Future changes in extreme precipitation and their association with tropical cyclone activity over the western North Pacific–East Asian region in 20 km MRI-AGCM simulations

Hirokazu Endo, Akio Kitoh, and Ryo Mizuta

Meteorological Research Institute, Japan

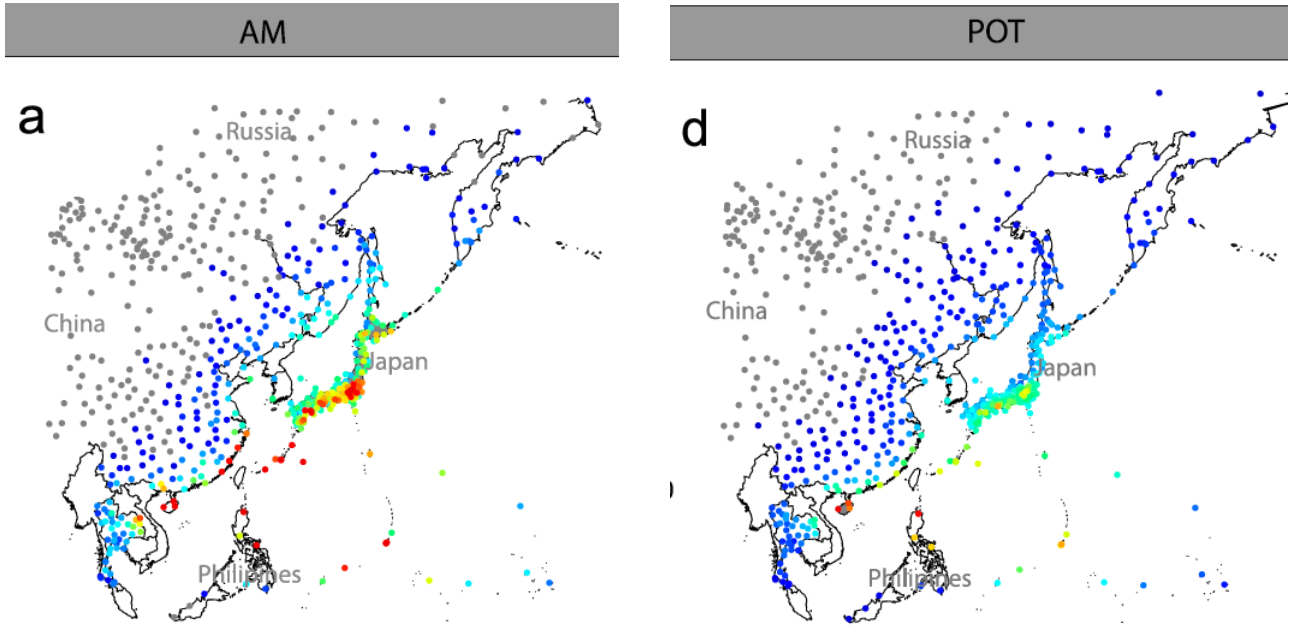
Endo, H., A. Kitoh, and R. Mizuta, 2022: Future changes in extreme precipitation and their association with tropical cyclone activity over the western North Pacific and East Asia in 20 km AGCM simulations. *SOLA*, **18**, 58-64, doi:10.2151/sola.2022-010.

Tropical cyclones (TCs) significantly contribute to extreme precipitation events in the WNP-EA region.

Annual maximum daily precipitation (Rx1d)

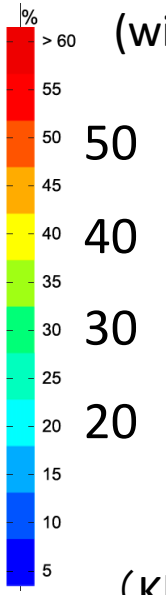
Heavy precipitation (>95%-tile) frequency

Observation



Contribution of TCs（%）

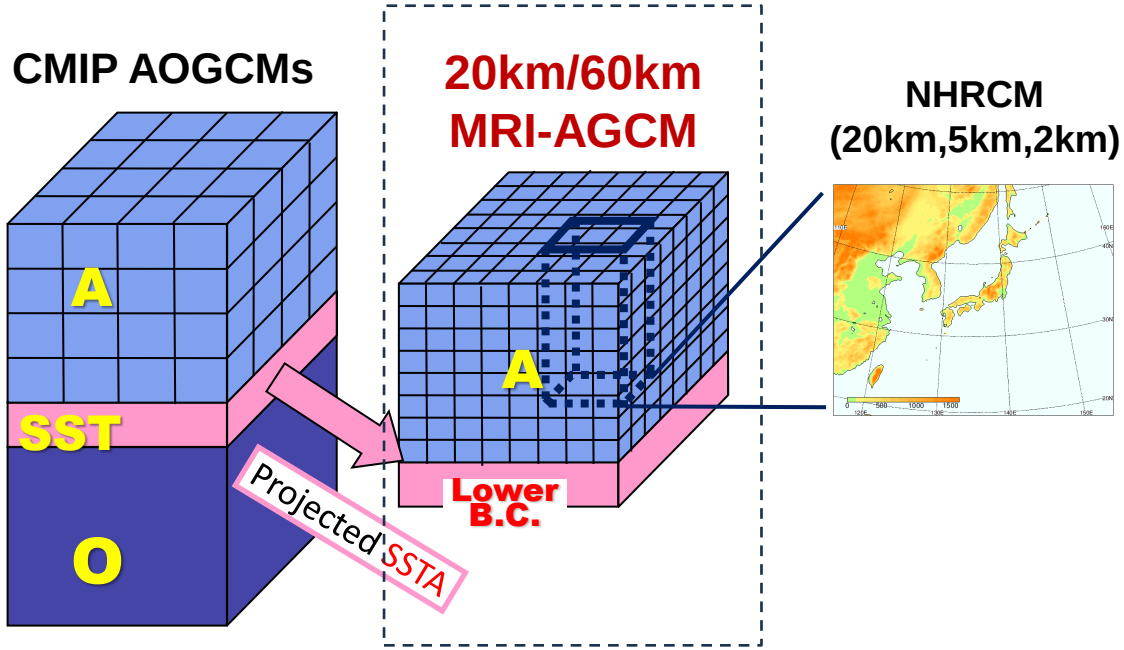
(within 500km from the center)

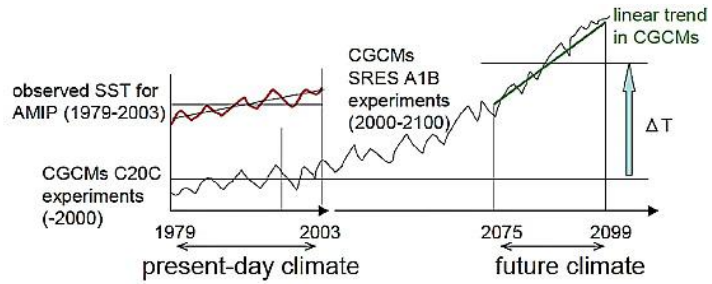


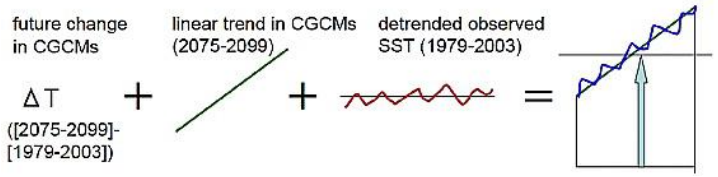
（Khouakhi et al. 2017, JCLIM）

Use of high-resolution model capable of reproducing TCs is preferable for future projections of extreme precipitation in the WNP-EA region.

