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Flexible Regional Ocean-Atmosphere-Land System Model (FROALS): An Overview

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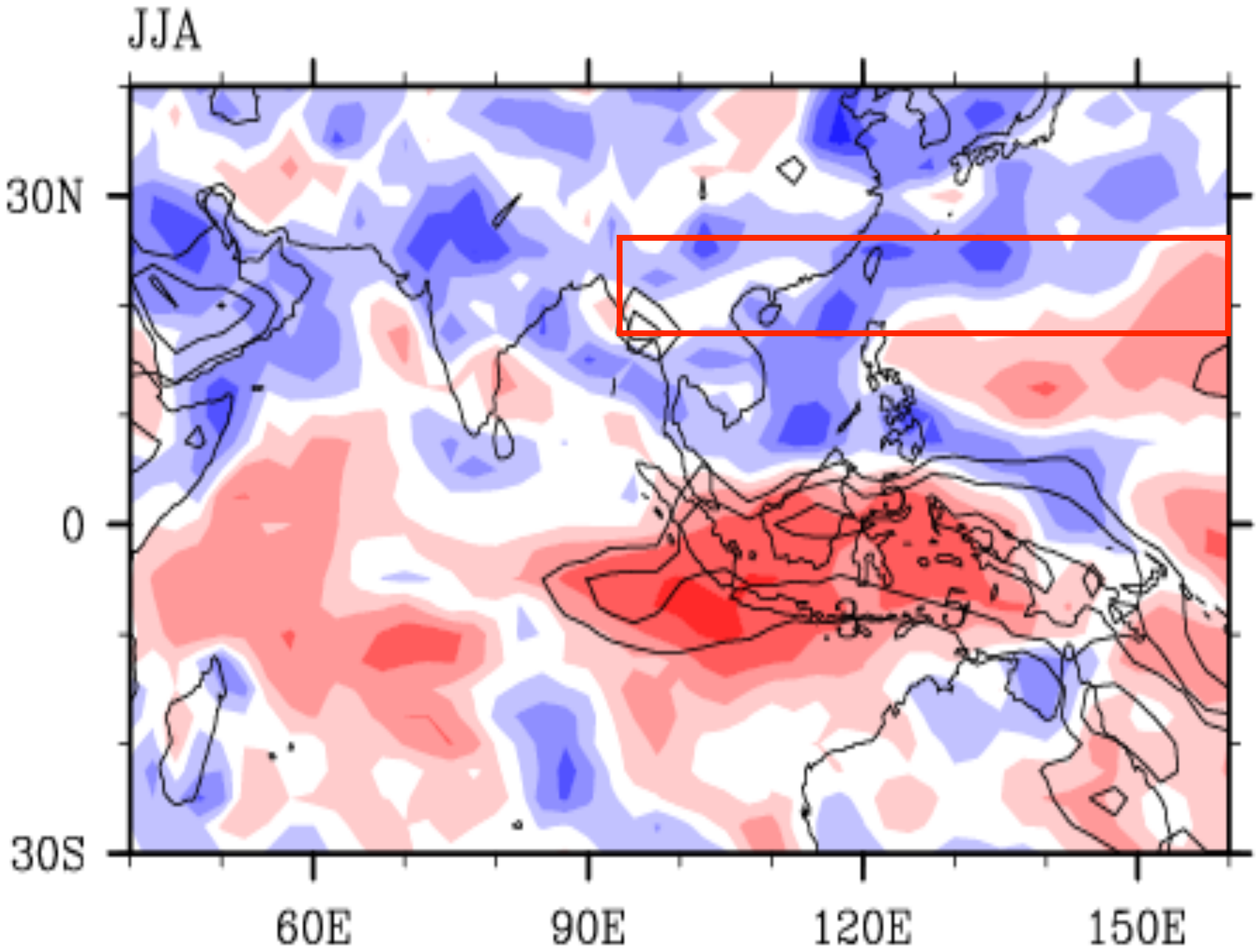
Outline

1. **Motivation**
2. **Framework of FROALS**
3. **Impacts of atmospheric/oceanic model components**
4. **Model evaluation and tuning:** Convection Suppression Criterion
5. **Model evaluation and tuning:** Optimal tuning
6. **CORDEX-EA Experiment:** historical simulation driven by NNRP2
7. **CORDEX-EA Experiment:** historical simulation driven by FGOALS
8. **CORDEX-EA Experiment:** RCP projection driven by FGOALS

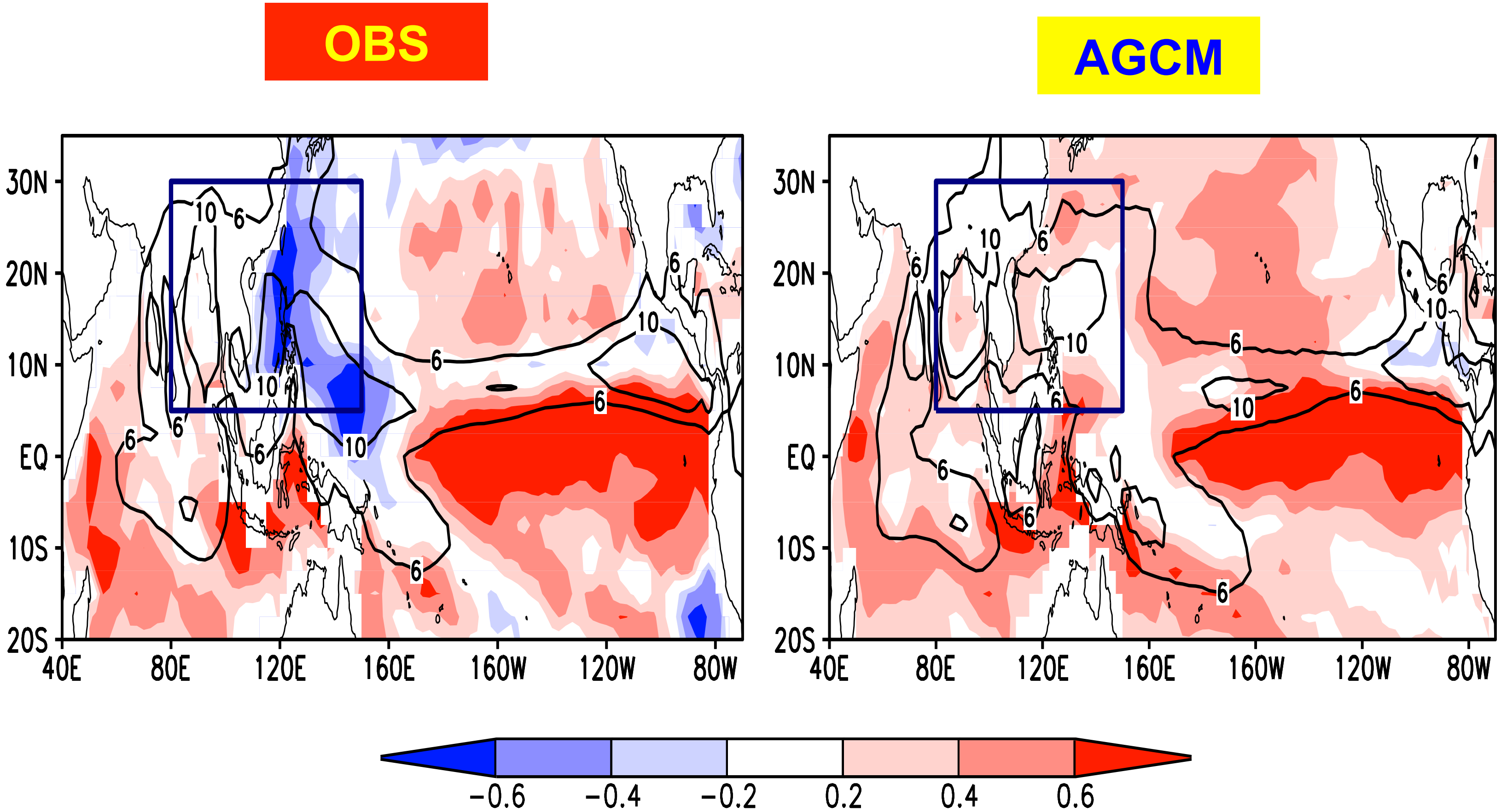
Spatial pattern of correlation coefficients between the observed and AGCM simulated rainfall anomalies



- High skill in tropical region
- Nearly no skill in summertime NWPSM area.

Zhou et al. 2009, How Well Do Atmospheric General Circulation Models Capture the Leading Modes of the Interannual Variability of the Asian-Australian Monsoon? ***Journal of Climate***, 22, 1159-1173

Correlation between Precipitation and SST in JJA



- More rainfall, colder SST: the ocean is forced by the atmosphere

Wang et al. 2005 GRL

Motivation

- **Ocean-atmosphere coupled model is needed to simulate/project monsoon variability over the Asian-Northwest Pacific domain.**
- **Motivation:** To develop a Regional Ocean-Atmosphere Coupled Model (ROAM), as supplementary downscaling tool of global climate system model.

FROALS: Flexible Regional Ocean Atmosphere Land System

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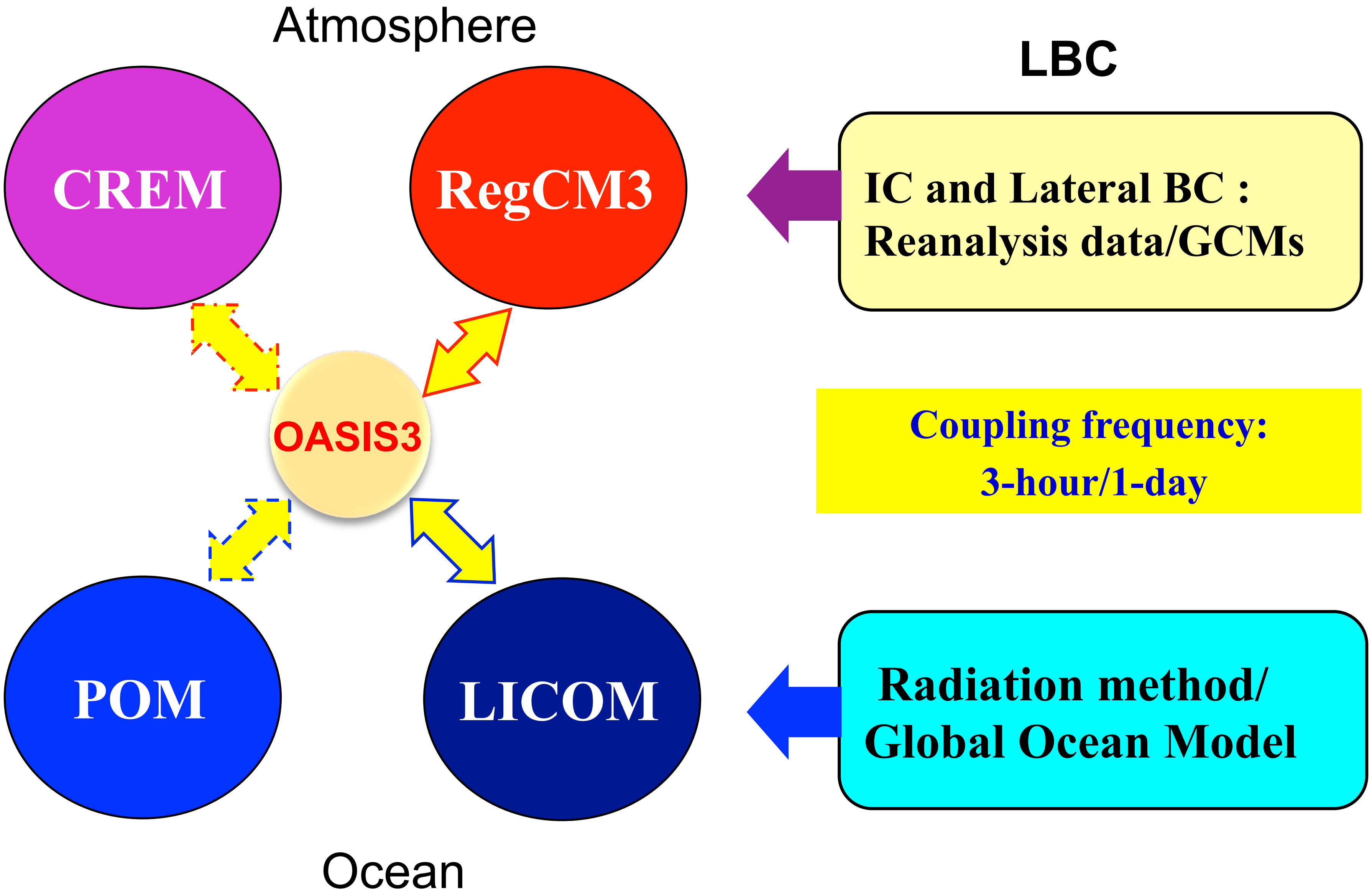
FROALS Framework



Atmospheric Components of FROALS

Model	CREM	RegCM3
Dynamical Core	AREM2.3（Yu R. 2004）	MM5（Grell, 1994）
H. Resolution	37 km（101×161）	45 km（113×136）
Convections	Betts-Miller（Betts and Miller, 1986）	Grell FC（Grell, 1993）
Large Scale Precipitation	Prognostic cold cloud （Xu et al., 1998）	SUBEX（Pal et al., 2000）
Radiation	UKMO（Edwards and Slingo, 1996; Sun and Rikus， 1999）	CCM3（Kiehl, et al., 1996）
Planetary Boundary Layer	None Local（Holtslag and Boville, 1993）	None Local（Holtslag and Boville, 1993）
Land Surface	BATS1e（Dickinson et al., 1989, 1993）	BATS1e（Dickinson et al., 1989, 1993）
Air-sea flux	Bulk (Zeng et al., 1998）	Bulk（Zeng et al., 1998）

Zou L. and T. Zhou**,** 2012: Development and evaluation of a regional ocean-atmosphere coupled model with focus on the western North Pacific summer monsoon simulation: Impacts of different atmospheric components. ***Sci China Earth Sci***, 2012, 55: 802-815

Ocean Components of FROALS

Model	POM2000	LICOM
Dynamical Core	Sigma-coordinate, free surface, Mellor (2004)	Eta-coordinate, free surface Zhang (1992)
H. Resolution	0.5*0.5	0.5*0.5
V. Resolution	L16	L30 (10m in upper 150m)
Vertical Mixing	Mellor and Yamada (1982)	Canuto et al. (2001)
Mesoscale eddy parameterization	-	Gent and McWilliams, 1990; Large et al. 1997
SW Radiation Penetration	-	Chlorophyll-dependent (Ohlmann, 2003)
Lateral BC	Climatology for S, T; Velocity (Orlanski, 1976)	**Global Model**
Air-Sea flux	Bulk formula (Zeng et al. 1998)	Bulk Formula

Zou L**.,** T. Zhou, 2013: Simulation of the western North Pacific summer monsoon by regional ocean-atmosphere coupled model: Impacts of oceanic components. ***Chinese Science Bulletin***, 59(7),662-673

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Case simulation (April 25-Aug 31, 1998)

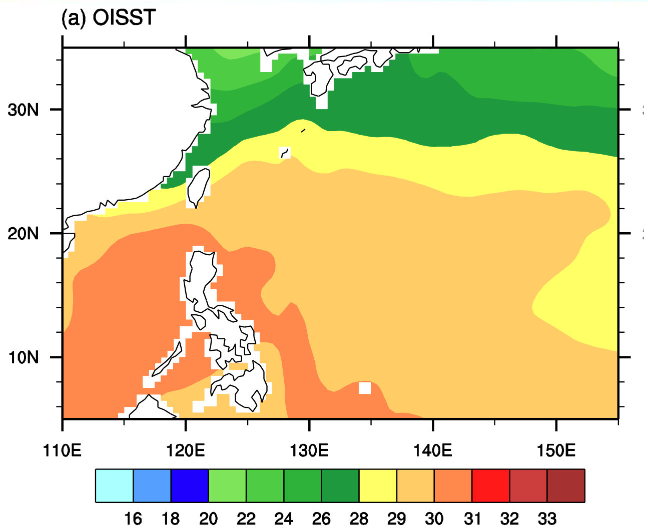
different atmospheric model

CREM_CTRL	RegCM_CTRL	CREM_POM	RegCM_POM	RegCM_LICOM
OISST2	OISST2	Coupled	Coupled	Coupled

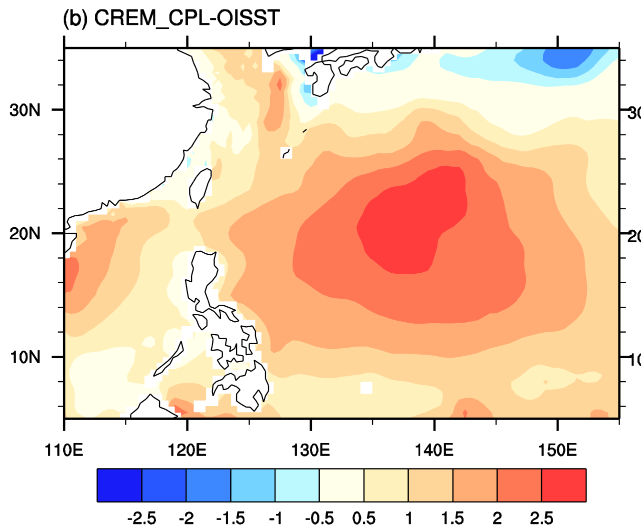
different oceanic model

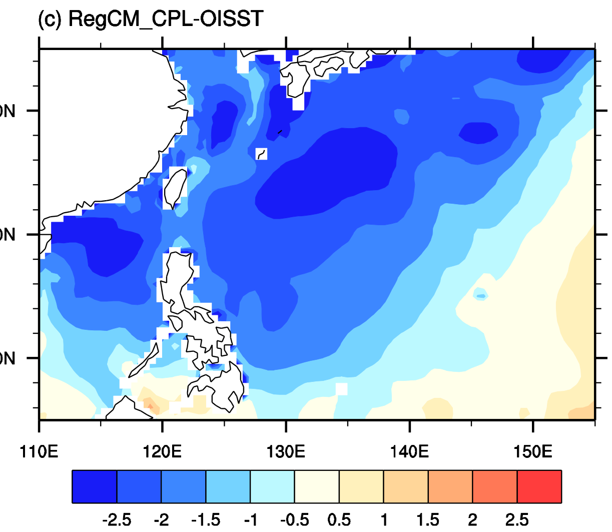
RegCM3+POM and CREM+POM: SST Bias

OISST



CREM_CPL-OISST



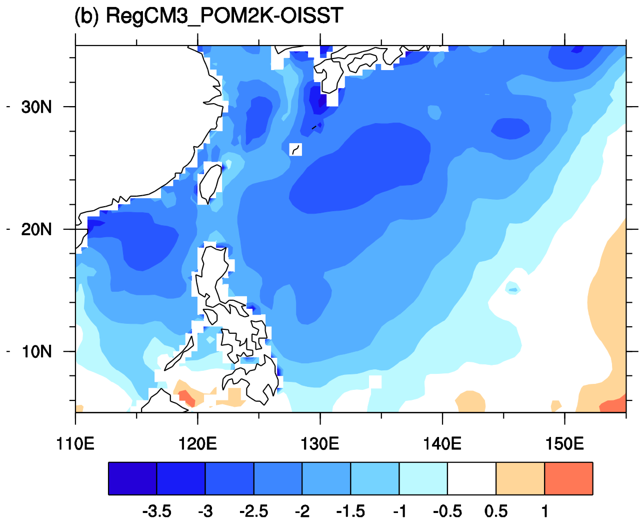


RegCM_CPL-OISST

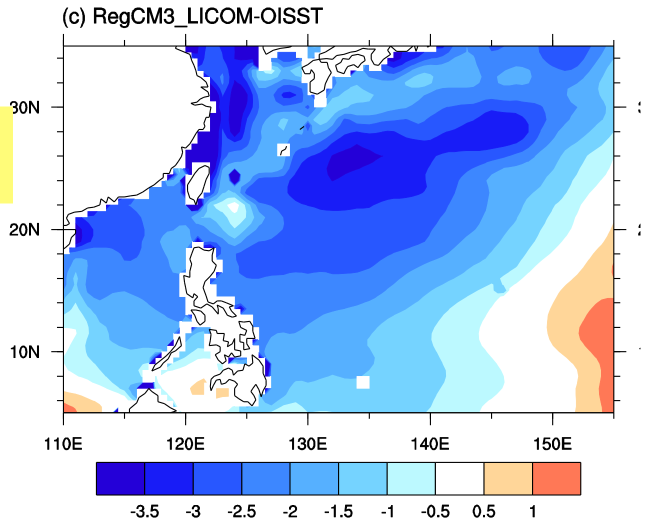
Zou Liwei, ZHOU Tianjun, 2012: Development and evaluation of a regional ocean-atmosphere coupled model with focus on the western North Pacific summer monsoon simulation: Impacts of different atmospheric components. ***Sci China Earth Sci***, 55, 802-815

RegCM3+POM and RegCM3+LICOM: SST Bias

RegCM3_POM



RegCM3_LICOM



Cold biases of simulated SST are evident in both simulations and they are very similar.

