National Weather Service Uncertainty Requirements for Operations Team Final Report

Recommendations for Forecast Office and National Center Uncertainty Information

April 2008

Acknowledgments

The NWS Uncertainty Requirements for Operations Team thanks NWS Headquarters, Office of Oceanic and Atmospheric Research (OAR), and the National Centers for Environmental Predictions (NCEP) for their support for this survey and report. The Team appreciates the time and other support of the NWS Weather Forecast Offices, River Forecast Offices, Regional Offices, and National Centers with this project. Thanks are extended to the University Corporation for Atmospheric Research for training support, and the atmospheric sciences' research community for their contributions in forecast uncertainty advancements including numerical modeling. In addition, the Team thanks the Department of the Treasury for the help with the survey arrangements, and the CFI Group, Inc, for their expertise and assistance with the survey, analysis and recommendations. The NOAA/NWS Forecast Uncertainty Steering Team provided valuable guidance and support for this project.

Table of Contents

I. Executive Summary

The NWS Uncertainty Requirements for Operations (NURO) Team was chartered as a sub-group of the NOAA/NWS Forecast Uncertainty Steering Team (NFUSE) in May 2007. The NURO mission was to collect information about the current use of and future needs for forecast uncertainty information by NWS Weather Forecast Offices (WFOs), River Forecast Centers (RFCs), and National Centers (NCs). This work resulted in the development and delivery of this report to NFUSE. Based on the Team's charter, all deliverables have been met and the mission has been completed (April, 2008).

To accomplish its mission, the NURO Team collaborated with CFI (Claes Fornell International) Group, Inc. to conduct a survey of all WFOs (Meteorologists-in-Charge [MICs], Science and Science Operations Officers [SOOs], and Warning Coordination Meteorologists [WCMs]), RFCs (Hydrologists-in-Charge [HICs] and Development and Operational Hydrologists [DOHs]) and NCs (Directors, Branch Chiefs, SOOs, WCMs). Analysis of the survey data and specific responses from the offices and centers support the conclusion that enhancements are needed for NWS forecast uncertainty guidance for field offices. These enhancements include expanded ensemble data access, enhanced visualization capabilities, improved access to verification information, and training to enhance services to users through the improved conveyance of forecast uncertainty.

The NWS provides forecast uncertainty information using various product formats (e.g., text, graphics). In addition, survey results indicate that forecast uncertainty information is also communicated through requests received from external users (e.g., emergency managers), especially for high-impact events. Respondents indicated that forecasts for several types of hydrometeorological events and forecast parameters could benefit from the inclusion or expansion of additional uncertainty information. Some of these forecast-event types include convective storms, precipitation, and short-term streamflows.

Development of uncertainty guidance training has not occurred in several offices according to a large percentage of survey respondents. Feedback in the survey indicated that training should focus on interpreting and applying forecast uncertainty guidance in forecasts. This instruction should involve ways to use forecast guidance to create products that enhance the communication of uncertainty details to users for decision-making support. Obtaining and clarifying uncertainty requirements from external user groups would help focus future NWS uncertainty initiatives (e.g., training, product development) to enhance services. Generating new or enhanced products with uncertainty guidance for field office forecasters and users will require additional computational, data storage and communication resources, and possible modifications to existing systems.

Overall, the respondents recommend that the NWS develop standardized forecast uncertainty information (e.g., guidelines). The response to user uncertainty requirements should contribute to enhancements in the generation of new products and forecast guidance and/or modification of existing products and forecast guidance. This effort may require modifications to future computer systems to create this information for all users. The Team recommends that the NWS continue to work collaboratively with NFUSE, NOAA, external users, and scientific community groups to enhance the generation and application of forecast uncertainty in products for public benefit.

Specific team recommendations are listed in Appendix A.

II. Introduction

The primary goal of the **NWS Uncertainty Requirements for Operations** (NURO) Team was to collect and ascertain the current use of and needs for forecast uncertainty information at Weather Forecast Offices (WFOs), River Forecast Centers (RFCs) and National Centers (NCs). This project sub-group of the NOAA/NWS Forecast Uncertainty Steering Team (NFUSE) consisted of several employees from various NWS offices. The NURO Team defined forecast uncertainty as: "a state of having limited knowledge in which it is impossible to exactly describe the existing state, or future outcome, of a hydrometeorological or climatological system". The ability to obtain and communicate the range of plausible forecast scenarios due to forecast uncertainty requires objective guidance and other types of hydrometeorological information.

Section III of this report provides the baseline of current uncertainty guidance available to WFOs, RFCs, and NCs. Section IV presents the method and analysis of a survey conducted in collaboration with the CFI (Claes Fornell International) Group, Inc., a private company specializing in user feedback to obtain additional forecast uncertainty information (e.g., requirements, current uncertainty resources) from WFOs, RFCs, and NCs. More detailed statistical summaries and analysis are available in Appendix G.

The NURO Team and CFI's analysis of the survey data resulted in several findings, including the identification of major themes, which are discussed in Section V. The findings also include the need to define user requirements, and needs for training, technology, and the use of numerical model guidance to generate and communicate forecast uncertainty. Section VI contains a report summary.

III. Current Uncertainty Tools in the NWS

The NURO team completed an assessment of the existing state of NWS uncertainty guidance available in field offices and NCs before conducting the survey. Several NWS groups, including NWS HQ and NCs provided baseline information. The assessment was used to develop relevant questions and possible answer choices for the national survey. The existing NWS uncertainty guidance information is grouped into three categories (Appendices C, D and E). The first group (Appendix C) shows the current available uncertainty tools and products in the Advanced Weather Interactive Processing System (AWIPS) for WFOs and RFCs, the National Centers' AWIPS (N-AWIPS), and the Automated Tropical Cyclone Forecast (ATCF) system used primarily at the Tropical Prediction Center and the Central Pacific Hurricane Center (CPHC). The second group (Appendix D) contains sources of uncertainty information available to field offices and NCs on the World Wide Web. Group three (Appendix E) provides existing NWS products that include uncertainty estimates.

