NOAA Hazardous Weather Testbed
Summer Experiment 2005:
Testing Forecast Tools for MCS Maintenance, Speed, and Severity

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1. Introduction

NOAA's Hazardous Weather Testbed (HWT) accelerates the transition of promising new meteorological insights and technologies into advances in forecasting and warning for hazardous mesoscale weather events. This is accomplished via a disciplined synergy between operations and research that is focused on real-time forecasting and evaluation activities conducted during active severe weather events.

2. HWT Summer Experiment 2005

During the warm season, quasi-linear Mesoscale Convective Systems (MCSs) occasionally develop into rapidly moving thunderstorm systems that produce widespread wind damage (e.g., derechos). These have a large societal impact which is exacerbated by increased outdoor summer recreational activities (such as boating, camping, festivals, etc.) which can leave people more vulnerable to rapidly changing weather conditions. Pioneering observationally-based derecho studies by Johns and Hirt (1987) and colleagues, more recent derecho proximity sounding studies by Evans and Doswell (2001), conceptual models of MCS motion by Corfidi (2003), and numerical modeling studies by Weisman and Rotunno (2004) and colleagues have provided important information on environments and physical processes supportive of derecho producing MCSs. However, accurate prediction of the organization, longevity, speed of movement, and severity of MCSs remains a key challenge for severe storm forecasters.

Recent work by Coniglio et al. (2004) examined MCSs over a 25 year period, providing new insights into the physical processes and environmental characteristics related to MCS life cycles and their association with severe weather occurrence. These studies confirm that accurately forecasting the genesis of long-lived MCSs will not be easily accomplished. However, additional follow-up work by Michael Coniglio has resulted in the development of two new ingredients-based conditional parameters that exhibit statistical skill in delineating the areal extent where maintenance and subsequent dissipation of existing MCSs is most likely to occur (MCS Maintenance Parameter or MMP), as well as the likelihood of rapid forward propagating MCSs (MCS Speed Parameter or MSP). These new parameters provide probabilistic information that supplements the existing Derecho Composite Parameter (DCP) developed by Evans, a non-dimensional, normalized indicator of environments that may support derecho systems.

The goal of the summer experiment is the improved prediction of warm season MCSs, specifically:

- The development and evolution of fast-forward propagating systems and derechos.
- The dissipation of the leading convection associated with forward-propagating MCSs.

We will focus on exploring the operational utility of these three parameters (MMP, MSP, and DCP) to provide useful information to SPC forecasters, resulting in improved forecasts of MCS phenomena. This will be accomplished through: 1) a systematic documentation of MCS occurrence including key characteristics (e.g., system track including genesis and ending points, speed of movement, association with severe weather), and an evaluation of the three parameters during the life cycle of the MCSs, and 2) feedback from operational SPC forecasters testing the parameters in real-time severe weather forecasting situations.

The MCS parameters will be available in NAWIPS workstations in the SPC Operations Room and the adjacent Science Support Area using input fields from the RUC and NAM models. Hourly diagnostic fields from the SPC Mesoscale Analysis system called "SFCOA", based on observed surface data and RUC 1-hour forecast background fields for the free atmosphere above the ground, will also be produced. The DCP is currently available in SFCOA, and will also be generated from RUC and NAM model output.

3. Objectives and Expected Outcomes

The primary objectives of the Summer Experiment 2005 are to:

- Assess the utility of the experimental MCS Maintenance, Speed and Derecho parameters to provide improved short-term outlook and watch scale severe weather guidance to SPC forecasters.
- Determine the ability of the parameters to provide useful guidance during the genesis, mature, and dissipation stages of long-lived MCSs.
- Enhance interactions and dialogue between applied research scientists and operational forecasters on topics of mutual interest.

The expected outcomes include:

- Documentation of warm season MCS occurrence, including life cycle characteristics of starting and ending locations, track, speed of movement, leading edge radar configurations, temporal longevity and possible diurnal influences, and association with severe weather production.

