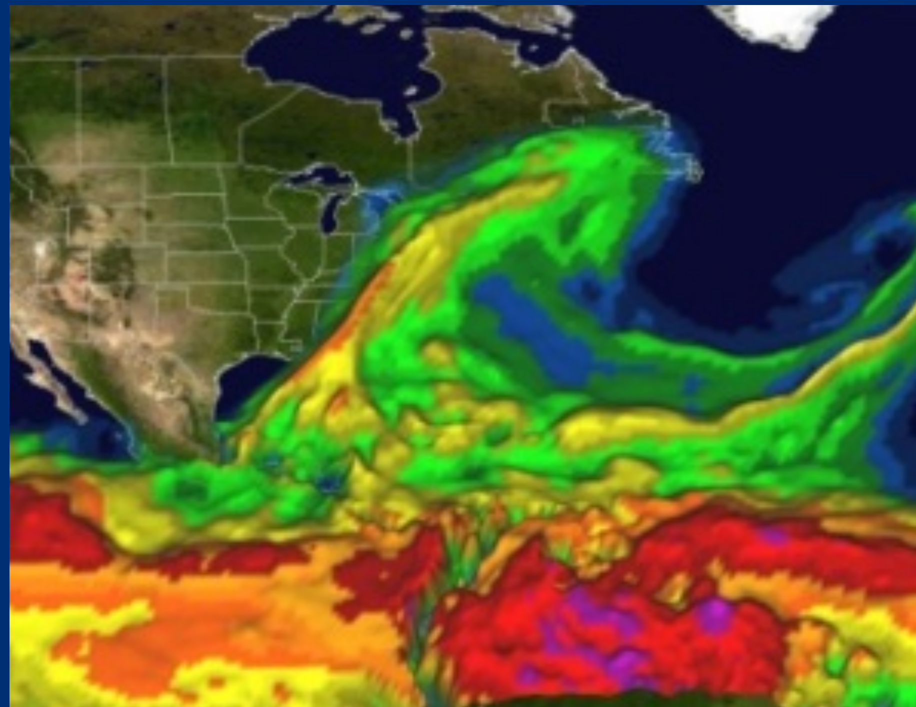
Evaluating the utility of atmospheric river detection in forecasting heavy rainfall events in the southeastern U.S.



6th NOAA Testbeds & Proving Grounds Workshop

April 18, 2015

Kelly Mahoney, Darren Jackson, Mimi Hughes, Gary Wick, Ellen Sukovich, Lisa Darby, Paul Neiman, Allen White, Rob Cifelli

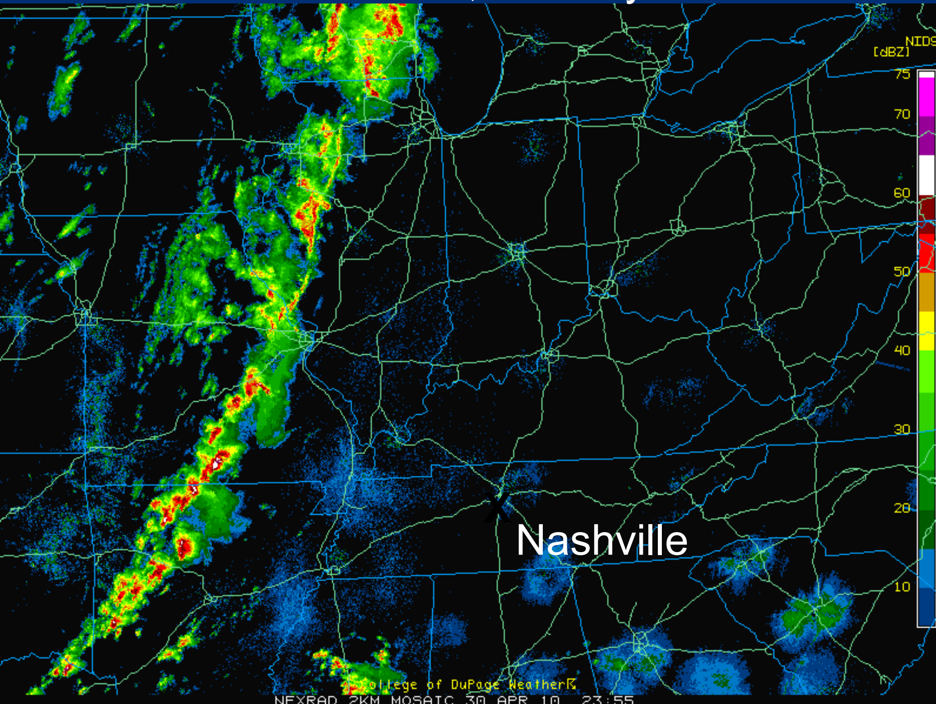
Motivation: Forecasting extreme precipitation in the southeast U.S.

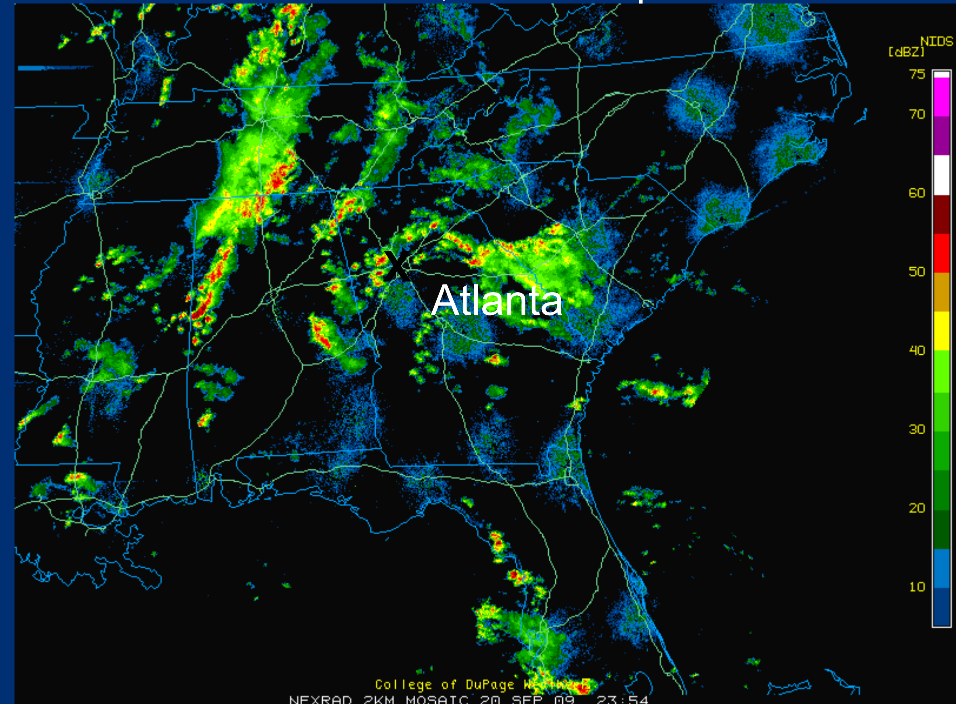
Motivation:

- Southeast U.S. experiences extreme rainfall during all seasons
- Large variability in types of weather systems capable of producing flooding; both coastal and mountainous terrain
- Known regional challenges exist for quantitative precipitation forecasting (QPF) especially for extreme precipitation
- Consider two “recent” events as example of extreme precipitation variability:
    - Nashville, TN (2010)
    - Atlanta, GA (2009)

Nashville flood, 1-2 May 2010

Atlanta flood, 20-22 Sep 2009

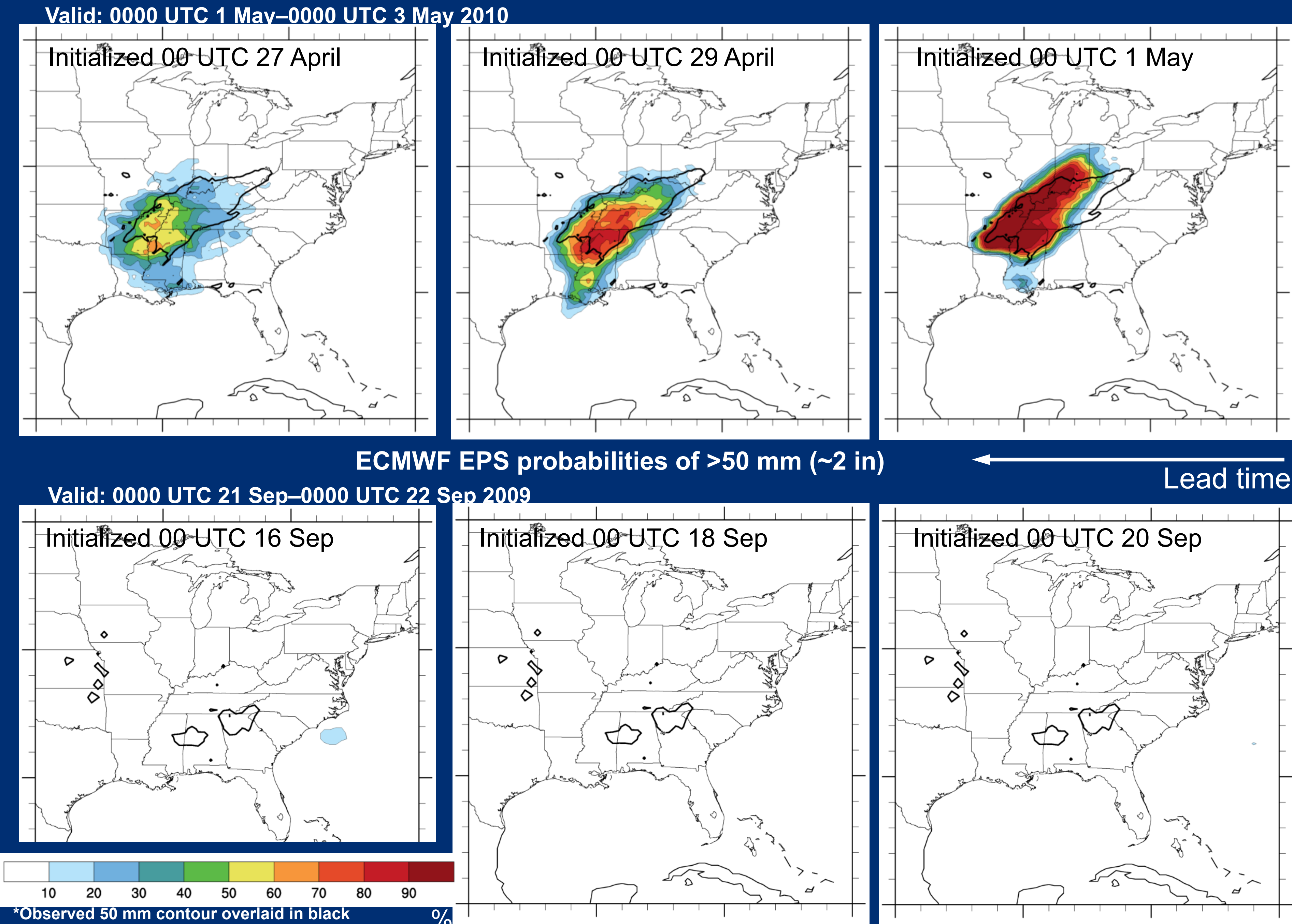




Downtown Nashville

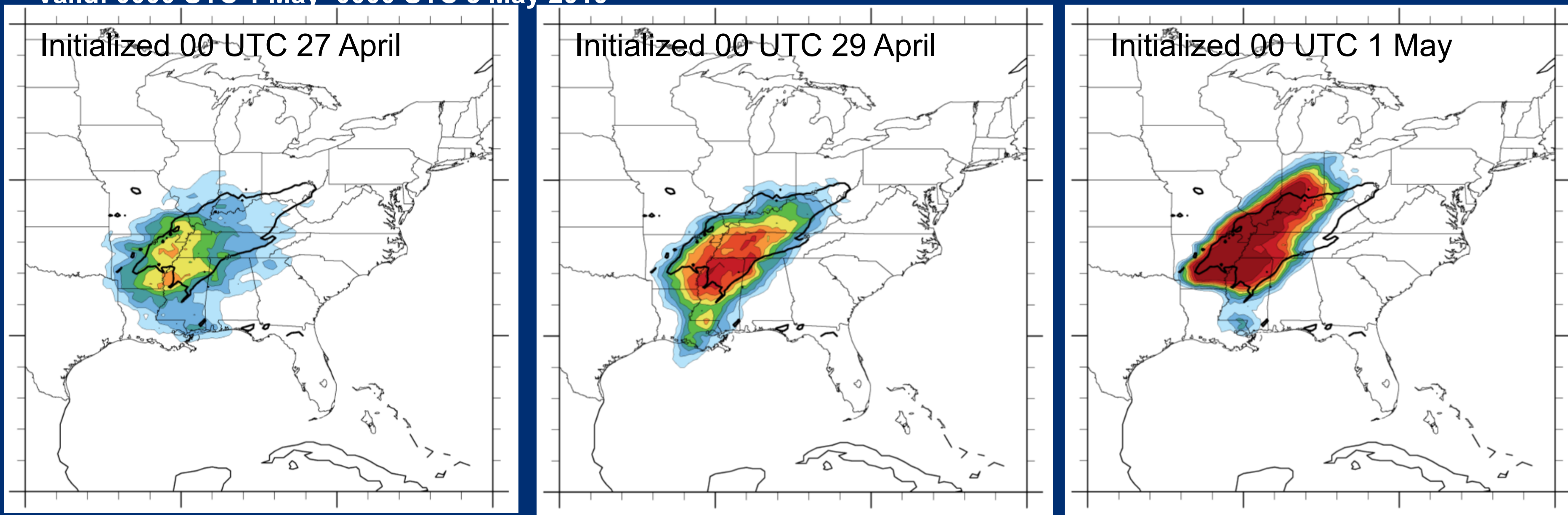
(Atlanta Journal-Constitution)

