Multi-model projection of tropical cyclogenesis over the western North Pacific using CMIP3 archive

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Outline

1. Introduction and key question.
2. Selection of models
3. Multi-model projection by counting the TC-like disturbances
4. Discussion on reasons for the projections obtained
5. Summary

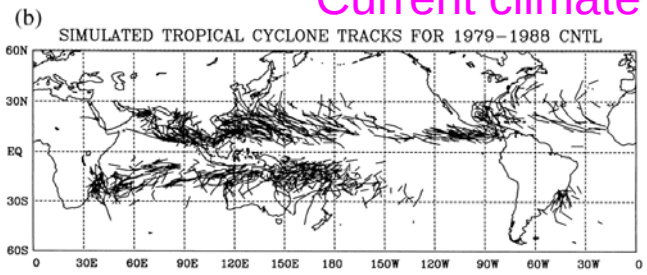
Introduction

- How would characteristics of tropical cyclone (TC) change due to the global warming?
- Most recent studies projected decrease trends in GLOBAL number of TC.

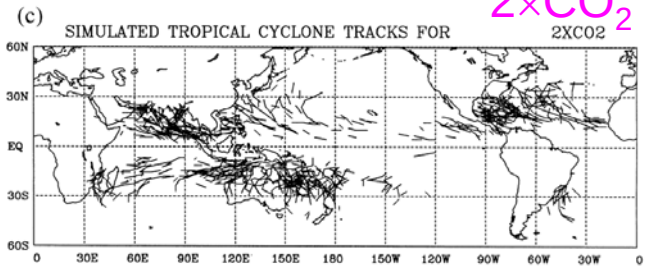
  (e.g. Sugi et al. 2002; McDonald et al. 2005; Oouchi et al. 2006; Bengtsson et al. 2007; Gualdi et al. 2008).
- How about REGIONAL trends?

  → Almost no consensus.

Current climate



$2 \times CO_2$



Sugi et al. (2002, JMSJ)

- Multi-model based approach can provide projections that are common among climate models and reduce uncertainties related to model selection.

Questions

- How would cyclogenesis frequency over the western North Pacific basin (0°–40°N, 100°E–180°) change due to the global warming?
  - We perform multi-model based approach by analyzing CMIP3 archives (output of climate model experiment contributing to IPCC AR4).
  - Advantage: Large number of samples (multi model, experiments, long-term simulation).
  - Disadvantage: Horizontal resolution of atmospheric model is relatively coarse.
- What are mechanisms for the projected trends?
  - We focus on local environmental conditions and activity of pre-TC disturbances.
  - Are genesis potential indices applicable to this problem?

Definition of TC-like disturbance

(1) 850-hPa relative vorticity (ζ_{850}) local maximum (=TC center) $\geq \zeta_t$.
(cyclonic vortex)

(2) (300-hPa temperature (T_{300}) at the center)–(environmental T_{300}) $\geq T_t$.
(warm core)

(3) Conditions 1 & 2 are satisfied at least 2 time steps.

(4) Genesis point is over the ocean.

