Projected future changes in tropical cyclones and their uncertainties by MRI-AGCM

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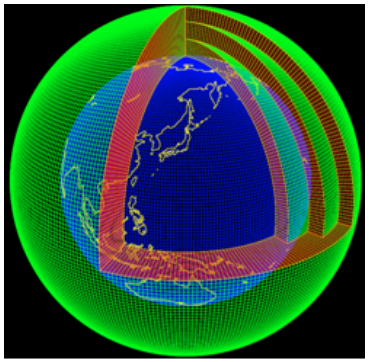
and KAKUSHIN Team 3

Relevant papers:

Murakami et al. (2012c, *Climate Dyn., Submitted*),
Sugi et al. (2012, *J. Meteor. Soc. Japan, In press*),
Murakami et al. (2012b, *Climate Dyn., In press*),
Murakami et al. (2012a, *J. Climate, In press*),
Murakami et al. (2011, *J. Climate*),
Murakami and Wang (2010, *J. Climate*),
Murakami and Sugi (2010, *SOLA*),
Sugi et al. (2009, *SOLA*)

Outline

- Review of previous studies on projected future changes in tropical cyclones (TCs)
- New high-resolution (20-km-mesh) MRI-AGCM and projected future change in TC activity
- Multi-physics and multi-SST ensemble experiments using 60-km-mesh MRI-AGCM
- Summary



20 km-mesh grids

Review of impact of global warming on TC activity

nature geoscience

REVIEW ARTICLE

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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]

Whether the characteristics of tropical cyclones have changed or will change in a warming climate — and if so, how — has been the subject of considerable investigation, often with conflicting results. Large amplitude fluctuations in the frequency and intensity of tropical cyclones greatly complicate both the detection of long-term trends and their attribution to rising levels of atmospheric greenhouse gases. Trend detection is further impeded by substantial limitations in the availability and quality of

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

1. **Consistent results** (consensus)
   - A reduced frequency of global TCs
   - A future increase in frequency of intense TCs
2. **Inconsistent results** (uncertainty)
   - Difference in projected future changes in TC frequency in a specific ocean basin

   Among 14 previous numerical studies, 5 indicated an increase in the North Atlantic, while 9 reported a decreasing frequency (Murakami and Wang, 2010)
3. **Challenging task** (unknown)
   - Effect of global warming on **regional TC activity**

History of MRI-AGCM development

MRI-AGCM3.0 (before 2007) **(Mizuta et al. 2006; Oouchi et al. 2006)**

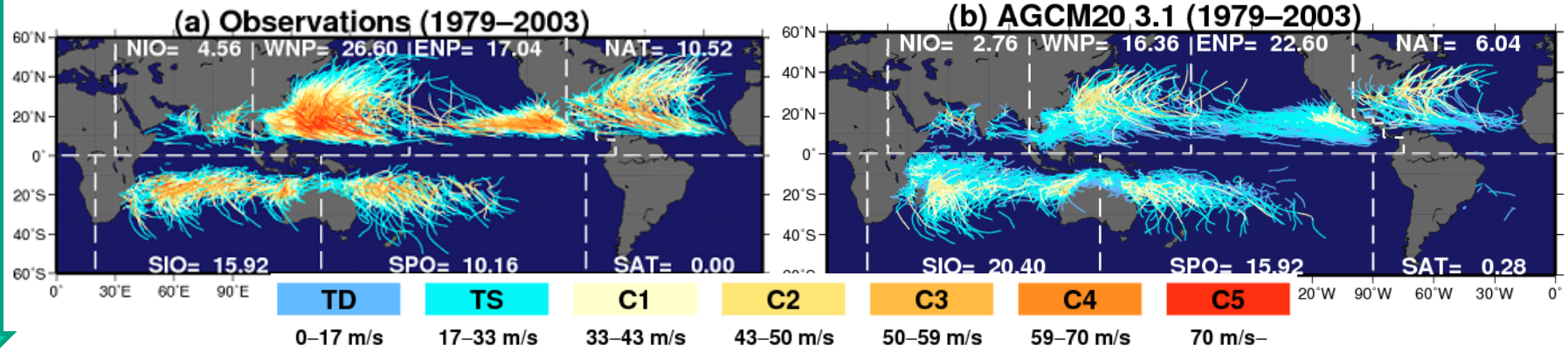
This model was developed from JMA operational NWP model.
First 20-km mesh climate model which simulates for multi decades.

very minor change

MRI-AGCM3.1 (since 2007) **AMIP-type experiments (Kitoh et al. 2009; Murakami and Wang 2010; Murakami et al. 2011)**

Previous version

The model had marked biases in geographical distribution of TCs and TC intensity.



MRI-AGCM3.2 (since 2009) **New version**

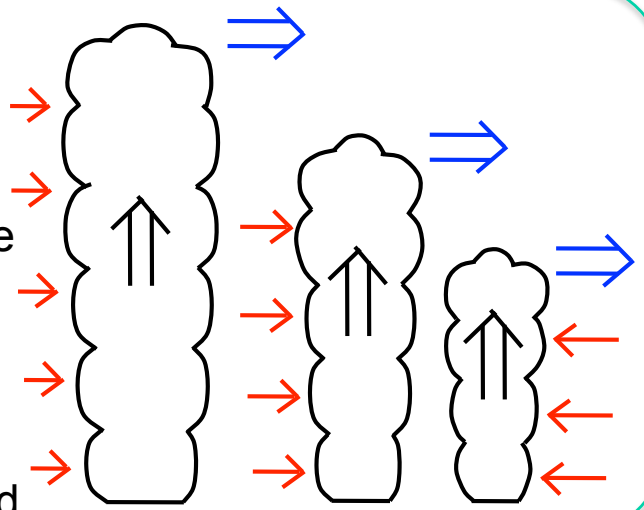
AMIP-type 25 years experiments are conducted using observed SST for the present-day climate.
Future projections of 25 years are conducted by prescribing CMIP3 ensemble mean SST and clustered SSTs.

Comparisons between v3.1 and v3.2 MRI-AGCMs

	Previous version (contributed to IPCC AR4)	New version (for IPCC AR5)
	MRI-AGCM 3.1 (Mizuta et al. 2006, *JMSJ*)	MRI-AGCM 3.2 (Mizuta et al., 2012)
Horizontal resolution	TL959 (20km)	
Vertical resolution	60 levels (top at 0.1hPa)	64 levels (top at 0.01hPa)
Time integration	Semi-Lagrangian	
Time step	6minutes	10minutes
Cumulus convection	Prognostic Arakara-Schubert	Yoshimura (Tiedtke-based)
Cloud	Smith (1990)	Tiedtke (1993)
Radiation	Shibata and Aoki (1989) Shibata and Uchiyama(1992)	JMA (2007)
GWD	Iwasaki et al. (1989)	
Land surface	SiB ver0109(Hirai et al.2007)	
Boundary layer	MellorYamada Level2	
Aerosol (direct)	Sulfate aerosol	5 species
Aerosol (indirect)	No	

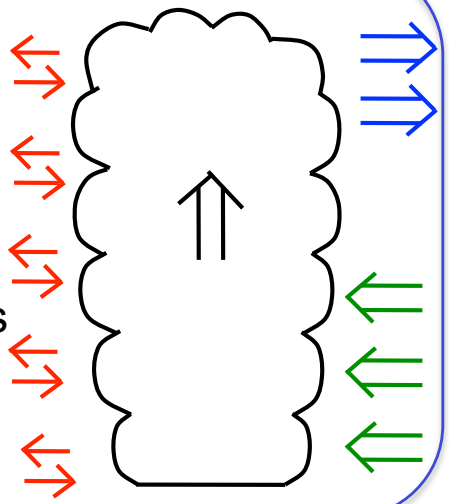
Arakawa-Schubert

Multiple convective updrafts with different heights depending on entrainment rates explicitly calculated

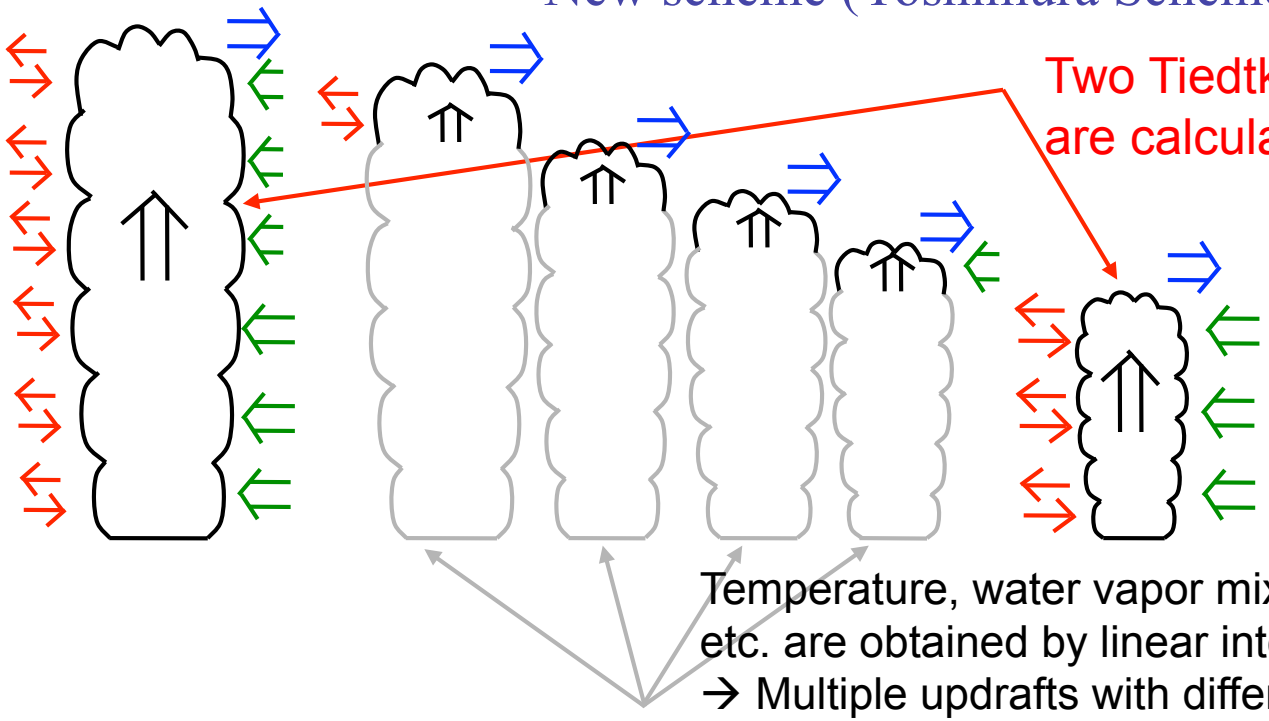


Tiedtke

Only a single convective updraft but represented as a more derailed entraining and detraining plume



