FORECASTS, IWT CONSIDERATIONS, AND DSS DURING CONTRASTING SEVERE WEATHER EVENTS

Jennifer M. Laflin*
NOAA/NWS Kansas City/Pleasant Hill, Missouri

Trenton B. Pittman
Johnson County Emergency Management and Communications, Olathe, Kansas

Joseph Lauria
WDAF-TV/Fox Channel 4, Kansas City, Missouri

1. Introduction

Considerations from three contrasting severe convective weather events that impacted the Kansas City Metropolitan Area are presented from the perspective of a National Weather Service (NWS) forecast office, as well as Integrated Warning Team (IWT) members in Emergency Management and local television media. Two of these events (8 April 2015 and 6 July 2015) were preceded by some degree of forecast uncertainty but had differing outcomes and impacts; while the third event (26 April 2016) was characterized by higher overall forecast confidence. Many of the preparations and pre-event actions of IWT partners are triggered by NWS national centers' outlooks and watches, forecasts and discussions from the NWS forecast office and media outlets, and other local products such as webinars and graphical hazardous weather outlooks; thus, forecast uncertainty and rapidly evolving forecast expectations may present challenges with preplanning activities throughout the IWT arena. These three events are explored using archived observations and analyses, convection-allowing model output leading up to the events, and the pre- and post-event actions of the local NWS forecast office in Pleasant Hill, Missouri; Johnson County, Kansas Emergency Management; and Fox affiliate WDAF-TV Channel 4 in Kansas City. Topics such as triggers for partner staffing and EOC activation, internal IWT communication of forecast uncertainty, and recommendations to improve severe weather messaging are discussed.

*_Corresponding author address_: Jennifer M. Laflin, NOAA/NWS Kansas City/Pleasant Hill, MO 64080 email: jennifer.laflin@noaa.gov

2. 8 April 2015

a. Event Overview

On the synoptic scale, progressive south-westerly upper-level flow and a series of upper-level impulses were expected to override a deepening surface low, which would then eject northeast from southeast Colorado out into the central Plains during the afternoon of 8 April 2015. The surface low's associated warm front and dryline were expected to serve as foci for surface-based convective initiation from Kansas through western Missouri, and when combined with the presence of several outflow boundaries, ample surface-based instability on the order of 3000 J kg^{-1}, and 40 to 50 kts of 0-6 km deep layer shear, this environment was expected to support the development of supercells throughout the afternoon and evening of 8 April (Maddox et al. 1980, Thompson et al. 2003). As a result, an enhanced risk for severe weather was issued by the NWS Storm Prediction Center (SPC) at the 1730 UTC Day 2 Convective Outlook (Fig. 1a) on 7 April 2015, and was then upgraded to a moderate risk at the 1630 UTC Day 1 Convective Outlook on 8 April 2015 (Fig. 1b), where the low-level jet was expected to increase and support tornadic supercells during the evening.

b. Messaging and Factors in Forecast Confidence

NWS Pleasant Hill, MO uses several different avenues for communicating anticipated hazardous weather to core partners, including the presentation of a webinar for emergency managers and other first responders when widespread, significant hazardous weather is forecast. Due to the anticipation of potentially tornadic supercells and that it would be the first major event of the season in the forecast area, a webinar was conducted by NWS Pleasant Hill on 8 April 2015 at 1700 UTC. During the webinar, the severe weather threat was communicated to partners as it was described in section 2a, since all forecast parameters and high-resolution convection-allowing model (CAM) output continued to support the going forecast.

By early afternoon, an initial round of storms had developed in far south central Kansas and was beginning to trek northeast. This area of thunderstorm development was not well represented by CAMs, and occurred both earlier and further south than expected. A severe thunderstorm watch was issued by the SPC at 1950 UTC for these developing storms and included far southern portions of the Pleasant Hill forecast area (Fig. 2), which created confusion with IWT members, especially those in the Kansas City Metropolitan Area who were not included in the watch. The type of watch issued (severe thunderstorm versus tornado) also resulted in confusion from partners both within and outside the watch area, since tornadic supercells were still considered a possibility, and the moderate risk for severe weather, including a 15% hatched tornado probability, was reissued 18 minutes earlier at 1932 UTC. These concerns were addressed by the Pleasant Hill office via phone, in a shared chat room among IWT members (NWSChat), and also in the Area Forecast Discussion (AFD) issued at 2039 UTC. The message that was communicated from the NWS both at the Pleasant Hill office and the SPC, was that an additional round of convection was still expected to develop later in the afternoon or evening, and that an additional watch or an expansion and upgrade (to a tornado watch) of the current watch was possible.

As forecast, additional convection did initiate across southeast Kansas between 2200–2300 UTC; however, these thunderstorms struggled to persist or maintain intensity, and ultimately dissipated before reaching the Pleasant Hill forecast area. Even so, CAM output continued to indicate the persistence of ongoing storms as well as the potential for additional rounds of convection across northern Oklahoma and southern Kansas for the late afternoon and into the evening, and the strengthening low-level jet seemed to still support the expected increasing tornado threat over the following several hours. Forecast uncertainty was beginning to increase due to the disagreement between radar trends and CAM output, and led to further questions from partners and the public in the Kansas City Metropolitan Area; however, messaging from the NWS stayed the course through the late afternoon and early evening, with the Pleasant Hill office describing a continued severe weather threat in NWSChat, in the 2212 UTC update to the situation report (graphical hazardous weather outlook), and on social media. This was also in messaged by the 2245 UTC mesoscale discussion issued by the SPC, which described an increasing severe weather threat over far eastern Kansas and the southern two-thirds of Missouri, as well as a possible need for an additional severe weather watch by 0000 UTC on 9 April.