- Documentation of the relationship between experimental MCS guidance parameters and MCS morphology, focusing on the ability of the parameters to provide quantitative predictive information about timing and location of severe MCSs .
- Expose SPC forecasters to cutting-edge research directed at addressing operational severe weather forecasting problems, and familiarize research scientists with real-world forecasting constraints of reliability, timeliness, and operational IT infrastructure requirements.
- Deliver new tools to operational severe weather forecasters resulting in improved severe MCS forecasts.

4. Description of Parameters

This program is motivated by the difficult problem of predicting warm-season Mesoscale Convective Systems (MCSs). We will examine the utility of three newly-developed parameters in providing guidance for short-term outlooks and watches on the maintenance and subsequent dissipation of the leading convection associated with forward-propagating MCSs, the forward speed of MCSs, and the potential for long-lived, severe-wind-producing MCSs (derechos). The three parameters to be evaluated are the:

- Conditional Probability of MCS maintenance (MMP)
- Conditional Probability of MCS forward speed > 18 m s^{-1} (35 kt) (MSP)
- Derecho Composite Parameter (DCP)

The MMP and MSP were developed from a data set of over 600 warm-season (May-August) MCSs that were identified with mosaic images of base and composite radar reflectivity data (no satellite data were used). In general, the MCSs that were identified had a well-defined, nearly contiguous line or arc of convection with lengths > 100 km for durations > 5 h. The genesis of the MCS was defined to be when the convection obtained a nearly contiguous line or arc of > 35 dBZ echoes and at least one area of > 50 dBZ echoes that was quasi-steady in its intensity or was intensifying and/or expanding in coverage. The dissipation stage of the MCS was defined to be when the area of > 50 dBZ echoes began to steadily decrease in coverage and/or intensity without returning to the same coverage or intensity at later times.

Each of the 600+ MCS events was examined for the existence of radiosonde data that sampled the inflow environment without any obvious contamination from convection. Although no set criteria were used in the identification of these soundings, all of the soundings were taken within 3 h (according to balloon release time) and 200 km of the leading convective line. A total of 269 observed proximity soundings from this data set were identified. When combined with 79 derecho proximity soundings from 1980-97 identified from an earlier data set, this gives a total of 348 warm-season MCS proximity soundings from a variety of MCS types. These soundings were used to develop the MMP and MSP as follows:

i. ***Probability of MCS maintenance (MMP)***

To focus on forward-propagating systems, those soundings that sampled the environment ahead of a system with a mean 3 h forward speed of < 10 m s^{-1} near the sounding time were removed, resulting in 290 soundings. These soundings were then classified subjectively into three categories based on the appearance of the MCS on radar reflectivity as follows (the number of soundings in each category is in parentheses):

- Initiation (76): The sounding was taken no more than 3 h before a nearly contiguous line of > 35 dBZ echoes and at least one area of > 50 dBz echoes was established.
- Mature (96): The sounding was taken ahead of a strengthening or quasi-steady leading convective line with a contiguous area of > 35 dBZ echoes and at least one area of > 50 dBZ echoes.
- Dissipation (115): The area of > 50 dBZ echoes along the leading convective line was steadily decreasing in coverage or intensity (or was not present at all).

Through hypothesis testing and discriminant analysis on hundreds of sounding parameters, it was found that a representation of the deep-tropospheric bulk shear and the lapse rate in the lower half of the cloud layer were excellent discriminators between the Mature and Dissipation groups (Fig. 1), along with a most unstable CAPE variable and the low-to upper-level mean wind speed.