The NWS produces valuable uncertainty guidance for external users and field offices. However, bandwidth limits prevent the transmission of the full spectrum of guidance and products to field offices. Future system changes are needed to enhance this capability. NWS web pages (Appendix D) provide additional forecast guidance. However, a lack of any type of uncertainty guidance can prevent forecast uncertainty information from being utilized in the forecast process.

Several NWS products (Appendix E) contain forecast uncertainty, including long-range river and seasonal climate outlooks. NWS text products provide forecast uncertainty through forecast discussions disseminated by NCs and WFOs. Some forecast offices have developed new products such as forecasts of snowfall, swell, and precipitation amounts in various displays that include uncertainty information.

IV. Survey Data Collection and Analysis Methods

Additional current forecast uncertainty information resources available to field offices and NCs were obtained by surveying all of the WFOs, RFCs, and NCs. The specific goals from the survey statement of work were to:

- Obtain and describe uncertainty guidance needs for NWS forecasters, especially guidance related to high-impact events (e.g., heavy snow, floods, and hurricanes);
- Identify current forecast processes, products, and services that could benefit from using forecast uncertainty information;
- Identify specific forecast uncertainty guidance needs for generating new and enhanced products and services; and
- Identify and describe barriers in using uncertainty information in forecast preparation and in expressing uncertainty information in forecasts.

Survey Formulation and Data Collection

Interviews with three NWS field managers were used to establish a baseline of potential forecast uncertainty requirements and other types of feedback that were then used to formulate the survey questions. These interviews, the assessment of current uncertainty tools (Section III), and other discussion between the NURO Team and CFI resulted in a survey of 21 questions (Appendix F).

The NWS and CFI Group sent separate e-mail invitations to the targeted NWS employees. The survey participants were Meteorologists in Charge (MICs), Warning Coordination Meteorologists (WCMs), Science and Operations Officers (SOOs) at WFOs, Hydrologists in Charge (HICs) and Development and Operational Hydrologists (DOHs) at RFCs, and directors, branch chiefs, WCMs, and SOOs at the NCs. Invitations were also sent to the Meteorological Services Division and Scientific Services Division chiefs at the regional offices. Respondents were allowed about four weeks to complete the survey, which was hosted by CFI on a secure server.

Data Analysis

The CFI Group provided the NURO Team with raw survey data, organizational level (e.g., regional, national) data analysis, verbatim (write-in) responses to questions, and a final report with recommendations. Basic statistical information from the quantitative questions in the survey is displayed in Appendix G with survey results grouped by NWS entity (e.g., WFOs, RFCs, NCs).

The NURO team identified main themes from the responses to the qualitative survey questions. These themes, and other survey analysis results, were used to develop the findings, recommendations and potential requirements presented in Section V.

V. Primary Findings and Team Recommendations

Numerical Weather Prediction and Data

Finding 1a: Ensemble model sources must be available in AWIPS, GFE, and N-AWIPS for forecasters. Most forecasters need all members of the NCEP Global Ensemble Forecast System (GEFS), all members of the NCEP Short Range Ensemble Forecast (SREF) system, and ensemble Model Output Statistics (MOS). NC forecasters were most interested in accessing ensemble data from the European Centre for Medium-Range Weather Forecasting (ECMWF), all individual SREF members, and the North American Ensemble Forecast System (NAEFS).

Respondents indicated that forecasters wish to view individual ensemble members since it allows them to view alternative scenarios noting extremes, assess member initializations, and interpret the ensemble mean and probability fields in a dynamical context.

Finding 1b: Forecasters prefer to view individual members of an ensemble in high-impact event situations. Forecasters at the NCs use more individual ensemble members.

NOTE: Finding 1b may be a result of the number of ensemble members that forecasters are currently able to view. Most of the WFO respondents preferred to view up to 10 members, which is near the number of GEFS members available in AWIPS. Forecasters from NCs have access to a larger number of individual members of the GEFS and SREF, and preferred to view a larger number of ensemble members.

Recommendation 1: The NWS should expand the access to uncertainty guidance in operational forecast systems, including individual ensemble data for field offices and NCs. This information should be provided in AWIPS II, the Graphical Forecast Editor (GFE) and other operational applications.

Finding 2: Respondents communicated that there is a lack of dispersion among ensemble members and that some systematic biases exist.

Recommendation 2: Model bias and ensemble under-dispersion should be improved by NOAA. Post-processing approaches such as bias correction should be explored to enhance ensemble output.

Finding 3: NWS forecasters should have access to ensemble verification information to enhance the capability to improve forecasts.

Recommendation 3: The NWS should provide ensemble verification information to forecasters, especially for use in high-impact events. Examples could include: comparisons of ensemble forecast skill to deterministic model forecast skill, comparisons of analog historical years or representations of normals for comparison. High-impact event verification metrics should be explored (e.g., extratropical cyclone track and intensity).

Finding 4: Spaghetti diagrams and mean and spread plots were the top preferred formats for visualizing uncertainty in meteorological fields.

NOTE: This finding may be a result of the fact that spaghetti diagrams and mean and spread plots are currently the methods of visualization most widely available to WFO forecasters.

Accordingly, forecasters may not have as much experience viewing uncertainty information in other formats.

Recommendation 4: NWS forecasters should have access to various visualizations of ensemble data to enhance analysis and forecasting capabilities. These visualizations could include plume diagrams, probability density functions (PDFs), postage stamp charts, exceedance probability and joint probability capability, spaghetti plots, and future visualizations. Ensemble visualizations should be considered for implementation in AWIPS II, including GFE.

Finding 5: Local research studies, forecaster experience, comparisons between models, and climatology were the most commonly used methods to assess forecast uncertainty (i.e., forecaster confidence) by forecasters outside the use of model ensembles.

Other methods used included consistency between model runs, rules of thumb, observations, and verification information.

Recommendation 5: The NWS should provide training for forecasters about uncertainty forecast guidance and how to apply this information in services and products. The identification and implementation of uncertainty guidance best practices should occur to enhance forecast capabilities and improve service.

Uncertainty Training

Finding 6a: A majority of the respondents indicated that local training about uncertainty guidance utilization has not been developed.

Of the respondents that did develop local training, several indicated that the training was established commensurate with existing AWIPS and GFE capabilities, the present forecast process, and to meet the needs of local uncertainty products such as Hazard Weather Outlooks (HWOs). Some offices have completed training on the availability of web-based ensemble guidance.

