Ensemble variability in rainfall forecasts of Hurricane Irene (2011)

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Motivation

- Ensemble runs of weather models such as the Global Forecast System (GFS) are becoming an important component of a forecaster's toolbox.

- Ensembles aid in probabilistic weather forecasting, clearly illustrating the amount of uncertainty in a given forecast, and allowing forecasters to evaluate various forecast scenarios.

- However, many ensemble forecasts today are evaluated merely in terms of ensemble mean and standard deviation.

- Our main goal is to develop new methods of evaluating ensemble models beyond the mean and standard deviation, and to understand the processes that give rise to differences in forecasts.

Motivation

- This work aims to understand what modulates precipitation variability in ensemble modeling of heavy rainfall events associated with tropical moisture sources by using Hurricane Irene (2011) as a case study.

  – Irene was one of the costliest storms to ever hit the Northeast, with an estimated $15.8 billion in damages.
  – A large portion of this cost was due to catastrophic inland flooding caused by widespread rainfall totals of 4-7 inches.

- Can we use features of ensemble models (besides the mean and standard deviation) to forecast when heavy precipitation events are likely to occur?

  – Also, what processes give rise to wetter and drier forecasts of Hurricane Irene?

Methods

- The 0000 UTC 27 August GFS ensemble precipitation forecasts were examined in terms of variability between members.

  - These GFS ensemble forecasts were created with the current operational version of the GFS.

- Members were ranked by the amount of precipitation they brought to the Catskill region of New York (41.5-42.5°N, 73.5-75°W) from 0000 UTC 27 to 0000 UTC 29 August.

  - The Catskills received some of the worst flooding associated with Irene, and are thus a good indicator of whether ensemble members could accurately forecast this heavy rainfall event.

- The synoptic characteristics of the ten wettest ensemble members were then compared to those of the ten driest members, to see if any large-scale patterns were behind the differences in forecasted precipitation.

Results: GFS

GFS 12-36 Hour Ensemble Mean Precipitation

GFS Ensemble Tracks

Catskills: < 75 mm
Catskills: >= 75 mm, < 125 mm
Catskills: >= 125 mm, < 175 mm
Catskills: >= 175 mm, < 200 mm
Catskills: >= 200 mm
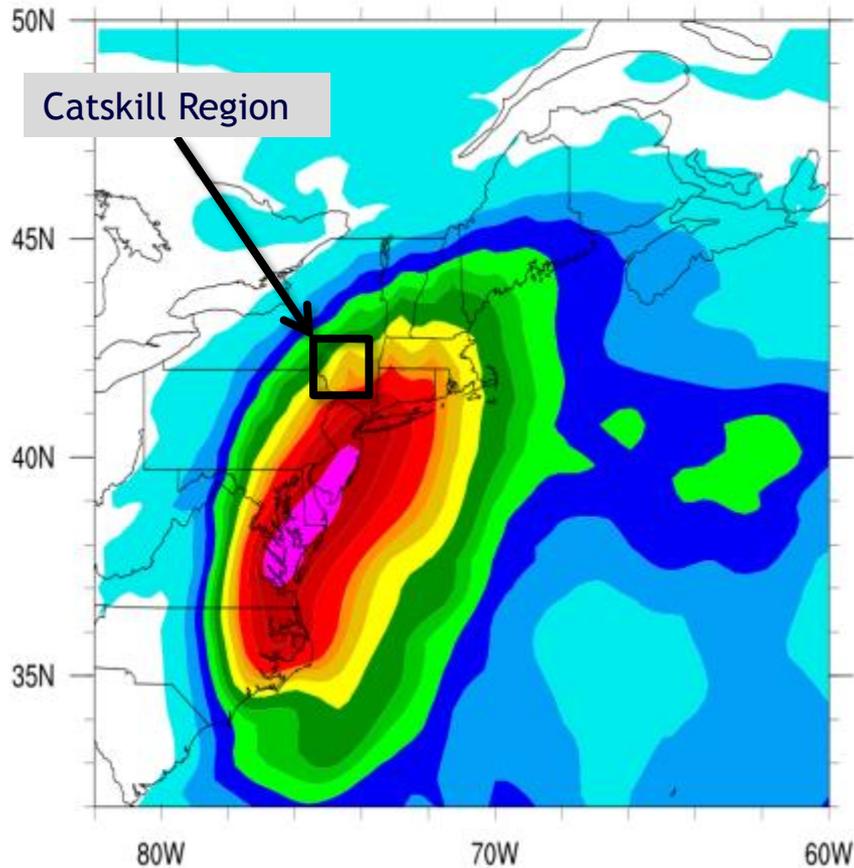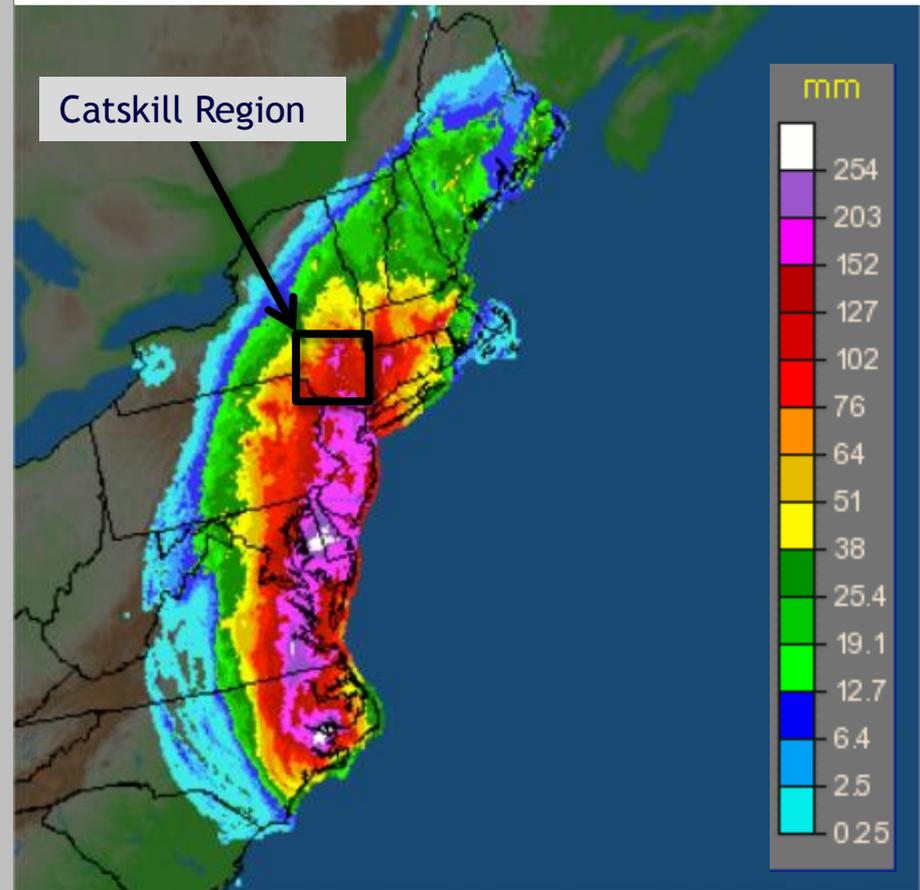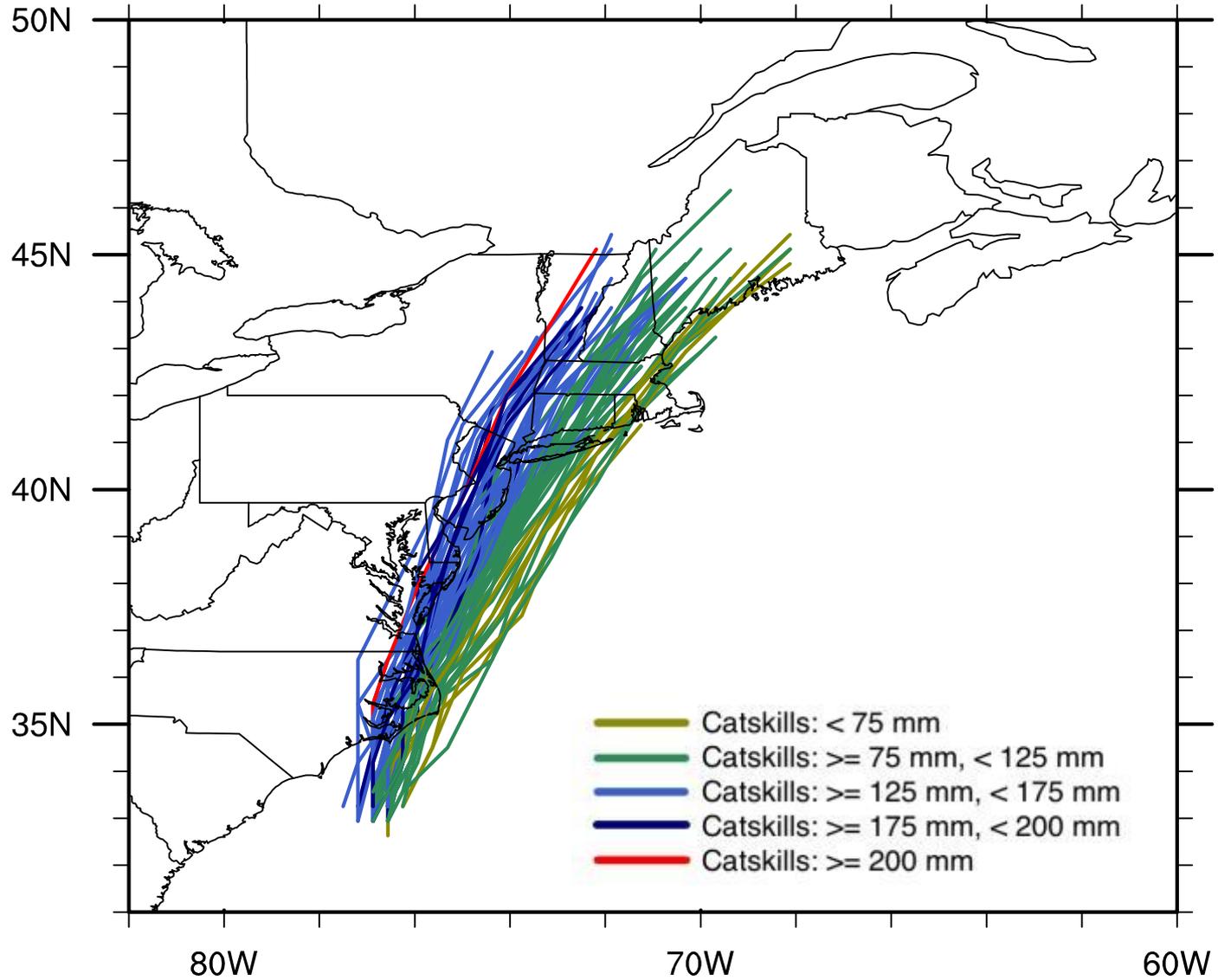
Why do some storms track farther west?

