Sensitivity of Tropical Cyclone Frequency and Intensity to Cumulus Convective Activity in a High Resolution GEOS-5 Model

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Introduction

1. It was found at the last meeting that realistic simulation of the Atlantic tropical storms and hurricanes (~0.5° resolution) was challenging relative to the other regions (e.g., Pacific).
2. Is increased (0.25°) resolution helpful for improving the simulation of the tropical cyclones in terms of storm numbers, intensity, and shape of tropical cyclone (e.g., warm core magnitude and its vertical location, maximum wind, SLP deepening, compactness of TC center, radius of maximum wind, etc.)?
3. Here we will focus on the impact of modifying the cumulus convective activity at 0.25° resolution. In particular we will examine the sensitivity to the minimum entrainment threshold.

Introduction

- **Determination of Cumulus Entrainment Limit**

$$\mu_m = \alpha / D$$

minimum entrainment rate (μ)

α=const (positive),

D = PBL depth ~ Diameter for the largest convective plume

- **Increase in the minimum cumulus entrainment rate (i.e., gradually turning off the cumulus parameterization) in the model to suppress the parameterized deep cumulus convection.**

Experiment and analysis

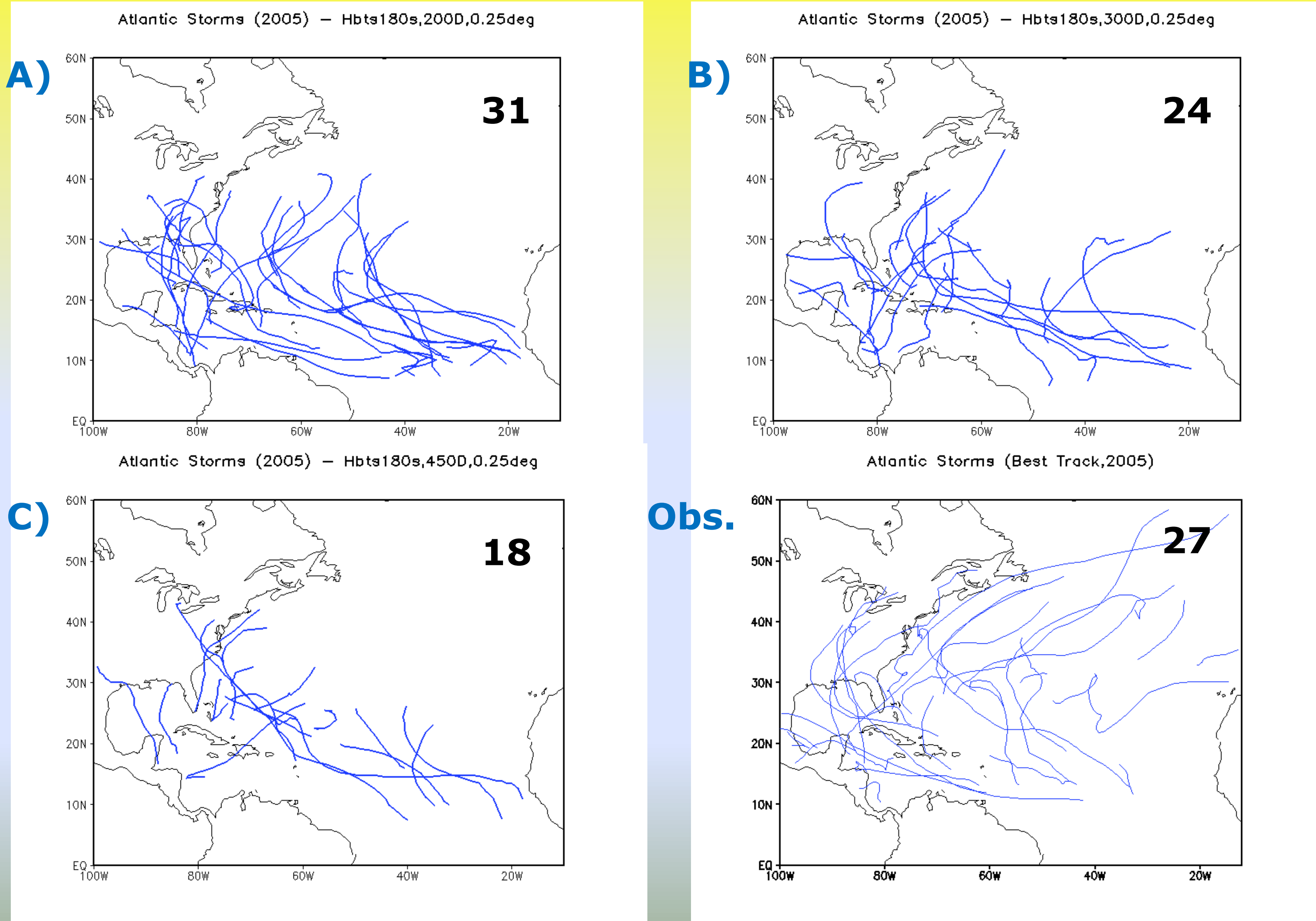
1. **Three different minimum entrainment rates (strong, less strong, weak(control, default)) were applied for the active hurricane year (2005) and inactive year (2006).**
2. **Three member ensembles are conducted for each entrainment experiment, all at the spatial resolution of 0.25 degree.**
3. **We examine the model's capability for reproducing the hurricane characteristics for two contrasting hurricane years (2005, 2006), with a focus on:**
   a. **the sensitivity of the storm simulation to the change in cumulus entrainment threshold, and**
   b. **how that change influences the atmospheric stability, which will determine the atmospheric circulation structures and TC characteristics**

The number of Atlantic TSs (member mean) wrt. different configuration of convective cloud scale (minimum entrainment rate (**referred to as MER**))

	MER= (μ_m=1.0km^{-1})	MER= (μ_m=0.7km^{-1})	MER= (μ_m=0.4km^{-1})	Obs.
2005	**31**	**24**	**18**	**27**
2006	**17**	**13**	**8**	**10**

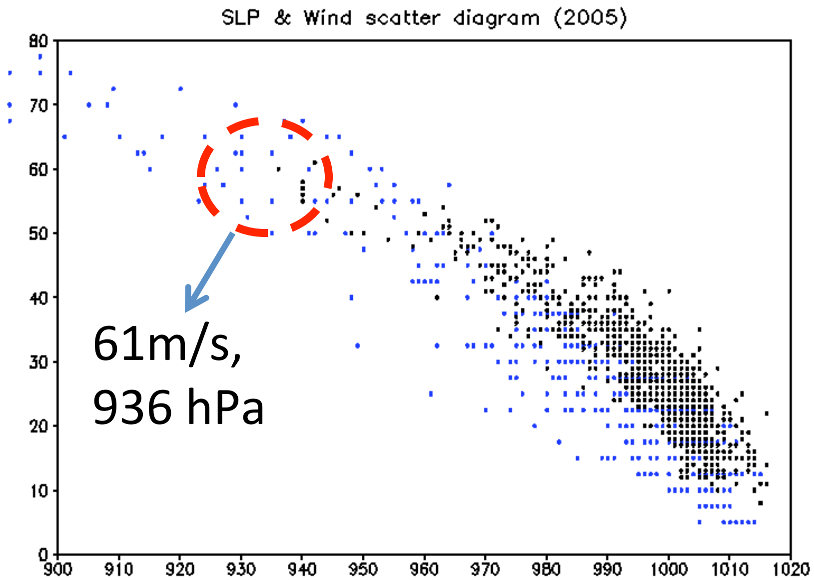
A) Strong MER	B) Less strong MER	C) Weak MER

Storm tracks wrt. different configuration of convective cloud scale (quarter-degree runs, 2005)

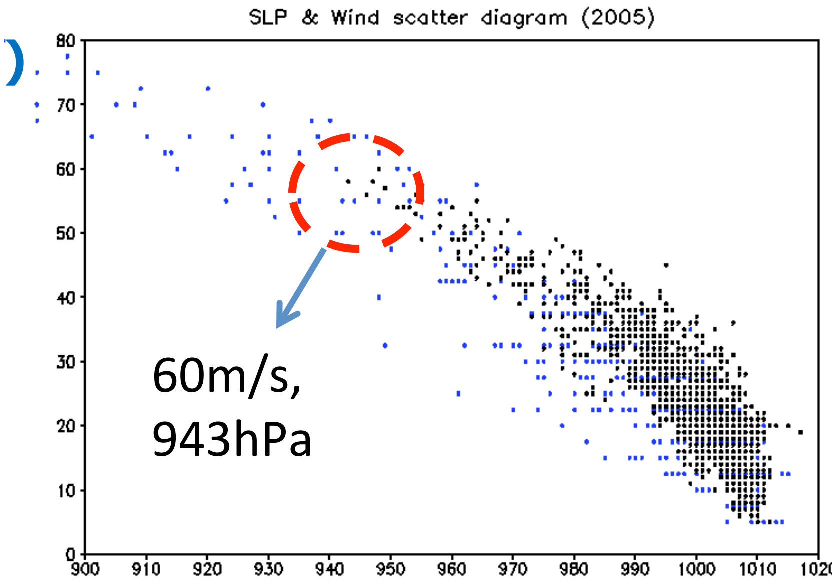


Scatter plot (wind .vs. SLP) wrt. different configuration of convective cloud scale (2005)

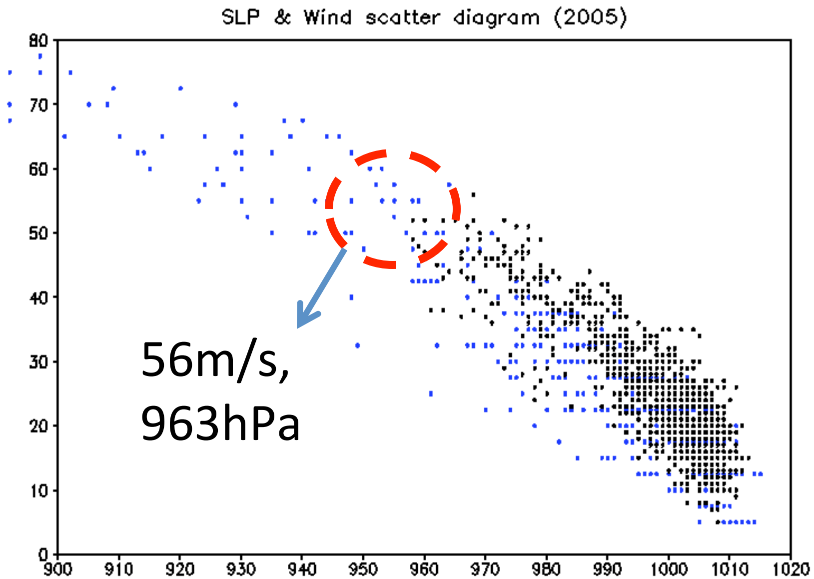
A)



