NWS Operations Proving Ground

Operational Evaluation Report

Connecting Expert Mesoanalysis to Enhanced Collaborative Severe Weather IDSS

An OPG-SPC Proof-of-Concept Experiment

NWS Operations Proving Ground
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EXECUTIVE SUMMARY

The importance of skillful mesoanalysis is becoming increasingly critical. The high levels of precision and accuracy necessary to accomplish the NWS's mission of life and property protection require the integration of complex, physical-sciences-based conceptual models rooted in mesoscale meteorology, with cutting-edge, high-resolution data sets -- such as GOES-16/17 imagery, WSR-88D MESO-SAILS data, MRMS, and hourly output from convection-allowing mesoscale models. These data sets are creating new opportunities for NWS forecasters to provide unprecedented forecast precision and enhanced short-term IDSS, and excel in accomplishing the agency's mission. This capability supports the NWS goal to transition its traditional product-centric, schedule-driven operating model, and begin exploring ways to provide a continual flow of actionable information leading up to, and during, rapidly evolving, high-impact events -- as envisioned by the FACETs framework.

In response to these opportunities, the NWS OPG - in collaboration with SPC and a team of recognized subject matter experts - planned and conducted three week-long proof-of-concept experiments in 2019, aimed at assessing the value of incorporating a dedicated mesoanalyst into high-impact convective event operations. Specifically, these workshops evaluated the viability of expert mesoanalysis to enhance intra-office communication; enrich SPC-WFO collaboration; translate insights about the evolving mesoscale environment into precise, tactical IDSS messaging; provide intelligent triage for warning forecasters; and ultimately enhance our capabilities in meeting the NWS mission of saving lives and property. In total, the evaluations included 30 WFO forecasters and a professional emergency manager. Each session was facilitated by the OPG staff and two to three SMEs.

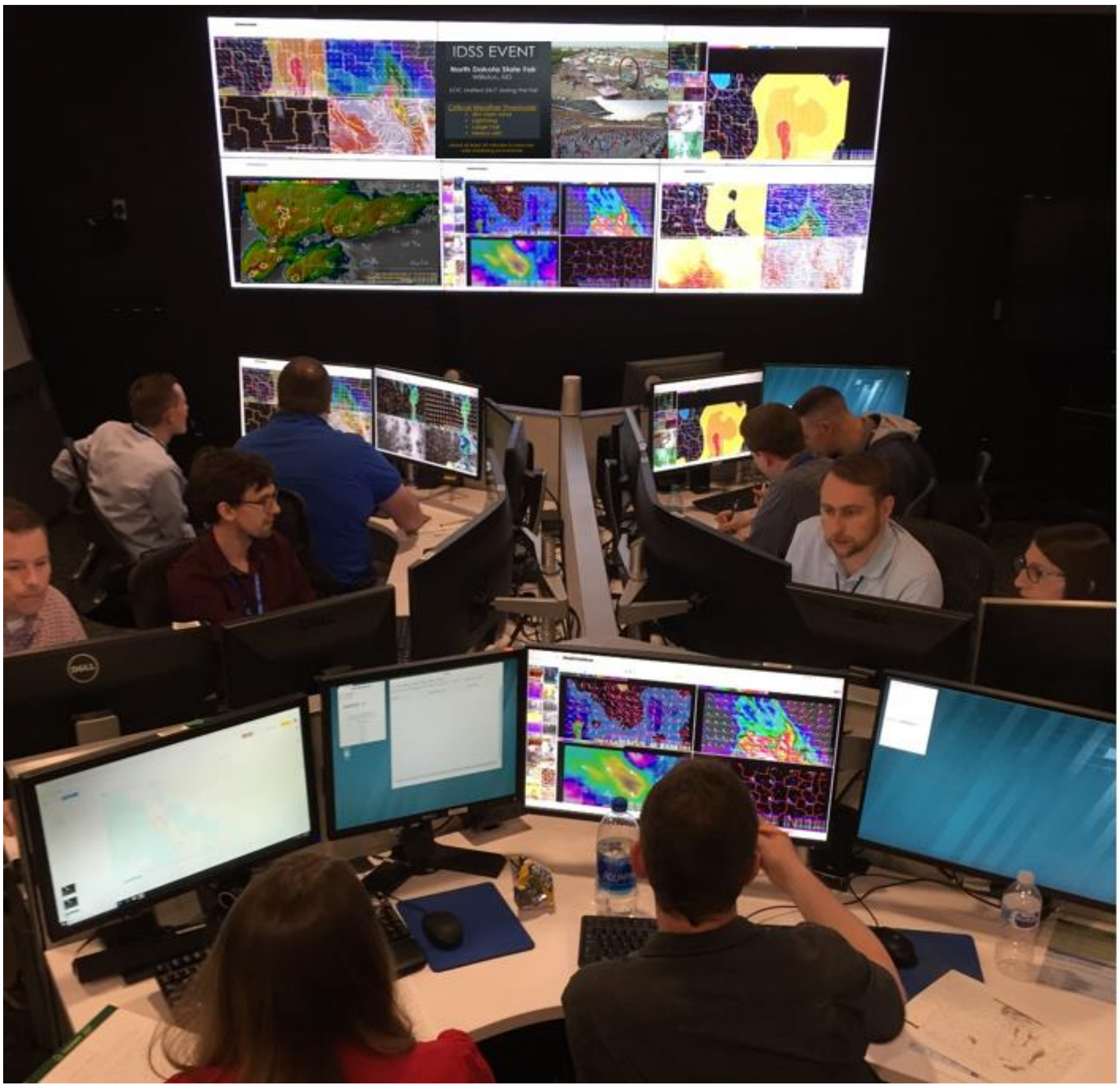
The enclosed report articulates the background, process and results of those evaluations in detail. Nine findings and recommendations emerged from the experiments, largely drawn from participant feedback. All nine findings, and their accompanying recommendations, are revealed in the body of the report with supporting context. However, for convenience and expedience, the entire list can also be found - isolated from the corroborating data and opinions - in Appendix 1.

All 30 participating forecasters shared the opinion that many aspects of NWS service delivery could be significantly enhanced if every WFO had the capacity to integrate the level of mesoanalysis, intra-office communication, and subsequent tactical IDSS messaging practiced during these mesoanalyst workshops. One forecaster went so far as to state, *"Bottom line: more lives would be saved if we could routinely and effectively integrate what we did here at the OPG into our WFO operations."*

At the same time, many expressed concern that few forecasters in their respective offices possess the expertise to perform the role proficiently at this time. In their opinion, a significant training effort will need to be undertaken to address this knowledge/skill gap. Ideas for both short-term and long-term solutions to this problem are outlined in this report.

Among its many advantages, skillful mesoanalysis enhances situational awareness and threat assessment; enables more accurate anticipation/prediction of convective initiation, mode, and hazards; leads to a positive impact on overall warning performance; contributes to precise, tactical IDSS messaging in the temporal gap between watches and warnings; and can bolster healthy culture by allowing people to operate in their strengths. Moreover, some of the lessons learned in investigating the application of mesoanalysis for convective events can be transferred to other service sectors: fire weather, marine weather, aviation weather, winter weather, etc.

Therefore, it is the unanimous opinion of the OPG staff, the workshop facilitation team, and all 30 forecasters who took part in these experiments that the NWS continue to invest in the development and application of these skills in WFO operations. It is, in fact, our strong belief, that the adoption of a dedicated mesoanalyst as part of a WFO's Severe Weather Operating Plan is the cornerstone for achieving an effective Collaborative Forecast Process for severe convective weather services, thus advancing our shared goal to build a Weather-Ready Nation.



Forecaster teams collaborate on a severe weather IDSS messaging task during an immersive displaced real-time (DRT) simulation case at the June 2019 OPG-SPC Mesoanalyst Boot Camp experiment.

1. BACKGROUND

The near-real-time availability of diverse high-resolution data sets is both advantageous and problematic for operational forecasters. For convective events alone, operational forecasters are presented detailed information about the state of the atmosphere from an unprecedented array of tools and technology. Examples include GOES-16/17 satellite imagery, WSR-88D dual-polarization radar data (especially MESO-SAILS), Multi-Radar/Multi-Sensor System (MRMS) products, hourly output from convection-allowing mesoscale models, probabilistic decision aids such as the NOAA/CIMSS ProbSevere Model, hourly objective analysis graphics from the Storm Prediction Center (SPC), guidance from the Statistical Severe Convective Risk Assessment Model (SSCRAM), and more. Simultaneously, the cadence of these myriad data inputs amplifies the potential for forecasters to miss or overlook critical information. The essential challenge, then, lies in determining which data are of primary importance and knowing how to mine those data to improve urgent warning and forecast decisions.

National Weather Service (NWS) forecasters participating in various evaluations at the NWS Operations Proving Ground (OPG) have suggested this challenge is best addressed by elevating the importance of expert mesoanalysis on the convective warning team. This is especially true in complex environments and scenarios characterized by rapidly evolving convective modes. In addition to enhancing warning performance, we at the OPG believe expert mesoanalysis could form the foundation for innovative services in the temporal gap between watches and warnings - a period ripe for capitalizing on our Weather-Ready Nation goal of conveying a continuum of free-flowing information aimed at assisting “deep relationship core partners” in preparing for, and potentially taking actions to mitigate, the impacts of hazardous weather.

The number of NWS Science and Operations Officers (SOOs) who support the idea of reinvigorating the mesoanalyst role has continued to grow in the recent past. Their assertion is this: If a Weather Forecast Office (WFO) forecaster has the ability to effectively synthesize knowledge of the evolving mesoscale environment, along with an understanding of core partner decision thresholds, that skill would enable an invaluable service enhancement – namely, timely advance notice of precise, actionable information to risk management professionals.

According to many of these SOOs, success in this endeavor is dependent on two prerequisite conditions:

(1) Ensuring that forecasters who perform the mesoanalyst role are equipped with a deep understanding of the conceptual models that link these high-resolution datasets to the assessment of potential impacts emanating from hazardous convective weather; and
(2) Ensuring that the mesoanalyst role is assigned as a dedicated position when Severe Weather Operating Plans (SWOP) are activated in preparation for high-impact events.

The second condition above arises from the fact that many field forecasters have indicated the mesoanalyst role is sometimes assigned as part of their SWOP, but often underutilized, or even compromised, by expecting an individual to fulfill it as one of several designated tasks during a severe weather episode.

Beginning in 2017 and 2018, the OPG staff took action to address these stated needs and opportunities. Several noted subject matter experts (SMEs) were invited to participate in a Mesoanalysis Think Tank in February 2018, to identify core science principles necessary for performing effective mesoscale analysis, optimal data sets to exploit for insight, and operational best practices deemed useful for building proficiency and maximizing efficient operations. That group, which included representatives from several field offices and the Storm Prediction Center (SPC), convened again in the summer of 2018 to sketch out initial plans for simulation cases to be used in a workshop for forecasters. The full roster of the Mesoanalysis Think Tank team is included in Appendix 2.

