THE IMPACT OF SATELLITE-DERIVED WINDS ON GFDL HURRICANE MODEL FORECASTS

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ABSTRACT

A series of experimental forecasts are performed to evaluate the impact of satellite-derived winds on numerical hurricane track predictions using the GFDL model. Over 100 cases are examined from 10 different storms covering 3 seasons (1996-1998), enabling us to account for the large case-to-case variability in the forecast results when assessing the wind impact. On average, assimilation of the GOES winds reduces track error at all forecast periods. The relative reductions in track error range from ~5% at 12 hours to in excess of 12% at 36 hours. Statistically significant reductions in track error are noted for the 24, 36, and 72 hour forecast periods. A composite analysis of the initial flow fields suggests that the reduction in track error may be associated with the ability of the GOES winds to more accurately depict the strength of vorticity gyres in the environmental flow.

1. Introduction

Numerical prediction of hurricane forecasts require accurate representation of the current meteorological conditions. Unfortunately, conventional measurements used to initialize forecast models are unavailable for vast areas of the tropical oceans. The sparsity of observations, both near the storm center and in the surrounding environment, is a key factor in limiting the accuracy of hurricane forecasts. Satellite winds from geostationary satellites offer a valuable supplement to conventional observations by providing measurements in these data sparse regions. This study seeks to determine the extent to which GFDL model forecasts can benefit from the direct assimilation of GOES winds. For this purpose, a series of over 100 parallel forecasts were performed spanning 10 storms and 3 Atlantic hurricane seasons (1996-1998).

2. Forecast Model: The GFDL Hurricane Prediction System

The dynamical model used in the hurricane prediction system is an outgrowth of a research model developed at GFDL and adopted by the National Weather Service as an operational hurricane forecast model in 1995. The prediction system uses a limited area, baroclinic model which solves the primitive equations using a finite-difference method in spherical coordinates with 18 sigma levels. To resolve the interior structure of a hurricane, a multiply-nested grid system is used consisting of two inner movable meshes ($1/6^{o}$ and $1/3^{o}$ resolution) nested within a coarser 75^{o}x75^{o} outer mesh (1^{o} resolution). The initial and lateral boundary conditions are defined by the NCEP global analysis. A 3-dimensional optimum interpolation (3DOI) scheme was developed to assimilate the GOES winds directly into the GFDL model.

3. Impact of GOES Winds on GFDL Track Forecasts

This section compares model forecasts integrated from two sets of experiments - a control run (CTRL) and an experimental run which includes the GOES winds (WIND). A set of 103 cases are examined for different 10 Atlantic storms spanning 3 seasons. For each case, 72 hour forecasts are performed. On average the assimilation of satellite winds improved forecasts for all verification times, with the reduction in track error ranging form 4% at 12 hr to 12% at 36 hr, with statistically significant reductions (95% confidence level) at 24, 36 and 72 hr (Figure 1). With the exception of the 12 hr forecasts, the inclusion of the satellite winds typically improved 60% of the cases.

