Summary of

6th NCEP Ensemble User Workshop

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College Park, Maryland 20740

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Executive Summary

The Ensemble User Workshop has been held at National Centers for Environmental Prediction (NCEP) every other year since 2000. This year's workshop was held in the conference center of NOAA Center for Weather and Climate Prediction (NCWCP) at College Park, Maryland, the new home of NCEP. The workshop took place on March 27-29, 2014 with over 100 participates from national and international institutions including NOAA-NWS, NOAA-OAR, US Navy, US Air Force, ECMWF, CMC, CMA, CWB and others. Like in previous workshops, the workshop's central theme is to support NWS in its transition from single value-deterministic to ensemble-based probabilistic forecasting and to convey forecast uncertainty in a user relevant form. This year, the specific theme was on how to support the NWS as it moves towards a seamless operational ensemble forecast system from storm-scale short-range to global to seasonal, and from atmosphere-only to ocean-wave and to coupled ensemble prediction systems. There were a total of 51 presentations in six broad categories listed as follows: (1) Review of current status and future plans of each operational ensemble forecast systems, (2) NWS users' feedbacks, (3) ensemble post-processing methods and generation of probabilistic products, (4) Special projects and international developments, (5) Products, data and verification, and (6) Community developments. In addition to the presentations, discussion periods were scheduled after each session.

Operational numerical weather and climate guidance are fundamental tools for the government, the private and the public industry to improve public safety, quality of life and economical decisions. Ensemble forecasting is the cornerstone to generate these products in the sense that they provide both deterministic and probabilistic guidance. NCEP generates operational ensembles in three distinct time scales and spatial domains: The Short-Range Ensemble Forecast System (SREF) for the CONUS and North American Domain, The Global Ensemble Forecast System (GEFS) for the global domain and for medium range (3days to 10 days, generally), and the CFSv2, which provides monthly-average and seasonal ensemble forecasts. NCEP also generates downstream ensembles including the wave ensemble and hurricane ensemble (HWRF ensemble). NCEP also collaborates with numerous partners to produce Multi-model Ensembles. The first and more advance collaboration is with Canada's CMC, to produce the North American Forecast Ensemble System (NAEFS). This system provides skillful and reliable guidance for day 1-16. In collaboration with CMC and the US Navy, another system routinely produced is the NUOPC ensemble. For seasonal forecasting, the CFSv2 is combined on a monthly basis with national centers to generate the National Multi-Model Ensemble (NMME); it is combined with the EUROSIP to create the International Multi-Model Ensemble (IMME). New capabilities are underway that includes extending the GEFS to 30 days, creating the Rapid Refresh ensemble, etc. This trend indicates that ensembles are moving to diverse directions and connecting with other areas such as Data Assimilation and seasonal forecasting.

Facing with the ever-growing role of ensemble forecasting for weather and climate guidance it is therefore important to provide the latest information on current and

future developments to users and also receive feedbacks from them. The workshop attempts to stimulate discussion on both of these directions.

1. Status and Plan of NCEP Ensemble Prediction Systems

In the first session, an overview of the status and plans of the SREF, the GEFS and the CFS was presented, followed by multi-model ensemble prediction systems NMME, IMME and NAEFS. Highlights of these presentations include the developments of the short range the HRRR Ensemble and its relationship with NARRE and SREF. These three short-range forecast systems fulfill distinct purposes within the NWS and meet requirements of the NCEP Centers, NWS, FAA and other users. One important problem is how to fit each of these systems into the limited operational available computer resources. Investigation into trade-offs in the design configuration (model resolution, domain size, ensemble size, etc.) is needed. Development in the medium range includes comparison of ensemble perturbation methods between the ETR, currently in operations and the hybrid EnKF, tuning of the Stochastic Total Tendency Perturbation (STTP) method, and the new Tropical Storm Relocation (TSR) method. All these improvements plus an increase in the model's horizontal resolution from 52km to 34km resulted in a significant reduction of RMSE in most of the variables including tropical storm track errors. Another development is the extension of the lead-time of the GEFS from 16 days out to 35 days. The plan is to evaluate the impact of coupling with the SST to determine what new design should be used in order to benefit the most from the forecast. For seasonal ensemble forecasting, presentations on the plan for CFSv3 and the NMME/IMME focused on the designs of the models and on the skill gains achieved when ensembles from the CFSv2 are combined with seasonal forecasts from other centers, respectively. Several important numerical issues need to be addressed in order to improve seasonal prediction. In practical terms, an essential requirement is to have sufficient computer and archiving capability to carry out several tests and evaluations. At the scientific level, it is important to identify model bias and the role of soil moisture. Also, improvements in ensemble spread in the CFS, and an increase in model diversity in the case of the NMME/IMME prediction system are needed.

