NOAA HAZARDOUS WEATHER TESTBED

EXPERIMENTAL FORECAST PROGRAM SPRING EXPERIMENT 2011

http://hwt.nssl.noaa.gov/Spring_2011/

HWT Facility – National Weather Center
9 May - 10 June 2011

Program Overview and Operations Plan

5/13/11 Version

Steven Weiss[1], Jack Kain[2], Mike Coniglio[2], James Correia[1], Israel Jirak[1], Chris Melick[1], Patrick Marsh[2] , Adam Clark[2], Chris Siewert[1], Conrad Ziegler[2], Ryan Sobash[3], Andy Dean[1], Tara Jensen[4], David Novak[5], Mike Bodner[5], and Faye Barthold[5]

(1) NOAA/NWS/NCEP Storm Prediction Center, Norman, Oklahoma
(2) NOAA/OAR National Severe Storms Laboratory, Norman, Oklahoma
(3) School of Meteorology, University of Oklahoma, Norman, Oklahoma
(4) NCAR/NOAA Developmental Testbed Center, Boulder, Colorado
(5) NOAA/NWS/NCEP Hydrometeorological Prediction Center, Camp Springs, Maryland

1. The NOAA Hazardous Weather Testbed

NOAA's Hazardous Weather Testbed (HWT) is a facility jointly managed by the National Severe Storms Laboratory (NSSL), the Storm Prediction Center (SPC), and the NWS Oklahoma City/Norman Weather Forecast Office (OUN) within the National Weather Center building on the University of Oklahoma South Research Campus. The HWT is designed to accelerate the transition of promising new meteorological insights and technologies into advances in forecasting and warning for hazardous mesoscale weather events throughout the United States. The HWT facilities include a combined forecast and research area situated between the operations rooms of the SPC and OUN, and a nearby development laboratory. The facilities support enhanced collaboration between research scientists and operational weather forecasters on specific topics that are of mutual interest.

The HWT organizational structure is composed of three primary overlapping program areas (Fig. 1). The first program area focuses on application of cutting edge numerical weather prediction models to improve hazardous convective weather forecasts under the auspices of the Experimental Forecast Program (EFP), and the second program tests research concepts and technology specifically aimed at short-fused warnings of severe convective weather under auspices of the Experimental Warning Program (EWP). A key NWS strategic goal is to extend warning lead times under the concept of "Warn-on-Forecast" through the development and application of convection-allowing numerical models to extend short-term predictability of hazardous convective weather. This provides a natural overlap between the EFP and EWP activities.

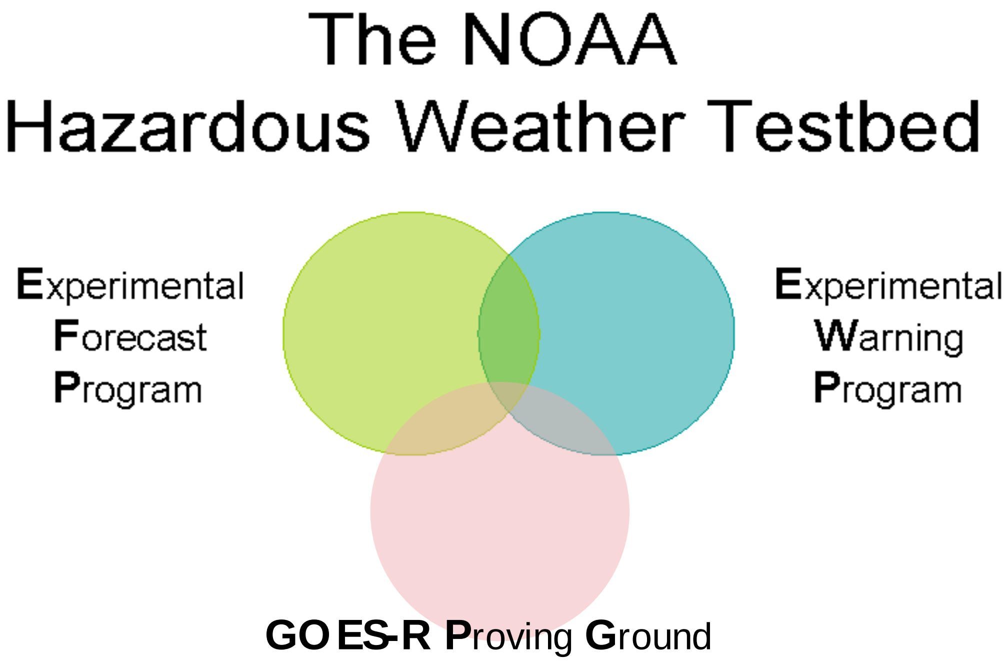


Figure 1: The umbrella of the NOAA Hazardous Weather Testbed (HWT) encompasses two program areas: The Experimental Forecast Program (EFP), the Experimental Warning Program (EWP), and the GOES-R Proving Ground (GOES-R).

As the distinction between warnings and short-term forecasts of convective weather gradually diminishes, the degree of overlap will continue to increase. Both programs reside beneath the overarching HWT organization with a focus on national hazardous weather needs.

In 2009 a GOES-R Proving ground was established at the SPC to test prototype satellite products from the next generation of geostationary satellites. The mission of the Proving Ground encompasses both warning and forecasting applications for hazardous mesoscale weather and testing and validation activities occur in the EFP and EWP parts of the HWT.

The specific mission of each HWT program branch is:

The Experimental Forecast Program - EFP

The EFP branch of the HWT is focused on predicting hazardous mesoscale weather events on time scales ranging from a few hours to a week in advance, and on spatial domains ranging from several counties to the CONUS. The EFP embodies the collaborative experiments and activities previously undertaken by the annual SPC/NSSL Spring Experiments. For more information about the EFP see http://www.nssl.noaa.gov/projects/hwt/efp/ .

The Experimental Warning Program – EWP

The EWP branch of the HWT is concerned with detecting and predicting mesoscale and smaller weather hazards on time scales of minutes to a few hours, and on spatial domains from several counties to fractions of counties. The EWP embodies the collaborative warning-scale experiments and technology activities previously undertaken by the OUN and NSSL. For more information about the EWP see http://www.nssl.noaa.gov/projects/hwt/ewp/.

The GOES-R Proving Ground – GOES-R PG

The GOES-R PG exists to provide pre-operational demonstration of new and innovative products as well as the capabilities available on the next generation GOES-R satellite. The overall goal of the Proving Ground is to provide day-1 readiness once GOES-R launches in late 2015. The PG interacts closely with both product developers and NWS forecasters. More information about GOES-R PG is found at http://cimss.ssec.wisc.edu/goes_r/proving-ground.html.

Rapid science and technology infusion for the advancement of operational forecasting requires direct, focused interactions between research scientists, numerical model developers, information technology specialists, and operational forecasters. The HWT provides a unique setting to facilitate such interactions and allows participants to better understand the scientific, technical, and operational challenges associated with the prediction and detection of hazardous weather events. The HWT allows participating organizations to:

- Refine and optimize emerging operational forecast and warning tools for rapid integration into operations
- Educate forecasters on the scientifically correct use of newly emerging tools and to familiarize them with the latest research related to forecasting and warning operations
- Educate research scientists on the operational needs and constraints that must be met by any new tools (e.g., robustness, timeliness, accuracy, and universality)
- Motivate other collaborative and individual research projects that are directly relevant to forecast and warning improvement

For more information about the HWT, see http://www.nssl.noaa.gov/hwt/. Detailed historical background about the EFP Spring Experiments, including scientific and operational motivation for the intensive examination of high resolution NWP model applications for convective weather forecasting, and the unique collaborative interactions that occur within the HWT between the research and operational communities, are found in Weiss et al. (2010 – see http://www.spc.noaa.gov/publications/weiss/hwt-2010.pdf)

2. HWT-EFP 2011 Spring Experiment Overview

Convective storms produce a wide variety of societal impacts resulting from tornadoes, large hail, damaging straight-line winds, heavy rain/flash flooding, and lightning. For example, the recent tornado outbreaks in April 2011 have caused hundreds of fatalities and several billion dollars in damage over the US. In addition, thunderstorm-generated heavy rain and flash floods are one of the leading causes of weather-related fatalities and property damage. According to NOAA economic statistics, warm-season thunderstorms cause ~70% of air traffic delays in the U.S. and cost the economy upwards of $4 billion dollars each year. Clearly, improved forecasts of thunderstorms will result in large societal benefits, and it is important for the HWT to explore additional thunderstorm processes and hazards during the Spring Experiment.

Building upon successful Experiments of previous years, the primary focus in 2011 will be the utilization of high-resolution convection-allowing numerical models and GOES-R next-generation products as guidance for the detection and prediction of hazardous convective weather. In addition to the traditional examination of the latest generation of advanced NWP modeling systems for the prediction of severe convective weather, there will be an expansion of collaborative efforts with the NCEP/Hydrometeorological Prediction Center to test and evaluate high resolution model forecasts of precipitation and excessive rainfall associated with warm season convection, including nocturnal MCS heavy rain events. Further, a new scientific emphasis will be placed on benchmarking the ability of convection-allowing models to predict details of convective initiation (CI), and to better understand environmental processes that impact storm initiation. CI is a key part of convective forecasting and is of interest to many specialized decision makers such as emergency managers, and the transportation and energy industries.

Each day during the experiment, a combination of experimental forecasting, subjective evaluation, discussion, and documentation activities will be conducted by a wide variety of participants, including operational forecasters, hydrologists, researchers, model developers, and university faculty and graduate students. The daily activity schedule includes routine interactions not only between the severe storm, CI, and QPF/heavy rain desks within the EFP, but there will be additional collaboration between the EFP and EWP participants. The latter activities are designed to enhance the natural operational progression from forecast to warning, and will serve to provide two-way feedback between the two closely related decision-making processes.

High-Resolution Numerical Models

The majority of guidance products for CI, severe weather, and QPF/heavy rainfall will be derived from 1) a 50 member Storm-Scale Ensemble Forecast (SSEF) system and 2) multiple deterministic convection-allowing models (CAMs). Most experimental model products will be based on WRF-model forecasts using no convective parameterization and 3-4 km grid spacing covering CONUS geographic areas. The model guidance will be generated by the NOAA/National Severe Storms Laboratory (NSSL), the University of Oklahoma's Center for Analysis and Prediction of Storms (OU-CAPS), the NOAA/National Centers for Environmental Prediction Environmental Modeling Center (NCEP/EMC), the NOAA/Earth System Research Laboratory Global Systems Division (ESRL/GSD, the NWS/Meteorological Development Laboratory (MDL), the Cooperative Institute for Meteorological Satellite Studies-University of Wisconsin (CIMSS-UW), and the Cooperative Institute for Research in the Atmosphere-Colorado State University (CIRA-CSU). A new concept being tested is the creation of a small seven-member Storm Scale Ensemble of Opportunity (SSEO), composed of existing CAMs that are available all year. This will help explore the minimum size ensemble system that is needed to provide useful information about the probability of convective events and a range of plausible scenarios.

The variety of model output will allow us to explore different types of model guidance including products derived from both ensembles and deterministic forecasts. As we move toward the Warn-on-Forecast concept, an important goal that will be addressed is the extraction and display of relevant storm hazard information from model-generated thunderstorms, and the development of probabilistic guidance (including some bias-corrected fields) that provides uncertainty information about specific convective threats such as tornadoes, hail, wind, and heavy rain.

This spring there will be a renewed emphasis on the specification and evolution of the mesoscale pre-convective environment as it applies to the CI challenge, while continuing to explore sensitivities to initial and lateral boundary conditions, radar data assimilation, model physics, model dynamic cores, and updates to initial conditions from multiple model runs including hourly short-term forecasts. Some aspects of model performance will be assessed subjectively during daily evaluation activities, and we will again work with the Developmental Testbed Center (DTC) to provide objective verification results.

GOES-R Proving Ground Satellite Products

A number of GOES-R products will be demonstrated this year within the EFP. These include 1) a suite of convective initiation nowcast and associated cloud-top cooling rate products (CIMSS; UAH), 2) an overshooting-top and "Enhanced-V" detection product (CIMSS), 3) simulated GOES-R ABI satellite imagery and band differences using WRF model 3D gridded fields and radiative transfer models (CIMSS; CIRA; NSSL; CAPS), and 4) simulated total lightning using ice hydrometeor fields from WRF models (SPoRT; NSSL; CAPS). In addition, multiple GOES-R Risk-Reduction products will be available for demonstration including a 0-9 hr Lagrangian differential theta-e/precipitable water "Nearcast" products (CIMSS) and a 0-3 hr severe hail probability product (CIRA).

More detailed information about the many experimental models and products is found in the following sections.

3. Convective Storm Hazards and Forecasting Challenges

Severe Convective Storm Forecasting

The Spring Experiment has traditionally focused on the testing and evaluation of cutting edge NWP models for the prediction of severe thunderstorms. SPC forecasters are tasked with predicting severe thunderstorm phenomena that occur on scales too small to be resolved by many observing and most operational NWP models. As a result, the forecasting methodology concentrated on diagnosing the synoptic and mesoscale environment and how it would evolve with time, and determine where/when deep convection may develop and the spectrum of storm types the environment can support. Thus, forecasters typically must use their experience and knowledge of convective processes to determine details such as the time and location of convective initiation, mode, intensity, and evolution. In recent years, higher resolution models capable of representing convective storms such as MCSs and even supercells have complemented the long-standing environment-based (e.g., CAPE/shear parameter space) forecast methodology. A key challenge, however, is to develop ways to extract meaningful stormscale information from high resolution model grids that can be used to identify potential severe storm characteristics, such as the strength of a storm updraft or whether the model storm contains rotating updraft.

Owing to considerable uncertainty in the specification of the pre- and near-storm mesoscale environment, coupled with model physics errors, convective-scale predictability is often low. Thus, single deterministic model solutions can contain large forecast errors of convective storms. Ensemble concepts at the stormscale have been applied since 2007 by CAPS in their Storm Scale Ensemble Forecast (SSEF) system, which continues to be tested and refined to provide useful information on the range of storm possibilities, and new products have been developed to assess the likelihood of model storm intensity and severe potential. During the Spring Experiment, forecast teams will continue to examine the utility of high resolution model guidance including the SSEF to help forecasters issue more detailed severe storm forecasts in time and space. Particular emphasis will be given this year on the creation of probabilistic severe storm forecasts for 3-hr periods over a movable mesoscale domain during the primary afternoon and evening diurnal cycle from 18-06 UTC. The region of interest will move daily over the CONUS east of the Rockies to coincide with areas of increased severe storm/heavy rainfall potential, and/or in regions where greater forecasting challenges exist. The ability of the SSEF to add unique information to observational data and standard mesoscale and convection-allowing model guidance will be a cornerstone of the severe thunderstorm components, as recent deadly tornado outbreaks in spring 2011 indicate that the issuance of higher temporal resolution severe thunderstorm forecasts is a key societal need.

Convective Initiation Forecasting

Convection initiation (CI) has been treated as a conditional, short term problem in severe storms forecasting. Factors thought to play a role in CI include the removal of a capping inversion either through PBL growth, large scale ascent, or internal boundary layer circulations such as horizontal convective rolls, sea breezes, outflow boundary and outflow boundary collisions, and deep convergence zones (fronts, drylines, wind-shift lines). See the reviews by Wilson and Roberts (2006) and Weckwerth and Parsons (2006). CI is inherently a local, organized turbulence process influenced by meso- and synoptic- scale environmental pre-conditioning. CI occurs on a variety scales from individual cells from a cloud field to linear line segments and can occur in episodes. An episode can range from minutes to hours and be associated with the same feature (e.g. front) thus can be anywhere from one to 100 km. Once the first storms appear it is necessary to separate out primary and secondary convection initiation where secondary convection is any subsequent initiation of storms triggered by active convection. This can be from gravity waves propagating ahead of a convective line, the so-called warm advection wing ahead of a strong line of storms, or from an outflow boundary from pre-existing convection.

The overall intent of making CI a focus for HWT is to see how well models anticipate and forecast CI such that CAMs can contribute to making first guess forecasts and aid the forecaster. Experimental forecasts of CI will be made over smaller, movable mesoscale domains that are often a subset of the severe component forecast domain. Thus documenting how well the models forecast CI, both spatially and temporally, and how much improvement a human forecaster can add to these forecasts is the first step in assessing the CAMs ability to provide useful guidance for CI forecasts. We hypothesize that CAMs should be relatively successful in anticipating CI since the mesoscale processes that precede CI should be well resolved. The primary factor in many cases is the persistent vertical circulation along a boundary which leads to moisture upwelling.

Although most research on CI focuses specifically on modeling and observations of drylines, persistent vertical circulations in the presence of upwelling moisture should be present along most, if not all, boundaries. Variations in the environmental LCL and LFC heights, available instability, depth and/or persistence of the convergence, parcel residence time in the updraft, lapse rate immediately above the boundary layer, or unfavorable large scale/mesoscale subsidence may all act to prevent CI.

Quantitative Precipitation Forecasting

The Spring Experiment will also include a QPF component to complement the traditional HWT focus on severe convection. Floods are a leading cause of weather-related deaths, as evidenced by the recent Atlanta, GA (2009), Nashville, TN (2010), and Caddo Gap, AR (2010) floods. It has been long noted that QPF scores exhibit lower skill during the warm season, and this is largely attributable to the dominant contribution from convection on warm season precipitation.
Traditional synoptic scale and mesoscale NWP models such as the GFS and NAM use convective parameterization schemes (CPS) to account for the sub-grid scale effects of deep convection, and the

CPS have tendencies to exhibit a number of systematic errors. These include: erroneous precipitation "bulls-eyes", considerable phase errors in time and space, especially for MCS development that accounts for much of the warm season rainfall across the US, and a low bias for the most critical heavy rain producing thunderstorm events. Previous studies have found that convection-allowing models have the ability to better predict convective mode, provide more realistic amplitude of rainfall, and better represent the diurnal cycle and propagation of rainfall systems. It has also been demonstrated that a SSEF with a relatively small number of members has improved QPF skill compared to a larger mesoscale ensemble using parameterized convection.

Post processing approaches have been developed to improve QPF, including various bias-correction approaches, neighborhood probabilities, and probability matched means. However, these approaches have rarely been tested in a real-time forecasting environment. In addition, unique and potentially useful information derived from a SSEF, such as the maximum member amount and spaghetti plots of the distribution of individual member predictions of heavy rainfall, may help forecasters better cope with data overload.

To addressing these outstanding issues, the QPF forecast teams will incorporate guidance from convection-allowing models, the SSEF, and post processed guidance (HRMOS, bias-corrected SSEF) to produce experimental probabilistic QPF forecasts for 6 hr periods valid 18-00 UTC, 00-06 UTC, and 06-12 UTC that cover the primary diurnal convective storm periods. Forecasters will use the experimental guidance to supplement traditional model guidance (e.g., NAM, SREF) in the forecasting process. The experimental forecasts will depict contours for the probability of exceeding (POE) 0.5" and 1" thresholds for each 6 hr period, using categorical terms of slight = 25%, moderate = 50% and high= 75% probability. In addition, to explore the utility of the convection-allowing models to better predict localized heavier precipitation amounts, each forecast that includes a probability of 1" or greater will also identify the expected maximum value within the 1" POE for each 6 hr period.

To facilitate collaboration and discussion, the QPF domain will be the same as the Severe Weather domain each day.