Future projection with high-resolution MRI-AGCM







(Kitoh et al. 2011)

Study of future changes in extreme phenomena and regional climate

- **Tropical Cyclones** (e.g. Murakami et al. 2012)
  → less number, more intense
- **Extreme Rainfall** (e.g. Kitoh and Endo 2016)
  → more frequent
- **Baiu/Meiyu rainband** (e.g. Kusunoki 2018)
  → stronger
- **Blockings** (e.g. Matsueda et al. 2009)
  → less frequent
- **Extratropical Cyclones** (e.g. Mizuta et al. 2011)
  → less number, more intense

Past: Observed SST
→ accurately represent regional climate

Future: Observed SST + CMIP ΔSSTs
→ reflect the variety of CMIP projections

● Purpose of this study

- **Using the 20 km-mesh MRI-AGCM, we investigate future changes in extreme precipitation in the WNP-EA region, focusing on the impact of TCs.**

- **The dependency of future projections on model resolution is discussed.**

● Model experiment

(a) Present-day climate simulations

SST	Period	Ensemble size
HadISST1.1	1979–2003	5

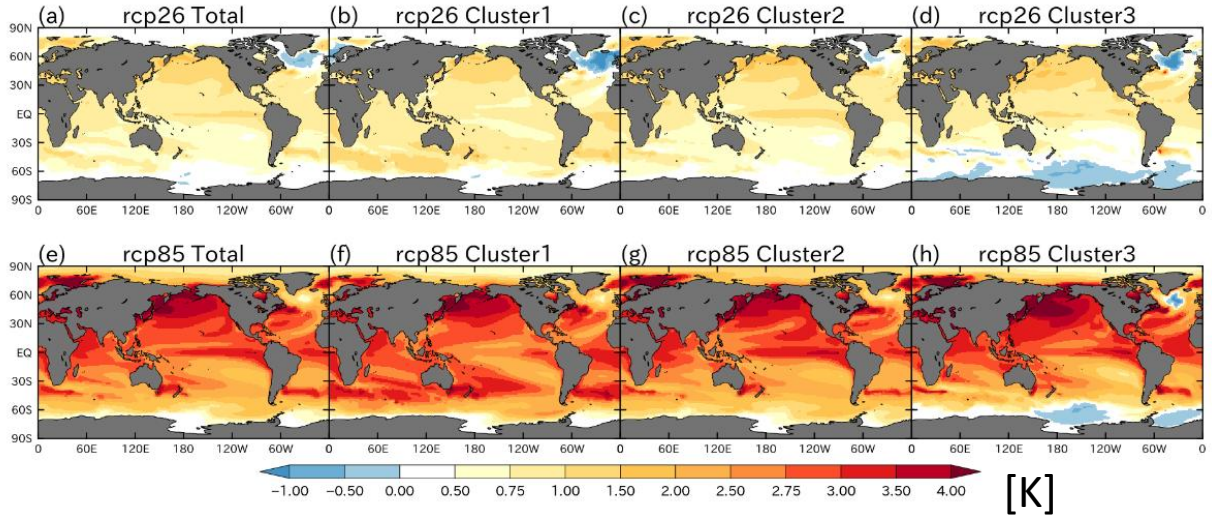
(b) Future climate simulations

SST	Scenario	Period	Ensemble size
CMIP5 MME	RCP2.6	2075–2099	1
CMIP5 cluster 1	RCP2.6	2075–2099	1
CMIP5 cluster 2	RCP2.6	2075–2099	1
CMIP5 cluster 3	RCP2.6	2075–2099	1
CMIP5 MME	RCP8.5	2075–2099	1
CMIP5 cluster 1	RCP8.5	2075–2099	1
CMIP5 cluster 2	RCP8.5	2075–2099	1
CMIP5 cluster 3	RCP8.5	2075–2099	1

Future SST anomaly

RCP2.6

RCP8.5

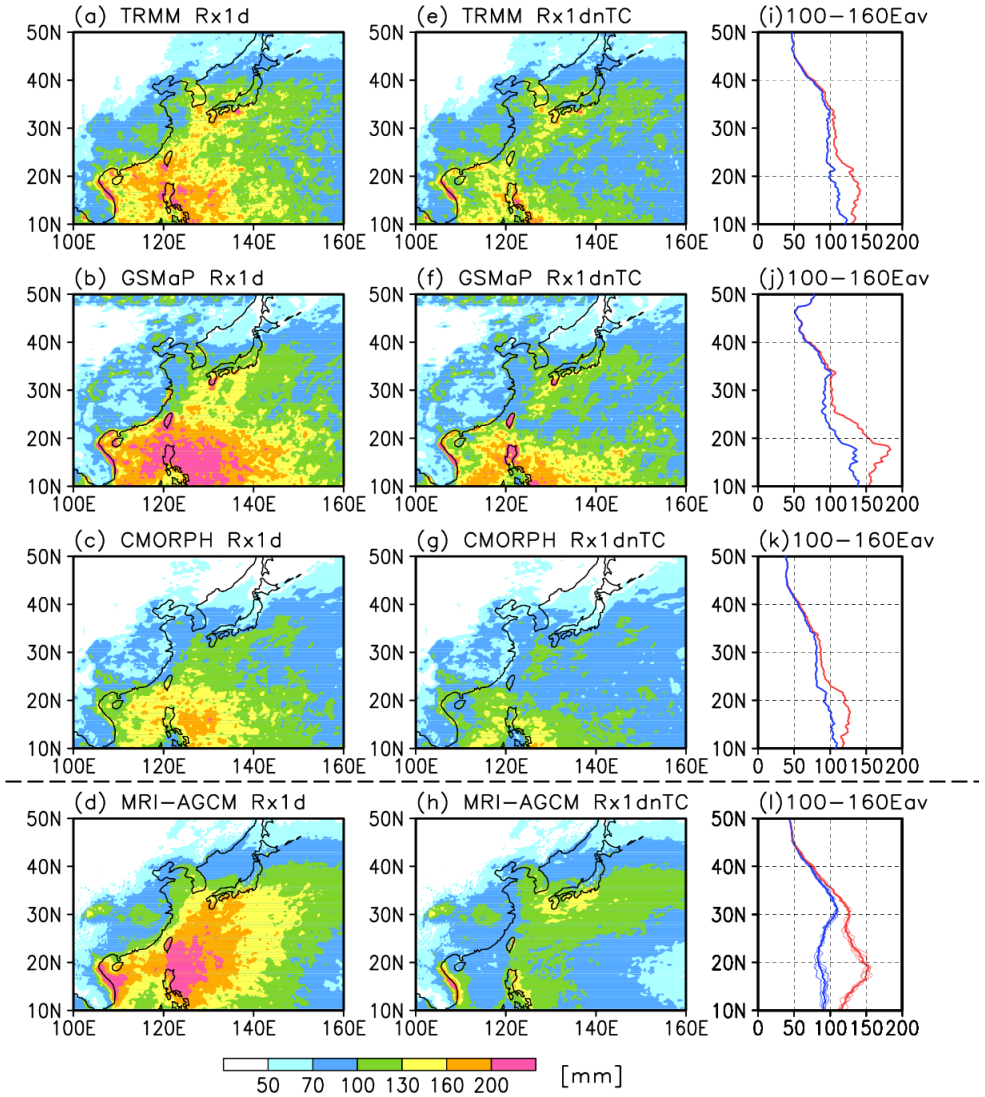


(Mizuta et al. 2014)

Present-day simulation of extreme precipitation with 20km MRI-AGCM

Obs: 2001-2014
Model: 1979-2003

Rx1d: Annual maximum of 1-day precipitation
Rx1d-nTC: Rx1d excluding TC-associated precipitation (within 500km)



Observation:

- **Rx1d is large around the Philippines (～20N) and over oceanic areas in East Asia.**
- **TCs influence Rx1d over areas south of 35N, particularly near 20N.**
- **Significant uncertainty in the magnitude of Rx1d among the datasets.**

MRI-AGCM:

- **The observed characteristics are well reproduced, although Rx1d is overestimated over the ocean south of Japan.**

