P5.8 A RECENT HISTORY OF THE GFDN TROPICAL CYCLONE FORECAST MODEL

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1. INTRODUCTION

A Fleet Numerical Meteorology and Oceanography Center (FNMOC) implementation of the Geophysical Fluid Dynamics Laboratory (GFDL) hurricane model (GFDN) has provided operational guidance since 1996 for tropical cyclones in all basins, including the Indian Ocean and Southern Hemisphere (Rennick 1998). This makes GFDN the only relocateable tropical cyclone model running in all tropical oceanic basins worldwide. The GFDL is a triply-nested moving mesh model that uses the National Centers for Environmental Prediction (NCEP), Global Forecast System (GFS) as its parent model, from which it derives it's boundary conditions. By contrast, GFDN is currently configured as a doubly nested moving mesh model that uses boundary conditions from the Navy Operational Global Atmospheric Prediction System (NOGAPS) model (Rosmond, et al. 2002). This paper will describe the recent history and background of GFDN, including model upgrades and performance trend.

2. BACKGROUND

Preceding 1996, the Navy relied upon climatological, statistical, or simple dynamical models for forecasting tropical cyclone track and intensity effecting naval activities (Rennick, 1998). The FNMOC has traditionally provided the Joint Typhoon Warning Center (JTWC) forecasters with numerical guidance products for their forecasts. In order to better serve Navy operations in the western North Pacific and world-wide, FNMOC operationally implemented a navy version of the GFDL model, GFDN. At inception, GFDN was almost identical to that which ran operationally at NCEP. In some subsequent seasons, GFDN lagged GFDL's operational version by one season with respect to upgrades (more on this in section 3). This is a result of timing, as operational upgrades from GFDL generally occur in the spring, shortly before the tropical cyclone season, leaving little time for setup and testing at FNMOC. Another difference between GFDL and GFDN has been the implementation of ocean coupling in GFDL since 2001. For the 2001 to 2005 seasons GFDL has had ocean-atmospheric coupling while GFDN has not.

The GFDN began operations as a triply-nested model that included computational nests with resolutions of 1°, 1/3°, and 1/6°. Convective adjustments, surface fluxes, second-order turbulence, infrared and solar radiation, and parameterization of surface features by vegetation type are the major features incorporated in GFDN (Rennick, 1998). The GFDN is initialized from the global, NOGAPS, analysis and an initialization message, specifying the observed structure of the cyclone. The tropical cyclone component is removed from the global analysis, and replaced by a synthetic vortex, generated by an axi-symmetric version of the forecast model constrained by the structure indicated by the initialization (bogus) message (Rennick, 1998). This bogus message information is most commonly pulled in from either JTWC or the National Hurricane Center (NHC). An asymmetric component is also added to the synthetic vortex (Kurihara et al. 1993 ; Kurihara et al. 1995). Boundary conditions are updated periodically from the forecast fields generated by NOGAPS.

The JTWC is a primary recipient of FNMOC Numerical Model output. As such, the strategy for running GFDN is tied to JTWC operations. When at least one tropical cyclone is active within the JTWC area of responsibility (AOR), they issue a tropical cyclone bogus message (TCBOG). This message, issued for the hours 0000, 0600, 1200, and 1800 UTC, when conditions warrant, lists active tropical cyclones in their AOR. Storms are ordered according to JTWC operational priorities. Among other things, the TCBOG contains location and pressure of storm center, direction of storm movement, speed of maximum wind, radius, and pressure of the last closed isobar (Rennick, 1998).

3. RECENT HISTORY OF UPDATES

3.1 2005 UPDATES

Among the updates to GFDN for 2005 is a new mass initialization, whereby mass initialization is removed from the tropical cyclone model and run from the mass field of the global model. Testing with GFDL has shown this to reduce forecast track errors. There is also change to moist physics, whereby evaporation of falling precipitation is considered in the large-scale package. Finally, the first major axi-symmetric upgrade effective in GFDL for the 2004 tropical cyclone season, was adopted in GFDN for the 2005 season (Bender et al. 2005). This upgrade would simulate a more realistic representation of the vortex spin-up.

Specific to FNMOC, a new storm sorting routine was added to GFDN in mid-season (August 2005). This routine allows more flexibility in prioritization of basins and in the number of storms that may be run. The storm sorter prioritization is unlikely to be modified, except in rare situations where computational resources are stretched.

