TC TORNADOES and SPC FORECASTS in TC SITUATIONS

Roger Edwards & Harry Weinman &

Storm Prediction Center
Norman, Oklahoma

METR 4403/5403: Applications of Meteorological Theory to Severe-Thunderstorm Forecasting

TC HERMINE TORNADOES HIT DALLAS

TC MUJIGAE TORNADOES HIT CHINA

Seven dead and 223 injured as tornadoes brought by Typhoon Mujigae ravage China's Guangdong province

Mimi Lau
mimi.lau@scmp.com

PUBLISHED : Monday, 05 October, 20
UPDATED : Tuesday, 06 October, 2

One of the tornadoes that struck Guangdong province on Sunday. Photo: SCMP Pictures

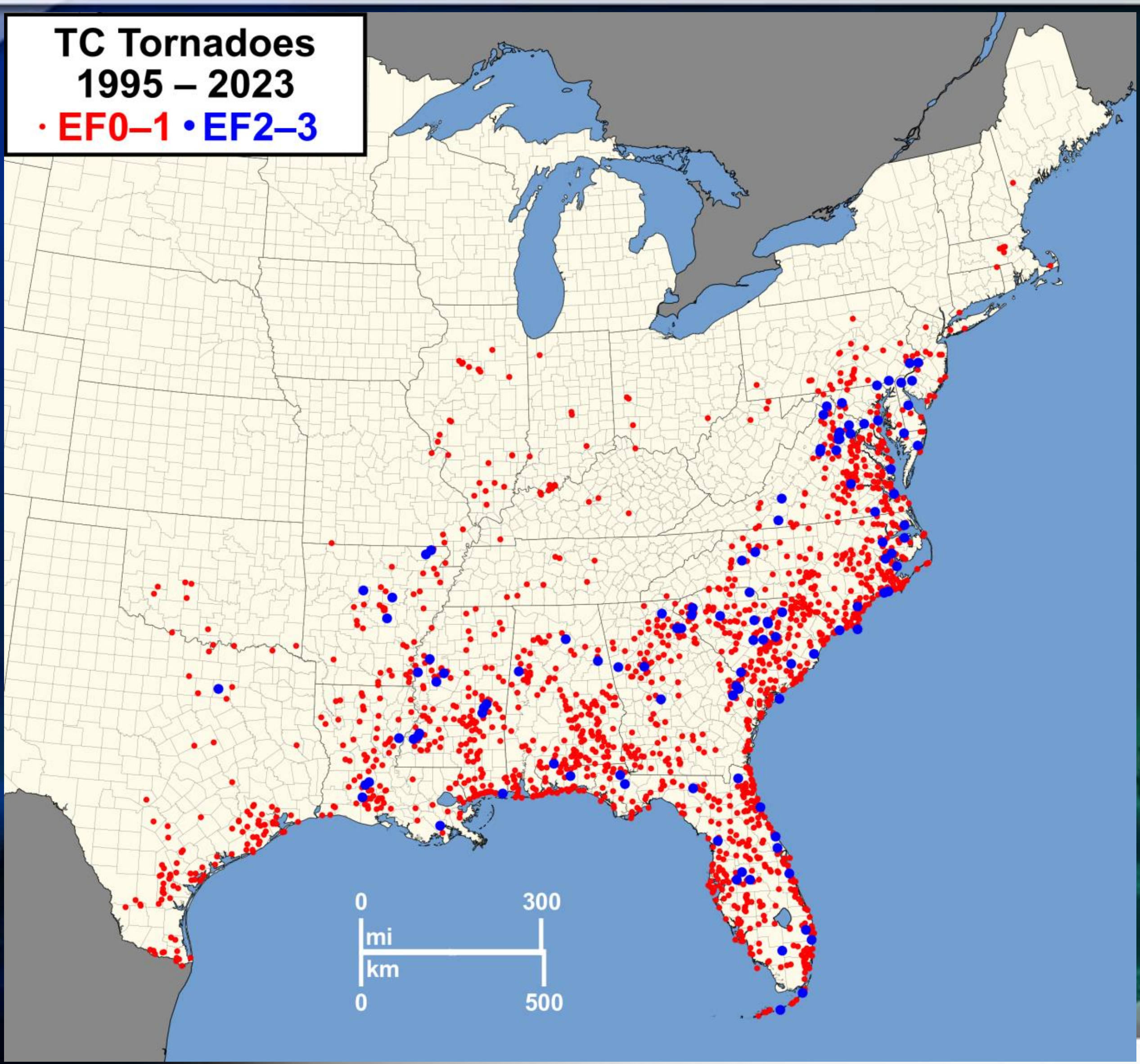
At least seven people were killed and 16 were reported missing in Guangdong on Sunday after Typhoon Mujigae and the tornadoes it generated ravaged the province, cutting power, water supplies and communications.

Six killed by 2 tornadoes (3 each).
One killed on boat in typhoon itself.
Image courtesy South China Morning Post.

TC TORNADO FACTS & CLIMATOLOGY

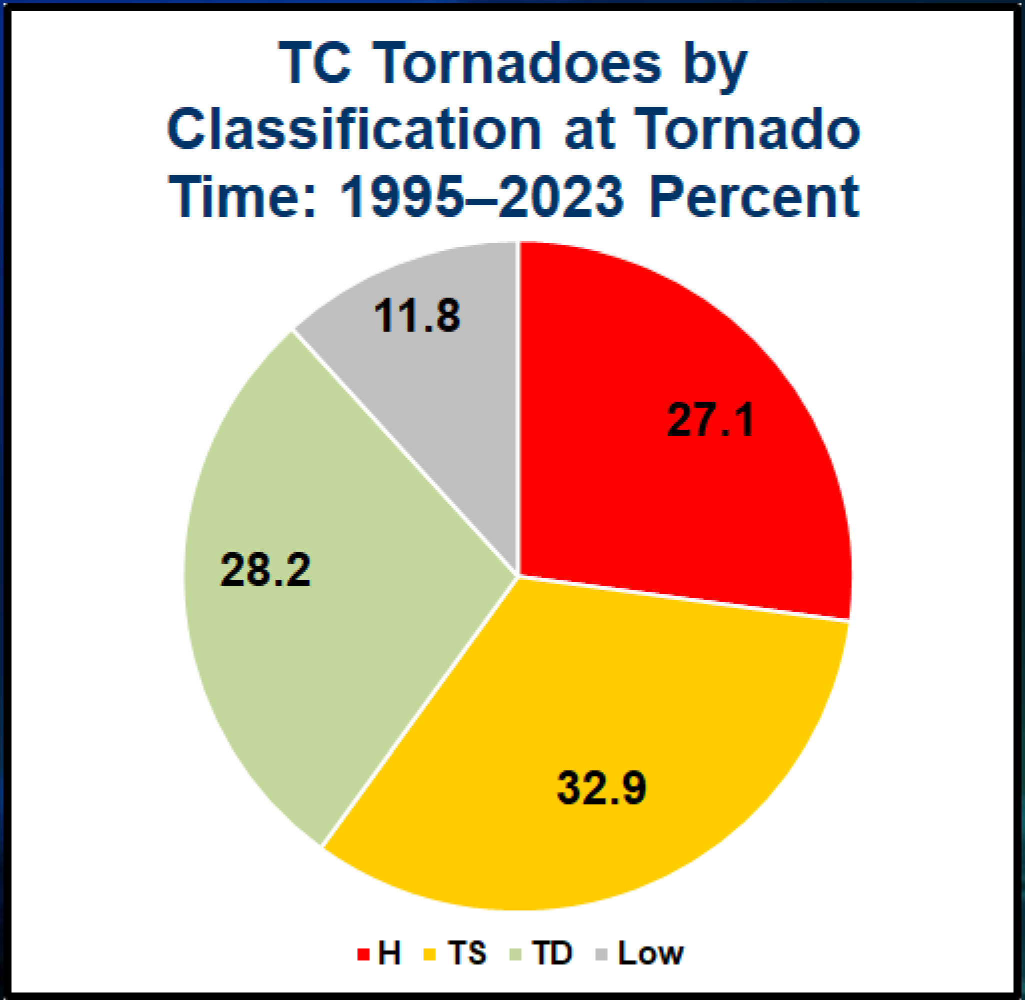
- MOST COMMON IN <50-kt WIND AREA
- MOST COMMON NNW-NE-SE OF CENTER
- MOST COMMON AND DAMAGING FROM MINI-SUPERCELLS (EF0-EF3, TWO F4S SINCE 1950)
- OCCASIONALLY REPORTED FROM NON-SUPERCELL RADAR FEATURES (WEAK – EF0-EF1)
- SHARP DECREASE >500 km FROM COASTS
- MORE COMMON DIURNALLY
- OCCUR OVER WATER AND CAN MOVE ASHORE
- OCCUR IN EVERY STAGE OF CLASSIFICATION
- DETAILED DISCUSSION IN EDWARDS (2012), EJSSM

TC TORNADO FACTS & CLIMATOLOGY



Geography of TCTOR events

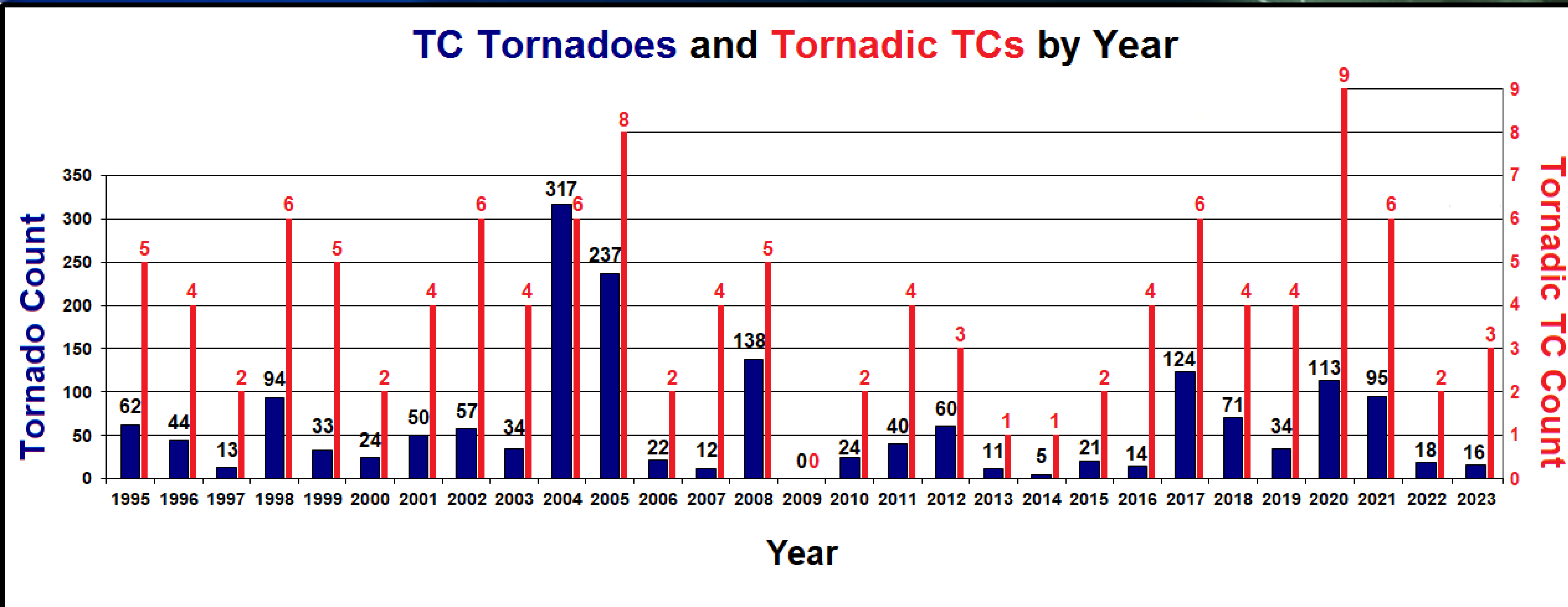
TC TORNADO FACTS & CLIMATOLOGY



TCTOR DATA: TC STRENGTH AT TORNADO TIME (from HURDAT)

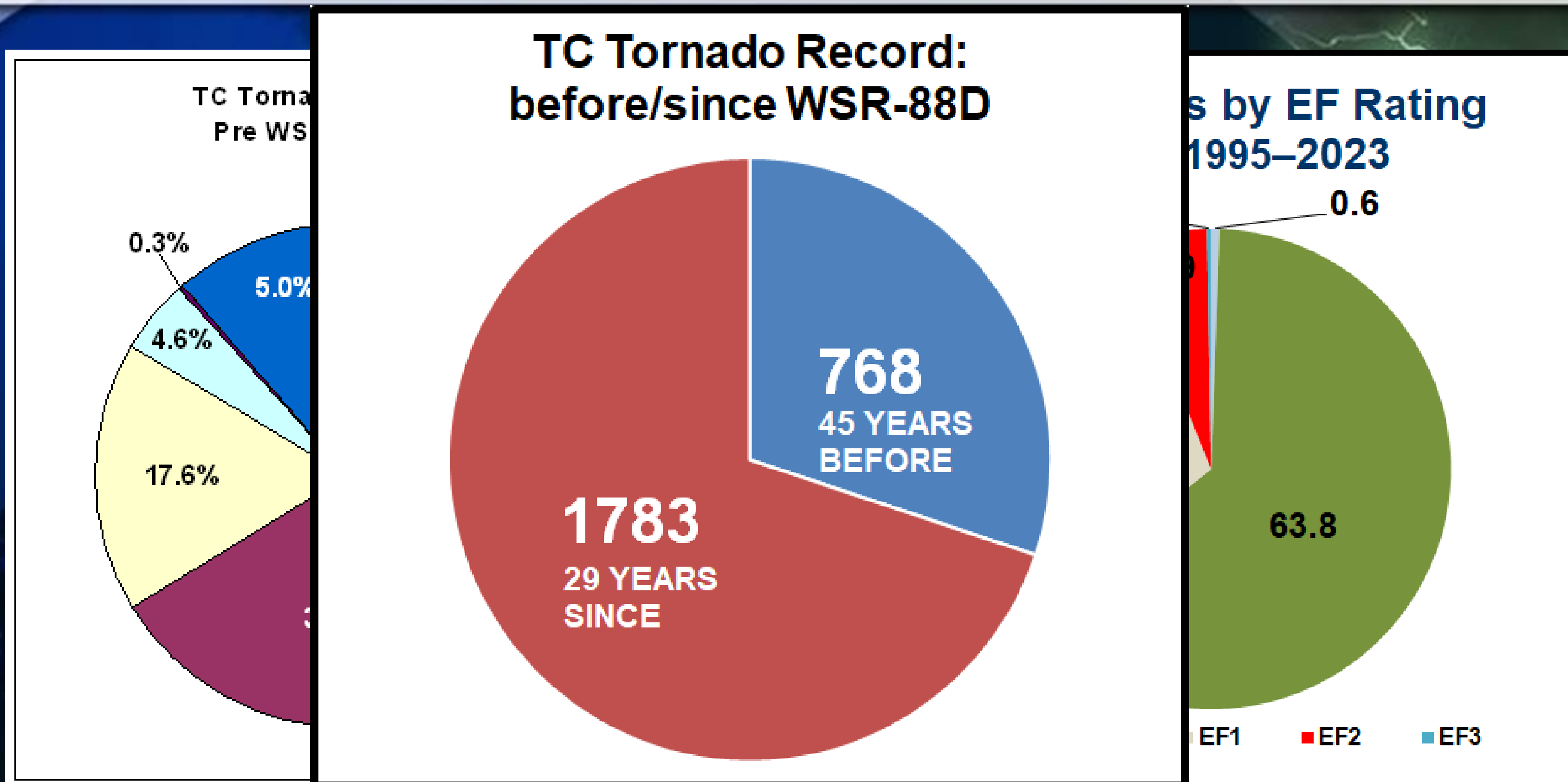
TC Category	Max Sus. Wind (mph)
MH 5	>155
MH 4	131-155
MH 3	111-130
MH 2	96-110
MH 1	74-95
TS 0	39-73
TD -1	<38
N -2	Not classified

TC TORNADO FACTS & CLIMATOLOGY



Highly variable year-to-year in WSR-88D era

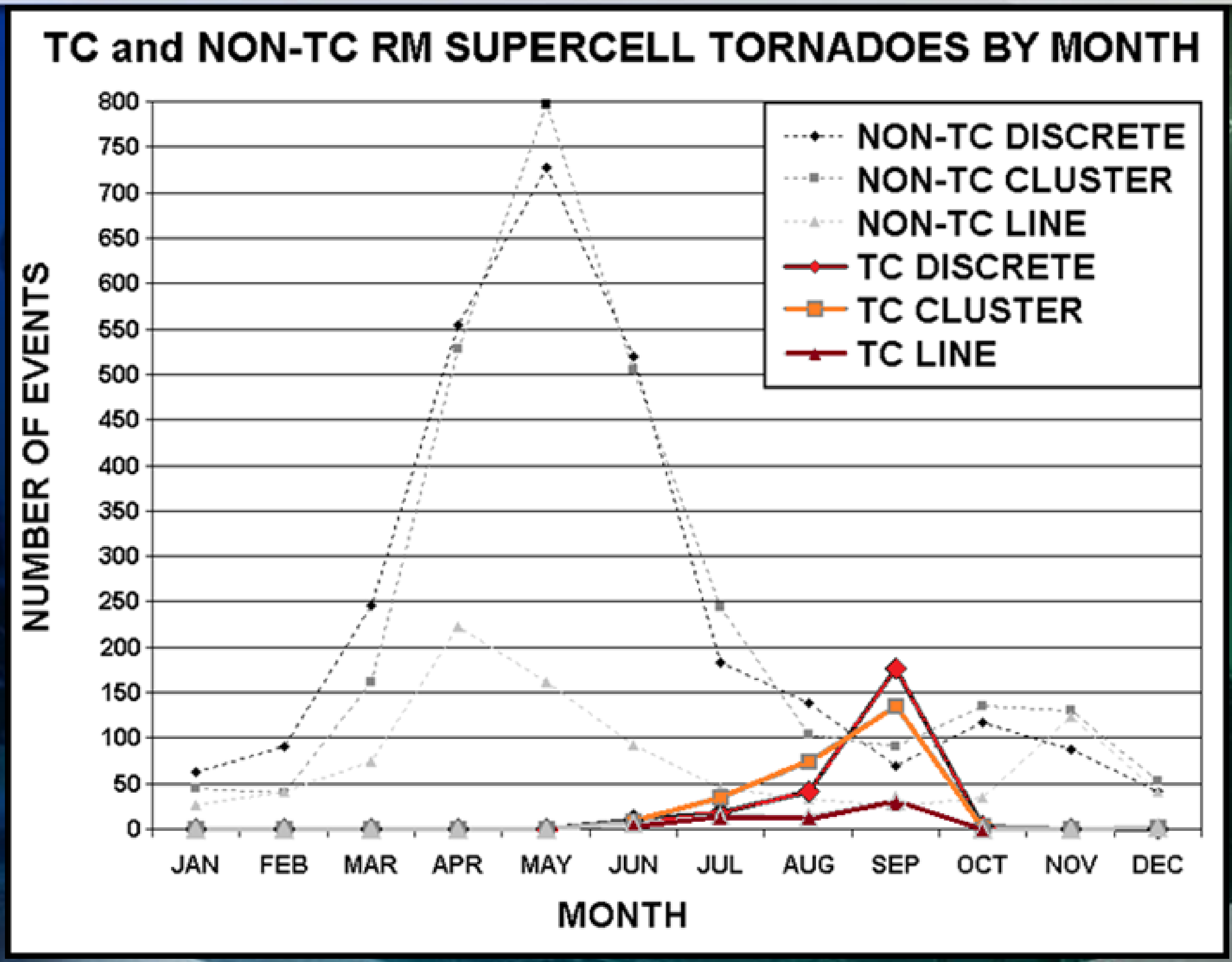
TC TORNADO FACTS & CLIMATOLOGY



88D era: Many more weak TC tornado reports, Many more TC tornado reports PERIOD!

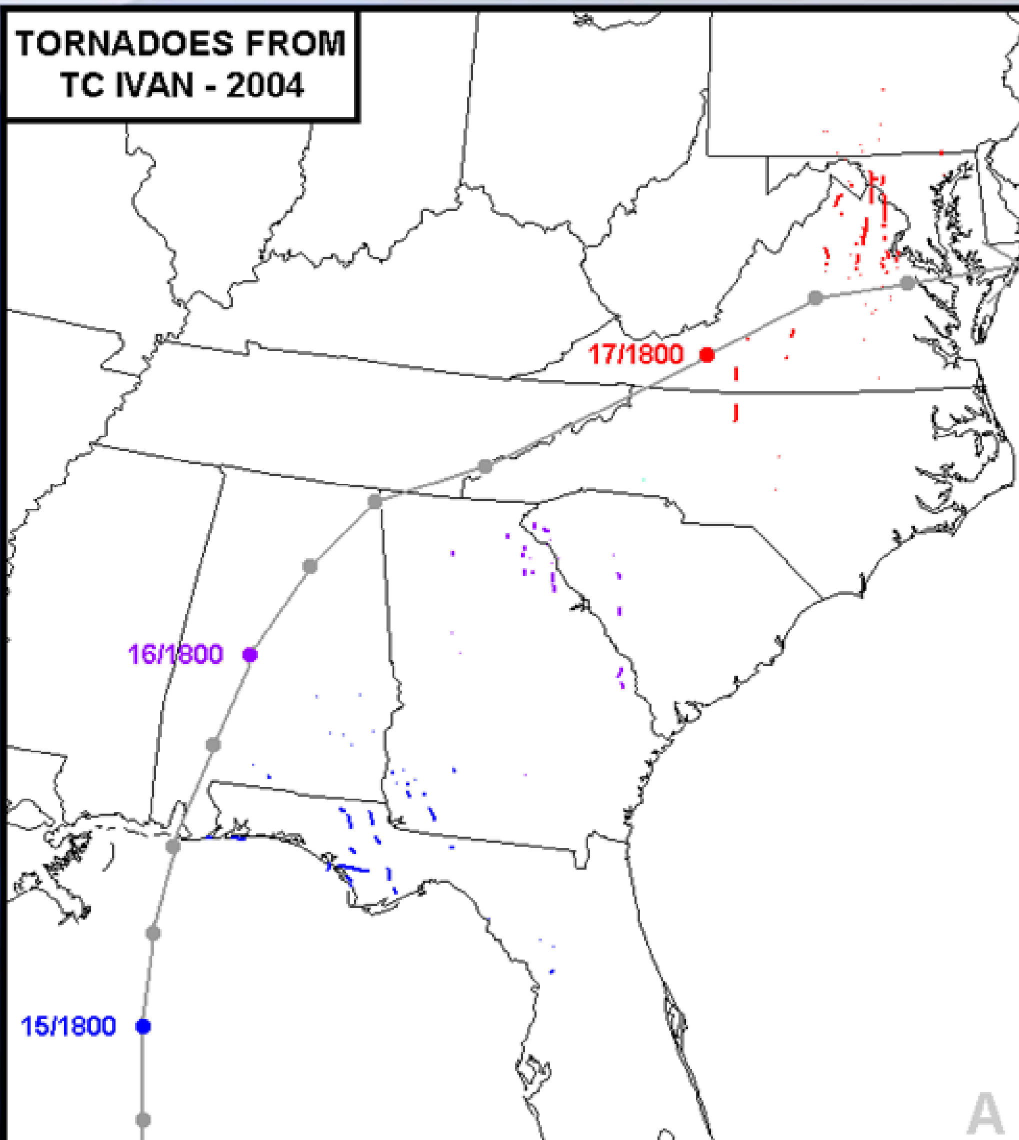
Pre-TCTOR data from Schultz and Cecil (2009)

TC TORNADO FACTS & CLIMATOLOGY



data from Edwards et al. (2012)

TC TORNADO FACTS & CLIMATOLOGY



...and the single-storm winner is

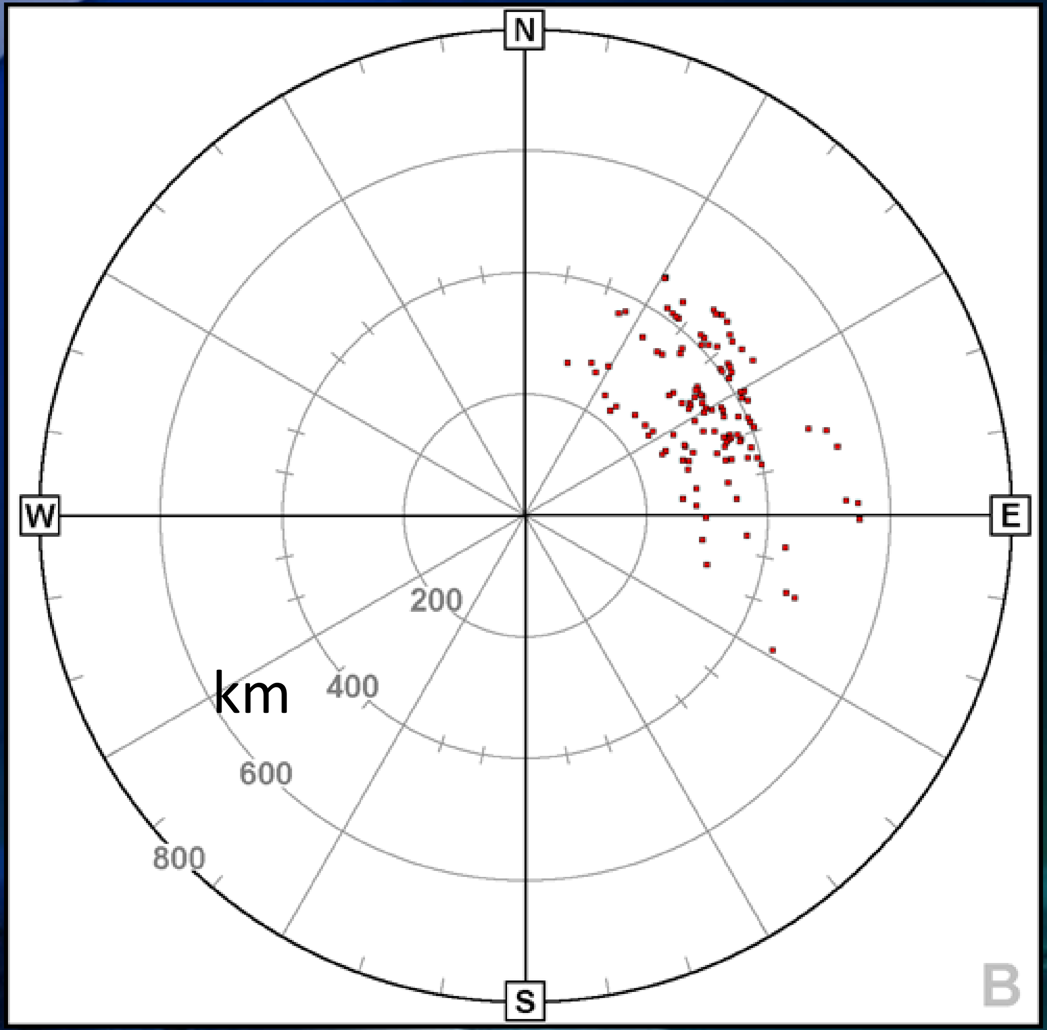
IVAN

118 in 3-DAY CYCLE

MAY HAVE SET ALL-TIME RECORD

(115 – BEULAH 1967)

TC TORNADO FACTS & CLIMATOLOGY



3 DAYS COMBINED

TOTAL TORNADO DISTRUBITION FROM CENTER FOR IVAN (2004)

VERY TIGHT!

TC TORNADO FACTS & CLIMATOLOGY

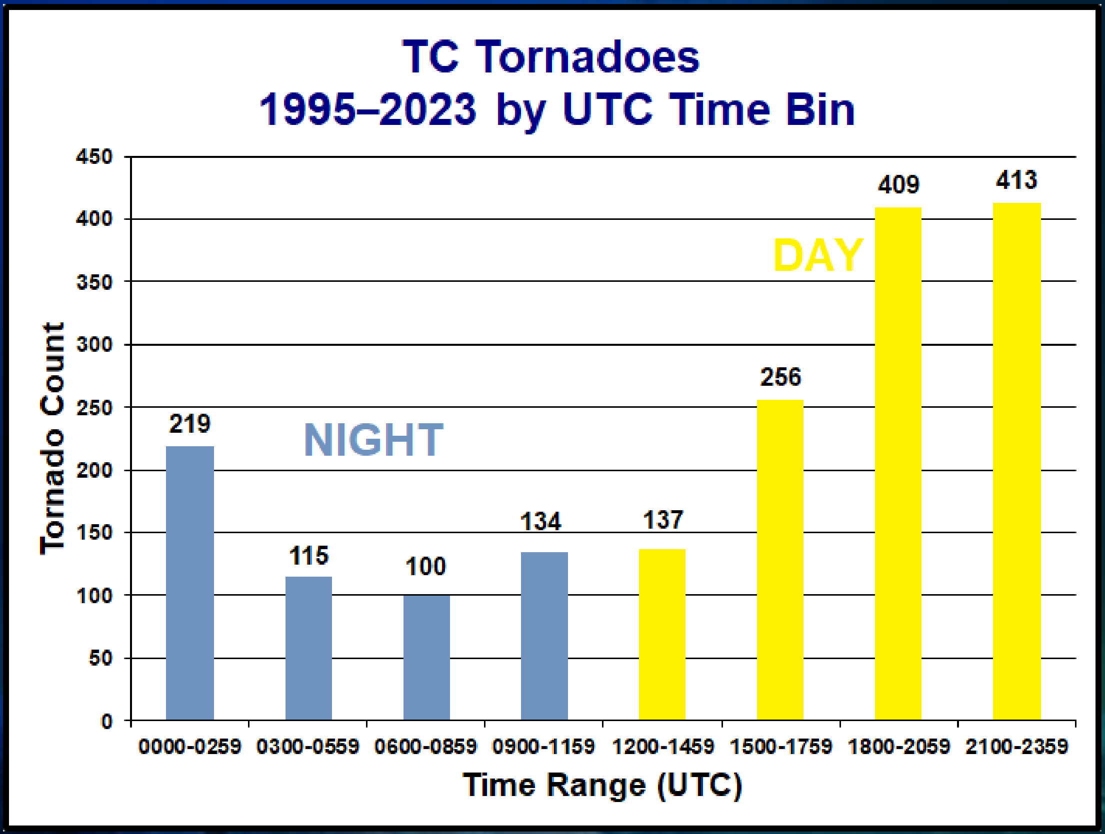
TROPICAL CYCLONE	YEAR	TORNADO REPORTS
H Ivan	2004	118
H Beulah	1967	115
H Frances	2004	103
H Rita	2005	97
H Katrina	2005	59
H Andrew	1992	56
H Harvey	2017	52
TS Fay	2008	50
H Gustav	2008	49
H Georges, H Cindy	1998, 2005	48

TOP-10 LIST

From TCTOR and pre-1995 formal references

Peak classification

CLIMATOLOGICAL APPLICATION TO FORECASTING CONCEPTS

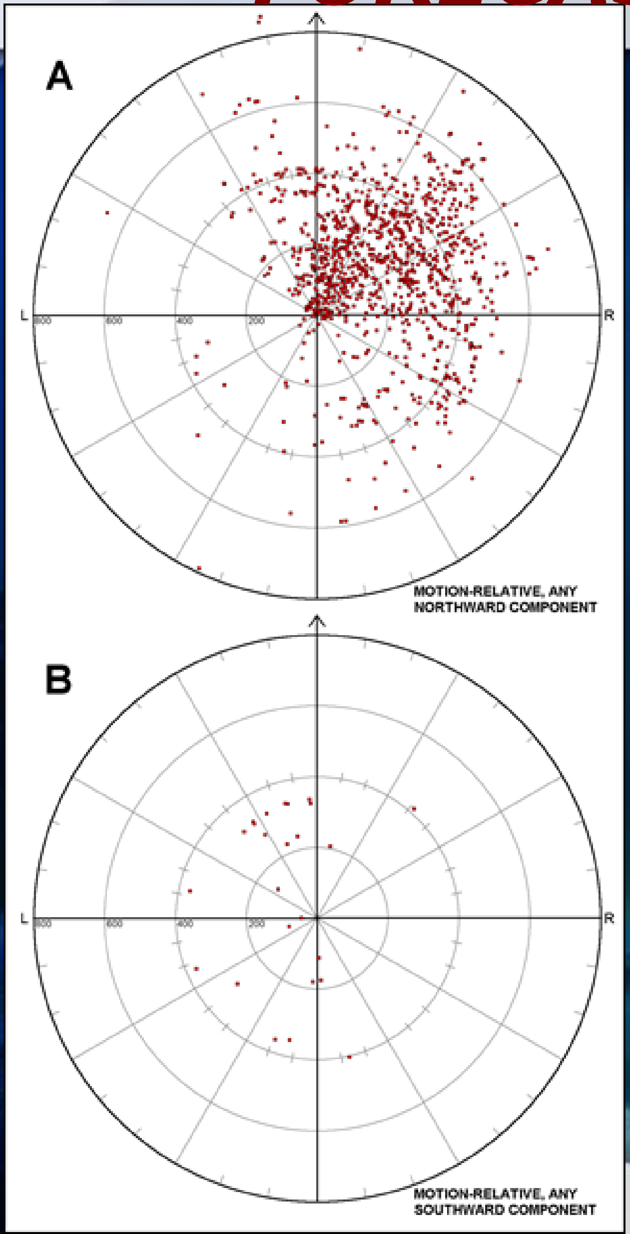


DIURNAL TREND:

In moist-adiabatic lapse rate environment, even subtle thermal warming under cloud cover greatly increases CAPE.

