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STATISTICAL-DYNAMICAL GUIDANCE FOR TROPICAL STORM TRACK FORECASTING

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1 – INTRODUCTION

An ensemble is a set of numerical weather simulations produced by (a) different models, (b) models which were initialized using different initial conditions, (c) models using different physical parameterizations, or a combination of all three. The GFS ensemble consists of 11 simulations produced from the GFS ensemble, each using different initial conditions; 1 control run, and 5 sets of paired positive/negative perturbations, each of the 5 produced from the breeding method.

From the set of simulations in an ensemble, an ensemble mean forecast can be produced. The ensemble mean provides a forecast of the position of the storm at a future time. The differences between ensemble members and the ensemble mean can provide guidance for probabilistic forecasting. If the ensemble members are in relative agreement on the future position of a tropical storm (the 'spread' between members is small), the probability that the storm will be near the site of the ensemble mean forecast is high. If, on the other hand, the ensemble members have very different future forecasts, the probability that the storm will be at the spot of the ensemble mean forecast is low.

As with the ensemble mean forecast position, the ensemble based probability forecast can be in error. For example, consider a case where an ensemble has a tendency to have too much spread compared to the actual root mean squared error of the ensemble mean forecast. This would yield an ensemble based probability which would not be consistent with the average forecast errors.

Observational data can be used to adjust raw model output to make a more accurate weather forecast. Model Output Statistics (MOS) (Glahn and Lowry, 1972) has proven an effective way of generating weather forecasts from a numerical model. Past forecasts are compared to past observations, and correlation functions between the two data sets are produces. These correlation functions are applied to future model forecasts.

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In this study, the GFS ensemble is used to produce a probability forecast for tropical storms in the Atlantic Basin. The spread of GFS ensemble members about the ensemble mean forecast is compared difference between the ensemble mean forecast and the verifying position. Forecasts of storms from the 2002 season are used to estimate the mean error and standard deviation error, and then applied to storms from the 2003 season to produce forecasts of absolute position and position probability. These forecasts are compared to the raw GFS ensemble based probability forecasts.

2 – METHODS

Ensemble mean forecasts were calculated for 12, 24, 36, 48, 60, and 72 hour forecasts. The ensemble mean forecast for forecast event number "j" using an n-member ensemble is:

(1) $$\bar{x}_j = \frac{1}{n}\sum_{i=1}^{n} x_{i,j}$$

Here, n is equal to 11, the number of members in the GFS ensemble. We choose to use only those forecast events in which all 11 ensemble members maintain a coherent storm until the verification time. The position of a storm in a model forecast was determined using the NCEP tropical cyclone tracker (Marchok, 2002). The difference between the forecast from ensemble member "i" and the ensemble mean forecast, for forecast event "j" is:

(2) $$e_{i,j} = (x_{i,j} - \bar{x}_j)$$

As a track forecast is a two dimensional problem, the difference between the mean and an individual member is a two dimensional quantity. After determining the direction of motion, position errors are transformed from north-error and east-error (Cartesian Coordinates) into along track and across track errors (Natural Coordinates).

Ensemble mean forecasts and differences between the mean and individual forecasts were calculated for lead times of 12, 24, 36, 48, 60, and 72 hours. During the 2002 season, there were 366 cases where the entire 11-member GFS ensemble forecast a storm at one of these lead times.

Estimates of the probability density function were calculated assuming a normal distribution of errors along track and across track. The variance of a population of n estimates of a value is given by:

$$s_j^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_{i,j} - \bar{x}_j) \quad (3)$$

Here, n is 11, as before. Variance is an infinite sample statistic, and comparing ensemble based variance to the squared error of an ensemble mean forecast is inappropriate. Instead, an average of ensemble estimates of variance must be compared to a sample variance, as done in Majumdar et al (2001). The average ensemble variance for “m” forecast events is:

$$s^2 = \frac{1}{m}\sum_{j=1}^{m}(s_j^2) \quad (4)$$

To make an estimate of the sample forecast error variance, the difference between the ensemble mean and truth was calculated for each forecast. This difference, squared, was one realization of forecast error. The sample forecast error variance would be the average of “m” such realizations:

$$\sigma^2 = \frac{1}{m}\sum_{j=1}^{m}(b_j - \bar{x}_j) \quad (5)$$

The value of s^2 (the average variance of the ensemble members about the mean) and σ^2 (the average squared error of the ensemble mean) are calculated for each forecast event (i.e. setting m to 366 – all cases). In both dimensions, s is about 1.5 times as large as σ, implying that GFS ensemble spread over-estimates the true uncertainty of GFS ensemble mean forecast errors (Table 1). When stratified by latitude, this ratio of s to σ is not constant. It is closer to 1.8 in the deep tropics, 1.5 around 30°N, and almost exactly 1.0 north of 31°N. This result implies that GFS ensemble spread is too great for storms in the deep tropics, but about right north of 31°N.

Table 1

Latitude	Ens SD Along	Ens SD Across	RMSE Along	RMSE Across
10N-21N	199	236	133	125
21N-28N	222	230	120	127
28N-31N	169	195	105	128
31N-41N	176	165	165	173
All	193	209	130	139

Table 1 – GFS ensemble standard deviation of members about the mean and root mean squared GFS ensemble mean forecast error for all 2002 Atlantic storms.

3 – FUTURE WORK

The standard deviation of the GFS ensemble members about their mean is on average approximately one and one half times the root mean squared error of the ensemble mean forecast, but varies with latitude.

This latitude dependent rescaling of ensemble spread will be applied to storms from the 2003 Atlantic season. Rescaled ensemble variance will be compared to the root mean squared error of ensemble mean forecasts.

4 – REFERENCES

Glahn, H. R. and D. A. Lowry, 1972: The use of model output statistics (MOS) in objective weather forecasting. *J. Appl. Meteor.*, **11**, 1203-1211.

Majumdar, S.J., C.H. Bishop, B.J. Etherton, I. Szunyogh, and Z. Toth, 2001: Can an Ensemble Transform Kalman Filter predict the reduction in forecast error variance produced by targeted observations? *Quart. J. Roy. Meteor. Soc.* **127**, 2803-2820.

Marchok, T. P., 2002: How the NCEP tropical cyclone tracker works. Preprints, 25th Conference on Hurricanes and Tropical Meteorology, (May 2002, San Diego, California). Amer. Meteor. Soc., Boston, MA.