Projected future changes of the global monsoon and Pacific typhoon activity

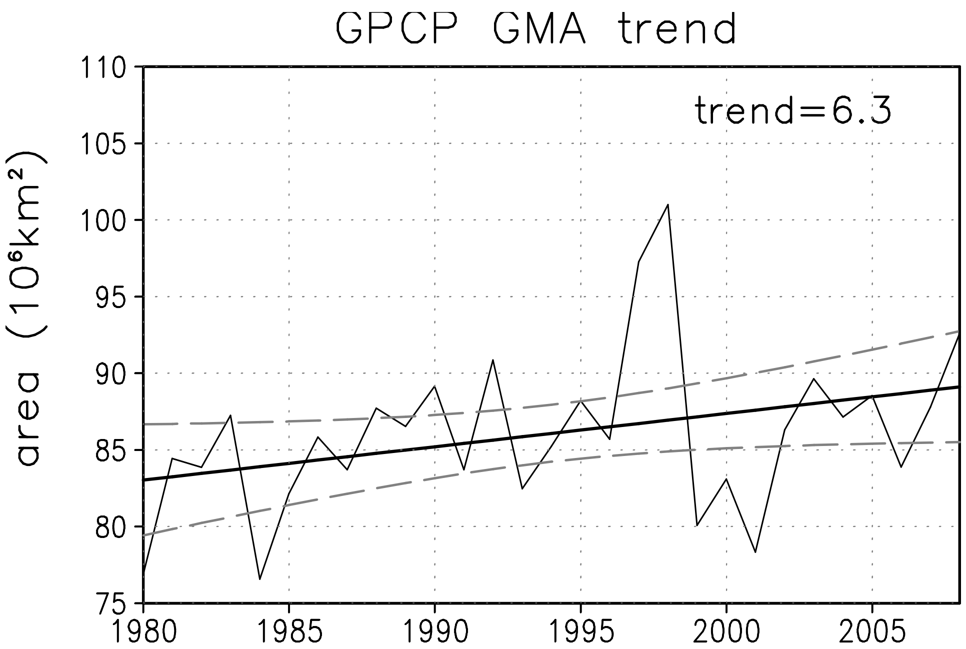
Tim Li

IPRC and Department of Meteorology, University of Hawaii

Co-workers: P.-C. Hsu (IPRC), M.-H. Kwon, J.-S. Kug (KODI), J.-J. Luo (JAMSTEC), H. Murakami, A. Kitoh (MRI), M. Zhao (GFDL)

Motivation 1: Observed global monsoon area (GMA) in past 30 years (1980-2009) showed an increasing trend (about 8% increase in 30 years, Hsu, Li, Wang, 2011).

- Will such an increase continue throughout the 21st century?



Motivation 2:

IPCC AR4 models projected a reduced TC frequency globally in late 21 century, but with a wide range of variability among the models.

► The uncertainty in future TC projection becomes even greater when a specific region is concerned (Knutson et al. 2010)

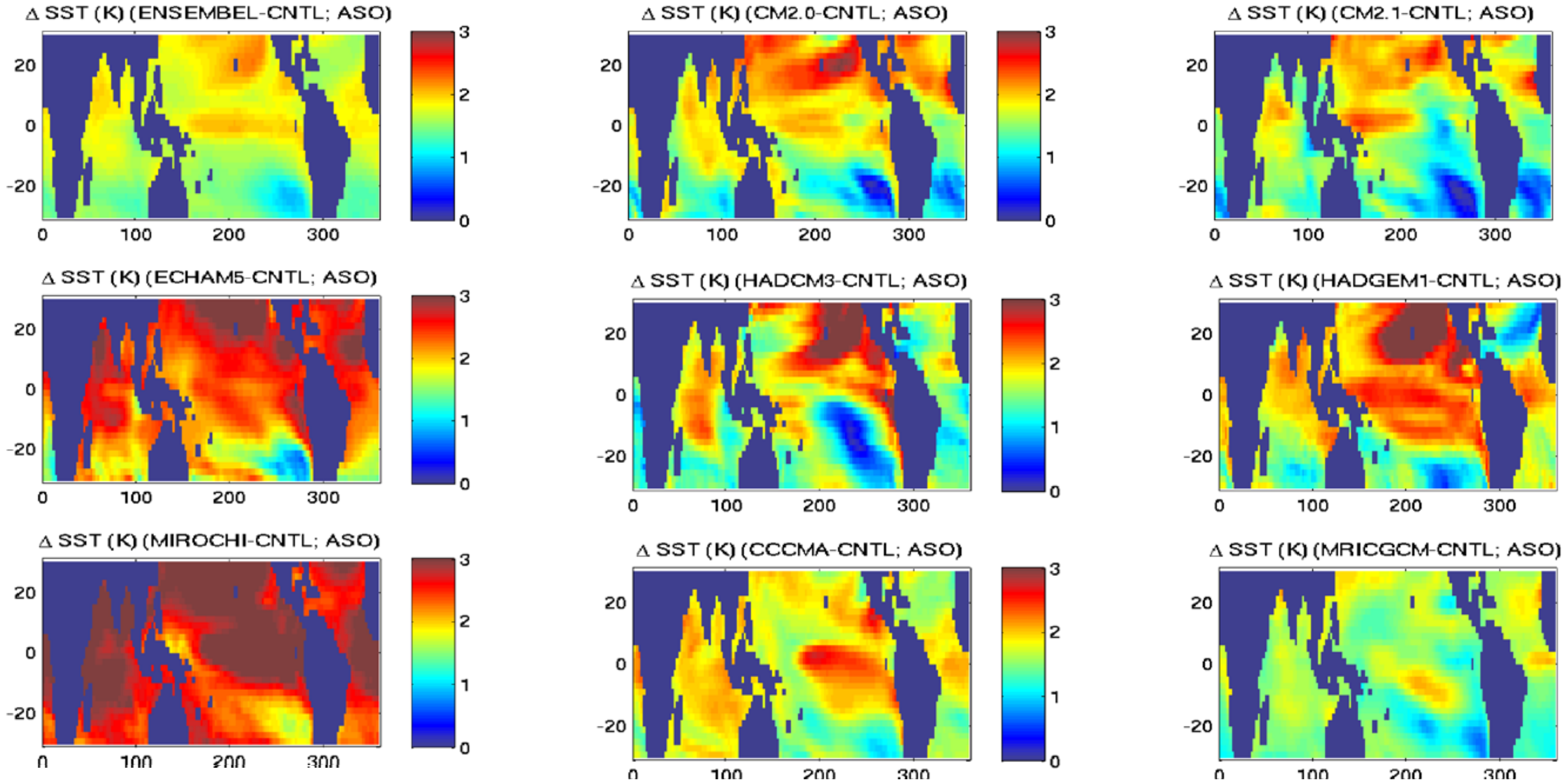
► AR4 resolutions ~ 200km (TC: weak vortex with no warm core)

Bengtsson et al. (2007) noted that T63 and T213 GCM simulations predicted very different future TC changes.

→ Necessary to use high-resolution global AGCMs

An issue to any climate projection problems is “can we obtain robust signals across different model physics and SST patterns?”

Specific question: What are the robust features of future change of the global monsoon and regional TC activity in North Pacific?



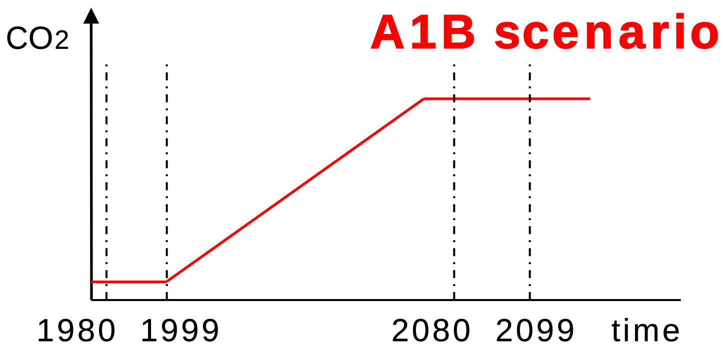
Late 21st century SST warming patterns from IPCC AR4 models

High-resolution AGCMs

- **MPI ECHAM5 T319L31 (40 km grid)**
  Tiedtke (1989) mass flux convection scheme
  Future SST pattern: T63 ECHAM5/MPI-OM (Jungclaus et al., 2006)
- **MRI T959 AGCM (20 km grid)**
  Prognostic Arakawa and Schubert convection scheme
  Future SST pattern: ensemble average of 18 AR4 models
- **GFDL HiRAM2.1 (50-km grid)**
  Modified Bretherton et al. (2004) convection scheme
  Future SST pattern: ensemble average of 18 AR4 models
- **Additional two sensitivity experiments**
  ECHAM5 T106 with spatially varying and uniform SST warming patterns

A time-slice integration method:

20C : 1980-1999 (20 years)
21C : 2080-2099 (20 years)



Global Monsoon Indices

Following Liu et al. (2009) and Hsu et al. (2011)