Examination of synoptic characteristics

Composite Difference Plots
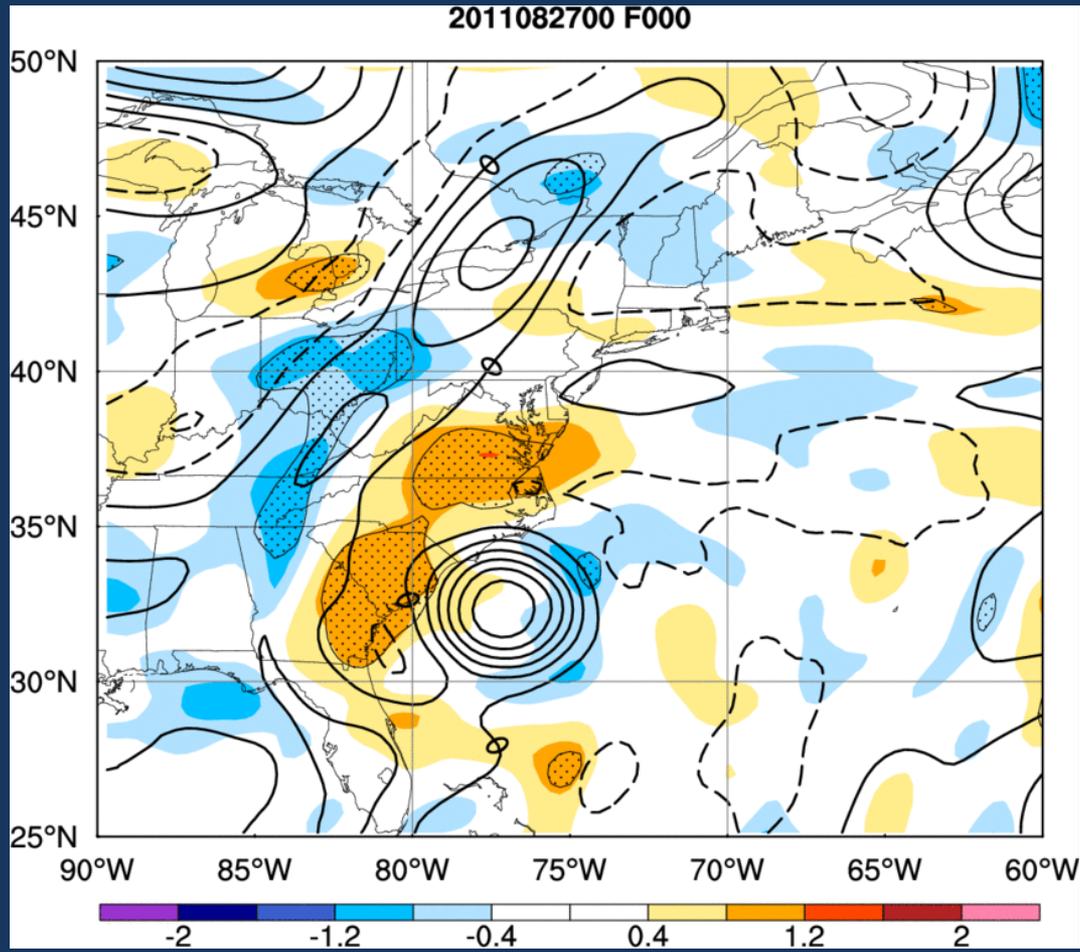
Composite Difference Plots

Comparison of 10 wettest ensemble members and 10 driest.

Contours: Ensemble mean.

Stippling: Significant at 95% level.
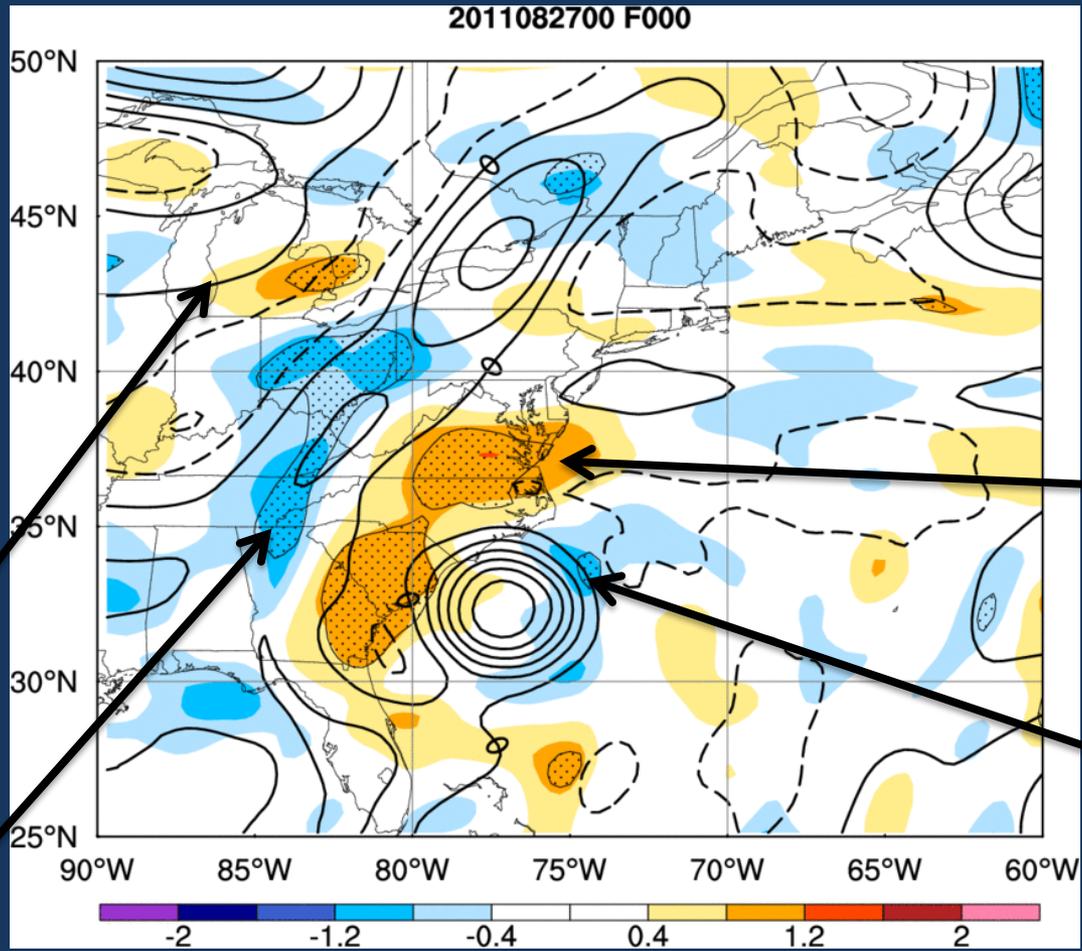
Colors: Standardized difference between wet and dry members.

Warm colors: Wet members have greater value.

Cold colors: Dry members have greater value.