Future changes in extreme precipitation with 20km MRI-AGCM

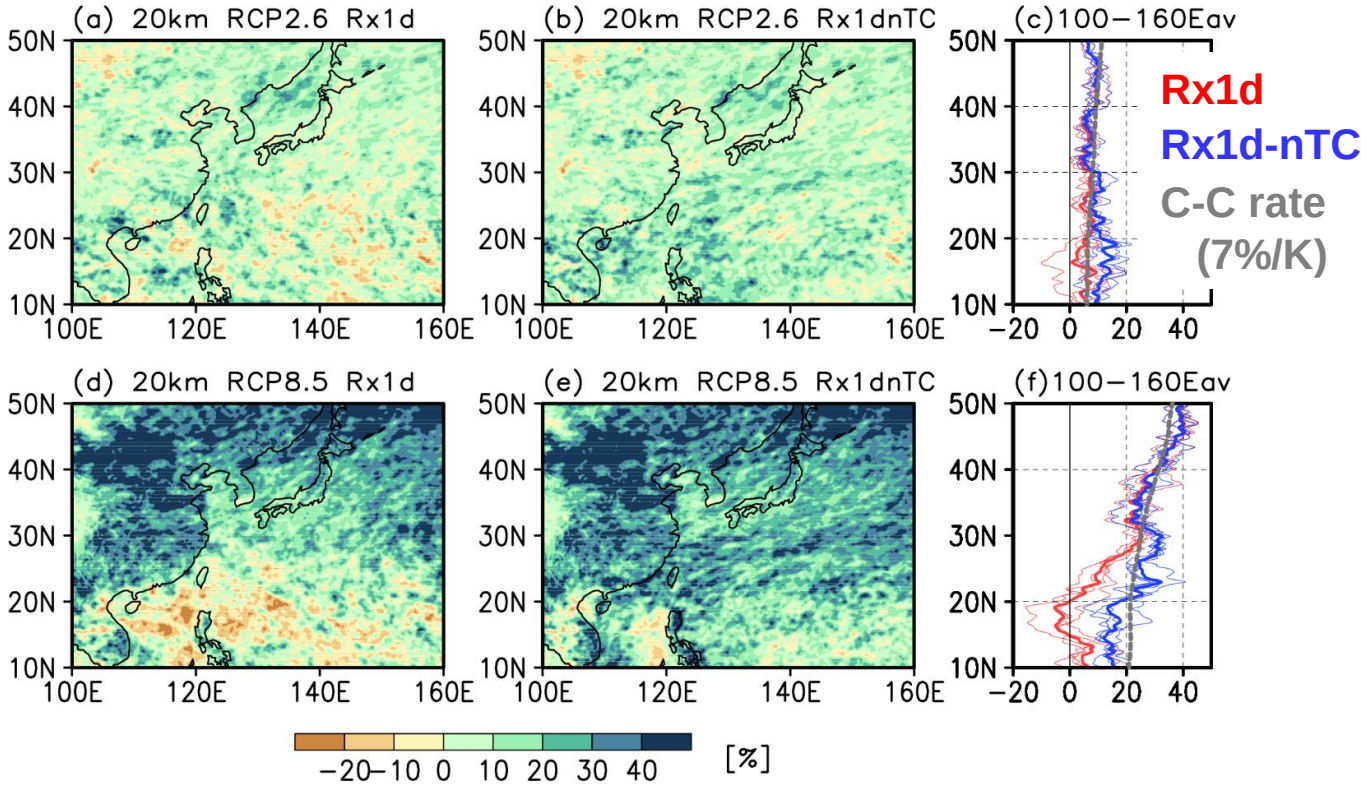
Climatological mean
2075-2099

Rx1d: Annual maximum of 1-day precipitation
Rx1d-nTC: Rx1d excluding TC-associated precipitation (within 500km)

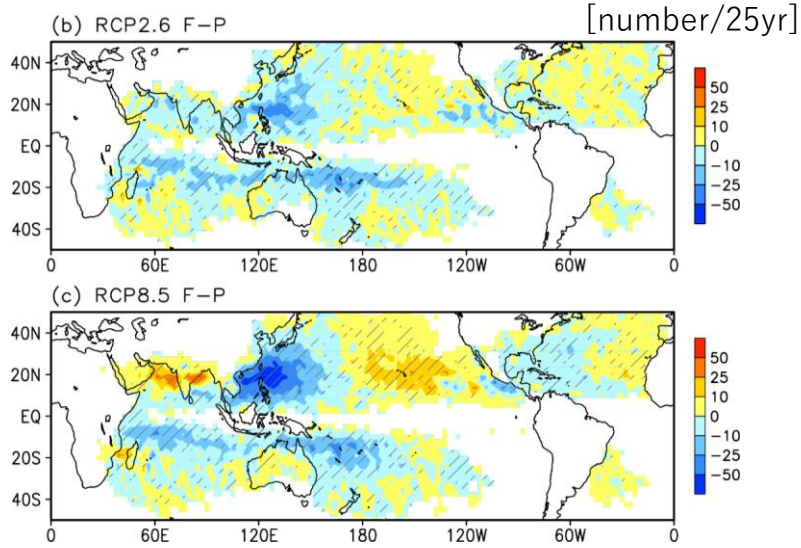
Rx1d **Rx1d-nTC**

RCP2.6

RCP8.5



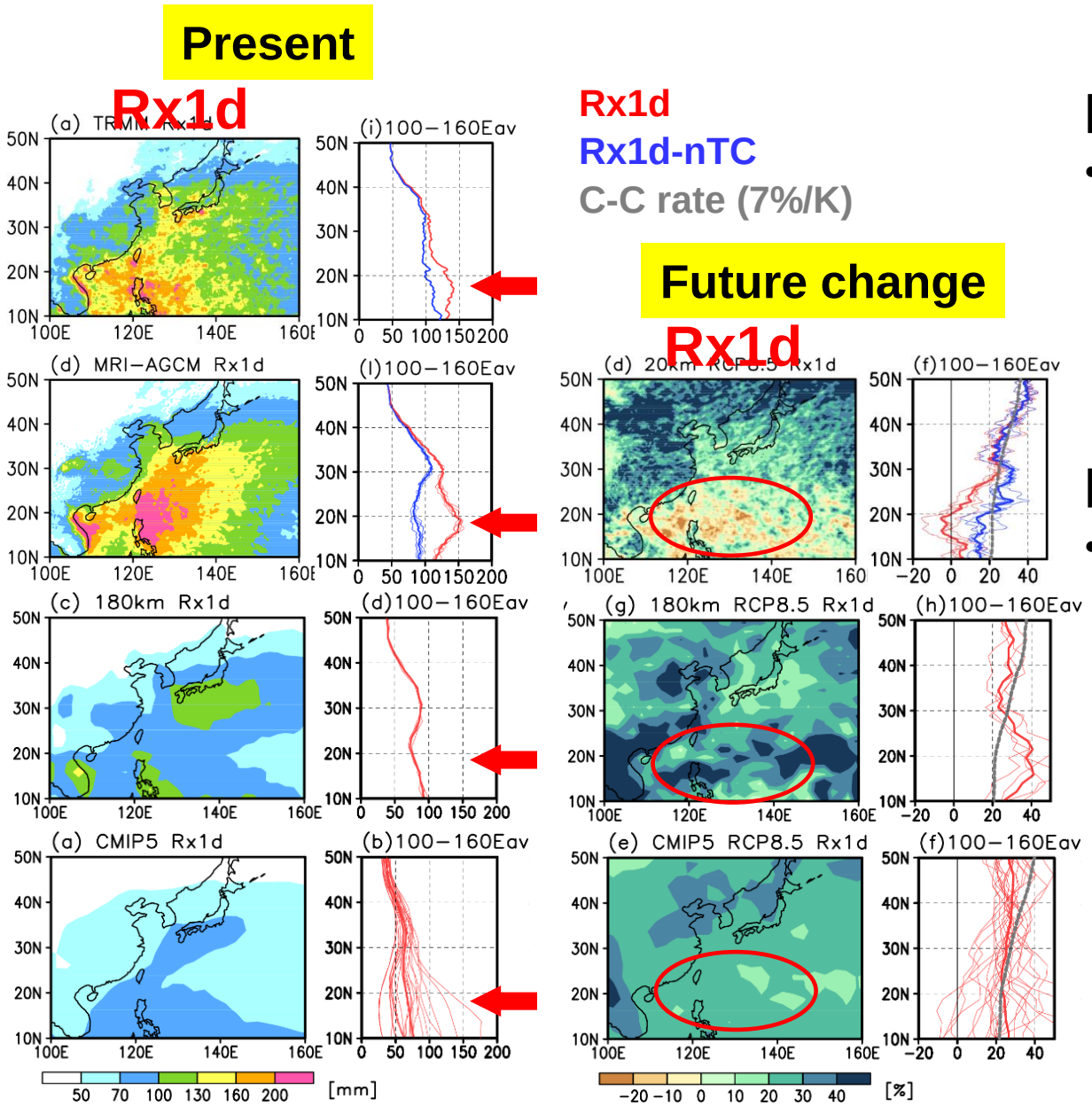
Tropical cyclone (TC) frequency



TC frequency is decreased in WNP
→ acts to reduce the mean Rx1d

- **Rx1d**: **- Overall increase, with higher rates of increase at higher latitudes <u>due to greater warming</u>.**
  - Unchanged or a slight decrease in the subtropics under RCP8.5.
- **Rx1d-nTC**: **- Increase over almost all areas, and the rate is close to the C-C rate (7%/K).**
  → <u>The effect of TCs contributes negatively to changes in the mean Rx1d.</u>

