State Key Laboratory of Numerical Modelling for Atmospheric Sciences
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Institute of Atmospheric Physics Chinese Academy of Sciences

FGOALS-f High-resolution Coupled Climate Model and the simulated Asian Summer Monsoon

Qing Bao [1]

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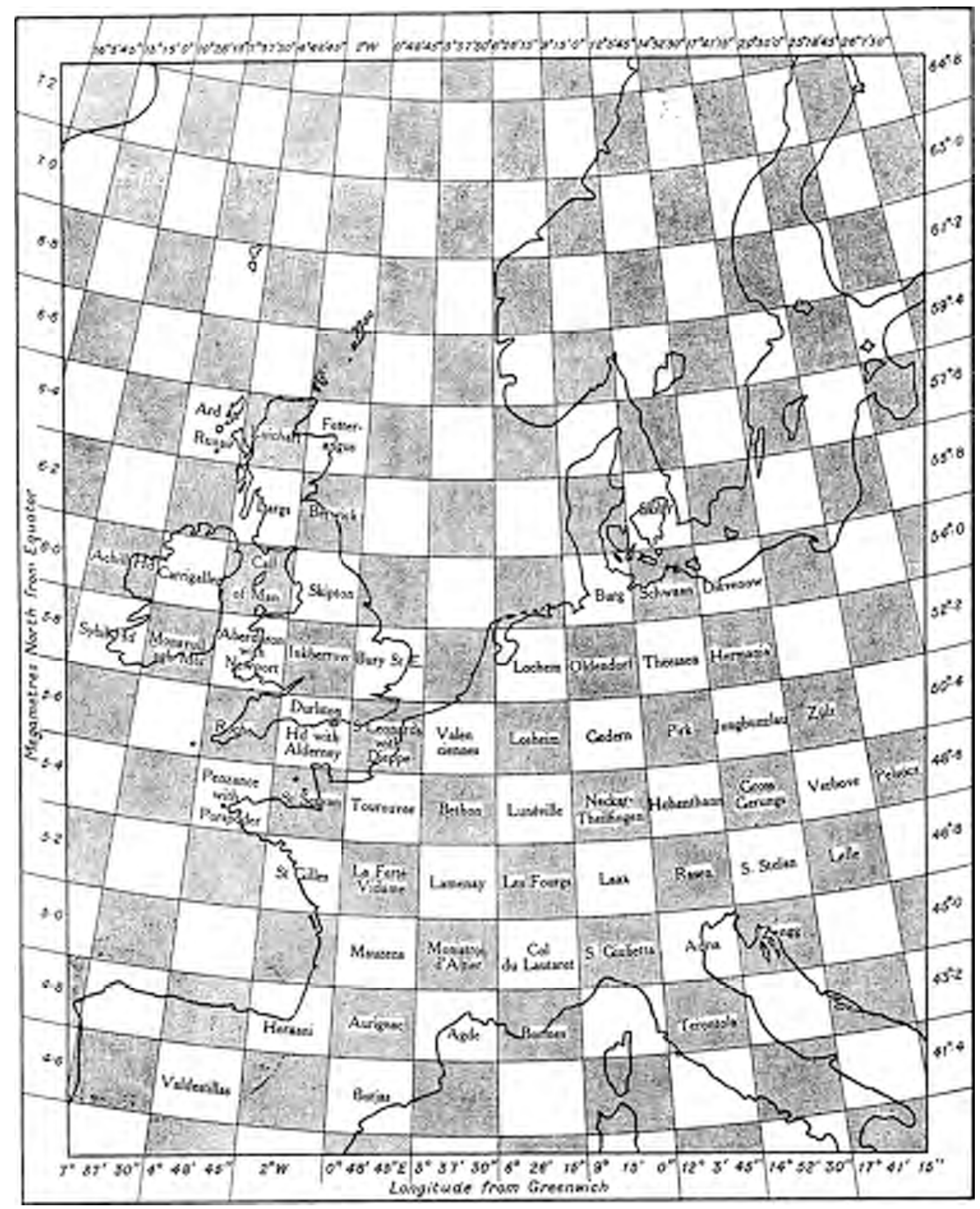
TTA 2017, ICTP, Aug 1, 2017

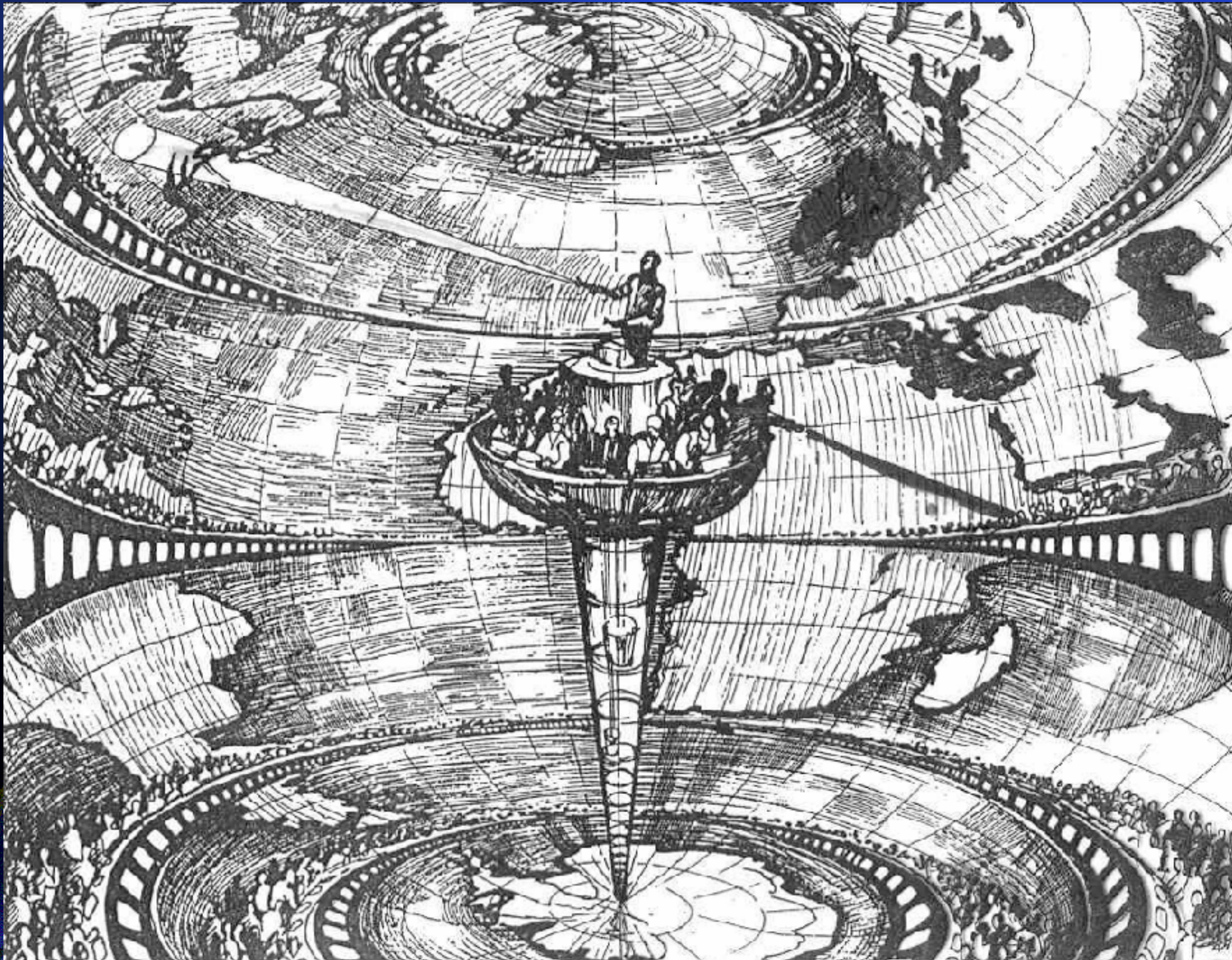
Climate modeling grew out of numerical weather prediction

Lewis F. Richardson (1881-1953)

In 1922, Richardson provided the first formulation of the atmospheric equations on a computational grid.

“If the coordinate chequer were 200 km square in plan, ... 64,000 computers would be needed to race the weather. In any case, the organisation indicated is a central forecast-factory.”



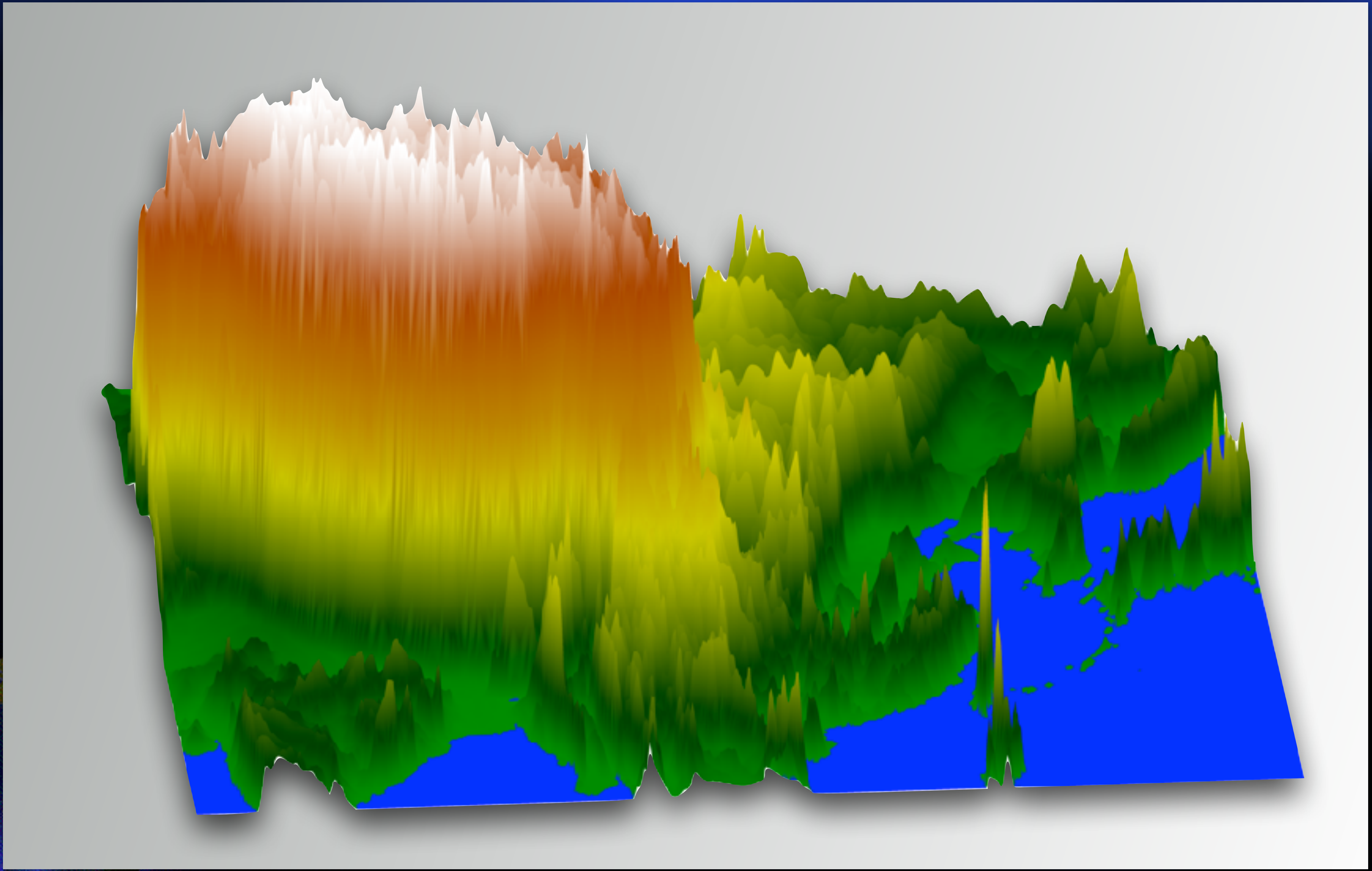


This illustration depicts Richardson's "forecast factory." *Image courtesy of L. Bengtsson.*

Outlines

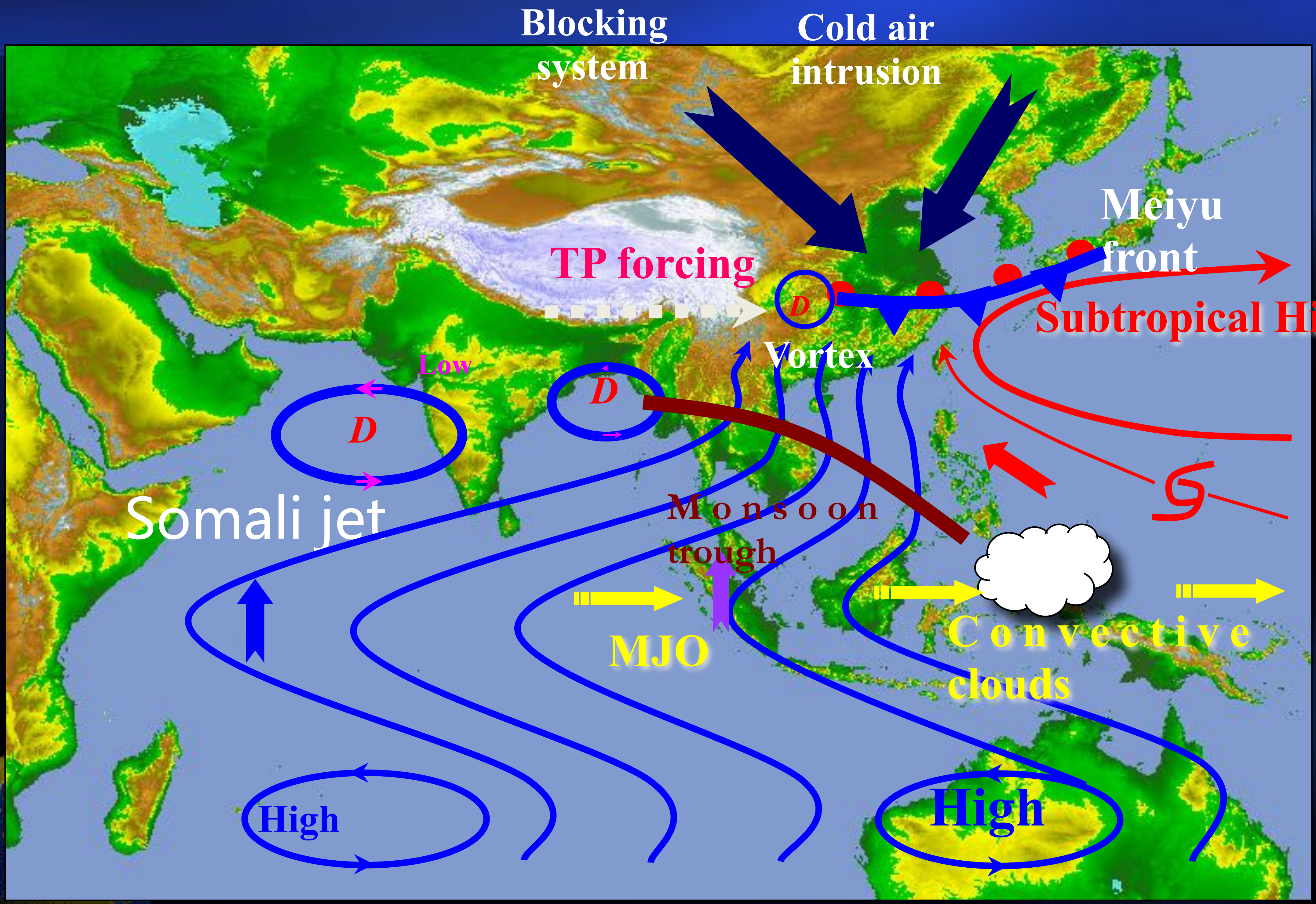
- Introduction
- FGOALS-f High-resolution Coupled Climate Model
- Simulated Asian Summer Monsoon
- S2S prediction system with FGOALS-f
- Summary

Complex topography over the Asian summer monsoon regions



Produced by 12.5km topography

Schematic diagram of Asian Summer Monsoon



(Zhang and Tao, 1998, CJAS)

nature International weekly journal of science

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Archive > Volume 515 > Issue 7527 > Comment > Article

NATURE | COMMENT

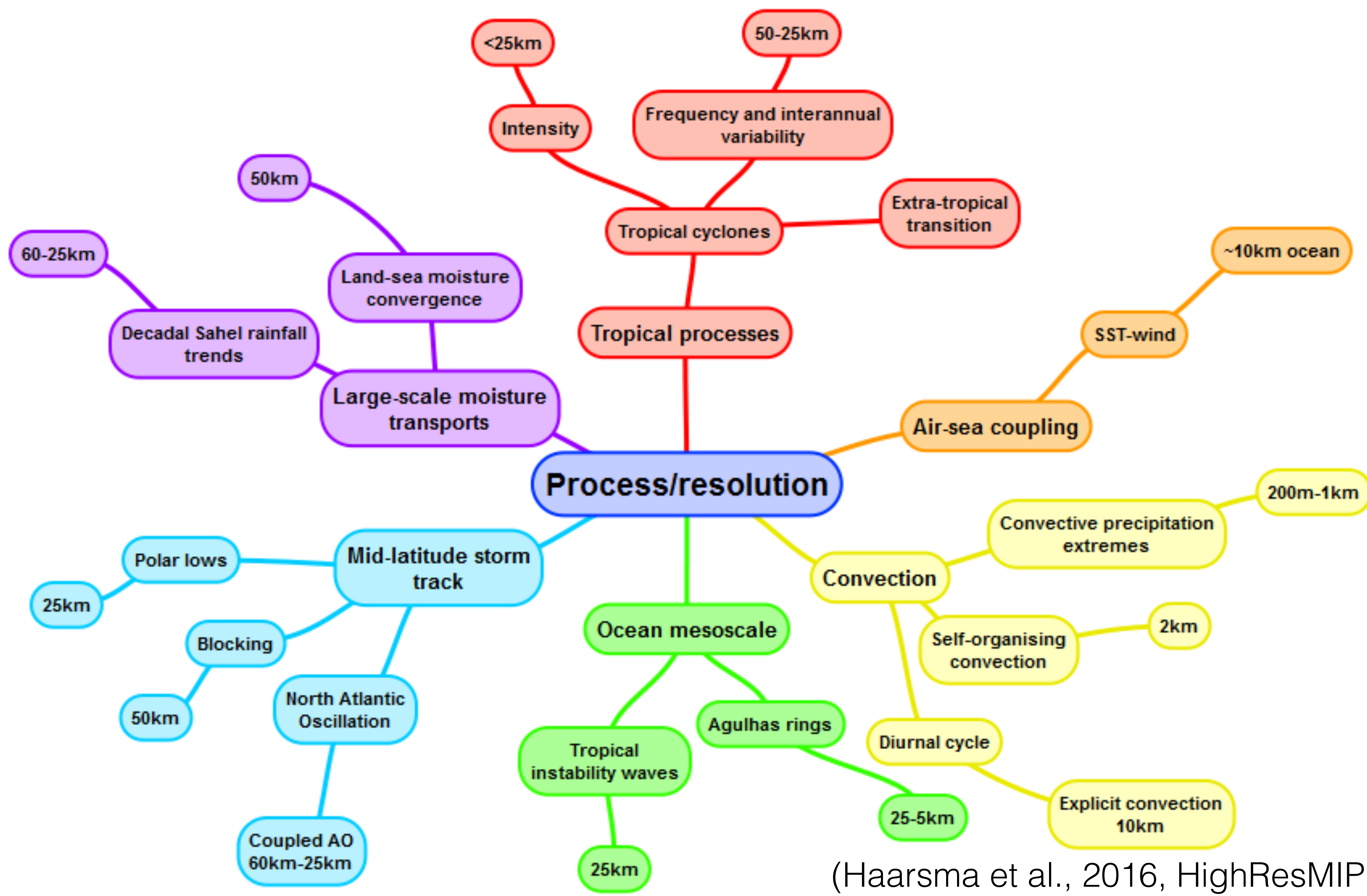
Climate forecasting: Build high-resolution global climate models

Tim Palmer

19 November 2014

International supercomputing centres dedicated to climate prediction are needed to reduce uncertainties in global warming, says Tim Palmer.

How to improve the modeling skills?



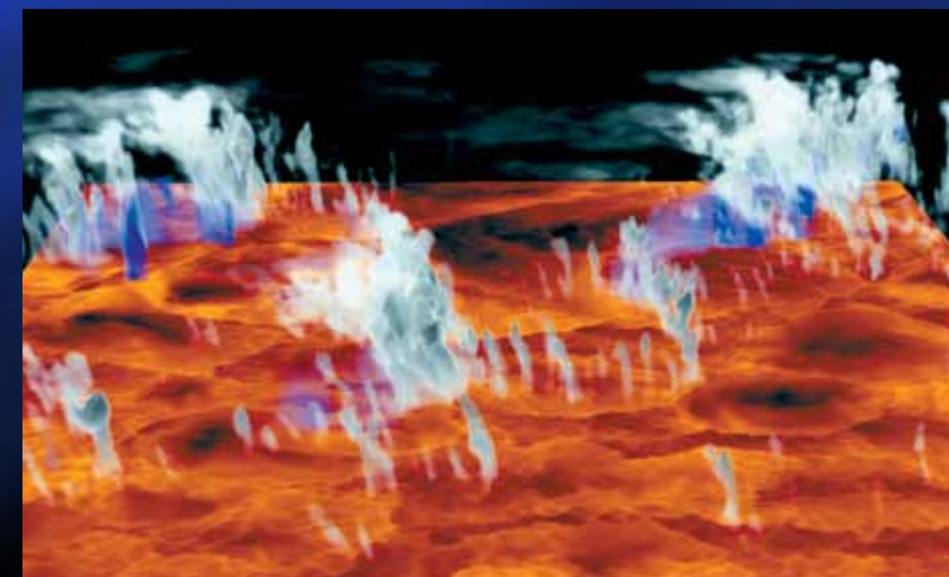
(Haarsma et al., 2016, HighResMIP)

Great Challenges in high-resolution climate modeling

Local effects such as thunderstorms, crucial for predicting global warming, could be simulated by fine-scale global climate models.

Build high-resolution global climate models

Tim Palmer, 2014 Nature | COMMENT

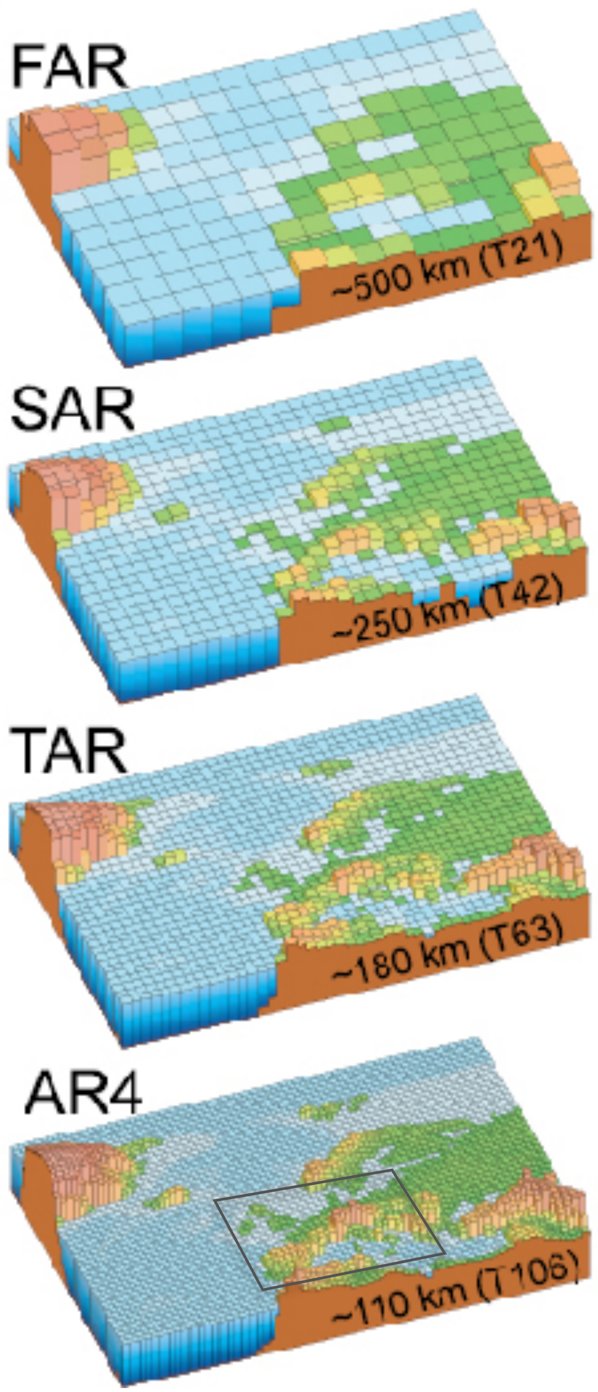


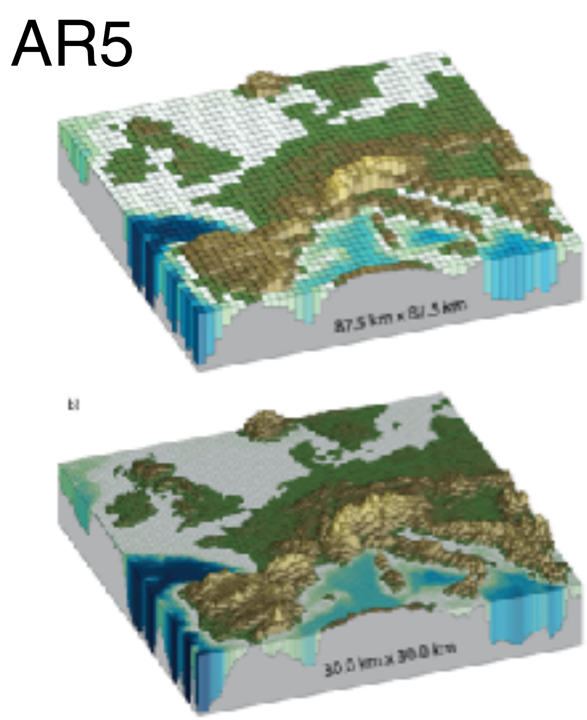
Simulation of convective cloud systems in a limited-area high-resolution climate model.

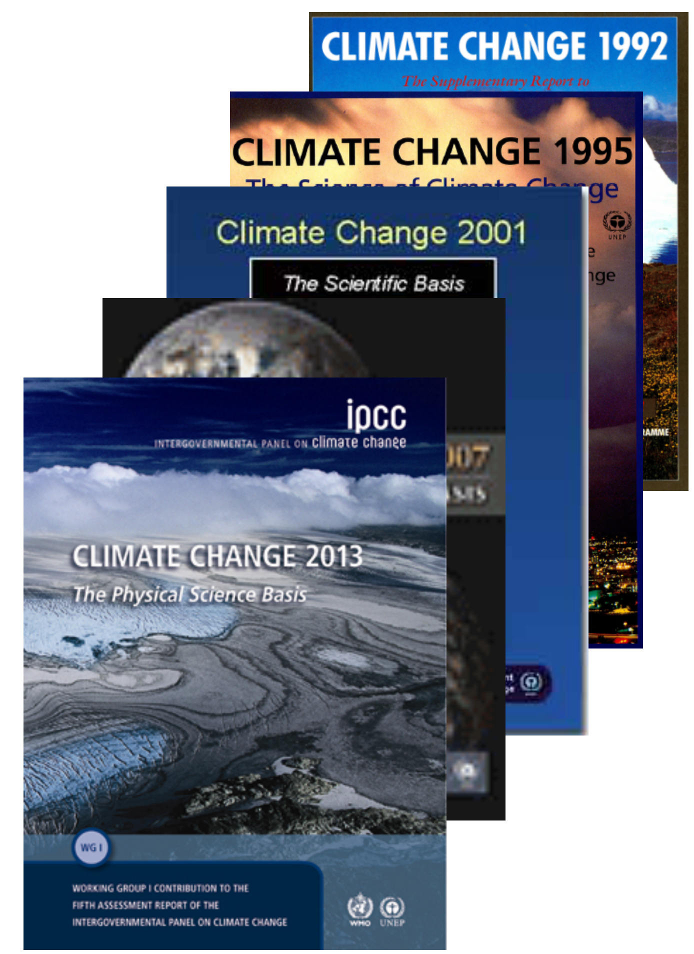
- Huge computational cost
- Parameterizations :
  - Approximate the average effects of convective clouds
  - Sensitive to some of the parameters

Resolving convective cloud systems

Developing the next-generation climate system models







- **To increase the resolutions of the model mesh**
- **To improve the physics of the model**

Great Challenges in CMIP models

BAMS
Bulletin of the American Meteorological Society
QUALITY ASSURANCE FOR MODELS
METEOROLOGY OVER SMALL HILLS
ICE NUCLEI MEASUREMENTS

However, an aspect of global coupled modeling that has changed little with improved model resolution and physics is that there are some systematic errors. Such persistent systematic errors noted in previous generations of global coupled models that still are present in the present generation include an overextensive and too-strong equatorial Pacific cold tongue, a double ITCZ, either weak or little intraseasonal convective activity in the Tropics [e.g., the Madden–Julian oscilla-

AMERICAN METEOROLOGICAL SOCIETY

（ Meehl, et al 2005, BAMS）

Recent Progress in the cumulus parameterization

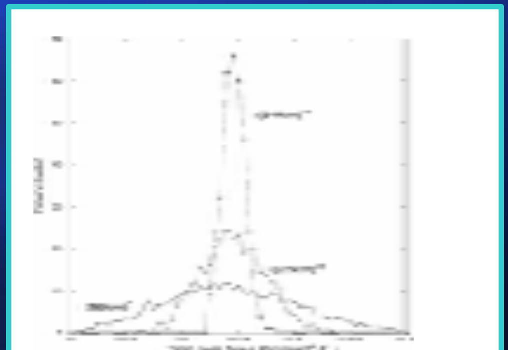
- Stochastic parameterization

  (Plant and Craig 2008;

  G. Zhang, et al , 2016 Tsinghua;

  Berner et al., 2017 , NCEP …)

  Great potential to increase the predictive capability of next-generation weather and climate models.

