High-Resolution Modeling under the Program for Risk Information on Climate Change (SOUSEI Program)

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SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

Global Change Projects using the Earth Simulator

KYOUSEI Project (FY2002-2006)

→ Contributed to IPCC AR4 (2007)

KAKUSHIN Program (FY2007-2011)

→ Contributed to IPCC AR5 (2013), SREX (2012)

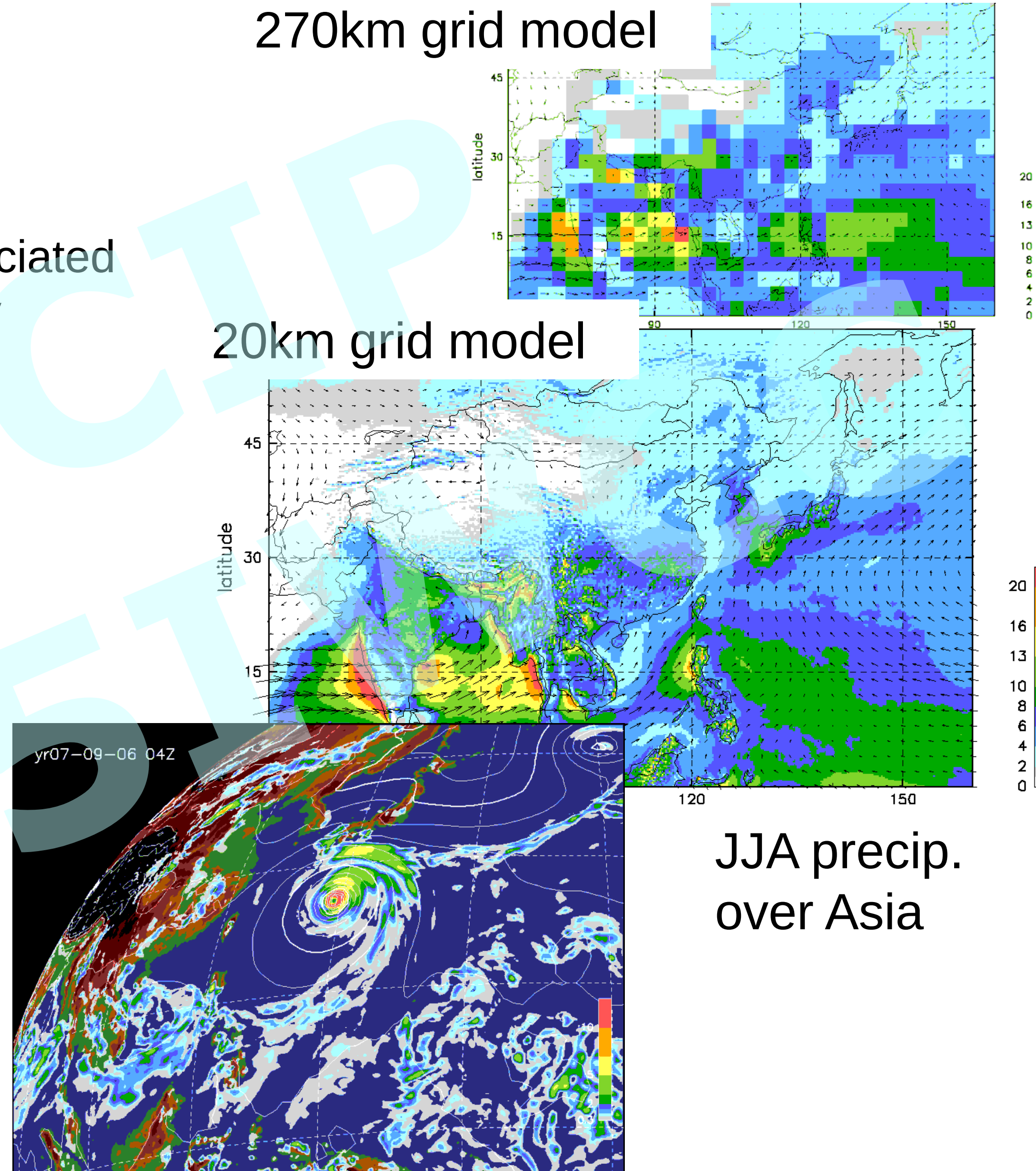
now
SOUSEI Program (FY2012-2016)
Program for Risk Information on Climate Change

Earth Simulator: ES1 (2002-2009) → ES2 (2009-2015) → ES3 (2015-)

High-resolution Atmospheric Global Climate Model

- High-resolution model
  - Small-scale structures such as tropical cyclones
  - Localized phenomena associated with small-scale topography

- Long-term simulations over several decades require good representations of:
  - Physical structures of the small-scale phenomena
  - Statistical climate of the small-scale phenomena
  - Global-scale climatology



Mizuta et al. (2006)

History of MRI-AGCM3

MRI-AGCM3.0 (before 2007) (Mizuta et al. 2006; Oouchi et al. 2006)
developed from JMA operational NWP model
first 20km climate model which simulates for multi-decades

very minor change

MRI-AGCM3.1 (since 2007) (Kitoh et al. 2009; Murakami et al. 2011)
AMIP-type experiment

introducing new parameterization schemes etc.

MRI-AGCM3.2 (current model) (Mizuta et al. 2012)

Reductions of the model biases of:
- insufficient precipitation amounts over the W. Pacific
- geographical distribution of tropical cyclones
- overestimated weak rain, underestimated heavy rain
- resolution dependence in terms of global-scale climate

Ensemble simulations with lower-resolution version

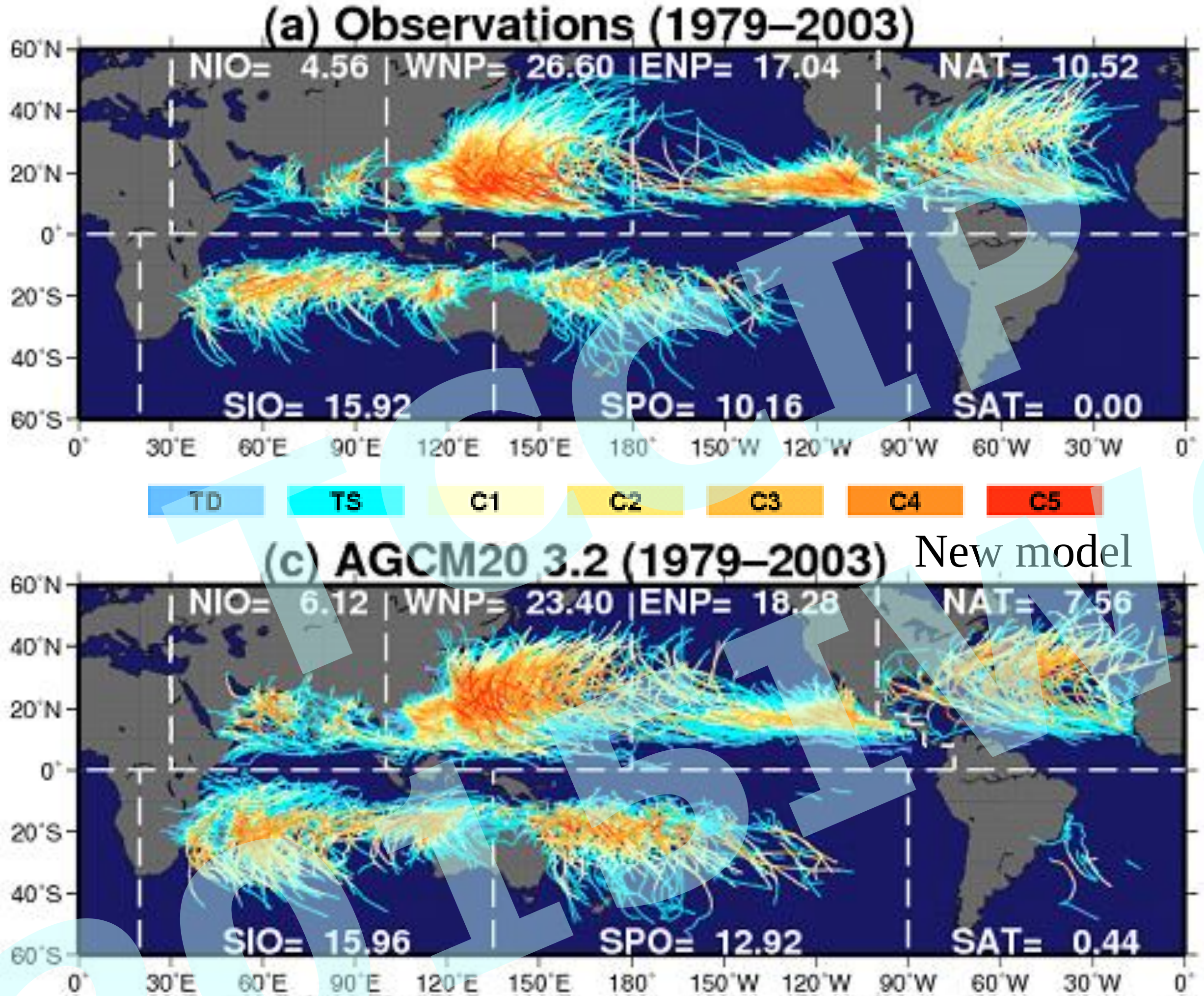
MRI-AGCM3.3 (2015~) including air-sea interaction

MRI-AGCM 3.1 vs 3.2

Previous version (for IPCC AR4) | New version (for IPCC AR5)

	MRI-AGCM 3.1 (Mizuta et al., 2006, *JMSJ*)	**MRI-AGCM 3.2** (Mizuta et al., 2012, *JMSJ*)
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 Arakawa-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	

Problems with the previous 20-km mesh MRI-AGCM



New model

Number for each basin denotes the annual mean number of TCs.

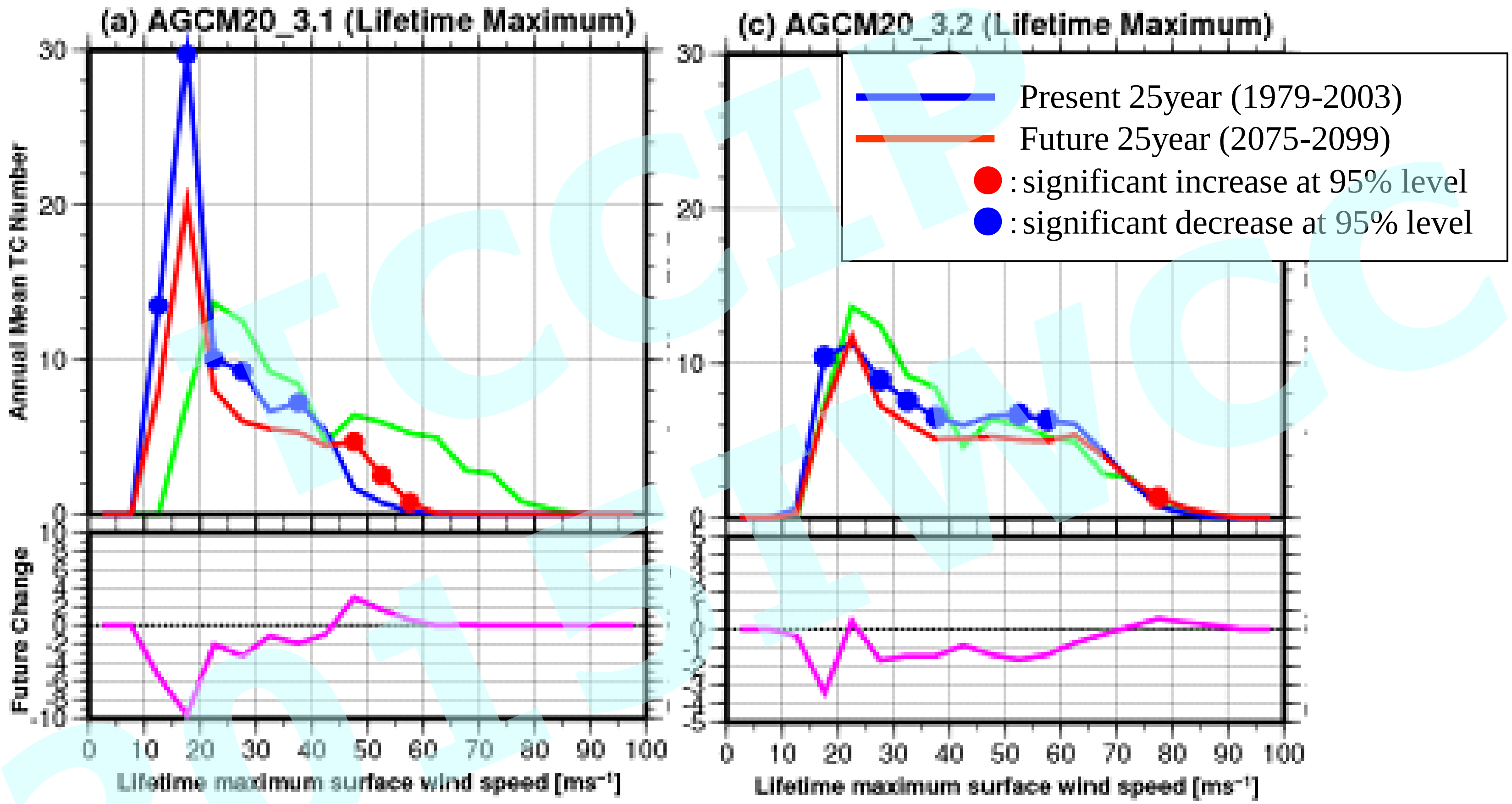
Predicted TC number in the WNP is underestimated   Improved

TC intensity is weak compared with observations   Improved

Murakami et al. (2012)

