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HURRICANE MICHAEL (2000): THE "TWO-WAY TC"

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1. INTRODUCTION

Tropical cyclones that undergo extratropical transition [ET] can evolve into devastating extratropical systems (e.g. Palmén 1958; Bowyer 2000). While tropical storms with partial baroclinic characteristics initially may accelerate the transition process (Bosart and Bartlo 1991), a climatology of ET in the North Atlantic revealed that tropical storms that reintensify post-transition are predominantly Cape Verde systems (Hart and Evans 2001). Hurricane Michael (2000) was an exception to these statistics: a tropical storm that formed from a subtropical low and ultimately reintensified post-transition to a 965hPa storm at 44°N over 20°C sea surface temperatures [SST].

The tropical and then extratropical transitions of Michael (2000) provide an intriguing case study for testing current theories of tropical cyclogenesis and extratropical transition. In this study we use satellite-derived winds, in concert with model analyses and MM5 simulations to analyze the mesoscale structural evolution of Hurricane Michael through these transitions. Bosart et al. (2002) provide an analysis of the multiple tropical and midlatitude interactions throughout the lifecycle of Michael from a potential vorticity [PV] perspective.

2. THE LIFECYCLE OF HURRICANE MICHAEL

On 13 October 2000, an upper cold low interacted with a surface front east of the Bahamas; the resulting surface low was classified as a subtropical storm on the 15th and continued developing over open waters as it made its first transition from a subtropical to tropical storm by 0000UTC 17 October 2000. At this time, Tropical Storm Michael had a deep, well developed warm core structure. Michael developed an eye later on the 17th, and continued intensifying until it made landfall over Newfoundland on the 19th. By landfall time, Michael was becoming increasingly asymmetric, evolving into an extratropical (or post-tropical) cyclone, but still maintained an eye and its lowest lifecycle central pressure of 965hPa. The peak winds and central pressure of Michael were sustained as the storm completed extratropical transition on October 20th. Over the period 17-20 October, the warm core signature of Michael eroded from above, to a clearly cold-cored, asymmetric low pressure system.

3. PHASE DIAGRAM LIFECYCLE SUMMARY

A three-dimensional cyclone phase space has been proposed to summarize the structural evolution of storms through tropical and extratropical transitions. The three diagnostics used are (i) storm asymmetry [B]; (ii) 900-600 hPa thermal wind [V_T^L]; and (iii) 900-600 hPa thermal wind [V_T^U] (Hart 2002a,b). The phase space for Michael (2000) is presented in Figure 1 using two cross-sections: B vs. $-V_T^L$ and $-V_T^U$ vs. $-V_T^L$. The full lifecycle of a cyclone is defined through the trajectory through the phase diagram, with time moving forward as one moves along the trajectory, from 1200UTC 12 October [labeled 'A'] to 1200UTC 23 October [labeled 'Z']. A purely tropical cyclone, defined as a symmetric warm core system (Elsberry 1995), will be confined to the bottom right quadrant of Figure 1a; a classic extratropical storm inhabits the top left quadrant of this figure.

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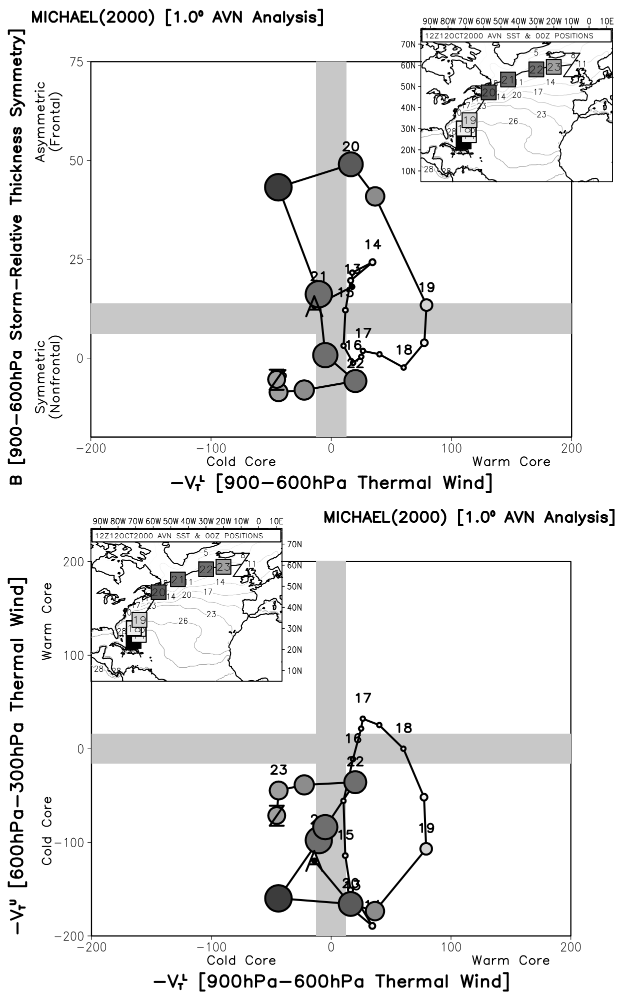