While many offices have developed at least some training on ensembles and uncertainty guidance, it is clear that a unified national approach and common objectives are not present. The most common training topic focused on ensemble utility and interpretation and tended to spotlight the SREF and GEFS products available in AWIPS, including ensemble MOS. Several offices trained on the availability of web-based ensemble guidance, with a couple of respondents identifying uncertainty graphics and the Storm Prediction Center's (SPC) severe storm SREF guidance as keynote topics.

The most common topics that training was available for included:

- High-impact events such as tropical cyclones, probabilistic QPF, and severe convective storms.
- Chaos theory, predictability, ensemble design, applications, interpretation, and post-processing, and
- Advanced Hydrologist Prediction System (AHPS) development and interpretation of probabilistic forecasts.

Finding 6b: NWS field forecasters use the Weather Event Simulator (WES) extensively for training. Forecasters requested that training case studies should continue to be developed and made available on the WES, or in a WES-like format.

Finding 6c: Respondents indicated that better training is needed on ensemble system design and the generation of perturbations, the determination of probabilities, and ensemble applications. More information is also needed on verification, i.e., showing ensemble skill compared to deterministic forecasts. Several respondents indicated that more training is needed on basic statistics and probability theory.

Finding 6d: Numerous respondents indicated that a need exists to better understand:

- (i) the type of uncertainty information their customers and partners require,
- (ii) how their customers will use uncertainty information, and
- (iii) methods of communicating the necessary information to their customers.

Respondents communicated that they need better training and tools to evaluate and communicate uncertainty, express uncertainty relative to climatology, train forecasters in decision support with incomplete information (e.g., high-impact rare events) and helping customers understand their impact thresholds.

Recommendation 6: The NWS should develop a training plan for the application of uncertainty guidance in NWS field offices to help bridge the knowledge gap between the use of ensembles and the expression of uncertainty. Training for forecasters should be considered in the following subjects: ensemble system design, applied statistics, interpretation and application of ensemble guidance, decision support systems, and expressing uncertainty in products. Existing training resources should be updated based on potential requirements from these survey results. The NFUSE Team should clarify training requirements for National Strategic Training and Education Plan (NSTEP), including requirements for forecast uncertainty guidance.

New Products and Policy

Finding 7a: Forecasters believe that NWS precipitation-related products would be most enhanced by the addition of uncertainty information. Specific products include QPF (e.g., probabilistic QPF), precipitation type, streamflow forecasts, and winter weather products.

Finding 7b: Forecast offices have developed and disseminated local products to convey or generate uncertainty information, such as probabilistic QPF (PQPF), local ensembles including the Weather Research and Forecasting (WRF) Model, and graphical representations of outlook grids. New field-office developed products could serve as examples of new ways for uncertainty conveyance in existing or new national products.

Finding 7c: Several users such as emergency managers, fire weather officials, and other external-user groups provided requests for uncertainty information from field offices, mostly for high-impact events. Respondents indicated that frequent types of uncertainty information requested by users included:

- hydrometeorological event (e.g., a freeze) probabilities or the probability of exceeding parameter thresholds (e.g., QPF, wind speed, or river level);
- qualitative measures of forecast confidence and

- information on event worst-case scenarios and the range of event possibilities.

Finding 7d: Challenges exist in conveying forecast uncertainty information.

Survey respondents provided information about potential barriers that exist in communicating forecast uncertainty information. These barriers include:

- deterministic text and graphical products,
- lack of training for both internal and external users about uncertainty information,
- various interpretations of uncertainty information by users and field offices, and,
- non-standardized methods of communicating uncertainty information.

Other potential difficulties in informing users about uncertainty information services include a limited knowledge of users' uncertainty needs, some users' inability to receive available graphical information, and a need to obtain more tools to generate uncertainty information and products for users.

Recommendation 7: The NWS should obtain and validate forecast uncertainty requirements and needs from users to develop new, or refine existing uncertainty information in forecast services. Consideration should be given to using social science research to determine the best formats and methods to convey uncertainty information to a widely-varying external customer base. The changes should be formalized in terms of national product uncertainty guidelines and policy.

Developing national forecast uncertainty guidelines and policy would help provide standardization for NWS field offices and NC's products. This effort should include field offices, NCs, NWS HQ, and regional offices' input and incorporate user uncertainty requirements. Providing this information would develop a path for future service developments, including the addition of more probabilistic information in products, for example, resulting in product quality enhancements.

Collaborative efforts by NOAA with the scientific community will steer the development and implementation path of new prediction products and the modification of existing services. Consideration should be given to improving methods of conveying uncertainty information through applying various text formats, additional probabilistic information, graphics, and flexible viewing capabilities in NWS technological systems.

Finding 8: Forecasters would like to be significantly involved in generating and/or interpreting uncertainty in forecasts.

More than half of the respondents addressed to what degree forecasters should be involved in developing uncertainty forecasts. About 75% of the respondents believed that significant direct forecaster involvement should occur, while about 13% thought that minimal (i.e., hands-off) forecaster involvement should occur. There was a split in the responses about whether that involvement should include adjusting objective guidance, or if the involvement should be restricted to communicating and interpreting products for customers. Of those that felt forecaster involvement should include adjusting objective guidance, potential adjustments suggested included:

- local perturbation of key features,

- elimination of errant ensemble members and the subsequent recalculation of probabilities and hydrometeorological fields,
- spatial adjustment of probability fields,
- selecting or adjusting the most probable ensemble member, and
- performing local subjective ensemble bias correction and quality control.

Suggested ways of communicating uncertainty in the responses included:
- interpreting forecasts for customers (decision assistance),
- explanation of alternative forecast scenarios,
- educating customers,
- adding uncertainty components to IFPS/GFE/NDFD, and
- developing products and product formats based on customer needs.

Recommendation 8: NWS systems (e.g. AWIPS II, GFE, NDFD) should enable forecaster involvement in adjusting uncertainty guidance and generating uncertainty products.

NWS Technological Systems

Finding 9: Future NWS display and product generation systems must be able to rapidly ingest, process, display, and generate uncertainty information for forecasters and products conveying uncertainty information for users.

