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Subject: CHANGES TO THE GFDL HURRICANE FORECAST SYSTEM FOR 2002 INCLUDING IMPLEMENTATION OF THE 2 NESTED GRID CONFIGURATION

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ABSTRACT:

This Technical Procedures Bulletin was written by Morris Bender, Timothy P. Marchok , and Robert E. Tuleya and describes the changes to the GFDL Hurricane Forecast System for 2002. The changes include implementation of a double nested grid configuration in which the region covered by 1/6 degree resolution was increased from a 5 degree domain to 11 degrees which corresponds to the region previously covered by 1/3 degree resolution and a change in the way the AVN model vortex is dampened and the GFDL model vortex is spun up. These changes resulted in significant decrease in track error in both the Atlantic and East Pacific forecasts. The largest improvements were in the 36-72 hr forecast periods where the track error was reduced about 16%.

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CHANGES TO THE GFDL HURRICANE FORECAST SYSTEM FOR 2002

INCLUDING
IMPLEMENTATION OF THE 2 NESTED GRID CONFIGURATION

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1.) Introduction

Since 1995, the GFDL Hurricane Prediction System has provided operational guidance for forecasters at the National Hurricane Center (NHC) in both the Atlantic and East Pacific basins (Kurihara, Tuleya and Bender 1998; hereafter referred to as KTB). In addition, a version of the GFDL model (GFDN) has been used by the Navy to provide operational guidance for storms in most of the other ocean basins as well (Rennick 1999). Although the model has shown great skill in track prediction, the GFDL Hurricane Prediction system has shown rather large intensity biases and limited skill in overall intensity prediction.

During the past several years considerable effort has been made to attempt to improve the model's ability to predict changes in storm intensity. To help reduce the model's tendency to over-intensify tropical cyclones, coupling of the atmospheric model with a high resolution version of the Princeton Ocean Model (POM) was added to the operational version for the 2001 hurricane season (Bender, et. al 2001, hereafter referred to as BGMT) as numerical studies have confirmed the importance of ocean coupling on storm intensity (Bender and Ginis 2000).

In addition, further improvements to the GFDL model have continued to be made. Since August 2001, a new high resolution, two nested version of the model was run in parallel at NCEP (National Centers for Environmental Prediction) for much of the hurricane season in both the Atlantic and East Pacific basins. Preliminary results showed significantly superior track and intensity forecasts. Post season analysis indicated several areas where further improvements could still be made to this new model, particularly in the model initialization. The final version of the forecast system was recently tested for a portion of the 2001 hurricane season which was rerun using the high resolution T254, 64 level AVN which will be operational during the 2002 season. Track errors from these reruns will be presented and compared with other hurricane models that were operational during the 2001 season as well as with the track performance of the new 2002 AVN model itself. Finally, some selected tracks will be shown, as well as the new GFDL model's intensity verification compared to the version of the hurricane model operational last year.

2.) Outline of changes to the GFDL forecast system in 2002

In this section, the changes to the new model are briefly outlined. With the installation of a new generation computer at NCEP , the computer power available for operational forecast models has been significantly increased. As a result, it has now become operationally feasible to run the GFDL model with ½ degree horizontal resolution in the outer nest, which is double the current resolution. This is also comparable to the resolution of the T254 AVN which is scheduled to become operational this summer . This important improvement should enable the model to predict the large scale fields much more accurately. In addition, in the new GFDL grid configuration, the region covered by 1/6 degree resolution was increased from a 5 degree square domain to 11 degrees. This area corresponds to the region previously covered by 1/3 degree resolution. It is anticipated this will lead to better representation of the storm and its interaction with the environment. Both theoretical (Wu and Emanuel 1993; Wu and Emanuel 1995) and numerical studies (Wu and Kurihara 1996) have shown that this interaction can play an important role in storm motion. An example of the new grid configuration is shown in Figure 1 for one case of Hurricane Humberto.

A unique aspect of the GFDL system is an initialization technique that removes the AVN vortex from the global analysis and replaces it with a high resolution, model consistent vortex that is produced by running an axi-symmetric version of the hurricane model. As outlined in KTB and BGMT, two filters are used to remove the original vortex from the AVN analysis. In the first filter, the AVN fields (A) of wind, temperature and surface pressure are partitioned into a large-scale component called the basic field (B) and the deviation field denoted as the disturbance field (D):

$$A = B + D \tag{1}$$

Next, using a second filter, the disturbance field is separated into the hurricane component (H) which will be removed from the analysis and a non-hurricane component (NH) that should be retained. The environmental field is then obtained by combining the non-hurricane component with the basic field over the entire model domain. In the filtering technique it is assumed that the hurricane component (H) that is to be removed is entirely confined within a filter domain (ro) so that the region of the global analysis beyond ro by definition remains unchanged.

However, tests have indicated that in the current operational system, the first filter is partitioning too much of the field into the disturbance component (D). Although part of this component may be added back into the analysis through the non-hurricane disturbance component, important information was sometimes removed within the filter domain which had a negative effect on forecasts, particularly when the steering flows were weak. In the new version of the model, the filtering characteristics have been modified by decreasing the amount of the filtering, to enable more of the smaller scale features of the global analysis to be retained near the storm center. It should be pointed out that the original filter was designed to entirely remove disturbances up to 1000 km, since the hurricane vortices in the earlier, coarser resolution AVN analysis were not well resolved and were sometimes this large. The storms are considerably smaller in the higher resolution AVN but the GFDL filter was not adjusted to take this into account.

With the present filter disturbances of larger wavelengths were also strongly damped (Fig. 2). For example, in the present operational system, only 40% of a 2000 km disturbance in the region of ro was retained in the global analysis (Fig. 2, red line). However with the new filter (Fig. 2, black line), about 65% of a 2000 km disturbances will now be retained. To ensure that the global vortex is still properly removed, the filter strength is increased at the lower levels (e.g., below 700 hPa) as a function of storm size and storm strength, The blue dashed-dotted line indicates the maximum damping that can occur in the lowest 150 hPa, for the deepest and largest storms (e.g., initial minimum surface pressure lower than 971 hPa or average storm size greater then 600 km).

