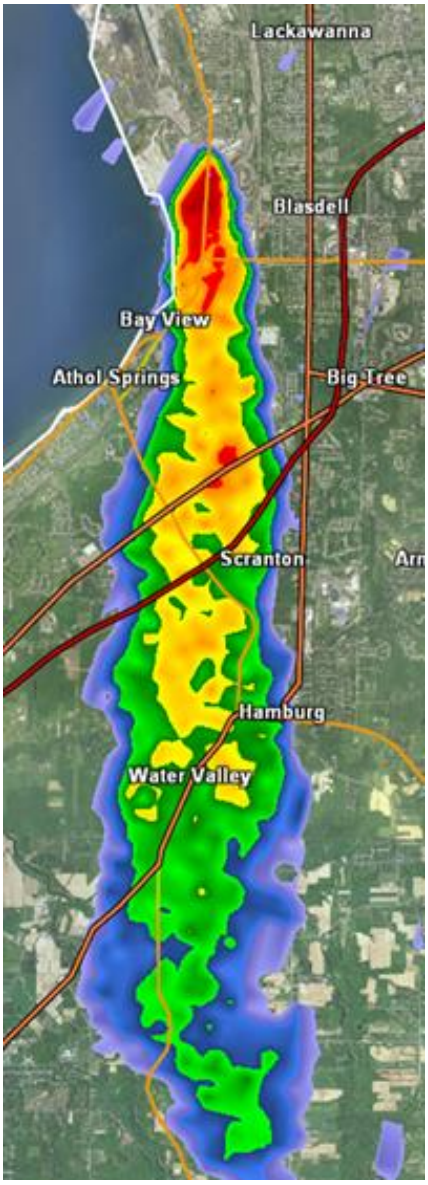
Smoke plume captured on weather radar



Former Bethlehem Steel Site Fire:

A Review of Relevant Weather Conditions

November 9 -11, 2016

Abstract: The smoke plume was detected on weather radar for the first three hours of the fire, showing the release of large particulate. The winds were consistent within each day, but varied between each day (directional changes were limited to a few hours): Wednesday (areas to the south and southeast impacted); Thursday (areas to the northeast impacted); and Friday (winds return to Wednesday's patterns). Stable air and inversion layers impacted plume dispersion. On Wednesday, the intense heat of the fire allowed the plume to penetrate into stable air causing it to be trapped as it moved downwind - reducing surface downwind concentrations. On Thursday and early Friday, the containment of the fire reduced the heat release rate, thus reducing the penetration of the rising plume into the stable air above - fumigation resulted. Later on Friday, the reduction in smoke (fire mostly out), neutral conditions (allowing for better vertical mixing), and a heightened inversion layer, substantially reduced ground-level concentrations.

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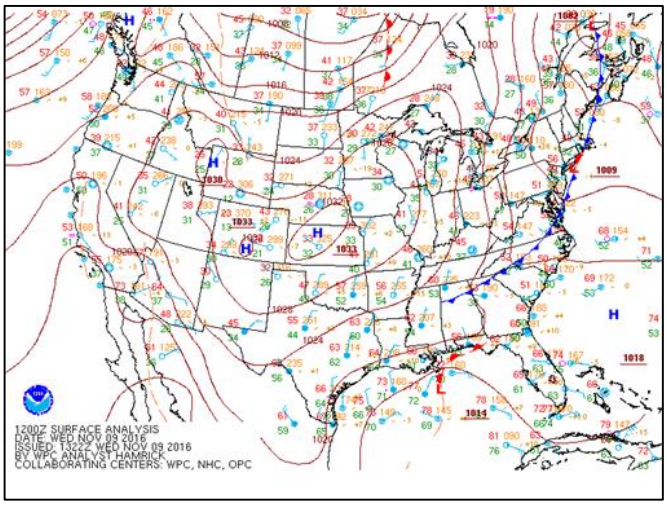
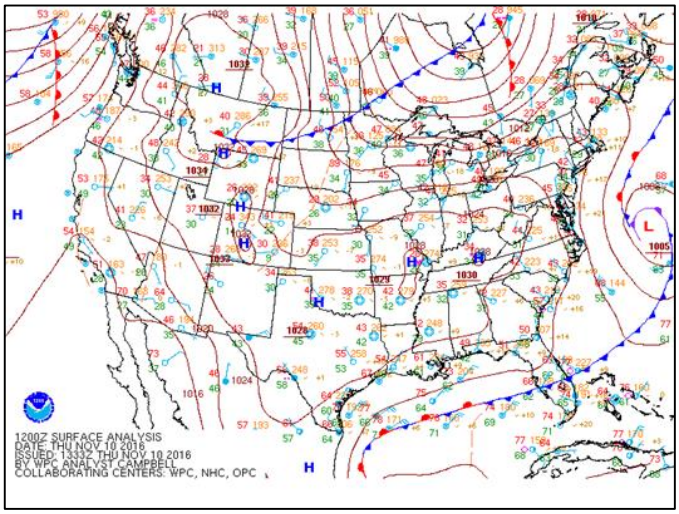
DECEMBER 26, 2016

