13D.3 EXTRATROPICAL TRANSITION: ONE TRAJECTORY THROUGH CYCLONE PHASE SPACE

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1. INTRODUCTION

A phase space has been proposed for diagnosing the evolving structure of all synoptic-scale cyclones (Hart 2002). This phase space represents a continuum of possible storm structures, characterized via their lower tropospheric (900-600hPa) thermal symmetry (B) and lower (900-600hPa) and upper (600-300hPa) tropospheric thermal wind measures ($-V_T^L$ and $-V_T^U$, respectively; Hart 2002). The phase space can be used to diagnose the evolution of cyclones that undergo single phase (pure tropical or extratropical cyclone) or multiple phases of existence (extratropical transition, tropical transition). The extratropical transition of tropical cyclones (TCs) is examined here as one trajectory through the phase space. The transition of a TC into an extratropical cyclone involves a dramatic evolution of energetics (Palmen 1958), structure (DiMego & Bosart 1982a; Harr & Elsberry 2000), and potentially predictability.

2. METHODOLOGY

The best-track dataset (Jarvinen et al., 1984) provides post-storm analysis of TC track, intensity, and phase. This dataset also provides one estimate of the conversion of the tropical cyclone into an extratropical cyclone. High-resolution (1.125° X 1.125°, 31 levels) European Center for Medium Range Weather Forecasting (ECMWF) reanalyses (Gibson et al. 1997) are used to further examine the transition lifecycle of 60 TCs from 1979 – 1993. For examination of the extratropical transition lifecycle, only the first of the two phase diagrams in Hart (2002) are examined here: $-V_T^L$ vs. B (Fig. 1). For each of 60 transitioning TCs from 1979-1993, phase diagrams of $-V_T^L$ Vs. B were examined for the initiation of extratropical transition, the completion of extratropical transition, and the length of the transition period. Finally, the evaluation of extratropical transition for an independent dataset (AVN and NOGAPS 1° operational analyses) for 1998-2001 are shown.

3. EXTRATROPICAL TRANSITION TRAJECTORIES

Cases of extratropical transition, while having their own unique details, all generally share the same direction of motion within the diagnostic cyclone phase space. The warm-core development of the TC intensification is exhibited as a rightward movement within the lower right quadrant (e.g. Fig. 1c). As the thermal gradient across the cyclone increases, the phase trajectory begins moving upward on the diagram. Extratropical transition is defined to begin here when the trajectory crosses B=10m (Section 4). At this point the cyclone resides in the upper right quadrant, which is asymmetric warm-core (hybrid structure). The strengthening thermal gradients across the cyclone lead to geostrophic adjustment of the cyclone and a weakening of the warm-core: the isobaric height gradient in the middle troposphere strengthens while the lower tropospheric isobaric height gradient weakens. Eventually, the thermal wind structure of the cyclone reverses to cold core ($-V_T^L$ becomes negative) and transition is defined to have completed (Section 4). Thereafter, the cyclone may evolve into a strong extratropical cyclone (Fig 1b,c) or may simply occlude and dissipate over the subtropics (Fig. 1a), largely depending on the upper level support for the cyclone (e.g. position with respect to a trough).

4. DIAGNOSING INITIATION & COMPLETION

Extratropical transition initiation within the cyclone phase space is diagnosed when the value of B exceeds 10m, as labeled on each of the three examples in Figure 1. The 10m threshold represents the distinction between an approximately tropical structure (thermally symmetric) and a marginally frontal structure (asymmetric). For the examination of 60 transitioning tropical cyclones (Figure 2) the upper limit for B for a TC of major hurricane (≥115kt) status was B≈10m. The 10-m threshold also provides for some freedom in accurate diagnosis of thermally symmetric TCs that, due to coarse resolution, may have a value for B that is close to, but not exactly, 0.