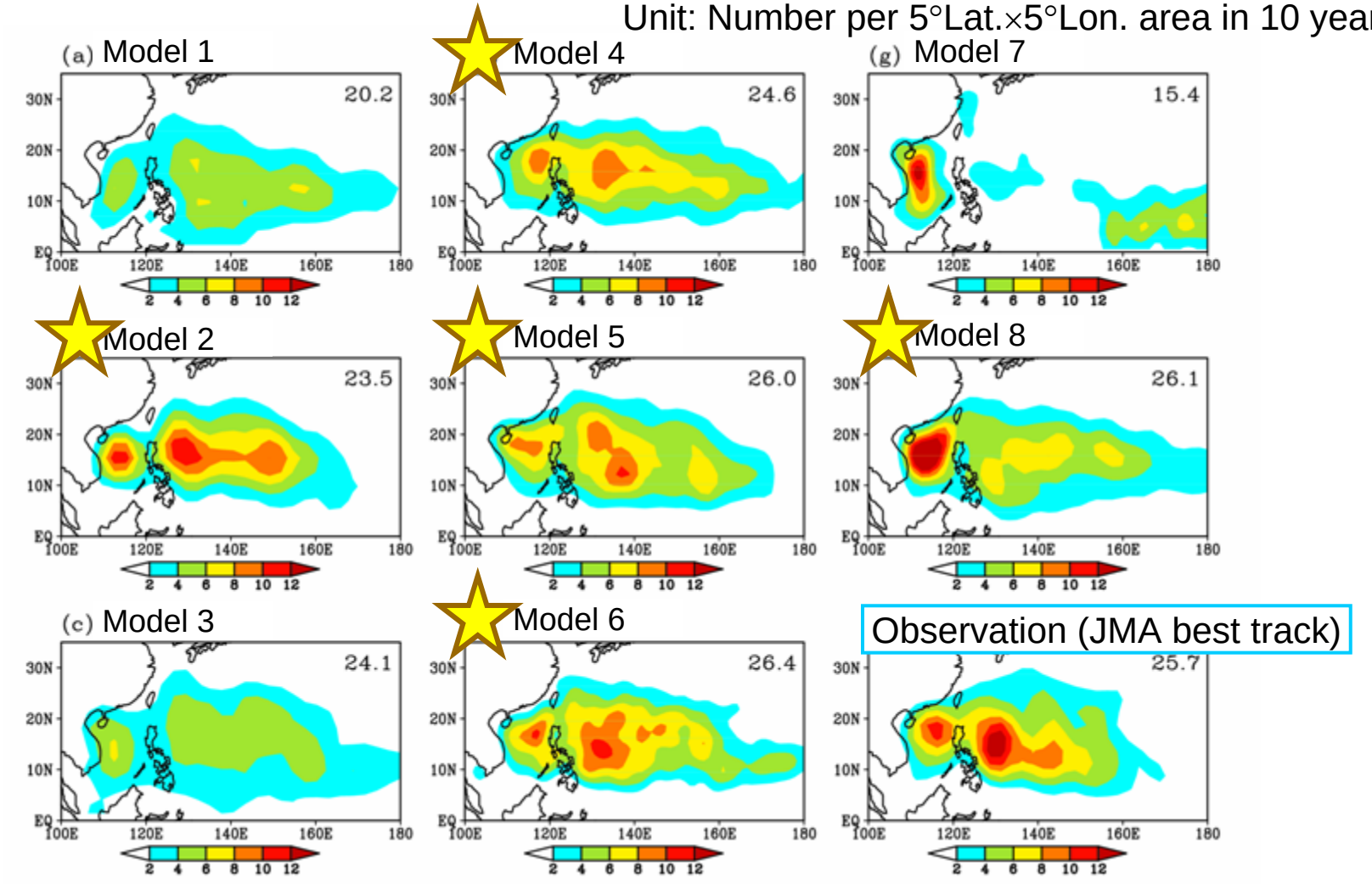
(5) At genesis time, maximum wind speed is greater at the 850-hPa level than at the 300-hPa level.
(exclusion of extra-tropical cyclones)

Thresholds (ζ_t, T_t) are determined independently for each model.

- Try to adjust meridional distribution of annual cyclogenesis frequency.

Simulated annual cyclogenesis (20C3M)

Unit: Number per 5°Lat.×5°Lon. area in 10 years.



- Five ★ models reproduce maxima over the South China Sea and east of Philippines, and relatively low cyclogenesis east of 160E.

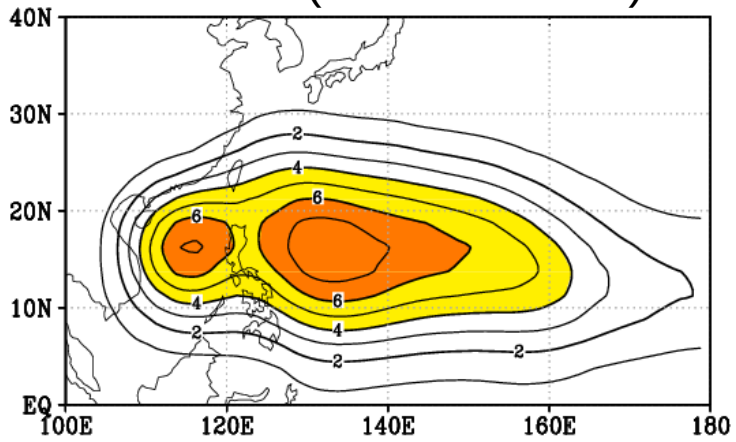
20C3M and SRES

- I compare the cyclogenesis frequency between 20C3M and average of SRES experiments.
  - 20C climate simulation (20C3M): 40-yr length.
  - SRES A1B, A2, and B1 experiments: 80-160-yr length.

