Wet weeks in the warm season: Patterns and processes supporting widespread multi-day precipitation episodes

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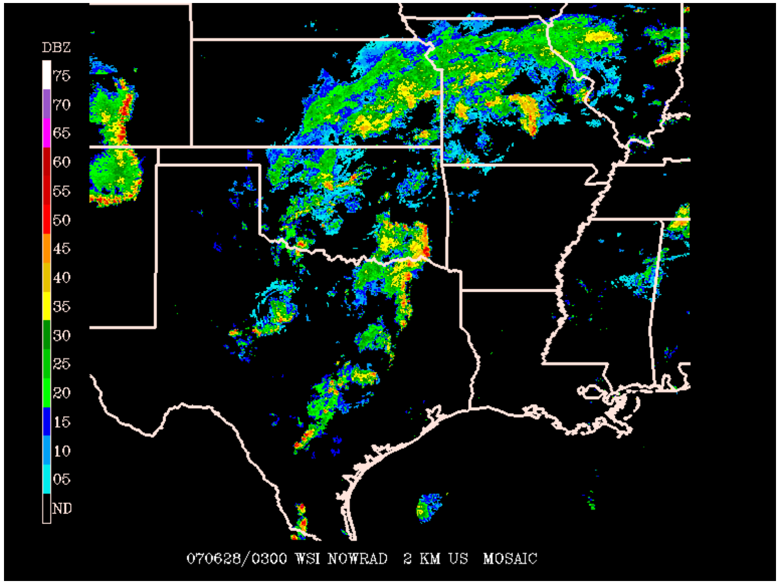
Acknowledgments: NSF grants AGS-0954908 and AGS-1157425

Based in part on work reported by Schumacher and Davis (2010, *WAF*); Schumacher (2011, *MWR);* Bodner et al. (2011, *Nat. Wea. Digest*); and Lynch and Schumacher (2013; *MWR)*

US CLIVAR Extremes workshop
21 August 2013

Purpose

- To identify the types of weather systems responsible for widespread heavy precipitation in the warm season
- To examine the skill and uncertainty in medium-range forecasts of these events
- To use medium-range ensemble forecasts to understand the processes that are favorable or unfavorable for the development of long-lived heavy rainfall



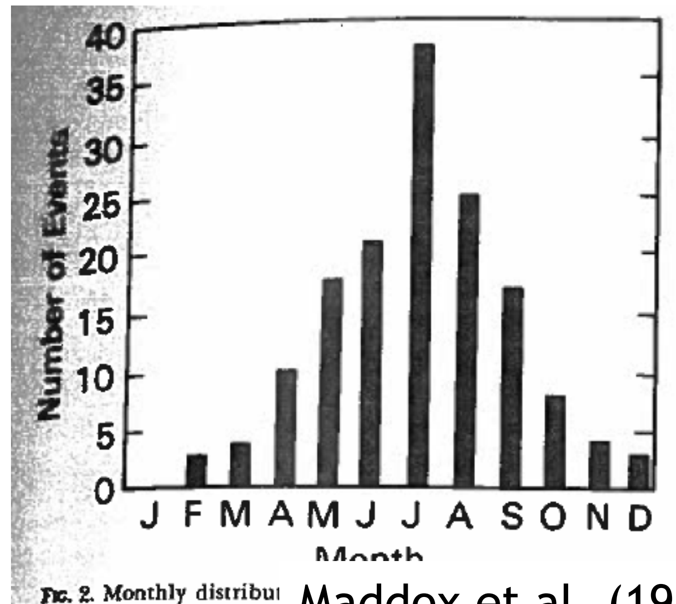
Coffeyville, KS, June 2007
http://www.coffeyville.com/images/floodfairgrounds.JPG

Ingredients for extreme rainfall—Doswell et al. (1996)

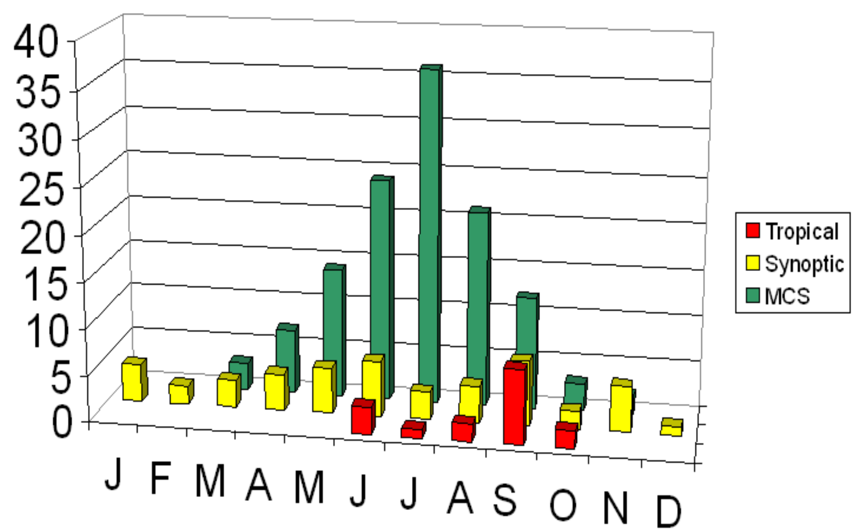
- Simply: $P = \bar{R}D$ (precipitation equals average rainfall rate times duration)
  - Or, in other words: the most rain falls where it rains the hardest for the longest!
- Three ingredients for high R: upward motion (convection), water vapor content, and precipitation efficiency
- Duration determined by system speed, size, and organization

How do we get extreme rainfall in the summer?

- On relatively short (< 24 hours) time scales, the number of extreme rain events (regardless of definition) is maximized in summer – most studies show a July maximum
- Owing to the greater availability of moisture and instability, organized convective systems are very common; most localized warm-season extreme rain events are associated with **mesoscale convective systems (MCSs)**



Maddox et al. (1979)



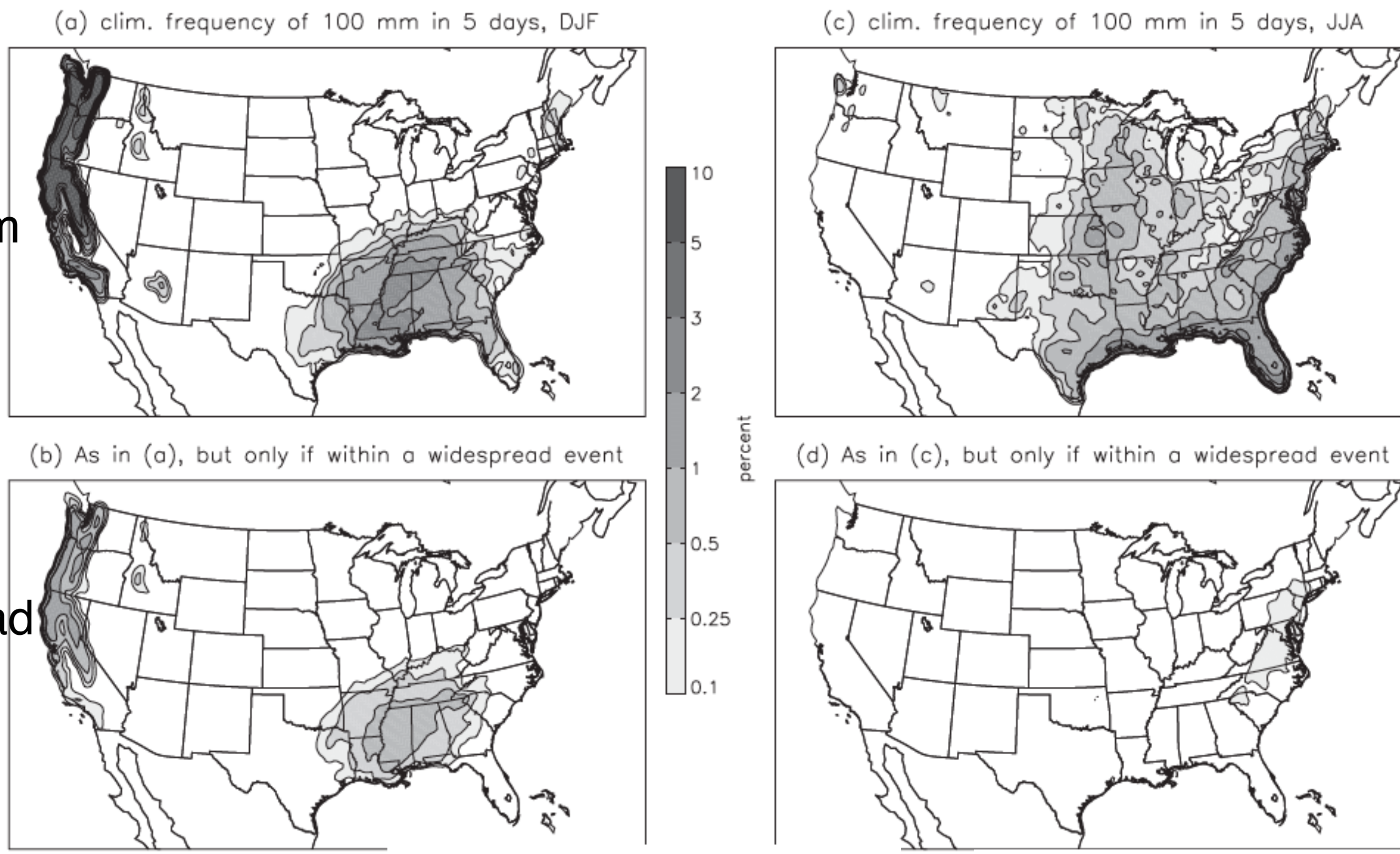
Schumacher and Johnson (2006)

How do we get extreme rainfall in the summer?

- On the other hand, the relative lack of large-scale forcing for ascent in summer makes **widespread** extreme rainfall events relatively rare

All 100 mm in 5 days DJF

Widespread 100 mm in 5 days DJF



All 100 mm in 5 days JJA

Widespread 100 mm in 5 days JJA

# of events per year

Schumacher and Davis (2010)

Case identification

- Used US Daily Precip Analysis from NOAA Climate Prediction Center
  - ~8000 gauges, gridded to 0.25° lat/lon grid
  - Too coarse for local extremes, but sufficient for widespread events
- Identified all 5-day periods in 1948-2013 where the 100-mm ($\approx$ 4 inch) rainfall contour covered 350+ grid points (approx. 800 000 km^2)
  - All events had local maxima > 200 mm, some > 700 mm
- Over this period, 22 cases in June, July, August (after removing overlapping 5-day periods)

How do we get widespread heavy rainfall in the summer?

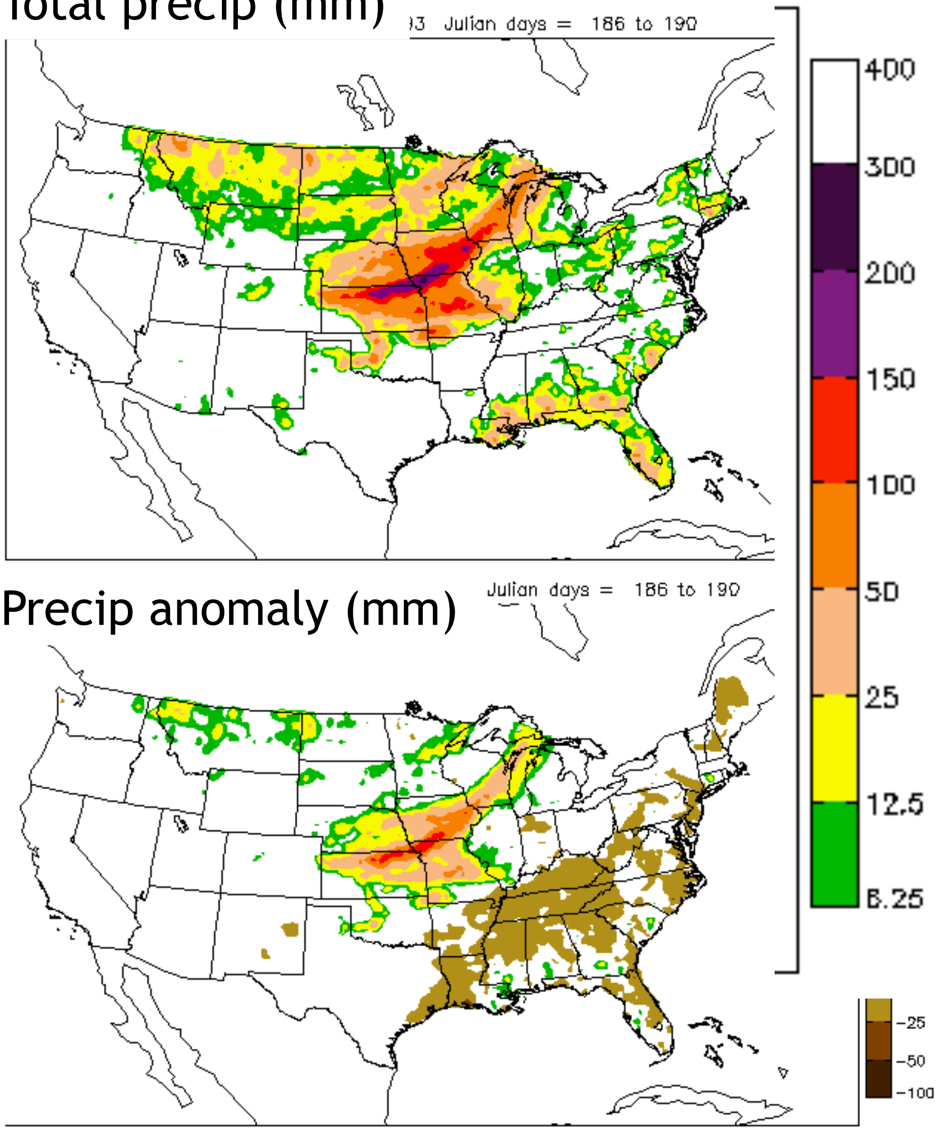
- Tropical cyclones
  - 13 of 23 events
  - Not the focus of today's talk
  - Includes notable events such as Agnes (1972), Fay (2008), Irene (2011)

- Persistent synoptic-scale troughs
  - 7 of 22 events

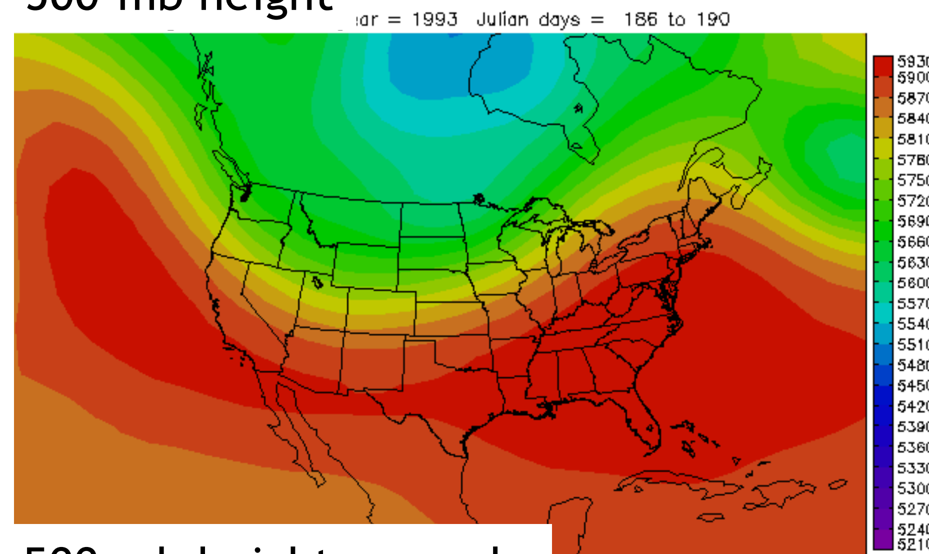
3-8 July 1993

Total precip (mm)

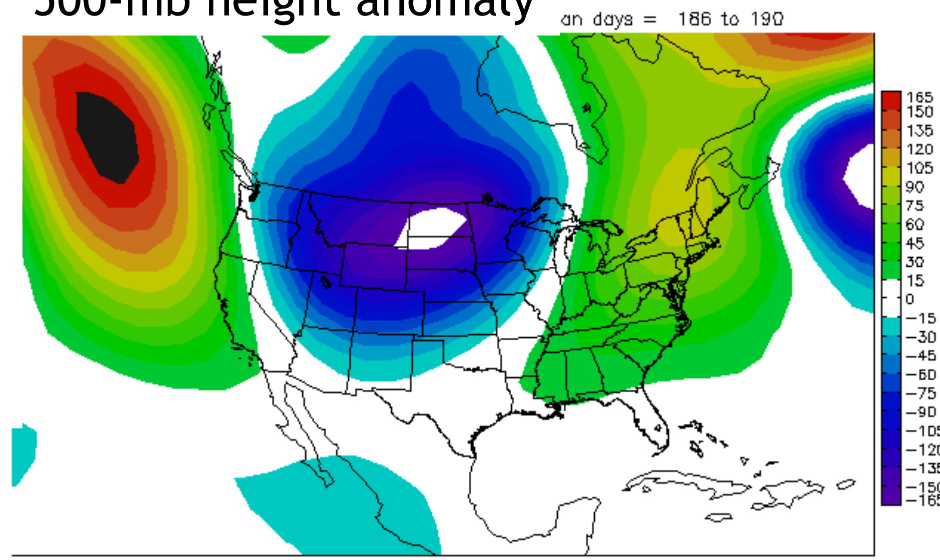
Precip anomaly (mm)



500-mb height



500-mb height anomaly



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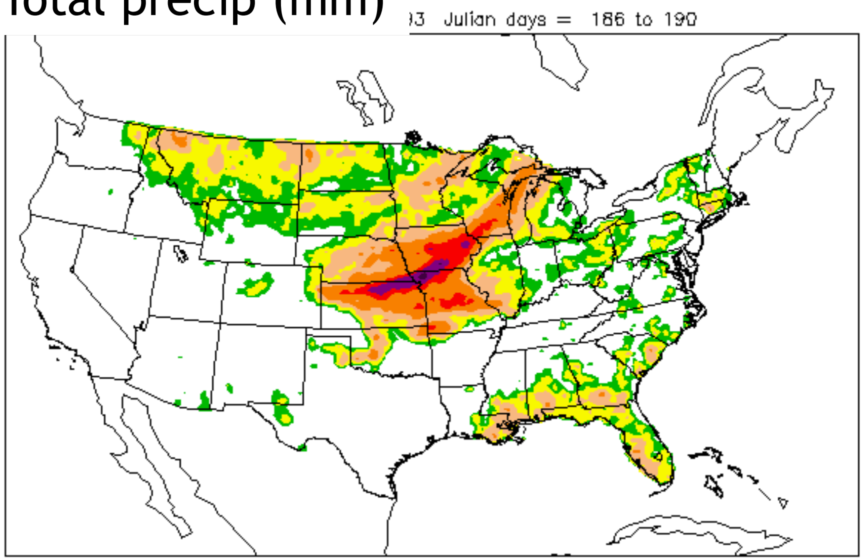
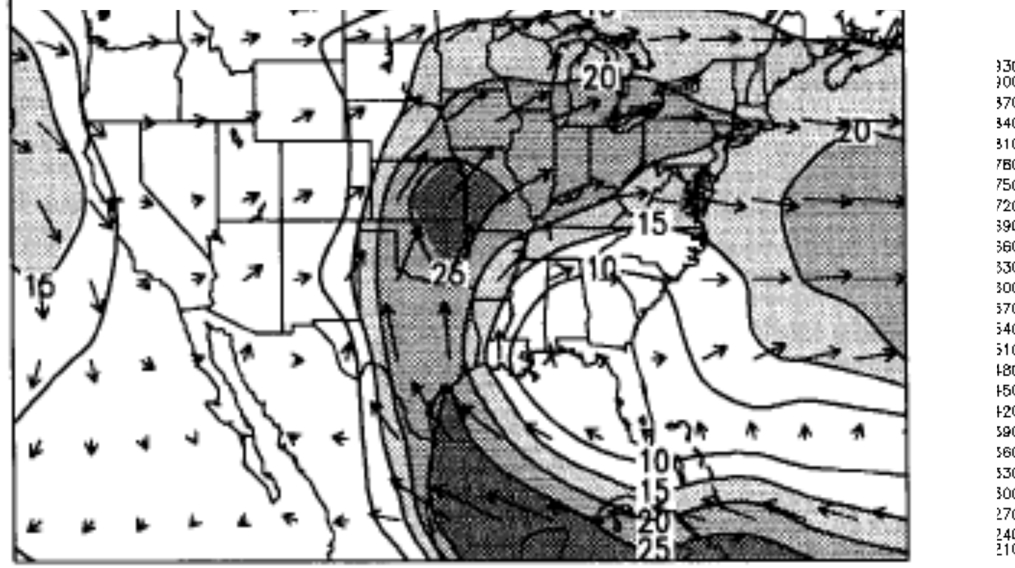
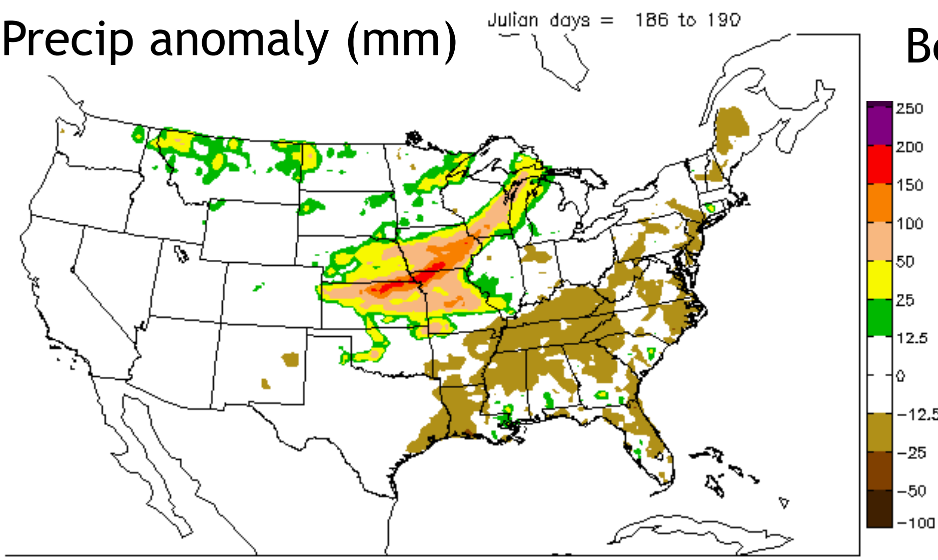


