Workshop on High-Resolution Climate Simulation, Projection and Application
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Comparison of tropical cyclones simulated by high-resolution MRI-AGCMs and NICAM

Masato Sugi[1*], Hiroyuki Murakami[1,2],
Kohei Yoshida[1] and Yohei Yamada[3]

1 Meteorological Research Institute, Japan
2 Geophysical Fluid Dynamics Laboratory, USA
3 Japan Agency for Marine-Earth Science and Technology, Japan

* msugi@mri-jma.go.jp

Outline

1. Introduction
2. Tropical cyclones simulated by high-resolution MRI-AGCMs and NICAM
3. Cumulus parameterization for high-resolution AGCM
4. Ensemble high-resolution AGCM simulations
5. Summary

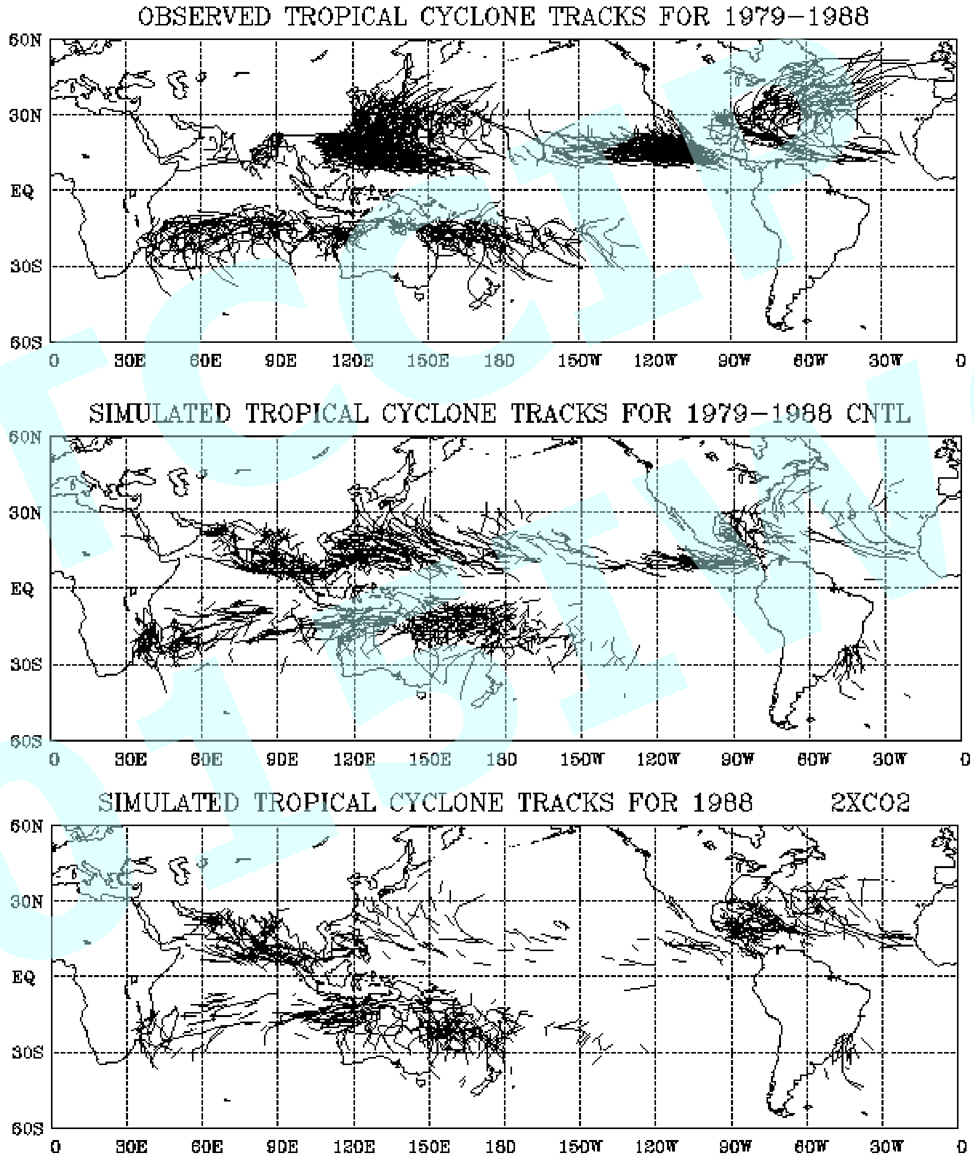
1. Introduction

History of TC simulation with high resolution AGCMs in Japan

year	model	resolution	integration	computer	speed	reference
1992-1996	JMA-GSM	T106 (120km)	10 year	CRAY-YMP	1 G Flops	Sugi et al. (2002)
2002-2007	MRI/JMA-AGCM	TL959 (20km)	10 year	Earth Simulator	40 T Flops	Oouchi et al. (2006)
2007-2012	MRI-AGCM 3.1,3.2	TL959 (20km)	25 year	ES2	130T Flops	Murakami et al. (2012)
2012-2016	NICAM	GL9 (14km)	30 year	K	10 P Flops	Yamada et al. (2015)

First TC simulation with a “high-resolution” AGCM

1992-1996	JMA-GSM	T106 (120km)	10 year	CRAY-YMP	1 GFlops	Sugi et al. (2002)

