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# IMPACT OF SATELLITE OBSERVATIONS AND FORECAST MODEL IMPROVEMENTS ON TROPICAL CYCLONE TRACK FORECASTS

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## 1. INTRODUCTION

Tropical cyclone (TC) track forecasts derived from the forecasts of global numerical weather prediction (NWP) models have become increasingly important in recent years as guidance to TC forecasters at both the National Hurricane Center (NHC) and the Joint Typhoon Warning Center. Forecasters at NHC routinely utilize forecast aids formed using the interpolated TC track forecasts from the Global Forecast System (GFS; Lord 1993) run at the National Centers for Environmental Prediction (NCEP), the Navy Operational Global Atmospheric Prediction System (NOGAPS; Hogan and Rosmond 1991, Goerss and Jeffries 1994) run at Fleet Numerical Meteorology and Oceanography Center (FNMOC), and the United Kingdom Meteorological Office global model (UKMO; Cullen 1993, Heming et al. 1995). The improvement in the TC track forecasting skill of the global NWP models since 1992 has been illustrated for both the western North Pacific (Goerss et al. 2004) and the Southern Hemisphere (Sampson et al. 2005). For both basins, the typical global NWP model 72-h forecast error today is comparable to the typical 48-h forecast error ten years ago.

Over the past decade improvements have been made to the global NWP systems in two major areas: (1) increased and more effective assimilation of satellite observations and (2) increased forecast model resolution and improvements to model physical parameterization schemes. For example, the direct use of satellite radiances replaced the use of retrievals in the GFS data assimilation system at NCEP in 1995 (Derber and Wu 1998) and the assimilation of high density multispectral *GOES-8* winds (Velden et al. 1997) into NOGAPS was initiated at FNMOC in 1996 (Goerss et al. 1998). Since the early 1990's the horizontal resolution of the NOGAPS global spectral model has tripled while its vertical resolution has nearly doubled. In 2000 a major change was made to the NOGAPS convective parameterization when the Emanuel scheme (Emanuel 1991, Emanuel and Zivkovic-Rothman 1999) replaced the Navy version of the relaxed Arakawa-Schubert (1974) scheme. Further modifications were made to the Emanuel scheme in 2001 and 2002 (Peng et al. 2004). Commensurate increases in resolution and improvements to physical parameterization schemes have been made to the other global NWP systems over the past decade.

The purpose of this study is to determine the impact that the assimilation of satellite observations and forecast model improvements have had upon the TC track forecasting performance of global NWP systems. Two sets of data assimilation experiments are conducted using NOGAPS. The first set is designed to illustrate the impact on the NOGAPS TC track forecasts of the assimilation of different types of satellite observations while the second set is designed to illustrate the impact of improvements to the NOGAPS global spectral model.

## 2. RESULTS AND CONCLUSIONS

The TC track forecasts of NOGAPS were evaluated for a number of data assimilation experiments conducted using observational data from August 14-September 30, 2004. This was a particularly active period with 12 hurricanes (including Charley, Frances, Ivan, and Jeanne), 5 typhoons, and 7 tropical storms. The operational configuration of NOGAPS, consisting of the Naval Research Laboratory Atmospheric Variational Data Assimilation System (NAVDAS; Daley and Barker 2001) with the assimilation of all available conventional and satellite observations and a T239L30 global spectral model (239-wave, triangular truncation, 30 vertical levels) with Emanuel convective parameterization, was used as the control run (NCTL).

The first set of experiments was designed to illustrate the impact on the NOGAPS TC track forecasts of the assimilation of different types of satellite observations. First, the NOGAPS control system was run over the 6-week period with the assimilation of only conventional observations (NCNV). The observations assimilated in this experiment consisted of rawinsonde and pilot balloon, aircraft, surface (land and marine), Australian bogus, and synthetic TC observations. Subsequent experiments were then run adding one set of satellite observations to the observations used in the previous experiment. For the second experiment (NATV), AMSU-A radiances were assimilated along with the conventional observations. The assimilation of SSM/I precipitable water observations (NRPW) was added next, followed by the assimilation of satellite feature-track winds (NSPW). The set of satellite feature-track winds used in this study include those produced from the five geostationary satellites (tropical and mid-