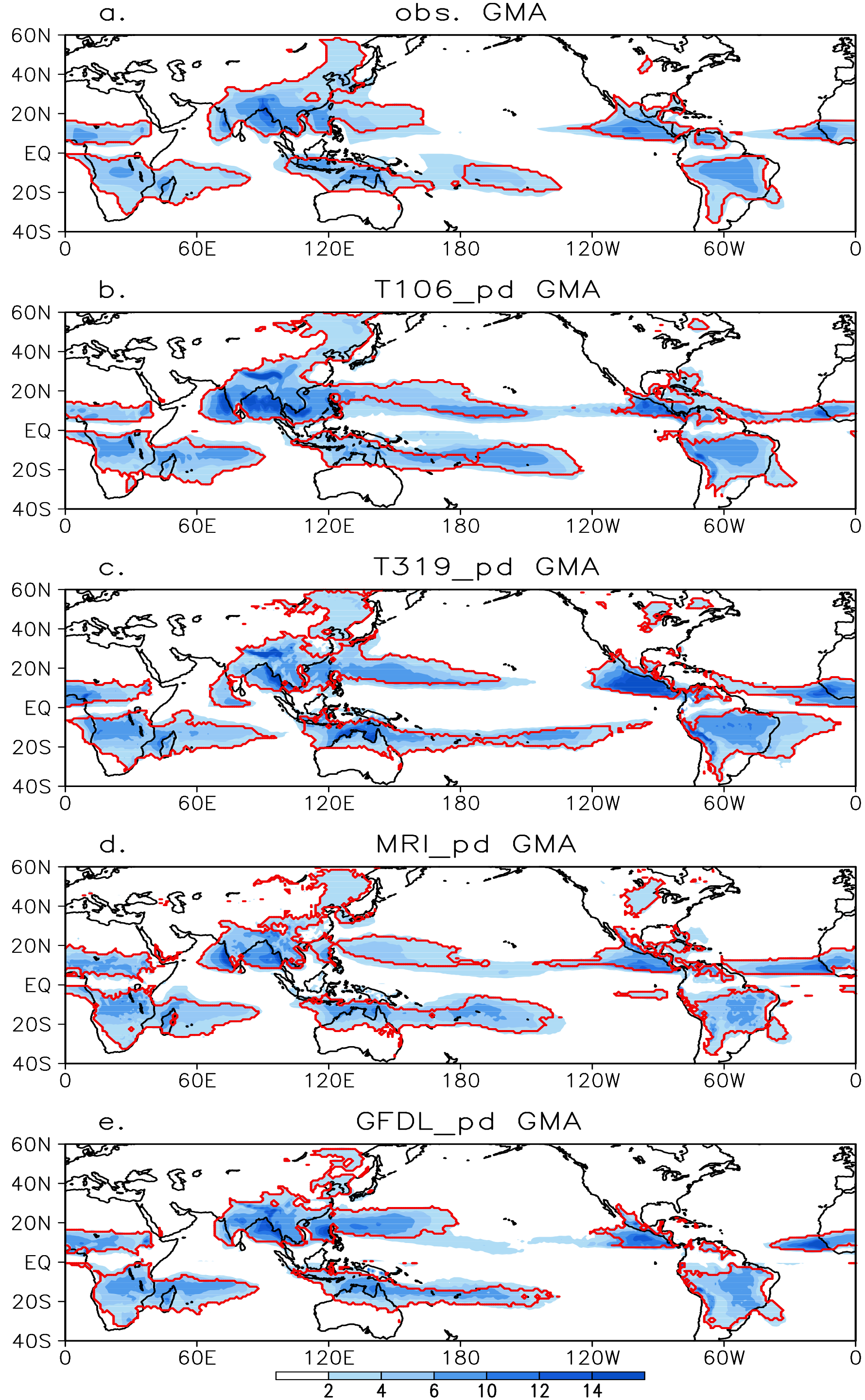
- **Global Monsoon Area (GMA)** is defined as regions where

  (1) annual precipitation range > 2mm/day
  [MJJAS-NDJFM]
  (2) local summer precipitation > 55 % of annual rainfall

- **Global Monsoon Precipitation (GMP):**
  total summer monsoon rainfall falling in the monsoon domain

- **Global Monsoon Intensity (GMI):**

  monsoon precipitation per unit area



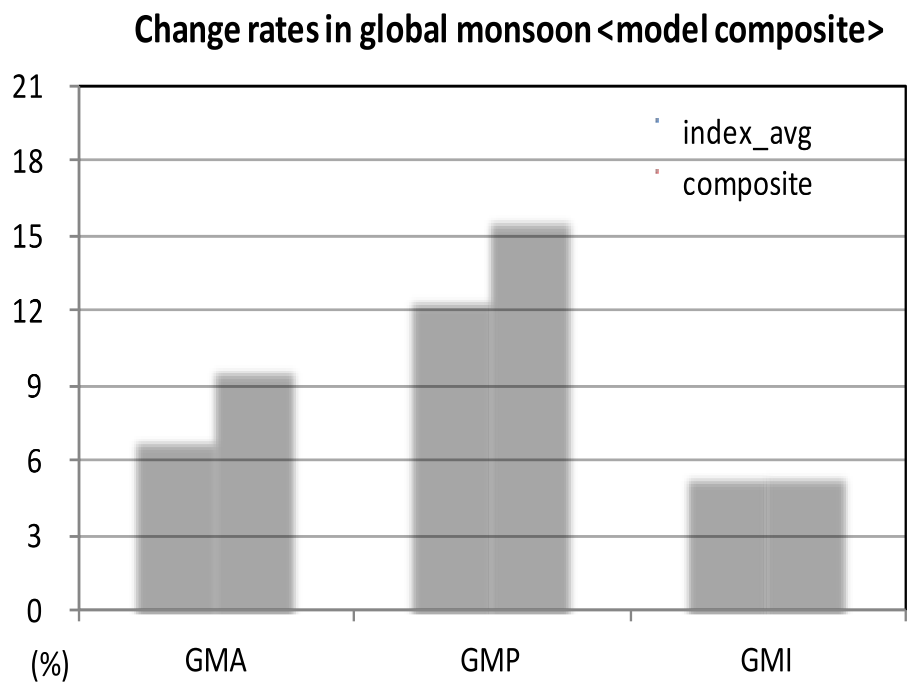
Observed and simulated GMA in present-day climate

red curve: GMA
shaded: annual precipitation range (mm/day)

Projected future changes of the global monsoon

Change rates in GMA, GMP and GMI between the present-day and late 21 century

Change rate (%)	**T106_mw**	**T106_sw**	**T319_sw**	**MRI_sw.e**	**GFDL_sw.e**
GMA	7.75	4.58	8.66	7.15	6.59
GMP	19.80	10.35	15.18	9.85	7.36
GMI	11.22	5.61	7.14	2.51	0.88



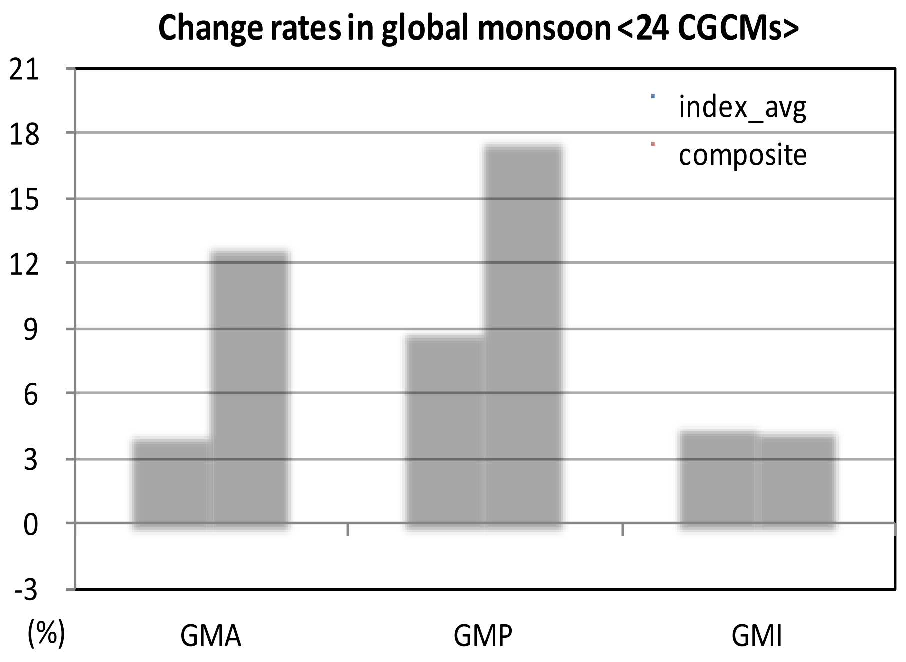
Blue bars: average of the indices calculated from each of 5 simulations (whisker denotes standard deviation)

Red bars: the indices calculated based on the composite of rainfall fields from 5 simulations.

➔ GMA, GMP and GMI all increase consistently among the model projections.

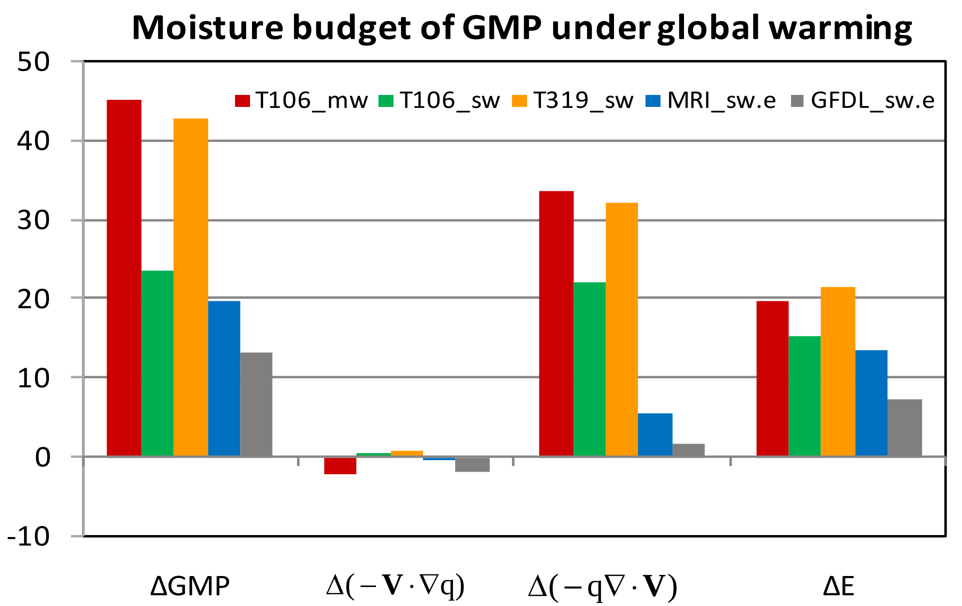
Projected future changes of the global monsoon from 24 IPCC AR4 CGCMs

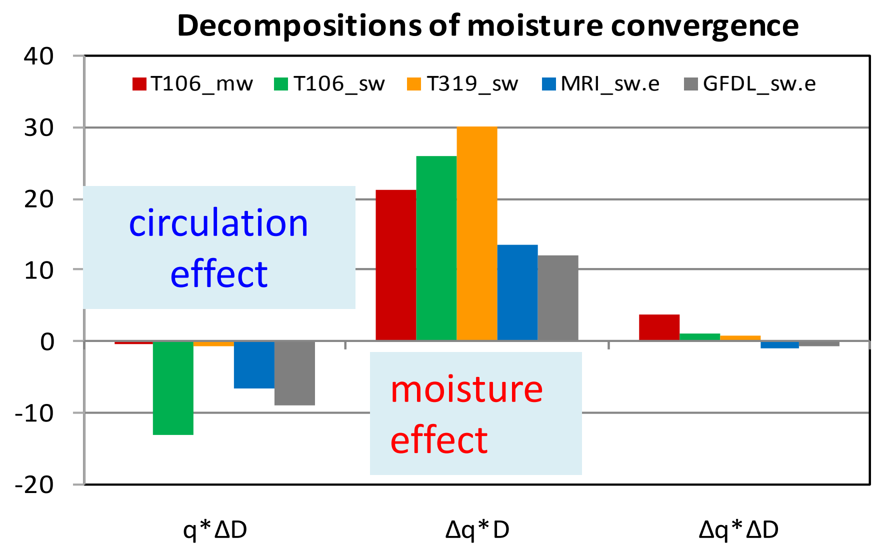
Time-slice method vs. continuous integration method; uncoupled vs. coupled