Dry air intrusions into TCs allow for gaps between convective rainbands

CLIMATOLOGICAL APPLICATION TO FORECASTING CONCEPTS

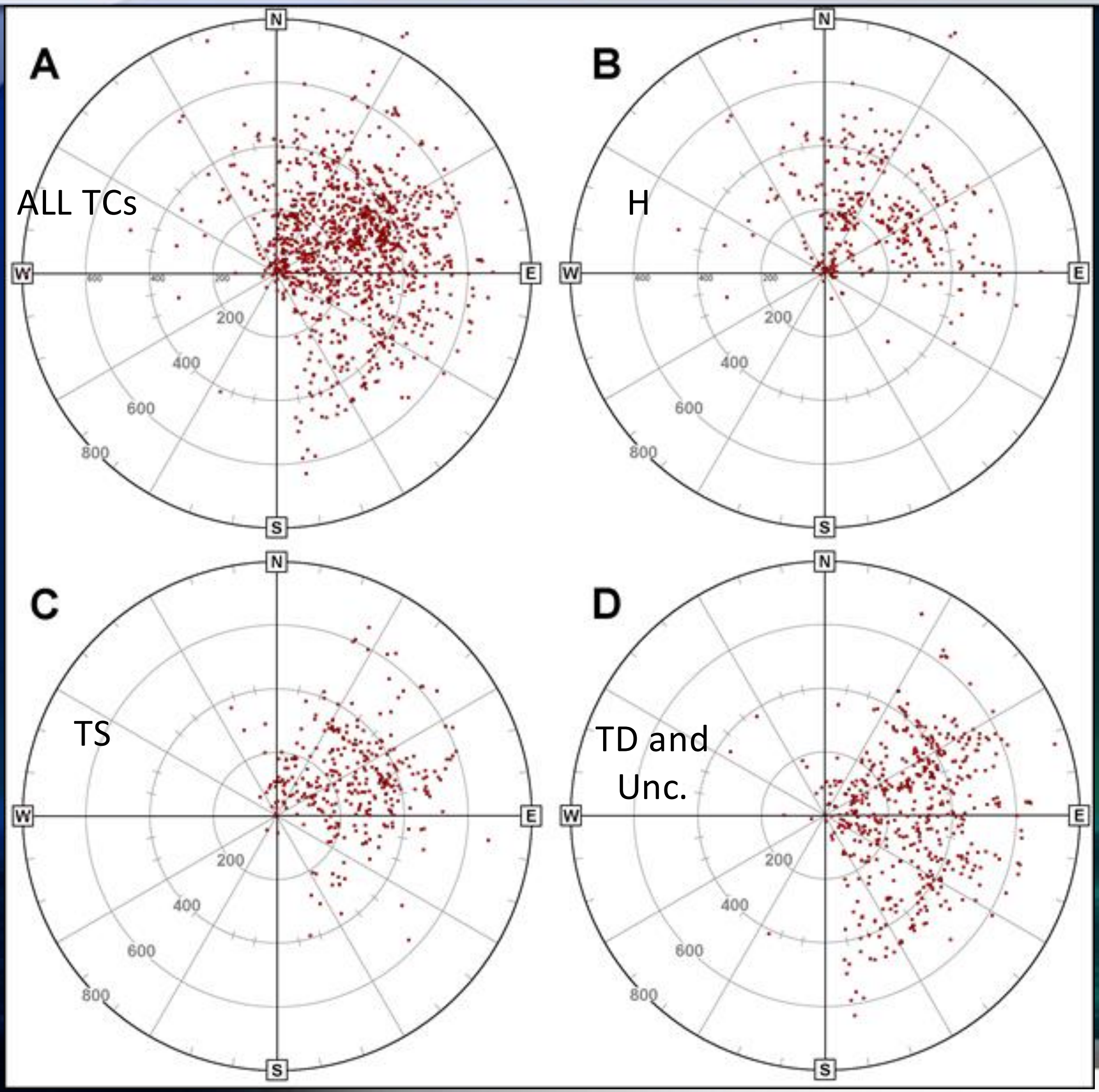


Motion-relative AZRAN of TCTOR events from center: Northward translation component

HOW MOTION-RELATIVE FAILS

Motion-relative AZRAN of TCTOR events from center: Southward translation component

CLIMATOLOGICAL APPLICATION TO FORECASTING CONCEPTS

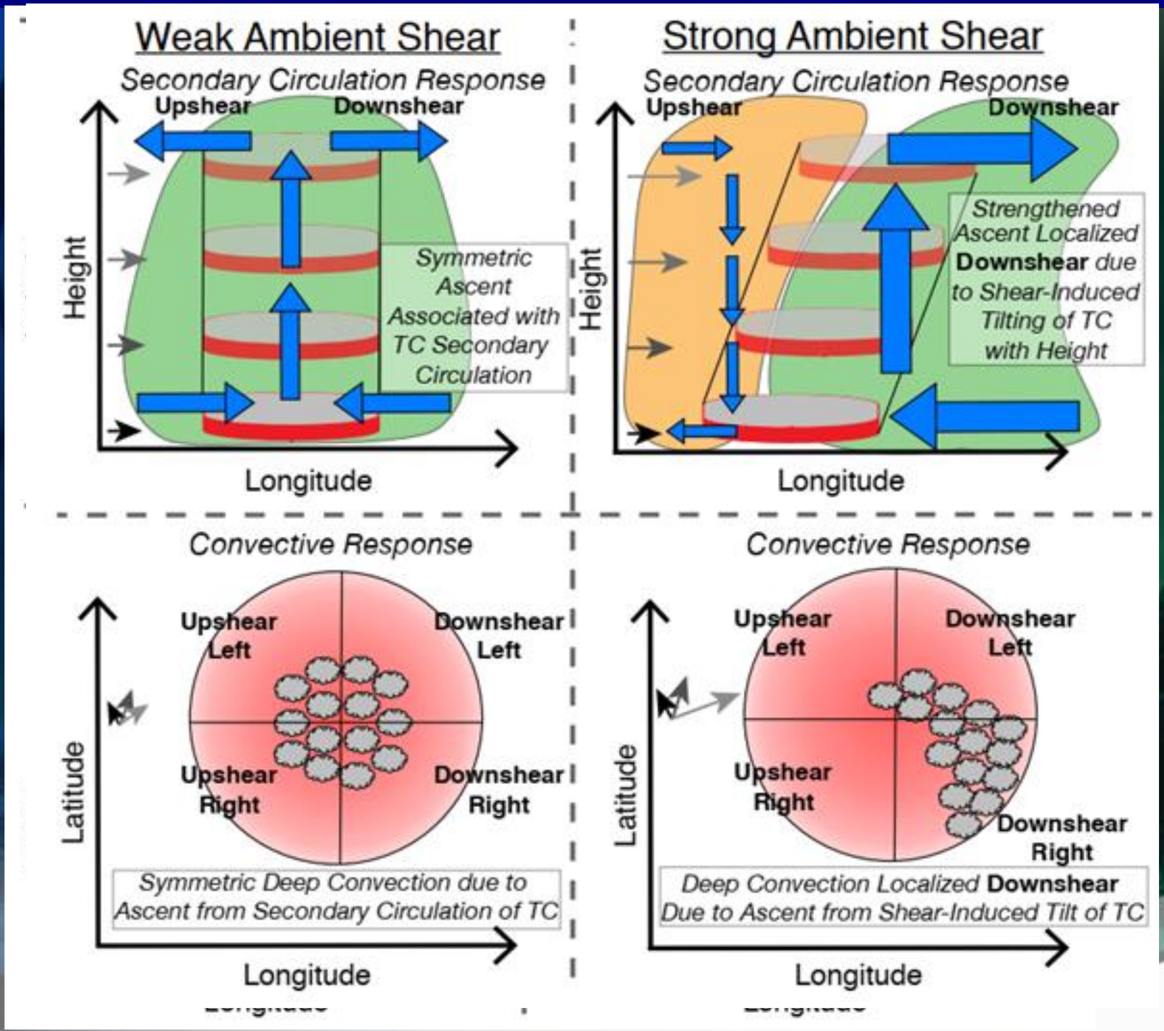


Tornadoes more common in SE sectors as TCs weaken…WHY?

…partly due to that sector's being over water when most are mature hurricanes!

CLIMATOLOGICAL APPLICATION TO FORECASTING CONCEPTS

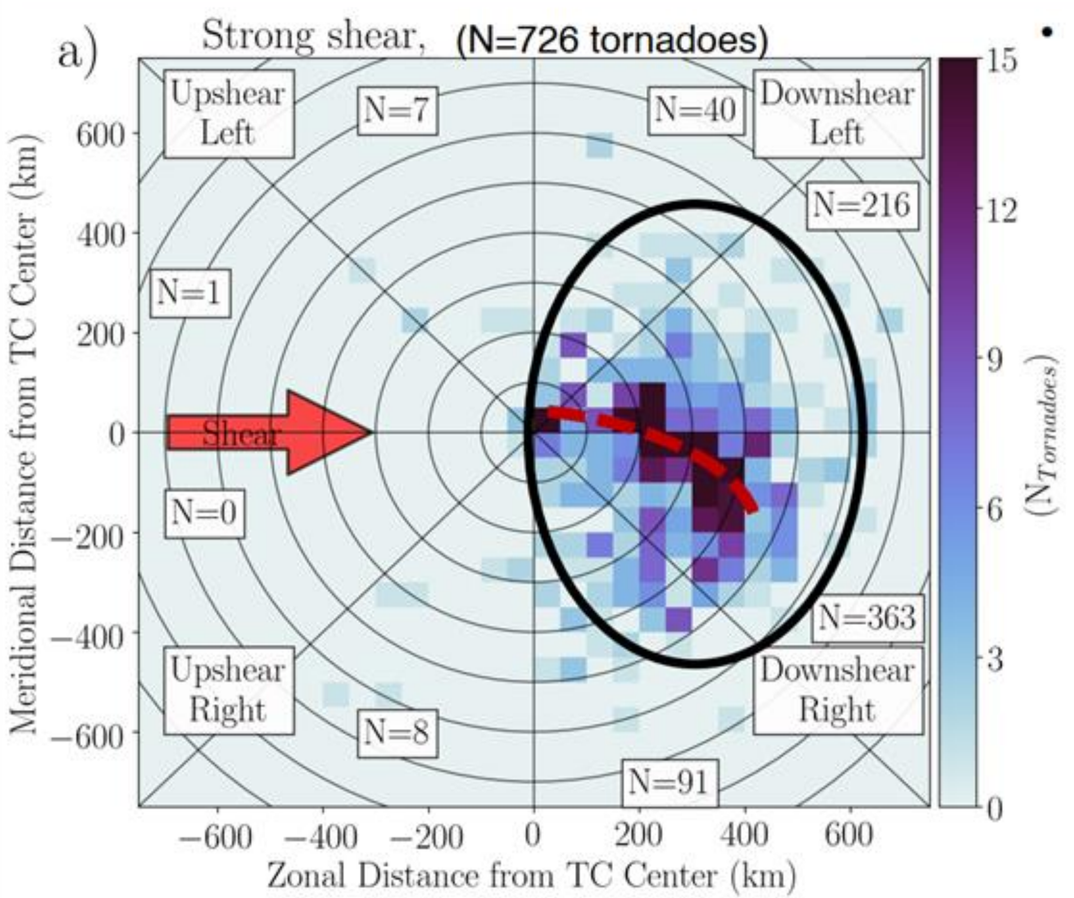
Shear-vector-relative distributions with physical basis (Schenkel et al. 2020 – October 2020 WaF)



CLIMATOLOGICAL APPLICATION TO FORECASTING CONCEPTS

Shear-vector-relative distributions with physical basis (Schenkel et al. 2020 – October 2020 WaF)

Tornado Frequency and Location in Strongly Sheared TCs



- Strongly sheared TCs associated with:
  1. Majority of tornadoes (57%);
  2. Nearly all tornadoes in **downshear half** of TC.

TC TORNADO FORECASTING CONCEPTS

Shifting from climatology-based and empirical to

INGREDIENTS-BASED THINKING

For supercells in midlatitude systems and tropical cyclones!

- **MOISTURE:** usually no problem
- **INSTABILITY:** helps to have diurnal heating with large antecedent BL theta-e to offset weak lapse rates aloft
- **(source for) LIFT:** Spiral bands, embedded boundaries concentrate threat on mesoscale and smaller – **FREQUENT HAND ANALYSIS is CRUCIAL!**
- **VERTICAL SHEAR:** Peak hodographs in climatologically favored N-NE-SSE sector, which is DOWNSHEAR

Edwards 2012

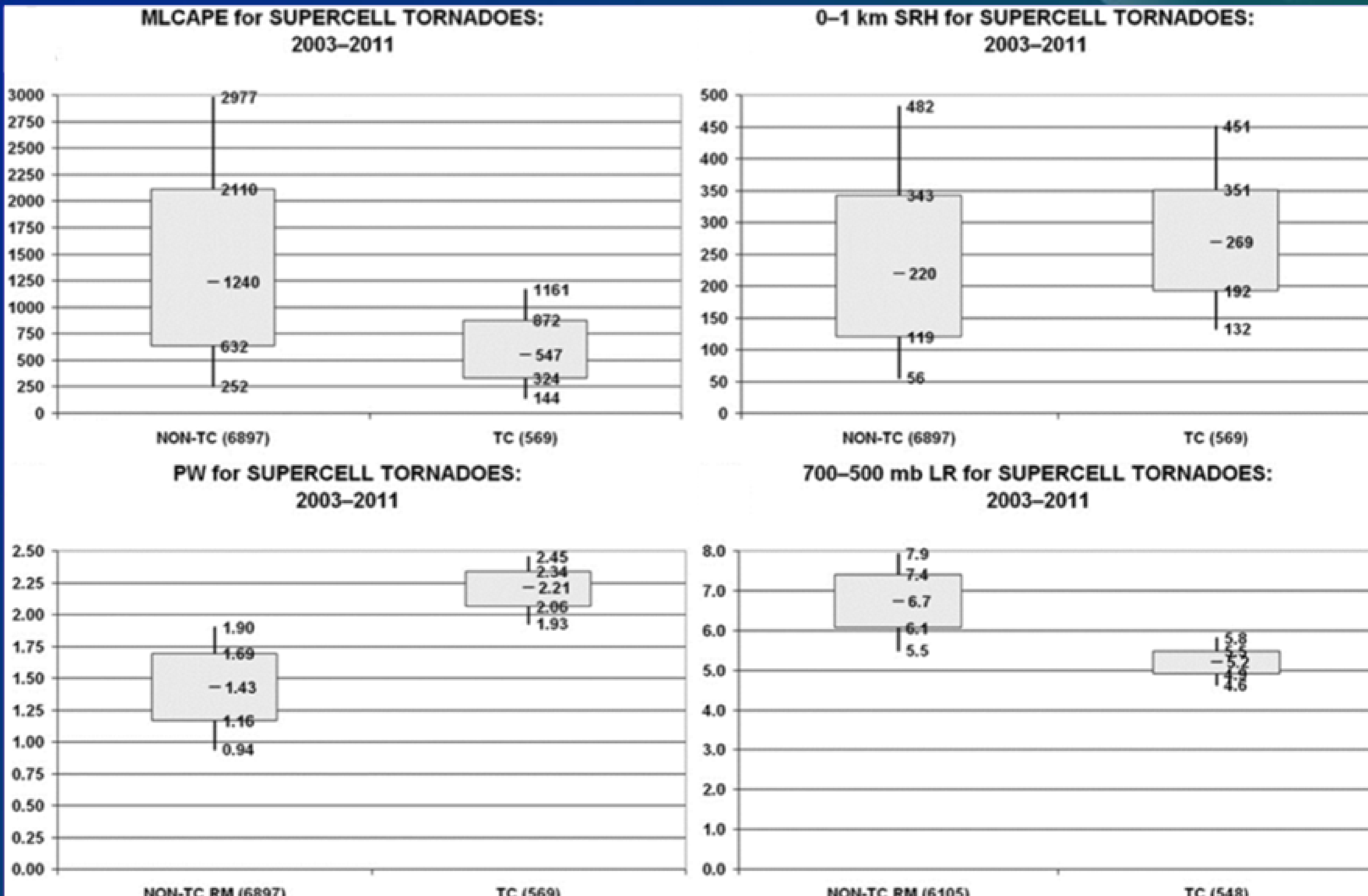
TC TORNADO FORECASTING CONCEPTS

Objectively analyzed parameters (e.g. SPC SFCOA)

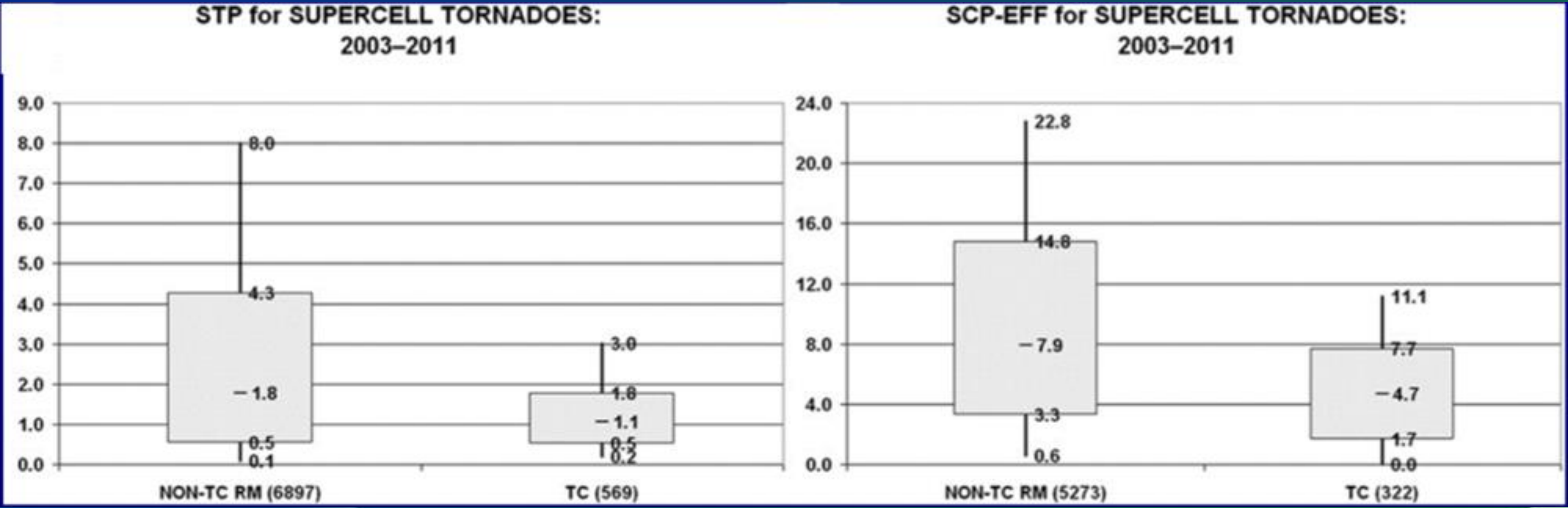
- **TESTED FOR 2003-2011 TC TORNADO ENVIRONMENTS**
- **LITTLE DIFFERENCE WITH ANY PARAMETER between WEAK & STRONG TC TORNADOES**
- **HIGH PW, WEAK LAPSE RATES, LOWER MLCAPE WITH TC vs. MIDLATITUDE TORNADOES**
- **LOWER/MORE COMPRESSED SCP AND STP DISTRIBUTIONS FOR TC TORNADOES**
- **RUC-BASED: WAS UNRELIABLE/INACCURATE WITH WIND AND PRESSURE TOWARD CENTER OF TS AND HURRICANE. TOO FEW CASES on RAPID REFRESH.**

Edwards et al. 2012

TC TORNADO FORECASTING CONCEPTS



TC TORNADO FORECASTING CONCEPTS

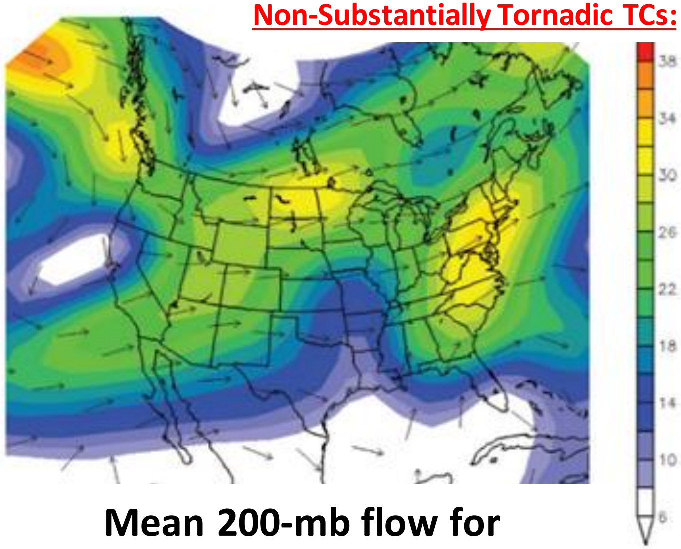


TC TORNADO FORECASTING CONCEPTS

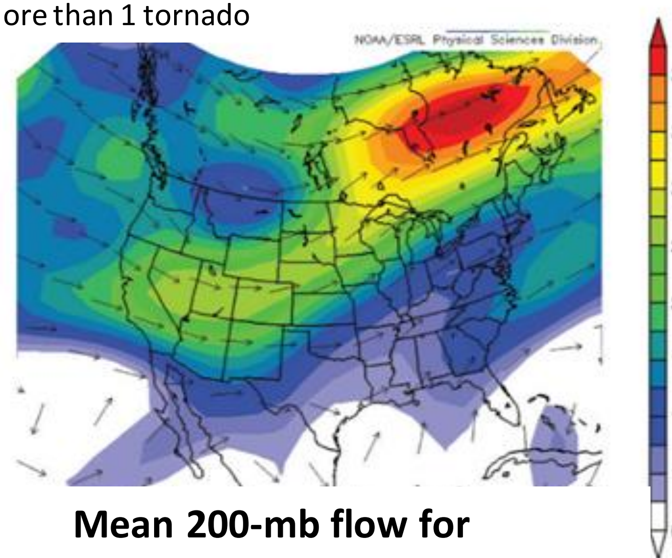
TC TORNADO FORECASTING CONCEPTS – SYNOPTIC PATTERNS

Substantially Tornadic TCs: Produce at least 4 tornadoes
Non-Substantially Tornadic TCs: Produce no more than 1 tornado

Fig. 3(c).



Mean 200-mb flow for Substantially Tornadic TCs



Mean 200-mb flow for Non-Substantially Tornadic TCs

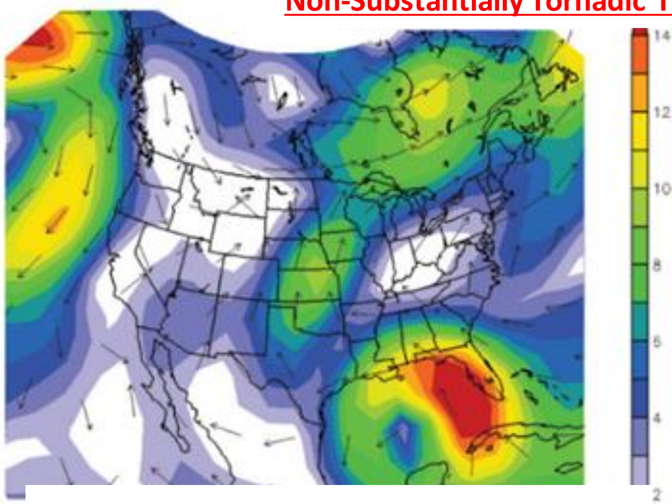
-Right entrance region of enhanced 200-mb jet streak enhances tornado potential over Southeast.

-Any upper-level jet streak associated with non-substantial tornadic TCs was much weaker.

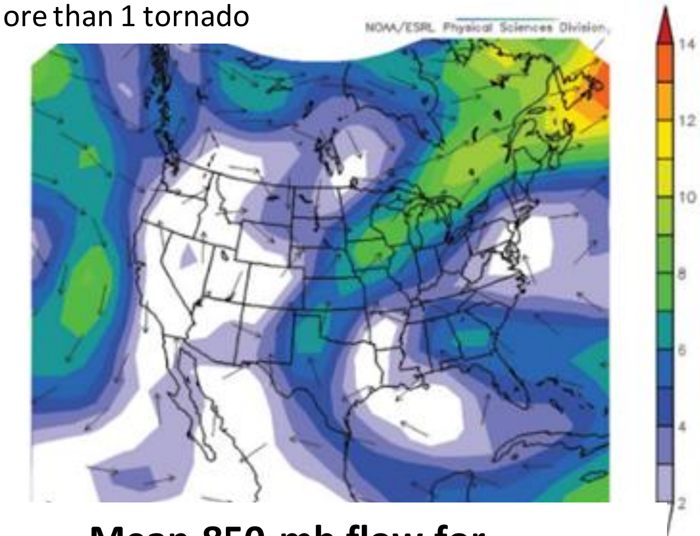
TC TORNADO FORECASTING CONCEPTS – SYNOPTIC PATTERNS

Substantially Tornadic TCs: Produce at least 4 tornadoes
Non-Substantially Tornadic TCs: Produce no more than 1 tornado

Fig. 4(c).



Mean 850-mb flow for Substantially Tornadic TCs



Mean 850-mb flow for Non-Substantially Tornadic TCs

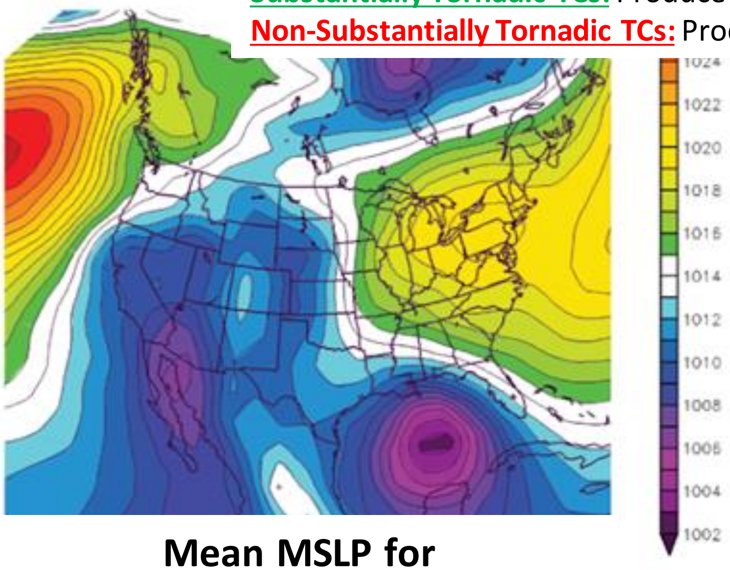
-850-mb flow field -- associated with subst. tornadic TCs -- well organized, large, and directionally-symmetric, with strongest flow in NE semicircle of cyclonic flow envelope

-In this region, SRH will be maximized, enhancing tornadogenesis potential

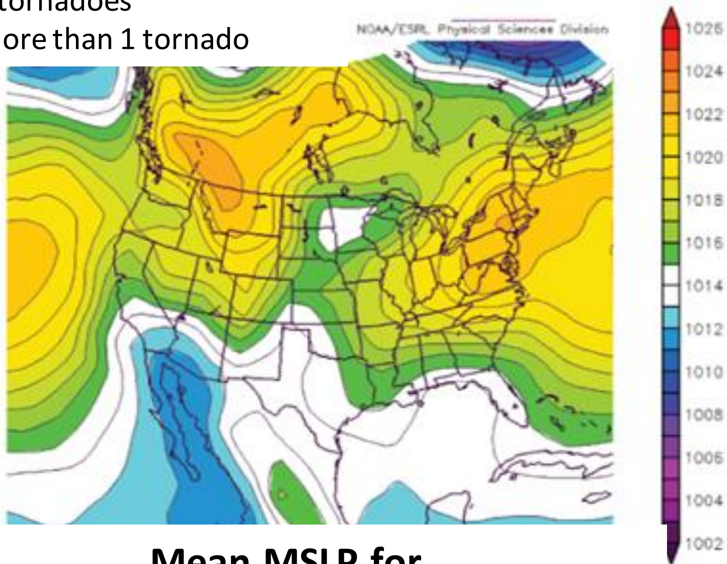
TC TORNADO FORECASTING CONCEPTS – SYNOPTIC PATTERNS

Substantially Tornadic TCs: Produce at least 4 tornadoes
Non-Substantially Tornadic TCs: Produce no more than 1 tornado

Fig. 5(c).



