Poster #806

# Understanding forecast errors in extreme precipitation events in the Southeast US


Kelly Mahoney[1], Ben Moore[1], Ellen Sukovich[1], Rob Cifelli[2]

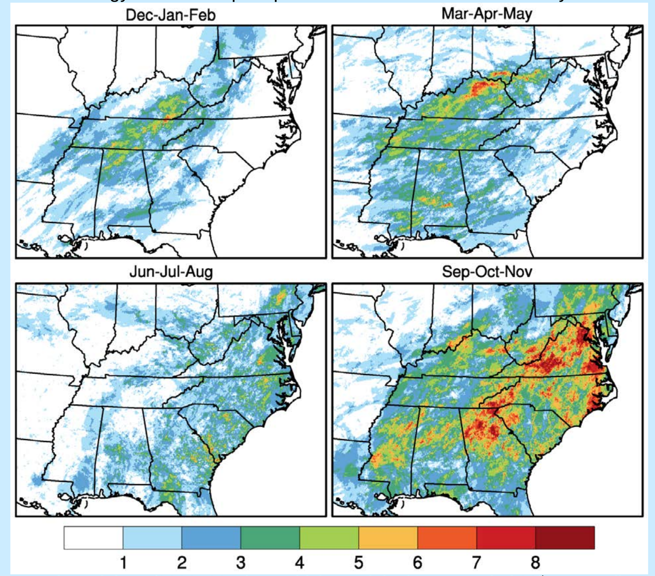
[1]CIRES/NOAA/University of Colorado, [2]NOAA/ESRL/PSD


## Motivation

### Extreme precipitation in the southeast U.S.:

- Southeast U.S. experiences extreme rainfall during all seasons
- Large variability in types of weather systems capable of producing flooding; region comprised of both coastal and mountainous terrain
- Known regional challenges exist for quantitative precipitation forecasting (QPF) and estimation (QPE) – especially for extreme precipitation
- Two relatively recent, high-impact flood events (Atlanta, Georgia region, September 2009; and Nashville, Tennessee region, May 2010) offer opportunity to compare key physical mechanisms, forecast challenges and successes for very different storm environments

Climatology of extreme precipitation events in the Southeast by season

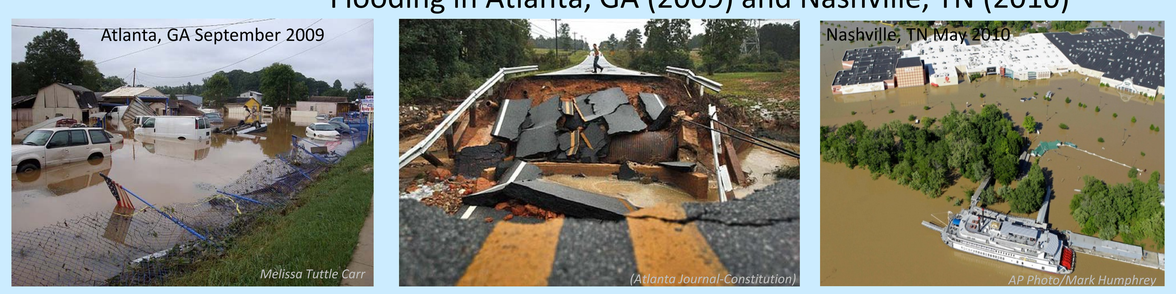



Number of days (2002–2011) on which precipitation exceeded 99th percentile threshold as part of an extreme precipitation event; separated by season

### NOAA's Hydrometeorological Testbeds:

*Advancing and improving extreme precipitation forecasts*

Flooding in Atlanta, GA (2009) and Nashville, TN (2010)




- HMT conducts research on precipitation and weather conditions that can lead to flooding
- Fosters transition of scientific advances and new tools into forecasting operations
- Accelerates development and prototyping of advanced hydrometeorological observations, models, and physical process understanding

