13B.3 OBJECTIVELY DETERMINED MODEL-DERIVED PARAMETERS ASSOCIATED WITH FORECASTS OF TROPICAL CYCLONE FORMATION

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1. INTRODUCTION

Improvements in operational global models have resulted in increased accuracy of 72-h tropical cyclone track forecasts. Therefore, in an effort to extend preparation lead-time, the National Hurricane Center (NHC) and the Joint Typhoon Warning Center (JTWC) began issuing track forecasts through 120 h in 2003. Since a tropical cyclone may form and intensify to a powerful storm within this 120 h window, there is an increased need for accurate prediction of tropical cyclone formation from operational global models. While it is important to establish the accuracy of forecasts of tropical cyclone formation in global models, it is also important to identify and understand factors that distinguish forecasts of circulations that develop into tropical cyclones from forecasts of vortices that do not develop.

To discriminate between forecasts of developing and non-developing vortices, it is necessary to catalog parameters that are relevant to tropical cyclone formation. These parameters must be identified in forecasts of varying lengths and in verifying analyses. Furthermore, it is important to capture these characteristics among several operational models.

An automated system for identification of forecast and analyzed characteristics of tropical vortices in operational global forecast models has been designed and implemented (Harr, 2006). The database defined by this Vorticity Tracking (VORTRACK) system is used in a combined cluster and Discriminant analysis of forecast and analyzed data to identify model parameters that have the most predictive value with regards to distinguishing between tropical vortices that are likely to develop into tropical cyclones and those that are not likely to develop. Therefore, the principal objective of this study is to create a tool that can estimate, from global model forecasts, the potential for a tropical vortex to develop into a tropical cyclone. This tool will be based on a probabilistic assessment of development derived from the linear discriminant analysis.

2. METHOD

Hennon and Hobgood (2003) suggest that several characteristics associated with the large-scale environment over the North Atlantic may provide significant measures that discriminate between cloud clusters that develop into tropical cyclones and those that do not develop. Using eight predictors from analyzed sets of large-scale fields, Hennon and Hobgood (2003) developed an objective tool, which was based on manual tracking of cloud clusters in satellite imagery, to determine the likelihood that a cloud cluster will develop into a tropical depression.

In the current study, an objective tropical vortex identification and tracking technique was utilized in the VORTRACK system to examine analyzed and forecast fields of three global operational numerical models during the 2005 tropical cyclone season over the North Atlantic and the eastern North Pacific. The three models examined include the Navy Operational Global Atmospheric Prediction System (NOGAPS), the Global Forecast System (GFS), and the United Kingdom Meteorology Office (UKMET) global model. Specifically, each model's performance with respect to forecasting tropical cyclone formation has been analyzed (Pasch et al. 2006). For each tropical vortex, which is defined by relative vorticity above a threshold value of 1.5 x 10^{-5} s^{-1}, fourteen parameters in model analyses and forecasts that are relevant to tropical cyclone formation (Table 1) are catalogued in the tropical vortex database.

Table 1. Model parameters defined for every circulation center that meets the tracking criterion.

850 hPa relative vorticity (10^{-5} s^{-1})
850-500 hPa average relative vorticity (10^{-5} s^{-1}) (ζ_{avg})
Shallow vertical wind shear (500 – 850 mb) (m s^{-1})
Deep vertical wind shear (200 – 850 mb) (m s^{-1})
850-200hPa geopotential height thickness (gpm)
Convective Precipitation
Total Precipitation
Vertical motion at 500 hPa
700-500 hPa vapor pressure
Sea-level pressure (SLP) minimum (mb) (SLP_{min})
SLP difference between vortex and environment (mb)
700-500 hPa warm core (K) ($WC_{700\text{-}500}$)
700-400 hPa warm core (K)
700-300 hPa warm core (K)

For each tropical vortex that did develop into a tropical cyclone during the 2005 season, the time of formation is defined as the time of the first best-track entry. Based on analyzed values from each model, threshold values for each of the fourteen parameters at the time of formation are defined. Cluster analysis is used to examine

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Corresponding author address: Christy G. Cowan, Dept. of Meteorology, Naval Postgraduate School, Monterey, CA 93943; email: cowan@nps.edu each parameter's ability to discriminate whether forecasts of a vortex belong to the group of developing vortices or non-developing vortices. A fuzzy discriminant analysis is then used to develop a weighted linear combination of parameters that will most accurately discriminate between developers and non-developers. The use of fuzzy boundaries allows the consideration that a parameter lies between groups rather than demanding a hard classification. Therefore, a probabilistic assessment is made based on the strength of association between a predictor and each cluster. This method is then further extended towards consensus forecasting to create a multi-model weighted combination

