Predecessor Rain Events Ahead of Tropical Cyclones

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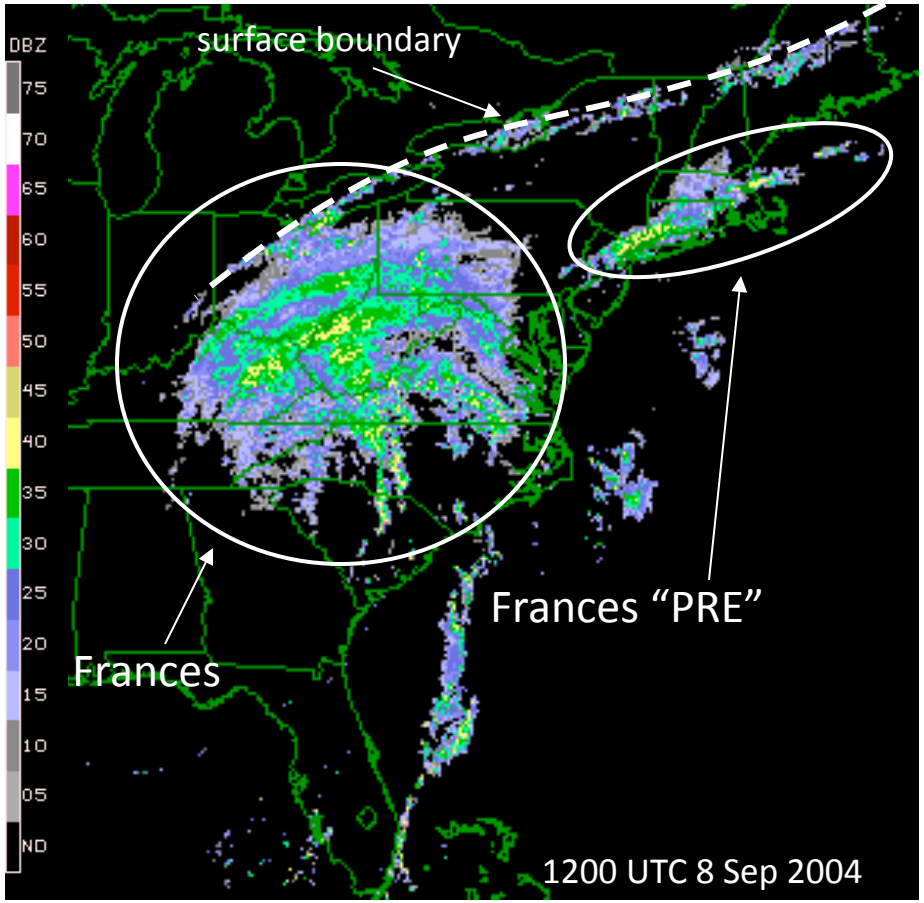
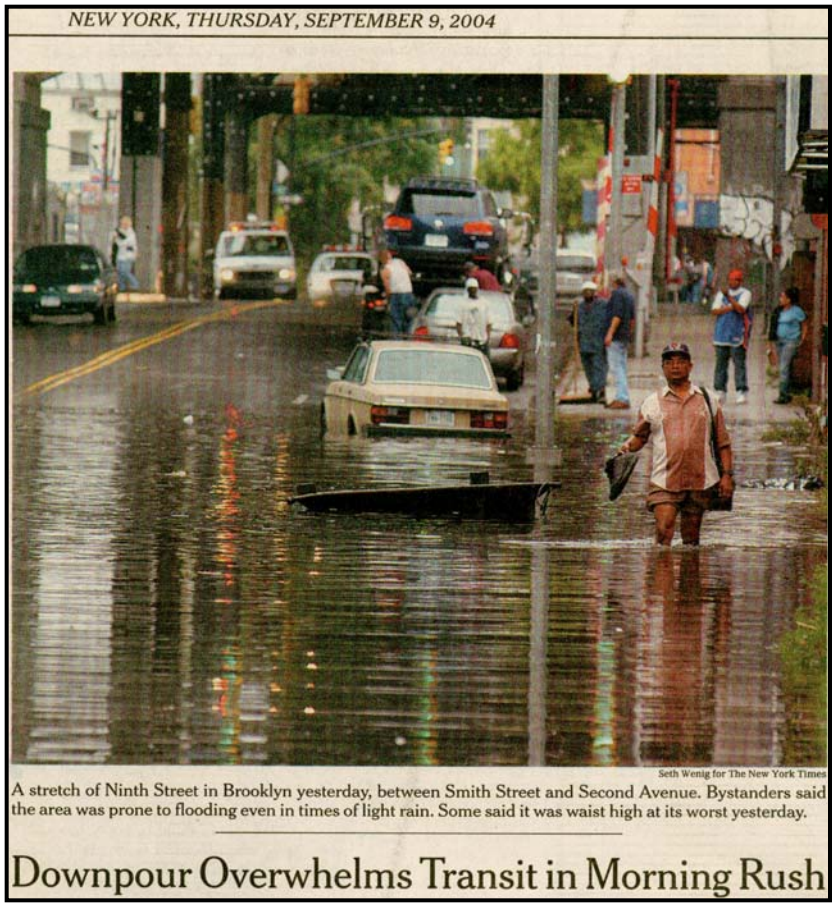
PREs Associated with Recurving TCs



Reflectivity composite from NCAR case selection archive



NEW YORK, THURSDAY, SEPTEMBER 9, 2004

Seth Wenig for The New York Times

A stretch of Ninth Street in Brooklyn yesterday, between Smith Street and Second Avenue. Bystanders said the area was prone to flooding even in times of light rain. Some said it was waist high at its worst yesterday.

Downpour Overwhelms Transit in Morning Rush

Article from the front page of the *NY Times* 9 Sep 2004

High-Impact TC Frances PRE on 8 Sep 2004

Motivation

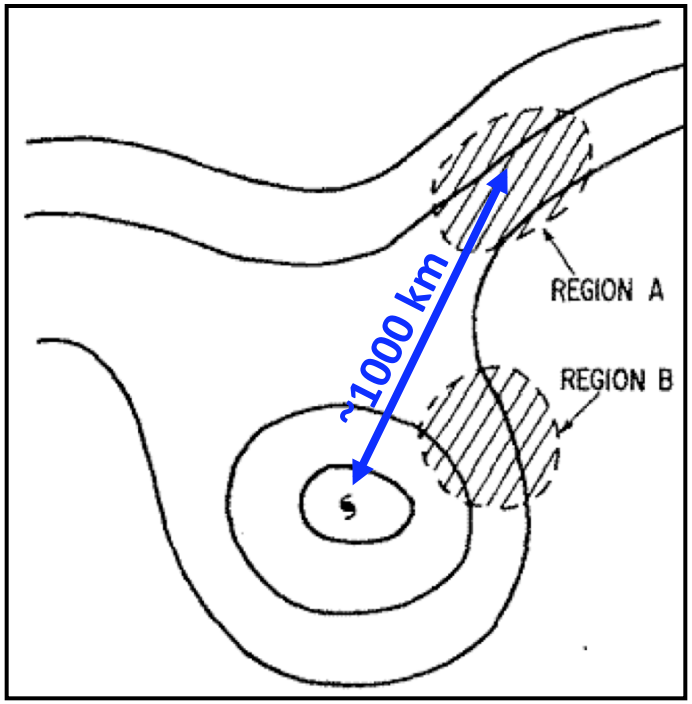
- PREs are high-impact weather events that frequently result in significant inland flooding
- High-impact PRE occurred with Tropical Cyclone (TC) Erin on 19 Aug 2007
- Band of heavy rain (>250 mm) over the northern Great Plains and Great Lakes region on 19 Aug associated with Erin moisture

Outline

- Definition of PRE
- Overall PRE statistics and composite (1995–2008)
- Case analysis of TC Erin PRE (19 Aug 2007)

Predecessor Rain Events (PREs)

- Coherent area of rain displaced poleward of TC
- Moisture transport from TC toward PRE
- Event duration ~ 15 h
- Maximum rainfall rates typically ≥ 100 mm $(24\ h)^{-1}$
- Time lag between PRE and TC passage ~ 36 h



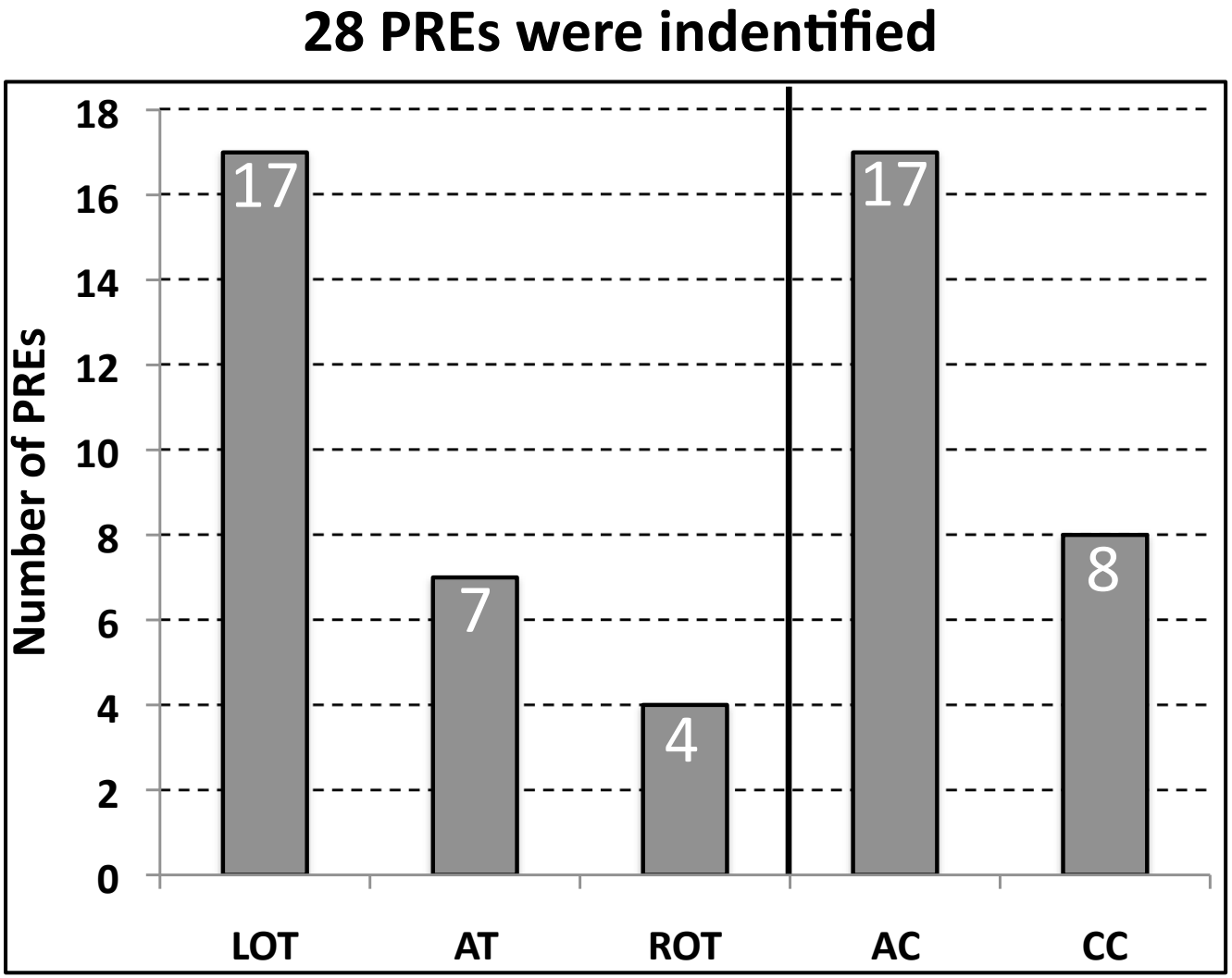
Bosart and Carr (1978) conceptual model of antecedent rainfall for TC Agnes (1972)

Detailed study of PREs in Cote (2007) and Galarneau et al. (2010), MWR, In Press.

PRE Identification and Stratification

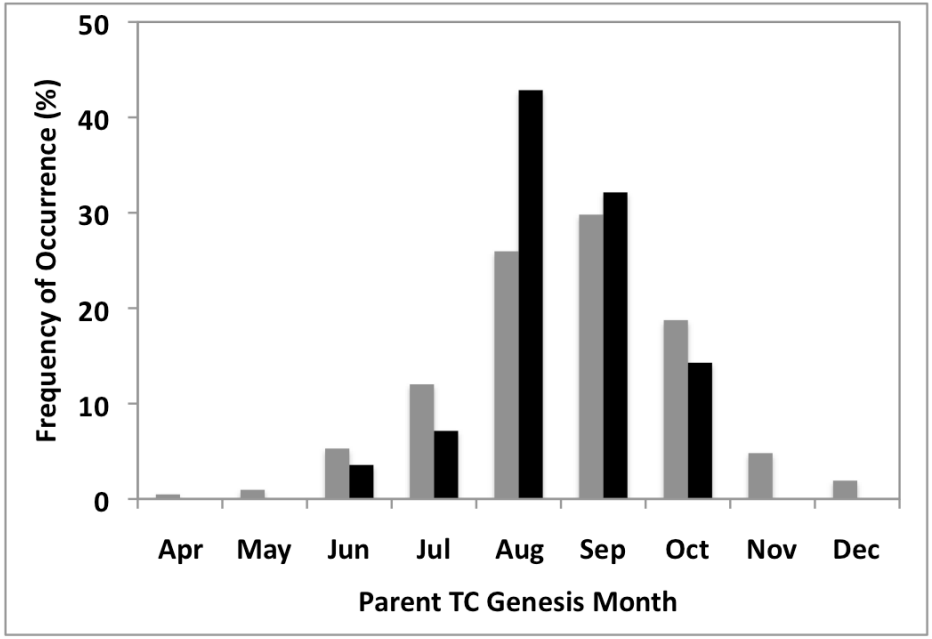
- PREs during 1995–2008 were manually identified by the following criteria:
  - Radar reflectivity values ≥ 35 dBZ within coherent area of rainfall persisting for ≥ 6 h
  - Clear separation on radar imagery between coherent area of rainfall and TC rain shield
  - Deep tropical moisture directly in TC circulation advected to region of coherent rain fall
  - Average rainfall rate ≥ 100 mm $(24\ h)^{-1}$ over entire life cycle
- PREs were then stratified into the following categories
  - Left-of-track (LOT); right-of-track (ROT); along-track (AT)
  - Anticyclonically curved 200-hPa jet (AC); cyclonically curved 200-hPa jet (CC)

Statistical Summary for PREs 1995–2008

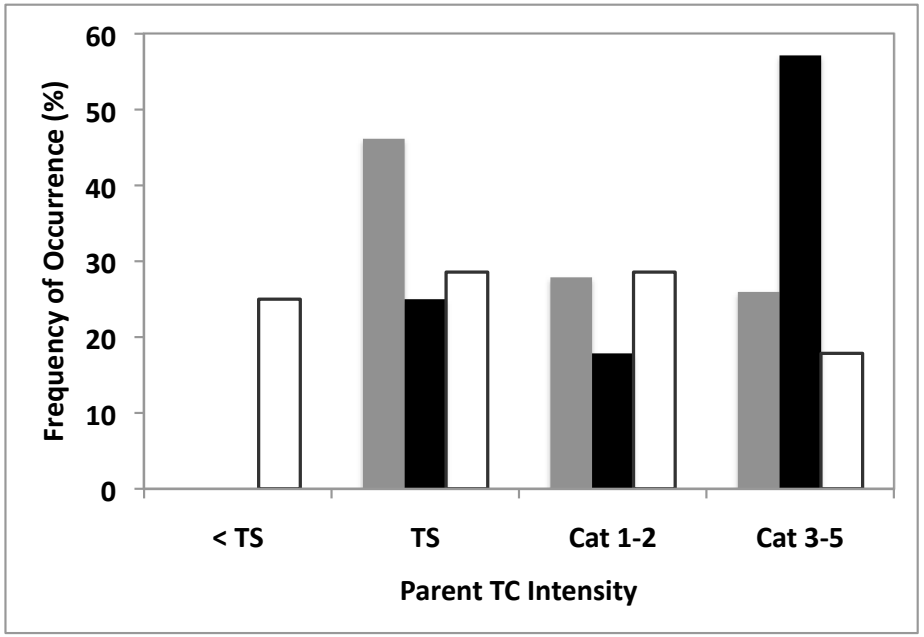


Statistical Summary for PREs 1995–2008

Parent TC Genesis Month



Parent TC Max Intensity

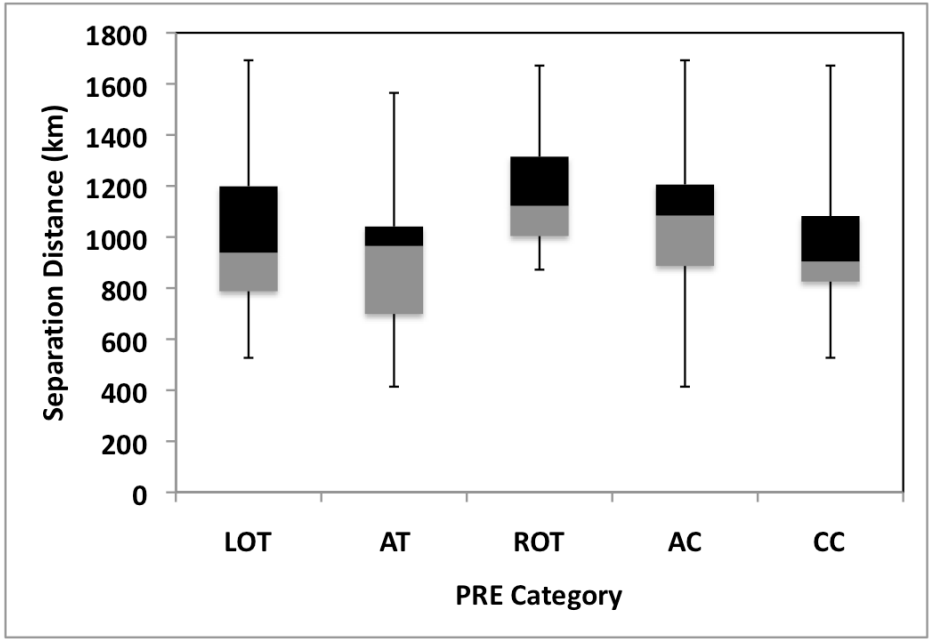


All North Atlantic TCs 1995–2008 (N=208)

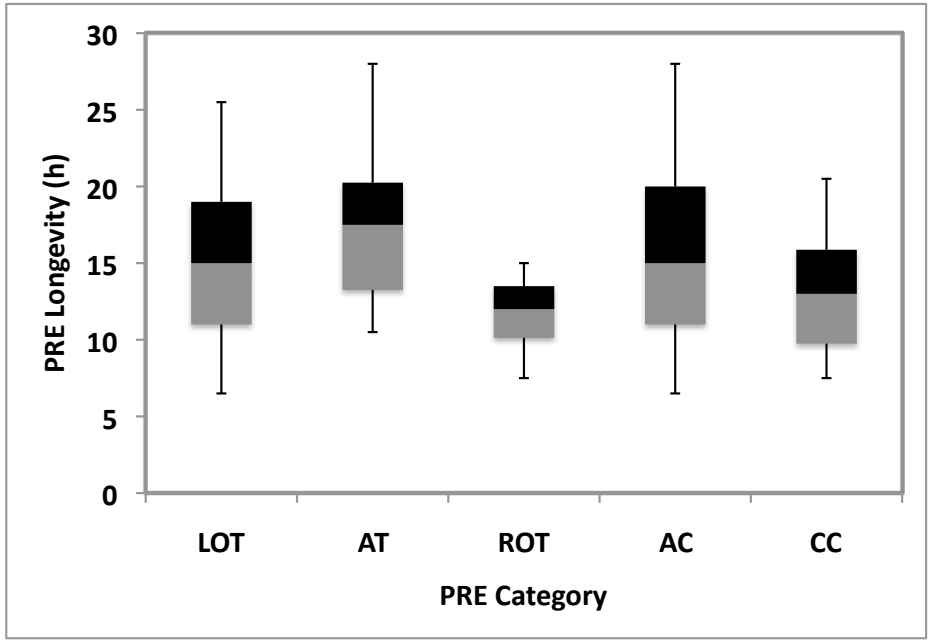
PRE Parent TCs 1995–2008 (N=28)