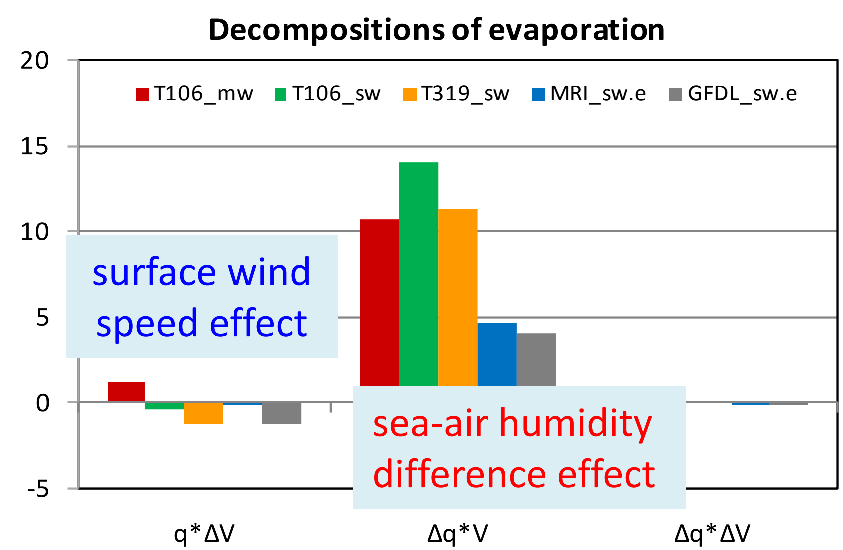
➔ Most of 24 AR4 models projected a future increase of GMA, GMP and GMI.

Relative roles of moisture and circulation changes in GMP change

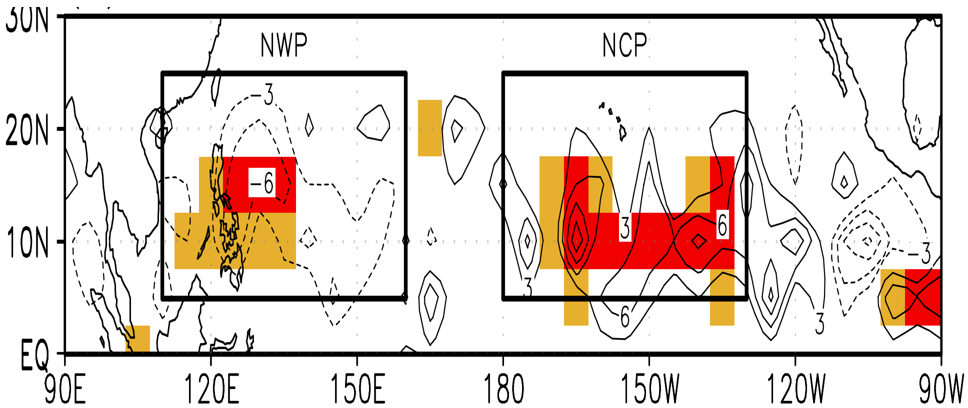


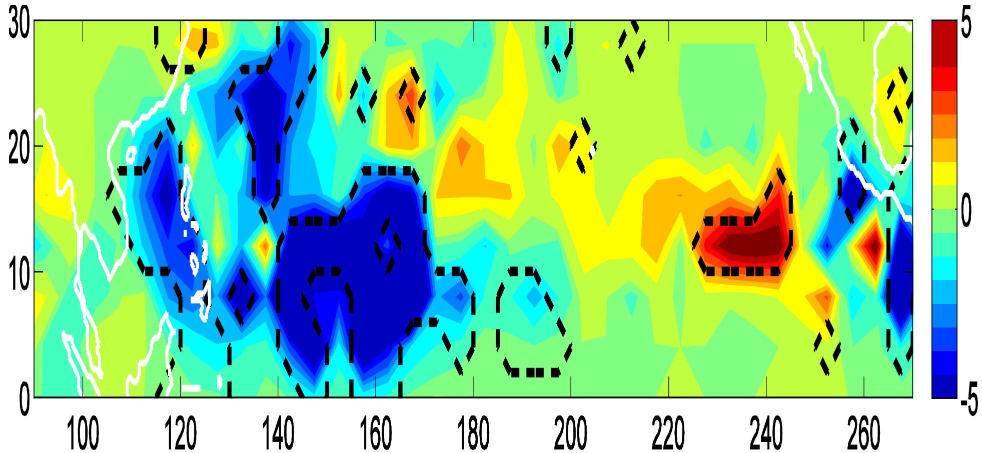


- The increase of the GMP is attributed to the **increased moisture convergence and surface evaporation**.
- The moisture effect is to a certain extent offset by the weakening of the monsoon circulation.



TC genesis frequency change (21C-20C) in North Pacific





Top (**ECHAM5 T319** simulations with future SST from ECHAM5/MPI-OM CGCM)

NWP: **-31%**

NCP: **65%**

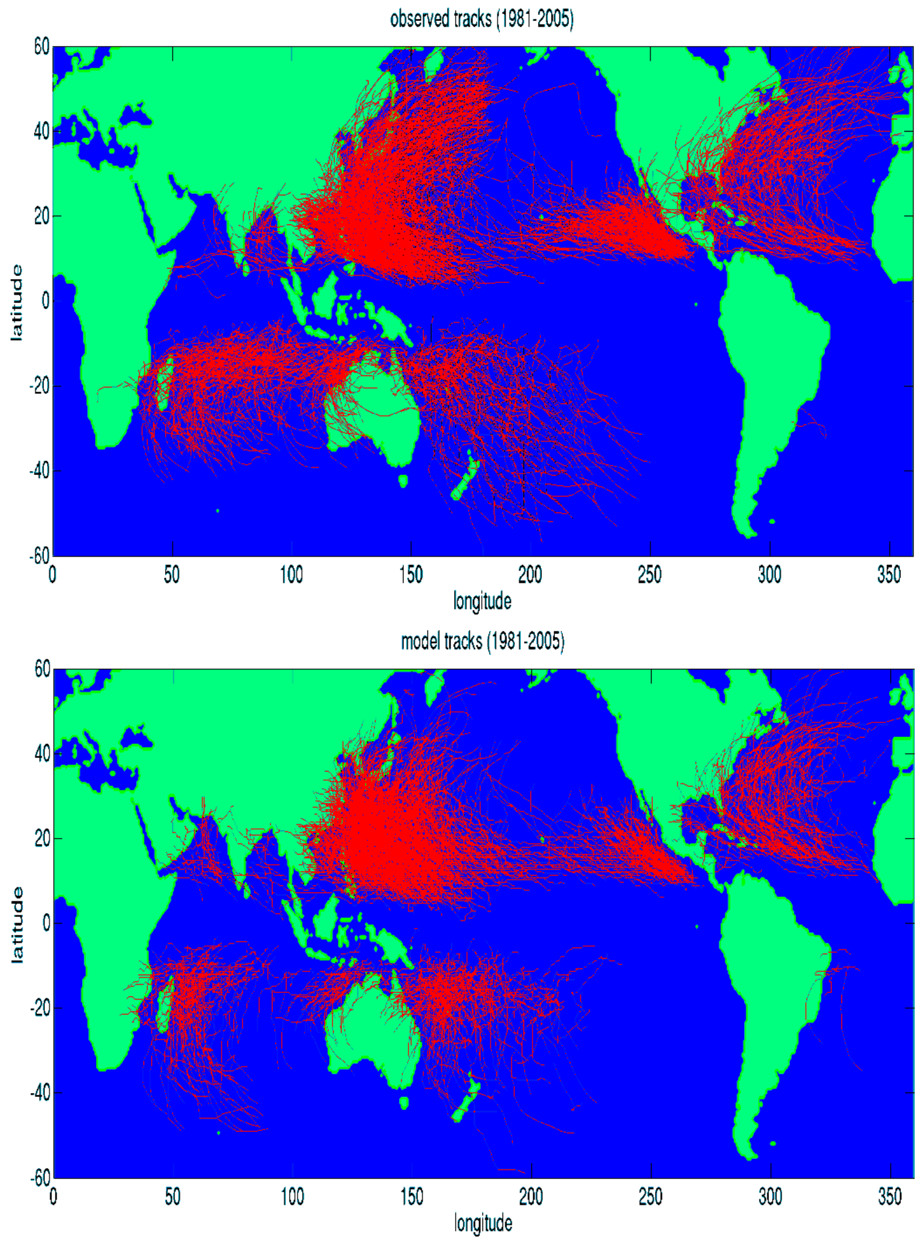
Bottom (**GFDL HiRAM2.1** simulations with ensemble SST from 18 IPCC AR4 CGCMs)

