Future changes in tropical cyclone activity projected by the new 20-km-mesh high-resolution MRI-AGCM

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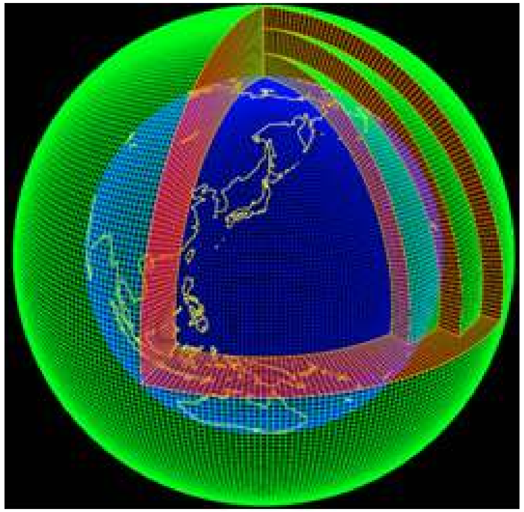
J. Climate (revised)

Relevant papers:

Murakami et al. (In press, *Clim. Dyn.*),
Murakami et al. (2011, *J. Climate*),
Murakami and Wang (2010, *J. Climate*),
Murakami and Sugi (2010, *SOLA*),
Sugi and Murakami (2009, *SOLA*),
Murakami et al. (2008, *J. Meteor. Soc. Japan*)

Outline

- Review of previous studies on projected future changes in tropical cyclones (TCs)
- New 20-km-mesh MRI-AGCM and methodology
- Performance of present-day simulation
- Projected future changes in TC activities.
- Summary



20 km-mesh grids

Review of impact of global warming on TC activities

nature geoscience

REVIEW ARTICLE

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Tropical cyclones and climate change

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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 tasks** (unknown)
   - Effect of global warming on TC activities in a specific ocean basin

History of MRI-AGCM development

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

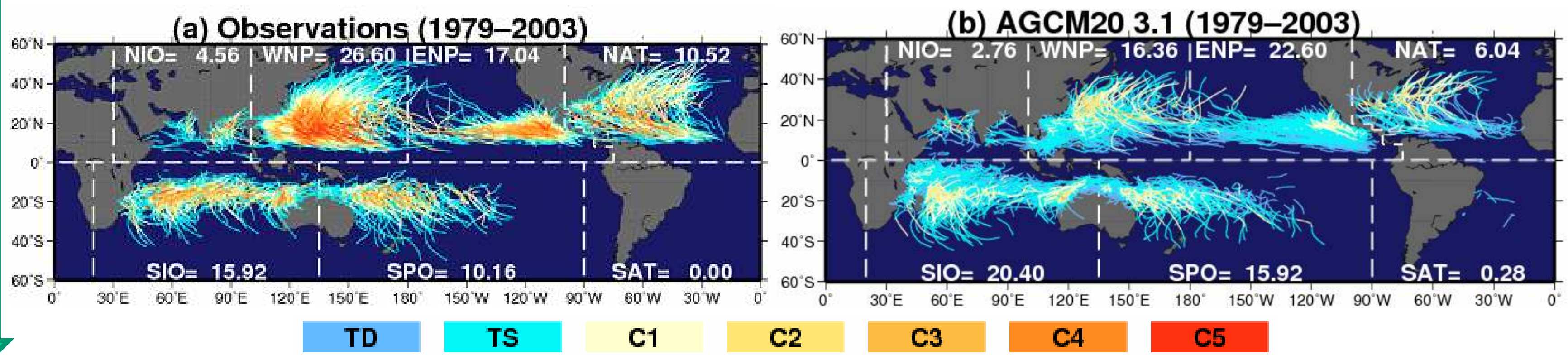
This model was developed from JMA operational NWP model.
First 20-km mesh climate model which simulates for multi decades.

very minor change

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

Previous version

Necessary to be improved because geographical distribution of TCs and TC intensity are insufficient.

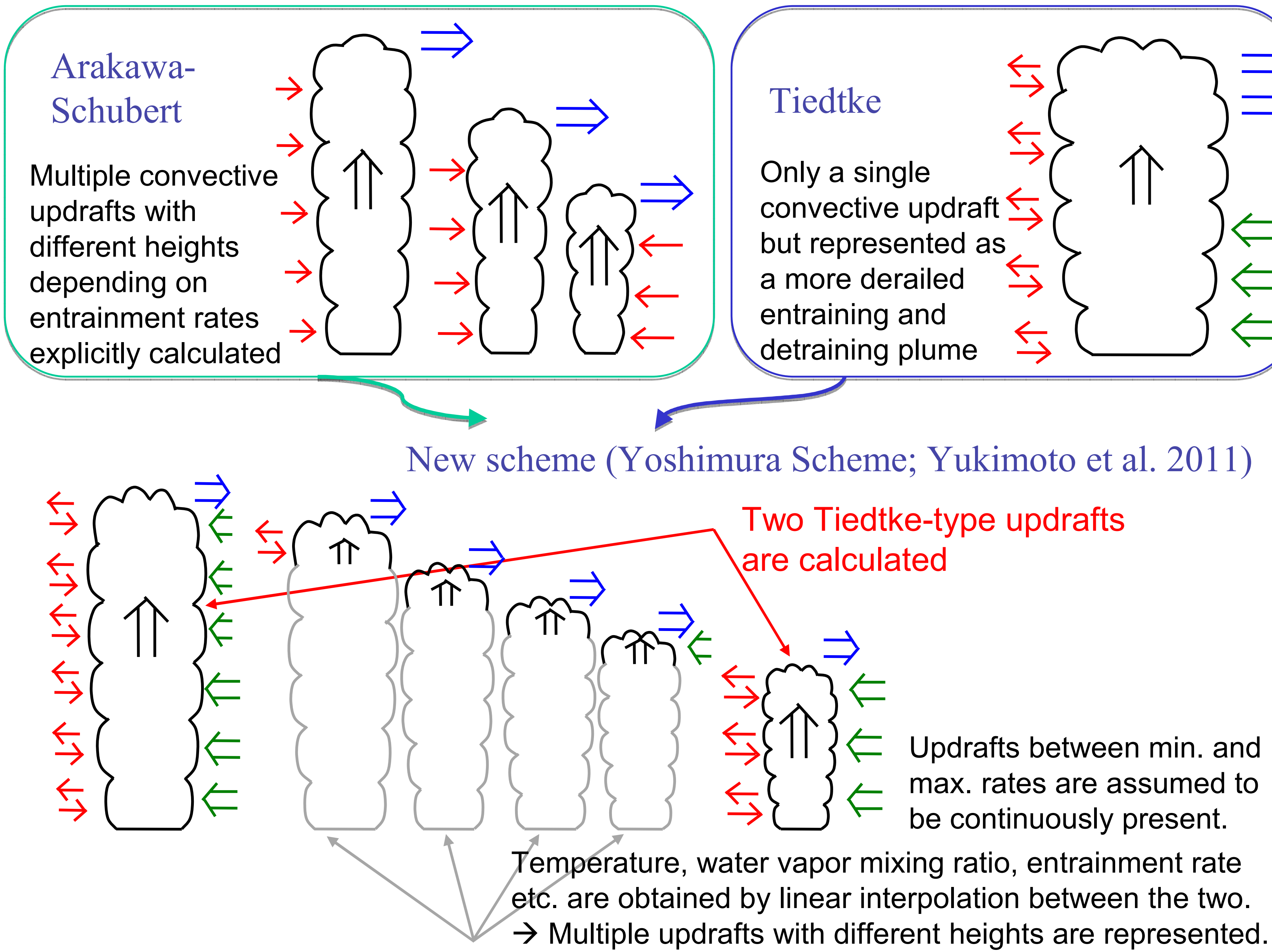


MRI-AGCM3.2 (from 2009) **New version**

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.

