4D.1 TRACK FORECASTING OF 2001 ATLANTIC TROPICAL CYCLONES USING A KILO-MEMBER ENSEMBLE

Jonathan Vigh*
Colorado State University, Fort Collins, Colorado

1. INTRODUCTION

The skill of tropical cyclone track forecasts has improved markedly over the past few decades (McAdie and Lawrence, 2001) as forecasters gained access to improved data, understanding, and numerical guidance. Vastly increased computing power and advances in numerical methods have resulted in dynamical forecast models with 72-hour errors half those of thirty years ago.

Track error is comprised of many sources including analysis error caused by inaccurate spatial and temporal sampling, incomplete representation of physical processes, discretization error, and truncation error. In high resolution full physics dynamical forecasting systems, the latter of these sources have been largely minimized. The remaining error results primarily from uncertainties in the initial analysis coupled with the inherent chaotic nature of atmospheric dynamics (instability mechanisms and nonlinear interactions between spatial scales). These factors set limits of practical and inherent predicability for any single deterministic realization (Leslie et al., 1998).

Running an ensemble with properly perturbed initial conditions is one way to reduce the uncertainty associated with the chaotic atmosphere. It has been shown that the mean of the ensemble is generally more accurate than a single deterministic forecast (Leith, 1974). If the ensemble perturbations accurately simulate the error statistics, the spread of the ensemble members can lead to estimates of forecast uncertainty. This could allow the reliability and lead times of watches and warnings to be increased, resulting in obvious practical and monetary benefits.

This preprint describes the development of an ensemble forecasting system simple and fast enough to be used operationally with minimal computing resources, yet with a sample size large enough to simulate the subspace of dynamical pathways available to the tropical cyclone.

**Corresponding author address:* Jonathan Vigh, Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523-1375; e-mail: vigh@atmos.colostate.edu

2. MODEL DESCRIPTION

A multigrid barotropic vorticity equation model (MBAR) is used to produce each of the forecast tracks (Fulton, 2001). MBAR was chosen because it reproduces the accuracy of the operational LBAR (a limited area shallow water spectral sine transform model) in approximately $\frac{1}{40}$ the computing time. The model is run on a 1-GHz Intel Pentium PC; each 120-hour track forecast takes 2.5 seconds, allowing the entire ensemble to run in an hour. There are three grid levels with the following resolutions: $h_1 = 125$ km, $h_2 = 63$ km, and $h_3 = 31$ km.

The model is initialized with 2 degree resolution deep layer mean wind fields derived from the Medium Range Forecast (MRF) global forecasting system. The winds from a bogus vortex with motion vector c, maximum tangential wind velocity V_m, size parameter b, and radius of maximum wind r_m are blended with the background fields to obtain the initial condition. MRF ensemble forecast fields supply time dependent boundary conditions at the edge of the 6000 km square domain.

3. ENSEMBLE PERTURBATIONS

Five classes of perturbations are considered: in the background environmental flow, in the deep layer mean averaging, in the equivalent phase speed c_{eqv}, in the vortex size/strength, and in the storm motion vector.

Perturbations of the environmental flow are obtained from the operational 00Z MRF ensembles. Five independent breeding cycles are used in the analysis cycle to estimate the subspace of fast growing perturbations, which are superpositions of the atmosphere's time-dependent Lyapunov vectors. Fast growing analysis errors are represented by the bred vectors. (Toth and Kalnay, 1997). These vectors are then added and subtracted from the control analysis to obtain a total of ten perturbed initial conditions plus the control.

The resulting perturbed ensemble wind fields are then vertically averaged using three different deep layer means: a standard deep layer mean over all the mandatory pressure levels from 850 hPa to 200 hPa, a medium layer mean from 850 hPa to 350 hPa, and a shallow layer mean from 850 hPa to 500 hPa. This accounts for possible variations in the storm steering layer.