The discussions that followed pertained to the configurations of the models that could optimize computer resources, and an interest to include other ensemble prediction systems, particularly the ECMWF into the mix. Concerns regarding the application of the GEFS beyond two weeks without coupling with the ocean and the use of computer resources for ensemble re-forecasts were expressed. A suggestion was made to explore computer-efficient configurations of the main NCEP NWP systems such as removing redundancy between SREF and high resolution GFS and possibly GEFS at short lead times. Remaining questions and suggestions are listed next:

- How to determine the optimal configuration (resolution, size, ICs/LBCs, physics, etc.)?
    - Testing by EMC, DTC, and/or research community?
- How to optimize use of computational resources?

    - Global, mesoscale, and cloud-permitting ensembles?
    - Time-lagged ensembles?
- Future of multi-center ensembles?
    - New "NAEFS" including ECMWF ensemble?
- Is the NAM necessary with a 13km GFS; is the SREF necessary with a higher-res GEFS and improved cloud-permitting ensemble capabilities? How to satisfy user needs in the most efficient way possible?

EMC does not have the resources to perform comprehensive testing on every configuration, but it is difficult for the outside community to work with NCEP models. It is a conundrum. WPC is working to combine all ensemble systems for probabilistic products (GEFS+CMC+ECMWF); it would be helpful if EMC could include the ECMWF in the NAEFS.

2. NWS Users and the Private Sectors

In the NWS user's category, there were two sessions one for the NCEP Centers review and another for NWS regions and private users. The main theme was the utilization of ensembles to generate probabilistic forecast guidance. Numerous approaches were described to provide the forecaster with the best possible information for each mission-specific forecast product. These approaches varied from calibrating a single ensemble system to merging ensemble systems to blending ensemble data with deterministic model data. In all cases, the goal was to provide the forecaster with the most reliable probabilistic information for generating forecasts. NCEP Centers welcomed improved versions of the SREF and GEFS and presented how they utilize the ensembles to feed their specific models and generate probabilistic forecast products of severe weather, hurricane, ocean waves, week 2 2m-temperature, etc. Evaluations of the NCEP ensemble systems indicate that while the performance of ensemble forecasts has improved over time there are still severe limitations in the form of error bias and under-spreading, particularly for extreme weather events and near surface variables. New developments of high resolution, "convection-allowed" models produce guidance for severe weather that looked more realistic than the traditional global and ensemble models. Although there is much to be learned, potential applications in the future are sought. Verification methods for high-resolution forecasts and ways to compare with the traditional (lower resolution) NCEP ensembles are areas of much research. Extreme weather and post-processing methods to calibrate the ensemble outputs were shown, as well as ways to blend outputs from different ensembles to generate products. In the second session, some NWS users are developing Decision Support Systems (DSS) with user interfaces to analyze probabilistic forecasts and manipulate the information effectively in real time. A highlight of these presentations is the use of ensemble Situational Awareness Table. This is a table with colors depicting the strength of a predicted anomaly with respect to climatology for each key weather parameter and for each lead-time. This provides a quick look of the extreme conditions that require special attention. Other NWS users focused on recent examples on how the GEFS and SREF have been used. An important variable to predict is the QPF, and in some cases it is

shown that both the GEFS and SREF are too similar but do not verify correctly. There is clearly not enough diversity among the two and there are under-dispersion problems. Private users rely on NCEP ensembles and ECMWF model for routine hazardous outlooks that lead to economical decisions such as pre-staging of resources or extra staffing to meet anticipated increase in customer call volume during severe weather events.

The discussion period following the presentations focused on ensemble forecasting and probabilistic guidance. One of the topics for discussion was how to best make use of ensemble guidance. It was noted that visualization tools are still underdeveloped and there is a training need for ensemble-based DSS. In addition, it was mentioned that the NDFD remains primarily deterministic and that ensemble systems should be used to add uncertainty information to the NDFD. Another topic of discussion involved identifying who is responsible for generating probabilistic guidance to avoid duplication of effort. In general, it was felt that EMC should provide the raw ensemble guidance and datasets while each user should develop their own mission-specific probabilistic guidance using the EMC-generated ensemble data. The more time spent by EMC in post-processing results in more dilute products and less time spent in model development and improving ensemble configuration and output.

