North Atlantic TC Genesis Climatology McTaggart-Cowan et al. (2008)

- Two metrics were used as predictors for the TC genesis pathway classification scheme
  - Upper-level positive Q-vector convergence
  - Lower-level thickness asymmetry
- Latent trajectory model (LTM) determined the evolution of the above metrics for each North Atlantic TC (1948—2004) during T—36 h to T—0 h
- The LTM-based climatology identified six classes of TC genesis pathway: nonbaroclinic, low-level baroclinic, trough induced, transient trough interaction, weak TT, and strong TT

Metrics used for LTM Classification

- 1000–700-hPa thickness asymmetry
- 400–200-hPa layer-averaged Q divergence, where Q is defined as:

$$\mathbf{Q} = -\frac{R}{\sigma p}\begin{pmatrix} \dfrac{\partial \mathbf{v}_{\mathrm{nd}}}{\partial x} \cdot \boldsymbol{\nabla}_p T \\ \dfrac{\partial \mathbf{v}_{\mathrm{nd}}}{\partial y} \cdot \boldsymbol{\nabla}_p T \end{pmatrix},$$

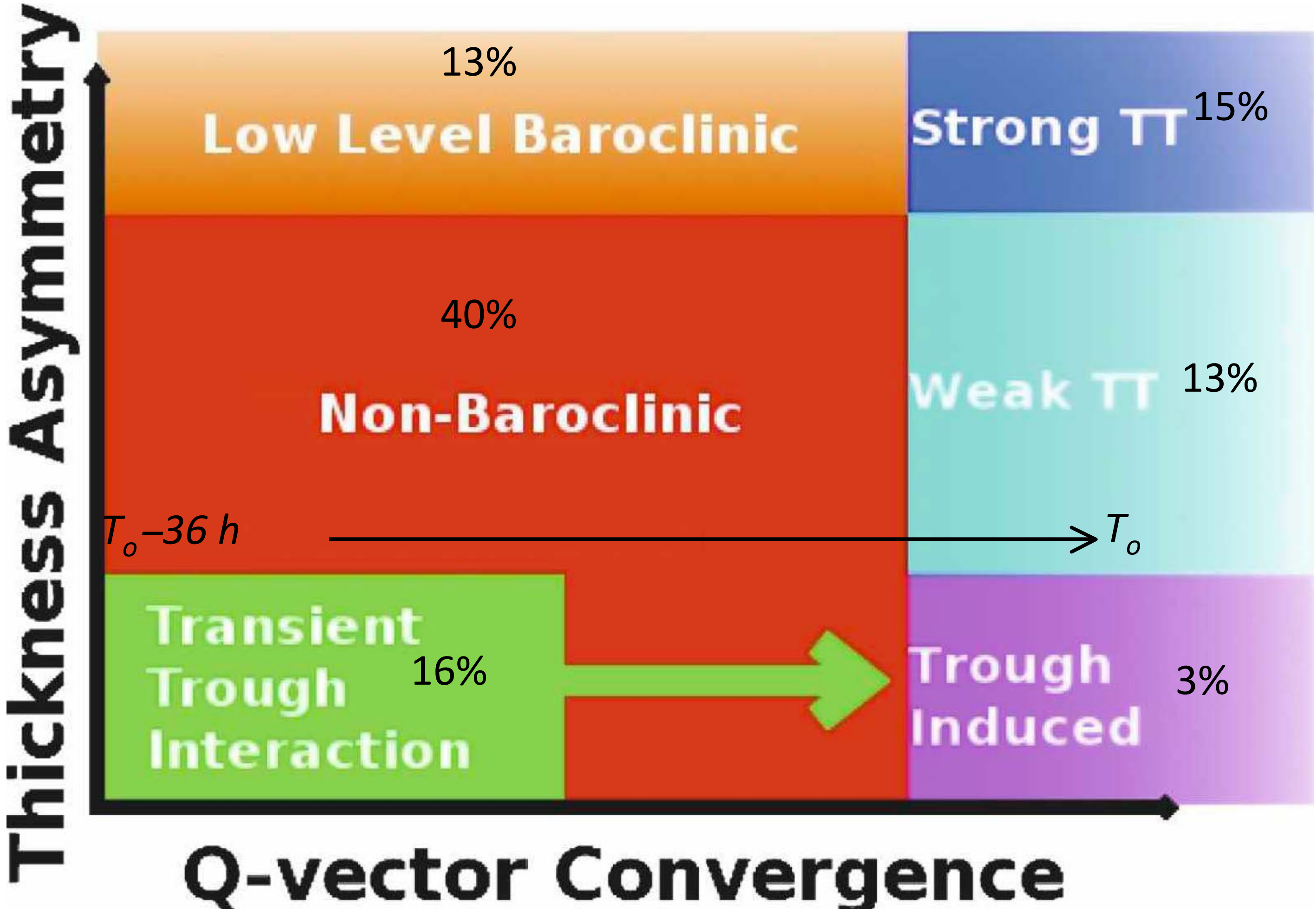
- The metrics were normalized by:

$$\tilde{Q} = n(Q) \equiv \frac{\ln(-Q)}{10} \quad \text{and}$$

$$\tilde{\mathrm{T}}\mathrm{h} = n(\mathrm{Th}) \equiv \ln(\mathrm{Th} \times 10^3),$$

North Atlantic TC Genesis Climatology 1948–2004

2D phase space of the LTM-derived categories for the *Q* and *Th* metrics



Th = low-level (1000–700 hPa) thickness asymmetry

Q = upper-level (400–200 hPa) Q-vector convergence

Fig. 9 from McTaggart-Cowan et al. (2008)

TC Genesis Pathway Spatial Distribution over the North Atlantic 1948–2004

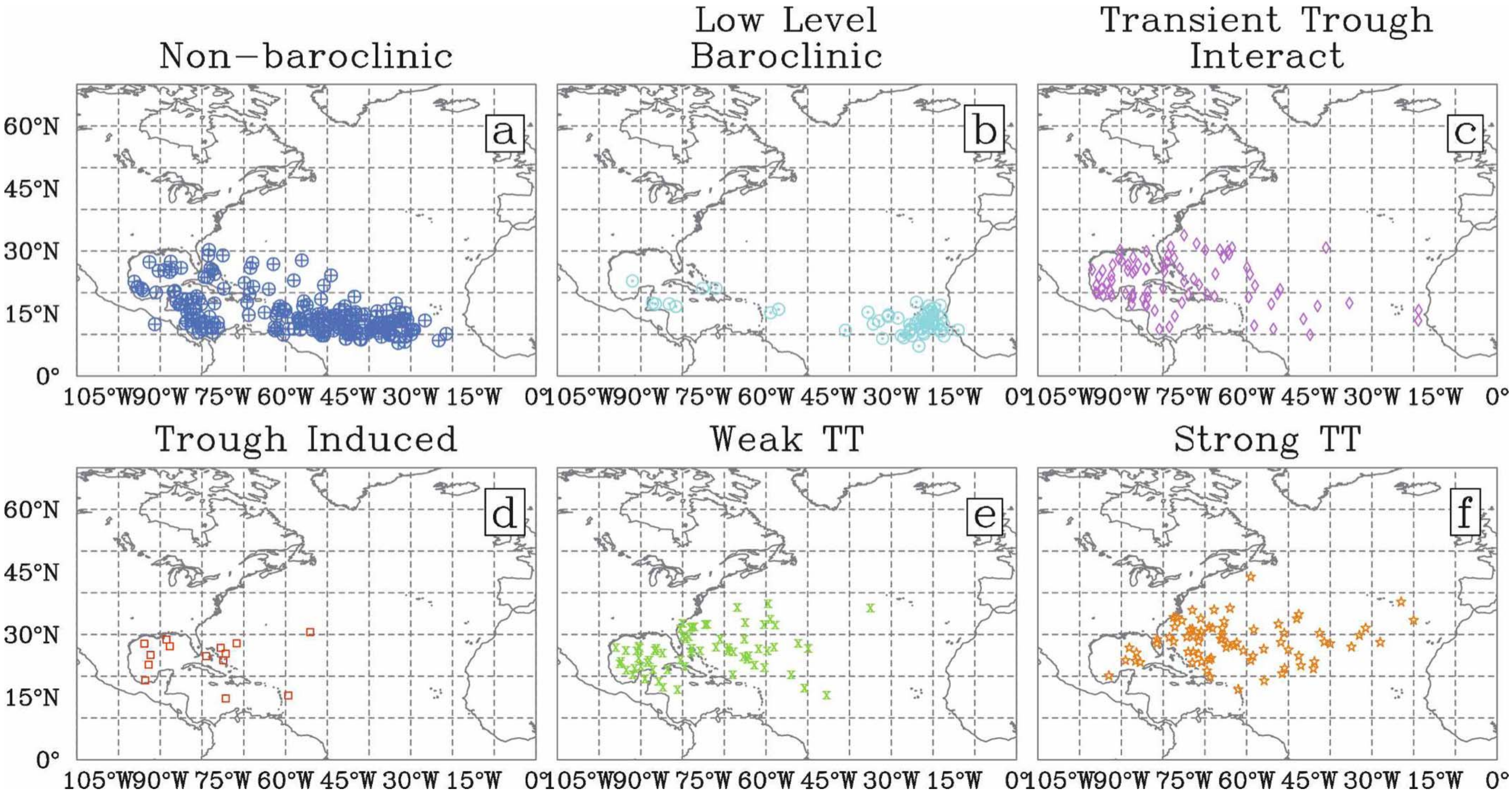


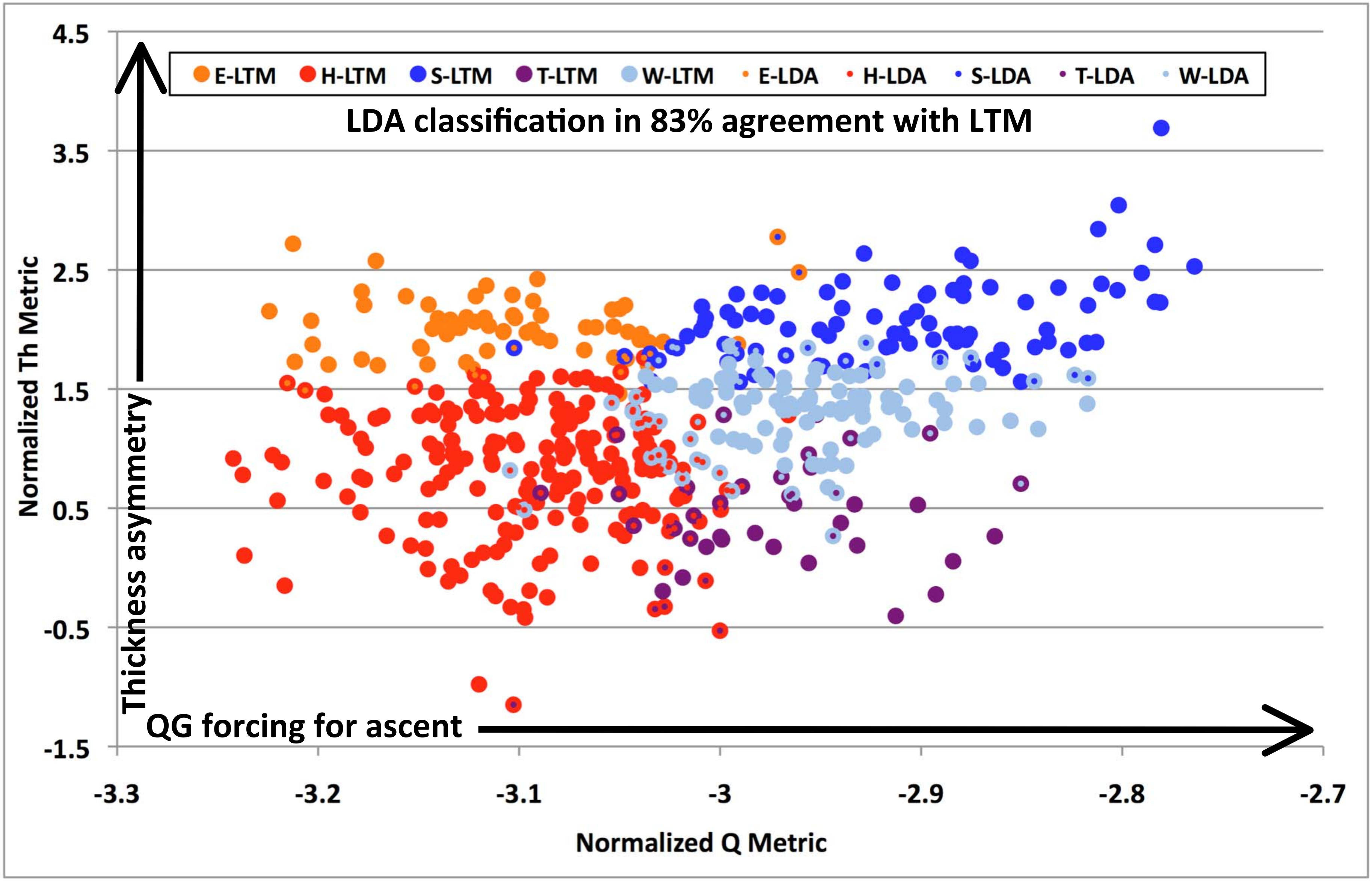
Fig. 10 from McTaggart-Cowan et al. (2008)

New TC Genesis Climatology

- Linear discriminant analysis (LDA) is used to assign TC genesis classes diagnostically
- The number of categories is known a-priori (based on the LTM climatology) rather than being diagnosed, and that each set of predictors (Q and Th metrics at T—12 h) are associated with a known outcome
- Storms in the transient trough interaction category from the LTM results are regrouped into the trough induced, weak TT, and strong TT groups depending on the Th metric

- The LTM results are used as a training set to develop a pair of discriminant functions that will optimally reproduce the results of the LTM itself
- Once the discriminant functions are identified, they can be used to predict classifications based on any pair of metric values
- The LDA-based results can be applied diagnostically to any point not included in the original LTM dataset, which represents a major advantage over the LTM whose results are only valid over the original dataset used
- Since the LDA classification metrics contain no information about the likelihood of TC genesis, the classification should be interpreted as "if an incipient vortex forms in this location, it will likely follow the 'X' pathway"

LTM/LDA Classification Comparison



LDA agreement with LTM:

All TCs **83%**; Weak TT **74%**
Low-level baroclinic **92%**; Nonbaroclinic **93%**
Strong TT **78%**; Trough induced **50%**

LDA Success Table

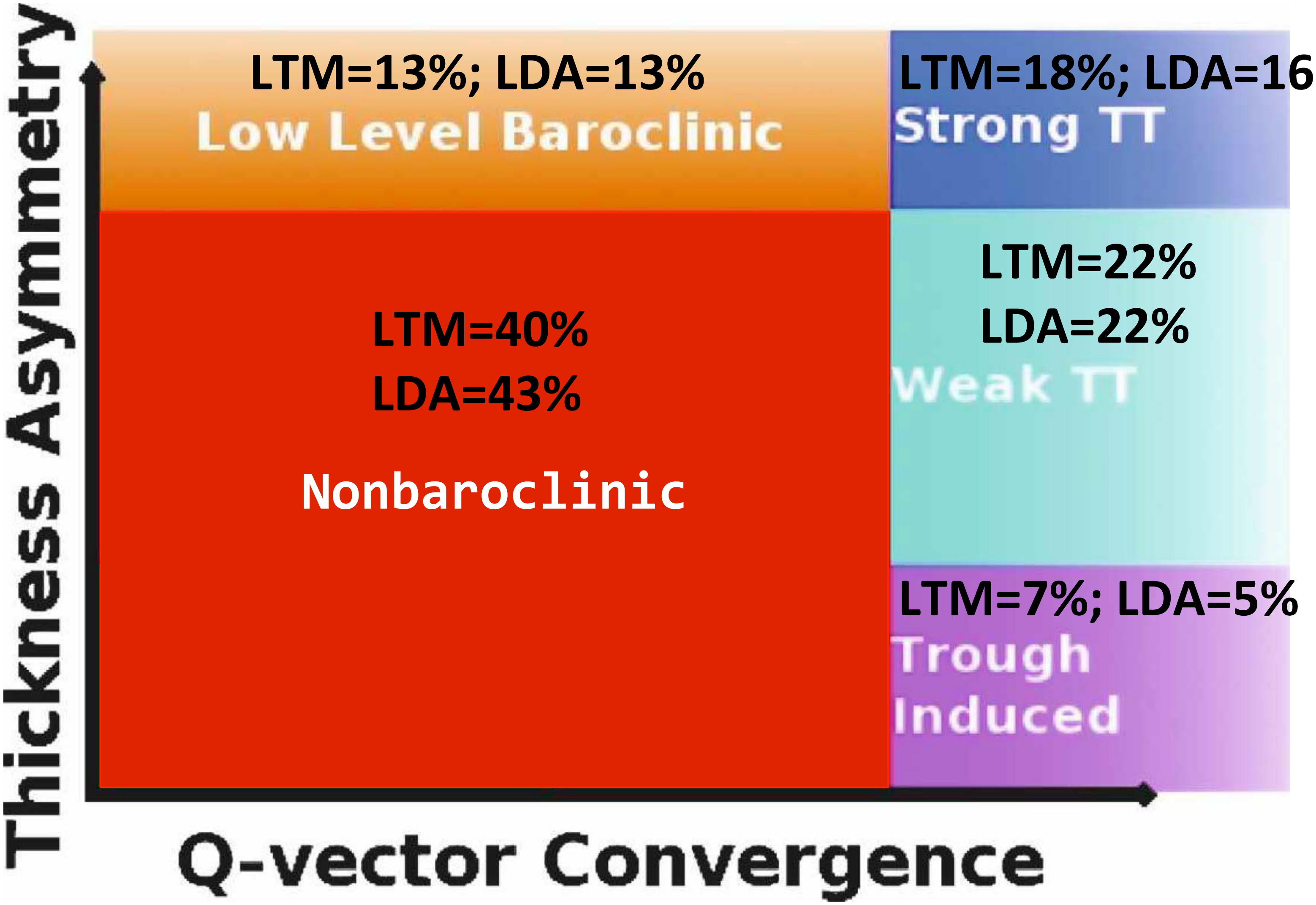
LDA predicted TC genesis class

LTM observed TC genesis class

	Low-level baroclinic	Non-baroclinic	Strong TT	Trough Induced	Weak TT
Low-level baroclinic	58	1	3	0	1
Non-baroclinic	5	189	0	4	2
Strong TT	3	0	70	0	15
Trough Induced	0	10	0	18	8
Weak TT	0	17	8	3	81

LTM/LDA Classification Comparison

The transient-trough interaction class from the LTM analysis was redistributed into the strong TT, weak TT, and trough induced classes.



LTM=13%; LDA=13%

LTM=18%; LDA=16%

LTM=40%
LDA=43%

LTM=22%
LDA=22%

LTM=7%; LDA=5%

N=496

LDA TC Genesis Climatology Summary

- LDA-based approach reproduces LTM-based climatology with 83% accuracy
- Some groups are better identified than others; but the application of a Wilks test shows that both discriminant functions have significant values with 99.9% confidence
- Misclassifications tend to occur along boundaries separating groups
- These misclassified storms generally have large membership probabilities in two different classes
- In light of these results, we are currently computing global TC genesis pathway analyses at 24-h intervals for the entire Reanalysis dataset (1948—2008) which will contain:
  - Q and Th metrics at each point
  - TC development pathway classification at each point
  - Joint probabilities of membership in each category at each point

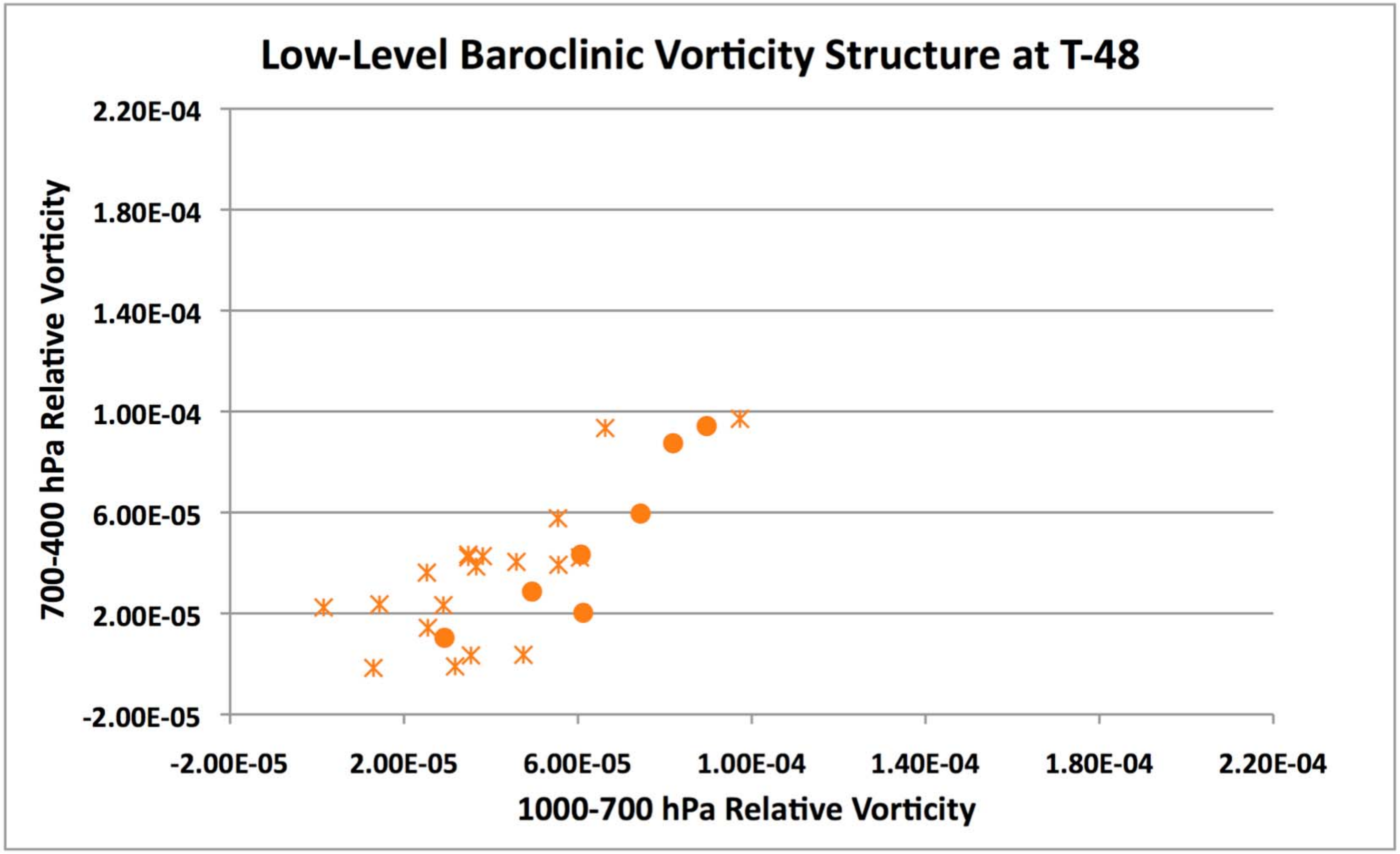
Preliminary TC/Null Scatterplots

Data and Methods

- 1.0° NCEP–GFS analyses
- Objectively locate and track disturbances to build case list of developing and nondeveloping disturbances during the 2004–2008 North Atlantic seasons, defined here as May through November
  - Disturbances must meet the following criteria:
    - Area-average (360 × 360 km) 900-hPa $\zeta \geq 4.0 \times 10^{-5}$ s^{-1} for 24 consecutive hours
    - Disturbance located over SST ≥ 25°C for 24 consecutive hours
    - Disturbance longevity ≥ 48 hours

1000–700 hPa Average ζ vs. 700–400 hPa Average ζ (s^{-1})

2°×2° Box Average

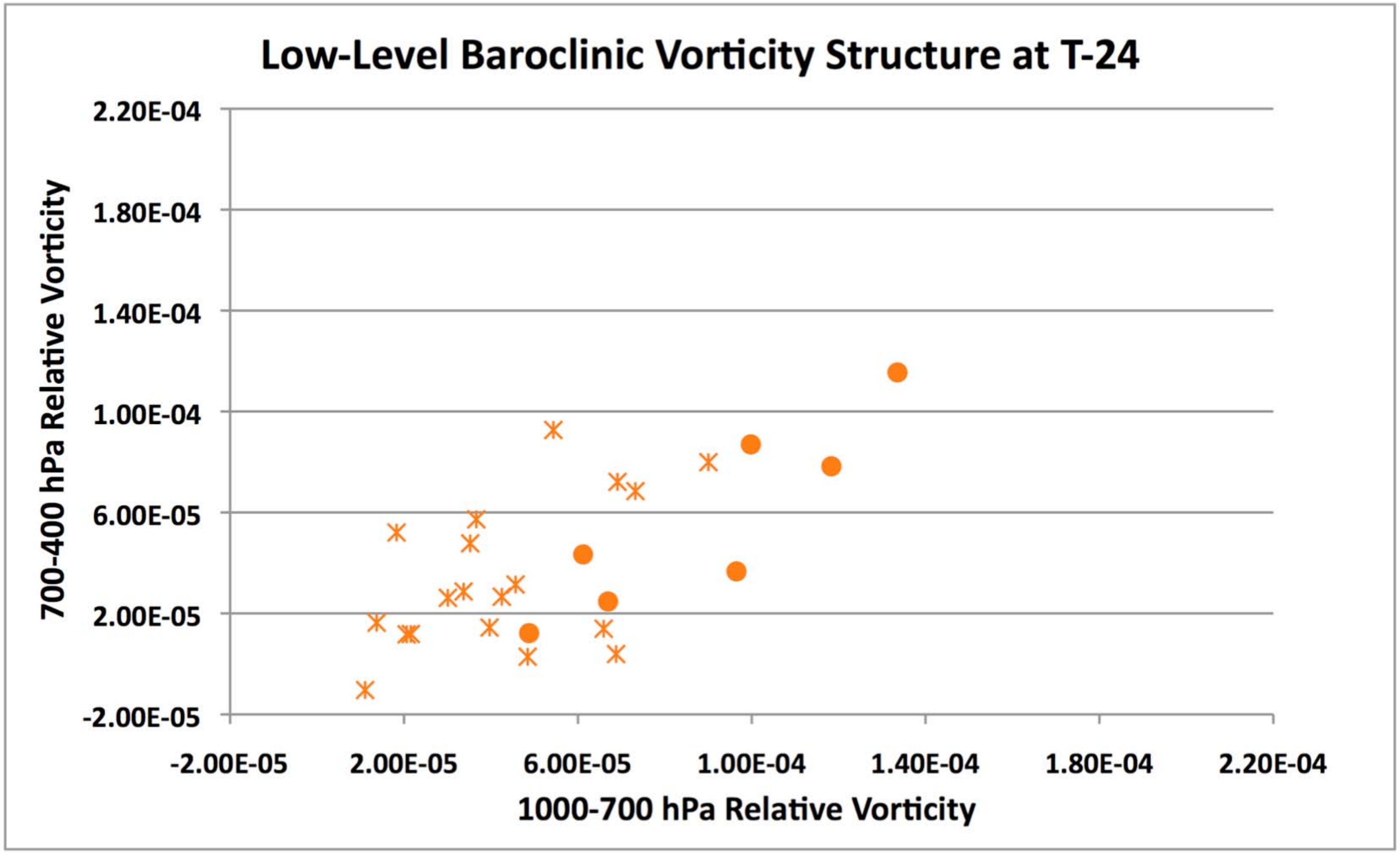


For TCs, T-0 is time of NHC-defined genesis

For null events, T-0 is time of initial peak in intensity

1000–700 hPa Average ζ vs. 700–400 hPa Average ζ (s^{-1})

2°×2° Box Average



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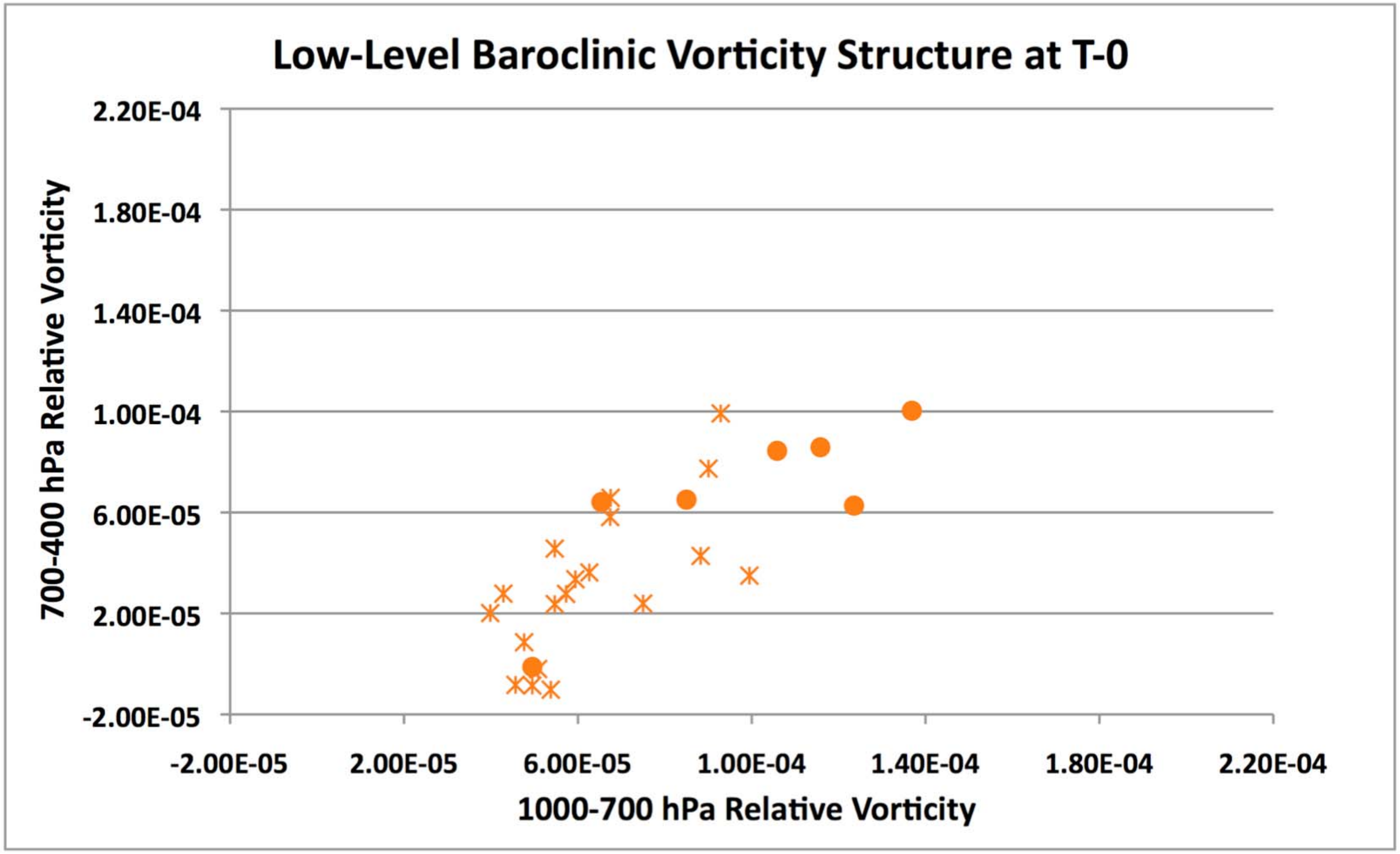