B)



C)



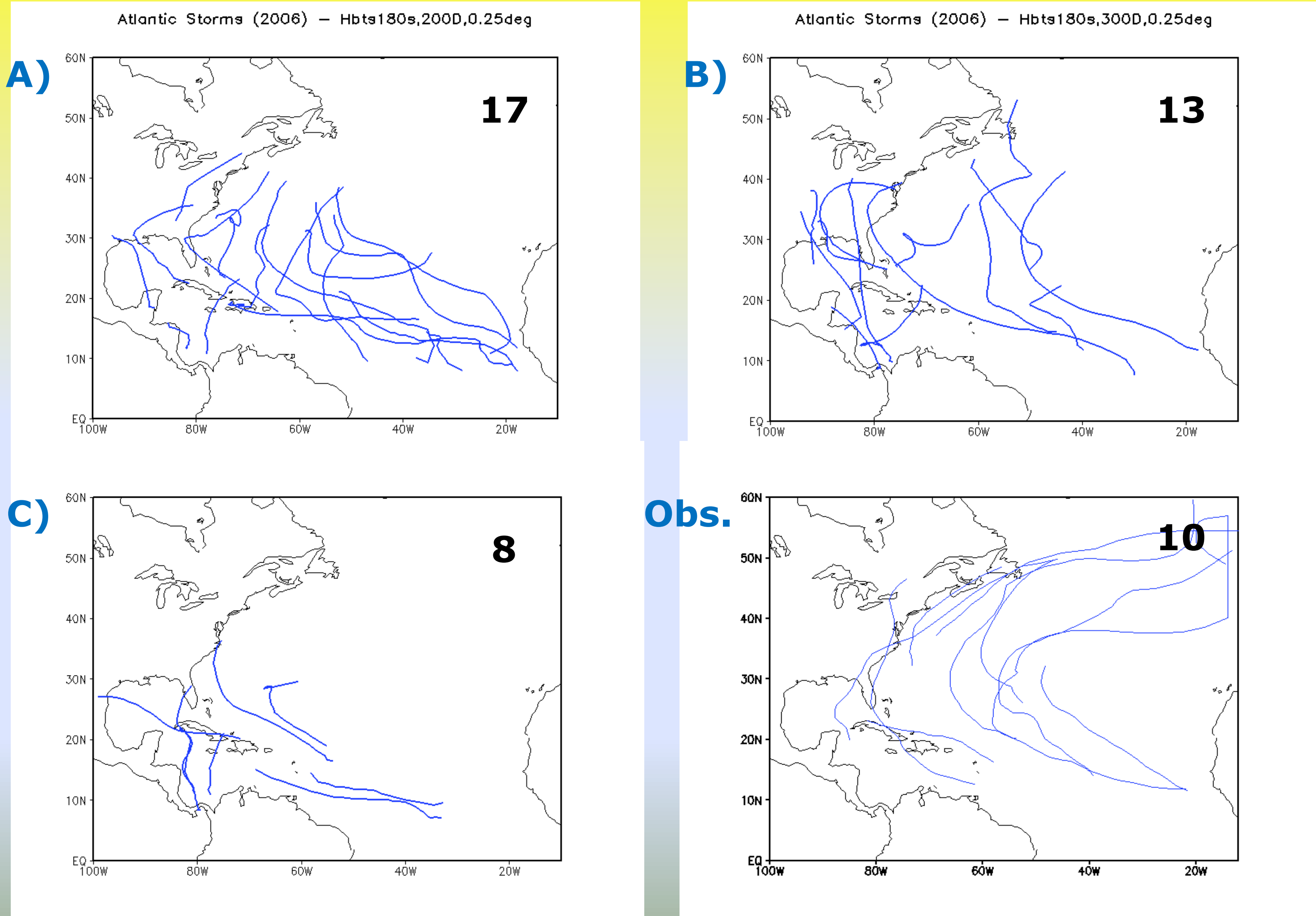
Blue: Obs., Black: Model

A) Strong MER

B) Less strong MER

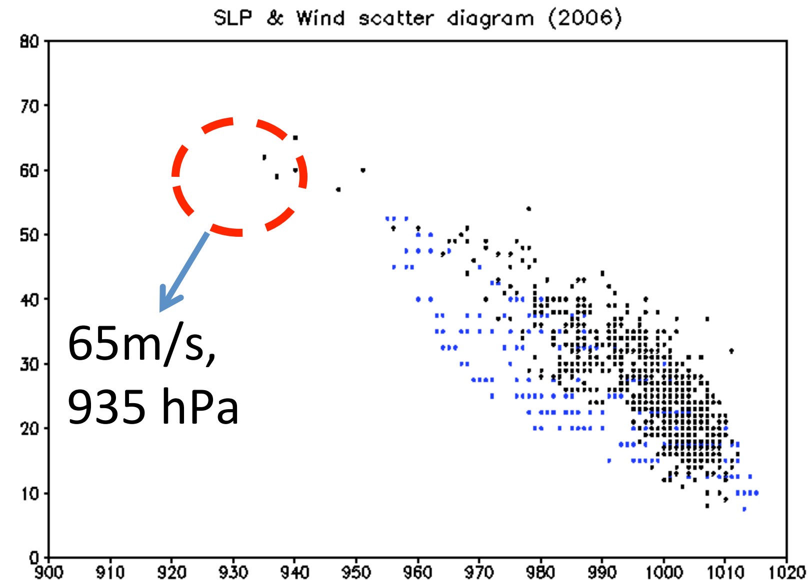
C) Weak MER

Storm tracks wrt. different configuration of convective cloud scale (quarter-degree runs, 2006)

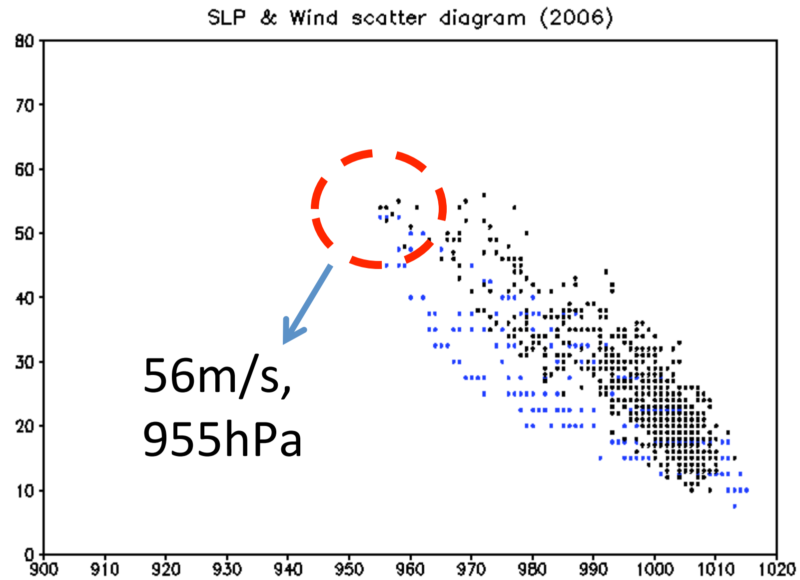


Scatter plot (wind .vs. SLP) wrt. different configuration of convective cloud scale (2006)

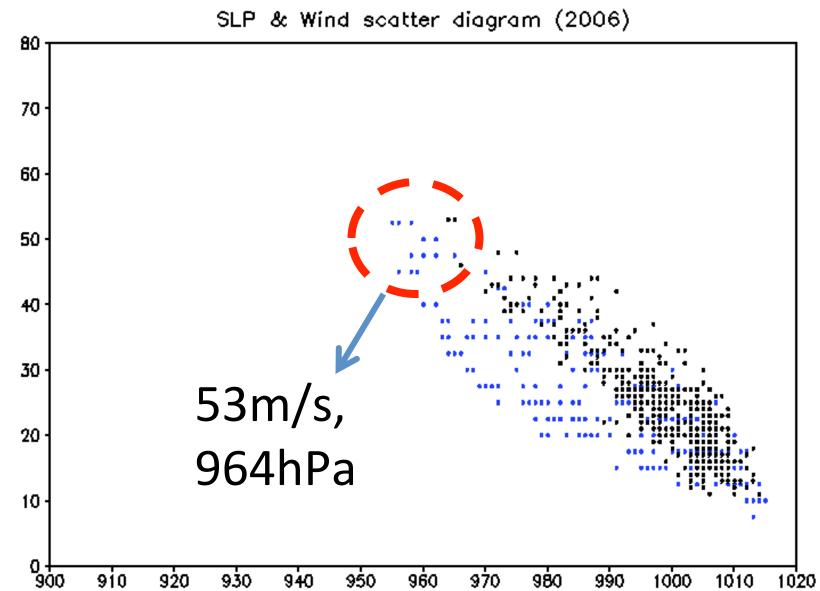
A)



B)



C)



