16D.6 A CLUSTER ANALYSIS DERIVED SYNOPTIC EVOLUTION OF EXTRATROPICAL TRANSITION IN THE NORTH ATLANTIC

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1. INTRODUCTION

The definition of *extratropical transition* (ET) is generally accepted to describe the evolution of a tropical cyclone into an extratropical cyclone. This transition involves an evolving cyclone structure that can bring ever-changing sensible weather effects to the public.

A first step in understanding ET is documenting the structural regimes characterizing ET cyclones. This step is crucial in understanding the evolution of such things as the wind and rain fields associated with ET events. In addition, knowledge of the different structures experienced by ET cyclones can help forecasters determine when a tropical cyclone is experiencing ET, leading to more timely and accurate forecasts. Finally, researchers can use this information to isolate ET events from other tropical cyclones, allowing for the possible development of a universal definition of ET.

It is equally important to determine the ever-changing environment surrounding the ET cyclone, since interactions between the cyclone and this environment are responsible for the cyclone's structural evolution. Identifying key environmental triggers for ET will allow for advanced warning of these events and will help forecasters isolate the most likely potential impacts a particular ET event will have on the public.

In this study, structure regimes derived from a non-hierarchical *cluster analysis* (CA) of ET events are used to infer the synoptic evolution surrounding the ET cyclone. The Cyclone Phase Space (CPS; Hart 2003) is used to diagnose the structure of the evolving ET cyclone (e.g. Evans and Hart 2003) and provides the framework for the development of the composite synoptic evolution.

2. ANALYSIS METHODOLOGY

2.1 Dataset and Cluster Analysis

The ET dataset consists of 19 Atlantic tropical cyclones declared extratropical by the National Hurricane Center over the years 1998-2002. CPS locations of these cyclones are generated using 12 hourly 1^{o} analyses from the Navy Operational Global Atmospheric Prediction System (NOGAPS). NCEP Global Forecast System (GFS) 12 hourly 1^{o} analyses comprise a second, distinct dataset used here.

A non-hierarchical (k-means) CA of the NOGAPS dataset reveals that 7 structure subgroups is a robust division of cyclone structures during ET. These subgroups include structures representative of tropical cyclones (clusters 1-3; fig. 1) and extratropical cyclones (clusters 5,6; fig. 1) (see Arnott and Evans 2004). The mean path taken by ET cyclones in the CPS is shown by the arrows (fig. 1), giving a structural evolution experienced by the typical North Atlantic ET cyclone.

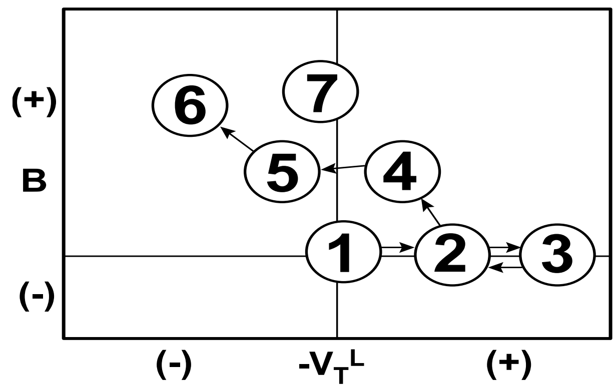

Fig. 1. The average CPS locations (B vs. $-V_T^L$) of the seven clusters from the k-means analysis of the NOGAPS dataset. Arrows indicate the mean path taken by North Atlantic ET events.

2.2 Synoptic Compositing

To derive the synoptic evolution of ET in the North Atlantic, model analysis fields are composited for each of the seven clusters. The synoptic composites from clusters 2, 4, and 6 in the NOGAPS dataset are discussed here. These clusters represent unique stages of the ET process. The mean path of ET through the CPS (fig. 1) progresses through these clusters sequentially. Therefore, analyzing the synoptic patterns associated with these clusters in the context of the mean CPS path will uncover how the environmental features surrounding the transitioning tropical cyclone evolve during ET. Parallel analysis of the GFS data yields very similar results.

3. COMPOSITE SYNOPTIC CLIMATOLOGY

A distinct tropical low-pressure system, isolated from the mean westerlies to its north, is evident in the *cluster 2 composite* (fig. 2a). The tropical low is approximately 25^{o} east of a positively-tilted upper-level synoptic-scale trough that overlies a weakness in the subtropical ridge surface pressure pattern. Cluster 2 cyclones exhibit a vertically oriented positive potential vorticity (PV) anomaly and an isentrope pattern consistent with the vertically aligned warm core associated with tropical cyclones (fig. 2d).