Highly variable predictability across types of extreme precipitation events



Highly variable predictability across types of extreme precipitation events

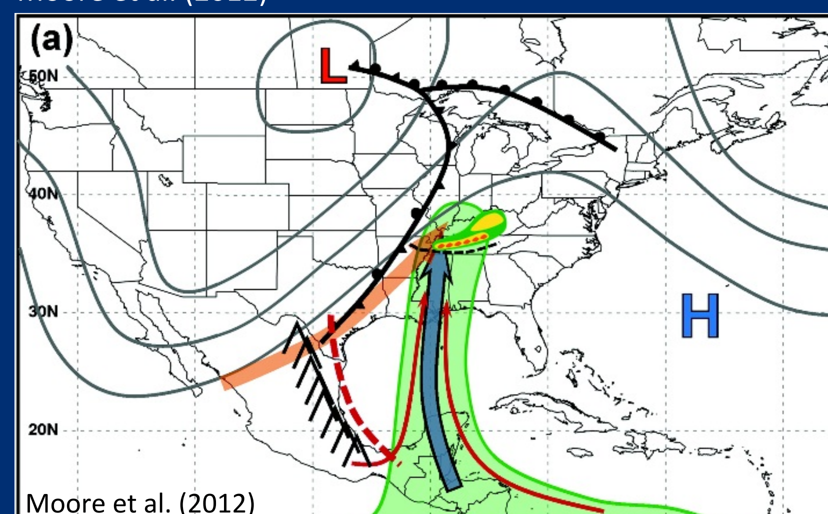
Valid: 0000 UTC 1 May–0000 UTC 3 May 2010



ECMWF EPS probabilities of >50 mm (~2 in)

Lead time

Moore et al. (2012)

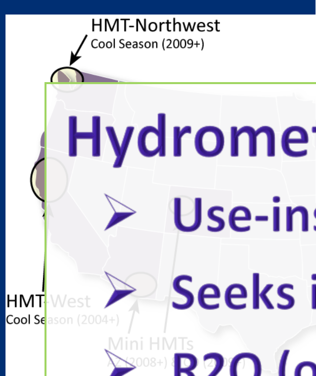


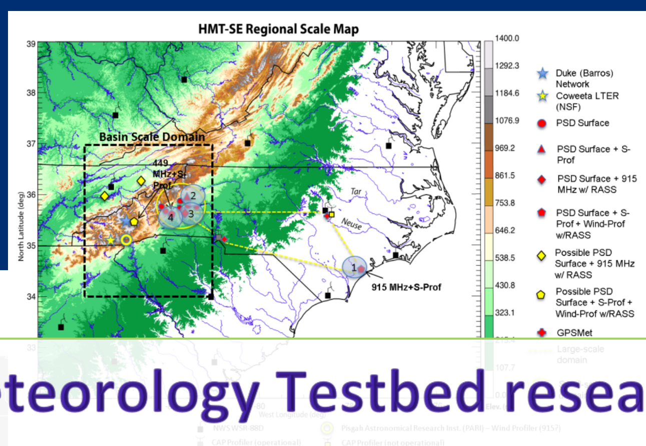
Moore et al. (2012) linked Tennessee floods to AR:

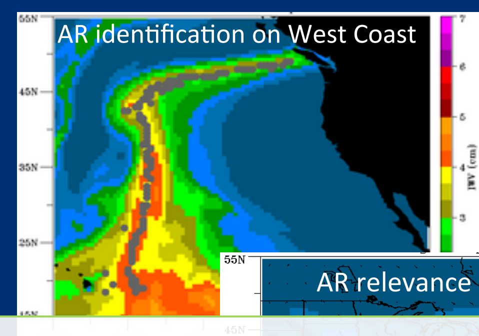
- "Heavy rainfall…supported by a *persistent narrow corridor of strong water vapor transport*…manifested as an AR"
- Contrast to maritime ARs: static feature; persistence allowed continuous "tapping" of tropical water vapor
- Mesoscale forcing for precipitation "fundamentally distinct from those typically associated with landfalling maritime ARs"
- Two quasi-stationary MCSs as opposed to persistent orographically forced stratiform/shallow convective precipitation

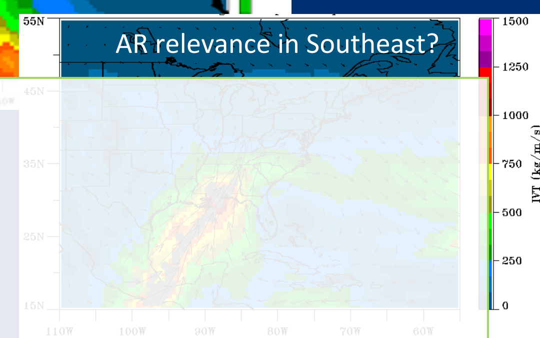
Science questions from the Hydrometeorology Testbed-Southeast (HMT-SE) project

- What is the climatology of extreme precipitation events in the southeast U.S.?
- What are the primary moisture sources and moisture transport mechanisms for extreme rainfall in the southeast U.S.? Are atmospheric rivers (ARs) relevant players here?
- What do recent flood cases indicate about critical forecast gaps?







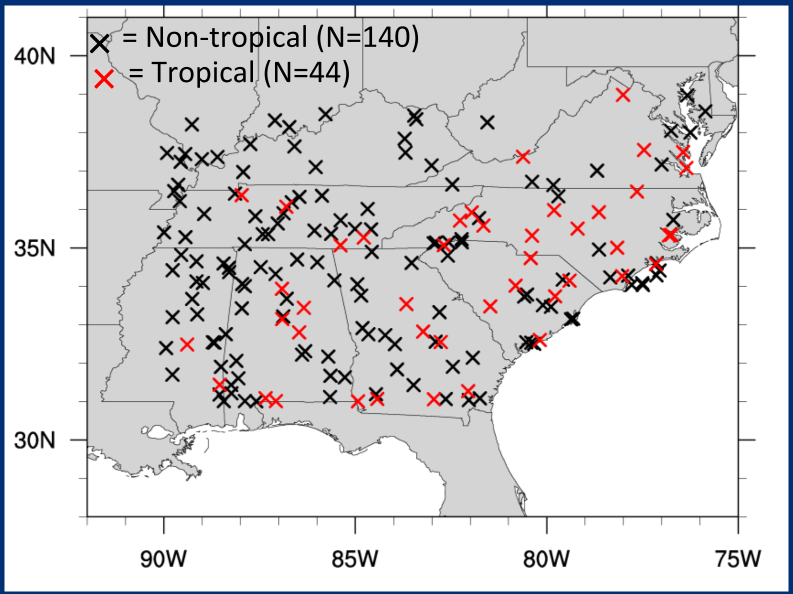


Hydrometeorology Testbed research:

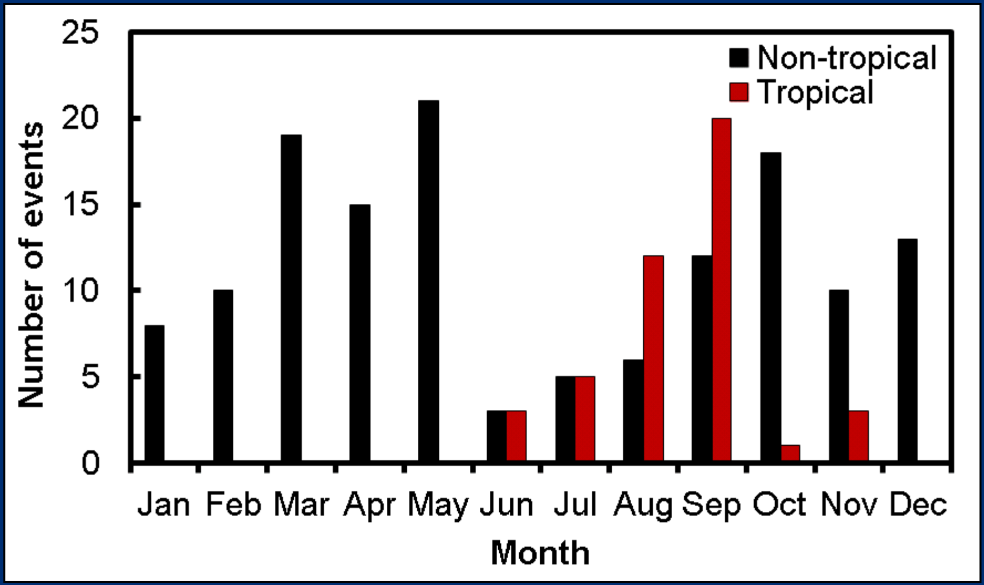
- ➢ Use-inspired and user-directed
- ➢ Seeks improved process understanding
- ➢ R2O (operations), R2A (applications), R2"X" (future user needs)

Stage IV, CFSR Climatology of extreme precipitation events in the Southeast

Climatology: Locations of extreme precipitation events

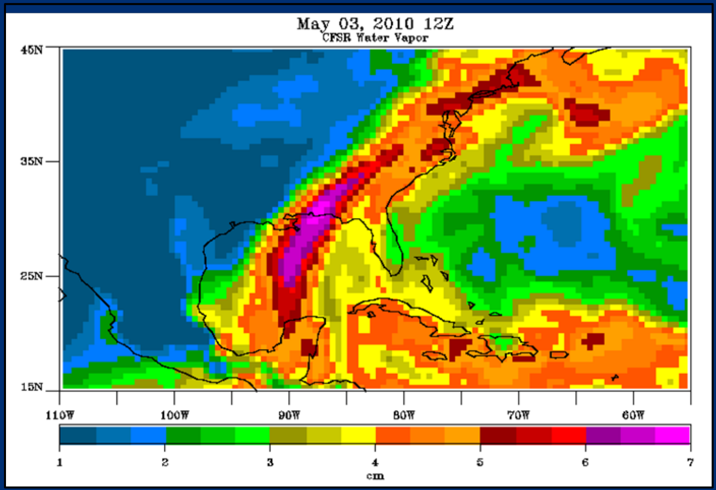


Monthly frequency distribution of non-tropical and tropical events



Select climatological findings:

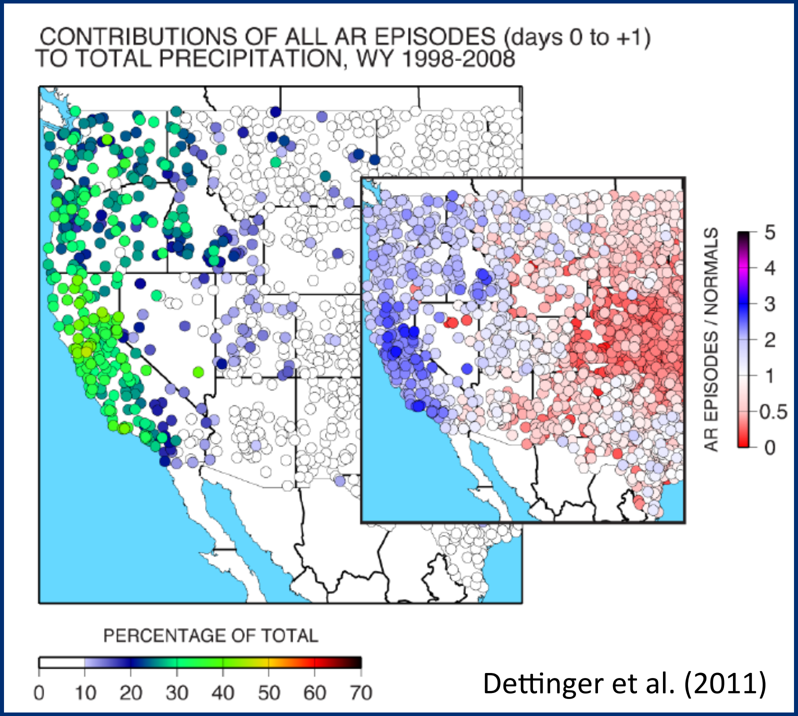
- Extreme precipitation events occur in all months in southeast; varied mechanisms (Moore et al. 2015)
- Nearly zero correlation observed between max precipitation and integrated water vapor transport (IVT) across all cases – but strong vapor transport, atmospheric rivers (ARs) identified for subset of events
- Relevance to what we know about heavy precip events on U.S. West Coast?



Benjamin J. Moore, Kelly M. Mahoney, Ellen M. Sukovich, Robert Cifelli, and Thomas M. Hamill, 2015: Climatology and Environmental Characteristics of Extreme Precipitation Events in the Southeastern United States. *Mon. Wea. Rev.*, **143**, 718–741.

