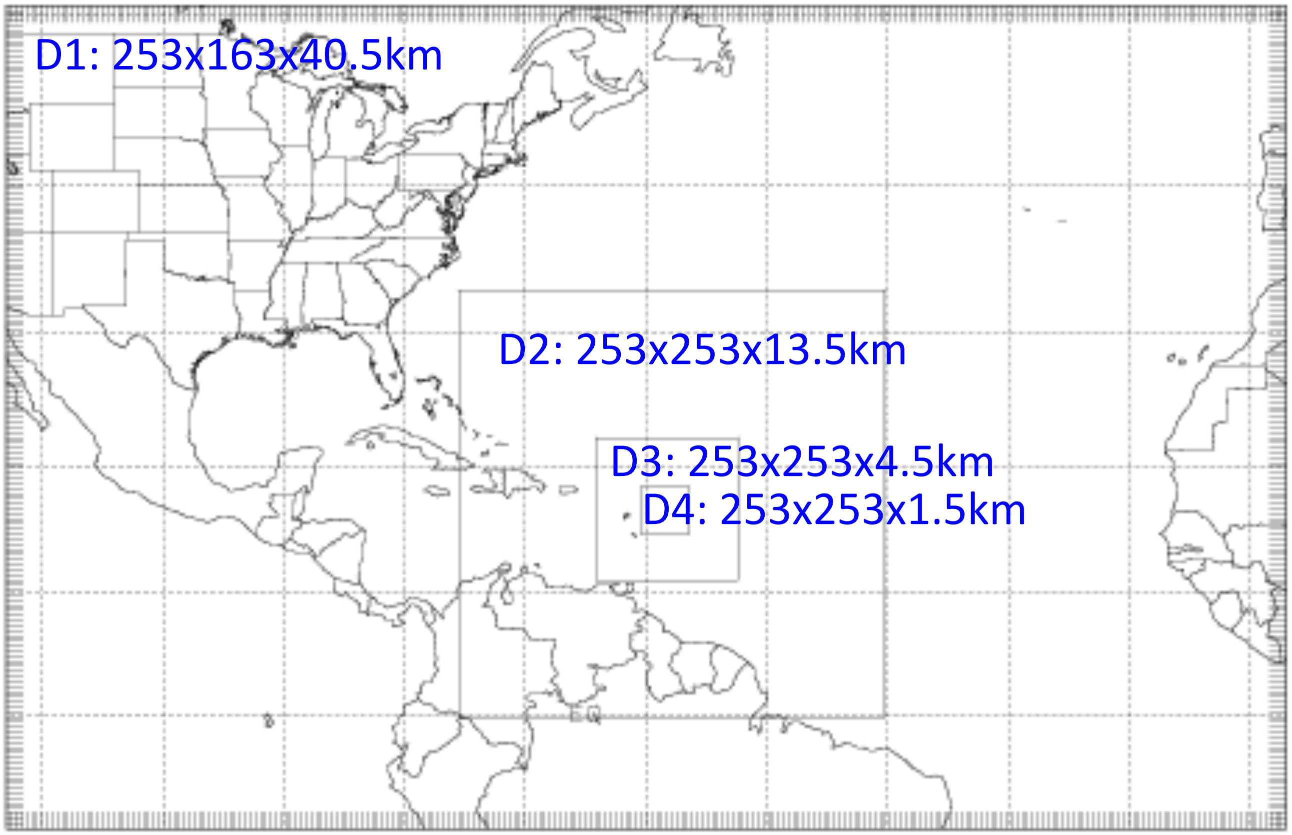
Dynamics and Predictability of the Formation of Hurricane Karl (2010) Revealed from Convection-Permitting Ensemble Analysis and Forecasting

Fuqing Zhang
Penn State University

Contributors: Xiaqiong Zhou, Bin Wang, Yonghui Weng, Xuyang Ge, Jon Poterjoy and Dandan Tao

PSU ARW-EnKF Real-time Configurations



- **35 vertical levels;**
- **WSM 6-class microphysics;**
- **YSU PBL;**
- **Grell-Devenyi CPS**

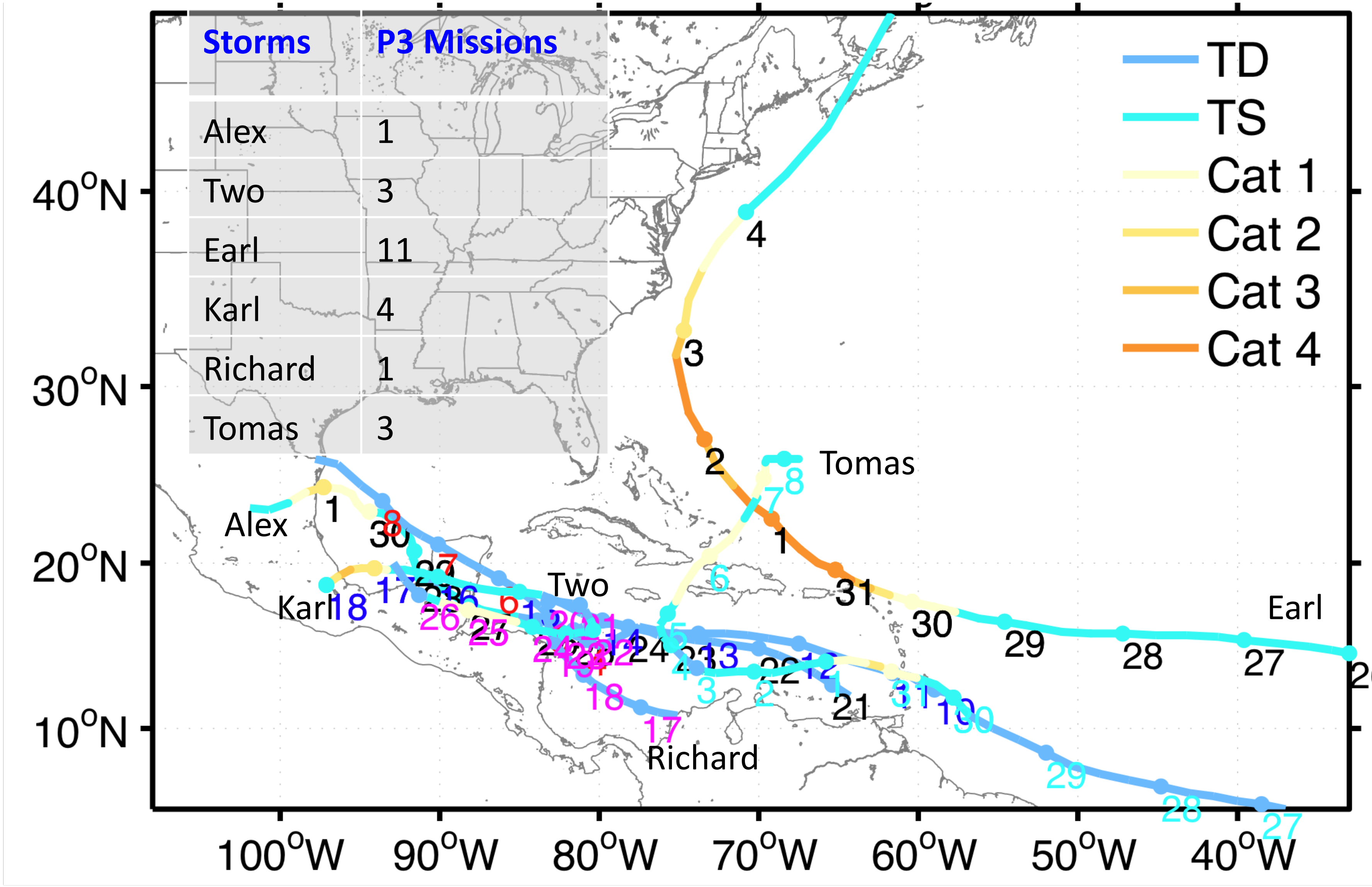
- **30-member ensemble;**
- **Gaspairi&Cohn 99' covariance localization with varying RoI**

- **IC & BC: GFS using 3DVAR background uncertainty**

- **Assimilation is performed over D1-3. D4 is used only for high-res forecast.**

- **The inner domains are centered with the storm's center**
- **Two realtime runs:**
  - **One every 12 h assimilating conventional obs in D1-D2 EnKF hybrid with GFS**
  - **One assimilation is performed over D1-3 where there is P3 airborne Doppler obs.**