2011082700 F000

300 mb Circulation – 00hr
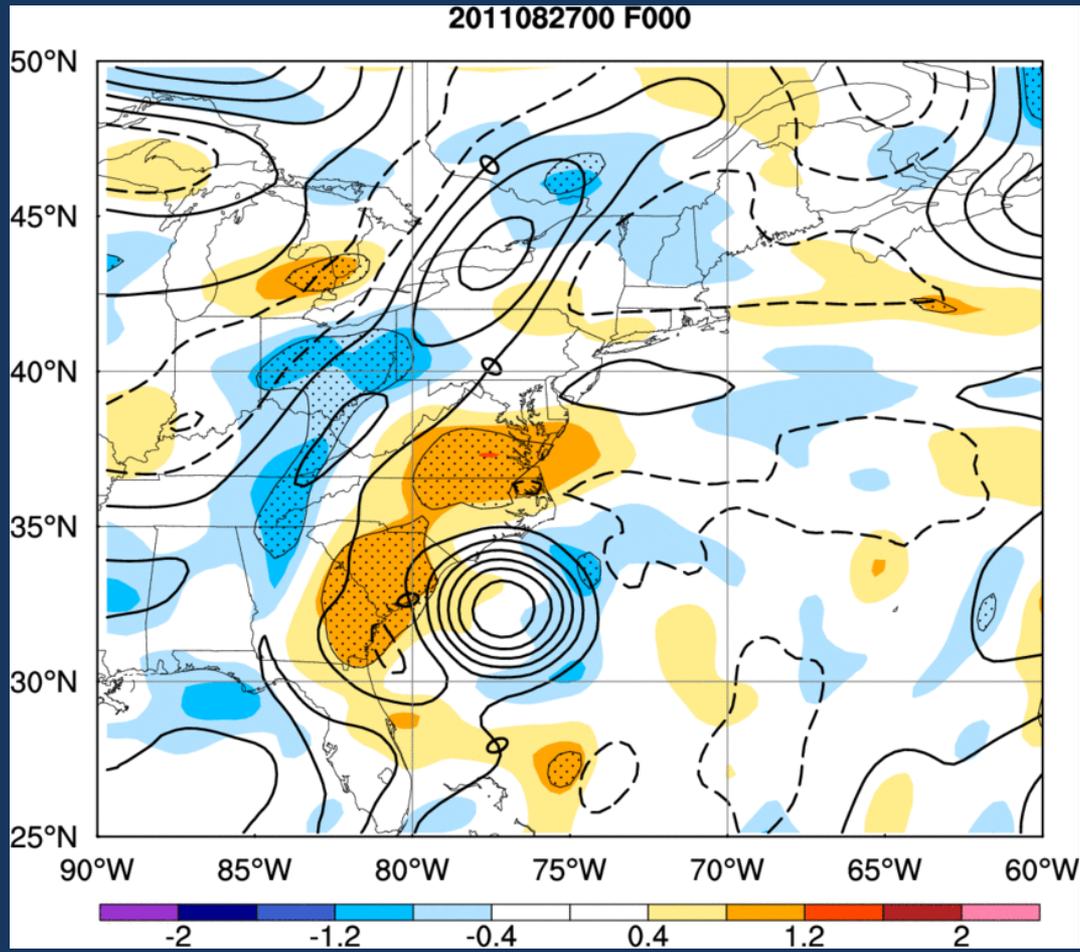
2011082700 F000

Interactions with a trough to the west caused Irene to track further inland in the wetter members.

300 mb Circulation – 06hr
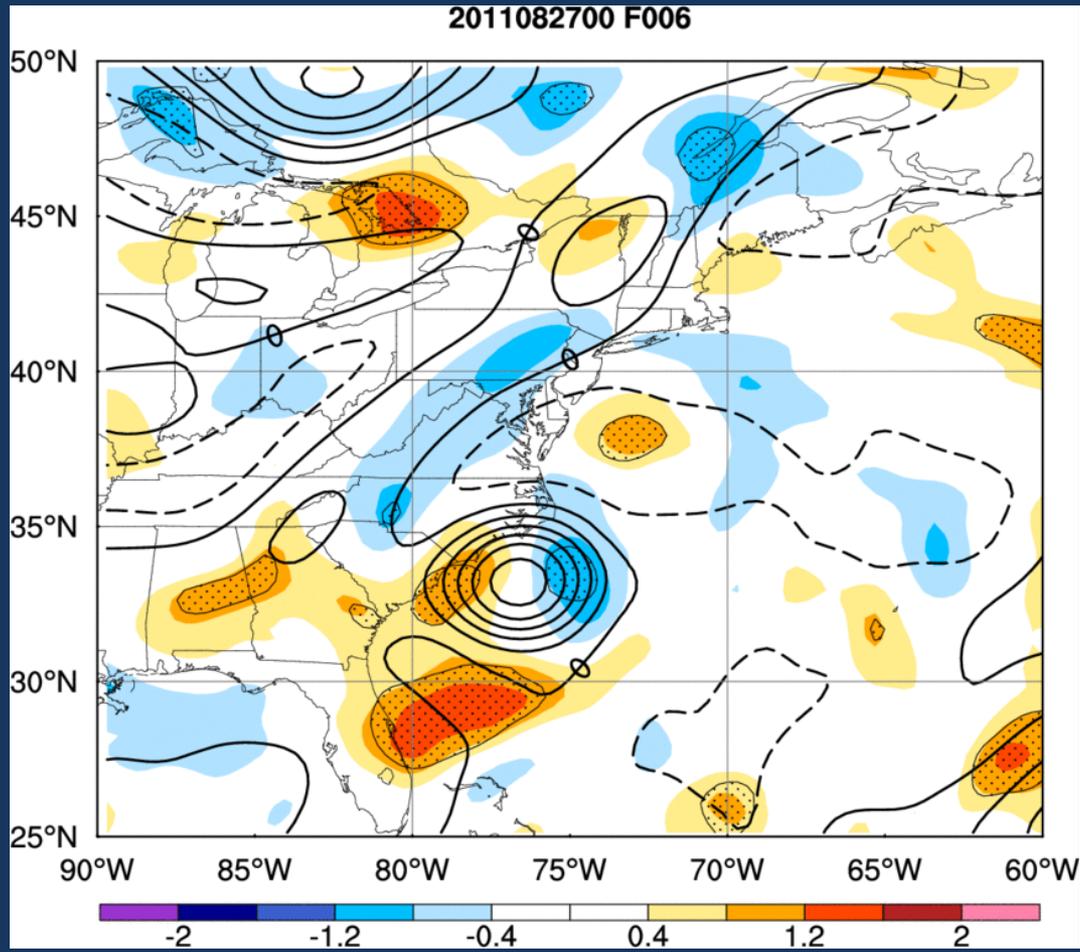
2011082700 F006

Interactions with a trough to the west caused Irene to track further inland in the wetter members.

300 mb Circulation – 12hr
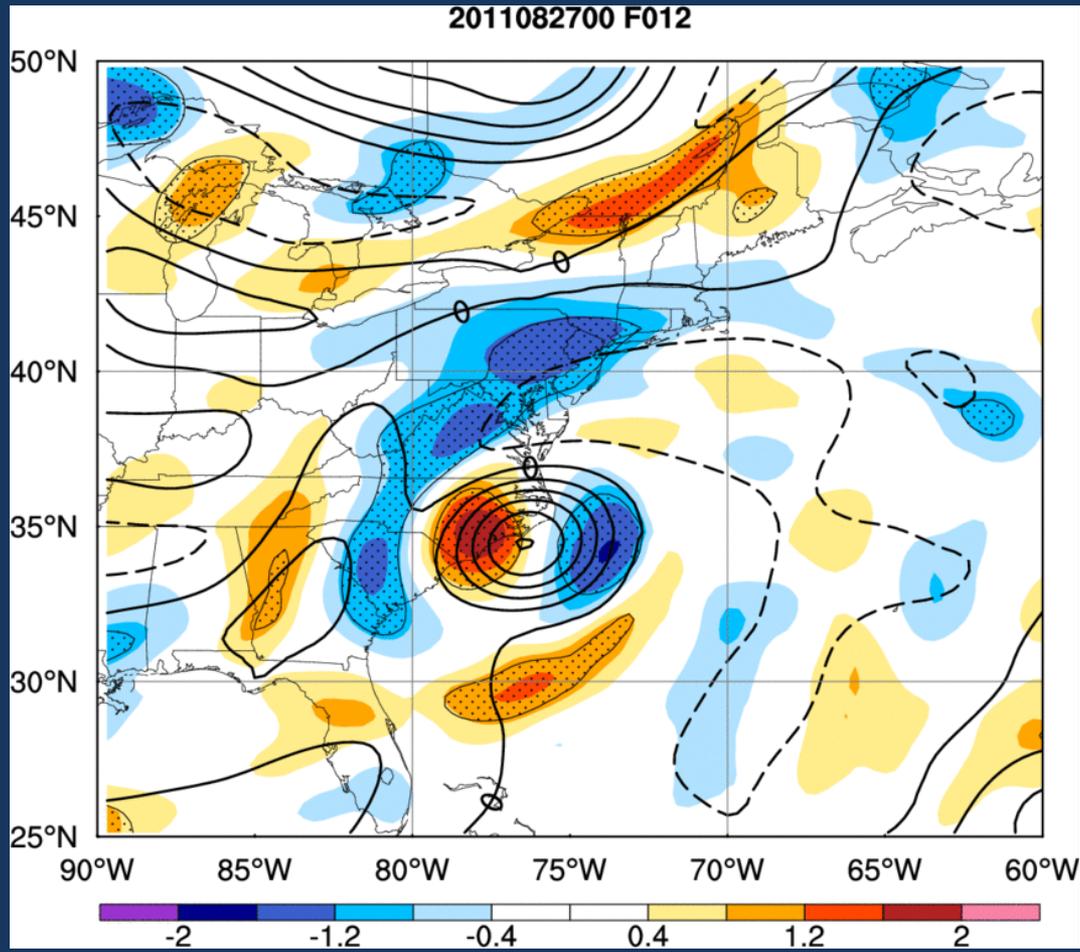
Interactions with a trough to the west caused Irene to track further inland in the wetter members.

