16D.1 MODEL BASED DIAGNOSIS OF THE GENESIS PHASE OF ATLANTIC HURRICANE KAREN

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1. INTRODUCTION

Tropical cyclones in the Atlantic Ocean typically develop in association with the westward movement of tropical waves in the middle and upper troposphere and are characterized by a tropospheric-deep tower of potential vorticity (PV) in their warm cores. Exceptions to this normal development sequence do, however, occur. Hurricane Karen, which developed slowly during October 2001, represents a recent example of atypical tropical cyclone development. The original disturbance associated with what would become Karen was clearly driven by extratropical mechanisms, but through time, rapidly secluded itself from the westerlies and finally acquired full tropical characteristics. In this paper we use the output from a high resolution MM5 simulation of the genesis and extratropical –to-tropical transition phases of the storm in order to diagnose this case of atypical tropical cyclogenesis.

2. MM5 MODELING METHODOLOGY

Karen was simulated using the NCAR/PSU MM5v3. The simulation was run with three stationary two-way nested domains, employing the Betts-Miller cumulus parameterization scheme on the outer domain and explicit cumulus modeling on the inner two domains. The domains were 68x88, 88x106, and 166x136 grid points, with grid spacings of 81 km, 27 km, and 9 km on the outer, middle, and inner domains, respectively. The model run was initialized at 0000 UTC 10 October 2001 and run for 72 hours, with the innermost domain simulation not initializing until six hours into the run. Boundary conditions were updated every 12 hours using the 2.5° x 2.5° resolution ECMWF TOGA dataset. Parcel trajectories, as well as the three-dimensional structure of the cyclone, were examined using VIS-5D.

3. SYNOPTIC OVERVIEW

A relatively vigorous midlatitude cyclone and associated baroclinic zone pushed through the western and central Atlantic Ocean basin through the period of 8-10 October 2001. The associated cold front stalled and fractured south of Bermuda during the day on 10 October 2001. In association with this frontal fracture, a closed low pressure center quickly developed. A convective burst occurred on 11 October over the eastern edge of this closed low pressure center beneath a region of ageostropic divergence in the right entrance region of an anticyclonically curved 50 ms^{-1} upper level jet. This burst served not only to broaden the area of lowest pressure but also to provide for the development of a warm core to the system. This forcing was countered by strong cold advection in the environment of the new low associated with the passage of the original front. The closed low that formed at the apex of the frontal fracture tracked northward farther into the large scale cold environment behind the original baroclinic zone and began to occlude on 11 October. Large scale cold advection behind the original system waned as the Bermuda High began to have a greater influence over the western Atlantic basin. This created a broad area of higher pressure to the north and northeast of the new cyclone. Weakened cold advection behind the original system prohibited the ingestion of cold low level air into the new cyclone, which became fully secluded from the polar reservoir of cold air to the north by 12 October. Seclusion from the polar reservoir has also been noted as characteristic in Pacific subtropical Kona cyclones (Otkin and Martin, 2004). The effects of this seclusion included a distinct weakening and subsequent halt to low level cold advection around the cyclone center, as well as a relaxation of vertical shear; the latter being characteristic of subtropical cyclones acquiring tropical characteristics (Davis and Bosart, 2003). Once these conditions were realized, a transition to a warm cored tropical cyclone proceeded in the presence of warm surface waters, large available latent heating, and low vertical wind shear.

4. PV TOWER FORMATION

The development of PV towers in extratropical cyclones tends to involve air with one of three origins: the warm frontal PV, cold frontal PV, and tropopause-level PV sectors (Rossa et al., 2000). The warm frontal PV usually forms the lowest portions of the PV tower, cold frontal PV the middle portions, and the tropopause-level PV forms the upper portions of the PV tower. The PV tower associated with the extratropical disturbance that eventually became Hurricane Karen formed in a similar, though subtly different, manner. Parcel trajectories show that air from the region along the dying cold front ascended

