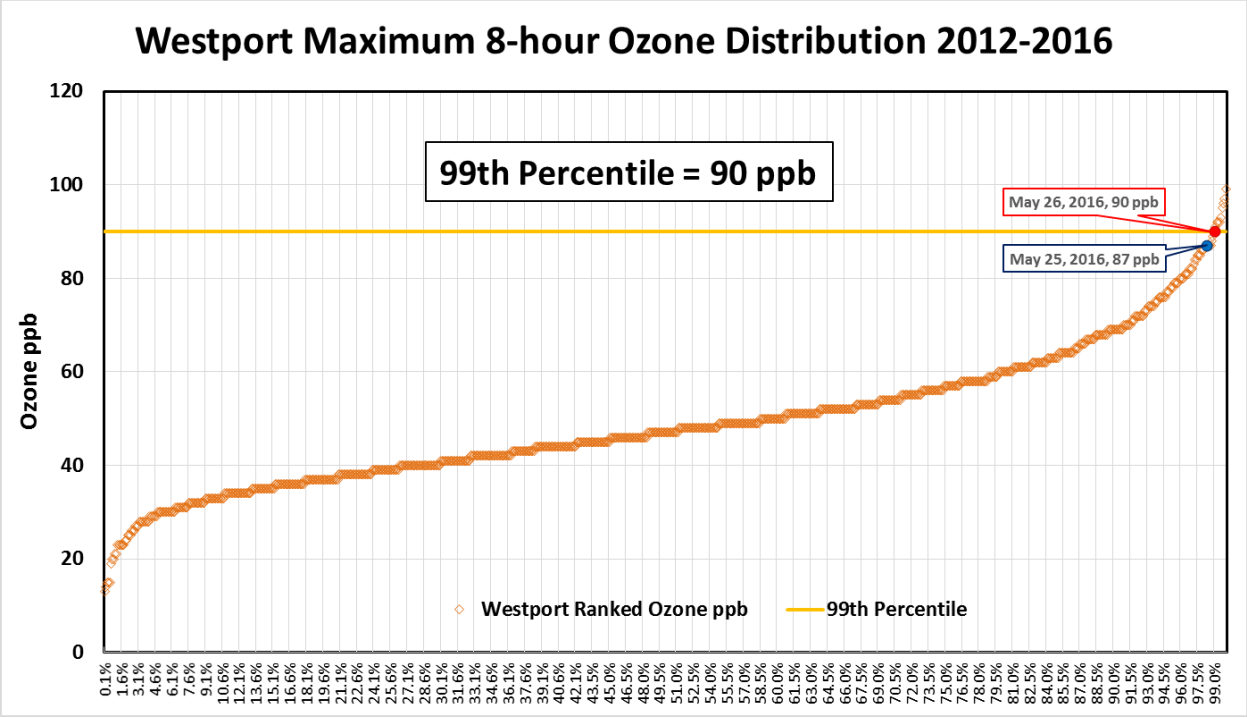


Figure 31. Ranked 8-hour Ozone Distribution for Westport CT 2012-2016

Figures 33 through 36 are plots of daily maximum ozone values for each of the four monitors of interest in Connecticut using five years of data. 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 33-36) when the filter is applied, but the percentile rankings do not always increase since there are generally 75% fewer 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 because ozone was likely transported from Long Island sound by the surface sea breeze. 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 already presented in figure 4. Back trajectories over New York State would pass over a region with NOx emissions generally below the 50^{th} percentile of the total.

Cornwall Connecticut

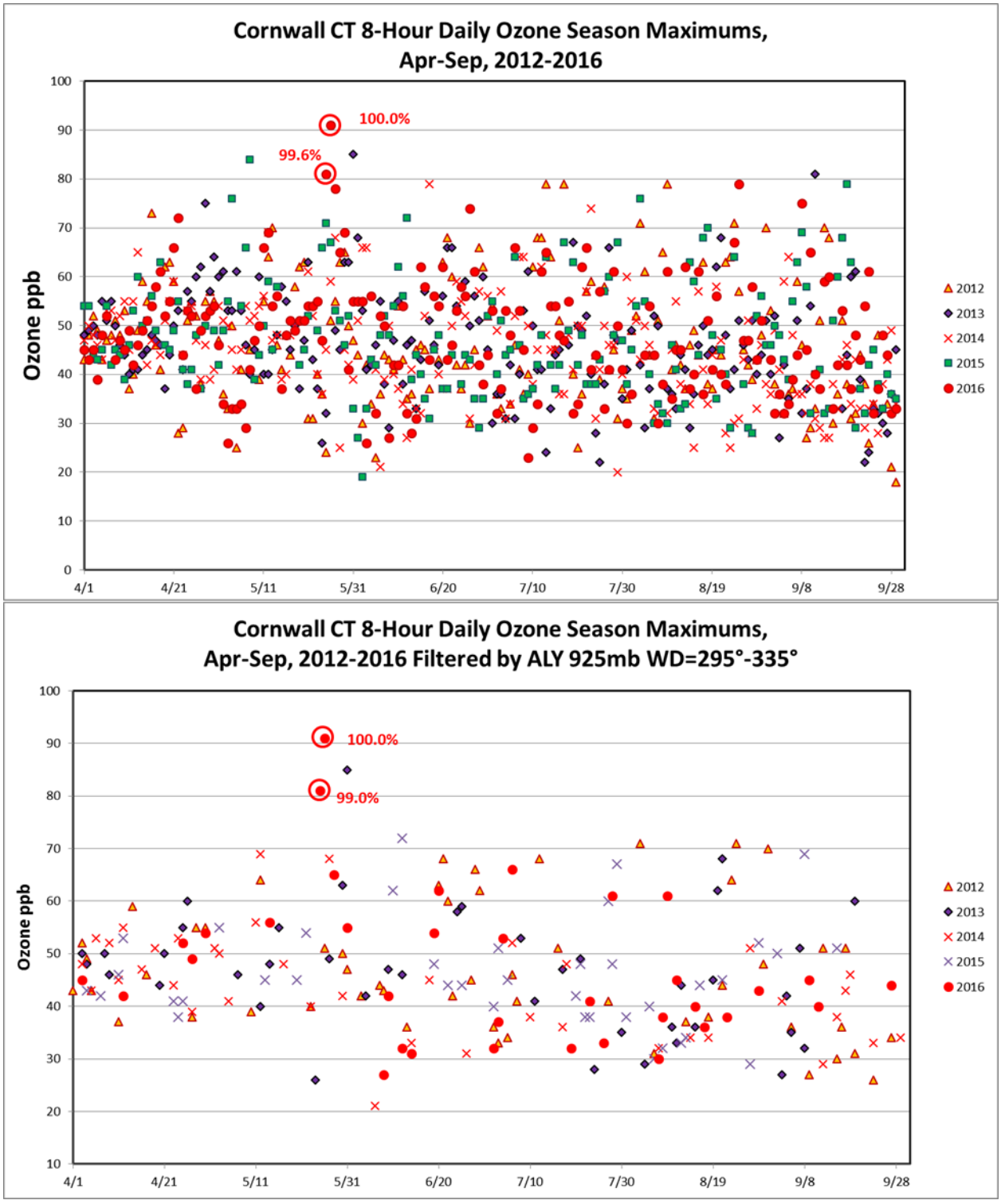


Figure 33. Cornwall CT Daily Ozone Season Maximums 2012-2016

East Hartford Connecticut

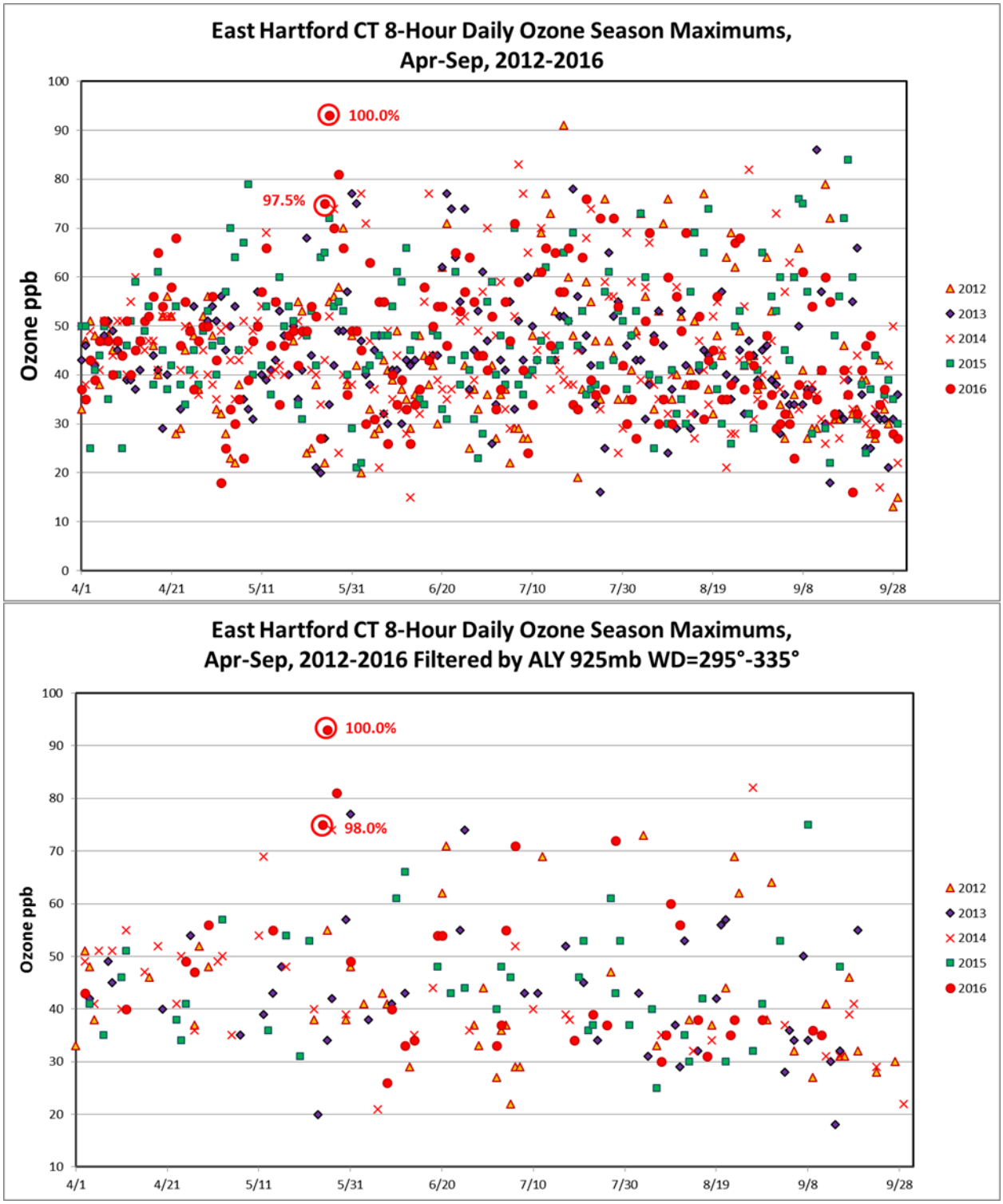


Figure 34. East Hartford CT Daily Ozone Season Maximums 2012-2016

Abington Connecticut

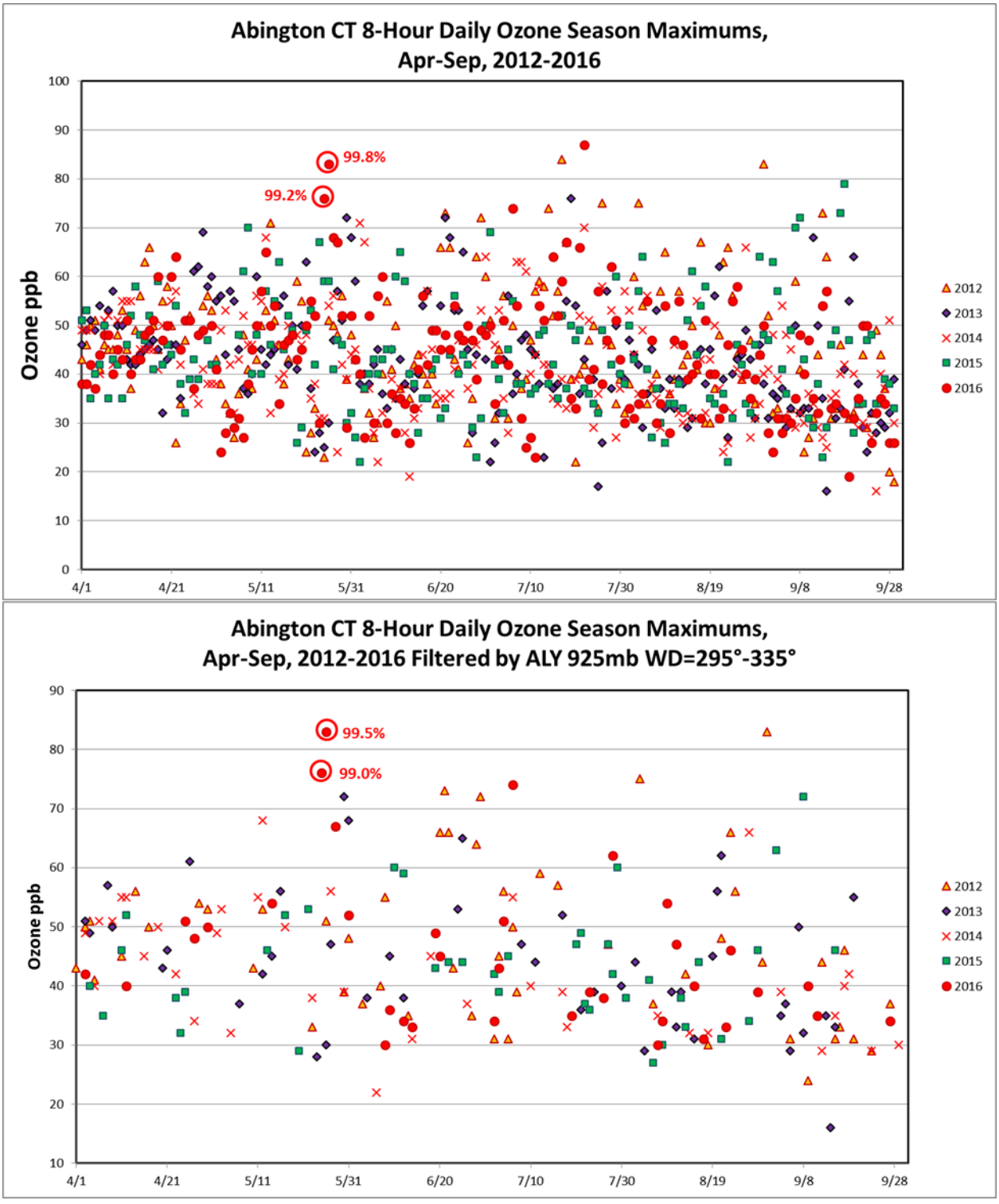
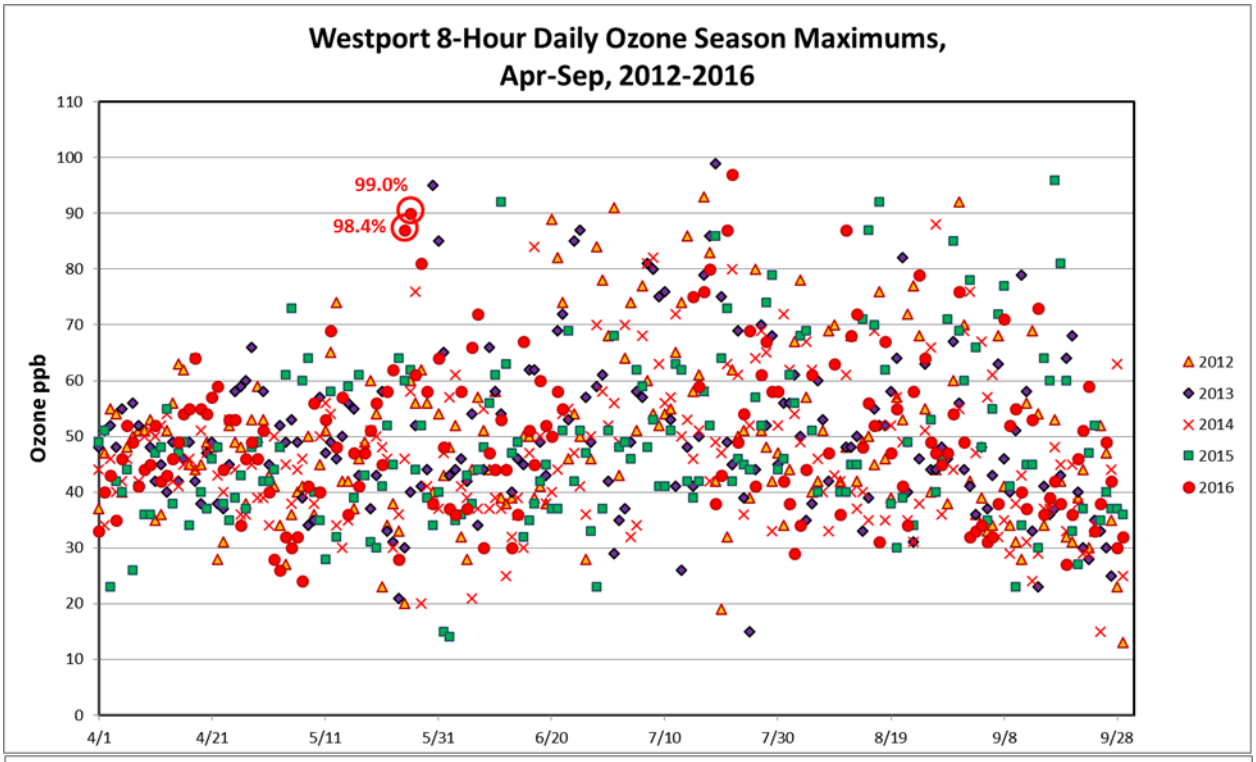


Figure 35. Abington CT Daily Ozone Season Maximums 2012-2016

Westport Connecticut



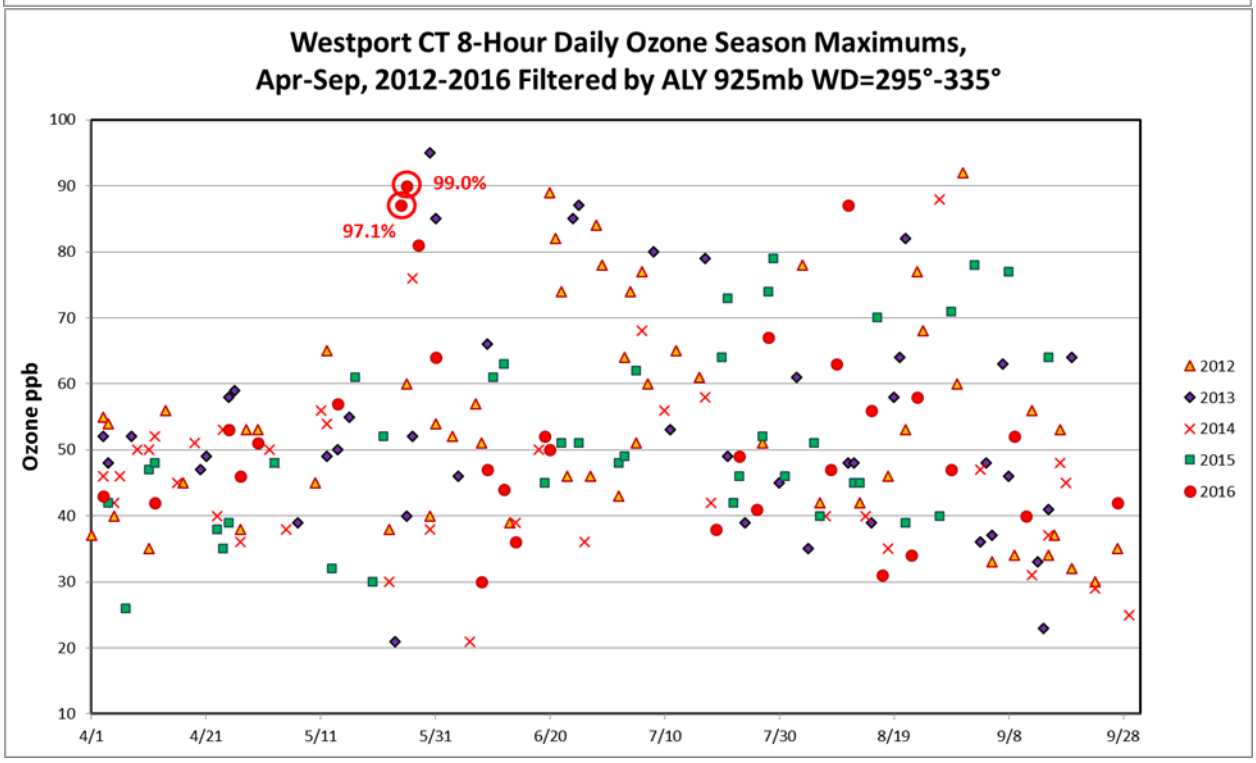


Figure 36. Westport CT Daily Ozone Season Maximums 2012-2016

4.4 Particulate and Smoke Related Monitored Data

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 37 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.

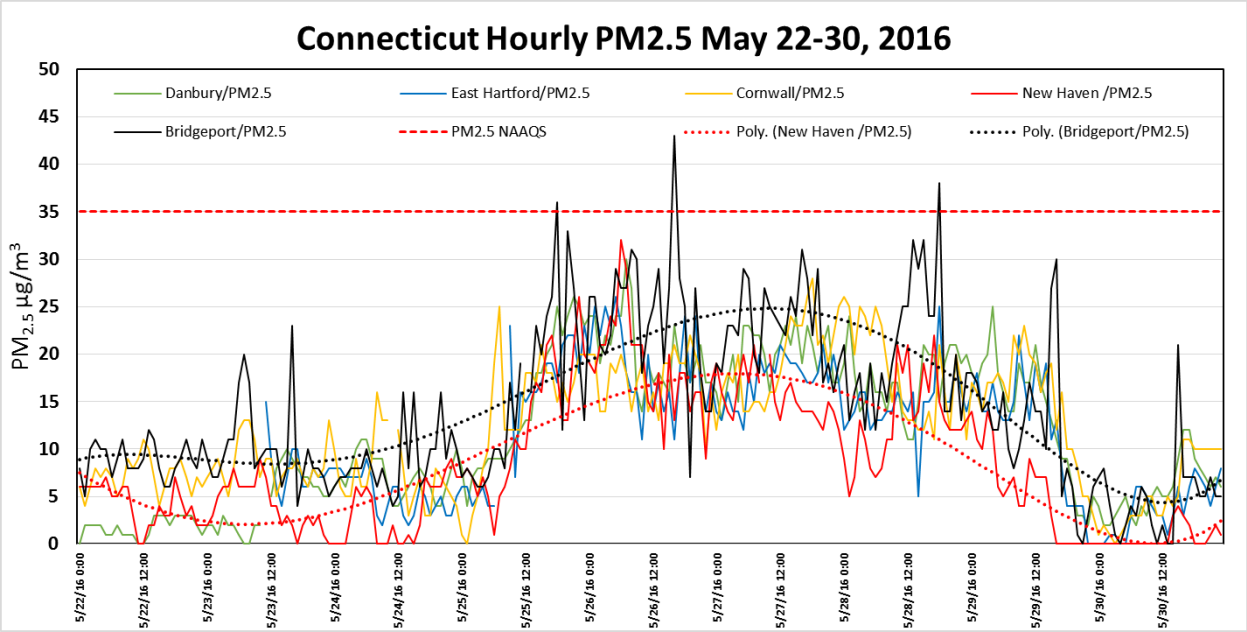


Figure 37. Hourly PM2.5 Concentrations Recorded at Connecticut Monitors from May 22-30, 2016

Connecticut has an aerosol backscatter ceilometer operating at our New Haven monitoring site, from which can be produced, a 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 38, 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.

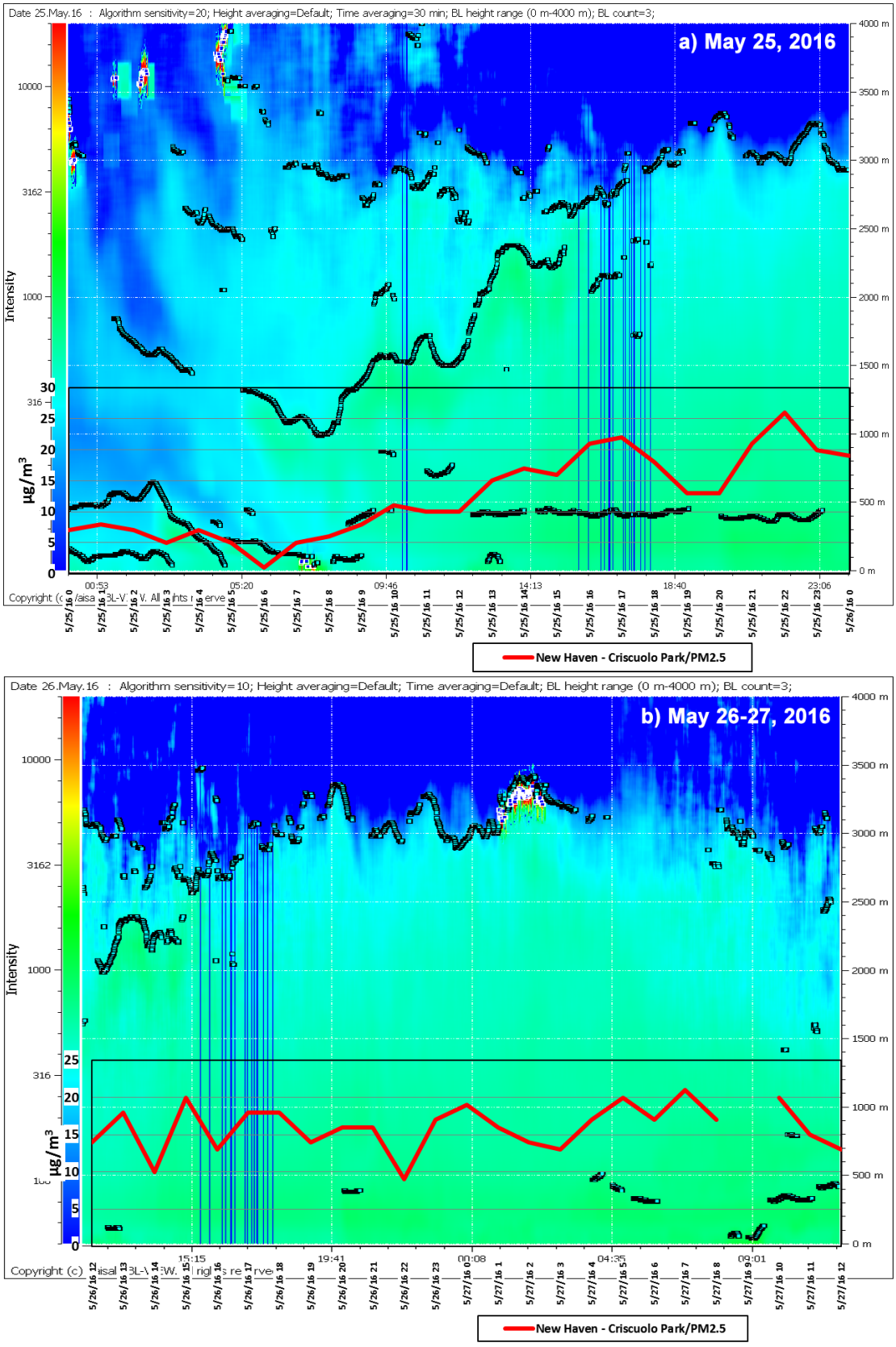


Figure 38. Aerosol Backscatter Intensity over New Haven with PM2.5 Levels

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 difference between the 370 and 880 Aethalometer measurements, in $\mu g/m^3$. It is a semi-quantitative indicator of biomass combustion. At rural summertime sites, DeltaC is very specific to wood smoke. Wood smoke has a BC component to it, ~ 10% of wood smoke 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.[20]

Our Cornwall monitor, in the northwest corner of the State, was one of the first sites to encounter evidence of smoke related pollutants during this event. The trends are consistent with what would be expected from a distant smoke plume. Figure 39 plots these pollutant trend with the hourly ozone concentrations. DeltaC (Figure 39c), indicative of wood smoke, shows large upward spikes starting on May 25th and BC (figure 39d) shows an increase in base levels together with increased hourly deviations. CO base levels (Figure 39b) also trend upward and increases on the order of 50% from the previous four days. Figure 39(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 40 and 41, East Hartford and New Haven respectively, show similar trends as the Cornwall monitor and Figure 42 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.

