14B.5 AN EVALUATION AND COMPARISON OF PREDICTIONS OF TROPICAL CYCLOGENESIS BY THREE GLOBAL FORECAST MODELS

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1. INTRODUCTION

Over recent years, there have been continued enhancements to resolution and physics in global numerical weather prediction (NWP) models at the various forecast centers. Presumably, these advances have led to continued improvements in each models' ability to forecast weather over the tropics. In particular, recent improvements in the skill of tropical cyclone (TC) track forecasts have often been attributed in part to increased accuracy of track predictions in operational global model forecasts. However, there has not been a systematic examination of forecasts of TC formation by the operational global models.

Because many high-resolution regional models are either run only when a TC is in advisory status, or because they do not cover remote ocean areas where TCs typically form, global model predictions of TC formation are a critical forecast aid. This is especially true at long forecast intervals prior to development of a strong convective signature that may be analyzed with a variety of satellite-based techniques (e.g., Dvorak 1984)

This study evaluates recent forecasts of tropical cyclogenesis made by the National Centers for Environmental Prediction Global Forecast System (GFS), the United States Navy Operational Global Atmospheric Prediction System (NOGAPS), and the United Kingdom Meteorological Office Global Model (UKM).

An objective tropical vortex identification and tracking technique is utilized to enable the determination of statistics such as probability of detection and false alarm rates of tropical cyclogenesis in the model forecast fields. Furthermore, forecasts of several physical quantities relevant to TC formation (e.g., warm core magnitude, vertical wind shear, mid-level moisture, etc.) are evaluated with respect to each tropical vortex that is correctly and incorrectly forecast to become a TC. This methodology allows further analysis of correct and incorrect forecasts of TC formation.

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2. METHOD

To evaluate the ability of a global model to forecast TC formation, it is necessary to systematically and objectively identify tracks and important physical characteristics of all tropical vortices in model forecast and analysis fields. The VORTRACK application (Harr 2006) has been developed to enable the diagnosis of output from NWP models as part of the process of forecasting the development of a tropical low into a TC, and to compute verification statistics on model forecasts of tropical cyclogenesis. There are two primary components to the VORTRACK system. The main data processing portion (Fig. 1) ingests grids generated by several operational global numerical forecast models. All tropical vortices are identified in analysis and forecast fields based on a minimum 850 hPa relative vorticity threshold. Additionally, for tropical vortices within a specified percentage of the minimum vorticity threshold, it is required that a majority of the vorticity is due to curvature versus shear. Tracks of all vortices are constructed based upon several criteria, including heading and speed of motion. Forecast vortices are matched to analyzed vortices based on criteria that include distances that vary with forecast interval. Additionally, analyzed and forecast

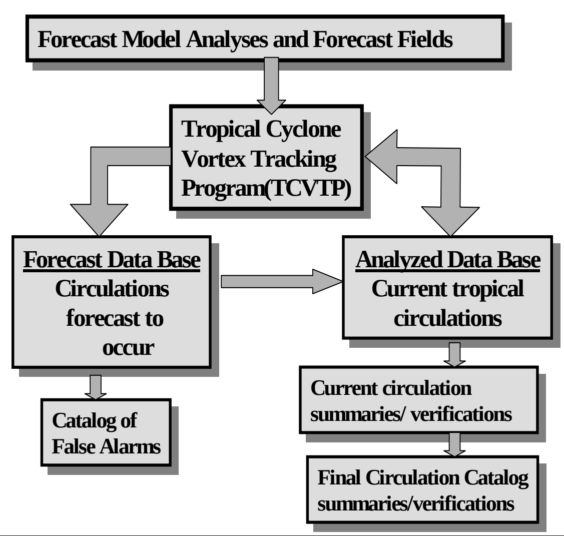


Figure. 1. *Schematic of the components of the primary processing component of the VORTRACK system. This component identifies, tracks, and catalogs all eligible tropical vortices contained in several operational global numerical forecast models.*

physical parameters (Table 1) that are relevant to TC formation are identified with respect to each precursor circulation. Model traits that are related to each current analyzed and/or forecast circulation are summarized at each analysis time. Upon the completion of a circulation's life cycle as either a non-developing (with respect to TC formation) or developing system, a comprehensive summary of the model performance is made and cataloged for comparison with future circulations.