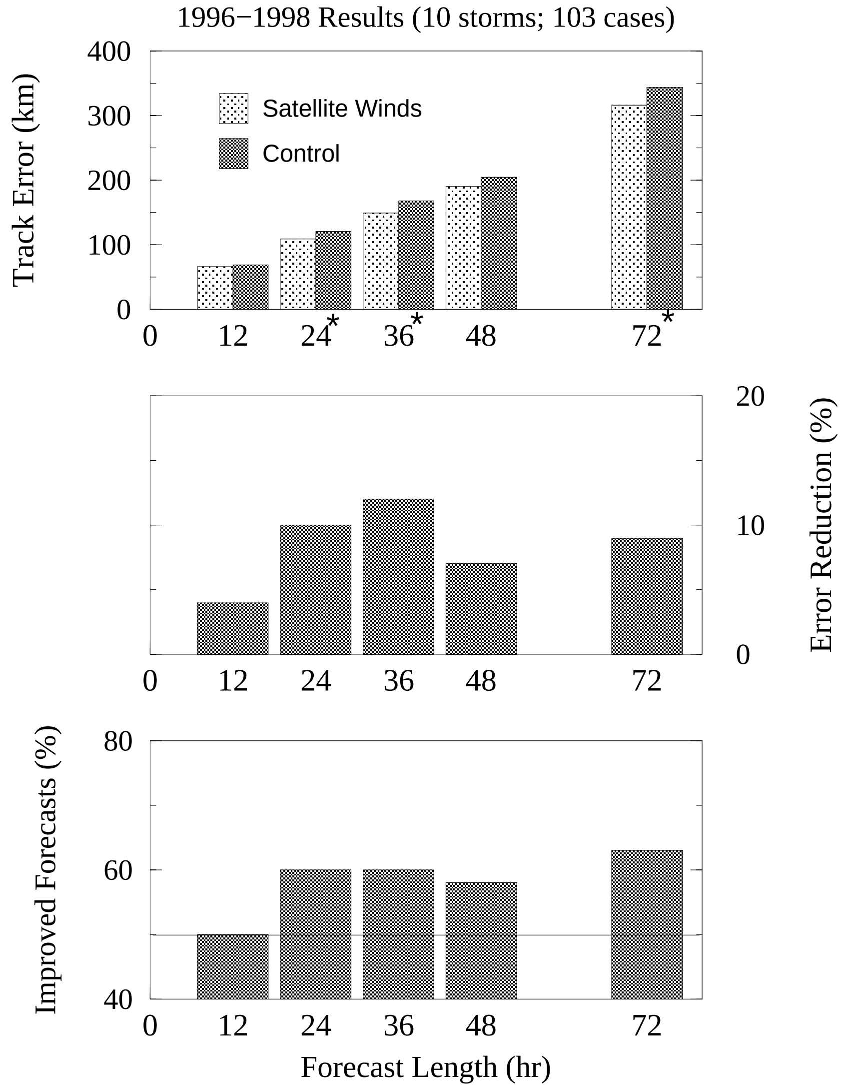

Figure 1. Summary of track errors. The mean track error (top), the percentage reduction in track error (middle), and the percentage of improved forecasts (bottom) due the assimilation of GOES winds. The reduction in track error are statistically significant at the 95% confidence level for the 24, 36 and 72 hour forecasts. The average error reduction for all forecast lengths (12-72 hr) is also statistically significant at the 95% confidence level.

To determine the impact of the satellite winds on the model flow fields, the initial wind conditions from the CTRL and WIND experiments are compared. Rather than examine the winds at individual model levels, we compute deep-layer-mean (DLM) flow, defined as the vertical pressure-weighted average of the initial condition wind field, for both the CTRL and WIND runs. To highlight the large-scale environmental or “basic” flow patterns, the DLM fields are then low-pass filtered with a wavenumber cutoff of ~1000 km. Since there are over 100 cases, each with widely differing synoptic conditions, it is difficult to analyze each case individually and reach a general conclusion. Instead, we have constructed composites of the mean track forecasts (Figure 2) and the mean DLM flow fields (Figure 3) by using the storm center as the frame of reference.