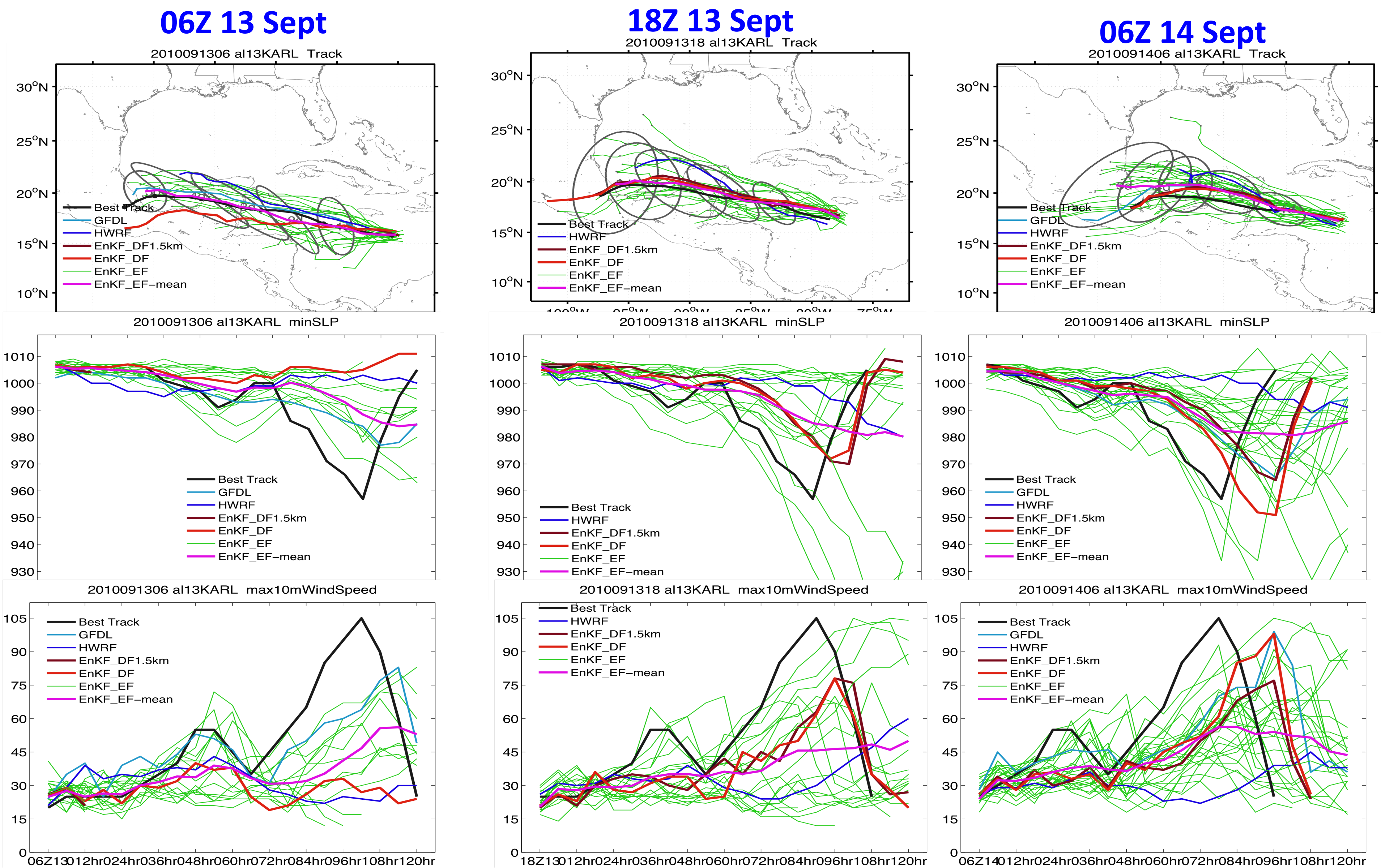
AL2010: 23 Missions/Cases Total



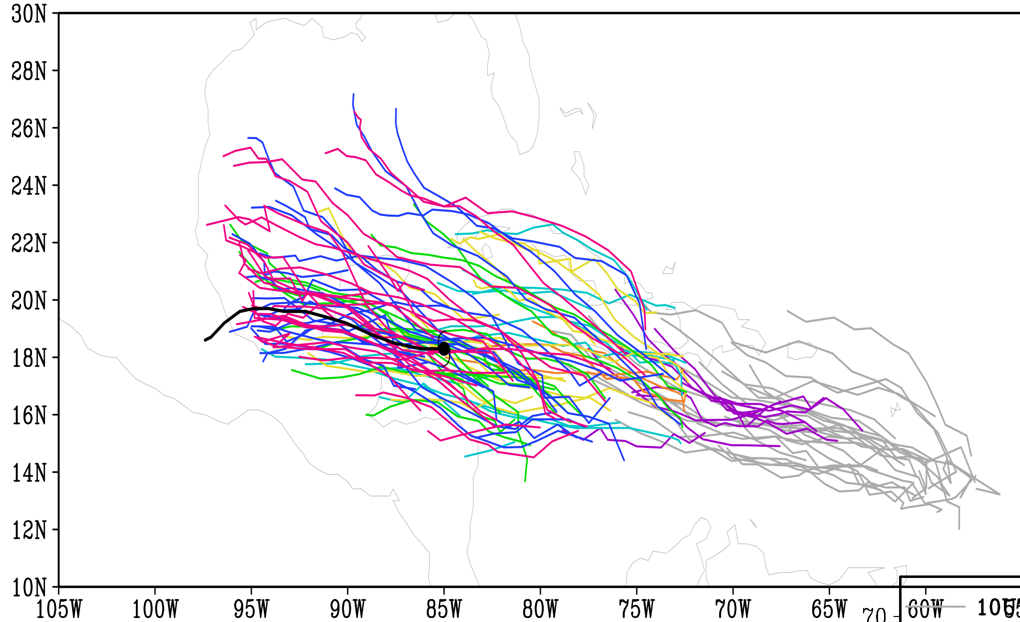
Storms	P3 Missions
Alex	1
Two	3
Earl	11
Karl	4
Richard	1
Tomas	3

NOAA P3 Airborne Doppler Missions for the 2010 Atlantic Hurricane Season

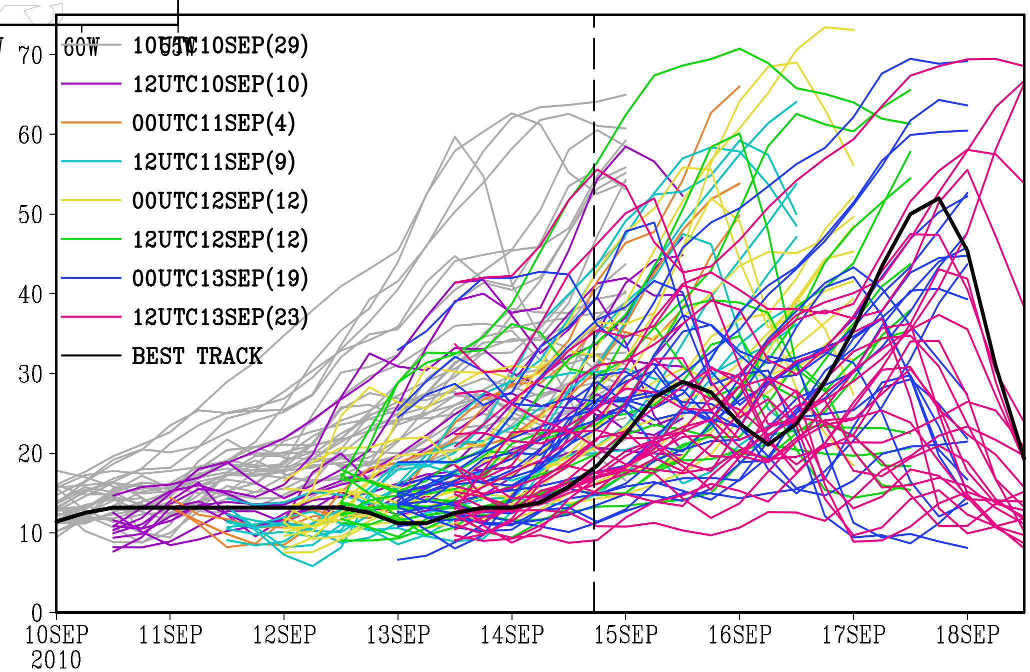
Assimilation Airborne Doppler Observations during the Formation of Karl



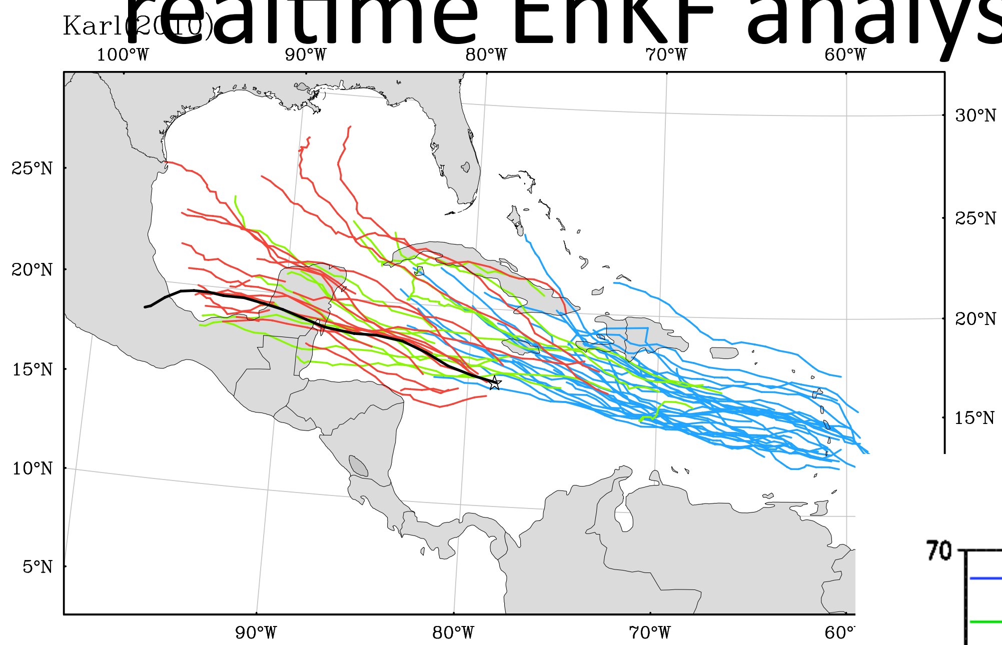
WRF 4.5-km realtime EnKF of conventional obs hybrid with operational GFS analysis



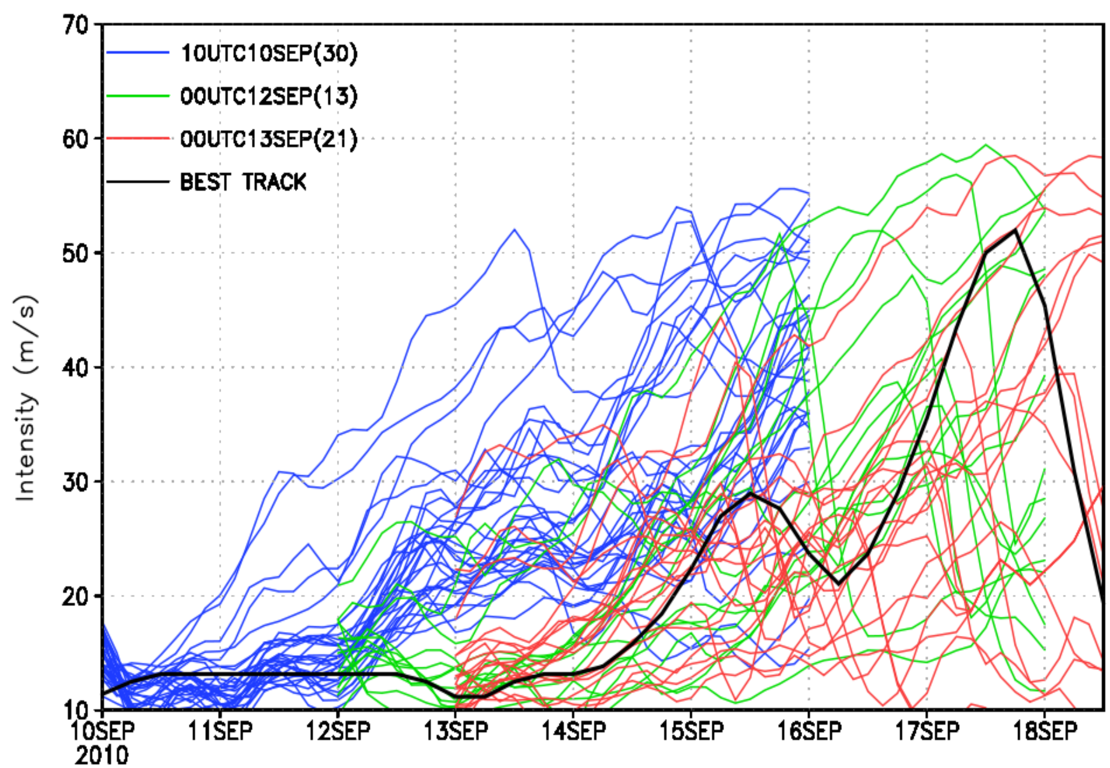
Every 12 h from 00Z 10 Sept
To 12Z 13 Sept



Recent reruns of ensemble forecasts with realtime EnKF analysis but w/ enlarged D3