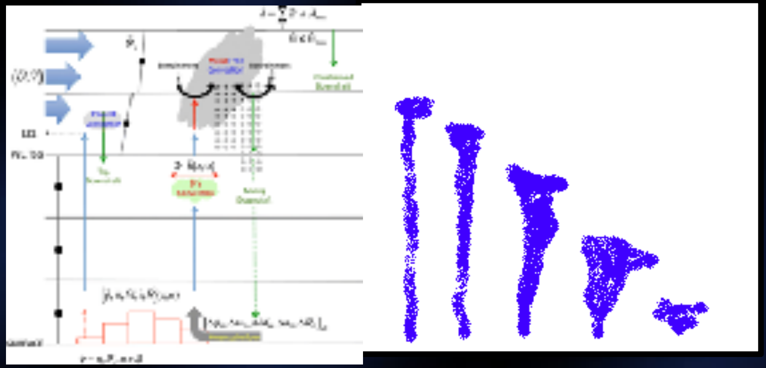


(Plant and Craig 2008)

- A Unified Convection Scheme (UNICON) (Park. 2014)

  Double plume convective parameterization

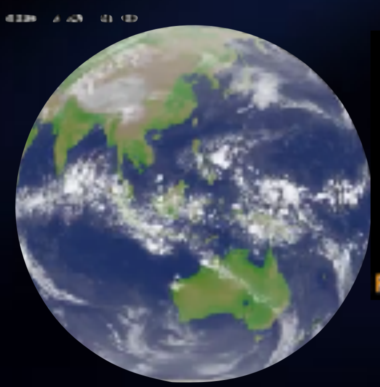
  (M. Zhao, GFDL)



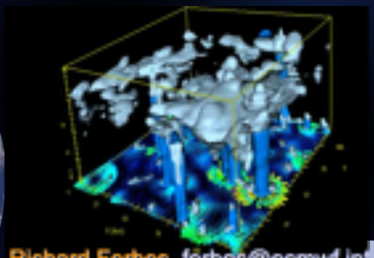
Sungsu Park, NCAR

- Cloud resolving scheme

  (Kodama et al 2015, NICAM)



Miura et al. 2007

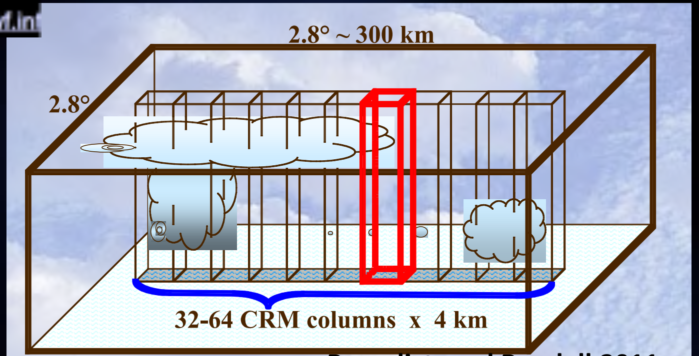


Richard Forbes, forbes@ecmwf.int

- Super-parameterization

  (Khairoutdinov,, and Randall,2001;

  Wang M. et al 2011, SPCAM, NCAR/PNNL)



Benedict, and Randall,2011

Chinese fastest supercomputers

Tianhe1	Tianhe2	Sunway TaihuLight
		
No. 1: 2010-2011	No. 1: 2013-2016	No. 1: 2016-

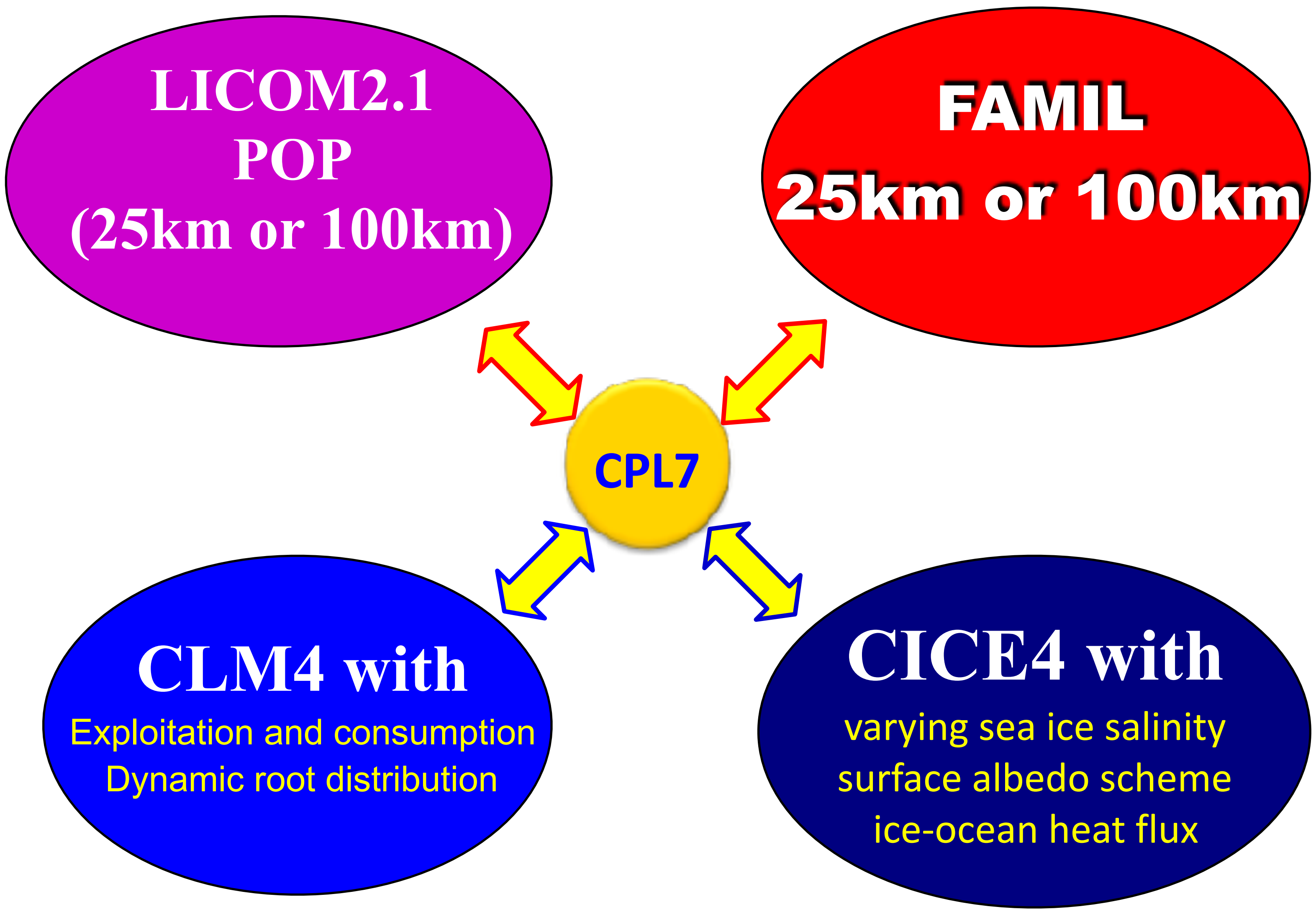
Supercomputer is/was the world's fastest

Main Targets

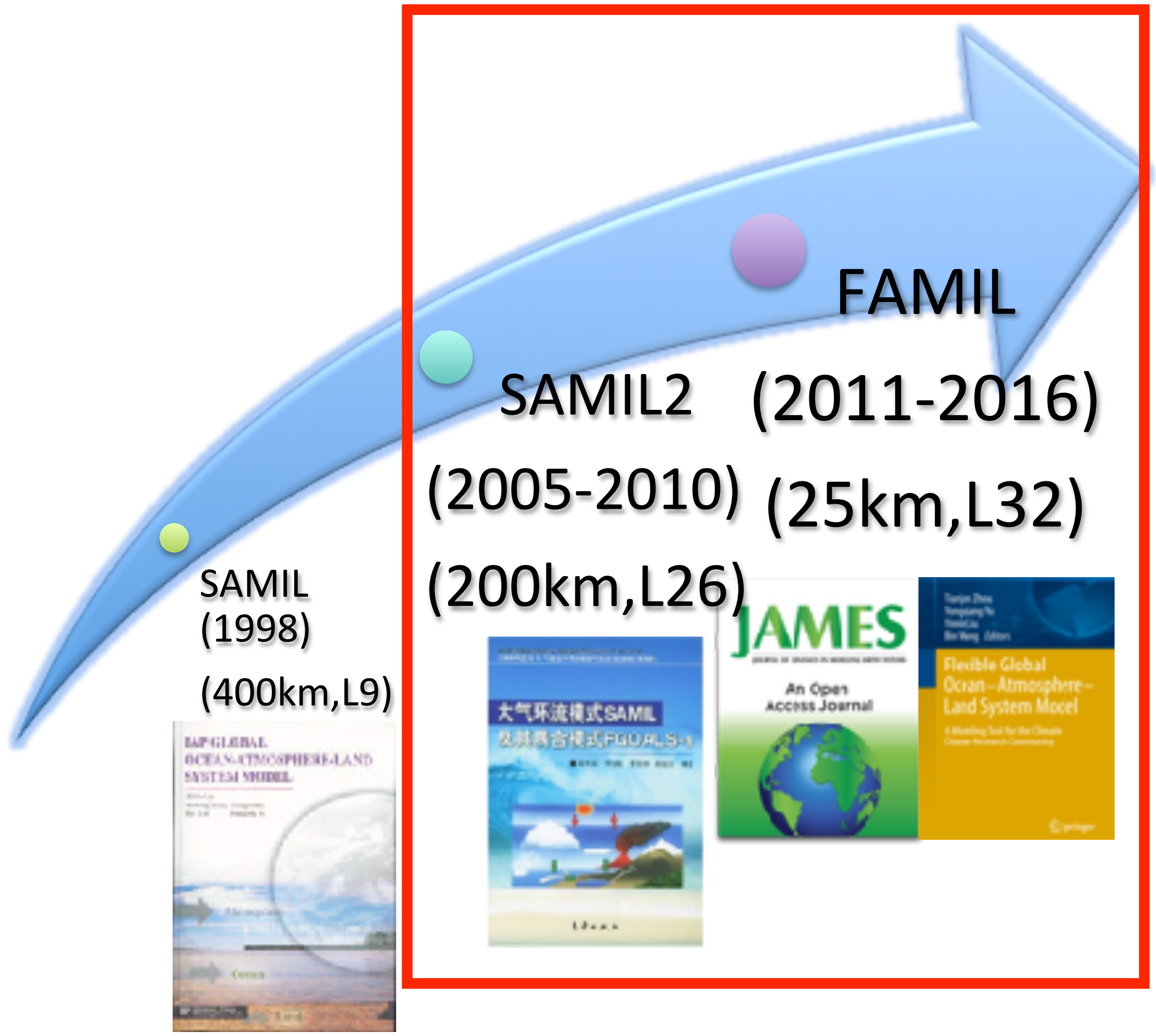
- To improve the weather and climate variability related with the cumulus convection

- To be scale-aware and computational effective

Climate System Model: FGOALS-f



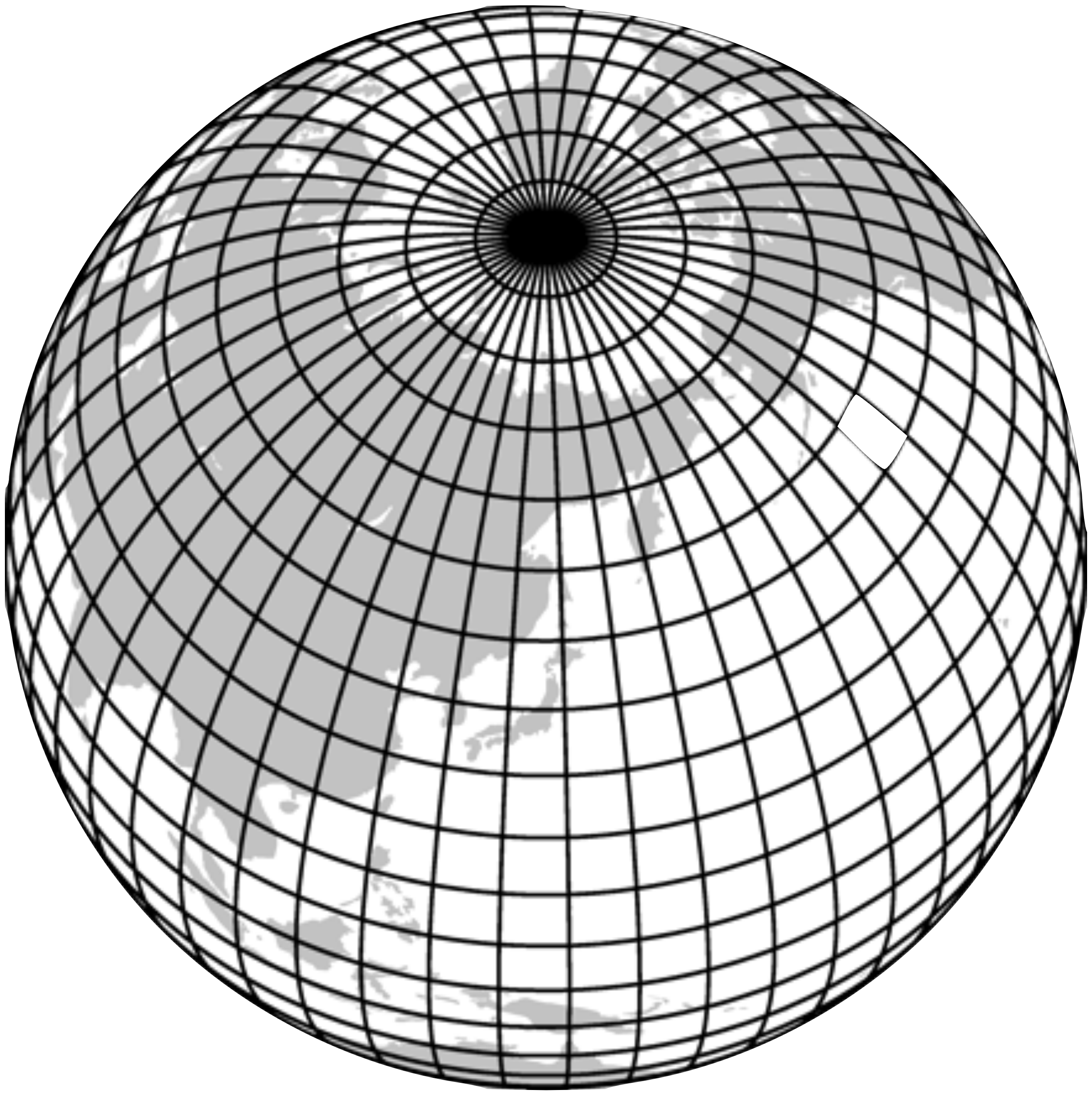
Introductions to AGCM S/FAMIL



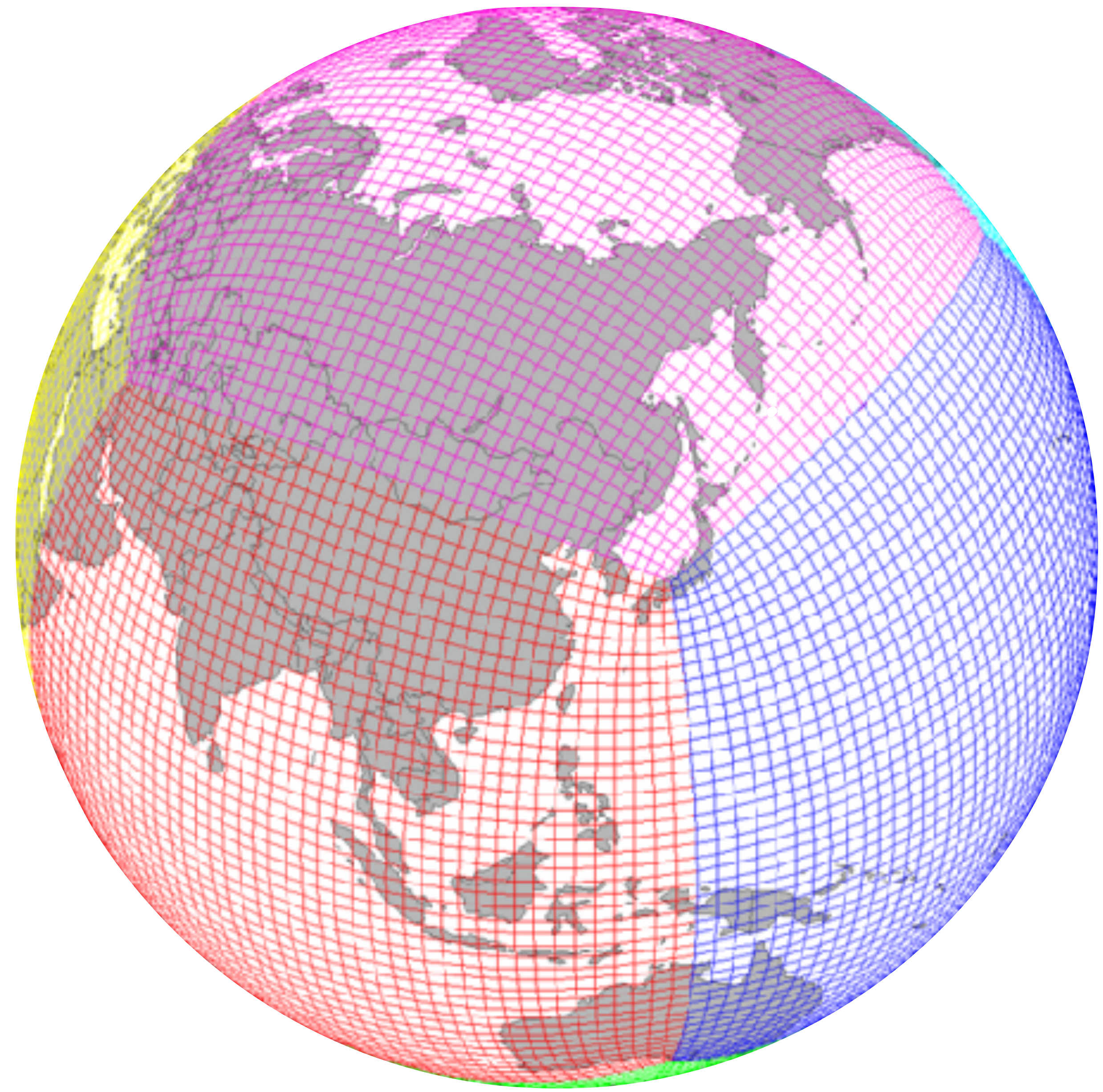
Finite-volume/**S**pectral **A**tmospheric **M**odel in **I**AP **L**ASG

包庆等,2005； 包庆等,2006; **Bao et. al, 2010;2013**;

Bao et al., 2014; Zhou **Bao*** et al.,2014;Zhou **Bao*** et. al 2015



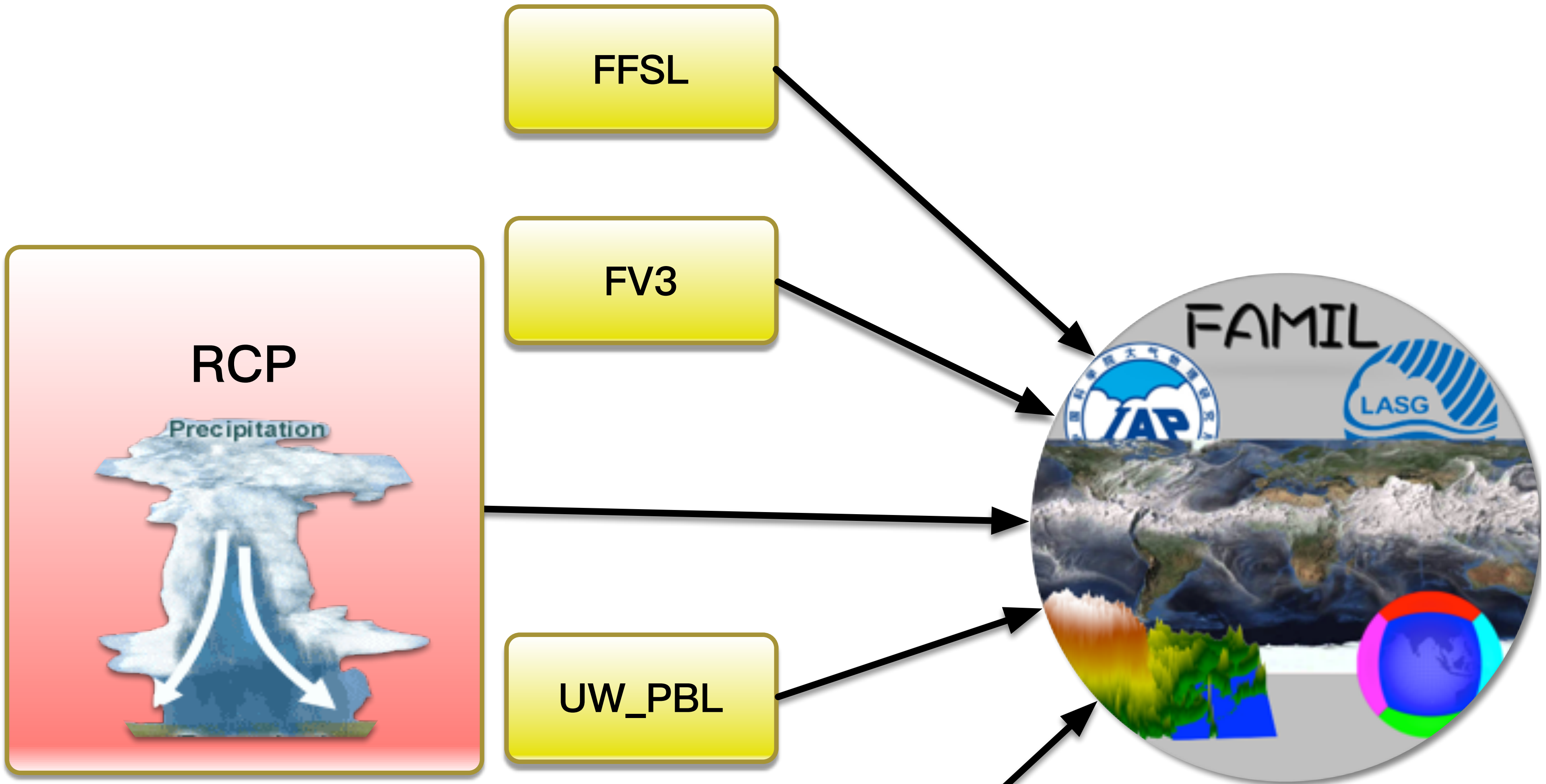
Williamson (2007).



Sadourny (1972).

FV3 dynamic core:Lin and Rood, 1996；Lin, 1997, 1998, 2004；Putman and Lin, 2007

High-resolution AGCM: FAMIL



Resolving Convective Precipitation

FGOALS-f in CMIP6

	CMIP5	CMIP6
Name	FGOALS-s2 (Bao et al., 2013)	FGOALS-f (He et al In prep;Bao In Prep.)
Atmosphere	SAMIL	FAMIL
Dynamic core	Spectral on lon-lat grid (Wu et al 1996; Bao et al., 2010)	Finite Volume on Cubed-sphere grid (Lin 1996,2004; Zhou et al. 2015)
Resolution	R42(2.81°X1.66°) L26	C96(1°X1°) L32 C384(0.25°X0.25°) L32
Radiation	Edwards J. M. and A. Slingo, 1996 Sun, Z., 2005	RRTMG (Clough et al, 2005)
Convection	Mass-flux Tiedtke, 1989;Nordeng,1994	Resolving Convective Precipitation Copyright (c) 2017 FAMIL development team One-moment bulk (Lin et al,,1983) Two-moment (Chen and Liu, 2004)
Microphysics	None	
Boundary Layer	Non local (Holtslag and Boville, 1993)	UW (Bretherton and Park,2009)

Computational performance

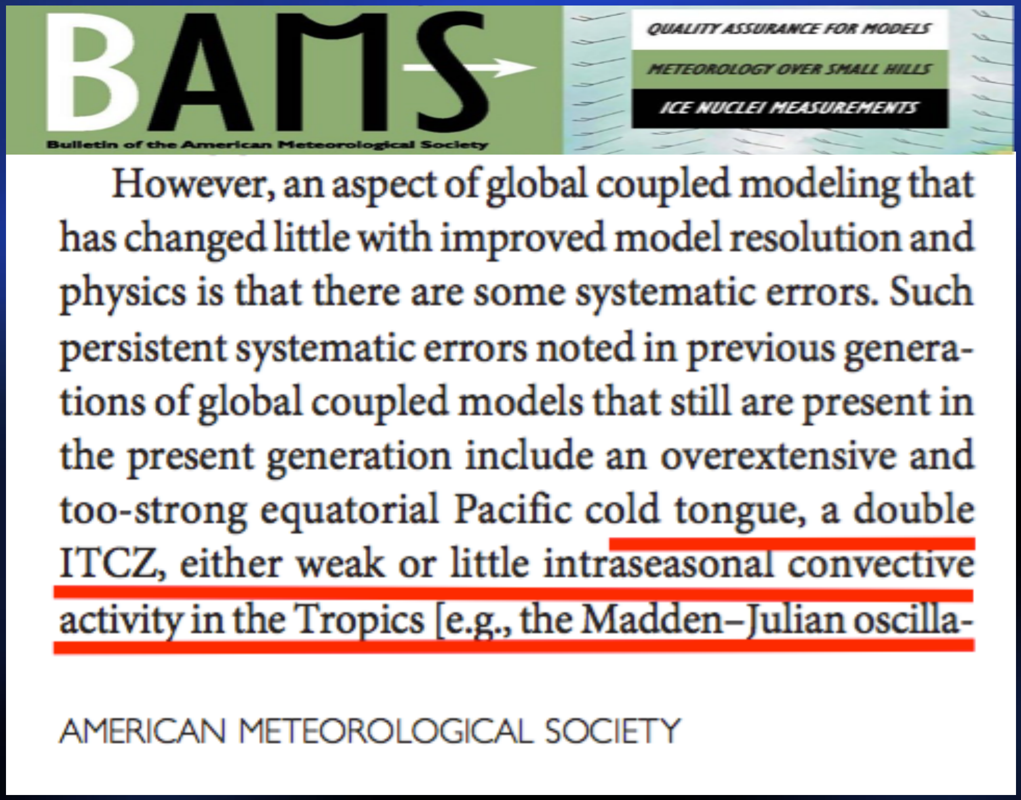
	NICAM (KODAMA et al. 2015)	FGOALS-f_C384	FGOALS-f_C96
CSM	AGCM	CGCM	CGCM
Resolution	atm/lnd: 14km	atm/lnd: 25km ocn/ice: 100km	atm/lnd: 100km ocn/ice: 100km
Computer	K computer	Tianhe-2	Tianhe-2
CPU cores	**5,120**	**864**	**864**
1 wall-clock day	**0.2 years**	**1.5 years**	**18 years**

Tropical Precipitation Variability in FGOALS-f

- ITCZ
- MJO/ISO
- ENSO
- Precipitation frequency & intensity
- Tropical cyclone

ITCZ

CMIP3



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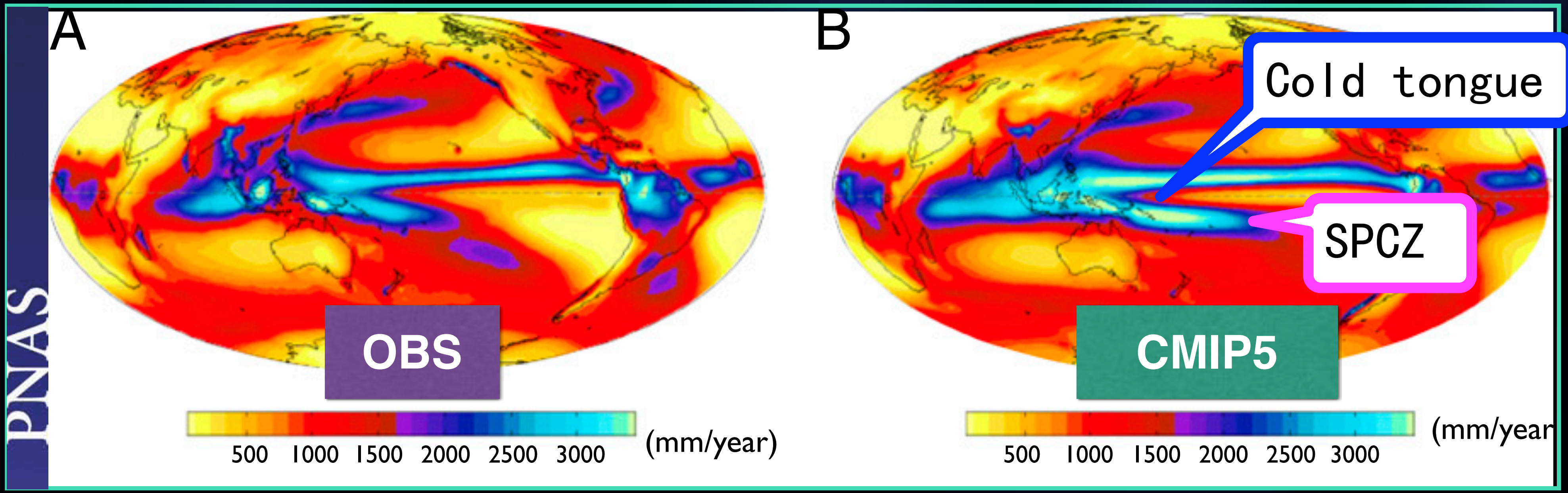
（ Meehl, et al 2005）

