P6.3 Using ERA40 in Cyclone Phase Space to Refine the Classification of Historical Tropical Storms

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I. INTRODUCTION

Understanding of cyclone structural evolution both during and beyond the tropical stage has increased tremendously over the past fifty years through various satellite-based, model-based, and analysis-based classifications. This new knowledge has brought forward the reanalysis of historical storms in the context of present understanding (Landsea et al. 2004) in order to extend and revise the National Hurricane Center's (NHC) North Atlantic hurricane database (HURDAT; Neumann et al. 1993). This reanalysis is vital for the filling of gaps within, and further improvement overall of the track and structural evolution of tropical cyclones.

II. DATA AND METHODOLOGY

Using ECMWF Reanalysis dataset (ERA40; Uppala et al. 2005), three parameters that classify a cyclone within a continuum of structure (warm to cold core, shallow to deep, and frontal to nonfrontal) can be calculated (Hart 2003). By plotting these three parameters against each other in a cyclone phase space (CPS), one can create a more complete description of the life-cycle of any particular cyclone. In this way, the structural classification of that cyclone can be scrutinized and refined within the best-track dataset. Though the hurricane reanalysis project officially covers the period from 1851 through the present, only the years from 1957 through 2001 are considered here due to constraints associated with the ERA40 data.

Prior to the inclusion of satellite data, cyclone observations (especially over the open ocean) were severely restricted. Thus, cyclones that occurred before the mid 1970s are often poorly represented in the ERA40 data which makes it quite difficult to refine the track or structure. For example, in the ERA40 representation of Category 3 Hurricane Donna (1960; not shown), the ERA40 showed no closed low, thus making the cyclone extremely difficult to locate, and even more difficult to evaluate structurally.

Beginning in 1973, the amount of satellite data assimilated into the ERA40 dataset increased continuously until it leveled off in the late 1980s. Thus, cyclone representation in the ERA40 data greatly improved. Consider the ERA40 CPS of Category 4 Hurricanes Esther (1961) and Gert (1999). The representation of Esther within the CPS shows a significantly weaker warm core than that of Gert (Fig. 1). Even with the addition of satellite data, however, cyclones remain grossly under-represented because of the ERA40 grid resolution of 1.125° (about 125 km).

The goal of this study is to, when feasible within the ERA40 data, extend and refine the structural characteristics of existing best-track cyclones. These refinements may include the tropical or extratropical transition points in the lifecycle or the genesis point of tropical cyclones that formed from cold-core origins. Finally, through a detailed examination of the full 45 years, several cyclones were found of warm-core or hybrid structure that may qualify for subtropical or tropical status, but were not documented within the existing best-track archive. Case examples of all these events are presented below, along with an evaluation of CPS intensity bias evolution over the ERA40 period.