Workshop details continued to be refined through the winter of 2018-2019. The team devoted well over a thousand hours collecting data, building exercises, compiling prerequisite materials, even filming and editing video lectures, which were made available as teaching aids and "train the trainer" resources. Links to many of those resources are provided in Appendix 3.

By spring of 2019, the team was ready to conduct a series of intensive, week-long immersive simulation experiences that came to be known colloquially as "Mesoanalyst Boot Camps." These interactive workshops focused on evaluating the application of expert mesoanalysis for three specific, interrelated operational benefits:

- improving situational awareness of the evolving pre-storm and near-storm environment among Weather Forecast Office (WFO) warning team members;
- using that insight to anticipate and communicate clear, precise information to emergency managers, community leaders, and other decision makers on the Integrated Warning Team (IWT); and
- enhancing collaboration – both within the office, as well as between WFOs and the SPC.

The value proposition of achieving these gains was measured against potential negative factors, such as staffing requirements, knowledge/skill gaps, workload burden, and other possible obstacles to operational implementation. Appendix 4 contains a generic agenda, with dates and details about the simulation cases removed (since some of those cases may be used again).

2. WORKSHOP PARTICIPANTS AND EVALUATION METHODOLOGY

Thirty evaluation participants were selected by committee from 101 applicants. All candidates were required to obtain supervisory endorsement before applying. The applications, comprised of five short-answer essay questions, were initially screened via blind assessment (i.e., names and WFO affiliations were omitted). The Top 50 were then evaluated with names and home WFOs appended, so that adjustments could be made to achieve a more balanced diversity of representation with respect to gender, region, office, and position.

Participants completed approximately 12 hours of prerequisite materials designed to establish a baseline knowledge of fundamental governing principles and operating practices. These foundational prerequisites were reinforced during the first two days of the workshops, with extensive instruction and hands-on exercises that enabled participants to solidify their familiarity and comfort with knowledge, skills and tools they would be expected to employ during simulations. Instructional session topics included:

- Skew-T/Hodograph Analysis
- Effective Inflow
- Parametric Calculations for Select SPC Mesoanalysis Fields
- Storm Motion and Evolution
- Convective Mode Transitions
- Perturbation Pressure Theory
- Review of the “Forecasting Organized Severe Storms” (FOSS) Video Lecture Series
- Satellite Applications for Convective Mesoanalysis and Short-Term Forecasting
- Convection-Allowing Models (CAMs) and CAM Ensembles
- Pre-Constructed AWIPS Bundles Useful for Diagnostic Purposes
- Use of SSCRAM and Experimental SPC Products
- Tutorial on the AWIPS PGEN Tool

SPC Lead Forecaster Rich Thompson and OPG SOO Matt Foster discuss the mesoscale environment with forecasters (foreground), while Ariel Cohen asks another team of forecasters about their current thinking (background). Several participants credited these impromptu interactions with subject matter experts with enhancing their learning experience during the mesoanalysis workshops at the OPG.

The centerpiece of the experiments consisted of four simulation cases, conducted in displaced real-time (DRT) on the Advanced Weather Information Processing System (AWIPS) platform. Working these historical cases allowed forecasters to practice convective mesoanalysis and Impact-based Decision Support Services (IDSS) messaging skills for a variety of convective modes across the temporal spectrum from a few hours before watch issuance, through convective initiation, to warning operations. Each simulation took place over a period of 3-4 hours, and each was accompanied by required support for at least one, and up to three, IDSS events. Forecasters worked in pairs to complete assigned tasks and interact with partners as appropriate.

Tasks included composing and disseminating mesoscale Area Forecast Discussions (AFDs), creating targeted IDSS graphics for social media, responding to partner requests in NWSChat, collaborating with SPC on watch issuance, providing briefings to an Emergency Management (EM) partner, and offering advice to the radar operator. During each simulation, assigned tasks were augmented by impromptu interactions with SMEs, facilitated group discussions, and feedback from participating collaborators and core partners. Feedback was also collected from the participating forecasters themselves – both formally (written end-of-week surveys) and informally (debrief sessions following each case and at the end of the week).

Performance metrics were established to assess forecasters' abilities to proactively anticipate convective hazards via mesoanalysis procedures, and their corresponding skill at messaging associated threats with enhanced spatiotemporal precision. Assessment categories included:

- Accurately assess environment and predict convective mode
    - *Measured by SME-led verbal evaluations in simulations*
- Accurately identify local areas where initiation of sustained deep convection will occur in the short term
    - *Measured by SME-led verbal evaluations and facilitator-assessed informal presentations by participating forecasters during simulations*
- Apply sound meteorological reasoning to identify hazardous weather types and communicate associated impacts with spatiotemporal accuracy and precision
    - *Measured by SME-led verbal evaluations and facilitator assessments of Mesoscale AFDs and/or informal discussions with participating forecasters*
- Clearly and concisely communicate the aforementioned phenomena in the form of Enhanced Short-Term Weather Outlooks that can be disseminated in the form of Situation Reports and social media posts
    - *Measured by facilitator-assessed graphics and Situation Reports prepared by participating forecasters*
- Correctly anticipate and adjust forecast information and messaging to account for changes in convective threats during event evolution, including the use of probabilistic information to convey likely and reasonable worst-case scenarios, as well as confidence
    - *Measured by SME-led verbal evaluations and facilitator-assessed informal presentations by participating forecasters during simulations; and by facilitator-assessed graphics and situation reports prepared by participating forecasters*
- Engage in collaborative information-sharing within the NWS integrated field structure, internal team members, and deep-relationship core partners in conveying a continuous flow of information.
    - *Measured by facilitator-assessed interactions among participants engaging in collaborative thought processes to craft unified science understanding and timely, actionable hazard messaging*

As stated above, participants completed written surveys at the conclusion of each week. The surveys contained 14 questions – 3 Likert Scale, 11 short essay (2 of them optional). Content of those surveys were gathered via anonymous Google forms. Summaries and common themes are outlined in the RESULTS section. The 14 questions posed to participants are listed in Appendix 5. If NWS management desires a more detailed review of survey results, the complete set of responses can be provided upon request.

In addition to the formal surveys, a final debrief was held on Friday morning of each session, consisting of a series of seven planned group discussion questions (see Appendix 6), followed by open-ended discussion of any topic the group wished to raise, related to their experience during the week and/or ideas about the adoption of these practices in operations. Topics included concerns associated with support or resistance, training needs, and thoughts about staying connected as a cohort, to share tools, successes and challenges after returning home. These discussions were not recorded but facilitators captured the main ideas in notes and on flip charts.

Simulations included assigned tasks, such as Mesoscale AFDs, IDSS messaging, SPC collaboration calls, and EM briefings. In this photo, forecasters share thoughts about potential impacts on an IDSS event with WDTD instructor Jim LaDue (standing).

3. RESULTS – KEY PARTICIPANT LESSONS AND INSIGHTS

A. Practical Operational Value and Alignment with Strategic Goals

All 30 participants shared the opinion that many aspects of NWS service delivery could be significantly enhanced if every WFO had the capacity to integrate the level of mesoanalysis, intra-office communication, and subsequent tactical IDSS messaging practiced during the Mesoanalyst Boot Camp (MBC) workshops. In fact, to describe the value of expert convective mesoanalysis, forecasters used phrases such as *"crucial to operational success", "extremely valuable both before onset and during the event", "incredibly beneficial", "critical in warning operations",* and *"absolutely essential",* among other comments.

Working through the simulation cases underscored this value at every phase of the convective life cycle. Prior to the initiation of deep convection, effective mesoanalysis can reveal insight as to when and where thunderstorms might form, often within a few counties. Capitalizing on this capability enhances the work of SPC by narrowing the focus of regions in which conditions favor the development of severe storms. Advance notice of information with this level of precision could allow EM partners to activate safety plans or initiate important resource allocation decisions with sufficient lead time to mitigate serious impacts. Once a convective event is underway, a skilled mesoanalyst can communicate insights gleaned through careful "met watch" of observational data to the entire operations team, thereby enhancing overall situational awareness and assisting with high-quality warning decision-making.

Failure to apply this concept has already been noted as a shortcoming in a number of formal post-event inquiries. Consider, for example, this comment from the 2006 Rogers, MN Service Assessment: *"The team believes two meteorologists assigned to analyze the information for the Rogers area would have been ideal, one to analyze all radar data, the second to assist with radar data interpretation, coordinate information, and evaluate environmental parameters. In addition to not having a second meteorologist to assist, the warning forecaster assigned to the Rogers sector entered the situation without knowing the details of the thunderstorm's evolution. This limited the forecaster's ability to assess trends (Recommendation 2)."*

The Rogers recommendation, referenced above, testifies to a longstanding recognition of significant, quantifiable benefits associated with assigning a second person to the task of maintaining and communicating situational awareness with the warning team. These benefits are amplified today with the availability of GOES-16/17 imagery and other high-resolution data. Through the continuous flow of environmental insight from a qualified mesoanalyst to the IDSS desk and even to the radar operator, the WFO is better positioned to provide ongoing updates on evolving risks and vulnerabilities to our partners, which then enables them to enact action plans in a timely manner. Ultimately, this information-centric operating concept is the defining precept of the *Forecasting a Continuum of Environmental Threats* (FACETs) framework.

FINDING 1: Skillful mesoanalysis, coupled with proactive communication, has the potential to enhance multiple aspects of NWS service delivery, ranging from tactical IDSS messaging to improved warning performance. It is arguably the cornerstone for advancing the NWS business model toward the FACETs paradigm, a strategic goal of the "Evolve NWS" initiative. Further, by enhancing our ability to accurately diagnose environments conducive for tornado development, the mesoanalyst's contribution toward collaborating with the radar operator to refine the timeliness and accuracy of warnings is aligned with the stated goal of the Tornado Warning Improvement and Extension Program (TWIEP) from the Weather Research and Forecasting Innovation Act of 2017 (a.k.a. The Weather Act).

RECOMMENDATION 1: NWS WFOs should adopt the practice of assigning a dedicated mesoanalyst in situations where convective development is imminent and associated hazards could reasonably be expected to pose a significant public safety threat. A skilled mesoanalyst can take the lead in assuring accurate situational awareness is maintained, communicating important details concerning short-term clues about the evolving near-storm environment, providing input to IDSS messaging and/or mesoscale informational updates - even advising the radar operator concerning environmental developments that result in improved timeliness and quality of warnings. The continuous flow of information - both internally and externally - that characterizes this operating concept is aligned precisely with the FACETs paradigm.