300 mb Circulation – 18hr
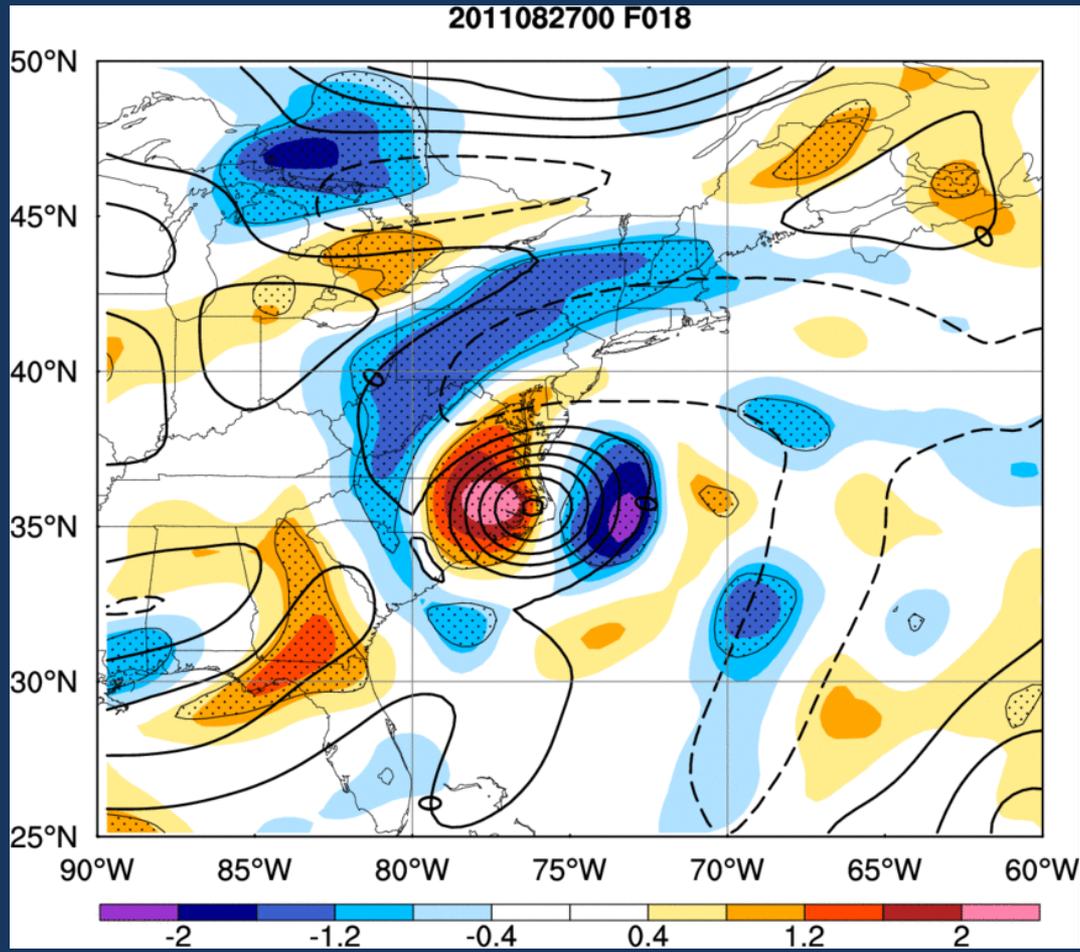
Interactions with a trough to the west caused Irene to track further inland in the wetter members.

300 mb Circulation – 24hr
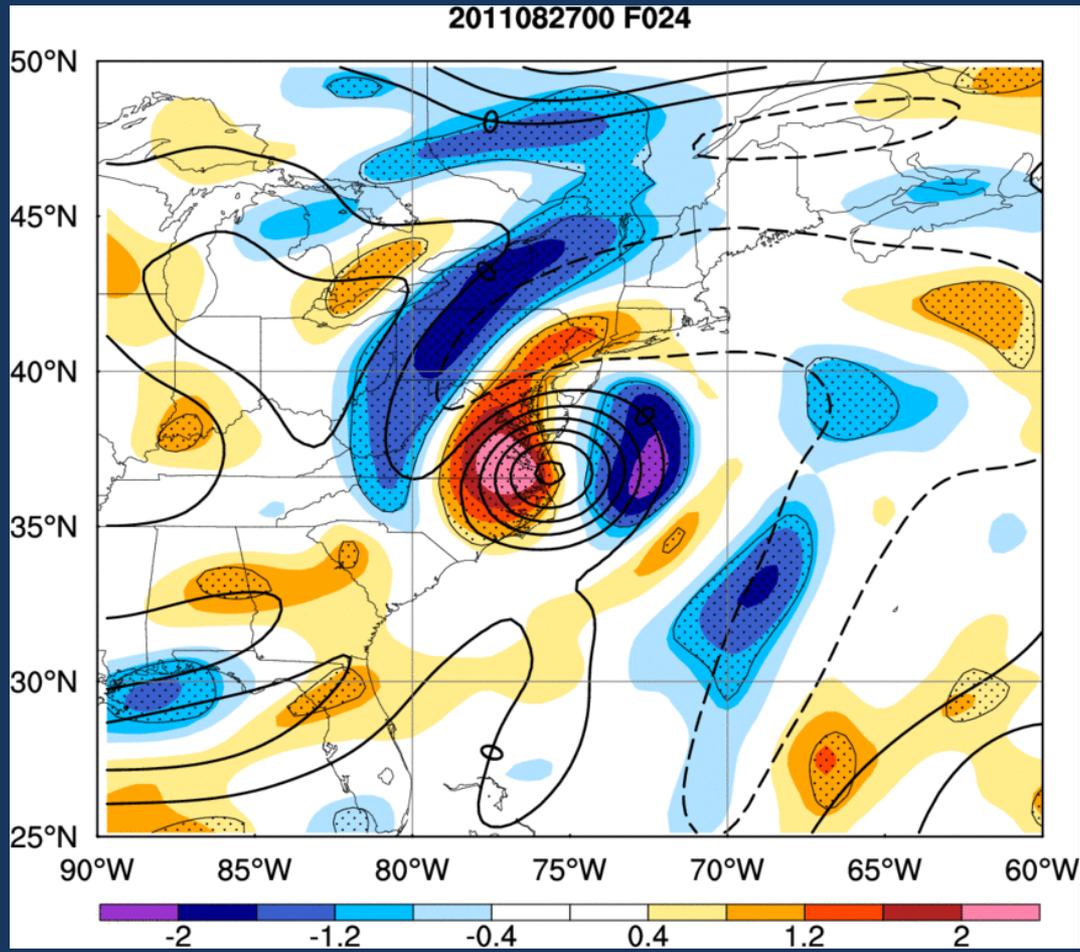
Interactions with a trough to the west caused Irene to track further inland in the wetter members.

300 mb Circulation – 30hr
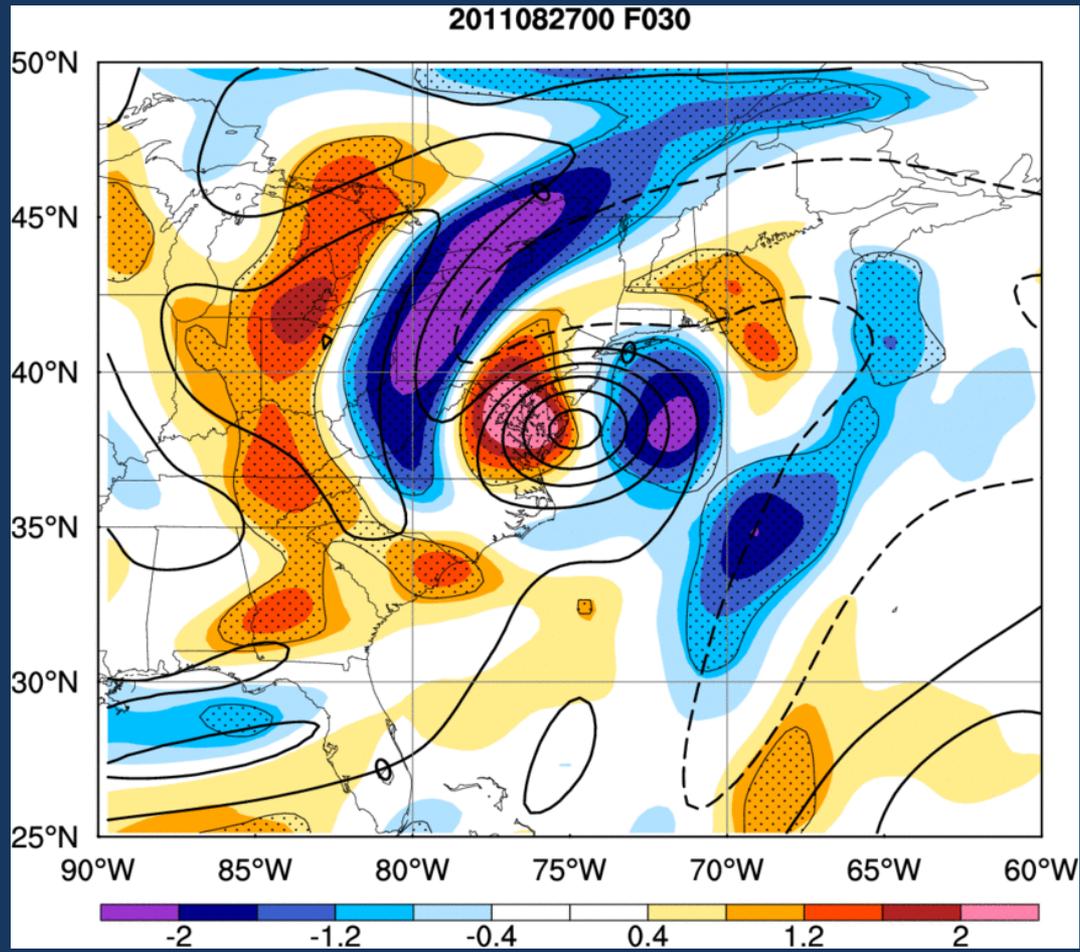
Interactions with a trough to the west caused Irene to track further inland in the wetter members.