00Z 10,
00Z 12
00Z 13 Sept

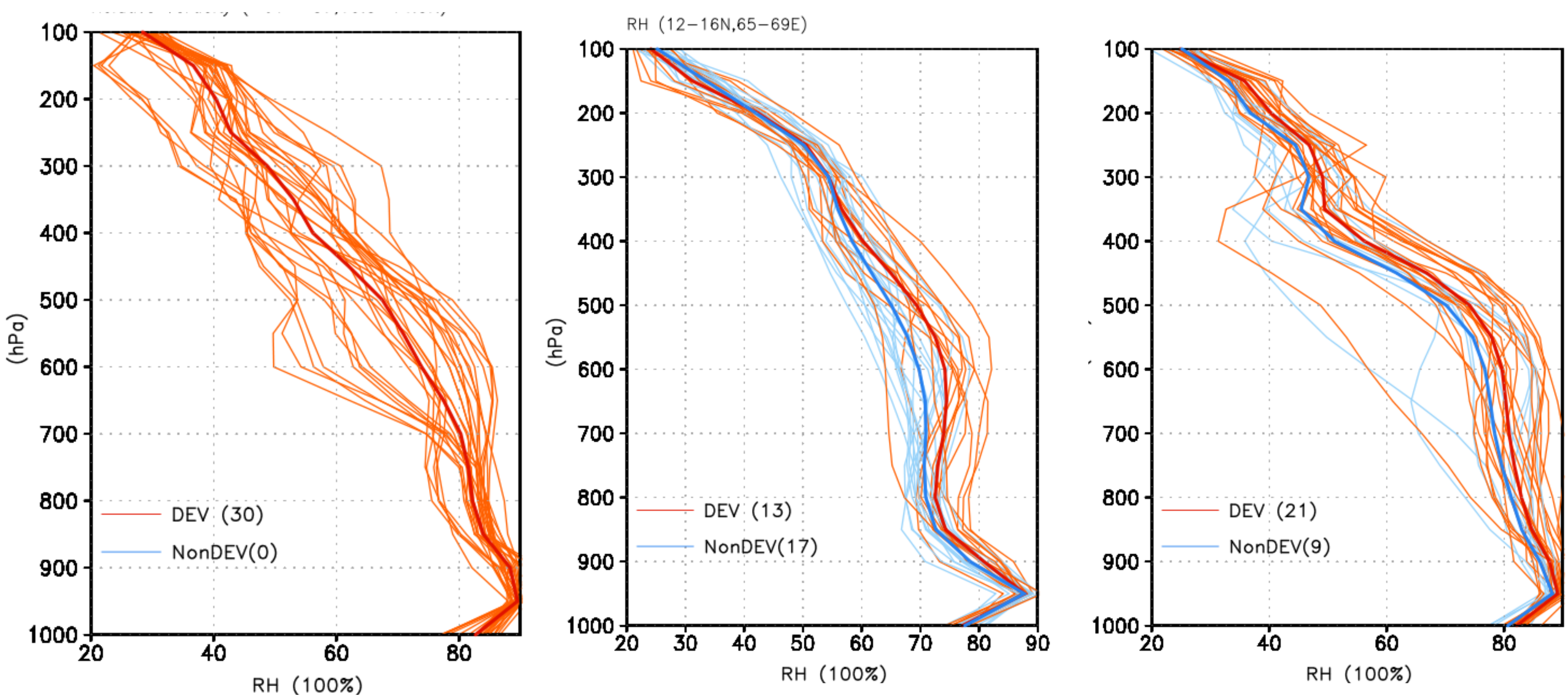


- **What controls the formation of Karl and how predictable?**

Difference in Environment Conditions

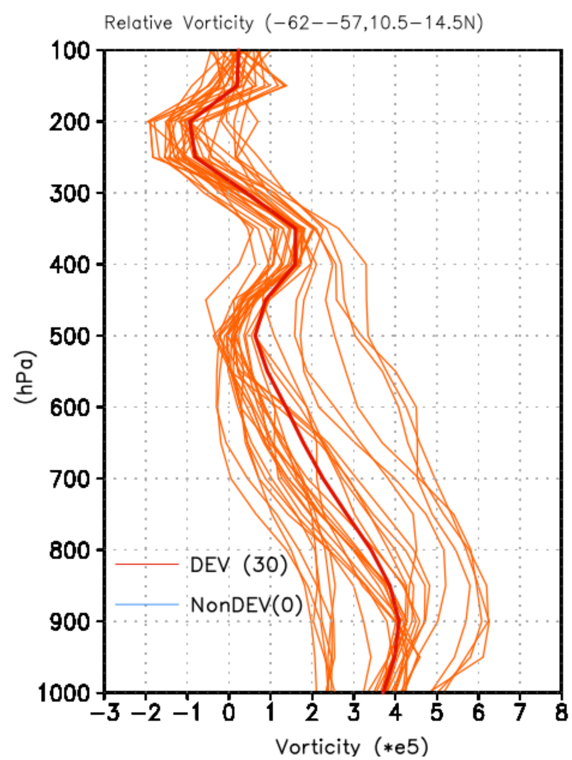
Area-Averaged Initial RH vertical profiles of developed and non developed tropical disturbances at T= 0 hr

00Z10SEP2010 00Z12SEP2010 00Z13SEP2010

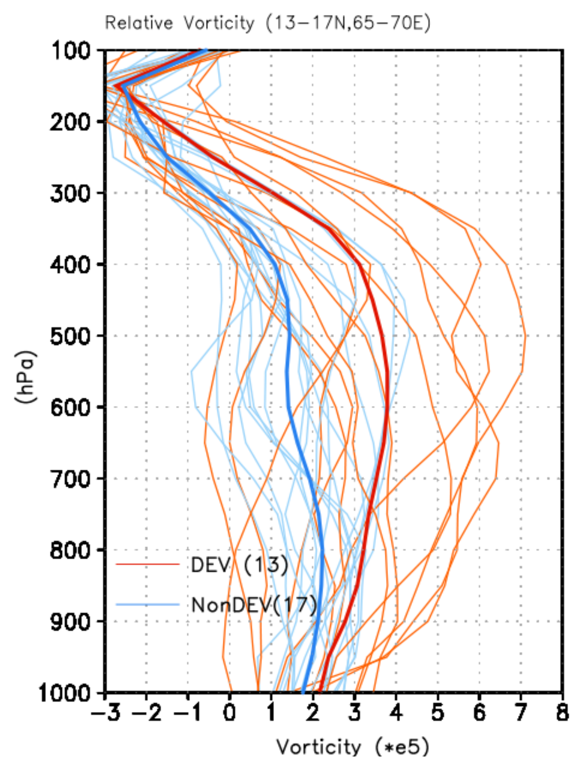


Relative vorticity vertical profiles for developed and non-developed tropical disturbances at T= 0 hr averaged in disturbance area

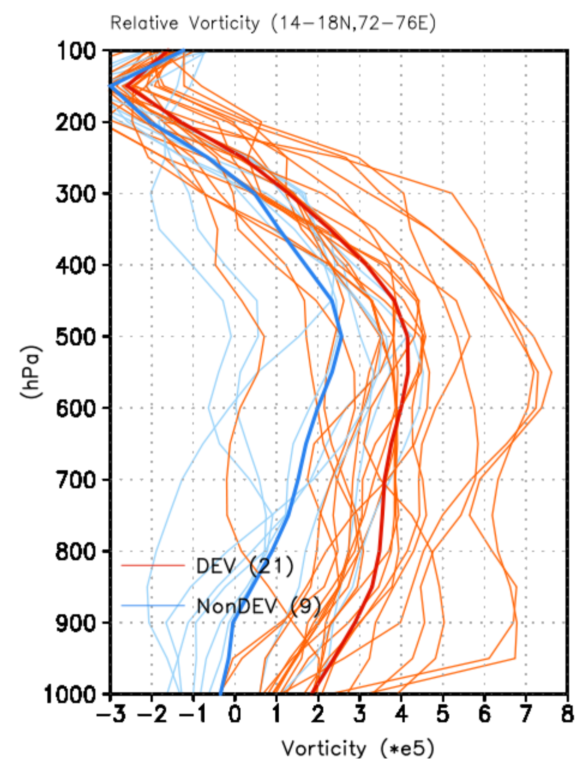
00Z10SEP2010



00Z12SEP2010



00Z13SEP2010



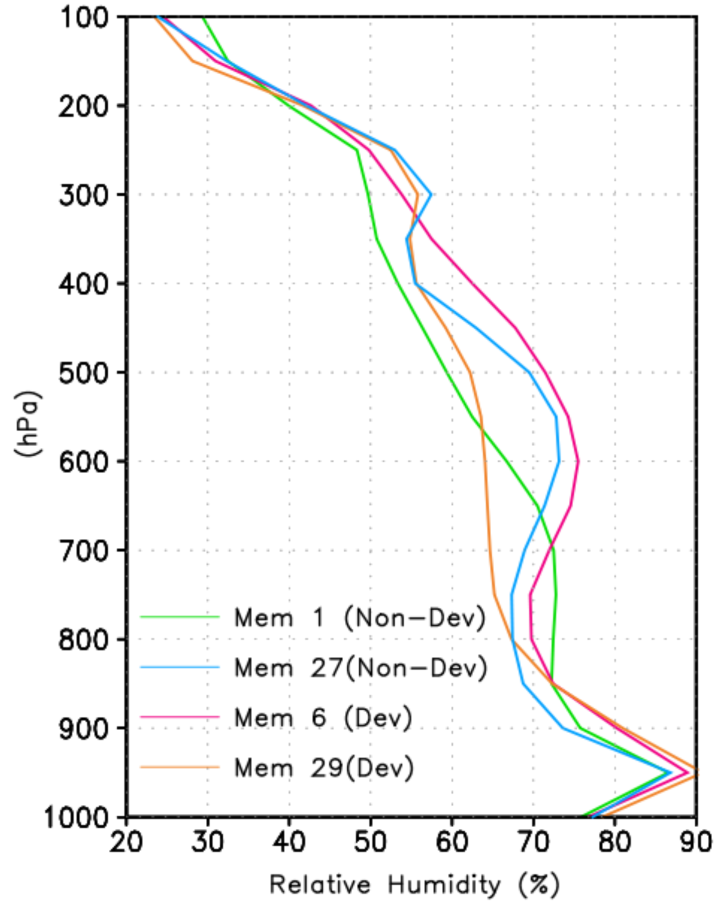
Difference in Environment Conditions for 00Z12 Ensemble: developed vs. non-dev

