Simulation of the Madden-Julian Oscillation in GCMs

: Progress and Issues

Daehyun Kim

*GCRM (global cloud resolving model): Next talk

MJO is still a challenging problem..

- No satisfactory theory that everyone agrees
- Inadequate simulation capability in most of the standard GCMs
  - Slingo et al. 1996: “models are poor”
  - Waliser et al. 2003 “models are poor”
  - Lin et al. 2006 “ models are poor”
  - Progress?? ☹

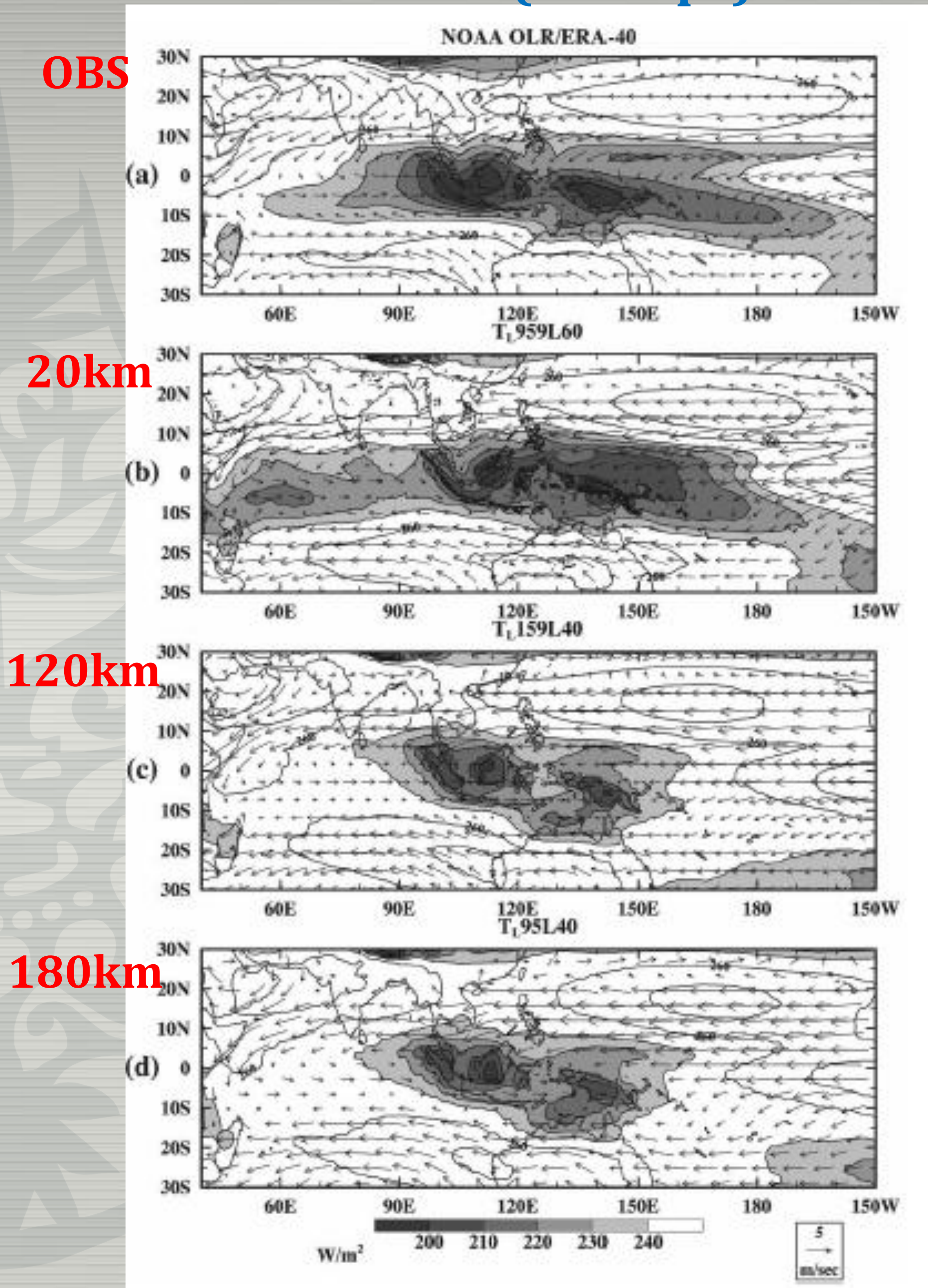
Progress

- Do we know what component of model configuration is important/unimportant?
  - Horizontal resolution: not important
  - Vertical resolution: positive impact
  - Air-sea coupling: some modification (e.g. amplitude)
  - Convection scheme: crucial