Weather Elements



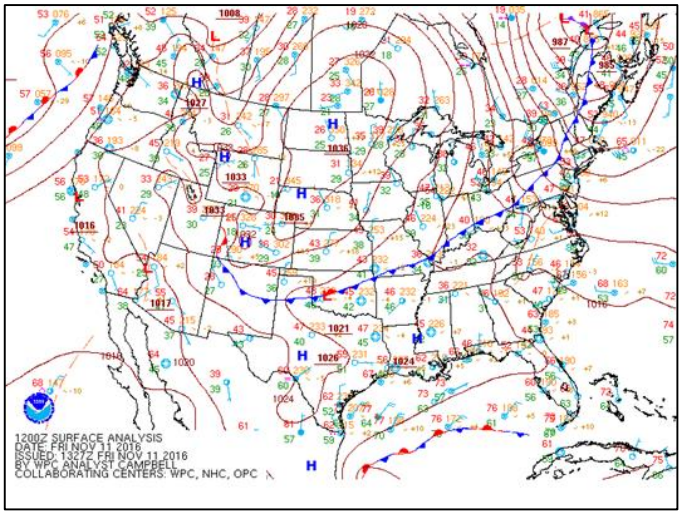
7:00 a.m., Wednesday, November 9, 2016

Wednesday, November 9th (KBUF)	
Max. Temperature (°F) 3:14 a.m.	52
Min. Temperature (°F) 11:59 p.m.	36
Avg. Temperature (°F)	44
Cloud Cover	8/10
Pressure (inHg)	30.02
Wind Speed - avg/max (mph)	9.5/22
Precipitation (in) (occurred prior to fire)	0.02
Weather (occurred prior to fire)	Fog



7:00 a.m., Thursday, November 10 2016

Thursday, November 10th (KBUF)	
Max. Temperature (°F) 8:41 p.m.	56
Min. Temperature (°F) 4:06 a.m.	32
Avg. Temperature (°F)	44
Cloud Cover	4/10
Pressure (inHg)	29.91
Wind Speed - avg/max (mph)	18.3/35
Precipitation (in)	0.00
Weather	Fog



7:00 a.m., Friday, November 11, 2016

Friday, November 11th (KBUF)	
Max. Temperature (°F) 12:23 a.m.	55
Min. Temperature (°F) 11:55 p.m.	35
Avg. Temperature (°F)	45
Cloud Cover	5/10
Pressure (inHg)	30.04
Wind Speed - avg/max (mph)	13.0/32
Precipitation (in)	0.00
Weather	No

The Lackawanna, NY (former Bethlehem Steel site) fire started on November 9, 2016, at 7:00 a.m.

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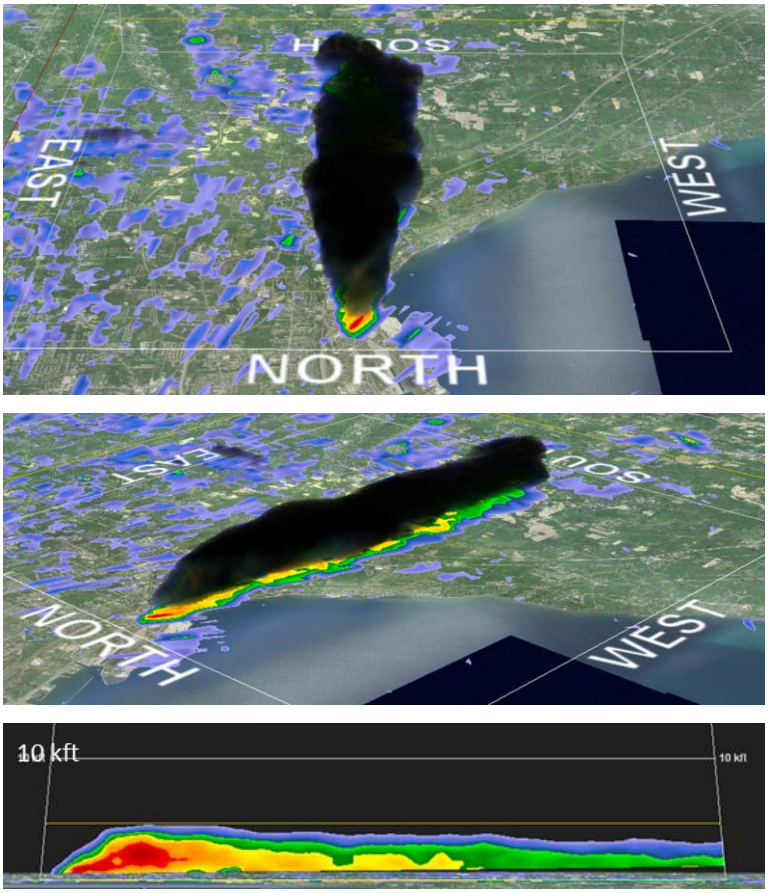
Weather Radar Detects the Lackawanna Plume