Recommendation 9: Modifications to existing and future (e.g., AWIPS II) NWS systems should occur to enhance the development and communication of uncertainty information in forecasts, including the need for more flexible software and the ability to quickly access significant information specific to high-impact events.

VI. Conclusions and Next Steps

The NURO Team conducted a survey of WFOs, RFCs, and NCs to assess the current use of and needs for forecast uncertainty information. The survey results showed that enhancements in uncertainty guidance, training, display systems and products are needed to help advance the use and conveyance of forecast uncertainty information to users. NWS efforts should continue to use effective methods to meet forecast offices' and users' forecast uncertainty needs. A collaborative effort by the NWS with other federal agencies and external users and partners should be made to better understand their requirements for the NWS to develop and enhance forecast uncertainty communication in existing and new products. These recommendations should improve the assessment and communication of uncertainty.

This report successfully completes the specific deliverable tasked to the NURO Team defined in Team's Charter (see Appendix B). Follow-on work by NFUSE will assist in the submission of forecast uncertainty training requirements to the NSTEP process. NFUSE will also work to initiate and promulgate forecast uncertainty needs into the NWS Operations and Services Improvement Process, the NOAA Planning, Programming, Budgeting, and Execution System, and other mechanisms as appropriate to develop and implement the forecast uncertainty information recommendations contained in this report.

VII. References

CFI Group, Inc., *National Weather Service Uncertainty Stud*y, October 4, 2007, Presentation.

COMET (Cooperative Program for Operational Meteorology, Education, and Training), *Ensemble Forecasting Explained*, 2007.

Morss, R. E., J. L. Demuth, and J. K. Lazo, 2008: Communicating uncertainty in weather forecasts: A survey of the U.S. public. *Wea. Forecasting.* Submitted.

National Research Council, 2006: *Completing the Forecast: Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts*. Committee on Estimating and Communicating Uncertainty in Weather and Climate Forecasts, The National Academies Press, 124 pp.

Appendix A: Summary of Recommendations

Recommendation 1: The NWS should expand the access to uncertainty guidance in operational forecast systems, including individual ensemble data for field offices and NCs. This information should be provided in AWIPS II, the Graphical Forecast Editor (GFE) and other operational applications.

Recommendation 2: Model bias and ensemble under-dispersion should be improved by NOAA. Post-processing approaches such as bias correction should be explored to enhance ensemble output.

Recommendation 3: The NWS should provide ensemble verification information to forecasters, especially for use in high-impact events. Examples could include: comparisons of ensemble forecast skill to deterministic model forecast skill, comparisons of analog historical years or representations of normals for comparison. High-impact event verification metrics should be explored (e.g., extratropical cyclone track and intensity).

Recommendation 4: NWS forecasters should have access to various visualizations of ensemble data to enhance analysis and forecasting capabilities. These visualizations could include plume diagrams, probability density functions (PDFs), postage stamp charts, exceedance probability and joint probability capability, spaghetti plots, and future visualizations. Ensemble visualizations should be considered for implementation in AWIPS II, including GFE.

Recommendation 5: The NWS should provide training for forecasters about uncertainty forecast guidance and how to apply this information in services and products. The identification and implementation of uncertainty guidance best practices should occur to enhance forecast capabilities and improve service.

Recommendation 6: The NWS should develop a training plan for the application of uncertainty guidance in NWS field offices to help bridge the knowledge gap between the use of ensembles and the expression of uncertainty. Training for forecasters should be considered in the following subjects: ensemble system design, applied statistics, interpretation and application of ensemble guidance, decision support systems, and expressing uncertainty in products. Existing training resources should be updated based on potential requirements from these survey results. The NFUSE Team should clarify training requirements for National Strategic Training and Education Plan (NSTEP), including requirements for forecast uncertainty guidance.

Recommendation 7: The NWS should obtain and validate forecast uncertainty requirements and needs from users to develop new, or refine existing uncertainty information in forecast services. Consideration should be given to using social science research to determine the best formats and methods to convey uncertainty information to a widely-varying external customer base. The changes should be formalized in terms of national product uncertainty guidelines and policy.

Recommendation 8: NWS systems (e.g. AWIPS II, GFE, NDFD) should enable forecaster involvement in adjusting uncertainty guidance and generating uncertainty products.

Recommendation 9: Modifications to existing and future (e.g., AWIPS II) NWS systems should occur to enhance the development and communication of uncertainty information in forecasts, including the need for more flexible software and the ability to quickly access significant information specific to high-impact events.

Appendix B: NWS Uncertainty Requirements for Operations (NURO) Team Charter

Vision:
NWS operational personnel will have access to the most effective, efficient tools, and related technical information, to generate and communicate uncertainty information to improve the quality of products and services for all users.

Mission:
To lead the gathering, organization, and validation of forecast uncertainty requirements from NWS operational field offices and NCs.

Success Criteria:

- Identify currently available uncertainty tools for NWS operational personnel.
- Identify general recommendations about future uncertainty tools and requirements for NWS operations.
- Submit Statements of Need (SONs) into OSIP, as needed.
- Identify uncertainty-training needs for operational personnel.
- Provide NURO progress reports to the NFUSE team as requested.
- Communicate the team's findings and developments in a formal document to the NFUSE team at assignment completion.
- Satisfaction of the above success criteria will occur by the proposed deadline with the exception of OSIP document submission.

Scope of Authority and Limitations:
The NURO has the authority from the NFUSE to obtain uncertainty needs from field offices. The team has authority to add new members as needed. NURO will obtain approval for funding needs and for formal managerial actions from appropriate sources if necessary.

Team Membership:

- Lee Anderson (NWS OST) and NURO lead
- Mary Mullusky (NWS OCWWS HSD) backup lead
- Dave Novak (NWS ERH)
- John Schaake (NWS OHD)
- Suzanne Lenihan (NWS OCWWS)
- Andrea Bleistein (NWS OST)
- Michael Brennan (NWS/NCEP/HPC)
- David Bright (NWS/NCEP/SPC)
- Greg Mann (NWS ISST)
- Paul Schultz (NOAA GSD)

Period of Membership: May 18, 2007 to completion of assignment on or about September 30, 2007.