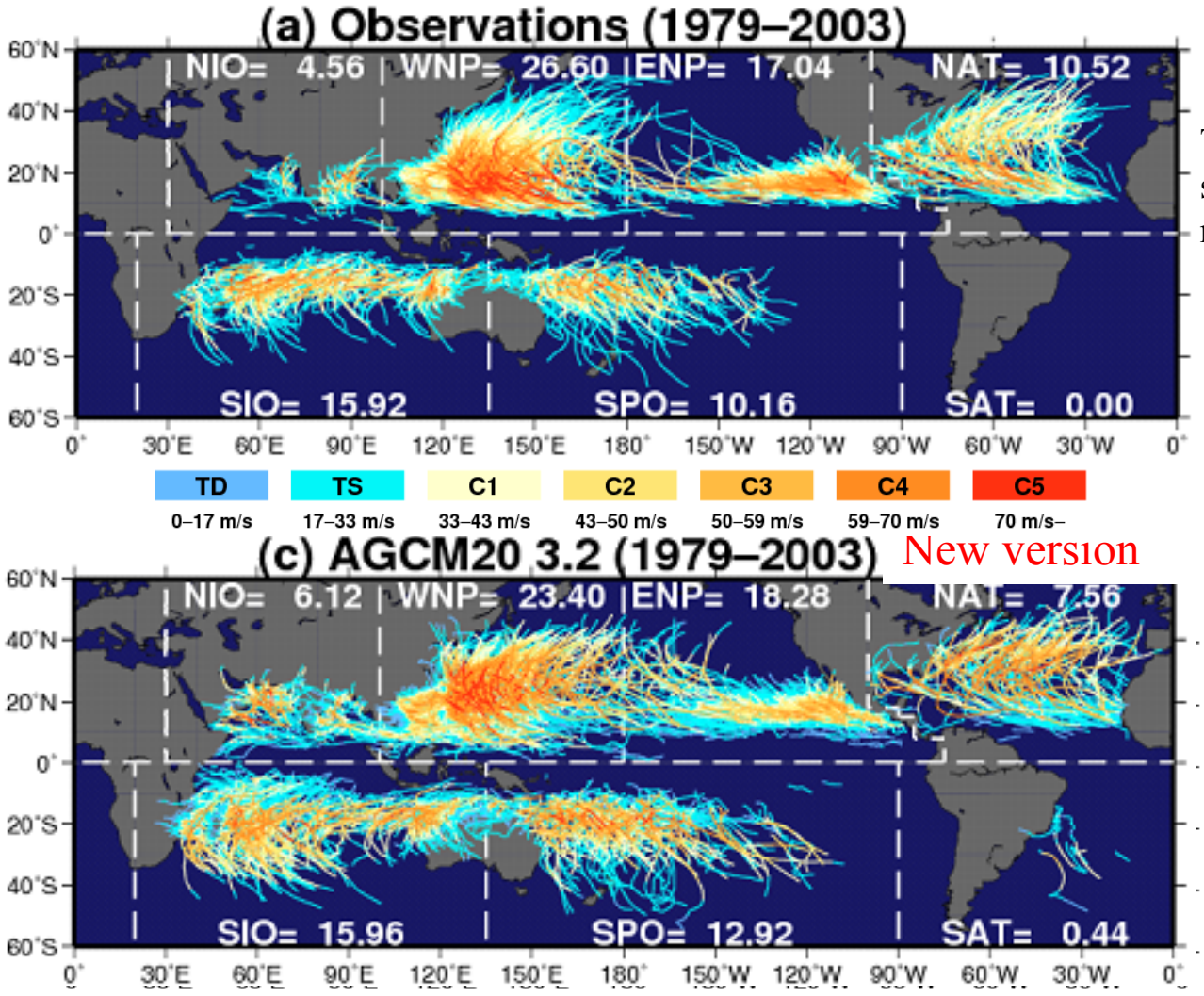
New scheme (Yoshimura Scheme; Yukimoto et al. 2011)



Updrafts between min. and max. rates are assumed to be continuously present.

Temperature, water vapor mixing ratio, entrainment rate etc. are obtained by linear interpolation between the two.
→ Multiple updrafts with different heights are represented.

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

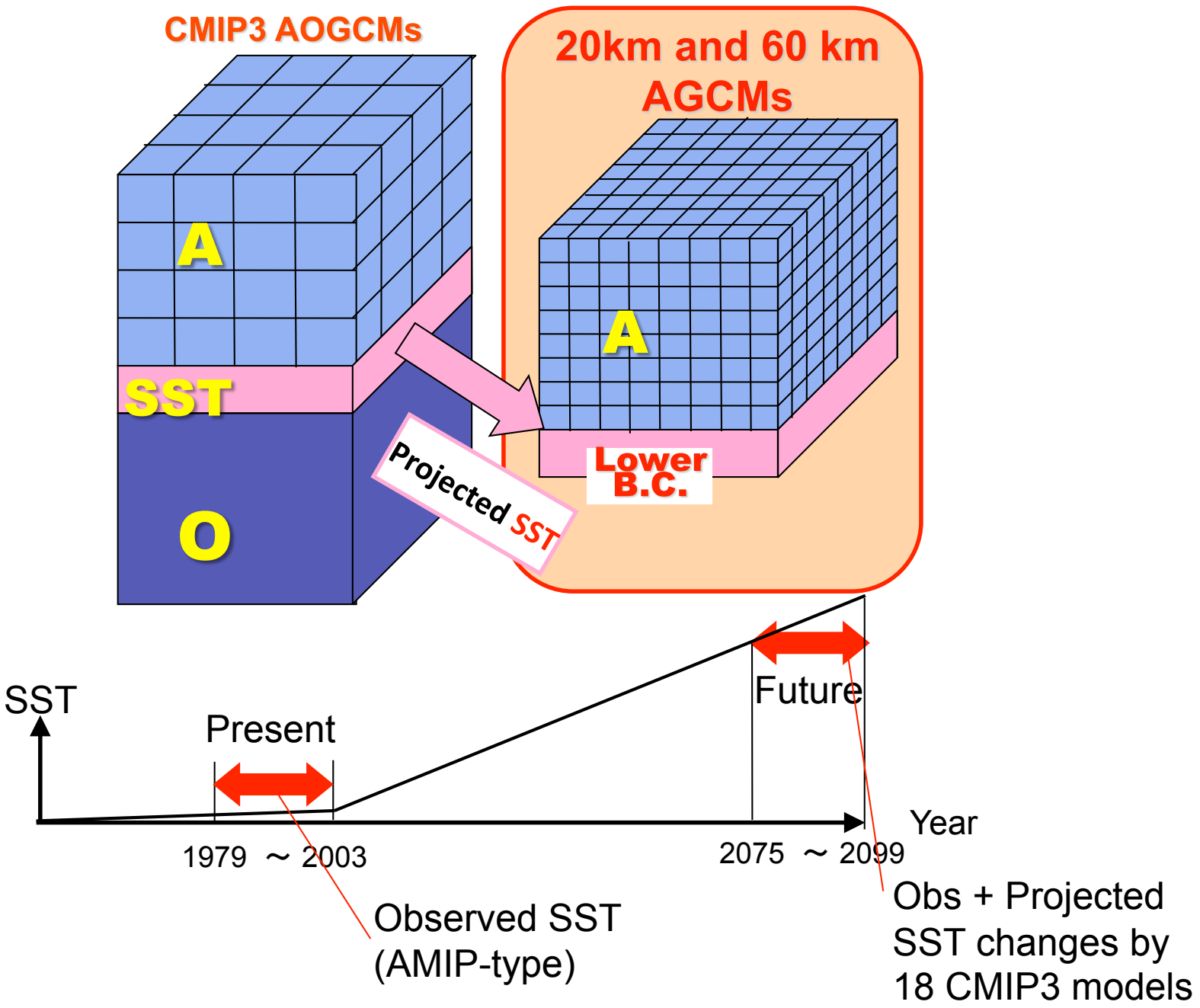


The number for each basin shows annual mean number of TCs.