Statistical Summary for PREs 1995–2008

PRE–TC Separation Distance

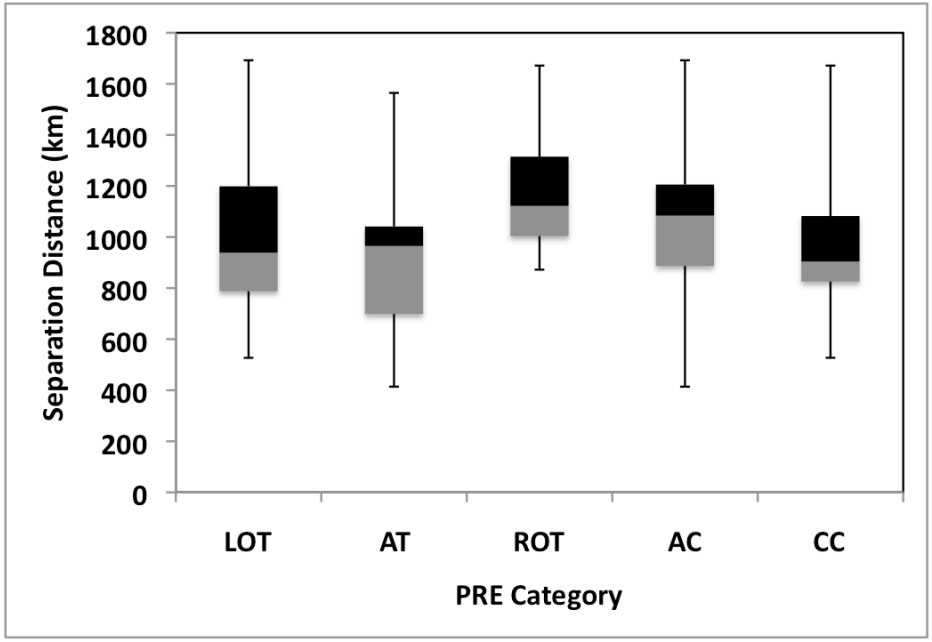


PRE Longevity

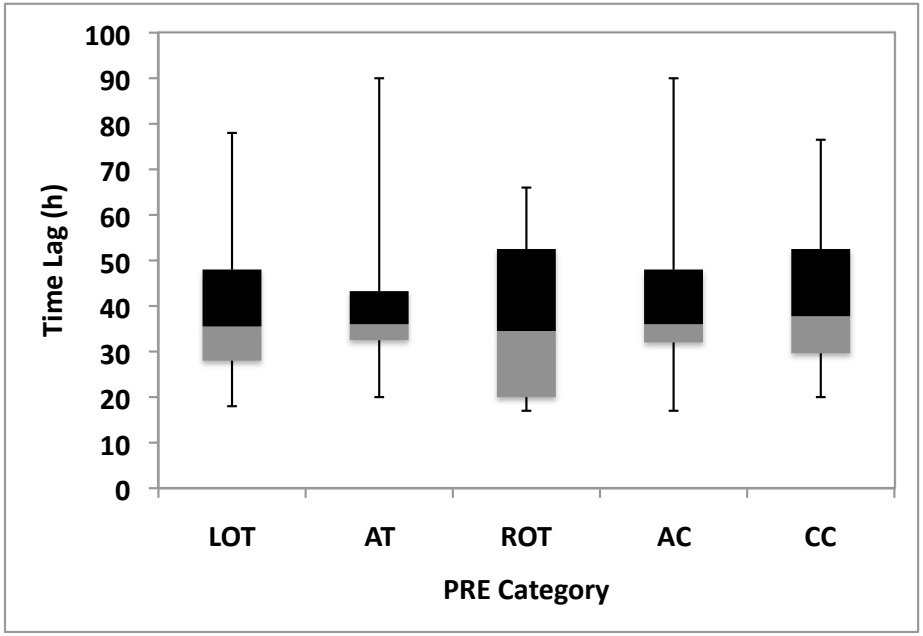


Statistical Summary for PREs 1995–2008

PRE–TC Separation Distance



PRE–TC Passage Time Lag



Key climatological numbers for forecasters:

- **PRE–TC separation distance ~1000 km**
- **PRE longevity ~15 h**
- **PRE–TC passage time lag ~36 h**

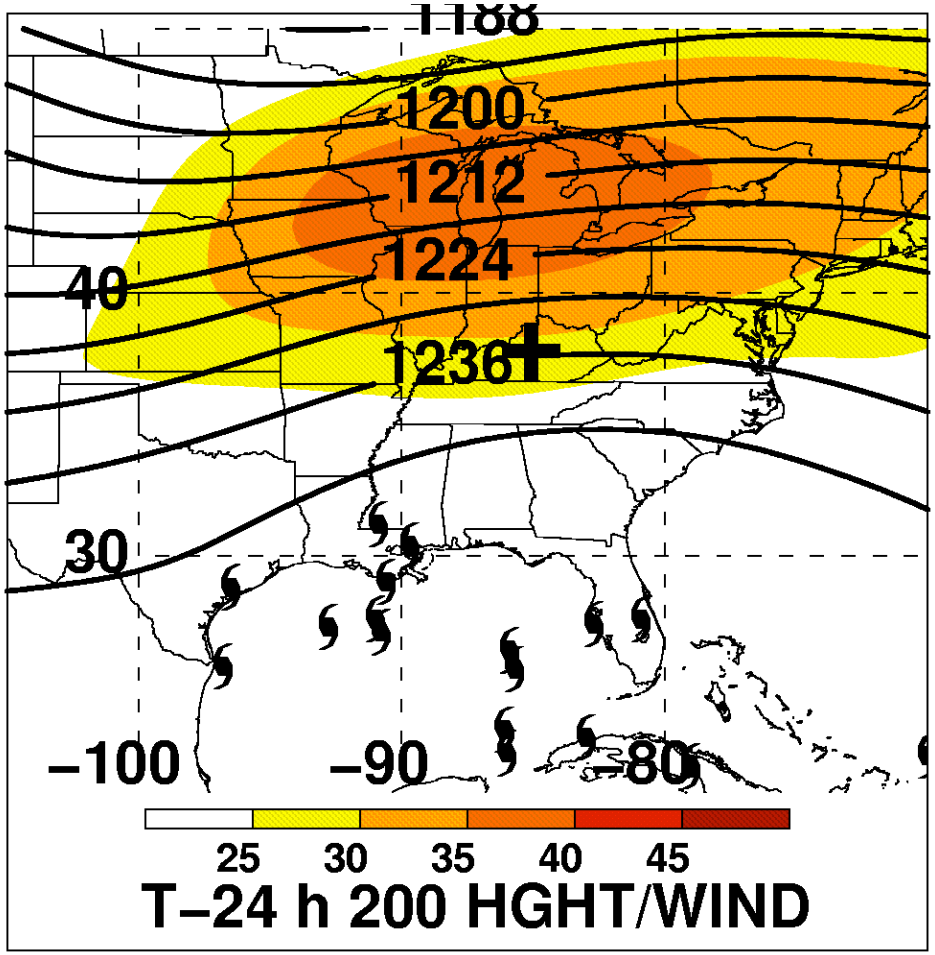
PRE Composite Analysis

- Composites were generated at 24-h prior to (T–24), at (T–0), and 24-h after (T+24) PRE initiation
- Composites were computed using the 6-hourly 2.5°×2.5° NCEP/NCAR reanalysis dataset
- Grids were shifted so all PRE initiation locations were at 38°N, 85°W (median initiation position for all PREs) prior to compositing; composite analyses are in PRE-relative coordinates

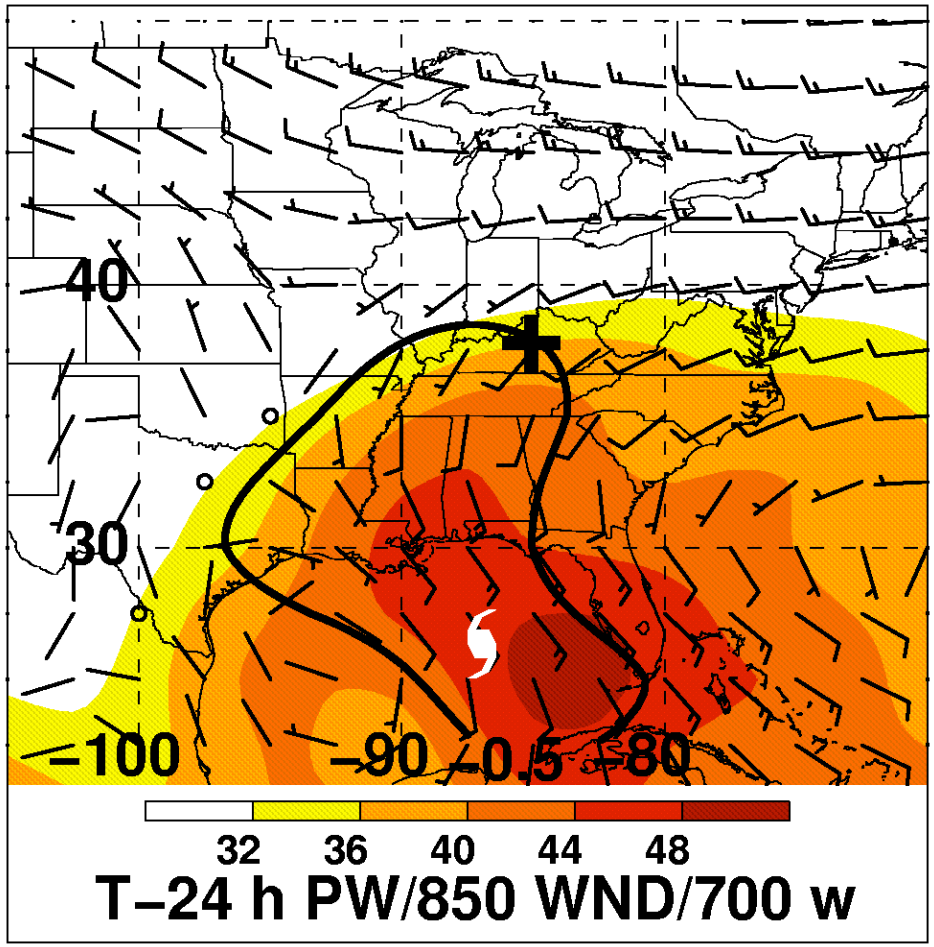
N=17

AC PRE Composite–Structure

200-hPa h (dam), wind speed (m s^{-1}), and PRE-relative TC positions



700-hPa ω (10^{-3} hPa s^{-1}), PW (mm), and 850-hPa wind (kt)



Composite analysis at 24-h prior to PRE initiation

+ = PRE initiation location; white TC symbol = median TC PRE-relative position

N=17

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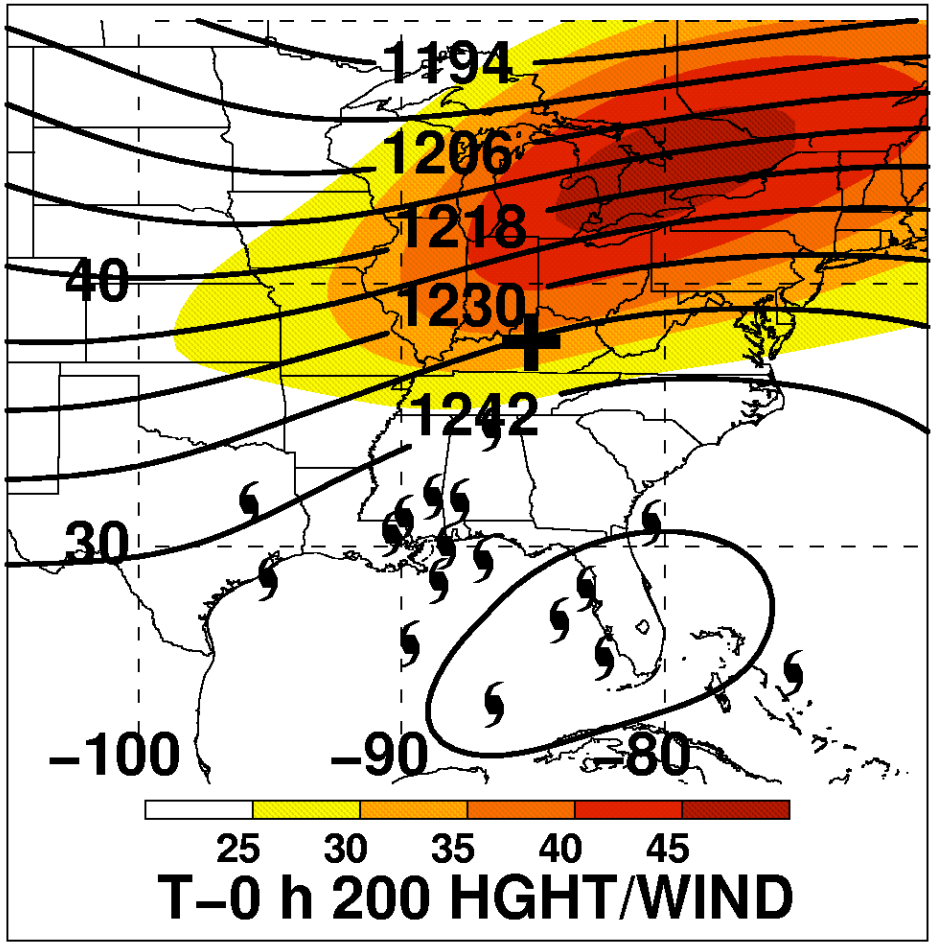
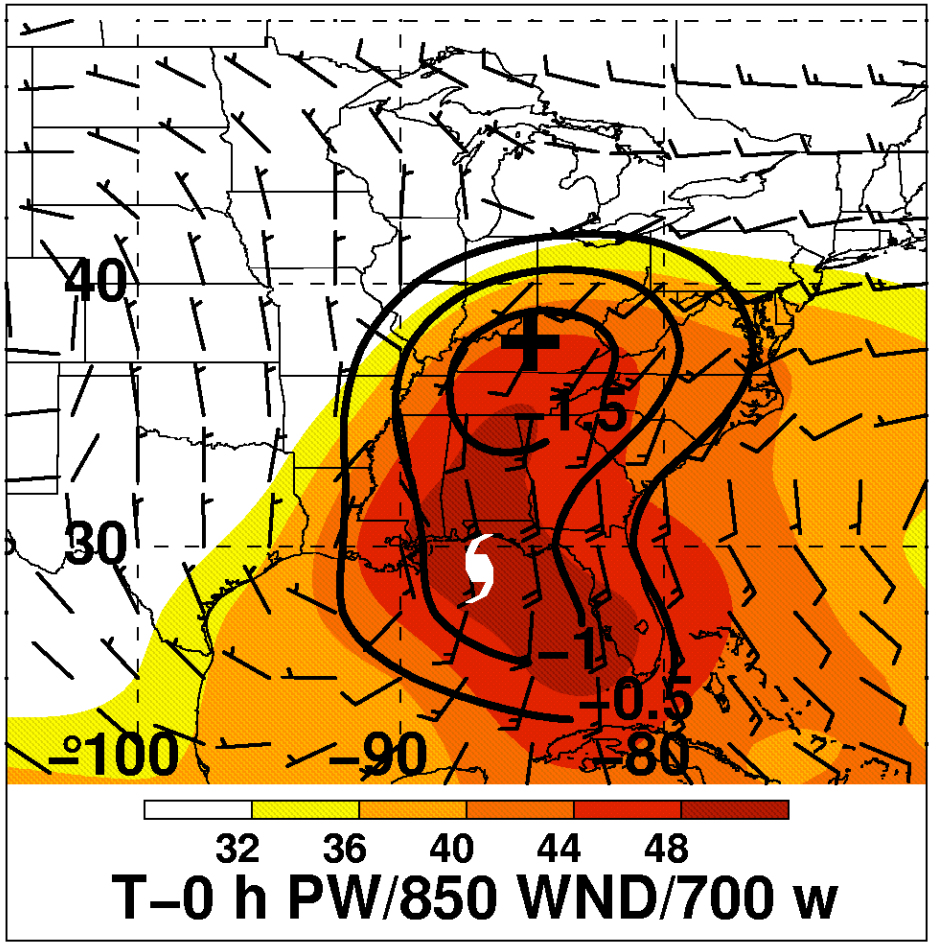
200-hPa h (dam), wind speed (m s^{-1}), and PRE-relative TC positions



700-hPa ω (10^{-3} hPa s^{-1}), PW (mm), and 850-hPa wind (kt)



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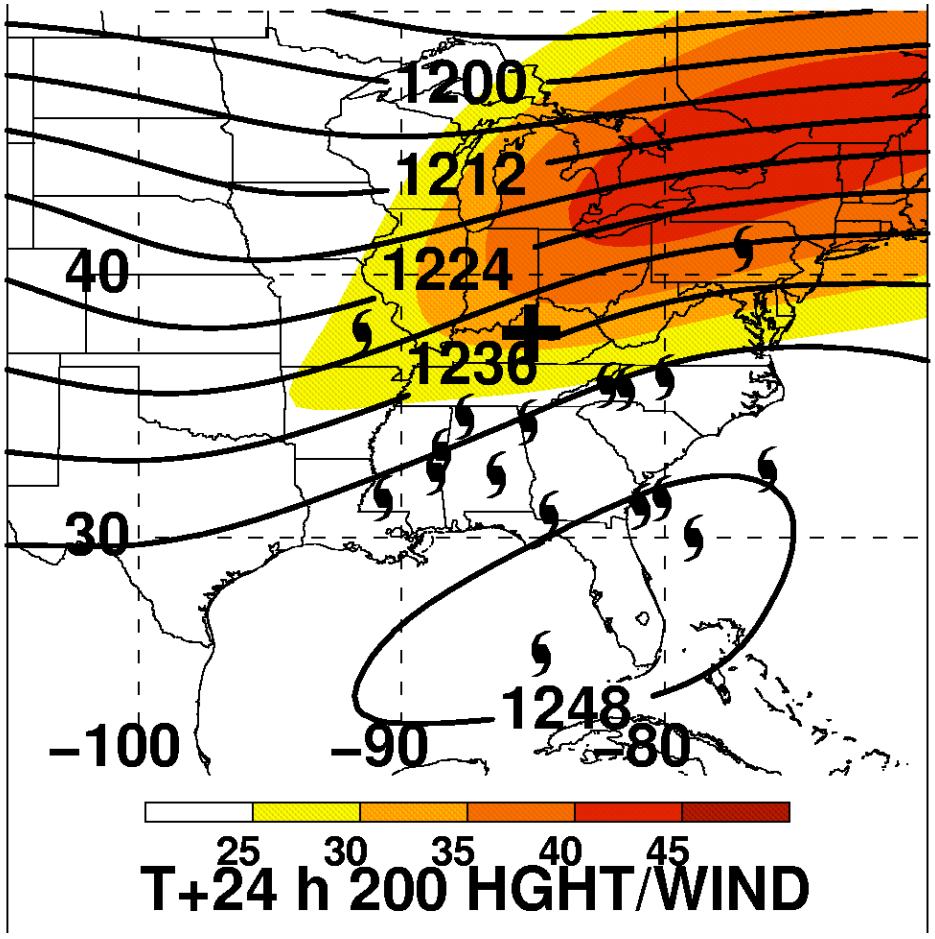
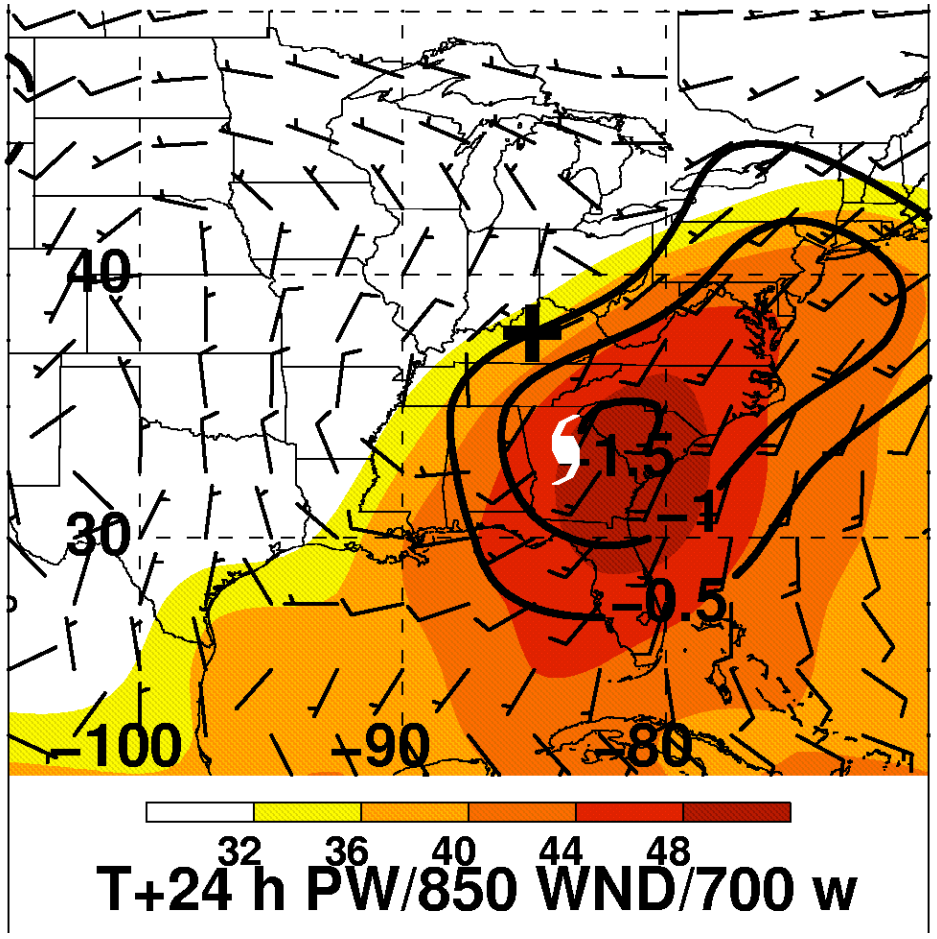


700-hPa ω (10^{-3} hPa s^{-1}), PW (mm), and 850-hPa wind (kt)



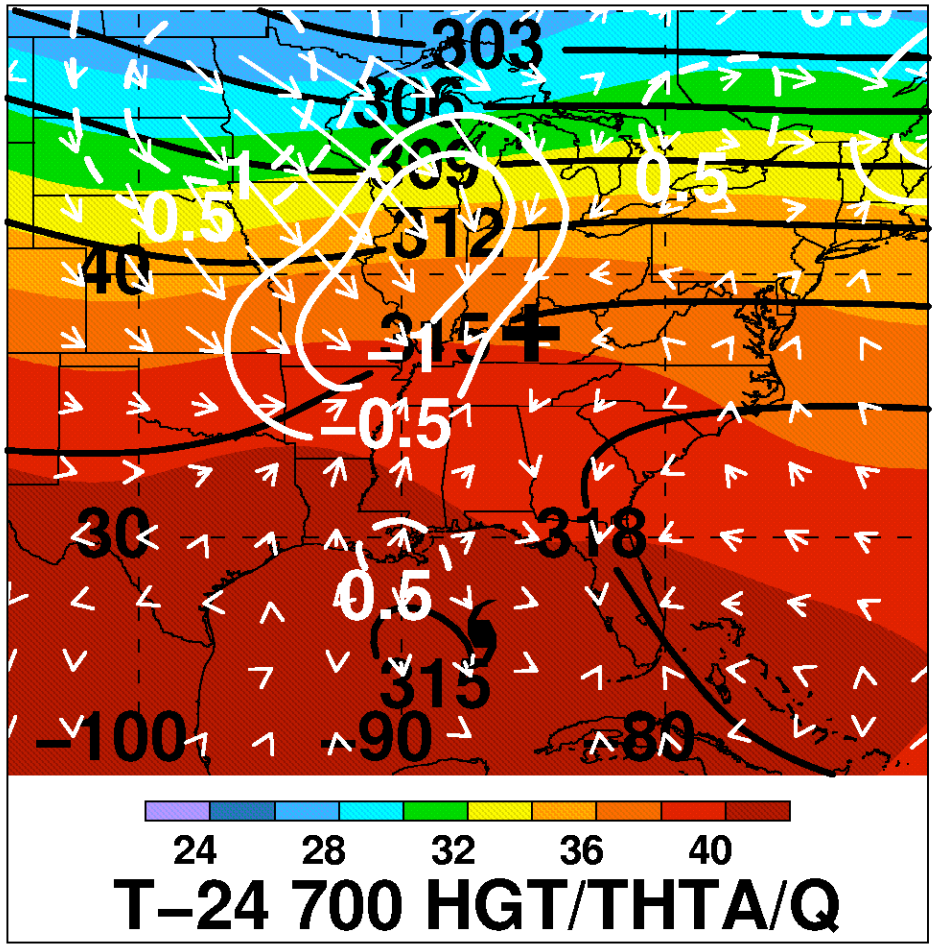
Composite analysis at 24-h after PRE initiation