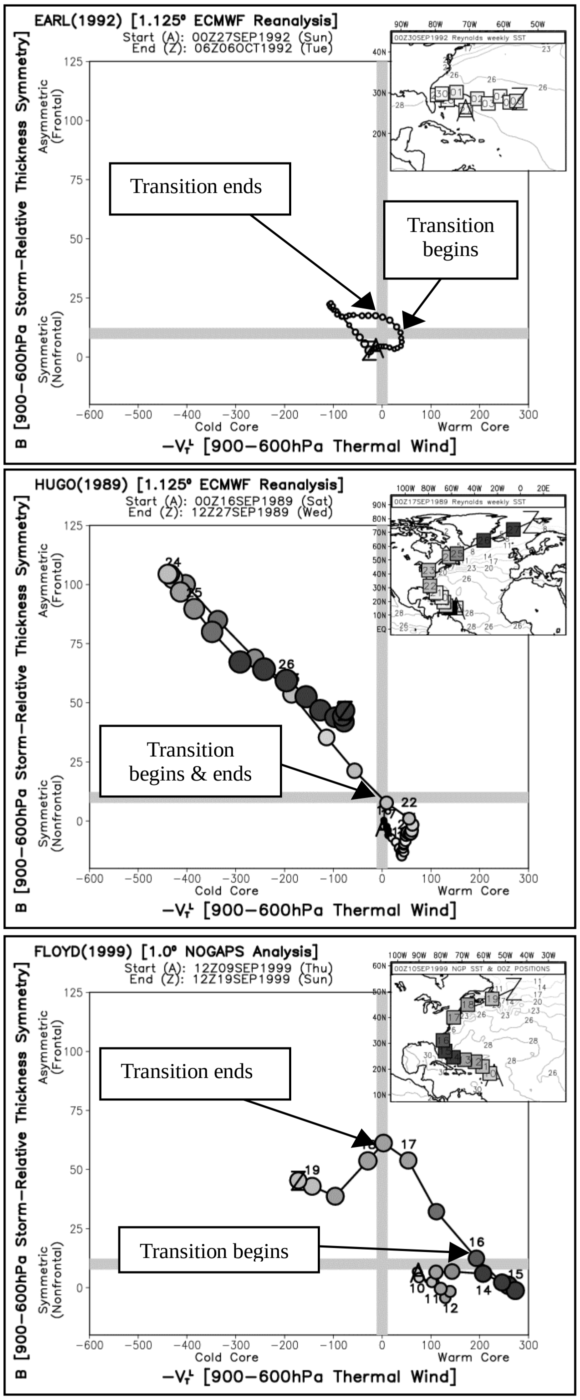

Figure 1: Illustrations of various trajectories of extratropical transition of TCs. a) Slow transition of a weak tropical storm [Earl (1992); 1.125° ECMWF reanalysis] b) Rapid transition of a landfallen hurricane [Hugo (1989); 1.125° ECMWF reanalysis]. c) Slow transition of a major hurricane [Floyd (1999); 1° NGP analysis]. The start and end of transition are labeled on each. 'A' indicates the beginning of the plotted lifecycle and 'Z' indicates the end. A marker is placed every 6hr in (a,b) and every 12hr in (c) to indicate analysis times. Positions at 0000UTC are labeled with the day (except on (a), for clarity). Marker shading indicates intensity (white > 1010hPa, black < 970hPa).

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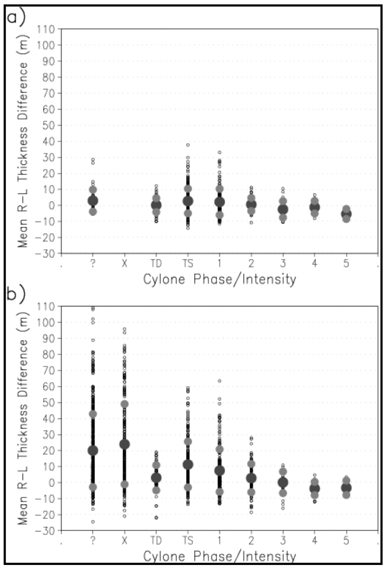

Figure 2: Scatter plot of NHC best-track cyclone phase/intensity versus B, for a) prior to peak best-track intensity and b) after peak best-track intensity. Mean value (dark larger circle) and one-standard deviation range (lighter larger circles) are denoted for each category. X= extratropical, TD=tropical depression, TS=tropical storm, 1-5= Saffir-Simpson (SS) hurricane scale. "?" = no best track data were available for that time (usually very early or late in the cyclone lifecycle). Data are from the full TC lifecycle of 60 transitioning TCs from 1979-1993 using 1.125°/31 level ECMWF reanalysis.

For those TCs that actually complete extratropical transition, such a status is diagnosed within the cyclone phase space when $-V_T^L$ becomes negative (cold-core thermal wind 900-600hPa structure). This diagnosis is also labeled in the examples within Figure 1. One independent measure of comparison for this transition completion diagnosis is the NHC best-track declaration of extratropical transition (Figure 3). The mean timing bias of –8 hr indicates that NHC generally declares transition completion 8hr later than the gridded ECMWF reanalyses would imply. While this is not a major difference in the mean, the large MAE and standard deviation imply that there are large case-to-case differences in transition lifecycle timing. These large differences are believed to be a result of the poor resolution of weaker storms. An independent sample of 13 TCs between 1998-2001 (e.g. Fig. 1c) using 1° operational AVN & NOGAPS analyses have shown improved agreement in transition lifecycle diagnosis between the best-track post-analysis and the thermal wind method described here. This may be attributable to an initially stronger warm-core signal in the operational analyses than the ECMWF reanalysis. This stronger warm-core signal may in part be due to the use of a bogus (synthetic) cyclone that is not present in the ECMWF reanalysis. The impact of the bogus in diagnosing and forecasting transition will be examined in the future.