By the expiration time of the ongoing severe thunderstorm watch at 0000 UTC on 9 April, it had become apparent to NWS forecasters at the Pleasant Hill office and the SPC that increasing shear from the low-level jet and model-indicated MUCAPE of 2500-3000 J kg^{-1} were not enough to overcome apparent subsidence behind early afternoon storms, and that the dryline and upper-level forcing had lagged further behind than expected, keeping the primary severe weather threat well to the southwest of the Pleasant Hill forecast area. The severe thunderstorm watch was allowed to expire at 0000 UTC, and a diminishing severe weather threat was described to partners in NWSChat and to the public on social media shortly thereafter.

c. Partner Considerations

In Johnson County, Kansas (Fig. 3), the county Emergency Operations Center (EOC) is staffed by at least one pre-designated duty officer following the criteria listed in the county emergency management department's duty officer matrix (Fig. 4). A morning round of storms impacting neighboring Jackson County, Missouri — in addition to the SPC Day 1 Convective Outlook tornado probability of 10% — prompted the initial activation of the EOC by the primary duty officer at ~1130 UTC on 8 April. Even after the first round of storms moved out of the area, the primary duty officer remained in the EOC for the remainder of the morning and afternoon to monitor the forecast, attend the webinar hosted by the NWS in Pleasant Hill, and to communicate with county officials, the media, and the public.

The first major challenge faced by Johnson County Emergency Management (JOCOEM) came with the issuance of the severe thunderstorm watch for bordering counties to the south at 1950 UTC. Prior to the watch issuance, they had been sharing and communicating the same message originating from the NWS, that significant severe weather and the possibility of a few tornadoes was expected in the afternoon and the evening. This apparent disconnect between the forecast — including the recently issued SPC Day 1 Convective Outlook — and the type and areal extent of the watch was not only confusing for JOCOEM, but even more so for the public and other government departments with whom they are tasked to communicate. Even following the explanation from the NWS that the watch could be expanded or upgraded later in the day, the idea of uncertainty in the forecast lingered with JOCOEM staff despite no explicit mention of uncertainty by the NWS. The duty officer continued to message the forecast for severe weather, but also posed questions in NWSChat in hopes to clarify whether or not the potential for severe weather was changing.

Once it became clear that the severe weather threat was decreasing for the remainder of the day, the primary question for JOCOEM became when to deactivate the EOC. Although tornado probabilities in the SPC Day 1 Convective Outlook had been lowered at the 0100 UTC issuance on 9 April, the 5% tornado probability contour remained over Johnson County, and storms, although weaker than was anticipated, lingered within a two-county radius. Severe weather chances, while downplayed by the NWS, were still not completely ruled out even after 0100 UTC due to the increasing low-level jet and observed 3676 J kg^{-1} of surface-based CAPE on the 0000 UTC 9 April KTOP observed sounding. Thus, following the duty officer matrix, JOCOEM continued to staff the EOC until 0500 UTC (midnight LDT) on 9 April — resulting in nearly 18 hours of continuous staffing and EOC activation.

Meteorologists in broadcast media are faced with a unique challenge, which is communicating a common, consistent message with other members of the IWT, while also continually reevaluating the forecast as new data arrive. In addition, many news stations such as WDAF-TV/Fox Channel 4 (hereafter, Fox 4) in Kansas City use the SPC Convective Outlooks as a basis for their automated graphics, and thus must address the NWS forecast and their level of agreement with it during any severe weather event. Fox 4 began the day on 8 April communicating the same message as the NWS and other partners in the Kansas City area, and continued with that message via a weather blog post at 1330 UTC, and on-air through the noon newscast. However, the watch issuance at 1950 UTC and the round of storms which moved through areas south of Kansas City during the mid-afternoon prompted an update to the weather blog. This update mentioned forecast uncertainty, and the possibility that ongoing storms south of the area may be "messing up the atmosphere for what could happen later;" although the potential for the ongoing storms to leave behind outflow boundaries supporting a second, robust round of storms and a continued tornadic threat was also discussed.

An isolated severe thunderstorm which brought significant hail to portions of the northern Kansas City Metropolitan Area became the primary focus for Fox 4 during the late afternoon and early evening; however, the potential for a second round of evening severe storms shifted quickly back to the forefront as the hail-producing storm dissipated and exited the Kansas City area shortly after 2300 UTC. At 2321 UTC, Fox 4 tweeted that the severe weather setup didn't "look right," and followed up shortly thereafter with another tweet suggesting that subsidence or cooling in the wake of the afternoon storms south of Kansas City could be inhibiting additional storm chances. These updates and the idea of forecast uncertainty came a bit earlier from Fox 4 than from the NWS, and prompted both questions and some doubt from the public on social media. A weather blog entry was then posted by Fox 4 after the 0000 UTC expiration of the watch, supporting the message from the NWS and reiterating the lowering severe weather threat for the remainder of the night.

d. Outcome

The second round of severe weather never materialized on 8 April for the Pleasant Hill forecast area, and afterward brought to light the importance of addressing forecast uncertainty through the duration of a severe weather event. Effective communication and use of uncertainty information has been a recent focus of the weather enterprise (Demuth et al. 2009, Hirschberg et al. 2011) and had been discussed previously at IWT meetings hosted by the Pleasant Hill office, but was specifically addressed in the context of this event at an IWT meeting in the fall of 2015. Through discussions it was revealed that both forecasters at the NWS and broadcast meteorologists became more uncertain about the potential for severe weather during the afternoon when current radar trends began to deviate from CAM output and from the previous forecast, but in effort to preserve the consistent message and avoid flip-flopping between solutions, this forecast uncertainty was not discussed at the time even internally within the IWT. As a result, several goals regarding uncertainty were identified at the meeting, including: 1) a renewed emphasis on continual reevaluation of the severe weather threat throughout an event; 2) a more frank and open communication within the IWT; and 3) more two-way versus one-way communication about the forecast between NWS and broadcast meteorologists.