+ = PRE initiation location; white TC symbol = median TC PRE-relative position

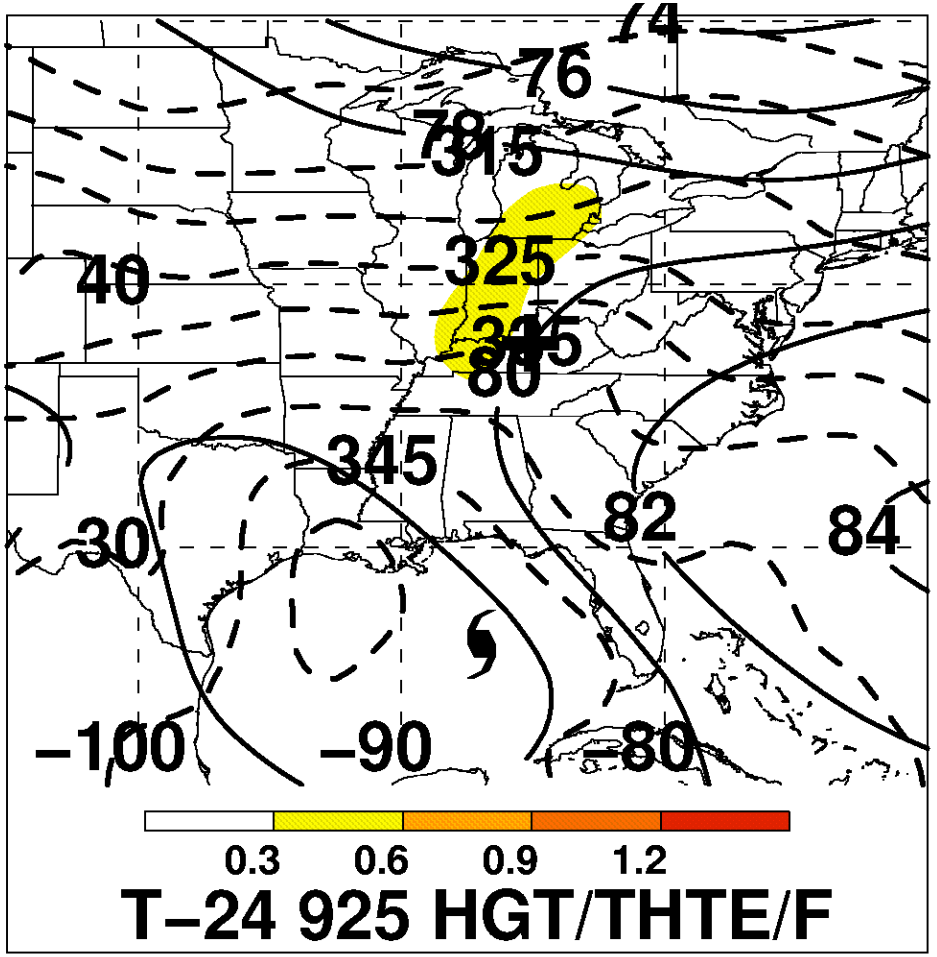
N=17

AC PRE Composite–Lifting Mechanisms

700-hPa h (dam), Q-vectors (10^{-8} K m^{-1} s^{-1}), θ (K), and Q divergence (10^{-12} K m^{-2} s^{-1})



925-hPa h (dam), θ_e (K), and frontogenesis [10^{-1} K (100 km)$^{-1}$ (3 h)$^{-1}$]



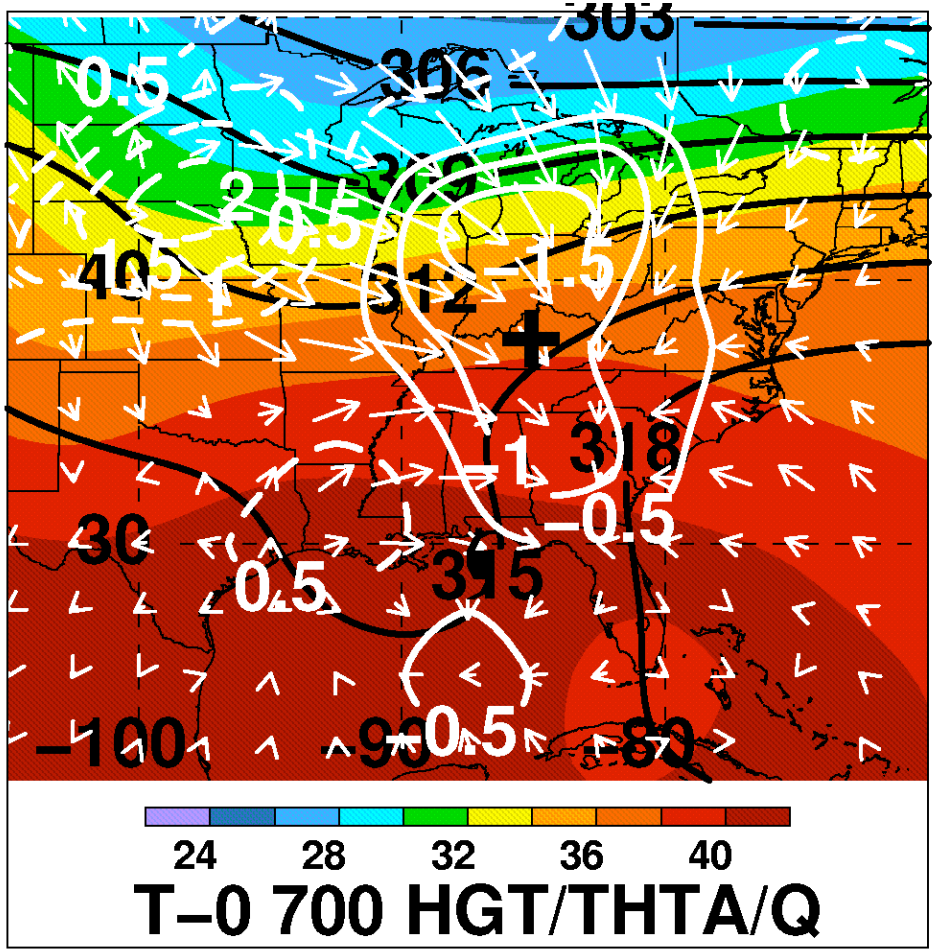
Composite analysis at 24-h prior to PRE initiation

+ = PRE initiation location; black TC symbol = median TC PRE-relative position

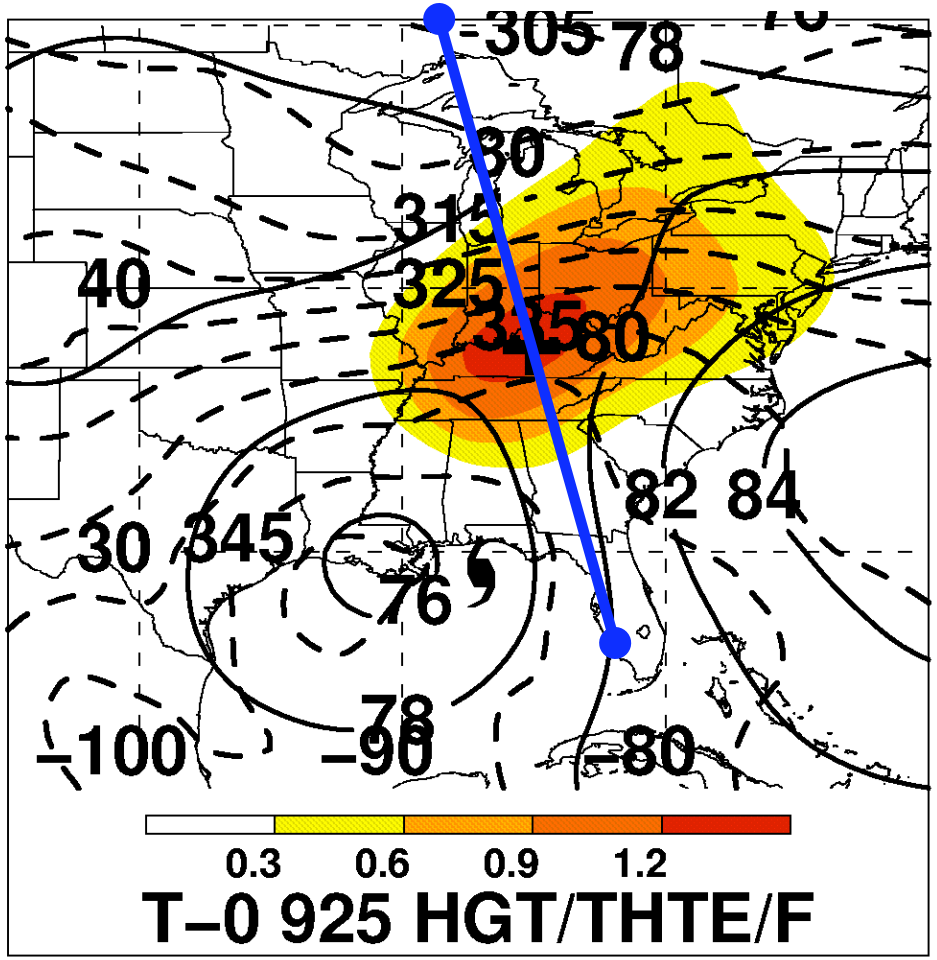
N=17

AC PRE Composite–Lifting Mechanisms

700-hPa h (dam), Q-vectors (10^{-8} K m^{-1} s^{-1}), θ (K), and Q divergence (10^{-12} K m^{-2} s^{-1})



925-hPa h (dam), θ_e (K), and frontogenesis [10^{-1} K (100 km)$^{-1}$ (3 h)$^{-1}$]



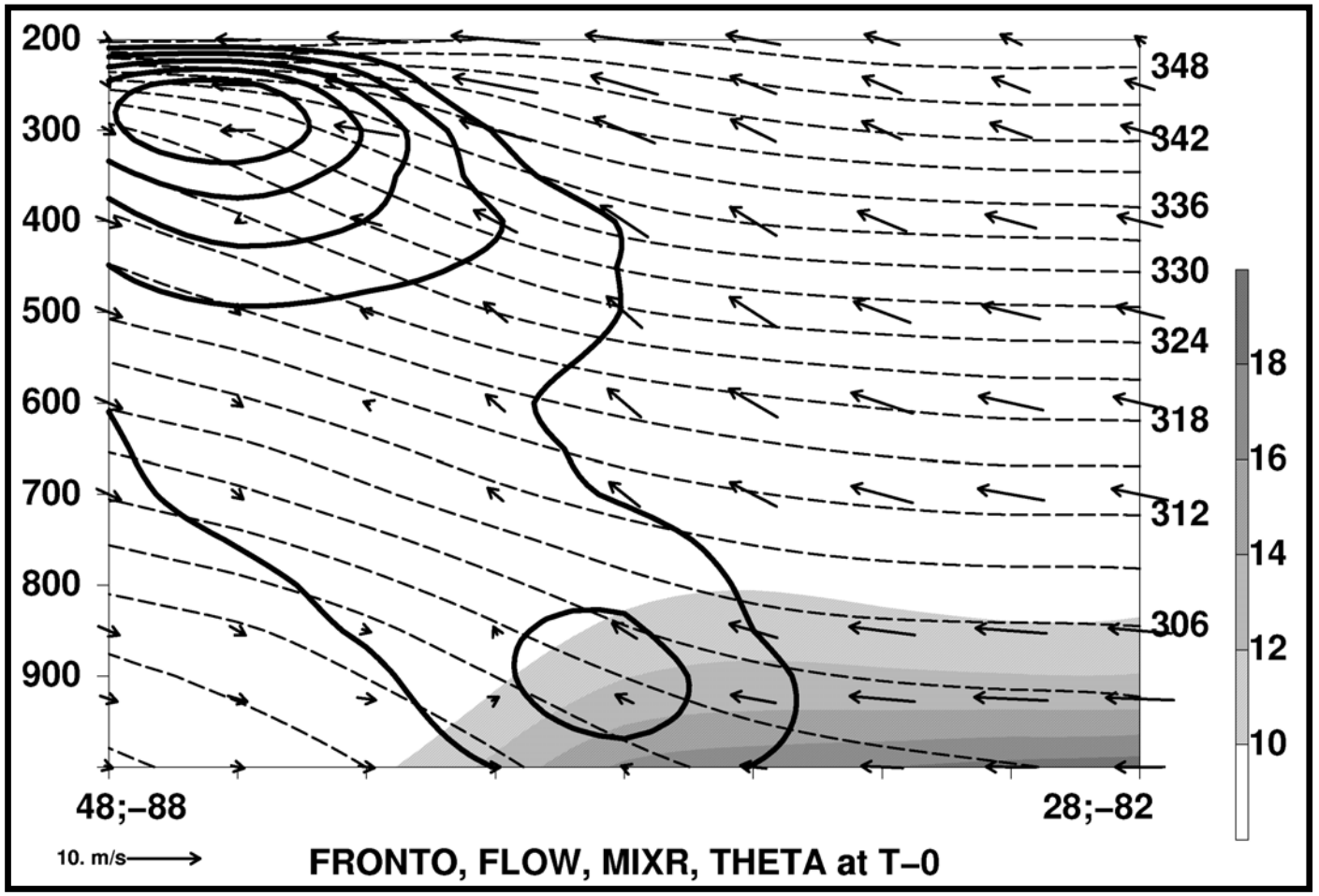
Composite analysis at PRE initiation

+ = PRE initiation location; black TC symbol = median TC PRE-relative position

N=17

AC PRE Composite–Lifting Mechanisms

Vertical cross section of frontogenesis [10^{-1} K (100 km)$^{-1}$ (3 h)$^{-1}$], mixing ratio (g kg^{-1}), θ (K), and circulation (m s^{-1})

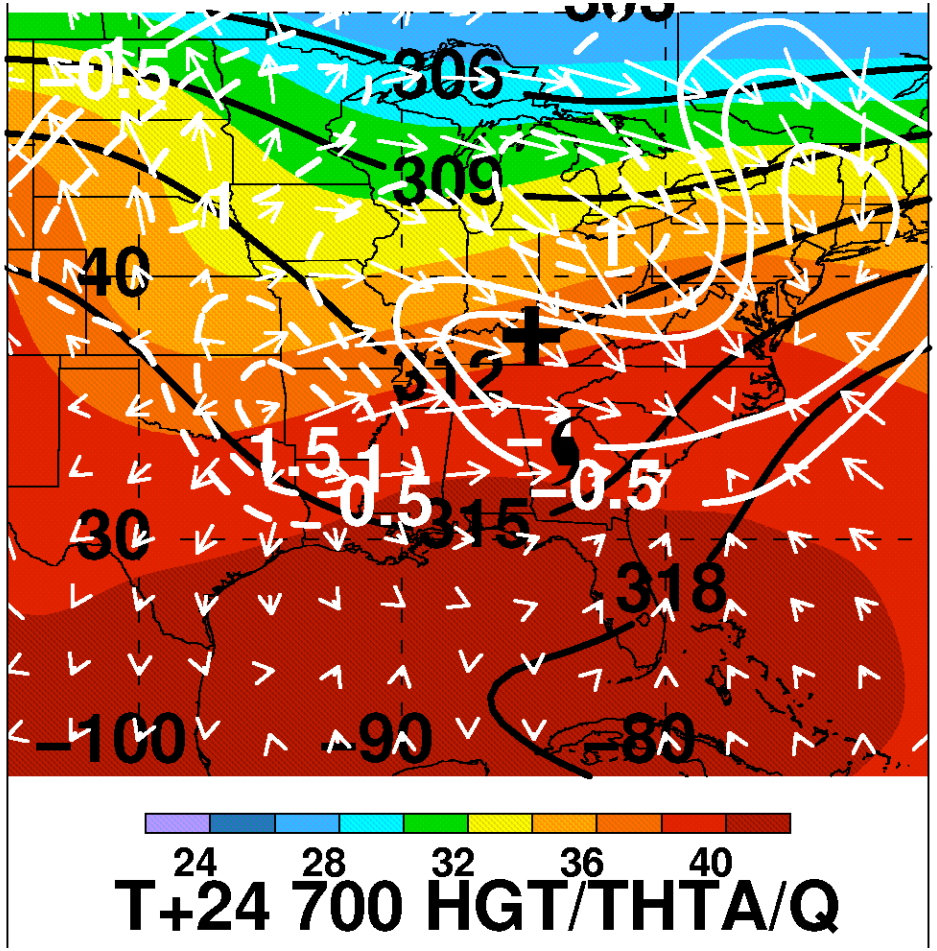


Composite analysis at PRE initiation

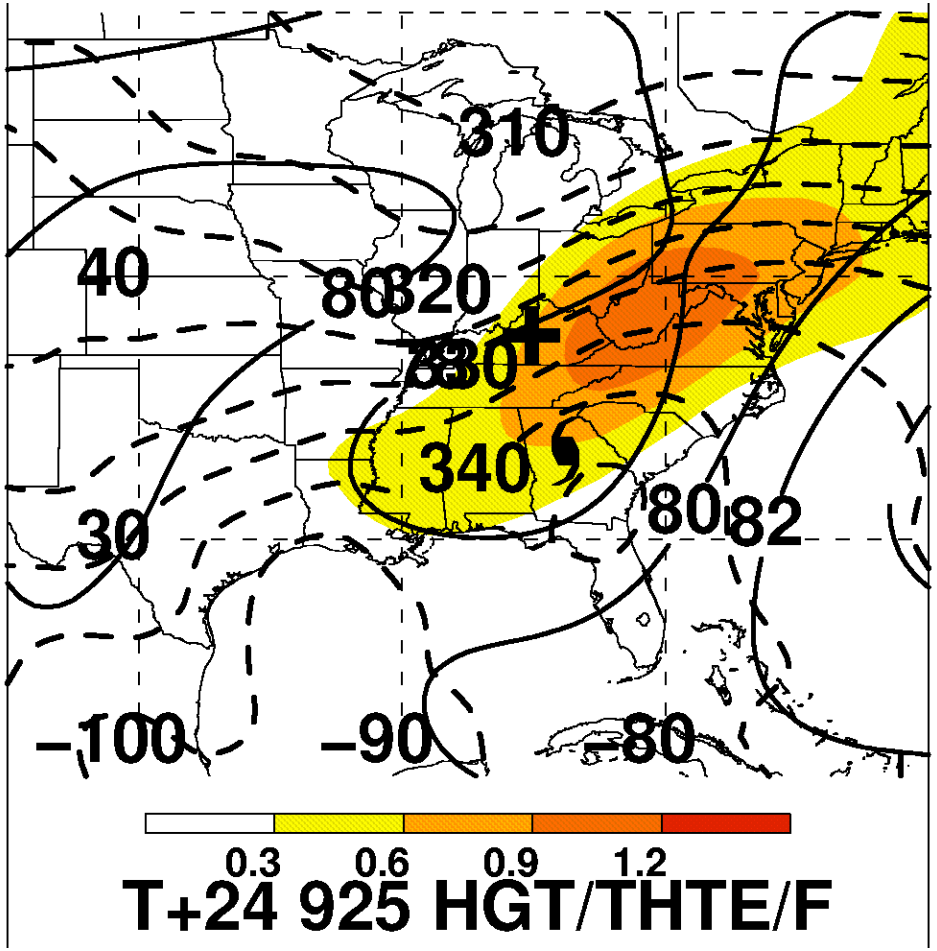
N=17

AC PRE Composite–Lifting Mechanisms

700-hPa h (dam), Q-vectors (10^{-8} K m^{-1} s^{-1}), θ (K), and Q divergence (10^{-12} K m^{-2} s^{-1})



925-hPa h (dam), θ_e (K), and frontogenesis [10^{-1} K (100 km)$^{-1}$ (3 h)$^{-1}$]



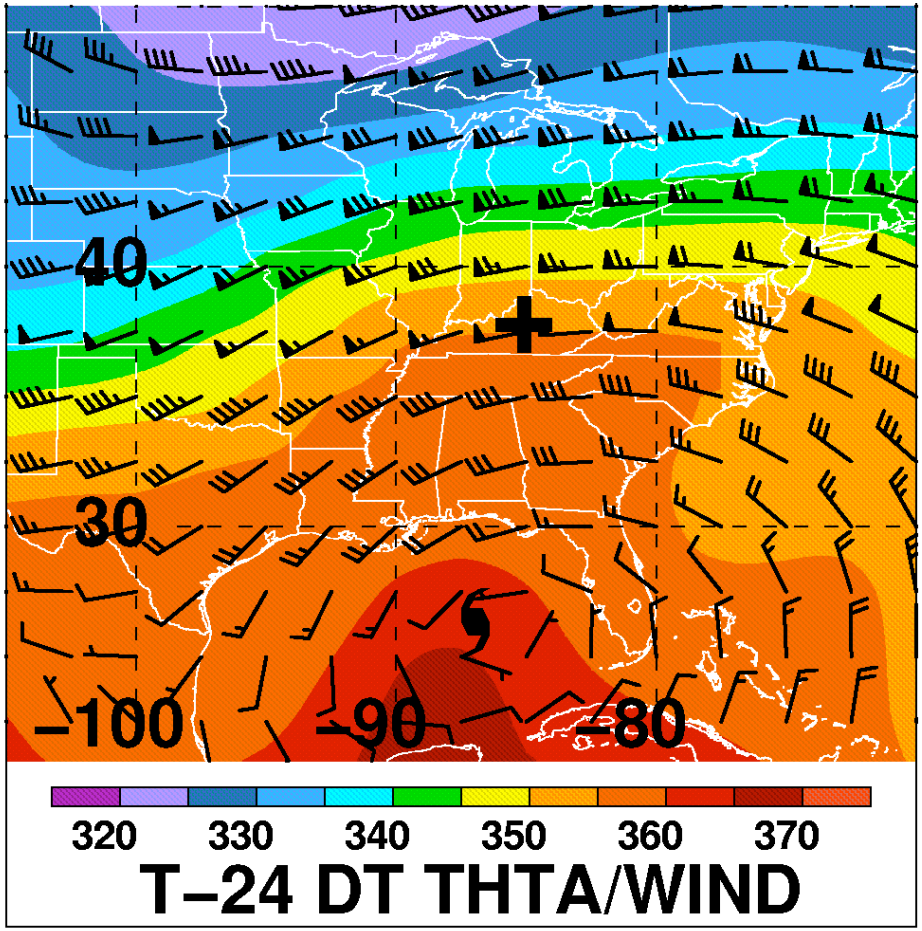
Composite analysis at 24-h after PRE initiation

