Where will typhoons occur more or less in the future?

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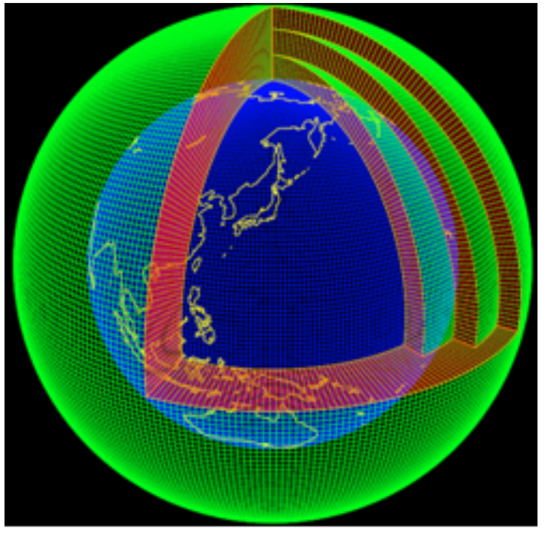
Murakami et al. (2011, 2012, J. Climate)

Outline

- Review of previous studies on projected future changes in tropical cyclones (TCs)
- Projected future changes in TC frequency of occurrence in the western North Pacific using a 20-km mesh global model.
- Summary



20-km mesh global model

Review of effect of global warming on TC activity

nature geoscience
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Knutson et al. (2010, *Nat. Geosci.*)

Tropical cyclones and climate change

Thomas R. Knutson[1]*, John L. McBride[2], Johnny Chan[3], Kerry Emanuel[4], Greg Holland[5], Chris Landsea[6], Isaac Held[1], James P. Kossin[7], A. K. Srivastava[8] and Masato Sugi[9]

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1. **Consistent results** (consensus)
   - Reduction in frequency of global TCs
   - Increase in frequency of intense TCs

2. **Inconsistent results** (uncertainty)
   - Projected future changes in TC frequency in a specific ocean basin

   Among 13 previous numerical studies, 5 indicated an increase in the WNP, while 7 reported a decreasing frequency (Murakami and Wang, 2010)

Regional changes in TC activity remain uncertain!

IPCC Assessment Reports

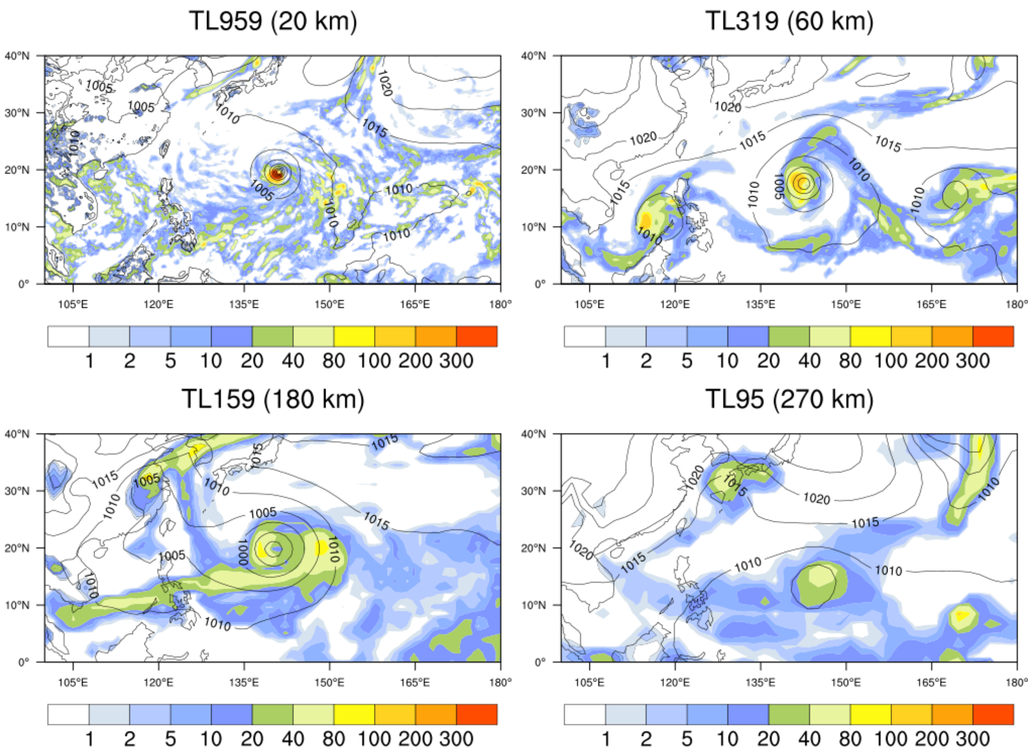
	FAR 1990 11 Chapters	SAR 1995 11 Chapters	TAR 2001 14 Chapters	AR4 2007 11 Chapters	AR5 2013 14 Chapters
observations	✓	✓	✓	✓✓✓	✓✓✓
paleoclimate				✓	✓
sea level	✓	✓	✓		✓
clouds					✓
carbon cycle			✓		✓
regional change			✓	✓	✓✓✓

To address regional change is one of the important topics in the IPCC AR5.

SREX 2011
(Extreme Events)

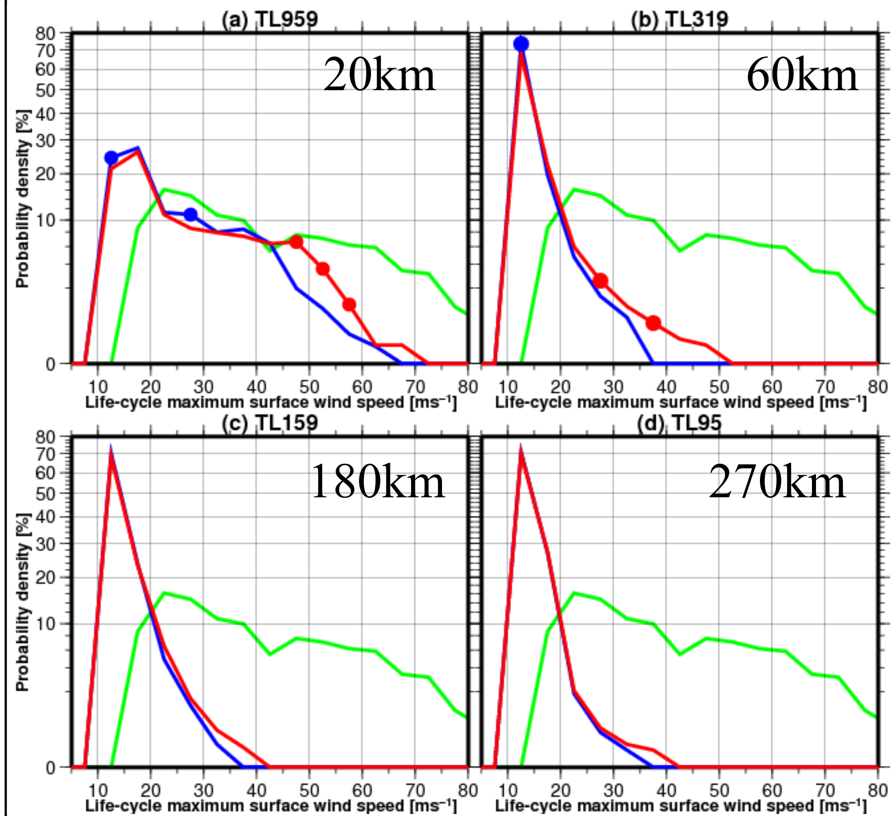
Why do we need a high resolution model?

·Projections by previous climate models are not reliable because the models are too coarse to resolve TC structures.



<u>High resolution model yields realistic TC structure.</u>

·Only models finer than 60 km-mesh show future increase in intense TCs (Murakami and Sugi, 2010).



Observations (1979-2003)

Present 25year (1979-2003)

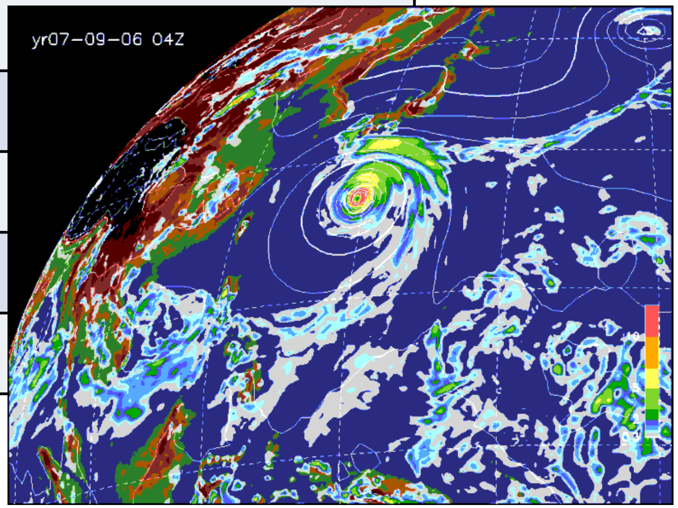
Future 25year (2075-2099)

