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PHASE SPACE-BASED EVALUATION OF NUMERICAL FORECASTS OF CYCLONE STRUCTURE EVOLUTION

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1. INTRODUCTION

Evaluations of the accuracy of the track and intensity forecasts is the traditional mode of verification for operational model simulations of tropical cyclones. While these characteristics are clearly important for identifying areas at most risk from the high wind core of a particular storm, the regions of damaging winds, precipitation, and wave activity are typicallly much greater in extent than the radius of maximum winds. Since cyclone structure is directly linked to the intensity and distribution of these sensible weather effects, mapping the evolution of the broadscale storm structure provides guidance on the likely intensity and distribution of its associated weather.

Although structure is clearly an important cyclone characteristic, validation of cyclone structure forecasts in operational numerical models has not been performed previously. The process of extratropical transition (ET) leads to immense changes in cyclone structure, thus a subset of storms that undergo ET provides an ideal testbed for evaluating structure change forecast skill in an operational model.

In this paper we propose a novel method for assessing operational forecasts of tropical cyclone lifecycles. The *Cyclone Phase Space* (CPS) of Hart (2003) is used to characterize and compare analyzed and forecast cyclone structures from operational numerical models. The CPS provides an objective measure of cyclone structure for model forecast validation and has been shown to capture the onset and completion of ET (Evans and Hart 2003). CPS-derived diagnoses of storm structure forecasts from the AVN and NOGAPS are compared with their verifying analyses out to 36 h. We employ the 7-cluster k-means solution of Arnott et al. (2004) as a baseline for these comparisons, with the goal of developing an objective reference frame for the validation of numerical model forecasts of storm structure.

2. METHODS

Two operational models are investigated: the Navy's NOGAPS[1] (Hogan and Rosmond 1991) and the NWS/NCEP AVN[2] model (Kanamitsu 1989).

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[1] Navy Operational Global Atmospheric Prediction System
[2] NWS National Centers for Environmental Prediction Aviation model, now known as the Global Forecast System, or GFS

The 1998-2002 Atlantic hurricane seasons are studied. This gives a dataset of 19 storms, resulting in 387 individual storm analysis times.

Substantial changes in the AVN initialization procedure prior to the active phase of the 2000 Atlantic season (Q. Liu 2003, personal communication) made it necessary to partition forecasts from this model into two sub-classes: from 1998-1999, the AVN initialization incorporated a synthetic vortex, so we refer to the model in this time period as AVN_{SV}; from 2000 forward, no synthetic vortex was used, but the vortex resulting from assimilation of all available observations was relocated to the operational fix, so this version of the model (covering the 2000-2002 storms) will be referred to as AVN_{VR}.

The three CPS parameters are: (i) the lower- and (ii) upper- tropospheric thermal winds (referred to as $-V_T^L$ and $-V_T^U$ respectively) and (iii) the lower-tropospheric thermal asymmetry (*B*) (Hart 2003). These three parameters are sufficient to distinguish when a TC commences and completes ET (Evans and Hart 2003). These are evaluated for each analysis and forecast time of each storm.

K-means clustering of the analysis times for each model realization (*NOGAPS*, AVN_{SV} and AVN_{VR}) resulted in a baseline climatology for each model. The resulting clusters for NOGAPS are shown in Fig. 1 (only *B* vs. $-V_T^L$ shown) and their correspondence between cluster membership and NHC classifications of Saffir Simpson scale (for the same storm times) are given in Fig. 2. The mean lifecycle of an ET event is indicated by the heavy arrows between the clusters. Clusters 2 and 3 are the "tropical" clusters, with most intense hurricanes in cluster 3; storms *undergoing* transition are in cluster 4. Correspondence between cluster membership with storm intensity and storm type is clear, confirming the ability of the CPS to represent structural factors important to storm intensity.

3. RESULTS AND DISCUSSION

Forecast structure was evaluated both via direct comparison of the forecast and validation time CPS values and by cluster comparisons. The second method is discussed here (see Evans et al. 2006 for results from the first method). Since each model has its own climatology and, without objective methods of determining the storm CPS directly from observations (not routinely available) no model can be taken as "truth." Thus (as noted above), the clusters determined from applying the k-means technique to the analysis sets for each model realization were used as the baseline for that model – i.e. NOGAPS forecasts were compared to NOGAPS analyses and so forth.

