State Key Laboratory of Numerical Modelling for Atmospheric Sciences
and Geophysical Fluid Dynamics(LASG)
Institute of Atmospheric Physics Chinese Academy of Sciences

# Development of High-Resolution AGCM at IAP/LASG



Q. Bao[1], L. Zhou[1], X. Wang[1], B. He[1], G. Nian[1], J. Meng[1], T. Dai[1],J. Li[1], Y. Liu[1], G-X Wu[1], W-C Wang[2]

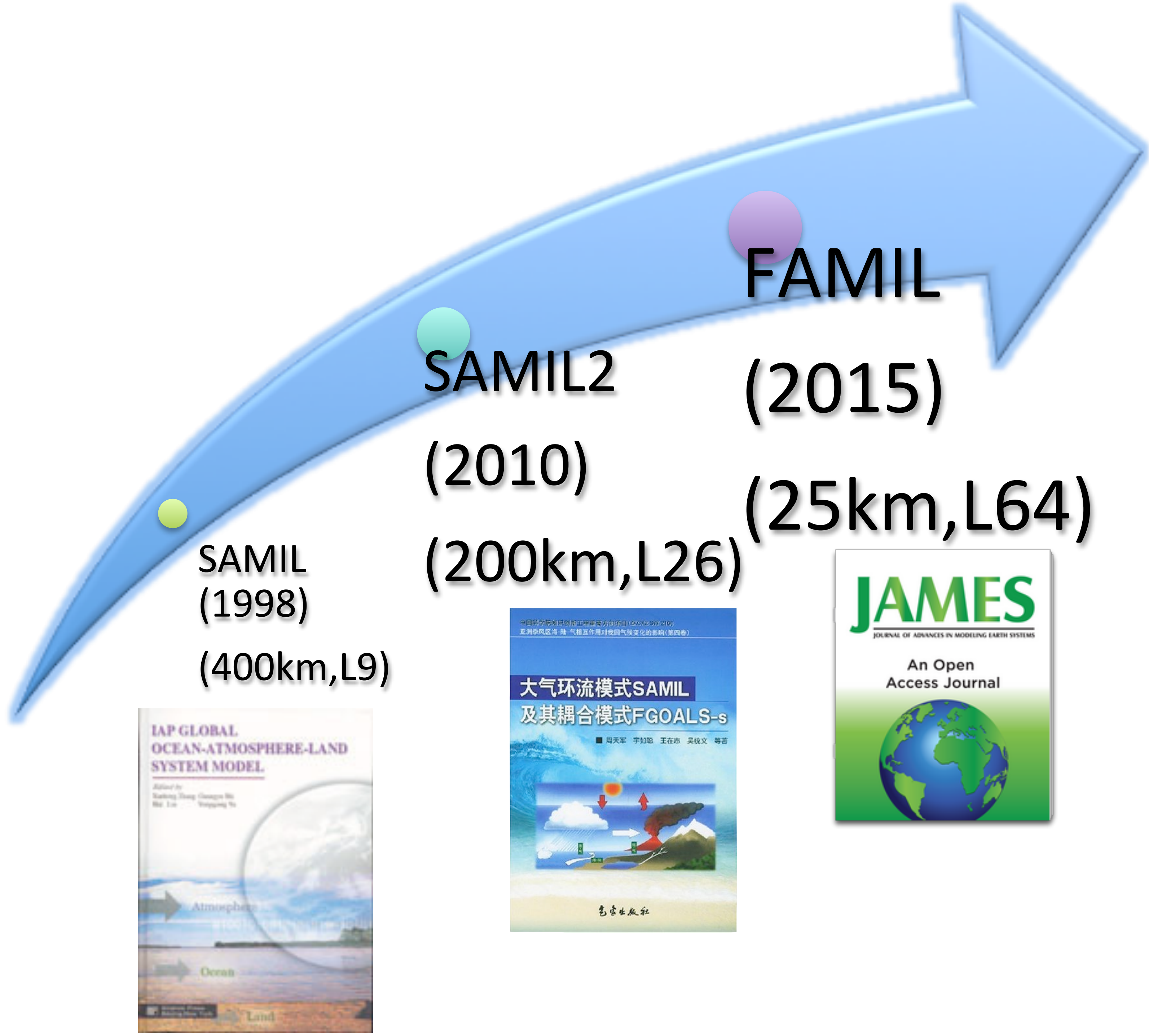
1. LASG,Institute of Atmospheric Physics, Chinese Academy of Sciences, China
2. Atmospheric Sciences Research Center, State University of New York at Albany, USA

Taipei 2015.01.20

# Outline

- Introduction to Finite-volume Atmospheric Model of the IAP/LASG (FAMIL1)
- Global energy and water balance: Characteristics from FAMIL
- Preliminary results from High-resolution FAMIL
- On-going work
- Summery

# Introduction:FAMIL




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

(Wu et. al, 1996; Zhang et. al, 2000;Wang et. al, 2003; Zhou et. al, 2005; Bao et. al, 2010;2013; Zhou et. al 2015,JAMES)

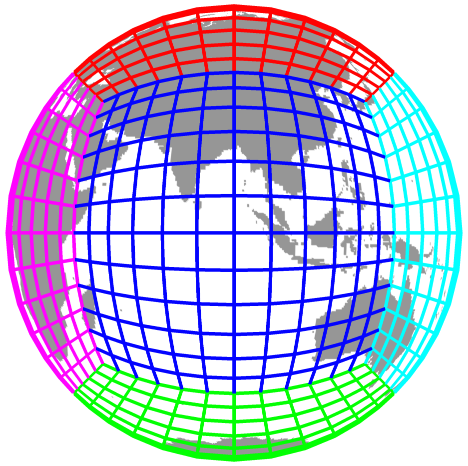
# Horizontal and vertical resolutions of FAMIL

## Horizontal resolutions:

200km,100km,50km,25km

FV on Cubed-sphere grids

Tianhe 1A



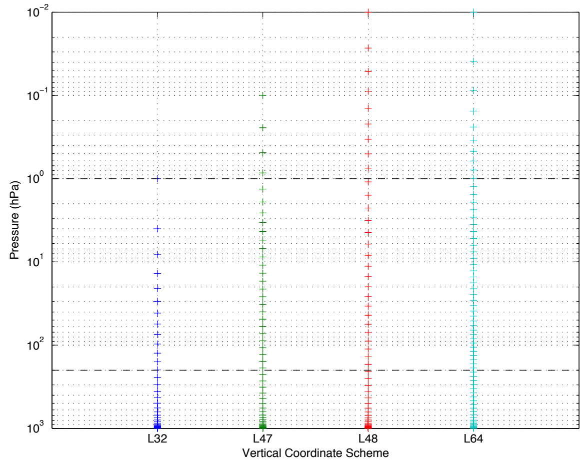
Lin and Rood, 1996
Lin, 1997, 1998, 2004
Putman and Lin, 2007
Wang et al., 2013

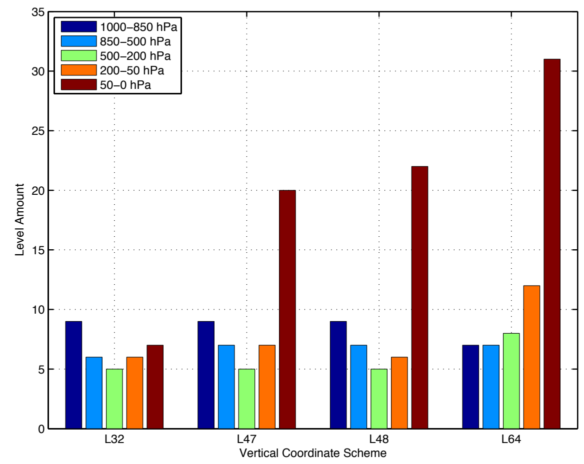
## Vertical resolutions

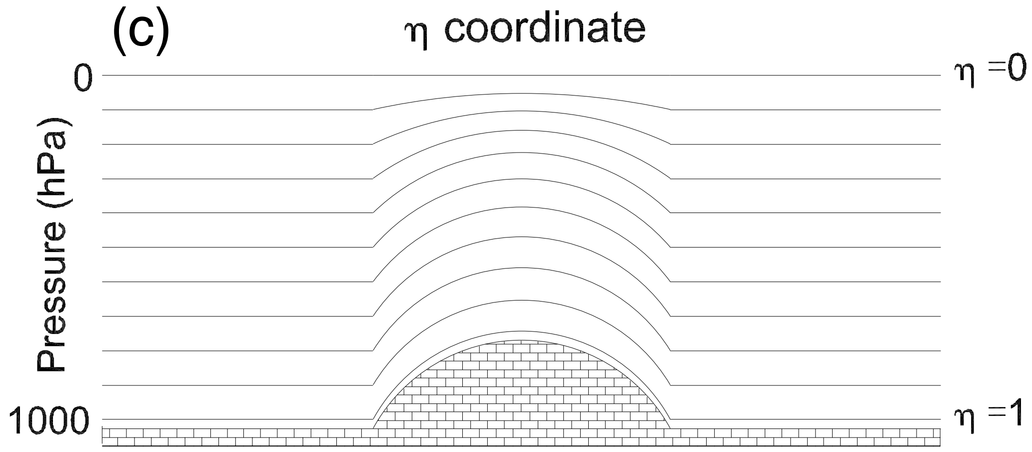
32 layers with model top 1hPa( usually 45km)

47 layers with model top 0.1hPa (usually 60km)

64 layers with model top 0.01hPa (usually 85km)

