Prediction of Consensus Tropical Cyclone Track Forecast Error and Correctors to Improve Consensus Tropical Cyclone Track Forecasts

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1. Introduction

Consensus tropical cyclone (TC) track forecast aids formed using TC track forecasts from regional and global numerical weather prediction models (Goerss et al. 2004) have become the primary TC track forecast guidance for forecasters at both the National Hurricane Center (NHC) and the Joint Typhoon Warning Center (JTWC). Forecasters at NHC routinely utilize consensus forecast aids (e.g., GUNA, CONU) formed using the interpolated TC track forecasts from the GFDL model (GFDI; Kurihara et al. 1993, 1995, 1998) and the Global Forecast System (AVNI; Lord 1993) run at NCEP; the Navy Operational Global Atmospheric Prediction System (NGPI; Hogan and Rosmond 1991, Goerss and Jeffries 1994) and the GFDL model (GFNI; Rennick 1999) run at FNMOC; and the UK Meteorological Office global model (UKMI; Cullen 1993, Heming et al. 1995). A GUNA forecast is formed when forecasts from GFDI, UKMI, NGPI, and AVNI are all available. A CONU forecast is formed when forecasts from at least two of GFDI, UKMI, NGPI, AVNI, and GFNI are available. Forecasters at JTWC routinely use a consensus forecast aid, CONW, formed using the interpolated TC track forecasts from the global spectral model (JGSI) and the typhoon model (JTYI) run at the Japan Meteorological Agency (Kuma 1996); an Australian regional model (TCLI; Davidson and Weber 2000); a barotropic model run locally (WBAI; Weber 2001, Sampson et al. 2006); and AVNI, NGPI, GFNI, and UKMI. Like CONU, a CONW forecast is formed when forecasts from at least two of the aforementioned aids are available. Over the course of a season and for all basins, the TC track forecast errors for these consensus aids have been found to be smaller

than the errors for the best of the individual models (Goerss 2000, Goerss et al. 2004, Sampson et al. 2005).

Funded by a previous JHT project, a study was conducted to determine to what extent the TC track forecast error of the consensus models (GUNA, CONU, and CONW) could be predicted prior to the time when official forecasts must be issued. Predictors of consensus forecast error were required to be quantities that are available prior to the time when official forecasts must be issued. Consensus model spread was defined to be the average distance of the member forecasts from the consensus forecast. Forecast displacement was defined to be the difference between the initial and forecast latitudes (or longitudes). The possible predictors examined in that study were consensus model spread; initial and forecast TC intensity; initial TC location and forecast displacement of TC location (latitude and longitude); TC speed of motion; and the number of members available to the consensus model (for CONU and CONW). Using stepwise linear regression and the pool of predictors, regression models were found to predict consensus model TC track forecast error for each combination of forecast length, consensus model, and basin. As a result of that study, a graphical predicted consensus error product (GPCE; Goerss 2007) was developed and installed on the Automated Tropical Cyclone Forecasting Systems (ATCF; Sampson and Schrader 2000) at both NHC and JTWC in 2004.

The two goals of this JHT project were to (1) verify GPCE for all basins and to revise the GPCE regression coefficients at the end of each season to prepare GPCE for the next season; and (2) apply the approach used to predict consensus model forecast error to determine correctors (e.g., the east-west and north-south components of consensus model error) to be applied to the consensus model forecast to produce "corrected consensus" forecast guidance for each basin. In Section 2 we summarize the work performed on this project to accomplish the first goal. The research conducted

to create corrected consensus TC track forecast guidance and the forecast performance of that guidance are described in Section 3.

2. Prediction of Consensus Tropical Cyclone Track Forecast Error

Over the course of this project, GPCE was verified for the 2004-2006 seasons for each forecast length for each basin. The GPCE verifications are displayed in Figs. 1-3 for the Atlantic, eastern North Pacific, and western North Pacific basins, respectively, along with the consensus model forecast errors for 2004-2006.

For 2004, GPCE was verified for the consensus models (CONU for NHC and CONW for JTWC) for each forecast length for the Atlantic, eastern North Pacific, and western North Pacific basins by determining the percent of verifying TC positions contained within the areas depicted by the product. For the 2004 Atlantic season, the areas displayed by GPCE drawn around the CONU forecast positions contained the verifying TC position 69%, 76%, 70%, 68%, and 52% of the time at 24h, 48h, 72h, 96h, and 120h, respectively (Fig. 1). With the exception of 120h, GPCE performed as expected in 2004. Upon closer examination it was found that for all storms except Ivan, the 120-h percentage for CONU was 65%. For Ivan, a stronger than normal storm at lower than normal latitudes, consensus model error was larger than average while the consensus model spread, a leading predictor for GPCE, was smaller than average. For the 2004 eastern North Pacific season, the areas displayed by GPCE drawn around the CONU forecast positions contained the verifying TC position 82%, 81%, 81%, 67%, and 65% of the time at 24h, 48h, 72h, 96h, and 120h, respectively (Fig. 2). For the 2004 western North Pacific season, the areas displayed by GPCE drawn around the CONW forecast positions contained the verifying TC position 74%, 77%, 76%, 76%, and 77% of the time at 24h, 48h, 72h, 96h, and 120h, respectively (Fig. 3).

Using the GPCE pool of predictors for the 2001-2004 seasons, revised regression models were derived for the 2005 season for all combinations of forecast length and basin. In addition to the aforementioned basins, regression models were derived for the Southern Hemisphere basins within the JTWC area of responsibility. The revised GPCE coefficients for 2005 were installed on the ATCF's at NHC and JTWC for CONU for the Atlantic and eastern North Pacific and for CONW for the western North Pacific and Southern Hemisphere.

