A New Dynamic-based Metric to Explore the Time and Intensity of Extratropical Transition of Tropical Cyclones

32nd Conference on Hurricanes and Tropical Meteorology, San Juan, PR

Tropical Extratropical Interactions II

by

Ajay Raghavendra and Shawn M. Milrad

Embry-Riddle Aeronautical University

Daytona Beach, FL

Extratropical Transition (ET) Often Results In

- Re-intensification
- Wind Field Expansion
  (Widespread tropical-storm force winds or greater e.g. Jones et al. 2003; Milrad et al. 2009)
- Precipitation Distribution Shifts Left of Track
- Inland Flash Flooding
  (Away from the cyclone center)

ET Forecasting Challenges and Issues with Existing ET Metrics

- Fails to account for static stability
  (Important to determine the magnitude of precipitation)
- Relies at least partially on internal tropical cyclone structure
  (Numerical models show less skill e.g. Kofron et al. 2010a,b)

We Propose

- A coupled dynamic-thermodynamic approach
- A focus on environmental flow characteristics, not TC structure

Dataset

- NCEP - Climate Forecast System Reanalysis (CFSR)
  (Modern, global, high resolution (0.5°) and reliable precipitation)
- HURDAT2 for TC Cyclone Phase Space Track
  (Hart 2003)

Photo credit: Paul Sisson, NWS Burlington, VT

Presentation Outline

- **Eady Moist Baroclinic Growth Rate (EMBGR) Metric**
- **Example Left Of Center (LOC) Case: IKE 2008**
- **Example Right Of Center (ROC) Case: LILI 2002**
- **Grid Centered Composite Technique**
- **LOC Composite**
- **ROC Composite**
- **Discussion and Conclusions**
- **References**
- **Acknowledgements**

Derivation of Eady Moist Baroclinic Growth Rate (EMBGR)

$$\sigma_{BI} = 0.31\, f\, \frac{\partial \vec{v}}{\partial z} N^{-1}$$

Eady Baroclinic Growth Rate
Eady 1949 and Hoskins and Valdes 1990

$$N_m^2 = \frac{g}{T}\left(\frac{dT}{dz} + \Gamma_m\right)$$

Moist Brunt-Vaisala Frequency (N_m)
Durran and Klemp 1982

$$EMBGR = 0.31\, f\, \frac{\partial v}{\partial z} N_m^{-1}$$

Eady Moist Baroclinic Growth Rate (EMBGR)

Advantages

- Objective evaluation of baroclinicity while also incorporating thermodynamics
- Accounts for moisture
- Relies on environmental flow characteristics and not tropical cyclone structure

(Relatively Well Forecast) (Difficult to Forecast)

Moist Absolute Unstable Layer (MAUL)

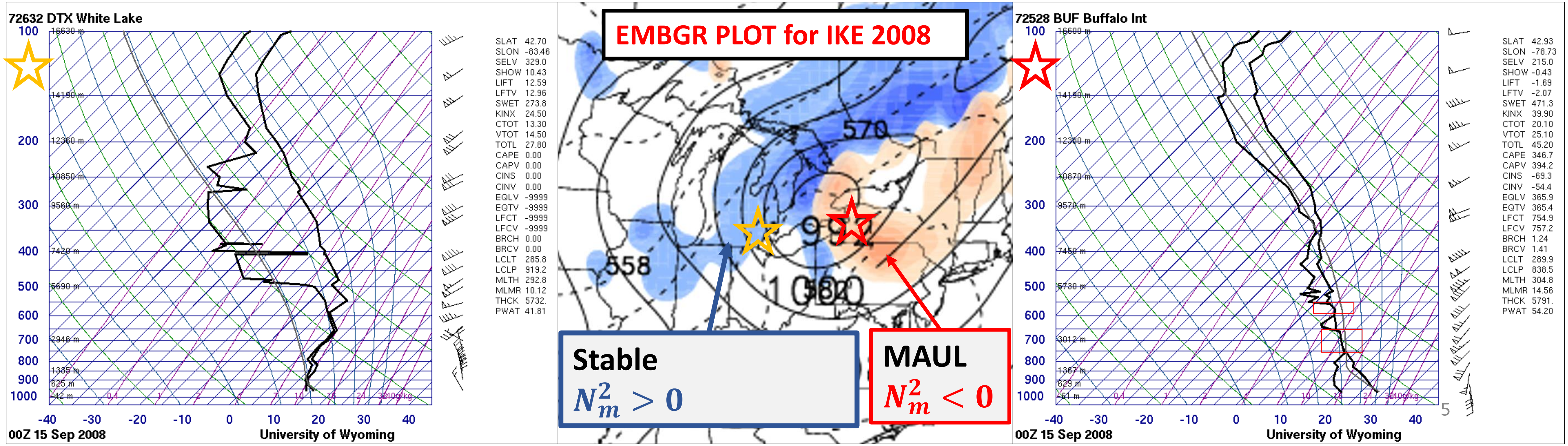
Bryan and Fritsch 2000

$$N_m^2 = \frac{g}{T}\left(\frac{dT}{dz} + \Gamma_m\right)$$

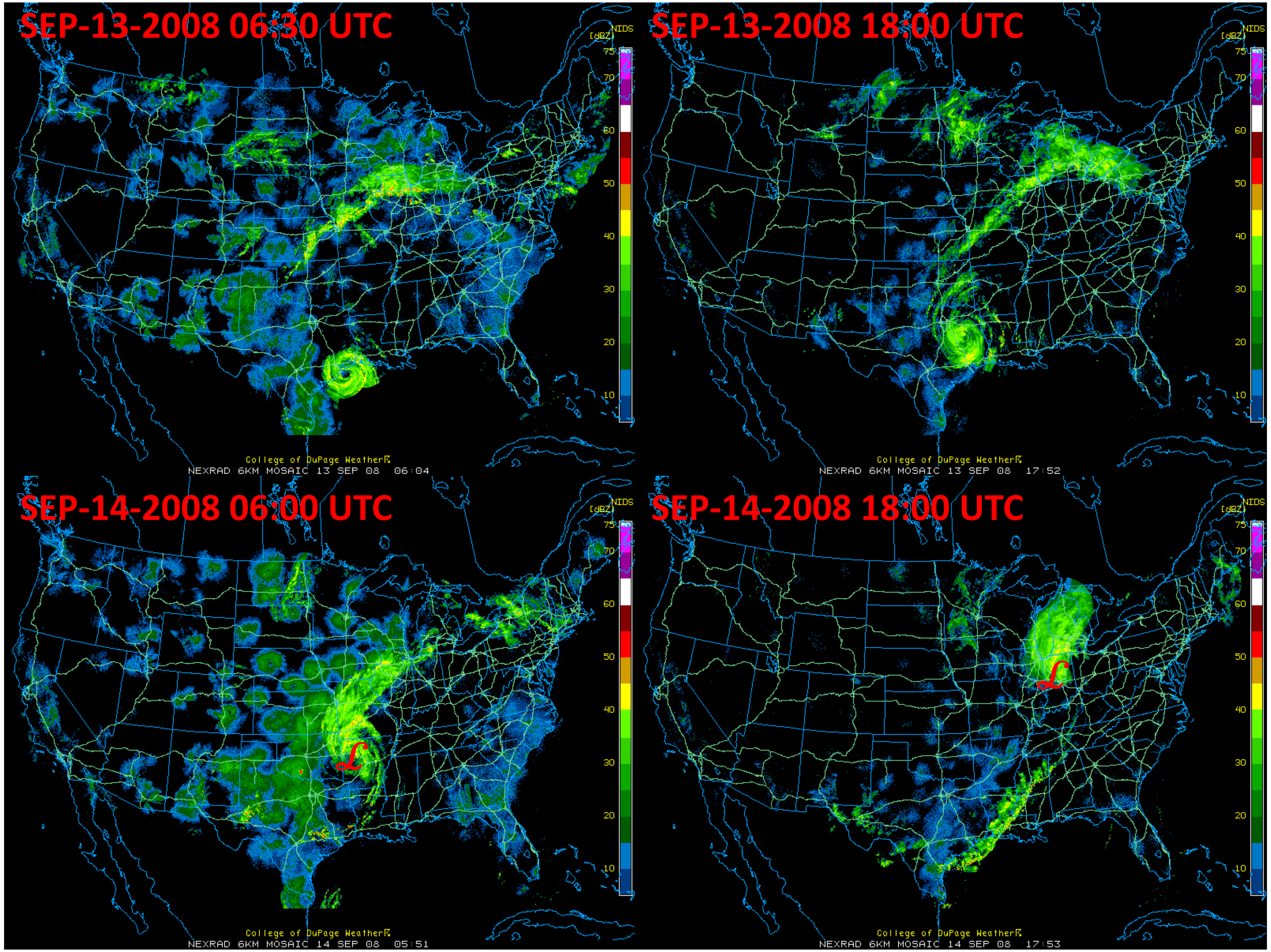
Moist adiabatic lapse rate $\Gamma_m \sim 6\,\frac{°C}{km}$ in the lower to middle troposphere.

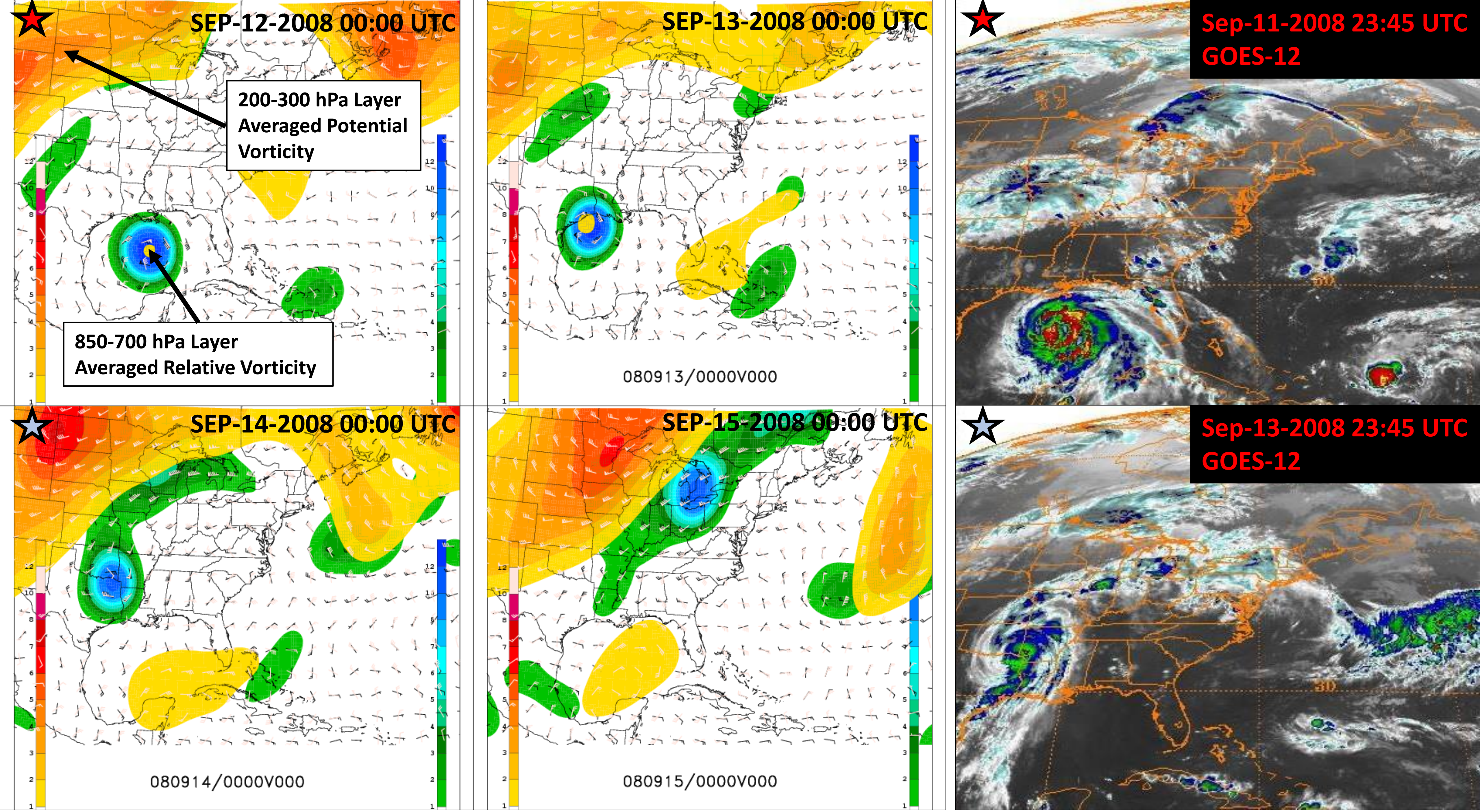
$N_m^2 < 0$ if $\frac{dT}{dz} > \Gamma_m$ i.e. Saturated environmental lapse rate is greater then the moist adiabatic lapse rate.