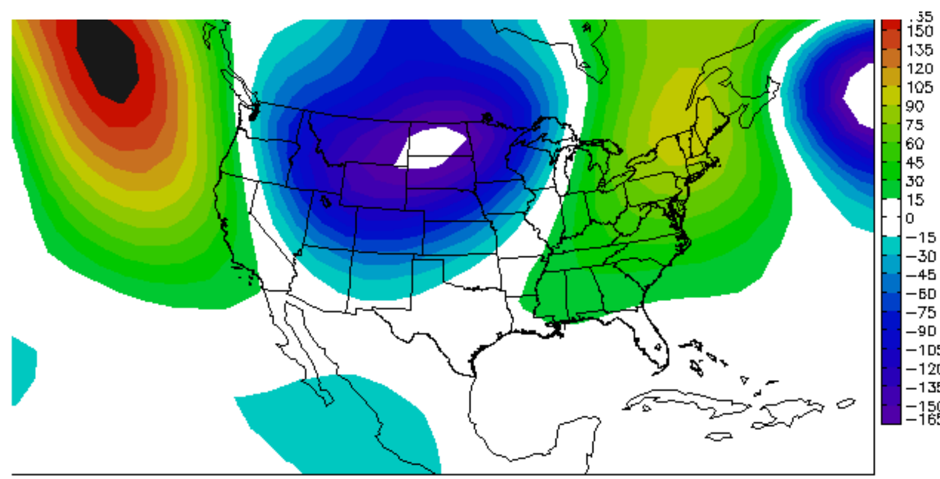
Vertically-integrated moisture transport



Precip anomaly (mm)

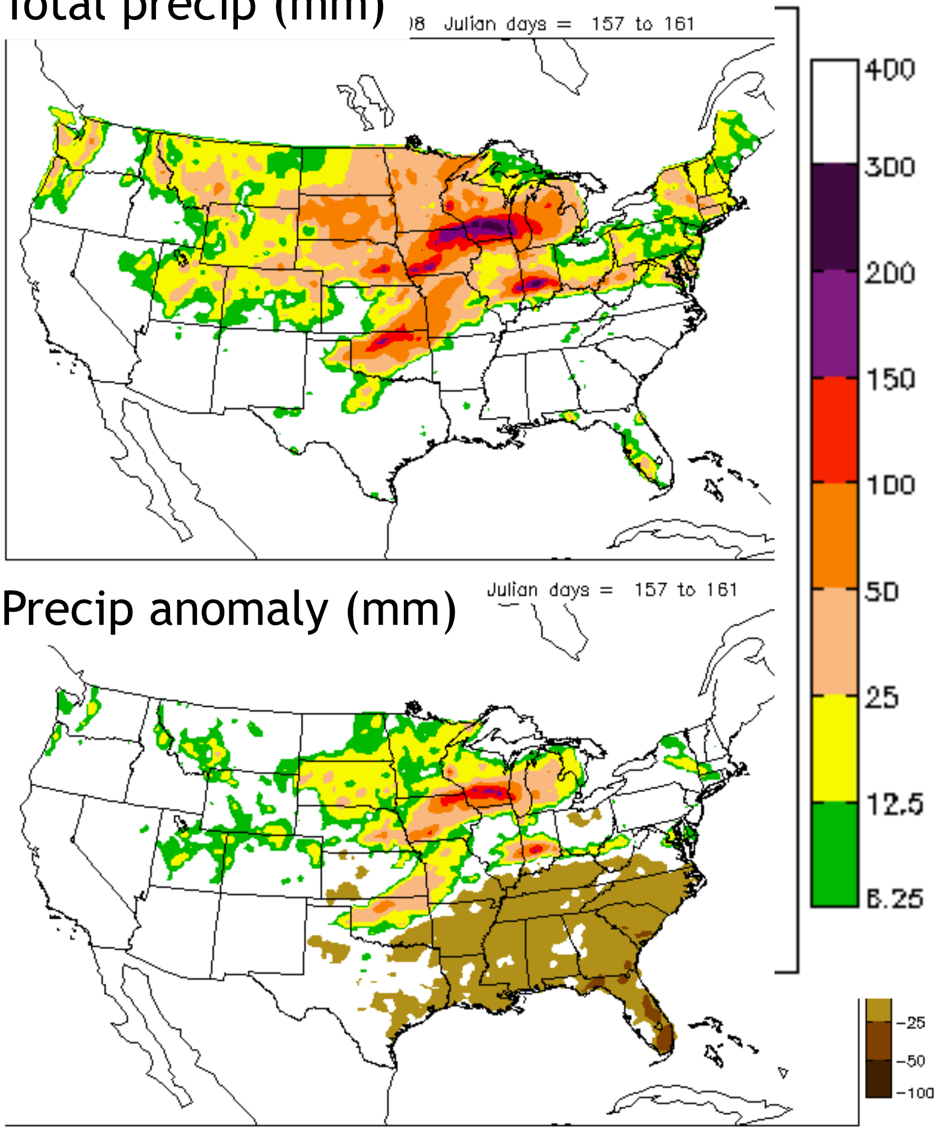


Bell and Janowiak (1995, *BAMS*) →

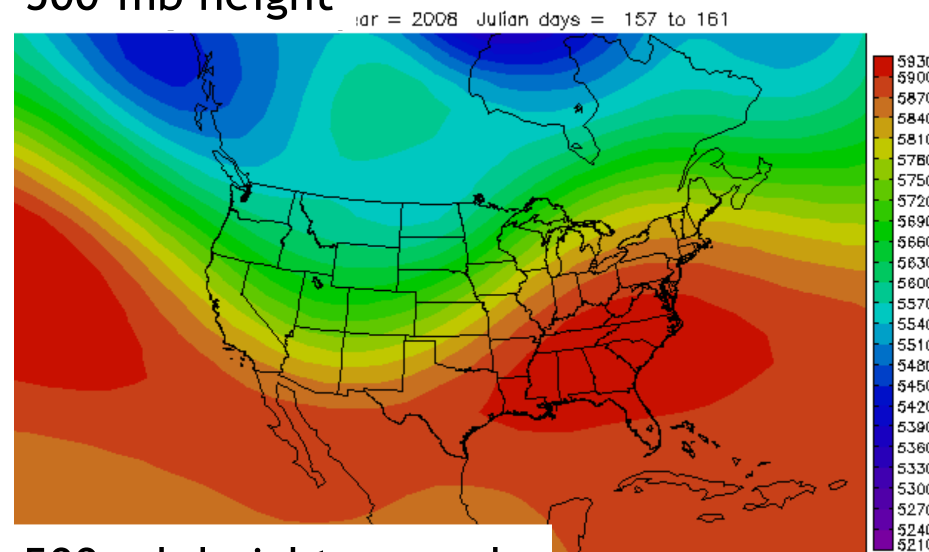


4-9 June 2008

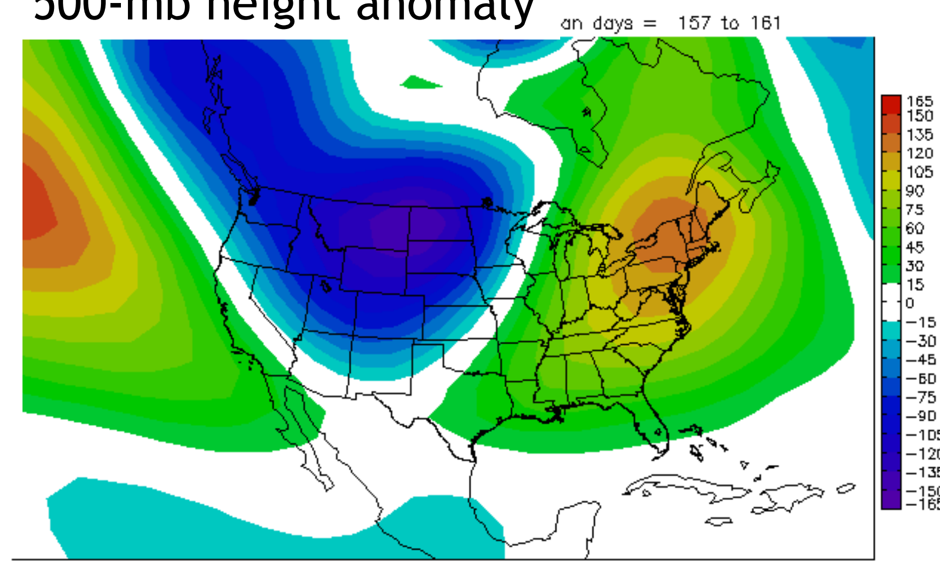
Total precip (mm)



500-mb height

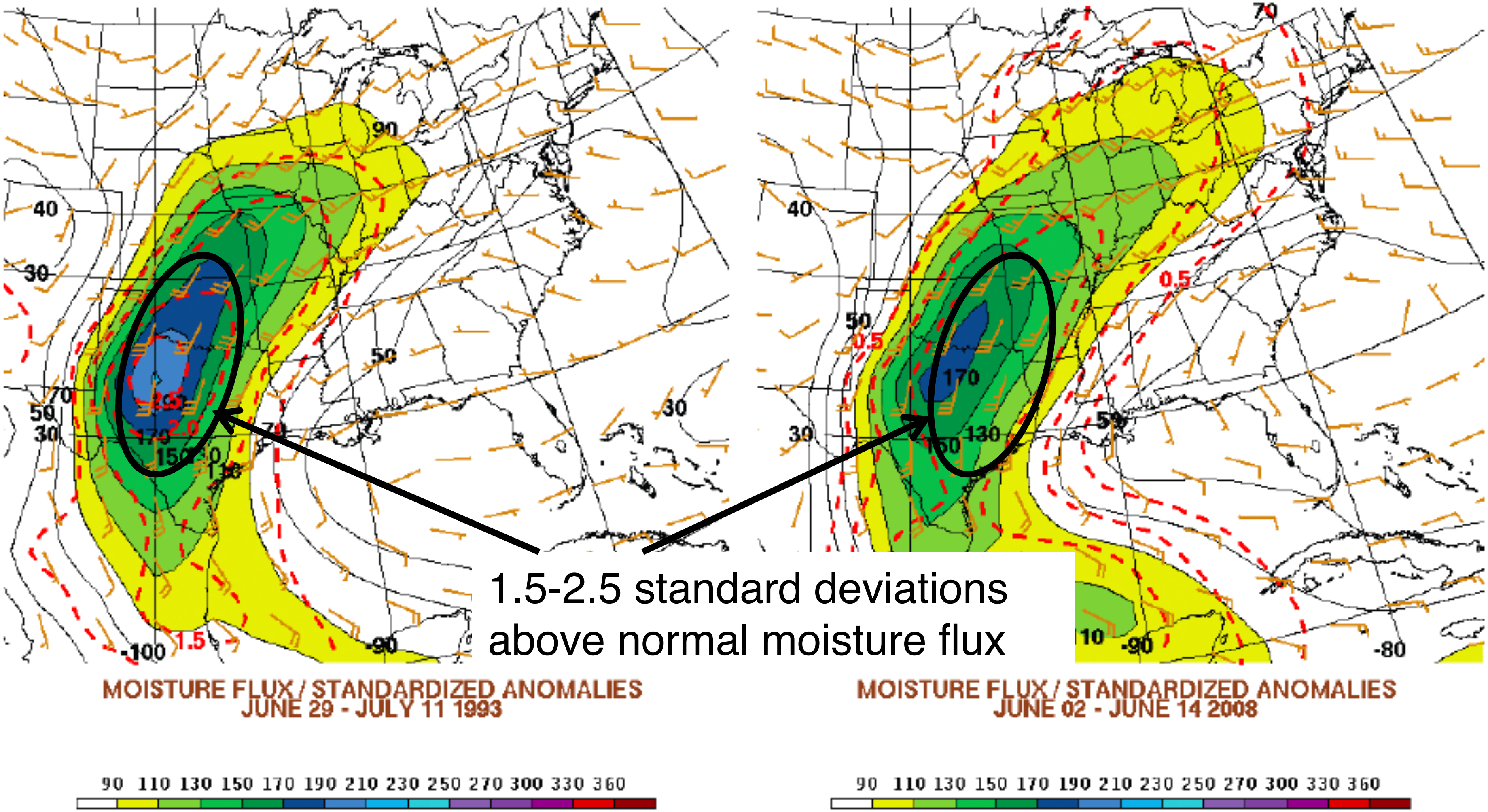


500-mb height anomaly



29 June – 11 July 1993

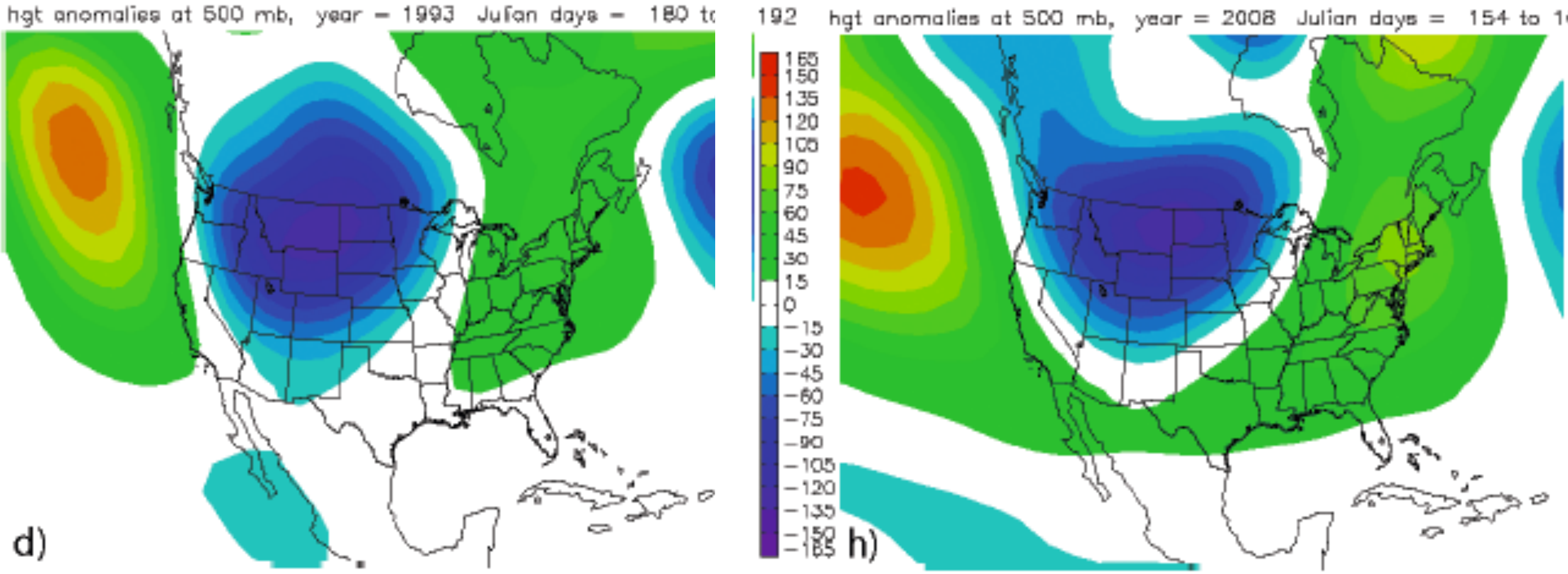
2-14 June 2008



850-hPa normalized moisture flux (color shading) and normalized anomalies (dashed)

Bodner et al. (2011)

500-mb height anomaly: 29 June – 11 July 1993 2-14 July 2008

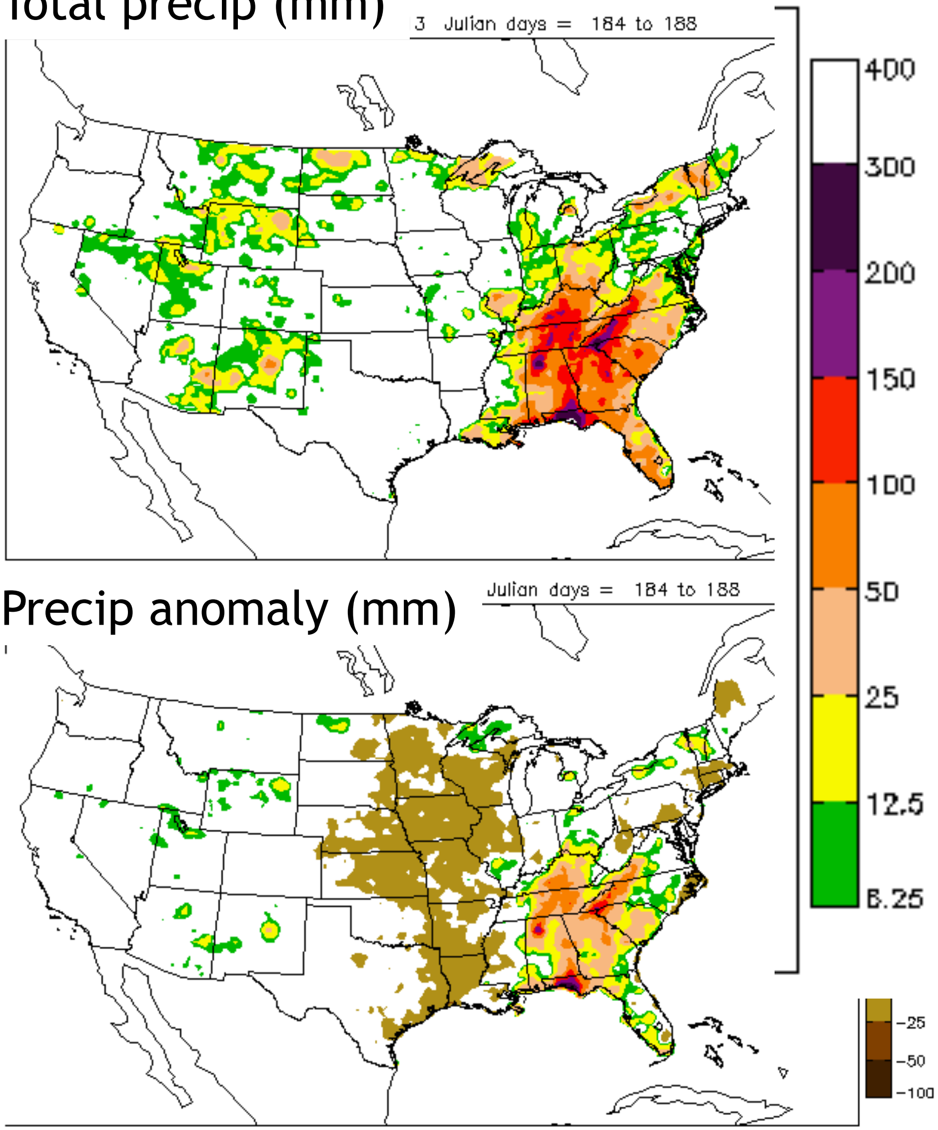


- Anomaly correlations between these two periods exceed 0.9; no other 13-day periods in the 1979-2008 periods were correlated nearly as strongly
- “Therefore we conclude that the only two times in the last 60 years that this 13-day average height pattern occurred for such a long period over North America were during 1993 and 2008.” -- Bodner et al. (2011)

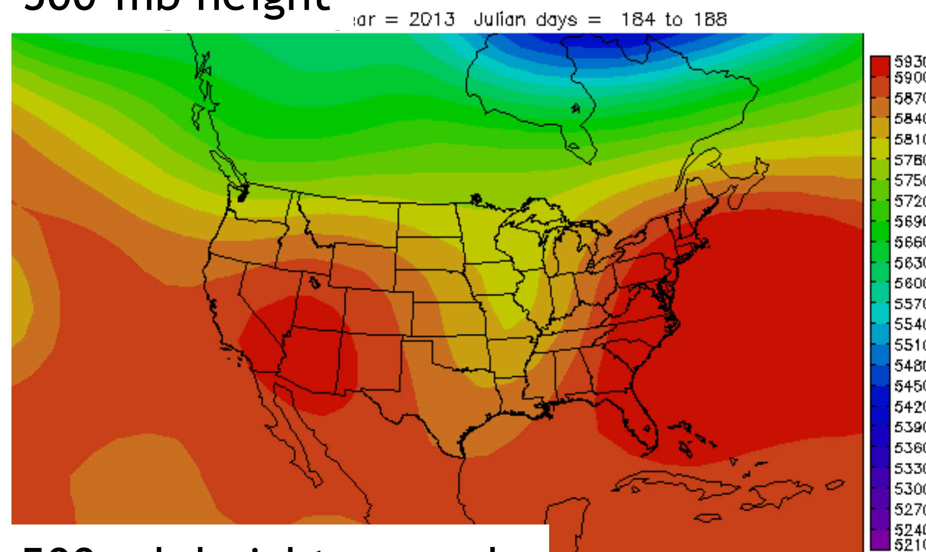
2-7 July 2013

Total precip (mm)

