9.4 The G-IV Surveillance Era, Targeting, and Ensemble Forecasts (1997-Present)

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I. Background

Tropical cyclones (TCs) generally exist in the data-sparse oceanic belt extending from near the Equator to the subtropics. Accurate TC track and intensity forecasting depends upon improvements to the observational network in these regions, and on accurate analysis and assimilation of these observations into numerical guidance. Between 1982 and 1996, the National Oceanographic and Atmospheric Administration (NOAA) Hurricane Research Division (HRD) conducted twenty "Synoptic Flow" experiments in the North Atlantic basin to gather observations in the TC core and environment and assess their impact on the numerical guidance. The NOAA WP-3D (P-3) research aircraft released Omega dropwindsondes (ODWs) to obtain wind, temperature, and humidity profiles below about 400 hPa within 1000 km of the tropical cyclone center. Dropwindsonde observations from "Synoptic Flow" experiments produced significant improvements (16%-30% error reduction for 12-60-h forecasts) in 15 cases from 1982 to 1995 in the primary numerical guidance for the National Hurricane Center (NHC) official track forecasts (Burpee et al. 1996). These track improvements were as large as the NHC official forecast improvements obtained during the previous 20-25 years and suggested that operational missions would be effective in reducing numerical track forecast errors.

In 1996, NOAA procured a Gulfstream IV-SP (G-IV) jet aircraft, and put it to use in operational "Synoptic Surveillance" missions in the environments of TCs threatening the continental United States, Puerto Rico, the Virgin Islands, and Hawaii. A new dropwindsonde, based on the Global Positioning System, was developed by the National Center for Atmospheric Research to replace the ODW. During the first two years of surveillance (1997-8), twenty-four missions were conducted, and the impacts were generally smaller than expected (Aberson 2002).

II. Development of Targeting Methods for TCs

Because of limited aircraft resources, techniques to maximize the positive impact of additional observations on track forecasts are necessary. These techniques generally involve locating regions in the numerical models in which very small differences in the initial conditions would grow most rapidly. Generally, these regions would be represented by Local Lyapunov Vectors; however, current restraints on computer power and the very high dimensionality of the numerical models makes calculating these vectors nearly impossible. A number of approximations to these vectors are currently available. One such technique involves the dominant singular vectors of the integral linear propagator of the non-linear dynamical system . However, the linear propagator for tropical mesoscale phenomena such as TCs is unlikely to be appropriate on the necessary time scale for surveillance missions (4 days). Further, the technique is relatively expensive computationally and requires a norm to measure perturbation growth and a verification region where the growth is to be minimized. In the current case, targeting is conducted to improve TC track forecasts, so no verification region is readily available. Other adjoint-based techniques suffer similar drawbacks.

Another technique involves bred vectors (Toth and Kalnay 1993). To start a breeding cycle, random perturbations are introduced to initial conditions and are repeatedly evolved and rescaled using the forecast model. Growing (decaying) perturbations amplify (decay), by definition, so that only the growing modes remain after a few cycles. Since forecast fields are the first-guess for subsequent data assimilation cycles, locations in which bred vectors are large have potentially large initial condition errors that have grown in recent forecast cycles.

III. Operational Surveillance Missions

During the first two years of operational surveillance with the G-IV, observations were taken in a regularly-spaced grid in the environments of TCs. Aberson (2003) showed that, during the first two years of surveillance, sampling of regions of large bred vectors with a regularly-spaced grid provides significantly larger improvements to numerical TC track forecasts than the previous technique. Most importantly, sampling in regions in which the initial condition errors are shown to be large, but in which bred vectors are small, is shown to have little, or even negative, impact on subsequent forecasts. Further, sampling of regions in which initial condition errors are small, but in which bred vectors are large, has large positive impact on model forecasts. As a result, since 1999, bred vectors have been targeted during operational surveillance missions, and the resultant impacts are shown in Fig. 1. The improvements have been increasing annually as the sampling technique has been refined and are approaching the values seen in Burpee et al. (1996).