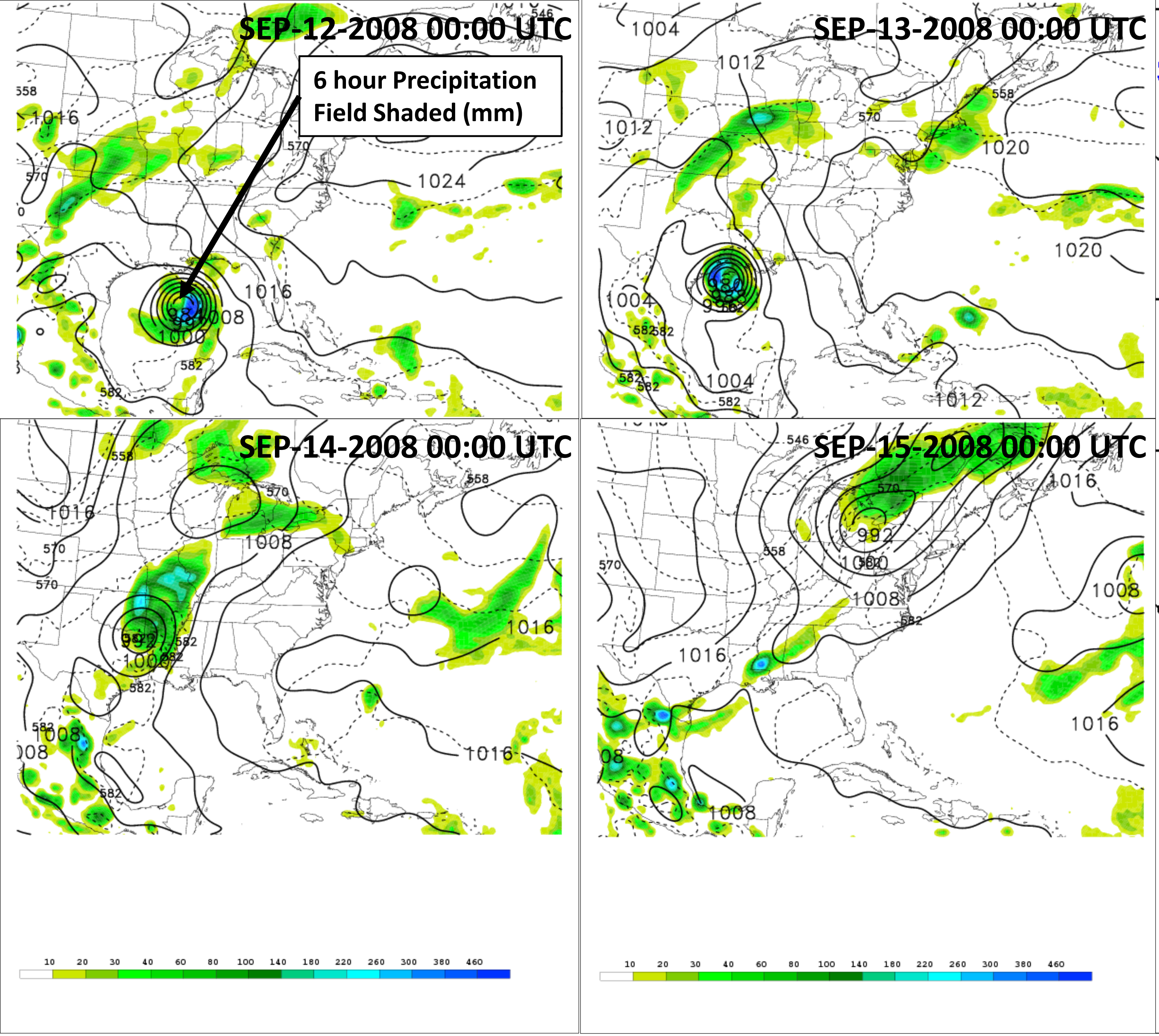
(Tropical Cyclone/mid-latitude cyclones are usually associated with a saturated environment)

