Coal City – Braidwood Tornado of June 22, 2015 and the Impact on the Braidwood Nuclear Generating Station Meteorological Monitoring System

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Abstract:

The United States Nuclear Regulatory Commission requires that nuclear facilities maintain a meteorological monitoring system to provide real time information in the event of an accidental radioactive release as well as for long term dispersion modeling. On June 22, 2015, the meteorological monitoring system at the Braidwood Nuclear Station in Braceville, Illinois was damaged during a tornado. The synoptic pattern associated with the damaging tornado and the efforts involved in restoring valid meteorological data to the Braidwood Station will be presented.

BRAIDWOOD STATION AND THE METEOROLOGICAL MONITORING TOWER

Exelon's Braidwood Station is a two unit Westinghouse pressurized water reactor (PWR) site in Braceville, Illinois, approximately 21 miles south-southwest of Joliet, Illinois. Unit 1 is an 1187 MW reactor that came online in July of 1988. Unit 2 is an 1155 MW reactor that came online in October of 1988.

U.S. nuclear facilities are required by the Nuclear Regulatory Commission to maintain meteorological monitoring towers to measure, at a minimum, wind speed, wind direction and temperature at two measurement levels. Guidance for the meteorological monitoring programs at nuclear power plants can be found in U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.23, Revision 1, dated March 2007.

The meteorological monitoring tower at Braidwood is approximately 2300 feet to the northeast of the plant center point. The 320 foot tower is a Rohn Model 90 guyed tower. The tower is inspected each spring to TIA-EIA-222-G specifications. The tower structure is inspected each spring to determine if maintenance is required. Guy wire tensions are checked during the inspection and the tensions are adjusted as needed.

BRAIDWOOD METEOROLOGICAL MONITORING SYSTEM

The Braidwood meteorological monitoring tower is instrumented with wind speed, wind direction and temperature measuring equipment at two levels. Dew Point is also measured at the lower level. Precipitation is measured at ground level.

The following two tables indicate the type of equipment that is mounted at the specified measurement heights as well as the data recording devices (data loggers) that are housed in an instrument shelter adjacent to the tower. The wind, temperature and dew point measurement systems were manufactured by Meteorology Research, Inc. (MRI). The rain gauge was purchased from Climatronics Corporation.

Table 1

Instrument Locations

Measurement	Sensor Type	Location	Elevation
Wind Speed	MRI 1022-S	Tower	203 ft.
Wind Direction	MRI 1022-D	Tower	203 ft.
Differential Temperature	MRI 1596602	Tower	199 ft.
Wind Speed	MRI 1022-S	Tower	34 ft.
Wind Direction	MRI 1022-D	Tower	34 ft.
Ambient Temperature	MRI 1596602	Tower	30 ft.
Dew Point Temperature	MRI 1993900000	Tower	30 ft.
Precipitation	Climatronics 100097-1	Ground	3 ft.

Table 2

Data Loggers

Measurement	Logger Type	Sampling Frequency
Winds, Temperatures, and Precipitation	Microtel 4.0 data acquisition system	1 sec.
Winds, Temperatures, and Precipitation	Johnson Yokogawa Corp. Digital Recorder (JYC DA100 and Contec IPC-PT/M300(PC)WOU) digital recorder	10 sec.

Murray and Trettel, Inc. of Palatine, Illinois is contracted to maintain and calibrate the meteorological monitoring equipment at Braidwood Station. Braidwood meteorological data is collected through an automated data collection process each morning. Hourly averaged data (precipitation data is an hourly total) from the previous 24 hours is reviewed each morning by a meteorologist. If it is determined that there has been a system or sensor failure, field maintenance staff is notified and arrangements are made to go to the site to perform unscheduled/emergency maintenance. Data traces from a digital recorder at the site are reviewed weekly for enhanced data quality assurance.

Preventative maintenance includes a monthly site visit and system calibrations every four months. All maintenance activities are documented and provided to the Braidwood site contact within monthly and annual reports. Murray and Trettel employs trained tower climbers to access the equipment for maintenance and calibrations. NRC Regulatory Guide 1.23 dictates that valid data recovery from the meteorological monitoring tower must be 90% or greater. Valid data recovery for the Braidwood meteorological monitoring tower generally exceeds 99% annually.