[20] 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

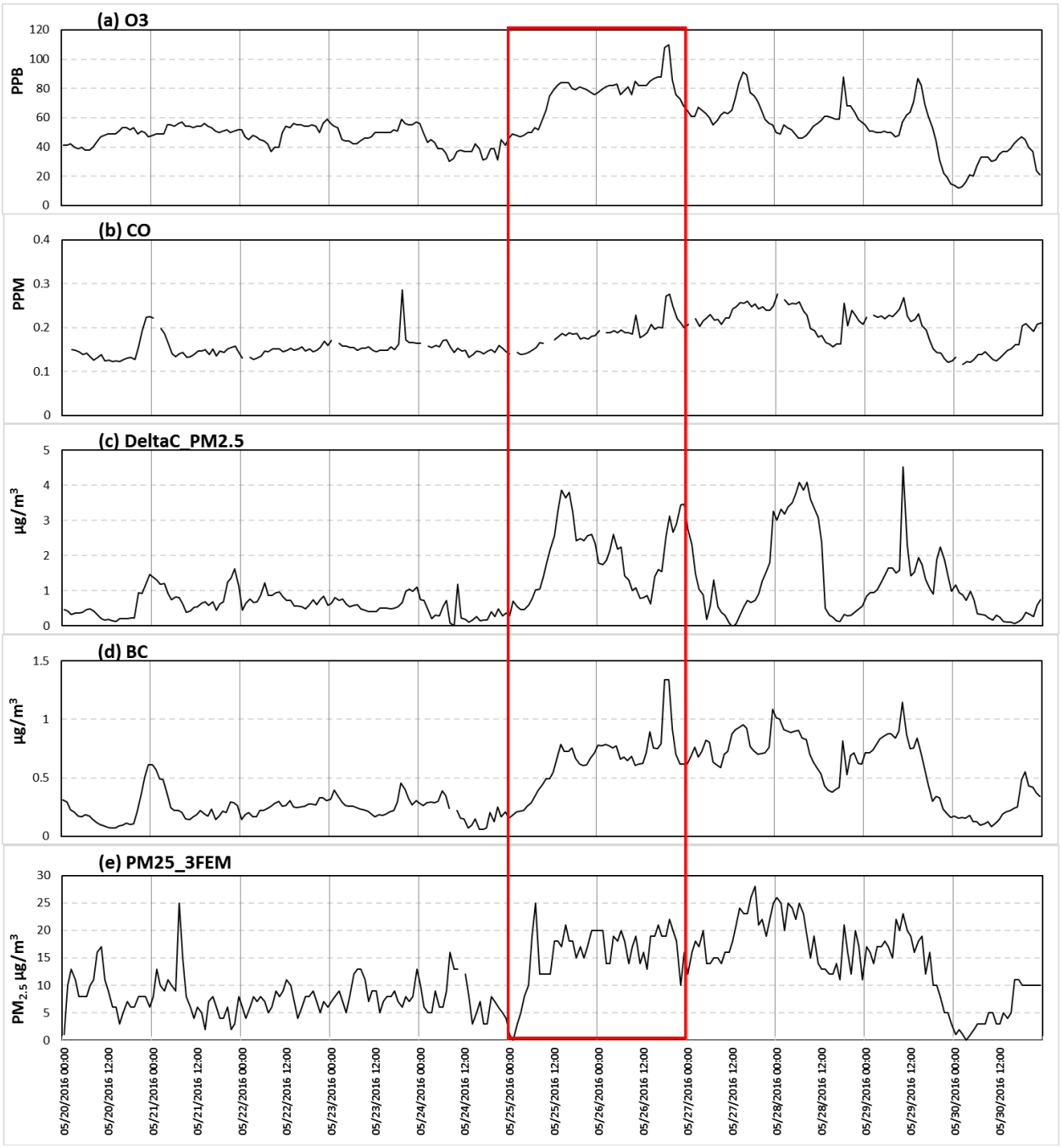


Figure 39. Monitored (a) Ozone, (b) Carbon Monoxide (CO) (c) DeltaC PM2.5 (d) Black Carbon (BC), and (e) PM2.5 at the Cornwall CT Monitor

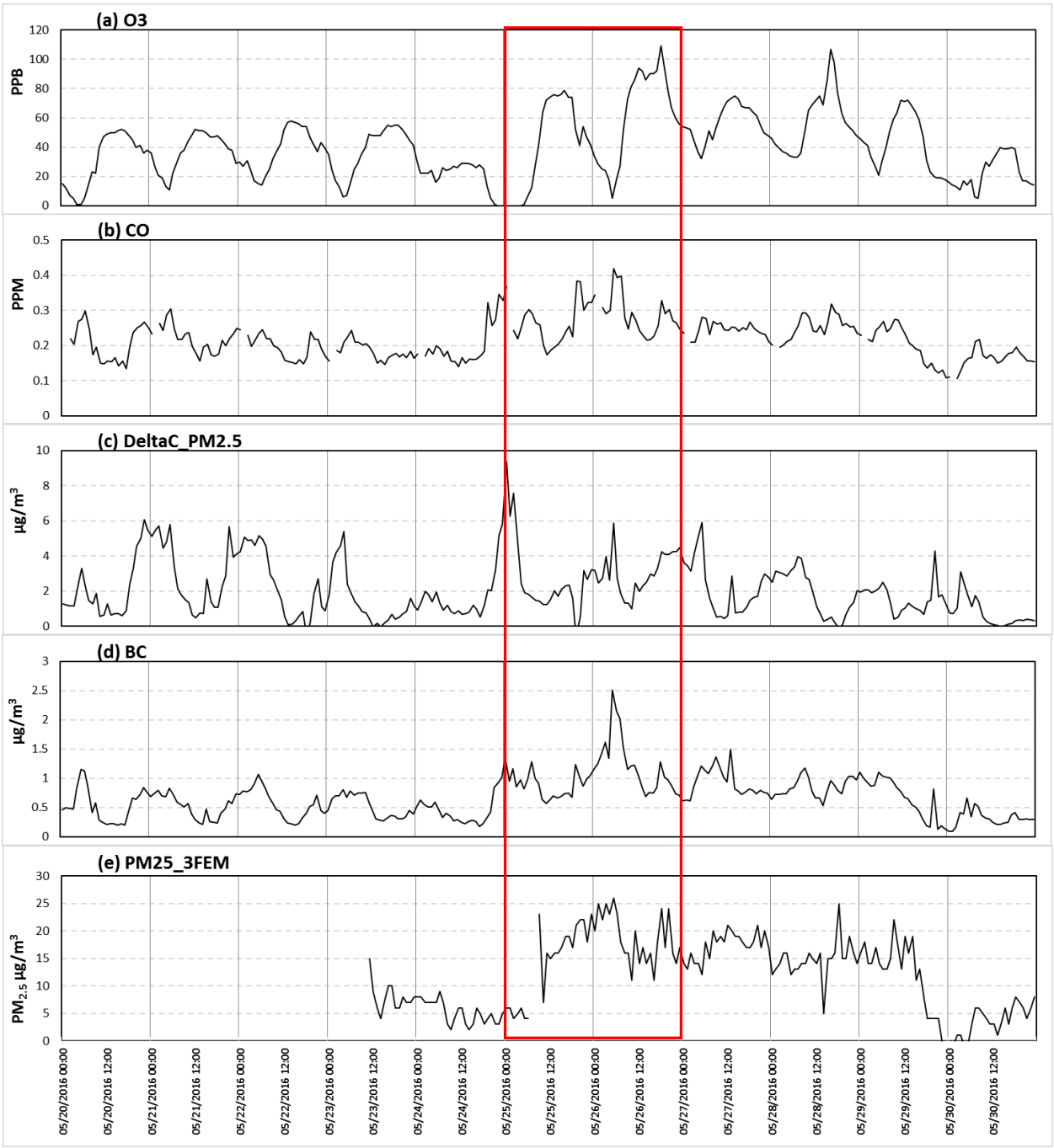


Figure 40. Monitored (a) Ozone, (b) Carbon Monoxide (CO) (c) DeltaC PM2.5 (d) Black Carbon (BC), and (e) PM2.5 at the East Hartford CT Monitor

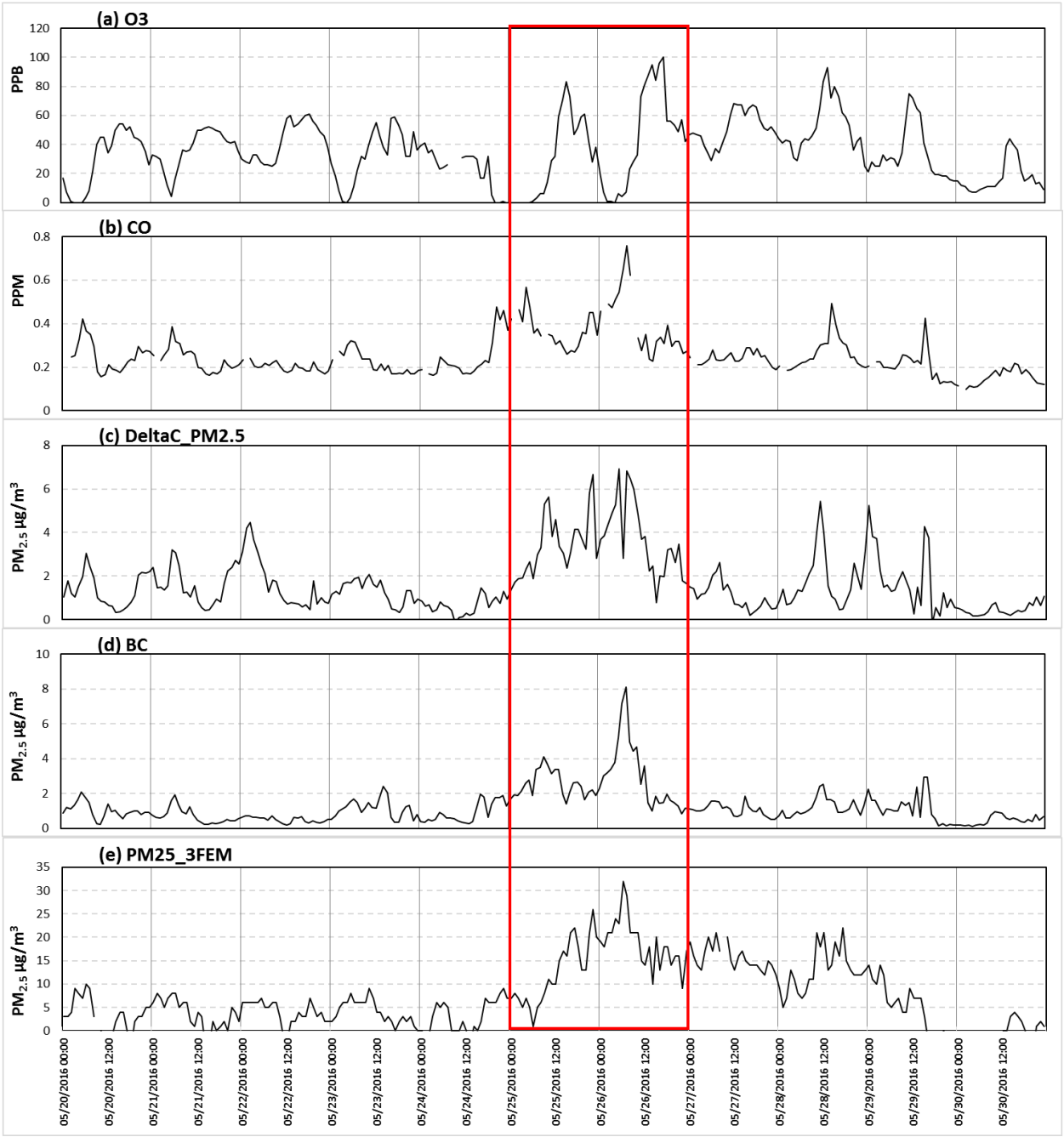


Figure 41. Monitored (a) Ozone, (b) Carbon Monoxide (CO) (c) DeltaC PM2.5 (d) Black Carbon (BC), and (e) PM2.5 at the New Haven CT Monitor

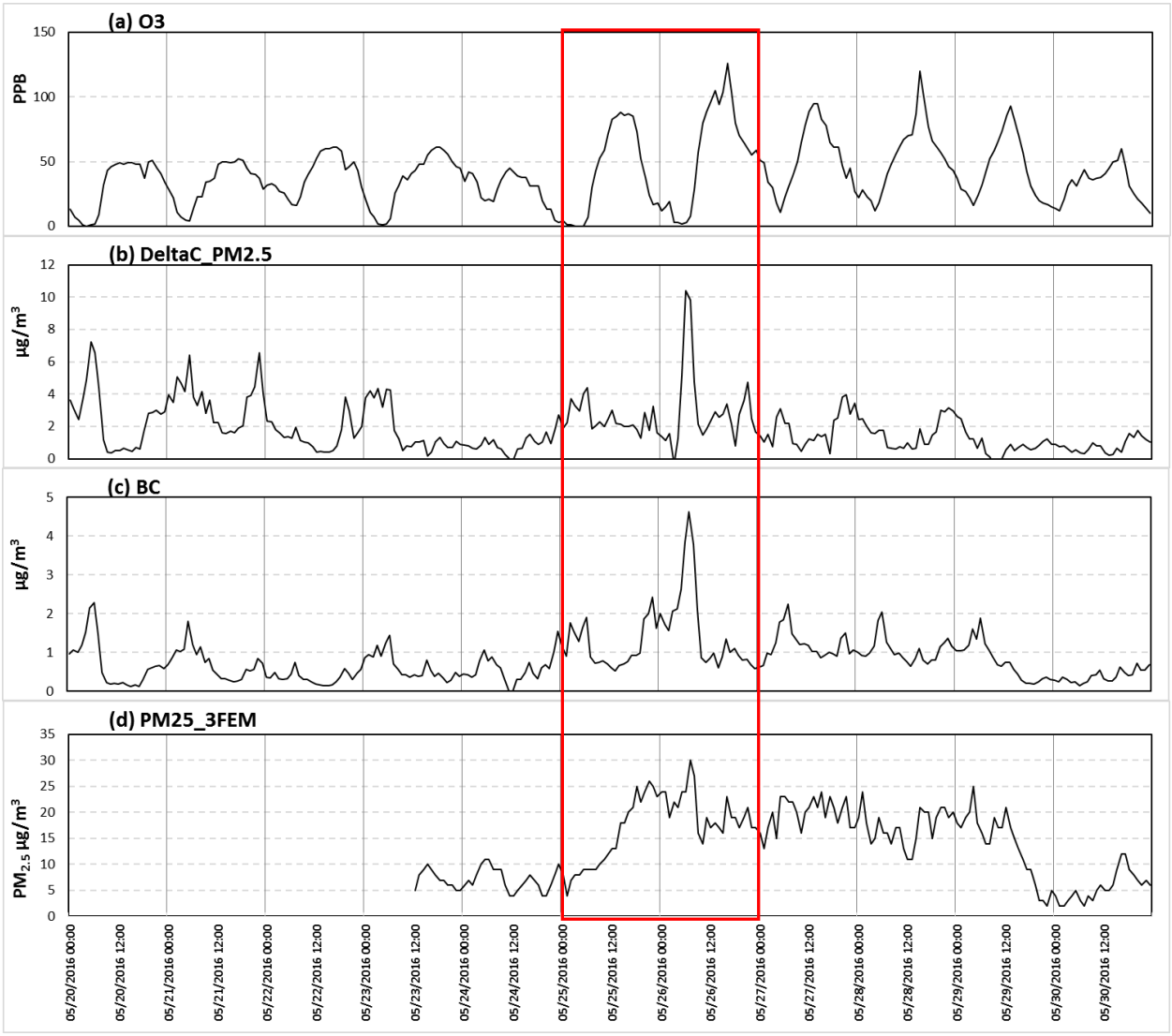


Figure 42. Monitored (a) Ozone, (b) DeltaC PM2.5, (c) Black Carbon (BC), and (d) PM2.5 at the Danbury CT Monitor

4.5 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. The nearby Leonia NJ monitor was selected 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 43 is a map showing the locations of those monitors and Figure 44 are charts of the monitored

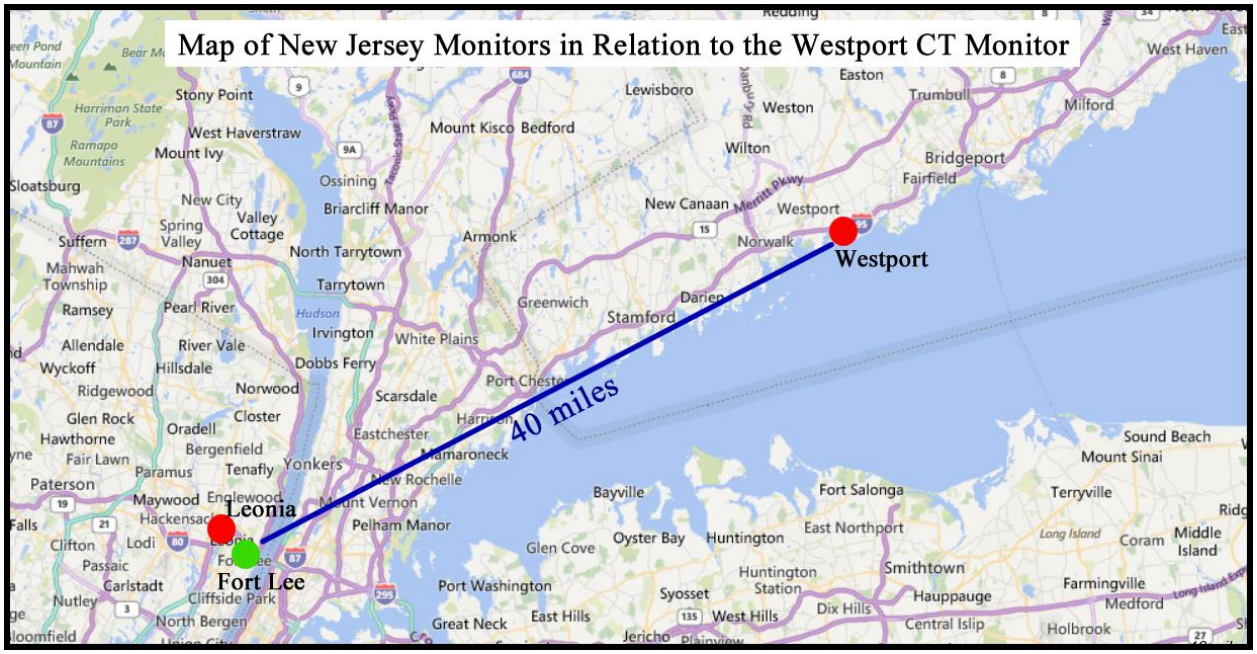


Figure 43. Map of Nearby New Jersey Monitors.

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 stopped reporting during May 27th, just as the PM2.5 parameters appeared to be peaking. These monitors are 12 miles from the Haze Cam location, from which images were presented earlier and show the presence of smoke over New York City.

Connecticut Hill New York

Since ozone exceedances are common in Connecticut due to transport from the southwest, we considered out-of-state monitors that are less influenced by southwest transport to demonstrate the unique influence of the wildfire on ozone levels during the event. The Connecticut Hill monitor in upstate New York, which is north and west of Connecticut, is an example that clearly shows this event was an outlier. Figure 45 shows daily 8-hour maximum monitored ozone for the years of 2011-2016 at the Connecticut Hill monitor and its location in New York. The 77 ppb 8-hour maximum ozone noted for May 25th, 2016, was the highest ozone value reported during those 6 years. The 2012 data 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 PM2.5 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 (PM2.5; 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.

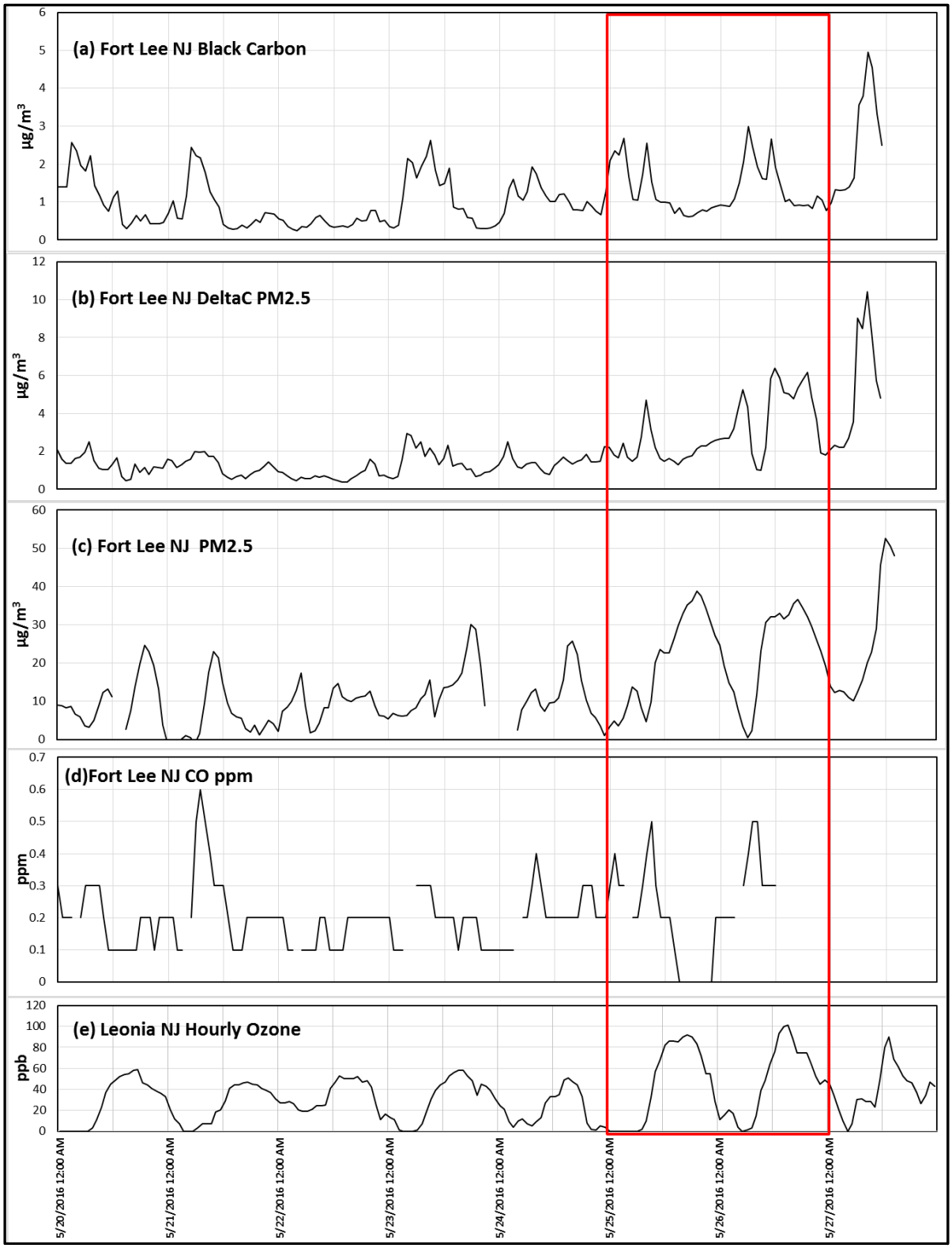


Figure 44. Monitored (a) Black Carbon, (b) DeltaC PM2.5, (c) PM2.5 (d) CO at the Fort Lee NJ monitor and (e) Ozone at the Leonia NJ Monitor.

