Factors affecting the distribution of tropical precipitation in CMIP5 models and their effects to future projections

Yukari N. Takayabu[1] and Nagio Hirota[21]

[1] AORI Univ. of Tokyo, Japan
[2] NIPR, Japan

- Takayabu et al. (2010; *J. Climate*)
- Hirota et al. (2011; *J. Climate*)
- Hirota and Takayabu (in revision; *Climate Dynamics*)

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Studies on Future Climate Projection of the Asian Region Utilizing CMIP5 Multi-Model Ensemble Data

(June 2012-March 2015)

1. Yukari N. Takayabu, AORI the Univ. of Tokyo
   Hisashi Nakamura, RCAST, the Univ. of Tokyo
2. Tomoaki Ose, MRI, JMA
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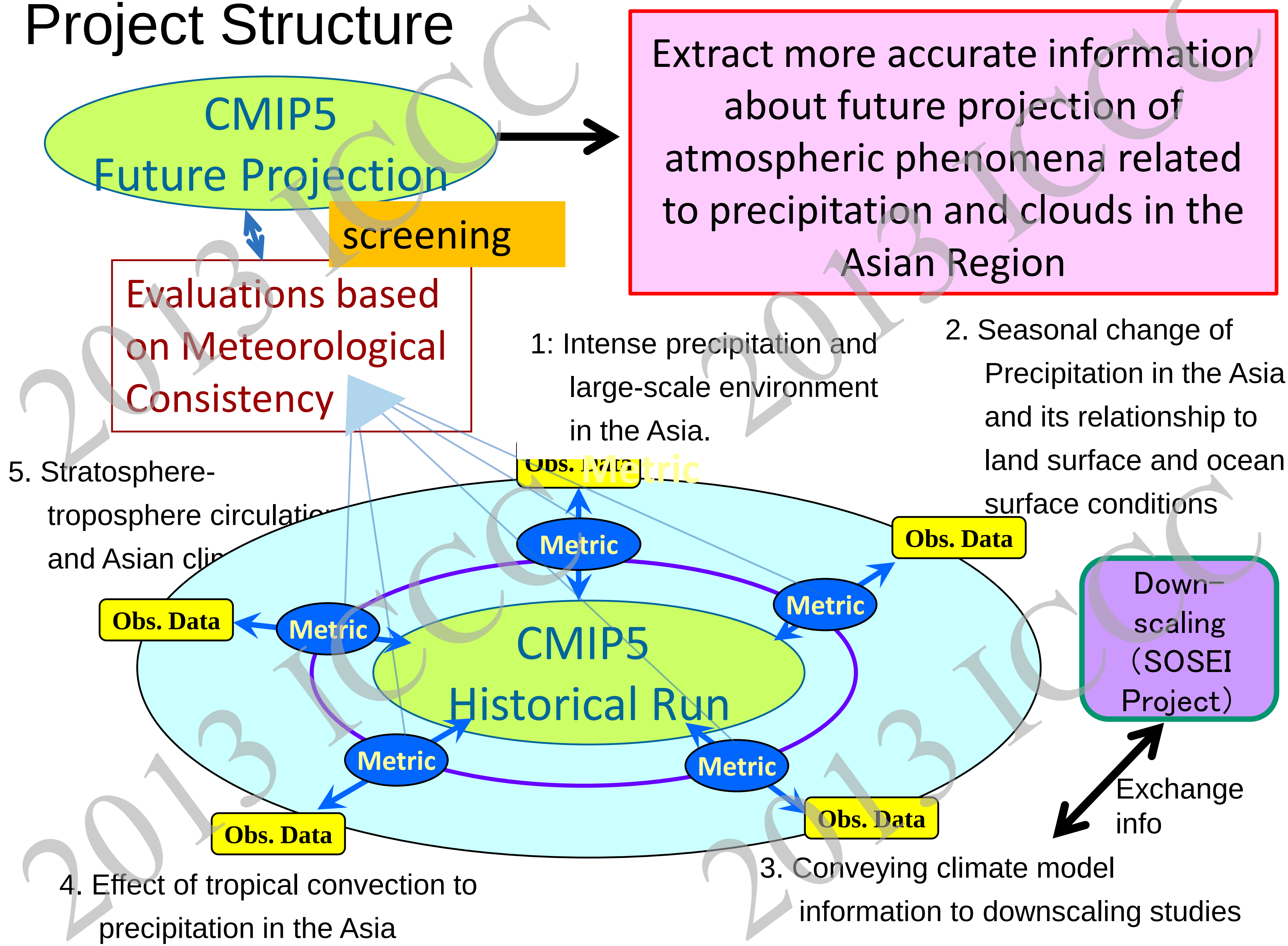
3. Hiroaki Ueda, Tsukuba University
4. Ryuichi Shirooka, JAMSTEC
5. Yoshio Kawatani, JAMSTEC

Succession of Theme2/S-5 project (2007-2012)
CMIP3 intercomparison in phenomena basis

Project Structure



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Background

Proper representation of precipitation over tropical oceans are essential for accurate simulation of atmospheric general circulation.

Tropical precipitation is controlled by

SST

- Cumulus convection is enhanced with higher SST

Humidity in mid-troposphere

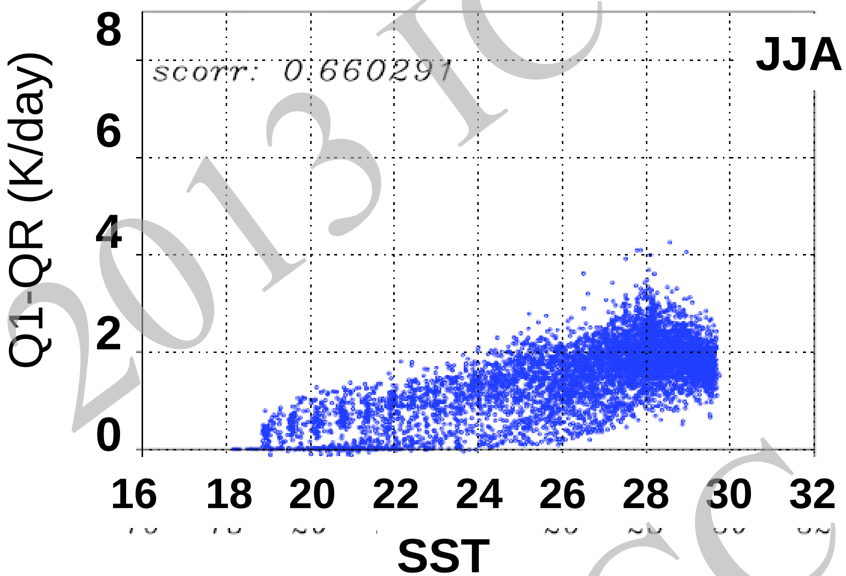
- Observations suggest the significant suppression of deep convection from the entrainment of dry environmental air.

(e.g. Yonenama and Fujitani 1995; Numatuti et al., 1995: Brown and Zhang, 1997: Sherwood, 1999; Bretherton et al. 2004; Takayabu et al. 2010, *JC)*

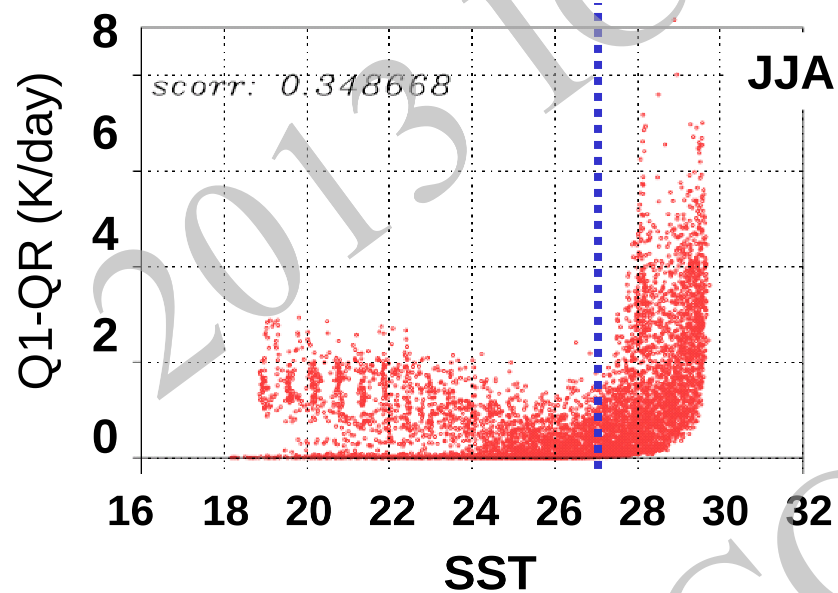
Effects of SST and subsidence on convective heating (TRMM SLH: satellite-derived)

(Takayabu et al. 2010)

2.0km heating: cumulus congestus

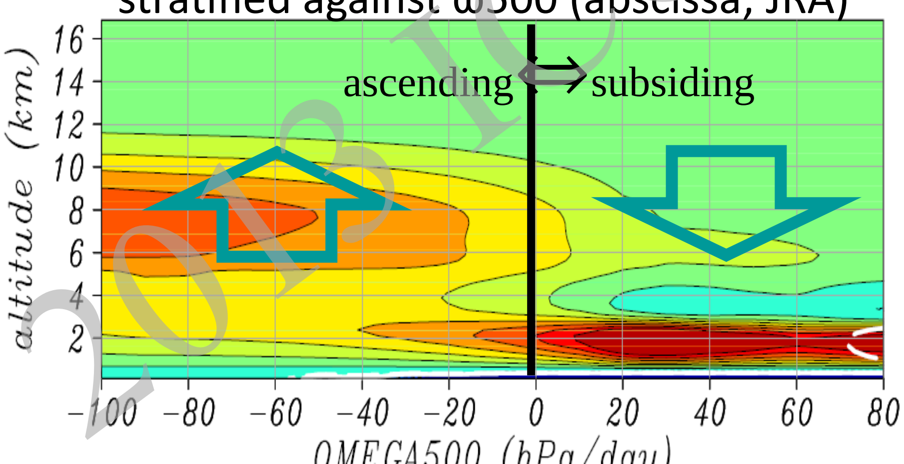


7.5km heating : Deep rain



Heating (color; TRMM SLH)

stratified against ω500 (abscissa; JRA)

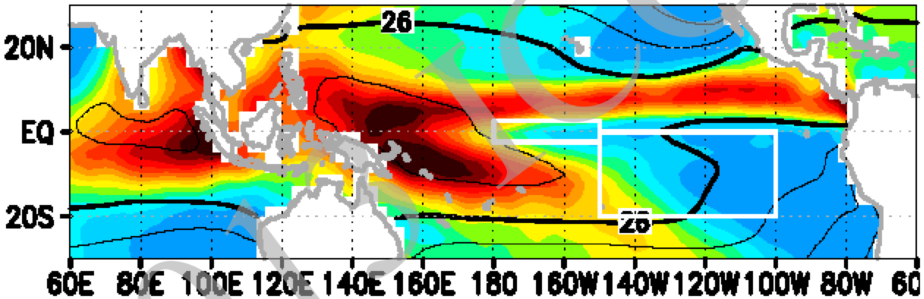


While congestus responds linearly to SST, obedient to low-level instability, deep rain is controlled by another factor.

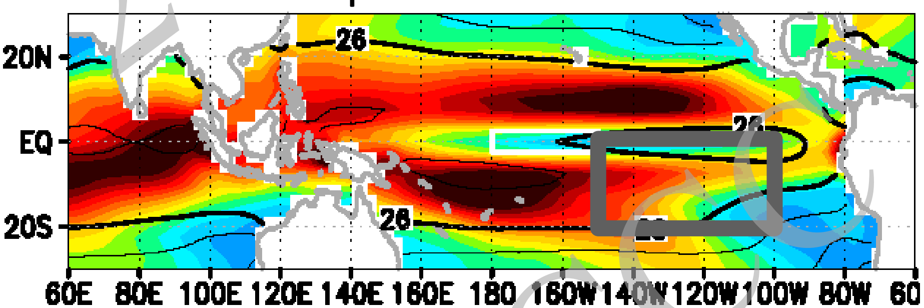
When heating profiles are stratified with vertical velocity, we can see mid-tropospheric dryness associated with subsidence strongly suppresses deep convection.