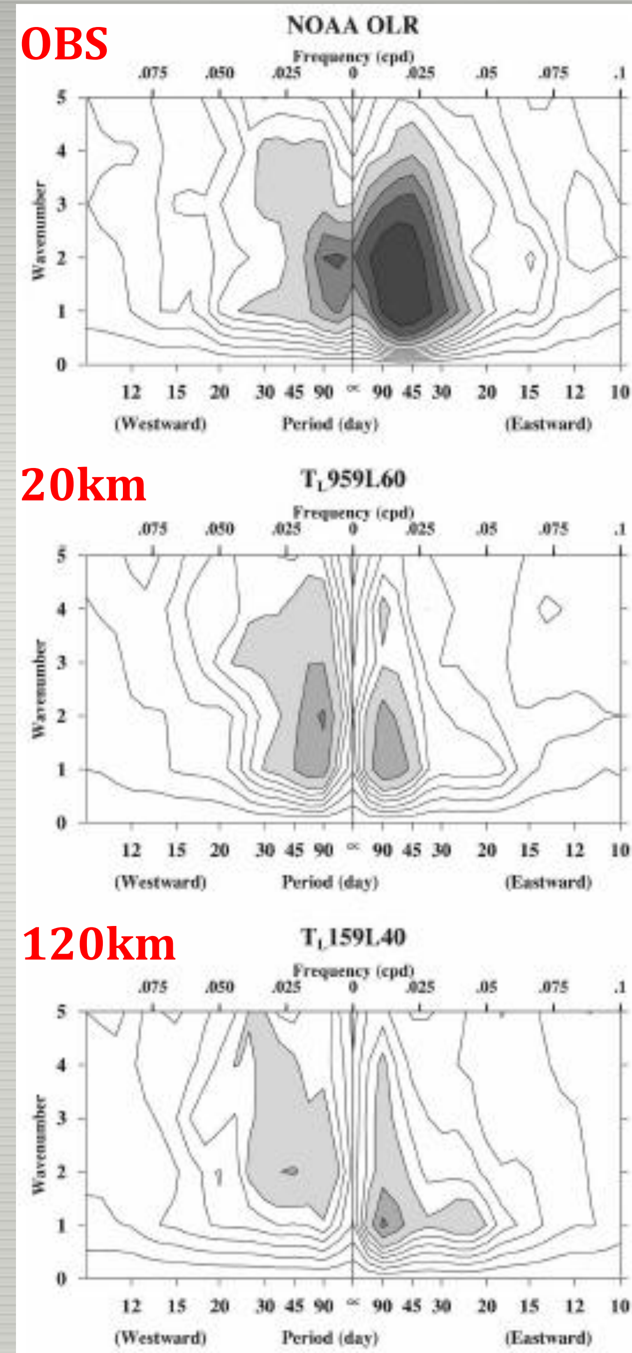
- Then, do we know how to improve representation of the MJO in GCMs?

- Yes, we know! ☺

Mean state (Nov-Apr)