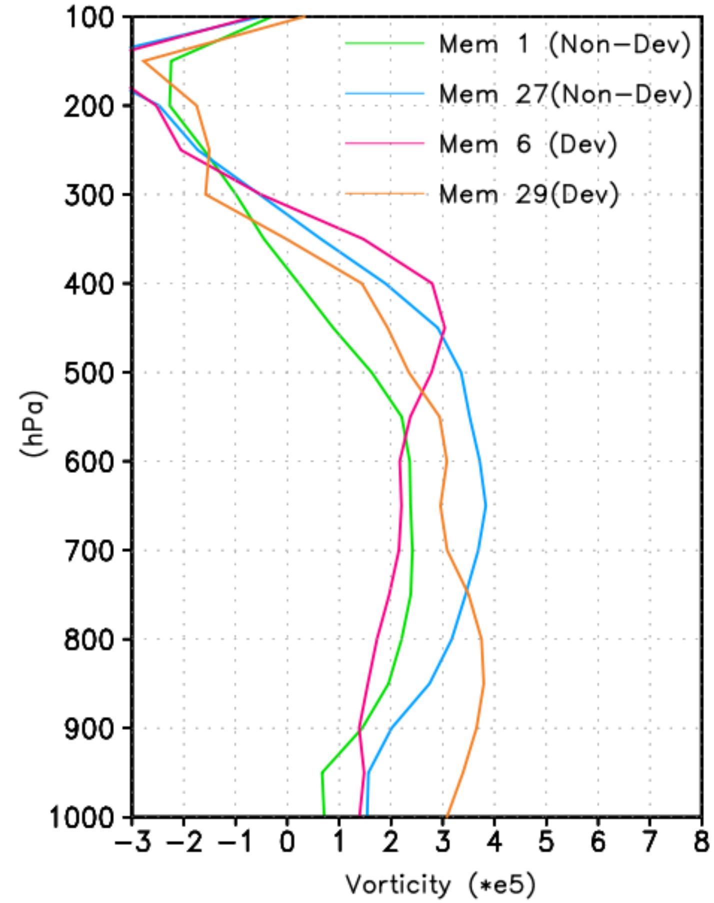
	RHTT (%)	VOR850 $(10^{-5}\ S^{-1})$	SHRD $(m\ s^{-1})$	SHRS $(m\ s^{-1})$	CAPE (J/kg)	MPI (Kt)	GPI
NON-DEV (17)	**65.9**	**2.7**	**6.4**	5.0	**1442**	148.2	**112.8**
DEV (13)	**71.3**	**3.2**	**8.8**	5.9	**1323**	149.6	**126.5**

00Z12SEP2010

RHTT: 700hPa-500 hPa relative humidity (<400km)
VOR850: 850 hPa relative vorticity (<400 km)
SHRD: 200-850 hPa horizontal wind vertical shear (<600 km)
SHRS: 500-850hPa horizontal wind vertical shear (<600km)
CAPE: Convective available potential energy (<400km)
MPI: Maximum potential intensity (Emanuel, 1986)
GPI: Genesis potential index (Emanuel, 2006)

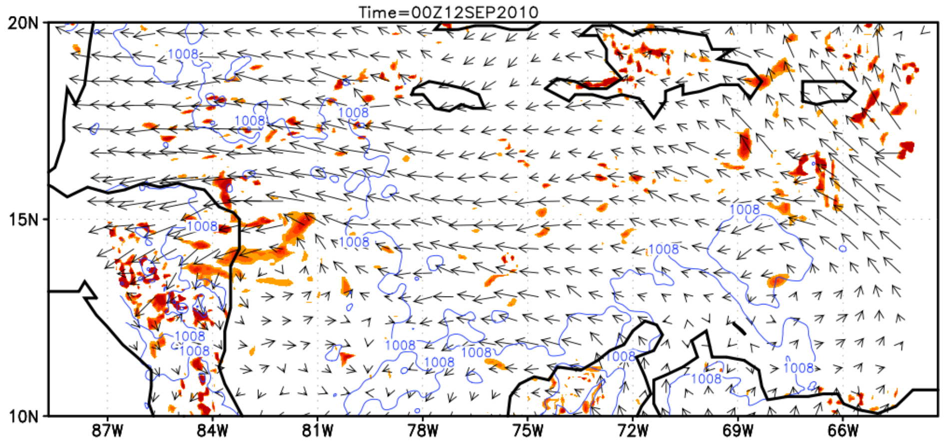
Difference in Environment Conditions : developed vs. non-dev examples



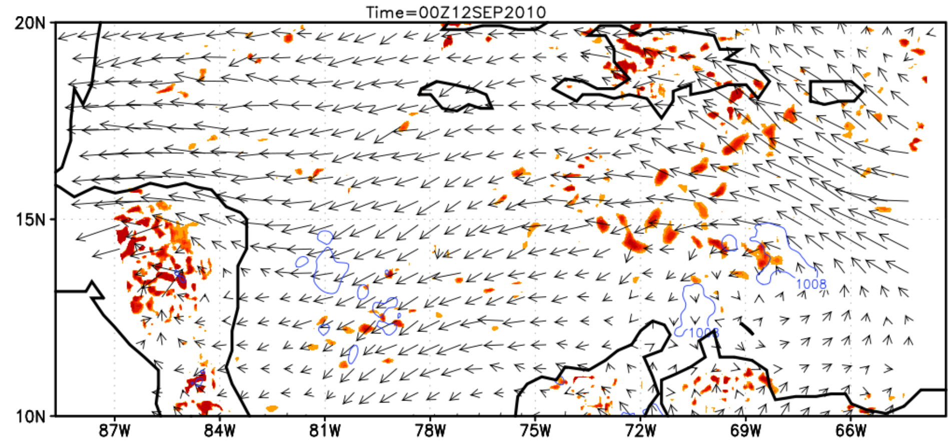


Developer vs. non-developer: 0h (00/12)

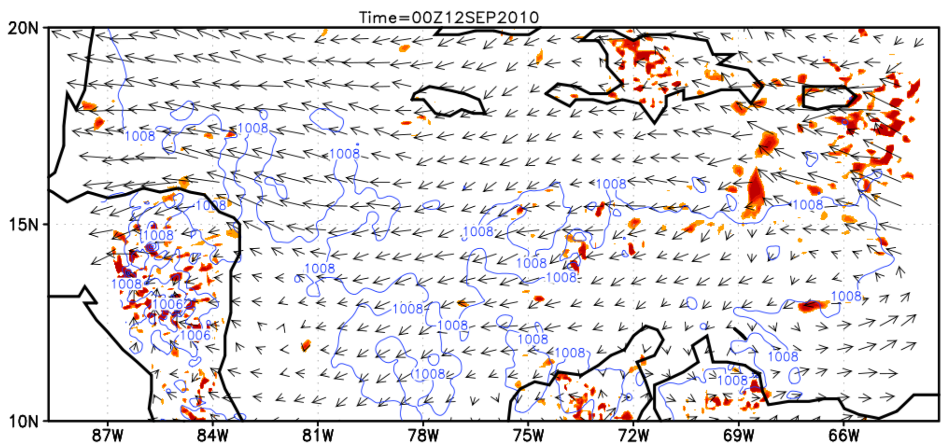
Member 1



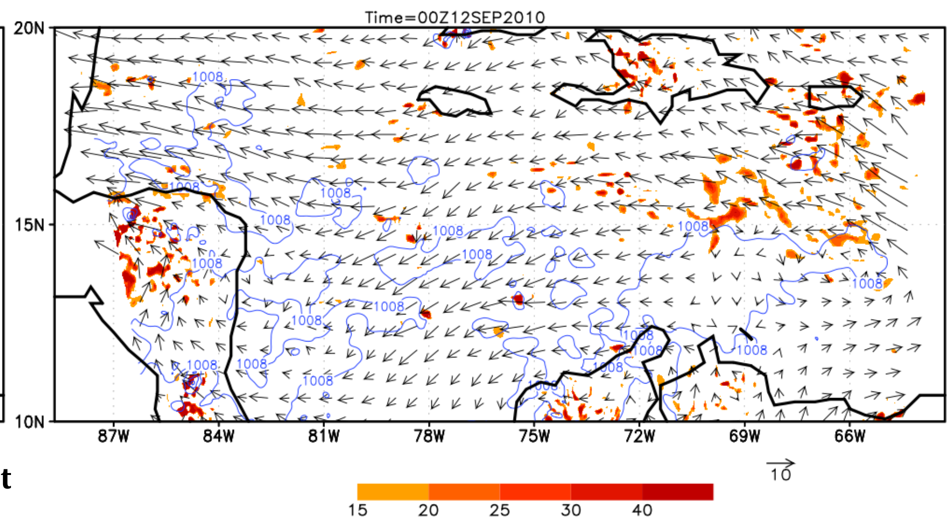
Member 29



Member 6



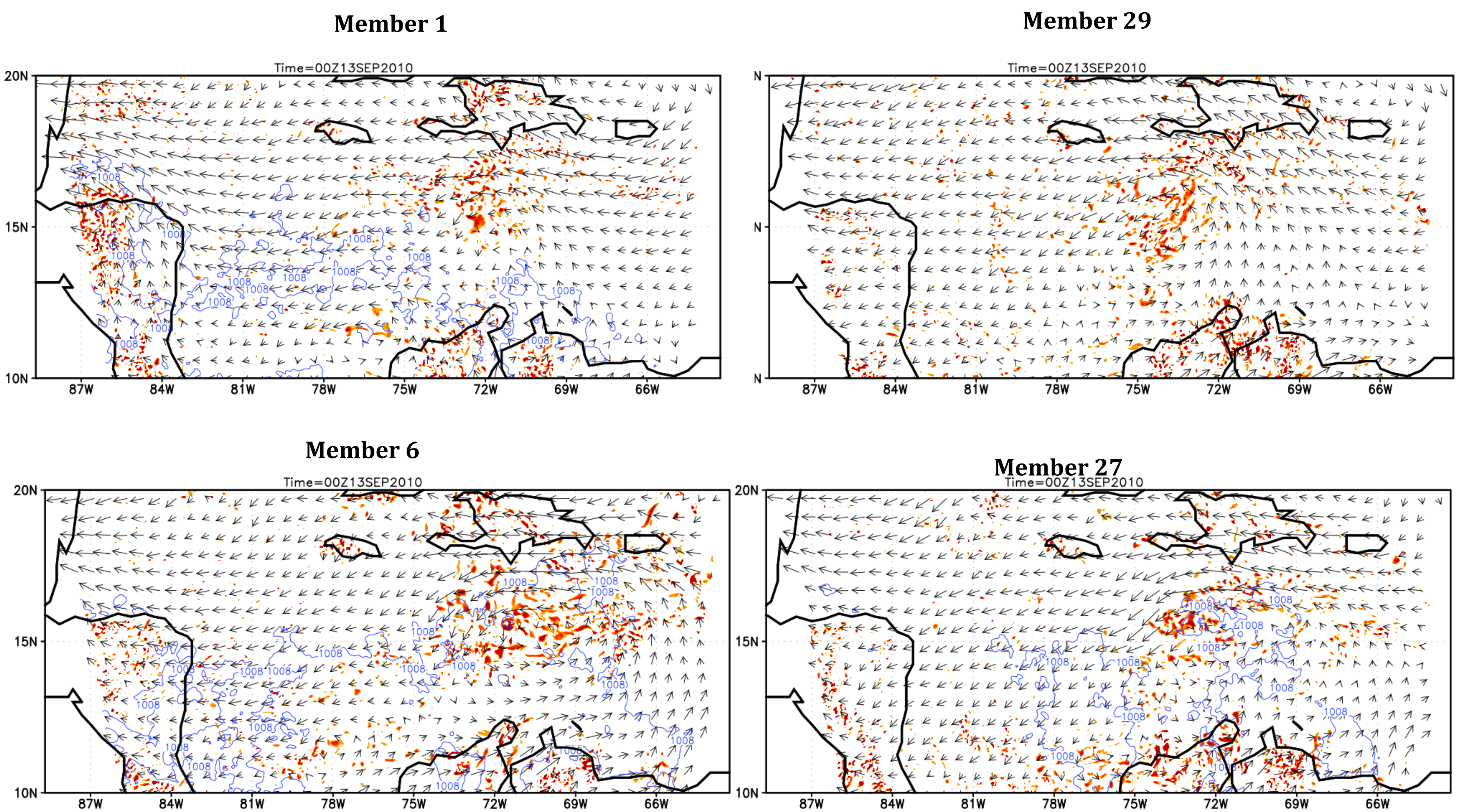
Member 27

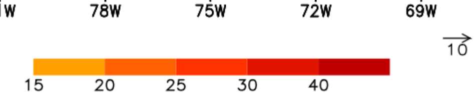


Surface pressure (contour), 700 hPa relative vorticit fields simulated in Member 1 , 6, 27 and 29

