13D.1 INFLUENCE OF THE DOWNSTREAM STATE ON EXTRATROPICAL TRANSITION: HURRICANE EARL (1998) CASE STUDY

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1 INTRODUCTION

The extratropical transition and reintensification (ET/R) of Atlantic hurricanes off the east coast of North America forms an excellent test-bed for the study of tropical-extratropical interactions. Despite significant research efforts, the complex interactions involved in ET/R make these extreme events very difficult to forecast. This paper focuses on the investigation of a double ET/R event which occurred in the North Atlantic basin between 5 and 7 September 1998. Hurricanes Danielle and Earl underwent simultaneous transitions in the eastern and western Atlantic, respectively. A "potential vorticity (PV) thinking" (Hoskins et al. 1985) diagnostic approach is used to elucidate fundamental differences in the lifecycles (Thorncroft et al. 1993) of these two ET/R events. A "sensitivity ensemble" approch is then used to identify the features responsible for modulating their differing structures. We begin with a brief description of the control simulation in Section 2, describe our sensitivity testing methodology in Section 3, and draw conclusions in Section 4.

2 PV ANALYSIS OF CONTROL

All of the simulations used in this study were produced using the Canadian Mesoscale Compressible Community (MC2) model. A hoizontal grid spacing of 35 km was found to be sufficient to reproduce the structure and intentsity of both systems. For a complete description and references, the reader is referred to McTaggart-Cowan et al. (2001).

Morgan and Nielsen-Gammon (1998) suggest that plots of the potential temperature (θ) and winds on the dynamic tropopause (defined as the 1.5 PVU surface, 1 PVU=10^{-6}m^{2}K kg^{-1}s^{-1}) can be coupled with maps of θ at the top of the boundary layer and lower-tropospheric Ertel PV to give a complete view of the atmosphere under the constraints of the Eady model. A broad region of cold topopause θ (trough) over Quebec at 0000 UTC 5 September (00/05, the initialization time for all runs) has been shown (McTaggart-Cowan et al. 2001) to be crucial to Earl's ET/R. Above the deep baroclinic zone which extends zonally across the North Atlantic in the initial conditions (not shown) exists a hydrostatically necessary enhanced θ-gradient on the 1.5 PVU surface. This indicates a steeply inclined tropopause and implies the existance of a strong zonal jet at upper levels. In the jet exit region, just upstream of Danielle, a shortwave trough is evident at 00/05. This feature triggers Danielle's reintensification.

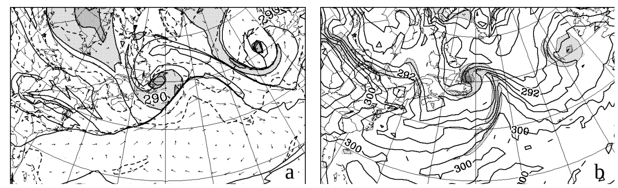

Figure 1: Dynamic tropopause θ (solid lines and shading) and winds, and 1000 hPa temperature (5 K intervals, dashed) from the control simulation (a). Panel (b) shows 925 hPa θ (4 K intervals) and 925-700 hPa mean PV (shading, 1 PVU increments).

The trough upstream of Earl rotates eastward across the coast over the first 24 hours of the simulation, then proceeds to dig rapidly as the system phase locks between 24 and 48 hours. This development at upper levels is characterized by the rapid cyclonic rollup of the cold dynamic tropopause θ above the center of the surface circulation (Fig. 1a). This evolution is consistent with the LC2 baroclinic lifcycle described by Thorncroft et al. (1993). Strong near-surface fronts are evident at maturity (Fig. 1b), indicating that the baroclinic mode is indeed important to Earl's redevelopment. The shortwave feature upstream of Danielle filaments rapidly in the control simulation and remarkably warm θ on the 1.5 PVU surface to the north and east of the developing system indicate that warm, tropical air is being transported rapidly northward ahead of the center. The PV streamer in this case wraps entirely around the outside of this warm region by 36 hours (Fig. 1a), essentially isolating the tropical air from its cooler surroundings. Lower-level baroclinicity is virtually non-existant in this system, and the mean internal PV field is more reminiscent of a tropical cyclone than a developed extratropical system (Fig. 1b).