SYNOPTICS FOR LEADING TO THE JUNE 22, 2015 BRAIDWOOD TORNADO

On June 18, 2015, at 500 millibars (approximately 18,000 feet above sea level) an upper air disturbance (trough), an important ingredient for the development and intensification of storms, moved across the northwest coast of the United States over Washington and Oregon. This system reached the Northern Rockies on June 20th then South Dakota and Nebraska on the 21st. The following day (June 22) this system arrived over Minnesota and Iowa in the morning and then Western Illinois late in the afternoon. Severe weather is most likely to occur within a couple of hundred miles downstream of these upper air disturbances. Meanwhile at the low level which is 850 millibars (approximately 5,000 feet above sea level) winds increased from 25-30 mph early in the day to a strong 45-50 mph by evening over Illinois. This level is instrumental in the transportation of moisture into a given area and is necessary for the formation of severe weather. At the surface, at approximately 7am CDT, a surface low pressure system was located over West Central Minnesota with a cold front extending southwest to Central Nebraska. By 7pm CDT this low had moved to Lake Superior with the cold front (convergence of different air masses) trailing to Extreme Northeast Iowa. Based on surface observations, the front entered Northwest Illinois close to the time tornadoes developed. The dewpoint (a measure of moisture) was an incredible 77-78 degrees in the area; indicative of extremely high moisture content in the lower atmosphere. In addition, there was strong jet at 300 millibars (about 30,000 feet above sea level) entering the region. Thus from a meteorological standpoint, considering all these factors, the atmosphere was conducive for severe weather and tornadic activity. This was verified with the release of upper air weather balloons (radiosondes) at 7pm CDT from Davenport (DVN) and Lincoln, Illinois (ILX). The former is about 125 miles west-northwest of Braidwood and the latter about 95 miles southwest of Braidwood. Radiosonde data indicated an extremely unstable atmosphere.

It is worthy to note that earlier in the day an area of thunderstorms passed to the north of Braidwood. The outflow from these storms likely created an additional boundary which later intersected with the cold front. Research has shown that this occurrence leads to an increased tornado threat. Further, the subsidence (sinking of air) behind the earlier area of thunderstorms created a reduction of the cloud cover that resulted in increased sunshine in the afternoon and early evening. This is known to increase

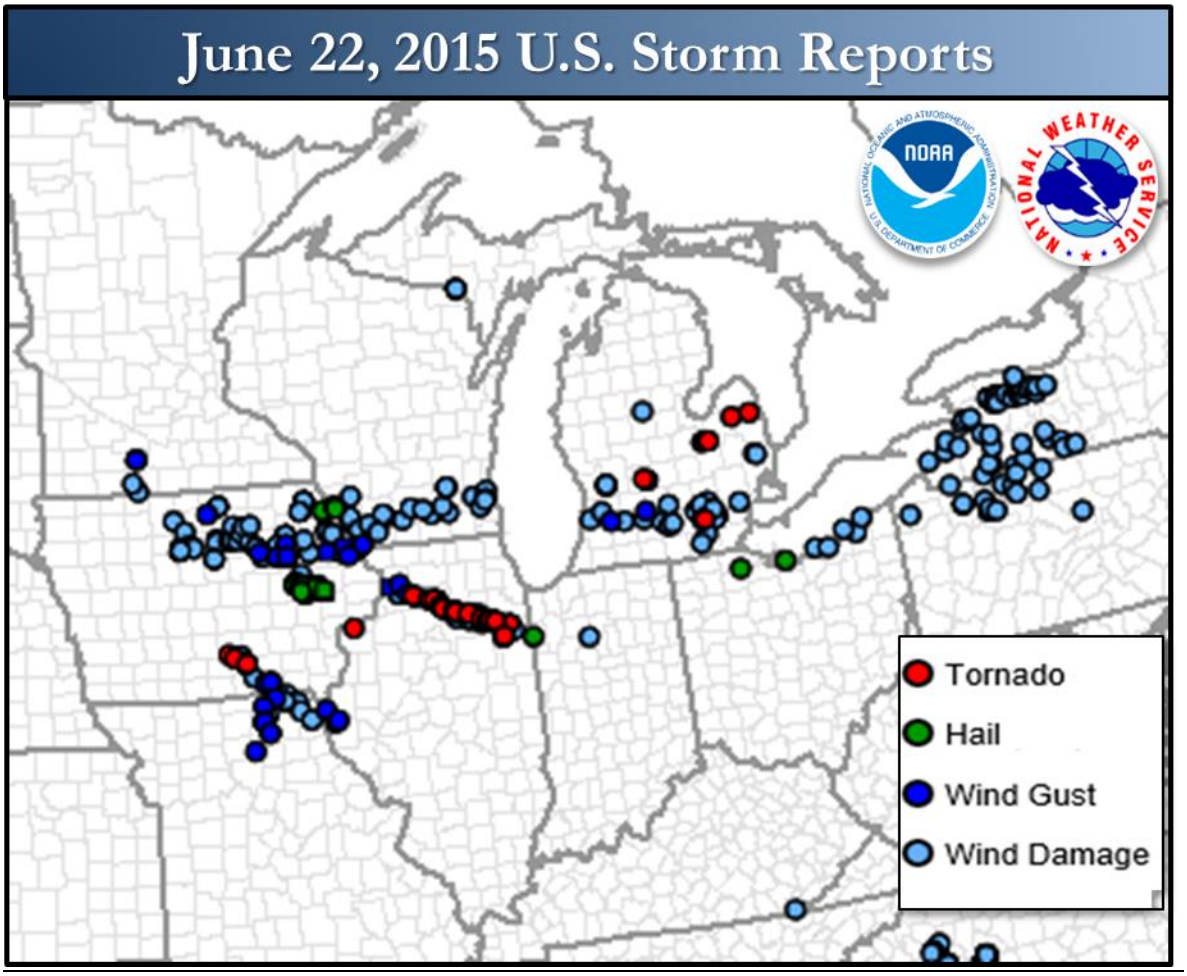
the instability which aids in the development of severe weather. In conclusion, the synoptic pattern and the instability combined to create a strong, long track tornado.