GrADS: COLA/IGES 2011-05-26-19:08

Developer vs. non-developer: 24h (00/13)





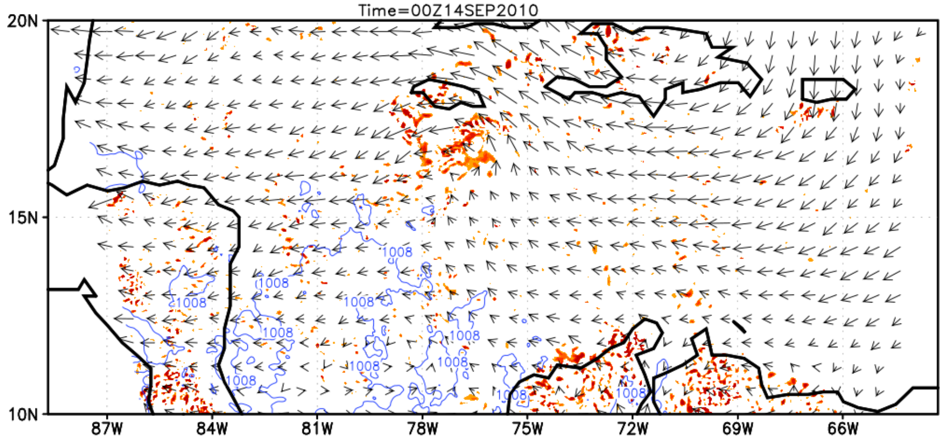
Surface pressure (contour), 700 hPa relative vorticit fields simulated in Member 1 , 6, 27 and 29

GrADS: COLA/IGES

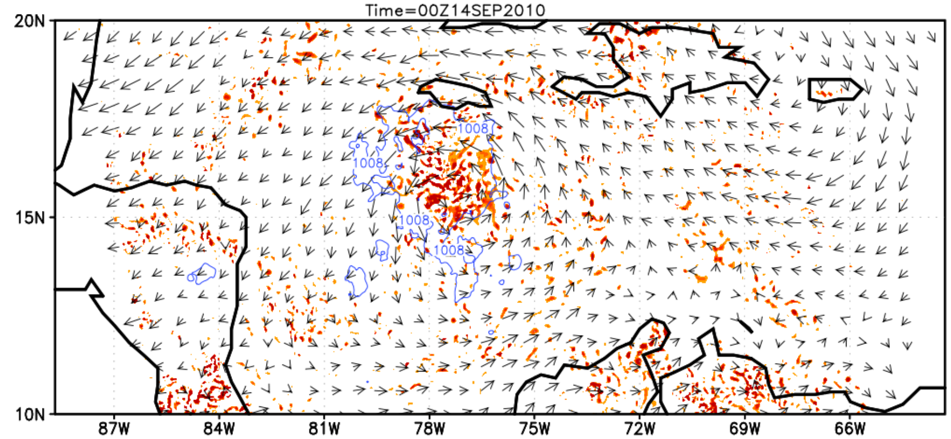
2011-05-26-19:08

Developer vs. non-developer: 48h (00/14)

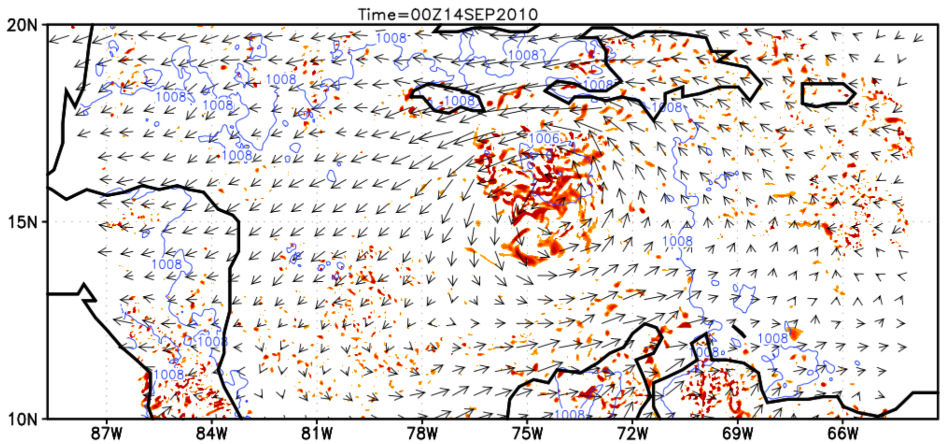
Member 1



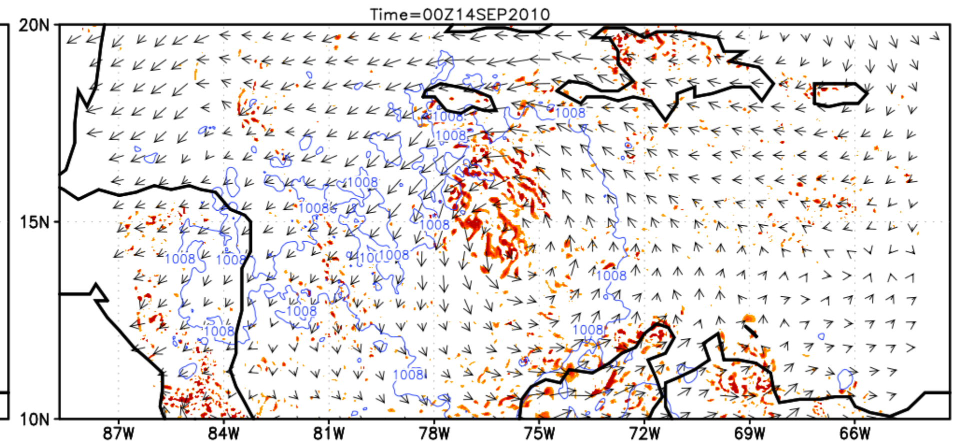
Member 29

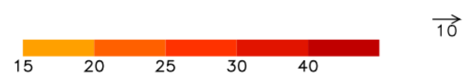


Member 6



Member 27

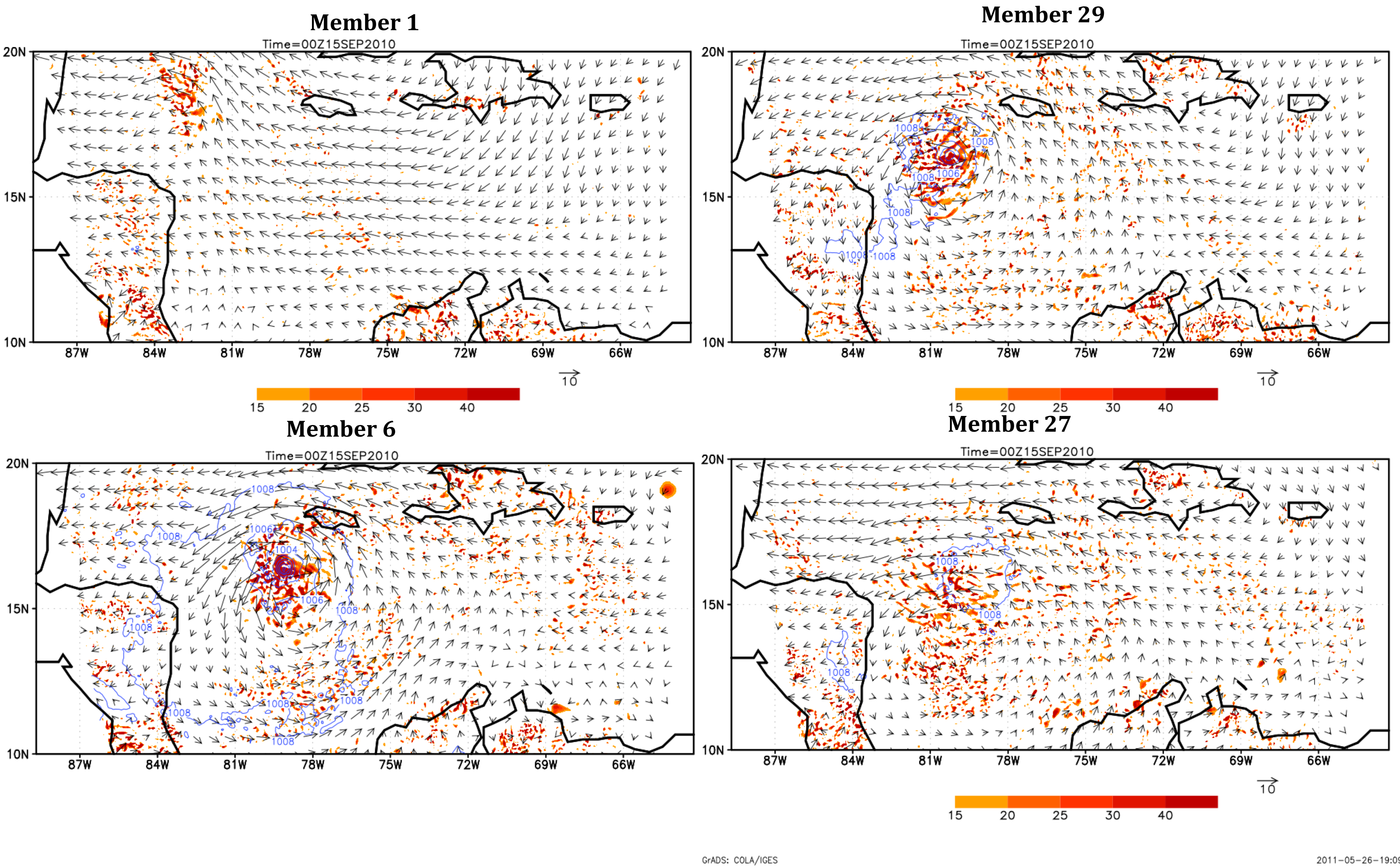




GrADS: COLA/IGES

2011-05-26-19:09

Developer vs. non-developer: 72h (00/15)