Space-time power spectra



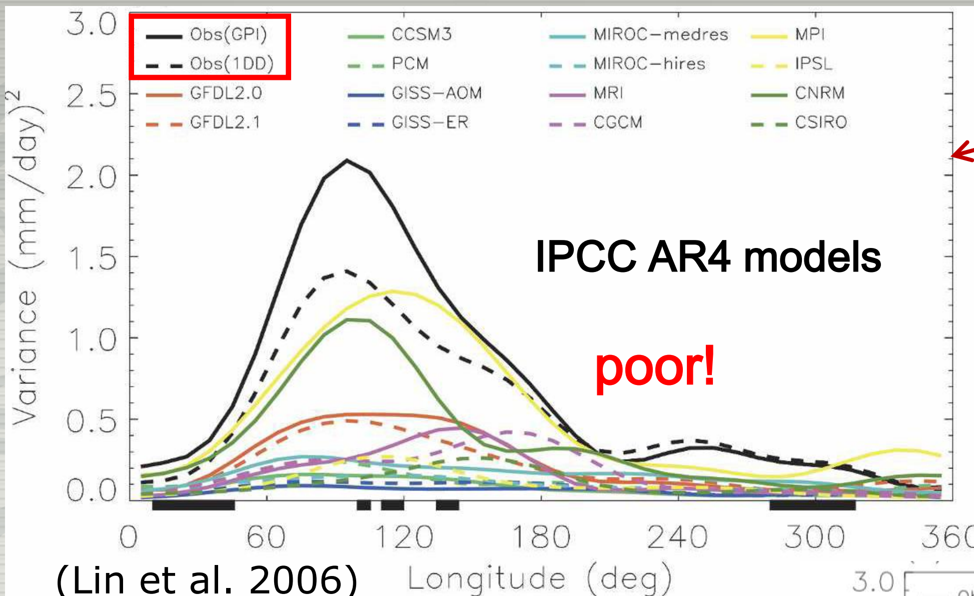
Rajendran et al. 2009, MRI/JMA AGCM

Cumulus parameterization

- Tokioka et al. 1988; Wang and Schlesinger 1999; Lee et al. 2001; Maloney and Hartmann 2001; Maloney 2002; Lee et al. 2003; Liu et al. 2005; Zhang and Mu 2005; Lin et al. 2008… more?

- Hypothesis: deep convection is a core component of the MJO, simulation fidelity of the MJO should depends on the way in which it is represented

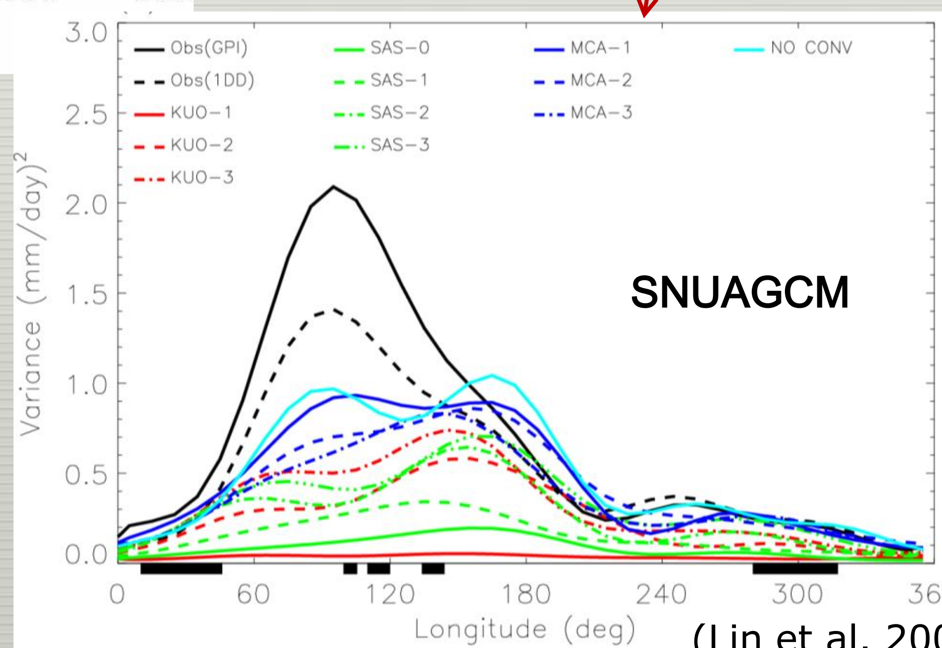
MJO Variance (eastward wavenumber 1-6, periods 30-70days)



(Lin et al. 2006)

different colors
- different climate models

different colors
- different convection schemes



(Lin et al. 2008)

