Future changes in tropical cyclone activity projected by multi-physics and multi-SST ensemble experiments using the 60-km-mesh MRI-AGCM

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Reference:

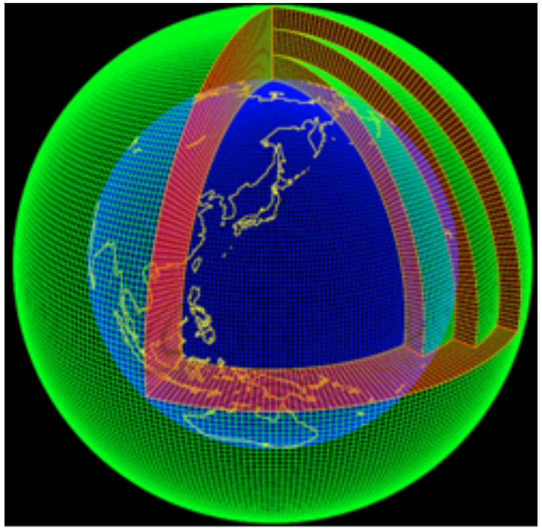
Murakami H., R. Mizuta, and E. Shindo, 2011: Future changes in tropical cyclone activity projected by multi-physics and multi-SST ensemble experiments using the 60-km- mesh MRI-AGCM. *Clim. Dyn.*, In press

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

Japan Agency for Marine-Earth Science and Technology (JAMSTEC), and Meteorological Research Institute

Outline

- Review of previous studies on projected future changes in tropical cyclones (TCs)
- Methodology for multi-physics and multi-SST ensemble experiments
- Results
- Summary



20 km-mesh grids

Review of impact of global warming on TC activities

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Tropical cyclones and climate change

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

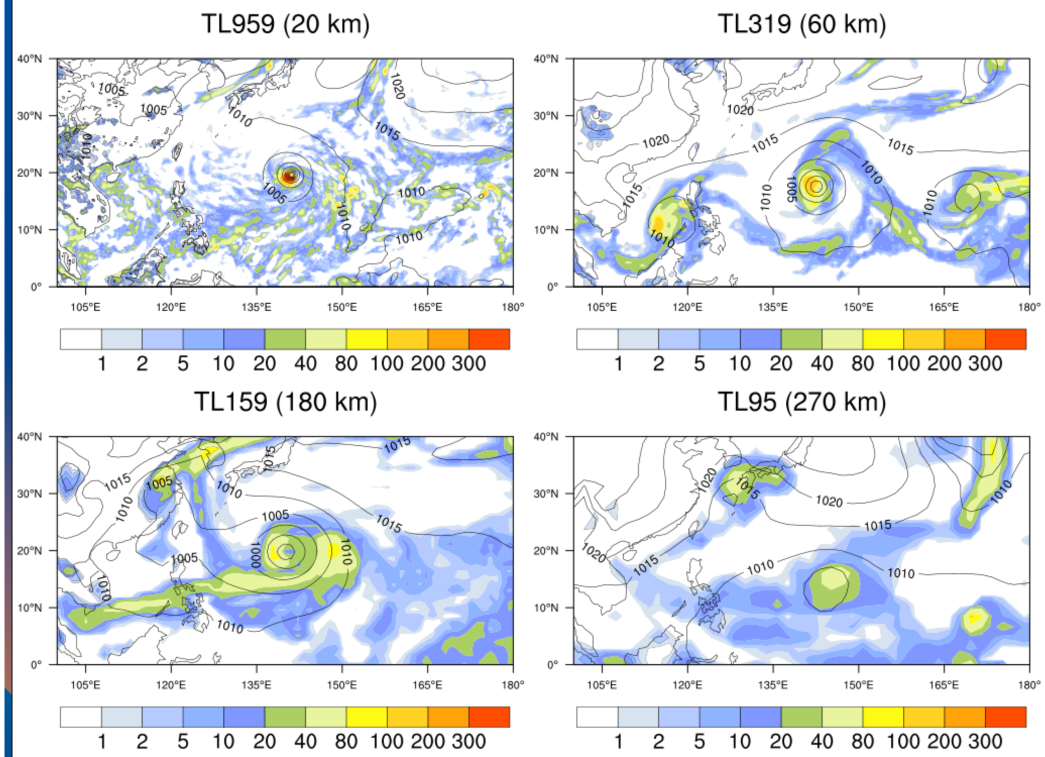
1. **Consistent results** (consensus)
   - A reduced frequency of global TCs
   - A future increase in frequency of intense TCs
2. **Inconsistent results** (uncertainty)
   - Difference in projected future changes in TC frequency in a specific ocean basin

     Among 14 previous numerical studies, 5 indicated an increase in the North Atlantic, while 9 reported a decreasing frequency (Murakami and Wang, 2010)

This inconsistency among projections arises from a number of factors, including differences in assumed spatial patterns of future changes in sea surface temperature (SST; Sugi et al. 2009; Zhao et al. 2009), differences in model physical parameterisations (Walsh et al. 2010), differences in the chosen global warming scenario (Stowasser et al. 2007), and differences in the methods used to detect TCs (Walsh et al. 2007).

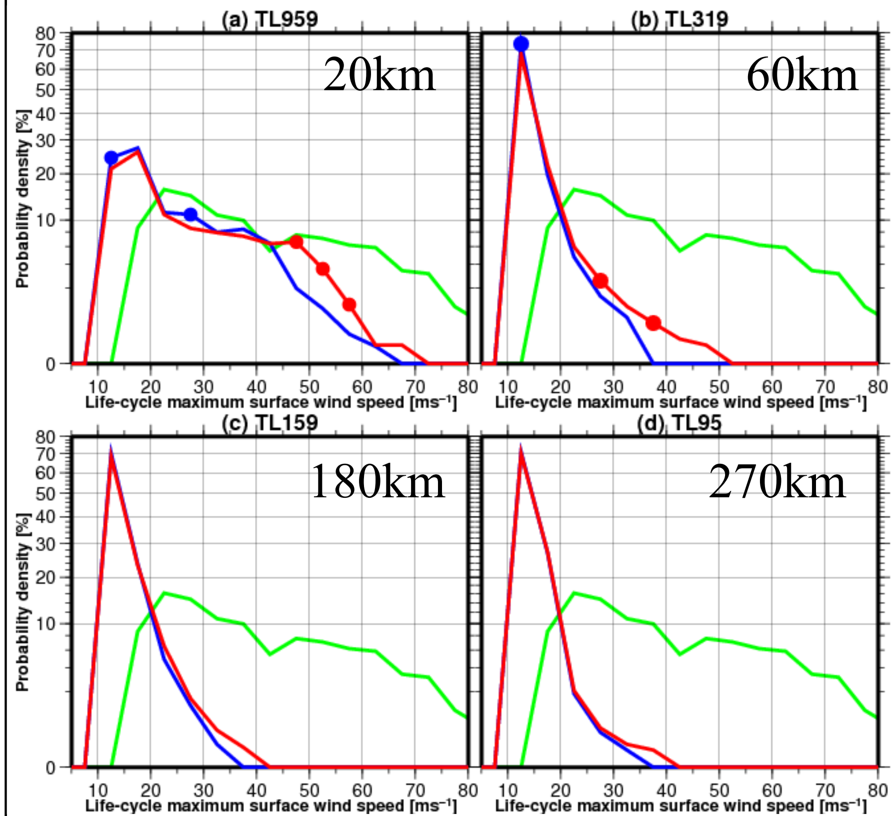
Why do we need a high resolution model?