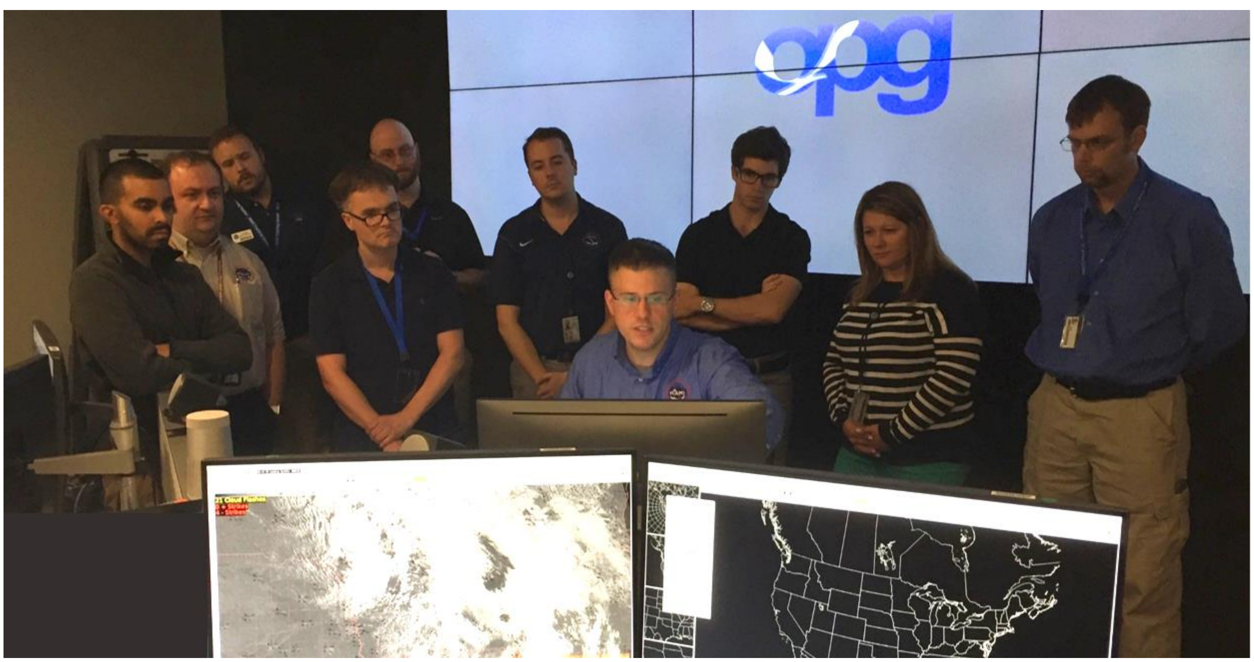
The "Evolve NWS" initiative, led by the Program Management Office (PMO), has been focusing significant effort to help the agency build a Weather-Ready Nation (WRN). One of the highest priority goals of "Evolve NWS" is to implement a mature and efficient collaborative forecast process (CFP). This effort is aimed at improving the usefulness and usability of our core products and services by ensuring our forecasts are reliable, accurate and consistent, which in turn, will strengthen our ability to save lives, protect property, and enhance the national economy. The CFP project has initially focused on the synoptic scale, driven by usage of the National Blend of Models as a common starting point. However, potential benefits of a CFP extend to other service sectors as well, including those arenas for which collaboration on the mesoscale is critical to understanding and messaging impending hazards. Adoption of a dedicated mesoanalyst as part of a WFO's SWOP is the key to this evolution in the realm of severe convective weather services. The benefits associated with precise, tactical IDSS messaging; improved warning performance, and the enabling of richer, more meaningful collaboration between SPC and affected WFOs, would justify investing in the development and implementation of this concept.

B. Knowledge/Skill Gap

The majority of forecasters who participated in the OPG proof-of-concept experiment stated that the diagnostics and predictions they learned to perform during MBC simulations were far more intricate and demanding than what passes for mesoanalysis at most forecast offices today. These forecasters, while supportive of the need for expert mesoanalysis, expressed concerns over whether there are enough people at their respective WFOs to fulfill the role proficiently. One forecaster wrote, *"One of the biggest deterrents [to the adoption of the mesoanalyst role] in my office is the disparity in knowledge between different meteorologists. The ideal solution would be* *for several others from my WFO to go through this mesoanalysis boot camp."* Forecasters who shared this opinion agreed that a significant effort will need to be undertaken to establish baseline knowledge of the core physical processes and conceptual models governing convective threat assessment before these practices can be expected to become integrated into operations effectively.

FINDING 2: There are fundamental theoretical principles and concepts that must be understood in order to build the skills necessary to perform expert mesoanalysis in WFO operations. Training will be required in order to build the knowledge and skills needed to perform the level of mesoanalysis that was taught and practiced at the OPG.

RECOMMENDATION 2: Prioritize development of resources and methods aimed at sharing knowledge of the core concepts, tools, and practices connected with skillful mesoanalysis. Resources developed by the Mesoanalysis Boot Camp facilitator team serve as an excellent starting point (see Appendix 3). A variety of forms could be employed to supplement and build upon these materials, including hands-on exercises, webinars, blog posts illustrating operational application for specific cases, interactive quick guides available within AWIPS as just-in-time reminders, and more. Participants were strongly in favor of the MBC experience being formalized into a regular training course, and the OPG has conveyed this suggestion to the NWS Chief Learning Officer (CLO). It is certainly possible such a course could be blended into the recurring cycle of Office of the Chief Learning Officer (OCLO) in-residence offerings, but ultimately that decision will be subject to competition with other priorities and budget constraints.



WFO Miami SOO Ariel Cohen (seated center) leads a post-exercise debrief. These group discussions were held at the conclusion of each case to reveal verification, assess team decisions, and address questions.

Two particular items are worth specific mention for interested SOOs and/or forecasters who desire practical instruction on the concepts emphasized in the OPG experiments. First, the "*Forecasting Organized Severe Storms*" series is available, both on the NWS Training Center YouTube channel and on the Commerce Learning Center. Those videos offer an excellent summary of the lectures that Dr. Ariel Cohen delivered during the MBC workshops. Second, there is a rich collection of content posted on the SPC website, composed of 91 lectures, primarily delivered by Ariel Cohen and Rich Thompson, as part of a University of Oklahoma convective forecasting course. Links to all of these resources, as noted earlier, are provided in Appendix 3. Additional ideas for enabling forecasters to build and maintain proficiency will be shared later in this report (Section 3.G. - *"Stopgap Measures for Interim Training and Alternative Service Provision*").

C. Proactive Mentality

One of the primary goals established by the original Mesoanalysis Think Tank was to inspire a mindset change for WFO forecasters who participated in the workshops. Numerous forecasters have observed that during rapidly evolving convective events – and especially when serving as the radar operator/warning forecaster - it is easy to become hyper-focused on radar structures and lose situational awareness of the near-storm environment. This sometimes results in falling behind and chasing new developments. When another forecaster, skilled in convective mesoanalysis, teams up with the radar operator, that problem is minimized. Someone is taking responsibility to communicate observations about the evolving boundary layer, anticipate new development, and provide triage for the radar operator, so that he/she knows which storms to interrogate first and most carefully. At least seven of the thirty MBC participants explicitly expressed appreciation for the value of being forced to commit to a prediction of what the radar is going to look like in an hour, and communicating that insight to both teammates and core partners – a task that was included in each of the four simulation cases.

Many forecasters also noted a renewed appreciation for the value of satellite analysis, not only as a tool to diagnose the current state of the atmosphere, but in making confident, proactive short-term predictions and crafting IDSS messaging about expected threats. One forecaster summed this up well in an end-of-week survey: *"I never fully appreciated the wealth of information to be gleaned from GOES imagery and surface obs. The ability to identify boundary layer features that play a key role in storm initiation, mode, and development; features like billow clouds that yield critical information about static stability and low level shear… Smart display arrangements and data fusion techniques can facilitate better communication and better decisions. I've taken dozens of hours of on-line courses…none of them demonstrated the utility of various spectral bands, RGBs, and other products as effectively as this workshop."*

A few participants also expressed the opinion that reliance on convection-allowing models (CAMs) for decisions related to local severe weather potential is becoming commonplace. This experience solidified their view that such reliance, while expedient, is somewhat irresponsible and arguably dangerous. One of the participants stated, *"I've noticed that many forecasters have developed a very bad habit of not questioning the outcome of CAMs in light of what's actually happening."* It is easy to understand why mesoscale model predictions of radar reflectivity can be enticing, but they can be misleading for a variety of reasons. It is extremely important to understand the strengths and limitations of high-resolution models, and to appreciate the fact that the state of the science does not permit us to substitute the use of CAMs for careful, conscientious assessment of the mesoscale environment through continuous monitoring of observational data.

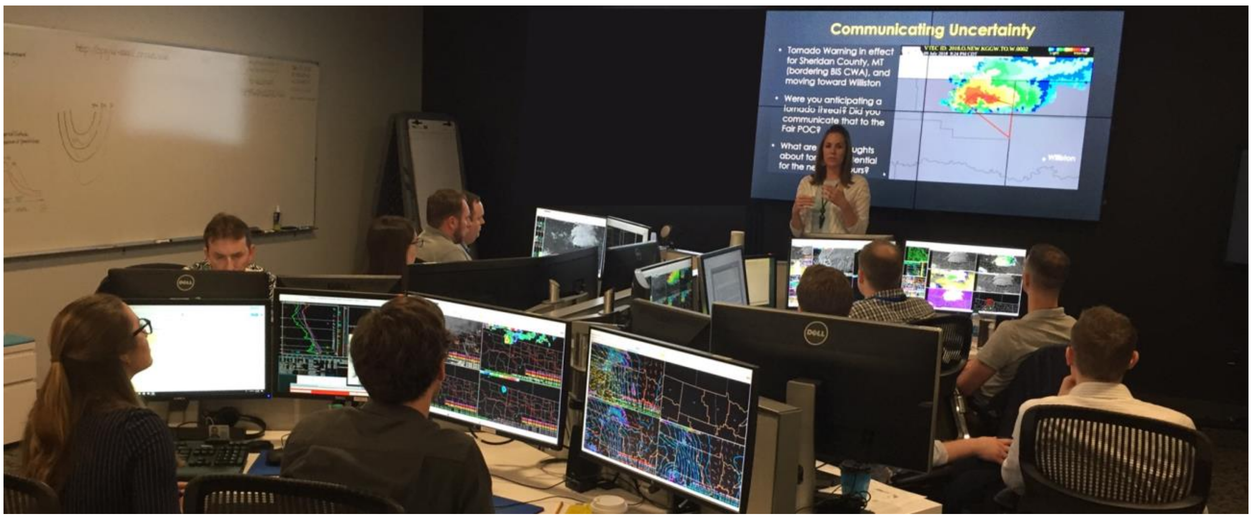
One forecaster identified this as a major personal take-away from the mesoanalysis workshop experience: *"I have a far greater understanding of how to integrate data from multiple sources (satellite, surface obs, soundings, SPC graphics), compare that information to conceptual models, and formulate an idea about the most likely convective mode and storm evolution for myself – before even looking at CAM solutions."*

FINDING 3: Skillful mesoanalysis facilitates developing the habit of integrating careful diagnostics with conceptual models and formulating an idea of convective evolution before consulting output from high-resolution, convection-allowing models. Foreseeing a spectrum of possible scenarios in advance can prevent forecasters from focusing on a particular outcome, leading to a reactive mode of operation once a convective system evolves differently than what was originally expected. This anticipatory mindset enhances all aspects of convective forecasting, from providing valuable insights to core partners via tactical IDSS to feeding critical near-storm environment information to the warning decision maker.