Appendix C: Forecast Uncertainty Information in Operational NWS Display Environments (AWIPS, N-AWIPS, ATCF) as of August 2007.

Product	WFO/RFC AWIPS Availability	NCEP N-AWIPS Availability
NWP MOS products	Fully available	Fully Available
NCEP GFS Ensemble (MREF) -20 members ~80 km resolution	10 of the 20 members. Can view individual member fields or means/spreads of the members. However, the mean/spread of the 10 members displayed in AWIPS is different than mean/spreads of the full ensemble given the missing 10 members.	Can view all 20 individual members and mean/spread
NCEP Short Range Ensemble Forecast (SREF) 21 members ~40 km resolution	Means, spreads, and probability of exceedance for several elements derived from full ensemble. No individual members	Can view individual fields from 15 of 21 (Eta and RSM) members. Mean/spread available for entire ensemble and WRF, RSM, and Eta members separately. Probability of QPF of .01, .10, .25, .50, 1, and 2 inches, and 6-, 12-, and 24-hour QPF that occurs in 60, 80, and 100% of members
Canadian ensemble 10 members ~80 km resolution	Not available	Can view ensemble mean for standard fields (including QFP)
North American Ensemble Forecast System (NAEFS - combined NCEP and Canadian ensembles) -36 members ~80 km resolution	Not available	Not available
ECMWF Ensemble	Not available	Degraded resolution, spaghetti plots and ensemble mean available to HPC through EMC website
RUC Convective Probability Forecast	Not available	Not available
NCEP Wave Watch 3 Ensemble	Not available	Available
Regional ensemble systems developed by academic partners (U Washington/ SUNY Stony Brook/ etc) ~10-20 members ~12-36 km resolution	Varied availability to select offices	Not available
Tropical Cyclone Surface Wind Speed Probabilities	Available	Available

Multi-model Ensembles (for marine wind forecasting in TAFB/NHC)	Not available	Can view several deterministic dynamical models (such as GFS, WRF, NOGAPS, UKM, ECMWF), one ensemble dynamical model (GEFS), and consensus models (such as GUNA).
Multi-model Ensembles (for marine wave forecasting in TAFB/NHC)	Not available	Can view output of WaveWatch III driven by differing dynamical models (GFS, GFDL [in tropical cyclones], NOGAPS, and UKM).
Ensemble Streamflow Prediction (ESPADP, EVS)	Run at RFCs. Number and characteristics of ensemble determined by RFC. In AWIPS.	Not available
Climate Forecast Ensemble (CFS)		

Automated Tropical Cyclone Forecast system (ATCF) – at TPC and CPHC

Multi-model Track Forecasts	Can view several deterministic dynamical models (such as GFS, GFDL, H-WRF, NOGAPS, UKM, ECMWF), one ensemble dynamical model (GEFS), simple consensus models (such GUNA and CONU), and corrected consensus models (FSU super-ensemble, CGUN, and CCON).
Multi-model Intensity Forecasts	Can view a few deterministic dynamical models (such as GFDL and H-WRF), a few statistical models (such D-SHIPS, LGE, and SHIPS-MI), and consensus models (FSU super-ensemble and ICON).
Multi-model Size Forecasts	Can view several deterministic dynamical models (such as GFS, GFDL, H-WRF, NOGAPS, UKM, ECMWF) and a few statistical models (MRCL and DRCL).
Graphical Predicted Consensus Error (GPCE)	Tool to estimate track forecast uncertainty based upon spread in multi-model ensembles.

Appendix D: NWS Forecast Uncertainty Information on the World Wide Web as of August 2007.

Product	Web Availability
NCEP GFS Ensemble (MREF) -18 members ~80 km resolution	http://wwwt.emc.ncep.noaa.gov/gmb/ens/
NCEP Short Range Ensemble Forecast (SREF) 21 members ~40 km resolution	http://wwwt.emc.ncep.noaa.gov/mmb/SREF/SREF.html
North American Ensemble Forecast System (NAEFS - combined NCEP and Canadian ensembles) -30 members ~80 km resolution	http://wwwt.emc.ncep.noaa.gov/gmb/ens/NAEFS.html
NCEP Wave Ensemble -seems to be in developmental stage. No documentation	http://wwwt.emc.ncep.noaa.gov/gmb/ens/index.html
NCEP ensemble cyclone track product	http://www.emc.ncep.noaa.gov/gmb/tpm/emchurr/tcgen/
SPC NCEP SREF severe weather ensemble fields	http://www.spc.noaa.gov/exper/sref/
SPC Enhanced Thunderstorm Outlooks	http://www.spc.noaa.gov/products/exper/enhtstm/
AWC CCFP	http://aviationweather.gov/products/ccfp/
HPC QPF Confidence Intervals	http://www.hpc.ncep.noaa.gov/qpfci/qpfci.shtml
HPC/SPC NCEP SREF derived probabilistic winter weather impact graphics - Experimental	http://www.hpc.ncep.noaa.gov/wwd/impactgraphics/
AHPS – weekly chances of exceeding levels	http://www.nws.noaa.gov/oh/ahps/
AHPS – chance of exceeding levels during entire period	http://www.nws.noaa.gov/oh/ahps/
Western U.S. Water supply	http://www.cbrfc.noaa.gov/westernwater
RFC interactive ensemble builder	http://www.cnrfc.noaa.gov/ahps.php
ERSL Reforecasts	http://www.cdc.noaa.gov/reforecast/narr/

Appendix E: NWS Products with Uncertainty Information as of August 2007.