Well known biases in climate models

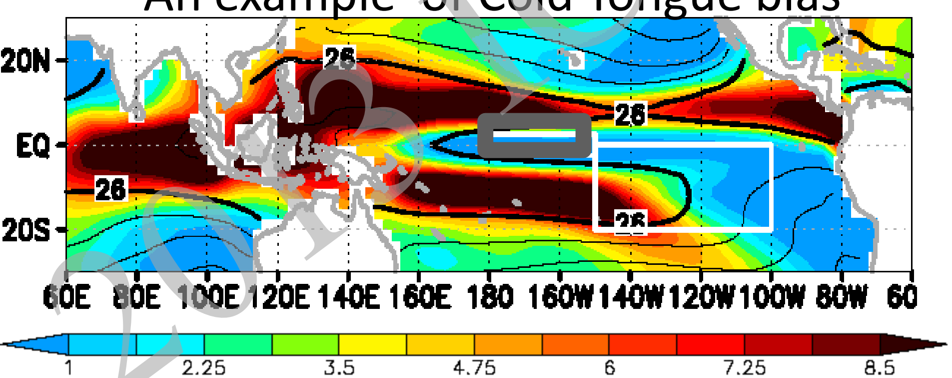
TRMM PR Prcp & HadI SST



An example of Double ITCZ



An example of Cold Tongue bias



Double ITCZ (DI) bias

- SST
- Convective parametarization
  - Sensitivity of deep convection to the mid-troposph humidity. (Hirota et al. 2011, *JC*)

DI index (Bellucci et al. 2010)

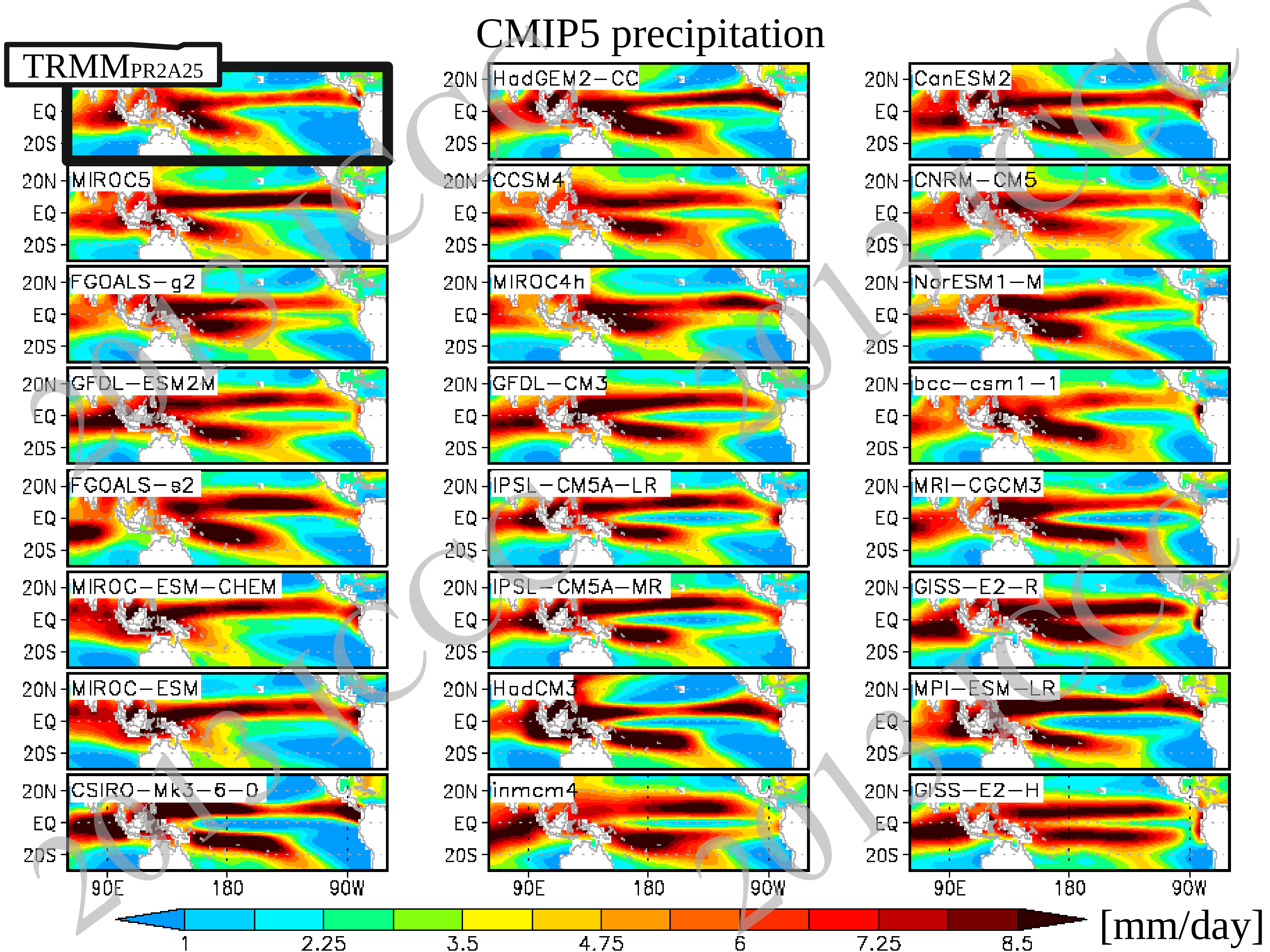
Precipitation (150-100W, 20S-Eq)

Cold Tongue (CT) bias

- Ocean Model Resolution (Robert et al. 2009; Zheng et al. 2009)
- Trade winds (Meehl et al. 2001)

CT index

SST (180-150W,3S-3N)



CMIP5 precipitation
TRMM PR2A25
HadGEM2−CC
CanESM2
MIROC5
CCSM4
CNRM−CM5
FGOALS−g2
MIROC4h
NorESM1−M
GFDL−ESM2M
GFDL−CM3
bcc−csm1−1
FGOALS−s2
IPSL−CM5A−LR
MRI−CGCM3
MIROC−ESM−CHEM
IPSL−CM5A−MR
GISS−E2−R
MIROC−ESM
HadCM3
MPI−ESM−LR
CSIRO−Mk3−6−0
inmcm4
GISS−E2−H
20N
EQ
20S
90E
180
90W
1
2.25
3.5
4.75
6
7.25
8.5
[mm/day]

Objectives

- Examine reproducibility of tropical precipitation by comparing CMIP3 and CMIP5 dataset, focusing on DI & CT biases.
- Discuss its relationship to
  - Sensitivity of cumulus convection to environmental conditions
  - Ocean model resolution
- Examine the effects of a model selection based on physical factors to the future projection.

Data

Climate Models

CMIP5 (historical; RCP45)

CMIP3 (20C3M; A1b)

Obs.

TRMM PR2A25 /HadISST/JRA25

Curent Climatology: 1981-2000
(TRMM:1998-2007)

Future projection: 2081-2100

Season: All Year

Domain: Tropical oceans (30S-30N)

CMIP3 (15)
BCCR
CNRM
CSIRO_0
CSIRO_5
GFDL_0
GFDL_1
GISS_AOM
GISS_E_H
GISS_E_R
IAP
INGV_ECHAM4
IPSL
MIROC_H
MIROC_M
MPI_ECHAM5

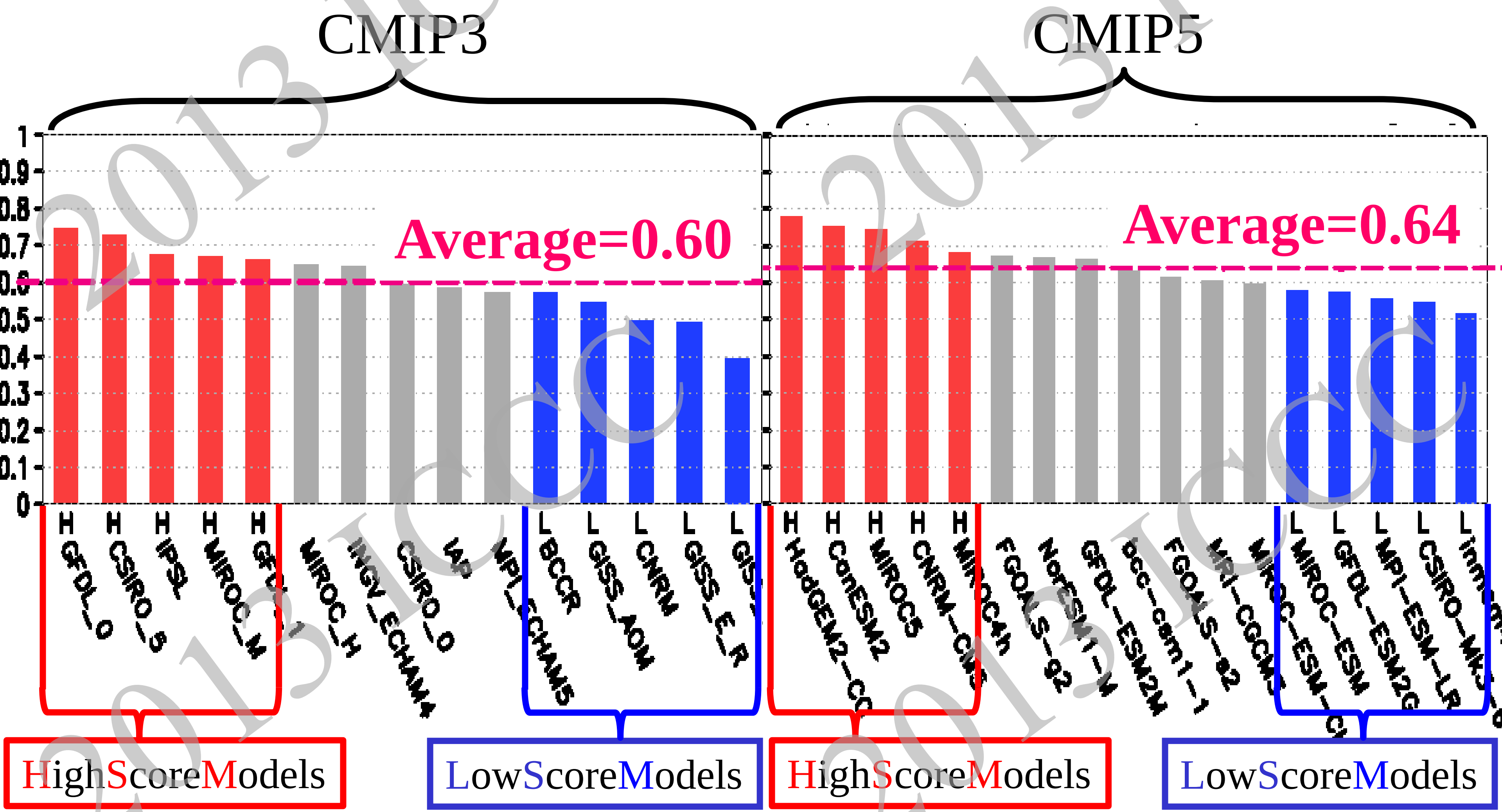
CMIP5 (17)
CNRM-CM5
CSIRO-Mk3-6-0
CanESM2
FGOALS-g2
FGOALS-s2
GFDL-ESM2G
GFDL-ESM2M
HadGEM2-CC
MIROC-ESM-CHEM
MIROC-ESM
MIROC4h
MIROC5
MPI-ESM-LR
MRI-CGCM3
NorESM1-M
bcc-csm1-1
inmcm4

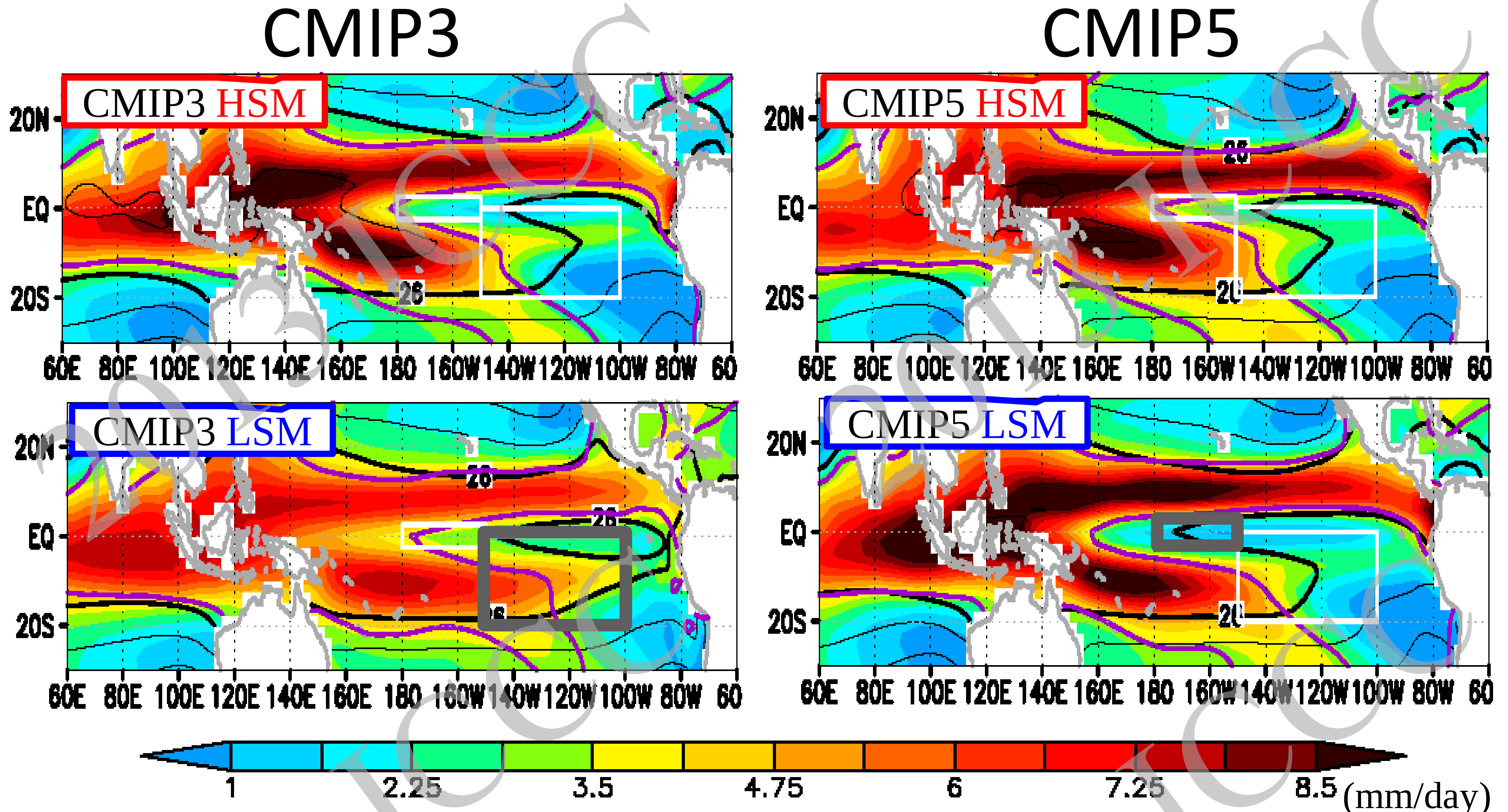
(Models with flux adjustment in CMIP3 are excluded.)