Another challenge underscored by this event is the difficulty in ramping down a significant severe weather threat, even after it becomes more probable than not that severe weather will not occur. Certain elements of the atmospheric environment, such as ample instability and an increasing low-level jet, kept forecasters from ruling out an additional severe threat well into the evening and early overnight hours of 8 April, and resulted in the continuation of extra staffing both at the EOC in Johnson County and at Fox 4. In addition, the product- and outlook-centric duty officer matrix used by JOCOEM emphasized the importance of updating official NWS products to reflect the forecast even as an event winds down, so that any partnering agencies who depend on these products can follow their protocol and are not left to their own interpretation of the threat.

3. 6 July 2015

a. Event Overview

On the morning of 6 July 2015, a shortwave trough and associated cold front was forecast to push eastward across the central and eastern Plains, and the combination of 1500-2000 J kg^{-1} of surface-based instability, surface convergence along the boundary, and 20 to 30 kts of 0-6 km deep layer shear was expected to support organized convection along the front. The SPC issued a slight risk for severe weather stretching from the Central Plains through Upper Mississippi River Valley in the Day 1 Convective Outlook (Fig. 5), and highlighted straight-line winds as the primary severe threat across the Lower Missouri Valley and South-Central Plains. While a 2% tornado probability contour was included in the Convective Outlook, the area highlighted was northeast of the Pleasant Hill forecast area where shear was stronger. In addition to the severe weather threat, very high precipitable water values of up to 2.5 in. and several recent episodes of flash flooding prompted the Pleasant Hill NWS office to issue a flash flood watch for the majority of the forecast area including the Kansas City Metropolitan Area.

b. Messaging and Factors in Forecast Confidence

Throughout the morning and early afternoon, a consistent message was communicated by the NWS:

that although a few strong to severe storms were possible, the overall severe weather threat was not high and the setup was typical for summer storms in the region. Deep layer shear was the primary limiting factor that prevented a more notable severe weather threat, as well as the nearly parallel orientation of the 0-6 km bulk shear vectors relative to the cold front that would force initiation later in the day.

Once storms developed along and just ahead of the cold front between 1800-1900 UTC, the initial storm mode was relatively disorganized but generally linear, with isolated stronger cores especially on the leading edge of the convection. The first severe thunderstorm warning in the region was issued by the local NWS office in Topeka, KS at 1939 UTC, and indicated the potential for up to 60 mph winds in portions of east central Kansas. Several additional severe thunderstorm warnings followed from the NWS offices both in Topeka and Pleasant Hill through 2100 UTC; then, the severe weather scenario began to quickly diverge from forecast expectations with the issuance of a tornado warning for northwestern portions of the Kansas City Metropolitan Area at 2102 UTC. A non-transient, distinct quasi-linear convective system (QLCS) tornado signature (Weisman and Trapp 2003, Trapp et al. 2005, Mahale et al. 2012) was evident in radar data both on the KEAX Weather Surveillance Radar-1988 Doppler (WSR-88D) and the TMCI terminal Doppler radar when the warning was issued, and was then followed by another QLCS tornado radar signature over the northeastern Kansas City Metropolitan Area, which necessitated the issuance of another tornado warning.

This shift in the ongoing and near-future severe threat required the NWS to react quickly and revamp messaging to IWT partners and the public, since the possibility of tornadoes had not been previously highlighted. In this case, the primary impetus of forecast uncertainty was the real-time deviation from expectations, and required the NWS to quickly determine what in the environment was supporting QLCS tornadoes, and whether or not the tornadic threat extended elsewhere in the forecast area. Communication to the public through social media was focused mainly on very near-term threats and the dissemination of ongoing warnings, while broader questions about the evolution of the event and any continuing tornadic threat for adjacent areas were addressed with partners in NWSChat and on the Metropolitan Emergency Radio System (MERS). Additional tornado warnings were issued that afternoon for portions of both the northeastern and then the southwestern Kansas City Metropolitan Area including Johnson County, KS, before storms became outflow dominant and less organized, and transitioned the primary severe weather threat back to straight-line winds as storms progressed east.

c. Partner Considerations

Based on the convective outlook and the duty officer matrix, JOCOEM was not required to activate the EOC on the morning of 6 July 2015; however, since this event occurred on a weekday, the primary duty officer and other staff were actively monitoring the potential for severe weather throughout the day. Routine updates were provided by the Pleasant Hill NWS office via the issuance of the situation report at 0908 UTC, 1719 UTC, and 1952 UTC, and through a daily hazardous weather briefing on MERS at 1800 UTC, which were received and used by JOCOEM staff to build their situational awareness and understanding of the severe weather threat for the day. All of these NWS briefings and products carried the same information, since no significant changes were made to either the SPC Day 1 Convective Outlook or to the forecast throughout the morning and early afternoon.

At the time of the first severe thunderstorm warning issuance in the Topeka forecast area (1939 UTC), the storms were far enough west of Johnson County, KS not to trigger EOC activation, but it nonetheless provided information to JOCOEM that storms were strengthening and that the severe risk was in line with forecast expectations. While a severe thunderstorm watch was issued by the SPC at 2035 UTC, and a severe thunderstorm warning issued by NWS Topeka did impact a Tier 2 county (Fig. 4), prior to 2100 UTC EOC activation was still not required without an SPC Day 1 tornado probability of at least 5%. However, once the first tornado warning was issued for Platte County, MO (Tier 2) at 2102 UTC, JOCOEM was not only required to activate the EOC, but also to activate and mobilize their network of weather spotters within the county ("ECS activation;" Fig. 4) to deploy ahead of the incoming storms. Fortunately, this activation provided JOCOEM with just over an hour to prepare and place spotters before the first tornado warning issuance that included Johnson County, KS at 2215 UTC. Additionally, reports from other IWT members placed into NWSChat and frequent updates from the NWS both in NWSChat and on MERS helped prepare JOCOEM for the tornado warning even before it was issued. In this case, the requirements of EOC staffing and activation described in the duty officer matrix helped JOCOEM prepare for and react to the increasing tornadic threat appropriately in spite of forecast uncertainty, and the combination of their detailed standard operating plan and support from the NWS allowed for both successful spotter deployment and warning dissemination throughout the event.