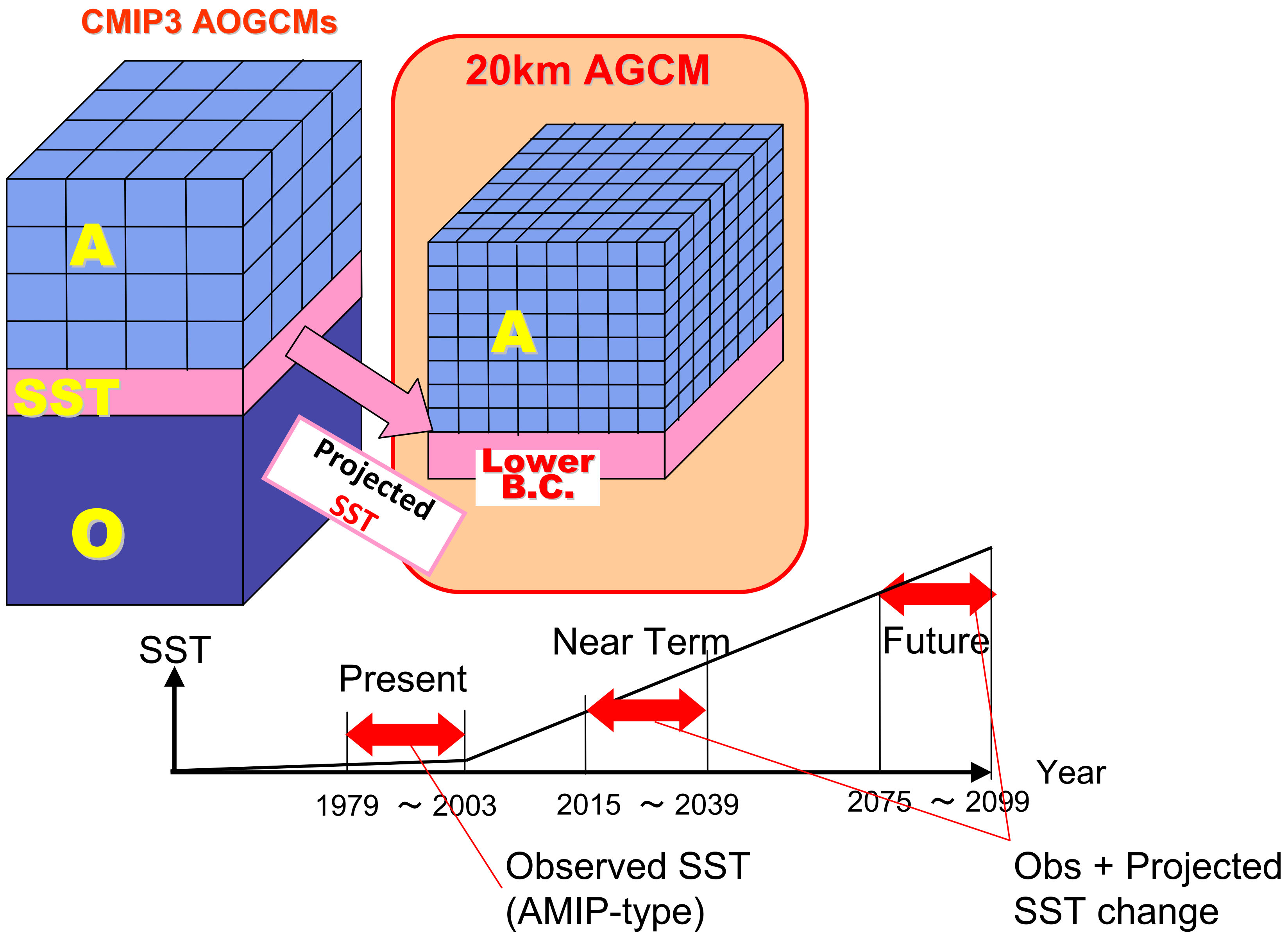
Comparisons between v3.1 and v3.2 MRI-AGCMs

	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., 2011, submitted)
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	



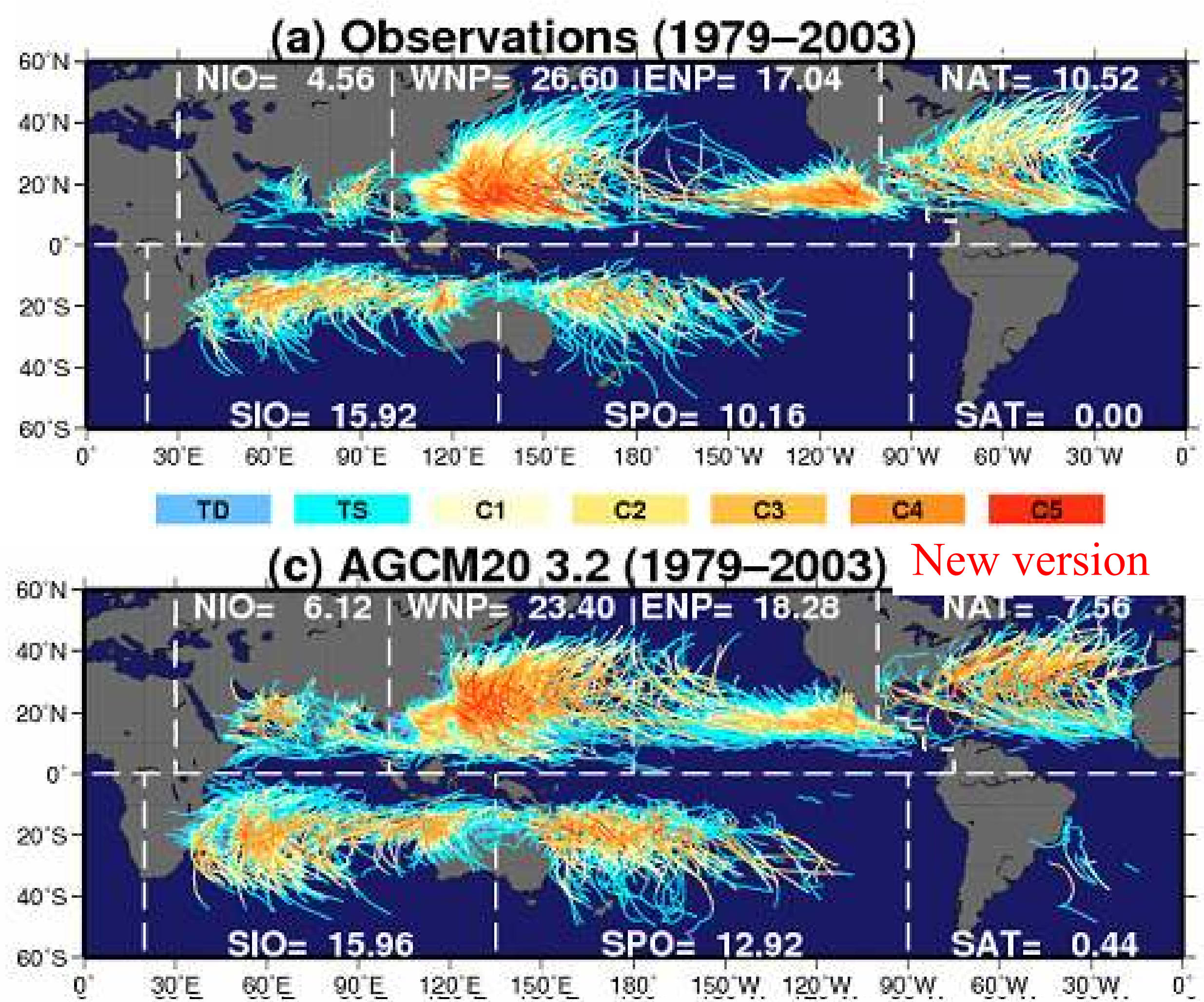
Arakawa-Schubert
Multiple convective updrafts with different heights depending on entrainment rates explicitly calculated
Tiedtke
Only a single convective updraft but represented as a more derailed entraining and detraining plume
New scheme (Yoshimura Scheme; Yukimoto et al. 2011)
Two Tiedtke-type updrafts are calculated
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.

Time-slice Experiment



Present-day simulations prescribed by observed SST (i.e., AMIP-style; 1979–2003)

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



The number for each basin show the annual mean number of TCs.

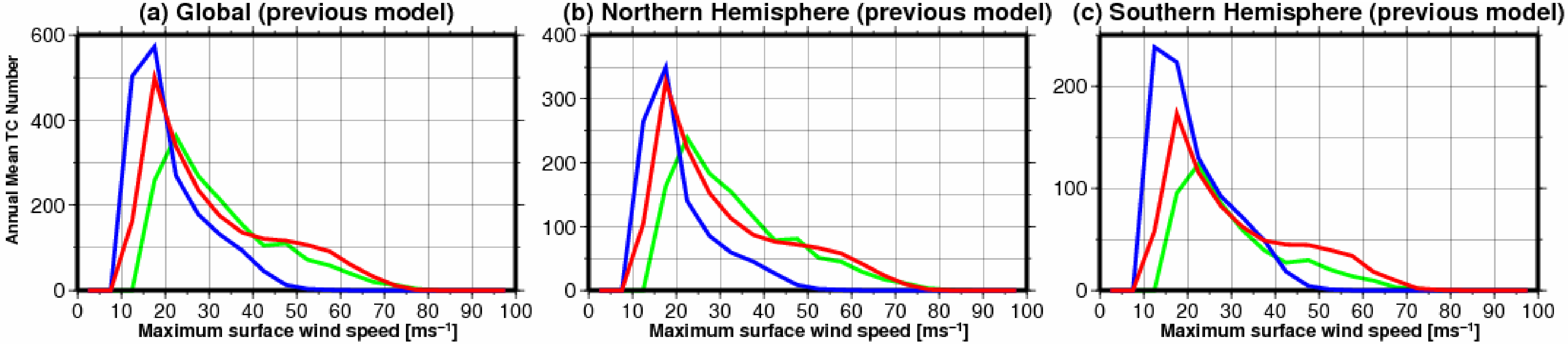
·Predicted TC number in the WNP is underestimated. Improved