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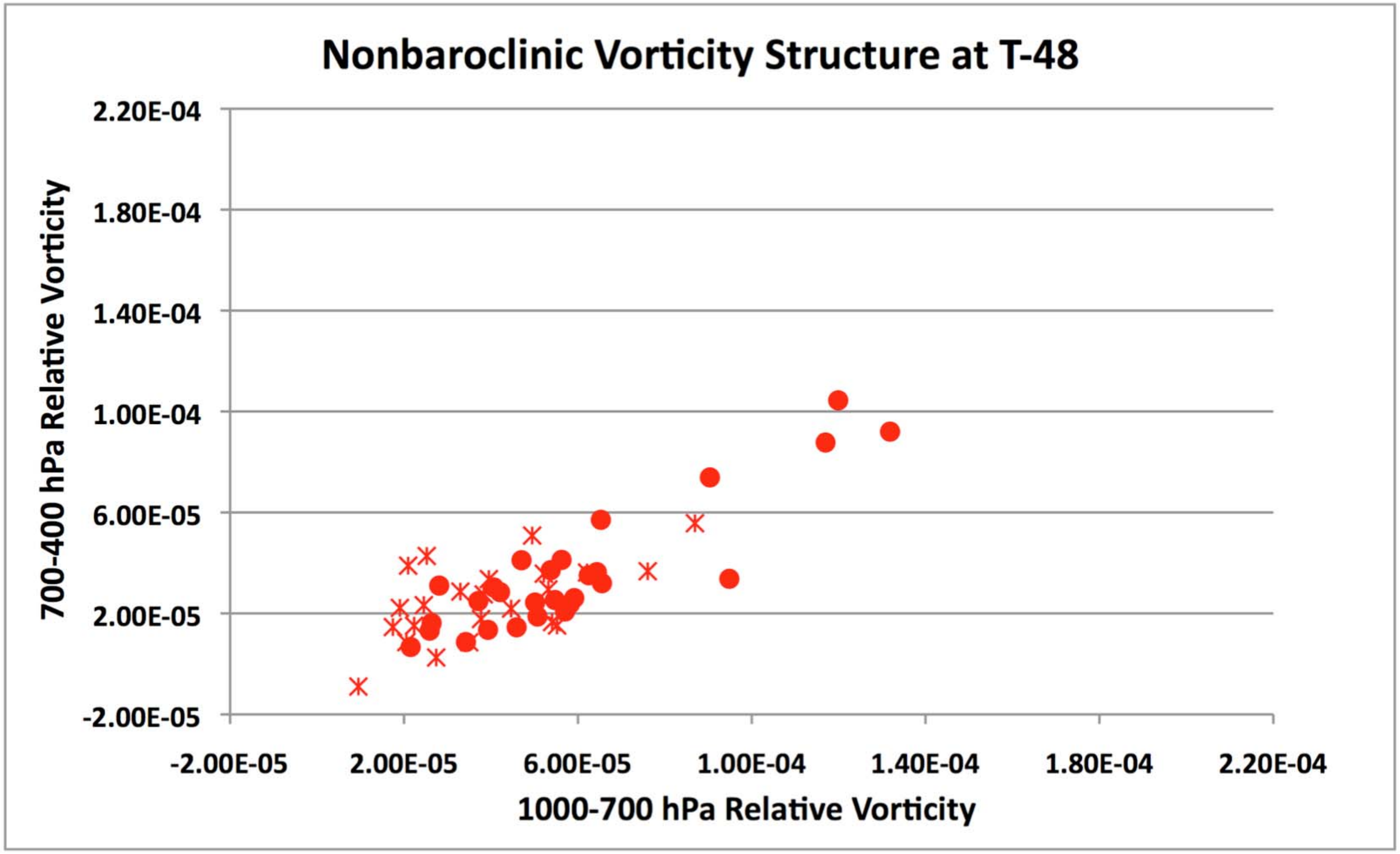

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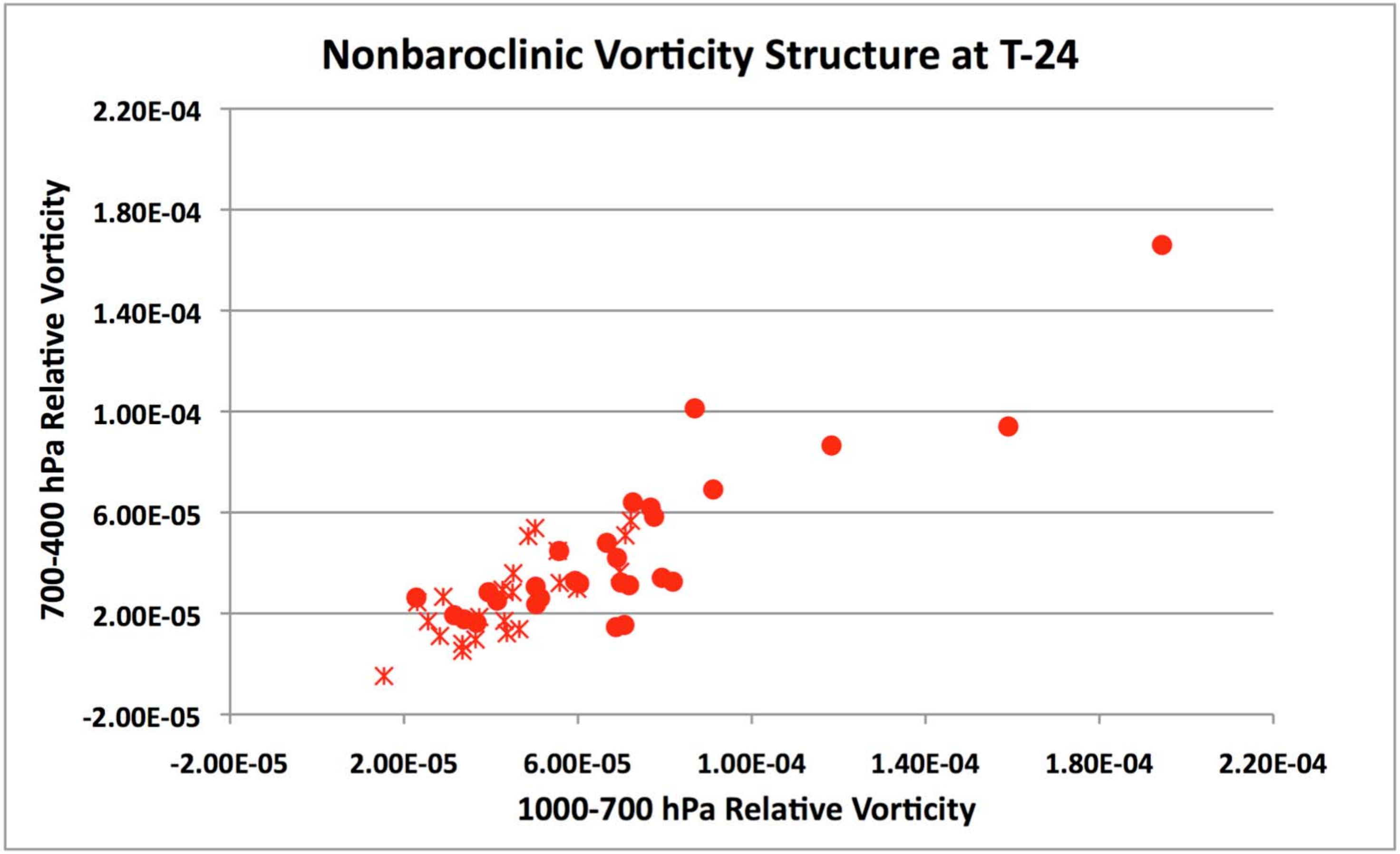

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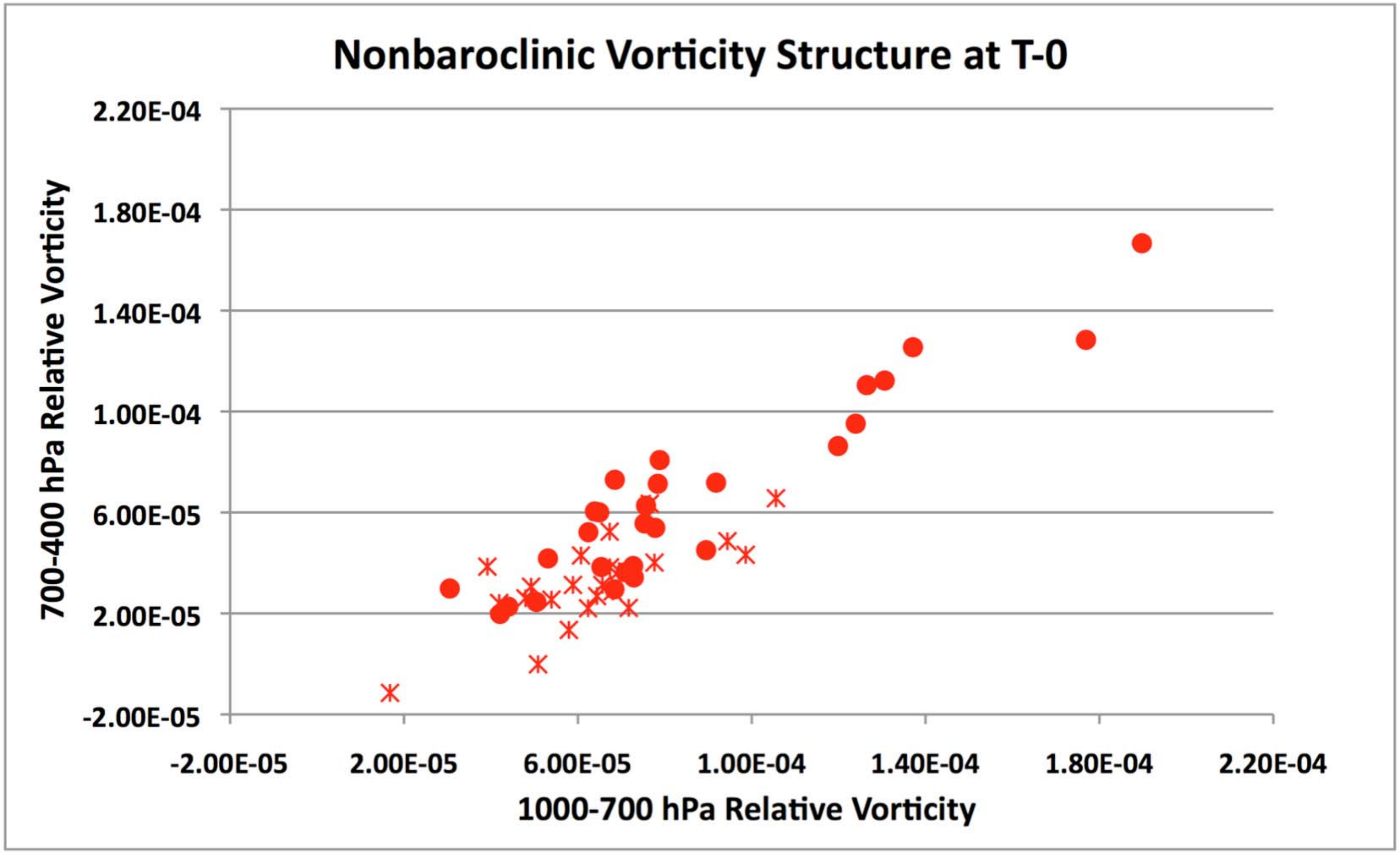

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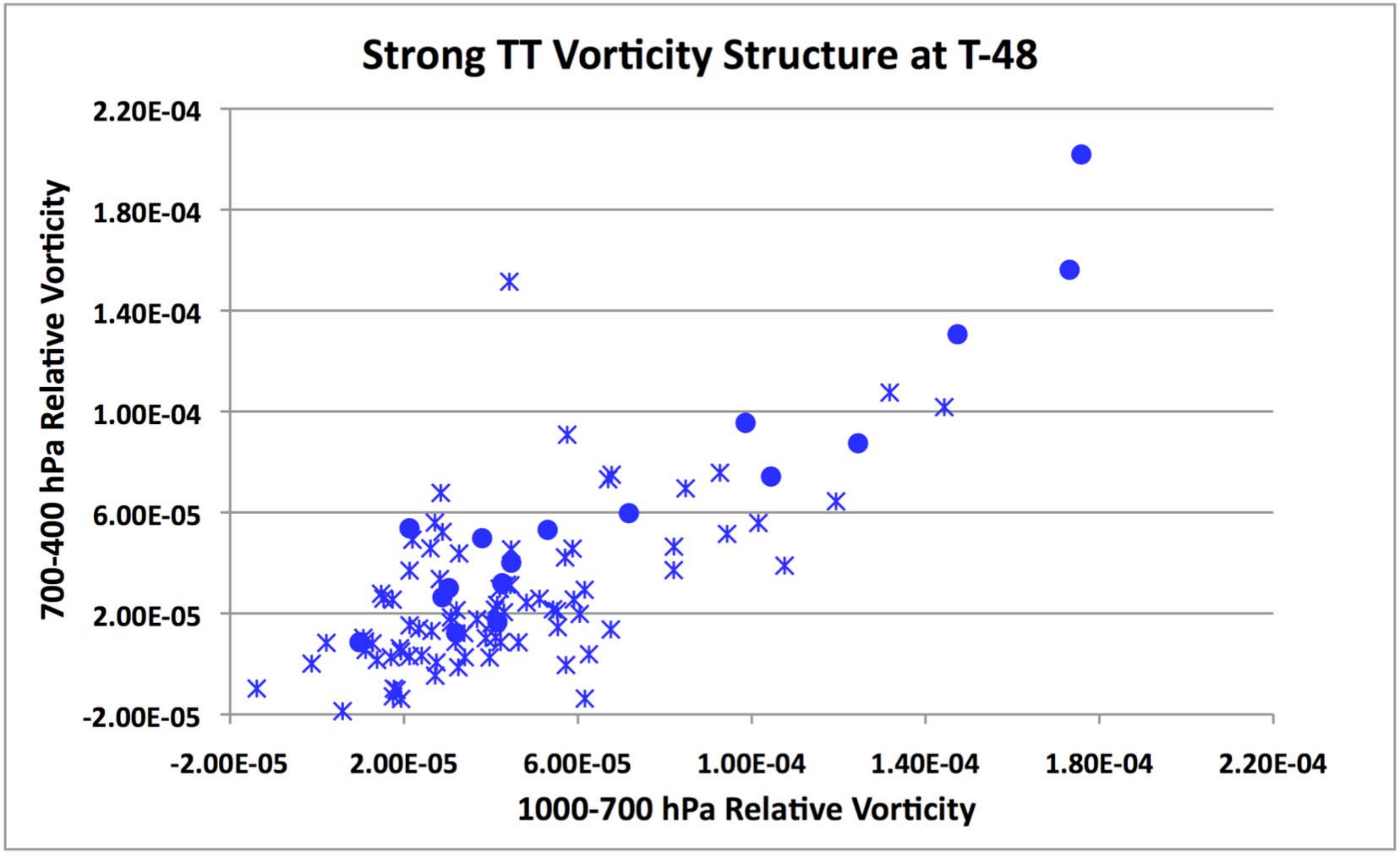

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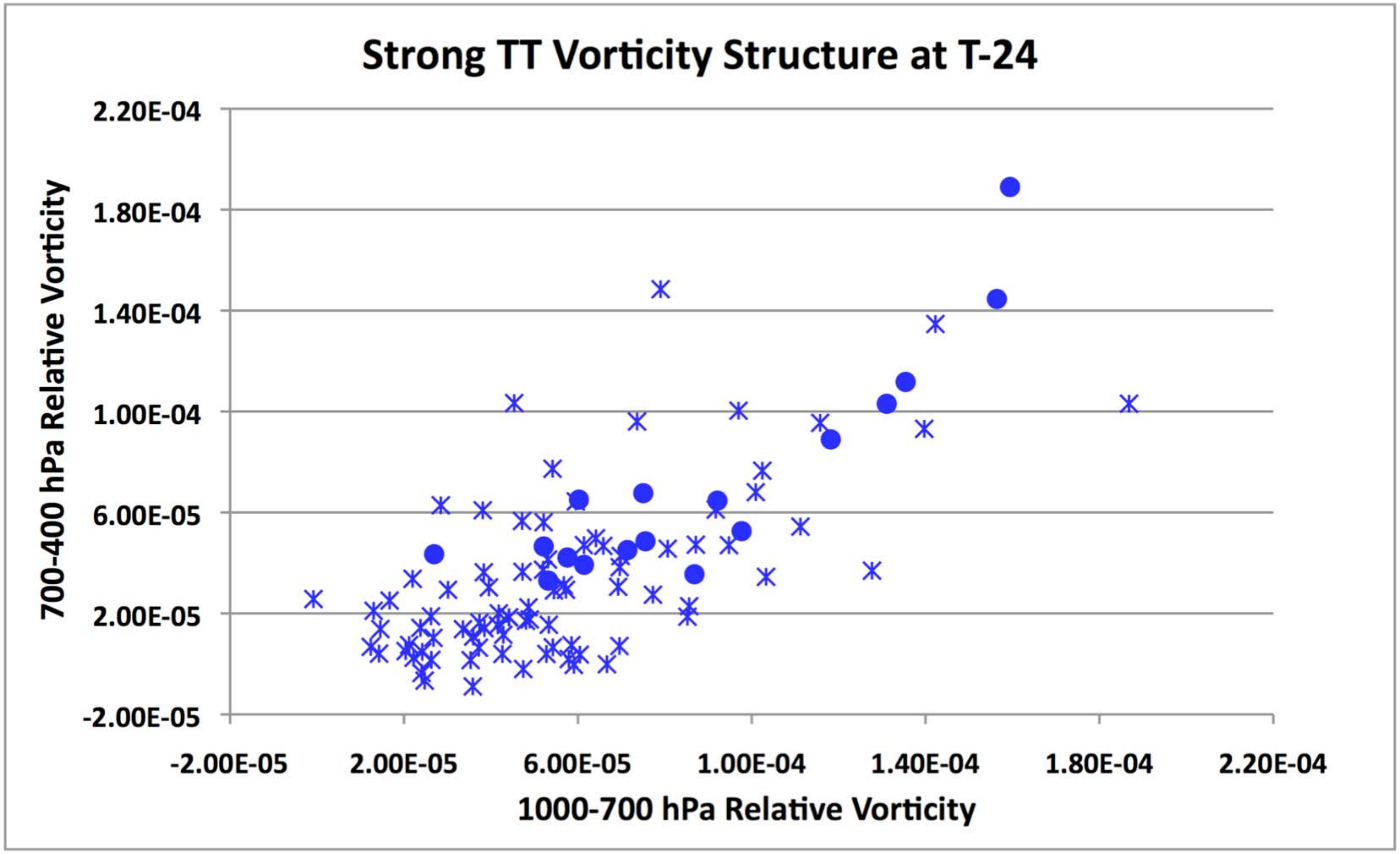

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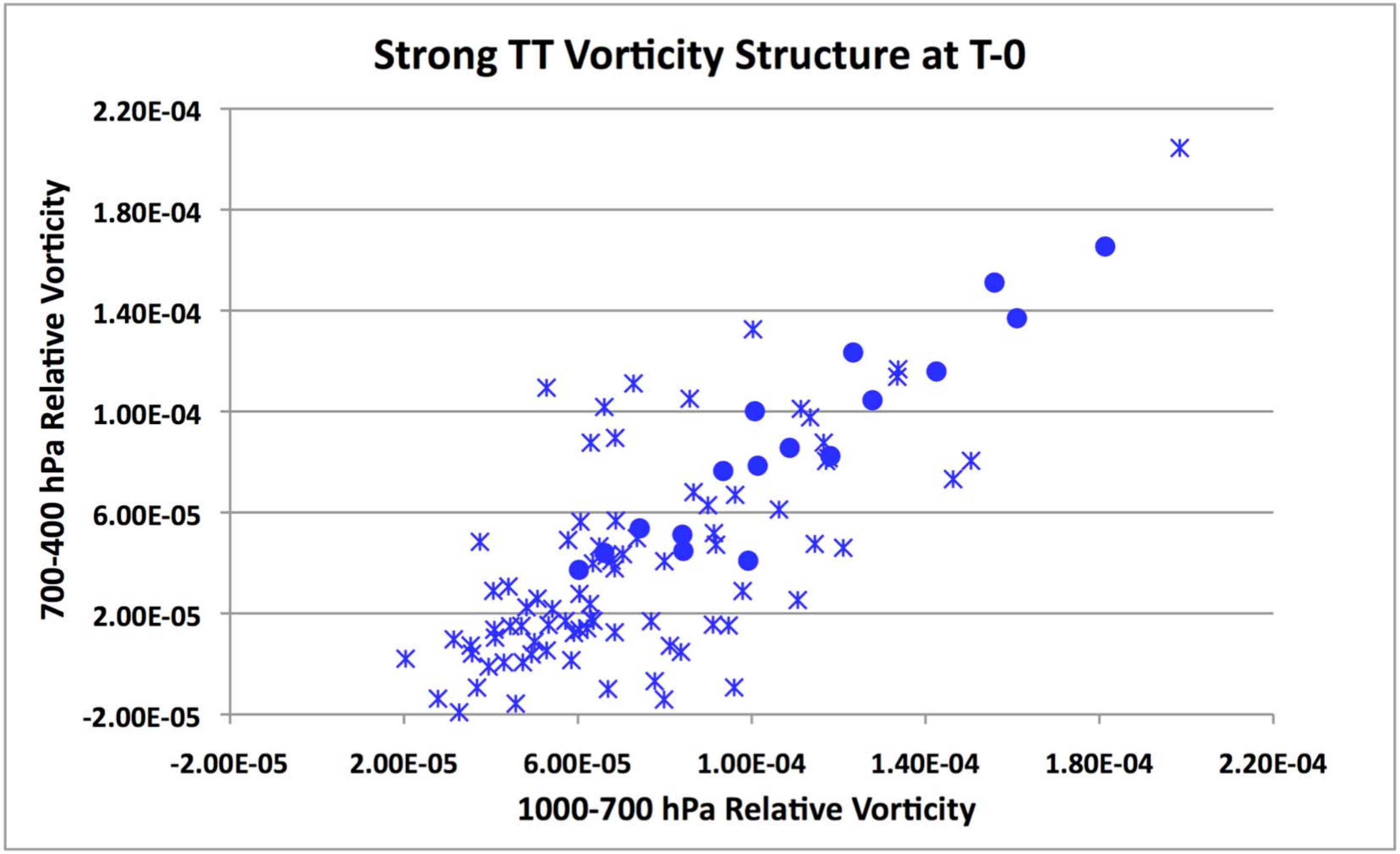

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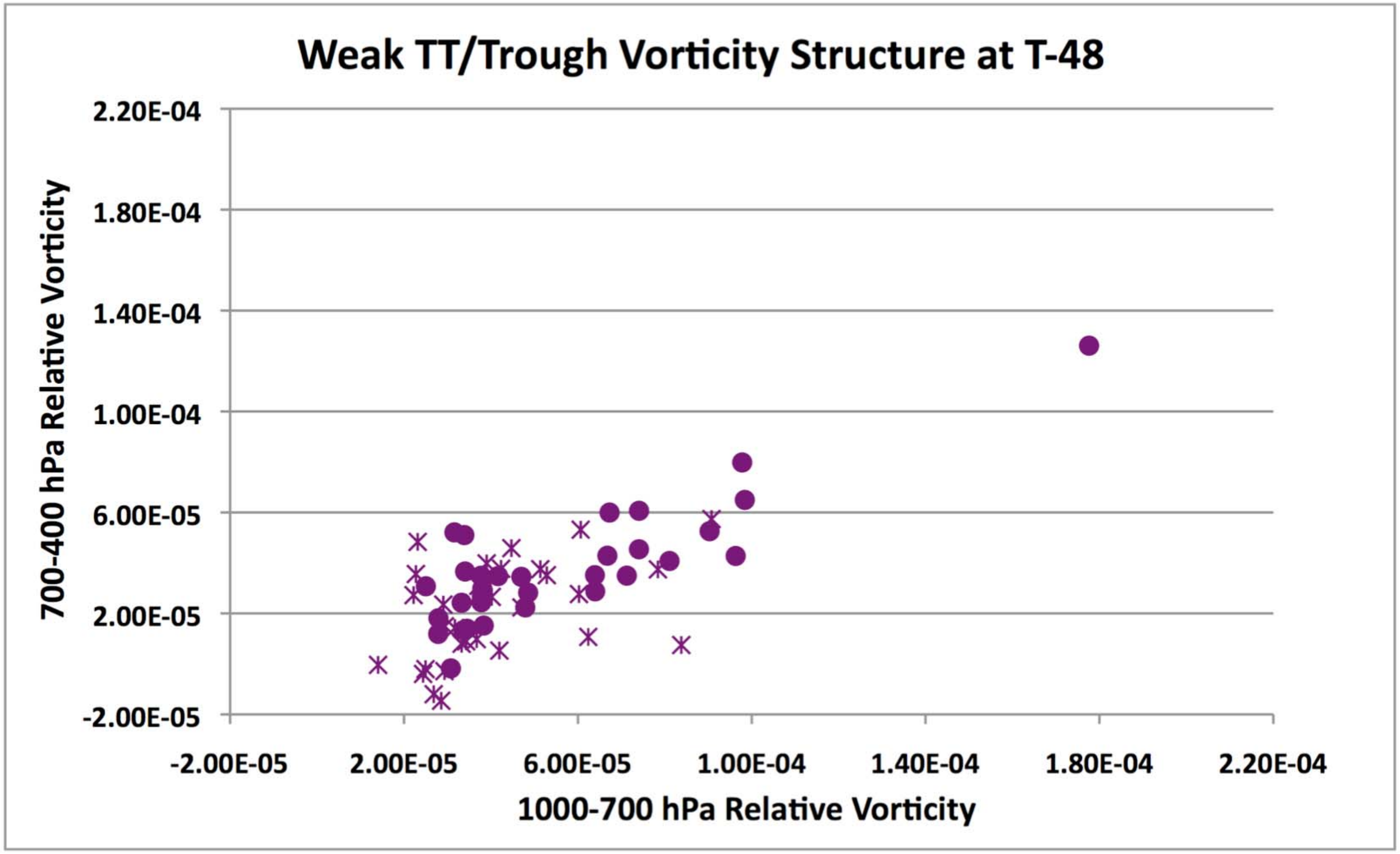

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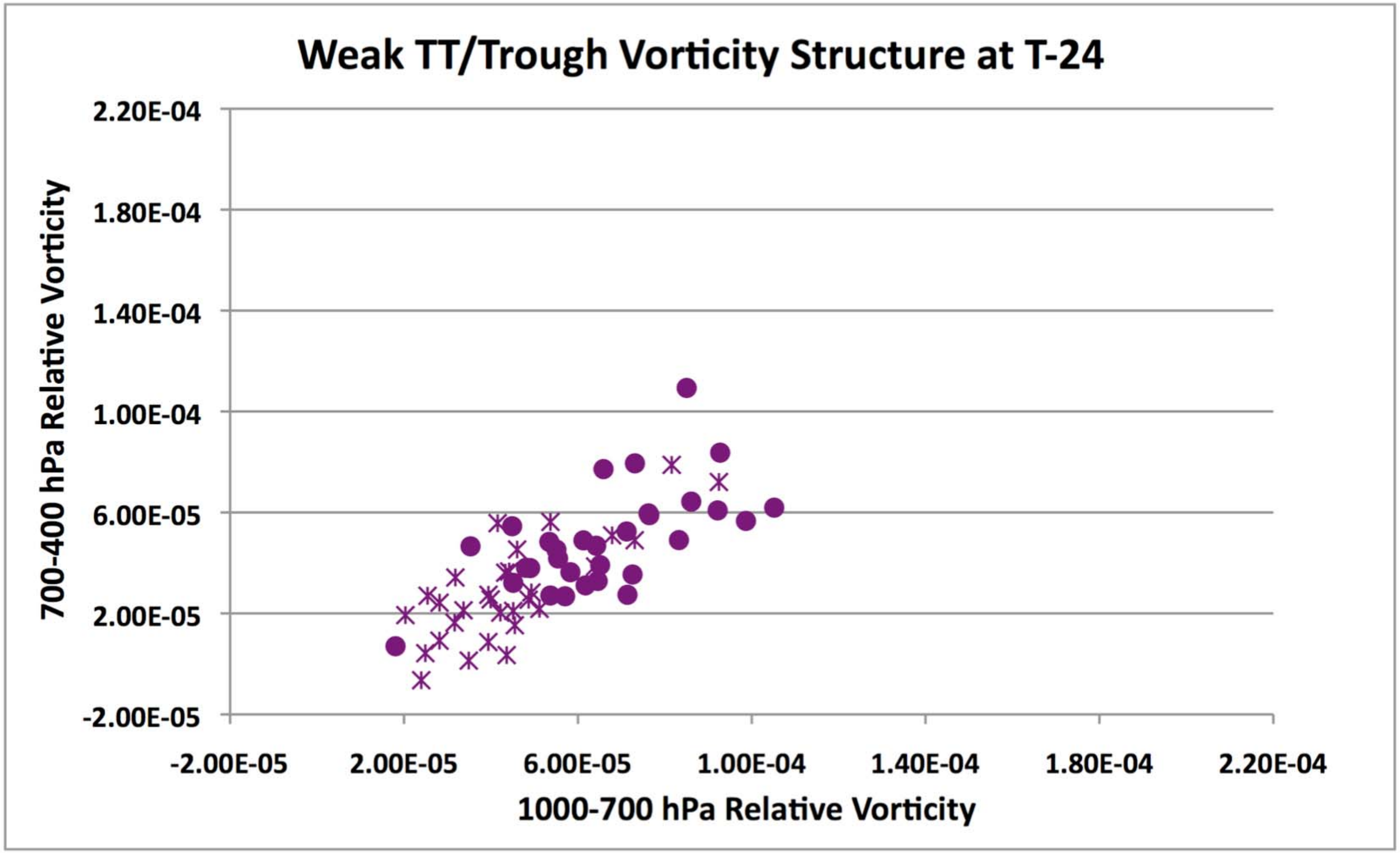

