Future changes in tropical cyclone activity in the North Indian Ocean projected by the new high-resolution MRI-AGCM

Hiroyuki Murakami (JAMSTEC, Japan),
Masato Sugi (JAMSTEC), and Akio Kitoh (MRI)

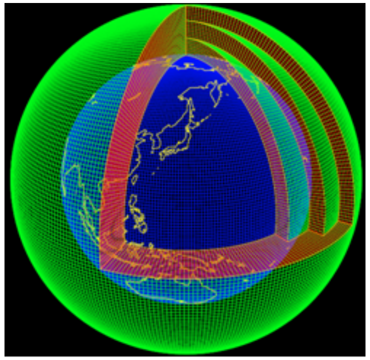
Submitted to *Climate Dynamics*

Other relevant papers:

Murakami et al. (2012b, *Clim. Dyn, In press*),
Murakami et al. (2012a, *J. Climate, In press*)

Outline

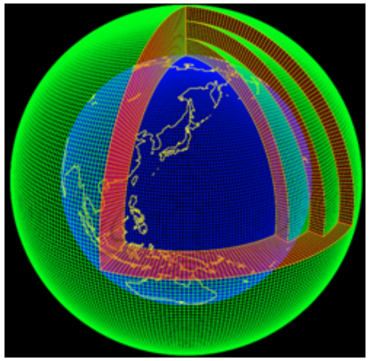
- New high-resolution (20-km-mesh) MRI-AGCM and projected future change in **global** TC activity.
- Projected future changes in TC activity in the **North Indian Ocean** by multi-physics and multi-SST ensemble experiments.
- Summary



20 km-mesh grids

Outline

- New high-resolution (20-km-mesh) MRI-AGCM and projected future change in **global** TC activity.
- Projected future changes in TC activity in the **North Indian Ocean** by multi-physics and multi-SST ensemble experiments.
- Summary



20 km-mesh grids

History of MRI-AGCM development

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

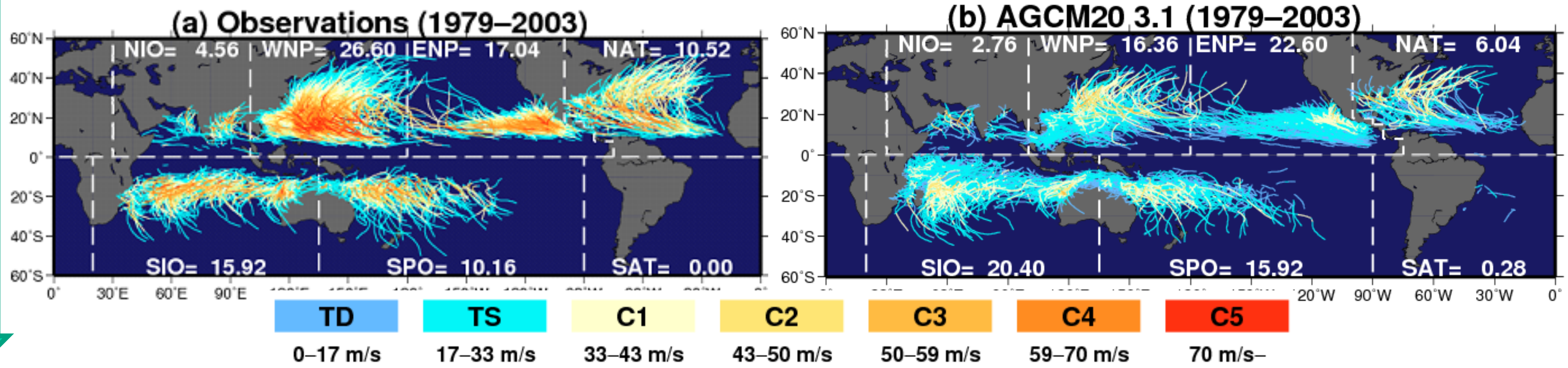
This model was developed from JMA operational NWP model.
First 20-km mesh climate model which simulates for multi decades.