+ = PRE initiation location; black TC symbol = median TC PRE-relative position

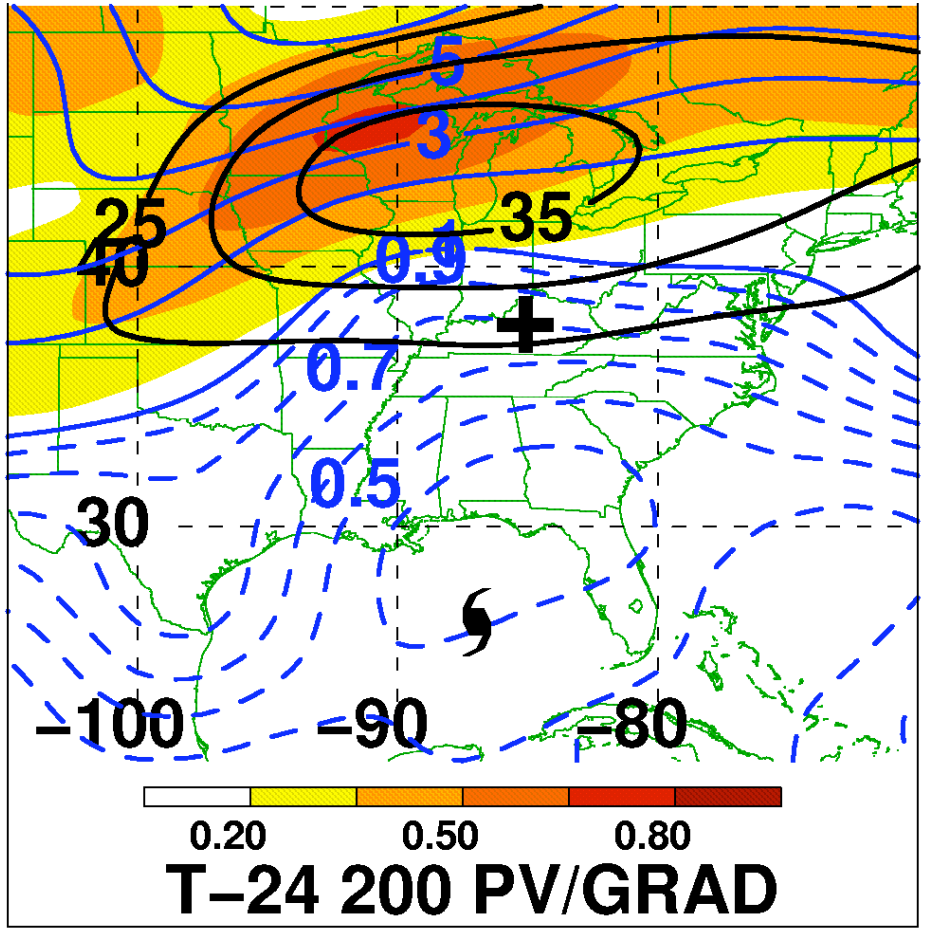
N=17

AC PRE Composite–Jet Intensification

DT θ (K) and wind (kt)



250–200-hPa PV (PVU), gradient (10^{-5} PVU m^{-1}), and 200-hPa wind speed (m s^{-1})



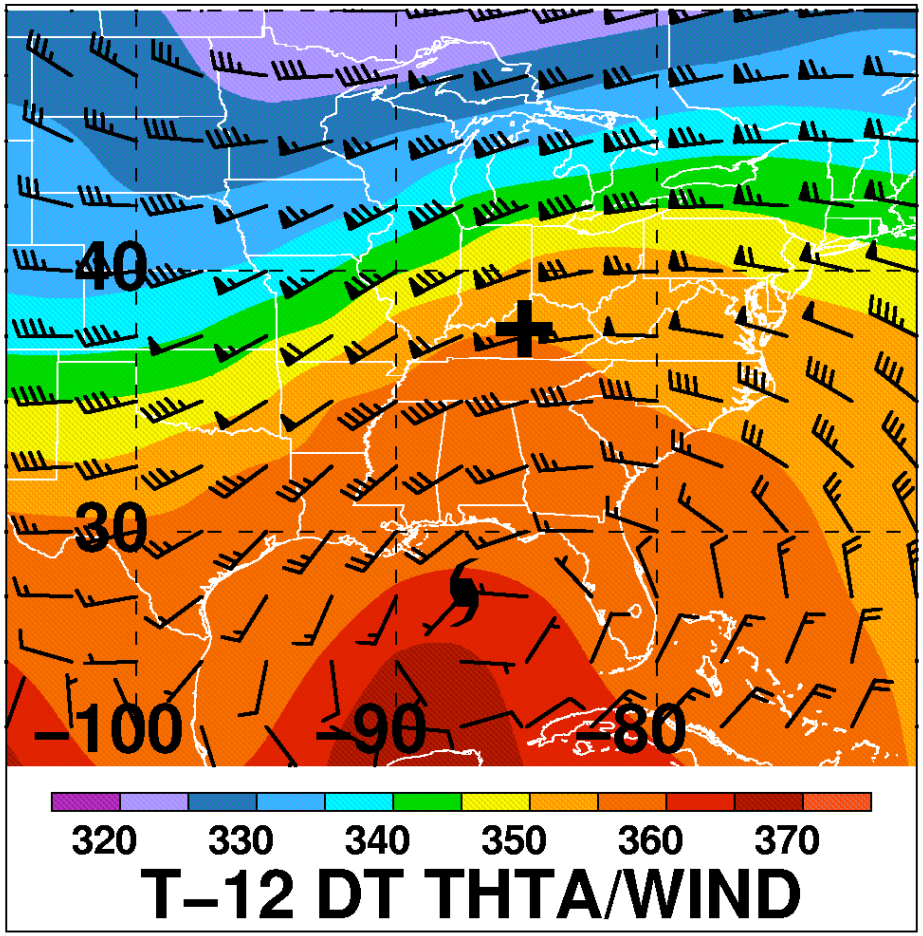
Composite analysis at 24-h prior to PRE initiation

+ = PRE initiation location; black TC symbol = median TC PRE-relative position

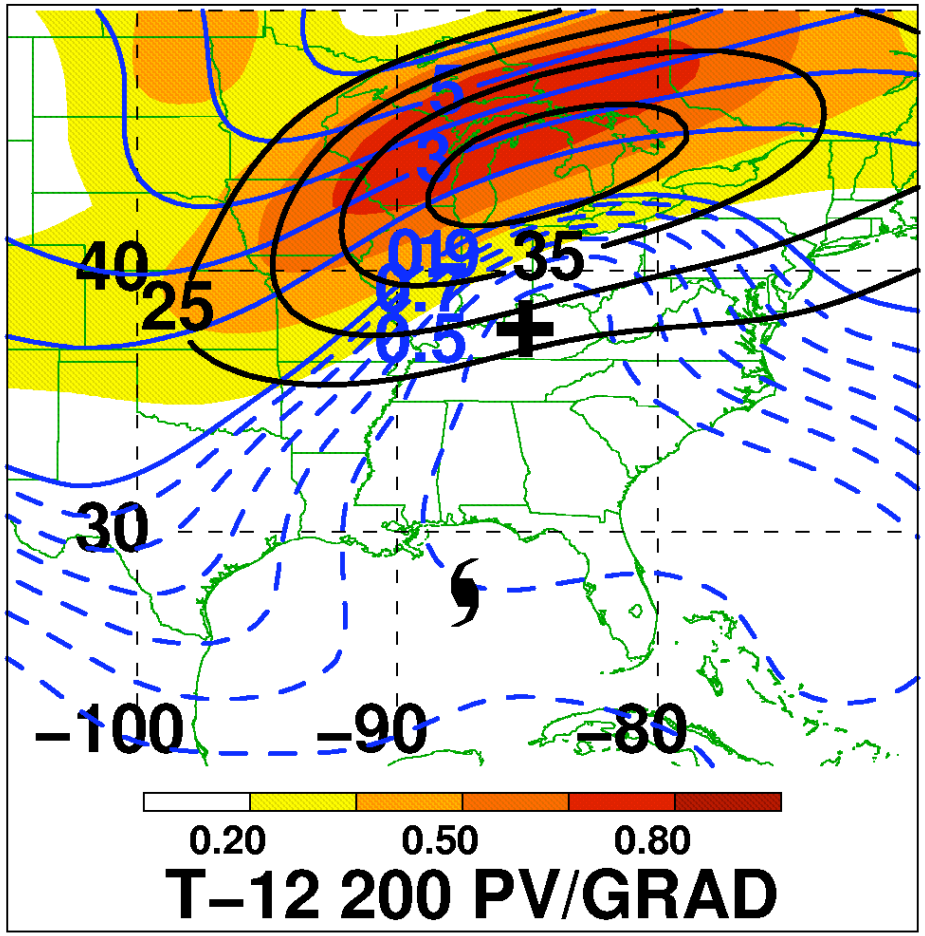
N=17

AC PRE Composite–Jet Intensification

DT θ (K) and wind (kt)



250–200-hPa PV (PVU), gradient (10^{-5} PVU m^{-1}), and 200-hPa wind speed (m s^{-1})



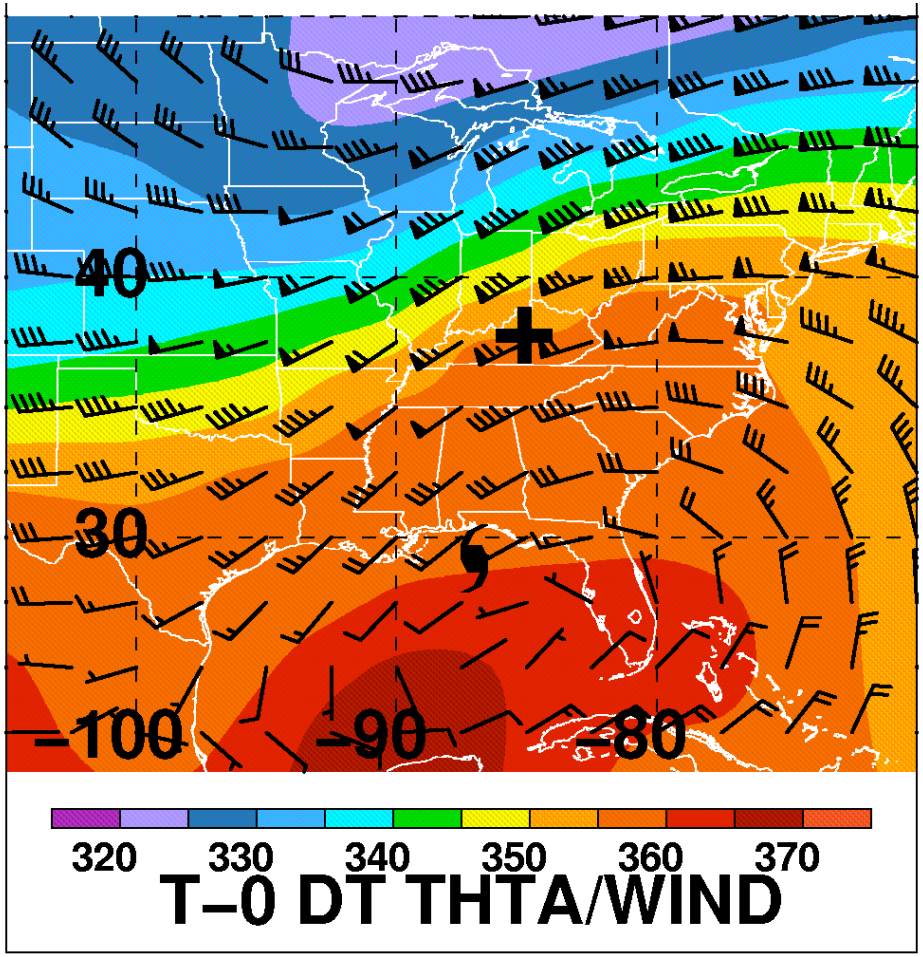
Composite analysis at 12-h prior to PRE initiation

+ = PRE initiation location; black TC symbol = median TC PRE-relative position

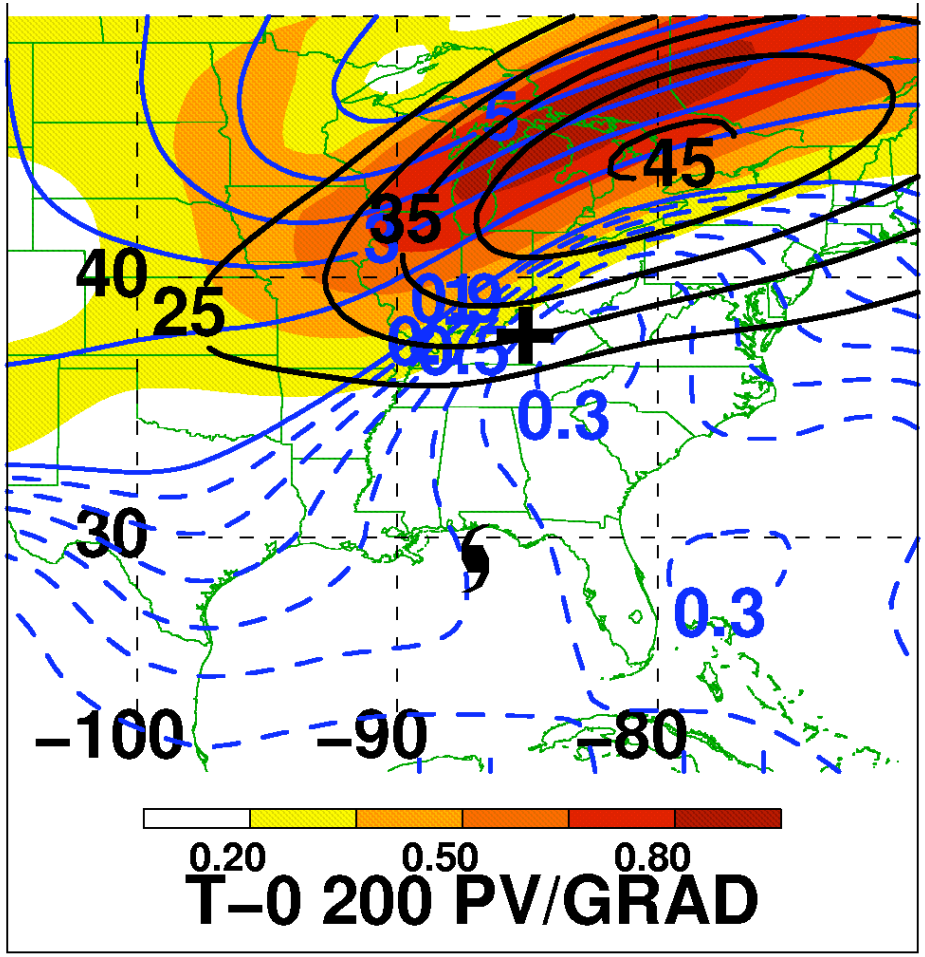
N=17

AC PRE Composite–Jet Intensification

DT θ (K) and wind (kt)



250–200-hPa PV (PVU), gradient (10^{-5} PVU m^{-1}), and 200-hPa wind speed (m s^{-1})



Composite analysis at PRE initiation

+ = PRE initiation location; black TC symbol = median TC PRE-relative position

PRE Statistics and Composite Summary

- PREs occurred anytime from June–October; were most common in August and September
- PREs typically occurred LOT and with AC jets
- PRE–TC separation distance ~1000 km; time lag ~36 h; longevity ~15 h
- PREs occur in favorable synoptic "envelope"
  - Equatorward jet-entrance region of 200 hPa jet
  - Western flank of 925-hPa θe ridge
  - East of 700-hPa trough
- PREs initiate as upper-level jet intensifies in response to increasing PV gradient between approaching upper-level trough TC-related diabatic outflow
- PREs are focused on the mesoscale by low-level frontogenetical forcing

PRE Summary Schematic for LOT and AC PREs

Fig. 5.1 from Cote (2007)

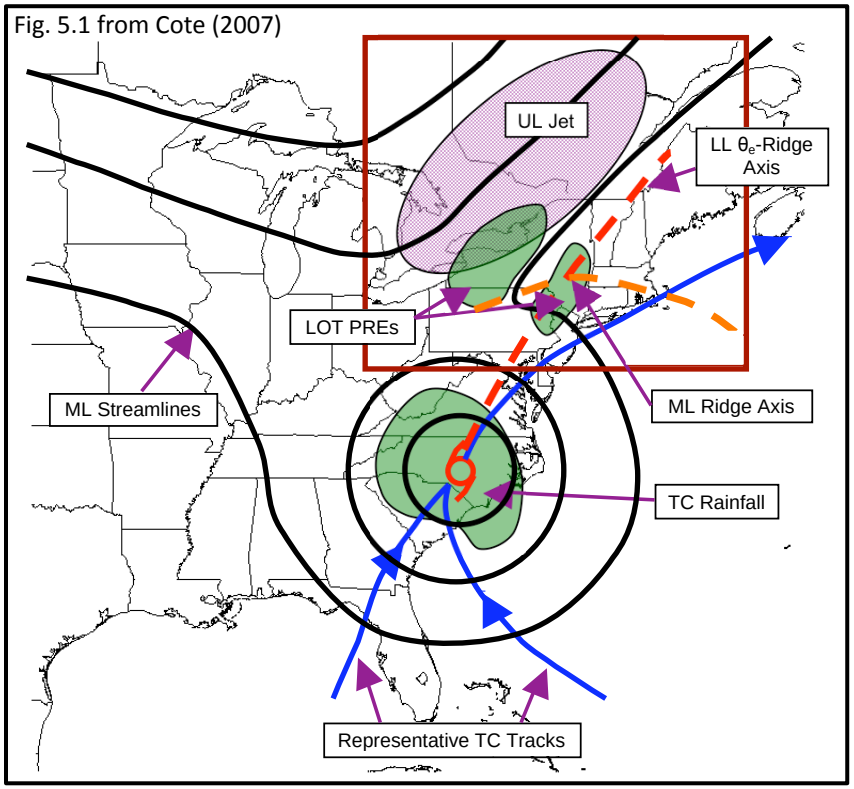
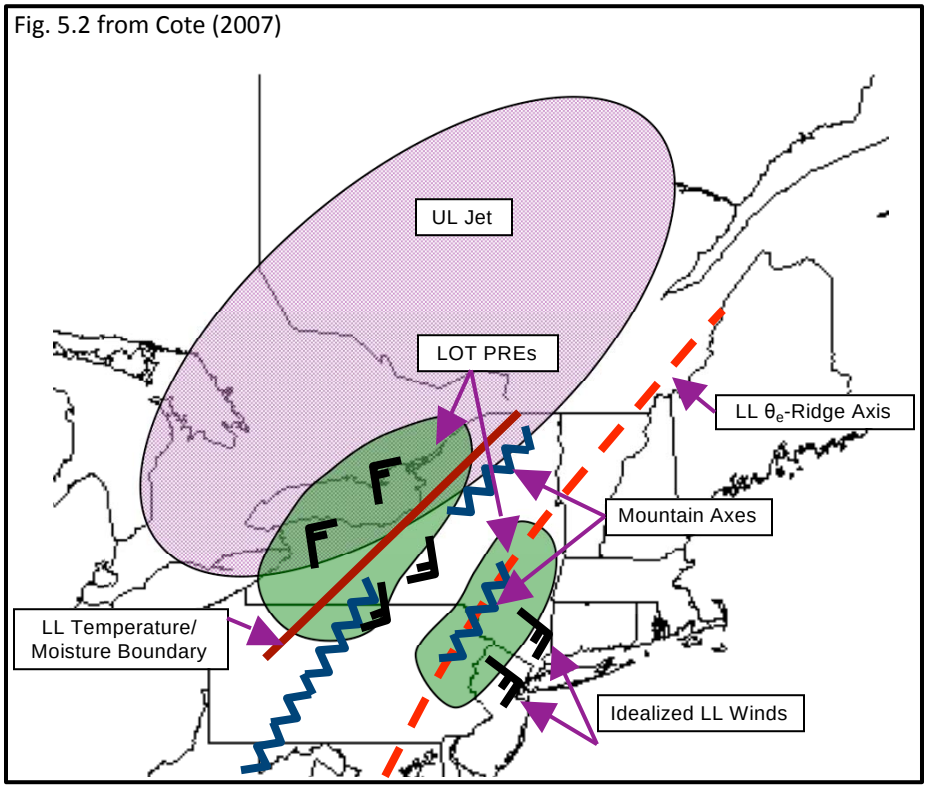


Fig. 5.2 from Cote (2007)