RECOMMENDATION 3: Reemphasize the importance of starting the forecast process with a comprehensive analysis and an initial formulation of the significant forecast elements before consulting high-resolution model solutions. For convective events, this entails determining the most likely timing and location of convective initiation; mode, intensity, and associated hazards; and potential for mode transition as the storm system evolves. This practice will strengthen a forecaster's ability to compare numerical model output against his/her own conceptual model, assess differences in solutions, and make better decisions about whether a particular depiction is consistent with the current and expected environment.

D. Use of Probabilistic Information

One of the secondary goals of the mesoanalysis workshops was to ascertain forecaster comfort with the use and communication of probabilistic information. To gauge this, several forms of probabilistic information were introduced during the sequence of simulation cases. These inputs included relatively straightforward practices, such as the conversion of probabilities to SPC severe weather threat categories, as well as more complex tasks, such as assessing and communicating evolving probability density functions (PDFs) as a weather event unfolds. In the end-of-week survey, one forecaster shared, *"Learning how to use the PDF approach to think about and show a range of outcomes was one of my top take-aways from the week."* That same forecaster went on to say, *"It's still a real challenge because almost no two situations are identical, but one has to be actively thinking about that spectrum, be able to tweak it as an event develops, and convey that in a simple means by voice, text, or graphic."* Forecasters were also afforded the opportunity to use and share insights about the use of short-term ensembles to determine confidence and potential outcome ranges. In addition, participants were given training and practice in the use of output from the SSCRAM for statistical context and guidance in severe weather threat assessment. While opinions were varied, in general, forecasters and our EM partner alike found some degree of value in synthesizing observational and statistical data with numerical guidance to formulate and convey envelopes of possible outcomes. However, most participants had received little training in the fundamentals of ensemble modeling, the development and interpretation of calibrated probabilities, or best methods for displaying and communicating such information. Finding 4 reinforces the need to invest in that knowledge, in order to facilitate a transition from focusing on the latest deterministic model runs toward effective use of probabilistic space in the forecast process.



Assessing and communicating uncertainty was addressed in multiple ways during the experiments. Here, Jenni Pittman (WFO Topeka SOO) discusses techniques for communicating uncertainty as it relates to one of the DRT cases. Increasingly, NWS core partners seek information that enables them to plan for reasonable worst case scenarios, in addition to mitigating risks associated with the most likely threats.

FINDING 4: Determining and communicating the risk of severe weather lends itself well to the introduction of probabilistic information. Considerable work needs to be done to resolve the best tools, methods, and display formats, but forecasters found value in synthesizing observational, statistical, and predictive data to formulate and convey envelopes of probability concerning a developing severe weather threat.

RECOMMENDATION 4: The NWS should invest in a concerted effort to identify tools and methodologies for illustrating and communicating the most useful portions of a pending weather event's probability density function (PDF). Deterministic forecasts are still the norm but there is increasing interest in the use of probabilistic information - and especially the development of calibrated probabilities - for crafting and communicating weather-related threats. The awareness that there is always some degree of uncertainty in weather forecasting, and thus a range of possible outcomes, reinforces the value of providing additional data to NWS core partners that informs critical decisions related to preparation, mitigation, recovery, etc. For example, the PDF is an excellent vehicle to conceptualize and message a situation for which the reasonable worst-case scenario involves significant

impacts to public safety, but its occurrence is characterized by high conditionality/low predictability. The Emergency Manager who participated in MBC (Johnson County, Kansas EM Trent Pittman) acknowledged such information could be extremely useful to him for creating "Plan B strategies" and other preparedness activities.

E. Organizational Culture

In order to build sufficient support and momentum for this practice to become an integral part of NWS operations, it will be as important to pay attention to the culture change challenge as it is to the proposed business model adjustments. During each of the experiments, many comments were made alluding to the fact that successful implementation of the paradigm shift we were promoting would be nearly as dependent on the local office culture as on the application of physical science concepts. The participants themselves were unanimous in their personal support of assigning the mesoanalyst as a dedicated role for high-impact events in their home WFOs. Some were confident that there would be strong support from their co-workers, but many were less optimistic. In fact, survey opinions were nearly split in half between those who anticipated excitement and those who expect a substantial degree of resistance (see Figure 1). Reasons stated for the projected pushback included: protracted staffing shortages; workload; a lack of urgency to change current practices that are deemed to be adequate; training requirements; and, in some cases, a perceived lack of managerial support.

Forecasters shared a number of specific ideas to ensure commitment to this paradigm: direction and support from management; a concerted effort to provide training to forecasters who are interested in developing these skills; examples of successes resulting from its application and failures that can be attributed to NOT employing it; and ideas for alleviating the challenges associated with staffing and workload. It should be noted that the imposition of additional workload was not a unanimously-held opinion. In fact, two forecasters expressly argued that mesoanalysis actually reduces workload if performed effectively. Multiple participants shared the opinion that training in team building and communication are as important in their office environments as the need for technical training. One forecaster in particular stated, "*Effective communication is absolutely essential to successfully implementing what we practiced this week. Clear, specific, two-way dialog, with openness to others' ideas is so critical to making this concept work. Operating in this manner requires a rather high emotional intelligence. The way the facilitators led us through conversations and debates this week - sometimes with very different opinions - was very effective. That's not how we communicate in my office and I'm not sure how to cultivate that culture.*"

Numerous service assessments identify failings in the warning and forecast process owing to loss of situational awareness, data overload, and/or lack of communication. Cultivating an office culture characterized by openness to others' perspectives, frequent, proactive communication, and deliberate, frank engagement is absolutely essential if we are to overcome such failings in future assessments. This is primarily a management responsibility.

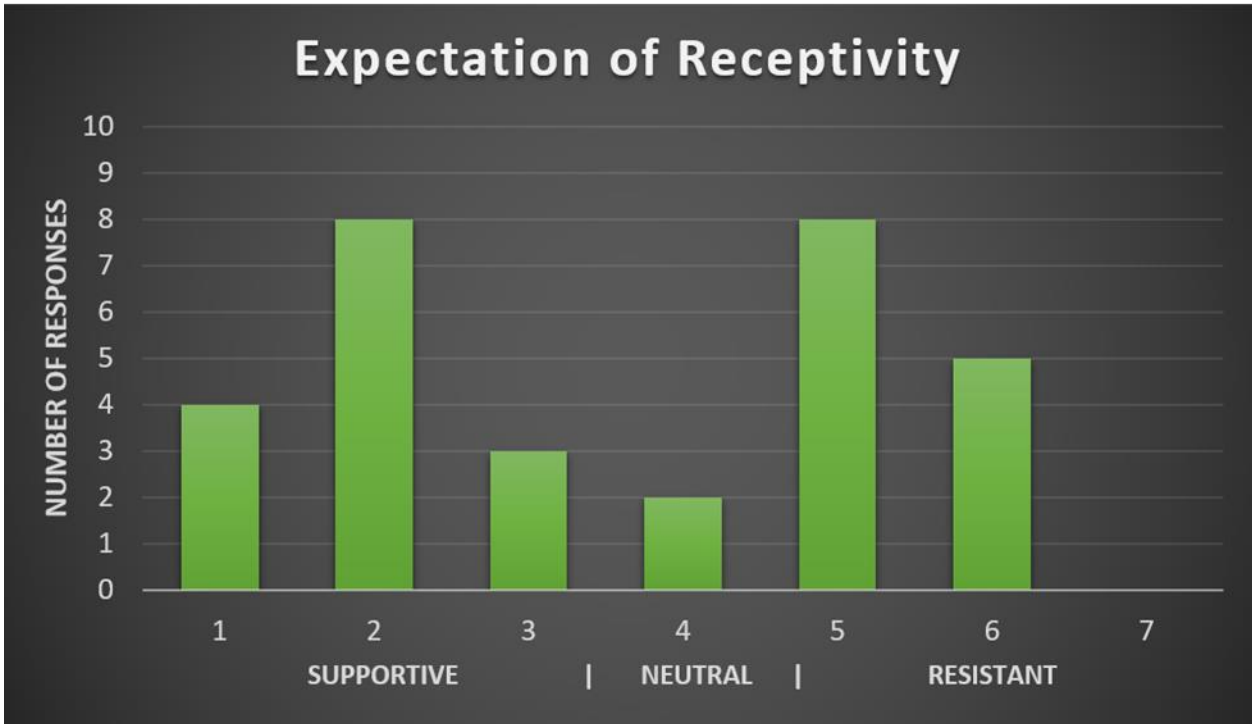


Figure 1 – Forecaster responses to the question: "What is your expectation about the receptivity of adopting the mesoanalyst operating concept in your office?" Responses are based on a 7-point Likert Scale (x-axis) with a value of "1" being "Most People Supportive" and a value of "7" being "Most People Resistant."

FINDING 5: While understanding the underlying physical science concepts is necessary for successfully implementing mesoanalysis in operations, it is also important to establish an environment where proactive communication is welcome and encouraged. Cultivating an office culture characterized by a general openness to others' perspectives, a continual exchange of ideas, and a deliberate engagement with stakeholders to learn what is important to them, is critical to translating skillful mesoanalysis into effective IDSS. This is particularly relevant given the fact that participants expressed a mixed mode of receptivity by their home staff to the idea of adopting the form of mesoanalysis taught and demonstrated at the OPG. This finding is consistent with internal NWS research (Smith, NWA 2017), which clearly demonstrated a positive correlation between healthy office culture and effective tornado warning performance. There is also a growing body of external research substantiating this point. In fact, there is significant evidence of a causal relationship between a healthy, engaged organizational culture and improved team performance (e.g., Pontefract, Forbes 2017; Miller, Emergenetics 2012; Chandy, Science Daily 2008). These results underscore the importance of addressing both behavioral and operational aspects of this change initiative.