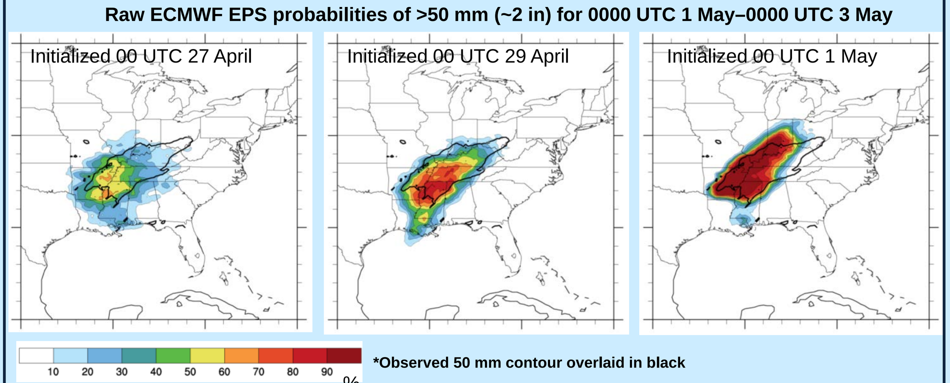
## Forecasting extreme precipitation: Strengths and challenges

HMT-SE QPF objectives

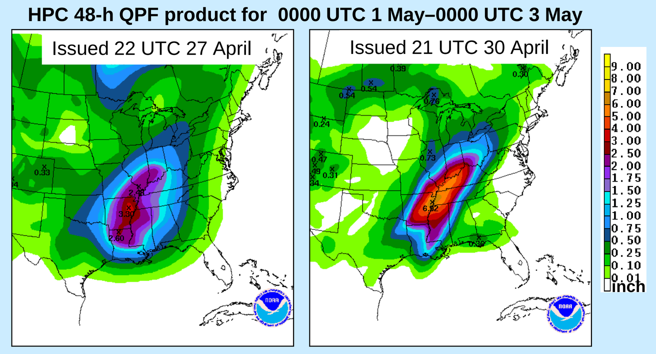
- Analyze climatology and event classifications toward improving understanding of large-scale and mesoscale dynamics associated with extreme precipitation;
- Improve understanding of region-specific physical processes impacting extreme event QPF;
- Facilitate researcher and forecaster collaboration to
  - (i) clarify processes/environmental parameters affecting extreme precipitation;
  - (ii) identify human and model QPF challenges; and
  - (iii) identify new or improved tools, definitions and classifications to connect relevant research findings to benefit operational forecasting

### Forecast success/high predictability: Nashville, Tennessee, May 2010

Raw ECMWF EPS probabilities of >50 mm (~2 in) for 0000 UTC 1 May–0000 UTC 3 May



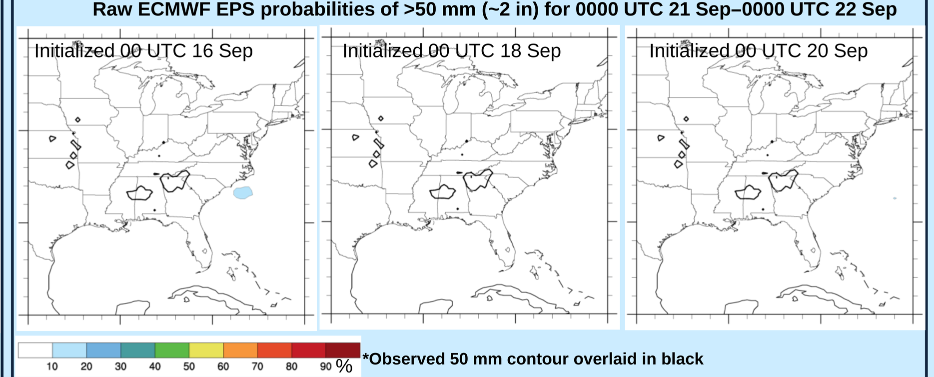

HPC 48-h QPF product for 0000 UTC 1 May–0000 UTC 3 May




- Several days in advance of event forecast models and forecasters identified potential for heavy rain event in the central/southern Mississippi Valley region
- QPF generally matched by observed rainfall (though amounts under-predicted)
- Axis of heaviest forecasted rainfall consistently west of observed axis (suggests difficulty forecasting formation and evolution of second MCS that produced flooding)