IV. Impact on the Synoptic Scale

The surveillance data will not only impact the TC track forecasts in the numerical guidance, but also may modify forecasts both downstream and upstream of the actual observations. For example, Fig. 2 shows the impact of dropwindsondes released around Hurricane Isabel at 0000 UTC 15 September 2003, 24 h into the forecast. Not only is a large impact seen around Isabel itself, but the midlatitude trough along the U. S. East Coast has amplified in the model solely due to the dropwindsonde data around Isabel. Such impacts are common, and were also important in the forecasts of the major winter storm that

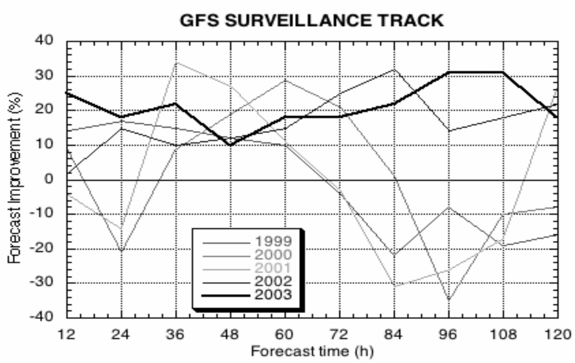

Figure 1. Annual percentage improvements to Global Forecasting System TC track forecasts due to targeted surveillance missions.

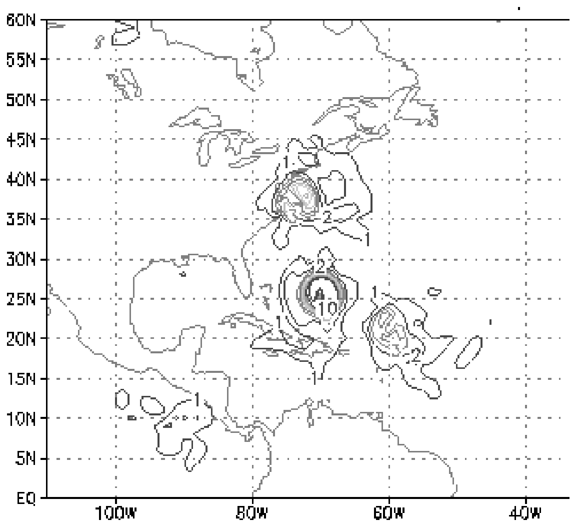

Figure 2. Impact of dropwindsonde data on GFS 24-h deep-layer-mean wind forecast from the Hurricane Isabel mission centered at 0000 UTC 15 September 2003. Hurricane Isabel was located near 25N 70W.

affected the U. S. East Coast as Tropical Storm Odette moved through the Caribbean in December, 2003.

V. The Future

The success of the G-IV surveillance program has led the Central Weather Bureau of Taiwan and the National Taiwan University to begin surveillance missions for TCs that may impact Taiwan. Two such targeting missions were conducted during the summer of 2003, and results will be reported elsewhere at the current Conference.

The current technique is subjective in that it relies on drawing flight tracks to target regions of large bred vectors near the TC. An effort to develop an objective technique for TC targeting is ongoing. The Ensemble Transform Kalman Filter (Bishop et al. 2001) utilizes information from any number of well-constructed ensemble forecasting systems to identify target regions. This method has been used during winter storms targeting since 1997 and became operational in 1999. Linear combinations of perturbations predict the forecast error variance reduction due to observations in particular areas; those areas in which the error variance reduction is greatest are to be sampled. The ETKF can identify targets given the location and error statistics of other observations allowing for recalculation of the predicted forecast error variance reduction for new observational networks. This serial targeting mimics an entire aircraft flight, or multiple flights, or a sequence of flights. For TC targeting, track differences at the projected landfall time can be traced to the targeting time with the aid of ensemble forecasts. The ETKF is also a data assimilation technique that has shown promise in TC track forecasting in a barotropic model (Aberson and Etherton 2004).

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