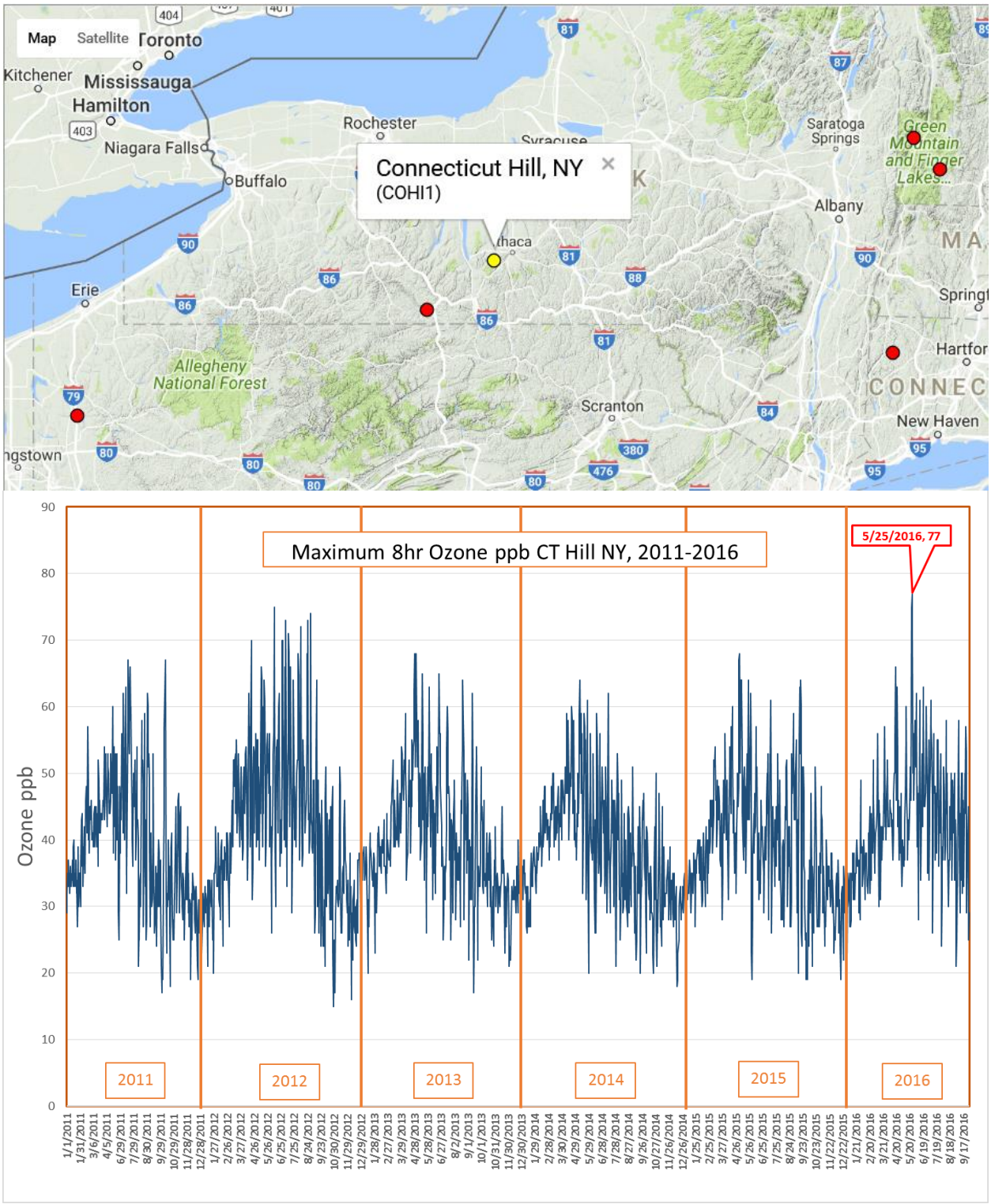


Figure 45. Monitored Daily Maximum 8-hour Ozone for 2011-2016 at Connecticut Hill, NY

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) by thermal optical methods.

Organic Carbon (OC) and Potassium (K) species are most closely associated with wildfire emissions, so we have selected the sites in Figure 46 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 47-53 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 .

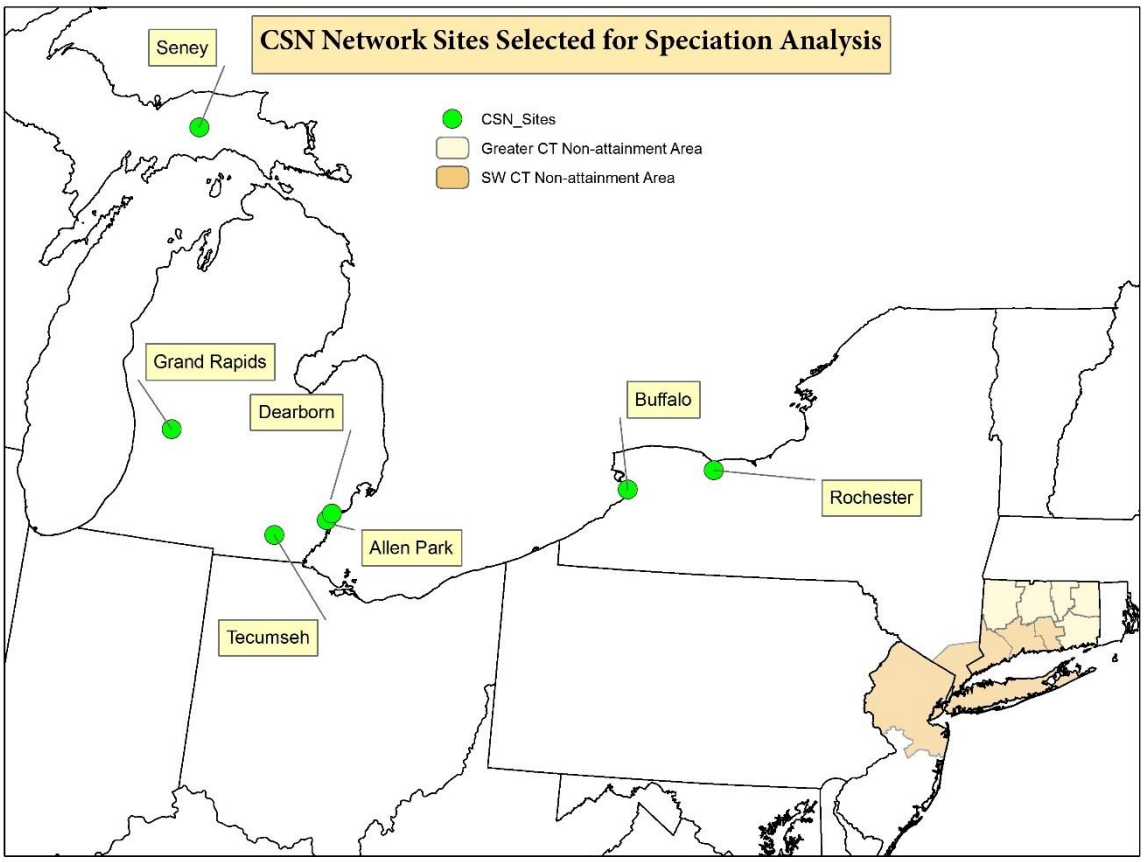


Figure 46. CSN Sites Selected for Speciation Analysis

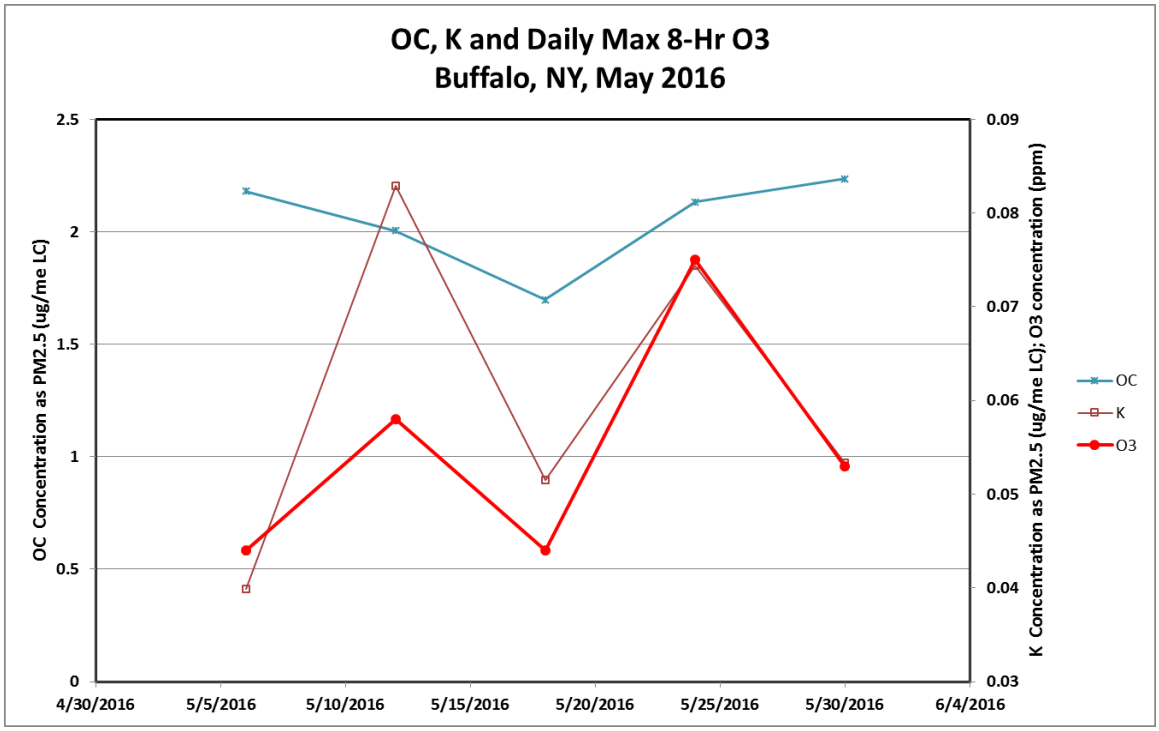


Figure 47. Buffalo New York CSN Data

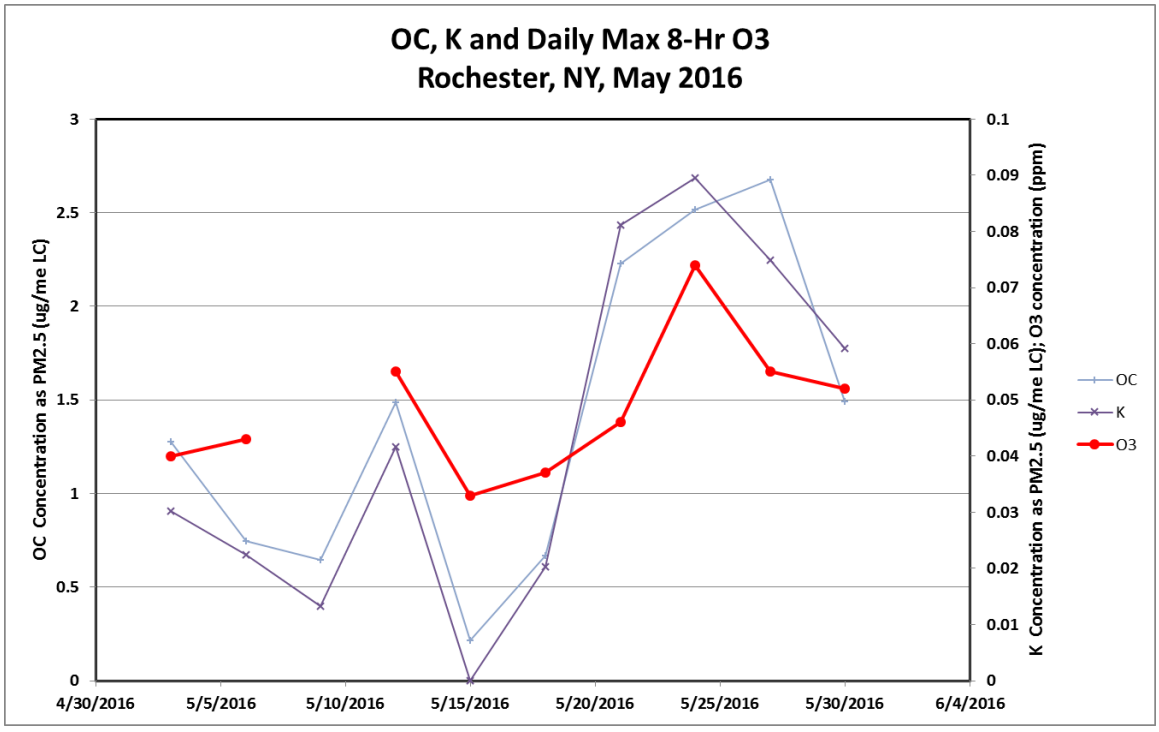


Figure 48. Rochester New York CSN Data

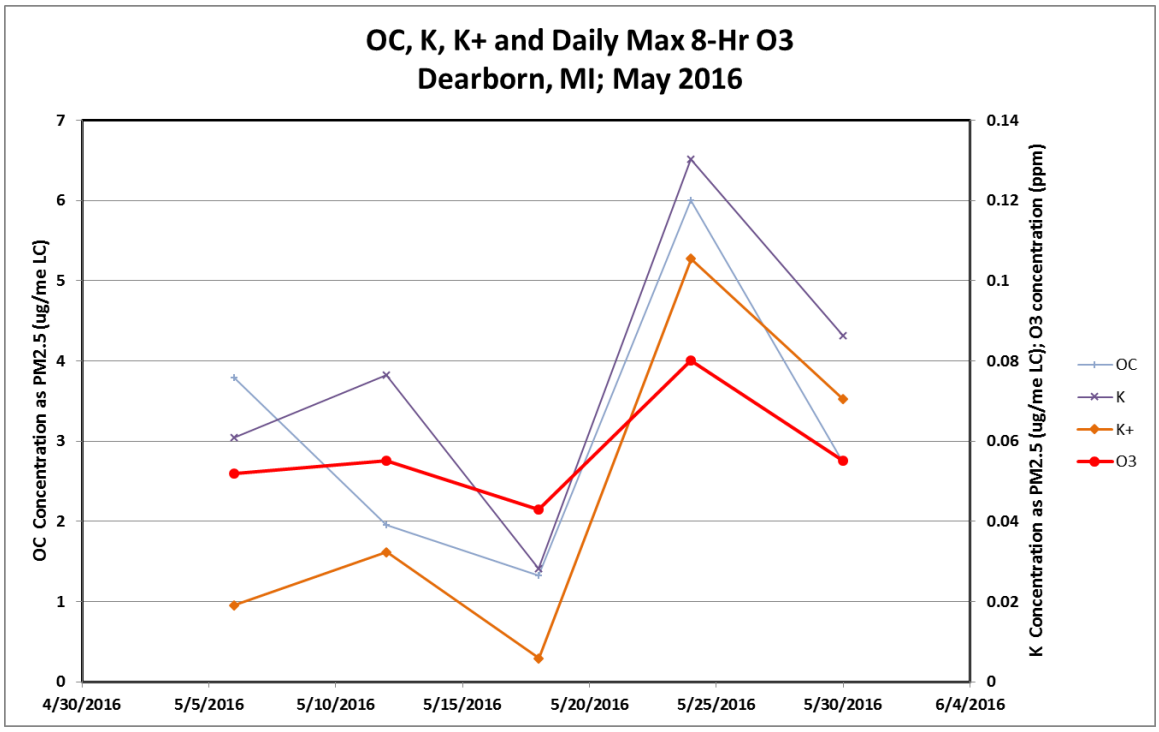


Figure 49. Dearborn Michigan CSN Data

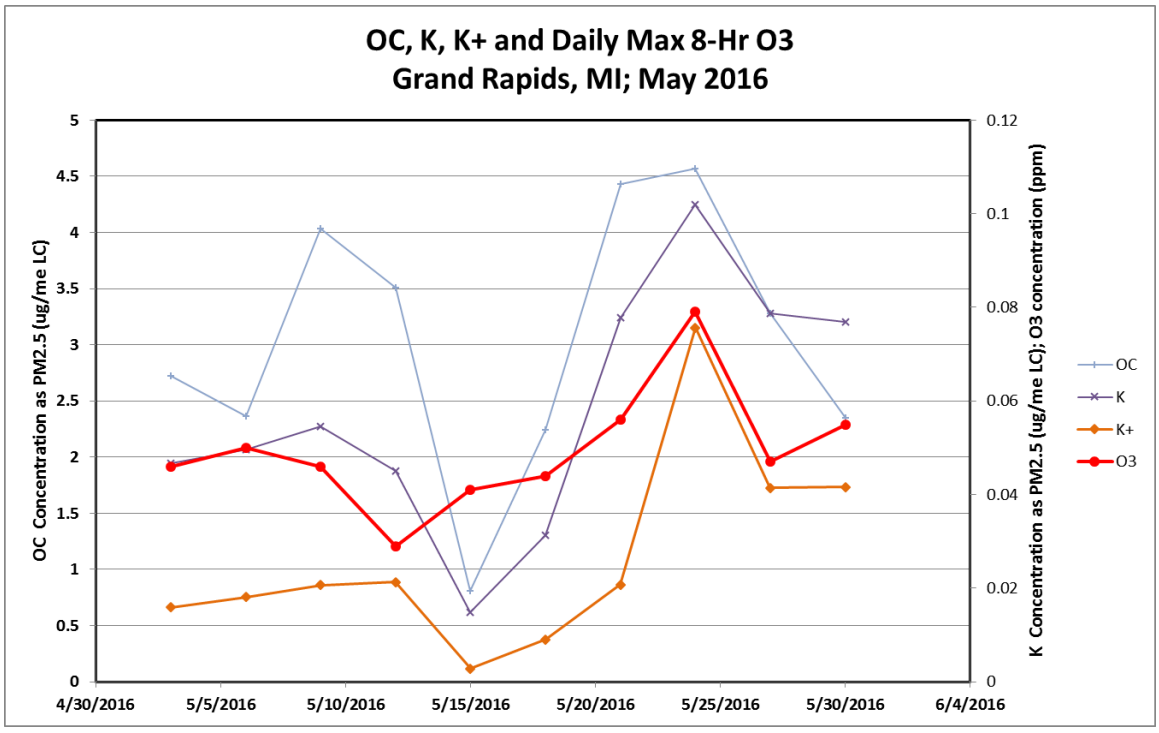


Figure 50. Grand Rapids Michigan CSN Data

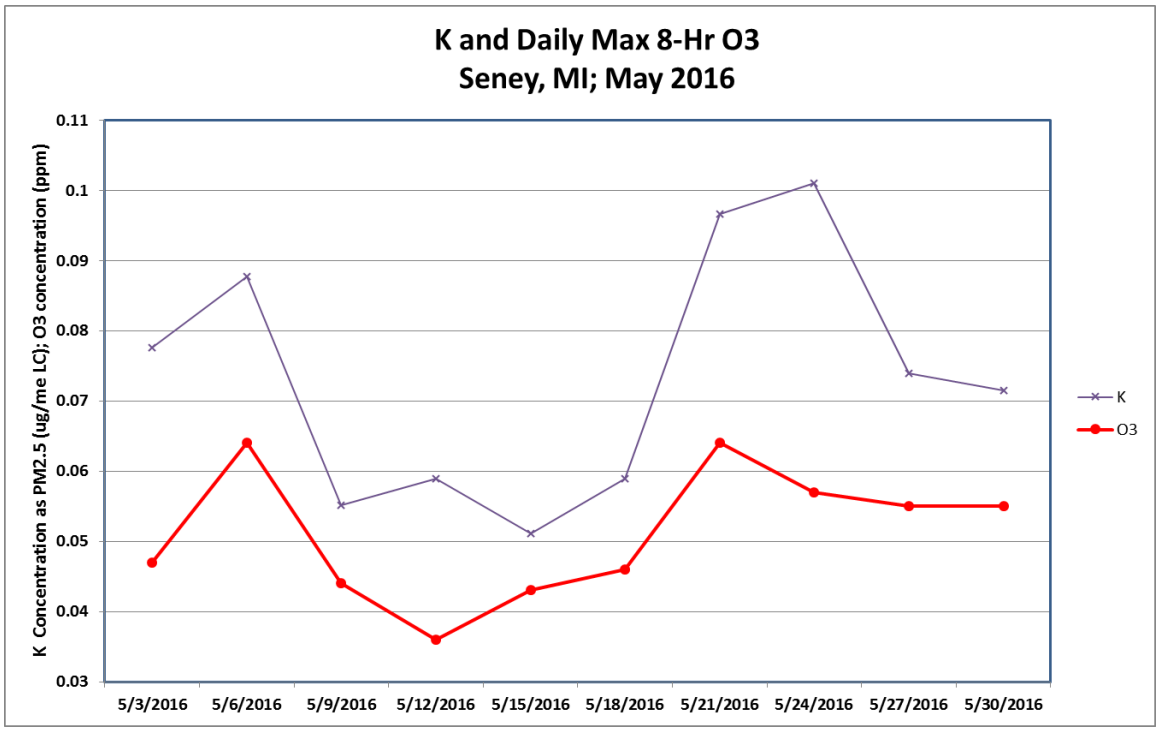


Figure 51. Seney Michigan IMPROVE Data

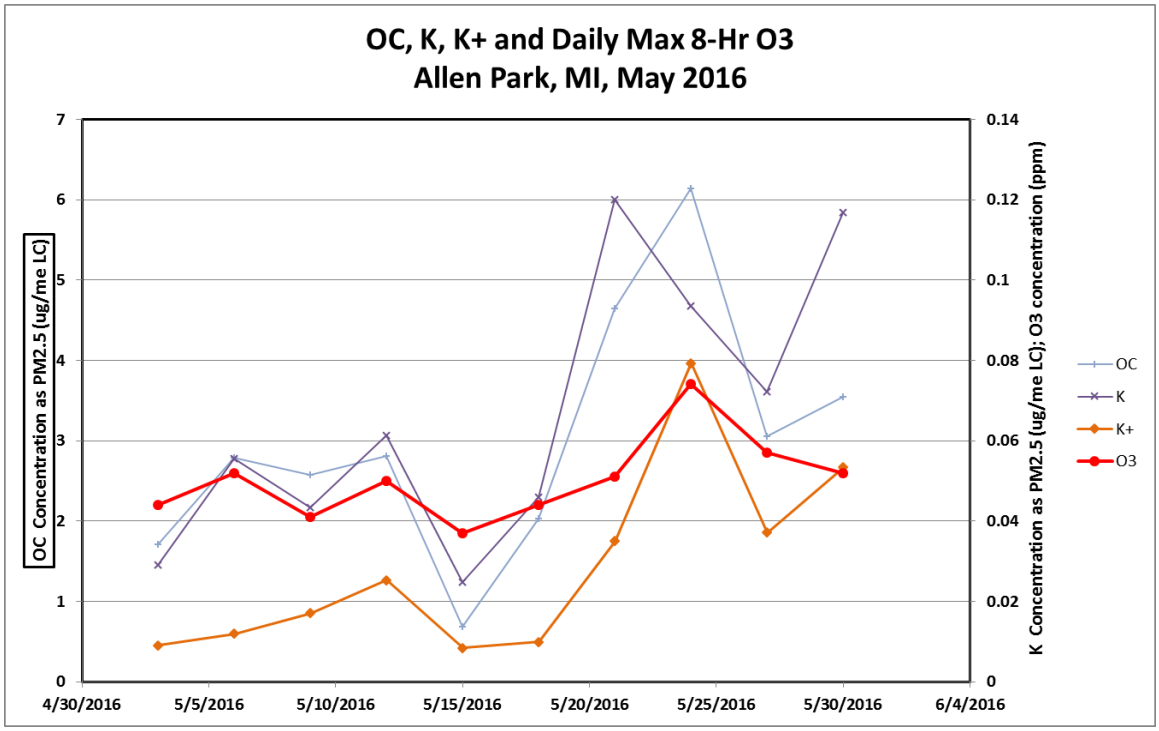


Figure 52. Allen Park Michigan CSN Data

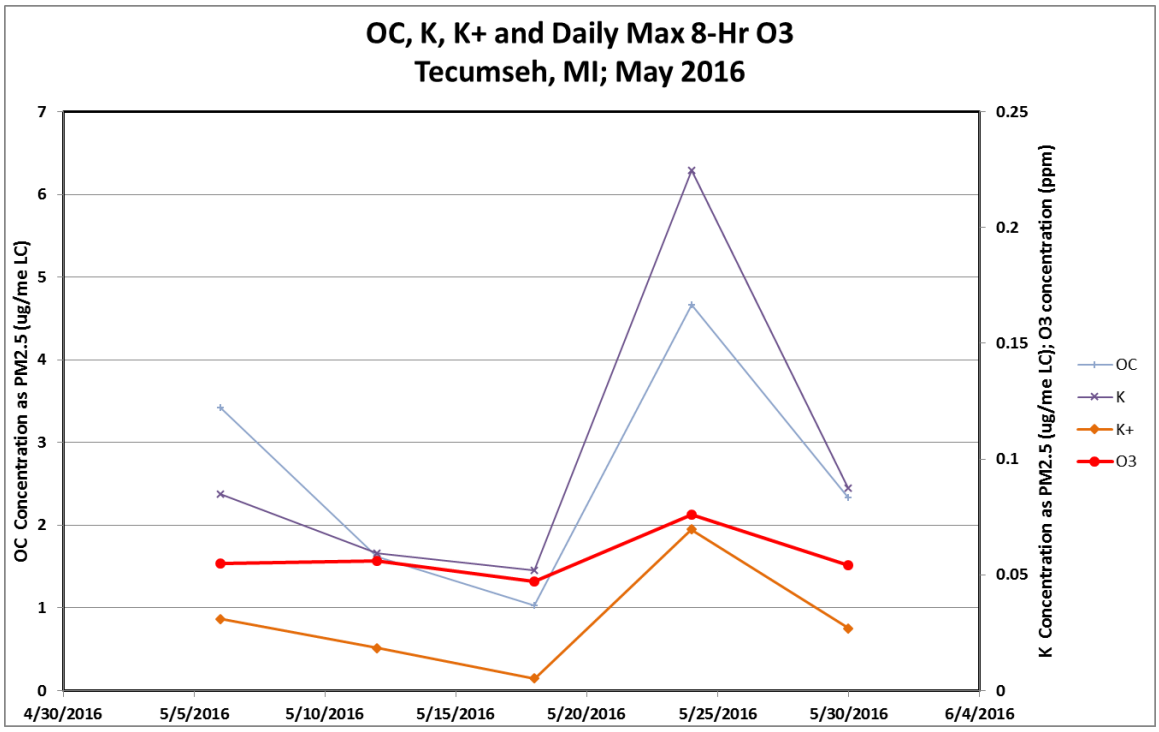


Figure 53. Tecumseh Michigan CSN Data

5. METEOROLOGICAL CONDITIONS DURING THE EVENT

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 54). The high pressure center over the Great Lakes was responsible for trapping pollutants from the wildfire 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 55), the skies cleared over New England and winds were mostly from the northwest throughout the boundary layer.

Of special interest are the 850 millibar (mb) height maps, since this is high enough in the boundary layer (~1500m) that long range transport can occur. In Figure 38, 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 56 we see 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, when absent of wildfires.

By May 25th (Figure 57a) the air flow loops around from Michigan, before turning southeast into New York and Connecticut. On May 26th (Figure 57b), 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 southwest, which could have caused some transport of pollutants from the I-95 corridor. Therefore, May 25-26th, 2016, did not fit any previous typical ozone scenario, and absent the wildfire plume, one would expect cleaner air coming into the region. By May 27th, high pressure moves off the coast, which brings cleaner maritime air into the State, lessening the effect of the plume on many of the monitors.

Figures 58-61 show site specific meteorological data graphed from May 24-28, 2016. The top graph for each site shows the hourly site temperatures plotted with the hourly ozone and the bottom graph plots the wind direction degrees plotted with the hourly ozone. The northerly wind direction is represented at both 0 and 360 degrees, so the wind graph will frequently switch between the two ranges when the wind is from the north. Beginning on May 25th, high temperatures at all the sites were well into the 80's (°F) and approached 90 °F at the East Hartford site. Generally sunny skies during May 25-28th provided sufficient conditions for ozone formation. It can be observed that the wind direction began from the west/northwest at the inland sites on May 25th, but quickly changed to the south at our Westport site because of the sea breeze. All sites showed the wind direction changing to the south and southeast as the synoptic weather pattern changed with the cold front approaching from the north. During May 27-28th, the wind were generally from the south pushing the plume inland and leading to the higher ozone in Cornwall on the 27th. Typically, southerly winds off the ocean tend to transport clean maritime air into the State, pushing an ozone plume north while lowering concentrations.