·TC intensity is weak compared with observations Improved

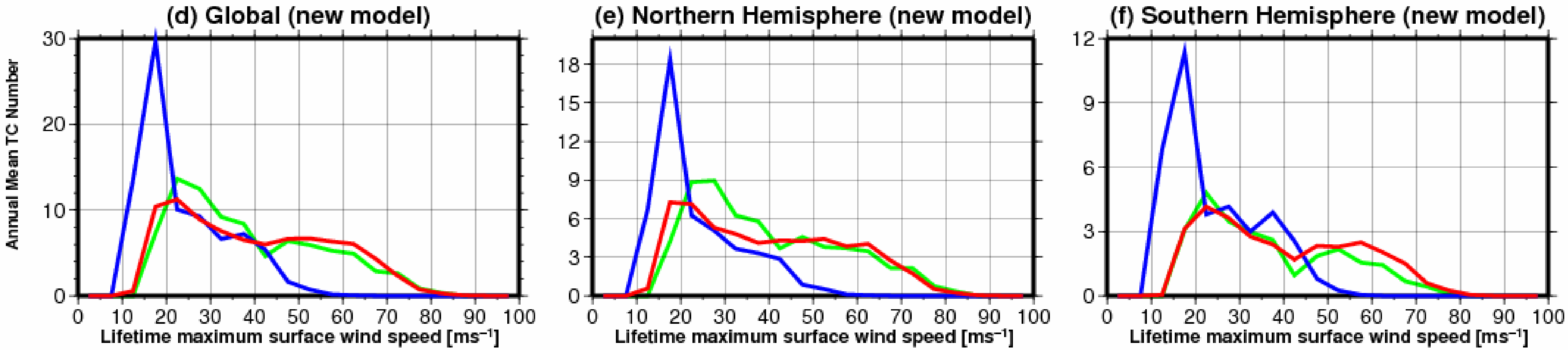
Comparison of TC intensity between versions

Observations
Previous version
New version

Annual mean TC frequency

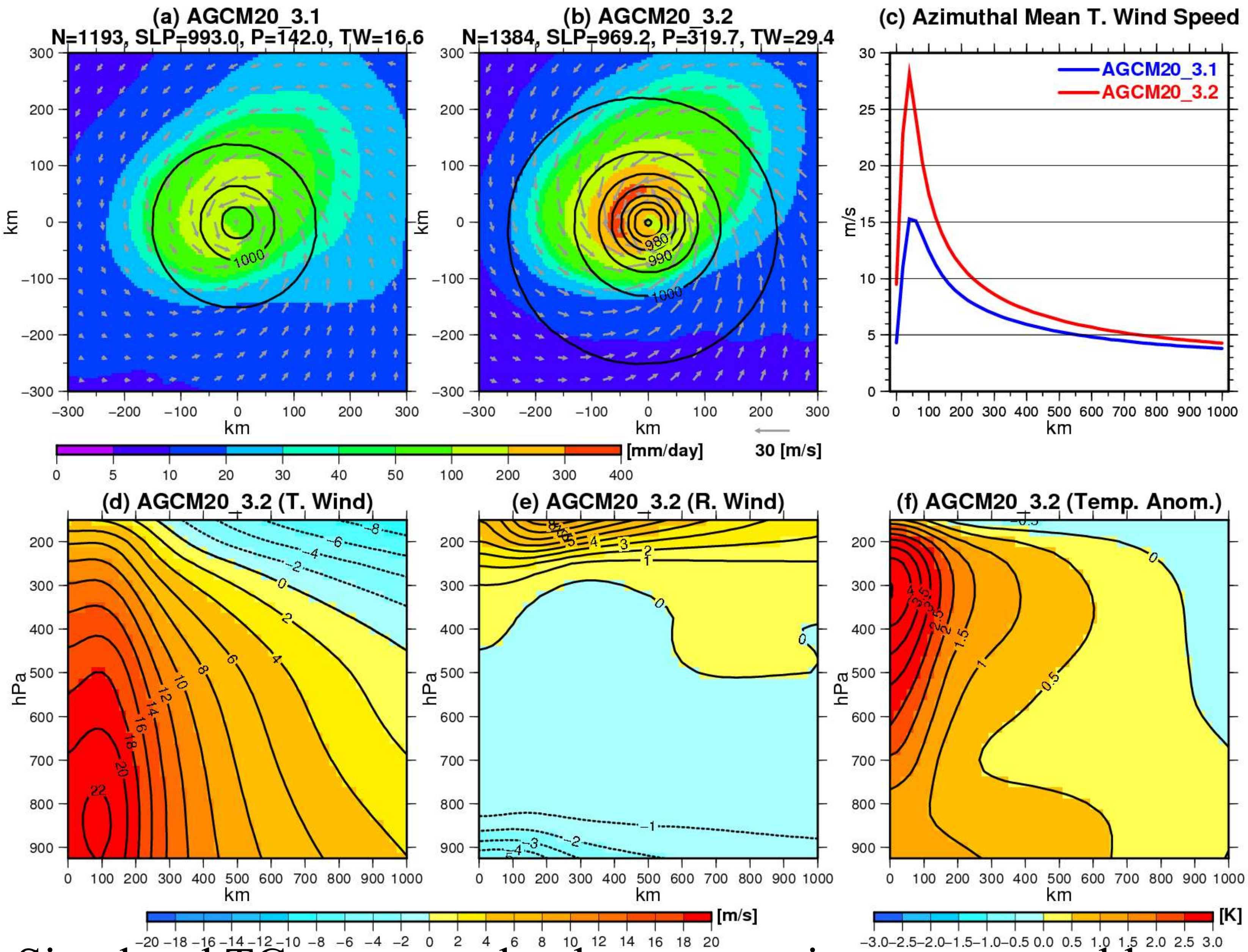


Annual mean TC number for the lifetime maximum wind speed



·TC intensity is substantially improved in the new version.

Comparison of composite TC structures

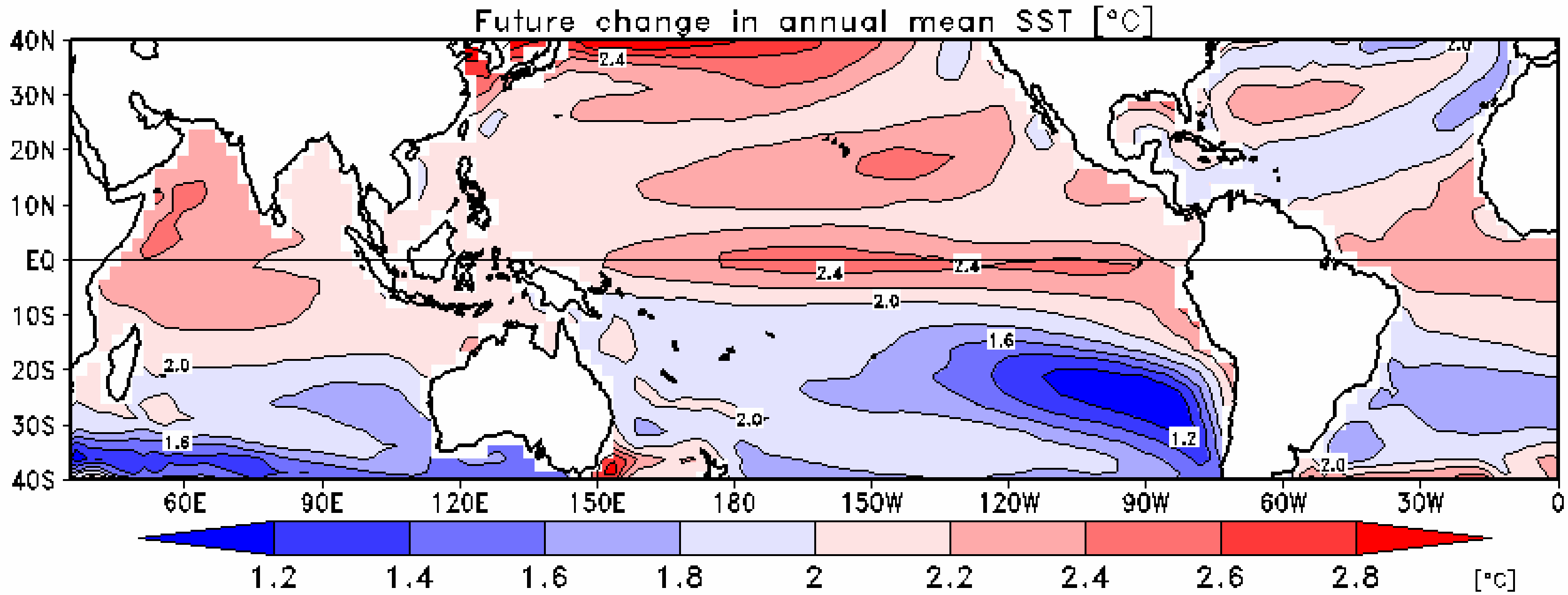


·Simulated TC structures by the new version are reasonable.