In a nondivergent barotropic model it has been recognized (Wiin-Nielson, 1959) that ultra-long Rossby waves experience excessive retrogression. The inclusion of the Helmholtz adjustment term (which depends on $\gamma = f/c_{eqv}$) in the prognostic equation can reduce this spurious retrogression. With f simply a function of latitude, this factor depends on the equivalent phase speed $c_{eqv} = \sqrt{gh_{eqv}}$. Decompositions of the tropical atmosphere project onto a variety of vertical modes, ranging from the external or first internal modes (for subtropical highs) to higher internal modes (for flow forced by deep convection). To handle this uncertainty, several values of c_{eqv} are chosen.

Several combinations of V_m, r_m, and b are used to simulate vortices of varying size and strength. Finally, the uncertainties associated with the storm motion are simulated by perturbing the motion vector by a given amount in the along-track and cross-track directions, or combinations thereof.

This study differs from previous studies with up to fifty members (Chan and Cheung, 1999) in that the various perturbation classes are cross multiplied:

11	environmental flow fields
3	layer means
3	values of c_{eqv}
3	storm sizes
×5	motion vectors
1485	members

to obtain an ensemble with 1485 members. One of the central questions addressed by this research is whether cross multiplication of perturbations leads to increased skill of the ensemble mean and better simulation of error statistics.

4. ANALYSIS

The ensemble is run over the 2001 Atlantic storms (excluding Allison and TD 2). Input to the ensemble system is generated from parameters available to operational guidance products at NCEP.

Various statistical characteristics of the ensemble forecasts are examined: the average error, bias, skill relative a single control, and skill relative to climatology and persistence (CLIPER) and other operational guidance. The spread of the individual members from the ensemble mean is investigated to determine the correlation between forecast reliability and spread. Probabilistic interpretations are possible with an ensemble this large, so the probability density field of future storm location is calculated for various times. In a related possibilistic interpretation, the ensemble can be looked upon as mapping out a subspace of all possible storm tracks. The reliability of this ensemble envelope is examined. Finally, statistical and adaptive methods of selecting more accurate subensembles are investigated. If research time permits, an interactive graphical interface will be developed, allowing the forecaster to distinguish the influence of the various perturbed parameters on the ensemble member tracks and associated subensemble mean tracks.

ACKNOWLEDGMENTS

The author would like to thank Mark DeMaria for his considerable input and guidance, Scott Fulton for the use of MBAR and his assistance in adapting MBAR for use with the MRF data, and Wayne Schubert for his helpful comments and suggestions.

This research was conducted with the support of an AMS Fellowship and funding from the Significant Opportunities in Atmospheric Research and Science (SOARS) program.

5. REFERENCES

Fulton, S. R., 2001: An adaptive multigrid barotropic tropical cyclone track model. *Mon. Wea. Rev.*, **129,** 138–151.

Cheung, K. K. W., and J. C. L. Chan, 1999: Ensemble forecasting of tropical cyclone motion using a barotropic model. Part II: Perturbations of the vortex. *Mon. Wea. Rev.*, **127,** 2617–2640.

Leith, C. E., 1974: Theoretical skill of Monte Carlo forecasts. *Mon. Wea. Rev.*, **102,** 409–418.

Leslie, L. M., Abbey, R. F., and Holland, G. J., 1998: Tropical cyclone track predictability. *Meteorol. Atmos. Phys.*, **65,**, 223–231.

McAdie, C. J., and M. B. Lawrence, 2000: Improvements in tropical cyclone track forecasting in the Atlantic basin, 1970–1998. *Bull. Amer. Meteor. Soc.*, **81,** 989–997.

Toth, Z., and E. Kalnay, 1997: Ensemble forecasting at NCEP and the breeding method. *Mon. Wea. Rev.*, **125,** 3297–3319.

Wiin-Nielsen, A., 1959: On barotropic and baroclinic models, with special emphasis on ultra-long waves. *Mon. Wea. Rev.*, **87,** No. 5, 171–183.