ARs and West Coast precipitation

- ARs explain 20% - 50% of West Coast annual precip (Dettinger et al. 2011)
- For many west coast locations, nearly all extreme precipitation associated with landfalling ARs (e.g., Ralph and Dettinger 2012)

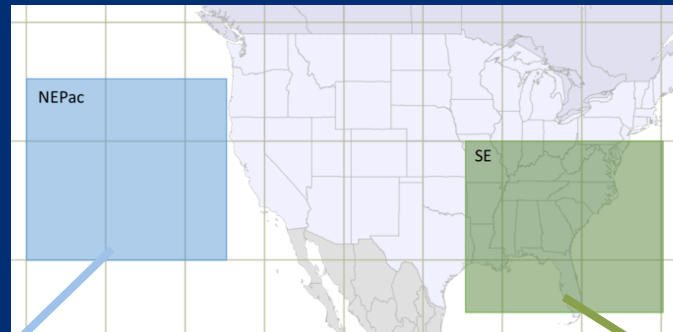


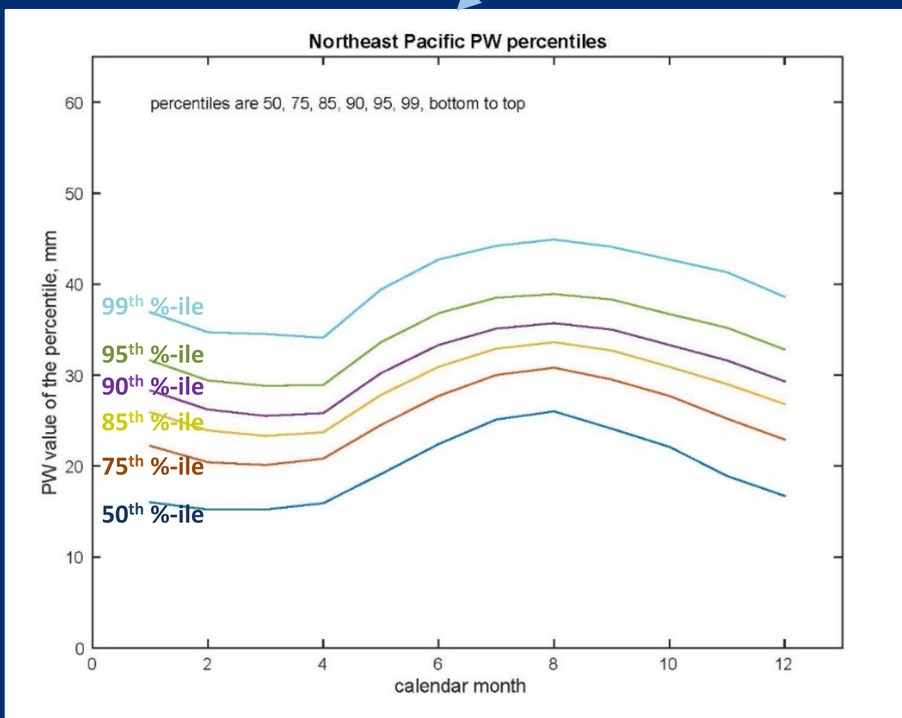
Dettinger et al. (2011)

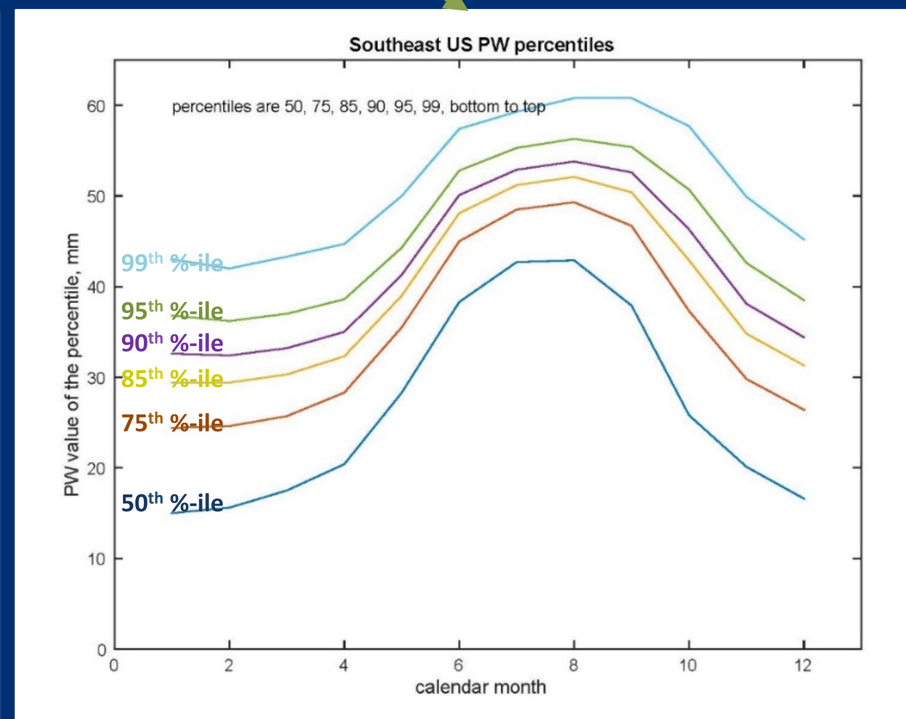
- Question: To what extent do ARs explain SEUS precip?
  - ➢ Starting point: West Coast/Northeast Pacific (NEPAC) vs. Southeast US (SEUS) comparison
  - ➢ Compare IWV (PW), IVT (CFSR climatologies)
  - ➢ Use comparisons to guide AR identification in SEUS

Precipitable water (PW) climatology: NEPac vs. SEUS

- CFSR 1980-2010
- SEUS has more dynamic seasonal cycle in PW
- Warm-season peak in both regions

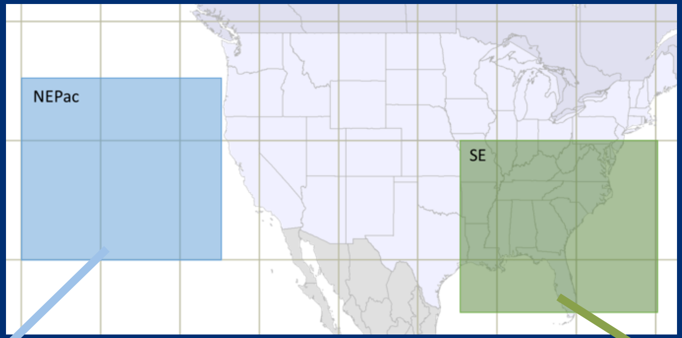


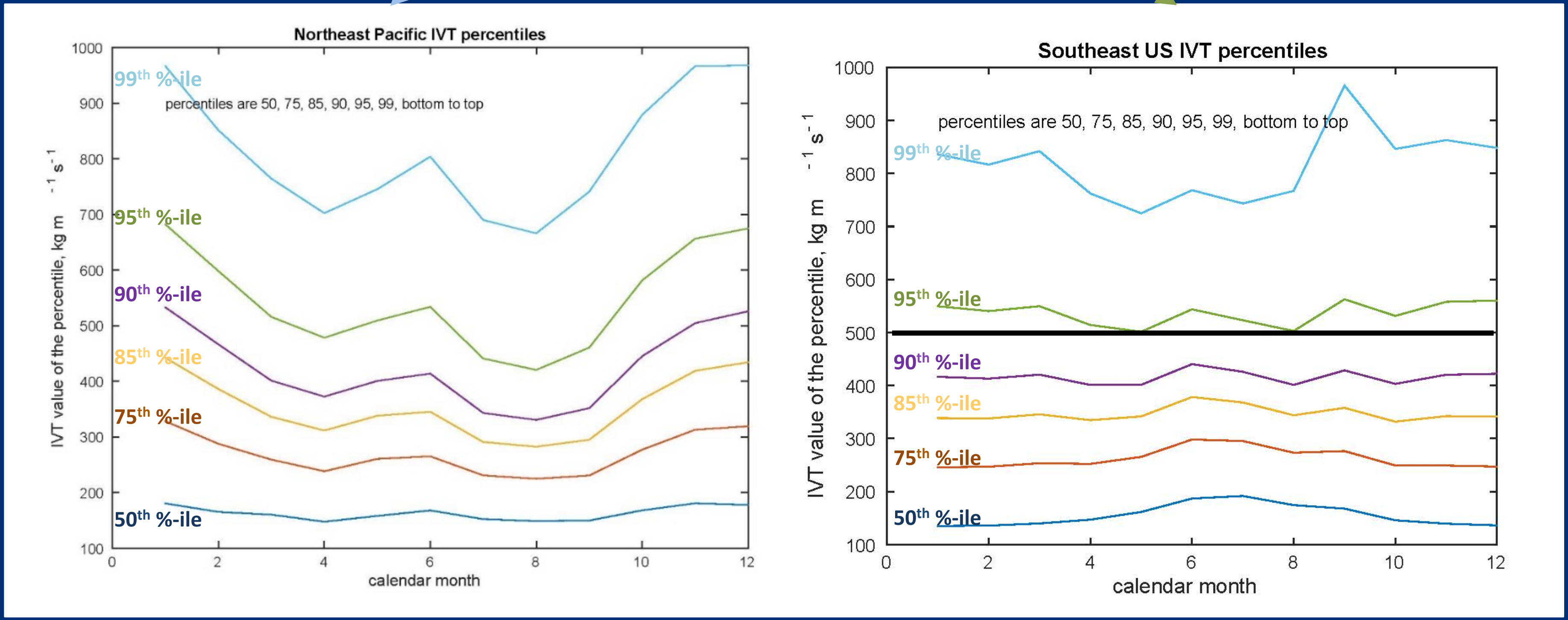




IVT climatology: NEPac vs. SEUS

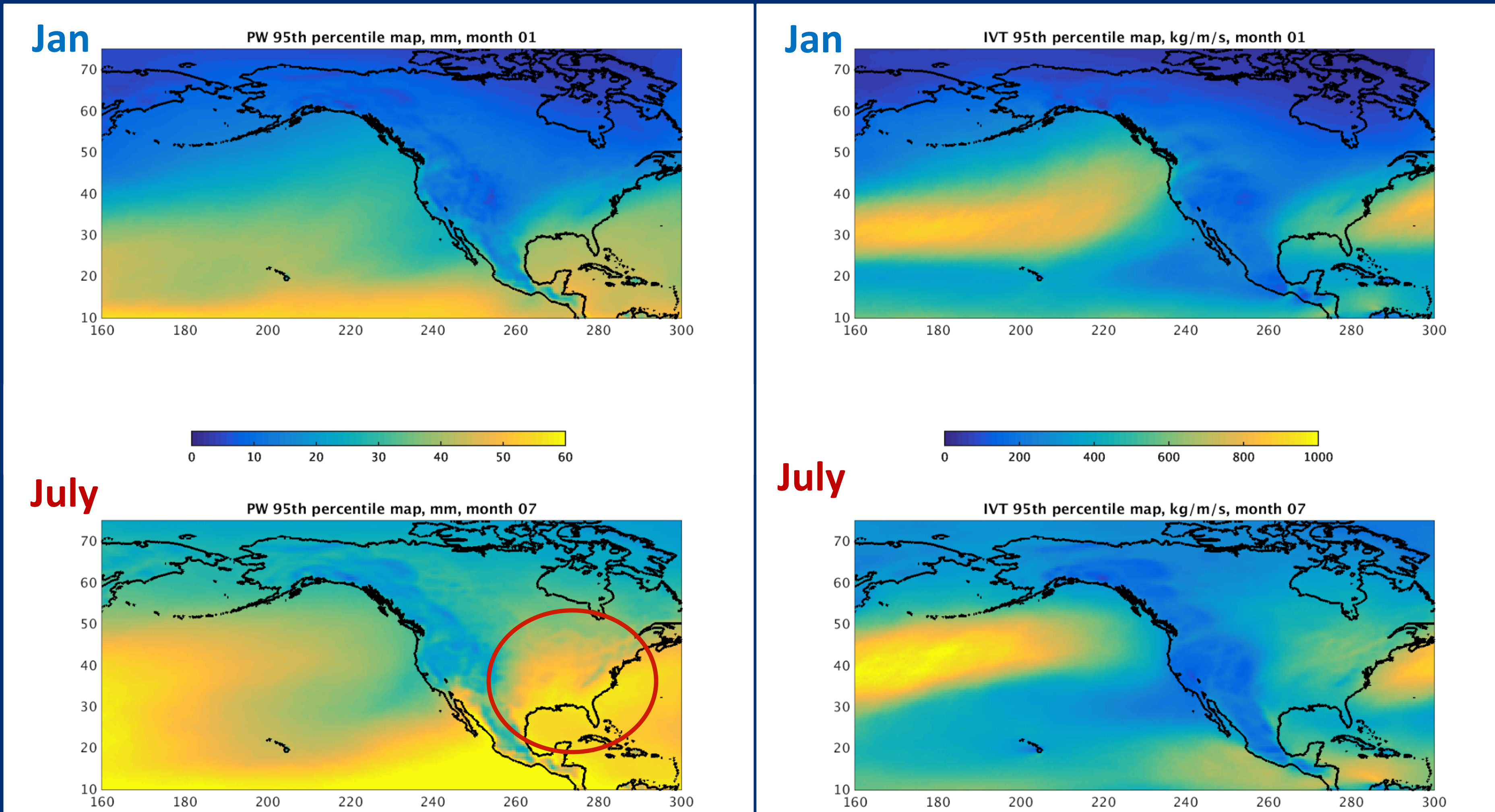
- CFSR 1980-2010
- IVT less seasonal in SE
- 500 kg/m/s ~95%-ile