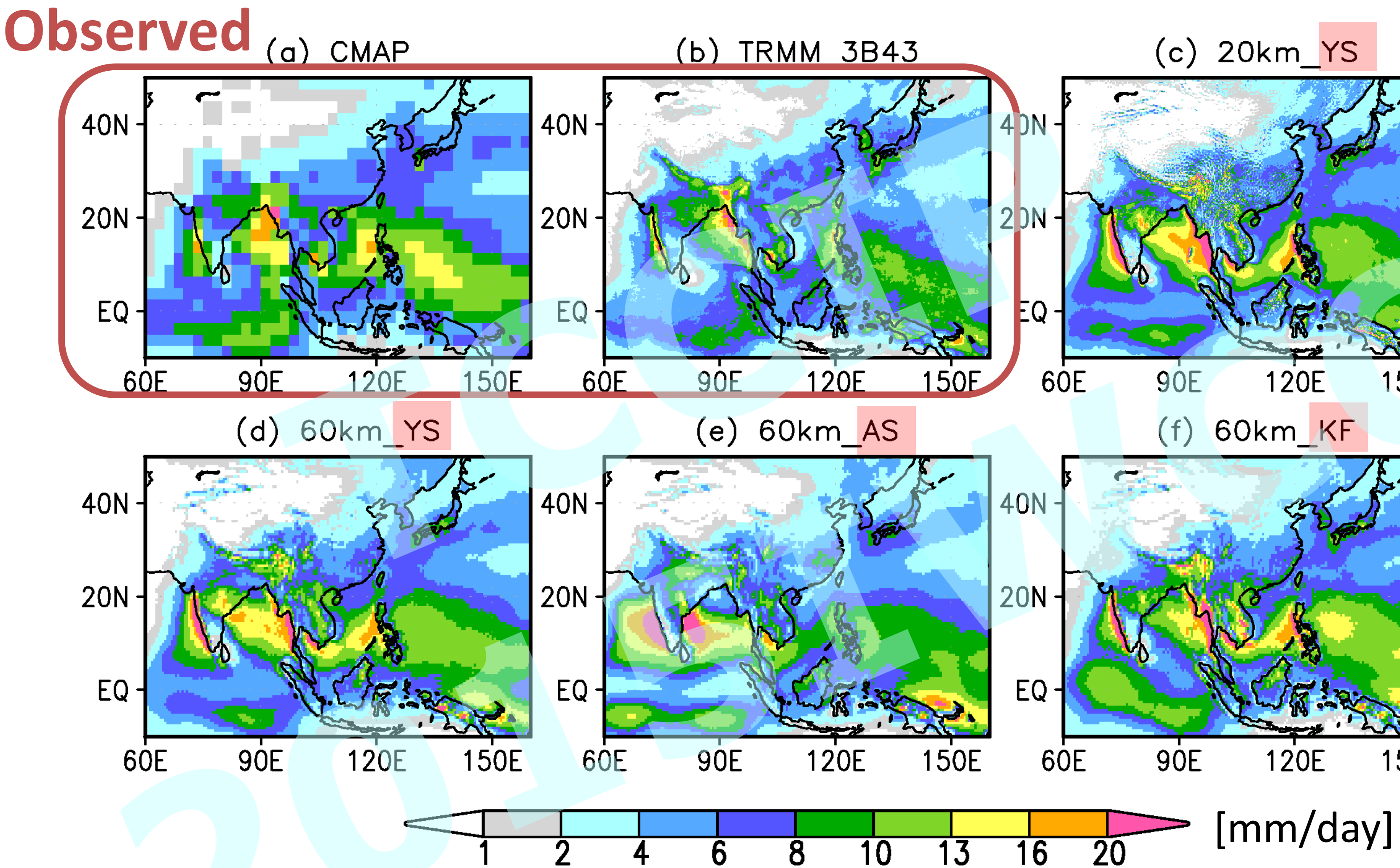
Comparison of projected future changes between models – TC intensity –

MRI-AGCM3.1 **MRI-AGCM3.2**



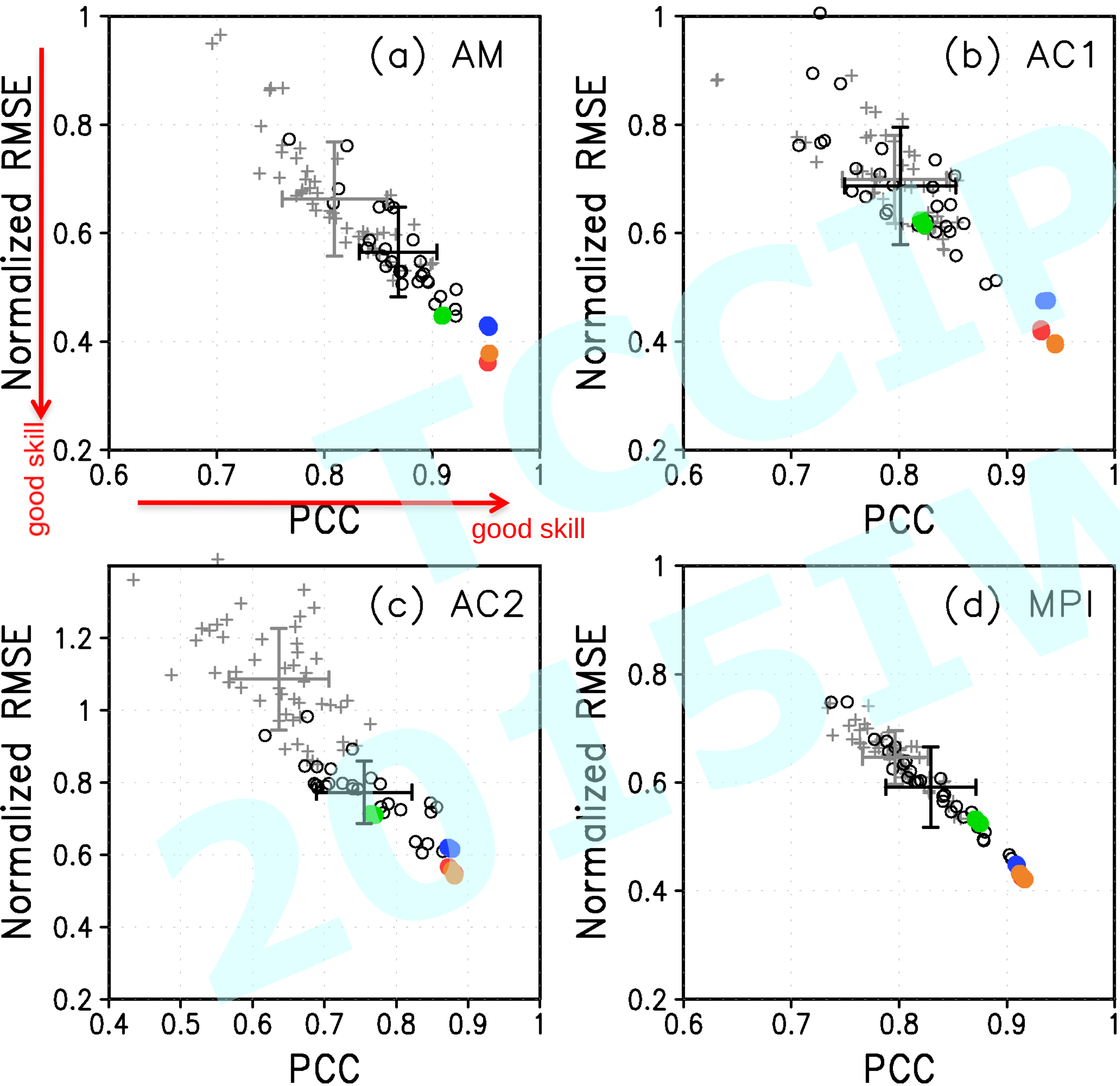
- Both models show significant decrease in the frequency of weak TCs
- New model (MRI-AGCM3.2) projects a more subtle increase in the frequency of intense TCs

JJA precipitation



All AGCMs successfully reproduces broad-scale rainfall patterns as well as orographic rainfall, although there are some differences among the models.

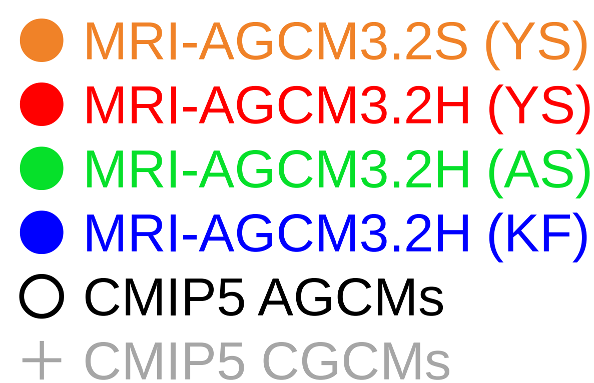
Performance of MRI-AGCM3.2S (20km) & H (60km)



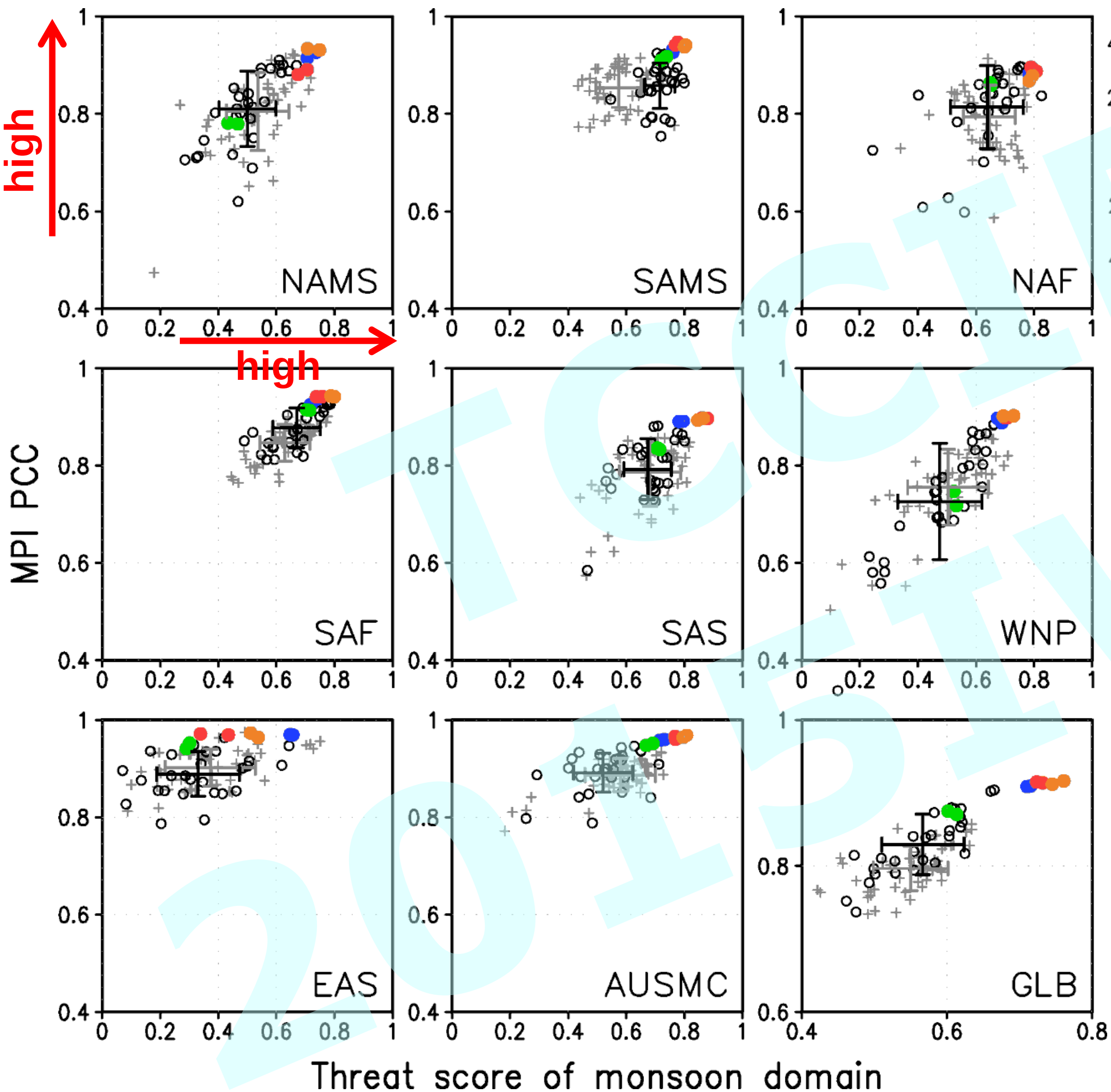
4 monsoon metrics based by Wang et al. (2011 Clim Dyn)

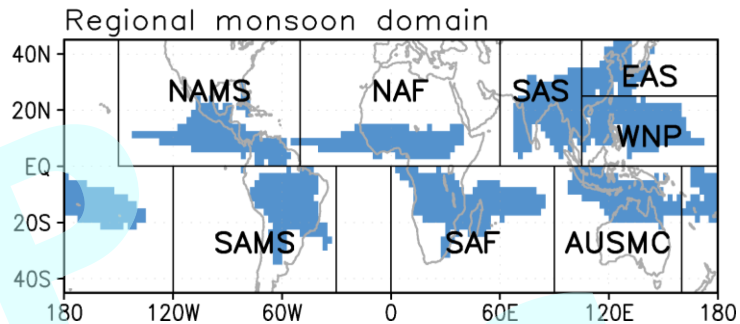
Area: 45S-45N
Ref.: (GPCP+CMAP)/2

RMSE: root mean square error,
PCC: pattern correlation coefficient



Performance of MRI-AGCM3.2S (20km) & H (60km)

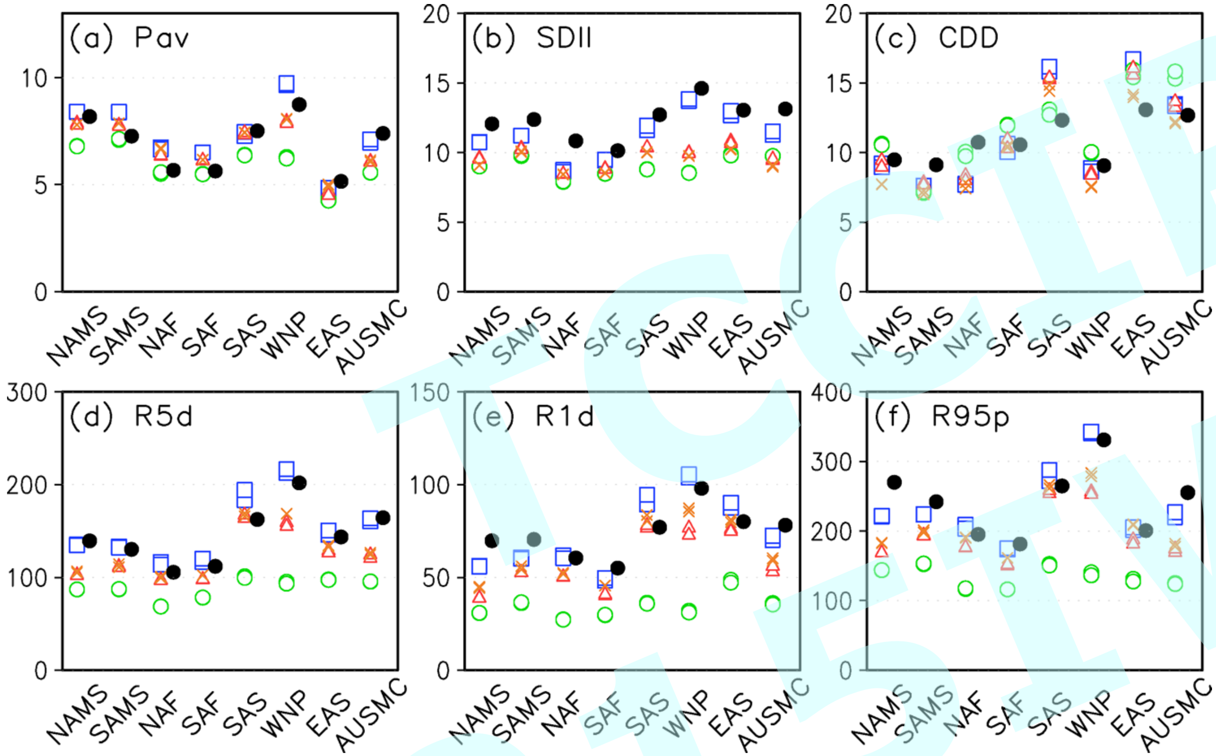


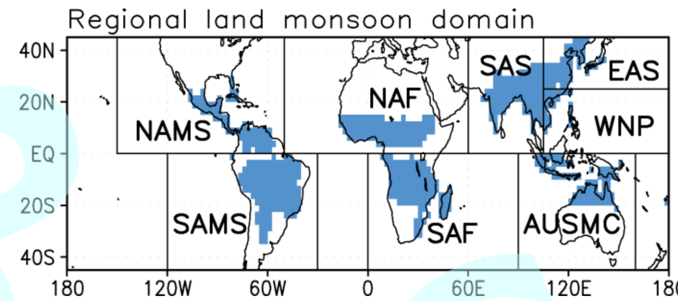


x-axis：pattern correlation of MPI = (max-min)／mean
y-axis：Threat score of monsoon domain

- MRI-AGCM is better than CMIP5 models
- 3.2H(AS) is not good
- Most models are poor for EAS monsoon
- WNP & EAS：
  CMIP5_AGCM < CMIP5_CGCM
  (air-sea interaction?)