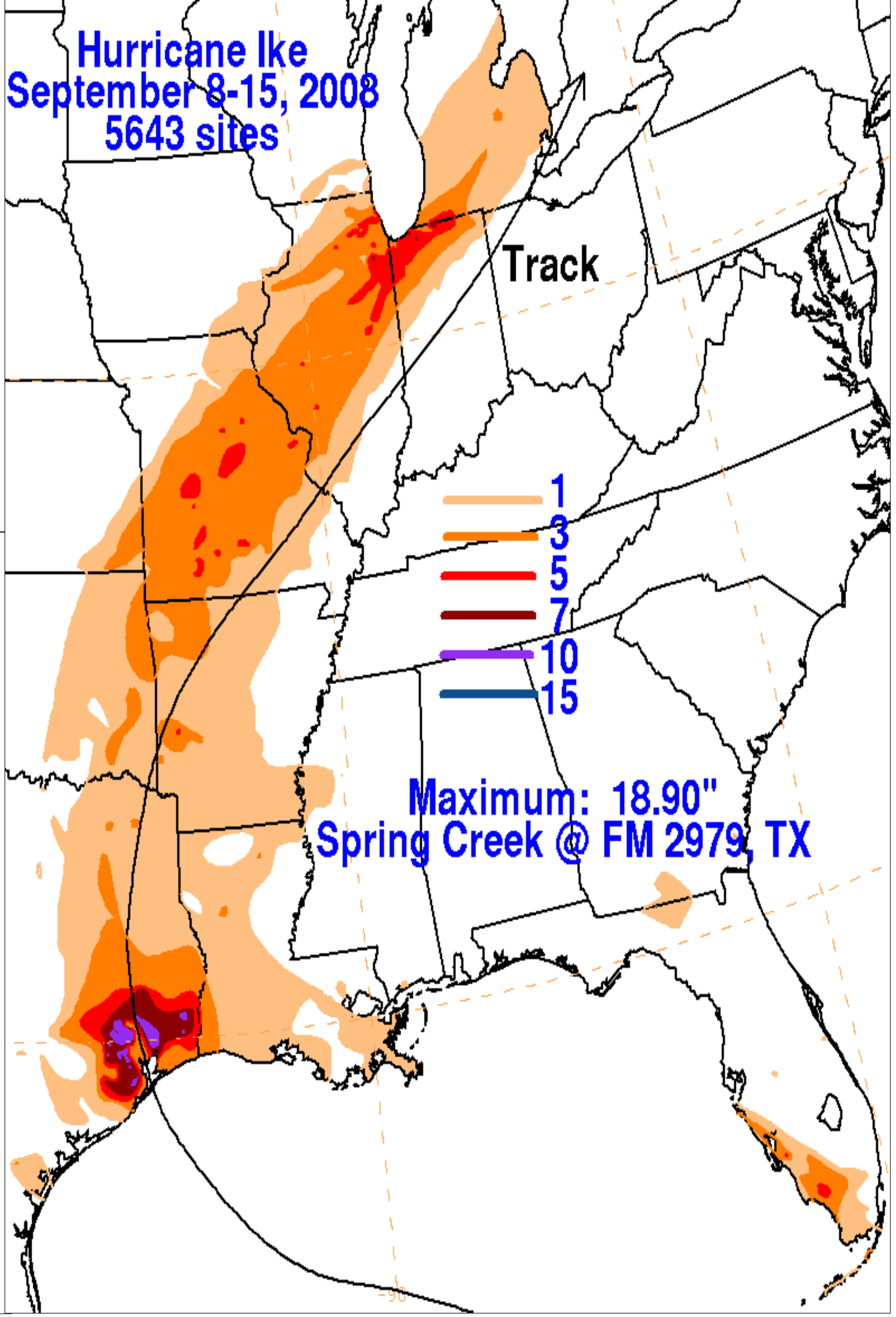


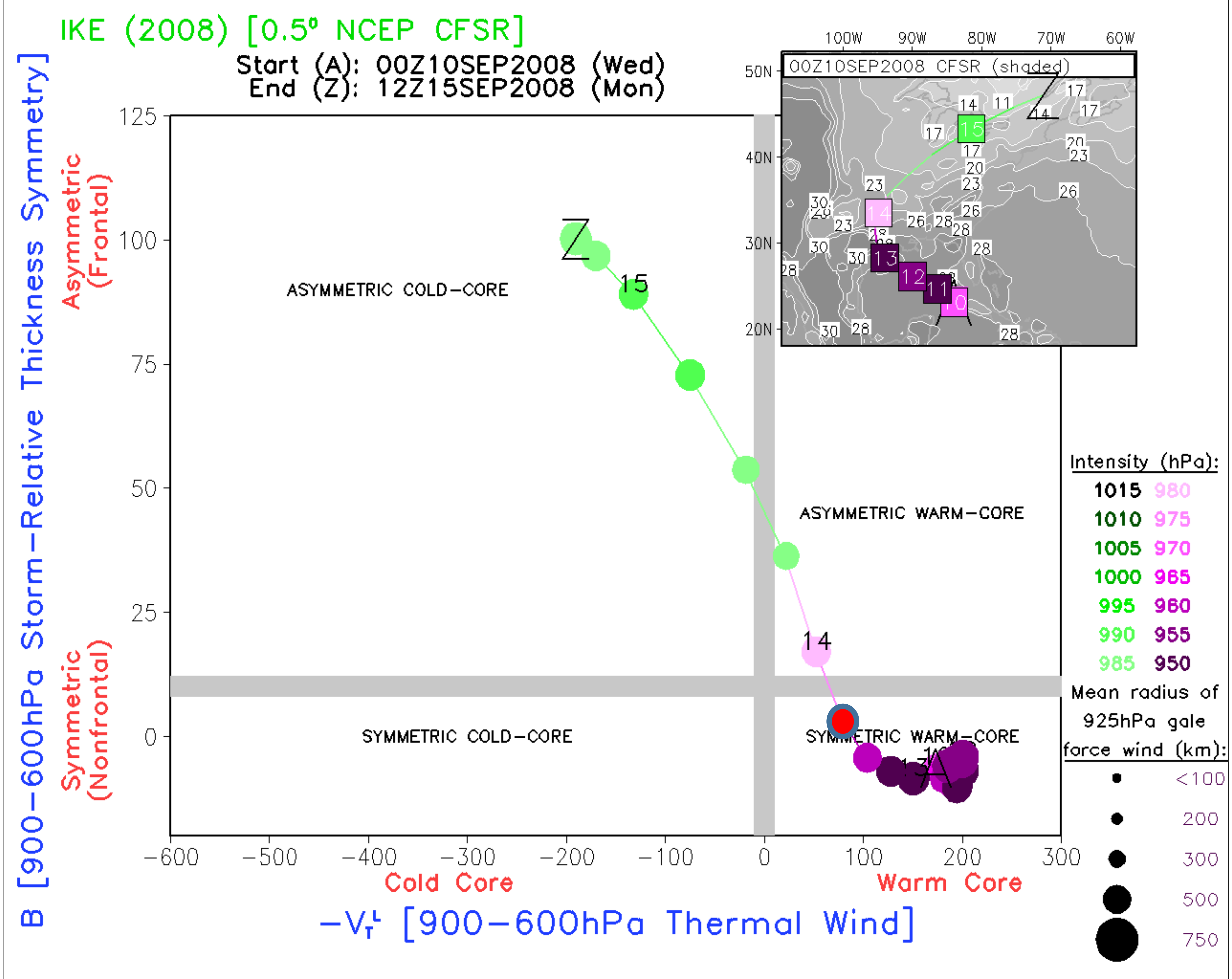
A Typical LOC Case – IKE (2008)




SEP-12-2008 00:00 UTC
200-300 hPa Layer Averaged Potential Vorticity
850-700 hPa Layer Averaged Relative Vorticity
SEP-13-2008 00:00 UTC
080913/0000V000
Sep-11-2008 23:45 UTC GOES-12
SEP-14-2008 00:00 UTC
080914/0000V000
SEP-15-2008 00:00 UTC
080915/0000V000
Sep-13-2008 23:45 UTC GOES-12

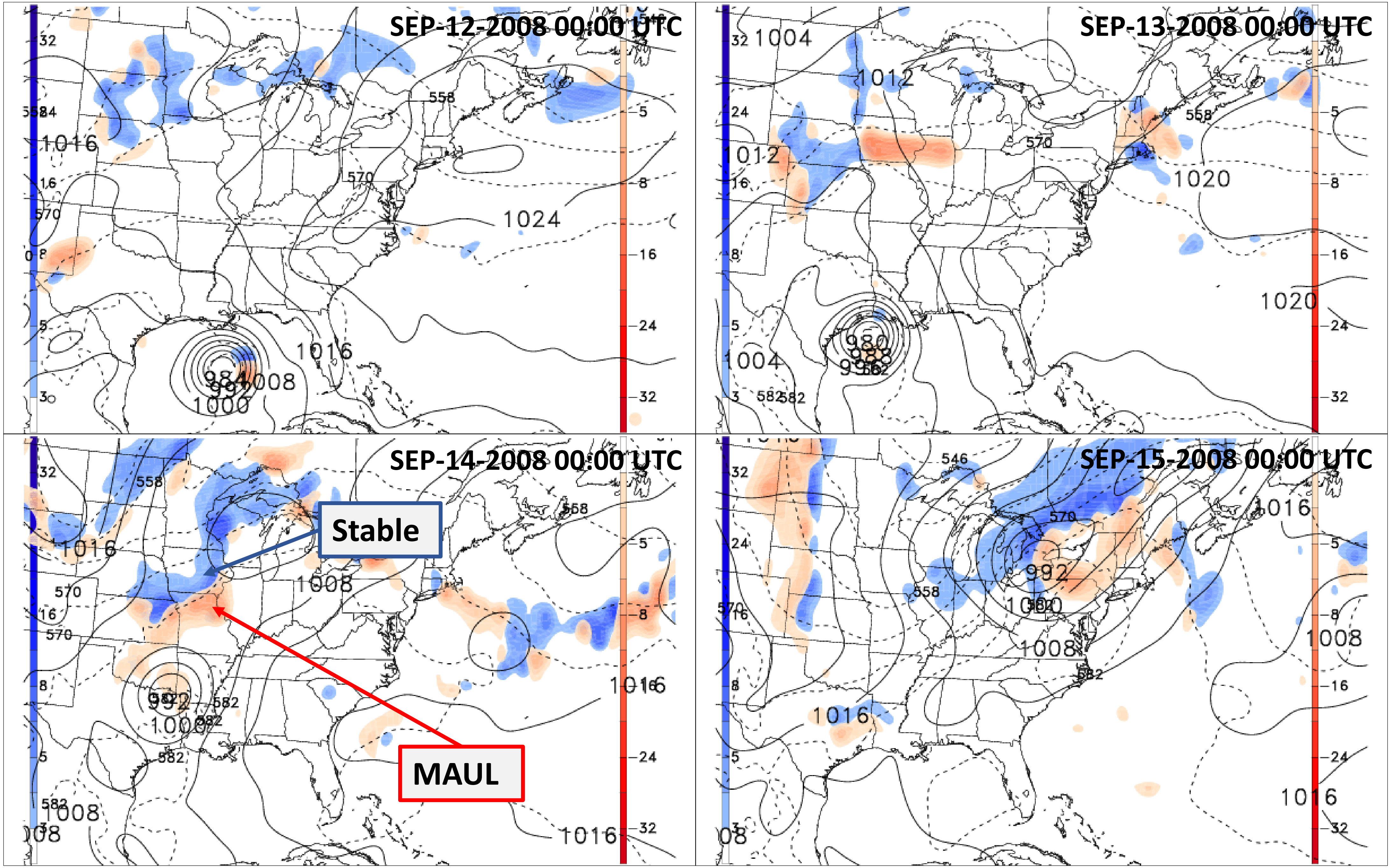

SEP-12-2008 00:00 UTC
6 hour Precipitation Field Shaded (mm)
SEP-13-2008 00:00 UTC
SEP-14-2008 00:00 UTC
SEP-15-2008 00:00 UTC
10 20 30 40 60 80 100 140 180 220 260 300 380 460


Hurricane Ike
September 8-15, 2008
5643 sites
Track
1
3
5
7
10
15
Maximum: 18.90"
Spring Creek @ FM 2979, TX