Blue: Obs., Black: Model

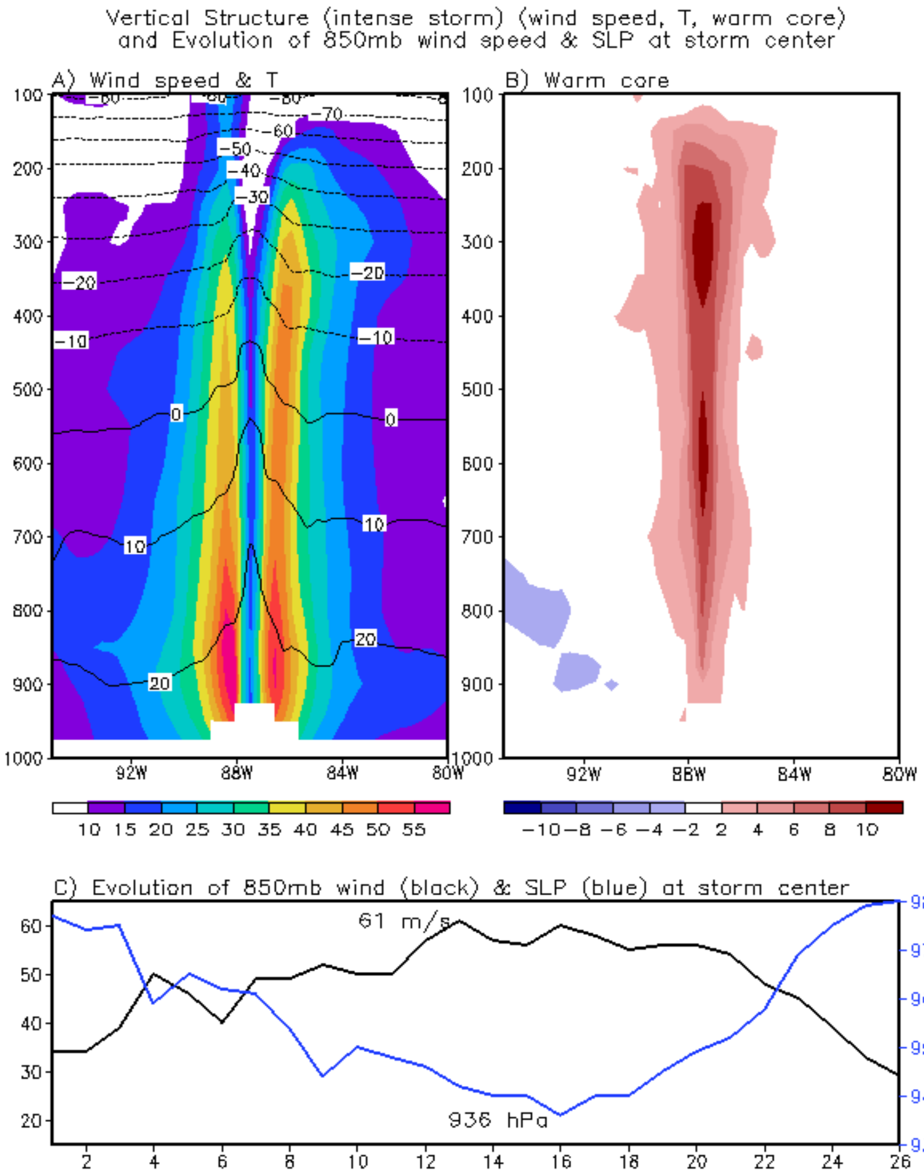
A) Strong MER

B) Less strong MER

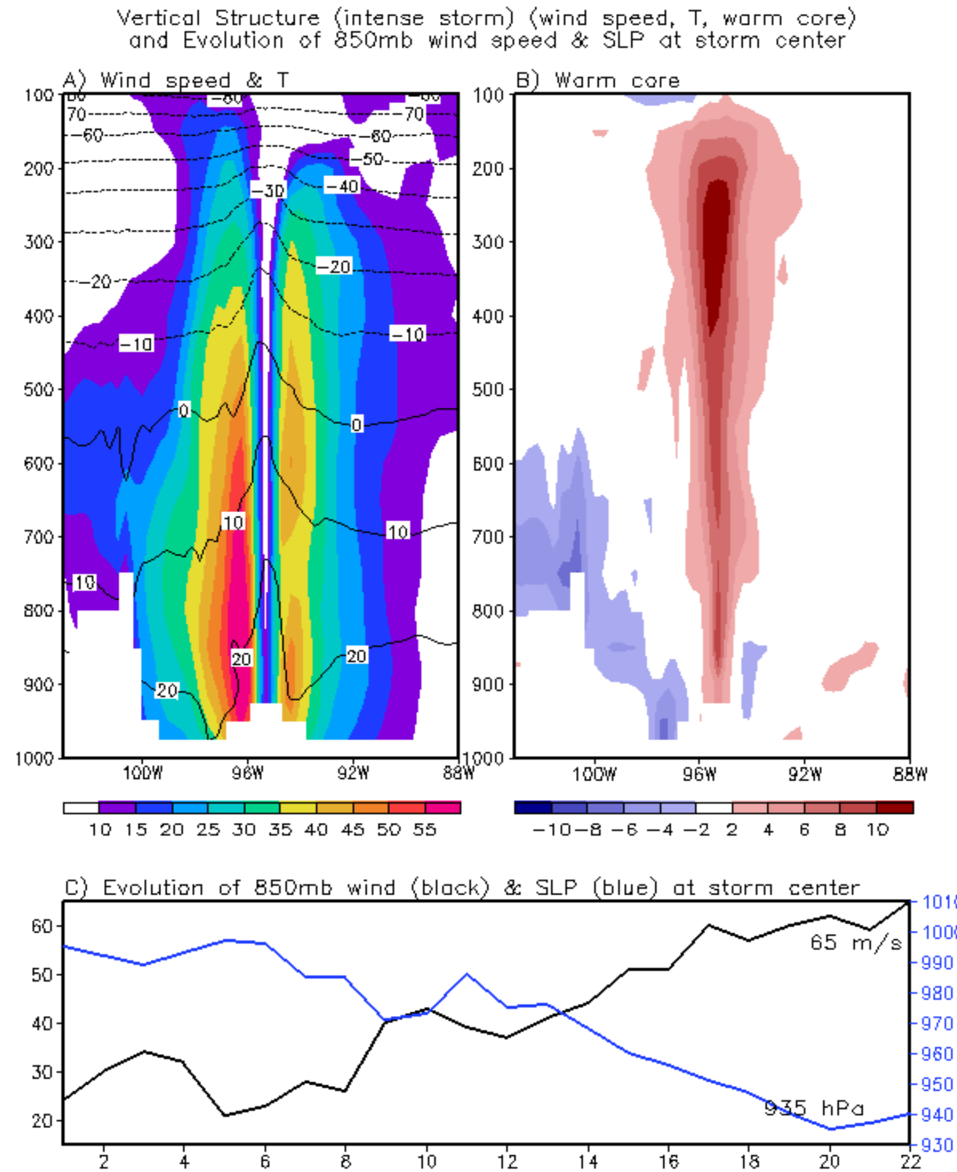
C) Weak MER

Vertical structure of the strong TS (2005, 2006)

Strong MER (2005)



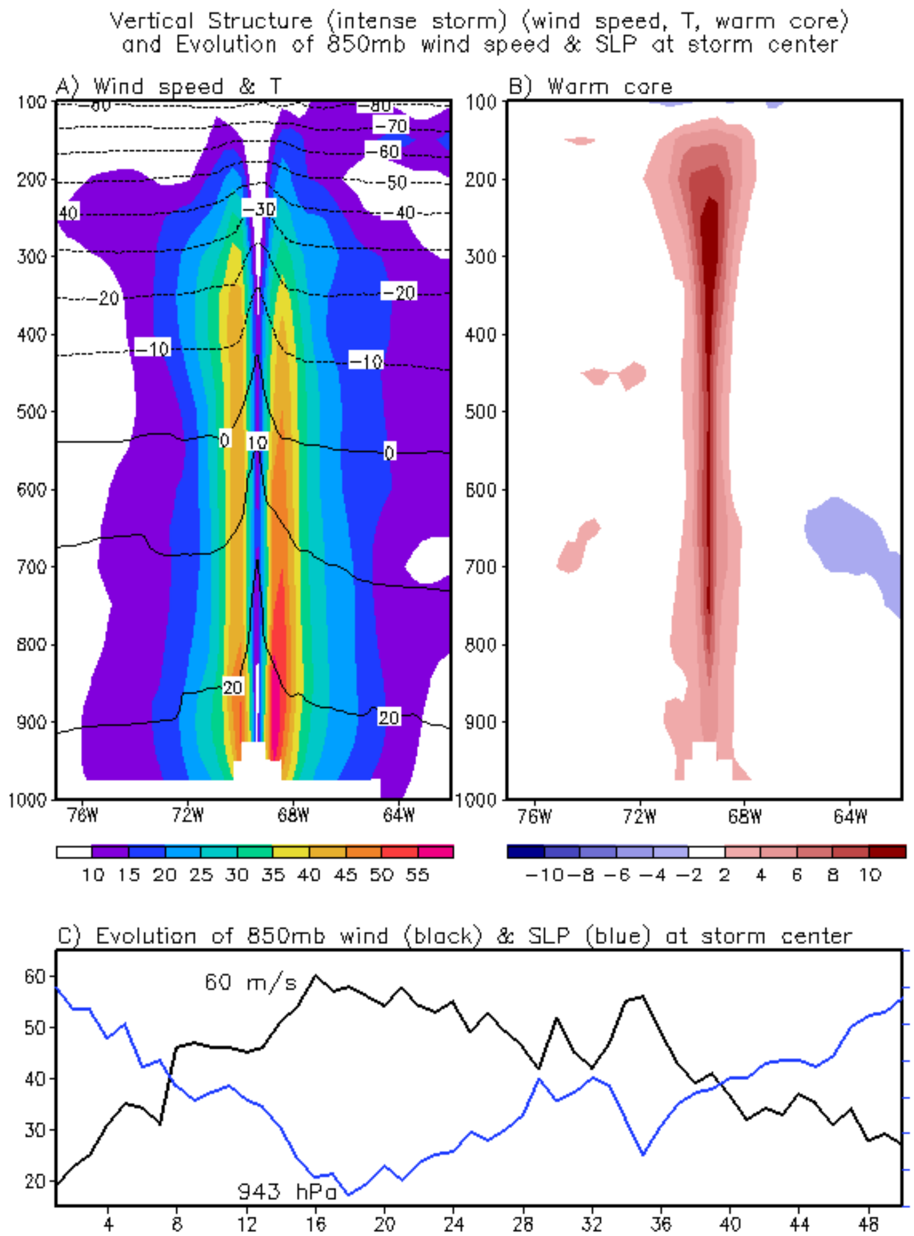
Strong MER (2006)