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

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

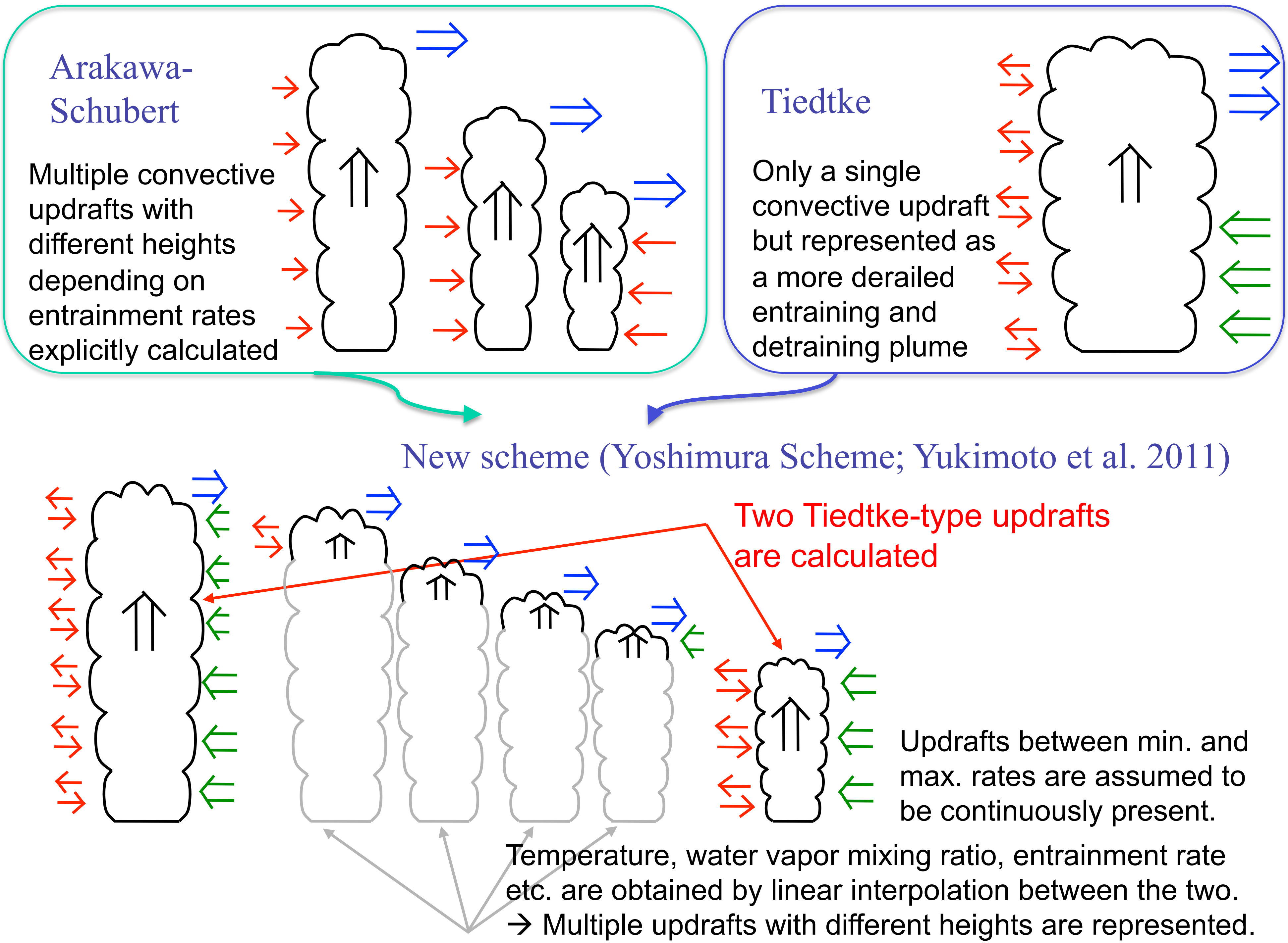


MRI-AGCM3.2 (since 2009) New version

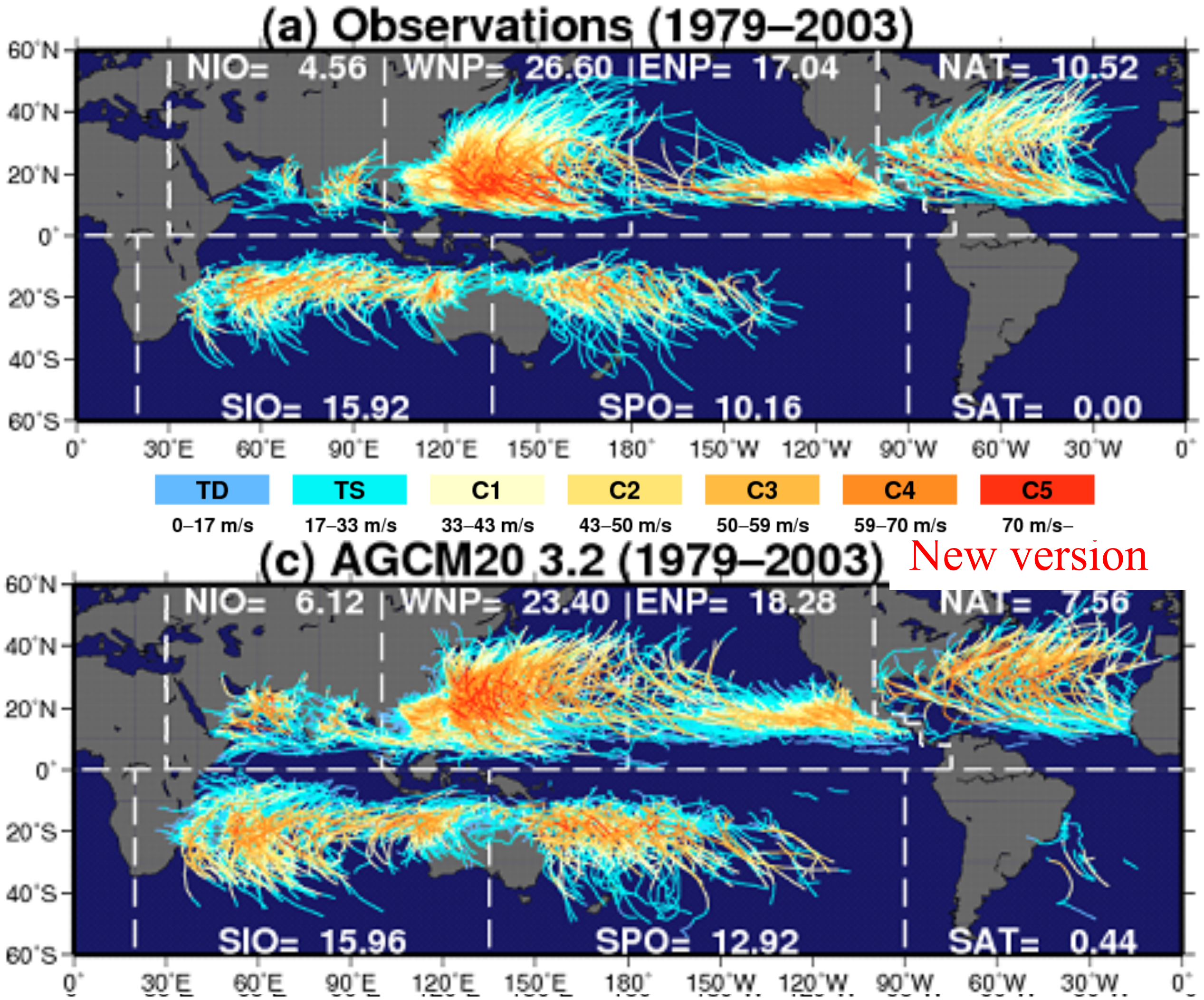
AMIP-type 25 years experiments are conducted using observed SST for the present-day climate.
Future projections of 25 years are conducted by prescribing CMIP3 ensemble mean SST and clustered SSTs.

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, In press)
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.

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

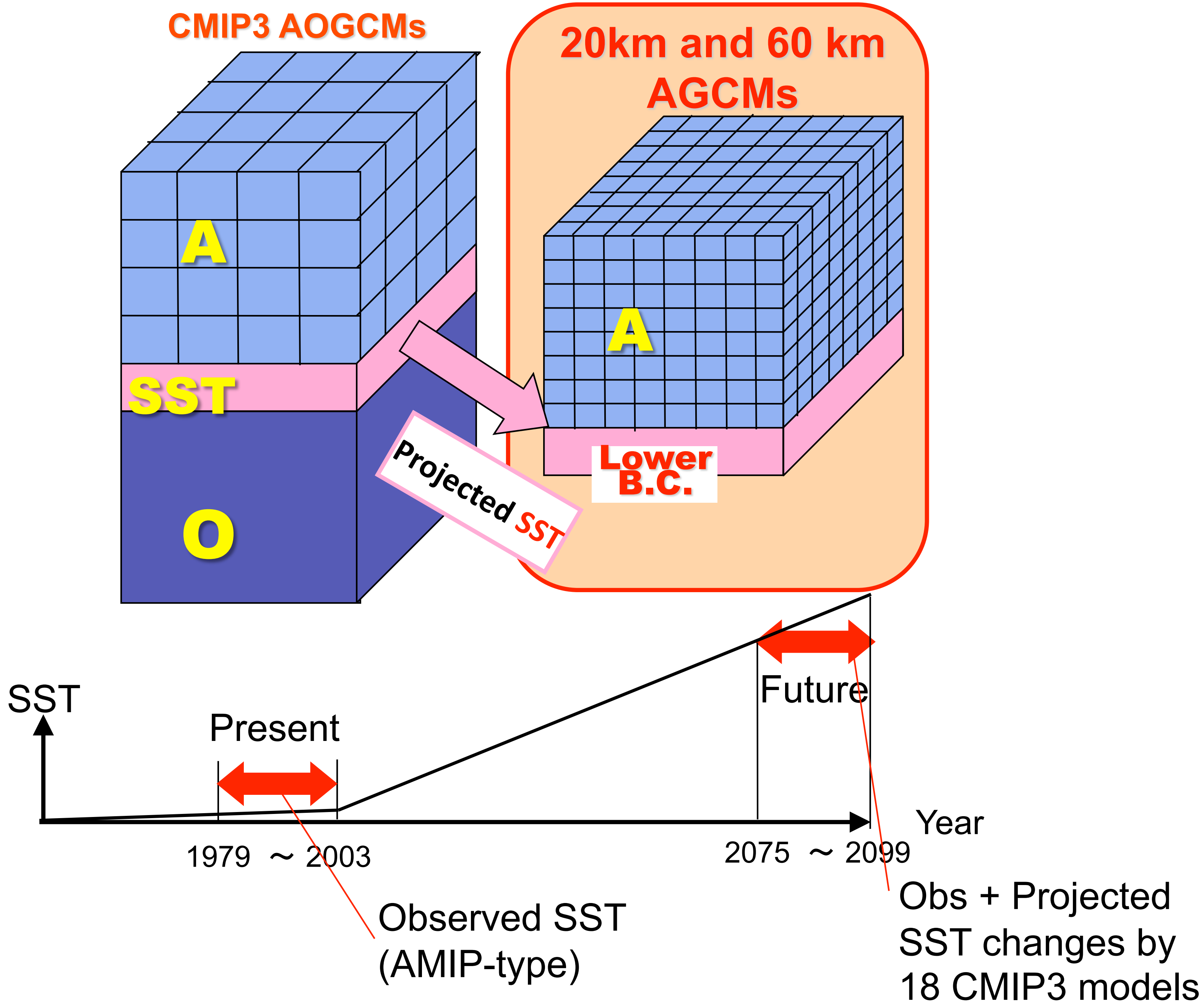


The number for each basin show the annual mean number of TCs.

·Predicted TC number in the WNP is underestimated. Improved

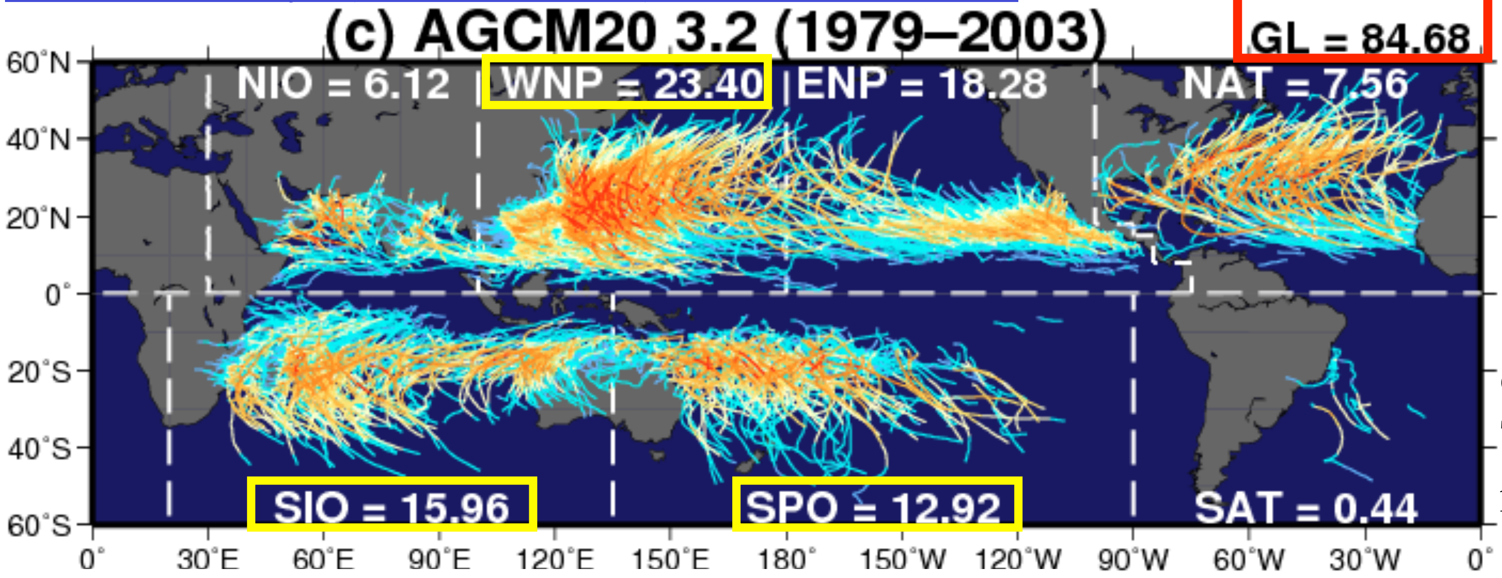
·TC intensity is weak compared with observations Improved