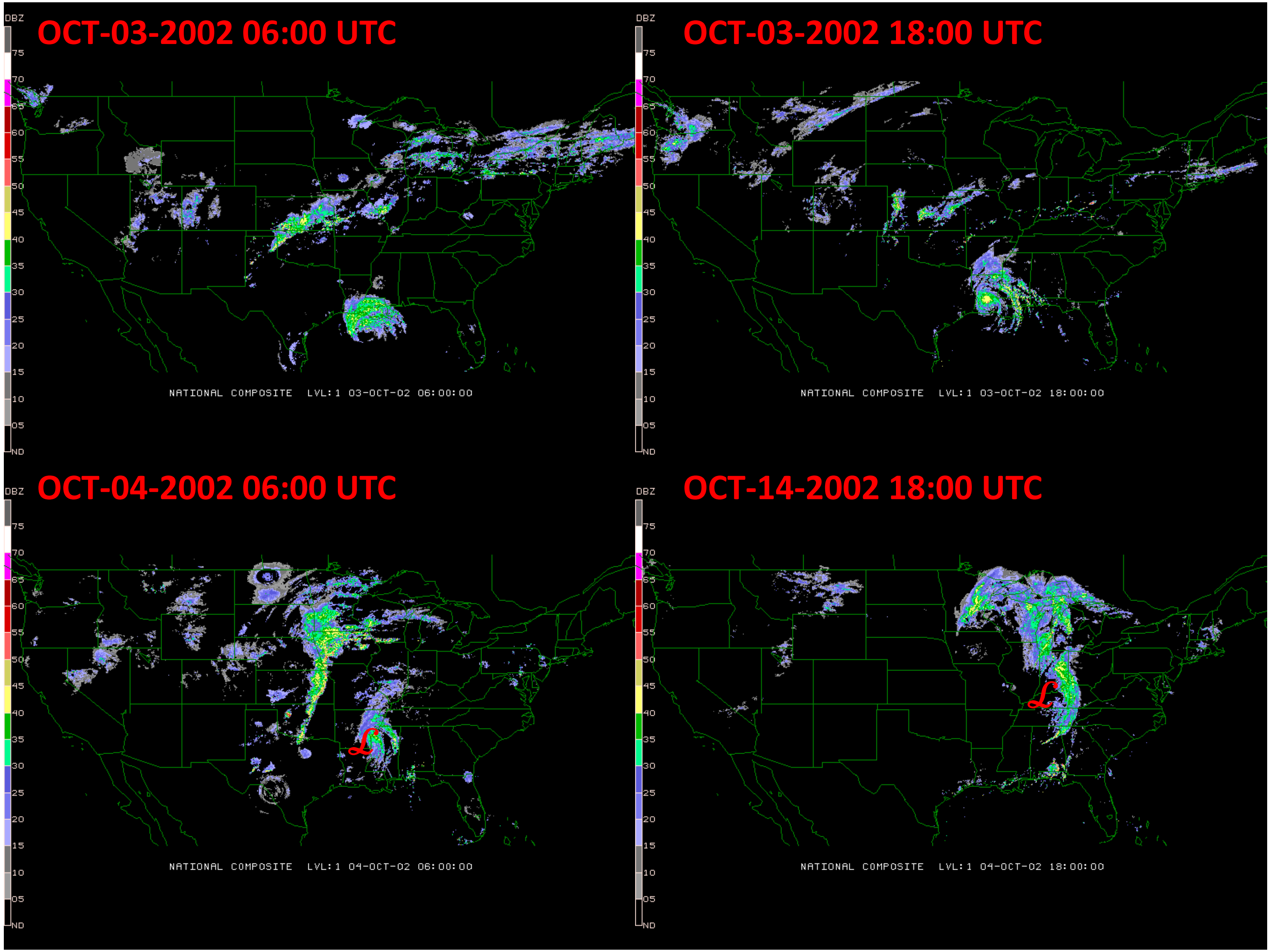


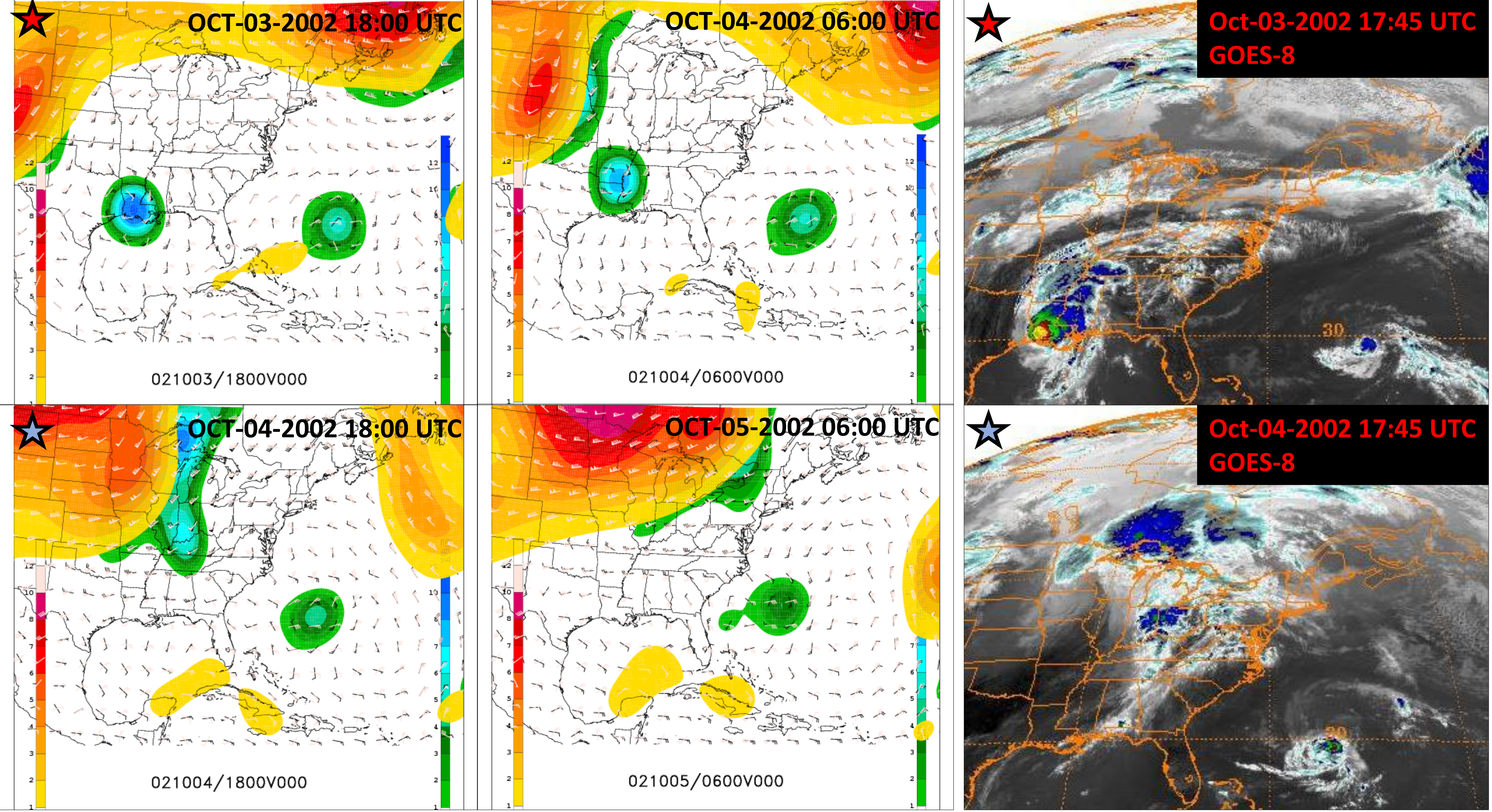
Time of precipitation shift

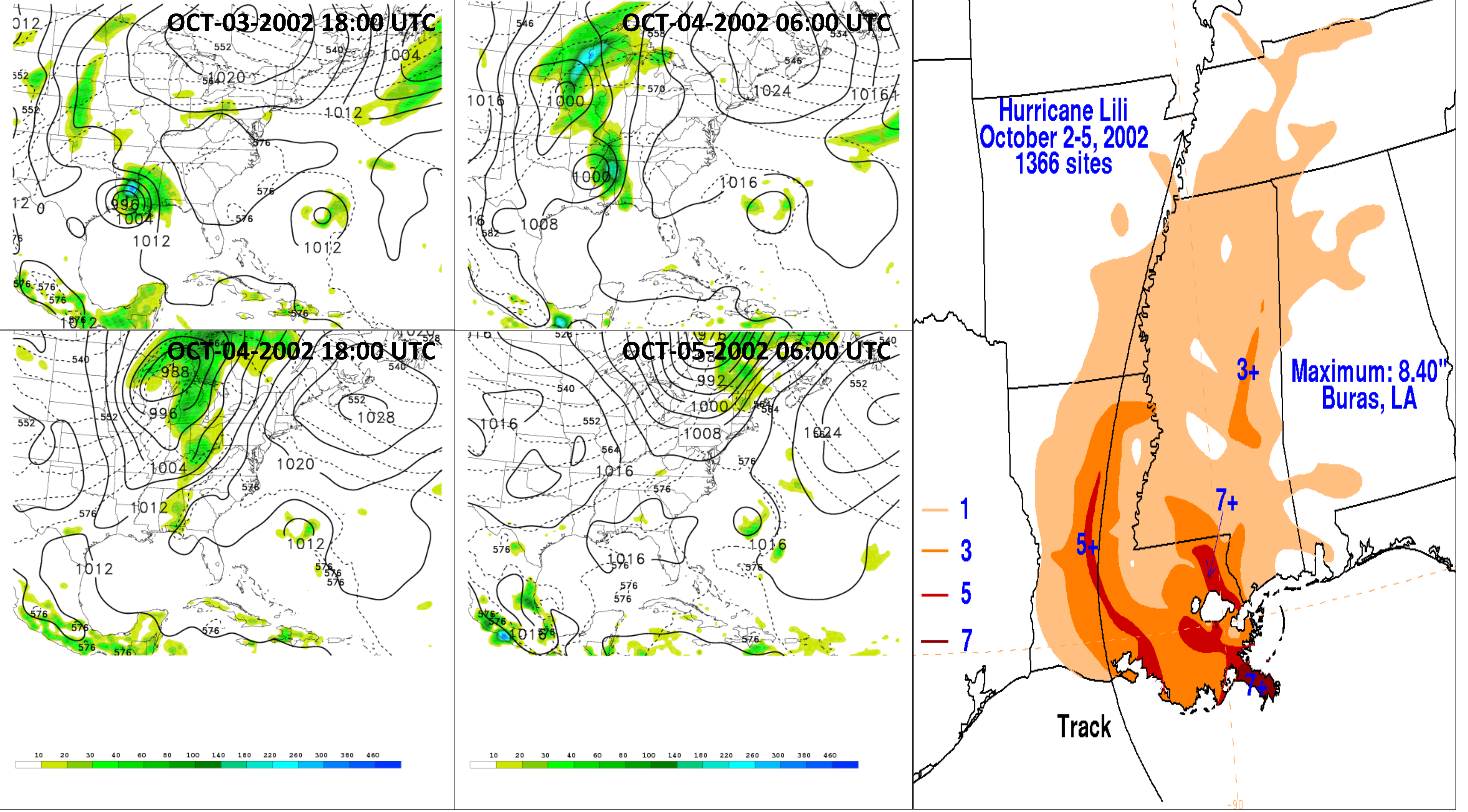
(Symmetric to LOC)


SEP-12-2008 00:00 UTC
SEP-13-2008 00:00 UTC
SEP-14-2008 00:00 UTC
SEP-15-2008 00:00 UTC
Stable
MAUL

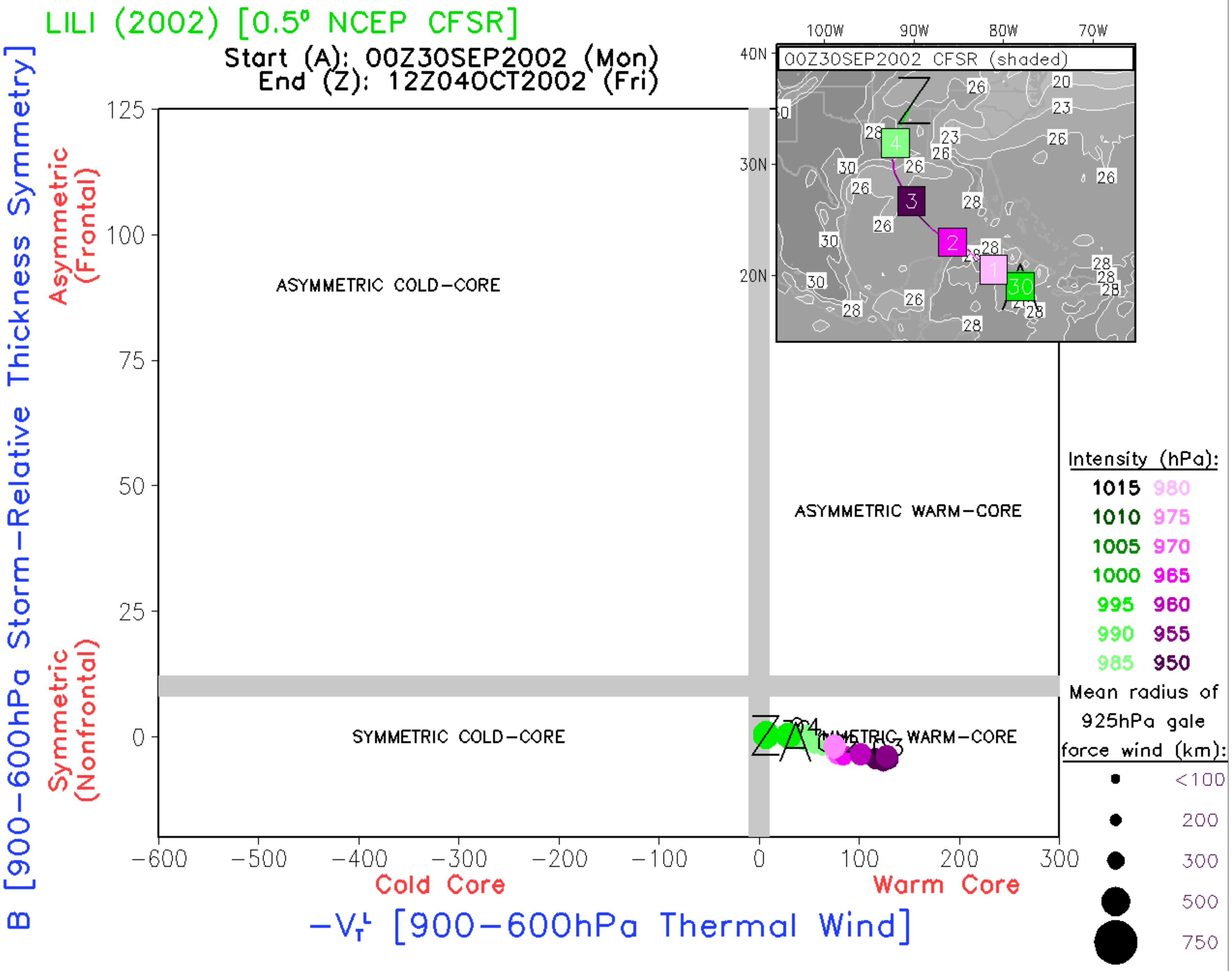
A Typical ROC Case – LILI (2002)



