Predictability Assessment and Improving Ensemble Forecasts

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PROJECT GOALS AND OBJECTIVES

The PI is examining atmospheric predictability with the goal of improving ensemble forecasts at ranges of 12 hours to 10 days. The research is addressing several issues, including:

- Documentation of analysis uncertainty from mesoscale and global analyses.
- Calibration of ensemble forecast system (EFS) output by artificial neural networks.
- Design of optimal EFS's, with an emphasis on precipitation forecasts.
- Design of stochastic physics parameterizations that improve under-dispersion in EFS's.

The PI also served as Co-Chief Scientist to Dr. Scott Sandgathe for ONR initiative on Predictability in the Atmosphere and Ocean, and presumably will continue to serve as Co-Chief Scientist on the initiative.

DOCUMENTATION OF ANALYSIS UNCERTAINTY

The PI is estimating lower bounds for the statistics of analysis errors Eo from differences between different analysis-forecast systems. This approach defines a “component" of the analysis uncertainty. Although this methodology is not as theoretically appealing as statistics from ensemble data assimilation or observing system simulation experiments, it is currently tractable, very economical, and useful guidance can be quickly obtained.

The PI has been comparing differences among NCEP LAM analyses from the NGM and ETA models and the global AVN model. It is important to consider LAM fields since scales not resolved by global analyses are presumably analyzed with greater certainty over the data rich, North American continent. Approximately three years of twice-daily analyses have been collected processed. In FY01, the PI began analysis of the data, with the computation of 2D spectra and vertical correlation coefficients of the difference fields to document the scale dependency of analysis uncertainty. The analysis has progressed little over the past year, exception for the collection of another year of data. PI is collaborating with DRI participants Errico, Baumhefner and Tribbia (NCAR) to document analysis uncertainty in global analyses. Analyses from ECMWF and NCEP are being compared, and similar statistics are being computed for the global difference fields. This work is the natural complement to the LAM documentation. A 2D spectrum is shown in Fig. 1for 500 mb temperatures. The variance for the difference between analyses is as large as the variance for ECMWF fields for wavenumbers higher than 36, which indicates global analyses of temperature contain little useful information for

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wavelengths shorter than 10^o latitude (~1,100 km). The beginnings of a manuscript are in early stages of preparation.

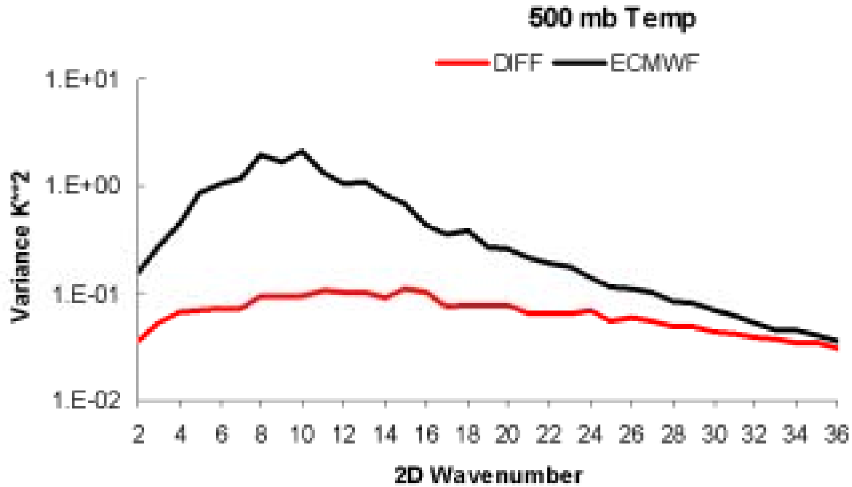

Fig. 1. Two-dimensional variance spectra for 500 mb temperatures for the 1991 boreal winter. Spectrum for differences between ECMWF-NCEP global analyses (red) and for ECMWF analyses (black). The difference variance equals or exceeds the analysis variance beyond wavenumber 36.