300 mb Circulation – 36hr

2011082700 F036
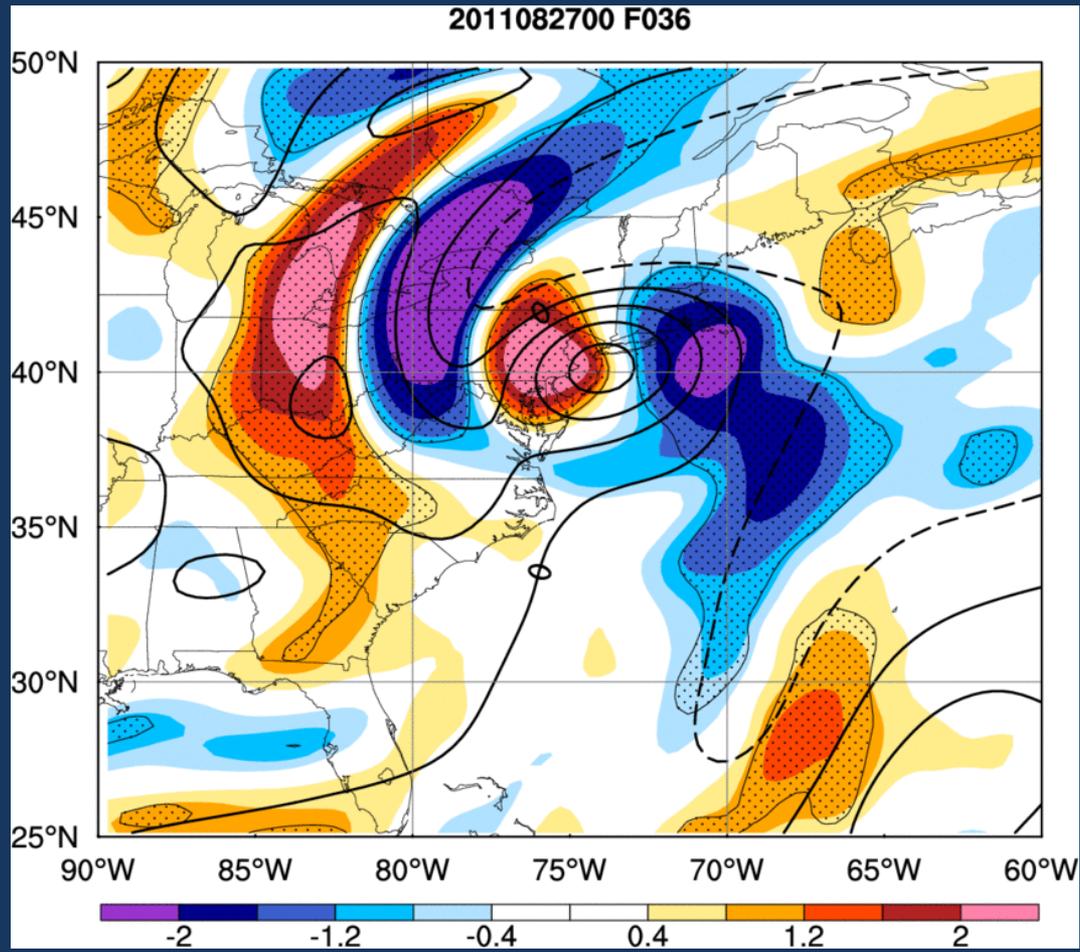
Interactions with a trough to the west caused Irene to track further inland in the wetter members.

300 mb Divergence – 36hr
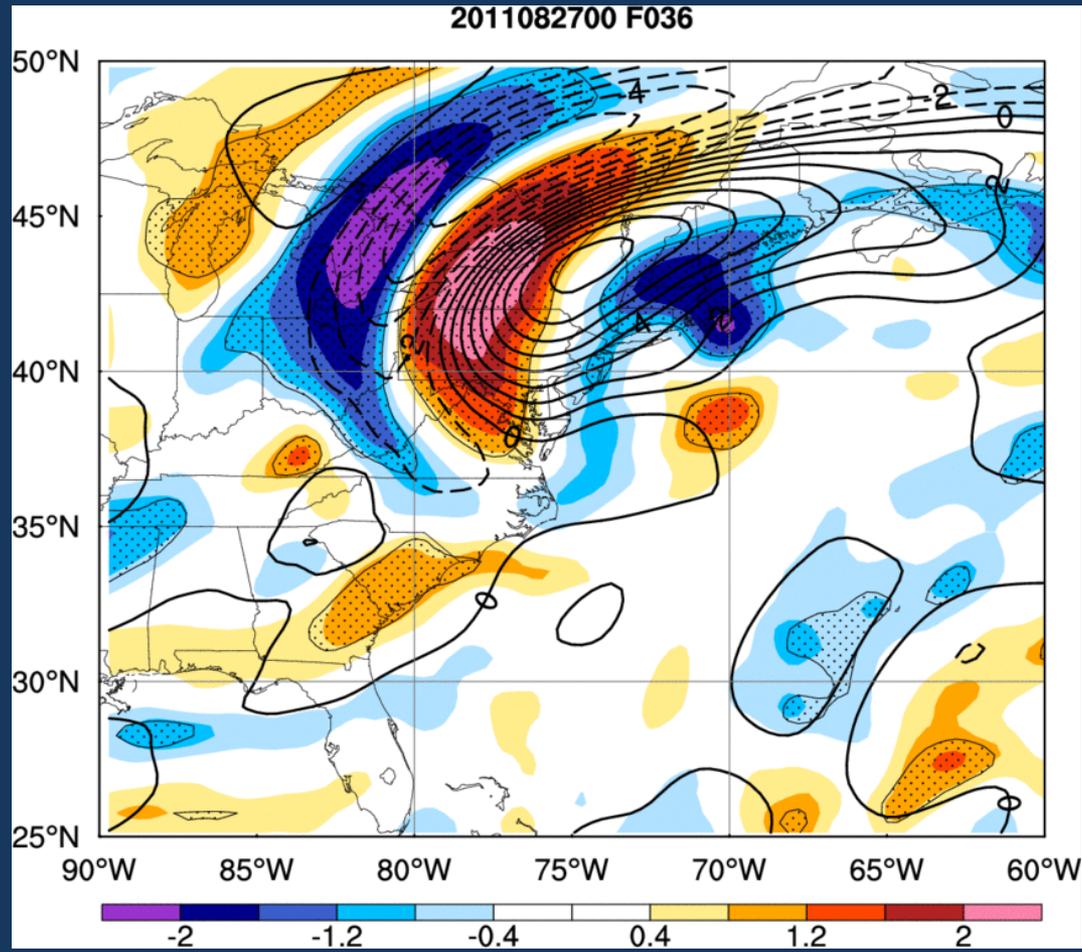
In the wetter members, Irene experienced greater outflow on its western side. This outflow may have contributed to keeping the approaching trough farther west.

700 mb Water Vapor – 36hr
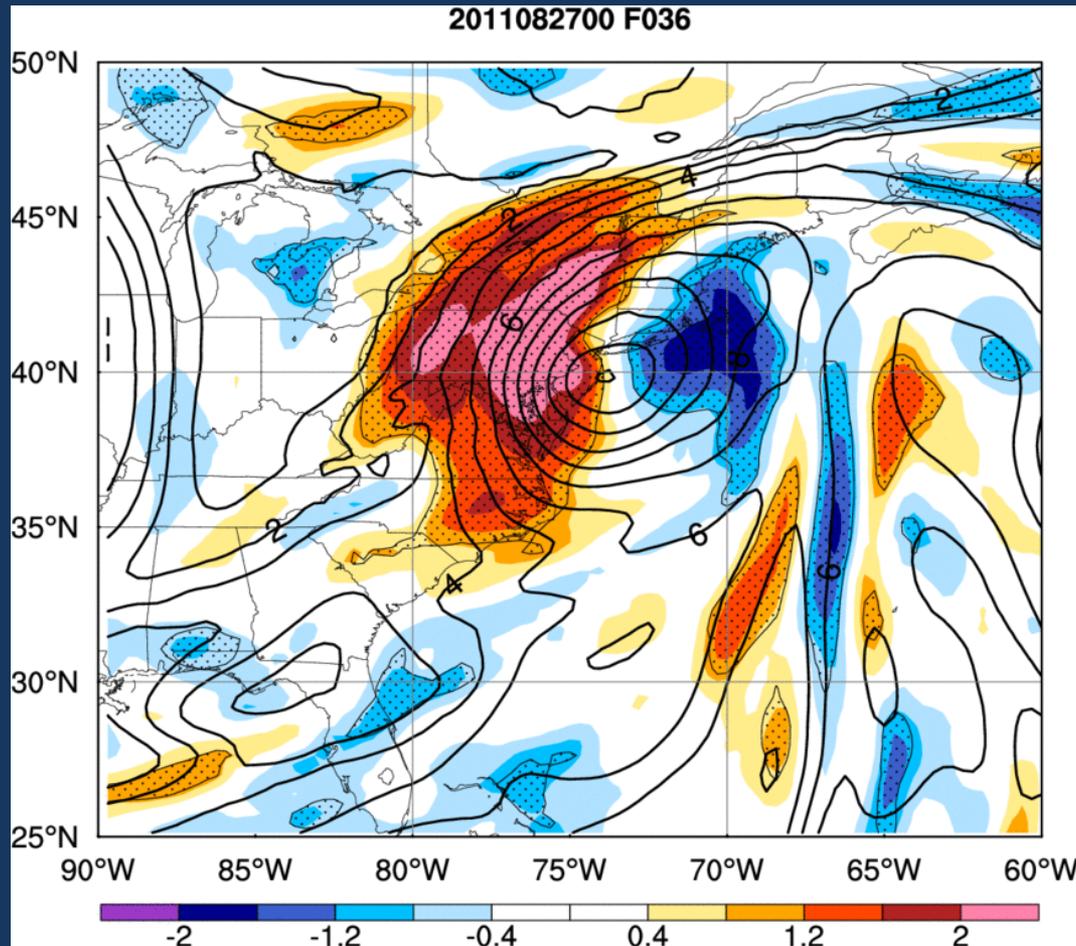
This change in storm position allowed the region of maximum water vapor to be positioned over the Catskill region.

