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SUMMARY OF METEOROLOGICAL CONDITIONS DURING THE NORTHEAST OXIDANT AND PARTICULATE STUDY (NEOPS-DEP) JULY 2002 INTENSIVE OBSERVING PERIOD

William F. Ryan
Russell Philbrick
The Pennsylvania State University, University Park, Pennsylvania

Richard Clark
Millersville University, Millersville, Pennsylvania

1. INTRODUCTION

The Northeast Oxidant and Particle Study (NEOPS) is an investigation of meteorological and chemical processes that control the evolution of air pollution episodes in near-urban environments. NEOPS is part of the North American Research Strategy for Tropospheric Ozone (NARSTO) and its main sampling site is located just northeast of center city Philadelphia. Intensive observing campaigns (IOPs) were carried out at this location during the summer seasons of 1998, 1999 and 2001. In July of 2002, a continuation of this project, under the auspices of the Pennsylvania Department of Environment Protection (DEP), was carried out. This paper summarizes the meteorological conditions encountered during the 2002 IOP and provides a preliminary analysis of several pollution episodes during that period.

2. BACKGROUND

The NEOPS-DEP summer intensive observing campaign was carried out from late June to early August 2002 and was based at the Baxter Water Treatment Plant in North Philadelphia (BAX) (Philbrick et al., 2002). NEOPS-DEP offers a unique dataset of *in situ* and remotely sensed observations that provide a three-dimensional view of pollution events in an urban environment. Research instrumentation used in 2002 included Raman lidar (Philbrick and Mulik, 2000), wind profilers, instrumented tethered balloons (Clark et al., 2002) and variety of surface-based measurements of O_3, its precursors, and fine particulate matter ($PM_{2.5}$).

3. WEATHER SUMMARY

The summer of 2002 in the mid-Atlantic region was dominated by the re-emergence of drought conditions. In early spring, moderate to severe drought conditions were present east of the Appalachian Mountains. Substantial rains during May and June ameliorated the drought across all but the southern mid-Atlantic. However, the remainder of the summer was very dry and, by the end of the NEOPS-DEP IOP, severe drought had returned to most of the region (Figure 1) (National Drought Mitigation Center, 2002). At Philadelphia International Airport (PHL), average temperatures for July were 1.0^{o}C above average with a precipitation deficit of 58.4 mm or approximately 48% of normal rainfall. This pattern continued into August with an additional 33 mm precipitation deficit. In addition to a warmer than average mean temperature, there were a large number of hot days in July with 17 days at or in excess of 32.2^{o}C (90^{o}F).

Across the mid-Atlantic region, very warm temperatures were reported in July with most of the region experiencing temperatures at or above the 80th percentile of the climatic record (Figure 2). Much warmer than normal conditions were also observed in the Great Lakes and mountain West. The only exceptions to the warm weather regime were in northern New England and Texas. The mid-Atlantic was extremely dry with the largest rainfall deficits across eastern NY, PA, NJ and DE and the eastern portions of VA and MD (Figure 3). Nearly the entire region ranked in the lowest 10th percentile for rainfall during the month.

In terms of the larger scale circulation pattern, July was characterized by the standard summer season feature of a broad ridge across the continental U.S. In the lower troposphere (850 mb), the Bermuda High regressed slightly westward across the southeastern U.S. (Figure 4). This pattern is consistent with seasonal climatology and is similar to conditions during the July 1999 IOP (Figure 5) (Ryan et al., 2002). The main distinguishing features of the low level circulation during the 2002 IOP were lower than normal geopotential heights over the Canadian Maritimes coupled with higher than normal heights over the Great Lakes (Figure 6). This couplet resulted in an enhanced northerly wind component across the eastern U.S. (Figure 7). This circulation anomaly

* *Corresponding author address*: William F. Ryan, Pennsylvania State University, Department of Meteorology, 409 Walker Building, University Park, PA, 16802, email: wfr1@psu.edu.

will feature importantly in several high O_3 cases during July.

4. O_3 CONCENTRATIONS

As expected during a drier and warmer than average July, O_3 concentrations were above average in the Philadelphia metropolitan area. For the set of 14 O_3 monitors operated within the Philadelphia forecast area – which encompasses southeastern PA, southern NJ, northern DE and extreme northeastern MD – average daily peak O_3 was 97.2 ppbv for the period June 28-August 6. This represents a slight increase (+4.3 ppbv) over average concentrations for the period from 1991-2001. While mean peak O_3 was only slightly above normal, the frequency of high O_3 cases was strongly enhanced. During the period June 28 to August 6, 11 days reached "Code Red" status (peak 1-h O_3 > 120 ppbv) compared to an average of 6.7 days for the period 1991-2001. This represents the highest frequency of Code Red cases in Philadelphia since 1993. During the NEOPS-DEP IOP there were four distinct multi-day pollution episodes that are discussed in greater detail below.

5. POLLUTION EPISODES

Four multi-day pollution episodes occurred during the 2002 NEOPS-DEP IOP: July 1-3, July 7-9, July 17-19 and August 1-5 (Figure 8). All episodes contained instances of monitors exceeding the 1-hour National Ambient Air Quality Standard (NAAQS) for O_3, or "Code Red", within the mid-Atlantic region. For the purposes of this paper, the mid-Atlantic region encompasses the states of PA, NJ, DE and MD. The most severe episode was July 7-9 with 28 regional monitors exceeding the 1-hour NAAQS. The most sustained episode was August 1-5 with 5 consecutive days exceeding the 1-hour standard. The number of monitors in excess of the 8-h standard was relatively constant across all four episodes averaging approximately 32-34 monitors per day with the exception of August 1-5 that averaged only 23 monitors per day. Key aspects of each episode are now discussed:

July 1-3

This was the mildest of the IOP episodes with only 5 regional O_3 monitors exceeding the 1-h NAAQS. In the Philadelphia metropolitan area, the episode was characterized by extremely warm and humid conditions with a brief pulse of significant haze. Maximum temperatures increased from 32.2^{o}C on July 1 to 37.2^{o}C (the warmest day of the month) on July 4. As is often the case in the mid-Atlantic, O_3 concentrations peaked in advance of the warmest weather.