Future Projection

Spatial pattern of prescribed future changes in SST

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

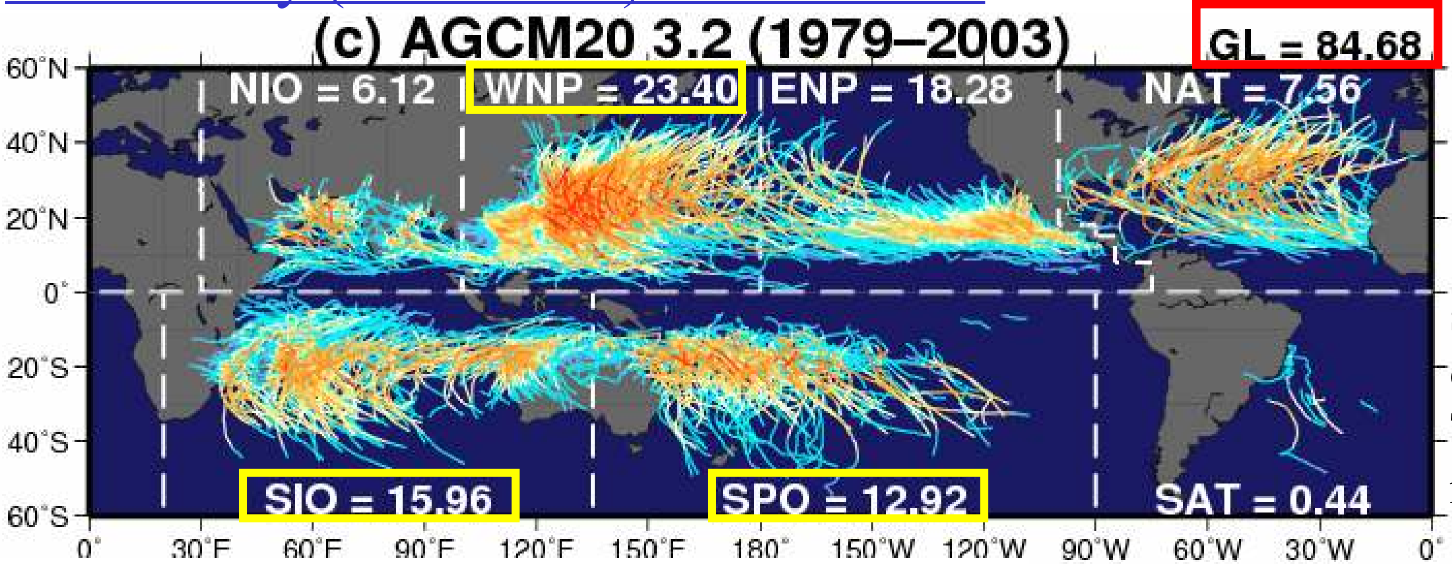


- Relatively larger increase in SST in the Northern Hemisphere than in the Southern Hemisphere.

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

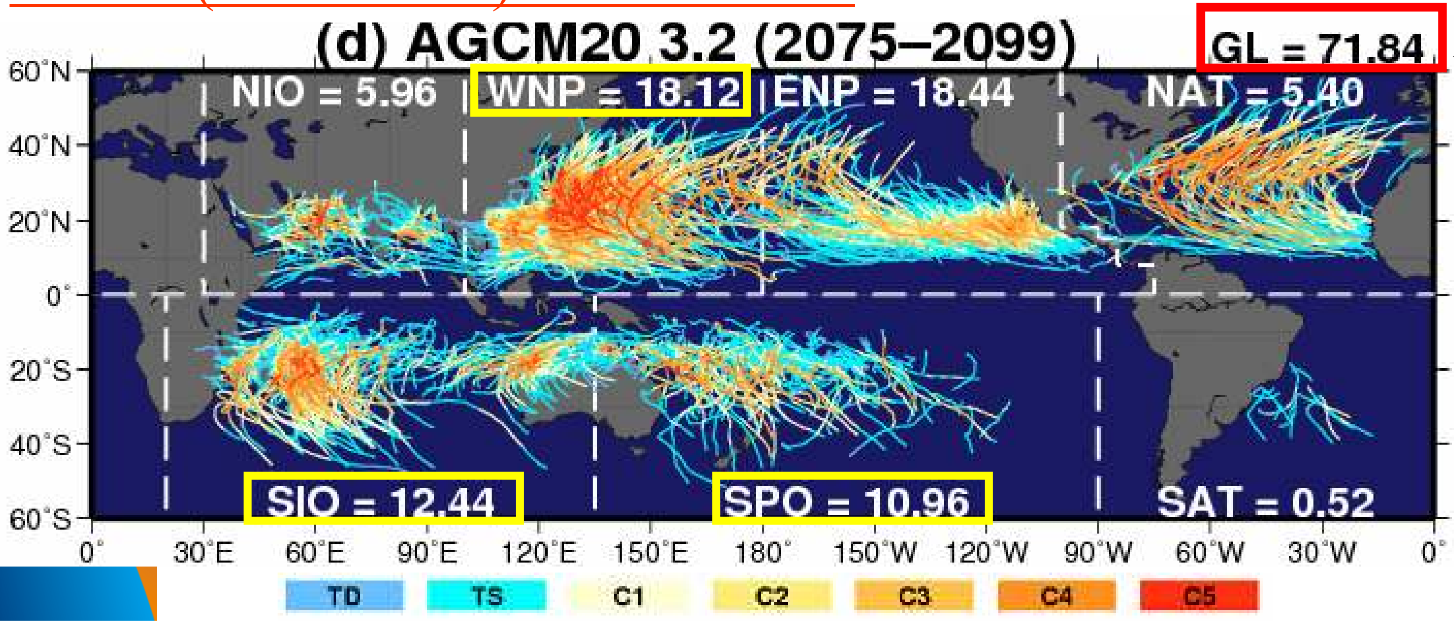
Future change in global TC distribution

Present-day (1979-2003) New version



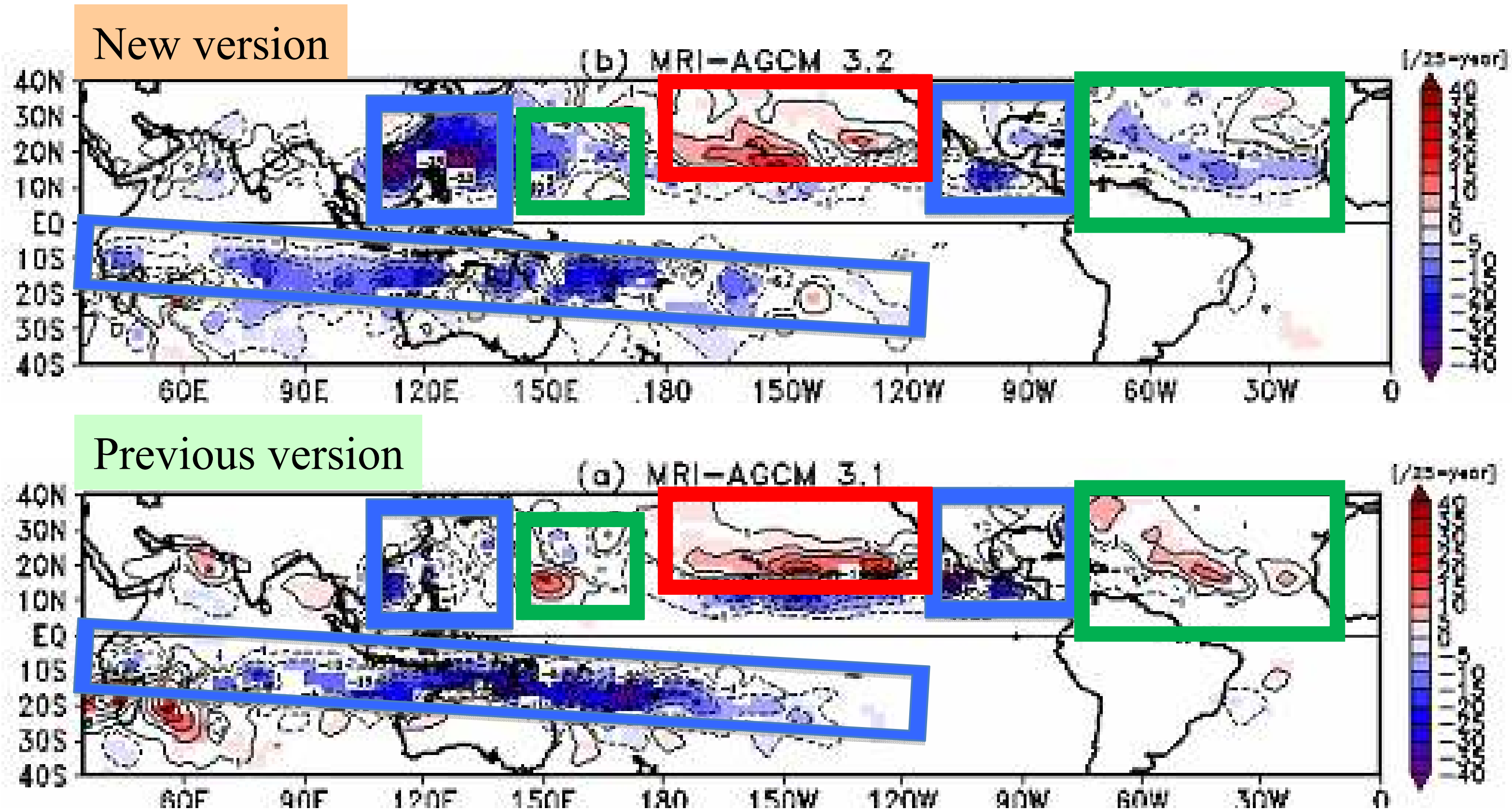
Statistically significant decrease in global TC genesis number by 15%.