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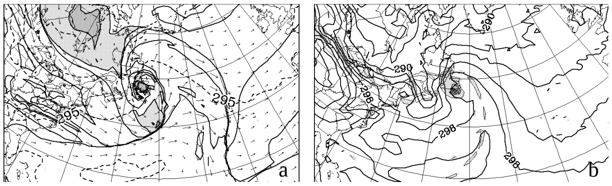

Figure 2: As for Fig. 2, but for the IDEALLAT member.

3 SENSITIVITY ENSEMBLE

We define a "sensitivity ensemble" (SE) as a set of sensitivity tests whose modifications are complimentary and equally valid. The consensus forecast from the SE yeilds insight into the sensitivity of the Earl's ET/R to the downstream state, while the model spread is indicative of predictability. A total of eight members (including the control) are used in the SE. Two use a PV modification and inversion approach (McTaggart-Cowan et al. 2001) to remove the ridge-trough pattern over the North Atlantic; three contain highly idealized zonal states downstream of Earl; and two involve modifications to the jet/front structure in the initial conditions.

A striking bifurcation in modeled evolution of Earl's ET/R after 24 hours of integration can be explained by comparing just two of the SE members. The initial conditions of the SIMJET3 simulation are characterized by a purely zonal flow over the North Atlantic with the total meridional temperature gradient defined by the boundary conditions. A region of enhanced baroclinicity exists at 50° north and results in a geostrophically balanced jet maximum at upper levels. This represents and idealized version of the observed jet in the control. The IDEALLAT simluation also contains perscribed zonal flow downstream of Earl. In this case, however, the mean north-south temperature gradient is spread evenly over the domain and no jet maximum exists.

The SIMJET3 simulation results in an LC2-type cyclonic rollup of upper-level PV as exhibited by the developing system in the control. Strong frontal features are present after 12 hours of integration, and persist throughout the redevelopment process. With a 960 hPa central pressure after 36 hours, we conclude that both the structure and intensity of Earl in the control simulation are remarkably well reproduced by this simulation containing a highly simplified initial downstream state.

The redevelopment of the storm in the IDEALLAT simulation is far more reminiscent of Danielle in the control than of Earl itself. A massive extension of the tropical tropopause northward to southern Greenland is evident over the first 24 hours of simluation. This is accompanied by the filamentation of the upstream trough and wrapping of PV streamers around the elevated tropopause to the south and east of the system as it matures (Fig. 2a). This isolation of the tropical air greatly reduces the near-surface baroclinicity in the viscinitiy of the developing cyclone (Fig. 2b), a characteristic of Danielle's redevelopment in the control.

4 SUMMARY AND DISCUSSION

The simultaneous ET/R of Hurricanes Danielle and Earl over the North Atlanic on 5 to 7 September 1998 is successfully simulated using the MC2 model. The redevelopment of the two systems, although similar from a traditional synoptic perspective, is shown to be dramatically different using PV diagnostics. A sensitivity ensemble is developed for the purposes of testing the sensitivity of Earl's ET/R to the initial downstream state. Some of the ensemble members (e.g. SIMJET3) produce a redevelopment which is similar to that that observed in the control simulation. However, those members in which the North Atlantic jet-front structure is heavily modified or removed (e.g. IDEALLAT) result in an ET/R process that closely resembles that of Danielle in the control simluation. We suggest that the jet/front structure is necessary for an LC2-type baroclinic redevelopment for ex-hurricane Earl. In particular, the jet's secondary circulation may act to enhance the production of a dry slot in the developing storm and fuel the cyclonic rollup observed at upper levels. Converseley, the absence of the jet's induced circulation enhances the advection of moist, tropical air ahead of the storm and results in the isolation of a tropical troposphere in the viscinity of the center. These results may prove useful in the predicion of ET/R structure and intensity and will be the subject of a future paper.

References

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