5. TRANSITION PERIOD LENGTH & TRACK COMPARISON

Comparison of B=10m to $-V_T^L < 0$ gives the length of the transition period (Fig. 4), qualitatively represented by the period the cyclone exists in the upper right quadrant of Figure 1. TCs forming in the deep tropics generally transition more quickly (Fig. 5a), while those forming north of 20°N often take more than 3 days to transition (Fig 5b.)

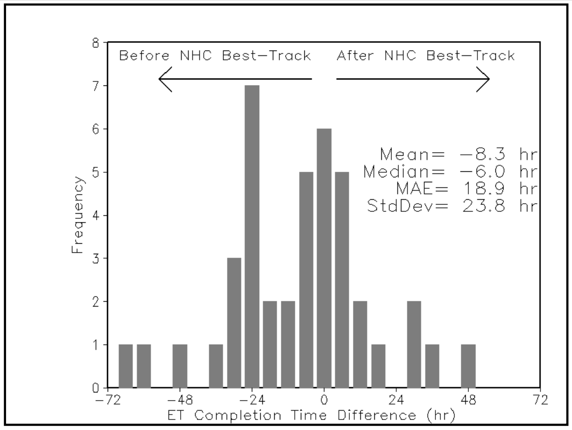

Figure 3: Comparison of best track transition completion time with the $-V_T^L < 0$ diagnostic of transition completion for 44 Atlantic TCs between 1979 and 1993.

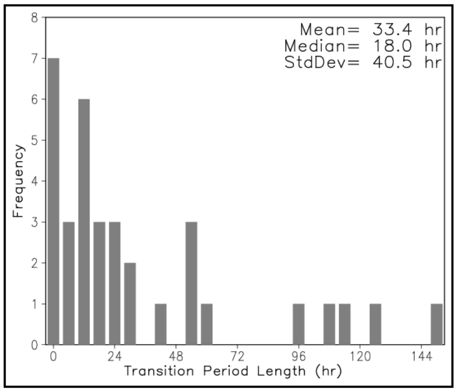

Figure 4: Frequency distribution of extratropical transition period length, i.e, the time elapsed after B=10m until $-V_T^L < 0$. While 60 transitioning cyclones were available within the 1979-1993 period of 1.125° ECMWF reanalyses used here, only 34 had unambiguous detectable signals in both diagnostics (generally the stronger cyclones) that allowed calculation of the length.

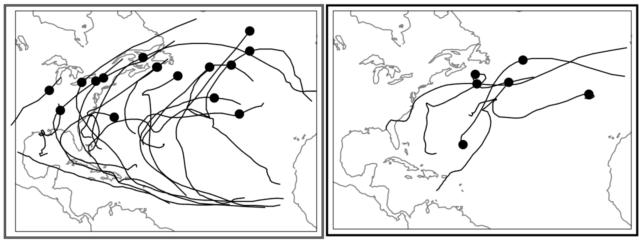

Figure 5: Comparison of the tracks of storms as a function of transition period length (Fig. 4): a) less than 18hr and b) greater than 72hr.

6. CONCLUDING SUMMARY

The extratropical transition of TCs as a trajectory through a diagnostic cyclone phase space was illustrated. The lifecycle of transition initiation, hybrid cyclone status, and transition completion are illustrated for 3 specific examples from a developmental dataset of 60 TCs (1979-1993) and an independent sample of 13 TCs (1998-2001). A typical transitioning Cape Verde TC will take less than 12hr to completion transition while a transitioning TC that forms north of 20°N may take more than 3 days to transition. The striking formation and track differences in Figure 5 strongly argue for a synoptic evaluation of the patterns differentiating slow vs. fast transitioners. This synoptic & phase space evaluation to identify patterns conducive to extratropical transition and rapid post-transition development is underway. Phase diagrams for the entire dataset as well as current and operational model - forecast cyclones can be found at: eyewall.met.psu.edu/cyclonephase.

7. ACKNOWLEDGMENTS & REFERENCES

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