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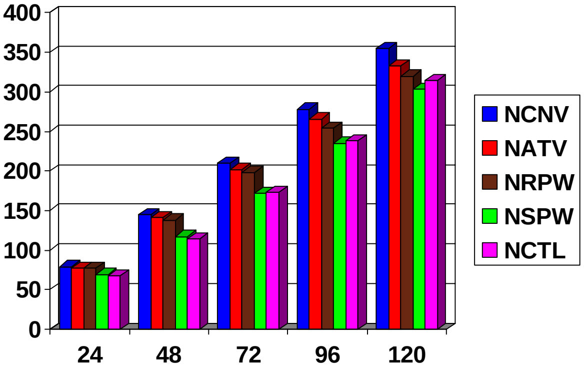

Fig. 1. Homogeneous comparison of NOGAPS TC track forecast error (nm) for August 14-September 30, 2004.

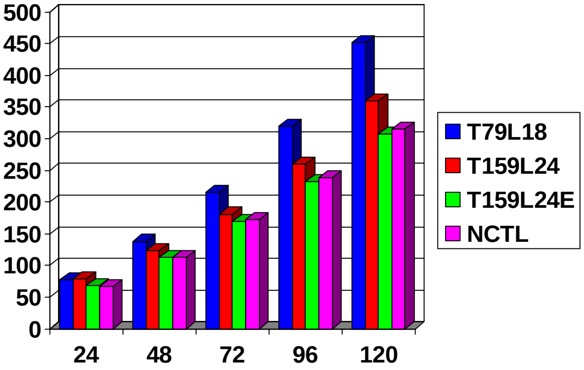

Fig. 3. Homogeneous comparison of NOGAPS TC track forecast error (nm) for August 14-September 30, 2004.

latitude coverage) along with those produced for the polar regions using the MODIS instrument on the NASA AQUA and TERRA satellites. Finally, the assimilation of QuikSCAT and ERS-2 scatterometer winds was added (NCTL).

The results of these experiments are summarized in Fig. 1, where the TC track forecast errors for the Atlantic and North Pacific basins are displayed. The number of forecasts was 289, 253, 212, 169, and 134 at 24h, 48h, 72h, 96h, and 120h, respectively. With the exception of the scatterometer observations, the addition of a new set of satellite observations resulted in improved TC track forecasts at all forecast lengths. The impact of the different sets of satellite observations is more clearly illustrated in Fig. 2, where the percent improvement with respect to the control experiment is displayed. The overall TC track forecast improvement due to the assimilation of satellite observations was 18% at 24h, 27% at 48h, 21% at 72h, 17% at 96h, and 13% at 120h. This improvement was significant at the 99% level for all forecast lengths except 120h where it was significant at the 95% level. At all forecast lengths except 120h, the improvement due to the assimilation of satellite feature-track winds was the largest and was significant at the 99% level for the 24-h to 72-h forecasts and at the 90% level for the 96-h forecast. While not statistically significant with this sample size, the improvements due to the assimilation of the AMSU-A radiances were consistently positive at all forecast lengths as were the improvements due to the assimilation of SSM/I precipitable water at all forecast lengths except 24h. The forecast improvement at 24h due to the assimilation of scatterometer observations was significant at the 90% level while the forecast improvement/degradation at the other forecast lengths was not statistically significant.

The second set of experiments was designed to illustrate the impact on NOGAPS TC track forecasts of improvements to the NOGAPS global spectral model. All of these experiments were run using the complete set of observations, conventional and satellite, used in the control run (NCTL). The model configuration for the first experiment was T79L18 with relaxed Arakawa-Schubert convective parameterization. For the second experiment the model resolution was increased to T159L24. The relaxed Arakawa-Schubert convective parameterization was replaced with the Emanuel convective parameterization in the third experiment (T159L24E). The

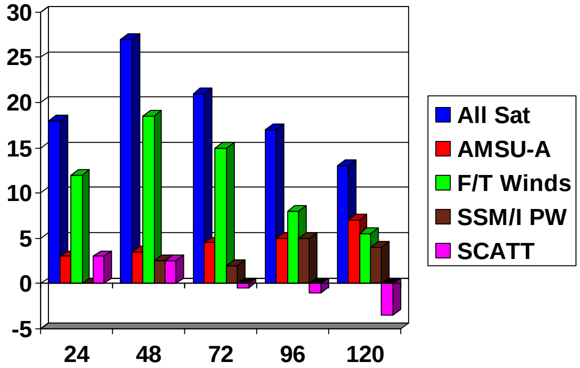

Fig. 2. Percent improvement in NOGAPS TC track forecast error for August 14-September 30, 2004.