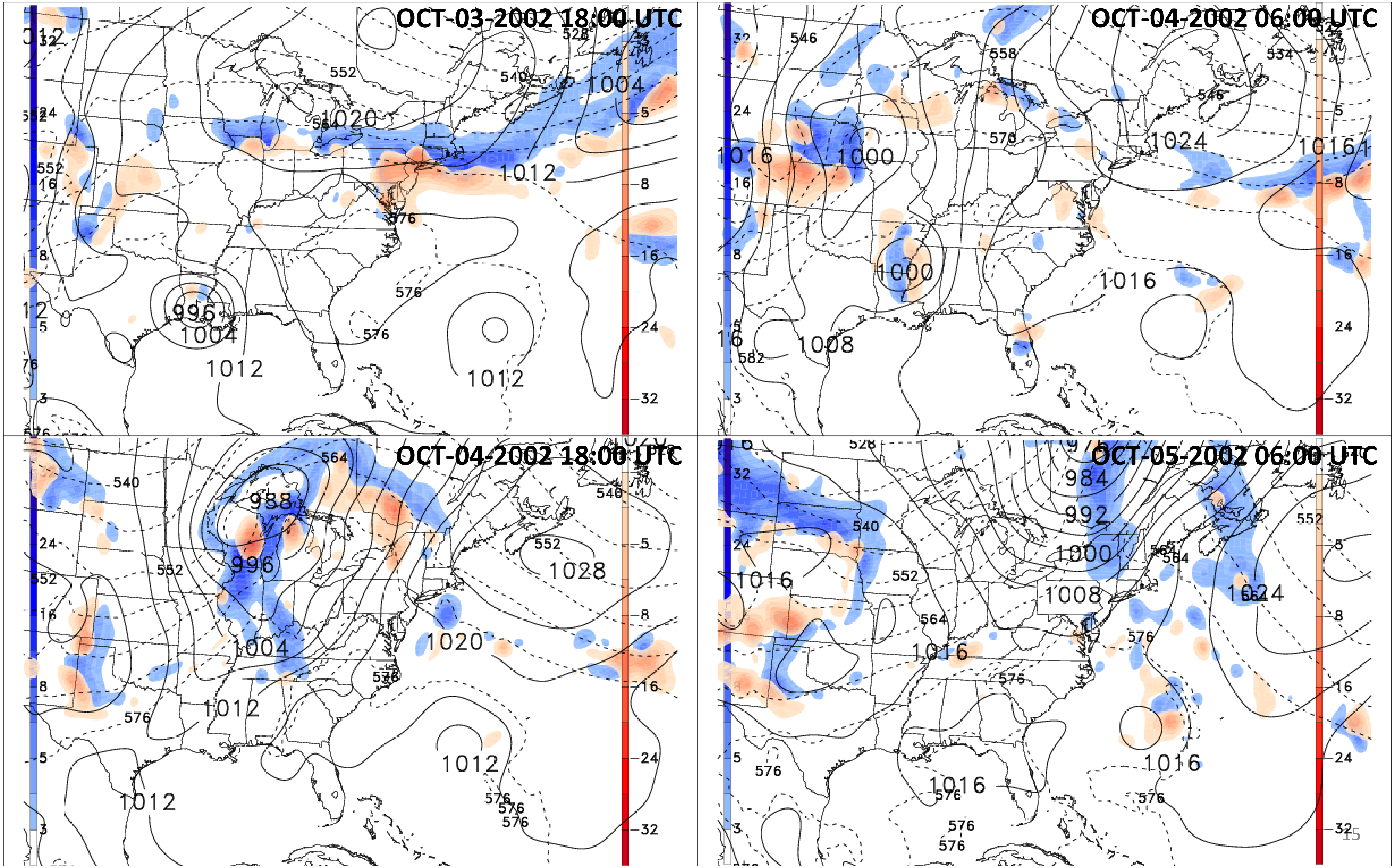

OCT-03-2002 18:00 UTC
021003/1800V000
OCT-04-2002 06:00 UTC
021004/0600V000
Oct-03-2002 17:45 UTC
GOES-8
30
OCT-04-2002 18:00 UTC
021004/1800V000
OCT-05-2002 06:00 UTC
021005/0600V000
Oct-04-2002 17:45 UTC
GOES-8
30



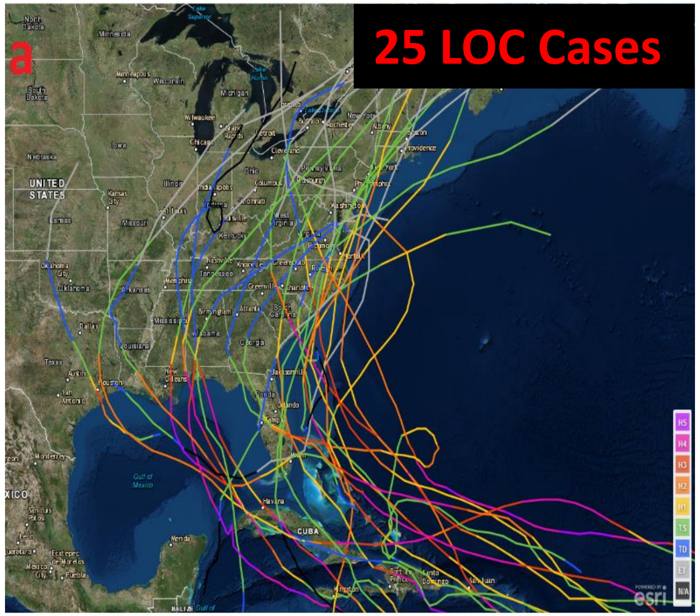
OCT-03-2002 18:00 UTC
OCT-04-2002 06:00 UTC
OCT-04-2002 18:00 UTC
OCT-05-2002 06:00 UTC
10 20 30 40 60 80 100 140 180 220 260 300 380 460
Hurricane Lili
October 2-5, 2002
1366 sites
Maximum: 8.40"
Buras, LA
Track
1
3
5
7
3+
5+
7+

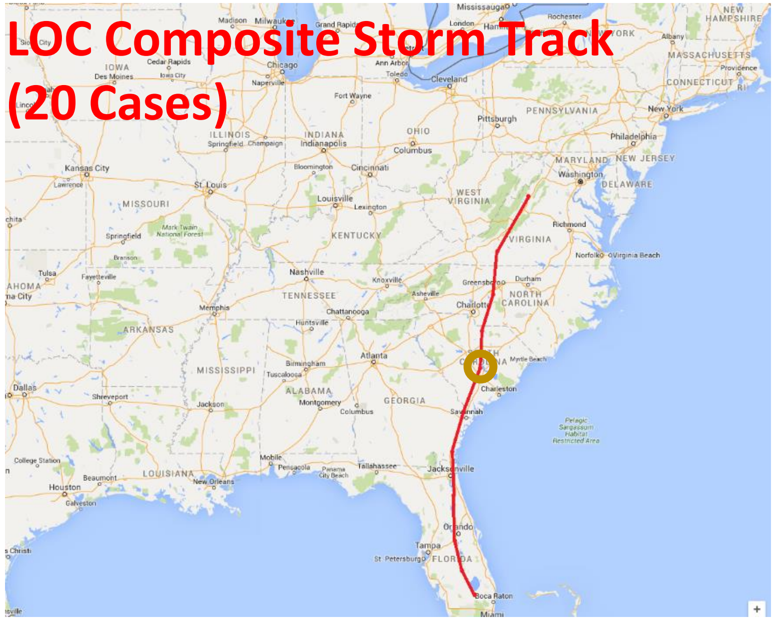


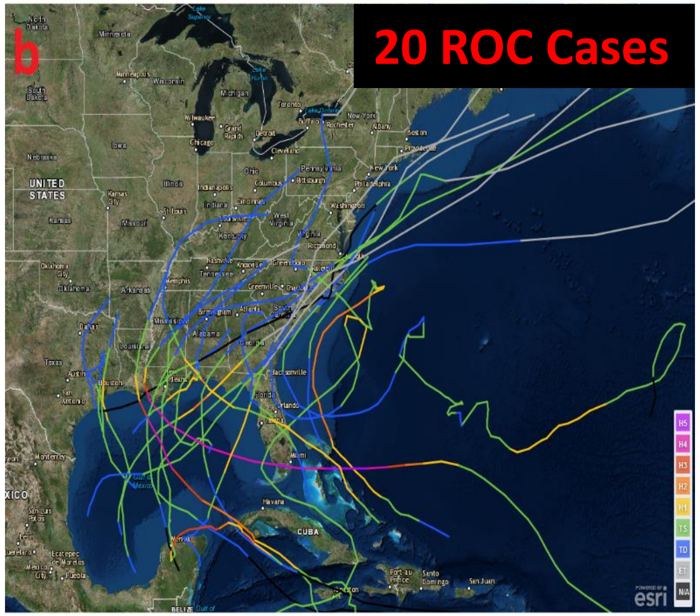
LILI (2002) [0.5° NCEP CFSR]
Start (A): 00Z30SEP2002 (Mon)
End (Z): 12Z04OCT2002 (Fri)
B [900−600hPa Storm−Relative Thickness Symmetry]
Asymmetric (Frontal)
Symmetric (Nonfrontal)
ASYMMETRIC COLD−CORE
ASYMMETRIC WARM−CORE
SYMMETRIC COLD−CORE
SYMMETRIC WARM−CORE
Cold Core
Warm Core
−V$_T^L$ [900−600hPa Thermal Wind]
00Z30SEP2002 CFSR (shaded)
Intensity (hPa):
1015 980
1010 975
1005 970
1000 965
995 960
990 955
985 950
Mean radius of 925hPa gale force wind (km):
<100
200
300
500
750