In many cases this improved filtering has led to dramatically better track forecasts. Figure 3 shows the large improvements for 2 forecasts of Tropical Storm Barry, which was embedded in a weak steering flow and eventually turned north, landfalling over extreme western Florida. We speculate that recent improvements in the AVN assimilation system have enabled more small-scale features to be correctly represented in the analysis which have contributed to the dramatic improvements in the AVN forecasts, and these features now need to be retained in the GFDL initial condition.

As summarized in KTB, during the next step of the initialization, a model-compatible specified vortex is generated and inserted back on to the environmental field at the correct storm position. The specified vortex is generated from the time integration of an axi-symmetric version of the hurricane prediction model. At the end of the axi-symmetric spin-up, the deviation of the water vapor mixing ratio at each point from the value at the outer storm region is added back onto the environmental moisture field to obtain the final moisture. As discussed in BGMT, it was found that this often led to excessive amounts of humidity in the storm region which contributed to the positive intensity bias during the first 12-24 hours of the forecast. To help remedy this in the version made operational in 2001, the amount of moisture added to the initial condition was made a function of storm intensity and the previous 6 hour intensity change (e.g., equations 4-5 of BGMT). However post season analysis indicated that this correction was too excessive and often lead to humidity values that were too dry near the interior of the storm. To correct this, the constant .5 in equation (5) of BGMT was modified to .65:

$$\text{pbase} = .65 + \text{bint} \qquad (2)$$

The extent of the filter domain (ro) is computed at 24 radial points surrounding the AVN vortex, determined by testing the radial profiles of the tangential component of the disturbance wind from the vortex center outward. The algorithms were tuned to minimize the extent of the analysis that needed to be modified, while guaranteeing that the global vortex was properly removed. However, post-season analysis indicated that these algorithms needed to be adjusted since in a number of forecasts part of the global vortex was retained causing distortion in the wind field. This negatively impacted a number of forecasts during the 2001 season. It is speculated that this problem may have arisen due to changes in the AVN vortex since implementation of its vortex relocation package (Liu et al., 2000). In the adjusted algorithms, a size of 200 km was set for the minimum value of ro in any given radial direction. Also, the algorithms were modified that determined a reasonable value for the radial distance where the search for ro is initiated. (Appendix A of Kurihara et al., 1995).

Finally, the computation of the asymmetric part of the GFDL vortex that is determined from the previous 12h forecast was improved to remove numerical noise in the wind field that arose due to inconsistences in the horizontal interpolations used in interpolating the environmental fields from the coarse resolution to the inner nest. This may have also negatively impacted some forecasts.

3.) Summary of Results

The test period in which the high resolution T254, 64 level AVN model was rerun began on 1200 UTC 27 August and ended on 0000 UTC 8 October, 2001. The AVN forecast fields were available every 12 hours. Forecasts were made using the new GFDL model for all storms in the East Pacific and Atlantic basins of tropical storm force or greater, as well as for several forecasts just before the storms were upgraded to tropical storm status. In addition, AVN fields were available for Hurricane Michelle for the 0z synoptic time. In total, 77 forecasts were made in the Atlantic and 55 forecasts in the East Pacific.

First, comparisons were made between the current operational GFDL model and the new GFDL model for all cases. The track error normalized with respect to CLIPER (Climatology-Persistence) is shown in Figure 4. Reduction in the average track error occurred at all forecast time levels in both the Atlantic and East Pacific. The average improvement at 48 and 72h ranged from 16 and 14% respectively in the Atlantic to 15 and 28% in the East Pacific. Note also that the average number of cases with superior performance in the one to three day forecast period ranged from 65% in the Atlantic to 68% in the East Pacific, with several of the forecast periods showing improvements for over 70% of the forecasts. Fig. 5 indicates the spread of forecast errors in the 48 and 72h forecast period and shows the large number of forecasts which exhibited significant reductions in forecast error with the new GFDL model.

Next, the average track error of the new GFDL model was compared with several of the other track models that were operational during the 2001 season (Fig. 6). The operational GFDL model performed similar to the UKMET global model in the Atlantic while NCEP's AVN global model performed admirably, with over 50% skill relative to CLIPER in the entire 24 to 72h period. It is encouraging that the new GFDL model performance was quite comparable to the last year's AVN in the later time period with the skill relative to CLIPER also exceeding 50% at 72h. On the other hand, in the East Pacific, although the new GFDL was dramaticlly better than the operational GFDL at all time periods, it was still considerably less skillful than the AVN at 72h. This was due to a severe north bias that the operational GFDL model exhibited (e.g., Fig. 7, bottom) near the coast of western Mexico. This bias was significantly reduced with the new model, but still was evident in some of the forecasts. Nevertheless, in many of the cases in the East Pacific, the new GFDL performed the best of all of the available numerical guidance and should be an excellent complement to the AVN model in the upcoming season (e.g., Fig. 7 and Fig. 8). For example, although the early GFDL forecasts of Hurricane Juliette exhibited problems due to the northward bias that turned the storm into the Mexican coast during the first several days, the rest of the forecasts were extremely accurate. While most of the rest of the numerical models including last year's operational GFDL model incorrectly turned the storm away from the Baja the new GFDL model correctly indicated that the storm could impact the extreme southern Baja (Fig. 8).

In the final set of track verifications, a homogenous comparison was made between the new GFDL model and the new AVN (Fig. 9). In the Atlantic, the new AVN performed significantly better then the new GFDL model in the 12-24h forecast period. However, similar to the current operational AVN, in the 48-72h forecast period the performance of the new GFDL and new AVN models was quite comparable. Indeed, at 72h the frequency of superior performance was nearly identical between the two models. In the East Pacific, the two models performed quite similarly during the first 48h with degradation of the GFDL model in the 72h period, again due to the north bias in a number of the forecasts.