3. EXAMPLE

Given a parameter from Table 1, P (e.g., ζ_{avg}, $WC_{700\text{-}500}$, SLP_{min}, etc) there is a threshold value, P_T, that is defined as the parameter average at the time of tropical cyclone (TC) formation, defined as T_0 in Fig. 1. Prior to intensifying to a tropical cyclone, a tropical vortex may have existed for some time, which is defined as T_{-60}, T_{-48}, etc., in Fig. 1. Throughout the life of the vortex, forecasts of P are made and verify at each analysis time defined along the abscissa in Fig. 1. Therefore, at T_0, there may be several verifying forecasts of varying forecast intervals (i.e., +12, +24, +36, etc.). If the analyzed vortex SLP in Fig. 1, is a developing tropical cyclone that formed at T_0, then, as drawn, no forecasts exceeded the threshold value for formation. Therefore, there was no forecast indication that this vortex would become a tropical cyclone. For each τ, we can compute the probability that the observed P will exceed P_T given that it was forecast to exceed P_T.

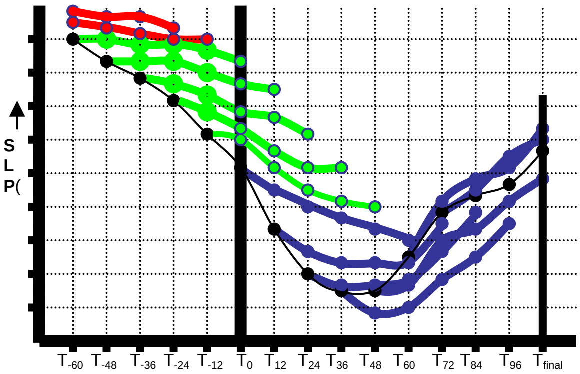


Fig 1. Schematic sea-level pressure (ordinate) trace for a tropical vortex that was identified as a tropical cyclone at T_0 (abscissa). The black circles connected with the black line define the analyzed sea-level pressure. Blue lines and circles represent forecast made after formation. Green lines and circles represent forecasts made prior to formation, but after the tropical vortex formed. Red lines and circles represent forecasts made prior to the formation of the vortex.

If some forecasts do indicate that the tropical vortex will intensify to tropical cyclone strength (Fig. 2), then there is an indication of formation that was made at varying time distances prior to the actual formation. At the time of formation in Fig. 2, verifying 12-h, 24-h, and 36-h forecasts indicated a SLP below the threshold. However, verifying 48-h and 60-h forecasts did not indicate formation. Therefore, three of five verifying forecasts indicated formation. As time proceeds from left to right in Fig. 2, the question is then when is there significant indication that the vortex will intensify to a tropical cyclone? Prior to T_{-24} no forecasts were below the threshold, then some forecasts were indicating formation. Therefore, at T_{-24} forecast characteristics shifted from the group of non-developing forecasts to the group of developing forecasts. Consequently, the probability that this vortex will develop into a tropical cyclone increases.

Based on the 14 parameters associated with forecasts and analyses of every tropical vortex in the VORTRACK database, it is possible to establish clusters that are associated with developing and non-developing vortices. Then, current forecasts may be classified in terms of the probability that it belongs to each group. Initially, the group characteristics must be identified for each parameter. However, it is possible that a forecast model may not be able to distinguish between developing and non-developing vortices. In this case, it would not be possible to identify groups into which individual forecasts may be classified to discriminate between developing and non-developing cyclones.

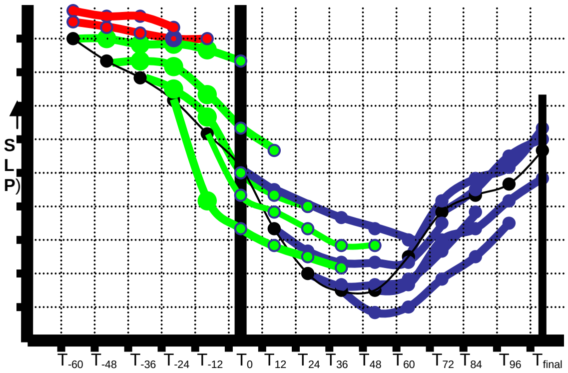


Fig. 2 As in Fig. 1, except forecast below the SLP threshold at T_0 are depicted.