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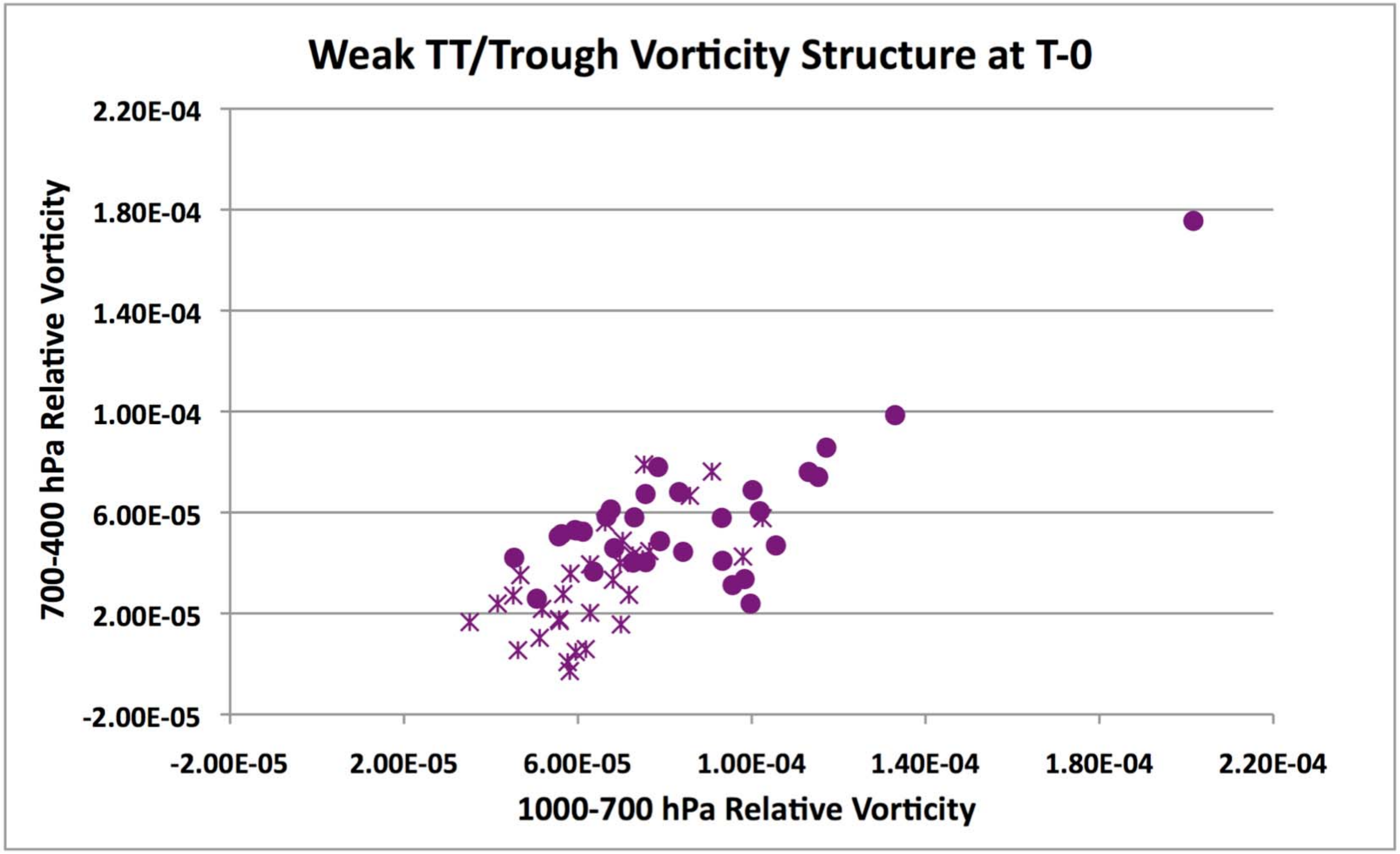

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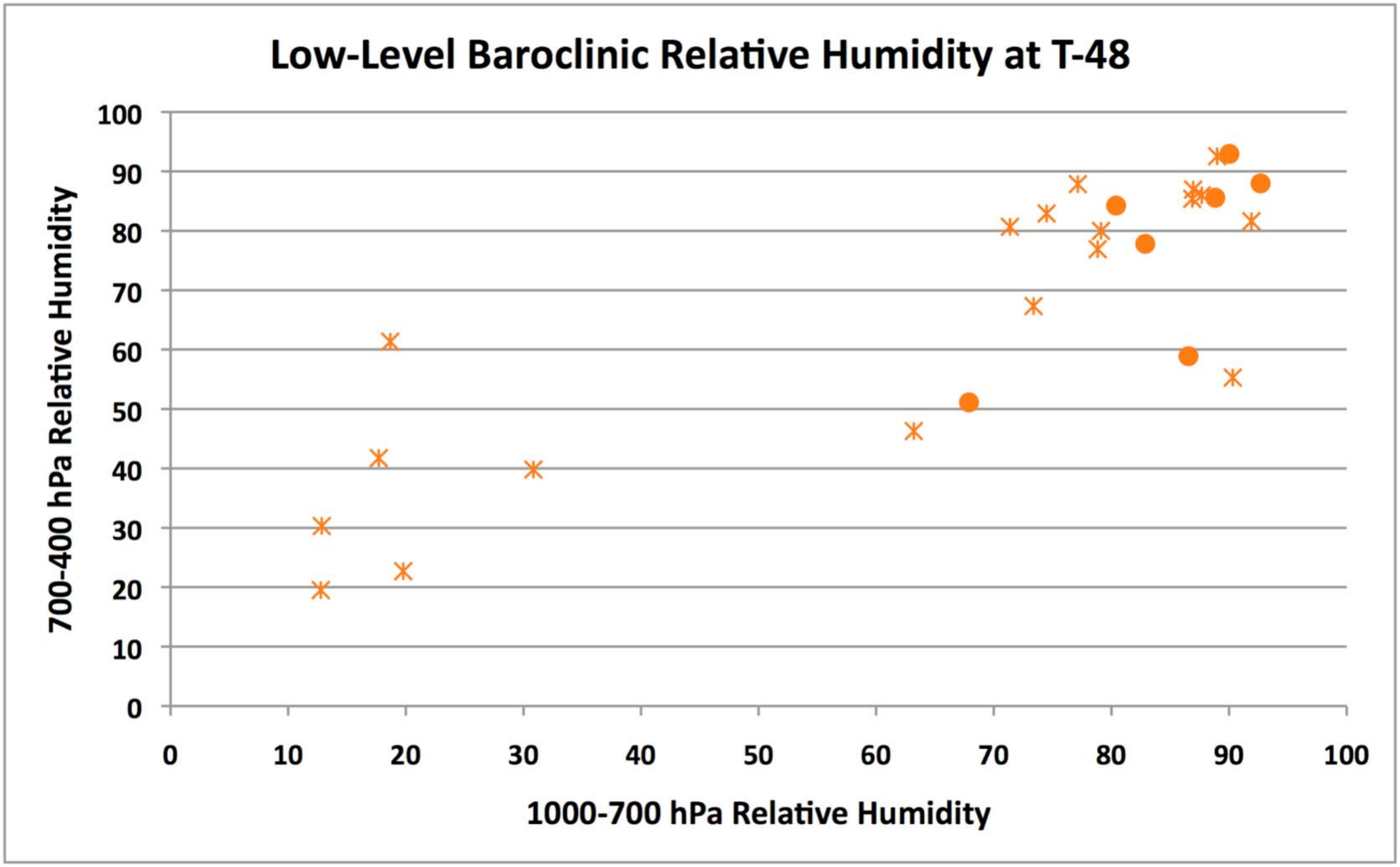
1000–700 hPa Average RH vs. 700–400 hPa Average RH (%)

4°×4° Box Average



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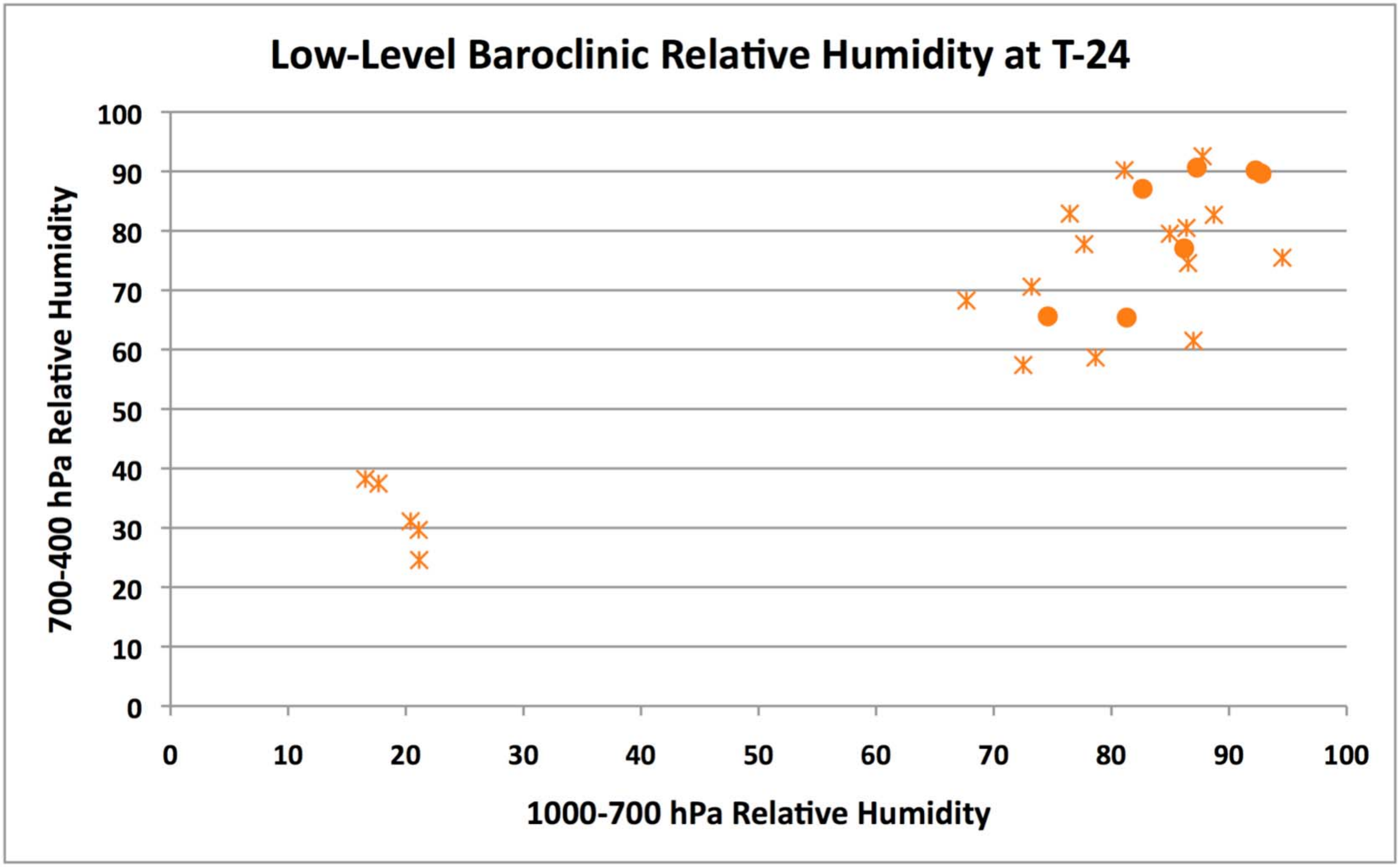

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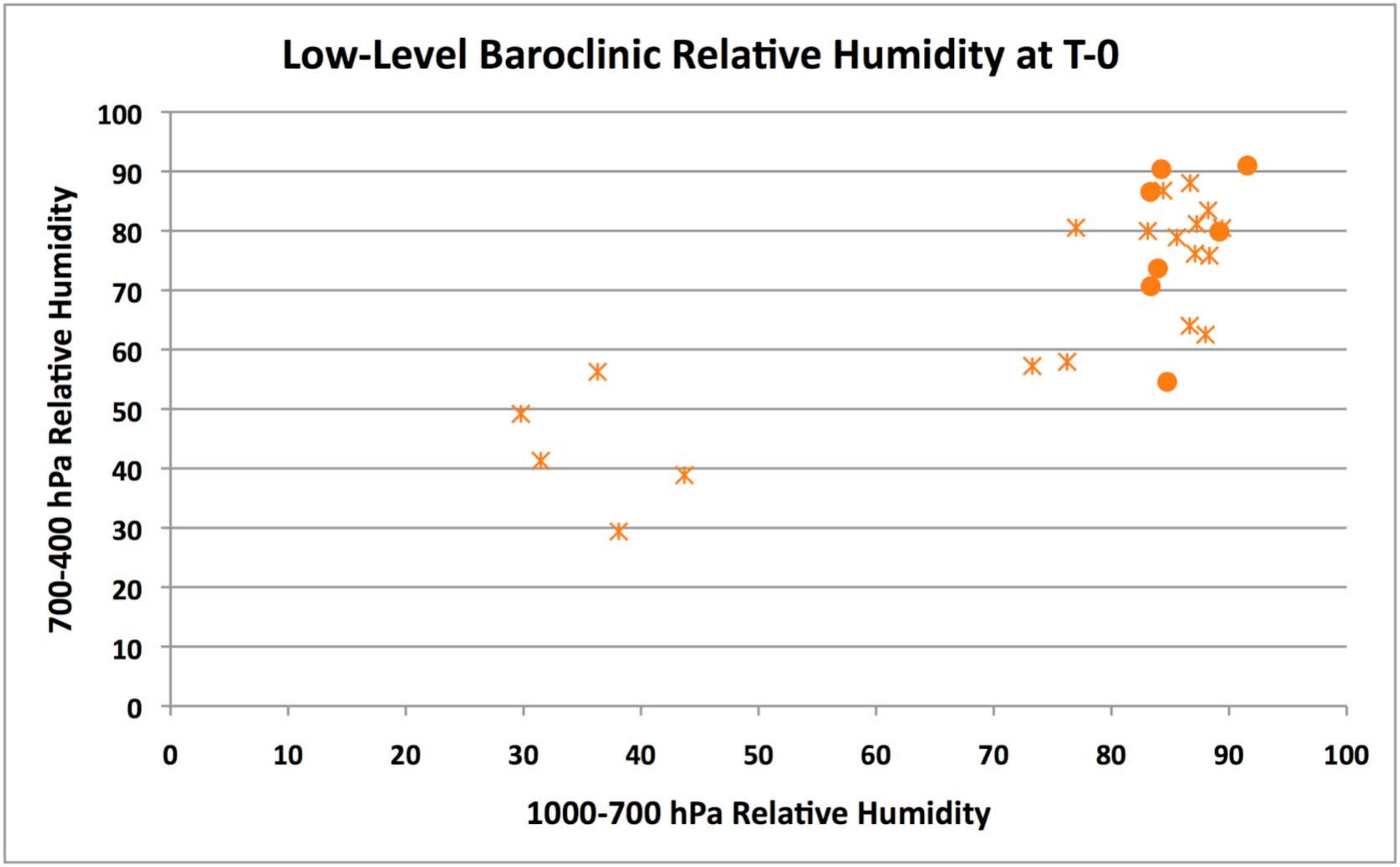

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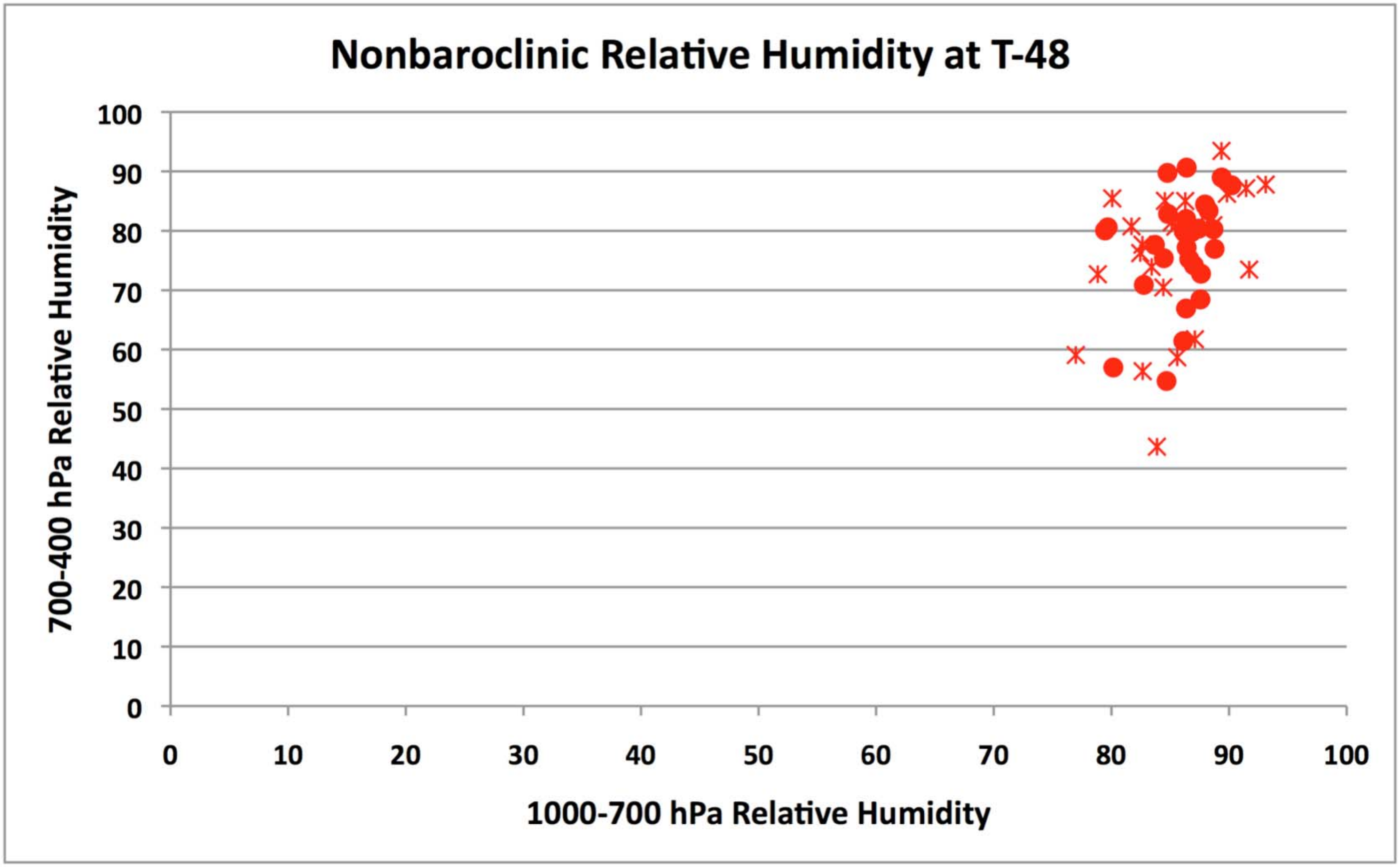

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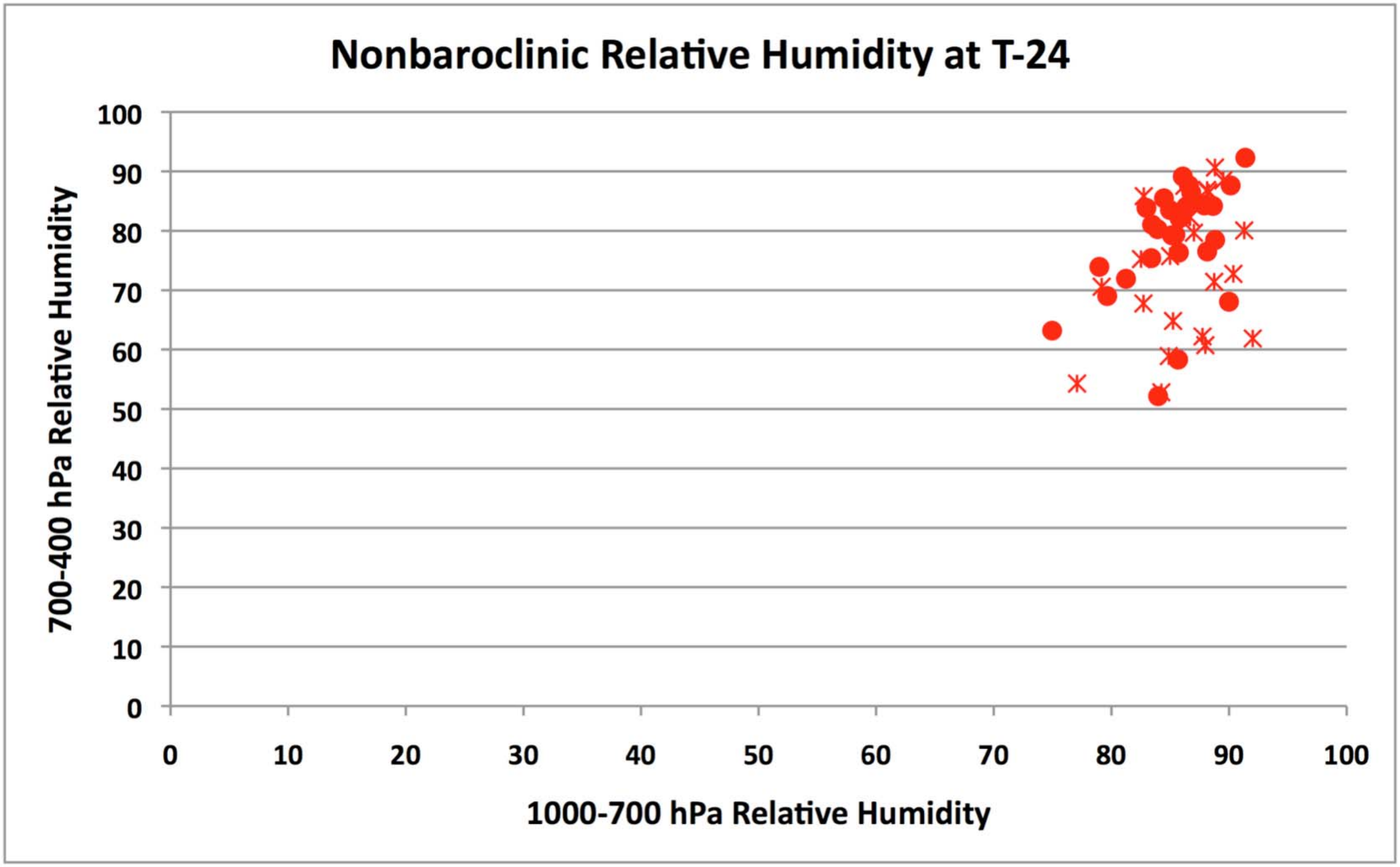

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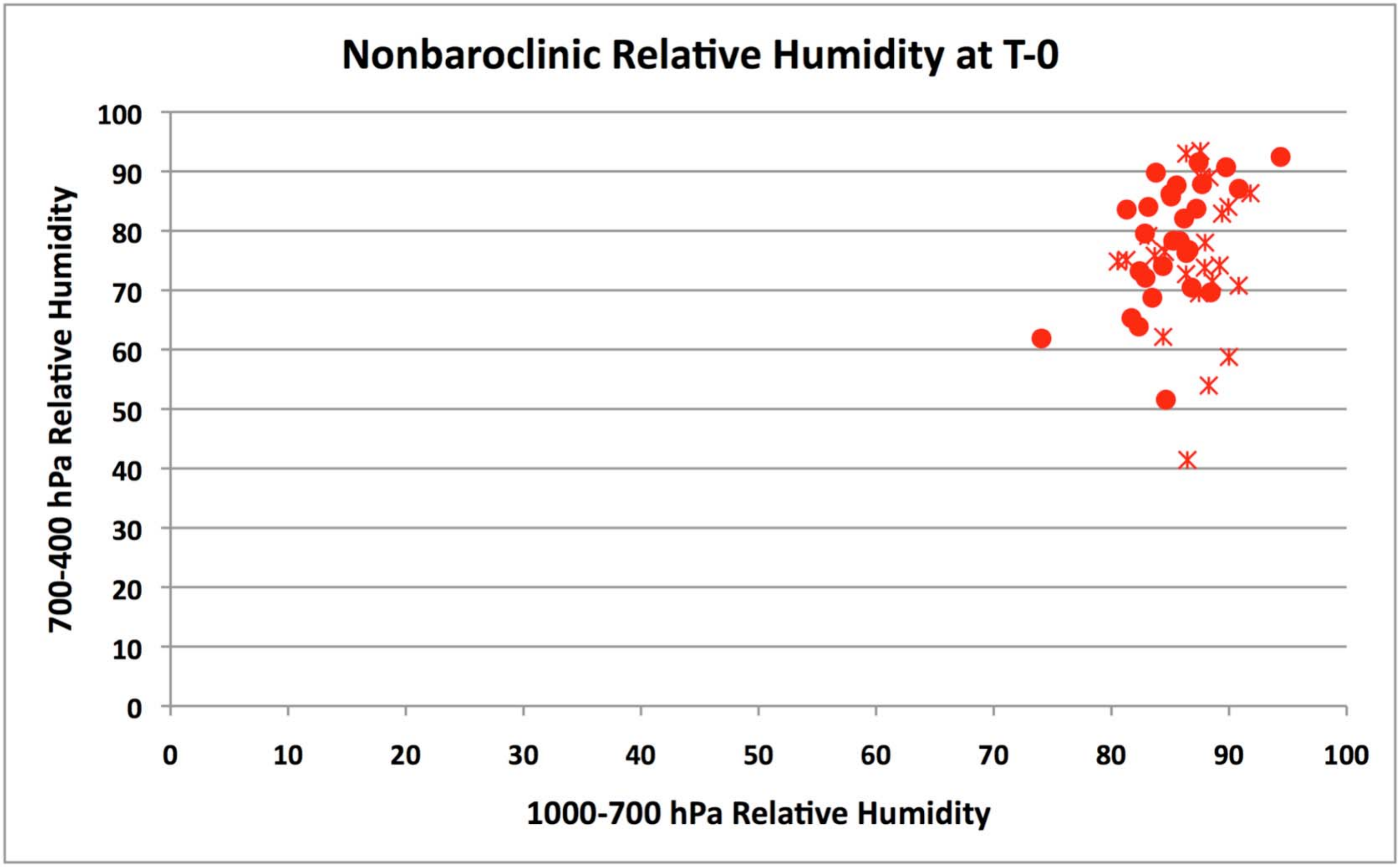

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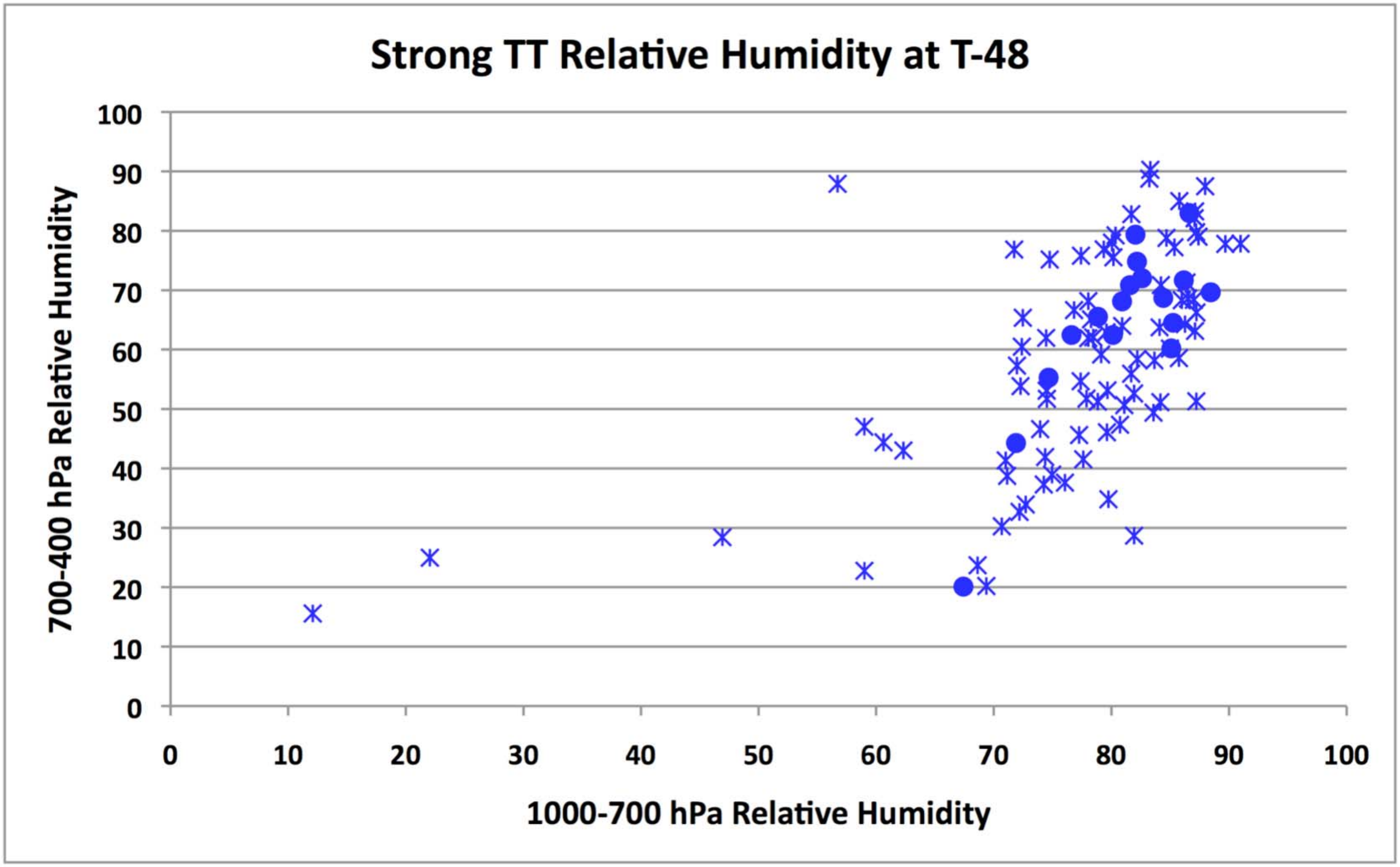