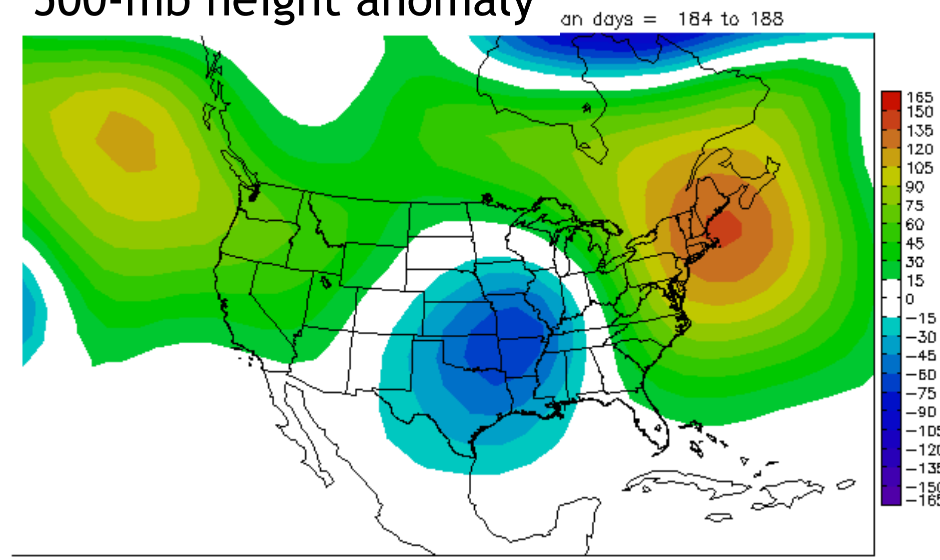
Precip anomaly (mm)



500-mb height



500-mb height anomaly



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- Tropical cyclones
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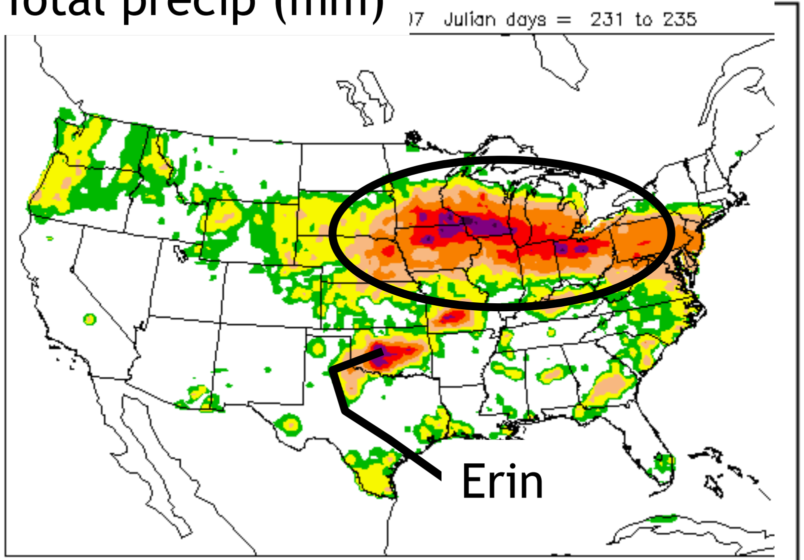
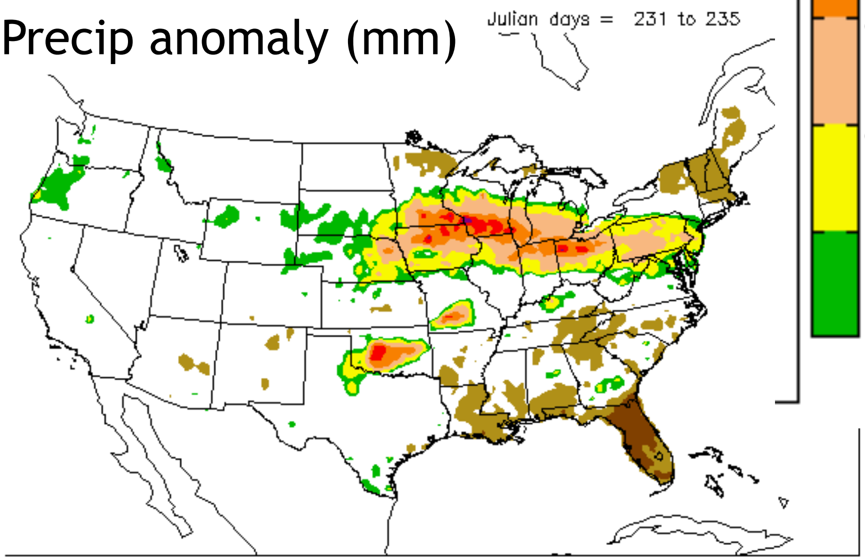
  - Includes notable events such as Agnes (1972), Fay (2008), Irene (2011)
- Synoptic-scale troughs
  - 7 of 22 events
  - Examples: 1993 and 2008 Midwest floods; early July 2013 rains in southeast
- Predecessor rain events (e.g., Galarneau et al. 2010; Schumacher and Galarneau 2012; Moore et al. 2012, MWR)
  - 2 of 22 events (ahead of TS Grace, 2003; and TS Erin, 2007)

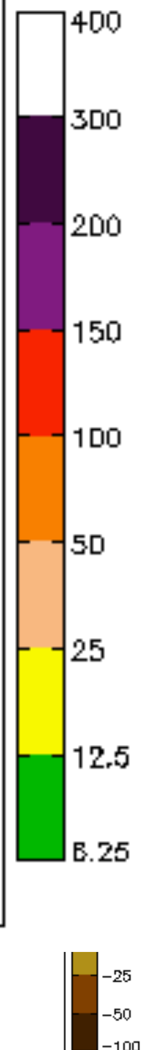
18-23 August 2007

Total precip (mm)



Precip anomaly (mm)





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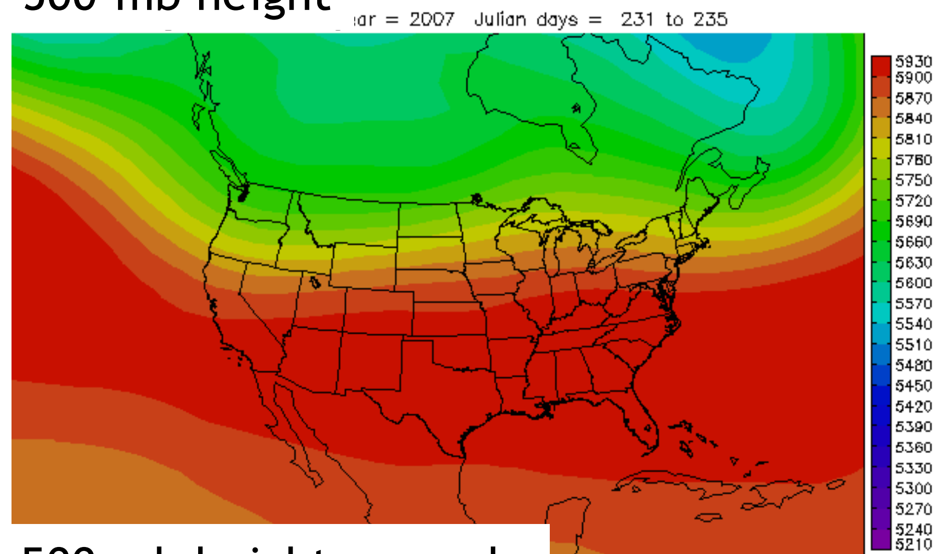
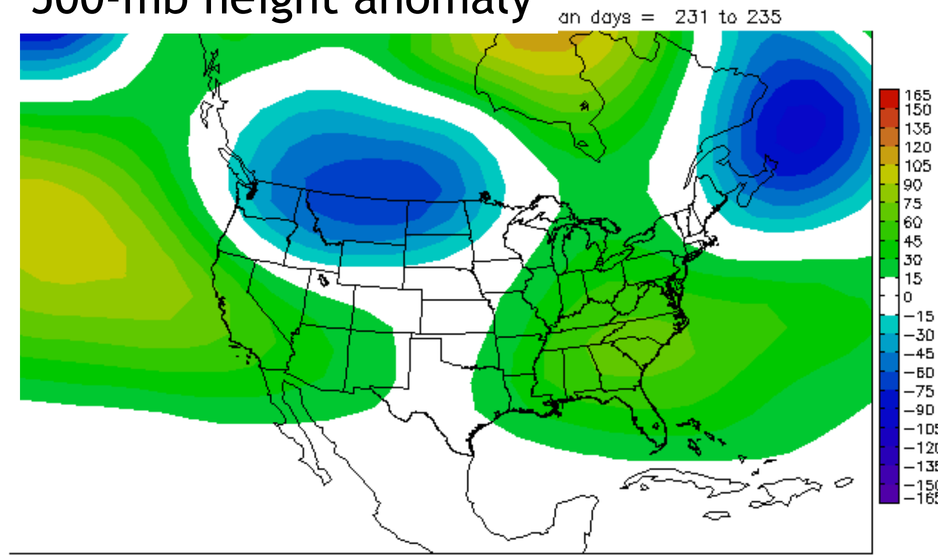
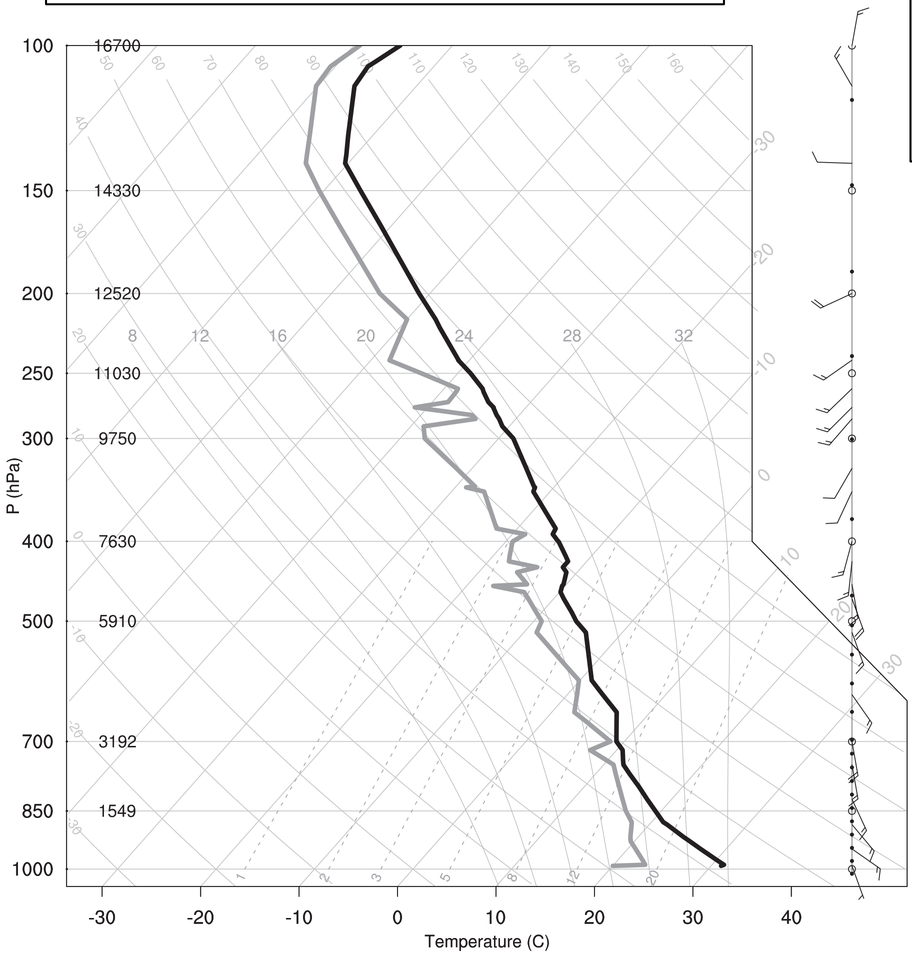


500-mb height anomaly

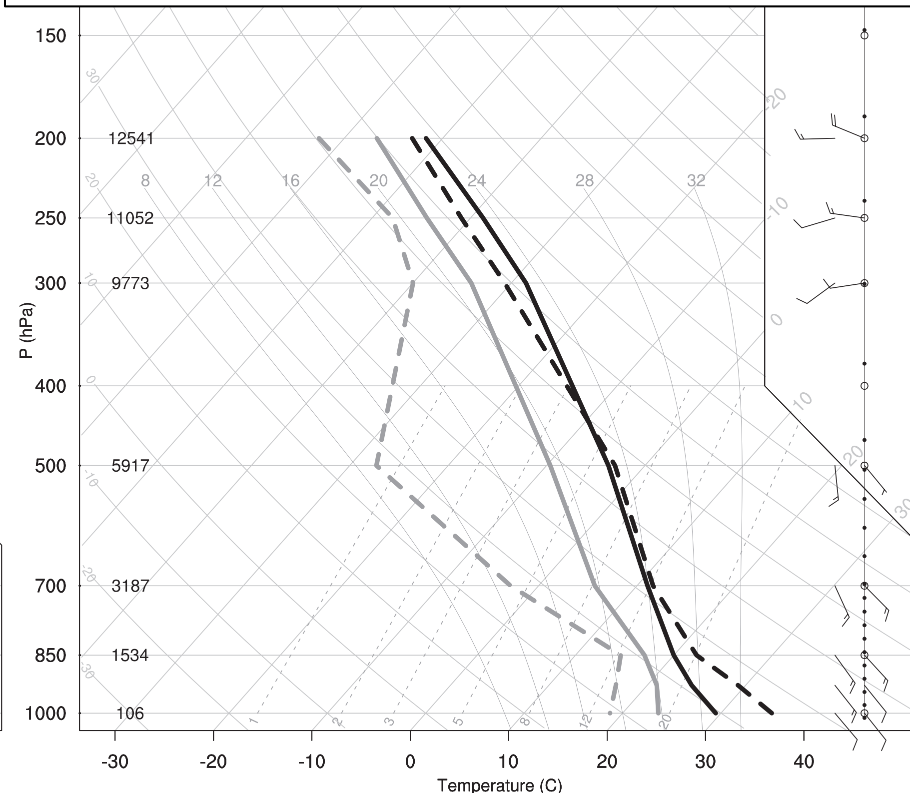


Predecessor Rain Events (PREs)

Observed FWD sounding,
00 UTC 18 Aug 2007

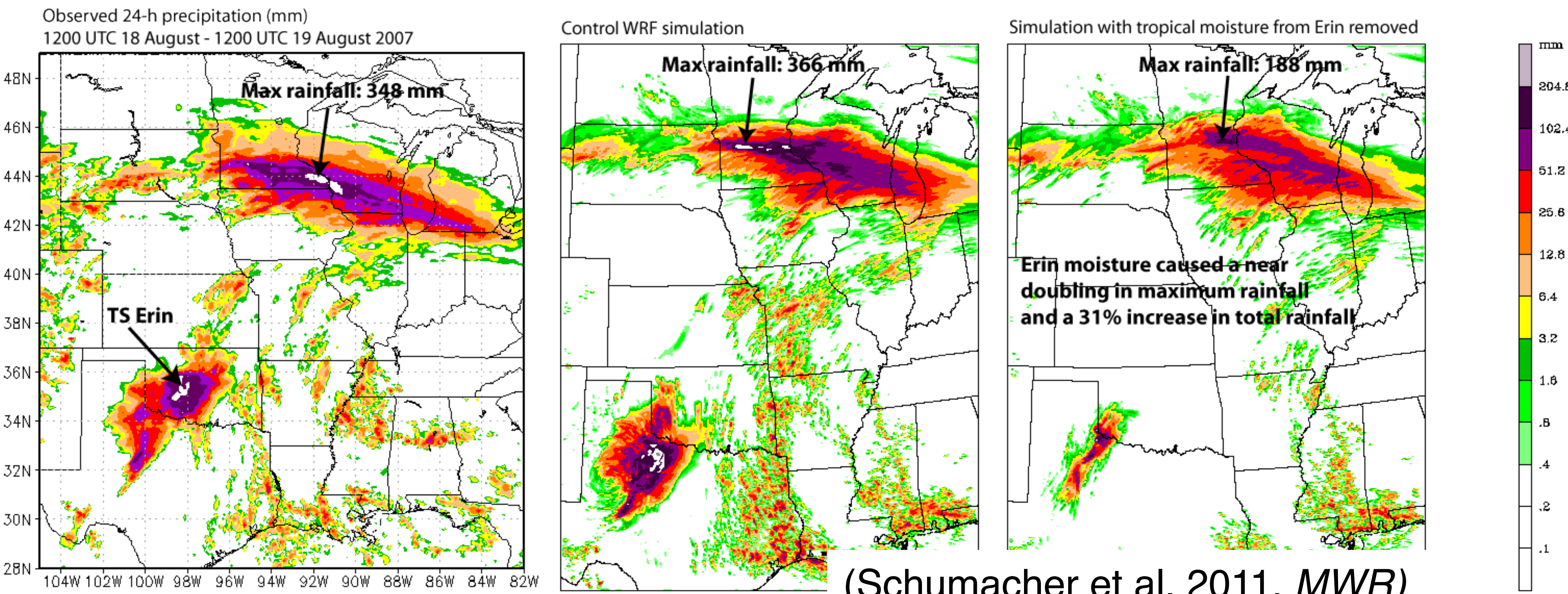


Solid: 40 ECMWF members with correct Erin track (median PW 55 mm)
Dashed: 47 ECMWF members with Erin dissipated or turned south (median PW 38 mm)



Schumacher et al. (2012, MWR)

Predecessor Rain Events (PREs)



(Schumacher et al. 2011, *MWR)*

- Reducing the atmospheric moisture around TC Erin in Oklahoma and Texas has a substantial influence on the rainfall in the MCS that occurred in Minnesota and Wisconsin
- In this sensitivity simulation, the maximum rainfall amount was reduced by ~50%, and the total rainfall by ~30%
- Thus, the tropical moisture from Erin took a notable heavy rain event and turned it into an unprecedented event with major impacts

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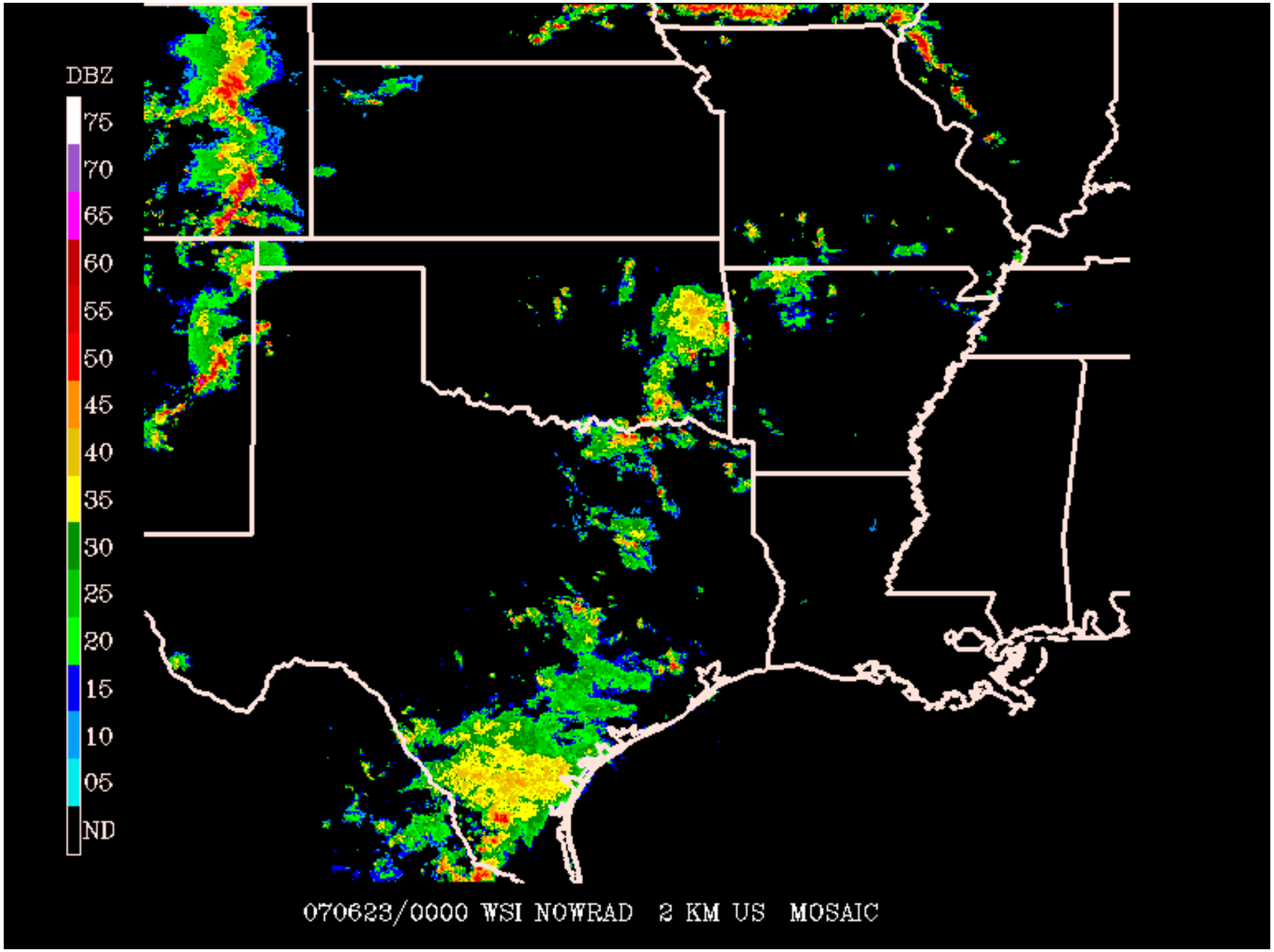
- Predecessor rain events (e.g., Galarneau et al. 2010; Schumacher and Galarneau 2012; Moore et al. 2012, MWR)
  - 2 of 22 events (ahead of TS Grace, 2003; and TS Erin, 2007)
- And this…