● : significant increase at 95% level

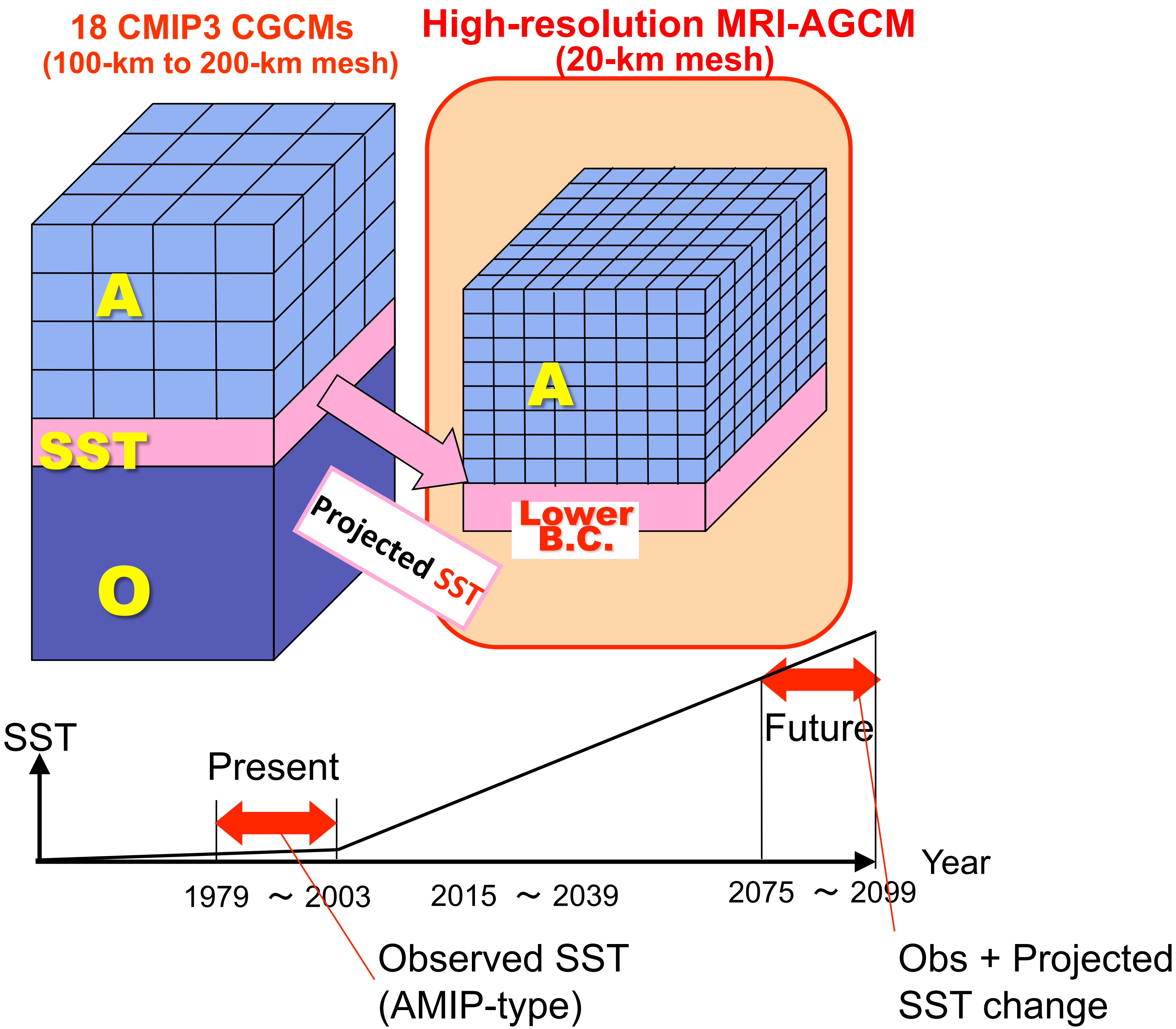
● : significant decrease at 95% level

Model Specifications

	MRI-AGCM3.0, 3.1 (Mizuta et al. 2006)
Horizontal resolution	TL959 (20km)
Vertical resolution	60 levels (top at 0.1hPa)
Time integration	Semi-Lagrangian
Time step	6minutes
Cumulus convection	Prognostic Arakara-Schubert
Cloud	Smith (1990)
Radiation	Shibata and Aoki (1989) Shibata and Uchiyama(1992)
GWD	Iwasaki et al. (1989)
Land surface	SiB ver0109(Hirai et al.2007)
Boundary layer	MellorYamada Level2
Aerosol (direct)	Sulfate aerosol
Aerosol (indirect)	No



Time-slice Experiment



Experimental Designs

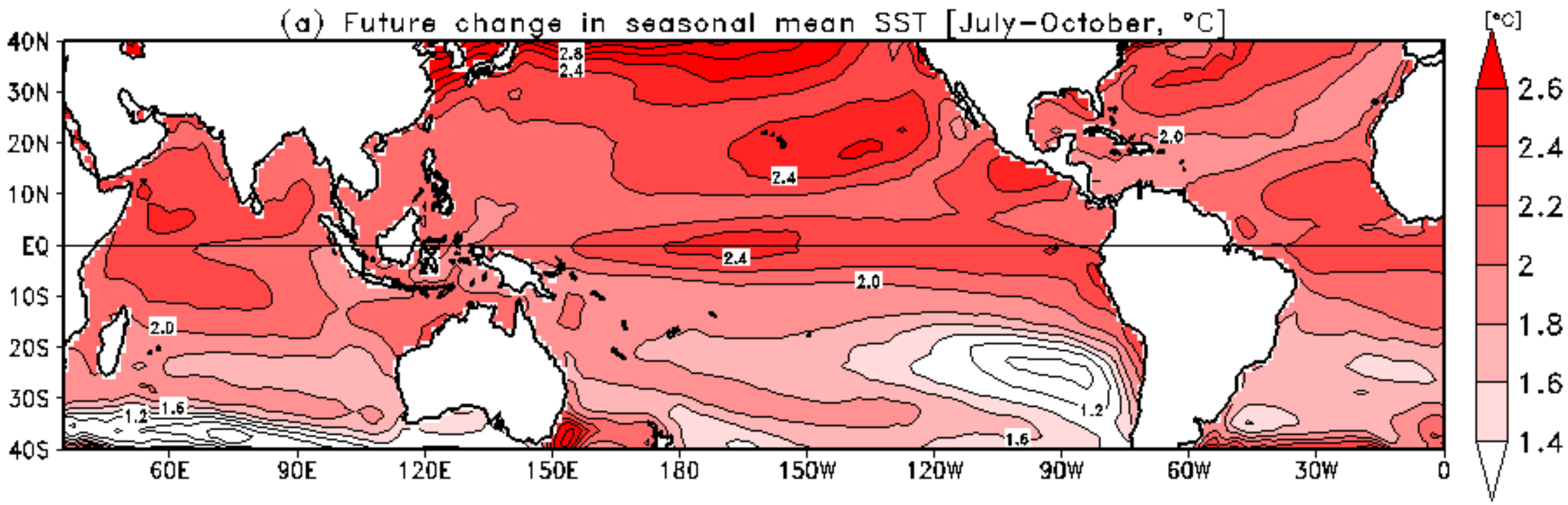
- Model: MRI AGCM 3.1 (20 km-mesh)
- Projection periods:

  Present-day exp. (PD) : 1979-2003 (25 yr)

  Future global warmed exp. (GW): 2075-2099 (25 yr)
- Prescribed Lower Boundary Conditions:

  PD: Observations (HadISST)

  GW: Ensemble mean of 18 CMIP3 models' SST under the IPCC A1B scenario



・Relatively larger increase in SST in the Northern Hemisphere than in the Southern Hemisphere.

・The SST increase is the largest in the tropical Central Pacific.

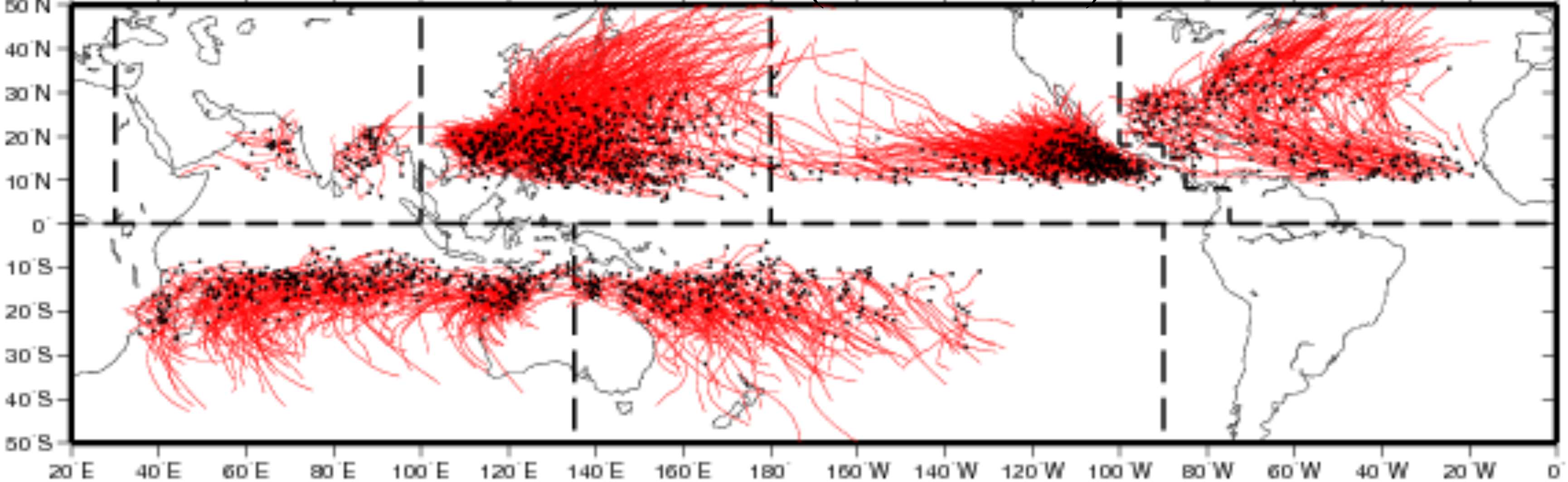
TC Detection Criteria

Based on Oouchi et al. (2006)