4. Developmental Testbed Center Objective Evaluation Background

New Objective Verification Approaches

Subjective verification of model forecasts has been a cornerstone to HWT activities in previous years. This approach has provided valuable insights into how forecasters use numerical models, and facilitates the gathering of information about the value of new guidance tools from the perspective of a forecaster. In addition, traditional verification measures (e.g., Equitable Threat Score or ETS) used for synoptic scale and mesoscale model forecasts of discontinuous variables such as precipitation typically provide less useful information (and even misleading information) about forecast accuracy as the scale of the phenomena being evaluated decreases. This is because the ETS is proportional to the degree of grid scale overlap in space and time between the forecasts and observations, and there is typically low predictability on convective scales. Despite these limits, operational severe weather forecasters have often found value in higher resolution forecasts of thunderstorms and convective systems, since they can provide unique information about convective mode, coverage, and evolution that is not resolved by mesoscale models using parameterized convection. In recent years, we have found that subjective evaluation has great potential to serve as a comparative benchmark for assessing new objective verification techniques designed for high resolution NWP from convection-allowing models (CAMs), and has had a significant positive impact on model development strategies.

In order to better utilize subjective and objective verification techniques in a complementary manner, simulated composite reflectivity and 6-hr QPF output from several model runs will be evaluated using subjective visual comparisons and objective statistical measures produced by the Developmental Testbed Center's (DTC) Model Evaluation Tools (MET). The focus this year will be on probabilistic predictions, particularly of extreme precipitation events and strong convection as it relates to convective initiation. All members of the Center for Analysis and Prediction of Storms (CAPS) Storm Scale Ensemble Forecast (SSEF) system will be evaluated for select variables (see Table 1). Ensemble products from the twenty-four or twenty-five member (ssef_s4ens), fifteen member (ssef_s4ens15), and five member (ssef_s4ens5) ensembles selected by the NOAA Storm Prediction Center (SPC) will also be evaluated. Operational (or near-operational) models will be used as a baseline for comparison. Probabilistic baselines include ensemble products from the Short Range Ensemble Forecast (SREF) and Hybrid Regional Ensemble Forecast (HREF), and High-Resolution Model Output Statistics (HRMOS) systems. The deterministic models include the 12 km operational North American Mesoscale Model (NAM), the 3 km High Resolution Rapid Refresh (HRRR), both 4km east HiResWindows (NMM and ARW), the 12 km NMM-B parent domain (NMMB_12) and 4 km CONUS nest (NMMB_4). Other contributing models, such as the Storm Scale Ensemble of Opportunity generated by SPC and the NOAA/GSD LAPS short-range deterministic and ensemble member will be brought in and archived for retrospective studies.

MET is designed to be a highly-configurable, state-of-the-art suite of verification tools. We will focus on the use of the object-based verification called Method for Object-based Diagnostic Evaluation (MODE) that compares gridded model data to gridded observations for the QPF and simulated reflectivity forecasts. MODE output including plots of the objects (see Figure 2) and the attributes associated with the objects will be used to evaluate the CAMs to diagnose different types of convective modes considered important in forecasting convective weather. We will also be providing plots of the smoothed fields for calculating neighborhood statistics (see Figure 2) along with aggregation of statistics such as Fraction Skill Score (FSS; see Appendix N). Traditional categorical verification statistics for both probabilistic and single-value (deterministic) fields will be computed. Some of these scores will be plotted and many of them will be available in the DTC database and displayed using the web-based METViewer interface. Details about the DTC MET system can be found at http://www.dtcenter.org/met/users/ . A description of the statistics and MODE attributes provided during the experiment can be found in the MET Users Guide (in Grid Stat and MODE sections as well as Appendix C) and can be downloaded from: http://www.dtcenter.org/met/users/docs/overview.php

Verification "truth" will be provided by NSSL National Mosaic and Multi-Sensor QPE (NMQ) multi-sensor Quantitative Precipitation Estimates (QPE) and three-dimensional radar reflectivity datasets. See http://www.nssl.noaa.gov/projects/q2/ for more information about the NMQ.

Table 1. List of variables (and thresholds) to be evaluated and ready during the subjective evaluation portion of the 2011 Spring Experiment. Evaluation of the Storm Scale Ensemble of Opportunity, several sub-ensembles representing physics experiments, and the LAPS short-range ensemble will be performed by DTC retrospectively. Additional variables, such as 1-hr Accumulated Precipitation and 1 km reflectivity and corresponding probability fields will also be evaluated as resources allow retrospectively.

Members	**REFC (20,30,35,40,50,60 dBZ)**	**APCP_06 (0.5,1.0,2.0")**	**Prob_APCP_06 (0.5,1.0,2.0")**
SSEF Ens (Mean, Max, Prob-Match, Prob-Neigh)	GSS, CSI, FBIAS, FSS MODE Attrib. Rank Histograms	GSS, CSI, FBIAS MODE Attrib. Rank Histograms	Brier Score, ROC, AUC, Reliability Dia. MODE Attrib.
SSEF Ens5,15 SSEF Ens Bias Corr. (Mean, Max, Prob-Match, Prob-Neigh)		GSS, CSI, FBIAS MODE Attrib. Rank Histograms	Brier Score, ROC, AUC, Reliability Dia. MODE Attrib.
<u>Prob. Baselines</u> SREF HREF HRMOS	GSS, CSI, FBIAS, FSS MODE Attrib.	GSS, CSI, FBIAS MODE Attrib.	Brier Score, ROC, AUC, Reliability Dia. MODE Attrib.
<u>Det. Baselines</u> HRRR EastNMM (HiRes) EastARW (HiRes) NAM_Ops NMMB_12 NMMB_4	GSS, CSI, FBIAS, FSS MODE Attrib.	GSS, CSI, FBIAS MODE Attrib.	
SSEF members	GSS, CSI, FBIAS, FSS MODE Attrib.	GSS, CSI, FBIAS MODE Attrib.	

Key: Traditional statistics include Gilbert Skill Score (GSS), Critical Success Index (CSI), Frequency Bias (FBIAS), Brier Score, Receiver-Operator Characteristic Curve (ROC), Area under ROC Curve (AUC), and Reliability Diagrams. The statistic calculated for the neighborhood is Fraction Skill Score (FSS). MODE attributes include centroid distance, intersection area, symmetric difference and more. Rank Histograms (or Talagrand Diagrams) and Spread will be provided for SSEF and SSEO ensembles.

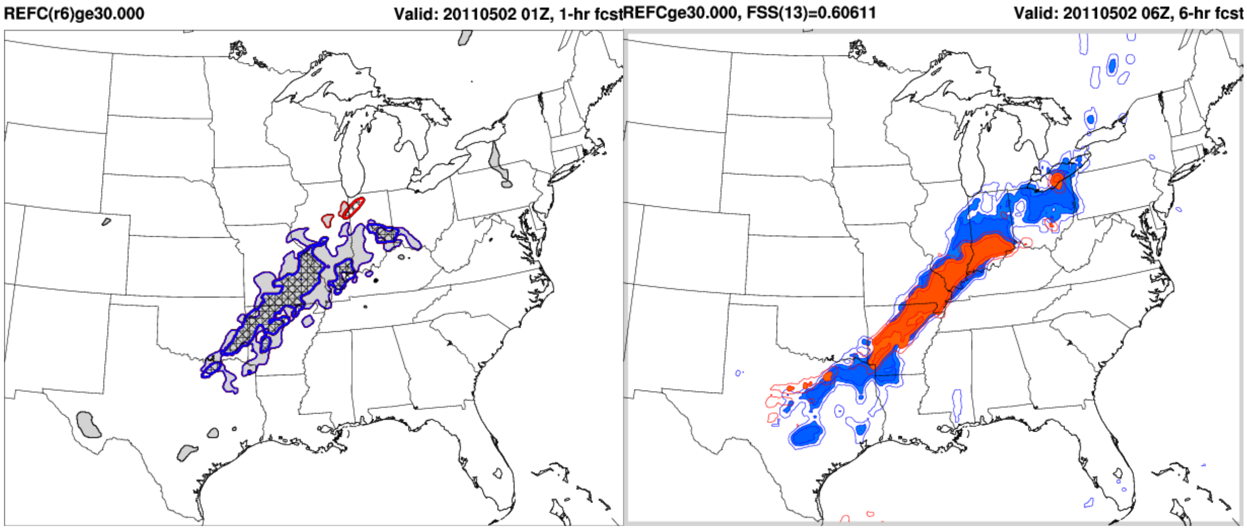


Figure 2. Example of MODE object plot (left) and Neighborhood plot (right). MODE objects: observation (hatched) and forecast (grey) objects/clusters of objects. Outline colors correspond to matched clusters. Black are unmatched objects/clusters. Neighborhood: fractional coverage of observation (orange) and forecast (blue) fields used in calculating Fraction Skill Score (FSS). Neighborhood reflected by number after FSS.

5. Experimental Models

The 2011 Spring Experiment will benefit from the continued participation and key contributions from CAPS, EMC, and GSD. Each of these core collaborators (along with NSSL) will generate high resolution, convection-allowing model guidance initialized at 00 UTC, and some will provide additional model runs at 12 UTC and/or other times during the convective day. Model domains cover from three-fourths to full CONUS regions, and most 00 UTC models produce forecasts to at least 36 hrs. For shorter-term hourly update forecasts, each GSD High Resolution Rapid Refresh (HRRR) run will go out to 15 hrs.

Special Convective Fields

A number of special convective fields have been developed and tested in the HWT in recent years to explore innovative ways of extracting unique information about convective storms and model performance. Several of these are listed below.

Hourly Maximum Fields (HMFs)

A key challenge for effective operational use of CAMs is the efficient extraction and display of information about model-generated convective storms and their associated hazards. Similar to actual thunderstorms, simulated convective storm features often evolve on convective time scales commonly measured in minutes, not hours. Thus, it is important to monitor model storm behavior at a higher frequency than hourly output provides. Rather than simply outputting model fields on a much more frequent basis, which would overburden operational bandwidth and workstations, a strategy has been developed to monitor and track small-scale, rapidly changing convective storm features every model time step between regular hourly model output times. The individual grid point temporal maxima during each hour are saved and output at the regular hourly intervals, providing a useful perspective on the maximum intensity and track of strong convective phenomena in the model forecasts.

This data processing is intended to fill in the temporal gaps between the standard top of the hour model output and provide unique information about the most intense storm attributes, which are unlikely to occur only at the hourly output times. Currently, the tracking of “history variables” is applied to; 1) low level simulated reflectivity, 2) updraft speed, 3) downdraft speed, 4) updraft helicity (UH), 5) 10-m wind speed, and 6) vertically integrated graupel grids.

With the exception of vertically integrated graupel from WRF-NMM models, the HMFs are available from all WRF model configurations used in the Spring Experiment. This approach represents an important step in exploring new ways to extract output fields and/or compute new diagnostics from convection-allowing models, and the output has been utilized in SPC operations for several years with promising results. The HMFs were first tested in the NSSL-WRF, and subsequently have been implemented in a number of CAMs across the country, including at EMC, GSD, NCAR, and AFWA.

Total Lightning Threat

There are three total lightning threat experimental parameters that represent microphysical properties of hydrometeor types and charge separation processes within the WRF model convective storms. This is based on work by McCaul and colleagues at SPoRT in Huntsville.

Lightning Threat 1: Upward flux of ice hydrometeors at the -15C level
Lightning Threat 2: Column integrated ice hydrometeors
Lightning Threat 3: Blended solution of Threats 1 and 2 that optimizes temporal variability best depicted by Threat 1 and areal coverage that is best depicted by Threat 2. Threat 3 is very heavily weighted by Threat 1. The units are *flashes* km^{-2} *per 5 min*.

These 3 fields are based on the hourly maximum of the ice hydrometeor fields and therefore should be considered to represent the hourly maximum total lightning threats, and are based on work done by McCaul and colleagues at SPoRT. It is recommended that users primarily focus on Lightning Threat 3 field since it statistically combines attributes of the two fundamental physical processes represented in Threats 1 and 2. The Lightning Threat products were implemented in the NSSL-WRF and verification results from 2010 indicate the fields skillful when compared to SREF thunderstorm guidance.

The explicit total lightning is highly dependent on the ability of the parent model to predict timing and location of convective storms. In addition to the NSSL-WRF, the lightning threat products have been implemented into the CAPS SSEF ARW members and HRRR model for this spring.

Simulated Satellite Imagery

Working with scientists at both CIRA/CSU and CIMSS/UW, simulated satellite imagery has been available since 2010 from the NSSL-WRF model gridded fields to represent output from a number of channels planned for the GOES-R satellite. The simulated imagery is generated from model gridded surface fields and vertical profiles of predicted moisture, temperature, and clouds, and is sensitive to the microphysics scheme employed in the numerical model.

Selected WRF forecast grids are distributed to both CIRA and CIMMS, where local versions of radiative transfer models are applied to create simulated radiance/brightness temperature fields. The images are then sent to the HWT for display in the N-AWIPS system. This new capability will allow users to directly infer the 4-D evolution of model dynamic processes and associated moisture fields, and to make visual comparisons between satellite observations and operational model output at resolutions comparable to GOES satellite imagery. The simulated GOES imagery allows forecasters to rapidly discern model forecasts of moisture transport, regions of ascent and subsidence, low clouds, and indications of the vertical extent of clouds including shallow and deep convection. Experience over the past year confirms that animated loops of model-derived simulated GOES imagery allow forecasters and model developers to subjectively ascertain dynamic processes within the model atmosphere very quickly and improve our understanding of model forecast evolution.

A new NSSL-WRF model product in 2011 will be a 10.35-12.3 micron band difference product from CIRA that is designed to illustrate capabilities that will be available with GOES-R. This difference is most sensitive to water vapor residing in the PBL, and it is hypothesized that this field has potential to provide information about low level moisture trends.

The simulated satellite imagery products are only available from the NSSL-WRF model. More details about the simulated imagery are found in the 2011 GOES-R Proving Ground Operations Plan.

Convective Initiation Fields

The occurrence of deep, moist convective initiation (CI) can be viewed from different observing platforms. For example, CI can be determined using remote sensing observations of radar reflectivity, satellite brightness temperature, and/or lightning generation, but it can also be assessed by measuring physical properties within the convective cloud. Since a first step in predicting CI is to evaluate ways to determine the occurrence of CI, several quantitative criteria have been developed to identify: 1) areas of convectively active (CA) clouds, and 2) initiation of new convectively active clouds, or CI, which is a subset of CA. For the CA test, we currently are evaluating 3 different sets of criteria separately. Each set is based on the premise that a storm ("convection") in a model forecast can be identified by the presence of a deep, moist, precipitating convective updraft, but the presence of such a feature is inferred in 3 distinct ways:

- **The lightning flash-rate-density (FRD) algorithm developed by McCaul et al. (2009)**. This algorithm, based on graupel flux at the -15^{o} C level and vertically integrated graupel, was originally formulated to predict the FRD of total lightning, but it is used here to infer the presence of (primarily) CG lightning, following the work of Miller et al. (2010). This is done by mapping National Lightning Detection Network (NLDN) strike data to the model grid, then comparing the climatology of model-predicted FRD to that of the NLDN data. A threshold value of FRD is determined iteratively to provide approximately the same frequency of grid-point activation (i.e, frequency of threshold exceedance) as given by the NLDN data over the same time period. For the 2011 Spring Experiment, a threshold value of 0.55 $\text{km}^{-2}(5\text{ min})^{-1}$ is used, based on calibration in the 4 km NSSL-WRF model from 11 March – 10 June 2010. Thus, for the "LTG" criteria set, a CA grid point is identified as any point at which the FRD exceeds 0.55 $\text{km}^{-2}(5\text{ min})^{-1}$.

- **Explicit measurement of updraft strength and precipitation content.** A model grid column is defined as "convectively-active" given the following conditions: (1) the maximum updraft exceeds a threshold value W_{min}; (2) EITHER the maximum graupel mixing ratio exceeds a threshold value Q_G (g/kg), OR the maximum rain mixing ratio exceeds a threshold value Q_R (g/kg), OR both conditions are met. Current threshold values of W = 5 m/s, Q_G = 2 g/kg, and Q_R = 1 g/kg allow for a range of intensities of surface-based or elevated, warm- or cold-season, and extra-tropical or tropical storms. To prevent shallow terrain-induced updrafts from being falsely identified as convection, the grid column is scanned from the top of the boundary layer to the equilibrium level (i.e., approximating the maximum probable CAPE-bearing layer depth) to identify the maximum local updraft value. These explicit model diagnostics comprise the "WQQ" set of criteria for CA.

- **Simulated reflectivity**. The 35dBZ threshold for simulated reflectivity (computed as in Kain et al. 2008) is used to identify a CA grid point, as in Roberts and Rutledge (2003), Mecikalski and Bedka (2006), and other studies. In order to avoid bright-banding effects, this threshold must be exceeded at the -10^{o} C level (see Gremillion and Orville 1999). This defines the "REF" criteria set for CA.

CA points are identified every time step during model integration. A list of specific model post-processed CI/CA fields from the NSSL-WRF, CAPS SSEF ARW members, and the HRRR model, as well as cited references, are found in Appendix A.

Spring Experiment Modeling Systems

CAPS 4 km Storm Scale Ensemble Forecast

A major CAPS contribution is a 50 member *Storm Scale Ensemble Forecast (SSEF) system* with grid spacing of 4 km and forecasts to 36 hrs covering a CONUS domain (Fig. 3). The forecasts utilize the resources of the National Institute for Computational Sciences (NICS)/University of Tennessee located at Oak Ridge National Laboratory. The SSEF is a multi-model ensemble with 41 ARW members, 5 NMM members, and 4 ARPS members. Nearly half of the members (21) contain mixed initial condition (IC)/physics perturbations (17 ARW and 4 NMM). There is also substantial physics-only diversity provided in many ARW members through the use of seven microphysics and five PBL schemes. These include four double-moment microphysics schemes, plus additional parameter perturbations in the WSM6 single-moment microphysics and two of the PBL schemes.

In all members, the background initial condition will come from interpolation of the 12 km NAM analysis. Mesoscale atmospheric perturbations will be introduced in the initial and lateral-boundary conditions of the mixed IC/physics members by extracting perturbations from EMC's operational Short Range Ensemble Forecast (SREF) system and applying them to the 21 members. Convective-scale perturbations will be introduced in the initial conditions of all but two members (one ARW and one ARPS) by assimilating reflectivity and velocity data from the national NEXRAD radar network and a cloud analysis as part of a CAPS 3DVAR system. This year CAPS will introduce a cycled 3DVAR data assimilation into one ARW and two ARPS members to determine if the cycling provides better dynamic balance at the start of the model integration. Comparison of output from these different data assimilation members will allow us to isolate the impact of different assimilation methods from other sensitivities at 4 km grid spacing.

Overall, the SSEF configuration builds upon lessons learned from the earlier SSEF systems tested during the 2007-2010 Spring Experiments, and the development this year of a larger multi-model, multi-physics, multi-IC SSEF is expected to be more robust and contain improved statistical performance. For operational forecasting applications, a core subset of 24 members consisting of the ARW, NMM, and ARPS control members plus the ARW and NMM mixed IC/physics perturbations will provide the basis for the SSEF post-processed statistical products. These core members were selected since earlier studies indicate that mixed IC/physics members contribute to most of the ensemble spread. The physics-only members will be used to isolate performance sensitivities and better understand the impact of different parameterizations. In addition, comparative forecast performance will be assessed for 5- and 15-member subsets of the SSEF, in order to determine if a smaller ensemble can provide useful guidance on the range of plausible solutions and the likelihood of hazardous convective weather events. Finally, new post-processing will include creation of bias-corrected precipitation products such as ensemble mean and exceedance probability guidance.