June 2007 event

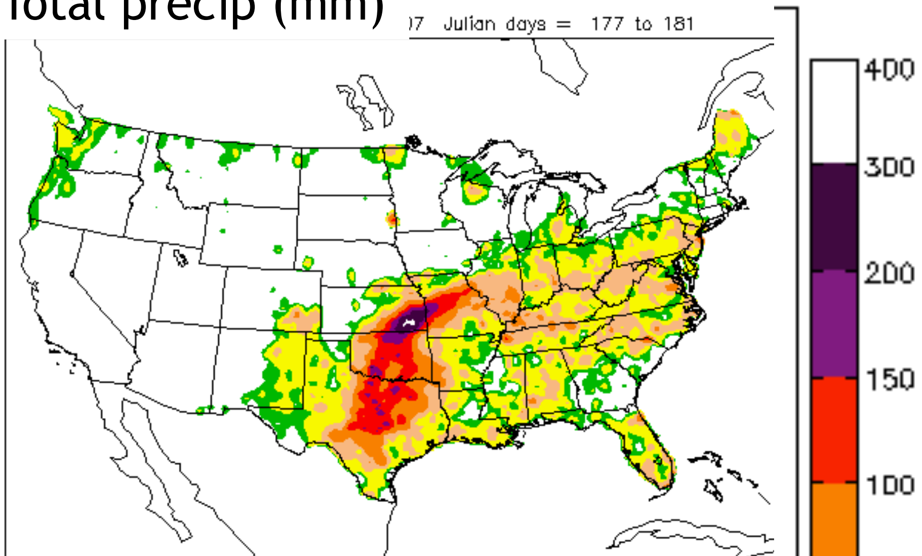
- MCV developed and grew upscale; latent heat release from deep convection maintained vortex, which then caused the initiation of further convection, and so on



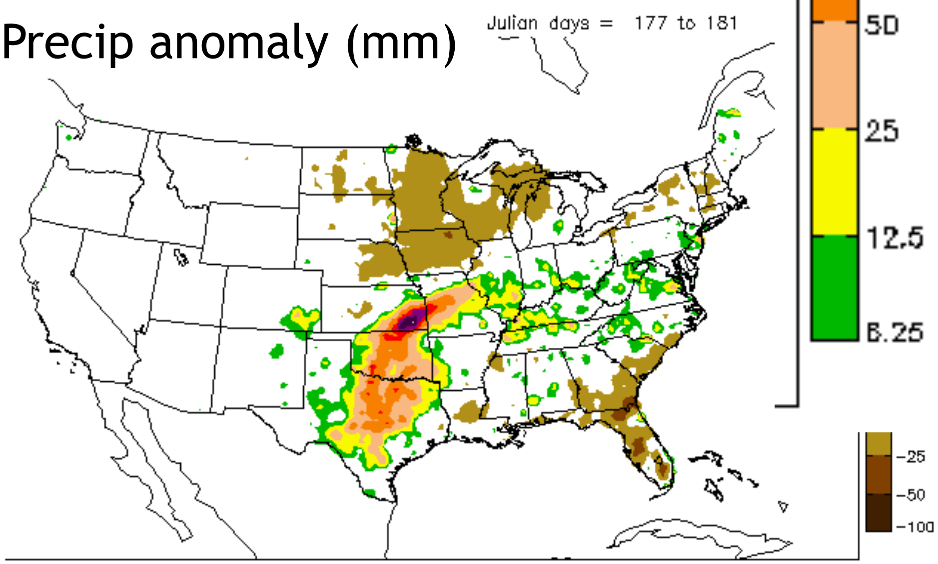
Radar loop

25-30 June 2007

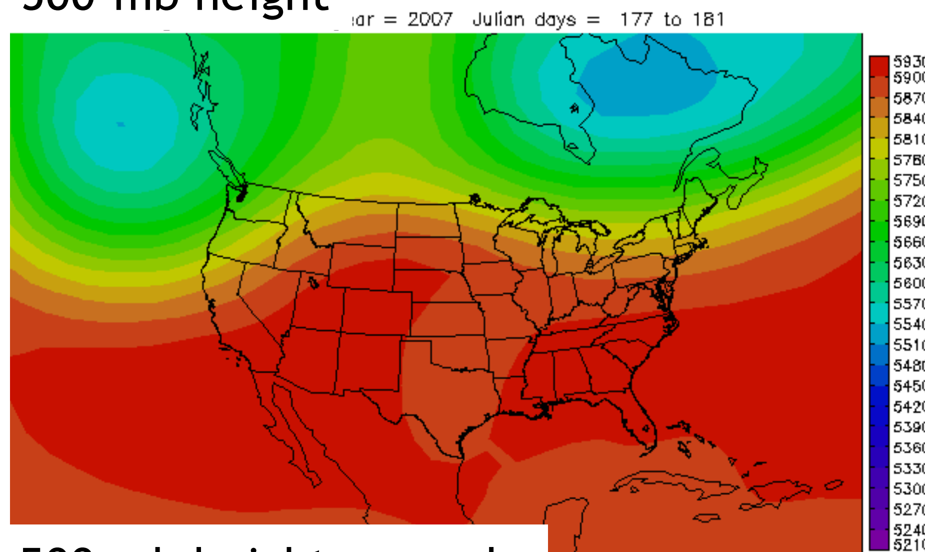
Total precip (mm)



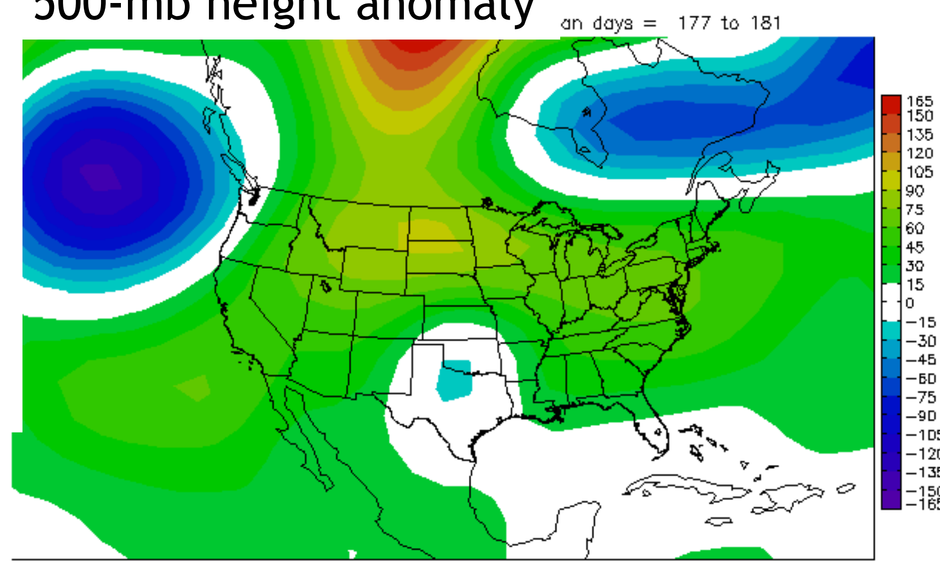
Precip anomaly (mm)



500-mb height



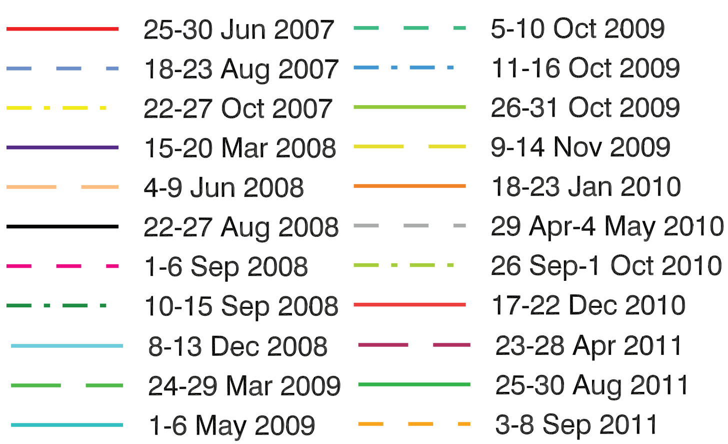
500-mb height anomaly



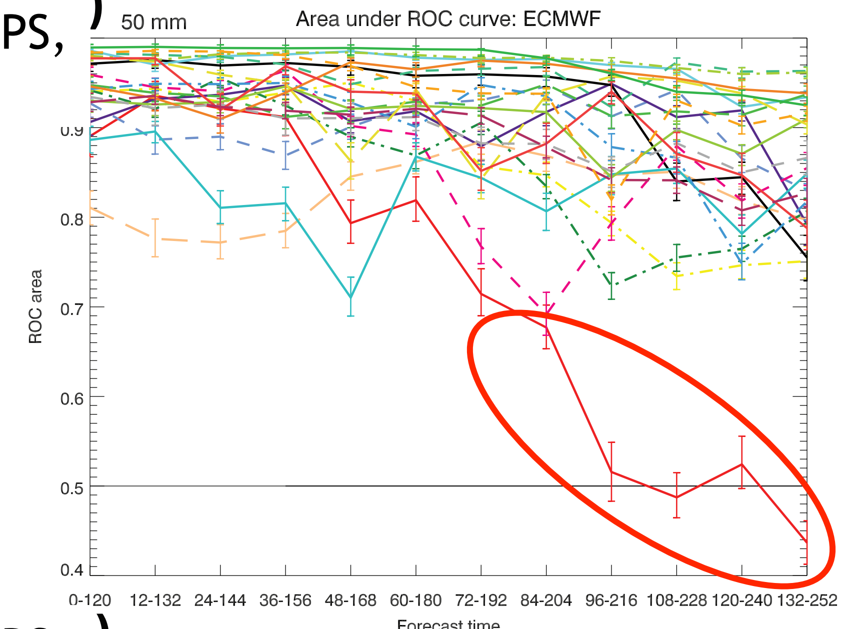
How far in advance do global ensemble prediction systems provide skillful forecasts of these widespread rain events?

Forecast skill for widespread heavy rain

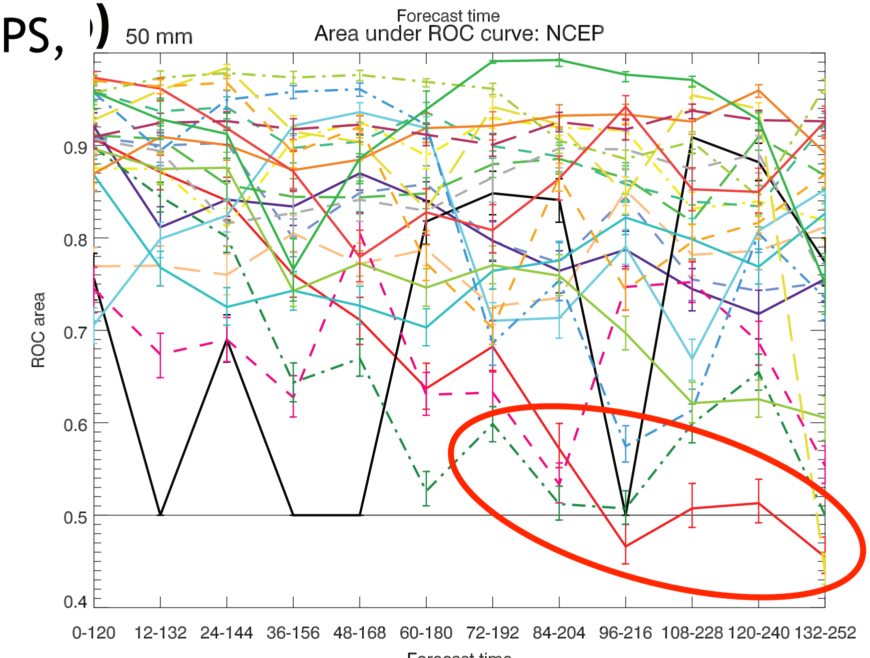
- Evaluated ECMWF and NCEP ensemble forecasts for widespread rain events over full years 2007-2011
- Area under the ROC curve shown here (0.5 = no skill, 1.0 = perfect)
- Event from June 2007 had the poorest forecasts at long lead times in all models



ECMWF EPS, 50 mm

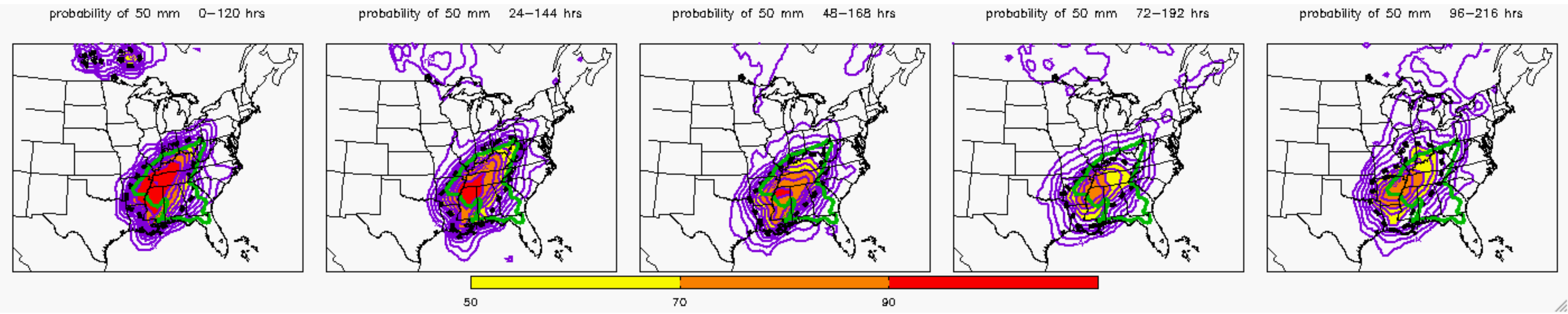


NCEP EPS, 50 mm



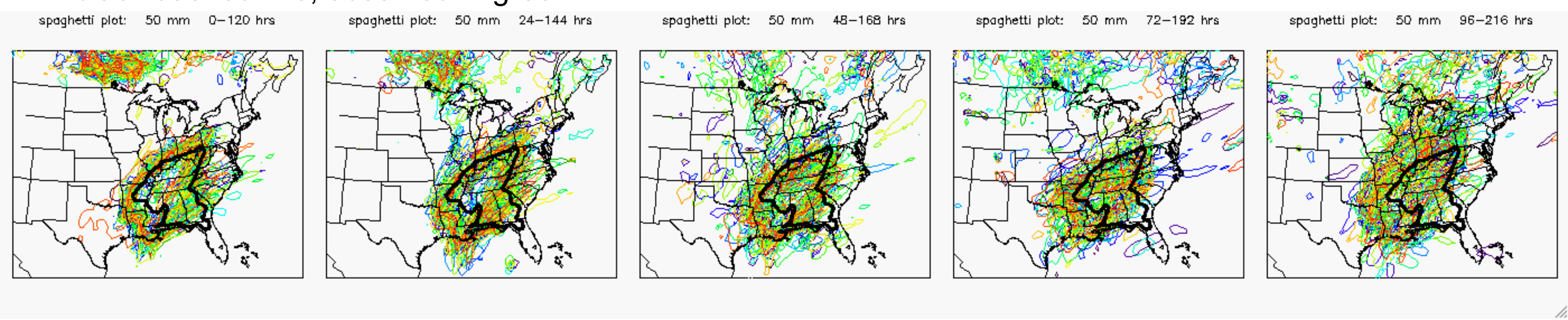
May 2010 (Nashville floods)

- Confidence decreases and spread increases with increasing lead time (as expected)
- Location of highest probabilities is excellent out to 96-to-216 hr forecast



Increasing lead time →

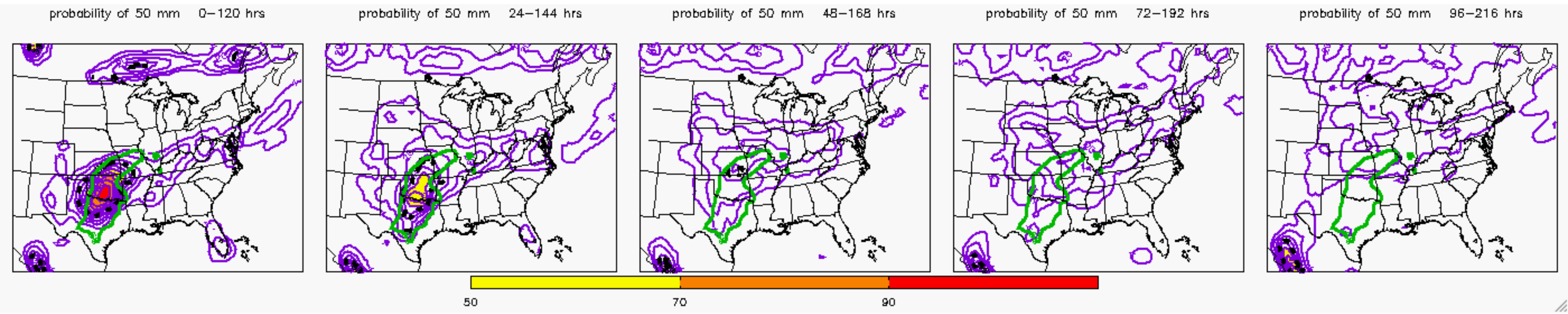
Ensemble probabilities of 50 mm in 120 hr in purple (every 10% with >50% color shaded), ensemble mean in black dashed line, observed in green



“Spaghetti” plot of 50 mm in 120 hr, observed in thick black

June 2007 (Southern Plains)

- Ensemble forecast is very good at shorter lead times, but at longer lead times, no indication of heavy rain in most of the area that received it, and a possibility of heavy rain in places that got no rain at all!