Why are there cold biases in RegCM3?

Zou Liwei, ZHOU Tianjun, 2014: Simulation of the western North Pacific summer monsoon by regional ocean-atmosphere coupled model: Impacts of oceanic components. ***Science Bulletin***, 59(7),662-673

Regional [10-30N, 120-155E] average of Surface Fluxes

W/m^2	OAFlux	CREM_CTRL	RegCM3_CTRL
Latent heat flux	103.7	47.8	165.3
Sensible heat flux	4.9	-1.7	23.9
Net shortwave flux	215.0~227.6	240.5	200.4
Net longwave flux	43.1	27.5	45.9
Net heat flux	63.3~75.9	166.9	-34.7

- **SST-Driven Run**: RegCM3 **underestimates** the **net heat flux**, and thus has an artificial **cold-heating**; After air-sea coupling, the **negative-heating** leads to **colder SST bias.**
- **The negative heating of RegCM3 come from excessive latent heat flux but deficient shortwave flux.**
- **CREM tells a different story.**

Summary for Cold SST bias (RegCM3 case)

More convections

↓

Drier Low-level Atmosphere

↙ ↘

More Latent Heat flux Loss | **Less SW radiation**

↓

Colder SST bias

Points-Part 1

- The atmospheric model is more important than the oceanic model in regional ocean-atmosphere coupled models.
- Cold biases of simulated SST are evident over WNP in regional coupled models with RegCM3.
- The biases of vertical profiles of temperature and humidity in the standalone RCM imply the sign of the simulated SST biases in the regional air-sea coupled model.

How to do the tuning?

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Convection Suppression Criterion

➢Threshold of Relative Humidity

Convection is suppressed when the RH averaged between the top and bottom of cloud is less than the threshold value:

$$\overline{RH} = \int_{z_B}^{z_T} q\, dz \Big/ \int_{z_B}^{z_T} q^{*}\, dz$$

Threshold values：

0.55 in Chow et al.(2006) for Emanuel

0.80 in Emori et al.(2001) for Arakawa-Shubert

Numerical Experiments

ROAM: RegCM3 + POM2000

	CPL_CTRL	RH_55	RH_65	RH_70	RH_75	RH_80
RH_c	No	0.55	0.65	0.70	0.75	0.80

Convection Suppression Criterion

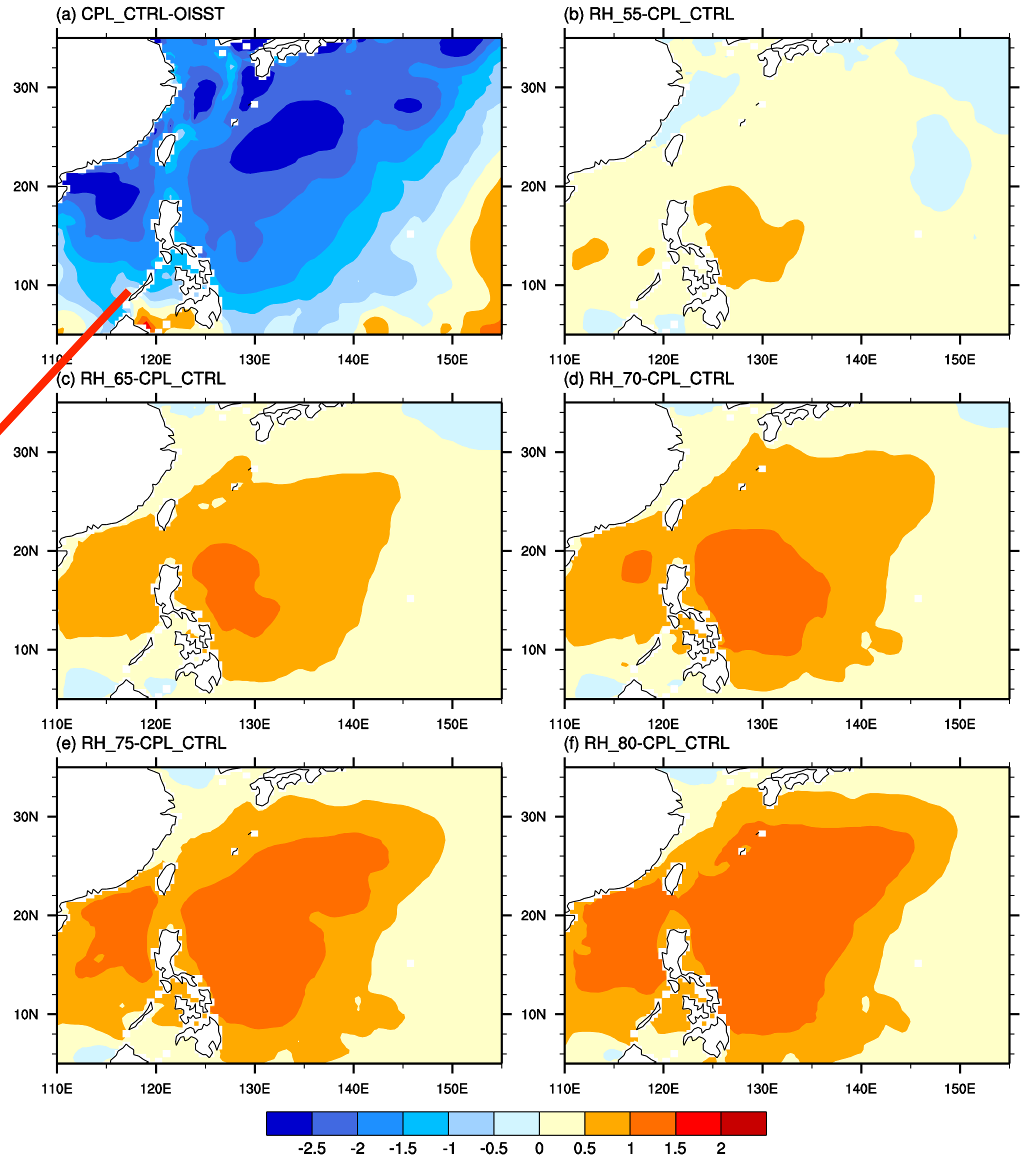
TRMM3A12 : Convective percentage during May-Aug 1998

Zou Liwei, ZHOU Tianjun, 2011: Sensitivity of a Regional Ocean-Atmosphere Coupled Model to Convection Parameterization over Western North Pacific, ***Journal of Geophysical Research-Atmosphere*****,** 116, D18106, doi:10.1029/2011JD015844.

Improved SST bias due to convection suppression

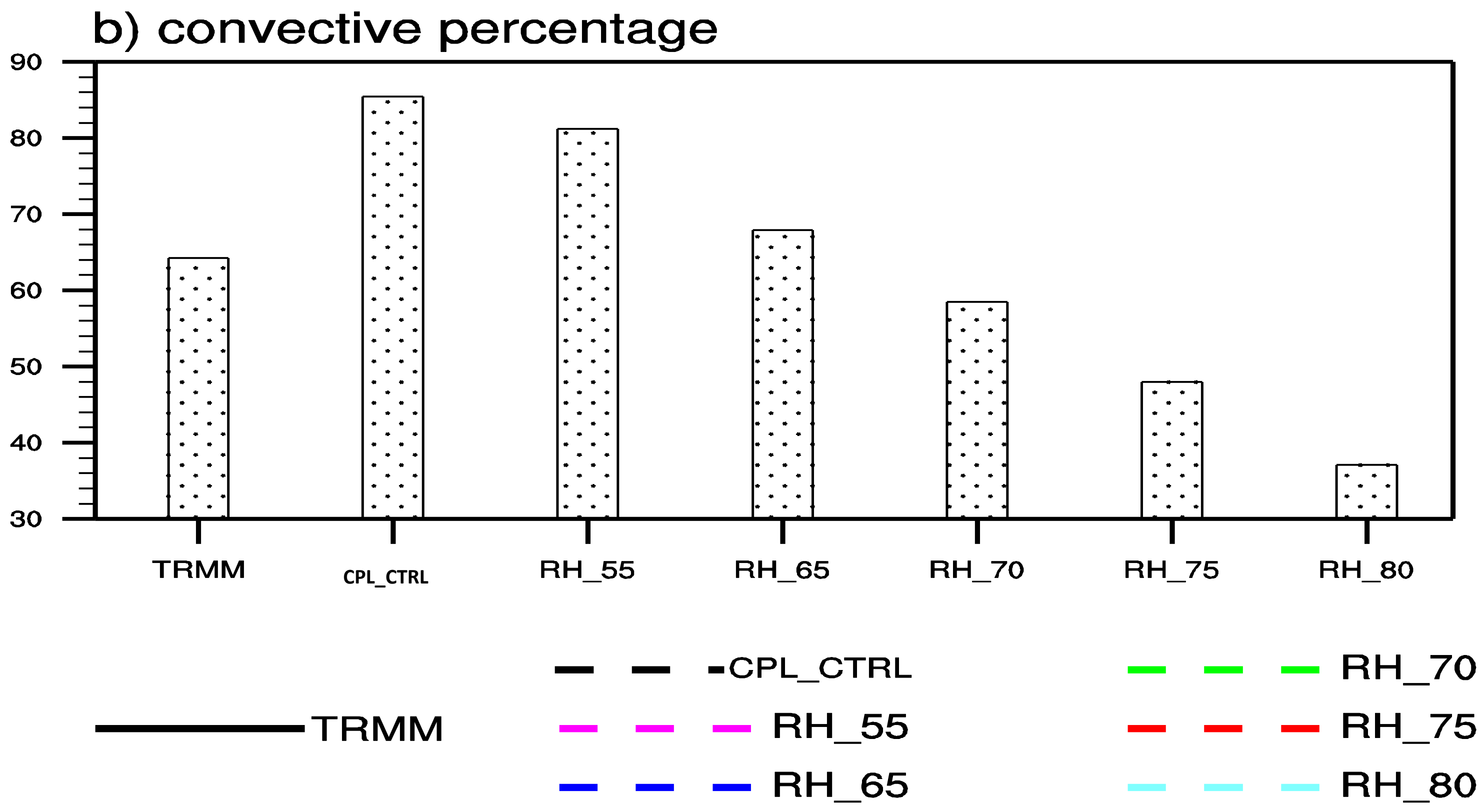
CPL_CTRL-OISST	RH55-CPL_CTRL
RH65-CPL_CTRL	RH70-CPL_CTRL
RH75-CPL_CTRL	RH80-CPL_CTRL

SST Bias in Control run



Zou L. and T. Zhou, 2011: Sensitivity of a Regional Ocean-Atmosphere Coupled Model to Convection Parameterization over Western North Pacific, *Journal of Geophysical Research-Atmosphere*, 116, D18106, doi:10.1029/2011JD015844.

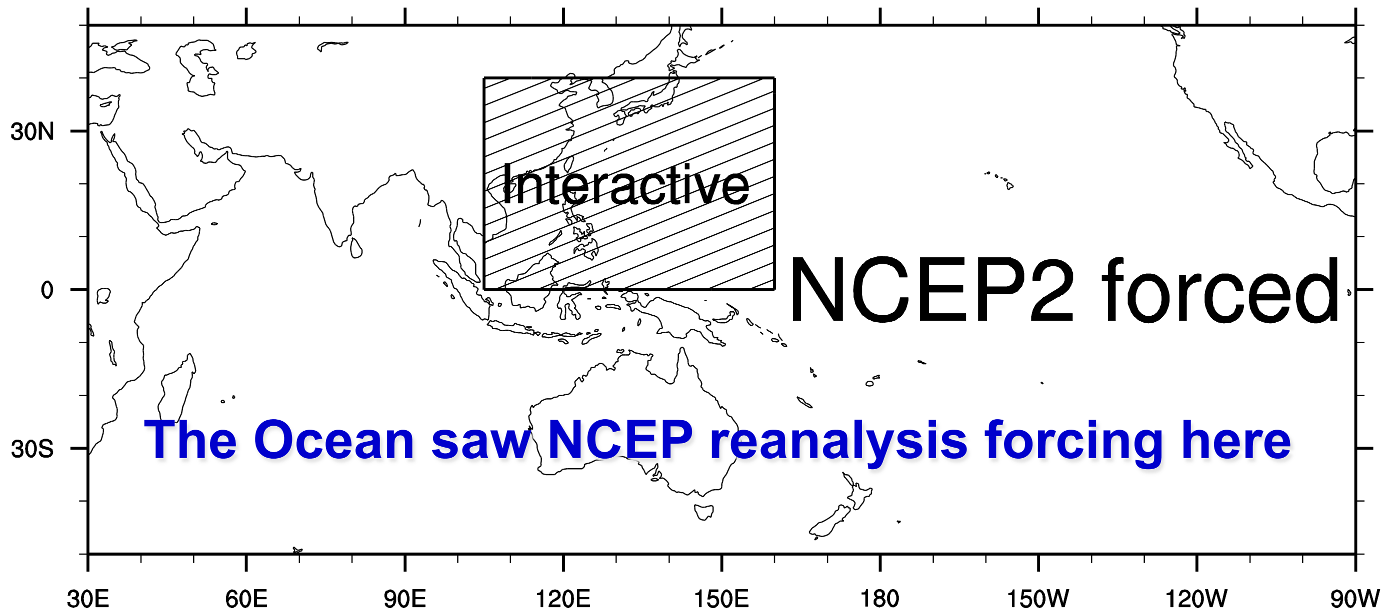
Percentage of Convective precipitation over ocean

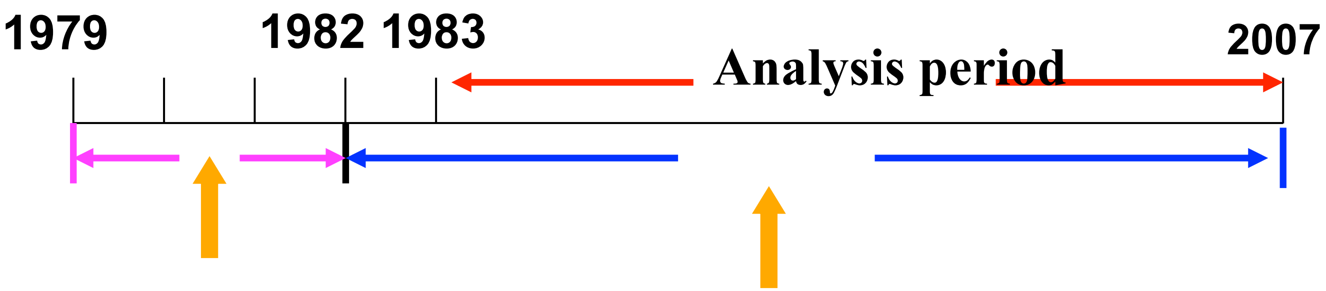


	CPL_CTRL	RH_55	RH_65	RH_70	RH_75	RH_80
SCC	0.21	0.33	0.43	0.44	0.39	0.40
RMSE(mm/day)	3.23	3.08	2.95	2.95	3.06	3.11

Zou L. and T. Zhou, 2011: Sensitivity of a Regional Ocean-Atmosphere Coupled Model to Convection Parameterization over Western North Pacific, *Journal of Geophysical Research-Atmosphere*, 116, D18106, doi:10.1029/2011JD015844.

Interannual variation of monsoon rainfall





spin-up of LICOM2 **Coupled modeling: 1982-2007**

Zou L. and T. Zhou, 2013: Can a Regional Ocean-Atmosphere Coupled Model Improve the Simulation of the Interannual Variability of the Western North Pacific Summer Monsoon ? ***Journal of Climate***, 26, 2353-2367.

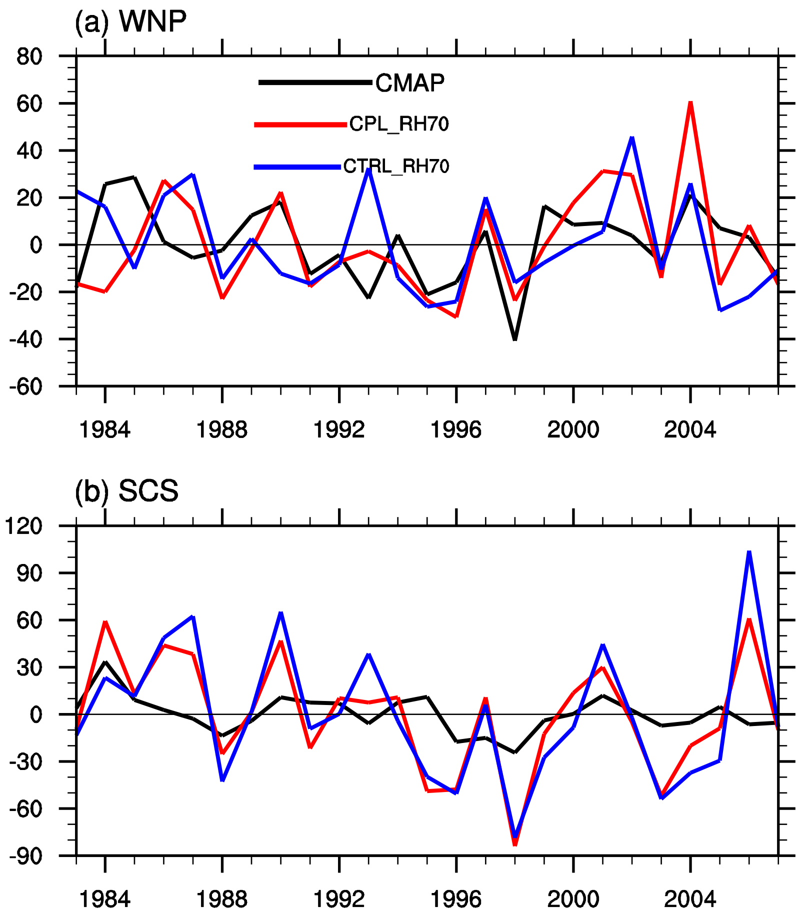
Regional average of prcipitation

NW Pacific

（10°N-25°N，120°E-150°E）

South China sea

（5°N-20°N，110°E-120°E）



Correlations

CTL	CPL
0.14	0.50

CTL	CPL
0.37	0.55

Zou L. and T. Zhou, 2013: Can a Regional Ocean-Atmosphere Coupled Model Improve the Simulation of the Interannual Variability of the Western North Pacific Summer Monsoon ? ***Journal of Climate***, 26, 2353-2367.

Points-Part 2

- Performance of regional ocean-atmosphere coupled model was improved when convection suppression was applied.
- Cold bias of SST is partly due to the overestimated frequency of convection.
- The interannual variation of monsoon rainfall is improved in the coupled model compared to the stand-alone RegCM3.

Zou L. and T. Zhou, 2011: Sensitivity of a Regional Ocean-Atmosphere Coupled Model to Convection Parameterization over Western North Pacific, *Journal of Geophysical Research-Atmosphere*, 116, D18106, doi:10.1029/2011JD015844.

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Multiple Very Fast Simulated Annealing (MVFSA)

Calibration of

RegCM3 over the

CORDEX-EA

Domain with the

MVFSA technique

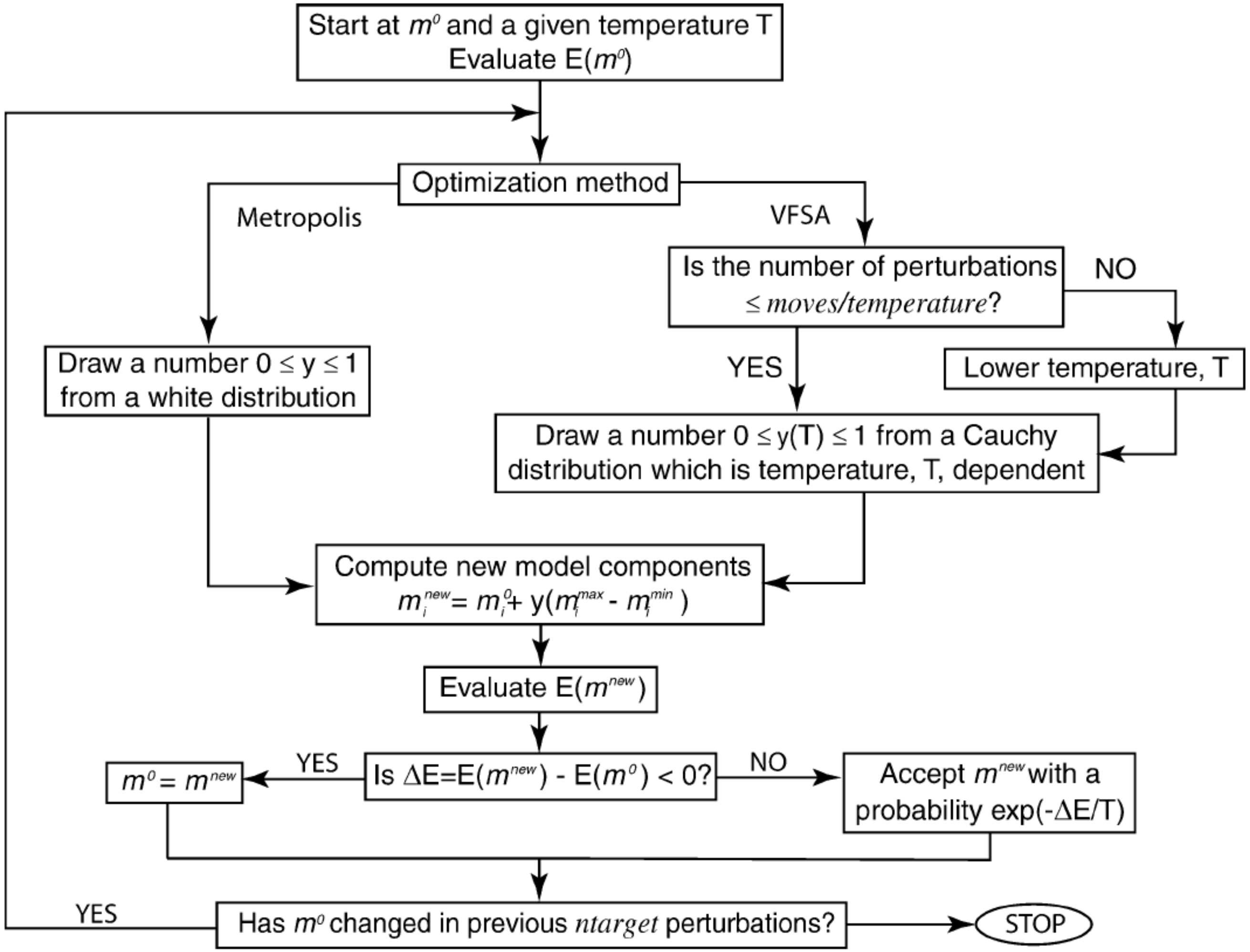


FIG. 1. Schematic diagram of the Metropolis and VFSA algorithms. Parameter *moves/temperature* gives the number of times a new model parameter set is selected and tested before lowering the temperature *T*. Parameter *ntarget* specifies the convergence criterion and is given by the maximum number of failed attempts at finding an acceptable parameter set before stopping.