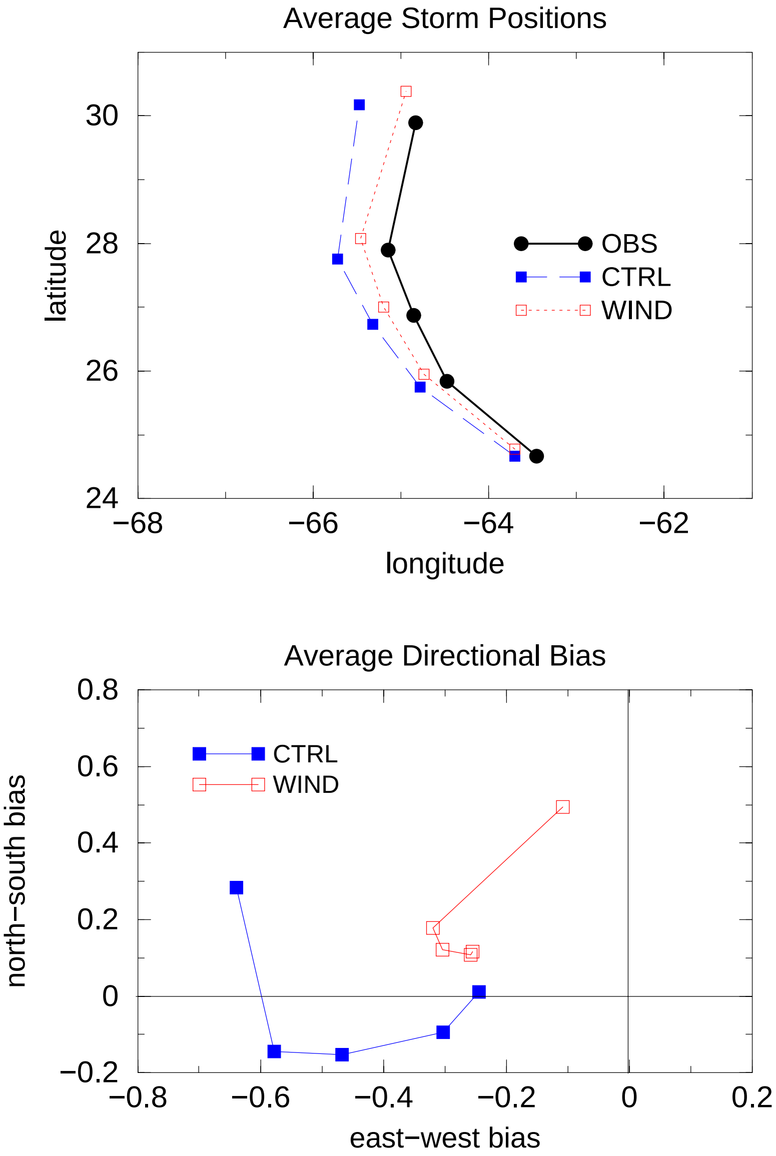

Figure 2. A composite of the mean storm tracks (top) from the observations (filled circle) and the CTRL (filled square) and WIND (open square) experiments. The bias in the CTRL and WIND predicted tracks are presented in the bottom.