Mean MSLP for
Substantially Tornadic TCs



Mean MSLP for
Non-Substantially Tornadic TCs

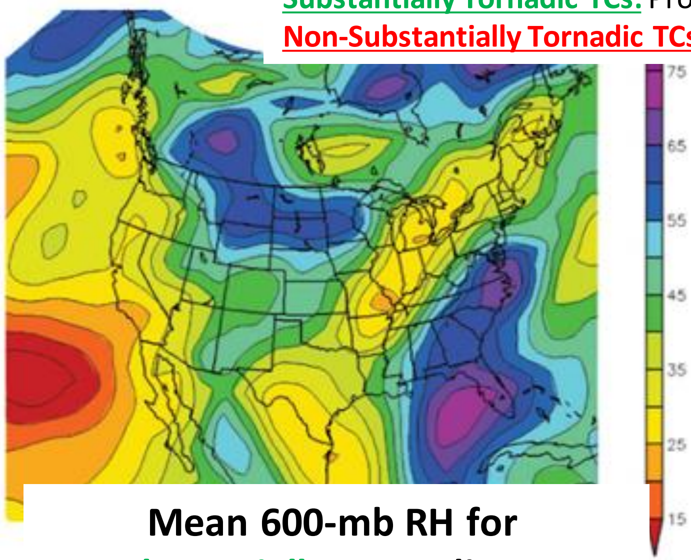
-The area of low pressure associated with subst. tornadic TCs well-defined and symmetric, as opposed to a broad trough

-Pressure gradient maximized in NE semicircle. In this region, SRH will be maximized, enhancing tornado potential

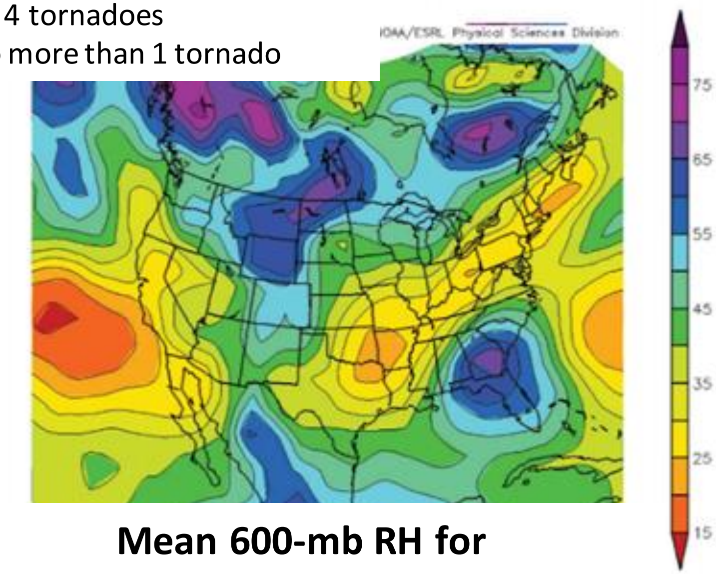
TC TORNADO FORECASTING CONCEPTS – SYNOPTIC PATTERNS

Substantially Tornadic TCs: Produce at least 4 tornadoes
Non-Substantially Tornadic TCs: Produce no more than 1 tornado

Fig. 6(c).



Mean 600-mb RH for Substantially Tornadic TCs



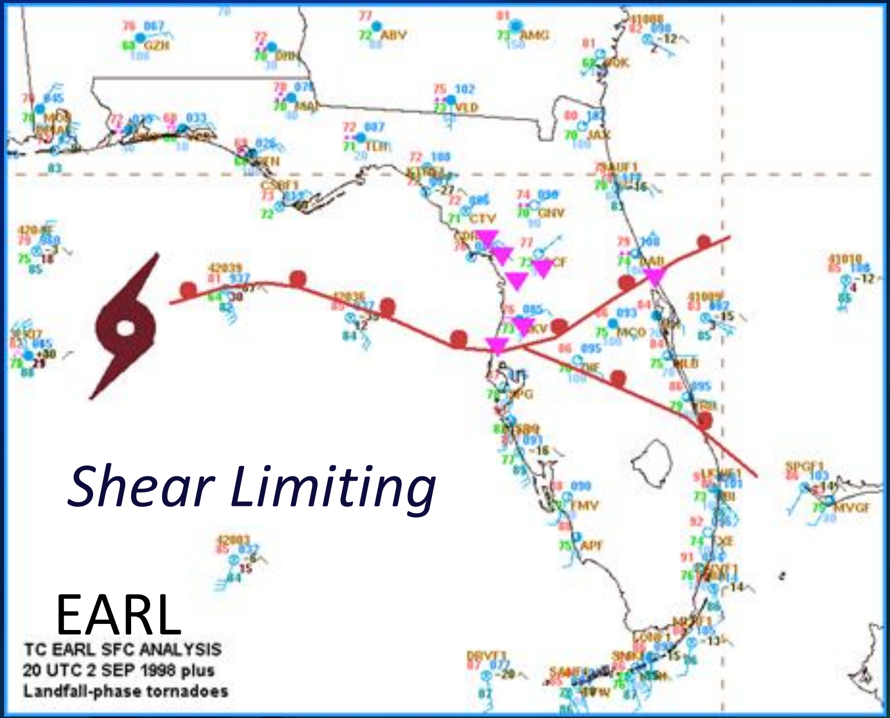
Mean 600-mb RH for Non-Substantially Tornadic TCs

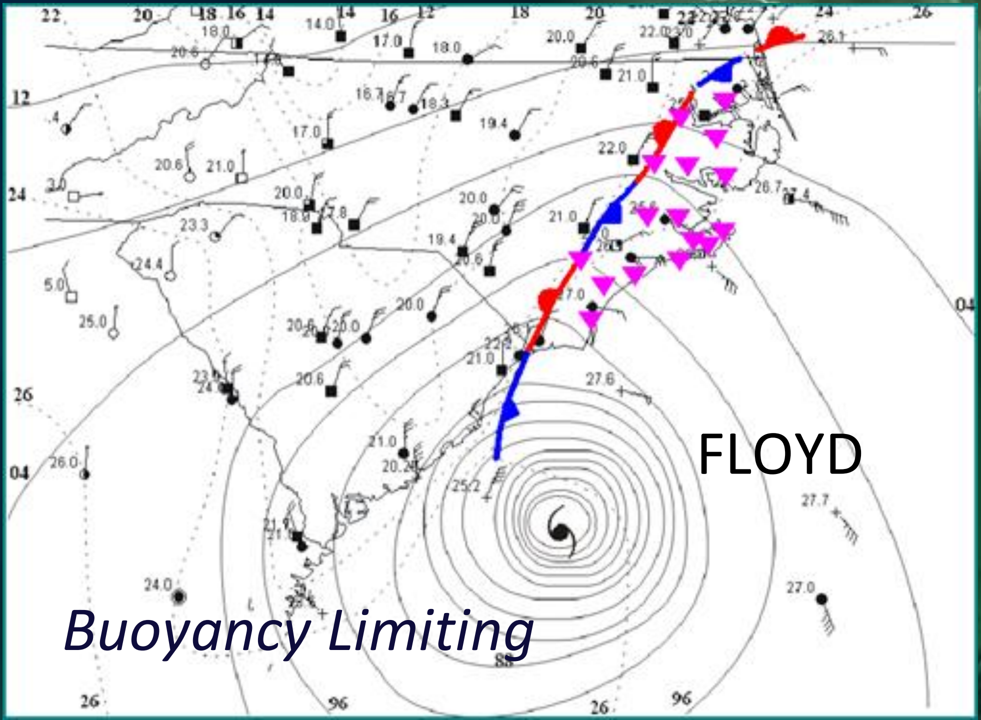
-Presence of a spatially-broad, yet strong, horizontal gradient in mid-level moisture is found over NW semicircle of cyclonic flow envelope

-Dry air driving this gradient enhances low-level buoyancy in vicinity of rain bands through mid-level dry air entrainment into the TC

TC TORNADO FORECASTING CONCEPTS – MESOSCALE BOUNDARIES

Baroclinic and wind boundaries can influence threat



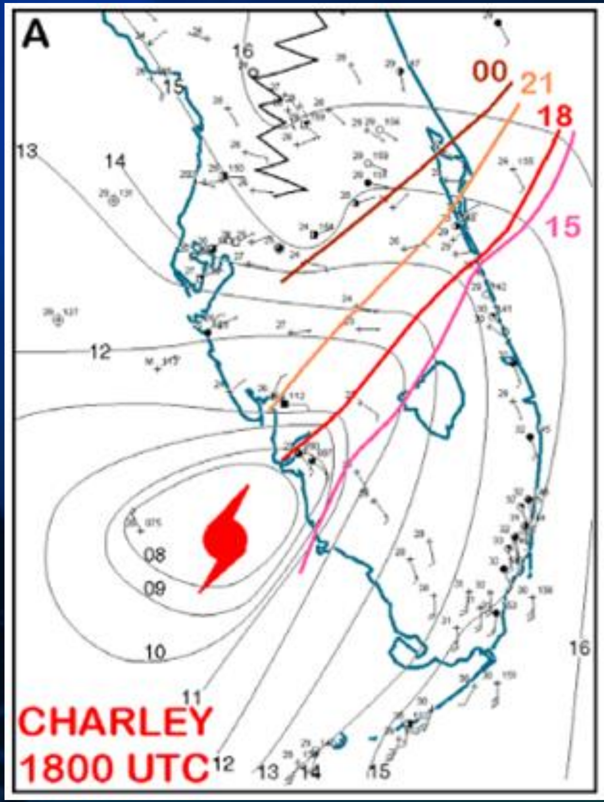


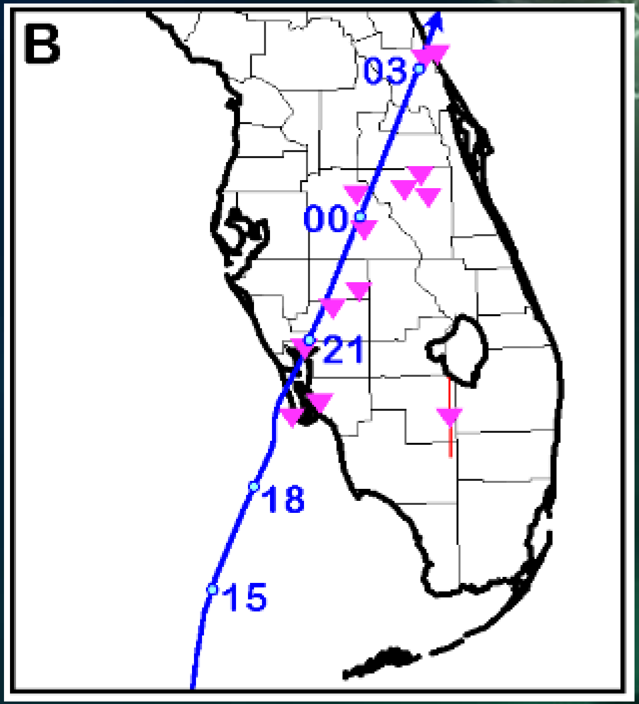
Favorable buoyancy on both sides, only favorable shear on cool side.

Favorable shear on both sides, only favorable buoyancy on warm side.

Edwards and Pietrycha 2006

TC TORNADO FORECASTING CONCEPTS – MESOSCALE BOUNDARIES



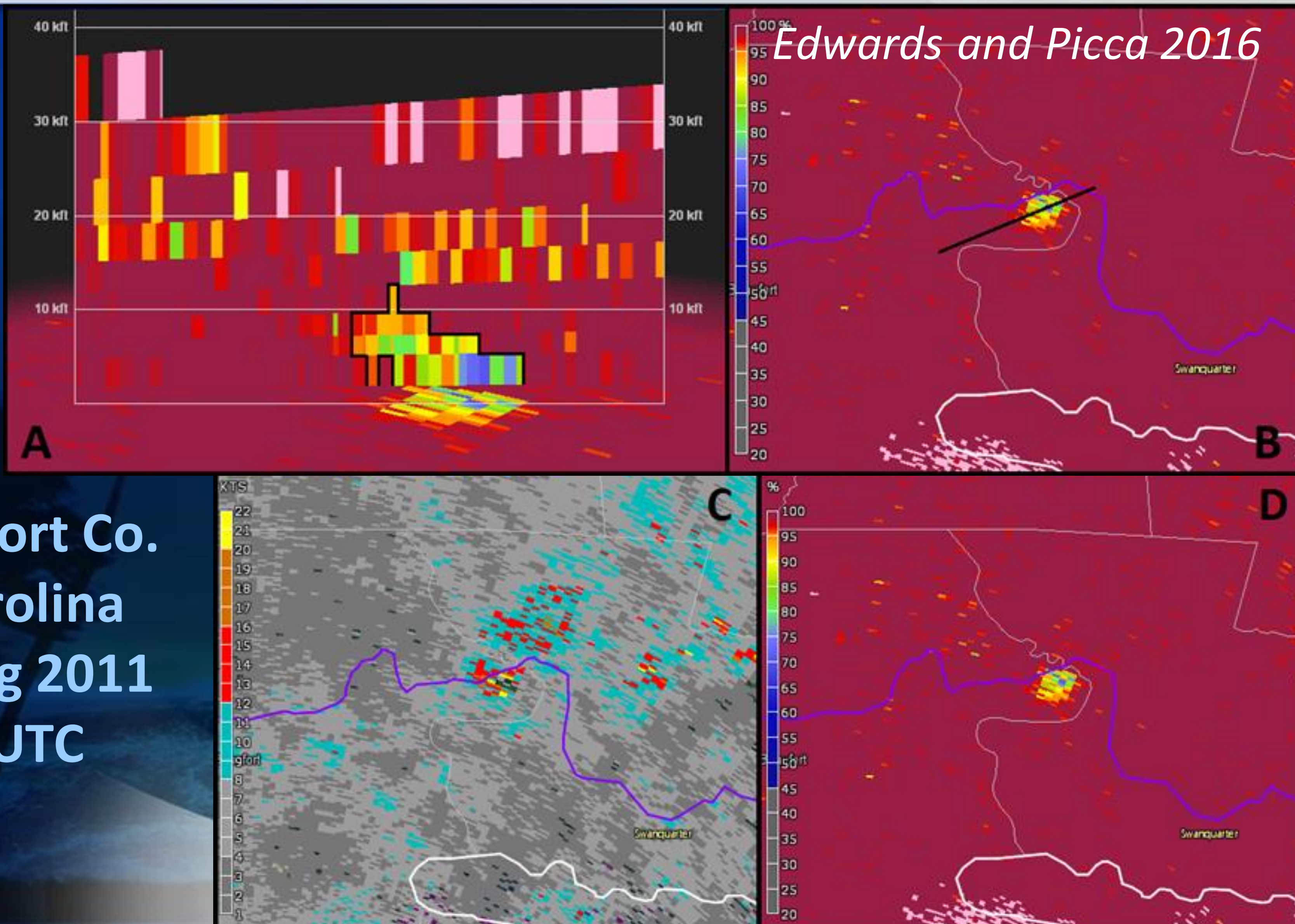


Buoyancy-Shear Overlap

Favorable buoyancy on one side, favorable shear on the other. (Slim corridor of overlap near the boundary)

Edwards and Pietrycha 2006

RADAR CONCEPTS for TC TORNADOES



Beaufort Co.
N. Carolina
27 Aug 2011
0203 UTC

RADAR CONCEPTS for TC TORNADOES

Tornado Warned Supercell

near Norge OK **TC**

Erin

PAR VCP 12 60° sector

0.5° oversampling in azimuth

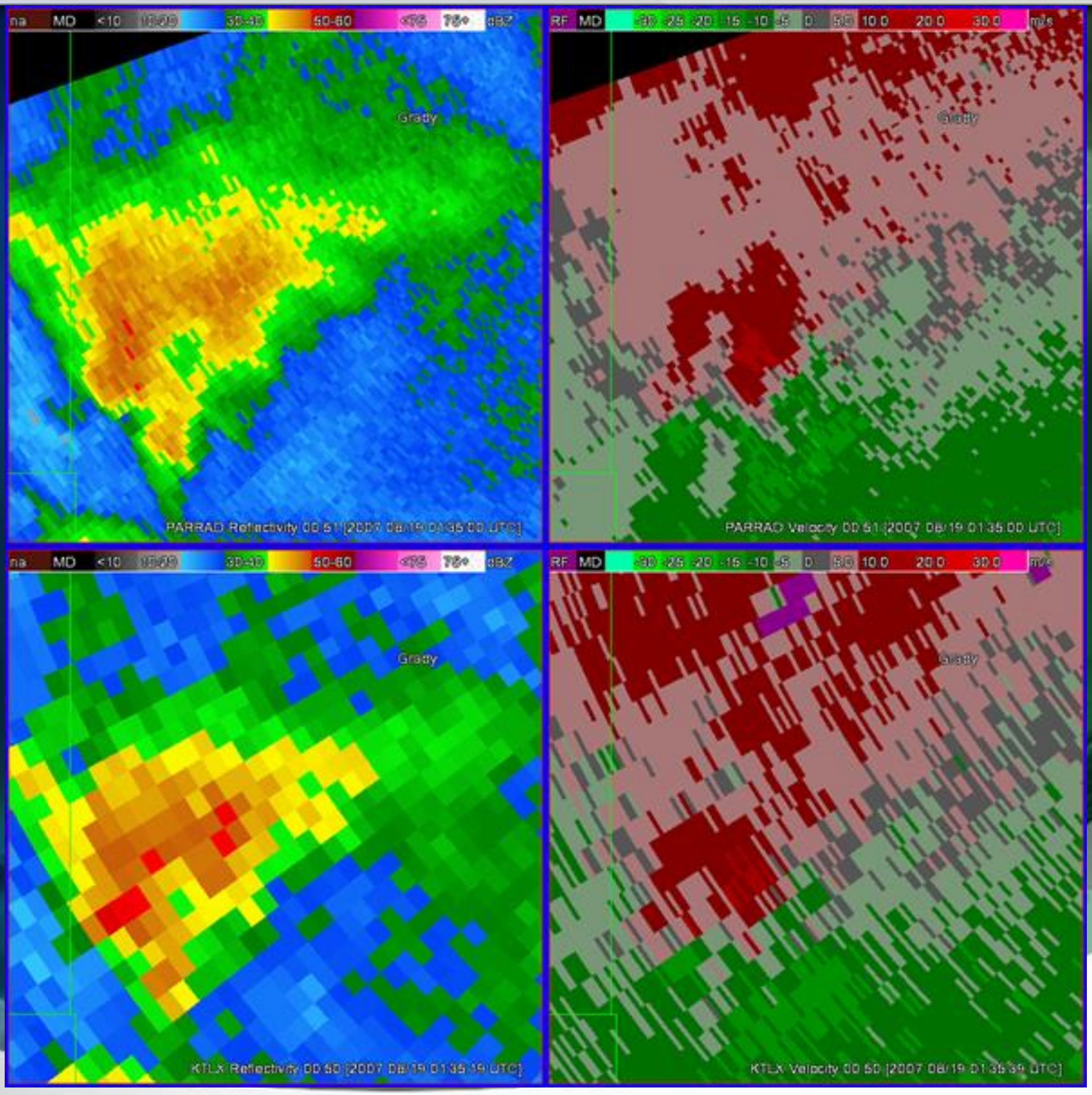
Interval ~ **43 s**

19 Aug 2007
0135-0154 UTC

WSR-88D

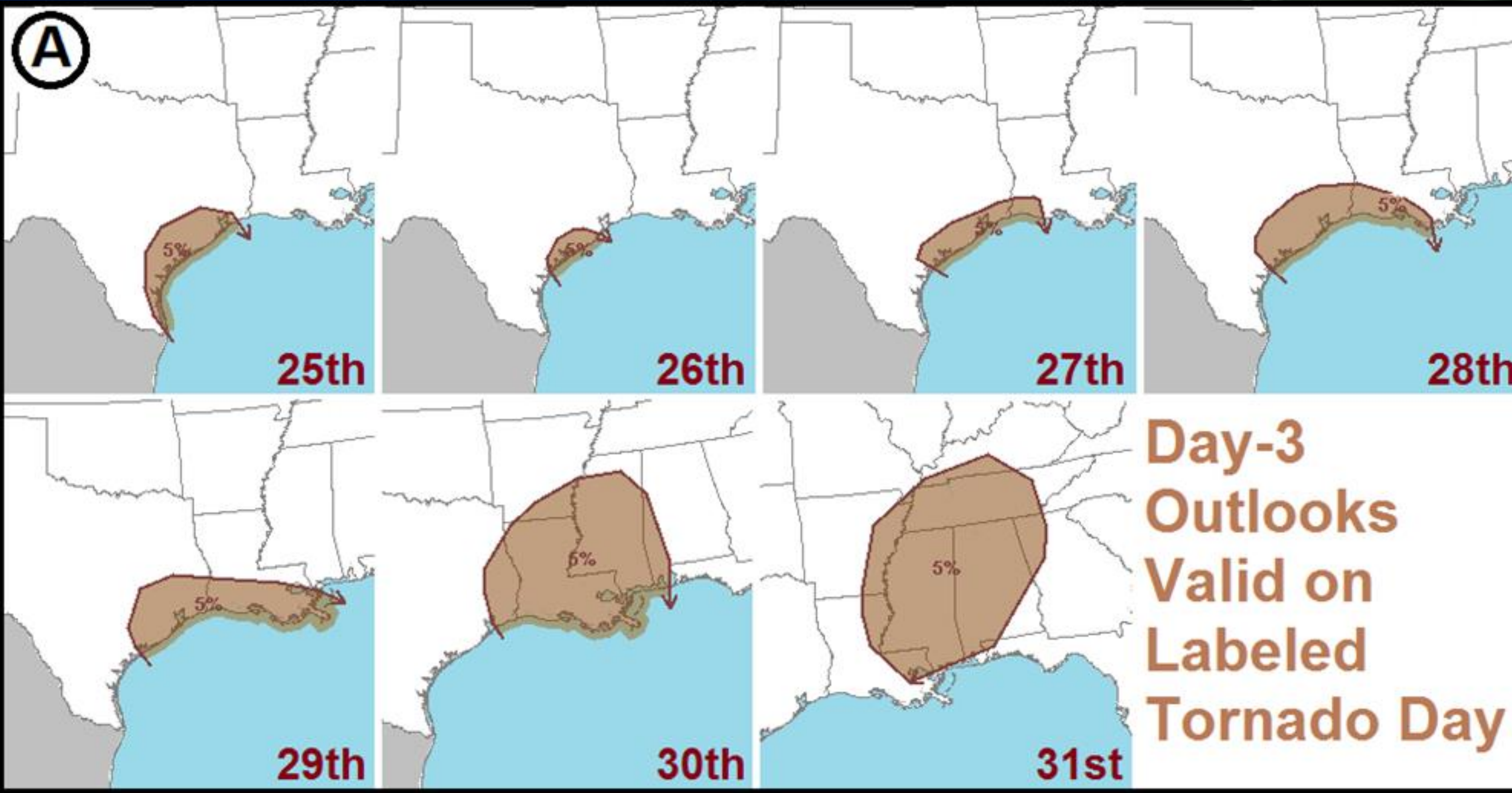
VCP 12

Interval ~ **4.1 min**



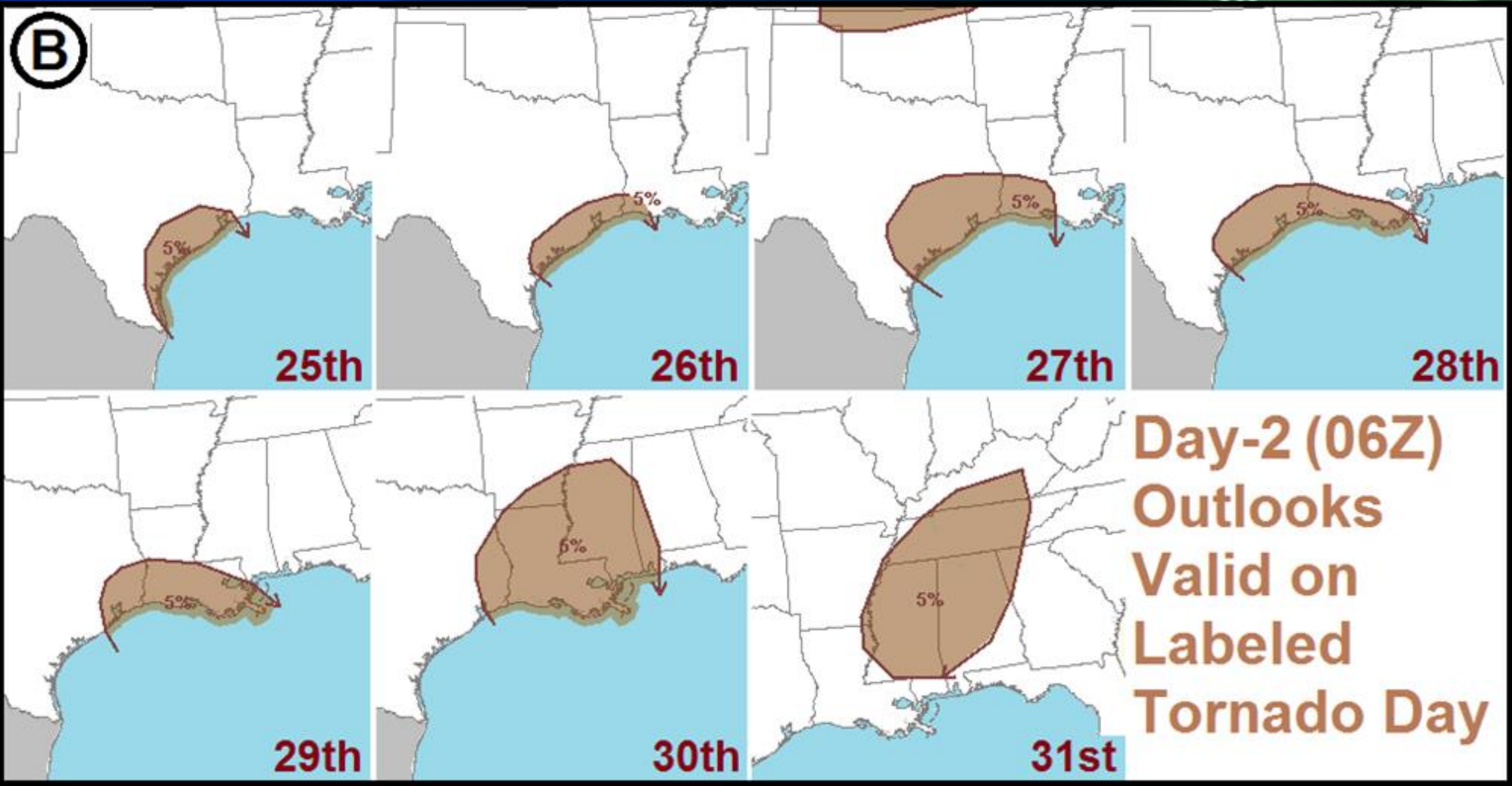
SPC FORECAST EXAMPLES FOR TCs

OUTLOOKS (Day-3 examples for HARVEY)



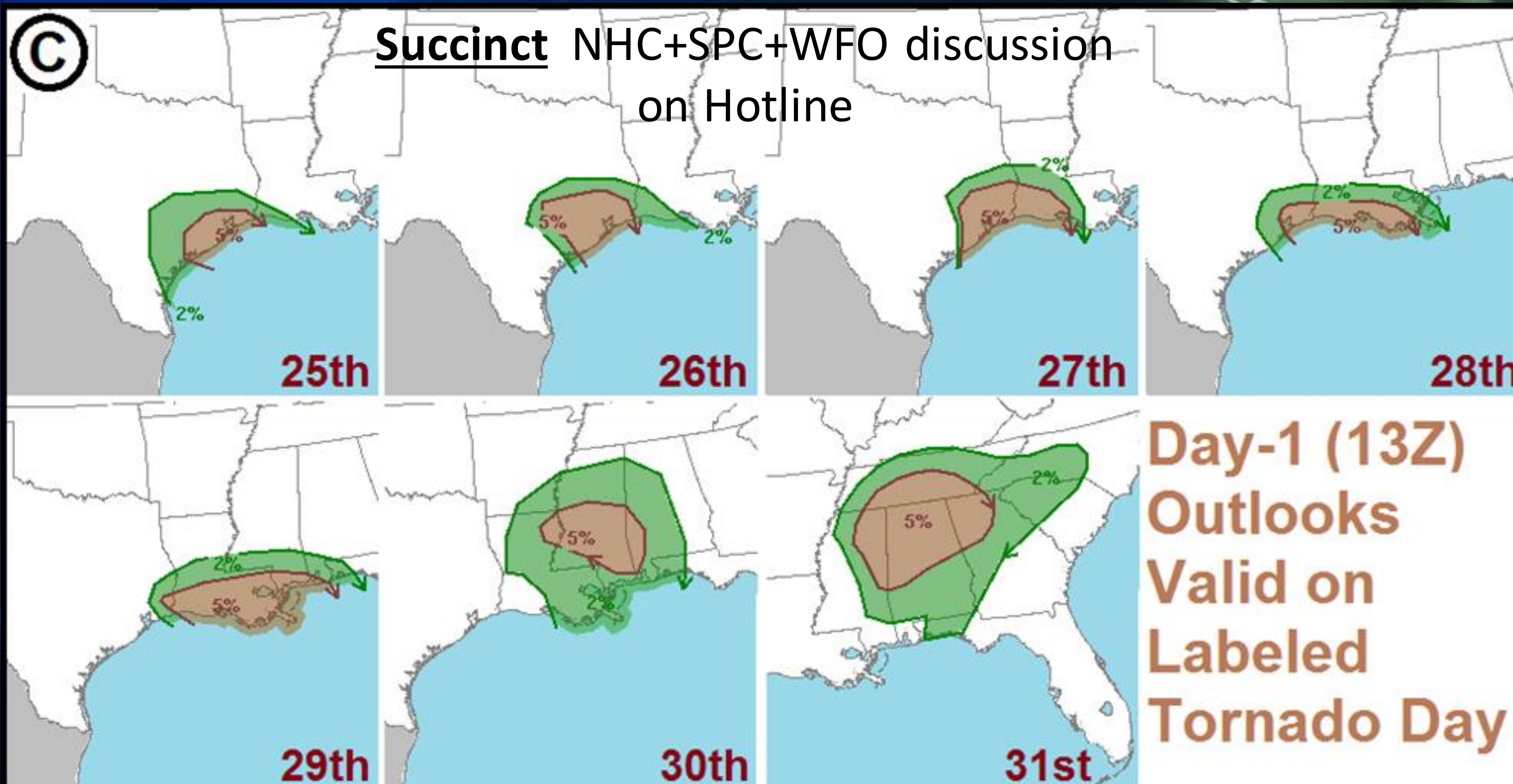
SPC FORECAST EXAMPLES FOR TCs

OUTLOOKS (Day-2 examples for HARVEY)

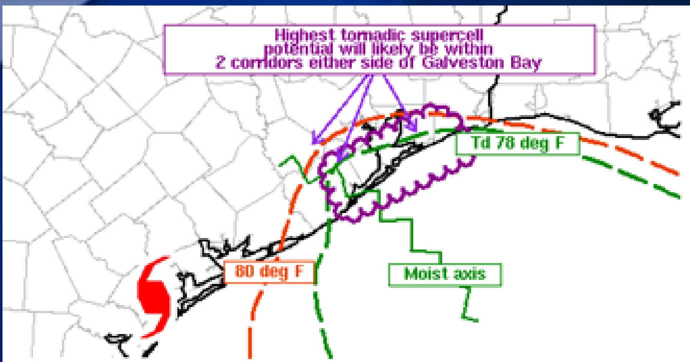


SPC FORECAST EXAMPLES FOR TCs

OUTLOOKS (Day-1 examples for HARVEY)



SPC FORECAST EXAMPLES FOR TCs



SPC MCD #1571

Mesoscale Discussion 1571
NWS Storm Prediction Center Norman OK
0117 AM CDT Sat Aug 26 2017

Areas affected...Upper Texas Coast

Concerning...Tornado Watch 465...

Valid 260617Z - 260645Z

The severe weather threat for Tornado Watch 465 continues.

SUMMARY...The highest potential for tornadic supercells will likely be within 2 corridors either side of Galveston Bay (Brazoria/Fort Bend and Chambers Counties) for the next 1-2 hours. A new tornado watch will be issued before 0700 UTC.

DISCUSSION...Latest subjective surface mesoanalysis indicates the 80 degree F isotherm encompasses Brazoria county northeast into Chambers county. The northwest area of a plume of 78 degree F dewpoints protrudes northwest from the northwest Gulf of Mexico into the immediate coastal area of Brazoria county. The latest RAP forecast sounding appears to be representative of the surface and around 1400 J/kg MLCAPE is noted. When inputting storm motion (135 degrees at 35-kt), the KHGX VAD indicates around 200 m2/s2 0-1 km SRH. With robust updrafts implied by the convective structures (echo tops 35-40k ft), the environment will continue to be favorable for low-level mesocyclones and a tornado risk over the next 1-2 hours.