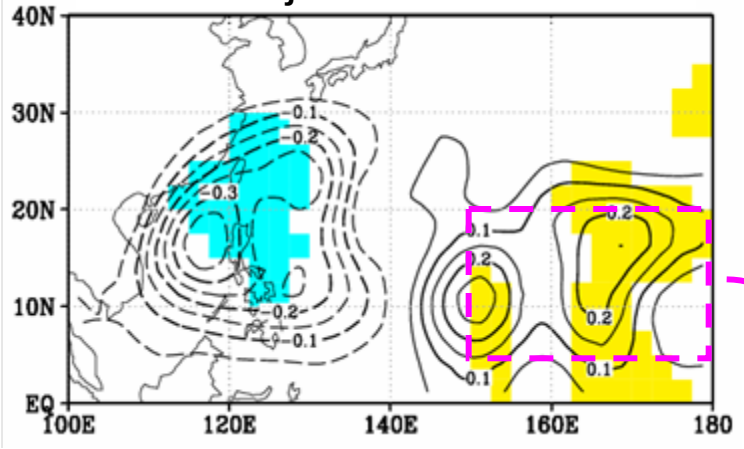
Model name	20C3M	SRESA1B			SRESA2		SRESB1			ΔT
	1961-2000	2046-2065	2081-2100	2181-2200	2046-2065	2081-2100	2046-2065	2081-2100	2181-2200	
CGCM3.1(T63)	x	x	x	x			x	x	x	3.2
CSIRO-Mk3.0	x	x	x	x	x	x	x	x	x	1.9
CSIRO-Mk3.5	x	x	x		x	x	x	x	x	2.9
ECHAM5/MPI-OM	x	x	x			x	x	x		2.9
INGV-SXG	x	x	x		x	x				2.9

Projected trends in annual cyclogenesis frequency

20C3M (5-model mean)



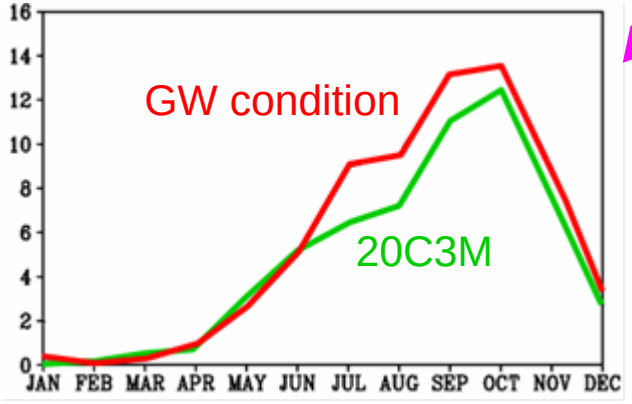
Projected trends



Yellow (blue) tone: all 5 models project increase (decrease) trends.

- ALL 5 models project
  - ➢ increase trends over central North Pacific (CNP) (during July–November), and
  - ➢ decrease trends over the South China Sea (SCS) and areas just to the east of Philippines.

Time series in (5–20°N, 150°E–180°)



Environmental conditions

- Environmental conditions favorable for cyclogenesis include:
  - Positive relative vorticity in the lower troposphere
  - Weak vertical shear of horizontal wind

  } Dynamic conditions

  - High Potential Intensity (PI) [Bister and Emanuel 2002]
    - ✓ Index of SST and atmospheric stability
  - High relative humidity in the middle troposphere

  } Thermodynamic conditions

Emanuel and Nolan (2004) Genesis Potential (**GP**)

$$GP = \left|10^5 \eta_{850}\right|^{1.5} \times \frac{1}{\left(1 + 0.1\left|\mathbf{u}_{850} - \mathbf{u}_{200}\right|\right)^2} \times \left(\frac{PI}{70}\right)^3 \times \left(\frac{H_{700}}{50}\right)^3$$

where η_{850}: 850-hPa absolute vorticity, $|\mathbf{u}_{850}-\mathbf{u}_{200}|$: vertical wind shear