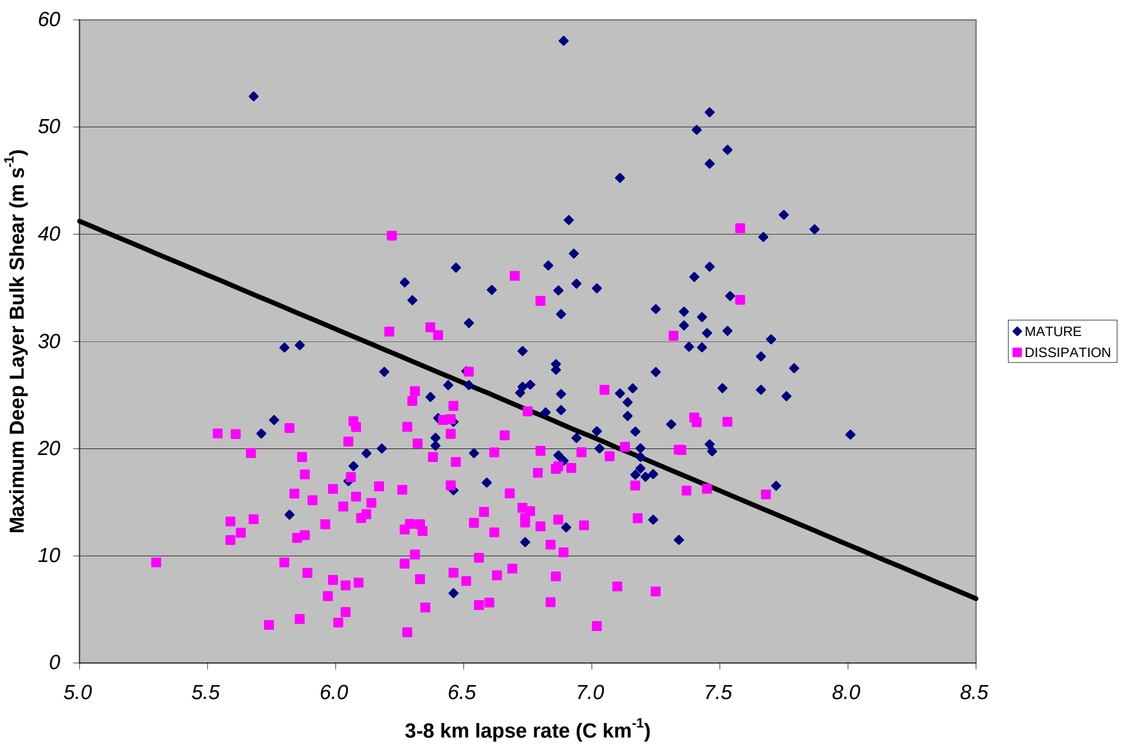

Figure 1. Scatterplot of 3-8 km lapse rate (C km^{-1}) versus the maximum bulk shear (between 0-1 km and 6-10 km) (m s^{-1}) for the mature and dissipation soundings. The solid line results from the linear discriminant analysis and groups 75% of the cases correctly.

Based on these findings the following four variables were used to develop the probabilities:

- maximum bulk shear (m s^{-1}) in the 0-1 and 6-10 km layer {maxshear}
- 3-8 km lapse rate (°C km^{-1}) {3-8 lr}
- a most unstable convective available potential energy variable (J kg^{-1}) {MUCAPE}
- 3-12 km mean wind speed (m s^{-1}) {3-12 mw}.

Logistic regression (Wilks 1995) was used on these variables to generate an equation that can be used with observational data or numerical model output to generate the conditional probability that an MCS will remain mature. The resultant equation is defined to be,

$\underline{\underline{For\ MUCAPE \geq 100\ J\ Kg^{-1}}}$:

$$MMP = \frac{1}{\left[1 + EXP\left(a_0 + (a_1 * \{\max shear\}) + (a_2 * \{3-8\ lr\}) + (a_3 * \{MUCAPE\}) + (a_4 * \{3-12\ mw\})\right)\right]}$$