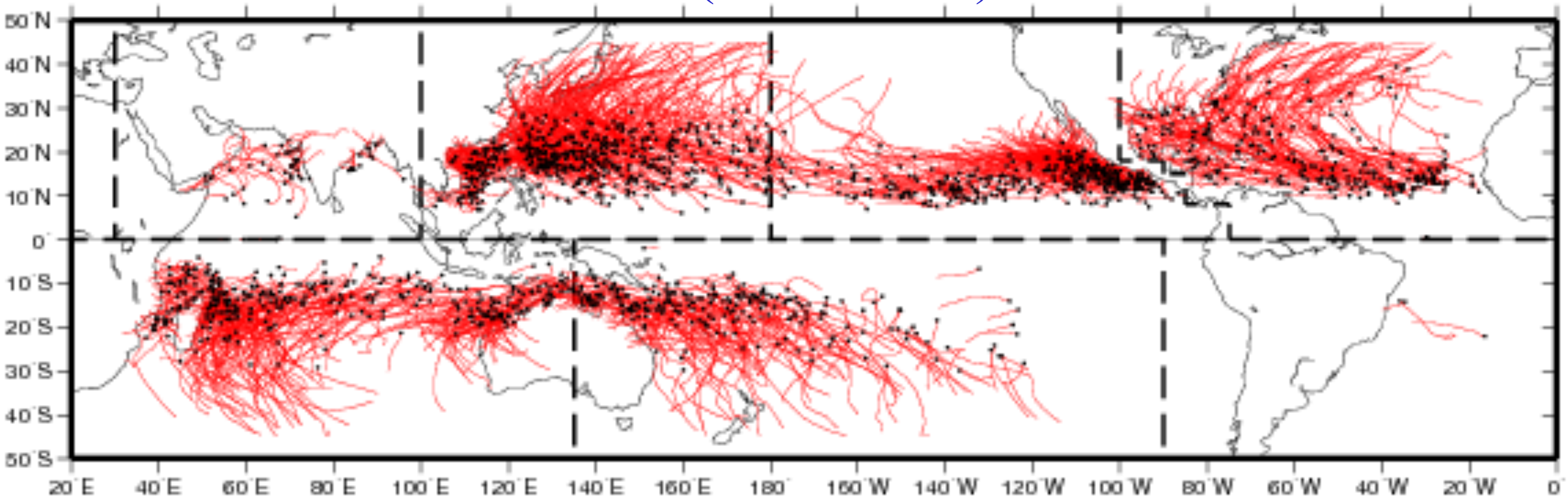
- Sea level pressure = 2.0 hPa lower than the surroundings area.
- 850 hPa Relative volticity = 3.0×10^{-5} /s
- 850 hPa Maximum wind speed = 10.0 m/s
- Warm Core: 1.0 K
- Duration =36 hours
- Maximum wind speed at 850 hPa should be greater than the 300 hPa (to exclude extra-tropical cyclones).

Simulated Global TC Tracks

Observations (1979-2003)



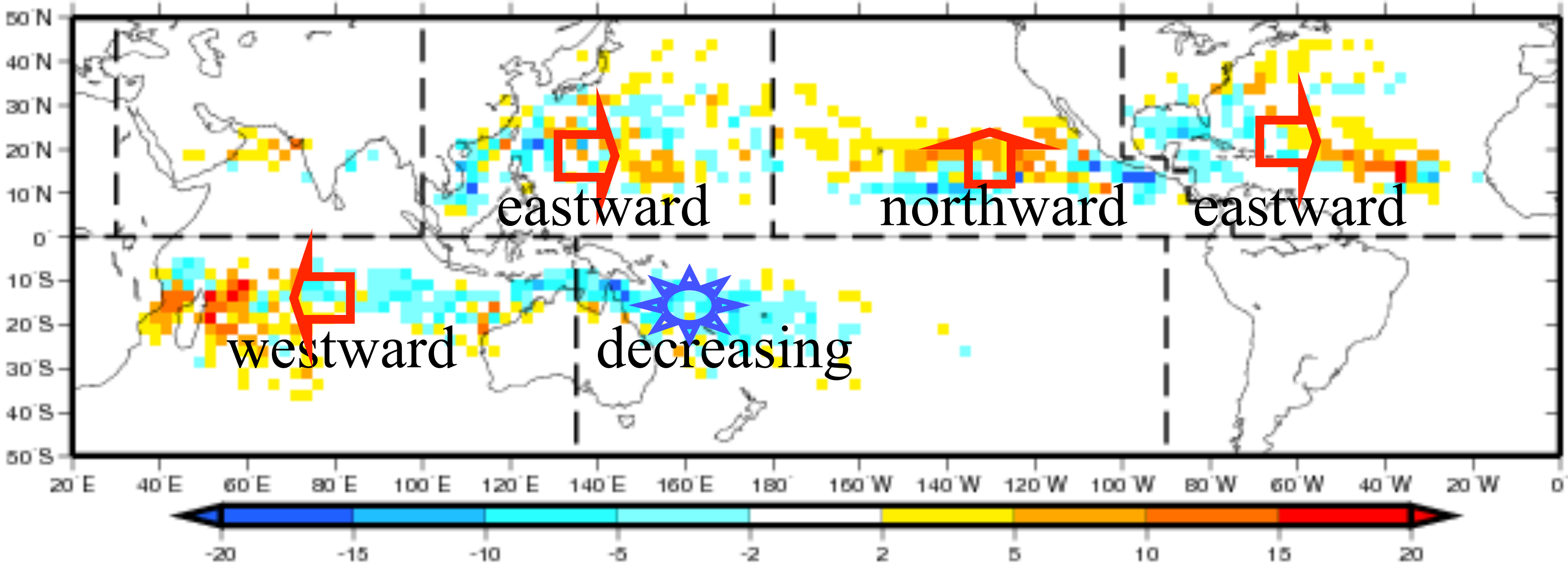
PD (1979-2003)

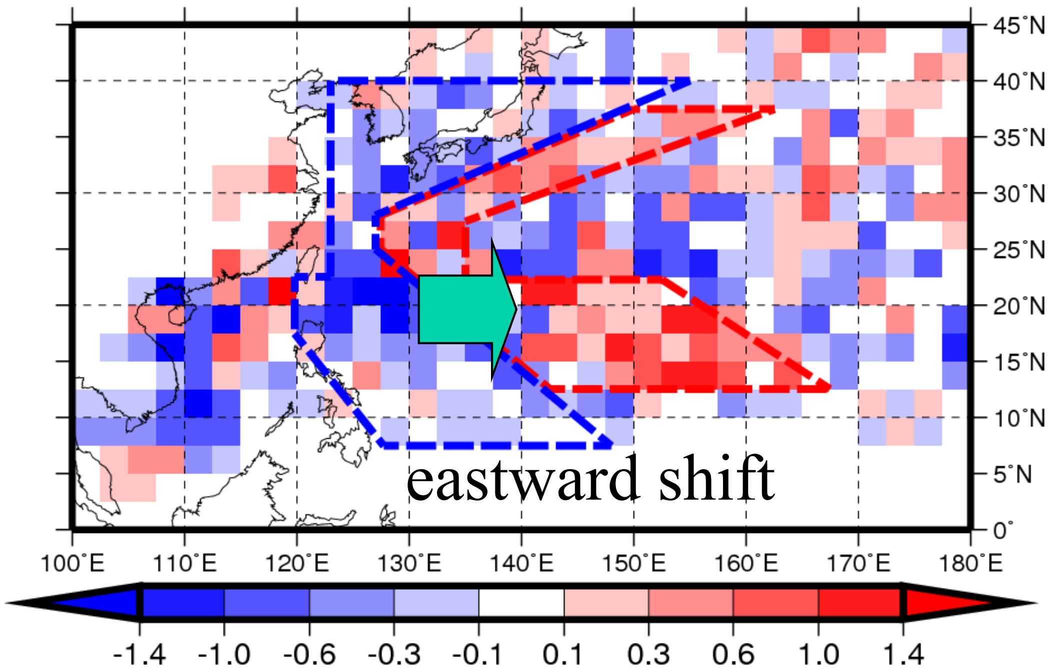


TC tracks are well simulated by the PD experiment.