·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 structures.</u>

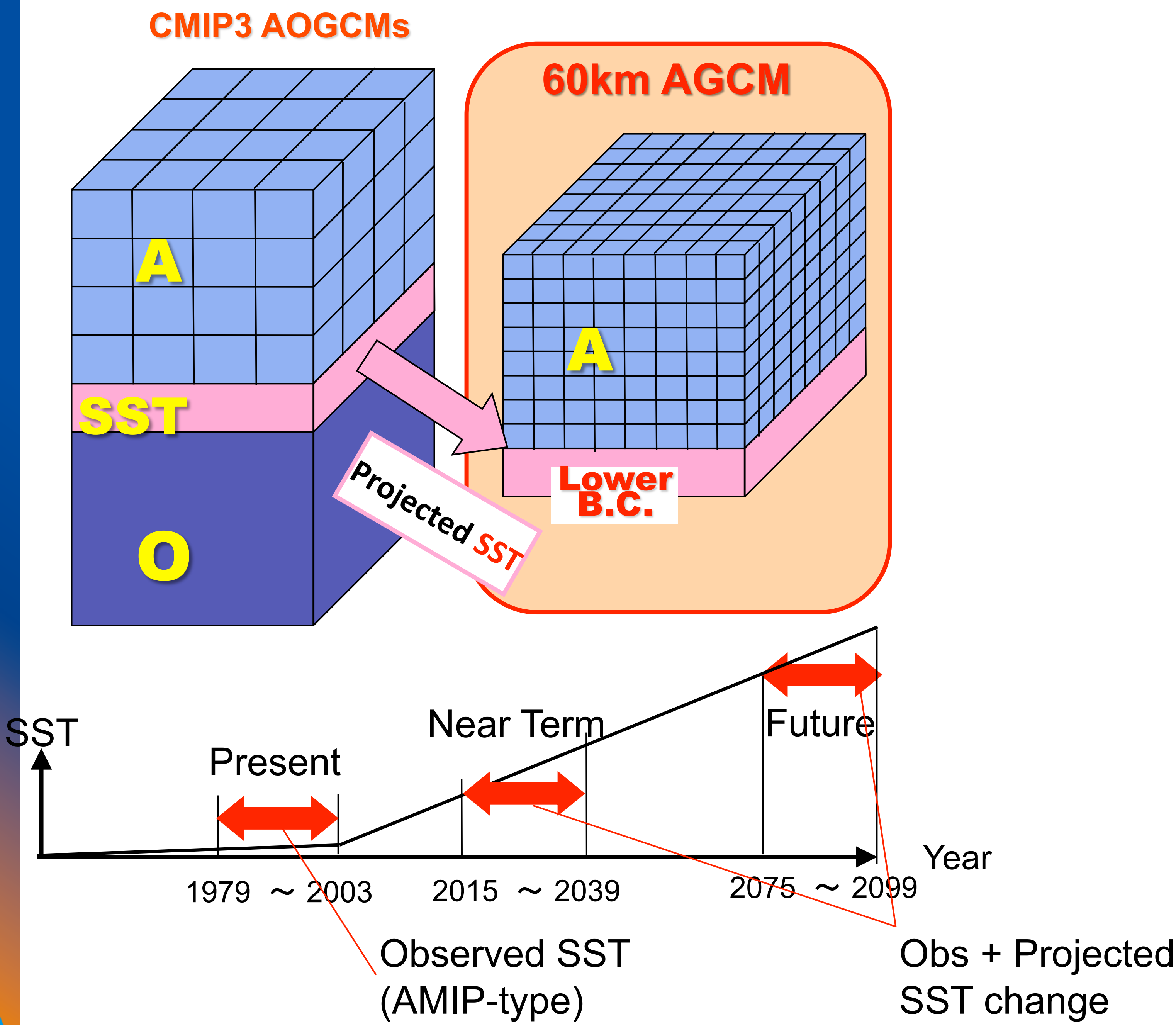
·Only models finer than 60 km-mesh show future increase in intense TCs (Knutson et al. 2010; Murakami and Sugi, 2010).



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

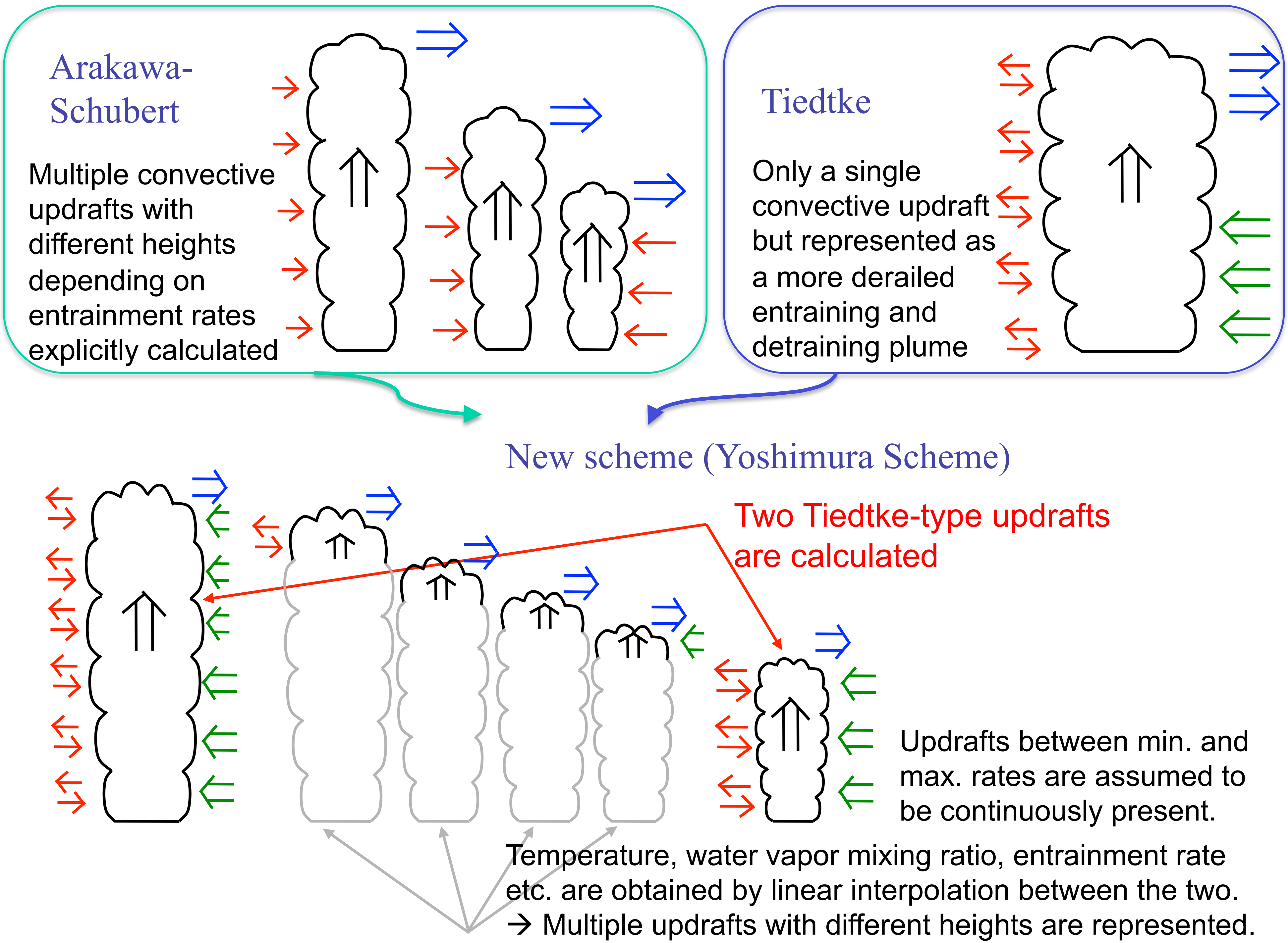
Multi-physics and multi-SST future projections

Time Slice Experiments



Three types of physics used for multi-physics exp.