Downscaling

- The 0.5 degree GFS output was downscaled to 15 km using WRF.
- This will allow for a better representation of mesoscale processes and the effects of terrain on precipitation distribution.
- The physics used were comparable to those used in HRRR.

Results: WRF

WRF 12-36 Hour Ensemble Mean Precipitation

WRF Predicted Accumulations (mm)

Catskill Region
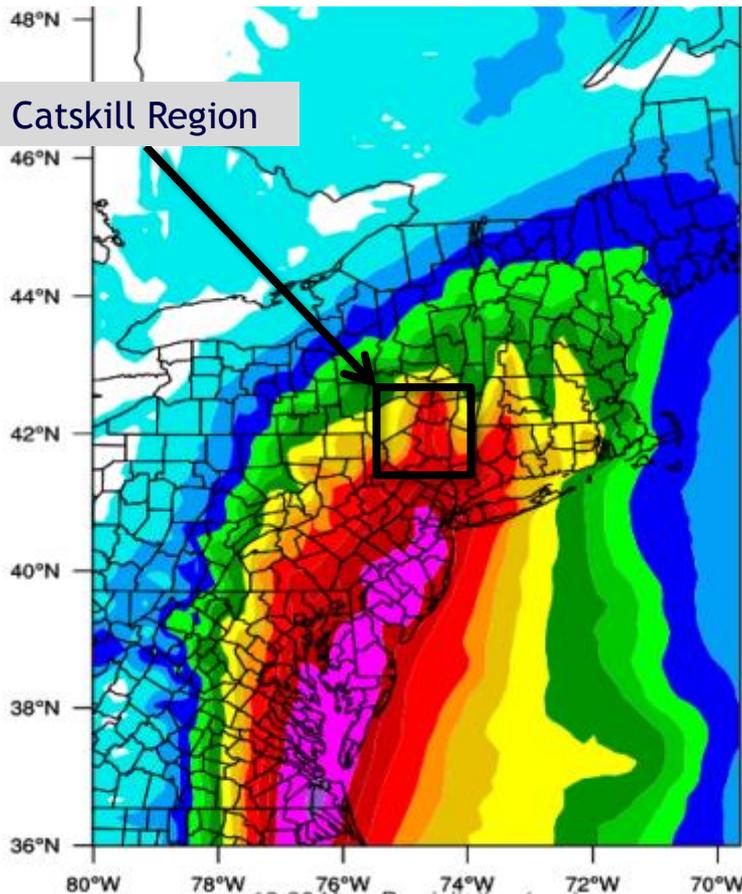
Observed Accumulations (mm)

Catskill Region
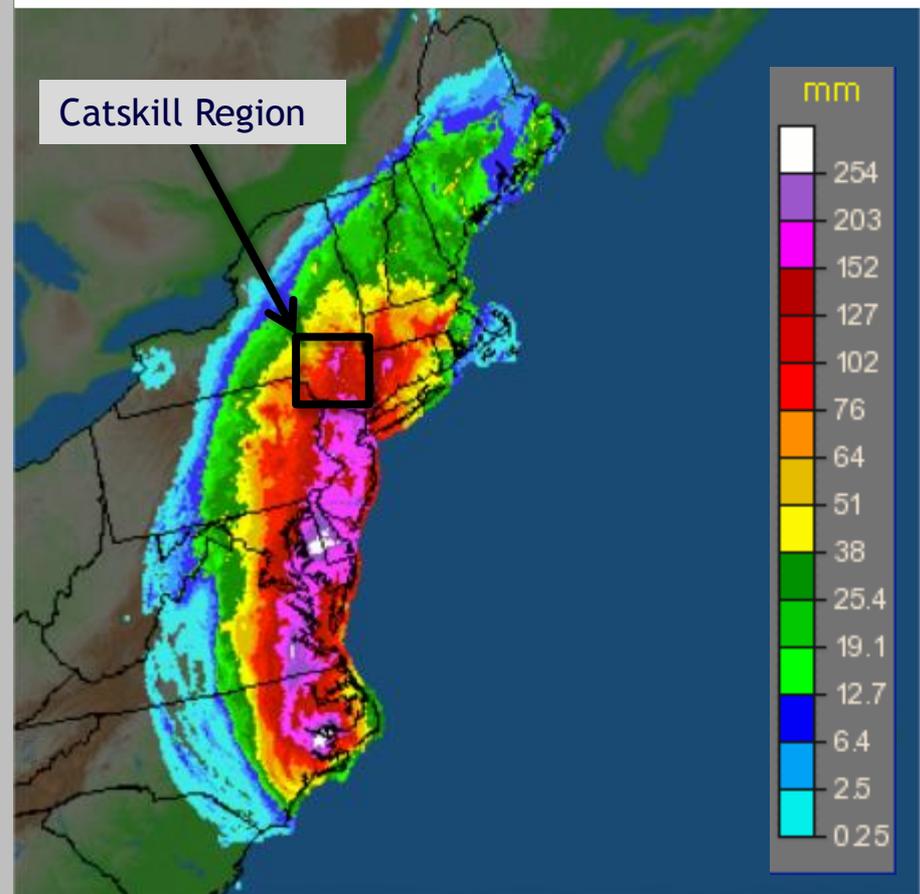
GFS vs WRF Ensemble Members

GFS Catskill Precipitation Distribution
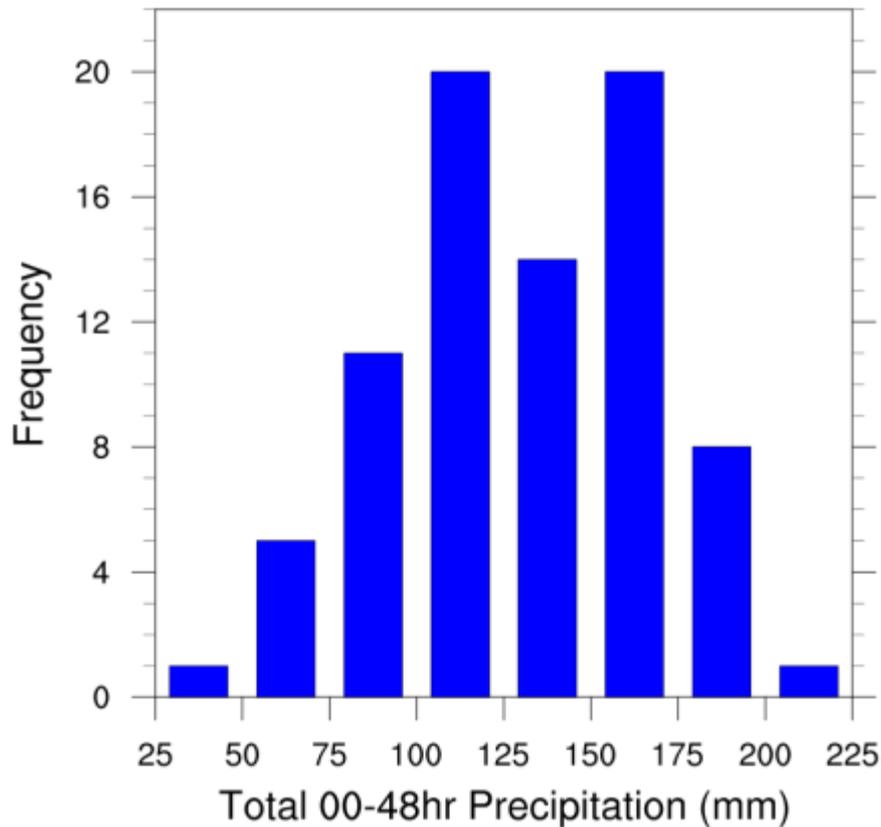
WRF Catskill Precipitation Distribution