3. Ensemble Post-processing Methods and Probabilistic Forecast Products

Presentations and discussion of ensemble post-processing methods and generation of probabilistic products and international collaborations were given during the second day of the workshop. Post-processing plays an important role to increase the accuracy of prediction particularly of the medium range forecasts so the majority of the talks focused on ways to calibrate the NAEFS and GEFS forecasts for weeks 1 and 2. Milestones of post-processing presented in this session include increasing the number of bias-corrected variables in the NAEFS systems, particularly surface wind and dew point temperature, as well as the kickoff of the blender project, which aims to develop a next-generation gridded guidance products for NDFD. A new method tested is the Updatable Bayesian Model Average (UBMA) with relative improvement over both the traditional BMA and other methods. UBMA was applied to calibrate the spread of the SREF with successful improvements. Two talks and ensuing discussions focused on the GEFS reforecast system developed at ESRL. Attention was drawn to the benefit of the reforecast including training of post-processing methods and rare events forecasts, and to the computational and archival costs associated with this new tool. A proposal was presented to continue investigation on the benefits of the forecasts for different users, ways to optimize the reforecast and suggestions that reforecasts should be considered on the designs of new NCEP NWP systems. Evaluations of the reforecast system include assessing the value added in forecast skill, optimal configuration and study whether a real time setup is possible. The recommendations include working with more down-stream applications.
Questions and points of discussion in this category are as follow:

- How do we make best use of ensemble guidance?
    - NDFD remains deterministic

    - Ensemble visualization tools are underdeveloped
    - Filling the training gap for ensemble-based DSS
- Division of labor between EMC and downstream users for probabilistic guidance development.
    - Is there a dividing line?
    - How to avoid duplication of effort?
    - Do users prioritize a high-quality underlying system or advanced post-processed products?
- Role of virtual labs and cloud for development and data dissemination?

It is difficult for NWS to make full use of ensembles when NDFD is deterministic.

4. Other Projects and International Developments

Ensemble forecasting methods are investigated, developed and applied to weather and related fields in many centers around the world. Several important centers sent a representative to present their progress and plans. The session initiated with an overview of the status WMO's THORPEX program. This program will end in 2014 and three legacy projects are proposed to continue: the Polar Prediction Project (PPP), the Sub-seasonal to Seasonal (S2S) prediction project and the High impact Weather (HiW). Most of these projects are will last 5 years. A description of each project was given. How these international activities will be mapped into U.S. programs and activities is still to be determined but many U.S. collaborators are involved on each of them. A series of workshops are being organized to define a strategy and next steps of U.S. involvement in the projects. A description of the ESPC and NUOPC was followed. ESPC is an inter-agency collaboration for coordination of R2O of a national Earth System Analysis and Prediction Capability. One of the highlights is the funding of demonstration projects and its interest on multi-model ensembles, as well as increasing air-sea-land coupled global prediction capability. Discussion on ensemble developments at ECMWF, NRL, CMC, CMA and CWB continued. Applications of ensembles in the AFWA were reported. AFWA uses the GEFS to feed its limited area meso-scale models in different parts of the world to generate probabilistic forecasts out to 72 h in strategic regions. AFWA aims to improve risk assessments related to weather.

Questions and points of discussions were:

- What new approaches the national and international community could use to enhance the effectiveness of post-THORPEX research and R2O work?
- What opportunities are there, beyond current projects in NAEFS, NUOPC, and ESPC, for agency collaboration on national and international scales?
- What forecast capabilities, and how could be exchanged between agencies on national and international scales?

5. Products and Data Distribution

Development and maintenance of product generation algorithms are two major tasks that numerical weather institutions have to carry out continuously and efficiently to satisfy user's demands. These tasks require preparation of codes to post-process and display information in a suitable format. In order to make products and maintain high quality standards, two other activities are necessary: data exchange and forecast verification. A series of talks were presented showing current software developments to specific users such as aviation applications, ensemble hurricane displaying and verification. Two verification packages were also presented: the CPC's new verification web tool and the NCAR MET verification tool. An important highlight of the CPC web tool is that it is primarily developed for use for CPC official forecasts, thus comparisons of parallel (beta) versions from other forecast systems will be readily available. MET has been developed continuously for about a decade and it is now even more flexible because it reads grib format data and contains tools to evaluate ensemble forecasts.

For the data exchange activity an update on NOAA Operational Archive and Distribution System (NOMADS - NCEP) was presented. NOMADS now archives and distributes ensemble data in real-time.

Topics of discussion:

- Needs and terms of ensemble data archive – prioritize raw data, products and images
- Distributed data or centralize: – Multi- data centers
    - Cloud computing
    - Servers with common protocol
- Is it practical to run more "query" software at the data archives or other ways to minimize large data transfers?