Finally, a comparison was made of the intensity predictions between the new and old GFDL models in the Atlantic. One of the most disappointing aspects of the performance of the GFDL model during the 2001 season was that the model did not show skill in the Atlantic in its prediction of intensity despite the operational implementation of the ocean coupling. This may have been due to the unusually high frequency of cases during the 2001 season in which the storms underwent strong vertical shear. The GFDL model's current physics, in particular the convective parameterization, is unable to properly represent the influence of strong vertical shear on the storm intensity. However, it is encouraging that the new GFDL model showed considerable improvement in the intensity prediction compared to the operational model, as indicated in Figure 10. In the 24 through 48h period the model averaged about 10-15% skill relative to SHIFOR, and even outperformed the operational SHIPS model (Statistical Hurricane Intensity Prediction System). At 72h, the intensity forecasts tended to degrade due to the over-intensification of the storms, particularly in the sheared situations. However the model still showed considerable improvement compared to the current operational GFDL model at that time period as well.

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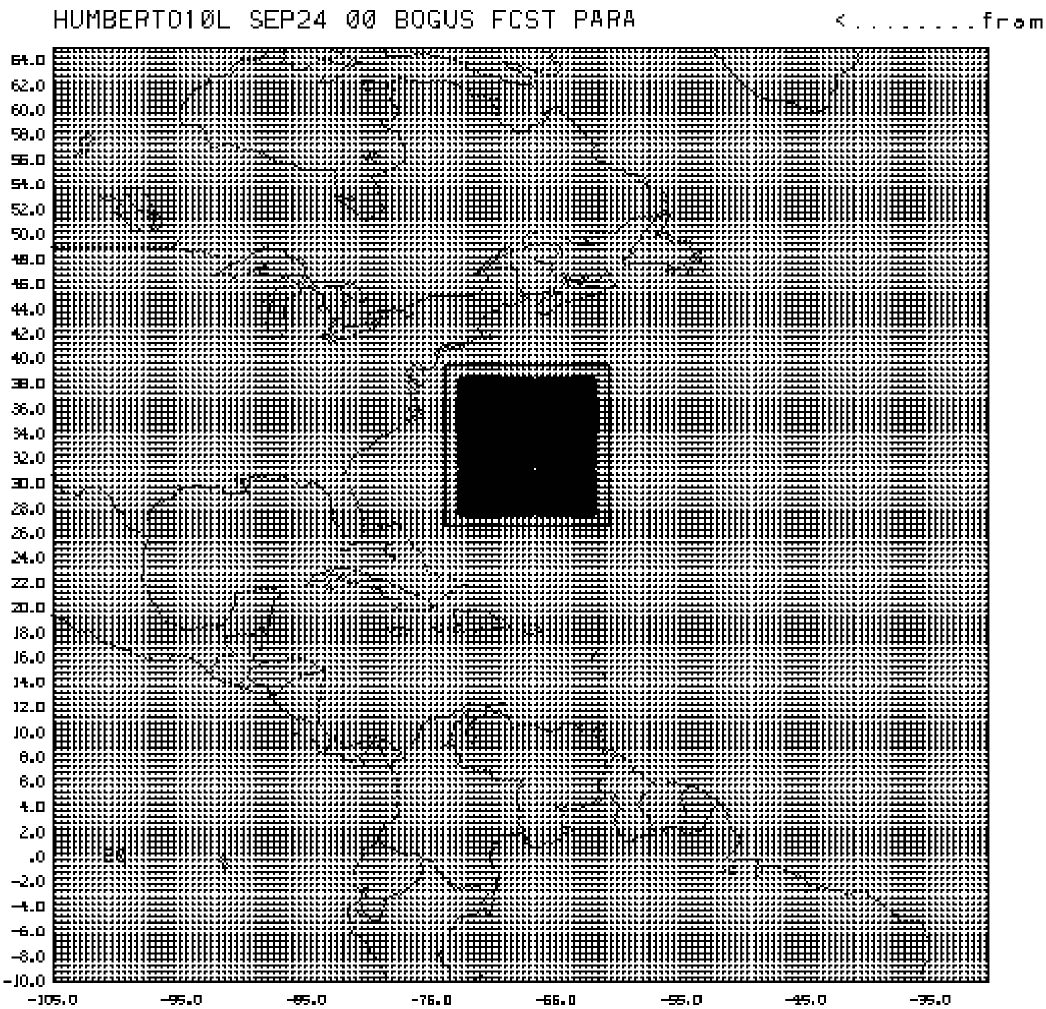

FIGURE 1. An example of the new two nested grid configuration for one case of Hurricane Humberto.