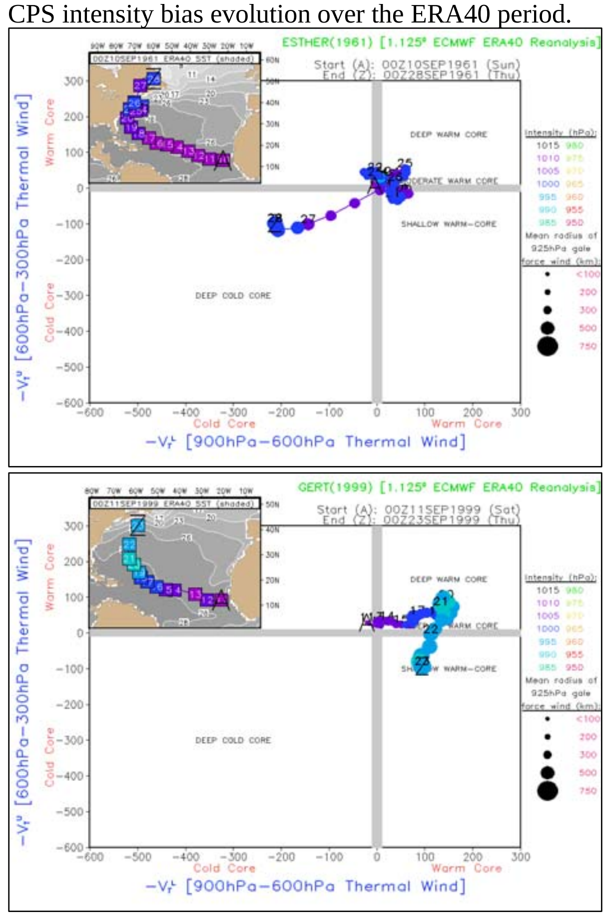

Figure 1: Comparison of the thermal structure of Hurricanes Esther (1961; top) and Gert (1999; bottom). Both hurricanes peaked at category four strength on the Saffir-Simpson scale. The vast difference in the CPS representation is probably due to the addition of satellite observations into the ERA40 dataset during the mid 1970s and early 1980s. 'A' and 'Z' refer to the start and end of the cyclone lifecycle, as tracked within the ERA40. Please see Hart (2003) for more detail on the cyclone phase space.

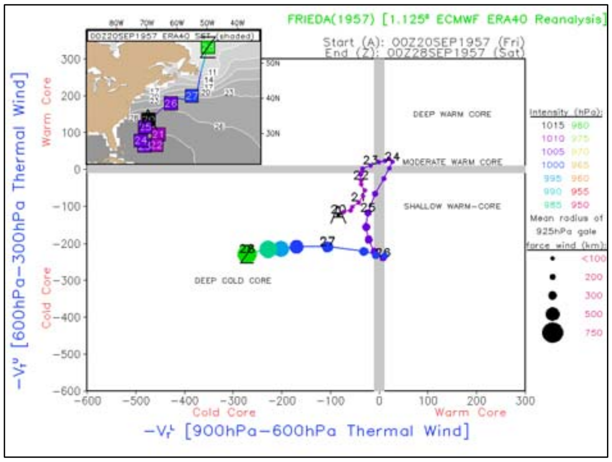

Figure 2: The ERA40 CPS of Hurricane Frieda (1957) shows a clear cold core (at point A, the 20th) prior to the tropical stage (moderate warm core) on the 24th.

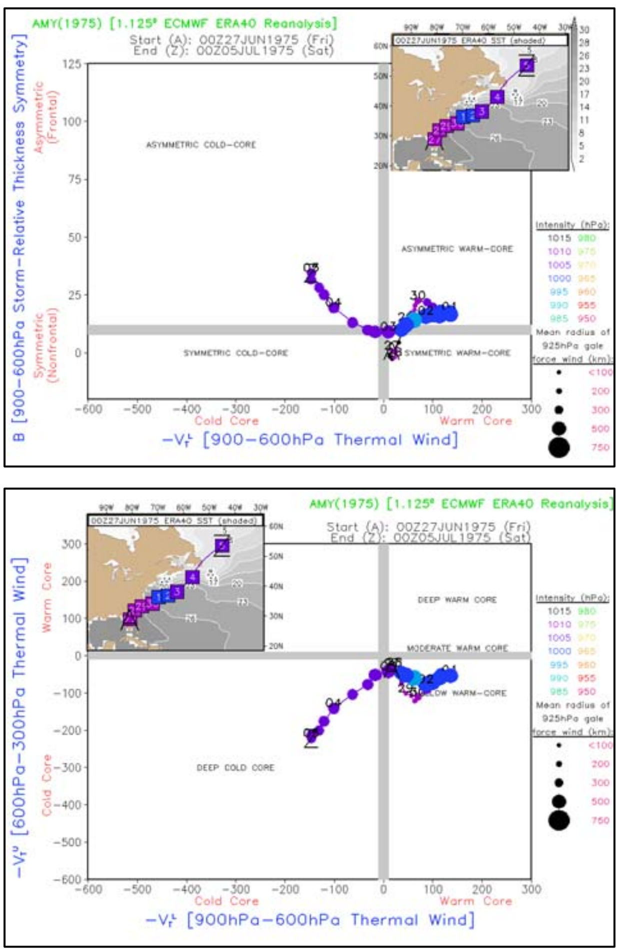

Figure 3: The ERA40 CPS of Tropical Storm Amy (1975) shows a structural more typical of a subtropical storm (asymmetric, shallow warm core), rather than a tropical storm (symmetric moderate/deep warm-core), as denoted in the best-track archive.

III. CASES

A. Refined genesis stage

In many cases, the best-track diagnosis of a cyclone begins with the tropical phase. However, many of these same cyclones actually had subtropical or even extra-tropical characteristics in their developing stages when they are tracked further back in time than the best-track origin, as shown by two examples below.