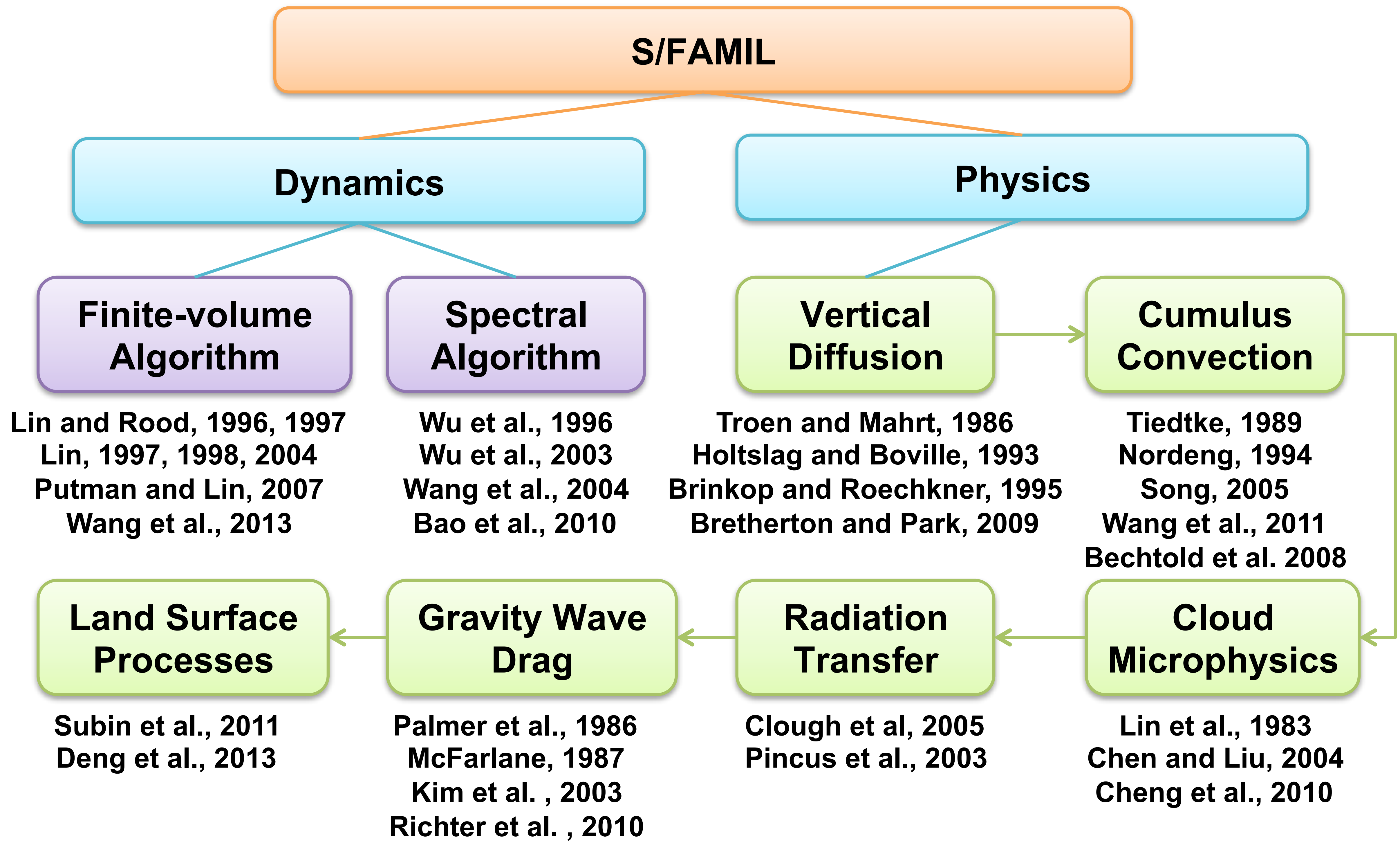


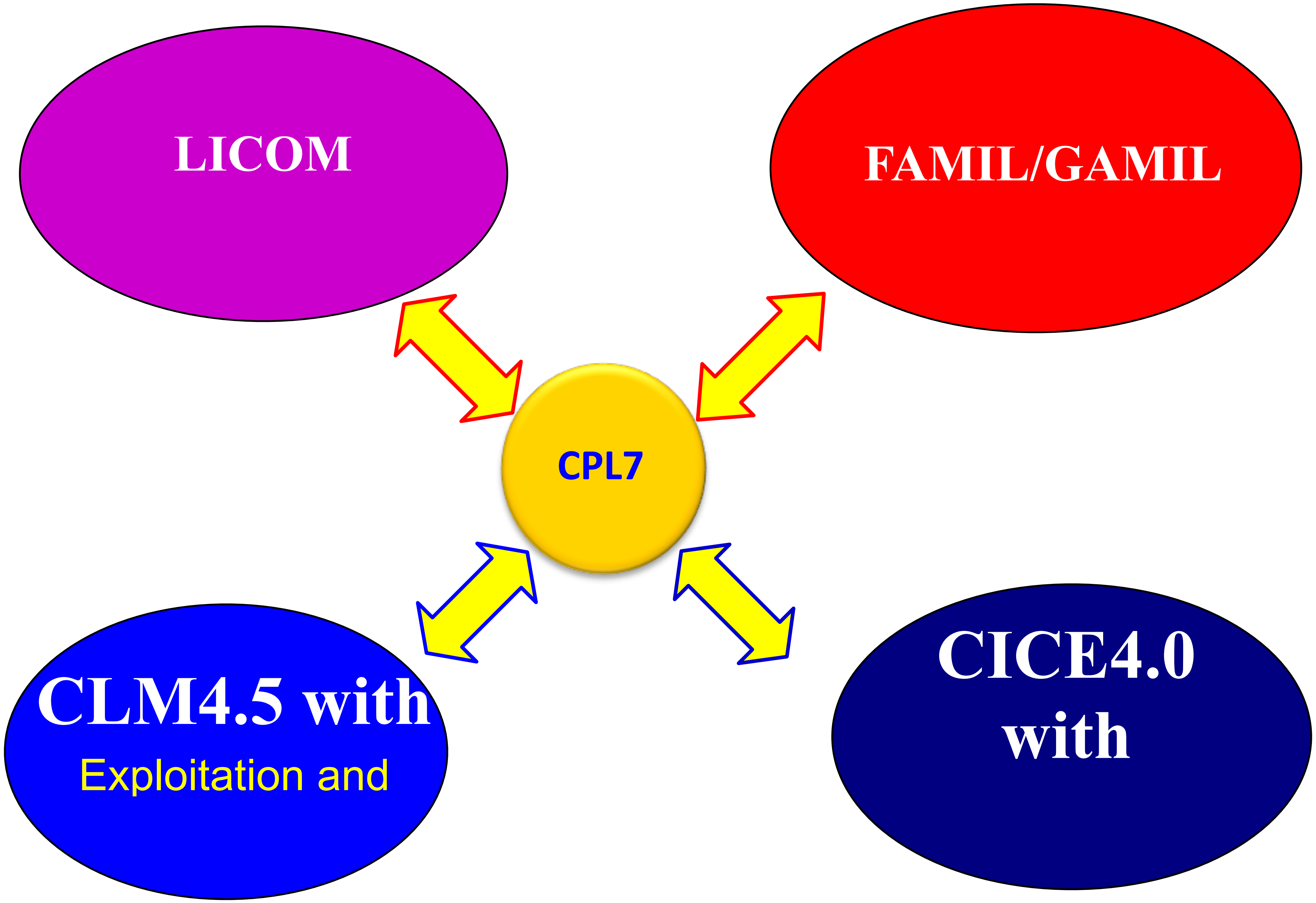




**Hybrid Vertical resolution: L32 (top at 1hPa),L64( top at 0.01hPa)**

# Finite-volume / Spectral Atmospheric Model of the IAP/LASG (S/FAMIL)

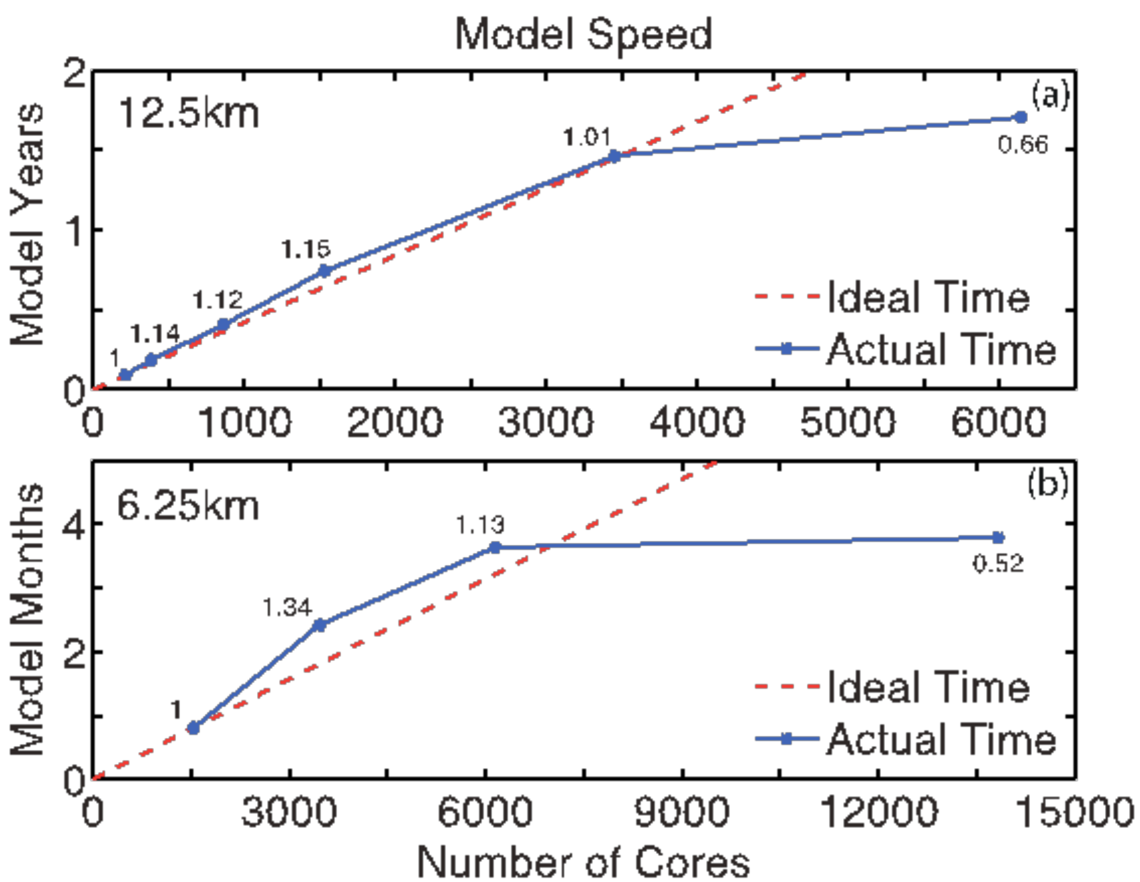


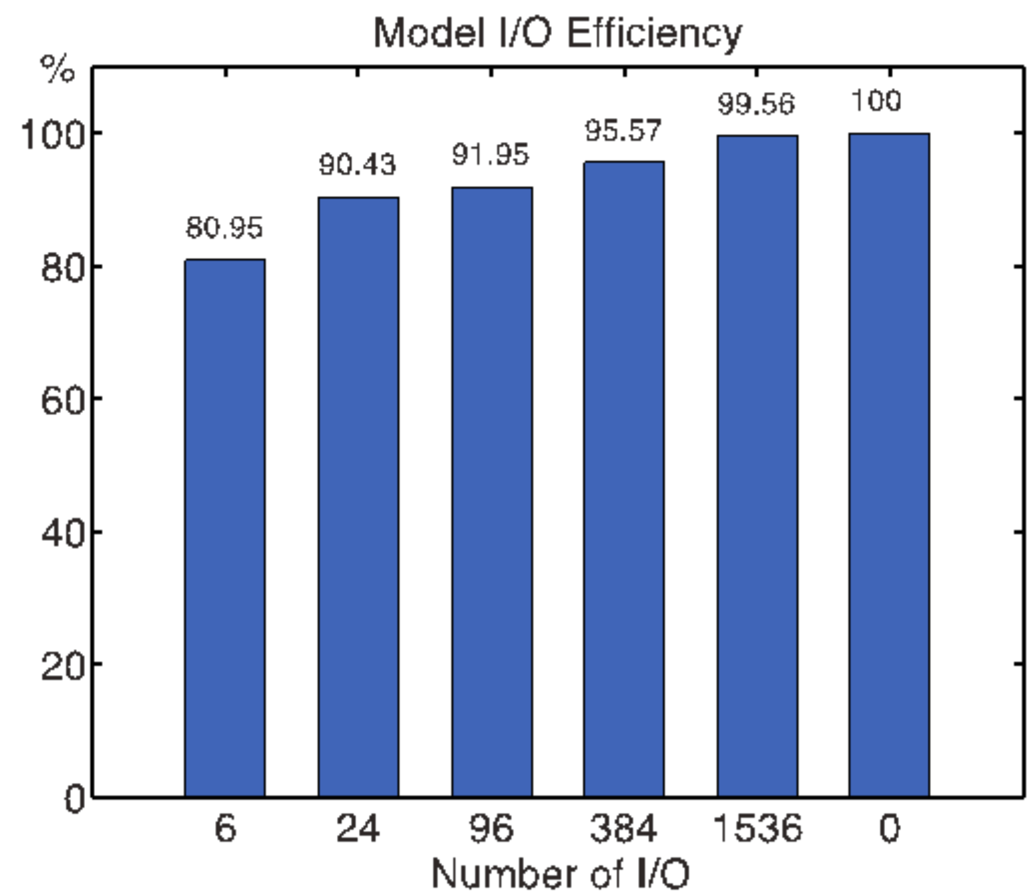
# Climate System Model: FGOALS3




**One atmospheric component of FGOALS3**

# Computational Performance of FAMIL




(Zhou, et al., 2012)

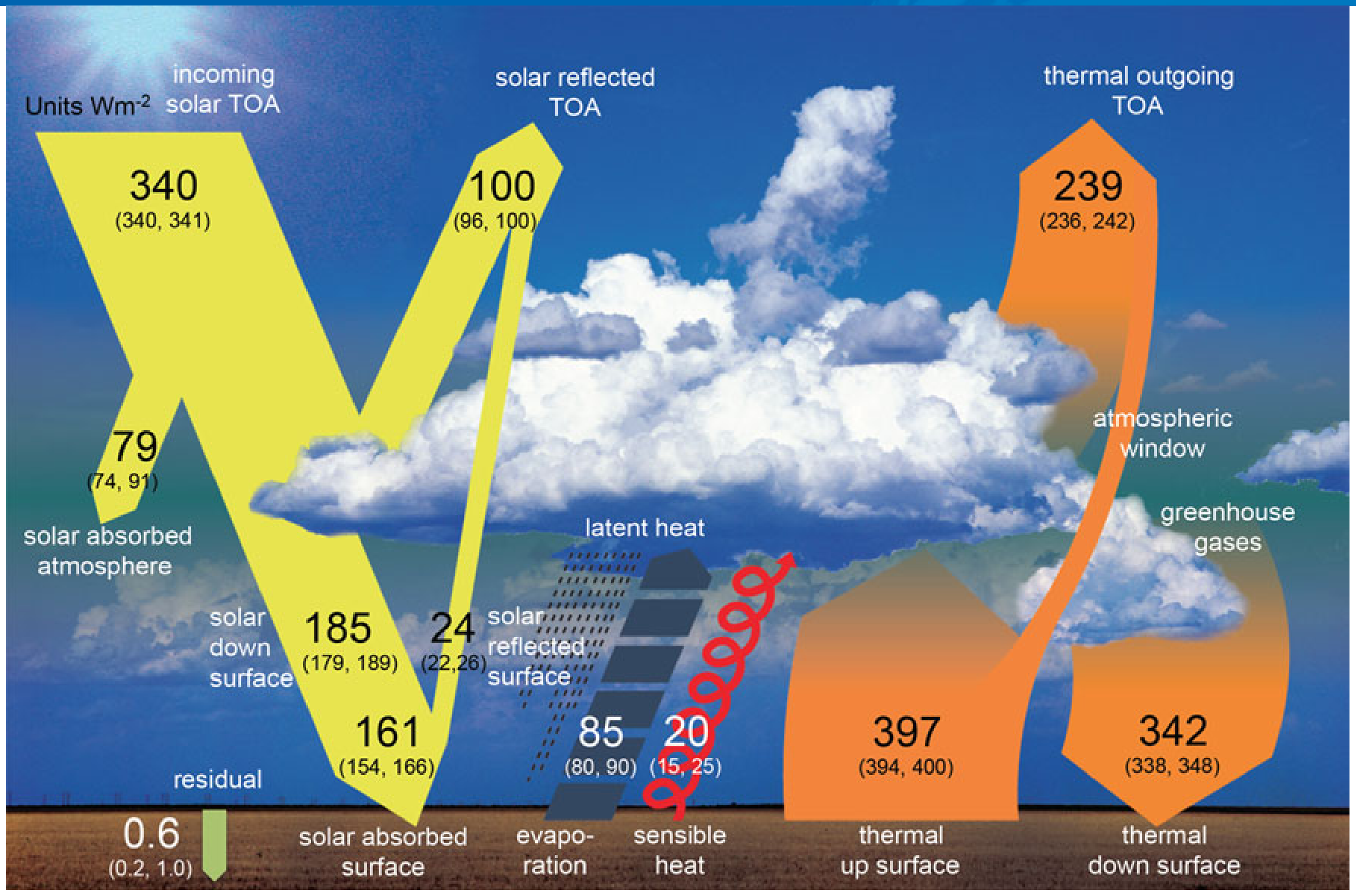
**Achievement of FAMIL on the 'Tianhe 1A' 10000-core Supercomputer**

# Global energy and water balance: Characteristics from FAMIL

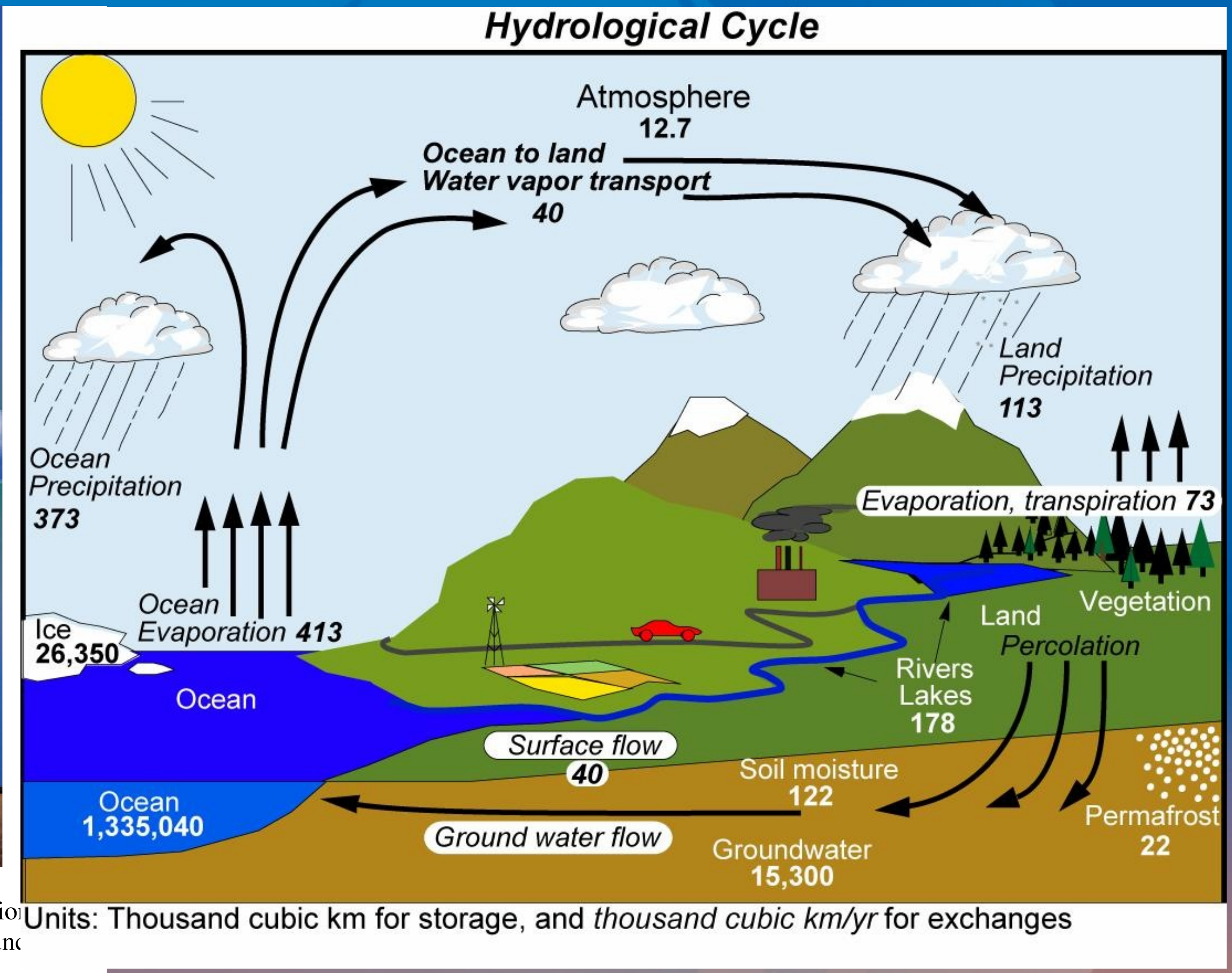
**Global energy and water balance: Characteristics from Finite-volume Atmospheric Model of the IAP/LASG (FAMIL1)**
JOURNAL OF ADVANCES IN MODELING EARTH SYSTEMS
September 2014Accepted Online: 28 NOV 2014Linjiong Zhou, Qing Bao, Yimin Liu, Guoxiong Wu, Wei-Chyung Wang, Xiaocong Wang, Bian He, Haiyang Yu and Jiandong Li
Published Online : 16 JAN 2015 11:25PM EST, DOI : 10.1002/2014MS000349

- **Description of a new generation AGCM (FAMIL), developed at IAP-LASG, and designed for CMIP6**
- **Evaluation of the simulated global energy and water balance in FAMIL**
- **Identification of possible solutions to reduce the bias**

# Motivations




. 1 Schematic diagram of the global mean energy balance of the th. *Numbers* indicate best estimates for the magnitudes of the bally averaged energy balance components together with their uncertainty ranges, representing present day climate conditio beginning of the twenty first century. Estimates and unc ranges based on discussion in Sect. 5. Units $Wm^{-2}$




Trenberth et al., 2007

Wild et al., 2013; IPCC AR5 Chapter 2

Energy Conservation:

$$\mathrm{LH} + \mathrm{SH} + \mathrm{RF} = \frac{\Delta(\mathrm{SE} + \mathrm{GE} + \mathrm{LE} + \mathrm{KE})}{\Delta \mathrm{t}}$$

Water Balance:

$$\mathrm{E} - \mathrm{P} = \frac{\Delta(\mathrm{Qv} + \mathrm{Qc} + \mathrm{Qr} + \mathrm{Qi} + \mathrm{Qs} + \mathrm{Qg})}{\Delta \mathrm{t}}$$

- Total energy contains sensible energy (SE), gravitational-potential energy (GE), latent energy (LE), and kinetic energy(KE)
- Total water contains water vapor (Qv), cloud water (Qc), rain water (Qr), cloud ice (Qi), snow (Qs), and graupel (Qg).