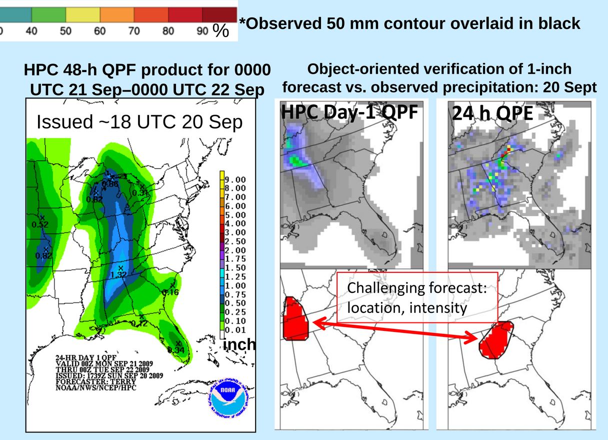
### Forecast challenge/low predictability: Atlanta, Georgia, September 2009

Raw ECMWF EPS probabilities of >50 mm (~2 in) for 0000 UTC 21 Sep–0000 UTC 22 Sep




HPC 48-h QPF product for 0000 UTC 21 Sep–0000 UTC 22 Sep

Object-oriented verification of 1-inch forecast vs. observed precipitation: 20 Sept




- Very little confidence in operational models for heavy rainfall potential
- Low NWP confidence reflected in human-generated forecasts at NCEP/HPC and Peachtree City NWS office
- Meteorological set-up had little predictability – focusing of heaviest precipitation strongly impacted/driven by small-scale processes and interactions in a "weakly-forced" synoptic environment

## A Tale of Two Cases:

## Nashville, Tennessee: May 1 – 3 2010

### Objectives and scientific questions

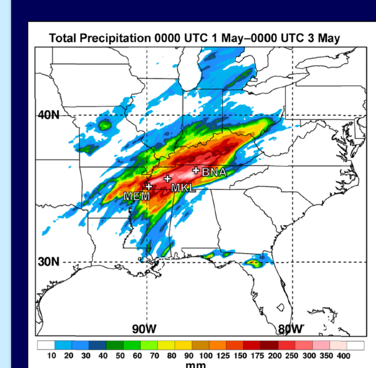
- Identify most prominent moisture sources; isolate roles of Pacific, Atlantic (Caribbean) moisture
- What was the role of terrain in favorable dynamics and thermodynamics, focusing of precipitation?
- How does sensitivity to key features relate to forecast successes, challenges?