Time-slice Experiment



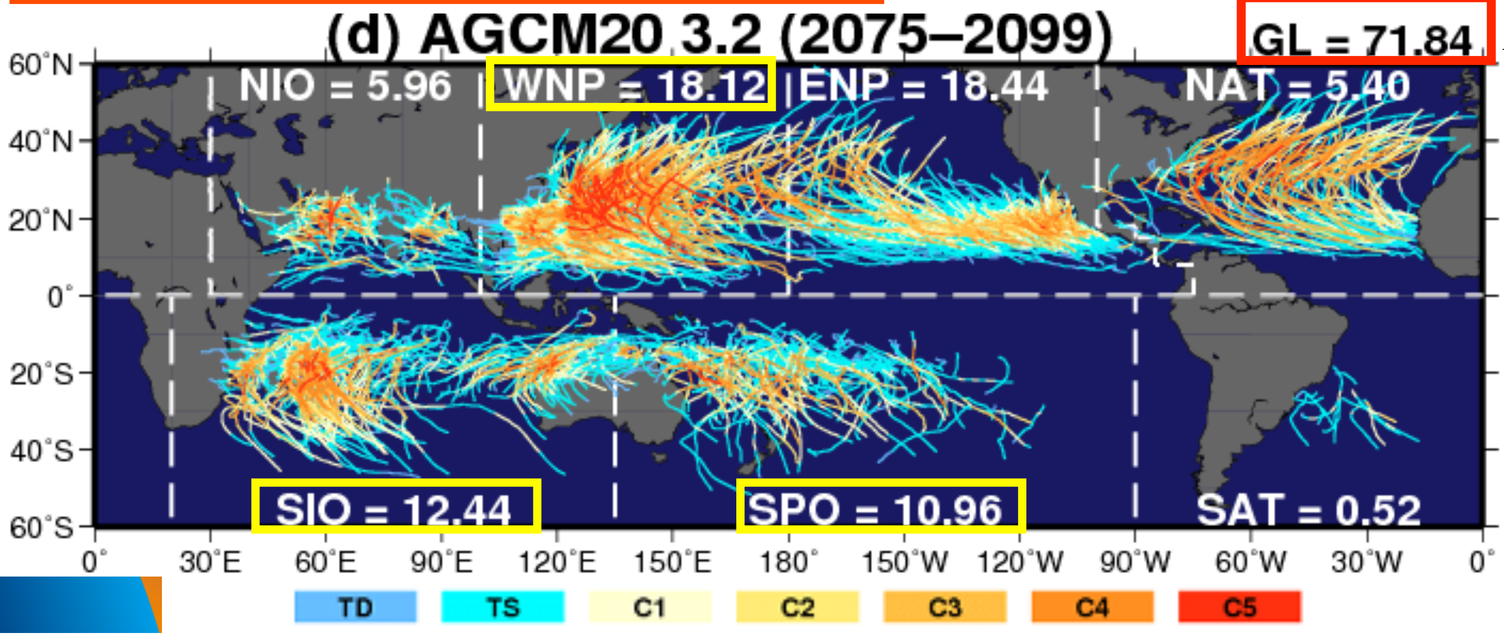
Future change in global TC distribution

Present-day (1979-2003) New version



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

Future (2075-2099) New version

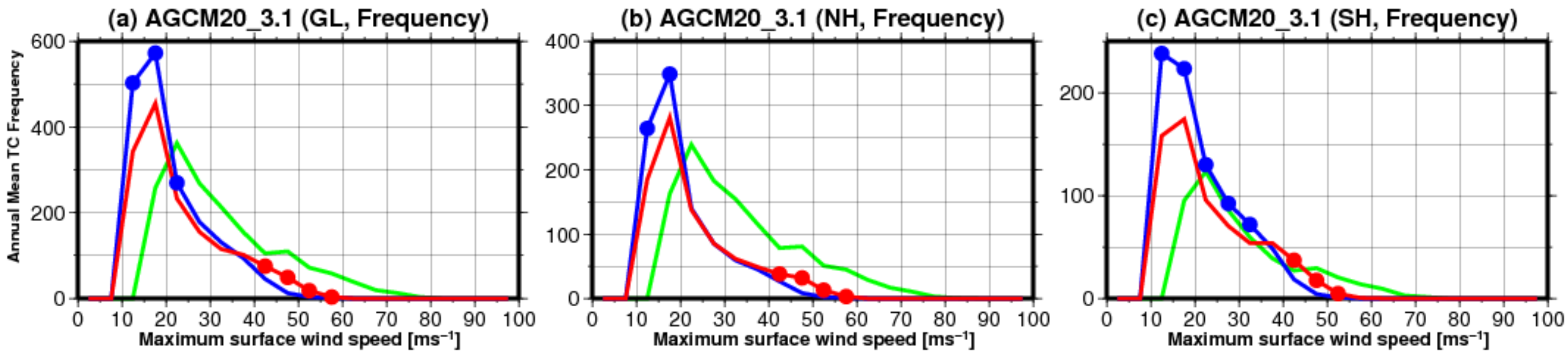


Marked decrease in the western North Pacific and Southern Hemisphere.

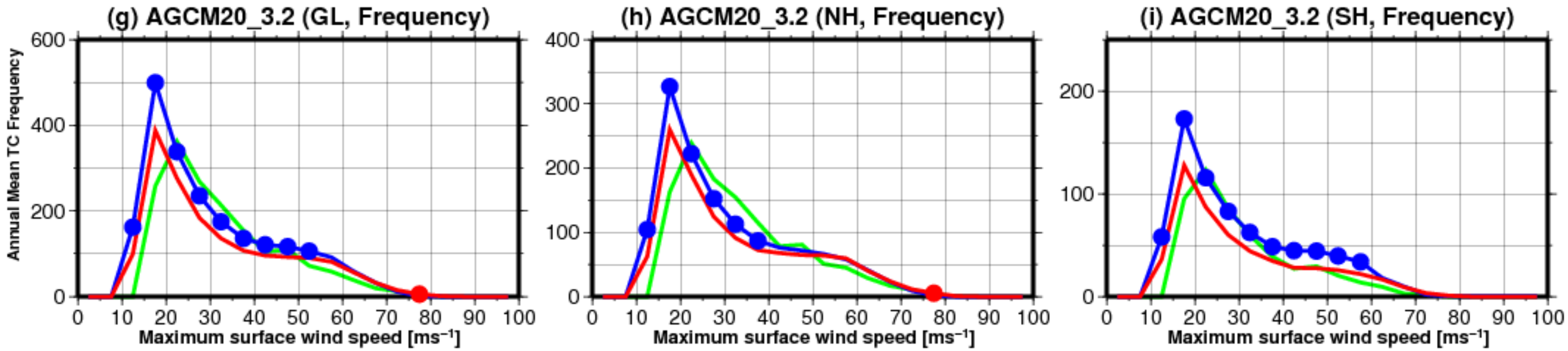
Projected future changes in TC intensity

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

Previous version



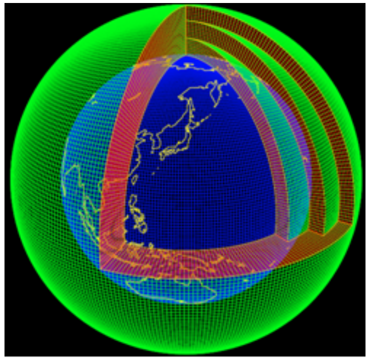
New version



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

Outline

- New high-resolution (20-km-mesh) MRI-AGCM and projected future change in **global** TC activity.
- Projected future changes in TC activity in the **North Indian Ocean** by multi-physics and multi-SST ensemble experiments.
- Summary