Using the procedures described previously, GPCE was verified for 2005 for the consensus models (CONU for NHC and CONW for JTWC) for each forecast length for the Atlantic, eastern North Pacific, and western North Pacific basins. GPCE was found to meet or exceed expectations (approximately 70-75 percent of verifying TC positions contained within the GPCE areas) for all basins and forecast lengths. For the 2005 Atlantic season, the areas displayed by GPCE drawn around the CONU forecast positions contained the verifying TC position 76%, 77%, 77%, 75%, and 75% of the time at 24h, 48h, 72h, 96h, and 120h, respectively (Fig. 1). For the 2005 eastern North Pacific season, the areas displayed by GPCE drawn around the CONU forecast positions contained the verifying TC position 76%, 84%, 83%, 90%, and 94% of the time at 24h, 48h, 72h, 96h, and 120h, respectively (Fig. 2). For the 2005 western North Pacific season, the areas displayed by GPCE drawn around the CONW forecast positions contained the verifying TC position 83%, 85%, 76%, 81%, and 78% of the time at 24h, 48h, 72h, 96h, and 120h, respectively (Fig. 3). For the Atlantic, the performance of GPCE was close to what was expected. Except at 24 h, the performance of GPCE for the eastern North Pacific greatly exceeded expectations. This result was consistent with the exceptionally small CONU forecast errors for that basin in 2005 (80 nm at 48 h, 111 nm at 72 h, 136 nm at 96 h, and 161 nm at 120 h) illustrated in Fig. 2. The GPCE performance for the western North Pacific exceeded expectations as well, but by a smaller amount. This result

was also consistent with the relatively small CONW forecast errors for 2005 (Fig. 3).

Using the GPCE pool of predictors from the 2001-2005 seasons, revised regression models to be used by GPCE for the 2006 season were derived and installed at both centers. For the 2006 Atlantic season, the areas displayed by GPCE drawn around the CONU forecast positions contained the verifying TC position 81%, 79%, 74%, 79%, and 77% of the time at 24h, 48h, 72h, 96h, and 120h, respectively (Fig. 1). For the 2006 eastern North Pacific season, the GPCE areas contained the verifying TC position 61%, 67%, 63%, 68%, and 67% of the time at 24h, 48h, 72h, 96h, and 120h, respectively (Fig. 2). For the 2006 western North Pacific season, the GPCE areas contained the verifying TC position 79%, 80%, 75%, 76%, and 69% of the time at 24h, 48h, 72h, 96h, and 120h, respectively (Fig. 3). For the Atlantic and the western North Pacific, the performance of GPCE was close to what was expected. For the eastern North Pacific, the areas displayed by GPCE contained the verifying TC position less often than expected. Because the GPCE areas had contained the verifying TC position much more often than expected for the eastern North Pacific in 2005, an adjustment was made to the radius calculations for 2006 decreasing their size. If that adjustment had not been made, the GPCE areas would have contained the verifying TC position 65%, 72%, 70%, 72%, and 71% of the time at 24h, 48h, 72h, 96h, and 120h, respectively, much closer to what was expected. This adjustment has been removed for the upcoming 2007 season.

Finally, using the GPCE pool of predictors for the 2001-2006 seasons, revised regression models to be used by GPCE for the 2007 season for all combinations of forecast length and basin were derived. The revised GPCE coefficients for 2007 were installed at NHC and JTWC for CONU for the Atlantic and eastern North Pacific and for CONW for the western North Pacific and Southern Hemisphere.

3. Prediction of Correctors to Improve Consensus Tropical Cyclone Track Forecasts

The techniques used to predict consensus error were applied to predict the east-west and north-south forecast error of the consensus models. Regression models to predict CONU and GUNA east-west and north-south forecast error for all forecast lengths in the Atlantic were derived using the GPCE pool of predictors for the 2001-2002, 2001-2003, and 2001-2004 seasons. These predicted errors were used as correctors to be applied to the consensus models for the 2003, 2004, and 2005 seasons, respectively. Henceforth, correctors produced using these regression techniques will be referred to as statistical correctors. The mean of the CONU and GUNA east-west and north-south forecast errors for all forecast lengths in the Atlantic were also found for the 2001-2002, 2001-2003, and 2001-2004 seasons to be used as correctors for the consensus models for the 2003, 2004, and 2005 seasons, respectively. Henceforth, these correctors will be referred to as bias correctors. For both CONU and GUNA, it was found that these bias correctors were more effective than the statistical correctors derived using the regression models for forecasts lengths less than or equal to 72h. For CONU, the application of only the statistical corrector for the north-south error was most effective at 96h and 120h. For GUNA, the application of the statistical corrector for the north-south error and the bias corrector for the east-west error was most effective at 96h and 120h. Using these strategies, corrected consensus forecasts (CCON and CGUN) were produced for the 2003, 2004, and 2005 seasons. For the 2003-2005 seasons, the CCON errors were 54 nm, 94 nm, 143 nm, 204 nm, and 268 nm at 24h, 48h, 72h, 96h, and 120h, respectively (Fig. 4). The respective errors for CONU were 56 nm, 97 nm, 145 nm, 211 nm, and 280 nm. The CCON improvements were significant at the 99% level at 24h, 48h, and 72h, the 90% level at 96h, and the 97% level at 120h. For the 2003-2005 seasons, the CGUN errors were 50 nm, 88 nm, 135 nm, 191 nm, and 251 nm at 24h, 48h, 72h, 96h, and 120h, respectively (Fig. 5). The respective errors for GUNA were 52 nm, 91 nm, 137 nm, 194

nm, and 257 nm. The CGUN improvements were significant at the 99% level at 24h, 48h, and 72h, the 80% level at 96h, and the 85% level at 120h. For both CCON and CGUN, the performance for the individual years was consistent with that displayed for the 2003-2005 seasons.