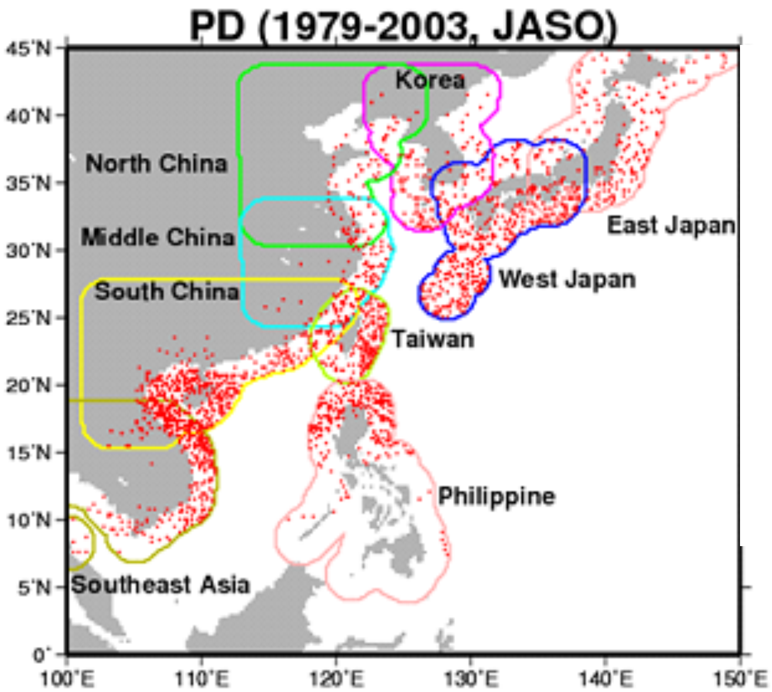
Future Projections

Future changes in the TC frequency of occurrence

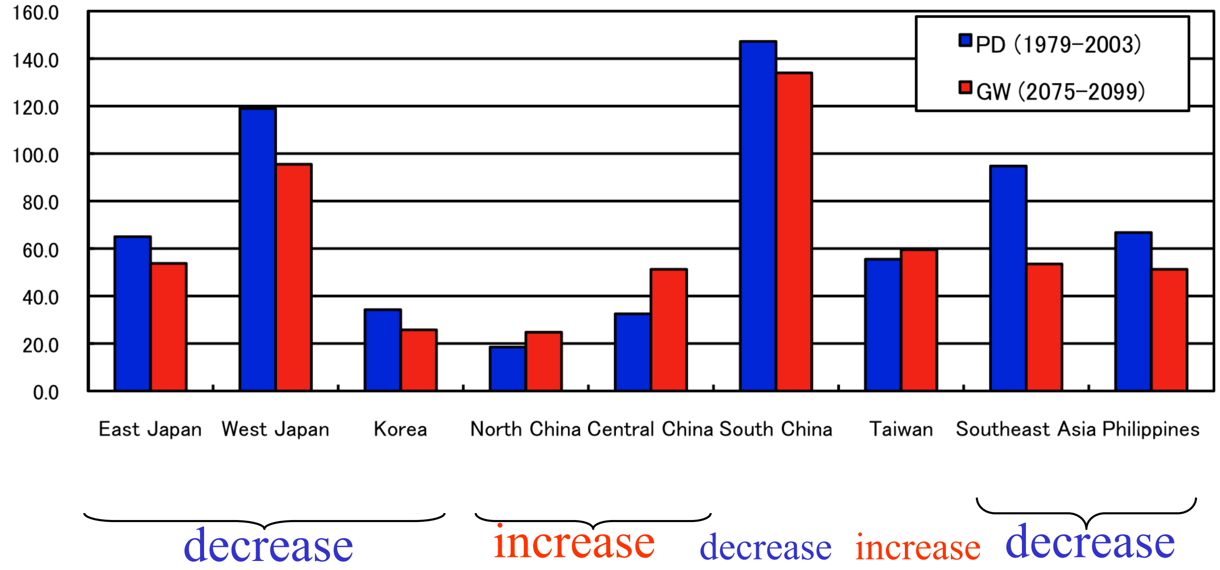




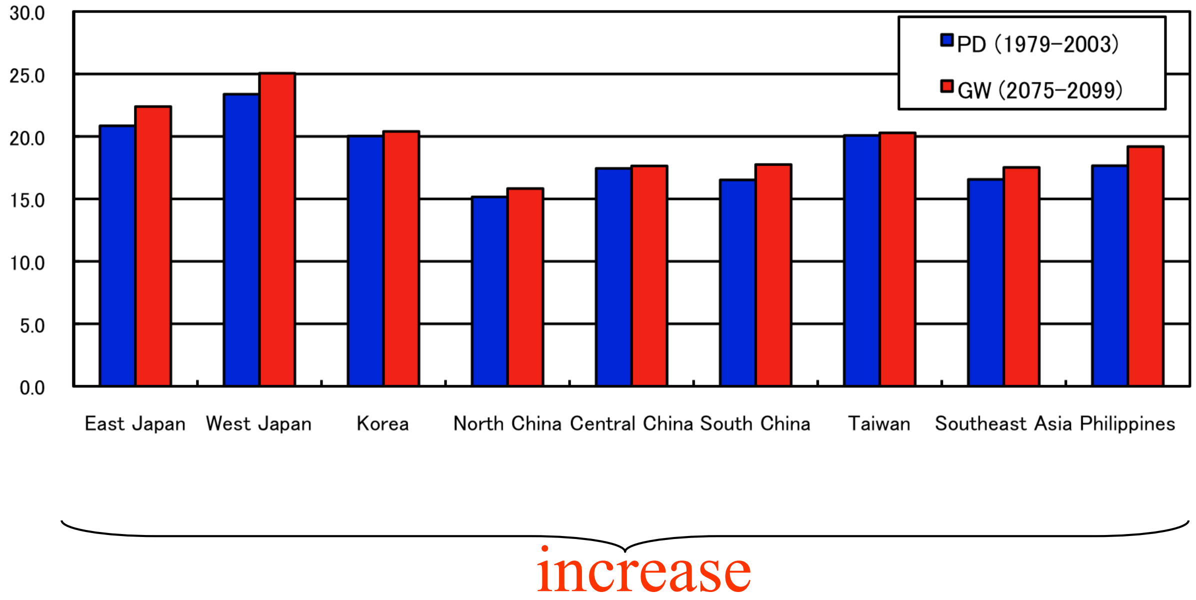
Future changes in “Landing” tropical cyclones



(a) July-October mean of TC frequency near coasts



(b) Mean maximum wind velocity of TCs near coasts

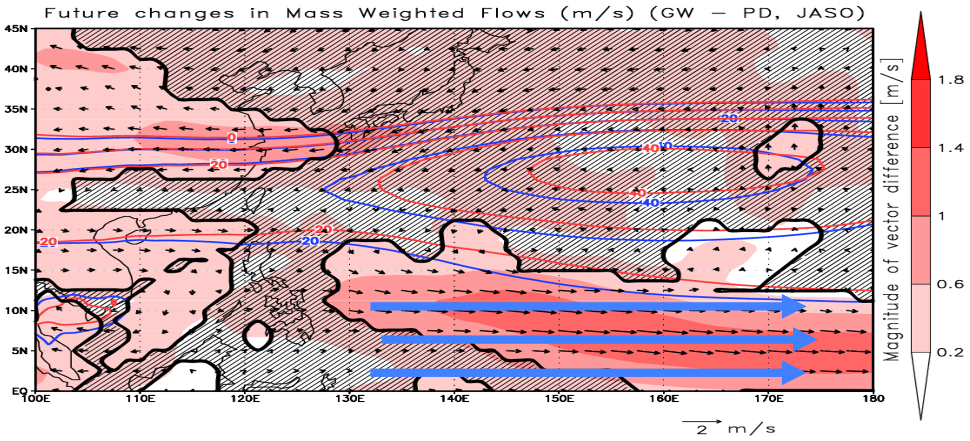


The frequency of tropical cyclones approaching Japan and Korea may decrease in the future.

However, once a TC approaches the coast lines, mean of maximum wind velocity is larger than the present climate, leading to a catastrophic damage in the future.

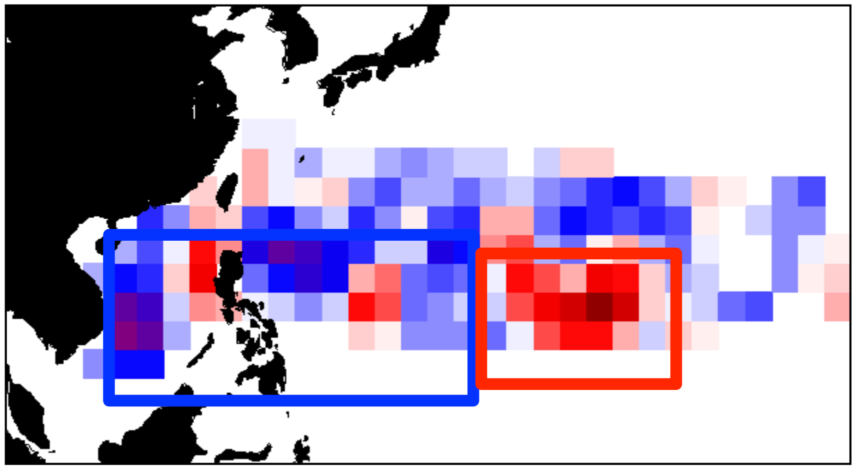
What causes TC track changes?

Steering flow (850-300hPa) changes



Steering flow changes (westerly flow anomaly) **partly** explain TC track changes by inhibiting westward TC motion.

TC genesis frequency changes



TC genesis location changes (eastward shift) **mainly** explain TC track changes.

