Untangling the Effects of Latent Heat Release on an Extratropical Cyclone Using Potential Vorticity Analysis

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Introduction

As a main driver of mid-latitude weather conditions, extratropical cyclones have a major impact on society, whether through food production, economics, or travel. These synoptic-scale events are full of intricate meso- and microscale processes that feed back, modifying cyclone strength. One process coming under more focused study is the latent heat release (LHR) from convective activity in the cyclone. As a whole, a cyclone will be intensified when a bubble of latent heating is placed at in the center. The heating leads to production of a positive potential vorticity (PV) anomaly, and subsequent cyclone intensification (Stoelinga 1996).

On a frontal scale, the impacts become more complicated. In the cold frontal region, addition of LHR will increase the propagation speed of a cold front, largely due to condensational heating; in addition, the lower-level jet speed is increased by 15-40% due to the diabatic PV anomaly (Reeves and Lackmann 2004, Lackmann 2002). Along the warm front, the addition of LHR increases the amplitude of the ridge downstream from the cyclone (Grams et al. 2011). Finally, in the occluded zone, northwest of the cyclone center, development of the "trough of warm air aloft" (trowal) is severely stunted or not present (Posselt and Martin 2004).

Case Selection

Much of the previous work on the effect of latent heat release has been conducted on transient extratropical cyclones, where the system as a whole exhibits a significant propagation speed. Intending to expand this work, we selected a quasi-stationary storm off the East Coast of the United States. Occurring in late November of 2006, the system remained nearly stationary for 3 days before moving out to sea, adding an additional temporal dimension to the incoming moisture flux. A persistent, north-south warm conveyor belt provided a continual source of tropical moisture into the warm sector of the storm. Therefore, this case sets up as ideal for exploring the effect of latent heat release on more stationary systems.

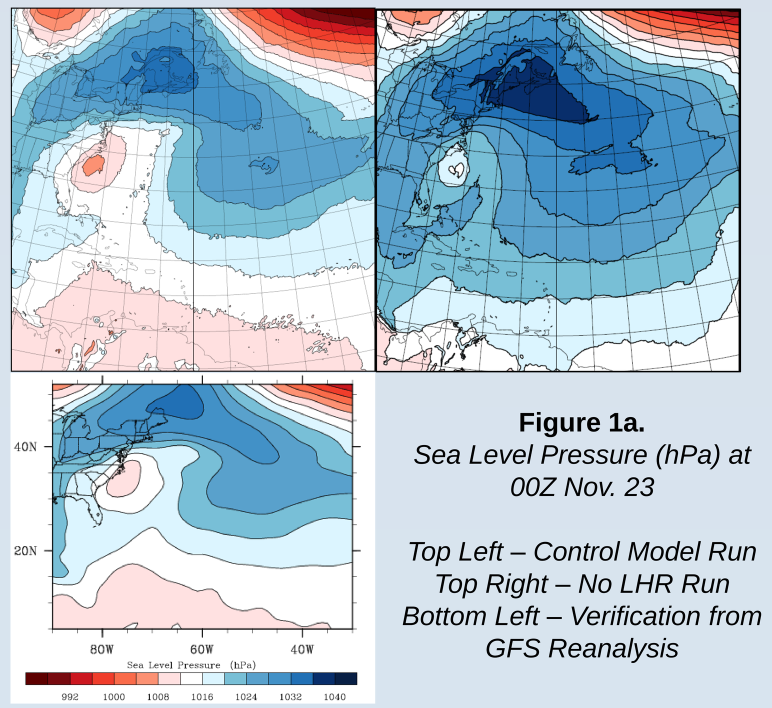


Figure 1a.
Sea Level Pressure (hPa) at 00Z Nov. 23

Top Left – Control Model Run
Top Right – No LHR Run
Bottom Left – Verification from GFS Reanalysis