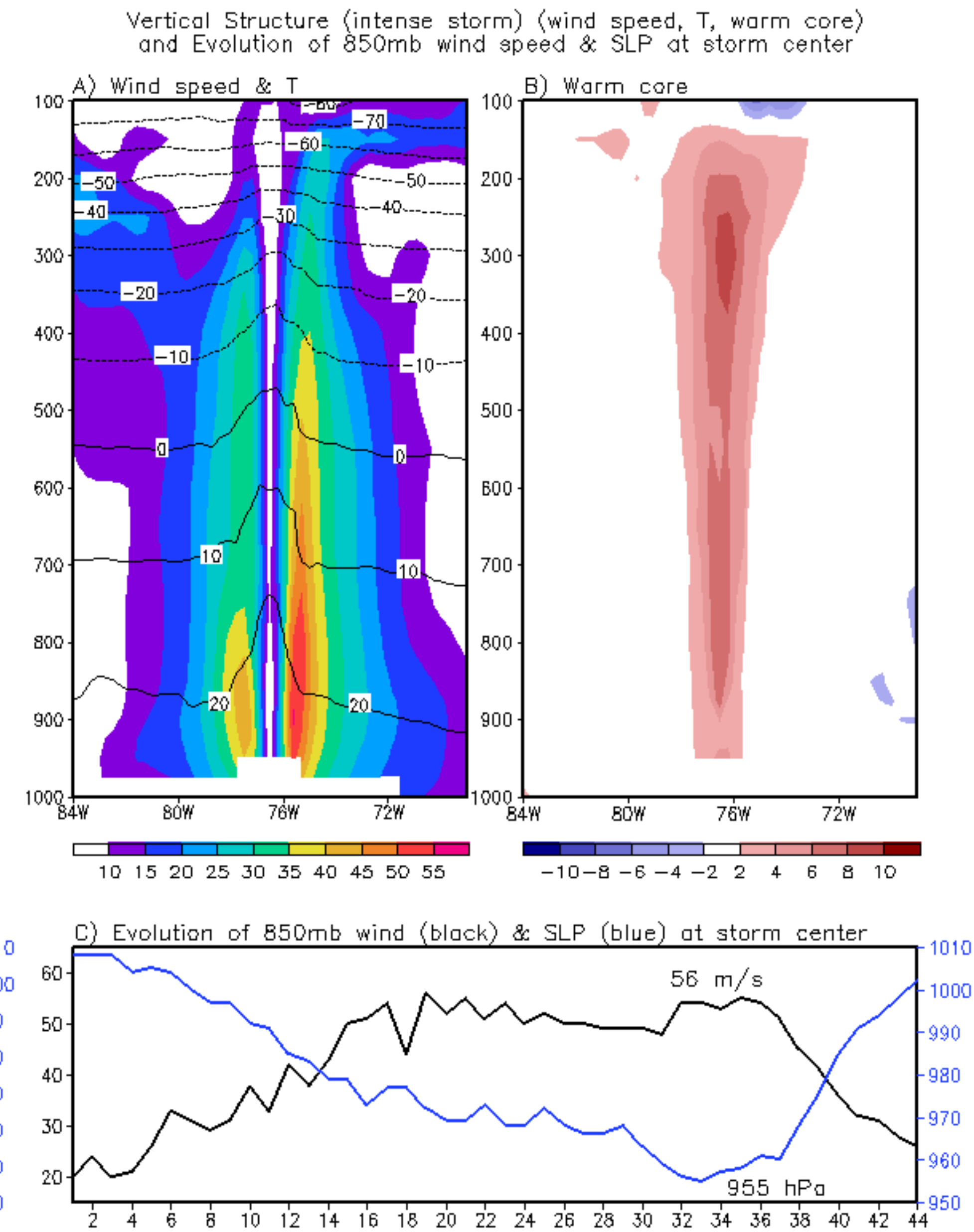
Sharp warm core at upper-troposphere, compact and well-defined eye, max wind at lower elevation, small radius of max wind (less than 50km)

Vertical structure of the strong TS (2005, 2006)

Less strong MER (2005)

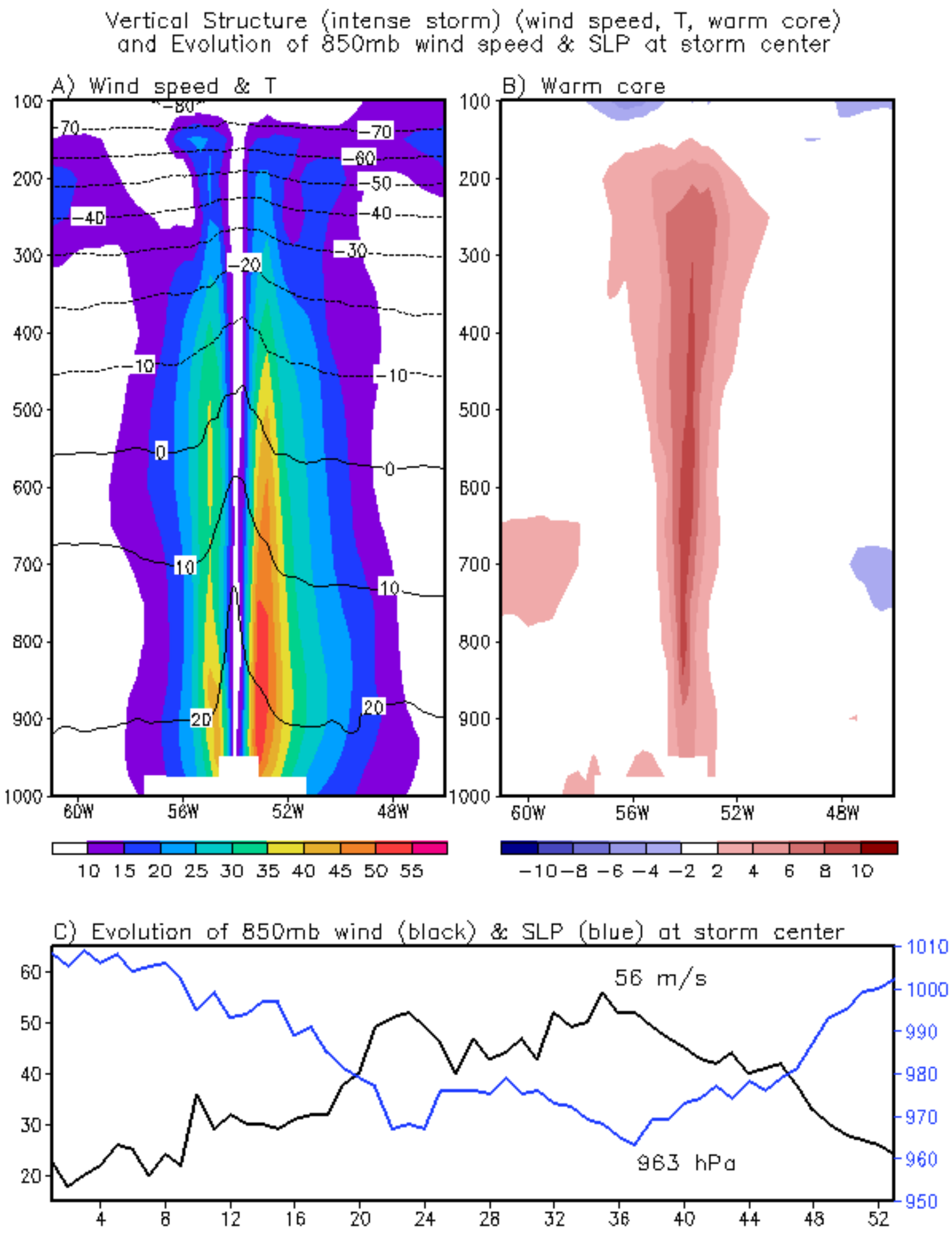


Less strong MER (2006)

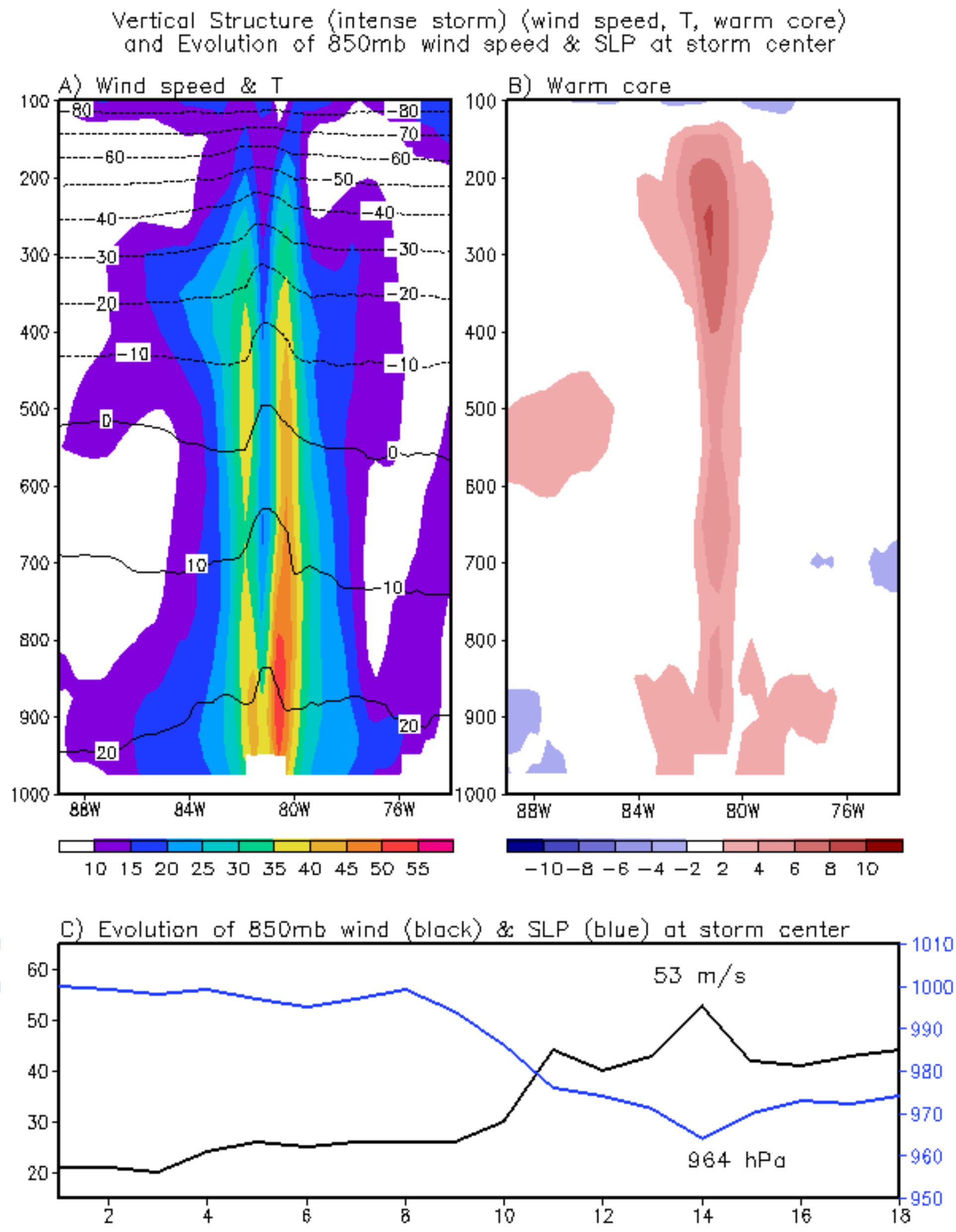


Vertical structure of the strong TS (2005, 2006)