Starting November 2005, GFDN start times were delayed by approximately 15 minutes to allow the NOGAPS preliminary runs to complete their 120-hr cycle. The reason for this change was to prevent a possible discontinuity in the NOGAPS forecast boundary conditions between the last preliminary forecast time and the next available operational forecast time from potentially degrading the GFDN forecast. Previously, the NOGAPS preliminary runs ended at 72 hours, after which GFDN would use the previous real or off-time NOGAPS forecasts, to the extent available, for boundary conditions. There is no evidence that the 6-hour old NOGAPS forecasts used for boundary conditions following the 72 hours of NOGAPS preliminary boundary conditions degraded GFDN forecasts.

3.2 2004 UPDATES

In July 2004, the GFDN forecast cycle was extended to 126 hours from 84 hours. A month later, starting August 2004, GFDN was run four times per day, up from the two cycles per day dating back to GFDN's inception in 1996. Previous to August 2004, GFDN would run off of the NOGAPS 0600 and 1800 UTC preliminary off-time and previous real-time forecast cycles.

3.3 2003 UPDATES

Updates for the 2003 tropical cyclone season included a new convective parameterization scheme, whereby a simplified version of the Arakawa-Schubert scheme and a non-local diffusion scheme replace the cumulus parameterization and Mellor-Yamada boundary-layer formulation. In short, this change allows vertical mixing into the boundary-layer controlling the amount of downdraft allowed into the boundary-layer and the amount of cumulus momentum mixing. In addition, a new mass initialization was developed (Bender, et al., 2003).

3.4 2002 UPDATES

Changes made operational for GFDL for the 2002 season, except those pertaining to atmosphere-ocean coupling, were implemented into operations for GFDN in the 2002 tropical cyclone season. Updates included a change back to 2 nests from the previous triple nest arrangement. This involved a doubling of the resolution of nest 1 and an expansion of nest 2, the region of finest (1/6°) resolution. This nesting change is maintained through 2005 for GFDN.

3.5 2001 UPDATES

As discussed in Section 2, GFDL diverged from GFDN for the 2001 season with the introduction of the atmosphere-ocean coupling.

Other changes included an equation for the prediction of turbulent kinetic energy being added to the diffusion parameterization. Tests indicated that this results in a substantially more accurate vertical profile of wind speed in the boundary layer and a much-improved vertical profile of wind speed in the boundary-layer for a more representative pressure-wind relationship. Changes were also incorporated into the initialization of the model's specified vortex (Kurihara, et al. 1993), which has led to an initial storm intensity that more closely matches the observed value. The vertical diffusion parameter was upgraded to a level 2.5 Mellor-Yamada turbulent closure scheme. Near the region of maximum winds this scheme enhances the transfer of momentum from above, leading to a more vertically mixed hurricane boundary-layer with higher surface winds. Together, these changes lead to a much improved pressure-wind relationship and improved wind forecasts (Bender, et al., 2001).

4. RECENT PERFORMANCE TREND

The following paragraphs summarize the performance trend of GFDN in the North Atlantic, Eastern North Pacific, and Western North Pacific since 2001. In Figures 1,2, and 3, the histogram bars correspond to the model error in nautical miles (nm), for each year, for the respective basin. Model error (ME) represents the great circle distance between the model forecast position and the actual best-track position. All verifiable forecasts are included in the statistical analysis, regardless of the initial or verifying strength of the tropical cyclone. The left y-axis is the scale for ME. The right y-axis shows the percent skill (%) against climatology and persistence (CLIPER), which represents the models performance compared to climatology. The larger the negative number, the higher the skill. To illustrate this in the following equation CLIPER error is defined as (CE).

Skill = [(ME – CE) / (CE)] * 100%

As can be seen in Figure 1, 2005 was the first season with a complete dataset of forecasts through 120 hours. The partial set of 120-hour forecasts for 2004 was omitted from this comparison, since only half the tropical cyclone season's 120-hour forecasts are available. Based on the short-term performance history presented in Figure 1, it is difficult to conclude that there is any performance trend. This is especially true since the year-to-year variability of tropical cyclones and the skill required to forecast them varies dramatically. That said, the general slope of track error in the North Atlantic at 24, 48, and 72 hours (Figure 1) is towards reduced errors over the 5-year sample.