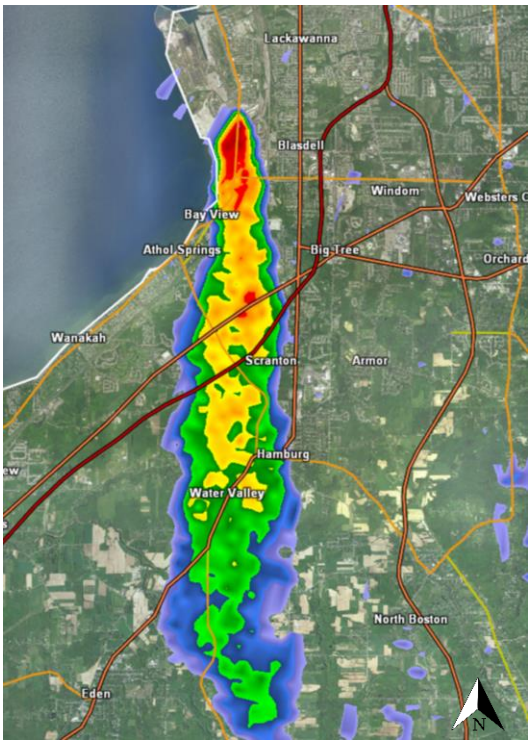
November 9, 2016

Weather radar detects precipitation (rain, snow, etc.), however, very small targets, such as cloud droplets (averaging about 10 microns), are not detected. Rain drops are typically 10 to 1,000 times larger than cloud droplets, so the plume that was detected on November 9th by weather radar is defined by the presence of large sized particles, well above PM-2.5 (<2.5 microns) and PM-10 (<10 microns) sized inhalable particles that are linked to health standards. The smallest size particulate detected was likely at about 500 microns (length of dust mite). The plume certainly included smaller inhalable particles and gaseous pollutants, but the plume, as shown on weather radar, is not defined by these smaller particles and gases. The plume was no longer visible on weather radar a few hours after the fire started.



Radar output (GR2Analyst) showing 3-D plume (top and middle). Plume cross-section shown on bottom. Image captured on 11/09/2016 at 8:03 a.m. (red to purple: decreasing amount of smoke).

Photos showing the plume on 11/09/2016. Credit: www.bizjournals.com (top) looking south, and Mark Mulville (bottom) looking west from Chestnut Ridge.



Radar output (GR2Analyst) captured on 11/09/2016 at 8:03 a.m. The plume (moving south) measures about 25 miles in length.

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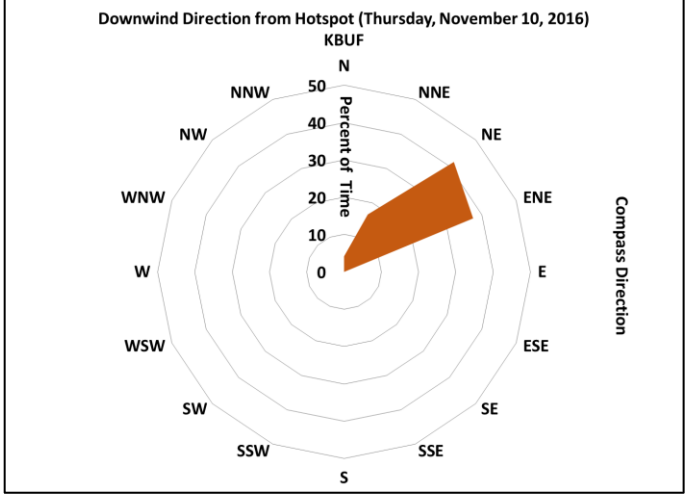
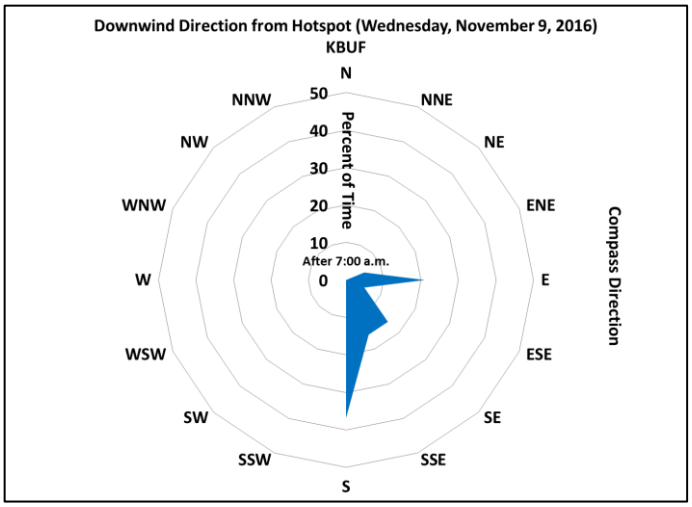
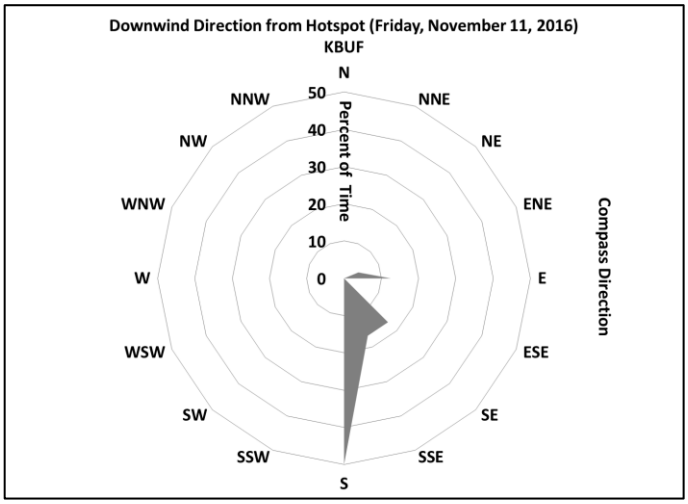
Impact Direction (KBUF)