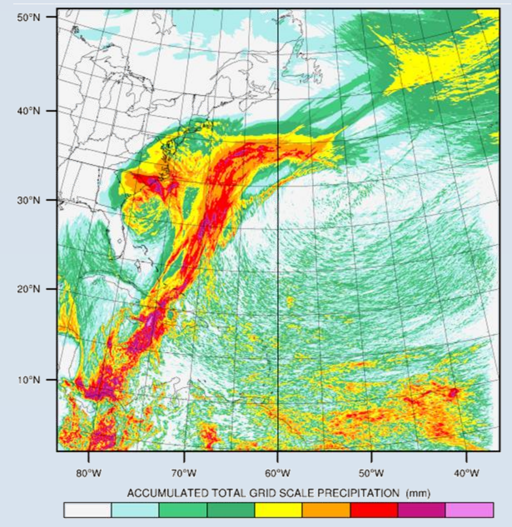


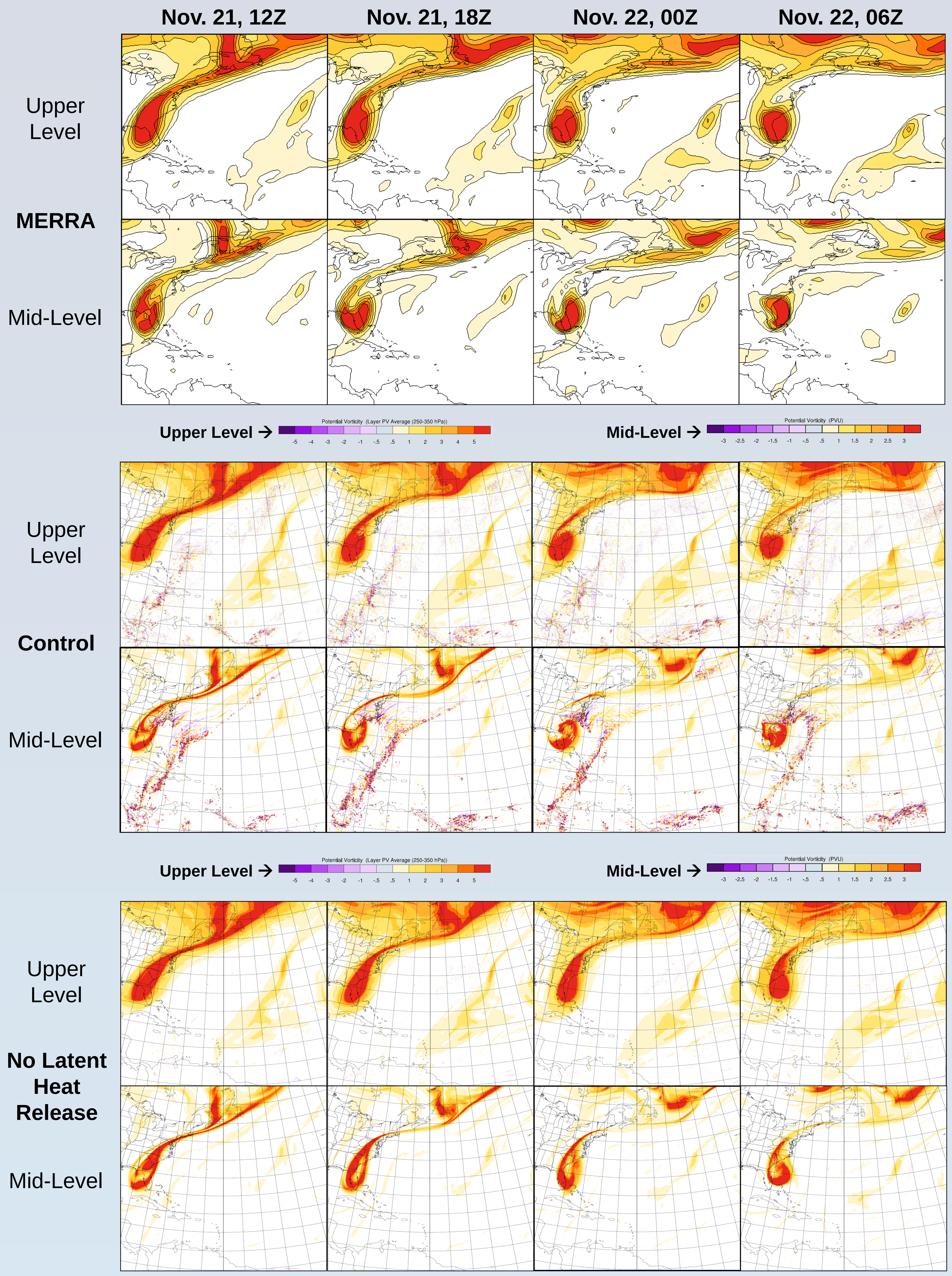
Figure 1b.
Accumulated Precipitation (mm) between 00Z Nov 21 – 00Z Nov 24