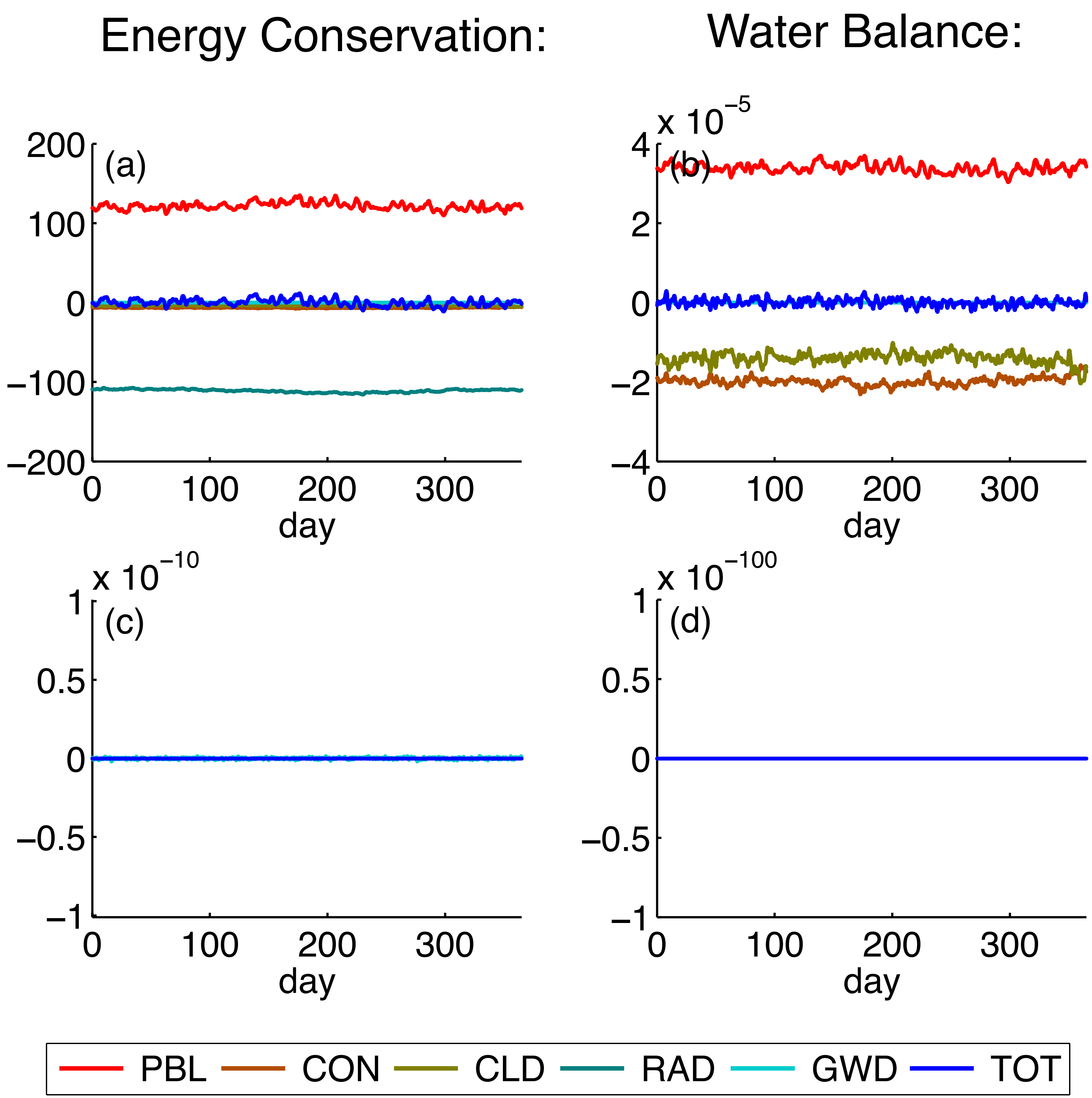



Figure A1 shows that, although different physical processes behave differently in terms of energy and water status and variation, all processes are conserved since total energy and water flux flowing through the upper and bottom boundary of the atmosphere is equal to the tendency of the vertically integrated total energy or water in the atmosphere. The orders of their differences are less than $10^{-10}$ and $10^{-100}$ for energy and water, respectively.

# Global Mean Energy Budgets

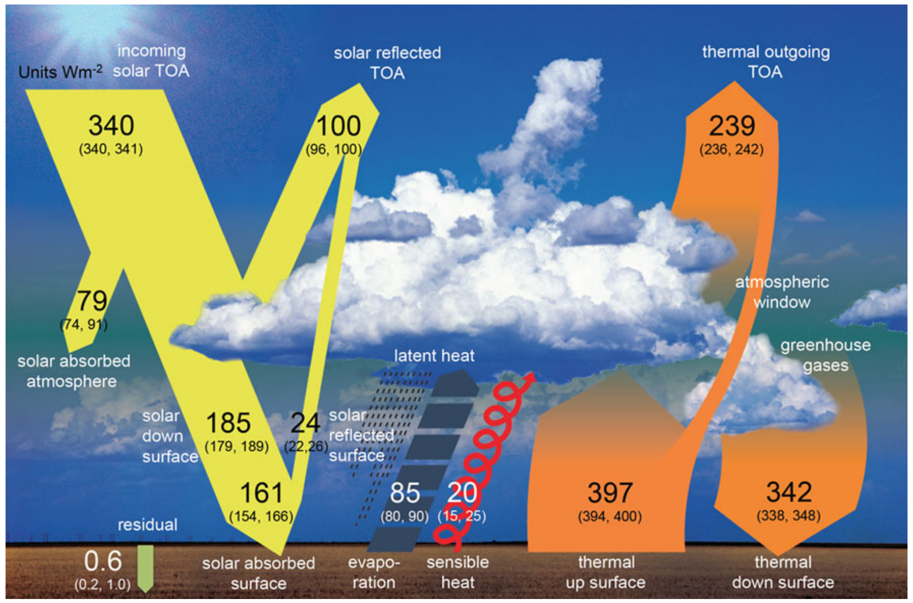
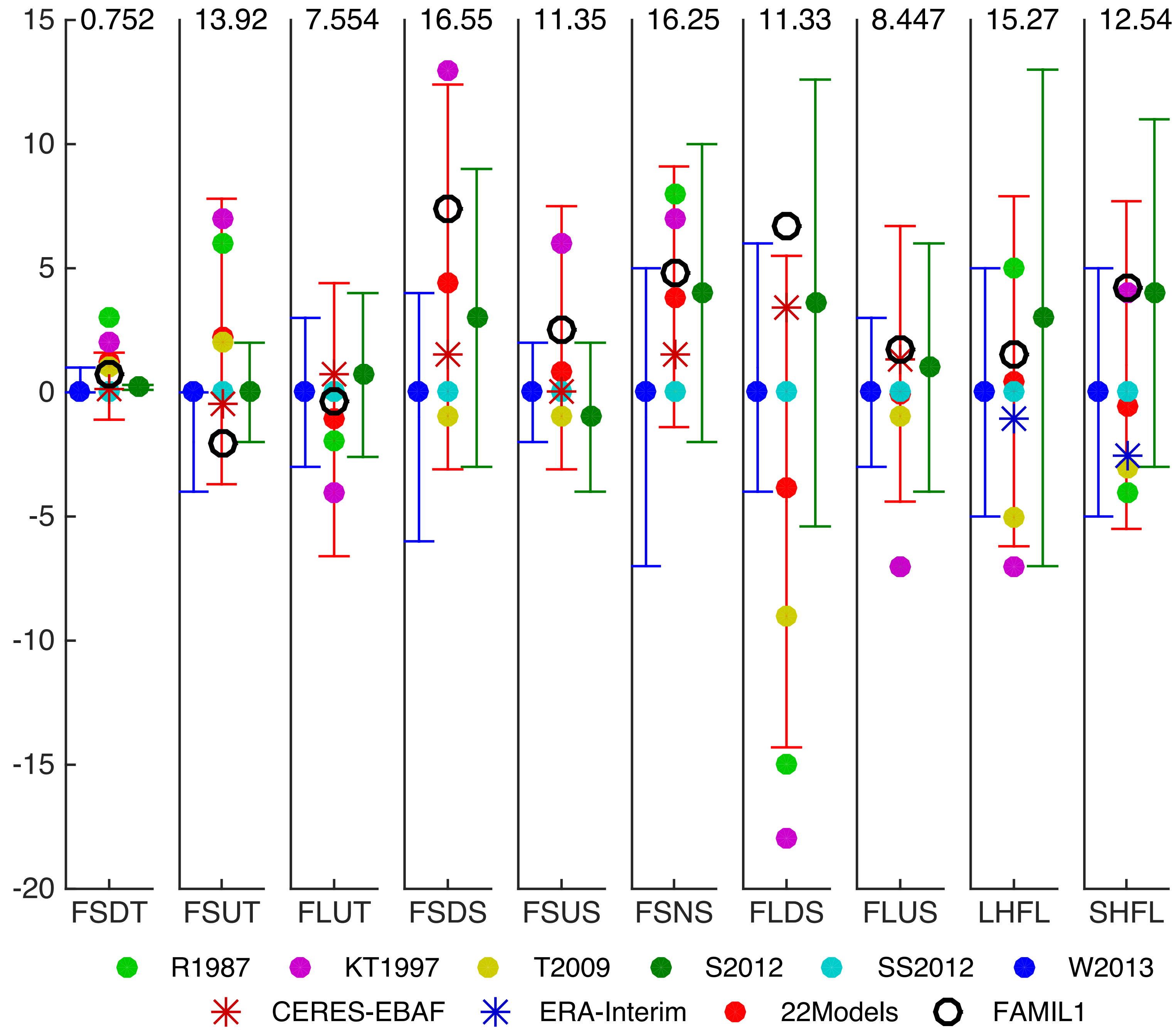
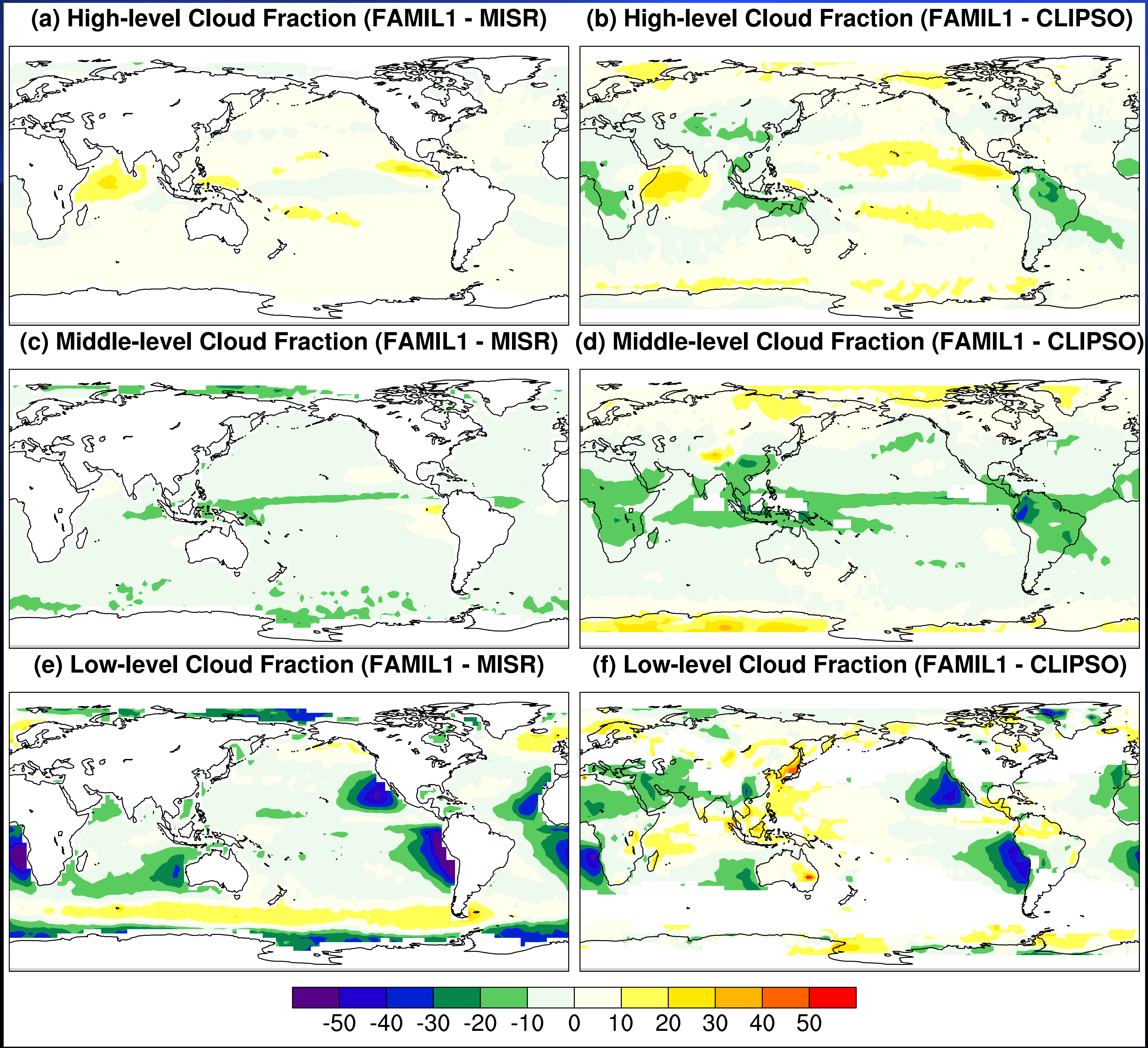



**Fig. 1** Schematic diagram of the global mean energy balance of the Earth. *Numbers* indicate best estimates for the magnitudes of the globally averaged energy balance components together with their uncertainty ranges, representing present day climate conditions beginning of the twenty first century. Estimates and uncer ranges based on discussion in Sect. 5. Units $Wm^{-2}$

| Top of Atmosphere | |
|---|---|
| (0) | Solar Down |
| (1) | Solar Up |
| (2) | Thermal Up |
| **Surface Atmosphere** | |
| (3) | Solar Down |
| (4) | Solar Up |
| (5) | Solar Net |
| (6) | Thermal Down |
| (7) | Thermal Up |
| (8) | Latent Heat |
| (9) | Sensible Heat |

Wild et al., 2013; IPCC



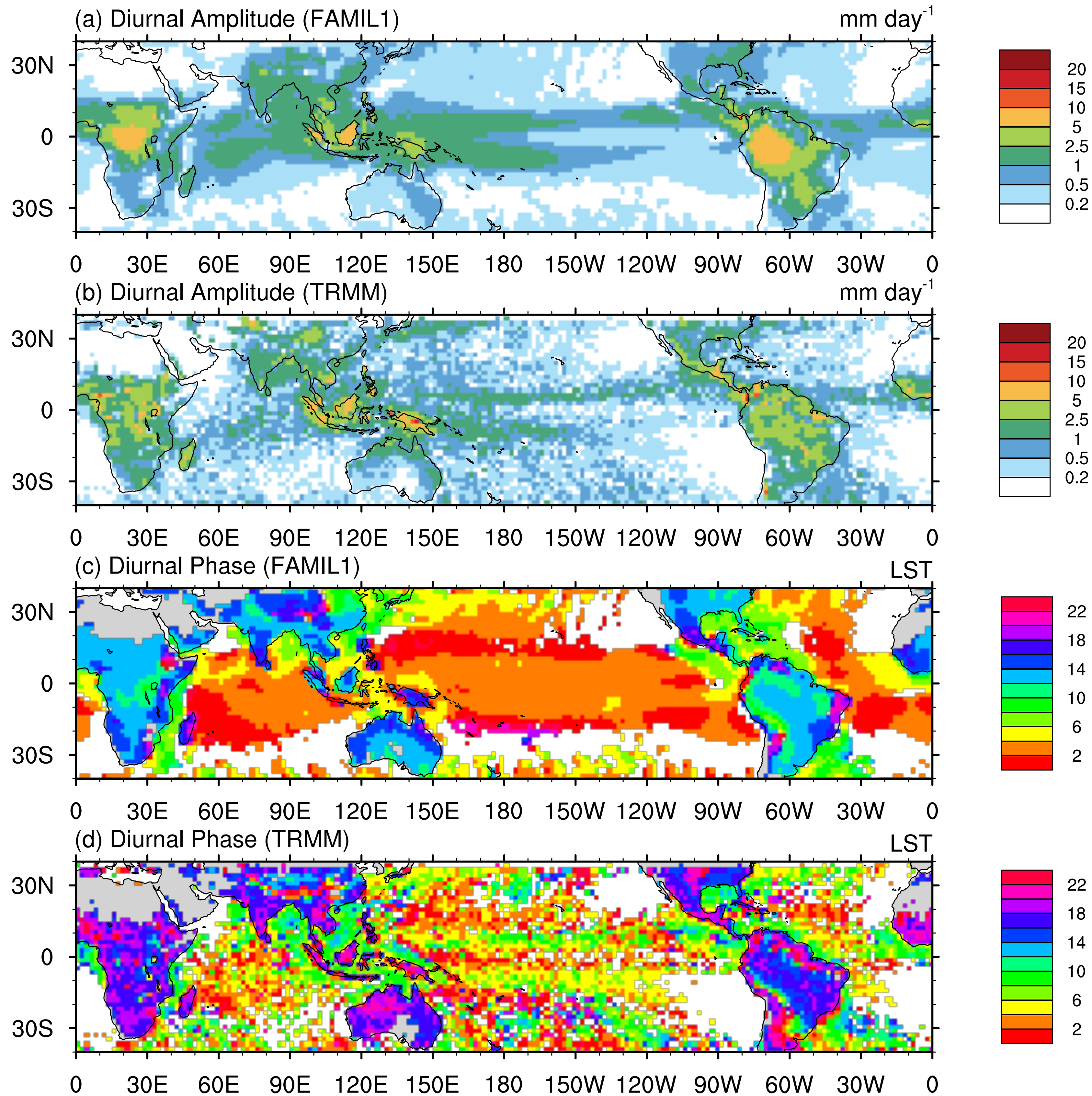

(a) High-level Cloud Fraction (FAMIL1 - MISR)
(b) High-level Cloud Fraction (FAMIL1 - CLIPSO)
(c) Middle-level Cloud Fraction (FAMIL1 - MISR)
(d) Middle-level Cloud Fraction (FAMIL1 - CLIPSO)
(e) Low-level Cloud Fraction (FAMIL1 - MISR)
(f) Low-level Cloud Fraction (FAMIL1 - CLIPSO)
-50 -40 -30 -20 -10 0 10 20 30 40 50

# Global mean of water balance

| Field | FAMIL | GPCP | CMAP | ERAI | MERRA | 16Models |
|---|---|---|---|---|---|---|
| Prec. | 2.986 | 2.672 | 2.653 | 2.848 | 2.793 | 2.987 |
| Evap. | 2.986 | | | 2.902 | 2.682 | 2.986 |
| E-P | 0.000 | | | 0.054 | -0.111 | -0.001 |