Product	Producer	Means of Estimating Uncertainty	Means of Communicating
AFD	WFOs	Forecast confidence, subjective	Text
NDFD -POP -SPC convective outlook -TPC wind speed probabilities -CPC 8-14 day outlook	WFOs/SPC/ TPC/CPC	Forecast confidence, NWP, MOS	Gridded Data
Point ‘n Click (POP)	WFOs	Forecast confidence, NWP, MOS	ICONs Meteograms
AFM (pop)	WFOs	Forecast confidence, NWP, MOS	Text
PFM (pop)	WFOs	Forecast confidence, NWP, MOS	Text
SFP/SFT (pop)	WFOs	Forecast confidence, NWP, MOS	Text
ZFP (pop)	WFOs	Forecast confidence, NWP, MOS	Text
CWF (pop)	Coastal WFOs	Forecast confidence, NWP, MOS	Text
GLF/NSH (pop)	Great Lakes WFOs	Forecast confidence, NWP, MOS	Text
HWO	WFOs	Forecast Confidence, Numerical Weather Models	Graphics, Text
FWF (chance wetting rain)	WFOs	Forecast confidence, NWP, MOS	Text
NPW (non-precipitation weather warning)	WFOs	Forecast Confidence, Numerical Weather Models	Text
WSW (winter storm watch)	WFOs	Forecast Confidence, Numerical Weather Models	Text
ESF (flood potential)	WFOs	Forecast Confidence, Numerical Weather Models	Text
HLS	WFOs	Numerical Weather Model, Forecaster Input	Graphics, Text
Degree of Confidence	WFO MKX	Numerical Weather Model, Forecaster Input http://www.crh.noaa.gov/mkx/?n=experimental-fcst-uncertainty	Graphics
Swell Height	WFO HNL	Forecaster input, Numerical Weather Model, Ocean Model	Text, Table

Probabilistic Snowfall	WFO PHI	Forecaster Input, Statistics http://www.erh.noaa.gov/phi/probabilities.html	Tabular, Text
Probabilistic Snowfall	WFO BUF	Forecaster Input, Statistics http://www.erh.noaa.gov/buf/SpotLES/qpsf1.htm	Tabular, Text
County rainfall exceedance probabilities	WFO TUL	Forecaster Input, Statistics http://www.srh.noaa.gov/tsa/pqpf.htm	Graphical, Text
Graphical Event Discussion	WFO OUN	All available guidance http://www.srh.noaa.gov/oun/enhanced.php	Graphical
Probabilistic Quantitative Snowfall and Freezing Rain Forecasts	HPC	Forecaster input, NWP	Graphics, Text
Excessive Rainfall Forecast	HPC	Forecaster input, NWP	Graphics, Text
Maximum Heat Index Probability Forecast	HPC	Forecaster Input, Numerical Weather Model	Graphics, Table
Day 3-7 500 mb Height Forecasts	HPC	Numerical Weather Model, Ensemble	Graphics, Text
Preliminary and Final Extended Forecast Discussions	HPC	Forecaster input, forecaster confidence, Numerical Weather Models, Ensemble, subjective	Text
Model Diagnostic Discussion	HPC	Forecaster confidence, NWP, Ensemble, subjective	Text
QPF Discussion	HPC	Forecaster confidence, Numerical Weather Models, Ensemble, subjective	Text
National Significant River Flood Outlook	HPC (based on RFC input)	Forecaster Input, Numerical Weather Model	Graphic
Probabilistic Convective Outlooks	SPC	Forecaster Input, Subjective	Graphics, Text, grids
Convective Watches	SPC	Forecaster Input, Subjective	Text, Table
Mesoscale Discussions	SPC	Forecaster Input, Subjective	Text
Fire Weather Outlooks	SPC	Forecaster Input, Subjective	Graphic
CCFP	AWC	Forecaster Input, Subjective	Graphic
Marine Weather Discussion (MIM)	OPC/TPC	Forecaster confidence	Text
Tropical Cyclone Track	TPC	Historical Error Distribution	Graphics (“Cone of Uncertainty”)
Tropical Cyclone Intensity	TPC	Historical Error Distribution	Text

Wind Speed Forecast and Probabilities	TPC	Forecaster Input, Numerical Weather Model, Historical Performance, Statistical Model	Graphics, Table, grids
Tropical Cyclone Discussion (for analyses/forecasts of track, intensity, and size)	TPC	Historical Error Distributions, Deterministic Multi-Model Ensembles, Single-Model Ensembles, GPCE, Simple/Corrected Consensus Models, Forecaster Confidence	Text
Wind Probabilities (34, 50, and 64 kt)	TPC	Historical Error Distributions of combined track, intensity, and size forecasts	Graphics, Text
Storm Surge Probabilities (Prob. Of > 5', 10% Exceedance Height - EXPERIMENTAL)	MDL/TPC	Historical Error Distributions of combined track, intensity, and size forecasts	Graphics
Tropical Weather Outlook (Possibility of tropical cyclone genesis in next 48 hr)	TPC	Deterministic Multi-model ensembles, single-model ensembles, forecaster confidence	Text, Graphics
Real-time Mesoscale Analysis	EMC	Observations and Numerical Weather Model	Grids
Seasonal Climate Outlook and 8 to 14 Day Outlook	CPC	Historical, Forecaster Confidence	Graphics, Text, grids
AHPS	WFOs/RFCs	Ensemble	Graphics, Tables, PDF
Short-Term Probabilistic Streamflow Hydrographs	RFCs	Statistics	Graphics
Significant River Flood Outlook	RFC	Forecaster Input, Numerical Weather Model	Graphics, Text
Water Supply Outlooks	CBRFC	Statistical regression based on past and present conditions.	Text
WSR-88D Products	WFO or OSF	Probabilistic information about thunderstorm phenomena (e.g., hail)	Graphics, Text

Appendix F: Uncertainty Guidance Survey for WFOs, RFCs and National Centers

NOAA NWS Uncertainty Usage Questionnaire 2007

Draft: 8/17/07

INTRODUCTION

Thank you for your participation in this survey. We will ask about your current uncertainty information usage in the survey and what you would like to see in the future. You will have opportunity throughout to provide anecdotal feedback.