a. CCON and CGUN for the Atlantic basin

Regression models to predict CONU and GUNA east-west and north-south forecast error for all forecast lengths in the Atlantic were derived using the GPCE pool of predictors for the 2001-2005 seasons. These predicted errors were used as statistical correctors to be applied to the consensus models for the 2006 season. The means of the CONU and GUNA east-west and north-south forecast errors for all forecast lengths in the Atlantic were also found for the 2001-2005 seasons to be used as bias correctors for the consensus models for the 2006 season. From previous work it was found that for both CONU and GUNA the bias correctors were more effective than the statistical correctors derived using the regression models for forecast lengths less than or equal to 72h. For CONU, the application of only the statistical corrector for the north-south error was most effective at 96h and 120h. For GUNA, the application of the statistical corrector for the north-south error and the bias corrector for the east-west error was most effective at 96h and 120h. Using these strategies, corrected consensus forecasts (CCON and CGUN) were produced for the 2006 season and CCON and CGUN were installed on the ATCF as experimental guidance. For the 2006 season, the CCON errors were 50 nm, 93 nm, 142 nm, 184 nm, and 240 nm at 24h, 48h, 72h, 96h, and 120h, respectively (Fig. 6). The respective errors for CONU were 50 nm, 96 nm, 144 nm, 187 nm, and 242 nm. The CCON improvements were small with only the 48h improvement significant at the 88% level. For the 2006 season, the CGUN errors were 46 nm, 84 nm, 136 nm, 162 nm, and 227 nm at 24h, 48h, 72h, 96h, and 120h, respectively (Fig. 7). The respective errors for GUNA were 48 nm, 86 nm, 139 nm, 168 nm, and 216 nm. The CGUN improvements were significant at the 80% level at

24h, 48h, and 72h. Using the GPCE pool of predictors for the 2001-2006 seasons, both CCON and CGUN have been updated and installed on the ATCF for the upcoming 2007 season.

b. CCON for the eastern North Pacific basin

Regression models to predict CONU east-west and north-south forecast error for all forecast lengths in the eastern North Pacific were derived using the GPCE pool of predictors for the 2002-2005 seasons. There was not a sufficient sample size to perform this analysis for GUNA. These predicted errors were used as statistical correctors to be applied to CONU for the 2006 season. The means of the CONU east-west and north-south forecast errors for all forecast lengths were also found for the 2002-2005 seasons to be used as bias correctors for CONU for the 2006 season. It was found that the application of the statistical correctors for all forecast lengths was the most effective strategy for CONU for the eastern North Pacific. Using this strategy, corrected consensus forecasts (CCON) were produced for the 2006 season. The CCON errors were 53 nm, 96 nm, 140 nm, 172 nm, and 180 nm at 24h, 48h, 72h, 96h, and 120h, respectively (Fig. 8). The respective errors for CONU were 54 nm, 99 nm, 144 nm, 180 nm, and 225 nm. The CCON improvements were significant at the 73-82% level for the 48-h to 96-h forecast lengths and at the 97% level for the 120-h forecast length. The most important corrector at the longer forecast lengths was found to be the east-west corrector. For the 120-h forecast, it was found that the initial latitude could be used to explain nearly 30% of the CONU east-west forecast error (Fig. 9). For TC's located south (north) of 15N the 120-h east-west correction is in the westerly (easterly) direction. The farther the TC is from 15N, the larger the correction. To a lesser extent this relationship between initial latitude and the east-west corrector was found at the other forecast lengths as well and is illustrated in the forecast tracks for Hurricane Daniel displayed in Fig. 10. For the 00Z forecast of 20 July 2006, CCON

provided a considerably better forecast than CONU. Using the GPCE pool of predictors for the 2002-2006 seasons, statistical correctors were computed and CCON was installed on the ATCF as experimental guidance for the eastern North Pacific for the 2007 season.

c. CCON for the western North Pacificbasin

Regression models to predict CONW east-west and north-south forecast error for all forecast lengths in the western North Pacific were derived using the GPCE pool of predictors for the 2003-2005 seasons. These predicted errors were used as statistical correctors to be applied to CONW for the 2006 season. The means of the CONW east-west and north-south forecast errors for all forecast lengths were also found for the 2003-2005 seasons to be used as bias correctors for CONW for the 2006 season. It was found that the application of the statistical correctors for all forecast lengths out to 72h and the application of the statistical correctors for the north-south forecast errors and the bias correctors for the east-west forecast errors at 96h and 120h was the most effective strategy for CONW for the western North Pacific. Using this strategy, corrected consensus forecasts (CCON) were produced for the 2006 season. The CCON errors were 57 nm, 92 nm, 136 nm, 188 nm, and 274 nm at 24h, 48h, 72h, 96h, and 120h, respectively (Fig. 11). The respective errors for CONW were 60 nm, 96 nm, 139 nm, 198 nm, and 284 nm. The CCON improvements were significant at the 99%, 92%, 75%, 99%, and 95% level for 24h, 48h, 72h, 96h, and 120h, respectively. Using this strategy, statistical and bias correctors were computed using the 2003-2006 seasons and CCON was installed on the ATCF as experimental guidance for the western North Pacific for the 2007 season.