The following is documentation concerning the Coal City – Braidwood tornado from the National Weather Service Forecast Office in Chicago.

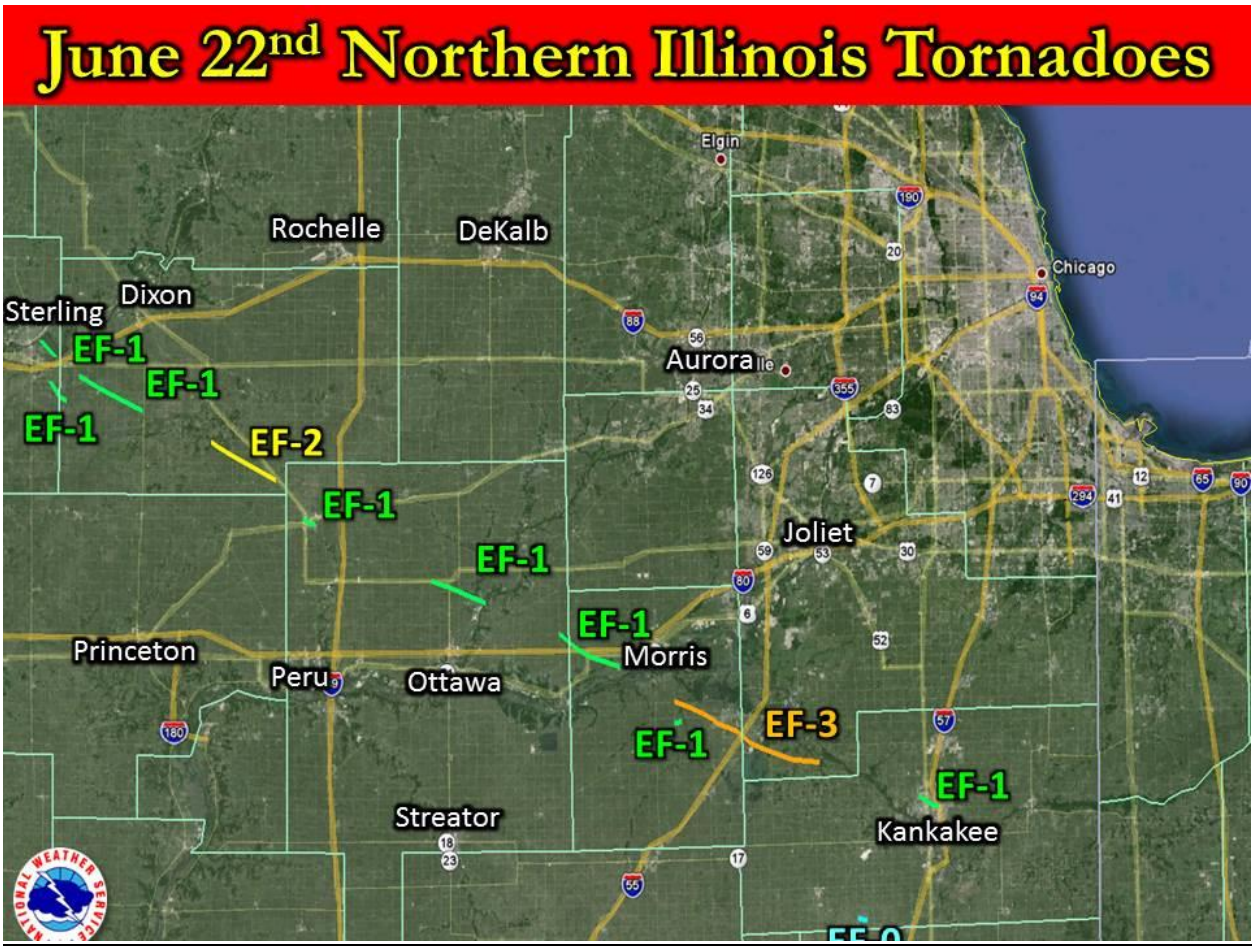
Fast Facts from the National Weather Service Forecast Office for Chicago