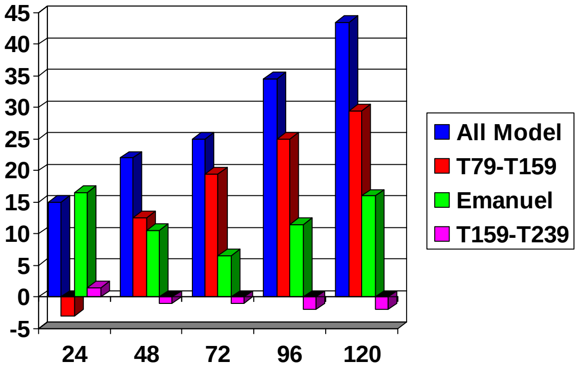

Fig. 4. Percent improvement in NOGAPS TC track forecast error for August 14-September 30, 2004.

control run from the first set of experiments, T239L30 model resolution with Emanuel convective parameterization, also served as the control run for the second set of experiments.

The results of these experiments are summarized in Fig. 3, where the TC track forecast errors for the Atlantic and North Pacific basins are displayed, and Fig. 4, where the percent improvement with respect to the control experiment is displayed. The number of forecasts was 288, 249, 210, 169, and 133 at 24h, 48h, 72h, 96h, and 120h, respectively. The overall TC track forecast improvement due to model improvements was 15% at 24h, 22% at 48h, 25% at 72h, 34% at 96h, and 44% at 120h. This improvement was significant at the 99% level for all forecast lengths. Except at 24h, the largest improvement was seen when the resolution was changed from T79L18 to T159L24. The improvements, which increased with increasing forecast length, were 12% at 48h, 20% at 72h, 25% at 96h, and 30% at 120h and were all significant at the 99% level. The improvements due to implementing the Emanuel convective parameterization were 16% at 24h, 10% at 48h, 6% at 72h, 12% at 96h, and 16% at 120 h. Except at 72h, these improvements were all significant at the 95% level. While increasing the model resolution to T239L30 improved forecast performance in the extra-tropics (not shown), it resulted in degradations in TC track forecasts (not statistically significant) at all forecast lengths except 24h.

The assimilation of synthetic tropical cyclone observations (Goerss and Jeffries 1994) is a critical part of the NOGAPS data assimilation system. Except in the Atlantic basin, where aircraft surveillance is routine, the information used to generate these observations, TC position and intensity, is almost entirely obtained using satellite imagery. As a final experiment, the NOGAPS control system was run without the assimilation of these synthetic observations. The resulting degradation in TC track forecasts was 49% at 24h, 39% at 48h, 23% at 72h, 15% at 96h, and 7% at 120h. These degradations were significant at the 95% level at all forecast lengths except 120h.

In summary, the impact upon TC track forecasts of the assimilation of all satellite observations was roughly comparable to the impact of all model improvements at 24h to 72h. At 96h and 120h, the impact of the assimilation of all satellite observations was roughly comparable to the impact of replacing the relaxed Arakawa-Schubert convective parameterization with the Emanuel convective parameterization. The impact obtained when the model resolution improved from T79L18 to T159L24 increased with increasing forecast length. As a result, the impact of all model improvements was two to three times greater than the impact of the assimilation of all satellite observations at 96h and 120h. With respect to TC track forecasting, the feature-track winds proved to be the most important set of satellite observations. Comparing the different sets of satellite observations, they had the largest impact at 24h to 96h. The assimilation of AMSU-A radiances had the largest impact at 120h. Finally, the impact of the assimilation of synthetic TC observations was found to be greater than the impact of the assimilation of all satellite observations at 24h and 48h and comparable at 72h and 96h.

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