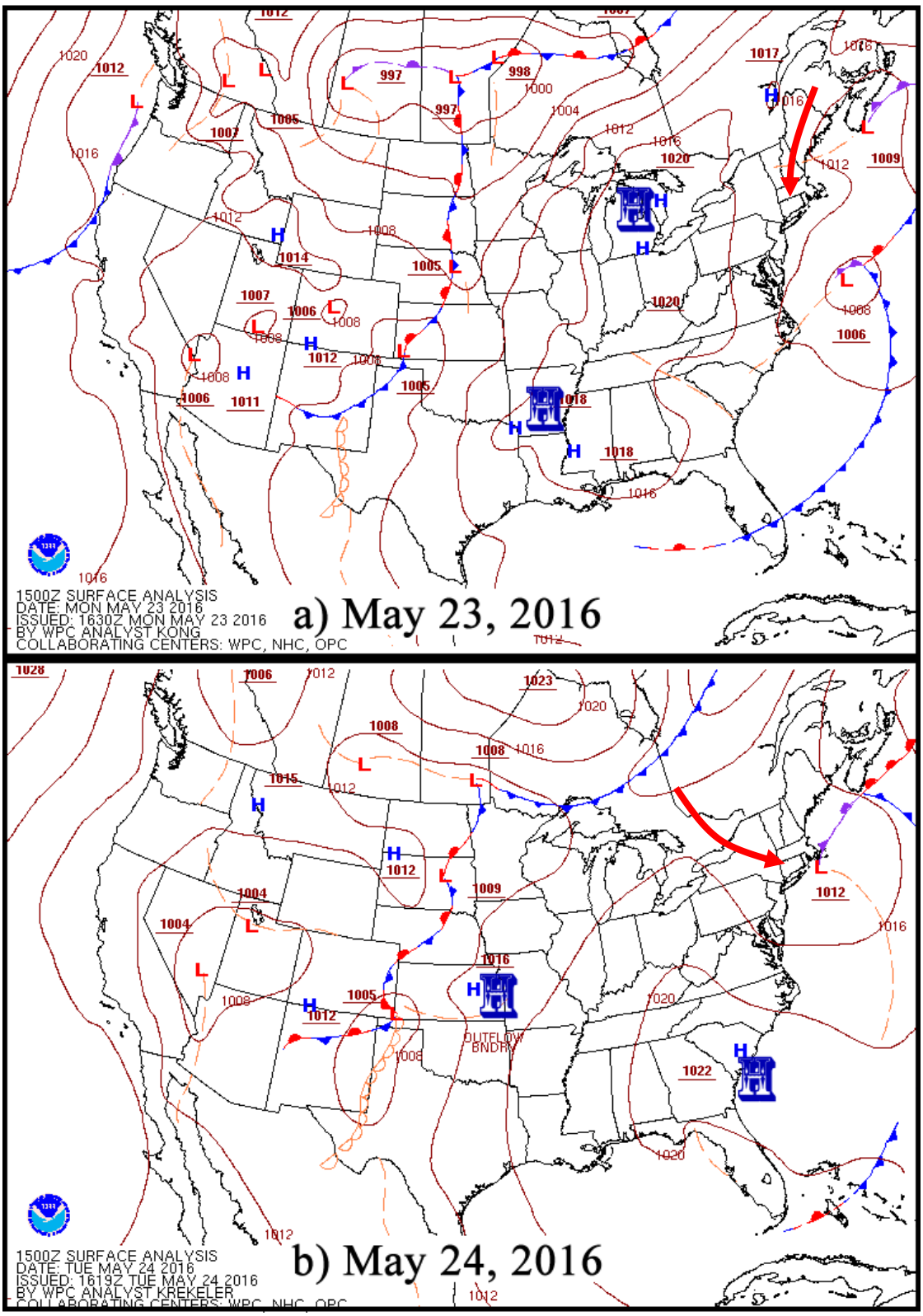


Figure 54. Surface Fronts for May 23-24 (a,b), 2016. Note the high pressure area over the Midwest on May 23-24th, creating subsidence and trapping the smoke plume pollutants over the Midwest.

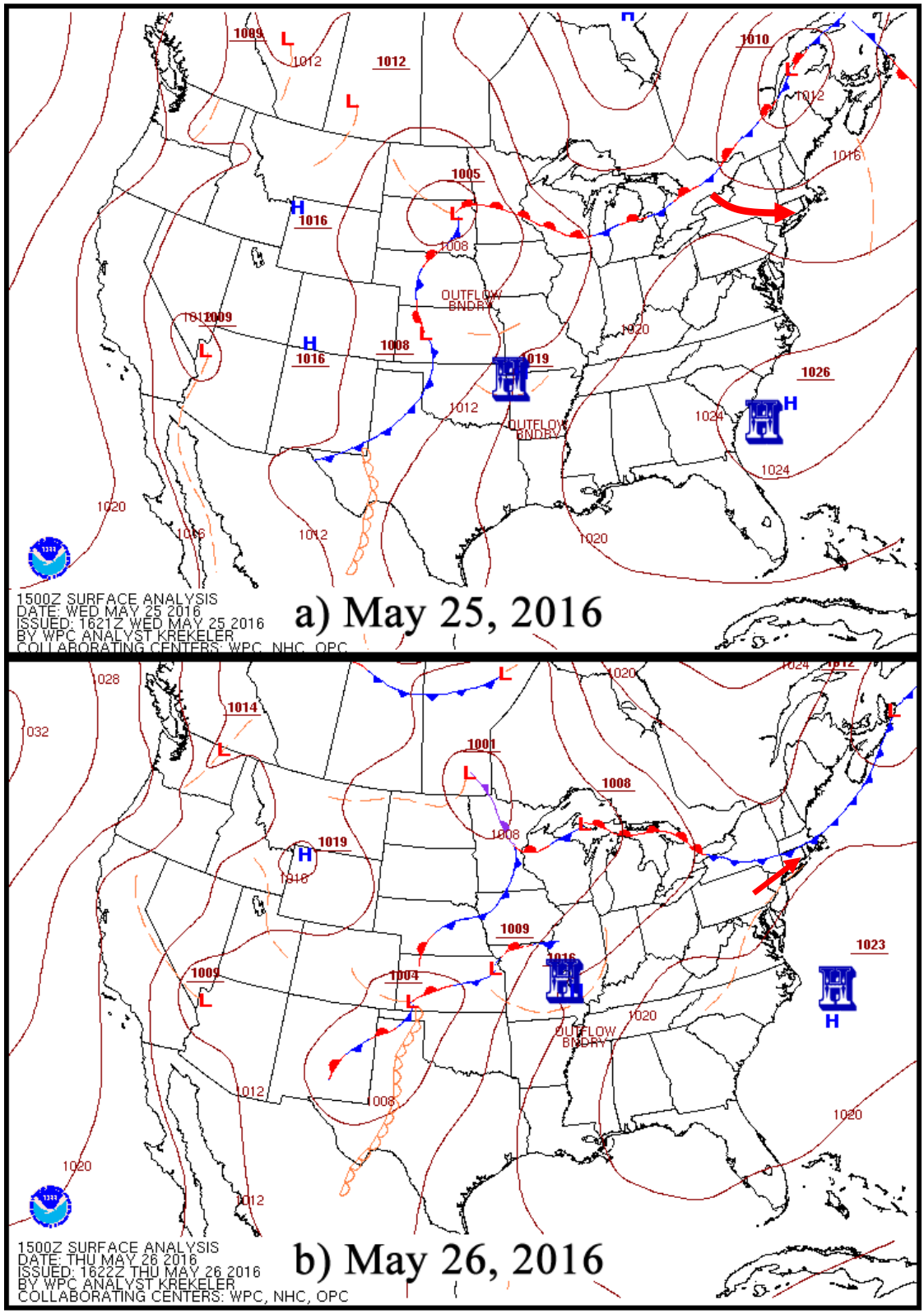


Figure 55. Surface Maps for May 25-26 (a,b), 2016. This shows northwest winds at the surface with approaching coldfront (a) turning the winds to the southwest(b) on May 26th.

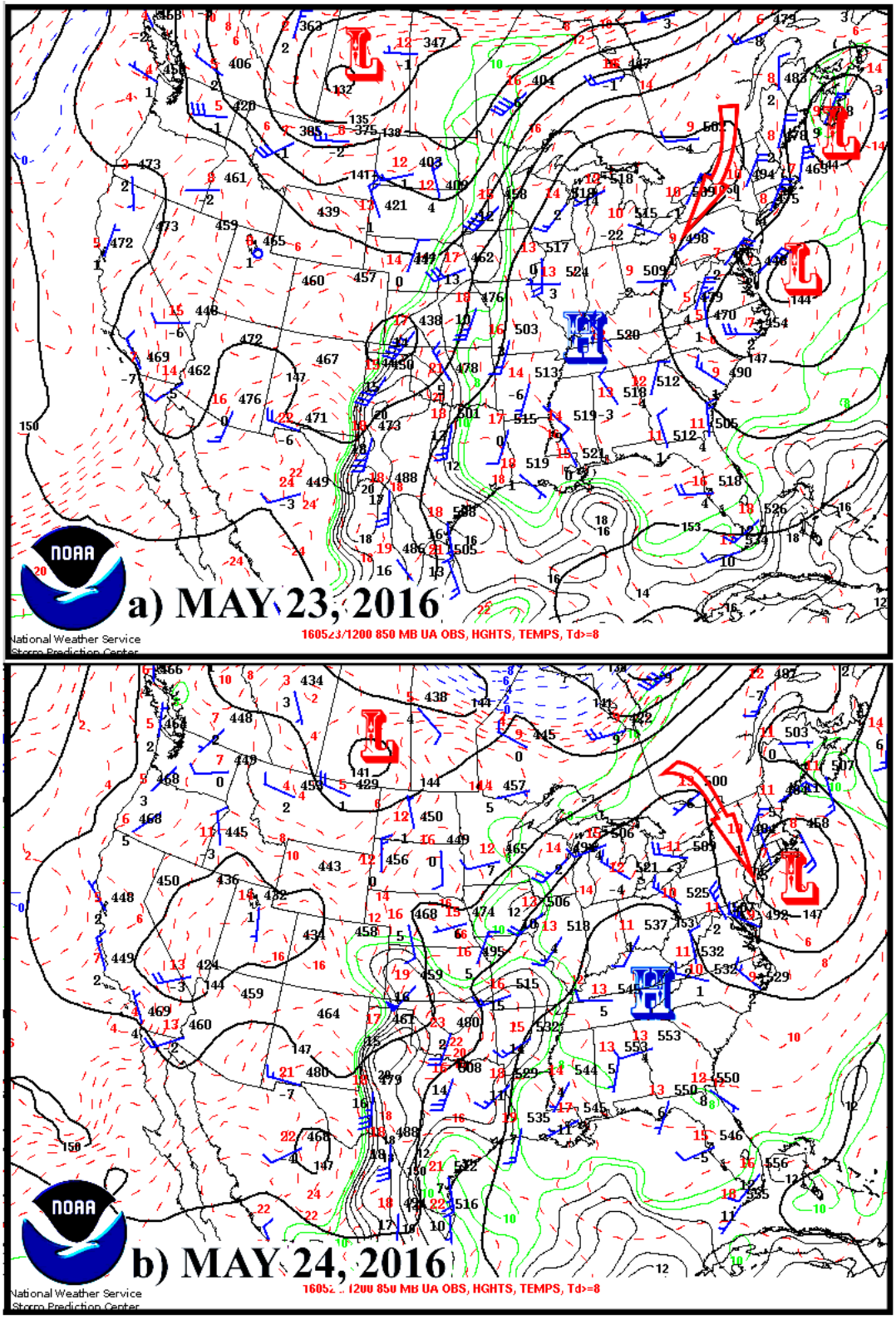


Figure 56. 850 mb Pressure Pattern with Winds for May 23-24 (a,b), 2016. Low pressure center off the New England coast creates a northerly wind at 850 mb.

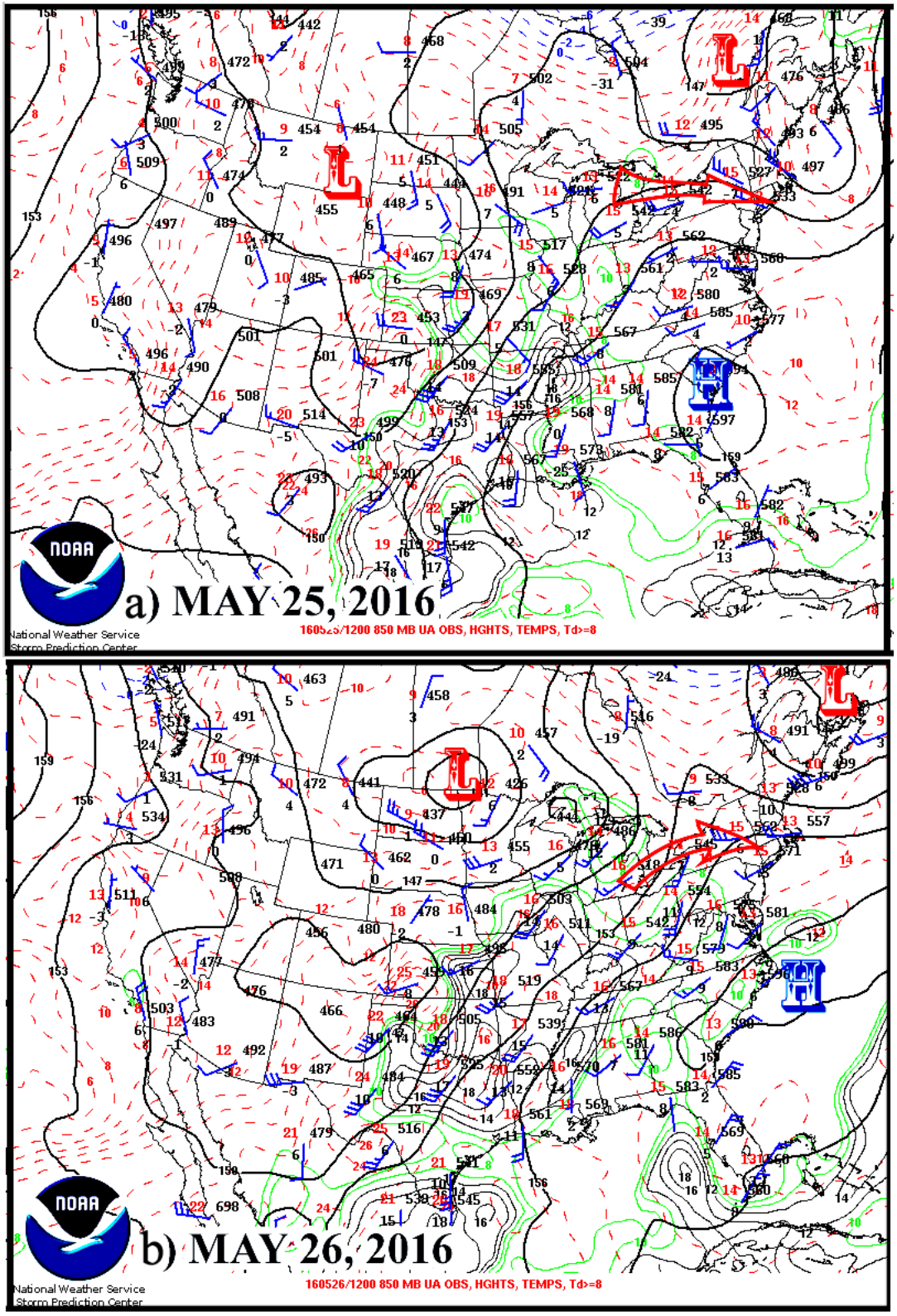


Figure 57. 850 mb Pressure Pattern with Winds for May 25-26 (a,b), 2016. High pressure center moves off the east coast causing the 850 mb transport winds to turn more westerly from Michigan.

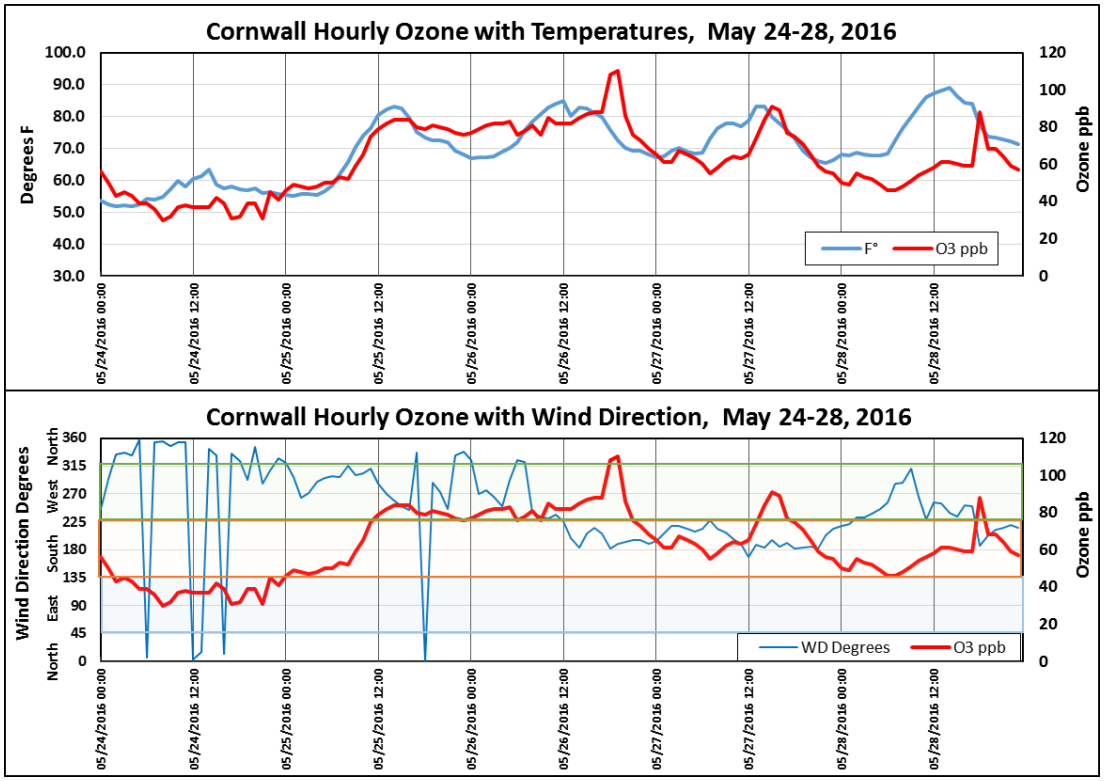


Figure 58. Cornwall Hourly Ozone vs. Temperatures (top); Hourly Ozone with Wind Direction (bottom).

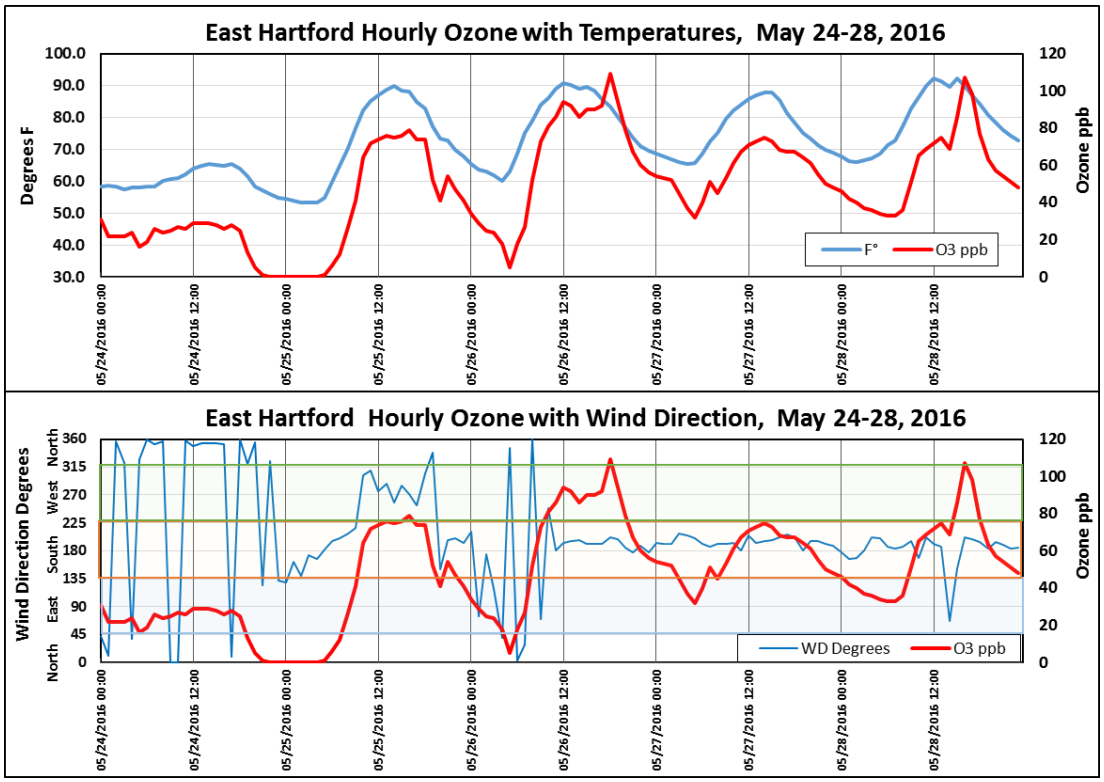


Figure 59. East Hartford Hourly Ozone vs. Temperatures (top); Hourly Ozone with Wind Direction (bottom).

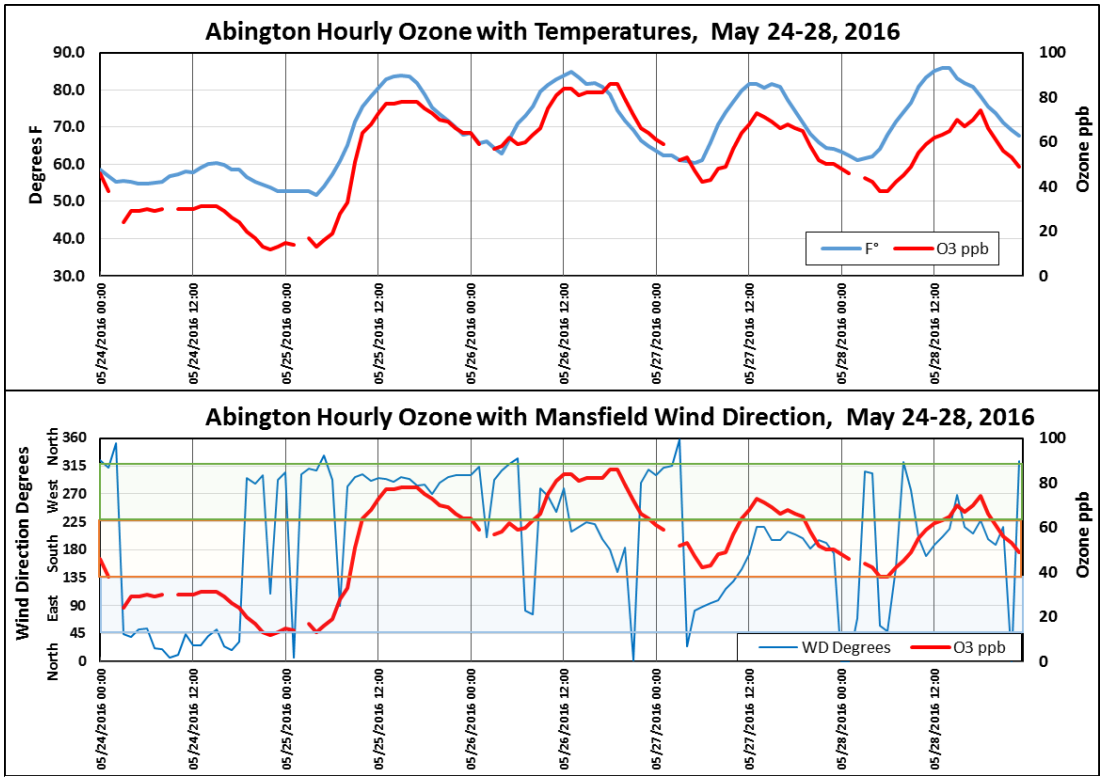


Figure 60. Abington Hourly Ozone vs. Temperatures (top); Hourly Ozone with Wind Direction (bottom).

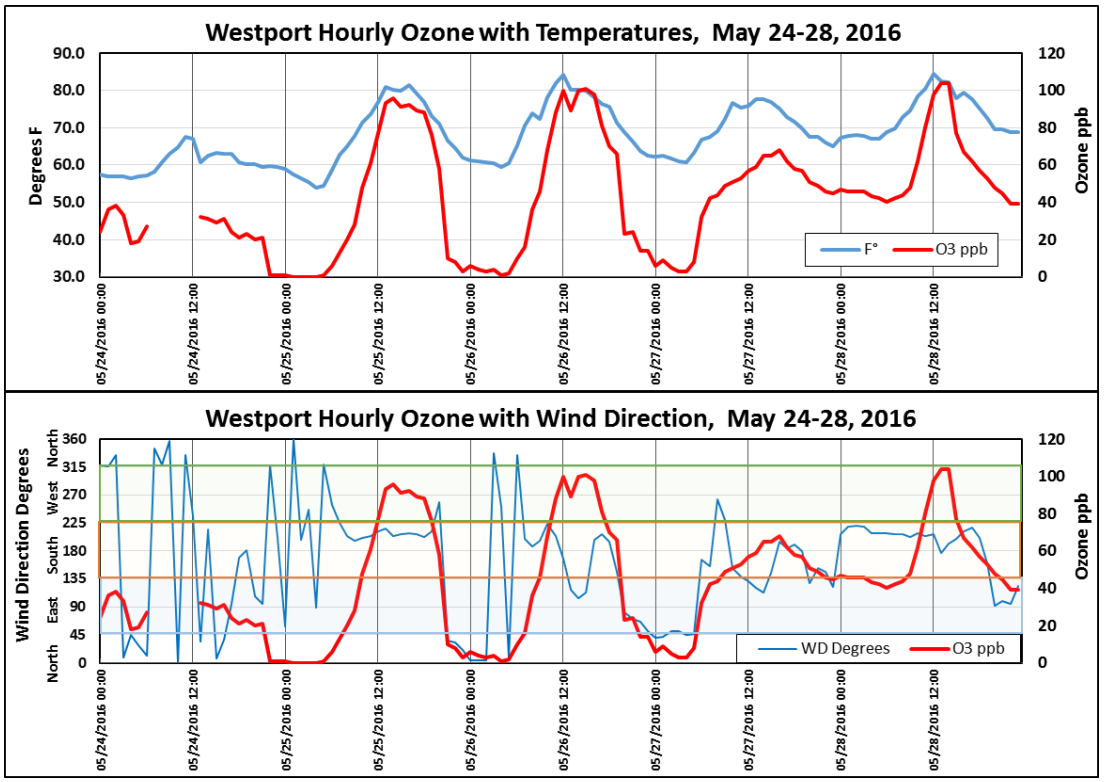


Figure 61. Westport Hourly Ozone vs. Temperatures (top); Hourly Ozone with Wind Direction (bottom).