Weak MER (2005)



Weak MER (2006)

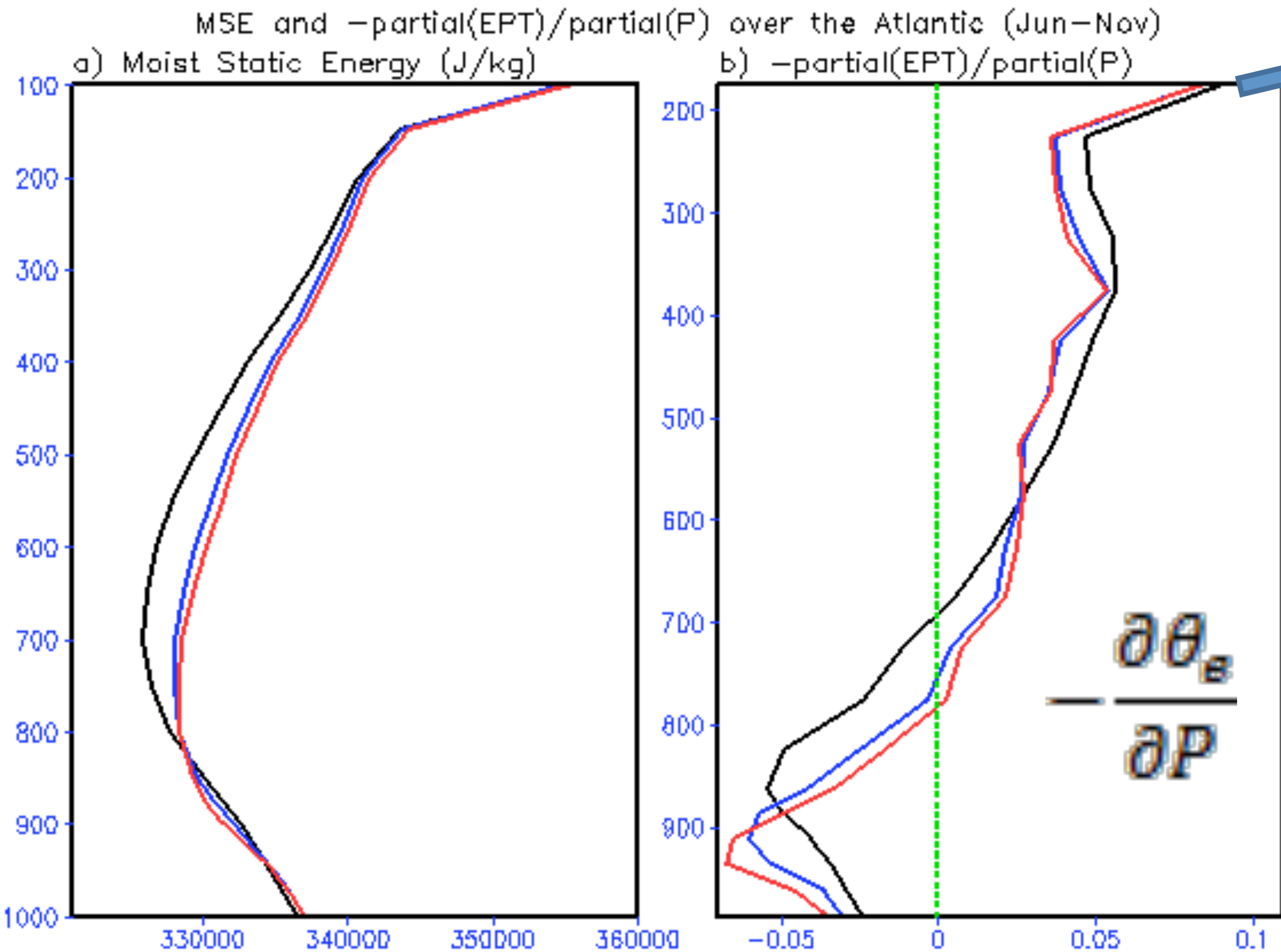


How can we explain the increased storm numbers and intensity under suppression of parameterized cumulus convection?

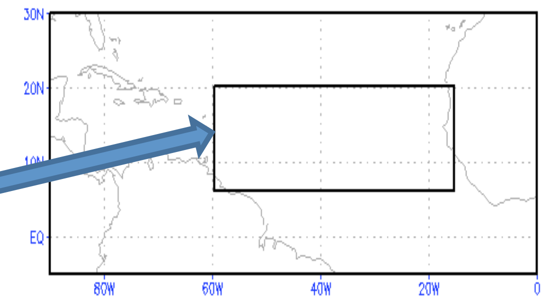
We focus on moist static stability and associated atmospheric features.

Moist Static E. and Vertical change in Theta E

Moist Static Energy **ThetaE ver. grad.**



$$-\frac{\partial \theta_e}{\partial P}$$



Relatively stronger theta_e decrease with height in the strong MER runs -> conditionally more unstable atmosphere

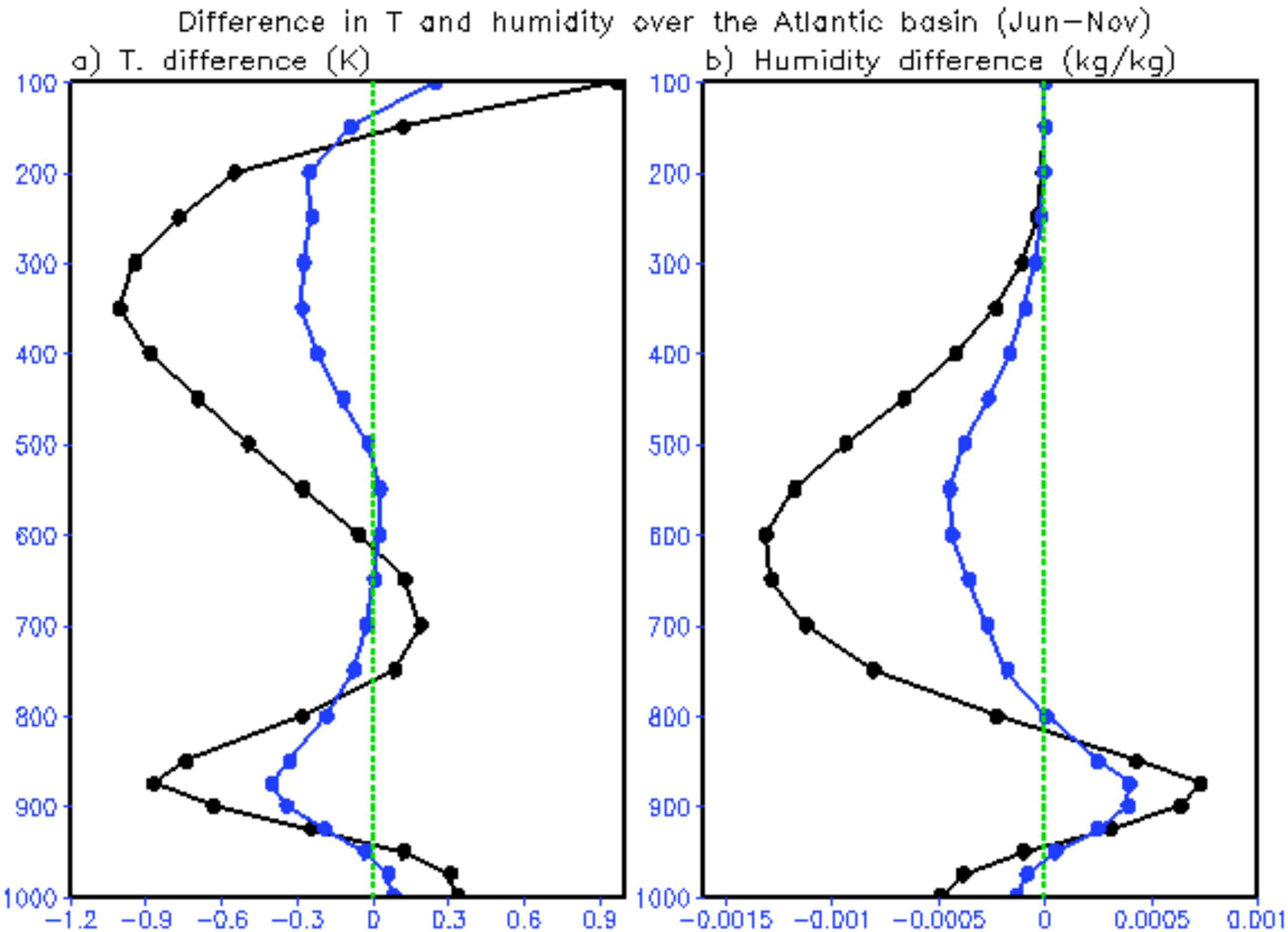
MSE is generally similar to equivalent potential T

Black: (A) **Red: (C)**

Blue: (B)

Temperature and Humidity difference profile

T difference **q difference**



Generally cool T response to the strong MER

Black: (A) – (C)

Blue: (B) – (C)

Drier at near-surface -> requires a flux of water vapor from the ocean sfc. to the air (positive LH flux possible)

