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Multiple Perspectives on the Effect of Latent Heat Release on an Extratropical Cyclone

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Summary

- Observational data and remote sensing data were combined with WRF model data to create a holistic perspective of a winter storm off the East Coast in November 2006.
- Companion model runs of the WRF were run, one without the effect of latent heat release, in order to diagnose potential effects from the removal of latent heat release.
- Removal of latent heat release did not significantly decrease the minimum sea level pressure of the surface low, but did significantly tighten the surrounding gradient.
- Latent heat release greatly contributes to the potential vorticity present in the storm, and, at lower levels, serves as a precursor to upper level PV erosion.

Introduction

Within the synoptic-scale of extratropical cyclones, meso- and microscale processes work to strengthen or weaken the entire cyclone to varying degrees. One such process is latent heat release, whose effect on a system wide scale is straightforward. Adding a bubble of latent heat at the center of a cyclone will lead to spin-up, and subsequent intensification of the cyclone (Stoelinga 1996).

However, the effect of latent heat in extratropical cyclones becomes much more complicated at the frontal scale and has merited a significant amount of study in recent years as the upscale linkages can be difficult to deconvolve. (Lackmann 2002, Reeves and Lackmann 2004, Posselt and Martin 2004, Grams et al. 2011). Our initial goal is to compare observations and modeling data of a long-lived extratropical cyclone off the east coast in November 2006. Confirming the accuracy of our model, we will then proceed to attempt diagnosing the effect of latent heat on the structure of the cyclone as a whole.

Case Selection

Because our intent is to compare and integrate observational data with model predictions in a unified analysis, we chose an extratropical storm that lingered off the east coast of the United States in November of 2006. Remaining nearly stationary between approximately 21-23 Nov. 2006, the storm was overpassed multiple times by NASA's A-Train constellation of satellites, including CloudSat and CALIPSO. These overpasses make up datasets which verify and enhance the modeling aspect of our study.

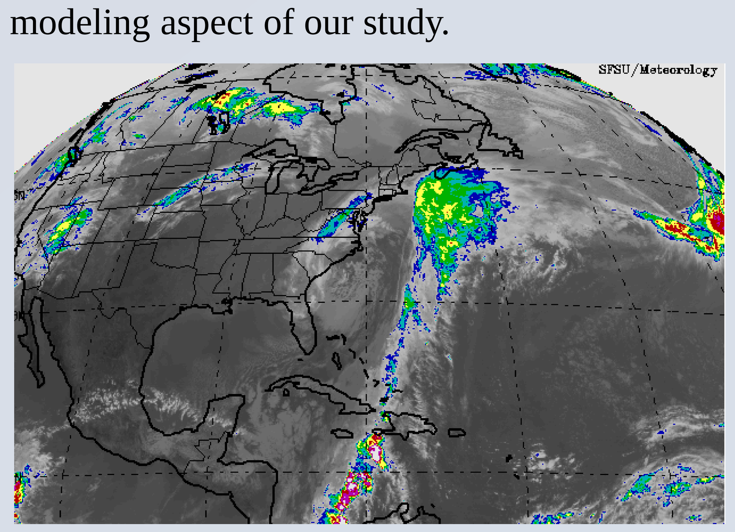


Figure 1. GOES IR image of the case storm at 18Z on 22 Nov.

Methods

- Ran two companion simulations using the Weather Research and Forecasting (WRF) model to isolate the effect of latent heat: a "full physics" model and a "no latent heat release" model, wherein the effects of latent heat release were removed. Specifically, the removal of latent heat release was performed via a namelist option wherein the latent heat of fusion and vaporization are both negated.
- Our nesting domain spanned a region 6000 x 6000 km in area, spanning from the North Atlantic to the Midwestern United States. Horizontal grid spacing was 20 km, with 50 vertical levels as an outer nest. 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.
- The Goddard Satellite Data Simulator Unit (GSDSU) was used to obtain simulated AMSR-E output from the WRF model data.