### Numerical model experiments

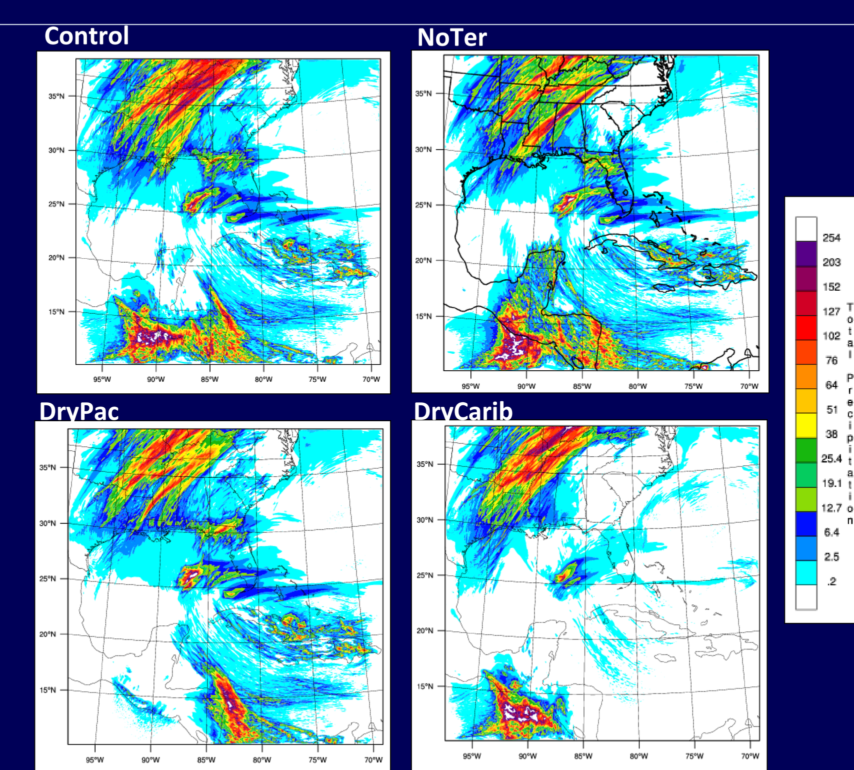
| | |
|---|---|
| **Model version** | WRF (ARW) Version 3.3.1 |
| **Simulation duration** | 72 hours (00 UTC 30 April 2010 – 00 UTC 3 May 2010); Model output frequency: 1-hour |
| **Resolution** | 4-km horizontal grid spacing; 54 vertical levels |
| **Model physics** | Explicit convection (no cumulus parameterization); Thompson microphysics; YSU PBL scheme; NOAH land-surface model; Dudhia, RRTM radiation |
| **Initial conditions** | NCEP Climate Forecast System Reanalysis (CFSR) data (Saha et al. 2010) |
| ***Model simulations:*** | *Simulation descriptions:* |
| **Control** | Control simulation; set-up as listed above |
| **DryPac** | Reduced humidity to near-zero values in initial and boundary conditions in SW corner of grid over Pacific Ocean (10N → 16N); (84W → 96W) |
| **DryCarib** | Reduced humidity to near-zero values in initial and boundary conditions in SE corner of grid over Caribbean Sea (10N → 24N); (70W → 85W) |
| **NoTer** | Terrain height set to zero everywhere in domain |

### Results

1. Total (72-h) precipitation

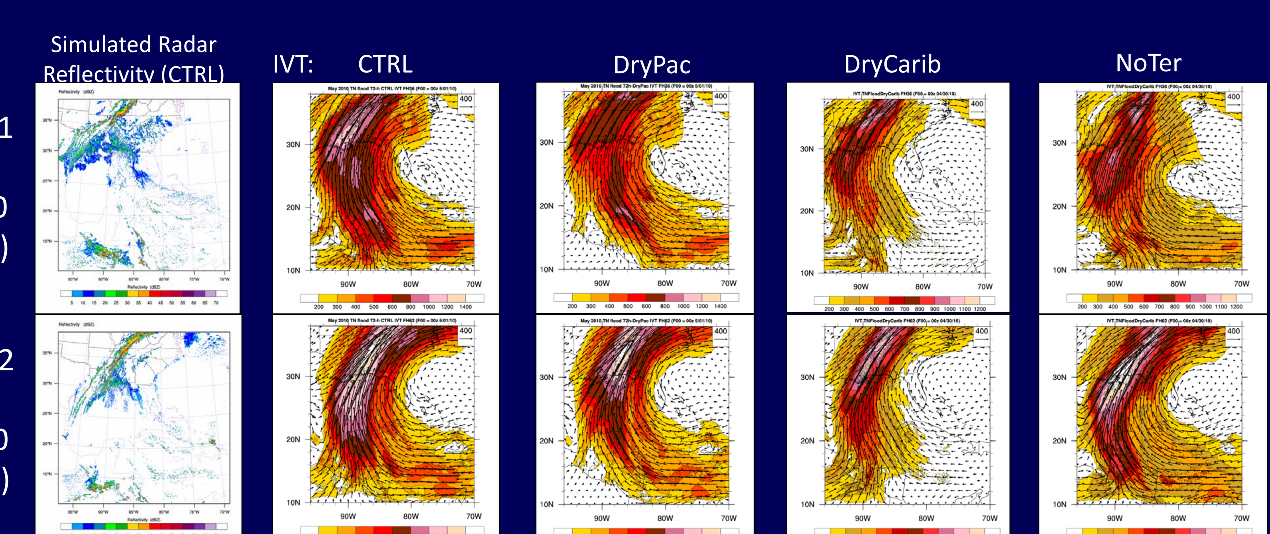



Total accumulated precipitation (shaded in mm according to the color bar) from the National Precipitation Verification Unit quantitative precipitation estimates product for 0000 UTC 1 May–0000 UTC 3 May 2010 (Moore et al. 2012)