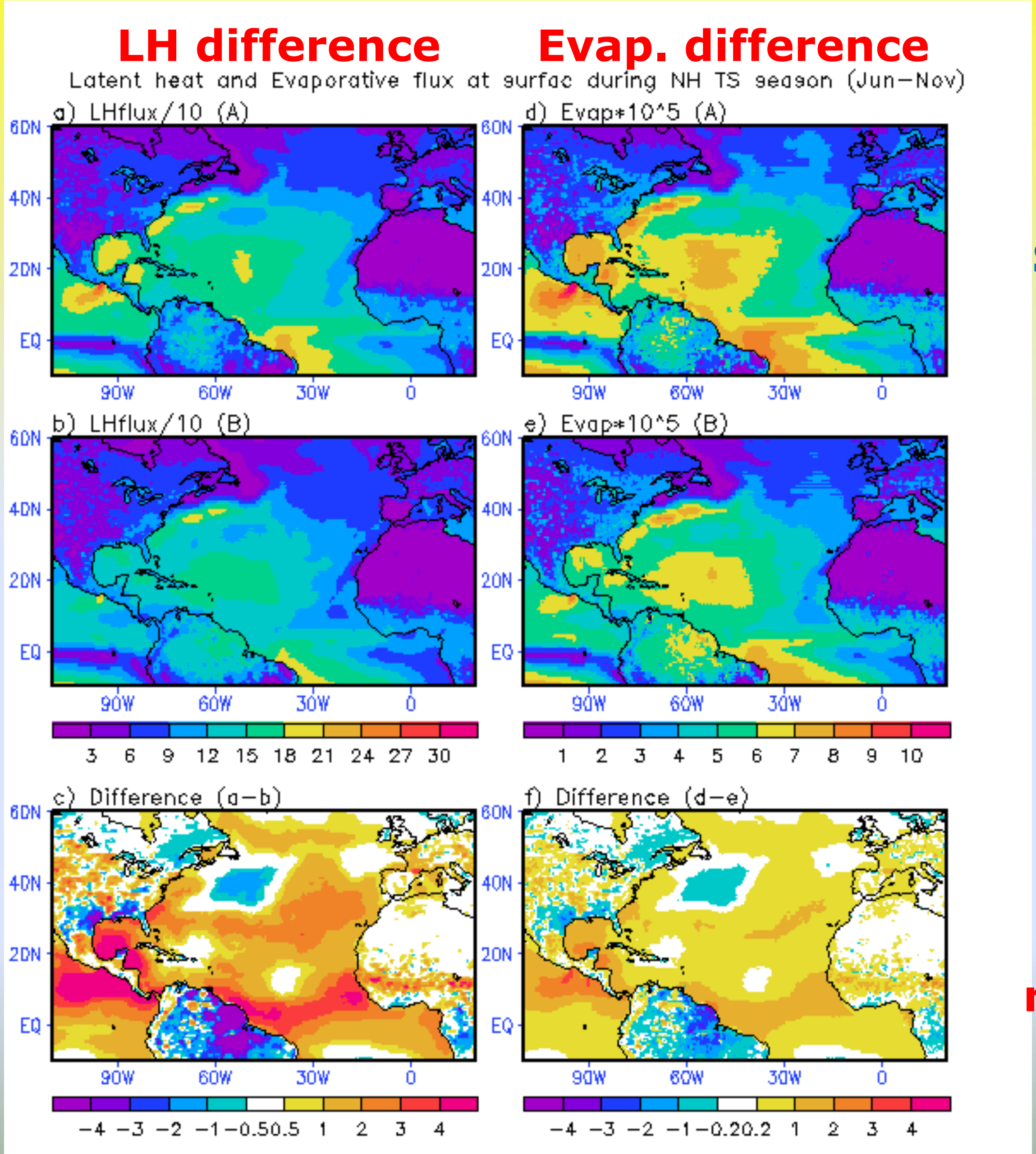
Moist at lower-level and dry at upper-level -> upward moisture flux possible

Latent heat and Evaporative fluxes

A)
Strong MER

C)
Weak MER

A) - B)



A)
Strong MER

C)
Weak MER

A) - C)

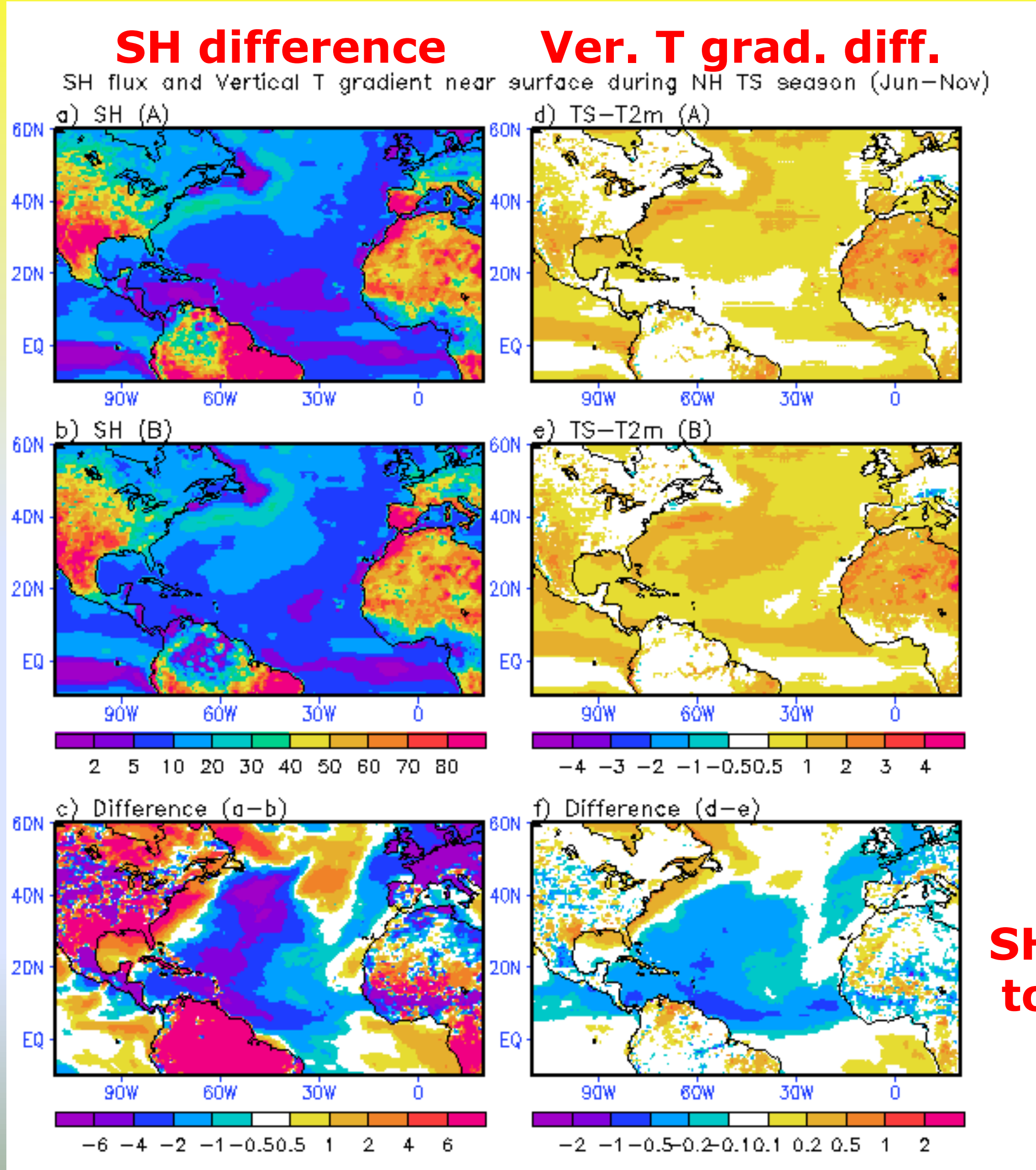
Positive LH reflects Evap fluxes.

SH flux and Vertical T gradient at near-surface

A)
Strong MER

C)
Weak MER

A) - C)



A)
Strong MER

C)
Weak MER

A) - C)

SH doesn't seem to contribute to moist static instability

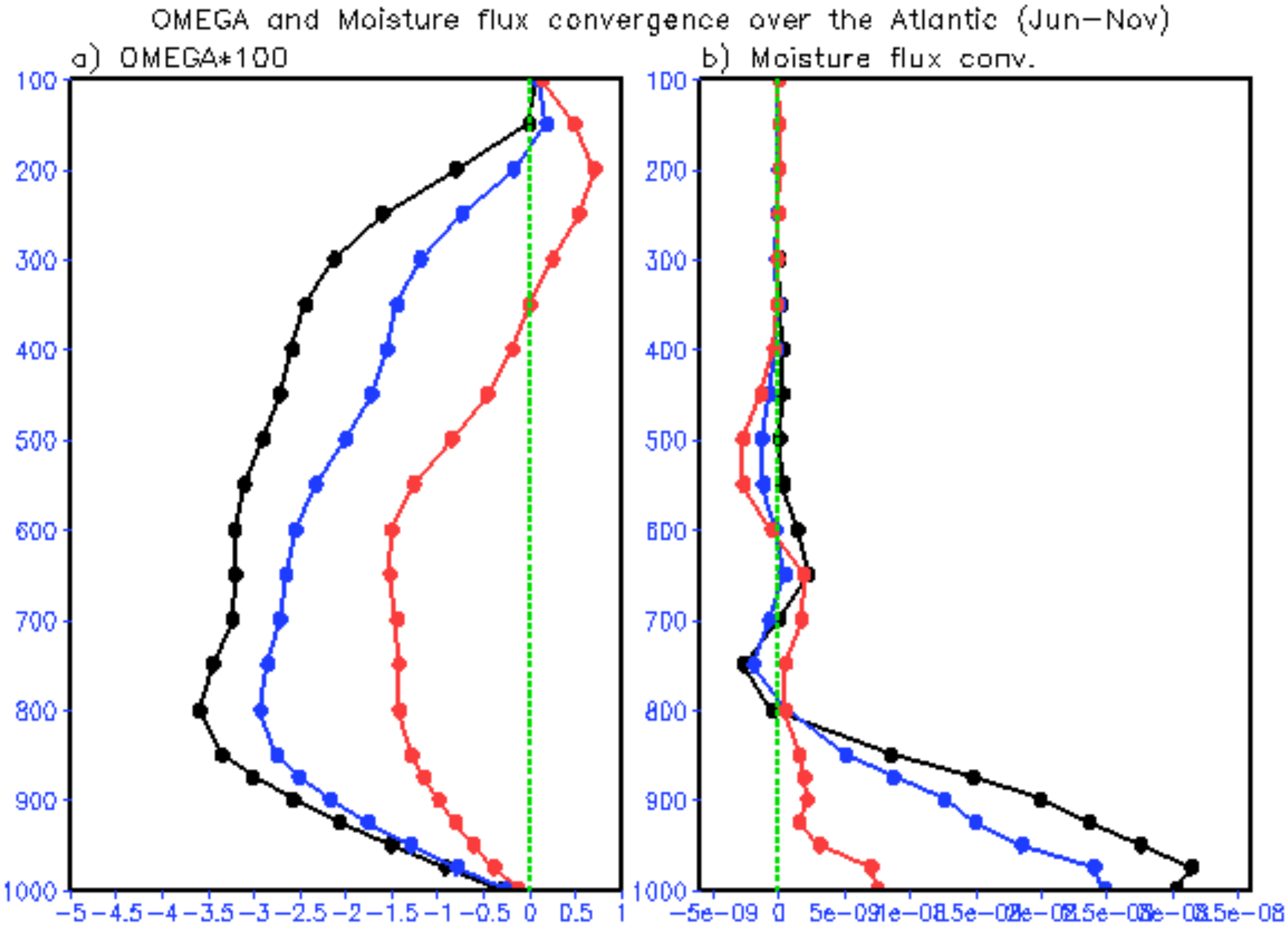
What takes place as a result of this atmospheric instability?