Results

Component 1 – Sea Level Pressure Analysis

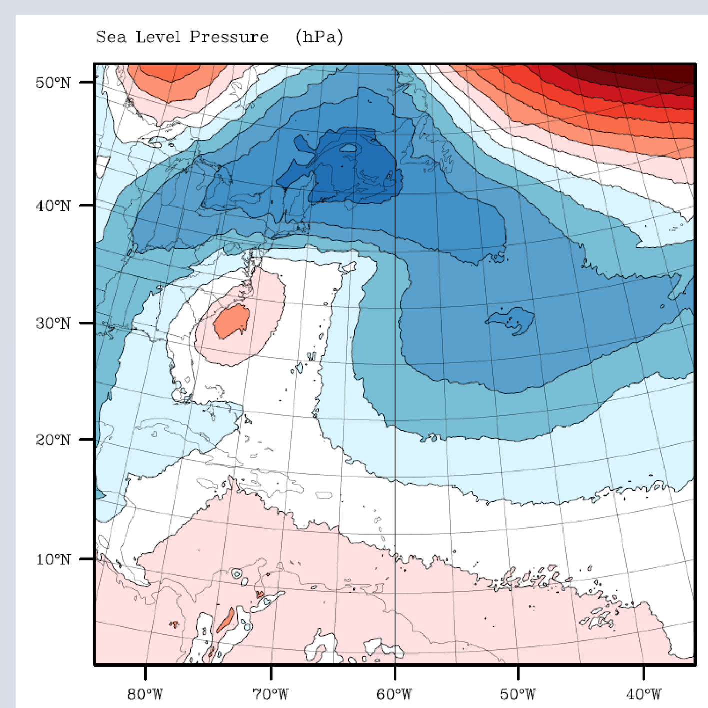
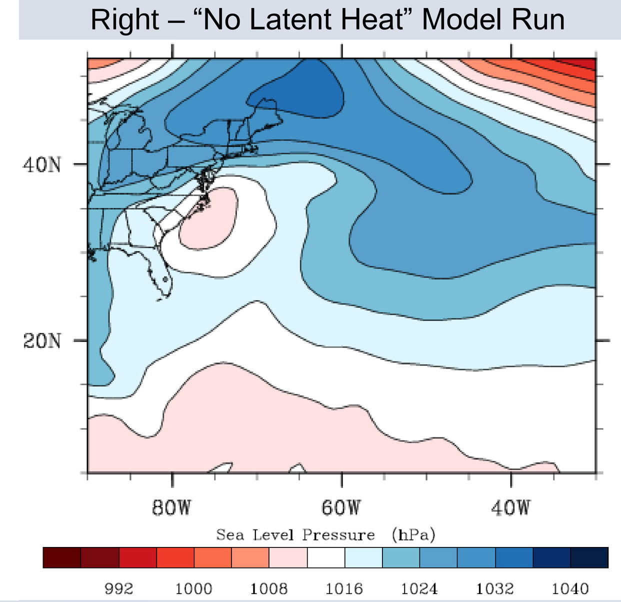
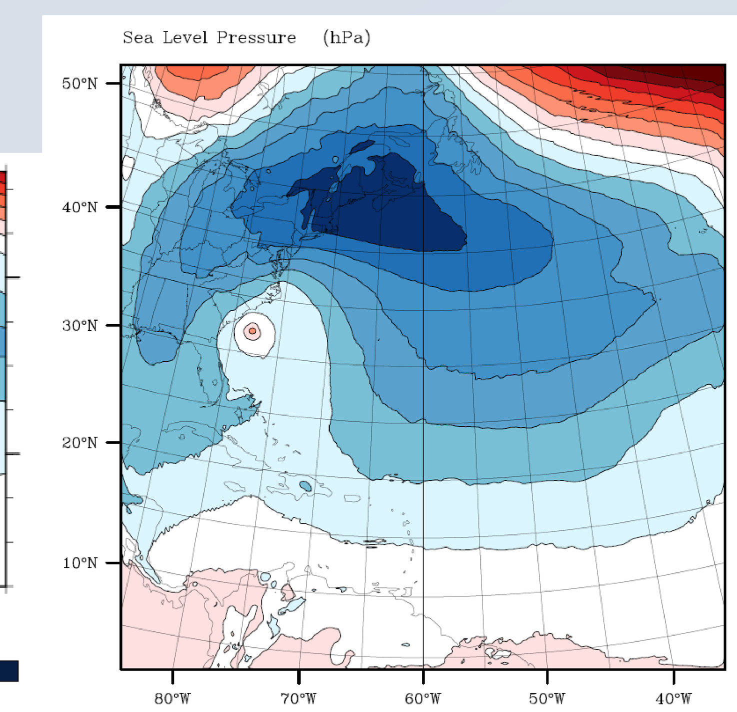
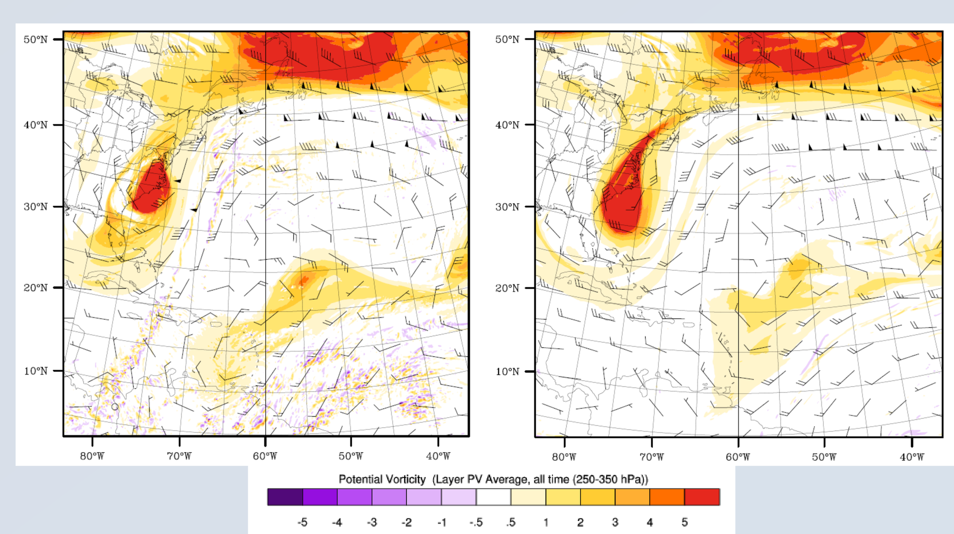