850 hPa relative vorticity	Sea-level pressure minimum (mb)
Shallow vertical wind shear (850-500 hPa)	Deep vertical wind shear (850-200 hPa)
850-200 hPa geopotential height thickness	700-500 hPa warm core
Vertical motion at 500 hPa	700-400 hPa warm core
700-500 hPa Vapor pressure	700-300 hPa warm core
850-500 hPa average relative vorticity	Sea-level pressure difference between the vortex and the environment
Total Precipitation	Convective Precipitation

Table 1. *Analyzed and forecast quantities used to identify physical characteristics associated with each tropical vortex. Warm core measurements are defined as a temperature difference between the vortex and the environment.*

The VORTRACK database is interactive via a web-based interface, allowing a user to examine current forecasts and verifying forecasts associated with each tropical vortex. A summary webpage is maintained for each global model (Fig. 2) for each time. On each page, current vortices and TCs are listed with options to examine data in tabular or graphical format, current errors with respect to the 14 parameters in Table 1, and displays of analyzed and forecast tracks.

Following specified periods of time (i.e., monthly, seasonal), various types of model summaries may be constructed. Queries to the database are constructed to extract information to examine model performance. As experience with the database increases, the library of queries will expand to accommodate user's interests in defining model evaluation measures.

3. PRELIMINARY RESULTS

The VORTRACK database is used to examine various aspects of global model forecasts associated with TC formation during the 2005 Atlantic hurricane season. In this study, 24 TCs are analyzed (Table 2). All storms following Alpha were not included, and Vince was not included.

Figure. 2. *A sample web page that allows views of current model output. Each light blue colored section corresponds to specific views of the current model output with respect to current TCs (top section), invest systems (middle section), and other tropical vortices (bottom section).*

TS Arlene	TS Bret	Hurricane Cindy
Hurricane Dennis	Hurricane Emily	TS Franklin
TS Gert	TS Harvey	Hurricane Irene
TD 10	TS Jose	Hurricane Katrina
TS Lee	Hurricane Maria	Hurricane Nate
Hurricane Ophelia	Hurricane Philippe	Hurricane Rita
TD 19	Hurricane Stan	TS Tammy
TD 22	Hurricane Wilma	TS Alpha

Table 2. *All TCs included in the analysis of global model performance with respect to TC formation.*

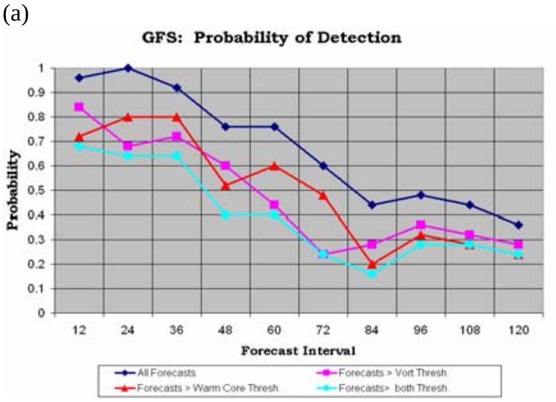
The formation time for each TC in Table 2 is defined as the time that the first advisory was issued by the National Hurricane Center. Although forecast data were included in the VORTRACK system at 6-h intervals, analyses were only available at 12-h intervals. Therefore, if the formation time was between 12-h intervals, it was lowered to the closest 12-h time prior to the actual formation time. The formation time was assigned to be earlier because NOGAPS and UKM model analyses after the formation time would include the synthetic bogus, forcing a TC into the model analyses.