Jackson et al., 2004

Parametric sensitivity and calibration for the EMANUEL convective parameterization scheme in RegCM3

Parameter	Default	Minimum	Maximum	Description
RHC	------	0.4	0.9	Convection is activated when the RH averaged from the cloud top to the cloud base is larger than a critical value (RHC). In the default setting, the convection is driven by the buoyancy, and effects of the large-scale environment are not considered.
$C_{asc_}$land	0.4	0.2	0.8	Autoconversion scale factor over ocean
$C_{asc_}$ocean	0.4	0.2	0.8	Autoconversion scale factor over ocean
$RH_{min_}$land	0.8	0.6	1.0	Grid-box RH threshold for cloudiness over land
$RH_{min_}$ocean	0.9	0.6	1.0	Grid-box RH threshold for cloudiness over ocean
Alpha	0.2	0.0002	0.8	Rate at which the cloud-base upward mass flux is relaxed to steady state
L_0	0.0011	0.0001	0.05	Amount of cloud water available for precipitation conversion

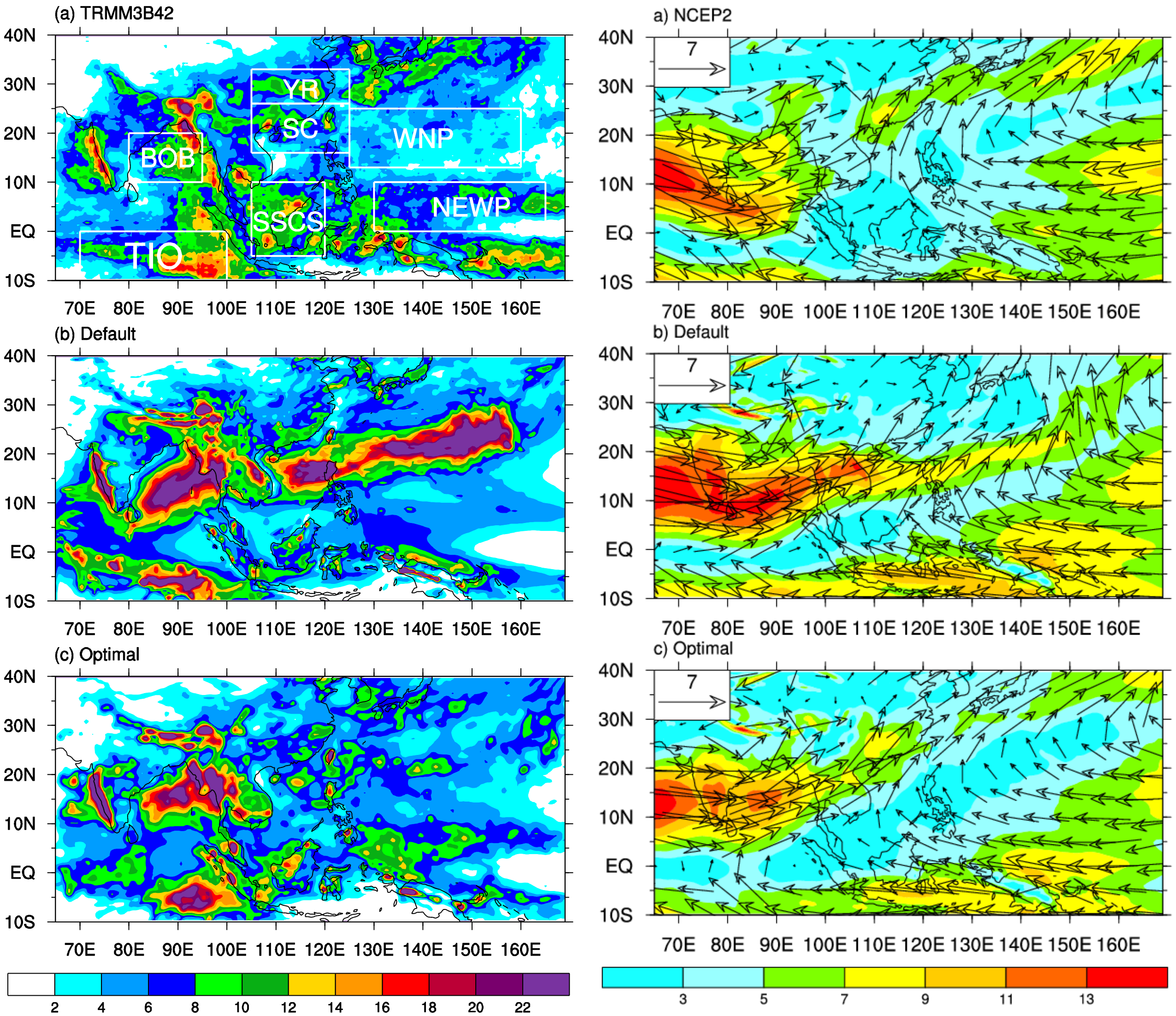
The 'multiple very fast simulated annealing' (MVFSA) algorithm is applied to optimize these seven selected parameters

Optimized simulation: rainfall (left) and wind at 850 hPa

TRMM &NCEP2

Control parameters

Optimal parameters



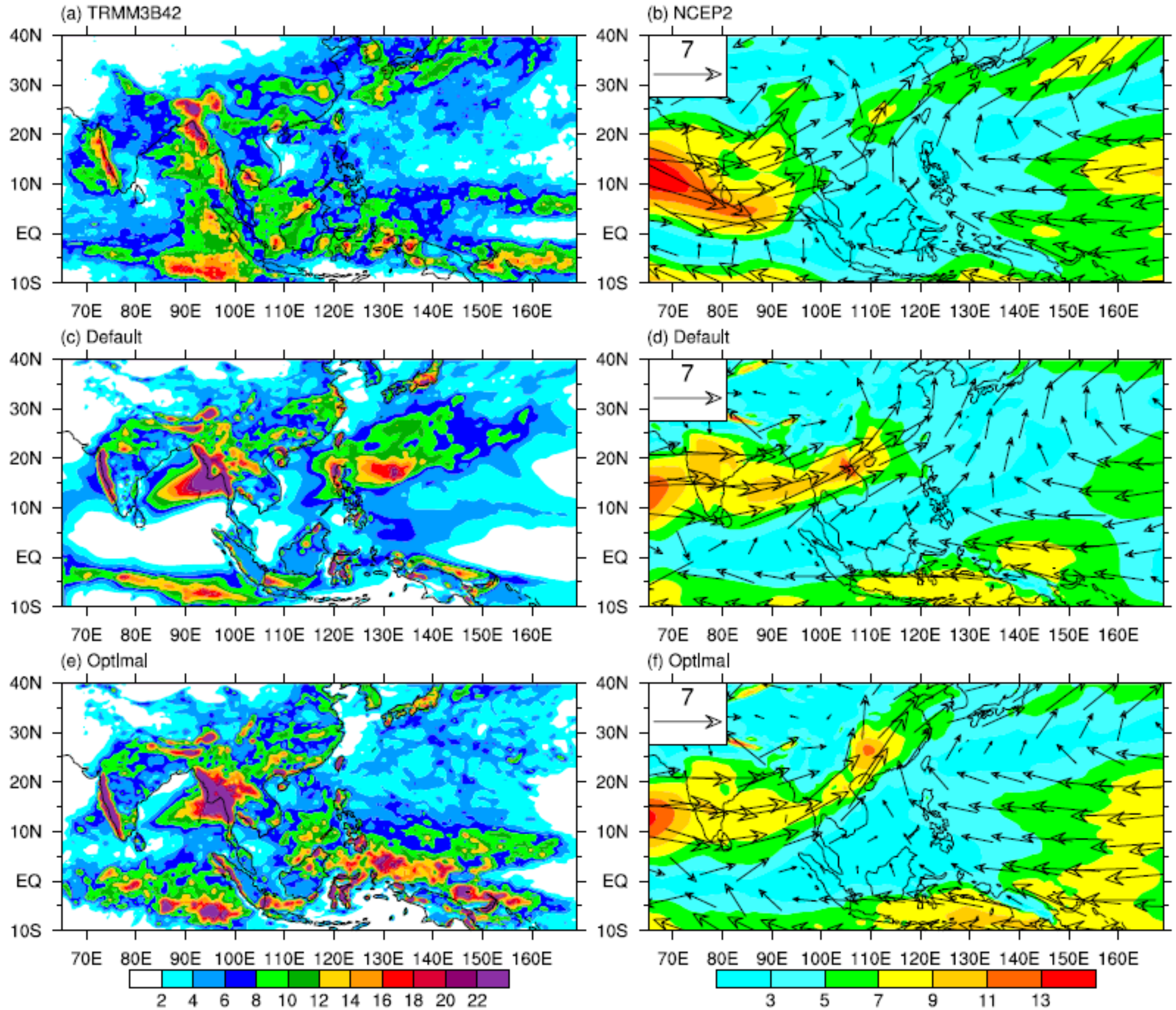
Zou Liwei, Qian Yun, ZHOU Tianjun, Yang Ben 2014: Parameter tuning and calibration of RegCM3 with MIT-Emanuel cumulus parameterization scheme over CORDEX East Asia domain. ***Journal of Climate,*** 27, 7687-7701

Whether the identified optimal parameters are suitable for the new version of RegCM: RegCM4 simulation

Obs

Control

Optimal



Points-Part 3

- Optimal parameters tuning improves the simulation of E. Asian summer monsoon rainfall and circulation.
- The identified optimal parameters are transferable to RegCM4.

Zou Liwei, Qian Yun, ZHOU Tianjun, Yang Ben 2014: Parameter tuning and calibration of RegCM3 with MIT-Emanuel cumulus parameterization scheme over CORDEX East Asia domain. ***Journal of Climate,*** 27, 7687-7701

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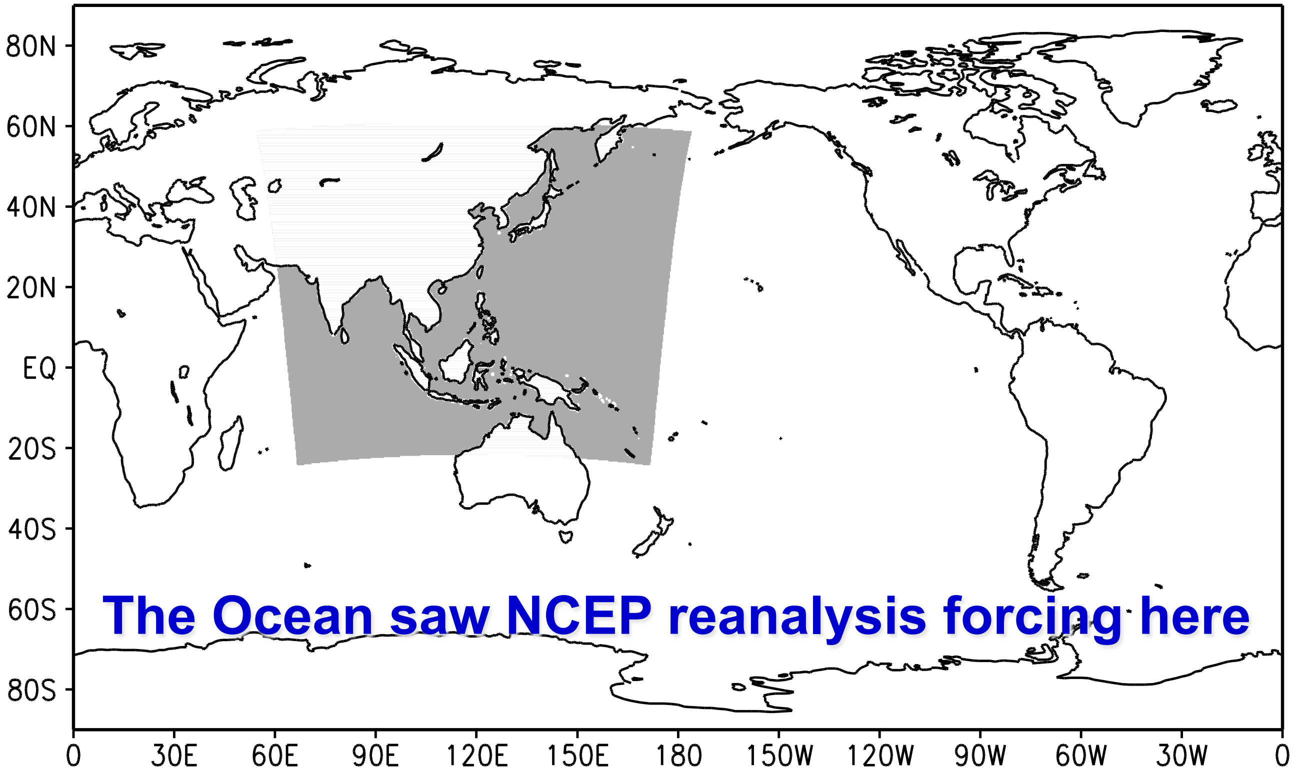
CORDEX-EA Historical run

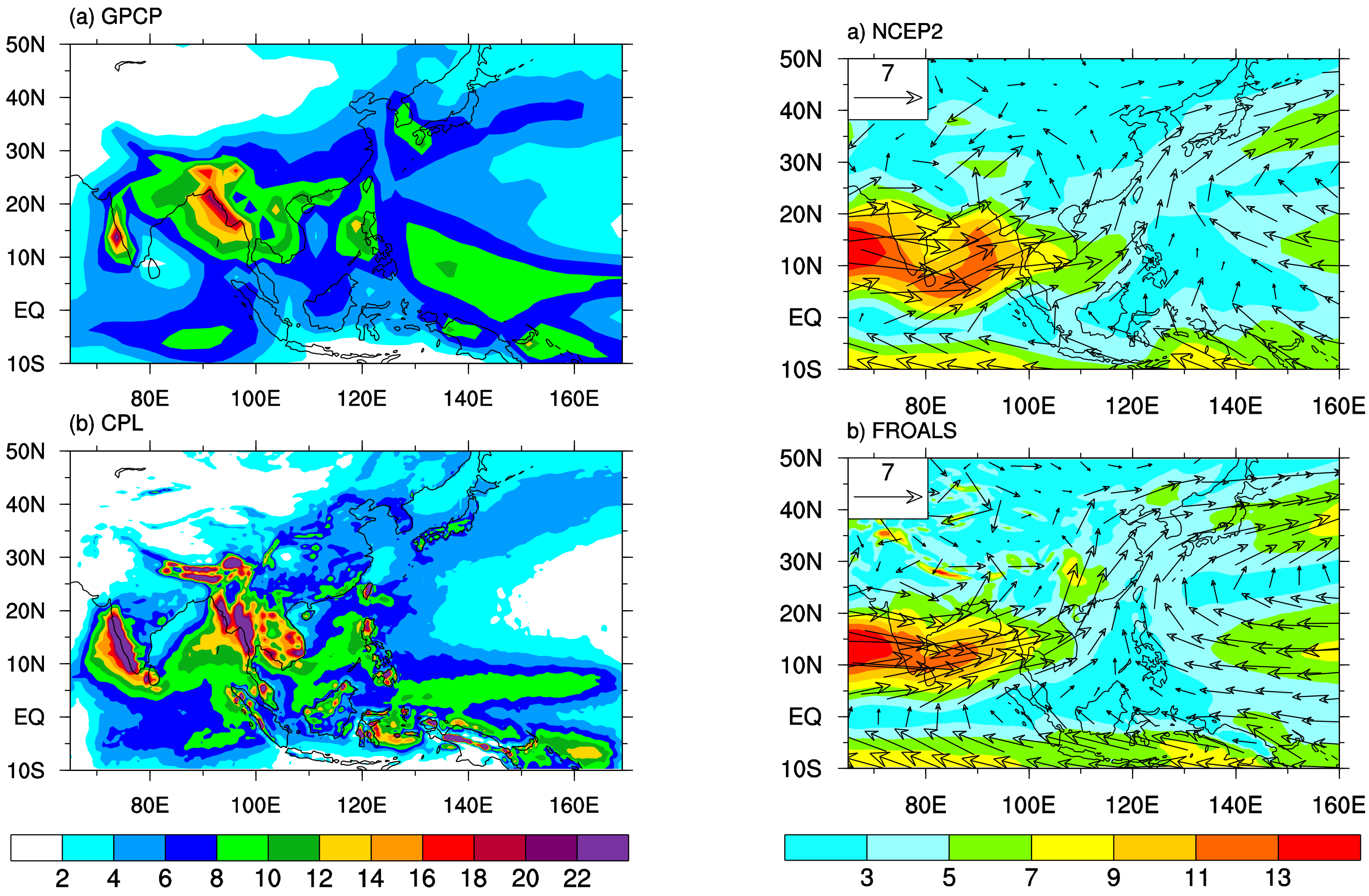


✓FROALS model is driven by NNRP2 data.