Impacted (downwind) direction from the hot spot is shown based on wind vane data obtained from the NWS site at the Buffalo Niagara International Airport (KBUF). KBUF is located about 10 miles to the northeast and inland from the hotspot. The wind vane is located at a 10 meter height, providing a good indication of regional winds during and after the Lackawanna fire. Three wind roses show the impact direction (180° from wind direction) for over a period of three days: Wednesday (after 7:00 a.m.), Thursday, and Friday. The bottom graph shows the hourly impacted direction for a three day period after the start of the fire.

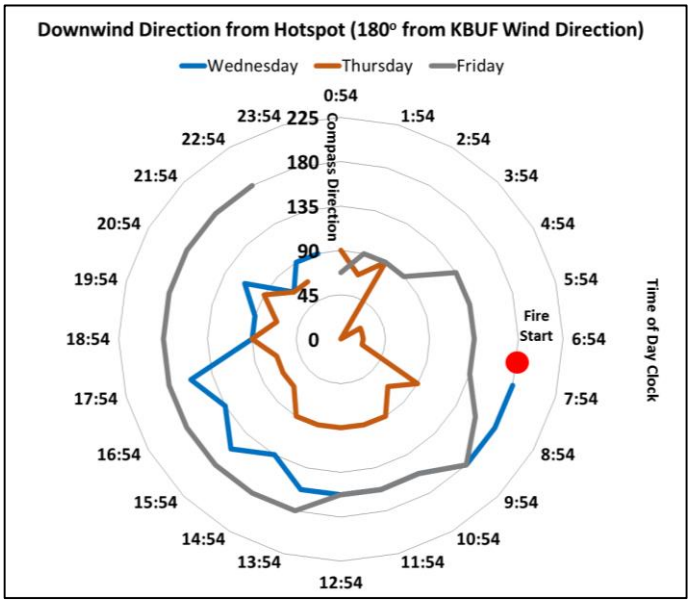






A Quick Interpretation

The wind roses show substantial consistency within each day, but a substantial variability between each day: Wednesday (areas to the south and southeast impacted); Thursday (areas to the northeast impacted); and Friday (winds return to Wednesday's patterns). The timing for the change in wind direction is best shown on the wind clock graph - the first change occurs on Wednesday evening over a period of only a few hours (between 6:00 and 7:00 p.m.) with a shift of the impacted direction changing from south to east/northeast; and again on Friday (east to south) over a period of a few hours, approximately between 4:00 to 9:00 a.m. The times between these shifts show a relatively consistent wind pattern. The KBUF data is mostly consistent with BUFN6 (see next page).



How to Read the Wind Clock Graph: Read time as you would a clock. Wind direction is shown on the concentric rings. Start at the point of the fire, then follow Wednesday (blue) clockwise around the clock. At midnight switch over to the next day (Thursday) and follow time clockwise around the clock. Do the same for Friday. The impacted direction (downwind) is shown in degrees (0° = North; 45° = northeast; 90° = East; 135° = southeast; 180° = south; 225° = southwest.

The Lackawanna, NY (former Bethlehem Steel site) fire started on November 9, 2016, at 7:00 a.m.