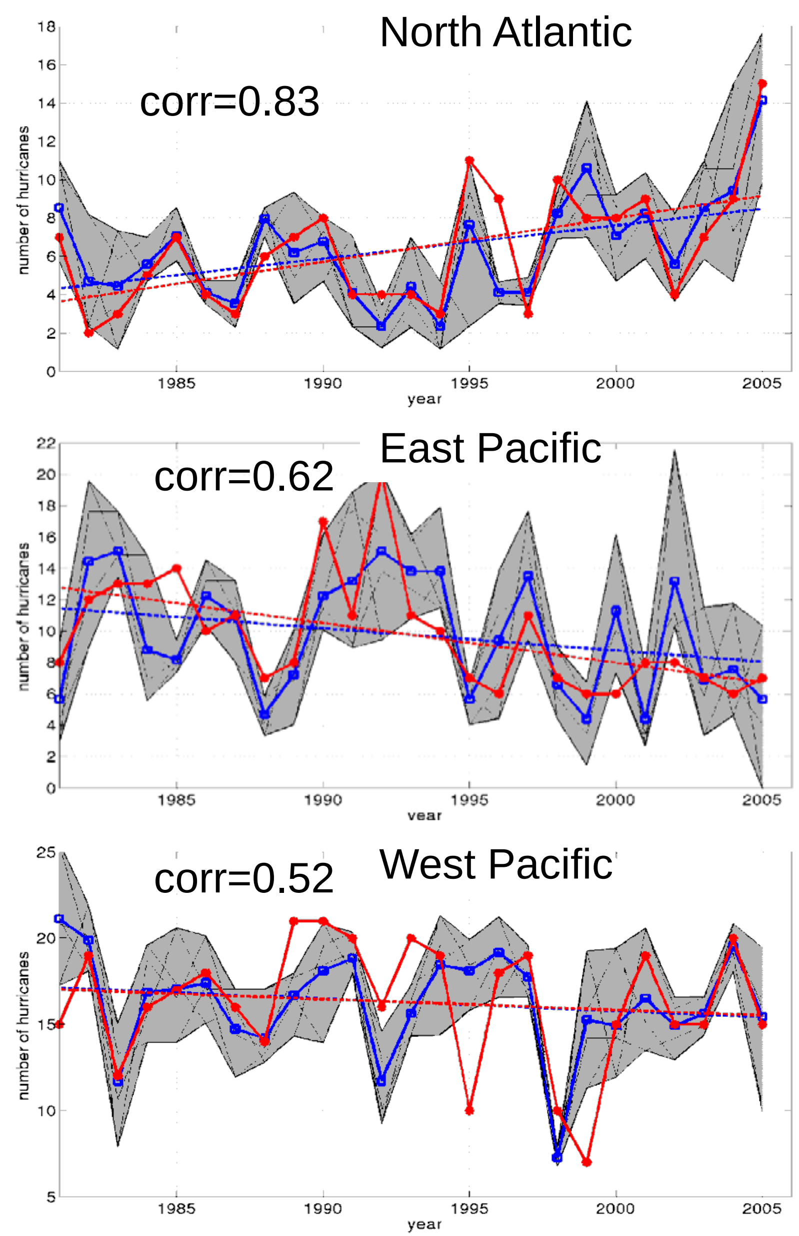
NWP: **-30%**

NCP: **19%**

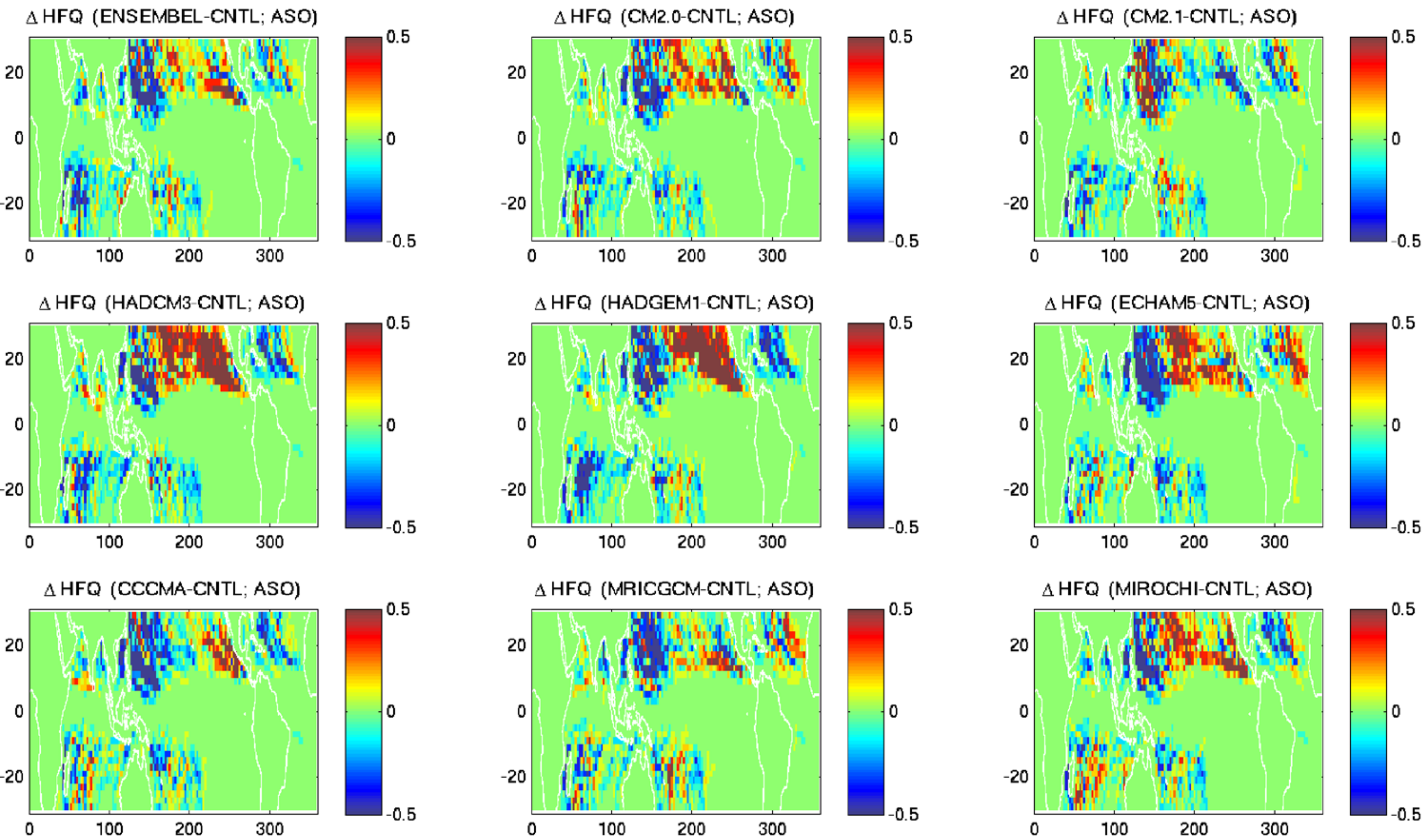
→ Two high-resolution AGCMs with very different physics packages and different future SST warming patterns project the similar east-west shift of TC genesis location between the western and central North Pacific.

GFDL HiRAM2.1 captures observed distributions of hurricane tracks (1981-2005) and interannual/decadal variations





Projected future changes of TC frequency from GFDL HiRAM2.1 with different future SST patterns



Conclusion

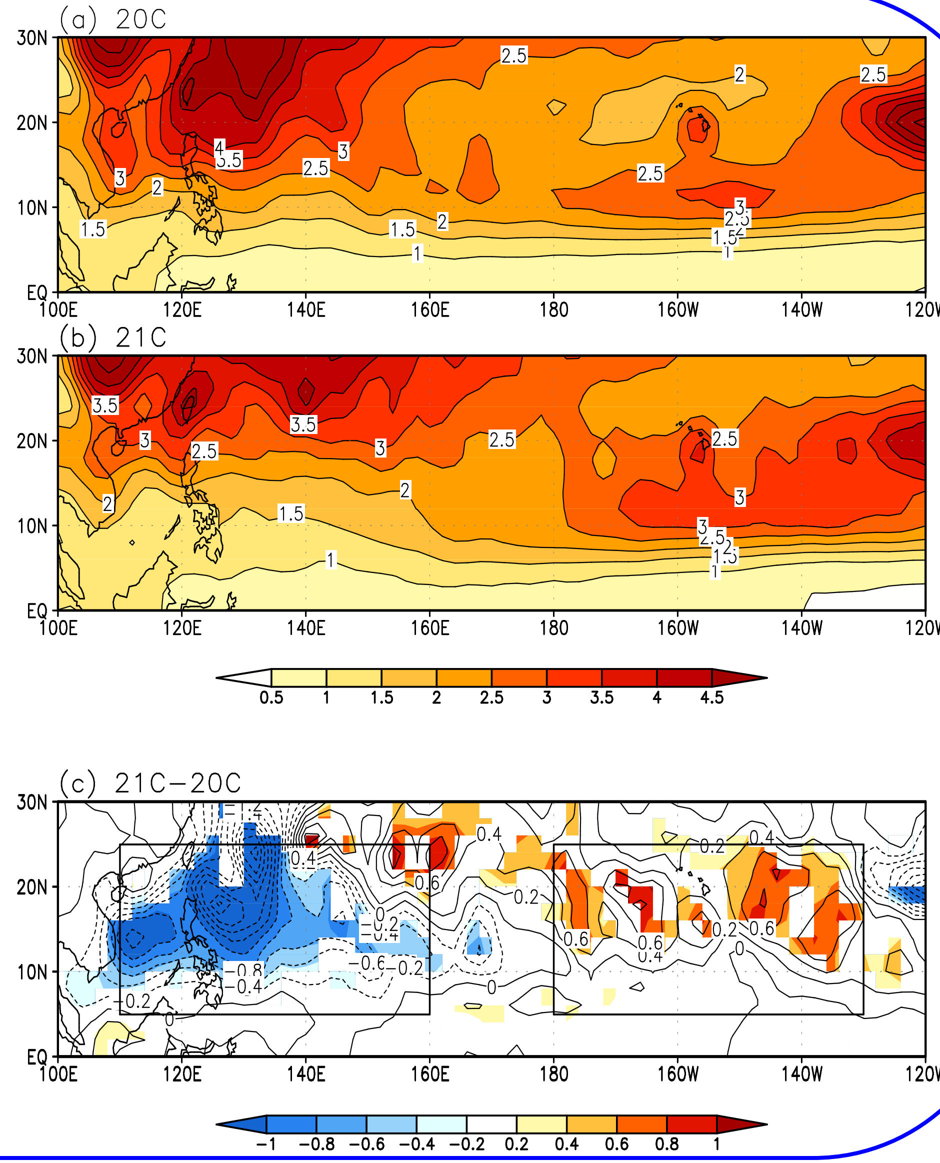
► High-resolution AGCM simulations project a consistent increasing trend of the GMA, GMP and GMI throughout 21 century, suggesting that the strengthened global monsoon is a robust signal across model physics and future SST patterns. The increase of global monsoon precipitation is attributed to the increased moisture convergence and surface evaporation.

► High-resolution AGCMs project a significant increase of TC frequency in CNP but a significant decrease in WNP. This signal appears robust from sensitivity runs with different model physics and different future SST patterns.


Thanks
Diamond Head

Change of variance of synoptic disturbances

2-8-day filtered 850hPa vorticity variance using Lanzcos digital filter



Synoptic activity decreases in the western Pacific but increase in central Pacific regions, respectively.

In (c) 95% confidence level is shaded.