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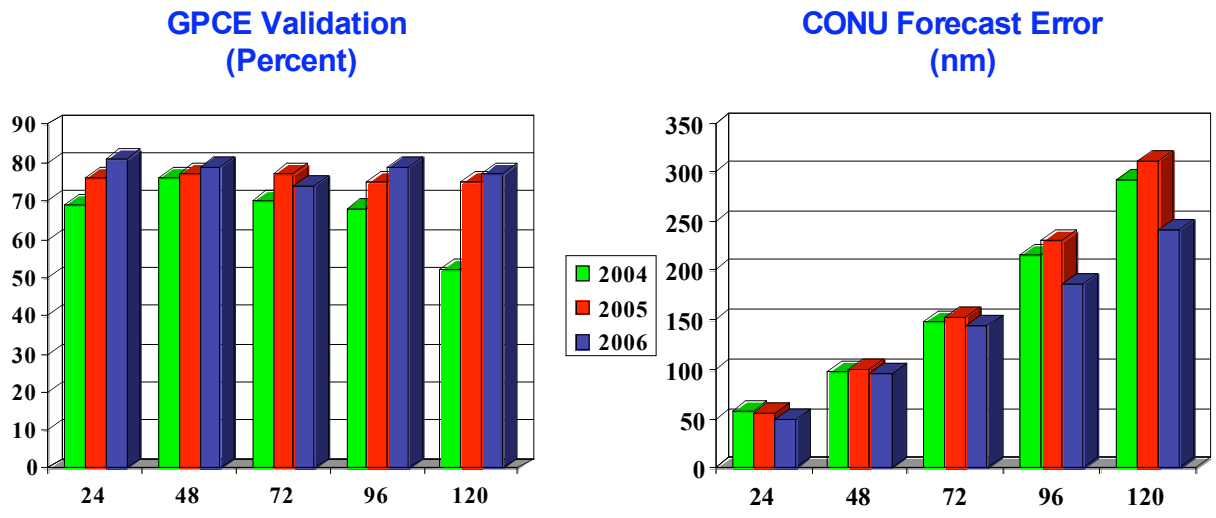

Fig. 1. GPCE validation and CONU forecast error for the Atlantic basin for 2004-2006.

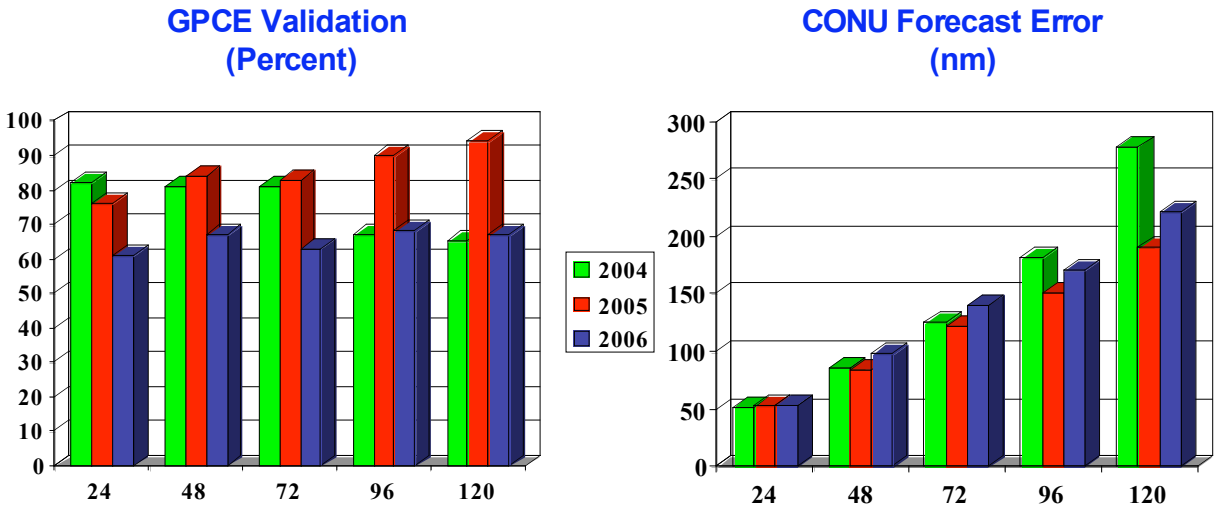

Fig. 2. GPCE validation and CONU forecast error for the eastern North Pacific basin for 2004-2006.

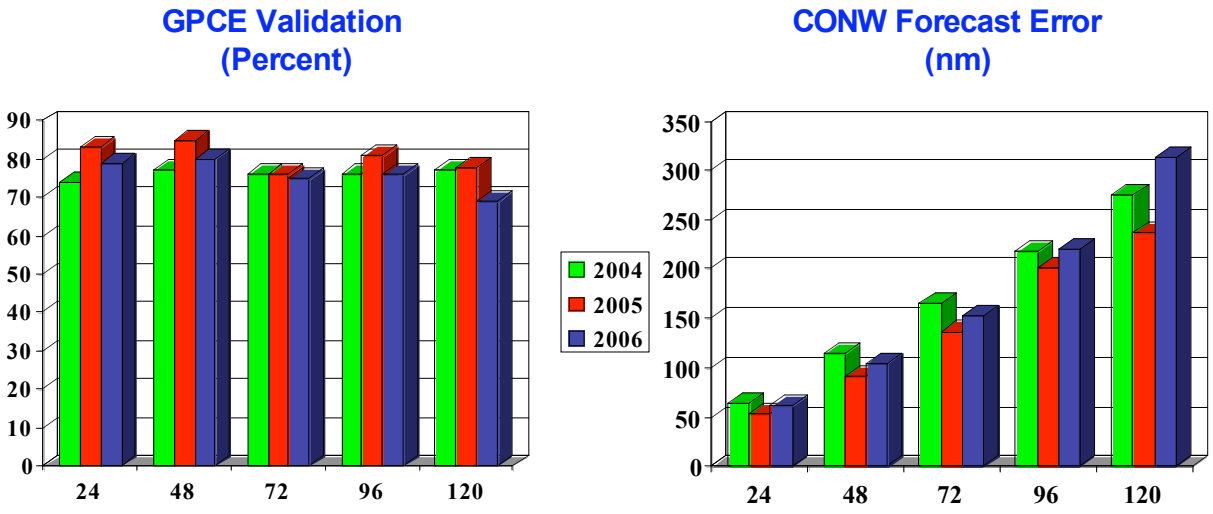

Fig. 3.GPCE validation and CONW forecast error for the western North Pacific basin for 2004-2006.