..Smith.. 08/26/2017

MESOSCALE DISCUSSIONS

Example: HARVEY (2017)

Issued for watch potential or watch updates

Situational, no deadlines nor rigid thresholds

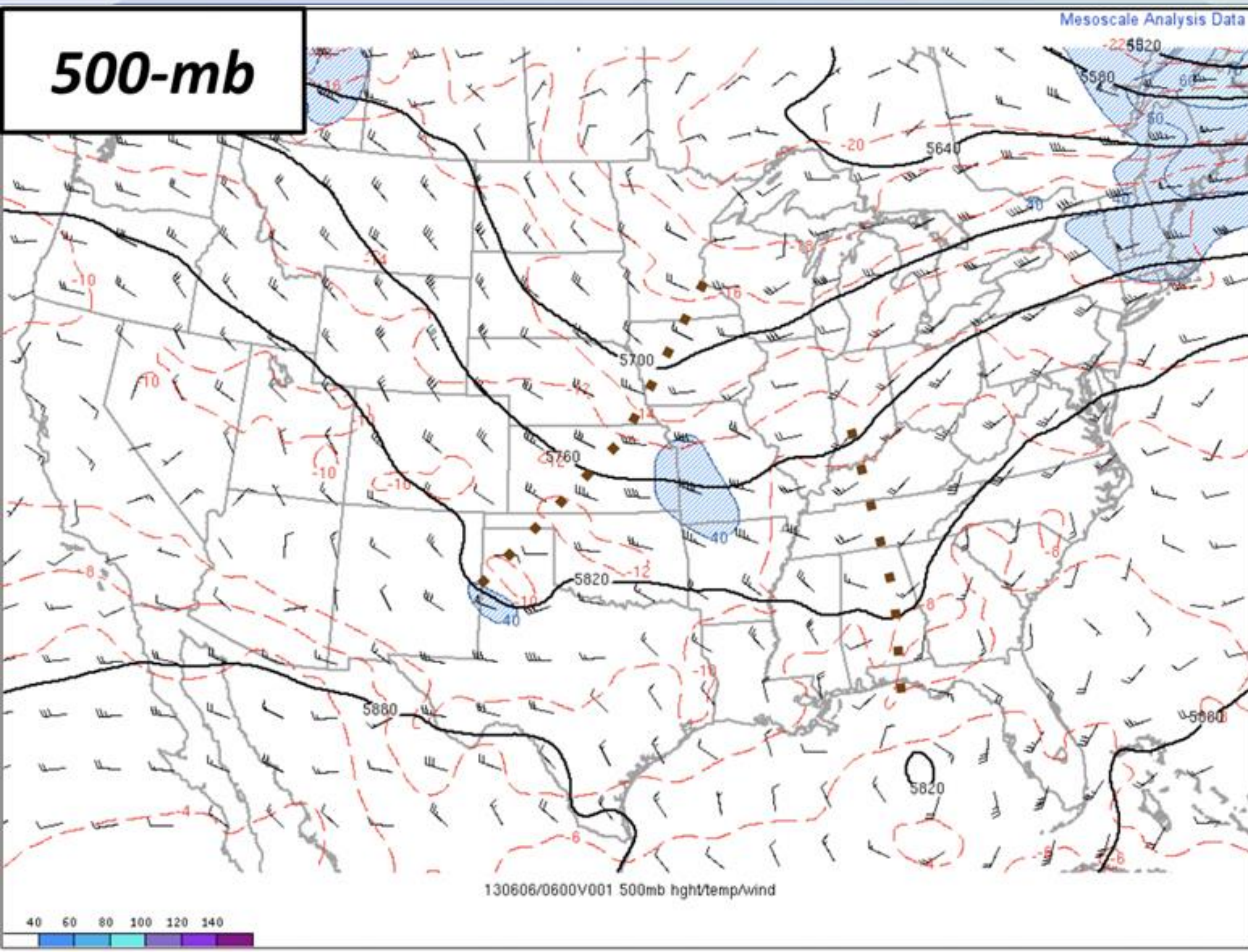
SPC FORECAST EXAMPLES FOR TCs

Example from Harvey (2017)

WATCHES

- **Coordinated SPC+WFO**
- **County based**
- **Cleared/extended by WFO**
- **Legacy polygon for aviation**
- **Tornado probabilities offered with watch**
- **Targeted to situational tornado threat**
- **Not necessary for all TCs.** ***Some TCs don't produce tornadoes!***

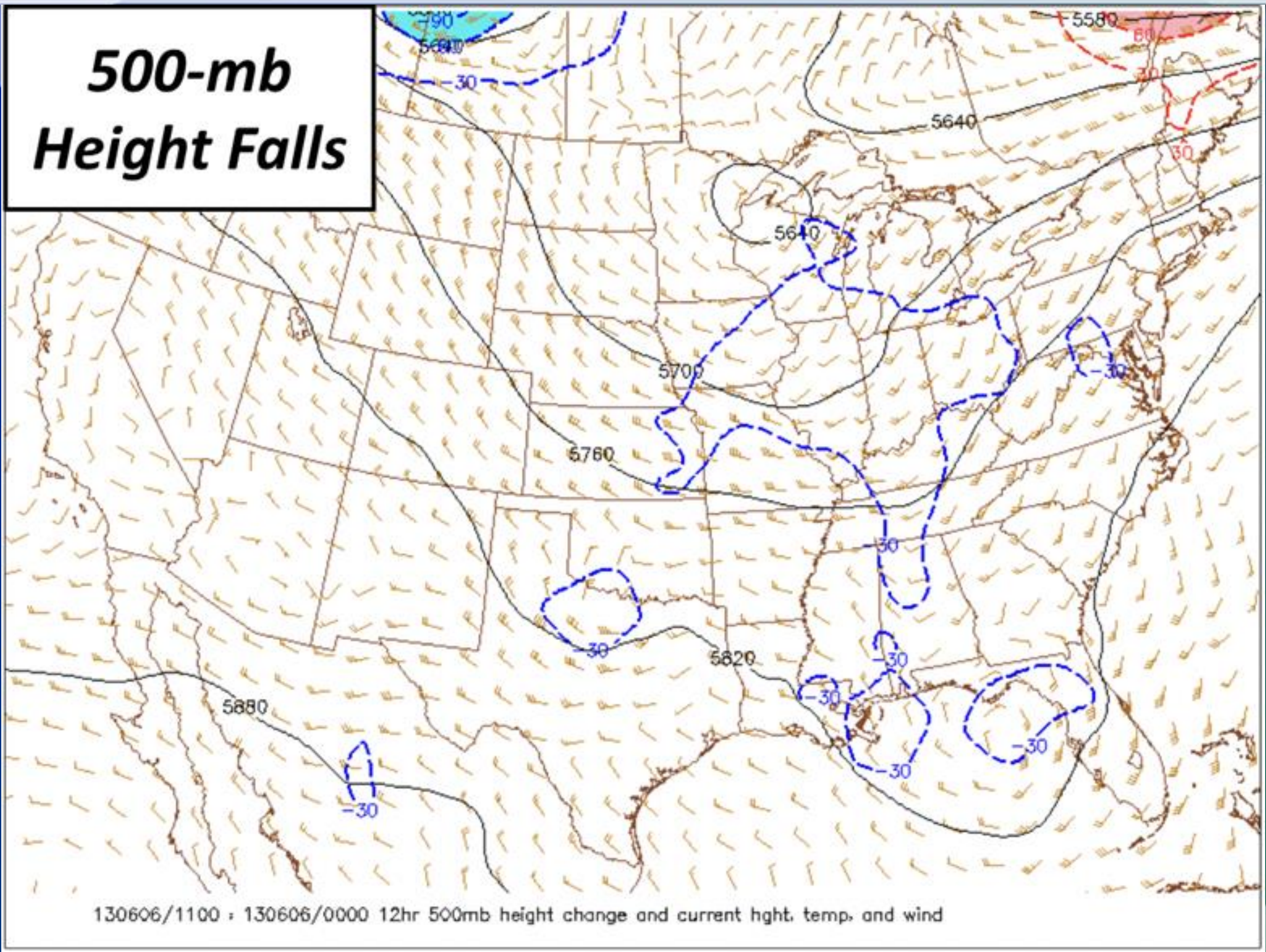
TC TORNADO EXAMPLE CASES 1 (ANDREA 2013)



-Southern-stream shortwave trough and accompanying upstream DAVA/subsidence-induced drying tracking eastward across SE CONUS

-Introduces the potential for baroclinic-related processes to inject into the cyclonic flow envelope -- fostering opportunities for a favorable meso environment for tornadogenesis

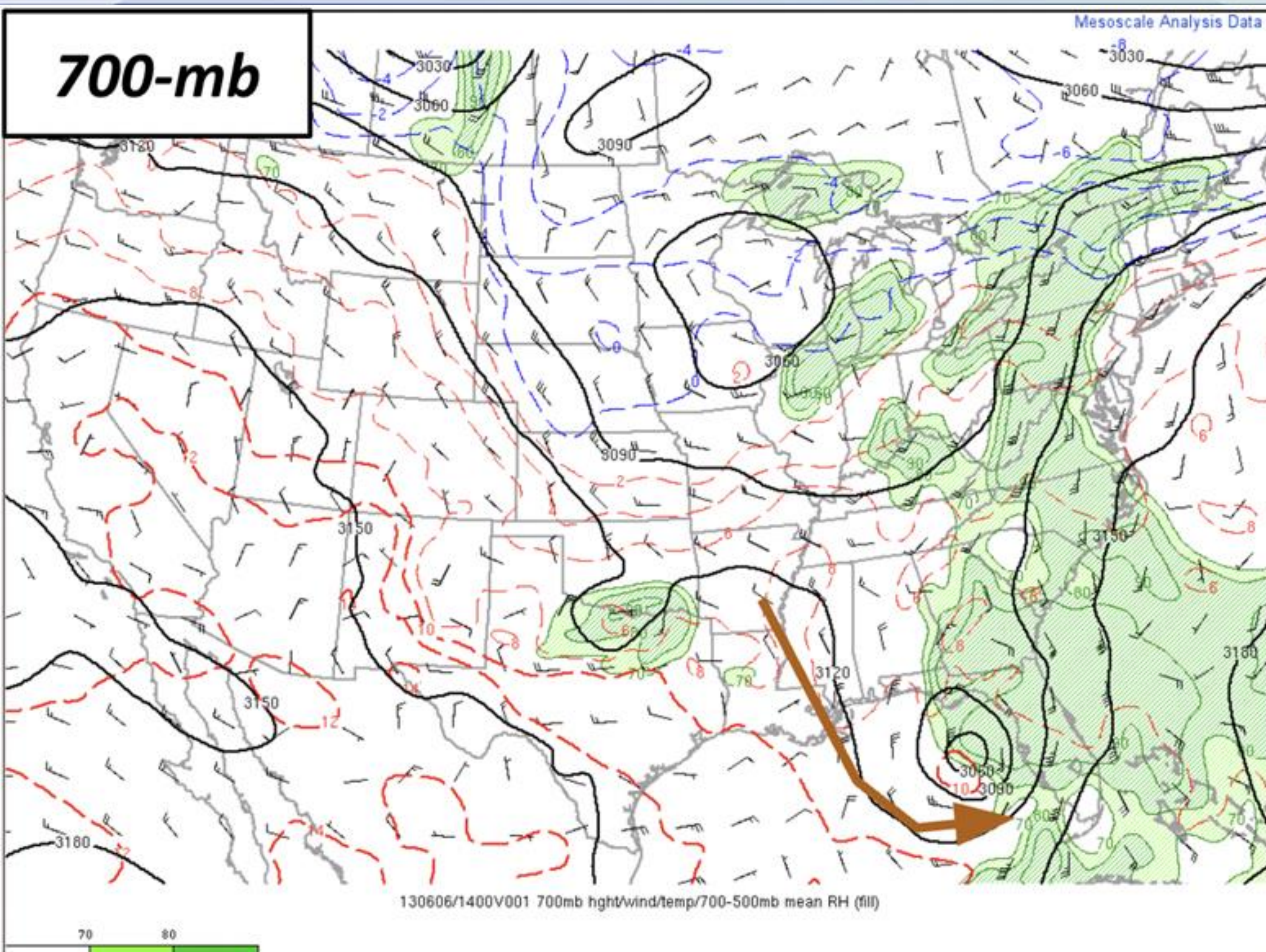
TC TORNADO EXAMPLE CASES 1 (ANDREA 2013)



-Mid-level height-falls associated with baroclinic shortwave trough spreading eastward into the tropical environment

-Essentially injecting baroclinicity into the cyclonic flow envelope -- facilitating a conducive mesoscale environment for tornadogenesis

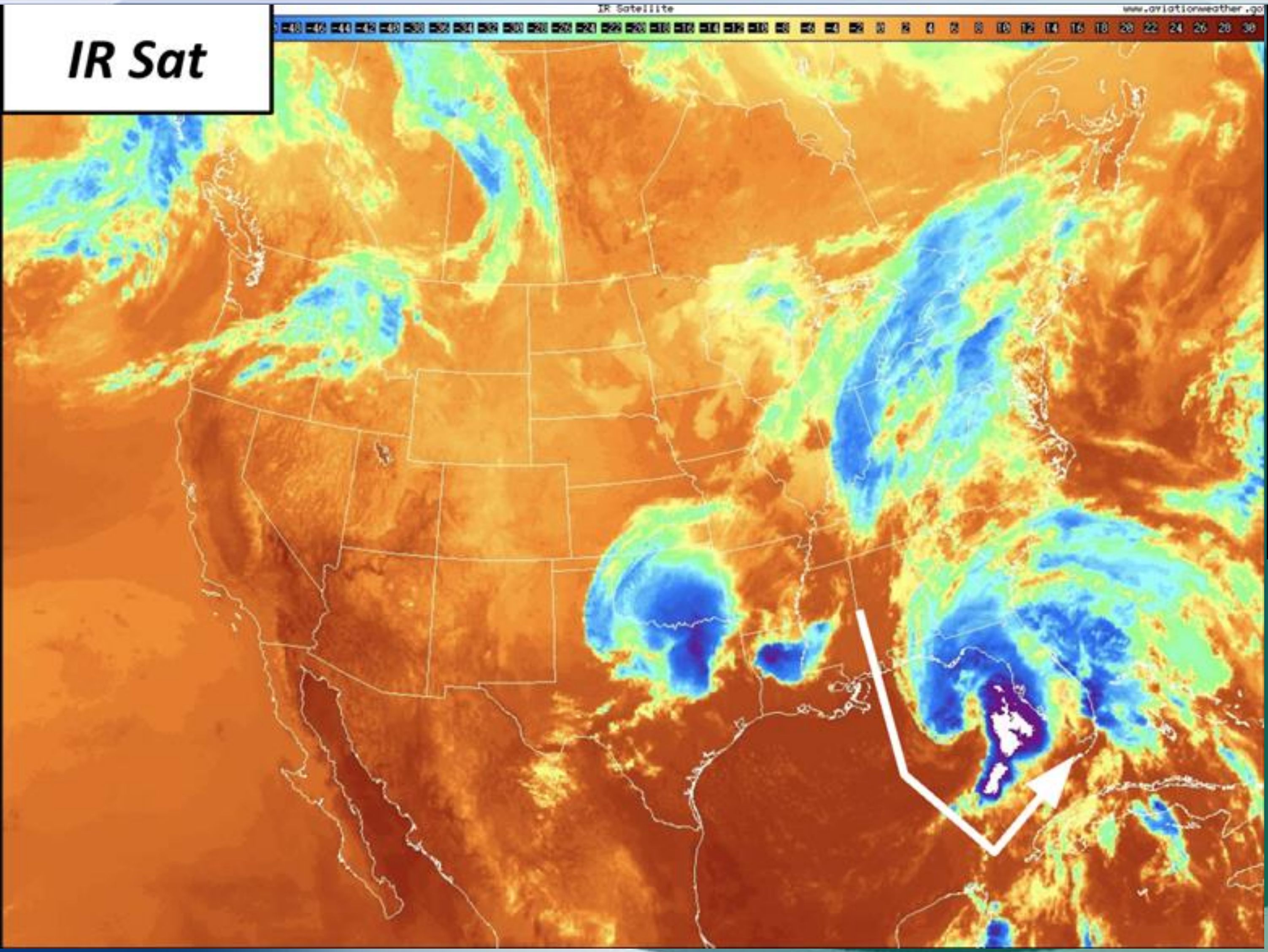
TC TORNADO EXAMPLE CASES 1 (ANDREA 2013)



-Mid-level dry air (associated with aforementioned shortwave trough) cyclonically wrapping into the TC

-This allows for favorable breaks between convection and resulting potent/ non-overturned air to ingest into convective updrafts

TC TORNADO EXAMPLE CASES 1 (ANDREA 2013)

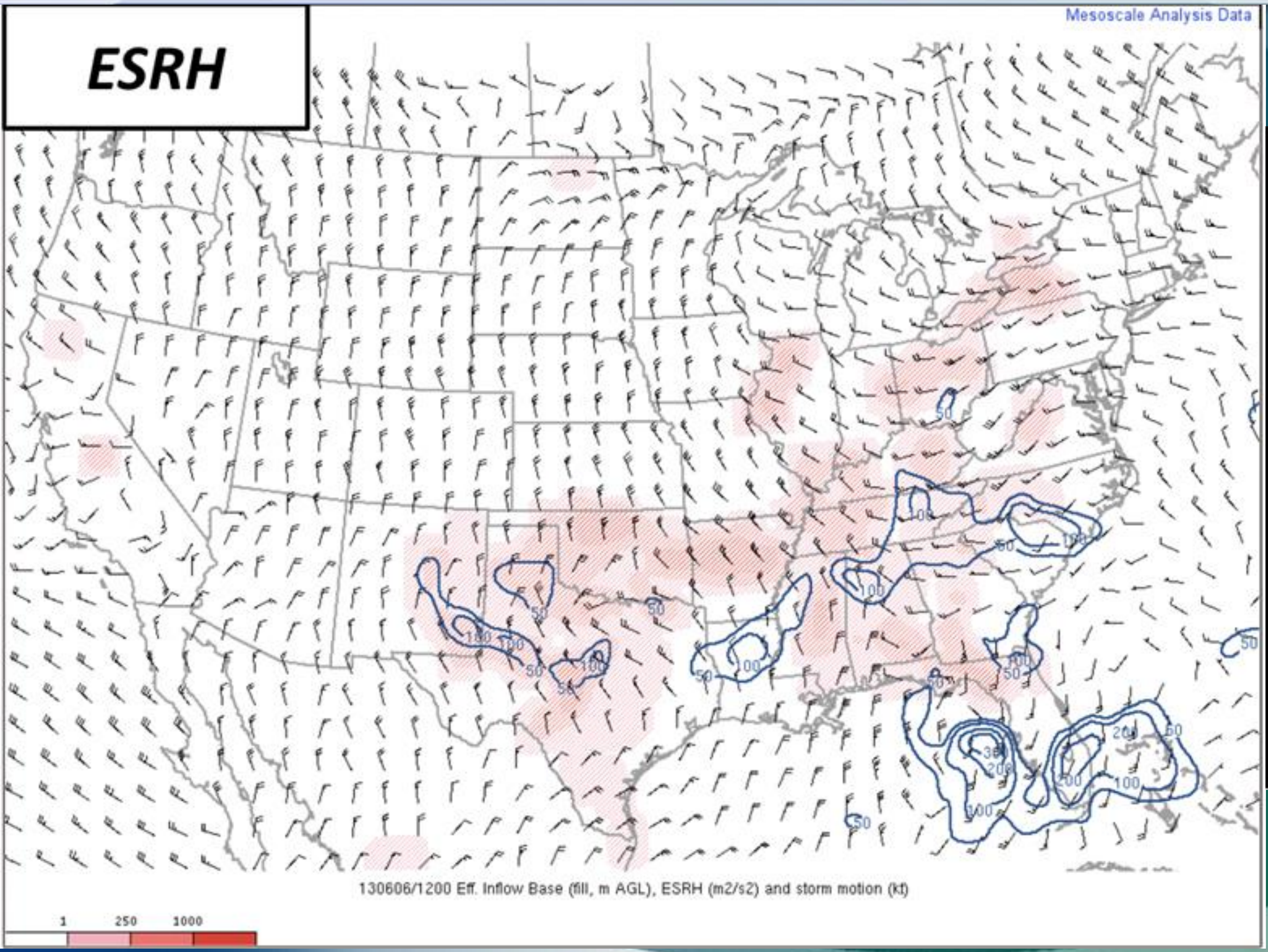


-Another depiction of dry air cyclonically enveloping the TC

- Mid-level dry air reduces mid-level theta-E values -- resulting in higher convective instability

-Dry slots can promote enhanced heating/ differential heating, setting up temporary baroclinic zones

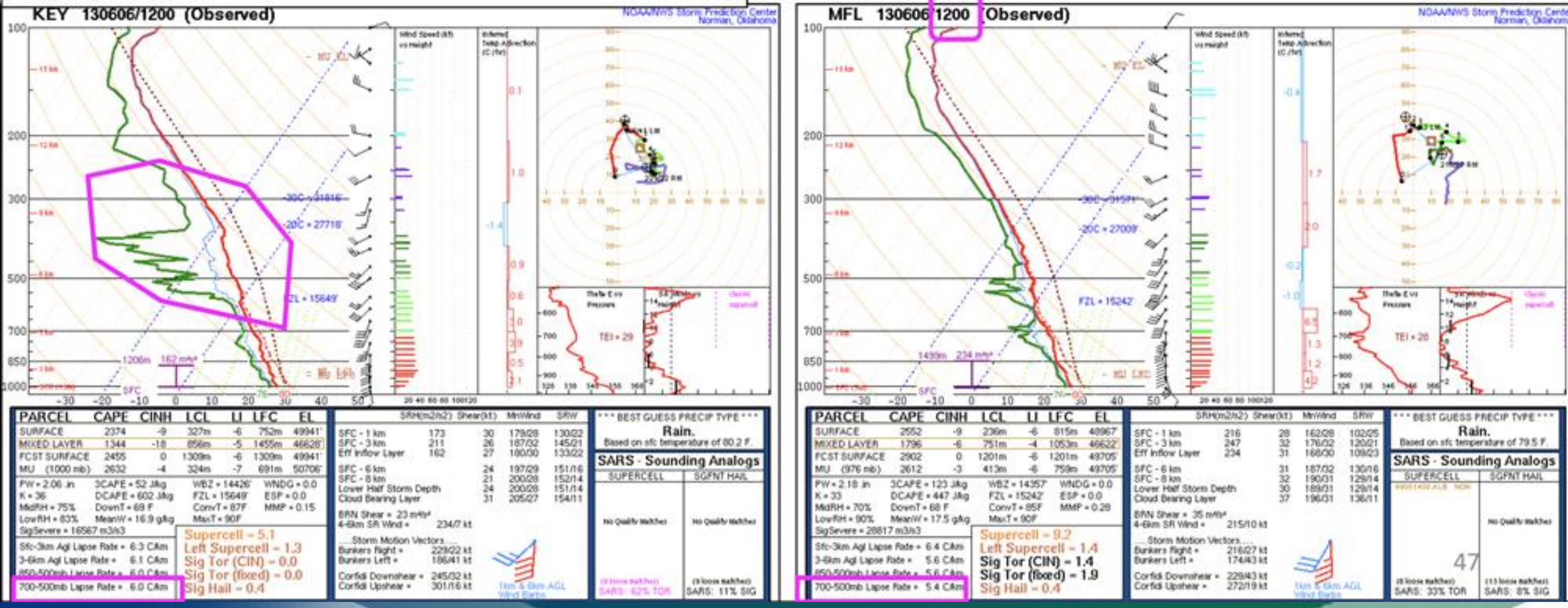
TC TORNADO EXAMPLE CASES 1 (ANDREA 2013)



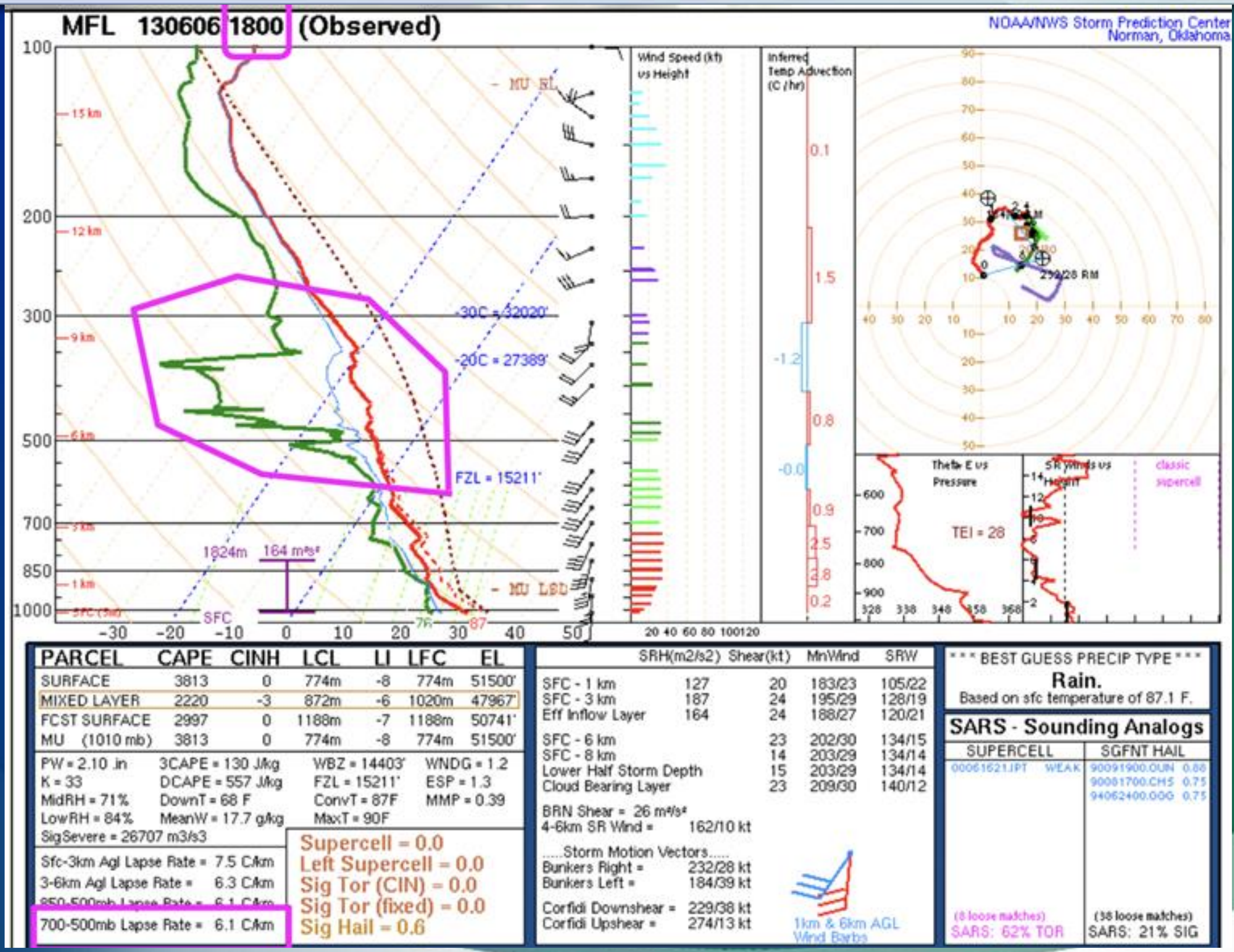
-Favorable environmental storm-relative helicity -- supportive of immediate updraft rotation -- owing to ingestion of air following helical trajectories into updrafts

TC TORNADO EXAMPLE CASES 1 (ANDREA 2013)

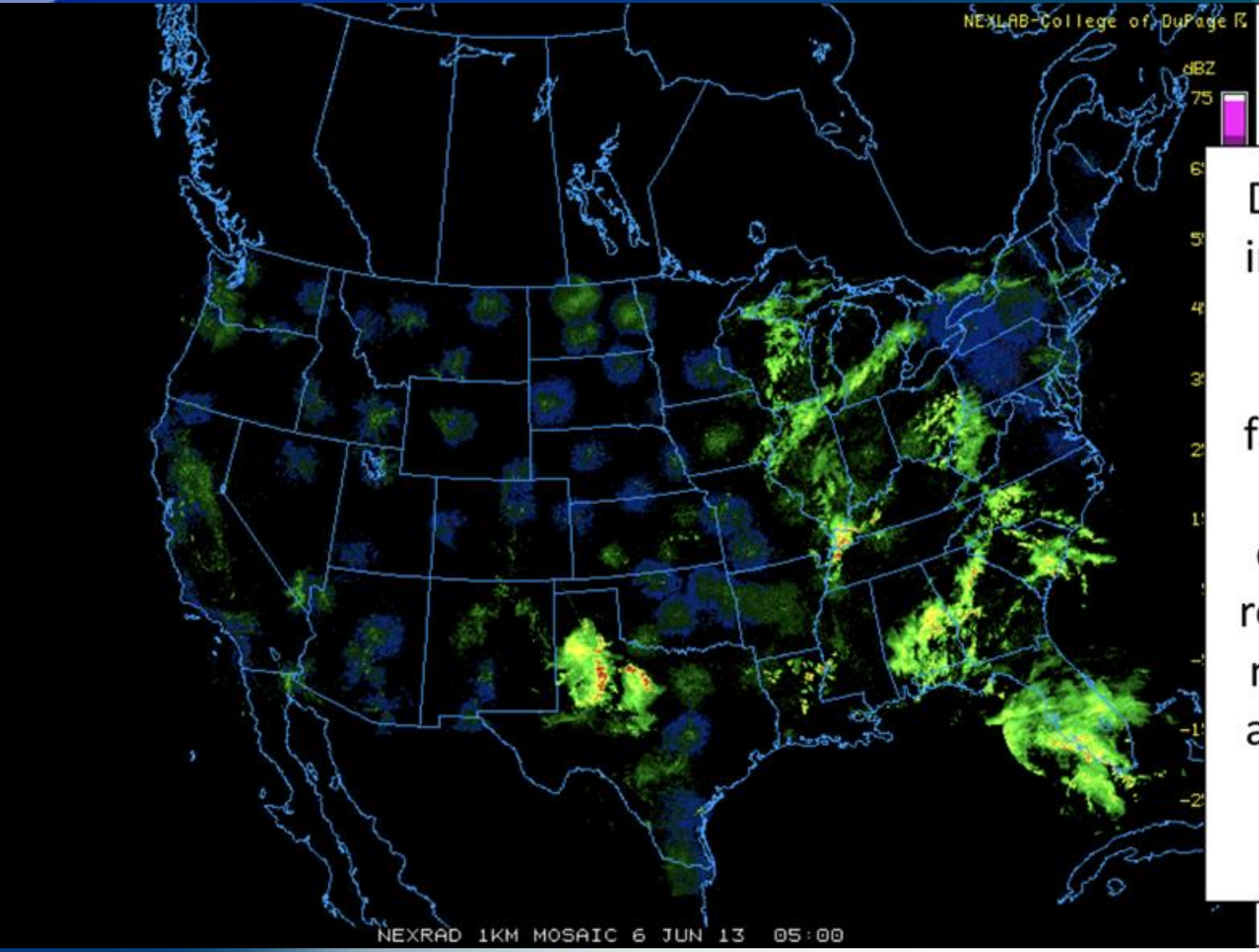
Upstream air mass at KEY depicts dry mid/upper-levels and steeper mid-level lapse rates (compared to downstream MFL data)



TC TORNADO EXAMPLE CASES 1 (ANDREA 2013)