High resolution model vs. low resolution model



Present-day:

- **Low-resolution models (MRI-AGCM180 and CMIP5 AOGCMs) underestimate the magnitude of Rx1d and fail to reproduce its peak of around 20N which is associated with TC activity.**

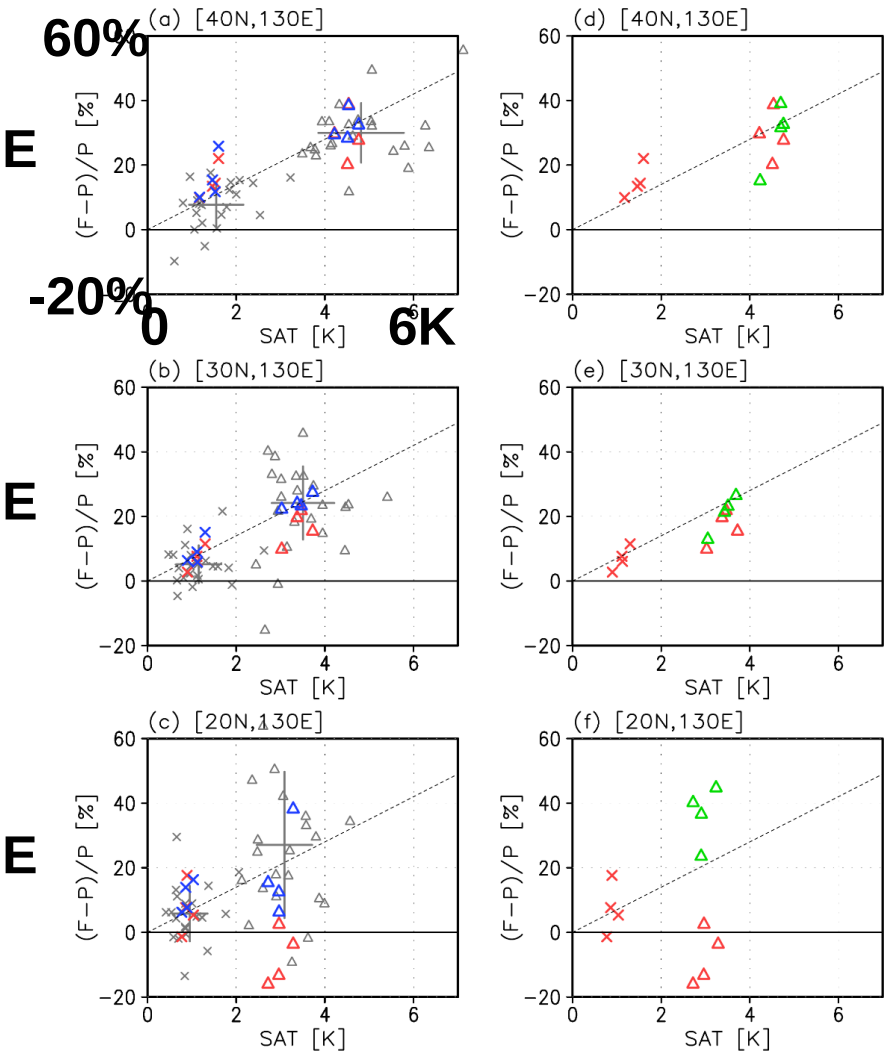
Future change:

- **Low-resolution models project a positive change everywhere, showing a marked difference in the subtropics compared to MRI-AGCM20.**

- Low-resolution models underestimate the effect of TC activity on present-day Rx1d.
- This limitation may result in inaccurate future projections of Rx1d.

High resolution model vs. low resolution model

× RCP2.6
△ RCP8.5



C-C rate (7%/K)

MRI-AGCM20 (Rx1d)
MRI-AGCM20 (Rx1d-nTC)
CMIP5 AOGCMs (Rx1d)

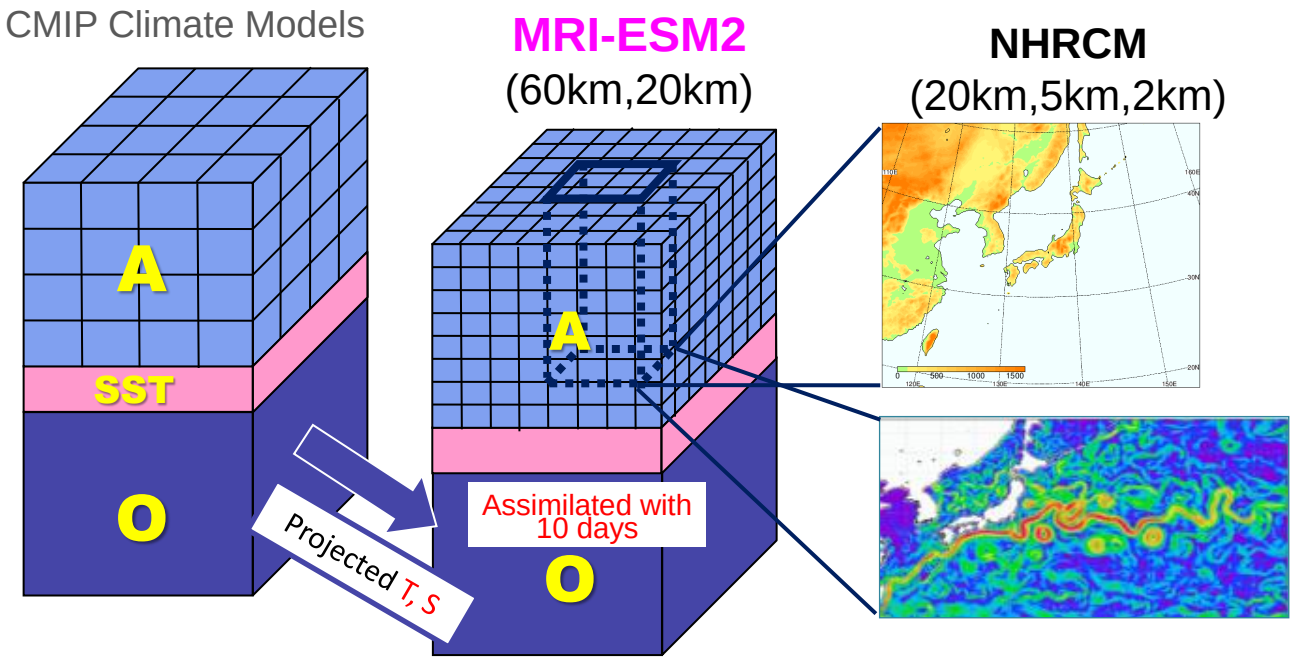
MRI-AGCM20 (Rx1d)
MRI-AGCM180 (Rx1d)

- **MRI-AGCM20 (Rx1d): A slight decrease in the subtropics under RCP8.5. However, when the influence of TCs is excluded, the increase approaches 7%/K (MRI-AGCM20 (Rx1d-nTC)).**
- **MRI-AGCM180 (Rx1d): Much higher rates in the subtropics compared to MRI-AGCM20 (Rx1d).**
- **CMIP5 AOGCM (Rx1d): Considerable variability among models especially in the subtropics. On average, they follow the C-C rate (7%/K).**

The mean Rx1d generally increases due to the thermodynamic effect, but it is negatively influenced by the modulation of TC activity, which is better represented by high resolution model.