Displacement of 500 hPa vorticity center from surface: members 6&29

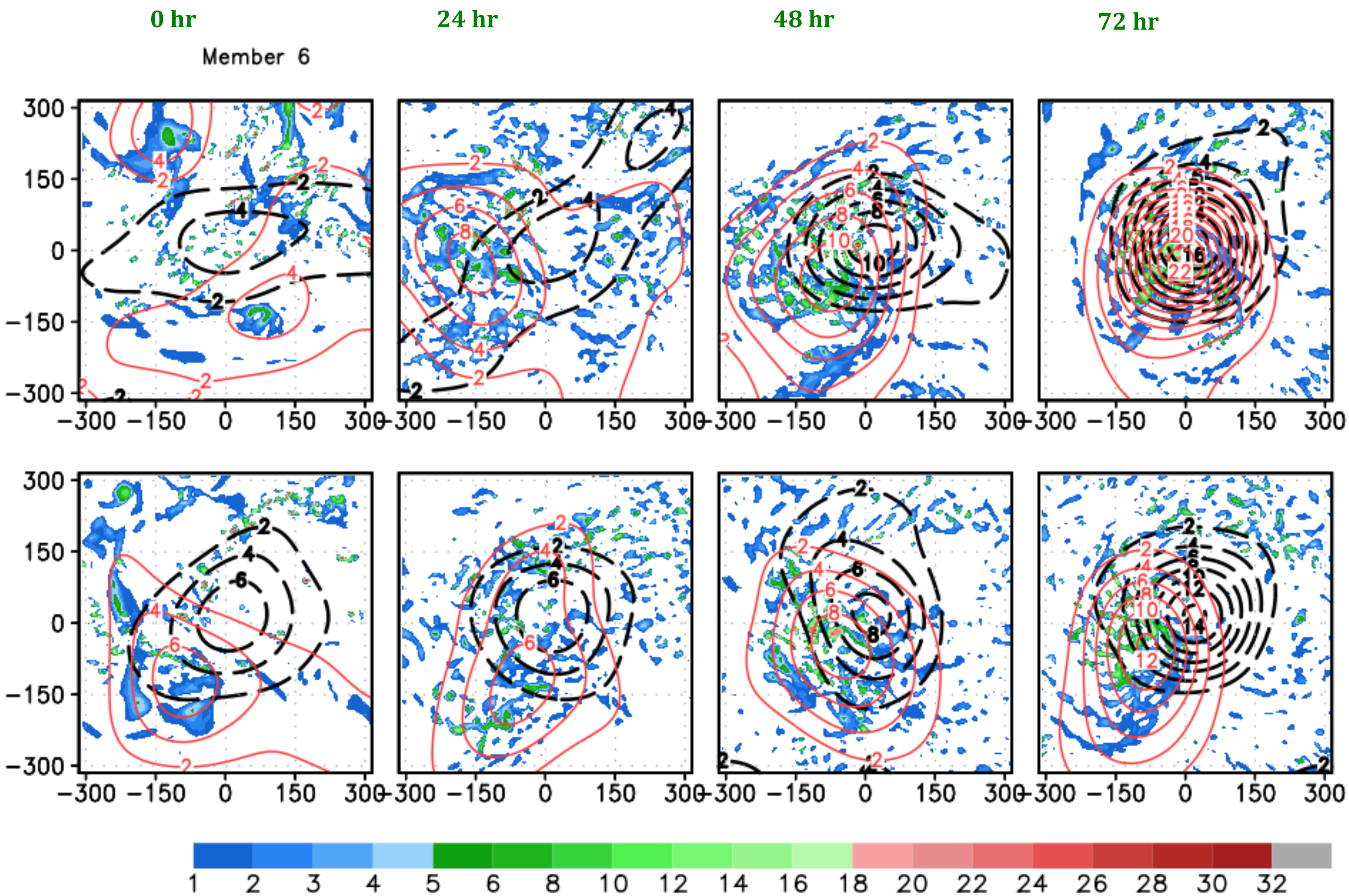


Figure 3. Horizontal distributions of relative vorticity at 500 hPa (shaded, 10^{-4} s^{-1}). The contours are relative vorticity in scales larger than 200 km at the surface (black, 10^{-5} s^{-1}) and 500 hPa level (red, 10^{-5} s^{-1}).

Displacement of 500 hPa vorticity center from surface: members 1&27

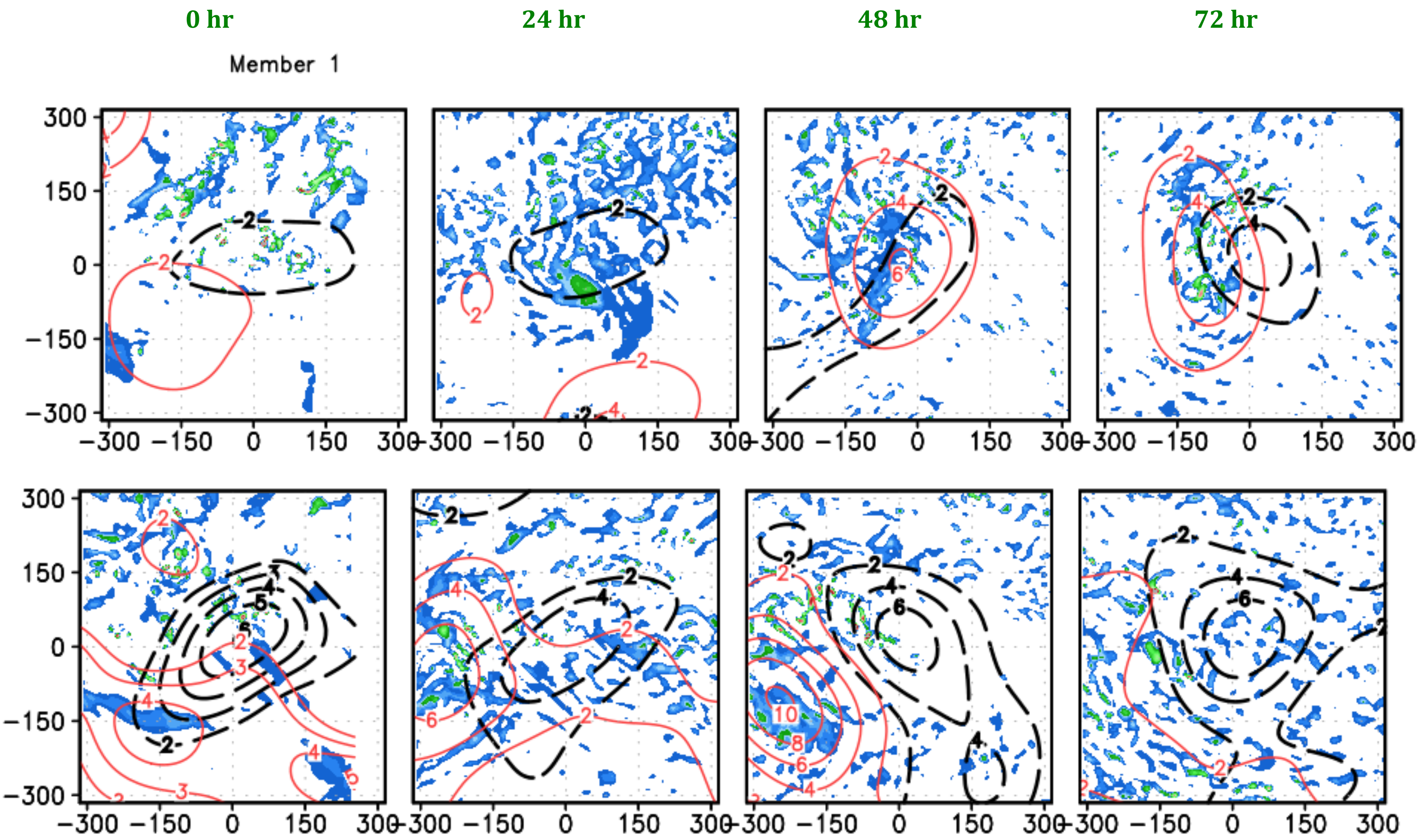
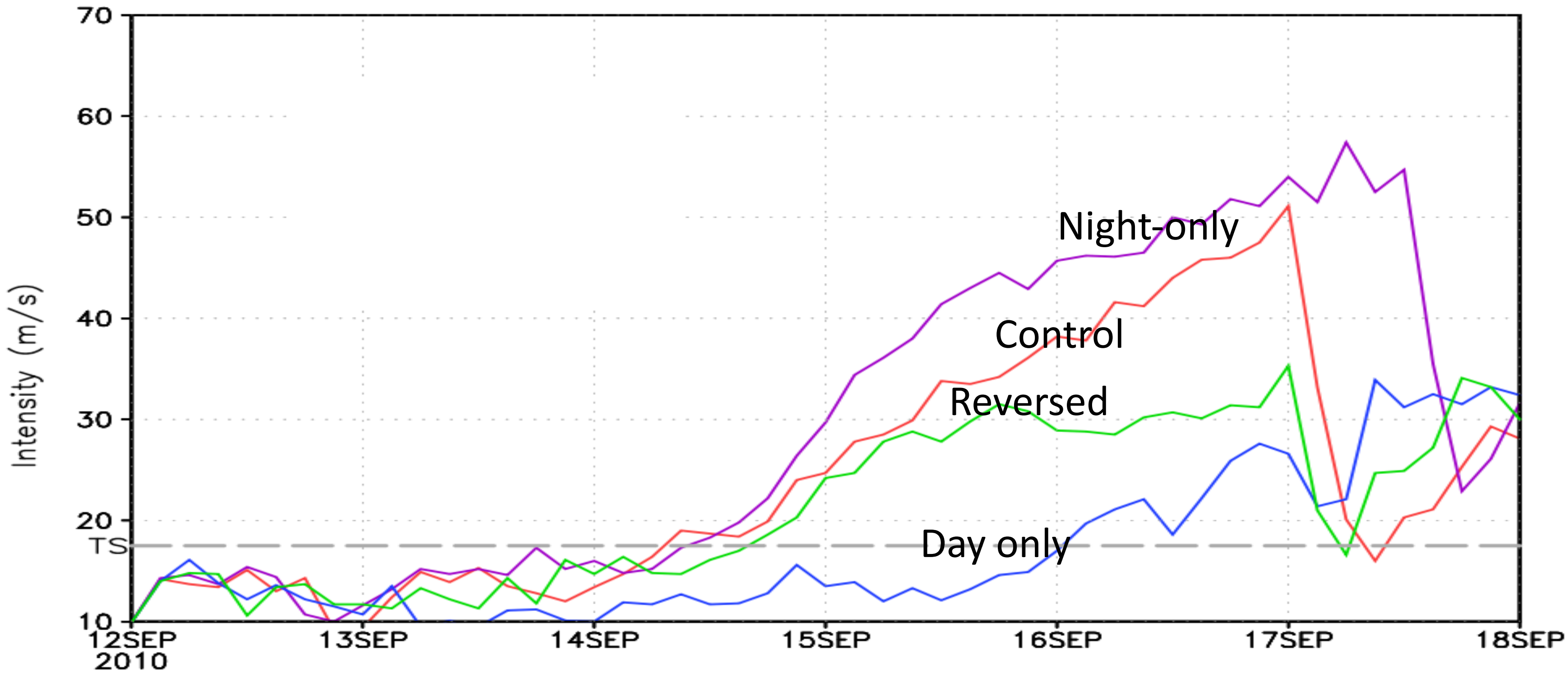