CMIP5 VS CMIP3

Taylor score for precipitation distribution (30S-30N ocean)

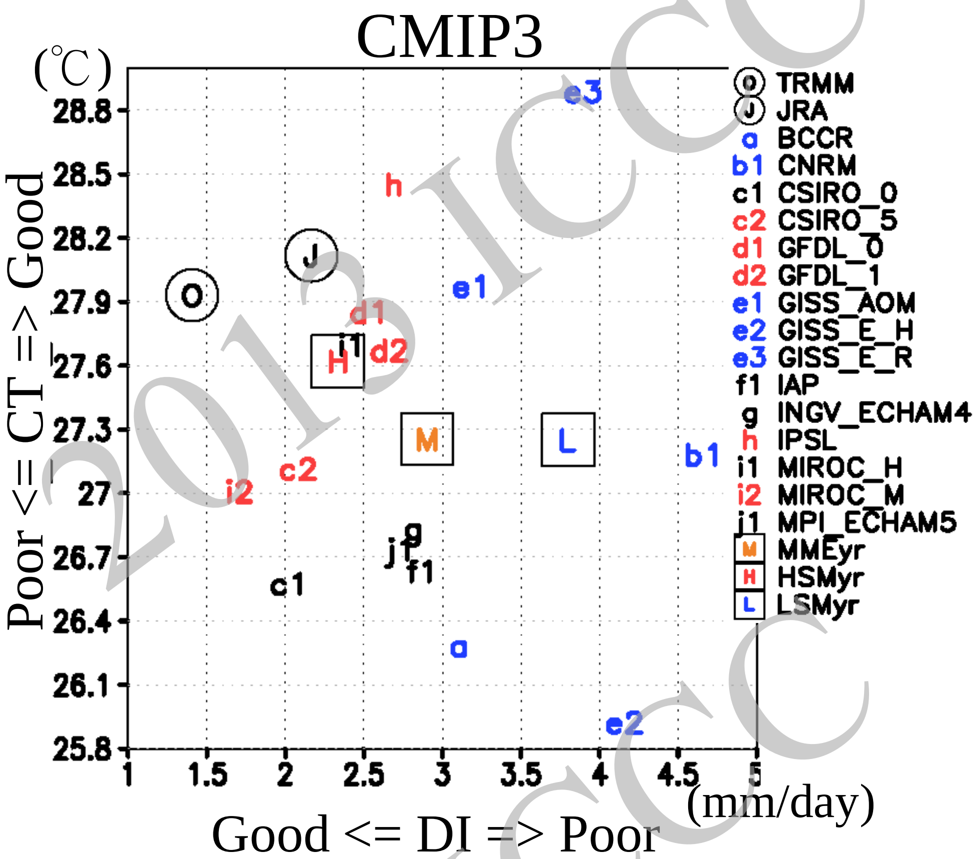
$$S \equiv \frac{(1+R)^4}{4(SDR + 1/SDR)^2}$$ (Taylor, 2001)

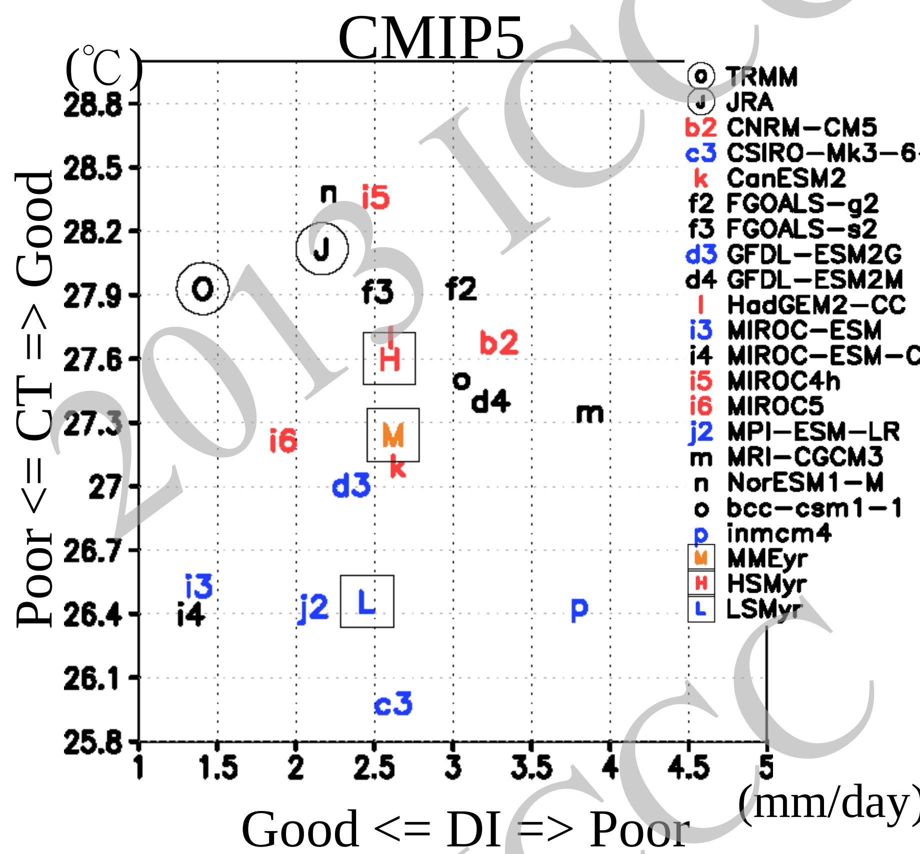




- Double ITCZ bias stands out in CMIP3/LSM
  DI index = 3.80 mm/day (>> 1.40 mm/day in observation)
- Cold tongue bias stands out in CMIP5/LSM
  CT index = 26.5 ℃ (<< 27.9℃ in observation)

Scores for Double ITCZ and Cold Tongue





Red : High Taylor Score Models

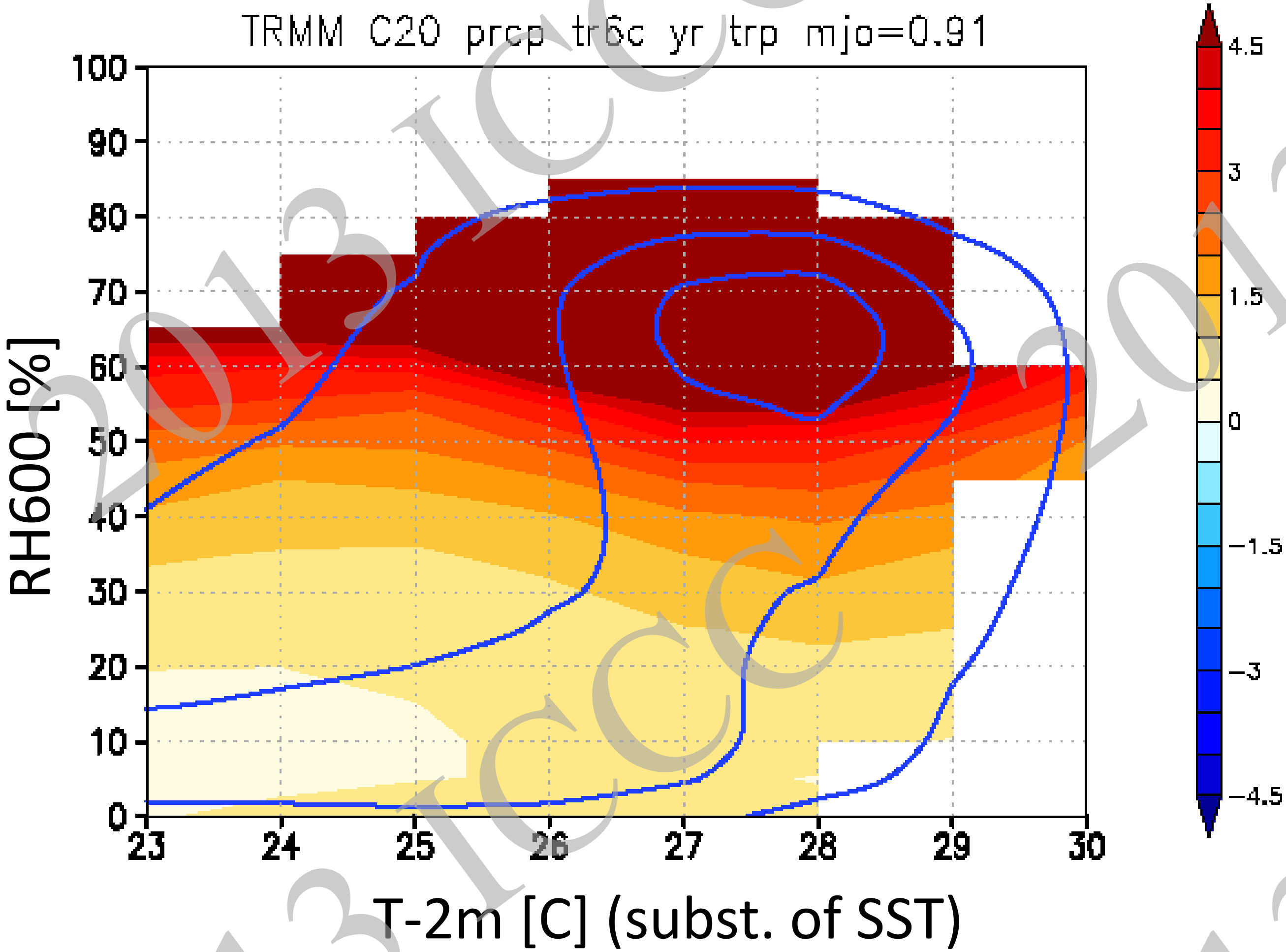
Blue : Low Taylor Score Models

In CMIP5 ensemble,

- Number of models with severe double ITCZ is reduced.
- Cold tongue bias stands out, since CT index remains similar.

WHAT CONTROLS THE DOUBLE ITCZ BIASE?

Precipitation (TRMM PR) in RH600-Tsfc diagram



Color: Average Precipitation Rate
Contour: PDF

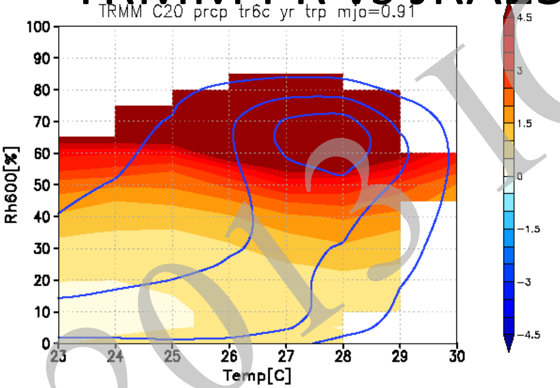
Precipitation tends to be more sensitive to RH600 than to SST

Precipitation Sensitivity Index:

Taylor score of RH600-Tsfc diagram referring to this observation

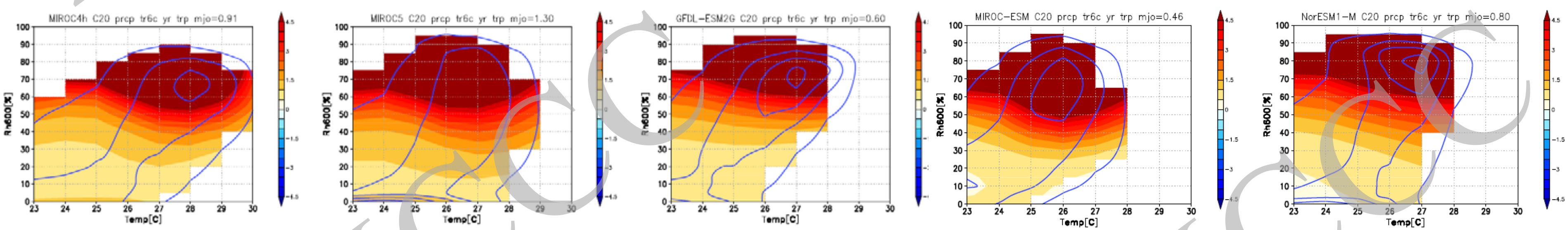
CMIP5 Intercomparison with Precipitation Sensitivity Index

TRMM PR vs JRA25

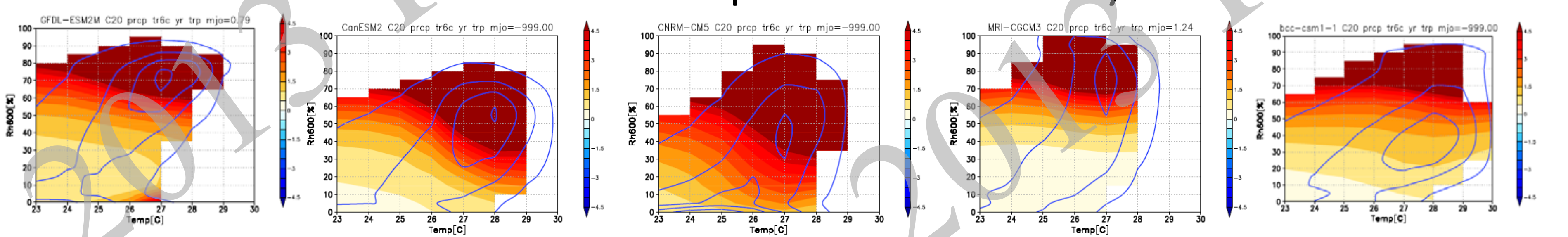


Good models are sensitive to the RH600.
Poor models are either more sensitive to SST or PDF is not good.