Future (2075-2099) New version



Marked decrease in the western North Pacific and Southern Hemisphere.

Comparison of projected future changes between models
– Frequency of TC occurrence –



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

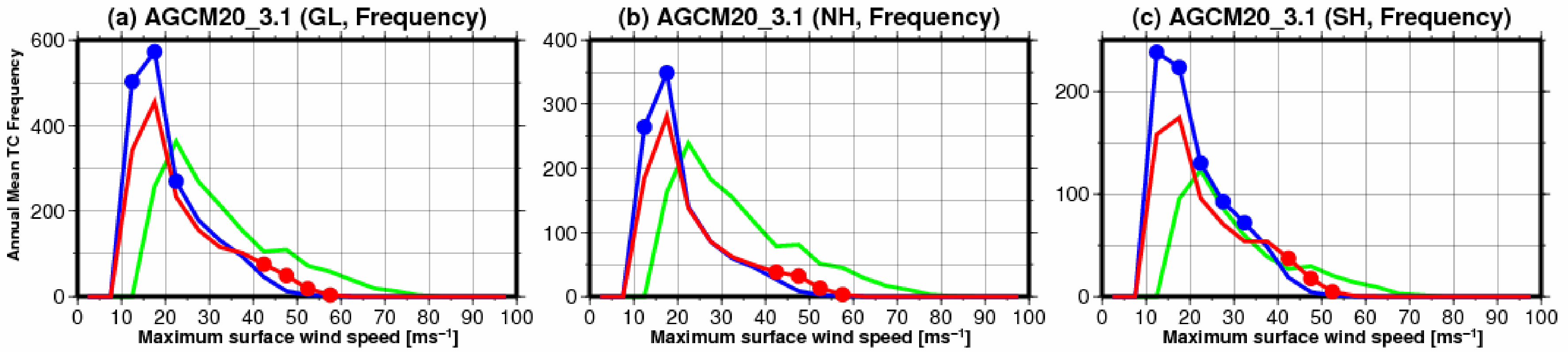
·Both versions show significant increase in TC frequency over the central Pacific.

·Inconsistent in the eastern quadrant of WNP and NAT.

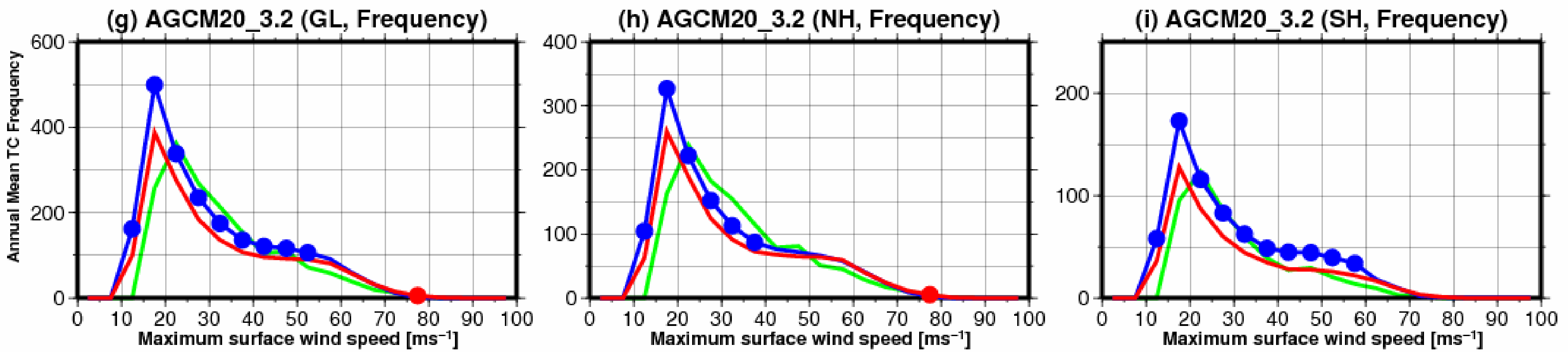
Projected future changes in TC intensity

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

Previous version



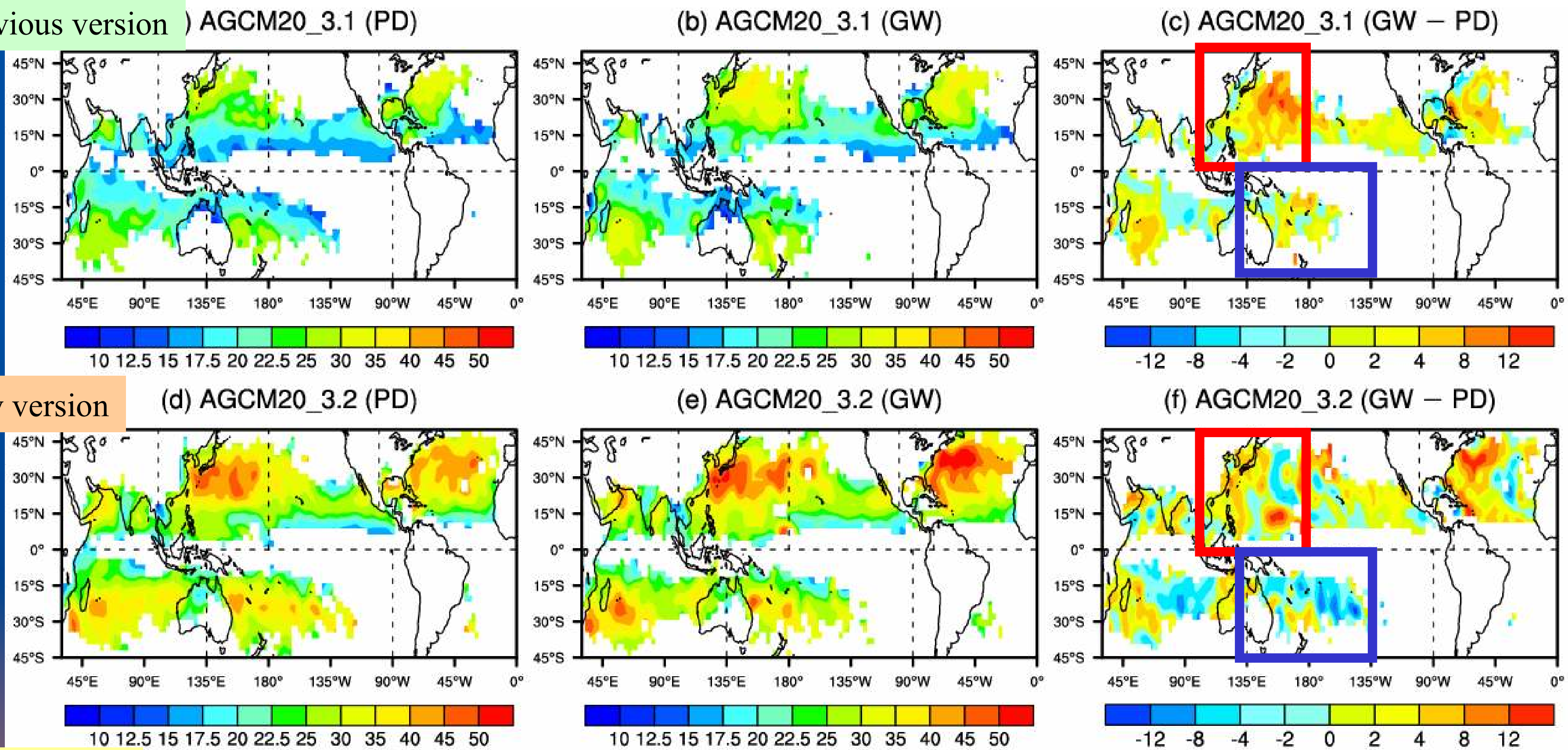
New version



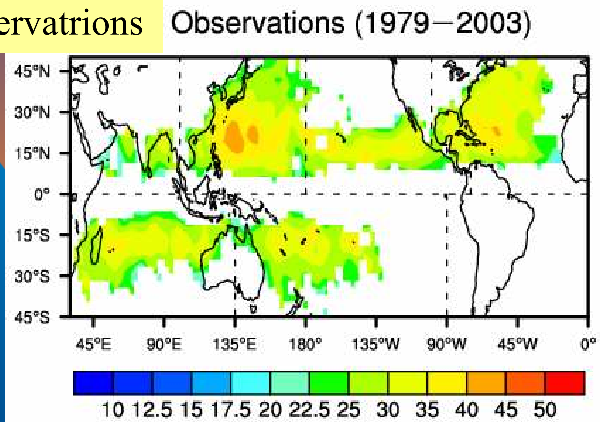
·Both versions show significant decrease in the frequency of weak TCs.