95th %-ile: PW

95th %-ile IVT

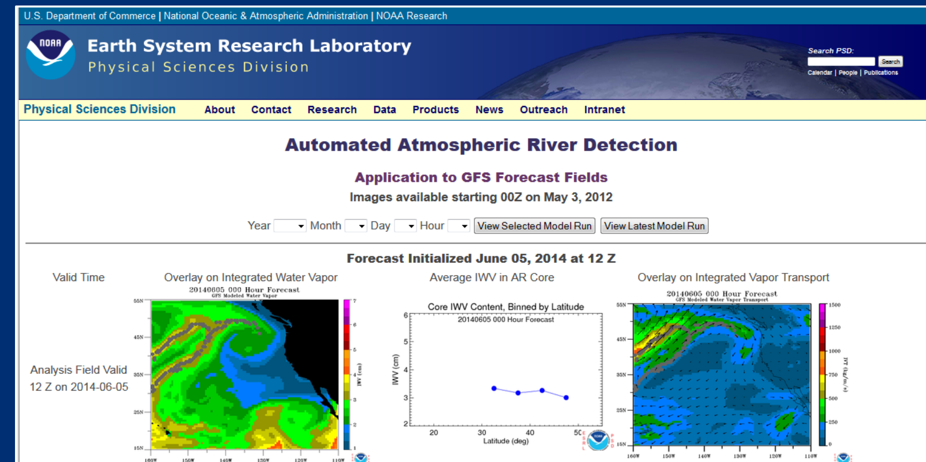


- IVT offers advantages over IWV for identifying ARs – especially in East
- Summertime background PW (IWV) very high in eastern US
- Shift from West Coast AR analysis/identification paradigm

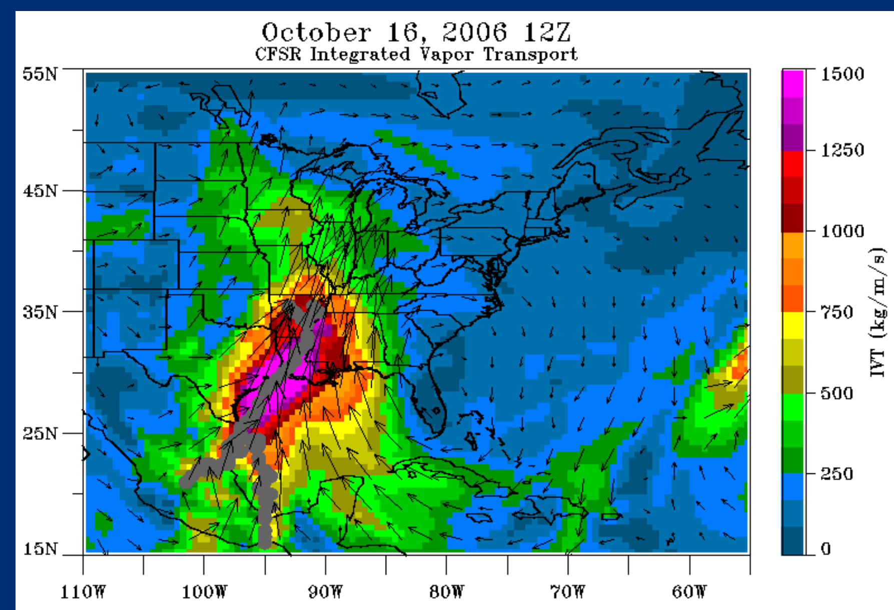
Identify ARs and match to heavy precipitation in the SEUS

Identify ARs:

1. Use adapted AR Detection Tool (ARDT; see Wick et al. 2013; 2014 Testbed Workshop)
   - Original ARDT "utilizes basic image-processing techniques such as thresholding and skeletonization to implement and extend the objective criteria for the length (>2000 km), width (<1000 km), and IWV content (>2 cm) for ARs that was first defined by Ralph et al. (2004) and used in multiple later studies."
2. ARDT adapted for IVT minimum threshold of 500 kg/m/s, domain extended
3. ARDT executed from Jan 2002 through April 2014 using CFSR 0.5°, 6-hourly data
4. Output parameters for detected ARs included time, location, IVT, AR axis points, AR width, and AR angle.



Current ARDT NOAA ESRL forecast page



Example of adapted ARDT-IVT: IVT (shaded), AR feature (gray dots)

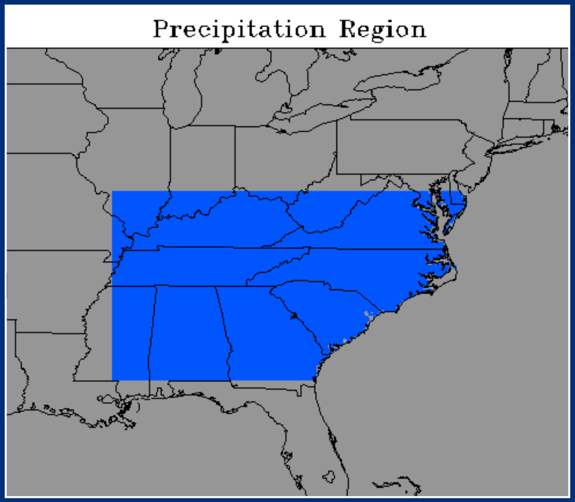
Wick, G. A., P. J. Neiman, F. M. Ralph, and T. M. Hamill, 2013: Evaluation of Forecasts of the Water Vapor Signature of Atmospheric Rivers in Operational Numerical Weather Prediction Models. *Wea. Forecasting*.

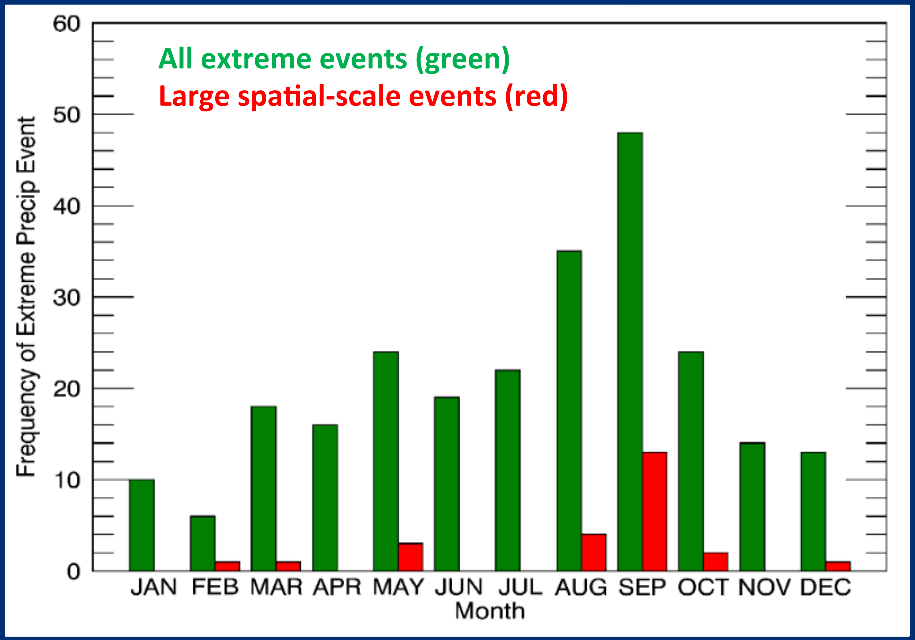
Wick, G. A., P. J. Neiman, and F. M. Ralph, 2013: Description and validation of an automated objective technique for identification and characterization of the integrated water vapor signature of atmospheric rivers. *IEEE Trans. Geosci. Remote Sens.*, **51**, 2166–2176

Identify ARs and match to heavy precipitation in the SEUS

2. Identify heavy precipitation events

1. Livneh et al. (2013) precipitation dataset (daily precipitation data derived from NOAA COOP station data mapped to 1/16° grid)
2. Extreme precipitation defined as gridpoint value > 100 mm/day in SE region
3. Define one extreme precipitation event per day
4. 249 daily extreme precipitation events identified (2002-2011)
5. "Large spatial-scale events" defined using 90th percentile of grid boxes exceeding threshold
   - Here > 171 grid boxes in exceedance of 100 mm/day defines a "large event"



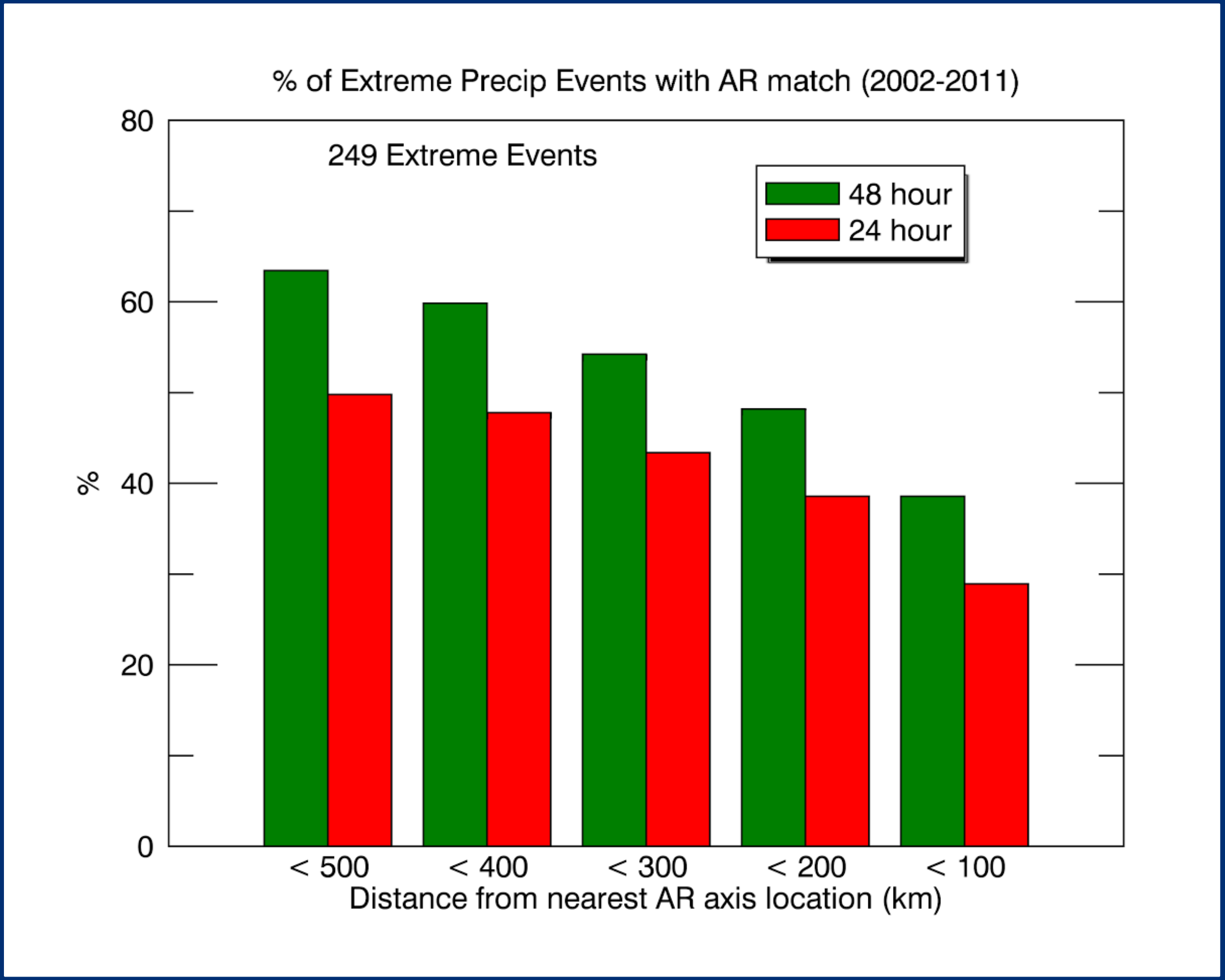


3. Analyze intersection of AR events and heavy precipitation events

- AR-precipitation collocation/ association definitions:
  1) Minimum distance
     - Between precipitation event average center point and at least one AR axis location
  2) Minimum time period
     - Precipitation event occurred within 24- or 48-hour period of AR

- Matching requirement stringency significantly affects AR-precip matches:
  - 500-km, 48-hour separation → 63% of events associated with AR
  - 100-km, 24-hour separation → 29% of events associated with AR

- Ensuing analysis:
  - 250-km minimum distance
  - 24-hour time period
  - (Overall matching 41%)

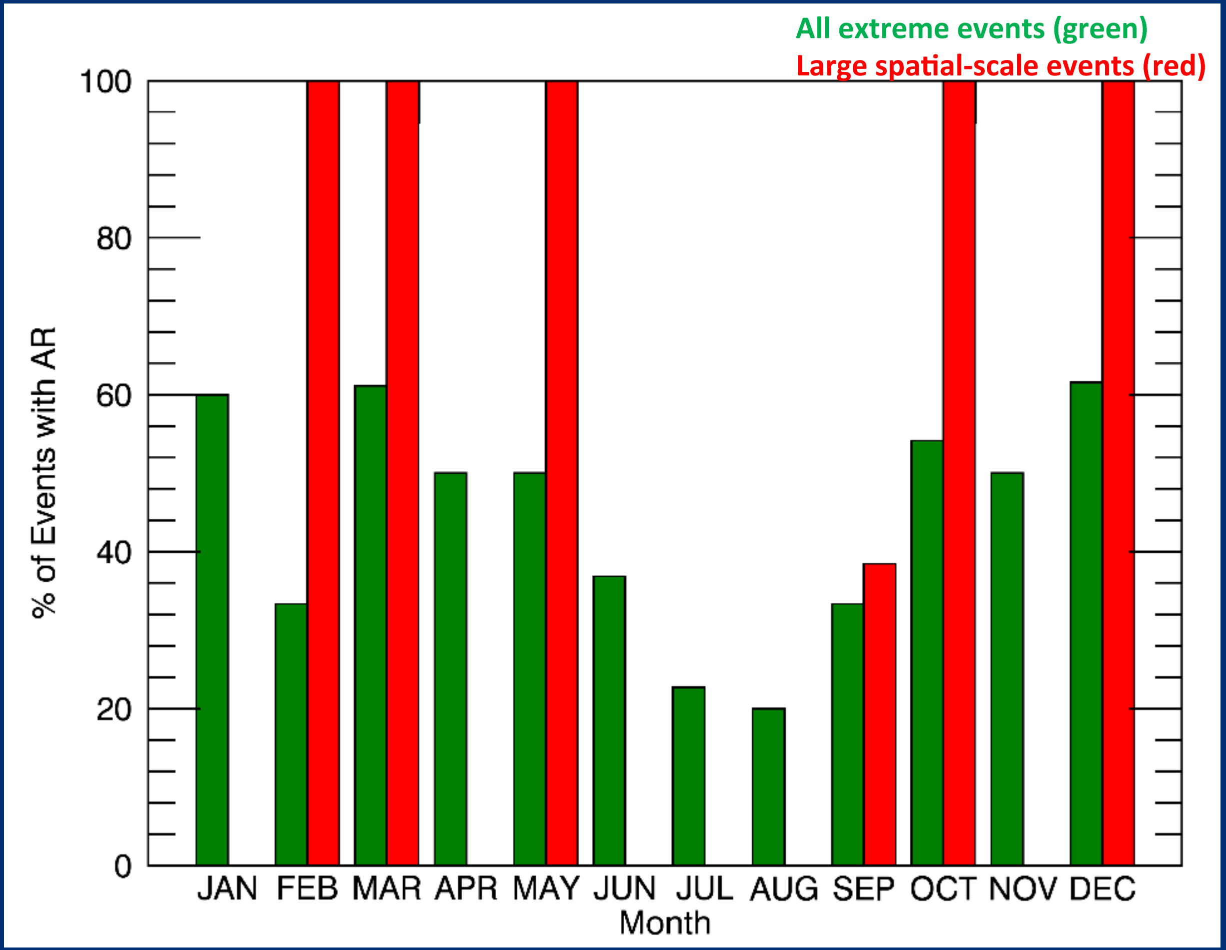


Percentage of extreme precipitation events that are associated with ARs delineated by separation distance (x-axis) and time range (red/24h vs. green/48h)

What can we learn about AR-linked precip events?