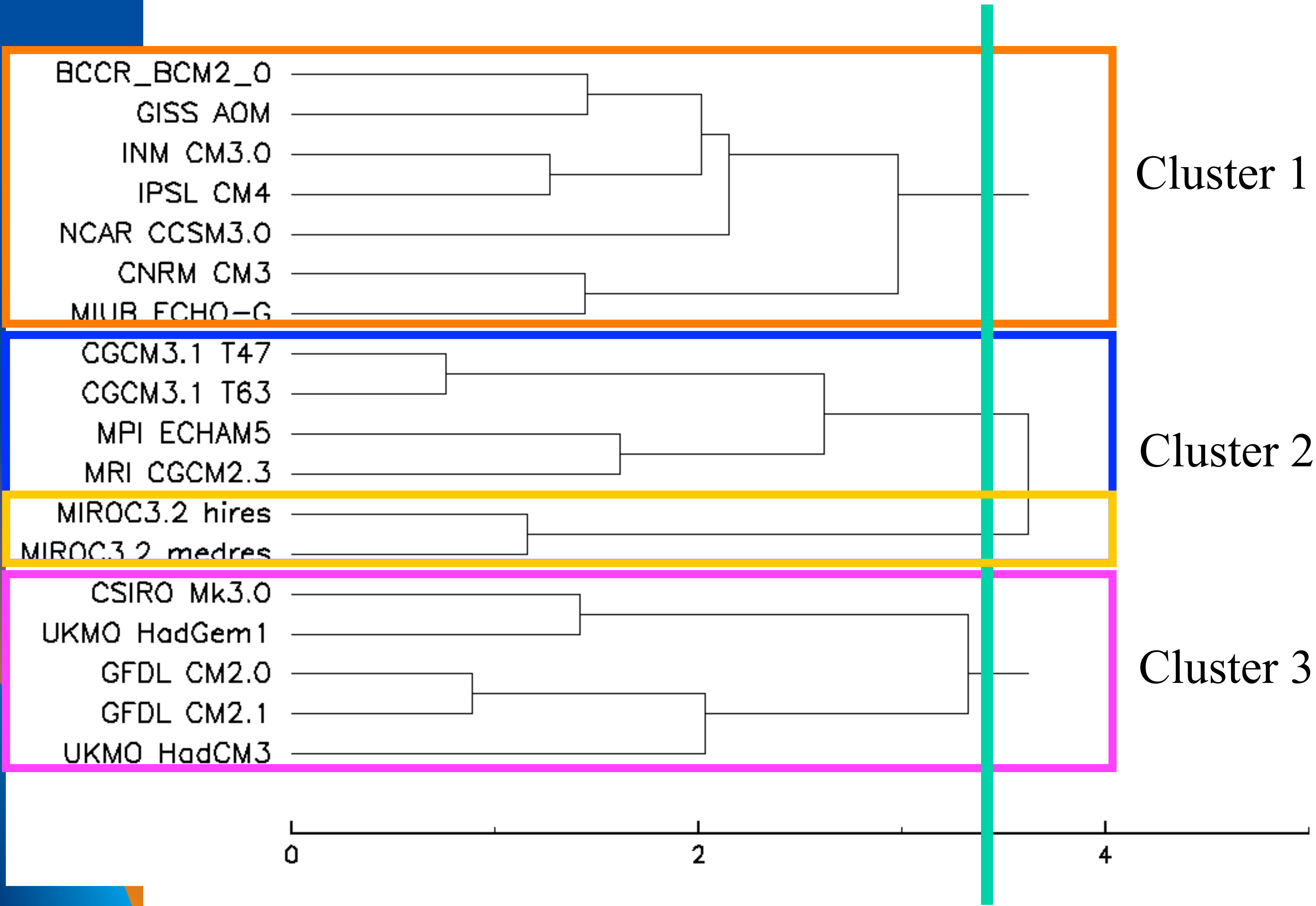
	MRI-AGCM 3.2 AS	MRI-AGCM 3.2 KF	MRI-AGCM 3.2 YS
Horizontal resolution	T_L319 (60km)		
Vertical resolution	64 levels (top at 0.01hPa)		
Time integration	Semi-Lagrangian		
Time step	20 minutes		
Cumulus convection	Prognostic Arakara-Schubert	Kain-Fritsch	Yoshimura (Tiedtke-based)
Cloud	Tiedtke (1993)		
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		


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)
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.

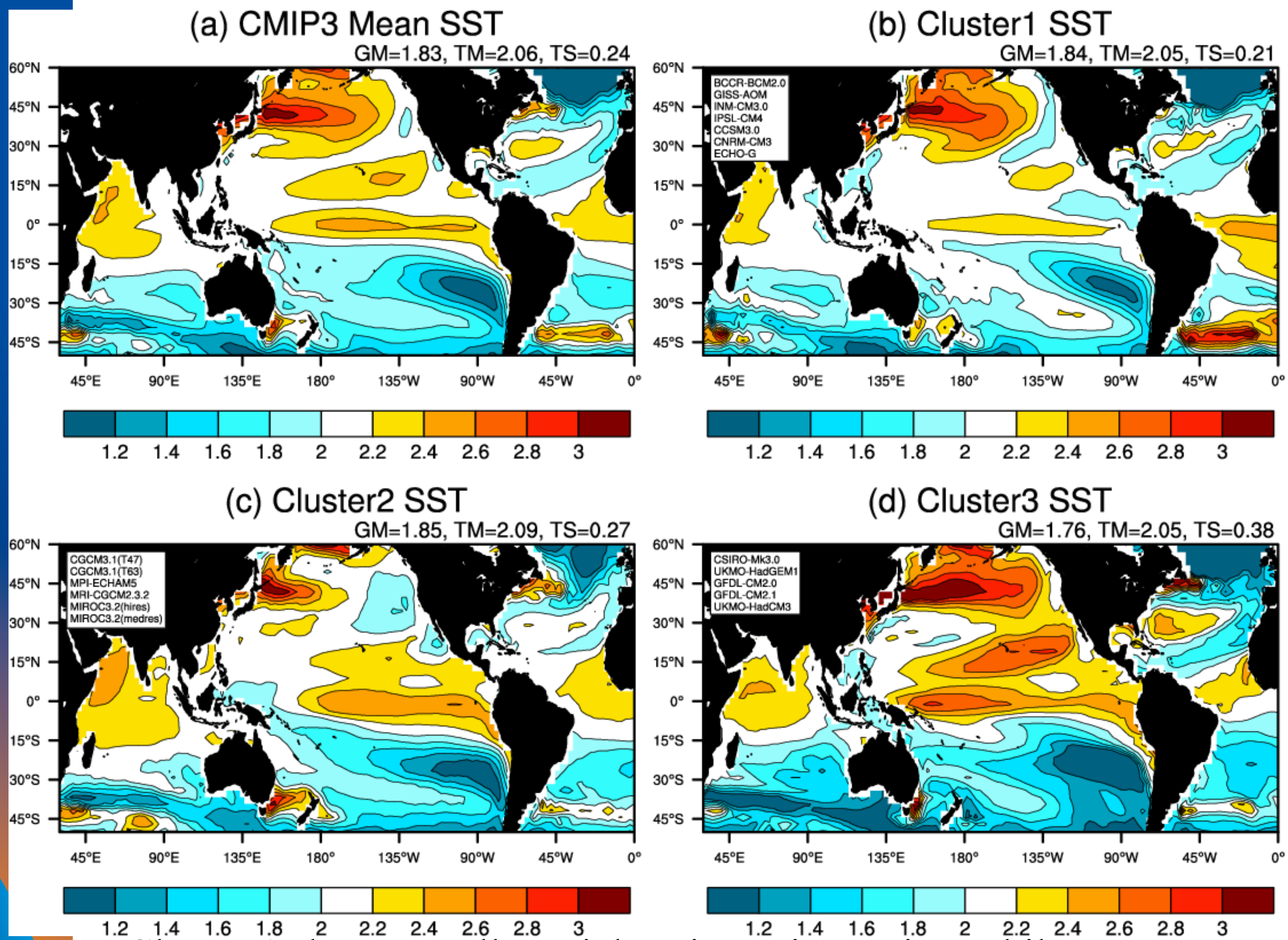
Multi-SST Ensemble Projections using 60-km-mesh model

1) For each CMIP3 model, a mean future change in SST is computed by subtracting the 1979-2003 mean SST from the 2075-2099 mean SST.
2) The computed mean future change in SST is normalised by dividing by the tropical mean (30°S-30°N) future change in SST.
3) The normalised value for each model is subtracted from the multi-model ensemble mean of the normalised value.
4) The inter-model pattern correlation r of the normalised values is computed between each pair of models.
5) Norms (or distances) are defined as $2 \times (1 - r)$ for each model, and the cluster analysis is performed using these norms.
6) When the final three groups are bounded, the clustering procedure is terminated.