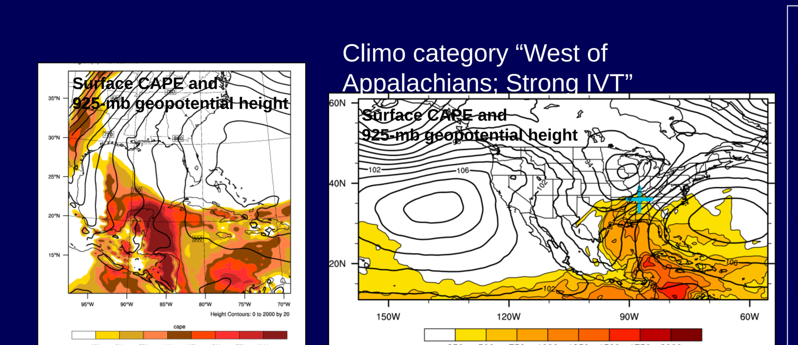



- Control simulation produces precipitation maxima > 200 mm in region and pattern closely matching observations
- Removal of terrain changes distribution; overall amounts still high. Impact likely has both dynamical (Lackmann 2013) and thermodynamical (Moore et al. 2012) causes due to alteration of warm, dry elevated layer from Mexican Plateau
- Decreasing moisture transport from tropical Pacific reduces precipitation maxima in TN by ~25 – 50%
- Decreasing moisture transport from tropical Atlantic/Caribbean reduces TN precipitation maxima by ~10 – 25%; decreases eastward extent of distribution

2. Two main MCS events & Evolution of integrated water vapor transport (IVT)




3. Connection to SE Extremes Climatology




#### Preliminary Conclusions: Nashville

- Moisture transport to flooded region has strong synoptic-scale dynamical forcing; even when a main tropical moisture conduit is interrupted, synoptic dynamics still produce considerable rainfall.
- Sensitivity to NWP model resolution, physics packages quite low
- This case is representative of other "strong IVT" cases in SE Extreme event climo (see Moore et al. presentation Thursday, 1/10)

## Atlanta, Georgia: September 20 – 22 2009

### Objectives and scientific questions

- Assess key (multi-scale) environmental features that lead to intense precipitation
- Investigate causes of low predictability with sensitivity testing (e.g., microphysics, PBL parameterization, etc.)
- How does the sensitivity to key features relate to forecast successes, challenges?