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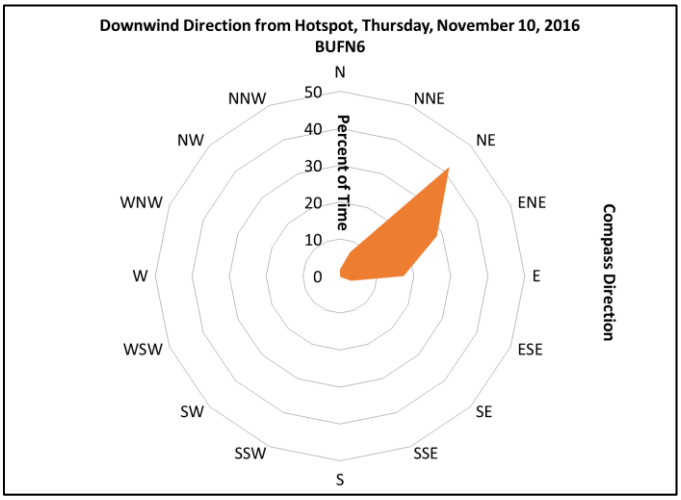
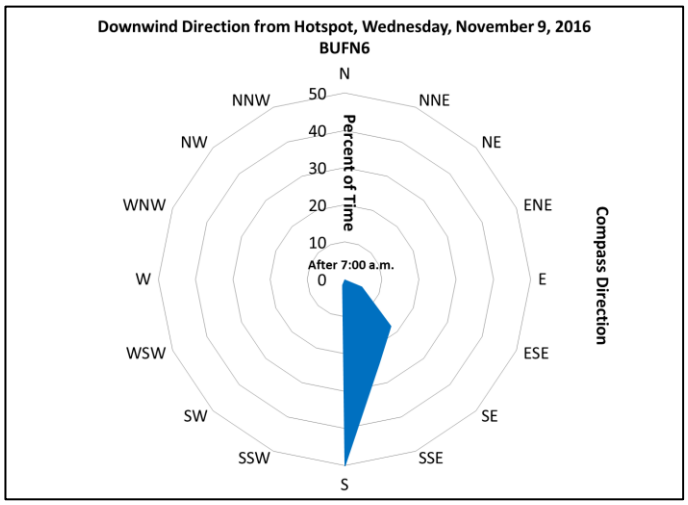
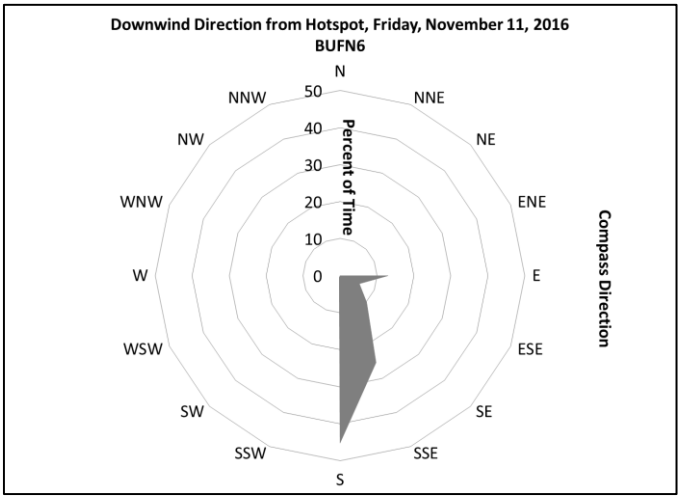
Impact Direction (BUFN6)

Impacted (downwind) direction from the hot spot is shown based on wind vane data obtained from the Coast Guard site (BUFN6) located at the mouth of the Buffalo River, about 5 miles to the NNW (long the shoreline) from the hotspot. The wind vane is located at a 8.5 meter height, providing a good indication of regional winds during and after the Lackawanna fire. Three wind roses show the impact direction (180° from wind direction) for over a period of three days: Wednesday (after 7:00 a.m.), Thursday, and Friday. The bottom graph shows the 6-minute impacted direction for a three day period after the start of the fire.







A Quick Interpretation

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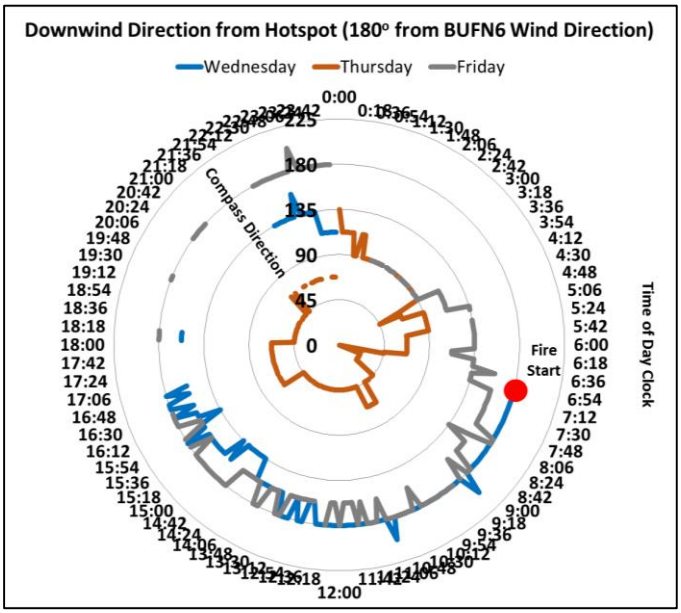

How to Read the Wind Clock Graph: Read time as you would a clock. Wind direction is shown on the concentric rings. Start at the point of the fire, then follow Wednesday (blue) clockwise around the clock. At midnight switch over to the next day (Thursday) and follow time clockwise around the clock. Do the same for Friday. The impacted direction (downwind) is shown in degrees (0° = North; 45° = northeast; 90° = East; 135° = southeast; 180° = south; 225° = southwest.