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



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



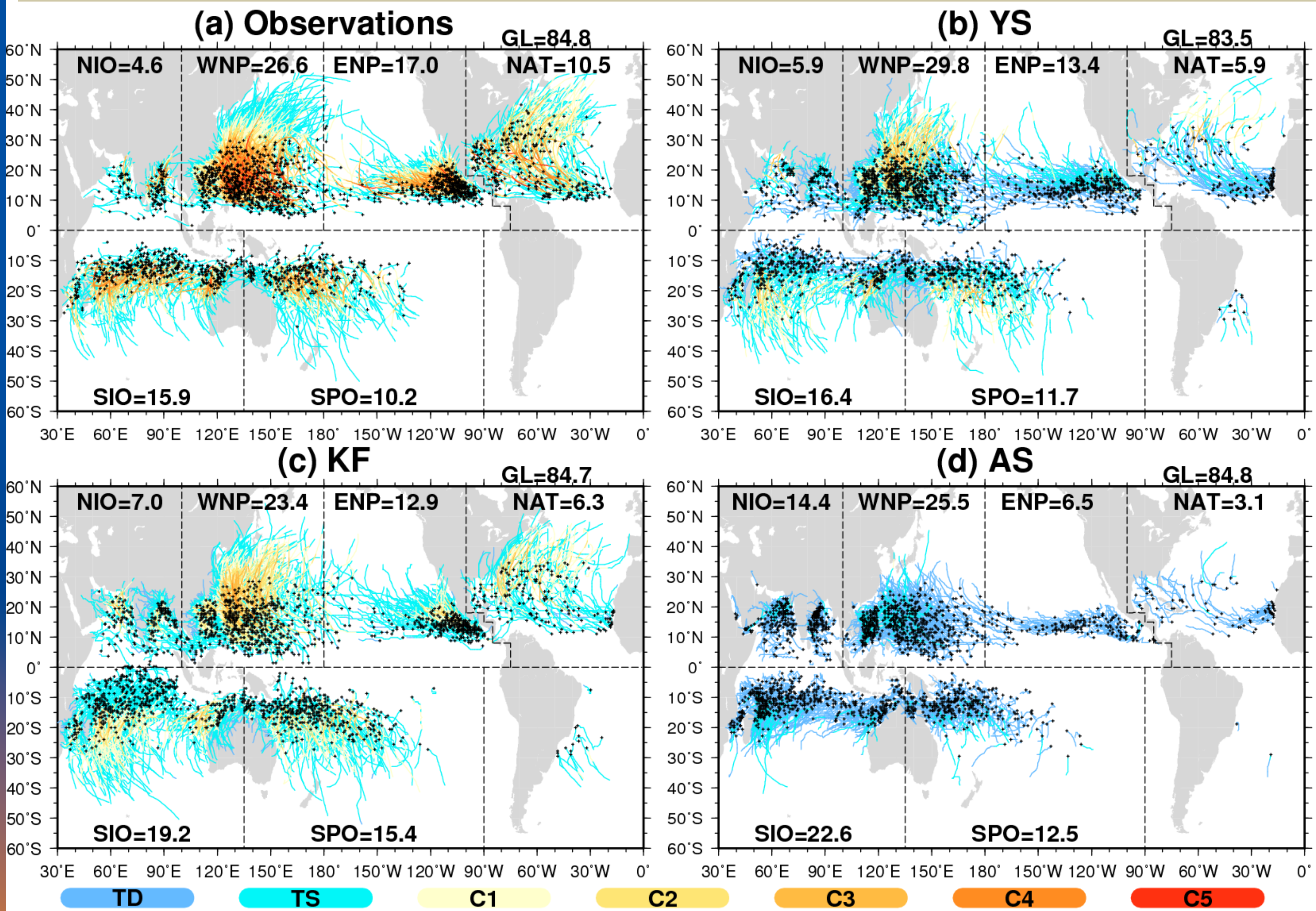
Cluster 1 shows small spatial variance in tropics, while Cluster 3 SST shows large spatial variance in tropics.

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

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

Abbreviation	Cumulus Convection Scheme	Prescribed Future SST
Y0	Yoshimura Scheme (YS)	18 CMIP3 Models Ensemble Mean
Y1	Yoshimura Scheme (YS)	Cluster 1
Y2	Yoshimura Scheme (YS)	Cluster 2
Y3	Yoshimura Scheme (YS)	Cluster 3
K0	Kain-Fritsch Scheme (KF)	18 CMIP3 Models Ensemble Mean
K1	Kain-Fritsch Scheme (KF)	Cluster 1
K2	Kain-Fritsch Scheme (KF)	Cluster 2
K3	Kain-Fritsch Scheme (KF)	Cluster 3
A0	Arakawa-Shubert Scheme (AS)	18 CMIP3 Models Ensemble Mean
A1	Arakawa-Shubert Scheme (AS)	Cluster 1
A2	Arakawa-Shubert Scheme (AS)	Cluster 2
A3	Arakawa-Shubert Scheme (AS)	Cluster 3