Performance of precipitation extremes





Extremes indices

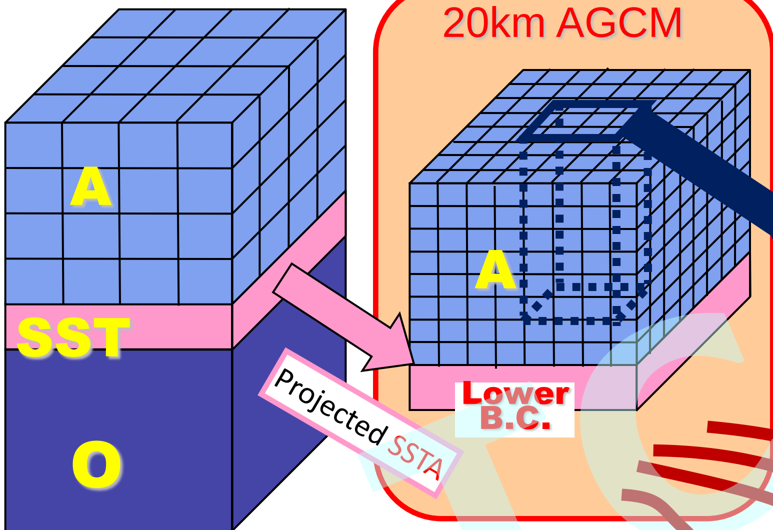
- **Pav** mean [mm/day]
- **SDII** intensity [mm/day]
- **CDD** consecutive dry days [day]
- **R5d** max 5-day precip [mm]
- **R1d** max 1-day precip [mm]
- **R95p** sum of above 95%-ile [mm]

× MRI-AGCM3.2S (YS)
△ MRI-AGCM3.2H (YS)
○ MRI-AGCM3.2H (AS)
□ MRI-AGCM3.2H (KF)
● obs（TRMM-3B42）

rainy season over land
re-grid to 60-km

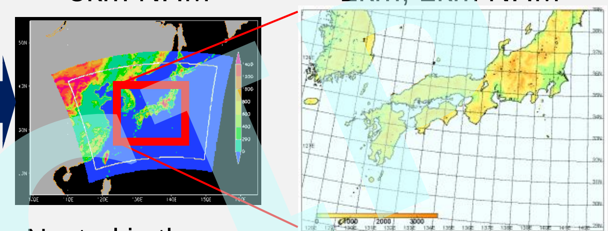
- **Pav & CDD: all models have high skill**
- **R5d、R1d、R95p: YS and KF are good, AS has negative bias**

Time-Slice Experiments using SST from CGCMs



Regional Climate Model

Dynamical Downscaling by RCM



Nested in the 20km AGCM

Nested in the 5km NHM

Impact Assessments

– Disasters
– Agriculture
– Water Resources

Study of Future Change in Extreme Events

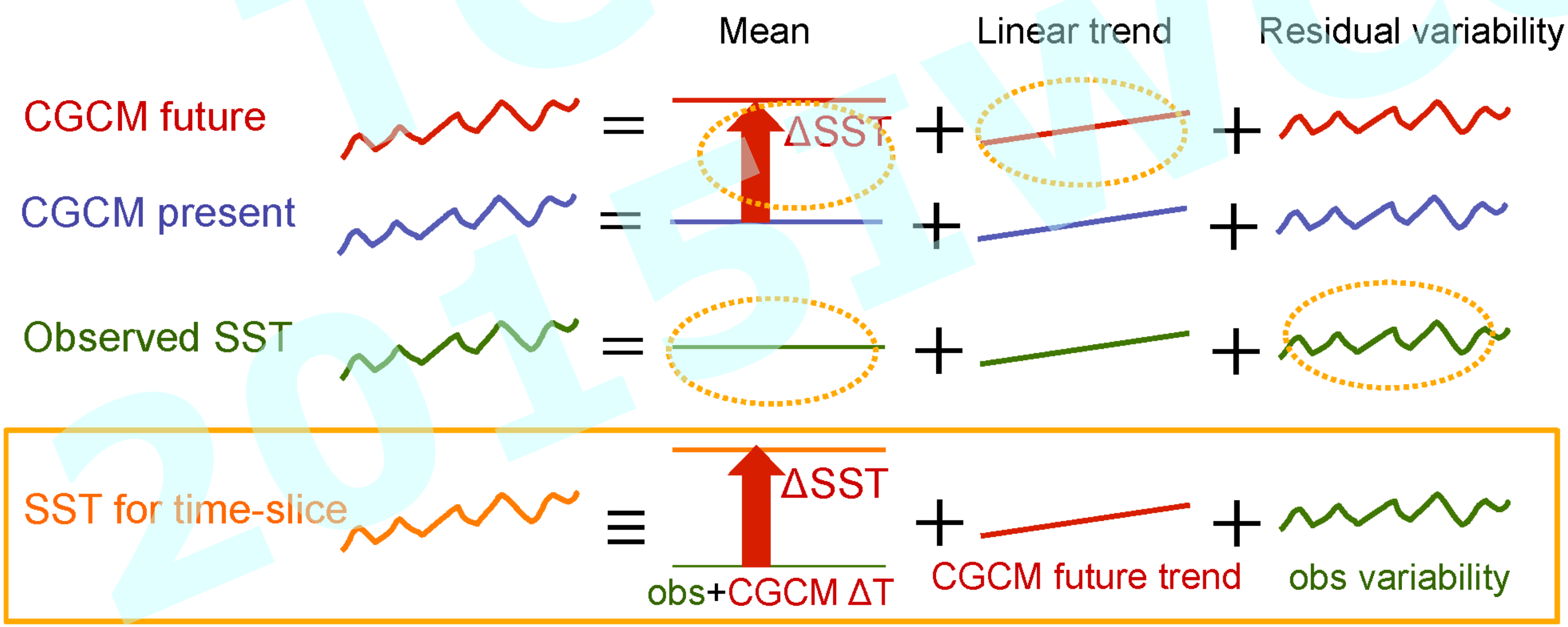
– Tropical Cyclones (e.g. Oouchi et al., Murakami et al.)
  →less number, more intense
– East Asia Monsoon (e.g. Kusunoki et al.)
  →seasonal migration delayed
– Extreme Rainfall (e.g. Kamiguchi et al.)
  →more frequent
– Blockings (e.g. Matsueda et al.)
  →less frequent
– Extratropical Cyclones (e.g. Mizuta et al.)

Regional Climate Change

– Outputs provided to researchers of each region
  (Korea, China, Taiwan, Philippines, Thailand, Indonesia, Viet Nam, Bangladesh, India, Israel, Saudi Arabia, Senegal, Spain, Netherland, UK, Ireland, Denmark, Switzerland, Germany, USA, Mexico, Columbia, Barbados, Belize, Bolivia, Peru, Ecuador, Brazil, Argentina, Australia, Papua New Guinea)

Setup of time-slice experiments

- Present-day climate experiment (1979-2003): AMIP-type
  - observed SST and sea–ice concentration
  - observed global–mean concentrations of CO2 and other GHGs
- Future climate experiment (2075-2099)
  - SST warming in the CMIP coupled models is added to the obs. SST
  - changing concentrations of GHGs following the emission scenario



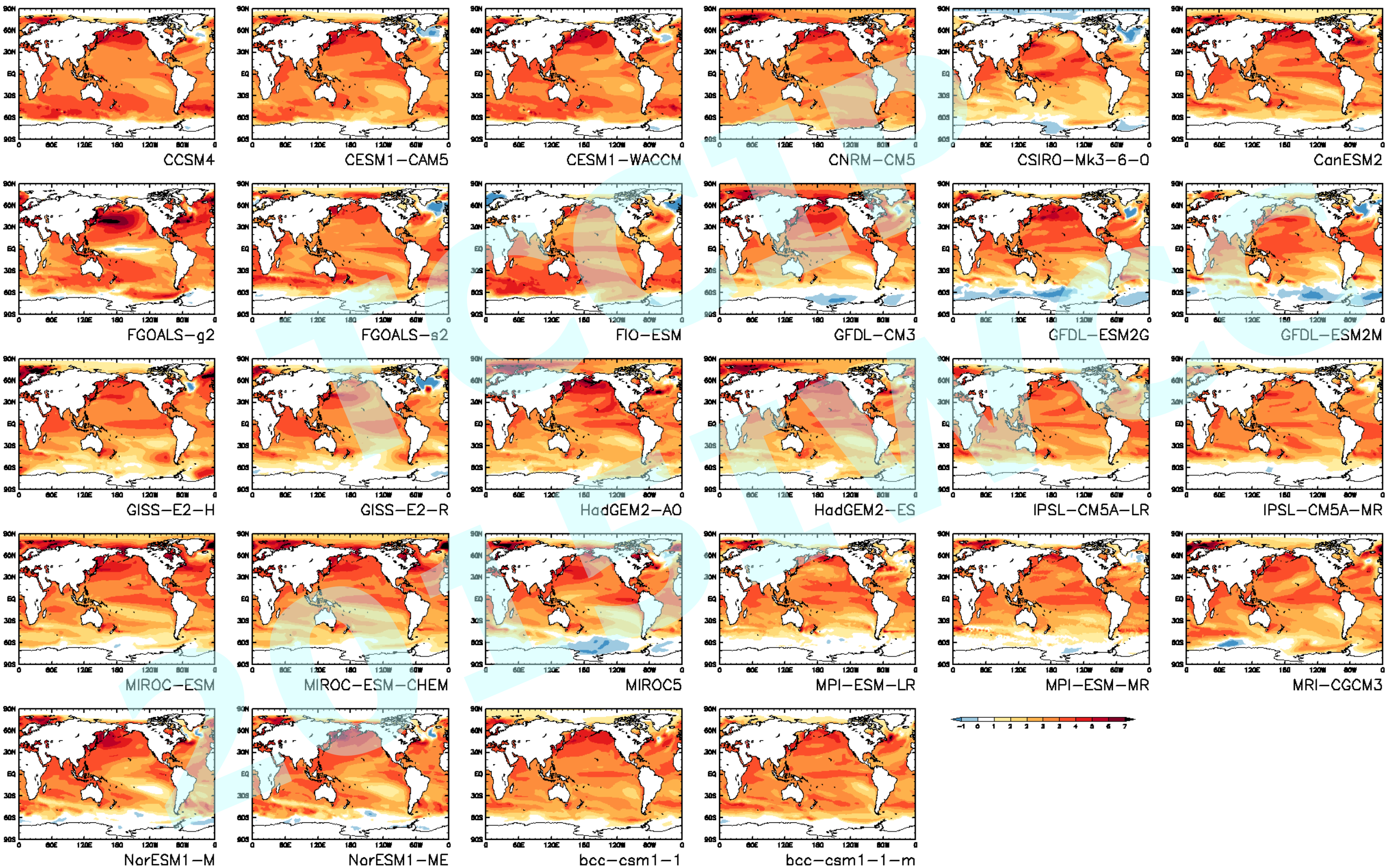
Cluster analysis of ΔSST pattern of CMIP5 models

- SST ensemble experiments uses 3 clusters of warming pattern, in addition to the average of all models.
- 28 CMIP5 models, of which historical+RCP2.6/4.5/8.5 results are available, are used.
- Basically the same method as before

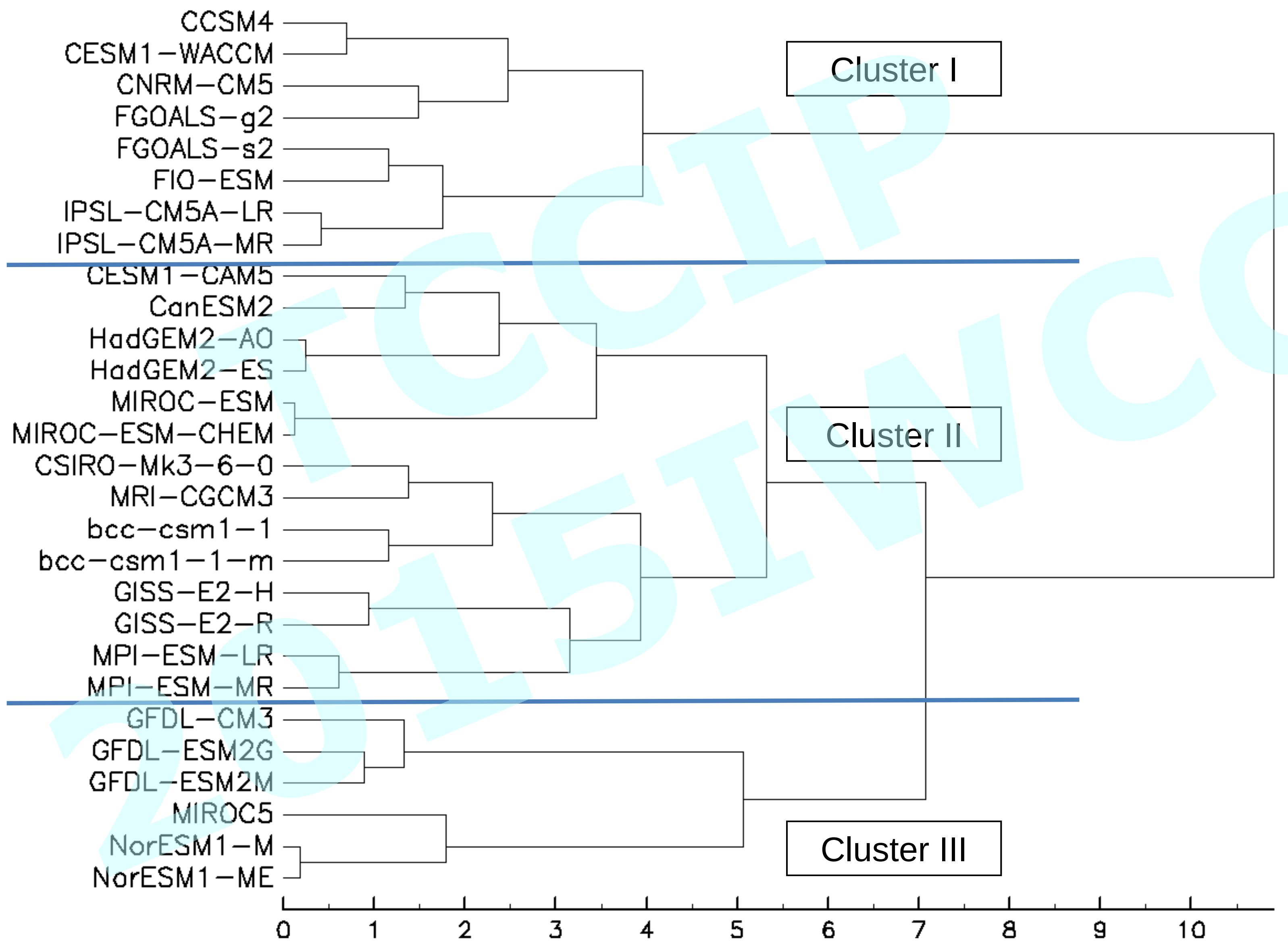
(Endo et al., 2013, JGR; Murakami et al., 2012, Clim. Dyn.)