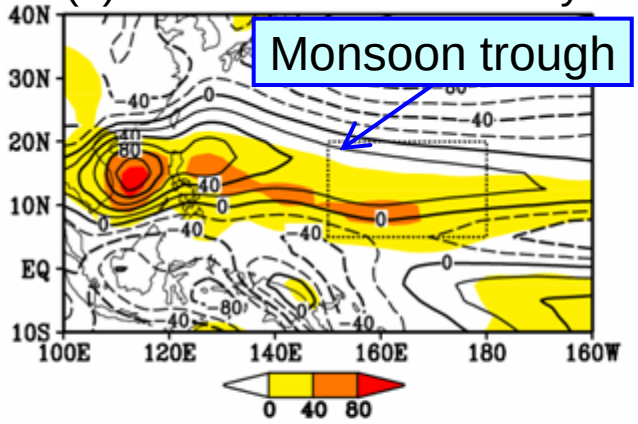
PI: potential intensity, H_{700}: 700-hPa relative humidity

GP definition was tuned with reference to the current climate.

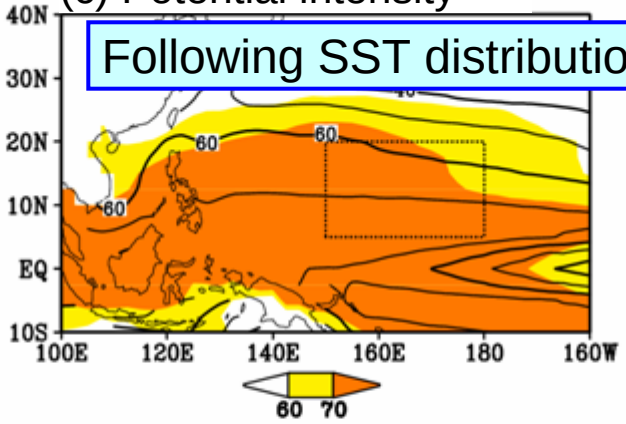
➔ Is GP applicable to global warming problem?

Jul-Nov. environmental conditions (20C3M & Obs.)