OCT-03-2002 18:00 UTC
OCT-04-2002 06:00 UTC
OCT-04-2002 18:00 UTC
OCT-05-2002 06:00 UTC

Grid Centered Composite



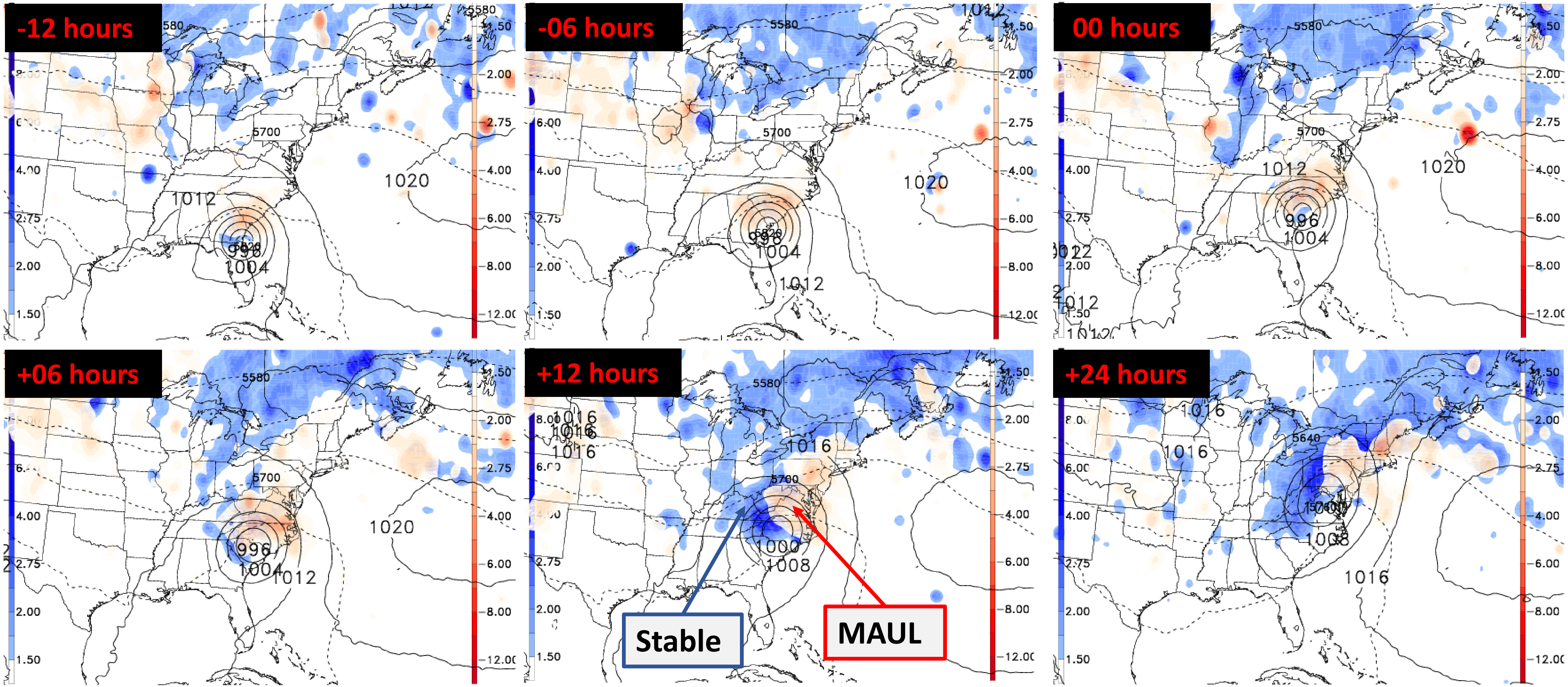


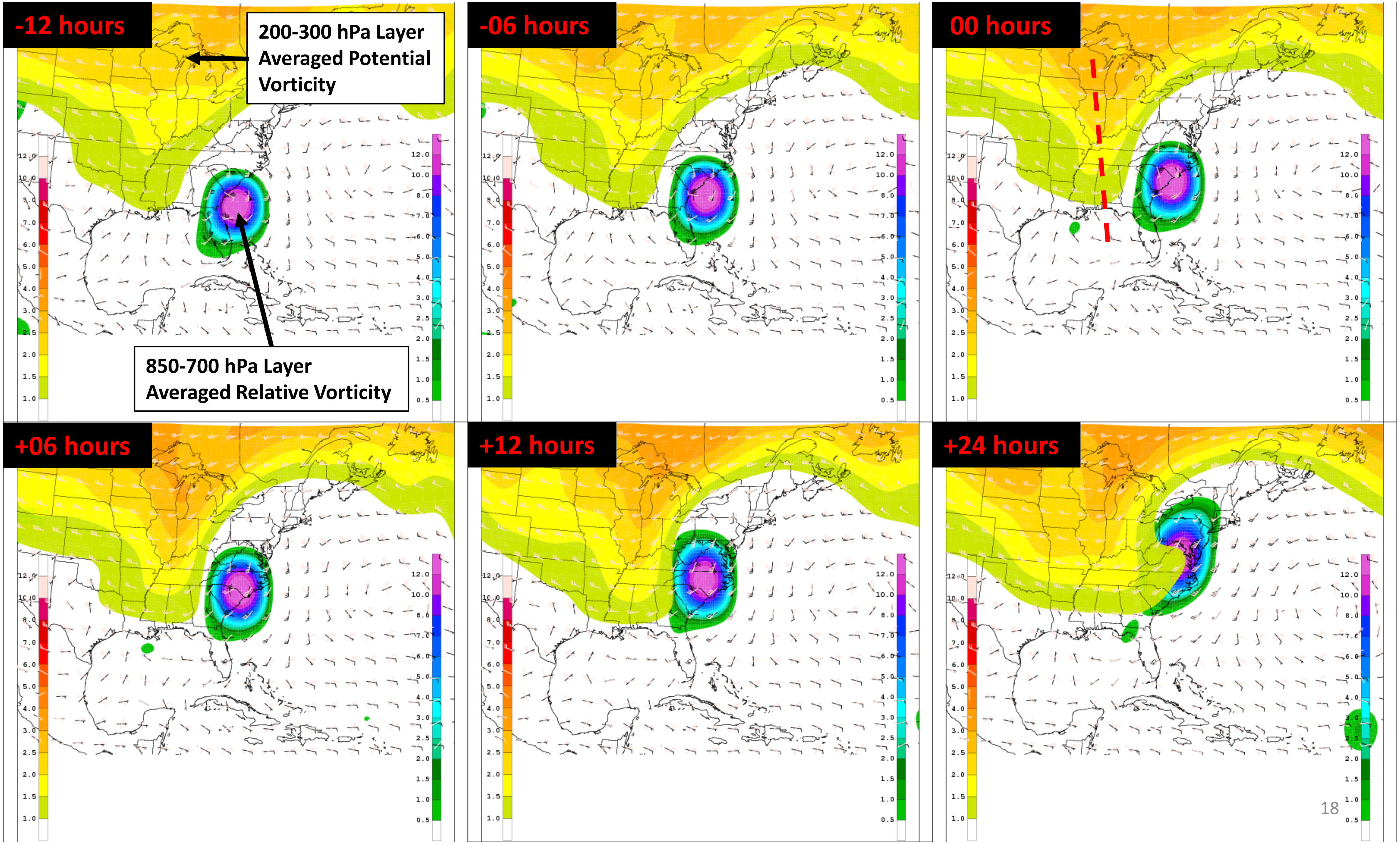


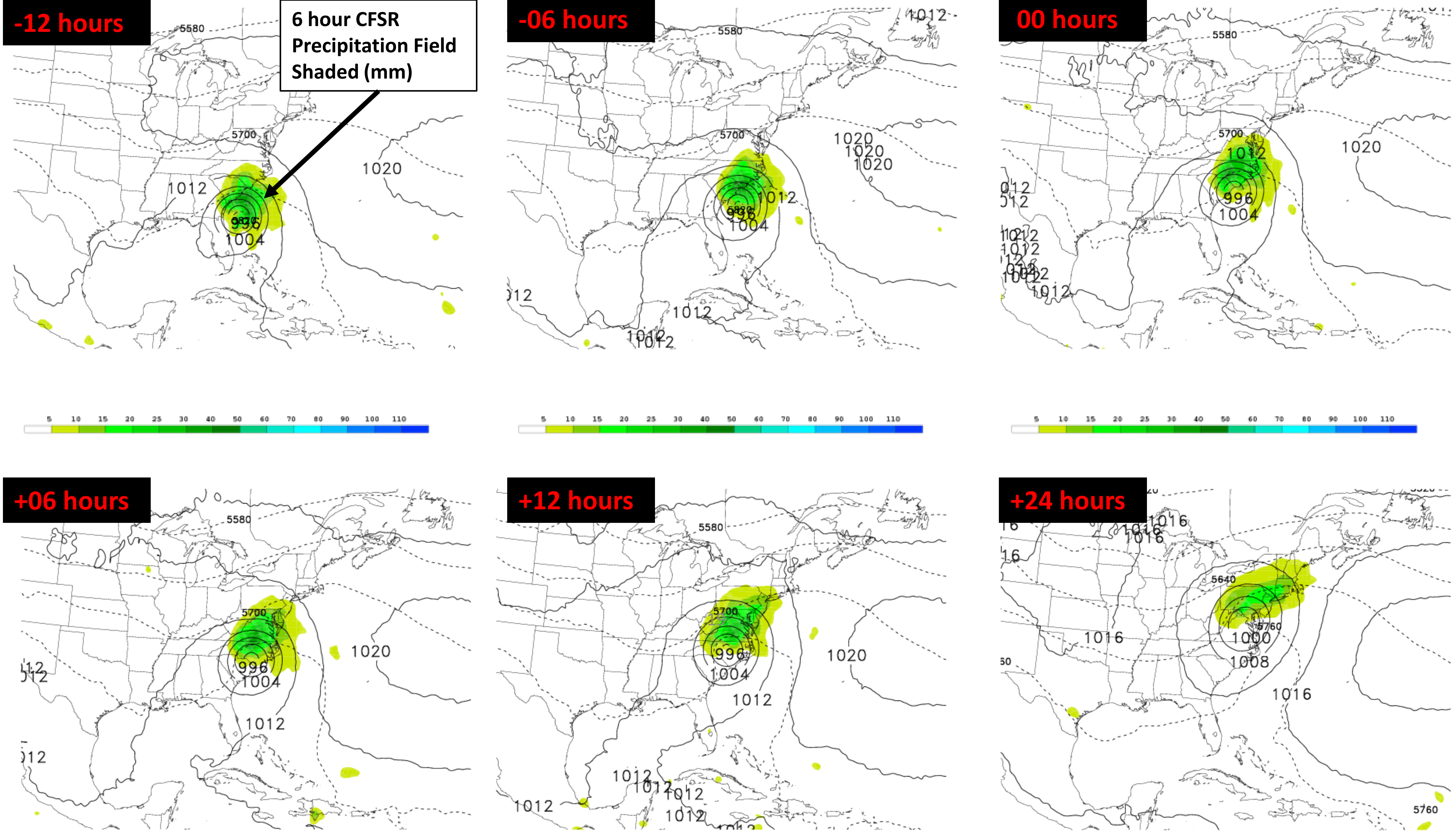
- LOC Cases - Time of precipitation shift (time: 00 hours)
- ROC Cases – Time of interaction with a mid-tropospheric trough (time: 00 hours)
- Background geography for reference only

- Time of precipitation shift (Symmetric to LOC)
- Time of interaction with mid-tropospheric trough