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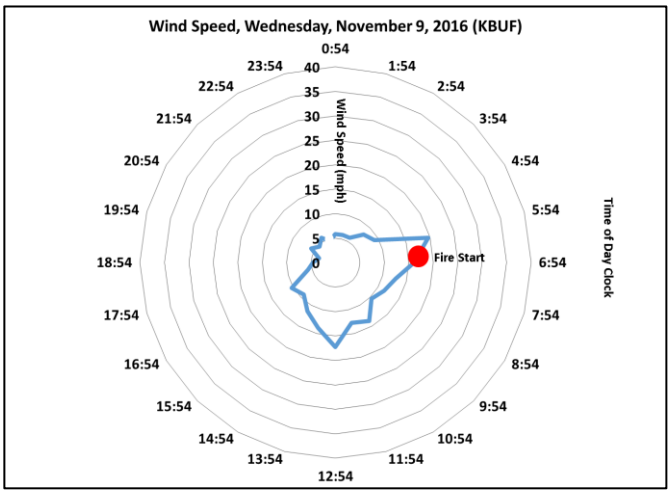
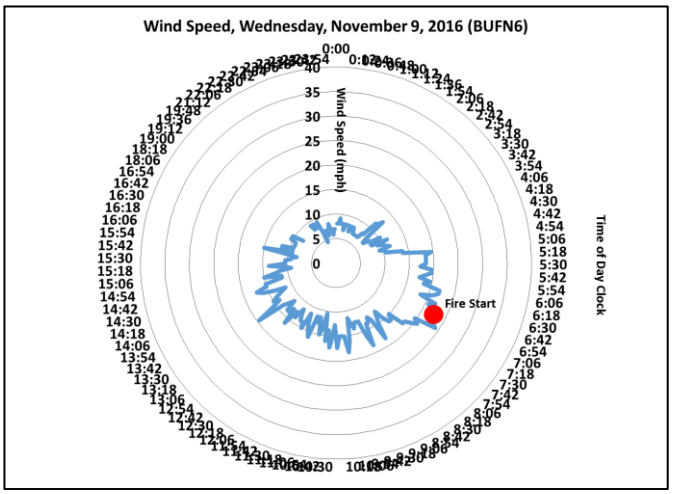
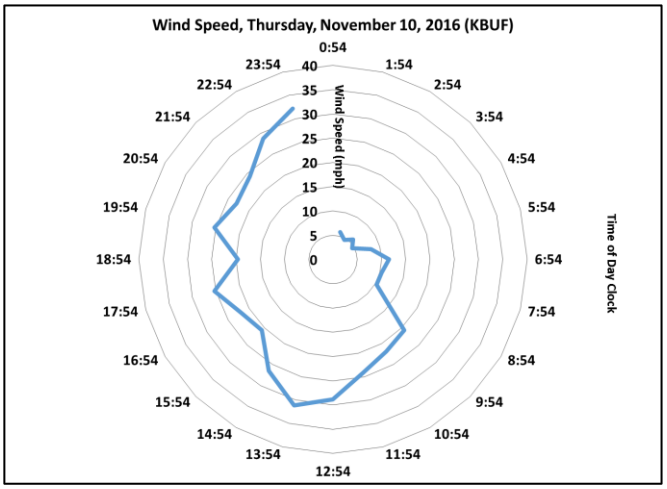
KBUF Wind Speed BUFN6



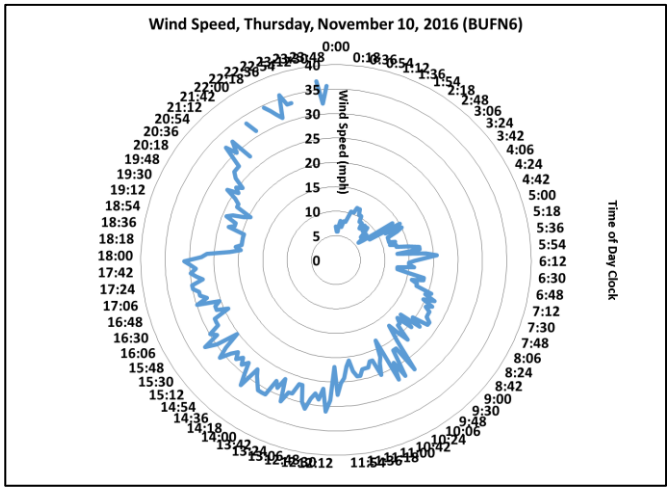
Mean Wind Speed = 9.3 mph, max = 21 mph
(after 7:00 a.m., start of fire)



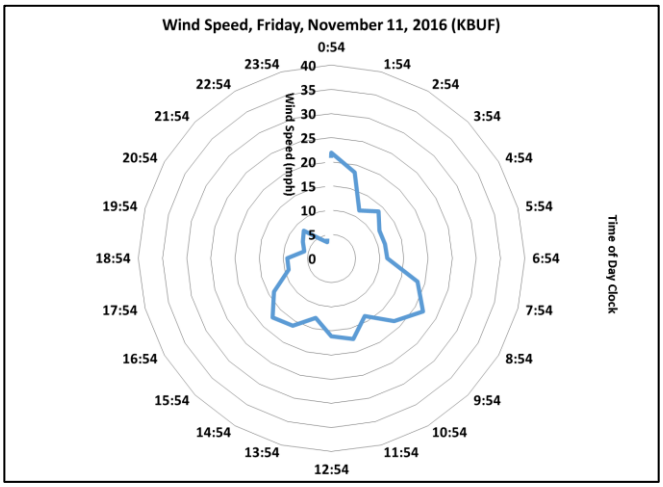
Mean Wind Speed = 12.9 mph, max = 24.2 mph
(after 7:00 a.m., start of fire)



