6.5 FORECAST SENSITIVITY OF EXTRATROPICAL TRANSITION INTENSIFICATION TO DOWNSTREAM SYNOPTIC-SCALE PERTURBATIONS

J.R. Gyakum and R.J. McTaggart-Cowan*
McGill University, Montreal, Quebec

1. Introduction

The transition of tropical cyclones into extratropical systems along the eastern seaboard is often accompanied by their rapid reintensification. It is well known that both the timing and the magnitude of the redevelopment depend strongly on upstream "midlatitude" quasigeostrophic forcings. The dense observation network over the North American continent should allow for high-quality analyses and the accurate prediction of these extratropical transition (ET) events. However, forecasts of ET are notoriously poor despite continued research efforts (e.g., Klein (2000), Thorncroft and Jones (2000), and many others).

A portion of this unpredictability can be explained if we consider the possible dependence of ET on *downstream* conditions. In particular, this study focuses on testing the sensitivity of a well-simulated transitioning cyclone (Hurricane Earl, 1998) to downstream synoptic scale potential vorticity (PV) perturbations present in the initial conditions.

2. Case Background

Hurricane Earl began as a tropical wave in the eastern equatorial Atlantic on 17 August 1998. It moved westward from the Cape Verde Islands towards the Carribean, but its development was supressed by the upper level outflow from the long-lived Hurricane Bonnie. Earl finally reached tropical depression status on 31 August after moving over the Gulf of Mexico. A weak hurricane, it reached Category 2 on the Saffir-Simpson hurricane scale before making landfall in Panama City, FL on 3 September. Hurricane Earl moved northeastward and weakened over the next 36 hours until moving off the Virginia coast on 4 September. By the initial time for the simulations presented here (0000 UTC 5 September), Earl had filled to 1004 hPa and lay 350 km east of the New Jersey coastline (top panel of fig. 1).

Over the next 36 hours, Earl underwent a rapid ET and reintensification which resulted in an intense 960 hPa low just north of Newfoundland at 1200 UTC on 6 September. Factors which have been shown to be important in this ET (McTaggart-Cowan et al. 2001) include a strong coastal baroclinic zone and an approaching upper level trough. In this paper, we suggest that the downstream environment played a role in Earl's ET.

Ex-hurricane Danielle was moving slowly across the North Atlantic at 0000 UTC 5 September as a 986 hPa extratropical low. A strong ridge had formed between the two systems which extended as far north as Greenland. Over the next 36 hours, Danielle also underwent rapid intensification, reaching a central pressure of 964 hPa. The primary forcing for the regeneration of Danielle appears to have been a digging upstream trough whose PV structure was favorable for phase-locking the upper and lower level disturbances.

The presence of Danielle may have had any of a number of influences on Earl's ET, including: enhancement of surface-layer fluxes in the cold pool, modification of the background static stability, perturbation of the North Atlantic jet structure, and enhancement of advective fluxes due to the "pinched" ridge. All of these processes act downstream of Earl; however, they are shown to play an important role in the nature of this extreme event.

3. Model and Testing Framework

The Canadian Mesoscale Compressible Community model was run with a 35 km grid spacing for all of the simulations presented in this paper. Initial and boundary conditions were supplied by the Canadian Meteorological Centre's operational analyses. A credible control simulation was obtained in which the deepening rate, track and structure of Earl were remarkably well reproduced (McTaggart-Cowan et al. 2001).

The sensitivity testing methodology employed for this study is based on the piecewise PV inversion framework developed by Davis and Emanuel (1991). The invertability principle of PV states that a given PV field, coupled with a balance equation, is adequate to describe the instantaneous atmospheric state. By identifying and removing individual PV anomalies in the initial conditions for the simulation, a quantification of the impact of each anomaly on the ET can be obtained. This method ensures that balanced anomalies are removed through the successive solution of the Ertel PV and nonlinear balance equations.

The set of anomalies removed for the sensitivity test presented here is limited to the negative-positive couplet of PV anomalies that result from the downstream ridge and ex-hurricane Danielle. The removal area encompasses much of the North Atlantic and affects all levels. As a result, the digging trough upstream of Danielle, the ridge between Danielle and Earl, the lower level circulation around Danielle, and the boundary layer warm and cold pools are all eliminated from the initial conditions of the test simulation (fig. 1).

* *Corresponding author address:* Ron McTaggart-Cowan, McGill Univ., Dept. of Atm. and Oc. Sci., Montreal, QC. (514) 398-5070; e-mail: rmctc@zephyr.meteo.mcgill.ca.

4. Results

The removal of the downstream synoptic-scale PV anomalies plays a role in the timing, structure, and track of ex-hurricane Earl's ET. Although both the control and "NOWAVE" simulations reach nearly the same intensity (963 hPa in the control and 965 in NOWAVE), the deepening is delayed by 12 hours in the sensitivity test. The tracks, which are initially very similar, separate after 36 hours as the control storm curl rapidly eastward while the NOWAVE storm continues in a northerly direction. By the end of the 48 hour simulation, a difference of over 250 km is found in the location of the low centers.