Performance of control simulations

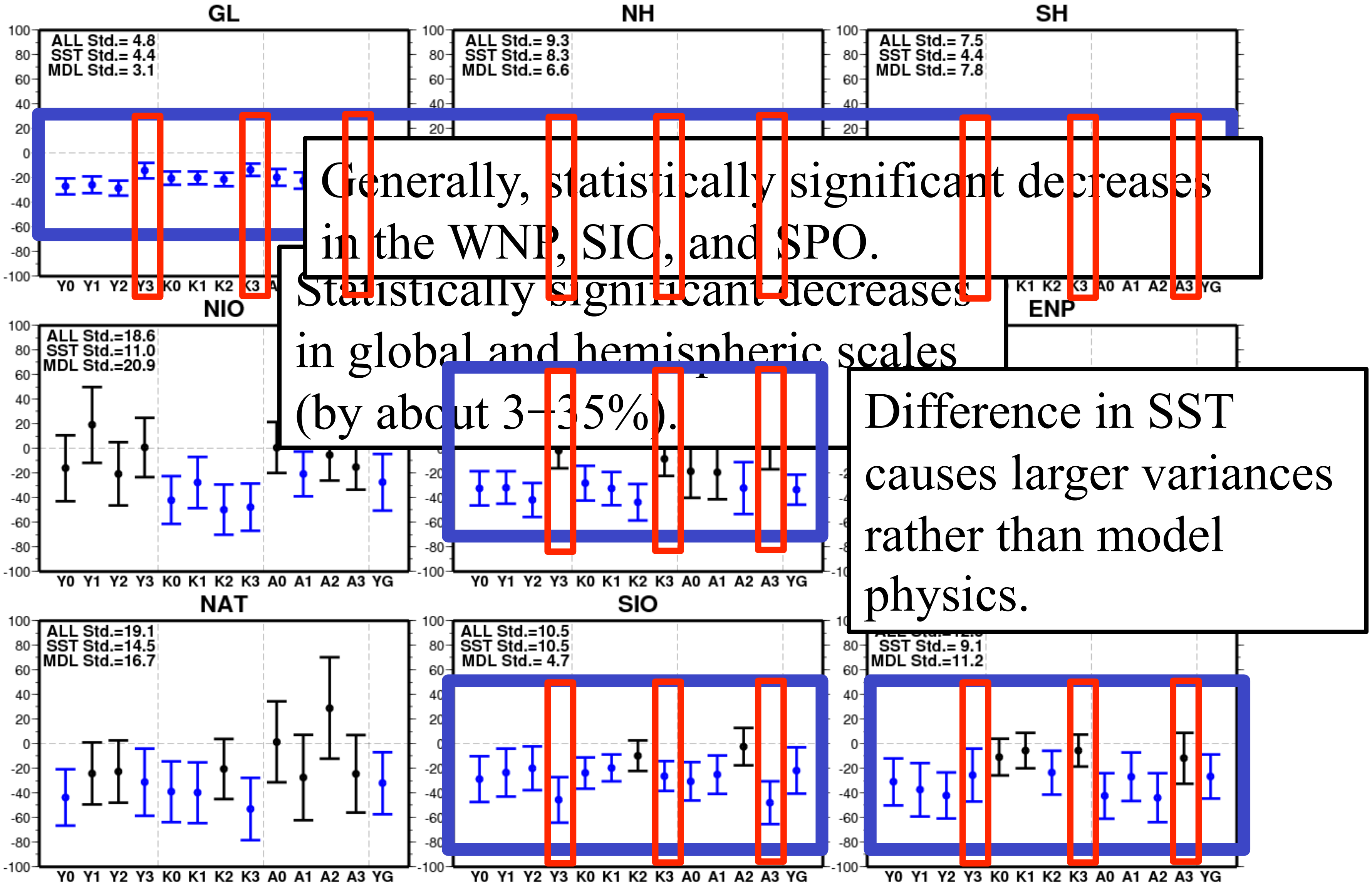


The YS and KF simulates reasonable TC global distribution, whereas AS has pronounced biases.

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

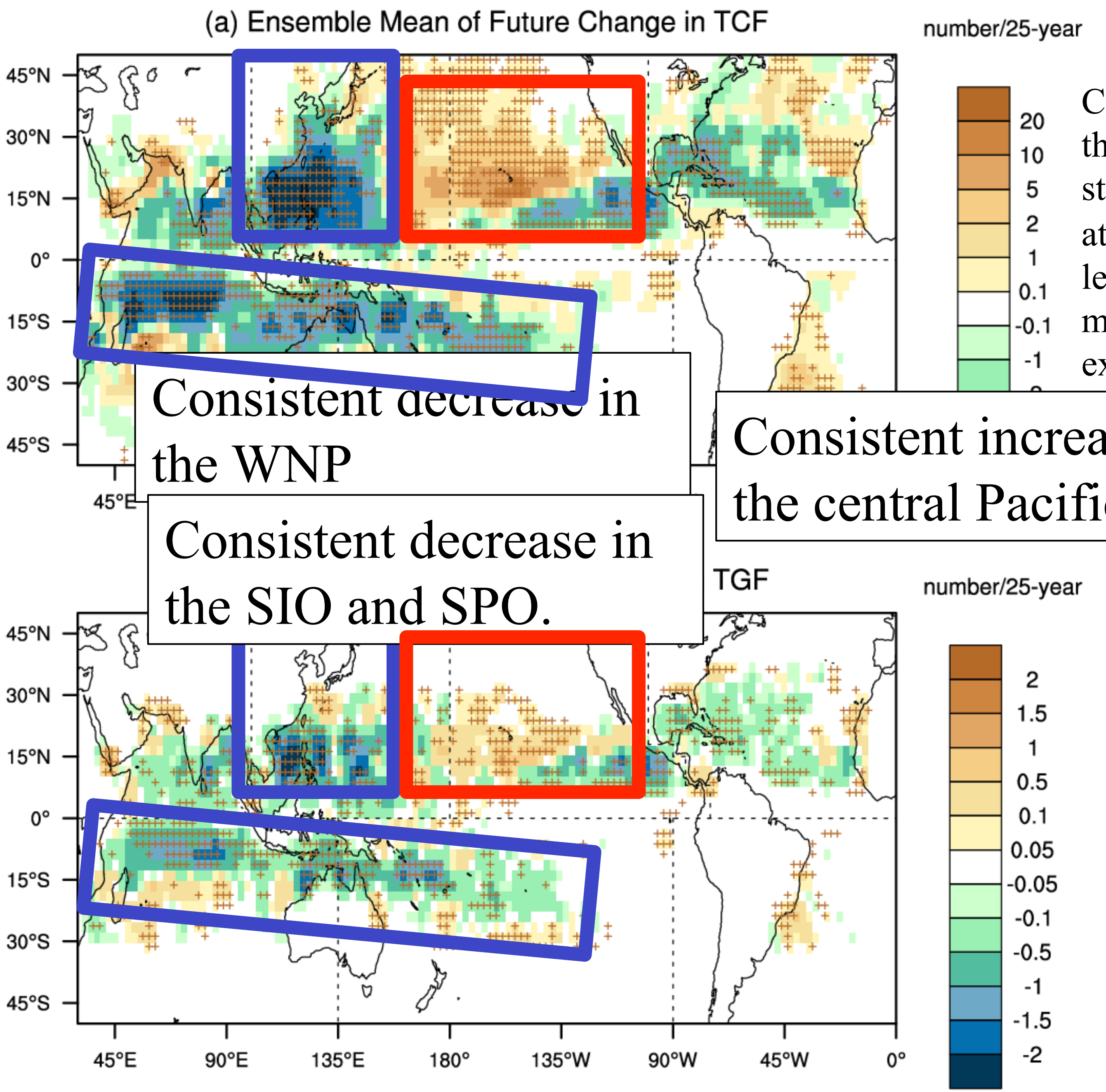


Generally, statistically significant decreases in the WNP, SIO, and SPO.

Statistically significant decreases in global and hemispheric scales (by about 3–35%).

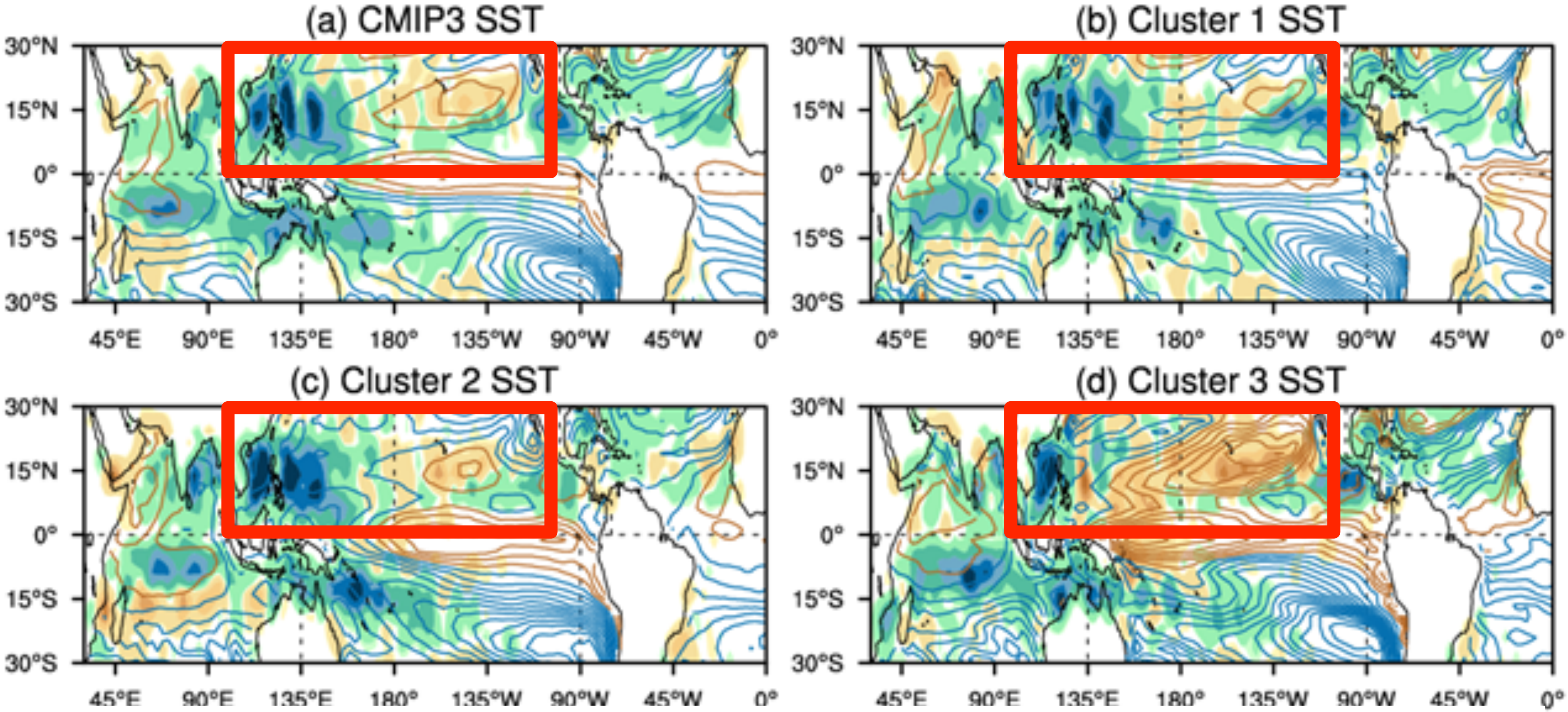
Difference in SST causes larger variances rather than model physics.