20 km-mesh grids

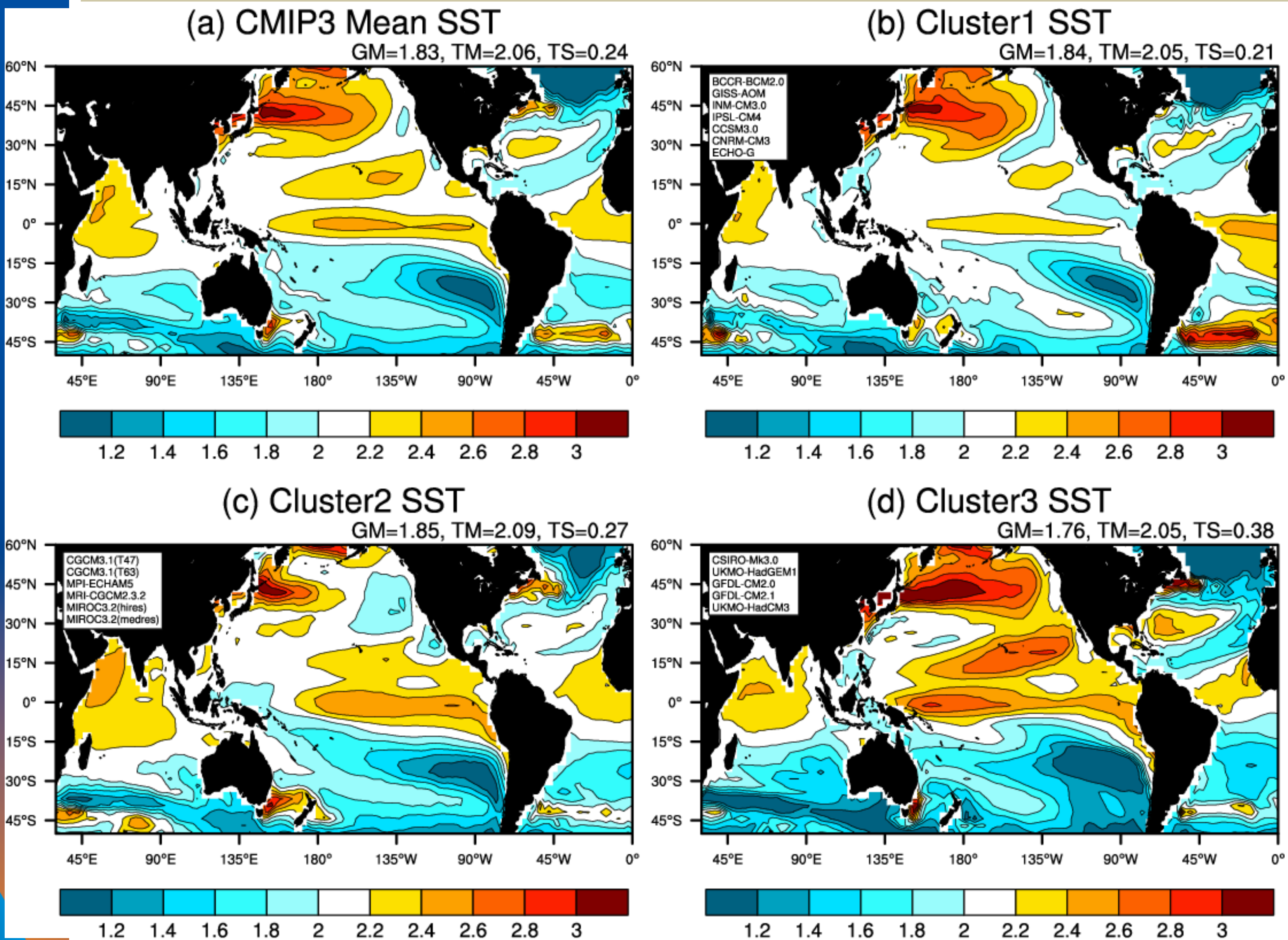
Multi-model & Multi-SST Ensemble Projections

15 multi-SST and multi-physics ensemble experiments were conducted for the 21st future projections.

Model Version	Resolution	Cumulus	CMIP3 Mean SST	Cluster 1 SST	Cluster 2 SST	Cluster 3 SST
MRI-AGCM 3.1	20km	AS	×			
	60km		×			
MRI-AGCM 3.2	20km	YS	×			
	60km		×	×	×	×
	60km	KF	×	×	×	×
	60km	AS	×	×	×	×

AS: Arakawa-Schubert Scheme
YS: Yoshimura (new) Scheme
KF: Kain-Fritsch Scheme

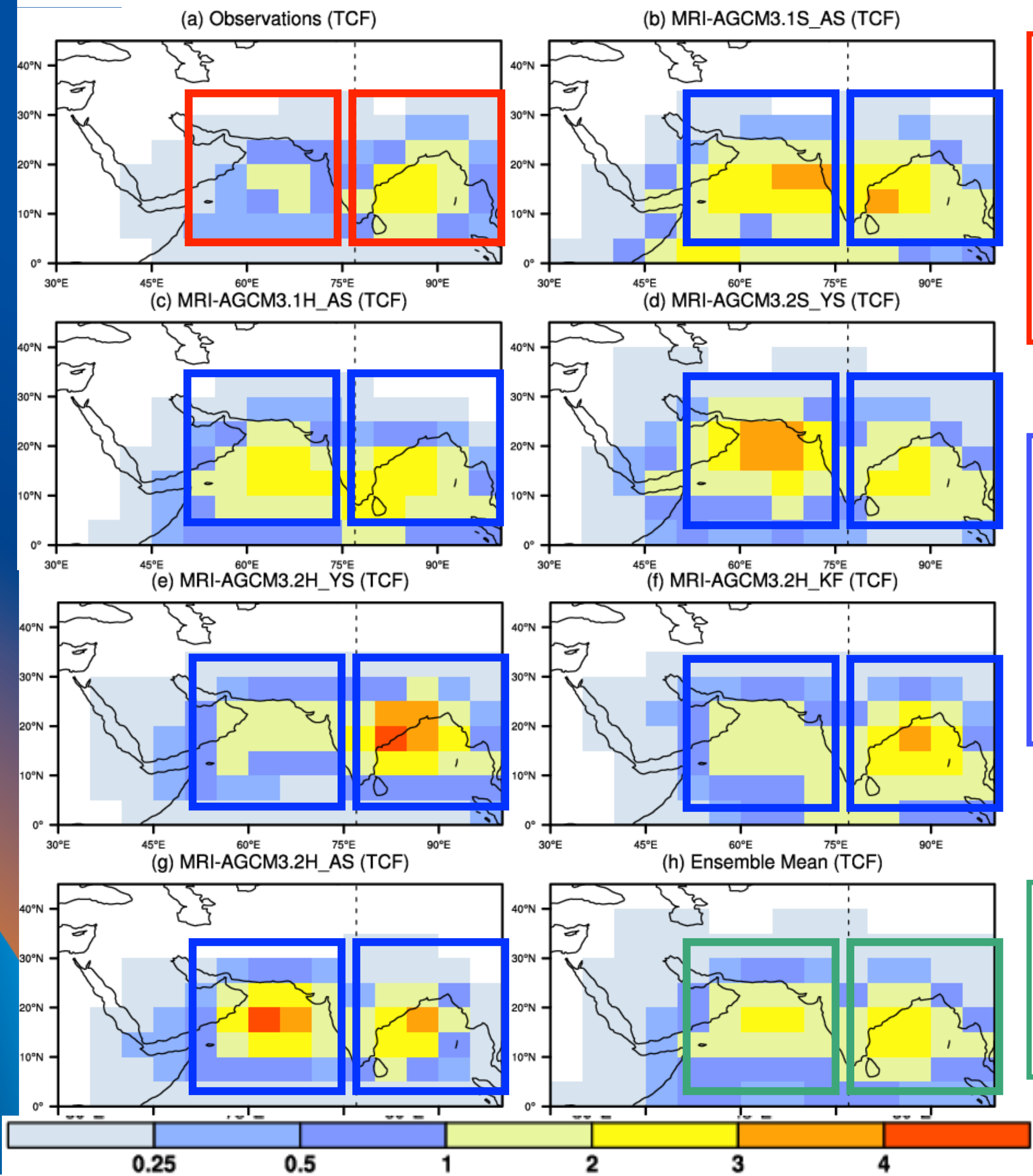
Multi-SST Ensemble Projections using 60-km-mesh model



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

Performance of Present-day Simulations

TC frequency (TCF) counted for each 5x5 degree box.