RECOMMENDATION 5: In order to build sufficient support and momentum for this practice to become an integral part of NWS operations, it will be as important to pay attention to the culture change challenge as it is to the proposed business model adjustments. The ultimate success of changing an operating concept is dependent on healthy team chemistry. Thus, while it will be crucial to provide technical training in the skills associated

with mesoanalysis, it is equally important to devote time and attention to evolving office culture - especially in the areas of building trust, assuring a sense of belonging, reinforcing opportunities for each person to make meaningful contributions in the new process, and learning to communicate freely with an openness to productive conflict (i.e., debate over ideas not personalities). As a starting point, there are several excellent resources and best practices available on the NWS Office of Organizational Excellence "Culture Portal" to assist NWS managers in leading these critical efforts locally.

F. Mesoanalyst Activation Triggers

As shown in Figure 2, eighteen of the thirty forecasters rated the SPC probabilistic category of Marginal Risk as that which best characterizes the situation for which they would ideally activate a mesoanalyst in operations. (Eight actually considered General Thunder as a triggering condition, while only four selected Slight Risk. No one selected Moderate Risk or higher.) This, however, is NOT what typically prompts activation of an assigned mesoanalyst for most SWOPs. An informal survey of several dozen offices indicates some WFOs do not assign someone to mesoanalyst duties until a watch is issued. Some stated that they will assign the role before storms form if they are located within a Moderate Risk area. On a related note, even for those WFOs that are more proactive, the mesoanalyst is rarely the only duty assigned and it is not unusual for it to be among the first to be abandoned when the staff gets extremely busy.

Thus, while all 30 forecasters agreed that a mesoanalyst can add value to operations during events for which risk and confidence are high, a substantial majority (60%) concluded that it is the marginal events - those for which development itself may be in question, or mode and hazards are uncertain - where dedicating a qualified forecaster to the mesoanalyst role paid the highest dividends. Several reasons were provided to explain this conclusion. For instance, when SPC places one's County Warning Area (CWA) in Slight Risk or higher, those categories tend to heighten attentiveness and, in some cases, trigger the activation of supplemental staffing. However, it is more likely for staffing to remain unaltered by a Marginal Risk. In such cases, the accomplishment of routine production duties can sometimes interfere with maintaining the level of situational awareness needed to stay ahead of rapidly developing convection. Forecasters on duty will then find themselves more likely to be in reactive mode until such time that additional staff can be called in and spun up. As one forecaster plainly stated, *"The times mesoanalysis matters most are the times that the outcomes are conditional, potentially high-impact (even if localized) and not obvious."* Several other forecasters noted that the workshop simulations which featured subtle, nuanced conditions were the most challenging for them, underscoring this opinion.

It should be noted that not all marginal events are connected to equivalent public safety threats. As an example, a Marginal Risk for isolated 60 mph downburst winds associated with inverted-V profiles in the Southwestern U.S. may not require boosting staffing levels. However, preparations would be warranted for a Marginal Risk area in the Great Plains that includes the potential for isolated supercell tornadoes if convective inhibition can be overcome. Thus, we are not arguing for SWOP activation to include a dedicated mesoanalyst based simply on the classification of a Marginal Risk by SPC. Rather, that determination should be made with proper discernment about the conditional probability of significant severe convective weather hazards developing in the next several hours. Coincidentally, that determination is best made via the benefit of skillful mesoanalysis.

FINDING 6: The majority of OPG workshop participants held the opinion that, for convective events, mesoanalysis is often most valuable in situations where the threat of organized severe storm development is highly conditional, not necessarily for scenarios where the likelihood of a major, classical outbreak is high. Eighteen of the thirty forecasters (60%) rated the SPC probabilistic category of "Marginal Risk" as that which best characterizes the situation for which they would ideally activate a mesoanalyst in operations.

RECOMMENDATION 6: WFOs should build into their SWOPs a plan to call for augmented convective met watch staffing for situations in which the SPC categorical risk is "Marginal" or higher, AND the associated PDF includes hazards that could reasonably be considered life-threatening. Moreover - as many of the MBC participants stated - once assigned, mesoanalysts should not be burdened with additional responsibilities that would detract from their effectiveness.

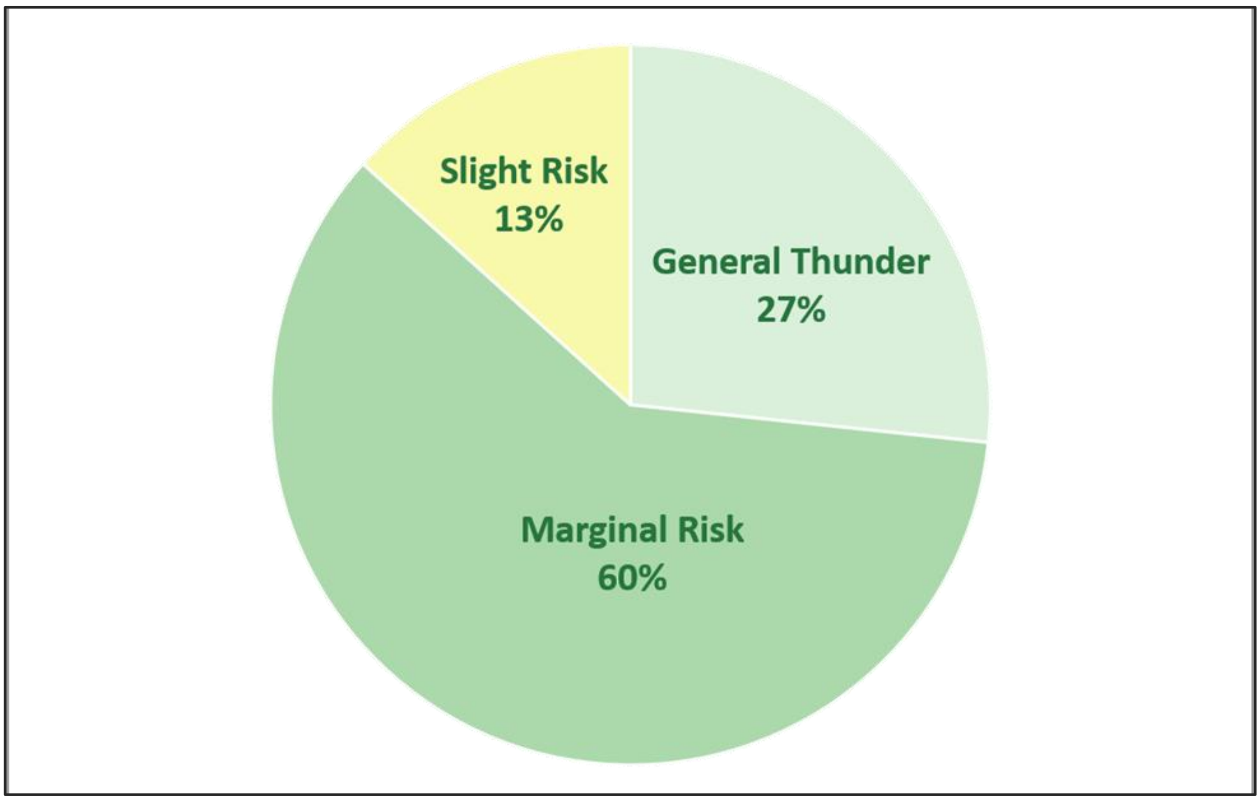


Figure 2 – Forecaster responses to the question: "At what SPC outlook category is a dedicated mesoanalyst necessary for effective situational awareness, IDSS, and warning operations?"

From a practical standpoint, it may be difficult for some offices to promote the practice of calling in additional people for events in which there is large uncertainty about the outcome, since it may be accompanied by unnecessary overtime costs. Regardless of the trigger point, forecasters were in strong agreement that the role of mesoanalyst is vital to maximizing success in a high-impact convective event. Analyzing, understanding, and communicating the evolving spectrum of threats is a valuable contribution to service.

G. Stopgap Measures for Interim Training and Alternative Service Provision

Most MBC participants held the opinion that few forecasters in their respective offices are properly equipped to perform the level of mesoanalysis taught and practiced during the MBC proof-of-concept experiments. They were not arguing that there is any lack of aptitude or interest, but rather that training and opportunity are needed to build proficiency and confidence in practice. Therefore, it is their opinion that a concerted effort must be made to develop formal training and, in the interim, to devise alternative methods for expanding the reach of this movement the OPG has initiated.

It is possible the NWS OCLO will see the need to develop a formal recurring training course, which integrates mesoanalysis skills into other offerings such as the Warning Decision Training Division's Radar Applications Course, Weather Operations Course for Severe Weather, etc. While the MBC team believes this should be a long-term goal, we also recognize that OCLO resources are finite and the development of future training is appraised against other competing priorities and available means.

There are several options to begin addressing this shortfall in the short term. One idea that the OPG is exploring is to facilitate "***Multi-Office Collaboration Exercises***." The practice of encouraging WFOs to free people up on benign weather days for partner visits, special project work, and training activities is growing in popularity (e.g., Central Region's "blue sky culture" or Western Region's "green days"). On a day like that, when routine production responsibilities can be handled by one forecaster, WFOs could coordinate with the OPG to conduct a pre-arranged simulation exercise designed to sharpen skills in mesoanalysis, tactical IDSS, and interoffice coordination. Under this construct, two or more offices could connect to the OPG AWIPS and work a facilitated case collaboratively from their own offices. If planned well enough, local EM partners could even be invited to participate. This method would reap some of the benefits of experiential training without the time and expense of traveling to the OPG for a week. In addition, multiple forecasters can participate in a job-relevant "learning by doing" problem-solving exercise. Finally, this approach would enable forecasters to become familiar with the functionality and capabilities of collaboration tools built into AWIPS.

Another idea for expanding the reach of the OPG experiments is to create "***Sub-regional Mutual Aid Teams***" for mesoanalysis and tactical IDSS support. Assume a WFO is expecting high-impact weather, and they would like to have a second set of eyes monitoring the near-storm environment but do not have anyone on staff available (or perhaps even capable) of dedicating themselves to the mesoanalyst role. If a mutual aid system were in place, that office could call upon expert assistance from another WFO for that purpose - provided the weather is benign in the CWA of the remote mesoanalyst. This approach shares some similarities with the NWS Supplemental Assistance Volunteer Initiative (SAVI) and Multimedia Assistance in Spanish (MAS) support models. However, unlike SAVI, it might be important for these teams to be organized such that assistance is provided from within a defined geographical zone, so that the remote input is coming from someone who has experience with similar weather challenges as the requesting office. In addition, a system would need to be devised for vetting appropriate expertise (not unlike the precedent established for Deployment-Ready forecasters).

These incremental training and proficiency development techniques could also be supplemented by other means: road shows, case study webinars, even blog posts and Virtual Laboratory (VLab) communities who share tools, techniques, ongoing challenges, and success stories of improved warnings or effective tactical IDSS that resulted from skillful mesoanalysis and subsequent intra-office warning team communication.