✓The optimized RegCM3 was employed as the atmospheric model

Zou Liwei, ZHOU Tianjun, 2016a: A Regional Ocean-Atmosphere Coupled Model developed for CORDEX East Asia: Assessment of Asian Summer Monsoon Simulation. ***Climate Dynamics***, DOI: 10.1007/s00382-016-3032-8

Asian summer monsoon in FROALS (mean state of rainfall and wind at 850hPa during 1989-201)



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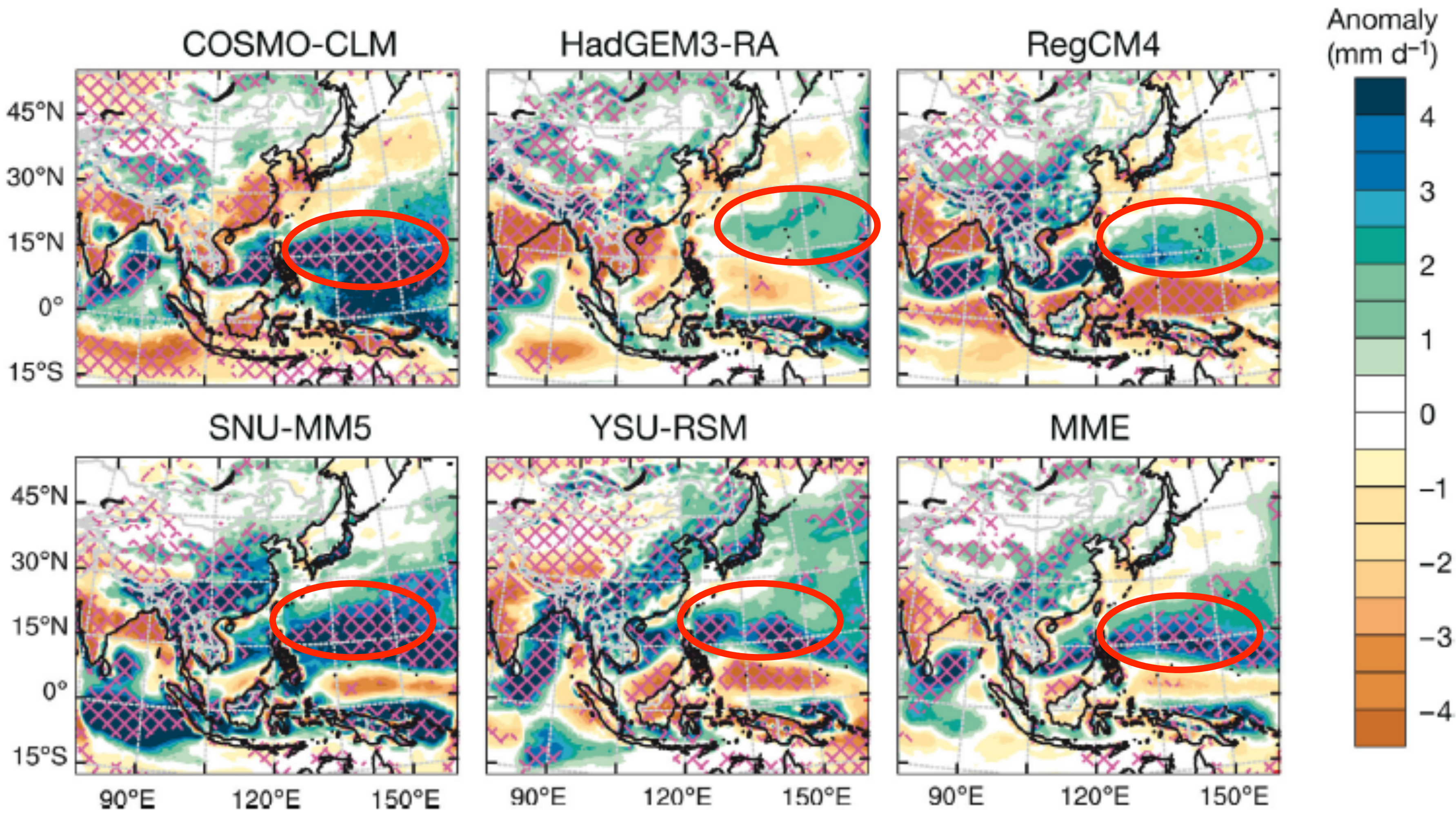
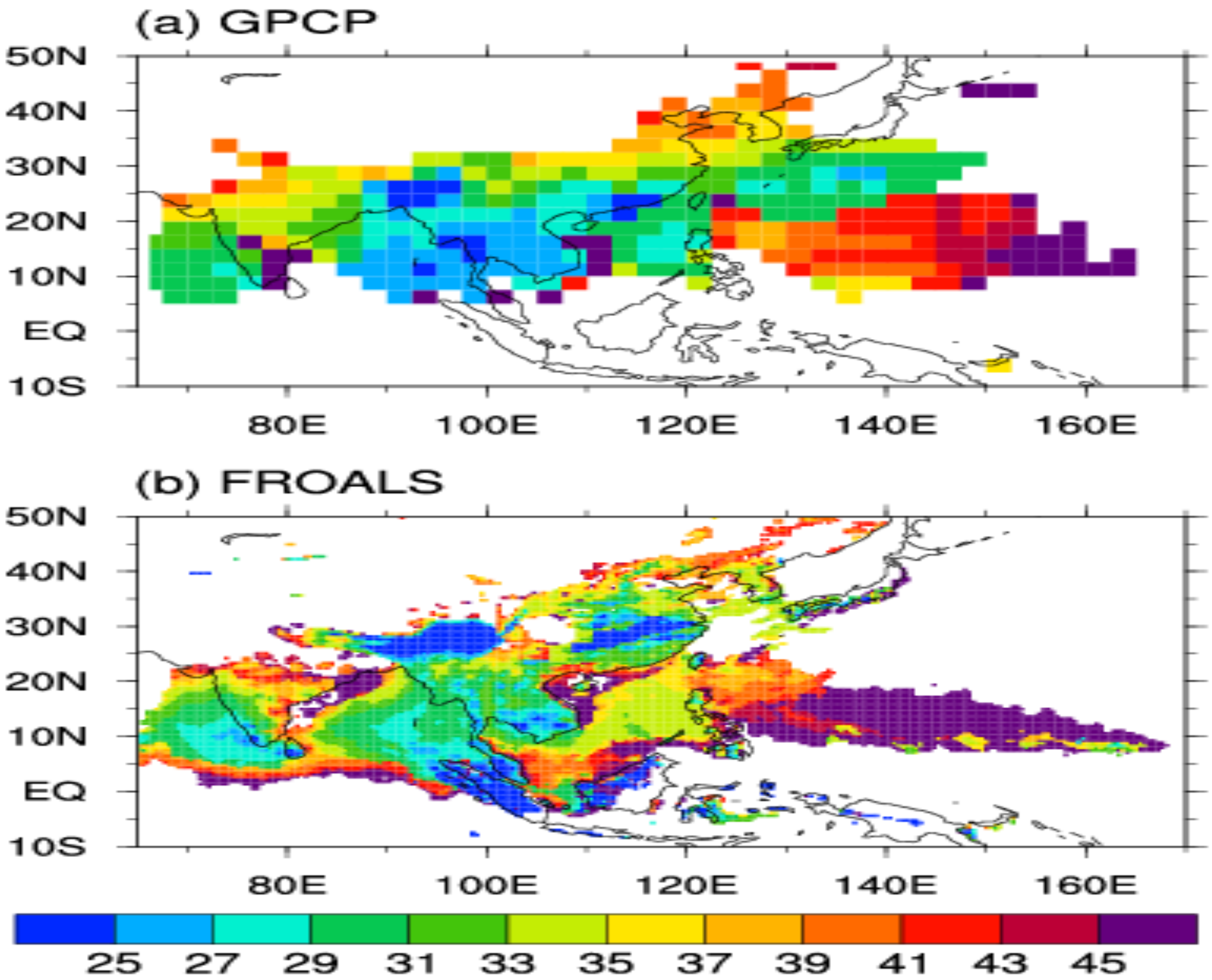
Summer rainfall biases in other RCMs over CORDEX East Asia



Wet biases over WNP

From Huang et al. 2015 Climate Research

Asian summer monsoon onset time (pentad)



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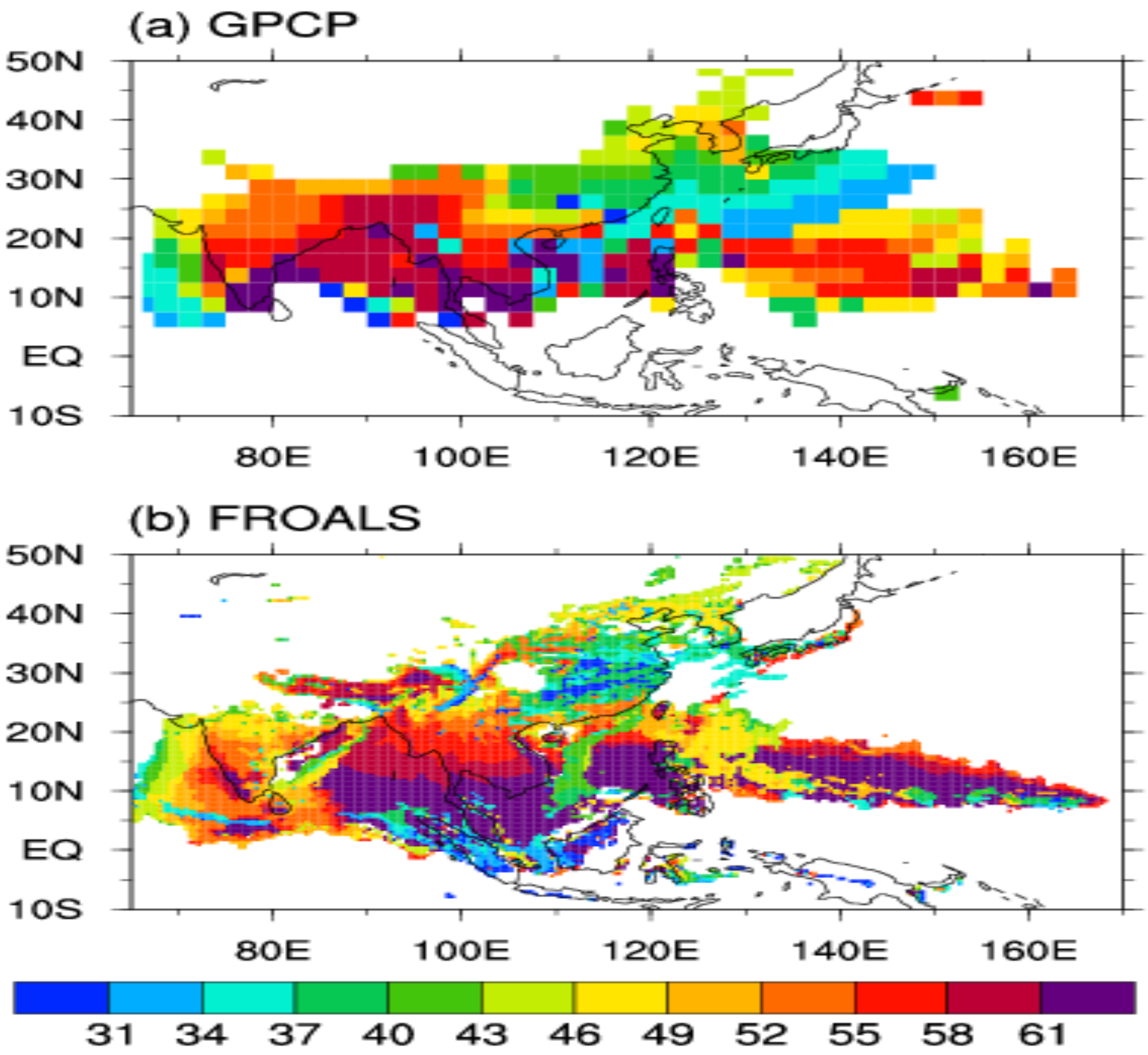
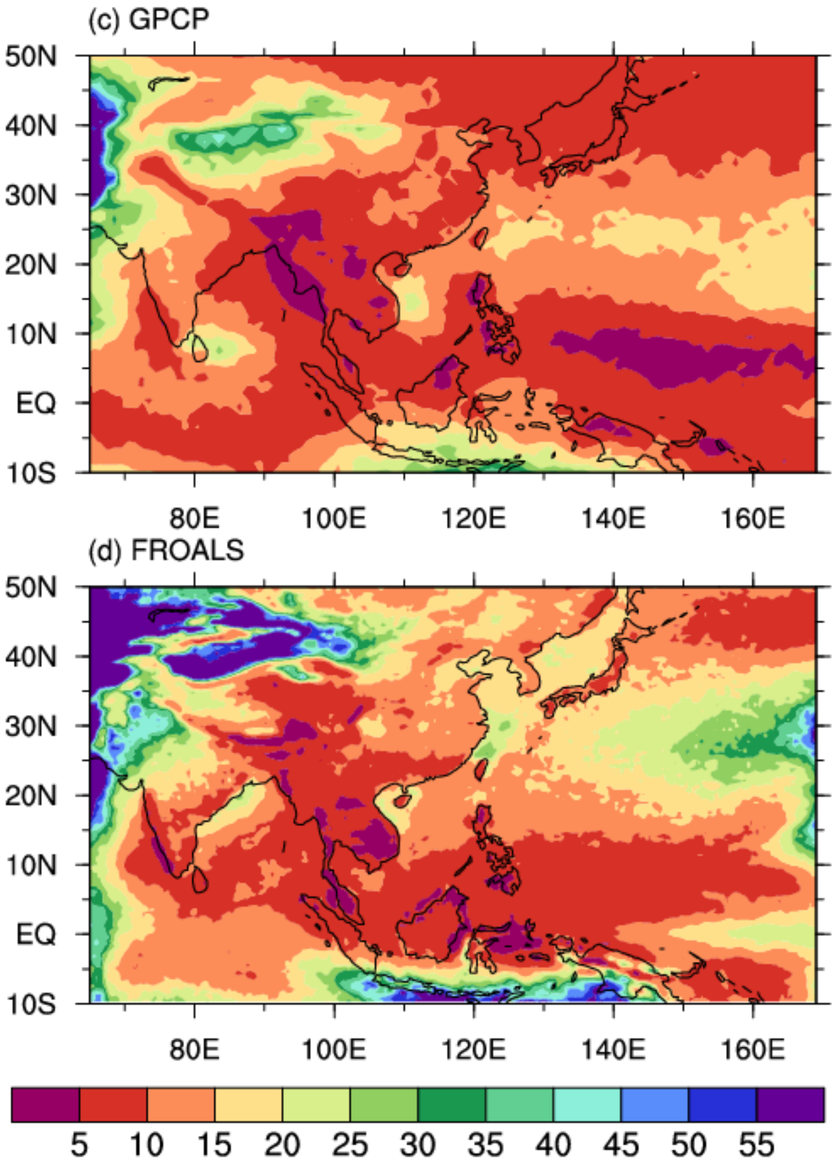
Asian summer monsoon withdrawal time (pentad)



Zou Liwei, ZHOU Tianjun, 2016a: A Regional Ocean-Atmosphere Coupled Model developed for CORDEX East Asia: Assessment of Asian Summer Monsoon Simulation. ***Climate Dynamics*** **DOI**: 10.1007/s00382-016-3032-8

Extremes: maximum consecutive dry days



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Points-Part 4

◆ The FROALS model shows reasonable skills in the simulation of Asian summer monsoon at various timescales based on the metrics designed by the CLIVAR monsoon panel.

Zou Liwei, ZHOU Tianjun, 2016a: A Regional Ocean-Atmosphere Coupled Model developed for CORDEX East Asia: Assessment of Asian Summer Monsoon Simulation. ***Climate Dynamics***, DOI: 10.1007/s00382-016-3032-8

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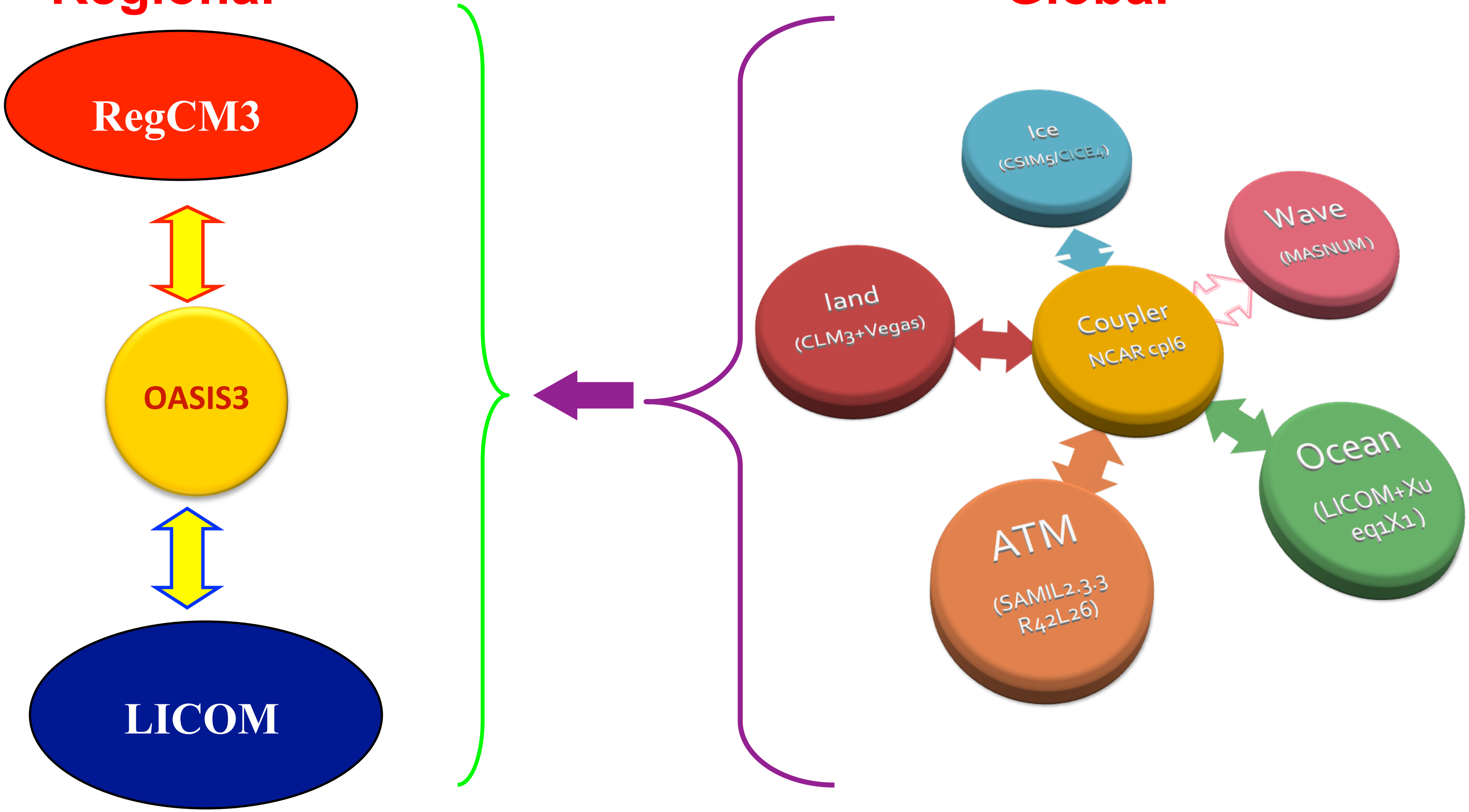
Global-Regional Nesting Modeling System

