6C.3 TARGETING STRATEGIES TO IMPROVE HURRICANE TRACK FORECASTS

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1. INTRODUCTION

The primary purpose of operational synoptic surveillance missions is to deploy targeted GPS dropwindsondes in the environment of a tropical cyclone, to improve 1-3 day forecasts of the cyclone's track and intensity. These subjectively-selected targeted observations have improved numerical NCEP GFS (Global Forecasting System) track forecasts by a percentage comparable to that achieved in the last 30 years due to advances in numerical modeling (Aberson 2001). However, it is expected that an *objective* strategy for targeting may be expected to improve tropical cyclone track and intensity forecast skill even further, since it would be able to identify the most sensitive regions in which observations are most likely to reduce forecast errors. Several such strategies have been devised and implemented for improvement of mid-latitude weather forecasts. The Ensemble Transform Kalman Filter (ETKF, Bishop *et al.* 2001, Majumdar *et al.* 2002) is presently used in National Weather Service operations to identify locations for aircraft to be deployed in order to improve winter weather forecasts (Winter Storm Reconnaissance: WSR). The purpose of the work described in this conference paper is to adapt and extend the ETKF for use in synoptic surveillance missions in the environment of tropical cyclones.

2. THEORY

The ETKF (Bishop et al. 2001) assumes that observed data are assimilated using ensemble-based error statistics at the targeted observing time t_a. It solves the Kalman Filter error statistics equations

$$\mathbf{P}_q^a = \mathbf{P}_r^a \mathbf{H}_q^T (\mathbf{H}_q \mathbf{P}_r^a \mathbf{H}_q^T + \mathbf{R}_q)^{-1} \mathbf{H}_q \mathbf{P}_r^a \quad (1)$$

$$\mathbf{P}_q^f = \mathbf{M} \mathbf{P}_q^a \mathbf{M}^T + \mathbf{Q} \quad (2)$$

for all feasible deployments of targeted observations. $\mathbf{P}_r^a$ represents the analysis error covariance matrix associated with routine observations at time t_a, and $\mathbf{P}_q^a$ is the corresponding estimate associated with routine observations plus the qth feasible deployment of targeted observations. $\mathbf{H}_q$ and $\mathbf{R}_q$ are the observation operator and error covariance matrix associated with the qth deployment, respectively. The propagator $\mathbf{M}$ maps perturbations at t_a to perturbations at the later forecast verification time t_f, and $\mathbf{Q}$ is the covariance matrix of model errors accrued between the respective times. $\mathbf{P}_q^f$ is the forecast error covariance matrix valid at the verification time that one would obtain if all the above quantities were estimated accurately.

The reduction in forecast error variance produced by the targeted observations is then rapidly calculated via a series of matrix transformations, via the **signal variance**

$$\mathbf{S}_q^f = \mathbf{M} \mathbf{P}_r^a \mathbf{H}_q^T (\mathbf{H}_q \mathbf{P}_r^a \mathbf{H}_q^T + \mathbf{R}_q)^{-1} \mathbf{H}_q \mathbf{P}_r^a \mathbf{M}^T \quad (3)$$

The signal variance is equal to the reduction in forecast error variance, only if error covariance information assumed by the ETKF and the operational data assimilation scheme are perfect, linear dynamics are obeyed, and the leading forecast error structures project onto the ensemble perturbations. While these conditions never hold in practice, the ETKF has demonstrated the ability to predict the reduction in forecast error variance due to the targeted observations (Majumdar *et al.*, 2001, 2002).

While the ETKF targeting strategy is reaching maturity for mid-latitude targeting, there is considerable room for improvement in its formulation for tropical cyclones. Attention is being focused on the following issues:

(i) The number of available operational ensemble forecasts is limited, compared with the dimension of the model state space. This *rank-deficiency* leads to the ETKF specifying spurious error statistics in the $\mathbf{P}_r^a$ and $\mathbf{S}_q^f$ matrices, which can result in the selection of an incorrect deployment region of targeted observations. A major challenge in our research is to mitigate this problem.

(ii) The choice of relevant variables and levels to be used in tropical applications of the ETKF is unclear. The operational formulation in WSR uses horizontal wind components and temperature (u,v,T) at 3 levels (850mb, 500mb and 250mb) as the observed and verification variables in the prediction of signal variance. For tropical cyclone prediction, a more appropriate verification variable would be the location and/or the intensity of the cyclone.