Genesis potential index

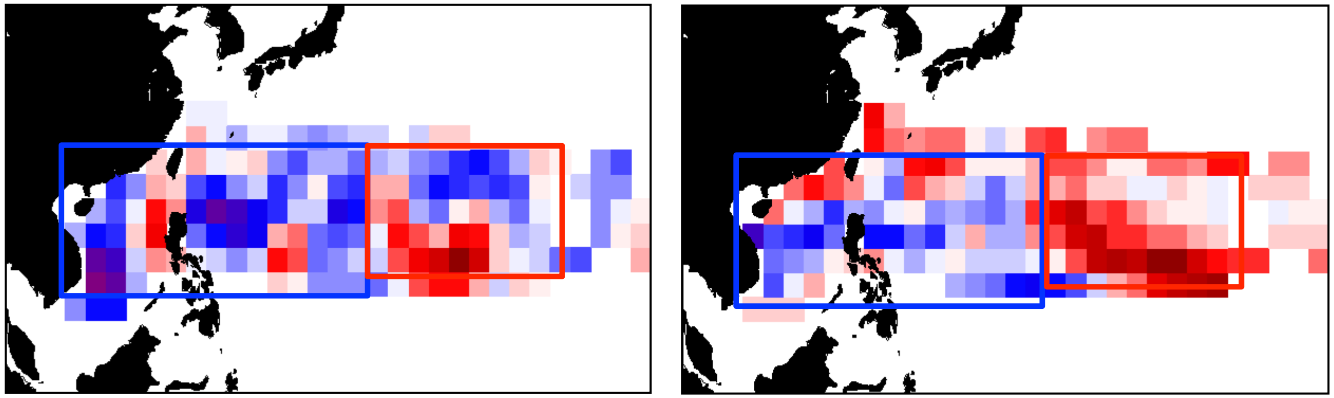
To determine the factors behind such genesis changes, we used a Genesis Potential Index (GPI) by Emanuel and Nolan (2004) with some modifications.

$$GPI' = \left|10^5 \eta\right|^{\frac{3}{2}} \left(\frac{RH}{50}\right)^3 \left(\frac{V_{pt}}{70}\right)^3 \left(1 + 0.1V_s\right)^{-2} \left(\frac{-\omega + 0.1}{0.1}\right),$$

Absolute Vorticity at 850hPa	Relative Humidity at 700hPa	Maximum Potential Intensity	Vertical Wind Shear (850-200hPa)	Vertical p-velocity at 500hPa

Future changes in TC genesis frequency

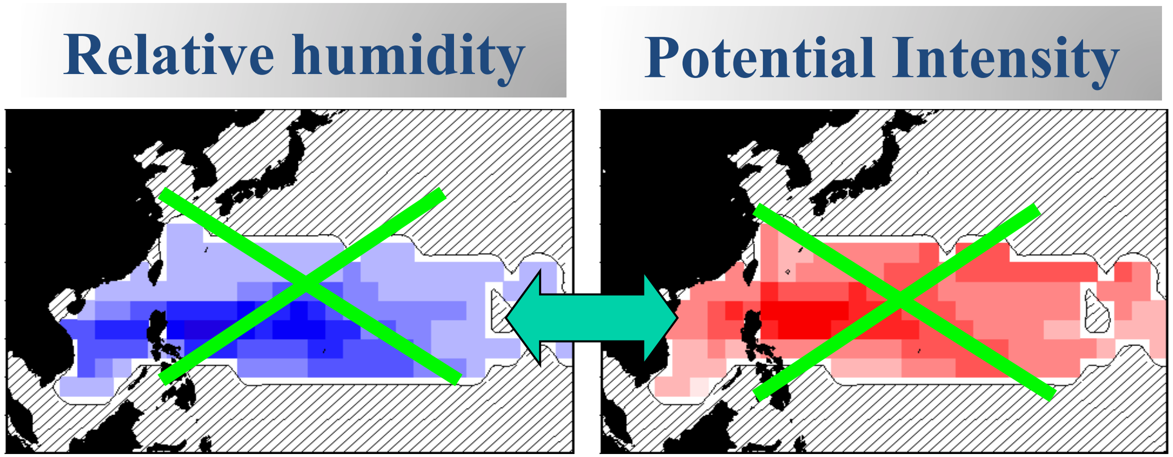
GPI changes



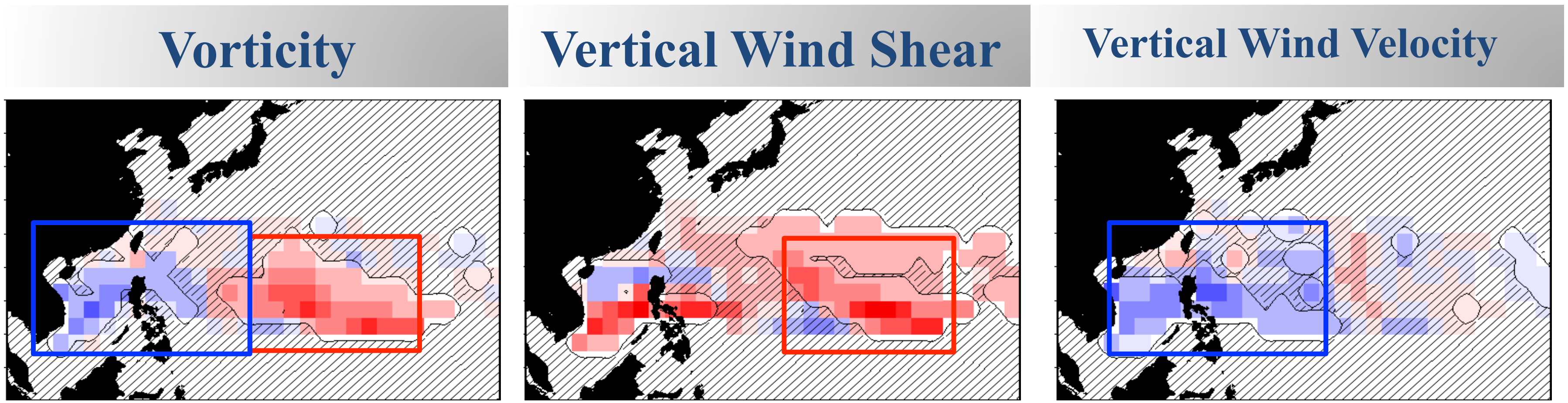
Spatial correlation coefficient is 0.55.

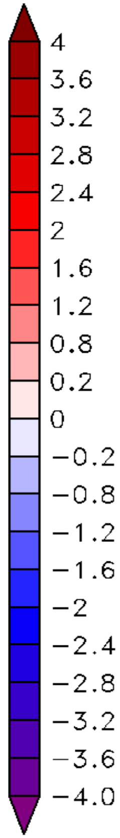
GPI performs reasonably well in reflecting the changes in TC genesis frequency.

Each term contribution to the changes in GPI



1. **Thermodynamic changes has less influence.**
   =>Relative humidity and Potential intensity tend to cancel each other.





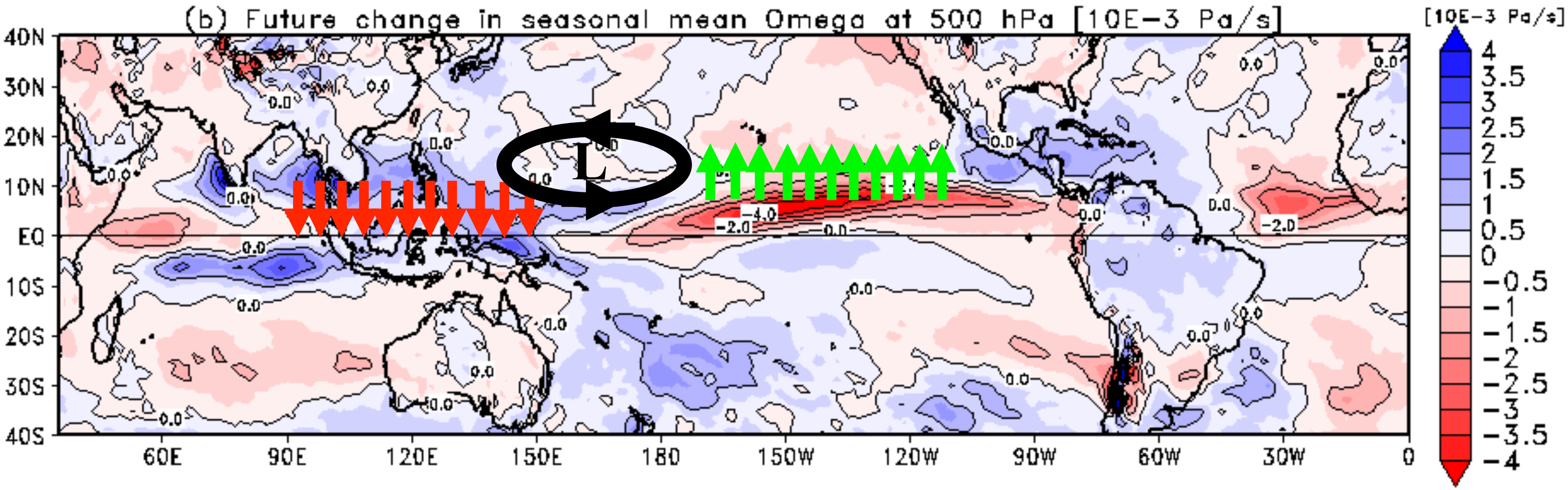
2. **Dynamical changes have great influences.**
   =>Vorticity and vertical wind shear contribute to the increase in GPI in the eastern WNP.
   =>Vorticity and vertical wind velocity contribute to the decrease in GPI in the western WNP.