External communication about the 6 July severe weather threat from Fox 4 meteorologists was very similar to that being disseminated by the NWS leading up to and during the event, both on air and through the weather blog. Once tornado warnings were issued by the NWS, Fox 4 meteorologists' responsibility as the primary communicators of the IWT became much more focused on the real-time dissemination of warning information, and much less on the short-term forecast for continued tornado potential. Broadcast meteorologists in the Kansas City Metropolitan Area also follow rigid guidelines to break into programming and provide wall-to-wall coverage when a tornado warning is active for the areas surrounding and encompassing the metro; thus forecast uncertainty only factored into their decision-making process when a tornado warning was no longer in effect, which only occurred over the 40 minute period between 2115-2155 UTC before several additional, temporally-overlapping tornado warnings were issued. Although no specific questions were posed in NWSChat by Fox 4 on 6 July, forecast information and severe weather reports entered into chat by the NWS and other IWT partners were used by their broadcast meteorologists in real-time. This material was then communicated to the public on-air, and also helped them maintain their own situational awareness through the rapid changes in the severe weather threat, mitigating at least some of the impact of increased forecast uncertainty.

d. Outcome

Several tornadoes were ultimately reported in and around the Kansas City Metropolitan Area on 6 July including two in Johnson County, KS, one which produced EF-2 damage just west of the Johnson County border in neighboring Douglas County, KS. No fatalities or injuries were reported, and all warnings were received and disseminated in a timely fashion by local officials and broadcast meteorologists throughout the area. Even so, forecast uncertainty played a significant role, and several takeaways were uncovered during and after the event.

The primary finding upon review of this event was the importance of providing short-term forecast updates to IWT partners (Pietrycha and Fox 2004), especially when conditions begin to diverge from the forecast and thus create uncertainty. While communication and dissemination of warning information take initial precedence when warnings — and especially tornado warnings — are active, downstream partners and media that cover a large area depend on forecast updates to accurately prepare and communicate within their jurisdictions. In addition, not all IWT partners will have the time or ability to ask questions and acknowledge information provided by the NWS during an active severe weather event, but are nevertheless dependent on forecast updates. This finding highlights the importance of not only the continual reassessment by the NWS of any severe threat, but also the timely communication of those reassessments to IWT partners.

This event also revealed a knowledge gap for several IWT partners, due to confusion about how the storms on 6 July supported tornadogenesis. QLCS and other non-supercell tornadoes are often not addressed with non-meteorologists in the IWT due to their complexity and relative rarity of occurrence; however, the lack of prior understanding led to real-time confusion when tornadoes formed in a non-supercell environment. Although these concerns can be — and in this case were — addressed during the event by the NWS, basic education and discussion about QLCS tornadoes prior to the onset of the severe weather season may help IWT members adapt and react more effectively in similar future situations.

4. 26 April 2016

a. Event Overview

The morning of 26 April began with a complex of thunderstorms producing large hail and damaging winds from portions of far northeast Kansas through central Missouri; however, the main severe weather threat was expected to occur later in the day when a deep upper low over the four corners region began to eject northeastward. Although morning storms and cloud cover were impacting portions of the eastern Plains, clearing skies were expected across the central Plains by afternoon, which would lead to the development of very steep midlevel lapse rates and 3000-4000 J kg^{-1} of surface-based instability. Deep layer 0-6 km shear of 30-40+ kts and the presence of a warm front as well as several outflow boundaries were expected to play a role in storm organization from central Kansas through northern Texas; making supercells with very large hail, damaging winds, and a few tornadoes the primary threat in those areas. As storms transitioned eastward, decreasing deep layer shear and instability, together with the time of day once storms arrived, was expected to cause storms to become less organized and more linear with time. Because of this, the main severe weather threats that were anticipated in the Pleasant Hill forecast area were straight-line winds and flash flooding, with the expectation that the severe threat would decrease from west to east and from evening through the night. A moderate risk for severe weather was indicated in the SPC Day 1 Convective Outlook across the central Plains, then dropped off sharply to an enhanced and then to a slight risk for severe weather across western portions of the Pleasant Hill forecast area (Fig. 6) where storm organization was expected to decrease.

As morning convection continued to translate southeastward across central Missouri, a well-defined outflow boundary trailed from a nearly stationary position near Salina, KS to the southwestern edge of the ongoing convection in Missouri, which continued progressively southward. This boundary eventually stalled across southern Missouri during the afternoon, and extended up to the northwest across eastern Kansas, setting up a preferential location for initiation of supercells (Laflin and Houston 2012) in eastern Kansas late that afternoon, as the atmosphere began to destabilize in its vicinity.

b. Messaging and Factors in Forecast Confidence

Due to the presence but limited eastern extent of the enhanced risk contour in the Day 1 Convective Outlook, on the morning of 26 April the NWS office in Pleasant Hill opted to send a short narrative email to their IWT partners, which also included an attachment of the latest situation report. In the email, the primary severe weather threats were described to be large hail, damaging winds, torrential rainfall, and possibly an isolated tornado threat west of the MO/KS border. It was also mentioned in the email and the situation report that the ability of the environment to recover from morning storms would determine the eastward extent of the severe weather threat, but that it was generally expected to decrease east of the MO/KS border. Multiple rounds of storms throughout the day were mentioned as a possibility, but timing for the main round of strong to severe storms was advertised to occur between 0100-0200 UTC in the Kansas City Metropolitan Area, and progressively later for the remainder of the Pleasant Hill forecast area.