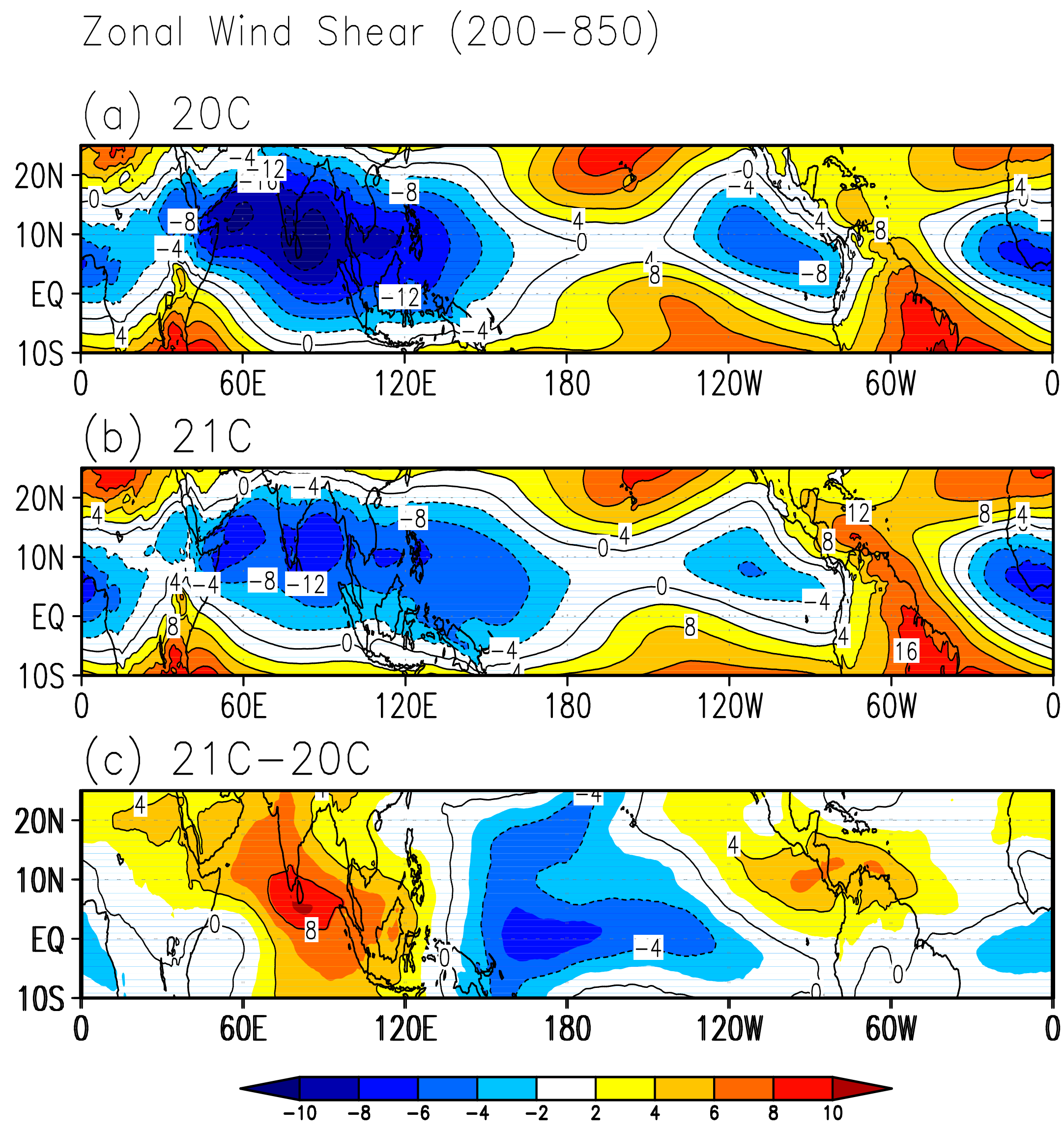
What causes the change of strength of the synoptic-scale activity?

→ Due to the changes in background vertical shear and divergence fields !

Easterly shear favors the development of tropical synoptic disturbances (Wang and Xie 1996; Li 2006)

↓

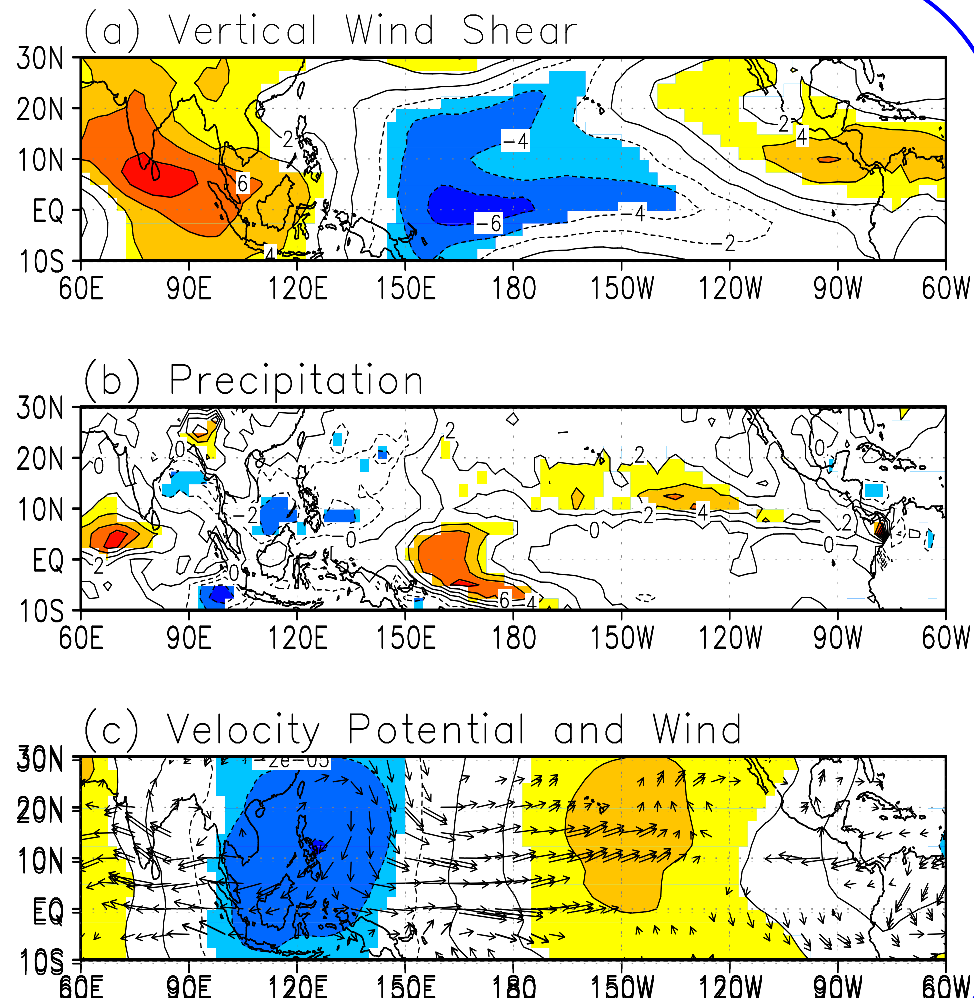
Enhanced synoptic activity leads to more TC genesis in central Pacific



Changes in monsoon rainfall and low-level divergence

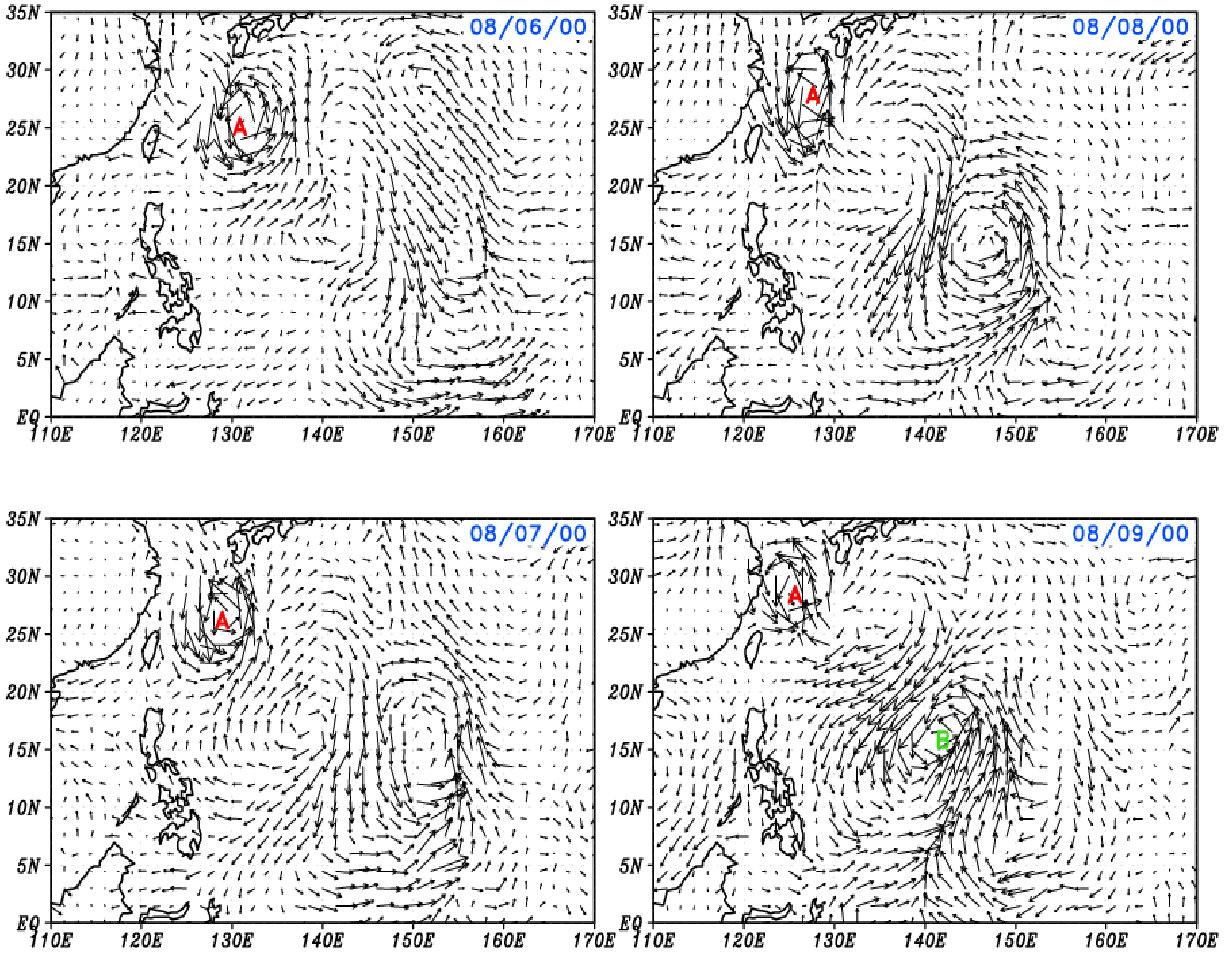
The change of the vertical shear results from the changes of **seasonal-mean monsoon rainfall /heating**, which is further caused by the change of strength of the **Walker circulation and low-level divergence**.

Difference fields (21C – 20C)



95% confidence level is shaded.