5 High Score Models in the Precipitation Sensitivity Index

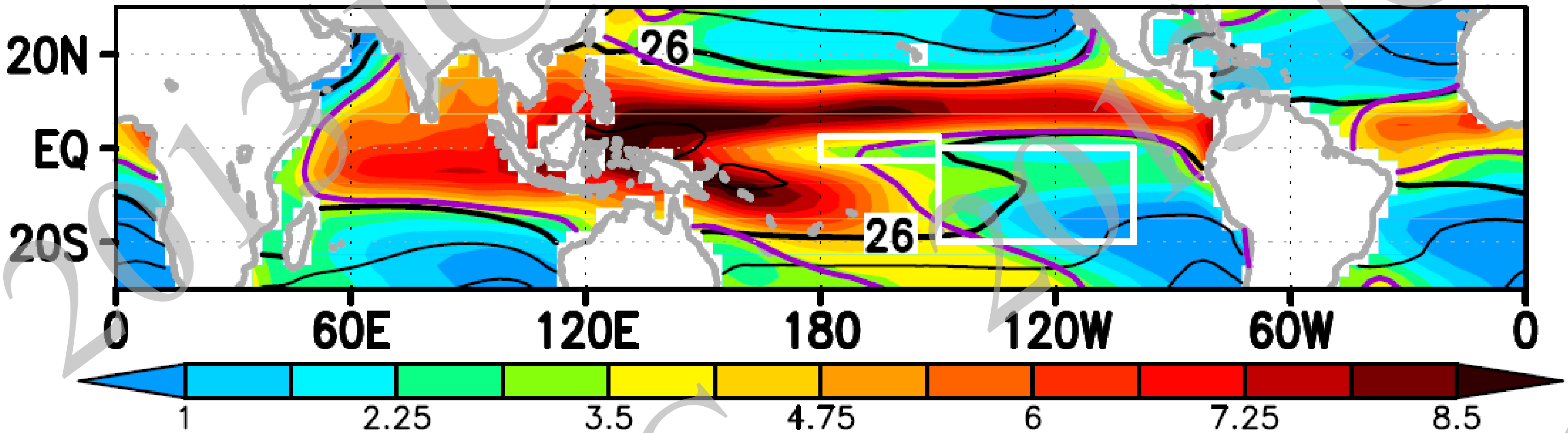


5 Low Score Models in the Precipitation Sensitivity Index

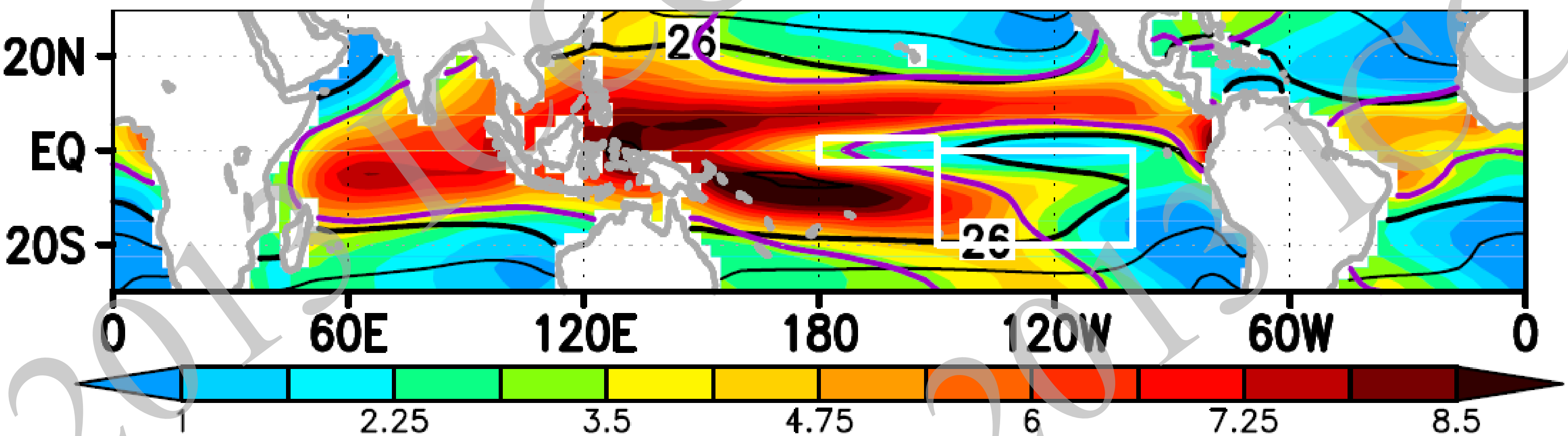


Comparison of Precipitation Distribution against Precipitation Sensitivity Index

5 High Score Models in the Precipitation Sensitivity Index

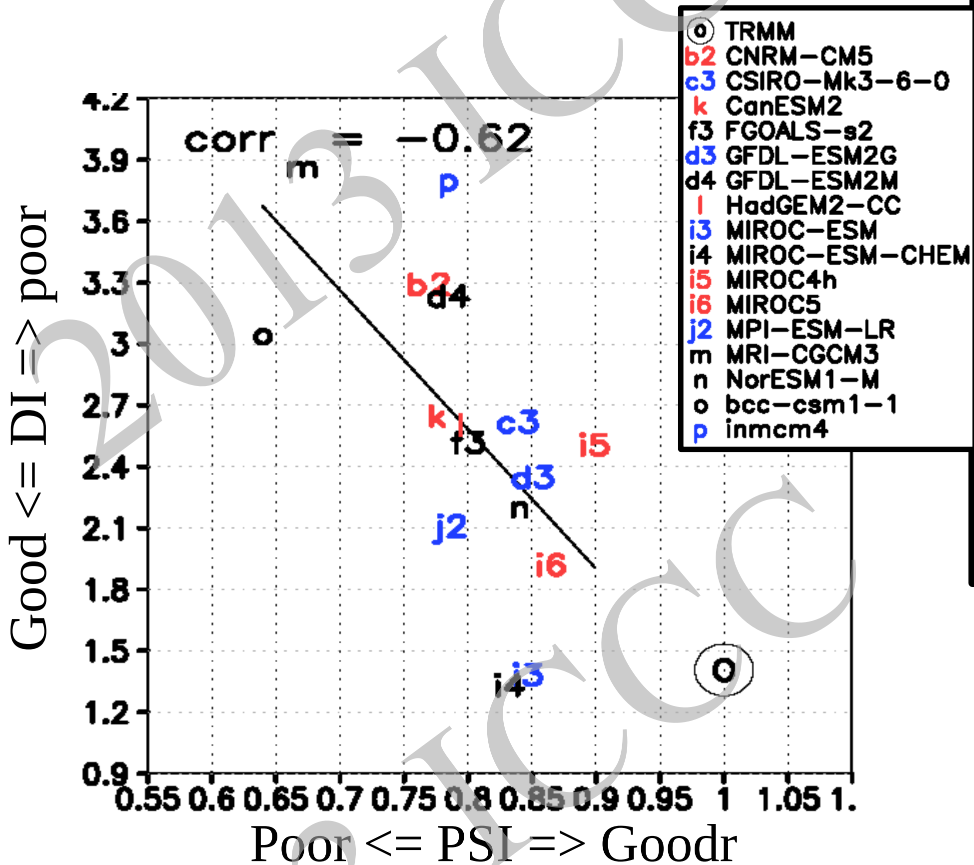


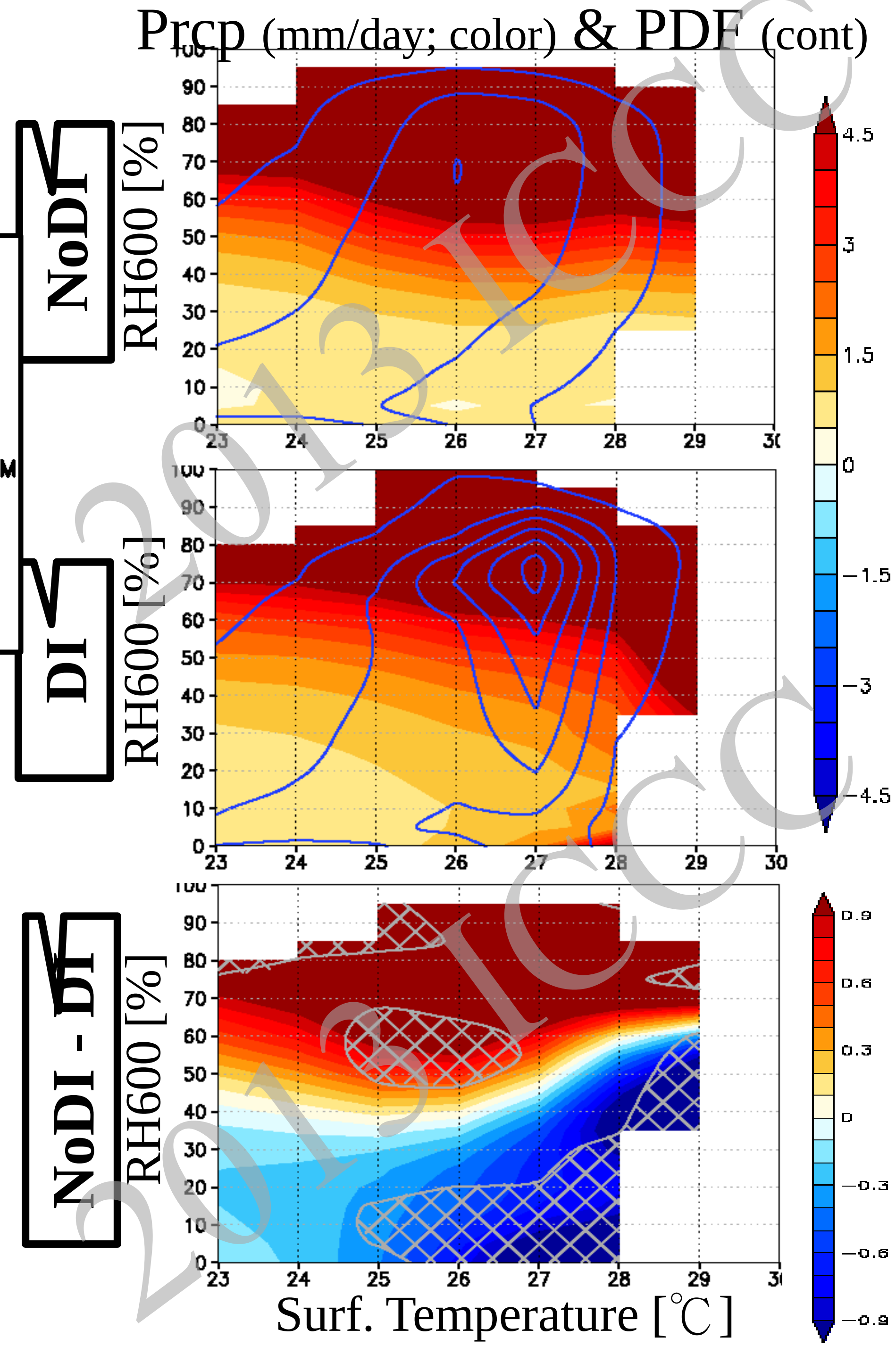
5 Low Score Models in the Precipitation Sensitivity Index