The removal of the PV anomalies associated with ex-hurricane Danielle and its upstream ridge results in near-zonal flow across the eastern North Atlantic. However, the removal of the cold pool appears to have hydrostatically strengthened the upper level ridge downstream of Earl. This enhanced ridge survives for the course of the simulation, and is likely responsible for the enhanced northward movement of the NOWAVE cyclone. Simultaneously, the jet structure over the North Atlantic shifts slightly northwards meaning that Earl has to move farther along the baroclinic zone before entering a region of jet-streak forced ascent. Changes in the nature of the cyclonic wrap-up of PV over the intensifying storm are also attributable to the change in its position relative to the jet maximum (Thorncroft et al. 1993).

At lower levels, the removal of the cold pool behind Danielle results in greatly decreased surface-layer sensible and latent heat fluxes. These fluxes may be critical in preconditioning the lower layers of the atmosphere for Earl's passage. Without the destabilization that they provide, Earl's warm frontal circulation is greatly reduced in magnitude, especially over the first 24 hours of the simulation. At later times (36 to 48 hours), the change in the warm advection pattern ahead of the advancing storm shows dramatically the effect of the downstream ridge present in the control simulation. In the control, a narrow band of strong southerlies to the east of Earl results in a similarly-narrow region of moderately intense warm advection. As Earl continues to move eastward, nearly catching up with the almost-stationary remnants of Danielle, its downstream meridional length scale contracts considerably in the control simulation. Between 36 and 48 hours, the baroclinic wave associated with the storm subsides considerably as Earl impinges on the ridge. In the NOWAVE simulation, a broad zone of warm advection is seen east of the center, and the baroclinic wave continues to grow in amplitude throughout. The resulting storm contains a much broader circulation that that produced in the control simulation.

5. Summary and Discussion

The results of this study suggest that the synoptic-scale environment *downstream* of a transitioning tropical cyclone play an important role in determining the outcome of the event. Both the downstream ridge and intensifying cyclone (ex-hurricane Danielle) are shown to influence the ET and reintensification processes at all levels in the troposphere. The mechanisms discussed here include: boundary layer processes, column stabilities, jet structures, and advection patterns. Although the list of possible interactions between an intensifying cyclone and its downstream environment is likely to be much longer than this, these forcings seem to have had a quantifiable impact on the nature of Hurricane Earl's transition and rapid reintensification.

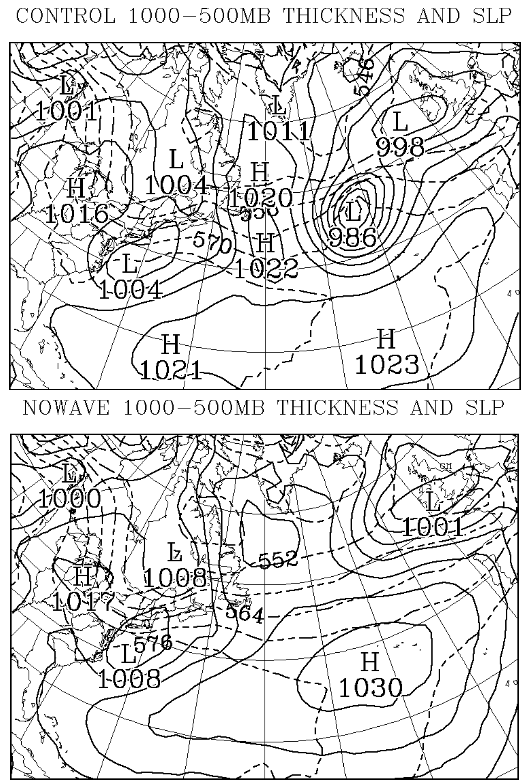

Fig. 1. Sea level pressure (solid, 4 hPa intervals) and 1000-500 hPa thickness (dashed, 6 dam intervals) for the initial conditions of the control (top panel) and NOWAVE (bottom panel) simulations valid 0000 UTC 5 September 1998.

Davis, C. and K. Emanuel 1991: Potential vorticity diagnosis of cyclogenesis. *Mon. Wea. Rev.*, **119**, 1929-1953.

Klein, P., P. Harr, and R. Elsberry 2000: Extratropical transition of western North Pacific tropical cyclones, 2000: an overview and conceptual model of the transformation stage. *Wea. Forecasting*, **15**, 373-396.

McTaggart-Cowan, R., J. Gyakum, and M.K. Yau, 2001: Sensitivity testing of extratropical transitions using potential vorticity inversions to modify initial conditions: Hurricane Earl case study. *Mon. Wea. Rev.* (in press).

Thorncroft, C., B. Hoskins, and M. McIntyre, 1993: Two paradigms of baroclinic-wave life-cycle behaviour. *Quart. J. Roy. Meteor. Soc.*, **119**, 17-55.

Thorncroft, C. and S. Jones, 2000: The extratropical transitions of hurricanes Felix and Iris in 1995. *Mon. Wea. Rev.*, **128**, 947-972.