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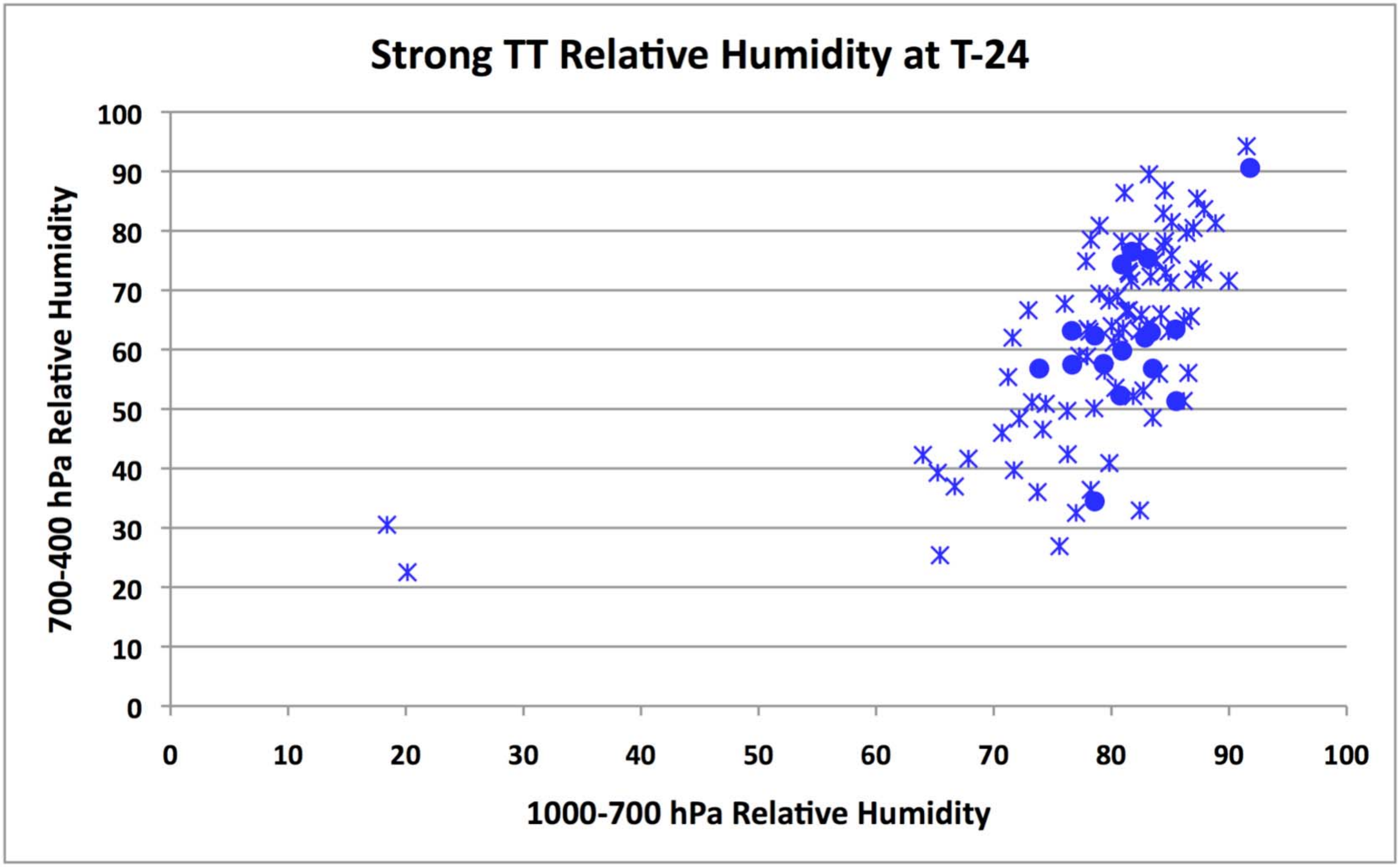

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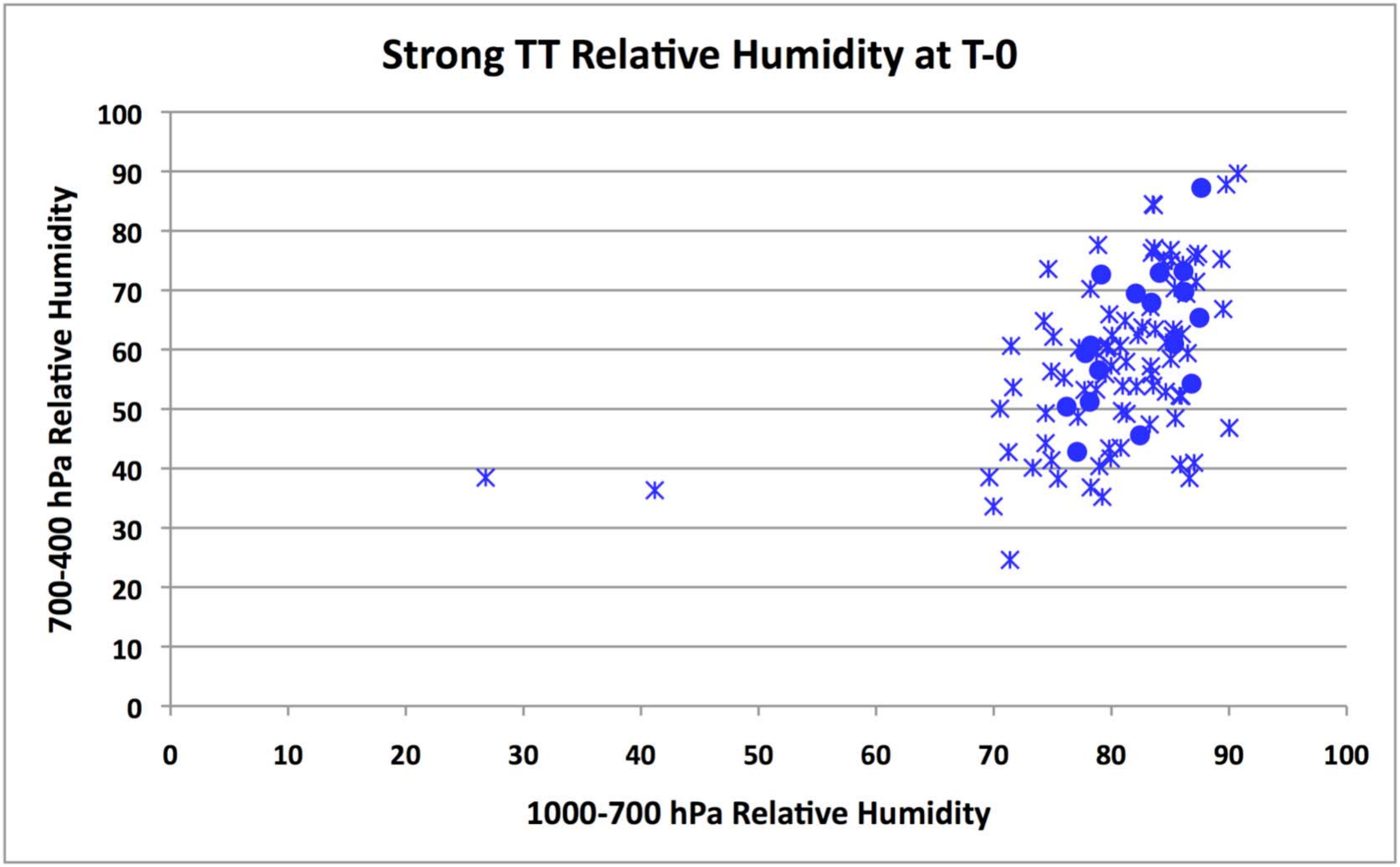

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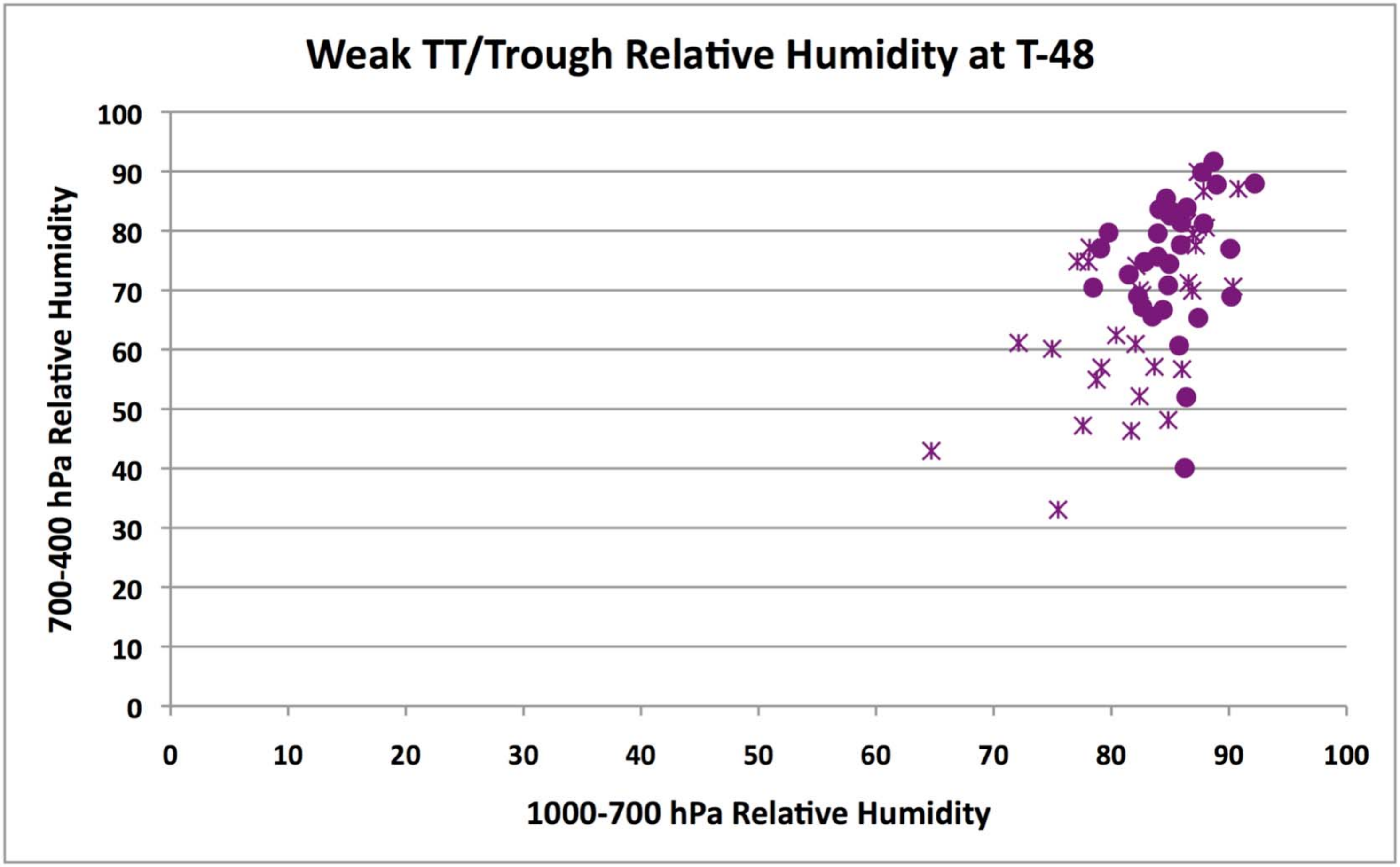

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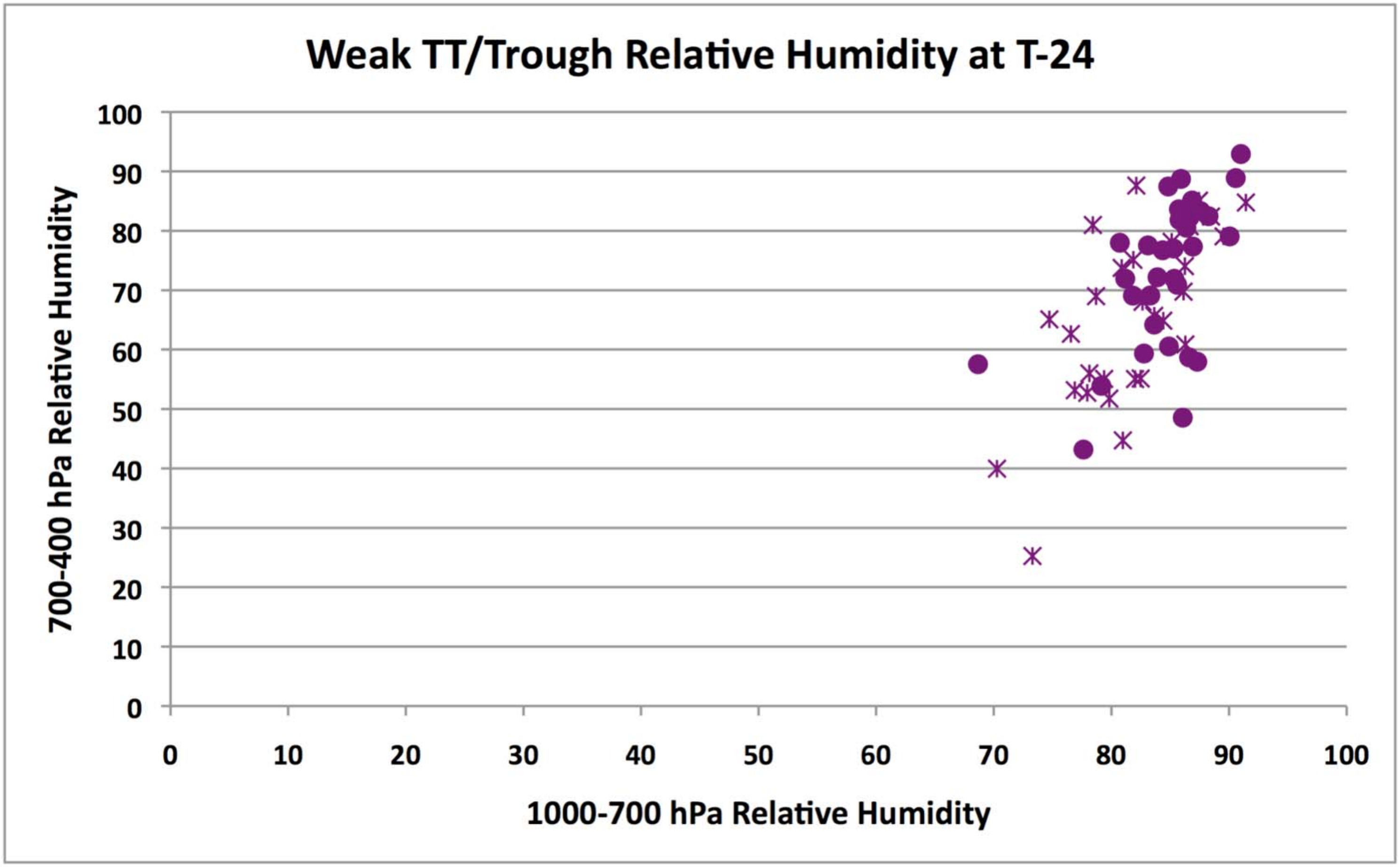

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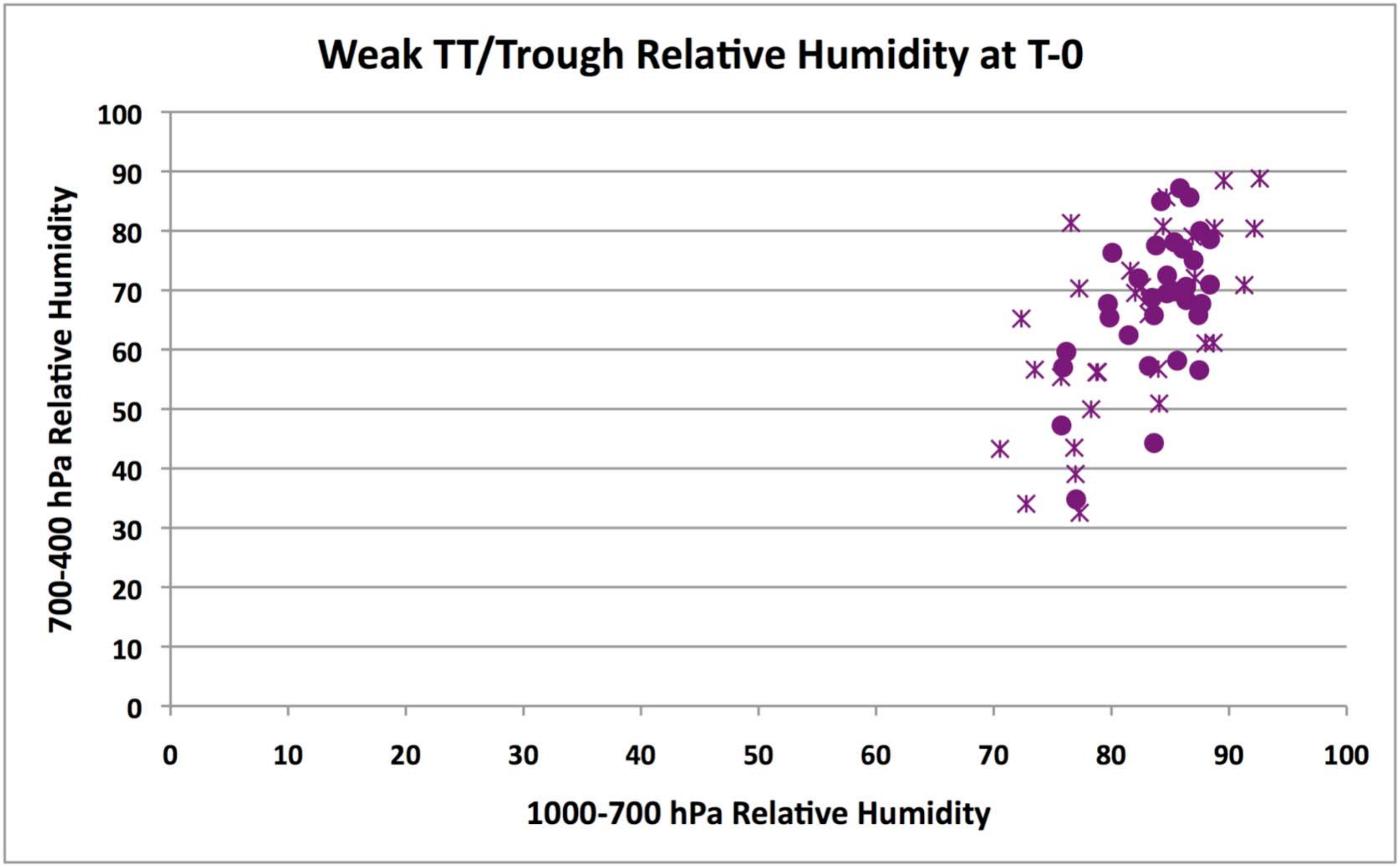

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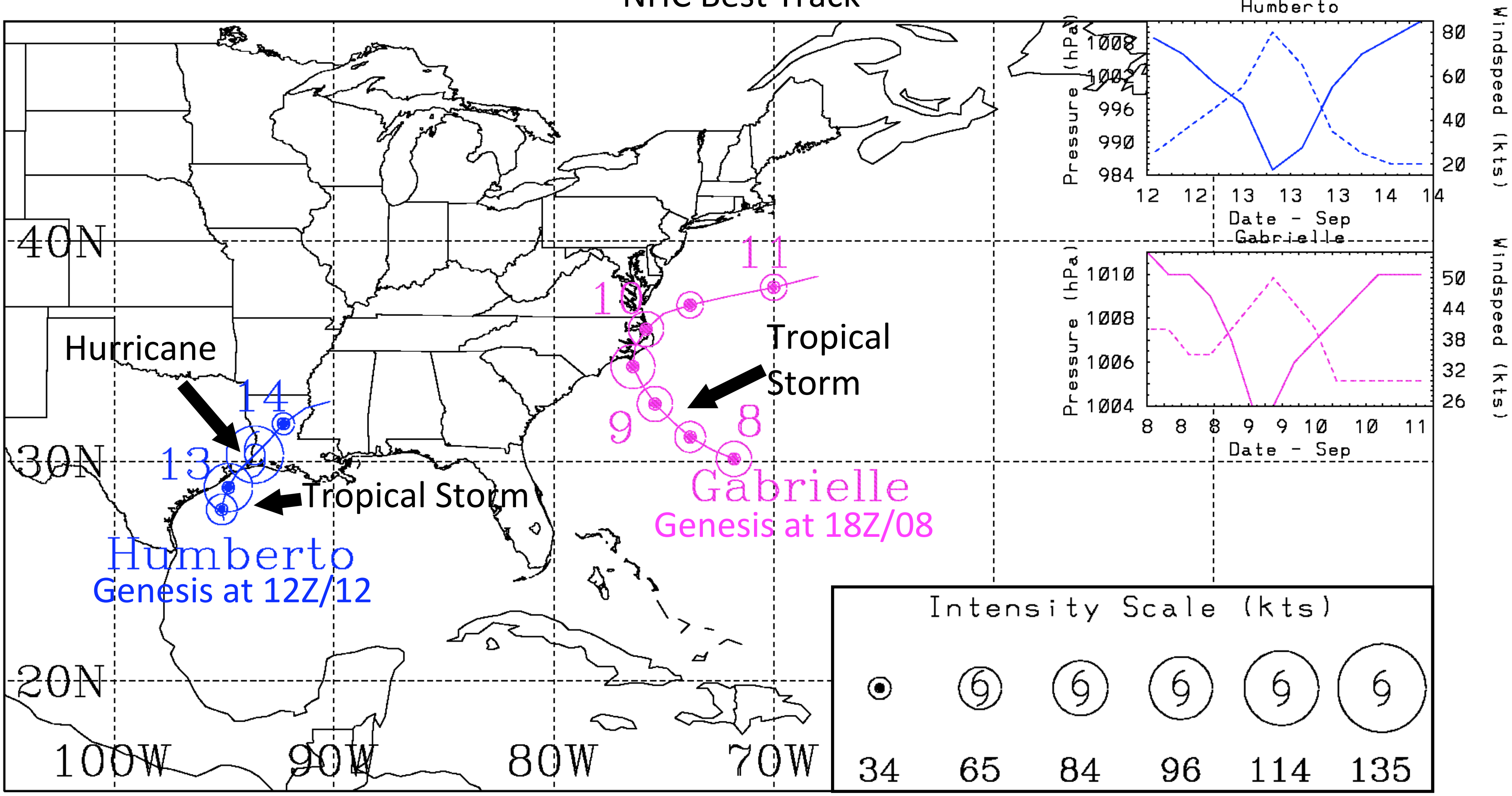
Case Example

Examples of Weak TT during 2007: TS Gabrielle/Hurricane Humberto

8–14 Sept 2007
NHC Best Track



Hurricane

Tropical Storm

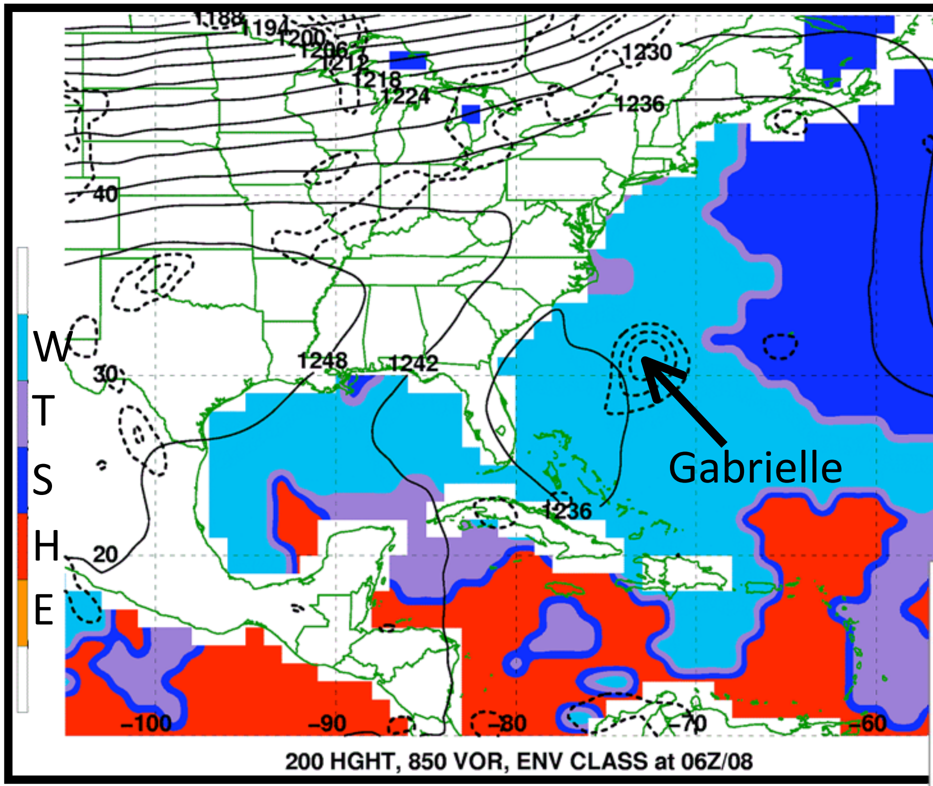
Tropical Storm

Genesis at 12Z/12

Genesis at 18Z/08

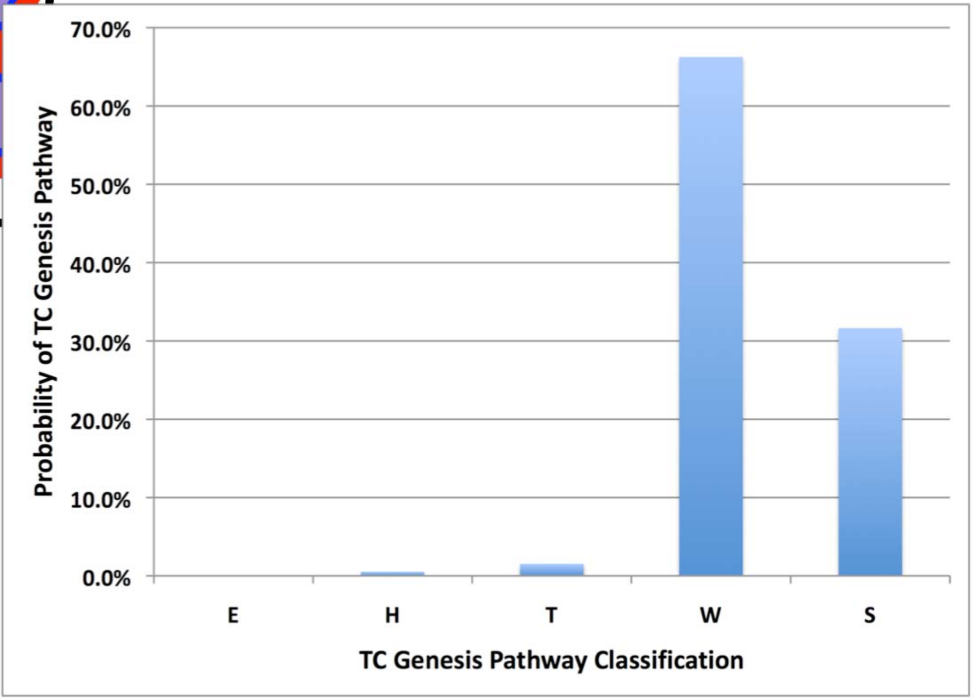
TC Gabrielle (2007) LDA Classification

0600 UTC 8 September 2007
12-h prior to TC genesis

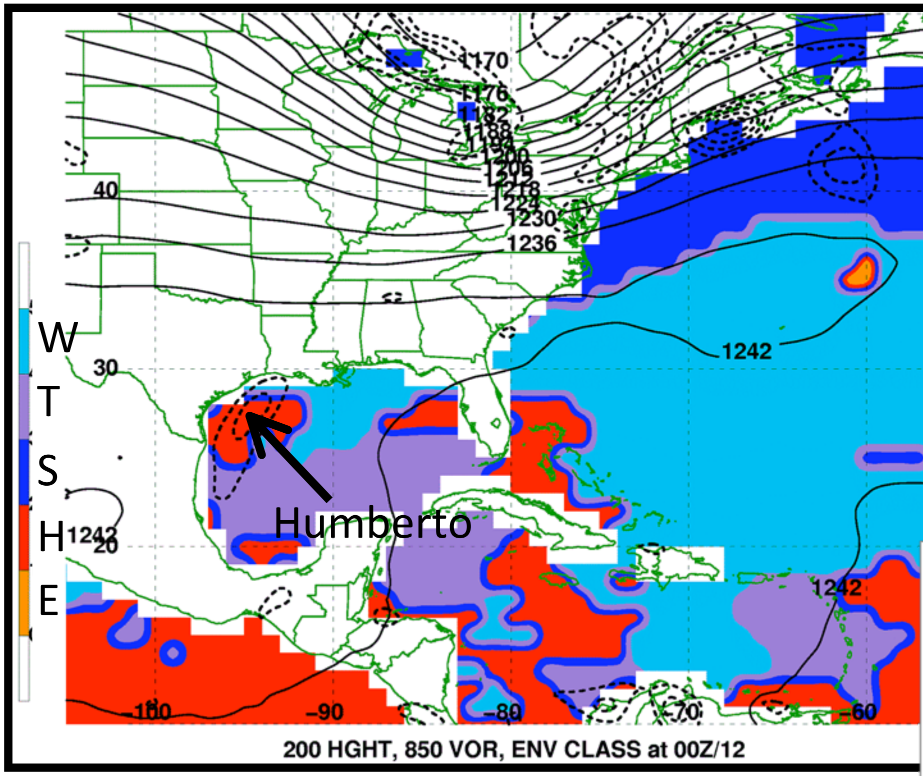


200 hPa geopotential height (dam),
850 hPa ζ (10^{-5} s^{-1}),
TC Class (shaded)

Probability of TC Genesis Pathway at T−12 h



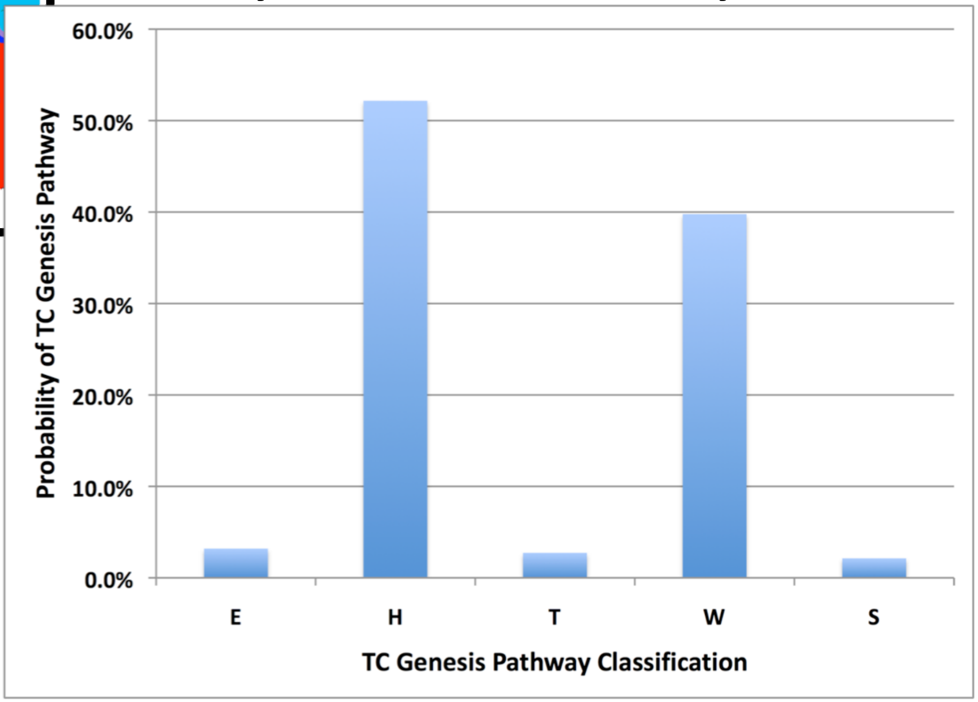
TC Humberto (2007) LDA Classification



200 hPa geopotential height (dam),
850 hPa ζ (10^{-5} s^{-1}),
TC Class (shaded)