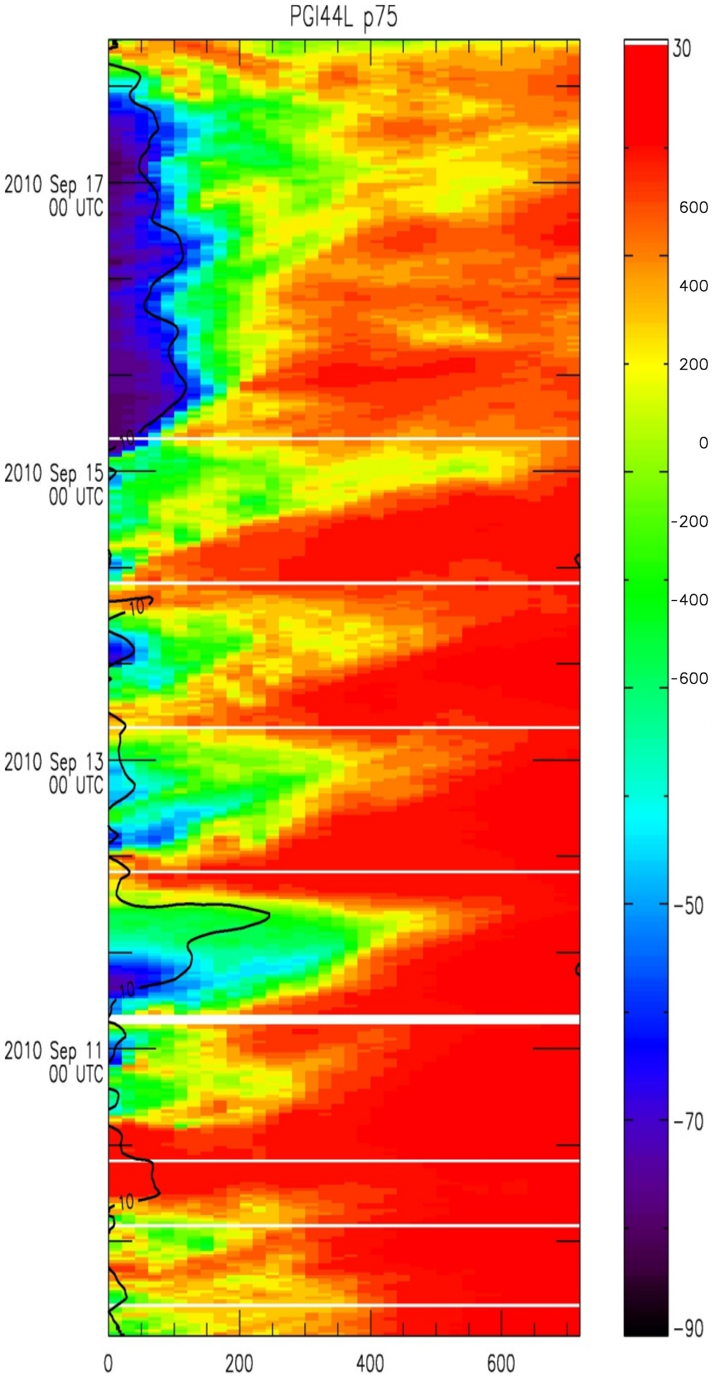
Figure 3. Horizontal distributions of relative vorticity at 500 hPa (shaded, 10^{-4} s^{-1}). The contours are relative vorticity in scales larger than 200 km at the surface (black, 10^{-5} s^{-1}) and 500 hPa level (red, 10^{-5} s^{-1}).

Impact of Diurnal Cycles: Intensity Change in radiation experiments

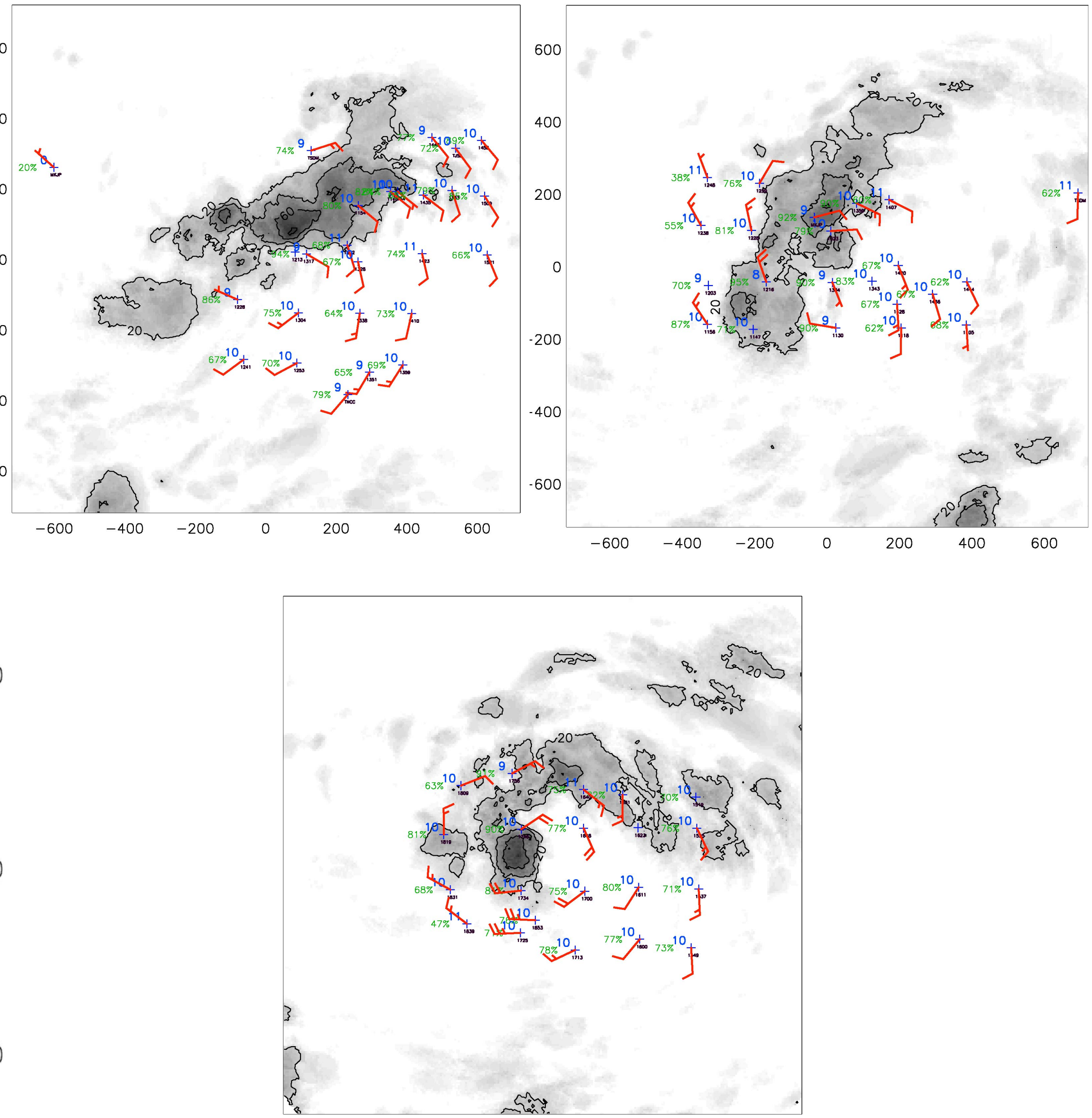


CONTROL: the natural 6th member of the EnKF ensemble runs starting 00Z 12 September
REVERSE: offset the initial and subsequent day time clock by 12 hours in the radiation scheme
DAY only: the time in SW scheme is fixed at 12ZUTC
NIGHT only: The time is fixed at 04ZUTC

Additional two runs: (1) no-radiation run, and (2) DAY2 that fixes the sun as in DAY but at a different angel



Sept. 12, 13 and 15 obs composite from Chris Davis



(obs stolen from Chris Davis' talk)

Sensitivity of vorticity &moisture to diurnal cycle

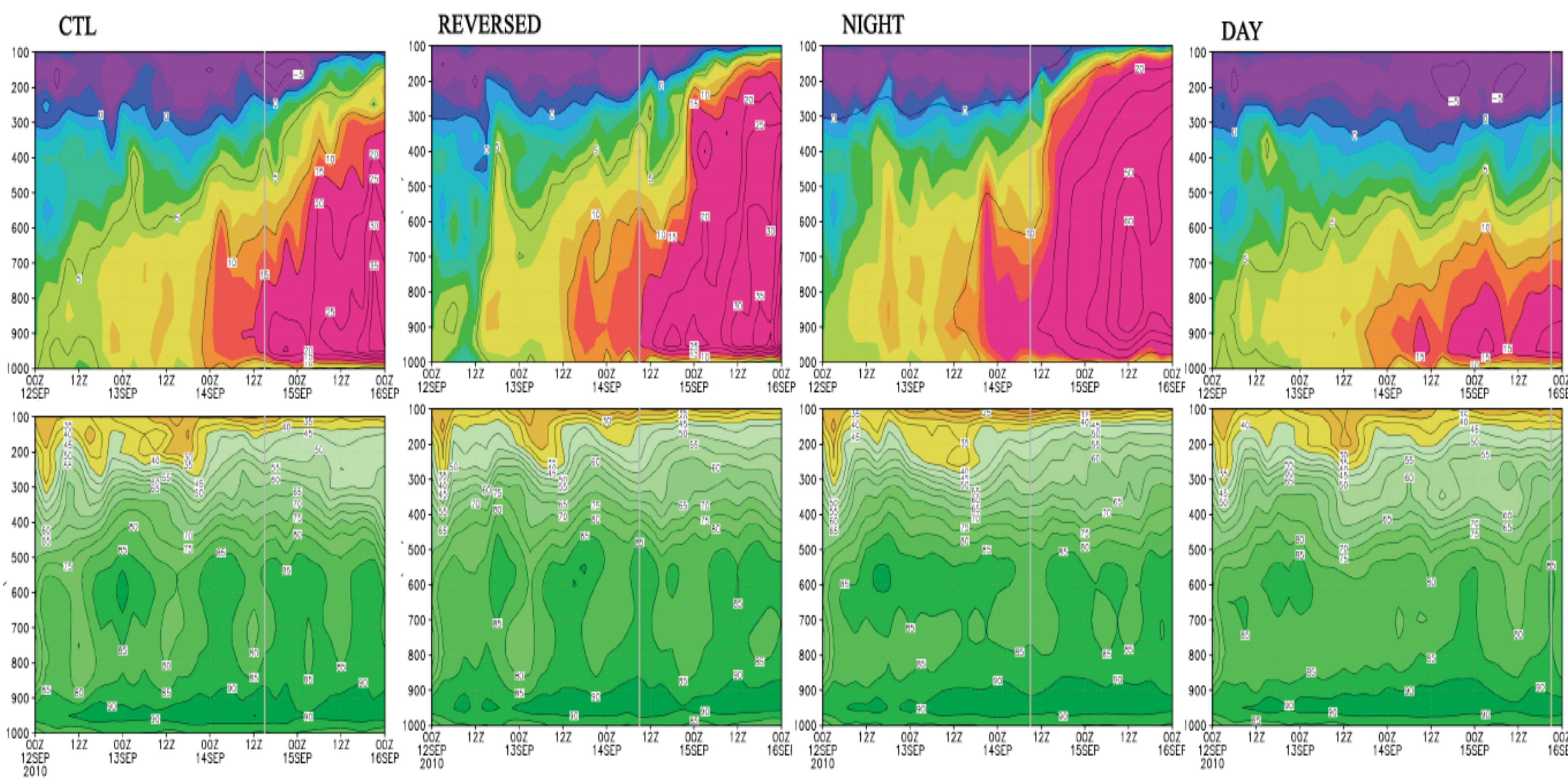


Figure 5. Time-height diagram of relative vorticity (upper panels) and relative humidity (lower panels) averaged within 225 km centered at the surface maximum. Gray line marks the time of tropical cyclone formation.