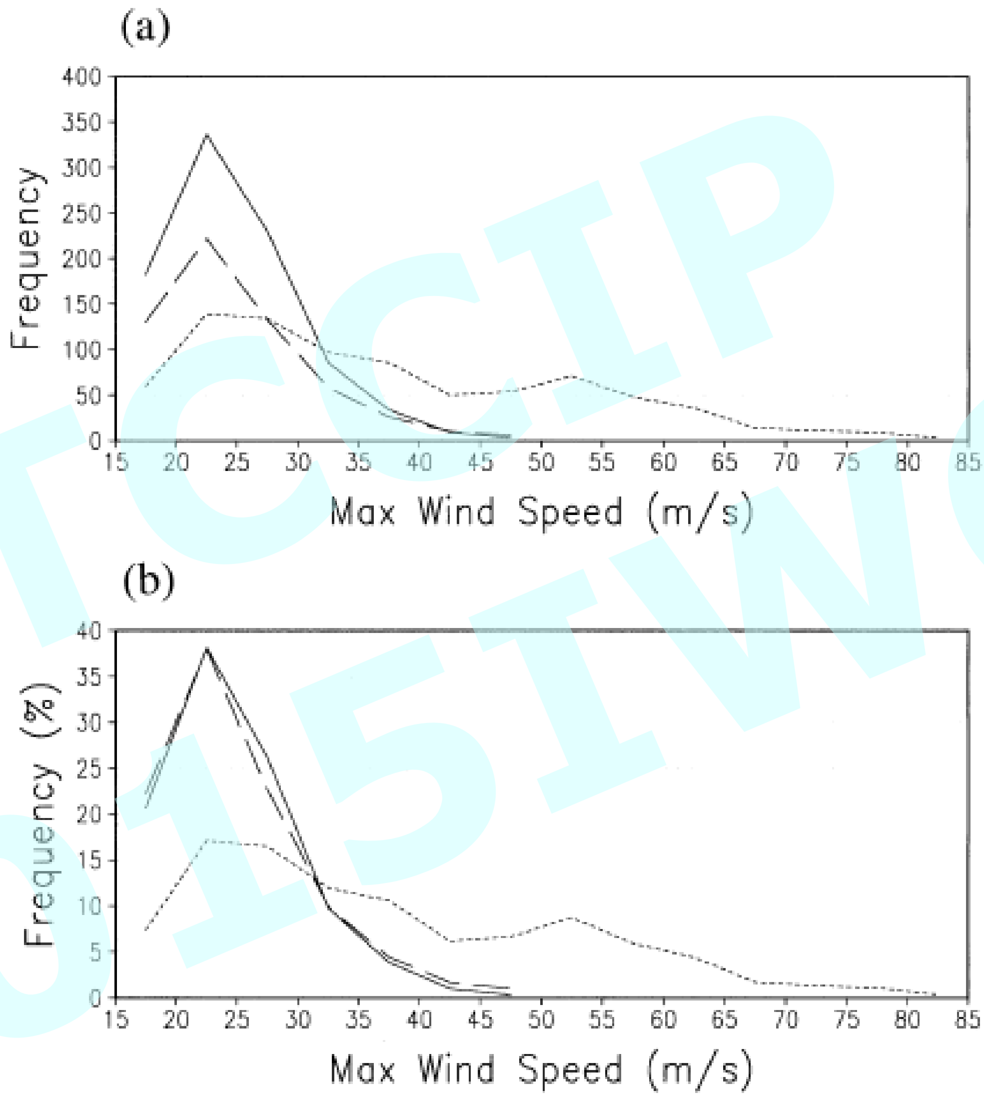


OBS

1xCO2

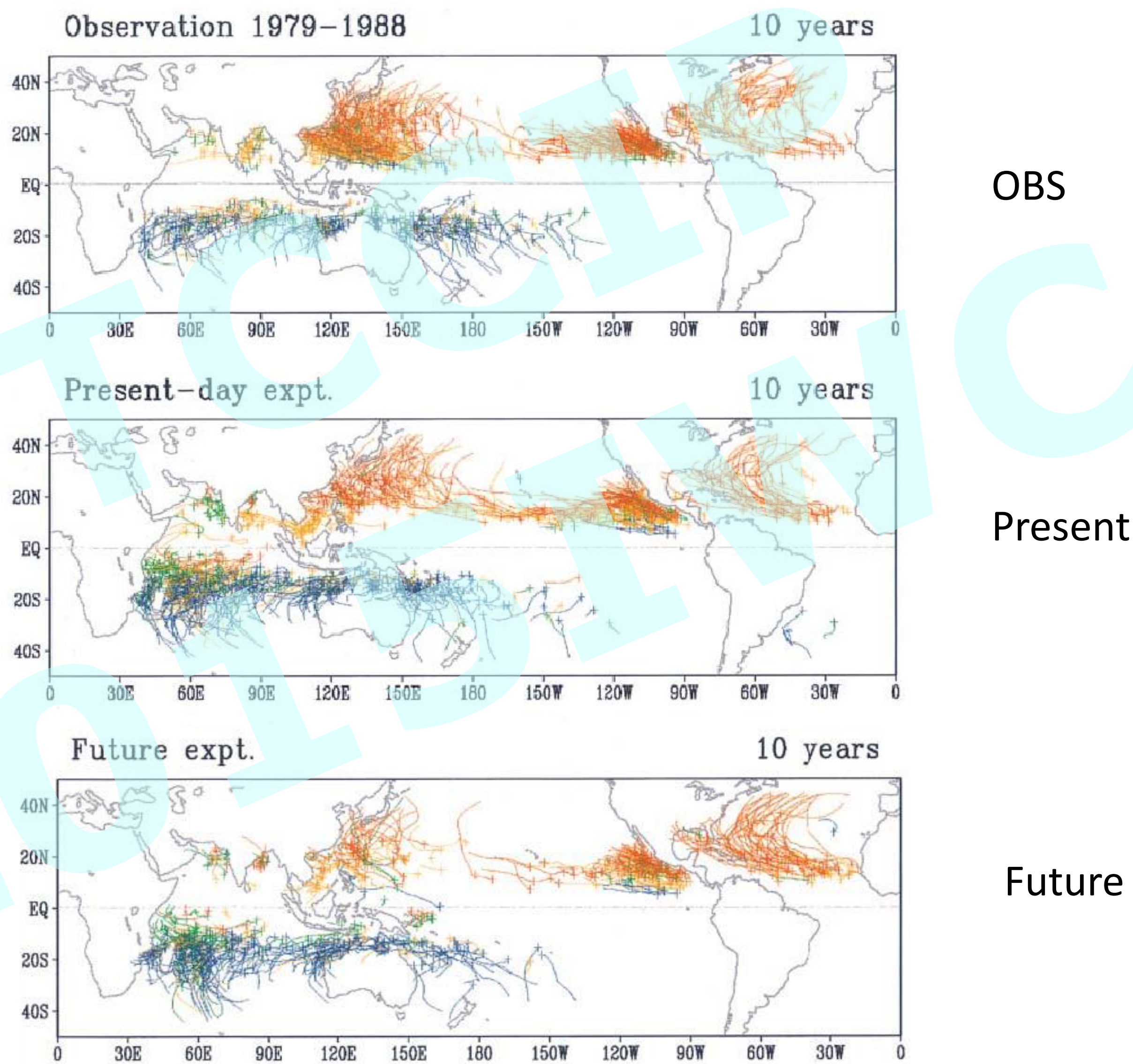
2xCO2

Sugi et al. (2002) JMSJ

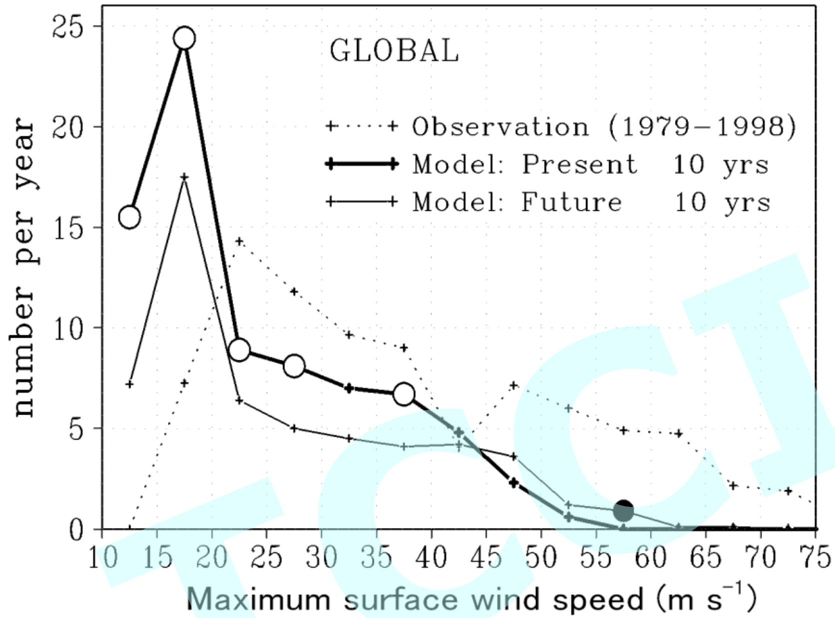


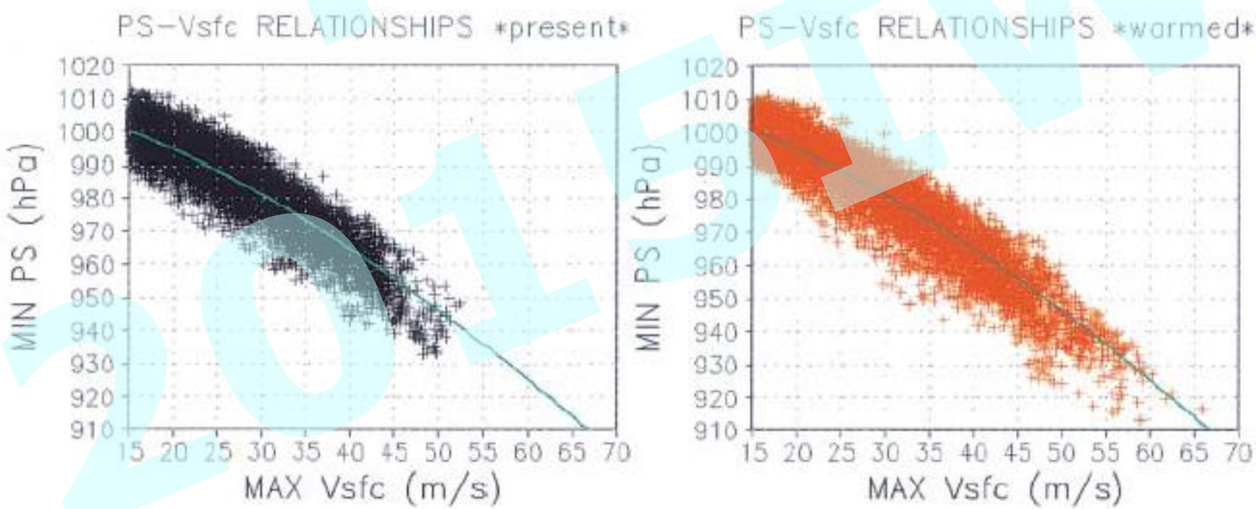
TC simulation with a high-resolution AGCM on the Earth Simulator