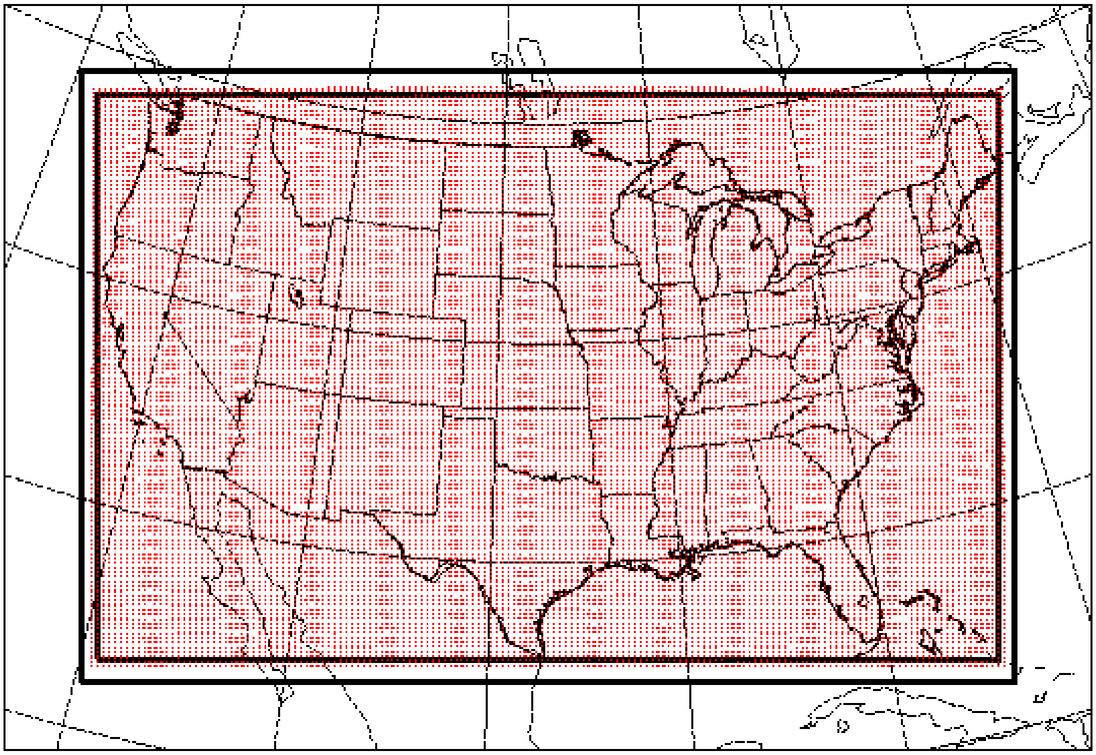


*Figure 3. CAPS computational domains for the 2011 Season. The outer thick rectangular box represents the domain for performing 3DVAR (**Grid 1** – 1200×780). The red dot area represents the WRF-NMM domain (**Grid 2** – 790×999). The inner thick box is the domain for WRF-ARW and ARPS and also for common verification (**Grid3** - 1160×720 at 4 km grid spacing).*

The CAPS SSEF member configuration is in Appendix B, with the 24 core members listed in red. The list of SSEF post-processed products for the HWT is in Appendix C.

EMC Models

CONUS 4 km WRF-NMM

SPC forecasters have used output from earlier versions of the experimental EMC WRF-NMM model since the spring of 2004. The current version is nested within the 12 km NAM and incorporates NAM ICs/LBCs. It is run throughout the year over a CONUS domain Fig. 4) twice daily at 00 and 12 UTC with forecasts to 36 hrs. Output is available to all forecasters via a web page at http://wwwt.emc.ncep.noaa.gov/mmb/mpyle/cent4km/conus/00/.

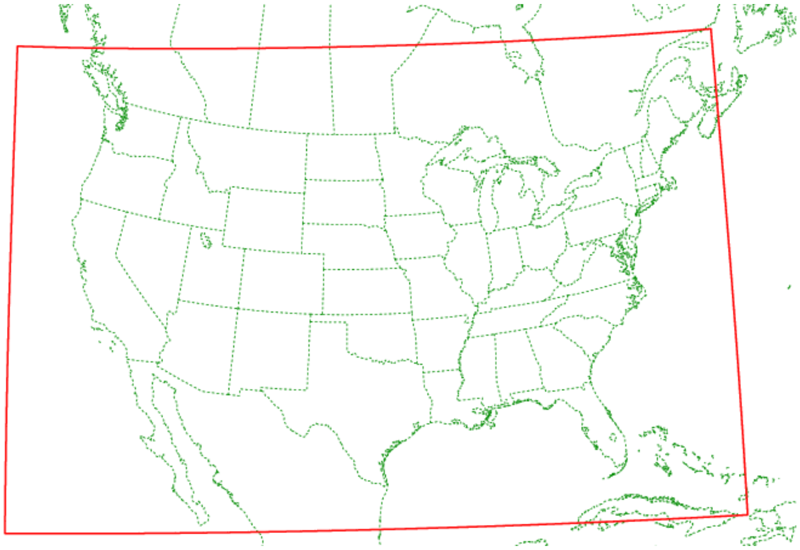


Figure 4. EMC 4 km WRF-NMM domain with 1239x920 horizontal grid points.

High Resolution Window 4 km WRF-NMM and 5.1 km WRF-ARW

Based on findings from the HWT Spring Experiments and operational use of early CAMs at SPC, the EMC implemented CAMs in the operational High Resolution Window (HiResW) operational run slot in 2007. WRF models are run three times daily covering much of the CONUS providing forecasts to 48 hrs. At 00 and 12 UTC, 4 km WRF-NMM and 5.1 km WRF-ARW models are run over the eastern three-quarters of the CONUS and western Atlantic Ocean, and these will be available for use in the HWT (Fig. 5). In addition, at 06 UTC the HiResW WRF models are run over a domain covering the western three-quarters of the CONUS and the eastern Pacific Ocean. In order to complete both WRF models in the same amount of time, the more computationally intensive ARW is run at coarser horizontal resolution than the WRF-NMM. The HiResW model runs are also nested within the 12 km NAM.

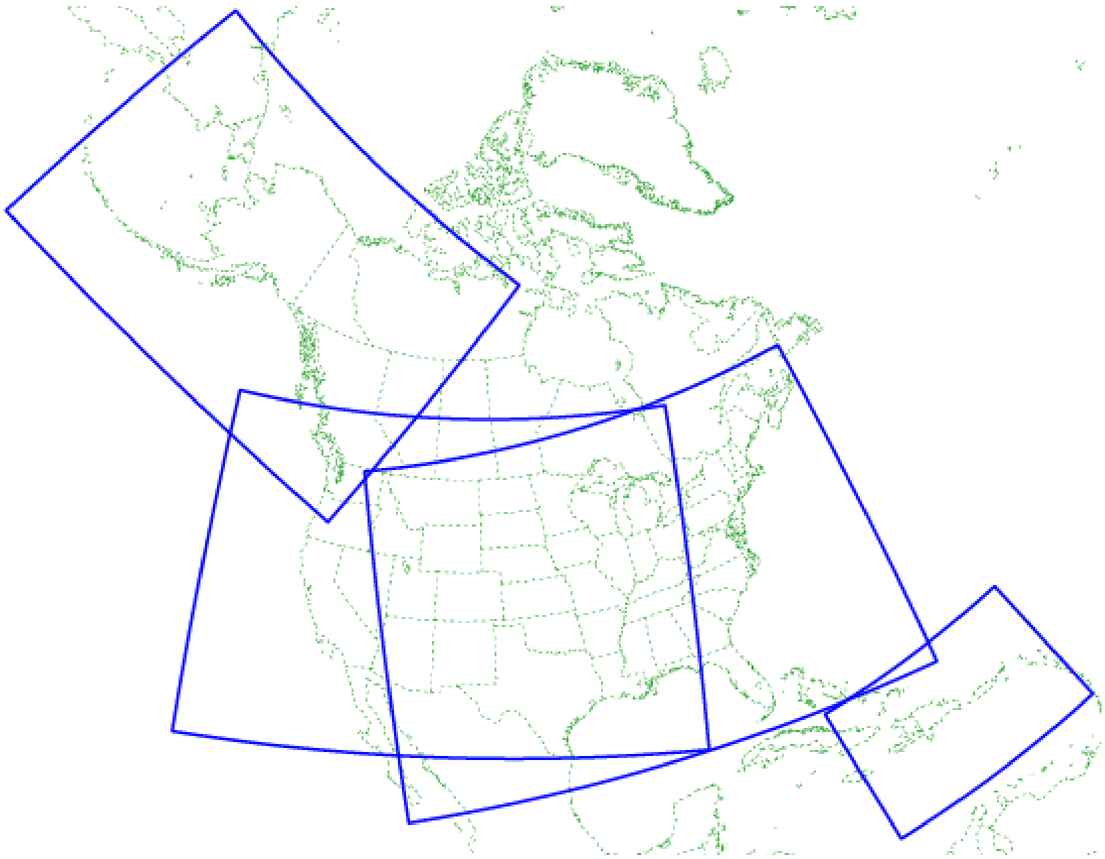


Figure 5. HiResWindow domains for (left to right) Alaska,West and East CONUS, and Puerto Rico. For the two CONUS domains, there are 1099x778 horizontal grid points for the 4 km WRF-NMM, and 874x614 horizontal grid points for the 5.1 km WRF-ARW.

NAM 4 km CONUS Nest

EMC is currently in the final testing phase of a new model to run in the North American Mesoscale (NAM) run slot, scheduled to replace the current 12 km NAM/WRF-NMM this summer. The new 12 km **N**on-hydrostatic **M**ultiscale **M**odel on a rotated Arakawa **B**-grid, hence the name NMMB, will run four times daily at 00, 06, 12, and 18 UTC providing forecasts to 84 hrs, and it will comply with the NOAA Environmental Modeling System (NEMS) framework. An advantage of the new NEMS-NMMB system is the ability to run concurrent higher resolution nests within the parent 12 km NMMB. Currently the nests are 1-way with LBCs coming from the parent model every time step. The 4 km NAM Nest will run four times daily with forecasts to 60 hrs (see Fig. 6 for NMMB domains). There are also plans to run very high resolution, small domain relocatable 1.33 km (1.5 km) Fire Weather Nests in the CONUS (Alaska).

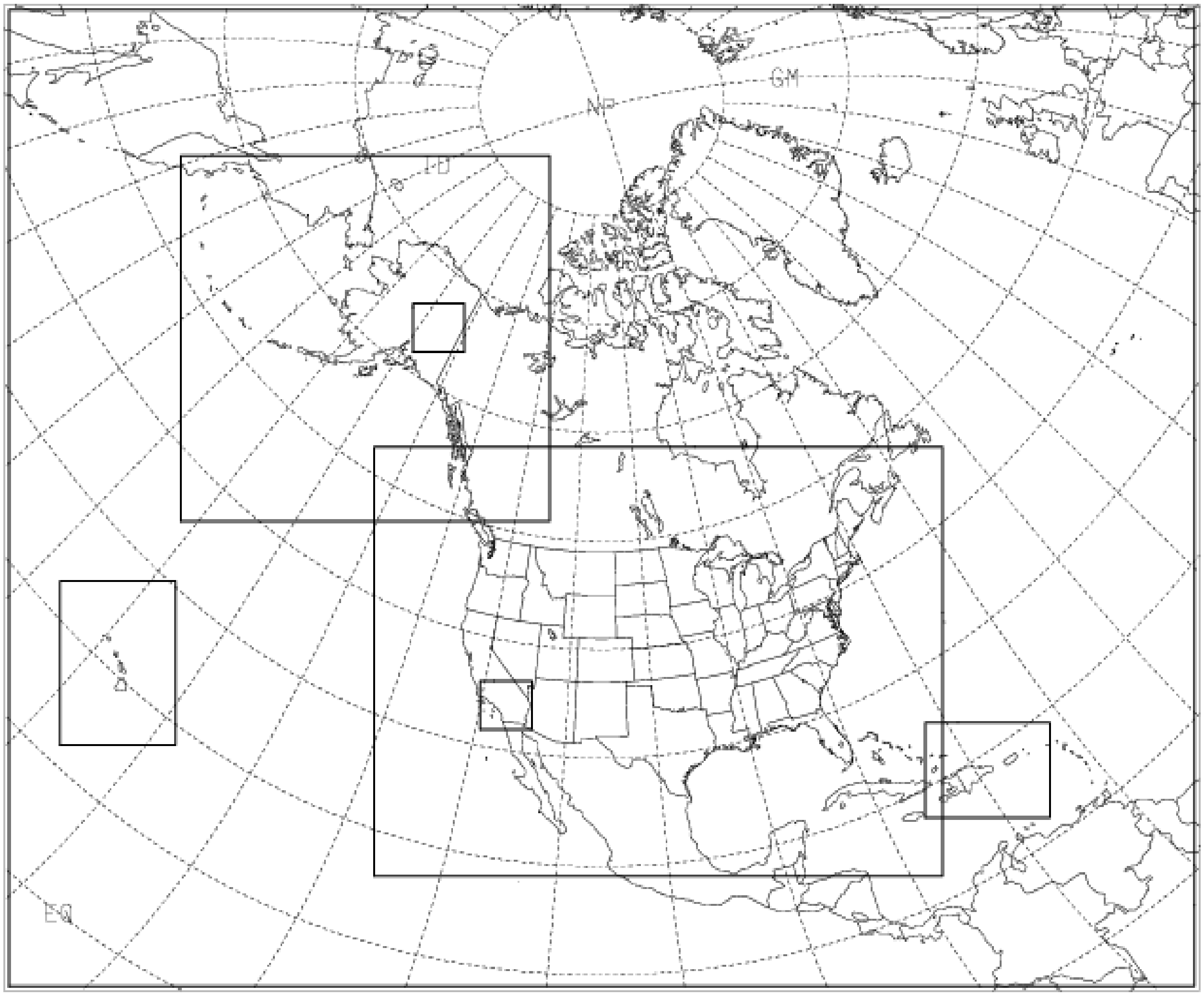


Figure 6. Domain of 12 km NAM-NMMB (outer edge), and 6 km Alaska, 4 km CONUS, and 3 km Hawaii and Puerto Rico Nests indicated by regional domains. Also shown are small relocatable Fire Weather Nests over the CONUS (1.33 km) and Alaska (1.5 km). The 4 km CONUS Nest contains 1371x1100 horizontal grid points.

NSSL 4 km WRF-ARW Model

SPC forecasters have used output from the experimental 4 km WRF-ARW produced by NSSL since the fall of 2006. This WRF model is run once daily at 00 UTC throughout the year over a full CONUS domain (Fig. 7) with forecasts to 36 hrs. Output is also available on the internet at http://www.nssl.noaa.gov/wrf/.

Figure 7. NSSL 4 km WRF-ARW domain with 1200x800 horizontal grid points.

Storm Scale Ensemble of Opportunity

Using output fields from existing deterministic CAMs initialized at 00 UTC, an experimental Storm Scale Ensemble of Opportunity (SSEO) is being created to provide summary and probabilistic information for a variety of convective weather threats. The SSEO currently consists of seven members: NSSL-ARW, CONUS WRF-NMM, HiResW WRF-NMM and WRF-ARW, NMMB Nest, and two time-lagged HiResW members from 12 hrs earlier. This SSEO will permit testing of a small storm scale ensemble that will be available year-round (not just during the Spring Experiment), and in principle it can be applied to a wide range of convective hazards during different seasons of the year. A group of QPF and convective storm attribute products have been tested during the early spring storm season and the initial results appear promising. There are plans to compare several SSEO and SSEF severe weather forecast products during the experiment to explore the minimum number of members needed to provide useful guidance on the range and likelihood of specific convective storm solutions.

GSD 3 km High Resolution Rapid Refresh (HRRR) Model

The experimental 3 km HRRR model is nested within the hourly development version of the 13 km Rapid Refresh (RR) model, which provides ICs/LBCs for the HRRR. The HRRR uses a version of the WRF-ARW with generally “RUC-like” physics. A unique aspect of the RR is the hourly GSI data assimilation system that incorporates a wide array of observational datasets including radar reflectivity via the radar-Diabatic Digital Filter Initialization. The HRRR integration is run over a full CONUS domain (Fig. 8) with forecasts to 15 hrs. At the initial time, the simulated HRRR reflectivity comes from a 1-hr RR forecast; downscaling from the RR 13 km grid to the HRRR 3 km grid occurs very quickly during the first hour.

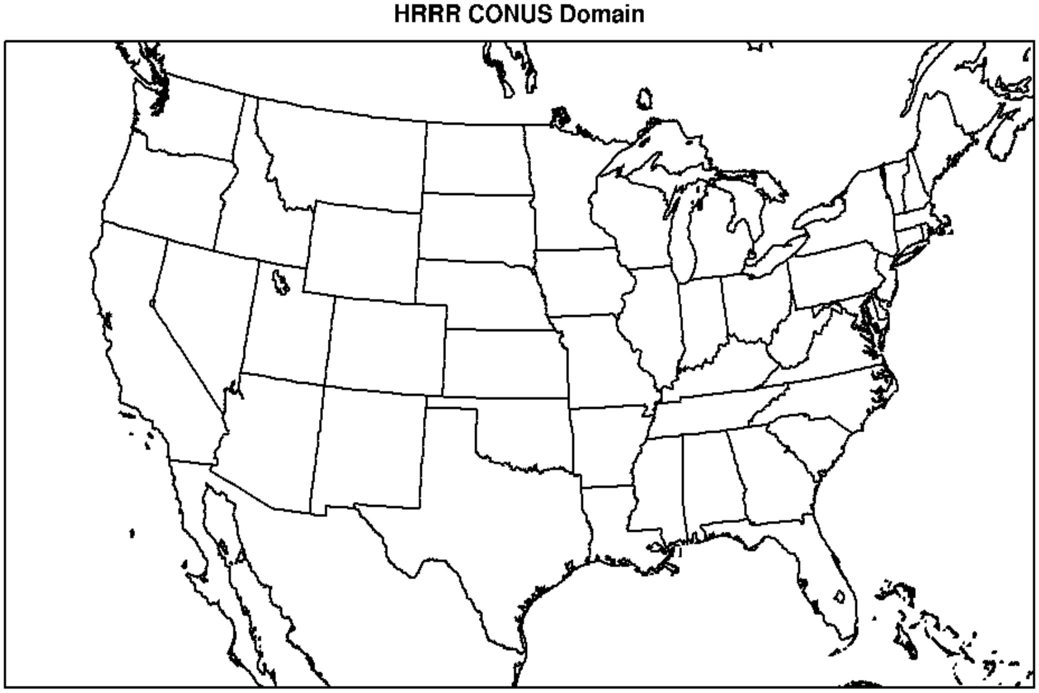


Figure 8. HRRR 3 km domain with 1800x1060 horizontal grid points.

NASA-SPoRT 4 km WRF-ARW Model

NASA-SPoRT in Huntsville has configured a WRF-ARW model that is identical to the NSSL-WRF except the NASA-ARW initialization includes the : 1) NASA 4 km Land Information System (LIS), 2) NASA 1 km MODIS/AMSU-E SST analysis, and 3) NASA 1 km MODIS Greenness Vegetation Fraction (GVF) analysis. In addition, swaths of Atmospheric Infrared Sounder (AIRS) retrieved temperature and moisture profiles from AQUA are assimilated nine hours after the initialization over the eastern two-thirds of the domain using the WRF 3DVAR system. This is done to update the upper-air model state based on observational data over potentially data void regions. A 9-hr NASA-WRF forecast is used as the background for this analysis, and once completed, the model continues for 27 hrs to complete the 36-hr forecast.

The use of these high resolution data sets will permit an examination of PBL sensitivity and its subsequent impact on convective storm development within the WRF-ARW, including the study of CI.