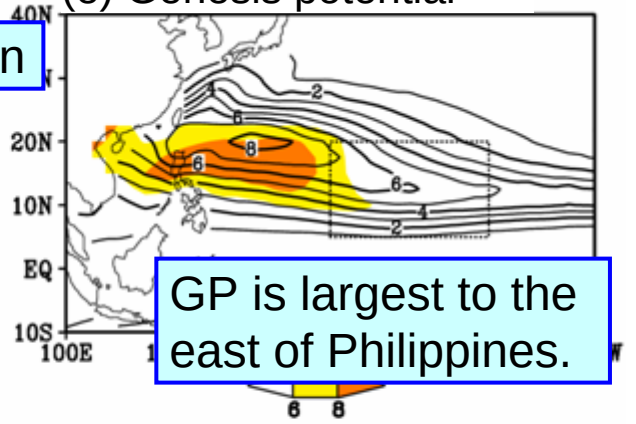
(a) 850hPa relative vorticity



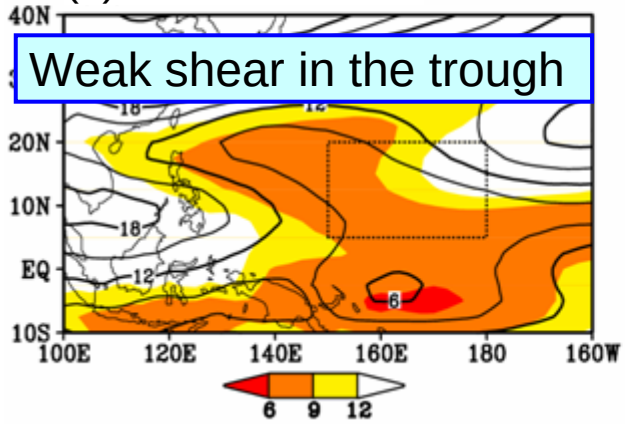
(c) Potential intensity



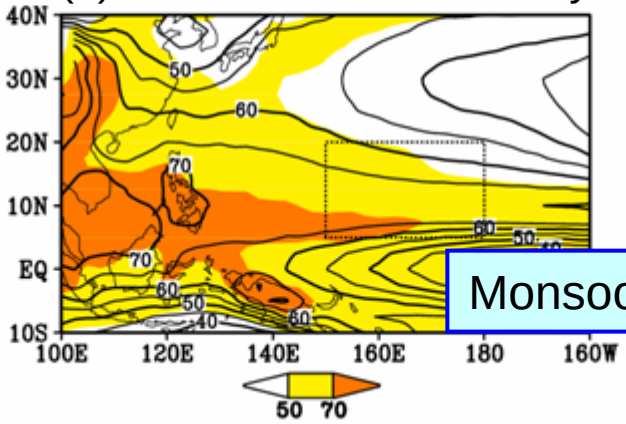
(e) Genesis potential



(b) Vertical shear



(d) 700hPa relative humidity



Contour:
20C3M of 5 models.

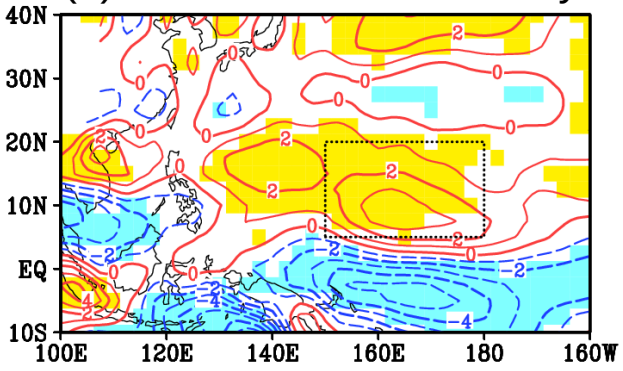
Color tone:
Observation

Monsoon trough and ITCZ

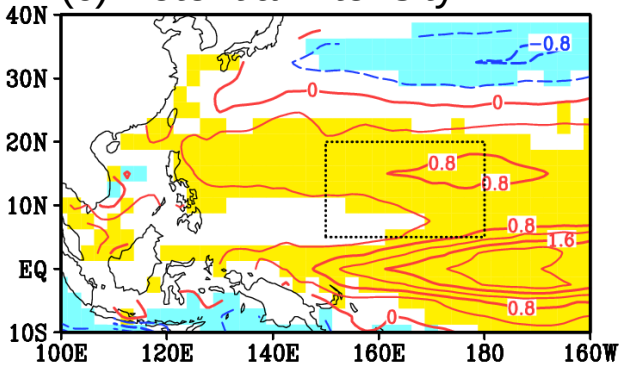
- Models reasonably simulate observed environment:
  - monsoon trough and associated weak shear area.
  - Higher PI and humidity in the tropical western North Pacific and South China Sea.