2002-2007	MRI/JMA-AGCM	TL959 (20km)	10 year	Earth Simulator	40 TFlops	Oouchi et al. (2006)



Oouchi et al. (2006) JMSJ





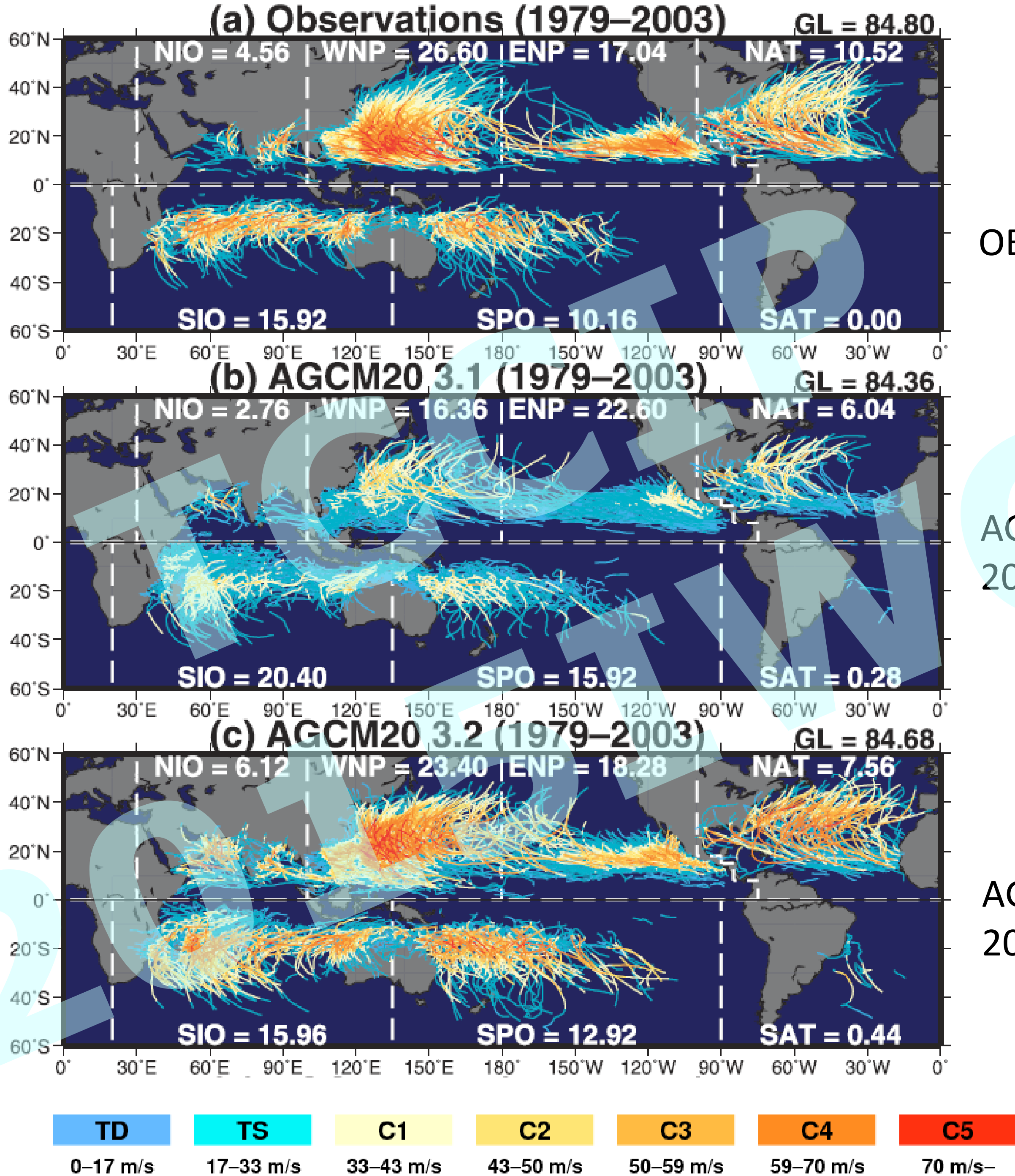
2. Tropical cyclones simulated by high-resolution MRI-AGCMs and NICAM

2007-2012	MRI-AGCM 3.1,3.2	TL959 (20km)	25 year	ES2	130 TFlops	Murakami et al. (2012)
2012-2016	NICAM	GL9 (14km)	30 year	K	10 PFlops	Yamada et al. (2015)

Model	Cumulus Parametrization Scheme
MRI-AGCM3.1	Arakawa-Schubert scheme (AS)
MRI-AGCM3.2	Yoshimura scheme (YS)
NICAM	No parametrization