WRF Ensemble Tracks

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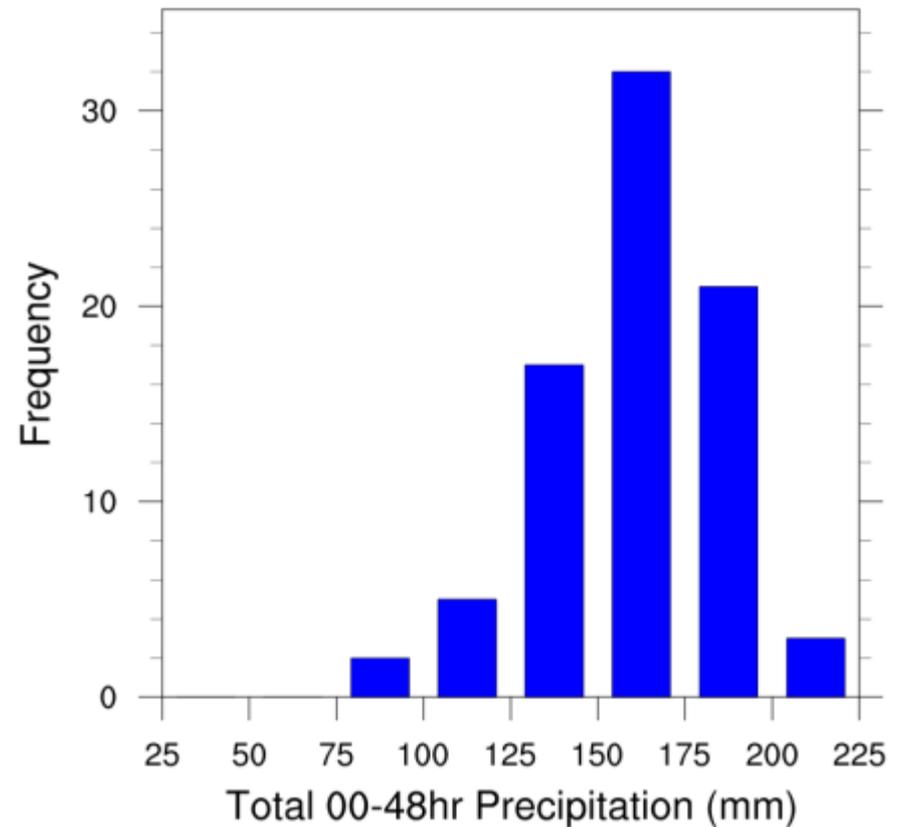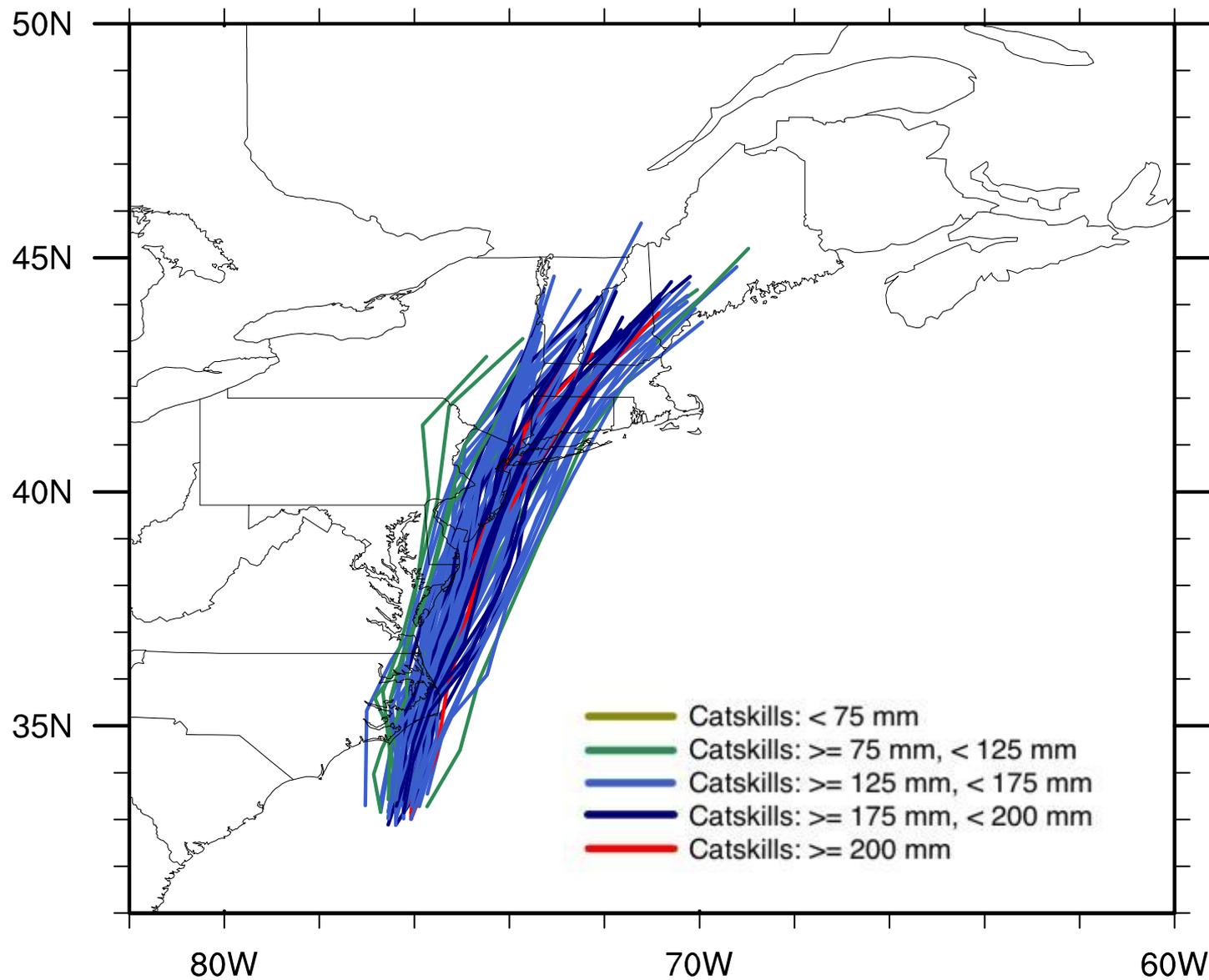
So what makes some members deliver more precipitation?

Examination of synoptic characteristics

300 mb Circulation – 36hr
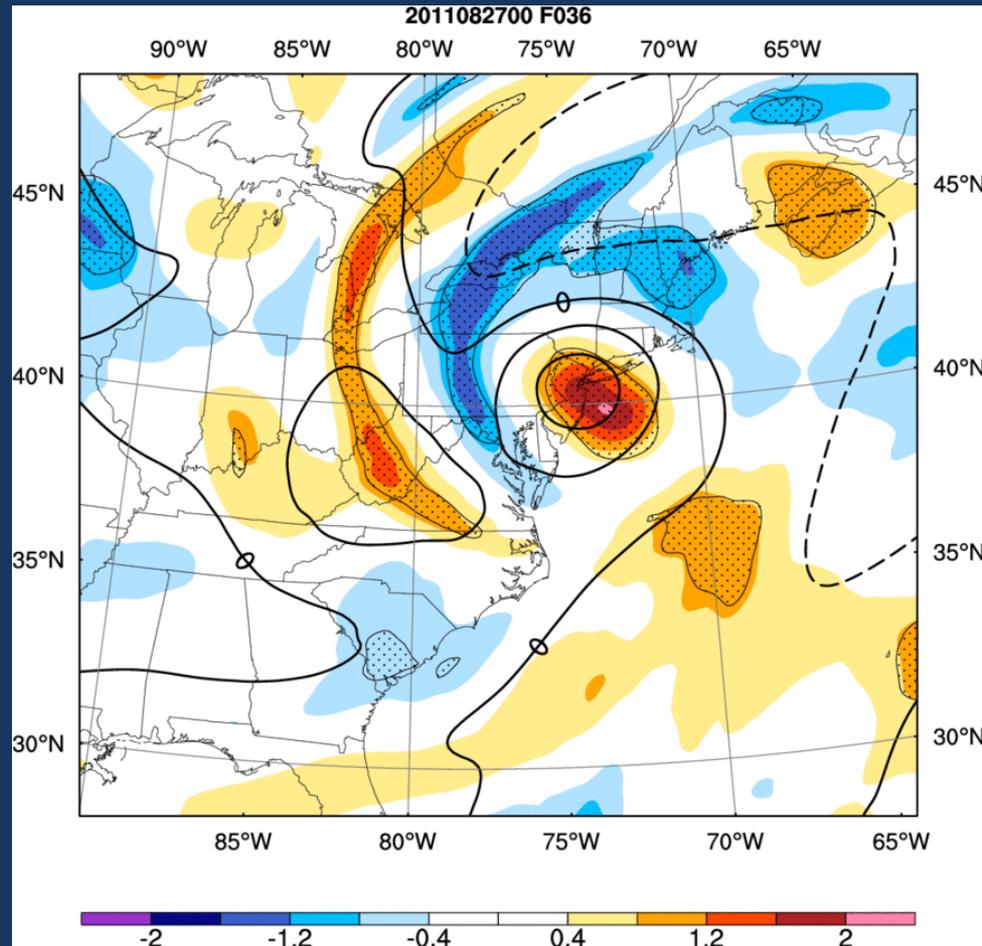
The wetter WRF members feature a stronger cyclonic circulation.