The ERA40 CPS of Hurricane Frieda (1957) shows a deep cold core (Fig. 2) and an asymmetric structure (not shown) for about three days prior to the development of a symmetric warm core structure. The asymmetric cold core structure suggests that Frieda actually developed from an extratropical feature rather than a tropical depression as indicated in the best track dataset. Furthermore, the NHC end of season report states that Frieda developed from a frontal system (Moore 1957), which supports the ERA40 CPS findings here that Frieda was initially extratropical in nature

The ERA40 CPS of tropical storm Amy (1975; Fig. 3) shows that it was probably subtropical in nature rather than tropical as suggested in the best track dataset. The ERA40 CPS indicates that Amy never developed the symmetric, deep warm core that is characteristic of tropical cyclones. In fact, the asymmetric ($B > 10$) shallow warm-core structure ($-V_T^L >> 0$ and $-V_T^U < 0$) denoted in Fig. 3 is typical of subtropical cyclones in the CPS (Hart 2003). Though the best track representation of Amy suggests it remained a tropical system, oddly the end of season TC report supports the theory that Amy was actually subtropical. This report states that trough interaction resulted in Amy acquiring subtropical rather than tropical characteristics, but that no attempt was made to distinguish the subtropical from the tropical portions of the storm track (Hebert 1976). Nevertheless, both the ERA40 CPS and the end of season report suggest that Amy was not a tropical storm, but rather a subtropical storm.

B. Refined extra-tropical transition (ET) time

In the best track dataset, Hurricane Faith (1966) has one of the longest, if not *the* longest track of any Atlantic tropical cyclone. In the best track dataset, Faith formed as a tropical depression on August 21 near 13°N and is classified as a tropical cyclone until September 6 at which point it was located at near 60°N. It is highly unusual for a cyclone to retain its tropical characteristics that far north, and ERA40 CPS shows that Faith probably began ET about three days prior to the sixth (Fig 4). At that time, it appears as though Faith had acquired an asymmetric cold core structure. Further evidence of ET is found in the expansion of the gale force wind field (Fig. 4). This expansion coupled with the development of a cold core and the transition from symmetric to asymmetric structure all suggest that Faith had completed ET by 1200UTC on September third.

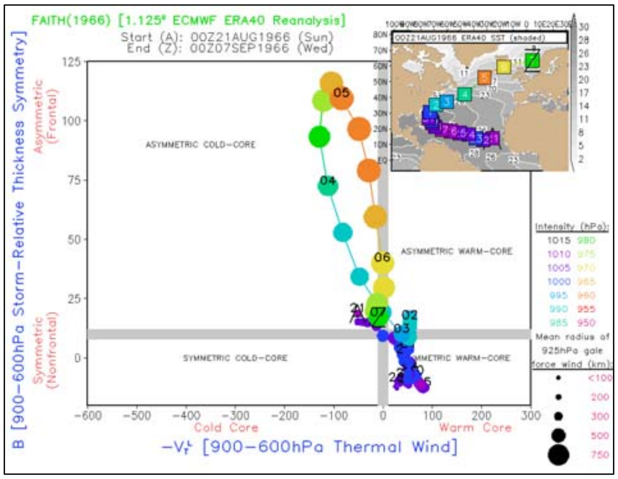

Figure 4: Reanalysis suggests that Hurricane Faith completed ET near 1200UTC on September third when it acquired an asymmetric cold core structure. ET is also evident in the wind field expansion that began on the third.

The reanalysis of Hurricane Carrie (1957; not shown) suggests that it too began ET about three days prior to the time listed in the best track data set. However, the ERA40 CPS representation of Carrie does not appear to be as reliable as that of Faith. The reanalysis indicates that Carrie never developed a warm core, which is highly unlikely since the hurricane peaked at category four intensity. More likely, Carrie provides a good example of the pre-satellite dependence of a cyclone's structural representation on the proximity to and the density of observing stations.

C. *Newly discovered storms*

Another application of the ERA40 CPS involves searching for previously undocumented cyclones. By using the ERA40 CPS, evidence can be found that suggests some unnamed historic cyclones actually did have subtropical or even tropical characteristics. Two examples are given here: a cyclone that developed off the coast of Florida in 1984 and another that developed in the Caribbean in 1987. Both of these cyclones also exist in the NCEP2 reanalysis data (Kanamitsu et al. 2002), which definitely suggests that they merit further scrutiny.