MRI-AGCM

Murakami et al. (2012) JCLI



OBS

AGCM3.1
20km

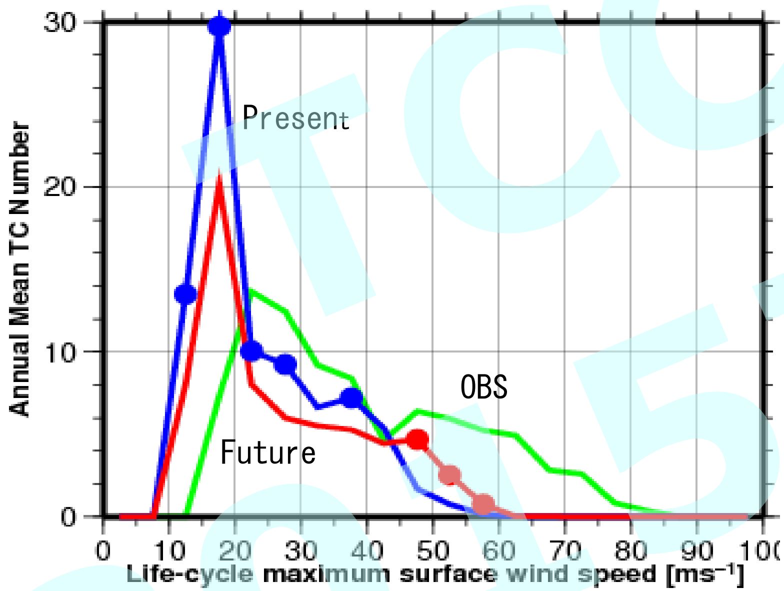
AGCM3.2
20km

TC Lifetime Maximum Wind Speed

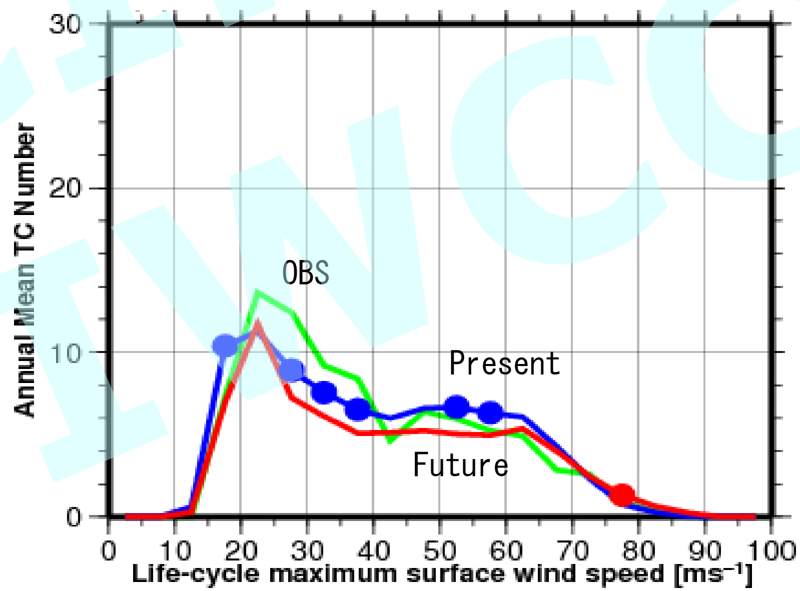
MRI-AGCM

Murakami et al. (2012) JCLI

MRI-AGCM3.1 20km



MRI-AGCM3.2 20km



OBS

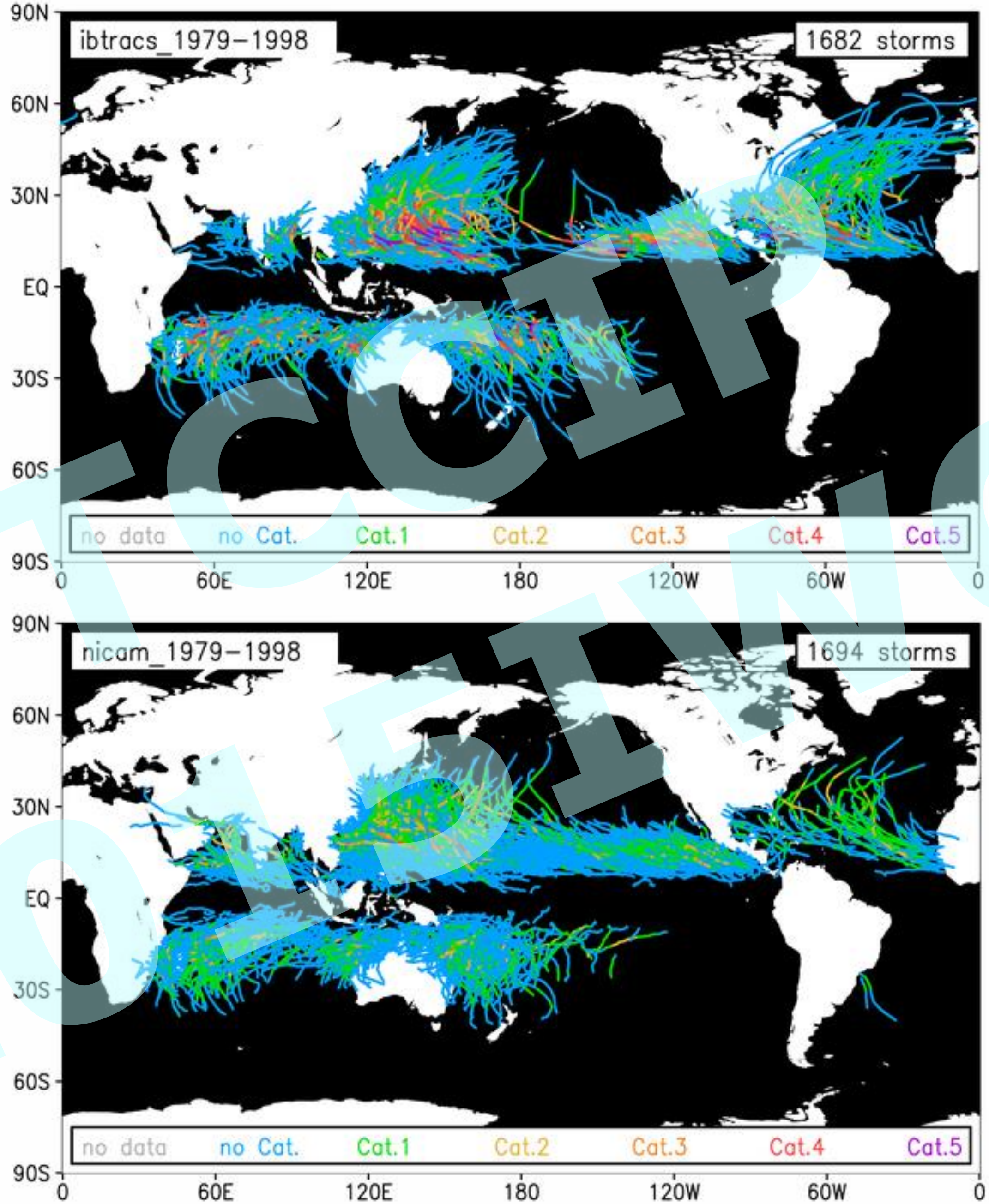
Present

Future

Significant increase at 95% confidence level

Significant decrease at 95% confidence level

NICAM



Yamada et al.(2015)

OBS
IBTrACS

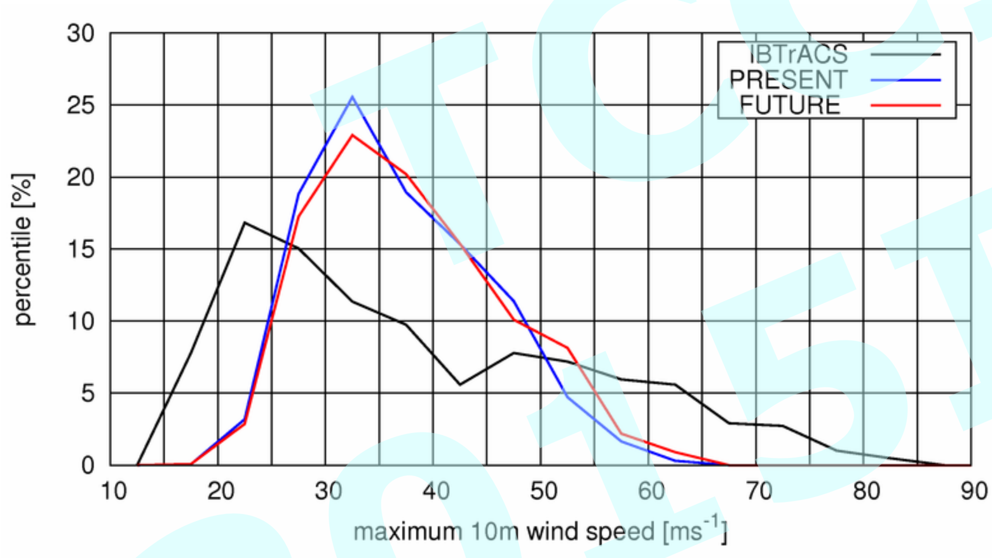
NICAM
GL9 (14km)

TC Lifetime Maximum Wind Speed

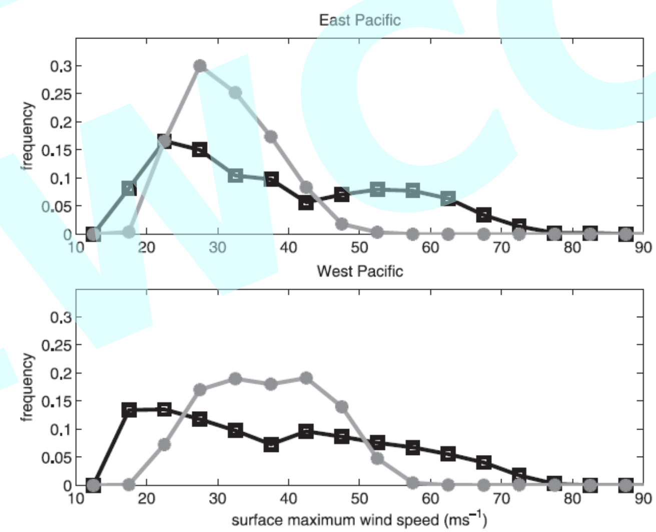
NICAM　Yamada et al.(2015)