- Linkage to larger-scale precipitation events

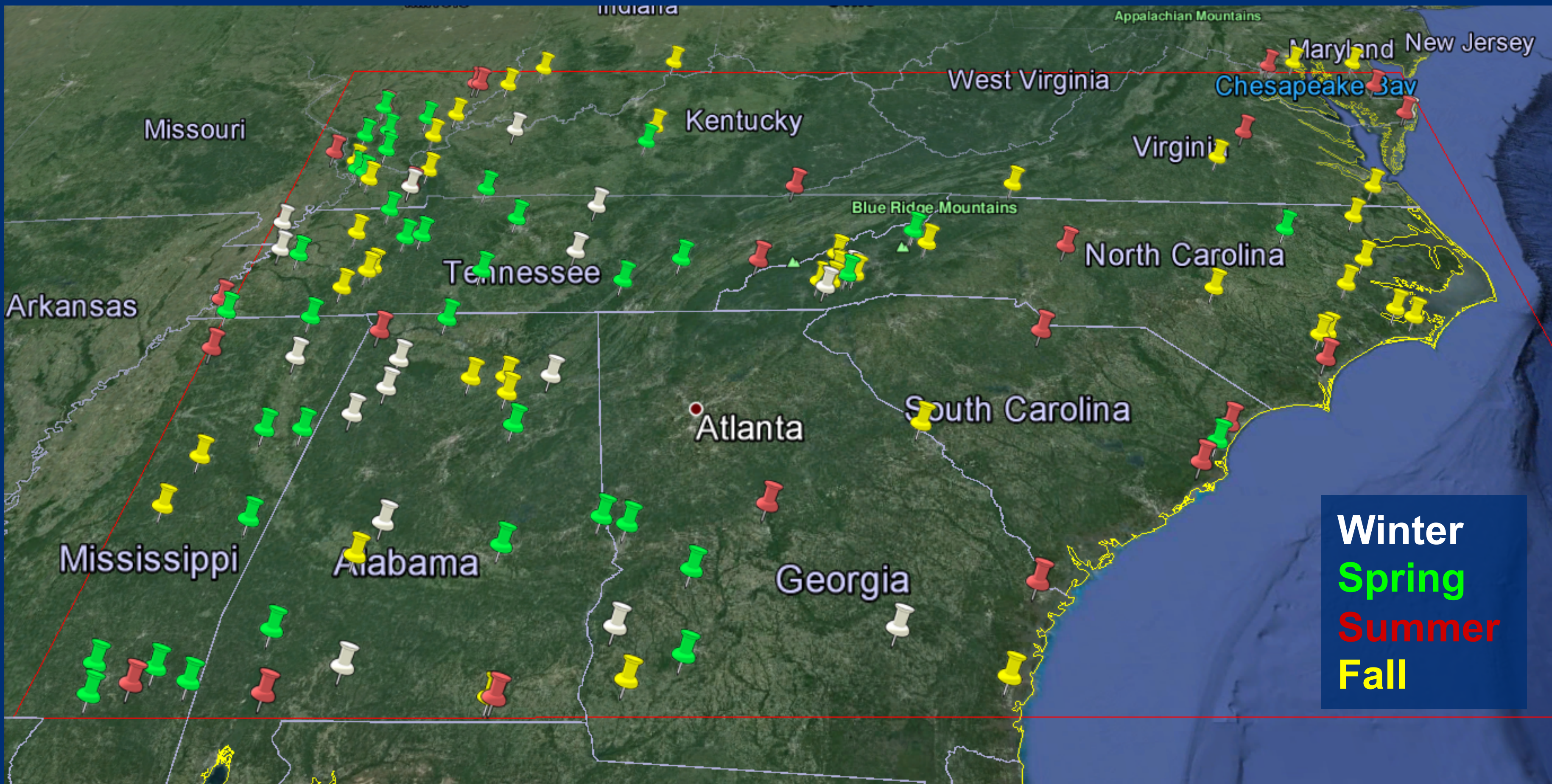
- % of events with an AR by month
- Large spatial scale events (red) very often matched with an AR (especially in transition season months)
- Summer events least likely to be associated with an AR



Matching required at least one collocation between AR and precipitation over 24-hour period within 250 km.

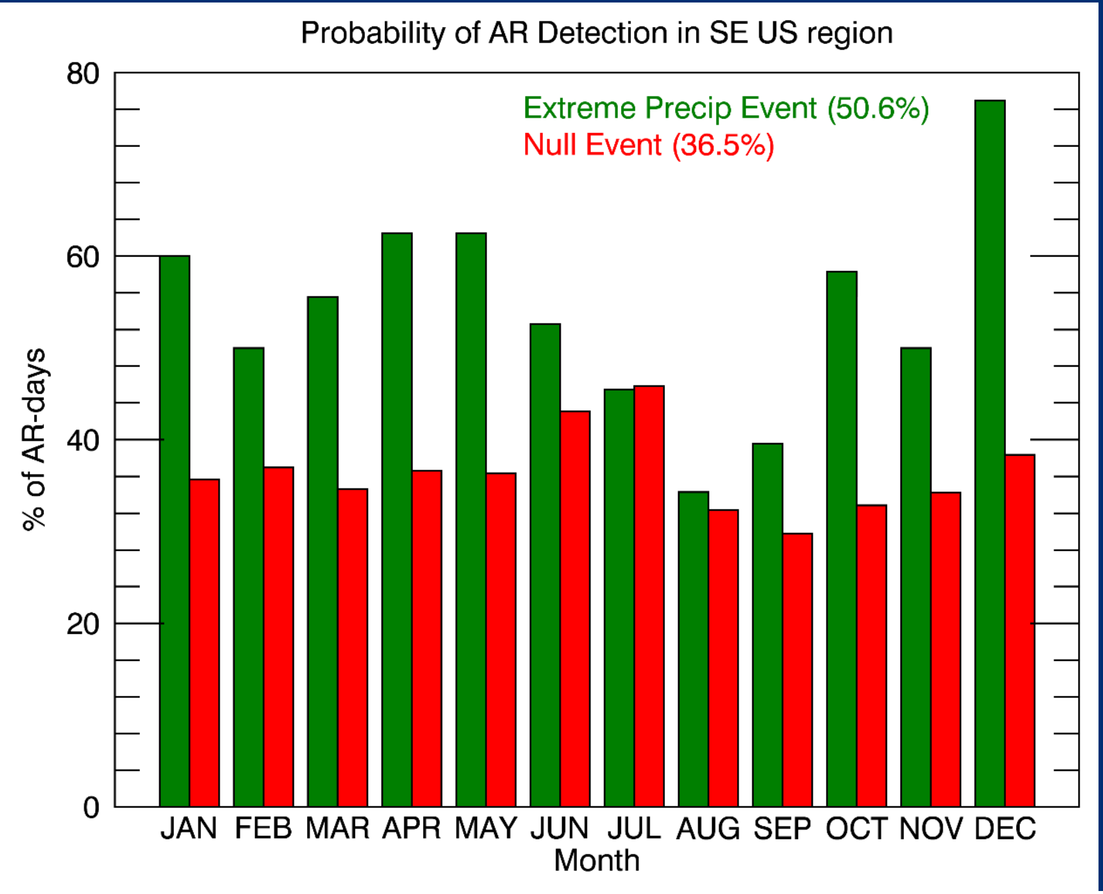
What can we learn about AR-linked precip events?

- Seasonality



- Locations of AR-precip matched events, season indicated by color
- Fall events suggest tropical influence (coastal regions, Appalachian mountains)
- Winter/Spring suggest Gulf of Mexico inflow/frontal influences
- Summer scattered

What about null events?
(AR present but non-extreme (<100 mm/day) precipitation)



Green: # of ARs matched to extreme event/ total # extreme event days

Red: # of ARs *not* matched to extreme event/ total # non-extreme event days

- **Annual average:**
  - There is a 50.6% chance an AR is identified with an extreme precipitation day
  - There is a 36.5% chance an AR is identified with a non-extreme precipitation day
- **ARs do not explain nearly as much extreme precipitation relative to the West Coast**

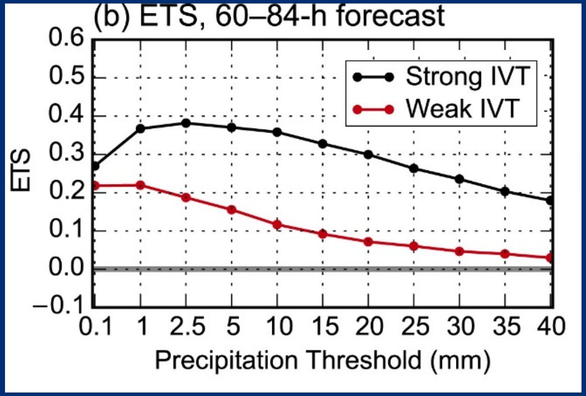
Summary and Future Work

- Extreme precipitation events occur in all months of the year, vary with respect to size, weather system type, environmental characteristics, geographic distribution
- Atmospheric Rivers have a role in a subset of SE precipitation, but only explain a (seasonally varying) fraction of events
- AR-/high-IVT environments generally more predictable

Ongoing and future work:

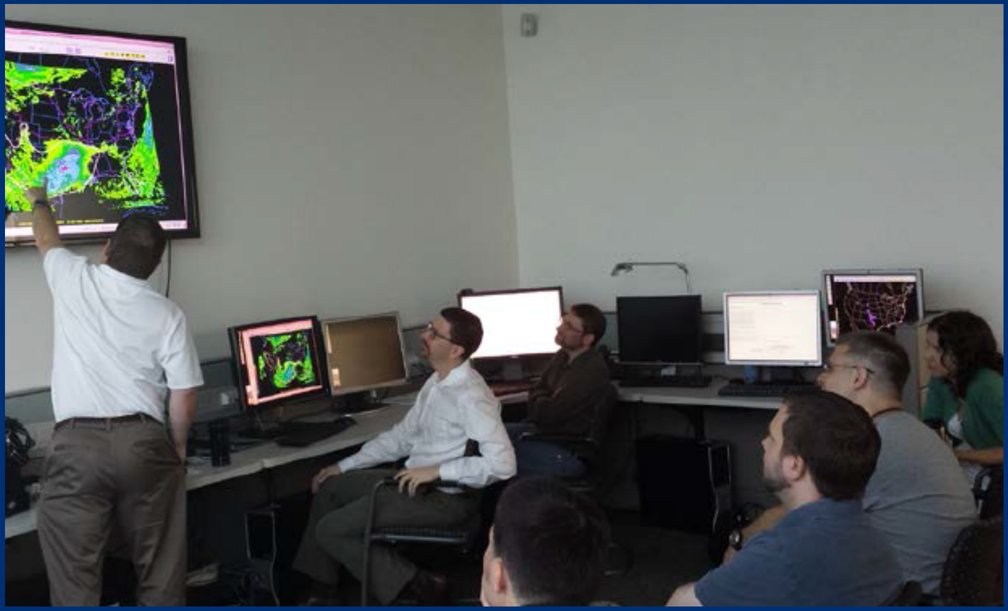
- Usefulness to forecasting yet to be tested (beginning this summer via WPC Flash Flood and Intense Rainfall Forecast Experiment)
- Explore utility of time-integrated quantities (i.e., duration, characteristics of sustained/stationary detected ARs) especially for longer-lead forecasts
- Identify details for forecast challenges for specific case subsets

"Strong IVT" vs. "Weak IVT" predictability analysis example: Equitable threat scores for 24-h precip at 60 – 84-h lead time from GEFS reforecast control member for extreme precipitation events (Moore et al. 2015)