$\underline{\underline{For\ MUCAPE < 100\ J\ Kg^{-1}}}$:

$$MMP = 0,$$

where the regression coefficients are $a_0 = 13.0$, $a_1 = -4.59 \times 10^{-2}$, $a_2 = -1.16$, $a_3 = -6.17 \times 10^{-4}$, $a_4 = -0.17$, and the remaining variables enclosed by {} are defined above. Fig. 2 shows a plot of the equation for MMP for the four parameters that are normalized by their respective minimum and maximum values in the data set. The steepness of the curve for MMP suggests that these empirical probabilities may have substantial skill in discriminating mature and dissipating MCSs. We envision the best real-time application of this parameter would use SFCOA or RUC model output at a time close to convective initiation. For example, the hourly RUC forecasts of this parameter should give guidance to the regions most likely to sustain MCSs that do develop, which could benefit Day 1 Severe Weather Outlooks, Mesoscale Discussion products, and the issuance of Severe Weather Watches. Although the MMP was designed to discriminate between mature and dissipating MCSs, the parameter may also be used on longer time scales with NAM output to give a general idea of where mature MCSs may be favored on longer time scales (assuming convection in the model doesn't erroneously remove instability).

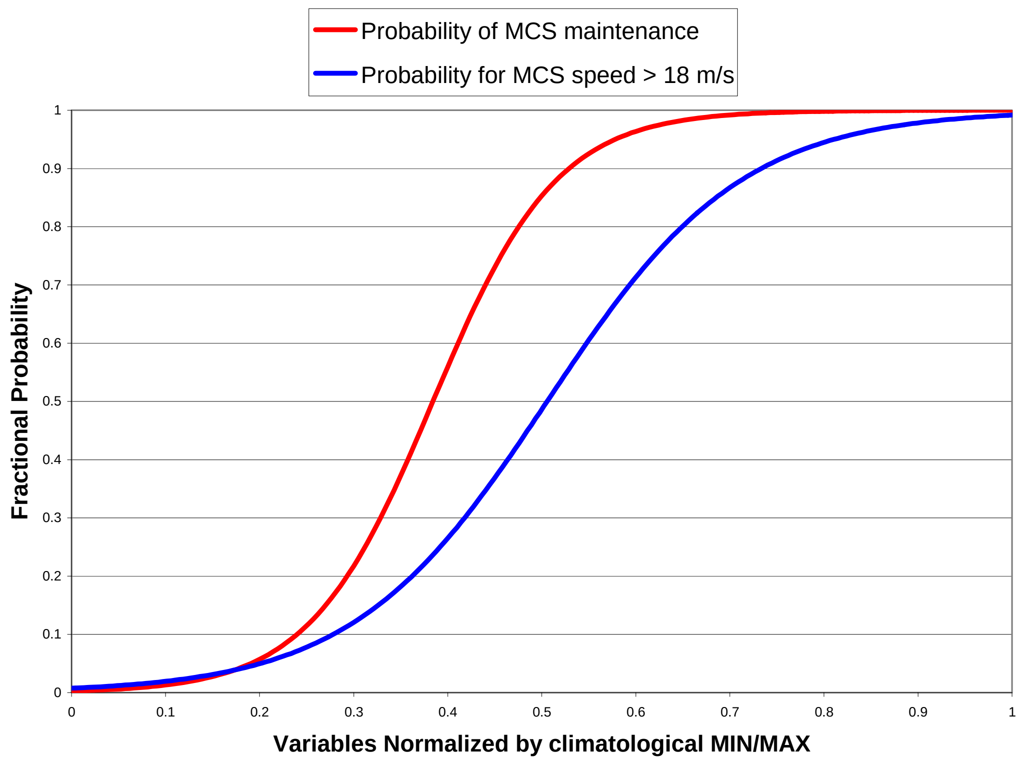

Figure 2. Probability of MCS maintenance (MMP, red curve) and MCS speed > 18 m s^{-1} (MSP, blue curve) based on logistic regression. The ordinate represents the input variables to the regression normalized by their minimum and maximum values in the data set. For example, if all four of the variables that went into the equation for MCS maintenance are exactly half way between their min and max values (0.5), then the regression equation predicts a ~90% chance that the MCS will be maintained. In general, a steeper curve means a better ability of the parameters to discriminate between the two groups.

ii. ***Probability of MCS speed > 18 m s^{-1} (MSP):***

To focus on the speed of MCSs during the organizing and mature stages, the dissipation soundings described earlier were not included in this group. The remaining 228 soundings were split into two groups as follows:

- "Slow" (98): MCSs with a mean speed < 18 m s^{-1}
- "Fast" (130): MCSs with a mean speed ≥ 18 m s^{-1}.