Scenario 1: WNP cyclogenesis associated with Rossby wave energy dispersion of a pre-exisitng TC (TCED)



A: Jelawat

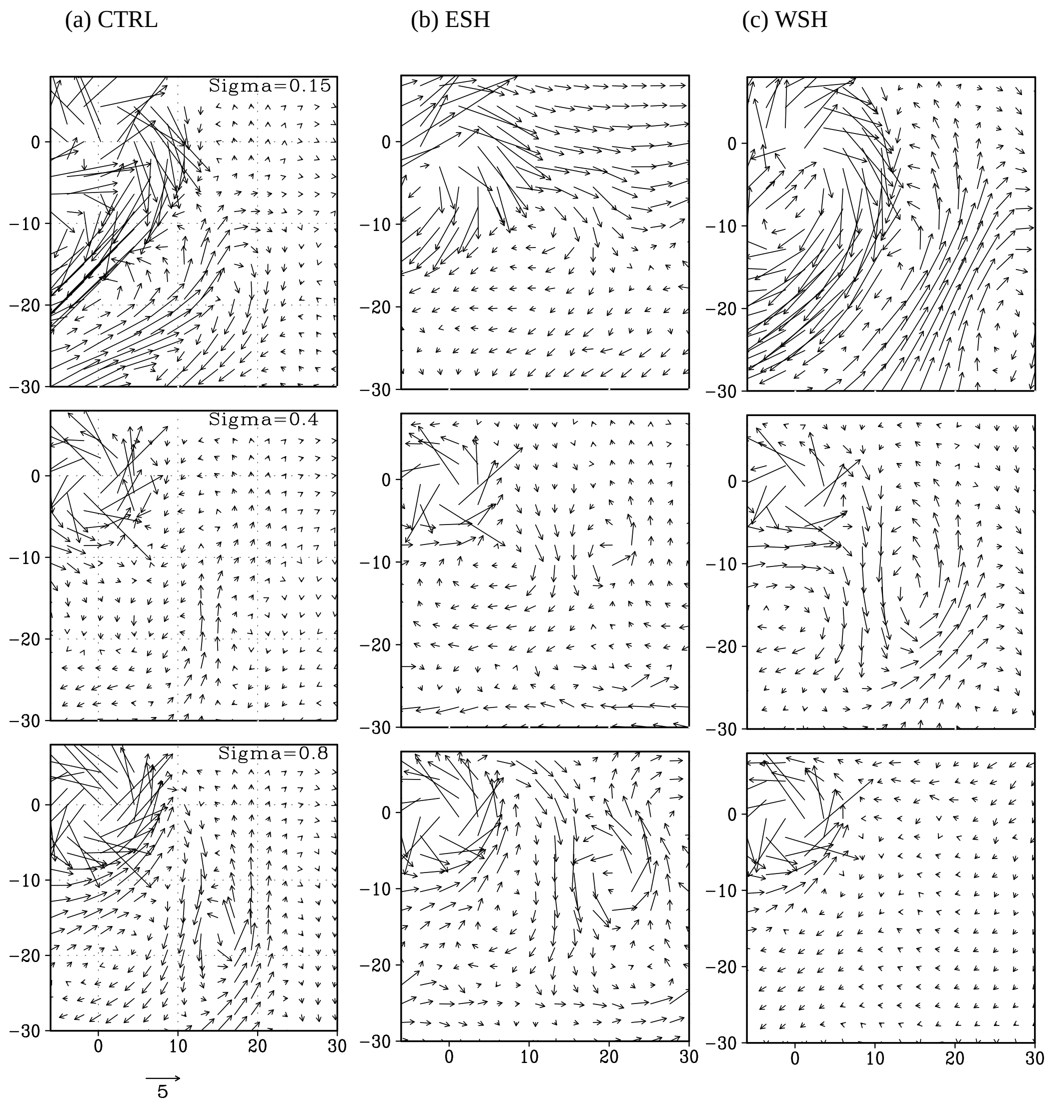
B: Ewiniar

3-8 day filtered QuikSCAT surface wind fields

Li et al. 2003, GRL

Easterly (westerly) shear favors the amplification of TCED-induced Rossby wave train in lower (upper) troposphere

Ge, Li, et al. 2007, GRL

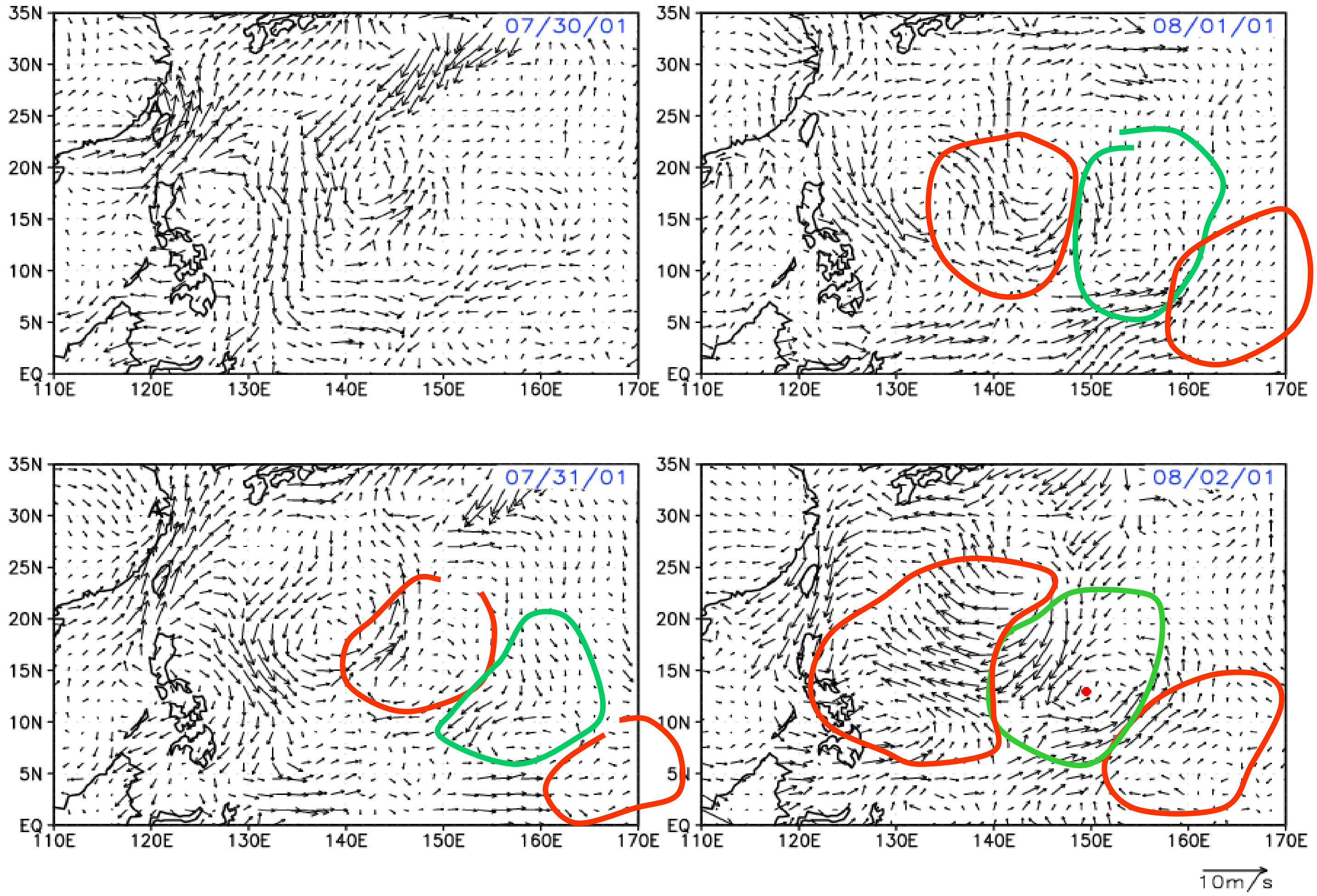


Upper-level

Middle-level

lower-level

Scenario 2: Cyclogenesis associated with synoptic wave train (SWT)