We can see much improved ITCZ structure in selected models

DI vs. Precipitation Sensitivity Index

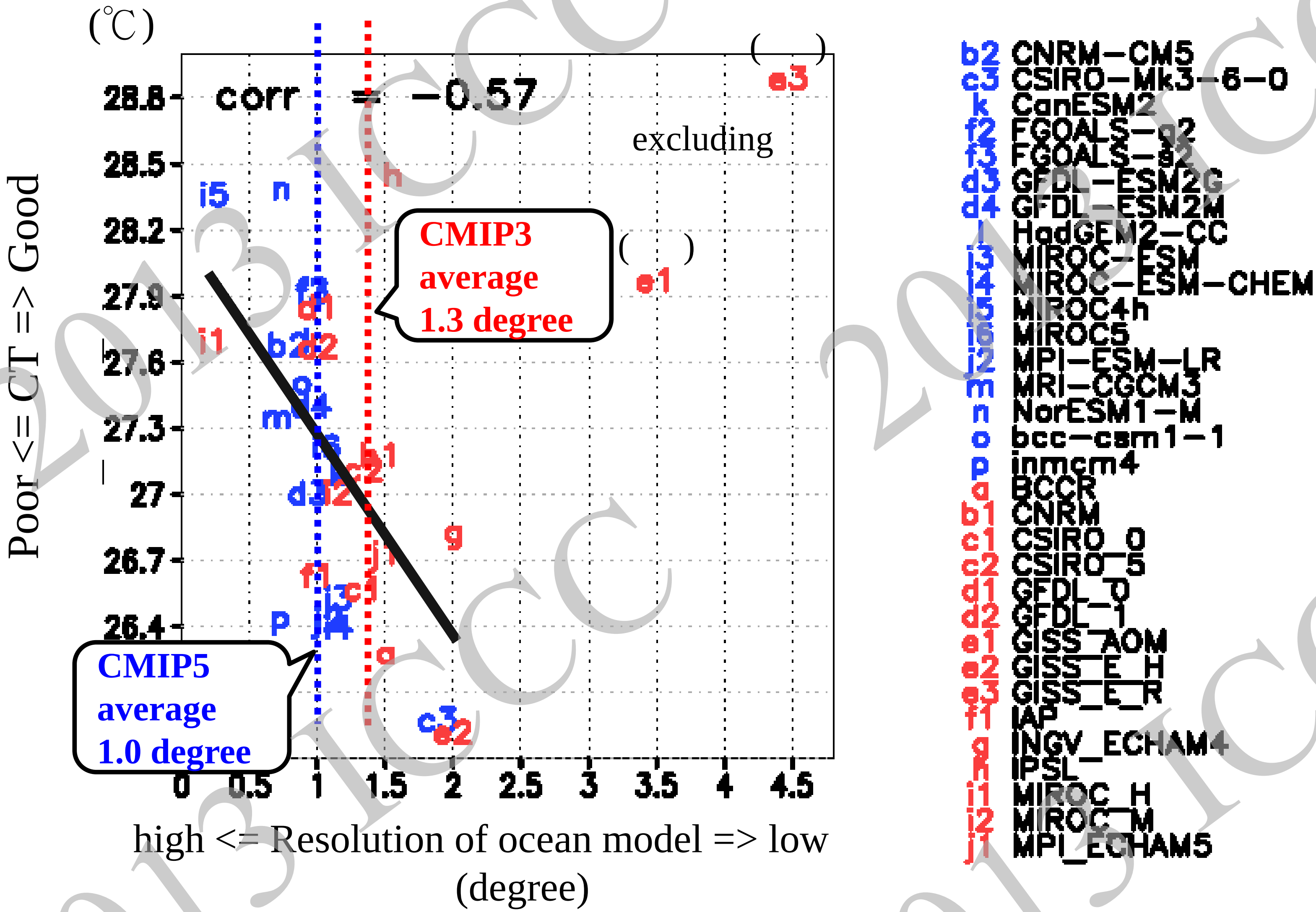




Proper representation of the sensitivities is important for improving DI.

WHAT CONTROLS THE COLD TONGUE BIAS?

Cold tongue vs Ocean resolution



Possible causes: Higher resolution models can simulate tropical instability waves(Robert et al. 2011), or circulations & thermal structure in the equatorial Pacific (Zheng et al. 2012) more accurately.

Selection of Models for Future Projection

Methodology:

An average of 5 Good models selected as

- Good representation of prcp sensitivity to RH600 & Tsfc
- Higher ocean model resolution

are compared with the all CMIP5 model ensemble average.

Previous Studies show

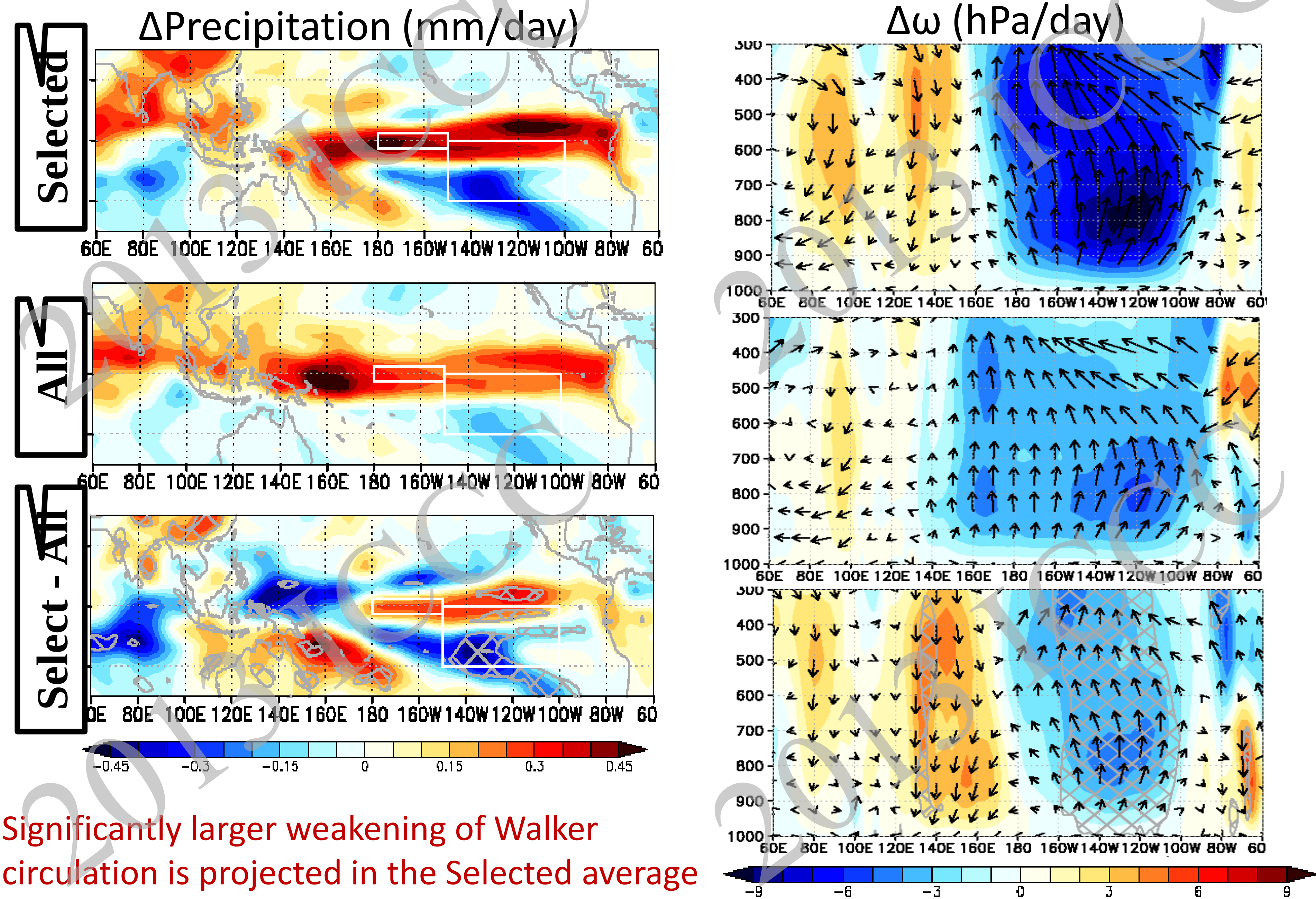
Weakening of Walker circulation.

(IPCC, 2007; Knutson and Manabe 1995;
Emori and Brown 2005; Vecchi et al. 2006;
Vecchi and Soden 2007; Xie et al. 2010;
Hirota and Takayabu 2012)

	Rep of prcp sensitivity	Ocn model Resolution
MIROC5	0.86	1.07
GFDL-ESM2G	0.85	0.93
MIROC-ESM	0.85	1.15
NorESM1-M	0.84	0.73
CSIRO-Mk3-6-0	0.84	1.88
MIROC-ESM-CHEM	0.83	1.15
FGOALS-s2	0.80	0.96
HadGEM2-CC	0.79	0.91
MPI-ESM-LR	0.79	1.08
inmcm4	0.78	0.73
~~GFDL-ESM2M~~	0.78	0.95
~~CanESM2~~	0.78	1.15
~~CNRM-CM5~~	0.77	0.78
~~MRI-CGCM3~~	0.67	0.70
~~bcc-csm1-1~~	0.64	0.88

Red = 5 selected good models
Blue = 5 low resolution models
Strikethrough = 5 models not sensitive to RH600

Projected Future Change (2081-2100)-(1981-2000)



Significantly larger weakening of Walker circulation is projected in the Selected average

Summary

- Compared to CMIP3, Taylor skill score for distribution of tropical precipitation of CMIP5 models is slightly improved.
  Double ITCZ bias is reduced, but Cold Tongue bias remained.
- Double ITCZ bias is closely related to sensitivity of deep convection to mid-tropospheric humidity.
  - A Precipitation Sensitivity Index is proposed.
- Cold Tongue bias is related to Ocean model resolution.
- Selection of models based on evaluations of physical factors is effective and results in significant differences in future projection: larger weakening of Walker Circulation in this case.

Hirota and Takayabu (in revision; Climate Dyn.)

Messages

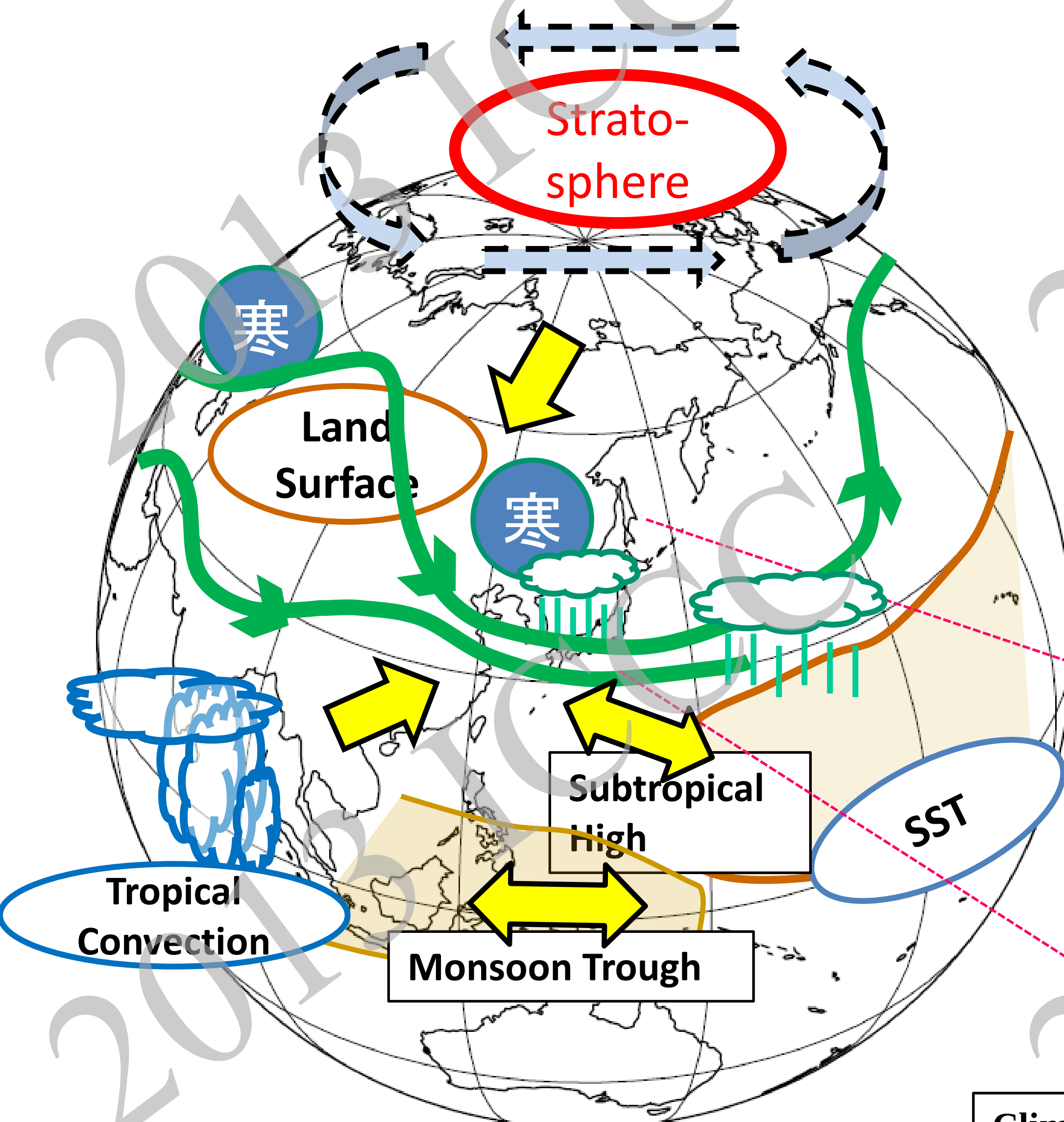
- Selection of the models should be based on understanding of physical factors causing the biases.

- Selection of a climate model ensemble based on physical factors works effectively to reduce the current climate simulation biases, and results in significant differences in future projections of general circulations.