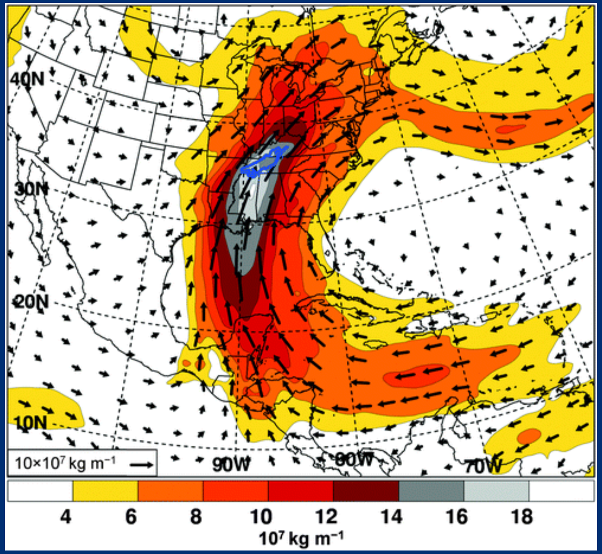


Plans for testing ARDT utility in WPC operations

- 2015 Flash Flood and Intense Rainfall (FFaIR) experiment
- Focus on Day 2 this year; possibly Day 3+ next year
- Test multiple ARDT AR definition thresholds



2014 HMT-WPC Flash Flood and Intense Rainfall (FFaIR) Forecast Experiment

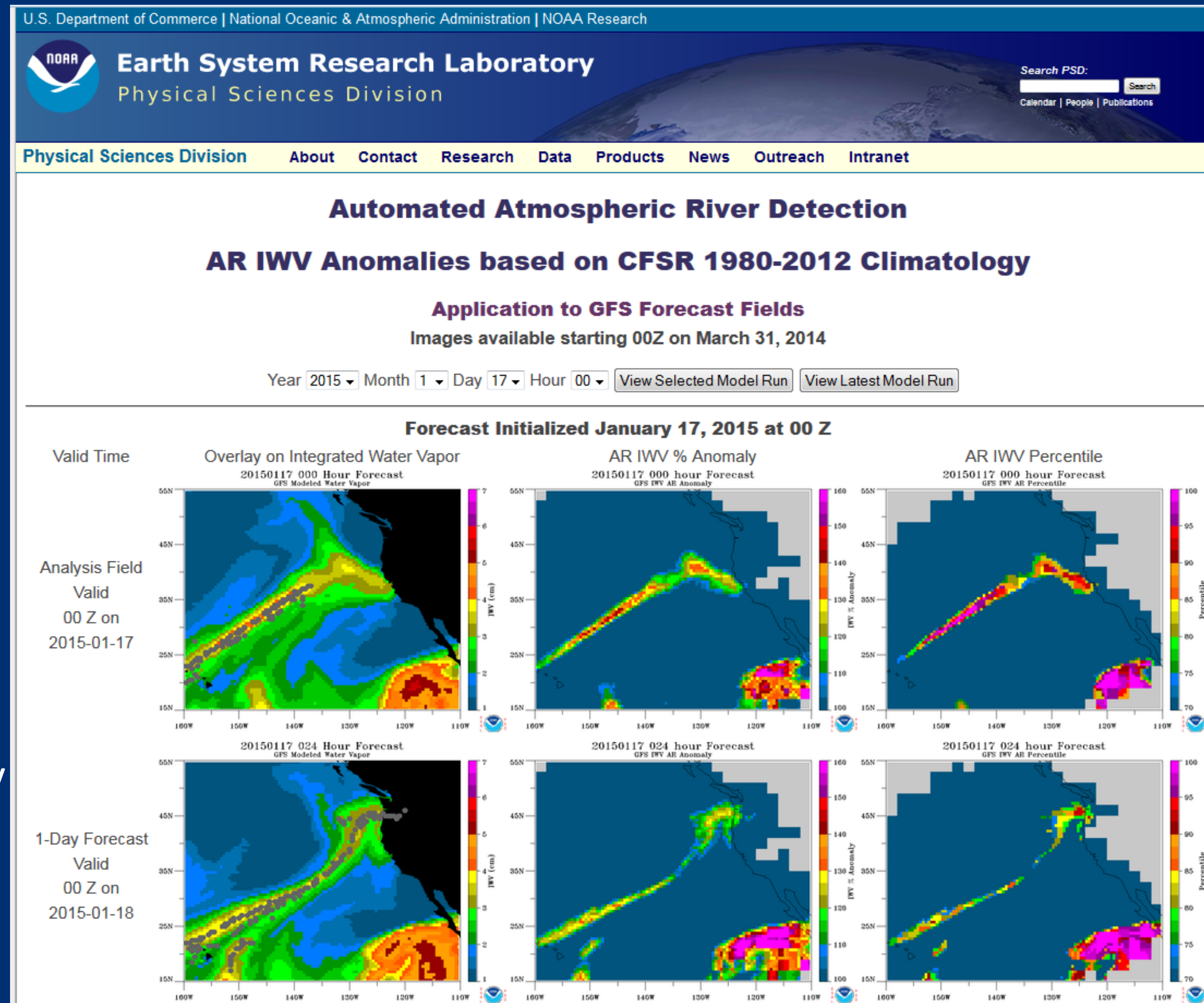


Time-integrated IVT (00 UTC 1 May – 00 UTC 3 May 2010. (Moore et al. (2012))

Plans for testing ARDT utility in WPC operations

<u>2015 HMT-WPC FFaIR plans</u>

- Using GFS forecasts:
- Convert ARDT to ARDT-IVT
- Expand geographic domain
- Display measures of AR intensity in terms of:
  - percent anomaly and
  - percentile relative to a climatology of AR events
- Define, consider utility of duration thresholds, adding additional models
- Survey forecasters on utility of current prototypes, gather suggestions for future efforts



Acknowledgments

- Darren Jackson, Ben Moore, Gary Wick, Rob Cifelli, Lisa Darby, Mimi Hughes, Paul Neiman, Ellen Sukovich, Allen White, Tom Workoff, Faye Barthold
- US Weather Research Program
- Sandy Supplemental Funding Award

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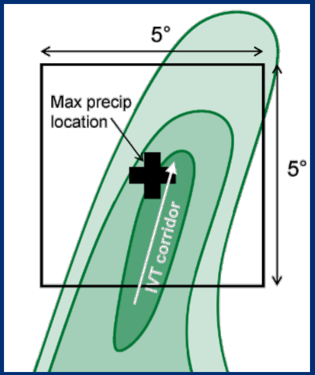
Extra slides

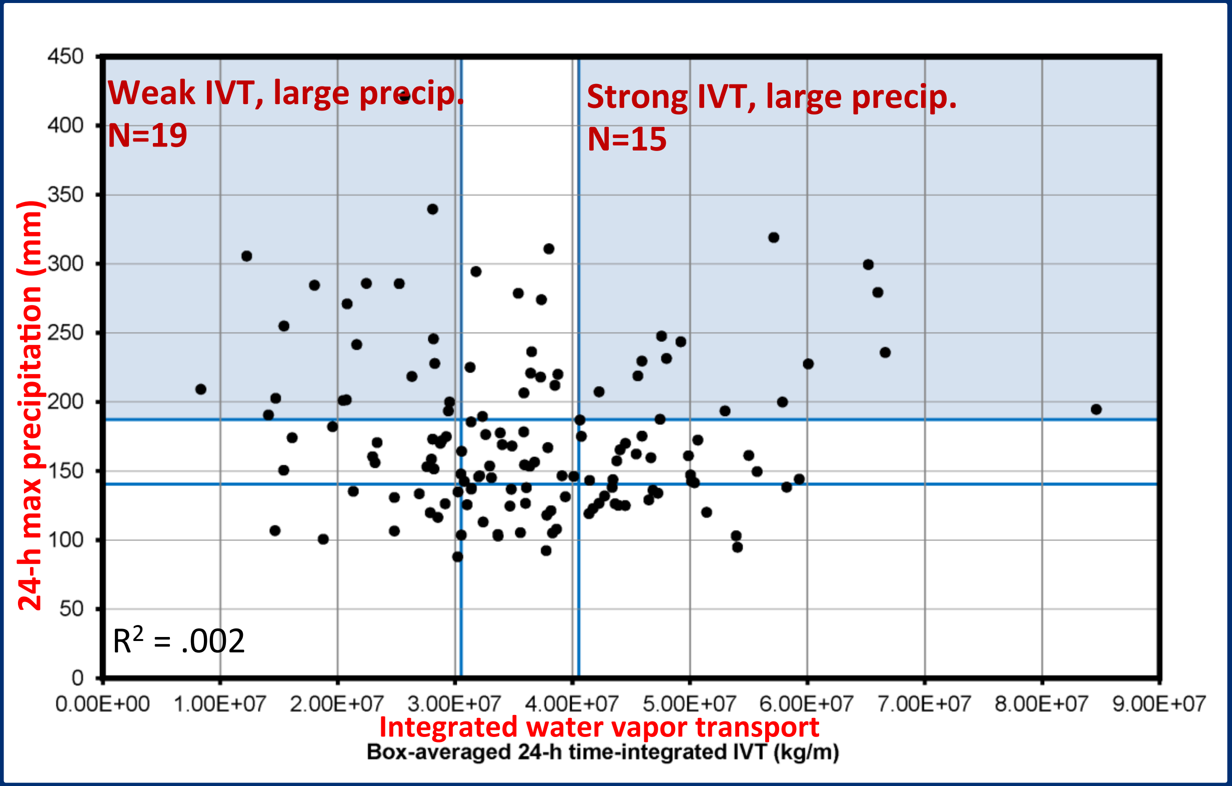
Moore et al. (2015) Southeast climatology:

How does magnitude of water vapor transport relate to precipitation amount?

Approach:

- Quantify water vapor transport using NARR vertically integrated water vapor transport (IVT)
- For each event, average the 24-h time-integrated IVT within 5° lat × 5° lon box centered on maximum precipitation location
- Examine correlation between maximum precipitation amount and IVT value



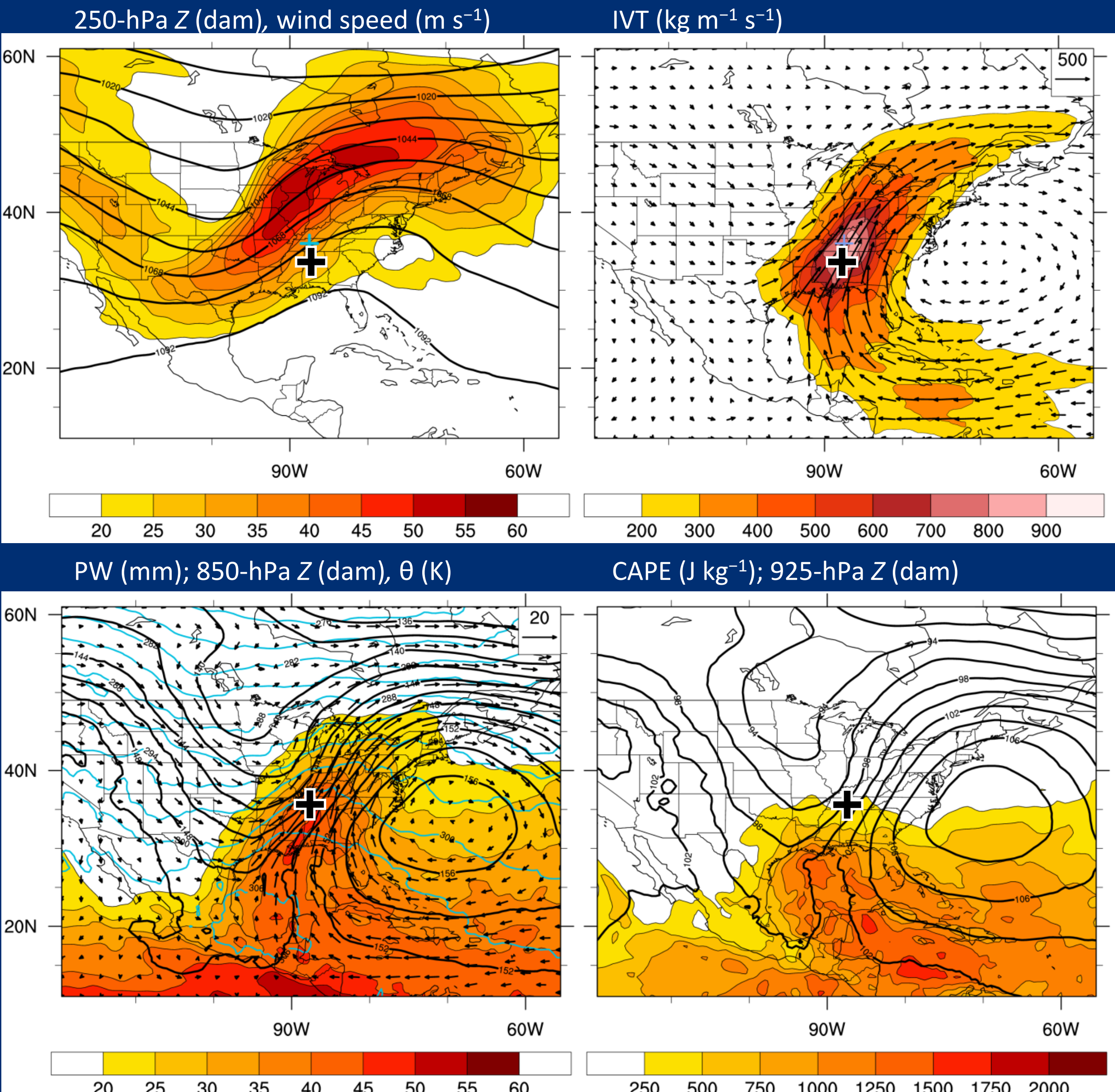


- Nearly zero correlation observed between max precipitation and IVT
- → How are events with large precipitation but weak IVT distinguished from events with large precipitation and strong IVT?
- → Compare events in the strongest, weakest IVT terciles for largest events

Benjamin J. Moore, Kelly M. Mahoney, Ellen M. Sukovich, Robert Cifelli, and Thomas M. Hamill, 2015: Climatology and Environmental Characteristics of Extreme Precipitation Events in the Southeastern United States. *Mon. Wea. Rev.*, **143**, 718–741.