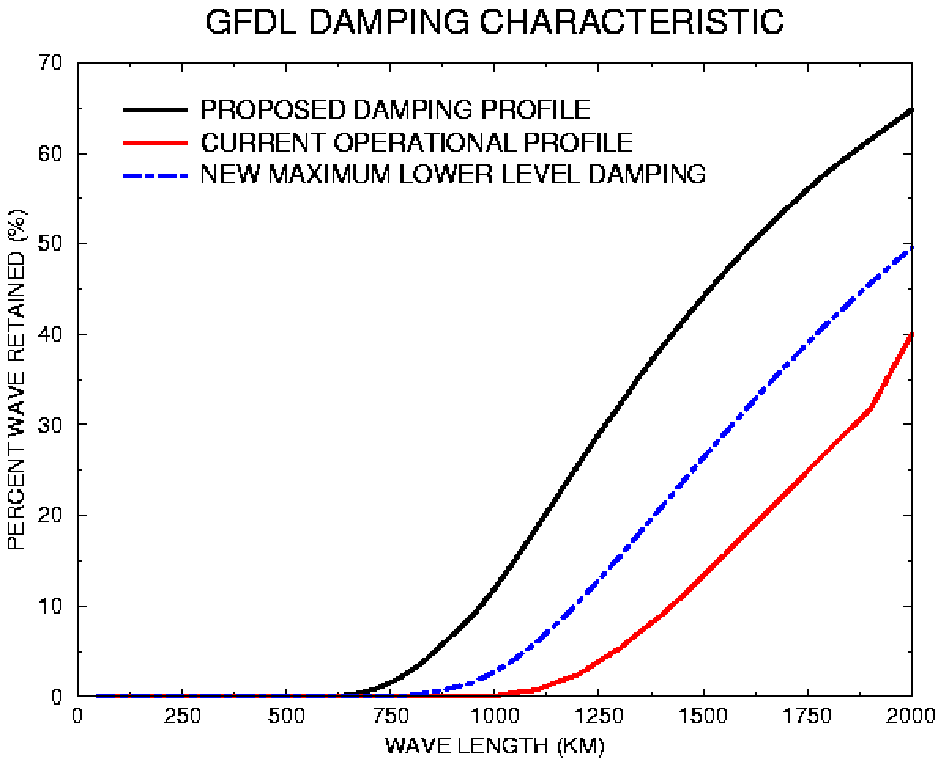

FIGURE 2. Damping characteristics of the current operational profile (red line), the proposed damping profile in the new GFDL model (black line), and the maximum lower level damping in the new model (blue dot-dashed line) which is a function of storm strength size, strength and vertical sigma height. The damping characteristic indicates the percent of the disturbance field retained as a function of the wave length (km) of the disturbance.

TROPICAL STORM BARRY

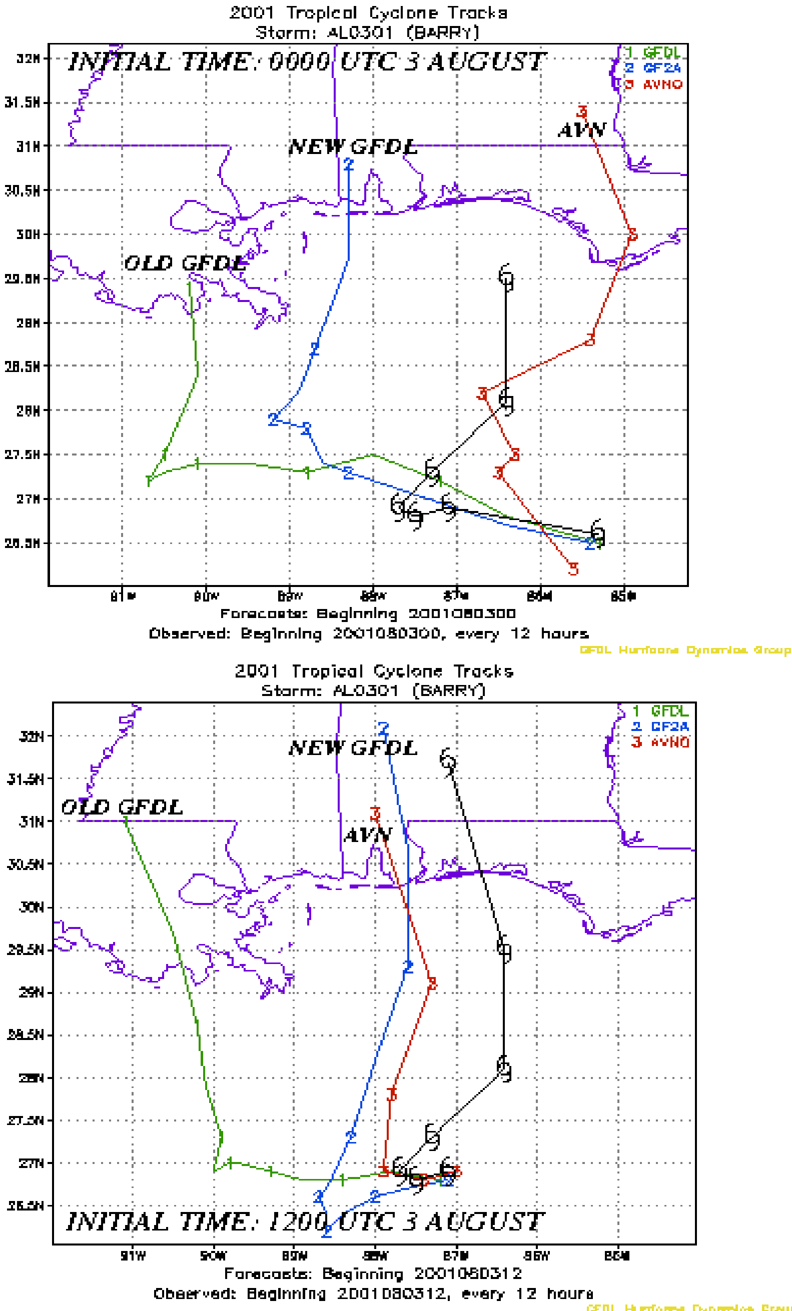

FIGURE 3. Forecasted 72h storm tracks for two cases of Tropical Storm Barry using the 2001 operational GFDL model (green line), the new two nested GFDL model (blue line), and the 2001 operational AVN model (red line). The actual storm track is indicated by the black line with the storm position at 12h intervals indicated by the hurricane symbol. Both GFDL forecasts were made using the 2001 operational AVN model as the boundary condition.