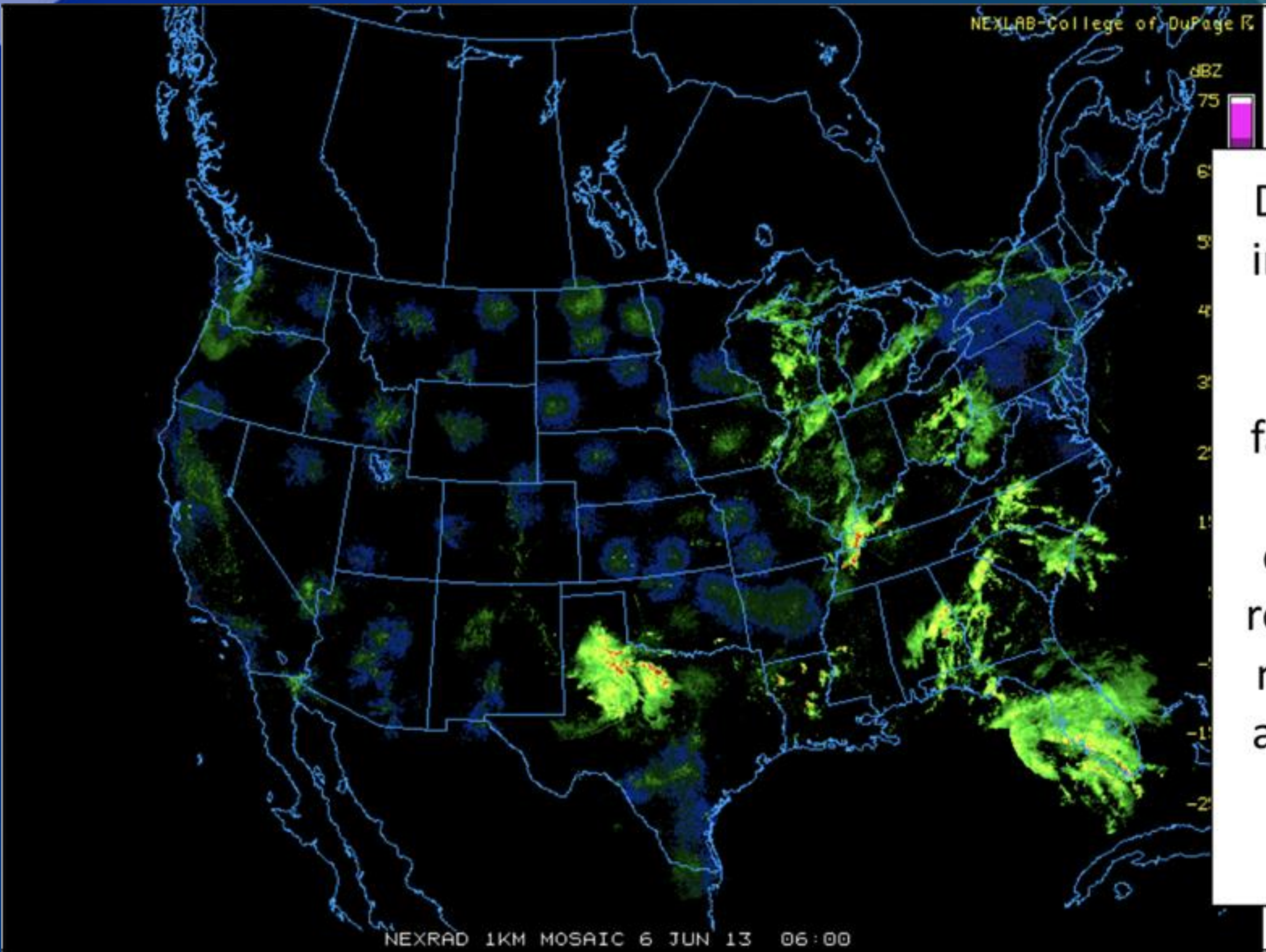


TC TORNADO EXAMPLE CASES 1 (ANDREA 2013)



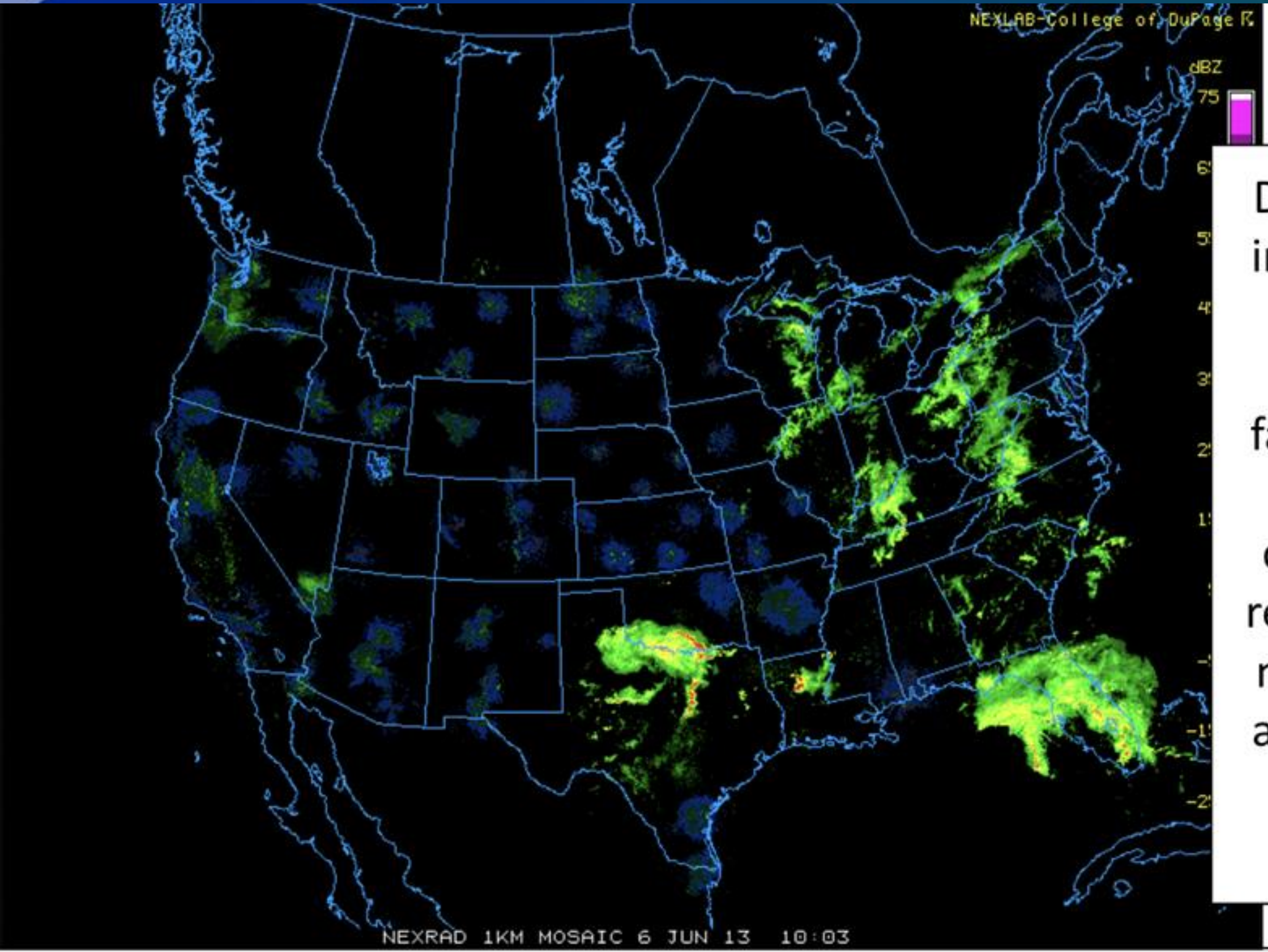
Dry air intrusion into the cyclonic flow envelope allowed for favorable breaks between convection and resulting potent/ non-overturned air to ingest into convective updrafts

TC TORNADO EXAMPLE CASES 1 (ANDREA 2013)



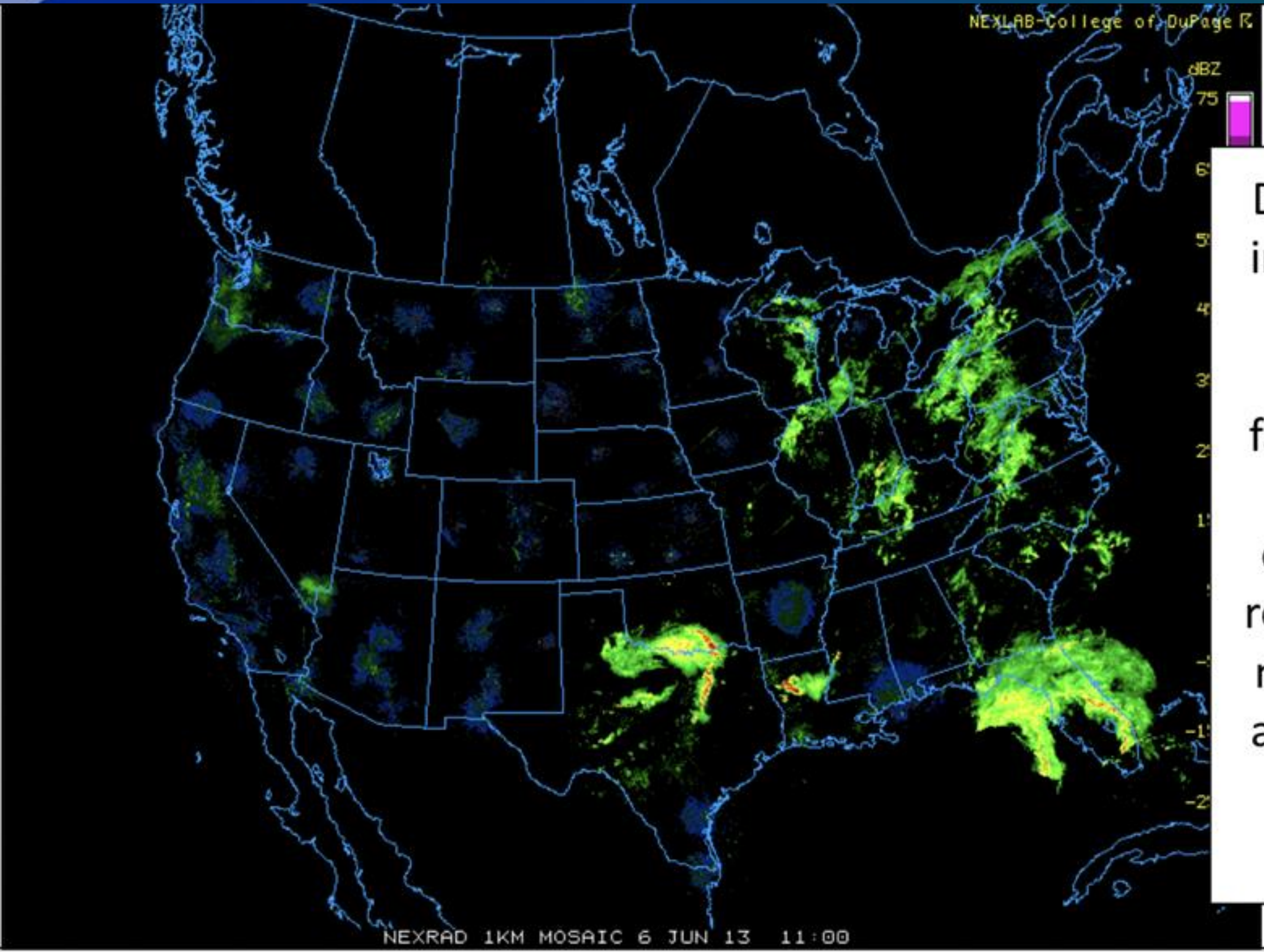
Dry air intrusion into the cyclonic flow envelope allowed for favorable breaks between convection and resulting potent/ non-overturned air to ingest into convective updrafts

TC TORNADO EXAMPLE CASES 1 (ANDREA 2013)



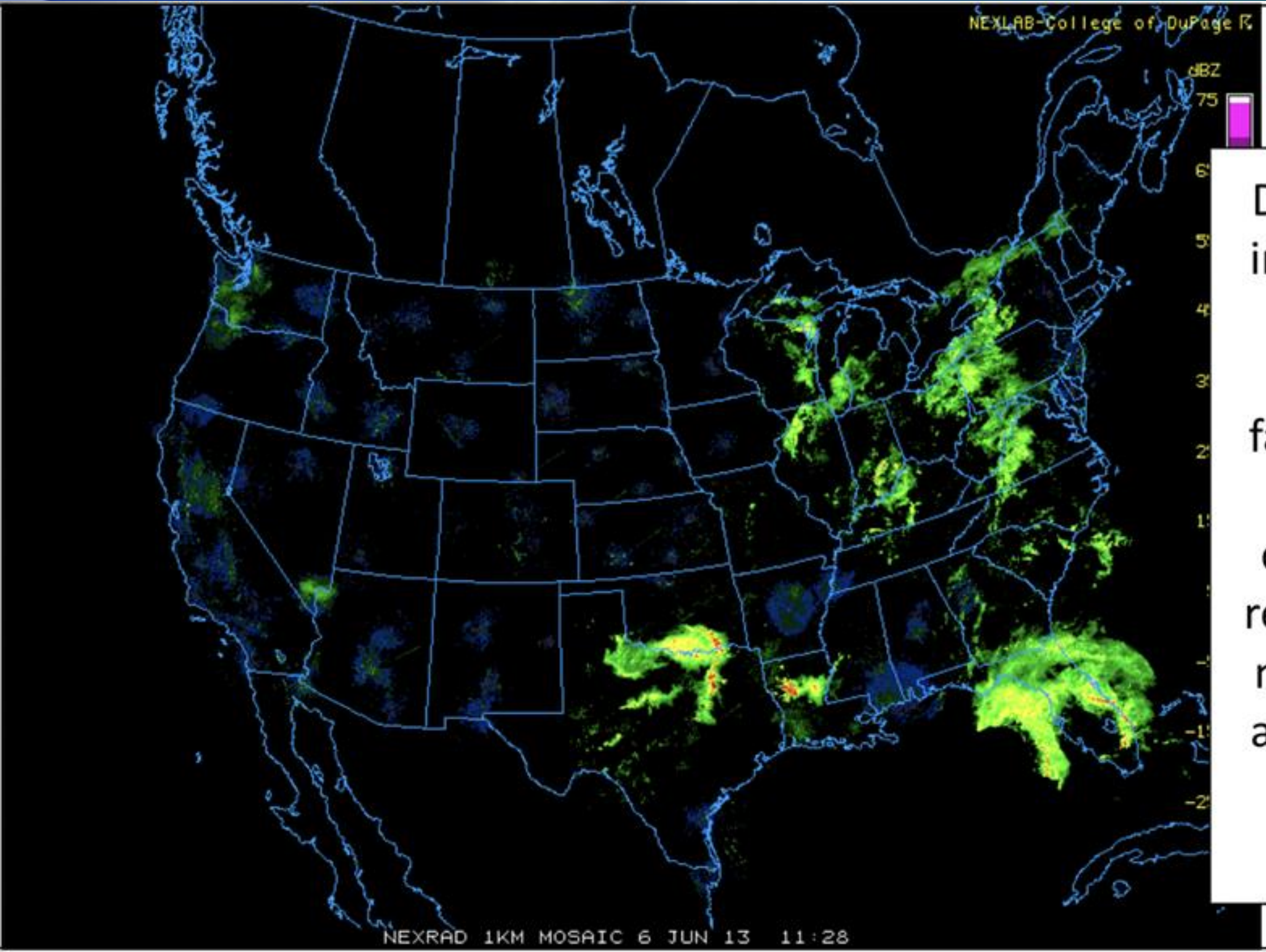
Dry air intrusion into the cyclonic flow envelope allowed for favorable breaks between convection and resulting potent/ non-overturned air to ingest into convective updrafts

TC TORNADO EXAMPLE CASES 1 (ANDREA 2013)



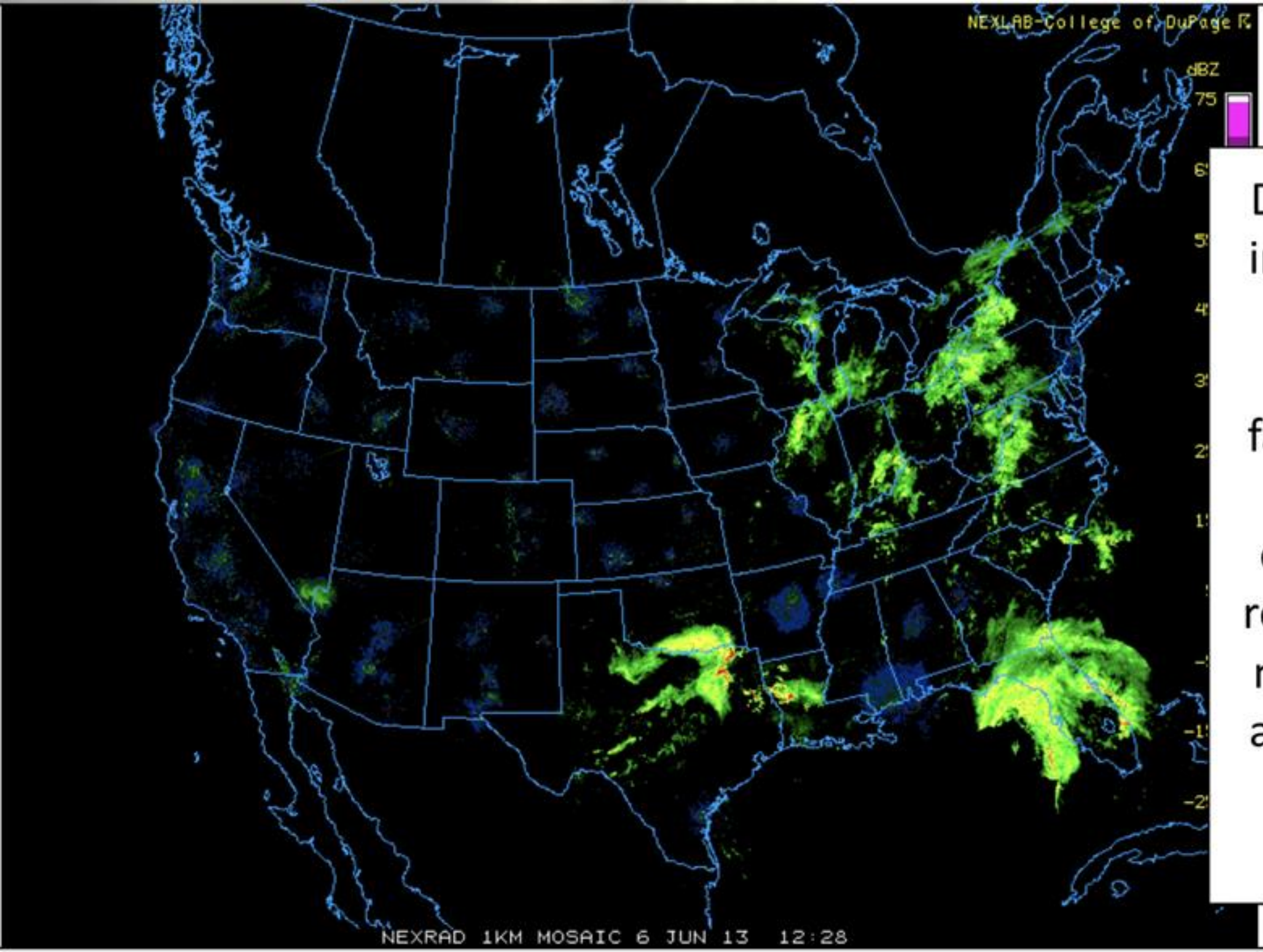
Dry air intrusion into the cyclonic flow envelope allowed for favorable breaks between convection and resulting potent/ non-overturned air to ingest into convective updrafts

TC TORNADO EXAMPLE CASES 1 (ANDREA 2013)



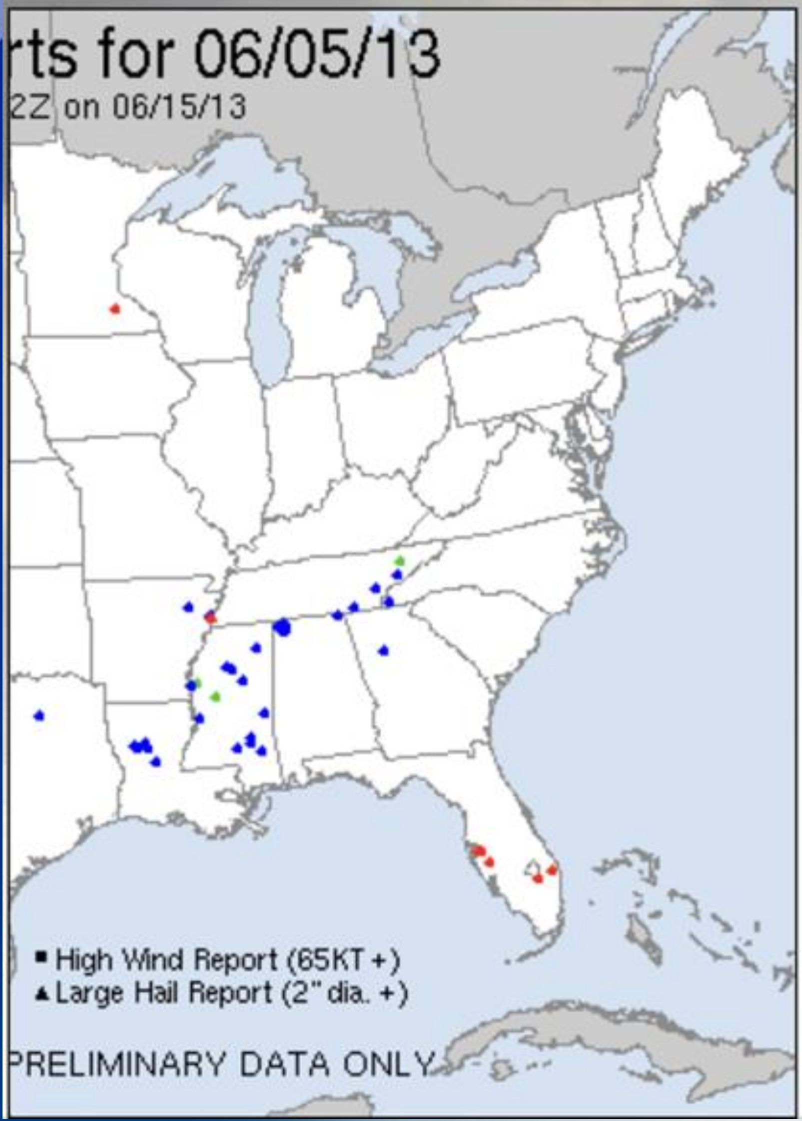
Dry air intrusion into the cyclonic flow envelope allowed for favorable breaks between convection and resulting potent/ non-overturned air to ingest into convective updrafts

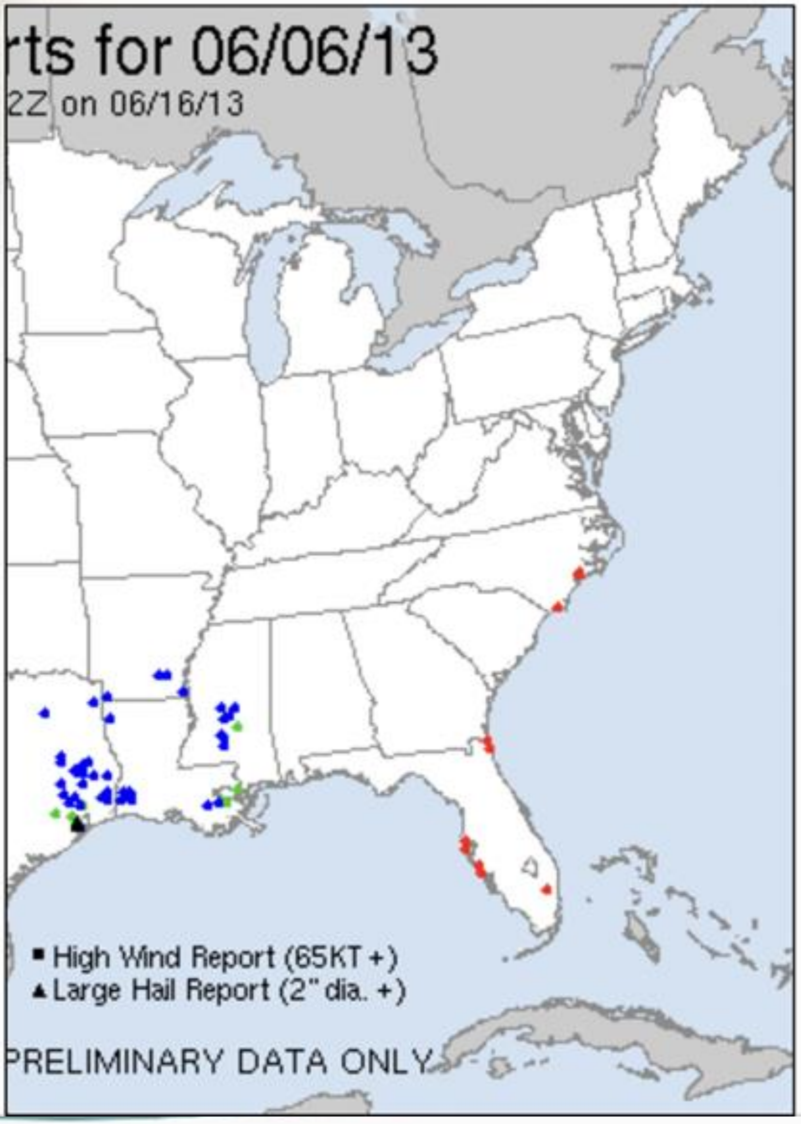
TC TORNADO EXAMPLE CASES 1 (ANDREA 2013)



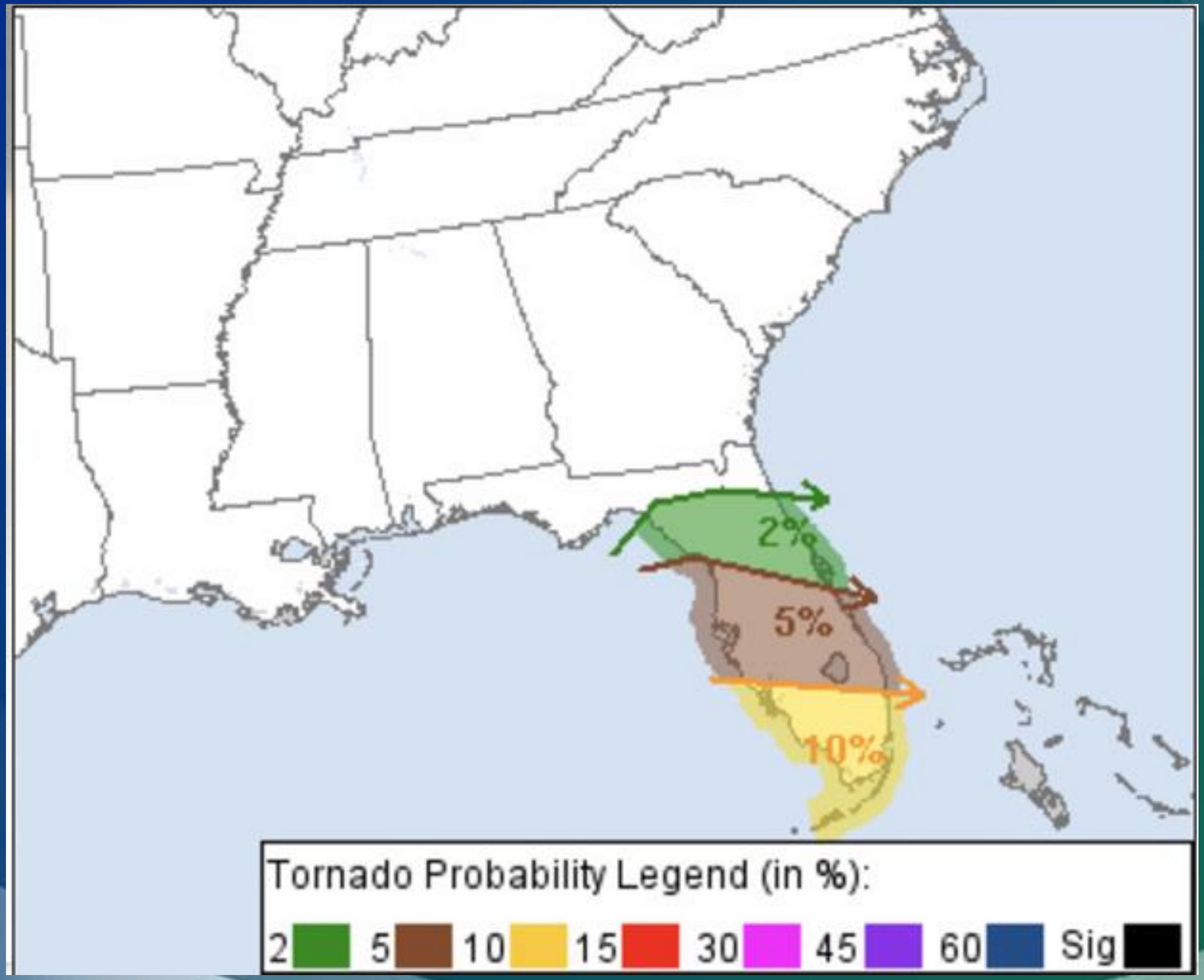
Dry air intrusion into the cyclonic flow envelope allowed for favorable breaks between convection and resulting potent/ non-overturned air to ingest into convective updrafts

TC TORNADO EXAMPLE CASES 1 (ANDREA 2013)



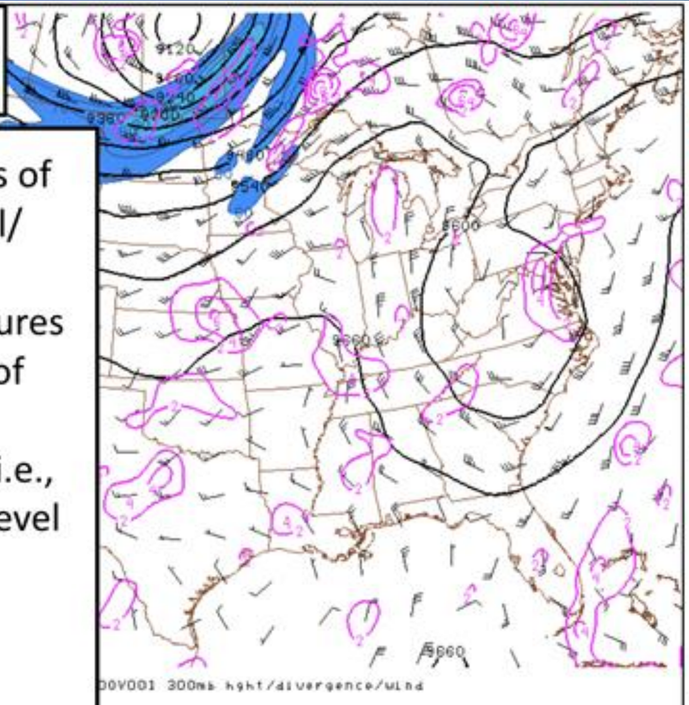


TC TORNADO EXAMPLE CASES 2 (ISAAC 2012)