The value of 18 m s^{-1} was selected as the break point because earlier research findings suggest that systems moving faster than this speed have an increased likelihood of producing damaging wind gusts (as long as the storms are rooted in the boundary layer). Again, through hypothesis testing and discriminant analysis, it was found that the low- to upper-level mean wind speed discriminated the two groups very well. In addition, it was found that the geographical signal in the data hindered the general use of the thermodynamic parameters (e.g., a value for θ_e that discriminates well over Louisiana doesn't discriminate well over North Dakota). To better isolate the physical signal for general use, the thermodynamic parameters were then converted to non-dimensional standard normal variables (Z-scores) based on their 7-year (1998-04) mean and standard deviation derived from radiosonde data. Among the Z-scores, the low- to mid-level difference in θ_e and the lapse rate in the lower half of the cloud layer were found to discriminate the two groups well. Based on these findings the following three variables were used to develop the probabilities:

1) Standardized values of the maximum vertical difference in θ_e between low and mid levels (unitless) {zmaxthediff}
2) 2-12 km mean wind speed (m s^{-1}) {2-12 mw}
3) Standardized values of the 2-6 km lapse rate (unitless) {2-6 zlr}

Using these three parameters, logistic regression was used again to generate an equation that can be used with observational data and numerical model output to generate the conditional probability that an MCS will move with speeds ≥ 18 m s^{-1} at maturity. The resultant equation is given by,

$$\underline{\underline{For\ MUCAPE \geq 100\ J\ Kg^{-1}}}:$$

$$MSP = \frac{1}{\left[1 + EXP\left(a_0 + (a_1 * \{z\max thediff\}) + (a_2 * \{2-12\ mw\}) + (a_3 * \{2-6\ zlr\})\right)\right]}$$

$$\underline{\underline{For\ MUCAPE < 100\ J\ Kg^{-1}}}:$$

$$MSP = 0$$

where the regression coefficients are $a_0 = -3.46$, $a_1 = 0.447$, $a_2 = 0.119$, $a_3 = 0.79$, and the remaining variables enclosed by {} are defined above. Although the regression curve for MSP is not as steep as the curve for MMP (Fig. 2), the curve still suggests the ability to discriminate between "slow" and "fast" MCSs. We envision the use of this parameter in combination with the MCS maintenance parameter to guide the forecaster toward the most likely regions of fast-forward propagating and mature MCSs.

iii. Derecho Composite Parameter (DCP):

This parameter is based on a data set of 113 derecho events compiled by Evans and Doswell (2001). The DCP was developed to identify environments considered favorable for cold pool "driven" wind events through four primary mechanisms: 1) Cold pool production [DCAPE], 2) Ability to sustain strong storms along the leading edge of gust front [MUCAPE], 3) Organization potential for any ensuing convection [0-6 km shear], and 4) Sufficient flow within the ambient environment to favor development along downstream portion of the gust front [0-6 km mean wind]. Normalized values were developed for each parameter using the 51 observed proximity soundings near "Weak

Forcing" derechos, which were compared to values from 31 proxy soundings from WF non-derecho MCSs. It was found that DCAPE > 980 J/Kg and MUCAPE > 2000 K/kg were *common* (25^{th} percentile), while sfc-6 km shear > 20 kt and sfc-6 km mean wind > 16 kt were *uncommon* (75^{th} percentile) in the non-derecho dataset. Though the ED01 dataset suggests the two kinematic parameters alone could be used to discriminate the derechos from non-derecho cases, it would be necessary to assume favorable thermodynamics exist. In order to remove this assumption, all four parameters were collected into a single composite parameter as follows:

DCP = (DCAPE/980)*(MUCAPE/2000)*(0-6 shear/20 kt)* *(0-6 mean wind/16 kt)

The ability of the DCP to discriminate between non-derecho and derecho MCSs can be inferred from Fig. 3, which shows complete separation of the interquartile ranges (25^{th} – 75^{th} percentiles) of the DCP between the non-derecho and derecho MCS data sets.