NEURAL NETWORK POST-PROCESSING OF ENSEMBLE FORECAST PRODUCTS

Because forecast fields produced by any NWP model always contain errors due to model deficiencies (e.g. lack of resolution, inadequate parameterizations, truncation error, etc), raw model output is often statistically post-processed to mitigate their impact. Post-processing also provides a way to relate model output fields to weather elements not explicitly forecast by the NWP model (e.g. visibility, probability of thunder).

Artificial neural networks (ANNs) are computer algorithms that are designed for nonlinear optimization. A back-propagation ANN was used to process to QPF output from the pilot ETA/RSM ensemble data set that was also used by Hamill and Colucci (1998). The ANN markedly improves the unprocessed ensemble and even shows higher skill than Model Output Statistics, the *de facto* operational standard based on multiple linear regression, for thresholds up to 1.00". The improvement comes from a better reliability, the forecast probability matching the observed frequency of occurrence, but forecast specificity, the ability to pick up day-to-day cases in event occurrence, did not improve. These results will be reported in a paper (Mullen et al. 2002, still in preparation).

DESIGN OF OPTIMAL ENSEMBLE FORECAST SYSTEMS

The PI and collaborator R. Buizza (ECMWF) examined the tradeoff between increased horizontal resolution and ensemble size on ensemble performance for precipitation. Experiments at resolutions of T159, T255 and T319 were analyzed. Potential values as a function of the Cost-Loss ratio at Day 5 for

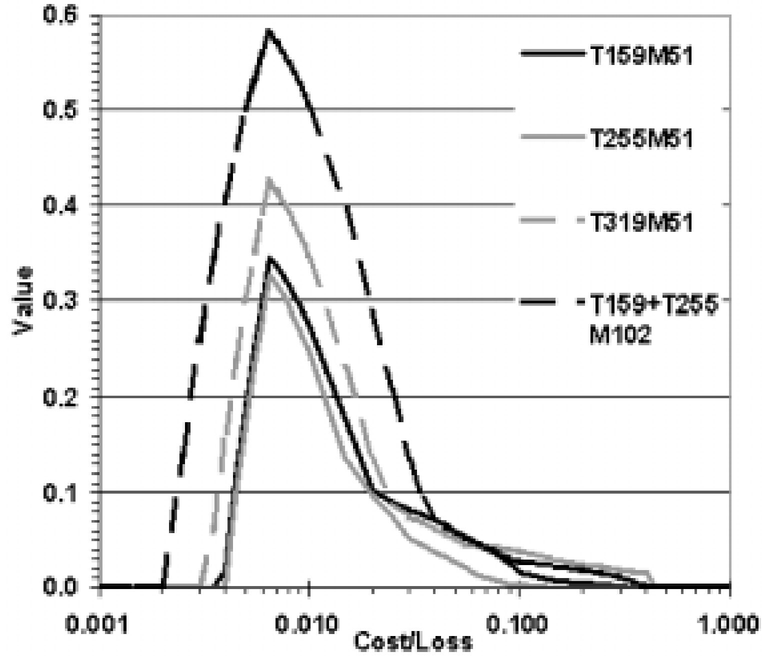

Fig. 2. Potential economic value, as a function of a user's Cost-Loss ratio, for four configurations of the ECMWF ensemble prediction system (EPS). The 102-member ensemble (T159+T255M102), comprised of two 51-member lower-resolution models (T159M51 and T255M51), provides higher value than the 51-member ensemble at higher resolution (T319M51). The comparison indicates that increased ensemble size can yield higher value for many users than higher resolution.

amounts above 50 mm in 24 h are shown in Fig. 2. Values are shown for four ensemble configurations: three 51-member ensembles at truncations of T159, T255 and T319, and a 102-member ensemble comprised of the T159 and T255 constructs. Note that the 102-member ensemble takes less CPU time than the T319M51 ensemble. Our analysis indicates that increased ensemble size can provide better value than increasing the model resolution, especially for rare (in terms of climatological likelihood of occurrence) events. The issue of how to invest CPU resource needs to be explored for more ensemble systems, various thresholds, etc. An in-press paper (Mullen and Buizza, 2002) reports these results.