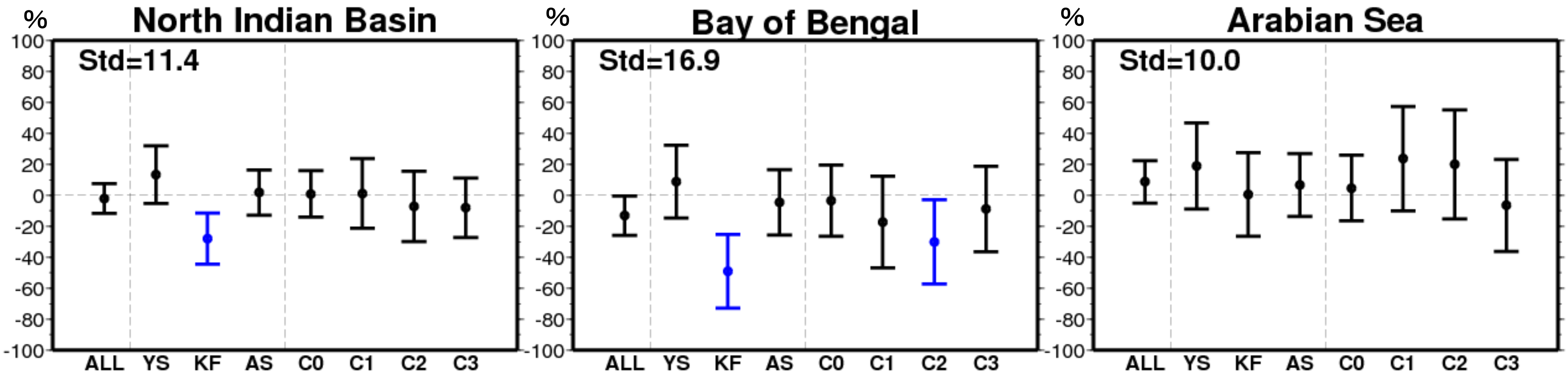
The observations show two spatial peaks (ARB and BOB in NIO) and spatial contrast in TCF, with larger values in BOB than in ARB.

The simulated TCFs also show the spatial peaks; however, some models show larger TCF in ARB than in BOB, which differs from observations.

The ensemble mean shows a reasonable TCF distribution in NIO and an overestimate in ARB.

Future changes in TC number [%] over the North Indian Ocean

Error bar indicates 99% confidence interval. Blue shows statistically significance.



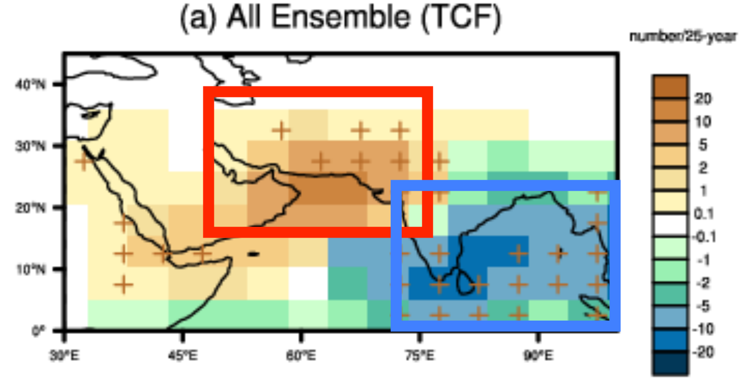
<u>All ensemble mean</u>

<u>Physical ensemble mean</u>
YS: Yoshimura scheme,
KF: Kain-Fritsch scheme,
AS: Arakawa-Shubert scheme

<u>SST ensemble mean</u>
C0: CMIP3 Mean SST,
C1: Cluster 1 SST,
C2: Cluster 2 SST,
C3: Cluster 3 SST

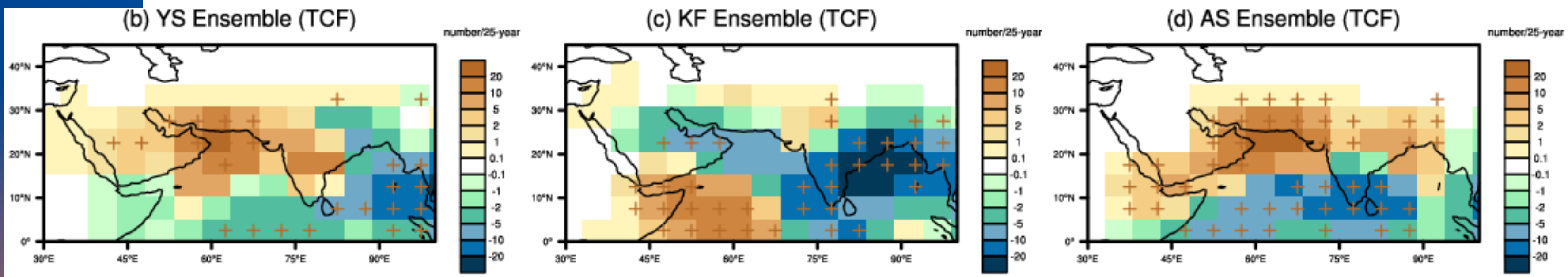
Generally, insignificant changes in TC number.
Uncertainty in physical process is larger than that in SST.

Future changes in TC frequency

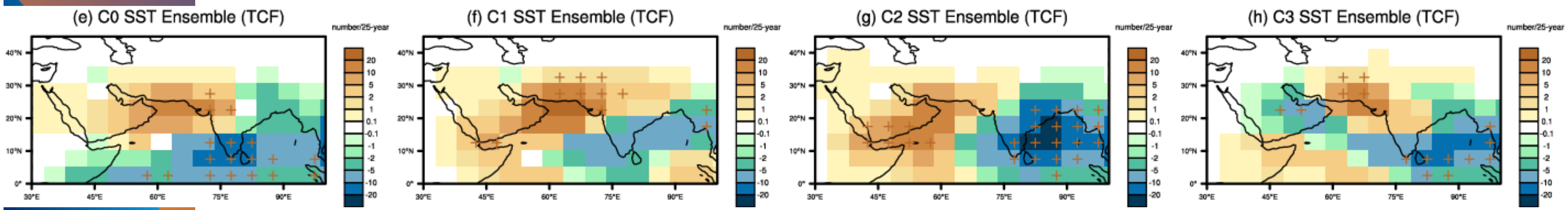


Plus symbol indicates that the difference is statistically significant at the 99 % confidence level or above and more than 80% experiments show the same sign of the mean change.

Consistent increase in Arabian Sea and reduction in Bay of Bengal.

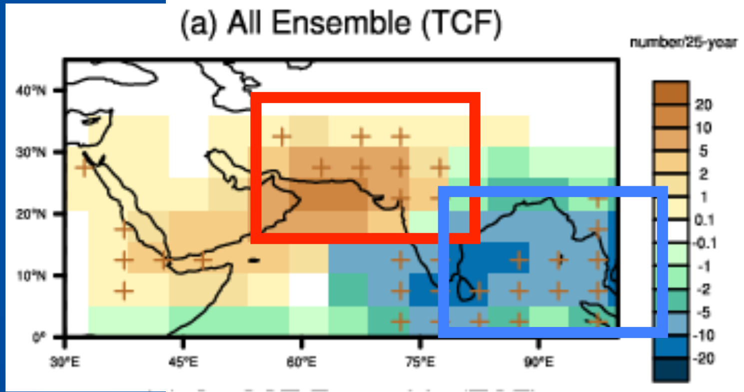


#Cumulus convection difference is sensitive



#SST difference is not sensitive

Analysis of TC Frequency

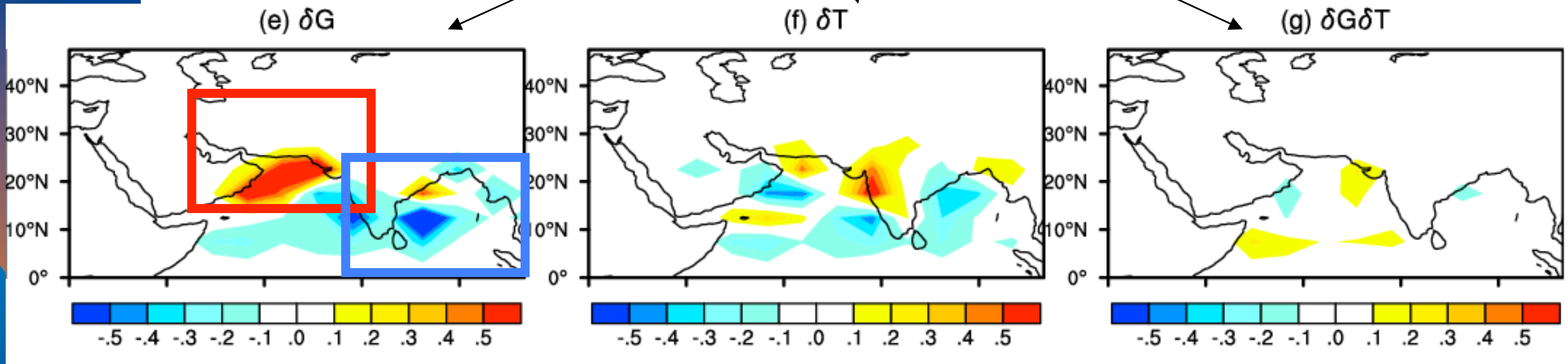


$$TCF(A) = \iint g(A_0)t(A, A_0)dA_0,$$

where A is a grid cell, $g(A_0)$ indicates TC genesis frequency on the grid cell of A_0, $t(A,A_0)$ is the probability of TC generated on A_0 travels to A.