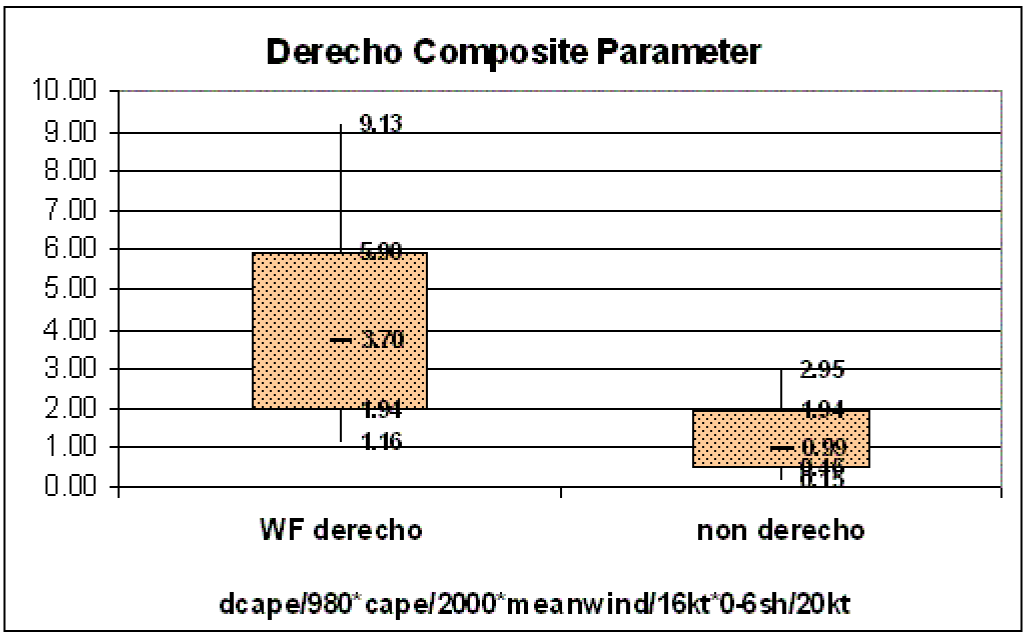

Figure 3. Bow and whisker plots of DCP calculated from 51"weak forcing" derecho proximity soundings and 31 "weak forcing" non-derecho proximity soundings.

5. MCS Documentation and Evaluation Plan

The forms for the daily MCS documentation and parameter evaluation can be found online at:

http://www.spc.noaa.gov/exper/Summer_2005

which should become available by 30 June. This site is intended to support the program activities as well as additional research and reference after the conclusion of the program.

The forms that will be used for the documentation and evaluation procedures can be viewed by SPC personnel at http://www.spc.noaa.gov/cgi-bin-spc/su05_form.pl.

The program will run from approximately 5 July to 19 August 2005. Members of SPC and volunteers from NSSL will document the occurrence of MCSs on the previous day and then evaluate the performance of the three parameters using the guidelines on the documentation forms. It is expected that this process will take, at most, three to four hours, and will be schedules to run from 8:30 am to 12:30 pm on Monday through Friday.

i. ***MCS Documentation***

Only those MCSs that reach maturity east of the Rocky Mountains will be documented. In general, the MCSs that we are targeting for this program are those that have a well-defined, nearly contiguous line or arc of convection with lengths > 100 km and durations > 5 h. The genesis of the MCS is defined to be when the convection obtains a nearly contiguous line or arc of > 35 dBZ echoes and at least one area of > 50 dBZ echoes that is quasi-steady in its intensity or intensifying and expanding in coverage. The dissipation of the MCS is defined to be when the area of > 50 dBZ echoes disappears or the area of > 35 dBZ echoes is no longer contiguous. Note: These are general guidelines. If the participants find that these guidelines do not provide an accurate description of the genesis and dissipation of the MCS, the participants will be asked to use their subjective interpretations of the genesis and dissipation of the MCS, and they will need to document their reasoning for why they strayed from the general guidelines on the appropriate location on the form.