Global annual mean precipitation, evaporation and E-P (evaporation minus precipitation) at the surface atmosphere from FAMIL1, GPCP, CMAP, EARI, ERA15, and 16 CMIP5/IPCC AR5 models. Averaging period of FAMIL is from 1979 to 2008. Units: mm day$^{-1}$

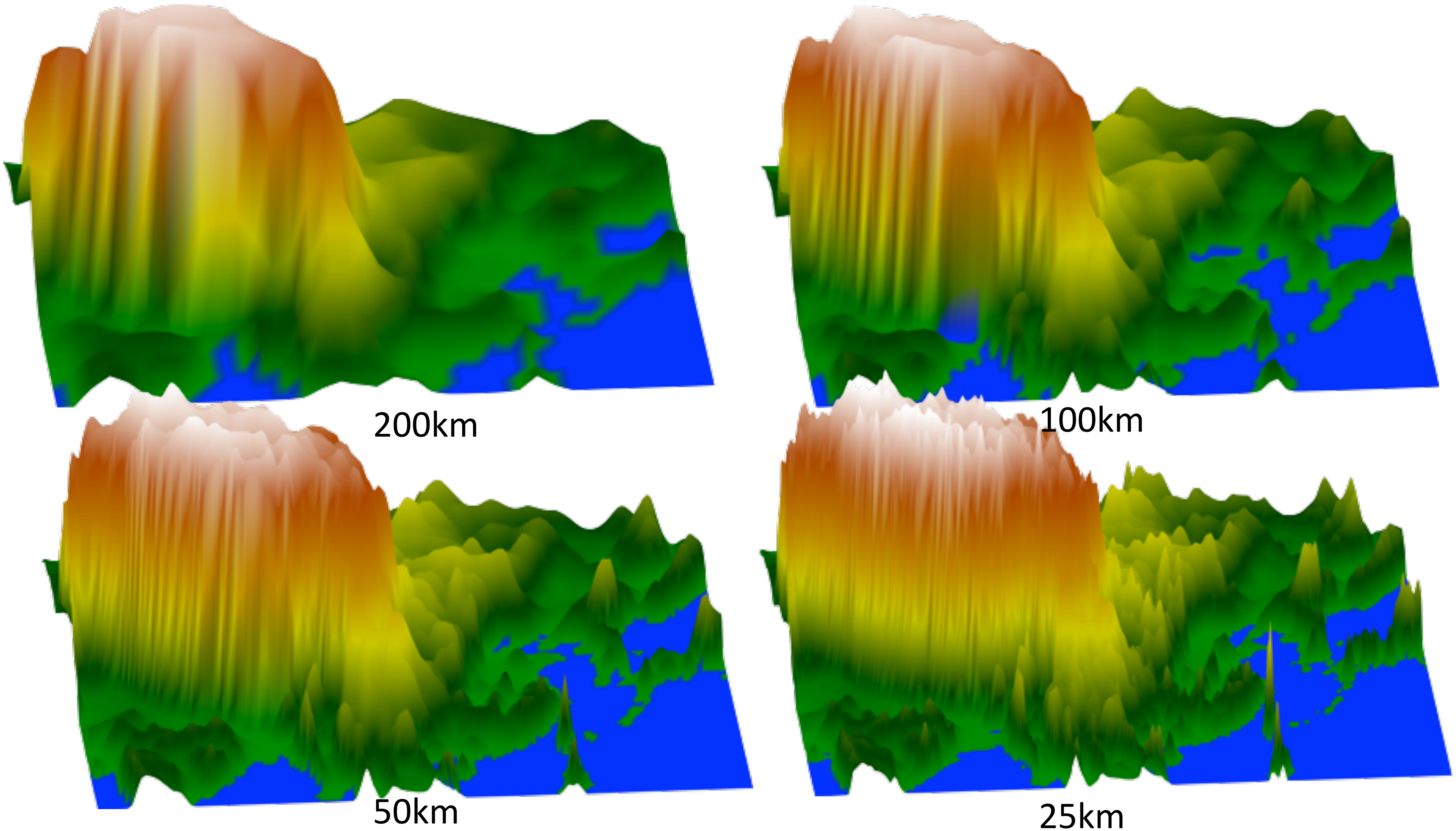
# Diurnal Amplitude and Phase of Precipitation in FAMIL



# Preliminary results from High-resolution FAMIL

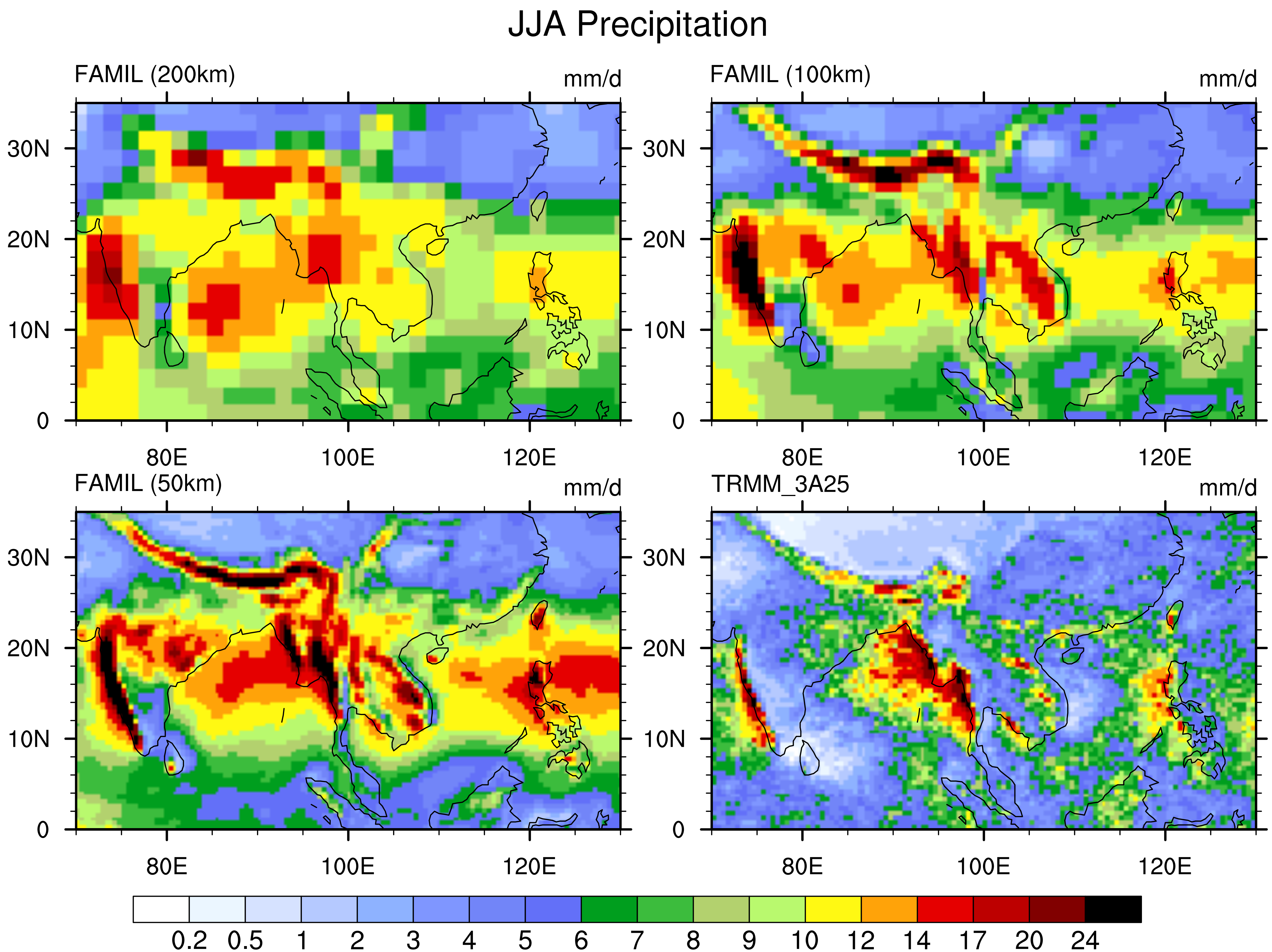
# Horizontal high resolutions:

## 200km,100km,50km,25km

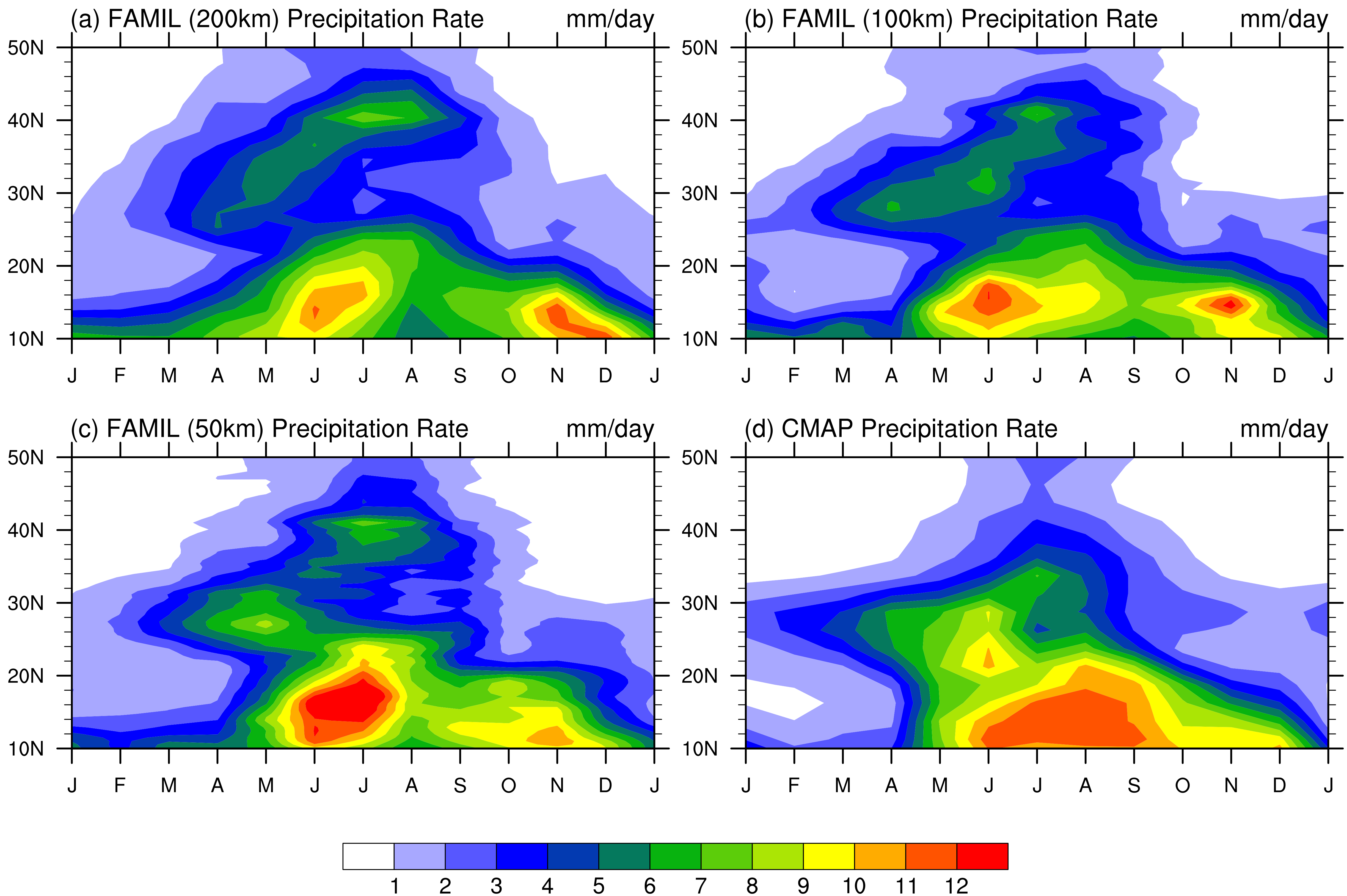



Topographic forcing of Eastern Asia with the different resolutions

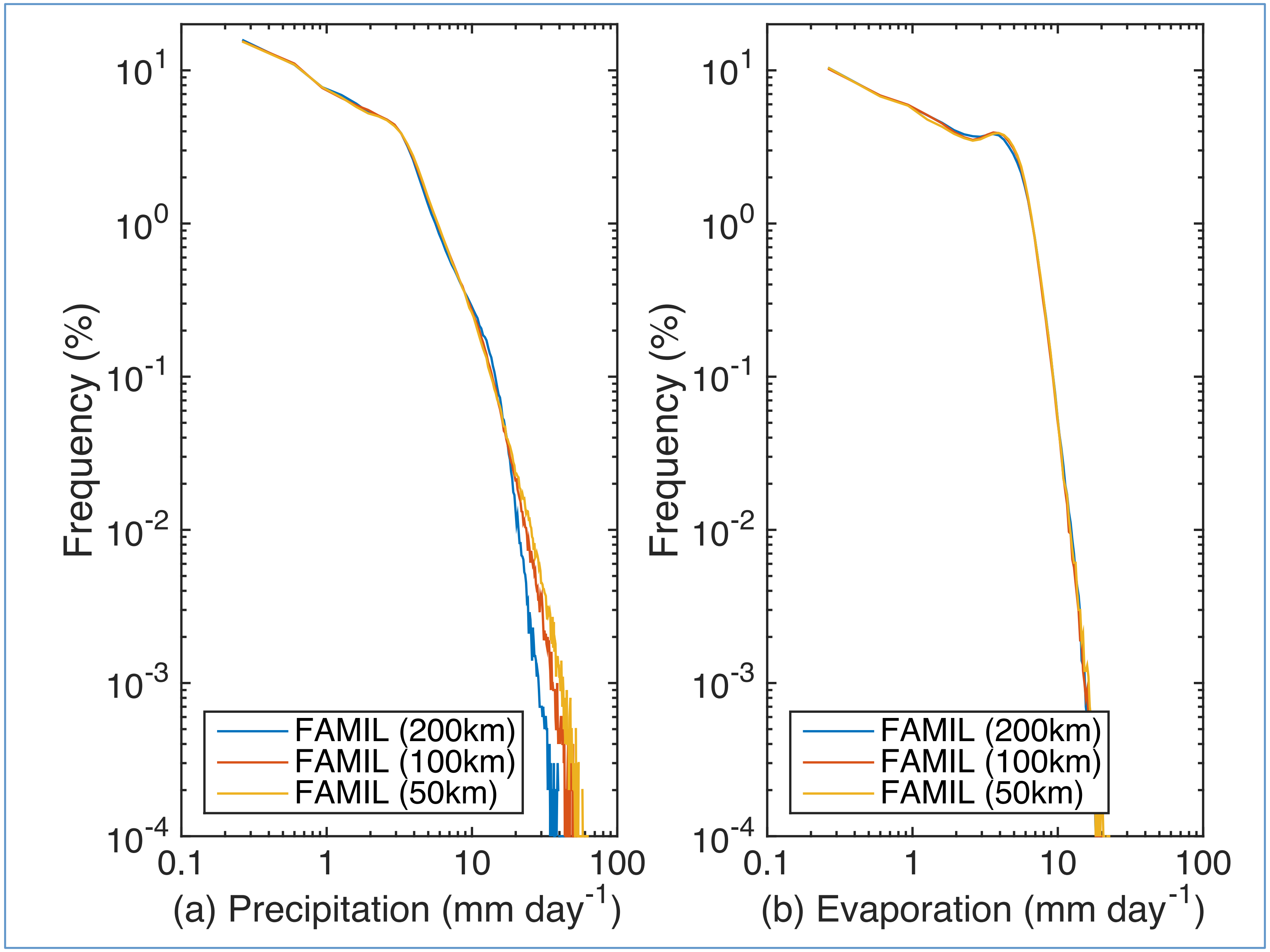
# Simulated Asian Summer Monsoon Precipitation with 200km, 100km and 50km resolutions