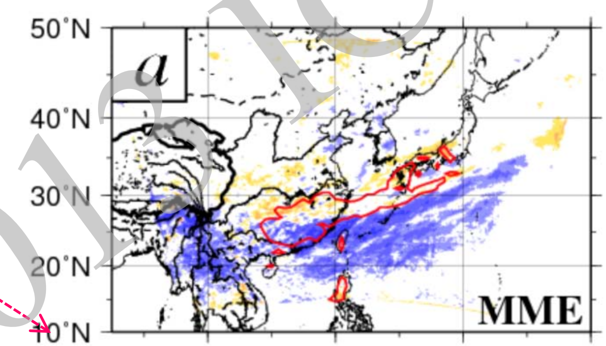

Thank you

Research Subjects

Various Phenomena related to precipitation change in the Asia



1. Intense precipitation and large-scale environment in the Asia.
2. Seasonal change of Precipitation in the Asia and its relationship to land surface and ocean surface conditions
3. Conveying climate model information to downscaling studies
4. Effect of tropical convection to precipitation in the Asia
5. Stratosphere-troposphere circulation and Asian climate

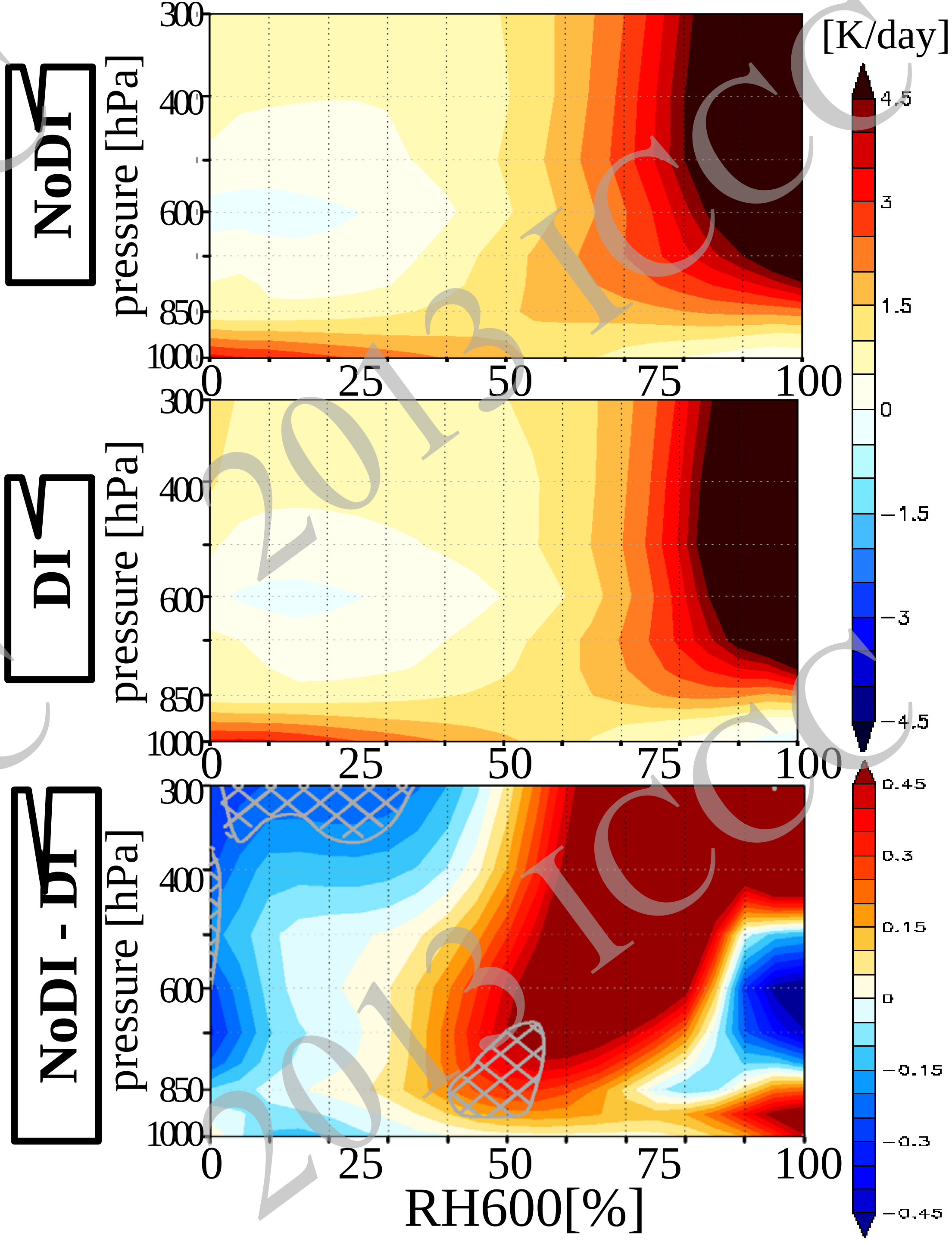


Climate model information for downscaling studies

Convective Heating vs RH at 600 hPa

In CMIP3 models without DI, deep convection is more sensitive to the mid-tropospheric humidity (Hirota et al. 2011, *JC*).

→ Similar results in CMIP5



Background

Proper representation of precipitation over tropical oceans are essential for accurate atmospheric general circulation.

Tropical precipitation is controlled by

SST

- Cumulus convection is enhanced with higher SST

Humidity in mid-troposphere

- Entrainment of dry environmental air to convection effectively suppresses deep convection (Takayabu et al. 2010, *JC*; …).

Well known biases in climate models

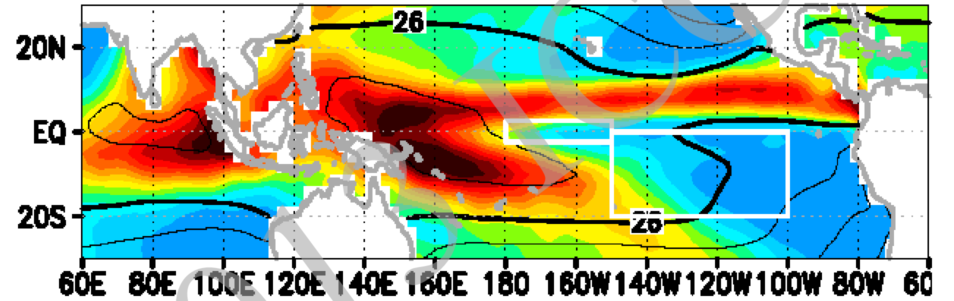
- Double ITCZ bias
- Cold tongue bias

Double ITCZ bias

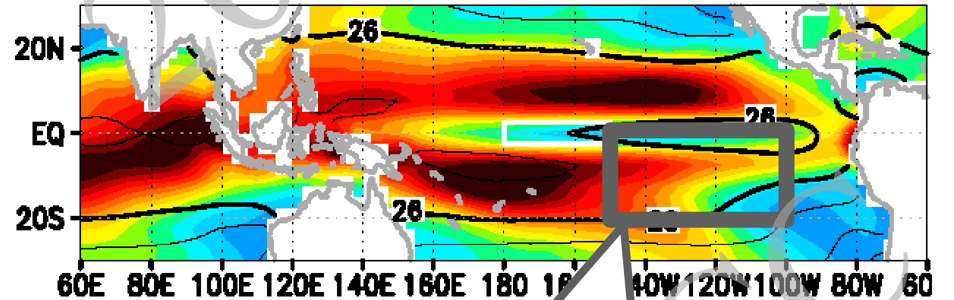
- SST bias
  - Coastline
  - Upwelling
  - WISHE
  - low level cloud
    (Mechoso et al. 1995; …)
- Convective parametarization
  - Sensitivity of deep convection to the mid-tropospheric humidity is too weak .
    (Hirota et al. 2011, *JC*; …).

Prcp(color) & SST(contour)

Obs: TRMM/HadISST



An example of Double ITCZ



Double **I**TCZ Index (Bellucci, 2010):
Precipitation averaged over southeastern Pacific (150-100W,20-0S)

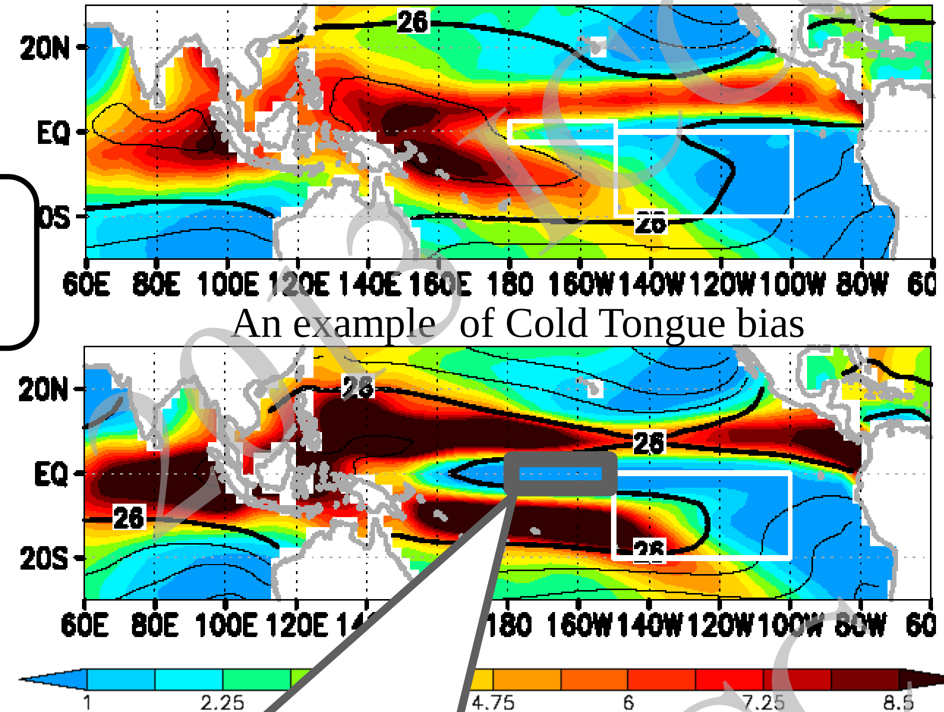
Cold tongue bias

- Tropical instability waves (Robert et al. 2009)
- Ocean circulations & thermal structure (Zheng et al. 2009)
- Trade winds (Meehl et al. 2001)

Ocn model resolution?

Prcp(color) & SST(contour)

Obs: TRMM/HadISST

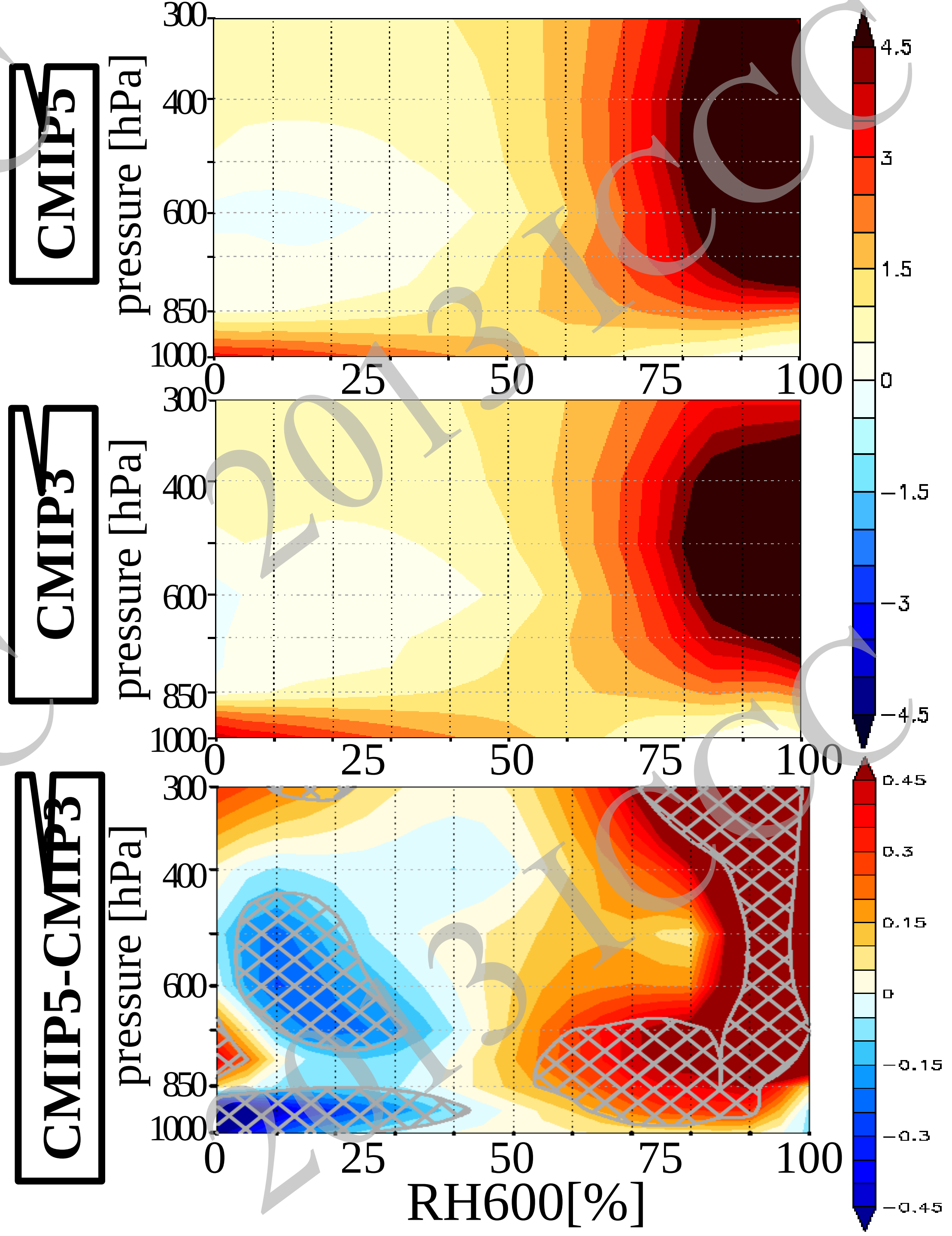


Cold Tongue Index :
SST over the equatorial central Pacific (180-150W,3S-3N)
(SST bias over entire tropical oceans is removed.)