Composite synoptic-scale environment of “strong IVT, large precipitation” events

N=15



Key characteristics

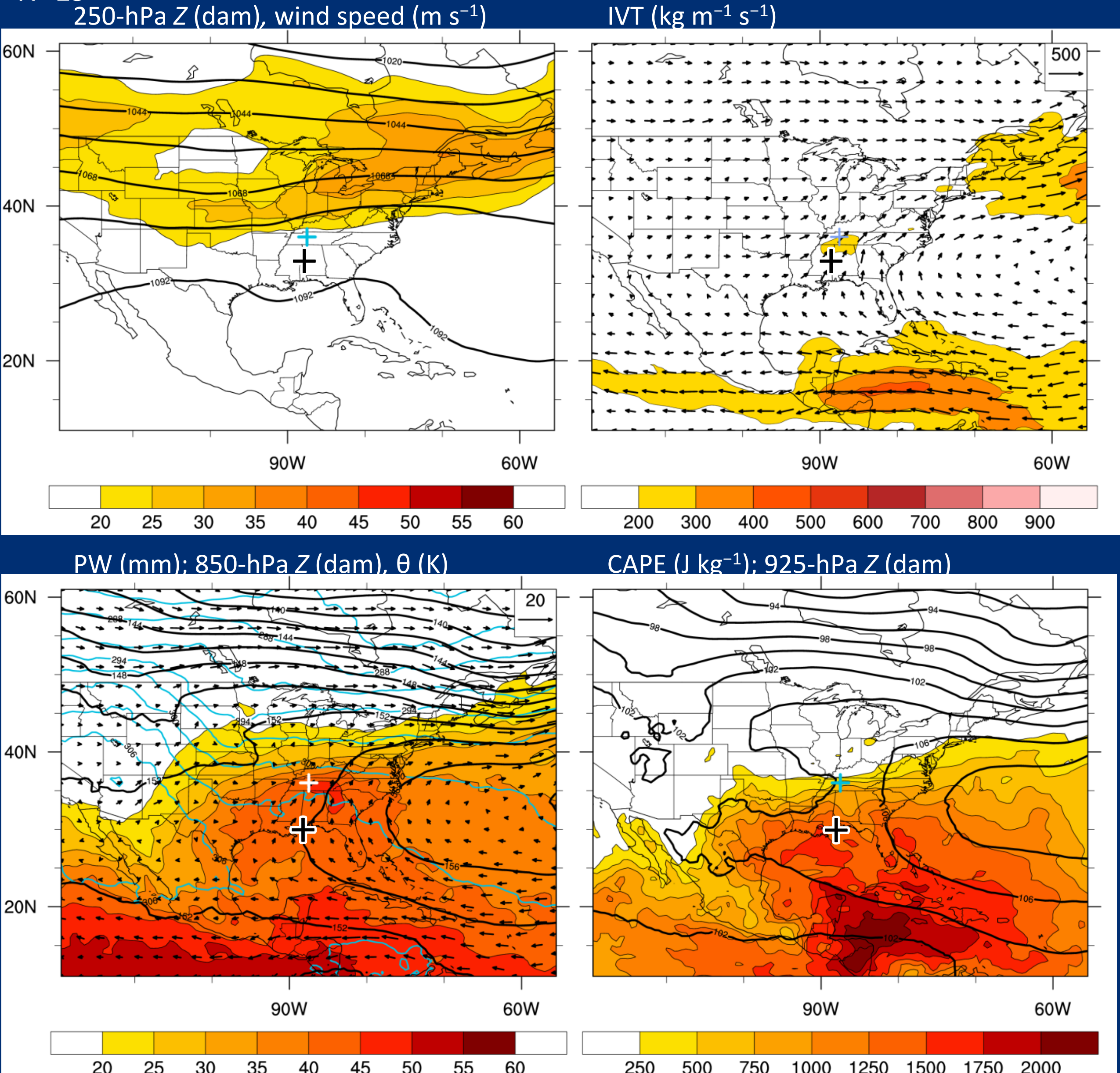
- Amplified upper-level trough-ridge couplet, strong jet streak
- Intense corridor of strong IVT from low latitudes; connection to subtropics/tropics?
- Strong low-level winds and poleward-extending water vapor plume between low-level trough and subtropical anticyclone; low-level warm advection in precipitation region
- Flow of warm, moist, unstable air associated with moderate CAPE

Benjamin J. Moore, Kelly M. Mahoney, Ellen M. Sukovich, Robert Cifelli, and Thomas M. Hamill, 2015: Climatology and Environmental Characteristics of Extreme Precipitation Events in the Southeastern United States. *Mon. Wea. Rev.*, **143**, 718–741.

* Composites are event-relative; geography shown for spatial reference and distance scaling only. Computed using CFSR at beginning of 6h period of largest precip

Composite synoptic-scale environment of “weak IVT, large precipitation” events

N=19



Key characteristics

- Zonal upper-level flow pattern; precipitation region located beneath equatorward entrance of weak upper-level jet streak and downstream of weak short-wave trough
- More gradual poleward low-level flow of very moist air around subtropical anticyclone
- Precipitation region on warm side of quasi-stationary baroclinic zone in weak warm advection
- Much larger CAPE values than “Strong IVT” composite

* Composites are event-relative; geography shown for spatial reference and distance scaling only. Computed using CFSR at beginning of 6h period of largest precip

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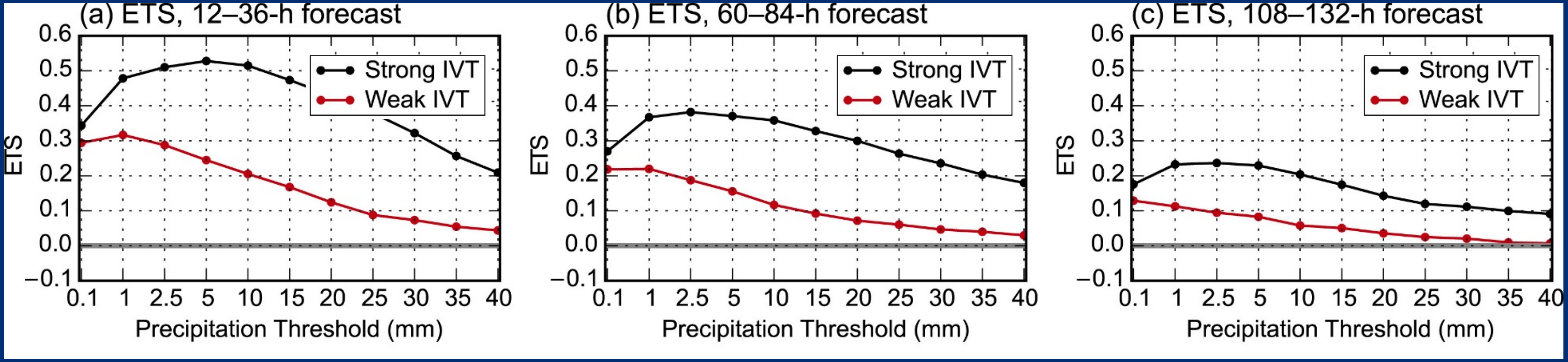
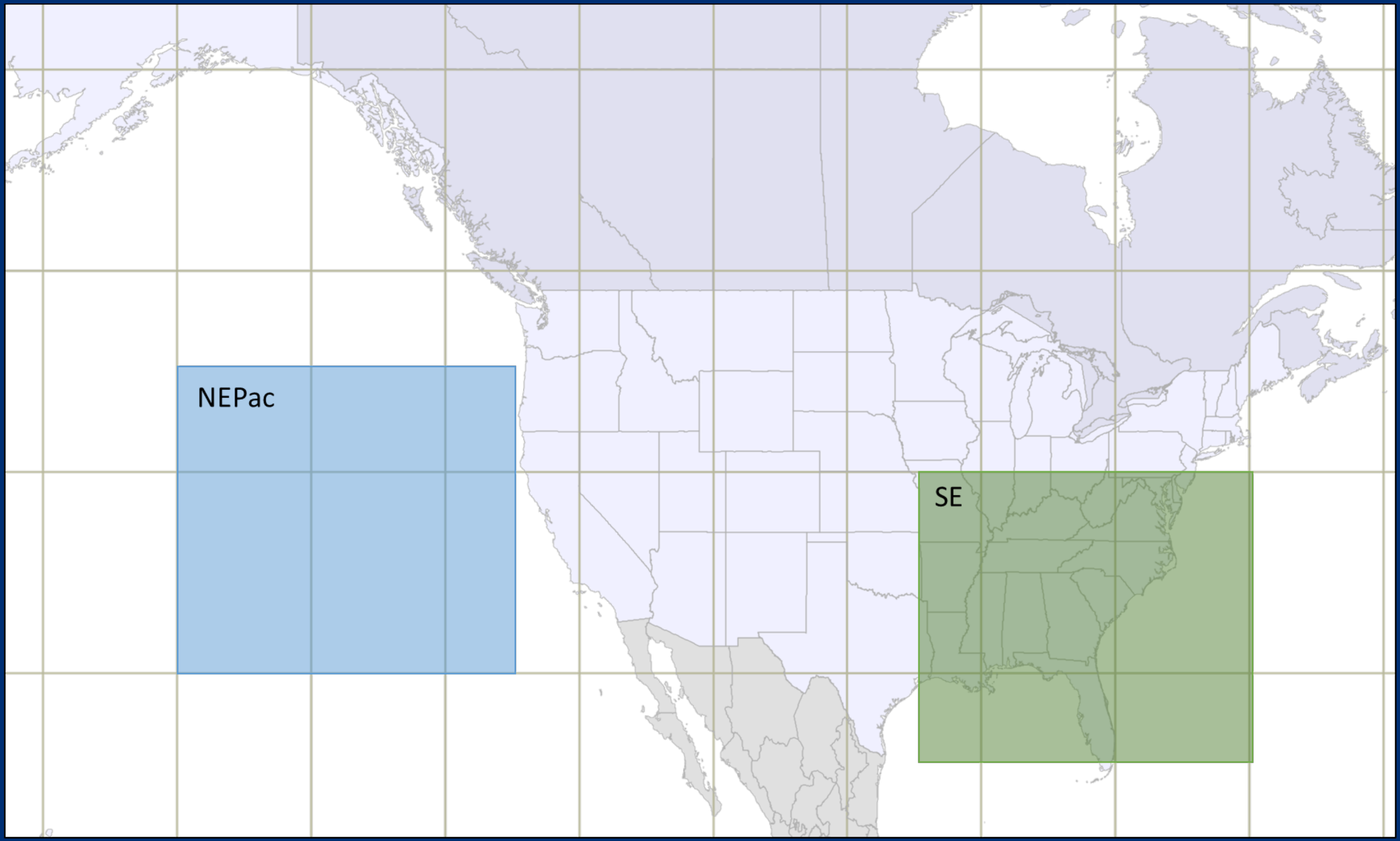
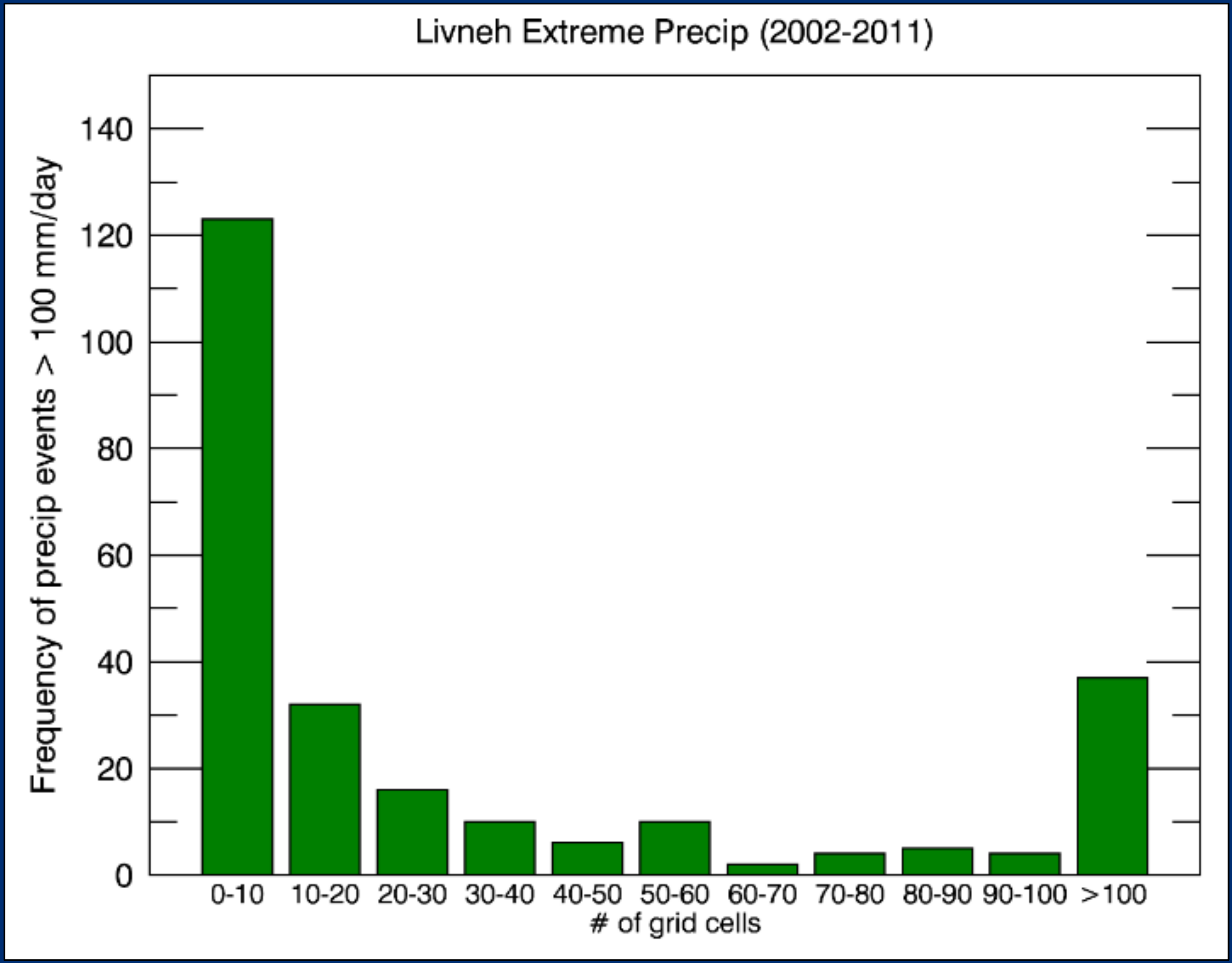
- AR-/high-IVT environments generally more predictable