The eastern North Pacific (Figure 2) graphic has historically been a region where tropical cyclone forecasts have shown generally less skill than the other two regions. And that is well reflected in the annual spread for the 24 to 72-hour forecast times of both the model track errors and skill. The 2003 season has an anomalous model skill trendline. This is likely due to a combination of factors including a smaller sample of verifiable GFDN forecasts and a few tropical cyclones that were particularly difficult to forecast. Most encouraging is the fact that the last three seasons of model error are markedly better than the first two seasons. Further, the skill scores of 2004 and 2005 are much better than the previous seasons, with model skill relative to CLIPER increasing with increasing forecast time. Results from only five seasons must be interpreted with caution, especially considering the great season-to-season volatility in number of tropical cyclones and skill required to forecast those cyclones.

The performance trend in the western North Pacific (Figure 3) is encouraging, especially at 72 hours, when 2005 track errors are smallest of the 5 seasons. The same is true of the 48-hour forecasts, though the 2003 season errors are so far above the rest of the seasons that it would be difficult to justify a trend towards reduced track errors over time. The 2005 season still has the smallest track errors of the sample when considering the aggregate 24, 48, and 72 hour forecast times. In summary, higher skill scores and lower forecast track errors in the most recent tropical cyclone season, when compared with the earlier years, is likely indicative of continued progress with improvements to the GFDN model.

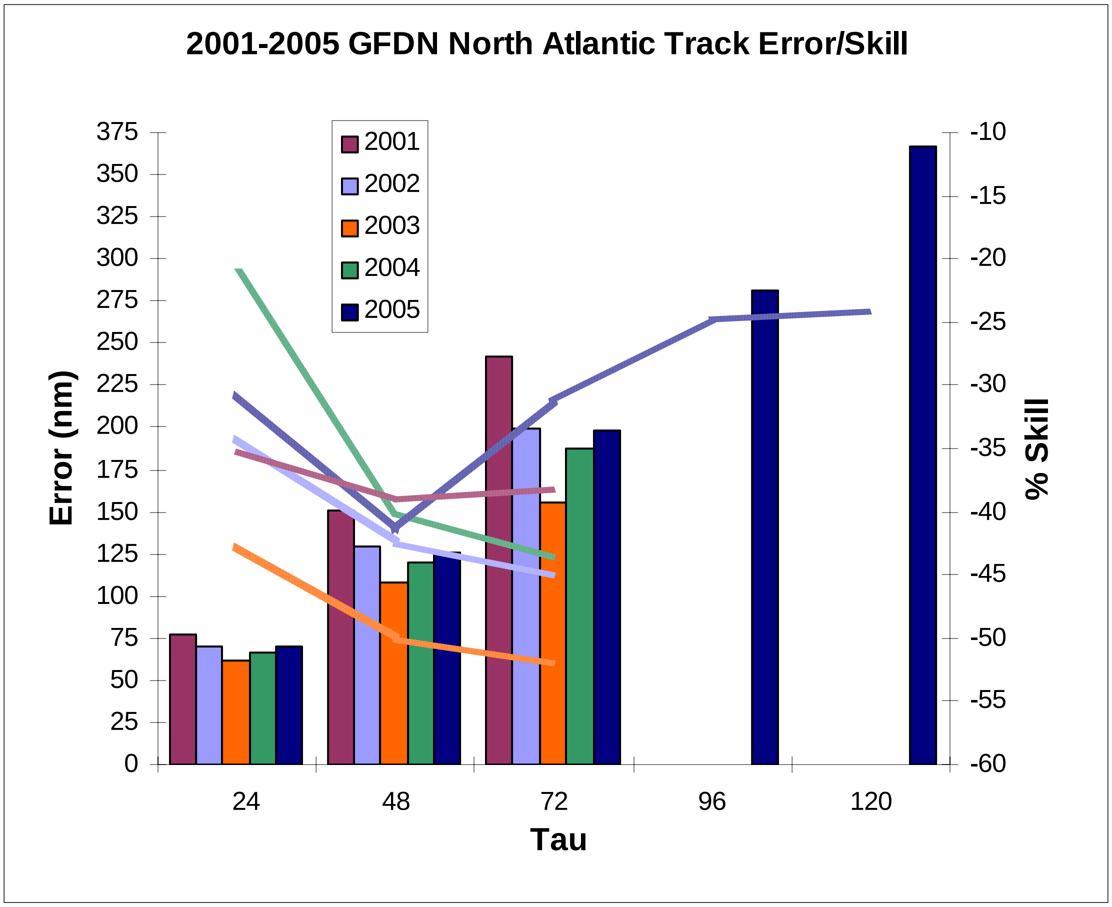

Figure 1. Model forecast track error histogram bars (left y-axis), and the model skill trendlines (right y-axis, %), both as a function of forecast time (hours), for the western North Atlantic basin. Smaller forecast track errors and larger negative skill scores equate to greater model skill.