FINDING 7: Some offices simply do not have the staffing and/or on-site expertise to take advantage of the value a skilled mesoanalyst might provide for local high-impact events. Moreover, those that do may be limited to one or two forecasters, who may not be available when needed. This shortcoming will present an ongoing challenge until such time that a sufficient number of forecasters can be trained appropriately and demonstrate the proficiency necessary to perform as effective mesoanalysts.

RECOMMENDATION 7: While it is possible the NWS will see the need to develop a formal recurring training course, availability of experts will be limited for some time. Incremental training options can be spun up fairly quickly (video offerings such as "FOSS," case study webinars, road shows, etc.), but even those will be insufficient to address short-term needs. Therefore, as an interim measure it may be worthwhile to create a roster of qualified forecasters to serve as sub-regional Mesoanalyst Mutual Aid Teams. For situations in which an office faces a potentially high-impact event, requests could be made to this team for assistance in the form of remote expert mesoanalysis to aid in their tactical IDSS, warning operations, etc. This concept has precedent in other service areas (e.g., SAVI, MAS, EM Regional Mutual Aid, etc.). Other options also worth exploring include SME-led road shows, Multi-Office Collaboration Exercises, case study webinars, and blog posts illustrating success stories where expert mesoanalysis led to effective tactical IDSS.

H. Strengthen Science-Services Teamwork through Specialization

During the end-of-week out-brief sessions, several participants expressed some form of the following opinion related to navigating office culture issues. There is a subset of field forecasters who prefer to devote themselves to supporting colleagues who are delivering IDSS by ensuring the forecast is based on the best science. This group understands the recent emphasis on IDSS and believes in its value, but they do not feel their skills and interests lie in the communication and relationship-building aspects of the mission. For other forecasters, there is concern about science being diluted as a consequence of IDSS being stressed. While it could be argued that this assumption is unfair and inaccurate, the perception is real and the only remedy is to introduce science-based endeavors back into operations. Dedicated mesoanalysis offers one example that addresses both of those concerns.

The NWS has traditionally approached workforce training in a manner that expects everyone to be proficient in every role. There is certainly merit to that approach but as the NWS continues to evolve toward a science-based service model characterized by a continuous flow of information and a more active partnership with emergency partners - including greater on-site support - it may be worthwhile to consider developing a mixed mode of expertise development. Some forecasters are simply more interested in the science aspect while others are drawn to the service and communication roles. Accommodating this, by requiring a baseline knowledge of both areas, and then creating pathways to developing genuine expertise in one or the other, could result in more effective performance, better customer service, and stronger job satisfaction among the employees.

Achieving the goal of a Weather-Ready Nation depends upon buy-in and broad-based action among field forecasters. Vision can be cast from the top-down but it only comes alive when embraced at the grass-roots level. It is absolutely essential that every forecaster believes that any change in the NWS business model will offer opportunities to apply his/her strengths to the accomplishment of the NWS mission. Supporting differential skill development and associated work assignments addresses the importance of cultivating expertise, leveraging that expertise on a consistent basis, and then expanding its reach through training and practice. This proof-of-concept experiment proved that mesoanalysis is a strong example of the essence of the WRN Roadmap, and is associated with all of the critical performance elements it promotes.

One of the most commonly cited take-aways in the participant surveys was an increased understanding of practical satellite applications for mesoanalysis. Here, OPG SOO Matt Foster leads a discussion about the Day Cloud Phase Distinction RGB recipe, and its value for detecting imminent convective initiation.

FINDING 8: Adopting the practice of assigning a dedicated mesoanalyst in WFO operations to enhance services during potentially high-impact events offers an attractive avenue of meaningful contribution for those forecasters whose skills and interests lie in providing the deep science necessary to support colleagues who are crafting and delivering IDSS messaging.

RECOMMENDATION 8: Consider developing a curriculum of specialized training – patterned after the IDSS PDS – that offers a mandatory series of professional competency units designed to establish baseline knowledge, and a follow-on track intended for the more science-minded meteorologist who is passionate about building advanced proficiency in his/her mesoanalyst skills.

I. SPC Collaboration

The opportunity to learn from, and interact directly with, SPC forecasters was one of the common take-aways shared in post-workshop surveys. The value of this interaction varied from gaining knowledge about mesoscale meteorology to obtaining a greater understanding about the forecast process and time constraints under which SPC operates. Insights about how SPC plans to evolve its own products and services were also identified as important benefits. A specific, noteworthy recurring comment – from surveys and informal discussions alike – was a realization that SPC desires meaningful collaborative discussions. One forecaster expressed it this way, *"Our office has some serious work to do in order to improve communication with SPC, but knowing that SPC is receptive to that communication is encouraging, and learning proper mesoanalysis will help WFO forecasters speak SPC's language."*

SPC collaborates regularly with WFOs on the issuance of watches but the content of those discussions varies widely. First, as it stands currently, a majority of the collaboration queries from WFOs to SPC relate to forecast questions well in advance of the watch-warning time frame. Short-term convective collaboration would represent a shift away from that focus on the extended forecasts, where uncertainty remains relatively large. In addition, assuming opinions shared by MBC participants are generalizable, a significant number of field forecasters are reluctant to provide input to SPC, either because they feel intimidated, lack confidence or, in some cases, they simply believe SPC is not interested in hearing their perspective. This last issue is one that is especially troubling to SPC forecasters. They welcome and encourage discussions in which ideas and insights about the evolving environment are shared. Their only caveats are that the discussions are focused on meteorology (and not gut feelings), and that they take place with respect for the time constraints under which SPC operates. Expansion of skillful mesoanalysis across the NWS would facilitate richer collaborations of this nature, producing mutual benefit to both SPC and WFOs.

FINDING 9: Many forecasters were unaware that the SPC is open to, and interested in, collaboration conversations regarding convective outlooks and watch issuances, as long as those conversations are based on meteorology and respectful of the time constraints under which SPC operates. By expanding the knowledge and skills associated with effective mesoanalysis, and adopting a more SPC-like anticipatory mindset concerning the

evolution of convective events, WFO-SPC collaborations can be enriched, with mutual benefit. These benefits also extend to plans for expanding, modifying, and evolving the products and services of both SPC and the local WFOs.

RECOMMENDATION 9: Encourage more proactive engagement between WFO forecasters and those at the SPC, based on discussions of mesoscale meteorology, for the purpose of improving the overall quality of NWS support to the nation through collaboration - in particular, mesoscale discussions, convective outlooks, watches, warnings, and IDSS. While SPC forecasters are experts in convective mesoanalysis, they are often in the position of monitoring multiple areas across a broad expanse of real estate. In addition, they are likely unaware of specific events that local offices may be supporting and perhaps of local effects that are sometimes important to the WFO.

4. PARTICIPANTS' TOP TAKE-AWAYS – COMMON THEMES

In order to determine which elements of the workshop were most effective - "most sticky," in the vernacular of adult training - participants were asked to identify their top three take-aways from the entire week-long mesoanalysis workshop experience. This exercise produced a series of recurring themes, the most prominent being:

- Use of satellite imagery to enhance understanding of ongoing physical processes (This encompasses introduction to some of the new, useful RGBs, as well as tips for interpreting features depicted in traditional spectral bands like visible and water vapor, and making connections to conceptual models about convective development)
- Working real cases together, solving problems and making critical decisions in collaboration with other forecasters enhanced the learning experience
- Interacting one-on-one with experts from SPC and the field, then following up with application-oriented debriefs and discussions
- Learning about, and experimenting with new tools and/or data sets that forecasters were previously either unaware of, or unfamiliar with (e.g., GLM, SSCRAM, SHARPpy, NSEA tools, PGEN, lesser used MRMS products)
- Application of the key concepts covered in the "*Forecasting Organized Severe Storms*" prerequisite training, especially those points related directly to predicting convective mode and connecting mode to hazards
- Training on in-depth analysis and interpretation of Skew-Ts and Hodographs better prepared them to glean insight into potential convective modes and hazards likely to be supported in proximity to that environment
- Pre-made procedures and bundles to assist with mesoanalysis responsibilities and tasks: both the collections aimed at diagnosing mode/evolution, and the satellite, radar, and MRMS bundles were explicitly mentioned
- Better understanding of SPC mesoanalysis graphics, what goes into them, strengths, limitations, etc. - practical knowledge that can be applied immediately

If OCLO decides to develop a formal training experience focused on building mesoanalysis expertise, these take-aways will serve as valuable input to the instructional design phase.

5. SUMMARY

Based on these proof-of-concept experiments, the OPG staff and MBC Facilitation Team believe that the adoption of a dedicated mesoanalyst as part of a WFO's Severe Weather Operating Plan is the cornerstone for achieving an effective Collaborative Forecast Process for severe convective weather services.

Any argument that the recent focus on IDSS is diluting the meteorology is soundly refuted when juxtaposed with practices such as this. To the contrary, effective mesoanalysis requires application of deep physical science principles and conceptual models to the rapidly evolving processes unfolding in observational data. This is one of several possible activities that will be unlocked by eliminating the need for extensive manual editing of NDFD grids. Moreover, some of the lessons learned in investigating the application of mesoanalysis for convective events can be transferred to other service sectors: fire weather, marine weather, aviation weather, winter weather, tropical weather, etc.

Among its many advantages, skillful mesoanalysis…

- …enhances situational awareness and threat assessment
- …is most valuable in highly conditional threat scenarios
- …lends itself to synthesizing and communicating ranges of reasonable outcome
- …forms the basis of an effective Severe Weather CFP (*WRN goal*)
- …facilitates continuous information flow (*FACETs paradigm*)
- …enables more accurate anticipation/prediction of convective initiation, mode, hazards
- …leads to a positive impact on overall warning performance
- …contributes to precise, tactical IDSS in the watch/warning information gap
- …can bolster healthy culture by allowing people to operate in their strengths

There are achievable solutions to address every obstacle to the full implementation of these practices in NWS WFOs. The OPG stands ready to contribute to those solutions in any way NWS leadership deems useful.

Respectfully submitted on behalf of the OPG and the MBC Facilitation Team,

Kim Runk, Director, NWS Operations Proving Ground

APPENDIX 1 - Findings and Recommendations

The following findings and recommendations were derived from analysis of the collective comments, suggestions, recurring opinions, and important takeaways shared by the thirty forecasters who participated in the 2019 Mesoanalysis Boot Camps. All nine of these items are embedded in the full preceding report but, for convenience, they are extracted and listed separately here, without the detailed supporting narrative.

FINDING 1: Skillful mesoanalysis, coupled with proactive communication, has the potential to enhance multiple aspects of NWS service delivery, ranging from tactical IDSS messaging to improved warning performance. It is arguably the cornerstone for advancing the NWS business model toward the FACETs paradigm, a strategic goal of the “Evolve NWS” initiative. Further, by enhancing our ability to accurately diagnose environments conducive for tornado development, the mesoanalyst’s contribution toward collaborating with the radar operator to refine the timeliness and accuracy of warnings is aligned with the stated goal of the Tornado Warning Improvement and Extension Program (TWIEP) from the Weather Research and Forecasting Innovation Act of 2017 (a.k.a. The Weather Act).