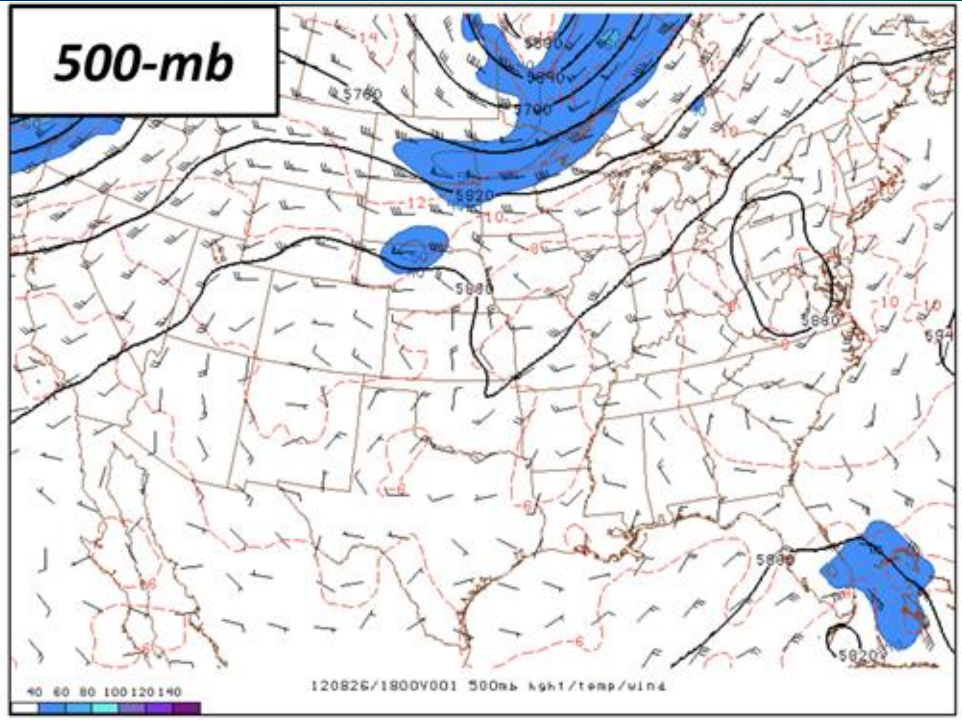
TC TORNADO EXAMPLE CASES 2 (ISAAC 2012)

300-mb

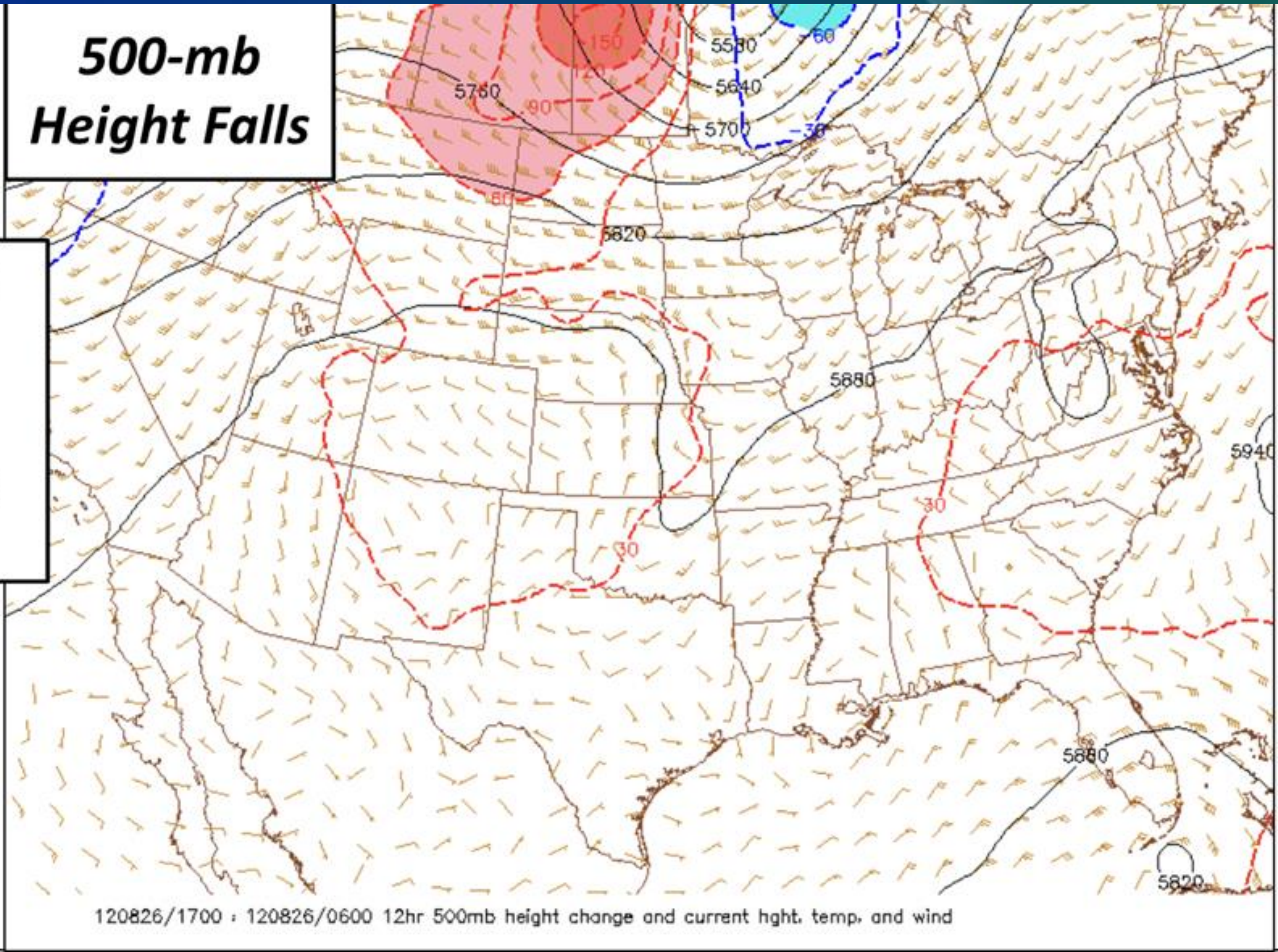


-No indications of any substantial/ favorable baroclinic features in the vicinity of the TC environment (i.e., strong upper-level jet streaks, shortwave troughs, etc.)

500-mb

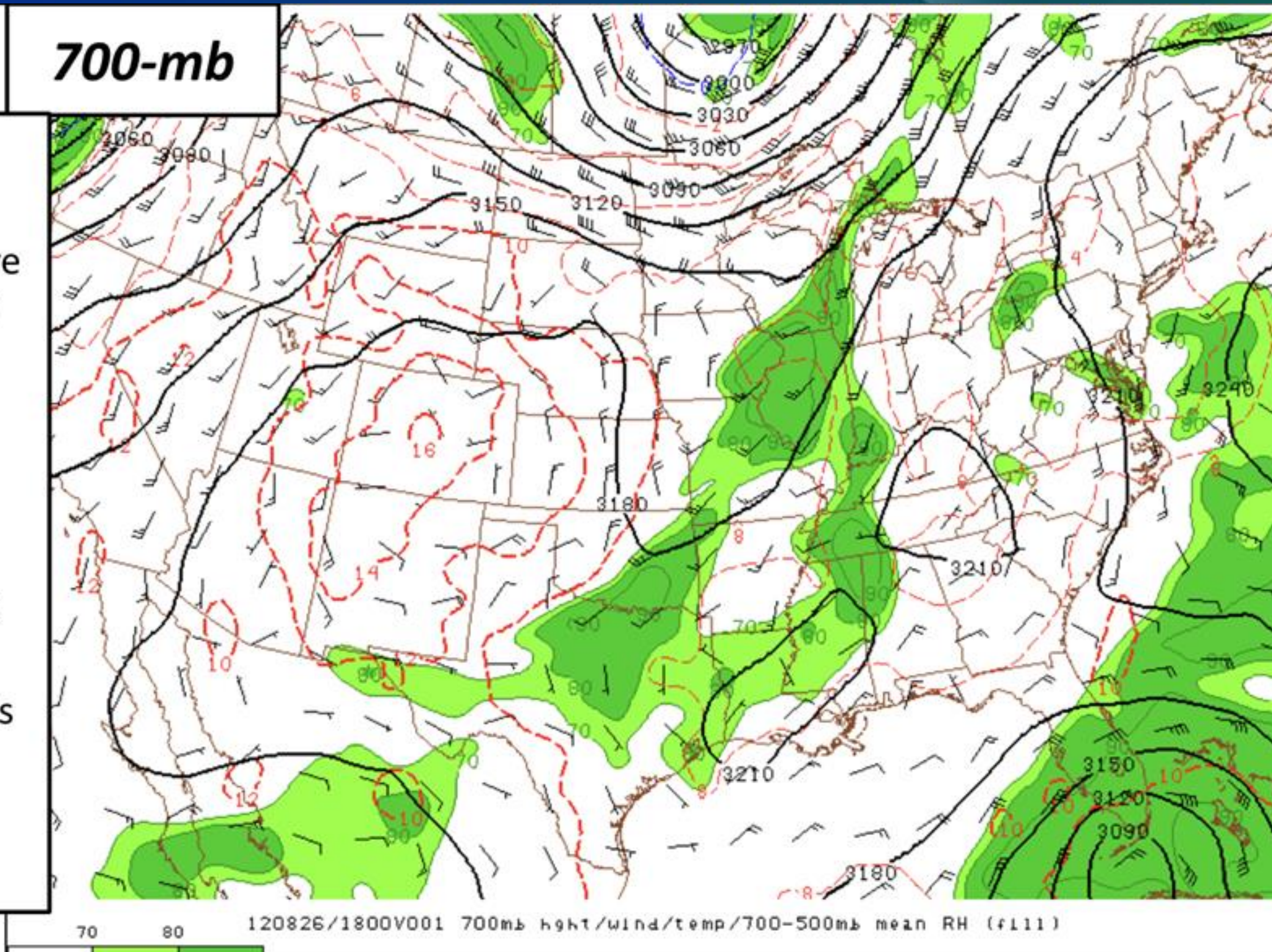


TC TORNADO EXAMPLE CASES 2 (ISAAC 2012)



-Lack of mid-level height falls corroborate previous notions (lack of baroclinic features)

TC TORNADO EXAMPLE CASES 2 (ISAAC 2012)

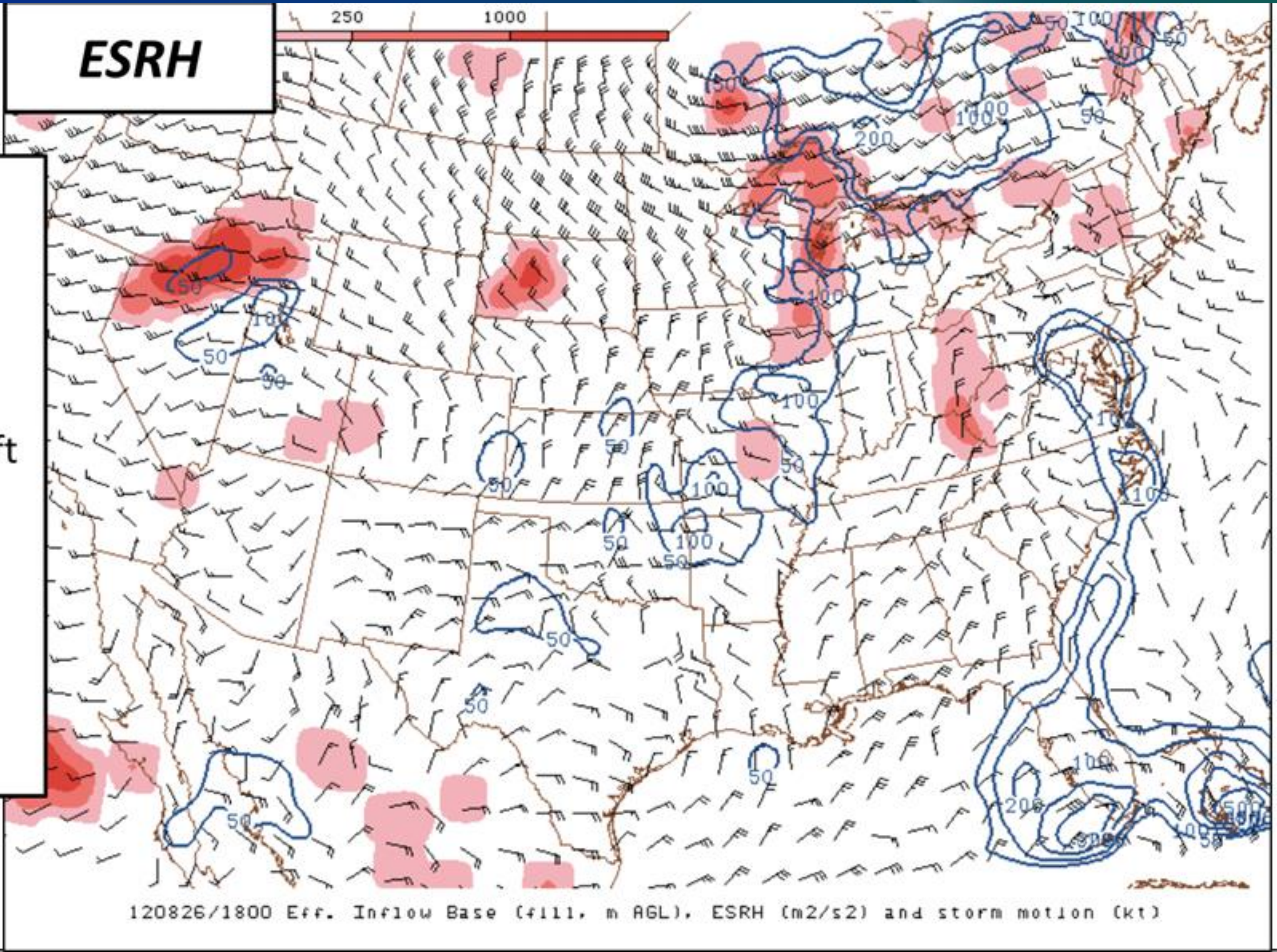


-Horizontal gradient in mid-level moisture is found over NW semicircle of cyclonic flow envelope

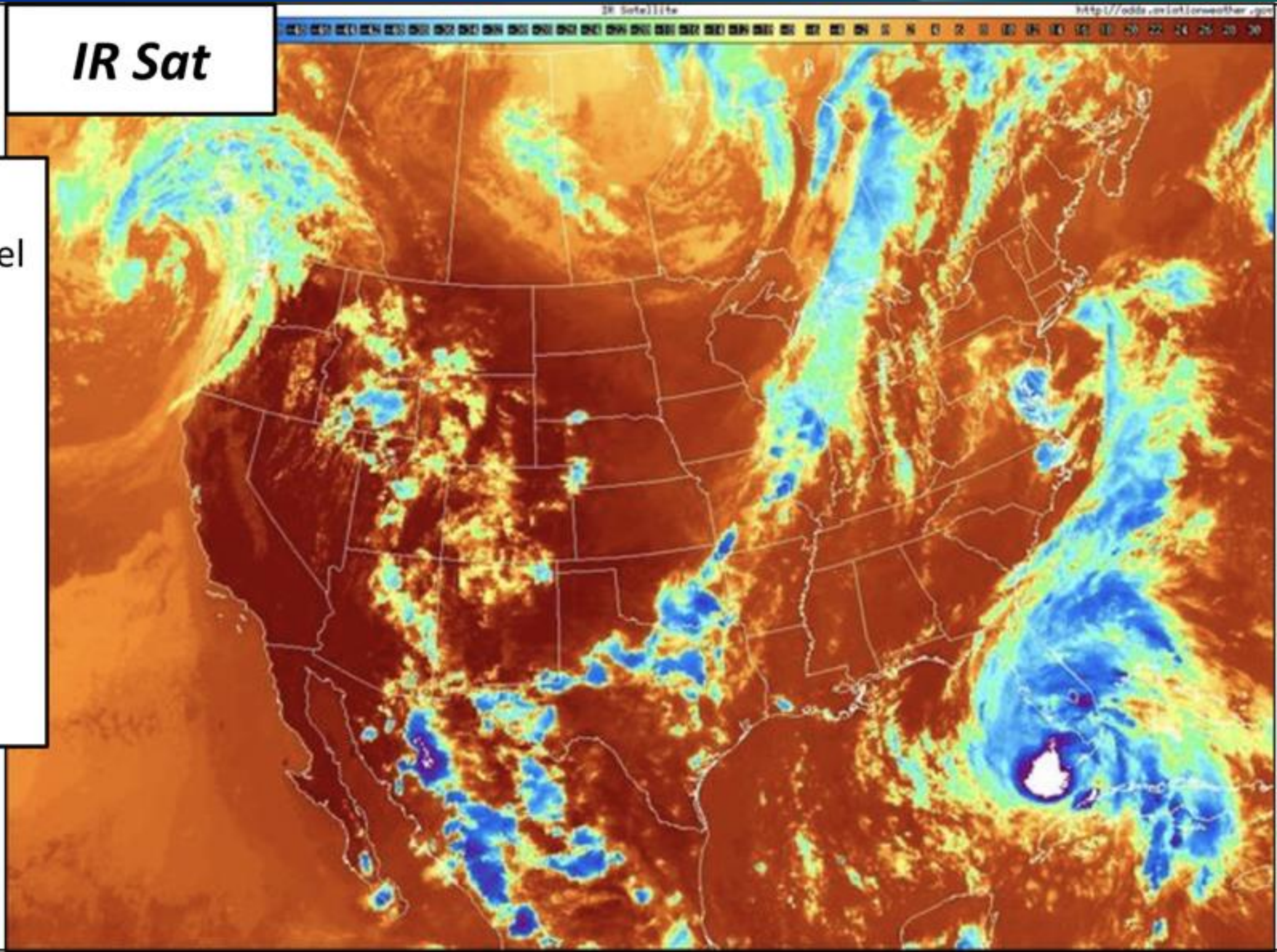
-Lack of baroclinic-related processes limits propensity for this dry air to cyclonically envelop the TC

TC TORNADO EXAMPLE CASES 2 (ISAAC 2012)

-Favorable environmental storm-relative helicity -- supportive of immediate updraft rotation -- owing to ingestion of air following helical trajectories into updrafts



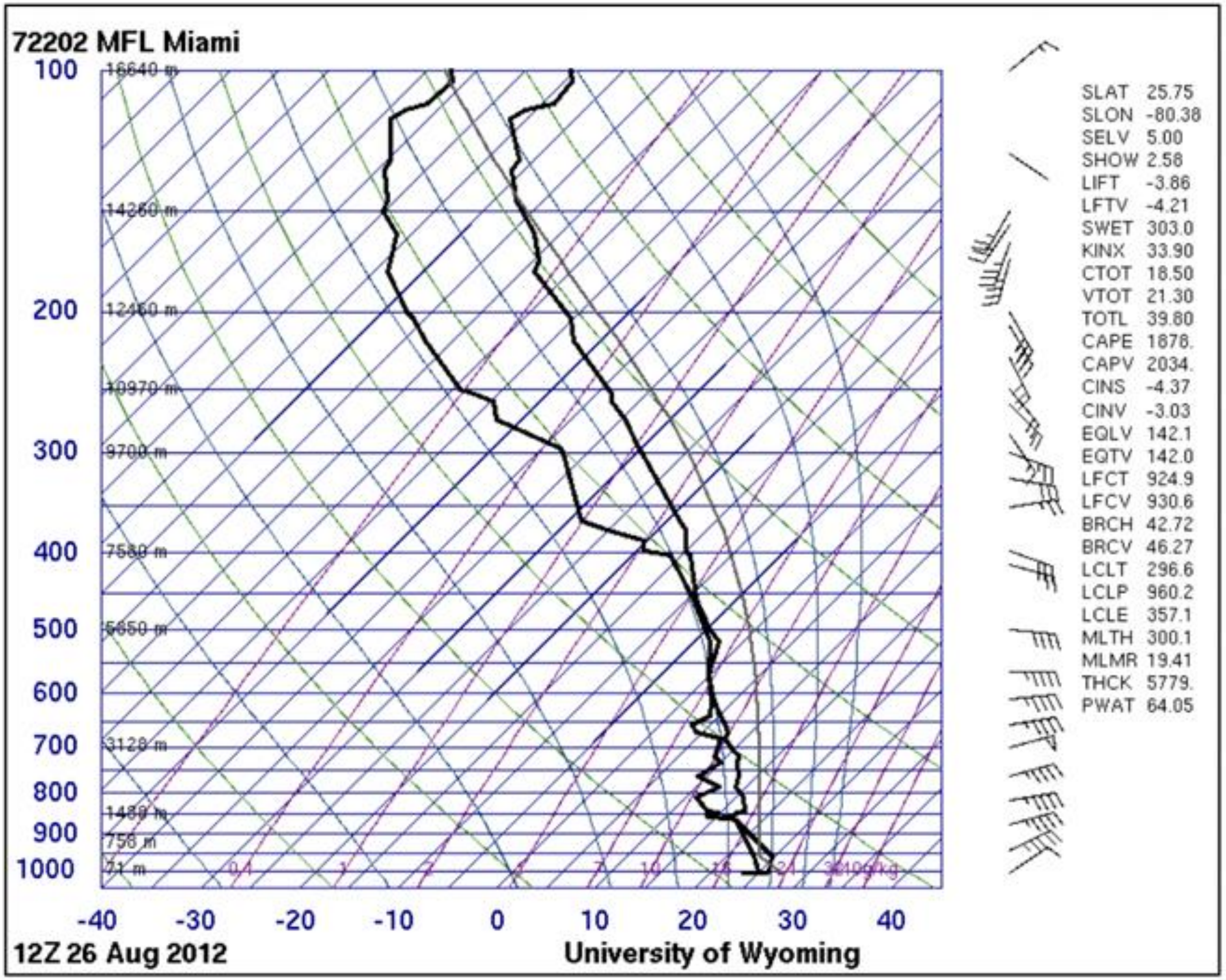
TC TORNADO EXAMPLE CASES 2 (ISAAC 2012)



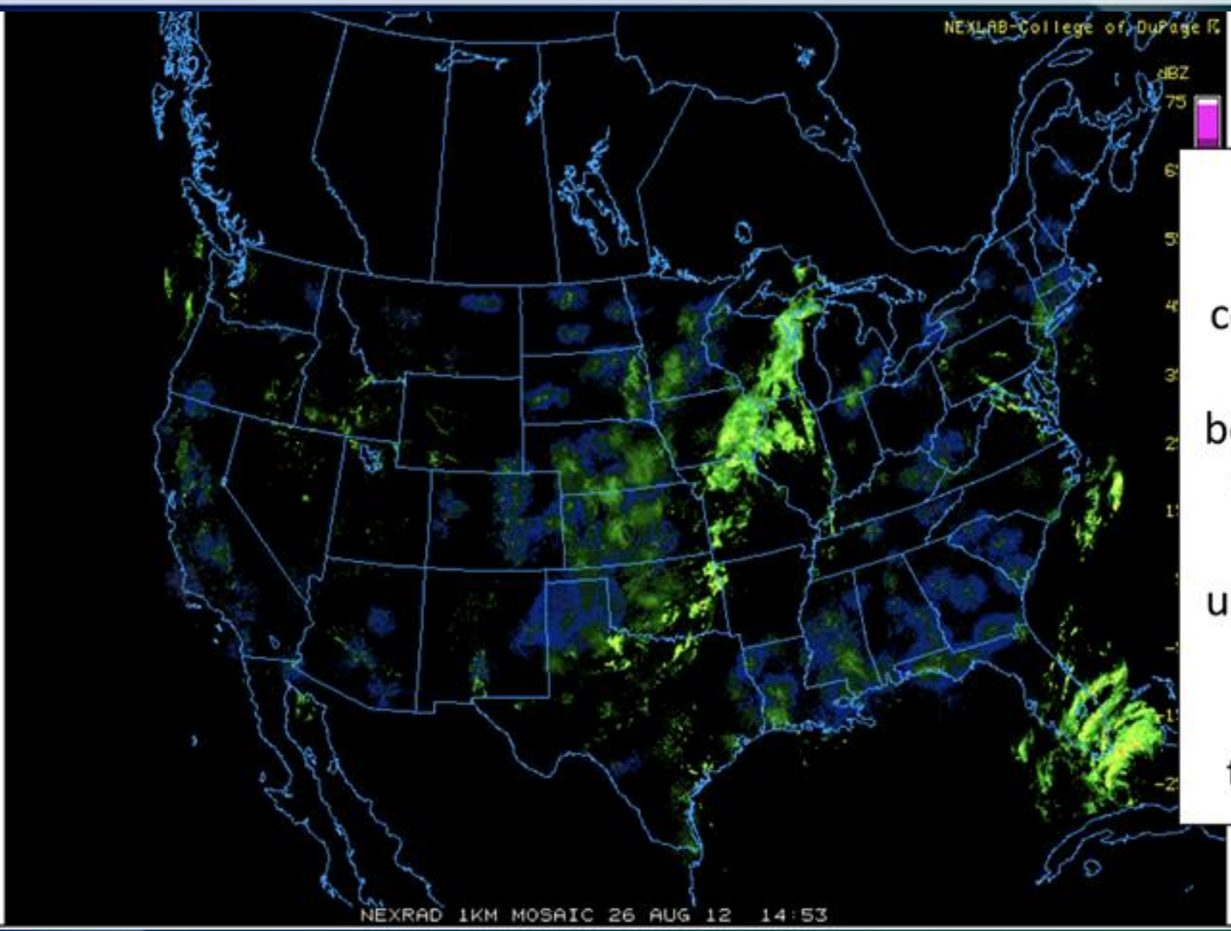
-No evidence of favorable mid-level dry air intrusions into the TC -- resulting in a generally unfavorable mesoscale environment for tornadogenesis

TC TORNADO EXAMPLE CASES 2 (ISAAC 2012)

-Moist-adiabatic lapse rate environment with accompanying weak mid-level lapse rates -- no evidence of mid-level dry air intrusion into the moisture-rich TC environment

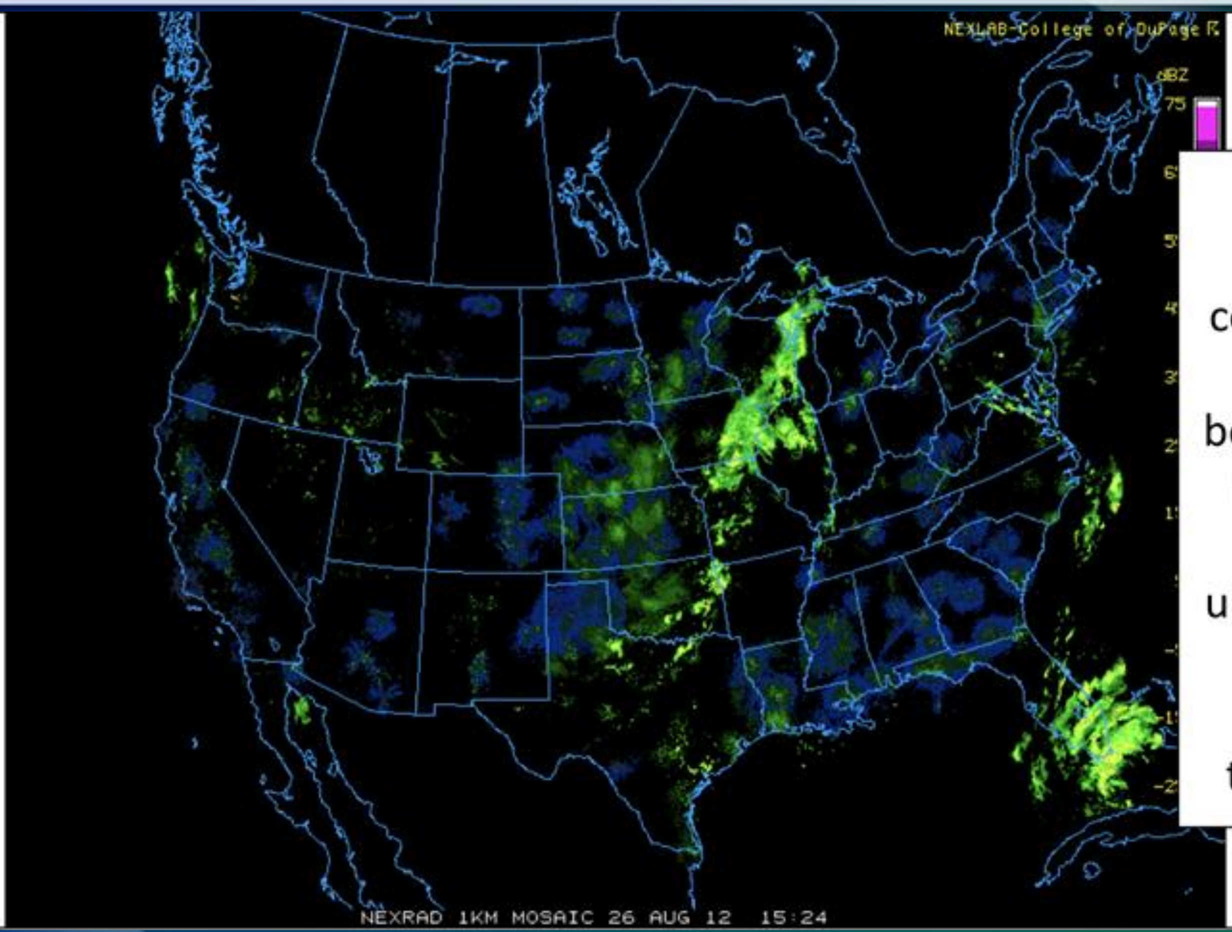


TC TORNADO EXAMPLE CASES 2 (ISAAC 2012)



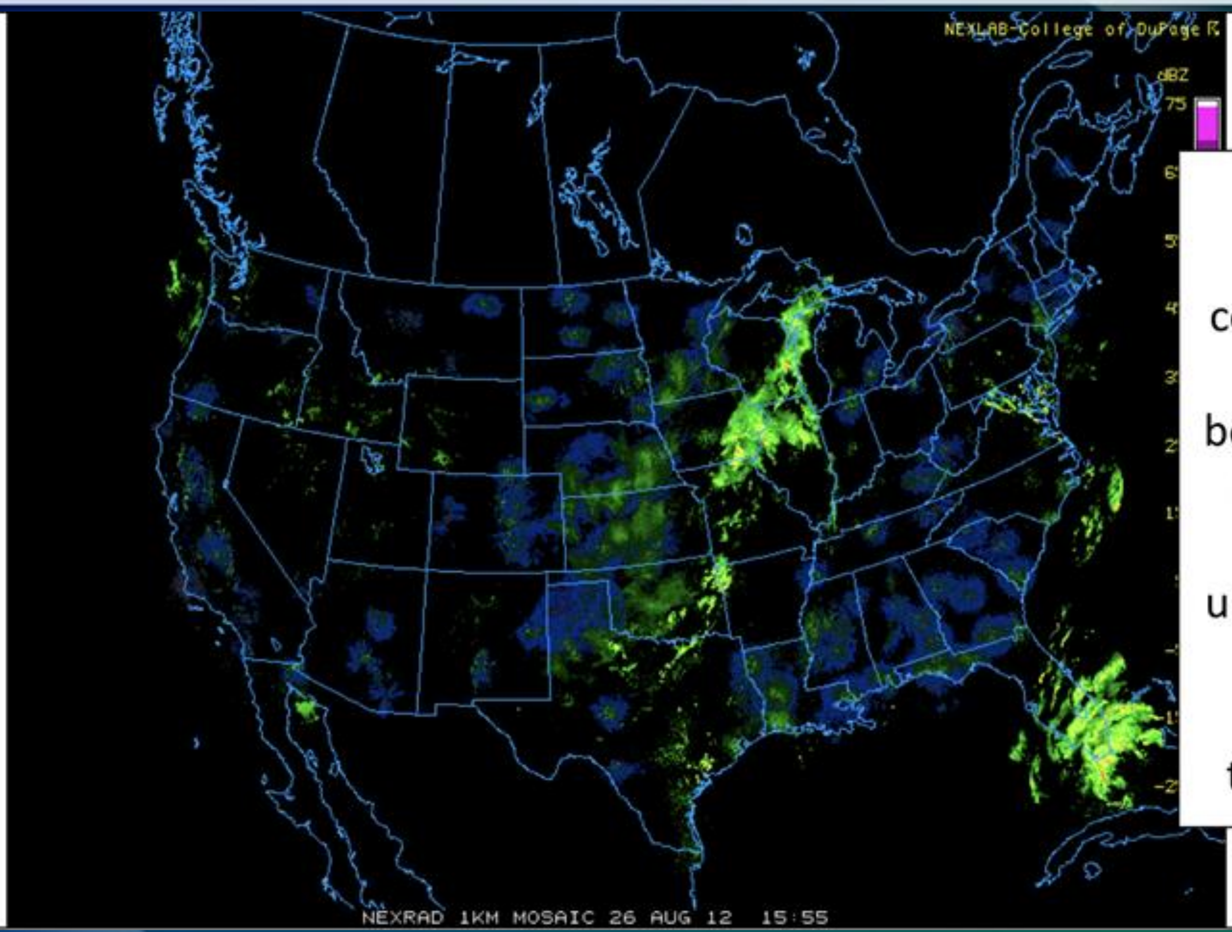
Large blob of continuous convection made it difficult for boundary layer to recover -- very little room for updrafts to ingest potent air supportive of tornadogenesis