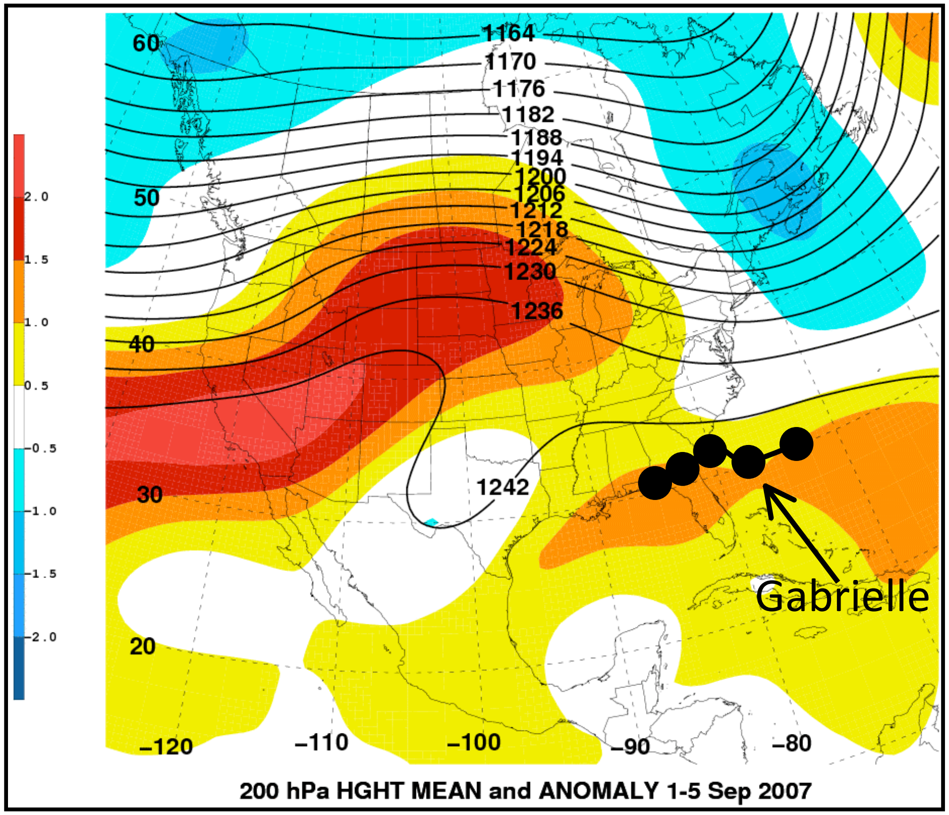
0000 UTC 12 September 2007
12-h prior to TC genesis

Probability of TC Genesis Pathway at T—12 h



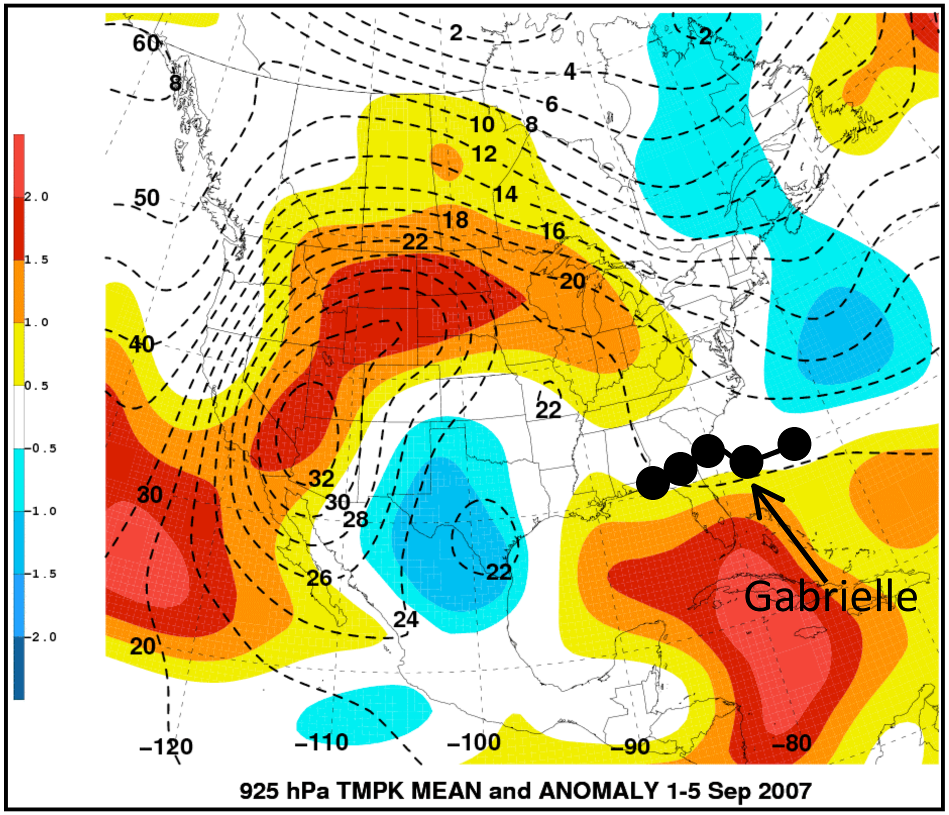
Synoptic Overview

200 hPa h mean (dam) and anomaly (σ)



200 hPa HGHT MEAN and ANOMALY 1-5 Sep 2007

925 hPa T mean (°C) and anomaly (σ)



925 hPa TMPK MEAN and ANOMALY 1-5 Sep 2007

1–5 September 2007

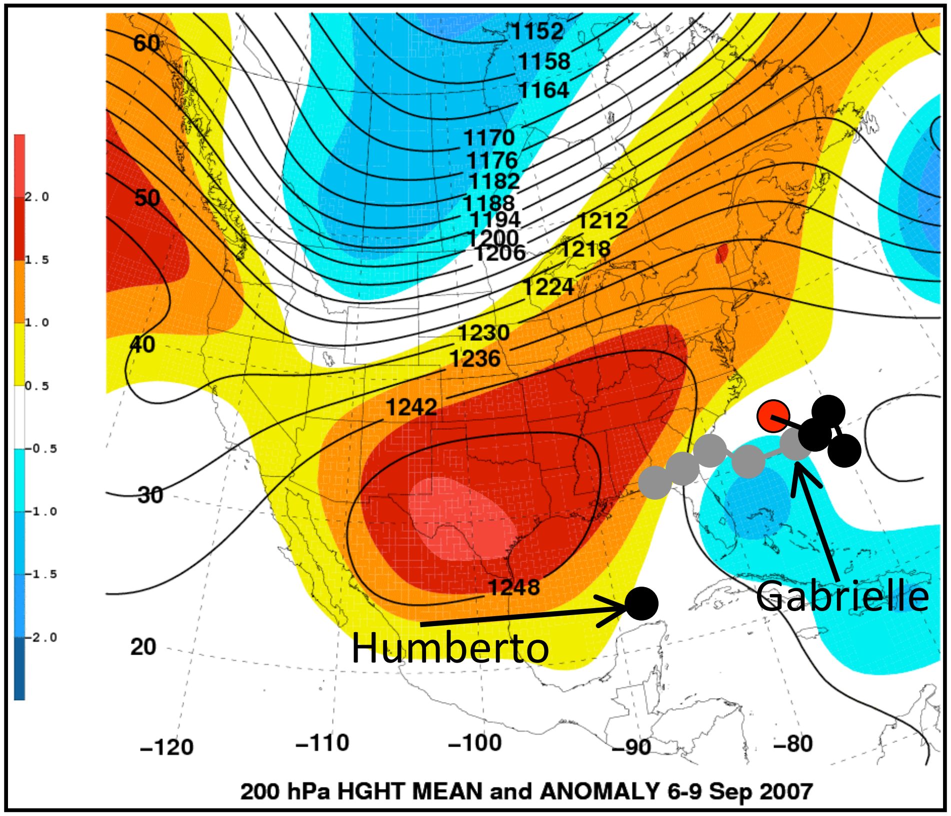
● = 00Z position

🔴 = 00Z position nearest
to time of TC genesis

Anomaly calculated from the 1948–2006 long-term 10–13 September mean

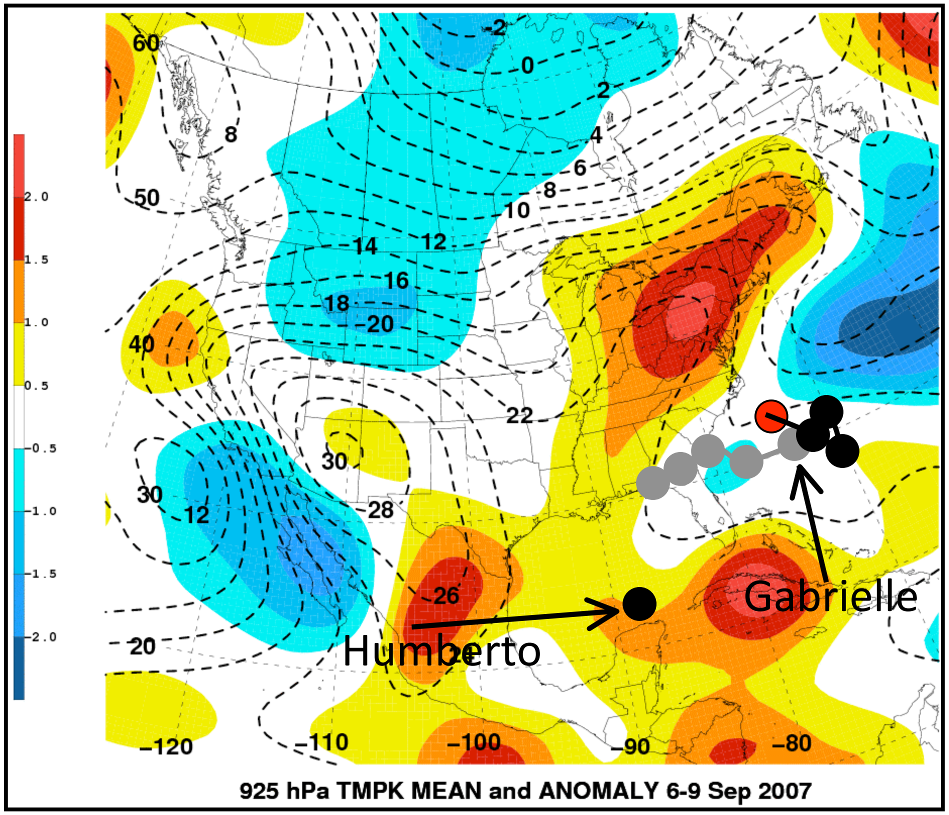
Synoptic Overview

200 hPa h mean (dam) and anomaly (σ)



200 hPa HGHT MEAN and ANOMALY 6-9 Sep 2007

925 hPa T mean (°C) and anomaly (σ)



925 hPa TMPK MEAN and ANOMALY 6-9 Sep 2007

6–9 September 2007

● = 00Z position

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Anomaly calculated from the 1948–2006 long-term 10–13 September mean

Synoptic Overview

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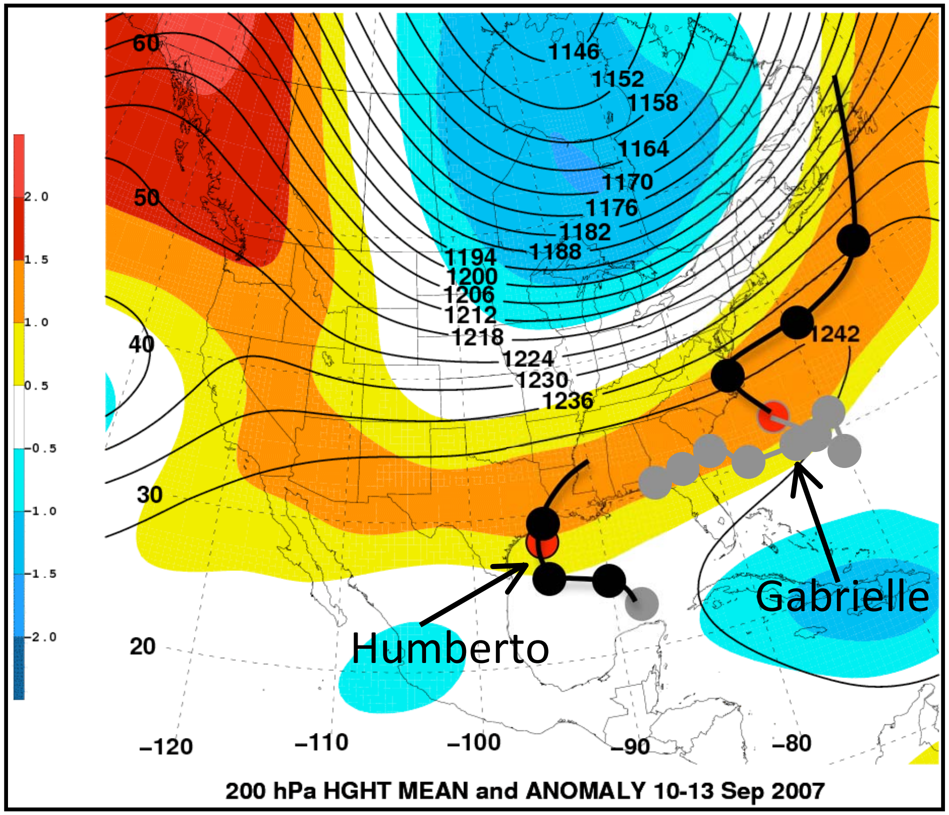
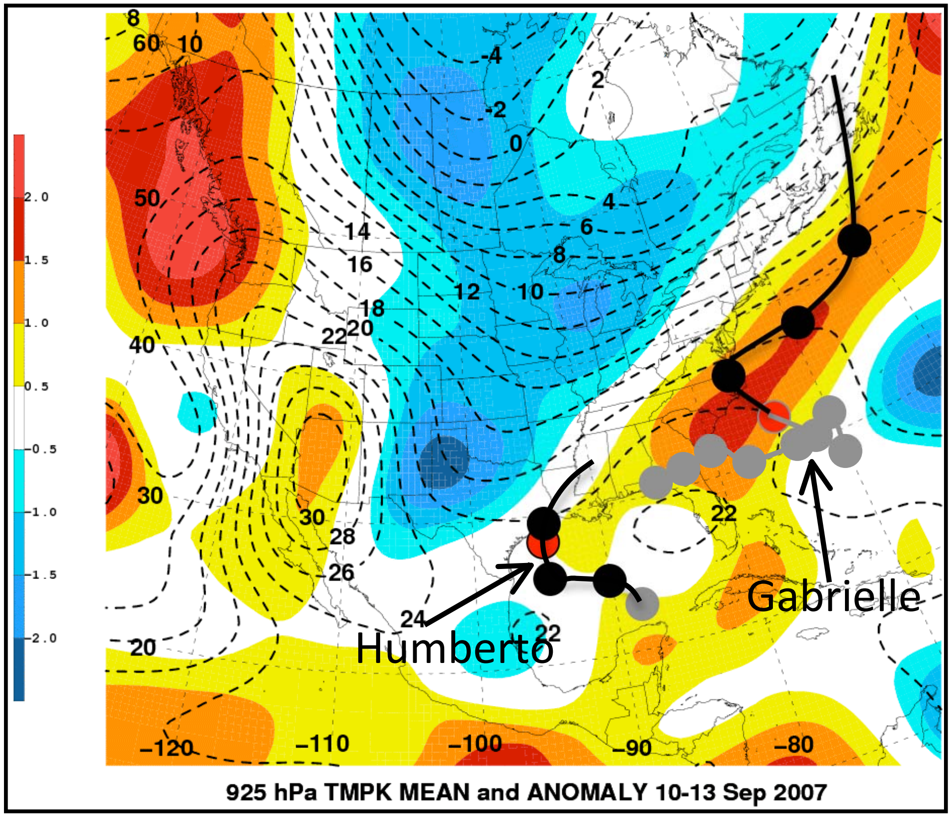


925 hPa T mean (°C) and anomaly (σ)



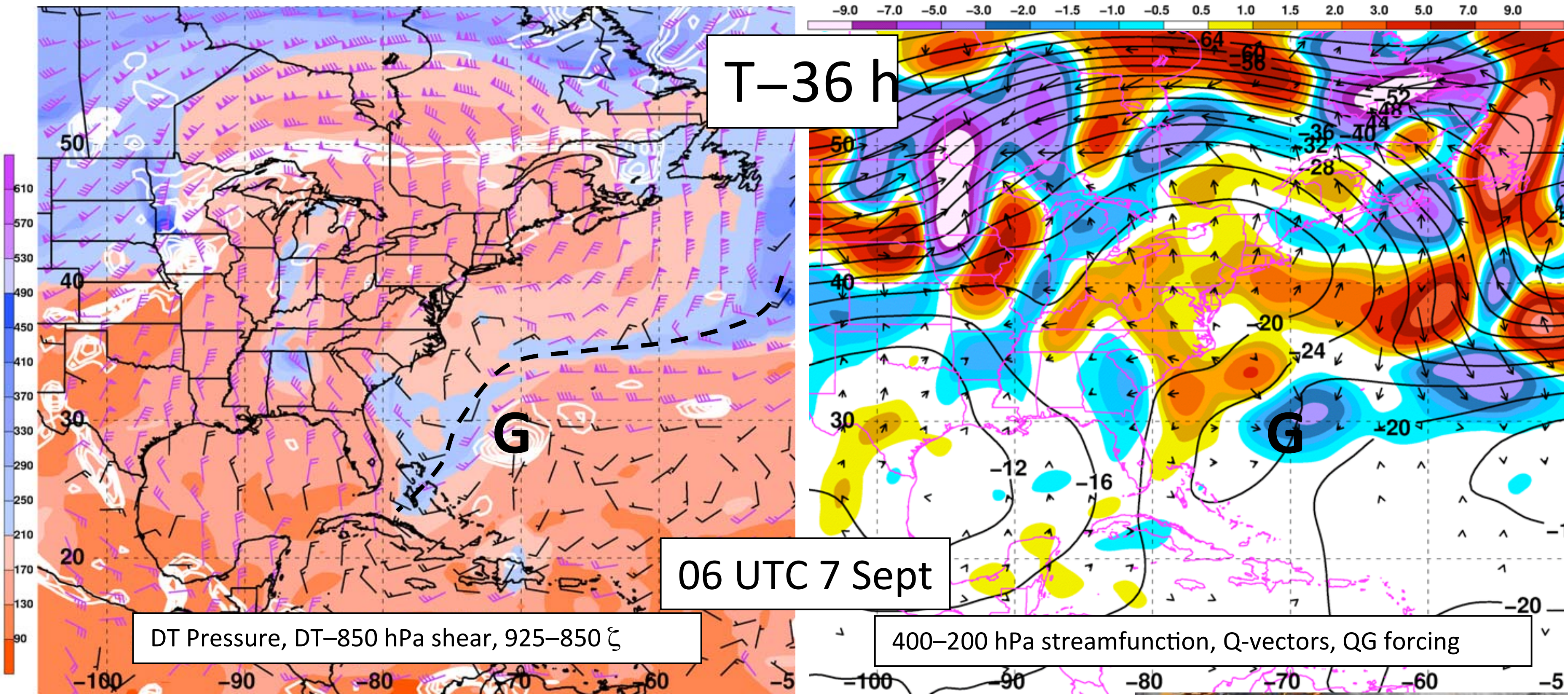
10–13 September 2007

● = 00Z position

🔴 = 00Z position nearest to time of TC genesis

Anomaly calculated from the 1948–2006 long-term 10–13 September mean

DT Analysis and QG Forcing

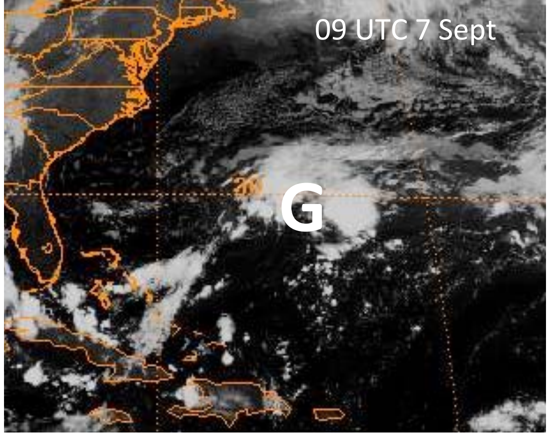


T–36 h

06 UTC 7 Sept

DT Pressure, DT–850 hPa shear, 925–850 ζ

400–200 hPa streamfunction, Q-vectors, QG forcing

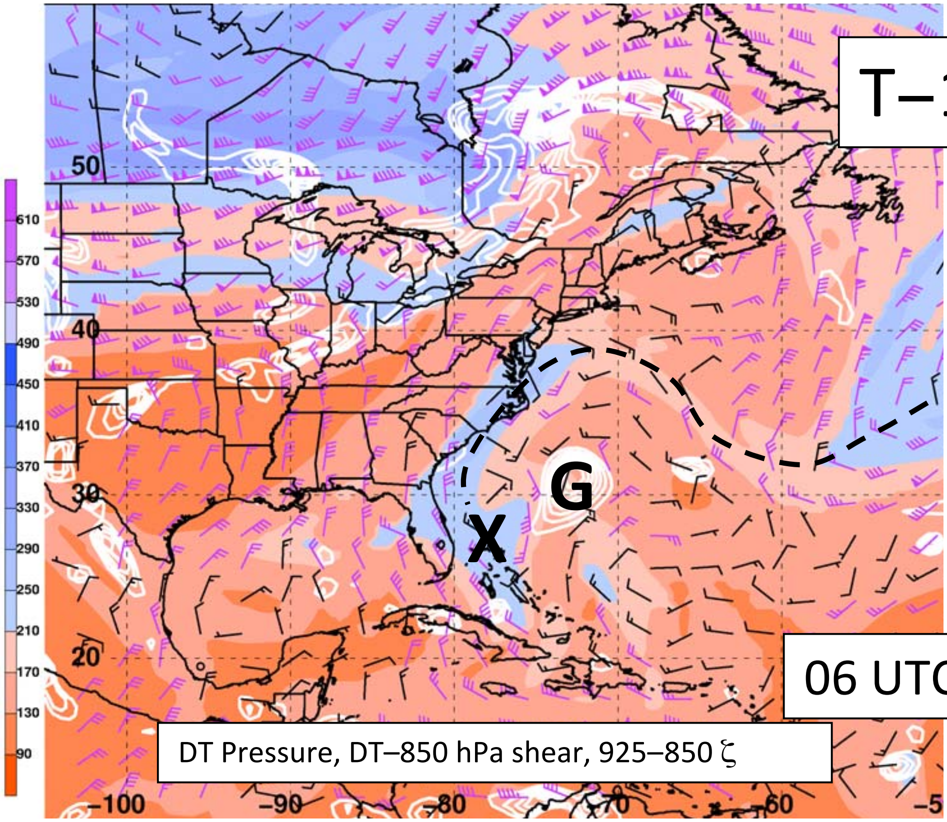


09 UTC 7 Sept

- Incipient Gabrielle vorticity organizes in region of deep convection associated with QG ascent forcing by PV streamer

DT Analysis and QG Forcing

T–12 h



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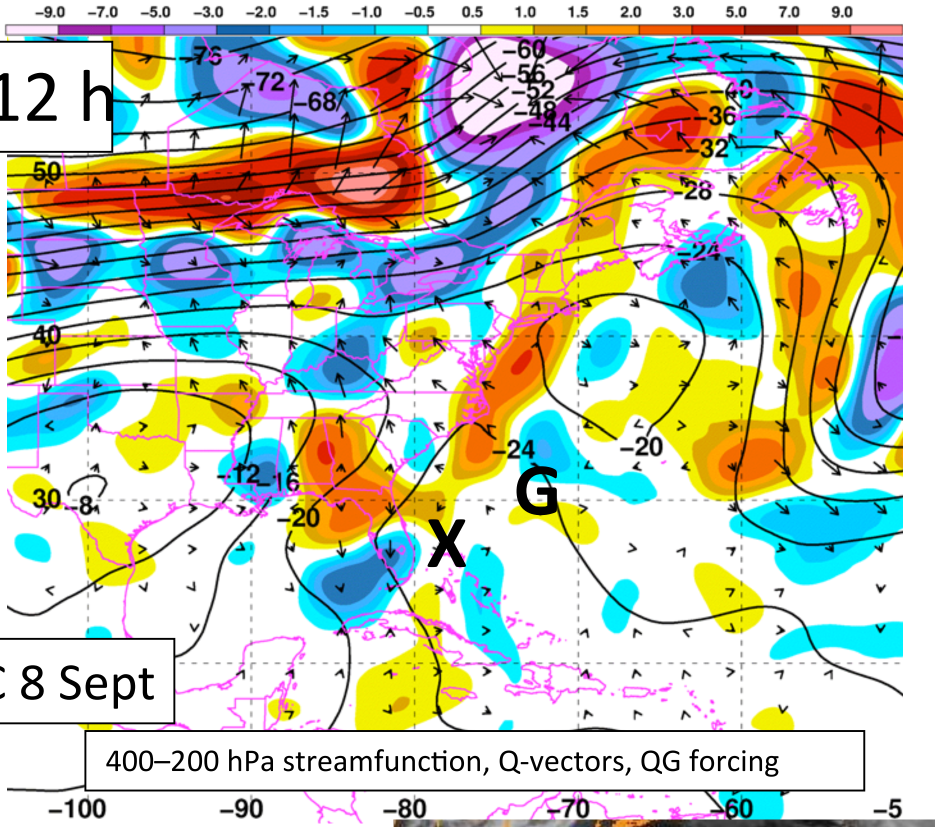
06 UTC 8 Sept



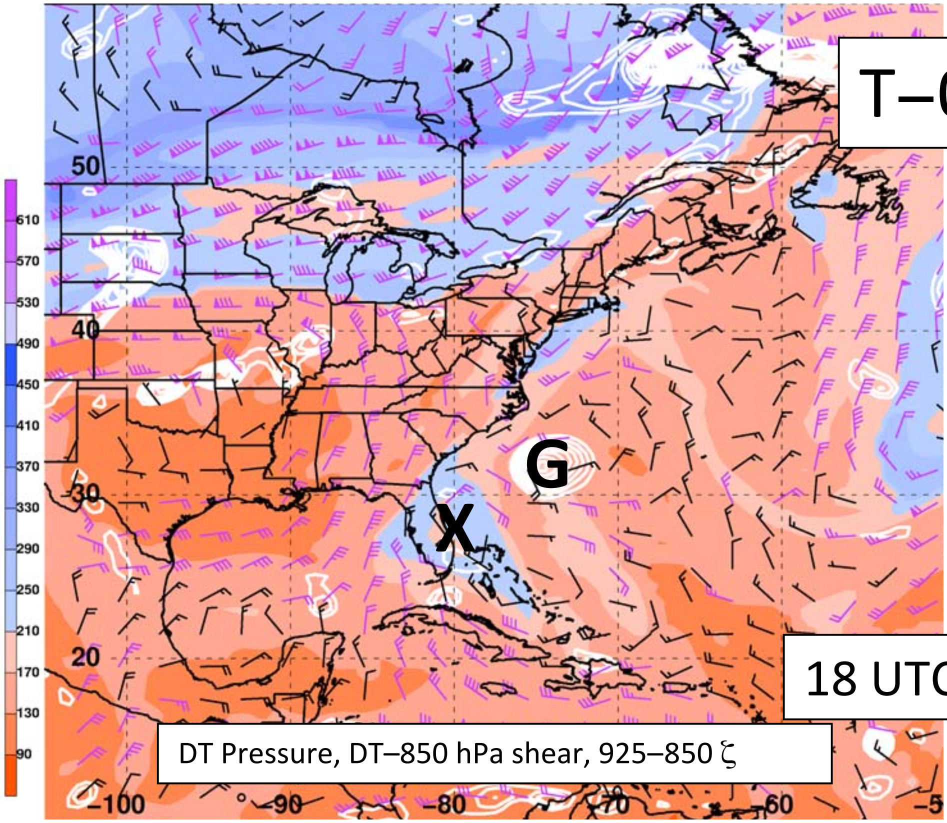
400–200 hPa streamfunction, Q-vectors, QG forcing

- Momentum and PV redistribution associated with deep convection reduces PV aloft and weakens deep-layer shear