# Simulated East Asian Annual cycle of Precipitation with 200km, 100km and 50km resolutions

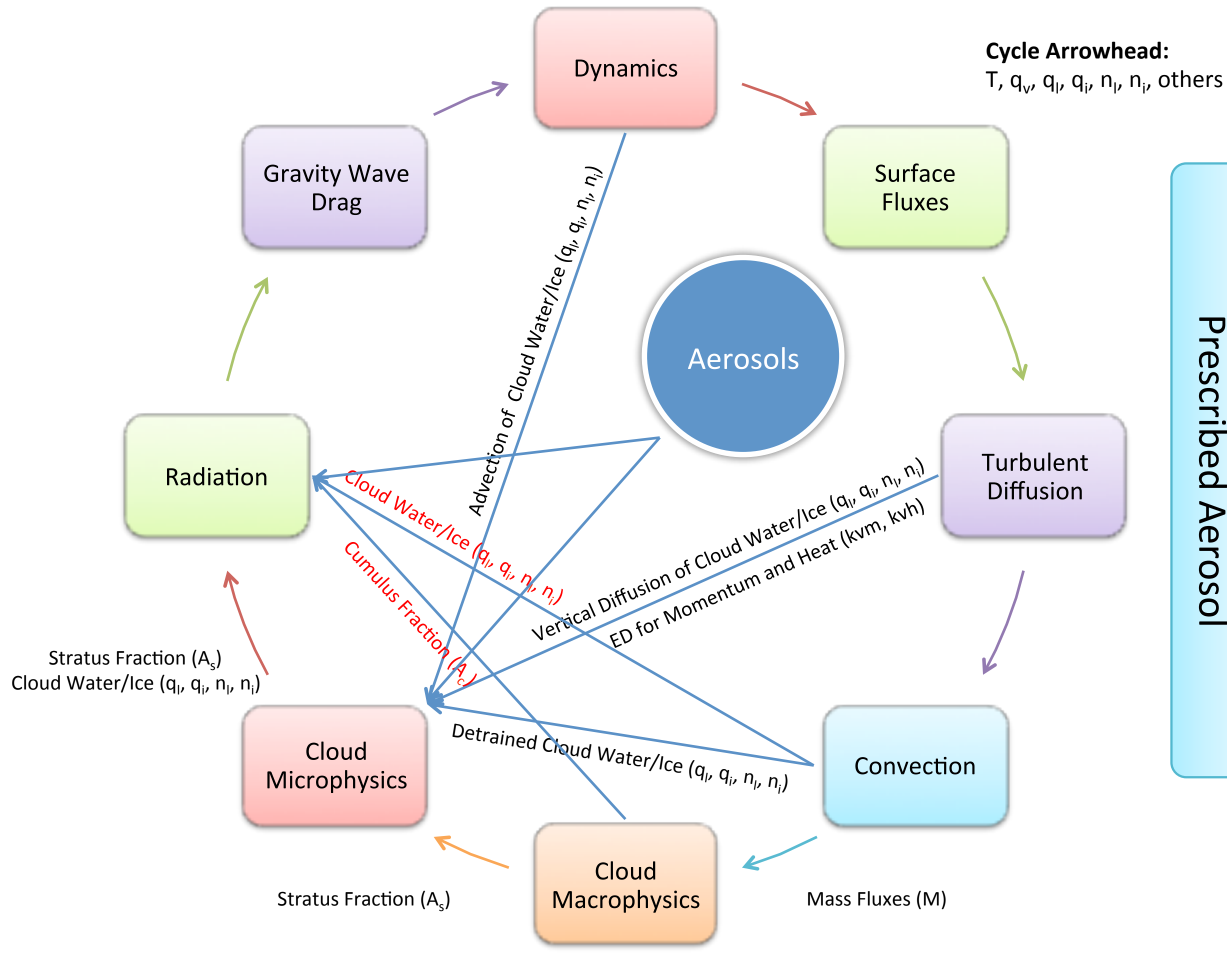


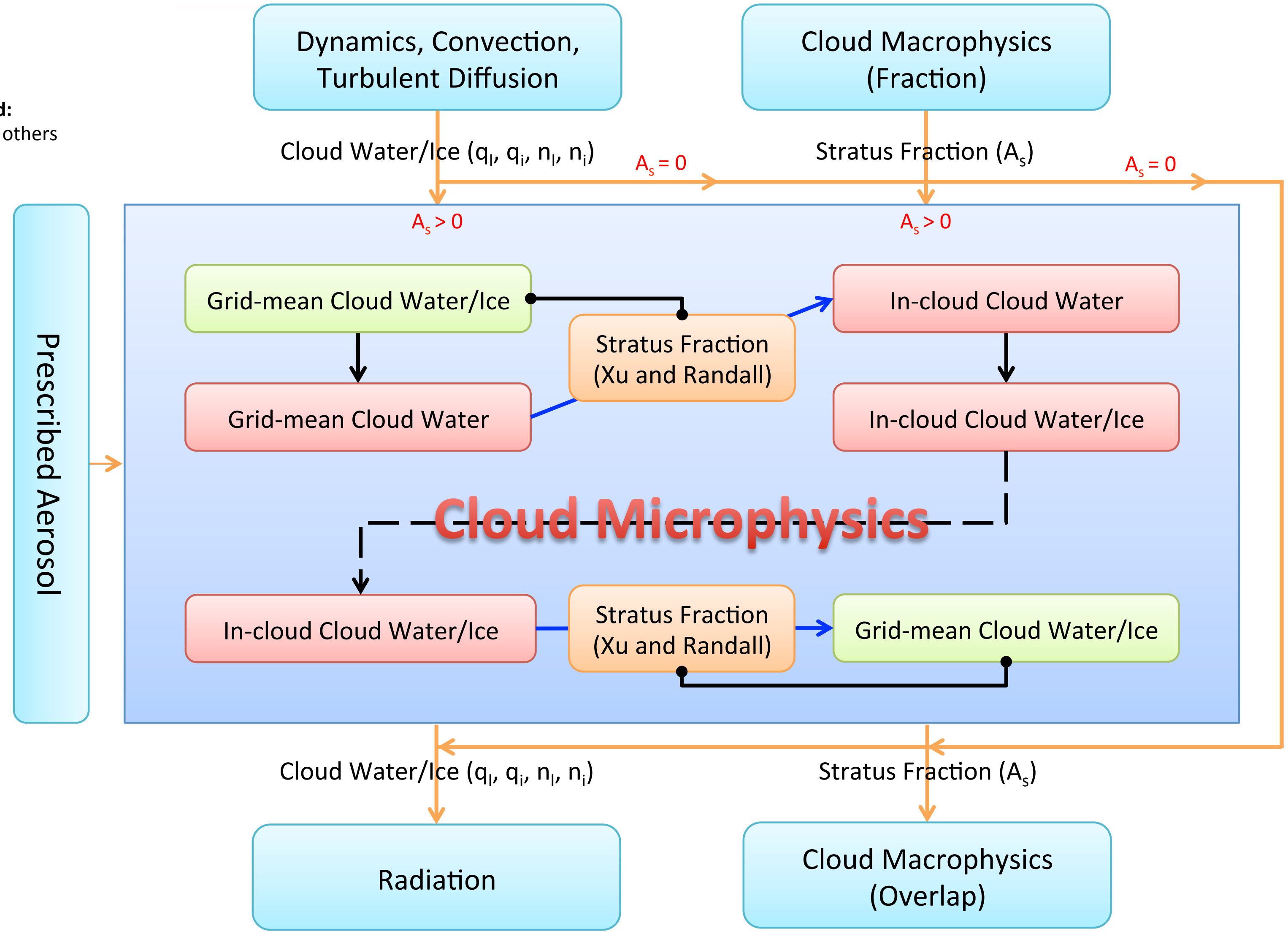
# Intensity frequency Analysis



# On-going work of FAMIL

# Flow Chart of FAMIL Physics and CLR2



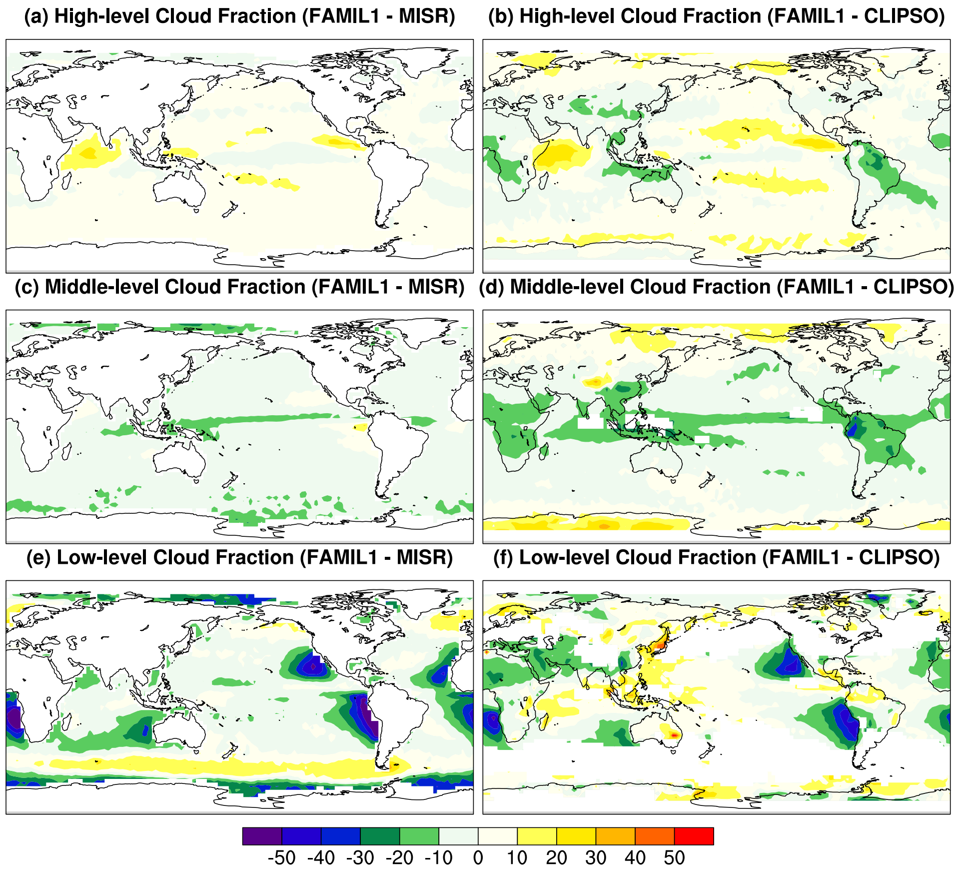




The Chen-Liu-Reisner(CLR2) Scheme (Chen and Liu 2004; Cheng et al., 2010;Chen et. al,2013) is a bulk water two-moment mixed-phase cloud microphysics scheme

- To Study the direct and indirect effects of aerosol on stratiform cloud in GCM;
- To build and evaluate a two-moment stratiform cloud scheme in GCM.

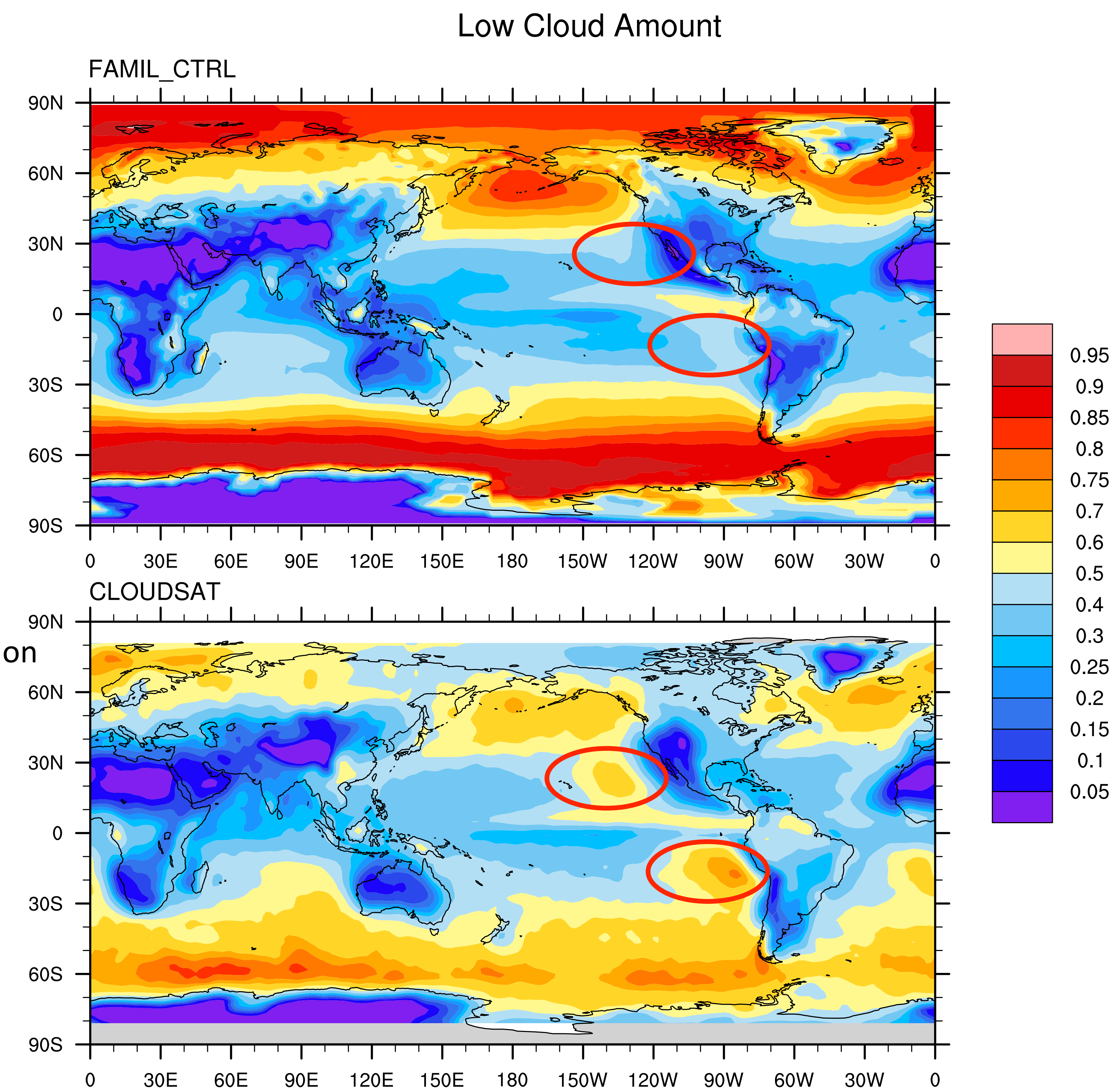
# Toward the Improvement of Low Cloud Simulations in LASG GCM