By definition, a TC at the time of formation will have positive relative vorticity and a warm core over the middle troposphere. Based on analysis fields, the values of vorticity from 850 hPa to 500 hPa and the warm core measured from 700 hPa to 500 hPa at the formation time were used to define threshold values (Table 3) associated with formation in each model. While there are a variety of ways to examine the forecasts associated with TC formation, summaries based on probabilities of detection and a measure of false alarms will be presented.

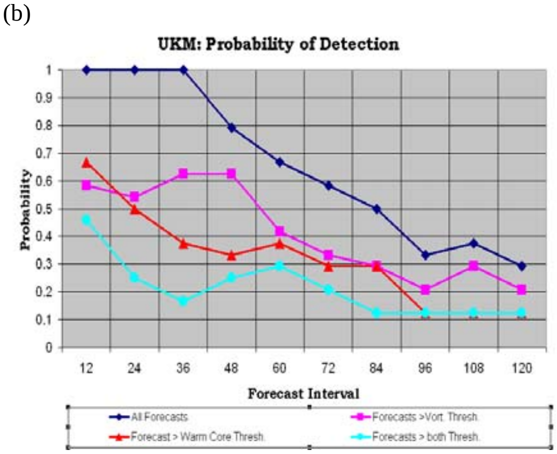
Model	850 – 500 hPa Vorticity Threshold (10^{-5} s^{-1})	700 – 500 hPa Warm Core Threshold (K)
GFS	4.32	0.19
UKM	3.67	0.18
NOGAPS	3.25	0.14

Table 3. *Threshold values of vorticity and warm core for each model based on the formation time of the TCs in Table 2.*

(a)



(b)



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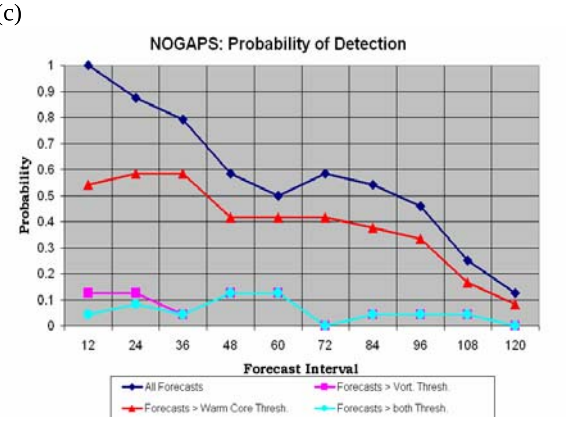

Figure 3. *Probability of detection for forecasts of TC formation based on all storms in Table 2 for (a) the GFS, (b) the UKM, and (c) NOGAPS.*

a) Probability of Detection

A probability of detection (POD) for each model was identified by examining forecasts at intervals from 12 to 120 h that verified at the formation time. Results are shown in Fig. 3. The POD was defined based on all forecasts that verified and were above the vorticity threshold, all forecasts that verified and were above the warm core threshold, and all forecasts that verified and were above both thresholds. Ideally, there could be 24 verifying forecasts for each forecast interval (12 h – 120 h). However, the number of verifying forecasts drops as the forecast interval increases. This could be due to the model not forecasting a vortex of sufficient strength to be tracked, or the forecast vortex was too far from the analyzed vortex to be within the limiting values for assigning a forecast track to an analyzed track.

Overall, the GFS model exhibited the highest POD values and NOGAPS exhibited the lowest values. There were interesting variations with respect to whether the vorticity or warm core thresholds were exceeded. For example, NOGAPS exhibited a large POD with respect to forecasts that exceeded the warm core threshold, but had an extremely low probability of detection for forecasts that exceeded the vorticity thresholds. Whereas the POD values for the GFS model associated with forecasts that exceeded vorticity and warm core thresholds were nearly the same, the POD for UKM forecasts that exceeded the warm core were consistently lower than the values associated with forecasts that exceeded the vorticity threshold.