Future changes in TC frequency and genesis frequency



Cross mark indicates that the difference is statistically significant at the 90 % confidence level or above and more than 10 experiments show … n of … nge.

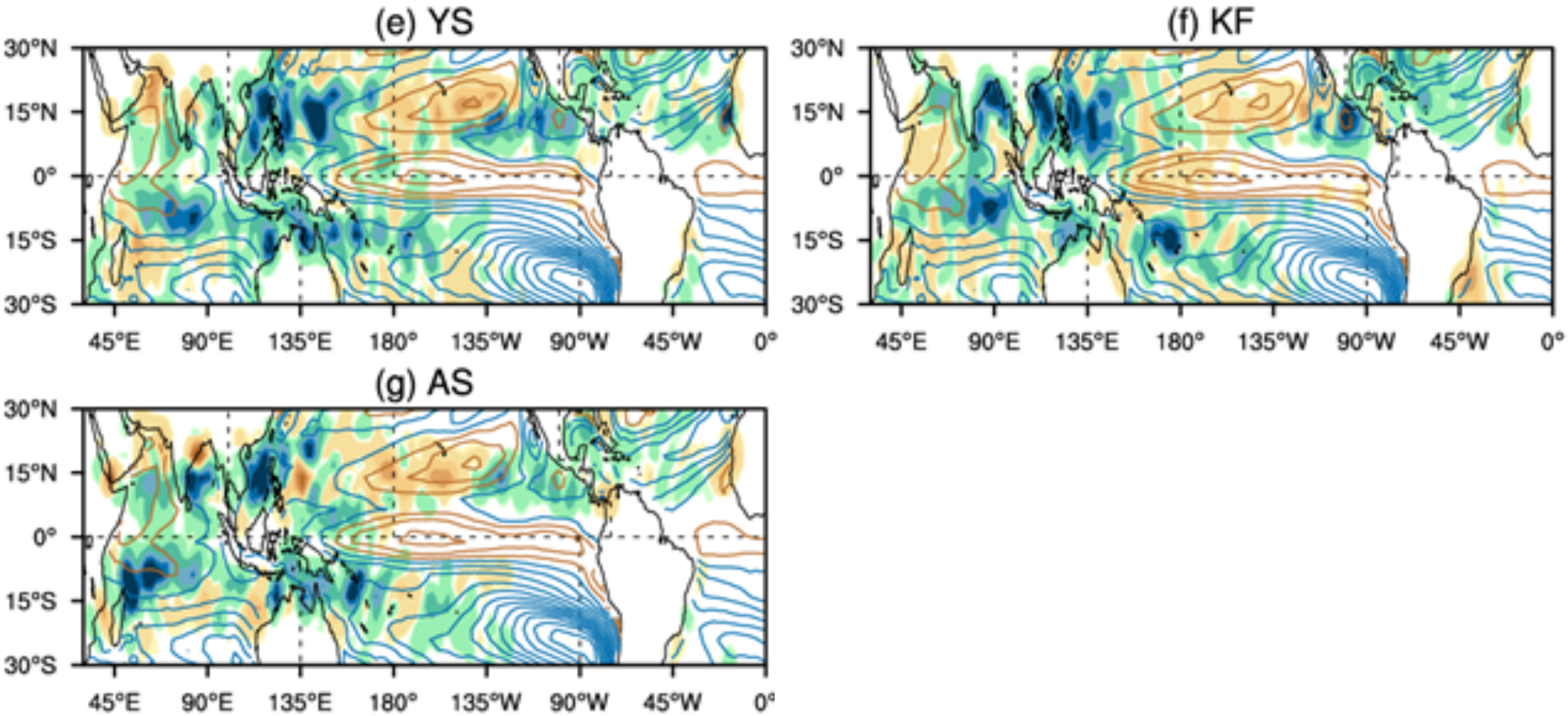
Future changes in TC frequency and genesis frequency



Ensemble mean future changes in tropical cyclone genesis frequency (TGF, shading) [number/25-year] and sea surface temperature anomaly (S_a, contours) [K] relative to tropical (30°S-30°N) mean.

Locations where S_a increases substantially show large increases in TGF as well.

Future changes in TC frequency and genesis frequency

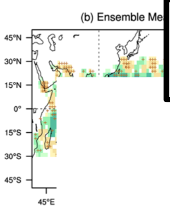


Ensemble mean future changes in tropical cyclone genesis frequency (TGF, shading) [number/25-year] and sea surface temperature anomaly (S_a, contours) [K] relative to tropical (30°S-30°N) mean.

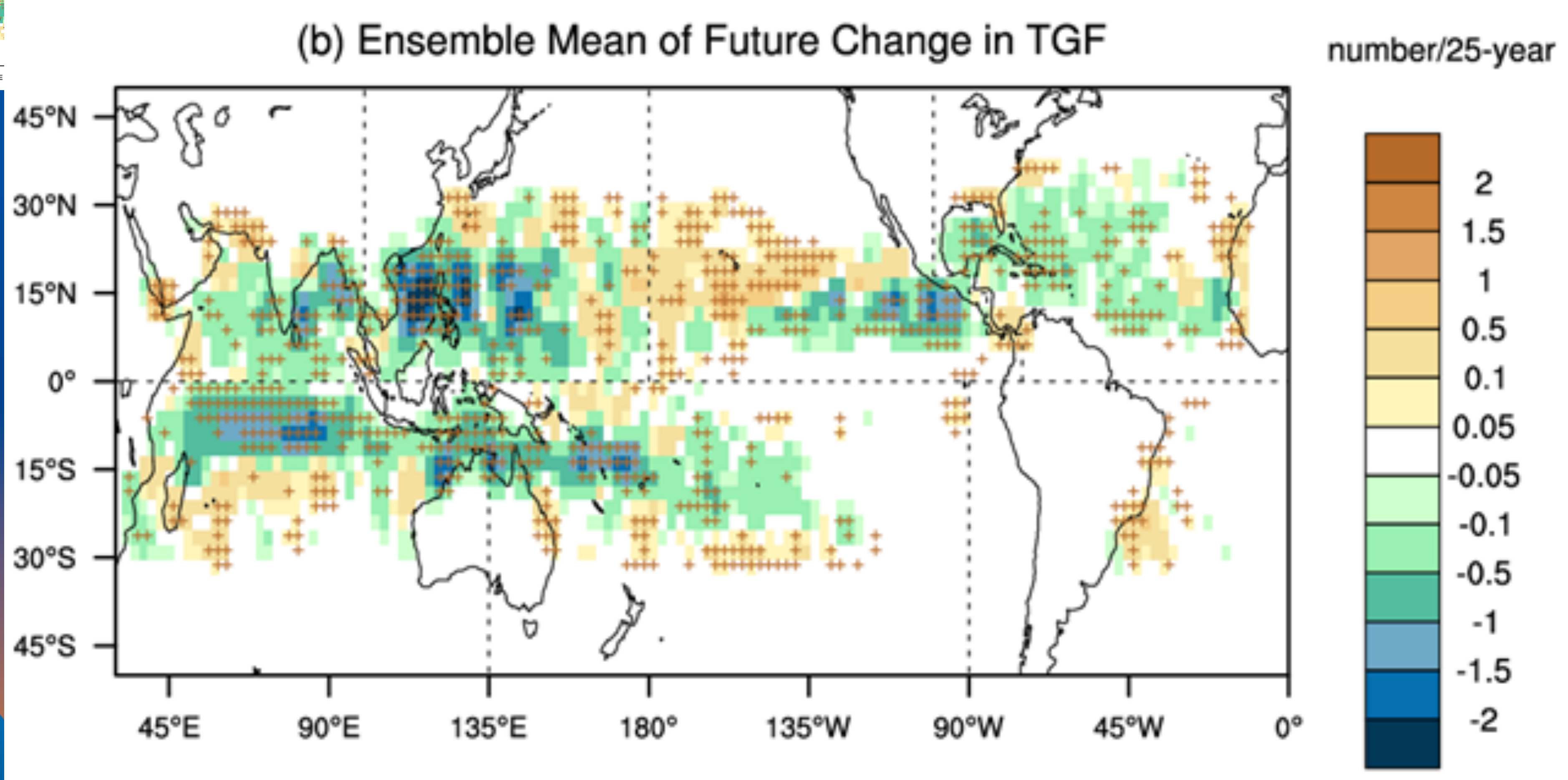
Projected future global changes in TGF are largely independent of the chosen cumulus convection scheme in the MRI-AGCM.