X. Wang, G. Nian, Q. Bao and B. He



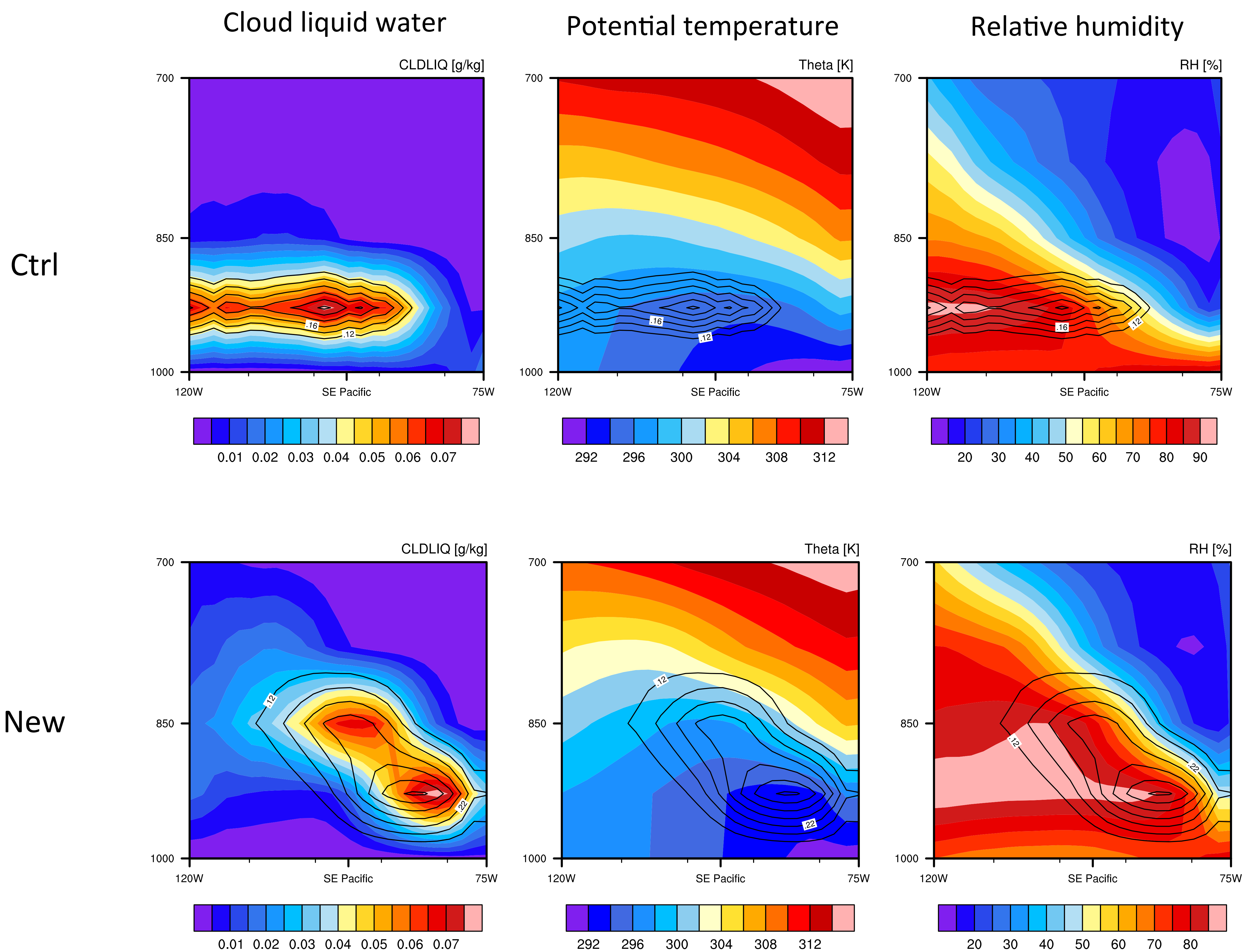
# Motivation

Non-local PBL scheme
with diagnosed PBL height

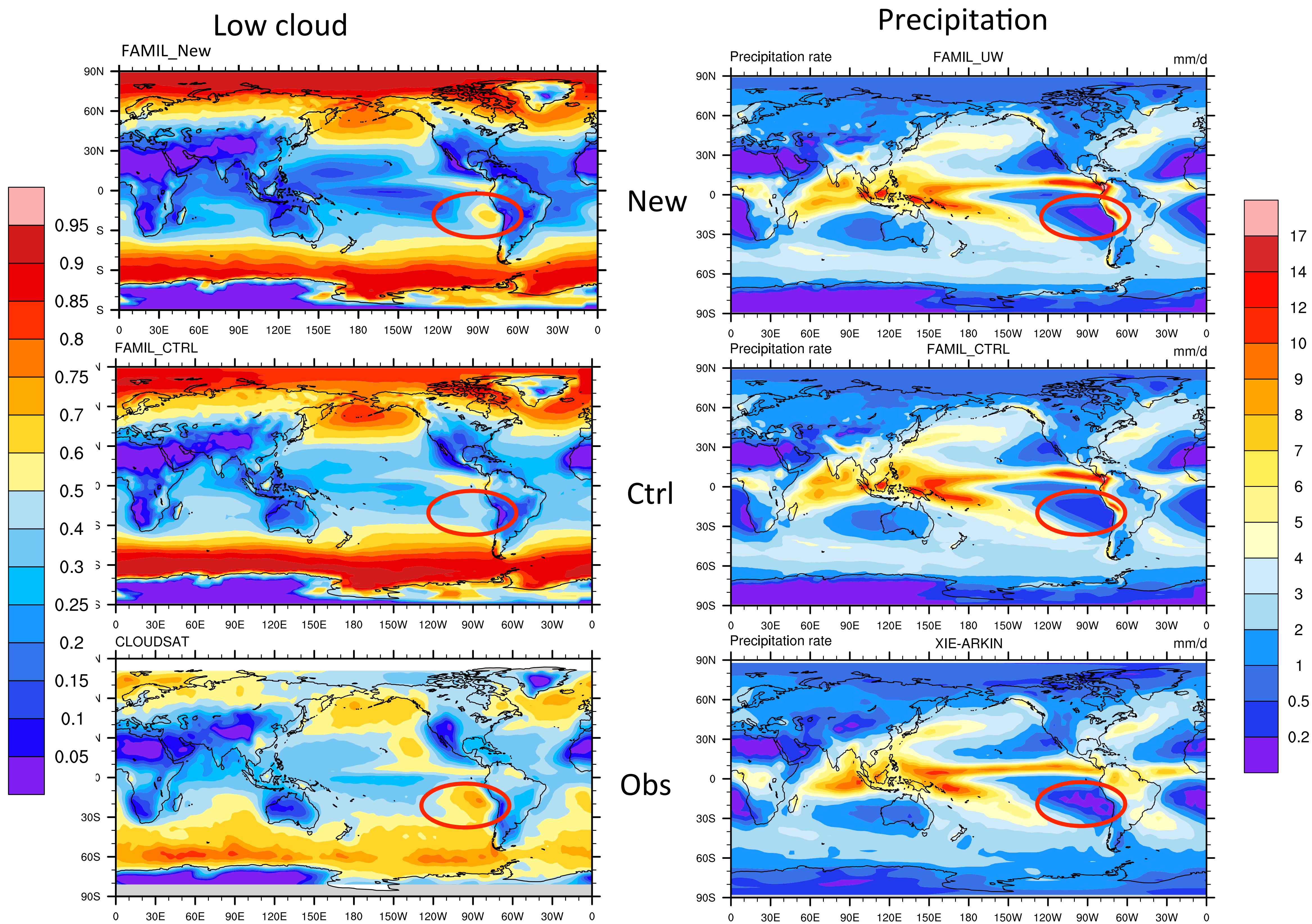



Modifications:

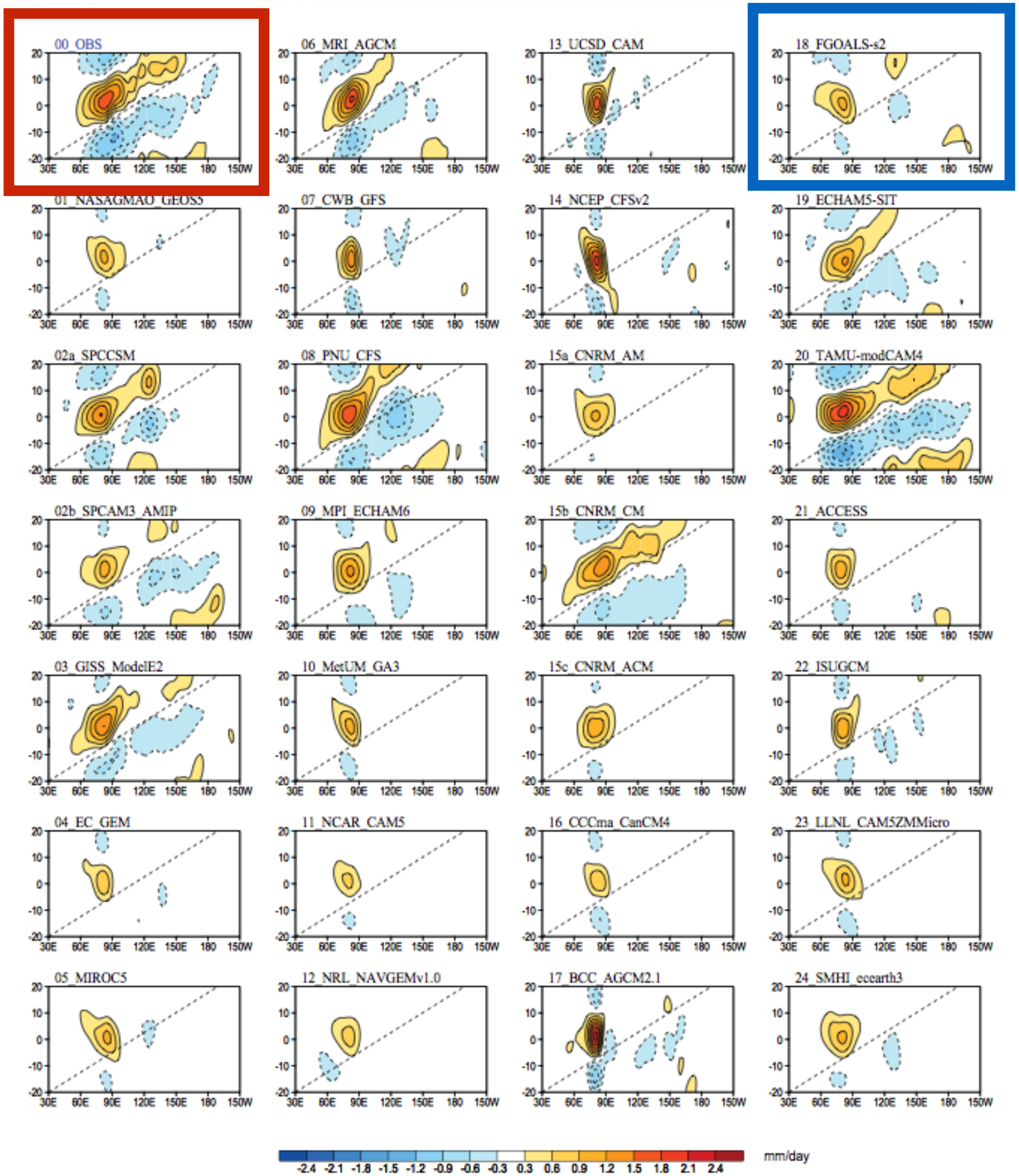
Turbulence Scheme
Cloud Cover Parameterization
Cumulus convection



Cloud liquid water
Potential temperature
Relative humidity
Ctrl
New
CLDLIQ [g/kg]
Theta [K]
RH [%]
700
850
1000
120W
SE Pacific
75W
.16
.12
.22
0.01 0.02 0.03 0.04 0.05 0.06 0.07
292 296 300 304 308 312
20 30 40 50 60 70 80 90
20 30 40 50 60 70 80

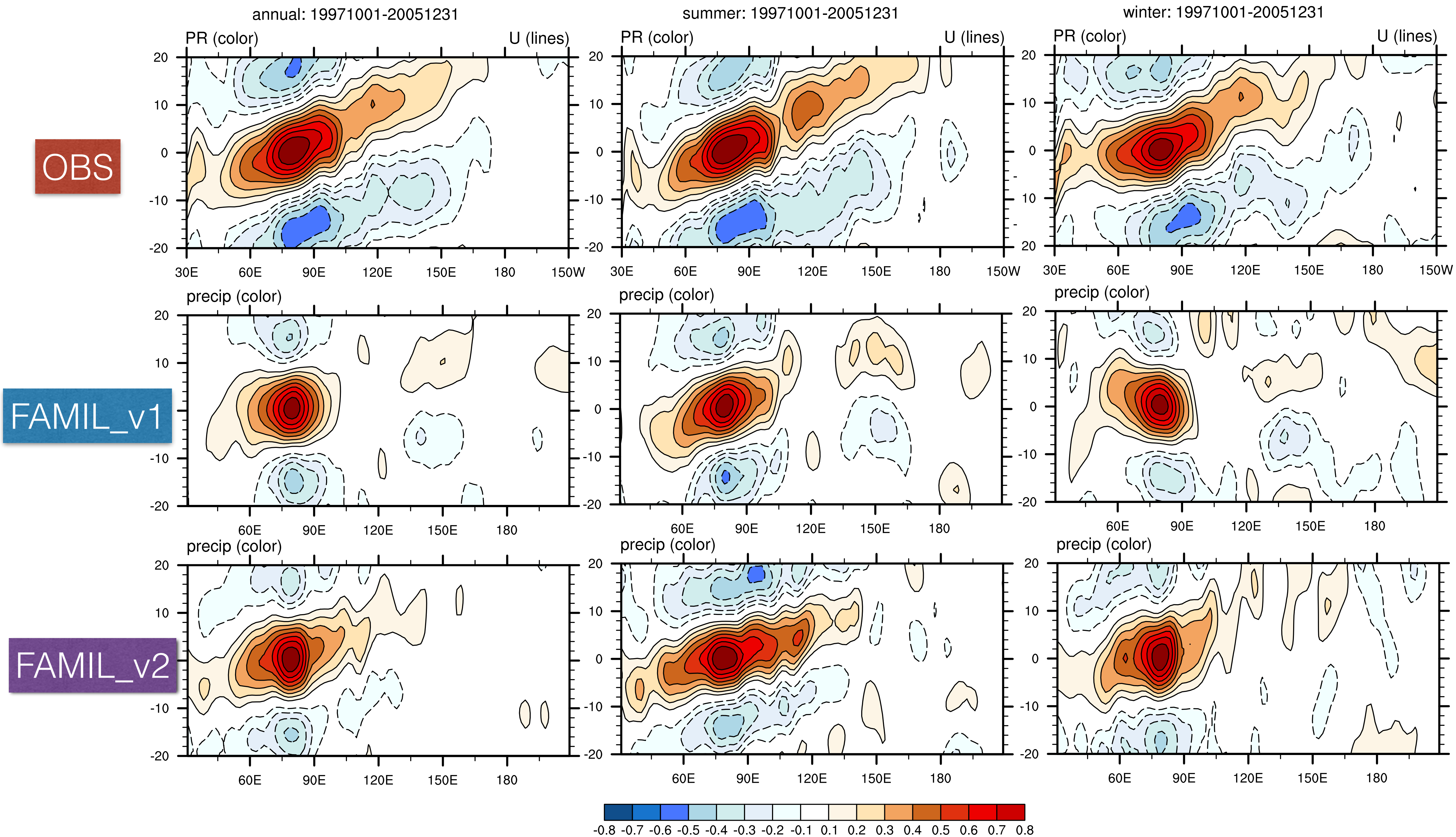

Low cloud
Precipitation
FAMIL_New
FAMIL_CTRL
CLOUDSAT
Precipitation rate
FAMIL_UW
FAMIL_CTRL
XIE-ARKIN
mm/d
New
Ctrl
Obs
0.95
0.9
0.85
0.8
0.75
0.7
0.6
0.5
0.4
0.3
0.25
0.2
0.15
0.1
0.05
17
14
12
10
9
8
7
6
5
4
3
2
1
0.5
0.2
90N
60N
30N
0
30S
60S
90S
0
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W

# MJO in CMIP5 models




Jiang et al., 2014

# MJO in FAMIL



annual: 19971001-20051231
summer: 19971001-20051231
winter: 19971001-20051231
PR (color)
U (lines)
OBS
FAMIL_v1
FAMIL_v2
precip (color)
30E
60E
90E
120E
150E
180
150W
20
10
0
-10
-20
-0.8 -0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

# Plan of FGOALS3 atmospheric team in CMIP6 （Horizontal resolutions）

- Long-term projections with ESM FGOALS3 (200km)
- Long-term projections with CSM FGOALS3 (100km)
- Near-term projections with FGOALS3 (50km)
- Stand-alone AGCM (25km)

# Global Monsoons Modeling Inter-comparison Project (GMMIP)

# Application for CMIP6-Endorsed MIPs

*Date: 22 September 2014*

**Proposed by:**

CLIVAR AAMP, CLIVAR-GEWEX MP in collaboration with LASG/IAP, PNNL, and CLIVAR/C20C+

***Primary Contacts*:**

Tianjun ZHOU (zhoutj@lasg.iap.ac.cn), Bin Wang (wangbin@hawaii.edu),
Andrew Turner (a.g.turner@reading.ac.uk), Yun Qian (yun.qian@pnnl.gov)
Bin Wang (wab@lasg.iap.ac.cn), James Kinter (ikinter@gmu.edu)

**Primary Science Questions:**

1) What are the relative contributions of internal processes and external forcing that are driving the 20$^{th}$ century historical evolution of global monsoons?
2) To what extent and how does the atmopshere-ocean interaction contribute to the interannual variability and predictability?
3) What are the effects of Eurasian orography, in particular the Himalaya/Tibetan Plateau, on the regional/global monsoons?
4) How well can developing high-resolution models and improving model dynamics and physics help to reliably simulate monsoon precipitation and it variability and change?

# Summery

- Description of a new generation AGCM: FAMIL developed at IAP-LASG, and designed for CMIP6
- Evaluation of the simulated global energy and water balance in FAMIL
- Preliminary results from 200km to 50km resolutions (Precipitation, Asian Summer Monsoon)
- Low cloud simulations are significantly improved in the newer version, in particular for the representation of marine stratocumulus clouds.
- GMMIP for CMIP6

# Thank you!

## TASK-1: Understanding 20th century changes of global monsoons

**Table 1:** Experiment list of GMMIP TASK-1

| EXP name | Integration time | Short description and purpose of the EXP design | Model type |
|---|---|---|---|
| HIST | 1860-2014 | 20th century historical run that includes all forcing (standard historical run of CMIP5); to understand the roles of natural and anthropogenic external forcings | CGCM |
| ANT | 1860-2014 | 20th century historical run that includes only anthropogenic forcing; to understand the roles of anthropogenic external forcing | CGCM |
| NAT | 1860-2014 | 20th century historical run that includes only natural forcing; to understand the roles of natural forcing | CGCM |
| EXT_AMIP | 1860-2014 | Extended AMIP run that covers the whole 20th century; both the anthropogenic and natural forcings are prescribed at 1990 level; to identify the forcing of dominant SST modes to monsoon | AGCM |
| HIST_IPO | 1860-2014 | Pacemaker 20th century historical run that includes all forcing, and the observational historical SST is restored in the tropical lobe of the IPO domain (20°S-20°N, 175°E-75°W); to understand the forcing of IPO-related tropical SST to global monsoon changes | CGCM with SST restored to the model climatology plus observational historical anomaly in the tropical lobe of IPO domain |
| HIST_AMO | 1860-2014 | Pacemaker 20th century historical run that includes all forcing, and the observational historical SST is restored in the AMO domain (0°-70°N, 70°W-0°); to understand the forcing of AMO-related SST to global monsoon changes | CGCM with SST restored to the model climatology plus observational historical anomaly in the AMO domain |

**TASK-2: Interannual variability of global monsoon precipitations**

AGCM simulations with specified SST generally have low skill in simulating the summer precipitation over global monsoon domains, especially the Asian-western Pacific summer monsoon domain. This can be partly attributed to the exclusion of air-sea coupled processes. It is argued that in the real world the air-sea interaction in monsoon domains appears as "monsoon-driving-ocean", but in an AMIP simulation, the interaction mechanism is "ocean-driving-monsoon" by construction (Wang et al. 2005). TASK-2 aims to understand the relative contributions of the tropical central and eastern Pacific Ocean (EP, 20°S-20°N, 175°E-75°W), western Pacific Ocean (WP, 20°S-20°N, 110°-170°E), tropical Indian Ocean (TIO, 20°S-20°N, 50°-100°E), and tropical Atlantic Ocean (TA, 20°S-20°N, 70°W-10°E) in driving the interannual variability of global monsoons.