The larger scale circulation during this episode reflects the mean monthly circulation anomaly noted above. An upper level trough became "cut off", or detached from the mean westerly flow, over New England (Figure 9). The closed cyclonic circulation, coupled with an advancing upper level ridge, resulted in a period of stagnation and re-circulation on July 1. While widespread 8-hour exceedances of the NAAQS were observed, peak 1-hour concentrations were just under the Code Red threshold.

Although visibility was good at PHL on July 1, significant haze was reported west of the Appalachians on July 1 and, as winds backed west on July 2 (Figure 10), this hazy and polluted air mass was advected over Philadelphia. PHL reported visibility falling abruptly in the late morning hours from 16.1 km at 1300 UTC to 6.4 km by 1800 UTC. This is the opposite of the usual diurnal visibility pattern where the lowest visibility is typically around sunrise improving by afternoon. The onset of the haze event coincided with higher peak O_3 concentrations as 5 monitors in MD and NJ exceeded the 1-hour NAAQS. The departure of the haze and high O_3 was as rapid as its onset with visibility increasing from 3.2 km at 1200 UTC on July 3 to 16.1 km by 1500 UTC. Although temperatures warmed further (36.1^{o}C) due to downsloping northwest winds, the number of 8-hour NAAQS exceedances dropped by 2/3rds and no 1-hour exceedances were reported on July 3. Temperatures reached a monthly maximum (37.2^{o}C) on July 4th but reductions in upstream O_3 of 10-20 ppbv; reduced local emissions for the holiday and deeper boundary layer mixing resulted in decreased local O_3 concentrations.

July 7-9

This unusual episode featured intense smoke from widespread wildfires in central Quebec. The pattern of a stalled cyclonic circulation over the Canadian Maritimes recurs in this case with dramatic consequences for local air quality (Figure 11). The first smoke plumes in Quebec were observed embedded in the cloud shield associated with the slow moving upper level low pressure center early on July 5. By later that afternoon, strong winds fanned the flames and advected the smoke plume over a wide area (Figure 12). At this time, the smoke was lofted above the boundary layer and there was little evidence of any effect on local air quality along its path. By July 6, smoke covered a wide area of the northeastern U. S. and was mixing to the surface at some locations (Figure 13). Visibility at PHL began to degrade beginning at 2000 UTC on July 6 and reaching 6.4 km by 2300 UTC.

Although winds remained brisk on July 7 at 5.1-6.7 ms^{-1} from the northwest, and temperatures reached only 29.4^{o}C, the first effects of the smoke on local air quality were seen in an isolated lobe of high O_3 (117 ppbv) in a portion of southern NJ. As the upper level ridge built slowly eastward on July 8, maximum temperature increased to 32.8^{o}C at PHL, the planetary boundary layer (PBL) became more stable, and smoke became intense with visibilities dropping to only 1.6-3.2 km. Widespread exceedances of the 1-hour standard were observed but were limited to a relatively narrow band with the highest concentrations in extreme southeastern PA exceeding 150 ppbv (Figure 14). Although winds shifted southwest on July 9 and visibility rose to 14.5 km by 1900 UTC, O_3 concentrations remained high across the region.

Emissions from forest fires contain large concentrations of O_3 precursors and, depending upon the location and time scale, can also contain enhanced O_3 concentrations (Wotawa and Trainer, 2000; Peppler et al., 2000; Wotawa et al., 2001). While further research is necessary to determine the magnitude of the effect on the wildfires on local air quality, it appears to have had a significant impact. For example, local peak O_3 concentrations were well in excess of both statistical O_3 forecast models, which rely to a large extent on historical data, as well as numerical forecast models which use recent emissions inventories (J. McHenry, personal communication).

July 17-19

The large-scale pattern at the onset of this episode was familiar with an upper level low over eastern Canada. The pollution pattern, however, developed in a markedly different manner due to differences in the structure of the lower troposphere. In this case, a north-to-south moving cold front ("back door front") reached just south of PHL by early on July 17 (Figure 15). Widespread haze was reported south and west of the boundary. Visibility at PHL was 16.1 km early on July 17 with very dry air (dew point of 10.6^{o}C) in place. As the frontal boundary dissipated and retreated northward, beginning at 1200 UTC, winds shifted southwest and the air mass modified quickly. Dew points at PHL rose to 19.4^{o}C by 1900 UTC.

While O_3 concentrations rose rapidly on July 17, with Code Red levels observed in the Philadelphia metropolitan area, visibility remained good. Haze was observed at PHL beginning at 0900 UTC on July 18 and continued without interruption through 2200 UTC on July 19. With classic westerly transport in place on July 18 (Ryan et al., 1998) advecting regional O_3 in the range of 70-80 ppbv into Philadelphia, the number of 8-h exceedances rose by 50%. However, 1-h peak concentrations were modulated by extensive cloud cover with only Edgewood, Maryland reaching the Code Red threshold (Figure 16).

Haze remains in place on July 19 along with westerly transport, fewer clouds and a more stable PBL. A band of high 1-h O_3 concentrations was observed in the PHL-NYC Corridor. A weak frontal boundary oscillated over NYC and, by afternoon, widespread convection broke out in NY and central PA with isolated thunderstorms over NJ and DE. A strong thunderstorm was observed at PHL at 2300 UTC and the episode ends with a cold front crossing the region early on July 20.