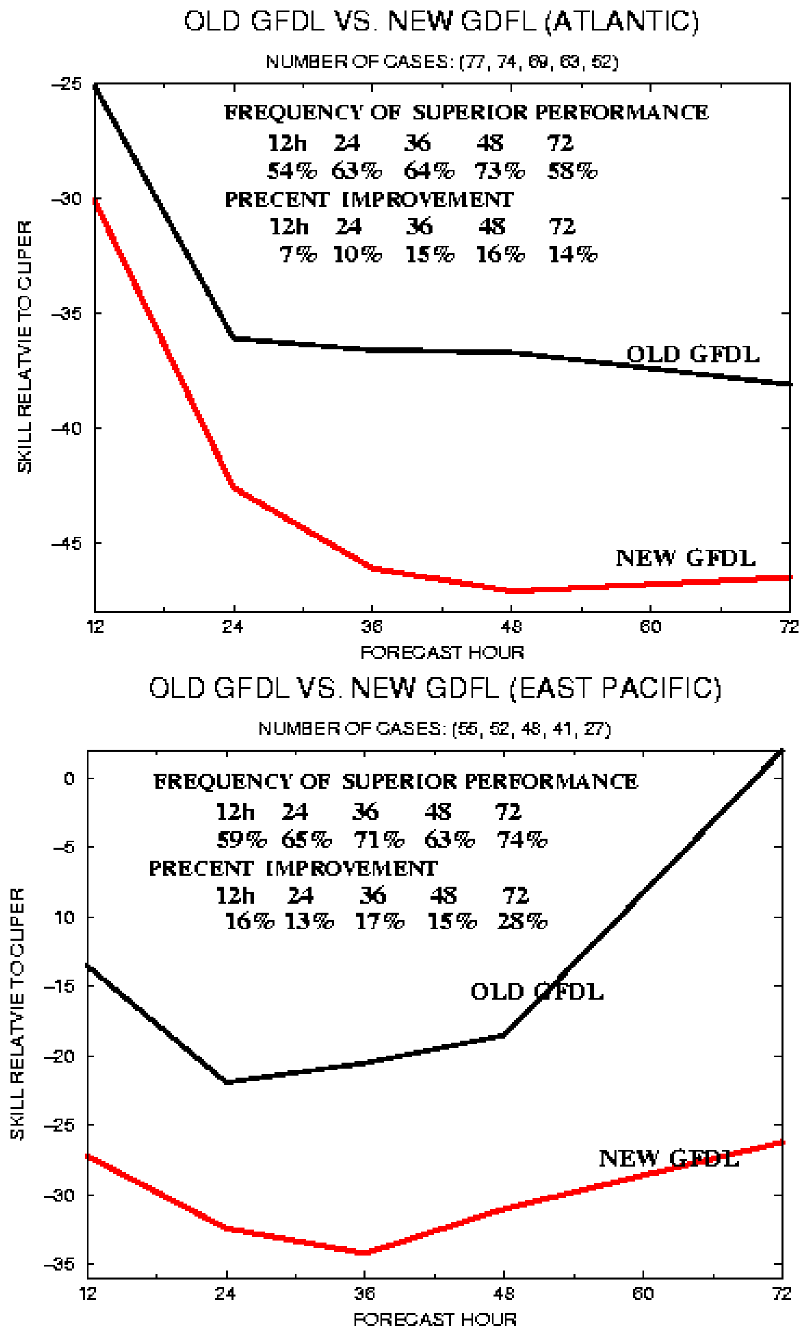

FIGURE 4. Average homogenous track error normalized with respect to CLIPER for all cases run with the new GFDL model using the new T254, 64 level AVN (red line) compared to the 2001 operational model (black line) in the Atlantic (top) and East Pacific (bottom). Frequency of superior performance and the percent of forecasts which were improved with the new model are indicated.