b) False Alarms

An important aspect of the VORTRACK system is its ability to track and catalog parameters associated with tropical vortices that do not become TCs. This allows assessment of false alarms. As a first step, an analyzed non-developing vortex (Table 4) was defined as any vortex in which the vorticity and warm-core threshold thresholds were not exceeded by the analyzed values. Furthermore, the vortex must have existed in a minimum of three consecutive 12-h analysis fields. This condition was required to remove spurious, short-lived vortices and to ensure that the vortex survived at least one diurnal cycle. Clearly, the total number of tropical vortices tracked in each model is very consistent (Table 4). Based on the thresholds for 850 hPa – 500 hPa vorticity and 700 hPa – 500 hPa warm core values (Table 3), all non-developing vortices that had forecasts at *any* interval that exceeded the thresholds were identified (Table 4). Admittedly, this is a cursory estimate of false alarms as no regard is given to the forecast interval or number of individual forecasts. However, it is clear that approximately 5% of the non-developing vortices in the GFS model had some forecasts that exceeded both thresholds. Only 2% of the non-developing forecasts in NOGAPS exceeded both thresholds and approximately 4.5% of the UKM forecasts exceeded both thresholds. If only the vorticity threshold need be exceeded, then approximately 10% of the GFS, 5.4% of the NOGAPS, and 8.7% of the UKM forecasts exceed the threshold. The number of false alarms in terms of vortex numbers is consistent with the POD. The GFS model has the highest POD and the highest number of false alarms while NOGAPS has the lowest POD and the lowest number of false alarms. It is clear from Table 4 that between 35% and 40% of forecasts of non-developing vortices exceeded the warm core threshold. This was found by Cowan et al. (2006) in their examination of potential predictors for a Discriminant analysis to identify forecasts of developing versus non-developing vortices.

Model	Non-developers (ND)	ND > both thresh.	ND > vort thresh.	ND > warm core thresh.
GFS	310	15	33	121
NOGAPS	315	6	17	121
UKM	309	14	27	101

Table 4. *Total number of non-developing vortices tracked in each model together with the number of non-developing vortices that had some forecasts that exceeded the vorticity threshold, warm-core threshold, or both thresholds.*

In the VORTRACK database, there are complete records associated with each non-developing forecast that contained forecasts that exceeded the thresholds. Further analysis of this preliminary data on false alarms will examine the characteristics associated with forecast interval and geographic location (Fig. 4). Furthermore, the characteristics associated with false alarms as revealed by additional parameters in the VORTRACK database are examined.

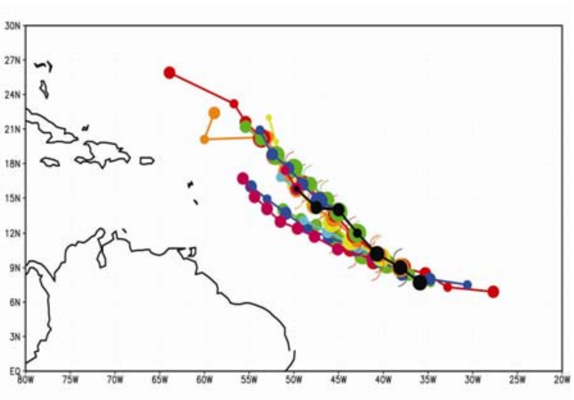

Figure 4. *An example of a non-developing tropical vortex that contained GFS forecasts that exceeded the vorticity and warm core thresholds. The black circles define the analyzed locations of the vortex in 12-h intervals. The colored positions and lines define forecasts at varying initial times. Forecasts that exceed the thresholds are plotted with a hurricane symbol.*

4. CONCLUDING REMARKS

An objective methodology to assess the prediction of tropical cyclogenesis in numerical models has been developed. Currently the technique uses threshold values of 850 mb relative vorticity and 700-500 mb temperature anomaly to specify the existence of a TC in the model fields. It was found that some global models, such as the GFS, provided quite reliable guidance (high POD with relatively few false alarms) for the prediction of TC formation in the Atlantic basin during 2005. Further applications of this technique are planned for upcoming hurricane seasons, so that the performance of the models can be tracked from year to year.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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