·Predicted TC number in the WNP is underestimated. Improved

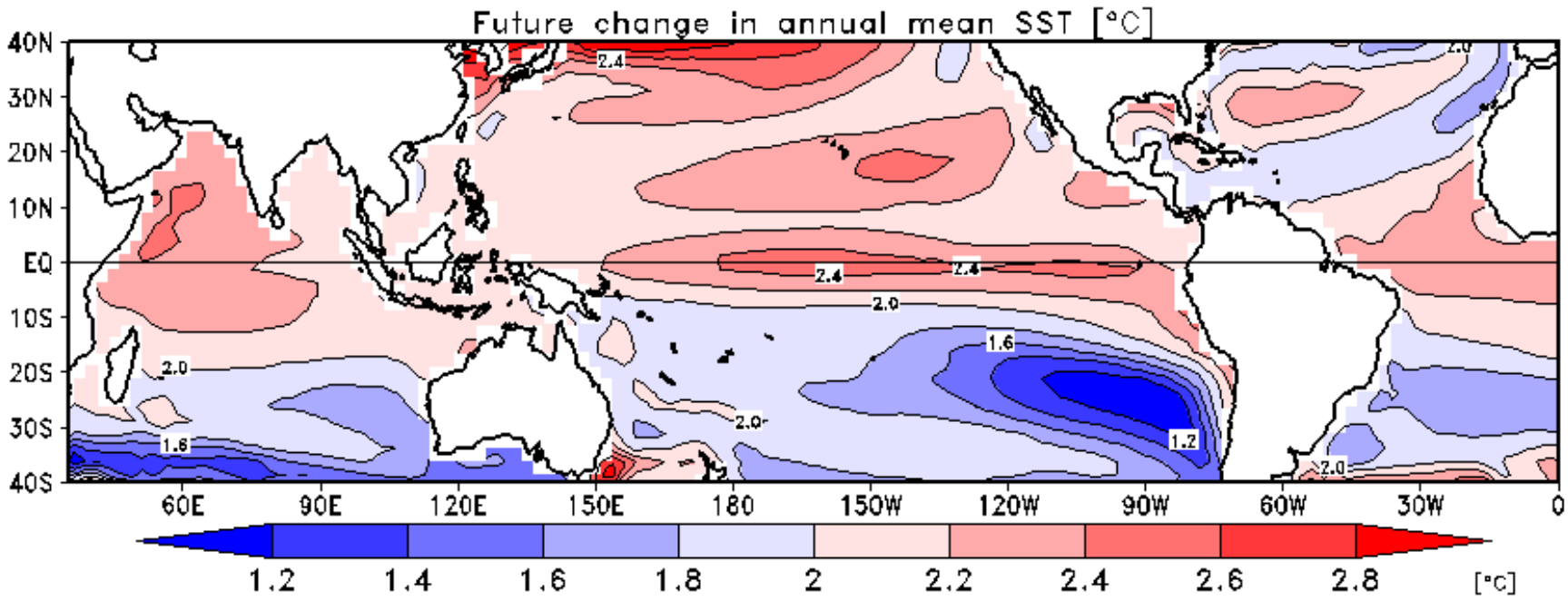
·TC intensity is weak compared with observations Improved

Time-slice Experiment



Spatial pattern of prescribed future changes in SST

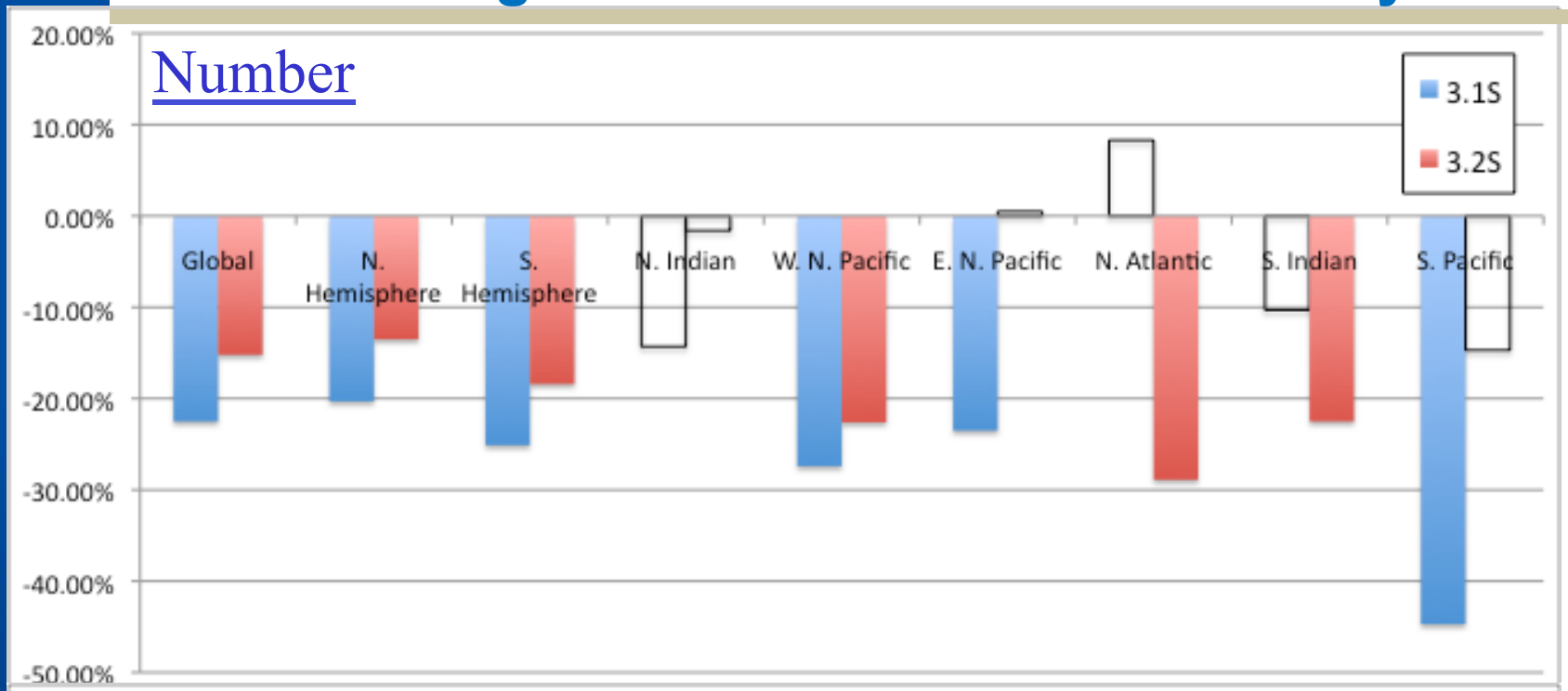
21st (2075–2099) – Present (1979–2003)

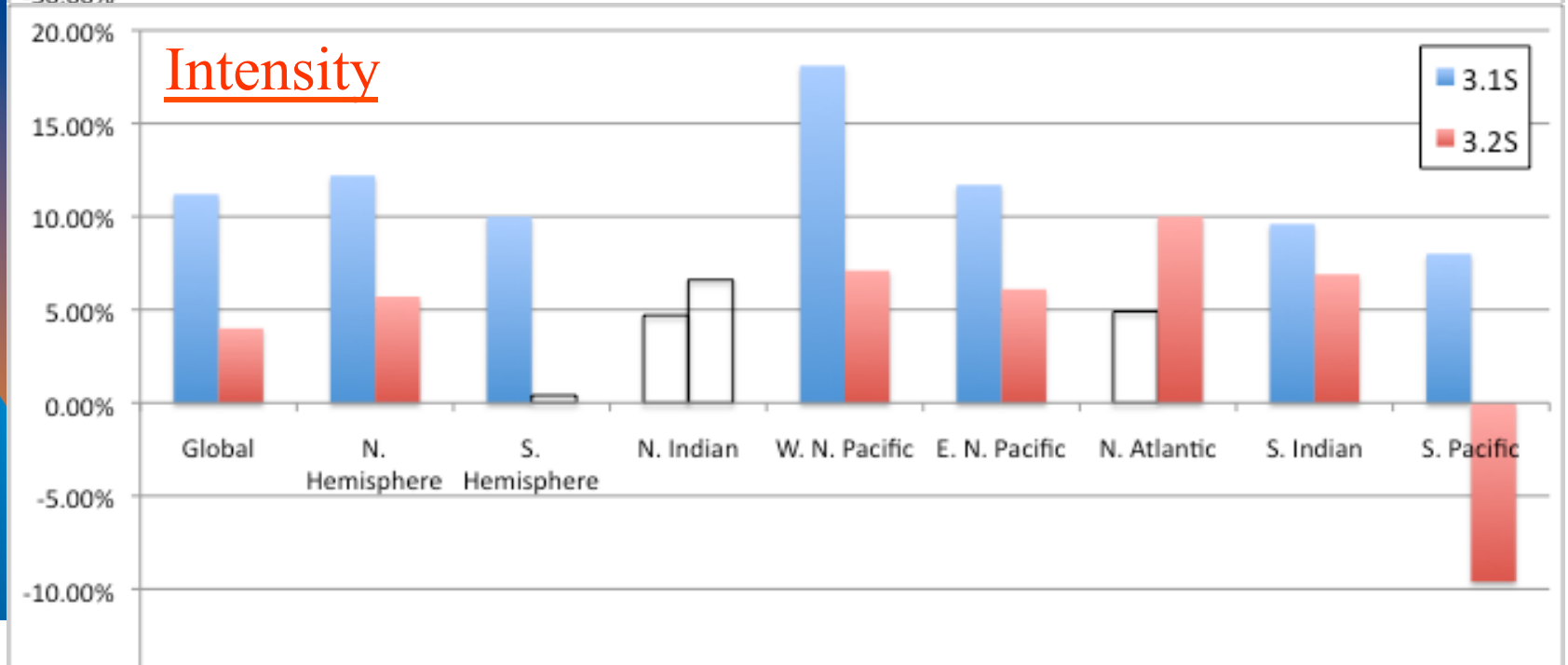


- Relatively larger increase in SST in the Northern Hemisphere than in the Southern Hemisphere.