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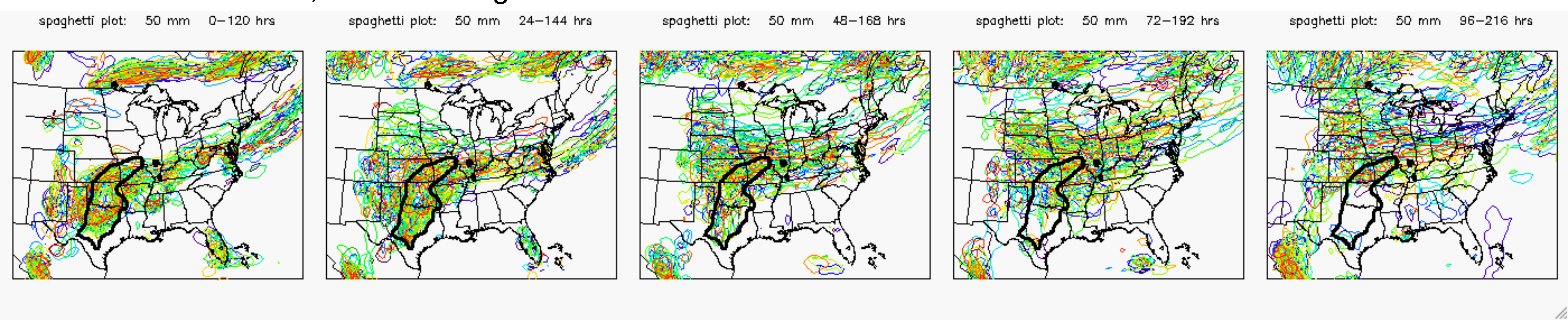
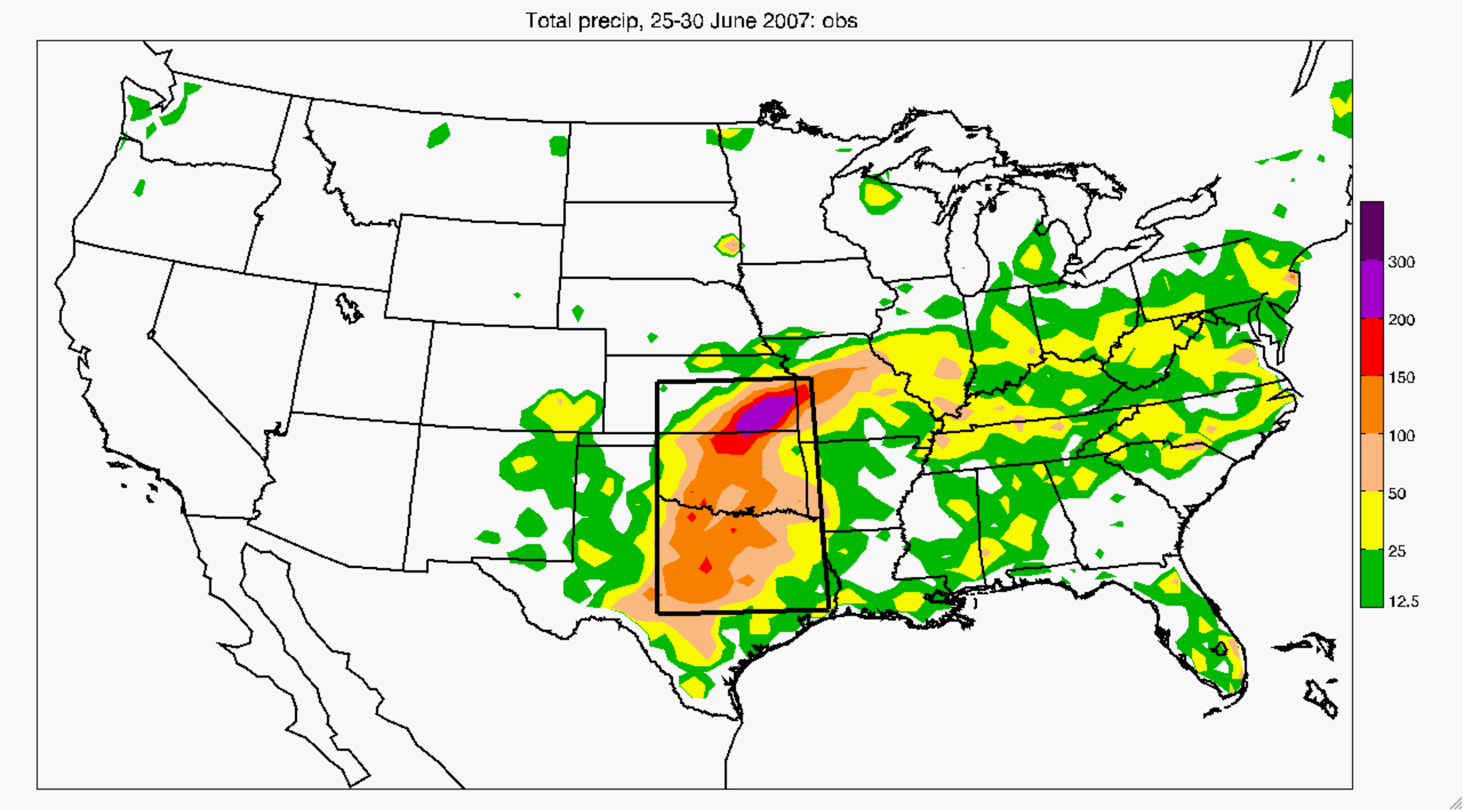


“Spaghetti” plot of 50 mm in 120 hr, observed in thick black

25-30 June 2007 rain event

Observed 5-day precip (resampled to the ensemble forecast grid)

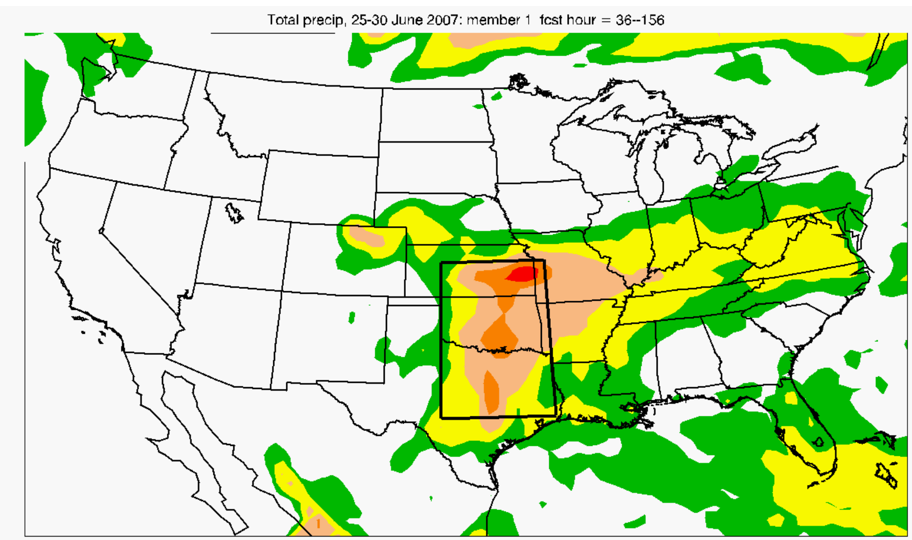


ECMWF ensemble, init 00Z/24 June

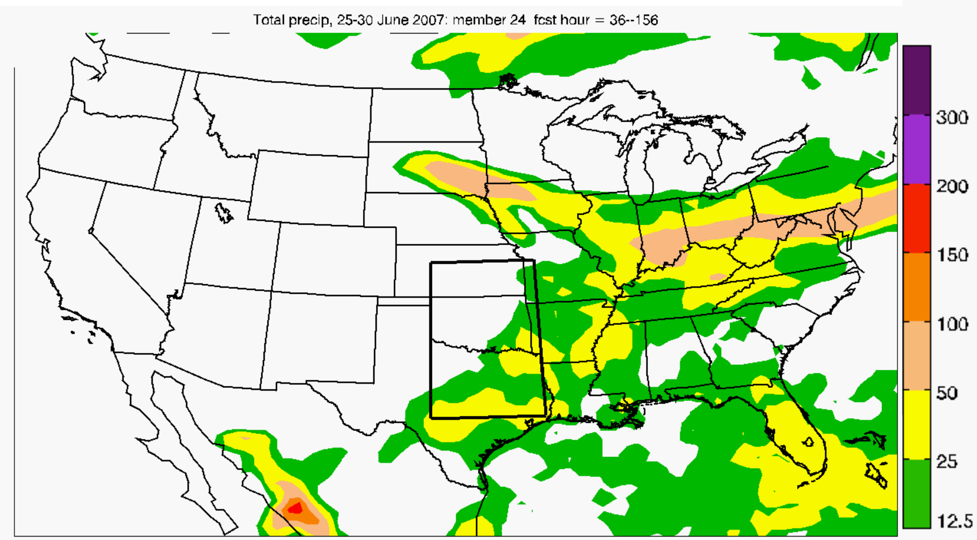
• This time chosen because it has good spread between good and bad forecasts of rainfall and the vortex

• All members underpredict the rainfall amounts, but several accurately capture the pattern

Best member: 36-156-hr precip



Worst member



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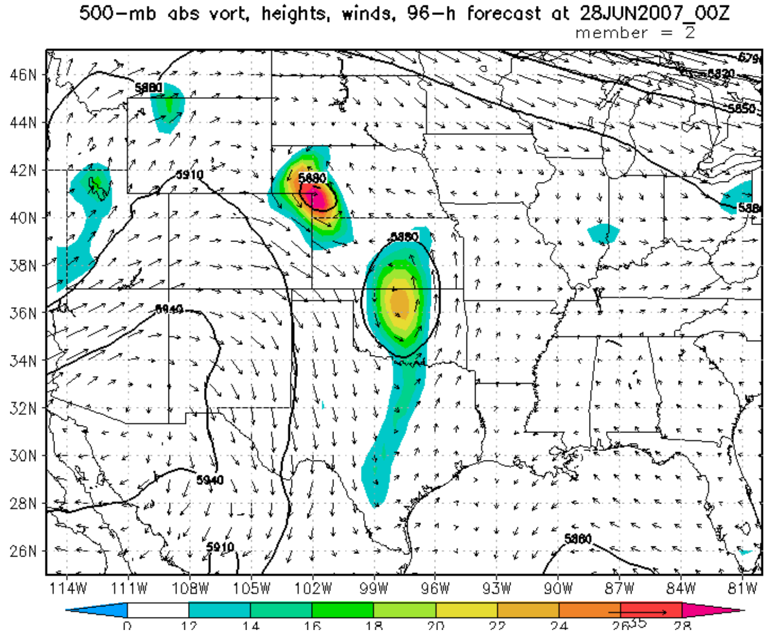

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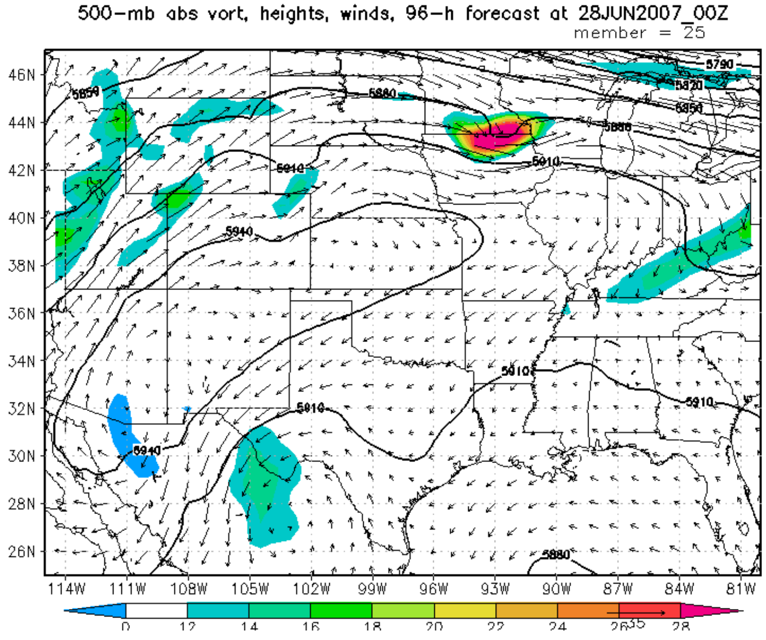


96-hr forecasts of 500-mb heights and vorticity (valid 00Z/28 June)

Analysis method

- What determines whether the warm-core vortex, and in turn the heavy precipitation (and in turn the warm-core vortex, and so on), develops and remains nearly stationary in the Plains?

- Use correlations, covariances, and developing vs. non-developing ensemble members to understand these issues

- Correlations and covariances are calculated with respect to the area-averaged, 36-156-h forecast precip over OK/KS/TX

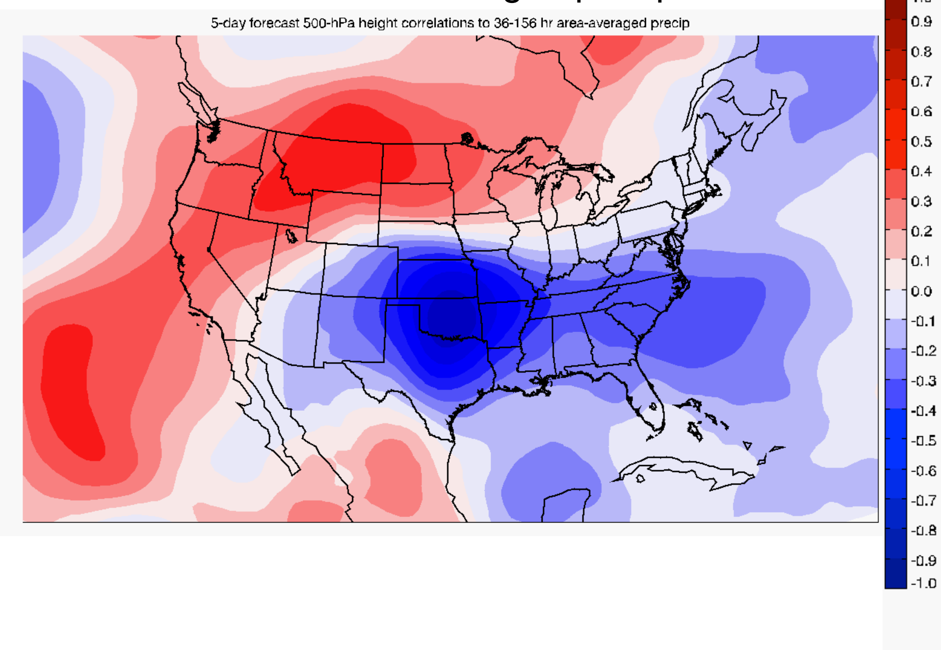
- Covariances divided by standard deviation of precip amount (as in Hakim and Torn 2008) so they are in physical units

- Starting analysis at 36 h into the forecast, assuming that “memory” of the initial perturbations has been reduced by this time

5-day-average correlations and covariances

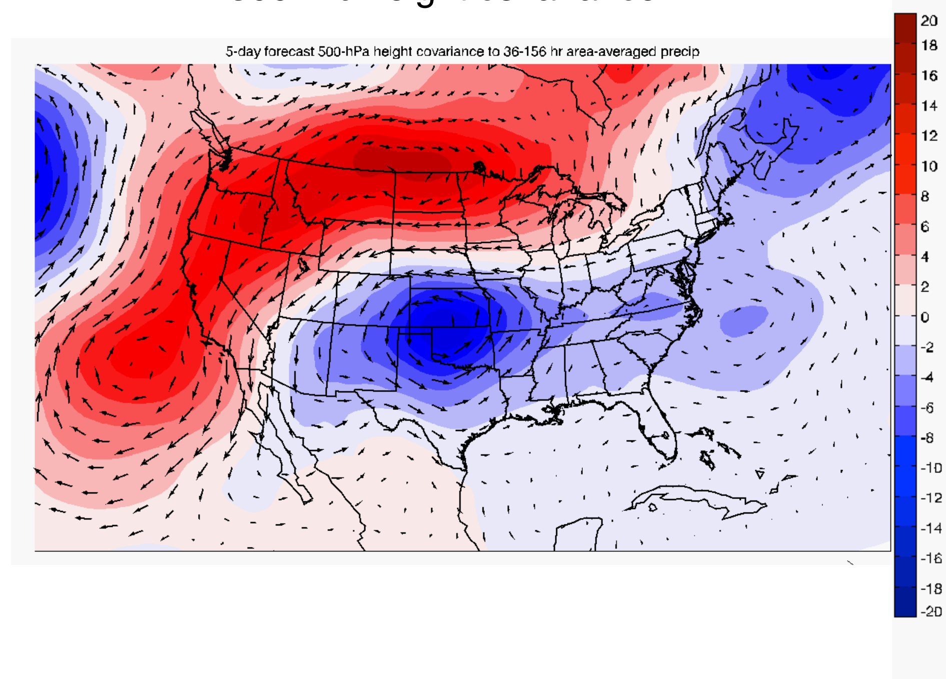
Before analyzing precursors, we should check out the overall behavior of the ensemble during this 5-day period

Correlation of 36-156-hr forecast 500-hPa height to 36—156-hr area-averaged precip



500-mb height covariance

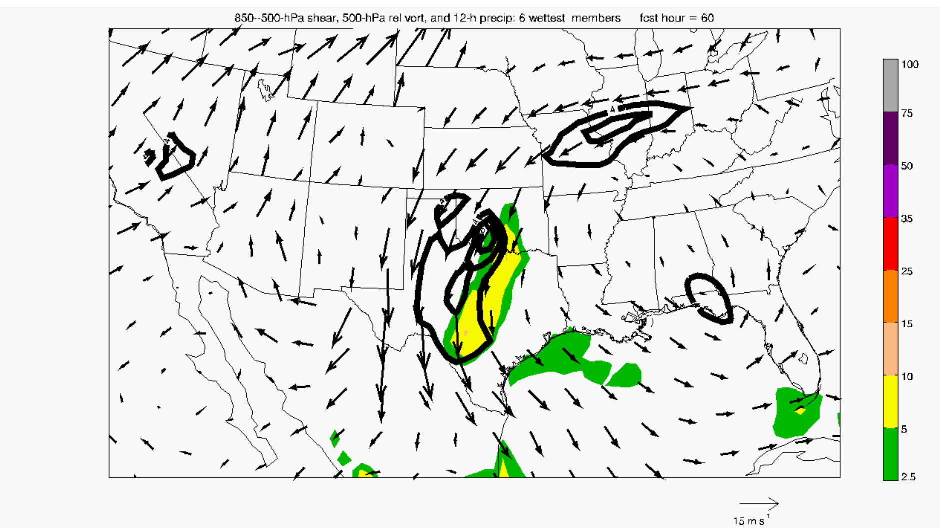
m



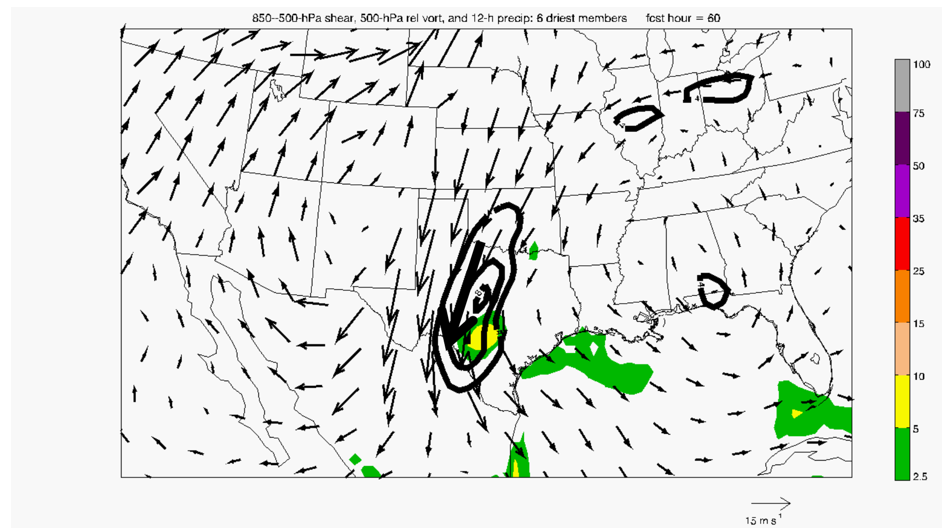
Comparison between wet and dry composites

- Between t=48 and 60 h, dry composite, with stronger shear, has precipitation only downshear, which causes the vortex to move farther south
- In wet composite, precipitation occurs closer to center of developing vortex: slower movement

850—500-hPa shear, 500-mb rel vort, 12-h precip: composite of 6 wettest members

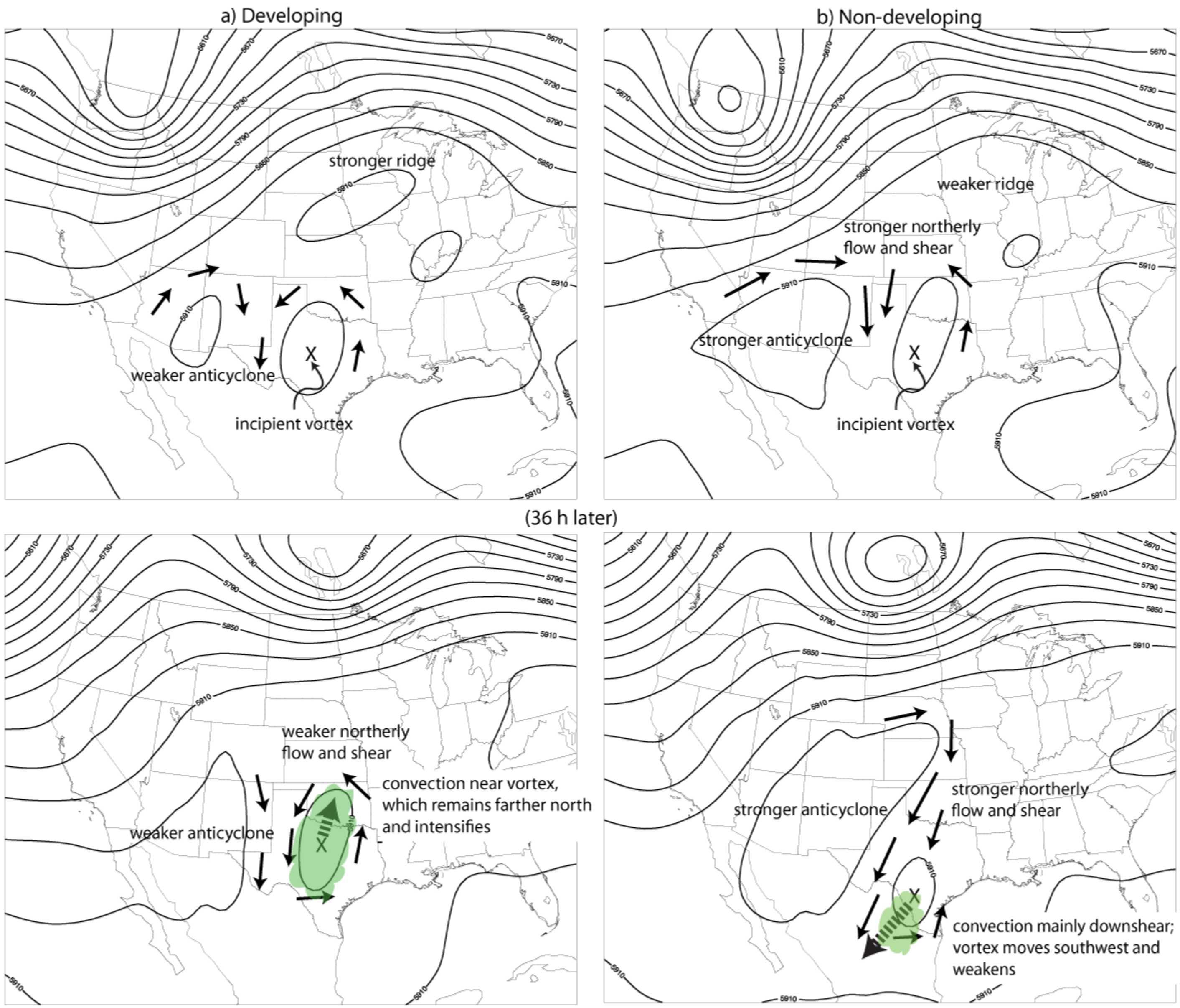


850—500-hPa shear, 500-mb rel vort, 12-h precip: composite of 6 driest members



Summary

Schumacher (2011, MWR)