LL = 925 hPa; ML=700 hPa; UL=200 hPa

TC Erin PRE 18–19 Aug 2007
Case Analysis – AC PRE example

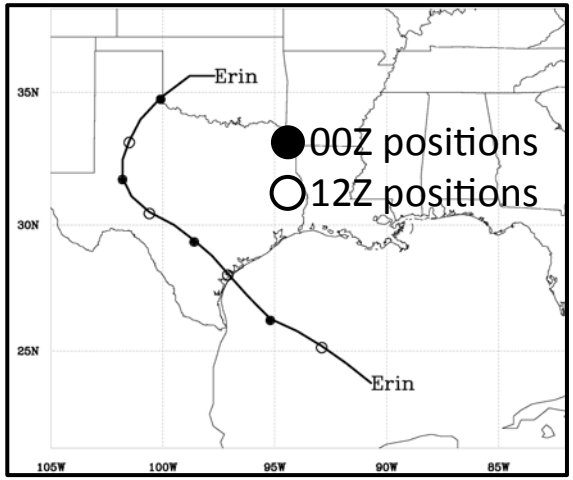
Photo from Minneapolis *Star Tribune*

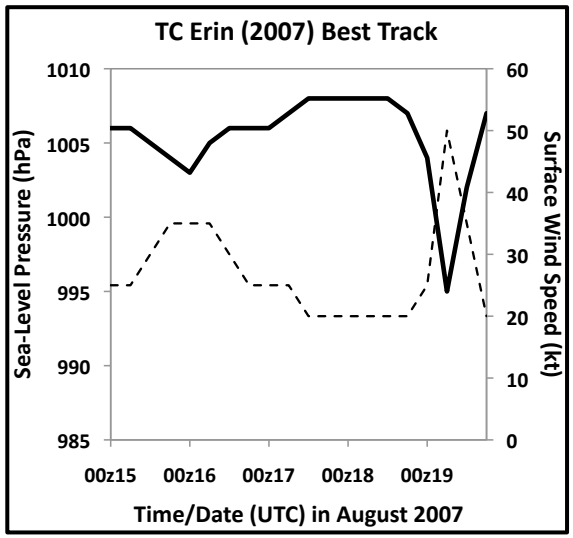
Photo from NWS La Crosse, WI

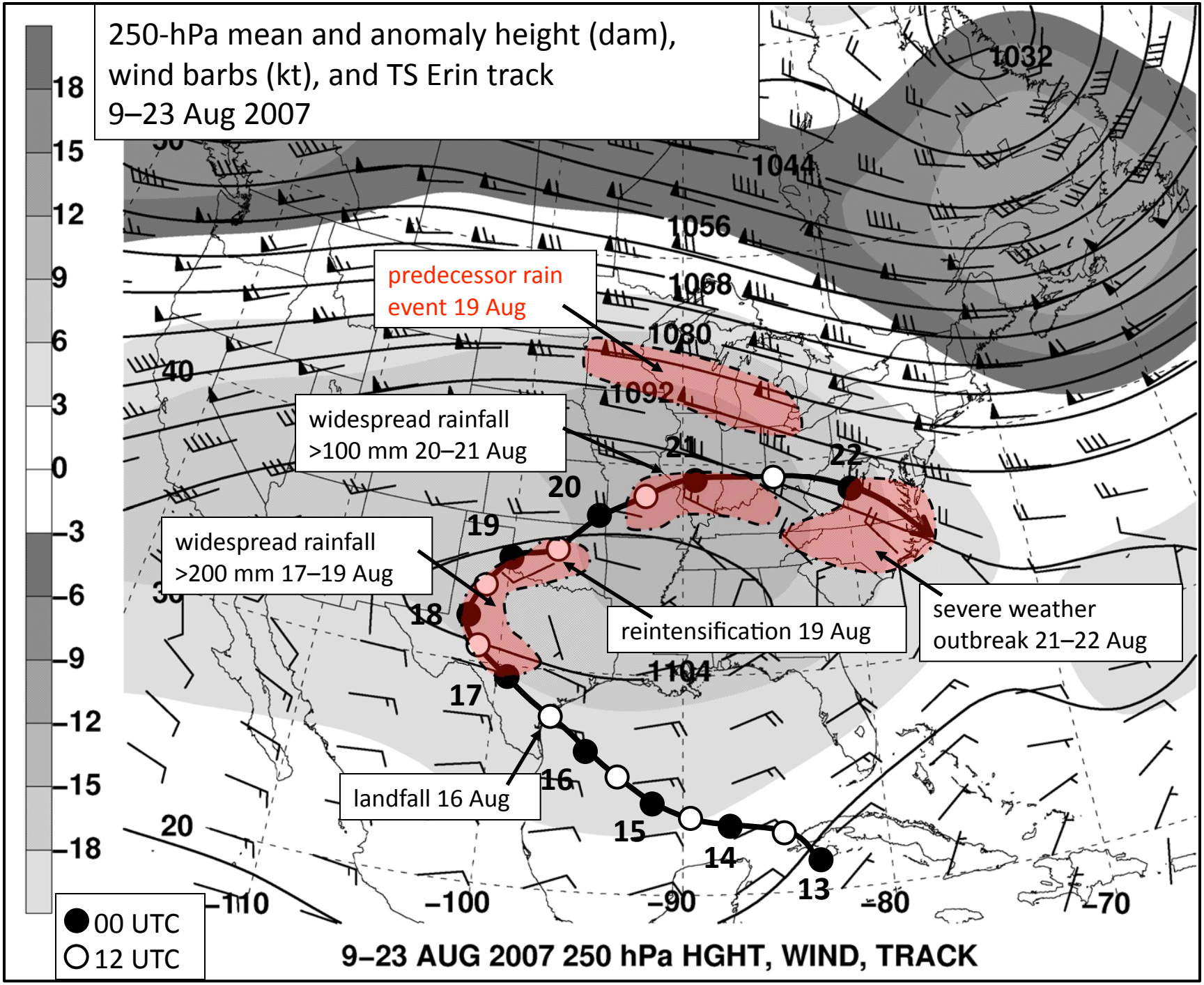
Datasets for Case Analysis

- 0.5° NCEP GFS analyses
- 20-km RUC analyses
- 2.5° NCEP–NCAR reanalysis
- WSR-88D level-III data from NCDC
- Radar and satellite imagery from NCAR case selection archive
- Soundings and surface data from UALB archive
- Precipitation data from the National Precipitation Verification Unit, NCDC ASOS archive, and the Weekly Weather and Crop Bulletin

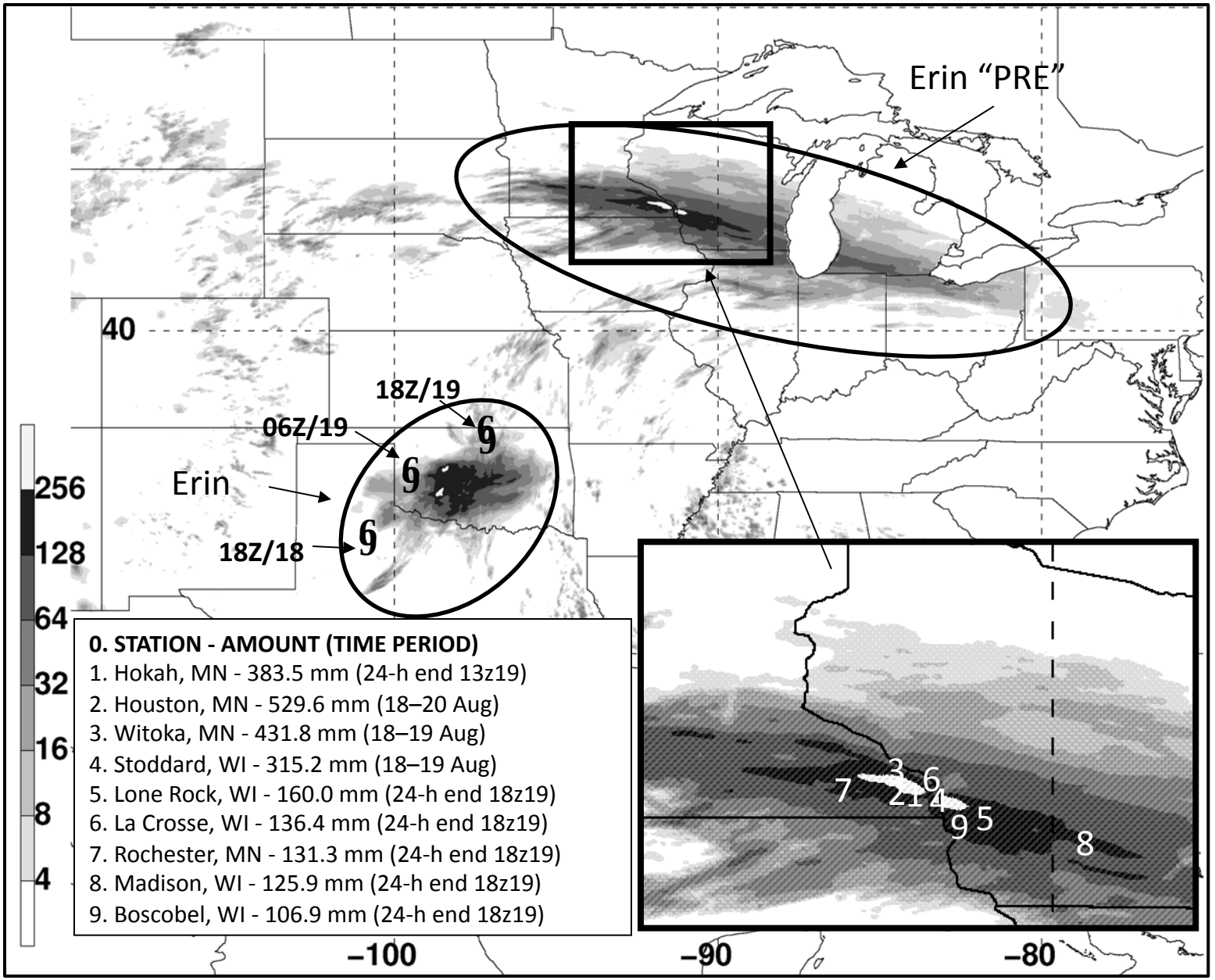
TC Erin (2007) NHC Best Track





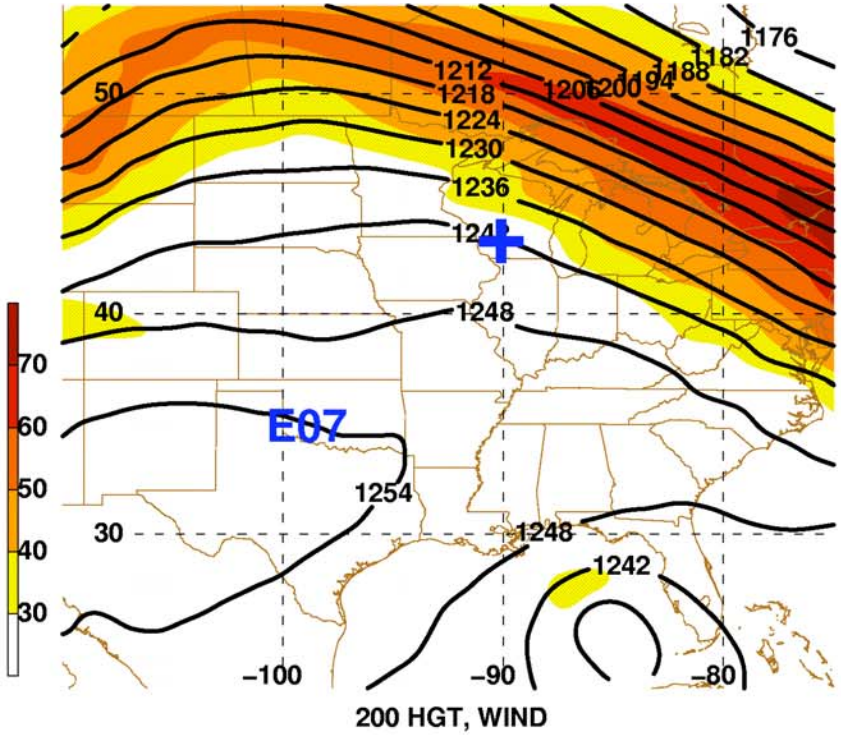

250-hPa mean and anomaly height (dam),
wind barbs (kt), and TS Erin track
9–23 Aug 2007
predecessor rain
event 19 Aug
widespread rainfall
>100 mm 20–21 Aug
widespread rainfall
>200 mm 17–19 Aug
reintensification 19 Aug
severe weather
outbreak 21–22 Aug
landfall 16 Aug
00 UTC
12 UTC
9–23 AUG 2007 250 hPa HGHT, WIND, TRACK

Total Precipitation (mm) 1800 UTC 18–1800 UTC 19 Aug 2007

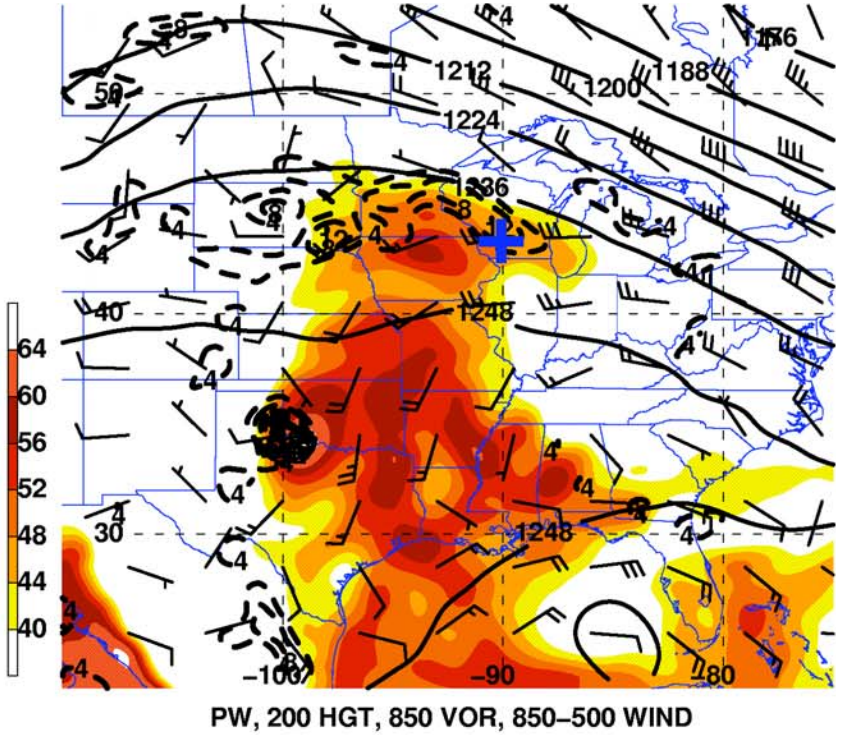


TC Erin PRE Analysis 0000 UTC 19 Aug

200-hPa h (dam), wind speed (m s^{-1}), 850-hPa ζ (10^{-5} s^{-1}), and TC Erin position



200-hPa h (dam), precipitable water (mm), 850–500-hPa mean wind (kt), and 850-hPa ζ (10^{-5} s^{-1})



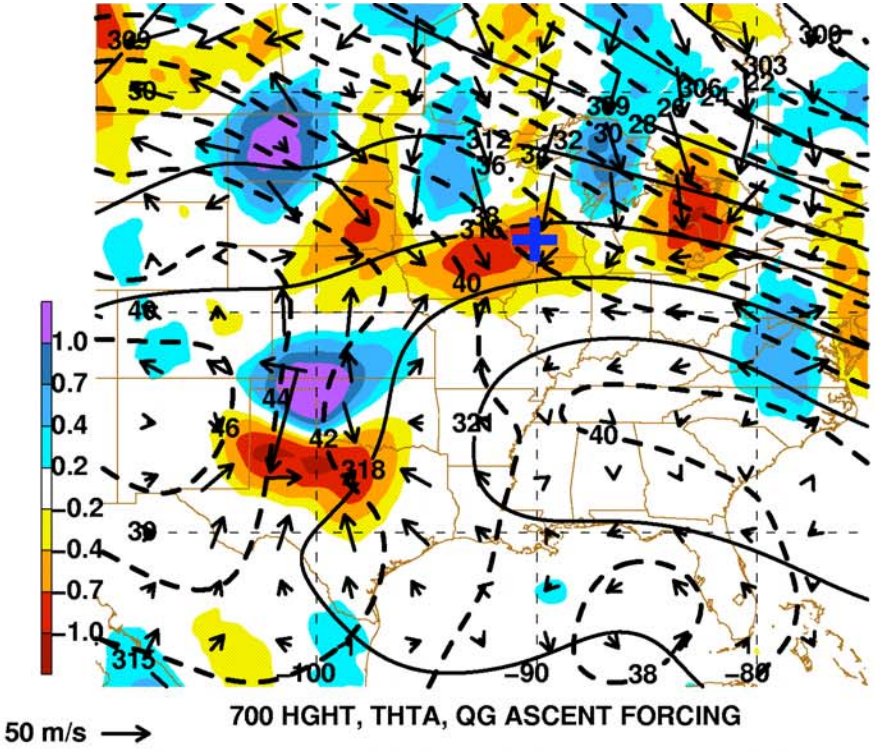
Analysis at time of PRE initiation

Data: 0.5° NCEP GFS analysis

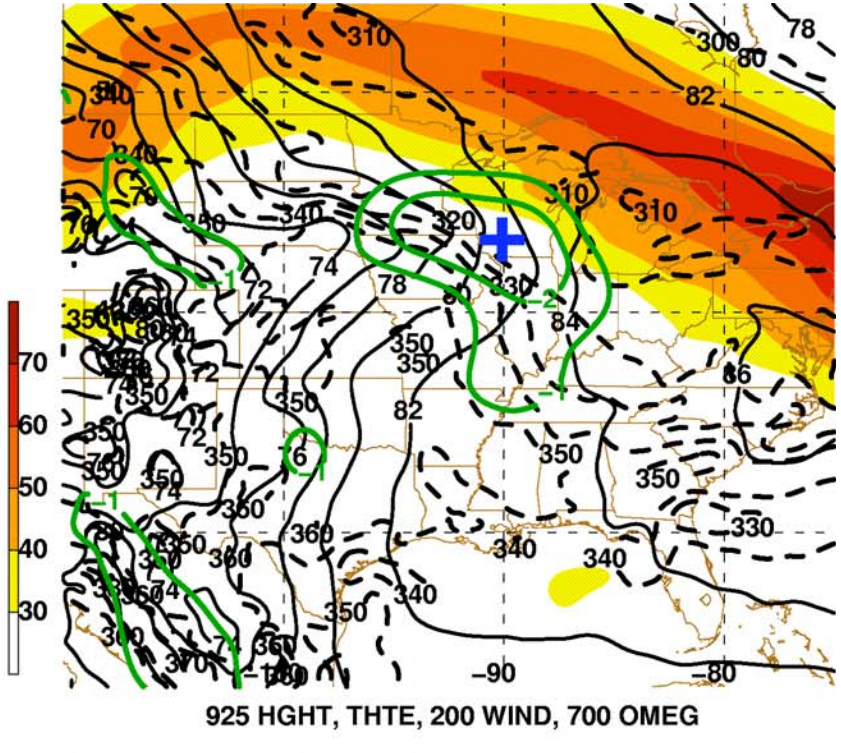
+ = PRE location

TC Erin PRE Analysis 0000 UTC 19 Aug

700-hPa h (dam), θ (K),
Q-divergence (10^{-12} K m^{-2} s^{-1}),
and Q-vectors (10^{-8} K m^{-1} s^{-1})



925-hPa h (dam) and θ_e (K),
200-hPa wind speed (m s^{-1}),
and 700-hPa ω (10^{-3} hPa s^{-1})



Analysis at time of PRE initiation
Data: 0.5° NCEP GFS analysis

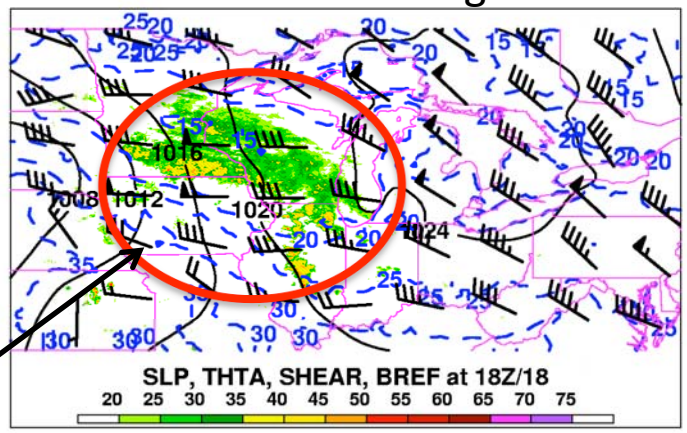
+ = PRE location

20-km RUC:
SLP (hPa),
Surface θ (°C),
0–6-km shear (kt),
BREF (dBZ)