(as shown on the next few slides……)

Strong upward motion, lower-level convergence and positive vorticity, moisture flux convergence, more resolved-scale convective activity --> increased TC numbers and intensity

Vertical motion (OMEGA) and Moisture flux conv.

Vertical Vel. (OMEGA) **Moist. Flux. Conv.**



Black: (A) **Red: (C)**

Blue: (B)

Stronger upward motion with larger MER (unstable condition),

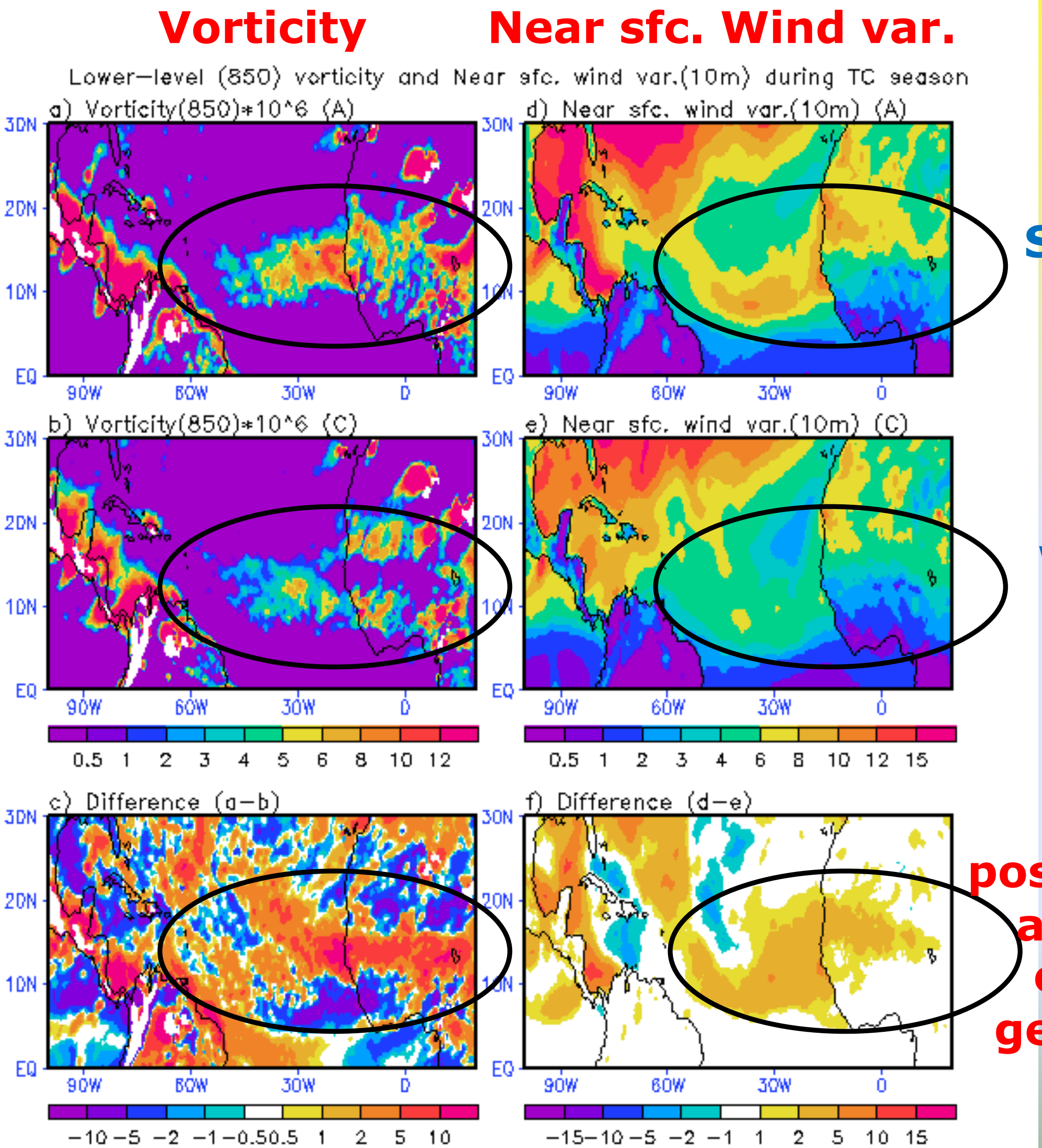
larger lower-level moisture flux convergence (active moist convection possible)

Vorticity (850) and Near sfc. wind var. (10m)

A)
Strong MER

C)
Weak MER

A) - C)



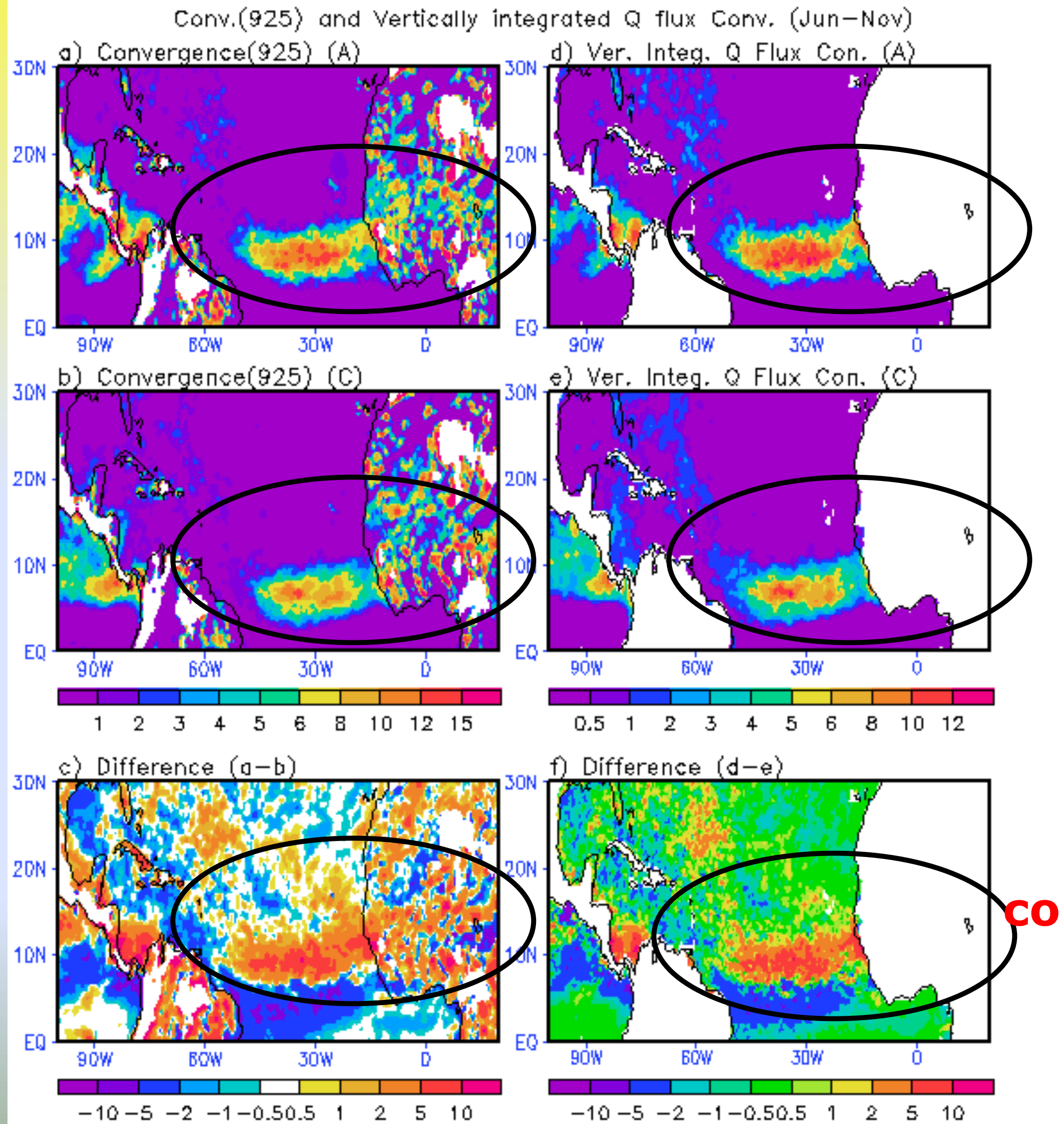
A)
Strong MER

C)
Weak MER

Enhanced positive vorticity and variance over the TC genesis region

Lower-level Convergence (925) and Vertically integrated moisture flux convergence

Convergence **VIMFC**



A)
Strong MER

C)
Weak MER

A) - C)

A)
Strong MER

C)
Weak MER

A) - C)

Stronger convergence and moist convection

Conclusion and Discussion

1. High-resolution (0.25 degree) with slight increase in MER produced better organized TC structures and more realistic TC numbers and intensity over the Atlantic.