Sensitivity of *w* and 850 Vt winds to diurnal cycle

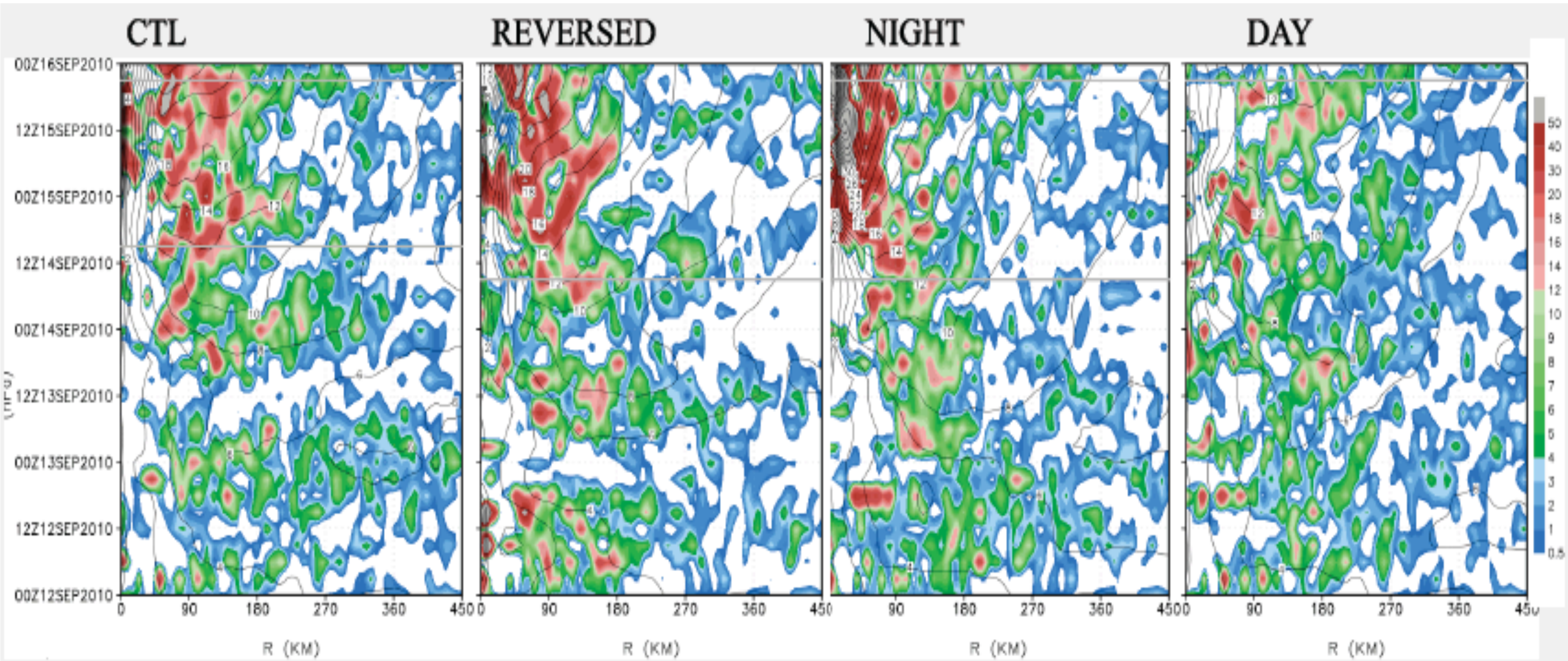


Figure 6. Time-radius diagram of azimuthally-averaged 500 hPa vertical velocity (shading, cm/s) and azimuthally-averaged 850 hPa tangential wind speed (contour, m/s).

Future work: building a 4-D observational analysis w/ Hybrid data assimilation Coupling 3/4DVar with EnKF

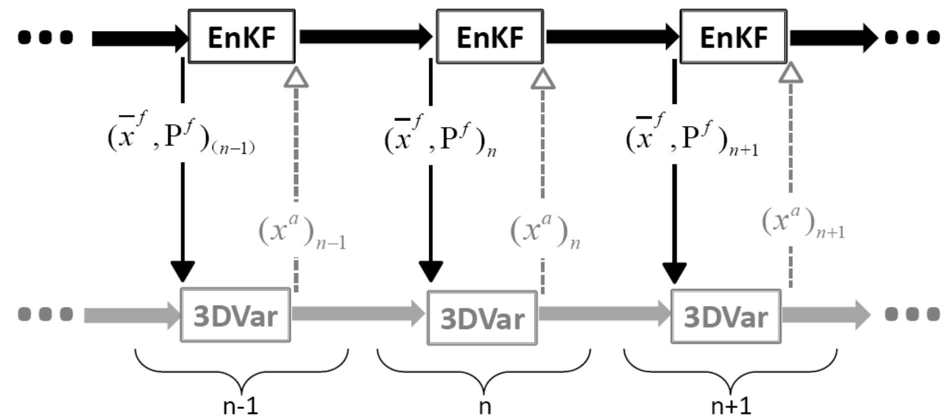
Necessary Variable Changes:

i)EnKF provides ensemble-based background error covariance (***P^f***) for 3D/4DVar

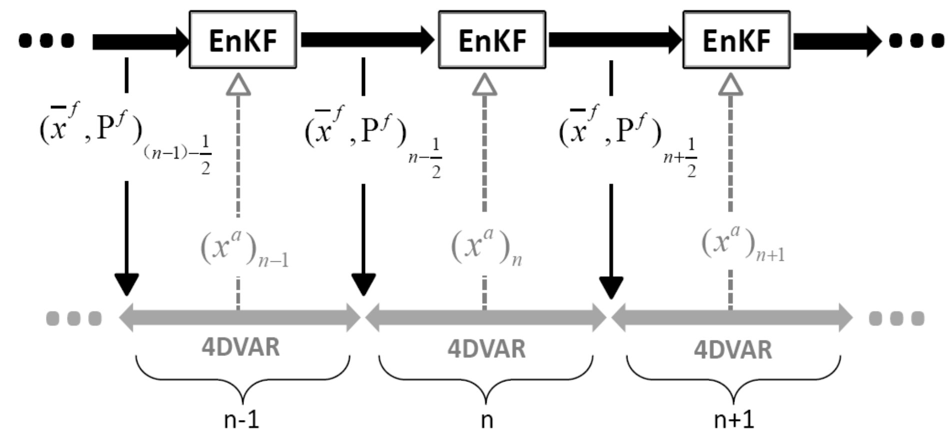
ii)EnKF provides the prior ensemble mean ($\bar{x}^f$) as the first guess for 3D/4DVar

iii)3D/4DVar provides deterministic analysis ($\bar{x}^a$) to replace the posterior ensemble mean for the next ensemble forecast

Coupler of EnKF-3DVar Hybrid (E3DVar):



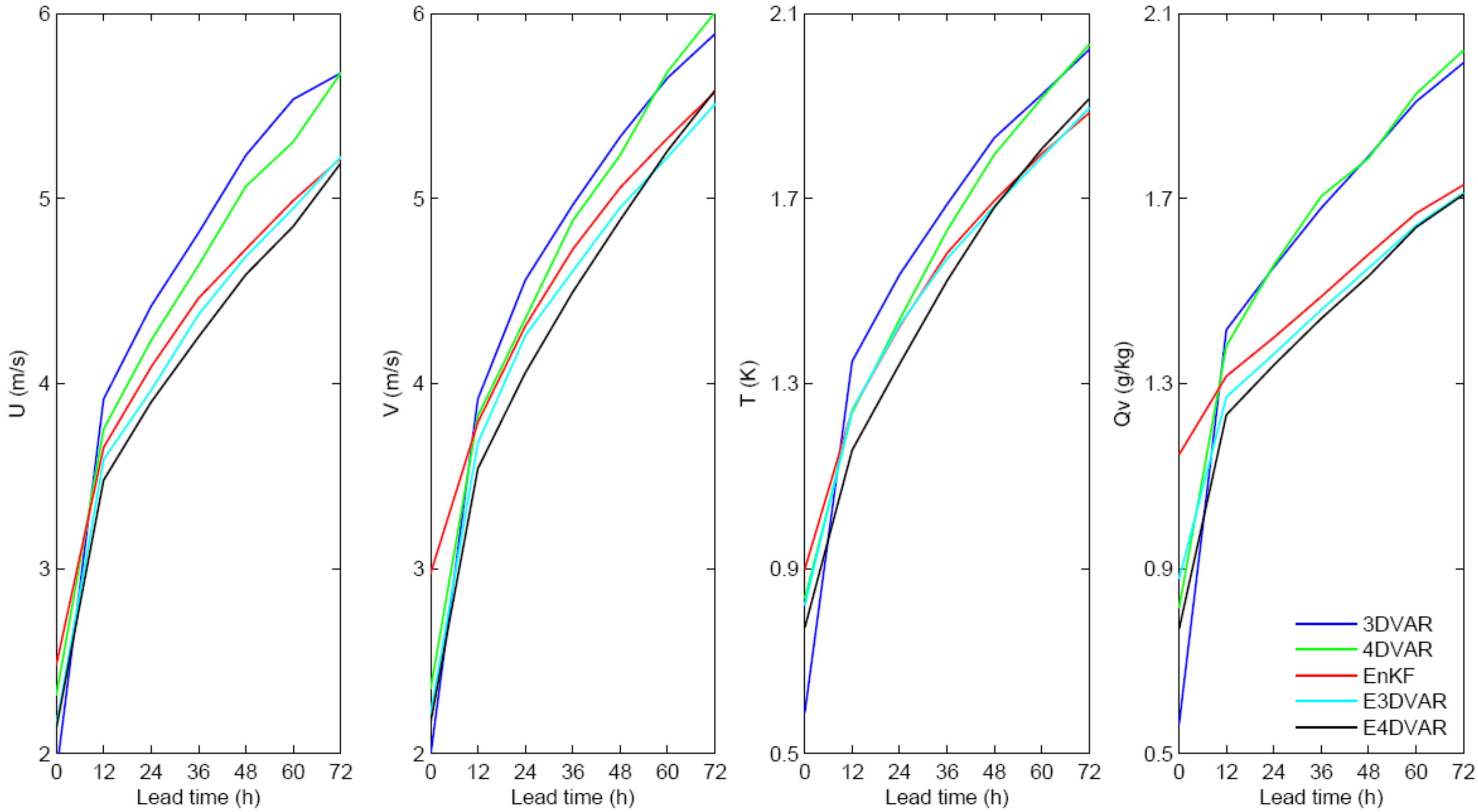
Coupler of EnKF-4DVar Hybrid (E4DVar):



(Zhang 2010; Zhang et al. 2009,2010)

Comparison of 3DVar, 4DVar, EnKF, E3DVar & E4DVar

0-72hr U, V, T & Q RMS forecast error over CONUS Jun 2003 (60 runs)



(Zhang 2010; Zhang et al. 2010)