1. For each model, a mean future SST change is computed by subtracting the 1979-2003 mean from the 2075-2099 mean.
2. The computed mean SST change is normalized by the tropical mean (30° S–30° N) SST change.
3. Multi-model ensemble mean of the normalized value is subtracted from that for each model.
4. The inter-model pattern correlation *r* of them are computed between all pairs 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.

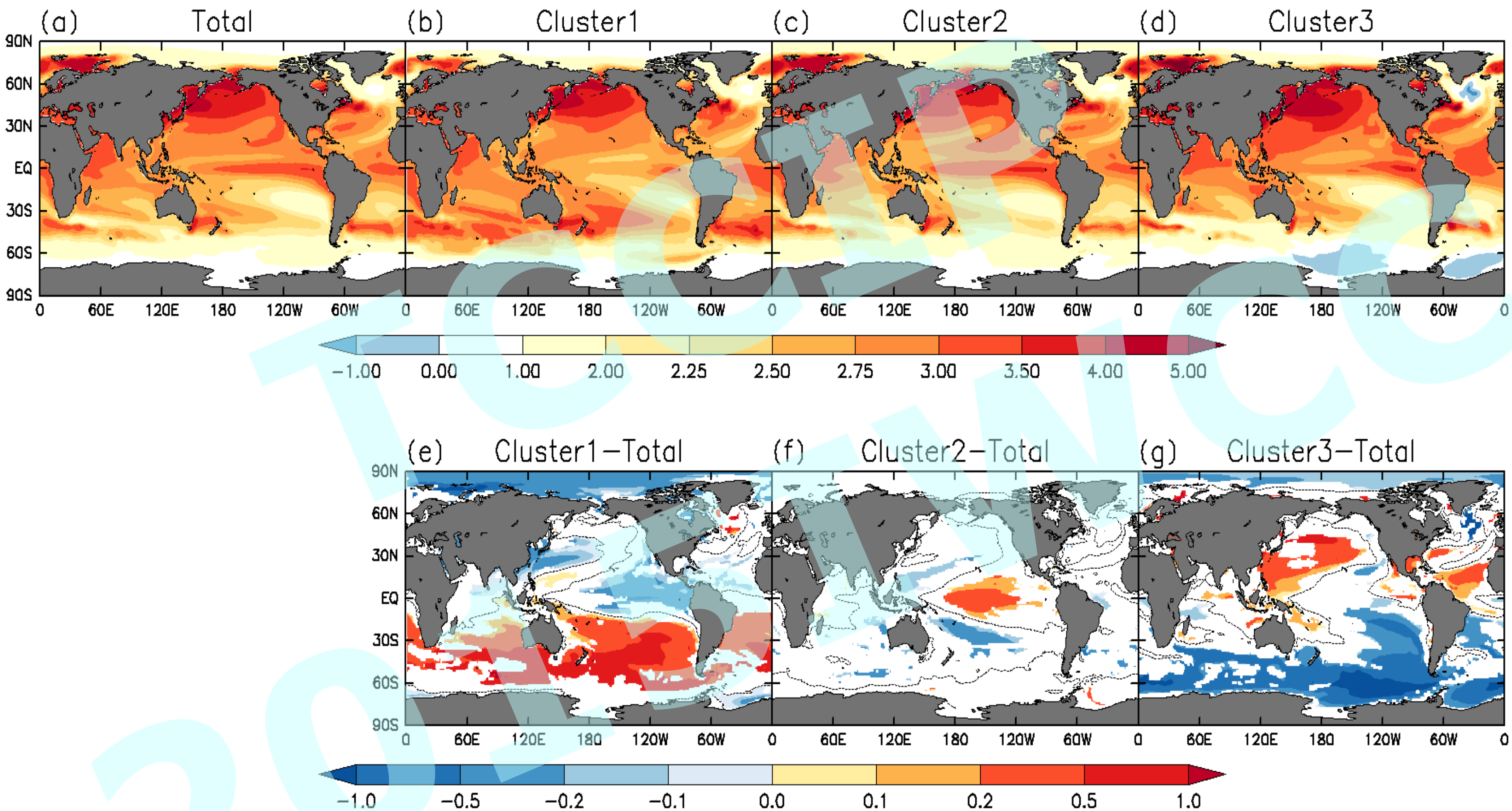
CMIP5 normalized SST change (RCP8.5-historical)



Cluster analysis results

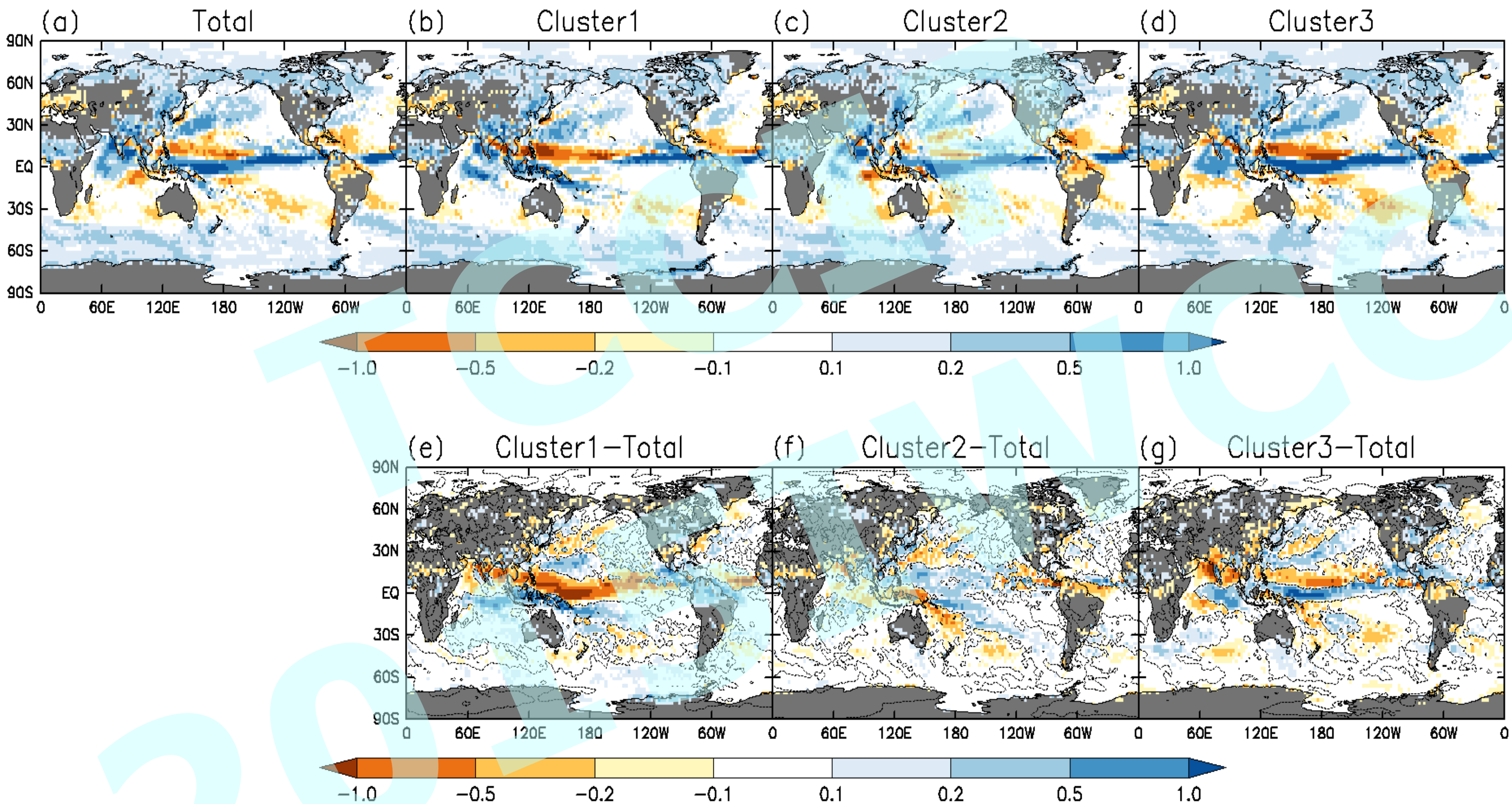


Cluster analysis of CMIP5 RCP8.5 SST



Mizuta et al. (2014)

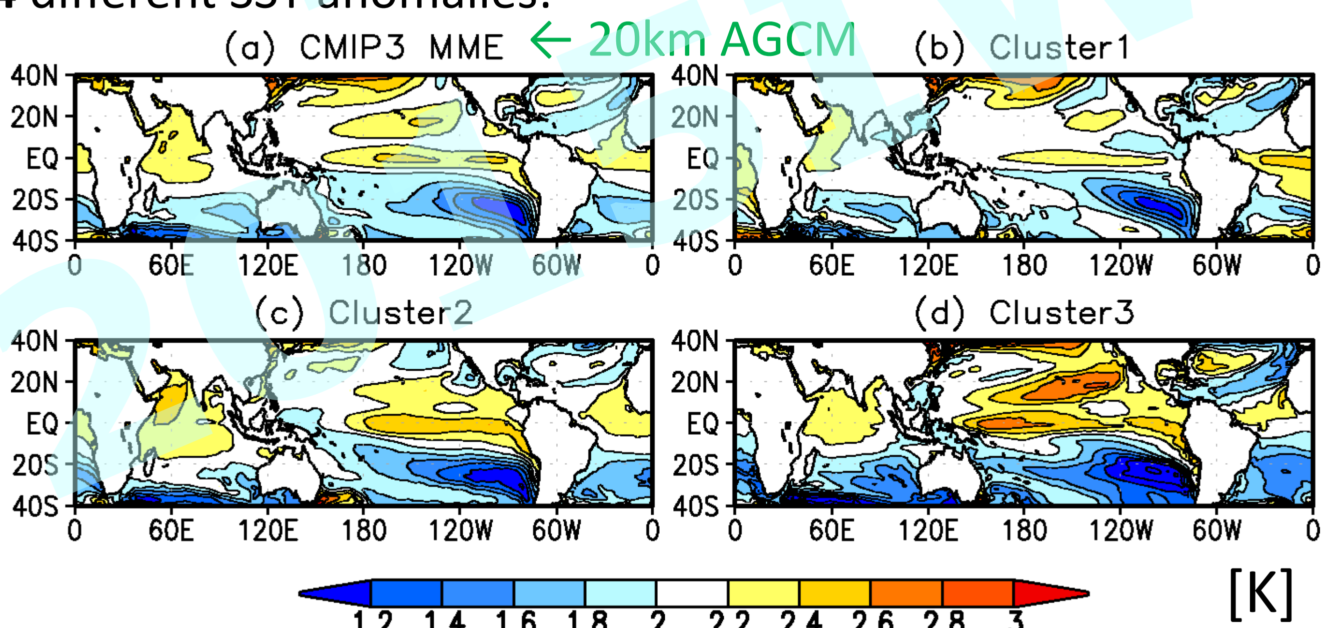
Composite of precipitation anomalies



Mizuta et al. (2014)

Ensemble projections by AGCMs

- Present-day climate experiment (1979-2003): AMIP-type
  - observed SST and sea-ice concentration
- Future climate experiment (2075-2099)
  - SST warming in the CMIP coupled models is added to the observed SST
- 20-km mesh AGCM: **1** projection
- 60-km mesh AGCMs: **3** physics × **4** SST (× **2** initial
  - ✓ **3** different physics:
    - Yoshimura (**YS**) Arakawa-Schubert (**AS**) Kain-Fritsch (**KF**) cumulus schemes
  - ✓ **4** different SST anomalies:



CMIP3(5)

A1B (RCP8.5)