**Table 2:** Experiment list of GMMIP TASK-2

| **EXP name** | **Integration time** | **Short description and purpose of the EXP design** | **Model type** |
|---|---|---|---|
| EP_PACE | 1979-2014 | Unnecessary to perform but as a period from TASK-1 HIST_IPO Exp during 1979-2014 | CGCM |
| WP_PACE | 1979-2014 | As EP_PACE, but for WP (20°S-20°N, 110°-170°E); to understand the forcing of WP SST to monsoon variability | CGCM |
| TIO_PACE | 1979-2014 | As EP_PACE, but for TIO (20°S-20°N, 50°-100°E); to understand the forcing of TIO SST to monsoon variability | CGCM |
| TA_PACE | 1979-2014 | As EP_PACE, but for TA (20°S-20°N, 70°W-10°E); to understand the forcing of TA SST to monsoon variability | CGCM |

**TASK-3: The role of Eurasian orography on the regional/global monsoons (Himalaya/Tibetan Plateau experiment)**

The goals of TASK-3 are to provide a benchmark of current model behavior in simulating the relationship of the monsoon to the Tibetan-Iranian Plateau (TIP, the highlands in 20-60°N, 25-120°E) so as to stimulate further research on the thermodynamical and dynamical effects of the TIP on the monsoon system. In particular the relative contributions of thermal and orographic mechanical forcing by the TIP to the Asian monsoon will be addressed.

The task extends the studies from the TIP to other highlands including highlands in Africa, N. America and S. America.

**Table 3:** Experiment list of GMMIP TASK-3

| EXP name | Integration time | Short description and purpose of the EXP design | Model type |
|---|---|---|---|
| CTRL (core) | 1979-2012 | AMIP run; standard CMIP6 Exp | AGCM |
| DTIP (core) | 1979-2012 | The topography of the TIP is modified by setting surface elevations to 500m; to understand the combined thermal and mechanical forcing of the TIP | AGCM |
| DTIP_DSH(core) | 1979-2012 | Surface sensible heat released at the elevation above 500m over the TIP is not allowed to heat the atmosphere; to compare of impact of removing thermal effects | AGCM |
| DHLD | 1979-2012 | The topography of the highlands in Africa, N. America and S. America TP is modified by setting surface elevations to a certain height (500m). | AGCM |

**TASK-4: High resolution modeling of global monsoons**

The monsoon rainbands are usually at a maximum width of 200 km. Climate models with low or moderate resolutions are generally unable to realistically reproduce the mean state and variability of monsoon precipitation. This is partly due to the model resolution. The TASK-4 aims to examine the performance of high-resolution models in reproducing both the mean state and year-to-year variability of global monsoons.

**The TASK-4 Experiment design includes**:

This TASK can be a joint activity of High Resolution Model Intercomparison Project (HighResMIP) led by Rein Haarsma (haarsma@knmi.nl) and Malcolm Roberts (malcolm.roberts@metoffice.gov.uk) under EU's Horizon2020.

The same AGCM AMIP simulations as in TASK-1, except with changes in resolution.

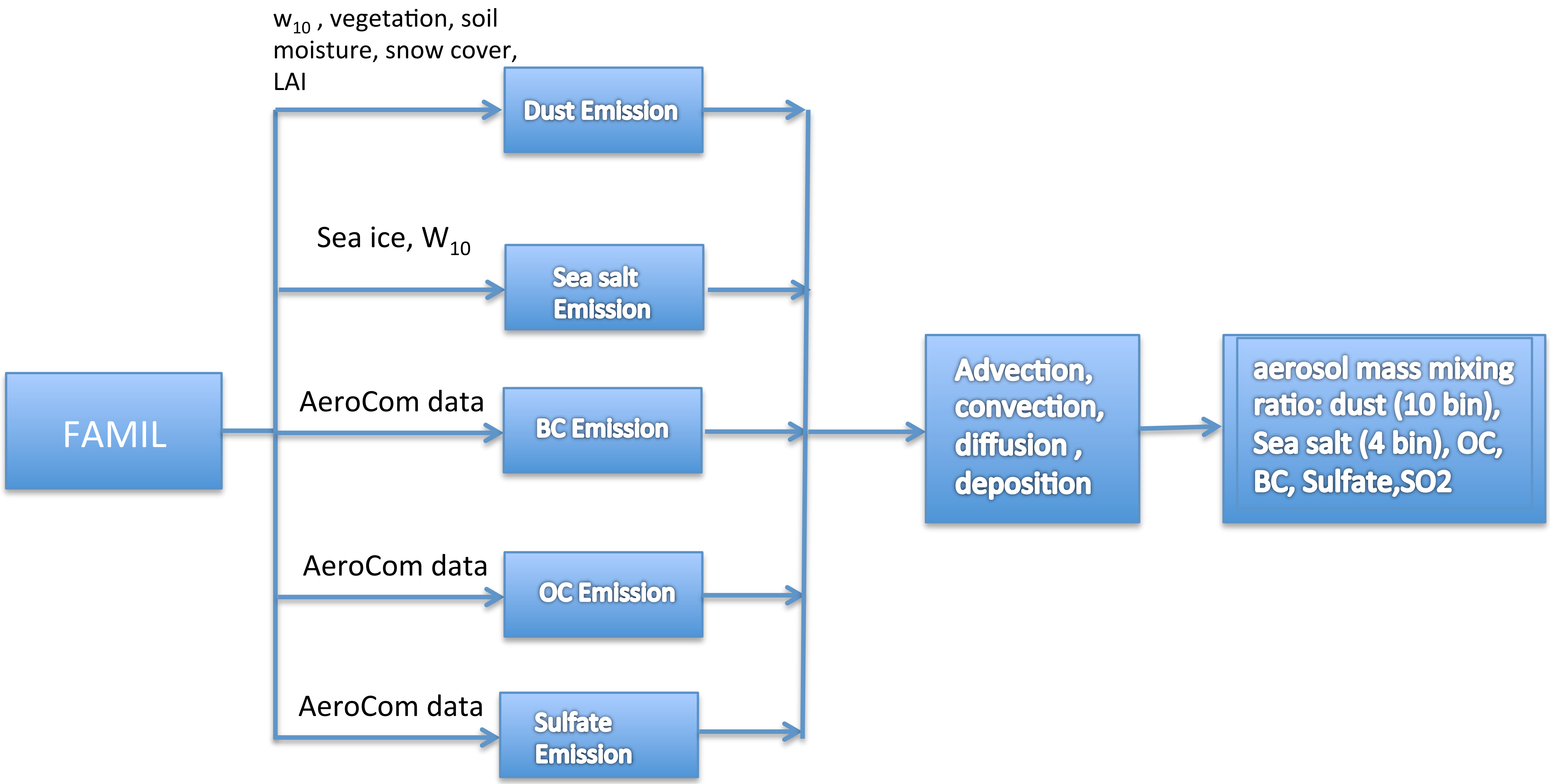
The horizontal resolutions should be approximately: ~ 25km, 50km, 100 km

The simulations will cover at least the period 1979-2014.

**Table 4:** Experiment list of GMMIP TASK-4

| EXP name | Integration time | Short description and purpose of the EXP design | Model type |
|---|---|---|---|
| AMIP_25 | 1979-2014 | Same as standard AMIP, but the horizontal resolutions are set to be: ~ 25km; to evaluate the performance of high resolution modeling | AGCM |
| AMIP_50 | 1979-2014 | Same as standard AMIP, but the horizontal resolutions are set to be: ~ 50km; to evaluate the performance of medium resolution modeling | AGCM |
| AMIP_100 | 1979-2014 | Same as standard AMIP, but the horizontal resolutions are set to be: ~ 100km; to evaluate the performance of low resolution modeling | AGCM |

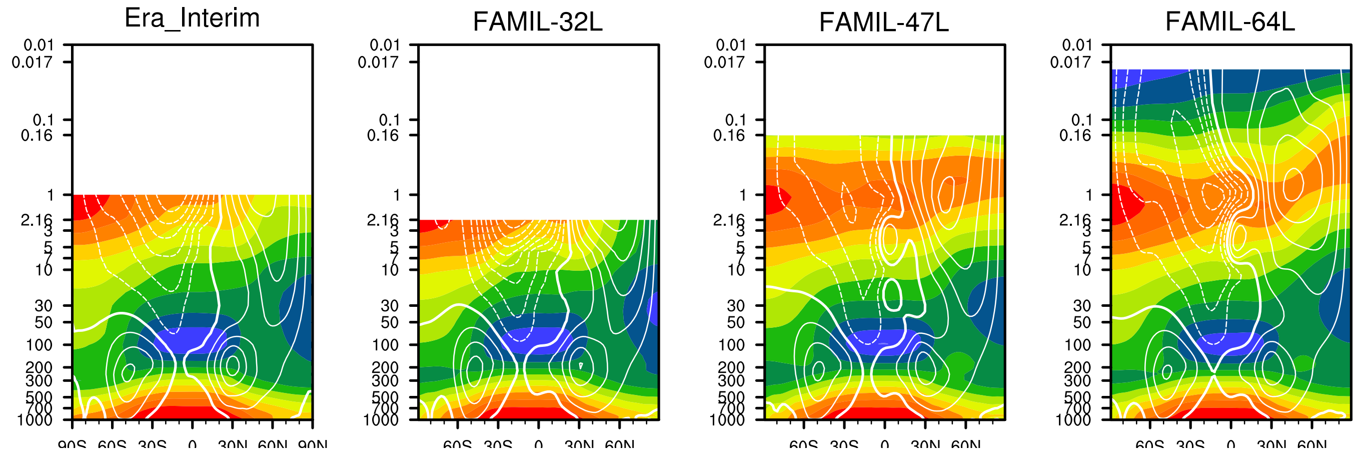
# Global online aerosol model: FAMIL+AEROSOL MODULE



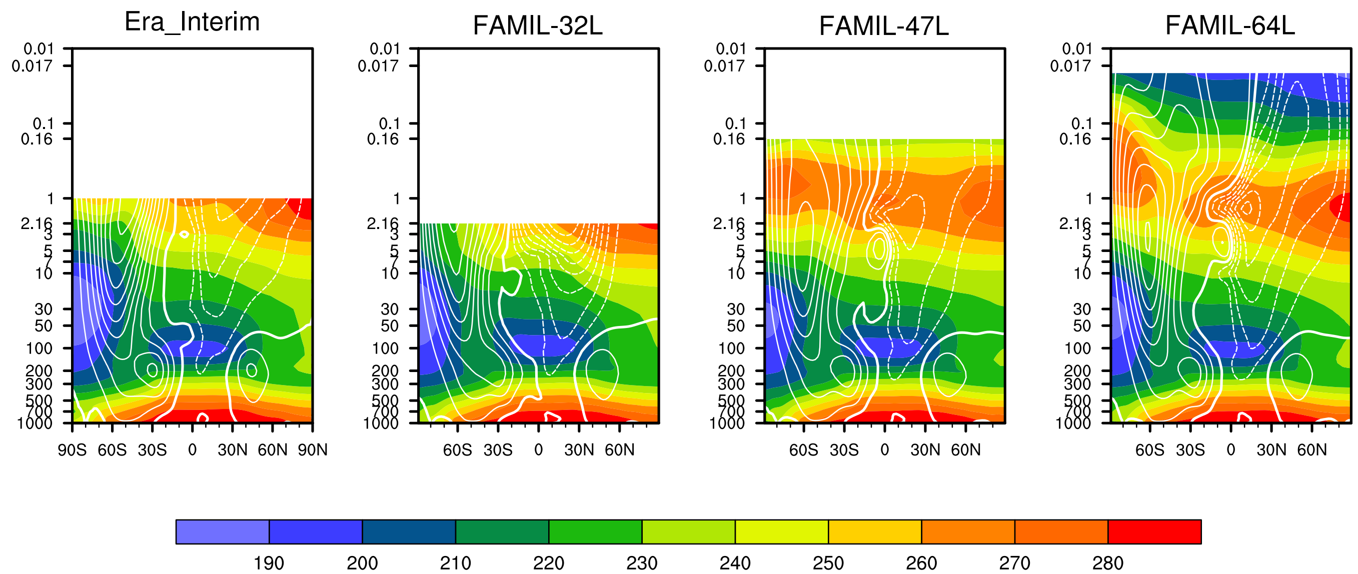

Structure of aerosol processes including emission, transport, and deposition in FAMIL

From DAI Tie

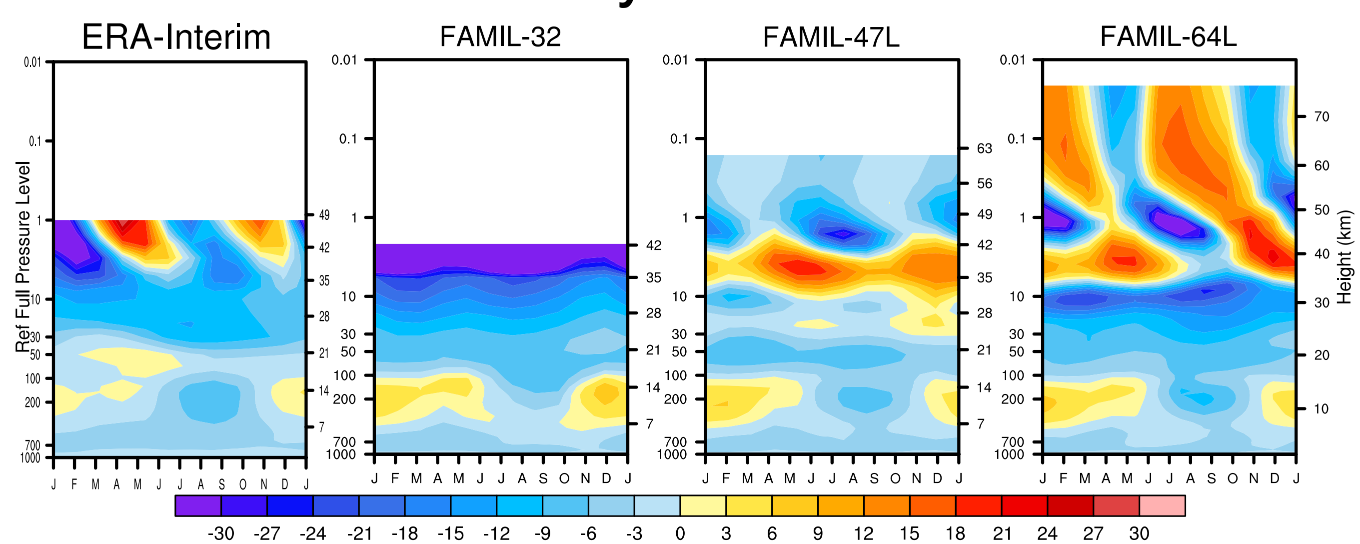
## Climatology of Zonal U and T in Jan




## Climatology of Zonal U and T in Jul




## U wind Annual cycle of zonal means




**Hybrid Vertical resolution has been improved from L32 (model top is 1hPa),L47( top at 0.1Pa) , to L64( top at 0.01Pa)**

# Future Plan

- High resolution modeling (FAMIL & FGOALS3)
  - Horizontal: 25km
  - Vertical : L64 (0.01hPa)
- Parameterizations of stratus and cumulous cloud and land surface in Tibetan Plateau
- Aerosol module
- Initialization module (for S2S)
- CMIP6
- Parallel efficiency
  - Supercomputer：Tian-He 1 & 2, CAS“元”