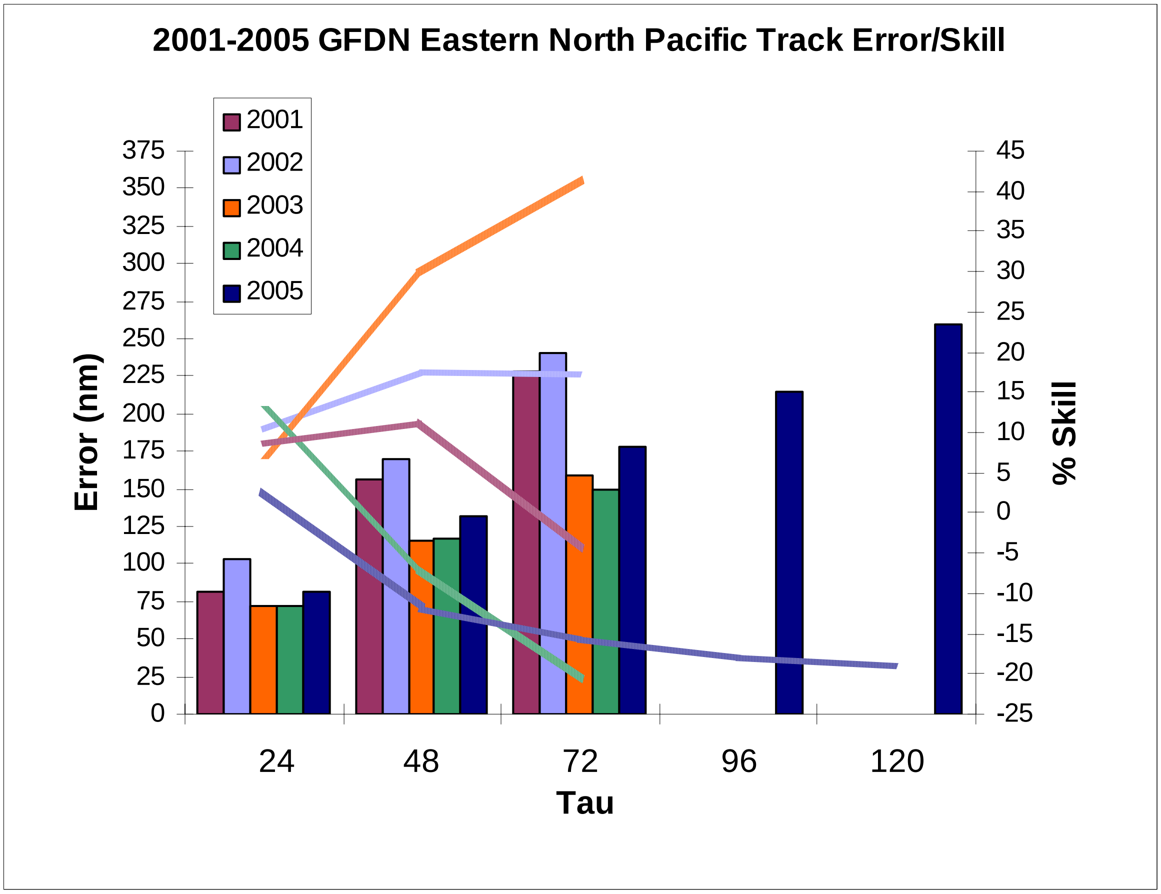

Figure 2. Model forecast track error histogram bars (left y-axis) and the model skill trendlines (right y-axis, %), both as a function of forecast time (hours), for the eastern North Pacific basin. Smaller forecast track errors and larger negative skill scores equate to greater model skill.