A few updrafts began to bubble along the stalled outflow boundary mentioned in section 4a between 1900-2000 UTC, and developed into a broken line of storms that progressed northeast over the next few hours toward Kansas City. In addition, a tornado watch was issued by the SPC at 1915 UTC for the majority of the eastern half of Kansas, but did not include the eastern tier of Kansas counties, and did not include any of the Kansas City Metropolitan Area. Due to the proximity of the tornado watch and the development of storms nearing the southwestern Kansas City Metropolitan Area, several IWT partners questioned whether these storms would strengthen; however, the message continually communicated by the NWS in NWSChat and on MERS was that the atmosphere had not yet fully recovered from earlier convection, and that this round of storms was not expected to persist or become strong to severe.

As expected, the eastern extent of storms over far eastern Kansas and western Missouri began to dissipate between 2130-2200 UTC, and the primary focus for severe storms remained several counties to the west of the Pleasant Hill forecast area. These storms continued to translate mainly north northeast through approximately 0100 UTC on 27 April, before finally beginning to make an eastward push. Storm mode had been relatively disorganized throughout the event, but a linear morphology was beginning to take shape across south central Kansas between 0100-0200 UTC, and a severe thunderstorm watch was issued at 0150 UTC for these storms as they began to progress eastward. A few counties in the southern Kansas City Metropolitan Area were included in the watch, but no questions were posed by IWT partners seeking clarification or additional information about the forecast or short-term severe weather potential, and uncertainty appeared low as the severe weather scenario unfolded generally as forecast.

c. Partner Considerations

As was the case on 8 April 2015, early morning storms, the issuance of a severe thunderstorm watch at 1120 UTC, and the location of the 5% tornado probability contour in the Day 1 Convective Outlook over Johnson County, KS should have dictated that the EOC be activated prior to 1200 UTC. However, through communication with the NWS in Pleasant Hill, it was determined that the 5% tornado probability contour was indicated for the additional rounds of convection that were forecast to occur later in the day. Similar to the 6 July 2015 event, since 26 April occurred on a week day, the duty officer and other JOCOEM staff actively monitored the forecast and weather conditions in the EOC through the morning and into the early afternoon even before the official activation. At 1915 UTC, a tornado watch was issued for neighboring Douglas County, KS, and once convection began to develop in the watch area southwest of the county, the EOC was officially activated at 2051 UTC. The watch remained in effect for Tier 3 counties through the late afternoon and evening, thus the primary duty officer continued to staff the EOC even after the mid-afternoon round of storms dissipated. Additionally, both the 2000 UTC and 0100 UTC (on 27 April) updates to the SPC Day 1 Convective Outlook kept Johnson County in the 5% tornado probability contour, which also obligated the EOC to remain activated until the next round of storms moved out of the area or until the severe weather threat diminished. Although no tornado warnings were issued for Johnson County during this event, a few severe thunderstorm warnings — including one for 80 mph straight-line winds — were issued while the EOC was active, and the information provided by the NWS in Pleasant Hill and the SPC helped the duty officer remain prepared and situationally aware throughout the event.

On air, Fox 4 meteorologists communicated a very similar forecast to the NWS, emphasizing that while a significant severe threat was expected west of their viewing area, severe chances would decrease from west to east and the main severe hazard would transition to straight-line winds as storms approached the Kansas City Metropolitan Area. In the weather blog, Fox 4 did mention one possible scenario where the outflow boundary mentioned in section 4a could fuel the initiation of a few stronger, potentially rotating storms during the afternoon, but placed a much greater emphasis on the former solution. Subsequent updates to the weather blog discontinued any discussion of stronger storms developing along the outflow boundary, and focused on communicating the flooding and straight-line wind threats associated with the late evening round of storms. Throughout the event, on-air weather updates focused solely on the evening threat and left the more technical, uncertain discussion about afternoon storms for readers of the weather blog.

d. Outcome

In contrast to the 8 April and 6 July events, this severe weather event was characterized by very little forecast uncertainty and few changes to the expected severe threat throughout the day. This sense of forecast certainty and consistency helped partners prepare and maintain situational awareness, and also avoided unnecessary staffing even through multiple rounds of convection. Strong communication and frequent updates through email, the situation report, NWSChat, and MERS kept the IWT informed, and seemed to prevent confusion even once storms began to enter the forecast area late that evening.

5. Discussion and Summary

Three severe convective weather events with varying degrees of forecast certainty are described, compared, and contrasted in order to discover commonalities, takeaway points, and goals for future situations. Through all three events, one common thread is immediately apparent: that frequent, open, and frank communication through all members of the IWT is necessary regardless of forecast confidence or certainty. Many times, NWS-produced graphics and information intended for the general public is also used by the NWS to brief IWT partners, but it is important to differentiate these users, especially when uncertainty is high. Tools such as NWSChat, MERS or other internal radio channels, webinars, and to some extent the situation report (hazardous weather outlook) are intended for use by the IWT, and can all be used by the NWS to illustrate not only the forecast but also forecast confidence and other supplemental information that will help decision-makers in all types of severe weather events.

Another key point uncovered by these cases is a need for agreement between NWS forecasts, official products, and briefings provided to the IWT. Many of the products originating from the NWS are used in different — and sometimes unexpected — ways by partners, and could have a large impact on staffing, EOC activation, and other official decisions; thus, it is important to make sure information is re-evaluated, updated, and consistent throughout the spectrum of products and services provided by the NWS. This will be particularly relevant as the NWS continues to evolve their decision support services (IDSS), integrates and collaborates more fully with the NWS national centers, and begins to add and/or modify existing forecast products and services.