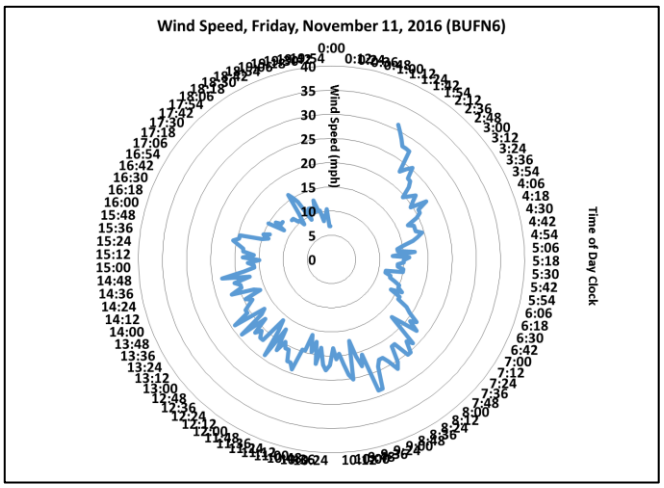
Avg. Wind Speed = 18.3 mph, max = 35 mph



Mean Wind Speed = 21.4 mph, max = 36.8 mph



Mean Wind Speed = 13.0 mph, max = 32 mph



Mean Wind Speed = 18.4 mph, max = 31.1 mph

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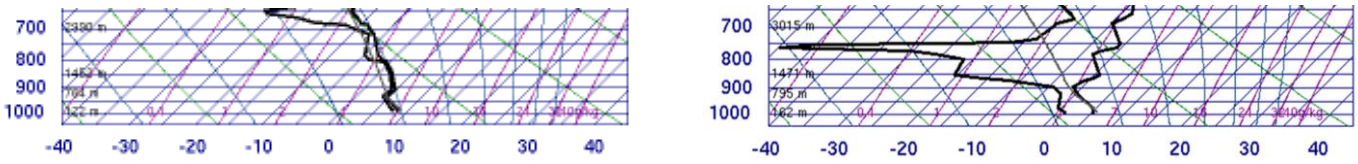
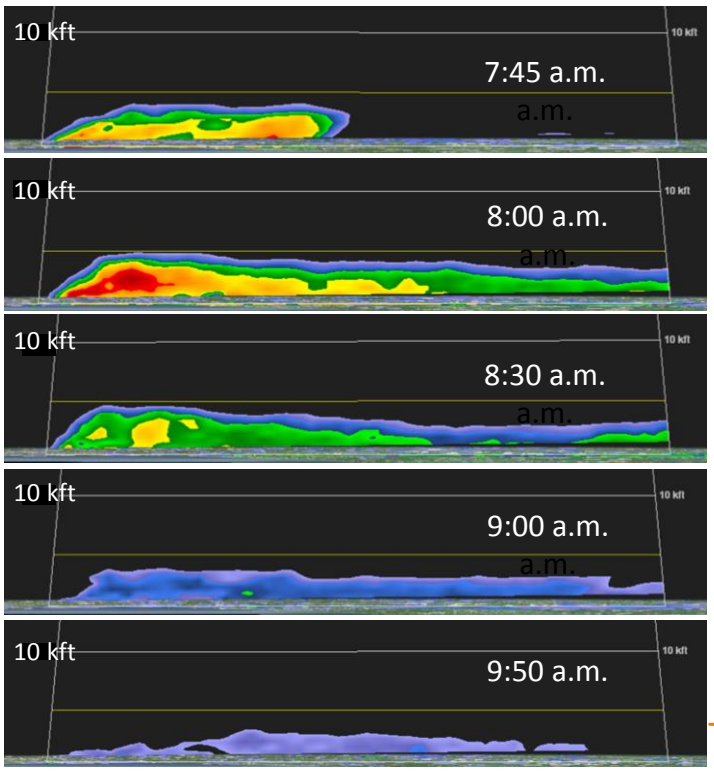
Atmospheric Stability (Wednesday)

At the start of the fire (~7:00a.m., Wednesday, November 9, 2016) atmospheric conditions were neutral/stable extending up to a temperature inversion at about 2,500 feet, and a second inversion at about 5,000 feet (between 8:00 and 10:00 a.m.) The lower inversion remained throughout the day, strengthening and rising to a height of about 3,700 feet, before lowering to 2,500 feet at the end of the day. A second, shallow ground inversion established itself after 6:00 p.m.

During the fire the smoke plume rose through the neutral/stable atmosphere due to the intense heat of the fire, but became trapped by the inversion and stable air. Radar imagery detected the smoke plume for a few hours after the start of the fire, confirming that the plume height was restricted. The lower level of the plume was at approximately 750 to 1000 feet above the surface, just below the cloud base (see photos). Vertical mixing was restricted, so the plume dispersed horizontally and downwind of the hotspot. While ground level concentrations would be affected (especially early on with the gravitational settling of large particles (ash) – even large debris), the concentration of pollutants would have been limited immediately beyond the hotspot by the high temperature of the fire, allowing the smoke to easily rise into the atmosphere. And downwind, as resistance to vertical motion trapped the smoke in the stable air layer – a plume behavior known as 'fanning'. Later in the day the ground-level inversion would have further restricted the downward dispersion of the pollutants. While, a deep layer of unstable air would have better dispersed the plume, the stable air on Wednesday trapped much of the plume above the ground level – limiting surface concentrations downwind – allowing it to be carried away and dispersed.