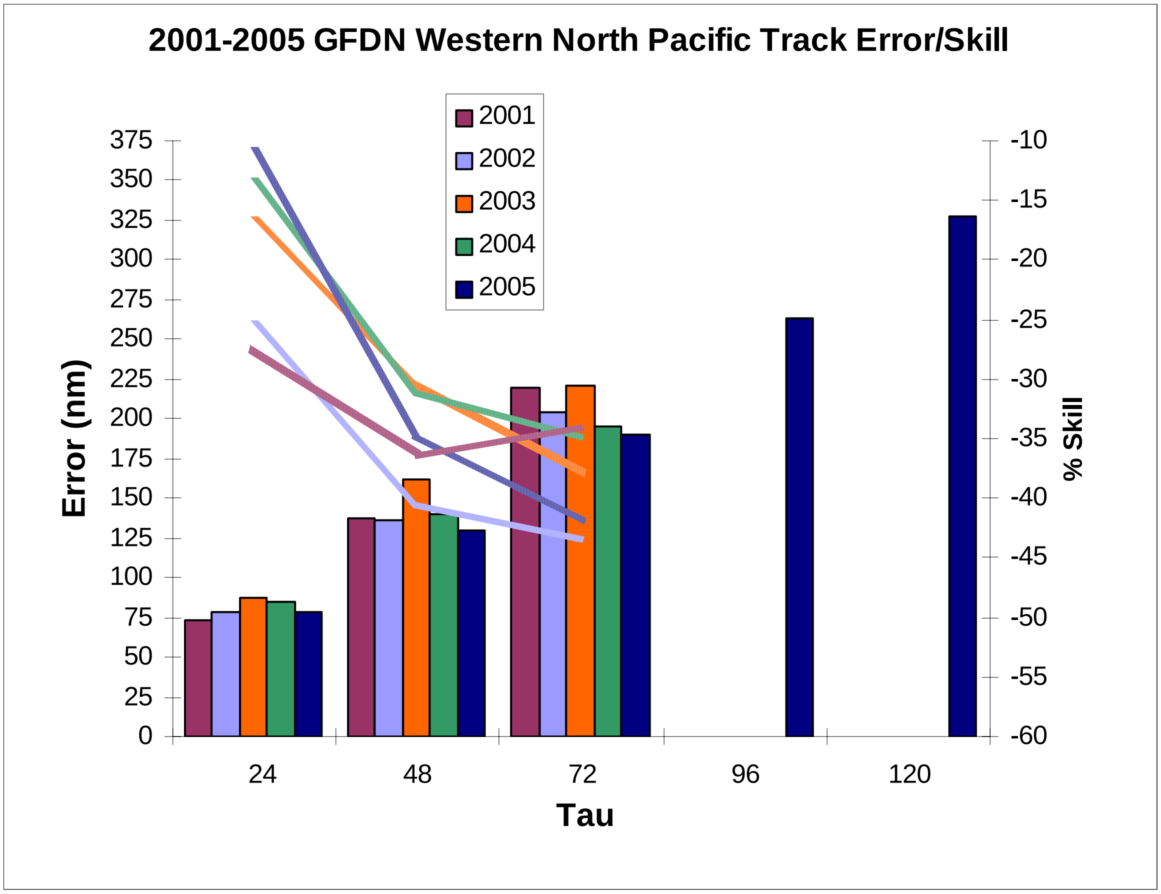

Figure 3. Model forecast track error histogram bars (left y-axis) and the model skill trendlines (right y-axis, %), both as a function of forecast time (hours), for the western North Pacific basin. Smaller forecast track errors and larger negative skill scores equate to greater model skill.

5. SUMMARY AND OUTLOOK

In the last five years GFDN has undergone a number of improvements including upgraded model initialization, better boundary-layer representation, and refinements to the convective parameterization and vortex spin-up process. These upgrades have likely been reflected by the overall improvement in forecast performance over the last five years. In addition, GFDN has seen an expansion of forecast length from 84 to 126 hours and an increase in coverage from two to four forecast cycles per day.

There are a number of proposed updates for 2006, that if implemented, should boost the performance of GFDN. These upgrades include a return to a third inner-nest with 1/12° resolution, while the second nest (1/6°) takes the same resolution as the inner-nest was the last few seasons. Other upgrades include changes to the microphysics package with both the Lin and Ferrier packages being added to GFDN (Lin, et al. 2004). The axi-symmetric model is upgraded with the identical physics GFDL used in their three-dimensional model to improve the vortex initialization package. For GFDL these combined changes show a substantial reduction in the track error (~10% at 3-5 days) on selected storms from the previous 2 tropical cyclone seasons (Bender,. 2005). Finally, FNMOC plans to make a major update to GFDN by coupling the model with the Princeton Ocean model such that GFDN will operate in similar form to GFDL. The timing of this implementation will depend on development, testing, and resource requirements.

6. ACKNOWLEDGEMENTS

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