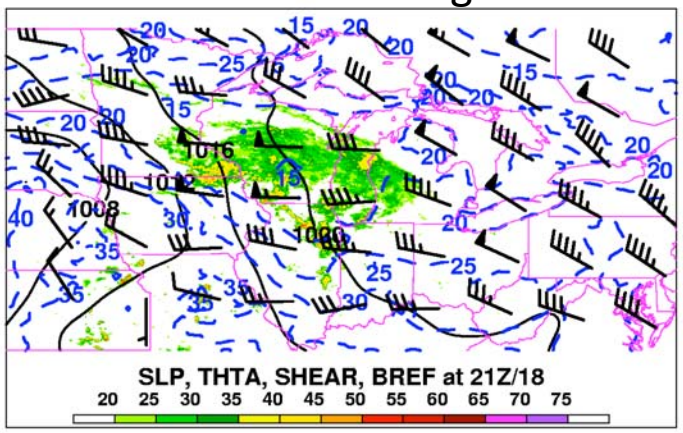
ongoing rain prior to arrival of Erin moisture

backbuilding cells after 00Z

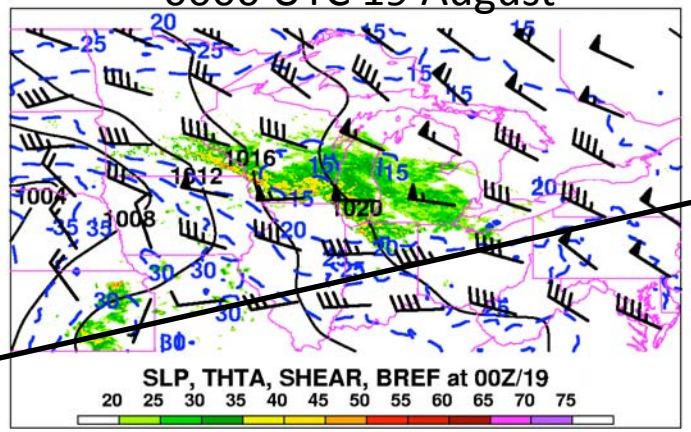
1800 UTC 18 August



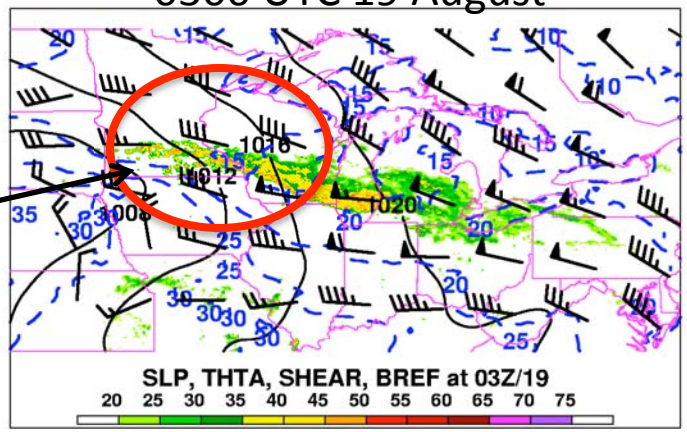
2100 UTC 18 August



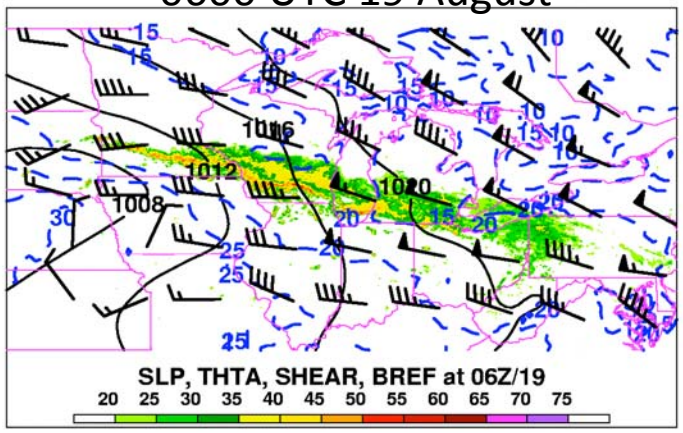
0000 UTC 19 August



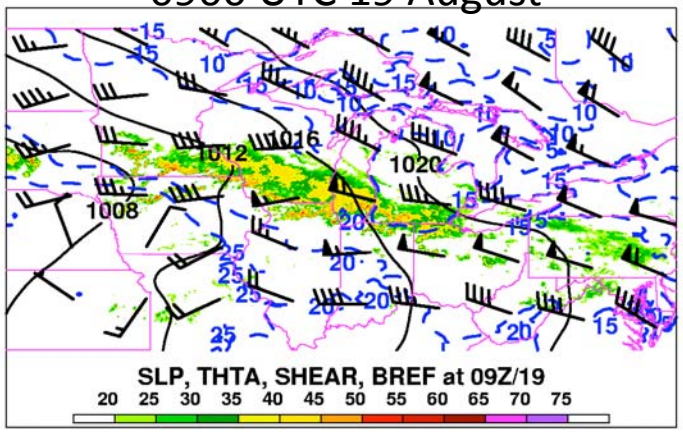
0300 UTC 19 August



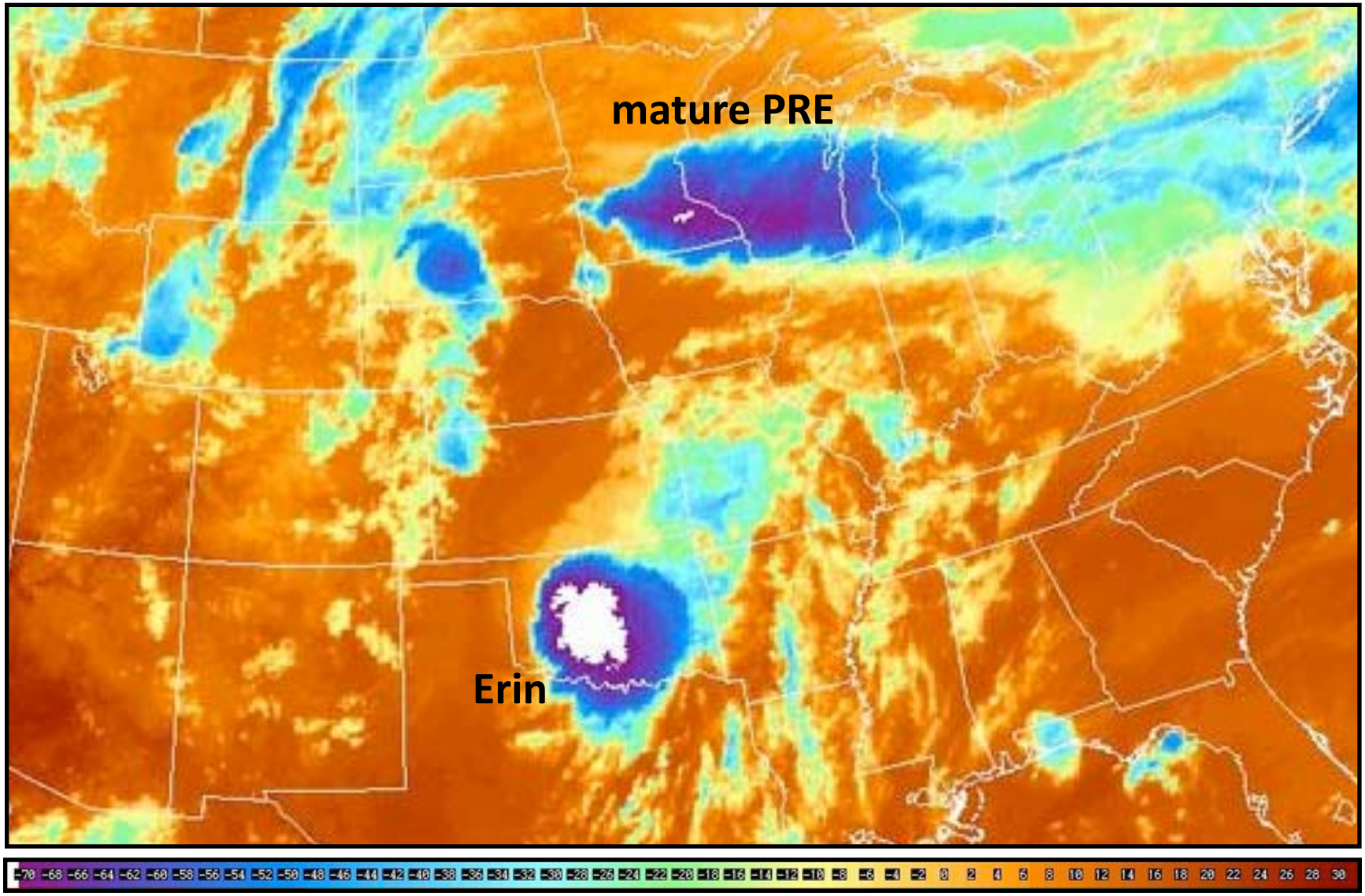
0600 UTC 19 August



0900 UTC 19 August

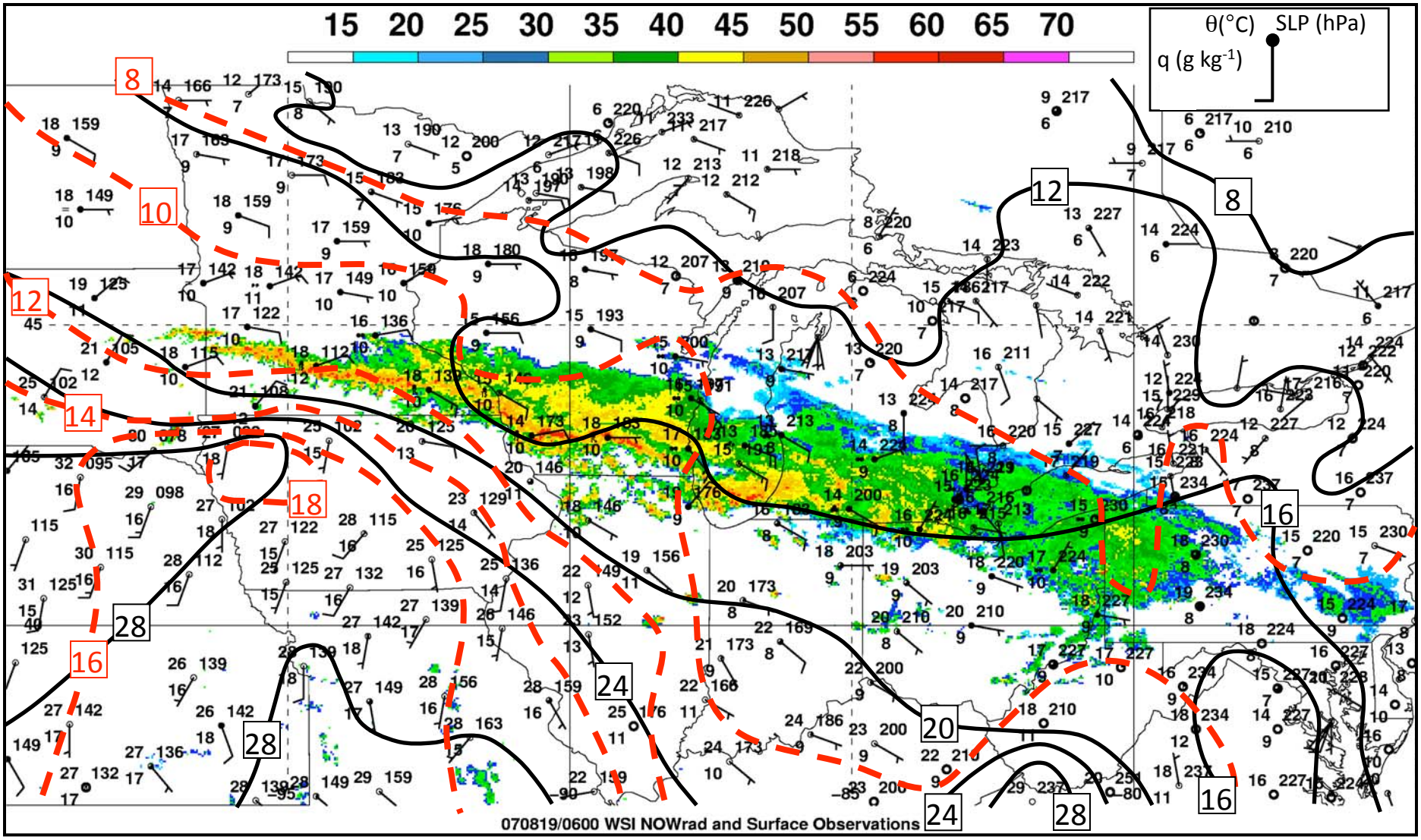


GOES-12 Infrared Image at 0600 UTC 19 Aug



Source: NCAR case selection archive

Manual Surface Analysis 06Z/19

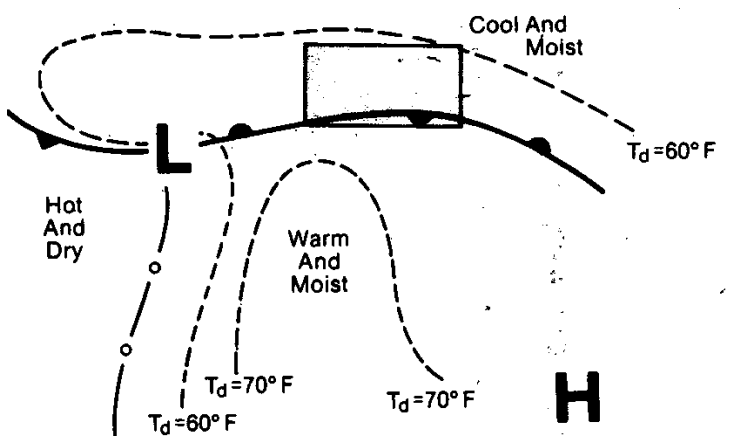


θ (°C)

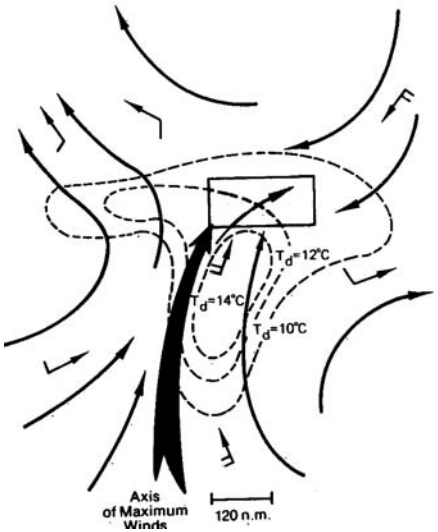
mixing ratio (g kg^{-1})

Frontal Events

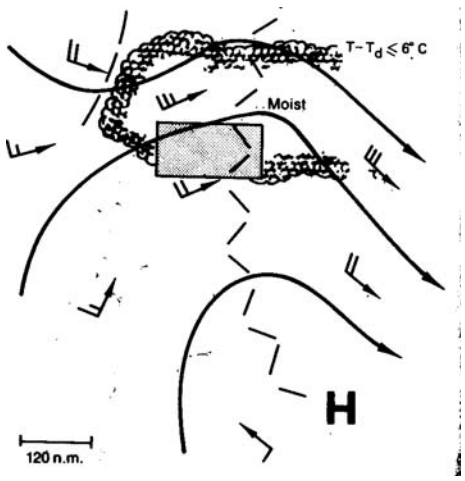
- Occur with a slow-moving or stationary front, often oriented E/W
- LLJ perpendicular to front, upper-level winds parallel
- Cells develop on cool side of front, move eastward down the front



surface



850 mb



500 mb

Maddox et al. (1979)

Frontal Events

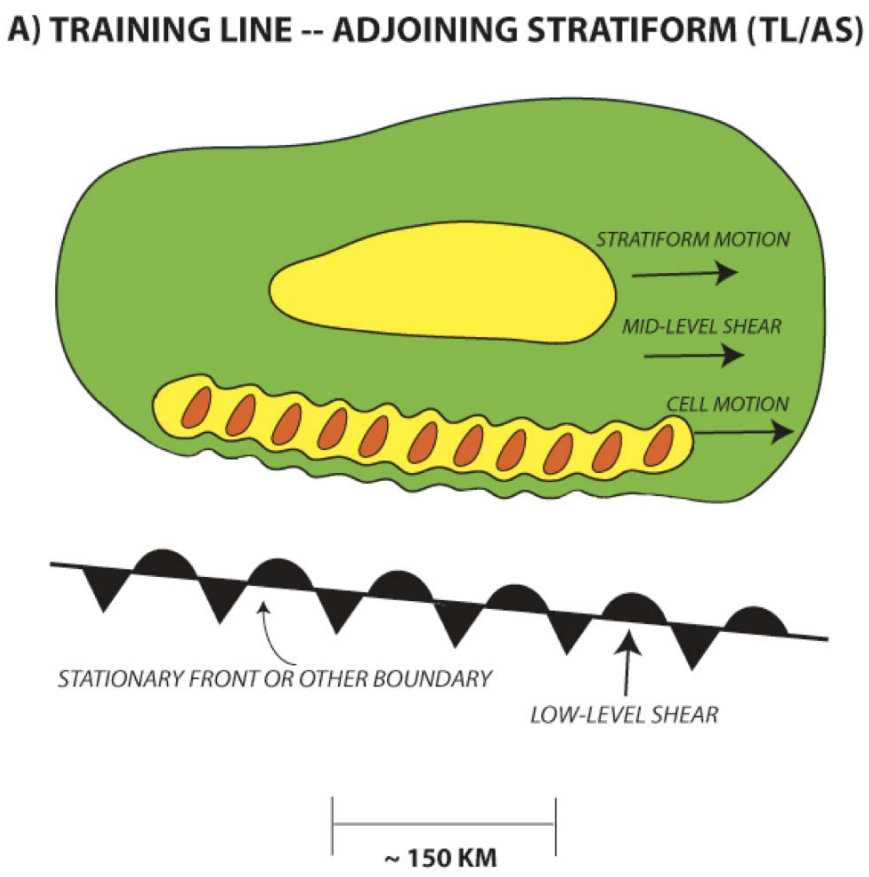
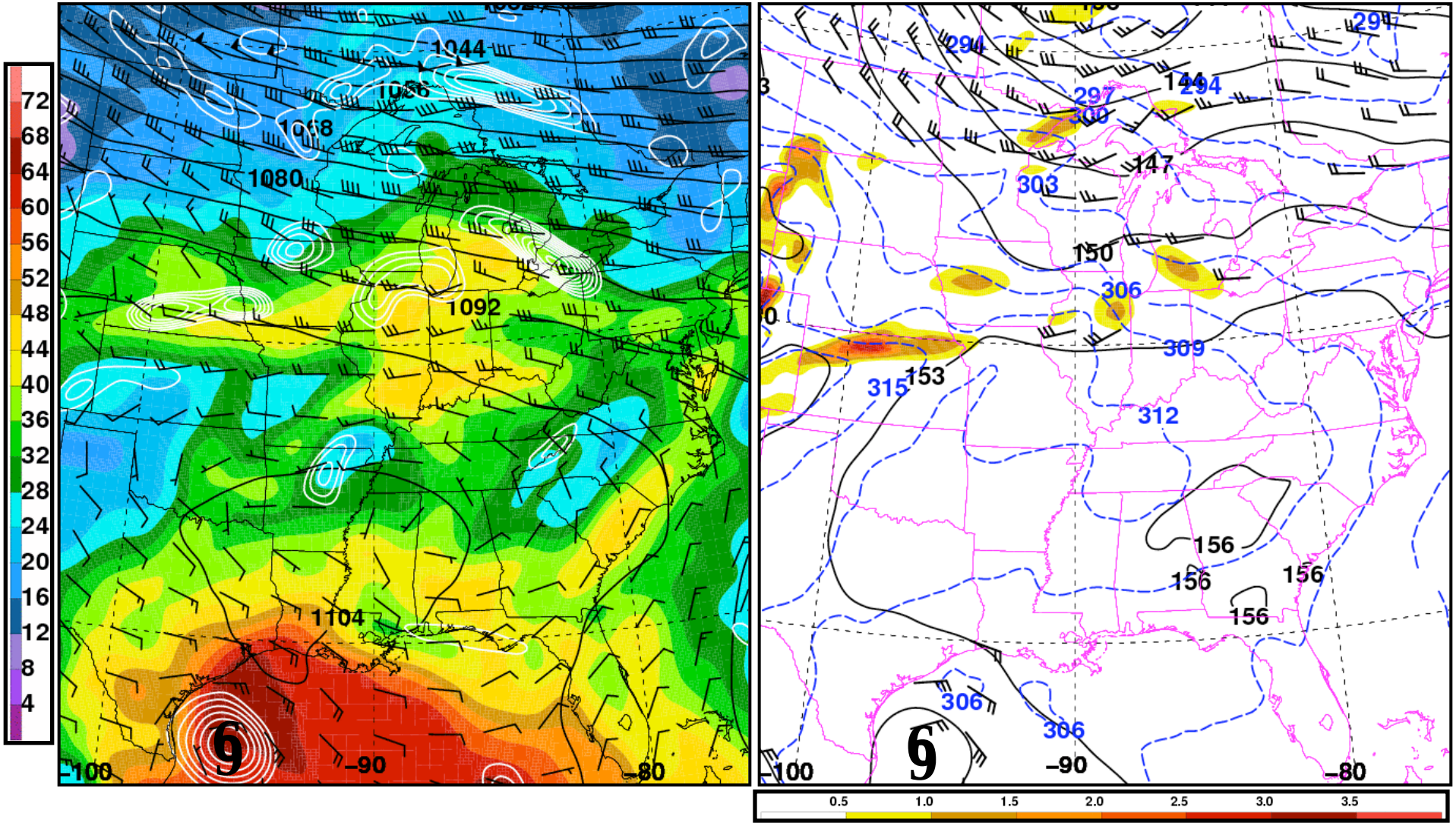


Fig. 3a from Schumacher and Johnson (2005)

250 hPa h (dam), 700 hPa ζ (10^{-5} s^{-1}), precipitable water (mm) 850–500 hPa mean wind (kt)

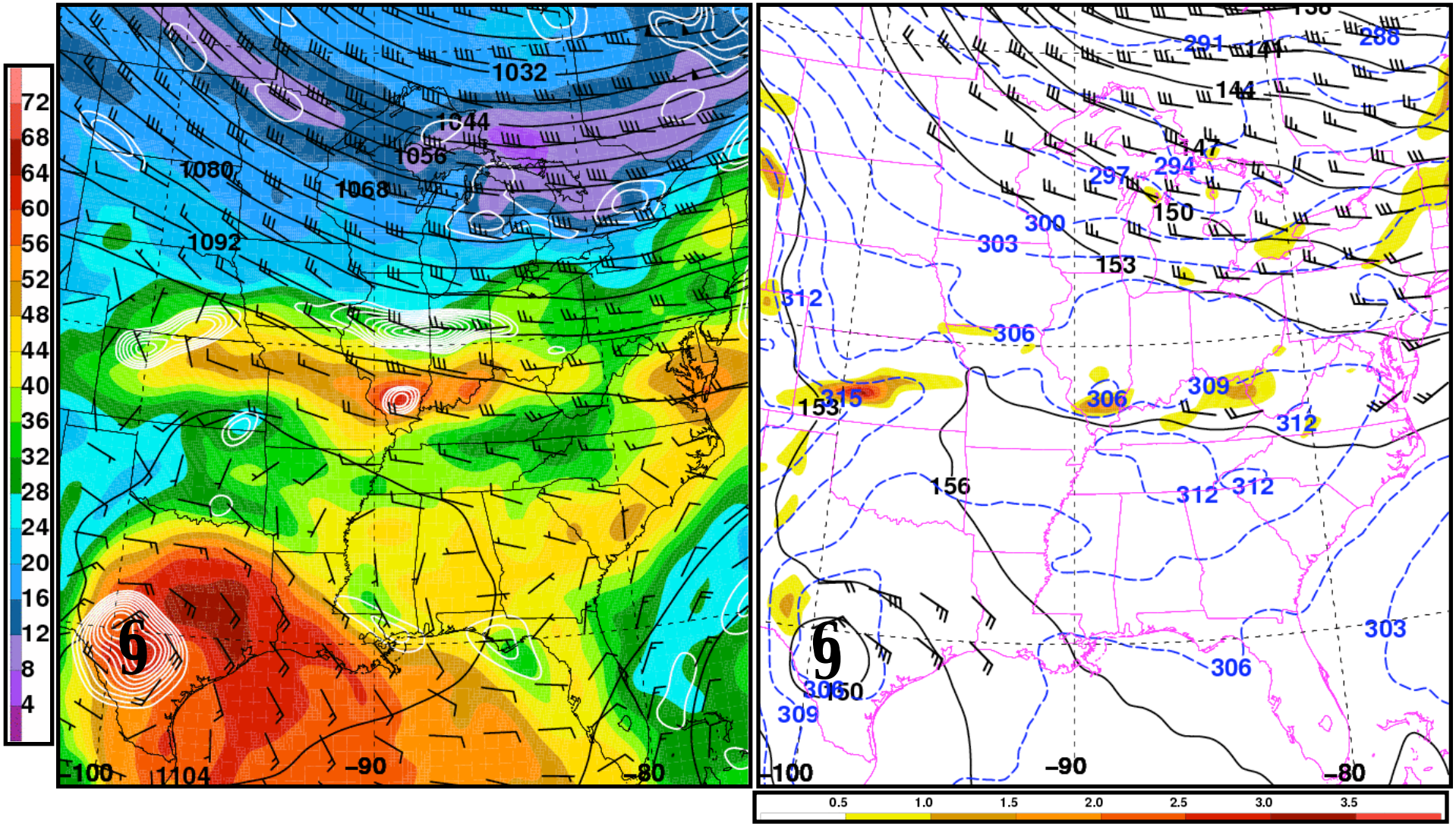
850 hPa h (dam), θ (K), wind (kt) 900–800 hPa frontogenesis [K (100 km)$^{-1}$ (3 h)$^{-1}$]