August 1-5

A hot and humid period preceded this episode with temperatures reaching 32-37^{o}C but strong winds and low regional O_3 concentrations kept local peak O_3 relatively low. A cold front crossed the region late on July 30 but the post-frontal air mass was strongly modified and neither temperatures nor O_3 fell significantly in its wake. By August 1, high pressure was centered over WV – the standard location for high O_3 periods – but boundary layer winds were uncharacteristically northeast. This "reverse Corridor" flow resulted in the highest O_3 concentrations found downwind of NYC in central and southern NJ. Haze reports were limited to regions much further south across VA and NC. Another back door front, which was across northern New England on August 1, dropped as far south as NYC on August 2. At PHL, temperatures rose to 36.7^{o}C with calm or variable winds and scattered early morning haze observations. Scattered monitors reported Code Red O_3 levels from Washington DC to the vicinity of NYC with more widespread 8-h exceedances in the mid-Atlantic and continued observations of 1-h O_3 > 100 ppbv west of the Appalachians.

Back trajectories for August 3 showed a transition to westerly transport aloft with considerable low-level wind shear and southerly (along Corridor) flow near the surface (Figure 17). PHL observed a shift to east-southeast winds at 1500 UTC. By late on August 3, the frontal boundary became nearly stationary from coastal ME to just north of NYC then extending west into central PA. This boundary washed out on August 4. Scattered haze was reported in the northern mid-Atlantic on August 4 with stagnation and re-circulation along the I-95 Corridor leading to high O_3 concentrations. Overnight on August 4, moderate southwest winds of 3.6-7.2 ms^{-1} pushed the haze well north into PA and New England. Scattered Code Red observations were found on August 5 in the Baltimore-Washington Corridor but cloud cover north of the Mason-Dixon Line modulated peak concentrations. A vigorous cold front reached PHL by 0800 UTC on August 6 ending this episode. In general, although daily exceedances of the 1-h standard are reported, the number of 8-h exceedances region-wide were much lower than previous episodes and the extent of haze reports were also much reduced.

6. DISCUSSION AND CONCLUSION

The 2002 NEOPS-DEP IOP was carried out from late June to early August at the Baxter Water Treatment Center in northeast Philadelphia. The summer of 2002 saw the re-emergence of severe drought conditions in the northern mid-Atlantic. For the month of July, PHL reported slightly above normal temperatures and well below normal precipitation. The larger scale circulation during the IOP featured a standard mid-summer pattern with the Bermuda High retrograding westward into the southeastern U.S. This pattern was similar to conditions during the 1999 NEOPS IOP. The main difference from average conditions in the lower troposphere was anomalously low geopotential heights over the Canadian Maritimes coupled with higher than average heights over the Great Lakes. This anomaly induced a stronger northerly wind component that had an impact on several high O_3 episodes.

The strongest pollution episode during the 2002 IOP occurred from July 7-9 in association with the advection into the region of intense smoke and haze from wildfires in central Quebec. O_3 concentrations rose first in southern NJ on July 7 with widespread exceedances of the 1-h O_3 standard and very poor visibility following on July 8 and 9. While high O_3 concentrations coincided with increased haze observations during the wildfire episode, during other pollution episodes haze pulsed into the mid-Atlantic on scales of 1-2 days and typically lagged the rise in local O_3 concentrations by a day (e.g., July 2, July 18-19 and August 2).

The 2002 NEOPS-DEP IOP featured local weather (hot and dry) conducive to multi-day pollution events within overall conditions that were not unlike standard summer season weather. Due to smaller scale anomalies in the overall flow pattern, a wide variety of transport and local weather conditions were observed during these high pollution periods. This mix of weather conditions represents a good cross-section of high pollution cases. Further analysis will concentrate on the difference and similarities in these cases and episodes from previous NEOPS IOPs.

ACKNOWLEDGEMENTS

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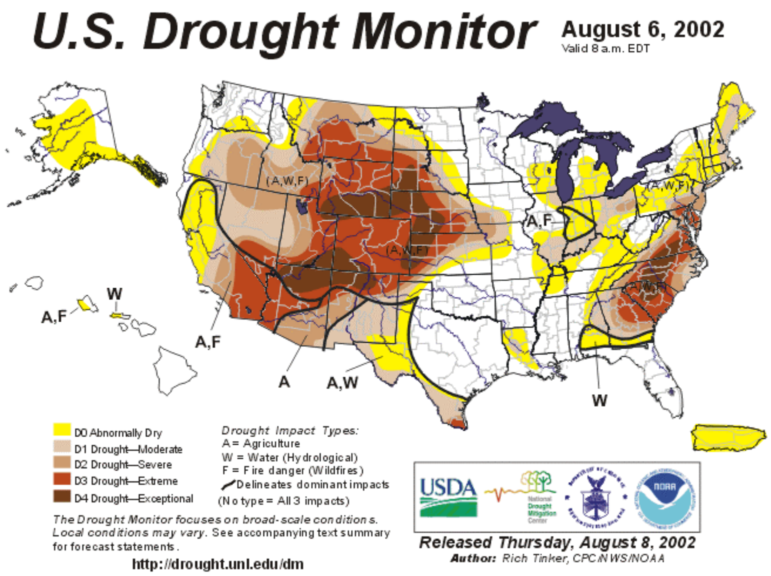

Figure 1. Drought Monitor report for August 6, 2002. For more details on drought analysis and monitoring, see, http://www.drought.unl.edu/dm/index.html.

