THE EXTRATROPICAL TRANSITION OF HURRICANE IRENE (1999)

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1 INTRODUCTION

Extratropical transitions of tropical cyclones occur in all ocean basins where tropical cyclones recurve polewards. After the tropical cyclone experiences extratropical transition (ET), a rapid deepening can take place resulting in the development of a very large and deep extratropical cyclone. The ET of hurricane Irene was an example of such an "explosive" event. Irene formed in the Caribbean on 13th October and experienced ET as it moved poleward resulting in a low pressure system that deepened 39 hPa in 24 h (according to the Met Office analysis).

The major question addressed here is what is the role of the hurricane in the explosive extratropical development. To answer this question forecasts have been performed using the Met Office Unified Model from initial states with and without the hurricane. Met Office analysis data were used to obtain the initial states. The hurricane can be identified very clearly in the analysis data as a potential vorticity (PV) tower (see 1 in Fig 1). The PV tower is associated with the cyclonic flow and the positive thermal anomaly of the hurricane core. The anticyclonic outflow of Irene is associated with a negative PV anomaly aloft (see 3 in Fig 1). The PV framework is the key to this study because with it we can (1) modify initial conditions (ie. remove the hurricane dynamics) and (2) identify and track different features involved in the ET process (Fig 1) as well as develop a conceptual picture of their evolution and interactions. Irene's PV tower, upper-level negative PV anomaly and surface potential temperature anomaly (Fig 1) were removed from the initial state using piecewise potential vorticity inversion following the method of Davis and Emanuel (1991). The moisture anomaly associated with the hurricane core (see 2 in Fig 1) was also removed by replacing it with an average value typical of outside the hurricane core. PV inversion allowed us to obtain the balanced flow and temperature fields associated with the modified PV field. For consistency the control run (with Irene) was also initialised with balanced fields. The initial date of the runs was chosen to be before Irene started to interact significantly with the extratropical environment (12 UTC 17th October 1999).

2 RESULTS AND DISCUSSION

In the control run the first interaction of Irene with the extratropics was with a baroclinic zone (see 5 in Fig 1). As a result an extensive warm front developed on the northern flank of Irene at 12 UTC 18th October. Around this time the PV and moisture tower associated with Irene (see 1 and 2 in Fig 1) started to decay. By 12 UTC 19th October – before the rapid deepening that characterised Irene's ET – there was no remaining signature of the hurricane's PV and moisture tower. However, during the time Irene decayed the mean sea level pressure (MSLP) at the center of the cyclone did not change significantly (fluctuating between 980 and 985 hPa) (Fig 2). Thus, an extratropical cyclone must have developed in the same region during the decay of Irene, giving the appearance of a transforming hurricane.

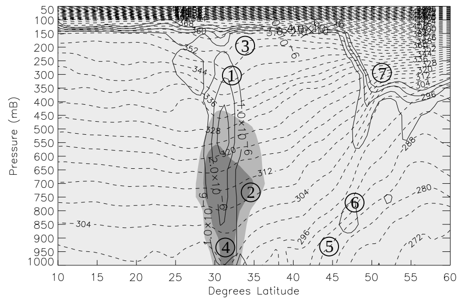

Figure 1: PV and other anomalies involved in the ET of hurricane Irene (1999) shown by a north-south vertical cross section across the center of Irene of PV (solid contour of 1,2,3 and 4 PVU), potential temperature (dashed contour with 4 K interval) and mixing ratio in grey scale (from 3×10^{-3} to 5×10^{-3} kg kg^{-1} in light grey and from 5×10^{-3} to 7×10^{-3} kg kg^{-1} in dark grey) from Met Office analysis data. The anomalies associated with Irene are: (1) a positive PV tower, (2) a moisture anomaly, (3) an upper-level negative PV anomaly depicted by a tropopause lift and (4) a surface potential temperature anomaly. The anomalies associated with the extratropical environment are: (5) a baroclinic zone, (6) diabatically generated PV along the baroclinic zone and (7) and upper-level positive PV anomaly.

At 12 UTC 18th October, upper-level forcing triggered a new extratropical cyclone north of Irene (Fig 3). This new extratropical cyclone occured when an upper-level positive PV anomaly (associated with an upper-level trough) moved over the baroclinic zone along the eastern coast of North America. Both in a different forecast from analysis fields and in analysis data the extratropical cyclone was triggered in the same position as Irene. The balanced fields used to initialise the control run had the effect of modifying slightly the upper-level trough. This affected the track of Irene during the control run and led to a separate development occuring north of Irene. However, in the control run the two cyclones (low-level forced ex-Irene and upper-level forced extratropical cyclone to the

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north) started to merge at 00 UTC 20th October (Fig 3) giving an extensive low pressure system. After the merging an explosive deepening occured (Fig 2) accompanied by a dry intrusion of stratospheric air descending towards the center of the surface cyclone, typical of extratropical explosive cyclogenesis.