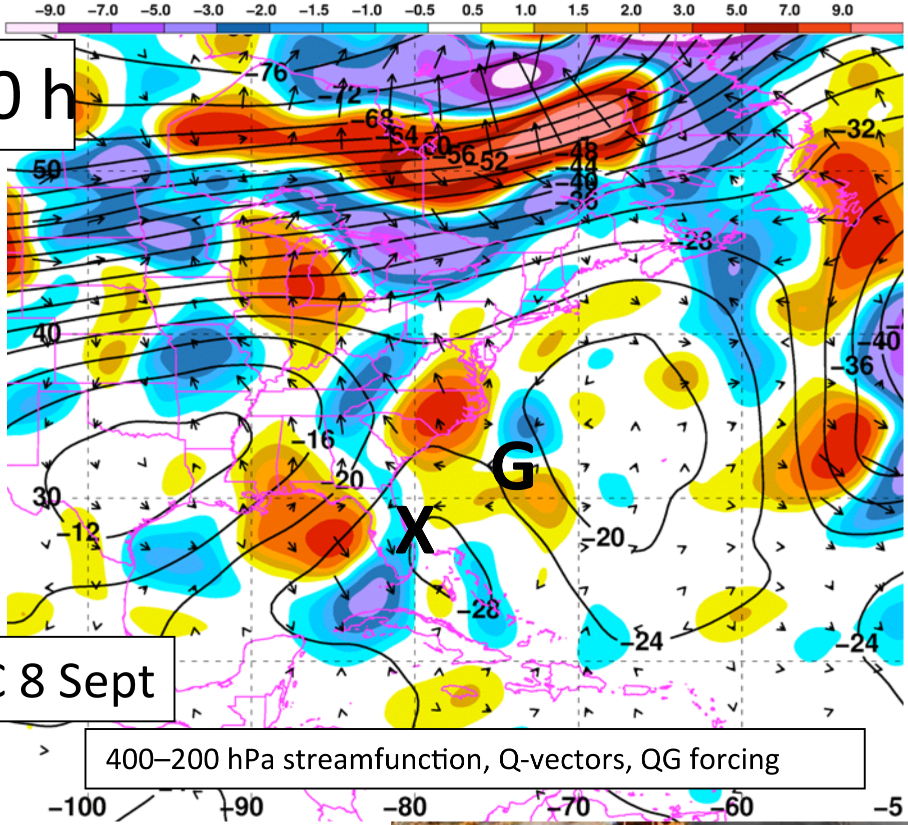
DT Analysis and QG Forcing

T–0 h

18 UTC 8 Sept

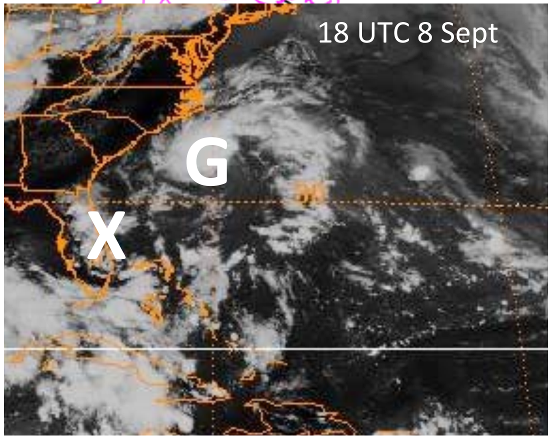


DT Pressure, DT–850 hPa shear, 925–850 ζ

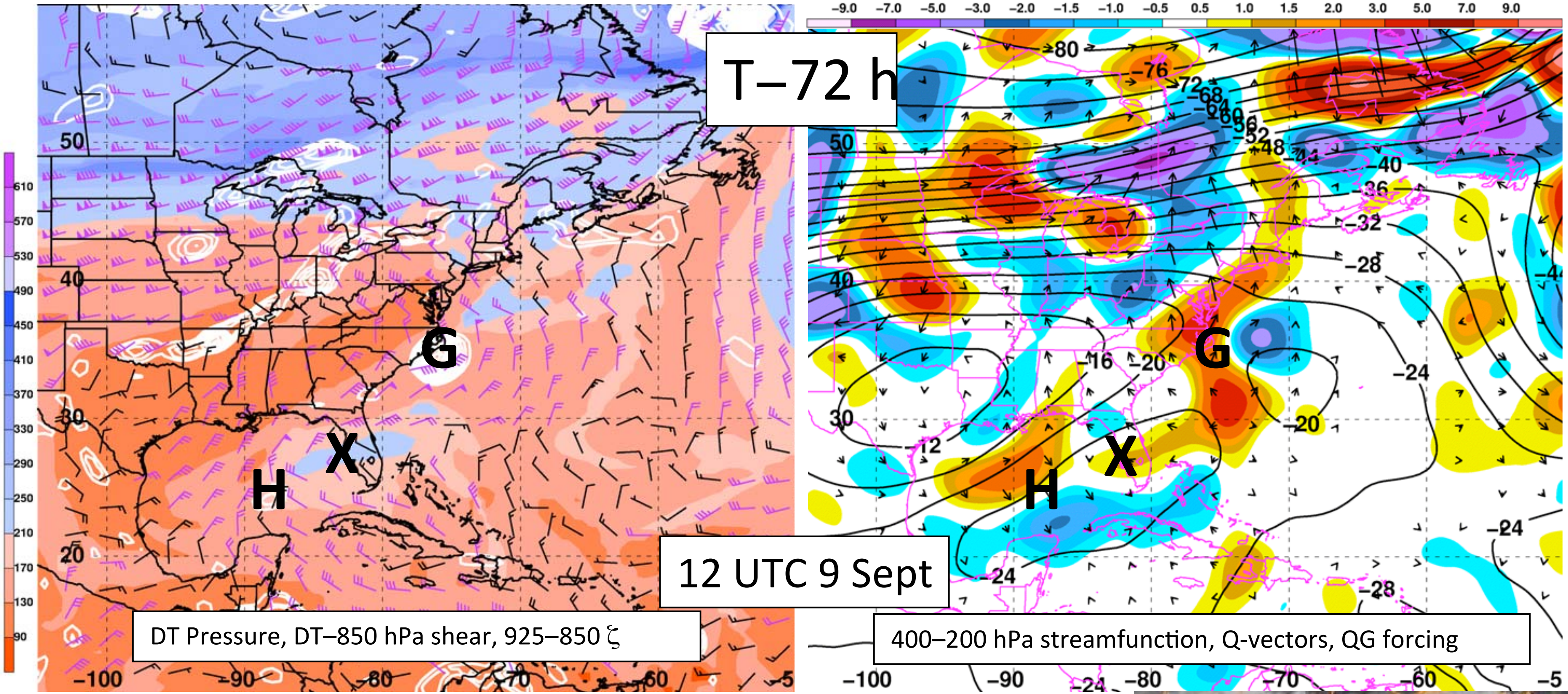


400–200 hPa streamfunction, Q-vectors, QG forcing

- Gabrielle reaches TS strength in region of weak deep-layer shear



DT Analysis and QG Forcing

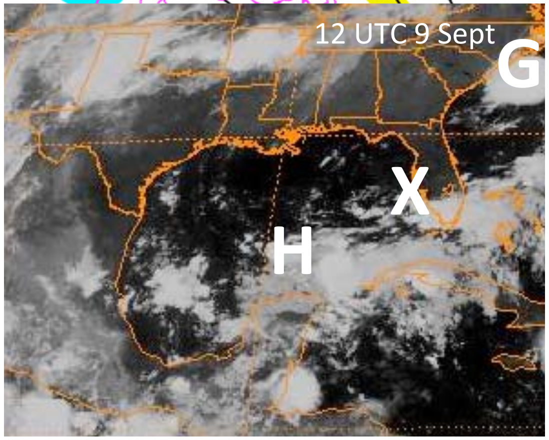

T–72 h

12 UTC 9 Sept

DT Pressure, DT–850 hPa shear, 925–850 ζ

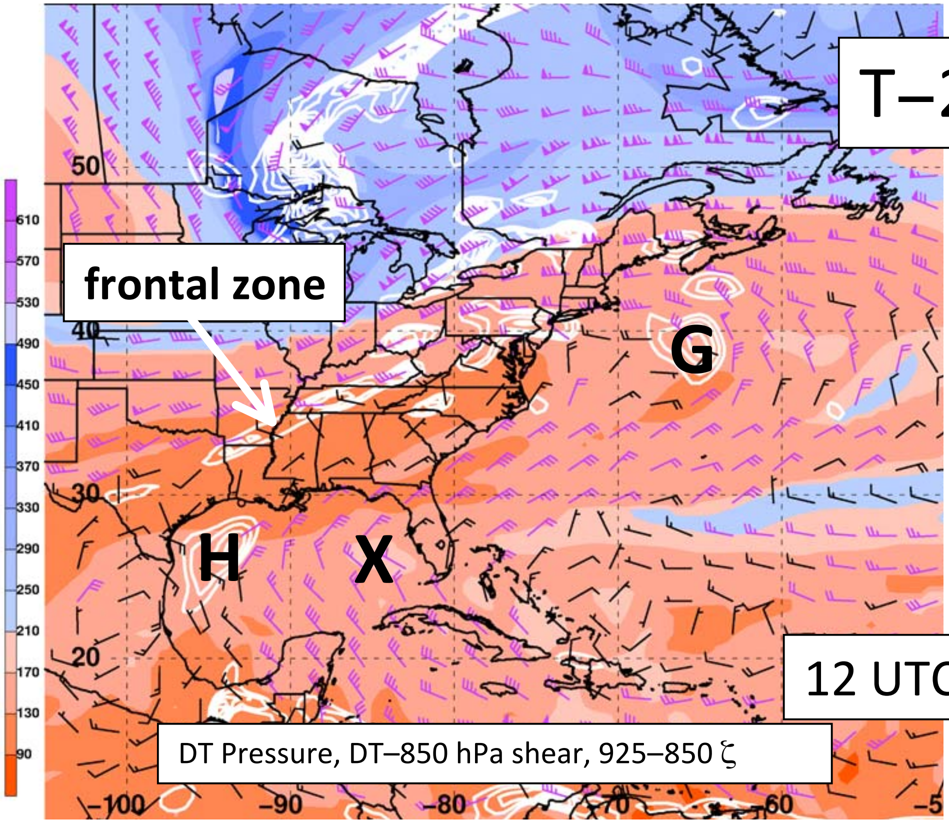
400–200 hPa streamfunction, Q-vectors, QG forcing

- Incipient Humberto vorticity organizes amidst deep convection in QG ascent forcing region west of Gabrielle PV tail fracture (‘X’)



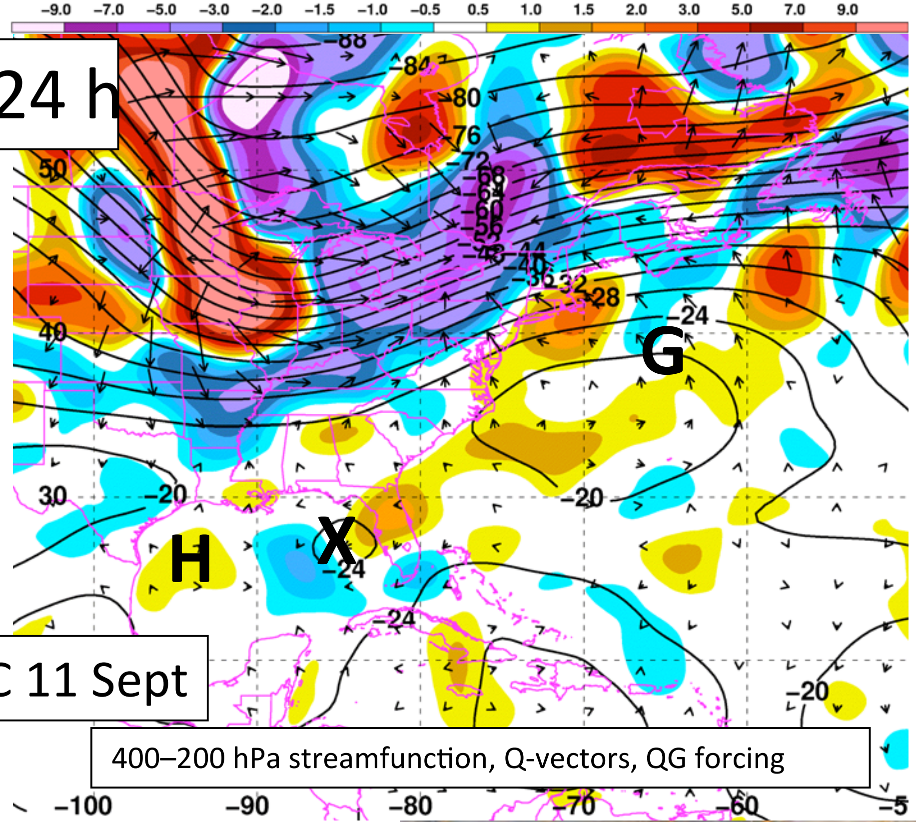
DT Analysis and QG Forcing

T–24 h



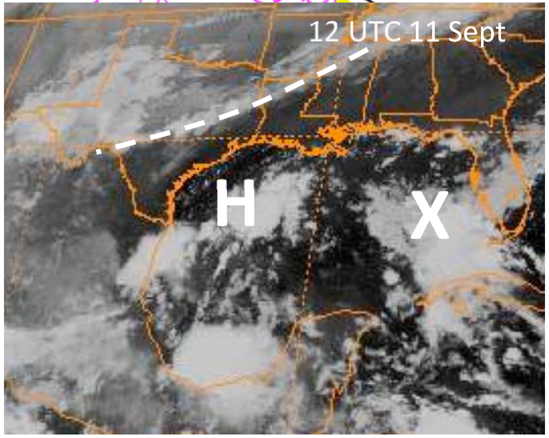
DT Pressure, DT–850 hPa shear, 925–850 ζ

12 UTC 11 Sept



400–200 hPa streamfunction, Q-vectors, QG forcing

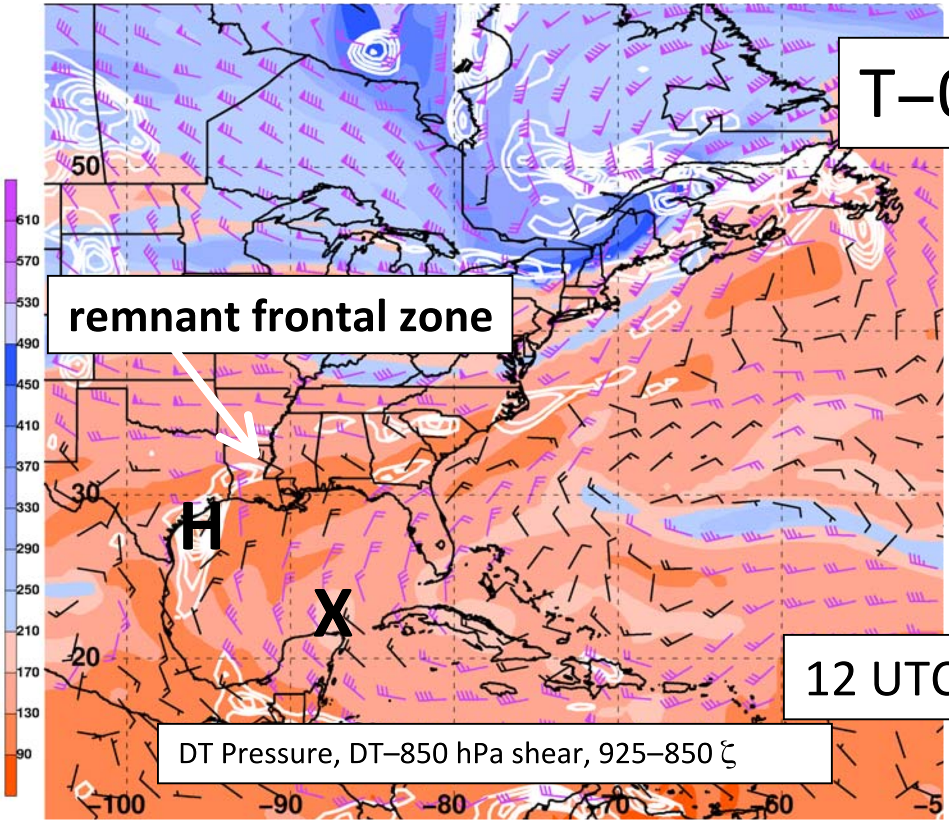
- Humberto vorticity in low deep-layer shear region in base of foldover ridge
- Shear reduced via barotropic PV interaction and momentum redistribution



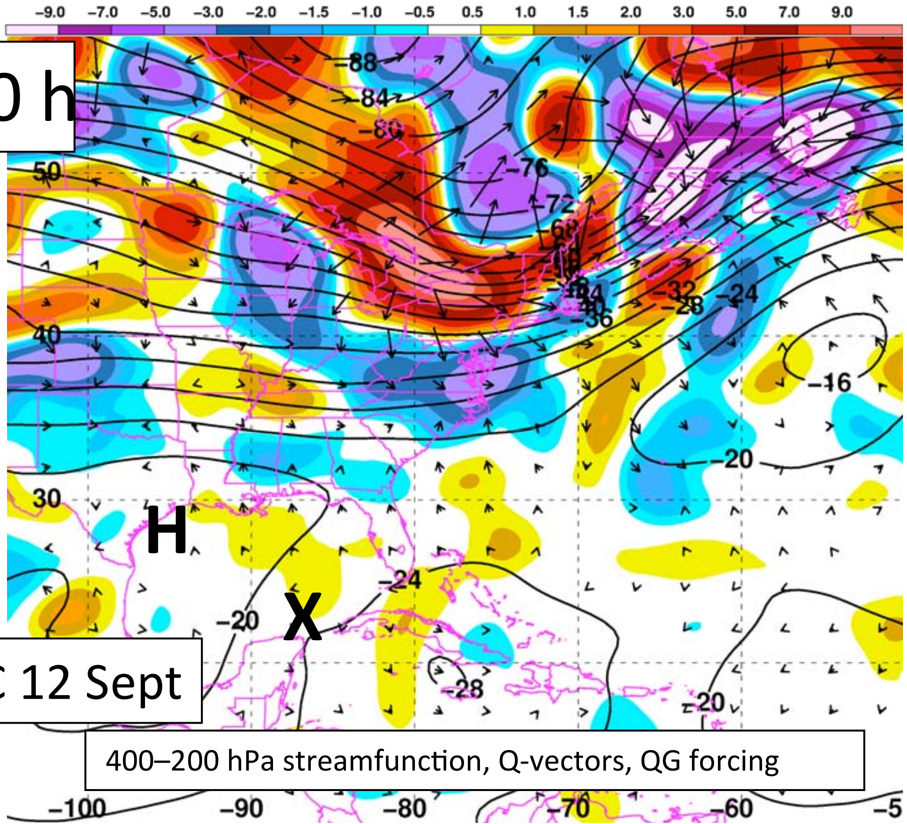
DT Analysis and QG Forcing

T–0 h

12 UTC 12 Sept

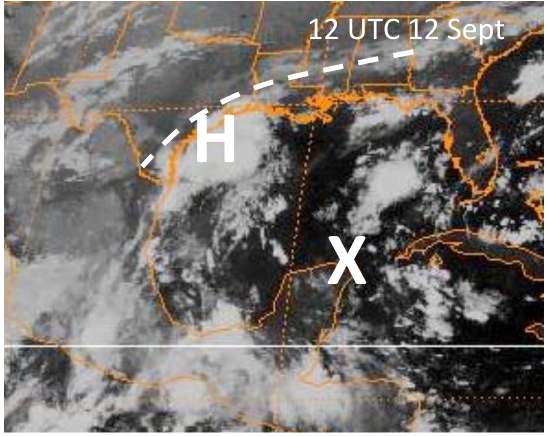


DT Pressure, DT–850 hPa shear, 925–850 ζ



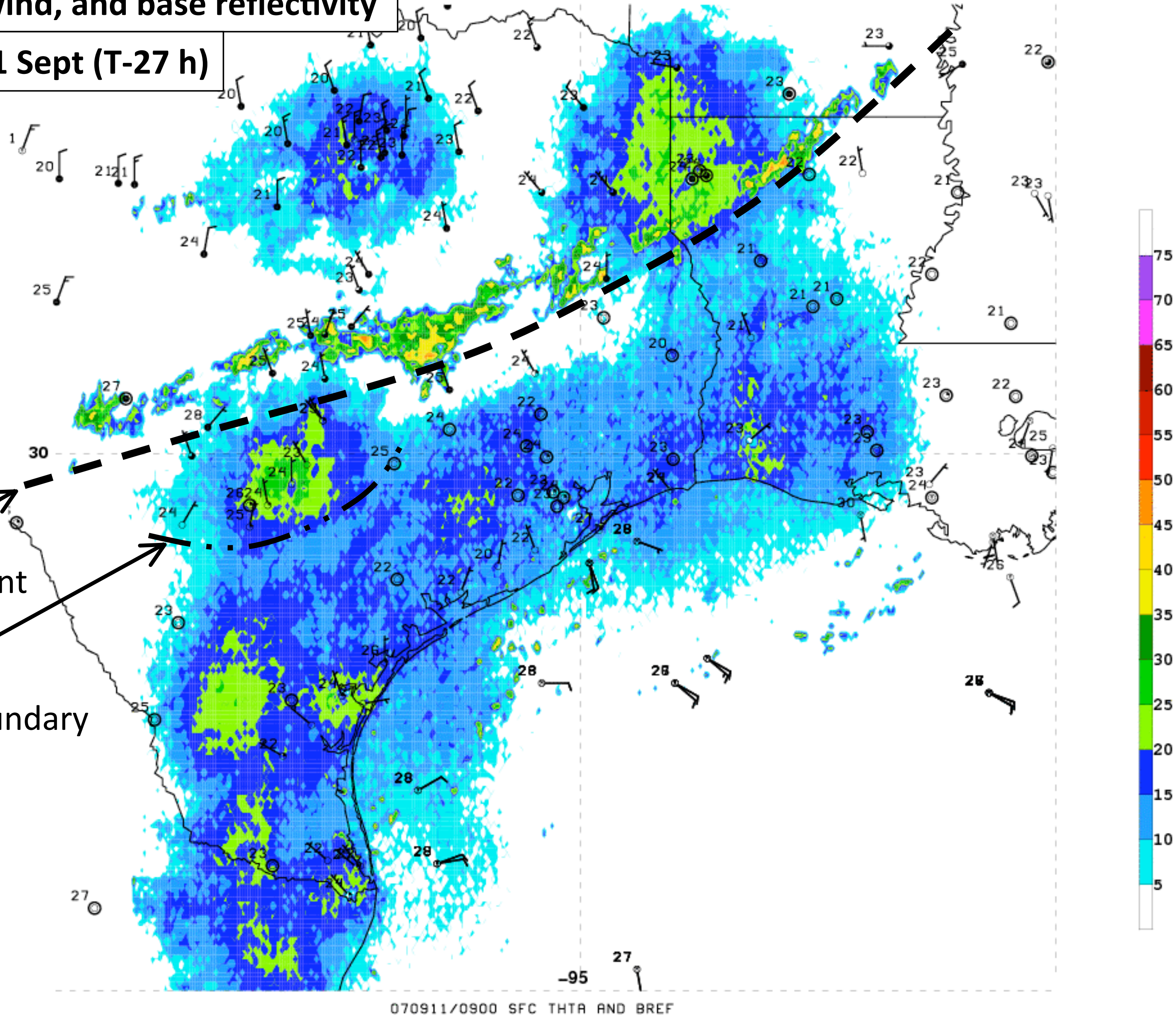
400–200 hPa streamfunction, Q-vectors, QG forcing

- Humberto rapidly intensifies to hurricane strength in weak deep-layer shear region in base of foldover ridge



Surface θ, wind, and base reflectivity

0900 UTC 11 Sept (T-27 h)

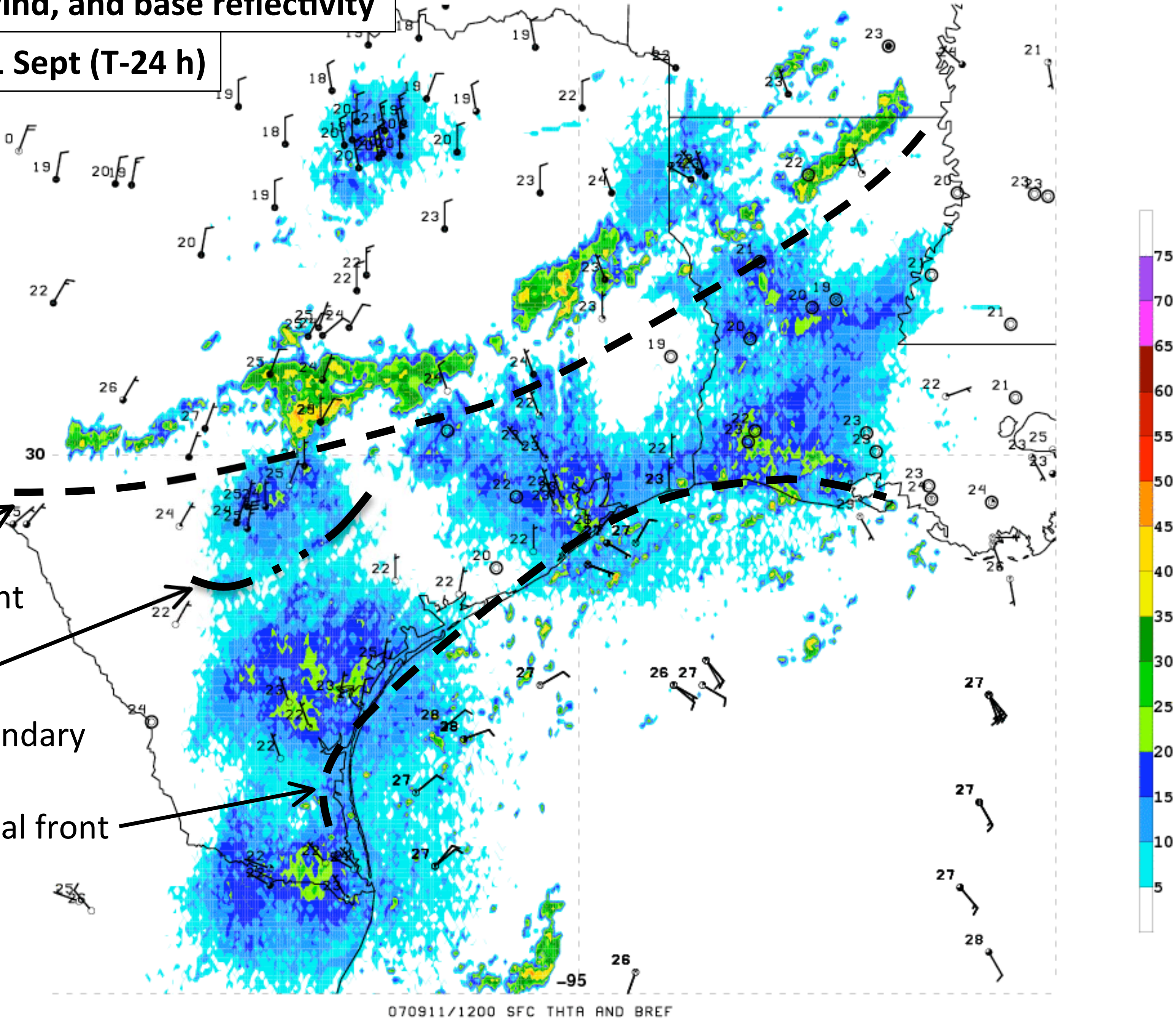


Synoptic front

Outflow boundary

Surface θ, wind, and base reflectivity

1200 UTC 11 Sept (T-24 h)



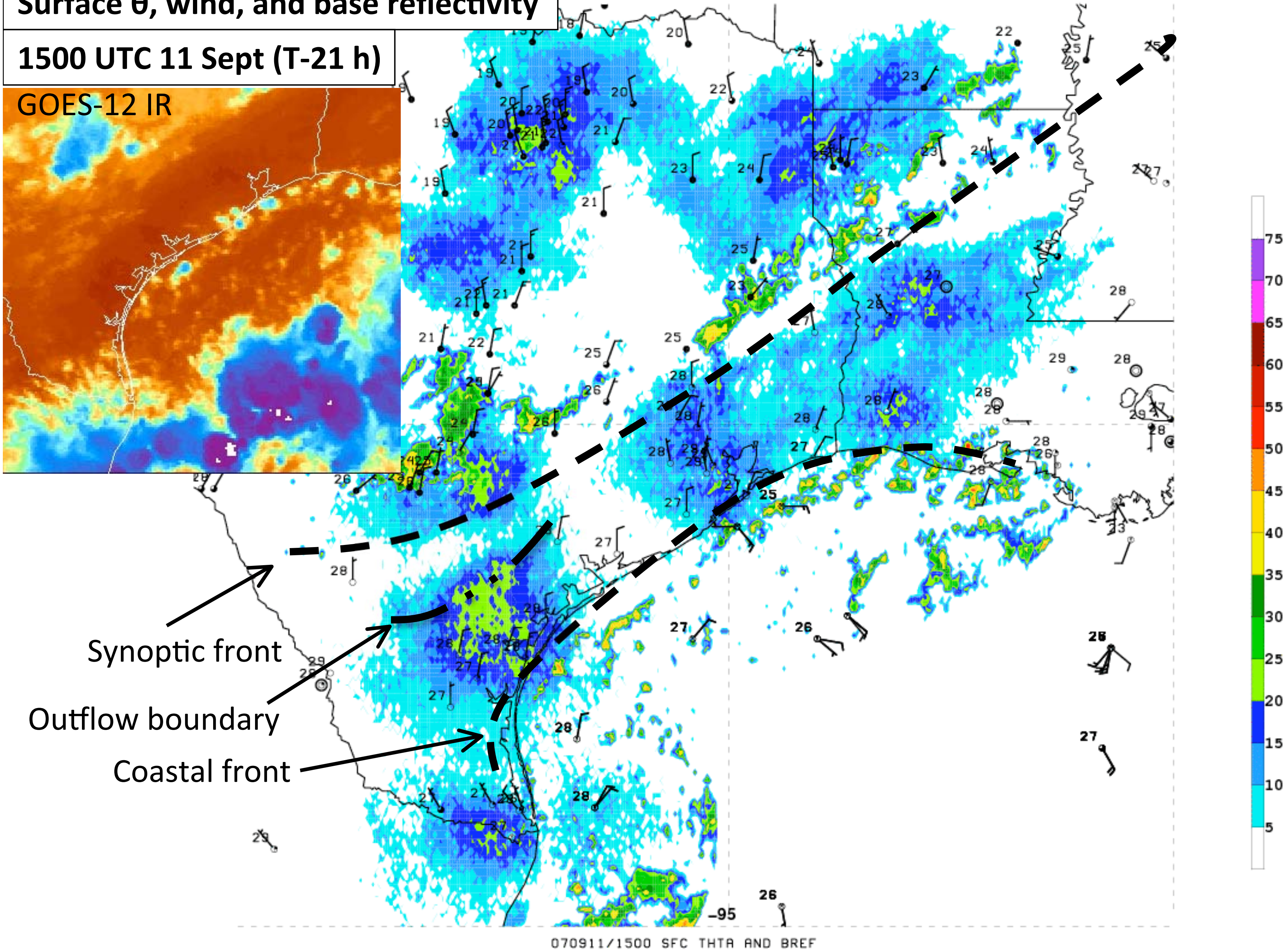
Synoptic front

Outflow boundary

Coastal front

Surface θ, wind, and base reflectivity

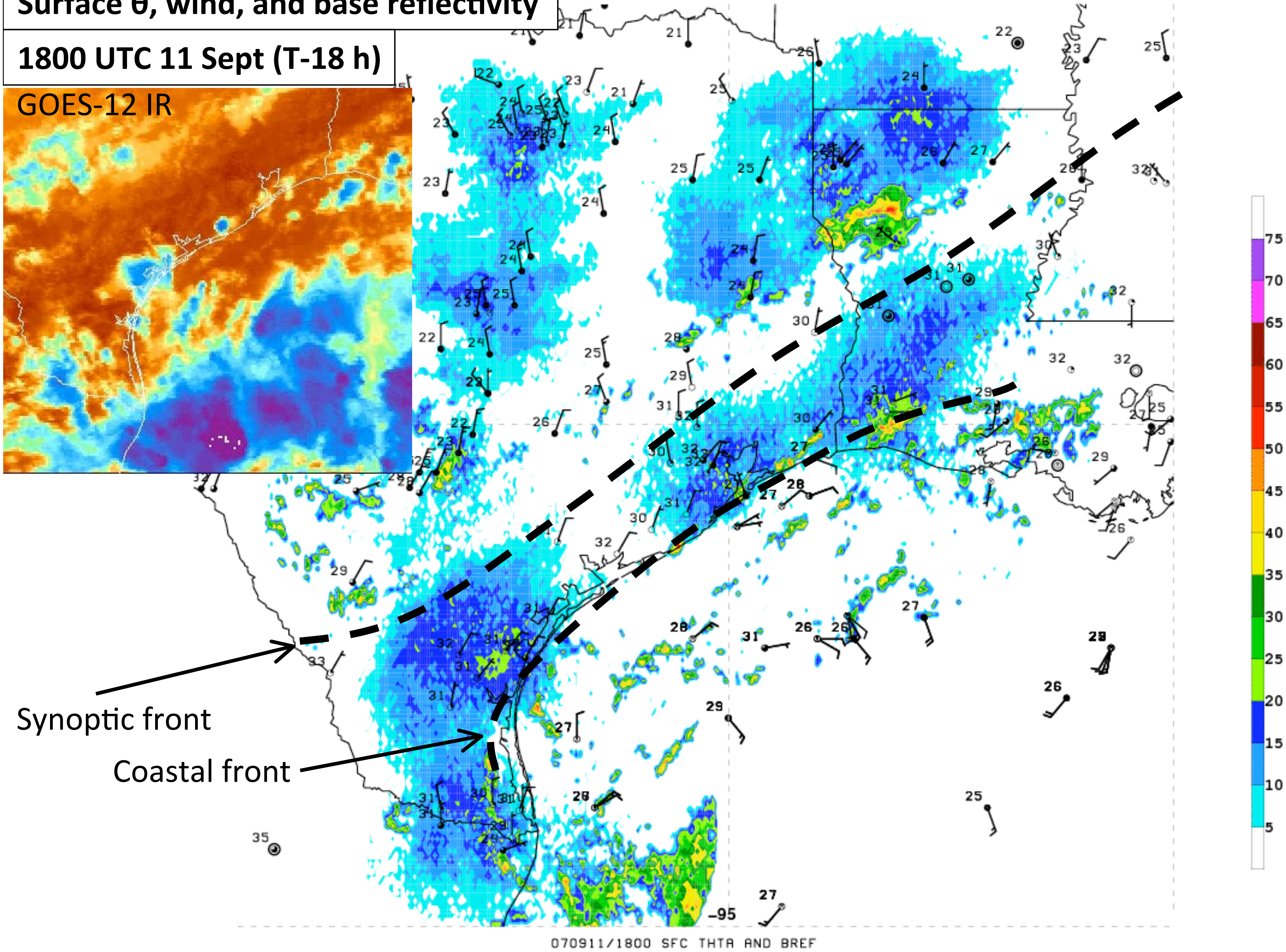
1500 UTC 11 Sept (T-21 h)