Two main recommendations from the discussion were: (1) Increase bandwidth for data transmission and (2) Set up priority for data transfers.

6. Community Developments

New broader scale developments that can impact ensemble forecasting were presented. The Bayesian Post-processing for Ensembles is a new post-processing framework that uses the Bayes principle for pre-processing, fusion and outputs of numerical products to satisfy various user needs. A second presentation focused on the various stochastic schemes for representing model uncertainty in the GFS. The status and plans of the CSTAR program, the DTC and the HFIP programs were also presented.

7. Presentations and List of Participants

A website with the list of presenters and presentations are posted at
http://www.emc.ncep.noaa.gov/gmb/ens/WkShopOct13/6th_User_workshop.shtml

The list of participants (include remote access):

1. Alcott, Trevor	NOAA/NWS/WRHD
2. Alpert, Jordon	NOAA/NWS/NCEP/EMC
3. Alves, Jose-Henrique	NOAA/NWS/NCEP/EMC - SRG
4. Antolik, Mark	NOAA/NWS/OST/MDL
5. Baker, Michael	NOAA/NWS/OST/MDL
6. Barela, Eric	AFWA NUOPC staff rep
7. Beauregard, Stephane	Canadian Meteorological Centre
8. Blake, Eric	NOAA/NWS/NCEP/NHC
9. Brennan, Michael	NOAA/NWS/NCEP/NHC
10. Bright, Davis	NOAA/NWS/NCEP/AWC
11. Brill, Keith	NOAA/NWS/NCEP/WPC
12. Bua, Bill	UCAR/COMET
13. Buizza, Roberto	ECMWF
14. Cammarata, Michael	NOAA/NWS/CAE
15. Carman, Jessie	NOAA/OAR/OWAQ
16. Charles, Michael	NOAA/NWS/NCEP/CPC
17. Chen, Yun	CMA/NMC, China
18. Chern, Jong-Gong	Central Weather Bureau, Taiwan
19. Clements, Elizabeth	NMOPDD PAC AG1
20. Cohen, Michelle	NOAA/NWS/OST/MDL
21. Collins, Dan	NOAA/NWS/NCEP/CPC
22. Crook, Jackie	Fleet Weather Center – Norfolk
23. Cui, Bo	NOAA/NWS/NCEP/EMC - IMSG
24. Cummings, Jim	Navy
25. Deshpande, Medha	Indian Inst. of Tropical Meteorology, Indian
26. DiMego, Geoff	NOAA/NWS/NCEP/EMC
27. Dominguez-Sarmiento, Christian	UNAM, Mexico
28. Dong, Quan	CMA/NMC, China
29. Du, Jun	NOAA/NWS/NCEP/EMC
30. Edwards, Daniel	AFWA
31. Eleuterio, Daniel	NAVY/ONR
32. Fan, Yun	NOAA/NWS/OST/MDL
33. Foisy, Todd	NOAA/NWS
34. Fracasso, Tony	NOAA/NWS/NCEP/WPC
35. Fresch, Mark	NOAA/NWS/OHD
36. Gilbert, Kathy	NOAA/NWS/OST/MDL
37. Glahn, Bob	NOAA/NWS/OST/MDL
38. Gottschalck, Jon	NOAA/NWS/NCEP/CPC
39. Gravelle, Chad	NOAA/NWS Operational Proving Ground
40. Gremillion, Mike	USAF
41. Grumm, Richard	NOAA/NWS/ER
42. Guan, Hong	NOAA/NWS/NCEP/EMC – SRG
43. Hamill, Tom	NOAA/OAR/ESRL/PSD
44. Hogsett, Wallace	NOAA/NWS/NCEP/WPC
45. Horner, Mike	AFWA
46. Hou, Dingchen	NOAA/NWS/NCEP/EMC