850 mb Zonal Winds – 36hr
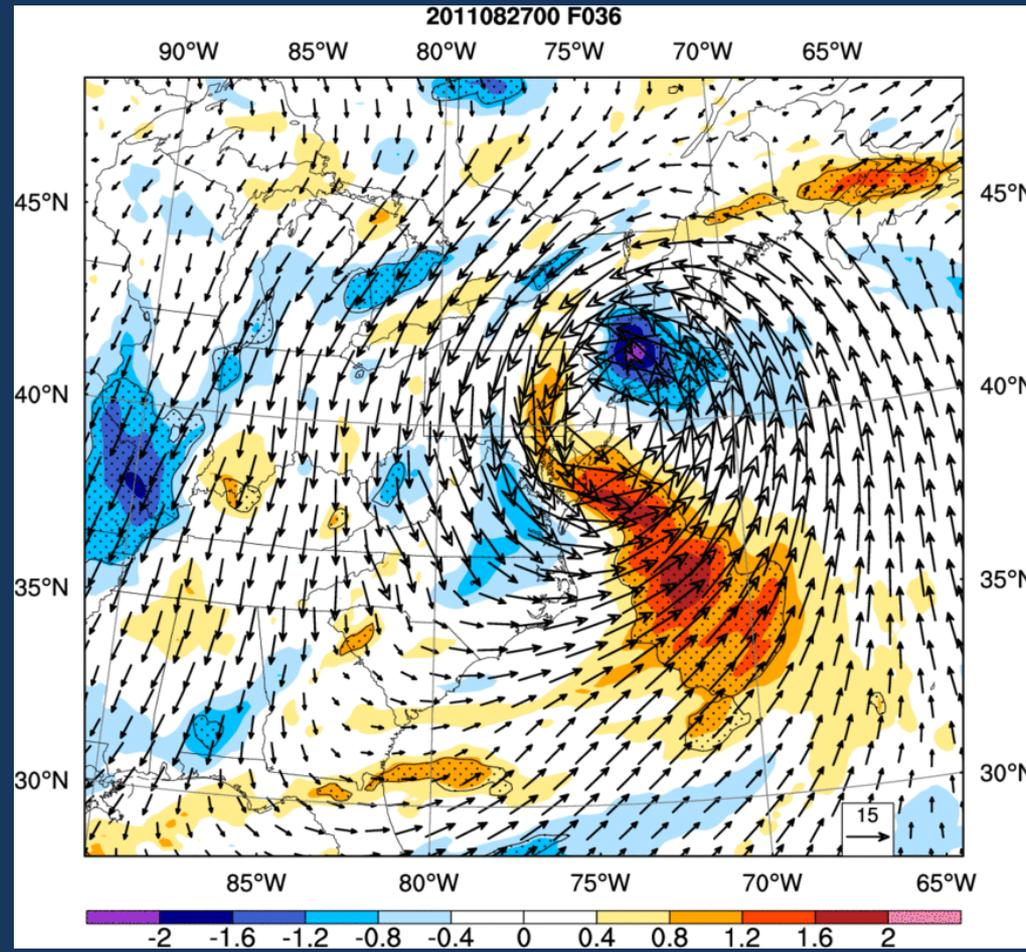
This means that stronger easterly wind was coming onshore in the New York area, generating confluent flow over the Catskill Plateau.

850 mb Frontogenesis – 36hr
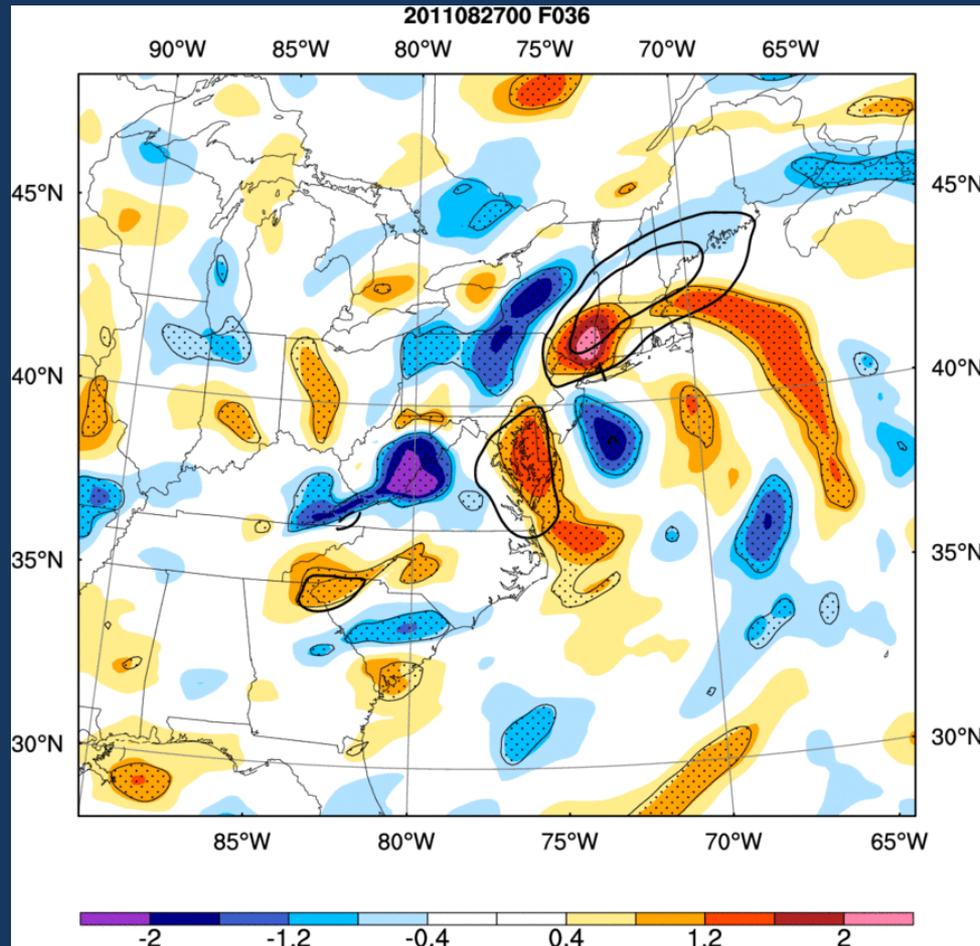
This confluence led to significant frontogenesis in the region, and thus greater forcing for vertical motion.

850 mb Water Vapor – 36hr
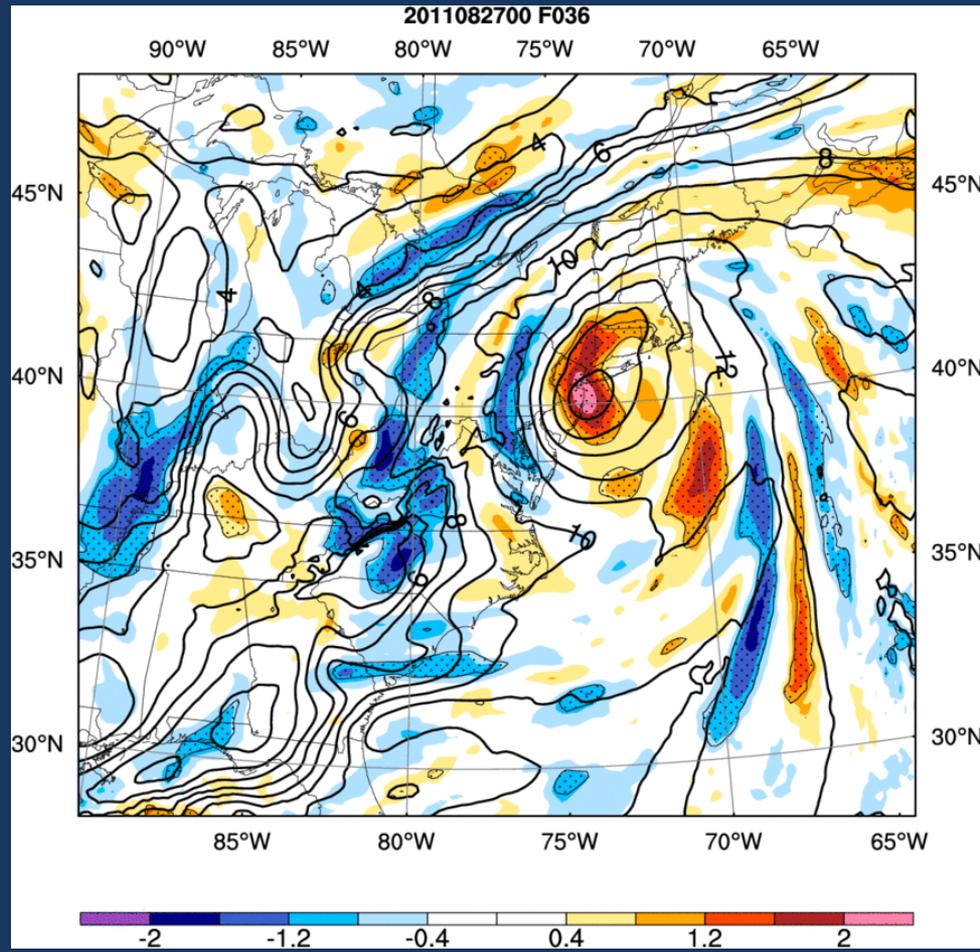
A stronger circulation allowed Irene to pick up more water vapor, created a positive anomaly over eastern New York.

Conclusions

- Precipitation differences in the GFS ensemble are largely due to the position of Irene.

  - Interactions with a trough to the west caused some members to track the storm farther inland, moving the area of maximum precipitation over the Catskills.

- Precipitation differences in the WRF ensemble are largely due to the modeled intensity of Irene's circulation.

  - A stronger circulation brought faster winds onshore near New York, which frontogenetically converged on the Catskill Plateau, leading to more rain for the region.

- Future work:

  - Identify origins of differences in both simulations.

  - Use WRF to downscale even further to 3 km, in order to better simulate the effects of terrain.

Questions?

WRF Specifications

- WRF V3.6
  - 15 km resolution over domain that includes most of eastern US and Western Atlantic.
  - Thompson Microphysics.
  - RRTMG LW/SW radiation.
  - MYNN PBL and surface scheme.
  - RUC LSM.

Hurricane Irene