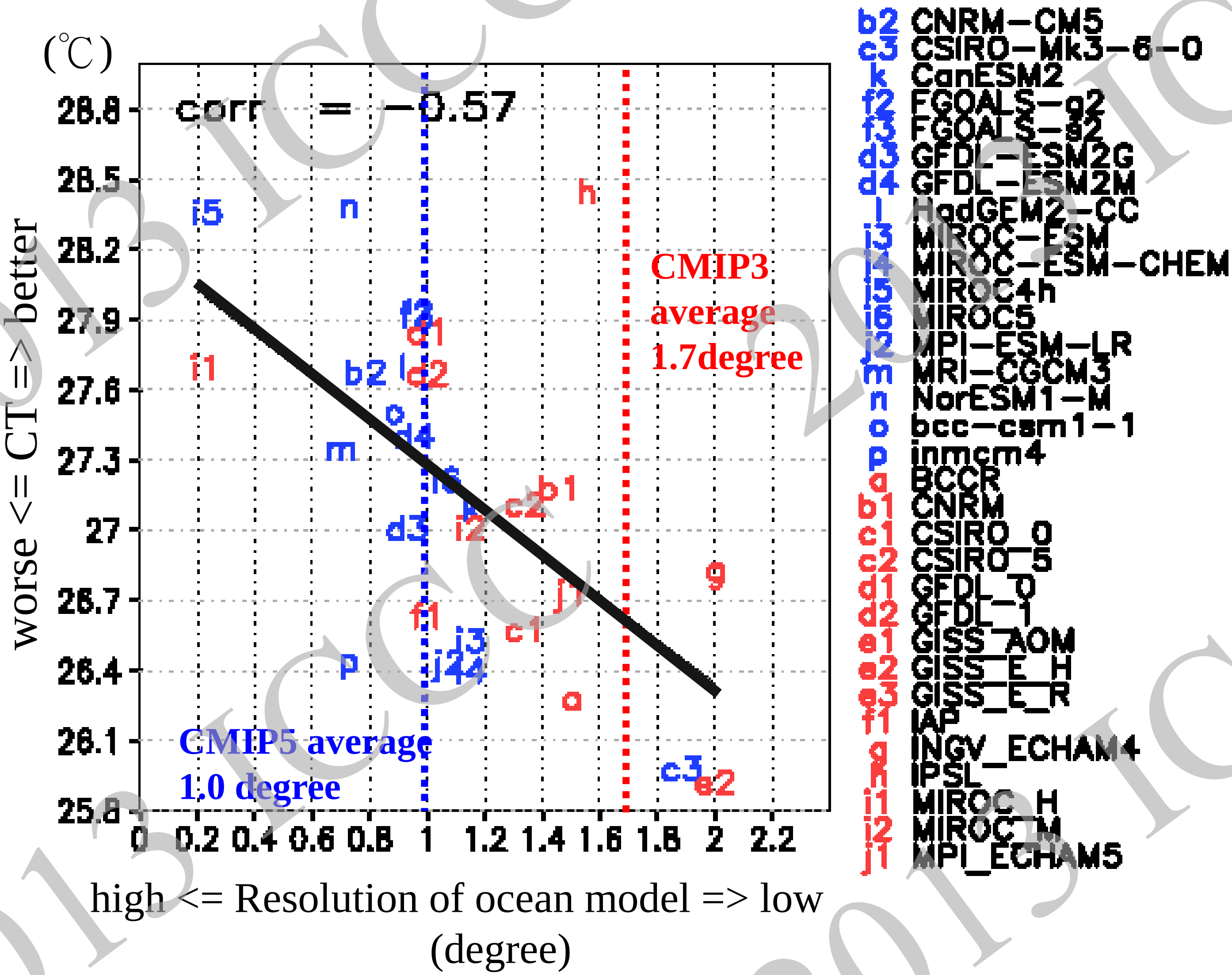
Convective Heating vs RH at 600 hPa

In CMIP3 models without DI, deep convection is more sensitive to the mid-tropospheric humidity (Hirota et al. 2011, *JC*).

Sensitivity of deep convection to humidity is increased from CMIP3 to CMIP5

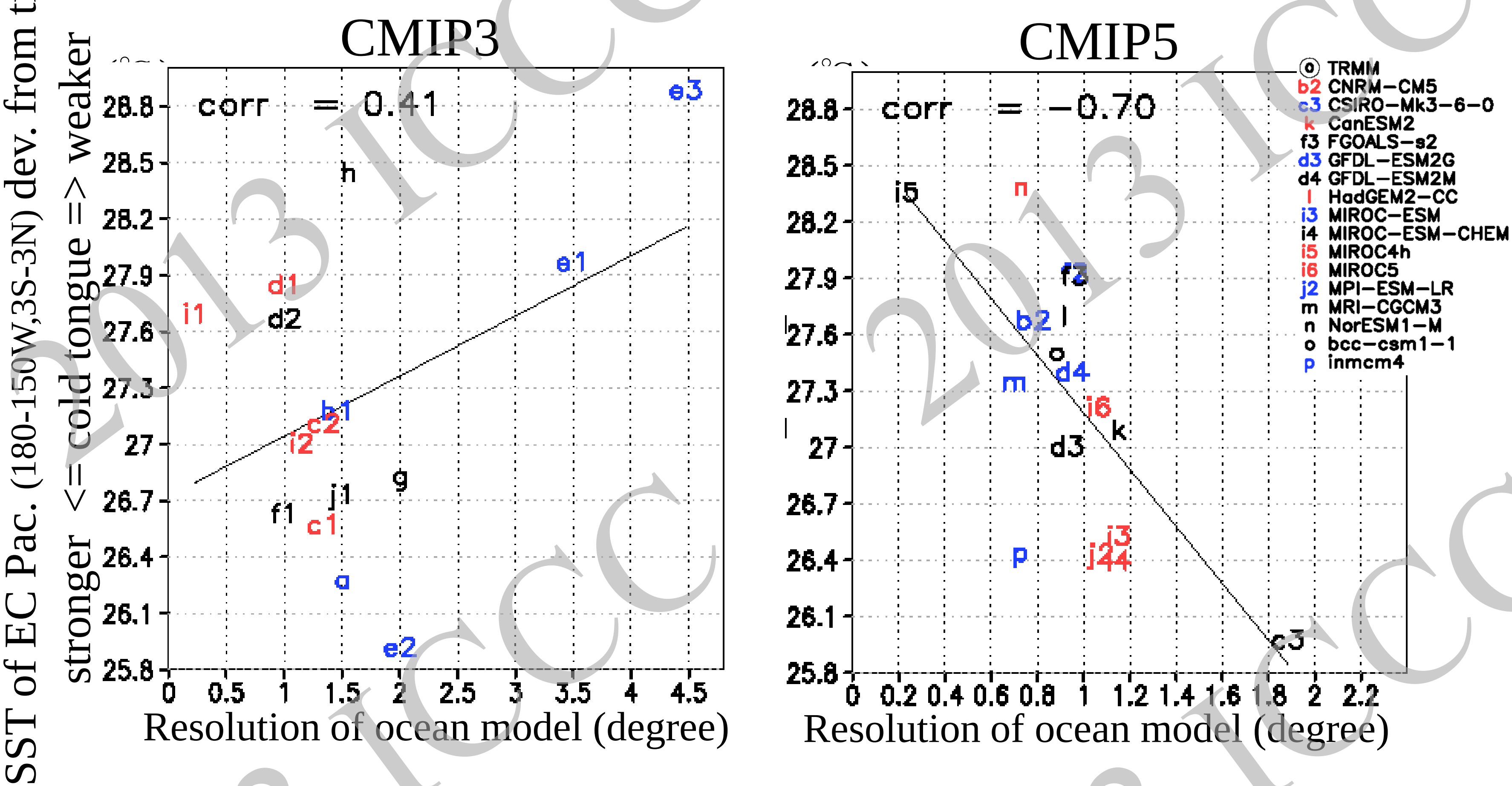


Ocean resolution?

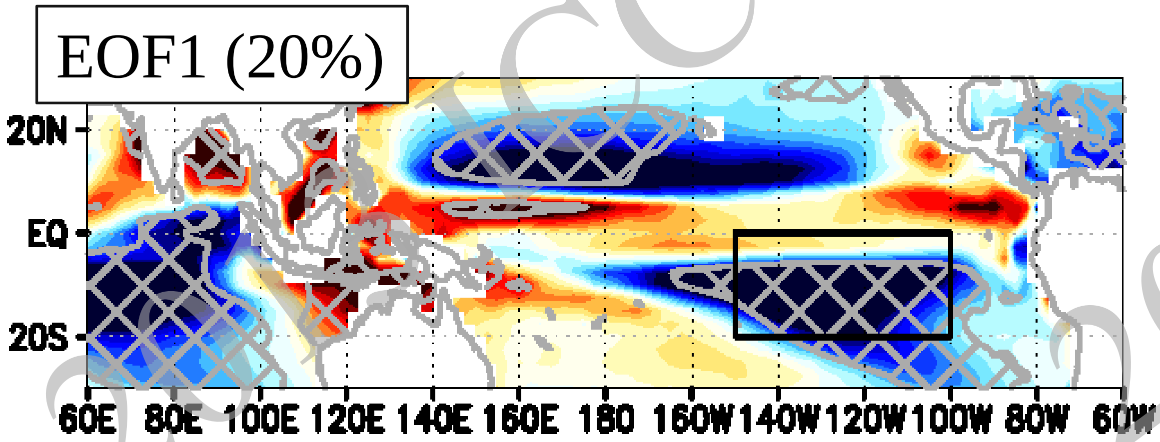


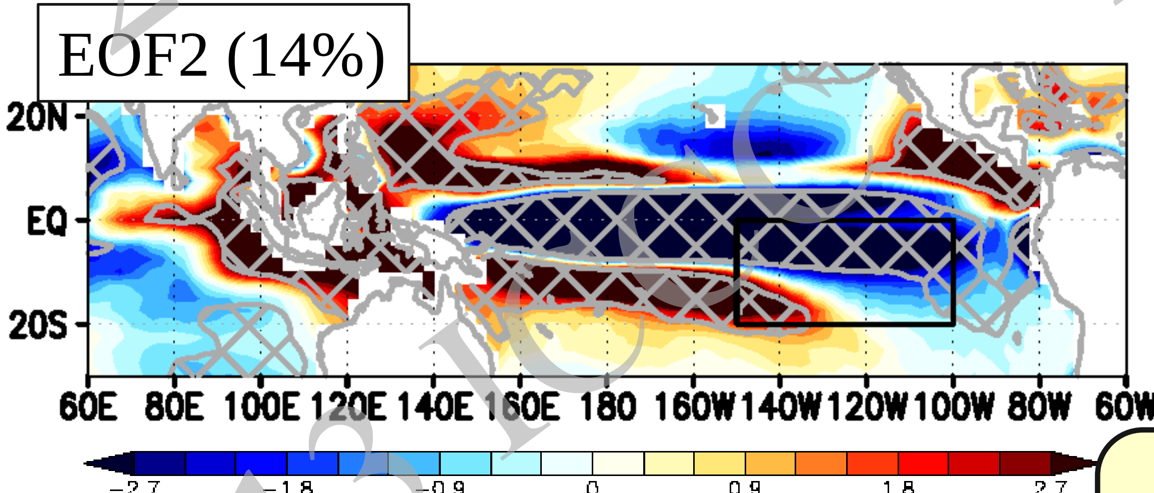
GISS_E_R & GISS_AOM with ~4deg. are excluded.

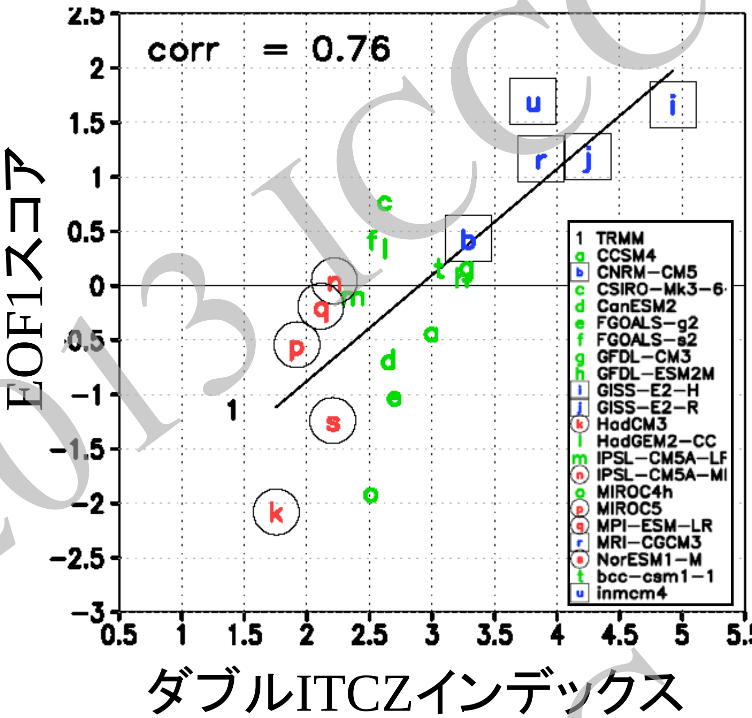
Ocean resolution?