·New version projects subtle increase in the frequency of intense TCs.

Spatial distribution of mean TC intensity [m/s]

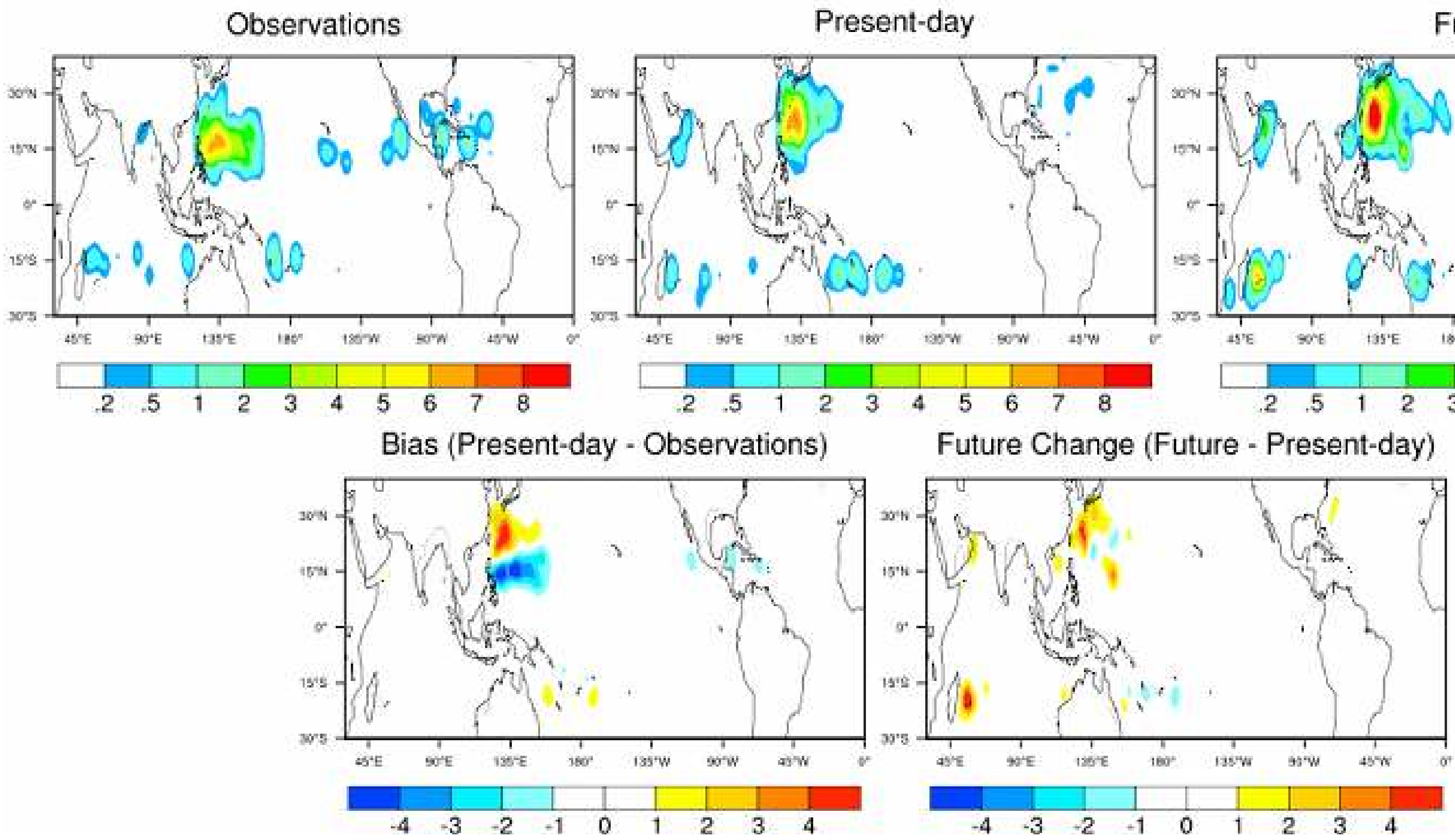


Observatrions



- Previous version shows large increase in TC intensity at the eastern WNP, while new version shows a striped pattern.
- Previous version shows a subtle increase in mean TC intensity in the South Pacific, whereas new version shows a marked decrease.
- According to Knutson et al. (2010), previous studies have also projected a weakening of TC intensity in the Southern Pacific; however, other studies also have projected a marked increase in TC intensity within this basin. => They highlight continuing uncertainty.

Future change in frequency of Category 5 (C5) occurrence



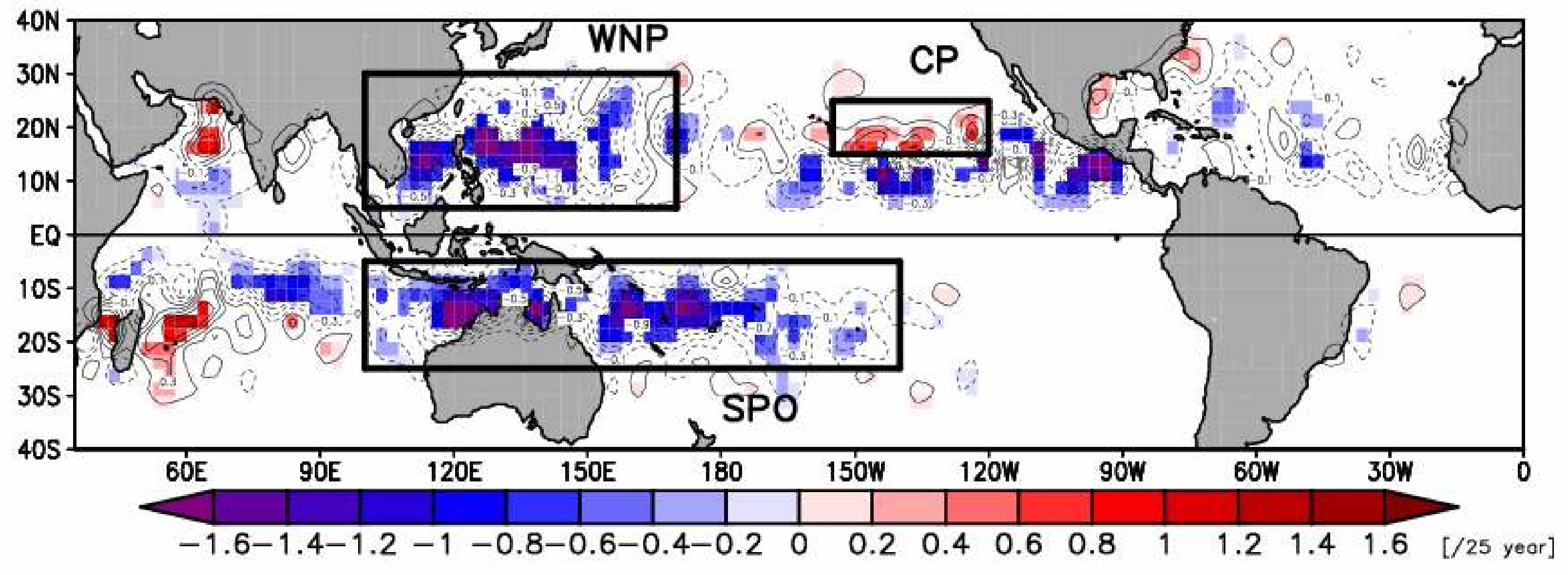
Unit: number per 25 years

·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.