Finally, it is essential to identify and address sources of confusion both before and during severe weather events. Even when forecast uncertainty is unavoidable, many partner questions and concerns can still be answered, and interaction between IWT partners could help the NWS respond effectively to common concerns and better refine the information being provided. Additionally, if some of the sources of partner confusion appear to be systemic or span several related but separate events, education and training on those sources well in advance of a future event may help avoid the repetition of those issues. In summary, effective communication is the common vein through all these findings, and its prioritization is crucial for the success of any IWT during active weather.

6. References

Demuth, J. L., B. H. Morrow, and J. K. Lazo, 2009: Weather forecast uncertainty information: an exploratory study with broadcast meteorologists. *Bull. Amer. Meteor. Soc.*, **90**, 1614-1618.

Hirschberg, P. A. and Coauthors, 2011: A weather and climate enterprise strategic implementation plan for generating and communicating forecast uncertainty information. *Bull. Amer. Meteor. Soc.*, **92**, 1651-1666.

Laflin, J. M., and A. L. Houston, 2012: A modeling study of supercell development in the presence of a preexisting airmass boundary. *Electronic J. Severe Storms Meteor.*, **7** (1), 1-29.

Maddox, R. A., L. R. Hoxit, and C. F. Chappell, 1980: A study of tornadic thunderstorm interactions with thermal boundaries. *Mon. Wea. Rev.*, **108**, 322-336.

Mahale, V. N., J. A. Brotzge, and H. B. Bluestein, 2012: An analysis of vortices embedded within a quasi-linear convective system using X-band polarimetric radar. *Wea. Forecasting*, **27**, 1520-1537.

Pietrycha, A. E., and M. A. Fox, 2004: Effective use of various communication methods during a severe convective outbreak. *Natl. Wea. Dig.*, **28**, 59-64.

Thompson, R. L., R. Edwards, J. A. Hart, K. L. Elmore, and P. M. Markowski, 2003: Close proximity soundings within supercell environments obtained from the Rapid Update Cycle. *Wea. Forecasting*, **18**, 1243-1961.

Thompson, R. L., B. T. Smith, J. S. Grams, A. R. Dean, and C. Broyles, 2012: Convective modes for significant severe thunderstorms in the contiguous United States. Part II: Supercell and QLCS tornado environments. *Wea. Forecasting*, **27**, 1136-1154.

Trapp, R. J., S. A. Tessendorf, E. S. Godfrey, and H. E. Brooks, 2005: Tornadoes from squall lines and bow echoes. Part I: Climatological distribution. *Wea. Forecasting*, **20**, 23-34.

Weisman, M. L., and R. J. Trapp, 2003: Low-level mesovortices within squall lines and bow echoes. Part I: Overview and sensitivity to environmental vertical wind shear. *Mon. Wea. Rev*., **131**, 2779-2803.

7. Figures

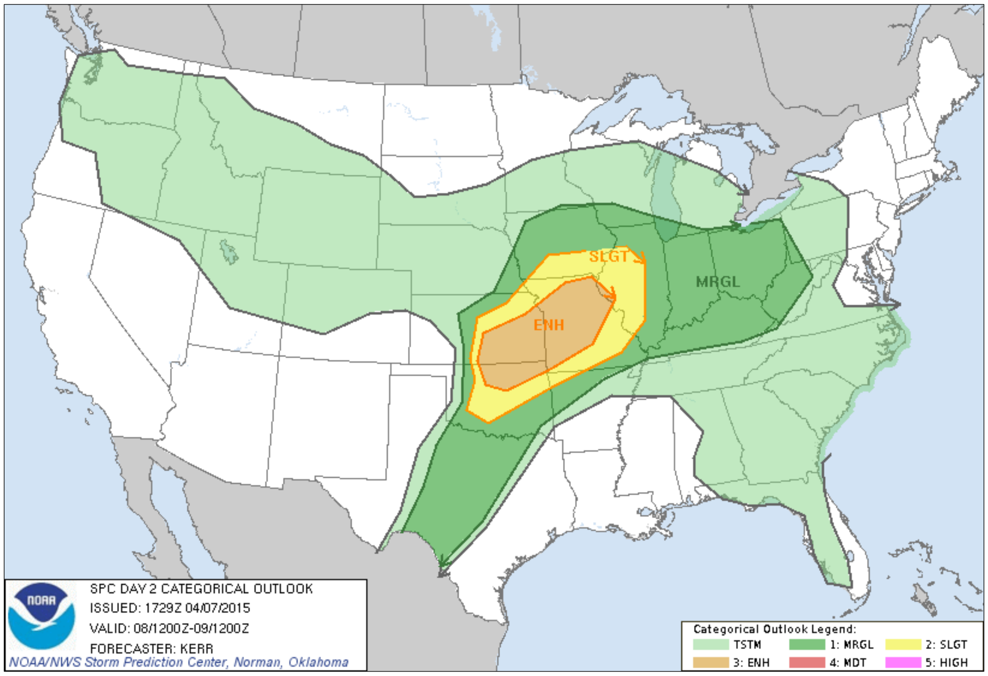

Figure 1a. SPC Day 2 Convective Outlook, issued at 1730 UTC on 7 April 2015.