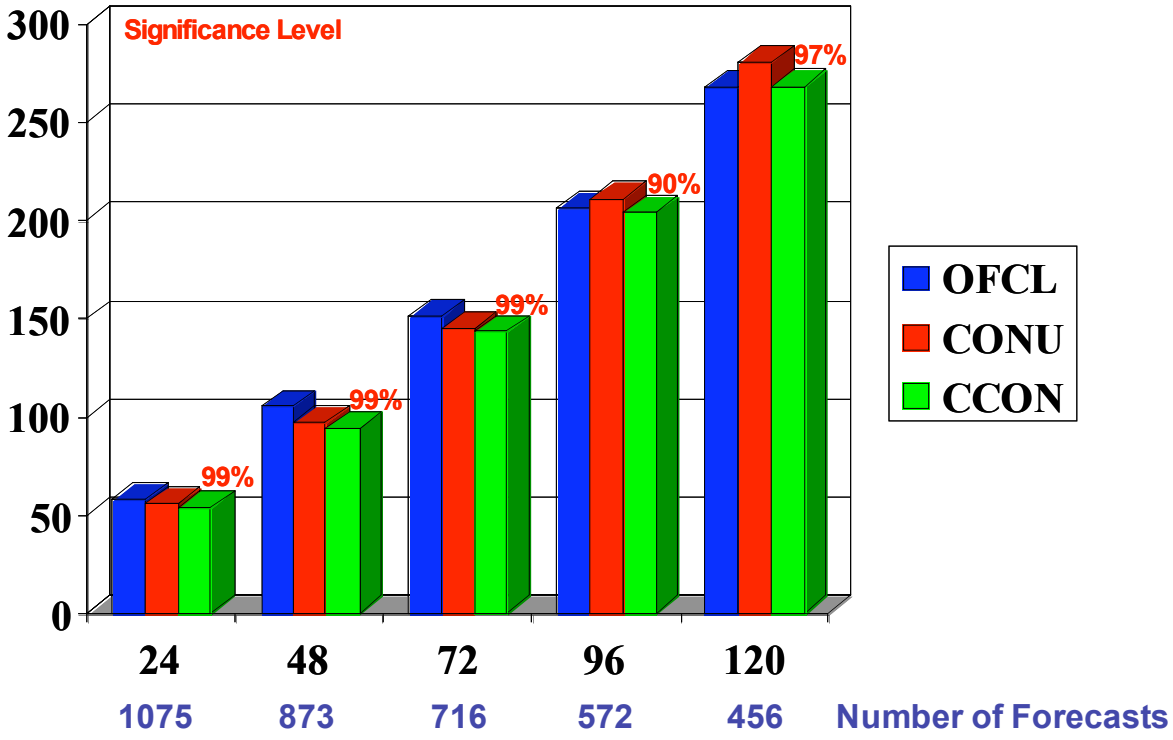

Fig. 4. Homogeneous comparison of tropical cyclone track forecast error (nm) for the Atlantic basin for 2003-2005. CCON is the corrected CONU forecast guidance.

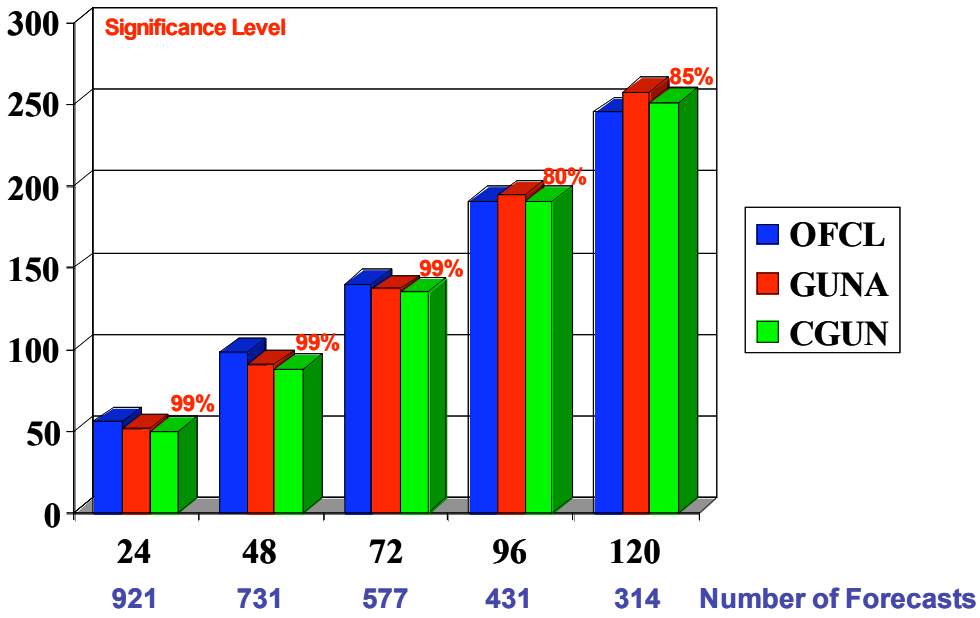

Fig. 5. Homogeneous comparison of tropical cyclone track forecast error (nm) for the Atlantic basin for 2003-2005. CGUN is the corrected GUNA forecast guidance.