RECOMMENDATION 1: NWS WFOs should adopt the practice of assigning a dedicated mesoanalyst in situations where convective development is imminent and associated hazards could reasonably be expected to pose a significant public safety threat. A skilled mesoanalyst can take the lead in assuring accurate situational awareness is maintained, communicating important details concerning short-term clues about the evolving near-storm environment, providing input to IDSS messaging and/or mesoscale informational updates - even advising the radar operator concerning environmental developments that result in improved timeliness and quality of warnings. The continuous flow of information - both internally and externally - that characterizes this operating concept is aligned precisely with the FACETs paradigm.

* * * *

FINDING 2: There are fundamental theoretical principles and concepts that must be understood in order to build the skills necessary to perform expert mesoanalysis in WFO operations. Training will be required in order to build the knowledge and skills needed to perform the level of mesoanalysis that was taught and practiced at the OPG.

RECOMMENDATION 2: Prioritize development of resources and methods aimed at sharing knowledge of the core concepts, tools, and practices connected with skillful mesoanalysis. Resources developed by the Mesoanalysis Boot Camp facilitator team serve as an excellent starting point (see Appendix 3). A variety of forms could be employed to supplement and build upon these materials, including hands-on exercises, webinars, blog posts illustrating operational application for specific cases, interactive quick guides available within AWIPS as just-in-time reminders, and more. Participants were strongly in favor of the MBC experience being formalized into a regular training course, and the OPG has conveyed this suggestion to the NWS Chief Learning Officer (CLO). It is certainly possible such a course could be blended into the recurring cycle of Office of the Chief Learning Officer (OCLO) in-residence offerings, but ultimately that decision will be subject to competition with other priorities and budget constraints.

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FINDING 3: Skillful mesoanalysis facilitates developing the habit of integrating careful diagnostics with conceptual models and formulating an idea of convective evolution before consulting output from high-resolution, convection-allowing models. Foreseeing a spectrum of possible scenarios in advance can prevent forecasters from focusing on a particular outcome, leading to a reactive mode of operation once a convective system evolves differently than what was originally expected. This anticipatory mindset enhances all aspects of convective forecasting, from providing valuable insights to core partners via tactical IDSS to feeding critical near-storm environment information to the warning decision maker.

RECOMMENDATION 3: Reemphasize the importance of starting the forecast process with a comprehensive analysis and an initial formulation of the significant forecast elements before consulting high-resolution model solutions. For convective events, this entails determining the most likely timing and location of convective initiation; mode, intensity, and associated hazards; and potential for mode transition as the storm system evolves. This practice will strengthen a forecaster's ability to compare numerical model output against his/her own conceptual model, assess differences in solutions, and make better decisions about whether a particular depiction is consistent with the current and expected environment.

* * * *

FINDING 4: Determining and communicating the risk of severe weather lends itself well to the introduction of probabilistic information. Considerable work needs to be done to resolve the best tools, methods, and display formats, but forecasters found value in synthesizing observational, statistical, and predictive data to formulate and convey envelopes of probability concerning a developing severe weather threat.

RECOMMENDATION 4: The NWS should invest in a concerted effort to identify tools and methodologies for illustrating and communicating the most useful portions of a pending weather event's probability density function (PDF). Deterministic forecasts are still the norm but there is increasing interest in the use of probabilistic information - and especially the development of calibrated probabilities - for crafting and communicating weather-related threats. The awareness that there is always some degree of uncertainty in weather forecasting, and thus a range of possible outcomes, reinforces the value of providing additional data to NWS core partners that informs critical decisions related to preparation, mitigation, recovery, etc. For example, the PDF is an excellent vehicle to conceptualize and message a situation for which the reasonable worst-case scenario involves significant impacts to public safety, but its occurrence is characterized by high conditionality/low predictability. The Emergency Manager who participated in MBC (Johnson

County, Kansas EM Trent Pittman) acknowledged such information could be extremely useful to him for creating "Plan B strategies" and other preparedness activities.

FINDING 5: While understanding the underlying physical science concepts is necessary for successfully implementing mesoanalysis in operations, it is also important to establish an environment where proactive communication is welcome and encouraged. Cultivating an office culture characterized by a general openness to others' perspectives, a continual exchange of ideas, and a deliberate engagement with stakeholders to learn what is important to them, is critical to translating skillful mesoanalysis into effective IDSS. This is particularly relevant given the fact that participants expressed a mixed mode of receptivity by their home staff to the idea of adopting the form of mesoanalysis taught and demonstrated at the OPG. This finding is consistent with internal NWS research (Smith, NWA 2017), which clearly demonstrated a positive correlation between healthy office culture and effective tornado warning performance. There is also a growing body of external research substantiating this point. In fact, there is significant evidence of a causality connection between a healthy, engaged organizational culture and improved team performance (e.g., Pontefract, Forbes 2017; Miller, Emergenetics 2012; Chandy, Science Daily 2008). These results underscore the importance of addressing both behavioral and operational aspects of this change initiative.

RECOMMENDATION 5: In order to build sufficient support and momentum for this practice to become an integral part of NWS operations, it will be as important to pay attention to the culture change challenge as it is to the proposed business model adjustments. The ultimate success of changing an operating concept is dependent on healthy team chemistry. Thus, while it will be crucial to provide technical training in the skills associated with mesoanalysis, it is equally important to devote time and attention to evolving office culture - especially in the areas of building trust, assuring a sense of belonging, reinforcing opportunities for each person to make meaningful contributions in the new process, and learning to communicate freely with an openness to productive conflict (i.e., debate over ideas not personalities). As a starting point, there are several excellent resources and best practices available on the NWS Office of Organizational Excellence "Culture Portal" to assist NWS managers in leading these critical efforts locally.

* * * *

FINDING 6: The majority of OPG workshop participants held the opinion that, for convective events, mesoanalysis is often most valuable in situations where the threat of organized severe storm development is highly conditional, not necessarily for scenarios where the likelihood of a major, classical outbreak is high. Eighteen of the thirty forecasters (60%) rated the SPC probabilistic category of "Marginal Risk" as that which best characterizes the situation for which they would ideally activate a mesoanalyst in operations.

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* * * *

FINDING 7: Some offices simply do not have the staffing and/or on-site expertise to take advantage of the value a skilled mesoanalyst might provide for local high-impact events. Moreover, those that do may be limited to one or two forecasters, who may not be available when needed. This shortcoming will present an ongoing challenge until such time that a sufficient number of forecasters can be trained appropriately and demonstrate the proficiency necessary to perform as effective mesoanalysts.

RECOMMENDATION 7: While it is possible the NWS will see the need to develop a formal recurring training course, availability of experts will be limited for some time. Incremental training options can be spun up fairly quickly (video offerings such as “FOSS,” case study webinars, road shows, etc.), but even those will be insufficient to address short-term needs. Therefore, as an interim measure it may be worthwhile to create a roster of qualified forecasters to serve as sub-regional Mesoanalyst Mutual Aid Teams. For situations in which an office faces a potentially high-impact event, requests could be made to this team for assistance in the form of remote expert mesoanalysis to aid in their tactical IDSS, warning operations, etc. This concept has precedent in other service areas (e.g., SAVI, MAS, EM Regional Mutual Aid, etc.). Other options also worth exploring include SME-led road shows, Multi-Office Collaboration Exercises, case study webinars, and blog posts illustrating success stories where expert mesoanalysis led to effective tactical IDSS.

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FINDING 8: Adopting the practice of assigning a dedicated mesoanalyst in WFO operations to enhance services during potentially high-impact events offers an attractive avenue of meaningful contribution for those forecasters whose skills and interests lie in providing the deep science necessary to support colleagues who are crafting and delivering IDSS messaging.

RECOMMENDATION 8: Consider developing a curriculum of specialized training – patterned after the IDSS PDS – that offers a mandatory series of professional competency units designed to establish baseline knowledge, and a follow-on track intended for the more science-minded meteorologist who is passionate about building advanced proficiency in his/her mesoanalyst skills.

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FINDING 9: Many forecasters were unaware that the SPC is open to, and interested in, collaboration conversations regarding convective outlooks and watch issuances, as long as those conversations are based on meteorology and respectful of the time constraints under which SPC operates. By expanding the knowledge and skills associated with effective mesoanalysis, and adopting a more SPC-like anticipatory mindset concerning the evolution of convective events, WFO-SPC collaborations can be enriched, with mutual benefit. These benefits also extend to plans for expanding, modifying, and evolving the products and services of both SPC and the local WFOs.

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APPENDIX 2 - Mesoanalysis Think Tank and Planning Committee Roster

Name	Position	Office
Dr. Ariel Cohen	SOO	WFO Miami FL
Chauncy Schultz	SOO	WFO Bismarck ND
Dan Hawblitzel	SOO	WFO Nashville TN
Seth Binau	SOO	WFO Wilmington OH
Brian Carcione	SOO	WFO Huntsville AL
Corey Mead	Lead Forecaster	WFO Omaha NE
Dr. Chad Gravelle	Tech Dev Met	NWS SRH STSD
Matt Foster	SOO	NWS OPG
Jennifer Pittman	SOO	WFO Topeka KS
Dr. Katie Crandall-Vigil	Research Scientist	OU-CIMMS
Kim Runk	Director	NWS OPG
Bill Bunting	Chief	SPC Forecast Operations Branch
Dr. Patrick Marsh	Chief	SPC Science Support Branch
Rich Thompson	Lead Forecaster	SPC
Dr. Jim LaDue	Master Instructor	NWS OCLO/WDTD

APPENDIX 3 - Links to Mesoanalysis Training Resources

1. Severe Thunderstorm Forecasting Video Lecture Series
https://www.spc.noaa.gov/exper/spcousom/

This was a collaboration between SPC, OU, NSSL, and the WDTD based on the three-semester-hour graduate-level course offered at OU about applications of meteorological theory to the forecasting of severe thunderstorms. Fundamentals of weather analysis, observational analysis, and core conceptual models relevant for many other applications are addressed. This course has provided an opportunity to bridge the academic and operational disciplines of meteorology, allowing students to learn from experienced forecasters who have performed research on a variety of topics. During spring 2017, many lectures comprising Meteorology 5403/4403 and other related lectures relevant to severe thunderstorm forecasting were recorded. YouTube links to these recordings and accompanying descriptions are provided as training material, and there are 91 videos.