Figure 1: Cyclone phase diagram of the lifecycle evolution of Hurricane Michael (2000). Data used are 1° AVN analyses every 12h. a) $-V_T^L$ vs. B and b) $-V_T^L$ vs. $-V_T^U$. The inset frame gives the track of the cyclone and the model analysis SST field (°C). 'A' indicates the beginning of the plotted lifecycle within the available analyses and 'Z' indicates the end. Symbols with shading indicative of cyclone minimum central pressure (white: > 1010hPa, black: < 970hPa) and size proportional to the mean radius of the 925hPa gale-force (> 17ms^{-1}) wind field (largest here is 400km) are plotted for 12 hourly analyses. Positions at 0000 UTC are labeled with the date.

Figure 1b provides a measure of the depth of the warm core signature of the storm: $-V_T^L$ is plotted on the ordinate and $-V_T^U$ on the abscissa. Thus, a storm with a deep warm core [900-300 hPa] will inhabit the top right panel of this diagram.

Based on these phase space characterizations, we evaluate the structural changes through Michael's evolution: from Figure 1a, it seems that Michael had become a symmetric warm cored system by 0000UTC on the 16th, ahead of the NHC declaration of tropical storm at 0000UTC on the 17th. The PV analyses of Bosart et al. (2002) concur with classification of Michael as a tropical storm 24h ahead of the best track.

Between 1200UTC on the 18^{th} and the 20^{th}, the storm took on hybrid characteristics, completing extratropical transition by 0000UTC on the 20^{th} as it exited Newfoundland, continuing eastward across the far north Atlantic.

Based on these storm phase classifications, Michael was tropical from 1200UTC/16 through 1200UTC/18; hybrid until 0000UTC/20; extratropical until at least the end of the analysis period at 1200UTC/23 October 2000. Comparison with analyses of MSLP, gale force wind area and 850-200hPa shear further supports these storm phase designations (Figure 2).