Mechanisms of future changes in TC genesis

Future changes in vertical wind velocity at 500 hPa

Rossby wave response:
Positive vorticity => Increase in TC genesis in the eastern WNP

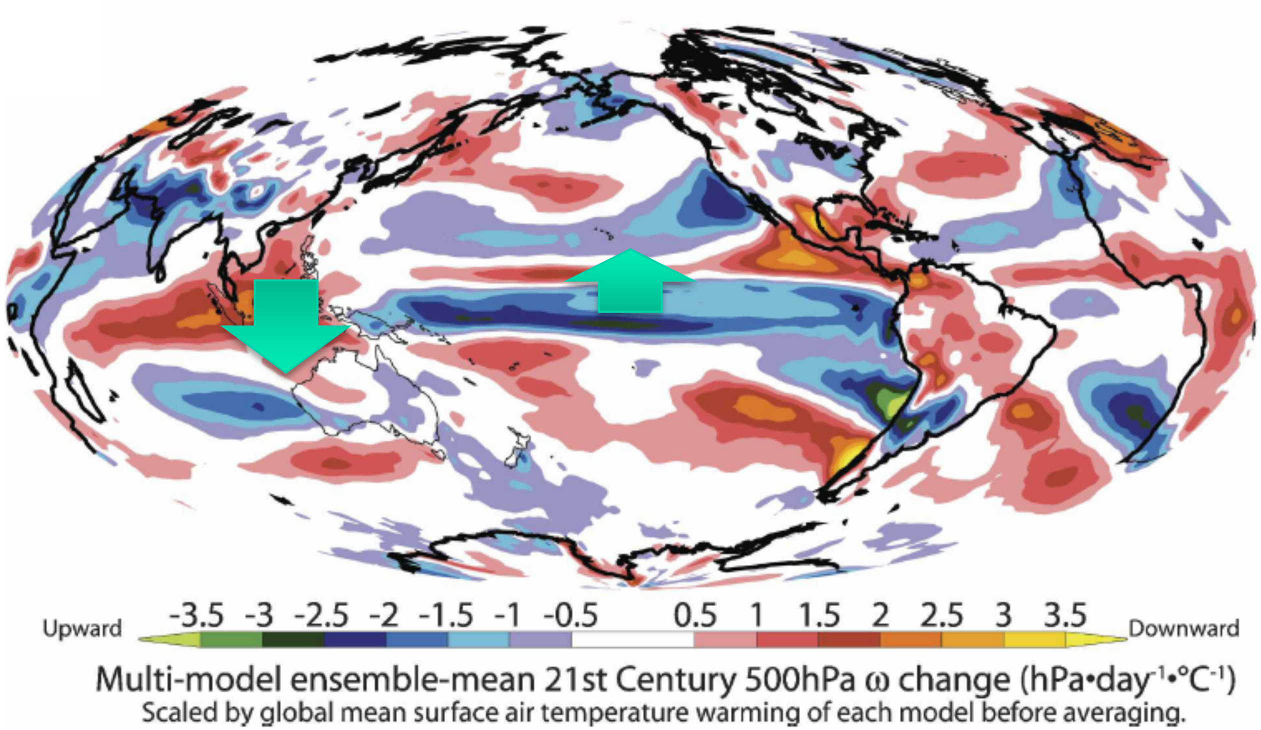
Downward anomaly



Weakening of the Walker circulation:
Decrease in upward motion => Decrease in TC genesis in the western WNP

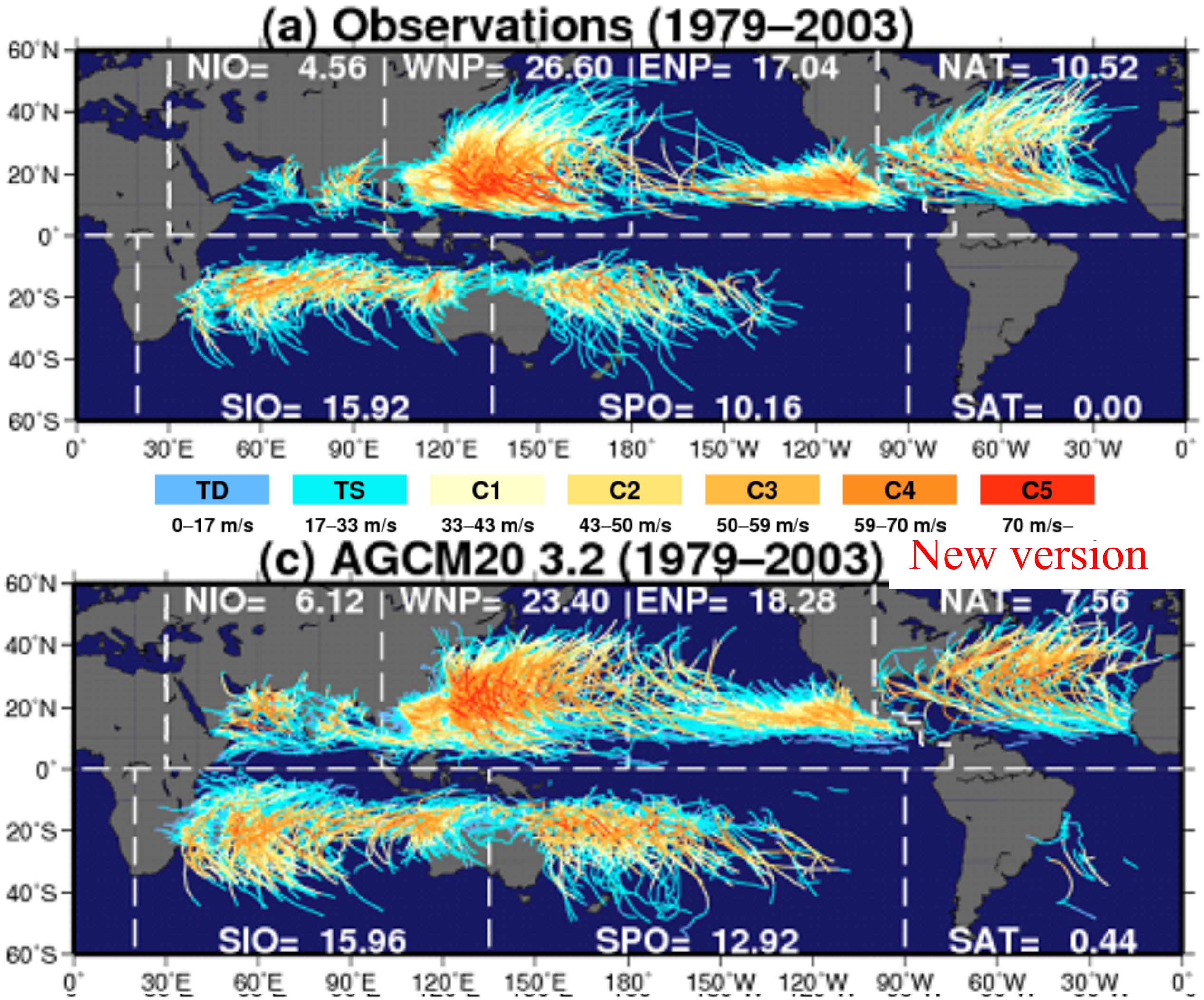
Upward anomaly

Weakening of Walker Circulation



Vecchi and Soden (2007, *J. Climate*) documented that CMIP3 models consistently project weakening of Pacific Walker Circulation in the future.

Improvements in TC climatology by the new 20-km mesh MRI-AGCM

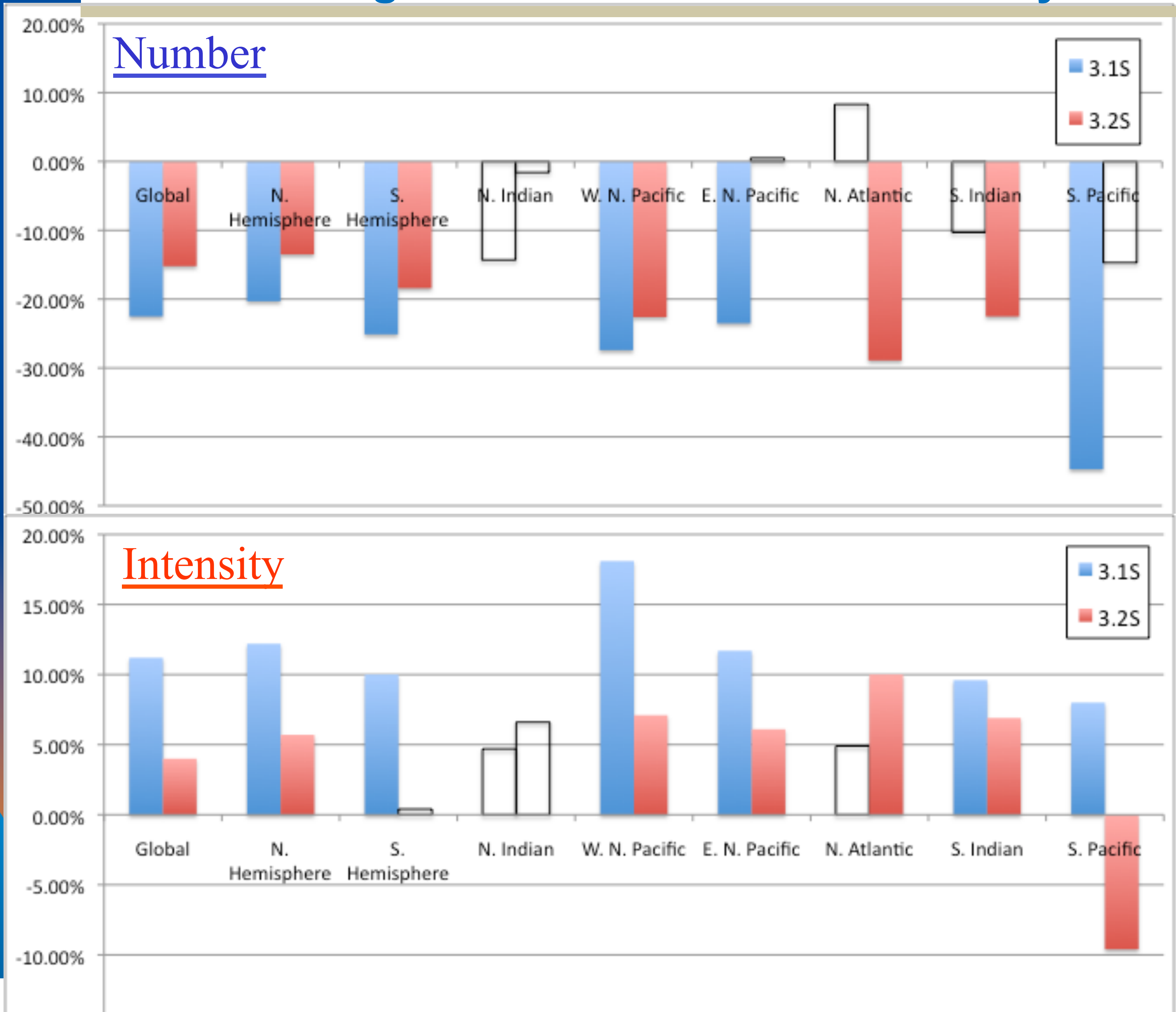


The number for each basin shows annual mean number of TCs.