"Strong IVT" vs. "Weak IVT" predictability analysis example: Equitable threat scores for 24-h accumulated precipitation forecasts at 36-h, 84-h, and 132-h lead time from GEFS reforecast control member for extreme precipitation events (Moore et al. 2015)

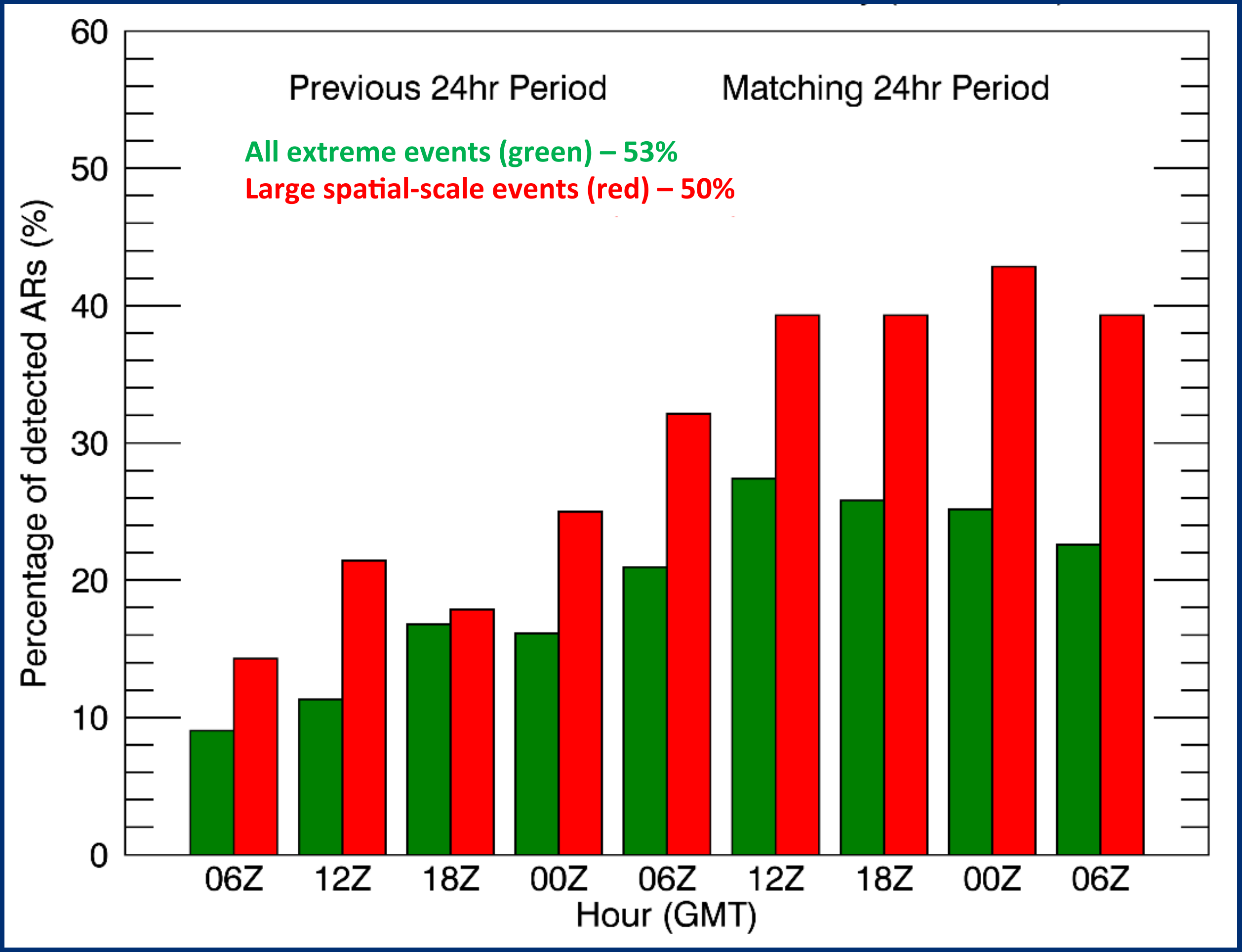



NEPac
SE


Livneh Extreme Precip (2002-2011)
Frequency of precip events > 100 mm/day
0
20
40
60
80
100
120
140
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
>100
# of grid cells

What can we learn about AR-linked precip cases?

- Matching ARs and precip as a function of time

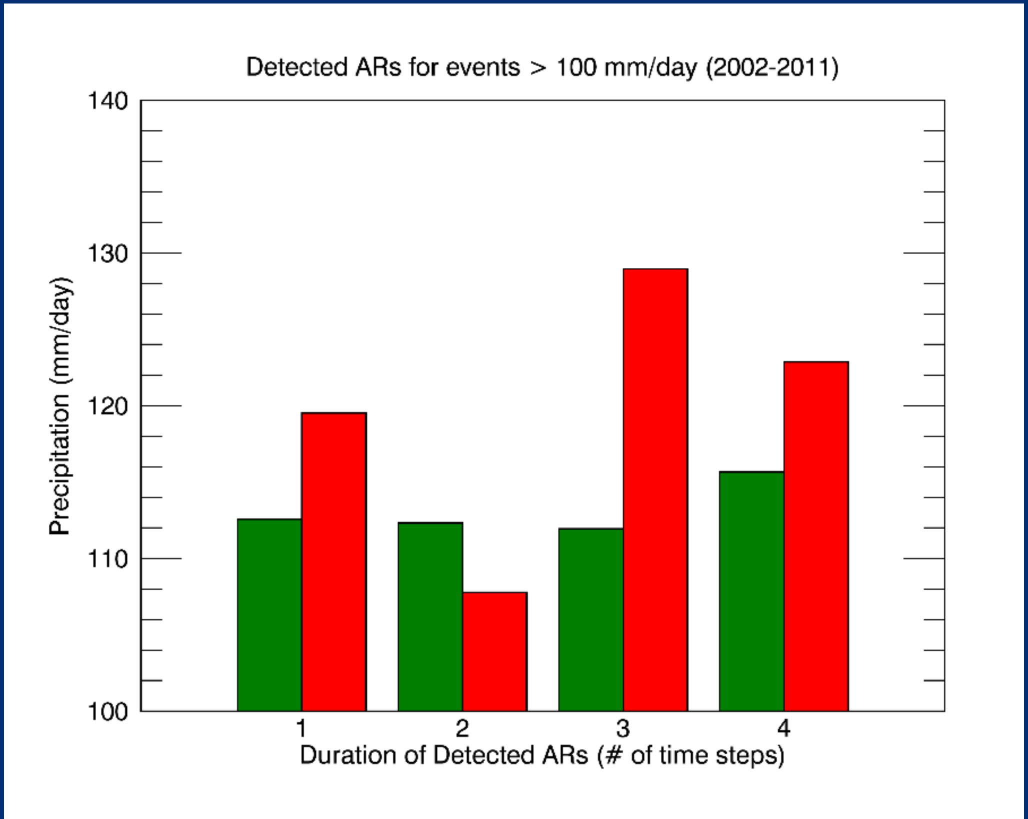


- Precip most likely to be matched to AR for:
  - Larger-scale events
  - Afternoon/evening of day when AR is present

What can we learn about AR-linked precip events?

- Duration

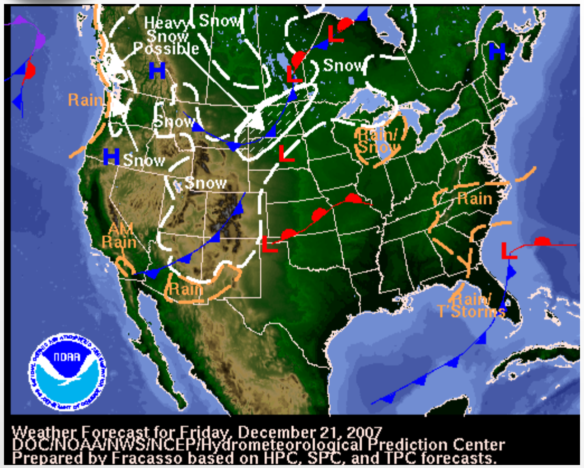
- This doesn't allow us to see duration of ARs prior to 24-h period
- Also, precip amount is avg (?) so hard to tell how intense event really was. Should use max precip, precip composite maps, flood reports, etc. to really link duration to impacts

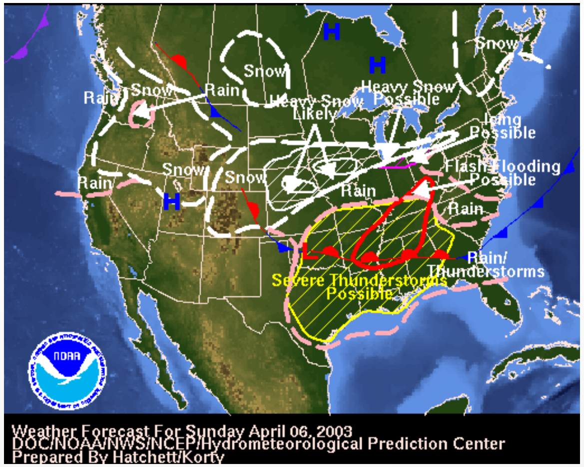


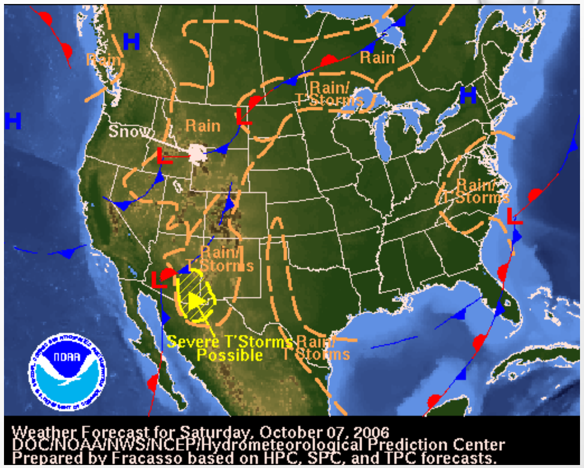
NULL CASE ANALYSES

HIGH PRECIPITATION AMOUNTS, NO ATMOSPHERIC RIVER, NO TROPICAL STORM

- Using Darren's list of days with > 100 mm/precipitation/day
  - Sorted days from most-to-least precipitation
  - Started looking at the Top 25 days
  - Cross-checked with the "AR 500 match" analyses to determine days when an AR was detected
  - Cross-checked with the Hurricane Research Division Reanalysis Project images to determine days when there was a Tropical Storm in the region
  - Eliminated all days when an AR or TS was present, regardless of its distance from the extreme precipitation event
  - Investigated the Top 3 days that remained
    - Identified meteorological features associated with the extreme precipitation event
      - Storm reports
      - NWS/WFO analyses (if available)
      - Synoptic maps
      - Other data as needed (radar, etc.)
    - CFSR Moisture Convergence maps (from Darren)
    - CFSR Water Vapor and Integrated Vapor Transport maps (from Darren)
    - May have included the second day of the event if it was a 2-day event
  - Future steps: Determine appropriate steps for continued analyses of these kinds of days
  - Develop potential research questions based on what we learn from the analyses







Savannah, GA

December 21, 2007

- 143.61 mm/day
- New daily rainfall record for this date for Savannah (7.12"). The old
- Record was 1.97" in 1947.

Coastal low/warm front

Localized precipitation leading to flash flooding

Central Mississippi

April 6-7, 2003

- 138.8 mm/day on April 6th
- All-time 24-hour max precip record at Jackson International Airport (8.5 inches)

Back-to-back slow-moving MCSs (2 in one day following approximately the same path); Stationary front and secondary meso-beta surface boundary

Virginia

October 7, 2006

- 131.51 mm/day

Slow-moving coastal low & stationary surface boundary; formation of rain bands, along with strong vertical motions leading to flash flooding (Gingrich and Lynch poster)

May 2010
Nashville, TN

AP Photo/Mark Humphrey