CMIP5



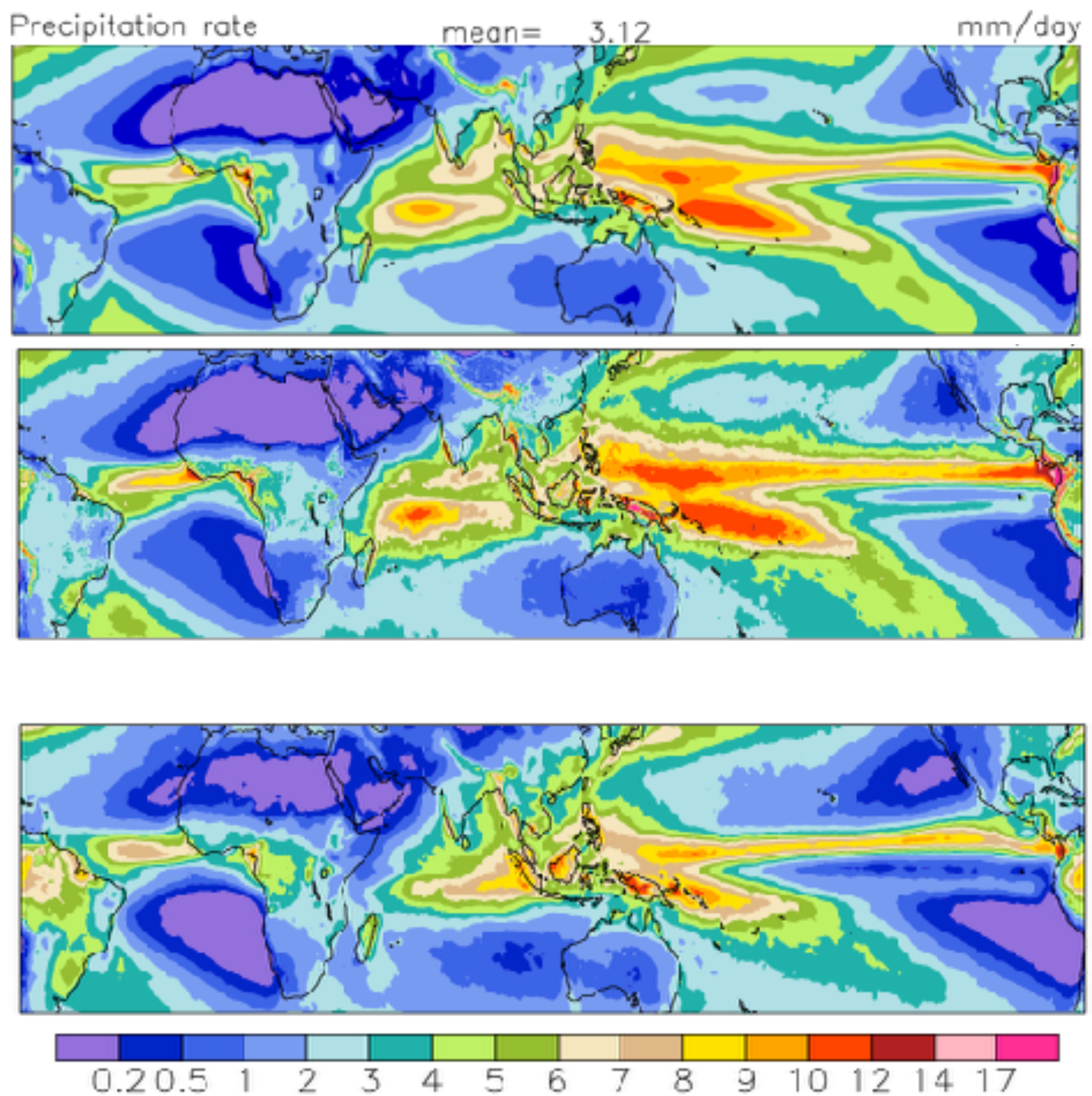
Hwang and Frierson 2013 PNAS

ANN Precipitation in FGOALS-f

C96 (1°)

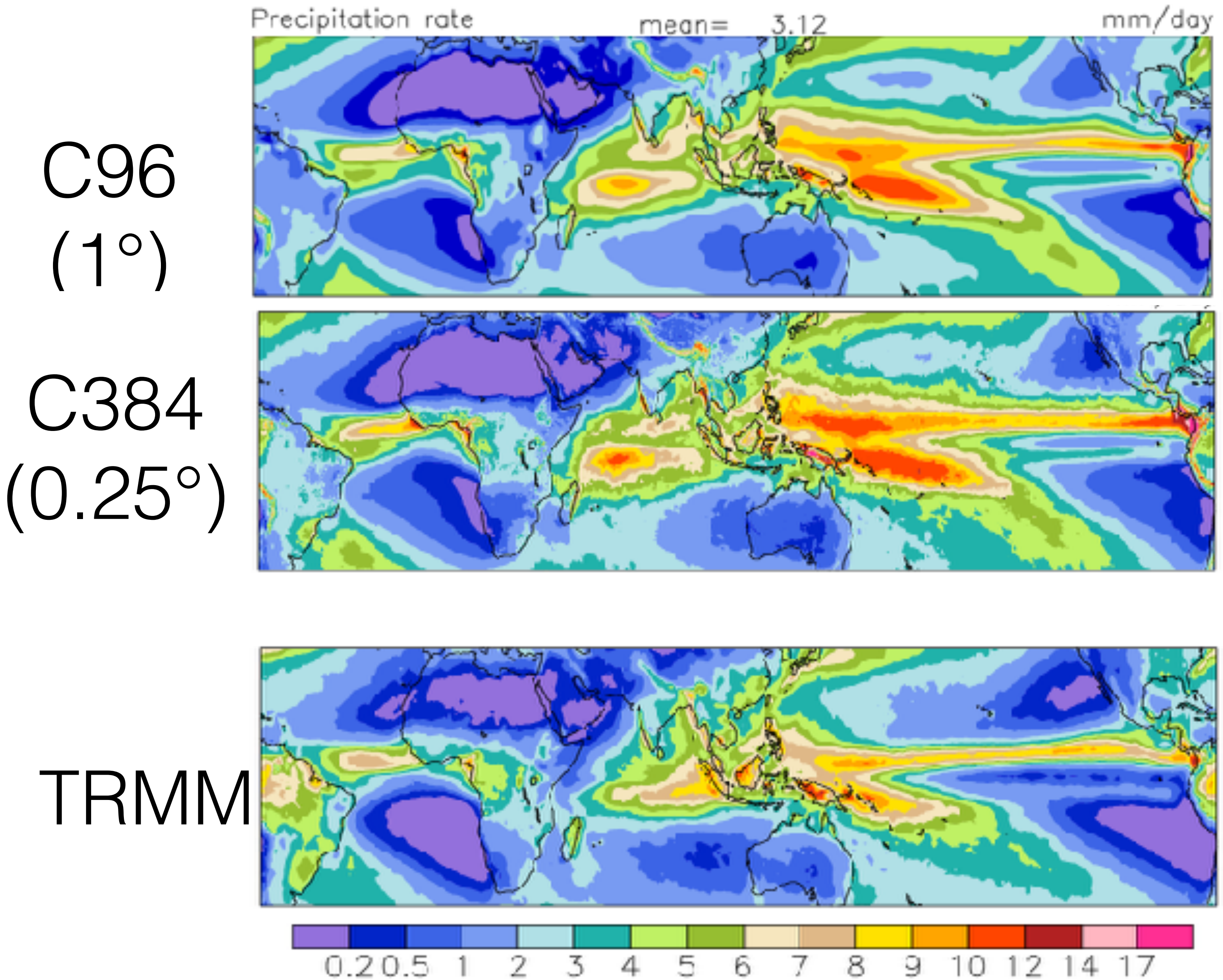
C384 (0.25°)

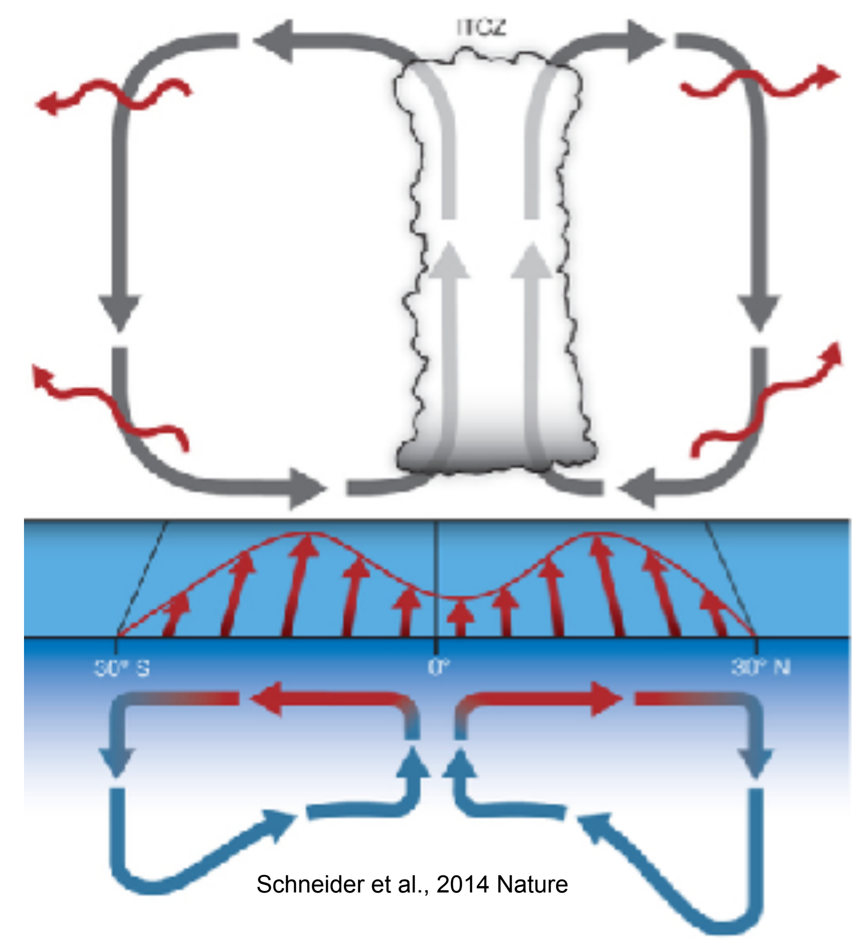
TRMM



FGOALS-f mitigates the double ITCZ problem

ANN Precipitation in FGOALS-f





Schneider et al., 2014 Nature

FGOALS-f mitigates the double ITCZ problem

Tropical Precipitation Variability in FGOALS-f

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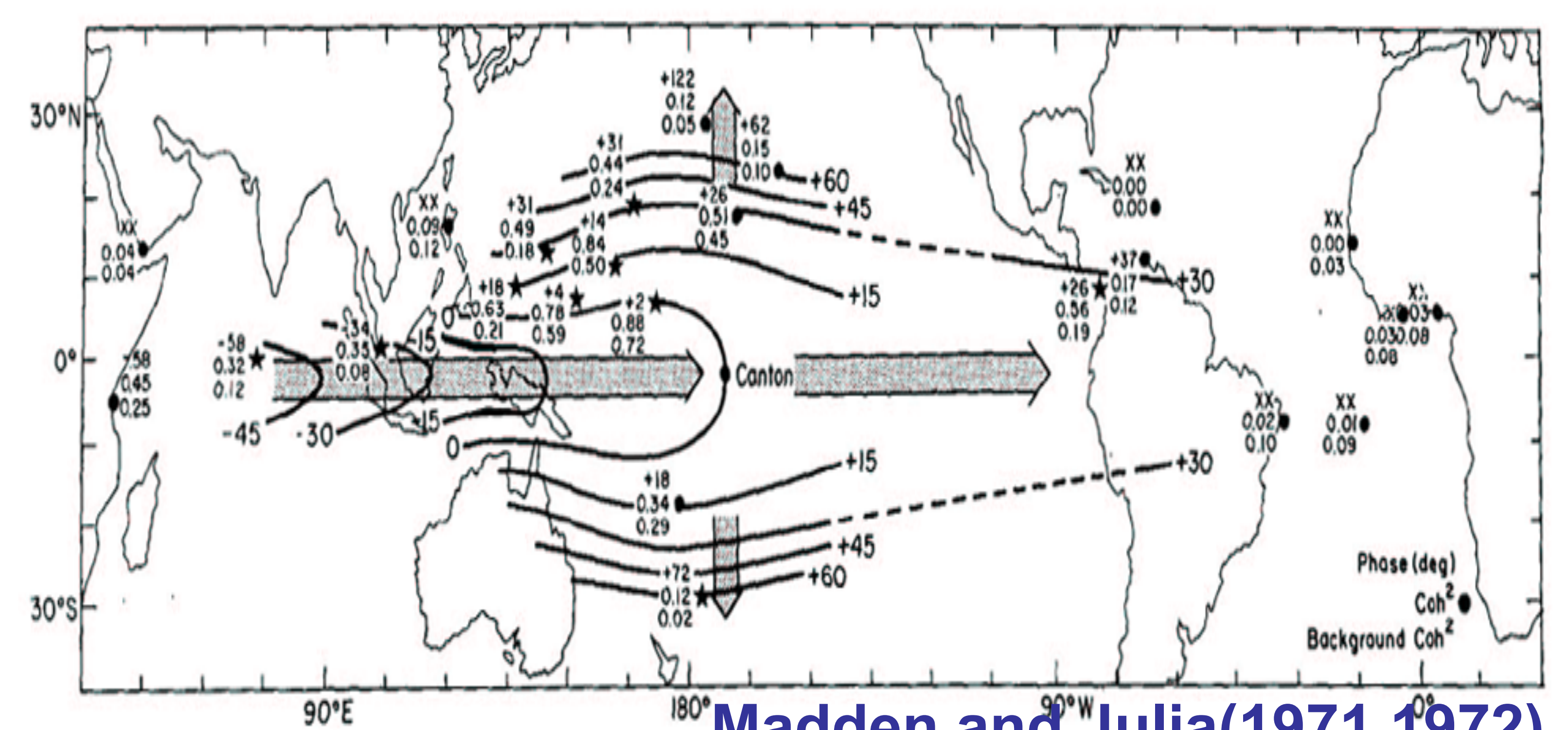
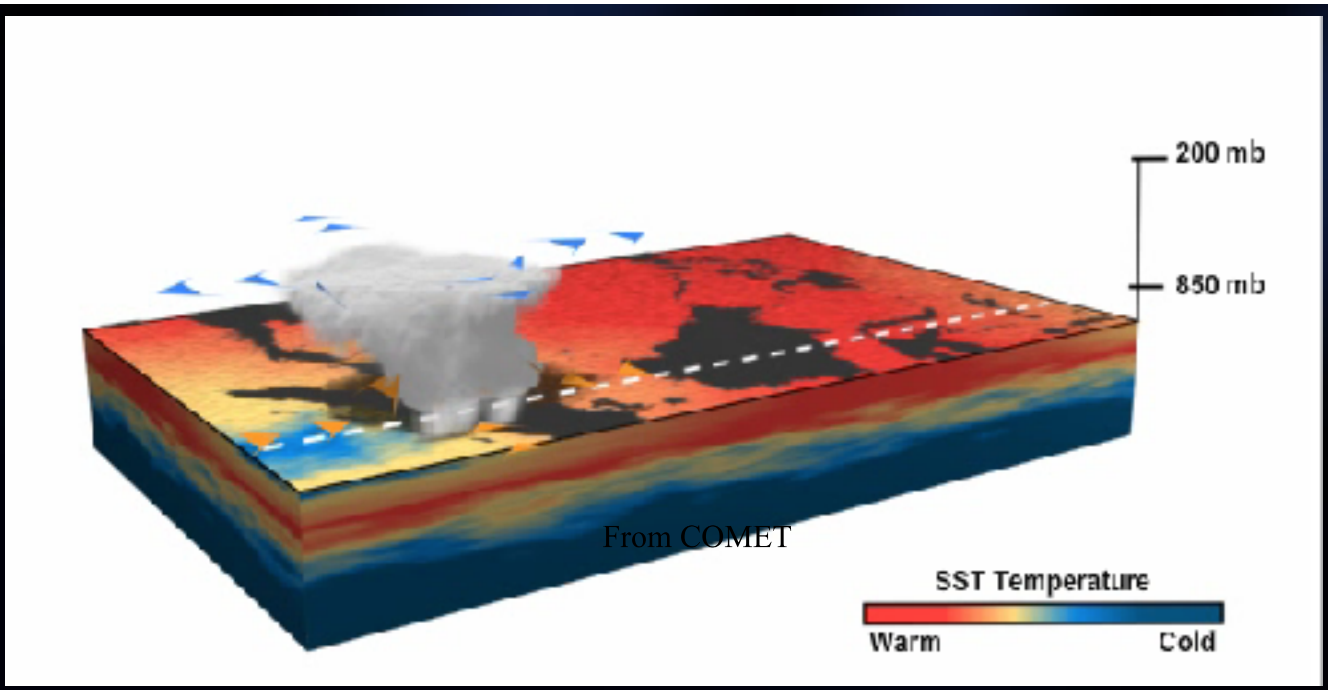
MJO/ISO



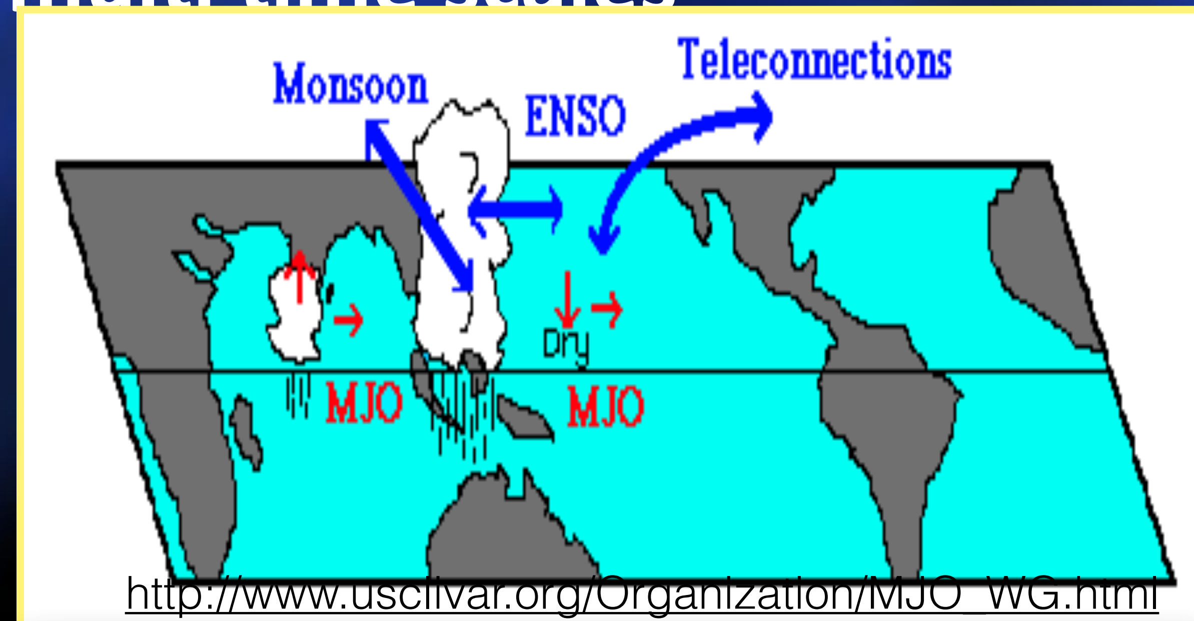
Madden and Julia(1971,1972)

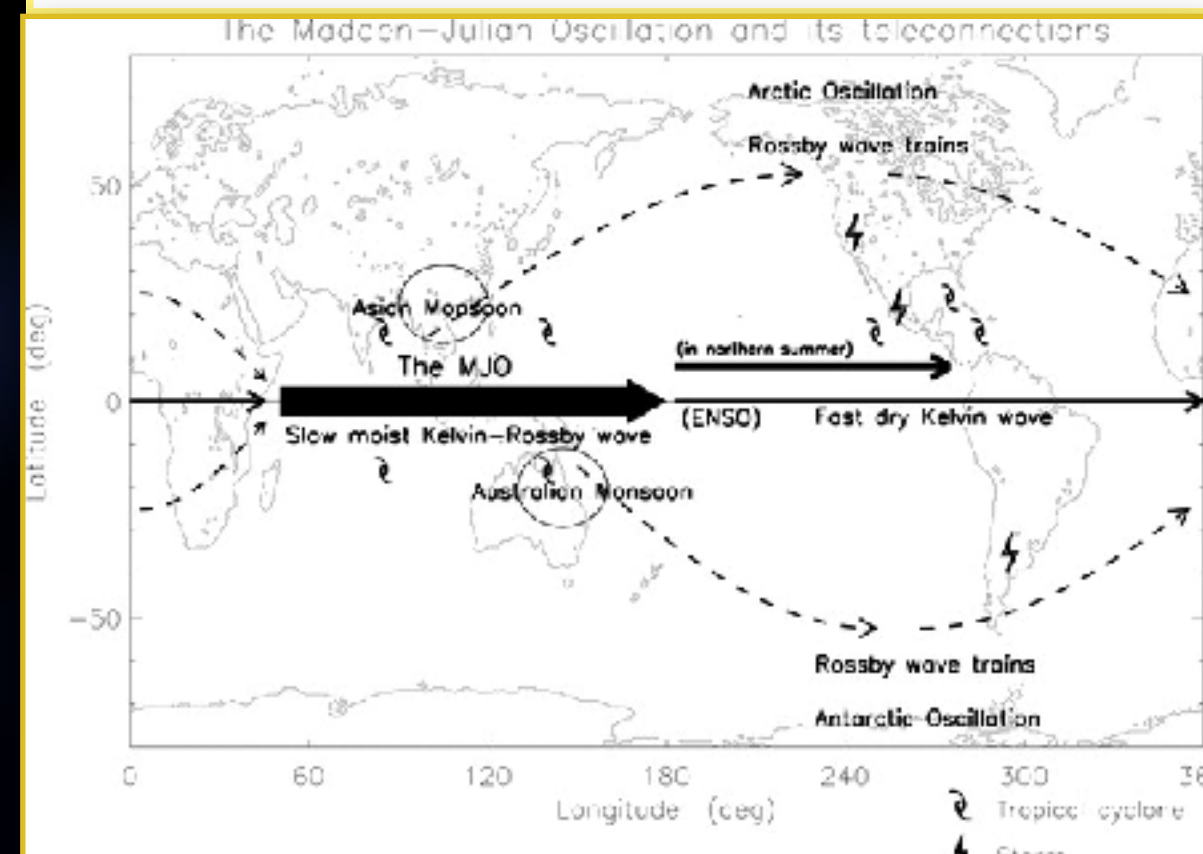


From COMET

Impacts of MJO (TISO)

- **Global weather and Climate in multi time scales**
  - TC/TS
  - Monsoon
  - ENSO
  - AO et al.
- **Regional weather and climate**
  - TC in IO and WP
  - Drought and flood
  - Asian climate
  - Predictability





(e.g., Yasunari 1979; Liebman et al. 1994; Kessler 2001； Lin et al, 2006)

MJO remains a great challenge in GCMs

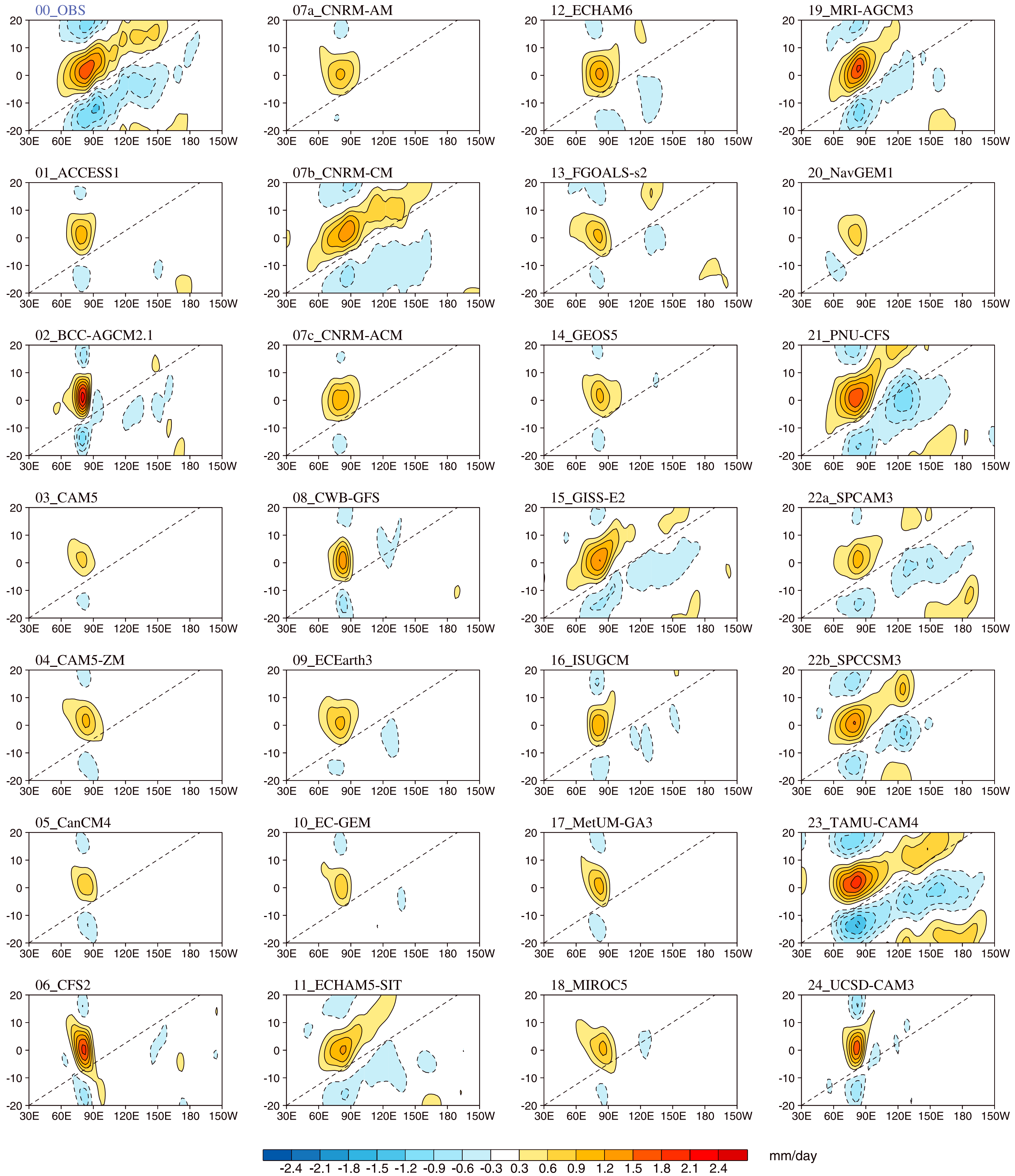


Figure 3. Longitude-time evolution of rainfall anomalies by lag regression of 20–100 day band-pass-filtered anomalous rainfall against itself averaged over the equatorial eastern Indian Ocean (75–85°E; 5°S–5°N). Rainfall anomalies are averaged over 10°S–10°N. Dashed lines in each panel denote the 5 m s^{-1} eastward propagation phase speed.

Indian Ocean MJO

Jiang, X., et al. (2015), Vertical structure and physical processes of the Madden- Julian oscillation: Exploring key model physics in climate simulations, J. Geophys. Res. Atmos., 120, 4718–4748, doi:10.1002/ 2014JD022375.