In collaboration with scientists at the NOAA National Severe Storms Laboratory, the value of mixed-ensemble forecast systems for QPF and PQPF is being explored for model resolutions comparable to the current 22-km ETA and ranges out to 36 h. Fig. 3 shows a three-panel plot with the area under the ROC curve (which measures the ability of a forecast system to discriminate events) and parameters for potential economic value. The panels give four thresholds for 24 h accumulations ending at 36 h for a 9-member mixed ensemble. ROC areas are positive for all thresholds. This indicates that hit rate for the ensemble exceeds that false alarm rate. The Max Value plot gives the maximum economic value; the panel shows that the ensemble has value relative to climatology for even the 1.00" threshold. The Value Width panel gives the interval of Cost/Loss ratios with positive values. Together, the Max Value and Value Width panels show that mixed ensembles offer value to many decision makers. These results are reported in a recent paper (Wandishin et al 2001).

Under ONR support in FY02, the PI will continue examining optimal configurations for ensemble forecast systems. The PI plans to explore predictability limits and the utility of high membership ensembles *O*(100) from daily forecasts with a mesoscale LAM (~10 km grid) with hardware acquired under DURIP support. The new hardware is ordered and is scheduled for delivery in Oct. 2002.

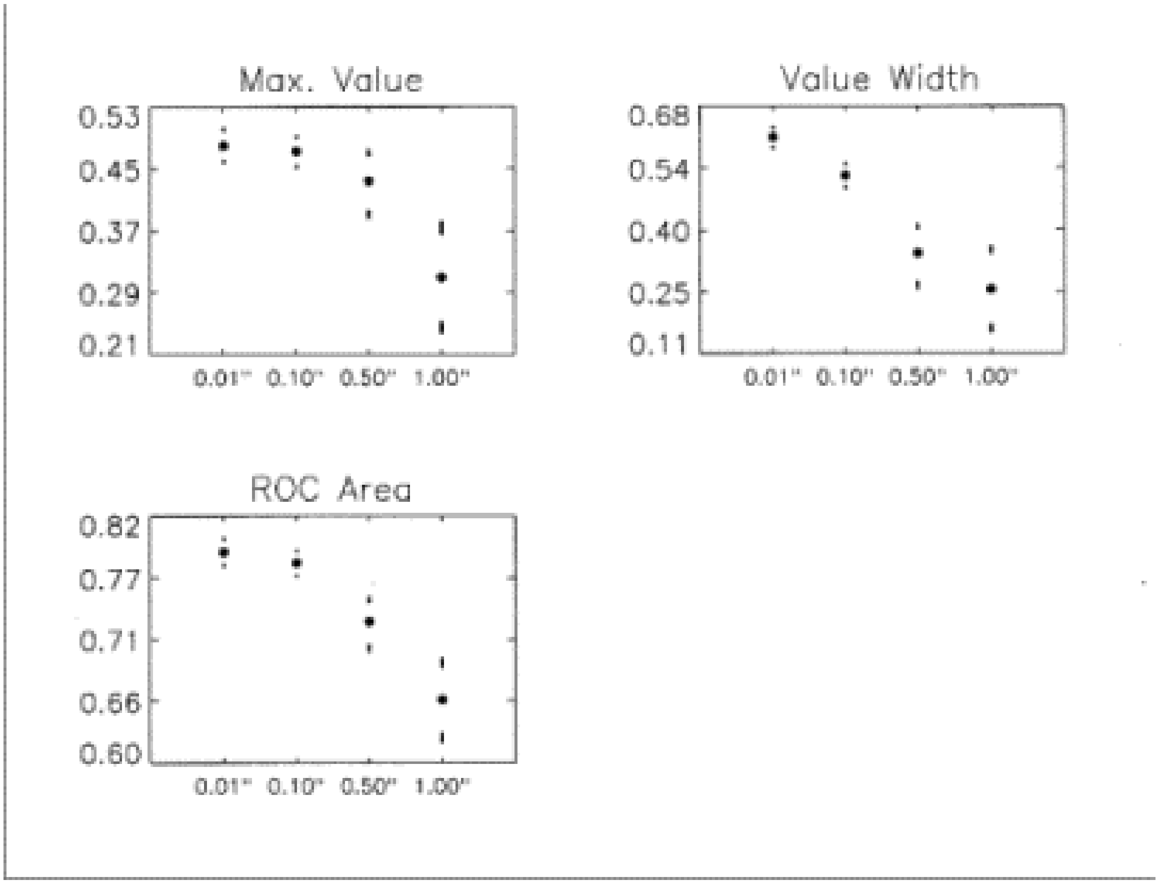

Fig. 3. Summary of cost-loss, value for 24 h rainfall totals valid at +36 h from a mixed-physics ensemble forecast system. Upper Left: Maximum Value for four thresholds. Upper Right: Width of interval with positive Cost-Loss ratios. Lower Right: Standardized area under the Relative Operating Characteristic curve. The results show that mesoscale ensemble systems can provide useful guidance to decision makers, but that value drops rapidly with increased precipitation threshold.

DESIGN OF STOCHASTIC MODEL PARAMETERIZATIONS