The ERA40 CPS of the cyclone that developed off the Florida coast on November 23, 1984 (Fig. 5) suggests that the cyclone was either tropical or subtropical when it developed. It then went through ET on the 24th and transitioned back to subtropical or tropical before dissipating on the 29th. Furthermore, the ERA40 representation of this cyclone shows a closed low with a central pressure of 1005mb. Though 1005mb is not very impressive in reality, for the ERA40 resolution, location, and time of year, it is not insignificant.

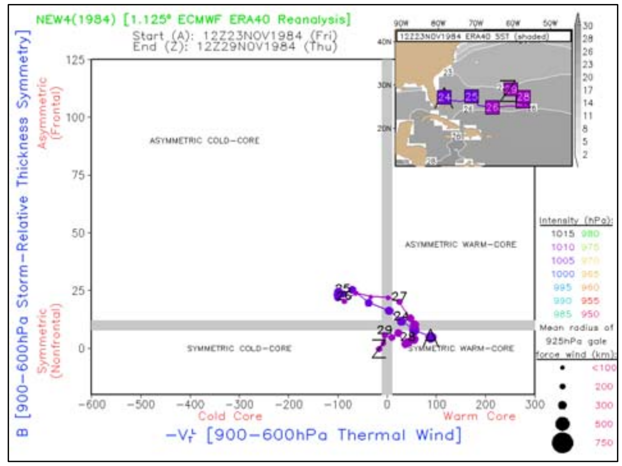

Figure 5: A possible undocumented tropical or subtropical cyclone found in the 1984 ERA40 data that eventually undergoes extratropical transition.

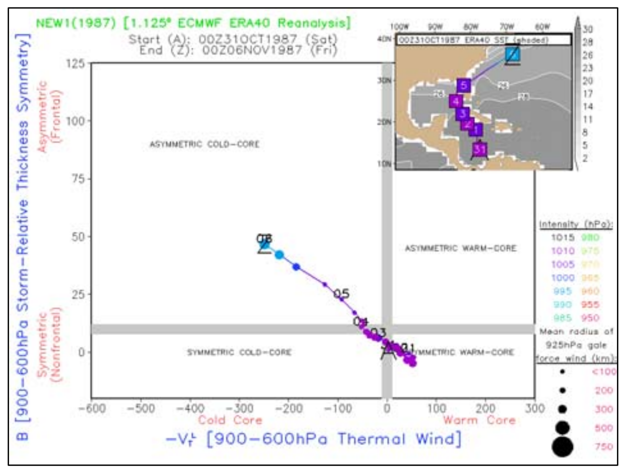

Figure 6- A possible undocumented tropical or subtropical cyclone found in the 1987 ERA40 data that eventually undergoes extratropical transition.

Similarly, the CPS representation of the 1987 Caribbean cyclone (Fig. 6) also shows a symmetric structure with a shallow warm core. The cyclone developed on October 31, 1987, and the peak lower-tropospheric thermal wind magnitude of 72 a day later is quite impressive for an ERA40 representation. Further, the ERA40 data shows that the cyclone had a central pressure of near 1005mb, and again, a low of this magnitude is not insignificant in the ERA40 data. The symmetric structure and warm core, coupled with the location of development and the strength of the central low pressure suggest that this cyclone is a tentative tropical depression that may or may not have reached tropical storm status before going through ET on the third.

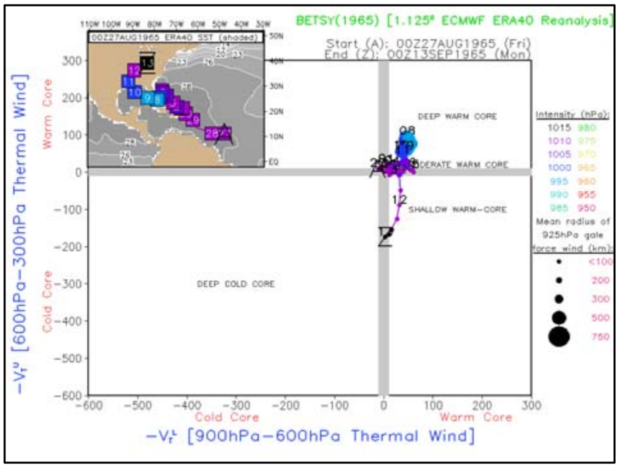

Figure 7: A major hurricane (Betsy 1965) remarkably well-represented by the CPS as a deep warm-core cyclone.