Future changes in TC frequency and genesis frequency

SST anomaly | Relative Humidity | Potential Intensity



What causes future changes in spatial distribution of TGF?



These parameters are more highly correlated in the WNP and ENP than the other basins, indicating TGF changes in these basins are sensitive to these parameters.

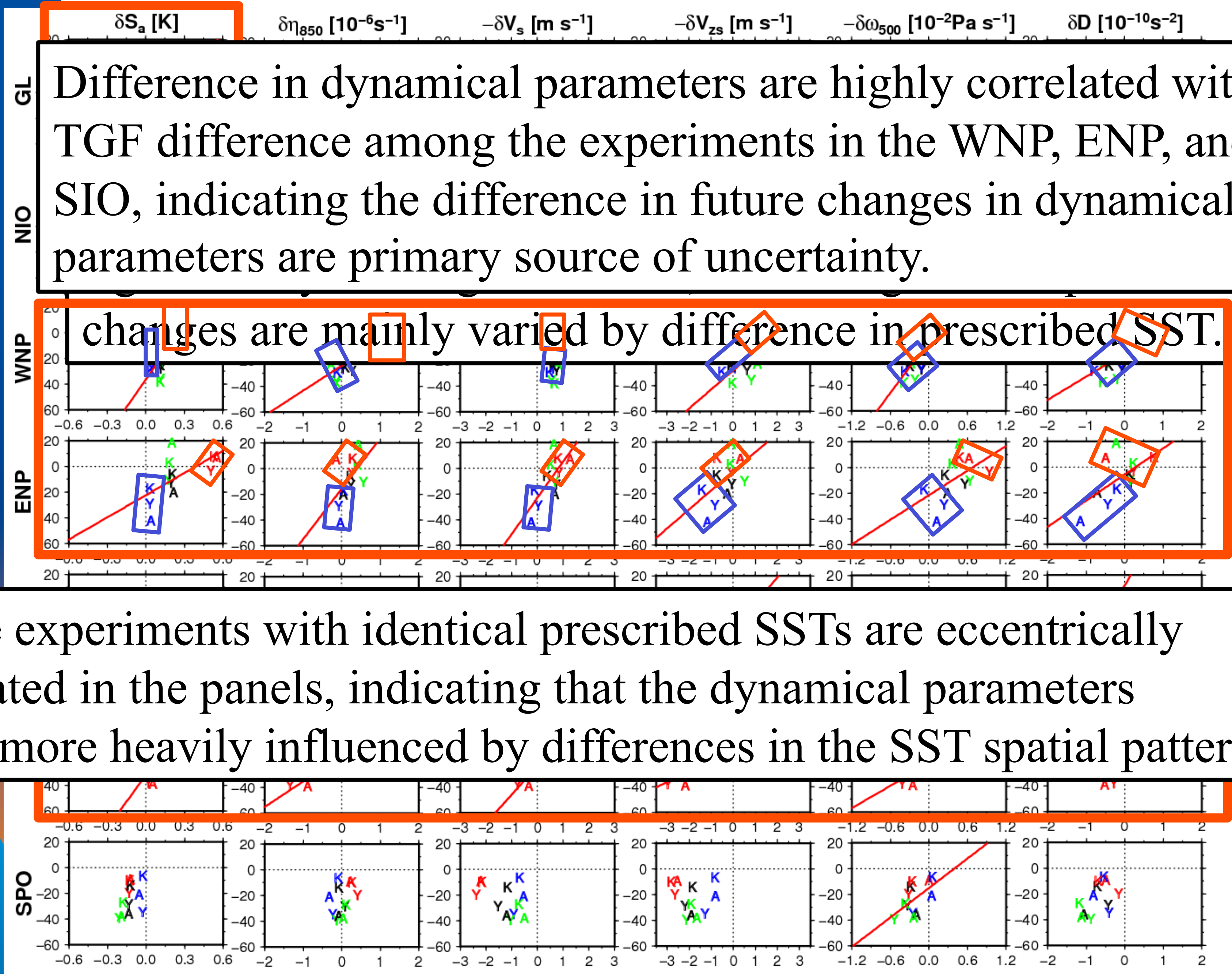
Factors responsible for Inter-experiment differences

	δS_a	δRH	δV_{pot}	$-\delta\chi$	$-\delta\Gamma_d$	$\delta\eta_{850}$	$-\delta V_s$	$-\delta V_{zs}$	$-\delta\omega_{500}$	δD
		Thermodynamic				Dynamic				
GL	**0.70**	-0.22	0.15	0.13	-0.66	0.22	-0.31	-0.28	-0.36	0.08
NH	**0.75**	0.24	**0.74**	0.41	-0.70	**0.53**	**0.69**	0.44	0.15	0.40
SH	0.47	-0.27	-0.06	-0.21	-0.04	**0.60**	**0.64**	0.43	**0.69**	-0.03
NIO	-0.48	0.33	0.31	0.40	-0.14	0.33	-0.81	0.44	-0.39	0.34
WNP	**0.66**	0.06	-0.06	0.23	-0.78	**0.78**	0.49	**0.68**	**0.63**	**0.61**
ENP	**0.64**	-0.00	**0.58**	-0.11	-0.43	**0.51**	**0.72**	**0.51**	**0.51**	**0.62**
NAT	-0.00	0.48	0.22	**0.59**	-0.65	0.43	0.41	**0.50**	-0.29	**0.78**
SIO	**0.71**	0.40	**0.50**	0.28	-0.47	**0.91**	**0.83**	**0.83**	**0.83**	0.40
SPO	0.45	-0.78	-0.21	-0.52	-0.31	0.35	-0.42	-0.10	**0.57**	0.43

Dynamic factors have high correlations, indicating these dynamic parameters are of primary importance for the inter-experimental differences.

Factors responsible for Inter-experiment differences

Y: YS, K: KF, A: AS, black: CMIP3 mean, blue:C1, green:C2, red:C3



Difference in dynamical parameters are highly correlated with TGF difference among the experiments in the WNP, ENP, and SIO, indicating the difference in future changes in dynamical parameters are primary source of uncertainty.

changes are mainly varied by difference in prescribed SST.