There will be an opportunity to document up to three MCSs that occurred on the previous day. For each MCS on that day that met the general guidelines the participants will document the time of genesis to nearest hour, the general location of genesis of center of leading line (nearest surface station), the time of dissipation to nearest hour, and the general location of dissipation of center of leading line(nearest surface station). The primary product examined for this documentation will be the regional display of radar base reflectivity data that is routinely available in the NMAP displays in the SSA room.

We will also be documenting the location of the center of the leading line (nearest surface station), the direction of motion of the fastest portion of the leading line to nearest 10 degrees, and the speed of fastest portion of leading line to nearest kt for each hour of the MCS between genesis and dissipation. The severe reports that were associated with the MCS also will be documented. It is expected that many events will occur that do not neatly fit into the guidelines for documenting the MCS. Therefore, an important part of this documentation will be the participants' comments on the structure and characteristics of the MCS (linear, bowed, forward propagating, backbuilding, etc.) and problems with defining the above attributes (e.g., line has many breaks in 50 dBZ areas, line drastically changed character every hour, etc.). To help visualize these comments, we ask the participants to trace the leading line of the MCS from genesis to decay using the NMAP tools. These files will be saved for reference for the post-Summer Program analysis.

ii. ***Parameter Evaluation***

The evaluation of the parameters is designed to document the performance of the parameters based on output from the operational versions of the Rapid Update Cycle (RUC), the North American Model (NAM), and SFCOA, all displayed on a 40 km grid. The RUC forecasts and SFCOA diagnostic output will be available hourly and the NAM every 6 hours (00, 06, 12, 18 UTC). [*Note- given the more likely short-term utility of the parameters, the NAM part of the evaluation may be dropped if workload for the SFCOA and RUC evaluations becomes too time consuming. This will be determined during a spin-up test period.*] We are most interested in determining the utility of the parameters in providing short-term outlook/mesoscale discussion/watch guidance. Therefore, we will focus on the model initializations closest to the time before MCS genesis. We will document the parameter values calculated from the SFCOA, RUC, and NAM output and SFCOA fields in the area just ahead of the MCS location for each available observation or forecast between genesis and dissipation. Since we expect there to be some variability of the parameter in the model environment ahead of the MCS, we ask that the evaluator use his/her judgment in assigning a representative parameter value. More specific instructions for this process are given on the evaluation form. After documenting the values, we then ask the participant to rate the perceived usefulness of each parameter on a scale from 0 to 10, 0 being of no use and 10 being perfect guidance. More objective statistical evaluation of the parameters also will be conducted after the conclusion of the Summer Program, as we view these two methods as being complementary.

In addition to documenting the parameter values and rating the parameters subjectively, an important component of the evaluation process will be the participant's comments about the perceived usefulness of each parameter from the SFCOA, RUC and the NAM. This will give the participant the opportunity to comment on any difficulties they encountered in assigning parameter values. In addition, we are interested in the participants' impressions on the evolution of the parameter's coverage and how it might help/hinder its usefulness. For example, it will be useful to know if parameter values and/or areal coverage of the parameter remains steady with time as the MCS moves toward an area, or if the area covered by the parameter contours continually increases in size and/or the maximum values steadily increase ahead of the MCS. The goal is to determine if the parameters provide lead time on short-term outlook and watch timescales on a consistent basis, and if any reliable trend information is provided. Other comments related to the usefulness of the parameter values from the participant's perspective along these lines are encouraged at this point.

Lastly, an important part of analyzing the parameters is to diagnose, if possible, reasons why they may have provided poor guidance for a certain MCS event. If this occurs, the participants will examine the individual ingredient fields that go into the formulation of the MCS parameters to see if an obvious failure mode can be determined (e.g., convection in the model removed CAPE erroneously or the model forecasts of wind shear were very poor, etc.). It will also be useful to document if an MCS parameter appeared to provide poor guidance but there was no obvious reason why it failed. Instructions for these comments are given on the evaluation form.

6. References

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