Convection scheme

: represent model diversity in MJO variability

Progress (from our experiences)

- We know what is important and what is not important
  - Horizontal resolution: not important
  - Vertical resolution: positive impact
  - Air-sea coupling: some modification
  - Convection scheme: crucial

- We know how to improve MJO in GCMs
  - Cumulus parameterization: mass-flux convection scheme

AMIP (Slingo et al. 1996)

Model	Deep convection
BMRC	Kuo
CCC	MCA
CNRM	Bougeault
CSIRO	MCA
CSU	AS+MCA
ECMWF	Tiedtke
GLA	AS
GSFC	RAS
LMD	Kuo+MCA
MRI	AS
NCAR	Hack
NMC	Kuo/Tiedtke
RPN	Kuo
UGAMP	Betts-Miller
UKMO	Gregory

CMIP3 (Lin et al. 2006)

Model	Deep convection
GFDL CM2.0	RAS
GFDL CM2.1	RAS
NCAR CCSM3	ZM
NCAR PCM	ZM
GISS-AOM	Russell et al.
GISS-ER	Del Genio and Yao
MIROC-hires	Pan and Randall
MIROC-medres	Pan and Randall
MRI	Pan and Randall
CCCMA	ZM
MPI	Tiedtke
IPSL	Emanuel
CNRM	Bougeault
CSIRO	Gregory and Rowntree

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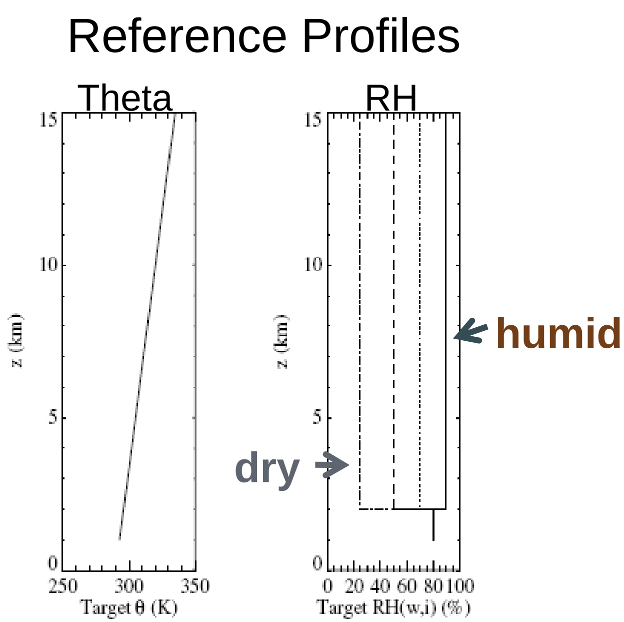
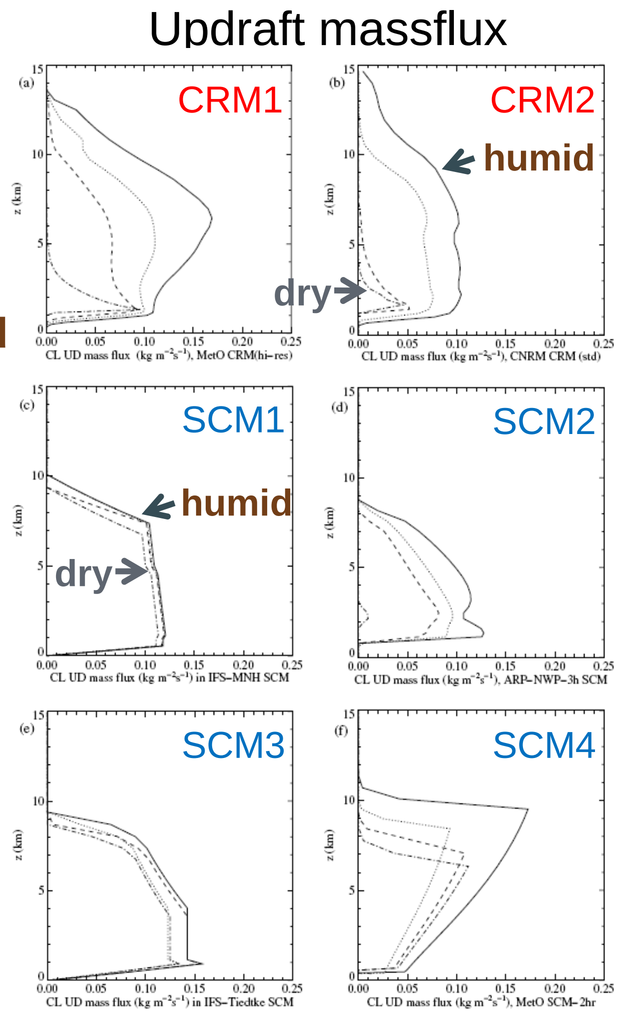
CSIRO	Gregory and Rowntree