- During the evening of June 22, twelve tornadoes occurred across northern Illinois. Ten of these were spawned from one long-lived, constantly cycling, rotating storm, known as a cyclic supercell storm, which tracked across Whiteside, Lee, LaSalle, Grundy, Will, and Kankakee Counties.
- The heaviest damage was in Coal City (Grundy County) and Braidwood (Will County) which was caused by an EF-3 tornado with maximum winds of 160 mph, and the Woodhaven Campground in Sublette (Lee County) caused by an EF-2 tornado with maximum winds of 130 mph.
- There were 14 injuries reported. There were no fatalities.
- The EF-3 Coal City to Braidwood tornado was the strongest tornado in Grundy County since an F3 tornado struck on July 17, 1972.
- The atmosphere was primed for severe weather, with very warm, humid conditions, low pressure moving north of the region, and a strong jet stream aloft. An outflow boundary from earlier storms during the late morning and early afternoon may have been key to where the long-lived tornado-producing storm tracked.
- In addition to tornado and wind damage, slow moving storms brought torrential rainfall of locally up to 3 to 5 inches to portions of Lee, Grundy, Will, and Kankakee counties, resulting in widespread flash flooding. This rain fell on top of soil already saturated from repeated heavy rains over the past few weeks.
- The possibility of severe weather in the region had been mentioned as early as Saturday (the tornado occurred on the following Monday night), with the focus shifting southward to northern Illinois Sunday afternoon and into Monday. A tornado watch and tornado warnings had been issued in advance of the storms.

NATIONAL WEATHER SERVICE STORM REPORTS



Midwest Storm Reports for June 22, 2015.



Tornado Tracks. The Coal City – Braidwood tornado is the one shown as an EF-3 tornado with a gold line.

TORNADO #10: COAL CITY TO BRAIDWOOD TORNADO

RATING:	EF-3
ESTIMATED PEAK WIND:	160 MPH
PATH LENGTH:	16.5 MILES
PATH WIDTH MAXIMUM:	THREE-QUARTERS OF A MILE.
FATALITIES:	0
INJURIES:	7
START DATE:	JUNE 22 2015
START TIME:	945 PM CDT
START LOCATION:	4 MILES SOUTHEAST OF MORRIS IL
	4 MILES WEST NORTHWEST OF CARBON HILL IL
START LAT/LON:	41.3082 / -88.3823
END DATE:	JUNE 22 2015
END TIME:	1012 PM CDT
ESTIMATED END LOCATION:	6.9 MILES SOUTHEAST OF BRAIDWOOD IL
ESTIMATED END LAT/LON:	41.2255 / -88.0897

SURVEY SUMMARY: DOZENS OF HOMES HEAVILY DAMAGED IN COAL CITY WITH THREE COMPLETELY DESTROYED. TWO OF THESE HAD AT LEAST PART OF

THEIR STRUCTURE BOLTED DOWN TO THE FOUNDATION WITH THE BOLTS SECURED BY NUTS. TWO HIGH TENSION METAL TRUSSES WERE DOWNED INCLUDING ONE THAT WAS CRUMPLED. HUNDREDS OF TREES WERE SNAPPED OR UPROOTED. NUMEROUS UTILITY POLES WERE DOWNED. THIS TORNADO DID CROSS PART OF THE PROPERTY OF THE BRAIDWOOD NUCLEAR GENERATING STATION CAUSING TREE DAMAGE.

NOTES: THIS WAS THE STRONGEST TORNADO TO STRIKE GRUNDY COUNTY SINCE AN F3 TORNADO ON JULY 17 1972.

THIS TORNADO CROSSED THE PATH OF AN EF-2 WHICH STRUCK 19 MONTHS EARLIER ON NOVEMBER 17 2013.

Matt Friedlein from the National Weather Service Forecast Office, Chicago, IL performed the survey of the tornado damage the day following the tornado. Mr. Friedlein provided the following information related to the tornado as it passed through/near Exelon's Braidwood Station property:

"The damage closest to the Exelon property or visually from what we could see on the property along with photos of damage onsite is consistent with EF-1 damage with some large hardwood trees uprooted and numerous smaller trees or tree tops snapped. The expected wind speed based on the EF-scale research is 90-100 mph for such damage. EF-2 damage was surveyed just two miles west-northwest of the plant and four miles east, so the tornado was going through some variance in intensity, not uncommon for a long track tornado.