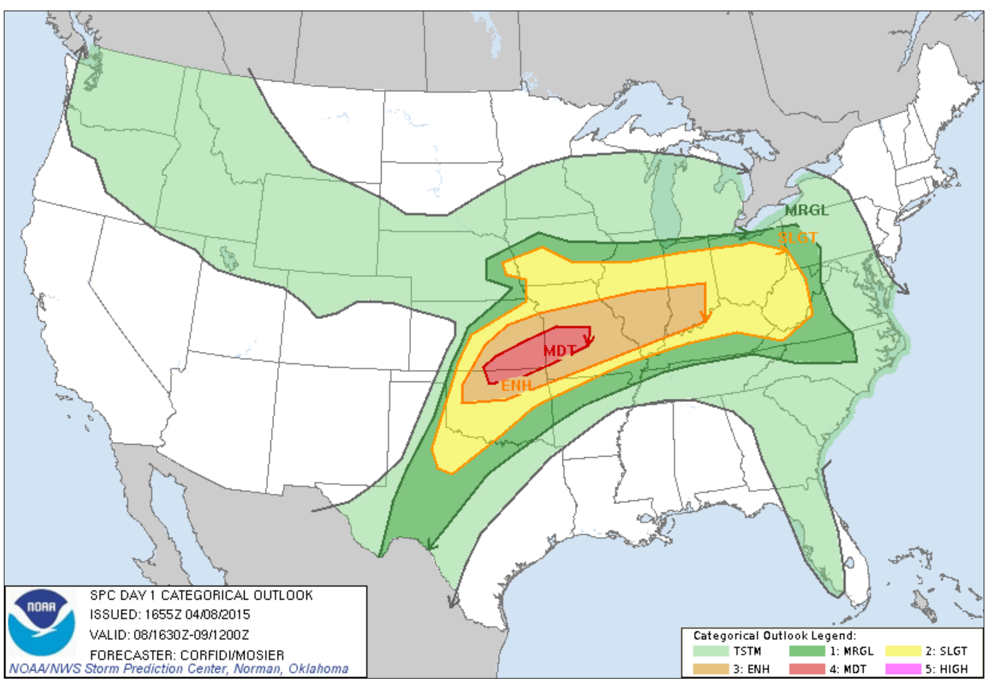

Figure 1b. SPC Day 1 Convective Outlook, issued at 1630 UTC on 8 April 2015.

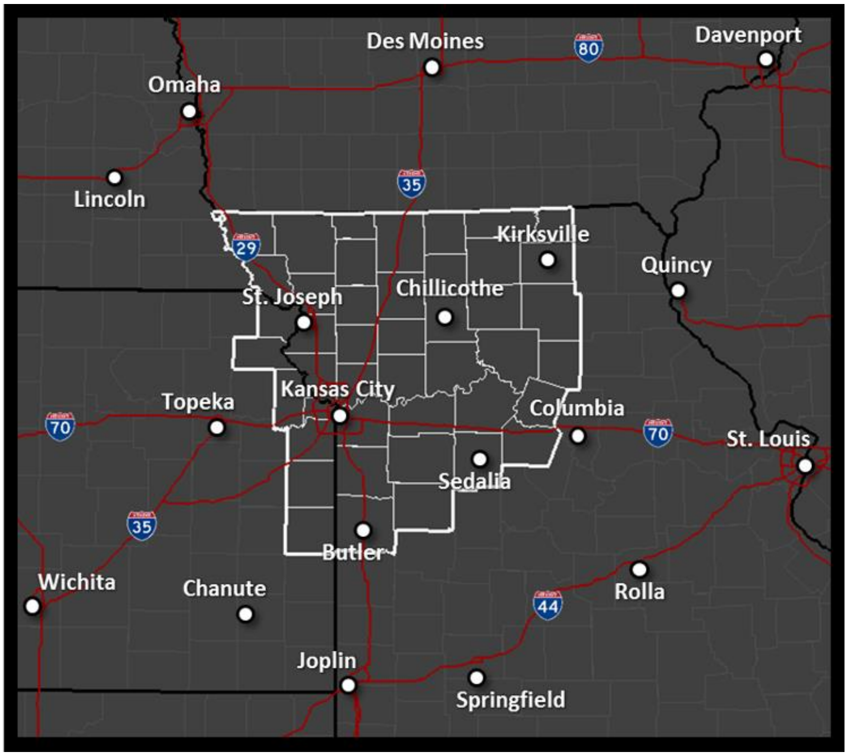

Figure 2. The Pleasant Hill, MO Forecast Area (outlined in white).

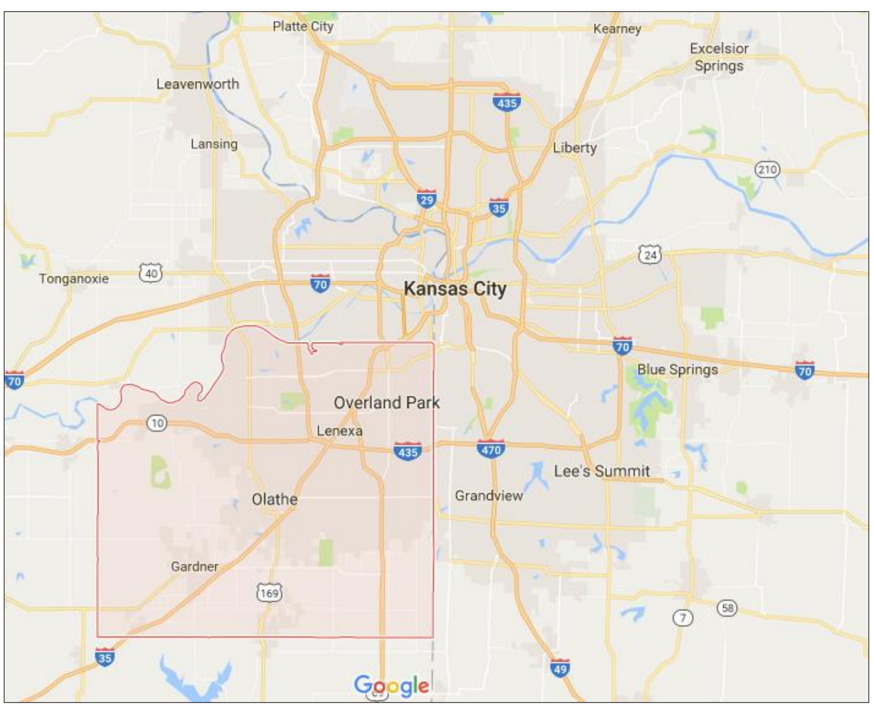

Figure 3. Map indicating the location of Johnson County, Kansas (county outlined and shaded in red).