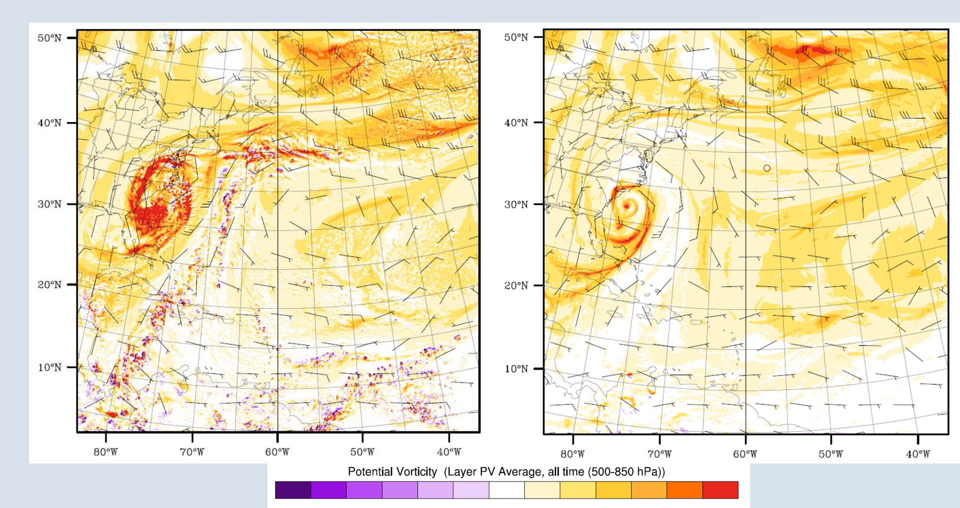
Figure 2. SLP Analysis at Nov. 23 00Z
Left – "Full Physics" Model Run
Below – GFS Reanalysis
Right – "No Latent Heat" Model Run





Component 2 – Potential Vorticity Analysis





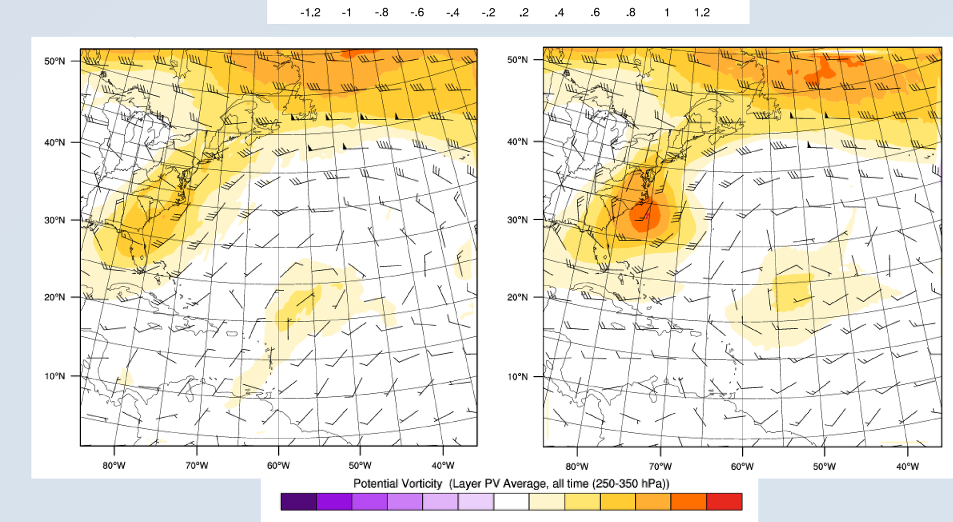


Figure 3.
Top Left Dual Plot : Layer Average PV (250-350 hPa) at 00Z 23 Nov.

Top Right Dual Plot: Layer Average PV (500-850 hPa) at 00Z 23 Nov.