Lack of sensitivity to environmental moisture





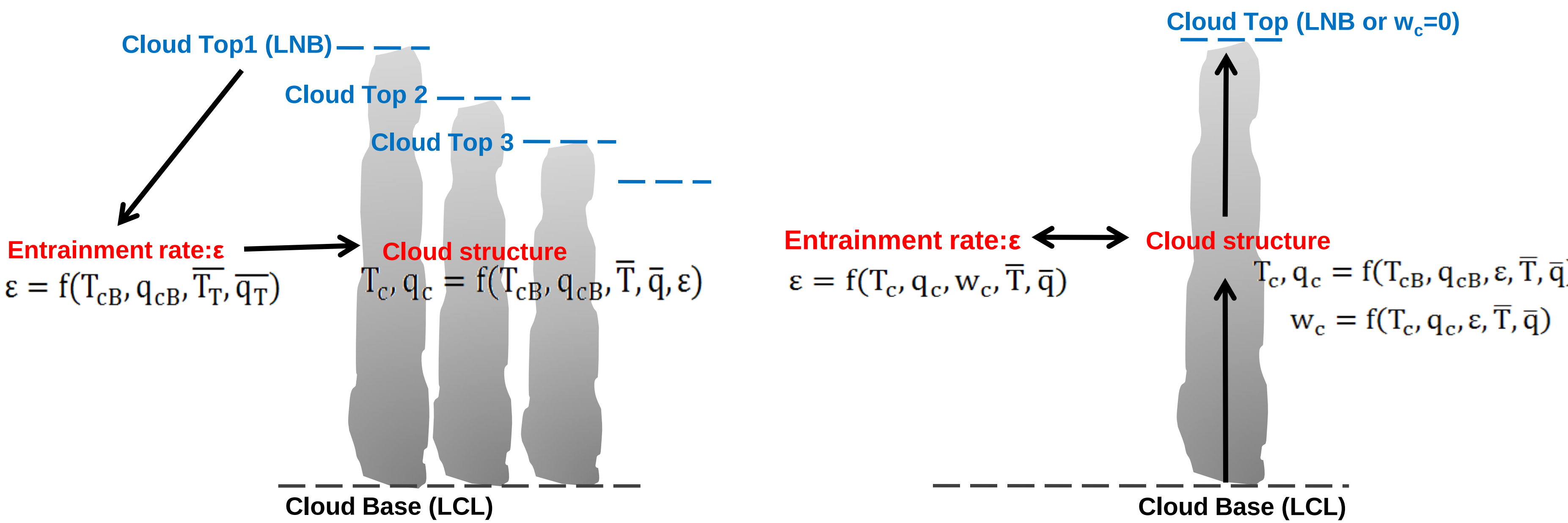
➔ SCMs lack sensitivity on environmental moisture (cloud top, strength)

Derbyshire et al. (2004)

How to improve MJO in your model

- Make convection scheme more sensitive to environmental moisture
  - If cloud top is determined first (as in many of AS-variants)➔ impose minimum entrainment rate
  - If cloud top is determined interactively ➔ increase entrainment rate
  - Additionally you can allow more evaporation from falling precipitation