New system

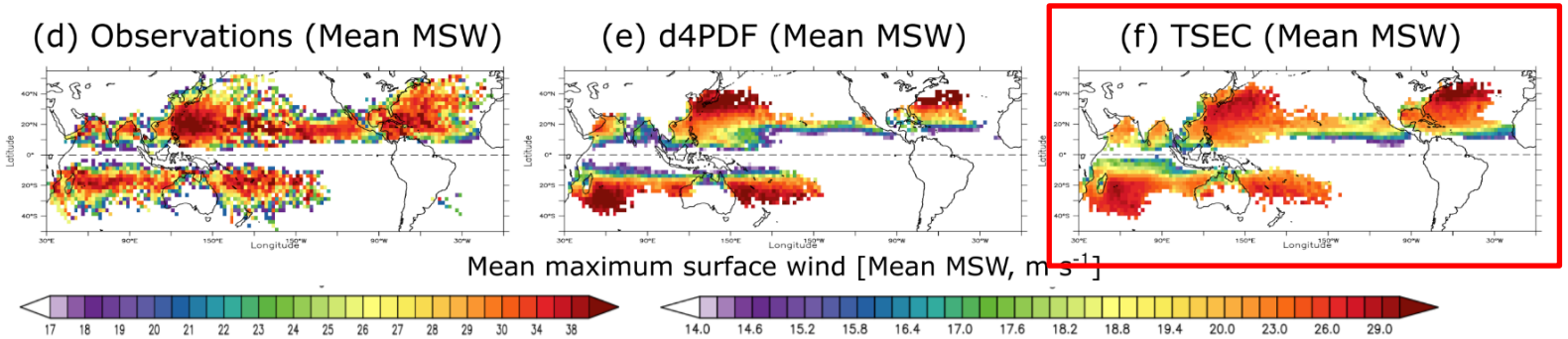
TSE-C (Temporally Sequential Experiments with Coupled model)



Ocean temperature (T) and salinity (S) are assimilated to observation with a relaxation time of about 10 days.

Global warming simulation:
Past **Observed T and S**
Future **Obs. + CMIP ΔT and ΔS**

Maximum surface wind speed (MSW) of tropical cyclone



Intense TC anomalously far poleward in WNP

TSE-C can simulate SST cooling after TC passage, leading to a reduction in intense TCs at higher latitudes compared to AGCM.

(Mizuta et al. 2025, in prep.)

Time lag at which the correlation between SST/precipitation is the highest is shown.