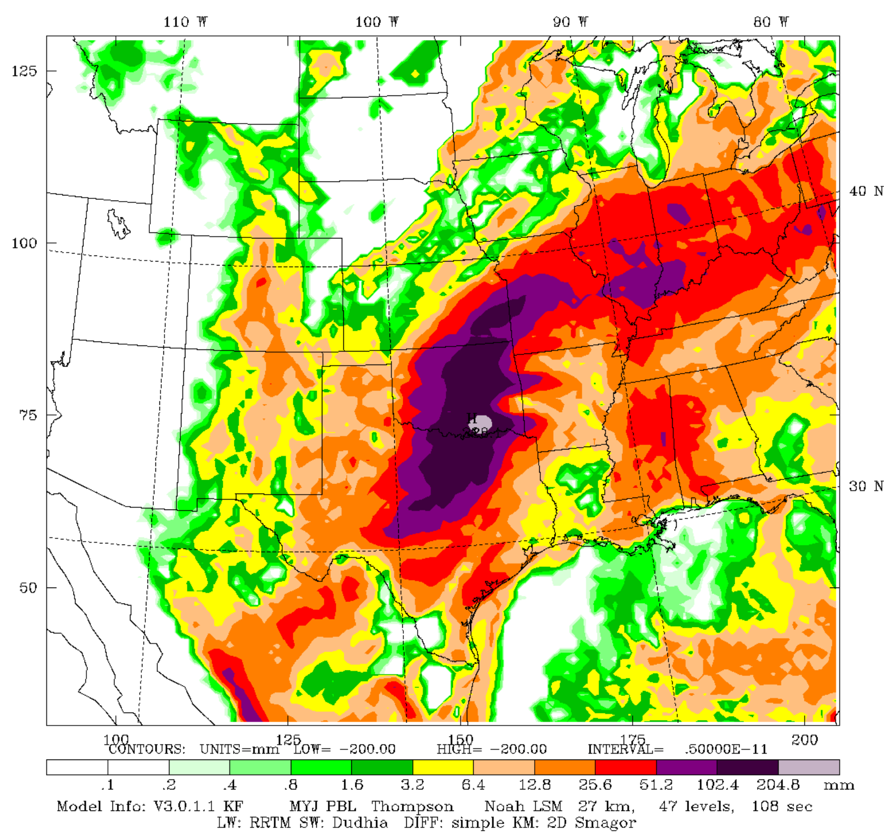


Summary and conclusions

- Common producers of widespread heavy precipitation in the summer are tropical cyclones and anomalously deep and/or persistent troughs
- “Predecessor rain events” (PREs) – where moisture is transported into midlatitudes ahead of recurving tropical cyclones – can also produce widespread summer rainfall
- A different mechanism---a long-lived mesoscale convective vortex---led to heavy rainfall in June 2007
- Global ensemble forecasts are generally quite skillful for widespread rain events, even in the 5-10-day range, but the June 2007 case was an exception
- Ensemble-based analysis of this case indicates that a slightly weaker anticyclone over the southwest US was favorable for the development of a stationary warm-core vortex over the Plains

WRF simulation initialized 00Z/26 June

- Initialized 48-hr later than the ECMWF ensemble we were just looking at
- Initialized with GFS initial/boundary conditions
- 27 km grid spacing (for now)
- Produces good forecast of precipitation pattern



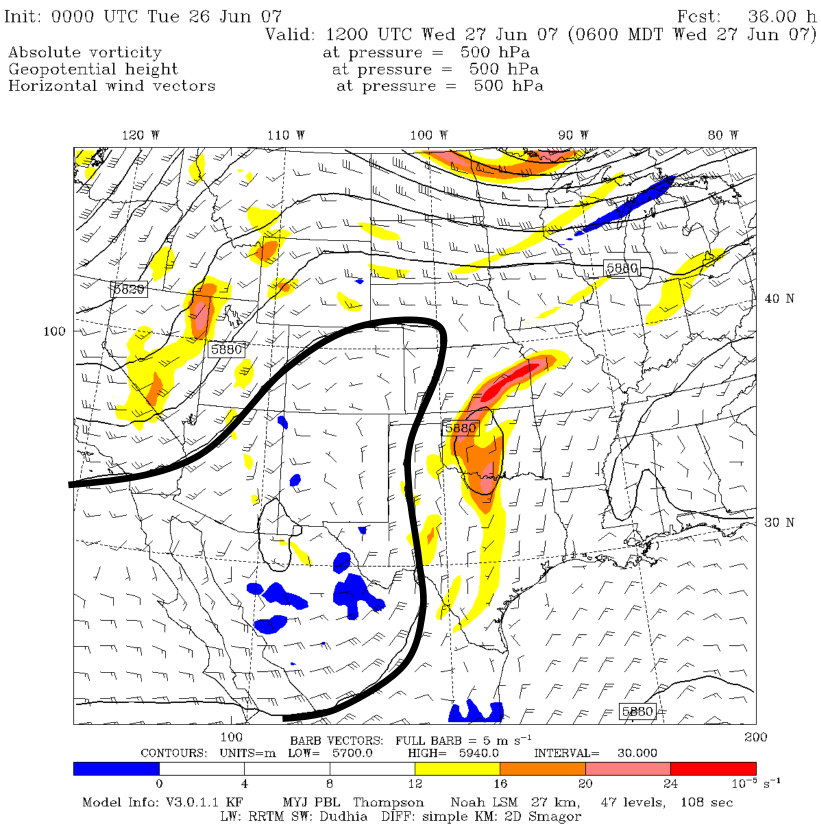
72-hr total precip ending 00Z/29 June

Role of convection

- Compare this WRF run with an identical run except latent heating/cooling is turned off (similar to Stensrud 1996)
- The vortex weakens by about t=36 in the no-latent run; intensifies in the control
- Note that in the no-latent run, the midlevel anticyclone has built northeastward and is stronger, leading to stronger northerlies in that area

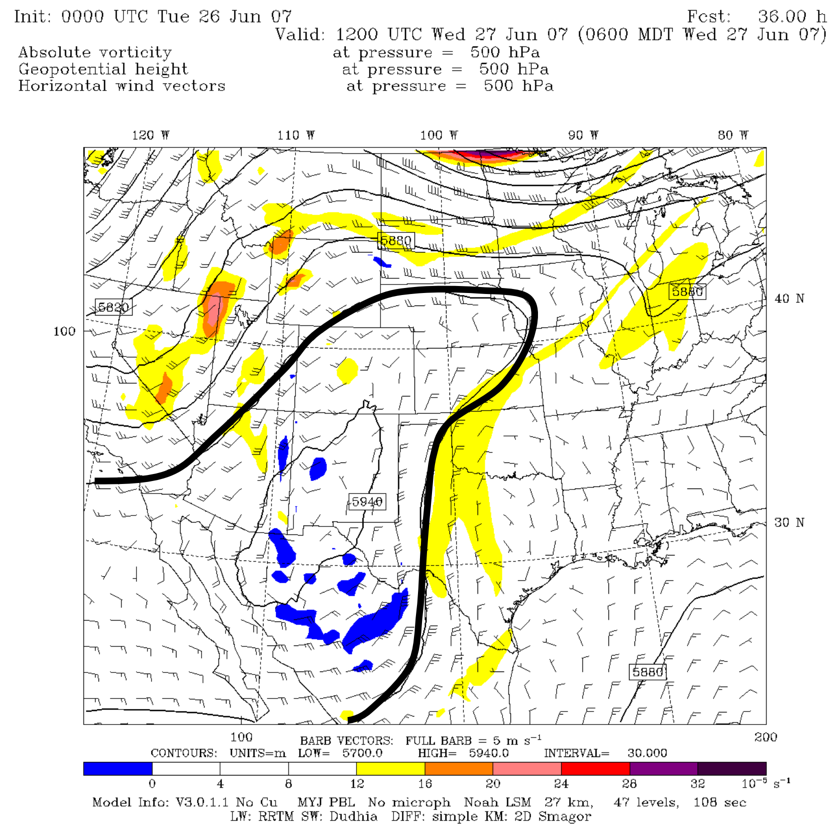
500-mb heights and vorticity

Control run, t=36 h



500-mb heights and vorticity

NOLATENT run, t=36 h

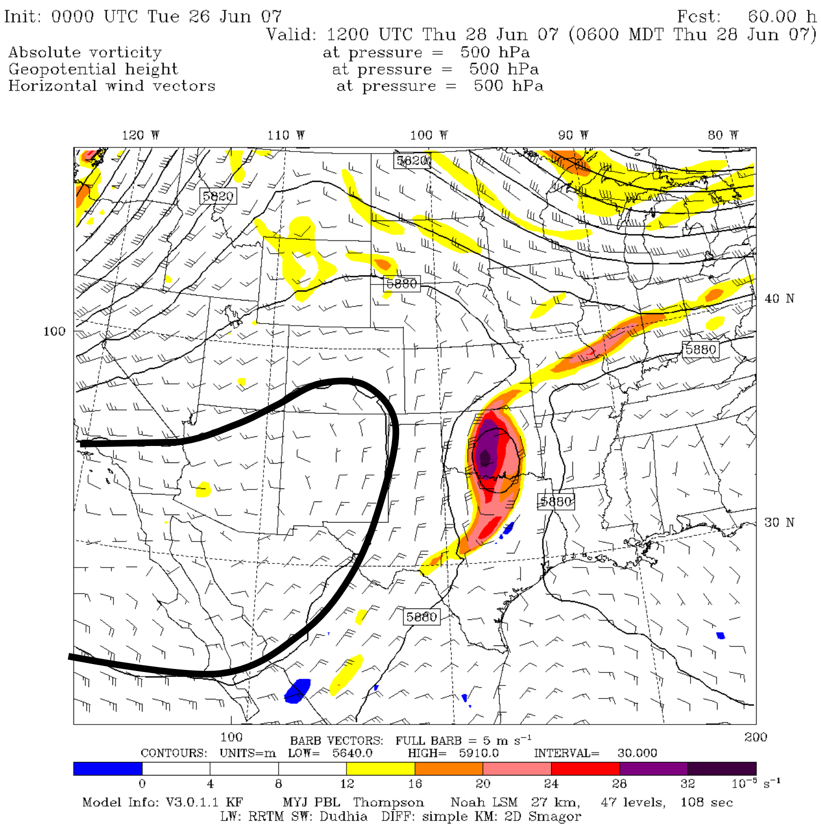


Role of convection

- This is even more pronounced by 24 hours later
- Compare the 5910 height contour (the highest value seen here) – on the right, it has made it into Nebraska, on the left it is still confined to the southwest

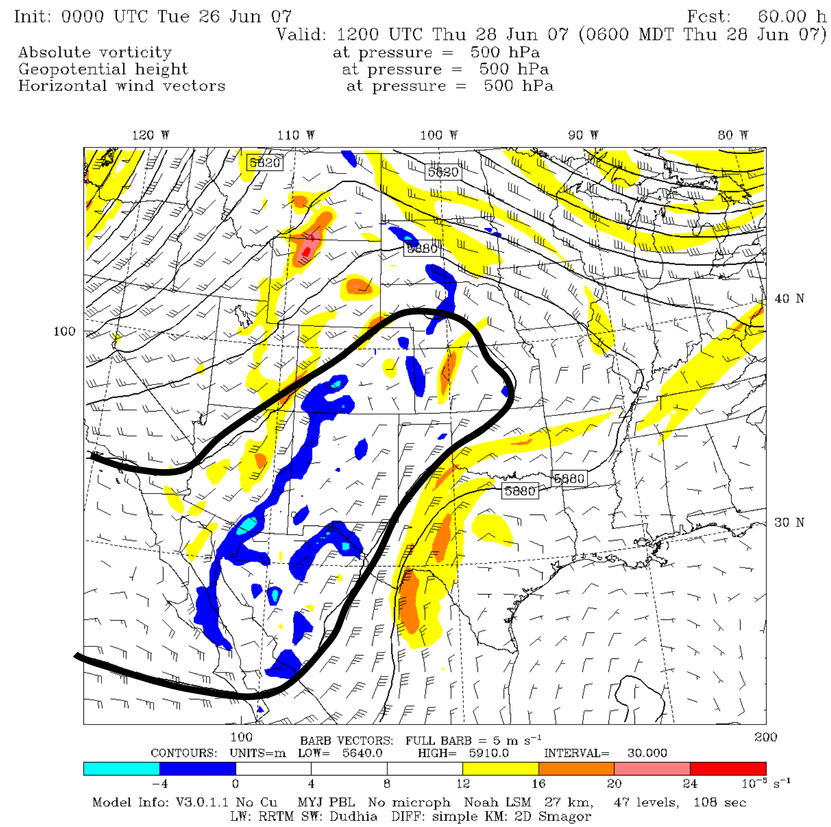
500-mb heights and vorticity

Control run, t=60 h



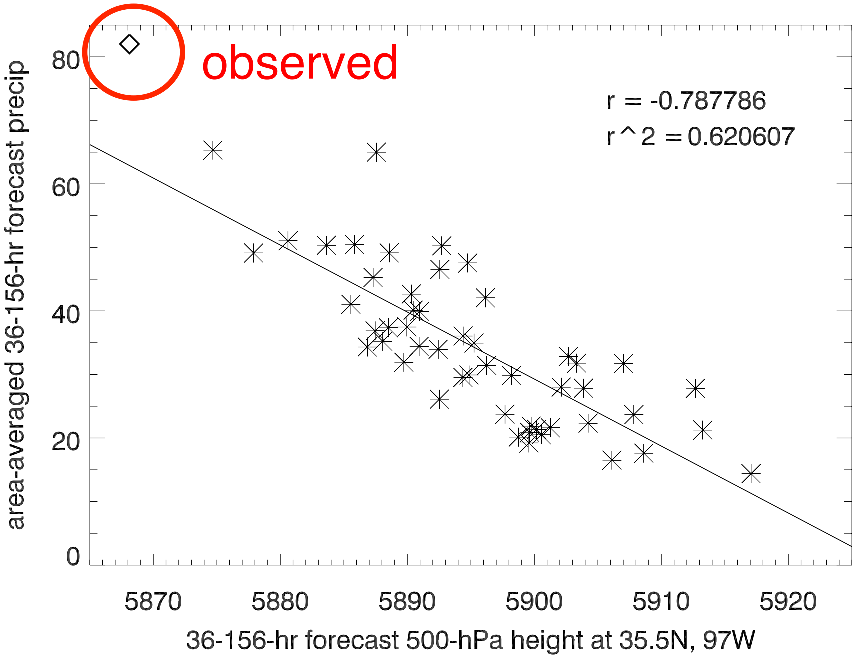
500-mb heights and vorticity

NOLATENT run, t=60 h



5-day-average correlations and covariances

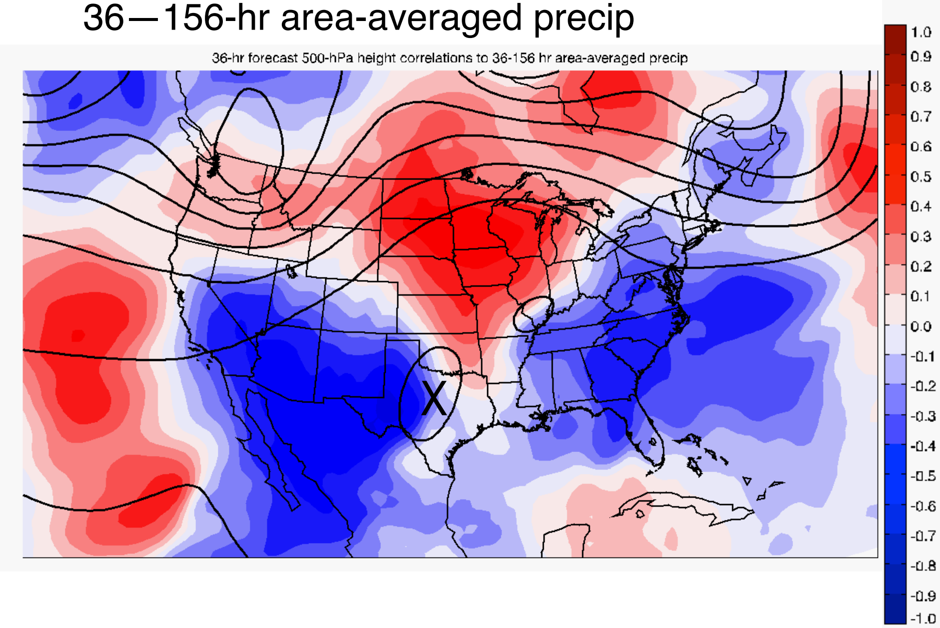
- In general, the members with lower heights (i.e., a vortex) have more rainfall
- All members underforecast the strength of the vortex and the amount of rainfall



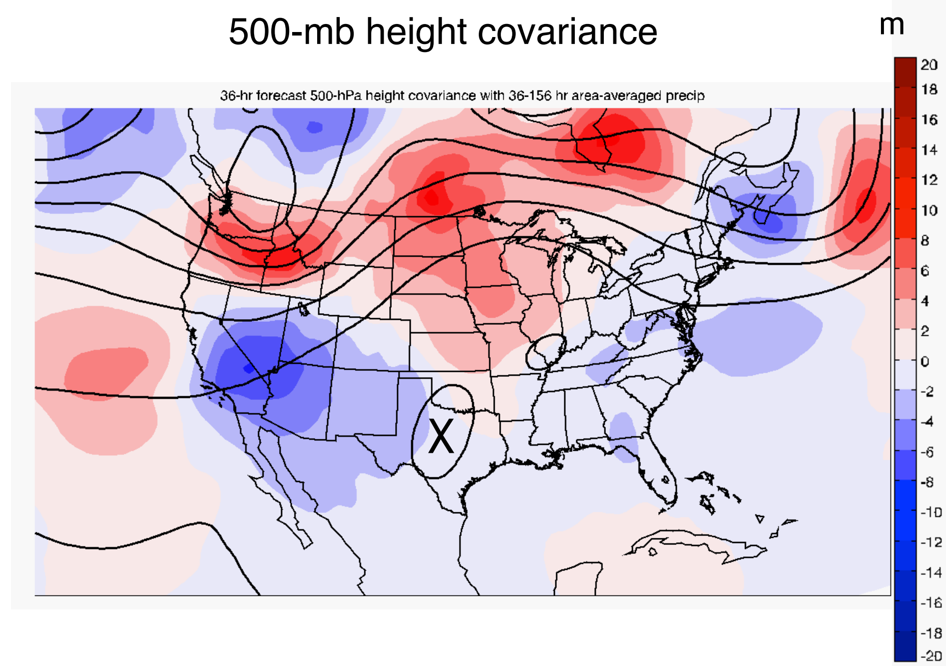
Correlations and covariances at t=36 h

- Relationship between earlier upper-level heights and later rainfall
- Apparently, lower heights in the southwest, and higher heights in the upper Midwest, are favorable for the vortex to develop

Correlation of 36-hr forecast 500-hPa height to 36—156-hr area-averaged precip



500-mb height covariance

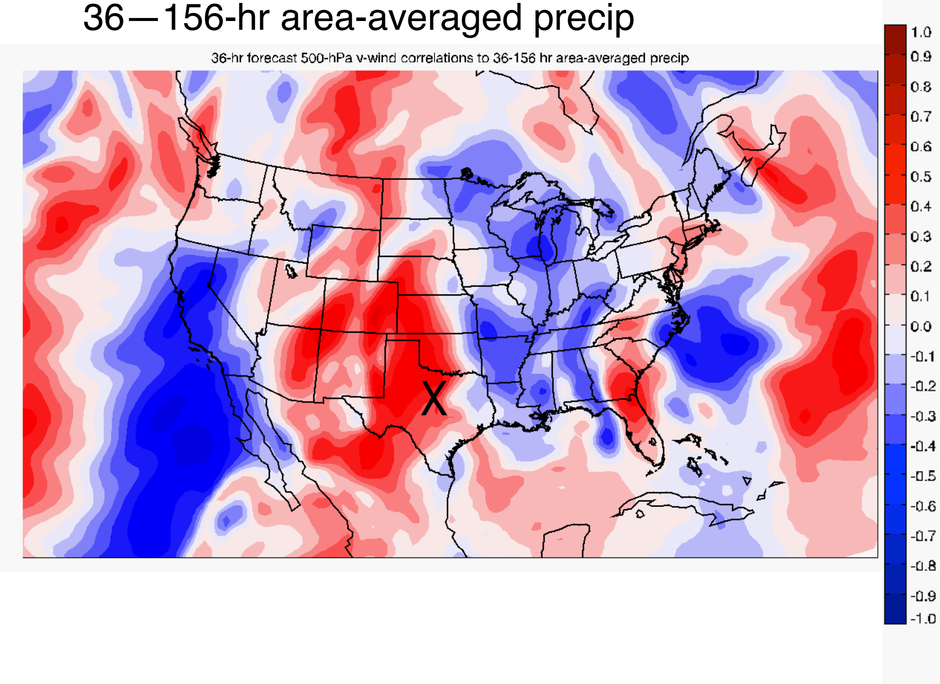


Black contours = ensemble mean height field
X = incipient vortex location in ensemble mean