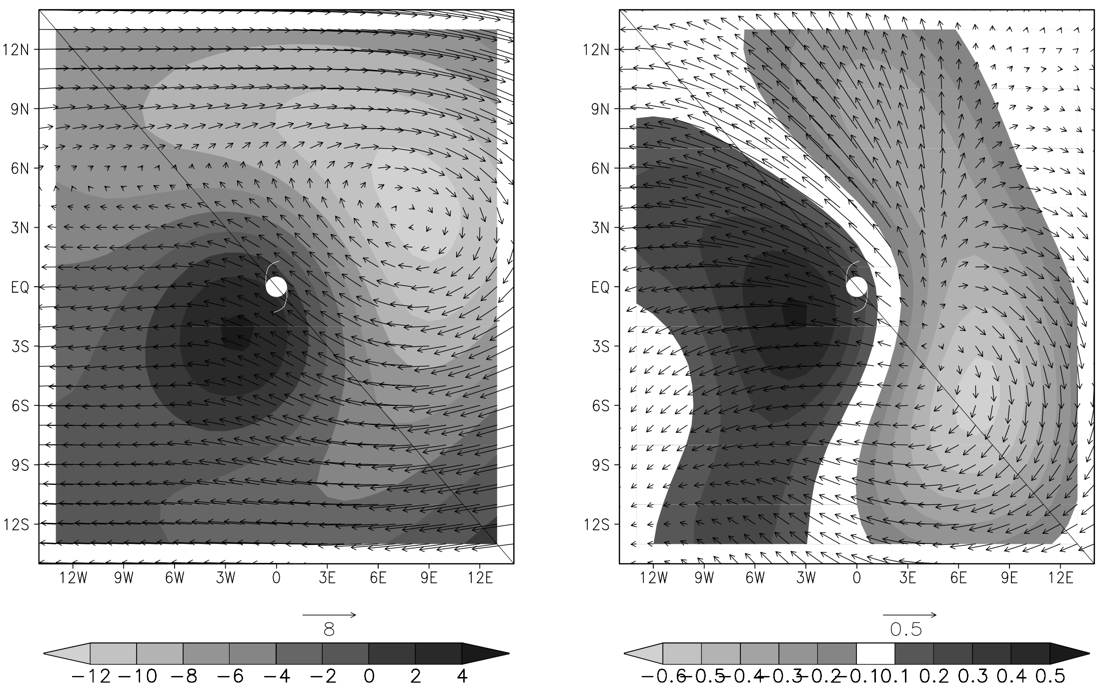

Figure 3. A storm-relative composite of the large-scale steering flow from the CTRL simulations (left) and the difference (WIND - CTRL) due to the assimilation of GOES winds (right) averaged over all 103 cases. Vectors depict the deep layer mean winds (in m/s) and shading depicts the corresponding vorticity field (in 10^6 s^{-1}). The hurricane symbol identifies the center of the storm used as the frame of reference to form the multi-storm composite.

Comparison of the mean forecast tracks for the CTRL and WIND experiments, from all 103 cases (Figure 2, top), provides a convenient summary of the improved performance of the track forecasts following the assimilation of GOES winds. The WIND forecasts clearly exhibit a tighter recurvature which, in turn, results in a marked reduction in the westward bias of the track forecasts (Figure 2, bottom), although at the expense of a modest increase in the northward bias. Since the WIND forecasts tend to move farther north than the CTRL, this would tend to hasten their recurvature (by moving the storms closer to the mid-latitude westerlies) and is consistent with the reduction in westward bias. Also note that the increased meridional bias relative to the CTRL only occurs for the 72 hr forecast, whereas the reduction in zonal bias is evident at all forecast times.

To examine the impact of the GOES data on the initial wind fields, Figure 3 illustrates the time-mean composite of the mean DLM flow from the CRTL runs (left) and the difference in DLM flow field (WIND-CTRL) due to the assimilation of GOES winds (right). In both these figures, the DLM flow is presented as vectors while the vorticity of the DLM vectors is depicted by shading. A key feature in the CTRL DLM field is the presence of a distinct β-gyre as evidenced by the anticyclonic circulation to the northeast and cyclonic circulation to the southwest of the storm center. Moreover, the difference in the vorticity of the DLM flow due to the assimilation of GOES winds also exhibits a distinct dipole structure (Figure 3, right). The DLM flow for the WIND experiments tends to have greater anticyclonic circulation to the northwest of the storm and greater cyclonic circulation to the southeast of the storm, consistent with an enhanced β-gyre. This suggests that, while the initial wind field from NCEP does contain a β-gyre like structure the strength of these gyres are, on average, underpredicted relative to that inferred from the GOES retrievals. This is consistent with the tendency for coarser resolution models (such as that used to provide the CTRL initial conditions) to form a weaker storm circulation and thus undepredict the advection of planetary vorticity. The stronger northward flow associated with the enhanced β-gyre in the WIND experiments agrees qualitatively with the northward displacement of the storm tracks relative to the CTRL (Figure 2), although it does not offer an immediate explanation for the reduction in westward bias.

4. Summary

Recent enhancements in the wind retrieval algorithm and improved satellite instrumentation has provided unprecedented capabilities to observe the atmospheric circulation over the traditionally data-sparse tropical oceans with high spatial and temporal resolution. As shown here, the assimilation of these winds, even in a relatively simplified manner, were able to make a significant contribution to the reduction in track error. Specifically, assimilation of the GOES winds reduced the average track error at all forecast periods with reductions in track error of up to ~40 km and relative reductions in track error ranging from roughly 4-12%. The number of improved forecasts also outweighed the number of degraded forecasts following the assimilation of the satellite winds, especially for the 24, 36, and 72 hour forecast periods where over 60% of the forecasts were improved.

While these results are encouraging, substantial work remains in this area and further improvements appear possible. In particular, the use of improved assimilation techniques, such as 4-D variational analysis, which can utilize the high-time resolution of the satellite data are particularly promising. In addition, more work is needed to better define the nature of the model error covariances which is critical to both 3D and 4D assimilation methods. In the future, we hope to pursue such directions in collaboration with existing efforts both within NOAA and abroad.