MJO remains a great challenge in GCMs

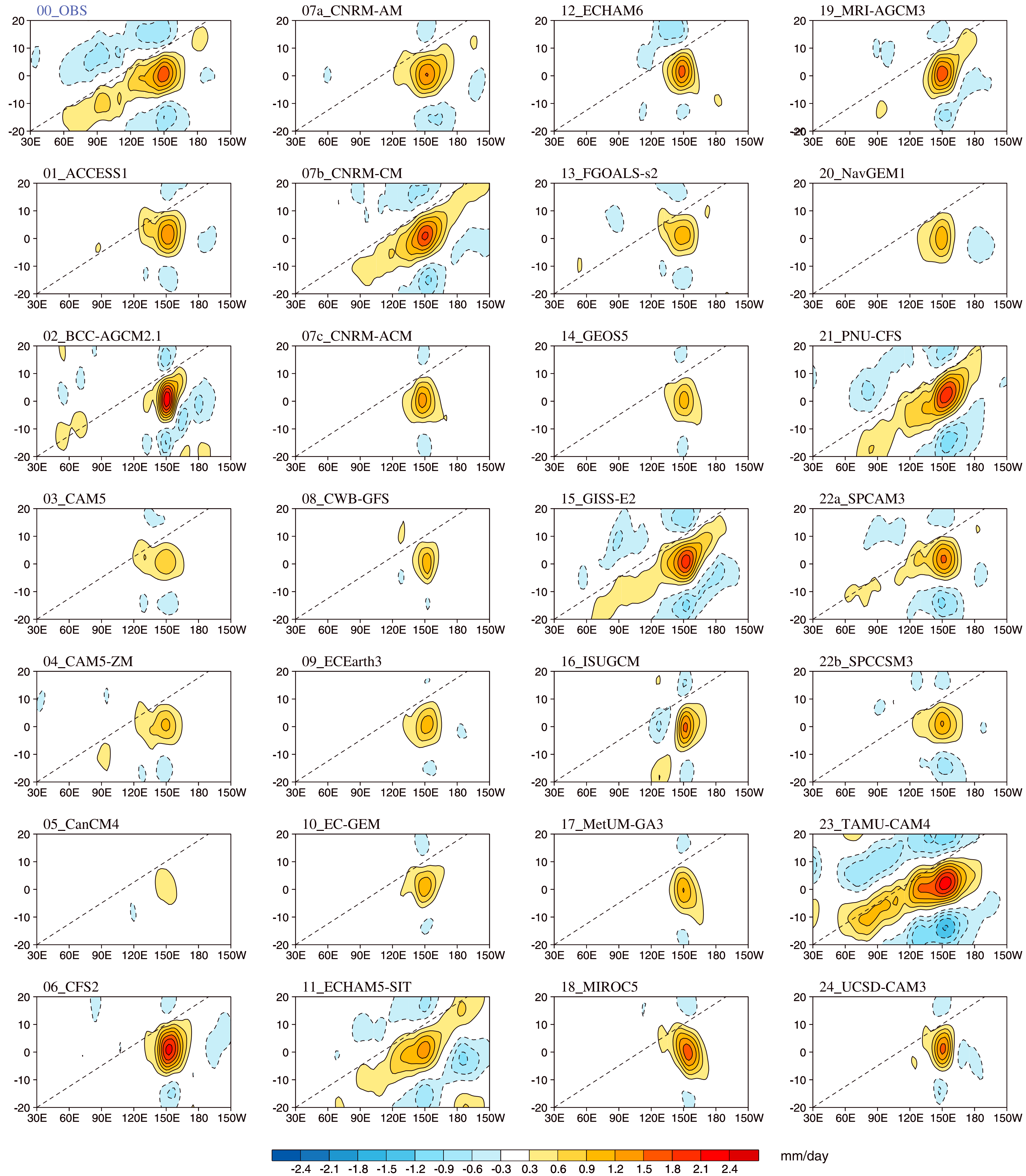
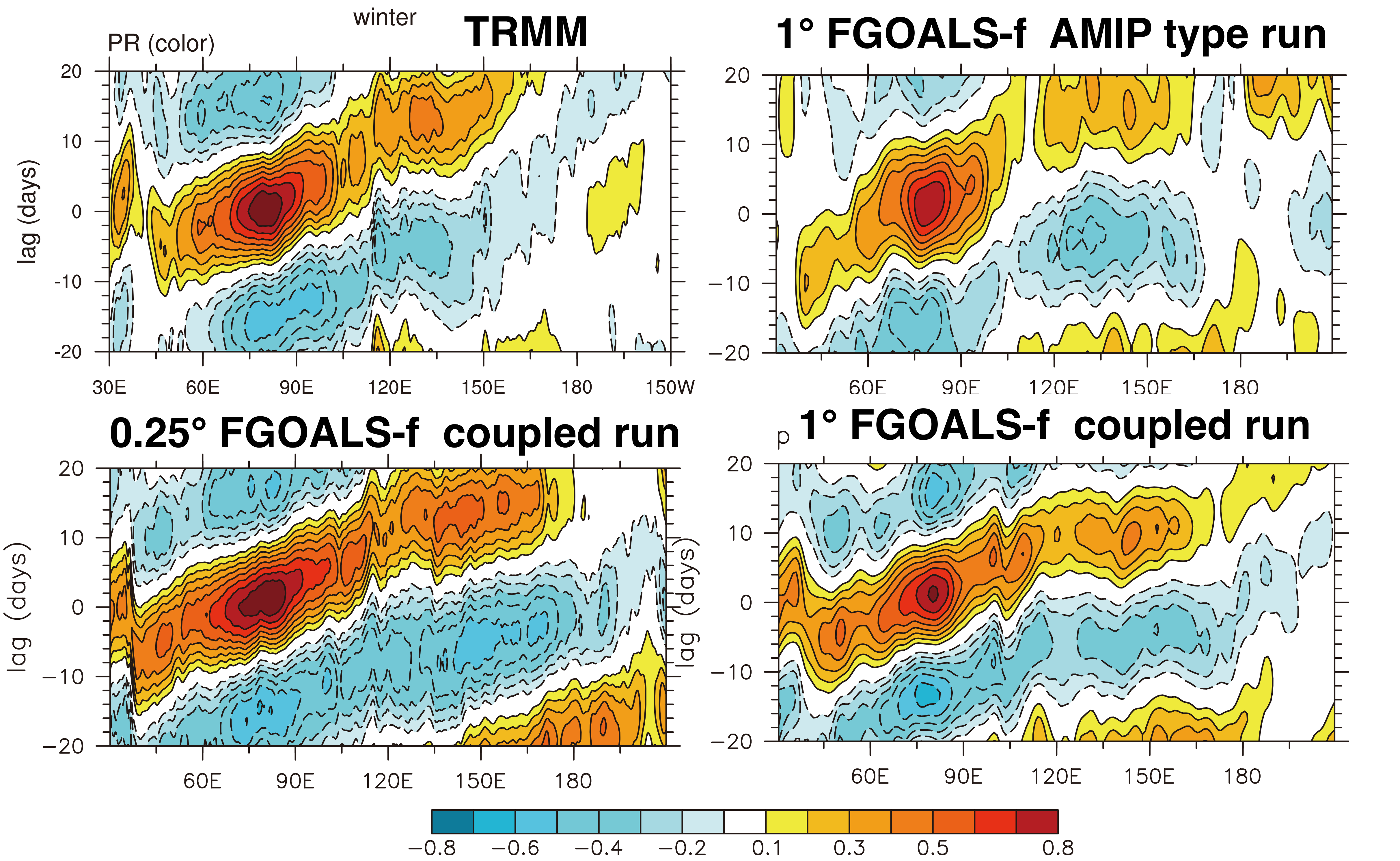


Figure 4. Same as in Figure 3 but by lag regression against rainfall over a western Pacific box (130–150°E; 5°S–5°N).

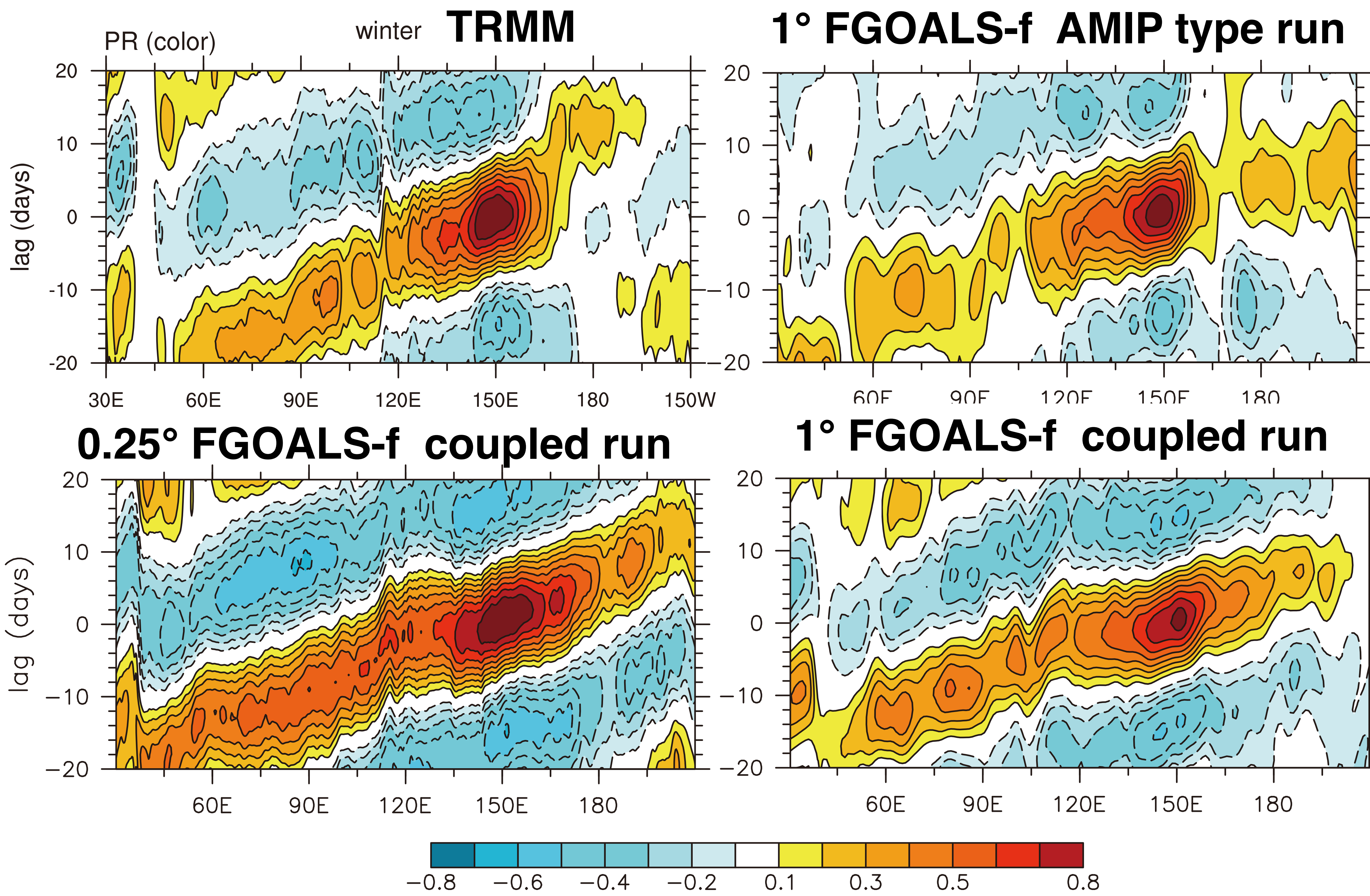
Western Pacific MJO

Jiang, X., et al. (2015), Vertical structure and physical processes of the Madden- Julian oscillation: Exploring key model physics in climate simulations, J. Geophys. Res. Atmos., 120, 4718–4748, doi:10.1002/ 2014JD022375.

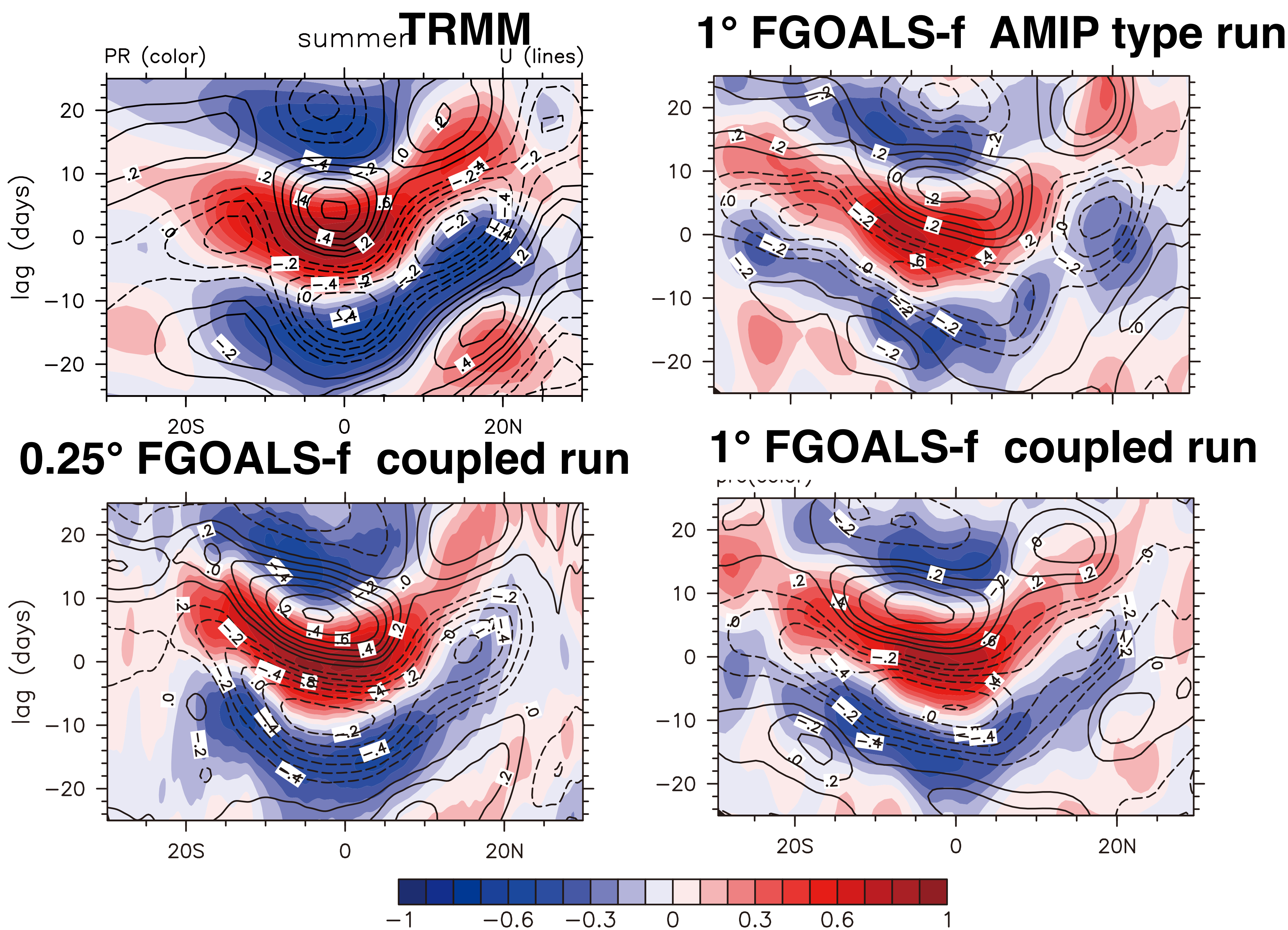
MJO over the equatorial eastern Indian Ocean in boreal winter



MJO over the equatorial western Pacific Ocean in boreal winter

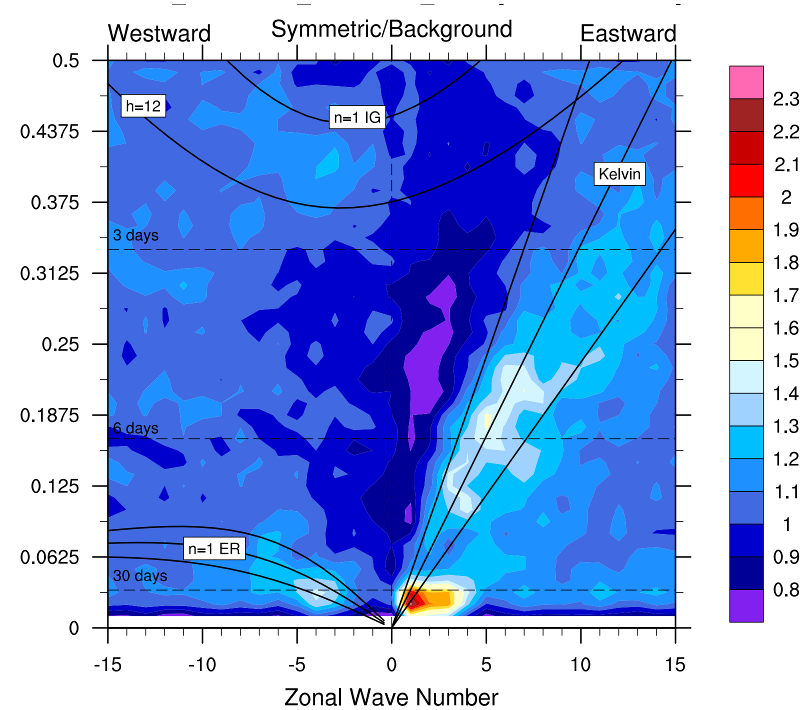


ISO over the Indian Ocean in boreal summer

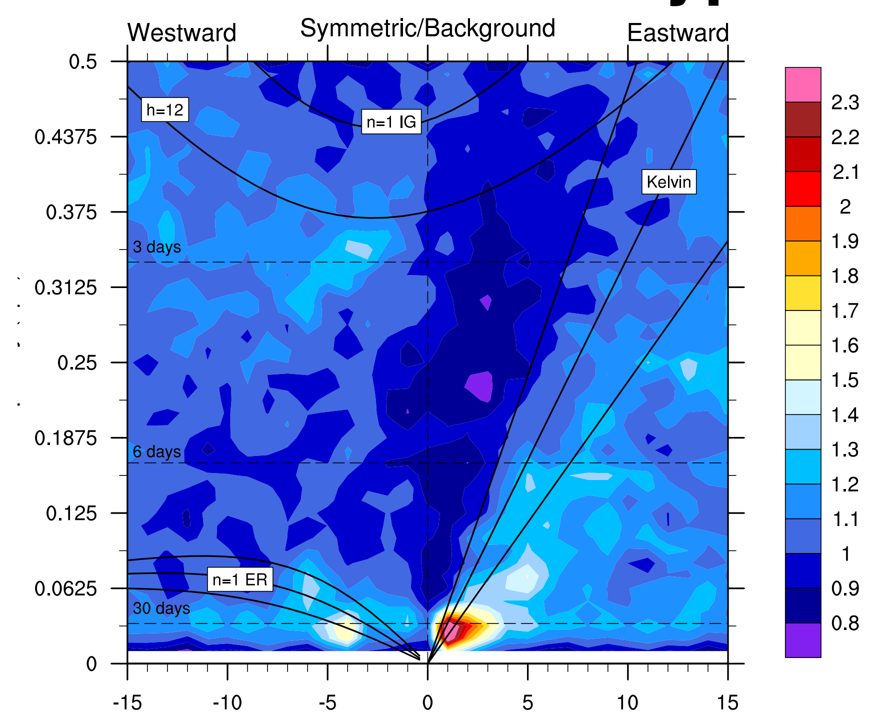


Convectively Coupled Equatorial Waves(CCEWs)

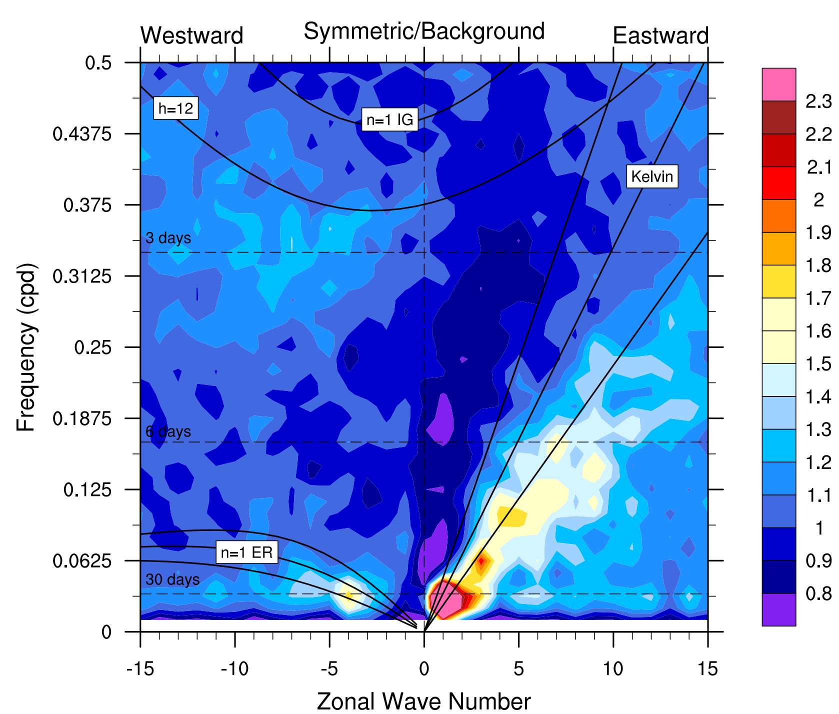
TRMM



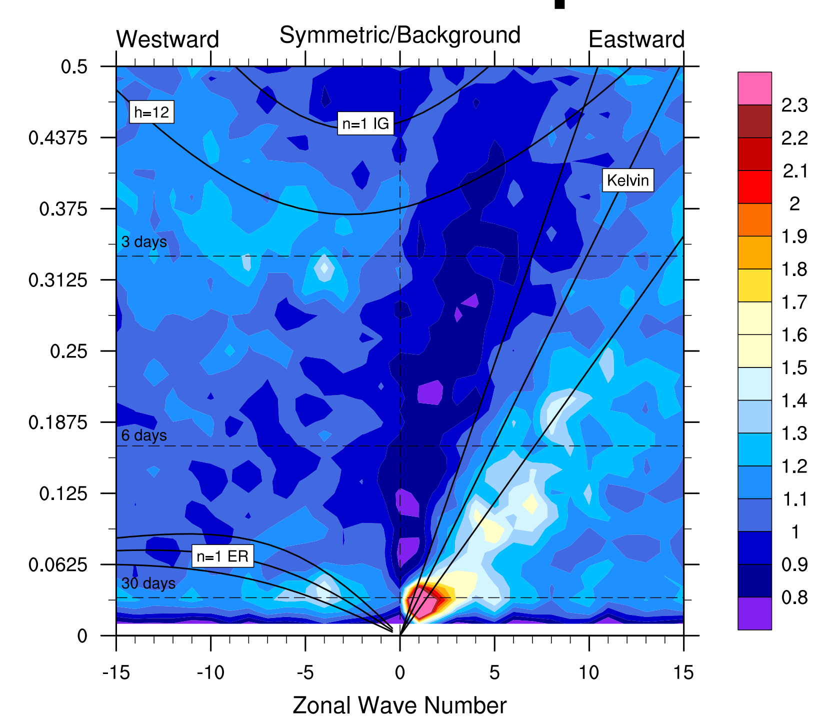
1° FGOALS-f AMIP type run



0.25° FGOALS-f coupled run



1° FGOALS-f coupled run



Convectively Coupled Equatorial Waves(CCEWs)

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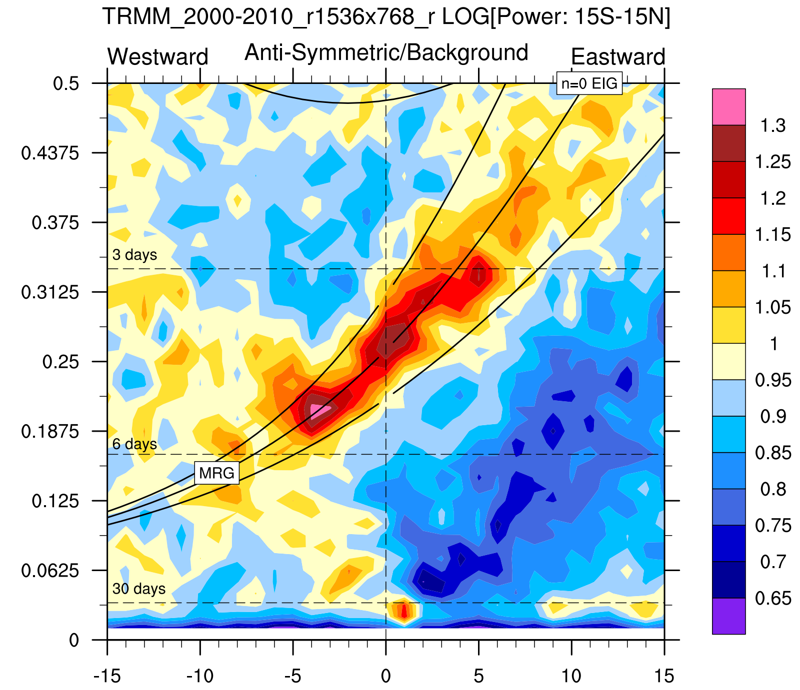
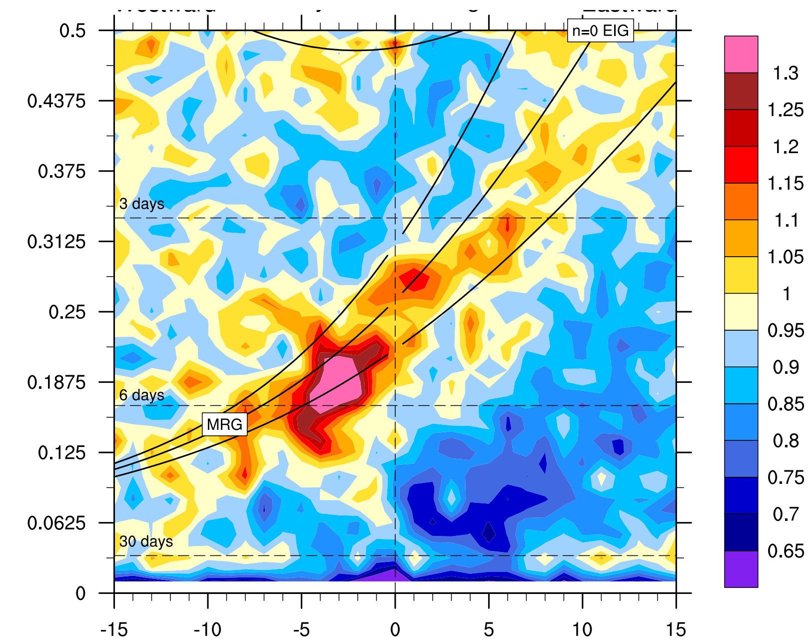
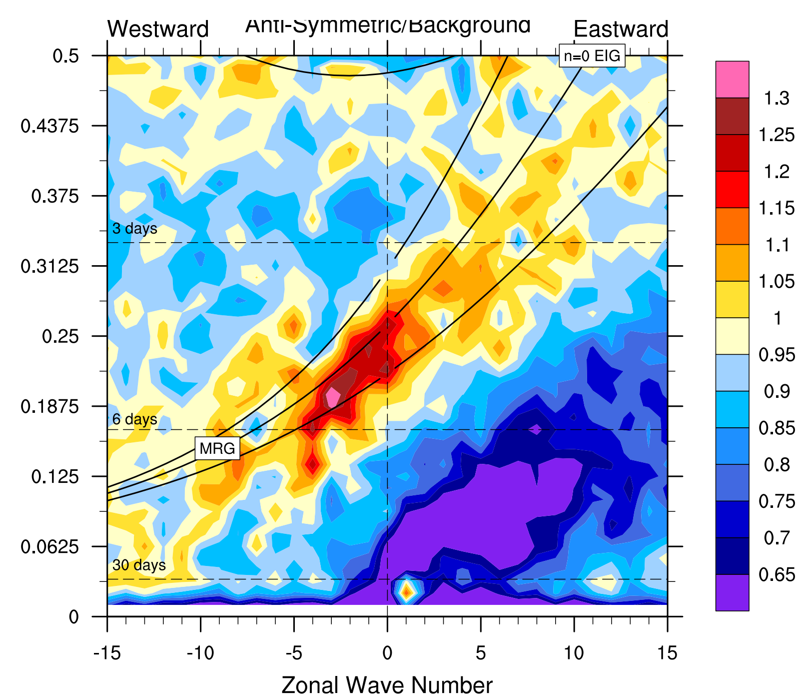