By definition, a tropical cyclone will have positive relative vorticity throughout the lower troposphere (ζ_{avg}) and a warm core ($WC_{700\text{-}500}$). Both of these parameters are contained in the VORTRACK database. As an example, consider only *one model* and only ζ_{avg} and $WC_{700\text{-}500}$ at verifying forecast times of τ= -12, -24, -36, -48, -60, -72, -84, -96, -108, and -120 hours. The forecast verifying time is defined to be at T_0 (formation time). The threshold values (ζ_T and WC_T) are computed from the set of analyzed formation cases over the Atlantic during 2005. Ideally, for each T_0, there would be 10 verifying forecasts. However, the number of verifying forecasts is typically reduced as a model may not forecast the vortex at medium ranges, or it may not be sufficiently close to the verifying position to be associated with the analyzed vortex. In the discriminant analysis for this example, there are k=20 attributes (ζ_{avg} and $WC_{700\text{-}500}$ at each of the 10 forecast times), g=2 groups (developing and non-developing), and n cases.

To simplify the discriminant analysis it is necessary to reduce the number of possible predictors. Each attribute (i.e., VORTRACK parameter) at each forecast time, is first examined to determine if it exhibits a tendency to discriminate between the two groups. This is simply done by examining scatter plots (Fig. 3) to determine if there is a separation between forecast values (for each attribute and forecast time) associated with non-developers and developers.

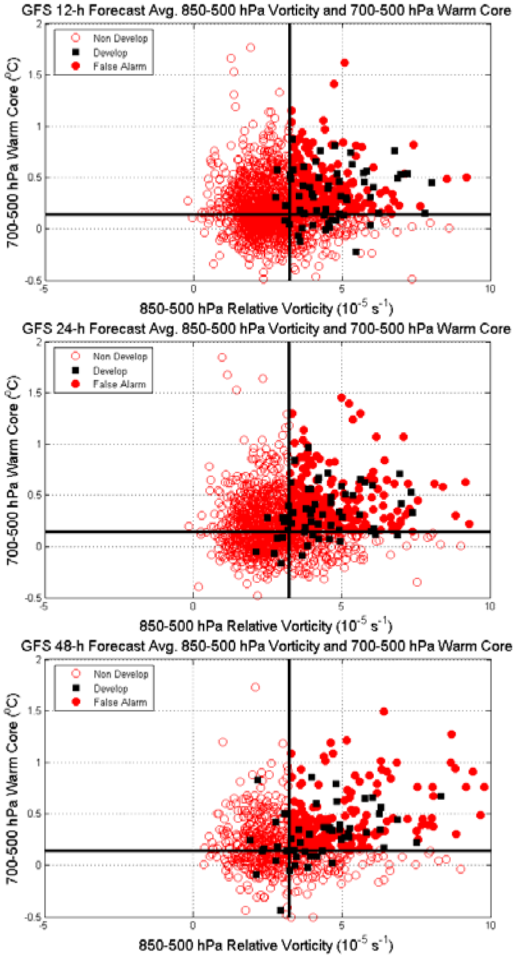


Fig. 3 Scatter plots of $WC_{700-500}$ and ζ_{avg} for (top) 12-h forecasts, (middle) 24-h forecasts, and (bottom) 48-h forecasts from the GFS model. The vertical black line defines the vorticity threshold and the horizontal black line defines the WC threshold. Red open circles define forecasts of non-developing vortices. Red closed circles represent forecasts associated with non-developing vortices that were forecast to have values above the WC and ζ thresholds. Black squares are associated with forecasts with developing vortices.

For the GFS model, there is a rather well-defined separation between forecasts associated with developing and non-developing vortices. However, there is also a rather large set of non-developing vortices that have forecasts above the vorticity and warm core thresholds, which are false alarms. While these two parameters do discriminate between developing and non-developing vortices, they do not discriminate between developing vortices and false alarms. Therefore, additional parameters will be examined to determine if they will contribute to further discrimination between groups.