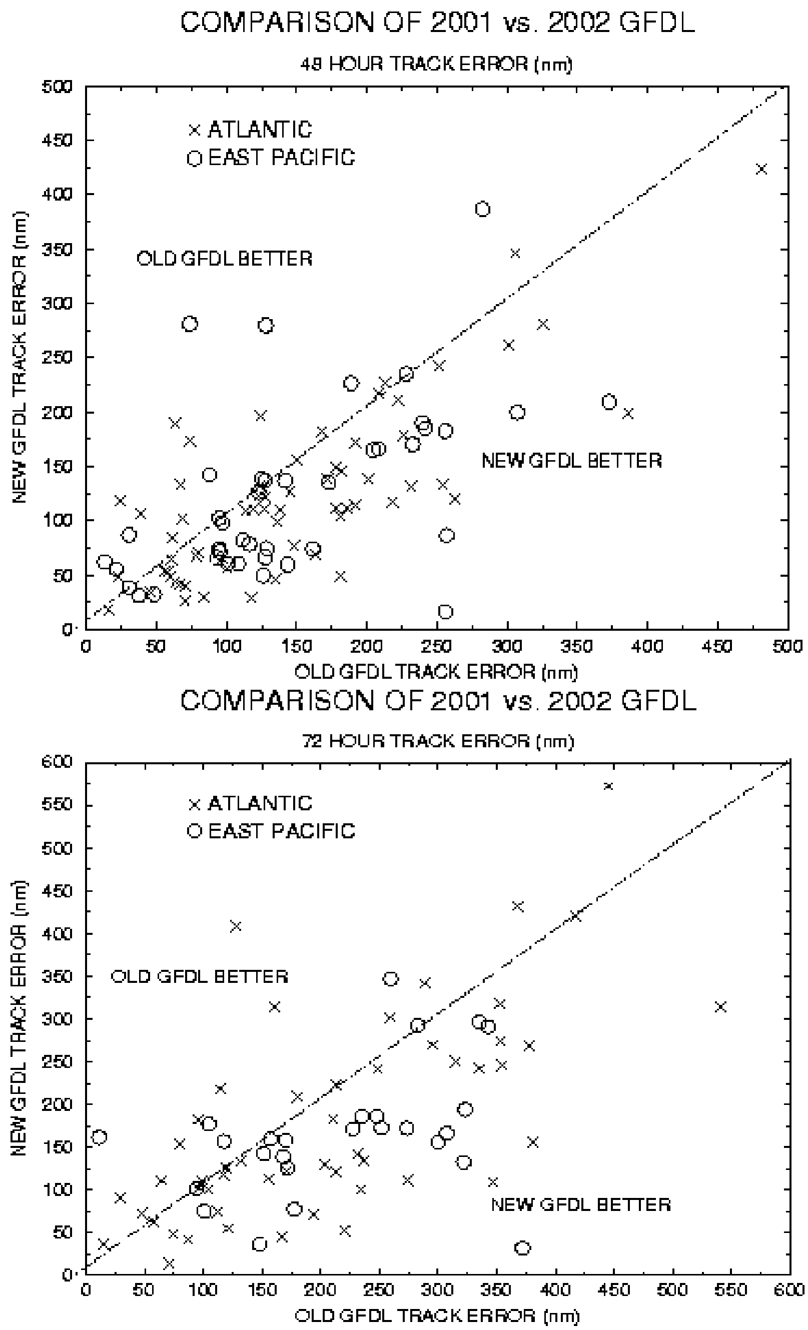

FIGURE 5. Scatter plots for the 48 h (top) and 72h (bottom) track error in nautical miles for all cases in the Atlantic (X) and East Pacific (O), comparing the new and old GFDL models. Those forecasts in which the new GFDL model exhibited smaller track error, are below the dotted line.

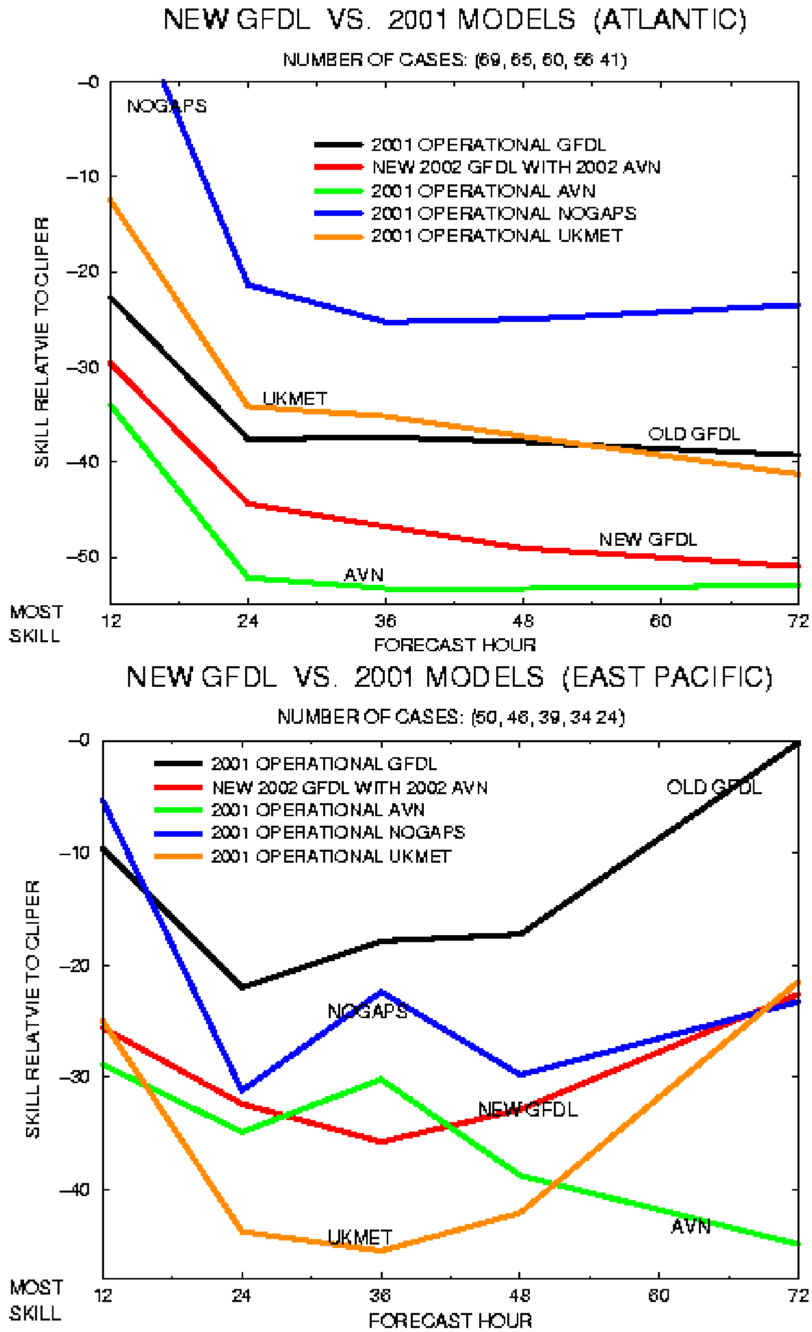

FIGURE 6. Average track error normalized with respect to CLIPER for a homogenous comparison of all cases run with the new GFDL model using the new AVN (red line) compared to the other operational models during the 2001 season in the Atlantic (top) and East Pacific (bottom).