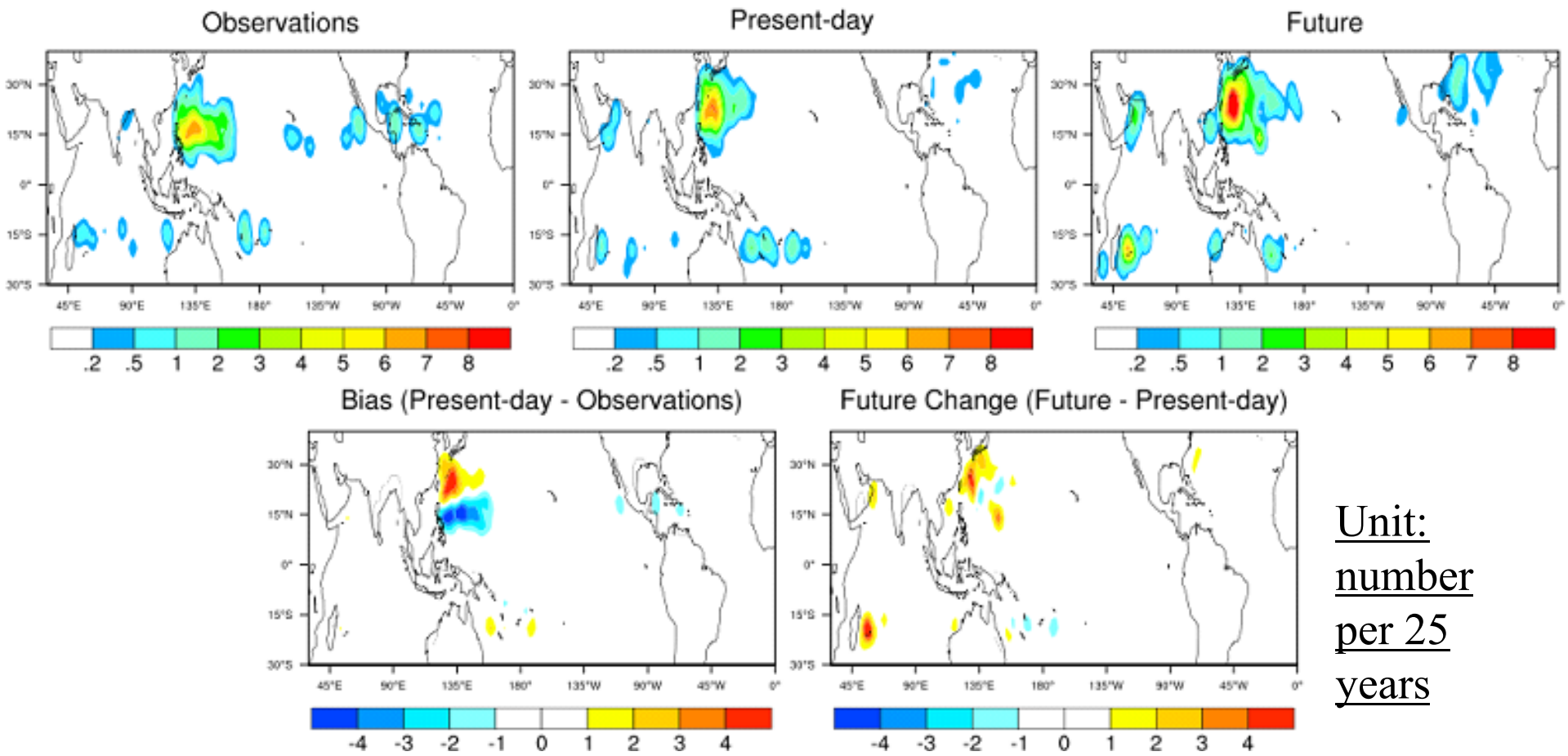
- The SST increase is the largest in the tropical Central Pacific (Xie et al. 2010).

Future changes in TC number and intensity





Future change in frequency of Category 5 (C5) occurrence



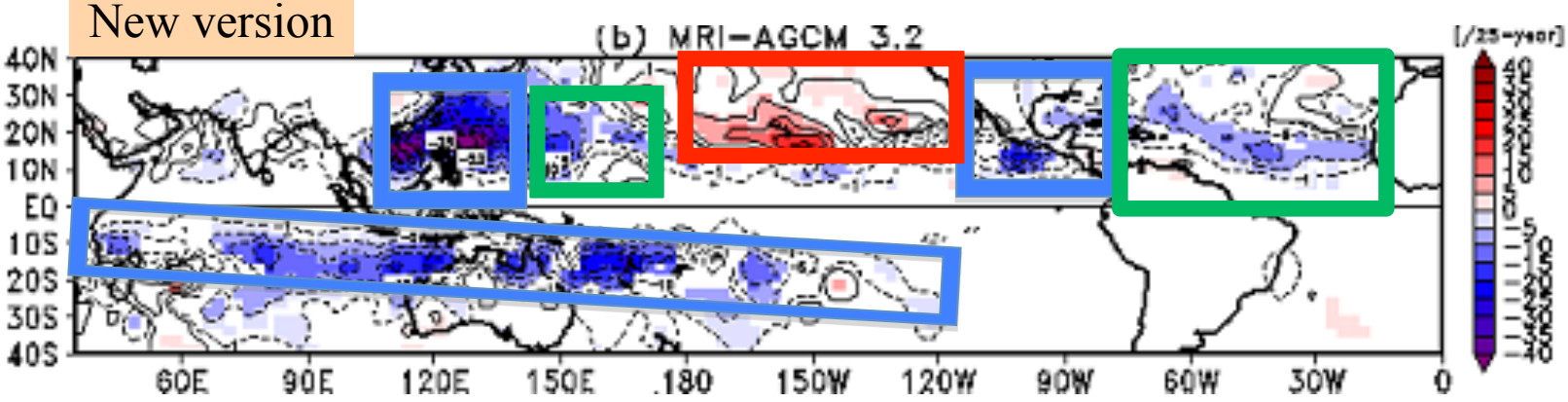
Unit: number per 25 years

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

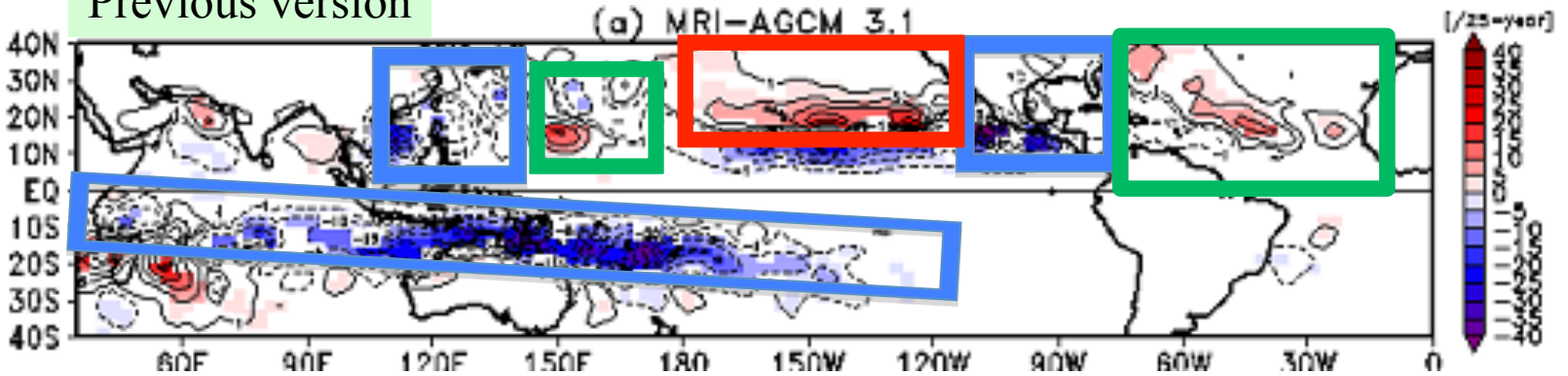
·Note that the tracks of C5 TCs in the present-day simulation show a northward shift relative to observations. This bias should be taken into account and corrected when interpreting the results.

Comparison of projected future changes in TC frequency between versions

New version



Previous version



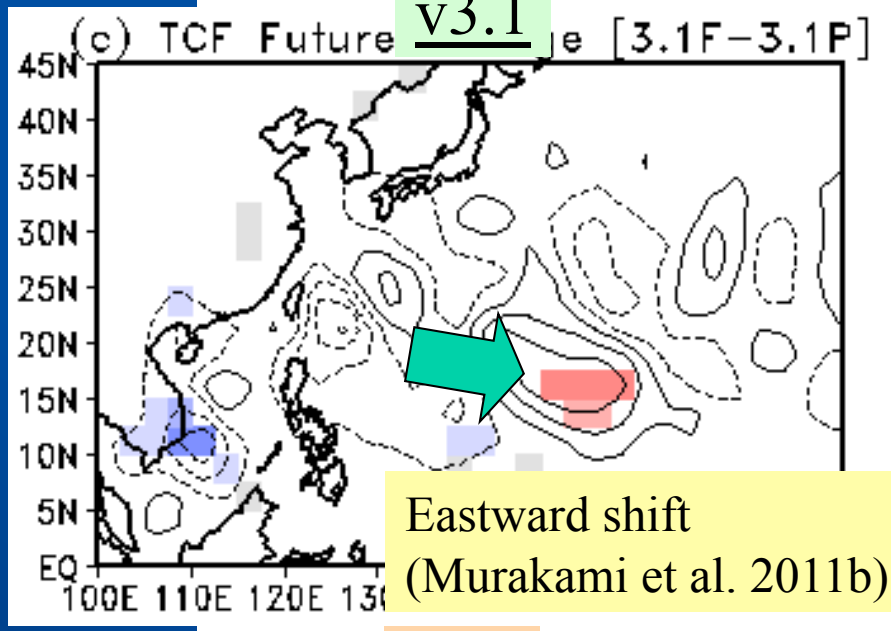
·Both versions show significant decrease in TC frequency over the South Pacific and western portion of WNP.

·Both versions show significant increase in TC frequency over the central Pacific.

·Inconsistent in the eastern quadrant of WNP and NAT.