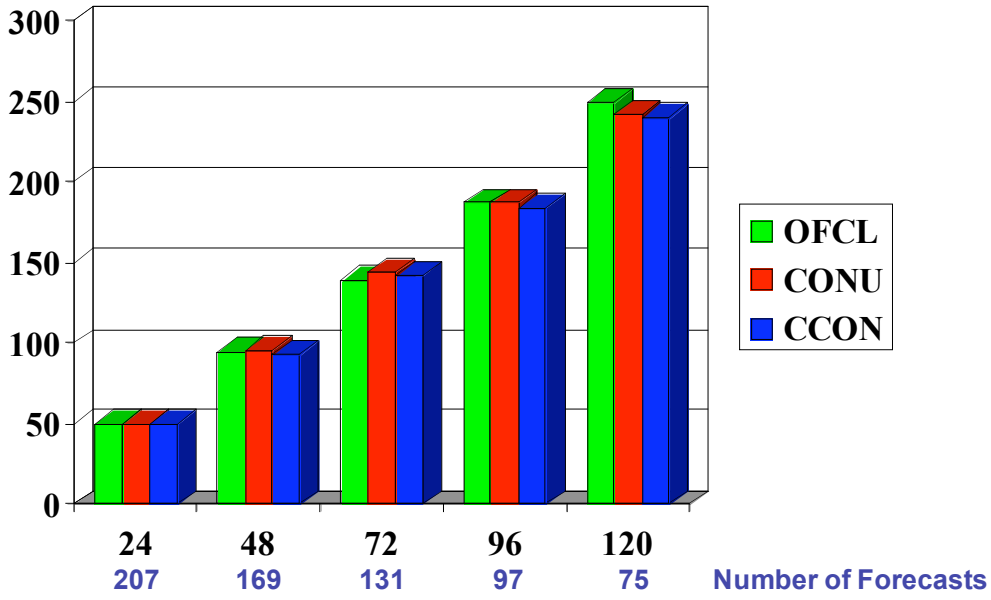

Fig. 6. Homogeneous comparison of tropical cyclone track forecast error (nm) for the Atlantic basin for 2006. CCON is the corrected CONU forecast guidance.

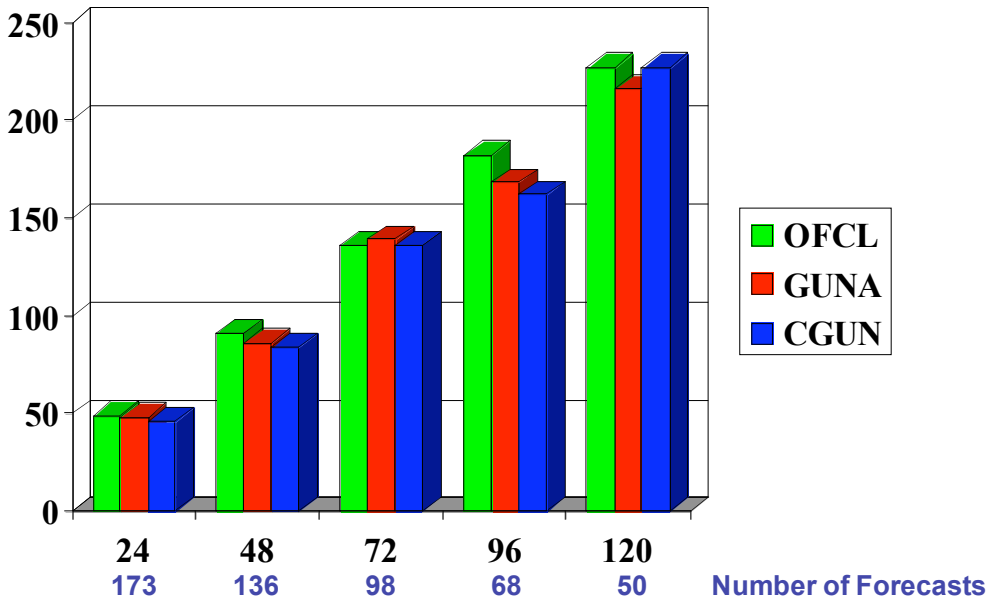

Fig. 7. Homogeneous comparison of tropical cyclone track forecast error (nm) for the Atlantic basin for 2006. CGUN is the corrected GUNA forecast guidance.

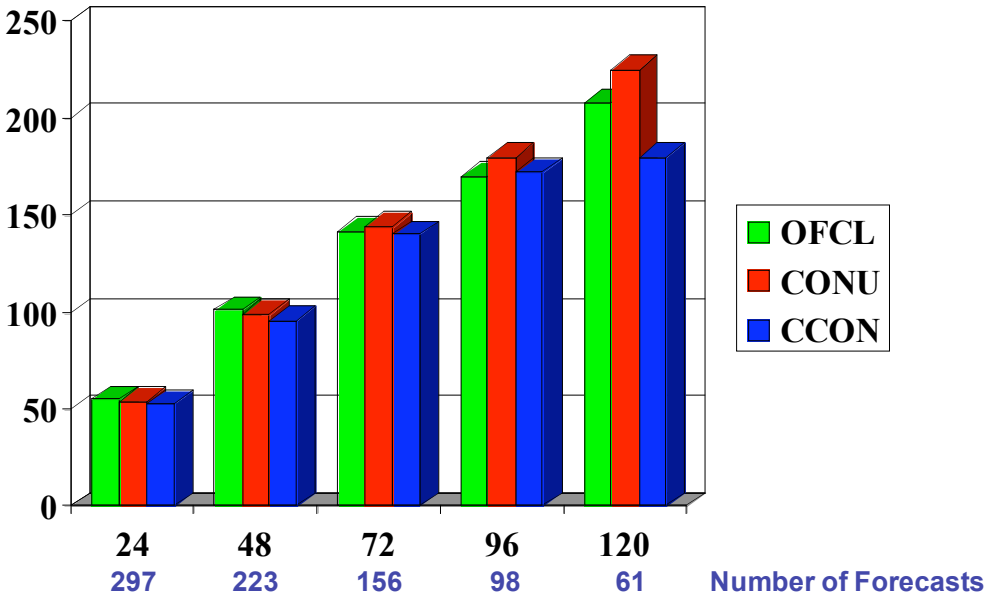

Fig. 8. Homogeneous comparison of tropical cyclone track forecast error (nm) for the eastern North Pacific basin for 2006. CCON is the corrected CONU forecast guidance.