TC TORNADO EXAMPLE CASES 2 (ISAAC 2012)



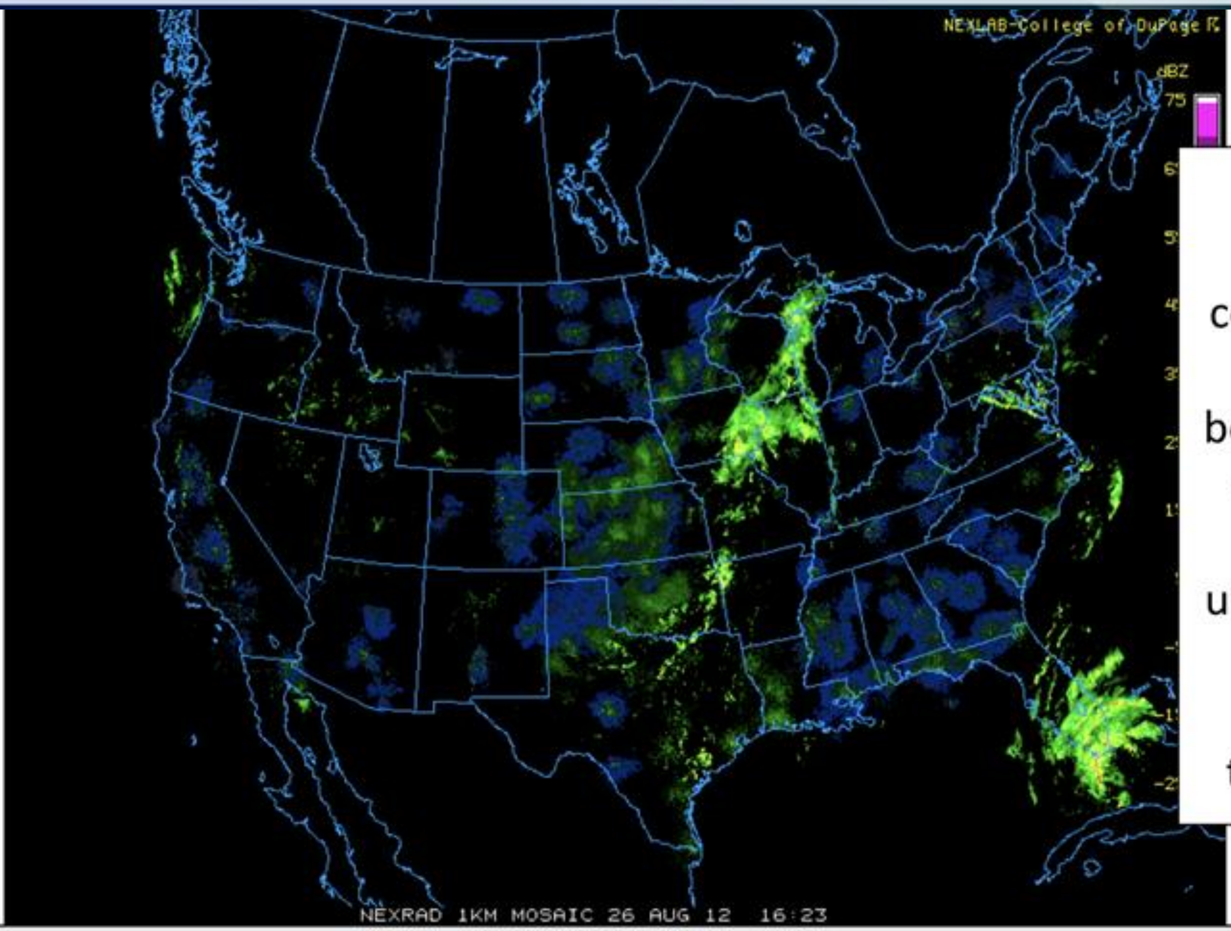
Large blob of continuous convection made it difficult for boundary layer to recover -- very little room for updrafts to ingest potent air supportive of tornadogenesis

TC TORNADO EXAMPLE CASES 2 (ISAAC 2012)



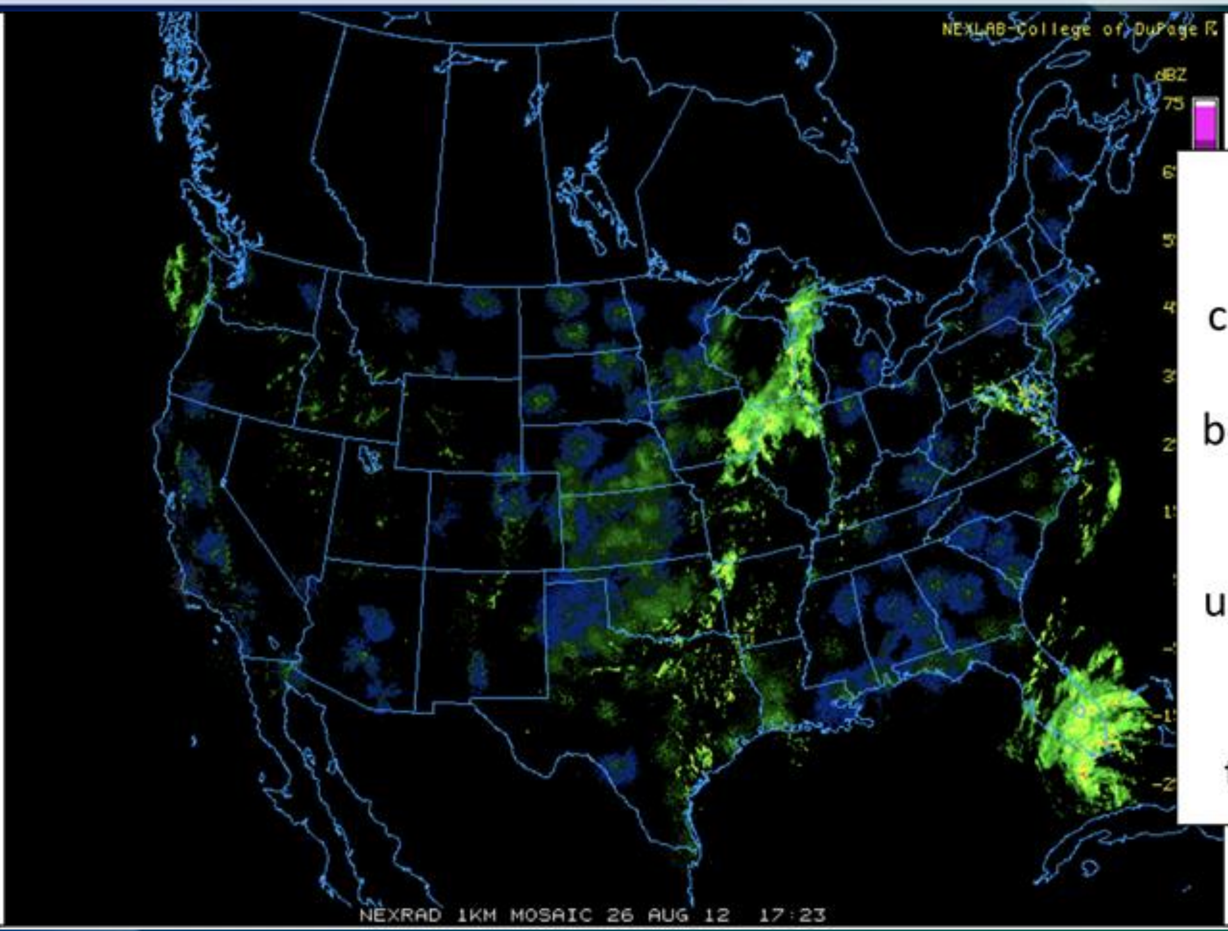
Large blob of continuous convection made it difficult for boundary layer to recover -- very little room for updrafts to ingest potent air supportive of tornadogenesis

TC TORNADO EXAMPLE CASES 2 (ISAAC 2012)



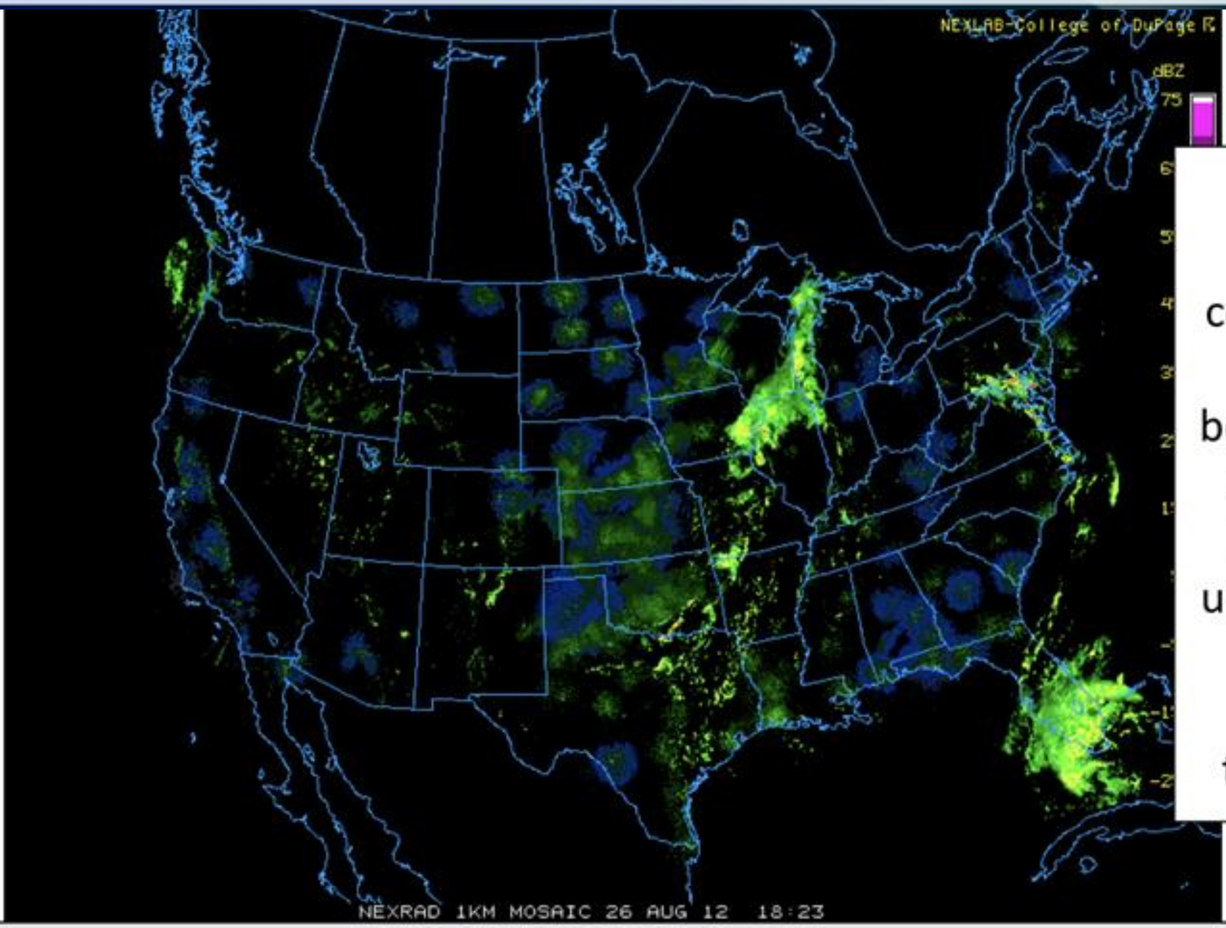
Large blob of continuous convection made it difficult for boundary layer to recover -- very little room for updrafts to ingest potent air supportive of tornadogenesis

TC TORNADO EXAMPLE CASES 2 (ISAAC 2012)



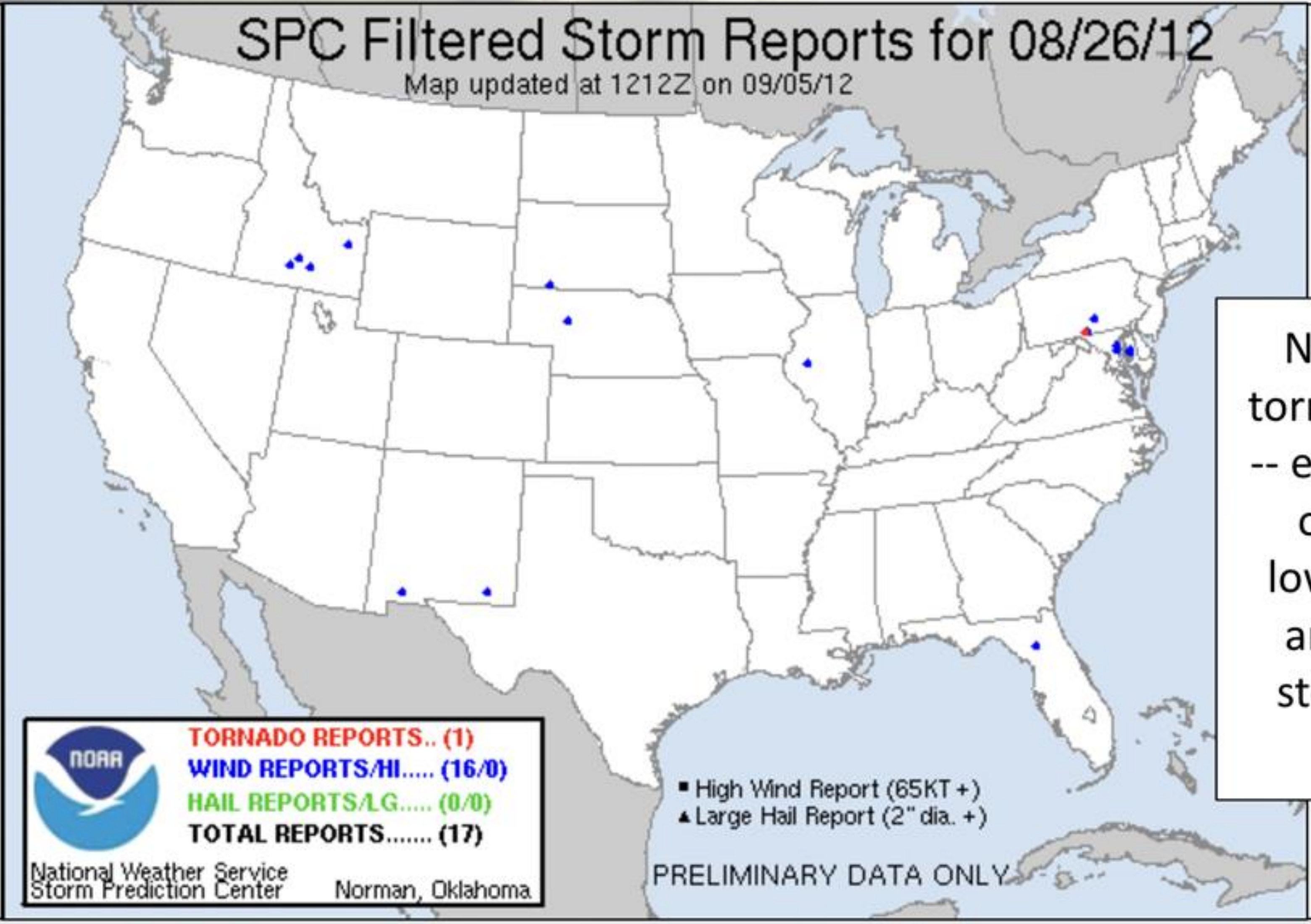
Large blob of continuous convection made it difficult for boundary layer to recover -- very little room for updrafts to ingest potent air supportive of tornadogenesis

TC TORNADO EXAMPLE CASES 2 (ISAAC 2012)



Large blob of continuous convection made it difficult for boundary layer to recover -- very little room for updrafts to ingest potent air supportive of tornadogenesis

TC TORNADO EXAMPLE CASES 2 (ISAAC 2012)

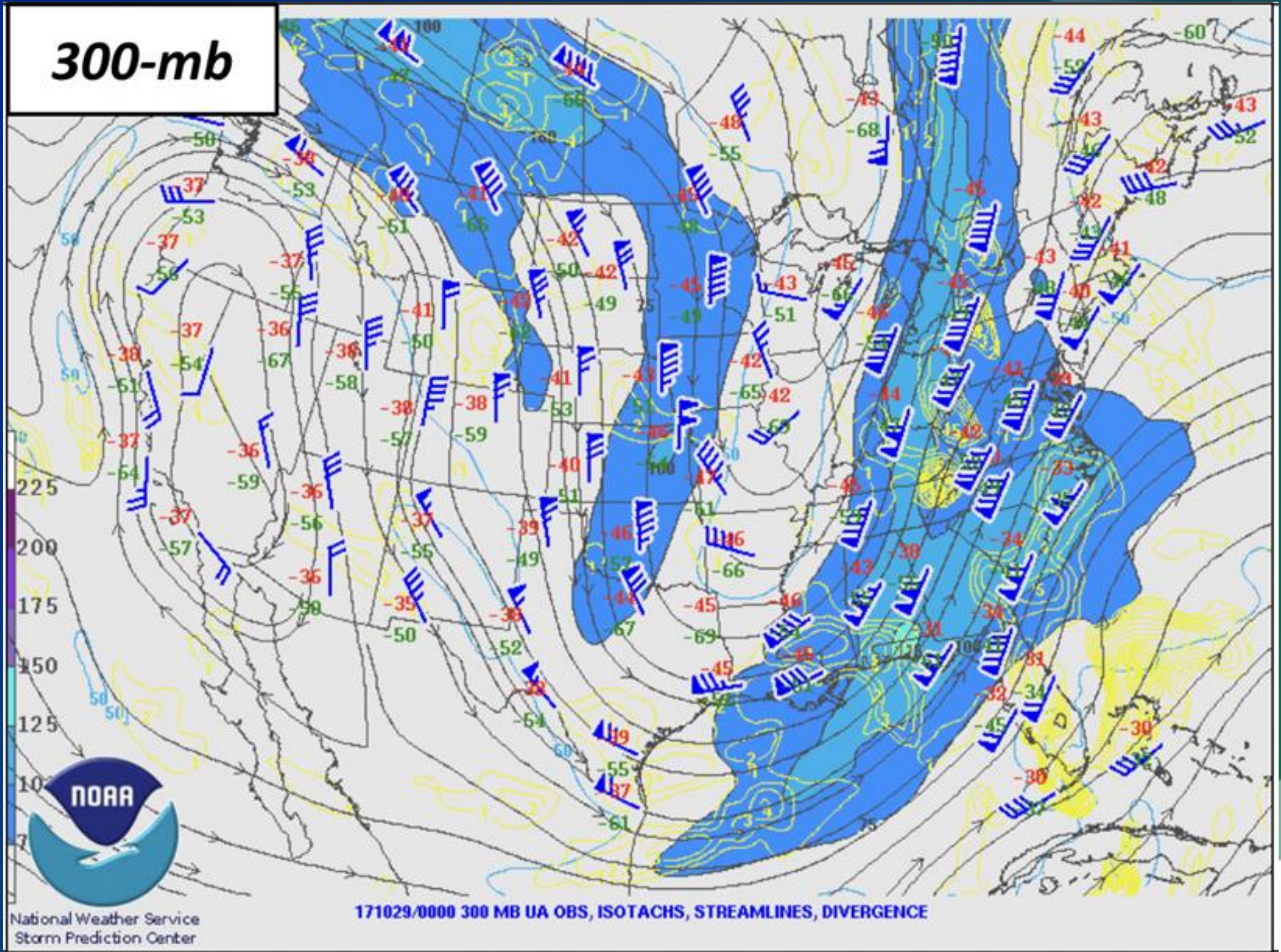


No reports of tornadoes in S FL -- even with tons of favorable low-level shear and resultant storm-relative helicity

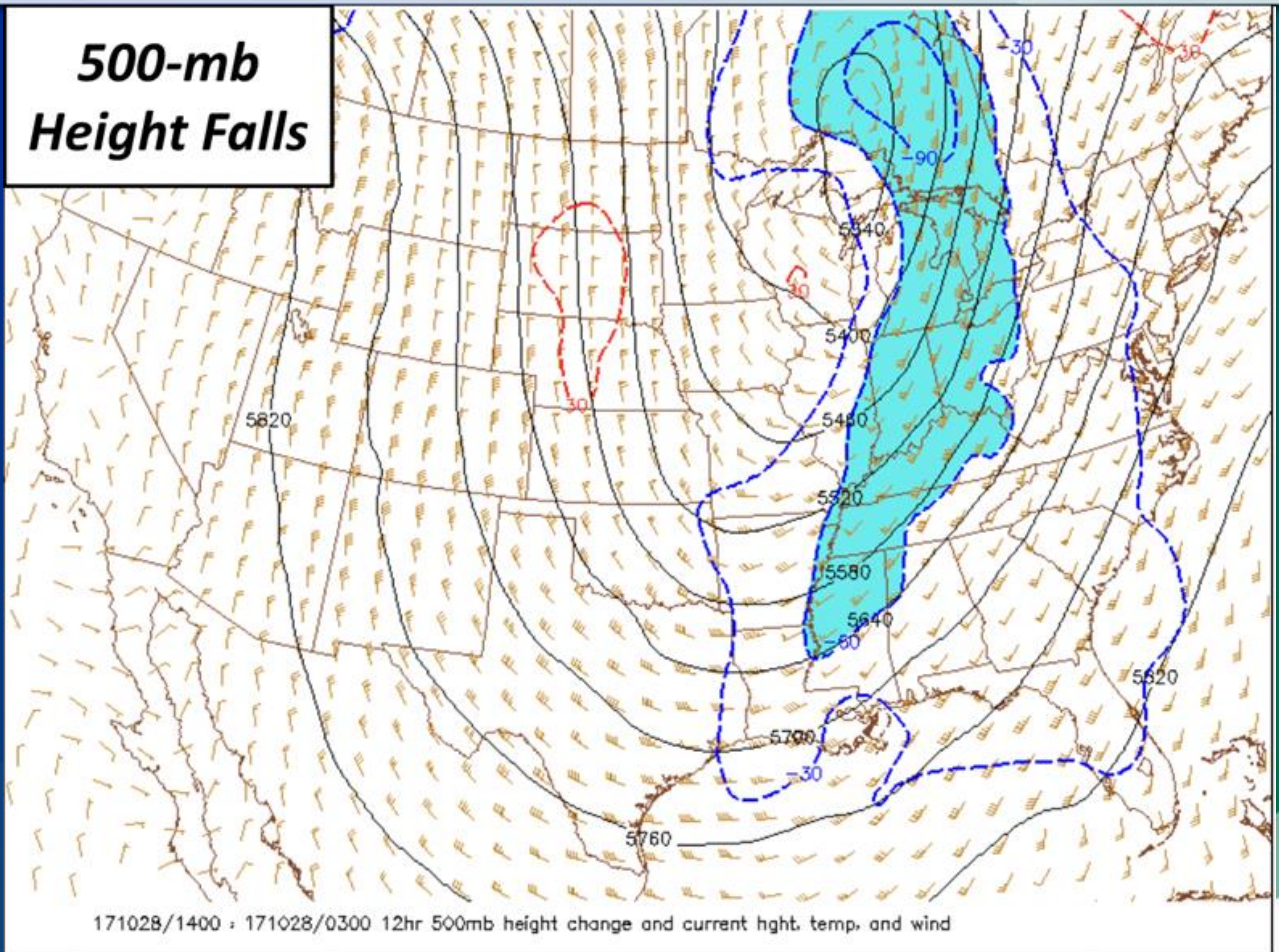
TC TORNADO EXAMPLE CASES 3 (NOW YOU TRY!)

Now you try! Does **Case 3** depict a favorable or unfavorable synoptic environment
for TC tornadoes?

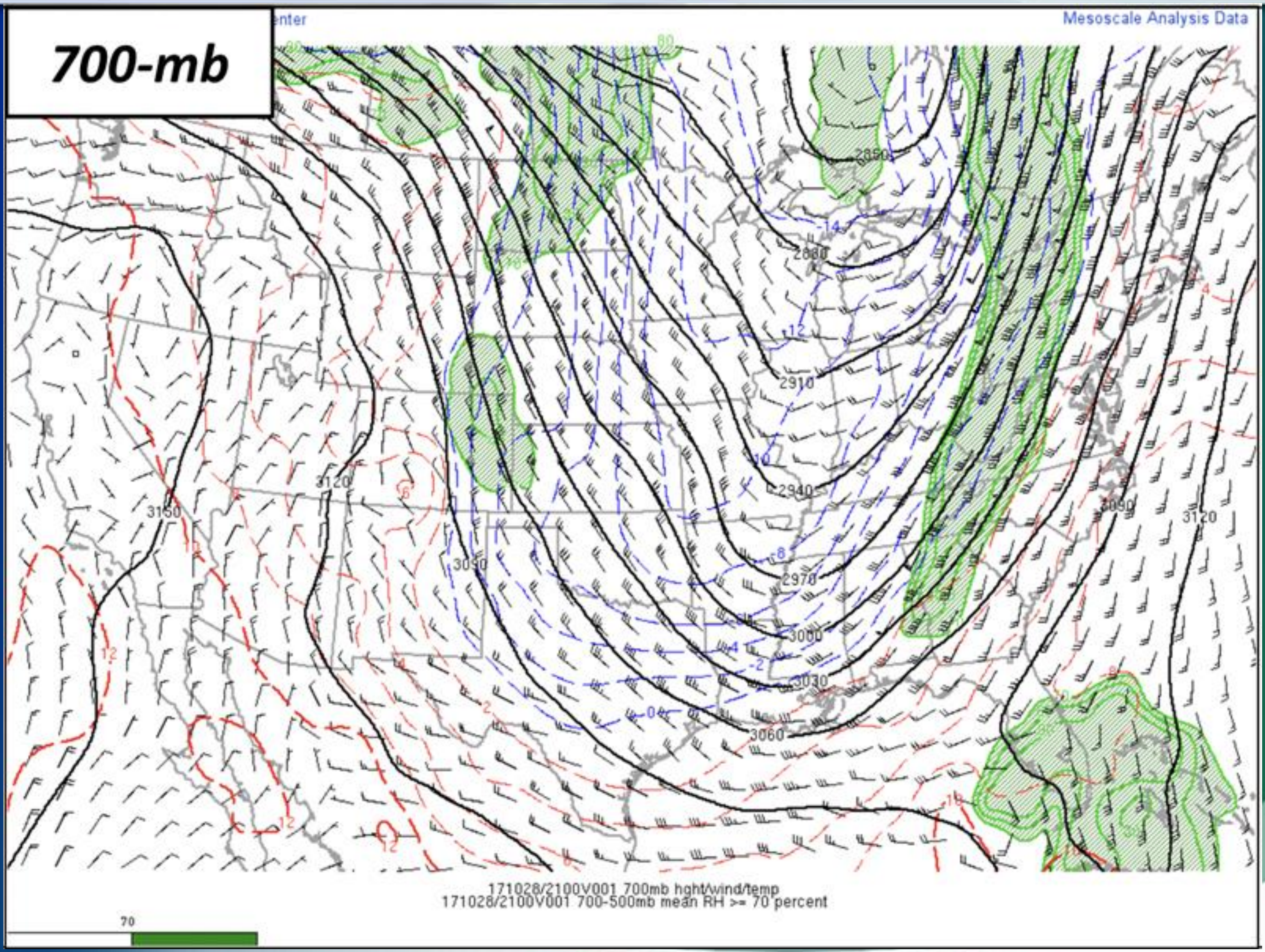
TC TORNADO EXAMPLE CASES 3 (FAVORABLE OR UNFAVORABLE?)



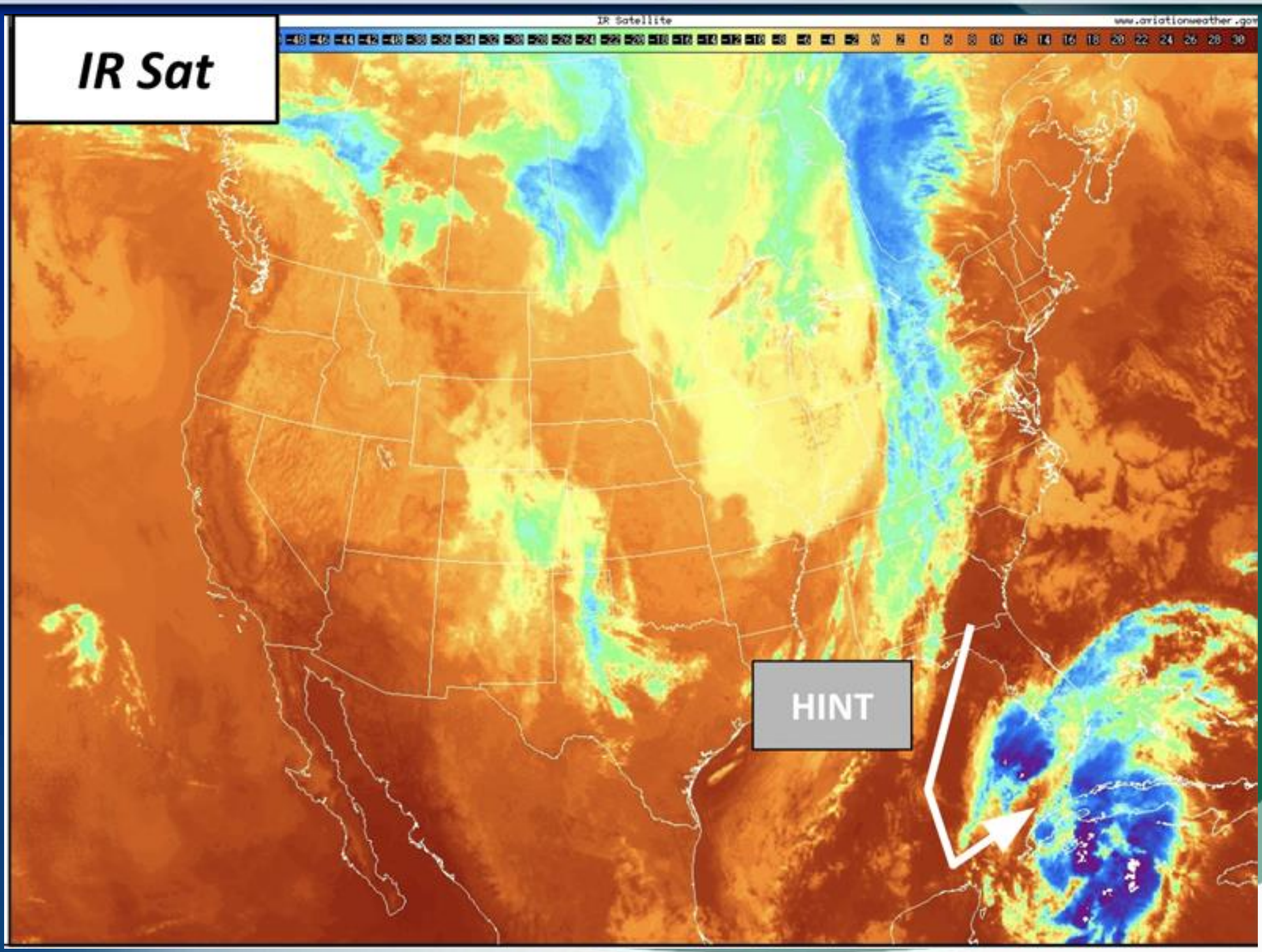
TC TORNADO EXAMPLE CASES 3 (FAVORABLE OR UNFAVORABLE?)