Projected change in environmental fields

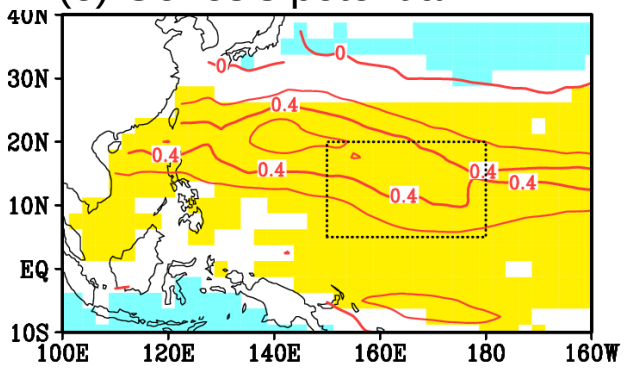
(a) 850hPa relative vorticity



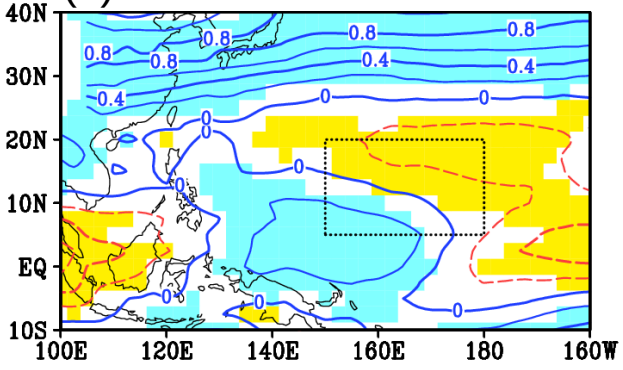
(c) Potential intensity



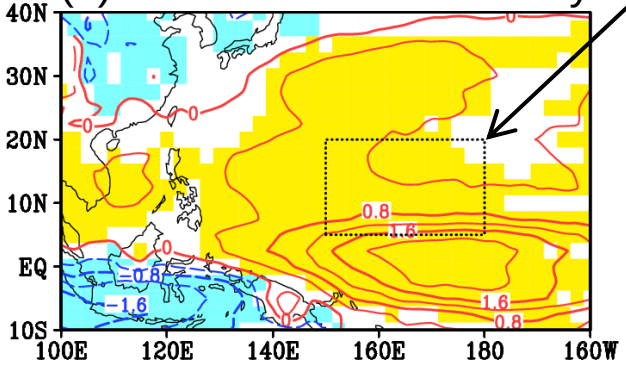
(e) Genesis potential



(b) Vertical shear



(d) 700hPa relative humidity



Central North Pacific (CNP)

Yellow (blue) tones:

At least 4 models project that condition would become more (less) favorable for cyclogenesis.

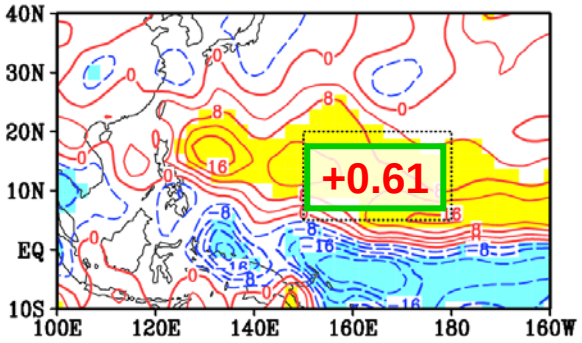
- Trends in dynamic conditions indicate eastward extension of the monsoon trough.
- Pattern of GP trend is completely different from that of cyclogenesis frequency.
- Vorticity, PI, and humidity would become more favorable for cyclogenesis over CNP.

➔ We will discuss which of the trends is more important for increase projection of cyclogenesis by analogy with the observed interannual variability.

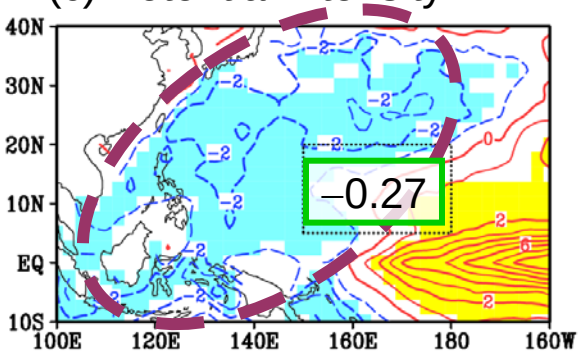
Interannual variability of environmental condition

Observation

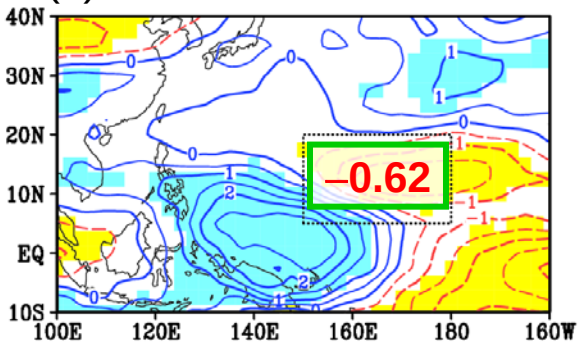
(a) 850hPa relative vorticity



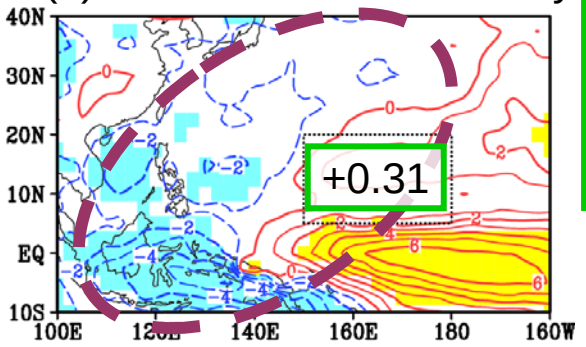
(c) Potential intensity



(b) Vertical shear



(d) 700hPa relative humidity



Environmental condition regressed on cyclogenesis over CNP

(5–20°N, 150°E–180°)