6. 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

6.1 Forward Trajectory Example

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. It wasn't until after May 20th that the weather conditions 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 for long range transport is the North American Regional Reanalysis (NARR) model, which uses the high resolution NCEP Eta Model (32km/45 layers), 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 wildfire plume and pass over Michigan after May 21st (Figure 62). The VIIRS satellite image on May 18th (see Figure 11) shows parts of the plume heading east over Hudson 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 63), which would trap the pollutants and later lead to the production of ozone over the Great Lakes' States.

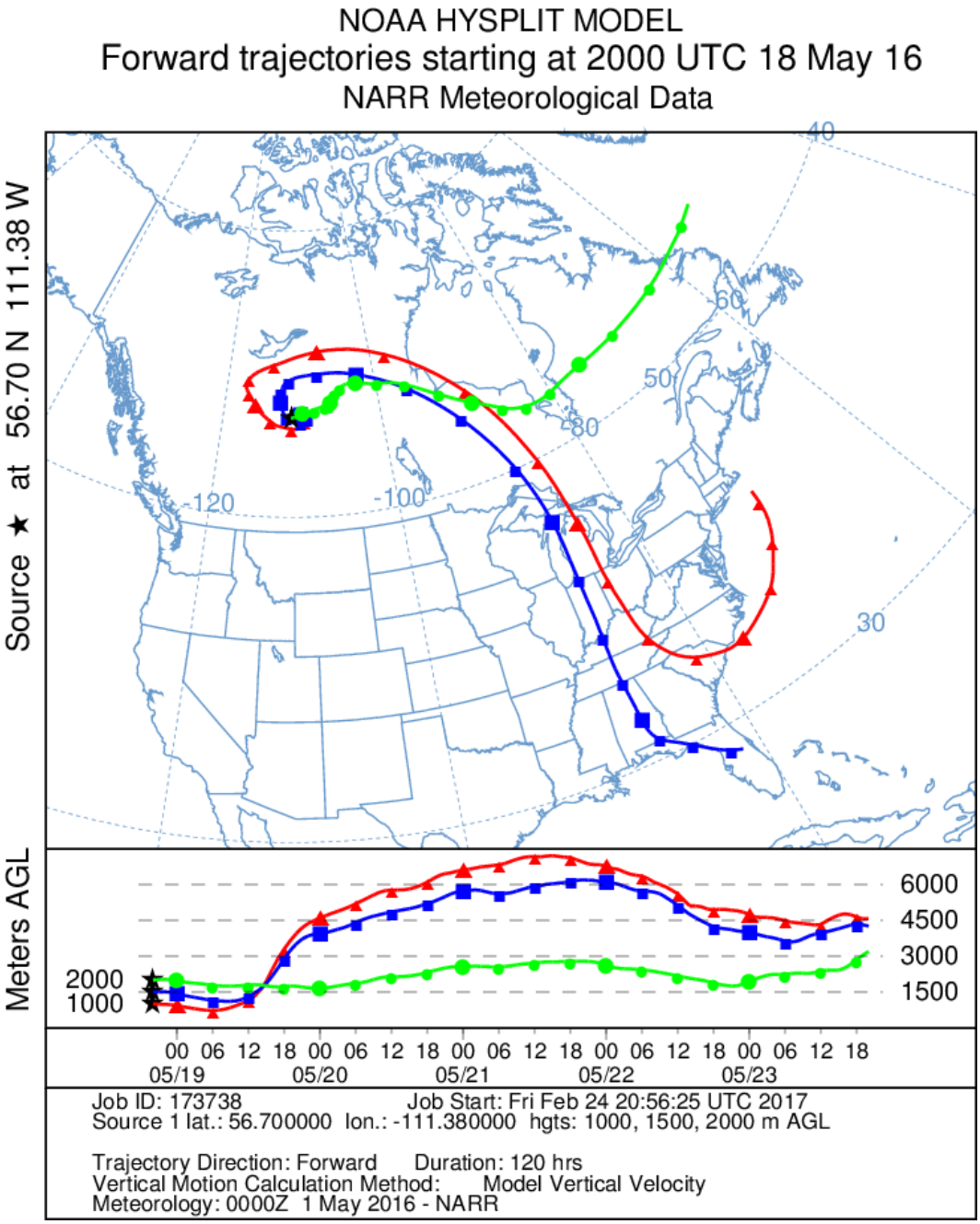


Figure 62. 120-hour HYSPLIT Forward Trajectories from Fort McMurray May 18-23, 2016

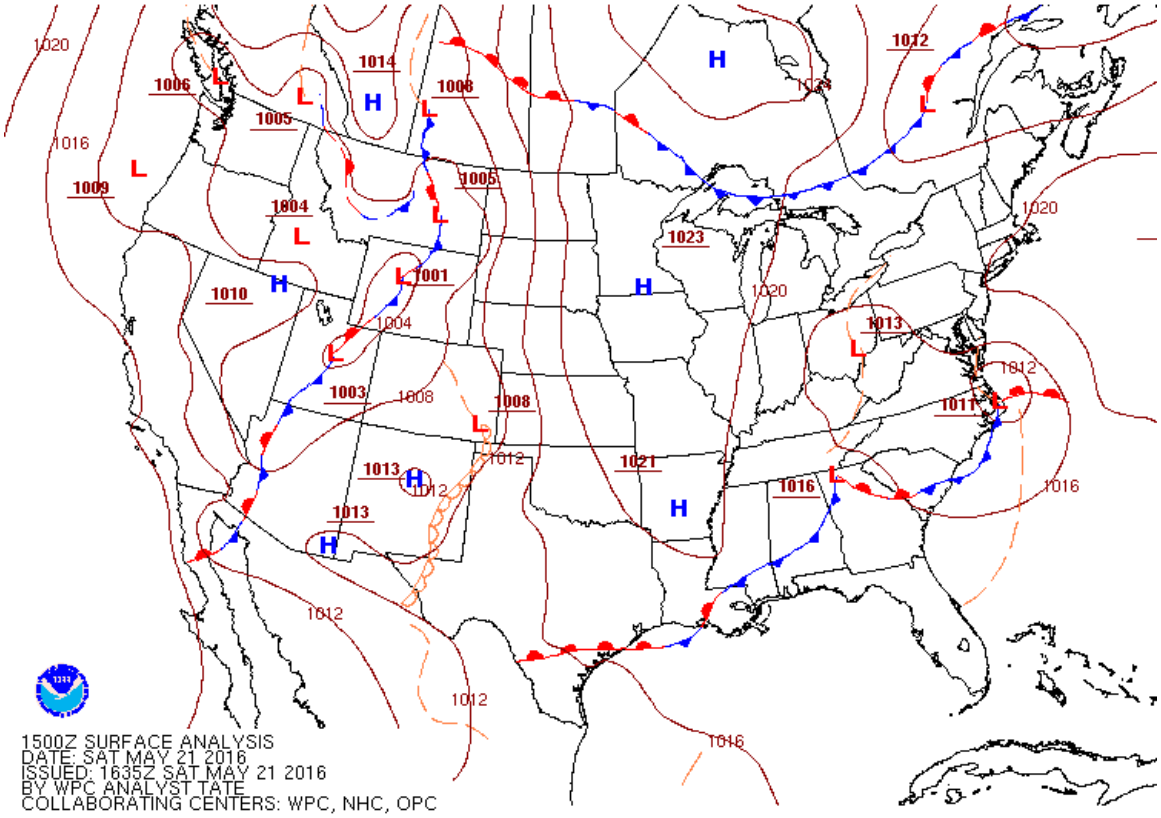


Figure 63. Surface Weather Analysis from May 21, 2016

6.2 Back Trajectory Analysis

Ozone began building up around the Great Lakes' on May 23rd and peaked on May 24th (Figure 64) 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 65). By May 24th, the wind had turned to the southwest, which allowed VOC's from the smoke to mix with emission sources to the south and rapidly produce ozone. Figure 66 shows a matrix of back trajectories ending at 1000m over western New England for both May 25th and May 26th. The source region, 48 hours before, is clearly the Michigan area on both days, but the trajectories shift southward on May 26th. The winds also turned southwestward over Long Island Sound (LIS) on May 26th, which may have provided some ozone enhancement from the New York City area.

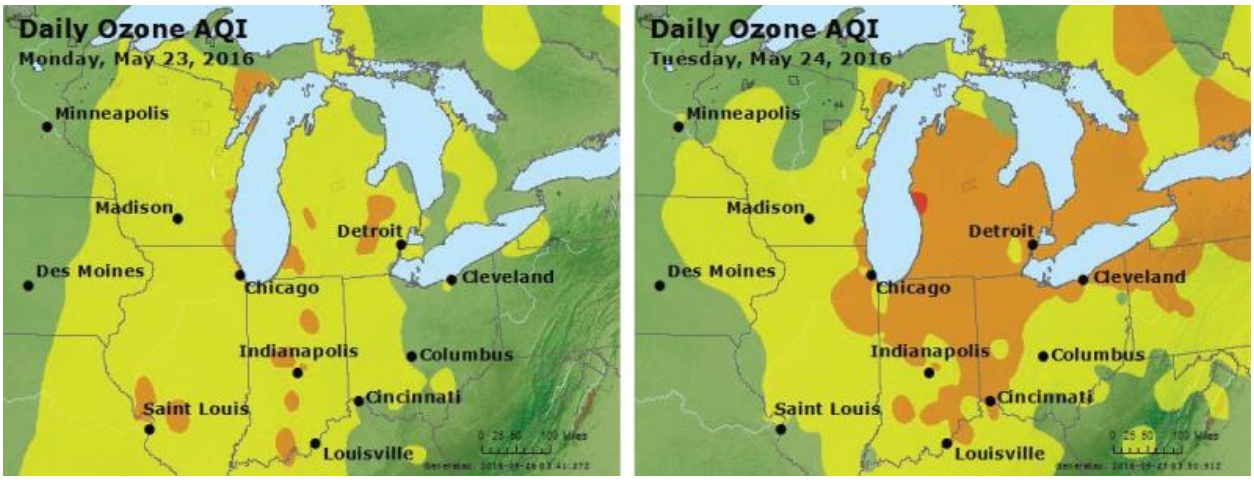


Figure 64. Ozone AQI Maps for May 23-24, 2016.

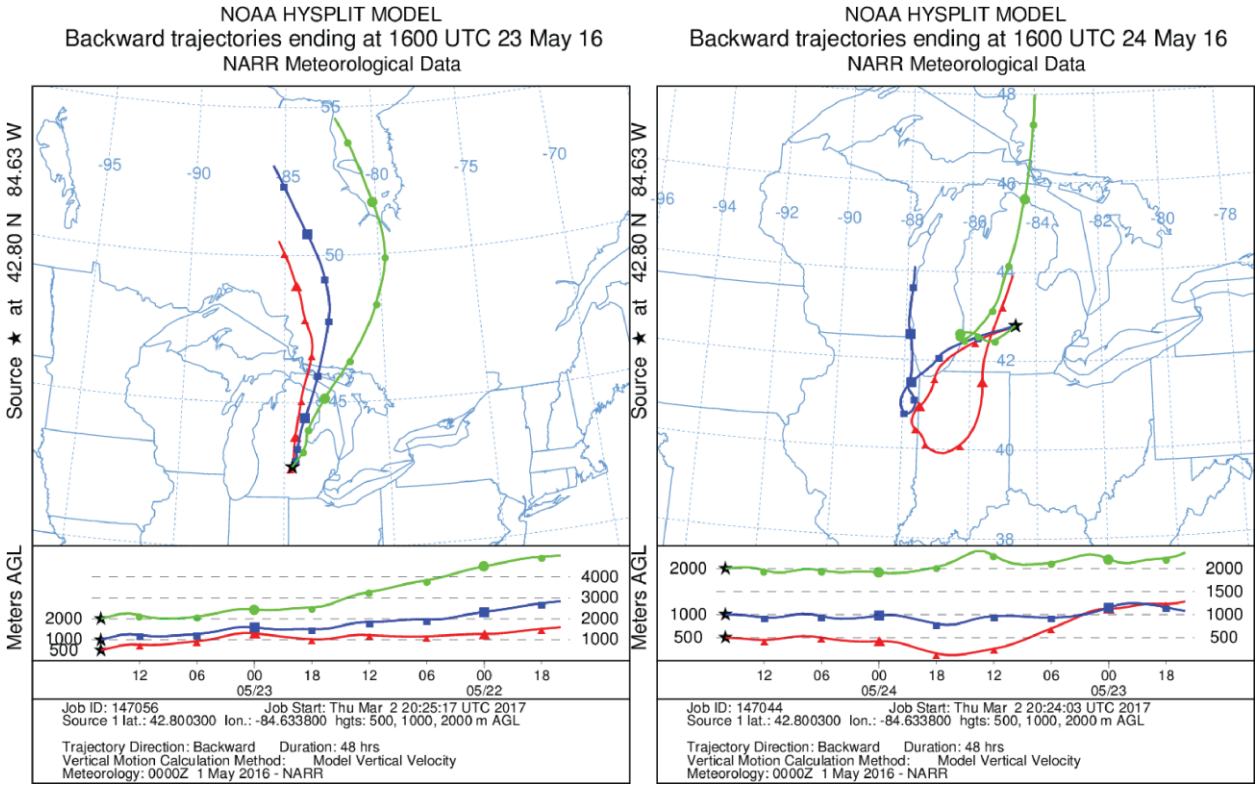


Figure 65. HYSPLIT Back Trajectories from Michigan, May 23- 24, 2016

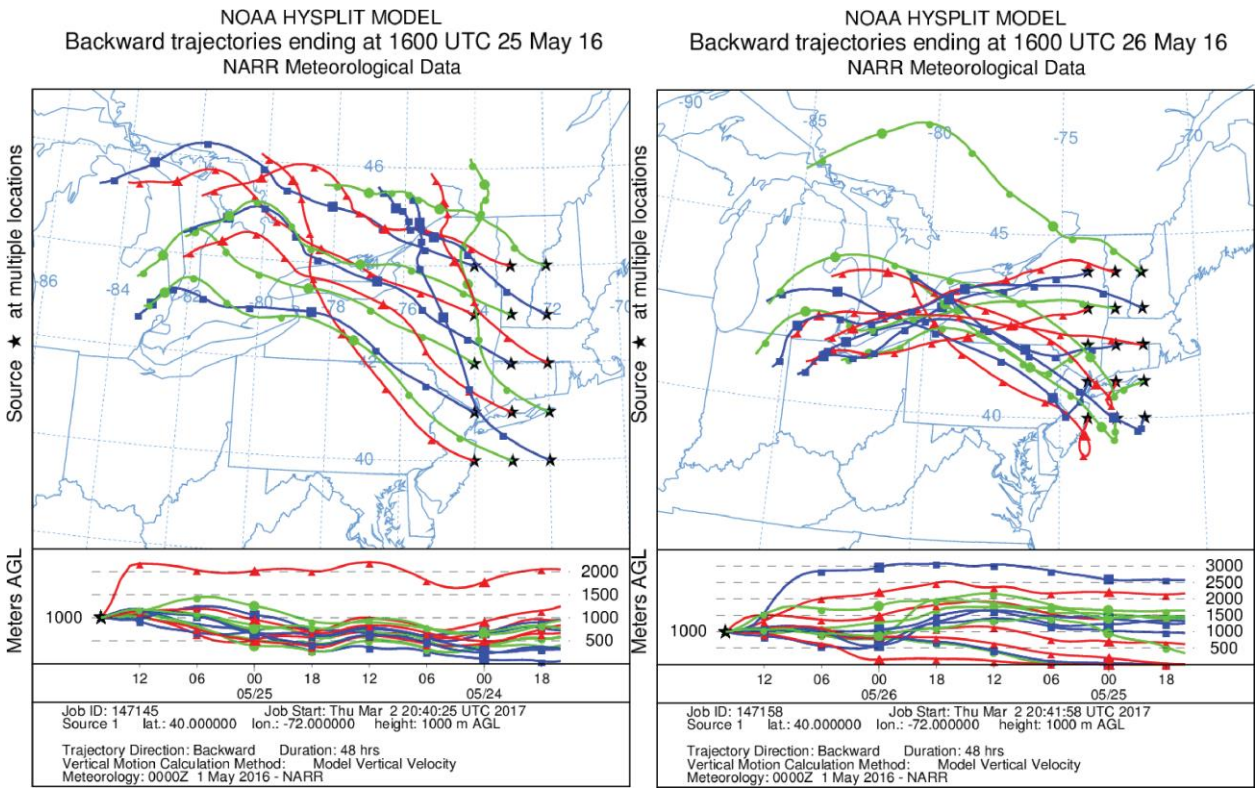


Figure 66. HYSPLIT 48-hour Back Trajectories from New England (left) May 25, 12:00EDT, (right)May 26, 12:00EDT.

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 point out 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 67 shows the 168-hour back trajectories ending at 8:00 am EDT on May 25, 2016. The 3000 meter trajectory has its start in far northern Canada, and the 500 meter level begins over Hudson Bay. These trajectories would likely pass through a very clean air mass, in the absence of wildfires. Two hours later (10:00am EDT), these back trajectories had already shifted westward (Figure 68). 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 69 shows the noon EDT 3000 meter back trajectory passing directly over the wildfire area. This path would bring the pollutants from the wildfire to Westport Connecticut over the course of six days. Finally, Figure 70 shows the fire locations with the aerosol plumes on May 20th with the HYSPLIT trajectory paths from May 19-25th. This clearly shows that the plume was present near the wildfire location and that the 3000 meter back-trajectory would have brought the 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 on May 25th, Figure 71 shows the winds coming from the northeast, which is normally a source of clean air at the surface. Figure 72 shows the winds coming from a more northerly direction ending at 10:00 am LDT and by 4:00 pm LDT (Figure 73), 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 and then to the south. Figure 74 reflects this in the low level trajectory turning to the southwest, 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 as the 4:00 pm LDT ending trajectory (Figure 75) already has the wind turning southerly and mixing with maritime air.

Westport monitored its 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 high concentrations monitored there or at the other monitors in Connecticut. Back trajectory analysis strongly suggests that the Fort McMurray wildfire was the main cause behind these ozone exceedances.

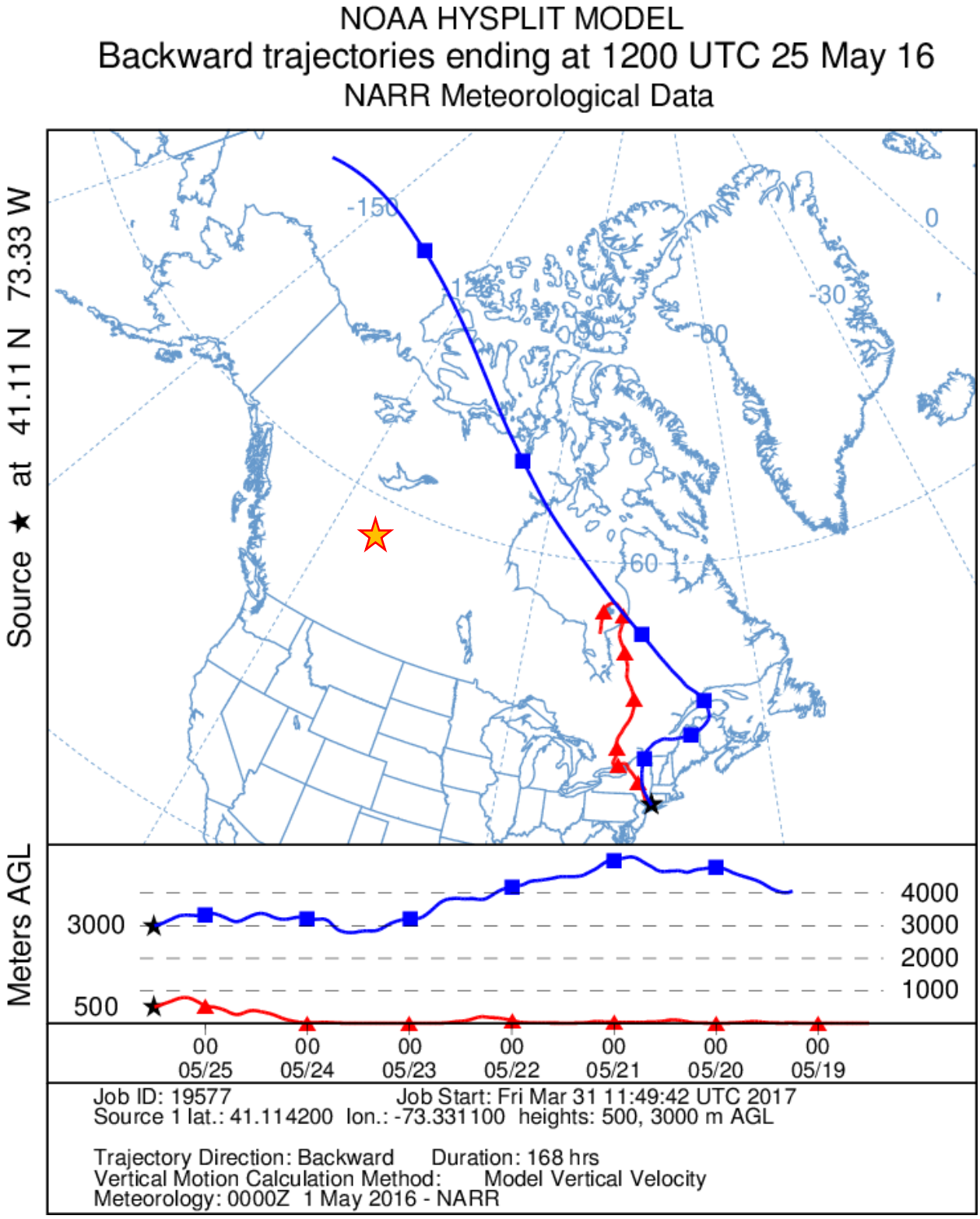


Figure 67. May 25, 2016 12 UTC Back Trajectories from Westport CT.

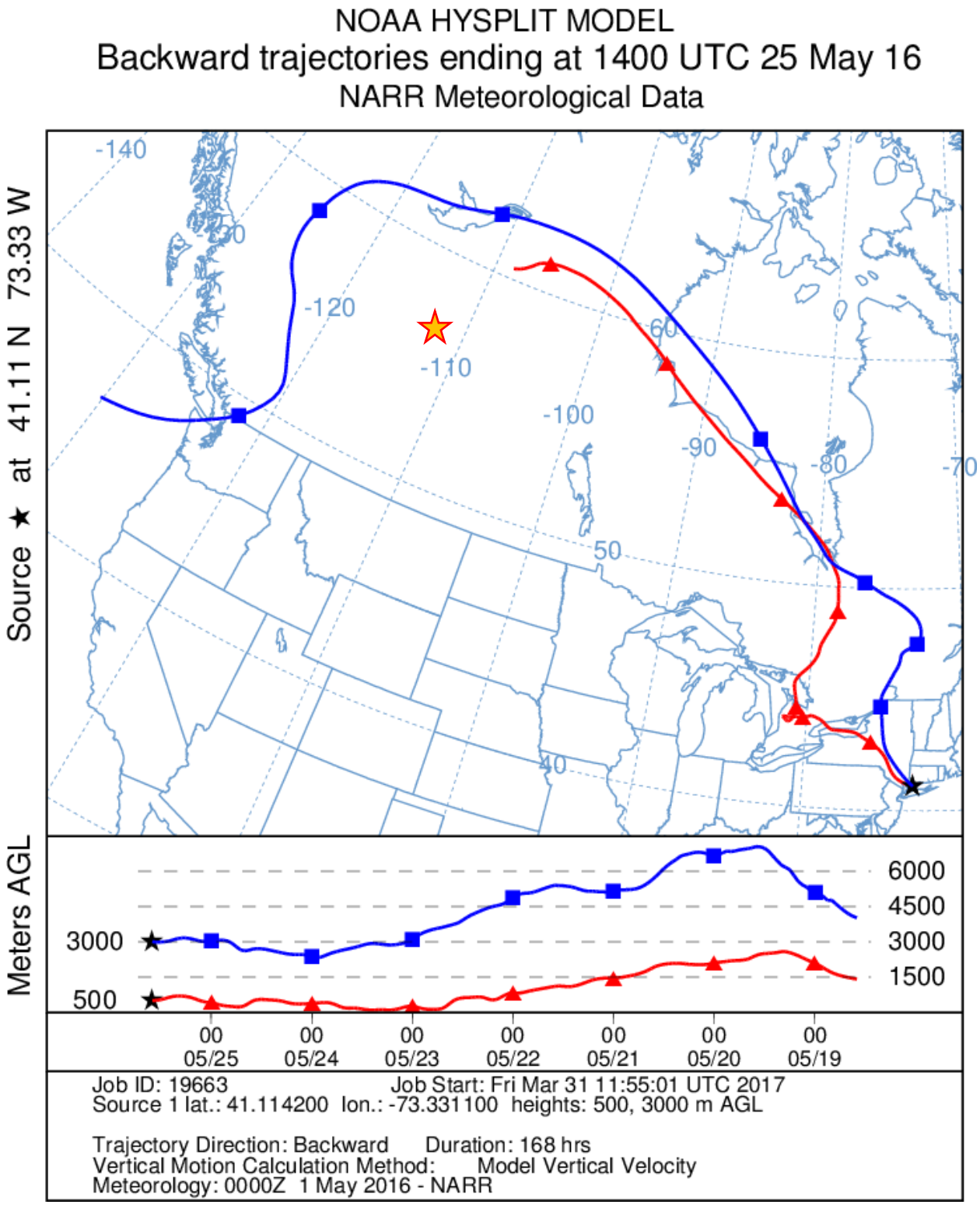


Figure 68. May 25, 2016 14UTC Back Trajectories from Westport CT.