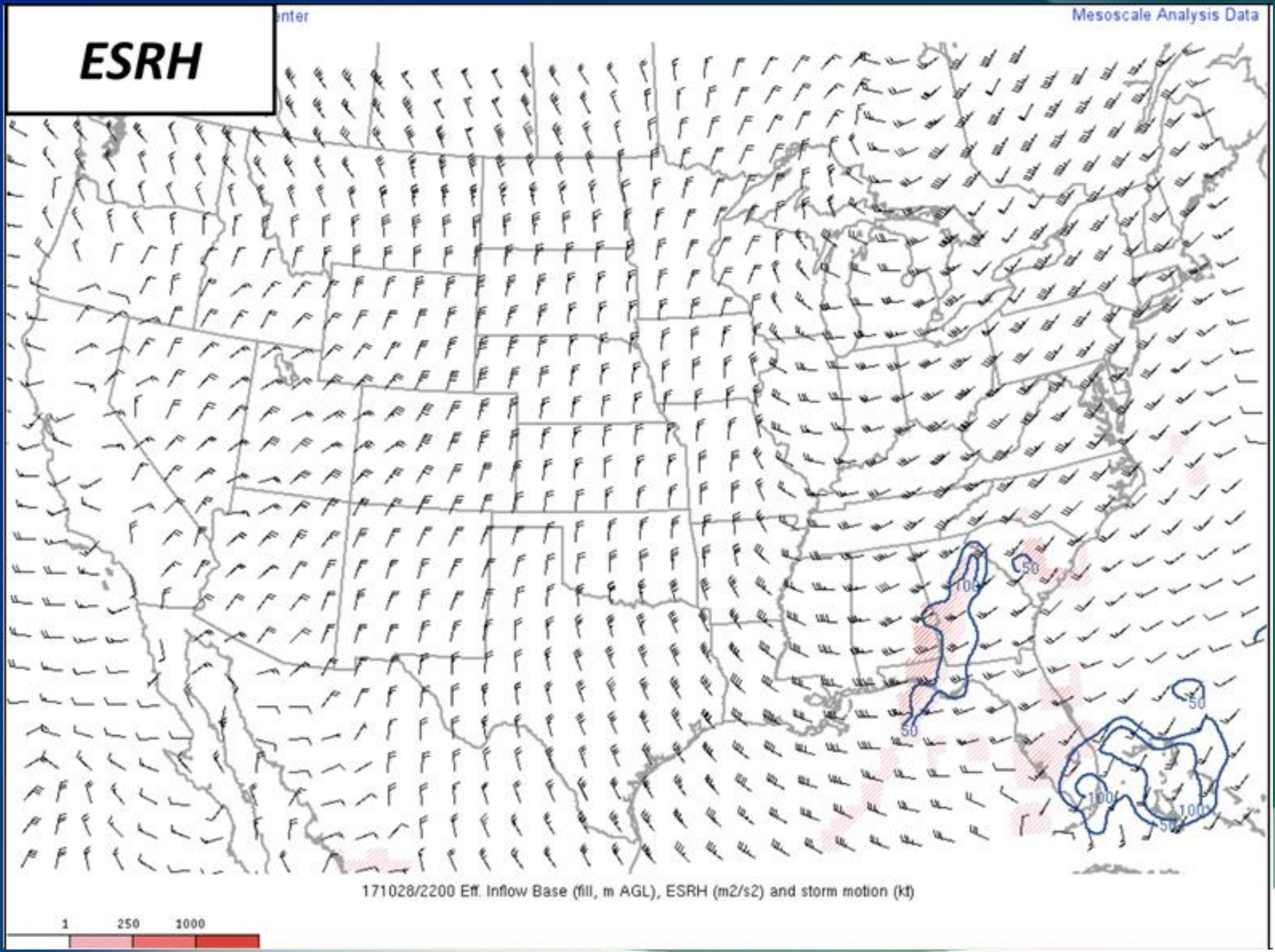
TC TORNADO EXAMPLE CASES 3 (FAVORABLE OR UNFAVORABLE?)



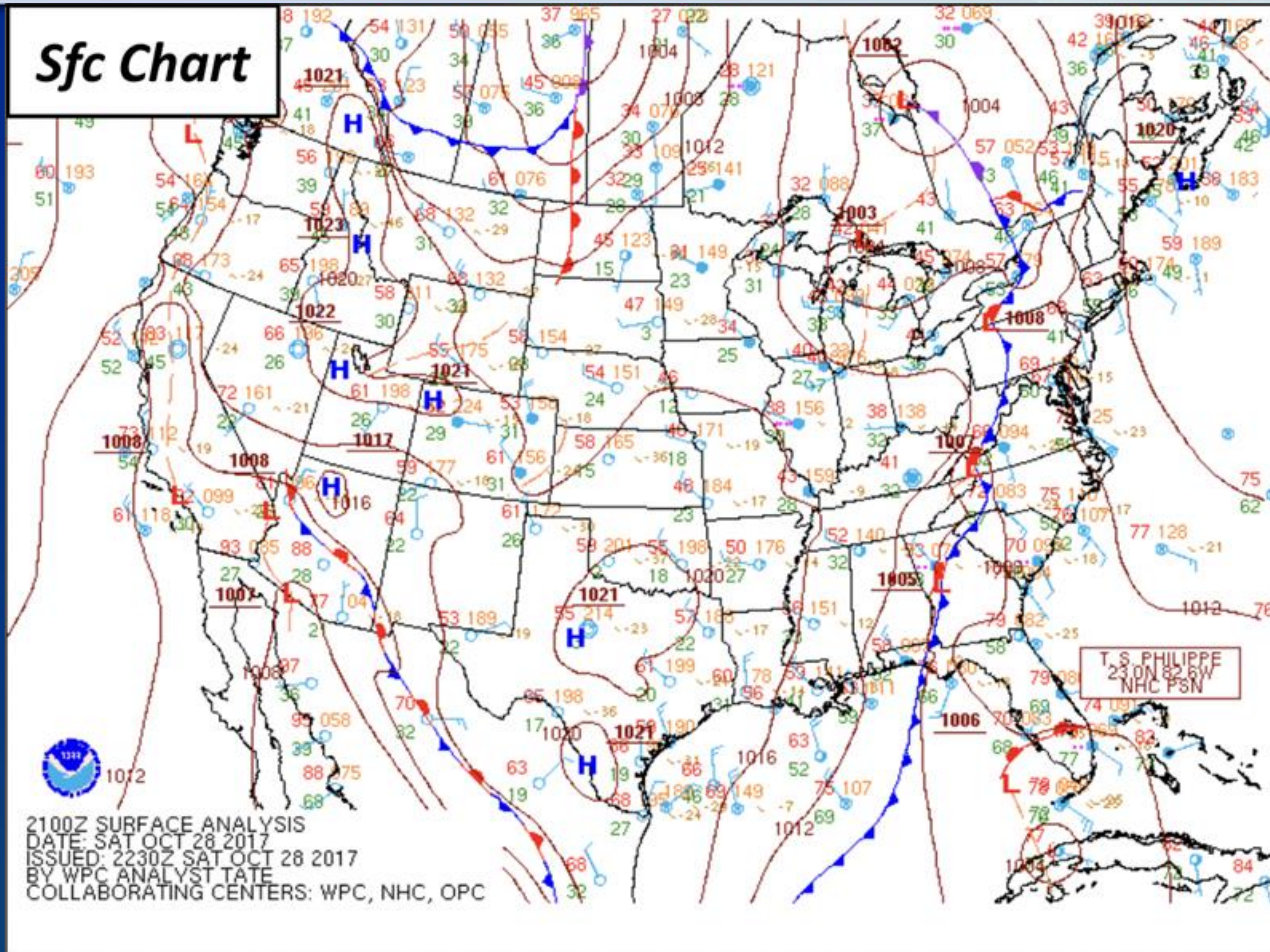
TC TORNADO EXAMPLE CASES 3 (FAVORABLE OR UNFAVORABLE?)



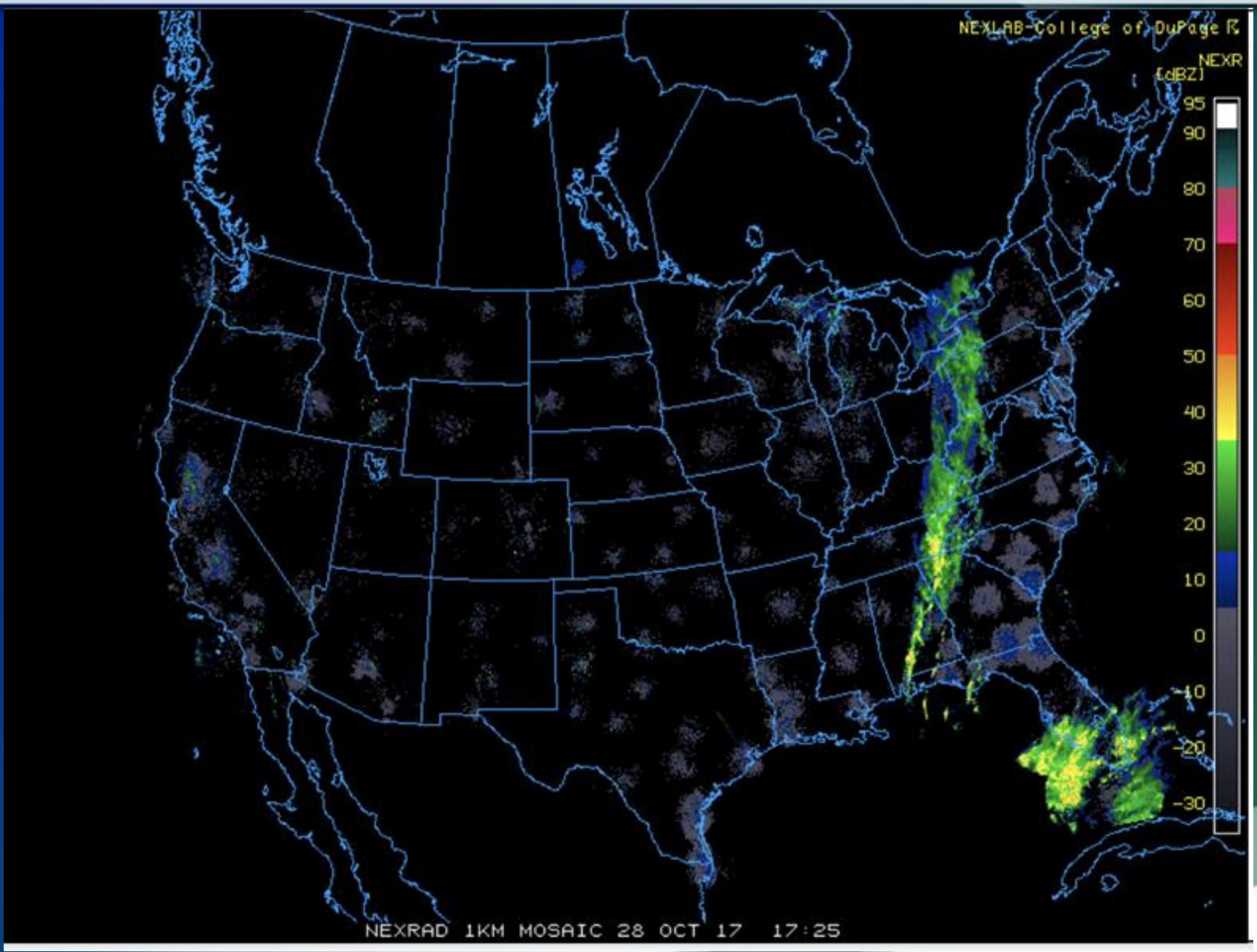
TC TORNADO EXAMPLE CASES 3 (FAVORABLE OR UNFAVORABLE?)



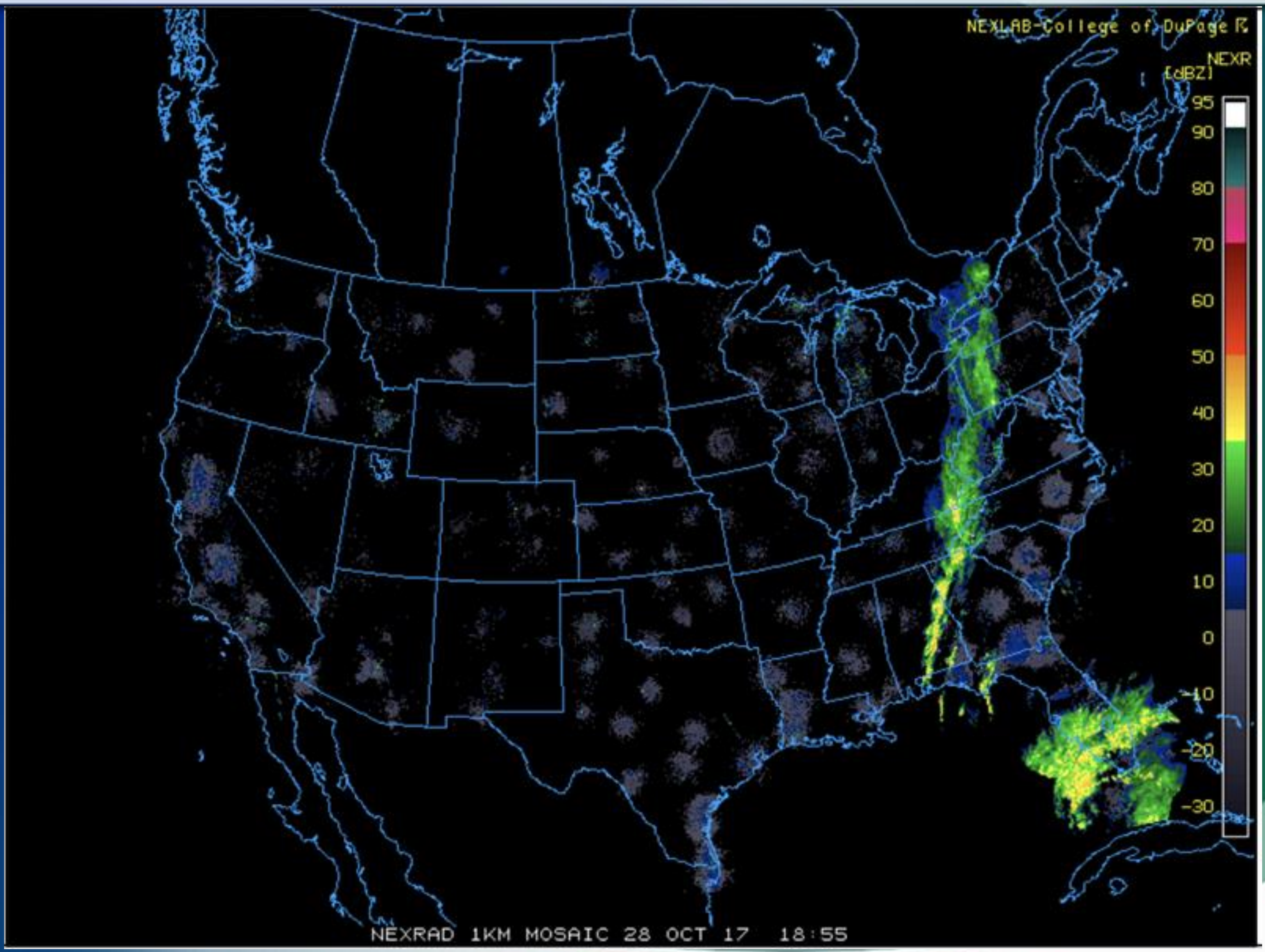
TC TORNADO EXAMPLE CASES 3 (FAVORABLE OR UNFAVORABLE?)



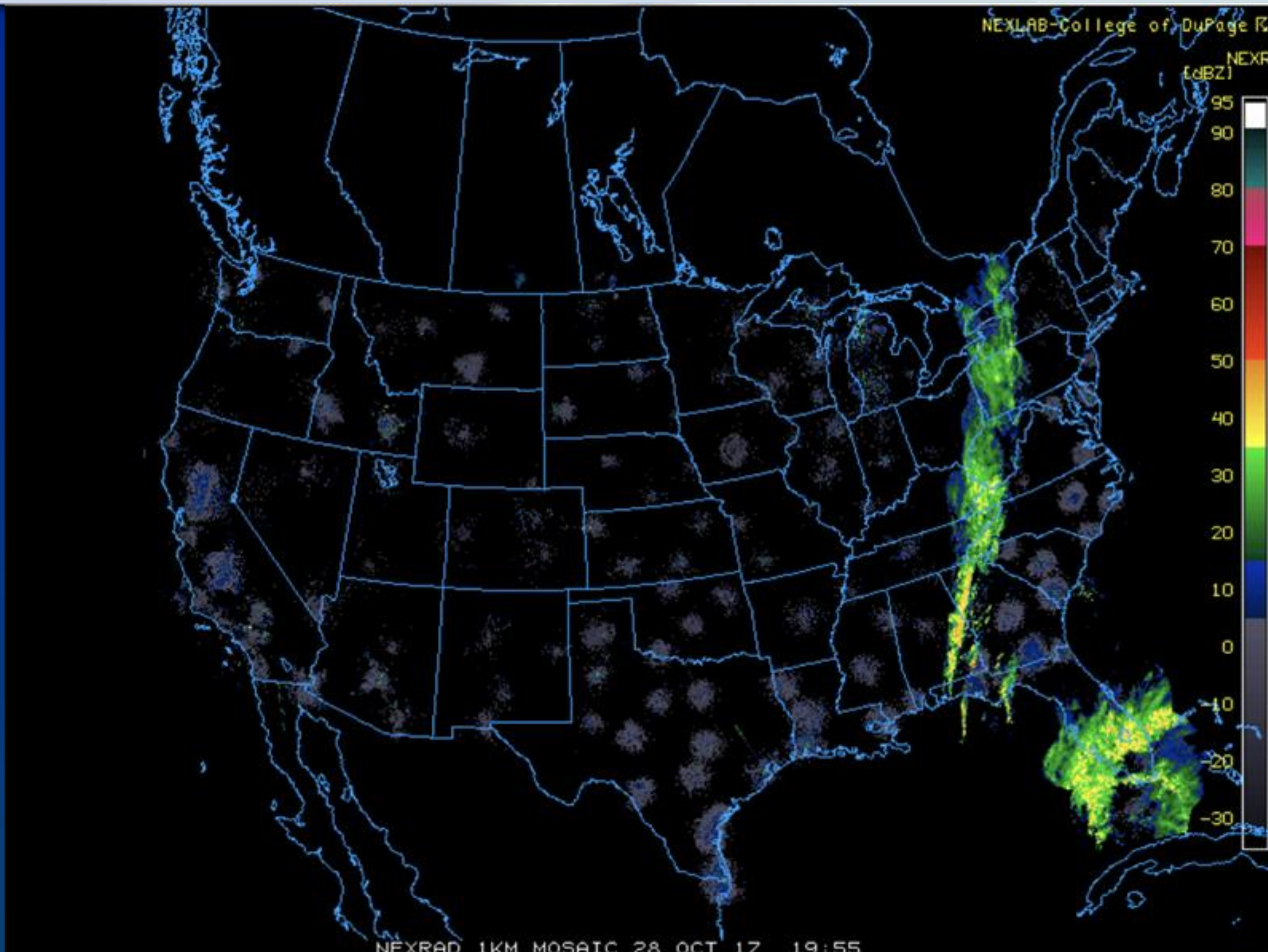
TC TORNADO EXAMPLE CASES 3 (FAVORABLE OR UNFAVORABLE?)



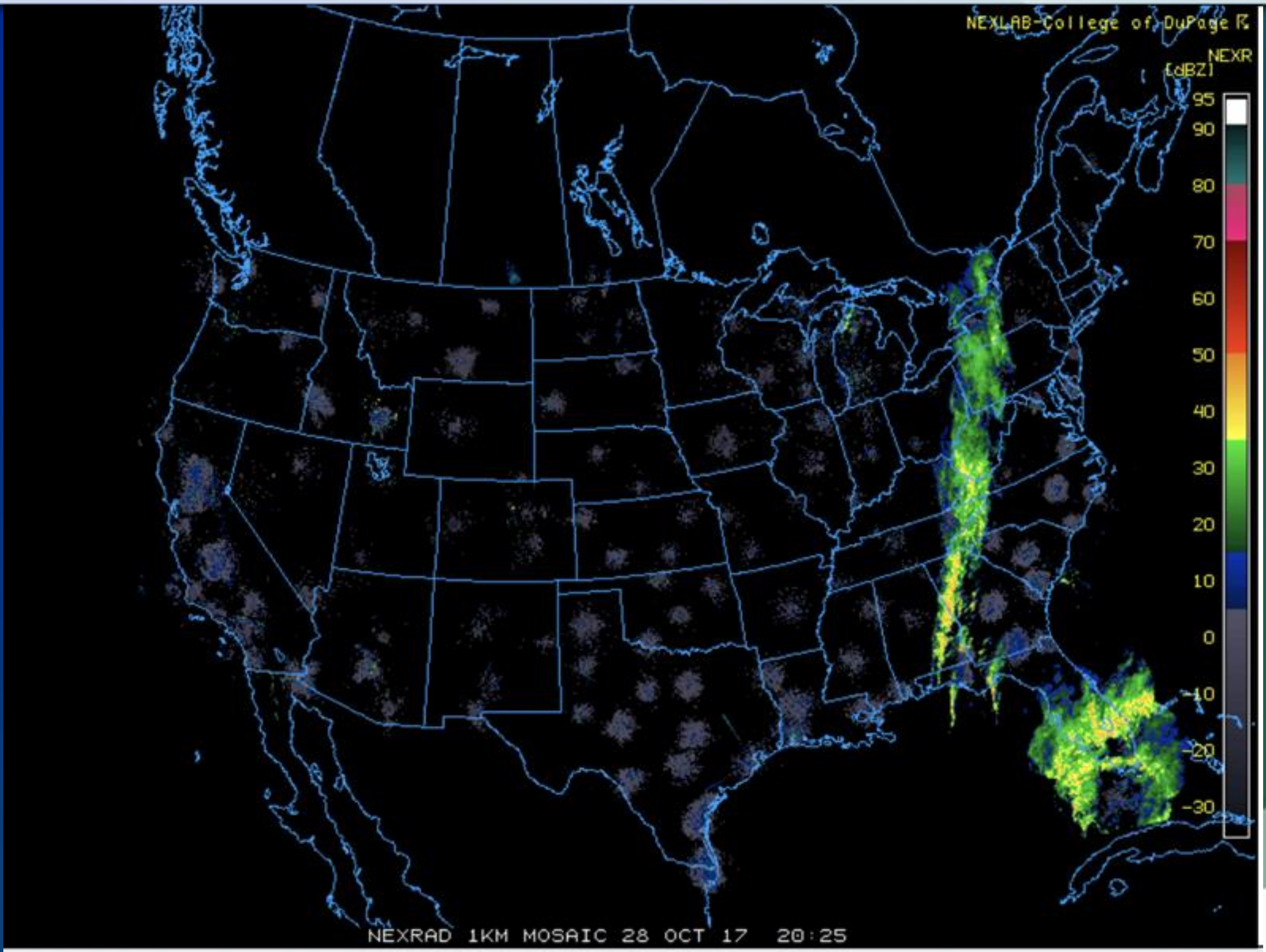
TC TORNADO EXAMPLE CASES 3 (FAVORABLE OR UNFAVORABLE?)



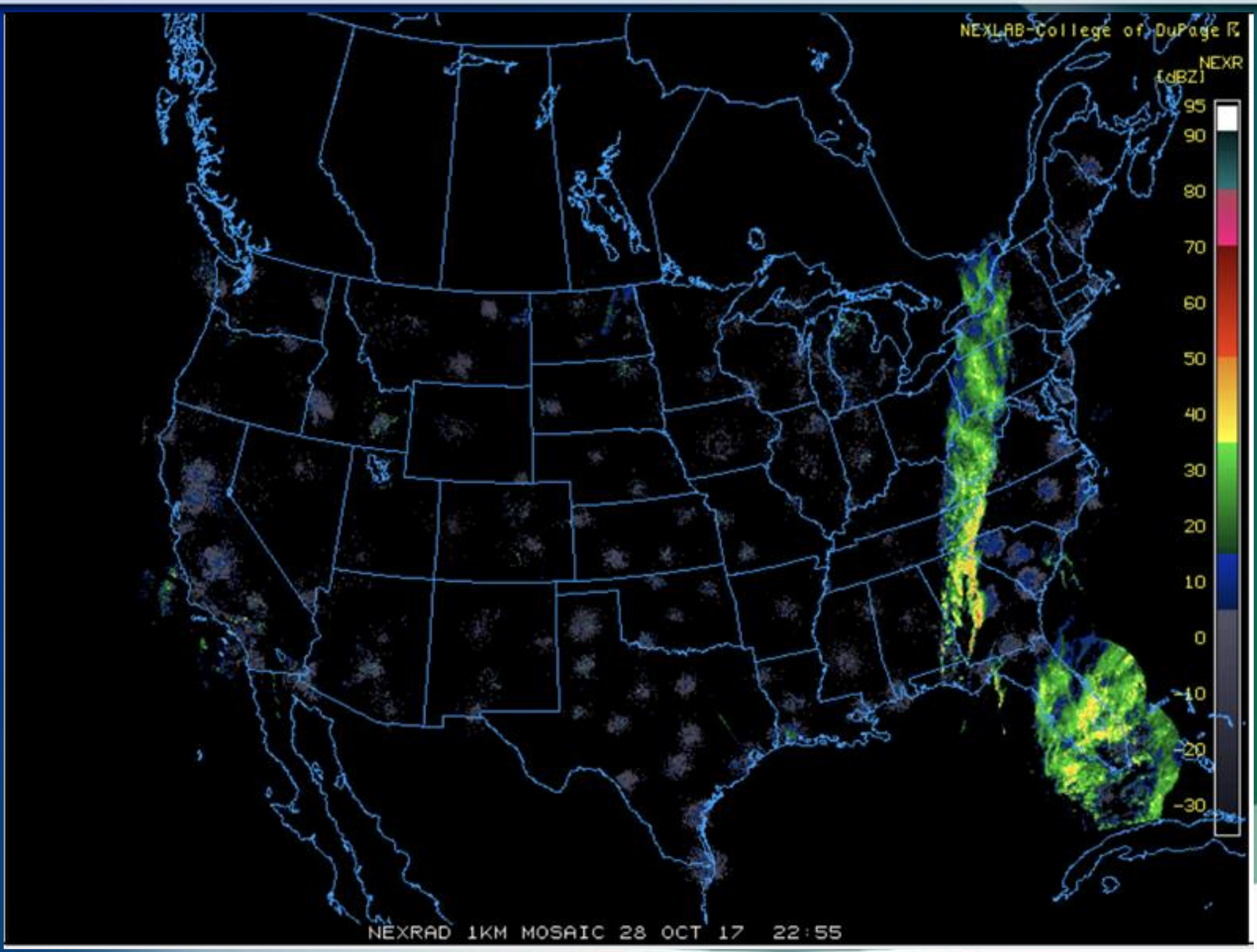
TC TORNADO EXAMPLE CASES 3 (FAVORABLE OR UNFAVORABLE?)



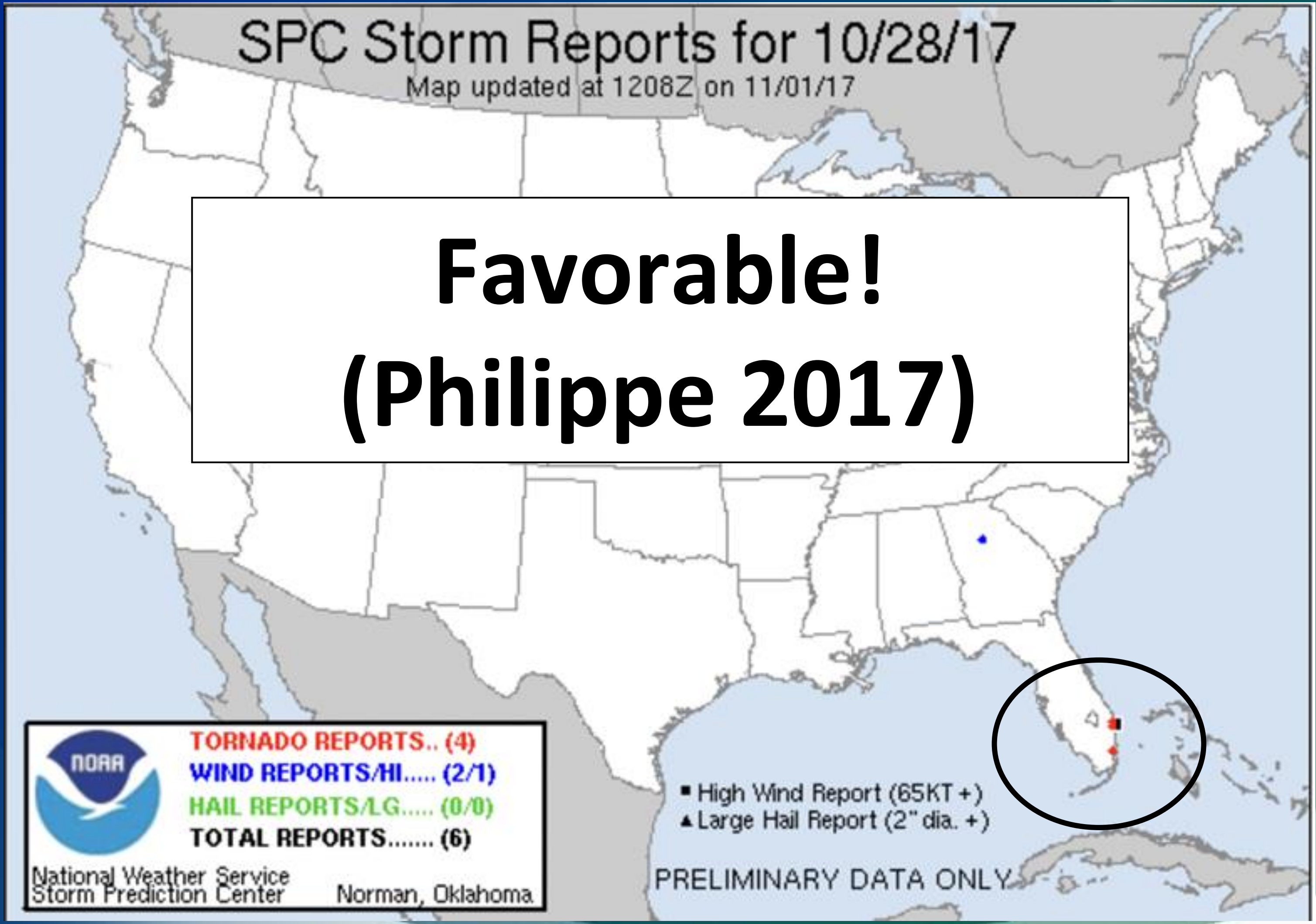
TC TORNADO EXAMPLE CASES 3 (FAVORABLE OR UNFAVORABLE?)



TC TORNADO EXAMPLE CASES 3 (FAVORABLE OR UNFAVORABLE?)



TC TORNADO EXAMPLE CASES 3 (FAVORABLE OR UNFAVORABLE?)



Favorable!
(Philippe 2017)

DATABASE and DOCUMENTATION ONLINE:

www.spc.noaa.gov/publications

Contact: Roger.Edwards@noaa.gov
Harry.Weinman@noaa.gov