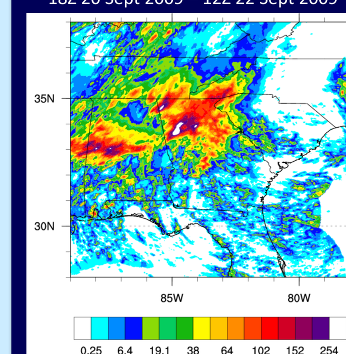
### Numerical model experiments

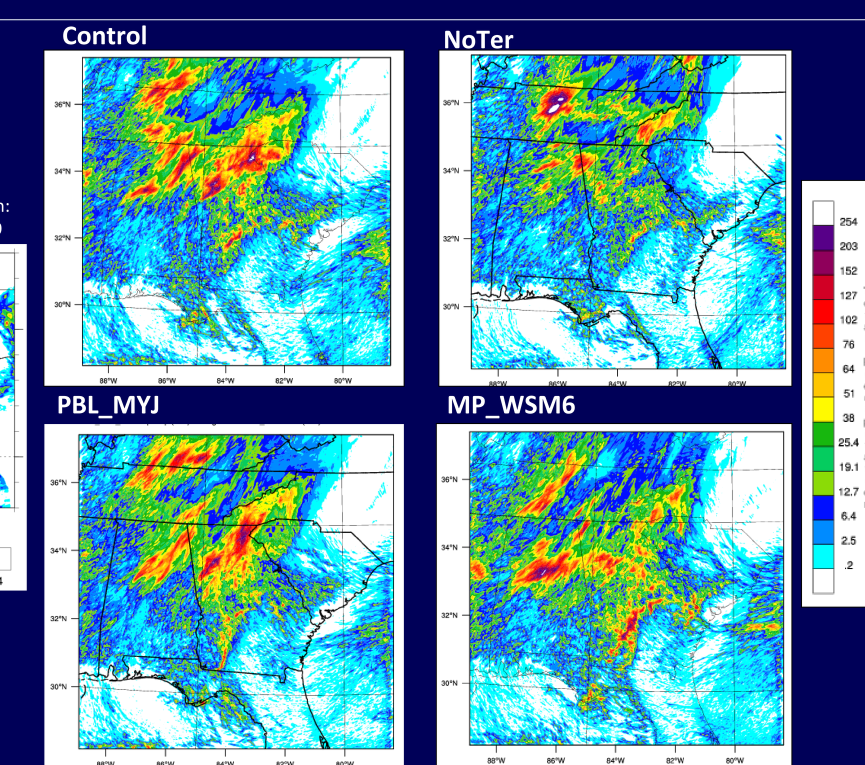
| | |
|---|---|
| **Model version** | WRF (ARW) Version 3.3.1 |
| **Simulation duration** | 42 hours (18 UTC 20 Sept 2009 – 12 UTC 22 Sept 2010); Model output frequency: 1-hour |
| **Resolution** | Horizontal grid spacing: 3-km outer domain, 1-km inner domain; 54 vertical levels |
| **Model physics** | Explicit convection (no cumulus parameterization); Thompson microphysics; YSU PBL scheme; NOAH land-surface model; Dudhia, RRTM radiation |
| **Initial conditions** | NCEP Climate Forecast System Reanalysis (CFSR) data (Saha et al. 2010) |
| ***Model simulations:*** | *Simulation descriptions:* |
| **Control** | Control simulation; set-up as listed above |
| **MP_WSM6** | Microphysics parameterization changed to WSM6 scheme |
| **PBL_MYJ** | PBL (and surface layer) parameterization changed to MYJ |
| **NoTer** | Terrain height set to zero everywhere in domain |