HiRAM　Zhao et al. (2009)

NICAM GL9 (14km)



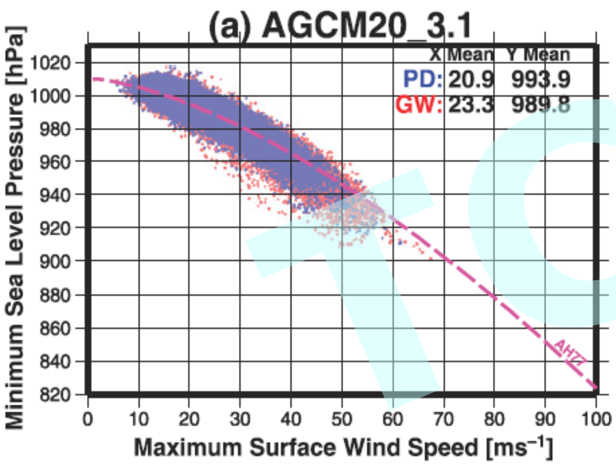
GFDL HiRAM2.1 (50km)

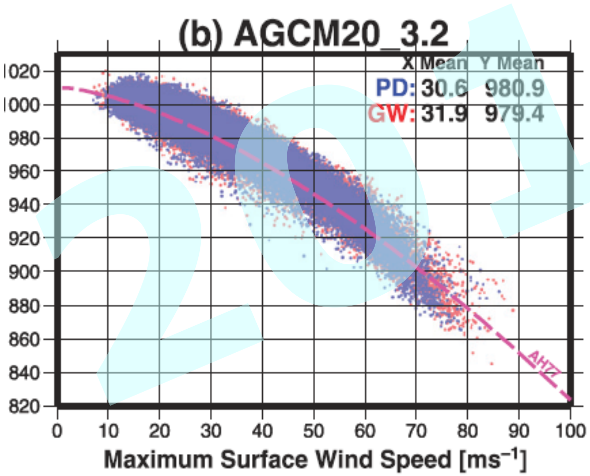


TC wind–pressure relation

MRI-AGCM

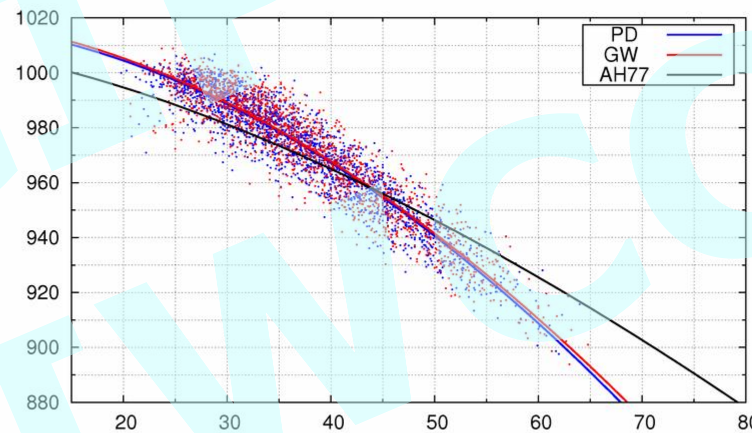
Murakami et al. (2012) JCLI

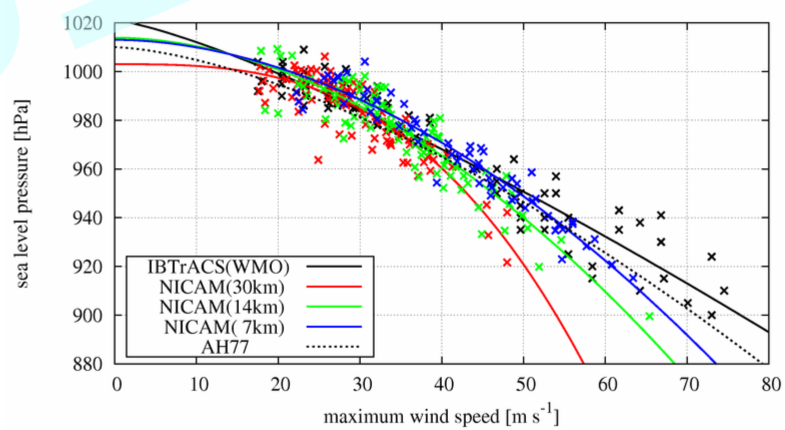




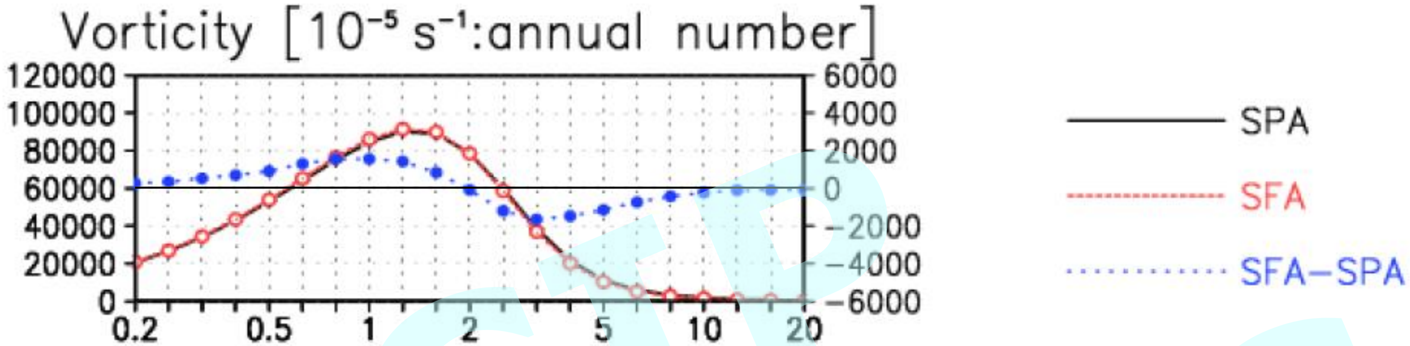
NICAM

Yamada et al.(2015)