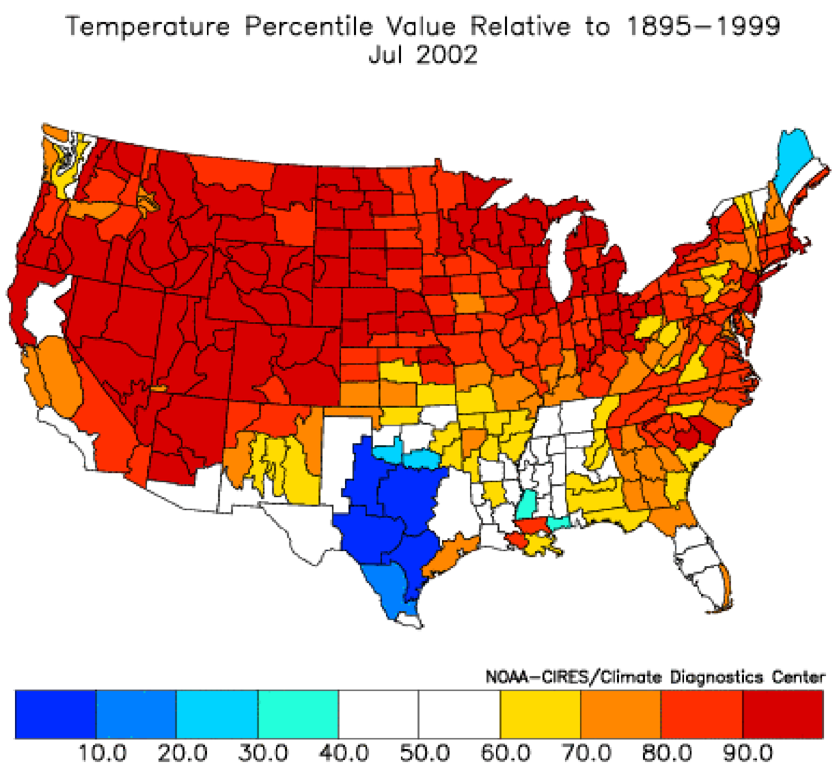

Figure 2. Surface temperature percentile rank for July 2002 compared to full climate series. Figure courtesy of the NCEP Climate Diagnostics Center.

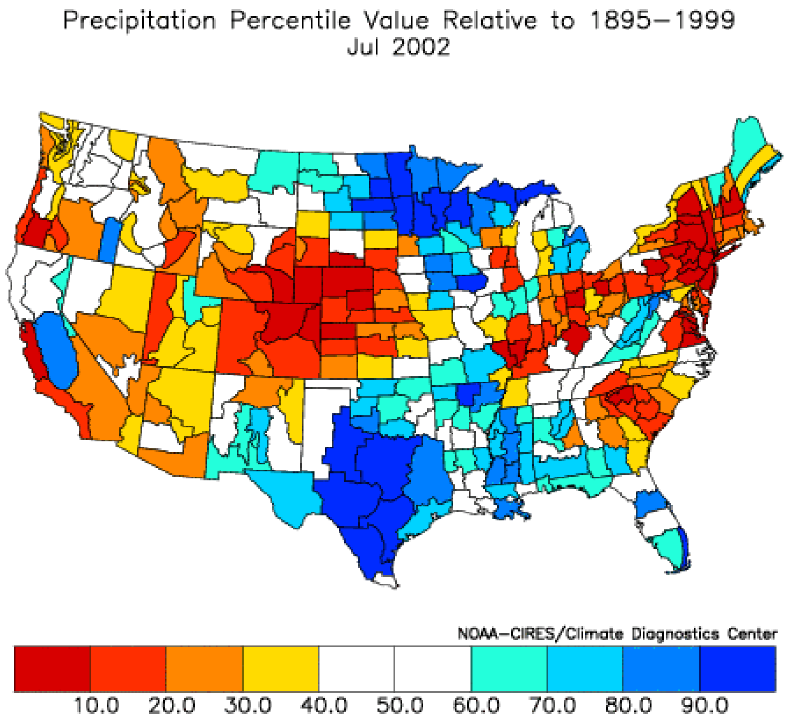

Figure 3. As in Figure 2 but for precipitation.

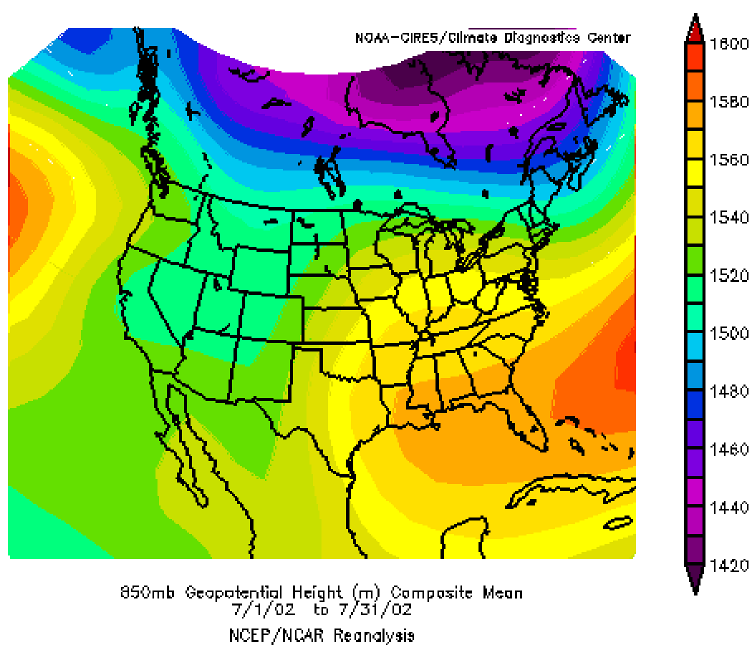

Figure 4. Mean geopotential height (in m) for the period July 1-31, 2002. Figure courtesy of NCEP Climate Diagnostics Center (CDC), http://www.cdc.noaa.gov/USClimate/.