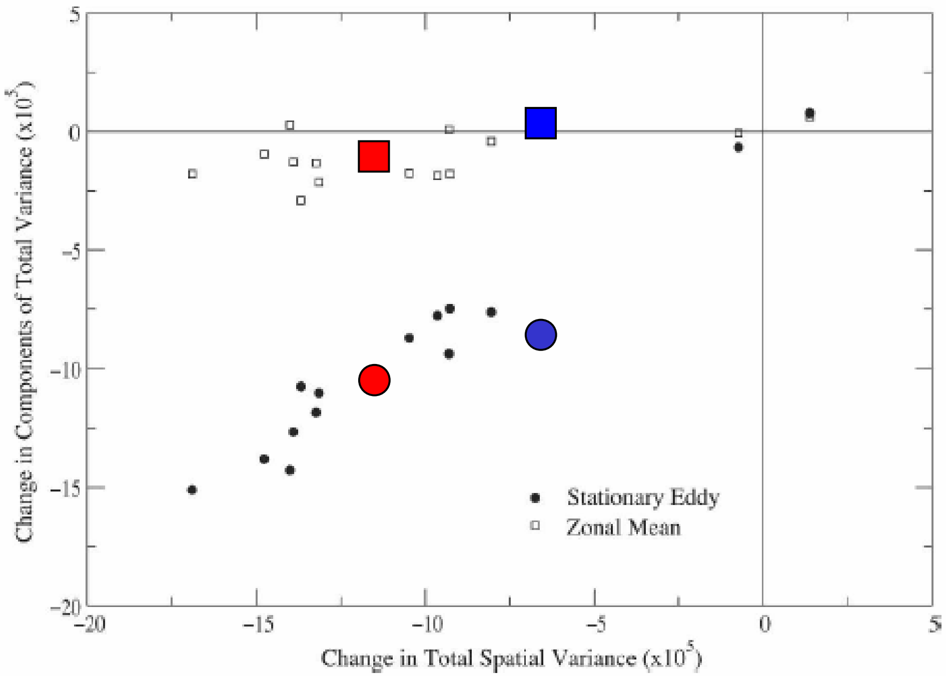
Mechanisms of future changes in TC genesis

Projected future changes in tropical cyclone genesis frequency



The changes are similar to the projected changes in TC frequency (TCF), indicating that the TCF changes are primarily controlled by the tropical cyclone genesis changes.

Weakening of Walker Circulation

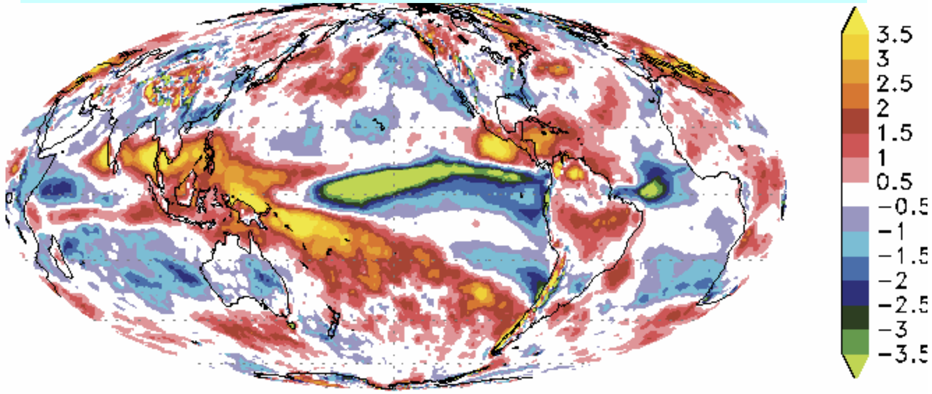


赤 : New version　□ : zonal

青: Previous version ● : asymmetric

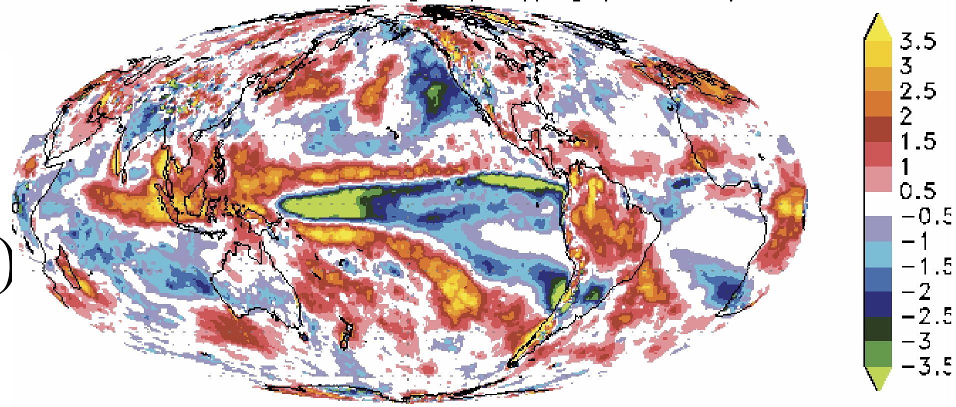
Vecchi and Soden (2007, *J.Climate*)

Previous version ($d\omega_{500}$)



Tropical total upward (downward) mass flux: -6.3% (-6.4 %)

New version ($d\omega_{500}$)



Tropical total upward (downward) mass flux: -5.1% (-5.1 %)

Projected Walker circulation is weakened in both versions.

Interpretation for the future changes in TC activity (I)

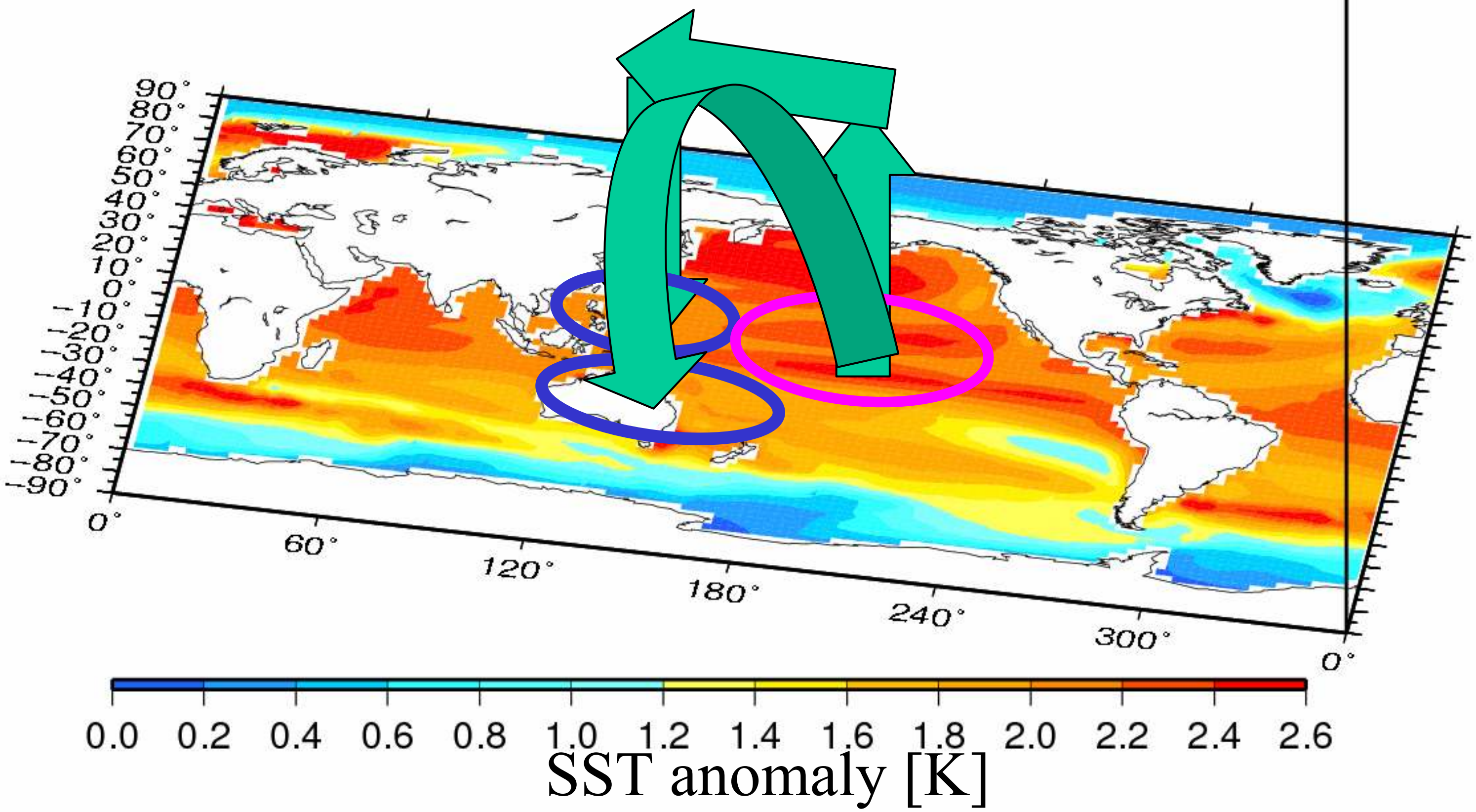
Weakening of pacific Walker circulation

⇨ Decrease in TC genesis number in the western WNP and South Pacific.

⇨ Increase in TC genesis number in the central Pacific.

SST increases more largely in the NH than in SH.

⇨ Marked subsidence in the SH causes decrease in TC genesis number.