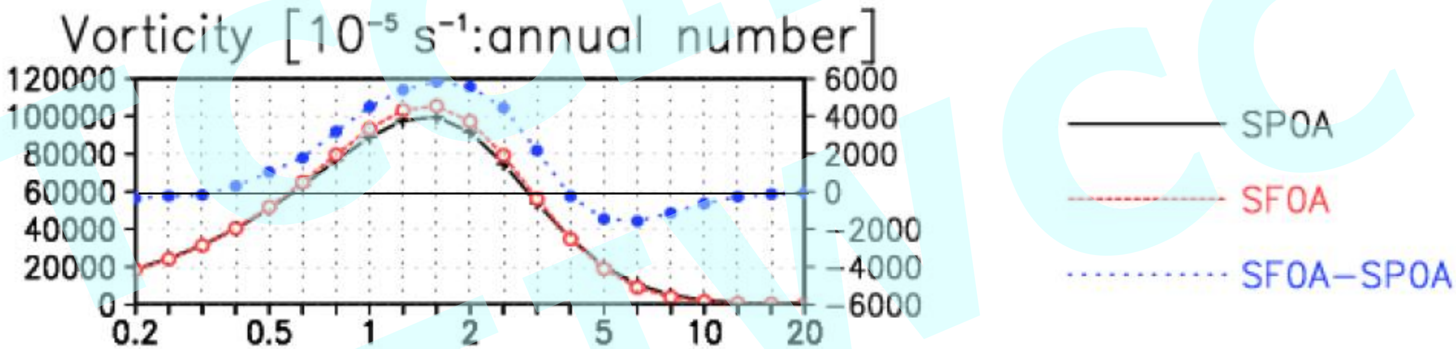




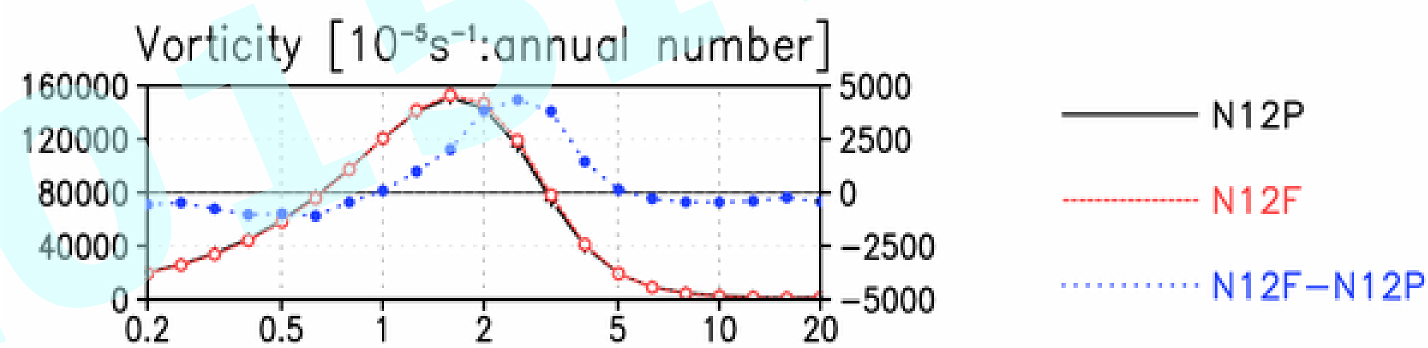
MRI-AGCM3.2
20km



MRI-AGCM3.1
20km



NICAM
14km



Yoshida 2013 and Yamada 2013

3. Cumulus parametrization for high-resolution AGCM

Gray Zone Problem

For the models with resolution of 20km - 2km, conventional cumulus parametrization scheme does not work well, while explicit cumulus convection is also problematic.

We selected 20km resolution for the Earth Simulator experiment instead of 10km resolution to avoid gray zone problem.

Cumulus convection is a subgrid scale phenomenon in gray zone. Therefore, parameterization is necessary.

Cumulus Parameterization calculates Q1 and Q2

$$\rho Q_1 = \rho Q_R + L(\bar{c} - \bar{e}) - \rho \frac{\partial \overline{s' w'}}{\partial z}$$

(1) (2)

$$-\rho Q_2 = -L(\bar{c} - \bar{e}) - \rho \frac{\partial \overline{q' w'}}{\partial z}$$

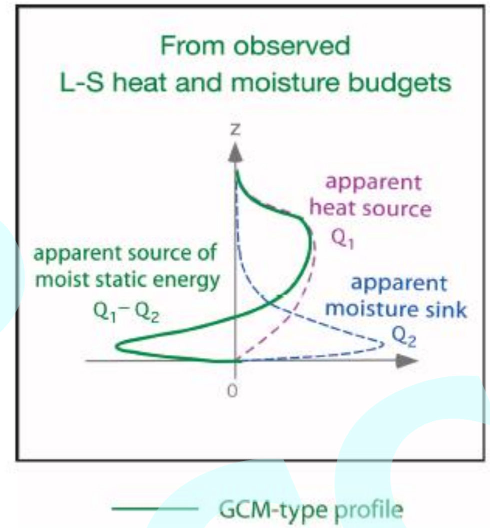
(1) (2)

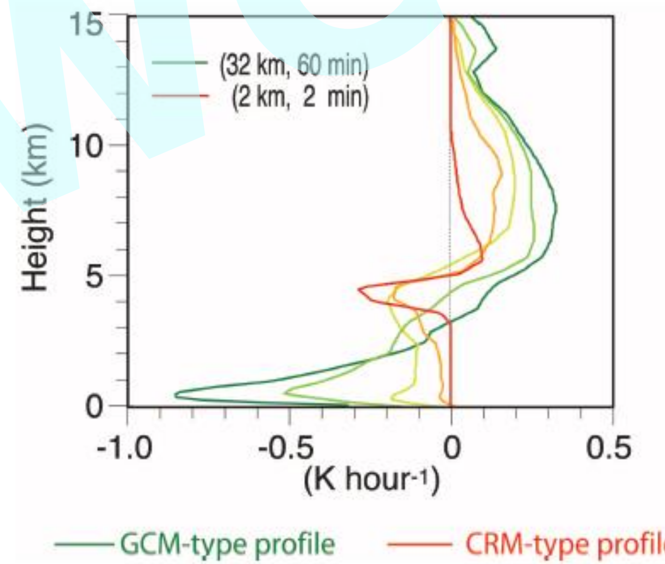
$$\rho Q_1 - \rho Q_2 = \rho Q_R - \rho \frac{\partial \overline{h' w'}}{\partial z}$$

(2)

(1) Microphysics

(2) Subgrid transport : not negligible in gray zone, decreases with increasing resolution and vanishes in CRM





Arakawa et al. (2011) ACP

Tropical cyclone genesis/development

Net heating = Q1 – Adiabatic cooling > 0 ⇒ warm core development
TC intensification

↑ ↑

moisture flux mass flux

↑ ↑

entrainment ← grid scale convergence

↓

Absolute vorticity convergence > 0 ⇒ vortex development
TC intensification

4. Ensemble high-resolution AGCM simulations of tropical cyclones

Recent IPCC report concluded that the number of very intense TCs will increase globally in the future.

However, it is noted that there are very large uncertainties, particularly in the projection of the regional changes in the frequency of very intense TCs.