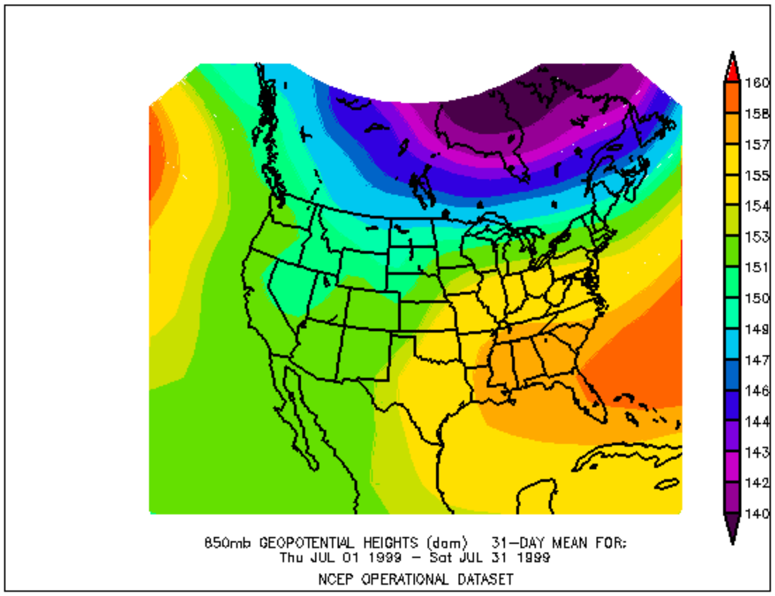

Figure 5. As in Figure 4, but for July 1-31, 1999.

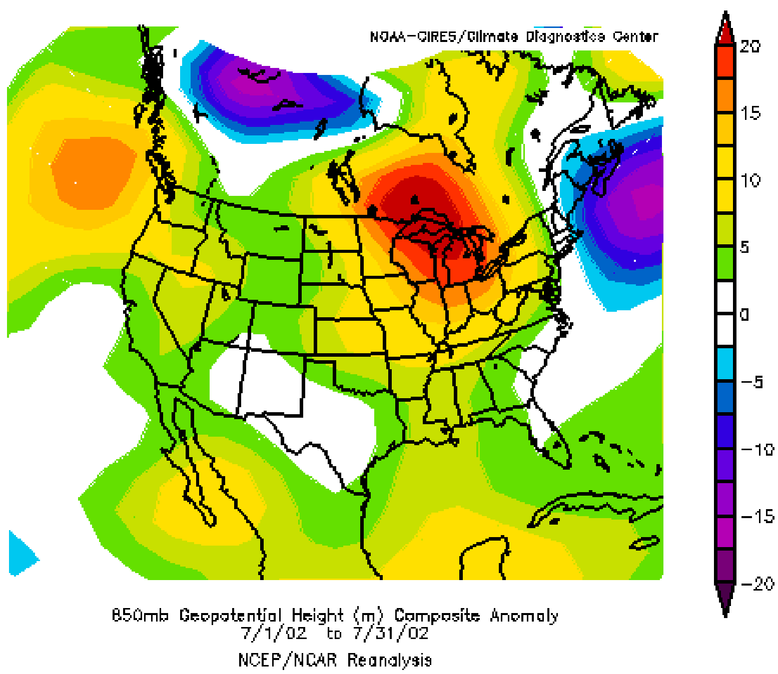

Figure 6. As in Figure 4, but for anomalies from mean conditions.

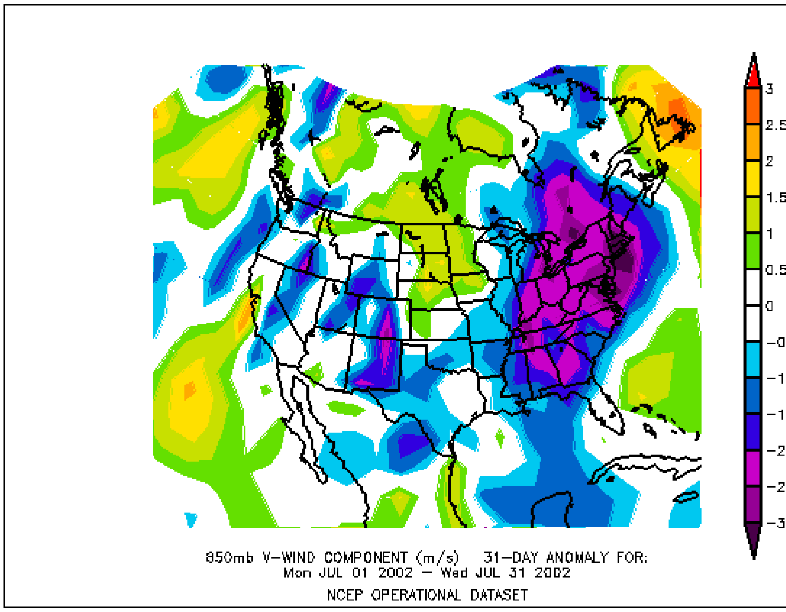

Figure 7. As in Figure 4 but for anomalies in the v-component of winds at 850 mb. Contours are in meters per second. Negative values (blue to purple) represent northerly winds in excess of mean conditions.

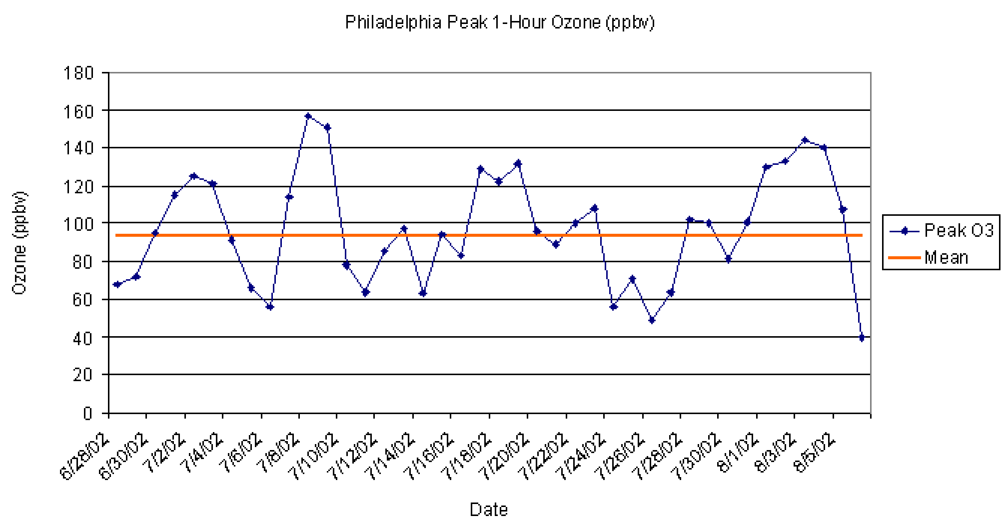

Figure 8. Daily peak 1-h average O_3 concentrations for the Philadelphia metropolitan area during the 2002 NEOPS-DEP IOP (blue line). The red line represents the mean peak O_3 levels during this period for 1991-2001.