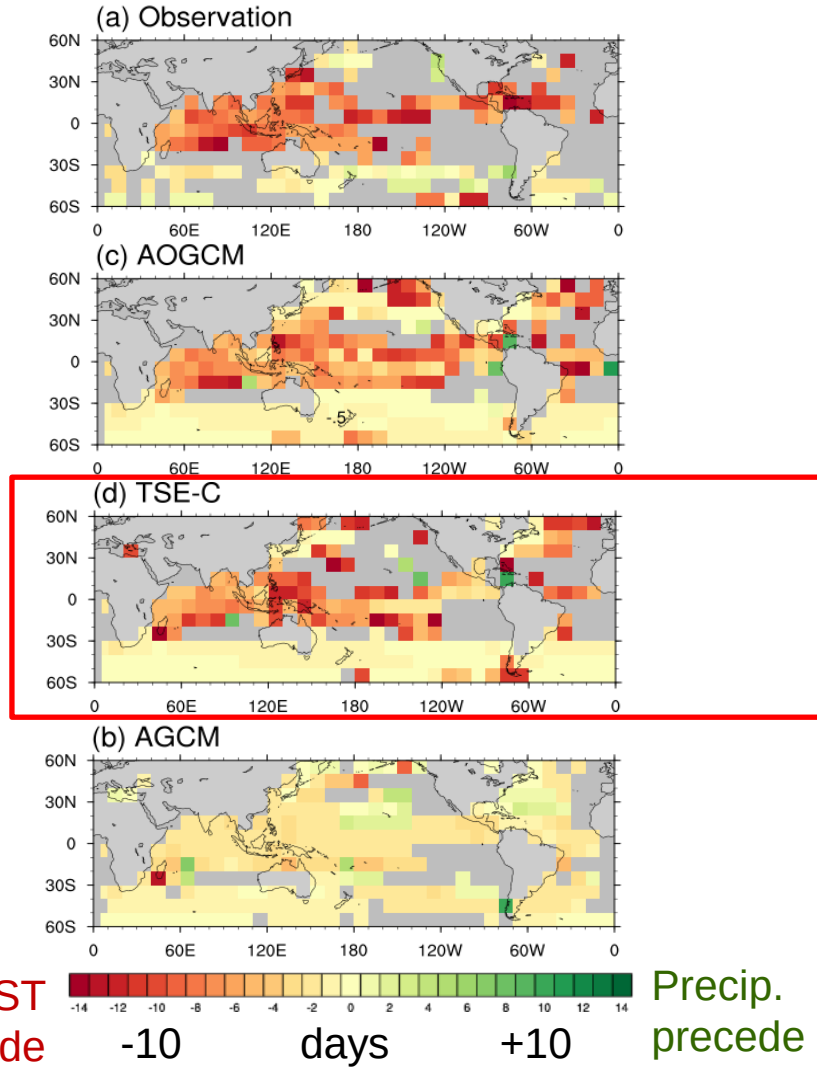
Time lag between SST/precipitation

Observation

MRI-ESM2
fully coupled

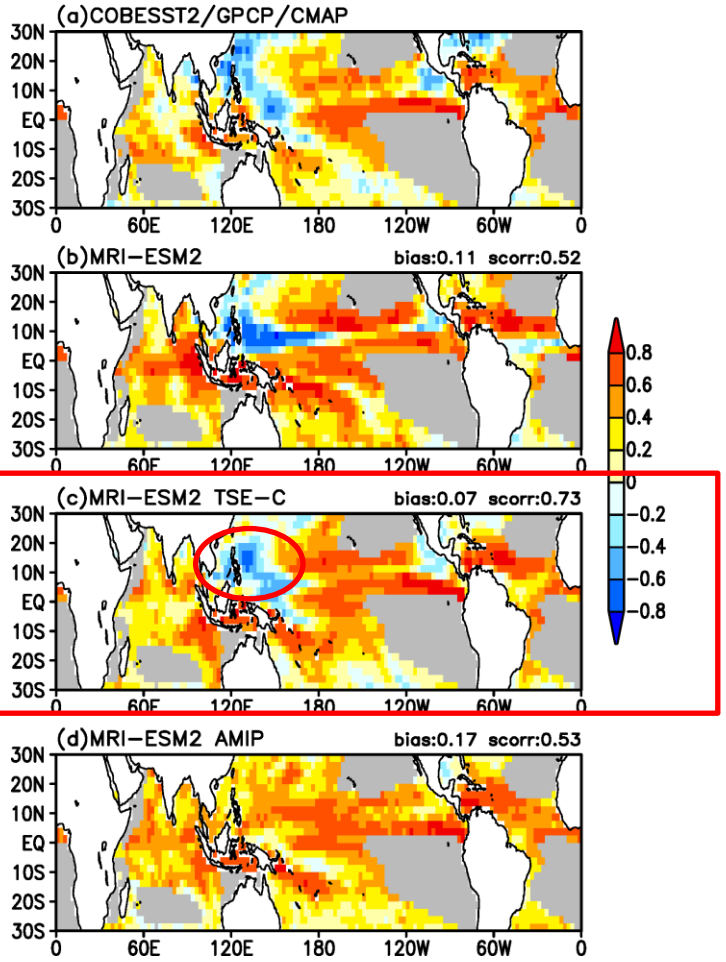
TSE-C
assimilated ocean

AGCM
prescribed SST



TSE-C reproduces the observed time lag between SST/precipitation variations

Local SST/precipitation correlation in JJA mean



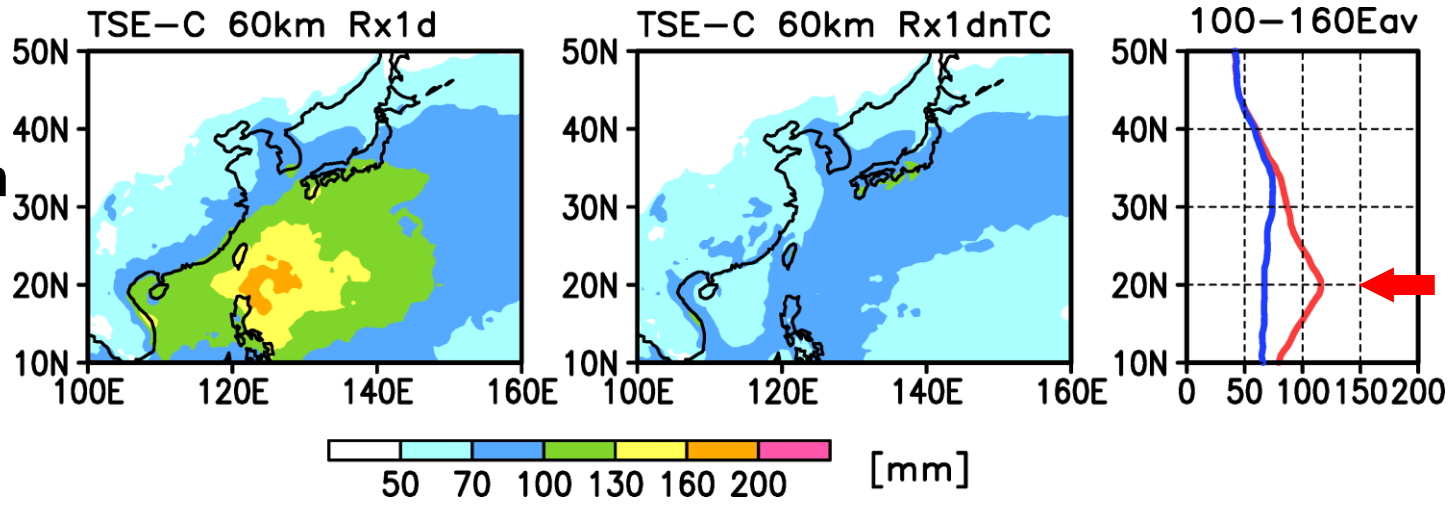
TSE-C reproduces the observed negative correlation over the WNP.

(Mizuta et al. 2025, in prep.)

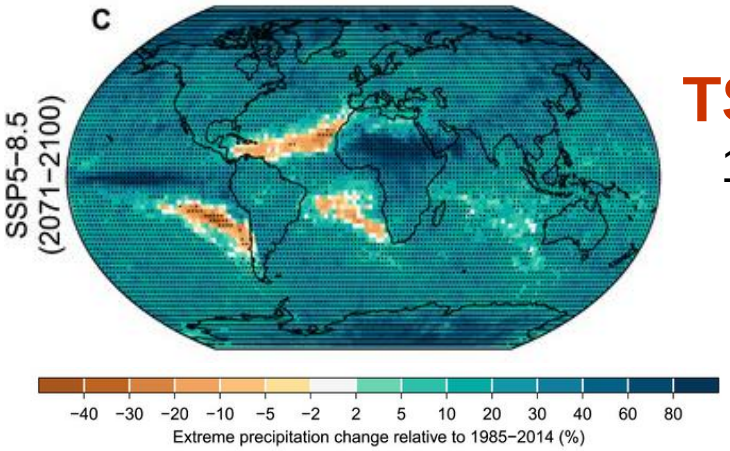
Present: 1961-2020
Future: 2041-2100

Rx1d **Rx1d-nTC**

TSE-C 60km
12 members
Present

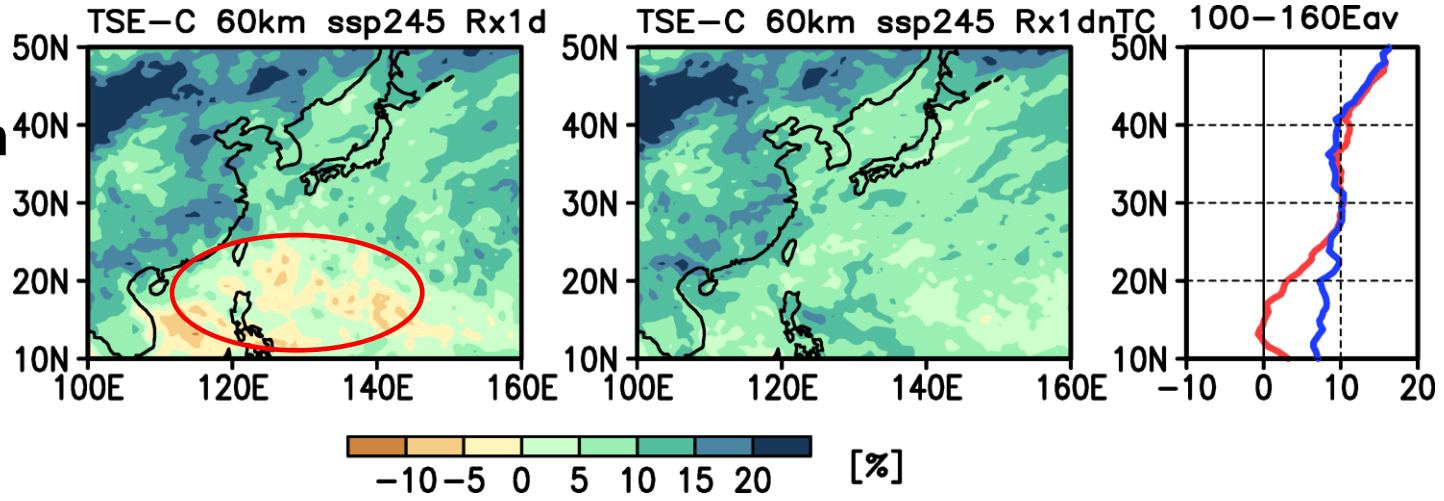


CMIP6 Rx1d



(Li et al. 2021 JCLIM)

TSE-C 60km
12 members
SSP2-4.5



In future simulations, Rx1d remains unchanged or slightly decreases in the subtropics. This is consistent with the results of the 20km-mesh AGCM simulations.

Summary

- **In the WNP-EA region, at higher latitudes, a greater rate of increase is projected for the mean Rx1d. This feature is explained by:**
  - **Greater warming at high latitudes**
  - **Decrease in TC frequency in the subtropics**

- **Future changes in the mean Rx1d in the subtropics are influenced by the positive effect of increased moisture and the negative effect of decreased TC frequency.**

- **Low-resolution models may have a systematic bias in their future projections of extreme precipitation due to underestimating the effect of TC activity.**

- **Multi-model analysis is necessary for future study.**

Endo, H., A. Kitoh, and R. Mizuta, 2022: Future changes in extreme precipitation and their association with tropical cyclone activity over the western North Pacific and East Asia in 20 km AGCM simulations. *SOLA*, **18**, 58-64, doi:10.2151/sola.2022-010.