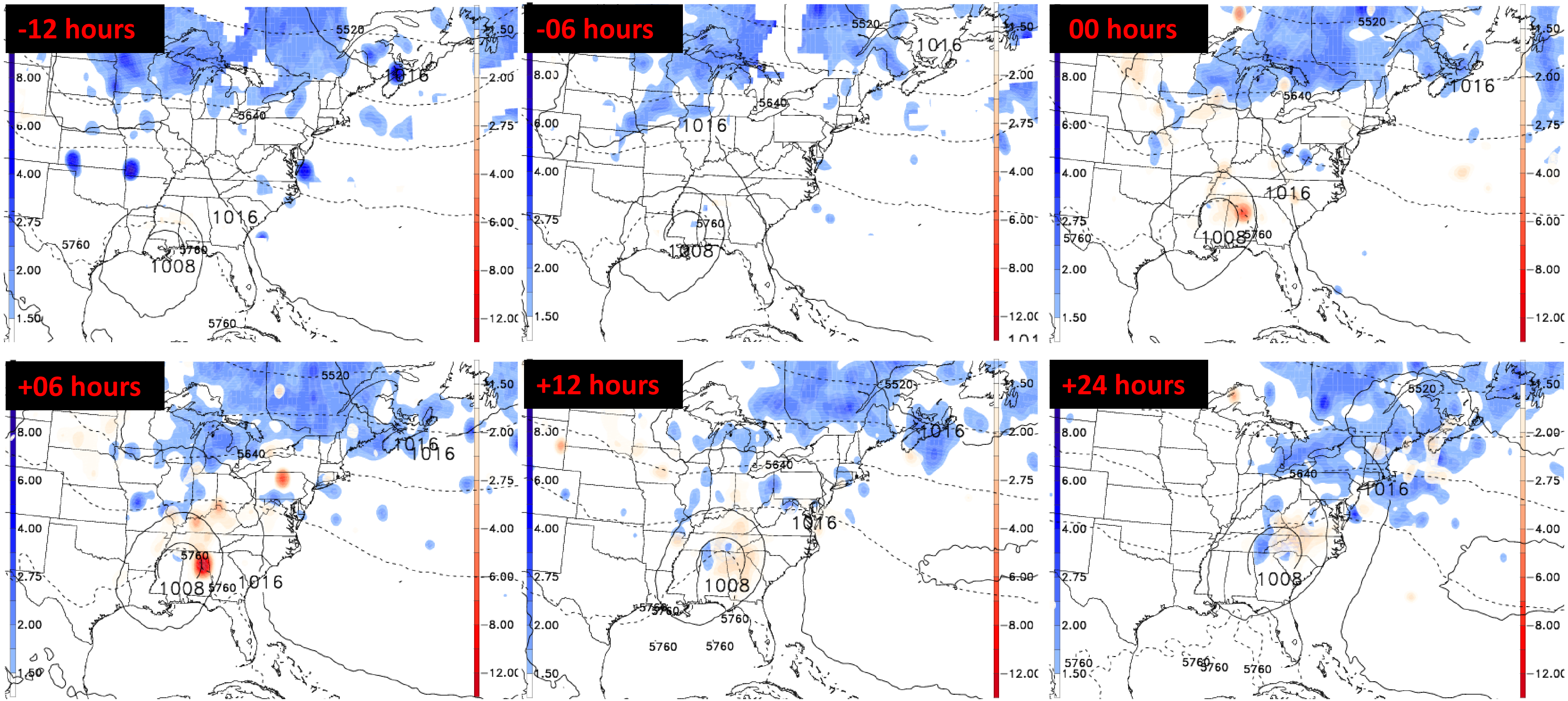
Composite EMBGR LOC Cases

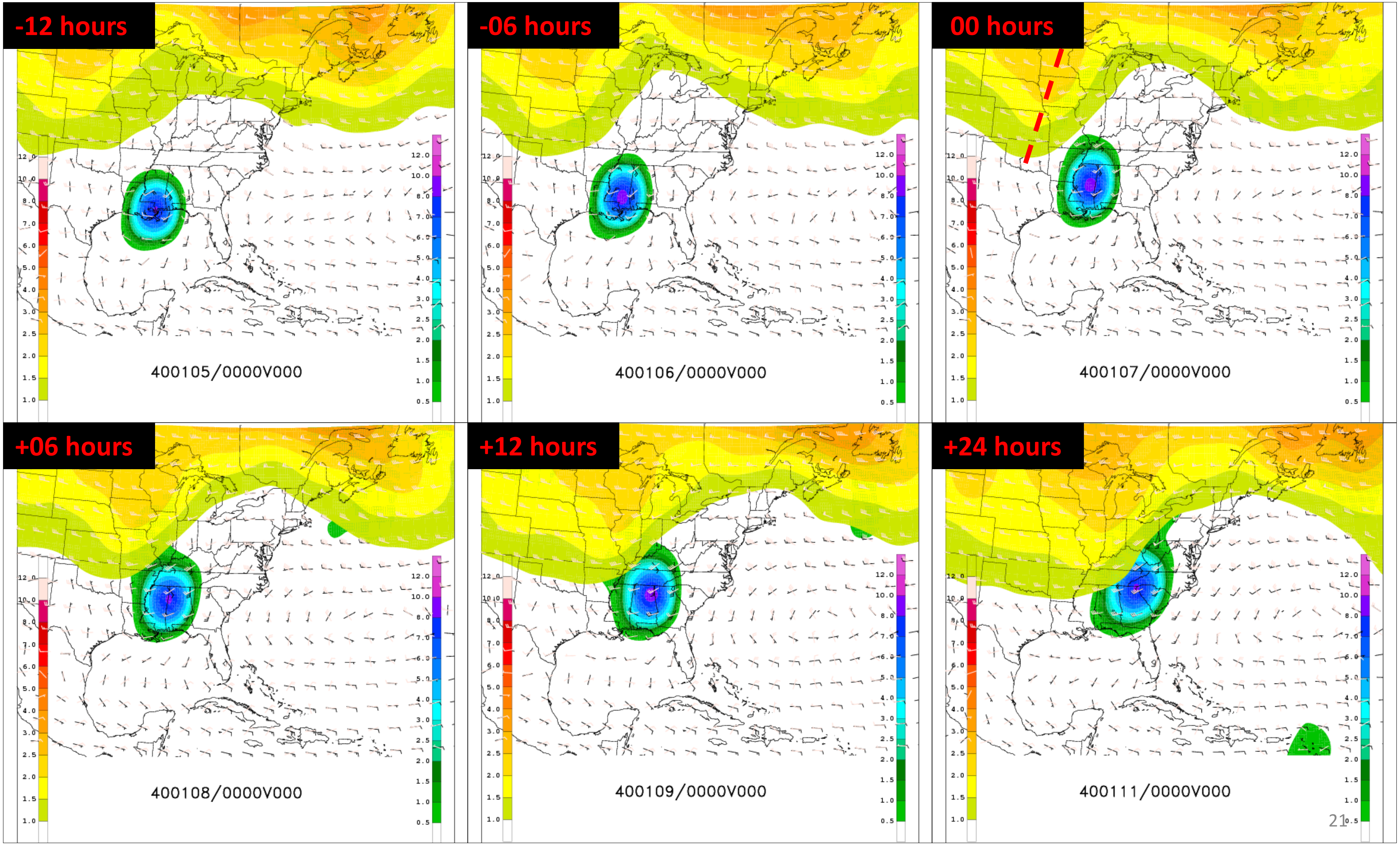


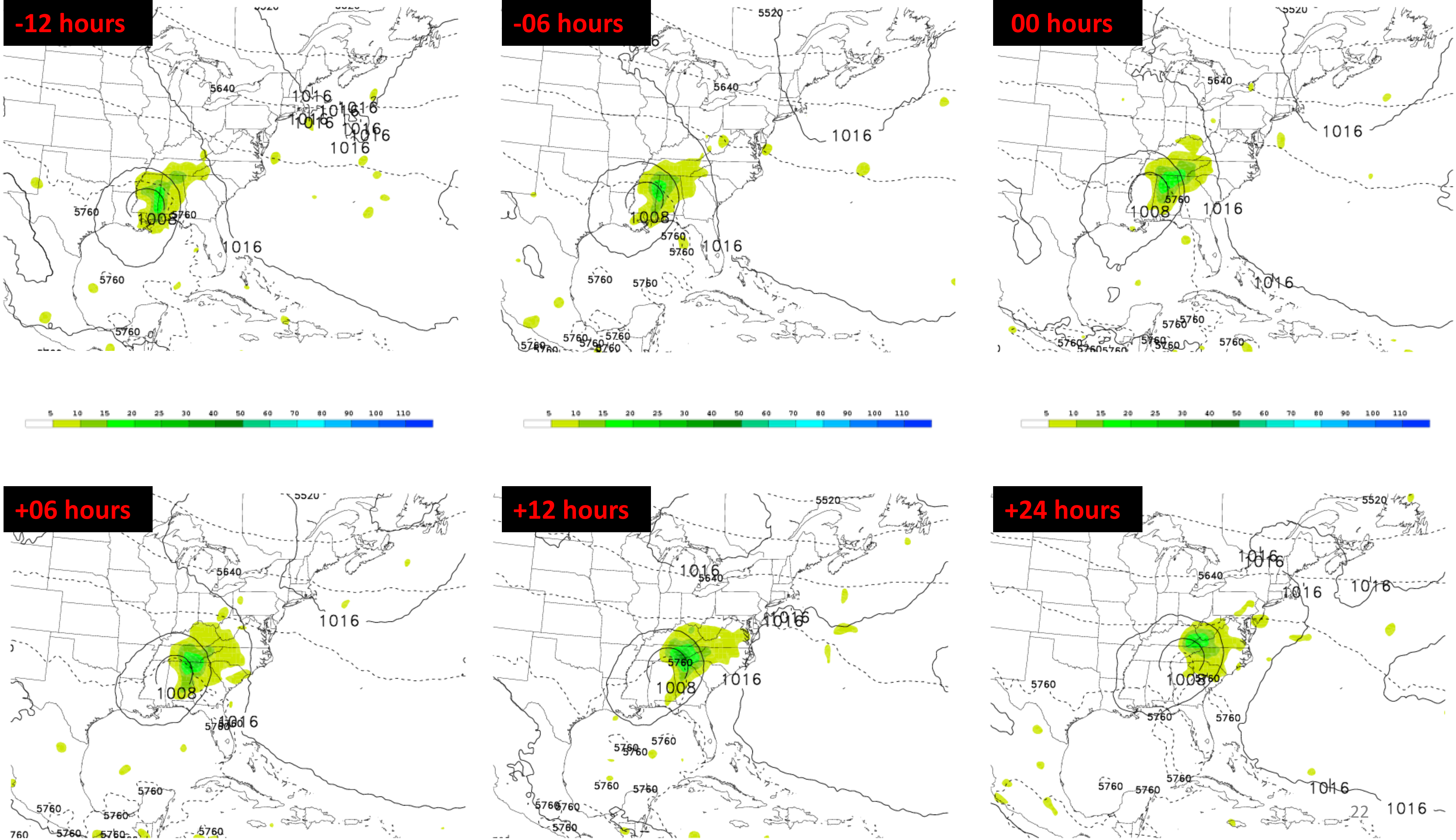

-12 hours
200-300 hPa Layer Averaged Potential Vorticity
850-700 hPa Layer Averaged Relative Vorticity
-06 hours
00 hours
+06 hours
+12 hours
+24 hours