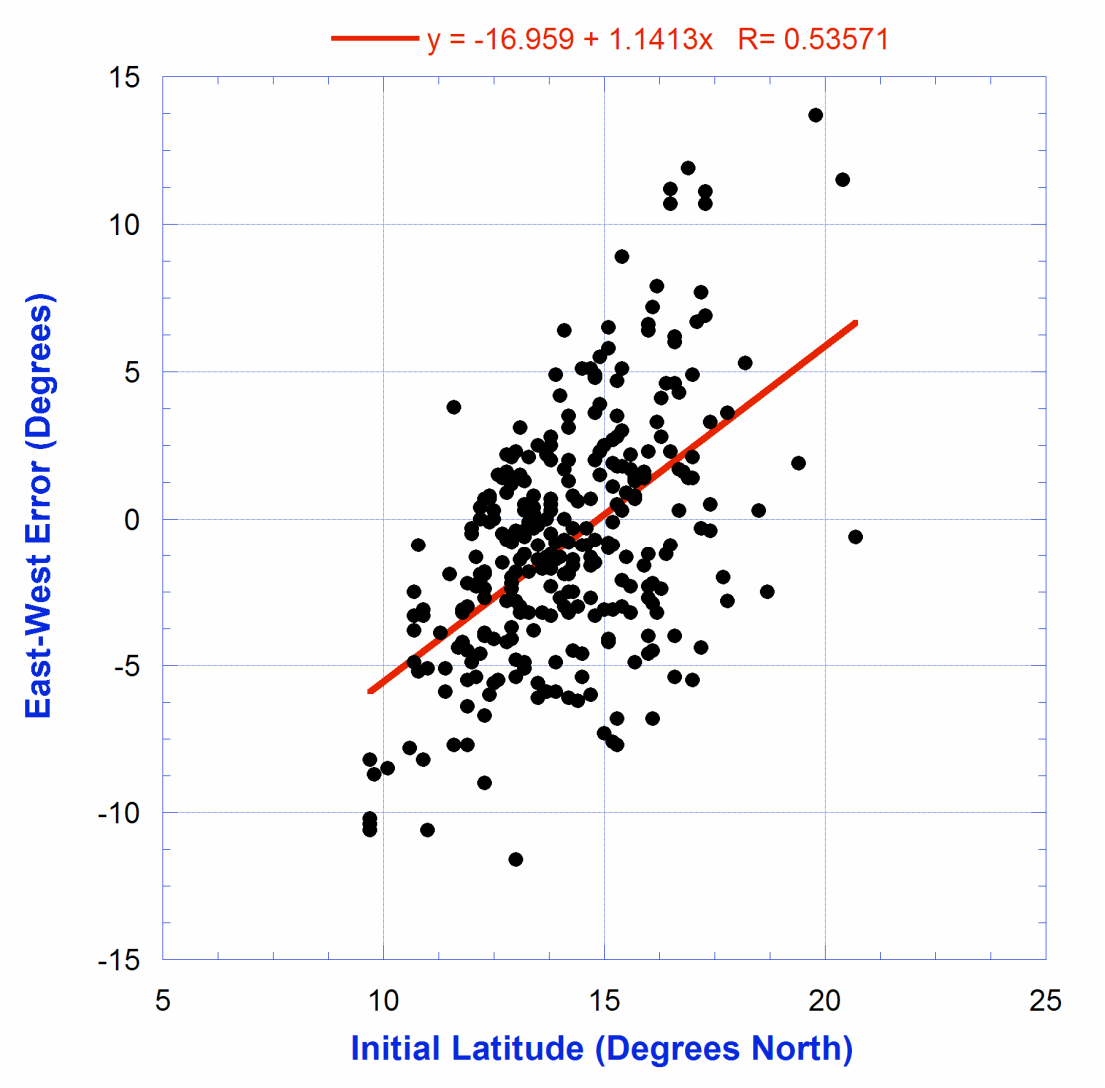

Fig. 9. CONU east-west 120-h track forecast error vs. initial latitude for the eastern North Pacific basin for 2002-2005.