### Results

1. Total precipitation

Observed (Stage IV) 42-h precipitation: 18Z 20 Sept 2009 – 12Z 22 Sept 2009

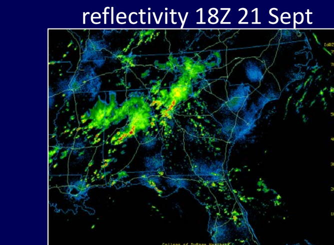


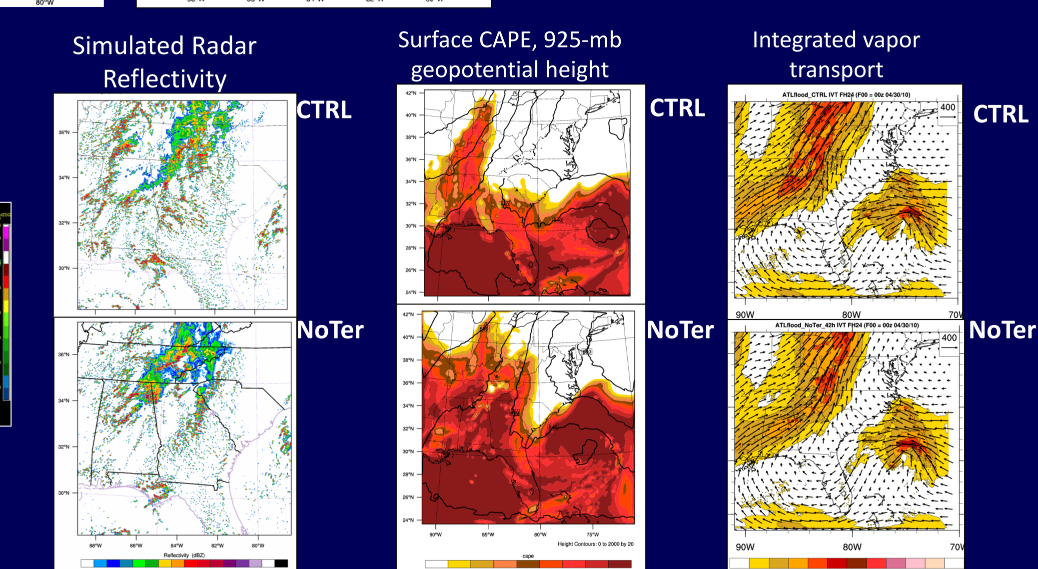



- Control simulation produces precipitation maxima > 200 mm in Atlanta metro area where maxima > 300 mm were observed (additional displacement errors over NE Georgia, Central MS/AL)
- Removal of terrain markedly shifts precipitation maxima NW (to TN) – suggests role of terrain in focusing convective triggering and stationary features (Shepherd et al. 2011)
- Changing microphysical parameterization reduces ATL precipitation maxima by ~25%; shifts distribution considerably
- Changing PBL parameterization has subtle impacts on precipitation maxima location, amounts
- Large sensitivities consistent with low predictability of event

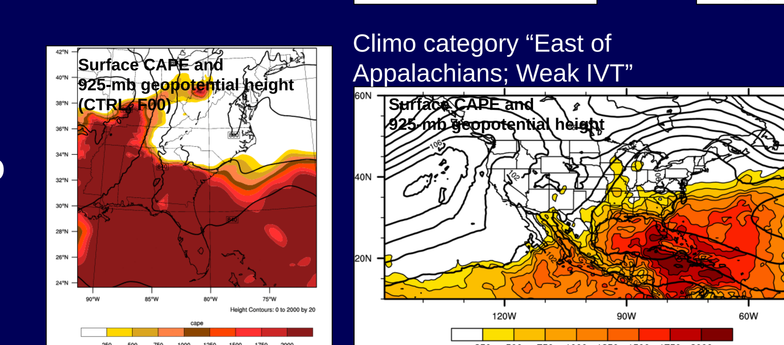
2. Terrain impacts on integrated water vapor transport (IVT) & CAPE: 18Z 21 Sept 2009

Observed radar reflectivity 18Z 21 Sept






3. Connection to SE Extremes Climatology




#### Preliminary Conclusions: Atlanta

- Terrain played role in focusing favorable thermodynamics (mostly later in event); earlier fields very similar between CTRL and NoTer
- Model physics changes highlight sensitivity to small-scale processes: PBL mixing, cloud microphysics
- Case representative (e.g., large CAPE, weak forcing, lower predictability) of other "weak IVT" cases in SE Extreme event climo (see Moore et al. presentation Thursday, 1/10)


## Summary

- The Southeast U.S. experiences extreme precipitation from a number of different phenomena, making quantitative precipitation forecasting (QPF) in this region especially challenging.
- The Nashville, Tennessee flood event of May 2010 and the Atlanta, Georgia flood event of September 2009 both produced 10+ inches of rainfall and catastrophic flooding, but were extremely different events with respect to their meteorological forcing.
- Contrasting the large environmental differences between the events and how specific features relate to predictability and forecast skill offers the potential for enhancing forecaster situational awareness of both the event itself and operational NWP model challenges and shortcomings.
- Using these two individual cases to exemplify event types defined by our Southeast Extreme Precipitation climatology facilitates research-to-operations capabilities such as creation of NWS AWIPS Smart Tools and case study-based training materials.


## Next steps

- Compare (hourly) rain rate distributions in simulations versus observations
- Clarify specific aspects of Atlanta event forecast that resulted in low predictability; investigate connections to other relevant events in climatology
- Explore how contemporary operational models would perform for Atlanta event; role of resolution?
- Extend investigation to predictability of larger dataset of events (see Moore et al.'s presentation (Thursday, 4:45pm, 3R2O) on extreme precipitation climatology, and Sukovich et al., Poster #809: QPF verification of human and model forecasts)
- Continue to investigate events in real-time via both operational models and HMT-Ensemble (e.g., presentations by Jensen et al. and Tollerud et al.), especially during HMT-SE Pilot Study 2013 – 2014.


## Acknowledgements

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Earth System Research Laboratory — Physical Sciences Division