Cloud model of mass flux cumulus parameterizations



❖ **Entrainment rate (passive)**
➔ smaller in deeper cloud

❖ **Minimum entrainment rate**
➔ turns off deep convection in dry column

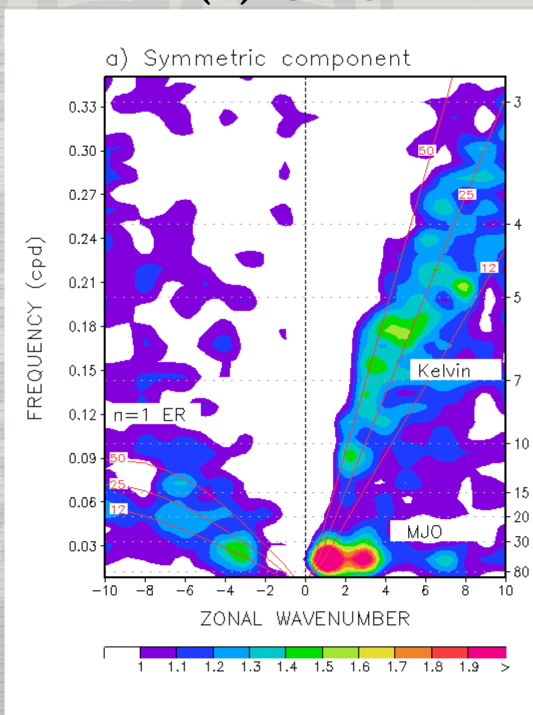
❖ **Entrainment rate (active)**
➔ Determines cloud top

❖ **Enhancing entrainment rate**
➔ makes cloud top lower in dry column

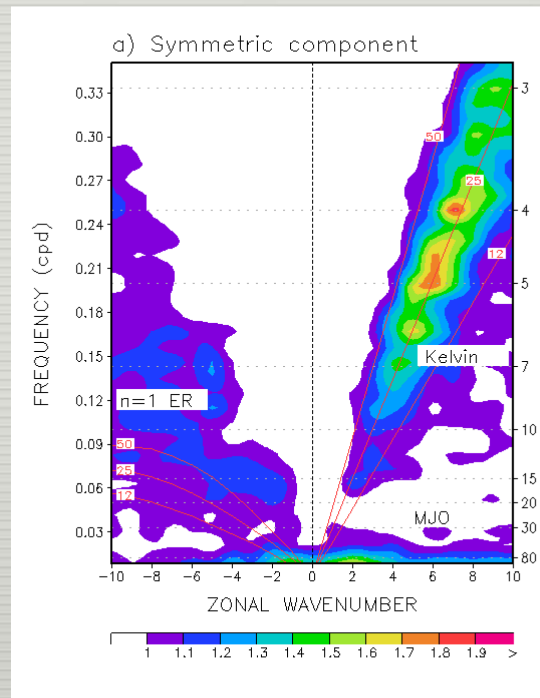
Results of GISS model

Wavenumber-frequency diagram (symmetric)