NCAR 3 km WRF-ARW Model

NCAR will run a 3 km ARW over the eastern two-thirds of the CONUS initialized once daily at 00 UTC, with forecasts to 48 hrs (Fig. 9). Initial and boundary conditions for daily 3 km forecasts come from an ensemble data assimilation system using NCAR's DART (Data Assimilation Research Testbed) system. The DART system coupled with WRF (WRF-DART) will mark the first use of this system for real-time convective forecasting. WRF-DART will be used in a continuously cycling mode assimilating METAR, marine, ACARS, satellite winds, GPS occultation, and radiosonde observations (approx. 38,000 observations assimilated each cycle). The 50 member ensemble will provide a set of CONUS mesoscale (15 km horizontal grid length) analyses every six hours. Daily at 00 UTC, a single analysis will be selected from the closest member (normalized RMSE) to the ensemble mean state for a select group of state vector fields. Within the cycling WRF-DART ensemble system WRFVAR perturbed GFS forecasts (6 and 12 hrs) are used to provide boundary conditions for each ensemble member. The analysis is updated every 6 hours. WRF-DART analysis runtime information is available on the web at:

http://www.image.ucar.edu/wrfdart/rt2011/index.htm

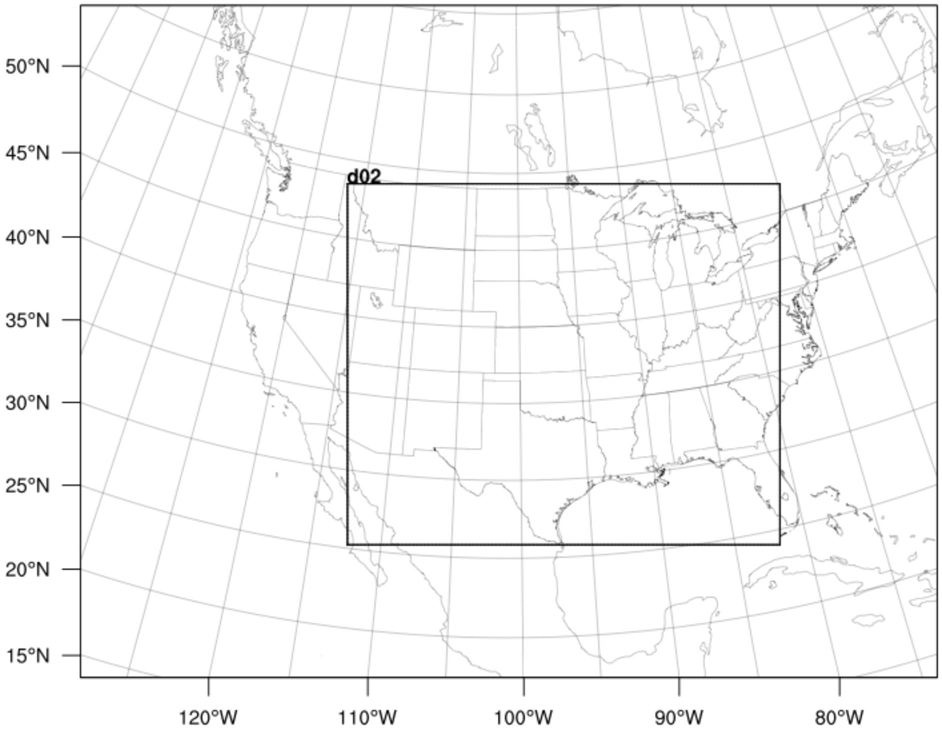


Figure 9. The outer domain is for the cycled WRF-DART analysis (15 km horizontal), with the inner domain (d02) at higher resolution (3 km horizontal). Thus, the outer domain mesoscale analysis provides initial and boundary conditions to the interior domain. GFS forecasts provide boundary conditions to the outer domain.

GSD 3 km LAPS Model

GSD has developed a version of the Local Analysis and Prediction System (LAPS) as part of the examination of different data assimilation systems on model initialization and short-term forecast performance. The LAPS includes a 3 km WRF-ARW model initialized once daily at 00 UTC over a CONUS domain with forecasts to 12 hrs. The "hot start" data assimilation incorporates a large variety of observational data sources including radar.

UW/CIMSS Lagrangian "Nearcast" Model

The "Nearcast" is a short-term Lagrangian trajectory model that incorporates hourly multi-layered retrieved parameters from the GOES sounder data, and provides forecast to 9 hrs of precipitable water and theta-e fields over different vertical layers. Results from the model enhance current operational NWP forecasts by successfully capturing and retaining details (maxima, minima and extreme gradients) in thermodynamic fields critical to the development of convective instability several hours in advance, even after subsequent IR satellite observations become cloud contaminated. This is the first year the Nearcast model has been available in the Spring Experiment, and it is expected to be used in short-term convective forecasting mainly at the CI and severe desks.

The configurations of the deterministic high resolution NWP models for the 2011 Spring Experiment is found in Table 4.

Table 4. Configurations of deterministic high resolution NWP models for the 2011 Spring Experiment. The HRRR is initialized hourly; the EMC models are initialized at 00 and 12 UTC; the NSSL-ARW, LAPS-ARW, and CAPS SSEF are initialized at 00 UTC. The CAPS, LAPS, and HRRR models include 3DVAR data assimilation systems; NCAR-ARW is initialized from WRF-DART EnKF system; other models are "cold-started".

Model	**Source**	**Forecast Hours**	**Hor. Grid (km)**	**Vertical Levels**	**PBL/Turb.**	**Microphysics**	**Radiation (SW/LW)**	**Land-Surface**	**IC/LBC**
CONUS WRF-NMM	EMC	36	4.0	35	MYJ	Ferrier	GFDL	Noah	32km NAM
HiResW WRF-NMM	EMC	48	4.0	35	MYJ	Ferrier	GFDL	Noah	32km NAM
HiResW ARW	EMC	48	5.1	35	YSU	WSM3	Dudhia/RRTM	Noah	32km NAM
NMMB Nest	EMC	60	4.0	60	MYJ	Ferrier	GFDL	Noah	12km NAM
NSSL-ARW	NSSL	36	4.0	35	MYJ	WSM6	Dudhia/RRTM	Noah	40km NAM
HRRR-ARW	GSD	15	3.0	50	MYJ	Thompson	Dudhia/RRTM	RUC-Smirnova	13km RR
LAPS-ARW	GSD	12	3.0	29	YSU	Thompson	Dudhia/RRTM	Monin-Obuhkov	13km RUC/GFS
SSEF ARW cntl	CAPS	36	4.0	51	MYJ	Thompson (3.3)	Goddard/RRTM	Noah	12km NAM
NCAR-ARW	NCAR	48	3.0	35	MYJ	Thompson	Goddard/RRTM	Noah	WRF-DART EnKF

6. GOES-R Proving Ground Products

The GOES-R Proving Ground activities are integrated directly into the HWT programs, with a number of prototype satellite products have applications in the EFP and EWP forecast and warning experiments. There are four GOES-R Baseline and Option-2 products identified to be demonstrated during the Spring Experiment at SPC. Additionally, the Spring Experiment will also demonstrate GOES-R Risk Reduction (R3) and GOES I/M Product Assurance Plan (GIMPAP) products. These products are listed in Table 5.

More details about the GOES-R Proving Ground Operations Plan are at:
http://hwt.nssl.noaa.gov/Spring_2011/GOESR_OPS_Plan_2011.pdf

Table 5. Products to be demonstrated during Experiment

<table>
<tr><th>Demonstrated Product</th><th>Category</th></tr>
<tr><td>Cloud and Moisture Imagery</td><td>Baseline</td></tr>
<tr><td>Lightning Detection</td><td>Baseline</td></tr>
<tr><td>Enhanced “V”/Overshooting Top Detection</td><td>Option 2</td></tr>
<tr><td>Convective Initiation</td><td>Option 2</td></tr>
<tr><td>Nearcasting Model</td><td>GOES-R Risk Reduction</td></tr>
<tr><td>Weather Research and Forecasting (WRF) based lightning threat forecast</td><td>GOES-R Risk Reduction</td></tr>
<tr><td>Convective Initiation (University of Wisconsin)</td><td>GIMPAP</td></tr>
<tr><td>Statistical Hail Probability (Cooperative Institute for Research in the Atmosphere)</td><td>GIMPAP</td></tr>
<tr><td colspan="2">Category Definitions:
Baseline Products - GOES-R products that are funded for operational implementation as part of the ground segment base contract.

Option 2 Products - New capability made possible by ABI as option in the ground segment contract. Option 1 in the ground segment contract will provide reduced product latency.

GOES-R Risk Reduction - The purpose of Risk Reduction research initiatives is to develop new or enhanced GOES-R applications and to explore possibilities for improving the AWG products. These products may use the individual GOES-R sensors alone, or combine data from other in-situ and satellite observing systems or models with GOES-R.

GIMPAP - The GOES Improved Measurement and Product Assurance Plan provides for new or improved products utilizing the current GOES imager and sounder</td></tr>
</table>

7. Objectives and Goals

The primary objectives of Spring Experiment 2011 are listed by component:

A. Severe Convective Storm Component (Leader: SPC)

- Continue test and evaluation of high-resolution convection-allowing models (CAMs) and Storm Scale Ensemble Forecast (SSEF) system to provide useful guidance to severe weather forecasters in a simulated operational forecasting environment. This will focus on improving temporal and spatial resolution in forecasts of initiation, mode, evolution, and intensity of convective storms.

- Provide focused feedback to model developers on the performance of the experimental SSEF and deterministic CAMs during severe thunderstorm episodes.

- Assess the value of SSEF convective storm products to provide enhanced temporal/spatial resolution guidance for experimental probabilistic 3-hr severe weather forecasts, using guidance products that are time-matched to the forecast periods. This proof-of-concept testing will explore the use of SSEF guidance as first-guess fields for forecasters creating high resolution severe thunderstorm forecasts, analogous to the current SPC high resolution enhanced thunderstorm outlooks.

- Explore the minimum number of SSEF members needed to provide statistically useful forecast guidance that spans the range of plausible solutions. This will be done through the comparative examination of smaller five- and 14-member subsets of the core SSEF, and from a separate experimental seven-member Storm Scale Ensemble of Opportunity (SSEO) consisting of existing deterministic CAMs models that are available all year.

- Compare the usefulness of calibrated severe thunderstorm probability guidance from environment-based SREF forecasts and explicit thunderstorm-based SSEF forecasts.

- Examine the skill of environmental predictions of CAPE and vertical shear from the SREF and the SSEF.

- Explore the initialization and short-term forecast performance of deterministic CAMs using different data assimilation schemes to better understand the impact of assimilating radar data on model predictions of convective storms.

- Assess the utility of GOES-R Proving Ground products such as WRF model simulated satellite imagery and output from a short-term Lagrangian "Nearcast" model, as part of an integrated data suite to support severe weather forecaster decision-making.

- Examine sensitivity of additional physics diversity in the SSEF (e.g., double-moment microphysics and new PBL schemes) on storm development in selected member comparisons.

- Through collaboration with the DTC, test new scale-appropriate objective verification metrics designed for high time/space resolution convective storm forecasts. The goal is to develop new performance measures that will provide more useful information about the accuracy of convective-scale forecasts compared to traditional measures that are best suited for larger scale forecasts.

- Build cross cutting relationships between members of the severe weather, CI, and QPF communities to strengthen collaborations focused on shared thunderstorm forecast challenges.

- Explore forecast consistency through creation of experimental probabilistic thunderstorm forecasts and subsequent discussions between severe weather, CI, and QPF forecast desks.

B. Convective Initiation Component (Leader: NSSL and SPC)

The primary objectives are to evaluate and quantify:

- Skill of currently available convection-allowing models (CAMs) for predicting CI and CA

- Utility of different criteria used for automatic detection of convection (CA) in models

- Utility of algorithm used to determine CI points as a subset of total convective points

Secondary objectives include:

- Develop new validation datasets for CI forecasts

- Evaluate the role of different physical process in the CI process by interrogating the model atmosphere and using unique model-output diagnostic tools

- Evaluate the sensitivity of model forecasts to different physical parameterizations and parameter variations within given parameterizations.

- Evaluate different definitions of CI by comparing results from different CI-detection algorithms that were developed specifically for the Spring Experiment, already existed, and/or are currently under development.

- Assess the ability of human forecasters to add value to model-generated forecasts of CI and CA.

- Evaluate new graphics for the detection of trends, outliers, and quirks in standard fields and assess their utility in providing a high-level overview across the entire ensemble rapidly [Non-standard data visualization].

- Establish increased direct communication and feedback with EWP activities as it relates to CI forecasting, and providing scenario information to warning forecasters such that precursors to CI can be evaluated.

- Evaluate new workstation tools for ensemble-product visualization and manipulation on the ALPS workstation

- Assess the utility of GOES-R Proving Ground products such as WRF model simulated satellite and lightning imagery, in addition to output from a short-term Lagrangian "Nearcast" model

- Build cross cutting relationships between members of the CI, severe weather, and QPF communities to strengthen collaborations focused on shared thunderstorm forecast challenges.

- Explore forecast consistency through creation of experimental probabilistic thunderstorm forecasts and subsequent discussions between CI, severe weather, and QPF forecast desks.

C. QPF Component (Leader: HPC)

- Document strengths and limitations of high resolution models and ensembles for precipitation forecasting in a simulated forecasting environment. Provide focused feedback to model developers on performance and model utility, and offer recommendations to operational modeling community on near-term and long-term model development needs to support improvements in QPF.

- Determine appropriate ways to use operational mesoscale models and ensembles (e.g, NAM, SREF) and experimental CAMs/SSEF in a complementary manner.

- Determine the skill of experimental guidance such as the HRRR, SSEF, NMMB, HiResWindow, and HREF (retrospective) versus operational baselines (NAM, SREF).
- Evaluate the performance of the pending 12 km and 4 km NMMB implementation relative to the current operational NAM.

- Assess the pros and cons of statistical regression (HRMOS) and bias-corrected probabilistic QPF guidance from the SSEF

- Determine whether the SSEO is a feasible "poor man's ensemble" approach to storm scale ensemble QPF.

- Share and test ideas on innovative post-processing techniques to extract maximum information from CAMs and SSEFs to reduce data overload.

- Investigate the practical number of members required to produce a skillful storm scale ensemble QPF (retrospective).

- Collaborate with the DTC to develop and test traditional and new objective verification measures to assess the accuracy of the experimental and baseline guidance.

- Build cross cutting relationships between members of the severe weather, convection initiation, and QPF communities to strengthen collaborations focused on shared thunderstorm forecast challenges.

Specific information about models and statistical guidance used in the QPF component are found in Appendix C.

8. Spring Experiment Web Site

A full description of all program objectives, types of model output, forecast products, evaluation and verification forms, a data archive, and other related links are available at the Spring Experiment web site:

http://hwt.nssl.noaa.gov/Spring_2011/

This web site is intended to support real time activities as well as additional research and reference after the conclusion of the program.

9. Dates and Location of the Spring Experiment

The 2011 Spring Experiment will run Monday- Friday from May 9 through June 10, 2011. The final Friday session on June 10 will end by noon as no forecast activities will take place on that day. The Severe Thunderstorm and QPF components will operate from 7:30 am- 4:00 pm, and the Convective Initiation component will run from 9:00 am-5:00 pm **On each Monday, a brief orientation session will start the day to introduce participants to the HWT and the planned experimental activities in each of the three components.** Beginning May 10, a full range of in-house and external participants will staff the program. Full time participants will work for periods of one week, with part-time visiting scientists and forecasters participating on a 2-3 day basis (schedule permitting). Program operations will be conducted in the Hazardous Weather Testbed facility (Room 2380) located on the second floor of the NWC between the SPC and WFO Norman operations areas. Each full time weekly team will complete daily experimental forecasts and participate in evaluation and verification activities; part-time visitors can participate in daily activities at levels appropriate with their interest and expertise. Staffing typically will include SPC and HPC forecasters serving to lead the Severe Thunderstorm and QPF components, NSSL and SPC scientists leading the Convective Initiation component, other SPC and NSSL participating staff, and a number of visiting scientists, model developers, forecasters, university faculty, and graduate students. A list of weekly participants is found in Appendix A.

10. Daily Operations Schedule

Participants in the experiment will create experimental forecast products and conduct evaluation activities in the HWT from 7:30 am – 5:00 pm on Monday-Friday. Each afternoon from 12:30-1:30 pm a briefing and discussion session is held. This will include EFP and EWP participants and will serve to facilitate interactions between the HWT forecast and warning programs. We anticipate that many weekly participants will rotate through the activities in each component (Severe, CI, QPF) during the week, spending 1-2 days in each section. This will allow participants to experience a broad range of convective storm impacts and forecasting challenges, and gain a greater appreciation of the challenges faced by operational forecasters and those tasked with creating improved forecast guidance tools.

Participants are expected to perform forecast and evaluation activities in a collaborative manner, such that results reflect a consensus decision. A break for lunch is scheduled during the ~Noon-12:30 pm period, but participants may eat lunch while conducting program activities or at their discretion any time during the day. Visitors may purchase lunch at a food court located on the south side of the first floor of the NWC. Below is a basic outline of the daily schedule for activities during the experiment; a more detailed description of experimental forecast product instructions is found in Appendices F-H; specific evaluation topic areas are found in Appendices I-K.

A. Severe Convective Storms Component

Daily activities conducted in northeast corner of HWT
Italics denotes Monday-only activities

7:30 am-8:00 am: *Weekly Orientation. (Some morning forecast and evaluation activities will be truncated on Mondays to permit sufficient time for the orientation.)*

7:30-8:15 am: Subjective verification of yesterday's experimental severe weather forecasts compared to radar reflectivity, warnings, severe storm reports, and post-processed "practically perfect" hindcasts based on coverage and intensity of severe storm reports.

8:15-10:30 am: In a semi-operational forecasting environment, the severe weather team will use guidance from 00z high-resolution WRF, SSEF, SSEO, morning HRRR, and 09z SREF/12z operational models and real time observational data to formulate probabilistic severe storm forecasts valid for the 18-21z and 21-00z time periods.

The forecasts will be made over a movable mesoscale domain placed over the part of the central-eastern US where the combined severe/QPF threat is deemed to be greatest and/or substantial forecasting challenges exist. The process will include collaboration discussions between the severe, CI, and QPF components prior to product completion to enhance consistency among the convective forecasts.

10:30 am-noon: Subjective evaluation of previous day's model guidance compared to observed radar and severe weather reports, focusing on the ability of the models to provide useful guidance to severe weather forecasters.

Noon-12:30 pm: Lunch; prepare for daily briefing and discussion.

12:30-1:30 pm: Daily briefing, and interaction with EWP (Tuesday-Thursday only). The severe weather, CI, and QPF teams will discuss today's forecast and evaluation activities, summarizing new insights, preliminary findings, lessons learned, and topic areas needing further examination. The discussion will serve as an initial EFP planning briefing for the upcoming afternoon EWP activities. Starting at 1:00 pm (Tuesday-Thursday only), several EWP forecasters will provide a summary of yesterday's stormscale evolution and associated warning challenges.

1:30-3:30 pm: In a semi-operational forecasting environment, the severe weather team will use guidance from 00z SSEF, SSEO, 12z EMC WRFs, latest HRRR, CIMSS Nearcast, 15z SREF and real time observational data to formulate new probabilistic severe storm forecasts valid for the 00-03z and 03-06z time periods over the same mesoscale domain. Collaborate with QPF team on convective forecasts during the 00-06z time period.

3:30-4:00 pm: Finalize daily activities including additional previous day model evaluation, share afternoon forecast with EWP as updated planning information for evening warning activities.