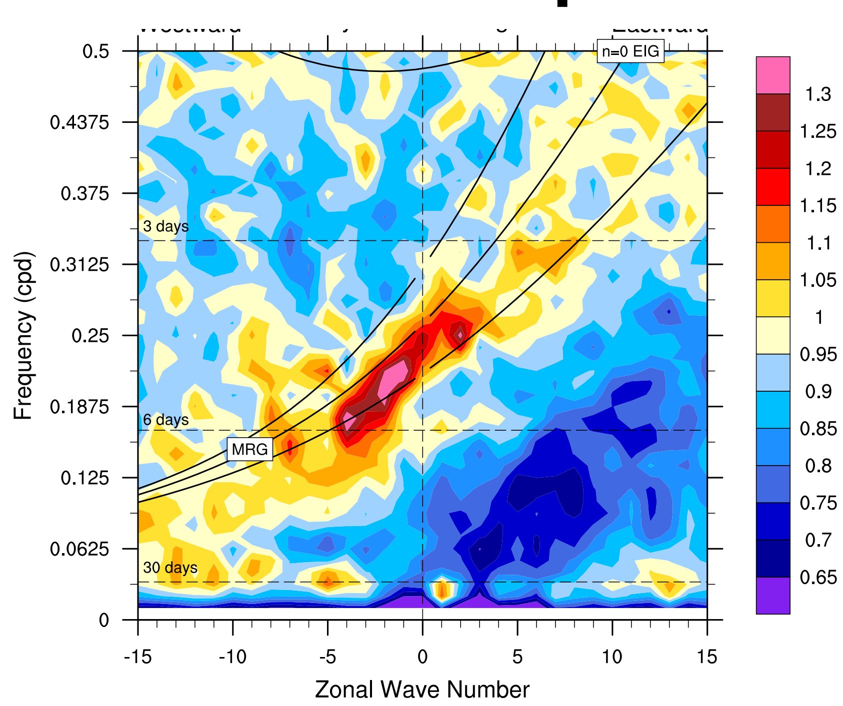
1° FGOALS-f AMIP type run



0.25° FGOALS-f coupled run



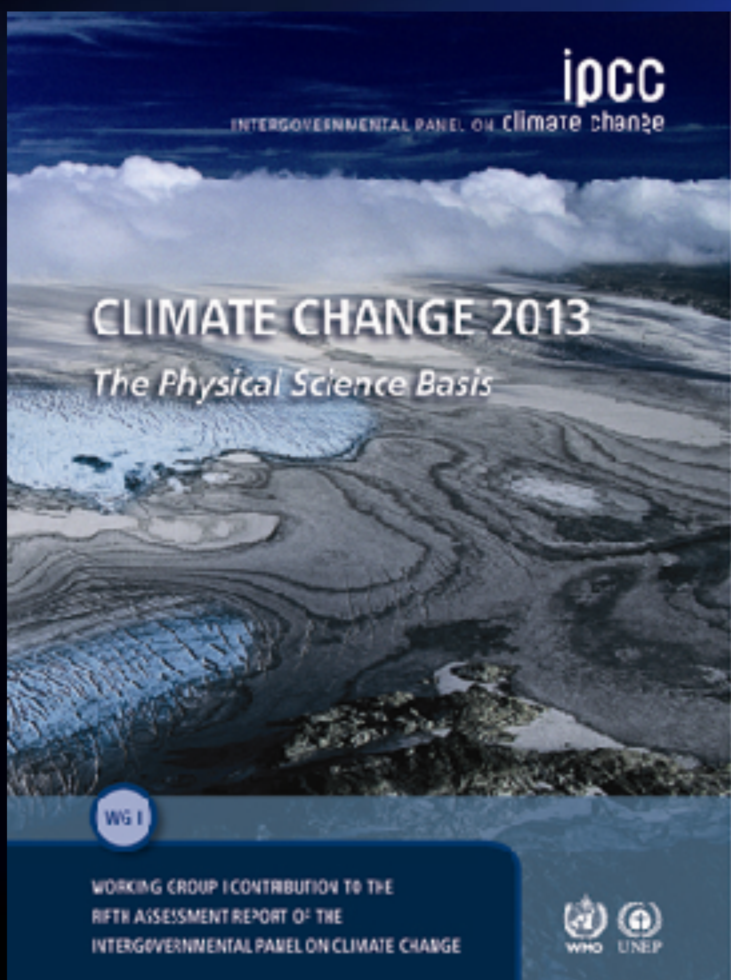
1° FGOALS-f coupled run

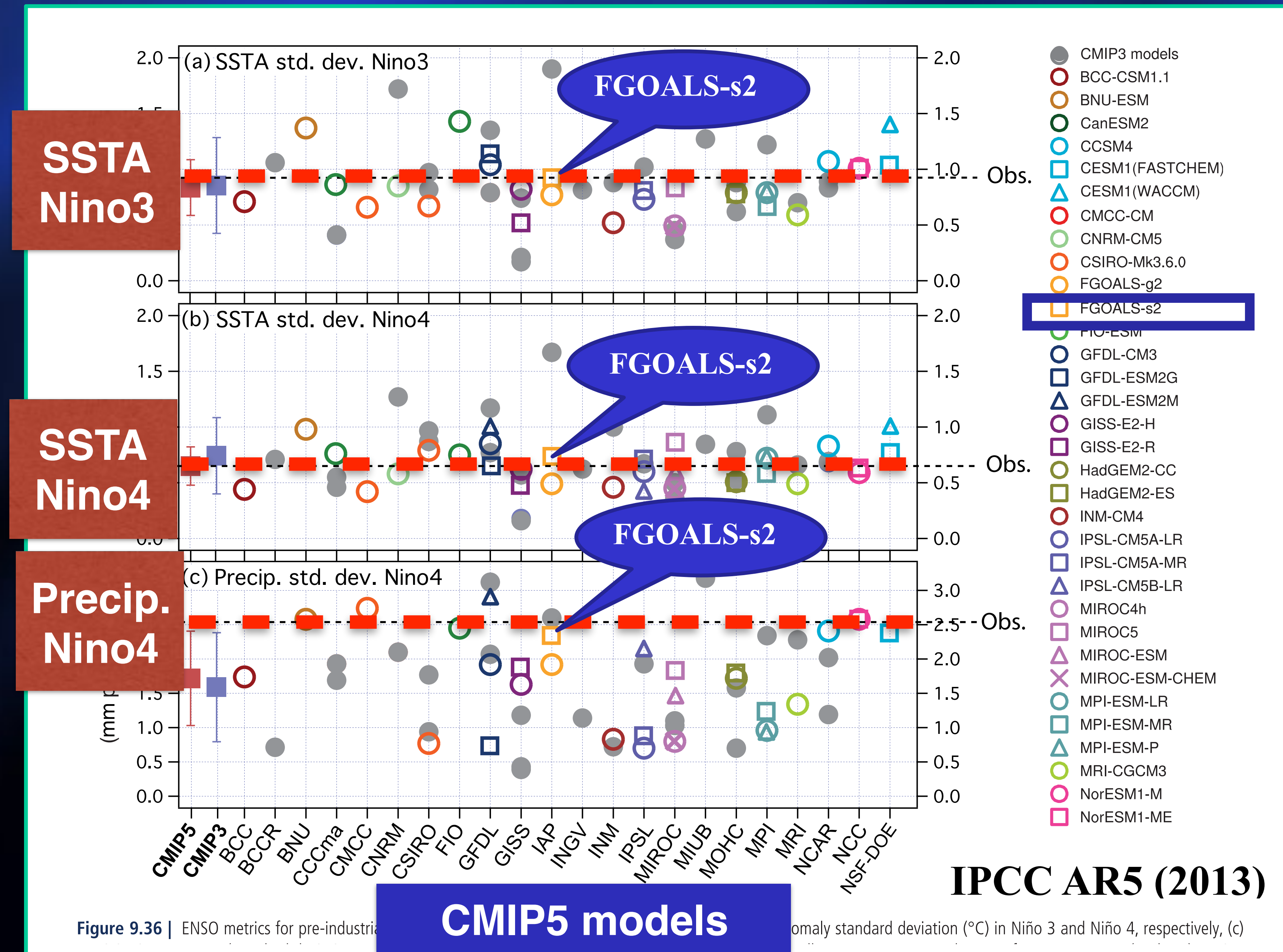


Tropical Precipitation Variability in FGOALS-f

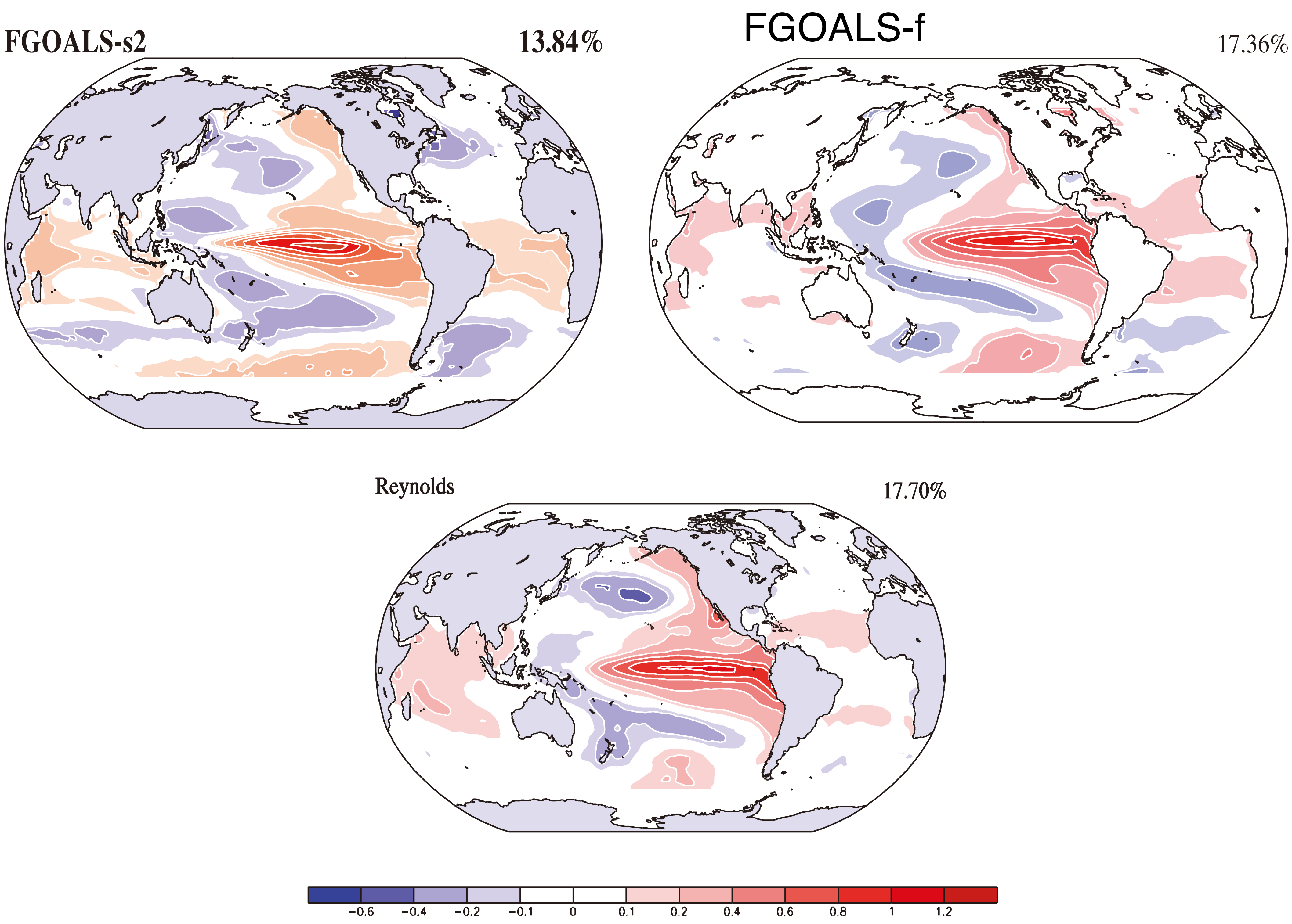
- ITCZ
- MJO/ISO
- ENSO
- Precipitation frequency & intensity
- Tropical cyclone

ENSO in FGOALS-s2 (CMIP5)





ENSO teleconnection pattern



Tropical Precipitation Variability in FGOALS-f

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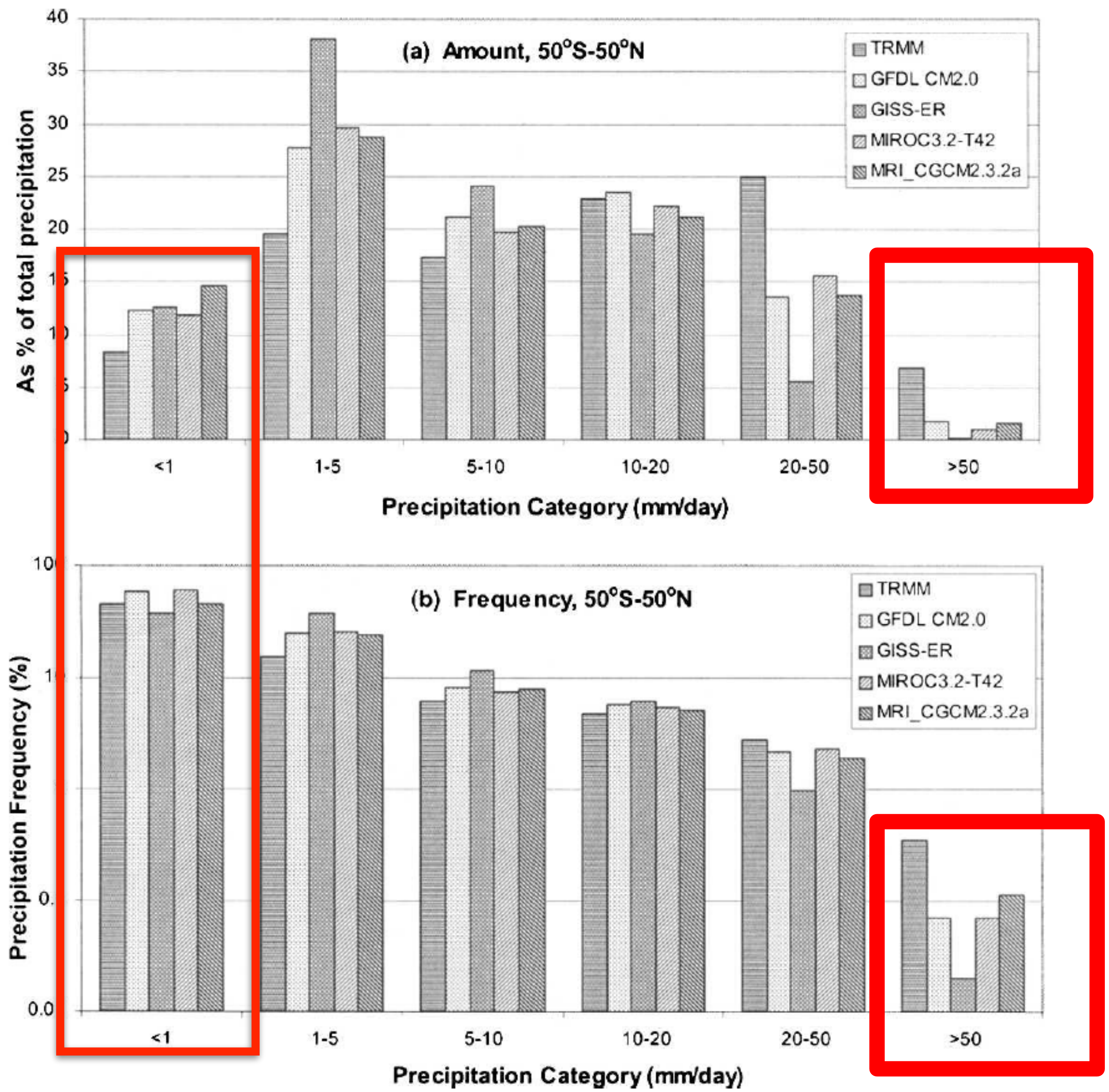
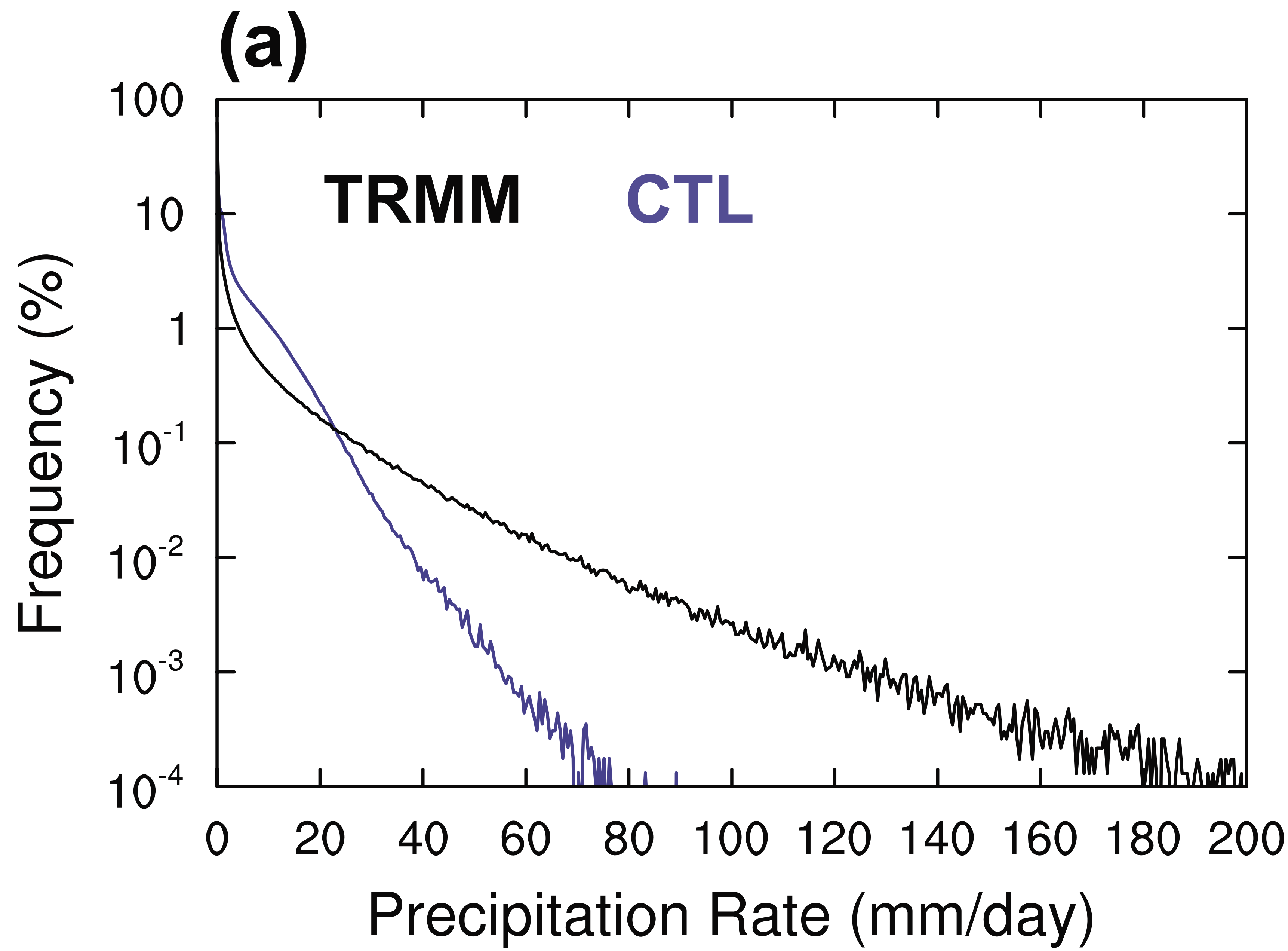
Precipitation frequency & intensity

CMIP3



Dai AG 2006 JC

NCAR CAM5. 3

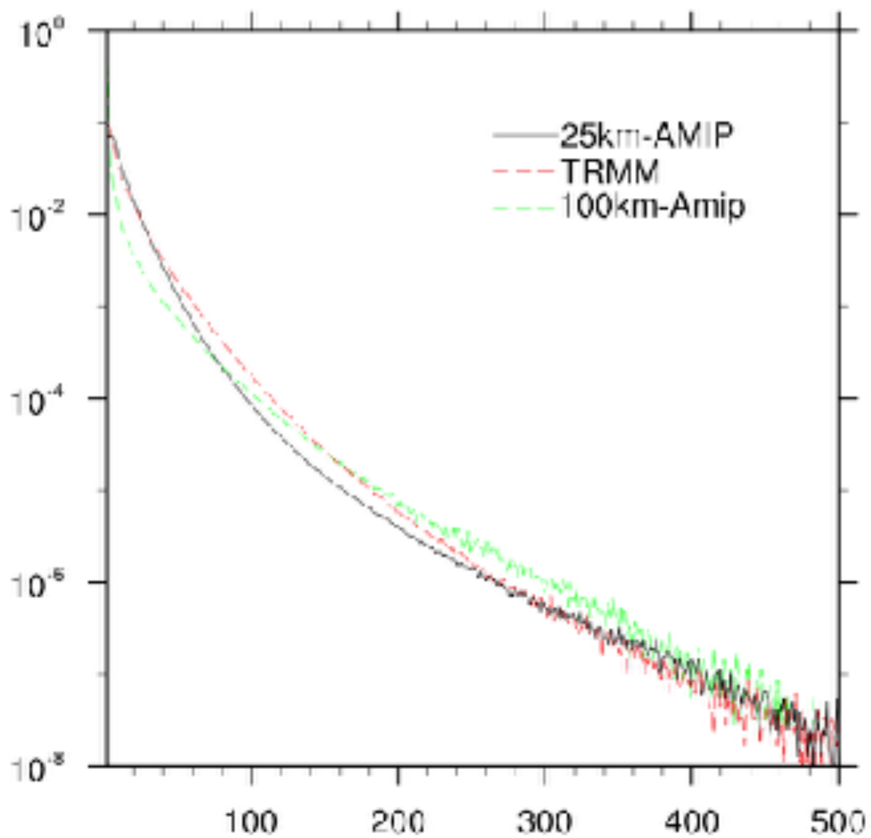


Revised Fig 3 Wang et al. (2016, GRL)

Precipitation frequency & intensity

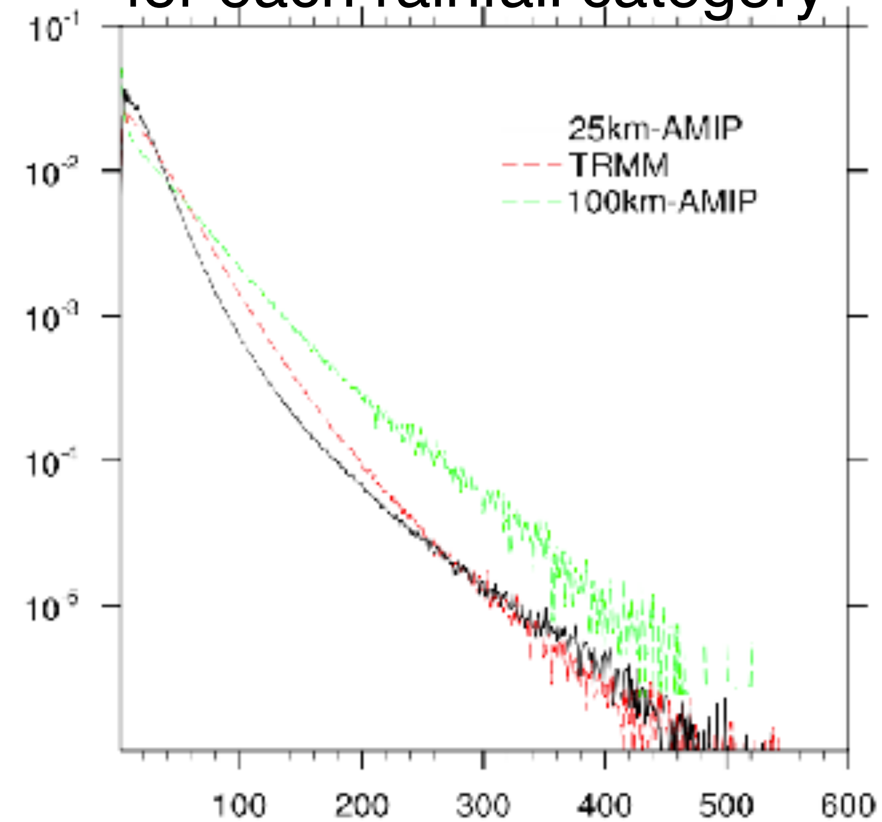
Tropic（20S-20N)

Frequency&intensity



降水强度天数比例	0-1 mm	1-10 mm	11-20mm	20-50mm	50-100 mm	100mm 以上
TRMM	9.4	53.95	18.06	14.86	3.27	0.47
25km	7.16	54.68	21.87	14.13	1.92	0.24
100km	47.79	40.22	5.32	4.74	1.54	0.39

Accumulated rainfall
for each rainfall category



降水强度贡献比例	0-1 mm	1-10 mm	11-20mm	20-50mm	50-100 mm	100mm 以上
TRMM	0.75	20.02	20.72	36.34	17.24	4.93
25km	0.6	25.26	25.94	35.02	10.4	2.79
100km	4.58	22.85	14.36	28.05	19.73	10.43

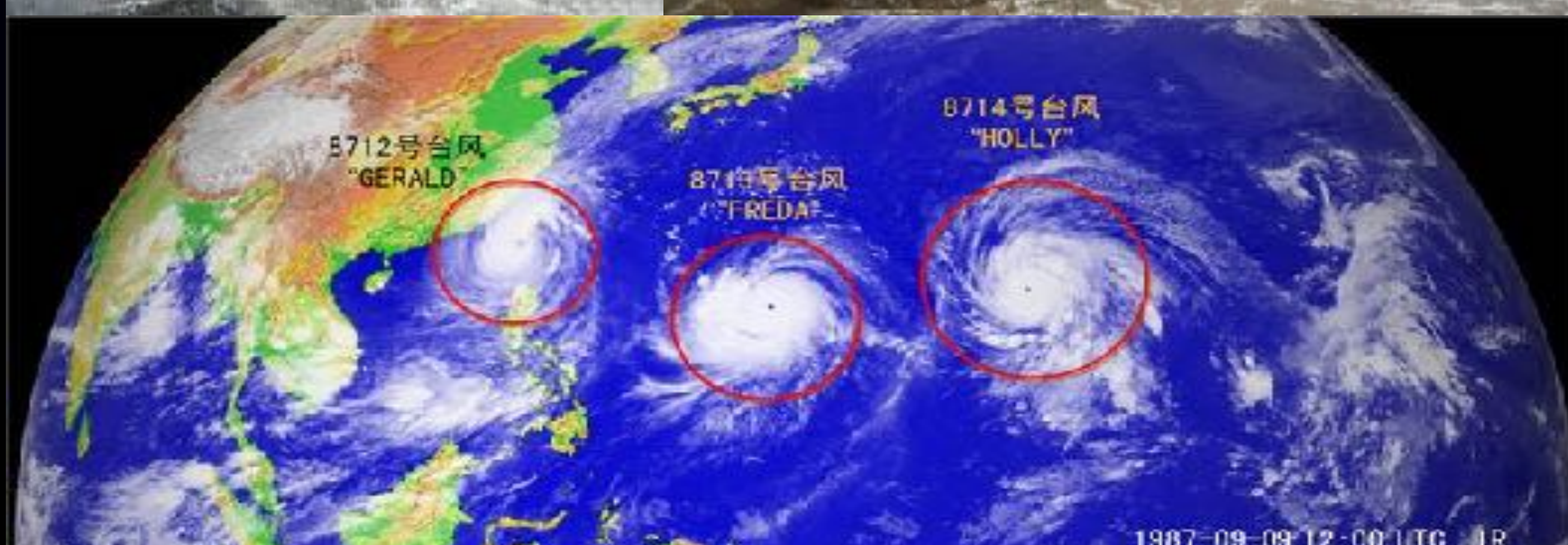
Units: mm/day

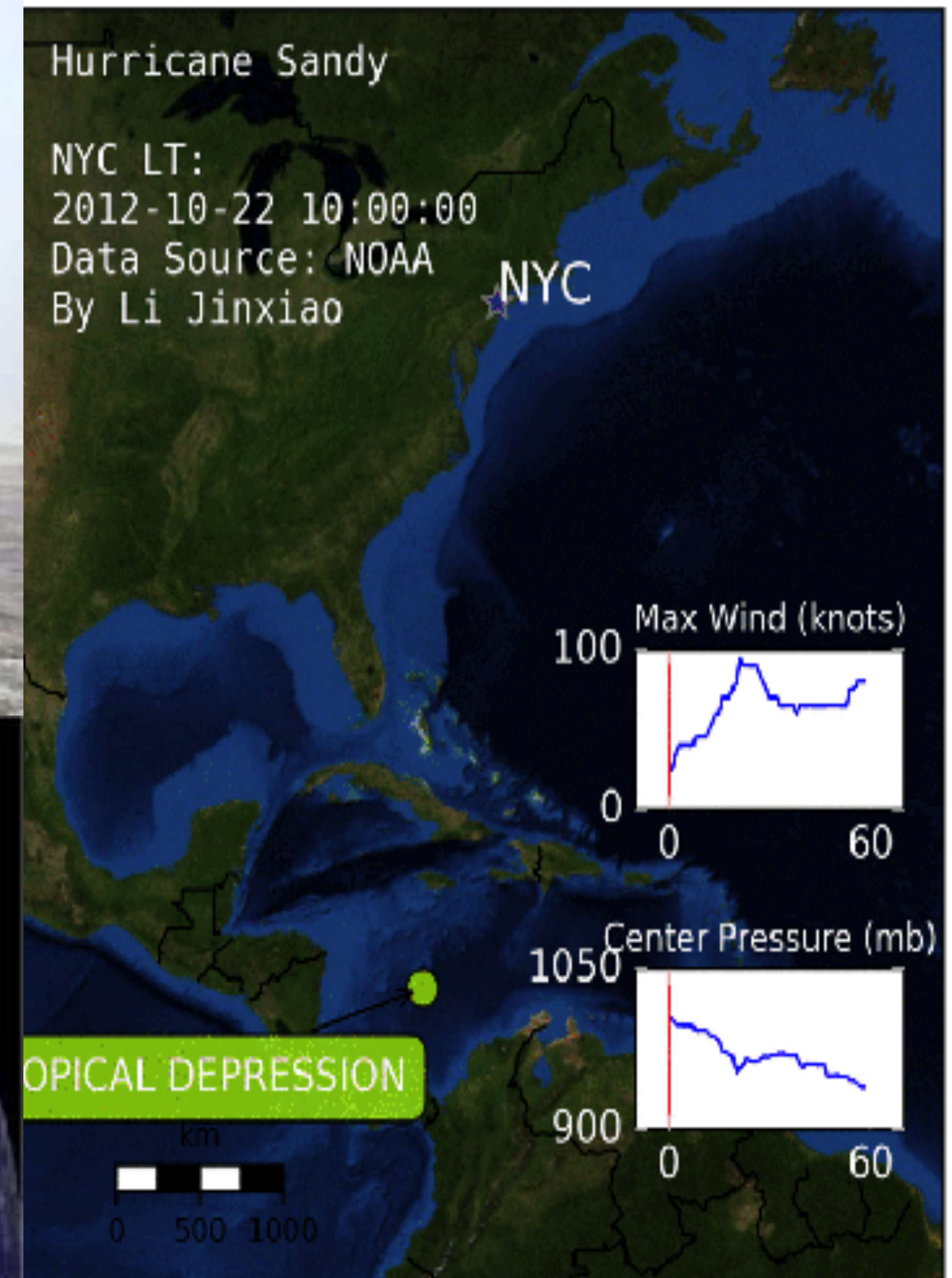
Tropical Precipitation Variability in FGOALS-f