The tornado moved an average speed of 36.7 mph along its path, and based on radar speed of the couplet from I-55 to west of the plant, it looked very close to that speed.

Immediately after the tornado had passed I-55, on South Kankakee Street, we were able to get a fairly good handle on the width being near three-quarters of a mile at that point, which was consistent with some damage on the far south end of Coal city/Diamond. That was also the widest the tornado was in its path. By the time it reached IL-129 and U.S. Highway 53 (very near the Braidwood plant boundary), it certainly looked as if it had narrowed, likely more toward one half mile wide or even a little below that. Given the SW-NE direction of those two roads, they cut perpendicular to the path, so that should be a decent estimate."

Using the estimated center point of the tornado, as determined by the National Weather Service, the Braidwood meteorological monitoring tower was within 700 feet of the center of the tornado and was likely within the tornado as it passed to the southeast.

DAMAGE TO BRAIDOOD'S METEOROLOGICAL MONITORING EQUIPMENT

At 10:26 p.m. CDT on the evening of June 22, 2015, Murray and Trettel's Chief Meteorologist informed the staff tasked with maintaining the Braidwood Station meteorological monitoring tower that a tornado had been reported in the town of Braidwood, IL (town center is approximately 1.25 miles from the Braidwood nuclear plant meteorological monitoring tower). The following was the notice e-mailed by the Chief Meteorologist Steve Mirsky:

WILL IL-KANKAKEE IL-GRUNDY IL-
1000 PM CDT MON JUN 22 2015

...A TORNADO WARNING REMAINS IN EFFECT UNTIL 1045 PM CDT FOR SOUTHWESTERN WILL...NORTHWESTERN KANKAKEE AND SOUTHEASTERN GRUNDY COUNTIES...

AT 959 PM CDT...A CONFIRMED LARGE AND EXTREMELY DANGEROUS TORNADO WAS LOCATED OVER BRAIDWOOD...OR JUST SOUTHWEST OF WILMINGTON...MOVING EAST SOUTHEAST AT 30 MPH.

THIS IS A PARTICULARLY DANGEROUS SITUATION.

HAZARD...DAMAGING TORNADO.

SOURCE...RADAR CONFIRMED TORNADO.

Steve Mirsky
Manager/Chief Meteorologist

Weather Command® / Murray and Trettel, Inc.
Empowering Decision Makers 24/7™

Twelve minutes later, the following e-mail was issued by Andrew Lotz, Murray and Trettel's Nuclear Project Manager:

All-

Please see the attached images.

Mike has been in touch with the control room at Braidwood. It seems as if the cups and vanes have been stripped clear, but the temperature sensors remain in service.

I had a live feed up of the digital recorder and saw 87.1 MPH at the 34 foot level and a disabled sensor at the 203' level during ten second updates. I believe there may need to be an emergency tower inspection performed on this tower.

-Andy

ONSITE METEOROLOGICAL DATA

One second meteorological data samples are collected by a Microtel data logger in a temperature controlled shelter adjacent to the Braidwood meteorological monitoring tower. One second meteorological data samples are collected by a Microtel data logger. The one second samples are used to generate hourly averages of all parameters with the exception of precipitation which is an hourly total.

A Yokogawa digital recorder is used a a backup recording device. The recorder also allows meteorologists to review data traces in order to more quickly detect sensor spiking or failure.

Murray and Trettel meteorologists review hourly data from the Microtel each morning and data from the digital recorder weekly.

The following are data samples from the Braidwood digital recorder and Microtel data logger during the tornado event:

Table 3

10 Second Data Samples from Braidwood Digital Recorder

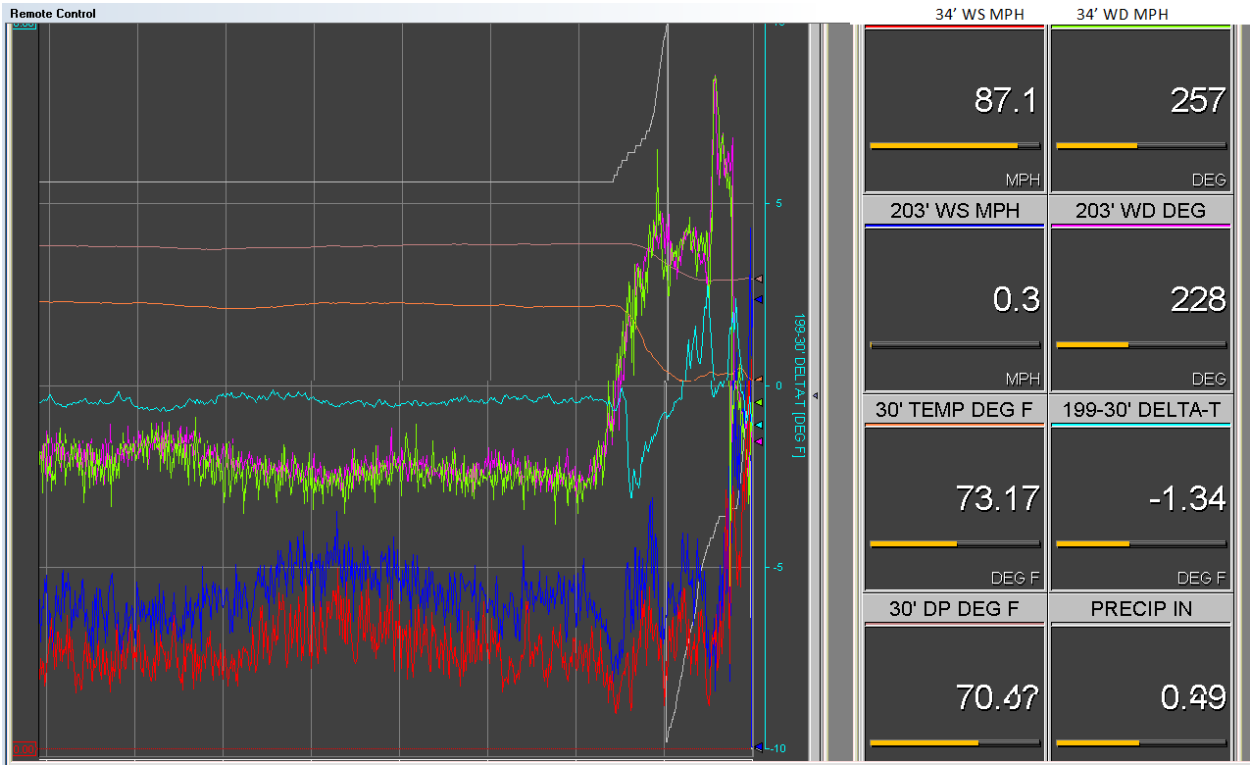
Date	Time	34' MPH	34' DEG	203' MPH	203' DEG	30' T DEG F	DT DEG F	DEWPT DEG F	PREC IN
06/22	20:57:50	27.1	254	33.6	264	74.23	0.20	71.12	0.36
06/22	20:58:00	22.3	261	47.7	251	74.14	-0.10	71.15	0.37
06/22	20:58:10	30.5	219	43.1	251	73.88	-0.19	71.18	0.39
06/22	20:58:20	34.6	250	46.6	247	73.63	-0.17	71.22	0.40
06/22	20:58:30	38.0	233	46.8	252	73.32	-0.28	71.24	0.42
06/22	20:58:40	32.9	230	44.3	244	73.17	-0.51	71.22	0.43
06/22	20:58:50	42.7	230	54.7	239	73.08	-0.87	71.21	0.45
06/22	20:59:00	34.0	215	58.9	238	73.06	-1.03	71.20	0.46
06/22	20:59:10	43.3	222	71.6	245	72.94	-0.91	71.14	0.47
06/22	20:59:20	53.6	182	54.1	189	72.96	-0.72	71.07	0.49
06/22	20:59:30	40.9	194	61.8	233	72.80	-0.30	71.00	0.49
06/22	20:59:40	73.2	243	78.9	248	72.82	-0.61	70.90	0.36
06/22	20:59:50	64.8	236	0.3	235	72.96	-0.94	70.83	0.00
06/22	21:00:00	87.1	257	0.3	228	73.06	-1.10	70.59	0.00
06/22	21:00:10	73.0	232	0.3	357	73.17	-1.34	70.43	0.00
06/22	21:00:20	53.5	256	0.3	330	73.18	-1.36	70.22	0.00
06/22	21:00:30	1.9	337	0.3	385	73.09	-1.14	70.00	0.01
06/22	21:00:40	1.1	369	0.3	369	73.13	-1.09	69.80	0.02
06/22	21:00:50	0.3	363	0.3	345	73.12	-0.77	69.70	0.03
06/22	21:01:00	0.3	371	0.3	359	72.93	-0.63	69.65	0.05

Precipitation from 20:39:30 to 20:59:30 (20 minutes) = 0.67"

The 203' wind speed sensor failed by 20:59:40. The 34' wind speed sensor failed by 21:00:30.