In collaboration with David Bright (PhD Candidate in ATMO), the feasibility of stochastic cumulus parameterization schemes is being tested with a LAM. The goal is the design schemes that give performance comparable to mixed-physics ensemble systems. The MM5 system and the Kain-Fritsch cumulus scheme are being used to investigate perturbations to the scheme's trigger function. Estimates of the life span of cumulus convection from radar data were used to model the temporal correlation as a 1st order auto-regressive AR(1) process with an e-folding time of 1 hr. Weak, spatial correlations implicitly come from the fact that the AR(1) process evolves slowly relative to the model time step.

Figure 4 (next page) shows an interesting result: the scheme leads to upscale error growth. Note the horizontal-scale of the precipitation perturbations by +24 h is clearly larger than the smallest resolvable "2δx" wavelength (72-km) in the model. This indicates the AR(1) temporal correlation can yield non-trivial, spatially-correlated perturbations.

Figure 5 summarizes the potential economic value for a 25mm/24h threshold and +24 h forecast. Results for four 10-member, ensembles are shown: a 12 km ensemble with Kain-Fritsch and MRF PBL schemes with only perturbed analyses (12KM label), a 36 km ensemble with KF and MRF schemes with only perturbed analyses (K-M label), a perturbed-analyses mixed-model 36 km ensemble based on 10 unique combinations of Cu schemes and PBL schemes (MIX label), and a 36 km stochastic KF and deterministic MRF scheme (K'-M label). Note only one parameter in the KF scheme is stochastic, the trigger function. The plot shows positive value for all configurations. For most users, the MIX is superior and the K-M inferior. The 12KM gives a slight improvement over the K-M. Note that the K'-M lies about halfway between the MIX and K-M lines. In another words, the single stochastic parameter K'-M scheme yields ~50% of the benefit of a mixed-model, perturbed-analyses scheme.