- ITCZ
- MJO/ISO
- ENSO
- Precipitation frequency & intensity
- Tropical cyclone

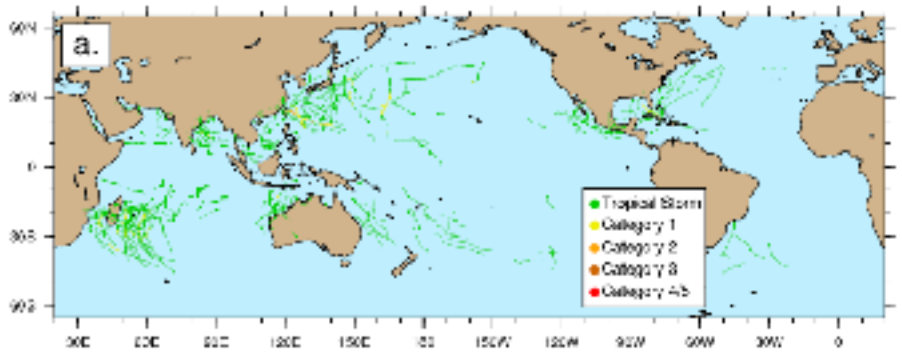
Tropical cyclone

"The present annual global damage from tropical cyclones is US$26 billion (which is equal to 0.04% of the gross world product (GWP). In 2100, global baseline damage more than doubles to US$56 billion per year (0.01% of GWP)".— Medelsohn, Emanuel et al, nature climate change, 2012

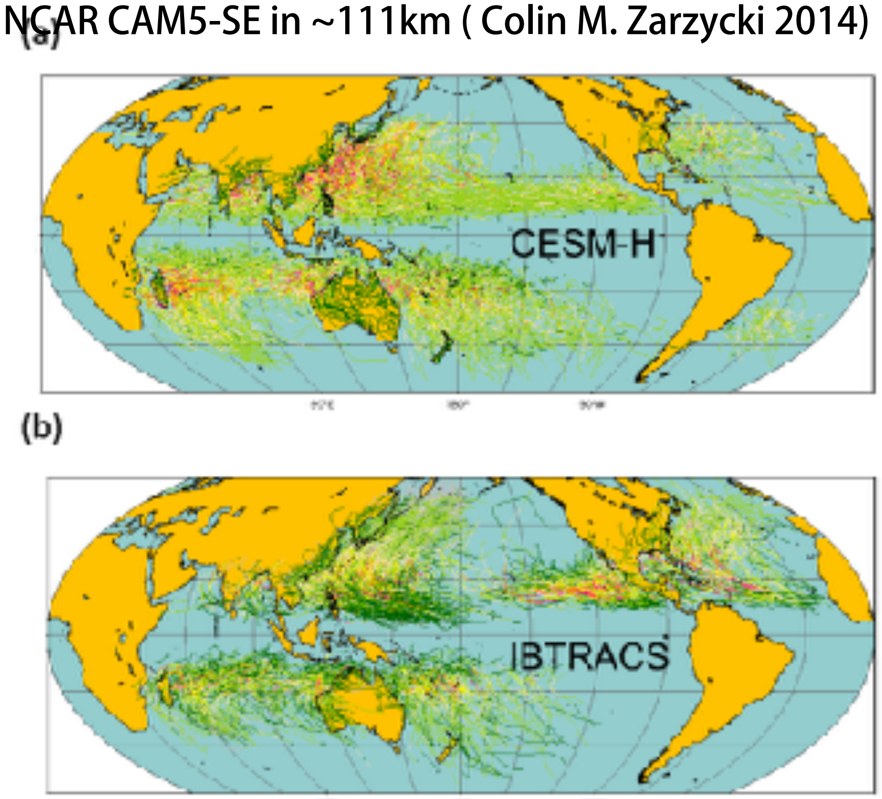




Tropical cyclone

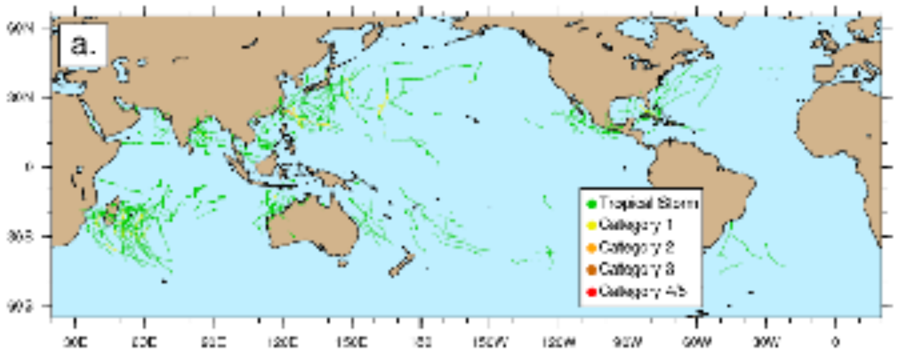


NCAR CAM5-SE in ~111km (Colin M. Zarzycki 2014)

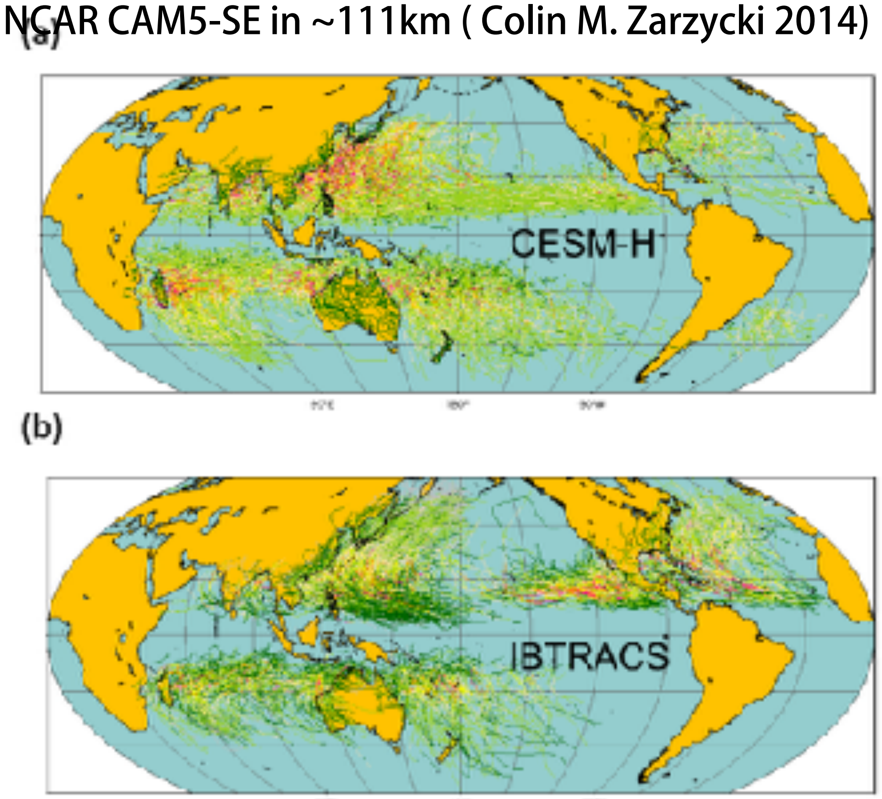


NCAR CESM in ~25km (C180) (R. Justin Small et al, 2014)

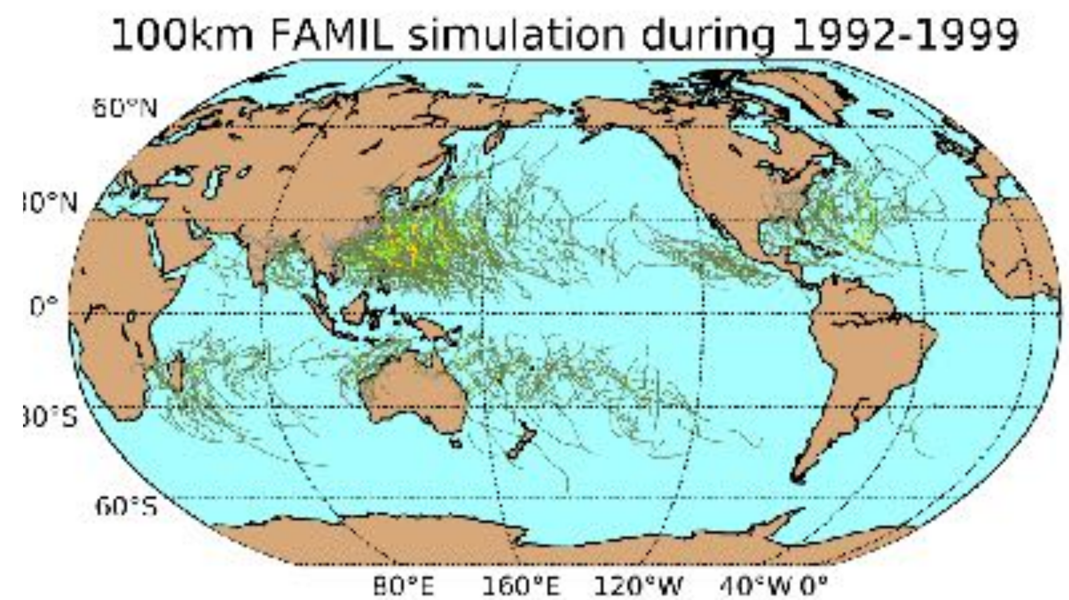
Tropical cyclone

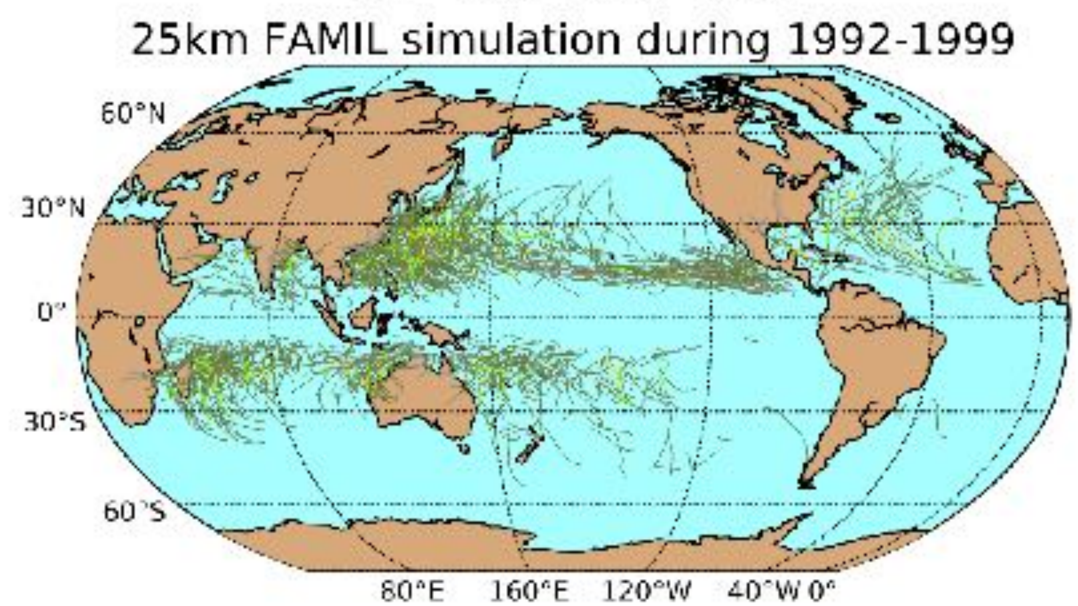


NCAR CAM5-SE in ~111km (Colin M. Zarzycki 2014)



NCAR CESM in ~25km (C180) (R. Justin Small et al, 2014)





Tropical cyclone

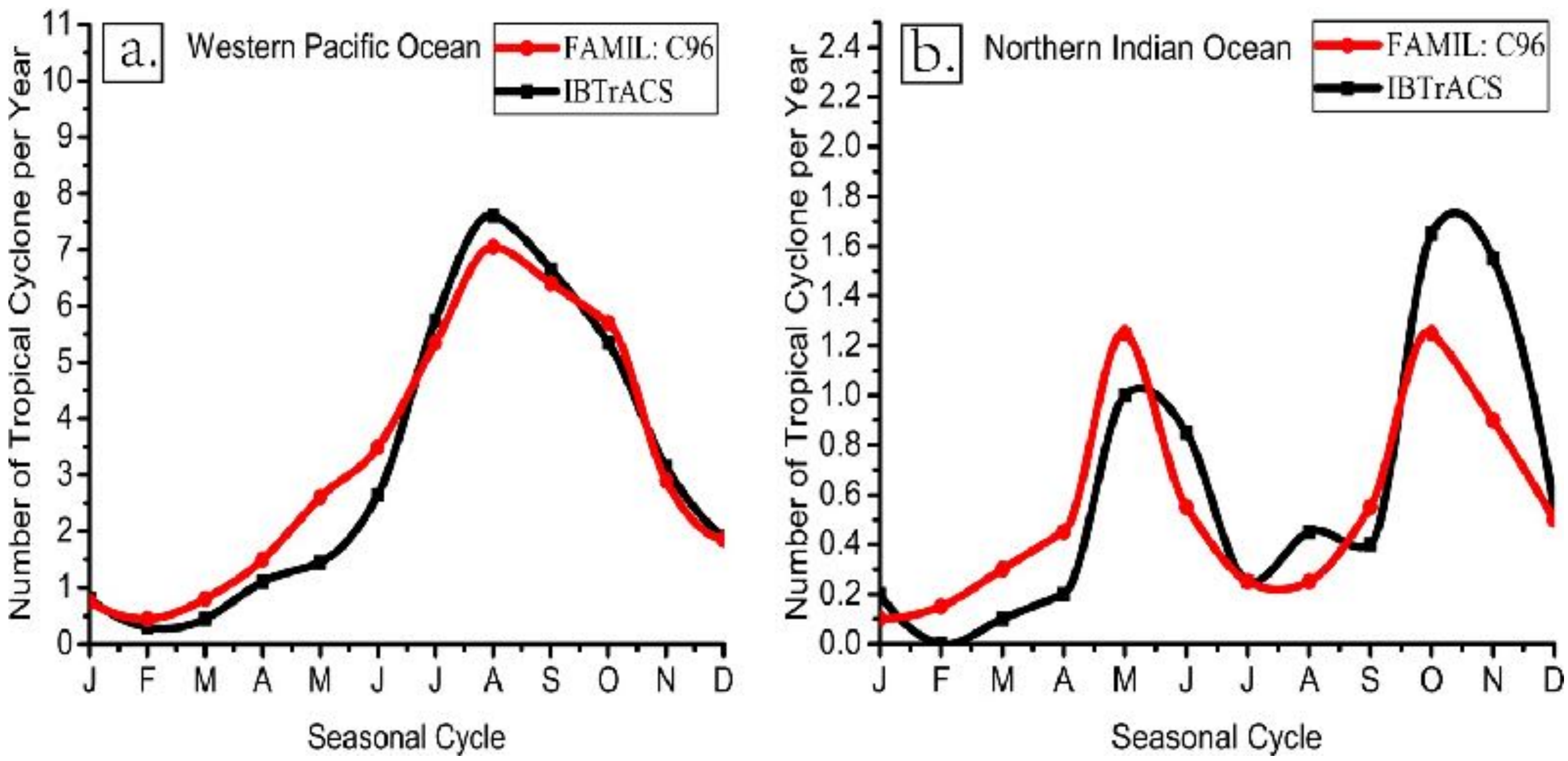


Fig.8. Seasonal cycle of tropical cyclones' numbers in Western Pacific Ocean (Fig 8a), and Northern Indian Ocean (Figure 8b). Time periods of FAMIL simulation and IBTrACS are both from 1983 to 2002.

Tropical Cyclone Roanu - May 2016

CNN **Sri Lanka floods**

Southwestern China Suffering from Drought

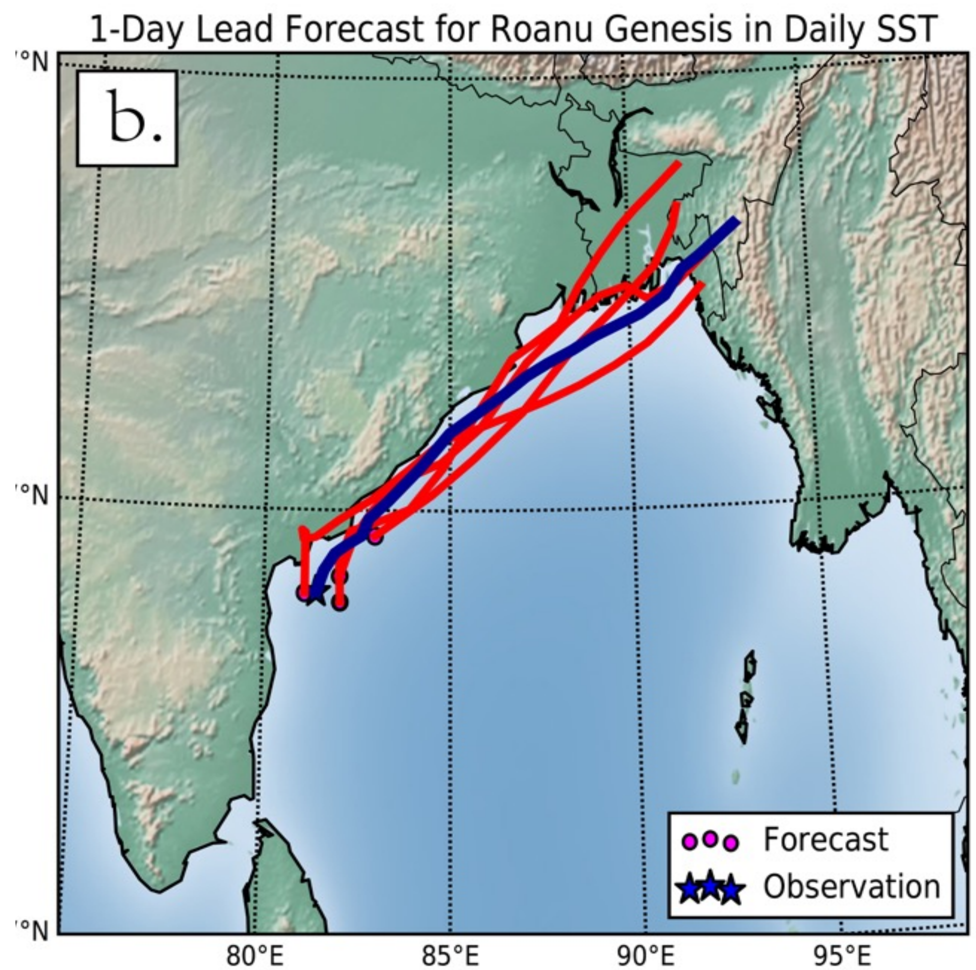
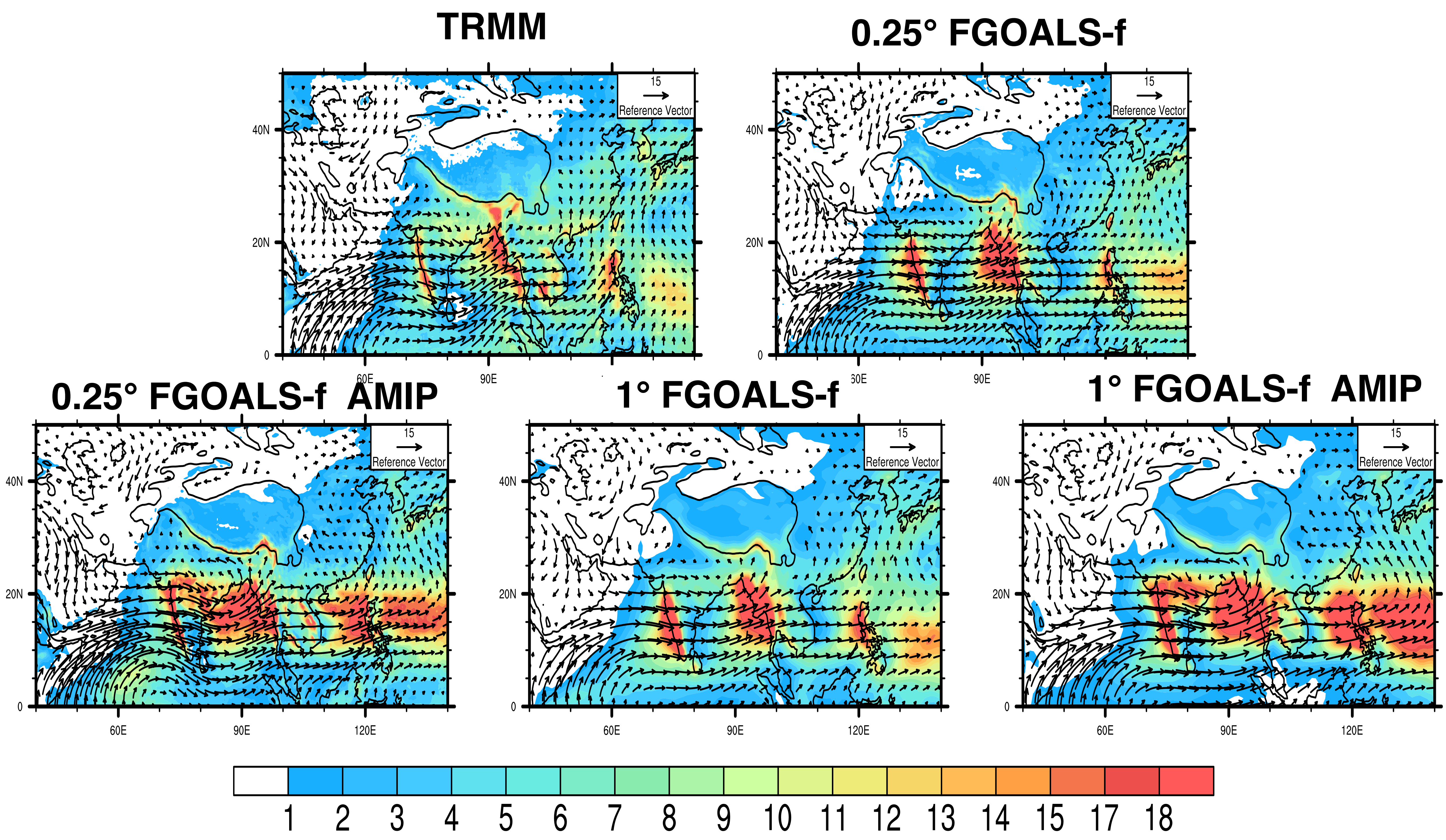


Fig.10. 1-day lead forecast for tropical cyclone named Roanu genesis and tracks in monthly sea surface temperature (left of panel) and daily sea surface temperature (right of panel). Blue star and line means observation from RSMC; red dots and lines means 4 assembles which use nudging method to drive model until the two days earlier than Roanu become to tropical storm, then do hindcast at every 6 hours.

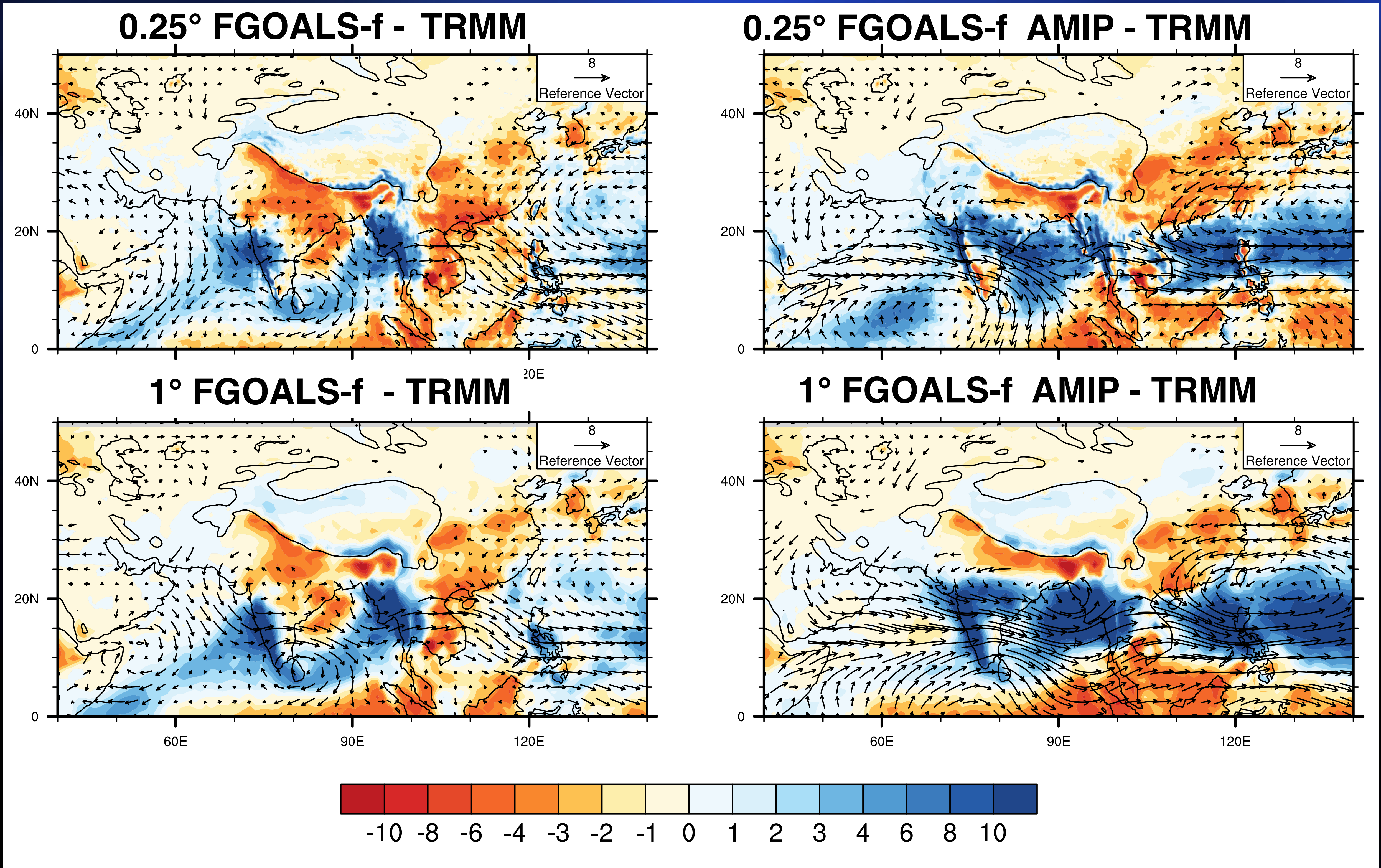
Outlines

- Introduction
- FGOALS-f High-resolution Coupled Climate Model
- Simulated Asian Summer Monsoon
- S2S prediction system with FGOALS-f
- Summary

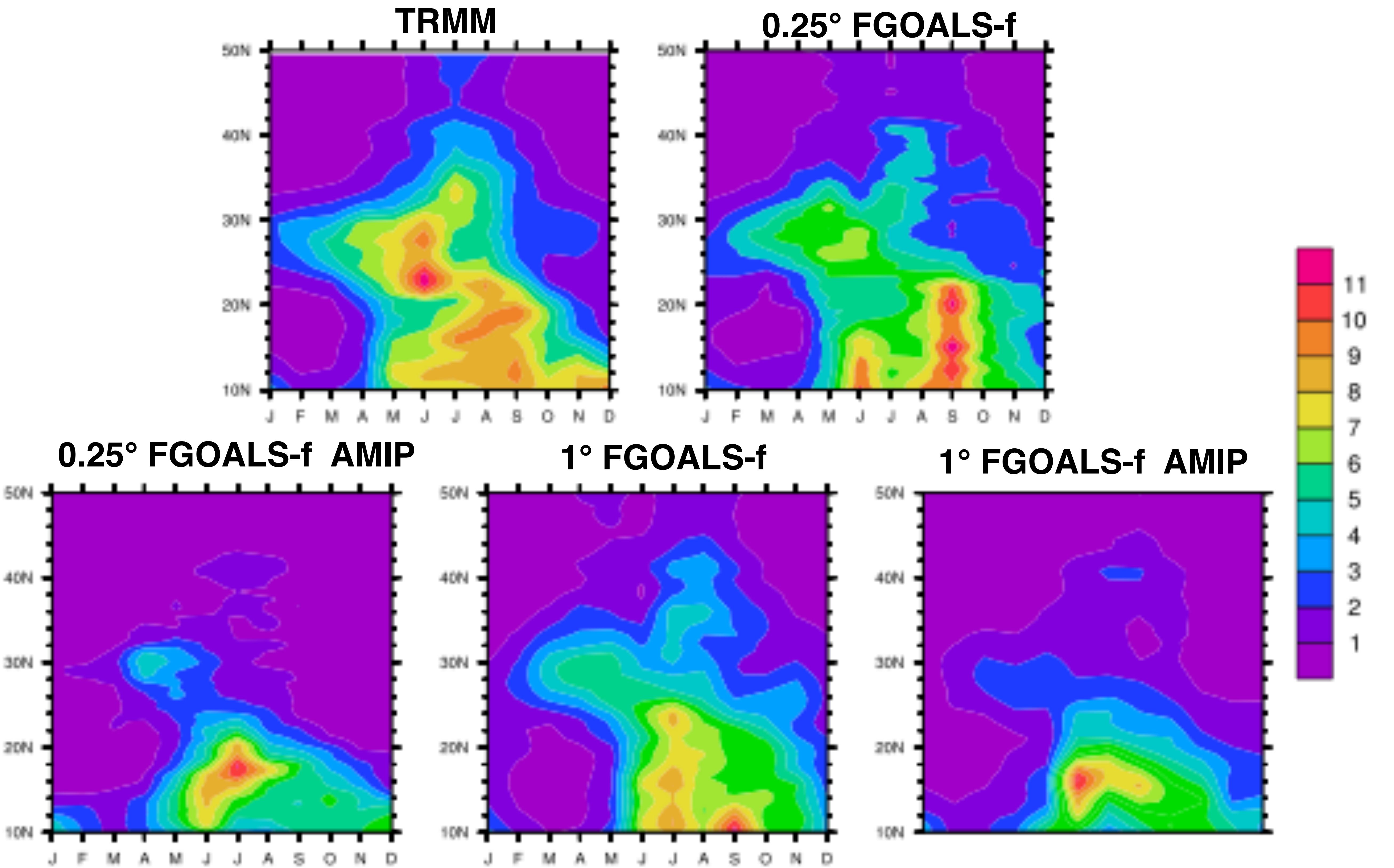
Asian Summer Monsoon (ASM)