Generating Uncertainty Information

1. Where are you employed in the NWS?

   a. National Center
   b. WFO
   c. RFC

2. In your office, what is the forecasters' knowledge level about ensemble systems and data?

   a. Expert (e.g., knowledgeable about ensemble design, methods to create perturbations, interpretation of probability distribution functions, differences between systems, chaos theory.)
   b. Some knowledge (e.g., know differences between systems, interpretation of probability distribution functions)
   c. Minimal Knowledge (e.g., occasionally use output)
   d. No knowledge

3. In your office, what is the forecasters' knowledge level about using uncertainty information in a forecast?
   a. Expert (Possess deep knowledge and apply the information daily)
   b. Advanced (Possess above average knowledge to apply the information frequently.)
   c. Some knowledge (Occasionally apply uncertainty information.)
   d. No knowledge

4. In your office, which of the ensemble datasets from the following list are used in forecast preparation?

Ensemble Datasets:

a. Ensemble MOS
b. NCEP GFS Ensemble (MREF)
c. NCEP Short Range Ensemble Forecast (SREF)
d.North American Ensemble Forecast System (NAEFS) (combined GFS and Canadian ensembles)
e. Climate Forecast Ensemble (CFS)
f. ECMWF Ensemble
g. NCEP Wave Watch III Ensemble
h. Ensemble Streamflow Prediction (ESPADP, EVS)
i. Local ensemble systems (please specify)
j. Other (please specify)

(only if 1=a) NHC/TPC Ensemble Datasets:

a. Multi-model Track Forecasts – Automated Tropical Cyclone Forecast system (ATCF)
b. Multi-model Intensity Forecasts – Automated Tropical Cyclone Forecast system (ATCF)
c. Multi-model Size Forecasts – Automated Tropical Cyclone Forecast system (ATCF)
d. Graphical Predicted Consensus Error – Automated Tropical Cyclone Forecast system (ATCF)

5. Considering the datasets your forecasters use, what are the issues you would most like to see addressed? Please rank order them from 1-5, with 1 being “Address first” and 5 being “Address last”.

a. the actual solution that falls too often outside the envelope of possible solutions generated by the ensemble (i.e., lack of dispersion among members)
b. the probabilities provided are not calibrated
c. the data format provided is not useful (e.g., need sensible weather elements on grid
d. data are not available in AWIPS/GFE/N-AWIPS
e. other (please specify)

6. What type of additional ensemble information do forecasters in your office need to prepare forecasts for high impact events?

Examples of High impact Events include:

Hurricanes
Tornadoes
Hail Storms
Damaging Winds (both thunderstorm and non-thunderstorm related winds)
Drought
Heat Wave
Ice Storms
Tsunamis
Heavy Snow
Floods (including flash floods)
Coastal Flooding
Hazardous marine conditions (e.g., high seas, gale force winds)
Forest and Grassland Fires
Dust Storms
Fog
Turbulence
Icing

7. What information, other than ensembles, is used by forecasters at your office to assess forecast uncertainty (e.g., a local study)?

8 Which of the following do you use in your office?
   a. AWIPS
   b. N-AWIPS

8.1. **(If 8=a)** For AWIPS users: Which of the following uncertainty guidance datasets do forecasters in your office most need in AWIPS/GFE?
   a. Full NCEP GFS ensemble (all members)
   b. Full NCEP SREF ensemble (all members)
   c. North American Ensemble Forecast System (NAEFS) (combined Canadian and U.S. global ensemble system)
   d. NCEP Wave Watch III ensemble
   e. MDL Ensemble MOS
   f. Other (please specify)

8.2. **(If 8=b)** Which of the following uncertainty guidance datasets do forecasting in your office most need in N-AWIPS?

a. North American Ensemble Forecast System (NAEFS) (combined Canadian and U.S. global ensemble members)
b. Full NCEP SREF ensemble (all members)
c. ECMWF ensemble (all members, mean/spread)
d. Full Canadian ensemble (all members)
e. MDL Ensemble MOS
f. Other (please specify)

9. Given a high impact event, how frequently would your forecasters view individual members of an ensemble, if available?
   a. all the time
   b. some of the time
   c. rarely
   d. never

9.2, Given a high impact event and a very large ensemble, how many individual members of an ensemble do you expect your forecasters would view? (choose one)

a. None
b. Up to 10
c. Up to 20
d. Up to 40
e. Up to 60
f. As many as are available

10. What is your forecasters' preferred format of visualizing uncertainty in a meteorological field (e.g., temperature or heights)? (select one)

a. Spaghetti diagram,
b. Box and whisker diagram,
c. Mean and spread plot
d. Probability density functions
e. 10 and 90 percentile value of forecast PDF (Probability Distribution Function) (presented with traditional most likely scenario) (Click here to view an example)
f.. Other (please specify)

11. What local applications, tools, or guidance, has your office employed for generating uncertainty in forecasts? (Open-end)

12. What do you think the role of the forecaster should be in developing uncertainty forecasts?

Uncertainty Training

13. Has your office developed local training for uncertainty guidance?
   a. Yes
   b. No

13.1 **(If 13=a)** What did the training entail?

14. On a scale from 1 to 10 where 1 is Poor and 10 is Excellent, please rate your forecasters' knowledge in these areas as they apply to preparing forecasts.

a. ensemble system design and perturbations
b. statistics
c. decision support
d. weather risk management
e. user requirements

14.1 **(If 14 a, b, c, d, e, or f less than 6)** What additional training would your forecasters benefit from to better prepare themselves to produce uncertainty forecasts for high impact events? (open-end)

15. Have your forecasters completed the COMET module "Ensemble Forecasting Explained?"

a. Yes
b. No

15.1 **(If 15=a)** To what degree has this training been applied in daily operations? (select one)

a. Apply this training occasionally in daily operations.
b. Apply this training nearly every day in daily operations.
c. Rarely apply this training in daily operations.
d. Never use this training in daily operations.

15.2 (If 15.1=c or d) How could the COMET module be more useful to your forecasters in their daily operations?

Communicating Uncertainty

16. What current deterministic forecast products, services, and processes would be most enhanced with additional uncertainty information?

17. What requests for uncertainty information has your office received from end users?

18. What local products has your office developed to specifically incorporate uncertainty information for end users? (An example could be probabilistic quantitative snowfall forecasts.)

19. What barriers have you identified in communicating uncertainty information in products and services?

Future Changes

20. What, if any, changes should occur in current NWS systems (e.g., AWIPS) for developing or communicating uncertainty in forecasts and outlooks?

21. What, if any, changes should occur in NWS practices and policies to support efforts to incorporate uncertainty information into NWS products and services user community benefits?