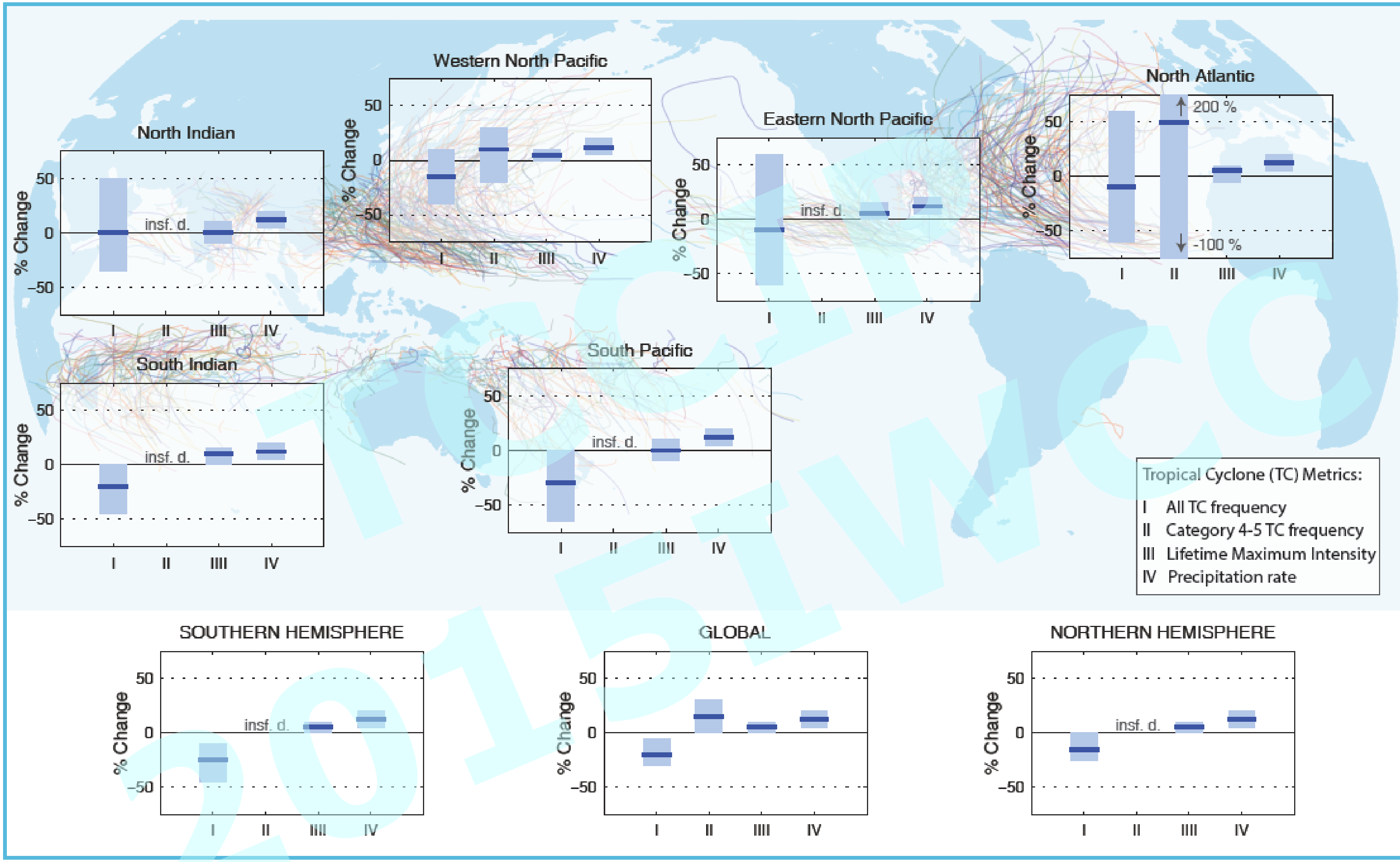


Figure 14.17

IPCC-AR5 (2013)

High-resolution MRI-AGCM Ensemble Experiments

Present Day Experiment (11 member)

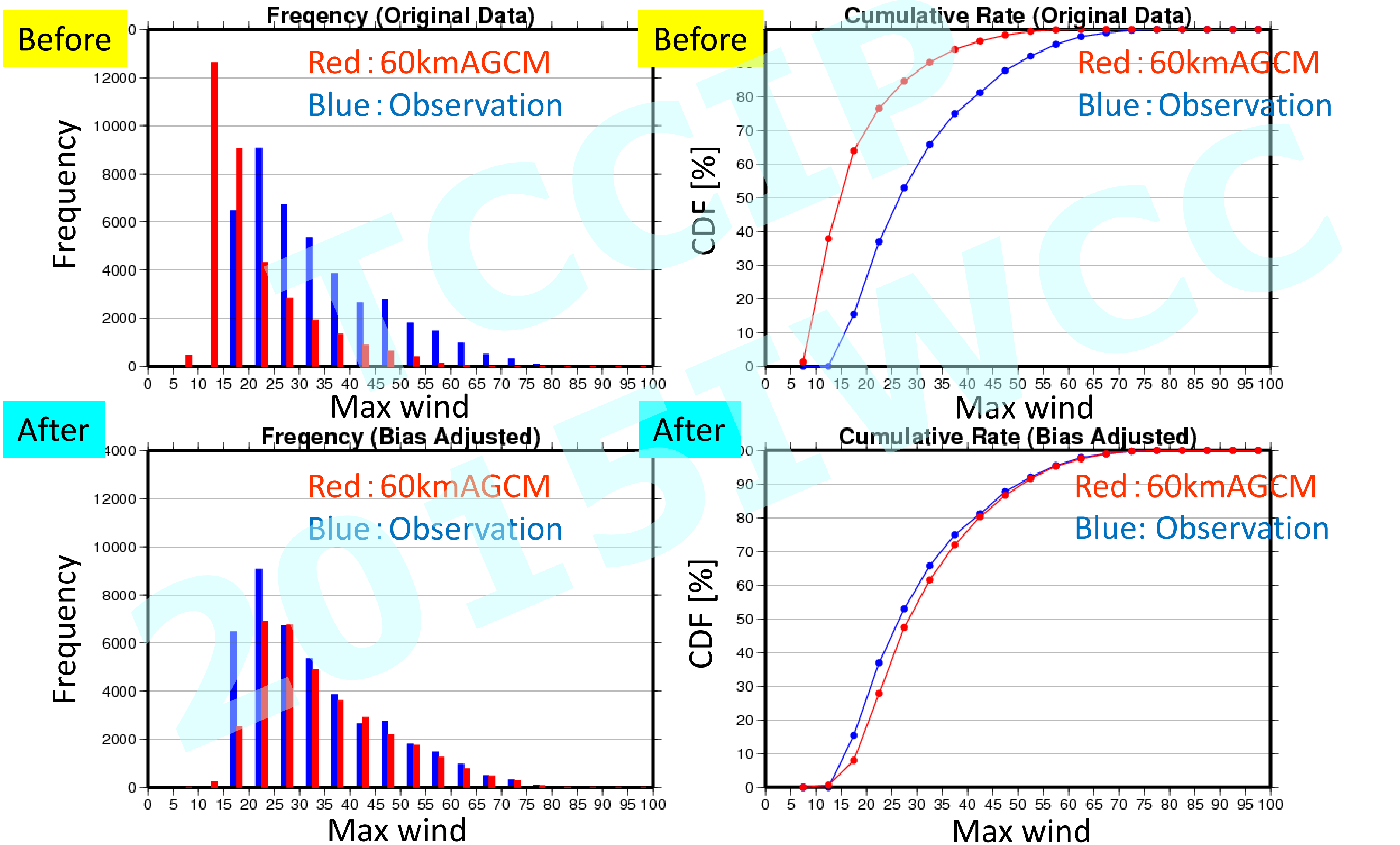
Model	Resolution	Convection	Initial Condition	SST	Member
HP0A	60km	AS	3	HadISST	3
HPA	60km	YS	3	HadISST	3
HPA	60km	YS, KF, AS	1	HadISST	3
SP0A	20km	AS	1	HadISST	1
SPA	20km	YS	1	HadISST	1

Global Warming Experiment (29 member)

Model	Resolution	Convection	Initial Condition	SSTA	Member
HF0A	60km	AS	3	CMIP3	3
HF0A	60km	AS	3	CSIRO	3
HF0A	60km	AS	3	MIROC	3
HF0A	60km	AS	3	MRI	3
HFA	60km	YS	3	CMIP3	3
HFA	60km	YS	1	Cluster 0-3	4
HFA	60km	KF	1	Cluster 0-3	4
HFA	60km	AS	1	Cluster 0-3	4
SF0A	20km	AS	1	CMIP3	1
SFA	20km	YS	1	CMIP3	1

TC intensity bias correction

Bias correction is based on CDFs for each ocean basin and each 5 degree latitude belt. Result of bias correction for 60kmAGCM3.2H is shown below.