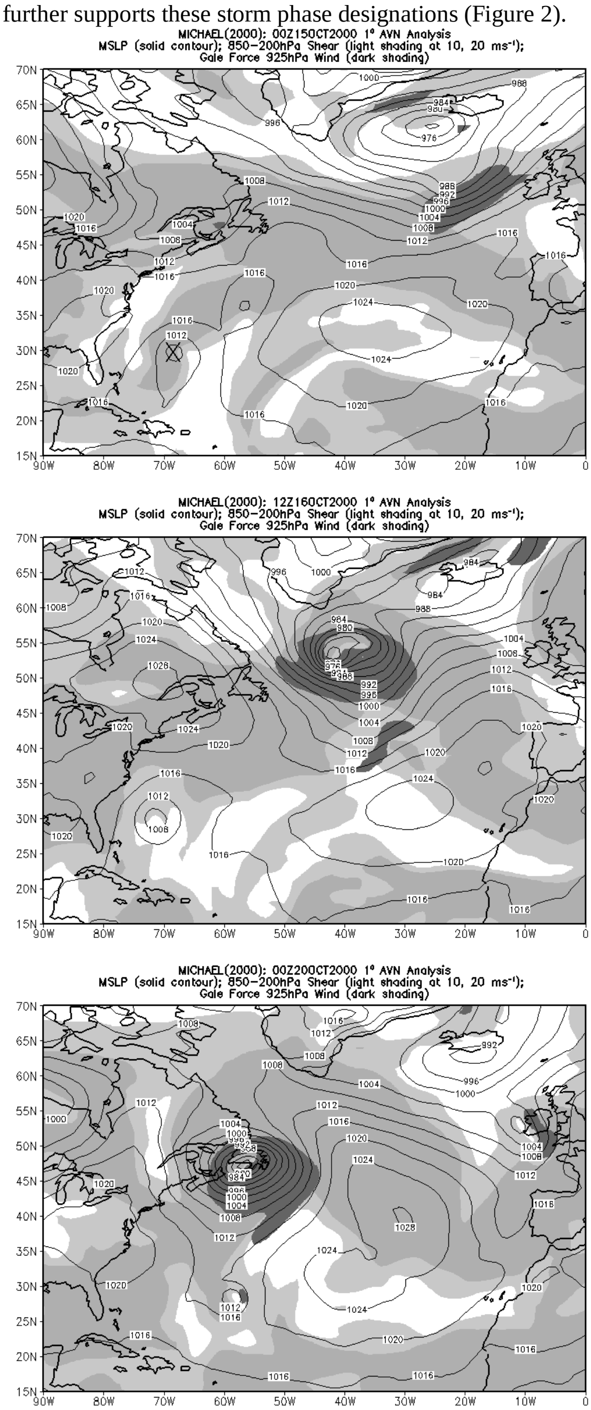

Figure 2: Sea level pressure (contours), 925hPa gale force winds (dark shading), storm position (X) and 850-200hPa vertical wind shear ($\geq 10ms^{-1}$ light shading, $\geq 20ms^{-1}$ medium shading) for 0000UTC/15 (top); 1200UTC/16 (middle) and 0000UTC/20 October 2000 (bottom). Data plotted are AVN $1^{\circ}x1^{\circ}$ analyses.

At 0000UTC October 15^{th} Michael is in a region of at least 20ms shear (850-200hPa; Figure 2). A substantial reduction of shear in the vicinity of Michael is observed in the next 24-36h (see Bosart et al. 2002 for time series) in the presence of an upper-level PV anomaly (not shown). Kimball and Evans (2002) have shown that this upper PV anomaly/low shear configuration is potentially favorable for tropical storm intensification. The result is a symmetric system [MSLP] at 1200UTC on the 16^{th}, but due to the coarse (compared to the core size) 1° analysis resolution, gale force winds are not resolved in the analyses (Figure 2).

Peak intensity of 965hPa is recorded at 1700UTC on the 19^{th}. By 0000UTC 20 October, the it has completed transition and a large area of near surface gale force winds is evident associated with an asymmetric MSLP structure and strong vertical wind shear (Figure 2 bottom panel). The spatial features documented here for both the 16^{th} and 20^{th} are congruent with the phase space analyses presented in Section 2.

4. MESOSCALE ANALYSIS METHODOLOGY

In order to analyze the mesoscale evolution of the transitioning storm, it is necessary to improve upon the $1^{\circ}x1^{\circ}$ resolution available from the AVN and NOGAPS global forecast model outputs. While satellite-derived winds [satwinds] are typically included in the data assimilation cycles of these models, they are usually sparsely sampled and so remain a valuable data source for mesoscale resolution analyses over the tropical and extratropical oceans. Incorporation of satwinds into mesoscale analyses of tropical cyclones remains a challenge (Soden et al. 2001). Analysis of these variations reveals substantial differences in the vortex structure evolution contributing to these tracks. For the simulations analyzed to date, choice of Betts Miller [instead of Kain Fritsch] convection results in a more intense storm with a deeper cyclonic signature and eastward track bias. Satwinds contribute to changes in upper level trough structure, modifying the environmental steering flow. Results from a range of simulations in which the effects of these variations are explored will be presented at the meeting.

5. ACKNOWLEDGMENTS

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