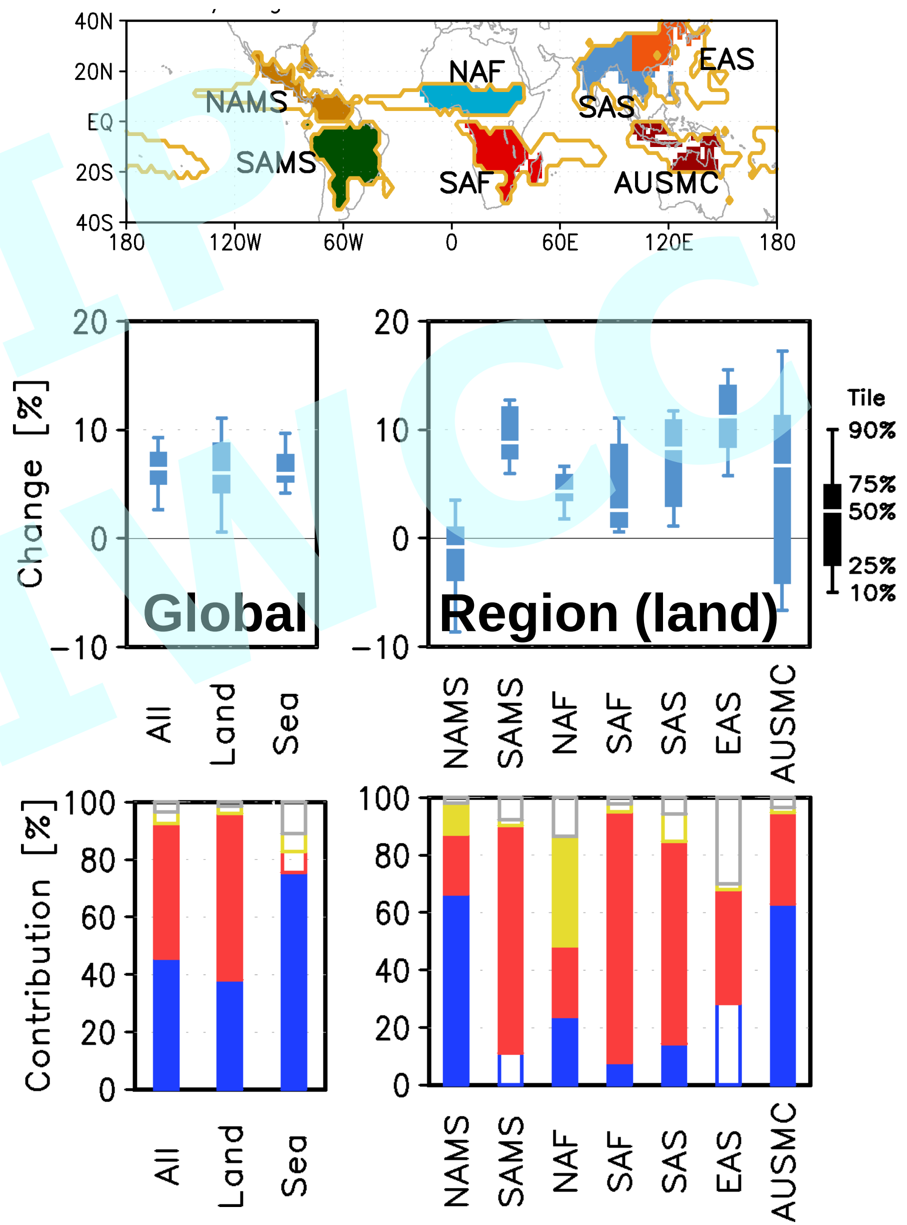
MME and 3 clusters from 18 (28) models

Uncertainty in monsoon precipitation changes

ΔSST（4）× cumulus（3）× initials（2）

$S = S_a + S_b + S_{ab} + S_e$

S: total variance
Sa: **SST**
Sb: **cumulus scheme**
Sab: cross (a and b) variance
Se: internal variability



- **East Asia**: Precipitation change ratio is largest and uncertainty is smallest
- **South Asia**, South America, South Africa: Cumulus scheme is responsible for inter-model variability
- North America, Australia and Maritime Continent: SST is responsible for inter-model variability

Global 60-km model ensemble

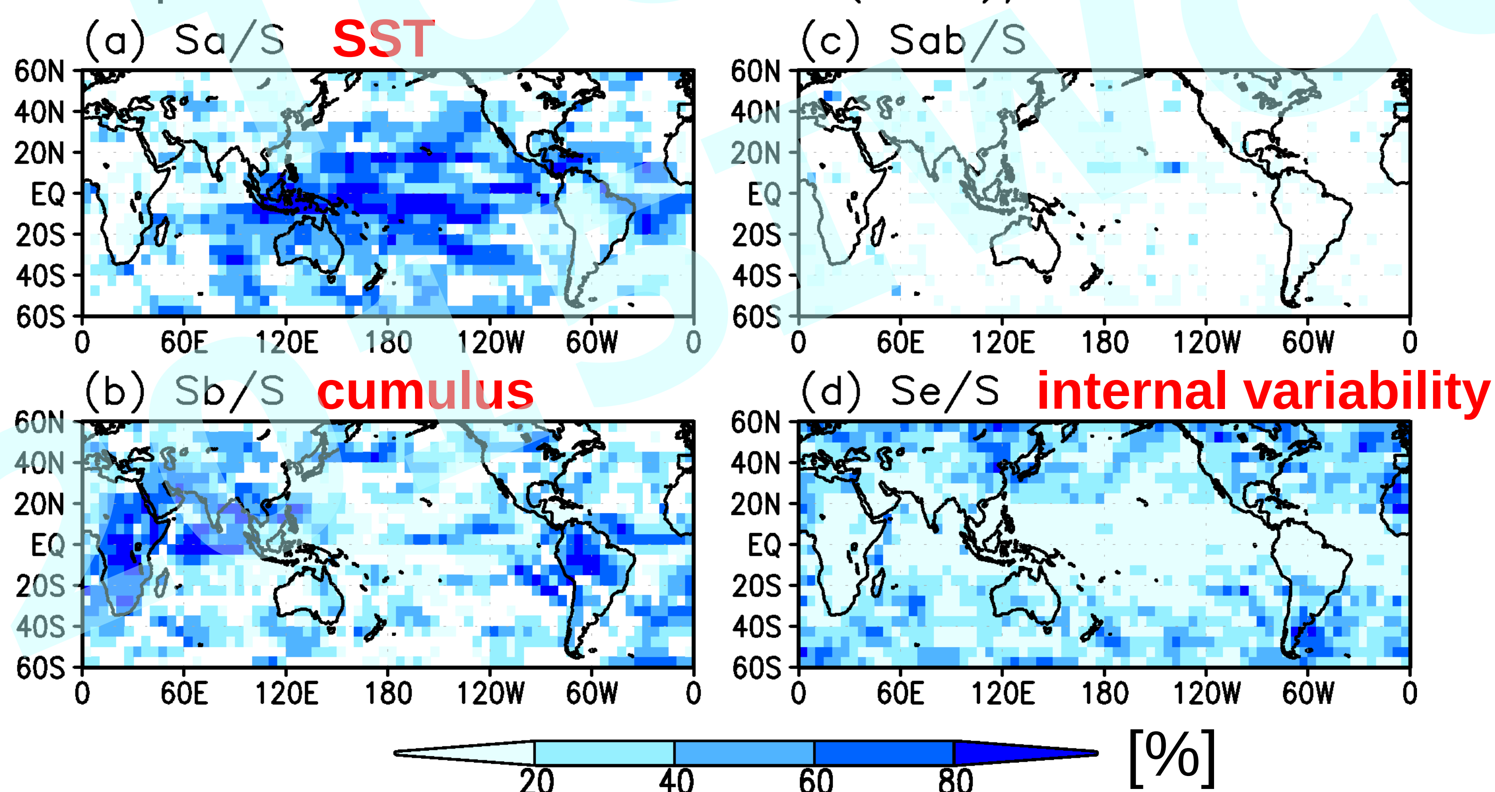
ΔSST（4）× cumulus（3）× initials（2）

Uncertainty in projections

$$S = S_a + S_b + S_{ab} + S_e$$

S: total variance
Sa: **SST**
Sb: **cumulus scheme**
Sab: cross (a and b) variance
Se: **internal variability**

Annual Precipitation HFAx24 PAV (F−P)/P



Uncertainty analysis

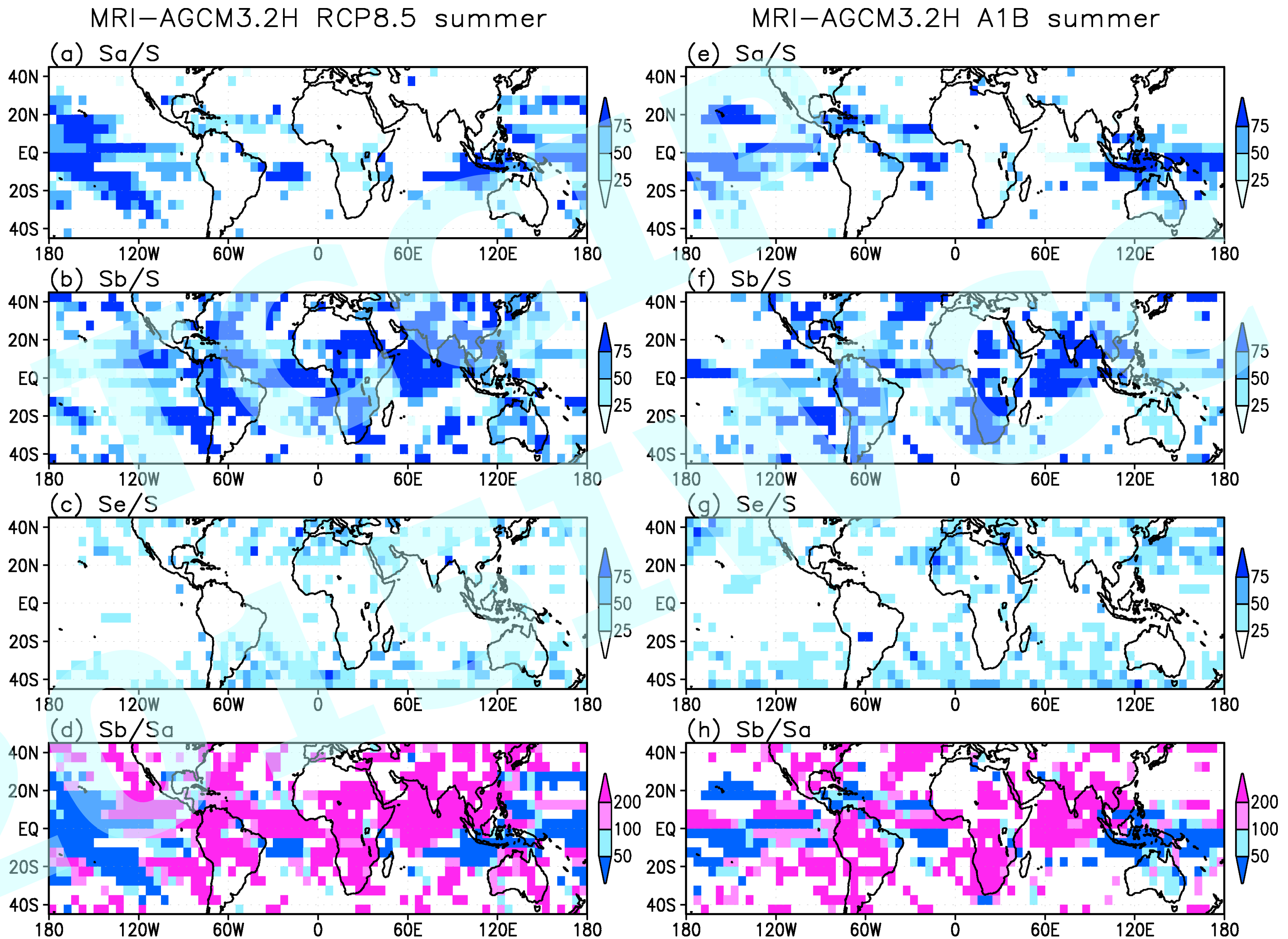
CMIP5 RCP8.5 SST | CMIP3 A1B SST

SST factor

cumulus scheme

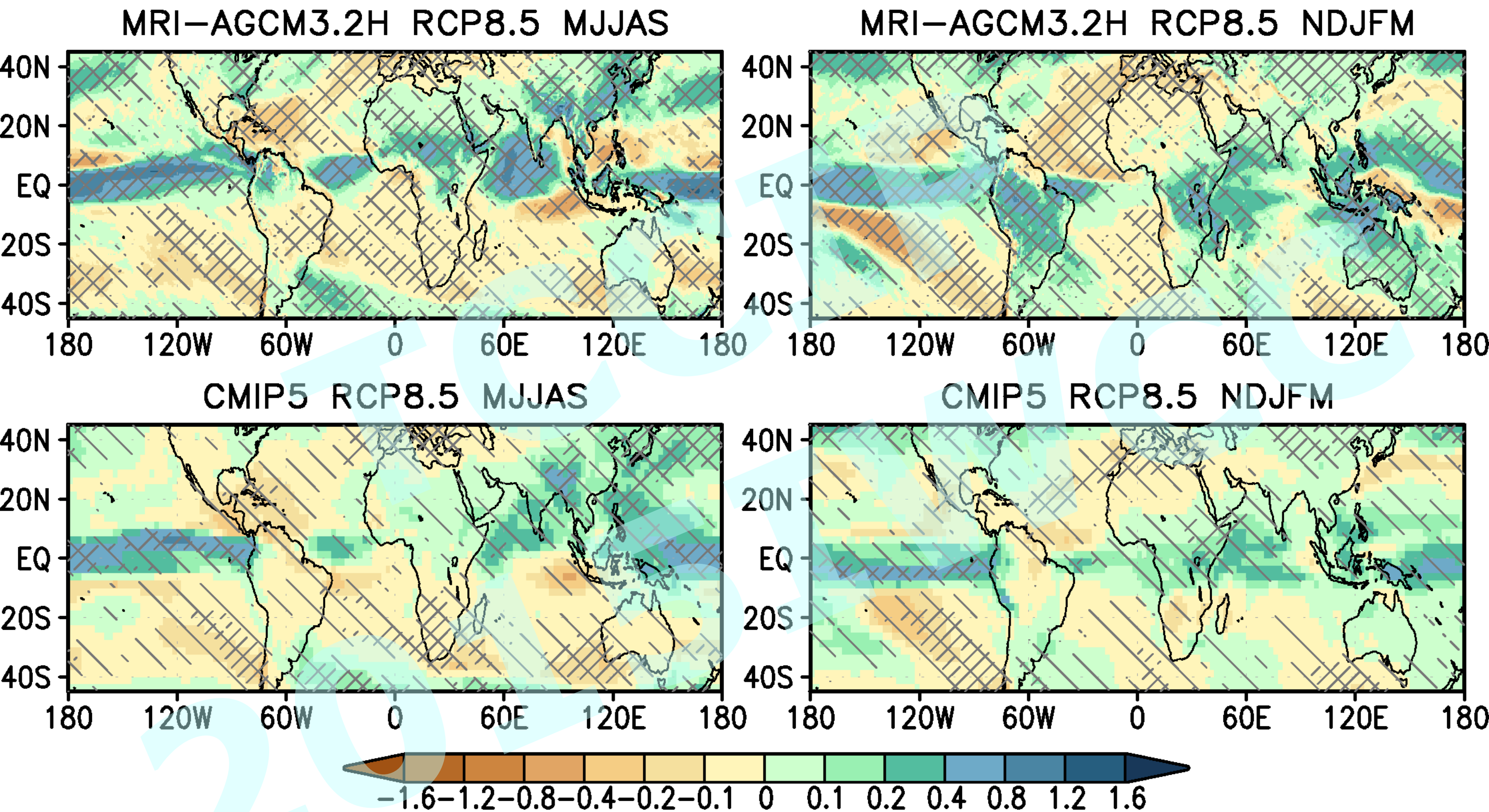
internal

SST
cumulus



In RCP8.5 where warming is larger, relative contribution of cumulus scheme on uncertainty becomes larger