Regional | **Global**

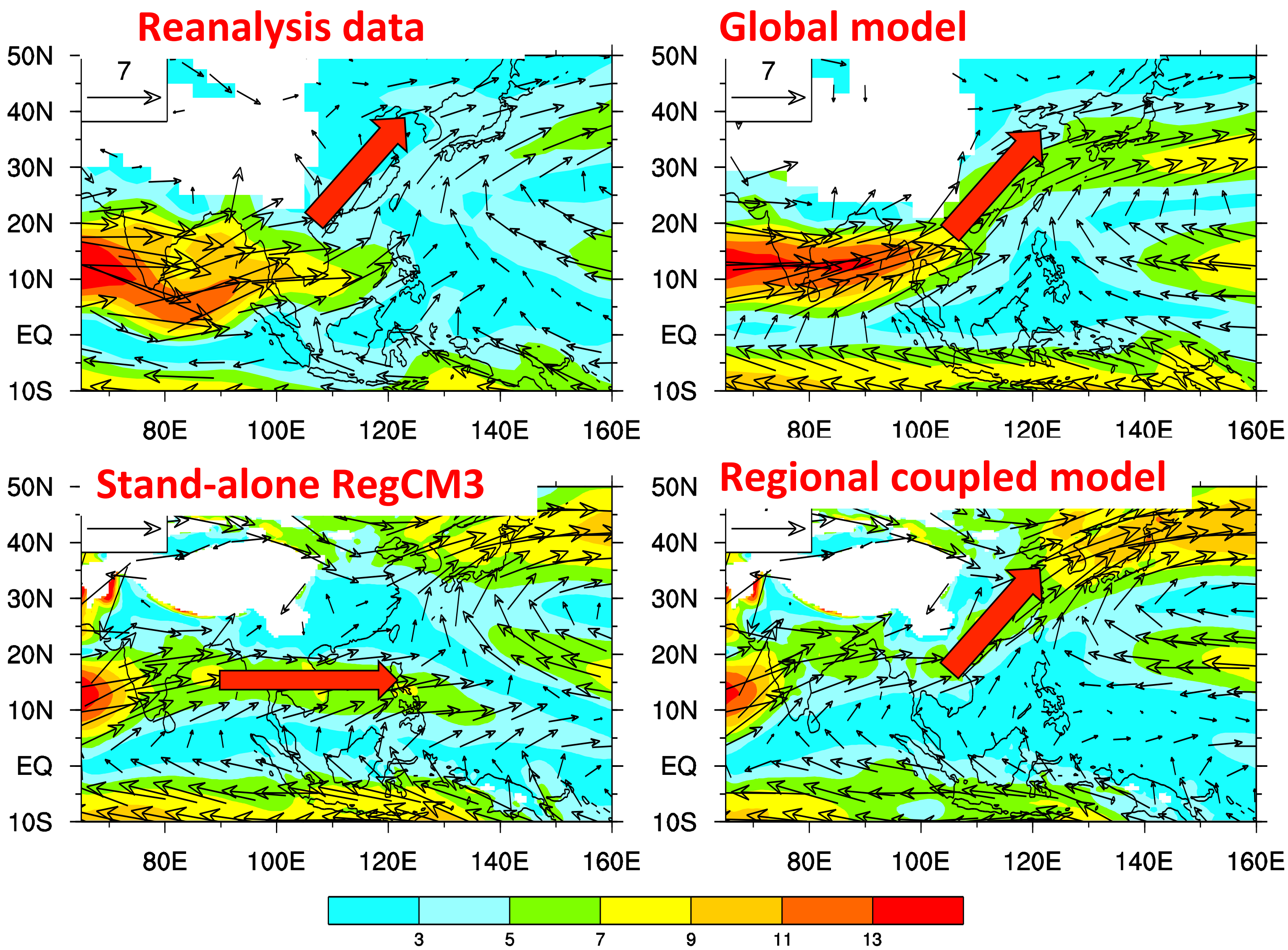


LASG/IAP FROALS | **LASG/IAP FGOALS**

CORDEX-EA Experiments in IAP

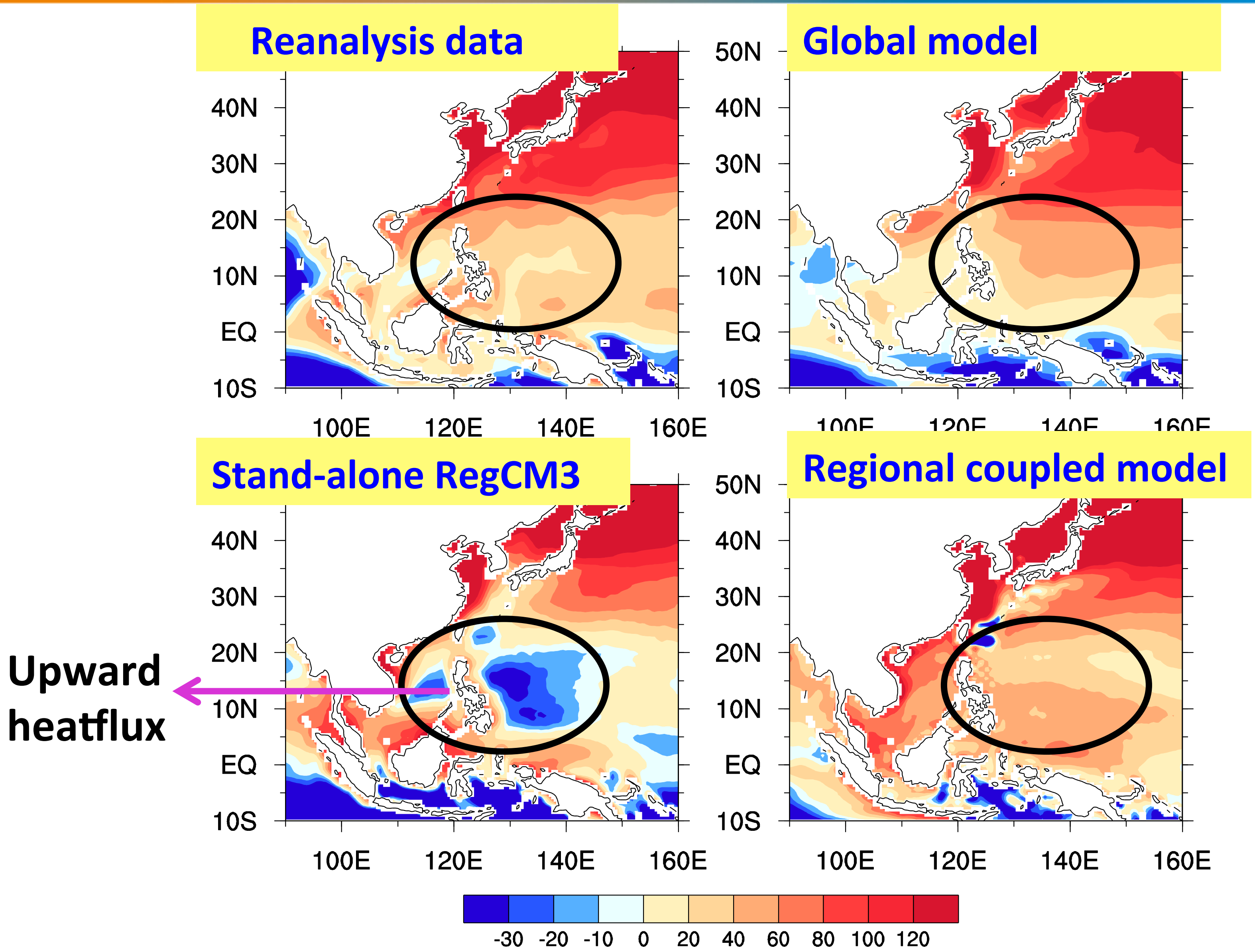
		RCP4.5	RCP8.5
RegCM3	1981-2005	2041-2070 2011-2040 2071-2099	2041-2070 2011-2040 2071-2099
FROALS	1981-2005	2041-2070 2011-2040 2071-2099	2041-2070 2011-2040 2071-2099

JJA mean 850 hPa wind and speed during 1981-2005



Zou Liwei, ZHOU Tianjun, Dongdong Peng, 2016: Dynamical Downscaling of Historical Climate over CORDEX East Asia Domain: A Comparison of Regional Ocean Atmosphere Coupled Model to Standalone RCM Simulations. ***J. Geophys. Res.*** , doi: 10.1002/2015JD023912

JJA mean net heat flux at sea surface for 1981-2005



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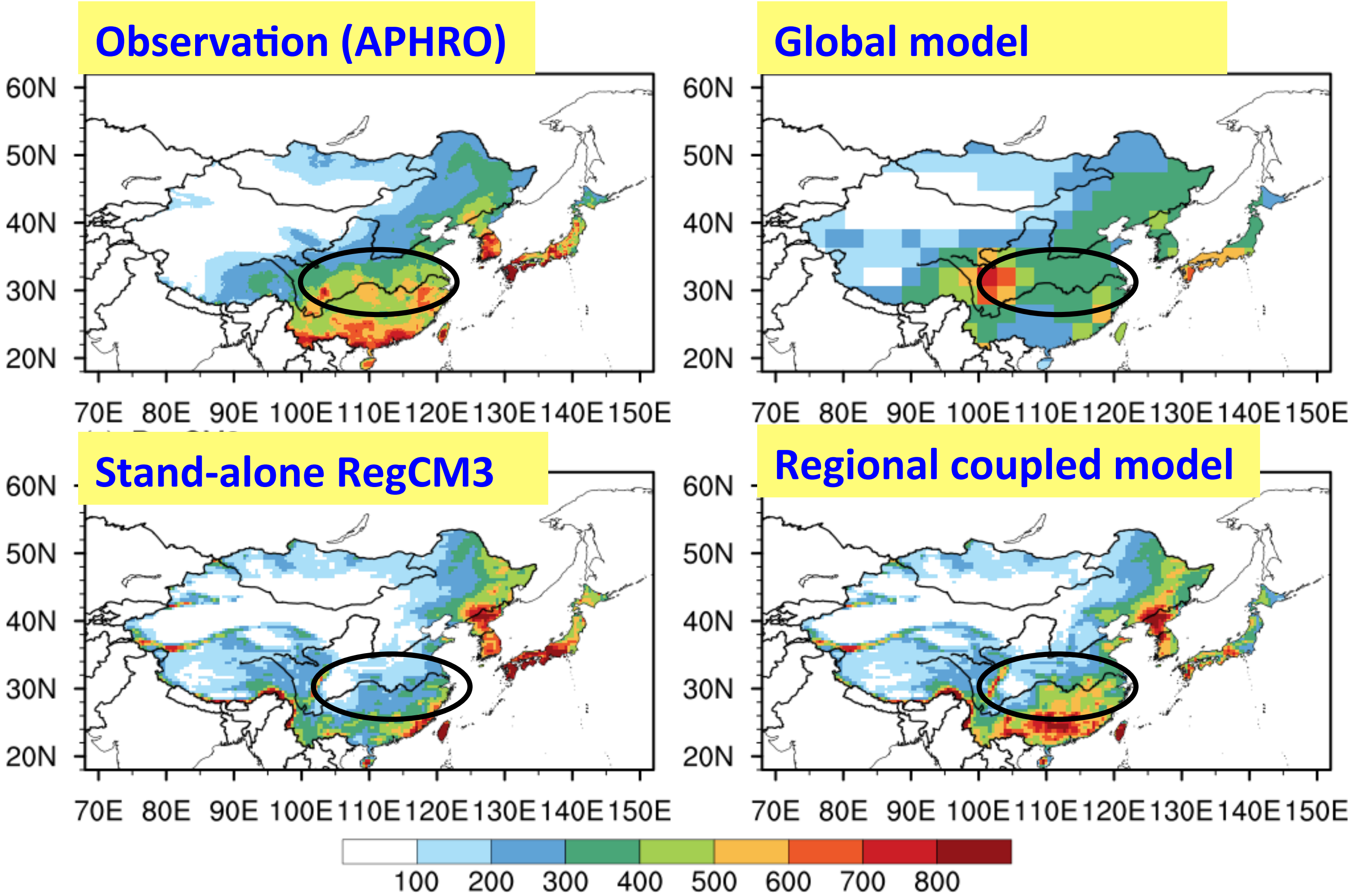
JJA mean total rainfall for present-day climate (1981-2005)



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Points-Part 5

- The added value of FROALS with respect to driving global climate model was evident in terms of rainfall.
- The performance of FROALS model was better than that of corresponding standalone RCM for East Asia.

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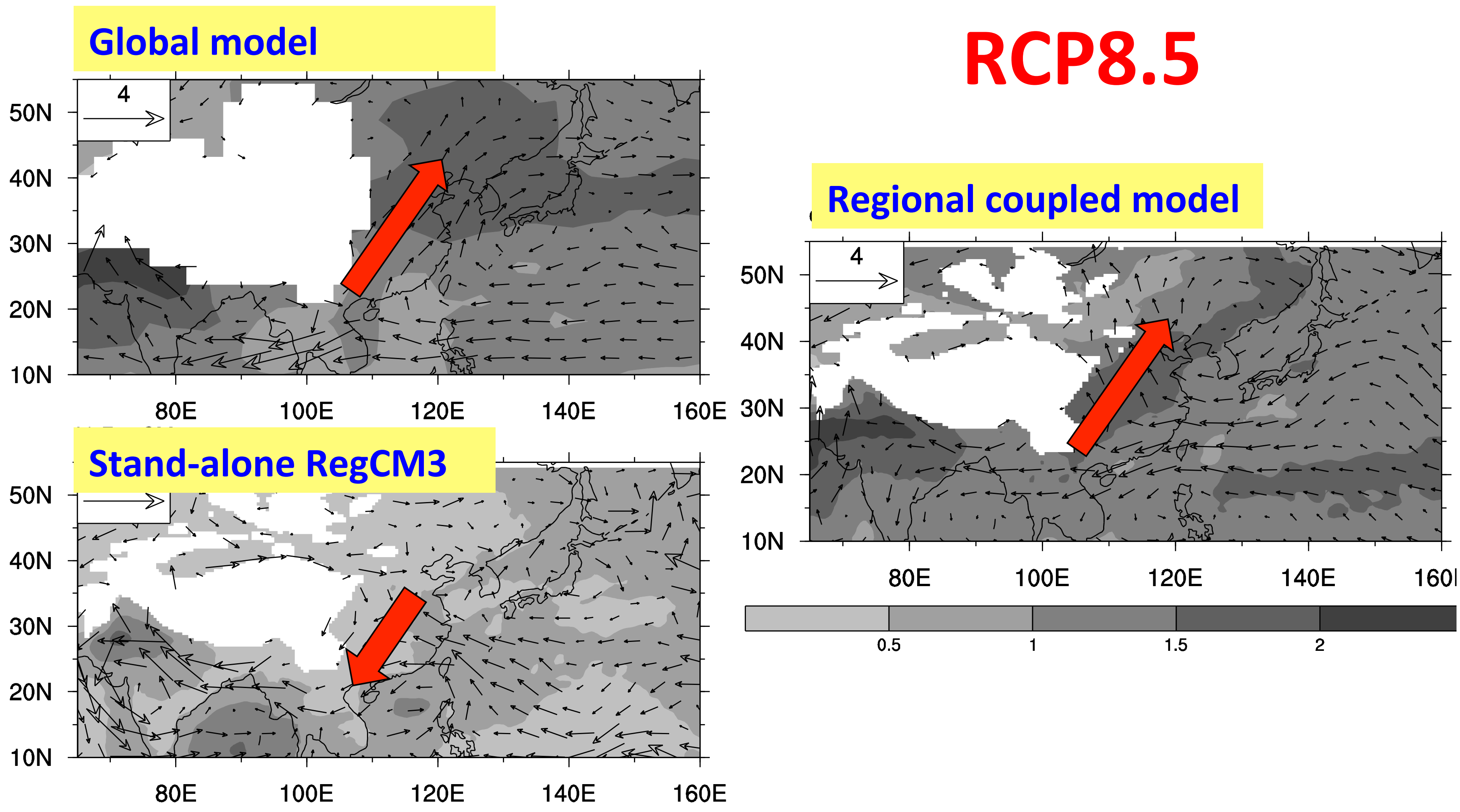
8. **CORDEX-EA Experiment:** ***RCP projection driven by FGOALS***

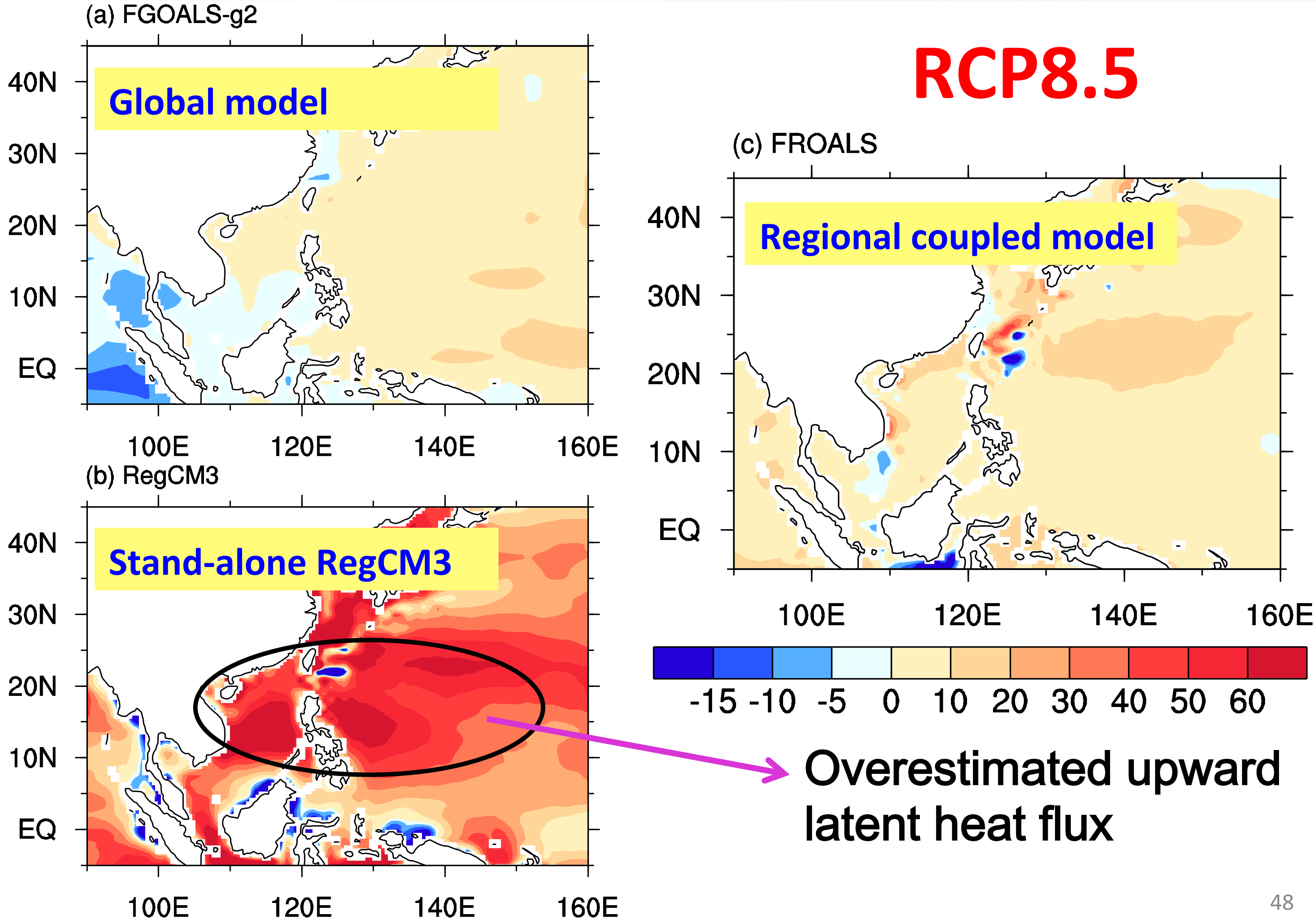
Projected changes of JJA mean 850-hPa low-level wind (vector) and the specific humidity (shaded) (2051-2070)



Zou, L., and T. Zhou, 2016: Future summer precipitation changes over CORDEX-East Asia domain under the RCP8.5 scenario downscaled by a regional ocean-atmosphere coupled model: A comparison to the stand-alone RCM, ***J. Geophys. Res.-Atmos.***, 121, 2691-2701, doi: 10.1002/2015JD024519

projected changes in the JJA mean latent heat flux

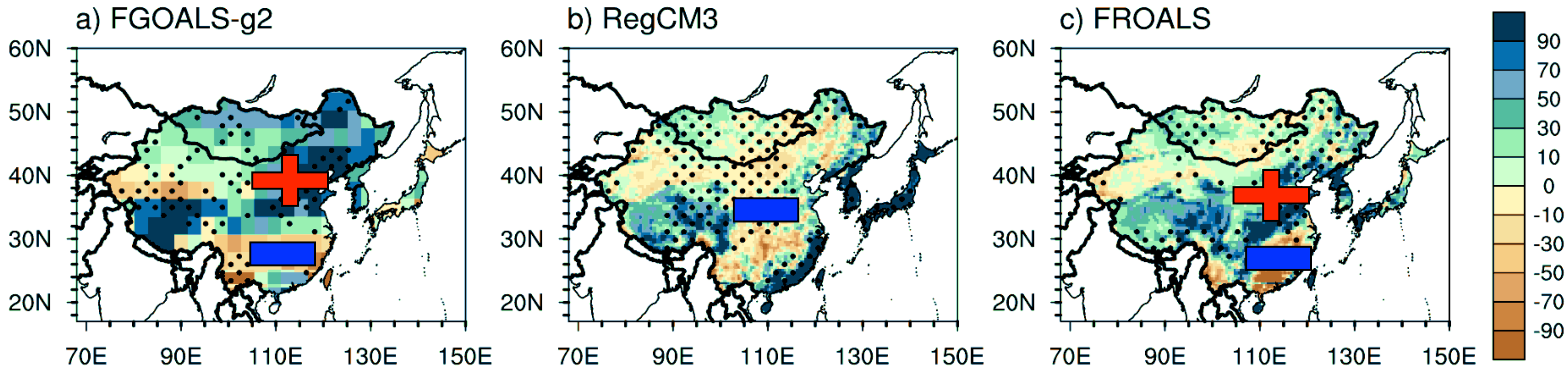
RCP8.5



Overestimated upward latent heat flux

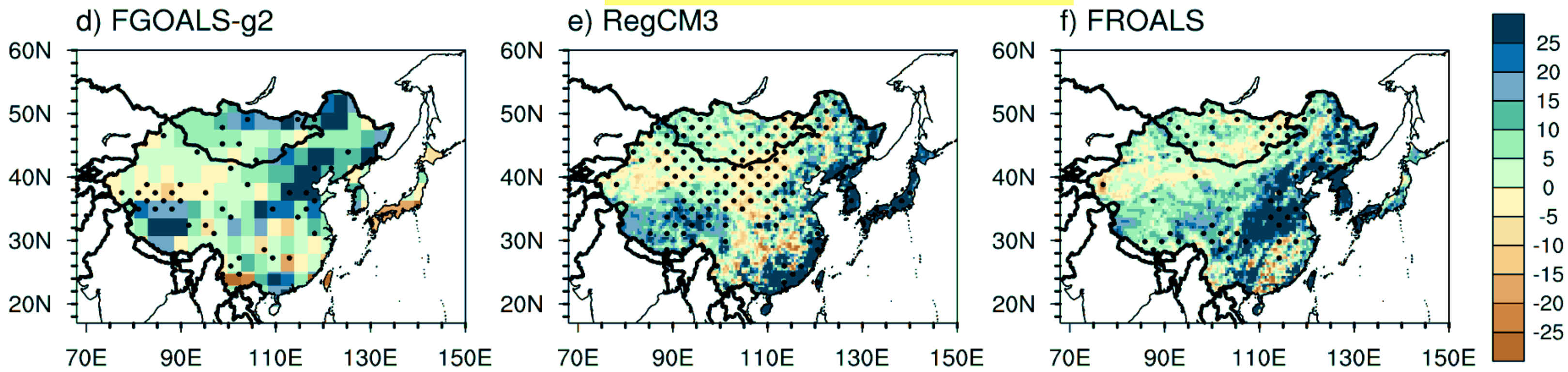
RCP8.5

Total rainfall



Global model **Stand-alone RegCM3** **Regional coupled model**

Extreme rainfall



Zou, L., and T. Zhou, 2016: Future summer precipitation changes over CORDEX-East Asia domain under the RCP8.5 scenario downscaled by a regional ocean-atmosphere coupled model: A comparison to the stand-alone RCM, ***J. Geophys. Res.-Atmos***., 121, 2691-2701, doi: 10.1002/2015JD024519

Points-Part 6

◆Stand-alone RegCM3 showed too strong responses to the underlying SST warming anomalies.