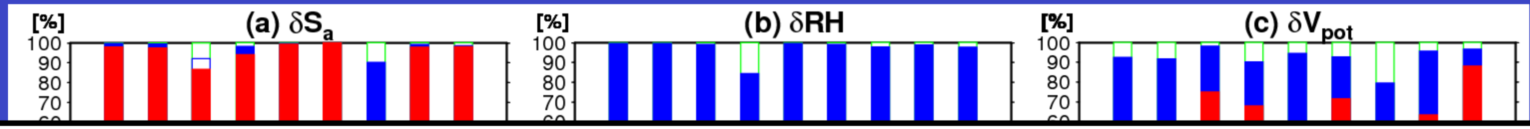
The experiments with identical prescribed SSTs are eccentrically located in the panels, indicating that the dynamical parameters are more heavily influenced by differences in the SST spatial patterns.

Responsible factor for inter-experimental variance

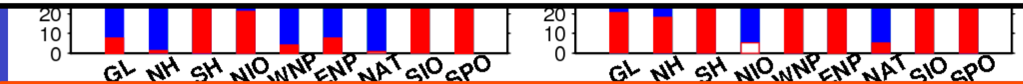
A two-way analysis of variance (ANOVA)

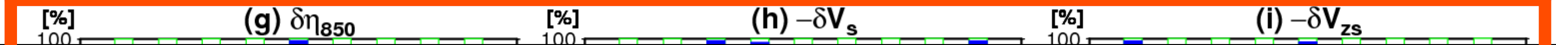
$$\sum_{i=1}^{a}\sum_{j=1}^{b}(X_{ij}-\overline{X}_{..})^2 = b\sum_{i=1}^{a}(\overline{X}_{i.}-\overline{X}_{..})^2 + a\sum_{j=1}^{b}(\overline{X}_{.j}-\overline{X}_{..})^2 + \sum_{i=1}^{a}\sum_{j=1}^{b}(X_{ij}-\overline{X}_{i.}-\overline{X}_{.j}+\overline{X}_{..})^2$$

All variance = Variance by diff. in SST + Variance by diff. in convection schemes + Residual

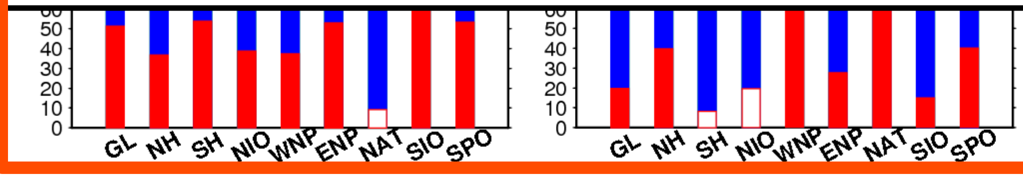


Dynamical factors that are highly correlated with TGF also appear to be more heavily influenced by differences in prescribed SSTs than by differences in the cumulus convection schemes.

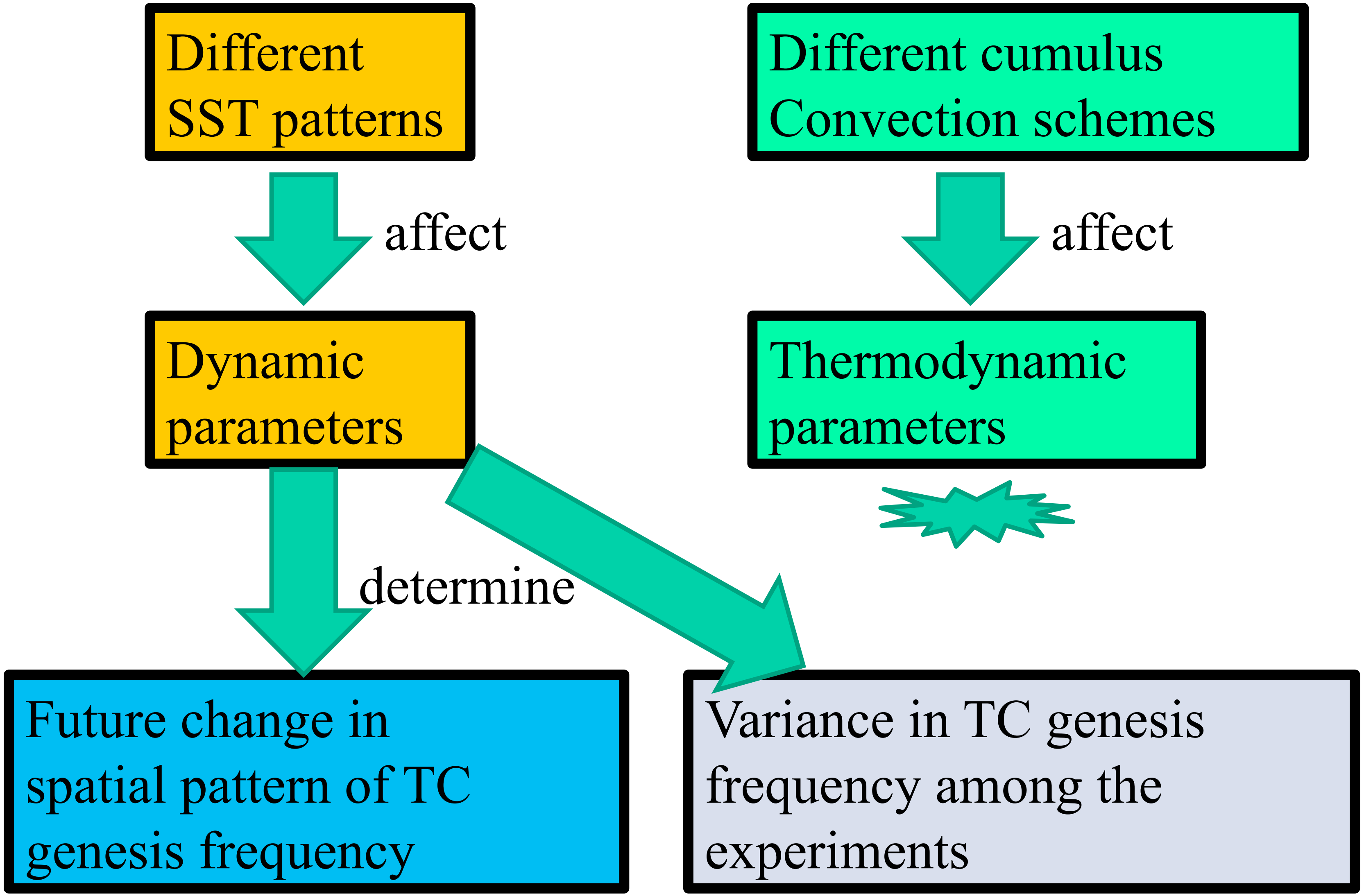




Thermodynamic parameters with exception of S_a, appear to be heavily dependent on the cumulus convection scheme, but these thermodynamic parameters are poorly correlated with the TGF changes as shown before.



Summary of statistical analysis



Spatial variation in SST is a source of uncertainty in projecting future changes in TC genesis frequency through responses of dynamical factors.
Further SST ensemble experiments are necessary to minimize those uncertainties.

Conclusion

In order to evaluate uncertainties, we conducted multi-SST and multi-model ensemble projections.

(a) Every ensemble simulation commonly shows decrease in global and hemispheric TC genesis numbers by about 5-35% under the global warming environment regardless of the difference in model cumulus convection schemes and prescribed SSTs.

(b) All experiments tend to project future decreases in the number of TCs in the western North Pacific (WNP), South Indian Ocean (SIO), and South Pacific Ocean (SPO), whereas they commonly project increase in the central Pacific.

(c) Future changes in spatial distribution of SST are major source of uncertainty in terms of future changes in TC genesis frequency through the dynamical responses. Further SST ensemble experiments are necessary for minimizing uncertainty.

Reference

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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.

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