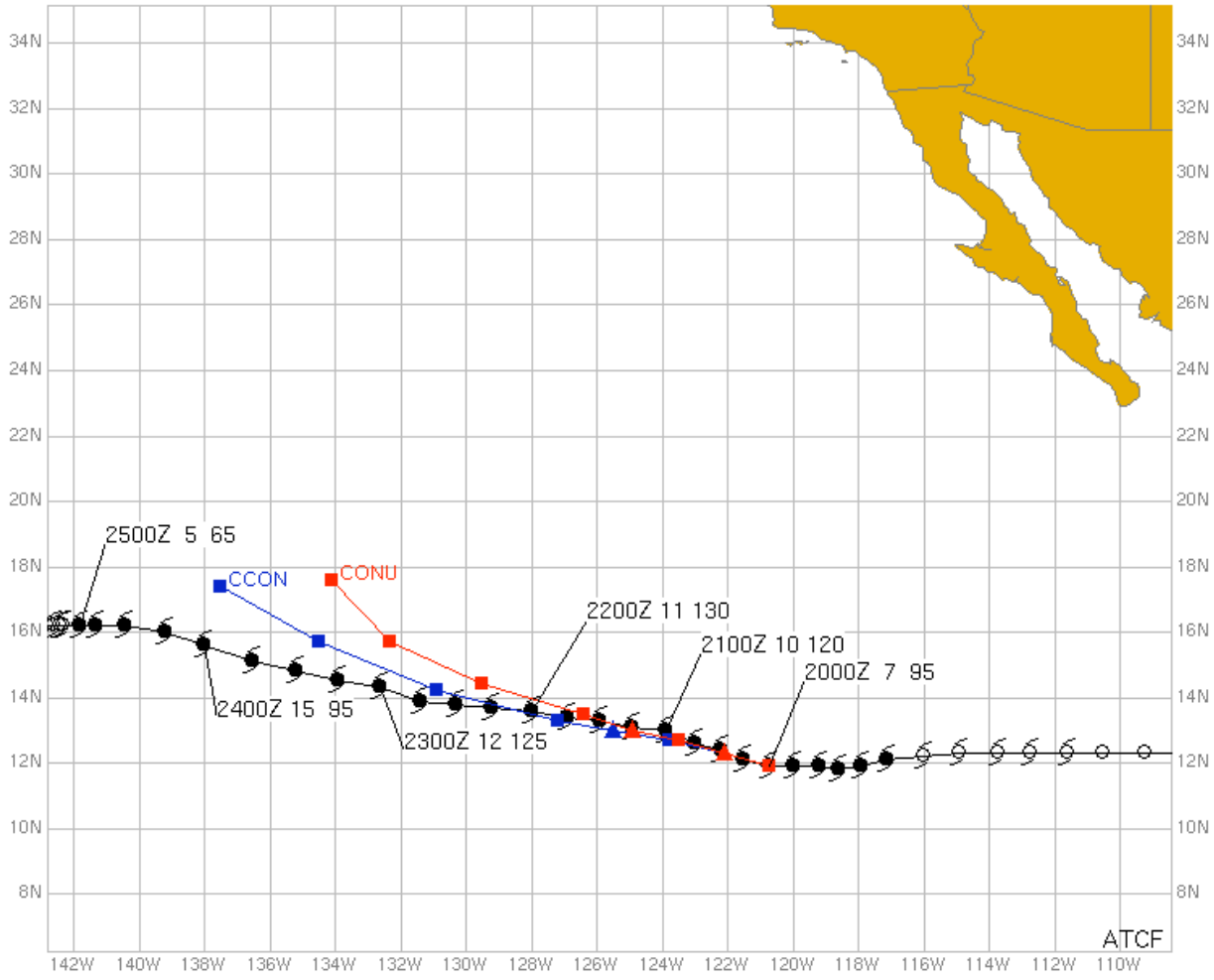

Fig. 10. CONU and CCON forecast tracks for Hurricane Daniel, 00Z 20 July 2006.

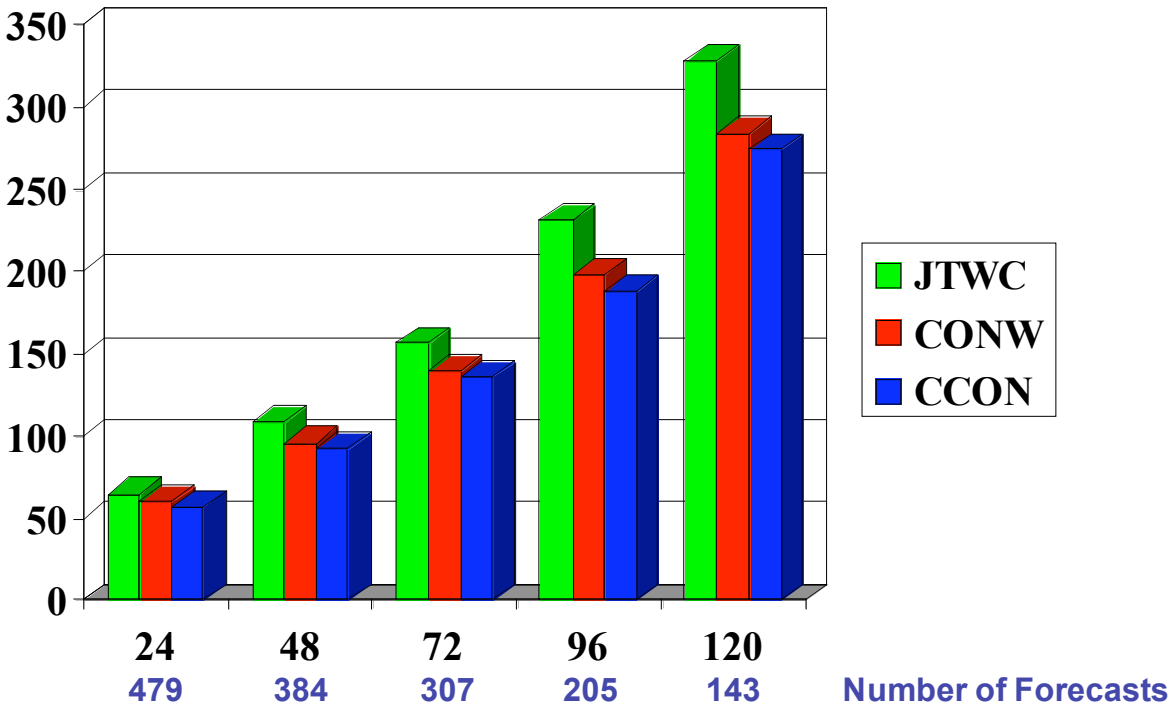

Fig. 11. Homogeneous comparison of tropical cyclone track forecast error (nm) for the western North Pacific basin for 2006. CCON is the corrected CONW forecast guidance.