4:00 pm: With EWP permission, several EFP participants can observe experimental warning activities during the late afternoon and assess linkage between EFP and EWP activities.

B. Convective Initiation Component

Daily activities conducted in northwest corner of HWT
Italics denotes Monday-only activities

***7:30 am-8:00 am**: Weekly Orientation. (Some morning forecast and evaluation activities will be truncated on Mondays to permit sufficient time for the orientation.)*

8:30-10:30 am: Verification of previous days CI forecasts followed by forecasting activities for CI consisting of generating a probabilistic spatial forecast over a specified time window and a temporal forecast over a spatial domain, selected in collaboration with the severe/QPF desks. Note that the CI domain will be smaller than the severe/QPF domain, and can be a subset of the severe/QPF domain or be located in a different geographic region.

The ***spatial forecast product*** will be created in NMAP for three 3-hr forecast periods (typically 18-21, 21-00, and 00-03 UTC) and consist of a categorical forecast of the likelihood of CI (low, moderate, high) within each of the three hour periods. The ***temporal forecast*** will be created using a web interface, and will include the overall probability of CI within the time window, the most likely time of CI, and an estimate of uncertainty in timing expressed as the beginning and end of the window of CI opportunity. Model experimental first-guess fields/summary displays will be used in the creation of the CI forecast products, and a web survey will be utilized during the forecast process to record relevant information (timing, location, products utilized, variables analyzed, experiment utilized, rationale, and forecast scenario).

11:00 am-Noon: Subjective evaluation of previous days' model forecasts of CI, and the assessment of CI from different algorithms using simulated reflectivity and lightning datasets. Discussion may also include interactions with severe desk and impact of CI on the severe forecasts for the afternoon, and with EWP forecasters working with the CI desk that will contribute to the afternoon/evening experimental warning activities.

Noon-12:30 pm: Lunch; prepare for daily briefing and discussion.

12:30-1:30 pm: Daily briefing, and interaction with EWP (Tuesday-Thursday only). The severe weather, CI, and QPF teams will discuss today's forecast and evaluation activities, summarizing new insights, preliminary findings, lessons learned, and topic areas needing further examination. The discussion will serve as an initial EFP planning briefing for the upcoming afternoon EWP activities. Starting at 1:00 pm (Tuesday-Thursday only), several EWP forecasters will provide a summary of yesterday's stormscale evolution and associated warning challenges.

1:30-3:30 pm: Nowcasting exercises using some of the GOES-R Proving Ground tools with EWP participants including products listed in Section 2 and Table 5. Some of these products may be directly relevant to definition of CI, including: CI nowcasts, cloud-top cooling rate, overshooting top detection, and proxy GLM lightning data from LMA regions. There is considerable flexibility in the afternoon schedule, so other products may also be examined depending on the daily areas of interest, such as utilization of the GSD ALPS workstation for forecast products from an updating ensemble or deterministic simulations, or analysis of observations (STMAS or LAPS analyses).

3:30-5:00 pm: Continue previous evaluation activities and/or discussion of other relevant issues related to CI, the forecast process.

C. QPF Component

Daily activities conducted in north center part of HWT
Italics denotes Monday-only activities

7:30 am-8:00 am*: Weekly Orientation. (Some morning forecast and evaluation activities will be truncated on Mondays to permit sufficient time for the orientation.)*

7:30-8:15 am: Subjective verification of yesterday's experimental QPF products compared to NSSL QPE ("truth").

8:15-10:30 am: In a semi-operational forecasting environment, the QPF desk will use observational data and guidance from 00 UTC CAMs and SSEF, available HRRR, and 00 UTC operational model guidance to create experimental probabilistic QPF products valid for 18-00 UTC and 00-06 UTC time periods. The forecasts will be over the same mesoscale domain selected for the HWT severe convective weather component, and will be for exceedance thresholds of 0.5" and 1.0" per 6 hrs. In addition, forecasts that contain a probabilistic 1" contour will include the expected maximum basin-average rainfall amount within the 1" region during the 6-hr period. The process will include collaboration discussions between the severe, convective initiation, and QPF components prior to product completion to enhance consistency among the convective forecasts.

10:30 am-noon: Subjective/objective evaluation of previous day's experimental model guidance compared to NSSL QPE, focusing on model and product ability to provide useful guidance to QPF forecasters.

Noon-12:30 pm: Lunch; prepare for daily briefing and discussion.

12:30-1:30 pm: Daily briefing, and interaction with EWP (Tuesday-Thursday only). The severe weather, CI, and QPF teams will discuss today's forecast and evaluation activities, summarizing new insights, preliminary findings, lessons learned, and topic areas needing further examination. The discussion will serve as an initial EFP planning briefing for the upcoming afternoon EWP activities. Starting at 1:00 pm (Tuesday-Thursday only), several EWP forecasters will provide a summary of yesterday's stormscale evolution and associated warning challenges.

1:30-3:30 pm: Update the 00-06 UTC period using the available HRRR and 12 UTC operational and CAM guidance. Forecast for the 06-12 UTC period using the 00 UTC SSEF guidance and any available operational and CAM guidance.

3:30-4:00 pm: Brief wrap-up discussion on afternoon forecasts, especially if relevant to EWP activities; complete daily tasks. The QPF component will compare forecasts with the operational HPC PQPF product.

4:00 pm: With EWP permission, several EFP participants can observe experimental warning activities during the late afternoon and assess linkage between EFP and EWP activities.

11. Acknowledgments

Special thanks and appreciation is extended to many people for their creative insights and assistance in Spring Experiment preparations, planning, and execution of numerous complex and ground-breaking technical and scientific activities. Without the combined efforts of many SPC and NSSL staff, the Spring Program could not be conducted. In particular, special thanks go to SPC's Gregg Grosshans for helping to establish model data flow and configuring the experimental forecasts for transmission and archival, and for helping to organize model display files, and Jay Liang and Joe Byerly for expertise in configuring and upgrading hardware/software, network and workstations in the HWT. Expert NSSL technical support was provided by Brett Morrow, Jeff Horn, Steve Fletcher, Greg Trotter, and Brad Sagowitz to address networking, data flow, hardware, and archive requirements, while Scott Dembek managed the NSSL-WRF real time modeling and product development system. Peggy Stogsdill (SPC), Brenda Gomez (SPC), and Linda McGuckin (NSSL) ably assisted with logistical and budget support activities.

The experimental activities could not take place without the dedicated collaborative efforts of many people at CAPS, EMC, GSD and NCAR who are working to enhance community efforts to improve severe weather forecasting. We acknowledge the amazing expertise of CAPS scientists Ming Xue, Fanyou Kong, Kevin Thomas, Yunheng Wang, and Keith Brewster for outstanding efforts to develop and run the 50 member SSEF; the National Institute for Computational Sciences/University of Tennessee, and the University of Oklahoma Supercomputing Center for Education and Research for providing technical support and computer facilities for the CAPS model runs; EMC scientists Matt Pyle, Eric Rogers, Zavisa Janjic, Brad Ferrier, Jun Du, and Geoff DiMego for developing and contributing the WRF and NAM models, and for scientific input and infrastructure support for the SSEF; Greg Thompson from NCAR for technical support and advice on the microphysics schemes in the ARW system and the SSEF configuration; GSD scientists Stan Benjamin, Steve Weygandt, John Brown, and Curtis Alexander for development of the CONUS HRRR model, including special efforts by Curtis to include special CI and lightning algorithm products into the HRRR for the Spring Experiment; Zoltan Toth, Steve Albers, Isidora Jankov, and their colleagues within GSD for contributing the LAPS model to the HWT; Barb Brown, Michelle Harrold, Paul Oldenberg, John Halley Gotway, Brian Etherton, Paula McCaslin, and colleagues from the DTC for their expert development of the MET verification systems and special efforts to tailor it for application during the Spring Experiment; Jon Case, Bill McCaul, and colleagues at NASA/SPoRT/Huntsville for implementation of the WRF Total Lightning Threat products in the NSSL-WRF and SSEF and contribution of the NASA-ARW model; Louie Grasso and Dan Lindsey at CIRA, and Jason Otkin and Justin Sieglaff at CIMSS for creating and providing simulated satellite imagery from the NSSL-WRF model; Wayne Feltz, Jason Brunner, and Justin Sieglaff of CIMSS for the enhanced-V/overshooting tops satellite products; John Mecikalski, Wayne MacKenzie, and John Walker of UAH, and Wayne Feltz and Justin Sieglaff of CIMSS and Kris Bedka of NASA/Langley for convective initiation satellite products; and CIMSS scientists Ralph Petersen and Bob Aune for access to their Nearcast model.

Special thanks go to the GOES-R Program Office, the National Weather Service, and the National Severe Storms Laboratory for providing visitor travel support. We further wish to recognize the full support of SPC and NSSL management; and the numerous contributions and insights provided by the many participants who clearly demonstrated the value of collaborative experiments involving the research, academic, and forecasting communities, and whose presence and enthusiasm resulted in a positive learning experience for everyone.

Appendix A: Convective Initiation Post-Processed Model Fields

Currently, a total of 7 post-processed fields are being produced from this raw CA/CI data for each set of criteria (total of 21 fields), for the 00Z NSSL-WRF forecast, 28 CAPS ensemble members, and possibly the HRRR:

GEMPAK NAME	DESCRIPTION
PRB1_CI_***	Probability of CI within 40 km during the previous hour (%)
BIN_CI_***	Grid point locations of CI during the previous hour (non-dim)
PRB3_CI_***	Probability of CI within 40 km during the previous 3 hrs (%)
TIM_CI_***	Elapsed time since CI at a point (mins)
TIM_CA_***	Elapsed time since CA at a point (mins)
CVG_CA_***	Coverage of convection (CC) within 20 km radius (%)
PRB_CVG_***	Probability of CC > 50% (%)

Where '***' denotes the three sets of criteria 'LTG', 'WQQ', and 'REF'. In addition, ensemble probability fields will be derived by computing the ensemble-mean values for each of the fields with units of %.

References:

Gremillion, M. S. and R. E. Orville, 1999: Thunderstorm Characteristics of Cloud-to-Ground Lightning at the Kennedy Space Center, Florida: A Study of Lightning Initiation Signatures as Indicated by the WSR-88D. *Wea. Forecasting,* **14**, 640-649

Kain, J. S., S. J. Weiss, D. R. Bright, M. E. Baldwin, J. J. Levit, G. W. Carbin, C. S. Schwartz, M. L. Weisman, K. K. Droegemeier, D. B. Weber, K. W. Thomas, 2008: Some practical considerations regarding horizontal resolution in the first generation of operational convection-allowing NWP. *Wea. Forecasting*, **23**, 931-952.

Miller, S. D., G. W. Carbin, J. S. Kain, E. W. McCaul, A. R. Dean, C. J. Melick, and S. J. Weiss, 2010: Preliminary investigation into lightning hazard prediction from high resolution model output. *Preprints, 25th Conference on Severe Local Storms*, Amer. Meteor. Soc., Denver, CO. Paper 4B.1

Roberts, R. D., S. Rutledge, 2003: Nowcasting Storm Initiation and Growth Using GOES-8 and WSR-88D Data. *Wea. Forecasting*, **18**, 562–584.

Mecikalski, J. R., K. M. Bedka, 2006: Forecasting Convective Initiation by Monitoring the Evolution of Moving Cumulus in Daytime GOES Imagery. *Mon. Wea. Rev.*, **134**, 49–78.

Appendix B: CAPS SSEF Member Configuration

Configurations for ARW members. NAMa and NAMf refer to 12 km NAM analysis and forecast, respectively. ARPSa refers to ARPS 3DVAR and cloud analysis, CYCLED refers to a 10-min ARPS 3DVAR cycle

Member	IC	BC	Radar data	Microphy	LSM	PBL
arw_cn	00Z ARPSa	00Z NAMf	yes	Thompson	Noah	MYJ
arw_c0 (18h)	00Z ARPSa	00Z NAMf	no	Thompson	Noah	MYJ
arw_cc (18h)	CYCLED	00Z NAMf	yes	Thompson	Noah	MYJ
arw_m4	arw_cn + em-p1_pert	21Z SREF em-p1	yes	Morrison	RUC	YSU
arw_m5	arw_cn + em-p2_pert	21Z SREF em-p2	yes	Thompson	Noah	QNSE
arw_m6	arw_cn – nmm-p1_pert	21Z SREF nmm-p1	yes	WSM6	RUC	QNSE
arw_m7	arw_cn + nmm-p2_pert	21Z SREF nmm-p2	yes	WDM6	Noah	MYNN
arw_m8	arw_cn + rsm-n1_pert	21Z SREF rsm-n1	yes	Ferrier	RUC	YSU
arw_m9	arw_cn – etaKF-n1_pert	21Z SREF etaKF-n1	yes	Ferrier	Noah	YSU
arw_m10	arw_cn + etaKF-p1_pert	21Z SREF etaKF-p1	yes	WDM6	Noah	QNSE
arw_m11	arw_cn – etaBMJ-n1_pert	21Z SREF etaBMJ-n1	yes	WSM6	RUC	MYNN
arw_m12	arw_cn + etaBMJ-p1_pert	21Z SREF etaBMJ-p1	yes	Thompson	RUC	MYNN
arw_m13	arw_cn + rsm-p1_pert	21Z SREF rsm-p1	yes	M-Y	Noah	MYJ
arw_m14	arw_cn + em-n1_pert	21Z SREF em-n1	yes	Ferrier+	Noah	YSU
arw_m15	arw_cn + em-n2_pert	21Z SREF em-n2	yes	WSM6	Noah	MYNN
arw_m16	arw_cn + nmm-n1_pert	21Z SREF nmm-n1	yes	Ferrier+	Noah	QNSE
arw_m17	arw_cn + nmm-n2_pert	21Z SREF nmm_n2	yes	Thompson	Noah	ACM2

arw_m18	arw_cn + rsm-p2_pert	21Z SREF rsm_p2	yes	WSM6	Noah	MYJ
arw_m19	arw_cn + rsm-n1_pert	21Z SREF rsm_n1	yes	M-Y	Noah	MYJ
arw_m20	arw_cn + rsm-n2_pert	21Z SREF rsm_n2	yes	M-Y	RUC	ACM2
arw_m21	00Z ARPSa	00Z NAMf	yes	Ferrier+	Noah	MYJ
arw_m22	00Z ARPSa	00Z NAMf	yes	Ferrier	Noah	MYJ
arw_m23	00Z ARPSa	00Z NAMf	yes	M-Y	Noah	MYJ
arw_m24	00Z ARPSa	00Z NAMf	yes	Morrison	Noah	MYJ
arw_m25	00Z ARPSa	00Z NAMf	yes	WDM6	Noah	MYJ
arw_m26	00Z ARPSa	00Z NAMf	yes	WSM6	Noah	MYJ
arw_m27	00Z ARPSa	00Z NAMf	yes	WSM6-M1	Noah	MYJ
arw_m28	00Z ARPSa	00Z NAMf	yes	WSM6-M2	Noah	MYJ
arw_m29	00Z ARPSa	00Z NAMf	yes	WSM6-M3	Noah	MYJ
arw_m30	00Z ARPSa	00Z NAMf	yes	WSM6-M4	Noah	MYJ
arw_m31	00Z ARPSa	00Z NAMf	yes	Thompson	Noah	QNSE
arw_m32	00Z ARPSa	00Z NAMf	yes	Thompson	Noah	MYNN
arw_m33	00Z ARPSa	00Z NAMf	Yes	Thompson	Noah	MYJ-P1
arw_m34	00Z ARPSa	00Z NAMf	Yes	Thompson	Noah	MYJ-P2
arw_m35	00Z ARPSa	00Z NAMf	Yes	Thompson	Noah	MYJ-P3
arw_m36	00Z ARPSa	00Z NAMf	Yes	Thompson	Noah	ACM2
arw_m37	00Z ARPSa	00Z NAMf	yes	Thompson	Noah	ACM2-A1
arw_m38	00Z ARPSa	00Z NAMf	yes	Thompson	Noah	ACM2-A2
arw_m39	00Z ARPSa	00Z NAMf	yes	Thompson-v31	Noah	MYJ
arw_m40	00Z ARPSa	00Z NAMf	yes	Thompson	Noah	YSU
arw_m41	00Z ARPSa	00Z NAMf	yes	Thompson	Noah	YSU-Thompson

Note 1: For all members: *ra_lw_physics*= RRTM; *ra_sw_physics*=Goddard; *cu_physics*=none

Note 2: All Thompson members, except v31 (*thompsonopt=1*), are using v33 (*thompsonopt=0*)

Note 3: Ferrier+ (*ferrieropt=1*) refers to a subset of changes in the updated version now in NEMS/NMMB. Ferrier is default (*ferrieropt=0*)

Note 4: WSM6 with M1 to M4 refers to various perturbations on intercept parameter N0 and density parameter

- WSM6: norain=8x10^{6} m^{-4}, n0graupel=4x10^{6} m^{-4}, dengraupel=500 kg/m^{3}
- WSM6-M1: norain=8x10^{6} m^{-4}, n0graupel=4x10^{4} m^{-4}, dengraupel=913 kg/m^{3}
- WSM6-M2: norain=8x10^{7} m^{-4}, n0graupel=4x10^{6} m^{-4}, dengraupel=500 kg/m^{3}
- WSM6-M3: norain=8x10^{5} m^{-4}, n0graupel=4x10^{2} m^{-4}, dengraupel=913 kg/m^{3}
- WSM6-M4: norain=8x10^{5} m^{-4}, n0graupel=4x10^{3} m^{-4}, dengraupel=913 kg/m^{3}

Note 5: A1 and A2 refer to modifying the ACM2 to account for weaker and stronger vertical mixing via the “p” parameter

- ACM2: acm2opt=0 (p =2)
- ACM2-A1: acm2opt=1 (p =1.33)
- ACM2-A2: acm2opt=2 (p =2.67)

Note 6: P1 to P3 refers to modifying the MYJ surface exchange coefficient for strong, weak, and f(surface roughness from vegetation)

- MYJ: czilopt=0 (czil=0.1), iz0tlnd=0
- MYJ-P1: czilopt=1 (czil=.01), iz0tlnd=0
- MYJ-P2: czilopt=2 (czil=1.0), iz0tlnd=0
- MYJ-P3: czilopt=0, iz0tlnd=1

Note 7: Core 24 members used in creation of HWT post-processed fields are denoted in red font.

Configurations for each individual member with NMM core

member	IC	BC	Radar data	mp_phy	lw_phy	sw-phy	sf_phy
nmm_cn	00Z ARPSa	00Z NAMf	yes	Ferrier	GFDL	GFDL	Noah
nmm_m2	nmm_cn + em-n2_pert	21Z SREF em-n2	yes	Ferrier+	GFDL	GFDL	Noah
nmm_m3	nmm_cn + nmm-n1_pert	21Z SREF nmm-n1	yes	Thompson	RRTM	Dudhia	Noah
nmm_m4	nmm_cn + nmm-n2_pert	21Z SREF nmm-n2	yes	WSM 6-class	RRTM	Dudhia	RUC
nmm_m5	nmm_cn + em-n1_pert	21Z SREF em-n1	yes	Ferrier	GFDL	GFDL	RUC

* For all members: *pbl_physics*=MYJ; *cu_physics*= NONE

** Ferrier+ refers to a subset of changes in the updated version now in NEMS/NMMB

Configurations for each individual member with ARPS

member	IC	BC	Radar data	Microphy.	radiation	sf_phy
arps_cn	00Z ARPSa	00Z NAMf	yes	Lin	Chou/Suarez	Force-restore
arps_c0 (18h)	00Z ARPSa	00Z NAMf	no	Lin	Chou/Suarez	Force-restore
arps_c10 (18h)	10-min cycle ARPSa	00Z NAMf	yes	Lin	Chou/Suarez	Force-restore
arps_c30 (18h)	30-min cycle ARPSa	00Z NAMf	yes	Lin	Chou/Suarez	Force-restore

* For all members: no cumulus parameterization

Appendix C: SSEF Post-Processed Products for the HWT

The underlined variables refer to hourly (or 3-hr) maximum. Variables with ‘*’ are also produced from two subsets of ensembles, one with 5 members (arw_cn, nmm_cn, arw_m4, arw_m10, arw_m11) and one with 15 members (same membership as in SE2010: arw_cn, arw_m4~m12, nmm_cn, nmm_m3~m5, arps_cn). The green-shaded variables are computed only from the 18 contributing ARW members.