To determine forecast success, CPS values for each forecast were assigned to the cluster number (Fig. 2) corresponding to the closest centroid. A forecast is evaluated to be “correct” if the analysis and forecast clusters at that storm time are the same. A summary statistic, S, was used to record the percentage of successful forecasts for each forecast lead time for each model (Fig. 3).

Key results from this analysis include that structure forecasts are shown to depart from the verifying analysis as forecast lead time increases. Further, biases in forecast cluster membership differ based upon the initialization procedure of the model being assessed.

The specific example of NOGAPS 36h forecasts is given in Fig. 3. Clearly, at this lead time there are structure validation issues for almost all storm types, but particularly for tropical (clusters 2 and 3) and transitioning (cluster 4) storms. This result was also evident for the other initialization method that imposed a strong tropical vortex in the initialization, AVN_{SV}.

4. FUTURE WORK

Inclusion of ET cases from the 2003-2005 seasons will increase the number of available forecasts for longer lead times, enabling the calculation of meaningful statistics at these forecast times. This work is ongoing.

5. ACKNOWLEDGEMENTS

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FIGURES

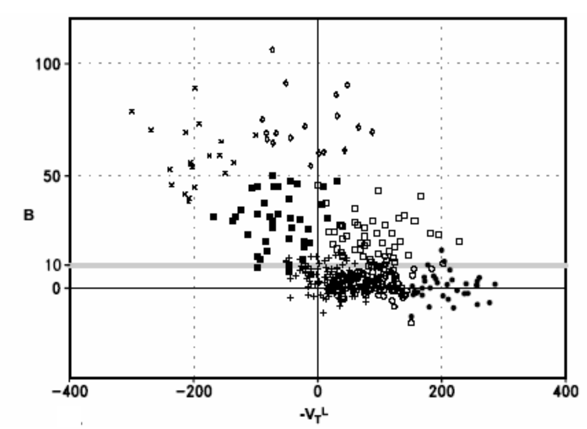

Figure 1. NOGAPS k-means solution for seven clusters. Only the $-V_T^L$ vs. B projection of the CPS is shown here.

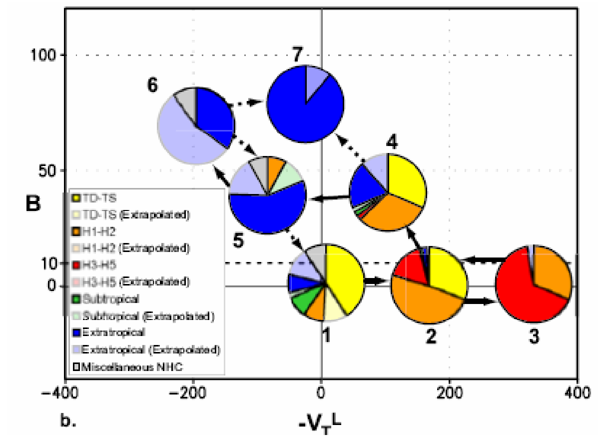

Figure 2. NOGAPS relative k-means cluster locations and NHC determined Saffir Simpson classification.

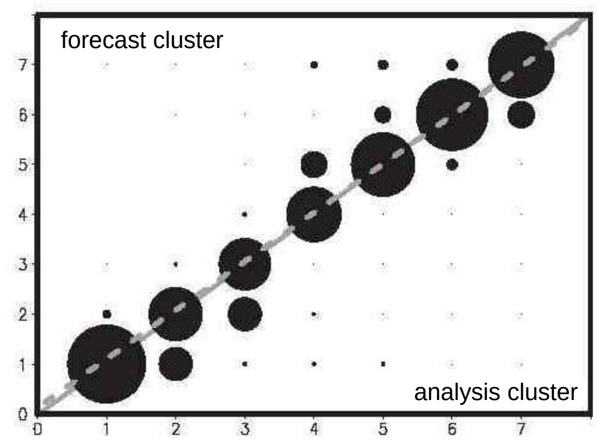

Figure 3. Comparison of analysis (abscissa) versus forecast (ordinate) cluster membership for 36h forecasts of North Atlantic ET events using the NOGAPS model. Circle size is proportional to percent of forecasts in the overlapping set (analysis cluster, forecast cluster).

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