D. Storms captured well

Although there are many cases in which large discrepancies within the best track portrayal of a TC can be improved by consulting the ERA40 CPS, there are also many cases in which the best track representation and the ERA40 CPS agree quite nicely. Hurricane Betsy of 1965 (Fig. 7), for example, was captured very well, though the representation of the track in the ERA40 is slightly farther south than the NHC's best track representation. The cyclone was tracked rather easily and the reanalysis shows a definite deep warm core structure. Furthermore, the best track ET and the reanalysis-indicated ET are within 12 hours of each other. The best track dataset suggests that Betsy had completed ET by 1200UTC on 12th of September, while the reanalysis suggests that ET did not start until 1200UTC on the 12th. This small discrepancy may be due to the fact that the ERA40 track remained slightly farther south of the best track representation.

IV. STATISTICAL ANALYSIS

As stated before, representation of TCs before and after the addition of satellite data into the ERA40 dataset differs significantly. Evidence of the evolving representation can be seen through a statistical analysis of the two periods. Figure 8 displays a comparison of the twenty-four hour running mean (to remove short-term variability) of the lower-tropospheric thermal wind ($-V_T^L$) and the upper-tropospheric thermal wind ($-V_T^U$) parameters for all Saffir-Simpson stages. For all Saffir-Simpson categories, the ERA40 representation of the hurricanes that occurred in the period 1980-2002 is significantly more robust than that of the hurricanes in the earlier period (1957-1979). It is important to keep in mind that as observing techniques and analyses improve, the ERA40 biases will change as well and that in future work, this evolving bias will need to be taken into consideration as the structural reanalysis is done.

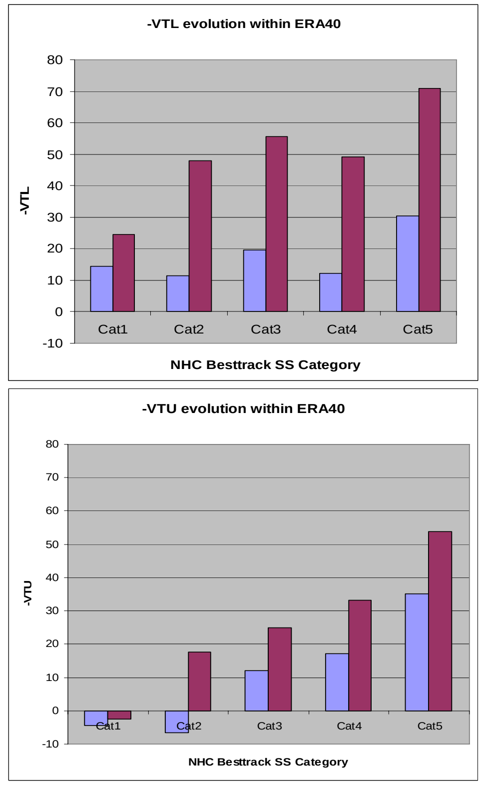

Figure 8- Statistical analysis of the rep-resent-ation of TCs within ERA40. As re-analysis continues, the evolving bias within the ERA40 will need to be examined. Blue: 1957-79. Maroon: 1980-2002.

V. CONCLUDING REMARKS

The cyclone phase space can be applied to the ERA40 dataset to refine historical cyclones of uncertain track and structural evolution. In particular, timing of tropical and extratropical transition and cyclone origins can all be clarified within the ERA40 CPS if the representation within is trustworthy. Further, previously undocumented cyclones of subtropical or tropical origin can be documented within the ERA40 CPS. Ultimately, since the ERA40 is not a fully observations-based analysis, all refinements and additions suggested by the ERA40 CPS must be confirmed by available surface, upper, marine observations, or satellite measurements when possible.

VI. ACKNOWLEDGEMENTS AND REFERENCES

This work has been sponsored by a grant from the NOAA Climate and Global Change Program on "The Atlantic Hurricane Database Re-analysis Project." The authors appreciate a review of this manuscript by Chris Landsea.

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