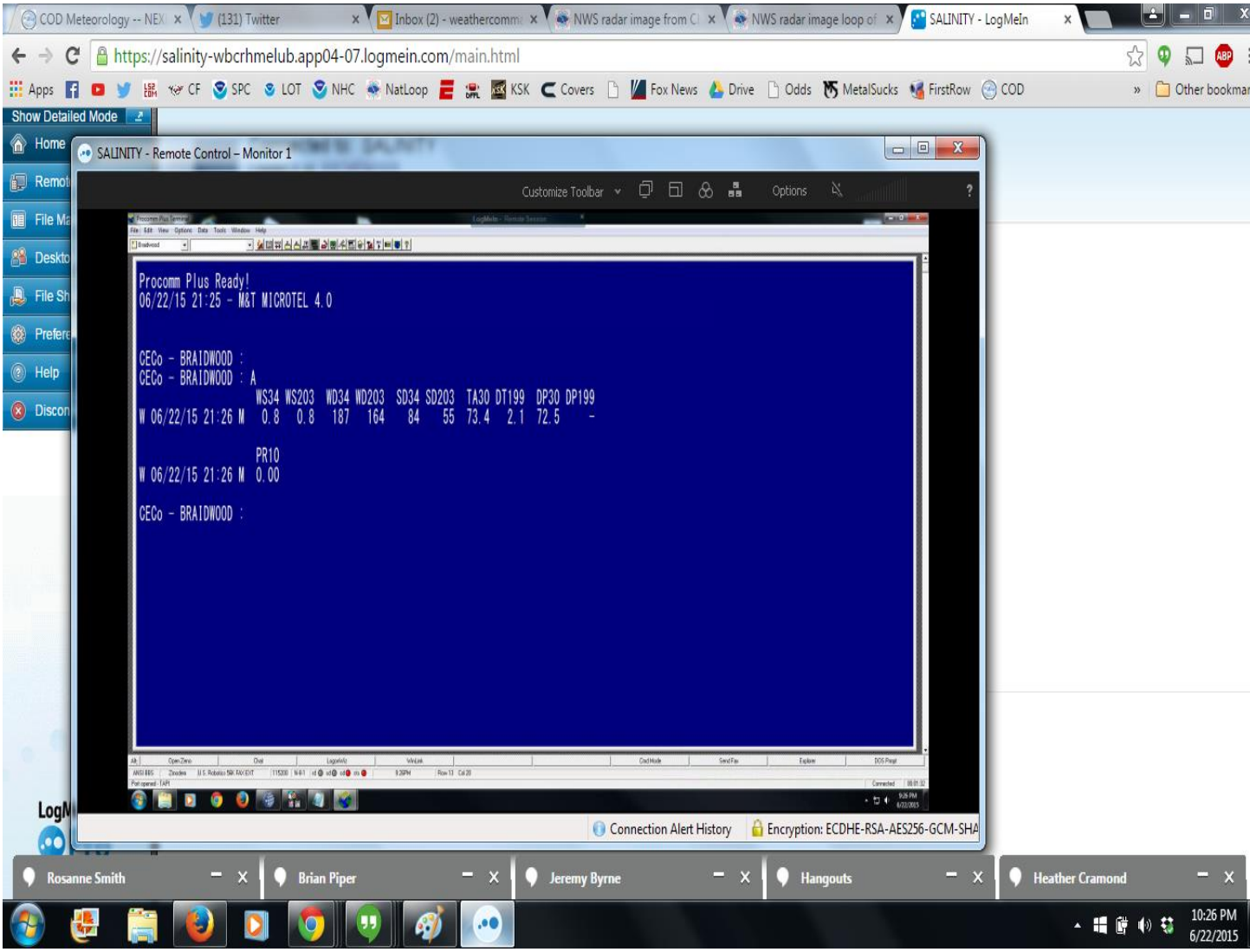
At approximately 21:00:00, both the lower and upper wind direction sensors ceased providing valid data.

The precipitation data on the digital recorder was erroneous at 20:59:40 and reset to 0.00 after that time. Between 20:39:30 and 20:59:30 (a 20 minute period), the Microtel data logger recorded 0.67" of precipitation.



The above snapshot of the Yokogawa digital recorder which resides in the instrument shelter adjacent to the meteorological monitoring tower at Braidwood, shows the 34' wind speed sensor reading 87.1 mile per hour. The digital recorder takes 10 second data samples. The 203' wind speed sensor had failed by the time the above snapshot had been take, evidenced by a wind speed value of 0.3 mph. The timestamp of the above snapshot was 20:59:20 CST (21:59:20 CDT).