Asian Summer Monsoon (ASM)



Annual cycle of EA precipitation

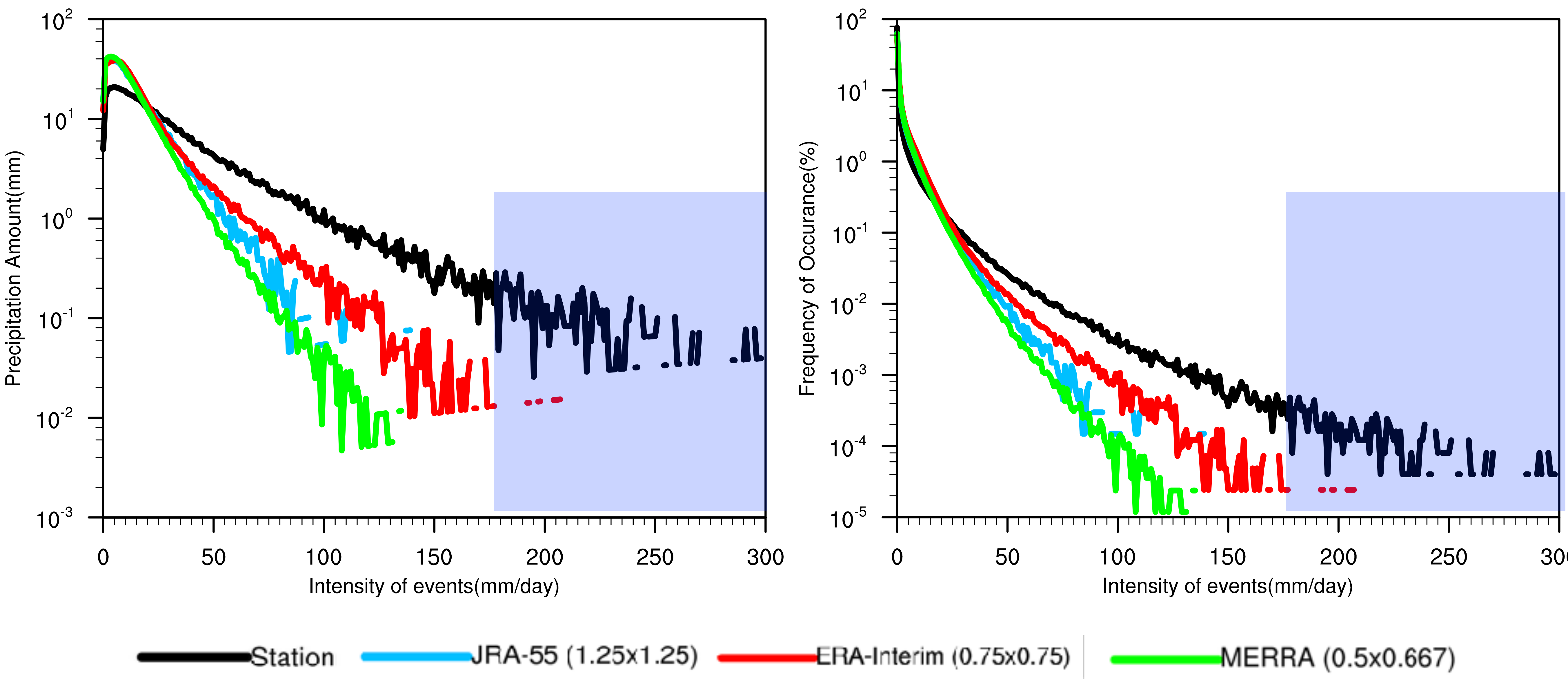


Extreme precipitation over china

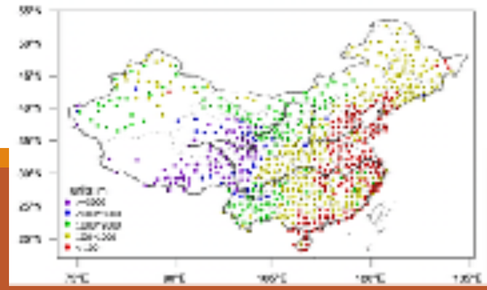
Extreme precipitation over china: reanalysis?

Accumulated rainfall (mm)

Frequency&intensity(%)



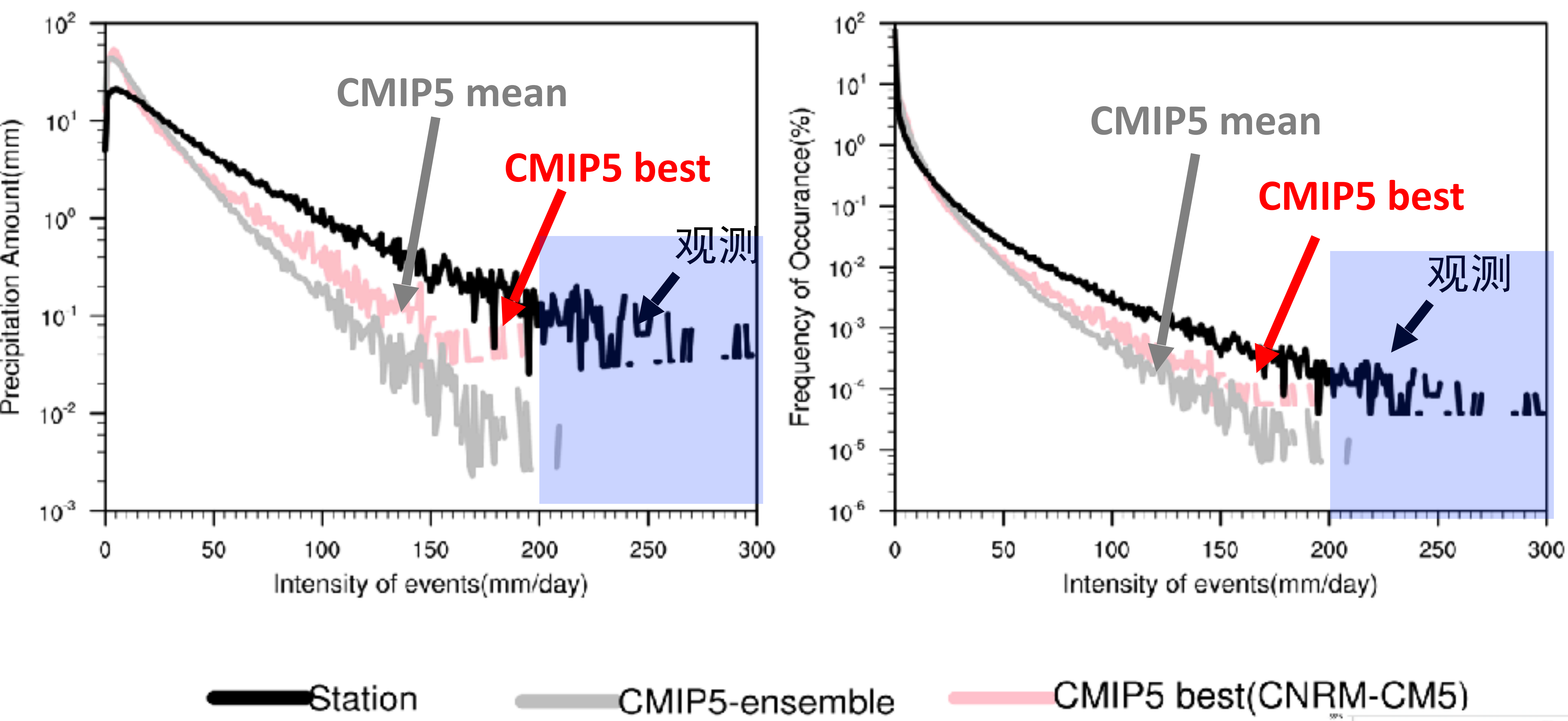
ERA最优，但是误差依然大

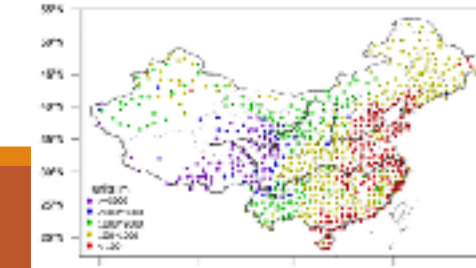


Extreme precipitation over china: CMIP5?

Accumulated rainfall (mm)

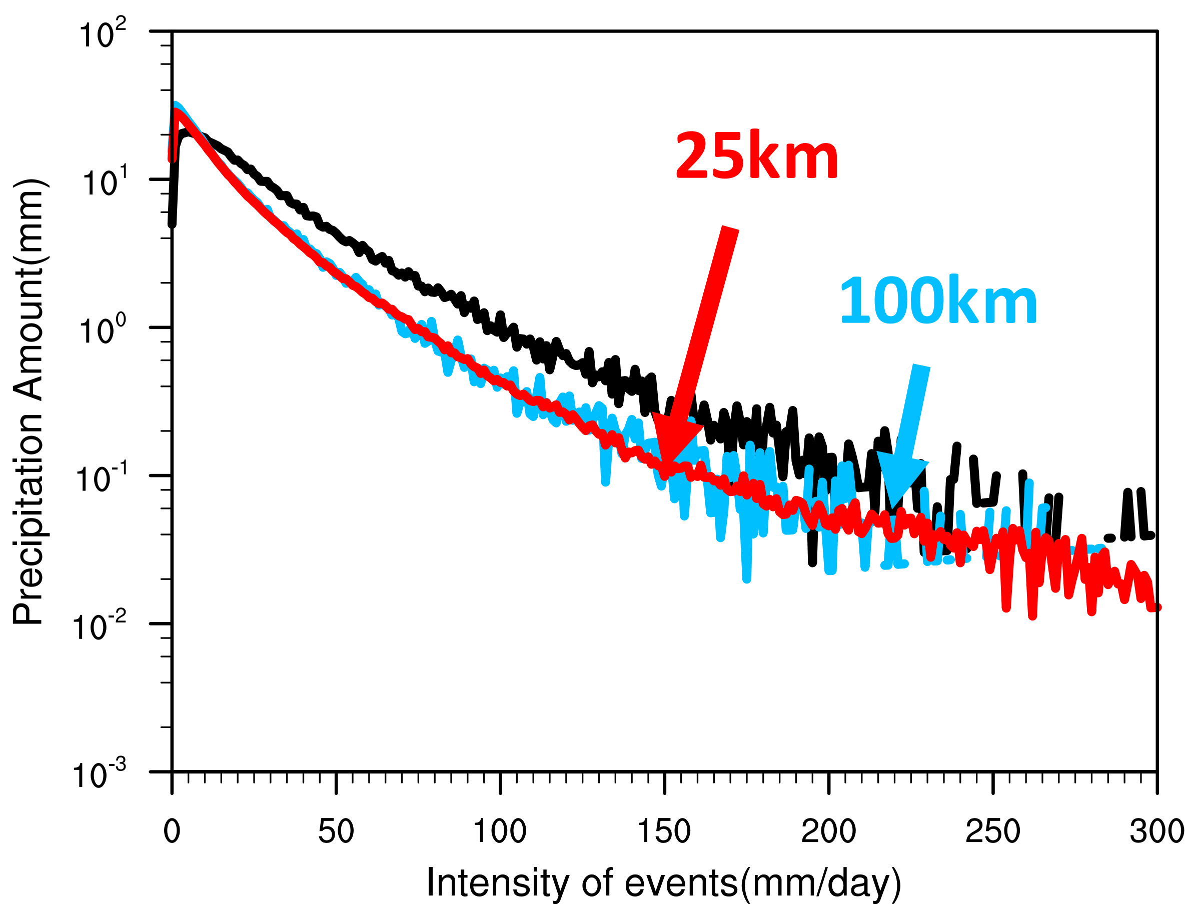
Frequency&intensity(%)



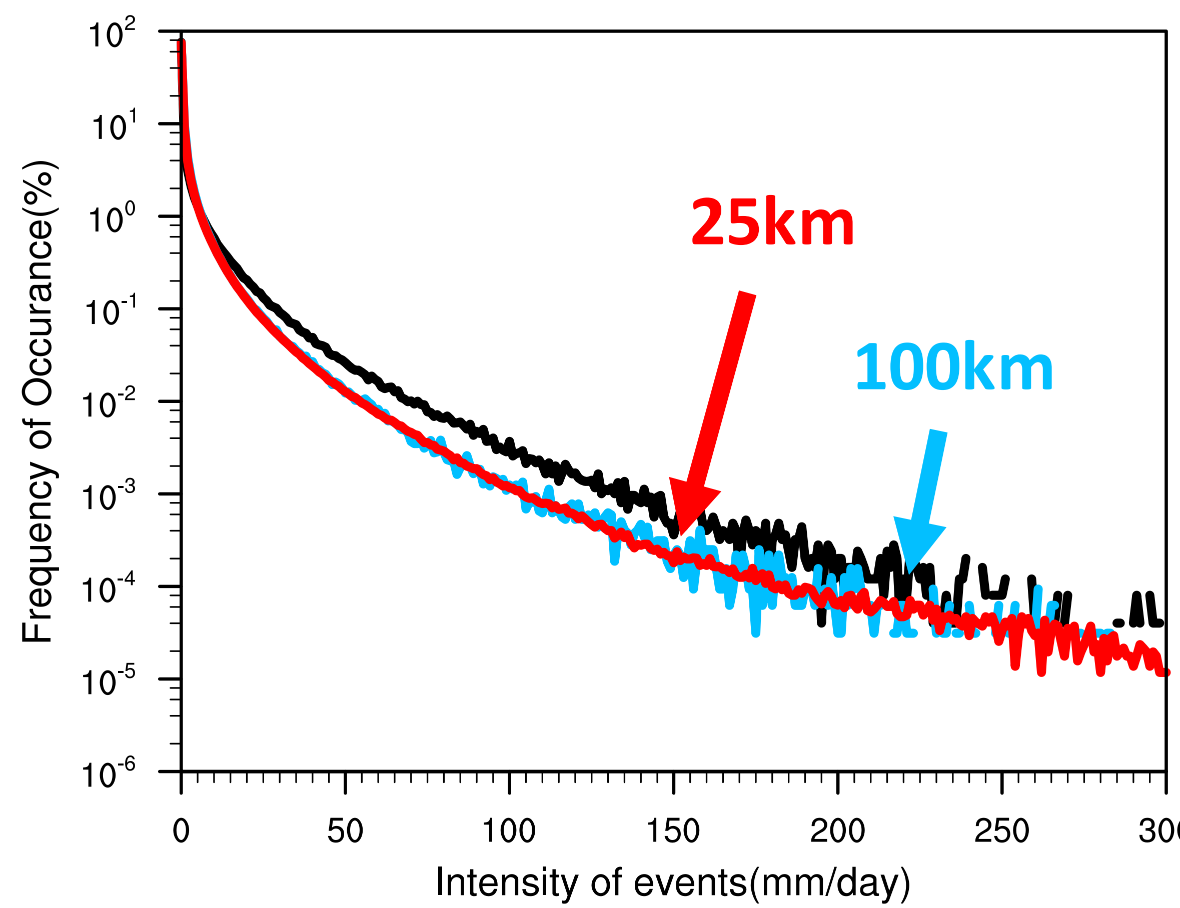


Extreme precipitation over china:FGOALS-f 100km vs. 25km

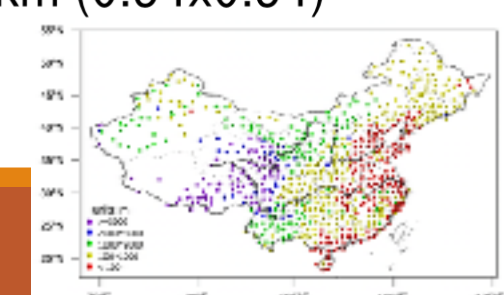
Accumulated rainfall (mm)



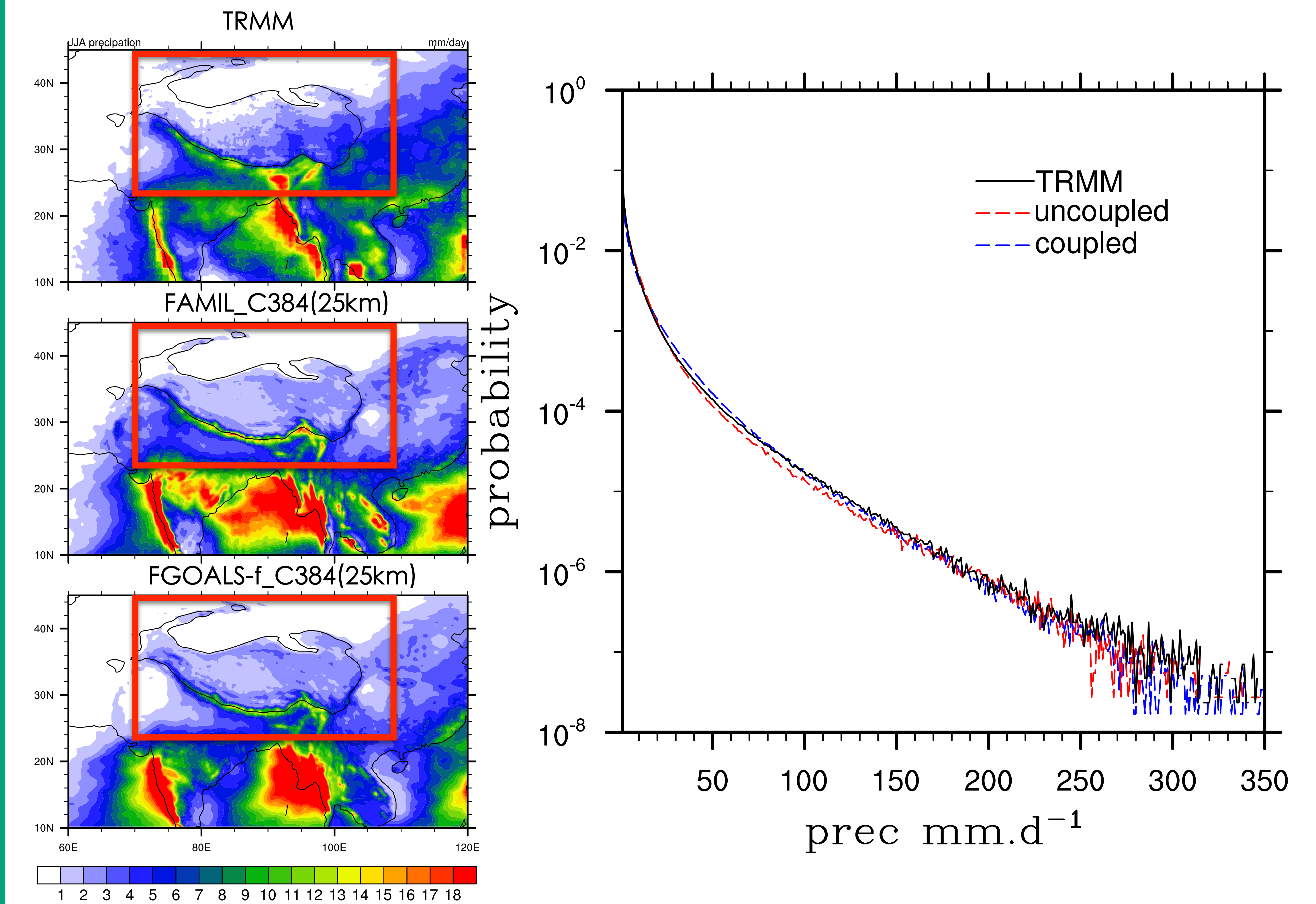
Frequency&intensity(%)



Station FGOALS-f 25km (0.24x0.24) FGOALS-f 100km (0.94x0.94)



Himalayan region



Outlines

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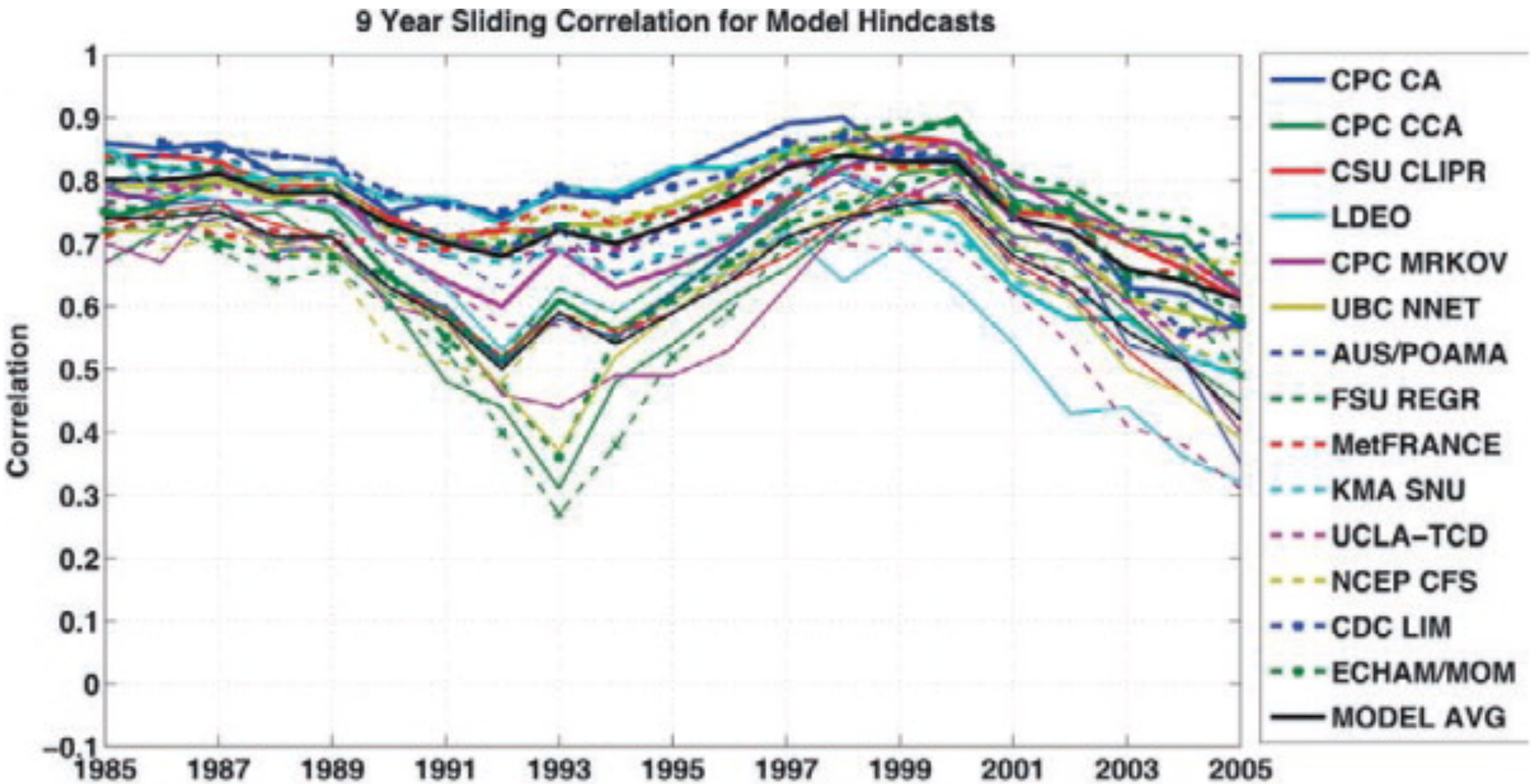
Practice is the sole criterion for testing knowledge（truth）实践是检验认识（真理）的唯一标准

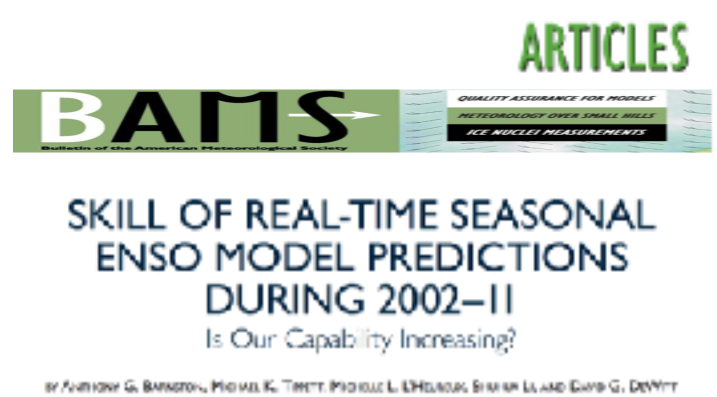
S2S prediction system

- FGOALS-f (atm/ocn: 1°)
- Nudging
  - atm： T/U/V/P/Z3 (6hr,JRA55)
  - ocn： PT (30day, EC-S4/GODAS)
- Time-lagged ensemble approach: 24~35
- Monthly Hindcast: 1981~ 2016 (36 years)
- **Real-time Forecast: Jun, 2017 ~ (~1.5day delay)**
- Forecast Users
  - ➡ Chinese MME , National Climate Center, CMA,China
  - ➡ National Marine Environmental Forecasting Center,SOA,China

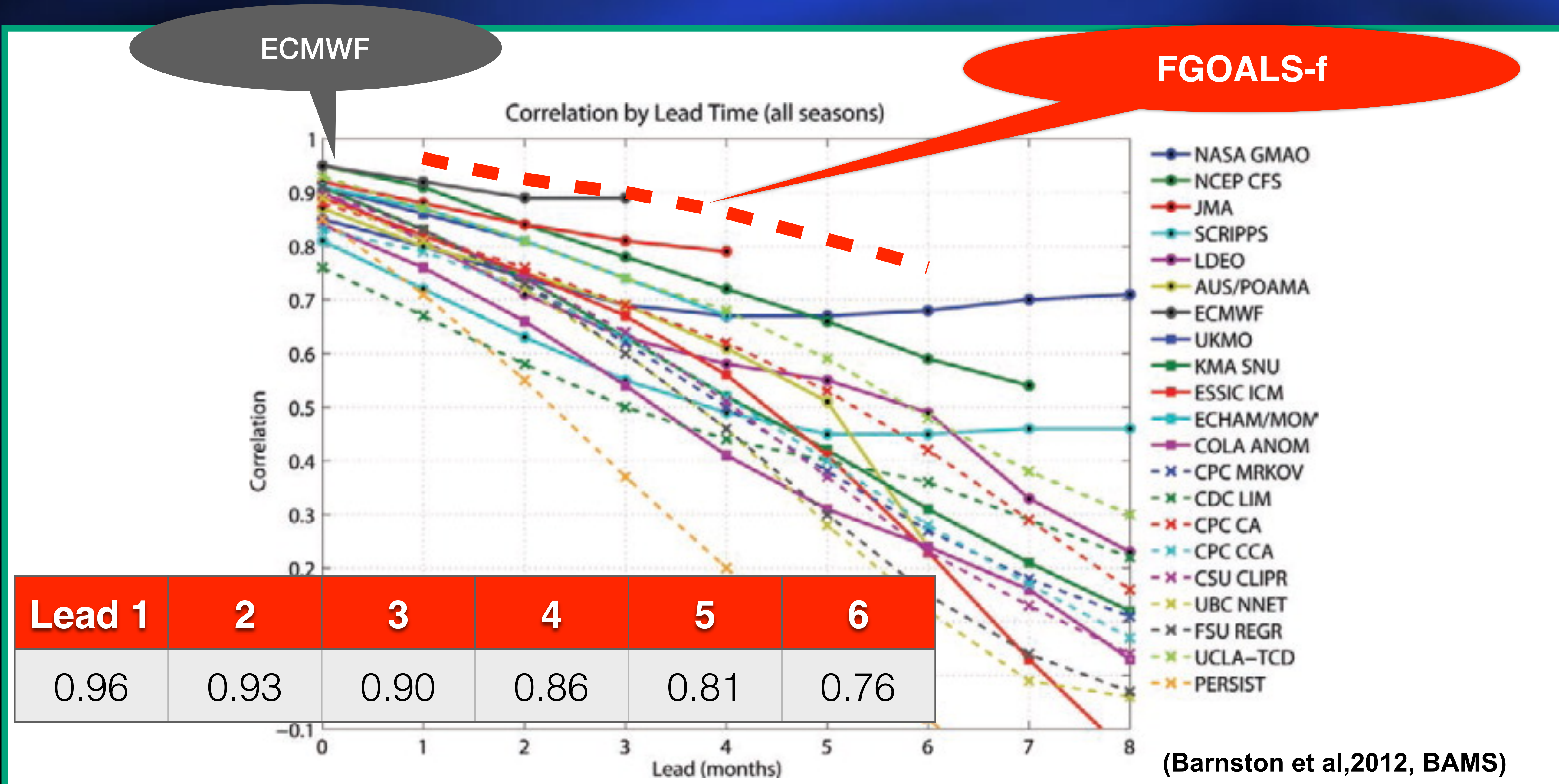
Skill of Seasonal ENSO prediction



(Barnston et al,2012, BAMS)