Correlations and covariances at t=36 h

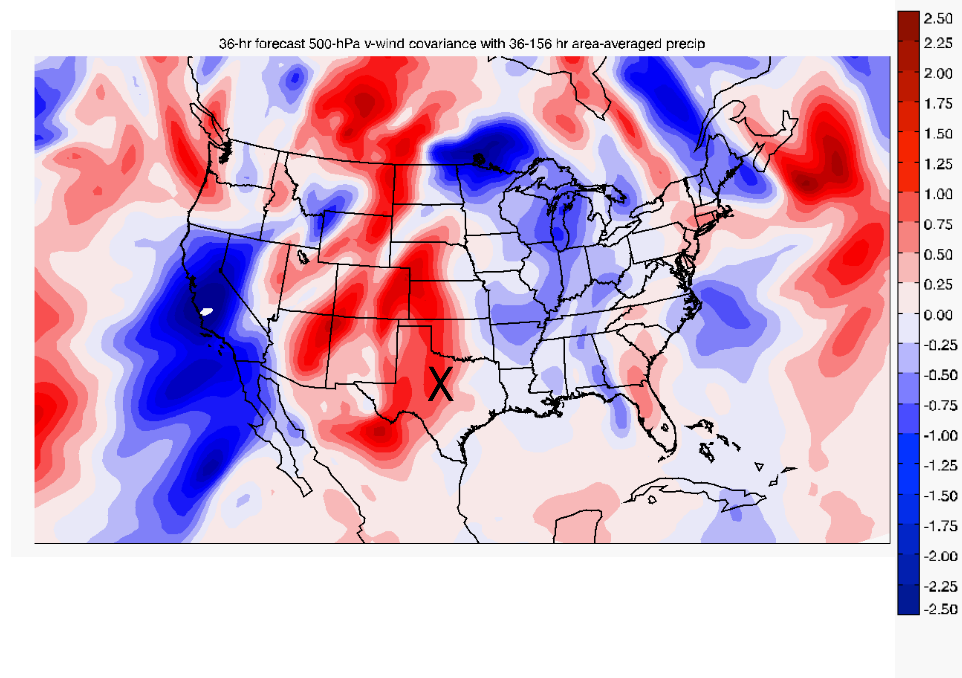
- Strong correlation/covariance between 500-mb v-wind strength over western Plains and later development (weaker northerlies associated with more precipitation)

Correlation of 36-hr forecast 500-hPa v-wind to 36—156-hr area-averaged precip



500-mb v-wind covariance

m/s

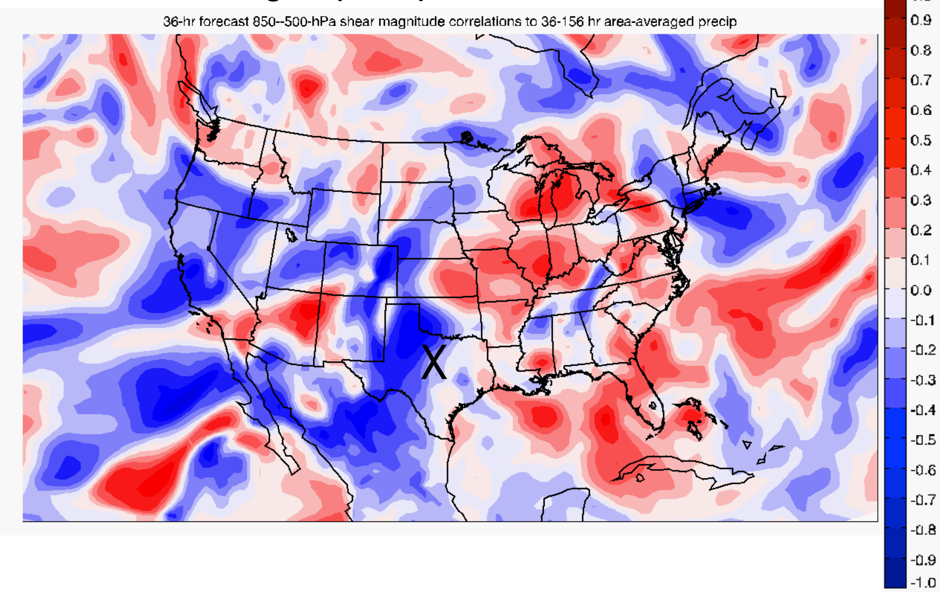


X = incipient vortex location in ensemble mean

Correlations and covariances at t=36 h

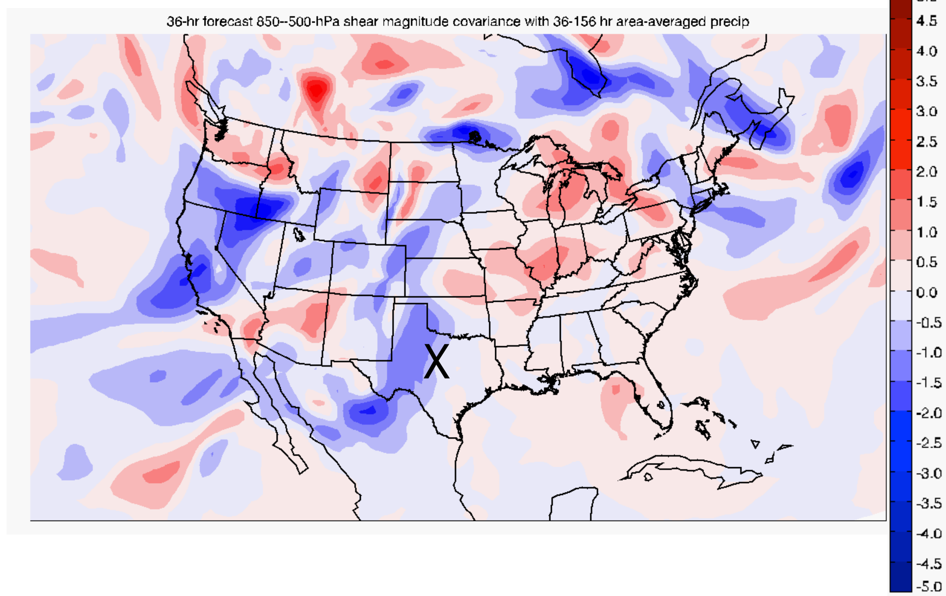
- An associated negative relationship with 850—500-hPa shear magnitude

Correlation of 36-hr forecast shear to 36—156-hr area-averaged precip



850--500-mb shear covariance

m/s

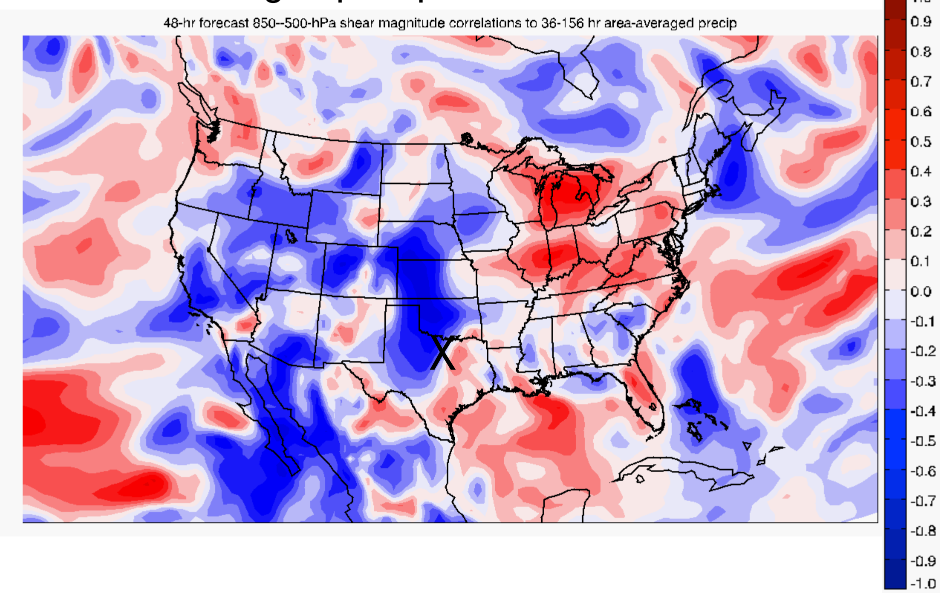


X = incipient vortex location in ensemble mean

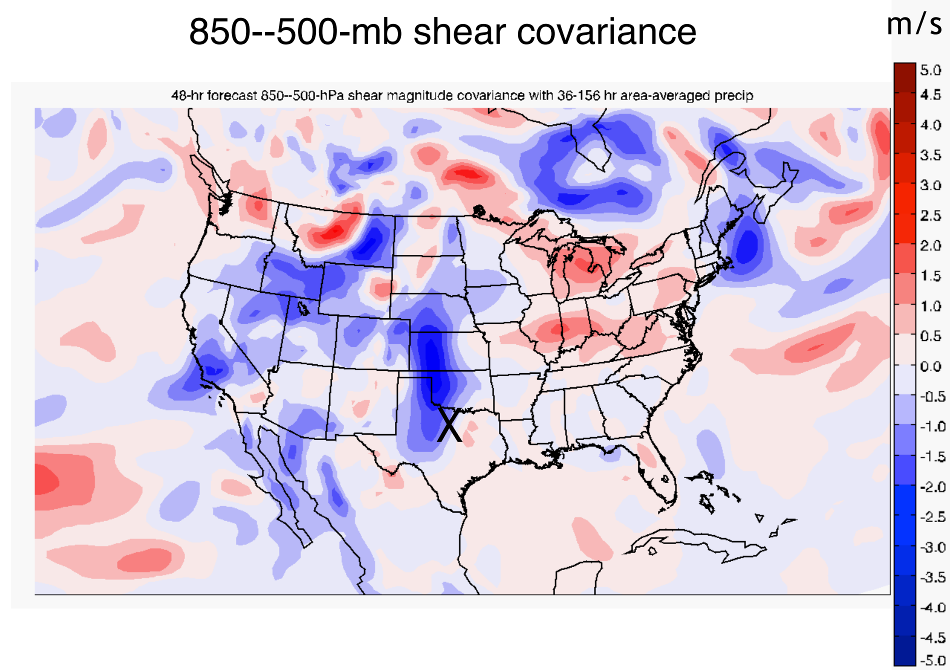
Correlations and covariances at t=48 h

- This relationship gets stronger by t=48 hr

Correlation of 48-hr forecast shear to 36—156-hr area-averaged precip



850--500-mb shear covariance



X = incipient vortex location in ensemble mean

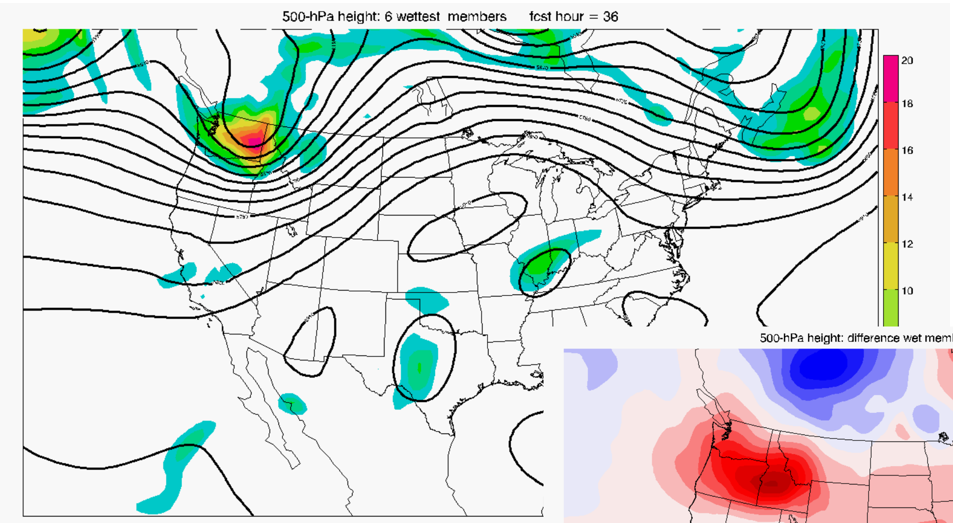
Wet vs. dry composites

- To better illustrate what is happening physically, create composite fields of the 6 wettest members and the 6 driest members (with respect to the area-averaged, 36-156-hr rainfall)
  - Other numbers of members show similar results

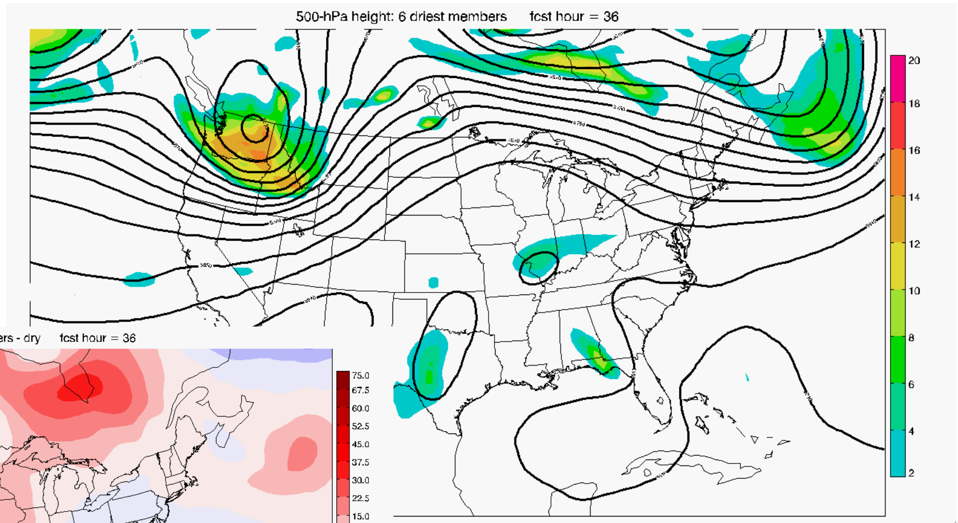
Comparison between wet and dry composites

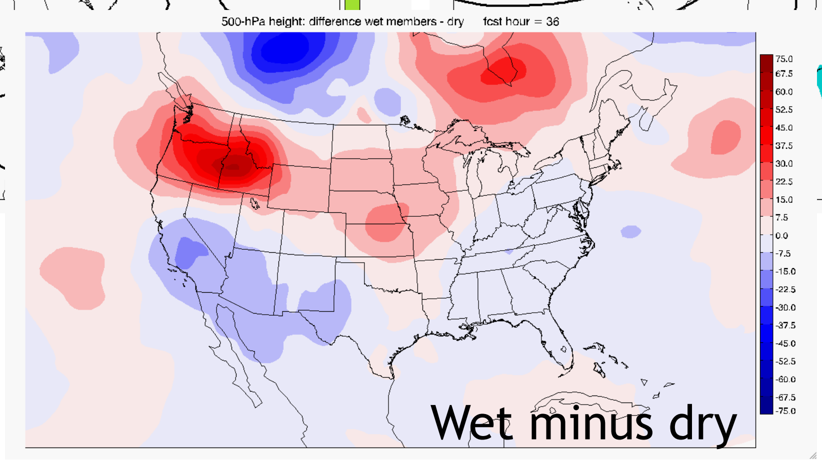
- At t=36, incipient vortex similar in both
- Anticyclone in southwest slightly stronger in dry members; ridge in Midwest stronger in wet members
  - These are consistent with the correlations/covariances

500-mb heights and vorticity: composite of 6 wettest members



500-mb heights and vorticity: composite of 6 driest members

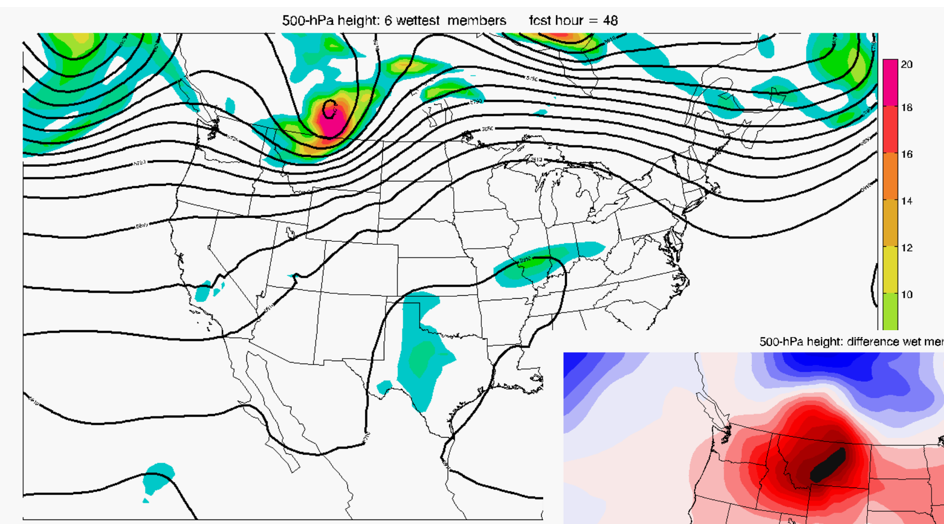




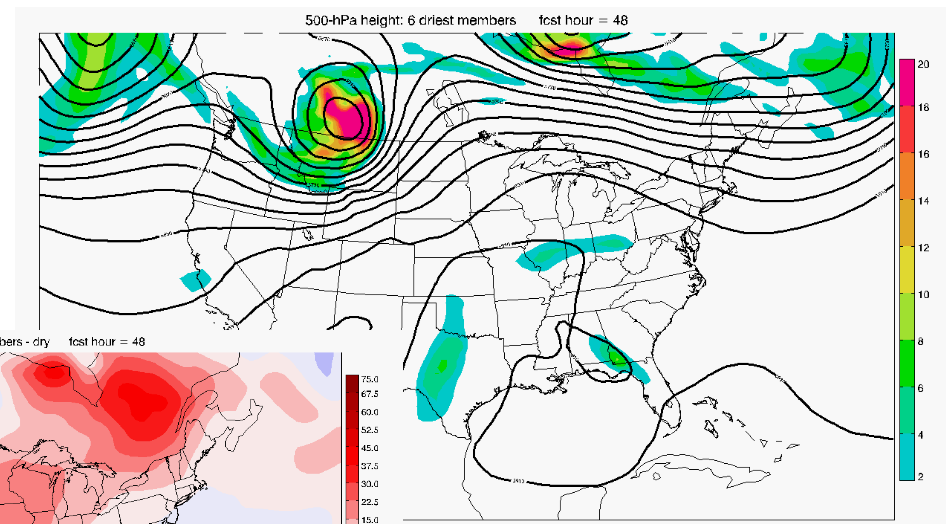
Comparison between wet and dry composites

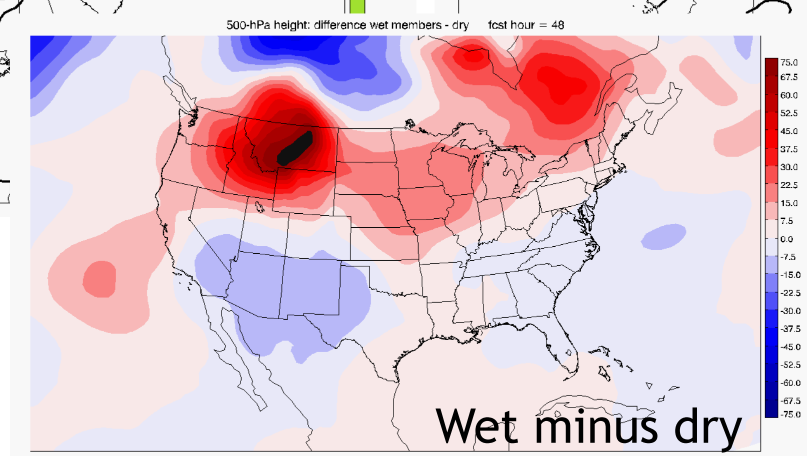
- At t=48, incipient vortex over TX still similar in both
- Stronger blocking ridge in the Midwest in wet runs deflects the trough over MT slightly northward compared with dry runs

500-mb heights and vorticity: composite of 6 wettest members



500-mb heights and vorticity: composite of 6 driest members

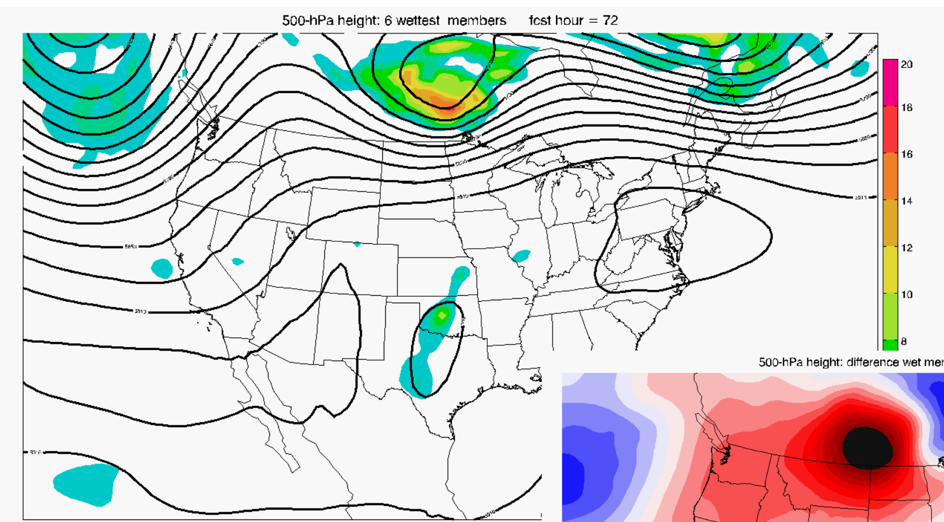




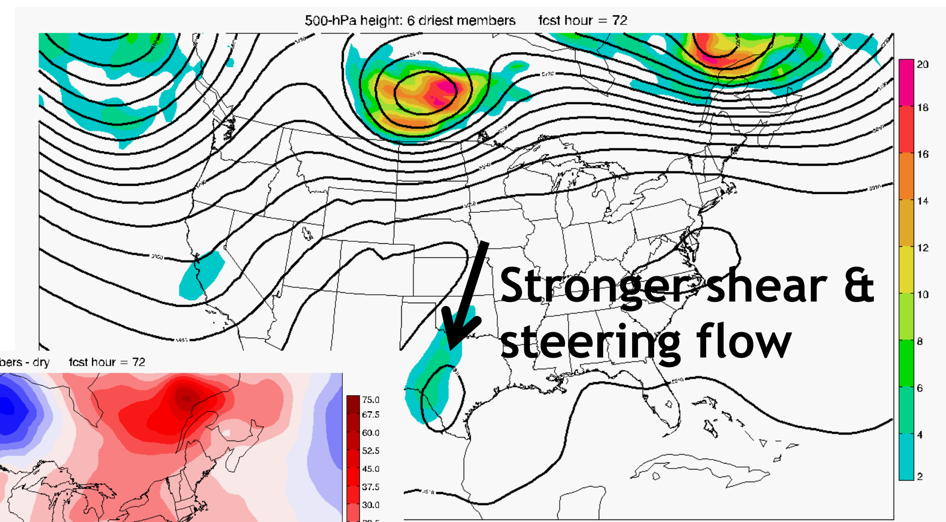
Comparison between wet and dry composites