·Predicted TC number in the WNP is underestimated. Improved

·TC intensity is weak compared with observations Improved

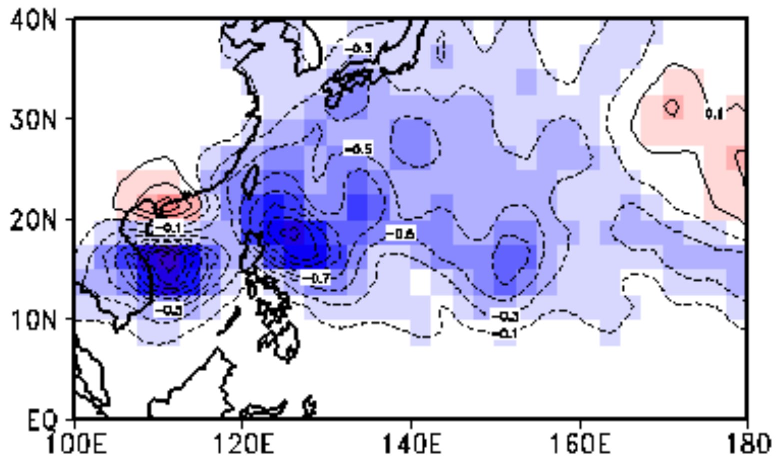
Future changes in TC number and intensity



Is the projected eastward shift in TC frequency robust?

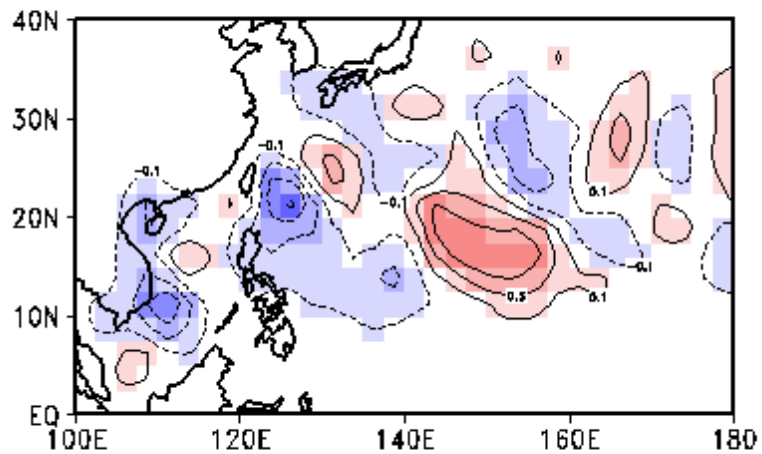
Projected future change in TC frequency of occurrence.

New version



Decrease everywhere

Previous version



Eastward shift

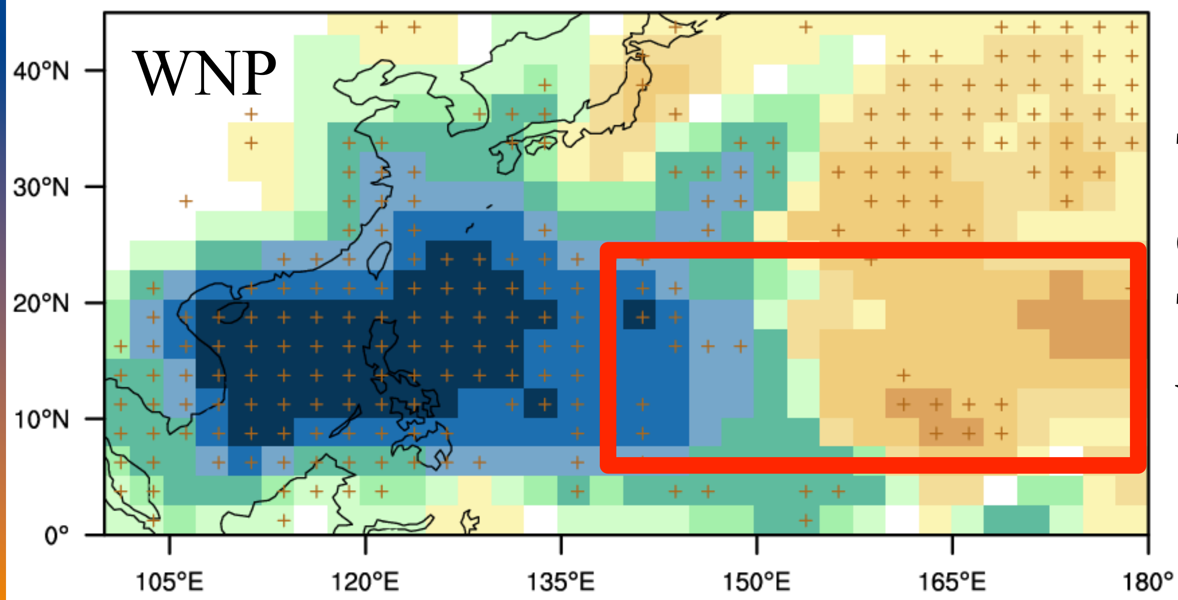
Which is true?

Multi-physics & Multi-SST ensemble projections

3 (cumulus) ×4 (SST) = 12 ensemble experiments

	YS Scheme	KF Scheme	AS Scheme
CMIP3 Mean SST	Y0	K0	A0
Cluster1 SST	Y1	K1	A1
Cluster2 SST	Y2	K2	A2
Cluster3 SST	Y3	K3	A3

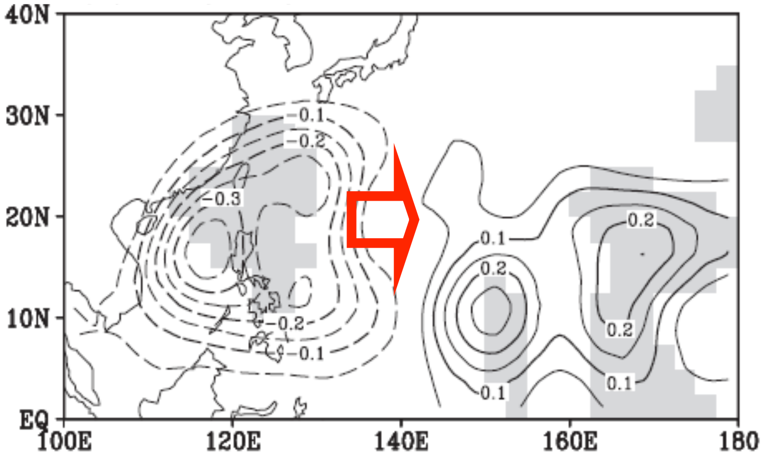
(a) Ensemble Mean of Future Changes in TCF



There is a projected eastward shift in TC tracks but with less robustness.

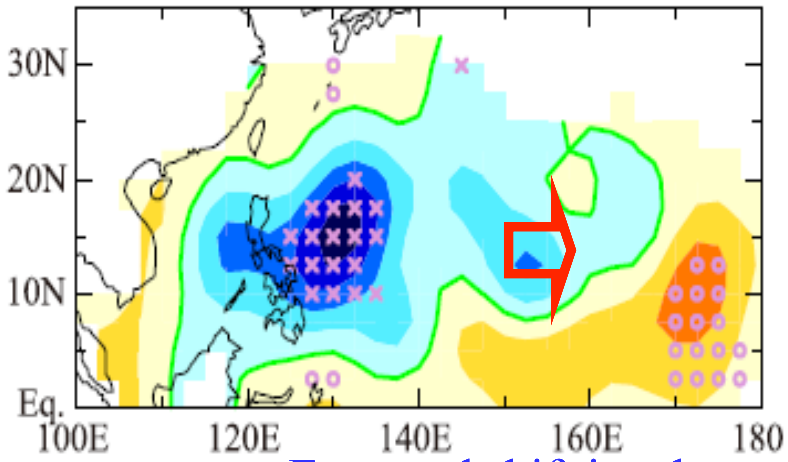
Is the projected eastward shift in TC frequency robust?

CMIP3 models (Yokoi and Takayabu 2009)



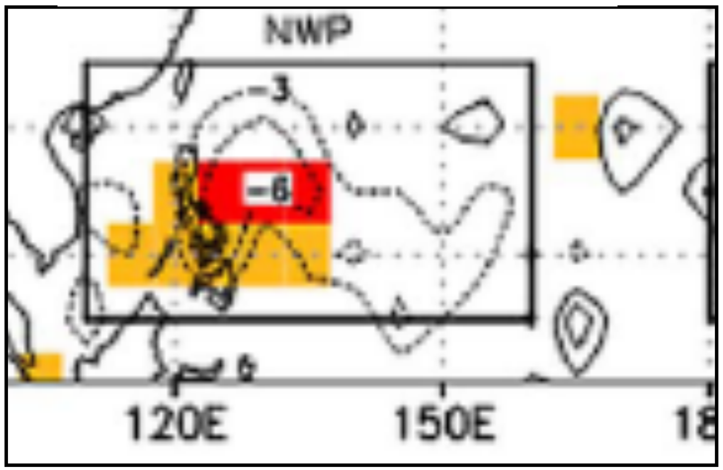
Eastward shift is robust.