0000 UTC 16 Aug 2007

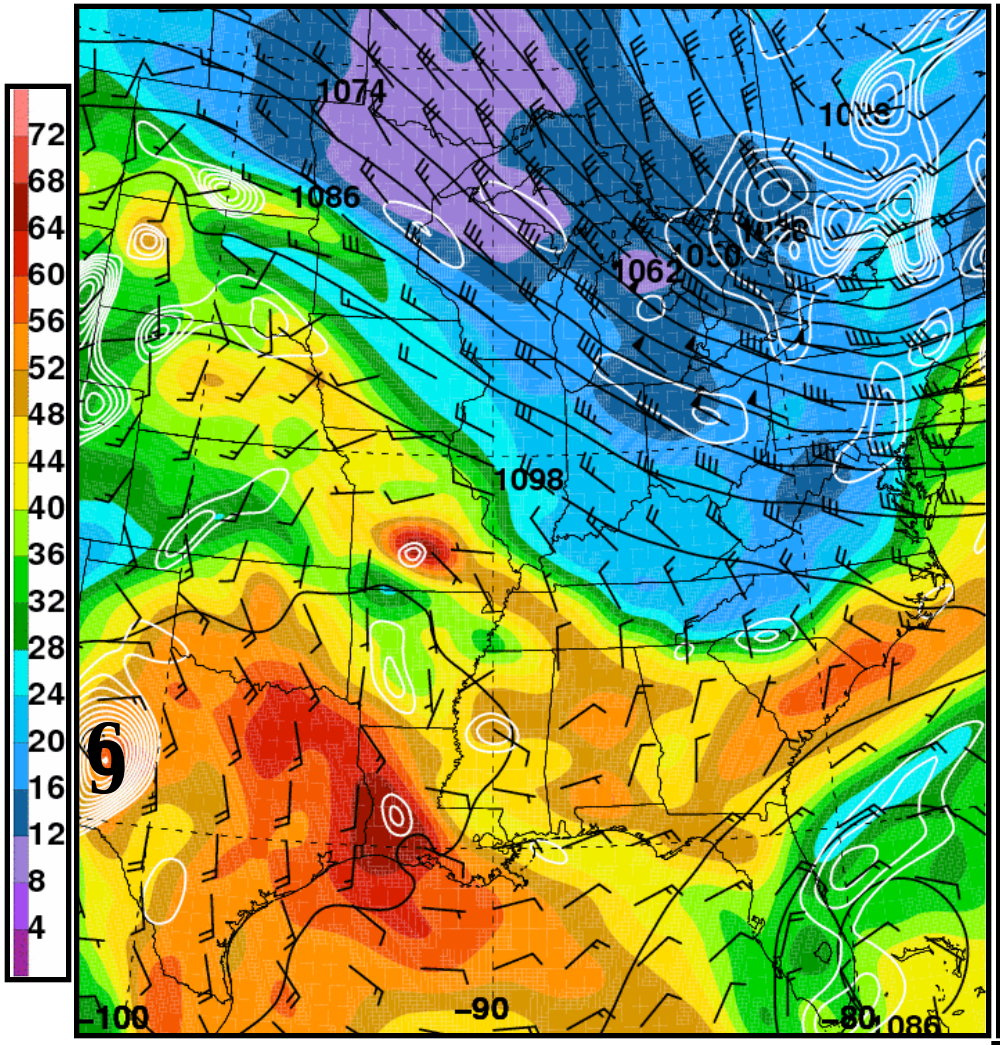
250 hPa h (dam), 700 hPa ζ (10^{-5} s^{-1}),
precipitable water (mm)
850–500 hPa mean wind (kt)

850 hPa h (dam), θ (K), wind (kt)
900–800 hPa frontogenesis
[K (100 km)$^{-1}$ (3 h)$^{-1}$]

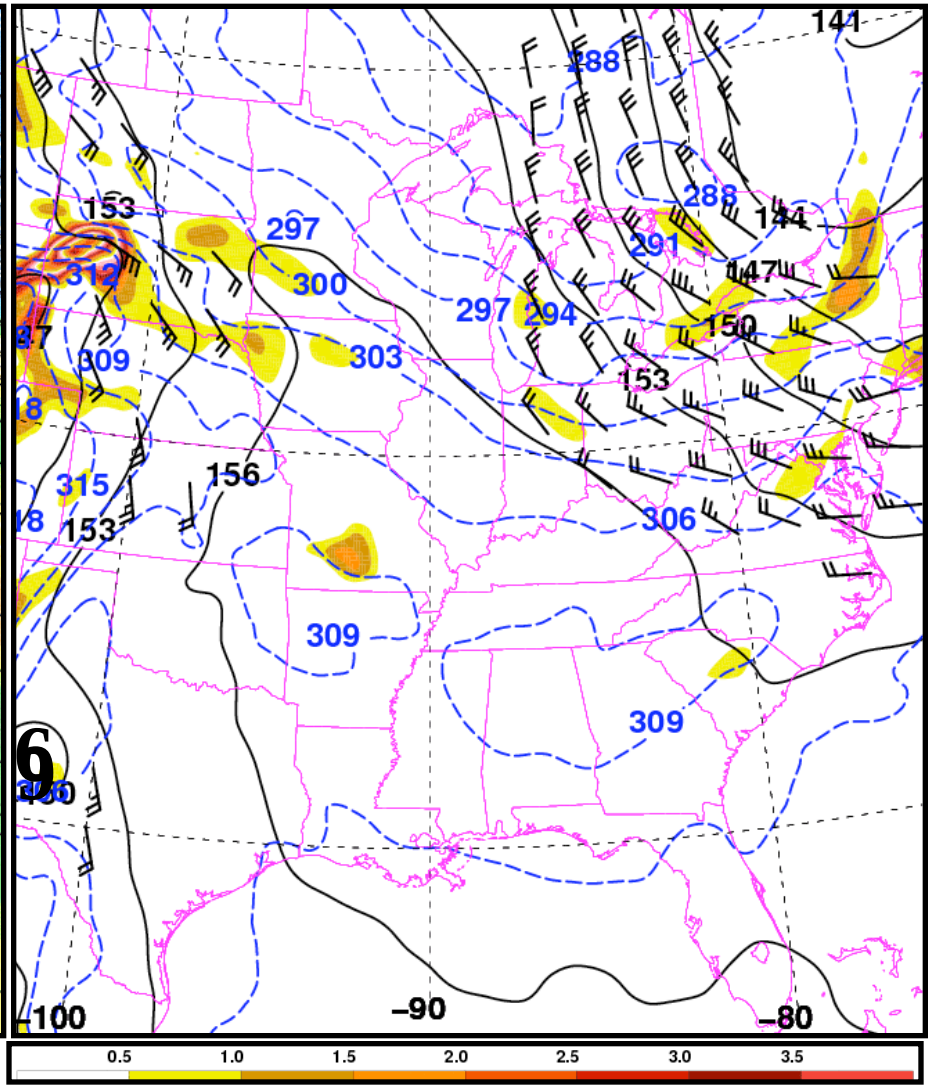


0000 UTC 17 Aug 2007

250 hPa h (dam), 700 hPa ζ (10^{-5} s^{-1}),
precipitable water (mm)
850–500 hPa mean wind (kt)



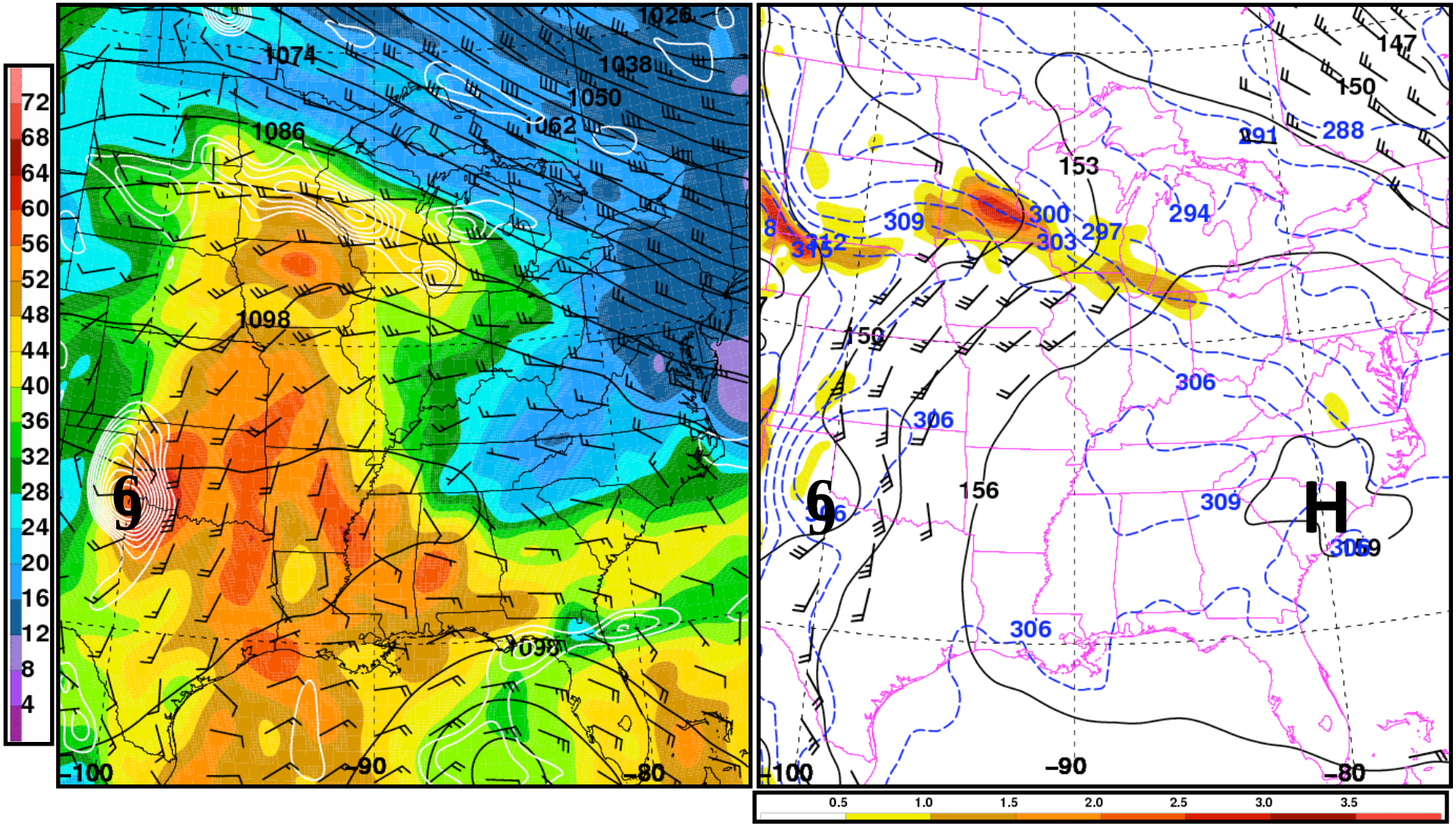
850 hPa h (dam), θ (K), wind (kt)
900–800 hPa frontogenesis
[K (100 km)$^{-1}$ (3 h)$^{-1}$]



0000 UTC 18 Aug 2007

250 hPa h (dam), 700 hPa ζ (10^{-5} s^{-1}),
precipitable water (mm)
850–500 hPa mean wind (kt)

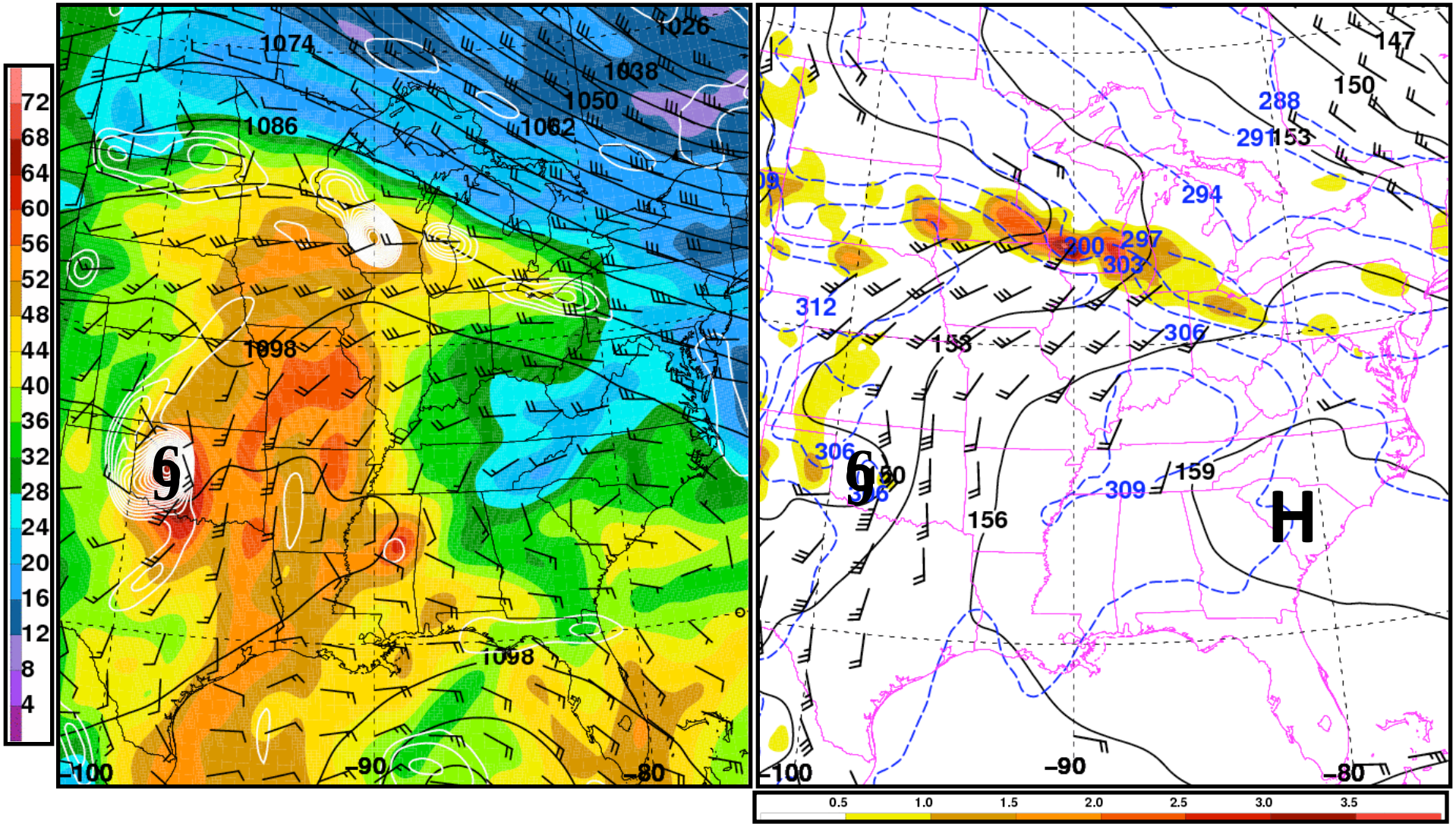
850 hPa h (dam), θ (K), wind (kt)
900–800 hPa frontogenesis
[K (100 km)$^{-1}$ (3 h)$^{-1}$]



0000 UTC 19 Aug 2007

250 hPa h (dam), 700 hPa ζ (10^{-5} s^{-1}),
precipitable water (mm)
850–500 hPa mean wind (kt)

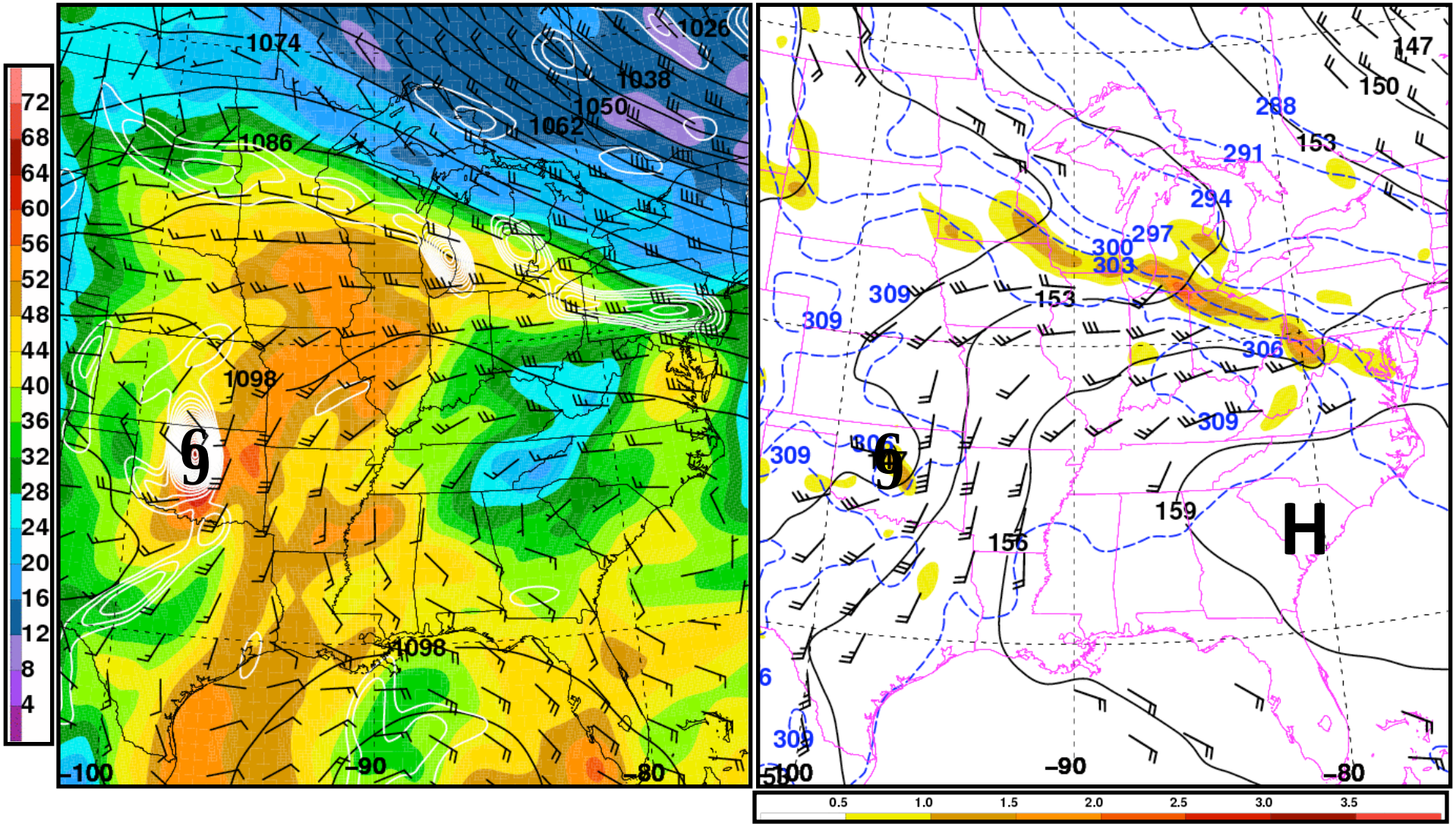
850 hPa h (dam), θ (K), wind (kt)
900–800 hPa frontogenesis
[K (100 km)$^{-1}$ (3 h)$^{-1}$]