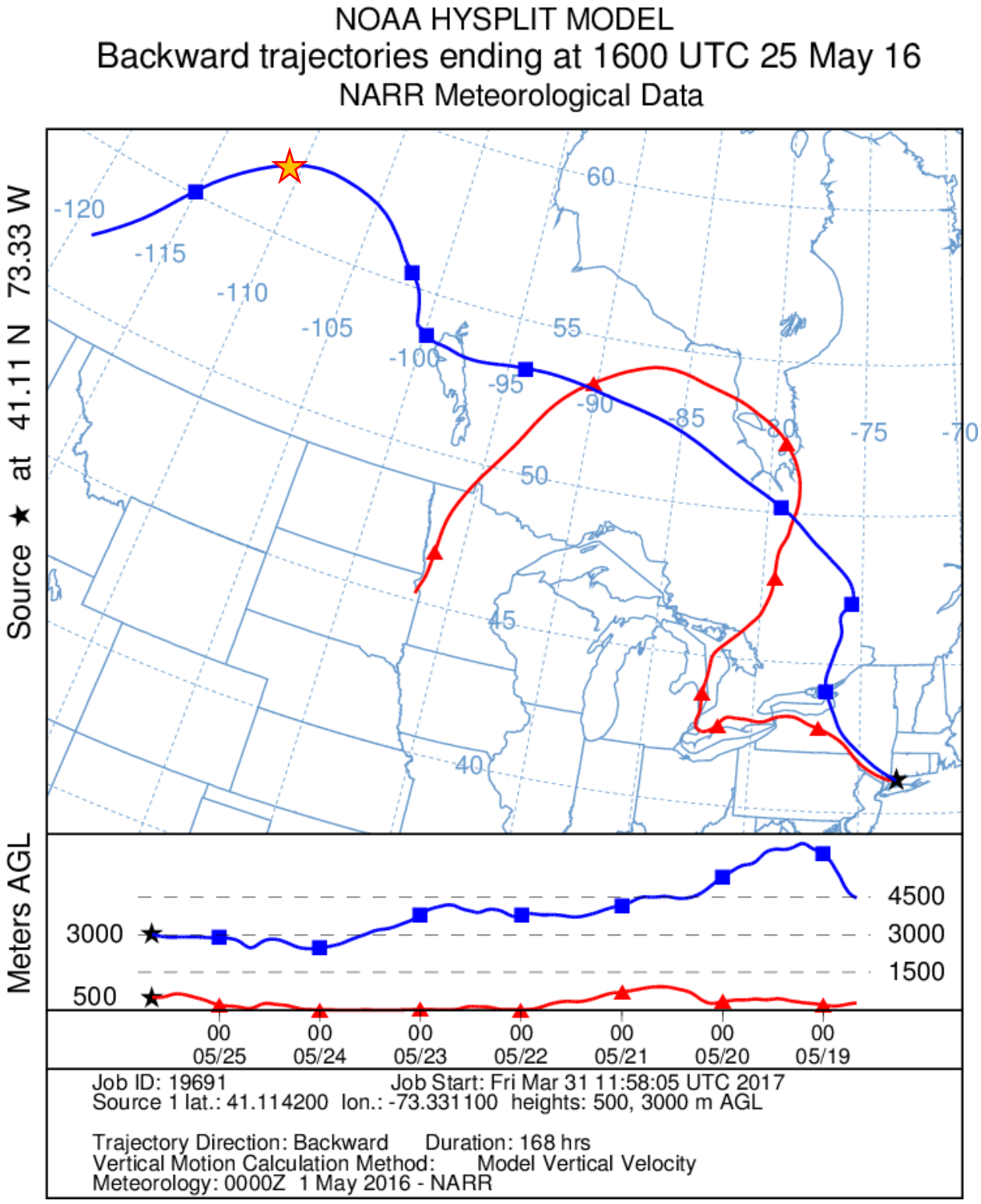


Figure 69. May 25, 2016 16UTC Back Trajectories from Westport CT.

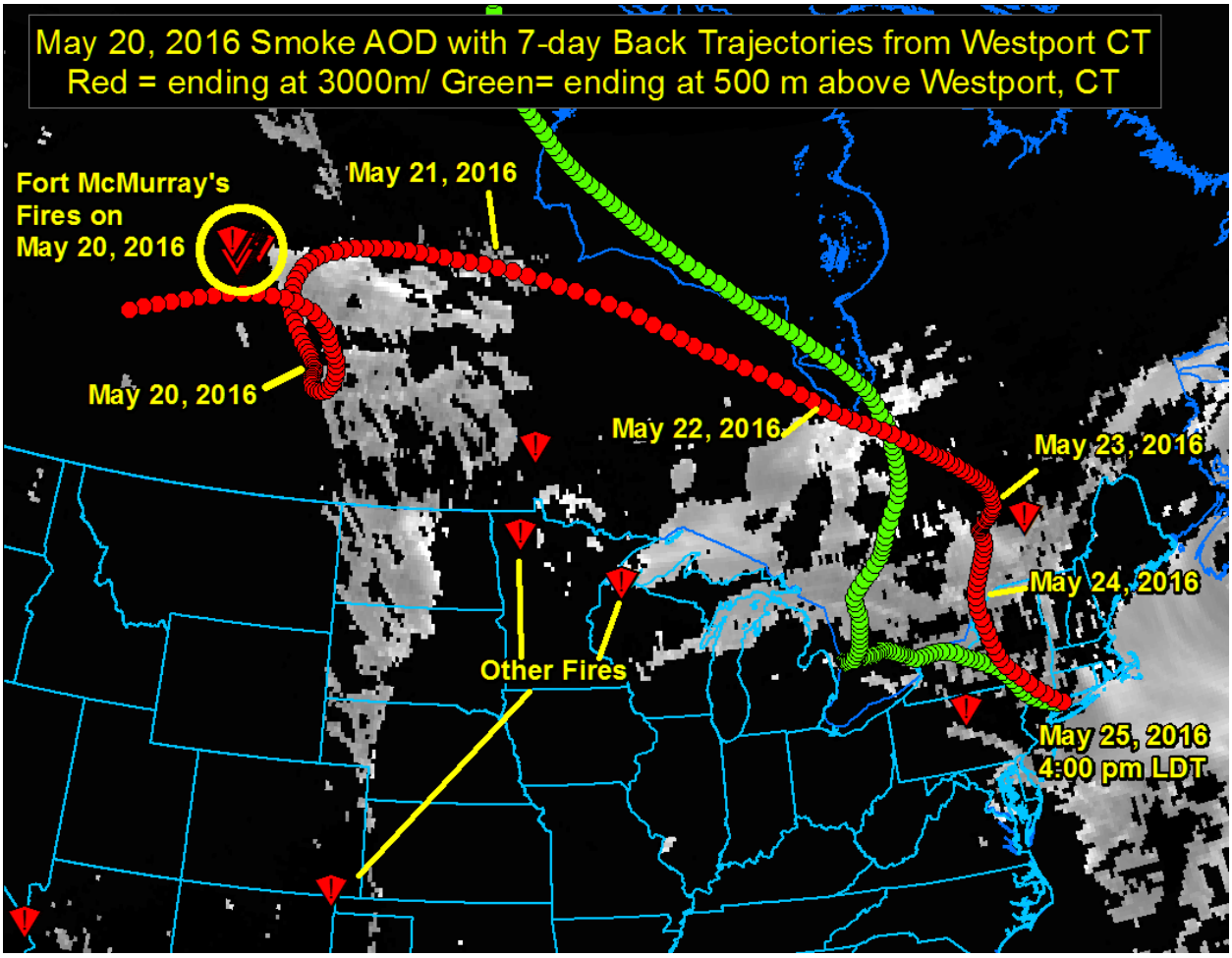


Figure 70. Hourly Back Trajectories ending at 4:00 pm LDT on May 25th with Fire Locations and Satellite AOD from May 20th, showing Path of Transport of Smoke Plume Pollutanst to Westport CT.

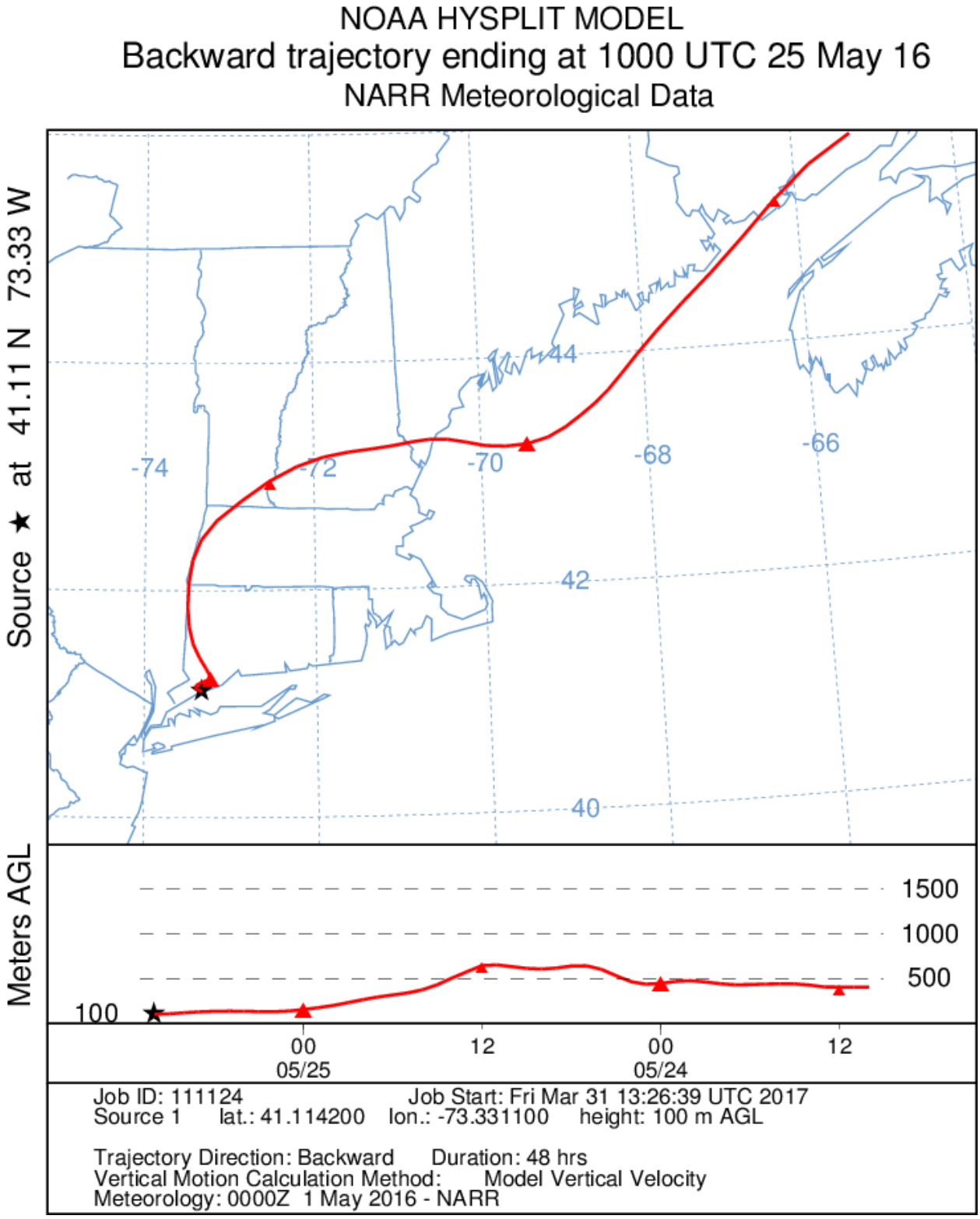


Figure 71. 100 meter Back Trajectory from Westport Connecticut ending at 6:00 am LDT May 25, 2016.

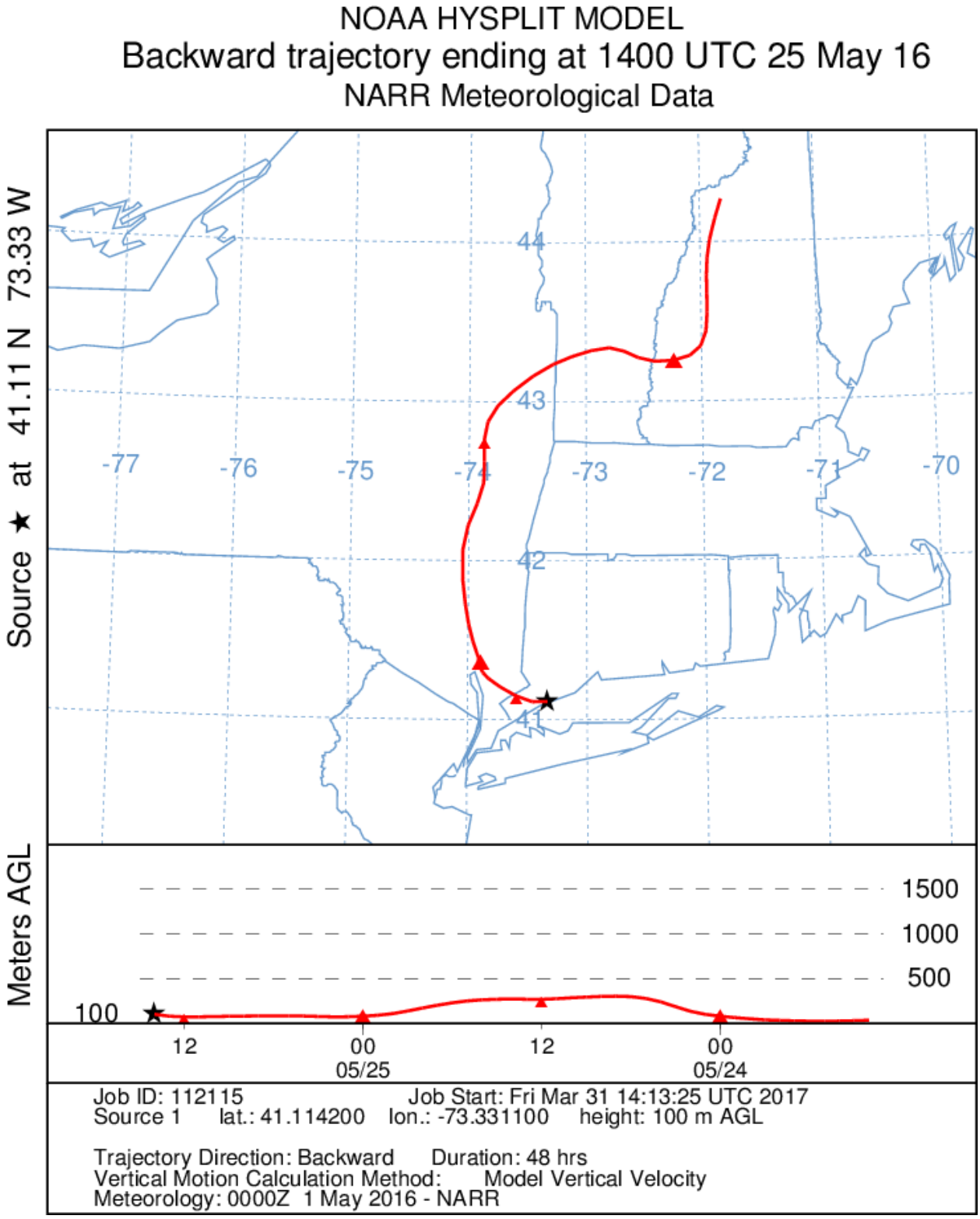


Figure 72. 100 meter Back Trajectory from Westport Connecticut ending at 10:00 am LDT May 25, 2016.

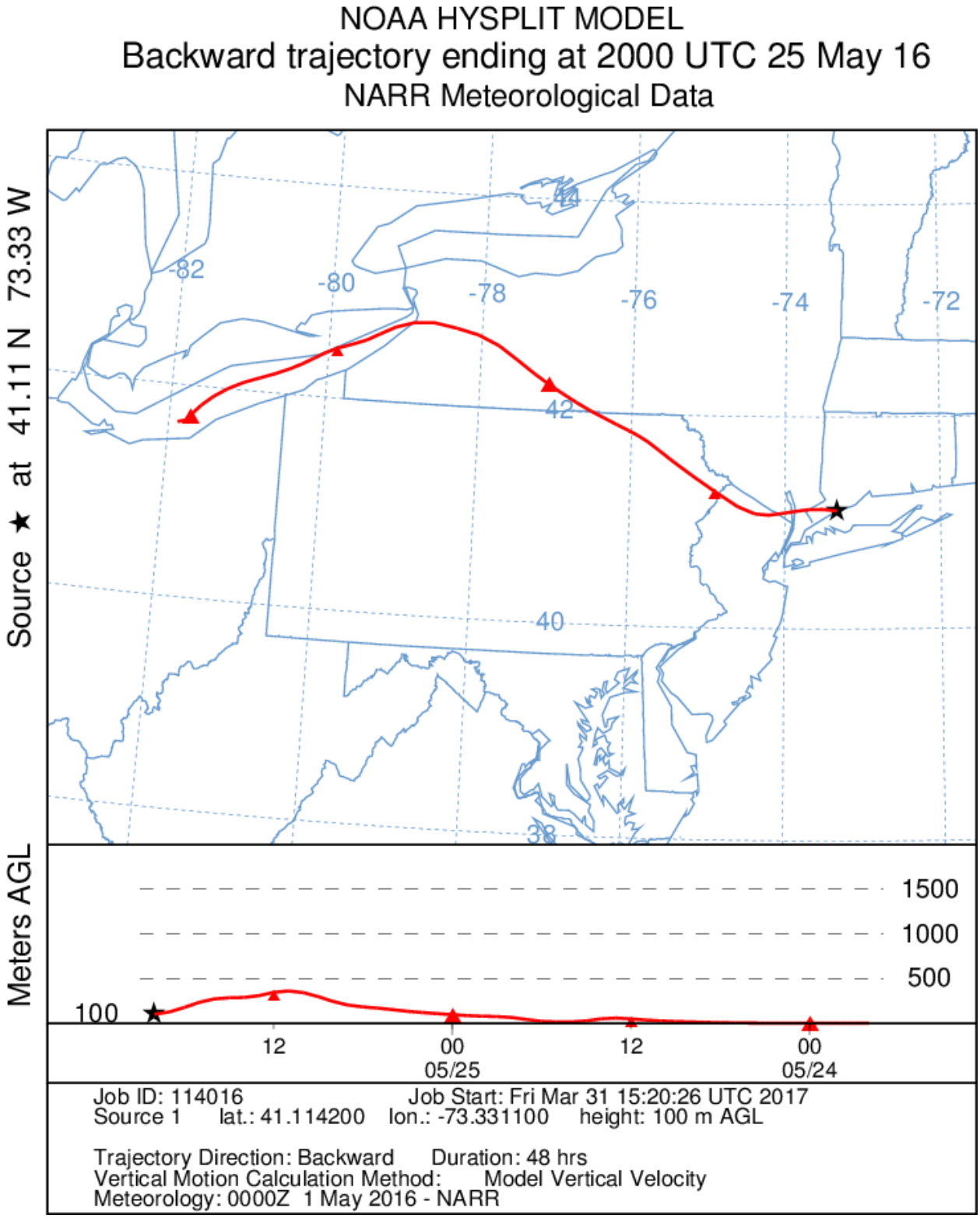


Figure 73. 100 meter Back Trajectory from Westport Connecticut ending at 4:00pm LDT, May 25, 2016.

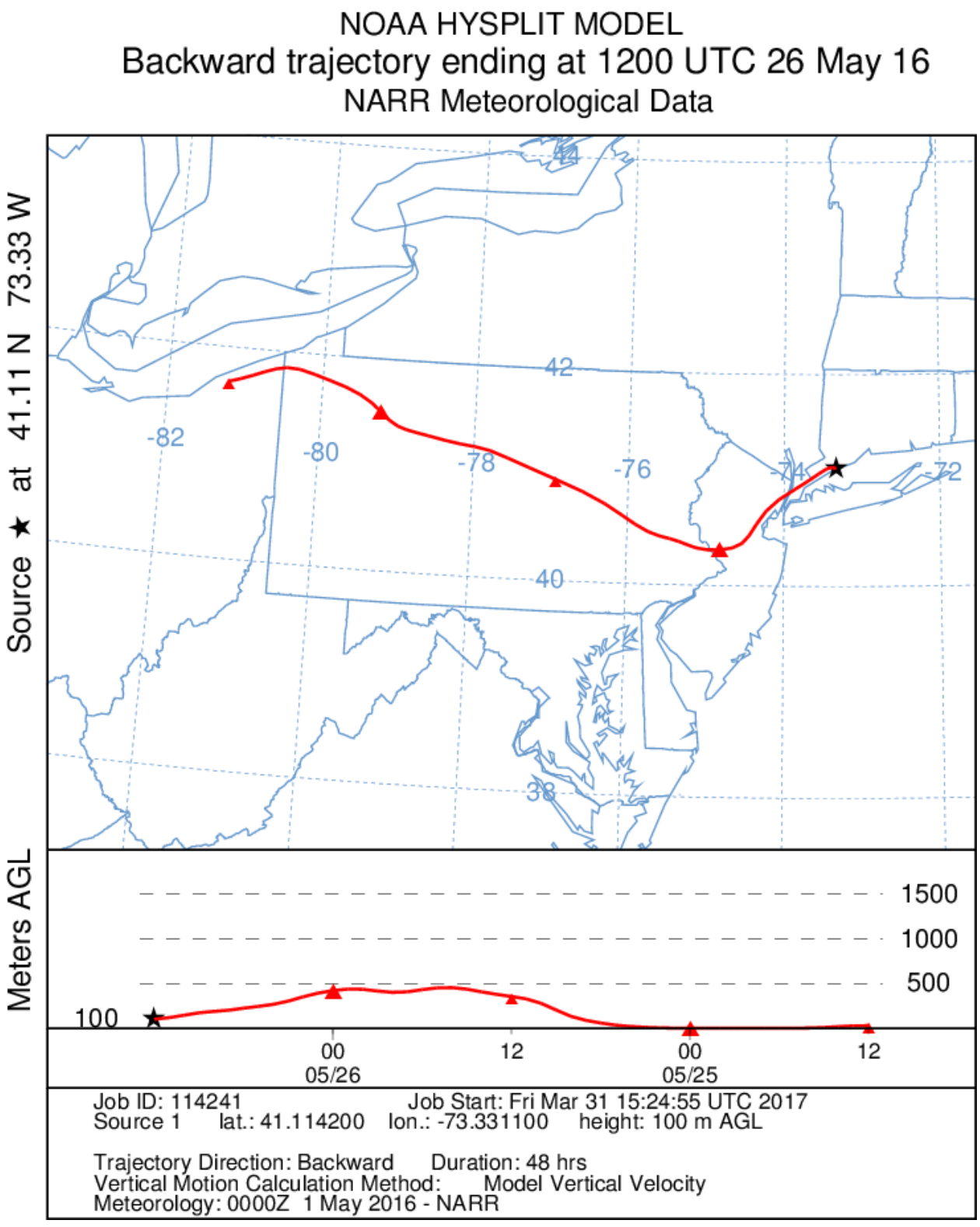


Figure 74. 100 meter Back Trajectory from Westport Connecticut ending at 8:00 am LDT, May 26, 2016.

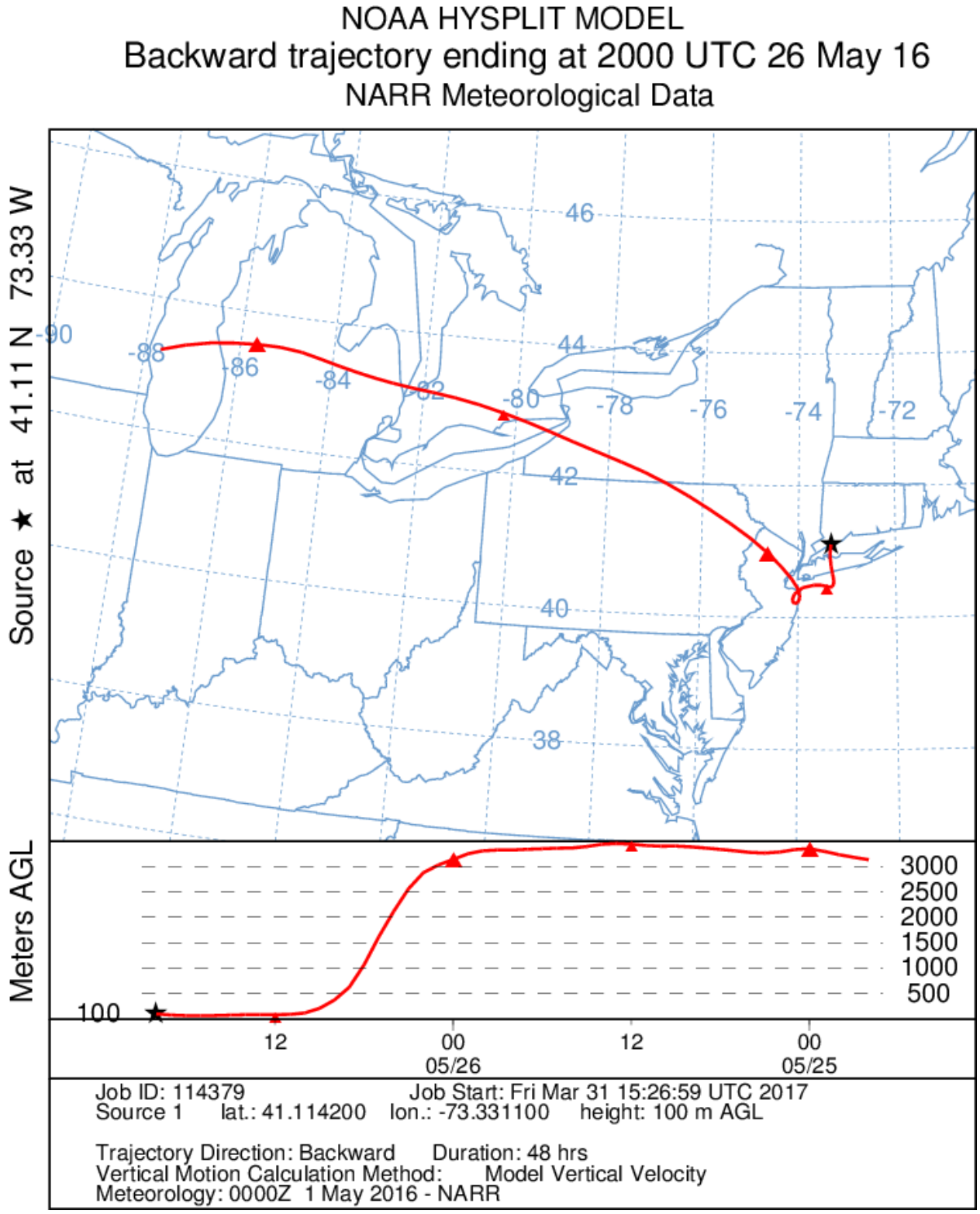


Figure 75. 100 meter Back Trajectory from Westport Connecticut ending at 4:00 pm LDT, May 26, 2016.

To further illustrate the unusually high ozone concentrations observed with the near surface wind flow, it is useful to plot 24-hour back trajectories using a higher resolution model, such as the North American Mesoscale Forecast System (NAM), which has a grid resolution of 12 km. The following figures for May 25th and May 26th start the back trajectories at 12:00 EST and 2:00 EST, respectively. For this, all four monitors in question were selected as end points. Using the Navigator Tool available on Airnowtech[21], it is straightforward to plot HYSPLIT back-trajectories an a map of ozone monitors with their hourly concentrations. Endpoint heights of 100 meters were chosen and 6-hour past intervals are labeled on the trajectories.

On May 25th at 12:00 EST (Figure 76), ozone levels were already above 80 ppb in Connecticut, but the back trajectories originate from the north and northwest, which is normally a source of low ozone and its precursors. On May 26th, at 16:00 EST (Figure 77), ozone levels are very high at all monitors in Connecticut. Except for Cornwall, the 24-hour back trajectories show southwest winds originating over the ocean and becoming southerly 6 hours earlier. The directional wind barbs line up well with these trajectories, adding more proof that surface winds along the I-95 corridor had little influence on these ozone levels.