Tone: 99% significance

Correlation coefficient

(Cyclogenesis Freq. vs Environmental condition)

over CNP

Red: 99% significance

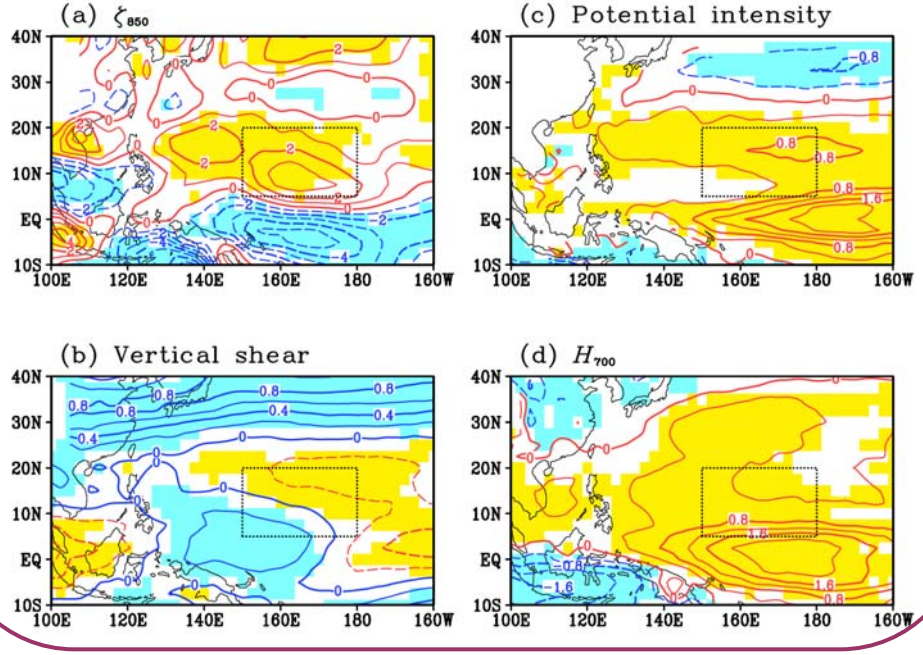
- Dynamic conditions (vorticity and shear) exhibit similar pattern to the projected one.
- Potential intensity and humidity do not exhibit significant correlation over CNP.
  - Since they are probably favorable for cyclogenesis every year, their slight changes due to the GW may not play a role in TC increase trend.
- Note: The pattern shown is quite similar to the ENSO-related one.

South China Sea (SCS)

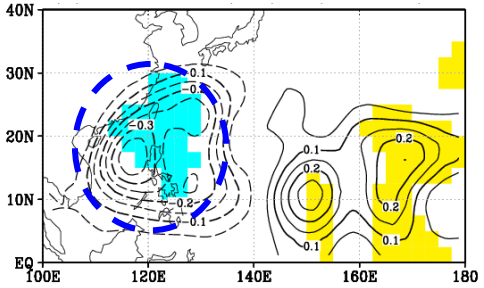
- Cyclogenesis is projected to decrease.
- Environmental conditions would become more favorable for cyclogenesis or exhibit no significant changes.

➔ We try to discuss the decrease projection in terms of the activity of tropical depression-type disturbances (TDDs), one of the pre-TC disturbances that can later be developed into TC.