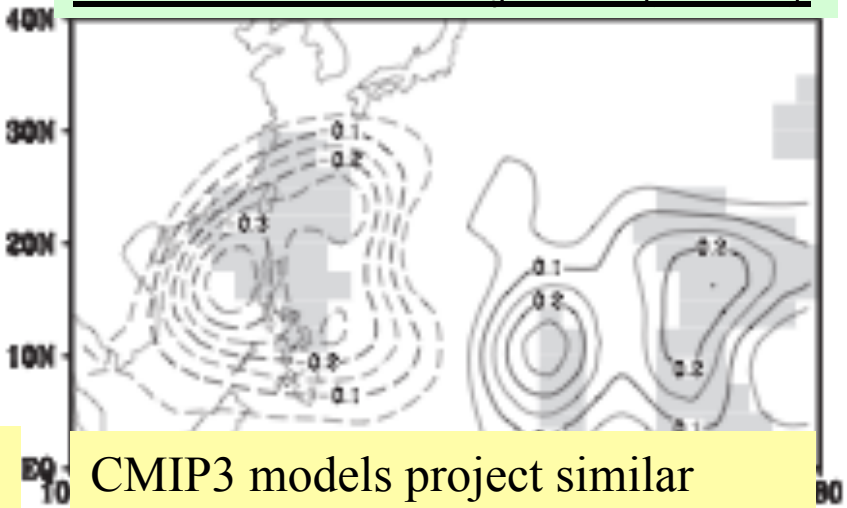
Uncertainty in regional change in TC frequency (WNP)

v3.1



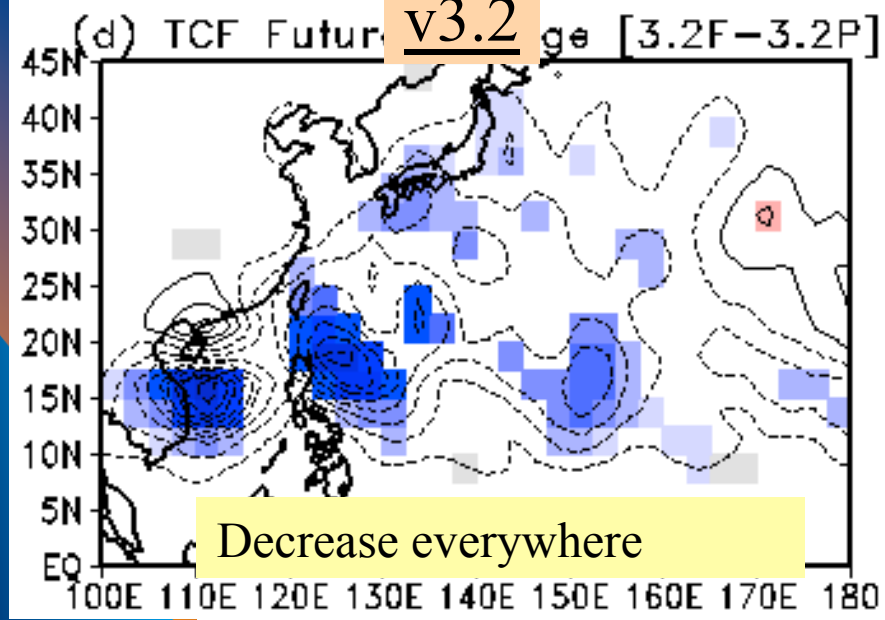
Eastward shift
(Murakami et al. 2011b)

Yokoi and Takayabu (2010)



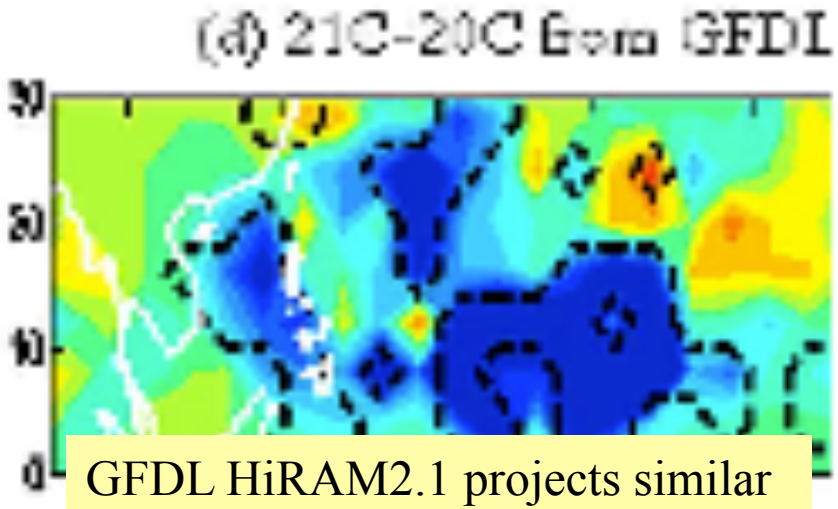
CMIP3 models project similar spatial pattern to v3.1.

v3.2



Decrease everywhere

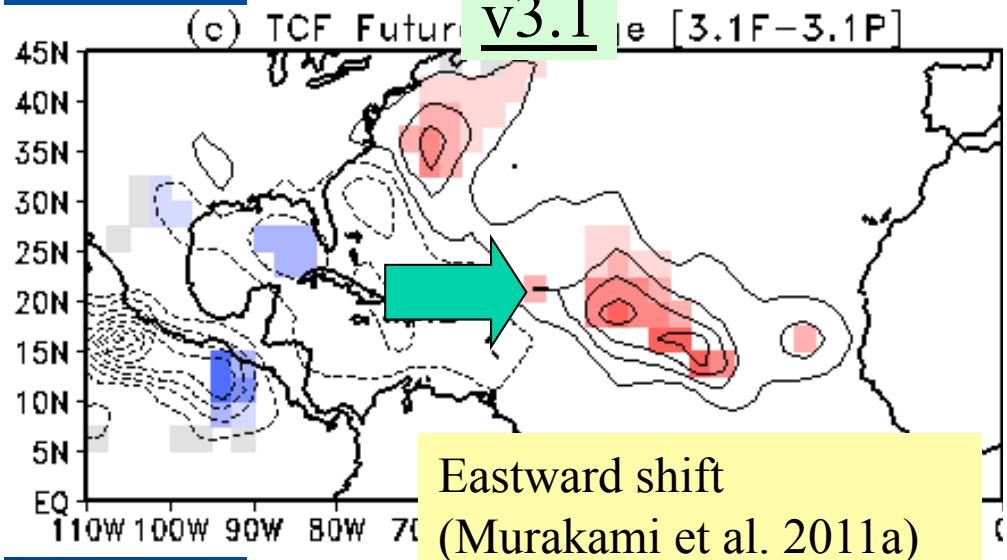
Li et al. (2011)



GFDL HiRAM2.1 projects similar spatial pattern to v3.2.

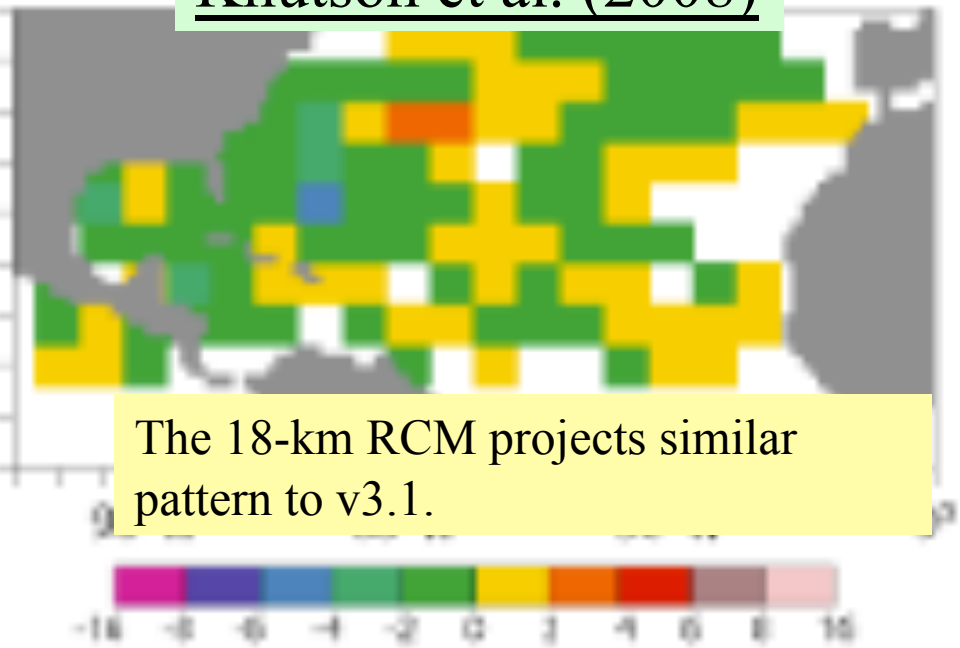
Uncertainty in regional changes in TC frequency (NAT)

v3.1



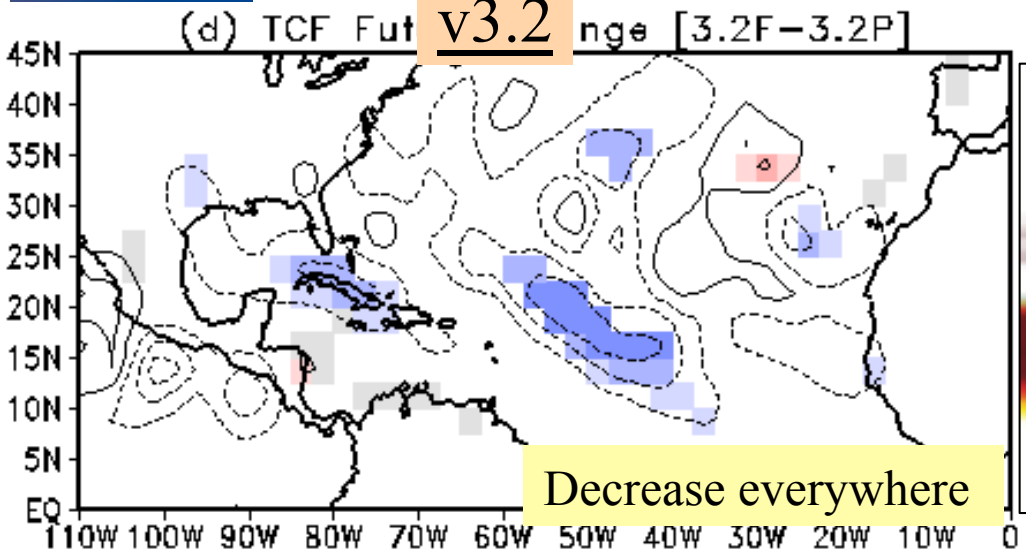
Eastward shift
(Murakami et al. 2011a)

Knutson et al. (2008)