In the *cluster 4 composite*, the tropical low pressure system begins to become embedded in the mean westerly flow to its north (fig. 2b). The cyclone, now west-northwest of the subtropical ridge, is recurving. The ver-

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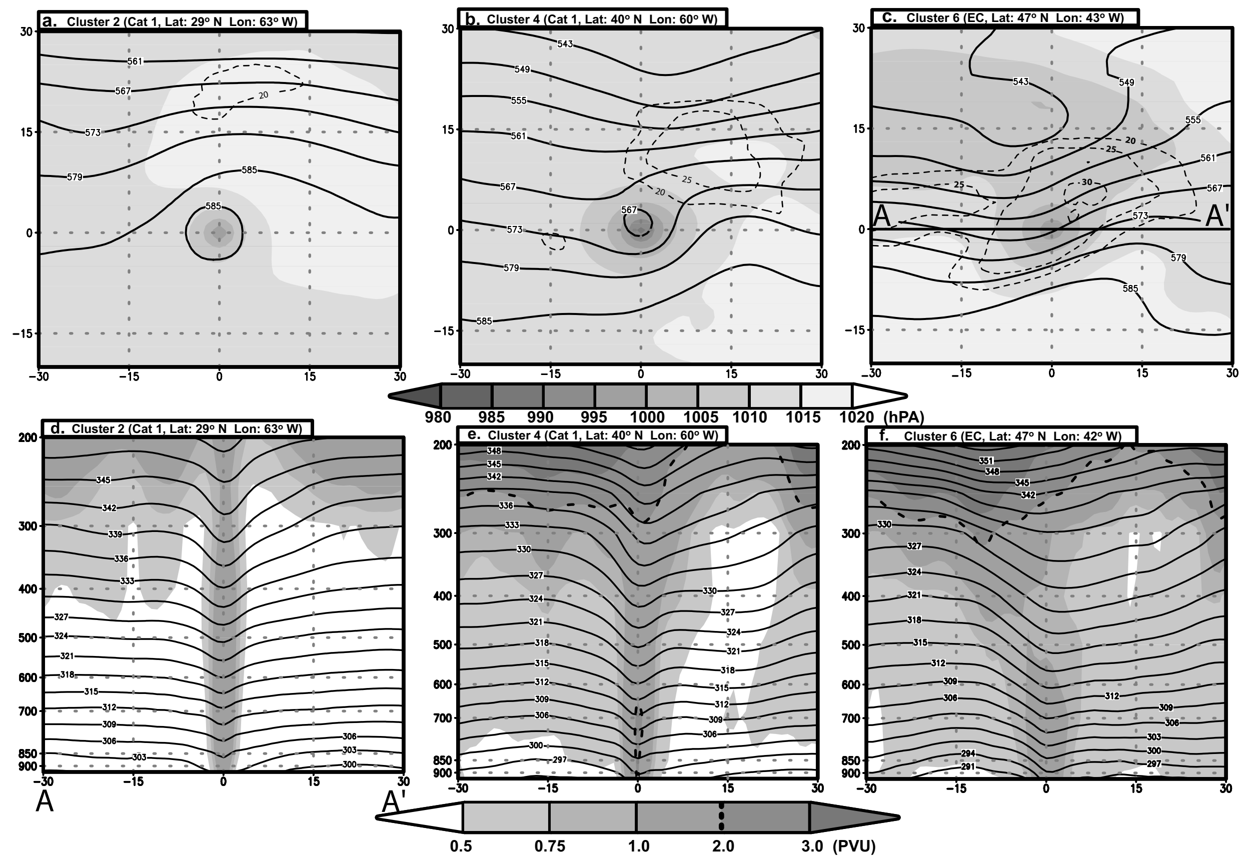

Fig. 2. (a-c) 500 hPa heights (contoured; interval 3 dm) sea level pressures (hPa; shaded, color bar) and 300 hPa wind velocity (dashed; interval 5 ms^{-1} above 20 ms^{-1}) for clusters 2, 4, and 6. (d-f) Vertical cross section [along A-A' shown in (c,d)] of potential temperature (contoured; interval 3K) and potential vorticity (PVU; shaded, color bar below) for clusters 2, 4, and 6. Top of each figure indicates cluster number, National Hurricane categorization of the majority of cyclones in the cluster, and the mean latitude and longitude for cyclones in each cluster.

tical cross-section (fig. 2e) shows that the PV anomaly associated with the tropical cyclone has developed a positive (west to east) tilt with height and is larger in horizontal extent. These changes are consistent with the increasing asymmetry ($\delta B>0$) of the cyclone. The isentrope pattern continues to suggest a warm core and the interaction of this pattern with that of the upstream trough (now 15^{o} west of the cyclone) creates a region of steeply sloped isentropes west of the cyclone, conducive to heavy precipitation (Atallah and Bosart 2003).

The *composite cyclone in cluster 6* is no longer a tropical system: the cyclone is now situated below the upper level jet and is approaching a larger scale surface low-pressure system to its north (fig. 2c). The positive PV anomaly associated with the cyclone core is broader, and no longer vertically aligned but rather sloping to the west with height (fig. 2f). A deep cold anomaly associated with the upper level trough tilts westward (and northward, not shown) with height to the west of the cyclone, with warmer air over the surface low. All of these characteristics are consistent with the structure of a mature extratropical cyclone.

4. CONCLUSIONS

A non-hierarchical CA of cyclone structures in tropical cyclones undergoing ET in the North Atlantic over the past 5 years reveals seven repeatable structure clusters. A composite synoptic evolution derived using these clusters demonstrates that each cluster represents a distinct stage of the ET process. Viewing these composites following the mean CPS path of ET cyclones demonstrates a logical progression of the synoptic pattern during ET.

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