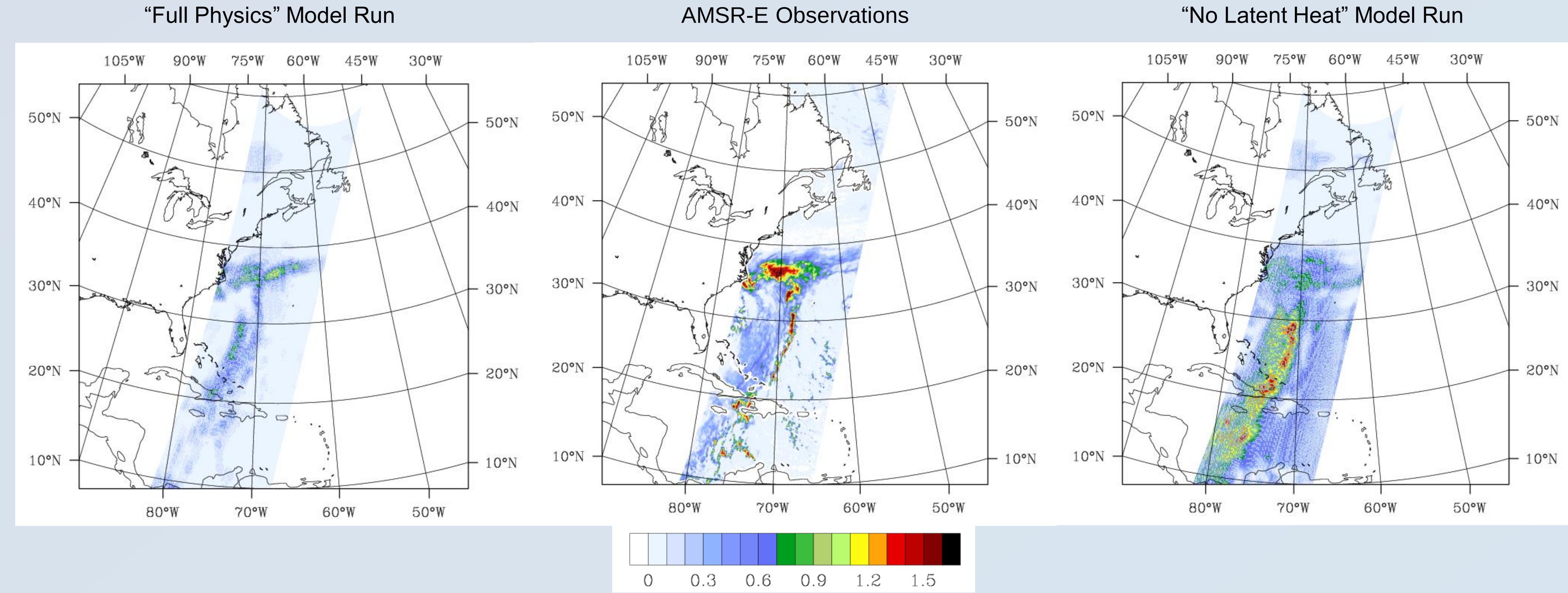
Bottom Right Dual Plot: Layer Average PV (250-350 hPa) averaged from 00Z 21 Nov. – 18Z 25 Nov.

For each dual plot:
Left: "Full Physics" Model Run
Right: "No Latent Heat" Model Run

Component 3 – Satellite Observation/Simulation

Figure 4. *AMSR-E Nov. 22 06Z – Combined Cloud/Ice Water Path (mm)*

"Full Physics" Model Run | AMSR-E Observations | "No Latent Heat" Model Run



Conclusions

- The removal of latent heat release in the model does not necessarily decrease the strength of the surface low. However, the gradient around that low tightens considerably.
- The latent heat release in the "Full Physics" run contributes to significant PV modification and creation in the warm sector of the extratropical cyclone.
- In the "Full Physics" run, PV generation in the lower levels of occluded sector act as a precursor to PV erosion in the upper levels of the atmosphere in the same zone, as the western portion of the Warm Conveyor Belt stretches into the cyclone.
- The removal of latent heat release stalled the propagation of the storm to the Northeast through strengthening of the high pressure system to the northeast of the low. This evidenced by the "PV Bullseye" in the time-averaged run.

Future Work

- Expansion our simulation of satellite data from model output beyond AMSR-E to other instruments such as CALIPSO, CloudSat, and MODIS.
- Performing a PV Inversion analysis to extract potential vorticity creation by solely diabatic forcings
- Exploring the effect of the "No Latent Heat Release" flag in the WRF, and modifying its range to target specific areas, such as the warm frontal region, for example.
- Exploring the effect of modifying the amount of latent heat release, both in greater and lesser quantities, to test the sensitivity of feedbacks within the system.

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Acknowledgments

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