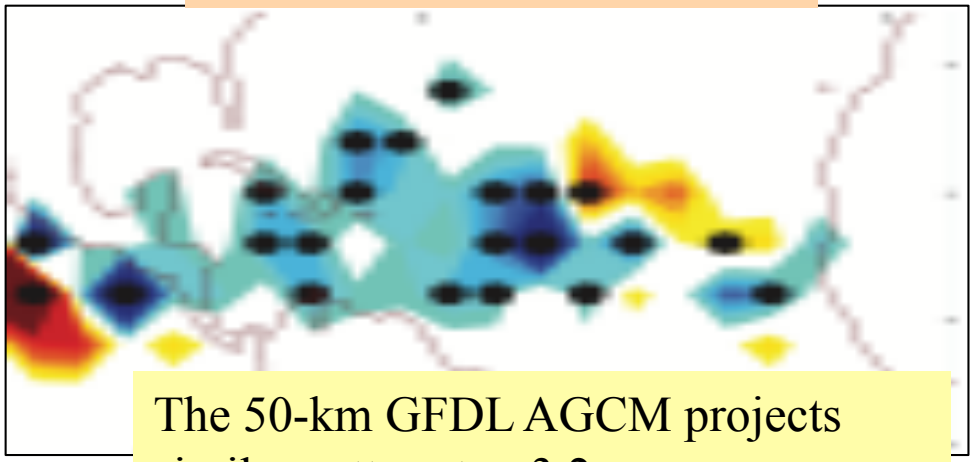
The 18-km RCM projects similar pattern to v3.1.

v3.2



Decrease everywhere

Zhao and Held (2012)

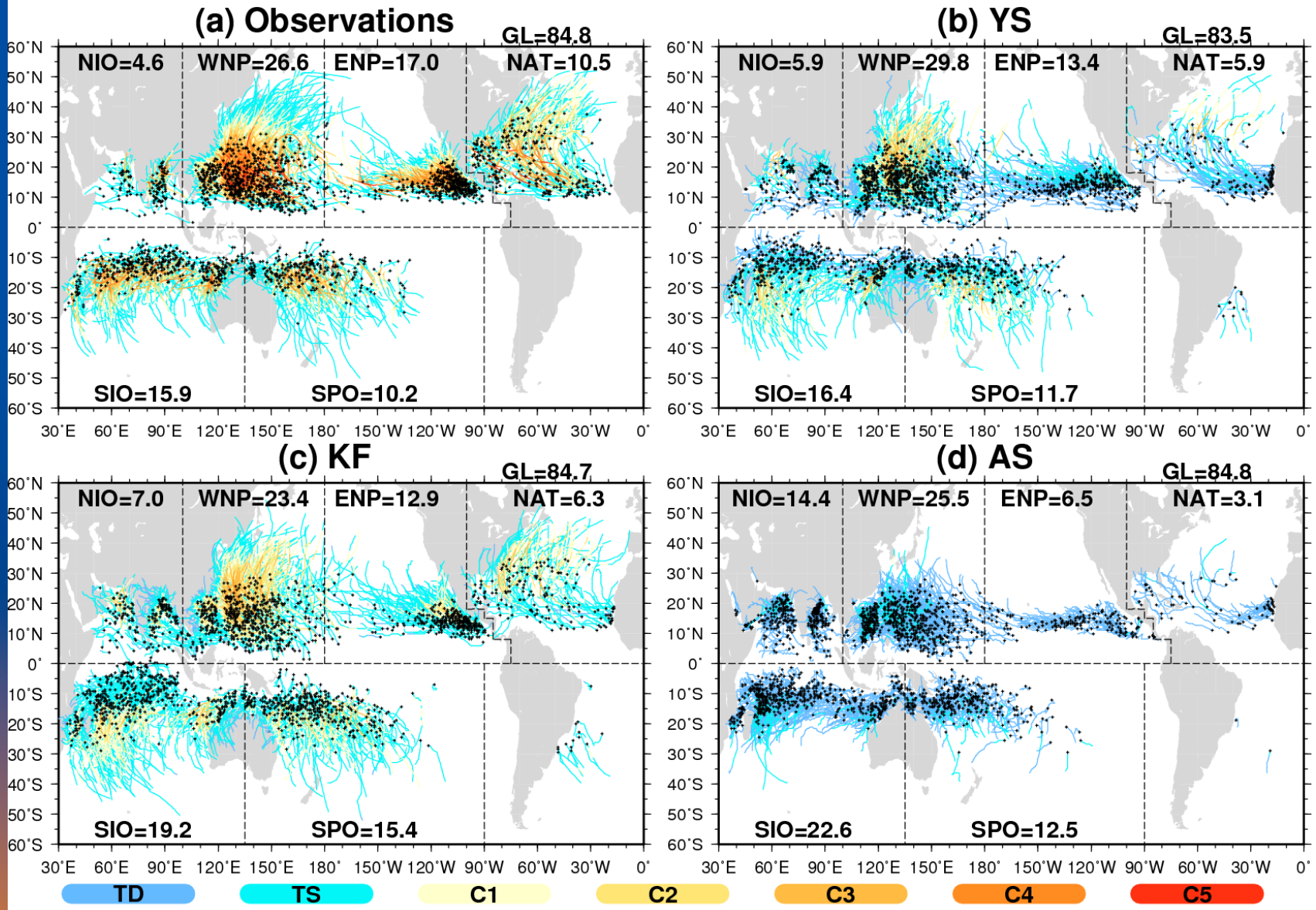


The 50-km GFDL AGCM projects similar pattern to v3.2.

Multi-physics ensemble experiment

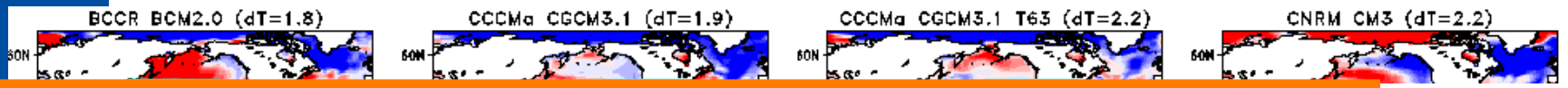
	MRI-AGCM 3.2 AS	MRI-AGCM 3.2 KF	MRI-AGCM 3.2 YS
Horizontal resolution	T_L319 (60km)		
Vertical resolution	64 levels (top at 0.01hPa)		
Time integration	Semi-Lagrangian		
Time step	20 minutes		
Cumulus convection	Prognostic Arakara-Schubert	Kain-Fritsch	Yoshimura (Tiedtke-based)
Cloud	Tiedtke (1993)		
Radiation	JMA (2007)		
GWD	Iwasaki et al. (1989)		
Land surface	SiB ver0109 (Hirai et al.2007)		
Boundary layer	MellorYamada Level2		
Aerosol (direct)	5 species		
Aerosol (indirect)	No		

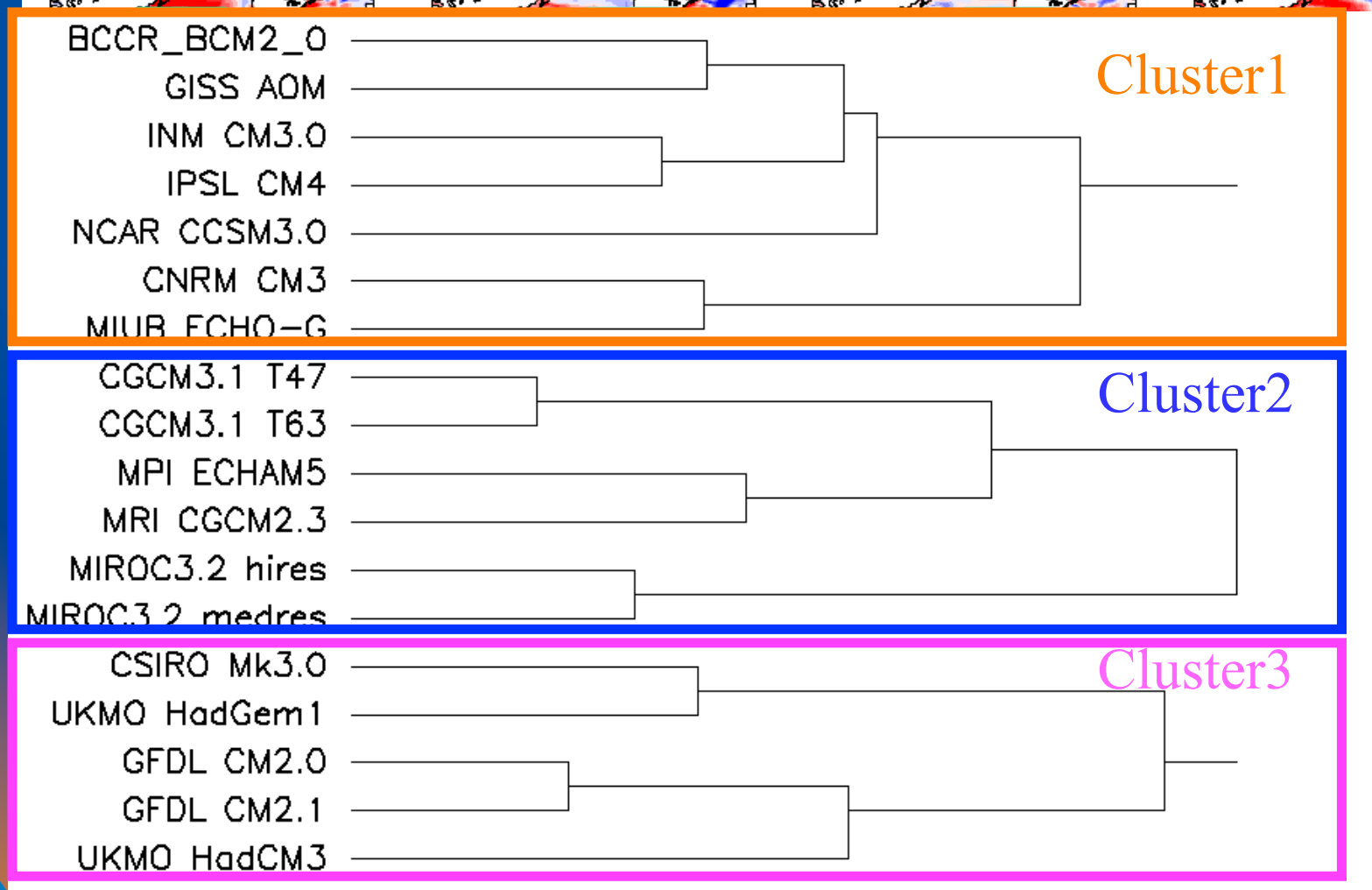
Performance of control simulations

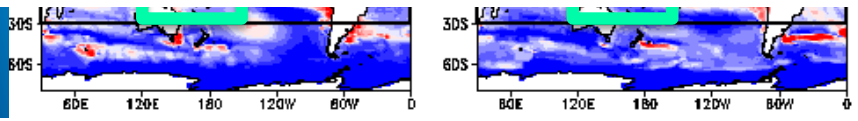


The YS and KF simulates reasonable TC global distribution, whereas AS has pronounced biases.