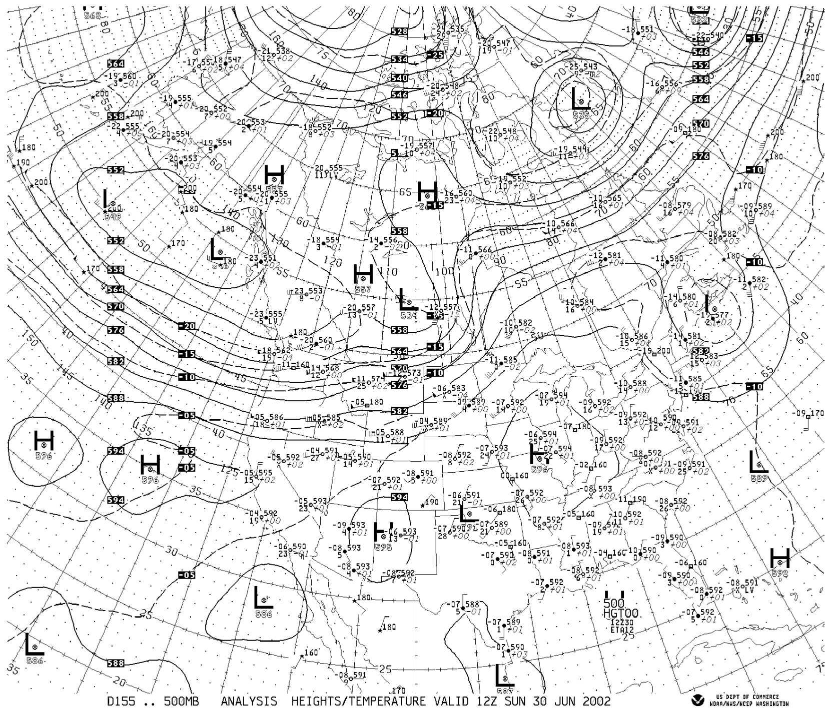

Figure 9. 500 mb NCEP analysis for 1200 UTC on June 30, 2002. Contours are geopotential height (in dm) with temperature (in Celsius) contoured in dashed lines. Station observations are plotted using standard conventions.

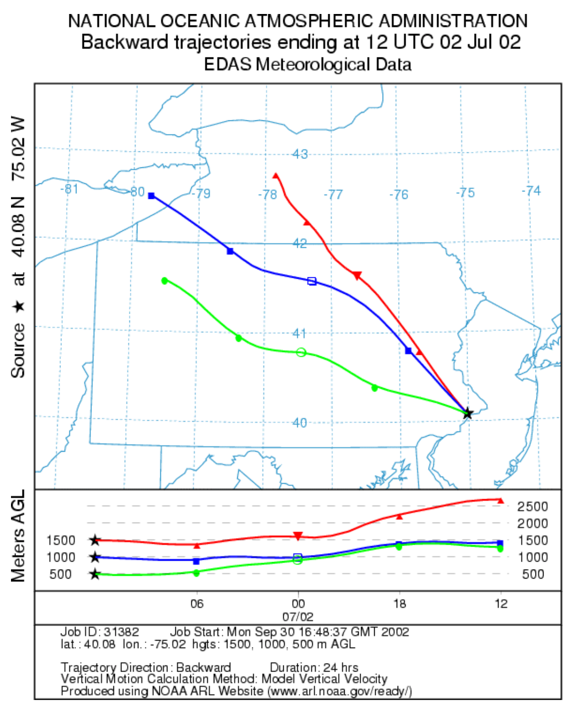

Figure 10. Back trajectories initialized at Philadelphia Northeast Airport (PNE) at 1200 UTC on July 2, 2002 and run for 24 hours at 500, 1000 and 1500 m agl. Back trajectories determined using the HYSPLIT-4 model (HYSPLIT, 1994) and the Eta Data Assimilation System (EDAS) analysis fields.

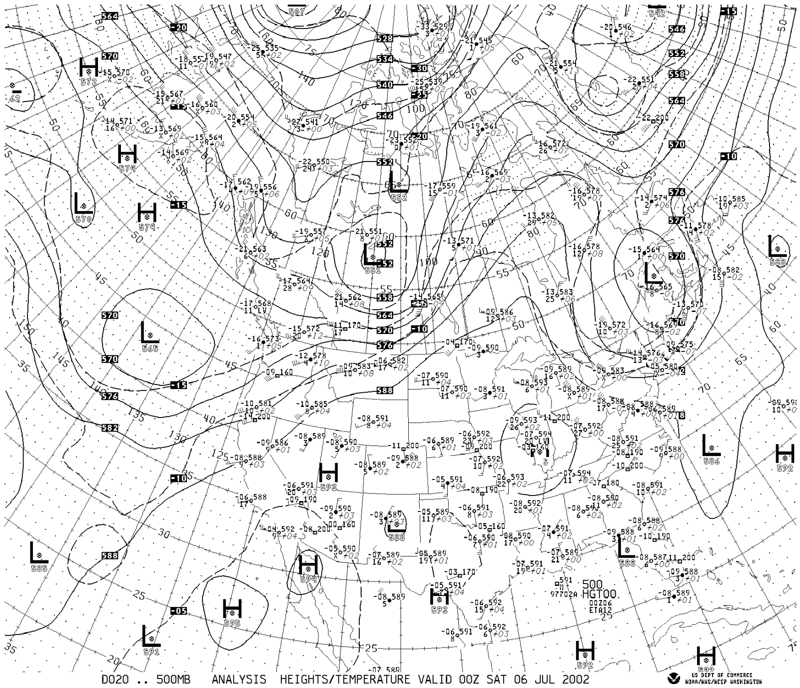

Figure 11. As in Figure 9, but for 0000 UTC on July 6, 2002.