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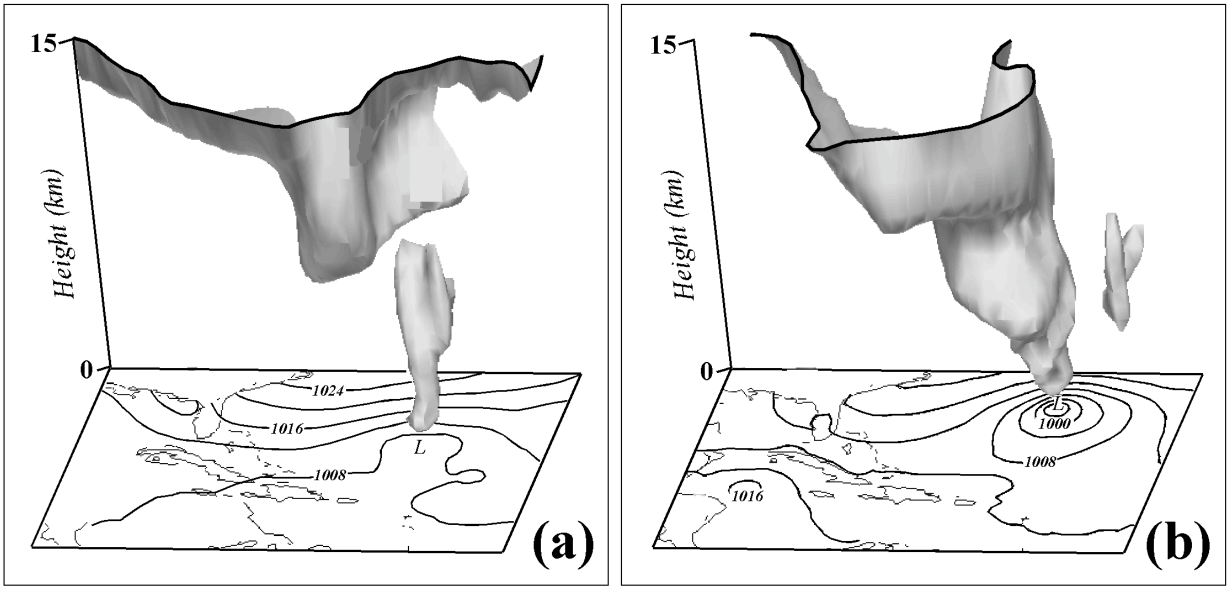

Fig. 1 Two stages in the evolution of the PV tower of Karen. Solid contours are sea level pressure, contoured every 4 hPa, and the 1.0 PVU surface is indicated by the gray shading for a) 18 UTC 10 October 2001 and b) 18 UTC 11 October 2001.

quickly and turned anticyclonically as it rose into the upper level flow. Low level trajectories associated with the warm frontal sector remained below 3 km throughout the development process, quickly encircling the low level cyclone center to create the lower branch of the cyclone's PV tower. This process also had the effect of concentrating high θ_e air at low levels around the center. The presence of this high θ_e air focused the aforementioned convective flare-up near the center of the cyclone and along the warm front. Meanwhile, strong subsidence associated with an intensifying tropopause fold upstream of Karen, forced tropopause-level air down as low as 3 km. This subsidence forced upper level high θ_e air downward to such an extent that a connection with the low level maximum of θ_e was achieved and a deep warm core was established. The high PV upper tropospheric parcels were thus able to descend along θ_e surfaces and connect with the high PV, lower tropospheric parcels ascending along the same θ_e surface. Snapshots of the two stages just discussed are illustrated in Fig. 1 with Fig. 1b representing the final PV tower over the center of the cyclone.

5. CONCLUSIONS

The cyclone that eventually developed into Karen was clearly extratropical at its initiation. Through time several processes occurred to significantly alter both the large scale environment in which Karen developed, as well as the mesoscale environment within Karen. Seclusion from the cold environment poleward of an antecedent cold front prohibited the siphoning of cold air into the circulation of Karen. This allowed latent heating associated with a convective burst to begin the warm core conversion process. This heating also led to the production of a low level PV anomaly , one component of the subsequent PV tower associated with Karen. Strong subsidence of high PV tropopause-level air to about 3 km promoted the final stages of PV tower development. In addition, by connecting upper and lower level θ_e anomalies, the subsidence played a significant role in the formation of the warm core. The synthesis of these factors, coupled with a long residence time over relatively warm ocean surface waters, encouraged the atypical development of Karen from an ill-defined convective flare-up along a dying baroclinic zone into a tropical storm.

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