◆The projection with Regional ocean-atmosphere coupled model is consistent with the global model in monsoon circulation and precipitation changes.

Zou, L., and T. Zhou, 2016: Future summer precipitation changes over CORDEX-East Asia domain under the RCP8.5 scenario downscaled by a regional ocean-atmosphere coupled model: A comparison to the stand-alone RCM, ***J. Geophys. Res.-Atmos***., 121, 2691-2701, doi: 10.1002/2015JD024519

Concluding Remarks

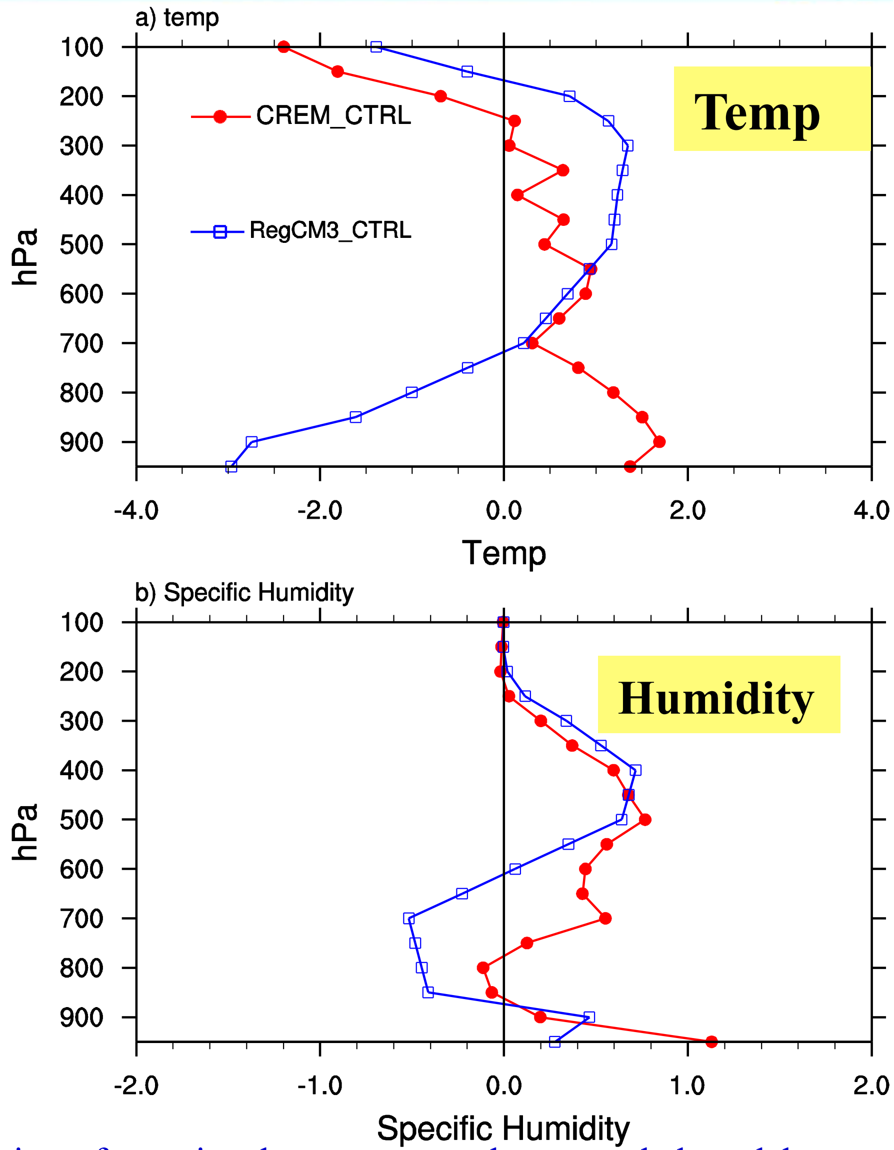
Regional ocean-atmosphere coupled model is needed for the CORDEX-EA downscaling.

Some Further Reading

1. Zou Liwei, ZHOU Tianjun, 2011: Sensitivity of a Regional Ocean-Atmosphere Coupled Model to Convection Parameterization over Western North Pacific, ***Journal of Geophysical Research-Atmosphere***, 116, D18106, doi: 10.1029/2011JD015844.
2. Zou Liwei, ZHOU Tianjun, 2012: Development and evaluation of a regional ocean-atmosphere coupled model with focus on the western North Pacific summer monsoon simulation: Impacts of different atmospheric components. ***Sci China Earth Sci***, 55, 802-815, doi:10.1007/s11430-011-4281-3
3. Zou Liwei, ZHOU Tianjun, 2013: Can a Regional Ocean-Atmosphere Coupled Model Improve the Simulation of the Interannual Variability of the Western North Pacific Summer Monsoon ? ***Journal of Climate***, 26, 2353-2367
4. Zou Liwei,Tianjun ZHOU, 2013: Improve the simulation of western North Pacific summer monsoon in RegCM3 by suppressing *convection,**Meteorology and Atmospheric Physics**,121,29-38,DOI* 10.1007/s00703-013-0255-7
5. Zou Liwei, ZHOU Tianjun, 2014: Simulation of the western North Pacific summer monsoon by regional ocean-atmosphere coupled model: Impacts of oceanic components. ***Chinese Science Bulletin***, 59(7),662-673
6. Zou Liwei, Qian Yun, ZHOU Tianjun, Yang Ben 2014: Parameter tuning and calibration of RegCM3 with MIT-Emanuel cumulus parameterization scheme over CORDEX East Asia domain. ***Journal of Climate,*** 27, 7687-7701
7. Zou Liwei, ZHOU Tianjun, 2016: A Regional Ocean-Atmosphere Coupled Model developed for CORDEX East Asia: Assessment of Asian Summer Monsoon Simulation. ***Climate Dynamics***, DOI: 10.1007/s00382-016-3032-8
8. Zou Liwei, ZHOU Tianjun, 2016: Future summer precipitation changes over CORDEX-East Asia domain under the RCP8.5 scenario downscaled by a regional ocean-atmosphere coupled model: A comparison to the stand-alone RCM. ***Journal of Geophysical Research - Atmospheres***, in press
9. Zou Liwei, ZHOU Tianjun, Dongdong Peng, 2016: Dynamical Downscaling of Historical Climate over CORDEX East Asia Domain: A Comparison of Regional Ocean Atmosphere Coupled Model to Standalone RCM Simulations. ***Journal of Geophysical Research - Atmospheres***, doi: 10.1002/2015JD023912

Thank You !

Vertical Profiles of Temp and Humidity over the ocean

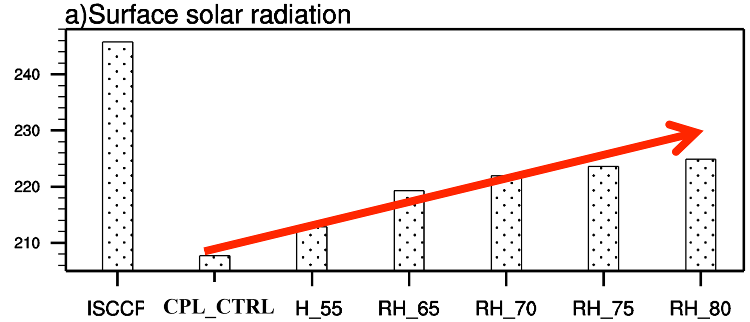


RegCM3 holds a colder & drier low level atmosphere:

- **More latent heat flux；**
- **Stable low-level atmosphere, more low cloud, less solar irradiance in the surface, and colder SST bias**
- **The story of CREM is different.**

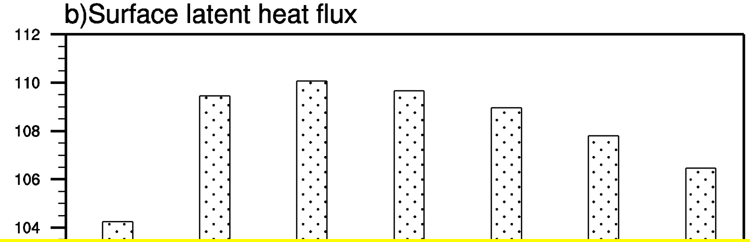
Zou Liwei, ZHOU Tianjun, 2012: Development and evaluation of a regional ocean-atmosphere coupled model with focus on the western North Pacific summer monsoon simulation: Impacts of different atmospheric components. ***Sci China Earth Sci***, 55, 802-815

SW flux



RH_55	RH_80
207.73	224.84

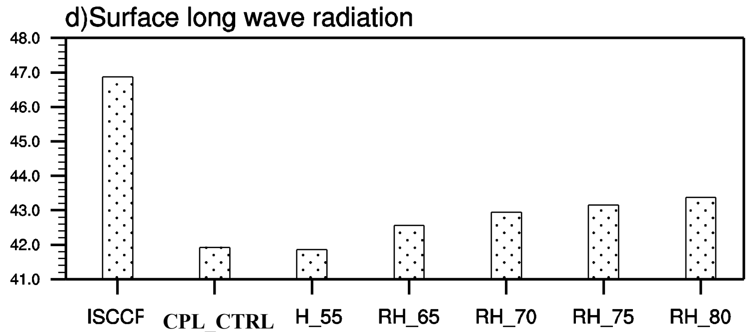
Latent Heat flux



RH_55	RH_80
109.46	106.47

Improvement of SST bias is resulted from more SW radiation input

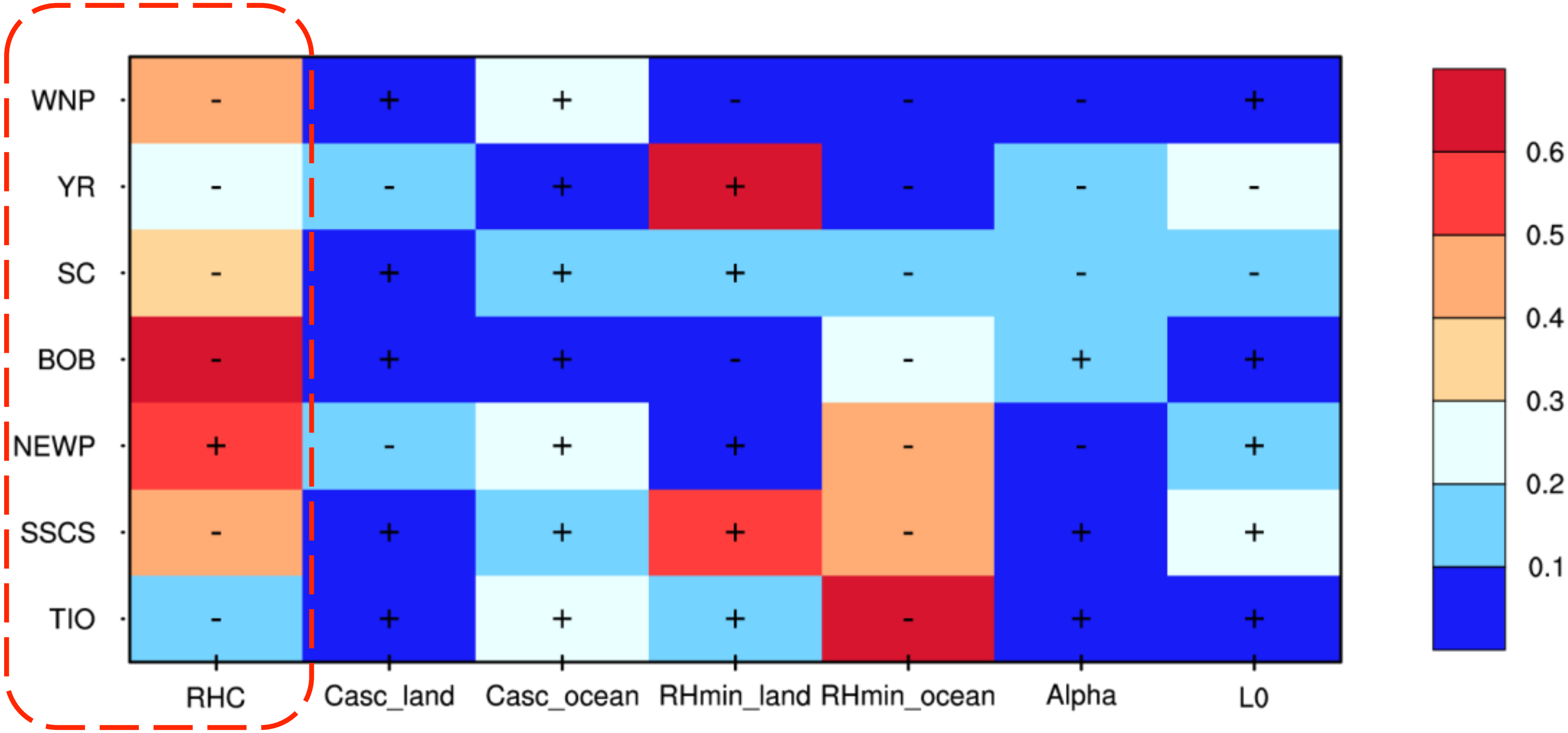
LW flux



RH_55	RH_80
41.92	43.37

Average of oceanic grids

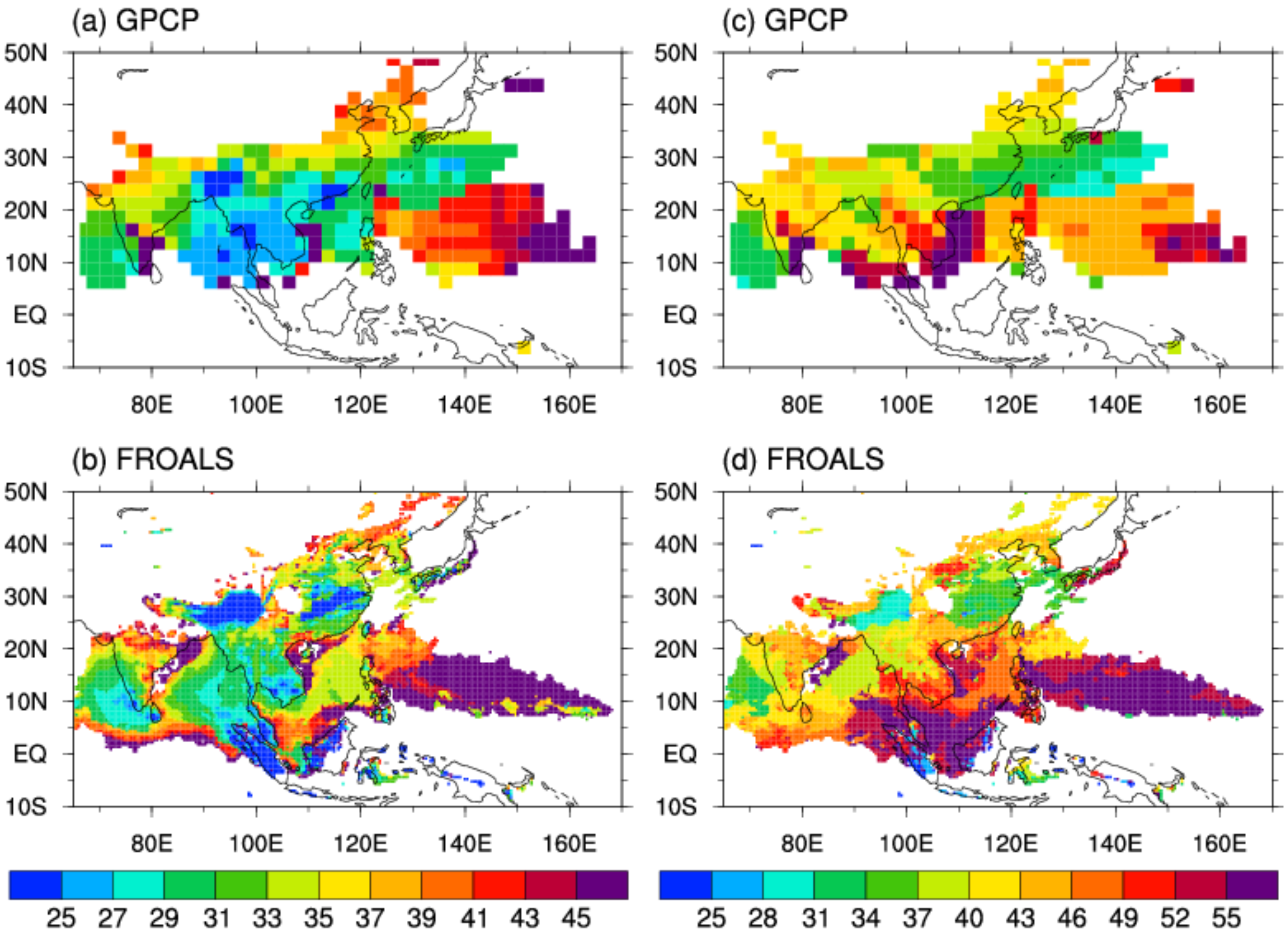
Parametric sensitivity: responses of total rainfall over the selected regions to the seven parameters



The parameter RHC is the most sensitive parameter, with high influence on the rainfall over all the regions except that over the Yangtze River valley and over the tropical Indian Ocean.

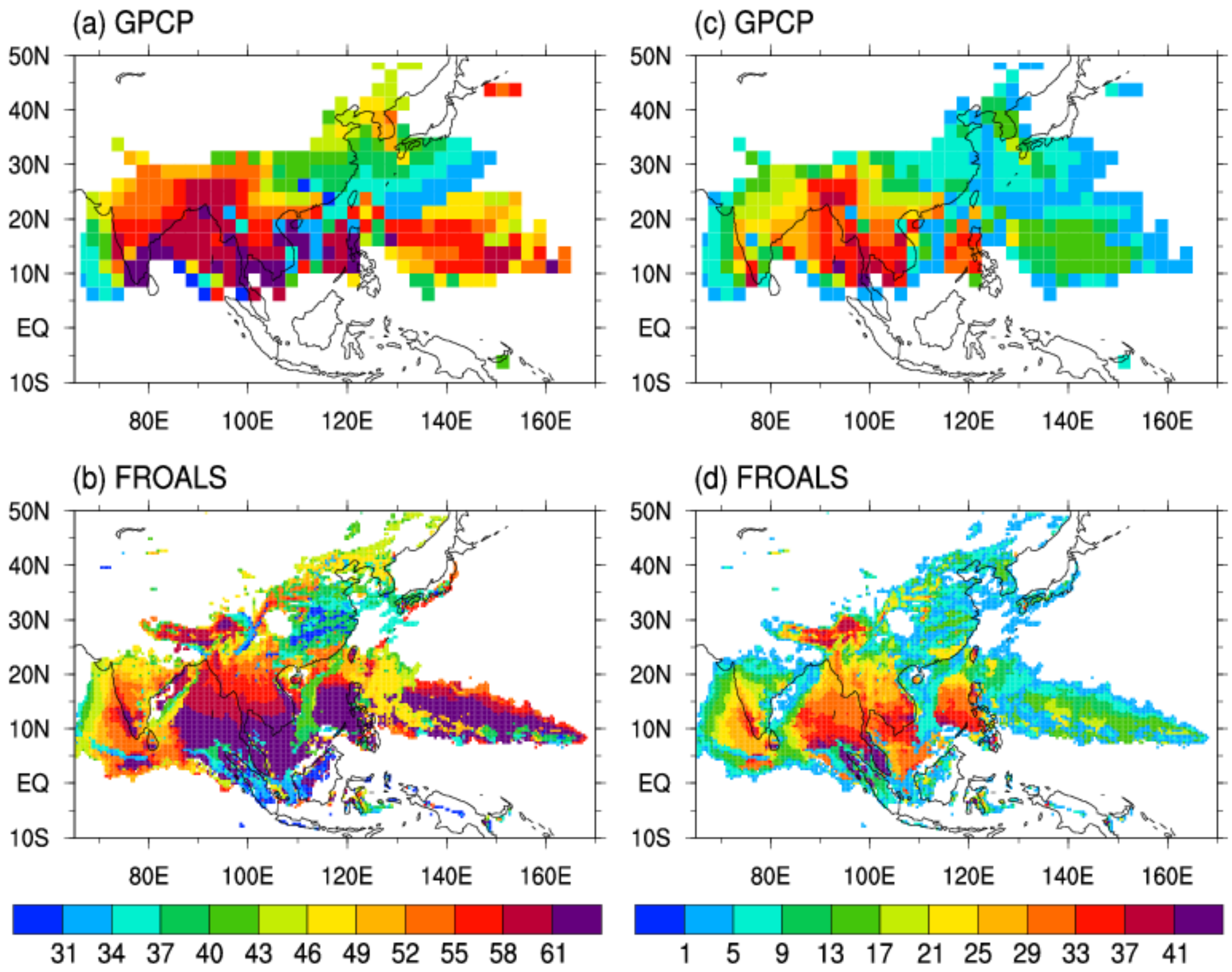
Zou L., Y. Qian, **T. Zhou**, B. Yang, 2014: Parameter tuning and calibration of RegCM3 with MIT-Emanuel cumulus parameterization scheme over CORDEX East Asia domain. ***Journal of Climate***, doi: http://dx.doi.org/10.1175/JCLI-D-14-00229.1