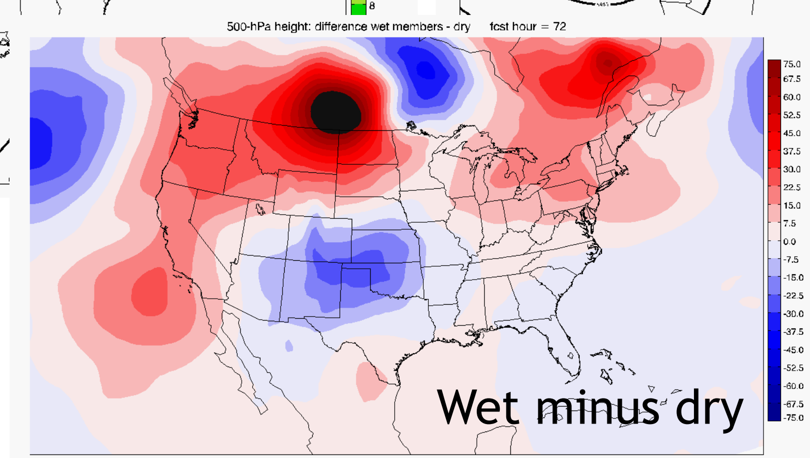
- By t=72 hrs, both have a closed height contour, but vortex is slightly farther north in wet runs
- Southwest anticyclone is stronger in the dry runs

500-mb heights and vorticity: composite of 6 wettest members



500-mb heights and vorticity: composite of 6 driest members

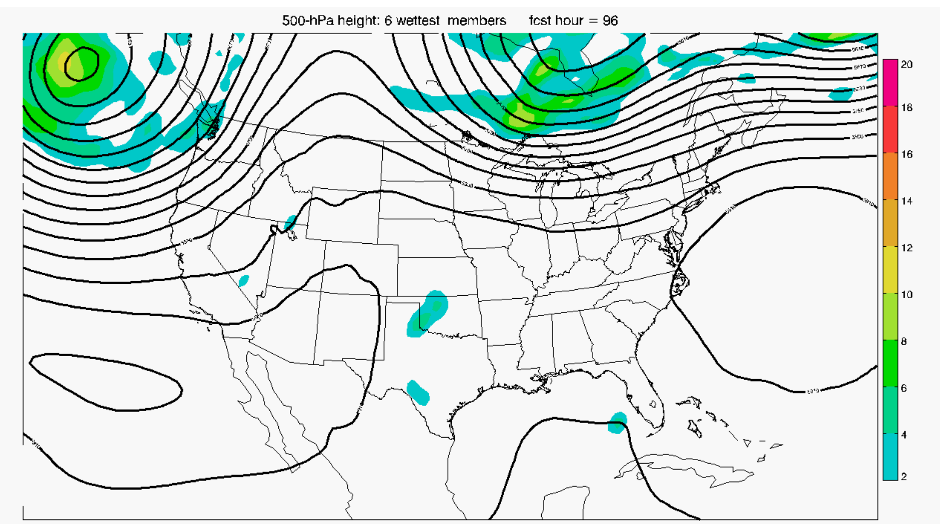




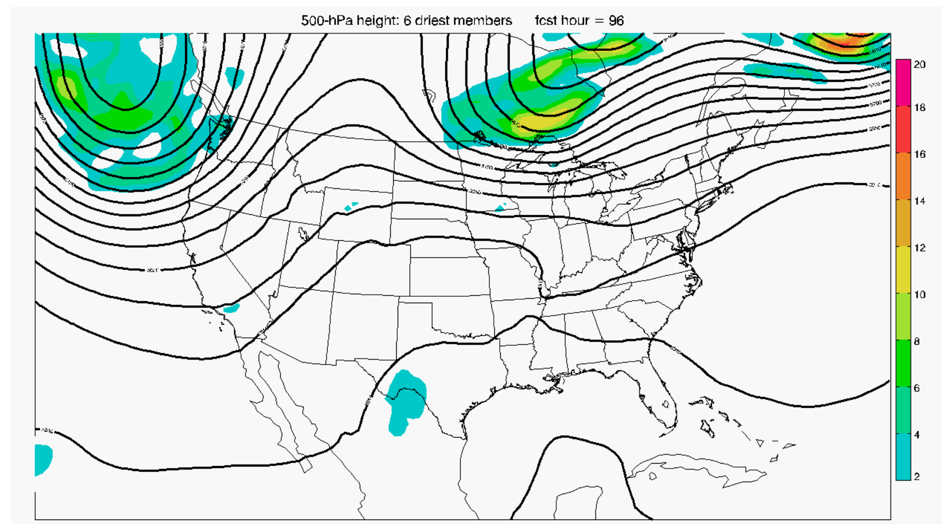
Comparison between wet and dry composites

- By t=96 hrs, the vortex has developed and remained over OK in the wet runs, but has been swept into Mexico in the dry runs

500-mb heights and vorticity: composite of 6 wettest members



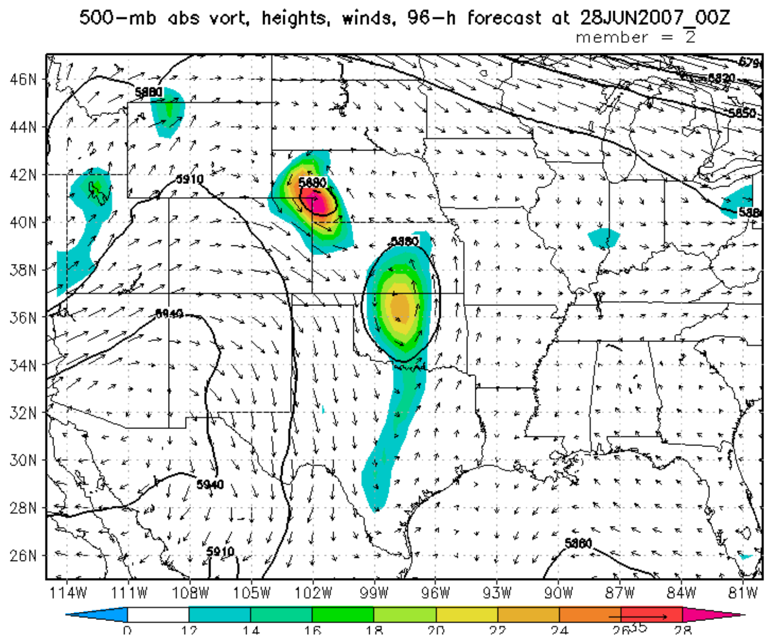
500-mb heights and vorticity: composite of 6 driest members



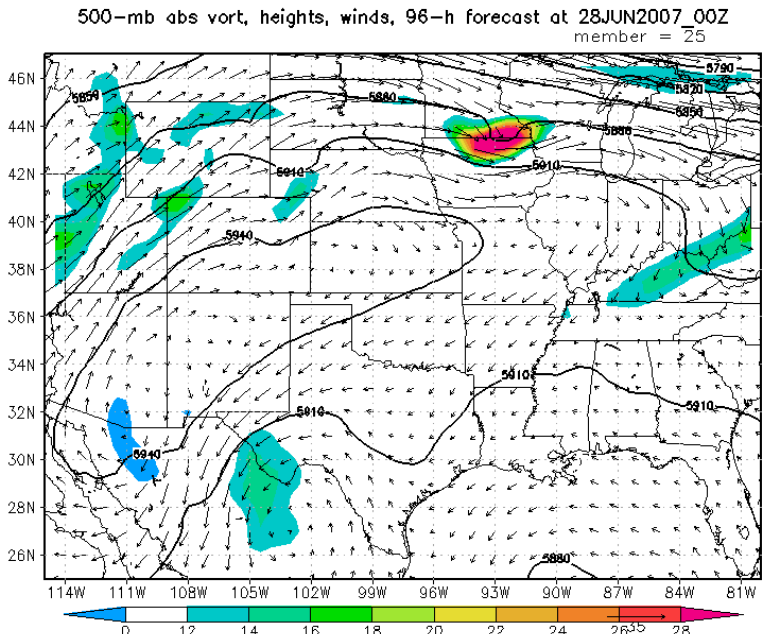
ECMWF ensemble, init 00Z/24 June

- Back to the best and worst members:

Best member



Worst member



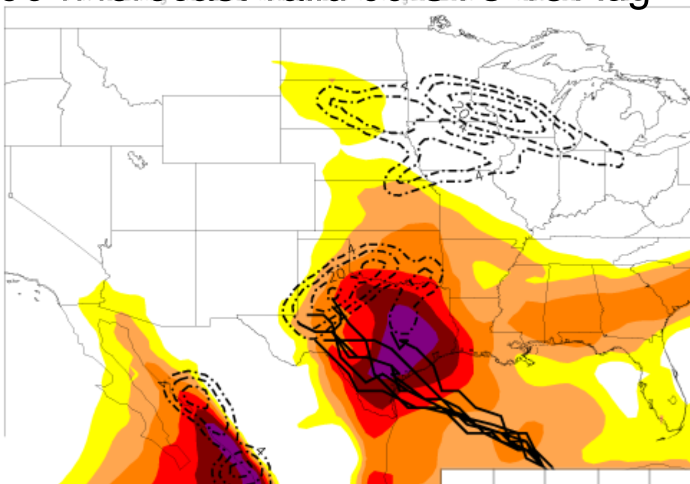
96-hr forecasts of 500-mb heights and vorticity (valid 00Z/28 June)

Other examples…

How much moisture is transported poleward ahead of a recurving tropical cyclone?

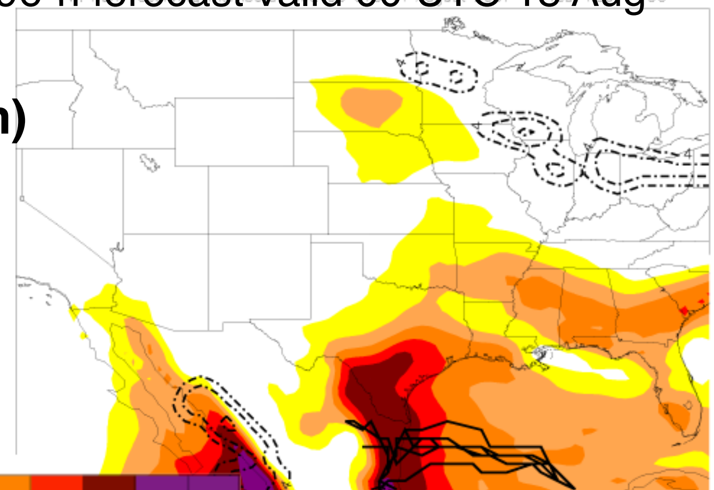
Recurving members (n=7)

96-h forecast valid 00 UTC 18 Aug

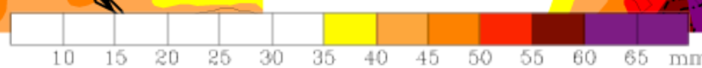


Southward turning members (n=6)

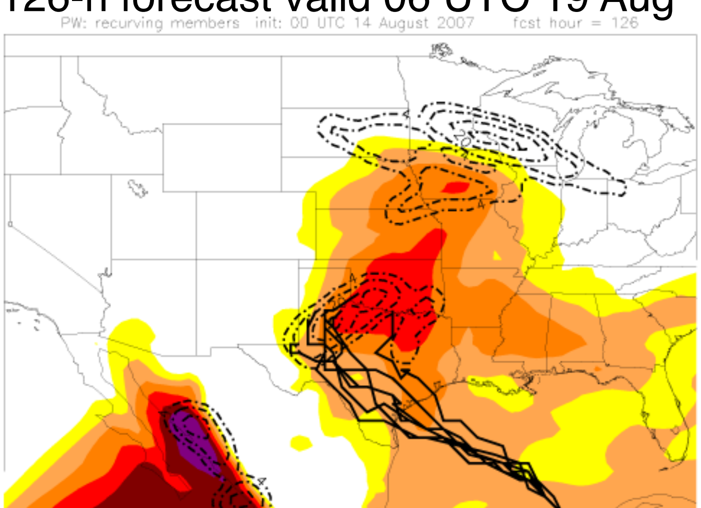
96-h forecast valid 00 UTC 18 Aug



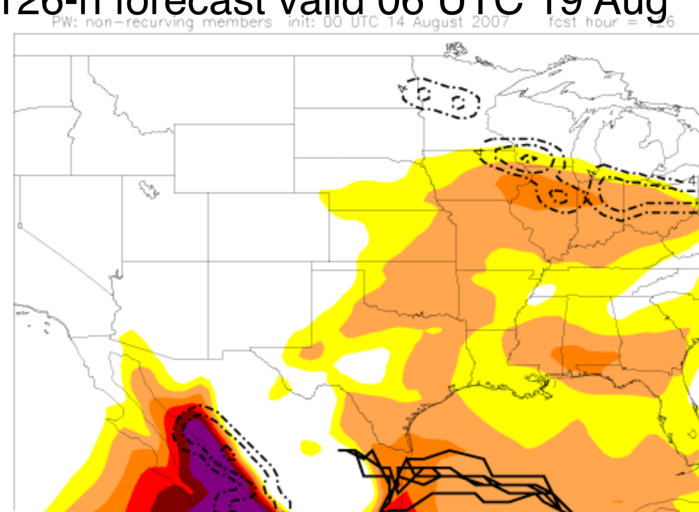
PW (mm)



126-h forecast valid 06 UTC 19 Aug

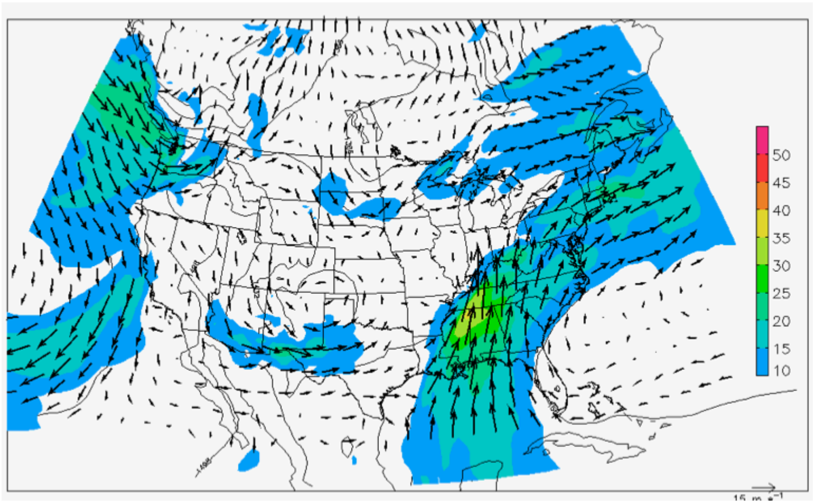


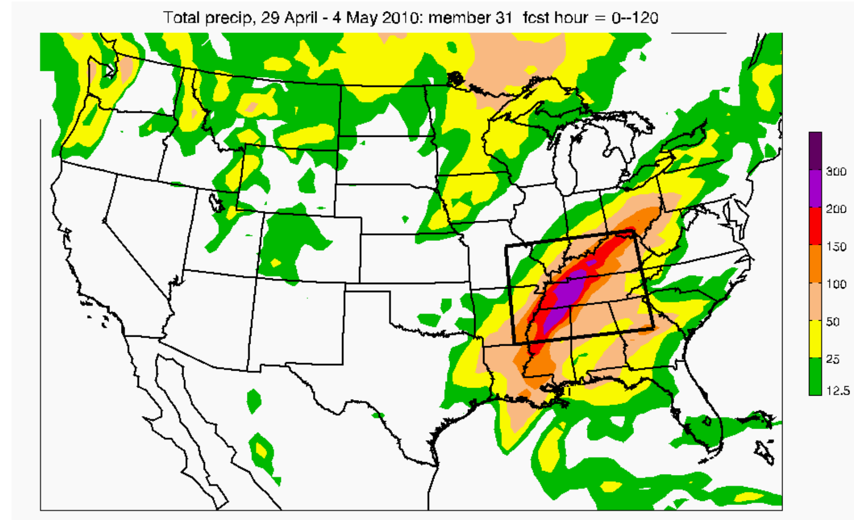
126-h forecast valid 06 UTC 19 Aug

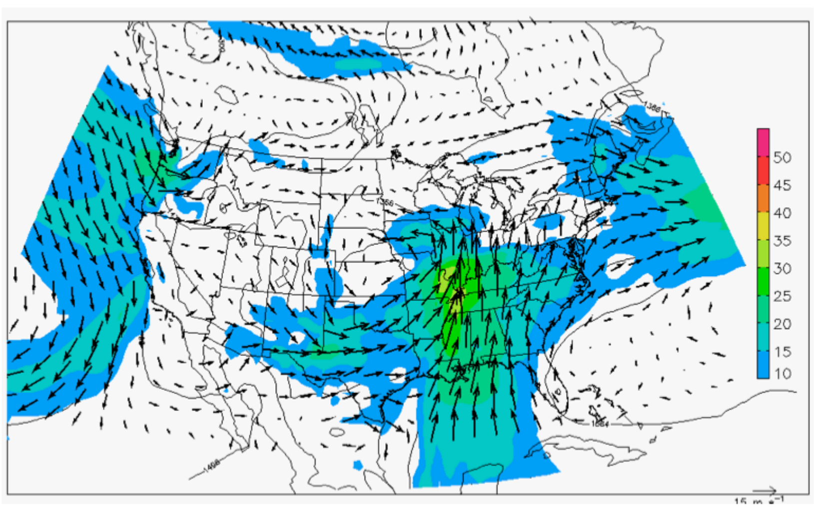


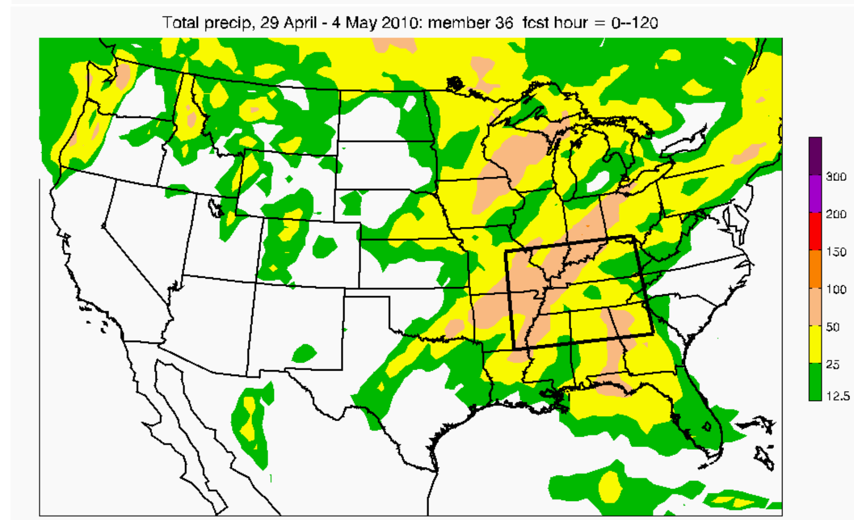
850-mb winds, 84-h forecast

120-h total precipitation









Nashville floods, May 2010: strong trough in central US was actually detrimental to the heavy rainfall

Figures from Sammy Lynch, TAMU

Summary and conclusions: widespread heavy rainfall

- The ECMWF ensemble analysis shows that the development of the vortex is related to the (lack of) strength of the northerly shear, which is in turn related to the (lack of) strength of the midlevel anticyclone over the southwest

- WRF simulations (not shown) show that deep convection and latent heating are also responsible for reducing the shear and weakening the anticyclone

- The ensemble-based diagnosis suggests possibilities for more idealized simulations

Summary and conclusions: widespread heavy rainfall

- For this rain event to get started, needed the synoptic-scale flow to be “just right” with weak deep-layer shear and steering flow over the Plains

- Once it got started, the deep convection created a positive feedback in terms of both the vortex intensification AND the reduction of deep-layer shear via latent heat release and PV redistribution (and momentum transport?) (similarities to Stensrud 1996)

- This feedback allowed the vortex and convection to be self-sustaining and for it to be nearly stationary for several days

- Both synoptic and mesoscale factors apparently contributed to the limited predictability for this system

- Similarities to TC genesis (the tropical transition mechanism of Davis and Bosart)