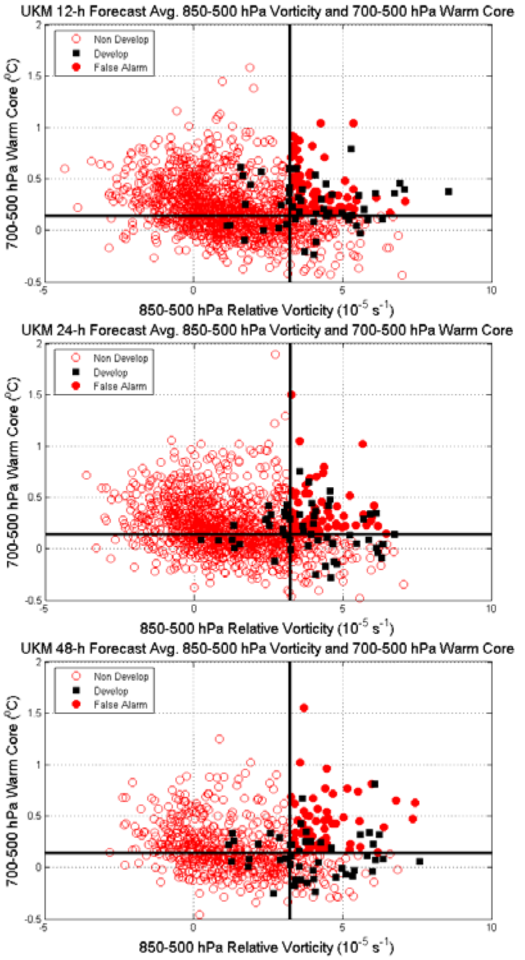
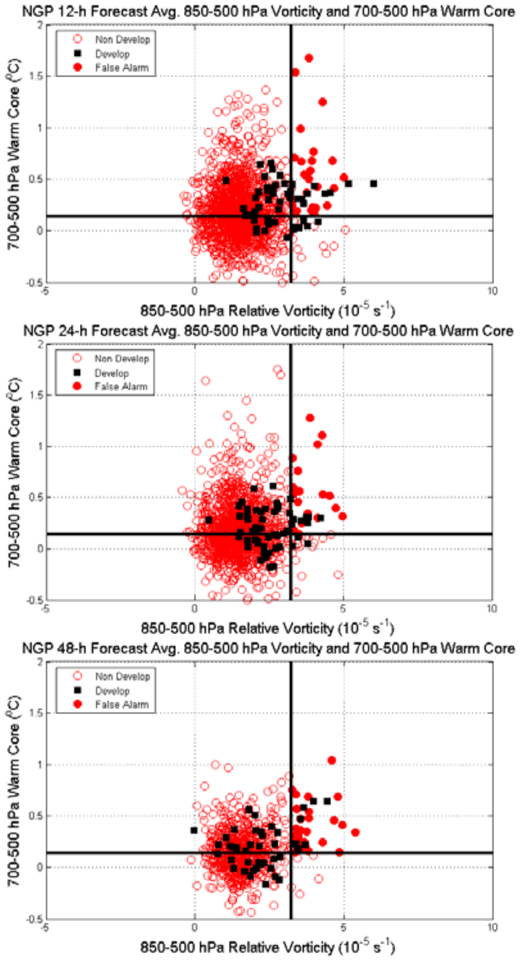


Fig. 4 As in Fig. 3, except for the UKMET model.

While the UKMET model (Fig. 4) does not exhibit as many false alarms as the GFS model, the separation between forecast parameters associated with developing vortices and non-developing vortices is not as large as with the GFS model. However, the separation does increase as the forecast interval decreases. This trait was not clearly exhibited in the GFS model. Also, while vorticity forecasts from the UKMET model seem to discriminate between groups, the warm core forecasts do not discriminate between groups.

Although the NOGAPS model contains the smallest number of false alarms, there is essentially no separation between forecasts of developing and non-developing vortices. While the separation does increase with decreasing forecast interval, it is not enough to suggest that these parameters would be useful in classifying forecasts between groups.



From this initial analysis, it is clear that a limited set of predictors may not be able to discriminate between forecasts of developing and non-developing vortices. Furthermore, the ability to discriminate between groups may not be evident until short forecast ranges. Then, the utility of the global model forecasts must be weighed against that of other data sources such as analysis of satellite signatures associated with the vortex convection.

The examination of the remaining VORTRACK parameters is being undertaken. Parameters that indicate significant predictive value with regards to formation will be included in the data matrix for use in the fuzzy linear discriminate analysis.. A final step will be to make the input data matrix multi-model. .

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