CMIP5 models (Yokoi et al. 2012)



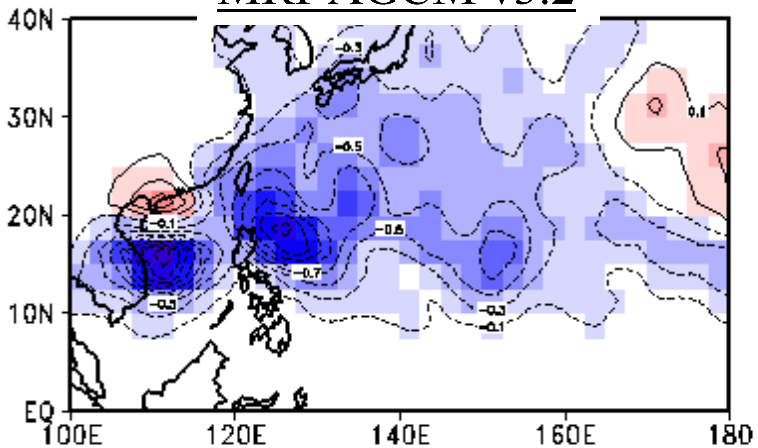
Eastward shift is robust.

ECHAM5 (Li et al. 2010)



Decrease everywhere

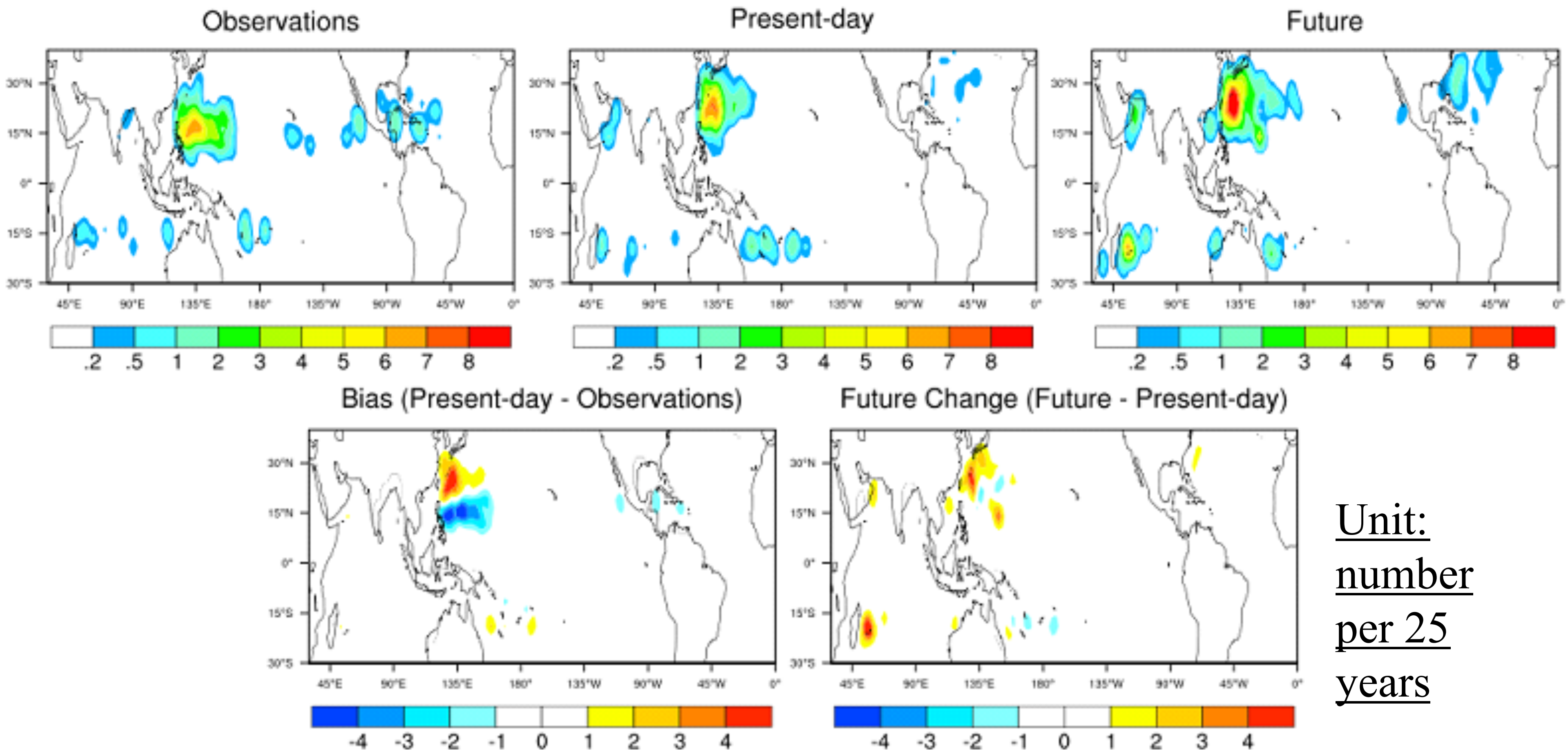
MRI-AGCM v3.2



Decrease everywhere

Although a number of models project eastward shift in TC tracks, uncertainty remains.

Future change in frequency of Category 5 (C5) occurrence



Unit: number per 25 years

·The frequency of C5 TCs appears to increase in the northern portion of the WNP basin.

·Note that the tracks of C5 TCs in the present-day simulation show a northward shift relative to observations. This bias should be taken into account and corrected when interpreting the results.

Conclusion

The projected TC activity change in the western North Pacific (WNP) indicates:

(a) Positions of the prevailing northward recurving TC tracks will shift eastward over the open ocean of the WNP.

(b) TC track changes are partially due to changes of the large scale steering flows, but primarily owning to the changes in TC-genesis locations.

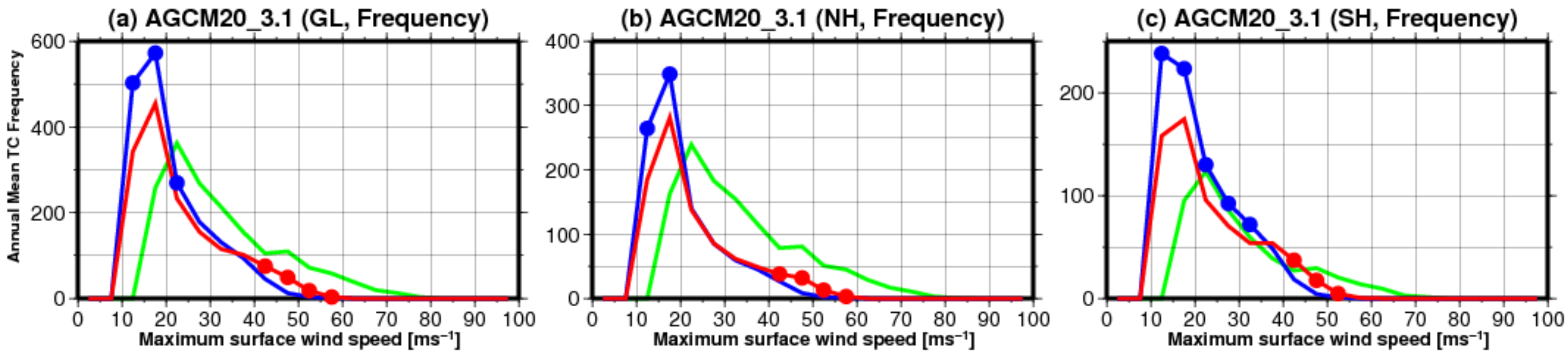
(c) The enhanced TC genesis in the eastern WNP is due to the increased *in situ* low-level cyclonic vorticity, reduced vertical wind shear, caused by Rossby wave response induced by enhanced diabatic heating in the central tropical Pacific.

(d) Uncertainty remains regarding position of eastward shift and even the projection of eastward shift in TC tracks. A number of ensemble projections are necessary to reduce uncertainty.

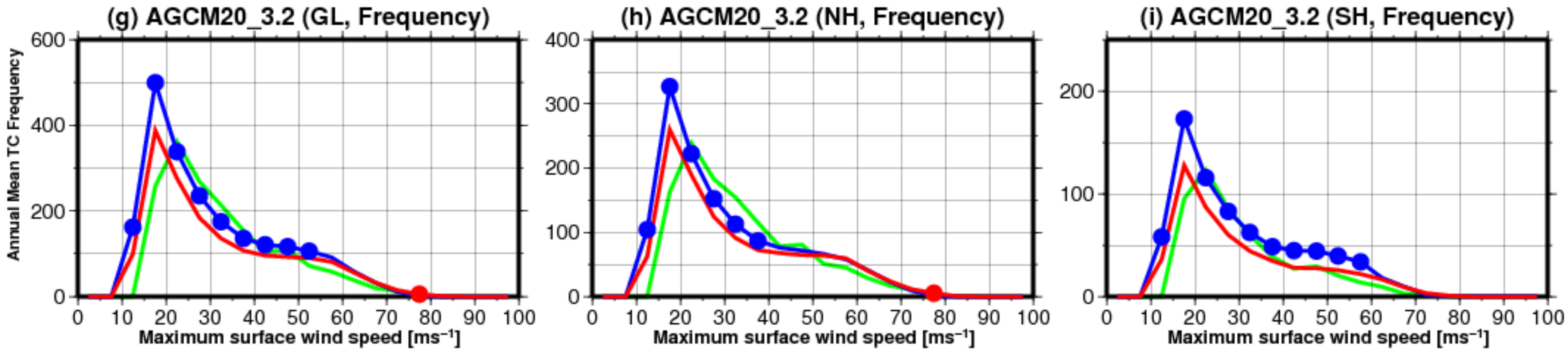
Projected future changes in TC intensity

Present 25year (1979-2003)
Future 25year (2075-2099)
●: significant increase at 95% level
●: significant decrease at 95% level

Previous version



New version



- Both versions show significant decrease in the frequency of weak TCs.
- New version projects subtle increase in the frequency of intense TCs.