2. "Forecasting Organized Severe Storms" Video Series

YouTube: https://www.youtube.com/playlist?list=PLYsC5TDceC_ZYXK9tpG0jJZ7rvLhFRDaO

CLC: https://doc.csod.com/client/doc/default.aspx - Search for "Forecasting Organized Severe Storms"

This training series addresses the ingredients and representing parameters for organized, severe convection, and identifies how we can leverage meteorological datasets to assess the convective environment. Included in the series is how conceptual models can be employed to identify severe-storm threat areas and the various convective hazards that emanate from organized severe storms. This video lecture series stemming from a collaboration led by the OPG.

3. Mesoanalyst Boot Camp Files

A. Forecasting Organized Severe Storms Exercise: Hands-on IDSS-enhancing activity applying concepts from the video lecture series to tactical threat assessment with a solutions manual
https://drive.google.com/drive/folders/182XxDvsz-xQgIBTdfwjUS65ZRFVsHLyx

B. Convective Outlook Preparation Exercise -- Activity, solutions, and train-the-trainer video
https://drive.google.com/drive/folders/10OJEMQ0C5gFDVejfkin2tjvyehAcp-wg

C. Resources on SSCRAM for contextualizing mesoscale environments in terms of severe-convective threat probabilistic quantification -- Training videos, activity, and solutions manual
https://drive.google.com/drive/folders/1ozXWYY9pp-M2b8L5oSbrrIIDpFHLpGhh

4. CLC Module: Satellite Mesoanalysis for Convective Initiation

https://doc.csod.com/client/doc/default.aspx - Search for "Nov 2017 GOES-16 Applications Workshop Session: Convective Initiation Applications"

APPENDIX 4 - Mesoanalyst Boot Camp Agenda

MONDAY	
8:00 AM - 9:00 AM	Welcome / Log in / Icebreaker / Ground Rule
9:00 AM - 9:20 AM	SAGE2 instructions / D2D Bundles
9:20 AM - 9:30 AM	Break
9:30 AM - 11:15 AM	Skew-T / Hodograph / Effective Inflow / Parameter Ingredients
11:15 AM - Noon	SPC Mesoanalysis and Convective Initiation
Noon - 1:00 PM	LUNCH
1:00 PM - 4:45 PM	FOSS Review, including Case Study and Pre-Test Discussion
4:45 PM - 5:00 PM	Debrief
TUESDAY	
8:00 AM - 8:15 AM	Group Photo / Intro for the Day
8:15 AM - 9:45 AM	Storm Motion and Evolution
9:45 AM - 10:00 AM	Break
10:00 AM - 10:30 AM	Convective Mode Transitions
10:30 AM - 11:15 AM	Perturbation Pressure Theory (Updraft/Shear Interactions)
11:15 AM - 11:45 PM	SSCRAM
11:45 AM - 12:45 PM	LUNCH
12:45 PM - 2:30 PM	Satellite Applications to Mesoanalysis & Forecasting
2:30 PM - 2:45 PM	Break
2:45 PM - 3:45 PM	CAMs and CAM Ensembles
3:45 PM - 3:55 PM	Quick Break
3:55 PM - 4:05 PM	PGEN Tutorial
4:05 PM - 5:00 PM	SPC Future Direction & Field Interaction, Open Discussion
WEDNESDAY	
8:00 AM-12:00PM	Simulation Case 1
12:00 PM-1:00 PM	LUNCH
1:00 PM-4:30 PM	Simulation Case 2
4:30 PM-5:00 PM	Debrief - Survey - Takeaways
THURSDAY	
8:00 AM-12:00PM	Simulation Case 3
12:00 PM-1:00 PM	LUNCH
1:00 PM-4:30 PM	Simulation Case 4
4:30 PM-5:00 PM	Debrief - Survey - Takeaways
FRIDAY	
8:30 AM-12:00PM	End-of-Week Surveys and Final Takeaway Debrief

APPENDIX 5 - End-of-Week Anonymous Survey Questions

1. Rate the effectiveness of the Monday/Tuesday training sessions and exercises to prepare you for completing the mesoanalyst simulations on Wednesday/Thursday.
   (7-pt Likert Scale: 1 = Extremely Ineffective, 4 = Neutral, 7 =Extremely Effective)

2. What, if anything, would you change to enhance or improve those sessions?

3. Rate the effectiveness of the four Wednesday/Thursday simulations to prepare you for evaluating the role of the WFO mesoanalyst.
   (7-pt Likert Scale: 1 = Extremely Ineffective, 4 = Neutral, 7 =Extremely Effective)

4. What, if anything, would you change to enhance or improve those simulations?

5. At what SPC outlook category is a dedicated mesoanalyst necessary for effective situational awareness, IDSS, and warning operations?

6. Based on your experience this week, please articulate your opinion concerning the value of a dedicated mesoanalyst for enhancing WFO services during high-impact weather events. Discuss how that value contrasts with competing priorities such as workload, staffing, etc., and ideas you can propose as possible solutions to those challenges.

7. We experienced and discussed a variety of issues related to both internal and external communication. Discuss the importance of effective communication in the collaborative forecast process.

8. What tools, data sets, or procedures did you find especially valuable in working through the simulation cases during this workshop?

9. Are there any tools or data sets the NWS does not currently have that would make the mesoanalyst position more effective?

10. What do you envision as the primary training challenge that needs to be addressed in order to ensure each office has the capacity and proficiency to conduct the type of mesoanalysis we've been practicing this week?

11. What is your expectation about the receptivity of adopting the mesoanalyst operating concept in your office?
    (7-pt Likert Scale: 1 = Most People Supportive, 4 = Neutral, 7 =Most People Resistant)

12. Please provide an explanation to support your answer to Question 11. (optional)

13. What are your top three personal take-aways from the entire week-long Mesoanalyst Boot Camp experience?

14. If there is anything else you would like to share about your experience this week evaluating the role of the mesoanalyst in NWS operations, please do so. (optional)

APPENDIX 6 - End-of-Week Final Debrief Session Questions

1. If I could change ONE thing about the entire week that would have enhanced the overall experience for me, it would be...

2. One or two things that worked really well, or were especially valuable to me…

3. Name at least two specific ways that you will champion the use of mesoanalysis to bridge science and services when you return home.

4. If you believe there will be some degree of resistance about adopting these practices at your WFO, what do you think will be the most common point of contention? What will be needed to overcome those concerns?

5. What challenges might you face if team chemistry does not foster open communication within the warning team? How would you propose resolving, or at least minimizing, that impact?

6. What would you like to see on a VLab Community Forum that would assist you in promoting and practicing the skills we worked on this week?

7. What are your thoughts about a SAVI-like cadre of mesoanalysts who could be available for offices who do not have the staffing (or perhaps the expertise) to spin up an on-site mesoanalyst to assist with a high-impact event?

APPENDIX 7 - Workshop Participants

Mesoanalyst Boot Camp 1 – May 2019

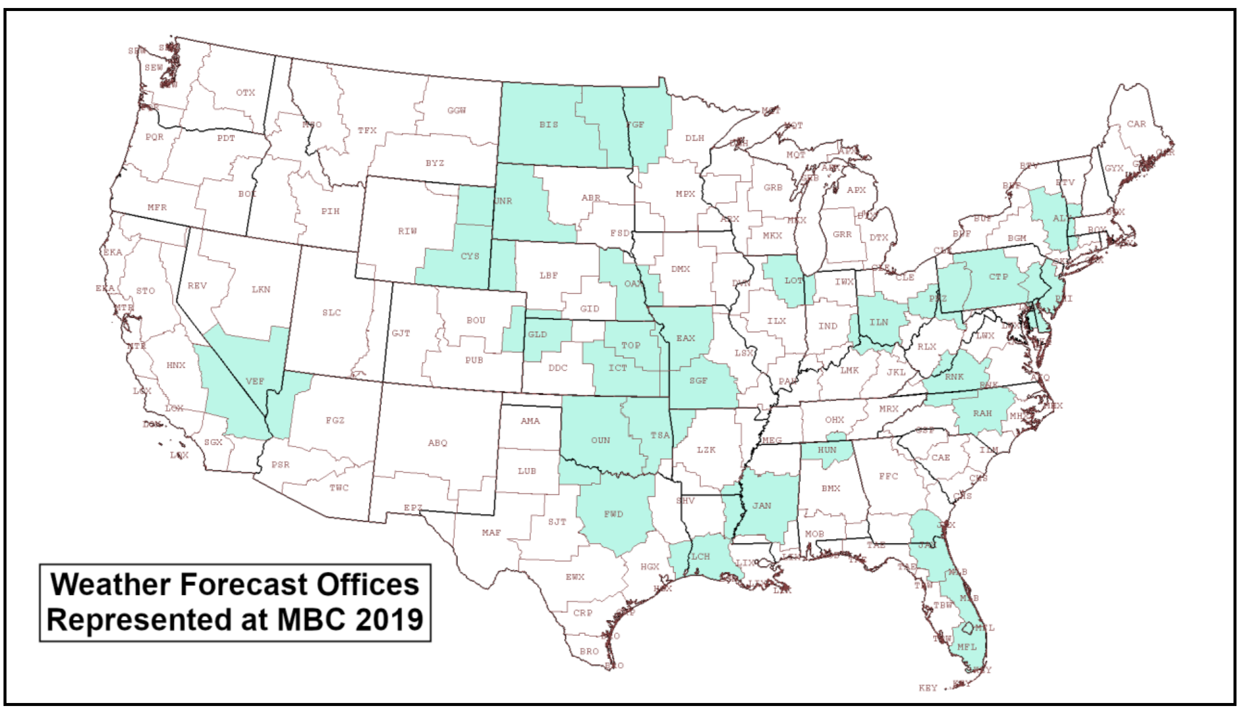
Front Row: Ariel Cohen, Chauncy Schultz, Brittany Peterson, Brian Haines, Kristen Cassady, Chad Gravelle
Middle Row: Kim Runk, Nate McGinnis, Tim Humphrey, Mike Evans, Matt Foster
Back Row: Andrew Loconto, Jenni Pittman, Jared Allen, Alex Edwards, Eric Wise, Rich Thompson

Mesoanalyst Boot Camp 2 – June 2019

Front Row: Randy Bowers, Katie Magee, Katie Crandall-Vigil, Matt Stalley, Keith Sherburn, Kim Runk
Middle Row: Rich Thompson, Corey Mead, Ariel Cohen, Daniel Lamb, Mike Jurewicz
Back Row: Jim LaDue, Jenni Pittman, Matt Friedlein, Christina Speciale, Matt Foster, Matthew Kramar, Alex Boothe

Mesoanalyst Boot Camp 3 – July 2019

Front Row:	Becky Kern, Kevin Rodriguez, Paul Fitzsimmons, Katie Crndall-Vigil, Thomas Vaughan
Middle Row:	Rich Thompson, Ariel Cohen, Andrew Moore, Bryan Baerg, Kim Runk, Robert Garcia
Back Row:	Ryan Difani, Jesse Lundquist, Jimmy Barham, Matt Foster, Jenni Pittman, Steve Cobb



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