A comparison between the control run and the run without Irene shows that the upper-level forced explosive extratropical cyclogenesis event occured in both runs (Fig 2). However, in the control run the deepening was further enhanced by the strengthening of the surface cyclone after the merging of ex-Irene with the upper-level forced extratropical cyclone. Removing Irene from the initial conditions had the effect of halving the deepening rate of the resulting extratropical cyclone from 1.0 hPa/hour over 54 hours to 2.3 hPa/hour over just 24 hours (Fig 2).

Irene had also a significant impact on the track of the resulting extratropical cyclone in the control run: when Irene was present in the initial conditions the track was more zonal (Fig 3). In the control run the positive upper-level PV anomaly associated with the upper-level trough was approached by a diabatically produced negative PV anomaly (Fig 4). This negative PV anomaly was associated with Irene's outflow and the warm conveyor belt of ex-Irene which produced new diabatic PV after the decay of Irene's PV tower. The resulting upper-level jet was stronger and more zonal in the control run (Fig 4) than in the run without Irene where the jet is weaker and more meridionally oriented (Fig 5).

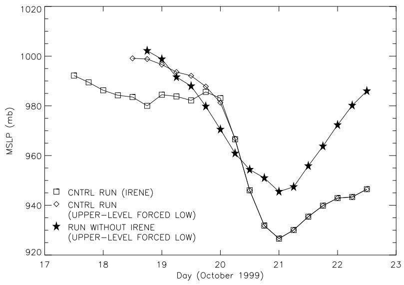

Figure 2: Time series of minimum MSLP at the center of the cyclones involved in the ET of Irene for the control run and the run without Irene. Data points are plotted every 6 h.

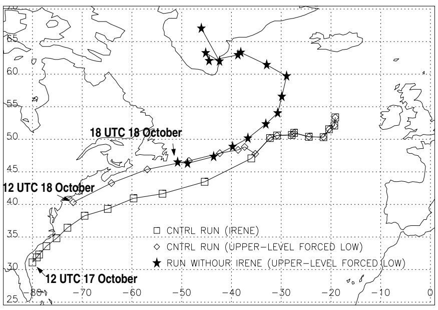

Figure 3: Tracks of the center of the cyclones involved in the ET of Irene in control run and the run without Irene. Storm center locations are plotted every 6 h.

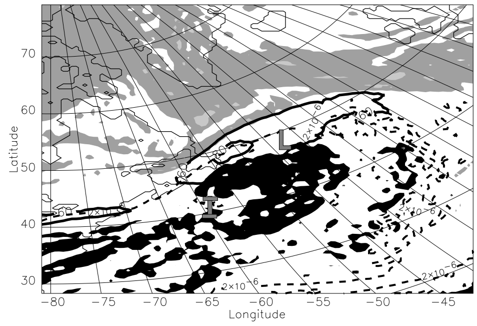

Figure 4: Isentropic PV on a 345 K surface (lying between 150 and 350 hPa) for the control run at 12 UTC 19th October. Shading denotes PV values: black, -2 to 0.3 PVU; dark grey, 7 to 9 PVU; light grey, 9 to 12 PVU. Dashed line is the dynamic tropopause (2 PVU contour). Upper-level jet on 345K isentropic surface depicted by 60 and 80 ms^{-1} isotachs. The locations of ex-Irene and the upper-level forced low at the surface are shown by "I" and "L" respectively.

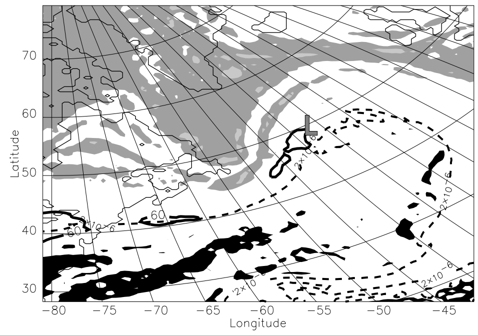

Figure 5: Same fields and time as in Fig 4 for the run without Irene.

3 CONCLUSIONS

Upper-level forced explosive extratropical cyclogenesis took place regardless of the presence of Irene. However, Irene had a significant impact on the extratropical development. First, as Irene moved polewards and interacted with a baroclinic zone, a new low-level forced extratropical cyclone developed while the hurricane decayed. This low-level forced extratropical cyclone (ex-Irene) merged with the upper-level forced extratropical cyclone, doubling the rate of the explosive deepening. Second, the diabatically produced negative PV anomaly (associated with the outflow of Irene and ex-Irene) interacted with the upper-level trough and modified the track of the resulting extratropical cyclone.

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