Asian summer monsoon onset (left) and Peak pentad (Right)

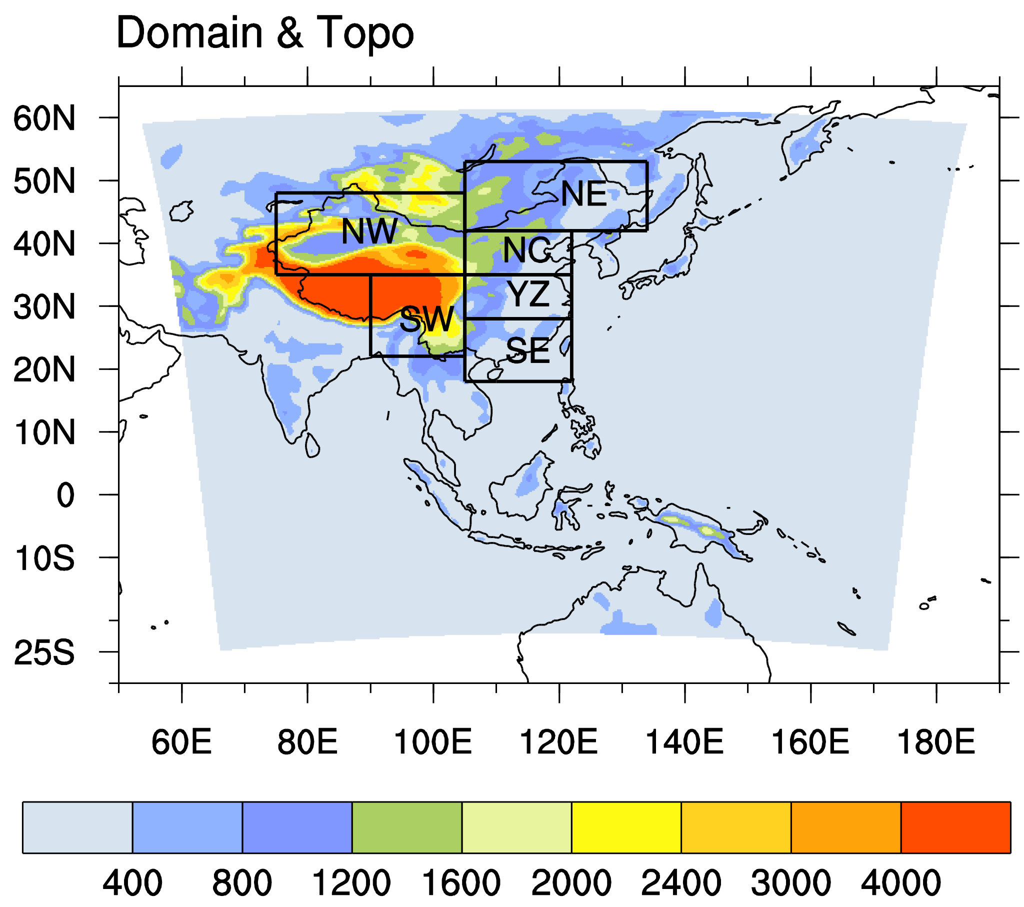


Zou Liwei, ZHOU Tianjun, 2016a: A Regional Ocean-Atmosphere Coupled Model developed for CORDEX East Asia: Assessment of Asian Summer Monsoon Simulation. ***Climate Dynamics***, in press

Asian summer monsoon withdrawal pentad (left) and monsoon duration pentad(Right)

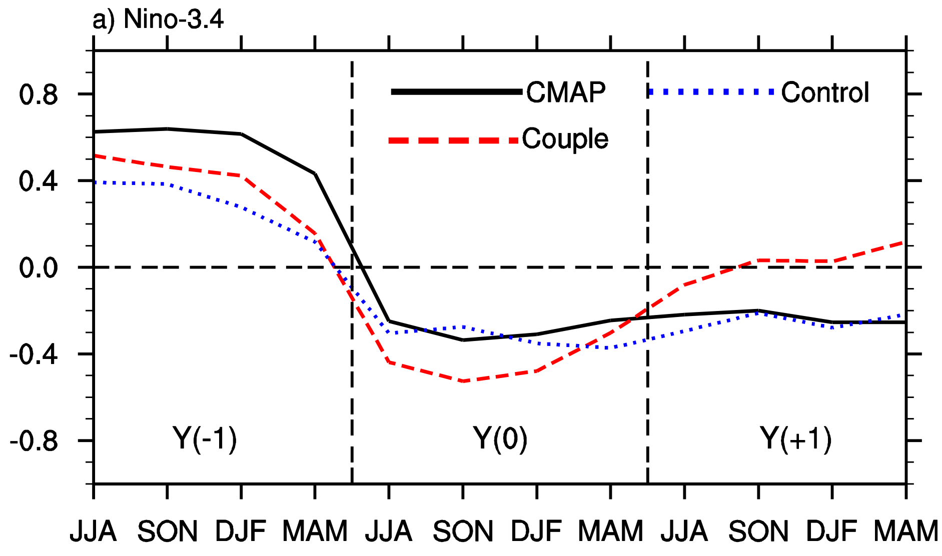


Zou Liwei, ZHOU Tianjun, 2016a: A Regional Ocean-Atmosphere Coupled Model developed for CORDEX East Asia: Assessment of Asian Summer Monsoon Simulation. ***Climate Dynamics***, in press

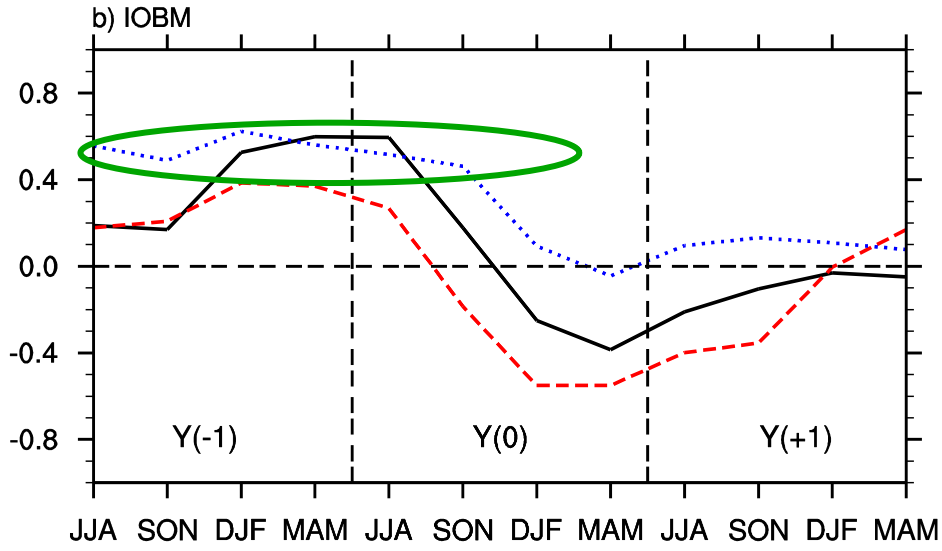

Domain & Topo
60N
50N
40N
30N
20N
10N
0
10S
25S
60E
80E
100E
120E
140E
160E
180E
NE
NW
NC
YZ
SW
SE
400
800
1200
1600
2000
2400
3000
4000

Lead/lag correlation of PC1 with Niño-3.4 and IOBM index

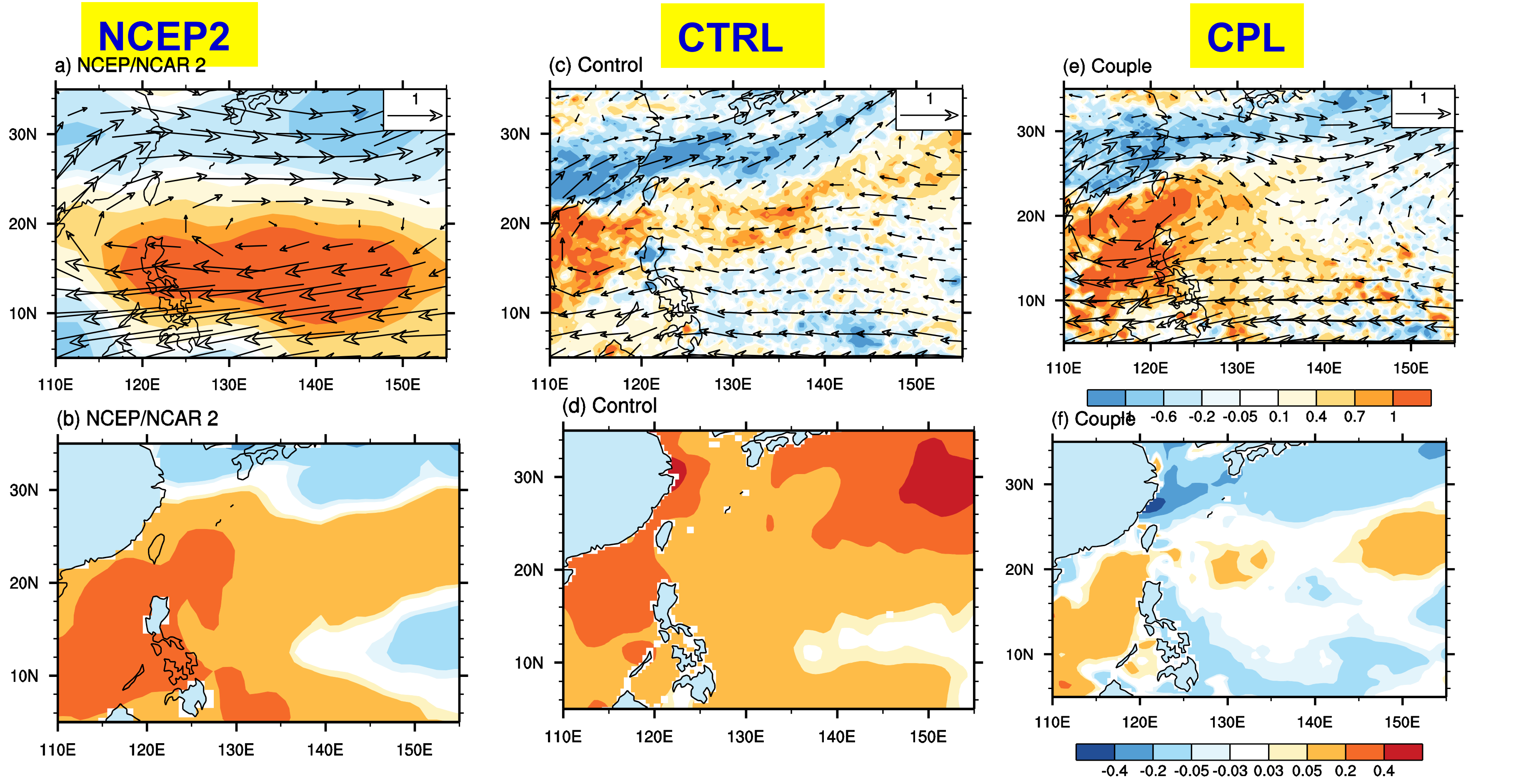
EOF1 peaks in the summer of El Nino decaying year



The Indian Ocean warming drives the monsoon changes



JJA Omege500, UV850 and SSTA associated with EOF1

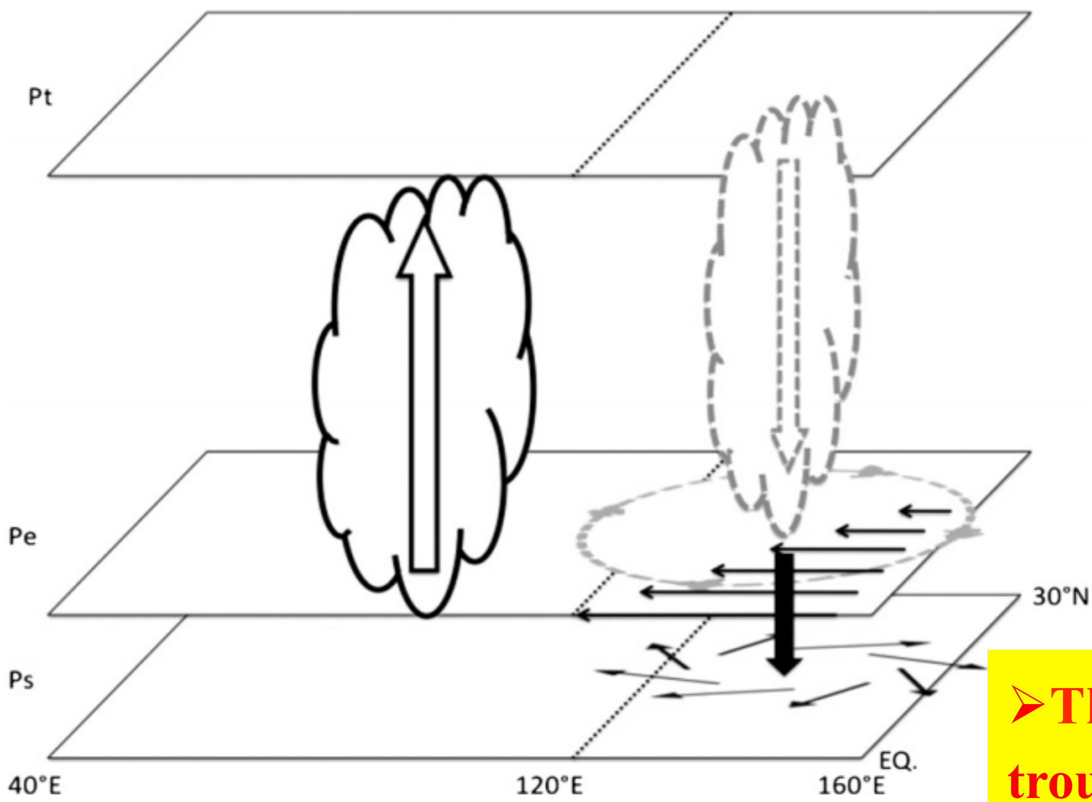


Obs: AC → downward motion → less prcp → less cloud, more SW flux → warmer SST

CRTL： Weak AC from LBC forcing;Warmer SSTA → upward motion→ more prcp → less SW flux

CPL： Better but still weaker AC; Weak downward motion → less prcp → SW bias improvement

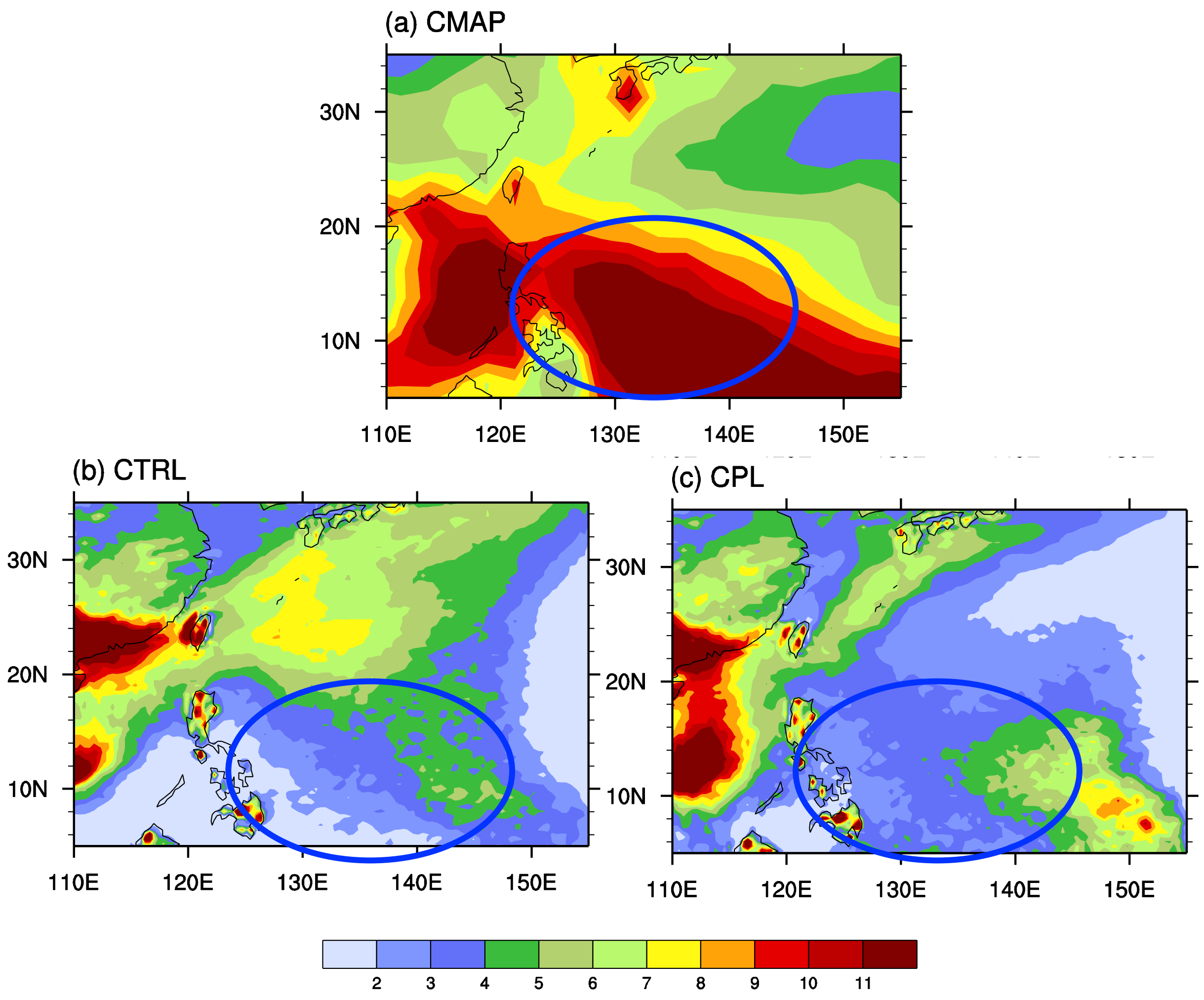
How does Indian Ocean warming impact NWPSM during El Niño decaying summer?



After Wu, Zhou and Li 2009, *J. Climate*

- **Warm Indian Ocean SST -> more convective heating -> force Kelvin wave -> easterly over tropical western Pacific.**
- **AC wind shear -> divergence in PBL -> less monsoon rainfall in NW Pac -> stimulate WNPAC.**
- **The mean position of monsoon trough dominates the WNPAC. The strong convection over the NW Pac monsoon trough leads to strong response to Kelvin wave forcing**

JJA mean rainfall in observation and simulation



The NW Pac monsoon trough is weak in RCM, leading to a weaker response to IOBM SST forcing.

Who is the slave: Atmosphere or Ocean ?