Red circle: Cyclonic flow

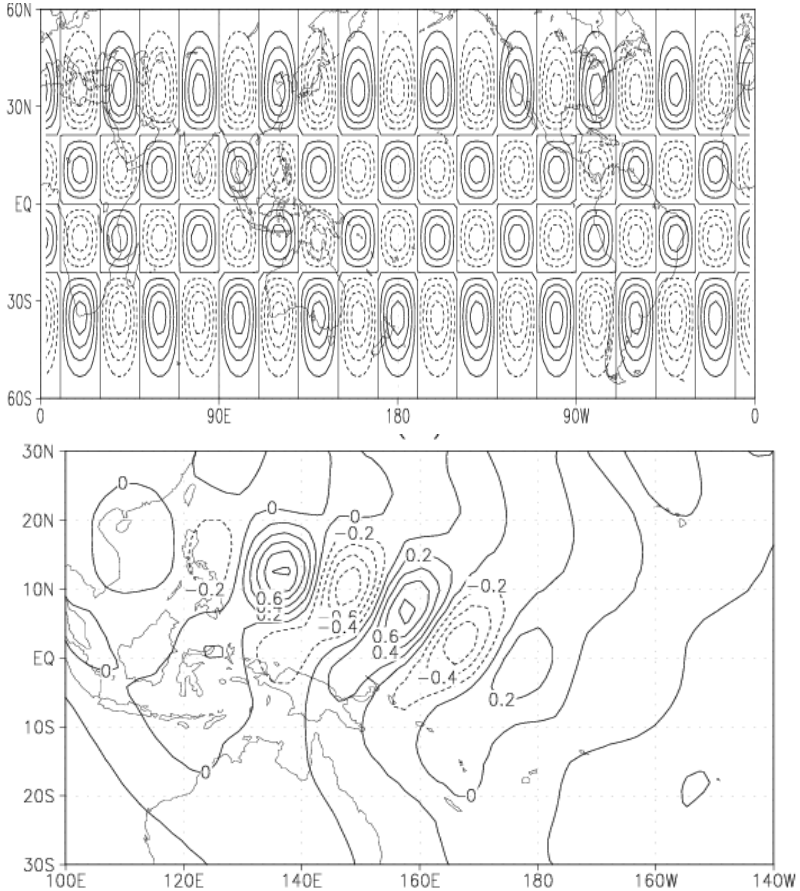
Green circle: Anti-cyclonic flow

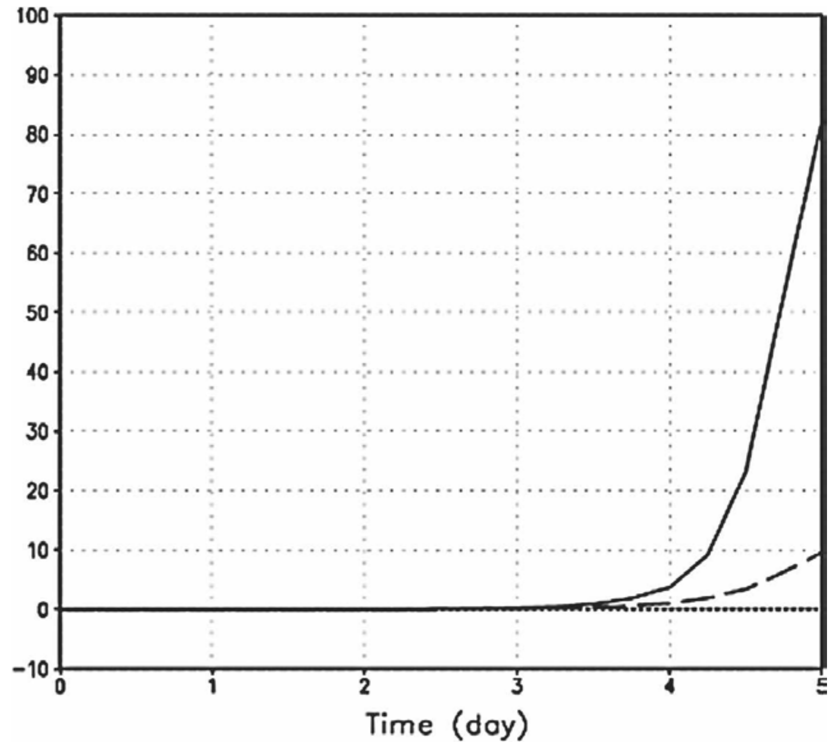
- Typhoon Manyi genesis location/time

Time sequences of 3-8-day filtered surface wind patterns associated with SWT. Red dot indicates the center location of typhoon “Man-yi” at the day of genesis.

This northwest-southeast oriented synoptic wave train is the dominant mode of atmospheric synoptic-scale variability in WNP (Lau and Lau 1990).

Origin of synoptic wave train in WNP





Left: Anomaly AGCM simulation with specified 3D summer (JJA) mean flows and SST and surface moisture condition

Li 2006, JAS

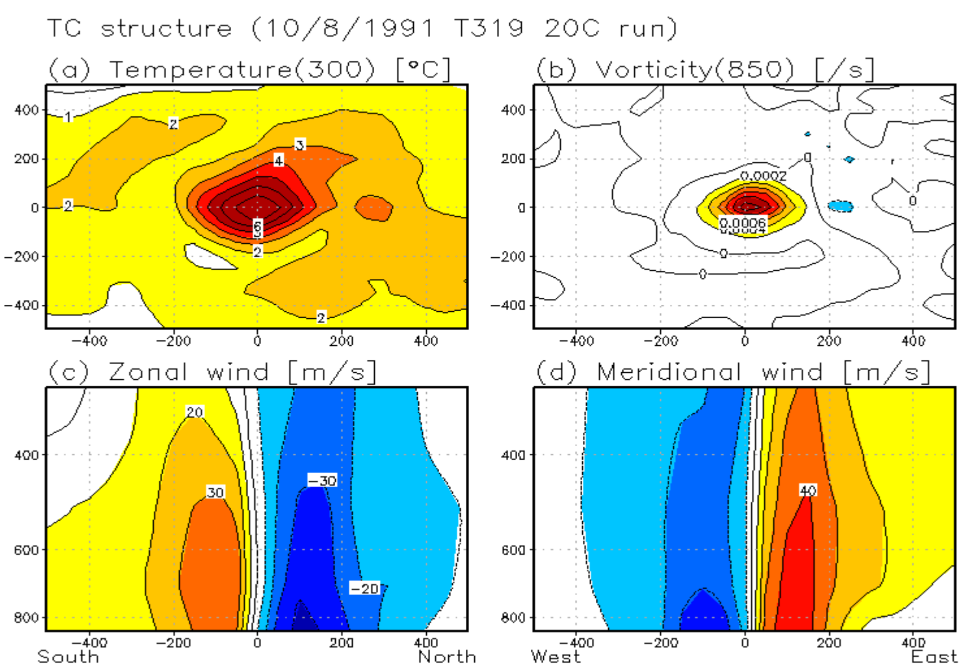
Right: Evolution of maximum perturbation kinetic energy under a constant easterly shear (solid line) and a constant westerly shear (dashed line).

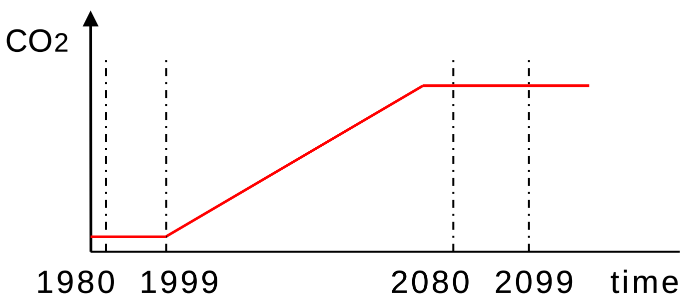
ECHAM5 T319 AGCM

Resolution: **T319**L31 (960x480 grids, **40 km grid**)
Scenarios : 20C3M, SRES A1B
Boundary condition (SST, T63 ECHAM5/MPI-OM)
(Jungclaus et al., 2006; AR4-IPCC))

Time-slice integrations

20C : 1980-1999 (20 years)
21C : 2080-2099 (20 years)





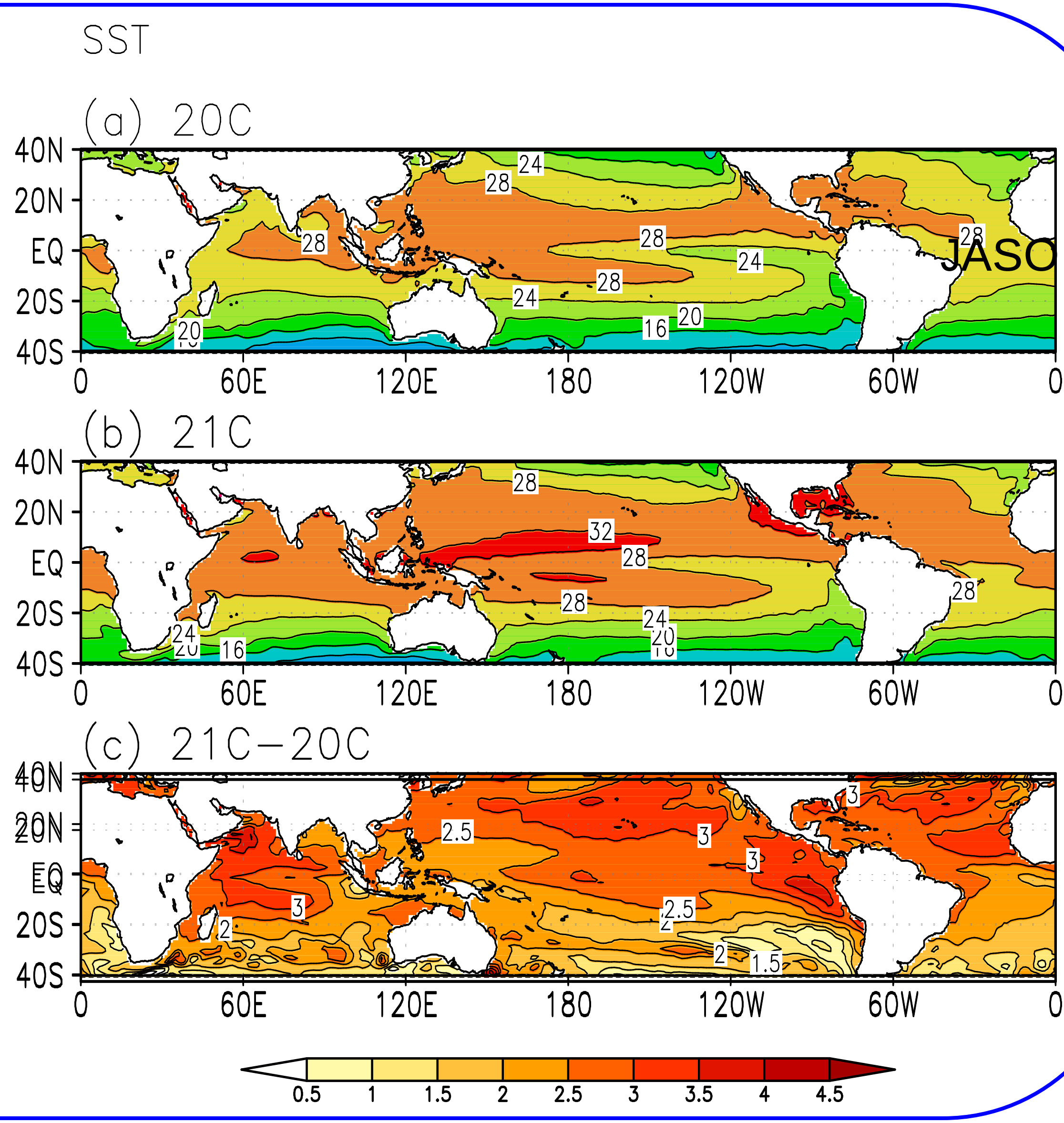
← T319 simulated TC warm core and wind profiles