Field	GEMPAK name	Unit	Type	Ens type
Sea level pressure	PMSL	hPa	Surface/single layer	Mean
850 hPa Z	HGHT850	m	Surface/single layer	Mean
500 hPa Z	HGHT500	m	Surface/single layer	Mean
250 hPa Z	HGHT250	m	Surface/single layer	Mean
850 hPa u-wind	UREL850	m/s	Surface/single layer	Mean
850 hPa v-wind	VREL850	m/s	Surface/single layer	Mean
250 hPa u-wind	UREL250	m/s	Surface/single layer	Mean
250 hPa v-wind	VREL250	m/s	Surface/single layer	Mean
500 hPa absolute vorticity	AVORT500	1/s	Surface/single layer	Mean
1-h precip	P01M_PM	mm	Surface/single layer	PM-mean
1-h precip	P01M_M	mm	Surface/single layer	Mean
1-h precip	P01M_MX	mm	Surface/single layer	Max
1-h precip ≥ 0.25 in	PR01MTH1_P	%	Surface/single layer	Prob
1-h precip ≥ 0.50 in	PR01MTH2_P	%	Surface/single layer	Prob
1-h precip ≥ 1.00 in	PR01MTH3_P	%	Surface/single layer	Prob
1-h precip ≥ 0.25 in	PR01MTH1_PN	mm	Surface/single layer	Prob-neighbor (ROI=0, sigma=30)
1-h precip ≥ 0.50 in	PR01MTH2_PN	mm	Surface/single layer	Prob-neighbor (ROI=0, sigma=30)
1-h precip ≥ 1.00 in	PR01MTH3_PN	mm	Surface/single layer	Prob-neighbor (ROI=0, sigma=30)
3-h precip ≥ 0.25-in	PR03MTH1_P	%	Surface/single layer	Prob
3-h precip ≥ 0.5-in	PR03MTH2_P	%	Surface/single layer	Prob
3-h precip ≥ 1.0-in	PR03MTH3_P	%	Surface/single layer	Prob
3-h precip ≥ 0.25-in	PR03MTH1_PN	%	Surface/single layer	Prob-neighbor (ROI=0, sigma=30)

3-h precip ≥ 0.5-in	PR03MTH2_PN	%	Surface/single layer	Prob-neighbor (ROI=0, sigma=30)
3-h precip ≥ 1.0-in	PR03MTH3_PN	%	Surface/single layer	Prob-neighbor (ROI=0, sigma=30)
6-h precip*	P06M_PM	mm	Surface/single layer	PM-mean
6-h precip*	P06M_M	mm	Surface/single layer	Mean
6-h precip*	P06M_MX	mm	Surface/single layer	Max
6-h precip ≥ 0.5-in*	PR06MTH2_P	%	Surface/single layer	Prob
6-h precip ≥ 1.0-in*	PR06MTH3_P	%	Surface/single layer	Prob
6-h precip ≥ 2.0-in*	PR06MTH4_P	%	Surface/single layer	Prob
6-h precip ≥ 0.5-in*	PR06MTH2_PN	%	Surface/single layer	Prob-neighbor (ROI=0, sigma=30)
6-h precip ≥ 1.0-in*	PR06MTH3_PN	%	Surface/single layer	Prob-neighbor (ROI=0, sigma=30)
6-h precip ≥ 2.0-in*	PR06MTH4_PN	%	Surface/single layer	Prob-neighbor (ROI=0, sigma=30)
6-h precip calibrated	P06M_PM_BC	mm	Surface/single layer	PM-mean
6-h precip calibrated	P06M_M_BC	mm	Surface/single layer	Mean
6-h precip calibrated	P06M_MX_BC	mm	Surface/single layer	Max
6-h precip ≥ 0.5-in calibrated	PR06MTH2_P_BC	%	Surface/single layer	Prob
6-h precip ≥ 1.0-in calibrated	PR06MTH3_P_BC	%	Surface/single layer	Prob
6-h precip ≥ 2.0-in calibrated	PR06MTH4_P_BC	%	Surface/single layer	Prob
6-h precip ≥ 0.5-in calibrated	PR06MTH2_PN_BC	%	Surface/single layer	Prob-neighbor (ROI=0, sigma=30)
6-h precip ≥ 1.0-in calibrated	PR06MTH3_PN_BC	%	Surface/single layer	Prob-neighbor (ROI=0, sigma=30)
6-h precip ≥ 2.0-in calibrated	PR06MTH4_PN_BC	%	Surface/single layer	Prob-neighbor (ROI=0, sigma=30)
Lowest model level temp	TMPF	F	Surface/single layer	Mean
Lowest model level dew point	DWPF	F	Surface/single layer	Mean
precipitable water	PWAT	mm	Surface/single layer	Mean
10 m U	UREL	m/s	Surface/single layer	Mean
10 m V	VREL	m/s	Surface/single layer	Mean
1 km AGL reflectivity	REFL1KM	dBZ	Surface/single layer	PM-mean
1 km refl ≥ 40 dBZ*	REFL1KMTH1_PN	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
3-hr max 1 km refl ≥ 40 dBZ*	REFL1KM_3h_PN	dBZ	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)

Composite reflectivity	REFLCMP	dBZ	Surface/single layer	PM-mean
Comp refl ≥ 40 dBZ	REFLCMPTH1_PN	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Surface-based CAPE	CAPE	J/kg	Surface/single layer	Mean
sbCAPE ≥ 500	CAPE05	%	Surface/single layer	Prob
sbCAPE ≥ 1500	CAPE15	%	Surface/single layer	Prob
sbCAPE ≥ 3000	CAPE30	%	Surface/single layer	Prob
Surface-based CIN	CIN	J/kg	Surface/single layer	Mean
sbCIN < -100	CIN100	%	Surface/single layer	Prob
sbCIN < -50	CIN050	%	Surface/single layer	Prob
sbCIN < -25	CIN025	%	Surface/single layer	Prob
Surface-based LCL	HLCL	m	Surface/single layer	Mean
Max Updraft helicity	VHEL	m^2/s^2	Surface/single layer	Max
Updraft helicity ≥ 25 m^2/s^2	VHEL25	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Updraft helicity ≥ 50 m^2/s^2	VHEL50	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Updraft helicity ≥ 100 m^2/s^2	VHEL100	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Max Updraft helicity (3-hr)	VHEL_3h	m^2/s^2	Surface/single layer	Max
Updraft helicity (3-hr) ≥ 25 m^2/s^2*	VHEL25_3h	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Updraft helicity (3-hr) ≥ 50 m^2/s^2*	VHEL50_3h	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Updraft helicity(3-hr) ≥ 100 m^2/s^2	VHEL100_3h	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Max sfc-400 hPa W	VVELMAX	m/s	Surface/single layer	Max
Max sfc-400 hPa W ≥ 10 m/s	VVELMAX10	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Max sfc-400 hPa W ≥ 15 m/s	VVELMAX15	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Max 3-6 km W ≥ 20 m/s	VVELMAX20	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Max sfc-400 hPa W (3-hr)	VVELMAX_3h	m/s	Surface/single layer	Max
Max sfc-400 hPa W (3-hr) ≥ 10 m/s*	VVELMAX10_3h	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Max sfc-400 hPa W (3-hr) ≥ 15 m/s*	VVELMAX15_3h	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Max 3-6 km W (3-hr) ≥ 20 m/s	VVELMAX20_3h	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)

0-1 km AGL wind shear	SHR01	1/s	Surface/single layer	Mean
0-1 km AGL wind shear ≥ 10 m/s	SHR01_10	%	Surface/single layer	Prob
0-1 km AGL wind shear ≥ 15 m/s	SHR01_15	%	Surface/single layer	Prob
0-1 km AGL wind shear ≥ 20 m/s	SHR01_20	%	Surface/single layer	Prob
0-6 km AGL wind shear	SHR06	1/s	Surface/single layer	Mean
0-6 km AGL wind shear ≥ 15 m/s	SHR06_15	%	Surface/single layer	Prob
0-6 km AGL wind shear ≥ 20 m/s	SHR06_20	%	Surface/single layer	Prob
0-6 km AGL wind shear ≥ 25 m/s	SHR06_25	%	Surface/single layer	Prob
Vertical-integrated Qg	COLQG	kg/ m^2	Surface/single layer	Max
Vertical-integrated Qg ≥ 20	COLQG20	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Vertical-integrated Qg ≥ 30	COLQG30	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Vertical-integrated Qg ≥ 40	COLQG40	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Vertical-integrated Qg (3-hr)	COLQG_3h	kg/ m^2	Surface/single layer	Max
Vertical-integrated Qg (3-hr) ≥ 20	COLQG20_3h	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Vertical-integrated Qg (3-hr) ≥ 30	COLQG30_3h	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Vertical-integrated Qg (3-hr) ≥ 40	COLQG40_3h	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Surface wind speed (10-m)	WMAGSFC	m/s	Surface/single layer	Max
Surface wind speed (10-m) ≥ 15 m/s	WMAGSFC15	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Surface wind speed (10-m) ≥ 20 m/s	WMAGSFC20	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Surface wind speed (10-m) ≥ 25 m/s	WMAGSFC25	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Surface wind speed (10-m) (3-hr)	WMAGSFC_3h	m/s	Surface/single layer	Max
Surface wind speed (10-m) (3-hr) ≥ 15 m/s	WMAGSFC15_3h	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Surface wind speed (10-m) (3-hr) ≥ 20 m/s	WMAGSFC20_3h	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Surface wind speed (10-m) (3-hr) ≥ 25 m/s	WMAGSFC25_3h	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Significant Tornado Parameter ≥ 1	SIGTOR1	%	Surface/single layer	Prob
Significant Tornado Parameter ≥ 3	SIGTOR3	%	Surface/single layer	Prob
Significant Tornado Parameter ≥ 5	SIGTOR5	%	Surface/single layer	Prob

Supercell Comp. Parameter ≥ 1	SCP1	%	Surface/single layer	Prob
Supercell Comp. Parameter ≥ 3	SCP3	%	Surface/single layer	Prob
Supercell Comp. Parameter ≥ 9	SCP9	%	Surface/single layer	Prob
W12 ≥ 0.5 m/s	W12P	%	Surface/single layer	Prob-neighbor (ROI=0, sigma=5)
MIXR12 ≥ 9 g/kg	Q09P	%	Surface/single layer	Prob
MIXR12 ≥ 12 g/kg	Q12P	%	Surface/single layer	Prob
MIXR12 ≥ 15 g/kg	Q15P	%	Surface/single layer	Prob
Lightning Threat 3 ≥ 0.02 flashes/km^2/5min	LIGT3_0.02	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Lightning Threat 3 ≥ 0.5 flashes/km^2/5min	LIGT3_0.5	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Lightning Threat 3 ≥ 1.0 flashes/km^2/5min	LIGT3_1.0	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Lightning Threat 3 ≥ 3.0 flashes/km^2/5min	LIGT3_3.0	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)
Lightning Threat 3 ≥ 6.0 flashes/km^2/5min	LIGT3_6.0	%	Surface/single layer	Prob-neighbor (ROI=40, sigma=10)

Appendix D: Models and Statistical Guidance for the QPF Component

Deterministic Experimental Guidance

Provider	Init Time	Model	Grid Space	Run Time	Notes
EMC	00/12Z	HiResW WRF-NMM	4 km	48 h	NAM IC/LBC
EMC	00/12Z	HiResW WRF-ARW	5.1 km	48 h	NAM IC/LBC
EMC	00/12Z	NMMB	12 km	60 h	NMMB IC/GFS LBC
EMC	00/12Z	NMMB nest	4 km	60 h	Nested within parent NMMB
GSD	Hourly	HRRR	3 km	15 h	RR IC/LBC; DDFI Radar, ARW core
MDL	00Z	HRMOS	Mapped to 4 km	192 h	Statistical regression based on GFS model. "Contiguous" product. (Charba and Samplatsky 2011)
NSSL	00Z	WRF-ARW	4 km	36 h	NAM IC/LBCs

Probabilistic Experimental Guidance

Provider	Init Time	Model	Grid Space	Run Time	Notes
CAPS	00Z	50 Member Storm Scale Ensemble Forecast (SSEF)	4 km	36 h	Multi-Model, Multi-Physics, Multi-IC SSEF with 3DVAR Data Assim. with Radar & Cloud analysis (ARW,NMM, ARPS, COAMPS); HMFs; Lightning; and CI Fields
CAPS	00Z	Bias-corrected SSEF	4 km	36 h	Running 14 day bias correction applied to 6 h QPF.
SPC, EMC, NSSL	00Z	7 Member Storm Scale Ensemble of Opportunity (SSEO)	4.0-5.1 km	36 h	Composed of Existing HiResW ARW (2), HiResW NMM (2), NSSL ARW (1), NMMB Nest (1); CONUS WRF-NMM; includes HiResW Time-Lagged Members;
MDL	00Z	HRMOS	Mapped to 4 km	192 h	Statistical regression based on GFS model. Probability products. (Charba and Samplatsky 2011)
NSSL	00Z	WRF-ARW	4 km	36 h	Neighborhood probabilities
EMC*	00Z	Hybrid High Resolution Ensemble (HREF)	4.0-5.1 km	48 h	SREF & HiResW; QPF Guidance (Mean, Prob.) (Du 2004)

*retrospective evaluation only

Charba, J. P., and F. G. Samplatsky, 2011: High-Resolution GFS-Based MOS Quantitative Precipitation Forecasts on a 4-km Grid. *Mon. Wea. Rev.*, **139**, 39–68.

Du, J., 2004. Hybrid Ensemble Prediction System: a New Ensembling Approach. Preprints, Symposium on the 50th Anniversary of Operational Numerical Weather Prediction, University of Maryland, College Park, Maryland, June 14-17, 2004, Amer. Meteor. Soc., CD-ROM (paper p4.2, 5pp). [available online: http://www.emc.ncep.noaa.gov/mmb/SREF/reference.html].

Appendix E: Spring Experiment Participant Schedule

EFP Spring Experiment 2011 Participants and Affiliations (5/11/11)

* GOES-R Visitor + Part-Time Visitor (1-3 days)

Week of May 9
+Steve Goss (NOAA/NWS/NCEP SPC)
+Greg Carbin (NOAA/NWS/NCEP SPC)
+Melissa Hurlbut (NOAA/NWS/NCEP SPC)
+Ariel Cohen (NOAA/NWS/NCEP SPC)
Steve Weiss (NOAA/NWS/NCEP SPC)
Chris Siewert (CIMMS/SPC GOES-R Proving Ground, Norman, OK)
Jim Correia (NOAA/NWS/NCEP SPC)
Patrick Marsh (NOAA/OAR/NSSL)
Adam Clark (NOAA/OAR/NSSL)
+Jack Kain (NOAA/OAR/NSSL)
Mike Coniglio (NOAA/OAR/NSSL)
Conrad Ziegler (NOAA/OAR/NSSL)
Corey Potvin (NOAA/OAR/NSSL)
Faye Barthold (NOAA/NWS/NCEP/HPC,Camp Springs, MD)
Isidora Jankov (NOAA/OAR/GSD, Boulder, CO)
Bill Gallus (Iowa State University, Ames, IA)
*John Walker (University of Alabama in Huntsville, Huntsville, AL)
*Dan Lindsey (CIRA/CSU, Fort Collins, CO)
*Wayne Feltz (CIMSS/UW, Madison, WI)
*Geoff Stano (ENSCO Inc./SPoRT Center, Huntsville, AL)
+*Ralph Petersen (CIMSS/UW, Madison, WI)

Week of May 16
Jeremy Grams (NOAA/NWS/NCEP SPC)
+Jonathan Garner (NOAA/NWS/NCEP SPC)
+Ariel Cohen (NOAA/NWS/NCEP SPC)
Steve Weiss (NOAA/NWS/NCEP SPC)
Chris Siewert (CIMMS/SPC GOES-R Proving Ground, Norman, OK)
Jim Correia (NOAA/NWS/NCEP SPC)
Patrick Marsh (NOAA/OAR/NSSL)
Adam Clark (NOAA/OAR/NSSL)
Jack Kain (NOAA/OAR/NSSL)
Mike Coniglio (NOAA/OAR/NSSL)
Conrad Ziegler (NOAA/OAR/NSSL)
Mike Douglas (NOAA/OAR/NSSL)
Nusrat Yussouf (NOAA/OAR/NSSL)
Bob Oravec (NOAA/NWS/NCEP/HPC Camp Springs, MD)
Greg Waller (NOAA/NWS/RFC, Fort Worth, TX)
Gary Skiwra (NOAA/NWS, Lubbock, TX)
Randy Skov (NOAA/NWS/CWSU, Atlanta, GA)
James Ott (NOAA/NWS/CWSU, Ft. Worth, TX)
John Brown (NOAA/OAR/GSD, Boulder, CO)
Glen Romine (NCAR, Boulder, CO)
Michelle Harrold (NCAR/DTC, Boulder, CO)
Neil Taylor (Environment Canada, Edmonton, Alberta)
+Don Berchoff (NOAA/NWS/OST, Silver Spring, MD)
+*Jason Otkin (CIMSS/UW, Madison, WI)
+*Dan Bikos (CIRA/CSU, Fort Collins, CO)
*John Mecikalski (University of Alabama in Huntsville, Huntsville, AL)

Week of May 23
+John Hart (NOAA/NWS/NCEP SPC)
+Jon Racy (NOAA/NWS/NCEP SPC)
+Jaret Rogers (NOAA/NWS/NCEP SPC)
Steve Weiss (NOAA/NWS/NCEP SPC)
Chris Siewert (CIMMS/SPC GOES-R Proving Ground, Norman, OK)
Jim Correia (NOAA/NWS/NCEP SPC)
Patrick Marsh (NOAA/OAR/NSSL)
Adam Clark (NOAA/OAR/NSSL)
Jack Kain (NOAA/OAR/NSSL)
Mike Coniglio (NOAA/OAR/NSSL)
Conrad Ziegler (NOAA/OAR/NSSL)
Dave Turner (NOAA/OAR/NSSL)
Valliappa Lakshmanan (NOAA/OAR/NSSL)
Bruce Sullivan (NOAA/NWS/NCEP HPC, Camp Springs, MD)
Lee Crowley (NOAA/NWS/RFC, Tulsa, OK)
Bob Ballard (NOAA/NWS, Honolulu, HI)
Jonathan Leffler (NOAA/NWS/CWSU, Chicago, IL)
+Tara Jensen (NCAR/DTC, Boulder, CO)
Curtis Alexander (NOAA/OAR/GSD, Boulder, CO)
Eric James (NOAA/OAR/GSD, Boulder, CO)
+Jim Ramer (NOAA/OAR/GSD, Boulder, CO
Jason Milbrandt (Environment Canada, CMC, Montreal)
Jon Case (ENSCO Inc./SPoRT Center, Huntsville, AL)
*Lee Cronce (CIMSS/UW, Madison, WI)
*Scott Rudlosky (CICS/Univ. of Maryland, College Park, MD)
*Chris Jewett (Univ. of Alabama in Huntsville, Huntsville, AL)
Lance Bosart (Univ. at Albany/SUNY, Albany, NY)
Kyle Griffin (Univ. at Albany/SUNY, Albany, NY)
Fred Carr (Univ. of Oklahoma, Norman, OK)
John Huhn (MITRE Corp., McLean, VA)