070911/1500 SFC THTA AND BREF

Surface θ, wind, and base reflectivity

1800 UTC 11 Sept (T-18 h)

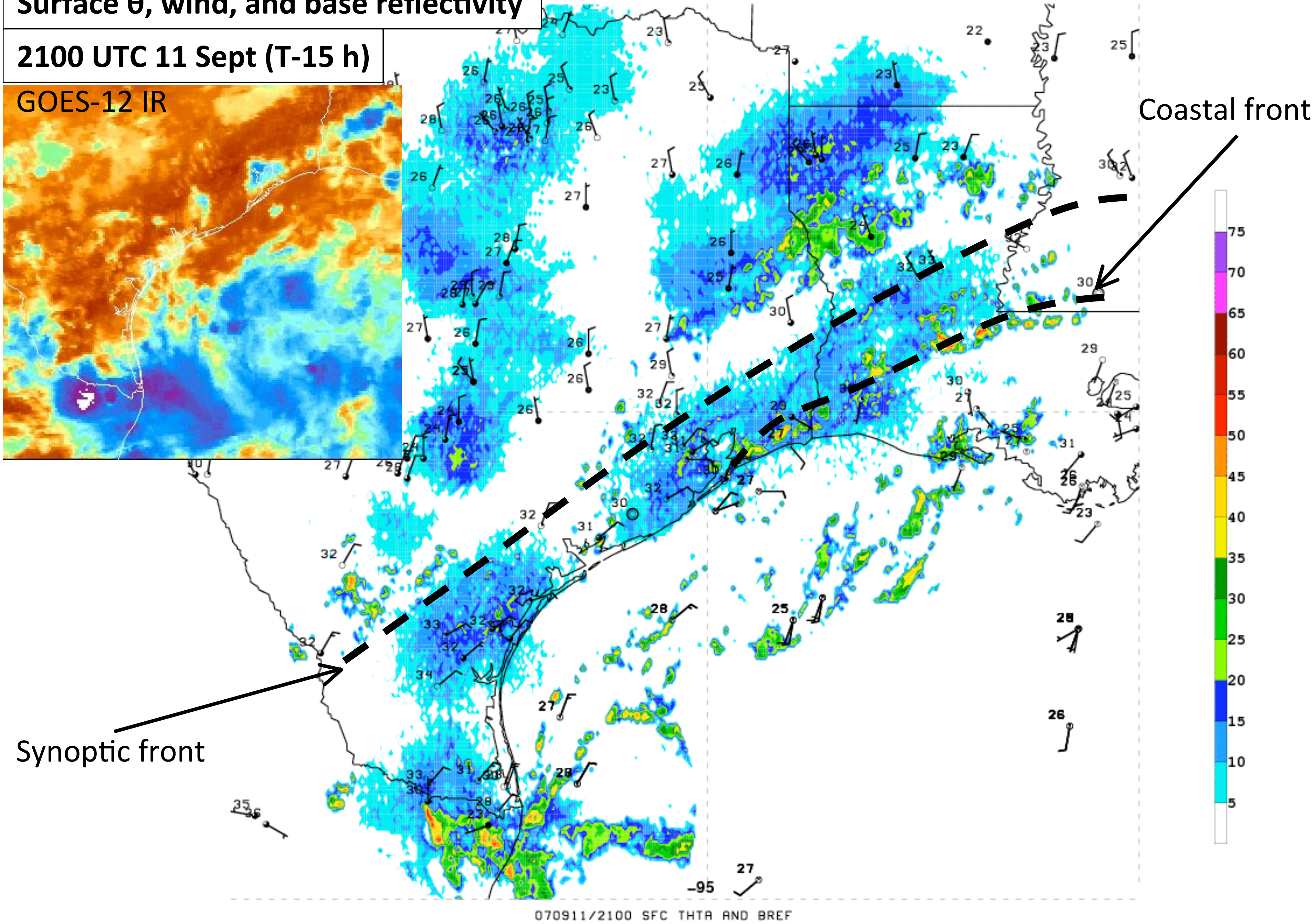


Synoptic front

Coastal front

Surface θ, wind, and base reflectivity

2100 UTC 11 Sept (T-15 h)

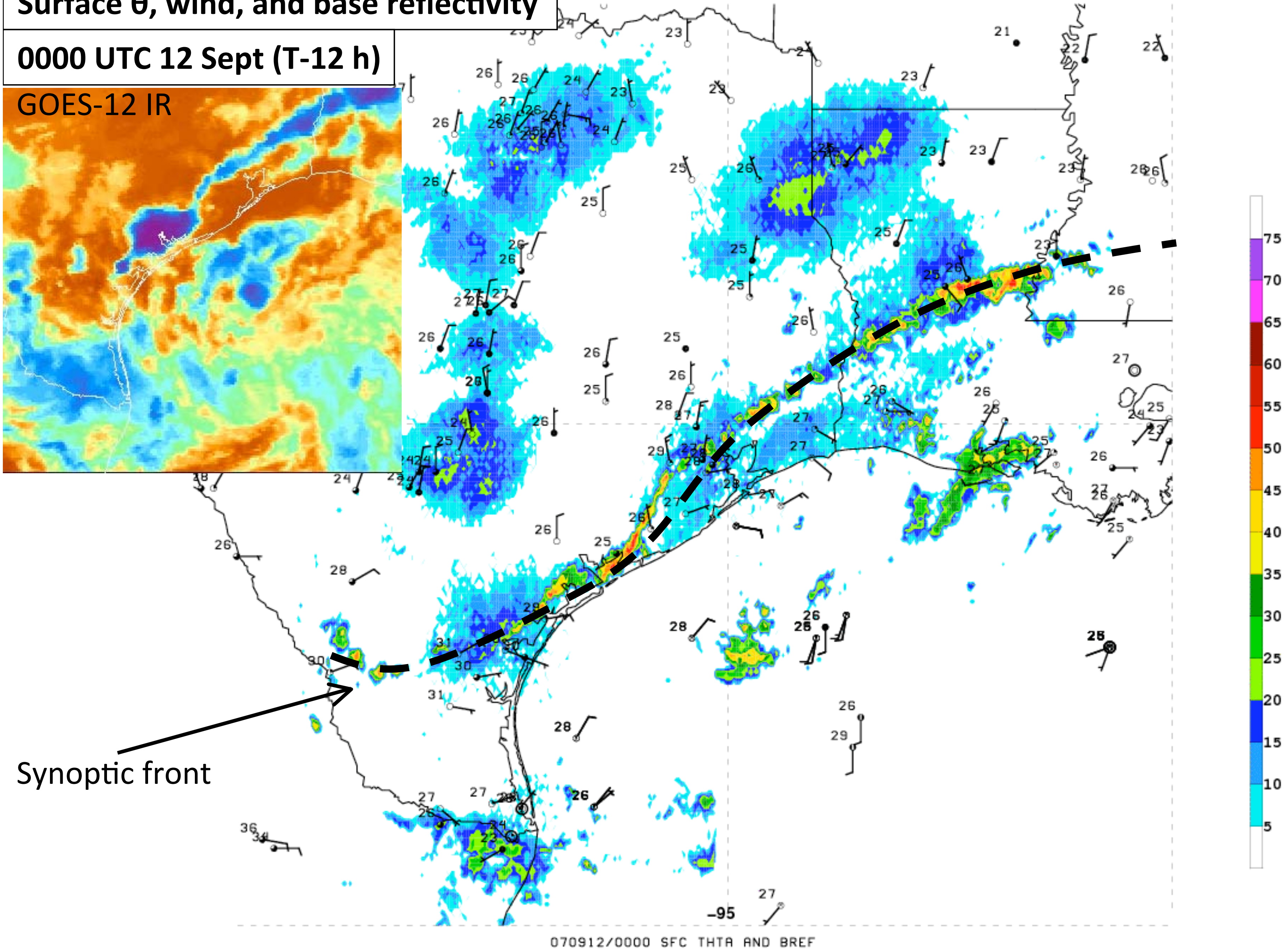


Coastal front

Synoptic front

Surface θ, wind, and base reflectivity

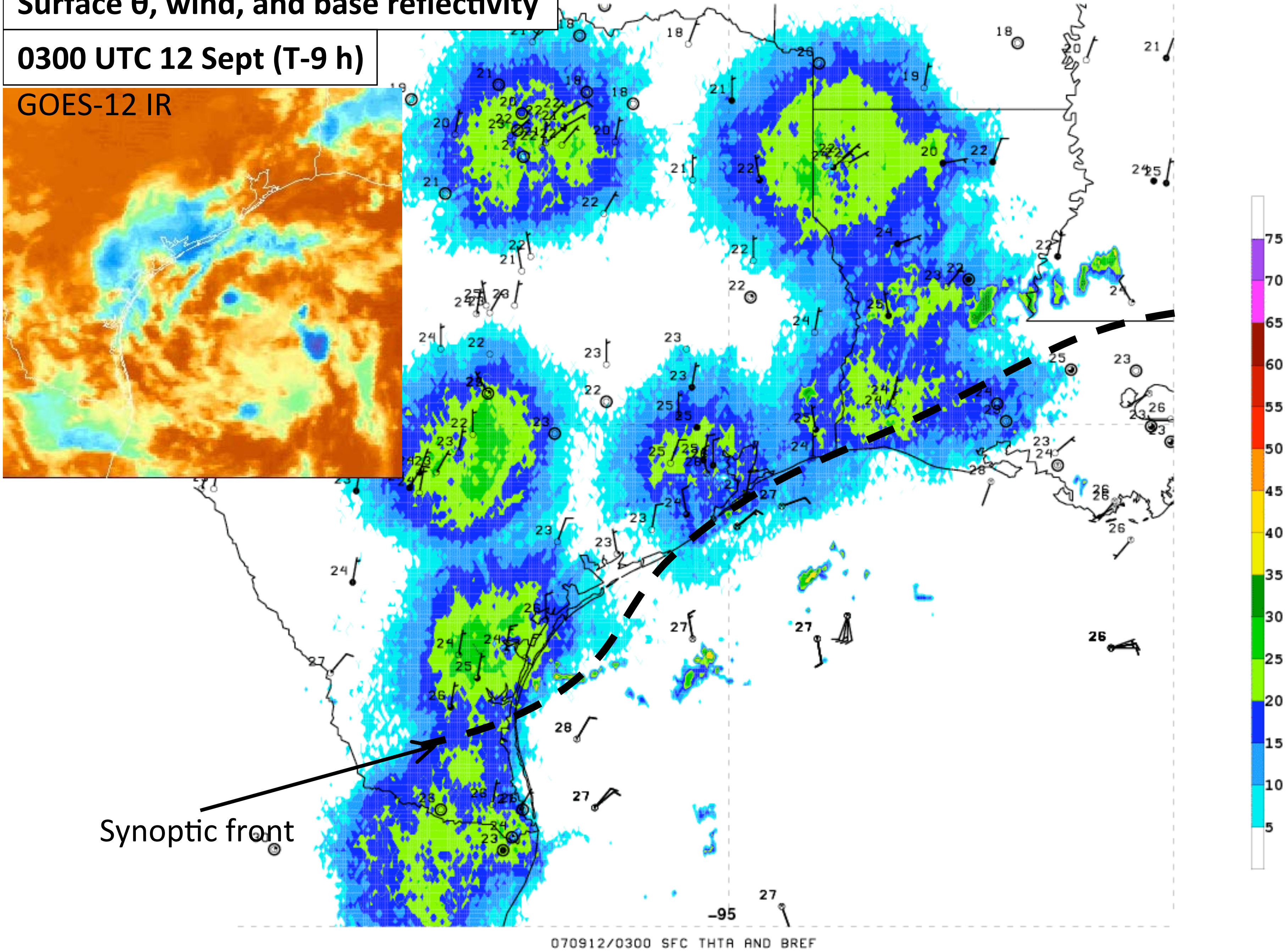
0000 UTC 12 Sept (T-12 h)



Synoptic front

Surface θ, wind, and base reflectivity

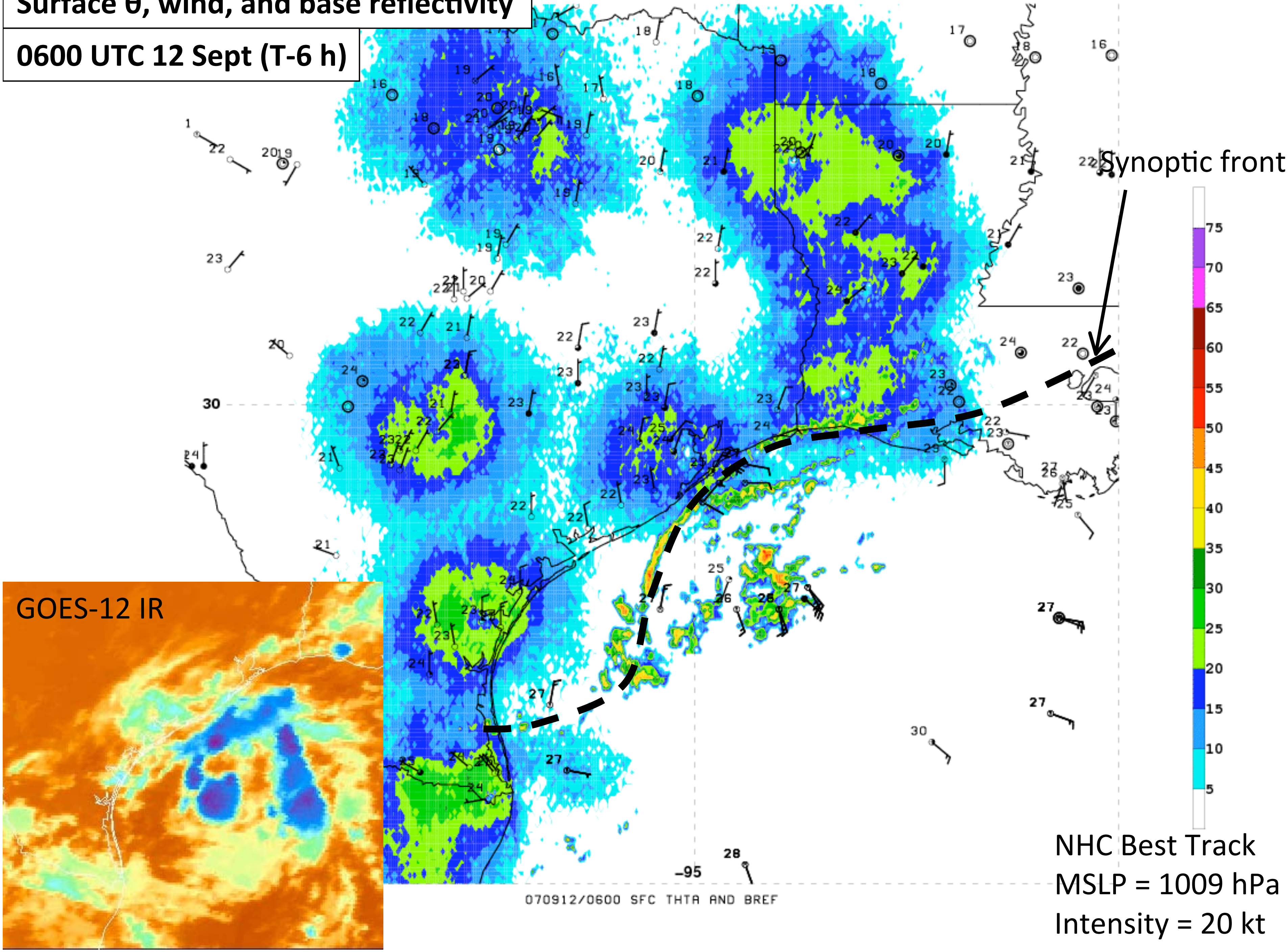
0300 UTC 12 Sept (T-9 h)



Synoptic front

Surface θ, wind, and base reflectivity

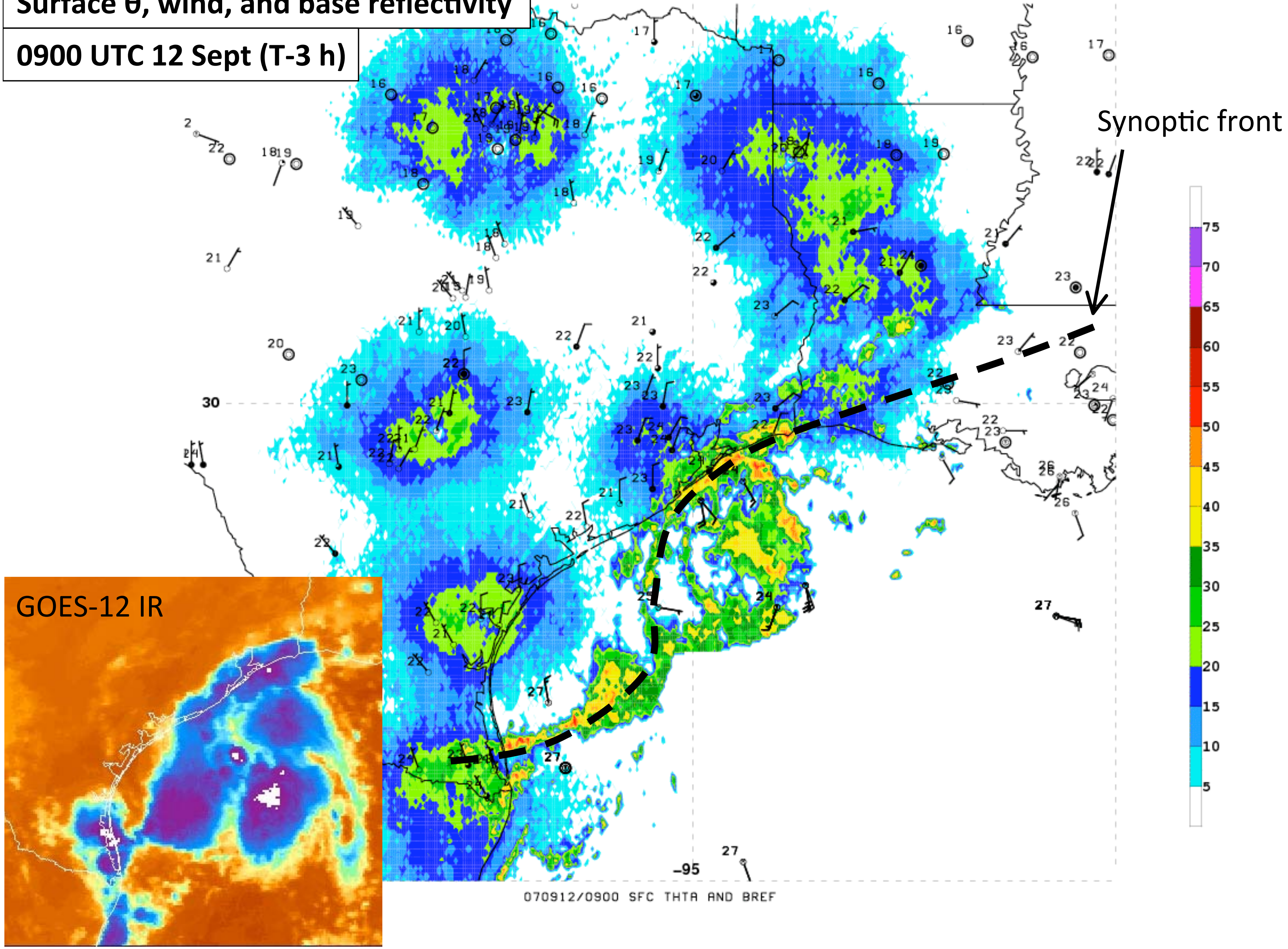
0600 UTC 12 Sept (T-6 h)