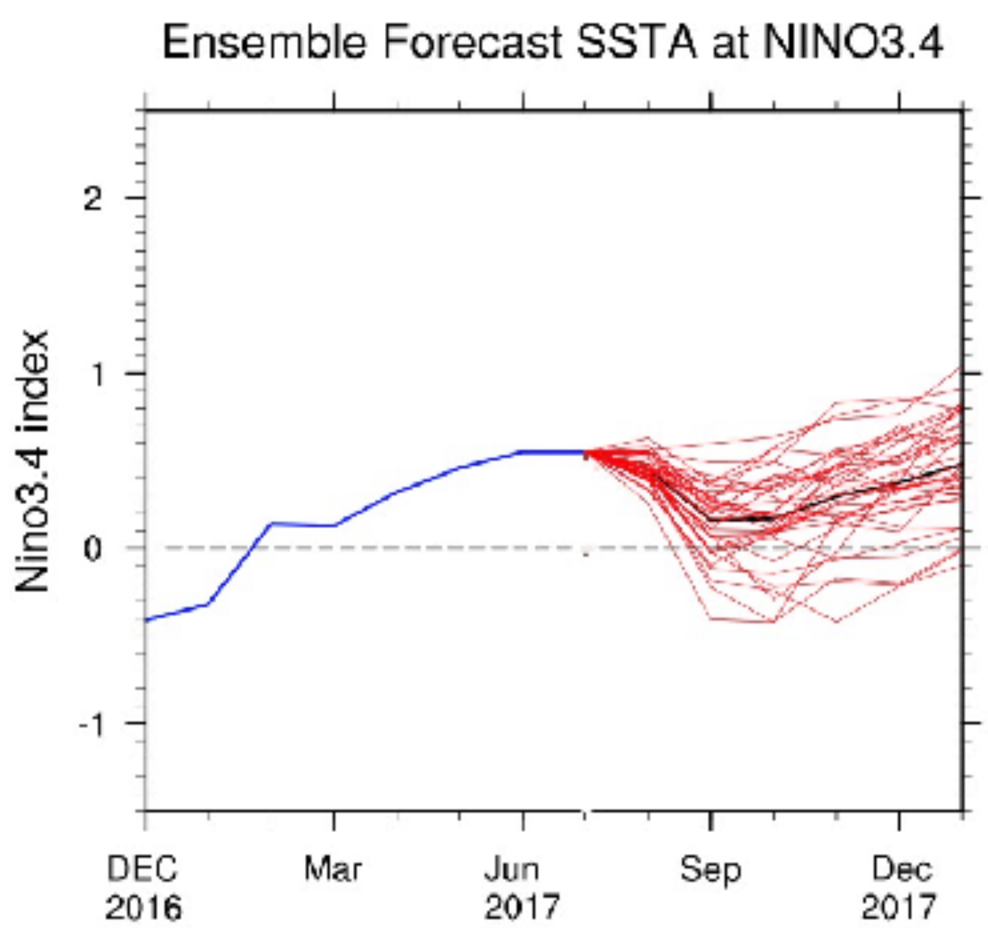
Skill of Real–time Seasonal ENSO Model Predictions during 2002–2011



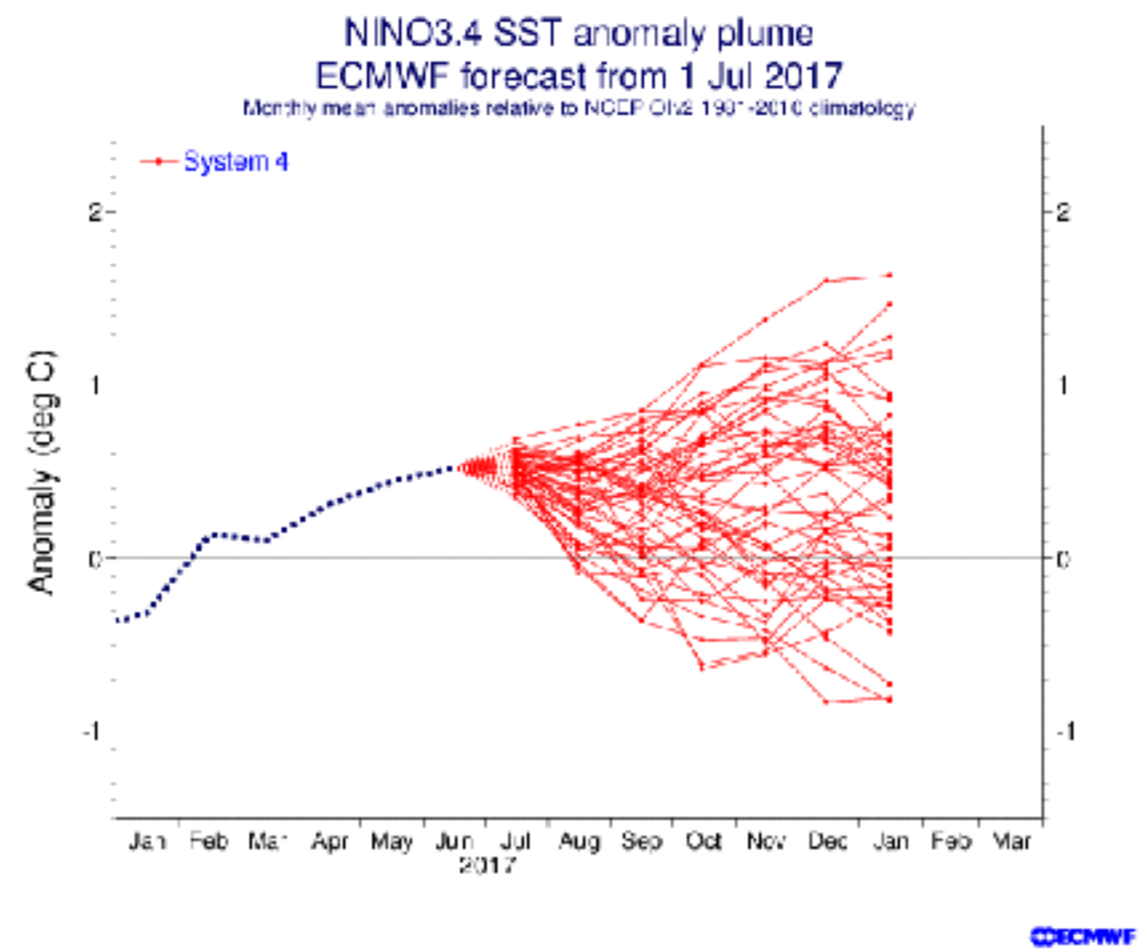
Lead 1	2	3	4	5	6
0.96	0.93	0.90	0.86	0.81	0.76

(Barnston et al,2012, BAMS)

Real-time Seasonal ENSO Predictions

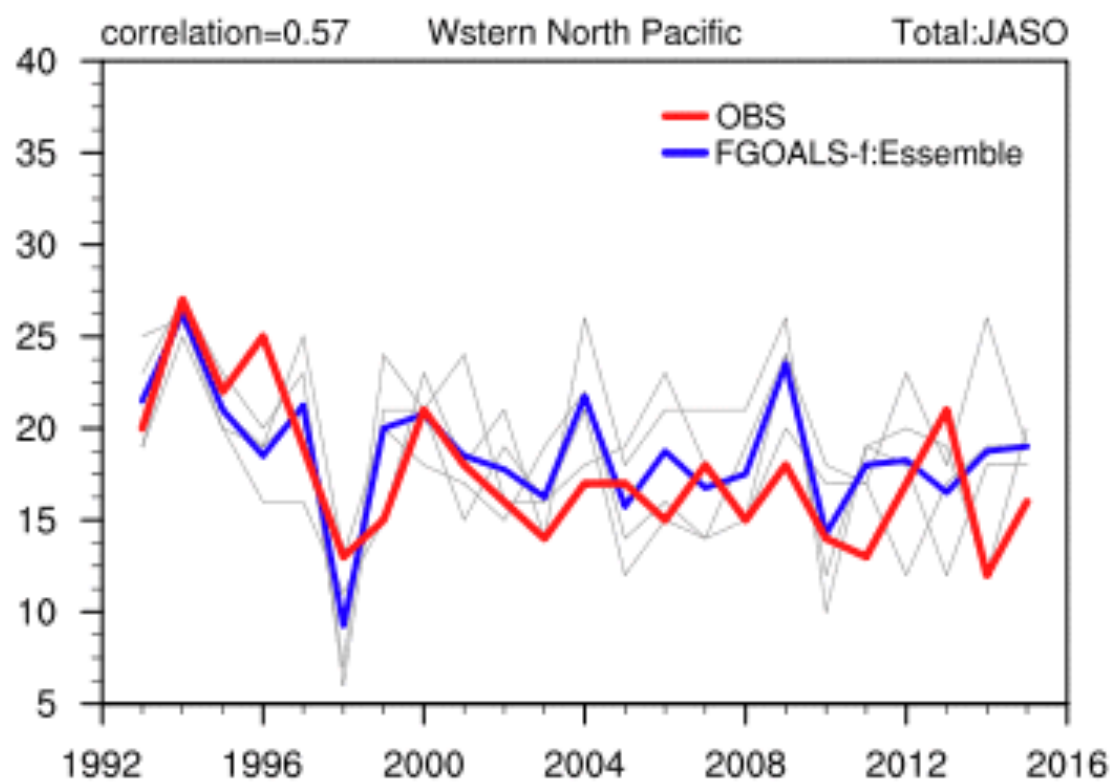


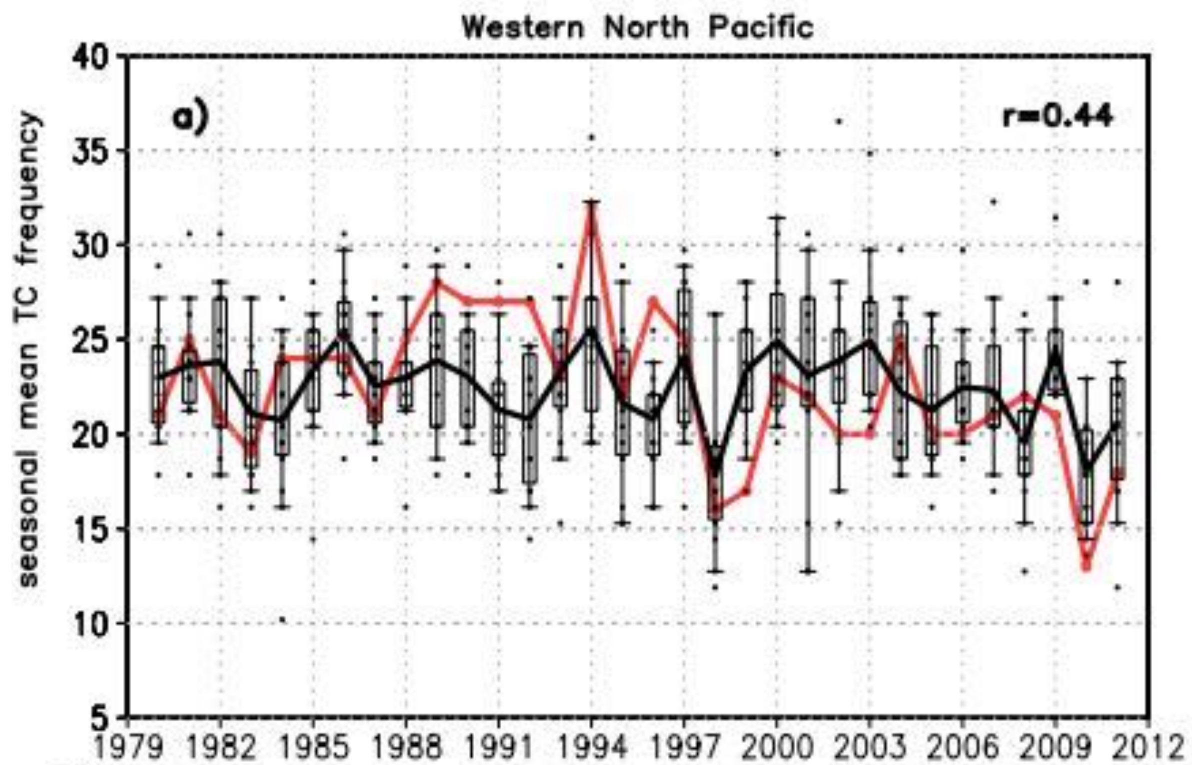
FGOALS-f: Jul 20, 2017预测



ECMWF: Jul 1, 2017预测

热带气旋（TC/Hurricane）



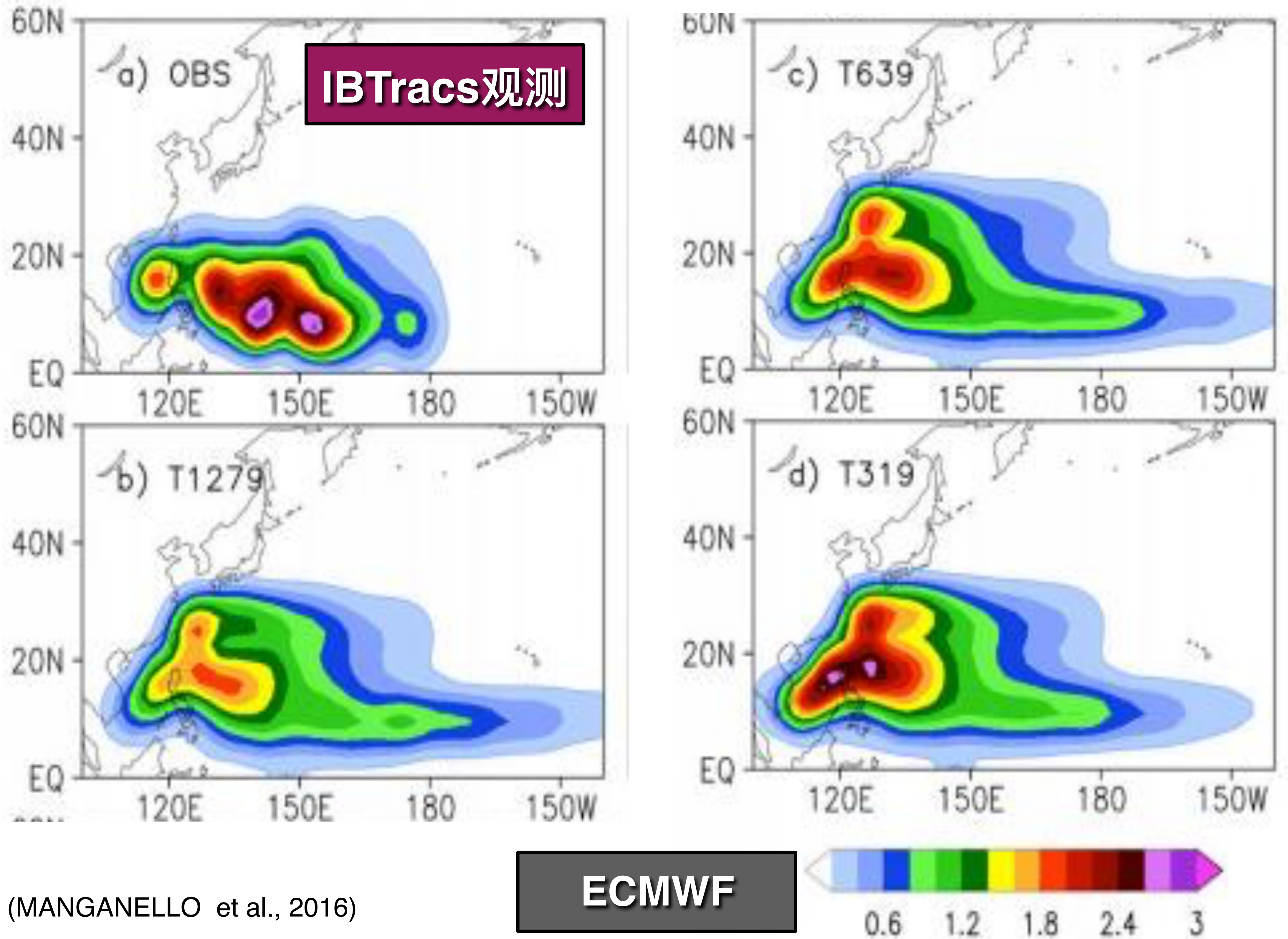


FGOALS-f: r=0.57 (95%)
C96 ~100km
L32 top 1mb
4 ensemble members
Hindcast from Jun

ECMWF: r=0.44
T319 ~62km
L91 top 0.01mb
51 ensemble members
Hindcast from May

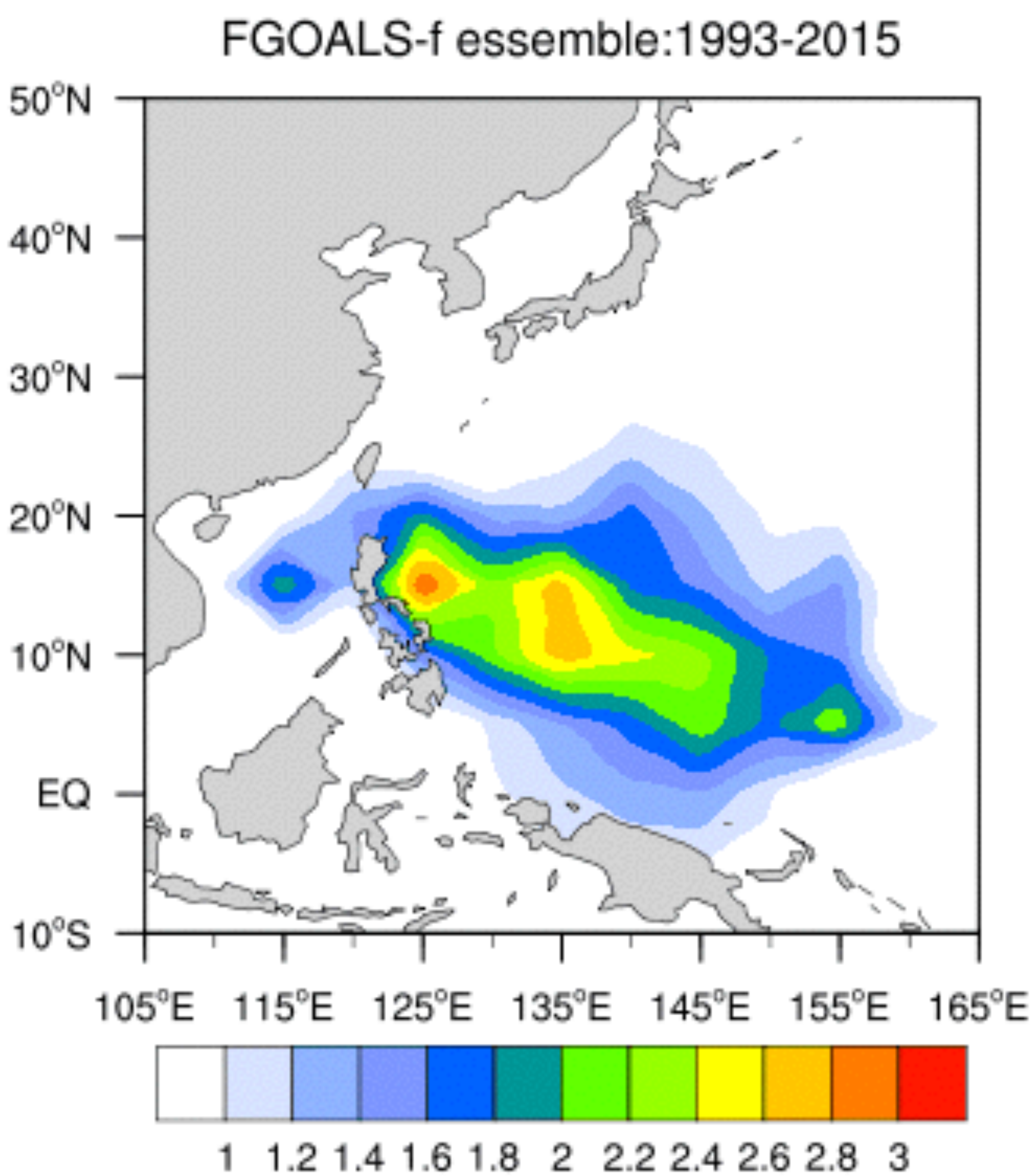
(MANGANELLO et al., 2016)

ECMWF: TC genesis frequency

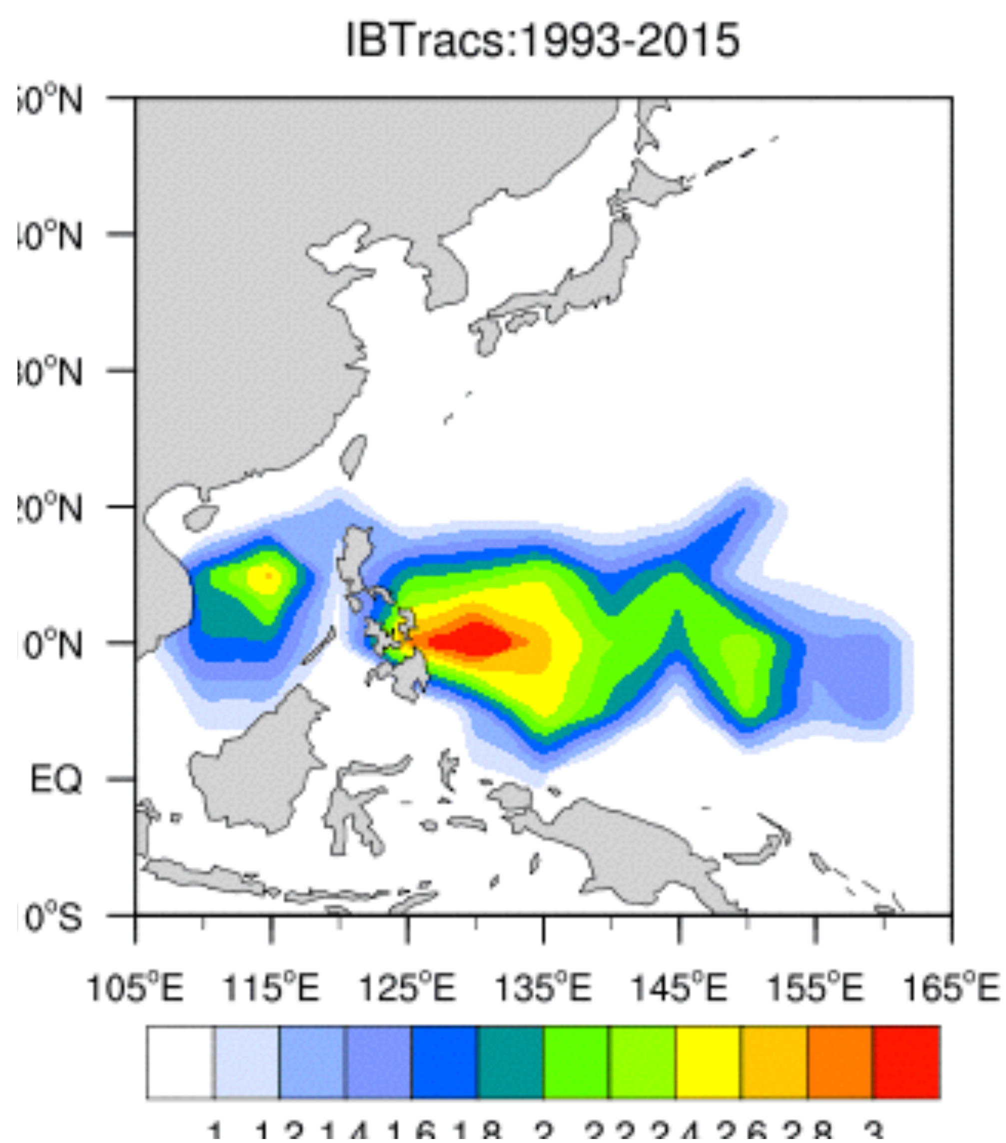


(MANGANELLO et al., 2016)

FGOALS–f: TC genesis frequency



FGOALS-f



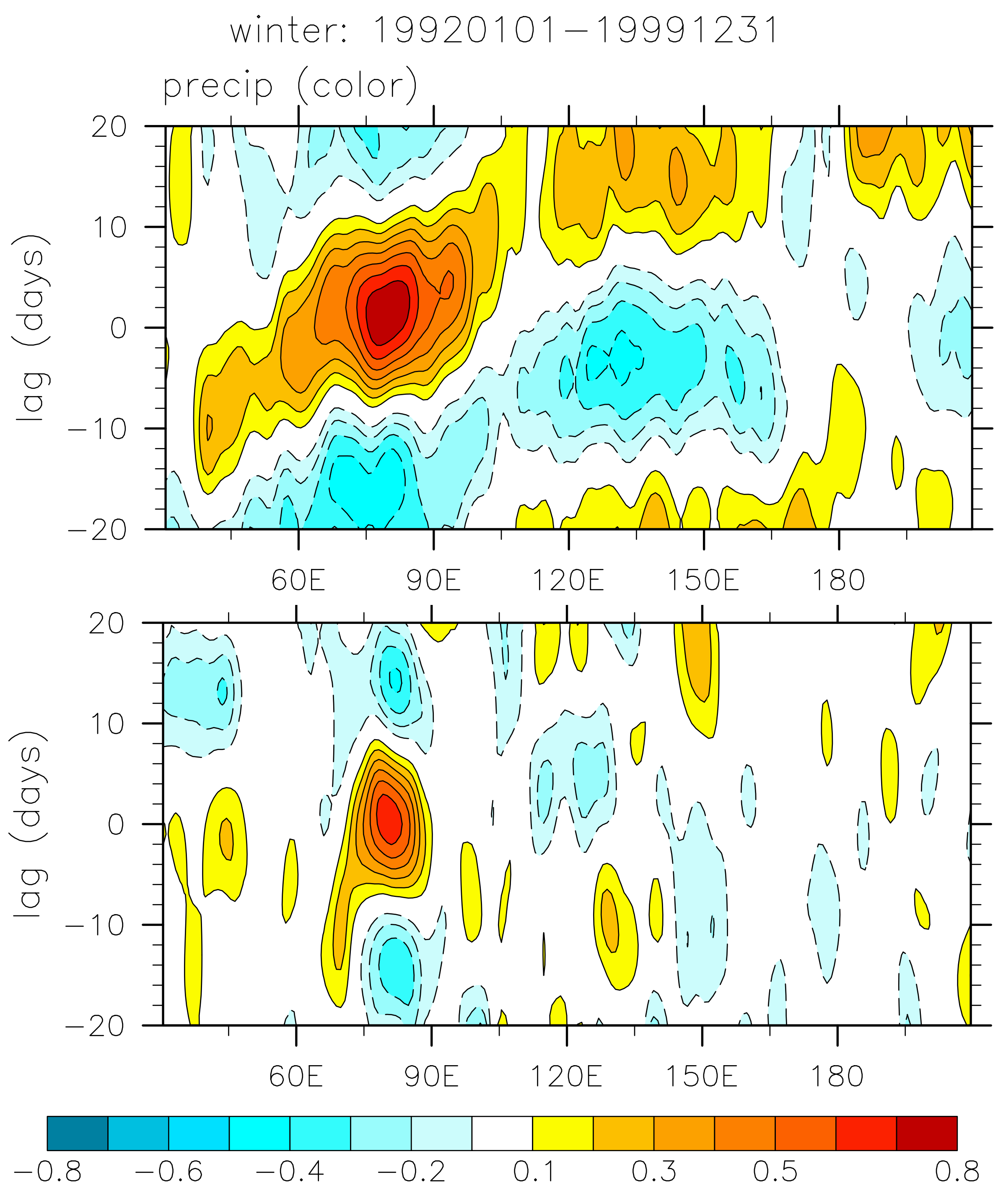
IBTracs

Summary

- FGOALS-f is targeting for higher resolution with a goal to improve both physical realism and simulation fidelity (mean&variability: ASM, ITCZ, TC, MJO, ENSO, extreme precipitation, …)
- The scale-aware RCP scheme used in FGOALS-f
  - mitigates the double ITCZ problem
  - improve simulation of ENSO teleconnection
  - improve MJO simulation
  - maintain a competitive simulation of WP/IO TC
- FGOALS-f prediction system shows substantial skill in ENSO and TC prediction

Thank you for your attention!

MJO in FAMIL (控制试验 & 无显式云试验)



Indian Ocean MJO

FAMIL ctrl

FAMIL No_RCP