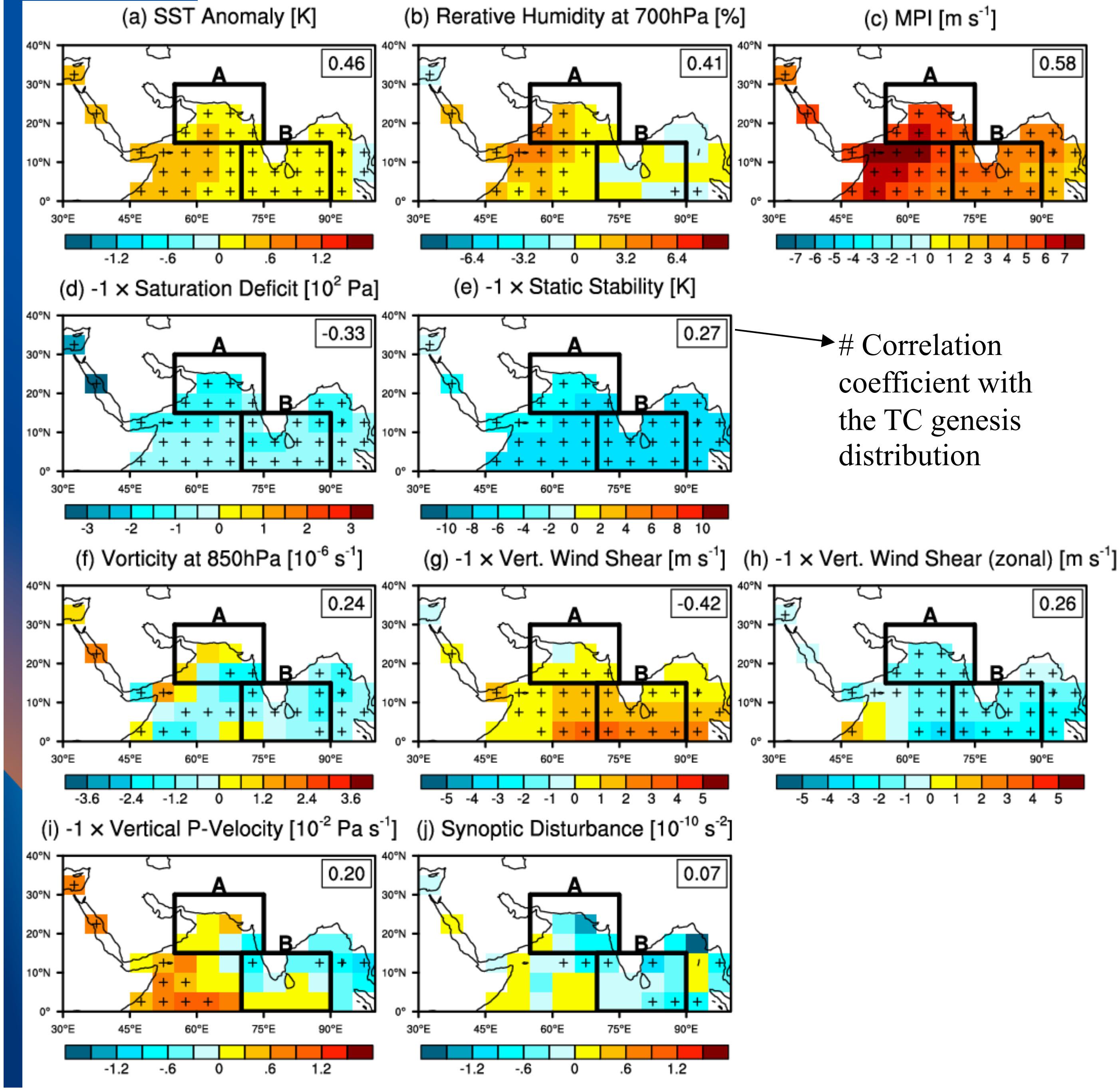
The TCF change can be decomposed into genesis and track factors.

$$\Delta TCF(A) = \Delta G \times T + G \times \Delta T + \Delta G \Delta T$$



<u>TC genesis factor is responsible for TCF changes both in Arabian Sea and Bay of Bengal.</u>

Factors responsible for TC genesis changes



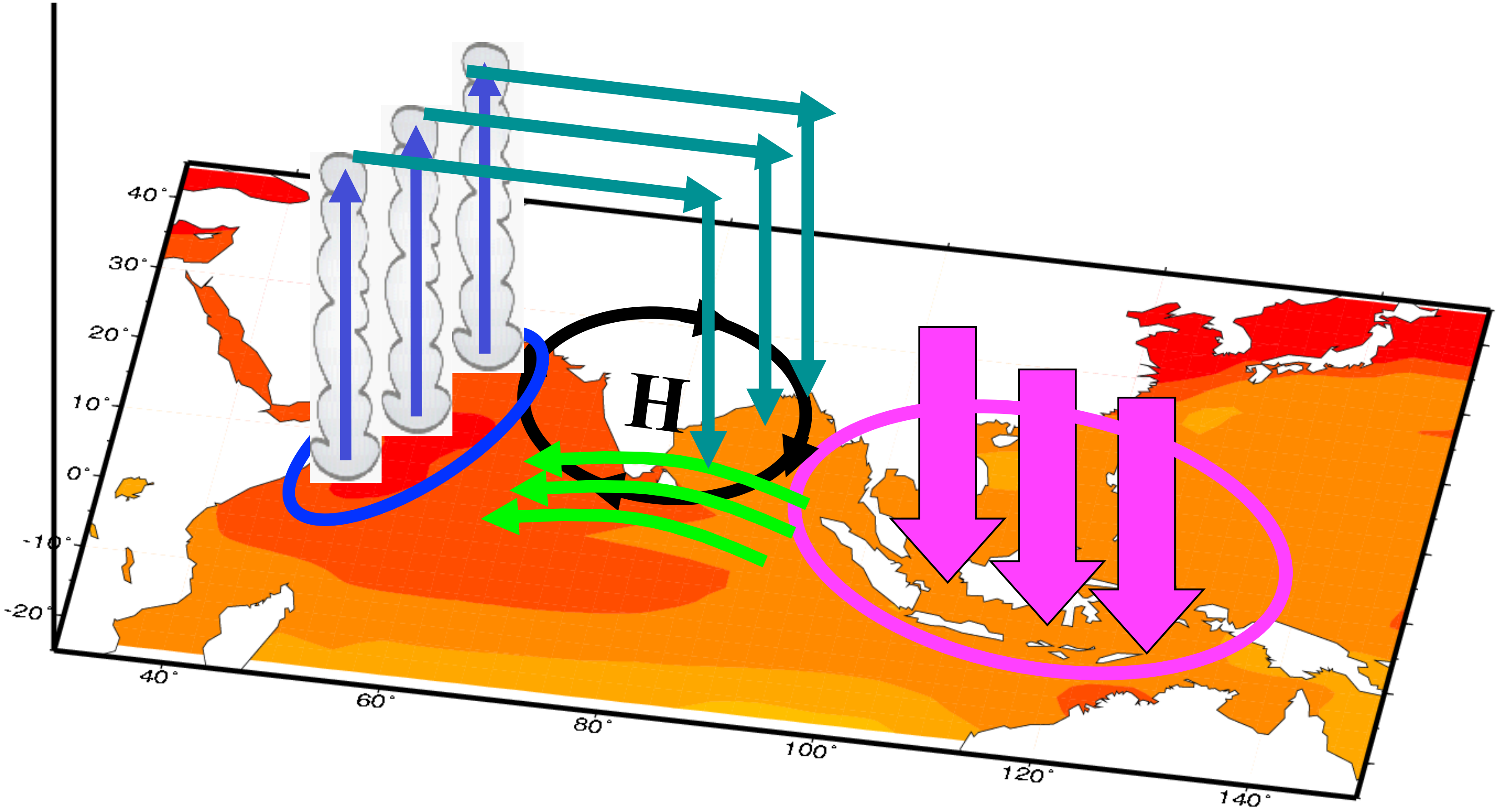
Correlation coefficient with the TC genesis distribution

Thermo-dynamic factors are responsible for TC genesis changes.

Dynamical factors are of secondary importance for TC genesis changes.

Interpretation for the future changes in TC activity in NIO

1. Projected weakening of Pacific Walker circulation.
2. Anti-cyclonic anomaly over NIO due to the Rossby-wave response.
3. Decrease in vertical wind shear and easterly shear.
4. SST increases largely in ARB, leading to enhancement of convection.
5. Local overturning circulation may cause subsidence over BOB.