3. PRELIMINARY RESULTS

Work is ongoing to redevelop the ETKF strategy for tropical cyclones. Hurricanes Claudette, Danny, Erika, Fabian, Isabel and Tropical Storm Odette are being investigated retrospectively, since targeted observations (selected subjectively based on ensemble variance) were collected for these storms. Fig.1 shows a basic ETKF targeting summary map of signal variance (see Majumdar *et al.* 2002 for more details), in which the aim is to improve a forecast of Hurricane Isabel, by taking targeted observations 3 days prior to its anticipated landfall. Based on the 2.5° resolution ECMWF ensemble, the ETKF suggests that extra observations should be collected in the

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environment of the storm, with a particular emphasis on the north-east (right rear) quadrant. This map is based on the same version of the ETKF that is used during WSR; adjustments will be made for tropical cyclones by (i) improving routine analysis error covariance specification in the ETKF, (ii) including both NCEP and ECMWF ensembles at 1 degree resolution, and (iii) including a new verification norm. The new results will be presented at the conference.

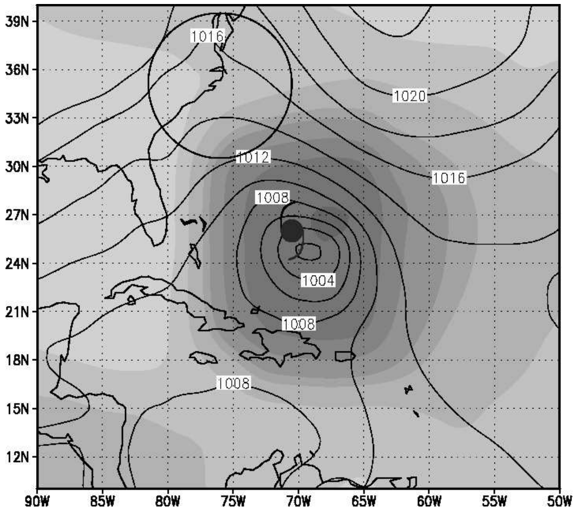

FIG. 1: ETKF summary map of predicted signal variance (reduction in forecast error variance) localized in a selected verification region, as a function of the targeted observing location. Darker shading indicates a more favorable area for targeted observations to be taken, to improve a 3-day forecast between t_a=00Z 16 Sep 2003 and t_v=00Z 19 Sep 2003. Results are computed using 50 ECMWF ensemble members at 2.5° resolution, initialized 60h prior to the targeted observing time t_a. The location of Isabel's actual position at 00Z 16 Sep is shown by the hurricane symbol. The 60-h ECMWF ensemble mean sea level pressure forecast valid at the same time is also shown, as is the circular forecast verification area at time t_v in which the signal variance is localized.

4. CONCLUSIONS AND FUTURE WORK

ETKF summary maps of signal variance, such as that shown in Fig.1, have been computed at coarse resolution for several tropical cyclone cases in 2003. In addition to identifying areas in the immediate environment of the cyclone, several maps have indicated that middle-upper level troughs that are poised to interact with the cyclone are also suitable for targeting. Attention is presently being focused on assessing the credibility of these targets, and on devising techniques to ameliorate long-distance correlations that may be spurious.

After further improvements have been made (more ensemble members at higher resolution, a more appropriate verification "norm" *etc*) the ETKF will also be tested quantitatively using tropical cyclone cases from the 2004 season. Using similar methods to those described in Majumdar *et al.* (2001), the ability of the ETKF to predict signal variance (and hence the reduction in forecast error variance) will be evaluated. This will involve using two sets of NCEP GFS analysis-forecast cycles: the "operational" cycle which assimilates all routine and targeted observations, and the "control" in which only the targeted observations are neglected. The difference between these two cycles is known as the "signal". If a linear, increasing relationship is obtained between the ETKF predictions of signal variance and the variance of NCEP GFS signal realizations, then the ETKF will have demonstrated promise in distinguishing between good and poor locations for targeting. In addition to the statistical tests, the propagation of the signal variance with time will be assessed dynamically along with the actual signal propagation evaluated using the parallel NCEP GFS analysis-forecast cycles.

It is expected that the ETKF will provide an improvement over the present subjective method of taking targeted observations in areas near the tropical cyclone where the ensemble variance is relatively high. This is because the ETKF summary maps often represent a modulation of this variance, tuned to the forecast system of interest. The degree of improvement that the ETKF may provide will remain unknown until the aforementioned issues are tackled. If the new, extended ETKF passes the qualitative and quantitative tests mentioned above, the transition will be made for its use as the targeting strategy for future operational synoptic surveillance missions.

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