Projected trends in environmental fields

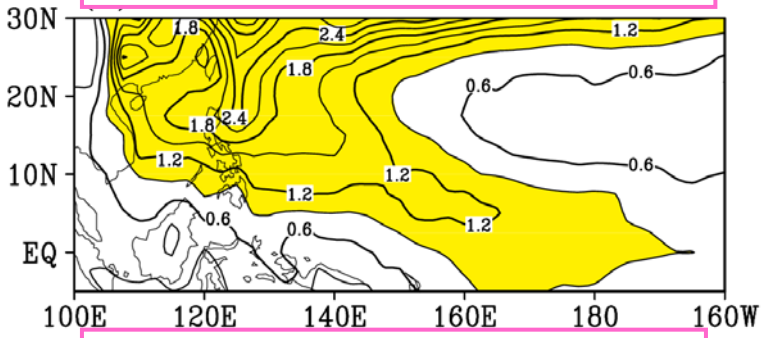


Projected trends in cyclogenesis frequency

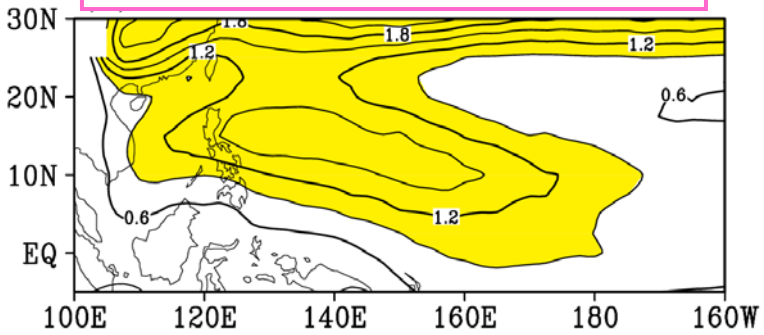


Activity in tropical depression-type disturbances (TDDs) that reach the South China Sea (SCS)

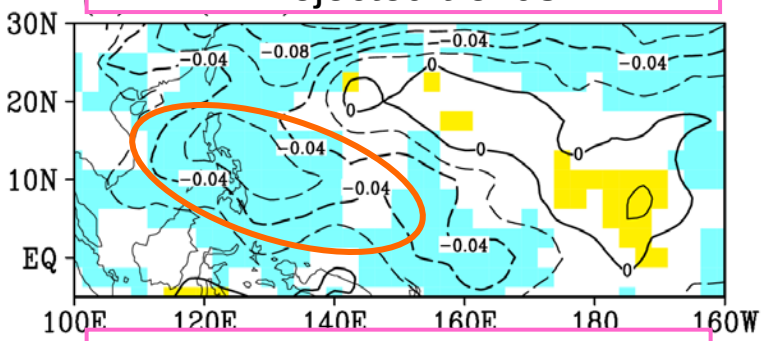
Observation



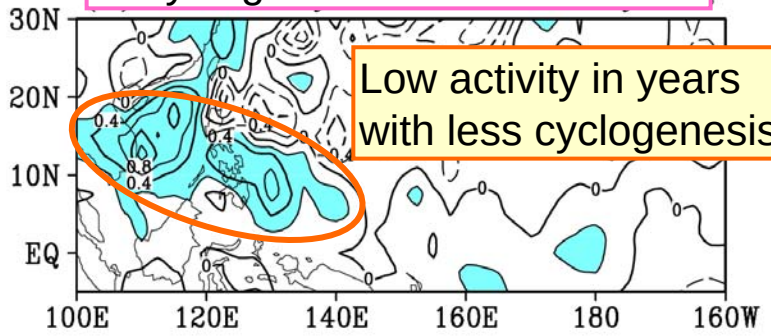
20C3M



Projected trends



Obs. IAV associated with cyclogenesis over the SCS



Low activity in years with less cyclogenesis.

- Active band of TDD orienting NW-SE direction is realistically simulated.
- The activity would decrease significantly over the SCS and to its southeast.
- Observed interannual variability exhibits similar pattern, implying that weakening trends of TDD activity may play a role in decrease trends in cyclogenesis over the SCS.

Summary

- We analyze output of CMIP3 climate model experiments to perform multi-model projection of tropical cyclogenesis over the western North Pacific.
- Five CMIP3 models realistically simulate horizontal distribution in cyclogenesis under the current climate.
- ALL of the five models project increase trends of cyclogenesis over the central North Pacific and decrease trends over the South China Sea and regions east of Philippines.
- The former increase trends are primarily attributable to projected eastward extension and intensification of the monsoon trough.
- The later decrease trends may be associated with weakening trends in activity of tropical depression-type disturbances.
- Genesis potential proposed in previous studies would increase all over the Western North Pacific Basin south of 25°N.

Reference: Yokoi and Takayabu, 2009, *JMSJ*, *in press.*


Thank you for your attention.