Week of May 31
Jared Guyer (NOAA/NWS/NCEP SPC)
+Bryan Smith (NOAA/NWS/NCEP/SPC)
Steve Weiss (NOAA/NWS/NCEP SPC)
Chris Siewert (CIMMS/SPC GOES-R Proving Ground, Norman, OK)
Jim Correia (NOAA/NWS/NCEP SPC)
Patrick Marsh (NOAA/OAR/NSSL)
Adam Clark (NOAA/OAR/NSSL)
Jack Kain (NOAA/OAR/NSSL)
Mike Coniglio (NOAA/OAR/NSSL)
Conrad Ziegler (NOAA/OAR/NSSL)
Nathan Hitchens (NOAA/OAR/NSSL)
Dusty Wheatley (NOAA/OAR/NSSL)
Thomas Jones (NOAA/OAR/NSSL)
Dave Novak (NOAA/NWS/NCEP/HPC, Camp Springs, MD)
Brian Guyer (NOAA/NWS, Albuquerque, NM)
Priscilla Nicosia (NOAA/NWS, Binghamton, NY)
Jeff Manion (NOAA/NWS/CRH, Kansas City, MO)
Mamoudou Ba (NOAA/NWS/MDL, Silver Spring, MD)
Chris Smallcomb (NOAA/NWS/WRH, Salt Lake City, UT)
Carl Bullock (NOAA/OAR/GSD, Boulder, CO)
Ellen Sukovich (NOAA/PSD/HMT, Boulder, CO)
Ben Moore (NOAA/PSD/HMT, Boulder, CO)

Clark Evans (NCAR, Boulder, CO)
Ana Genoves (Agencia Estatal de Meteorología (AEMET), Madrid, Spain)
*Justin Sieglaff (CIMSS/UW, Madison, WI)
Pete Manousos (FirstEnergy, Akron, OH)
Bill McCaul (USRA/NASA/SPoRT Center, Huntsville, AL)

Week of June 6
+Greg Dial (NOAA/NWS/NCEP SPC)
+Steve Goss (NOAA/NWS/NCEP SPC)
+Liz Stoppkotte (NOAA/NWS/NCEP SPC)
Steve Weiss (NOAA/NWS/NCEP SPC)
Chris Siewert (CIMMS/SPC GOES-R Proving Ground, Norman, OK)
Jim Correia (NOAA/NWS/NCEP SPC)
Patrick Marsh (NOAA/OAR/NSSL)
Adam Clark (NOAA/OAR/NSSL)
Jack Kain (NOAA/OAR/NSSL)
Mike Coniglio (NOAA/OAR/NSSL)
Conrad Ziegler (NOAA/OAR/NSSL)
Dave Novak (NOAA/NWS/NCEP HPC, Camp Springs, MD)
James Paul (NOAA/NWS/RFC Tulsa, OK)
Tim Collins (NOAA/NWS/NCEP/OPC, Camp Springs, MD)
Jeff Evans (NOAA/NWS Tallahassee, FL)
Ken Pomeroy (NOAA/NWS/WRH Salt Lake City, UT)
Phil Shafer (NOAA/NWS/MDL, Silver Spring, MD)
David Dowell (NOAA/OAR/GSD, Boulder, CO)
Leigh Cheatwoodl (NOAA/OAR/GSD, Boulder, CO)
Paula McCaslin (NCAR/DTC, Boulder, CO)
Stan Trier (NCAR, Boulder, CO)
Brad Zavodsky (NASA/SPoRT Center, Huntsville, AL)
*Jim Gurka (NOAA/NESDIS, Greenbelt, MD)
*Jordan Gerth (CIMSS/UW, Madison, WI)
*Ralph Petersen (CIMSS/UW, Madison, WI)
*Bob Aune (CIMSS/UW, Madison, WI)
*Lori Schultz (Univ. of Alabama in Huntsville, Huntsville, AL)
Russ Schumacher (Texas A&M University, College Station, TX)
Ana Genoves (Agencia Estatal de Meteorología (AEMET), Madrid, Spain)
Pieter Groenemeijer (European Severe Storms Laboratory, Wessling, Germany)

Appendix F: Instructions for Creating and Submitting Experimental Severe Thunderstorm Forecasts

1. Experimental Severe Thunderstorm Forecast Graphics

Probabilistic severe weather forecasts will be issued **in the morning** for the 18-21z and 21-00z time periods. **In the afternoon**, additional forecasts will be issued for the 00-03z and 03-06z time periods. The severe weather forecast graphics will be similar in format to operational SPC outlooks, except only total severe storm probability contours will be formulated (no categorical outlook, and no general thunderstorms will be forecast). The same probability contours used in the operational outlooks will be used for the severe forecasts (5, 15, 30, 45, and 60 %); an area delineating potential for significant severe storms will be included when the probability for significant severe is 10% or greater. The Probability-to-Categorical conversion for total severe is identical to that used for the SPC Day 2 Outlook, and is shown below.

2. Drawing and Saving the Experimental Forecasts in NMAP

a. For the morning and afternoon forecasts, the forecaster will draw in NMAP separate probability contours for each valid period, and will save each forecast as a separate graphic product. The process will utilize NMAP software that is used in SPC operations. When saving each experimental forecast graphic, the following modifications are required:

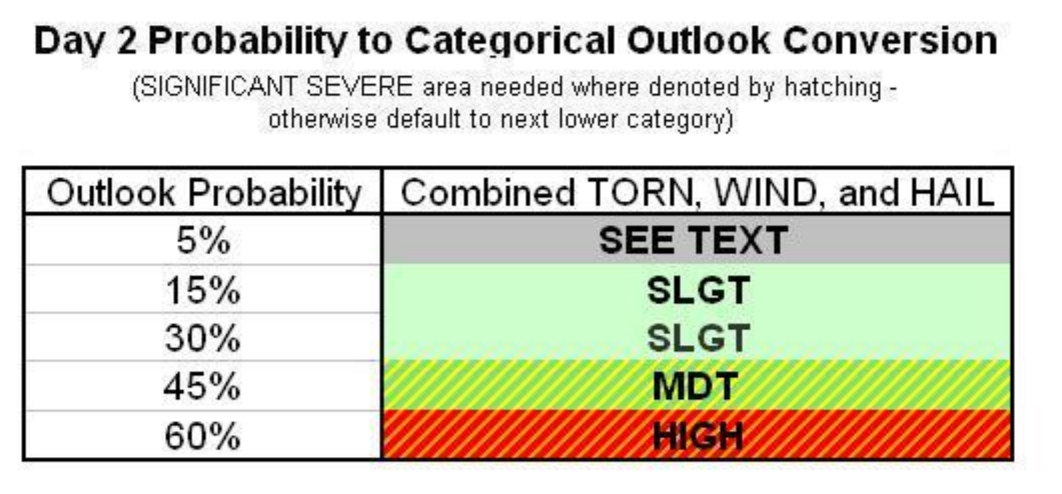
1) In the format outlook box, ***change valid time to 1800z to 2100z; 2100z to 0000z, etc)***
Be sure to change date when crossing00z
2) In the product save box, ***replace "outlook" with "svr"***

b. Enter command in xterm window: sp11bg svr # (such as sp11bg svr 2)

where # is the NAWIPS workstation number (1-6) where the graphic is created. This script archives the severe weather forecast, attaches date/time to the graphics file, and sends graphics to the web page.

3. Completing Model Discussion Section on Internal Web Page

a. On HWT Spring Experiment web page click on Experimental Forecast Generation (Severe Team)
b. Click on "Morning Forecast" or "Afternoon Forecast" and the two-period severe forecast graphics will appear
c. Complete Discussion Text Box and when finalized, click on Submit.



Day 2 Probability to Categorical Outlook Conversion

(SIGNIFICANT SEVERE area needed where denoted by hatching - otherwise default to next lower category)

Outlook Probability	Combined TORN, WIND, and HAIL
5%	SEE TEXT
15%	SLGT
30%	SLGT
45%	▨ MDT
60%	▨ HIGH

Appendix G: Instructions for Creating and Submitting Experimental Convective Initiation Forecasts

1. Experimental CI Spatial Graphics in NMAP

In the morning, CI forecasts will be issued over a specified small mesoscale domain for three separate 3-hr time periods, which can be any 3-hr period (18-21, 20-23z etc.). The categorical CI graphics for each period will delineate areas of potential CI using descriptive terms of Slight, Moderate, and High, which denote the likelihood of CI within the domain. In addition to the categorical contours, a predicted time (UTC) of the first CI during each 3-hr period will be placed within the highest categorical contour on the graphic. If no contours are drawn on the 3-hr spatial CI graphic, a specific initiation time is not necessary.

2. Drawing and Saving the Experimental Forecasts in NMAP

a. For the spatial forecasts, the forecaster will draw in NMAP categorical contours for each valid period, and will save each forecast as a separate graphic product. The process will utilize NMAP software that is used in SPC operations. When saving each experimental forecast graphic, the following modifications are required:

1) In the format outlook box, ***change valid time to 1800z to 2100z; 2000z to2300z, etc)***
Be sure to change date if crossing00z
2) In the product save box, ***replace "outlook" with "ci_STN"***
Where STN is the CI domain centerpoint station ID

b. Enter command in xterm window: sp11bg ci # (such as sp11bg ci 6)

where # is the NAWIPS workstation number (1-6) where the graphic is created**.** This script archives the CI spatial forecast, attaches date/time to the graphics file, and sends graphics to the web page.

3. Completing Model Discussion Section via Survey Monkey

Survey Monkey will have questions to answer for the CI forecast process. This takes the place of some of the writing. The discussion can be about added insights, scenario, and any other troubles associated with making the forecast.

4. Experimental CI Temporal PDF Forecasts on Web Page

a. Carefully read the instructions

b. To edit the line graph, click the image. (It might automatically open for the 2nd line graph)

c. Edit the values in the human time series only.

d. Click the "Debug" tab and click the show URL button on the bottom left. copy the URL into the text box below. Make sure this is done for both images

e. Save the finished line graphs to the local directory as png files

f. Enter any relevant text for how you came to consensus. Include the straw-poll of the CI times by each forecaster, including the window, and uncertainty.

g. Before clicking submit, you must understand that clicking submit saves a file to the server and erases all your work. So do not click twice, otherwise you will have top redo the forecast.

h. Click submit.

Appendix H: Instructions for Creating and Submitting Experimental QPF Products

1. Experimental QPF Graphics

In the morning, two-period QPF products for the probability of exceeding (POE) 0.5 inch/6 hrs and the probability of exceeding 1.0 inch/6 hrs will be issued for the 18-00z and 00-06z time periods. **In the afternoon**, the forecast for the 00-06z period will be updated, and an additional forecast for the 06-12z period will be issued. The probabilistic QPF graphics are analogous to several operational HPC forecast products (such as excessive rainfall and heavy snow) in that categorical descriptive terms of Slight, Moderate, and High are used to denote forecast probabilities. For the experimental QPF products, Slight=25%, Moderate=50%, and High=75%. In addition to the categorical contours, a predicted maximum 6 hr rainfall amount within the highest categorical contour for the 1 inch POE will be included in the graphic. If no contours are drawn on the 1 inch POE graphic, a maximum amount is not necessary.

2. Drawing and Saving the Experimental Forecasts in NMAP

a. For the QPF forecasts, the forecaster will draw in NMAP separate categorical contours for both exceedance thresholds for the first valid period, and repeat the process for the second valid period. Each of the four graphics will be saved as a separate product. The process will utilize NMAP software that is used in SPC operations. When saving each experimental forecast graphic, the following modifications are required:

a. For the 18-00z and 06-12z forecasts:

1) In the format outlook box, ***change valid time to 1800z to 0000z,or 0600z to1200z***
Be sure to change date when crossing00z
2) In the product save box, ***replace "outlook" with "qpf_50" or "qpf_100"***
Be sure to change date when crossing00z

b. For the morning 00-06z preliminary forecast:

1) In the format outlook box, ***change valid time to0000z to 0600z***
Be sure to change date when crossing00z

2) In the product save box, ***replace "outlook" with "qpf_prelim50" or "qpf_prelim100"***

c. For the afternoon 00-06z update forecast:

1) In the format outlook box, ***change valid time to0000z to 0600z***
Be sure to change date when crossing00z

2) In the product save box, ***replace "outlook" with "qpf_final50" or "qpf_final100"***

d. Enter command in xterm window: sp11bg qpf # (such as sp11bg qpf 4)

where # is the NAWIPS workstation number (1-6) where the graphic is created**.** This script archives the QPF forecast, attaches date/time to the graphics file, and sends graphics to the web page.

3. Completing Model Discussion Section on Internal Web Page

a. On HWT Spring Experiment web page click on "Experimental Forecast Generation (QPF Team)"
b. Click on "Morning Forecast" or "Afternoon Forecast" and the two-period QPF graphics will appear
c. Complete Discussion Text Box and when finalized, click on Submit.

Appendix I: Severe Component Subjective Evaluation Topic Areas

Each day the severe team members will conduct a number of evaluation activities to assess the performance of the experimental probabilistic severe weather forecasts, and the model guidance available to the severe team. The assessment should represent a consensus of all members of the team. The following list of evaluation topics will be available for evaluation, but we expect that not all topics will necessarily be completed each day. Rather, there will be some flexibility in the evaluation activities based on evolving scientific findings, specific interest areas of interest to weekly participants, etc. Topic areas marked by an asterisk (*) are expected to be completed each day.

A. Yesterday's Severe Team Experimental Forecasts

*1. Briefly discuss the primary convective evolution that occurred between 18-06 UTC in yesterday's forecast domain based on observed reflectivity, warnings, and storm reports. Focus on initiation, mode, and mesoscale evolution during the afternoon and evening, including whether or not deep convection and severe convection were occurring at 18 UTC.

*2. Subjectively evaluate yesterday's Severe Weather Forecasts for each of the 3-hr forecast periods, using a rating scale from Very Good to Very Poor. Areas with greater severe storm occurrence, higher forecast probabilities, and the forecast or occurrence of significant reports, should be given more weight in the rating process.

Provide additional comments about the reasons for each forecast rating - e.g., regions where the forecast was good, and where it was not. Include aspects of predicted and observed coverage, and any displacement errors that were factors in your rating, e.g., the primary axis of severe weather was east of the forecast location.

B. Yesterday's Model Forecasts

- Deterministic Model Basic Simulated Reflectivity and Satellite Imagery –

*1. Compare performance of yesterday's high-resolution convection-allowing model forecasts using simulated 1 km AGL reflectivity fields from 00z NSSL-ARW, and EMC Hi-Res Window WRF-NMM and WRF-ARW, CONUS WRF-NMM, and new NMMB Nest for the 18-00 and 00-06 UTC periods.

2. Evaluate the utility of the NSSL WRF Simulated Satellite Imagery to provide integrated information about the evolution of synoptic/mesoscale features, associated moisture transport/gradients, clouds, and convective storm development.

- SSEF Basic Simulated Reflectivity –

*3. Evaluate the ability of the SSEF displays of the neighborhood exceedance probability of reflectivity >= 40 dBZ within 40 km of a grid point and the spaghetti chart of simulated reflectivity >= 40 dBZ from each member to provide useful information about the mesoscale evolution of convection within the evaluation domain during the 18-06 UTC period.

- SSEF Hourly Maximum Field 3-hr Probability -

*4. Evaluate the utility of the SSEF HMF neighborhood (within 40 km of a grid point) exceedance probability to provide useful information to severe storm forecasters about the timing, location, character and intensity of model-generated deep convection, including severe weather occurrence and report type. Conduct the evaluation for the 18-06 UTC time period by comparing the probability field and severe reports occurring during each 3-hr period for the following products: Updraft Helicity, Updraft Speed, Surface Wind, and Vertically Integrated Graupel.

- Radar Assimilation Sensitivity –

*5. Examine the evolution of composite reflectivity from different CAPS members and the HRRR and LAPS models during the first 6 hrs of each forecast, focusing on the initial correspondence with observed radar, stability of model storm evolution, and correspondence with observed composite reflectivity.

- Microphysics Sensitivity –

6. Comment on any differences and perceived level of skill in forecasts of composite reflectivity for members with different microphysics parameterizations, including the control member CN (Thompson), m25 (WDM6), m26 (WSM6), m24 (Morrison), and m23 (Milbrandt-Yau) during the 18-12 UTC period, based on comparisons with observed composite reflectivity.

- PBL Sensitivity -

7. Comment on any differences and perceived level of skill in forecasts of 1 km AGL reflectivity and surface temperature/dew point for members with different PBL parameterizations, including the control member CN (MYJ), m31 (QNSE), m32 (MYNN), m36 (ACM2), and m40 (YSU) during the 18-06 UTC period, based on comparisons with observed base reflectivity.

- SSEF/SREF Environment Comparison –

*8. Compare the SSEF and SREF Mean CAPE and 0-6 km Shear at 3-hrly intervals during the 18-06 UTC period. Using the SPC hourly Mesoscale Analysis fields as "truth", assess the skill of the SSEF forecasts compared to the SREF forecasts.

9. Comment on the usefulness of the SSEF and SREF exceedance probability forecasts of SCP and STP during the 18-06 UTC period. How well did they indicate whether the environment was conditionally favorable for supercells and significant tornadoes, using the SPC Mesoscale Analysis displays of SCP and STP as "truth"?

- SSEF/SREF Calibrated Severe Probability -

*10. Evaluate the utility of the operational and experimental SREF products, and the experimental SSEF product, to provide useful severe storm guidance, by comparing the probability forecasts with observed severe storm reports for the 18-21, 21-00, 00-03, and 03-06 UTC periods. Consider the degree of correspondence between forecast probability values and coverage of severe reports, and timing/location errors, during the rating process.

11. How does the SREF experimental and SSEF experimental calibrated severe thunderstorm guidance compare to the SREF operational guidance?

- SSEF/SSEO Comparison –

12. Evaluate the utility of the spaghetti charts showing member forecasts of reflectivity $\geq$ 40 dBZ and neighborhood exceedance probability of reflectivity $\geq$ 40 dBZ by comparing the forecasts with observed base reflectivity during the 18-06 UTC period. As part of the evaluation, consider the correspondence between the probability values and the observations, and if the observations tend to fall within the ensemble forecast pdf.

13. Evaluate the utility of the neighborhood exceedance probability of Hourly Maximum Updraft Helicity $\geq$ 25, 50, and 100 m2/s2, as useful guidance for severe weather forecasting. Compare the forecast probability fields with the occurrence of severe reports, focusing on correspondence between probability values and severe storm coverage and intensity.

Appendix I: CI Component Subjective Evaluation Topic Areas
(Under Development)

Appendix K: QPF Component Subjective Evaluation Topic Areas

Each day the QPF team members will conduct a number of evaluation activities to assess the performance of the experimental probabilistic QPF forecasts, and the model guidance available to the QPF team. The assessment should represent a consensus of all members of the team. The following list of evaluation topics will be available for evaluation.

A. Yesterday's QPF Team Experimental Forecasts

1. Evaluate the accuracy of each experimental forecast by comparing it with the NSSL Q2 6 hr QPE data. Assess how well the forecast probabilities correspond to areas of heavier observed rainfall.

2. Evaluate the accuracy of the afternoon updated 00-06 UTC forecast by comparing it with the NSSL Q2 6 hr QPE data. Is the updated (afternoon) forecast better than the initial (morning) forecast?