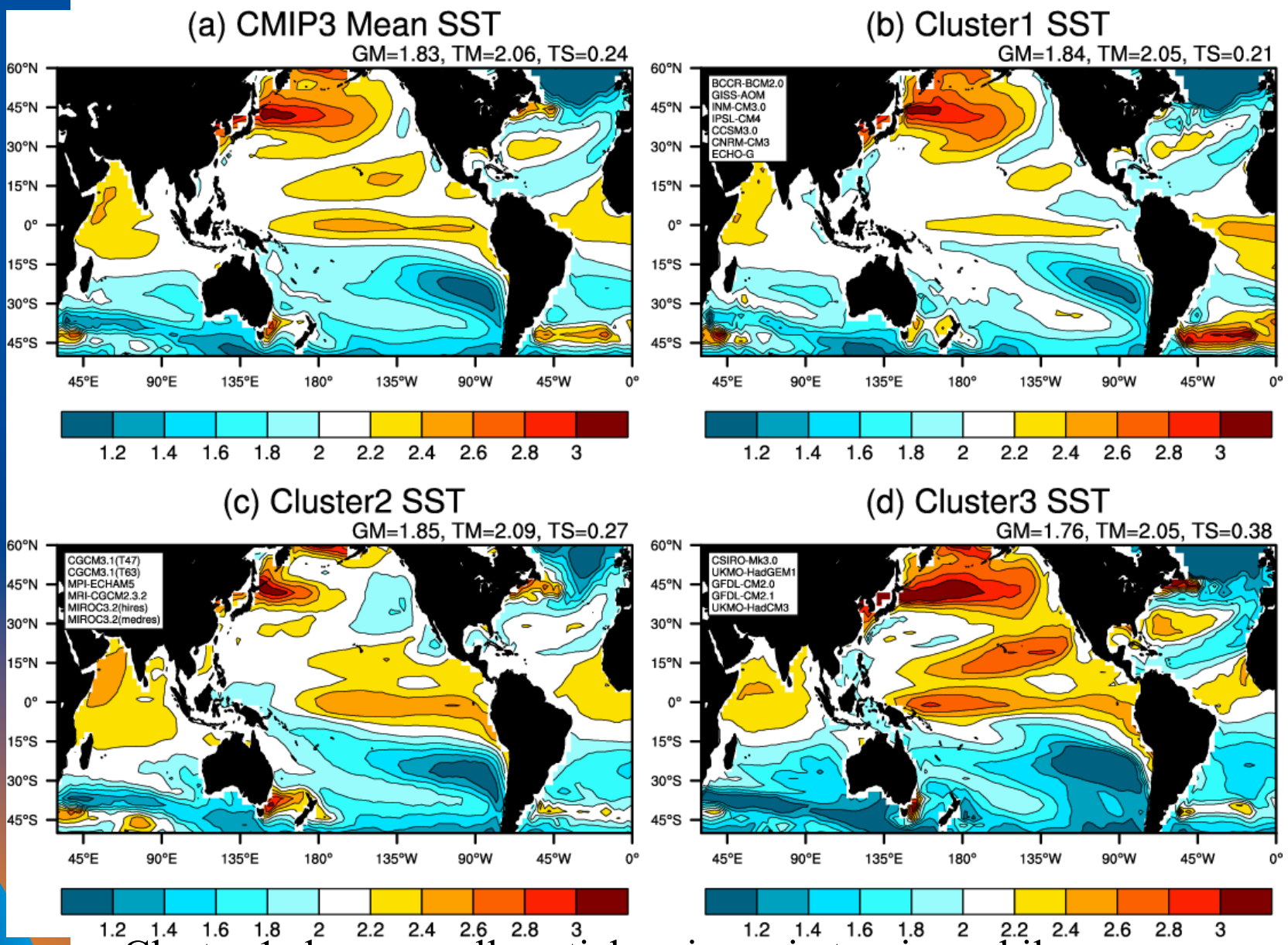
Prescribed SST anomalies for multi-SST Ensemble Projections







Prescribed SST anomalies for multi-SST Ensemble Projections



Cluster 1 shows small spatial variance in tropics, while Cluster 3 SST shows large spatial variance in tropics.

Multi-physics & Multi-SST ensemble projections

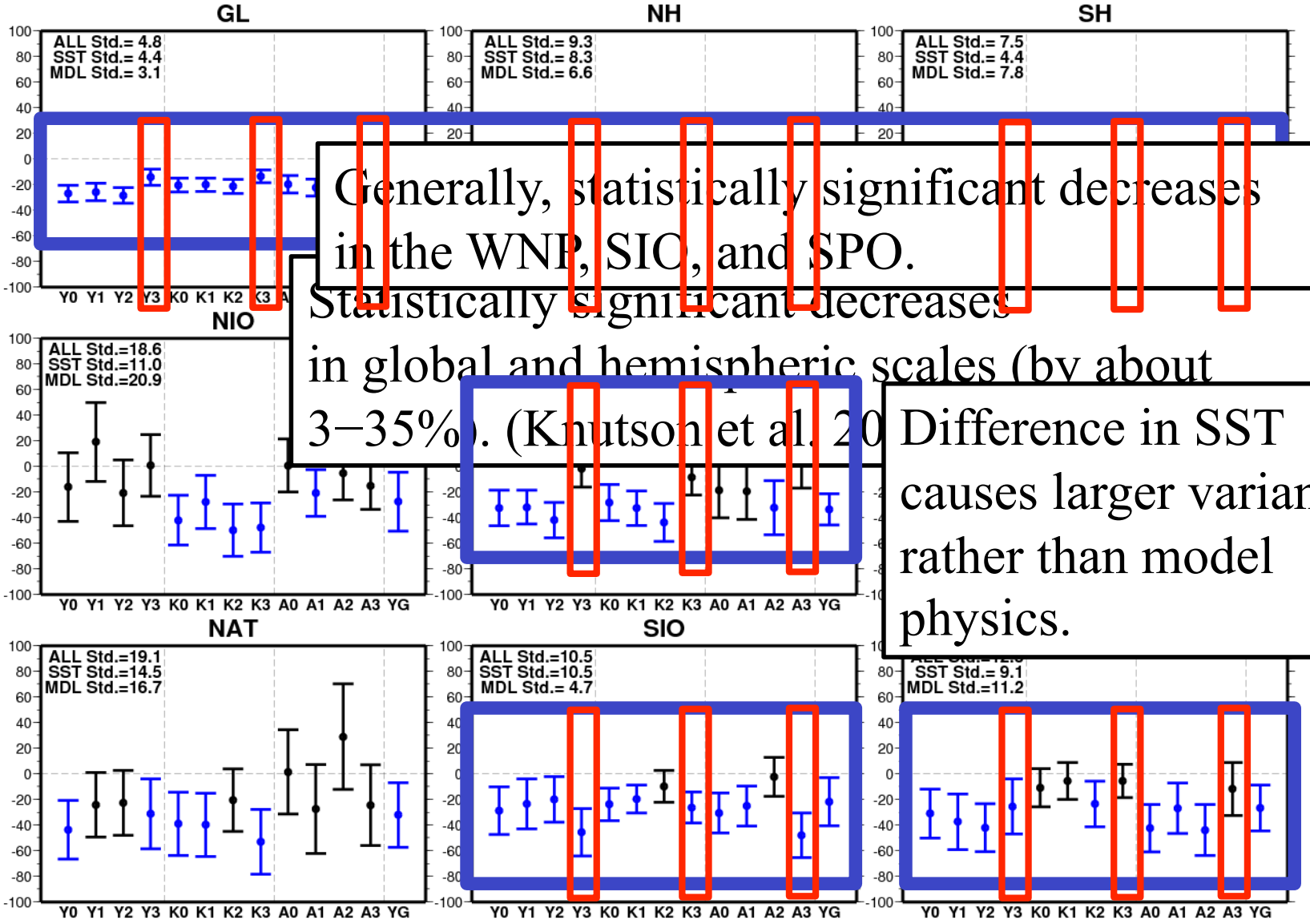
3 (cumulus) ×4 (SST) = 12 ensemble experiments

	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

Future changes in TC number [%]

Y: Yoshimura, K:Kain-Fritsch, A: Arakawa Shubert

0: CMIP3 mean SST, 1:Cluster 1, 2:Cluster 2, 3: Cluster 3, G: Global uniform



Generally, statistically significant decreases in the WNP, SIO, and SPO.