Methods

- We ran two companion simulations using the Weather Research and Forecasting (WRF) model to isolate the effect of latent heat: a "full physics" control model and a "no latent heat release" model, wherein the effects of latent heat release were removed via the namelist.
- Two domains were used in the model runs. Our nesting domain spanned a region 6000 x 6000 km in area, with a horizontal grid spacing of 20 km, and 50 vertical levels. The nested domain was 5600 x 5600 km in area, at a horizontal grid spacing of 4km, and 50 vertical levels.
- Simulations were run for the time period from 00Z on November 21 through 18Z on November 25.

Results

Fig 2. Potential Vorticity Comparisons



Conclusions and Future Work

- As expected, when latent heat release is removed from the environment we see a decrease in the central pressure of the system, and in the strength of the system as a whole.
- When latent heat release is included in the model run, a "notch" in the PV maximum associated with the system develops to the northwest of the cyclone center, in the occlusion zone. This is consistent with the results of Posselt and Martin (2004).
- The "notch" develops due to latent heat release at lower levels, and propagates vertically upwards, resulting in a time lag of approximately 6 hours between PV erosion at the mid-levels and upper levels.
- In contrast to previous studies, latent heat release in the warm frontal region at the northern-most extent of the warm conveyor belt, appears to have little effect on the upper tropospheric PV distribution.

Steps to further this work include:

- Expanding comparisons to involve satellite retrieval data, as seen in Figure 3 below.
- Experimenting with targeted removal/addition of latent heat release, exploring the sensitivity of the system to both magnitude and location of latent heat release.
- Exploring the effect of varying degrees of latent heat release on the system, at levels both less than and greater than the actual value, in order to gauge the response function of the system.

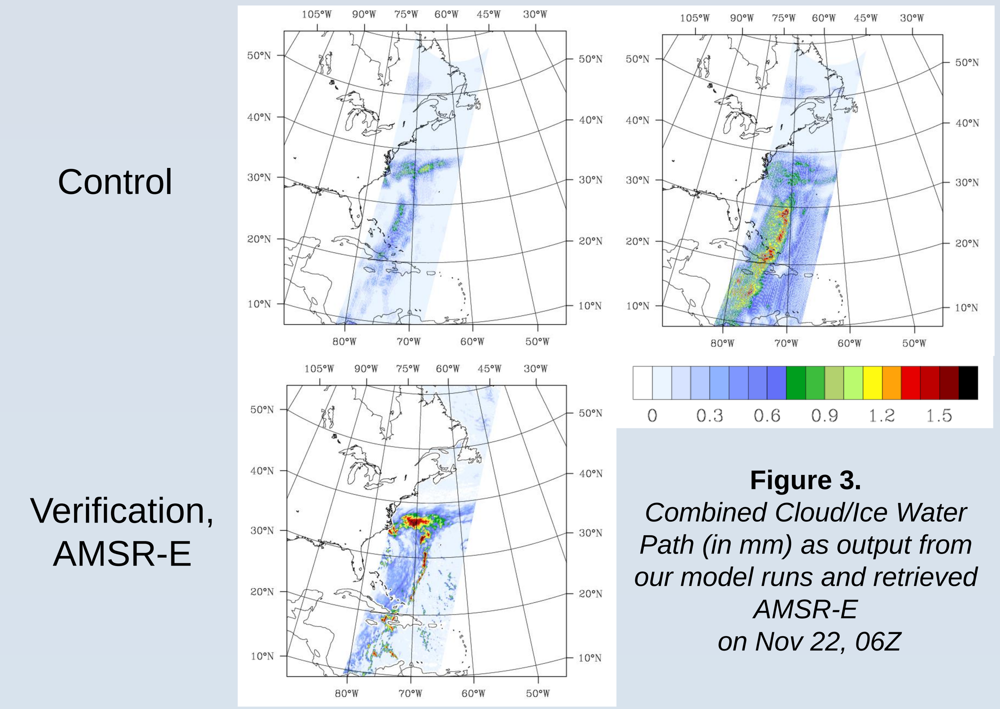


Figure 3.
Combined Cloud/Ice Water Path (in mm) as output from our model runs and retrieved AMSR-E on Nov 22, 06Z

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