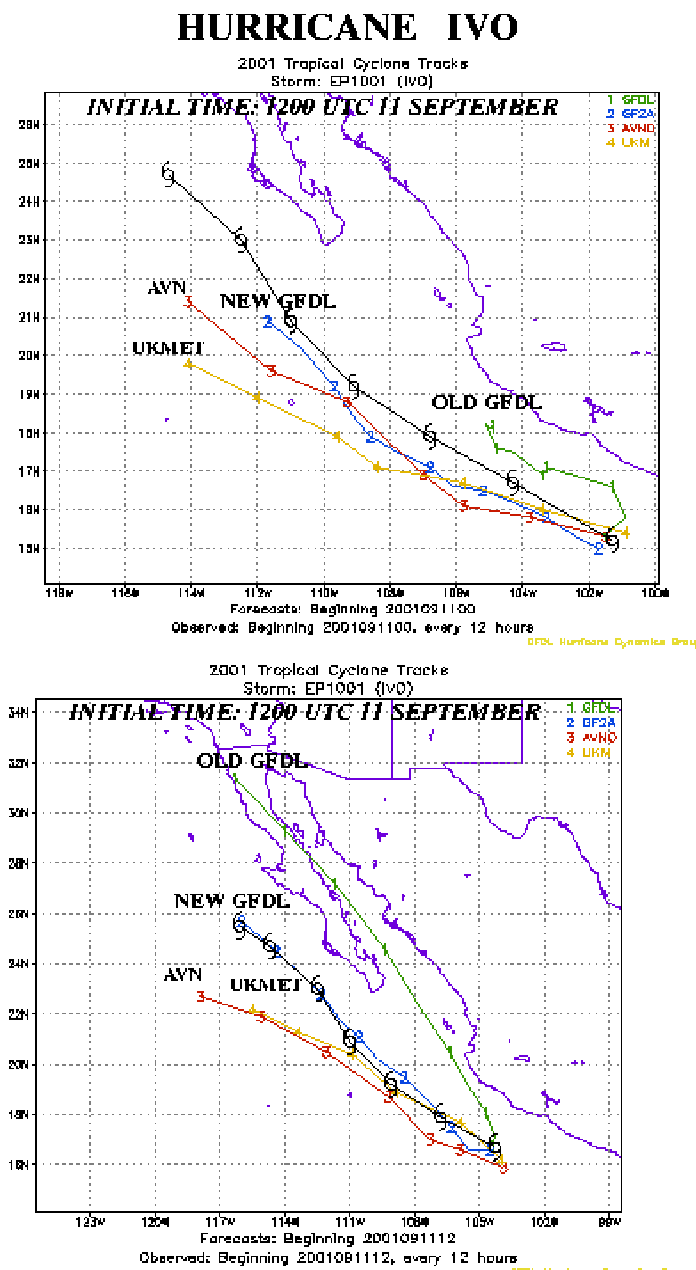

FIGURE 7. Forecasted 72h storm tracks for two cases of Hurricane Ivo in the East Pacific, using the 2001 operational GFDL model (green line), the new GFDL model (blue line), the 2001 AVN model (red line) and the 2001 UKMET model (yellow line). The actual storm track is indicated by the black line with the storm position at 12h intervals indicated by the hurricane symbol.

HURRICANE JULIETTE

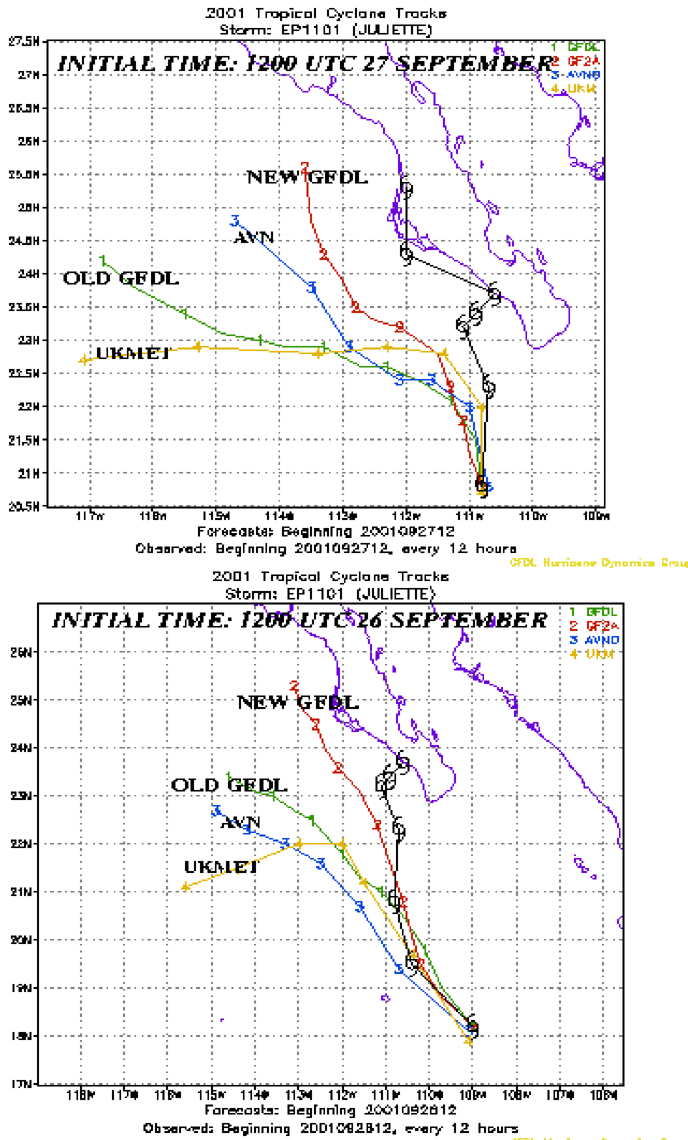

FIGURE 8. Forecasted 72h storm tracks for two cases of Hurricane Juliette in the East Pacific, using the 2001 operational GFDL model (green line), the new GFDL model (red line), the 2001 AVN model (blue line) and the 2001 UKMET model (yellow line). The actual storm track is indicated by the black line with the storm position at 12h intervals indicated by the hurricane symbol.