◆**Observation, the ocean is a slave to atmospheric forcing:** AC → downward motion → less prcp → less cloud, more SW flux → warmer SST

◆**Offline RegCM3 run, the atmosphere is a slave to SST forcing:** Weak AC from LBC forcing; Warmer SSTA → upward motion→ more prcp → less SW flux

◆**Coupled Simulation, the in-correct SST forcing is reduced:** Better but still weaker AC; Weak downward motion → less prcp → SW bias improvement

Summary for model bias

Control Exp (offline RegCM3 run)：

"Correct" but weak atmospheric response to LBC forcing

+"In-correct" however strong SSTA forcing

→ Large Model bias

Coupled Exp (RegCM3+LICOM)：

"Correct" but weak atmospheric response to LBC forcing

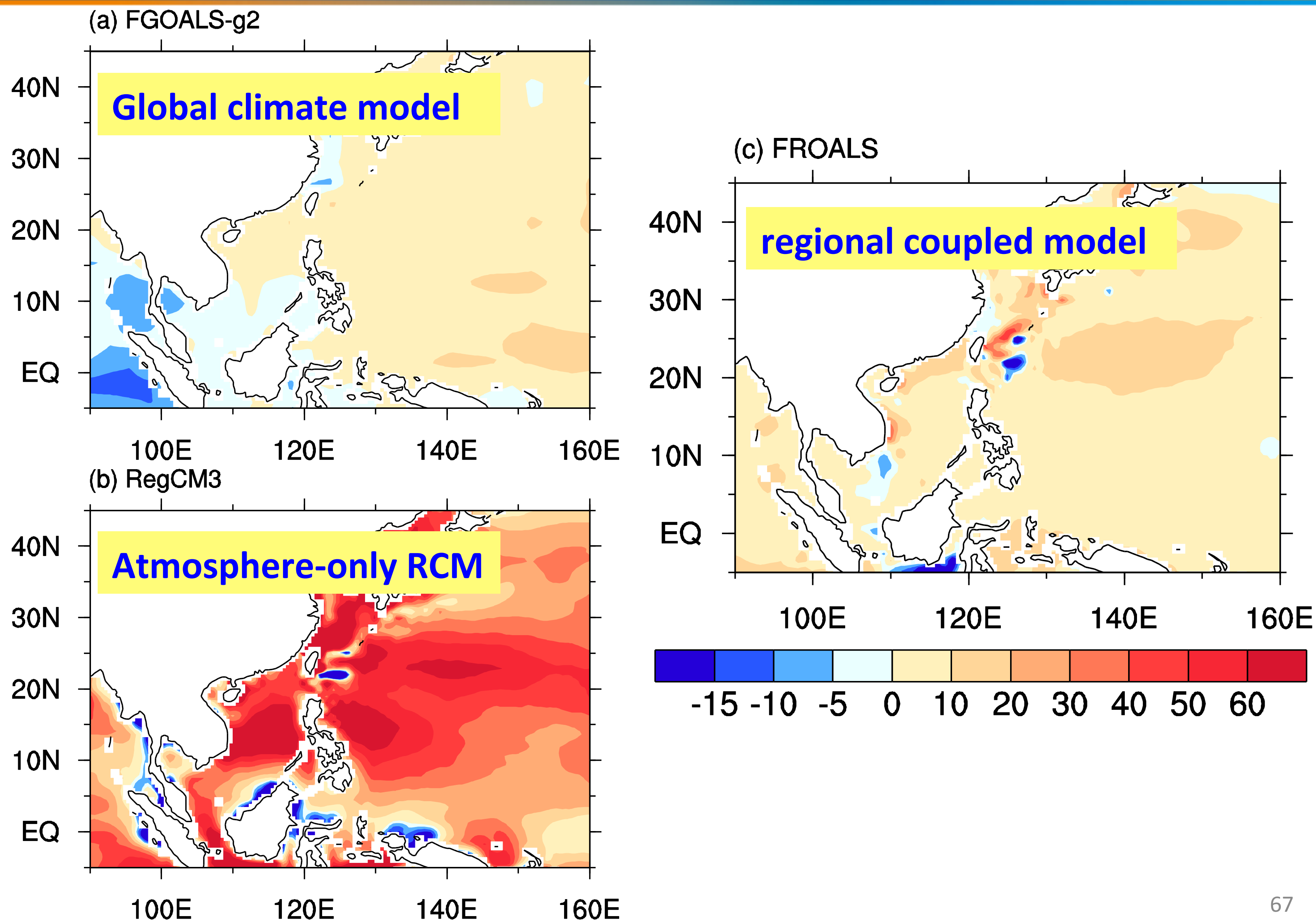
+"In-correct" but fortunately weak SSTA forcing

→Improvement of Simulation

For details, please see

- Zou Liwei, Zhou Tianjun, 2011: Sensitivity of a Regional Ocean-Atmosphere Coupled Model to Convection Parameterization over Western North Pacific, *Journal of Geophysical Research-Atmosphere*, 116, D18106, doi:10.1029/2011JD015844.
- Zou Liwei, Zhou Tianjun, 2012: Development and evaluation of a regional ocean-atmosphere coupled model with focus on the western North Pacific summer monsoon simulation: Impacts of different atmospheric components. *Sci China Earth Sci*, 2012, 55: 802-815
- Zou Liwei, Zhou Tianjun, 2013: Can a Regional Ocean-Atmosphere Coupled Model Improve the Simulation of the Interannual Variability of the Western North Pacific Summer Monsoon ? *Journal of Climate*, 26, 2353-2367
- Zou Liwei, Zhou Tianjun, 2014: Simulation of the western North Pacific summer monsoon by regional ocean-atmosphere coupled model: Impacts of oceanic components. *Chinese Science Bulletin*, 59(7),662-673
- Zou Liwei, Zhou Tianjun, Peng Dongdong, 2015:

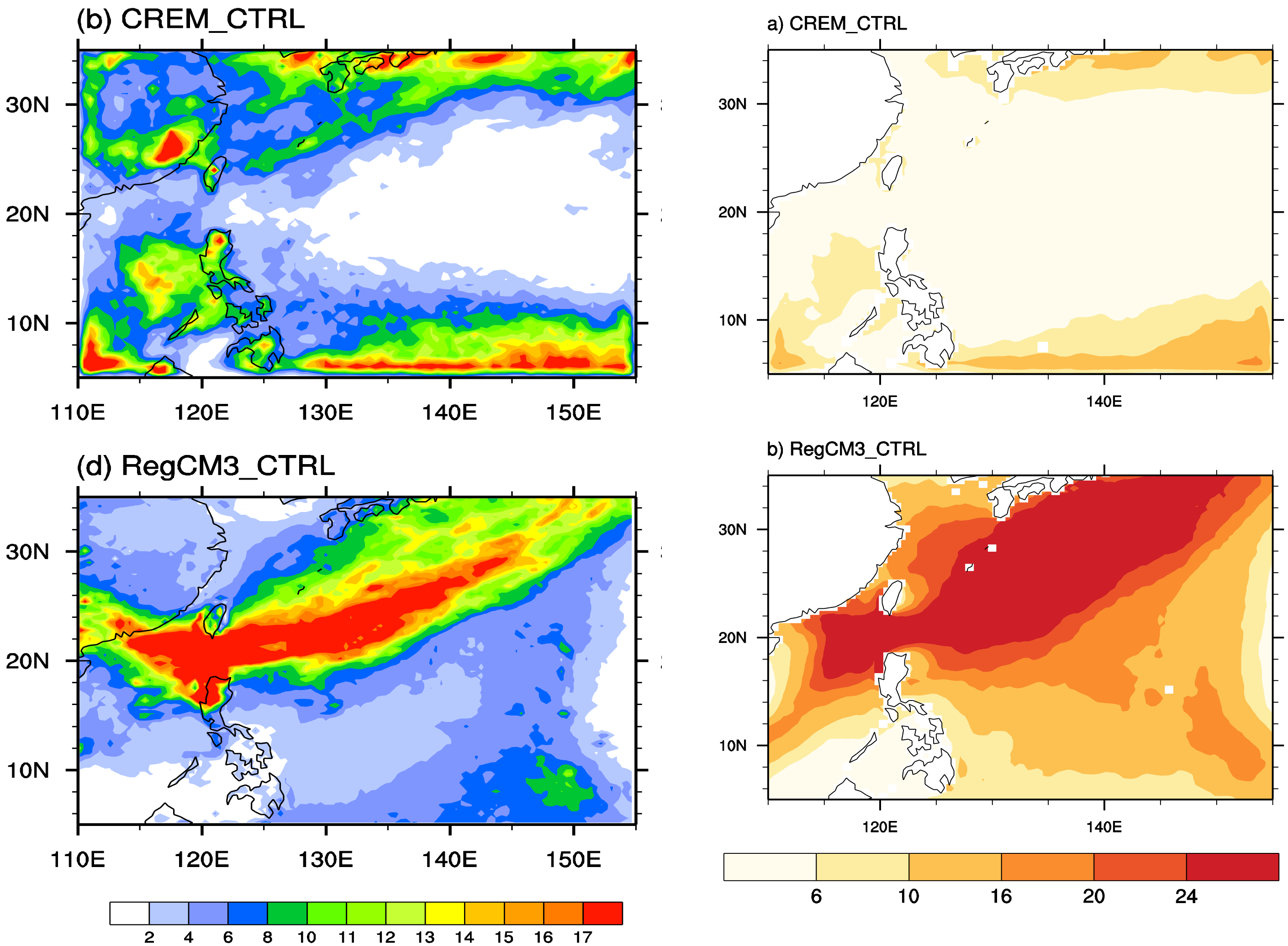
projected changes in the JJA mean latent heat flux



Rainfall and **low cloud** in control runs

CREM

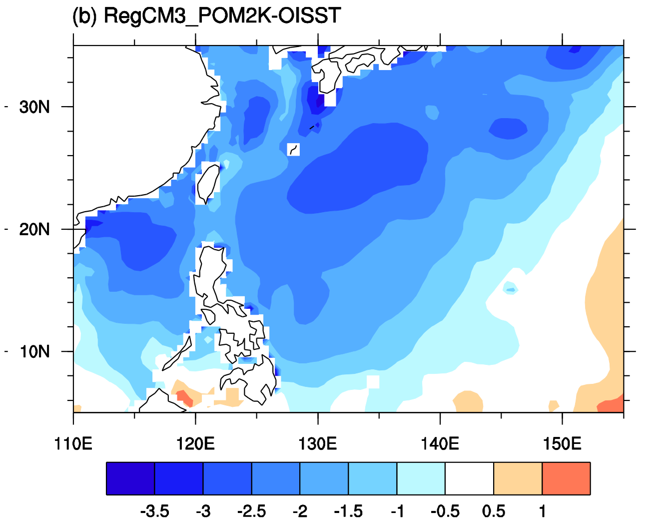
RegCM



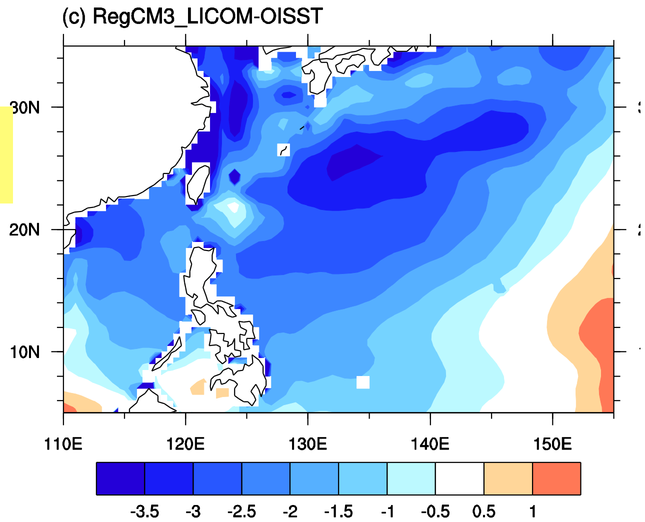
The contribution of convective prcp is more than 90% in RegCM3

Common cold biases of simulated SST

RegCM3_POM



RegCM3_LICOM



Cold biases of simulated SST are evident in both simulations and they are very similar.

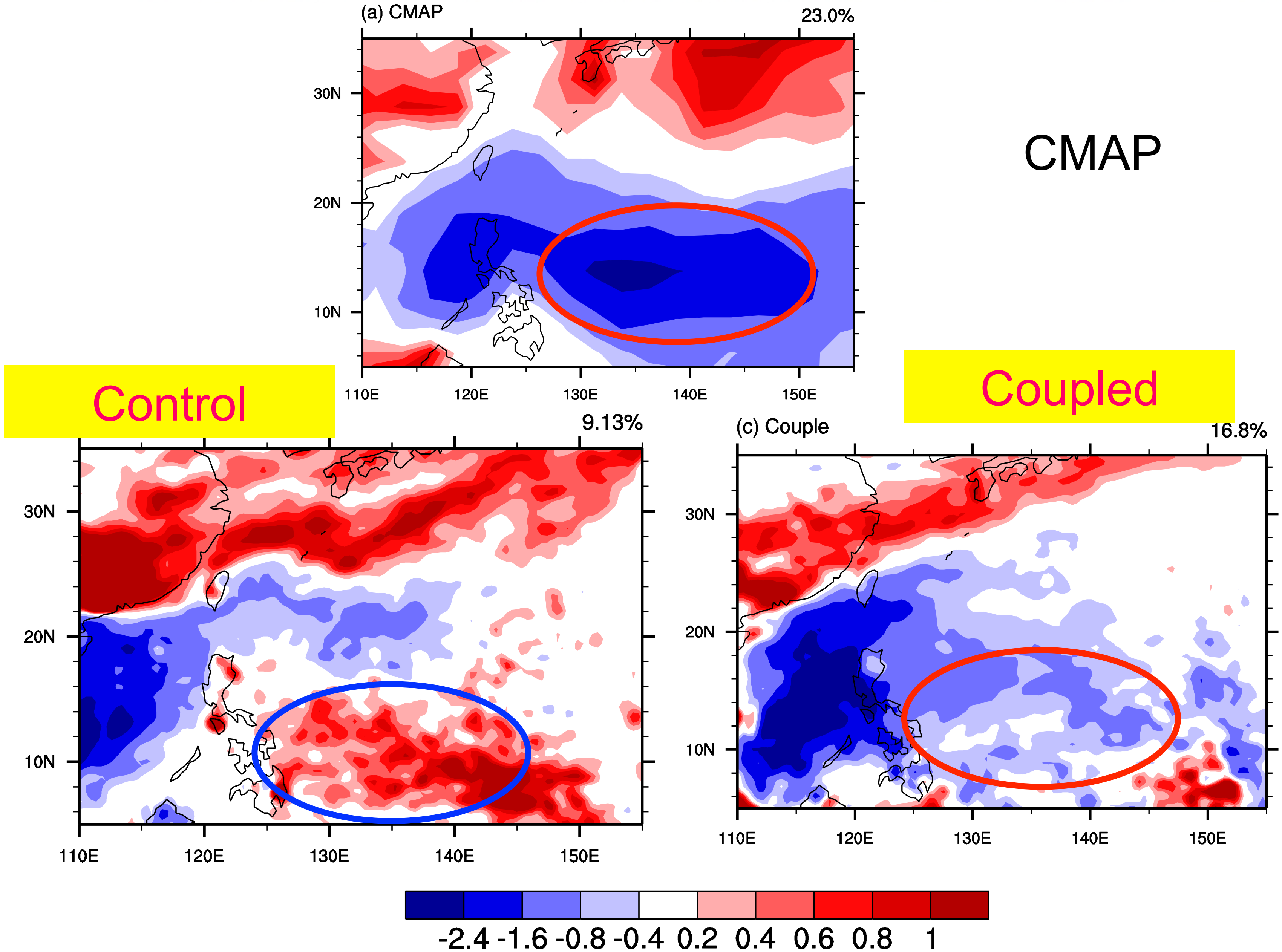
Zou and Zhou (2014) Sci. Bull.

Numerical Experiments

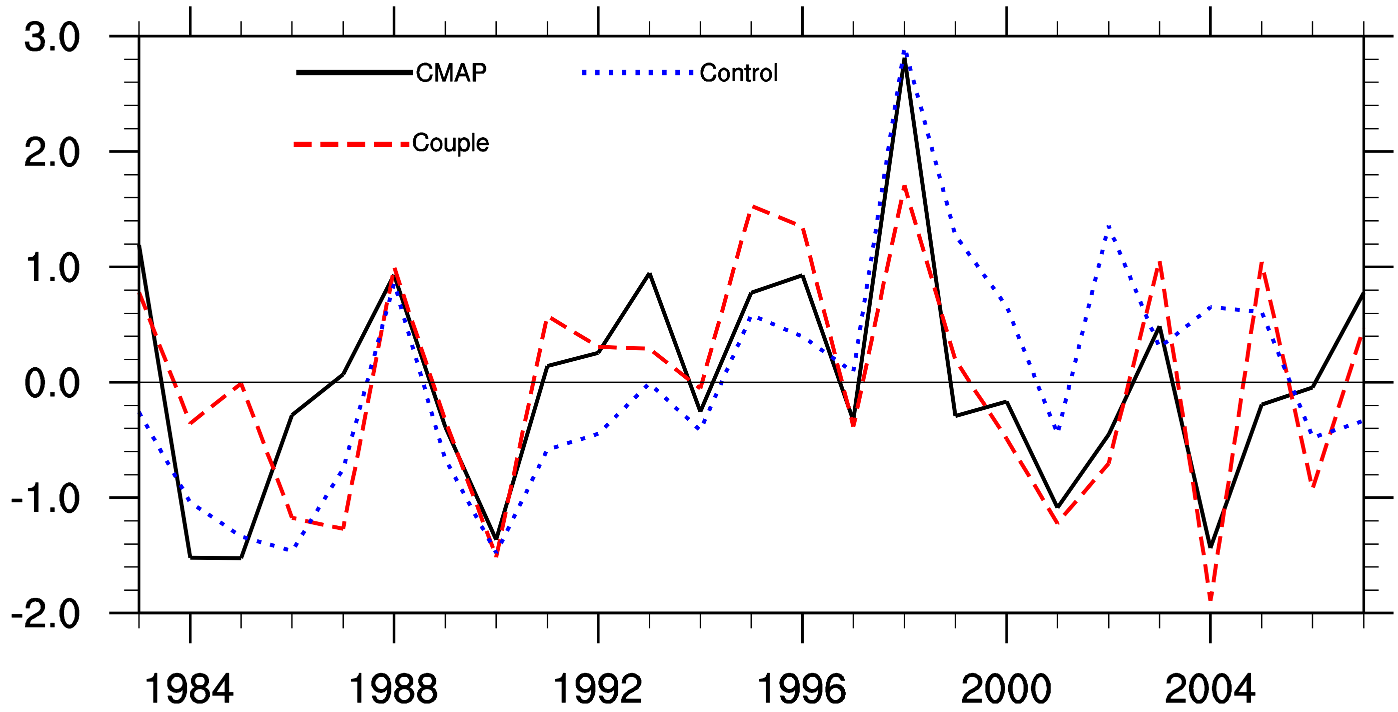
- **Control Run:** **OISST2-driven RegCM3 run**
- **Couple Run:** **RegCM3 coupled to LICOM2**

Precipitation：CMAP data covering 1983-2007

EOF1 of JJA precipitation



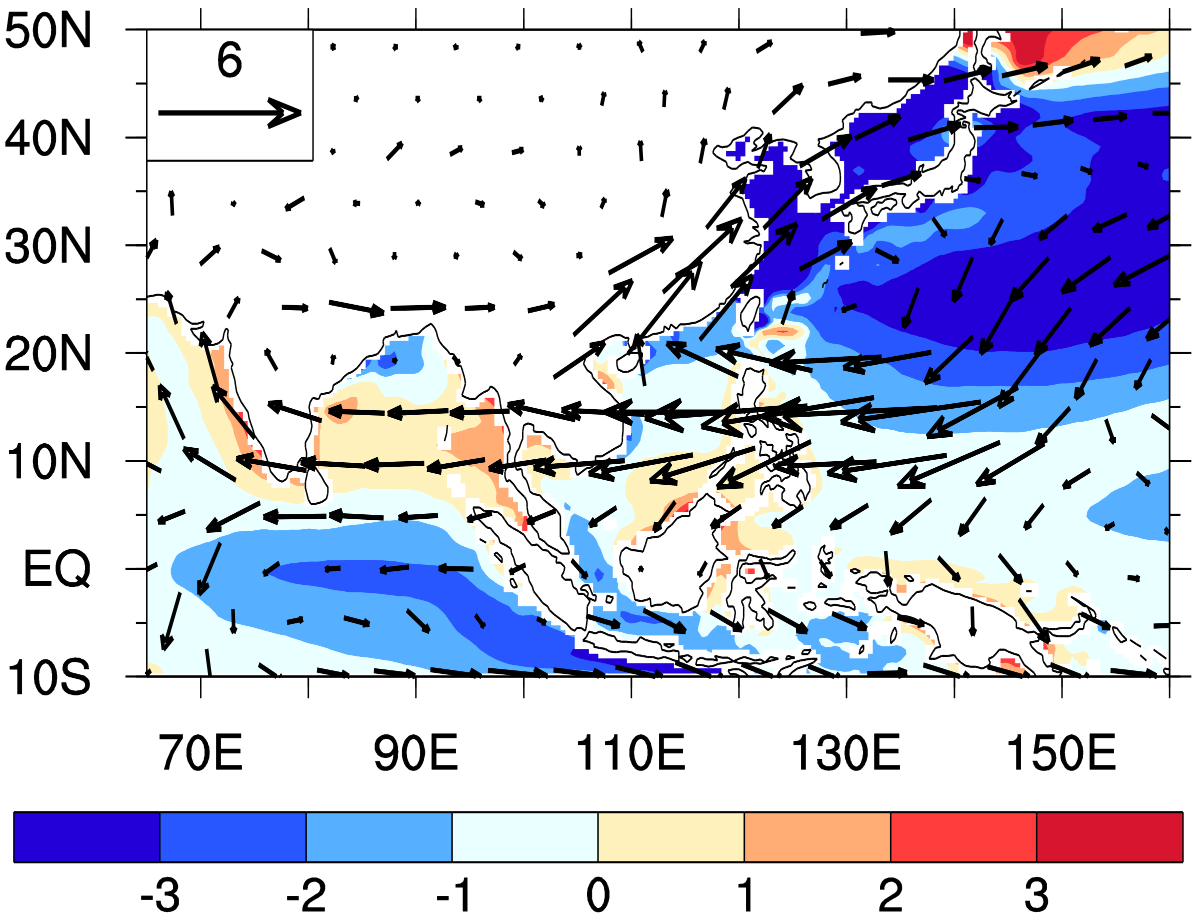
PC1 Time Series



CTRL	CPL
0.58	0.74

Zou and Zhou (2013) J. Climate

Differences of JJA mean SST and 850 hPa low-level wind between the regional coupled model and the standalone RCM



Zou et al. 2015 J. Geophys. Res. Atmos. (under review)