Appendix G: Survey Results by WFO, National Centers, and RFC

		National Center	WFO	RFC
Sample Size		**7**	**214**	**16**
Q1.	**Where are you employed in the NWS?**			
	National Center	100%	0%	0%
	WFO	0%	100%	0%
	RFC	0%	0%	100%
Q2.	**In your office, what is the forecasters' knowledge level about ensemble systems and data?**			
	Expert	29%	5%	0%
	Some knowledge	57%	72%	69%
	Minimal knowledge	14%	23%	31%
	No knowledge	0%	0%	0%
Q3.	**In your office, what is the forecasters' knowledge level about using uncertainty information in a forecast?**			
	Expert	29%	5%	0%
	Some knowledge	43%	43%	25%
	Minimal knowledge	29%	51%	75%
	No knowledge	0%	0%	0%
Q4.	**In your office, which of the ensemble datasets from the following list are used in forecast preparation?***			
	Ensemble MOS	29%	80%	6%
	NCEP GFS Ensemble (MREF)	86%	89%	44%
	NCEP Short Range Ensemble Forecast (SREF)	29%	81%	25%
	North American Ensemble Forecast System (NAEFS)	29%	16%	0%
	Climate Forecast Ensemble (CFS)	14%	10%	25%
	ECMWF Ensemble	43%	18%	0%
	NCEP Wave Watch III Ensemble	43%	7%	0%
	Ensemble Streamflow Prediction (ESPADP, EVS)	0%	6%	100%
	Local ensemble systems	29%	8%	13%
	Other	0%	6%	6%

Q4.1.	**In your office, which of the Automated Tropical Cyclone Forecast (ATCF) system ensemble datasets from the following list are used in forecast preparation?*,[1]**			
	Multi-model Track Forecasts	71%	--	--
	Multi-model Intensity Forecasts	29%	--	--
	Multi-model Size Forecasts	14%	--	--
	Graphical Predicted Consensus Error	43%	--	--
Q5.a.	**The actual solution falls too often outside the envelope of possible solutions generated by the ensemble**			
	1 - Address first	33%	17%	21%
	2	33%	20%	29%
	3	17%	25%	36%
	4	17%	33%	14%
	5 - Address last	0%	4%	0%
	Average rank order	2	3	2
Q5.b.	**The probabilities provided are not calibrated**			
	1 - Address first	29%	8%	33%
	2	14%	21%	40%
	3	29%	36%	13%
	4	29%	32%	13%
	5 - Address last	0%	3%	0%
	Average rank order	3	3	2
Q5.c.	**The data format provided is not useful**			
	1 - Address first	0%	11%	20%
	2	0%	38%	20%
	3	33%	27%	27%
	4	50%	20%	20%
	5 - Address last	17%	4%	13%
	Average rank order	4	3	3
Q5.d.	**Data are not available in AWIPS/GFE/N-AWIPS**			
	1 - Address first	33%	60%	23%
	2	50%	18%	0%
	3	17%	8%	23%
	4	0%	12%	46%
	5 - Address last	0%	1%	8%

	Average rank order	2	2	3
Q5.e.	**Other**			
	1 - Address first	50%	14%	20%
	2	0%	10%	20%
	3	0%	8%	0%
	4	0%	2%	0%
	5 - Address last	50%	67%	60%
	Average rank order	3	4	4
Q8.	**Which of the following do you primarily use in your office?**			
	AWIPS	0%	100%	100%
	N-AWIPS	100%	0%	0%
Q8.1.	**Which of the following uncertainty guidance datasets do forecasters in your office most need in AWIPS/GFE?*,[2]**			
	Full NCEP GFS ensemble	--	78%	69%
	Full NCEP SREF ensemble	--	81%	31%
	North American Ensemble Forecast System (NAEFS)	--	44%	38%
	NCEP Wave Watch III ensemble	--	25%	0%
	MDL Ensemble MOS	--	56%	19%
	Other	--	13%	25%
Q8.2.	**Which of the following uncertainty guidance datasets do forecasters in your office most need in N-AWIPS?*,[3]**			
	North American Ensemble Forecast System (NAEFS)	86%	--	--
	Full NCEP SREF ensemble	57%	--	--
	ECMWF ensemble	100%	--	--
	Full Canadian ensemble	57%	--	--
	MDL Ensemble MOS	29%	--	--
	Other	29%	--	--
Q9.	**Given a high impact event, how frequently would your forecasters view individual members of an ensemble, if available?**			
	All the time	57%	27%	19%
	Some of the time	43%	57%	44%
	Rarely	0%	15%	31%
	Never	0%	1%	6%
Q9.2.	**Given a high impact event and a very large ensemble, how many individual members of an ensemble do you expect your forecasters would view?**			

	None	0%	3%	31%
	Up to 10	29%	62%	50%
	Up to 20	29%	21%	6%
	Up to 40	29%	3%	0%
	Up to 60	0%	0%	0%
	As many as available	14%	10%	13%
Q10.	**What is your forecasters' preferred format of visualizing uncertainty in a meteorological field (e.g., temperature or heights)?**			
	Spaghetti diagram	29%	43%	31%
	Box and whisker diagram	0%	6%	13%
	Mean and spread plot	14%	24%	6%
	Probability density functions	0%	4%	6%
	10 and 90 percentile value of forecast PDF	0%	16%	25%
	Other	57%	7%	19%
Q13.	**Has your office developed local training for uncertainty guidance?**			
	Yes	43%	21%	31%
	No	57%	79%	69%
Q14.	**Forecasters' knowledge**	**Score**	**Score**	**Score**
	Ensemble system design and perturbations	46	41	33
	Statistics	44	45	42
	Decision support	53	54	37
	Weather risk management	40	54	36
	User requirements	57	55	48
Q15.	**Have your forecasters completed the COMET module "Ensemble Forecasting Explained?"**			
	Yes	29%	42%	13%
	No	71%	58%	88%
Q15.1.	**To what degree has this training been applied in daily operations?**			
	Apply this training occasionally in daily operations	0%	61%	0%
	Apply this training nearly every day in daily operations	100%	22%	50%
	Rarely apply this training in daily operations	0%	17%	50%
	Never use this training in daily operations	0%	0%	0%