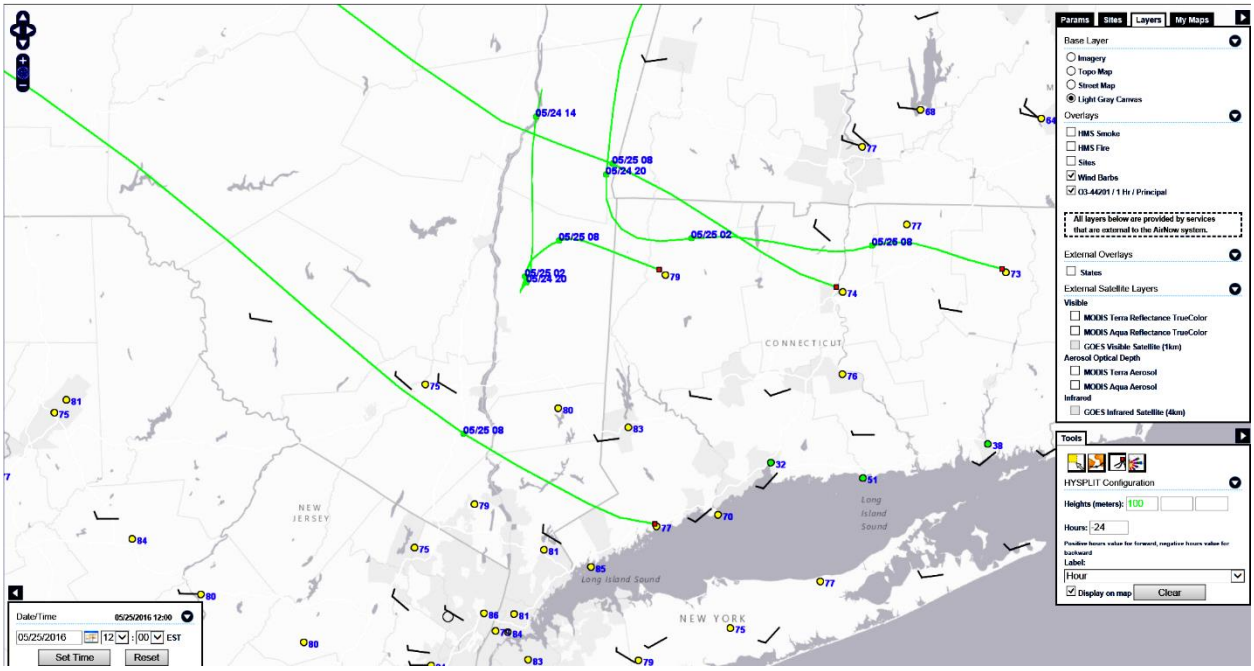


Figure 76. May 25th 24-hour Back Trajectories ending at 12:00 EST.

[21] http://www.airnowtech.org/

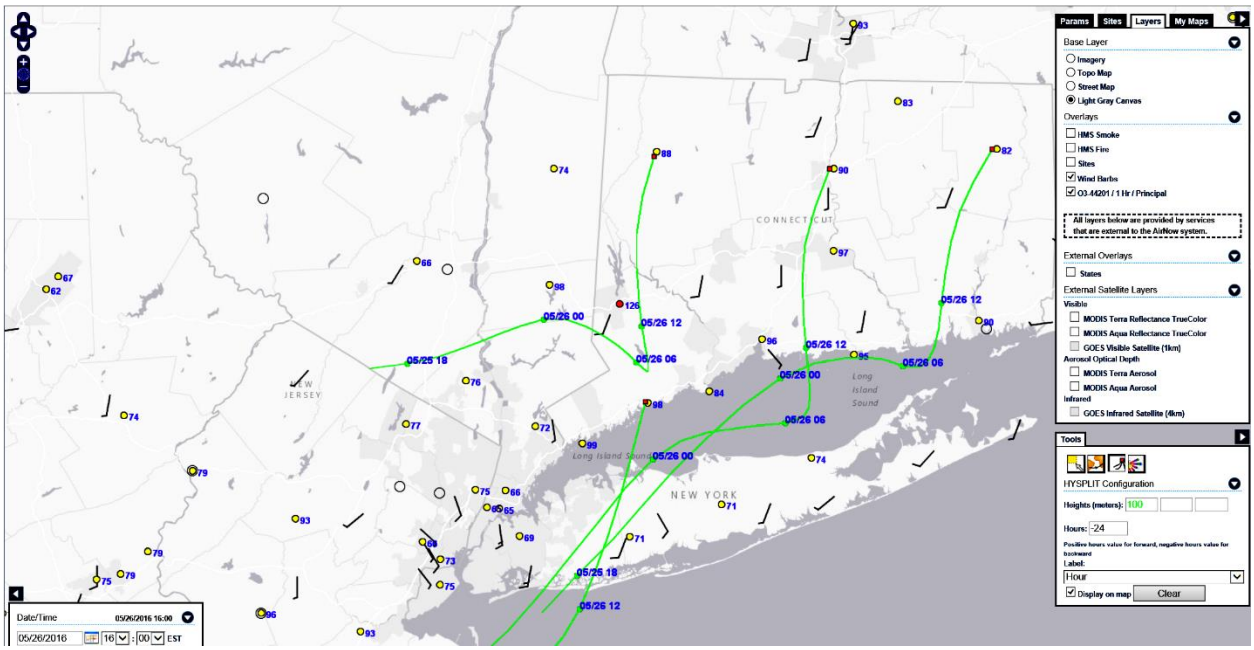


Figure 77. May 26th 24-hour Back Trajectories ending at 16:00 EST.

7 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

7.1 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. Investigating this date further, Figure 78 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 illustrates how extreme heat is no longer the main factor for an ozone exceedance in Connecticut.

July 6, 2010 is a good example to show 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 a particular 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.

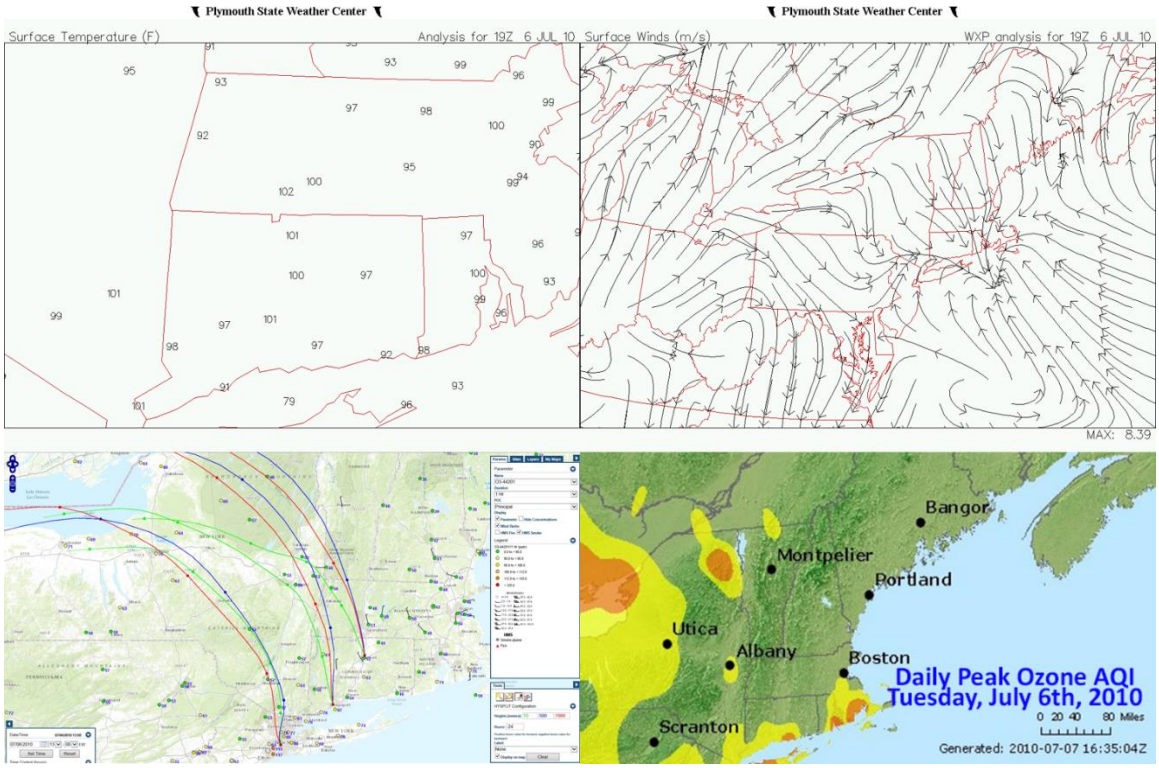


Figure 78. Temperatures and Winds around Connecticut on July 6, 2010

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 to identify days with meteorology similar to the event:

- 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 wind speed 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 from the 12z sounding that the 850mb wind from ALY was from 320 degrees at 23 knots. Figure 79 is a

graphic of the 12z sounding on May 25th. The wind speed/ wind direction flags on the right vertical bar shows northwest wind flow from all levels above the surface.

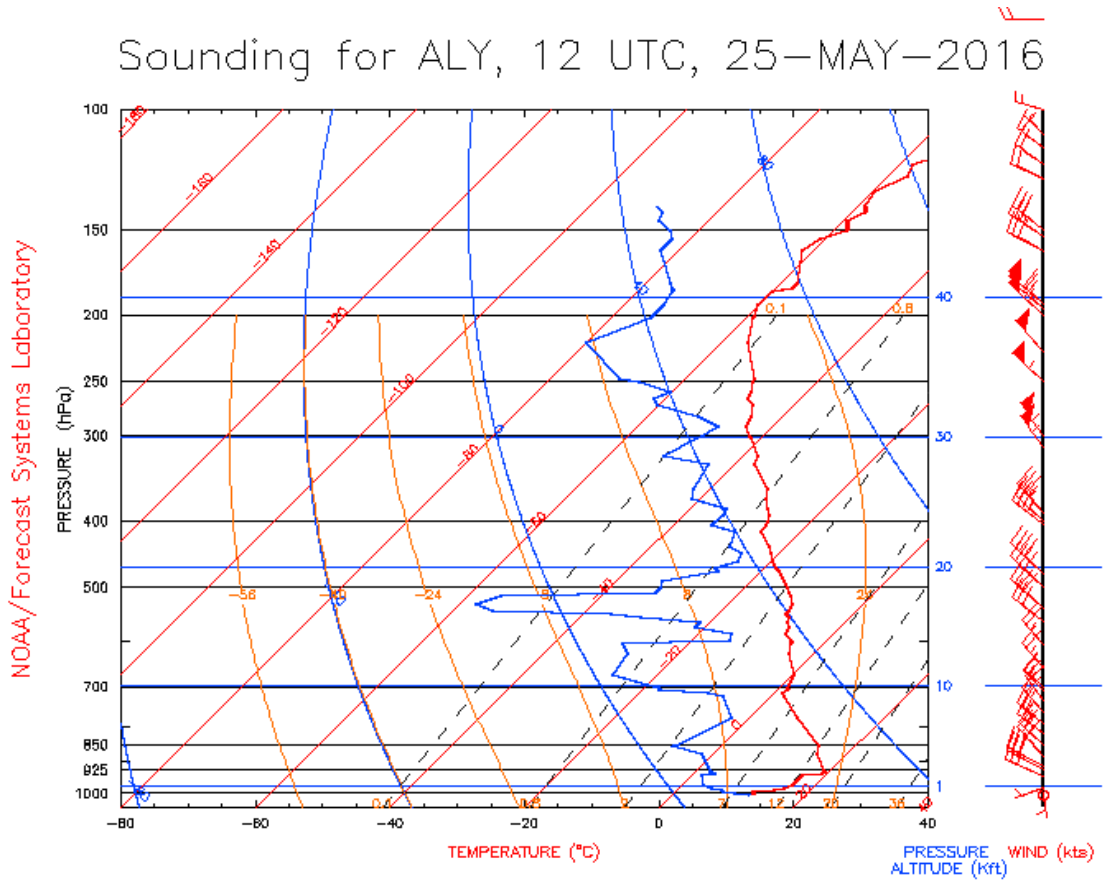


Figure 79. 12z ALY Sounding from May 25th, 2016

7.2 Similar Day Maps

An 850 mb height map (Figure 80) 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 Bay in Canada. With 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 81 is the May 25th HYSPLIT trajectories showing the 500 and 1500 meter back trajectories originating near Lake Huron. Figures 82-86 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, in contrast to the elevated ozone levels seen on May 25th, 2016.

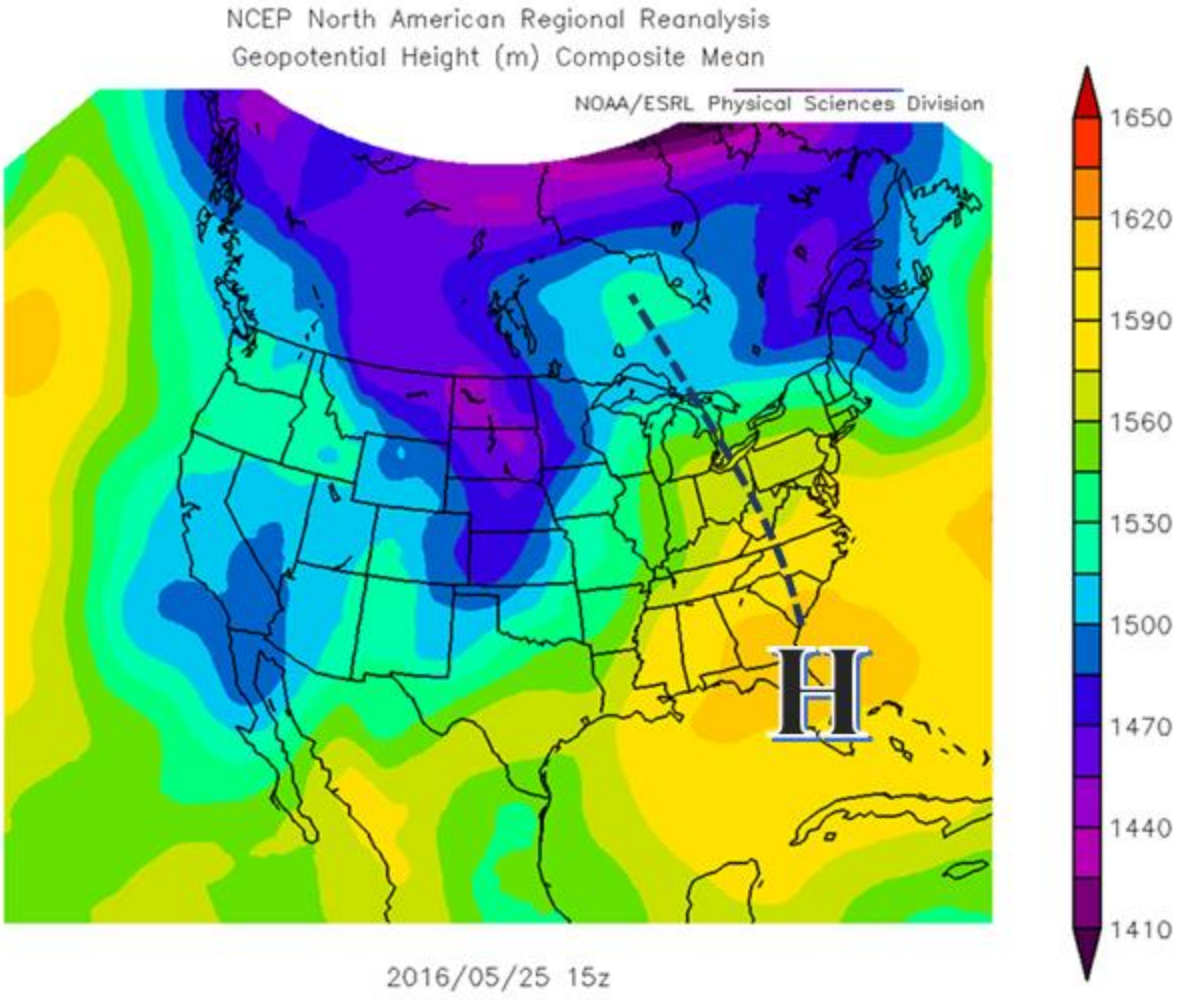


Figure 80. 850 mb Reference Pressure Pattern for May 25th, 2016

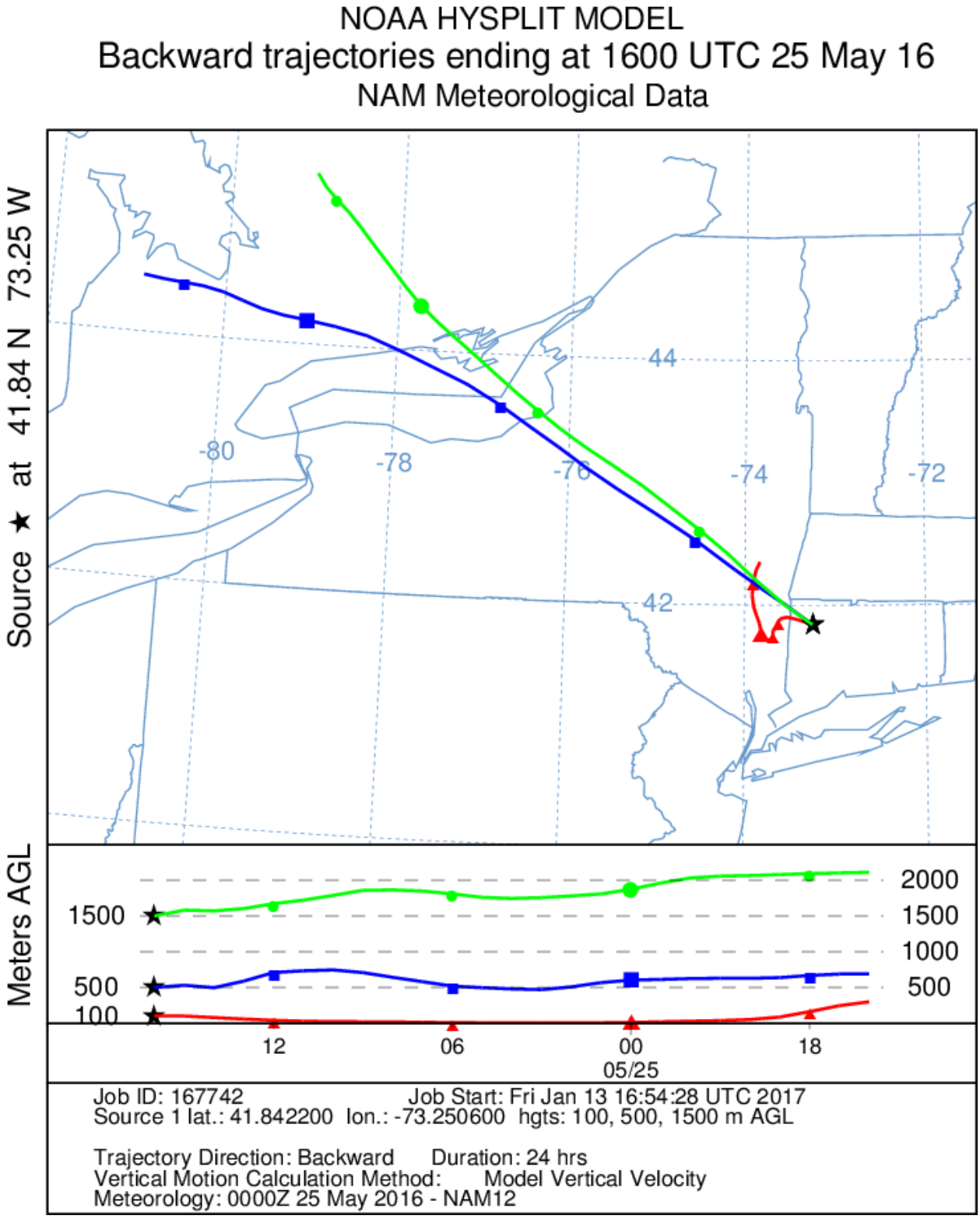


Figure 81. HYSPLIT Reference Trajectories from May 25th, 2016

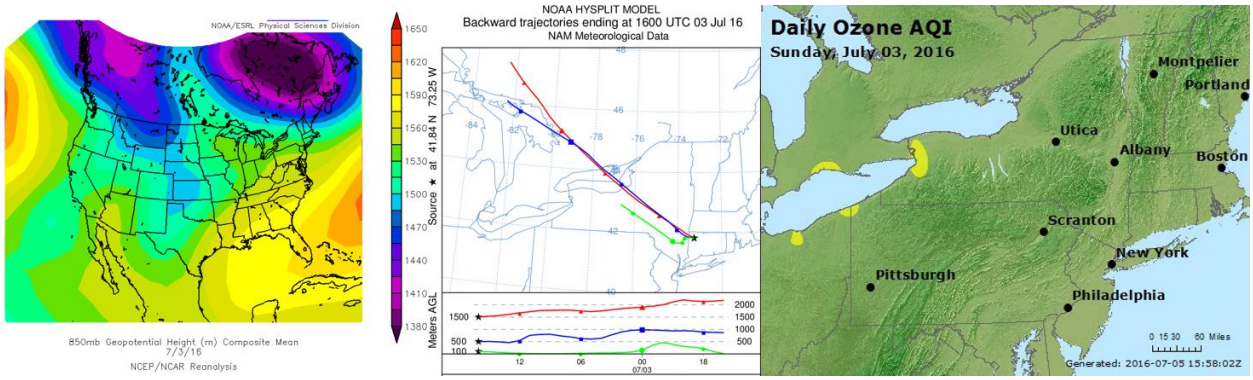


Figure 82. Matching 850 mb Pressure Pattern with Back Trajectories July 3, 2016

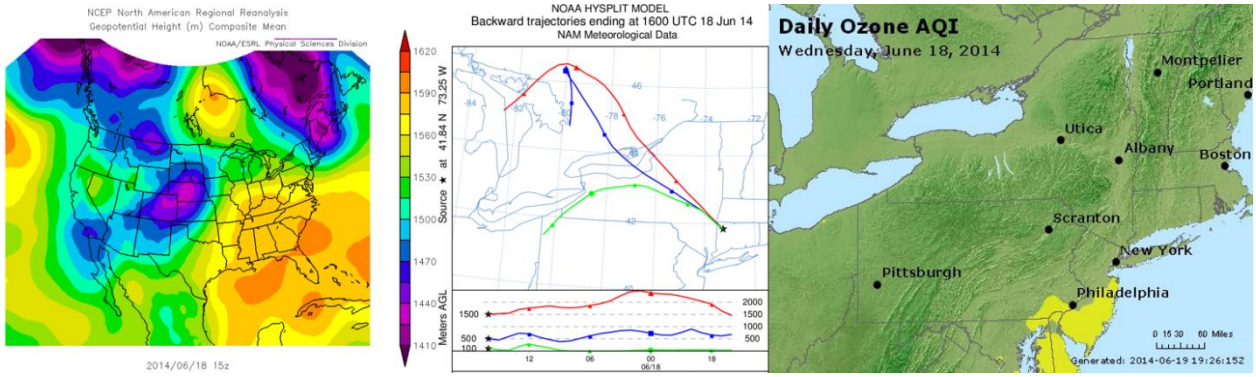


Figure 83. Matching 850 mb Pressure Pattern with Back Trajectories June 18, 2014.

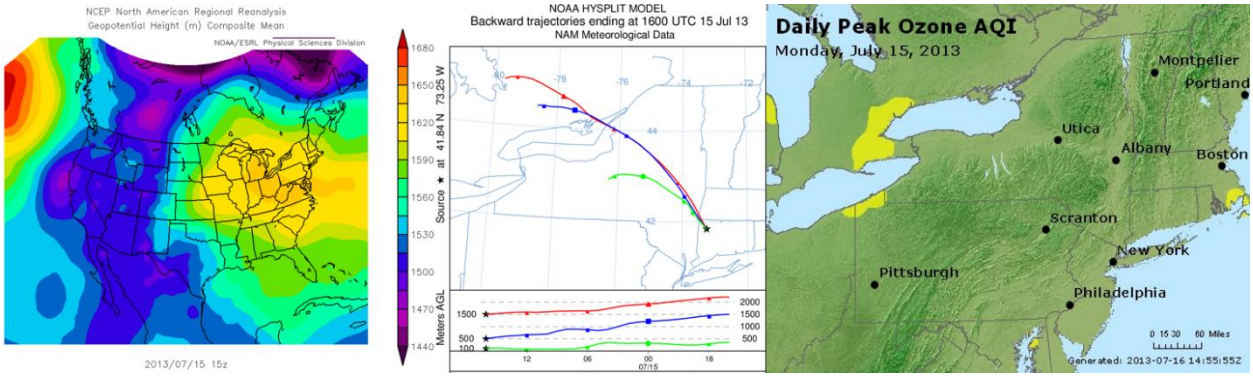


Figure 84. Matching 850 mb Pressure Pattern with Back Trajectories July 15, 2013.

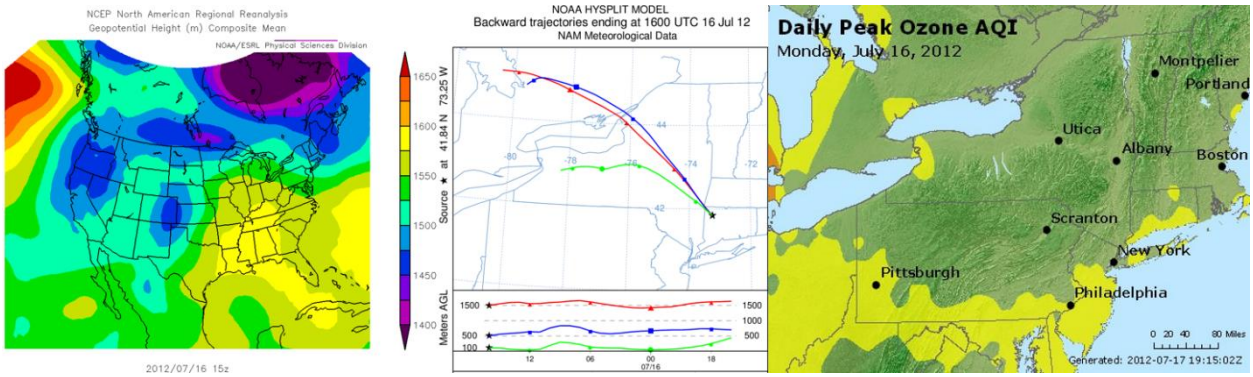


Figure 85. Matching 850 mb Pressure Pattern with Back Trajectories July 16, 2012.