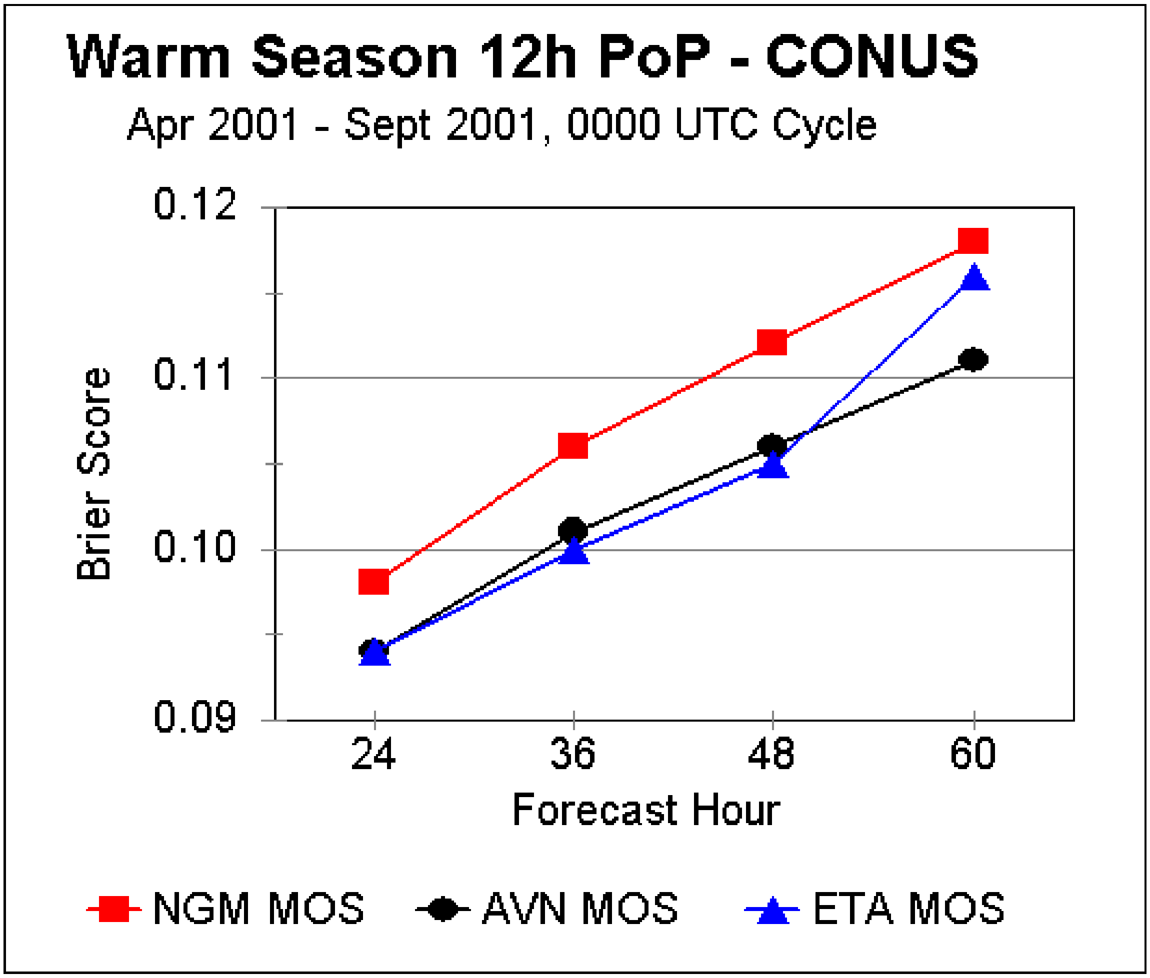

Figure 9. Same as Fig. 8, but for 12-h PoP guidance.

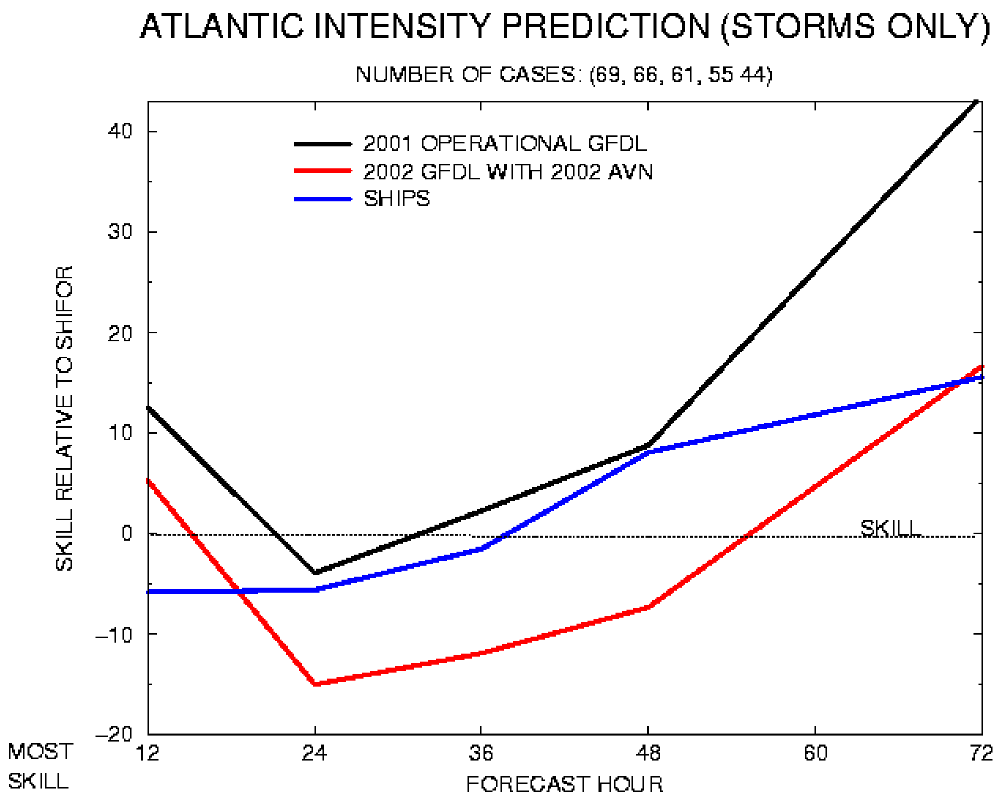

FIGURE 10. Average intensity error normalized with respect to SHIFOR for a homogenous comparison of all Atlantic cases run with the new GFDL model (red line) compared to the 2001 operational GFDL model (black line) and the 2001 operational SHIPS model (blue line).