# 全球高分辨率大气环流模式FAMIL对全球能量和水份循环的模拟性能

## FAMIL1物理过程

能量守恒关系：

$$LH + SH + RF = \frac{\Delta(SE + GE + LE + KE)}{\Delta t}$$

水分守恒关系：

$$E - P = \frac{\Delta(Qv + Qc + Qr + Qi + Qs + Qg)}{\Delta t}$$

- 能量和水分守恒调整

等号左边：大气柱上下边界的能量／水分输送
等号右边：大气柱内部垂直积分能量／水分变化

实现每时间步长内，每个大气柱，上下边界的能量／水分输送等于大气柱内部垂直积分能量／水分变化

Zhou, L., Q. Bao* , Y. Liu et al., JAMES

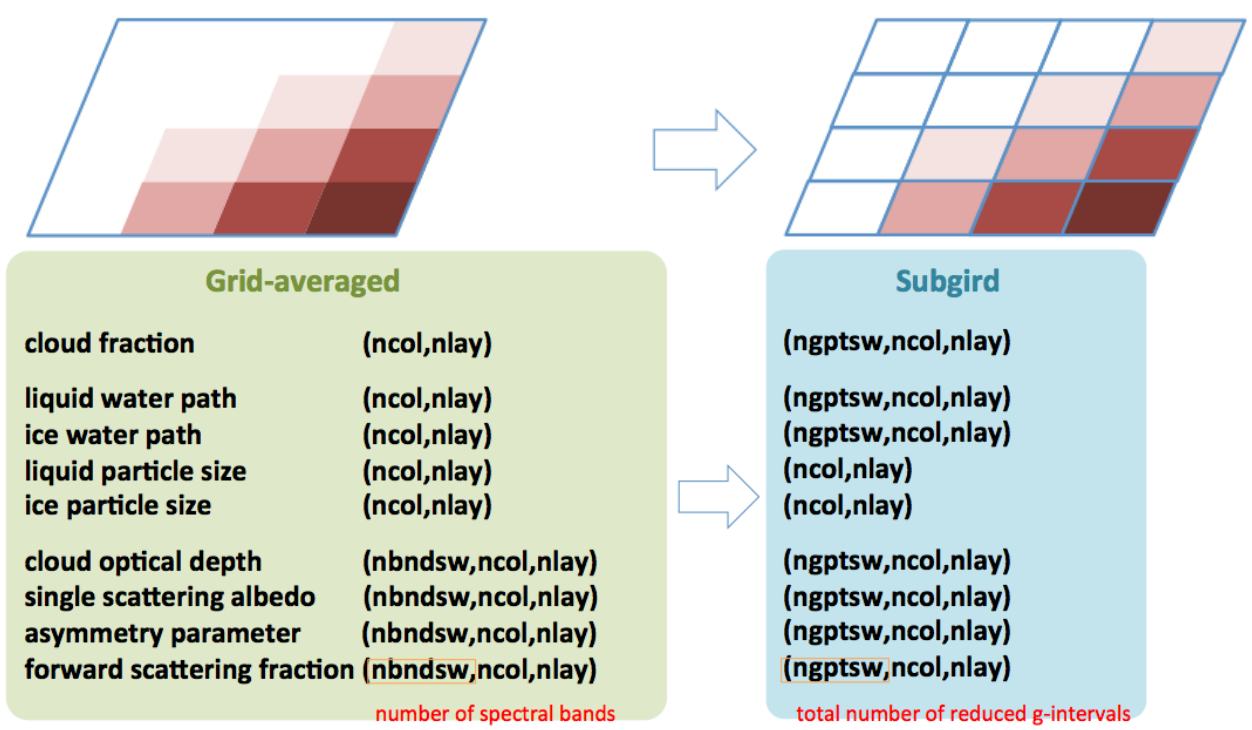
# 辐射方案：SES2(UKMO) ==> RRTMG/McICA

| UKMO | LW BAND(cm-1) | Species |
|---|---|---|
| 1 | 25~250 | H2O |
| 2 | 250~520 | H2O |
| 3 | 520~800 | H2O,CO2O3N2O |
| 4 | 800~980 | H2O, CO2 CFC11 CFC12 CFC113 CFC114 |
| 5 | 980~1100 | H2O, CO2 O3 CFC11 CFC12 CFC113 CFC114 |
| 6 | 1100~1400 | H2O, CH4, N2O |
| 7 | 1400~2000 | H2O, N2O |
| 8 | 2000~4000 | H2O, CO2, CH4, N2O |

| RRTMG | LW BAND(cm-1) | Lower Level | Mid/Upp Level |
|---|---|---|---|
| 1 | 10~250 | H2O | H2O |
| 2 | 250~500 | H2O | H2O |
| 3 | 500~630 | H2O,CO2 | H2O,CO2 |
| 4 | 630~700 | H2O, CO2 | CO2, O3 |
| 5 | 700~820 | H2O,CO2, CFC | CO2, O3,CFC |
| 6 | 820~980 | H2O,CFC | CFC |
| 7 | 980~1080 | H2O | O3 |
| 8 | 1080~1180 | H2O,CFC | O3 |
| 9 | 1180~1390 | H2O, CH4 | CH4 |
| 10 | 1390~1480 | H2O | H2O |
| 11 | 1480~1800 | H2O | H2O |
| 12 | 1800~2080 | H2O,CO2 | |
| 13 | 2080~2250 | H2O, N2O | |
| 14 | 2250~2380 | CO2 | CO2 |
| 15 | 2380~2600 | CO2,N2O | |
| 16 | 2600~3250 | H2O, CH4 | CH4 |

| UKMO | SW BAND(cm-1) | Species |
|---|---|---|
| 1 | 2000~4000 | H2O, CO2, CH4, N2O |
| 2 | 4000~5988 | H2O, CO2, CH4, N2O |
| 3 | 5988~8474 | H2O, CO2, O2 |
| 4 | 8474~12048 | H2O |
| 5 | 12048~14285 | O3, H2O, O2 |
| 6 | 14285~15873 | O3, H2O, O2 |
| 7 | 15873~20000 | O3, H2O |
| 8 | 20000~22222 | O3 |
| 9 | 22222~50000 | O3 |

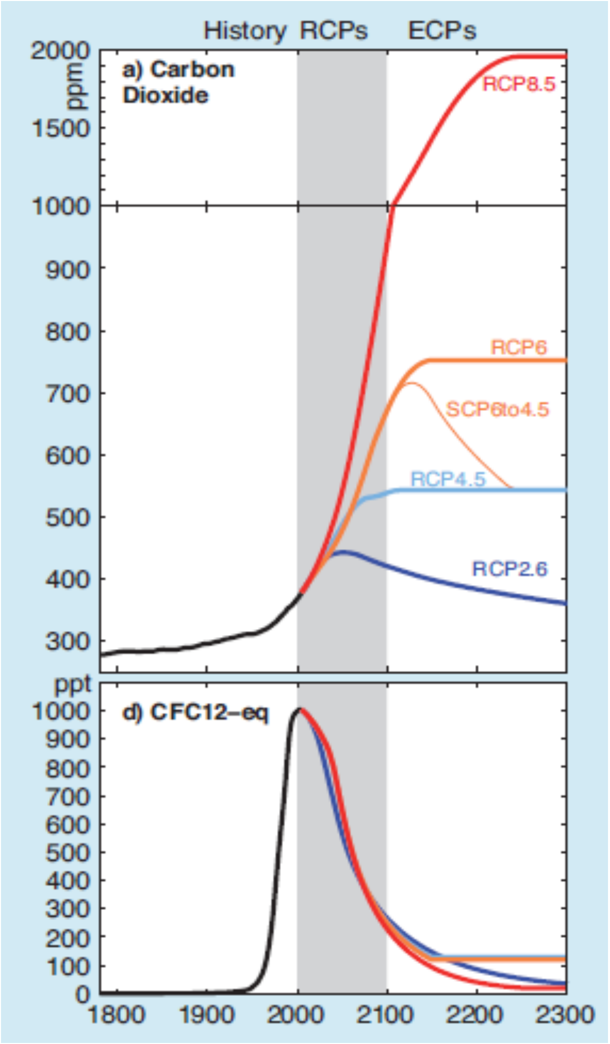
| RRTMG | SW BAND(cm-1) | Lower Level | Mid/Upp Level |
|---|---|---|---|
| 2 | 2600~3250 | H2O,CH4 | CH4 |
| 3 | 3250~4000 | H2O,CO2 | H2O,CO2 |
| 5 | 4000~4650 | H2O, CH4 | CH4 |
| 5 | 4650~5150 | H2O,CO2 | CO2 |
| 6 | 5150~6150 | H2O | H2O |
| 7 | 6150~7700 | H2O,CO2 | CO2 |
| 8 | 7700~8050 | H2O,CO2 | O2 |
| 9 | 8050~12850 | H2O | |
| 10 | 12850~16000 | H2O,O2 | O2 |
| 11 | 16000~22000 | H2O | |
| 12 | 22000~29000 | H2O | |
| 13 | 29000~38000 | O3 | O3 |
| 14 | 38000`50000 | O2,O3 | O2,O3 |

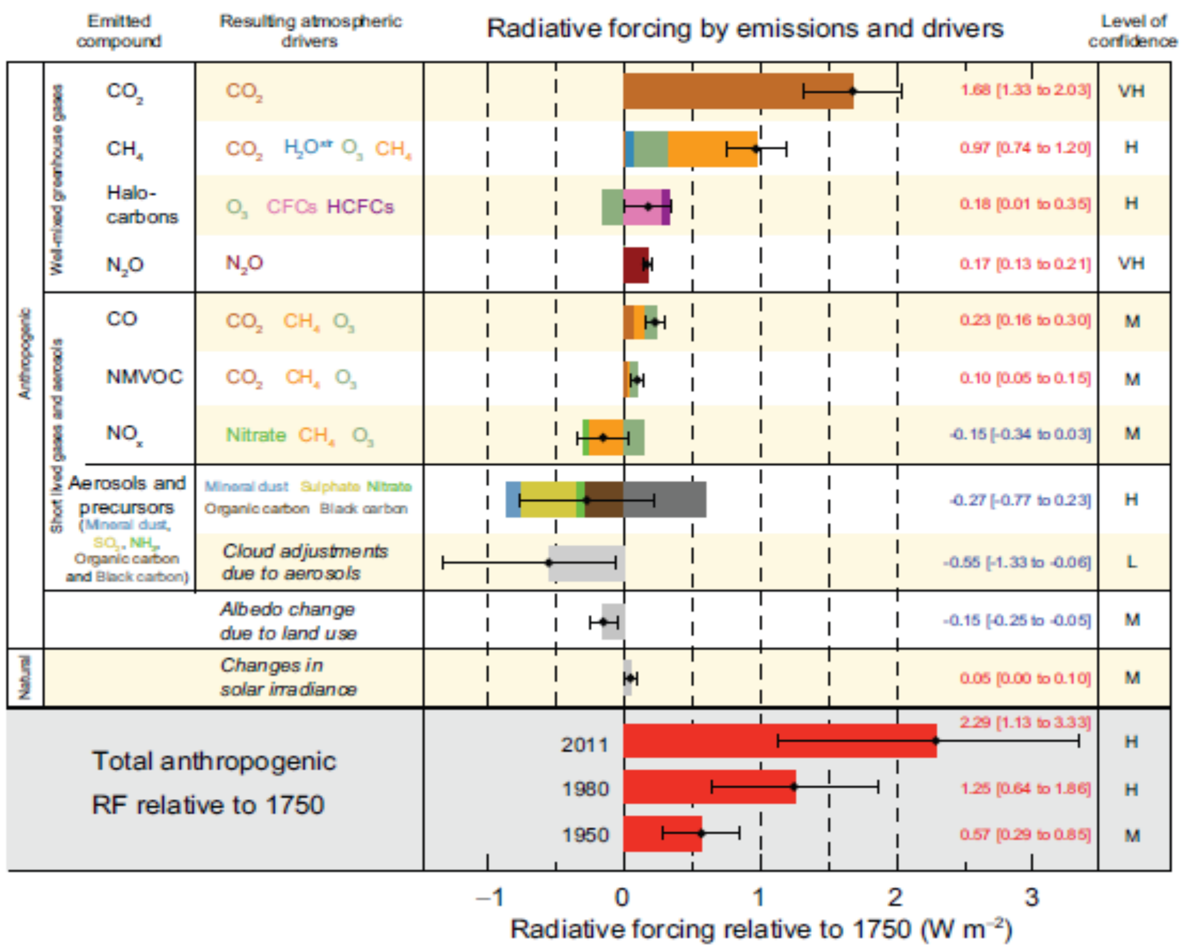



- RRTMG辐射方案波段分辨率提高（LW：16；SW：14），计算精度提高
- RRTMG考虑次网格云量的辐射效应

# 2014：架构和物理过程方面的研发进展

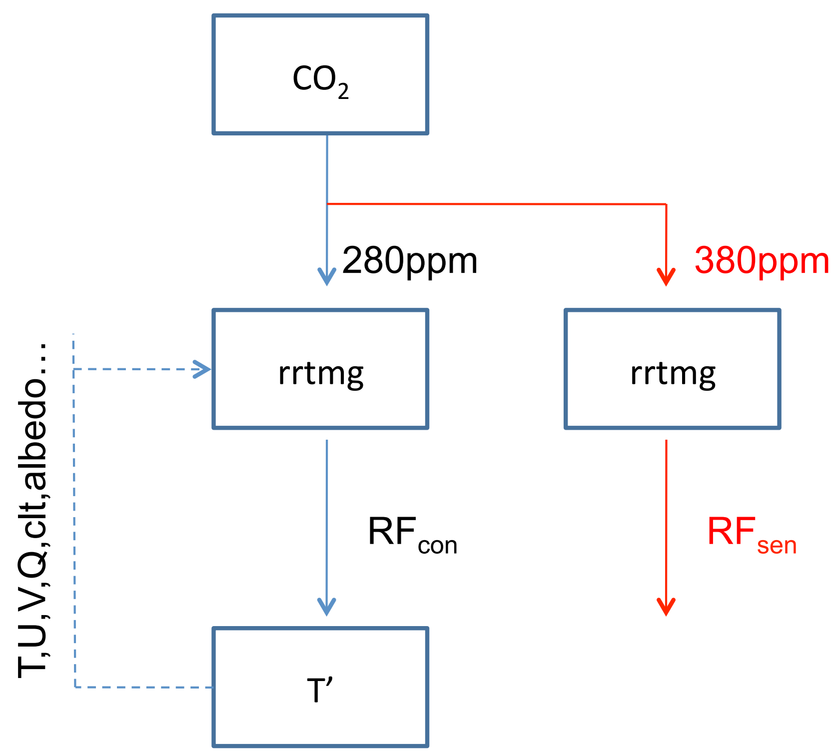
- 辐射方案：**SES2 ==> RRTMG/McICA**

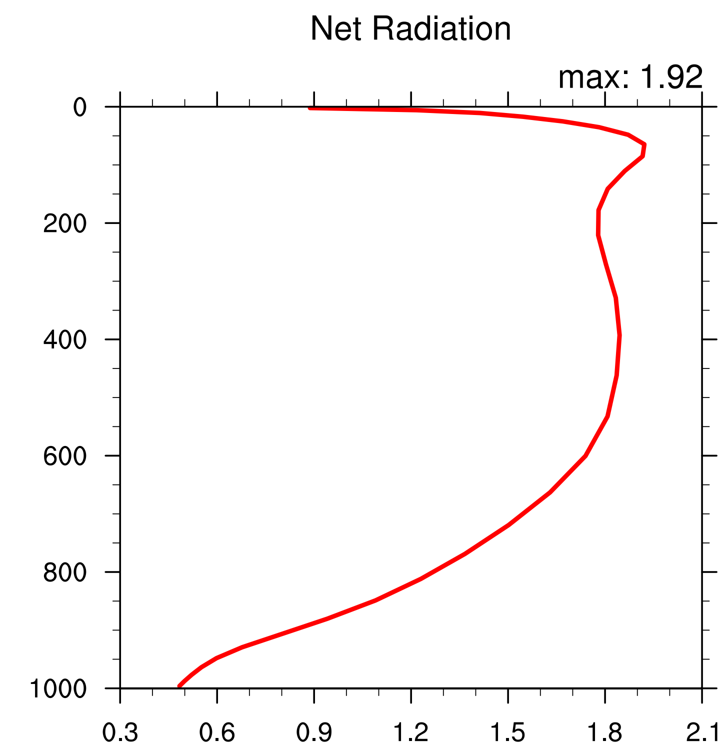


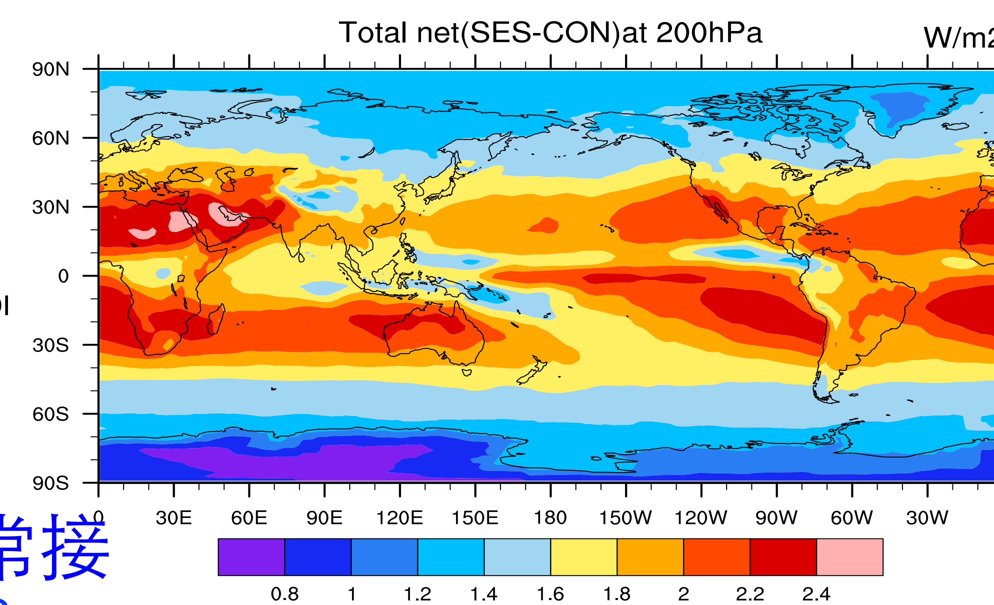

Based on IPCC AR5, the concentration of $CO_2$ arise from about 280ppm to 380ppm during 1750 to 2011, the corresponding Radiative Forcing (RF) for $CO_2$ alone is 1.68 W/m$^2$ with a range of 1.33 W/m$^2$ to 2.03 W/m$^2$.

# 辐射方案：SES2 ==> RRTMG/McICA




To test RF of $CO_2$ in the CESM-FAMIL with the RRTMG radiation calculation, One AGCM run has been taken out while the SES2 has been called twice with the $CO_2$ value of 280pmm (CON) and 380ppm (SEN) respectively. Moreover, the $Rf_{con}$ are cycled in the integration while $Rf_{sen}$ is offline. This method guarantees the evaluation of the RFs of different $CO_2$ is directive while exclude other climate feedbacks.




Differences of net radiation between SEN and CON at 200hPa. (units: W $m^{-2}$).

F/SAMIL中$CO_2$的辐射强迫为1.7W/m$^2$，非常接近IPCC AR5多模式集合平均结果1.68 W/m$^2$

RRTMG计算的温室气体、气溶胶等气候外强迫的辐射效应合理