0600 UTC 19 Aug 2007

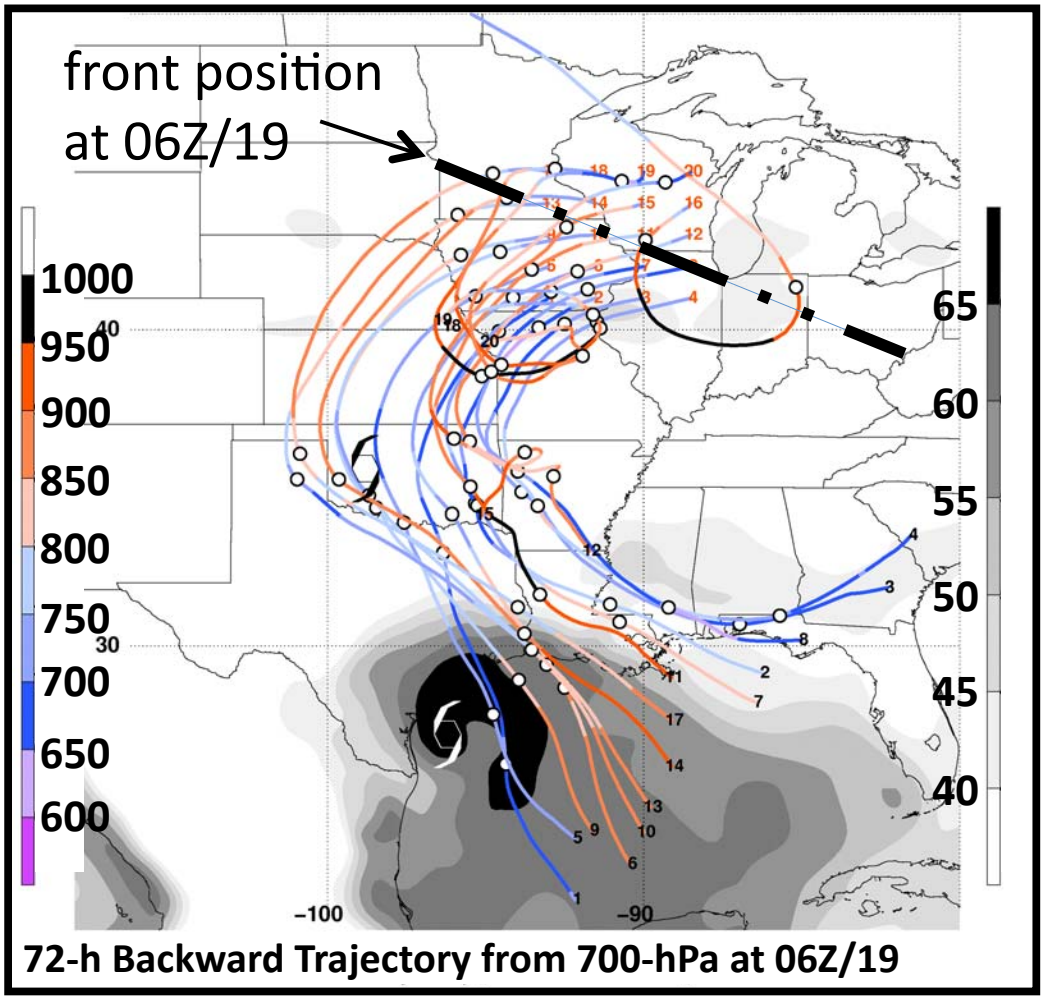
250 hPa h (dam), 700 hPa ζ (10^{-5} s^{-1}),
precipitable water (mm)
850–500 hPa mean wind (kt)

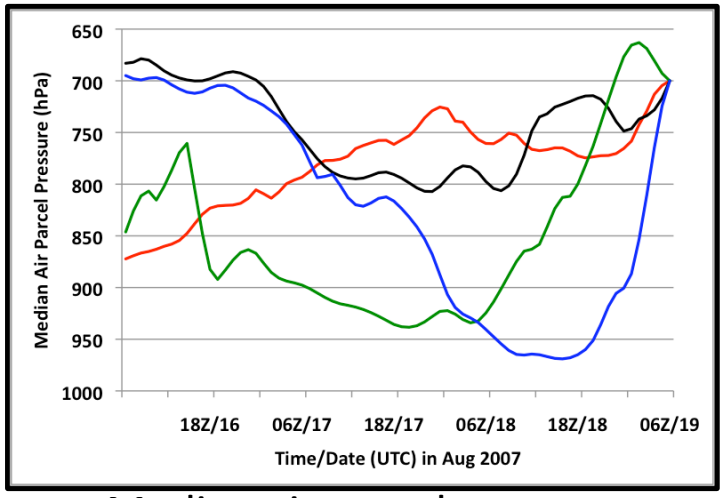
850 hPa h (dam), θ (K), wind (kt)
900–800 hPa frontogenesis
[K (100 km)$^{-1}$ (3 h)$^{-1}$]



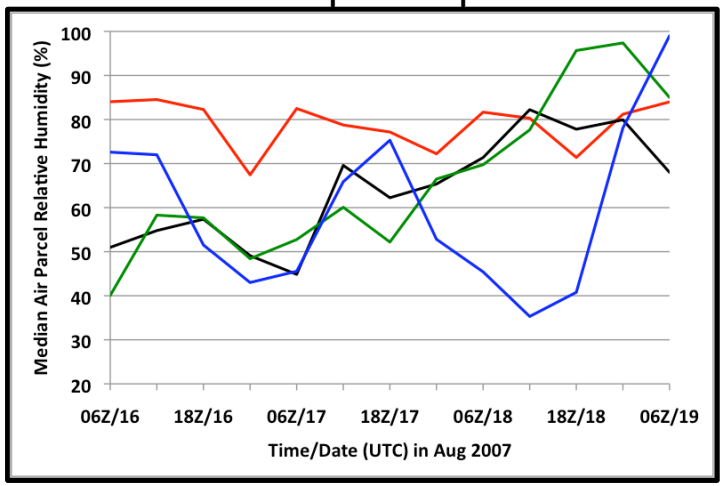
1200 UTC 19 Aug 2007

72-h backward trajectories beginning at 0600 UTC 19 Aug
Precipitable water analysis at 0600 UTC 16 Aug





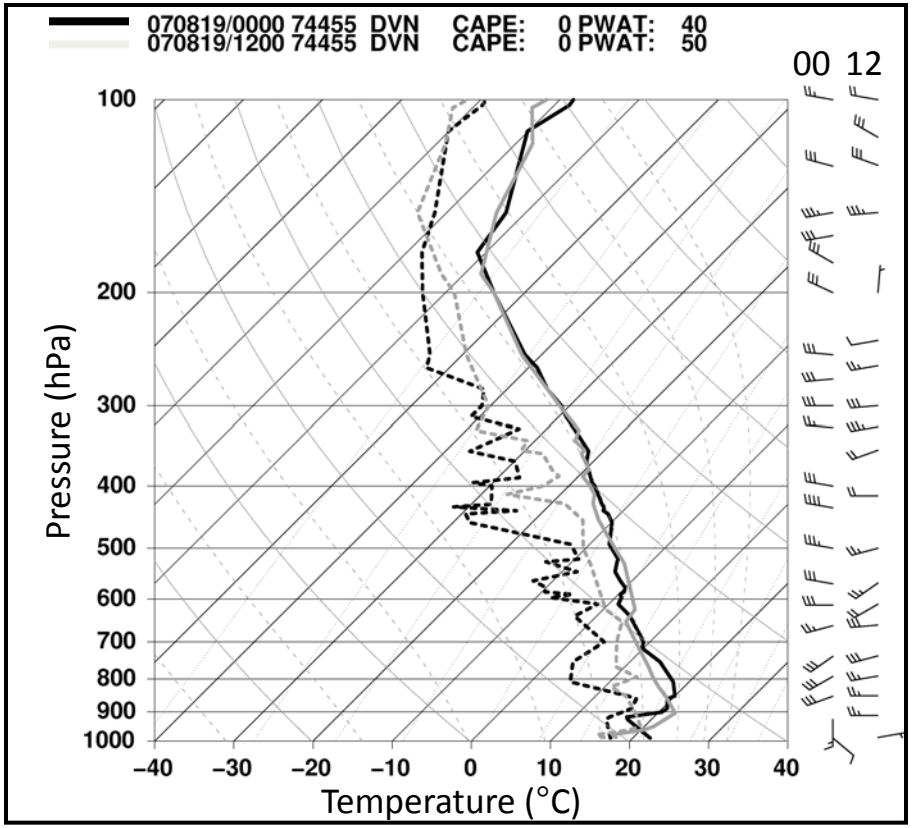
Median air parcel pressure



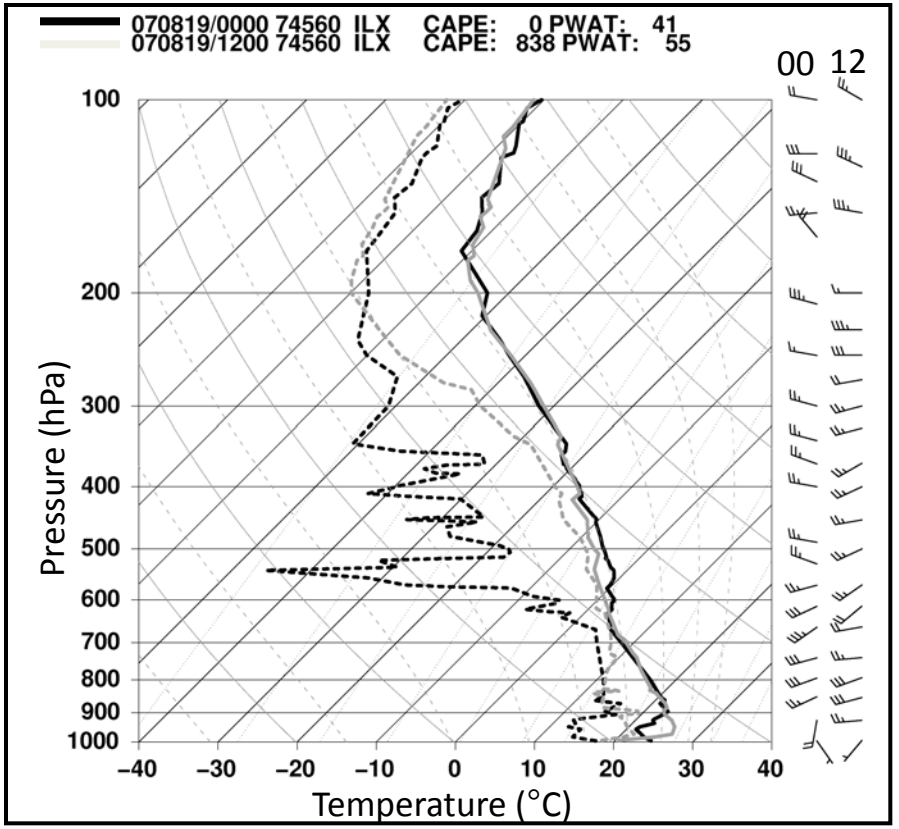
Median air parcel relative humidity

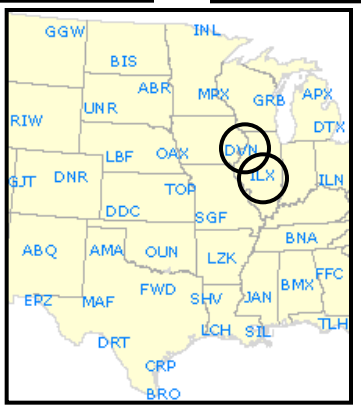
Source region: north of boundary; south of boundary
TC Erin plume; southeast US

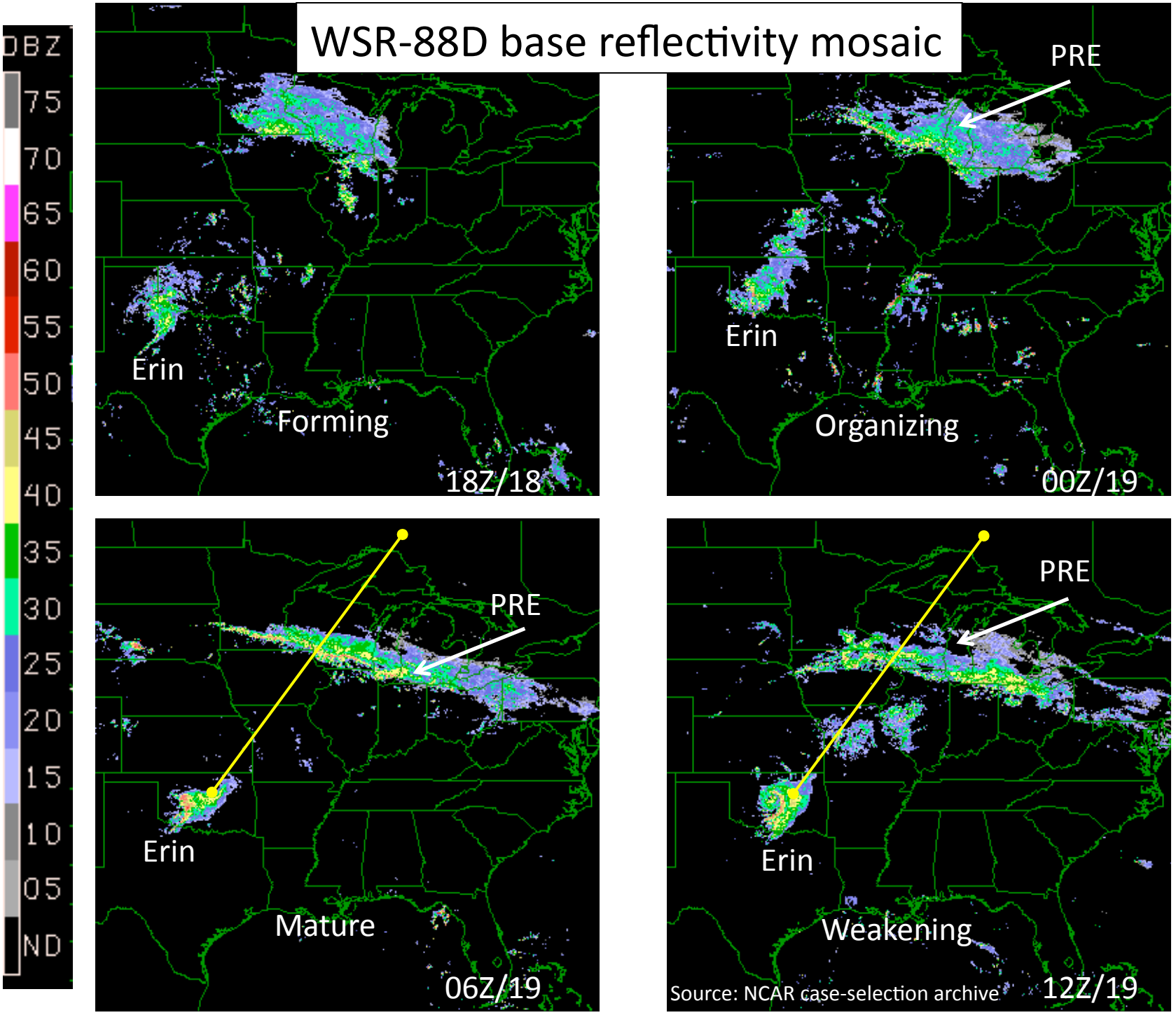
DVN sounding at 0000 and 1200 UTC 19 Aug



ILX sounding at 0000 and 1200 UTC 19 Aug

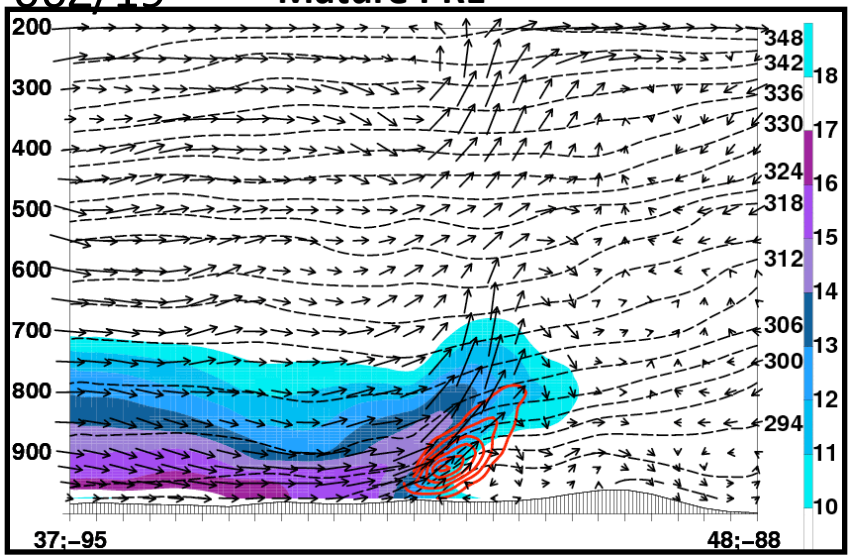




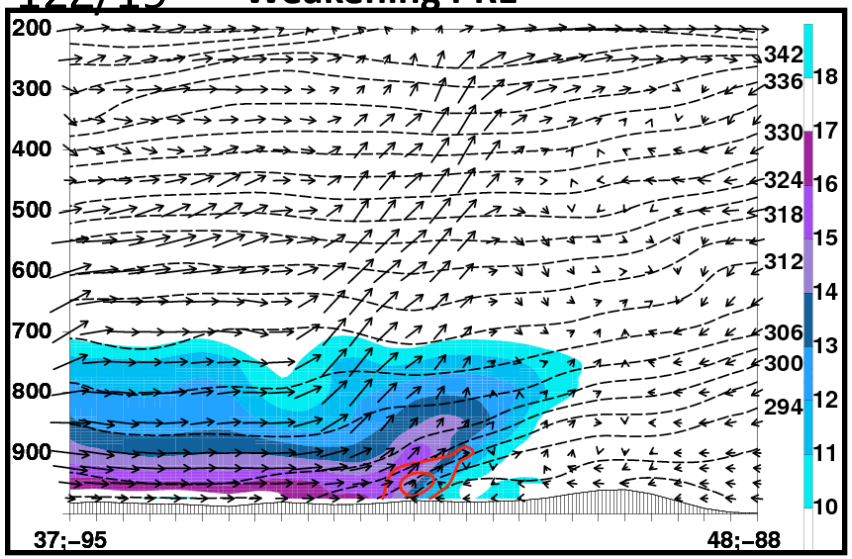

WSR-88D base reflectivity mosaic
DBZ
75
70
65
60
55
50
45
40
35
30
25
20
15
10
05
ND
Erin
Forming
18Z/18
PRE
Erin
Organizing
00Z/19
PRE
Erin
Mature
06Z/19
PRE
Erin
Weakening
12Z/19
Source: NCAR case-selection archive

Mixing ratio (g kg^{-1}), θ (K), tangent flow, frontogenesis [K (100 km)$^{-1}$ (3 h)$^{-1}$]

06Z/19 **Mature PRE**



12Z/19 **Weakening PRE**



q_v (g kg^{-1}), θ (K), tangent flow, frontogenesis [K (100 km)$^{-1}$ h^{-1}]

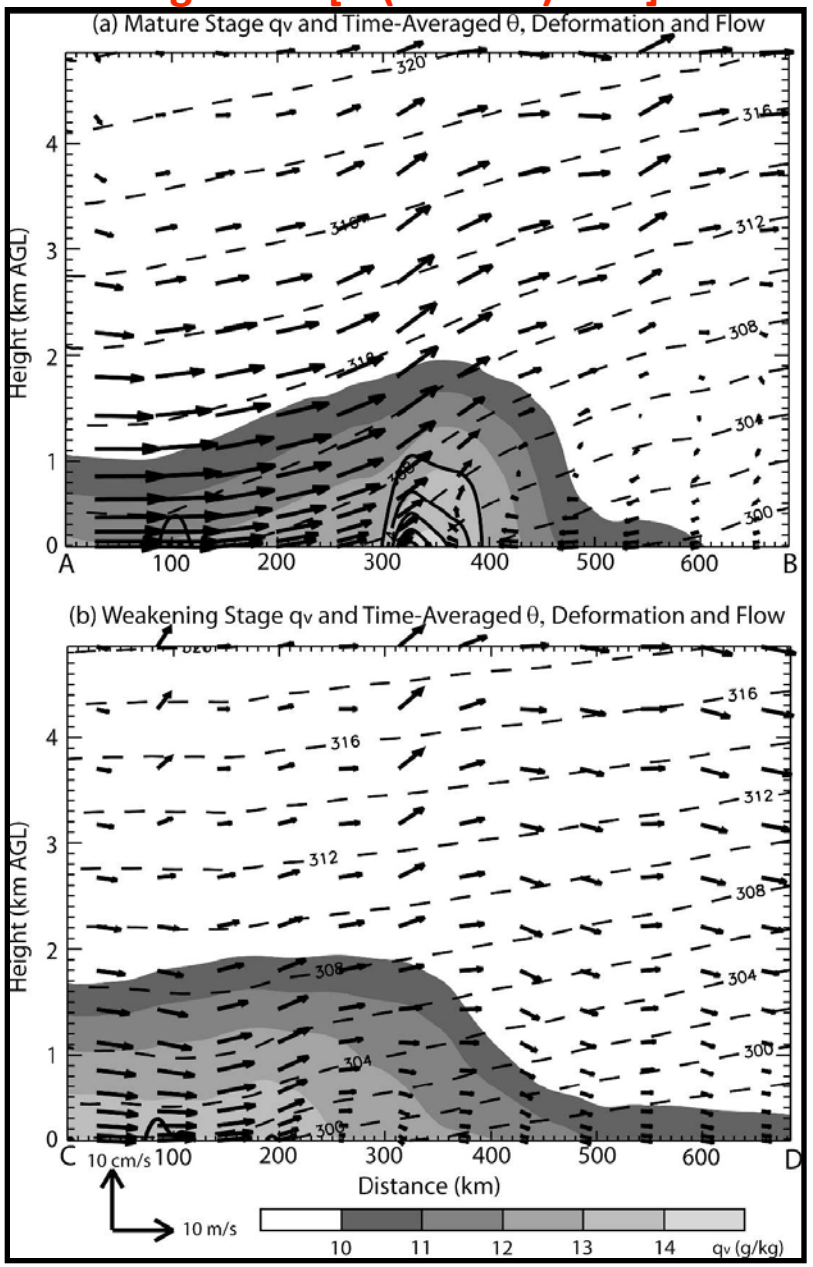


Fig. 16 from Trier et al. (2006)

Case Analysis Summary

- Widespread rains > 250 mm fell during 0000–1200 UTC 19 Aug over Wisconsin and the southern Great Lakes region
- Deep tropical moisture transport from TS Erin enhanced precipitation rate
- TS Erin PRE occurred in region of focused ascent over and north of baroclinic zone within equatorward jet-entrance region
  - Linkage to, e.g., Maddox et al. (1979), Uccellini et al. (1979), and Schumacher and Johnson (2005)

Case Analysis Summary

- Poleward advection of moisture likely aided by strong low-level southerly flow east of TS Erin
- Strong low-level southerly flow driven by increasing height gradient between TS Erin and strengthening ridge over southeast U.S.
- Low-level frontogenetical forcing maximized during overnight hours and provided a focus for vigorous ascent during mature stage of PRE
  - Linkage to, e.g., Trier et al. (2006)