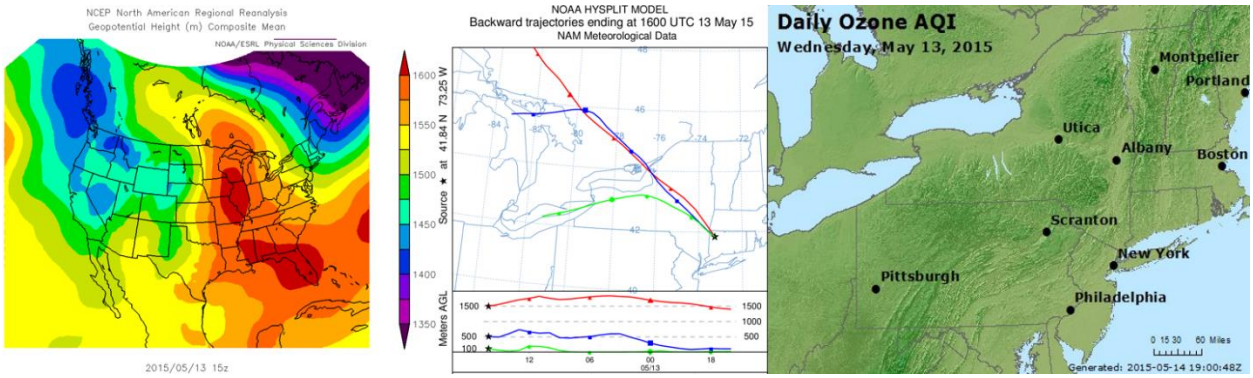


Figure 86. Matching 850 mb Pressure Pattern with Back Trajectories May 13, 2015

8. 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 particulate emissions since the summer of 2014, however, gaseous wildfire emissions, which would have included ozone precursors, have not been input into the ozone forecast which would likely lead to under-prediction of wildfire induced ozone events. 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 29, 2016 was determined to have a similar weather pattern as May 25, 2016. Figure 87 shows the model output for the two days beside the observed AQI levels. It is widely recognized that the model over-estimates ozone concentrations in the northeast U.S. during the mid-summer, however, in the May 25th case, 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 88 shows the model bias for May 25th, 2016, with 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 for data exclusion (Figures 89-91). 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 during the event. Predictions for the 24th are, as typical, nearer to observed ozone concentrations. The strength of this bias on such a large area indicates the magnitude of the impact that the plume likely had on the region.

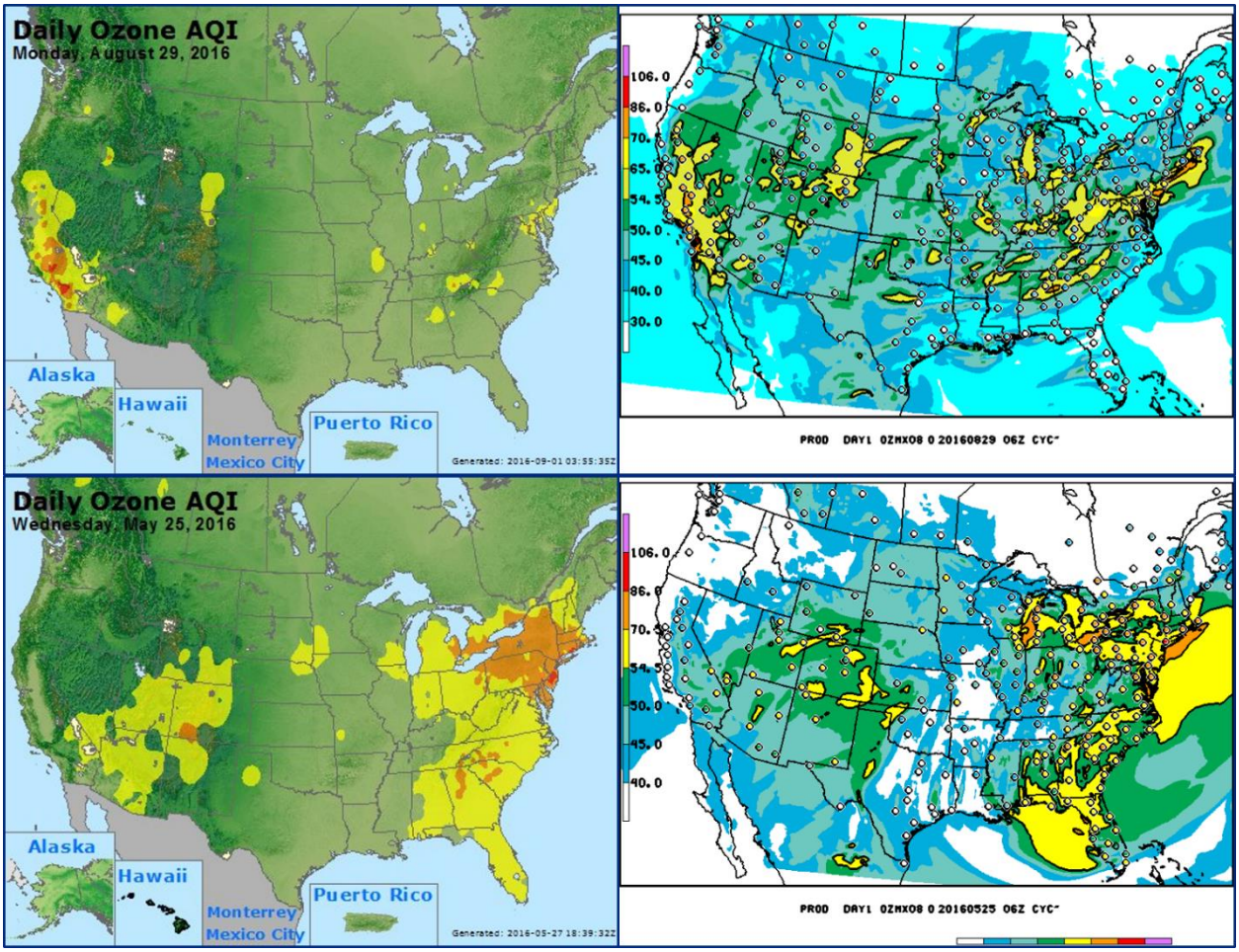


Figure 87. Comparing Similar Day Model Output from August 29th to May 25, 2016 with Observed AQI

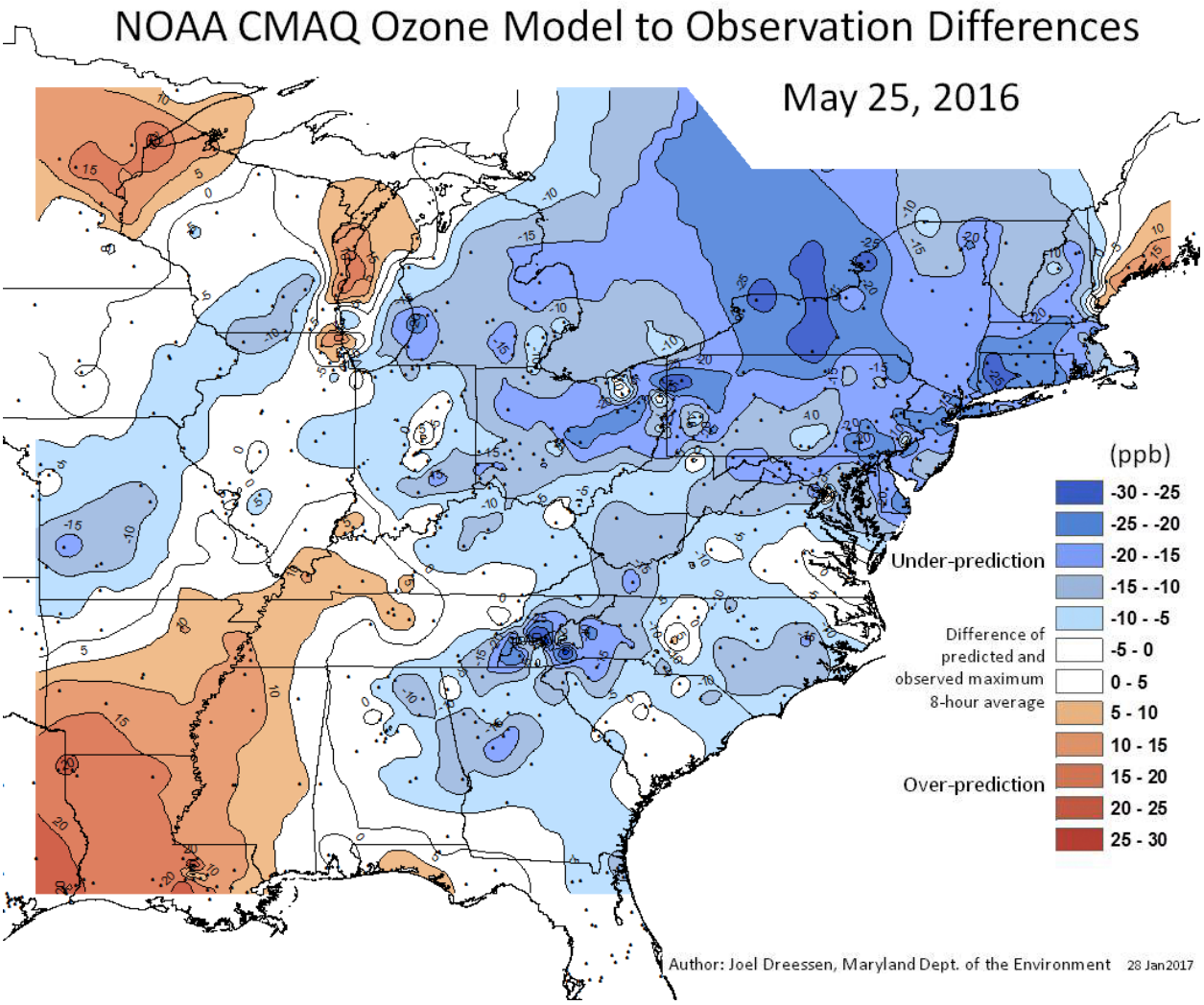


Figure 88. NOAA CMAQ Model Bias Isopleths for May 25, 2016

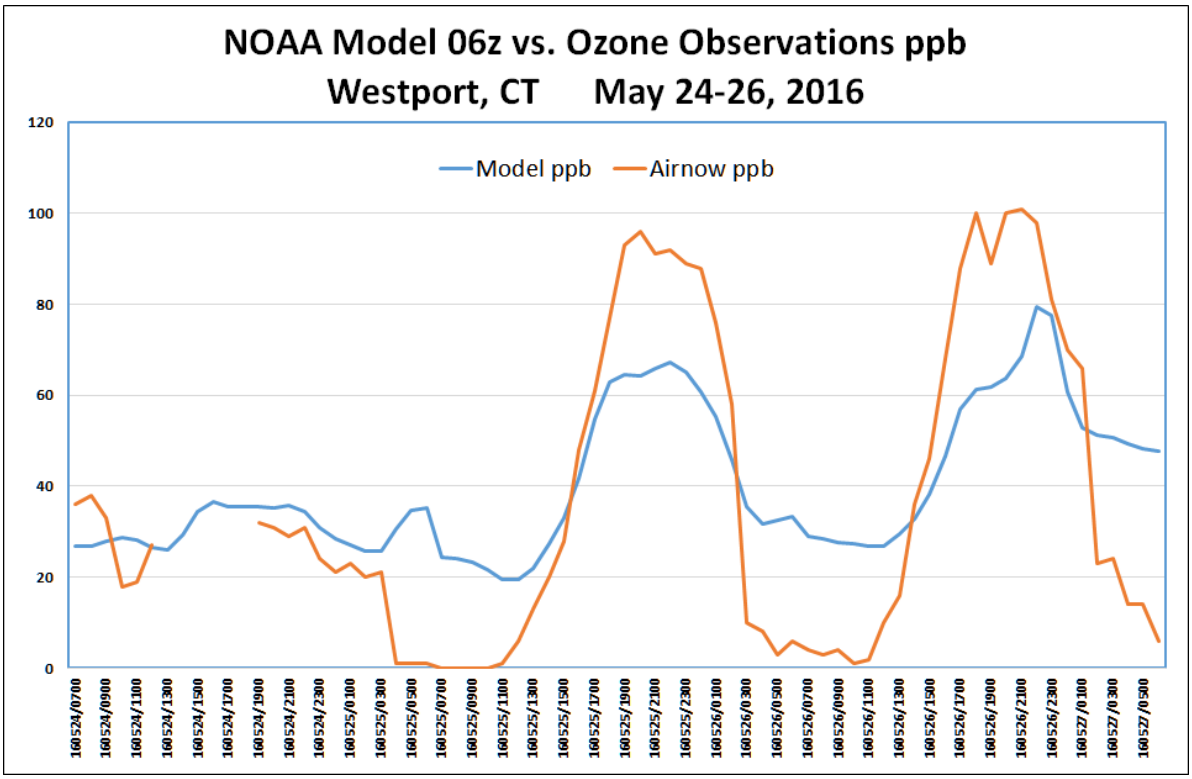


Figure 89. Westport CT NOAA Model vs. Observed Ozone, May 24-27, 2016

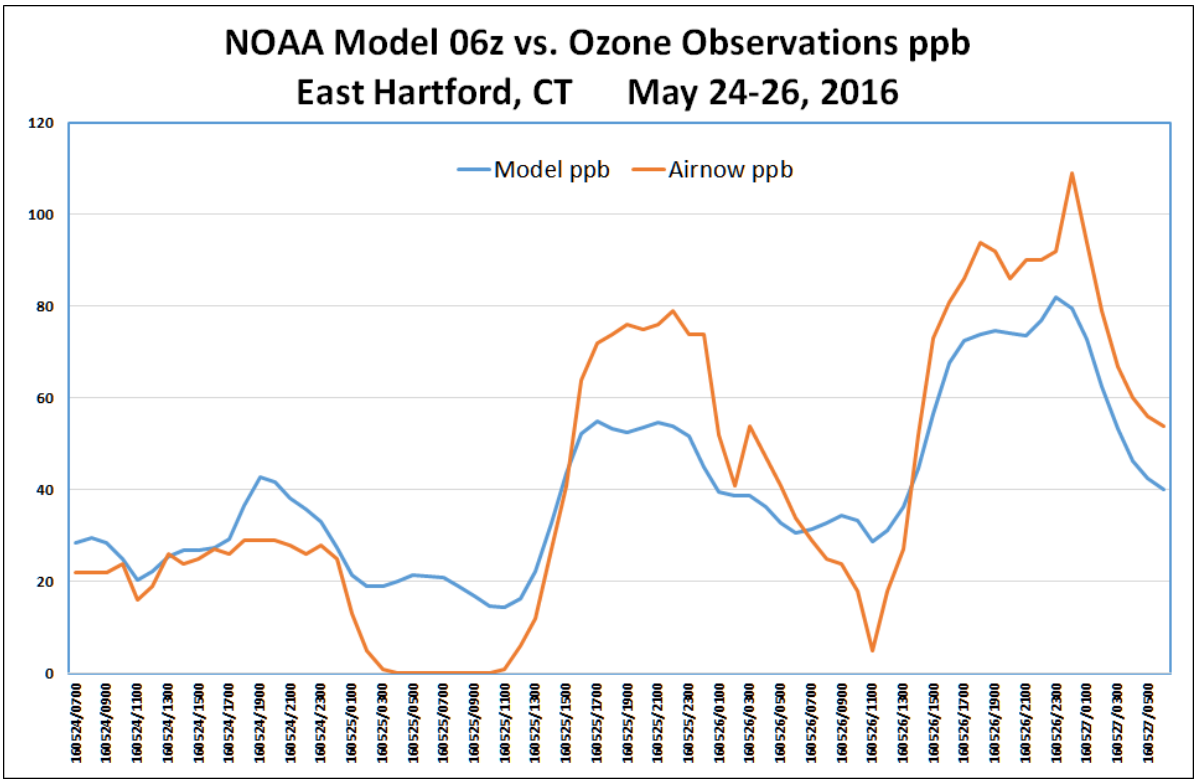


Figure 90. East Hartford NOAA Model vs. Observed Ozone, May 24-27, 2016

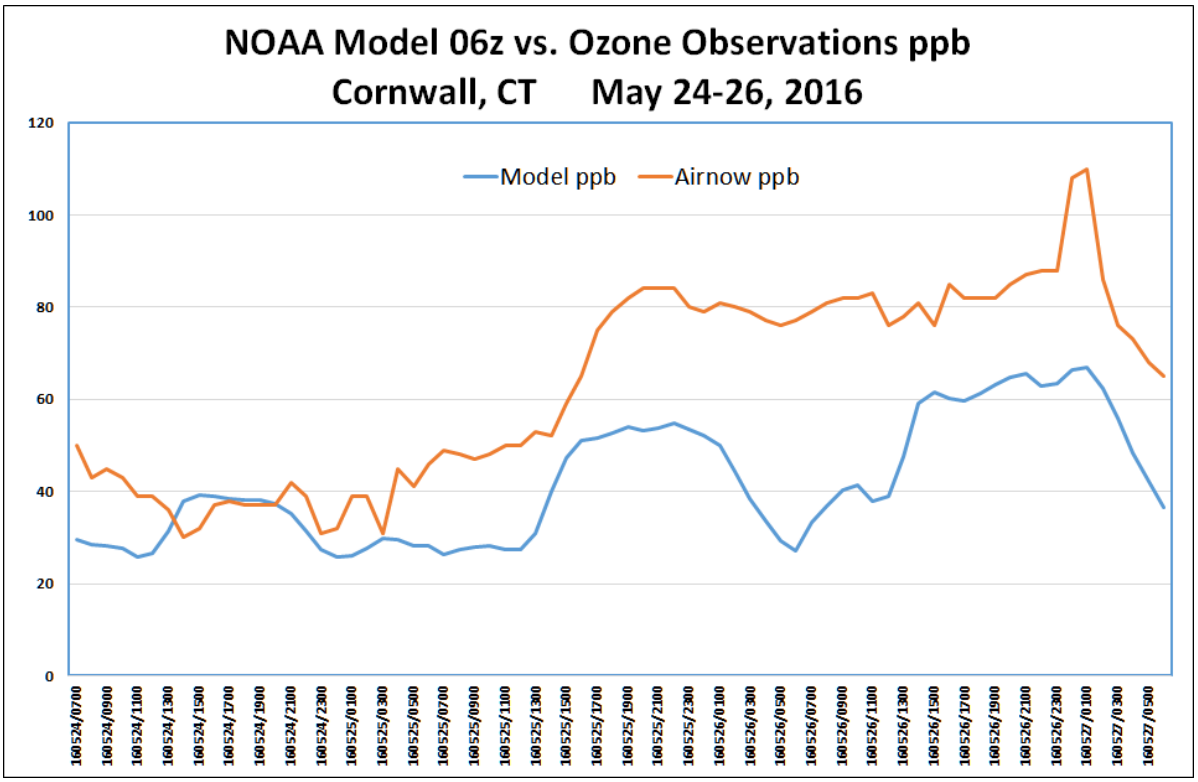


Figure 91. Cornwall CT NOAA Model vs. Observed Ozone, May 24-27, 2016

9. SUMMARY

Throughout May 2016 an intense and historically massive wildfire burned near Fort McMurray, Alberta Canada that generated a smoke plume which travelled thousands of miles. On May 25th, the wildfire plume, along with the ozone produced from it, was transported east and southeast to New England and the Mid-Atlantic States resulting in some of the highest ozone concentrations in the region for the summer of 2016.

Weather conditions in the northeastern United States were not conducive to ozone formation as the event initiated on May 24th and 25th and although conditions became more favorable for ozone formation after May 25th, it is evident from our analysis that that the wildfire plume had a significant effect on the ozone levels for several days. Figure 92 shows the movement of the ozone plume from the Great Lakes to the east coast from May 24th through its dissipation on May 29th.

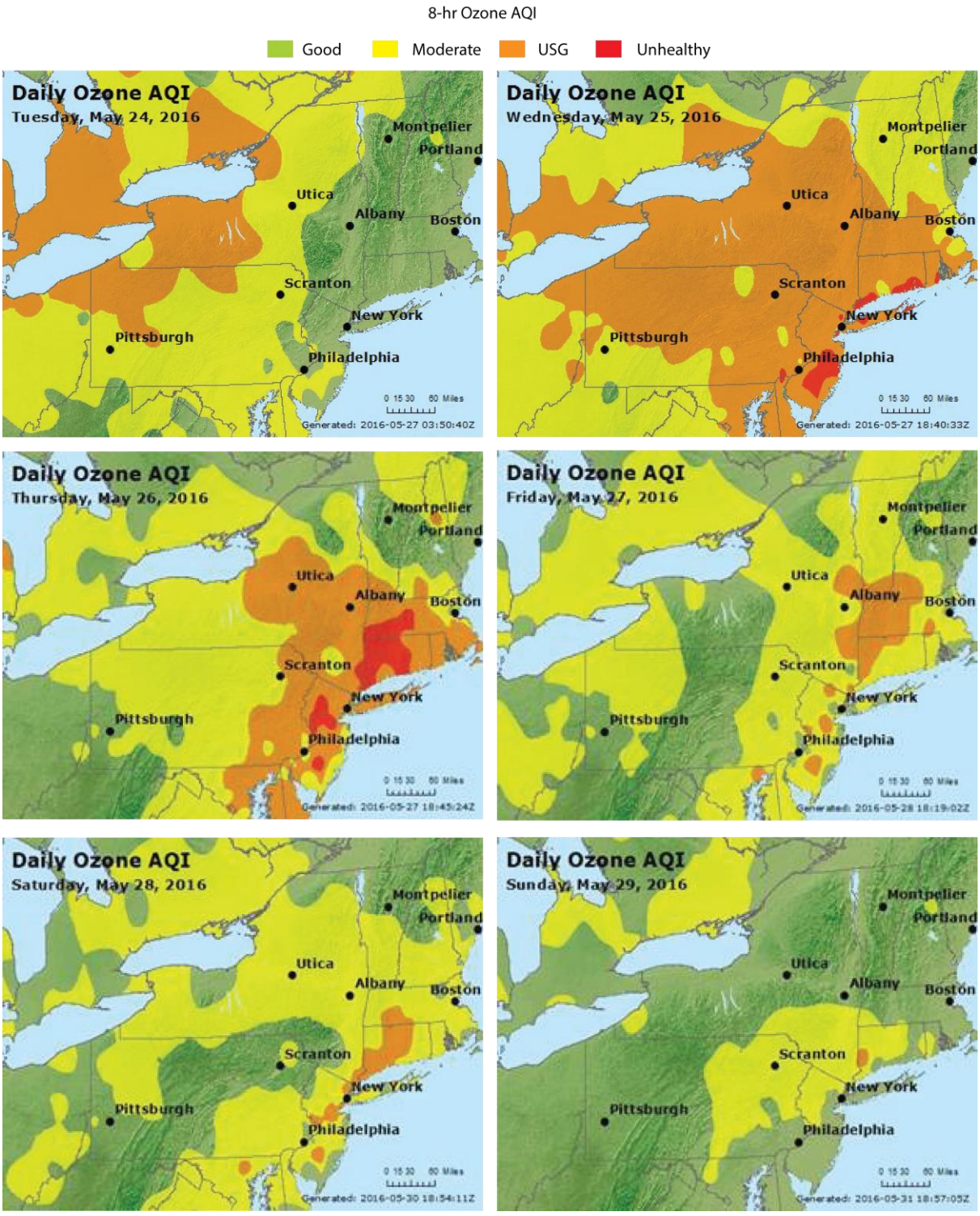


Figure 92. AQI Map of the Event.

Four monitors in Connecticut, Abington, Cornwall, East Hartford and Westport, were affected by the smoke plume in a regulatory meaningful way on May 25th and 26th. The effect was to the extent that one or both of these days at each of these four monitors were in the 99th percentile of five years of ozone season data. The movement of the ozone plume from the northwest into Connecticut was unusual and coincident with the travel of the smoke plume from the Fort McMurray fire. Furthermore, there were no sources other than the Fort McMurray fire to which the episode could be attributed. Review of days with similar meteorology indicate that exceedances were otherwise unlikely to occur. Analysis of the ozone predictive model indicates that the wildfire may have contributed 20 to 30 ppb to monitored ozone levels throughout the region. All evidence supports the position that the wildfire event affected air quality to the extent that it caused the ozone exceedances or caused them to be among the highest values recorded during the season.

Consistent with the Exceptional Events Rule (40CFR50.14) the data from the four monitors, Abington, Cornwall, East Hartford and Westport, for the days of May 25th and 26th should be excluded from any regulatory determinations. Figure 93 is a map showing the 2016 design values for Connecticut after the data exclusion for this exceptional event is approved.

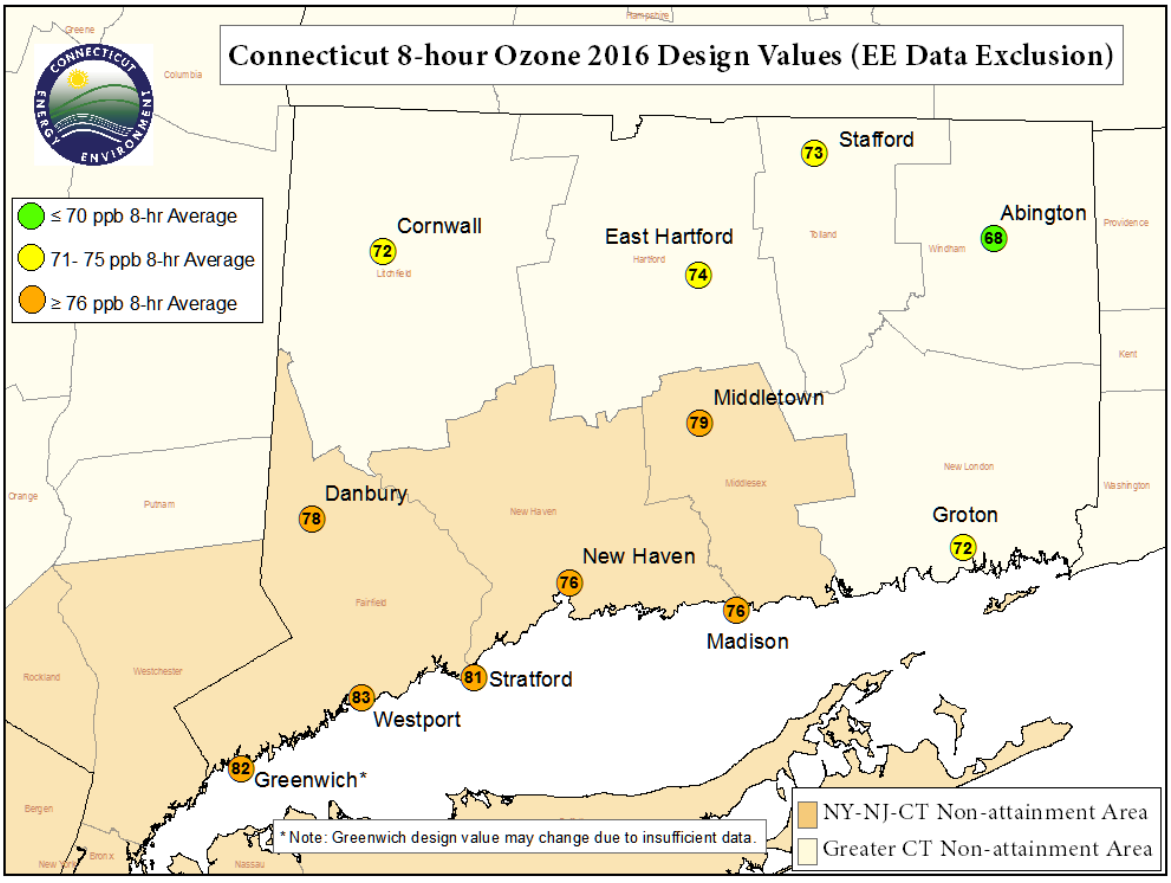


Figure 93. Map of 2016 Connecticut 8-hour Ozone design Values after Data Exclusion.