NHC Best Track
MSLP = 1009 hPa
Intensity = 20 kt

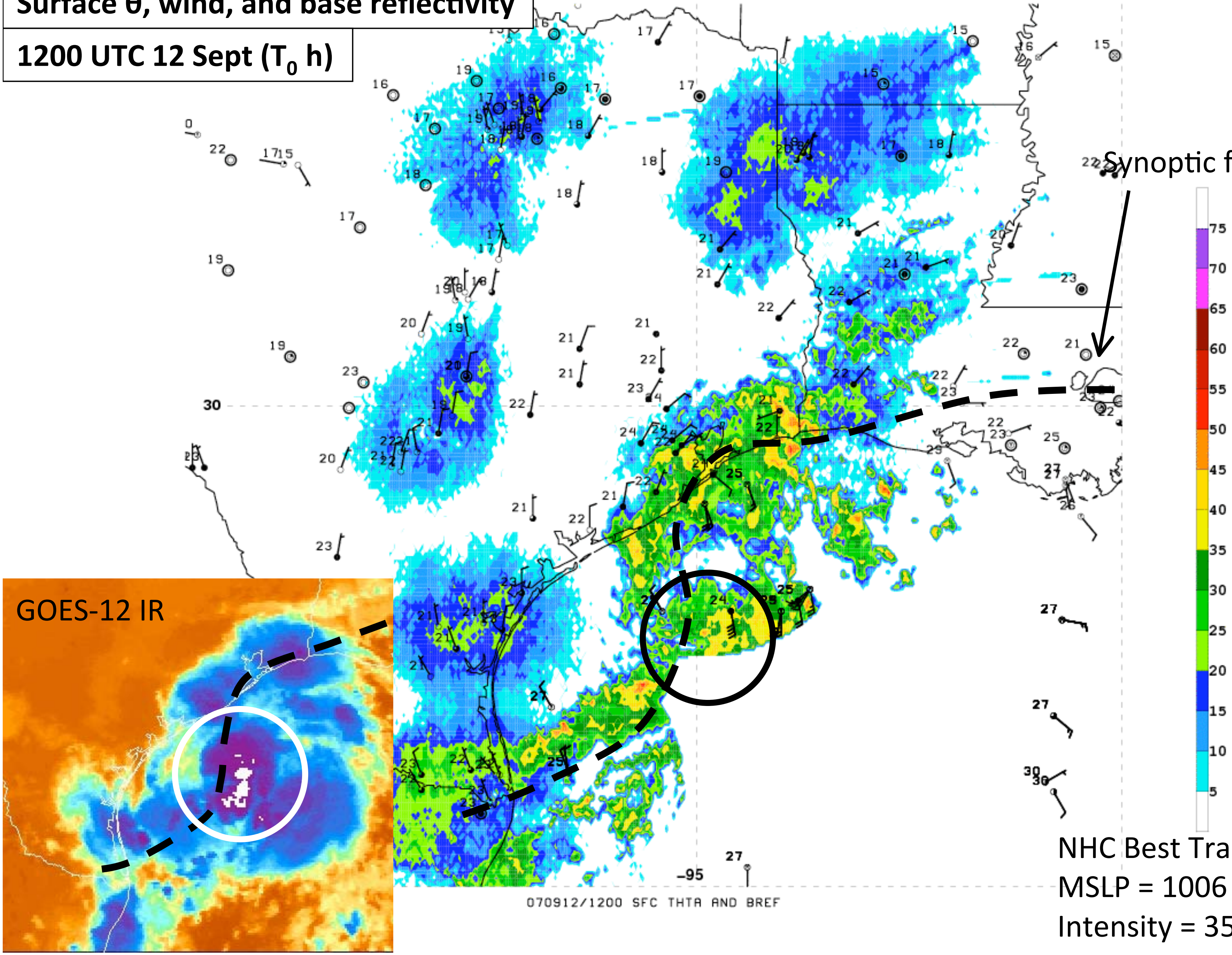
Surface θ, wind, and base reflectivity

0900 UTC 12 Sept (T-3 h)



Surface θ, wind, and base reflectivity

1200 UTC 12 Sept (T_0 h)

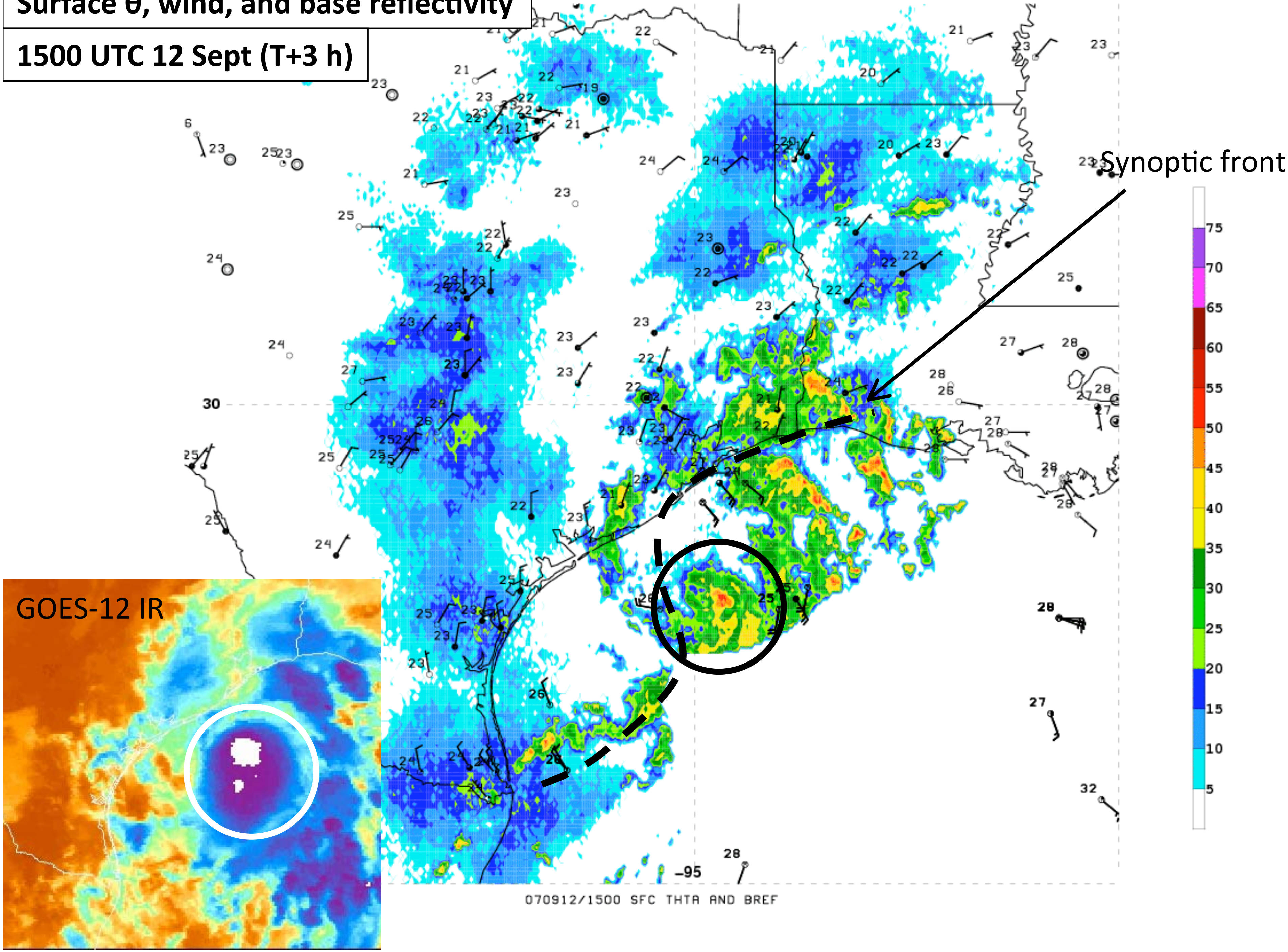


Synoptic front

NHC Best Track
MSLP = 1006 hPa
Intensity = 35 kt

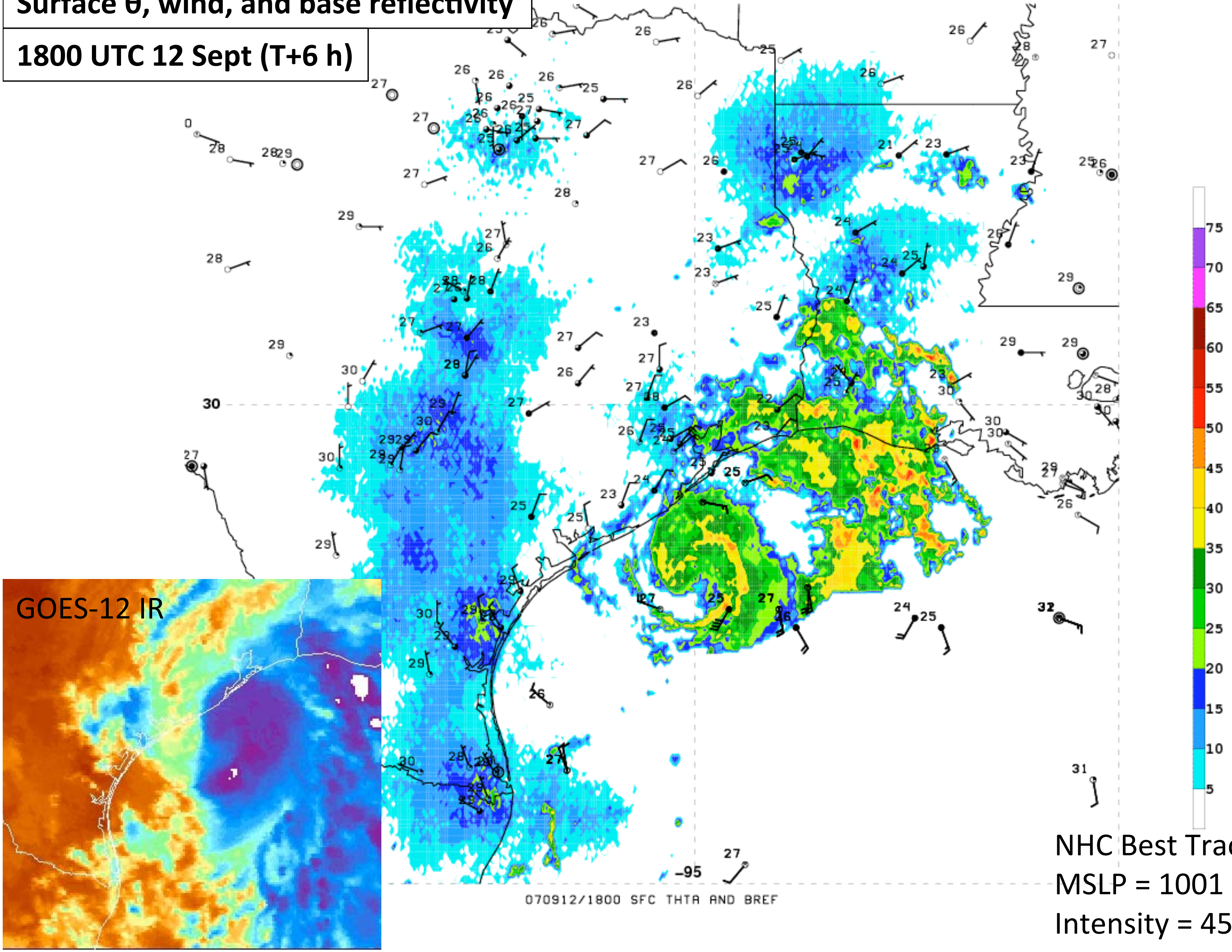
Surface θ, wind, and base reflectivity

1500 UTC 12 Sept (T+3 h)



Surface θ, wind, and base reflectivity

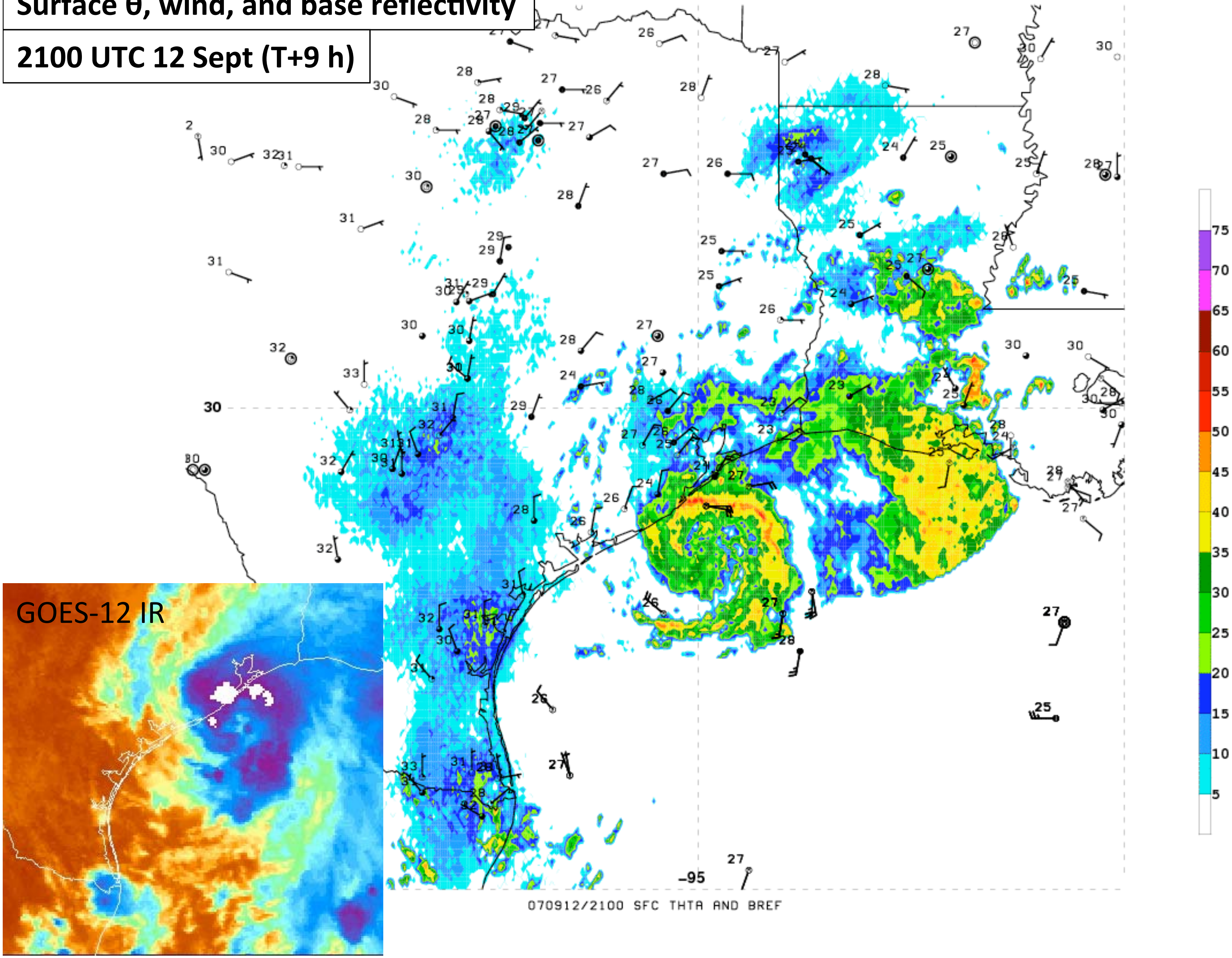
1800 UTC 12 Sept (T+6 h)



NHC Best Track
MSLP = 1001 hPa
Intensity = 45 kt

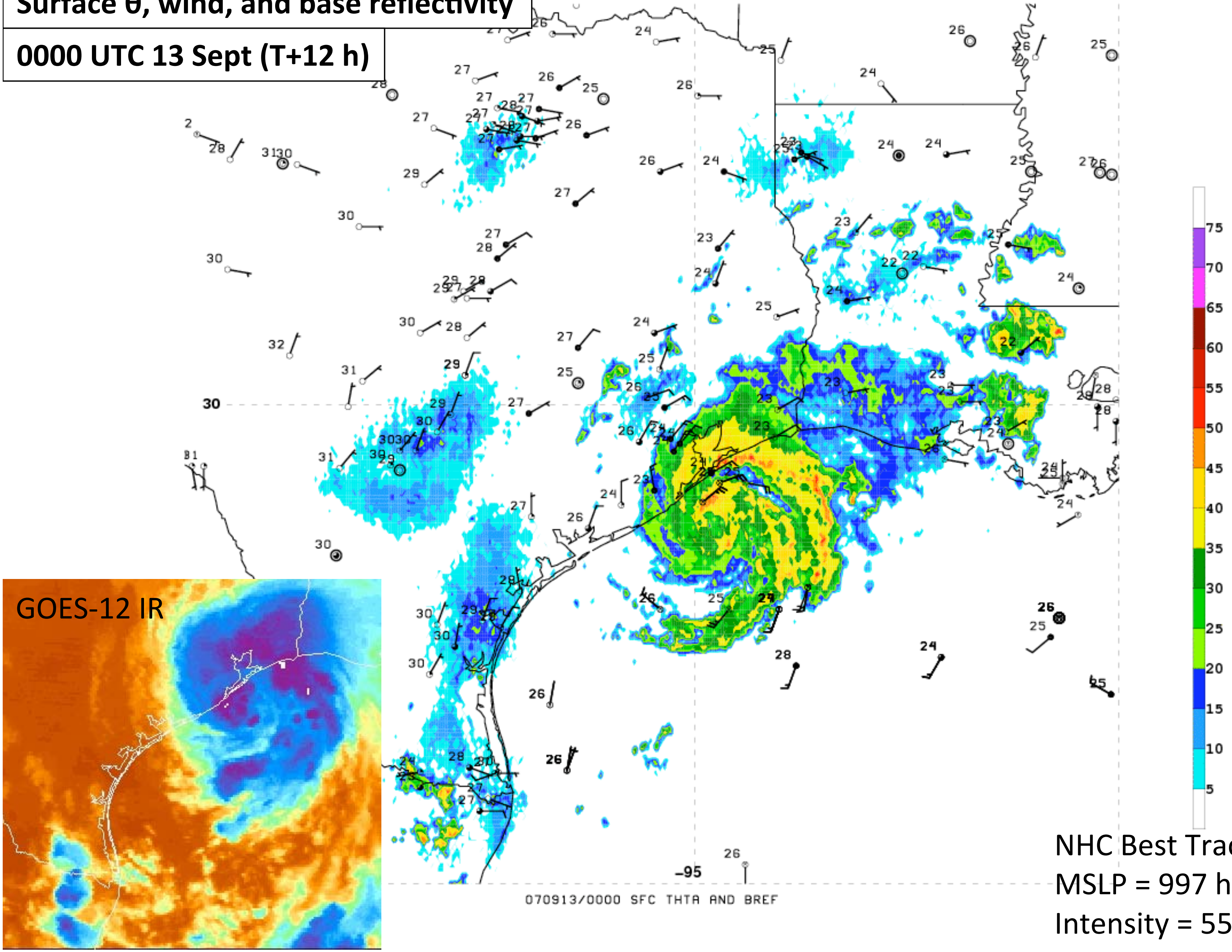
Surface θ, wind, and base reflectivity

2100 UTC 12 Sept (T+9 h)



Surface θ, wind, and base reflectivity

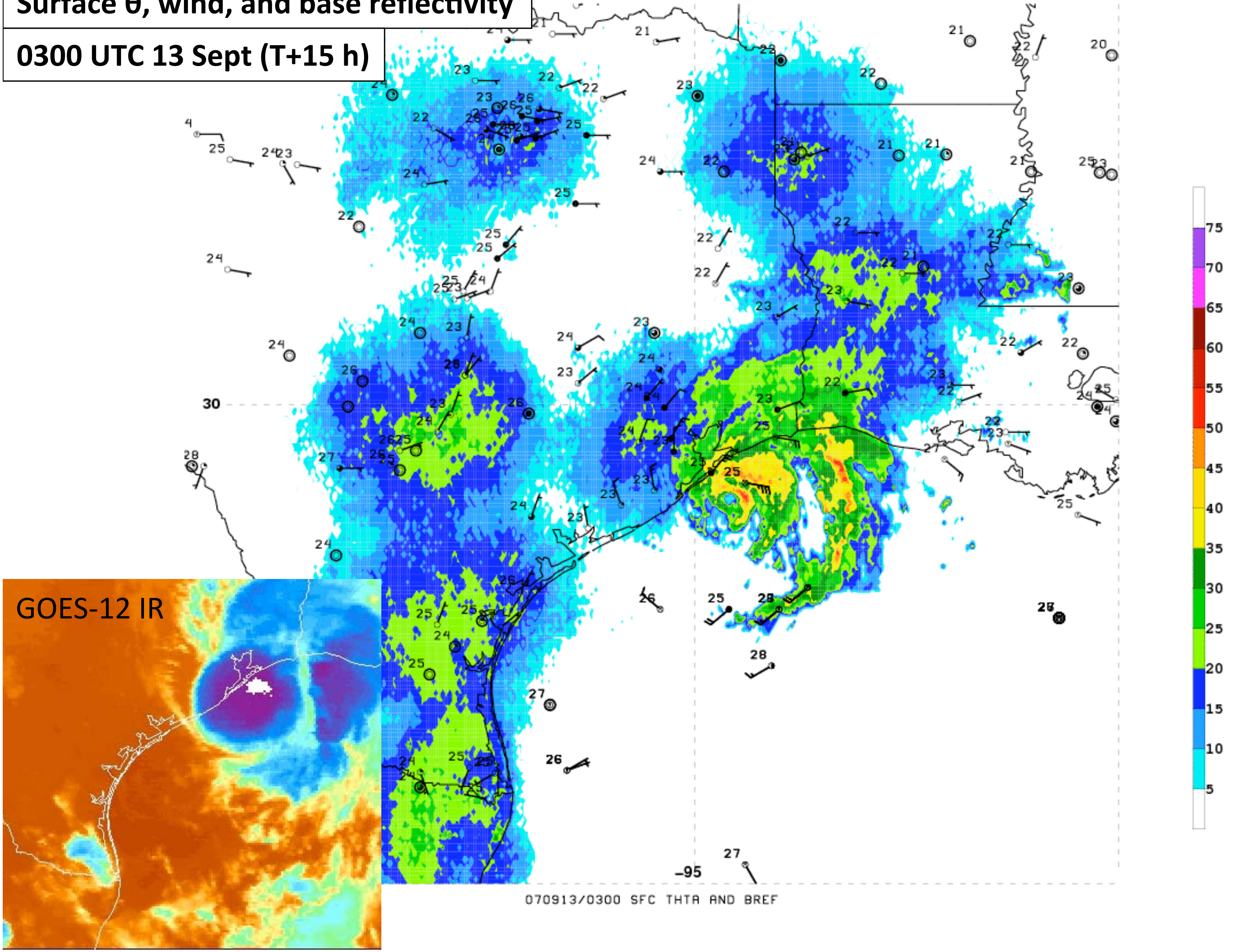
0000 UTC 13 Sept (T+12 h)



NHC Best Track
MSLP = 997 hPa
Intensity = 55 kt

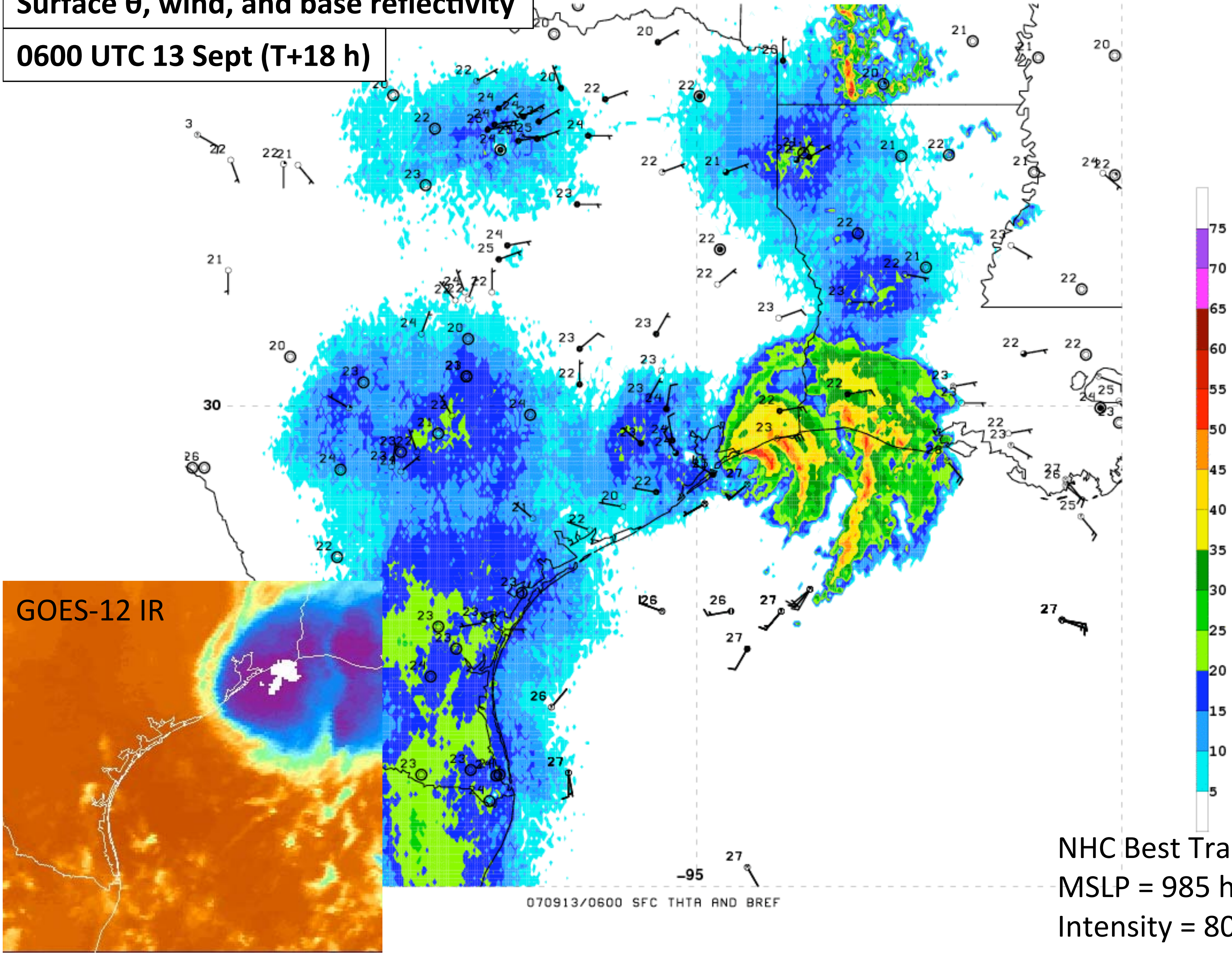
Surface θ, wind, and base reflectivity

0300 UTC 13 Sept (T+15 h)



Surface θ, wind, and base reflectivity

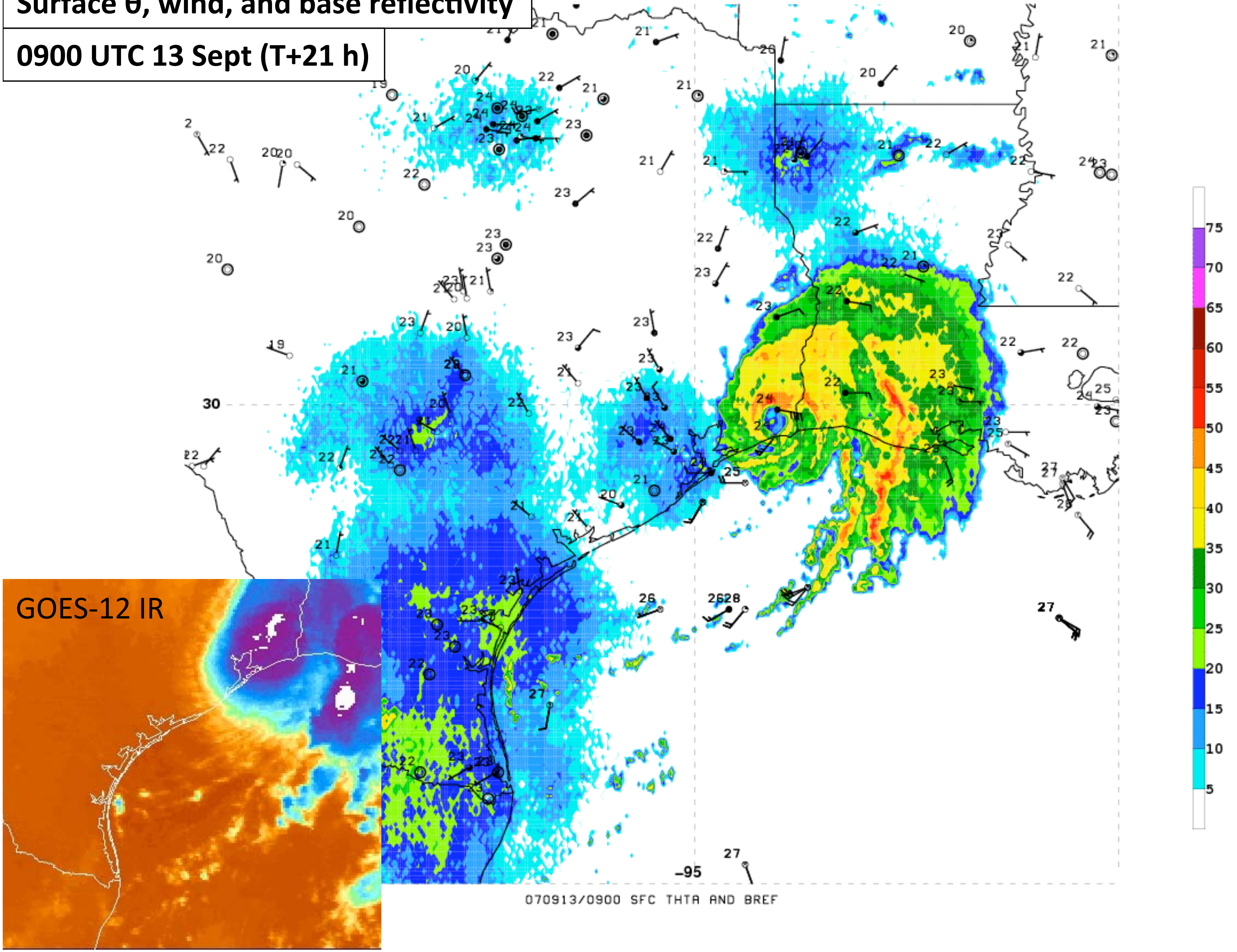
0600 UTC 13 Sept (T+18 h)



NHC Best Track
MSLP = 985 hPa
Intensity = 80 kt

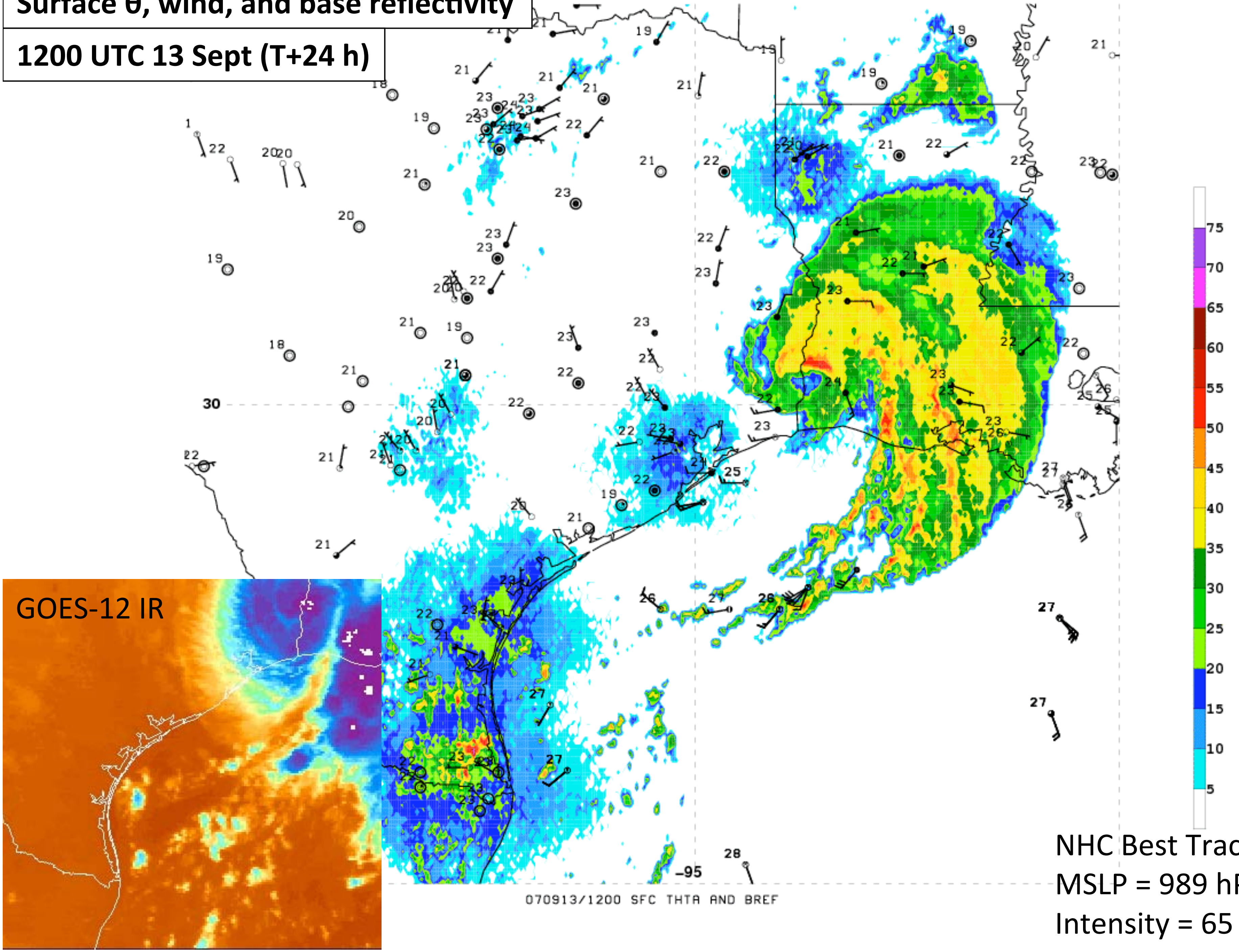
Surface θ, wind, and base reflectivity

0900 UTC 13 Sept (T+21 h)



Surface θ, wind, and base reflectivity

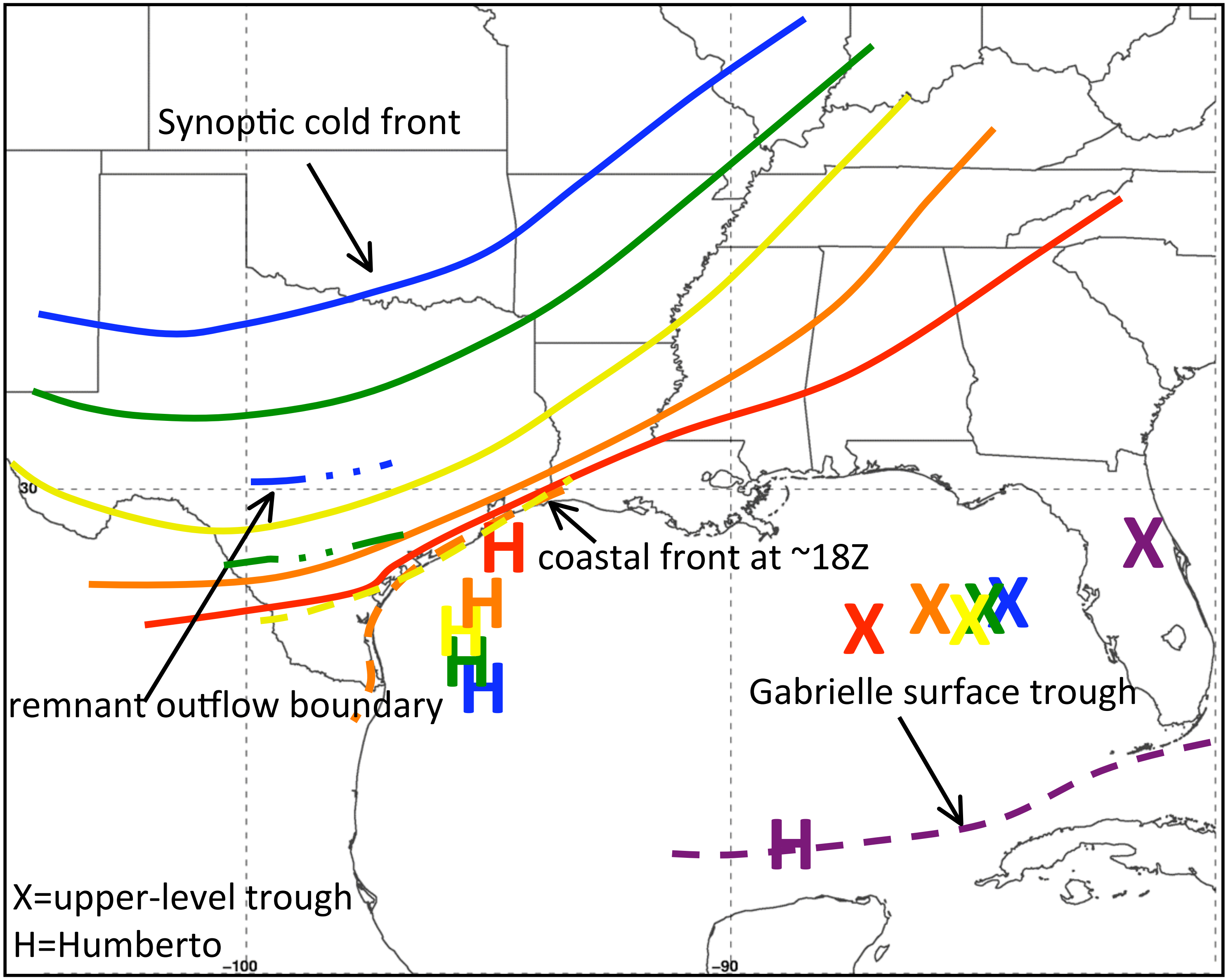
1200 UTC 13 Sept (T+24 h)



NHC Best Track
MSLP = 989 hPa
Intensity = 65 kt

Frontal Continuity Map

00Z/09
00Z/11
06Z/11
12Z/11
18Z/11
00Z/12



Synoptic cold front

coastal front at ~18Z

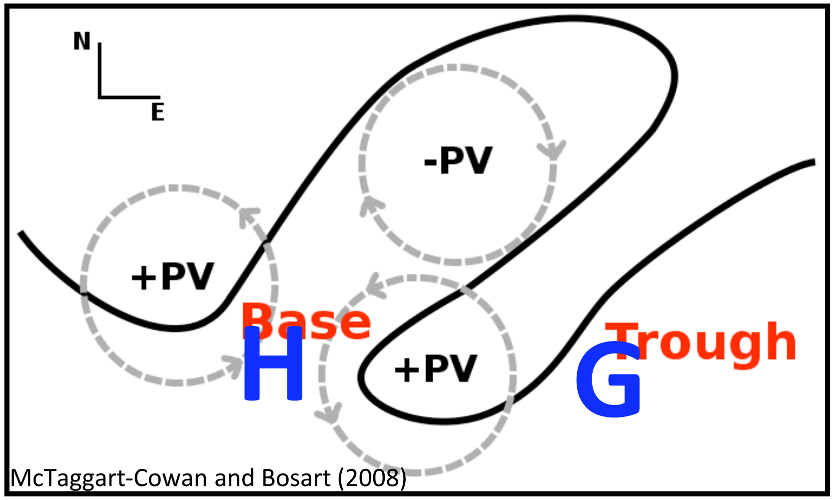
remnant outflow boundary

Gabrielle surface trough

X=upper-level trough
H=Humberto

Case Study Summary: Synoptic-scale

- TT of Gabrielle and Humberto occurred on equatorward flank of a low-level baroclinic zone and upper-level PV streamer
- The southwest end of the Gabrielle PV streamer fractured during genesis, subsequently moved southwestward, and triggered incipient Humberto
- Humberto moved into weak deep-layer wind shear region in base of the foldover ridge, west of the Gabrielle PV anomaly
- Humberto subsequently rapidly organized via TT along new synoptic front near TX coast in reduced shear region



McTaggart-Cowan and Bosart (2008)

Case Study Summary: Mesoscale

- Synoptic surface front and convective outflow boundary merged with developing coastal front along the TX coast by 18Z/11
- Deep moist convection organized along the synoptic front and within the incipient Humberto circulation as Humberto interacted with the front on 12 September
- A small-scale intense vortex formed along the southwestern flank of the coastal front near the western part of Humberto's broad cyclonic circulation, leading to genesis by 12Z/12
- The small-scale vortex grew upscale and rapidly intensified to 80 kt by 06Z/13 September just prior to landfall