Conclusion (I; Global)

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, WNP, South Indian Ocean, and South Pacific Ocean, whereas they suggest pronounced increase in the Central Pacific.

(c) A significant increase in the frequency of intense TCs with global warming occurs.

Conclusion (II; North Indian)

We have conducted multi-SST and multi-physics experiments for addressing future changes in TC activity in the North Indian Ocean (NIO).

(a) Future ensemble projections suggest insignificant changes in TC genesis number in NIO.

(b) Future projections suggest significant and robust increase (decrease) in TC frequency over the Arabian Sea (Bay of Bengal).

(c) The changes of TC frequency are caused mainly by those of TC genesis frequency rather than TC tracks.

(d) Future changes in large-scale thermo-dynamic factors (i.e., relative humidity and maximum potential intensity) appear to be the main influence on TC genesis change in NIO.

Reference

Murakami, H., and co-authors, 2011: Future changes in tropical cyclone activity projected by the new high-resolution MRI-AGCM. *J. Climate,* In press.

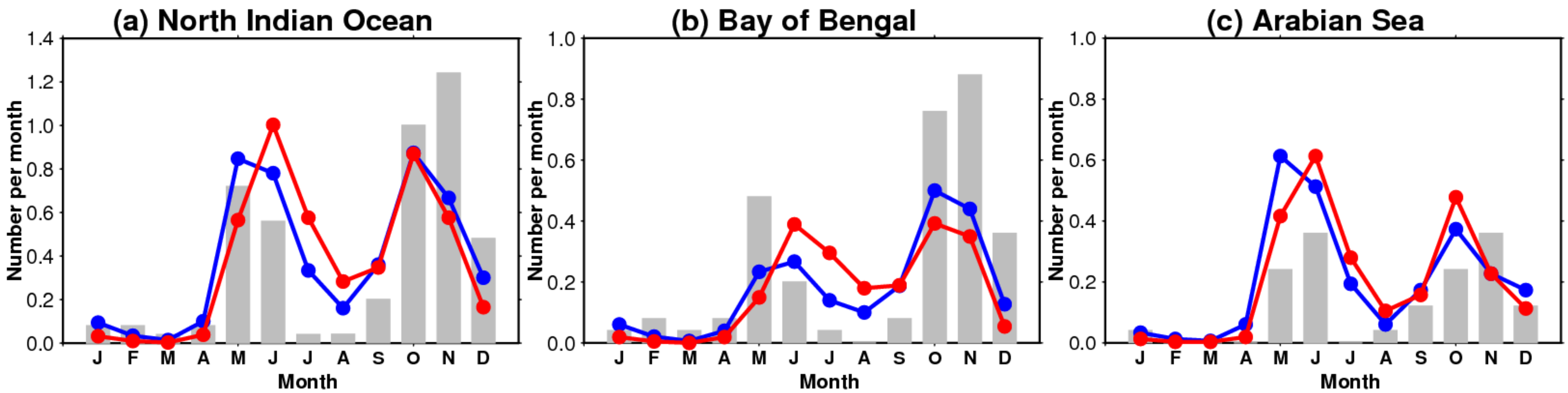
Murakami, H., R. Mizuta, and E. Shindo, 2011: Future changes in tropical cyclone activity projected by multi-physics and multi-SST ensemble experiments using 60-km mesh MRI-AGCM. *Clim. Dyn.* In press.

Murakami, H., B. Wang, and A. Kitoh, 2011: Future change of western North Pacific typhoons: Projections by a 20-km-mesh global atmospheric model. *J. Climate*, **24**, 1154–1169.

Murakami, H., and B. Wang, 2010: Future change of North Atlantic tropical cyclone tracks: Projection by a 20-km-mesh global atmospheric model. *J. Climate*, **23**, 2699–2721.

Murakami, H. and M. Sugi, 2010: Effect of model resolution on tropical cyclone climate projections. *SOLA*, **6**, 73–76.

Seasonal Cycle of Tropical Cyclone Number



Observations (25-yr, 1979-2003)

Ensemble mean of present-day experiments. (25-yr, 1979-2003)

Ensemble mean of future experiments (25-yr, 1979-2003)

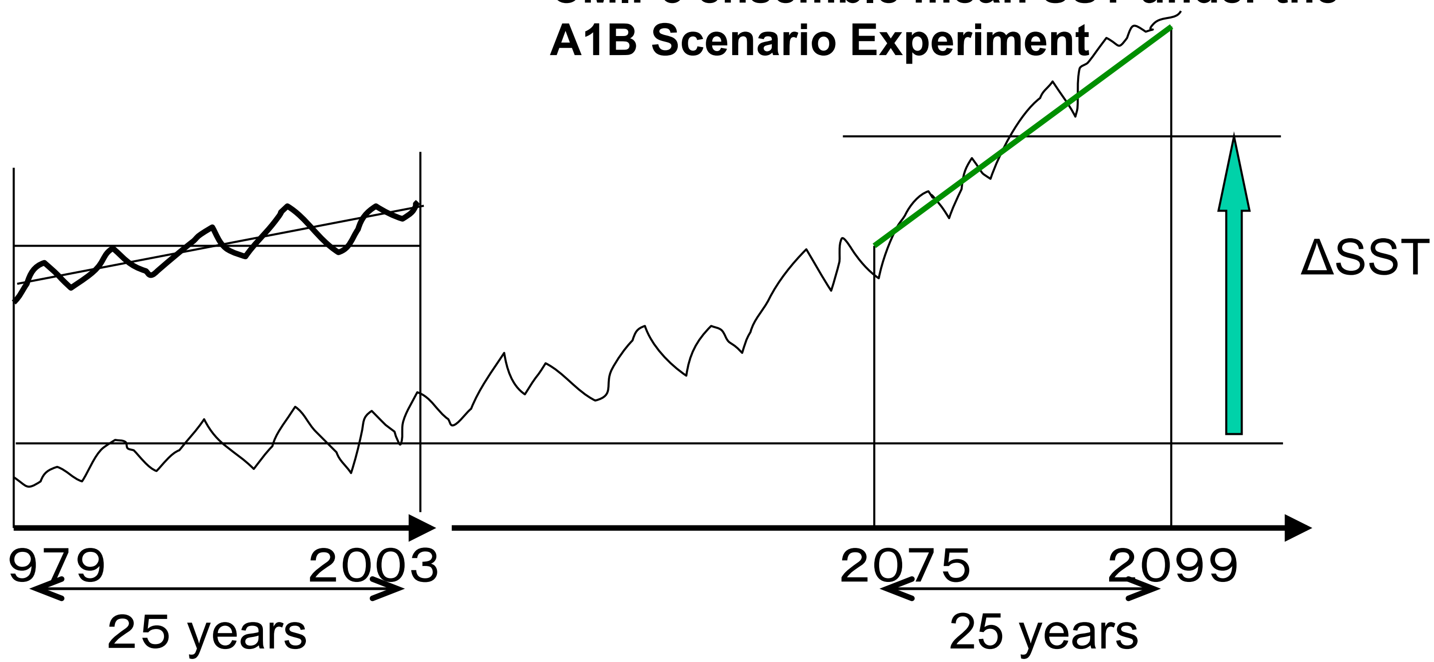
How to prescribe future SST

Mizuta et.al (2008)