SST distributions from ECHAM5/MPI-OM T63 CGCM

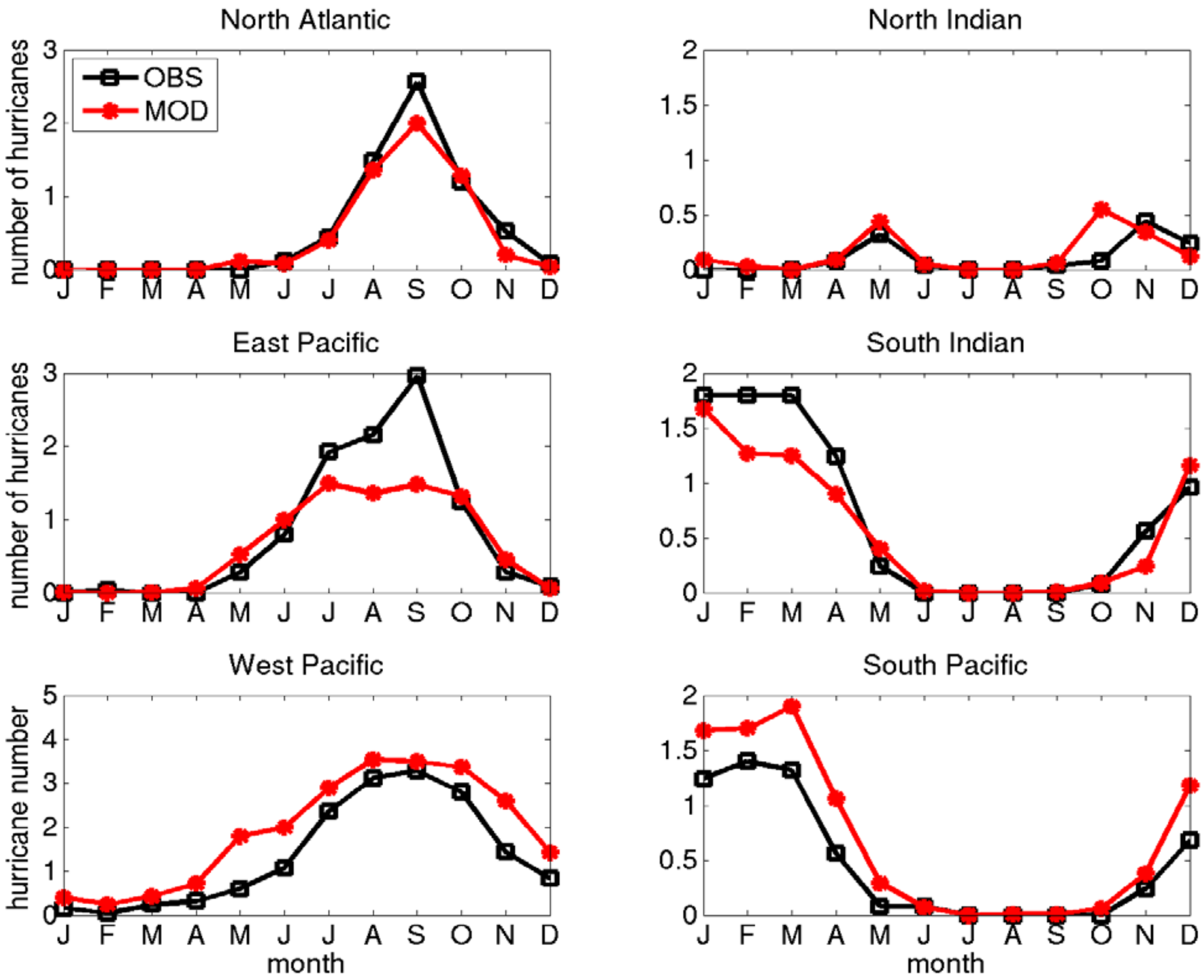
SST boundary condition specified in T319 atmospheric GCM, ECHAM5.

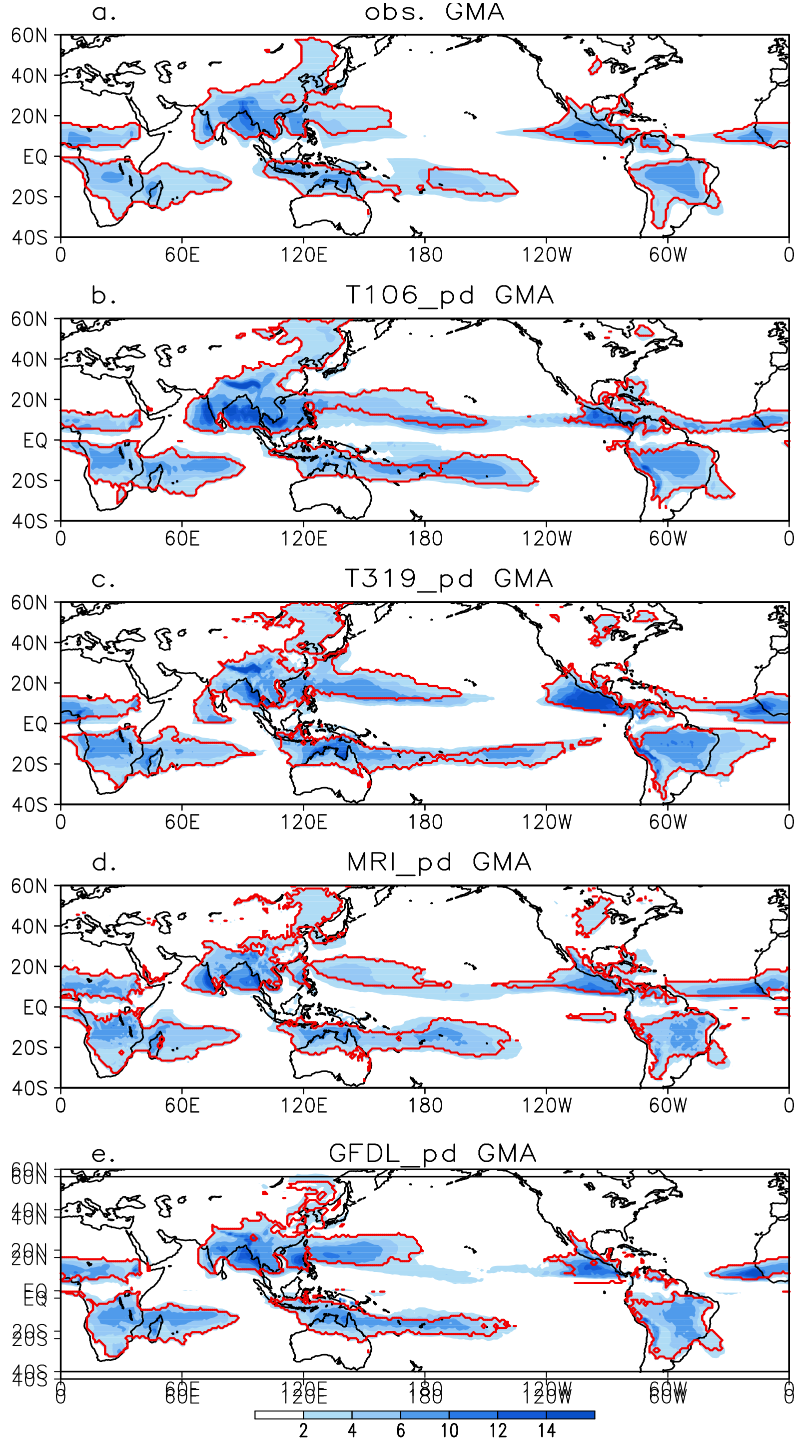
SSTs in tropics are increased at a range of 2 ~ 4 degrees.

SST warming in the western Pacific is less than that in the eastern and central Pacific.



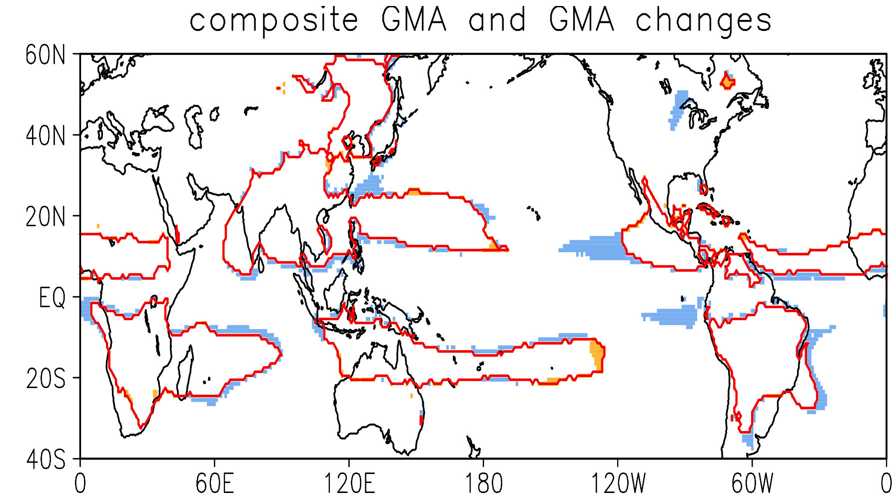
Seasonal cycle of hurricane frequency over various ocean basins from HiRAM2.1





Left: observed and simulated Global Monsoon Area in present-day climate

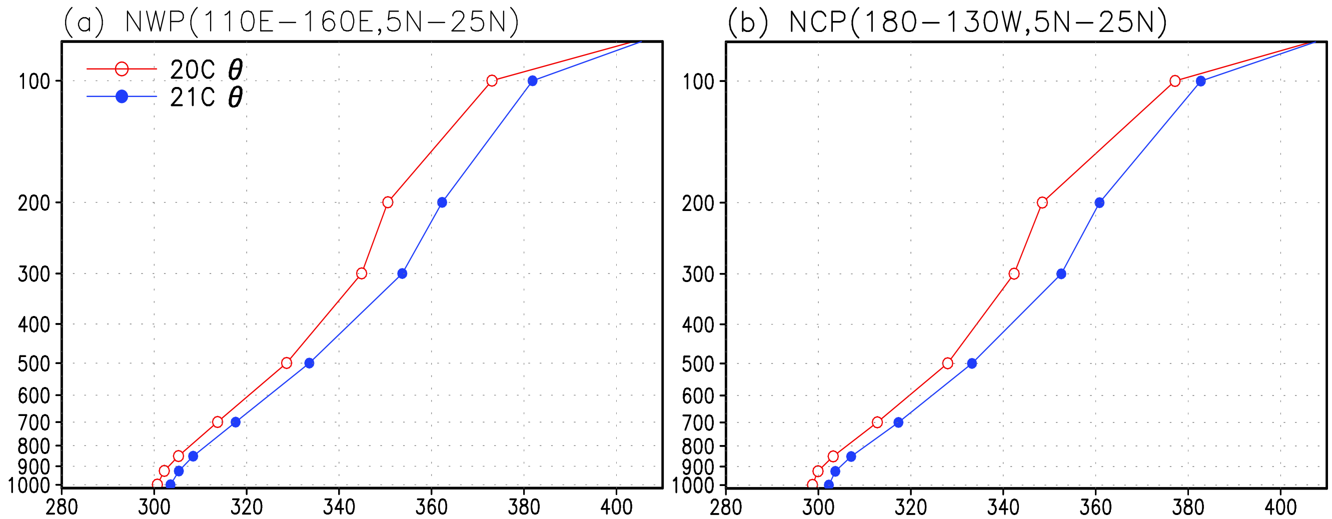
Below: composite present-day GMA and future change



Another way to confirm whether a projected signal is real is to provide a physical interpretation of the projected change.

Question: What causes the opposite changes of TC frequency in western and central Pacific?

Potential temperature



Maximum increase of temperature appears in upper troposphere → increase of atmospheric static stability in both regions

Thus, the change of the static stability cannot explain opposite trends of TC frequency in western and central Pacific.