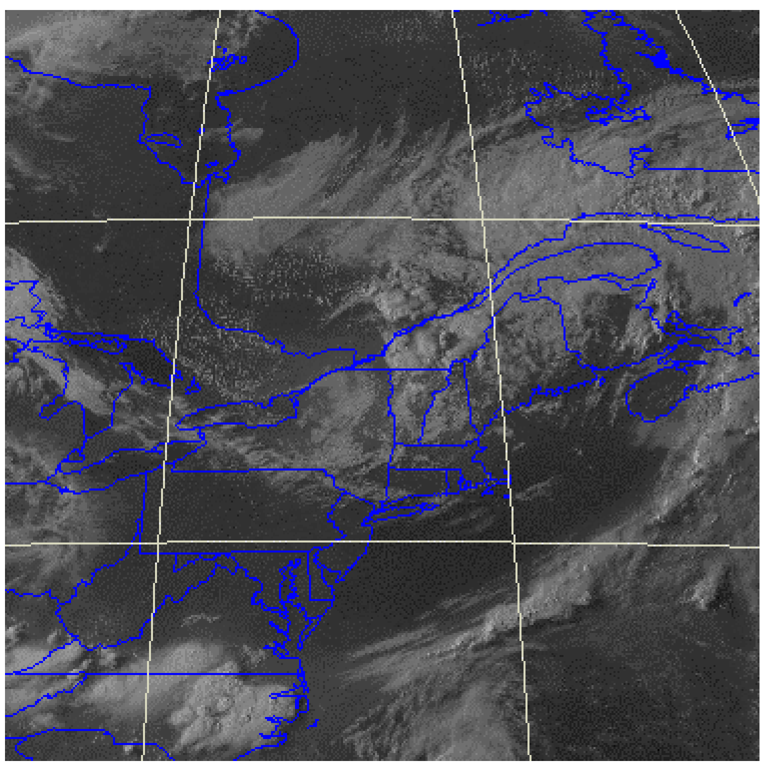

Figure 12. GOES 8 visible image for 2215 UTC on July 5, 2002. Plumes of wildfire smoke are seen in the upper center of the image east and southeast of James Bay, Canada.

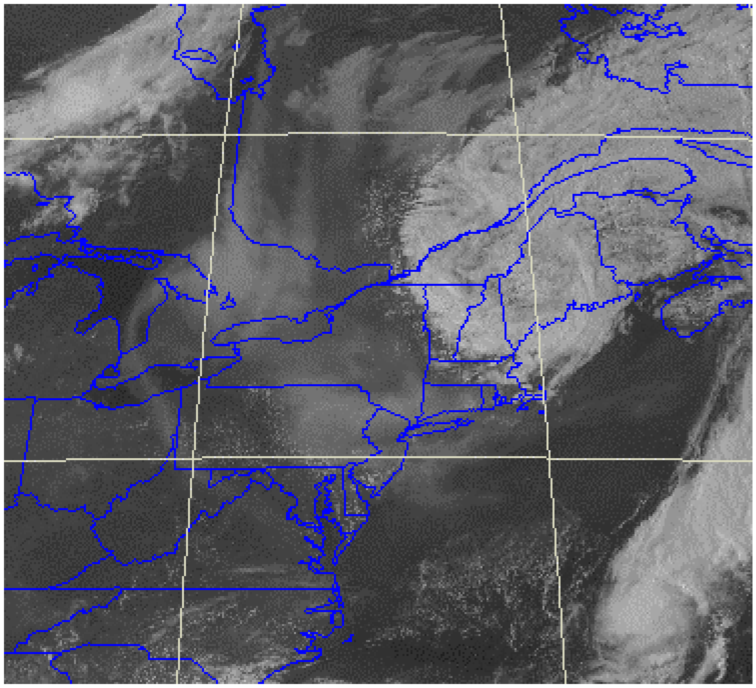

Figure 13. As in Figure 12 but for 2015 UTC on July 6, 2002.

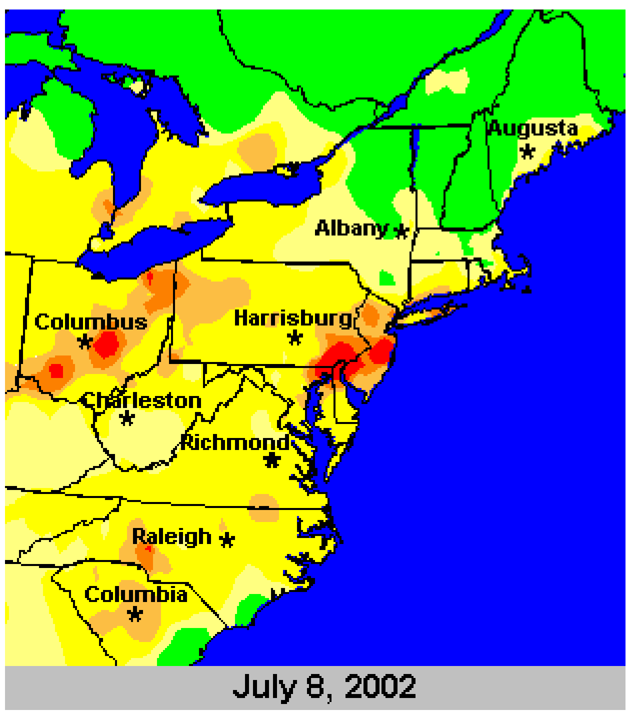

Figure 14. Peak 1-h O_3 observations for July 8, 2002. Figure courtesy of the EPA AIRNOW network. See, http://www.epa.gov/airnow. Contours are as follows: light orange (100-110 ppbv), dark orange (111-124 ppbv) and red (≥ 125 ppbv).