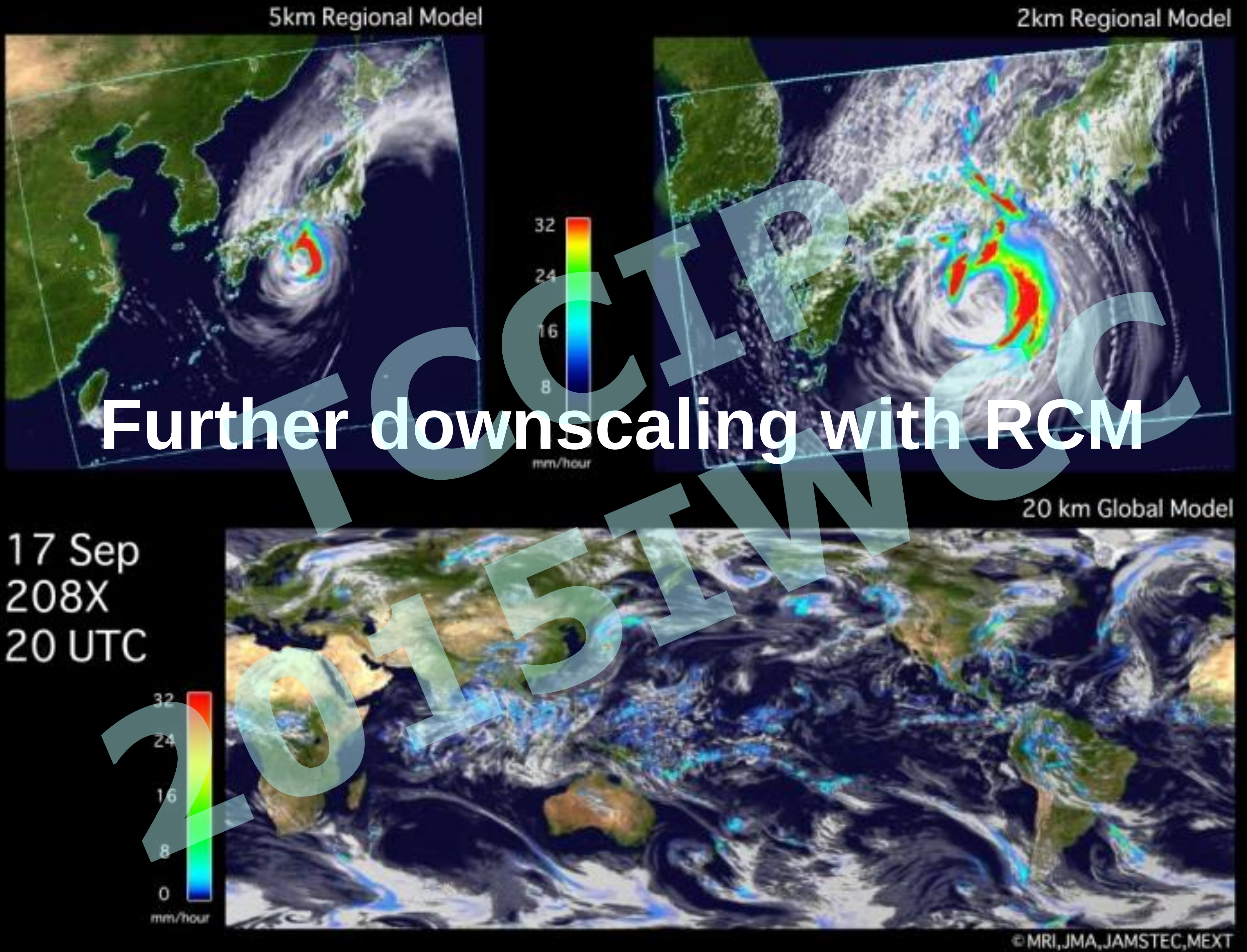
Precipitation change: MRI-60km vs CMIP5

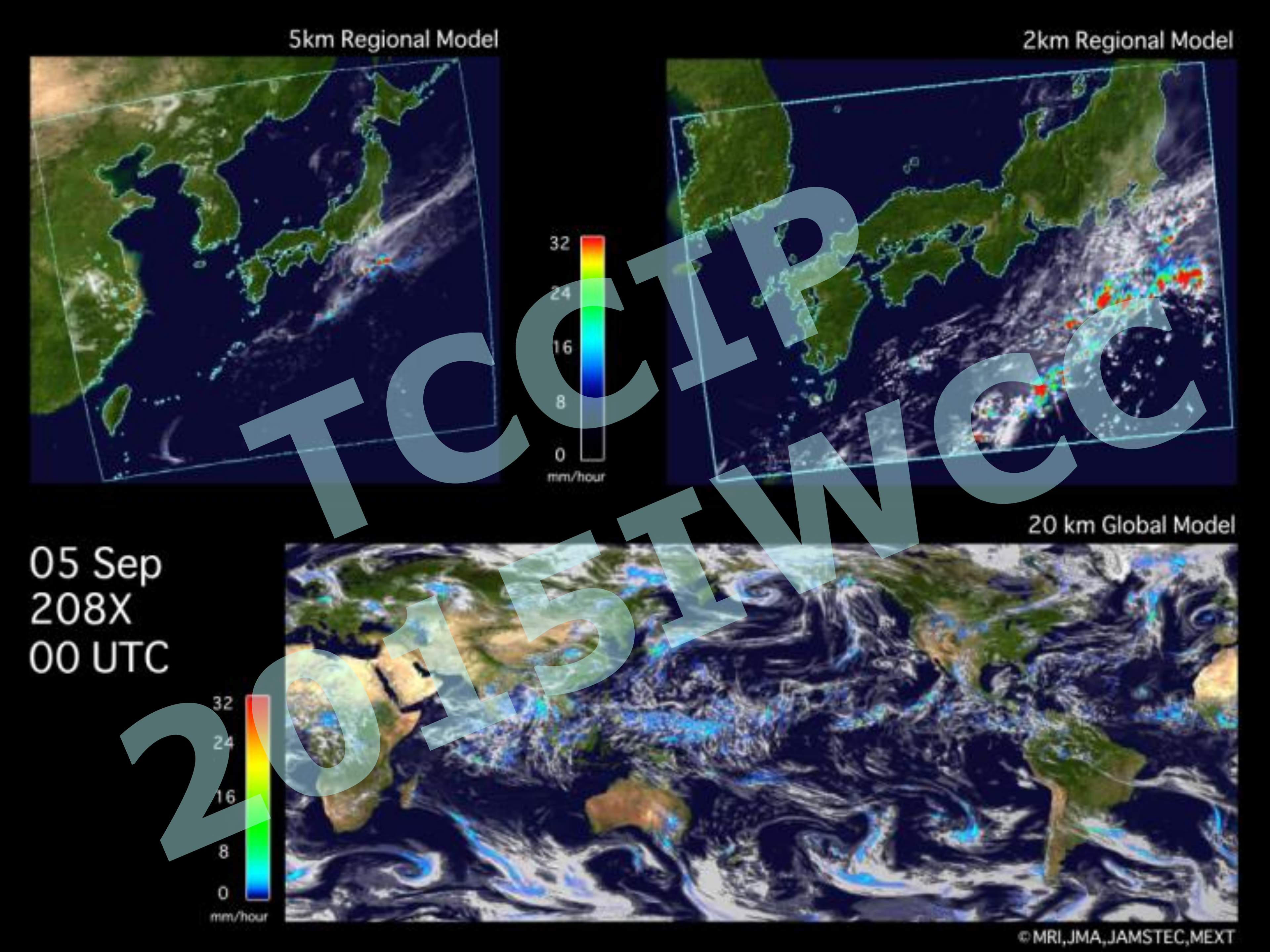


MRI-AGCM3.2H: 12 member SST & physics ensemble
CMIP5: 28 models
Normalized by global annual mean SAT change
Hatch: sign agreement more than 66%(90%) models

General pattern agree each other
> large SST increase = precipitation increase
Not agree over the western North Pacific

Further downscaling with RCM

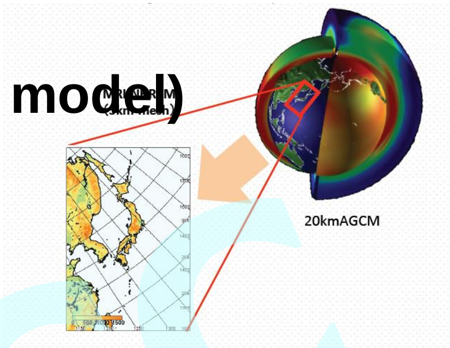



5km Regional Model
2km Regional Model
32
24
16
8
0
mm/hour
20 km Global Model
05 Sep
208X
00 UTC
32
24
16
8
0
mm/hour
© MRI,JMA,JAMSTEC,MEXT

High-resolution AGCM-RCM experiments

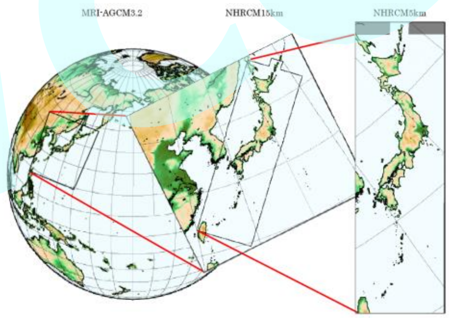
1: KAKUSHIN Program (2007-2011) + SOUSEI Program (2012-2016)

AGCM 20km + RCM 5km (+ RCM 2km with urban model)
1 ensemble, SRES A1B
4 ensemble (SST), RCP8.5



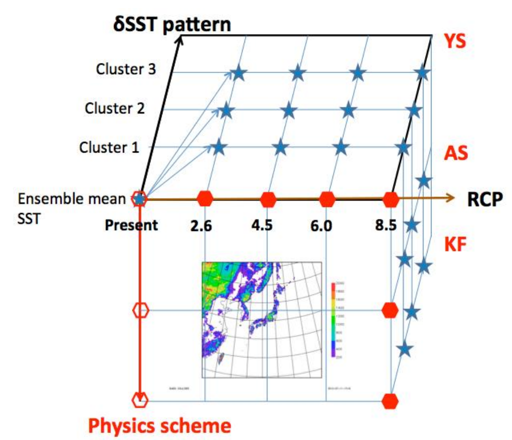
2: JMA Global Warming Projection Volume 8 (2013)

AGCM 20km + RCM 15km + RCM 5km
1 ensemble, SRES A1B



3: MoE Climate Projections for Adaptation (2014)

AGCM 60km + RCM 20km
18 ensemble (SST, RCP, cumulus)



Matrix of ensemble experiments

Global 60km (MRI-AGCM3.2H) + Regional 20km (NHRCM)

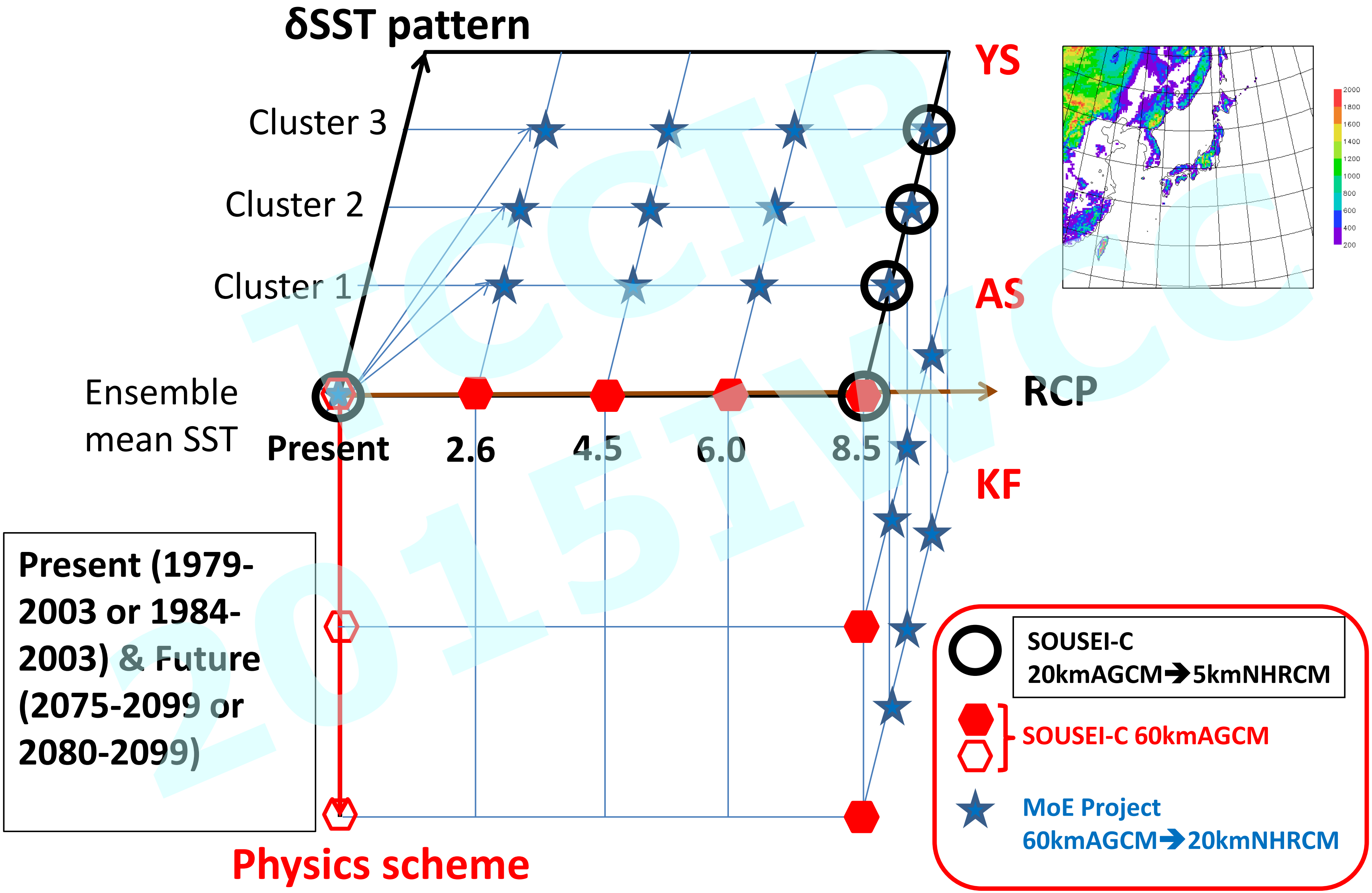
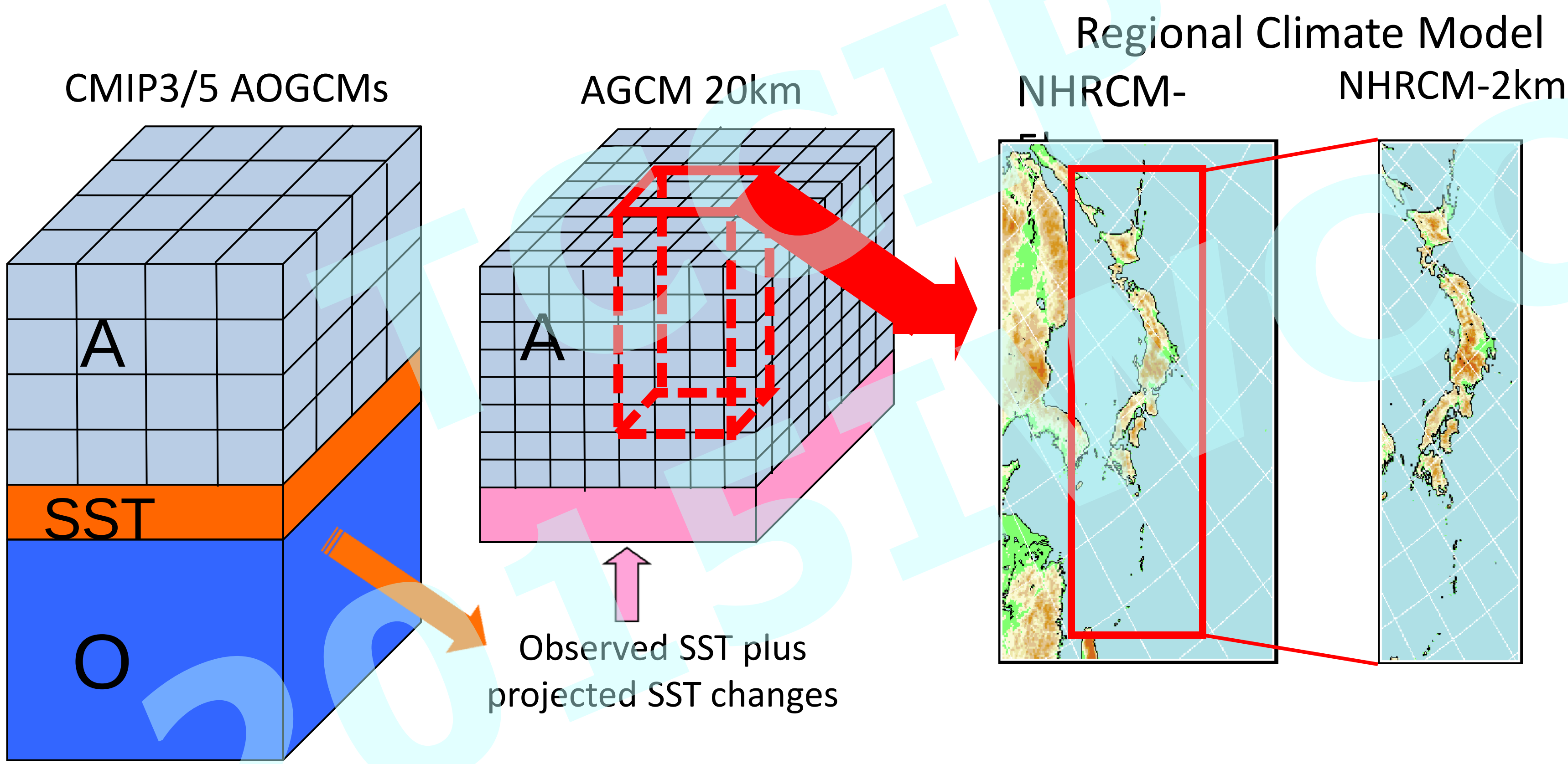