2. Further increase in MER produces even stronger TCs, but tends to overestimate the TC numbers

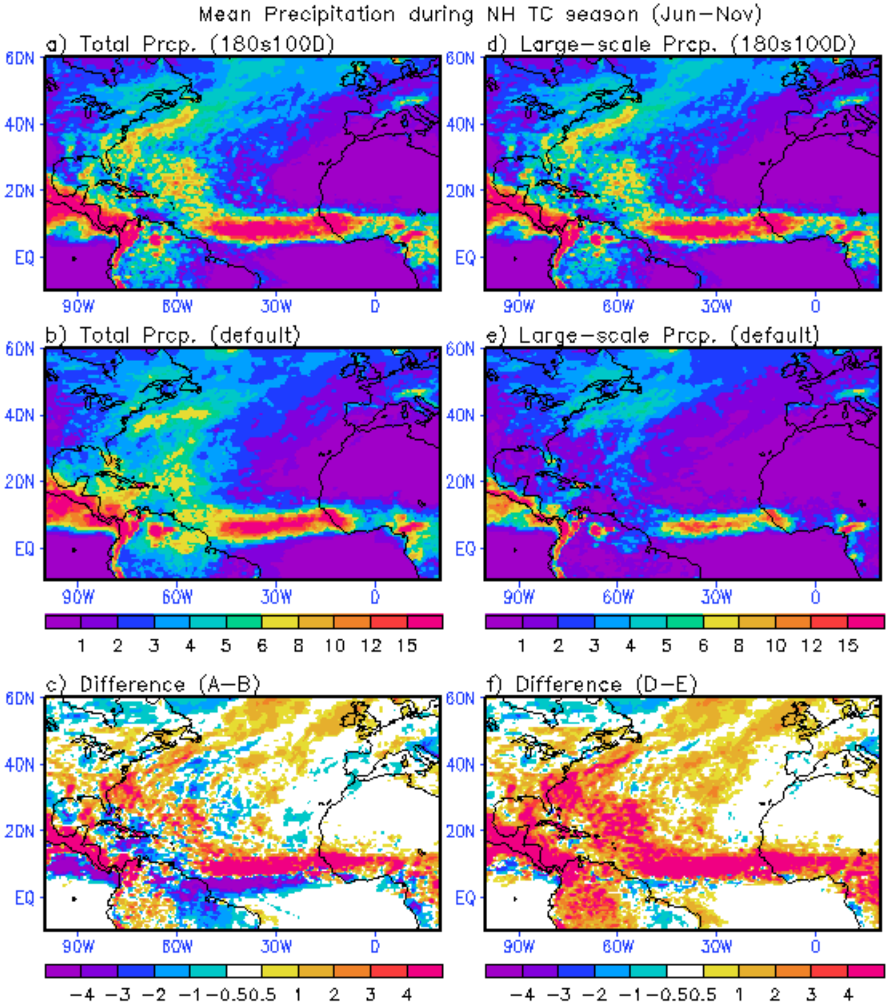
3. Increase in MER constrains the parameterized deep convective activity (result: increase in large-scale prcp., decrease in convective prcp.). Stronger suppression of the cumulus parameterization constructs more unstable atmosphere (LH flux, lower-level moistening and upper-atmosphere cooling contributes to development of unstable atmosphere).

4. Upward motion and moisture flux convergence is enhanced. It results in more tropical storms and hurricanes. Strong hurricane (category up to 4) is captured.

Precipitation bias (total, large-scale)

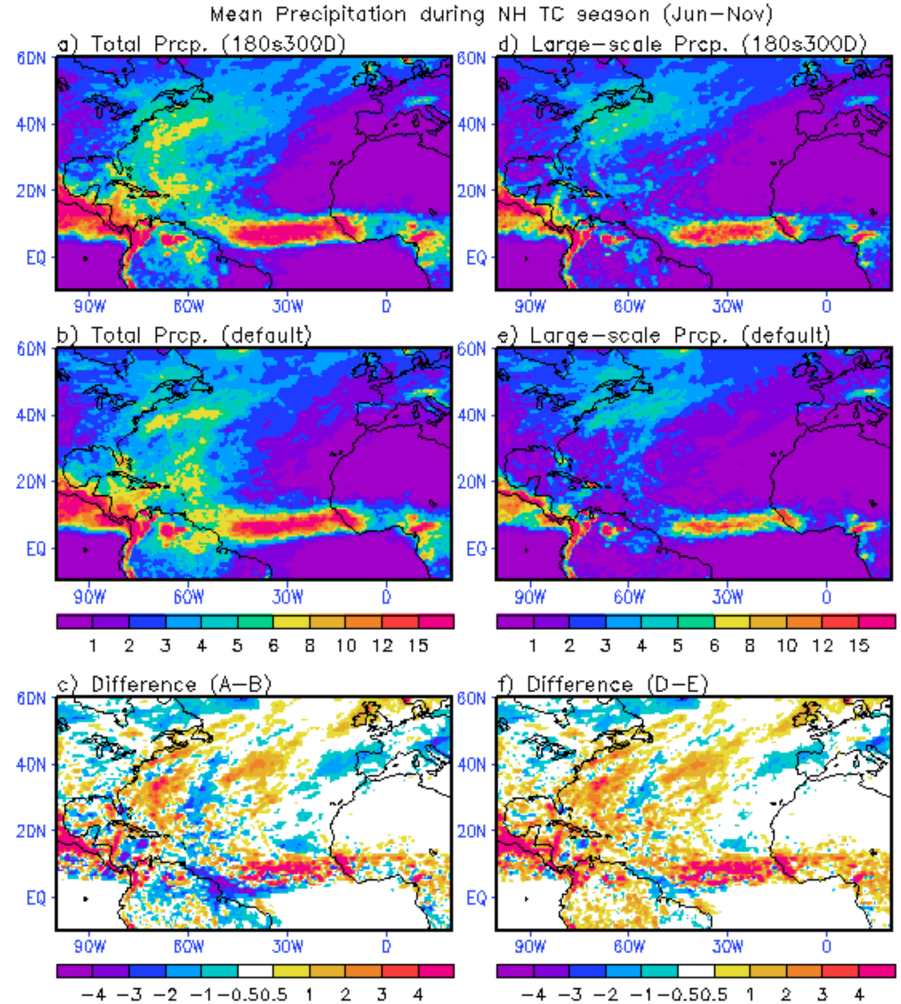
Strong MER — **Less strong MER**

Total — **Large-scale Prcp.**



A) - C)

Total — **Large-scale Prcp.**



B) - C)

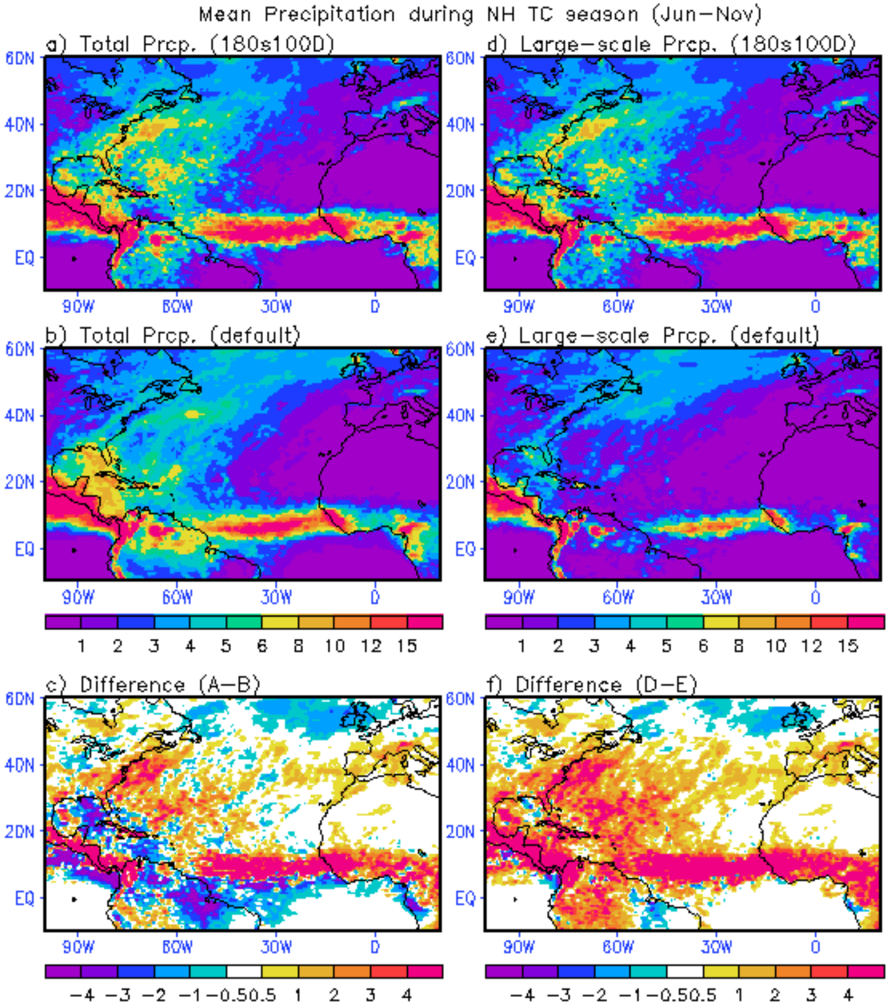
Total precipitation bias (mm/day, area averaged over the Atlantic basin (90W-0E, 0N-50N)

	A) – C)	B) – C)
2005 **Obs. =3.62**	**4.89 – 4.40 = 0.49**	**4.43 – 4.40 = 0.03**
2006 **Obs. =3.57**	**5.02 – 4.42 = 0.60**	**4.51 – 4.42 = 0.09**

Precipitation during hurricane season in 2006

Strong MER

Total **Large-scale Prcp.**



A little strong MER

Total **Large-scale Prcp.**