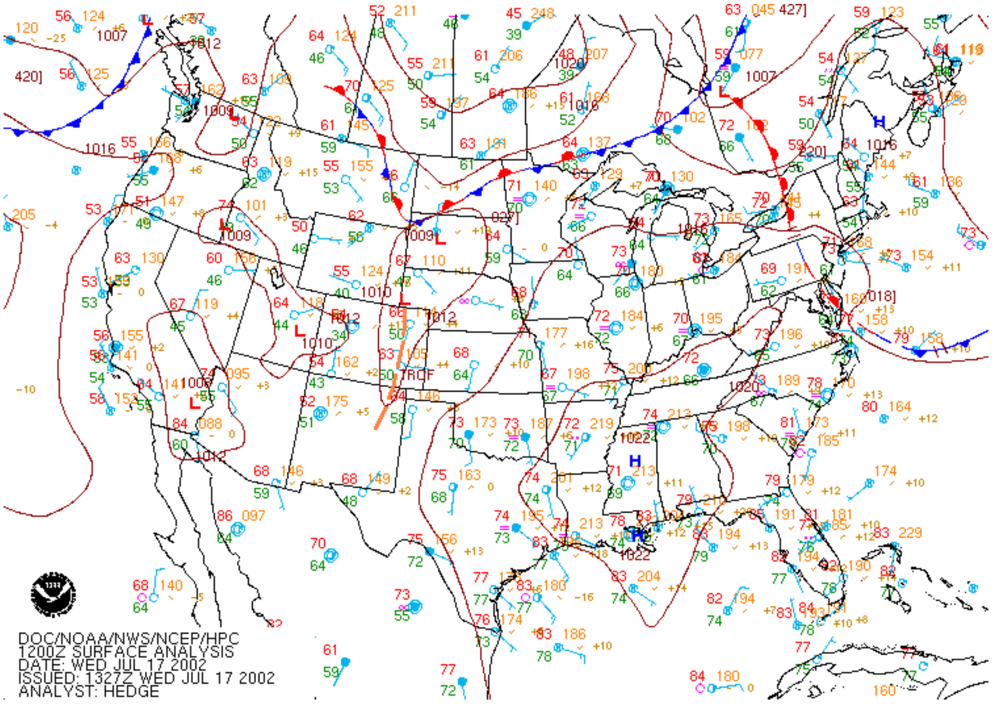

Figure 15. NCEP surface analysis for 1200 UTC on July 17, 2002.

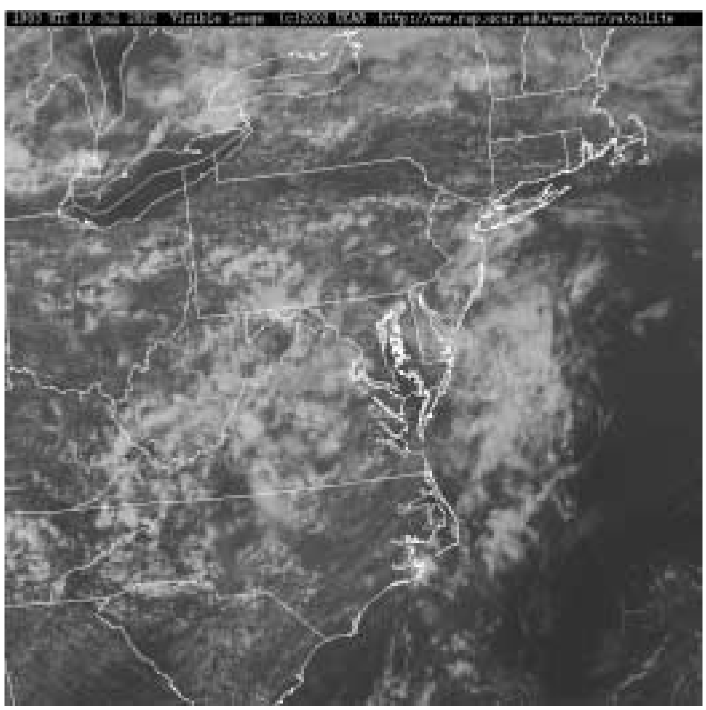

Figure 16. GOES 8 high resolution visible image for 1903 UTC on July 18, 2002.

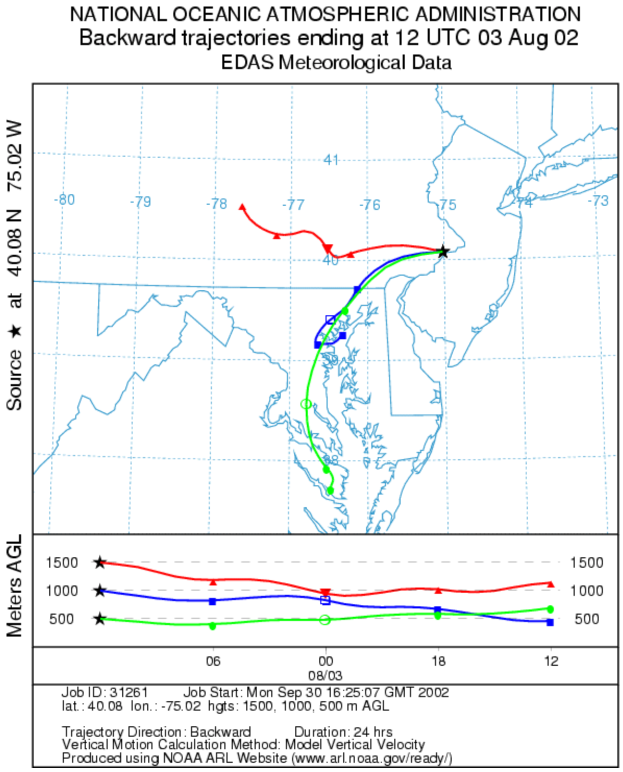

Figure 17. As in Figure 10 but for 1200 UTC on August 2, 2002.