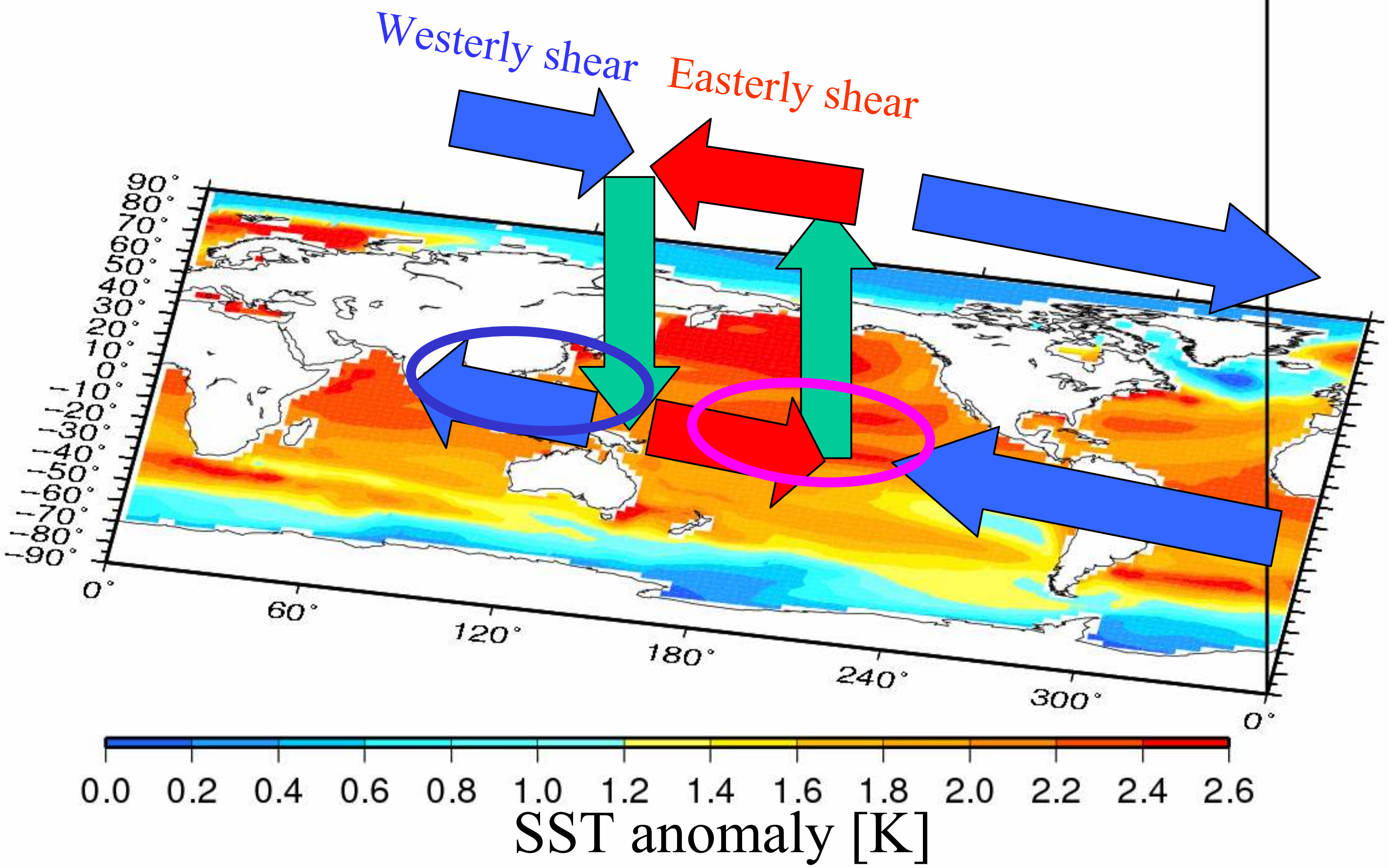
Interpretation for the future changes in TC activity (II)

Weakening of pacific Walker circulation

⇨ Increase in vertical easterly wind shear causes enhancement of activity of synoptic-scale disturbances, leading to increase in TC genesis in the central Pacific.

⇨ Increase in vertical westerly wind shear causes inactivation of synoptic-scale disturbances, leading to decrease in TC genesis in the western WNP.

⇨ Increase in vertical wind shear causes decrease in TC genesis number in the NAT.

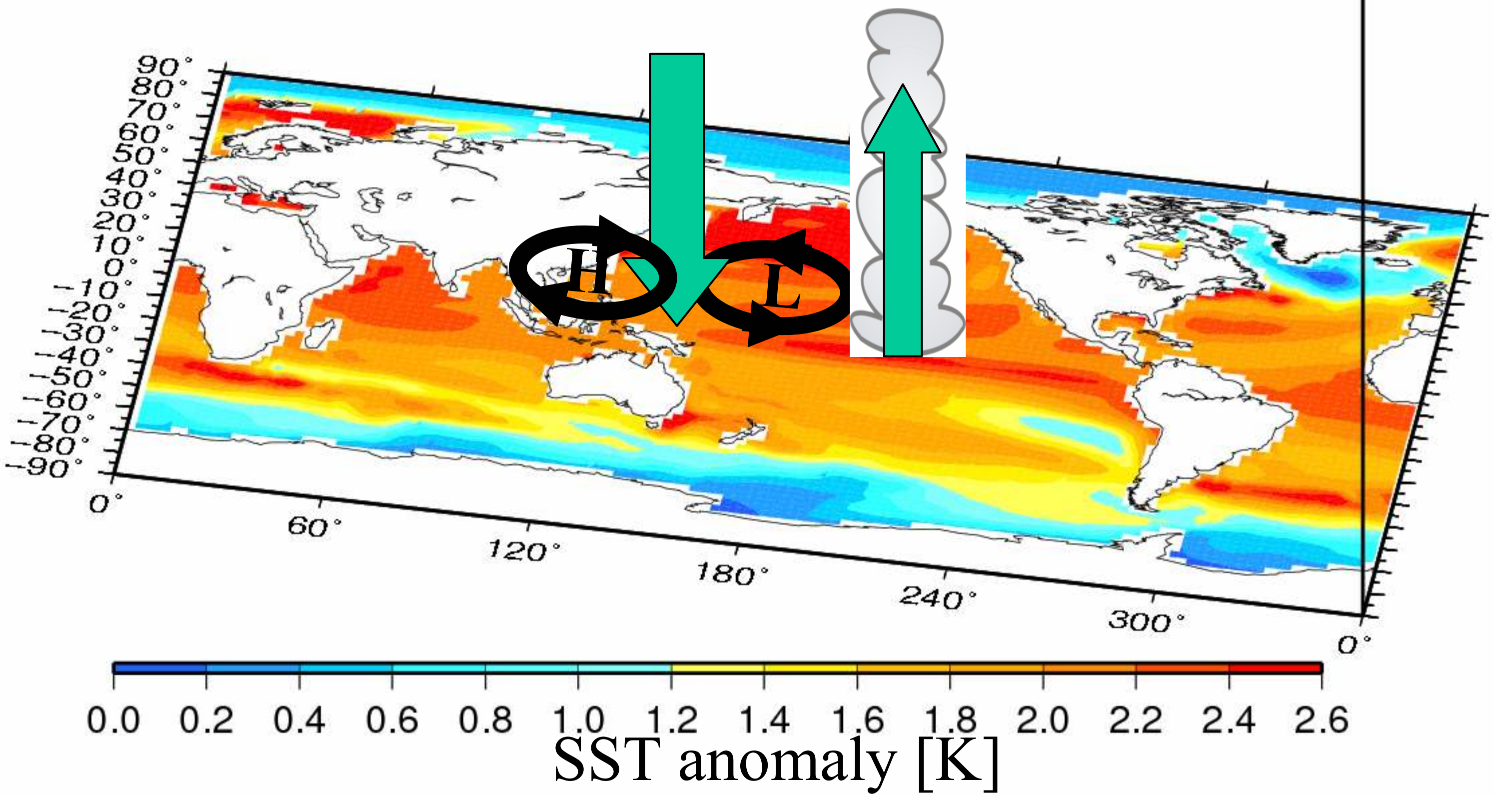


Interpretation for the future changes in TC activity (III)

Increase in equatorially antisymmetric heating over central Pacific

⇨ The increase in diabatic heating causes cyclonic vorticity anomaly in the southeastern WNP thgough the Rossby wave response (Gill 1980); resulting in increase in TC genesis at the southeastern quadrant of WNP (but this is not clear in the new version).

⇨ The decrease in diabatic heating causes anti-cyclonic vorticity anomaly in the western WNP, resulting in decrease in TC genesis.



Conclusion

We have developed a new 20-km-mesh high-resolution AGCM for addressing future changes in TC activity. New findings compared with the previous version 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. This is because new version shows significant decrease in TC intensity in the South Pacific.

(d) The new version suggests that the frequency of Category 5 TCs increases in the northern portion of the WNP, indicating that TC-related socioeconomic damage may become more severe under global warming.

(e) Above all, projected future changes in TC activity in the global and hemispheric scales are robust between versions; however, those in regional scales are inconsistent in terms of degree and even in sign. These discrepancies highlight continuing uncertainties in the future changes in regional TC activity. Further study is needed to explore the uncertainties.

Reference

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