The following is a screen shot of a one minute sample from the Microtel data logger which also resides in the instrument shelter at Braidwood. The one minute averages were taken at 10:26 p.m. CDT (the logger time is set to Central Standard Time). The 34' and 203' wind speed sensors were at low threshold value (0.8 mph) as both sensors had been damaged during the tornado. Although the direction sensors were providing direction values, the data was not valid.



Murray and Trettel's Field Service Manager, Mike Marx, called the Braidwood Control Room to verify that communication between the meteorological monitoring tower and the Control Room had not been impacted by the tornado. Although the wind speed and direction data was invalid, data from the meteorological monitoring tower was still being received in the Control Room.

Murray and Trettel staff made plans to arrive at Braidwood early on the morning of June 23 to assess the damage and perform repairs if possible.

Murray and Trettel field staff arrived at Braidwood early on June 23. The field service personnel however were initially not able to drive to the meteorological monitoring tower due to downed wires and trees. Later that morning, Braidwood staff was able to provide Murray and Trettel personnel with access to the tower. By noon on the day following the tornado, the 34' wind speed, 34' wind direction and 203' wind speed had been repaired and were sending valid data to the Braidwood Station Control Room. The 203' wind speed sensor had been completely removed from the tower (the sensor was never found). The wind direction cable was also ripped from the tower during the tornado passage. A new wind speed signal cable had to be built in Murray and Trettel's shop. The field technicians returned the next morning (6/24/15) with the new wind speed signal cable and a calibrated wind speed sensor. The 203' wind speed sensor was back in service by 10 a.m. CST on June 24.

As mentioned earlier, the temperature, dew point and precipitation sensors were not affected by the tornado. The precipitation gauge recorded 2.60" of precipitation between the hours of 9 p.m. CST on June 22 and 1 a.m. on June 23, 2015.

34’ wind measurement system. Wind speed sensor is hanging upside down and cups are caught in the cable. Wind direction sensor is intact but not providing valid data.

The following provides the number of hours of invalid data for the wind speed and wind direction parameters:

Table 3

Invalid Instrument Hours

Measurement	Invalid Hours	Elevation
Wind Speed	37	203 ft.
Wind Direction	14	203 ft.
Differential Temperature	0	199 ft.
Wind Speed	13	34 ft.
Wind Direction	13	34 ft.
Ambient Temperature	0	30 ft.
Dew Point Temperature	0	30 ft.
Precipitation	0	Ground

203’ wind measurement system. Wind speed sensor is missing. Wind direction sensor is hanging upside down.

EMERGENCY TOWER INSPECTION

Annual inspections of Exelon’s meteorological monitoring towers are performed each spring. The inspections are performed to verify the structural integrity of the tower and to check other physical characteristics such as guy wire tensions and guy anchor conditions below the surface.

If wind speed reaches or exceeds 90 miles per hour, an emergency tower inspection is performed. An emergency tower inspection was performed on June 24, 2015 (less than 48 hours after the tornado). It was determined that no structural damage to the tower had occurred.

CONCLUSIONS

A tornado impacted the Braidwood Nuclear Generating Station meteorological monitoring tower during the night of June 22, 2015. The EF-3 tornado had a path length of 16.5 miles, a maximum path width of three-quarters of a mile and an estimated peak wind of 160 mph.

Damage to the meteorological monitors on the Braidwood monitoring tower was limited to the wind system (wind speed and wind direction sensors were impacted at the 34' and 203' monitoring locations on the tower).

Prompt response by Murray and Trettel field services personnel limited system down time. Both wind direction sensors and the lower level wind speed sensor were restored to operational status within 14 hours of the tornado. The 203' wind speed sensor was restored to operational status within 37 hours of the damaging tornado (a new wind speed cable had to be made by a technician to replace the cable lost during the tornado).

The meteorological monitoring tower was likely located within the southern edge of the tornado vortex as it traveled across the Braidwood Nuclear Generating Station property.

Rapid communication of the events that lead to the damage of the measurement systems on the Braidwood Station meteorological monitoring tower significantly improved the ability to limit the loss of data after the passage of the tornado.

REFERENCES

National Weather Service Forecast Office Chicago, IL, Coal City – Braidwood Tornado site survey documentation.

NRC Regulatory Guide 1.23, Revision 1, 2007, Meteorological Monitoring Programs for Nuclear Power Plants.

TIA/EIA-222-G, Structural Standards for Steel Antenna Towers and Antenna Supporting Structures.

ACKNOWLEDGEMENTS

We thank the National Weather Service Forecast Office and in particular, Matt Friedlein for images, documentation and feedback from his survey of the September 22, 2015 Coal City – Braidwood tornado. We also than Thomas R. Piazza, CCM for his review.