Figure 2



Regional Climate Model
CMIP3/5 AOGCMs
AGCM 20km
NHRCM-
NHRCM-2km
A
SST
O
A
Observed SST plus
projected SST changes

Summary

- Bias correction for GCM is a must for dynamical downscaling.
- Global high-resolution time-slice experiment is one of good choices for downscaling by avoiding SST bias in the present climate.
    - Good performance in the present-day AMIP
    - Observed present SST + CMIP5 ensemble mean future DSST
    - Done or being done by MRI 20km, HiRAM 25km and CAM5 30km
- As the model is global, projected data are available anywhere in the world.
- Further downscaling with a few km cloud-resolving RCM can also be applied to any region to investigate local extreme weather events such as heat waves from foehn and heavy rainfall.

予備スライド

MRI's CMIP6 Plan

Models: MRI-ESM1.x, MRI-AGCM3.xS, (NHRCM)

Infrastructure:

Fujitsu 1.2 Pflops at MRI (Mar. 2015~) approx. 25% for CMIP6

# of years of experiments:

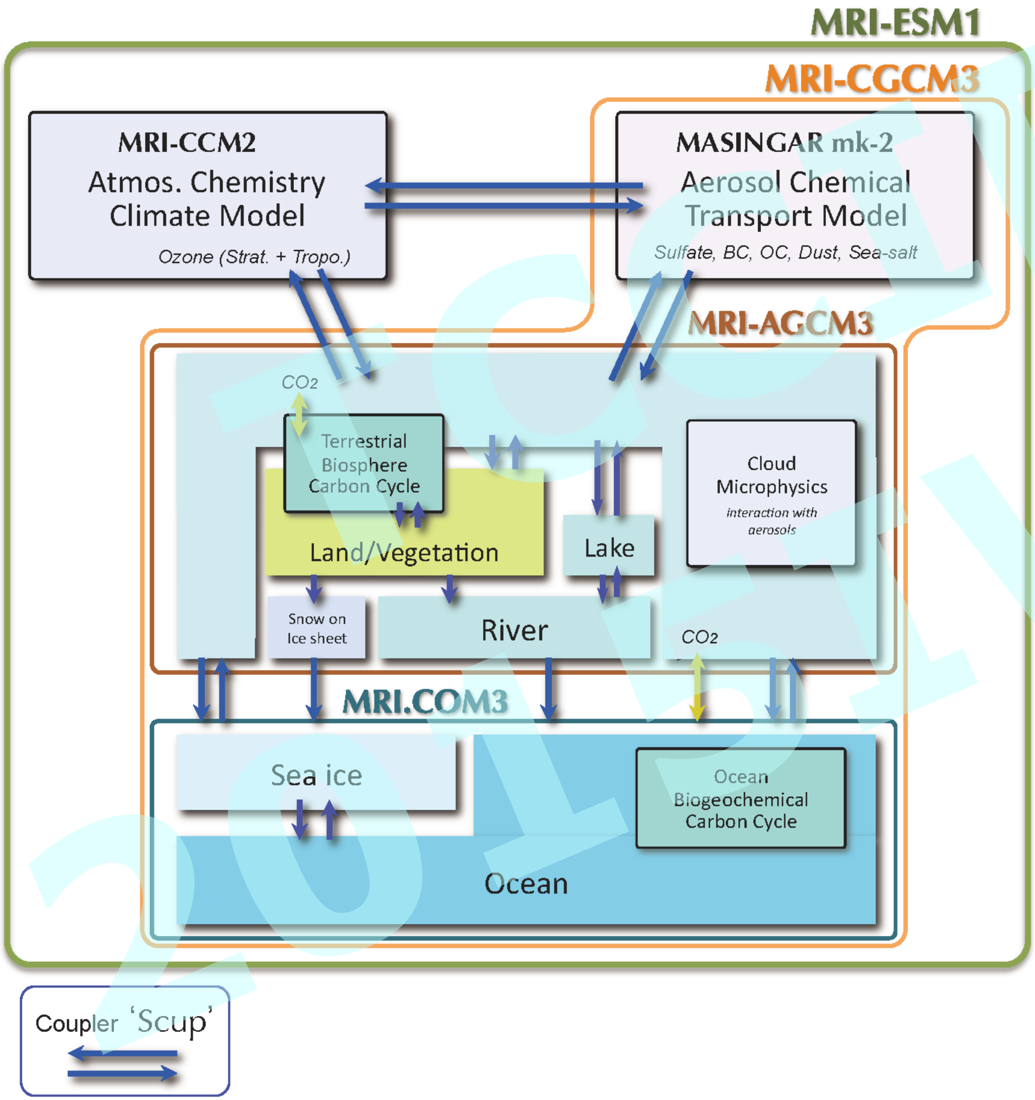
20,000 years (MRI-ESM1.x)

200 years (MRI-AGCM3.xS)

MIPs to contribute to:

- *Planning*:
  AeroChemMIP, C4MIP, CFMIP, DAMIP, DCPP
  HighResMIP, OCMIP6, PMIP, VolMIP, (CORDEX)
- *Under consideration*:
  GeoMIP, (GDDEX), GMMIP, LS3MIP
  ScenarioMIP

Meteorological Research Institute Earth System Model ver. 1



MRI-CGCM3
= AGCM + OGCM
+ Aerosol

MRI-ESM1
= AGCM + OGCM
+ Aerosol
+ Ozone
+ Carbon cycle

CMIP5 version

AGCM: T_L159 L48
(H.~120km, Top:0.01hPa)

OGCM: 1°×0.5° L51

Aerosol: T_L95 L48
(H.~180km, Top:0.01hPa)

Ozone: T42 L48
(H.~280km, Top:0.01hPa)

MRI-ESM1.x for CMIP6

	CMIP5	CMIP6
Model Name	MRI-CGCM3 MRI-ESM1	MRI-ESM1.x
Atmos. Horiz. res.	TL159 (≈120 km)	←
Atmos. Vert. res.	L48, Top=0.01hPa	L80, 41 (>100hPa), 39 (<100hPa) Top=0.01hPa
Ocean Horiz. res.	1° × 0.5° (Tripolar grid)	←
Ocean Vert. res.	L51	←
Atmos. chem.	Aerosols (MRI-CGCM3) All (MRI-ESM1)	All (tropo. & storato., incl. volc. aer.)
Biogeochem.	Yes (MRI-ESM1)	Yes (depends on the experiment)

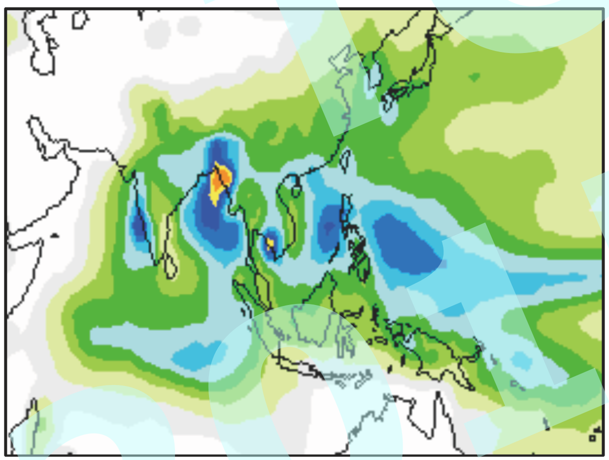
Many improvements

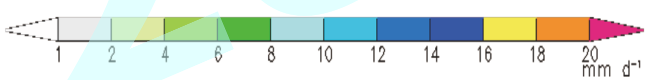
- Stratospheric QBO
  Increased vertical layers and introduction of non-orographic GWD (Hines-scheme)
- Low clouds
  CTE-EIS stratocumulus parameterization, vertical layers, cloud physics, etc.
- Asian summer monsoon
- Sea ice distribution in the winter North Atlantic

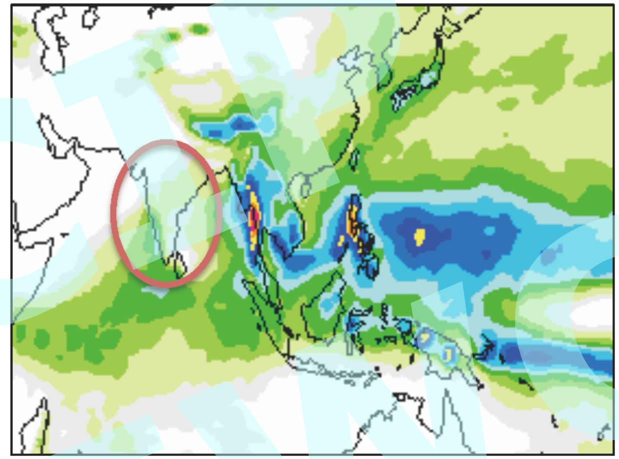
Asian Summer Monsoon Precipitation

Precipitation
JJA mean

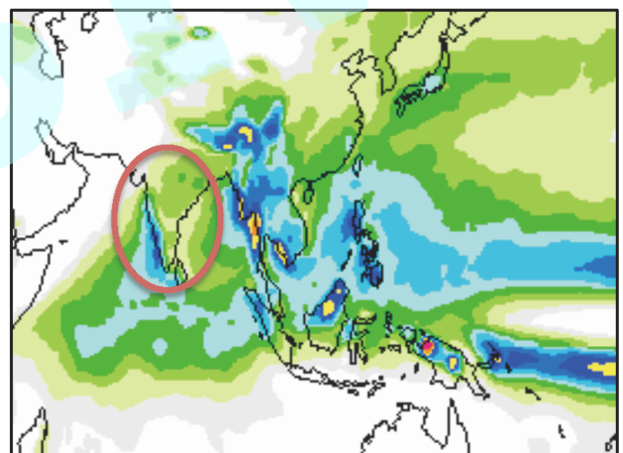
CMAP (1987-1996)







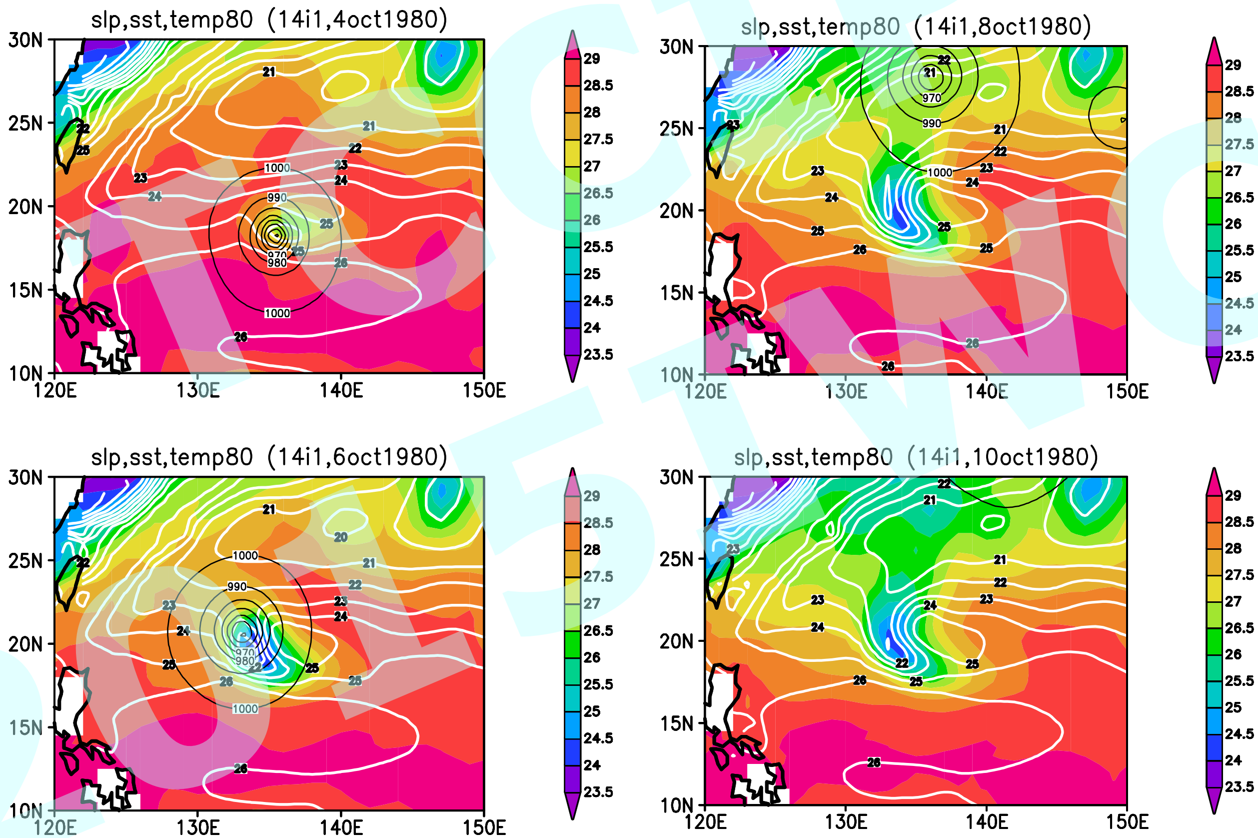
CMIP5
esmHistorical
(1987-1996)