-12 hours
6 hour CFSR Precipitation Field Shaded (mm)
-06 hours
00 hours
+06 hours
+12 hours
+24 hours
5 10 15 20 25 30 40 50 60 70 80 90 100 110

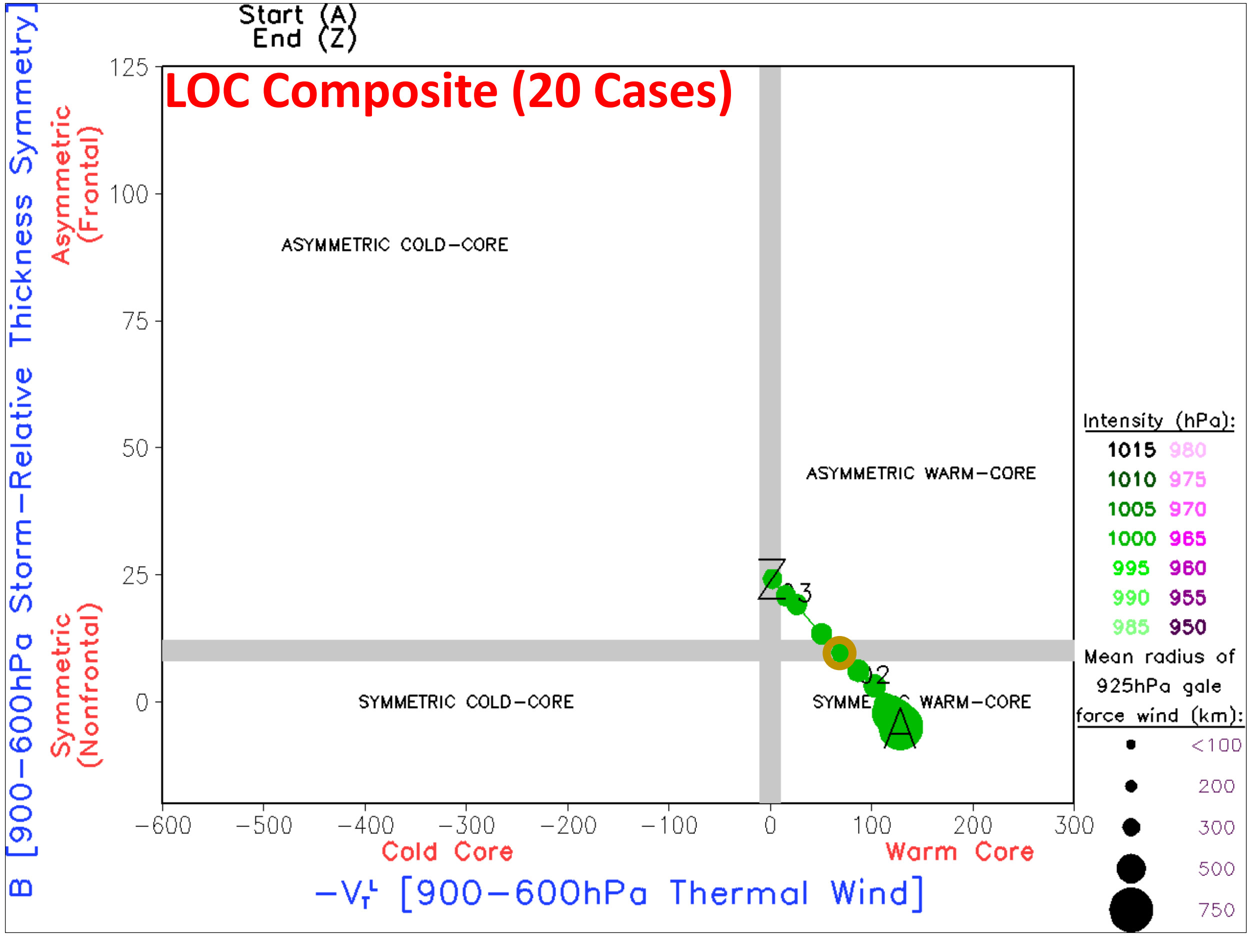
Composite EMBGR ROC Cases

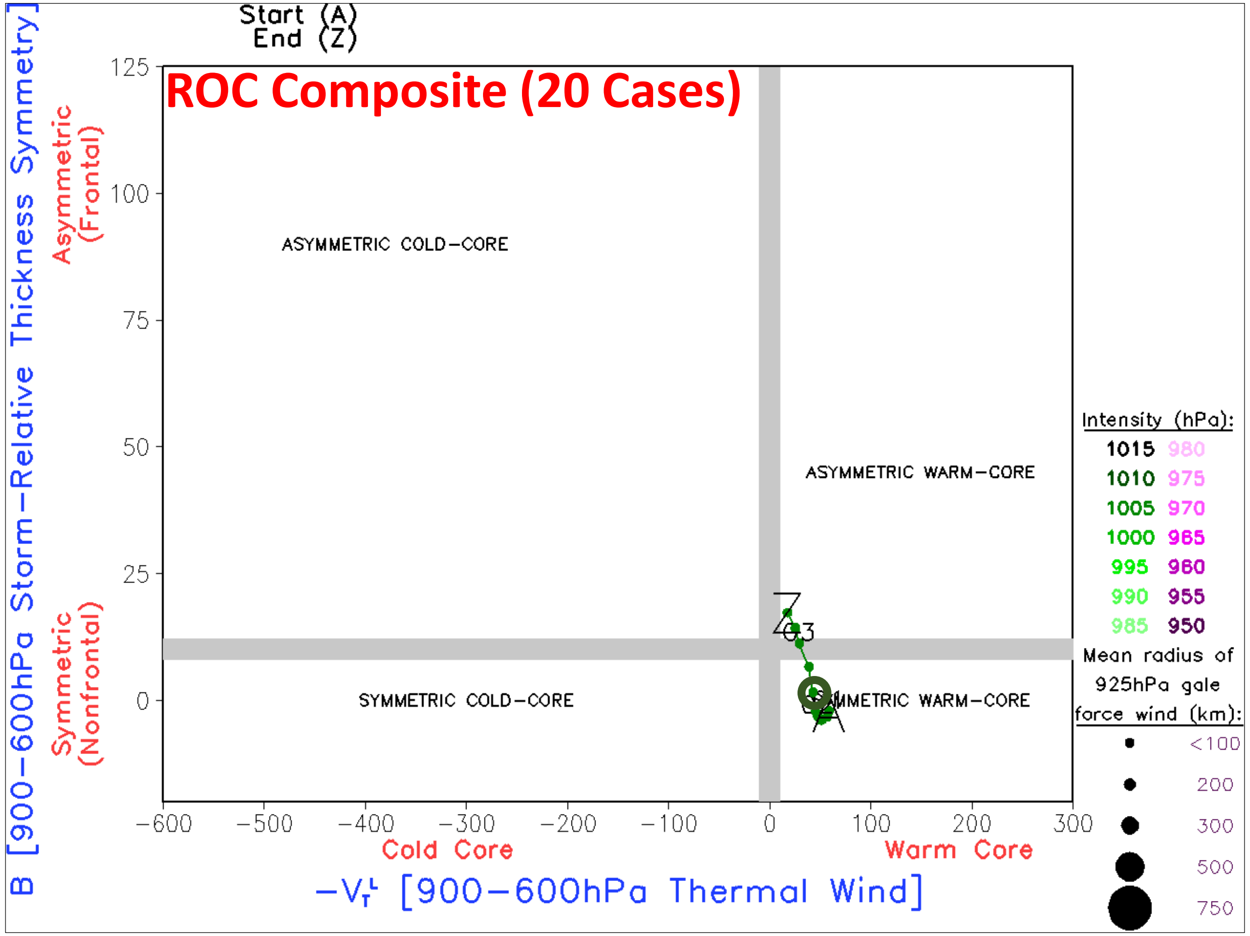



-12 hours
400105/0000V000
-06 hours
400106/0000V000
00 hours
400107/0000V000
+06 hours
400108/0000V000
+12 hours
400109/0000V000
+24 hours
400111/0000V000


-12 hours
-06 hours
00 hours
+06 hours
+12 hours
+24 hours
5 10 15 20 25 30 40 50 60 70 80 90 100 110
1016
1008
5760
5640
5520

Composite Phase Space Plots





- Time of precipitation shift (Time 0 hours)
- Time of interaction with mid-tropospheric trough (Time 0 hours)

RESULTS AND CONCLUSIONS

Advantages of EMBGR as an ET Metric

- **12-24 hours lead time for time of ET**
- **Increasing spatial extent of EMBGR provides a qualitative method to identify intensifying ET events**
- **Time tendencies in EMBGR enables differentiation between intensifying (LOC cases) and decaying (ROC cases) ET events**

Future Work

- **Explore the predictability in real time operational models Research-to-Operations (R2O)**
  Reanalysis data vs. Operational (deterministic and ensemble) models may not produce identical results
- **Analyze quantitative techniques to understand intensity of ET using EMBGR**

REFERENCES

Atallah, E. H., L. F. Bosart, and A. R. Aiyyer, 2007: Precipitation distribution associated with landfalling tropical cyclones over the eastern United States. *Mon. Wea. Rev.*, **135**, 2185–2206.

Bryan, G. H., and J. M. Fritsch, 2000: Moist absolute instability: The sixth static stability state. *Bull. Amer. Meteor. Soc.*, **81**,1207–1230.

Cordeira, J. M., and L. F. Bosart, 2010: The antecedent large-scaleconditions of the ‘‘Perfect Storms’’ of late October and early November 1991. *Mon. Wea. Rev.*, **138**, 2546–2569.

Durran, D. R., and J. B. Klemp, 1982: On the effects of moisture on the Brunt-Vaisala frequency. *J. Atmos. Sci.*, **39**, 2152-2158.

Hart, R.E., 2003: A Cyclone Phase Space Derived from Thermal Wind and Thermal Asymmetry. *Mon. Wea. Rev.*, **131**, 585–616.

Jones, S. C., and Coauthors, 2003: The extratropical transition of tropical cyclones: Forecast challenges, current understanding, and future directions. *Wea. Forecasting*, **18**, 1052–1092.

Kofron, D. E., E. A. Ritchie, and J. S. Tyo, 2010a: Determination of a consistent time for the extratropical transition of tropical cyclones. Part I: Examination of existing methods for Finding “ET Time”. *Mon. Wea. Rev.*, **138**, 4328–4343.

Kofron, D. E., E. A. Ritchie, and J. S. Tyo, 2010b: Determination of a consistent time for the extratropical transition of tropical cyclones. Part II: Potential vorticity metrics. *Mon. Wea. Rev.*, **138**, 4344–4361.

Milrad, S. M., E.H. Atallah, and J.R. Gyakum, 2009: Dynamical and precipitation structures of poleward moving tropical cyclones in eastern Canada, 1979 – 2005. *Mon. Wea. Rev.*, **137**, 836-851.

Acknowledgements

- Embry-Riddle Honors Program
- Dr. Anantha Aiyyer

  North Carolina State University
- Dr. Robert Hart

  Florida State University CPS code (http://moe.met.fsu.edu/~rhart/software.php)
- Shealynn Cloutier-Bisbee

  Embry-Riddle Aeronautical University, FL