47. Huhn, John	MITRE
48. Jankov, Isidora	NOAA/OAR/ESRL – CIRA
49. Jensen, Tara	NCAR/DTC
50. Ji, Ming	NOAA/NWS/NCEP/OPC
51. Jirak, Israel	NOAA/NWS/NCEP/SPC
52. Kluepfel, Chuck	NOAA/NWS/OCWWS
53. Kolts, Brian	First Energy
54. Kraft, Andy	Fleet Weather Center - Norfolk
55. Kuchera, Evan	AFWA
56. Ilczuk, Richard	Fleet Weather Center - Norfolk
57. LaCroix, Kevin	NAVY/CNMOC
58. Lapenta, William	NOAA/NWS/NCEP
59. Laudier, Natalie	Office of Navy Research Global
60. Levit, Jason	MITRE
61. Lord, Stephen	NOAA/NWS/OST
62. Luo, Yan	NOAA/NWS/NCEP/EMC - IMSG
63. Lutz, Kurt	NUOPC project office
64. McCarren, Dave	NAVY/CNMOC – NUOPC project office
65. Mills, Thomas	USN/JTWC
66. Miretzky, Brian	NOAA/NWS/ERHQ
67. Moore, Thomas	USAF A30-W
68. Mostek, Tony	NOAA/NWS
69. Motta, Brian	NOAA/NWS/OCWWS
70. Noel, Jim	NOAA/NWS/OHD-RFC
71. Novak, David	NOAA/NWS/NCEP/WPC
72. Oberfield, Mark	NOAA/NWS/OST/MDL
73. Orndorff, Brian	NOAA/OAR/OWAQ
74. Ou, Mellissa	NOAA/NWS/NCEP/CPC
75. Pasch, Richard	NOAA/NWS/NCEP/NHC
76. Pelletier, Yves	Canadian Meteorological Centre
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79. Peroutka, Matt	NOAA/NWS/OST/MDL
80. Rausch, Robert	NOAA/NWS/NCEP/WPC
81. Ready, Reginald	NOAA/NWS/NCEP/NCO
82. Reynolds, Carolyn	NAVY/NRL
83. Roth, Michael	NAVY
84. Rozumalski, Robert	NOAA
85. Rudack, David	NOAA/NWS/OST/MDL
86. Saha, Suranjana	NOAA/NWS/NCEP/EMC
87. Satterfield, Elizabeth	NAVY/NRL
88. Schaake, John	Consultant
89. Schemm, Jae-Kyung	NOAA/NWS/NCEP/CPC
90. Scheuerer, Michael	NOAA/OAR/ESRL/PSD
91. Schicjtel, Michael	NOAA/NWS/NCEP/WPC
92. Schultz, Paul	NOAA/OAR/ESRL/GSD

93.	Sestak, Michael	NAVY/FNMOC
94.	Shafer, Phillip	NOAA/NWS/OST/MDL
95.	Shaffer, Mark	NAVY
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99.	Sisson, Paul	NOAA/NWS Burlington, VT
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107.	Tien, Alex	The MITRE Corporation
108.	Toepfer, Frederick	NOAA/NWS/OST
109.	Tolman, Hendrik	NOAA/NWS/NCEP/EMC
110.	Tongue, Jeffrey	NOAA/NWS/ER-NY
111.	Toth, Zoltan	NOAA/OAR/ESRL/GSD
112.	Townsend, Howard	NOAA/NMFS
113.	Tracton, Steve	NOAA/NWS/NCEP retiree
114.	Unger, David	NOAA/NWS/NCEP/CPC
115.	Vandendool, Huug	NOAA/NWS/NCEP/CPC
116.	Van, Ross	NOAA/NWS Training Division
117.	Veenhuis, Bruce	NOAA/NWS/OST/MDL
118.	Vojak, Nicholas	USN/JWTC
119.	Wagner, John	NOAA/NWS/OST/MDL
120.	Waldstreicher, Jeff	NOAA/NWS/ER-HQ
121.	Wang, Hui	CMA/NMC, China
122.	Warren, Steve	NOAA/ESPC
123.	Wells, Ernie	NOAA/NWS/OHD
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127.	Wu, Limin	NOAA/NWS/OHD
128.	Wu, Wanru	NOAA/NWS/OHD
129.	Yang, Bo	NOAA/NWS/NCEP/EMC – SRG
130.	Young, Douglas	NOAA/NWS
131.	Yuan, Huiling	Nanjing University, China
132.	Zhang, Xiakun	NOAA/NWS/NCEP/EMC - Visitor
133.	Zhang, Zhan	NOAA/NWS/NCEP/EMC – IMSG
134.	Zhao, Xiaolin	CMA/NMC, China
135.	Zheng, Minghua	SUNY – Stony Brook
136.	Zheng, Yongguang	U. of Oklahoma, CAPS – CMA
137.	Zhou, Binbin	NOAA/NWS/NCEP/EMC - IMSG
138.	Zhou, Jiayu	NOAA/NWS/OST

139.	Zhou, Xiaqiong	NOAA/NWS/NCEP/EMC - IMSG
140.	Zhu, Yuejian	NOAA/NWS/NCEP/EMC