Skew-T plots from KBUF showing air temperatures (right black line) at different heights at (A) 7:00 a.m. and (B) 7:00 p.m. The right jog of the temperature profile indicates an inversion. More precise data and timing was obtained from BUFkit forecasting software.



Photos showing the plume on Wednesday. Upper photo shows the bottom of the trapped plume (credit: Mark Mulville). The lower photo shows the plume over Hamburg, NY. (credit: WIVB web site).

A cross-section of the plume was obtained from radar (GR2Analyst). The height of the smoke plume and concentration of smoke are shown over the short time the plume was detected by radar (red to purple: decreasing amount of smoke).

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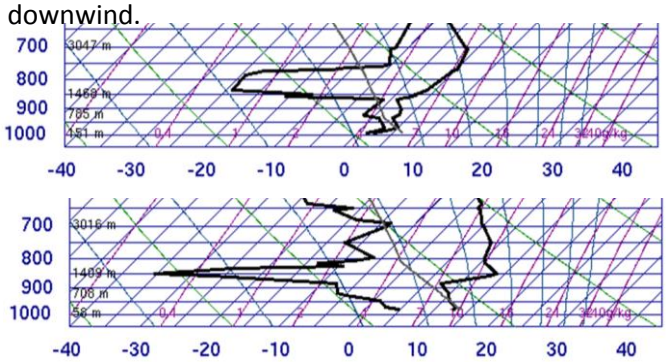
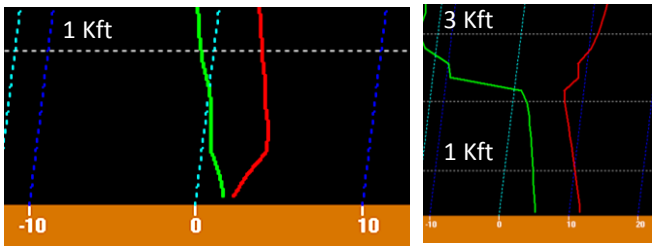
Atmospheric Stability (Thursday & Friday)

Thursday

Atmospheric conditions were stable (restricted vertical mixing) through the day, with an inversion at about 2,500 feet. While the heat of the fire and stable air may have trapped the plume and limited downwind concentrations on Wednesday, the situation changed on Thursday – especially for the area immediately downwind of the fire (northeast quadrant). Containment of the fire reduced the heat release rate at ground level, which, along with increasing wind speeds, reduced the penetration of the rising plume into the stable air above. The plume's penetration would have been further hampered, until about 9:00 a.m., by a ground level inversion – surface fumigation could result within a half to one-mile area located downwind of the fire. Pollutants would disperse along the northeast axis of the wind and horizontally – vertical mixing limited – reducing ground-level pollutant concentrations with distance traveled downwind.



Skew-T plots from KBUF showing air temperatures (right black line) at different heights at (top) 7:00 a.m. and (bottom) 7:00 p.m. The right jog of the temperature profile indicates an inversion. More precise data and timing was obtained from BUFkit forecasting software.

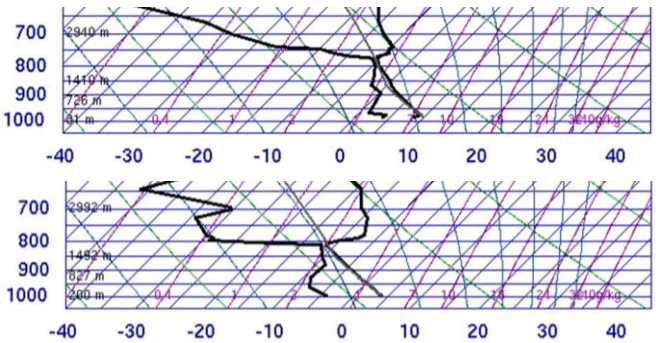


Skew-T plots (BUFkit) show the ground level inversion (left) at 4:00 a.m. and the 2,500 foot inversion (right) at 4:00 p.m. Temperature shown as a red line.

Haze, apparent in Lackawanna on Thursday (shown above), is a result of the stable air and the fire's reduced heat rate that prevented the smoke from rising easily, as compared to the situation on Wednesday (left image) where the intense heat allowed the plume to rise into the stable air to be trapped above the surface - limiting surface pollutant concentrations (credit: WKBW-TV (above), and The Business Journals (left).

Friday

Conditions early on Friday were similar to Thursday (smoke unable to lift into the air resulting in high concentrations of pollutants in proximity to the hotspot), but as the day progressed neutral atmospheric conditions allowed for better vertical mixing. This, combined with the reduction of smoke (fire mostly out) and an inversion ceiling at about 6,000 feet, would substantially reduce local ground level pollution concentrations.



Skew-T plots from KBUF showing air temperatures (right black line) at different heights at (top) 7:00 a.m. and (bottom) 7:00 p.m. The right jog of the temperature profile indicates an inversion. More precise data and timing was obtained from BUFkit forecasting software.

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