Supplement

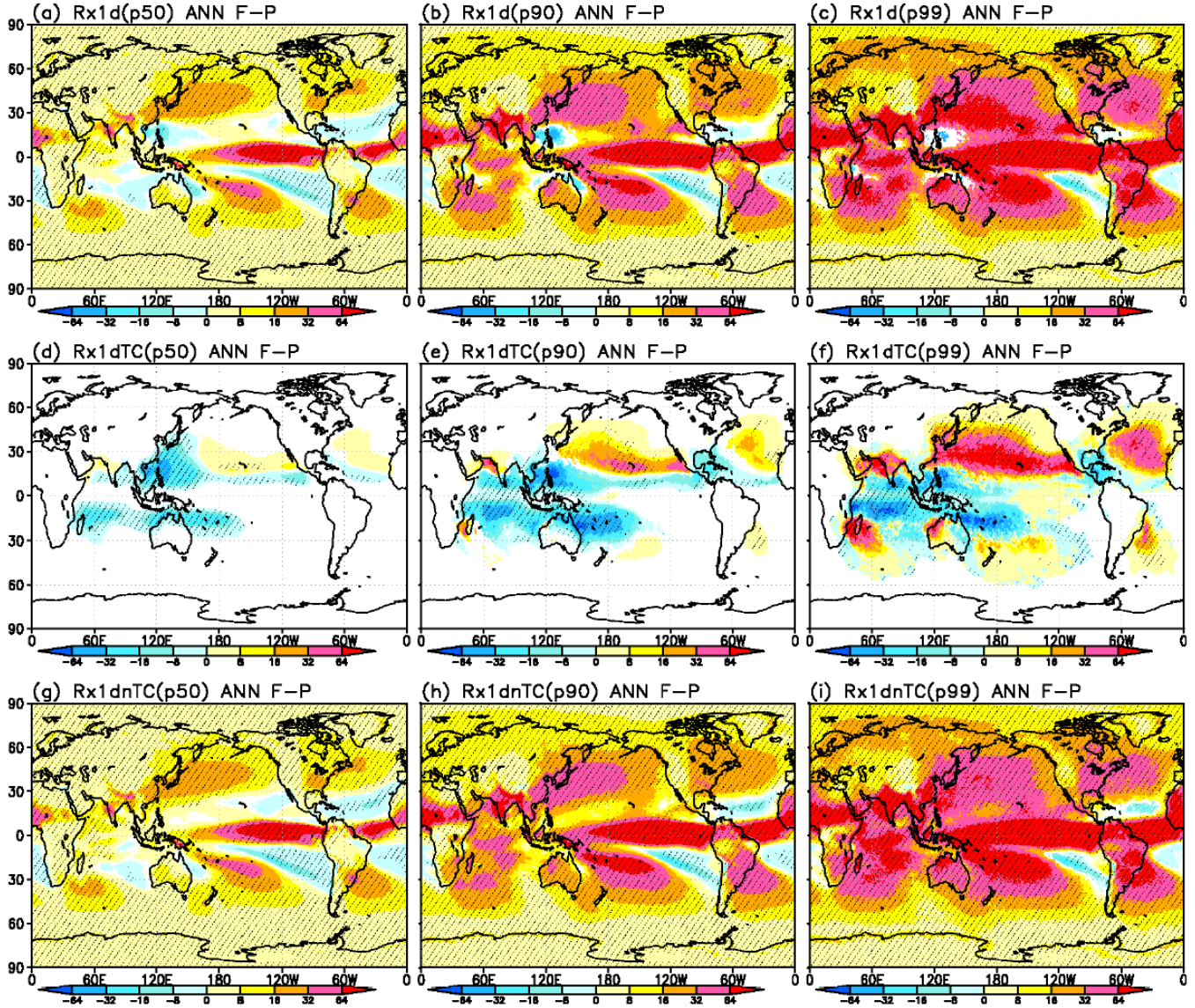
d4PDF
60km MRI-AGCM

50 percentile **90 percentile** **99 percentile**

Rx1d

Rx1d-TC

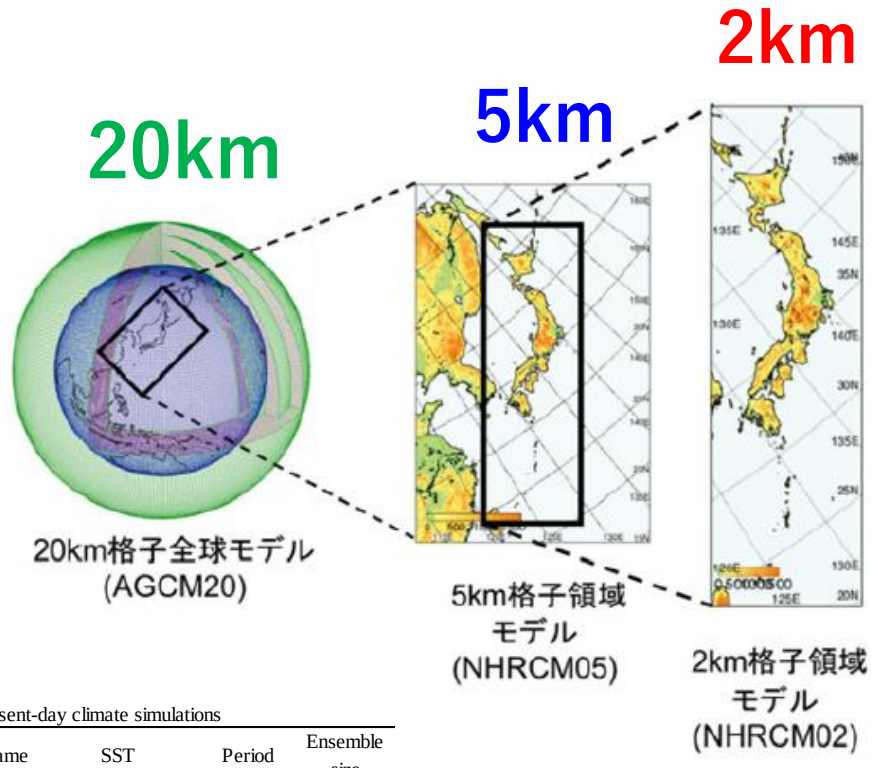
Rx1d-nTC



95%有意な格子に着色、
斜線は6つのΔSSTメンバで同じ偏差符号

The median of Rx1d-TC decreases in the WNP-EAS region, while the 90th/99th percentile values increase in EAS.

5km/2km-mesh projection over Japan



(Murata et al. 2017, SOLA)

(a) Present-day climate simulations

Run name	SST	Period	Ensemble size
SPnn[a]	HadISST1.1	1979–2003	5

(b) Future climate simulations

Run name	SST	Scenario	Period	Ensemble size
SF26C0	CMIP5 MME[b]	RCP2.6	2075–2099	1
SF26C1	CMIP5 cluster 1	RCP2.6	2075–2099	1
SF26C2	CMIP5 cluster 2	RCP2.6	2075–2099	1
SF26C3	CMIP5 cluster 3	RCP2.6	2075–2099	1
SF85C0	CMIP5 MME	RCP8.5	2075–2099	1
SF85C1	CMIP5 cluster 1	RCP8.5	2075–2099	1
SF85C2	CMIP5 cluster 2	RCP8.5	2075–2099	1
SF85C3	CMIP5 cluster 3	RCP8.5	2075–2099	1

[a] nn denotes the number of members with different atmospheric initial conditions: nn = 01–05
[b] Multi-model ensemble mean