Provide additional comments about the reasons for each forecast rating - e.g., regions where the forecast was good, and where it was not. Include aspects of predicted and observed rainfall, and any displacement errors that were factors in your rating, e.g., the primary axis of heavy rain was east of the forecast location.

B. Yesterday's Model Forecasts

- Deterministic Model QPF Guidance Compared to Operational NAM -

3. For the 18-00 UTC, 00-06, and 06-12 UTC forecast period please rate the degree to which the 00 UTC experimental 12km NMMB, 4 km NMMB nest, HRW-NMM, and NSSL WRF-ARW forecasts of 6 hr precipitation provided additional value over the 00 UTC operational NAM.

- HRRR Model QPF Guidance Compared to Experimental NMMB Nest -

4. For the 18-00 UTC forecast period, please rate the degree to which the 12 UTC HRRR 6 hr precipitation forecast provided additional value over the 12 UTC 4-km NMMB nest.

- SSEF, SSEO, and HRMOS Guidance Compared to SREF Mean QPF -

5. For the 18-00 UTC, 00-06, and 06-12 UTC forecast period please rate the degree to which the 00 UTC SSEF mean, SSEO mean, and HRMOS mean 6 hr precipitation forecasts provided additional value over the 21 UTC SREF mean.

- Bias-Corrected SSEF Compared to Raw SSEF Mean QPF -

6. For the 18-00 UTC, 00-06, and 06-12 UTC forecast period please rate the degree to which the 00 UTC bias corrected SSEF mean and probability matched SSEF mean 6 hr precipitation forecasts provided additional value over the 00 UTC SSEF mean.

- General Comments on Utility of Post-Processed QPF Guidance -

7. What is your overall impression of the available post-processed guidance (spaghetti plots, neighborhood probabilities, ensemble maximum QPF, HRMOS probabilities)?

Appendix L: Practically Perfect Forecasts

(From Brooks, H. E., M. Kay, and J. A. Hart, 1998: Objective limits on forecasting skill of rare events. *Preprints*, 19th Conference on Severe Local Storms, Minneapolis, Minnesota, American Meteorological Society, 552-555.)

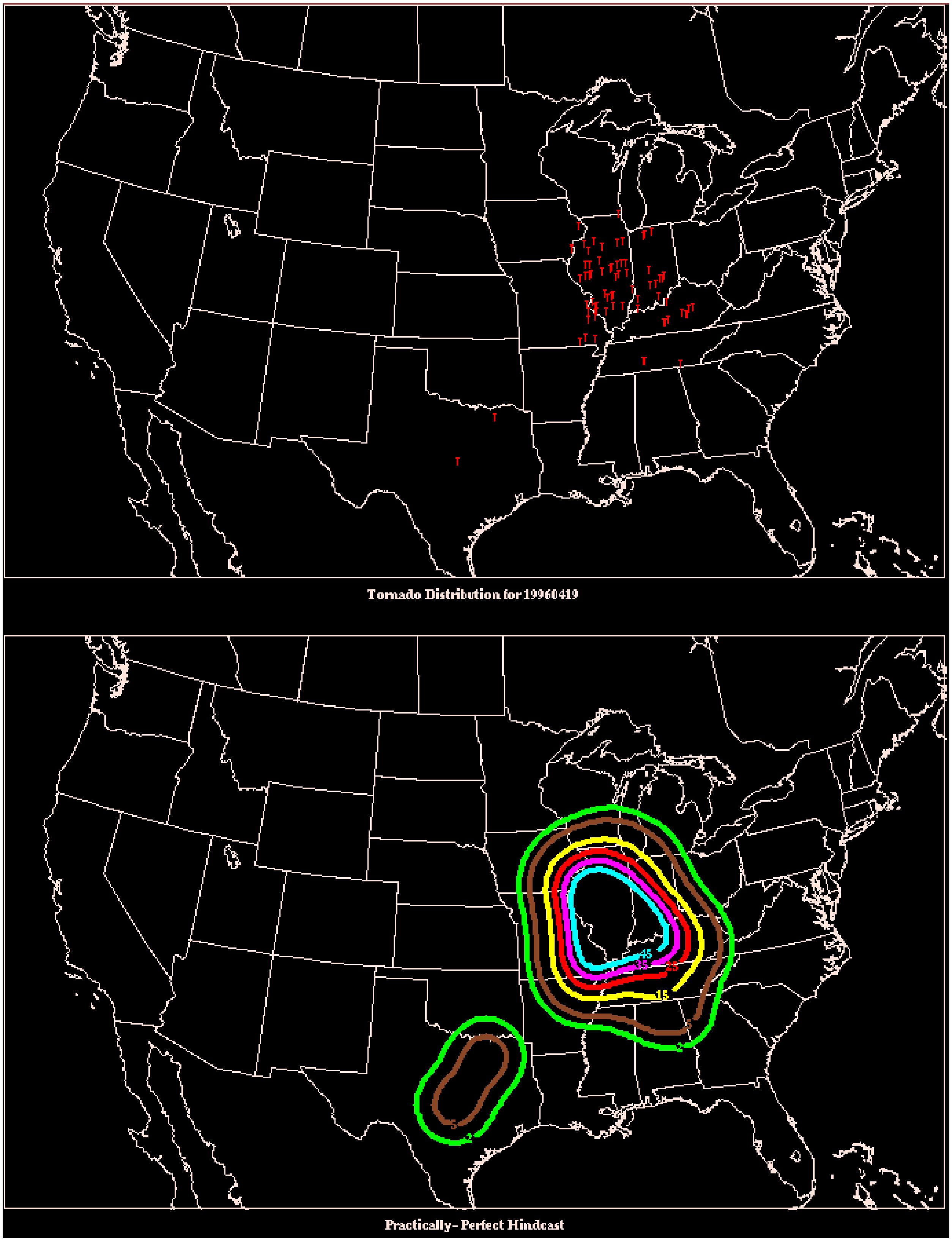
Severe weather forecasts such as SPC outlook and watch products are issued with the explicit expectation that there will be “false alarms” (parts of the forecast for which there are no events) and “missed detections” (events which are not included in the forecast). Thus, the expected range of values of the probability of detection (POD) or false alarm rate (FAR), for example, does not run from 0 to 1 in practice. The concept of a “practically” perfect (PP) forecast can then be used to estimate the minimum and maximum scores that a forecaster could reasonably be expected obtain given real world distributions of severe weather reports and the low predictability of specific severe convective storms in advance. In general, that range will be much smaller than the absolute minimum and maximum, but will provide a range over which meaningful forecast performance can be judged.

To compute the PP forecast, reports of severe weather are recorded on a grid with each grid box representing an area 80 x 80 km. (This grid corresponds to SPC Outlook products where probability values correspond to a probability within 25 miles of each grid point.) All severe weather reports are considered equal and the computation considers only whether a box has had an event or not. The PP forecast is then created by smoothing the events using nonparametric density estimation with a two dimensional Gaussian kernel. Specifically, at each grid point in the domain, the PP forecast value, *f*, is given by

$$f = \sum_{n=1}^{N} \frac{1}{2\pi\sigma^2} \exp\left(-\frac{1}{2}\left[\frac{d_n}{\sigma} \right]^2 \right)$$

where *dn* is the distance from the forecast grid point to the *n*-th location that had an event occur, *N* is the total number of grid points with events, and σ is a weighting function that can be interpreted as the confidence one has in the location of the forecast event. Increasing σ is equivalent to increasing the uncertainty associated with the forecast as one would do with increasing lead time of the forecast. That is, in the context of severe weather forecasting, very small σ can be thought of as being associated with the warning stage, while larger σ is associated with the watch or convective outlook stages. For SPC forecasts a value of 3 used.

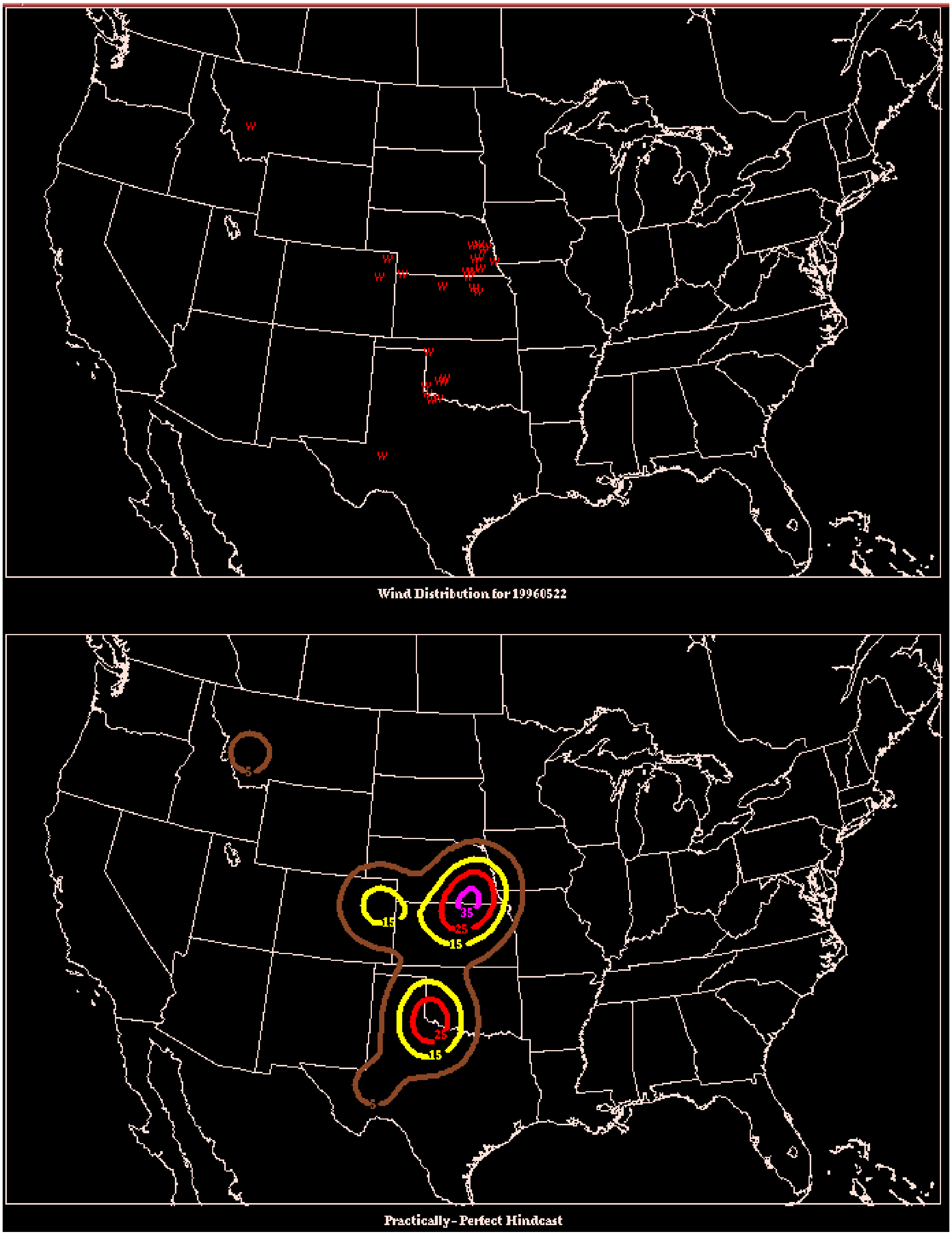
Examples of PP forecasts based on actual severe weather reports are shown on the next two pages. As part of the subjective evaluations of the severe and QPF team experimental forecasts, PP “hindcasts” are created and displayed to provide an approximate benchmark of what a “good” forecast might look like.



Tornado Distribution for 19960419

Practically-Perfect Hindcast

19 April 1996 tornado reports (top) and PP forecast (bottom) based on tornado reports


Wind Distribution for 19960522

Practically-Perfect Hindcast

22 May 1996 wind damage reports (top) and PP forecast (bottom) based on the wind reports only

Appendix M: WRF Model Identification of Convective Storms with Rotating Updrafts – Computation of Updraft Helicity

1. Storm Relative Environmental Helicity

Helicity, H, is a scalar measure of the potential for helical flow (i.e., the pattern of a corkscrew) to develop in a moving fluid defined by

$$H = \vec{V} \bullet \nabla \times \vec{V} \,.$$

Expressed in its component form,

$$H = u(\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}) + v(\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}) + w(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}) \,.$$

The portion of helicity associated with the *storm relative streamwise component* is that along the ambient horizontal velocity vector, or

$$H_s = -(u - c_u)(\frac{\partial v}{\partial z}) + (v - c_v)(\frac{\partial u}{\partial z}) \,,$$

where is the storm motion and terms involving w neglected. Integrating H_s vertically through the thunderstorm inflow layer, z, yields the *storm relative environmental helicity*, SREH,

$$SREH = -\int_{z_o}^{z} [(u - c_u)(\frac{\partial v}{\partial z}) - (v - c_v)(\frac{\partial u}{\partial z})] dz \,.$$

SREH is a commonly used parameter to assess the severe thunderstorm potential of the environment and is often integrated from the surface to 1 - 3 km AGL. Order of magnitude values of SREH are ~ O(50) to O(300) m^2/s^2 in environments that tornadic storms.

2. Updraft Helicity

With the availability of numerical models containing sufficient resolution to resolve convective processes explicitly, it is now possible to calculate a *vertical component of helicity* associated with the convective updraft. This is the vertical integral of the third term in equation (2) and referred to as *updraft helicity*, U_H. Thus,

$$U_H = \int_{z_o}^{z} [w(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y})] dz = \int_{z_o}^{z} [w\zeta] dz$$

where is the vertical component of the relative vorticity at grid points where w > 0. In post processing the WRF members for the SPC/NSSL Spring Program, equation (5) is integrated vertically from z_o = 2 km to z = 5 km AGL using a midpoint approximation. Data are available every 1000 meters AGL, so equation (5) is computed as

$$U_H = \int_{z_o}^{z} [w\zeta] dz \approx \sum_{z=2000m}^{z=5000m} (\overline{w\zeta}\Delta Z) = (\overline{w\zeta}_{2,3} + \overline{w\zeta}_{3,4} + \overline{w\zeta}_{4,5}) \times 1000 ,$$

where the over bar indicates a layer average and the subscripts indicate the bottom and top of the layer in kilometers. Early experience indicates that typical values of U_H associated with WRF predicted supercell thunderstorms are have U_H of at least ~O (50) m^2/s^2 and that significant supercells have U_H ~O (150) m^2/s^2.

Appendix N: The Fractions Skill Score

Taken from Schwartz et al. (2010), after work by Roberts and Lean (2008)

Probabilistic forecasts are commonly evaluated with the Brier score or Brier skill score by comparing probabilistic forecasts to a dichotomous observational field. However, one can apply the neighborhood approach to the observations in the same way it is applied to model forecasts, changing the dichotomous observational field into an analogous field of observation-based fractions (or probabilities). The two sets of fraction fields (forecasts and observations) then can be compared directly. Fig. 11 shows the creation of a fraction grid for a hypothetical forecast *and* the corresponding observations. Notice that although the model does not forecast precipitation $\geq q$ at the central grid box when the surrounding neighborhood is considered, the same probability as the observations is achieved (8/21 = 0.38). Therefore, within the context of a radius r, this model forecast is considered to be correct.

After the raw model forecast and observational fields have both been transformed into fraction grids, the fraction values of the observations and models can be directly compared. A variation on the Brier score is the fractions Brier score (FBS) given by

$$\mathrm{FBS} = \frac{1}{N_v}\sum_{i=1}^{N_v}[\mathrm{NP}_{F(i)} - \mathrm{NP}_{O(i)}]^2, \qquad (6)$$

where $\mathrm{NP}_{F(i)}$ and $\mathrm{NP}_{O(i)}$ are the neighborhood probabilities at the ith grid box in the model forecast and observed fraction fields, respectively. Here, as objective verification only took place over the verification domain, i ranges from 1 to N_v, the number of points within the verification domain on the verification grid. Note that the FBS compares fractions with fractions and differs from the traditional Brier score only in that the observational values are allowed to *vary* between 0 and 1.

Like the Brier score, the FBS is negatively oriented—a score of 0 indicates perfect performance. A larger FBS indicates poor correspondence between the model forecasts and the observations. The worst possible (largest) FBS is achieved when there is no overlap of nonzero fractions and is given by

$$\mathrm{FBS}_{\mathrm{worst}} = \frac{1}{N_v}\left[\sum_{i=1}^{N_v}\mathrm{NP}_{F(i)}^2 + \sum_{i=1}^{N_v}\mathrm{NP}_{O(i)}^2\right]. \qquad (7)$$

On its own, the FBS does not yield much information since it is strongly dependent on the frequency of the event (i.e., grid points with zero precipitation in either the observations or model forecast can dominate the score). However, a skill score can be constructed that compares the FBS to a low-accuracy reference forecast ($\mathrm{FBS}_{\mathrm{worst}}$) and is defined as the fractions skill score (FSS):

$$\mathrm{FSS} = 1 - \frac{\mathrm{FBS}}{\mathrm{FBS}_{\mathrm{worst}}}. \qquad (8)$$

The FSS ranges from 0 to 1. A score of 1 is attained for a perfect forecast and a score of 0 indicates no skill. As r expands and the number of grid boxes in the neighborhood increases, the FSS improves as the observed and model probability fields are smoothed and overlap increases.

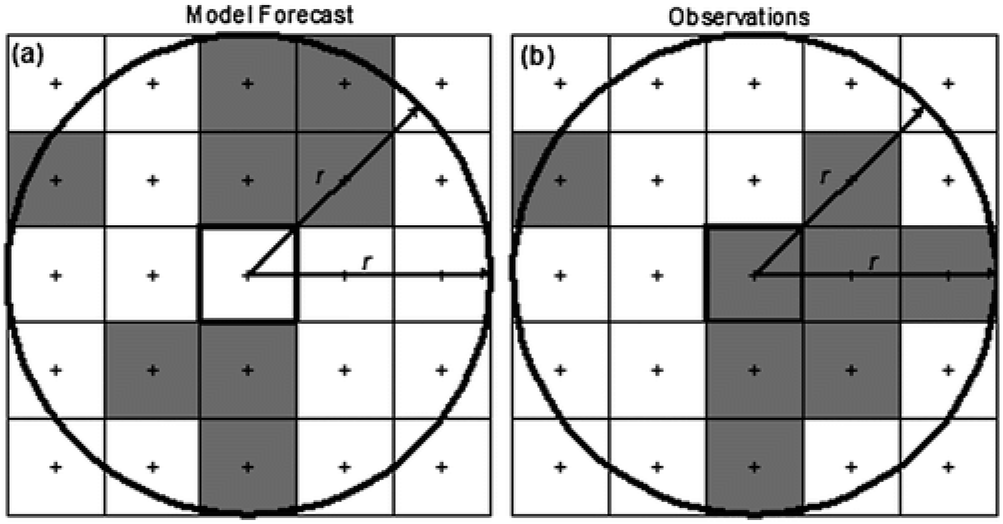


Fig. 11. Schematic example of neighborhood determination and fractional creation for (a) a model forecast and (b) the corresponding observations. The precipitation exceeds the accumulation threshold in the shaded boxes, and a radius of 2.5 times the grid length is specified.

Roberts, N. M., and H. W. Lean, 2008: Scale-selective verification of rainfall accumulations from high-resolution forecasts of convective events. *Mon. Wea. Rev.*, **136**, 78–97.

Schwartz, C., S., and co-authors: Toward improved convection-allowing ensembles: Model physics sensitivities and optimizing probabilistic guidance with small ensemble membership. *Wea. Forecasting*, **25**, 263-280.