MRI-ESM1.x
Test
(1987-1996)

海面水温をリストアした
結合モデル（準結合モデル）実験

10日程度までの時間スケールの大気海洋相互作用を取り入れる。

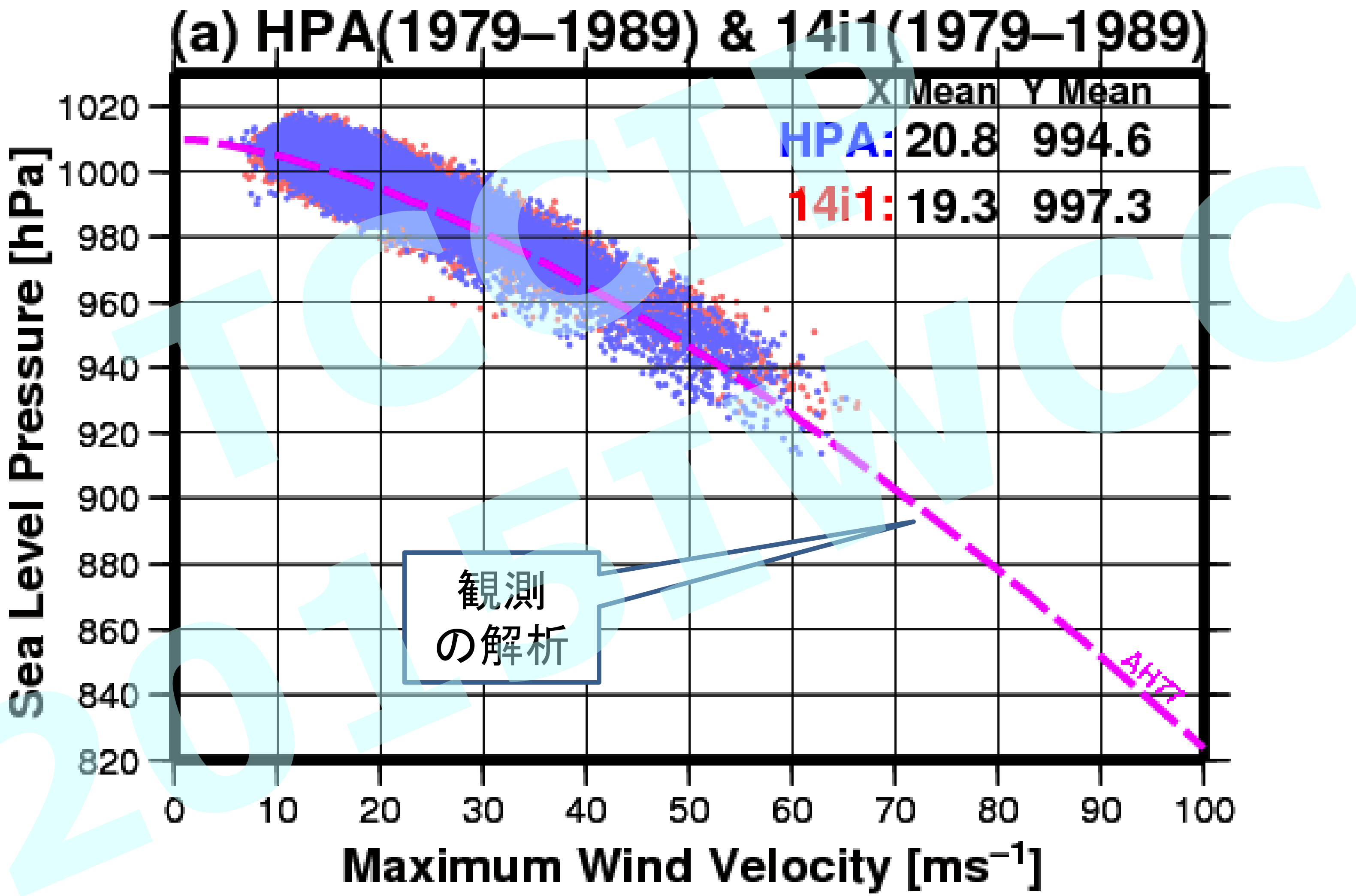


60km-AOGCMで再現された台風通過時の海面気圧SLP（黒コンター：hPa）、海面水温SST（陰影：℃）および80m深水温（白コンター：℃）

T. Ogata et al.

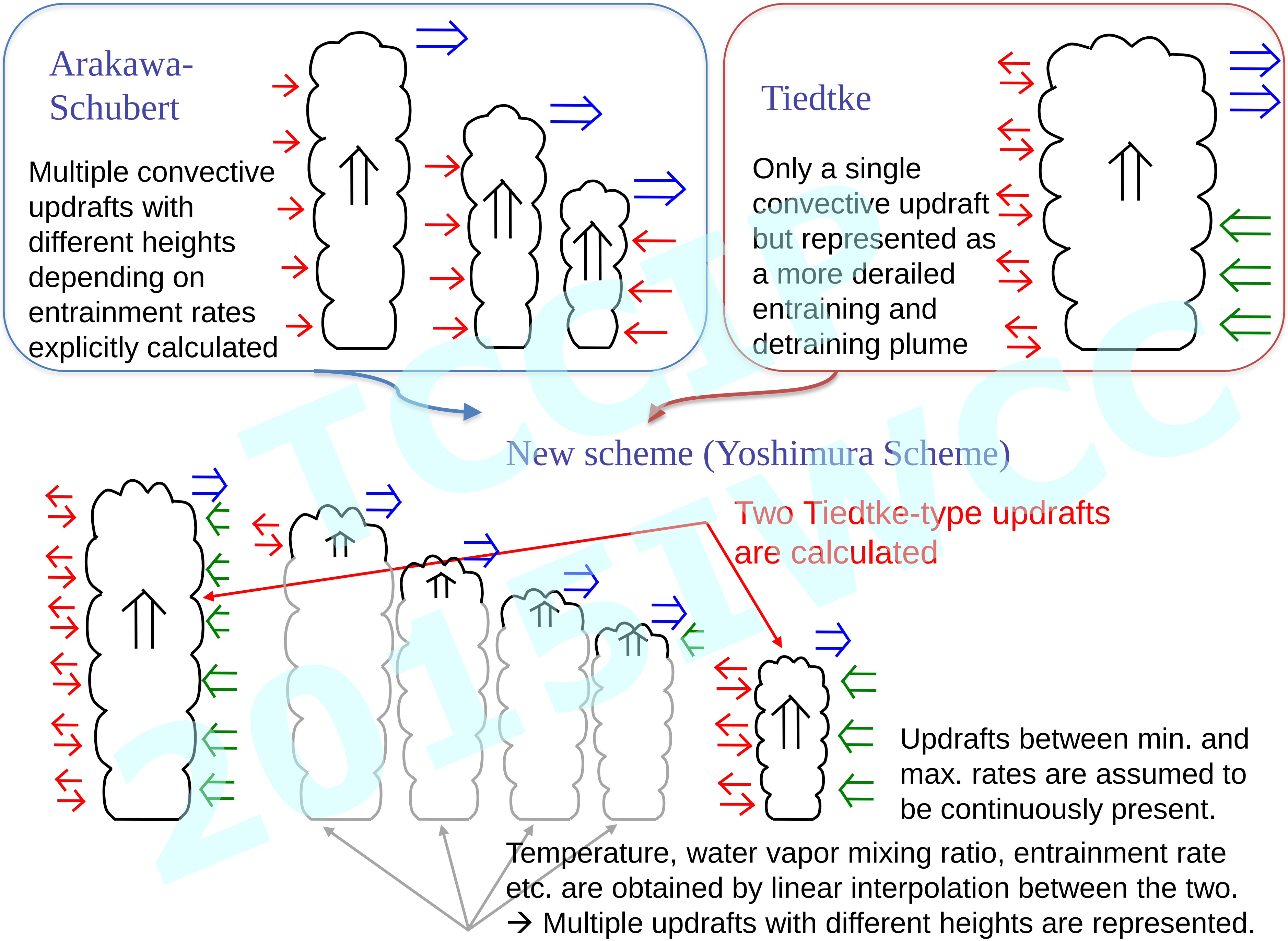
台風の最大風速-海面気圧の関係

準結合実験（14i1）と大気モデル実験（HPA）

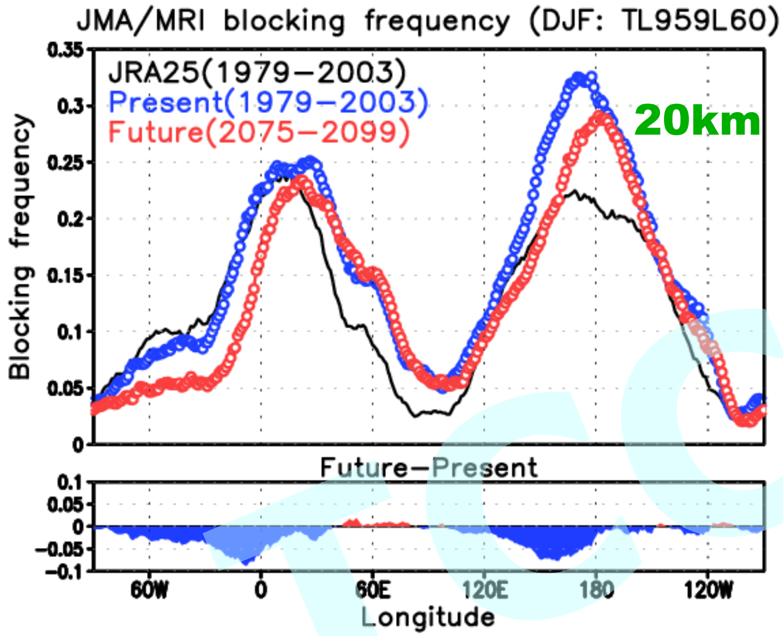


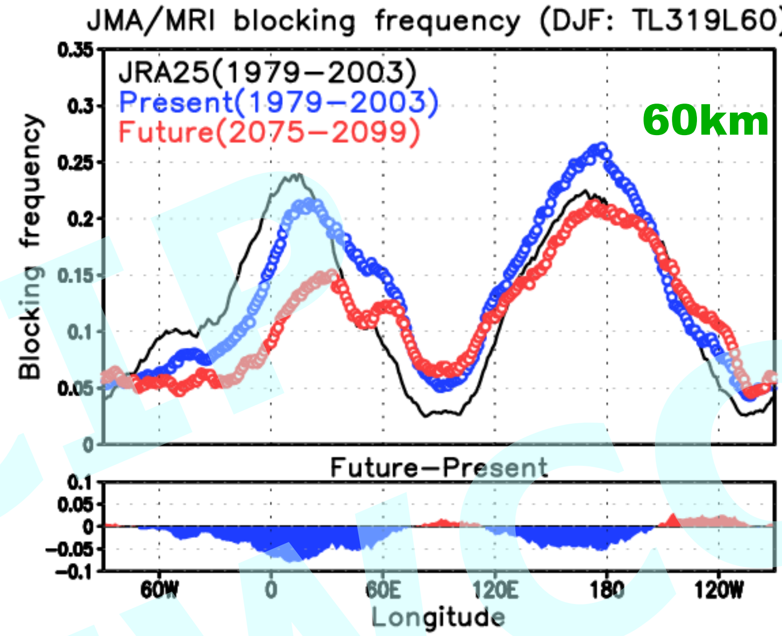
準結合実験（14i1）では、大気モデル実験（HPA）に比べて、熱帯低気圧の強さが弱くなっていることが確かめられた。

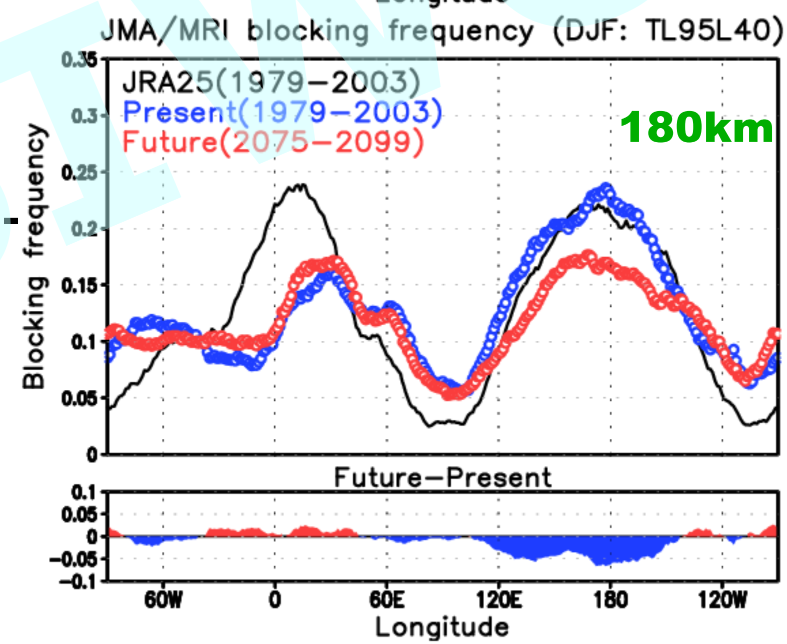
H. Murakami


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.

Northern Hemisphere wintertime blocking







The higher the resolution, the more accurate the simulated Euro-Atlantic blocking frequency

Frequencies of Euro-Atlantic and Pacific blockings are projected to decrease

Matsueda et al. (2009) JGR