NHRCM5km
Future change in Rx1d

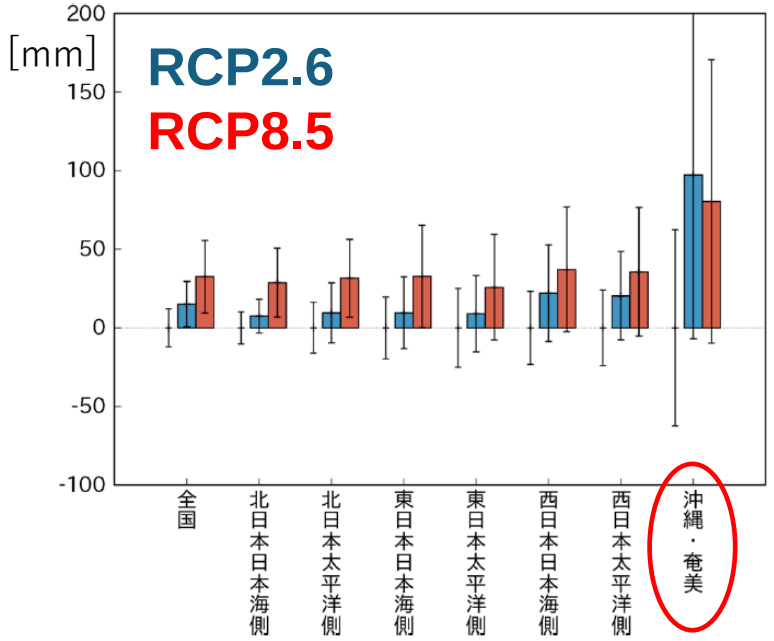


図 5.2.16　気象庁の予測による年最大日降水量の将来変化（mm）

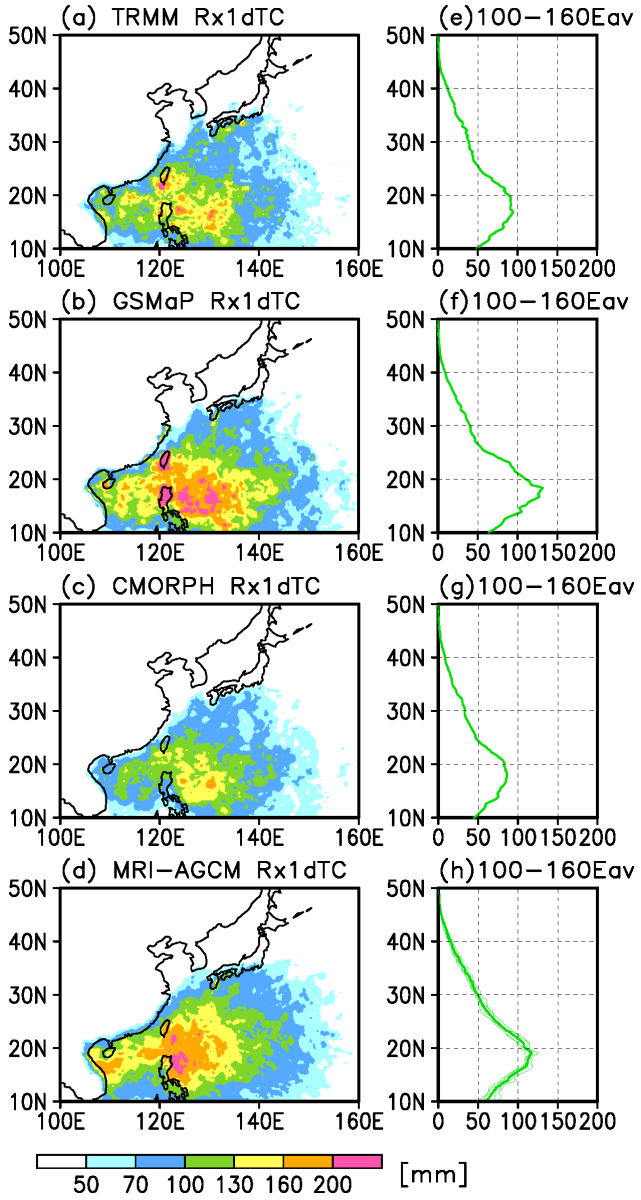
Rx1d: Annual maximum of 1-day precipitation

(JMA and MEXT, 2020)

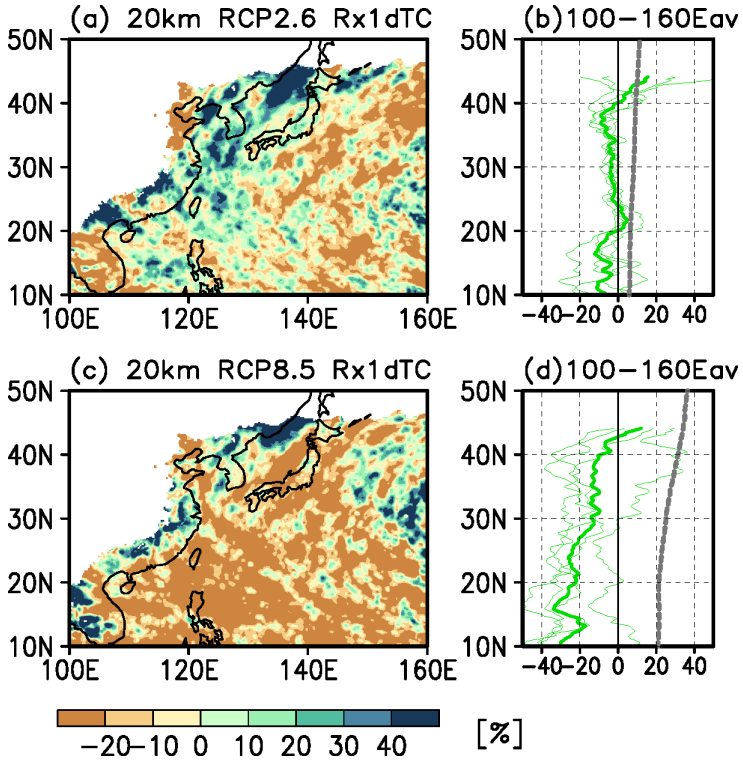
In Okinawa, Rx1d change is smaller for the RCP8.5 scenario than for the RCP2.6, despite a greater warming for the RCP8.5.

What is responsible for the unexpected result in Okinawa?

Rx1d-TC (Present)

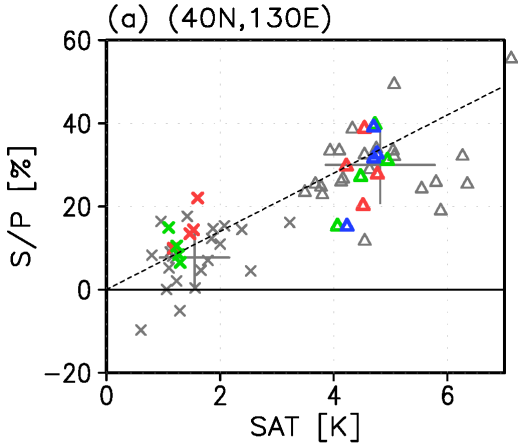


Rx1d-TC (Future change)

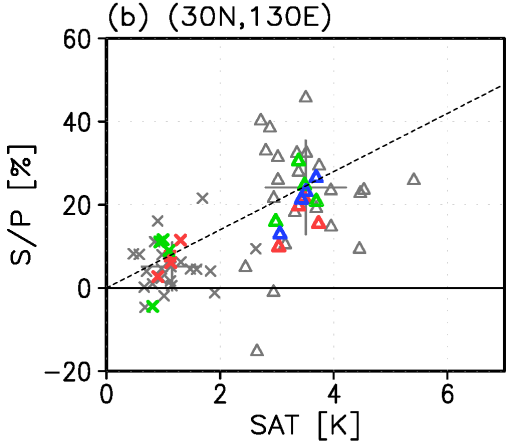


Rx1d

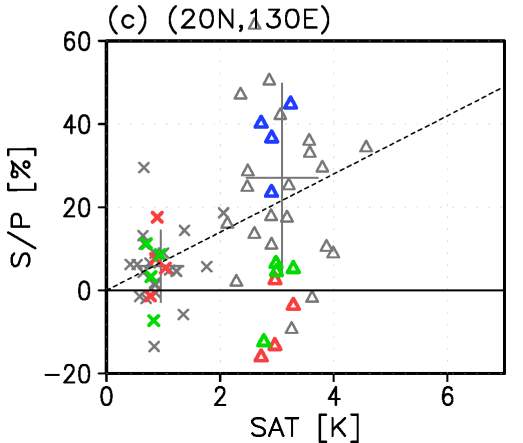
40N/130E



30N/130E



20N/130E



C-C rate (7%/K)

MRI-AGCM 20km/60km/180km

CMIP5 AOGCM

× RCP2.6

△ RCP8.5

Evaluation of climatological patterns with the Taylor Skill Score

- For many variables, the score is comparable to that of the highest-performing CMIP6 models.
- Compared to d4PDF, the performance varies depending on the variable, but overall, it is at a similar level.

× CMIP6 CGCM (historical, 41 models)
× CMIP6 AGCM (amip, 47 models)
× TSE-C 60km (12 members)
× d4PDF 60km (12 members)