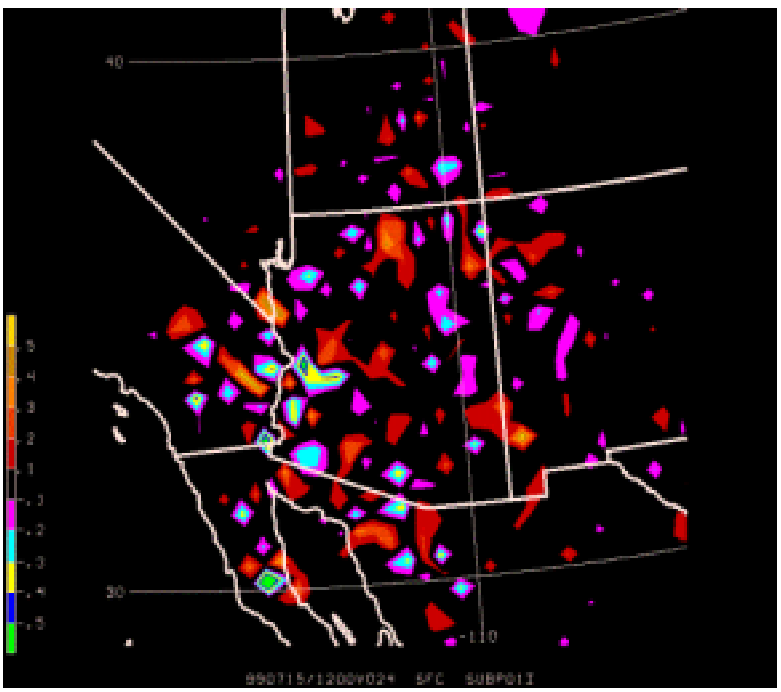

Fig. 4. Difference between a stochastic physics forecast and the control forecast without stochastic physics for 24 h rainfall totals valid at +24 h. Differences occur at scales longer than twice the grid point spacing, which indicates the occurrence of upscale error growth.

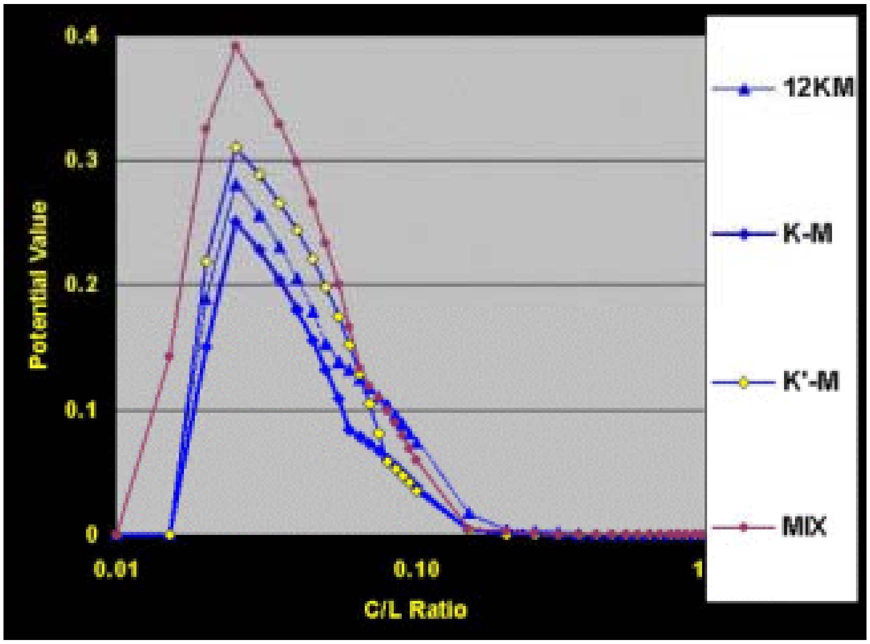

Fig.5. Potential Value as function of a hypothetical user's Cost/Lost Ratio for 4 different ensemble configurations. The mixed-physics ensemble (MIX) provides the greatest potential value to most users. The Kain-Fritsch with MRF PBL scheme (K-M) provides the least value to most users. A stochastic version of the Kain-Fritsch cumulus scheme with the MRF PBL package (K'-M) provides better value than a 12 km version (12KM) of the K-M ensemble. The results show that including a stochastic representation for one process in the Kain-Fritsch scheme can provide about half the increased value for a full mixed-physics ensemble.

PUBLICATIONS (IN PRESS, SUBMITTED OR IN PREPARATION)

Mullen, **S. L.**, and R. Buizza, 2002: The impact of horizontal resolution and ensemble size on probabilistic precipitation forecasts by the ECMWF ensemble prediction system. Wea. Forecasting, **17**, in press.

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In-House/Out-of-House Ratios

All research is 100% out-of-house.