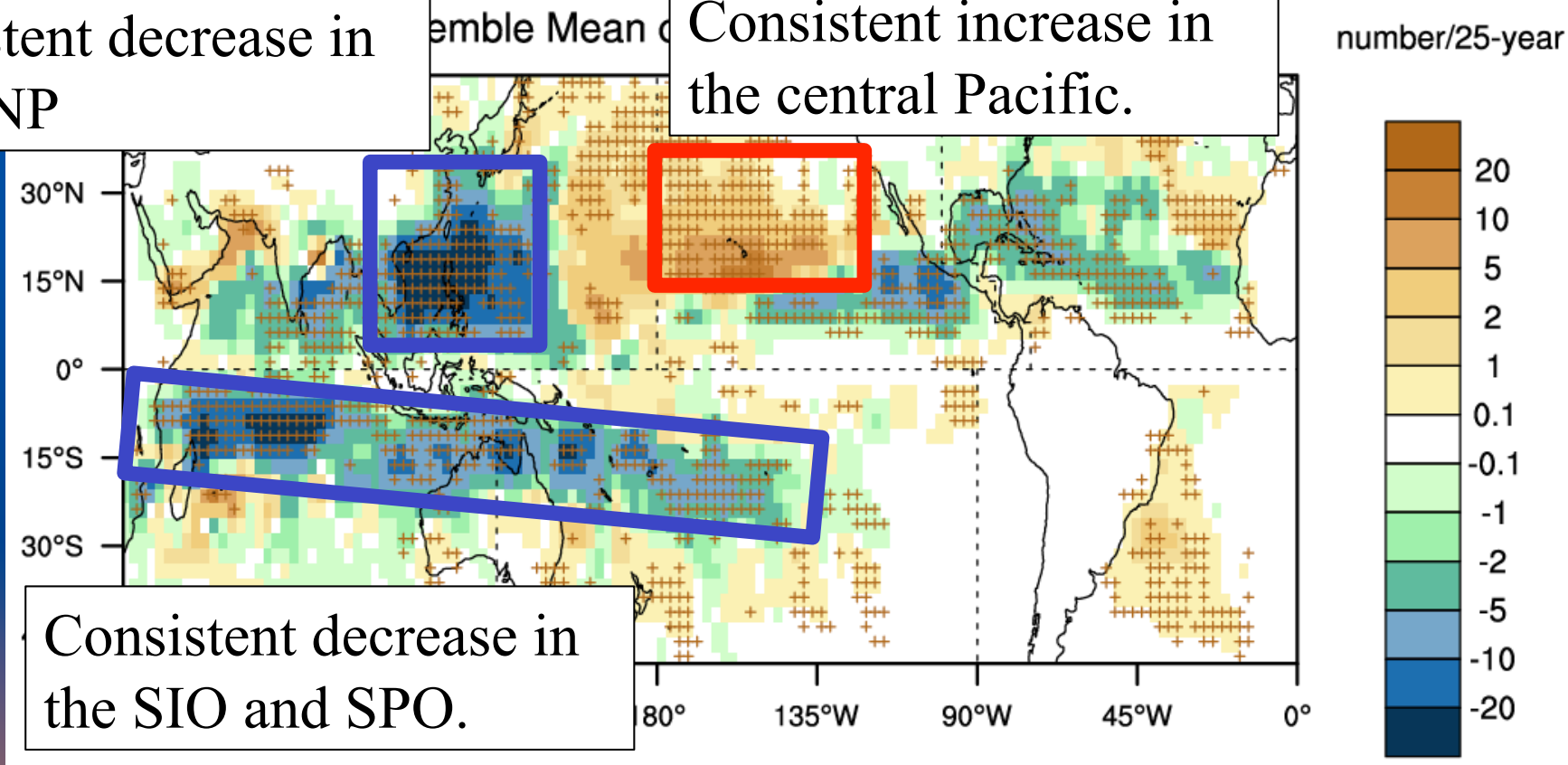
Statistically significant decreases in global and hemispheric scales (by about 3−35%). (Knutson et al. 20

Difference in SST causes larger variances rather than model physics.

Ensemble mean of future changes in TC frequency

Consistent decrease in the WNP

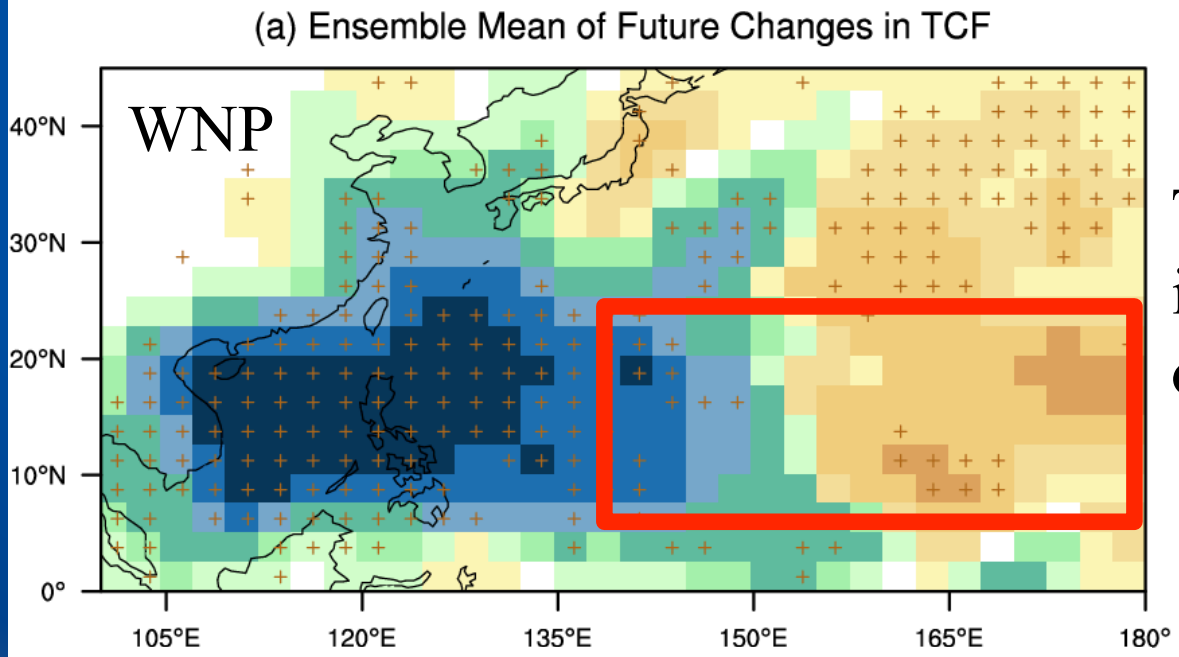
Consistent increase in the central Pacific.



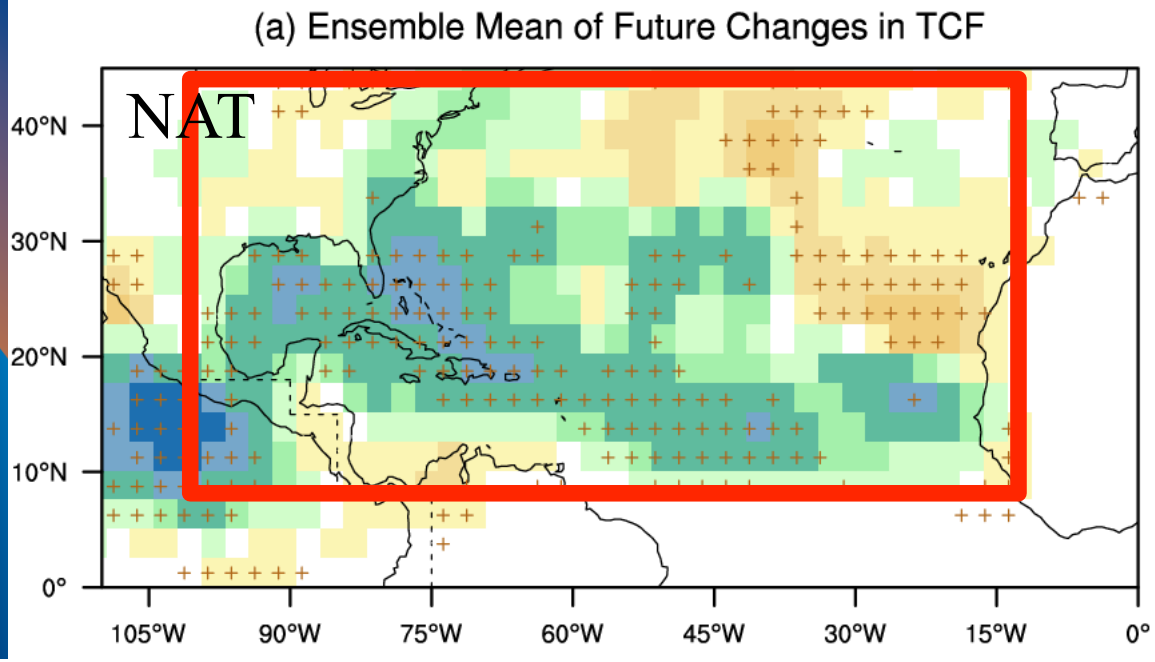
Consistent decrease in the SIO and SPO.

Plus mark indicates that the difference is statistically significant at the 90 % confidence level or above and more than 10 experiments show the same sign of the mean change.

Ensemble mean of future changes in TC frequency



There is no robust change in the southwest quadrant of WNP.



Projected eastward shift may be robust in NAT. But mean shift is further east compared with that projected by the 20-km-mesh previous version.

Conclusion

We have developed a new 20-km-mesh high-resolution AGCM for addressing future changes in TC activity. In order to evaluate uncertainties, we also conducted multi-physics and multi-SST ensemble projections.

New findings are as follows.

(a) Compared with the previous version, new version yields a more realistic global distribution of TCs. Moreover, the new version is able to simulate extremely intense TCs (Categories 4 and 5).

(b) Future projections consistently suggest a significant decrease in TC genesis number in global, both hemispheres, western WNP, and SPO, whereas they suggest pronounced increase in the Central Pacific.

(c) A significant increase in the frequency of intense TCs with global warming occurs in both versions. However, the increase is smaller in the new version than in the previous version. New version also projects a marked decrease in mean intensity in South Pacific Ocean.

(d) Future changes in TC frequency at regional scales are inconsistent among the ensemble experiments. These discrepancies highlight continuing uncertainties in the future changes in regional TC activity. Further study is needed to explore the uncertainties.