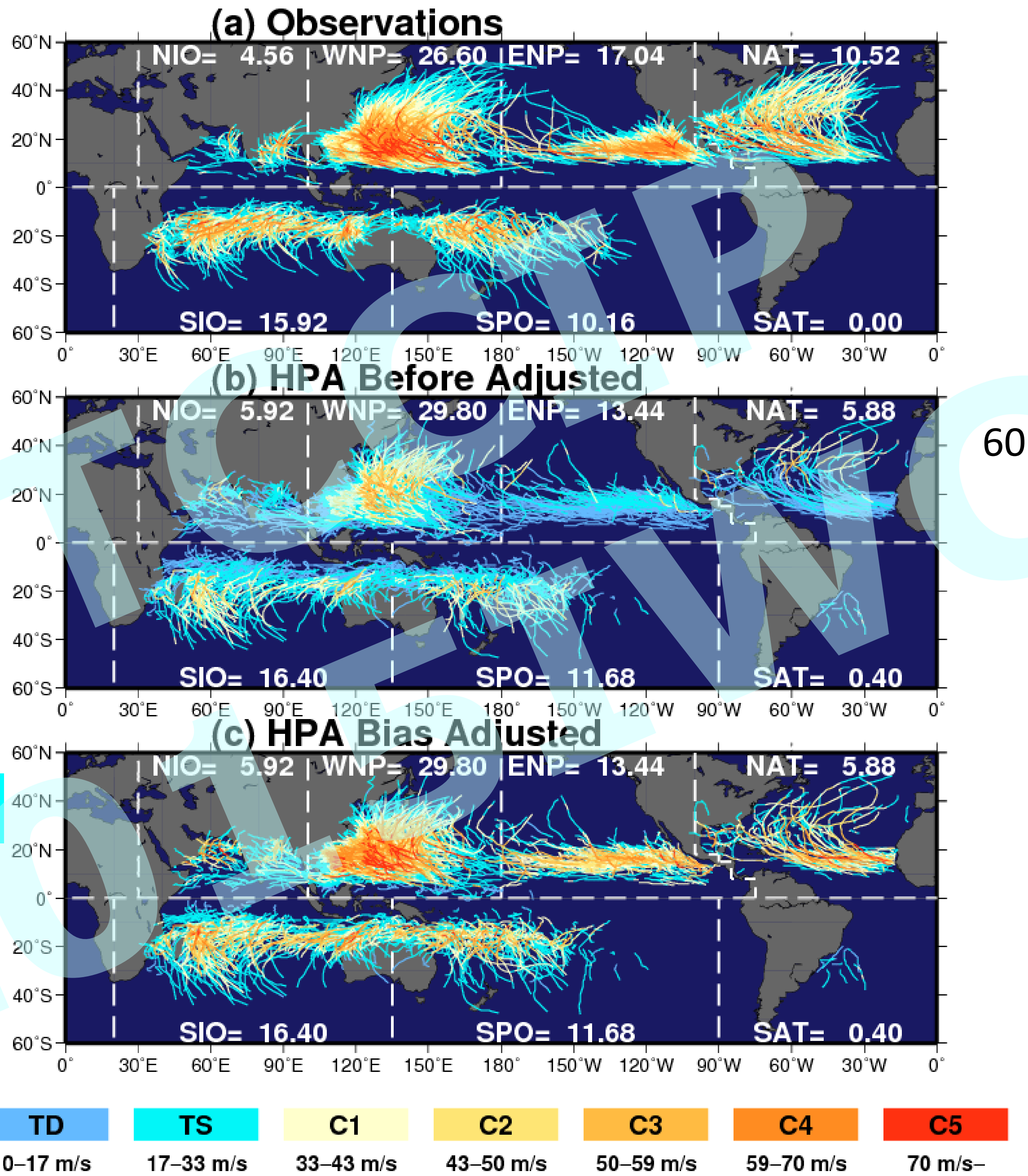
Result of intensity bias correction (TC track with intensity)

Observation

Before correction

After correction

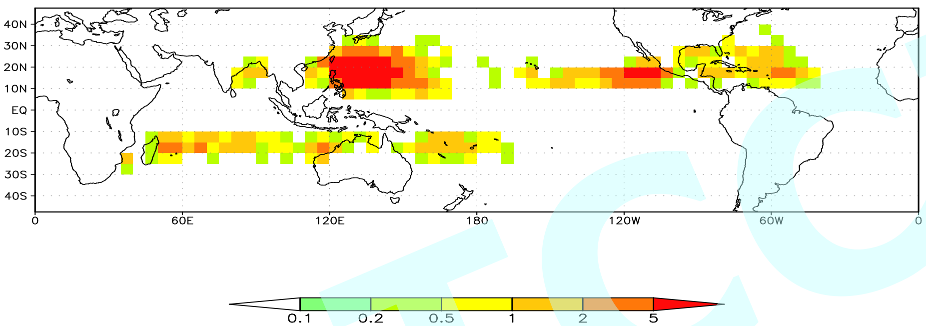
60km AGCM3.2H



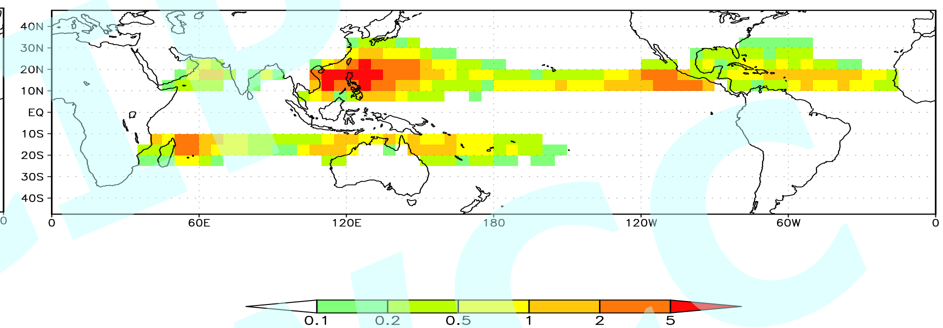
Category 4-5 TC Frequency Changes

Numbers per 10years in 5^{o}x5^{o} grid box

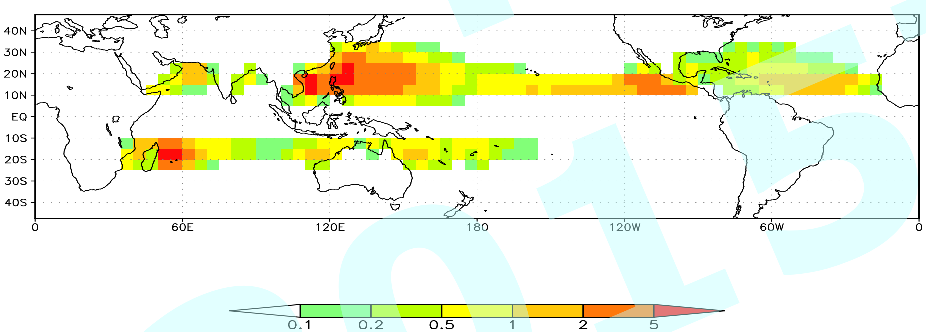
Observation (BEST TRACK)



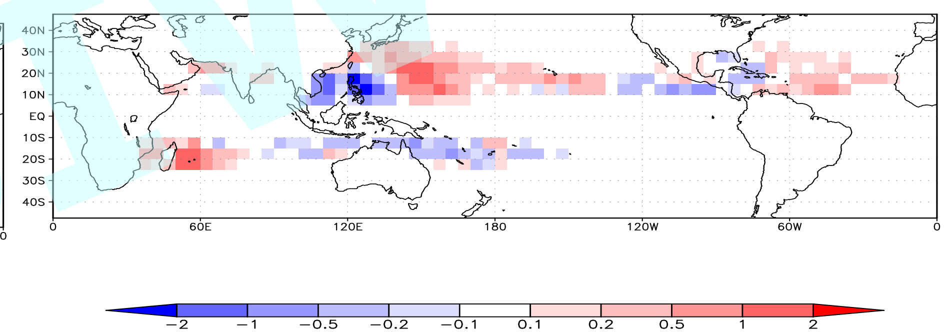
Present（11 members）



Future（29 members）



Changes (Future-Present)



Number of Cat 4-5 TCs generally increases in most regions, except for south-western part of WNP and near Australia, and ENP, Caribbean Sea and Gulf of Mexico.

Sugi and Murakami (2015)

Summary

1. Cumulus parameterization

   Simulation of TC by high-resolution AGCM significantly depends on the cumulus parameterization. We need to develop a good parameterization for gray zone. Q1, Q2 and entrainment should be re-examined.

2. Ensemble experiment

   For TC climate study, not only high spatial resolution but also high statistical resolution is important. We have demonstrated that ensemble experiment with TC intensity bias correction is very useful to improve the statistical resolution.