マルチモデル間EOF

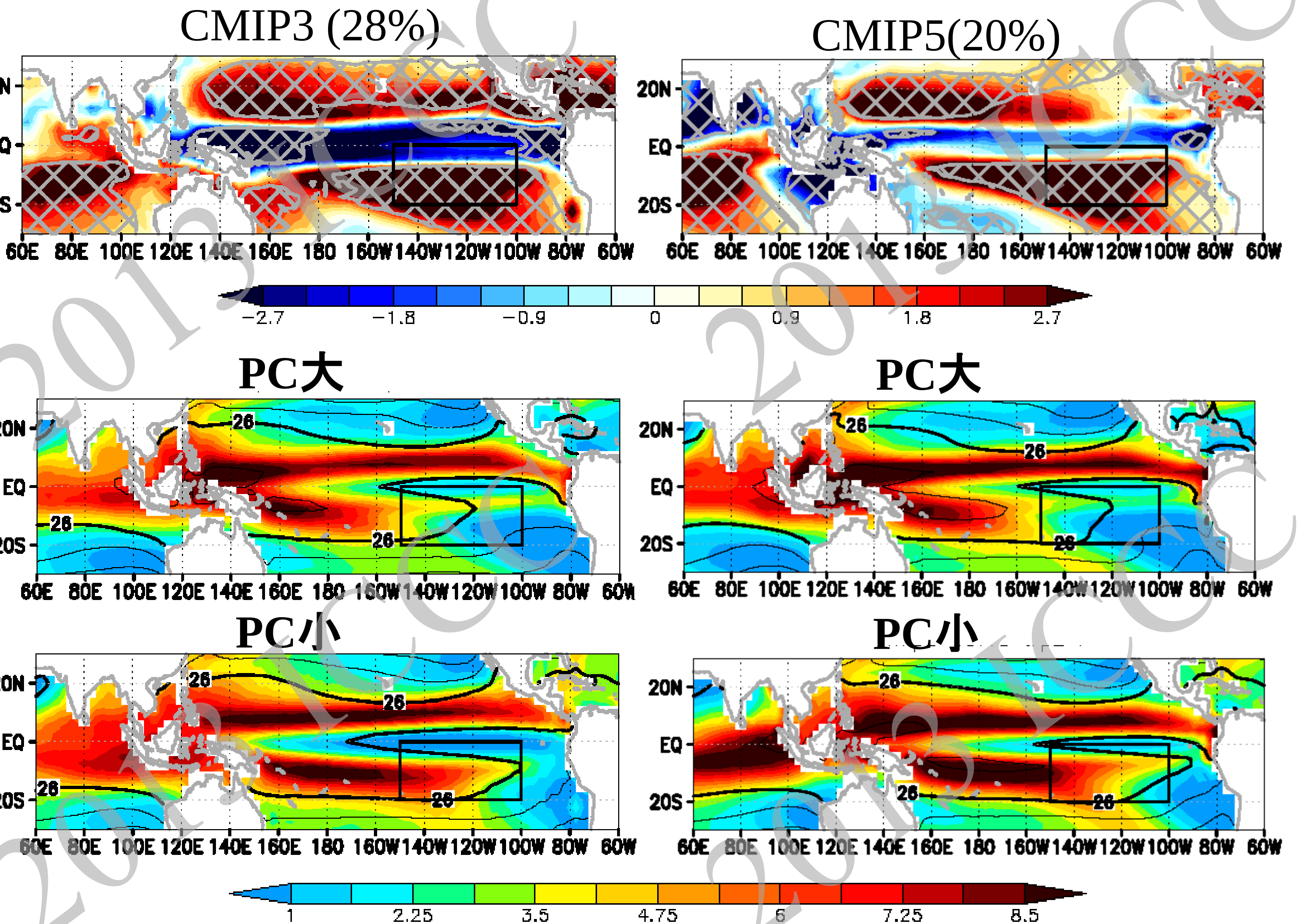






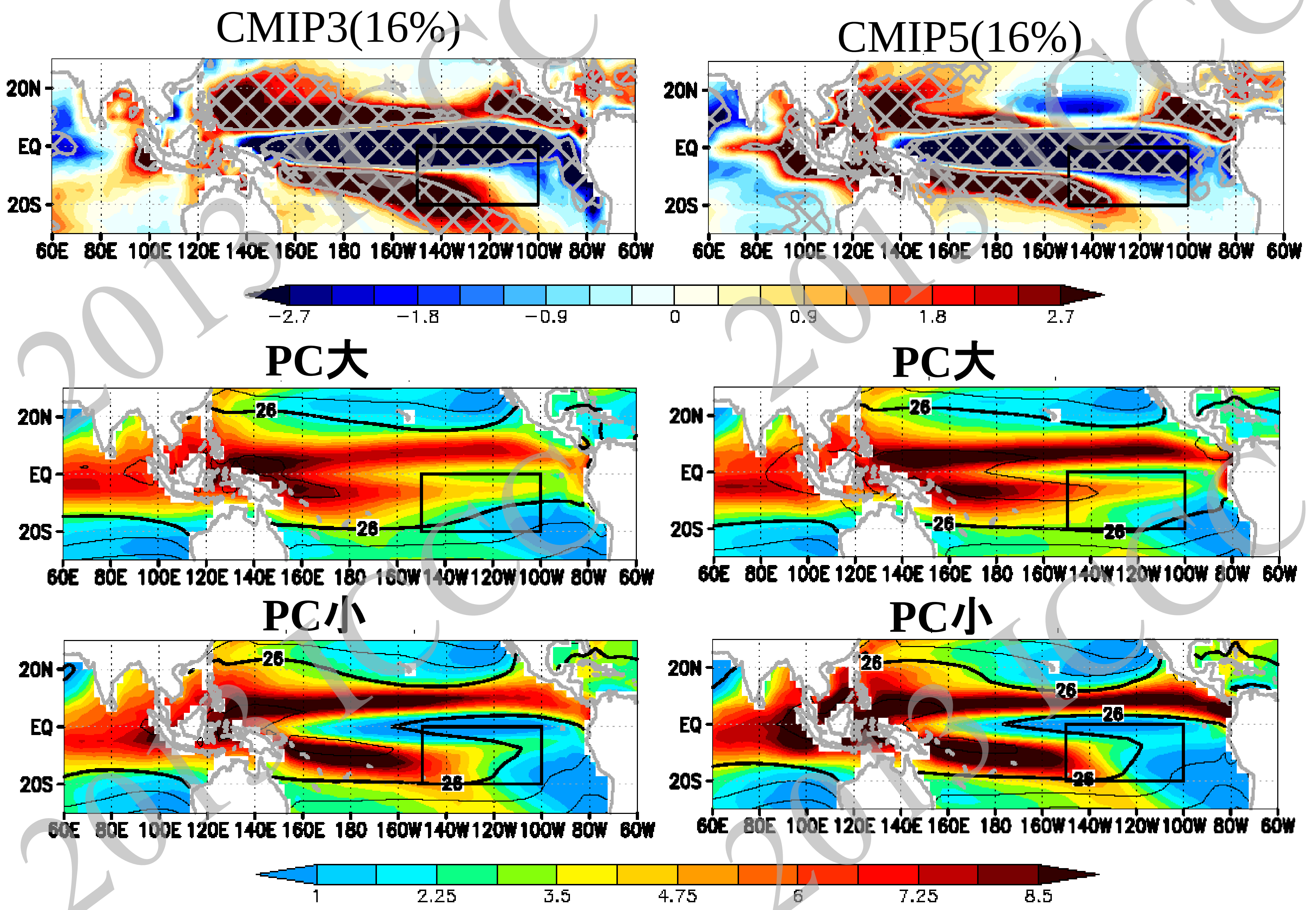
EOF1 ≒ DI index
EOF2 → Cold Tangue

EOF1



CMIP3 (28%)
CMIP5(20%)
20N
EQ
20S
60E 80E 100E 120E 140E 160E 180 160W 140W 120W 100W 80W 60W
−2.7 −1.8 −0.9 0 0.9 1.8 2.7
PC大
PC大
26
PC小
PC小
1 2.25 3.5 4.75 6 7.25 8.5

EOF2

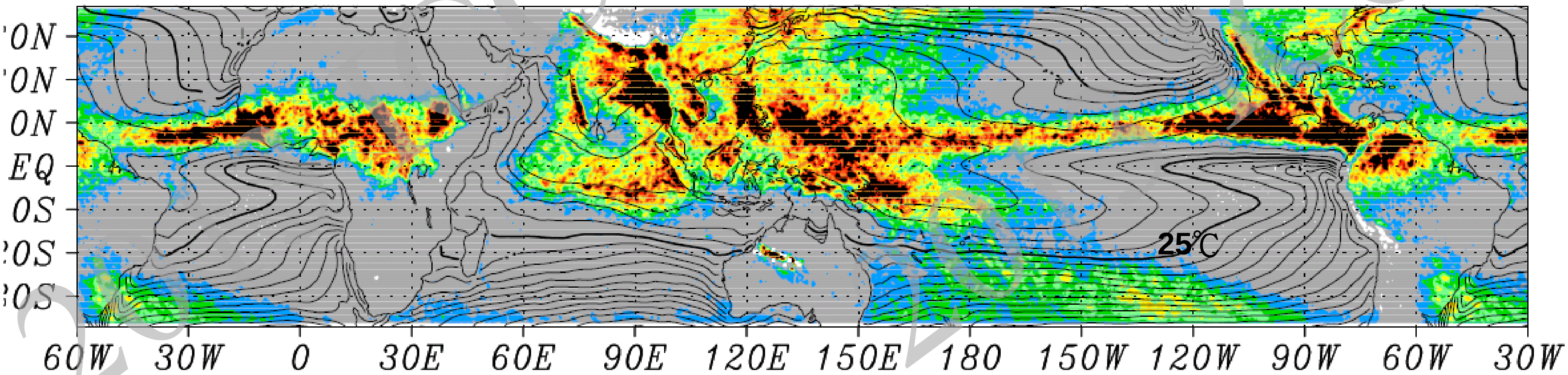


CMIP3(16%)
CMIP5(16%)
20N
EQ
20S
60E 80E 100E 120E 140E 160E 180 160W 140W 120W 100W 80W 60W
−2.7 −1.8 −0.9 0 0.9 1.8 2.7
PC大
PC大
PC小
PC小
26
1 2.25 3.5 4.75 6 7.25 8.5

10-year mean Q1-QR & SST JJA 98-07

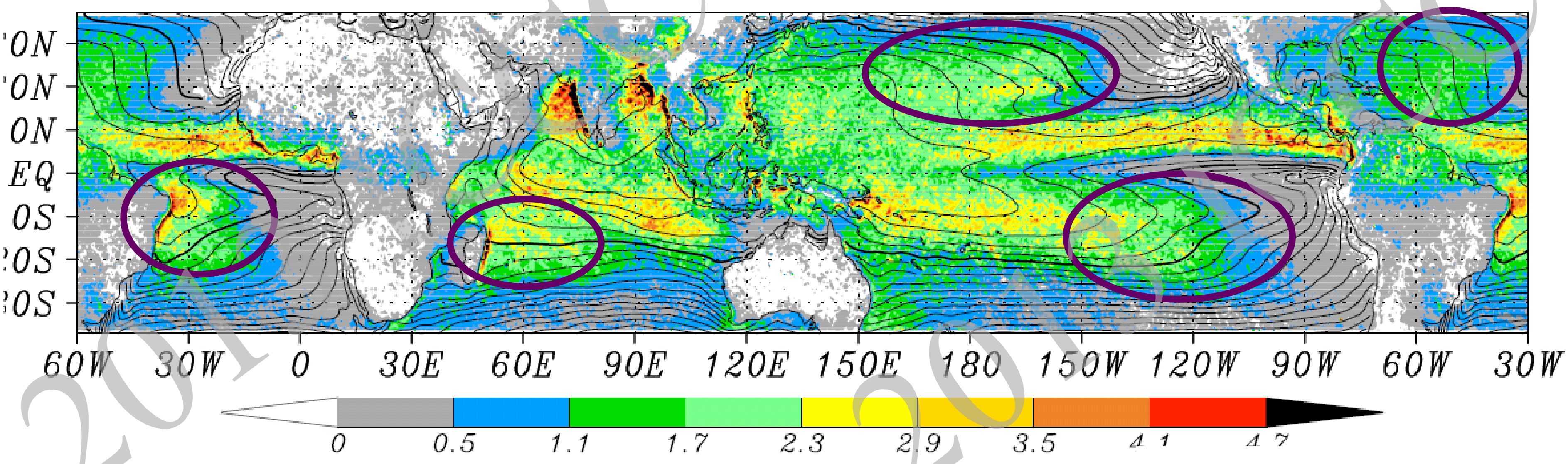
Deep Organized Systems

7.5km



Cumulus Congestus

2.0km



(Takayabu et al. 2010)