Present SST

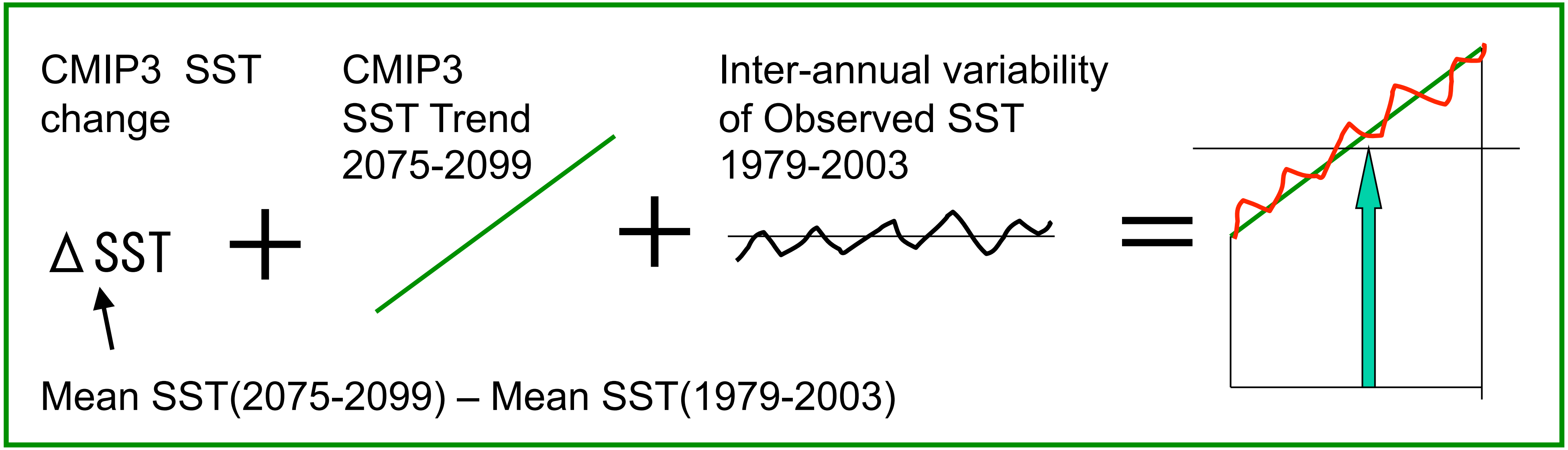
Observed SST
1979～2003

AR4_20thCentury
Exp. SST -2001



Future SST

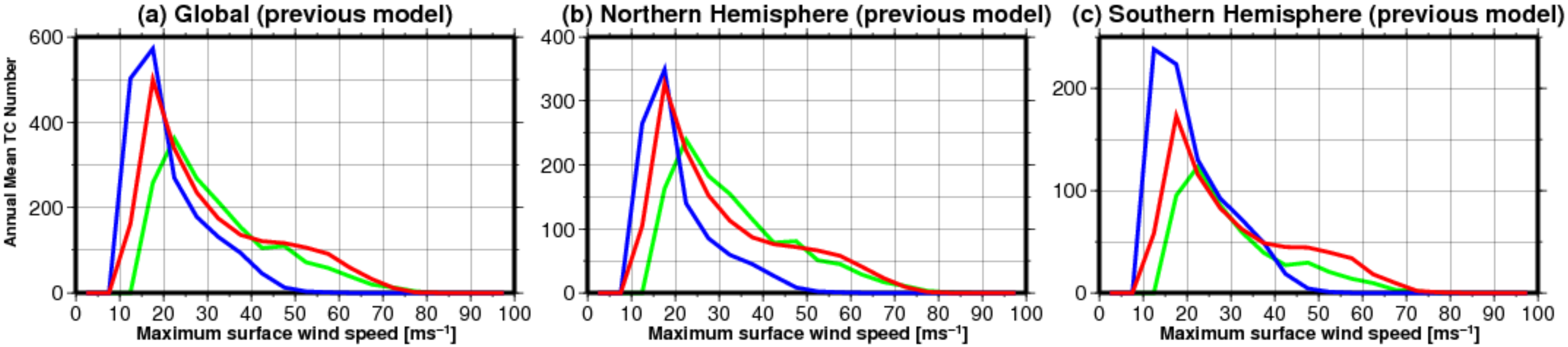
also applies for 2015-2039



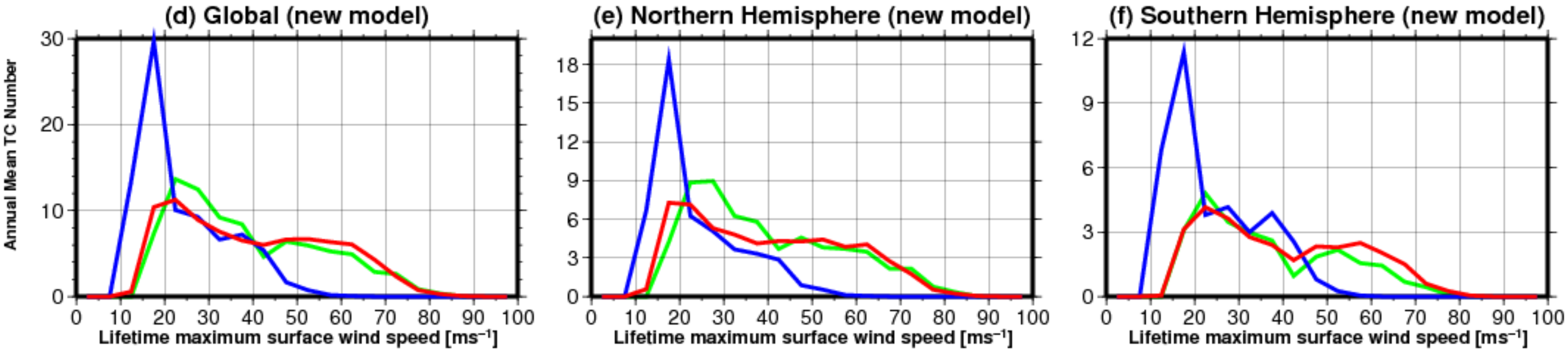
Comparison of TC intensity between versions

Observations (25-yr, 1979-2003)
Previous version (25-yr, 1979-2003)
New version (25-yr, 1979-2003)

Annual mean TC frequency

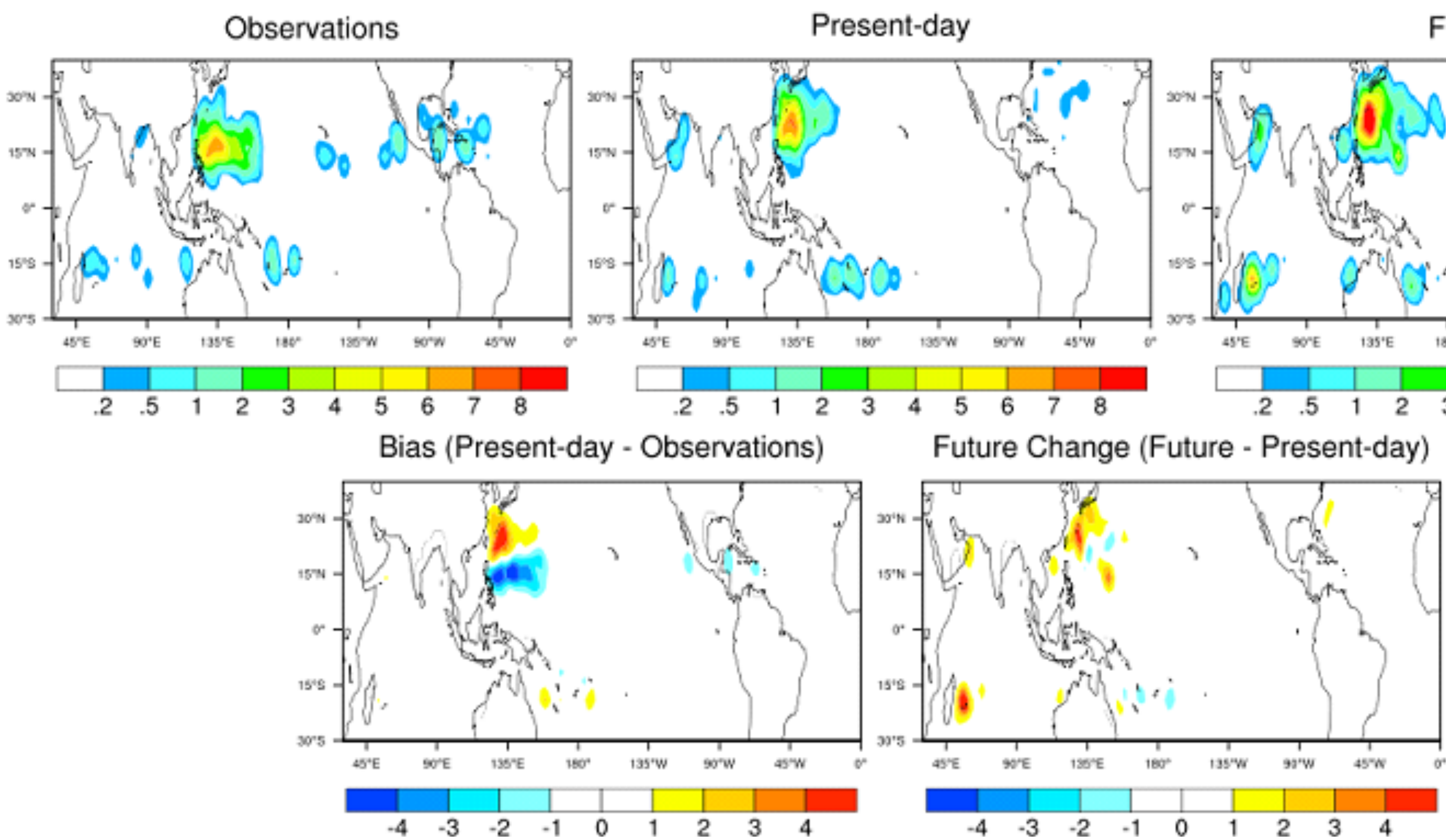


Annual mean TC number for the lifetime maximum wind speed



·TC intensity is substantially improved in the new version.

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.