	Severe or potentially severe storms approaching Johnson County within Tier 1 counties (green)	Severe Thunder-storm Watch issued for Johnson County	Severe or potentially severe storms approaching Johnson County within Tier 2 counties (yellow)	Severe storms in counties under a tornado watch are approaching Johnson County within Tier 2 counties (yellow)	Tornado Watch issued for Johnson County or a Tier 3 county (amber)	Storm systems producing tornado warnings are approaching Johnson County and within Tier 2 counties (yellow)	Tornado Warning issued for Johnson County or a Tier 3 county (amber)
Decision to activate is up to Duty Officer judgment	X	X					
Monitor weather from EOC			X[1]	X	X	X	X
ECS actiivation				X[2]	X[2]	X	X

1. Day 1 Tornadic Outlook is ≥ 5% for the county per the SPC Outlook
2. At the DO's discretion

The counties in the amber ring are Tier 3

The counties in the yellow ring are Tier 2

The counties in the green ring are Tier 1

Figure 4. Johnson County, KS Emergency Management Duty Officer Matrix.

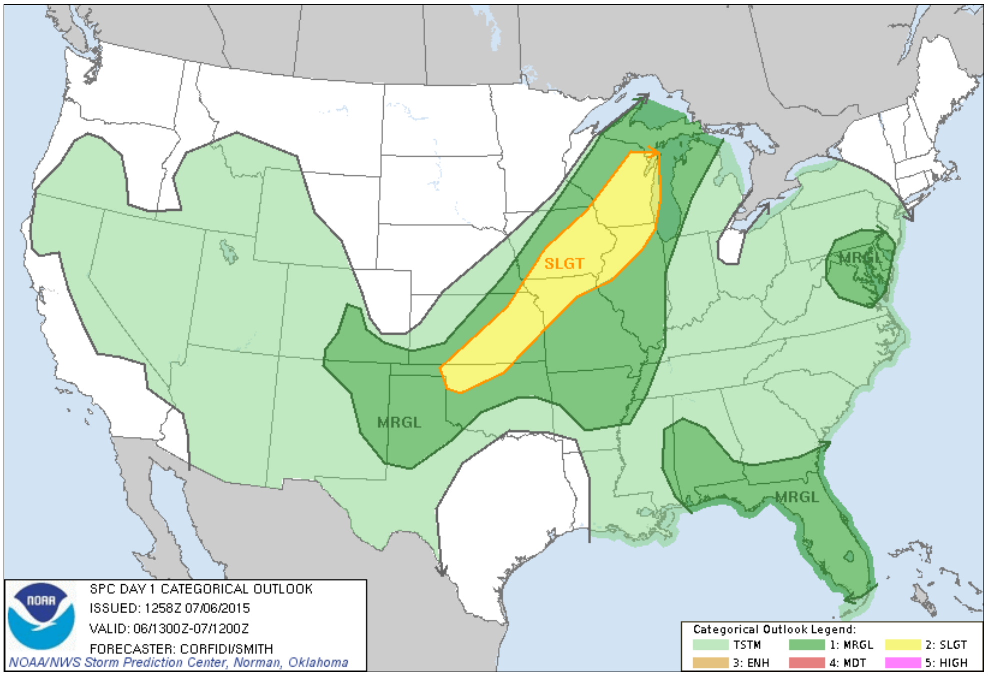

Figure 5. SPC Day 1 Convective Outlook, issued at 1300 UTC on 6 July 2015.

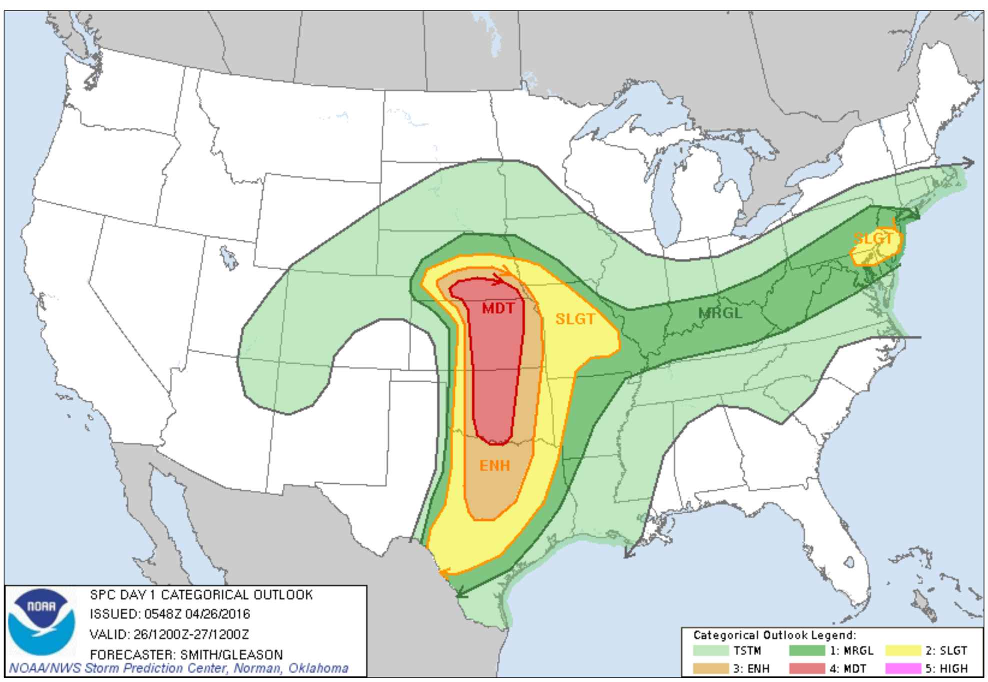

Figure 6. SPC Day 1 Convective Outlook, issued at 0600 UTC on 26 April 2016.