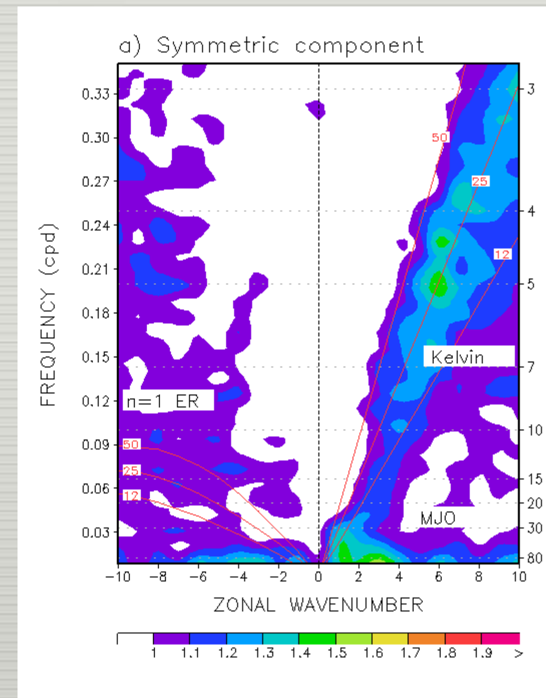
(a) GPCP



(b) A01



(c) A22



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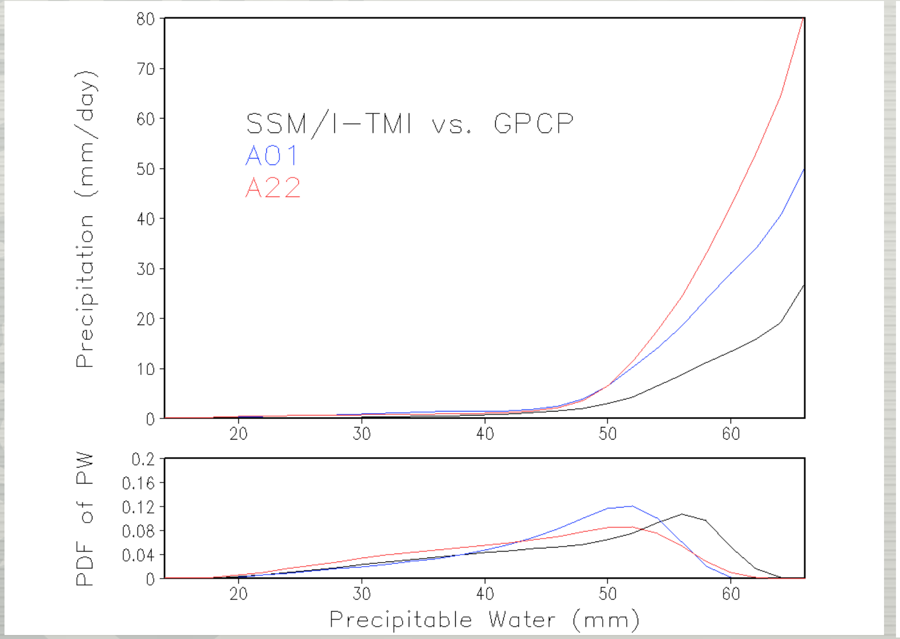
Poster session (Daehyun Kim)

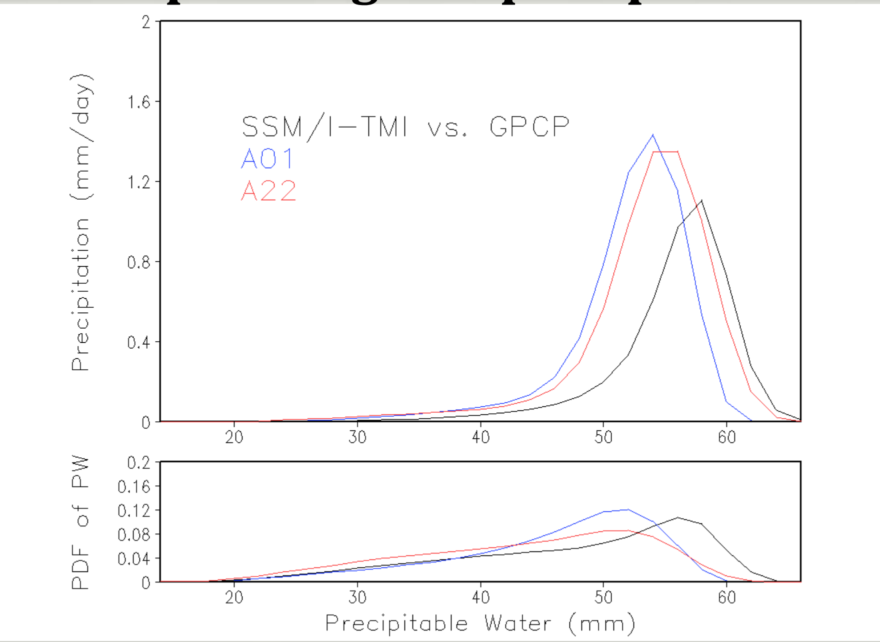
Moisture-convection interaction

Composite based on precipitable water – GISS models

Precipitation



pdf-weighted precipitation



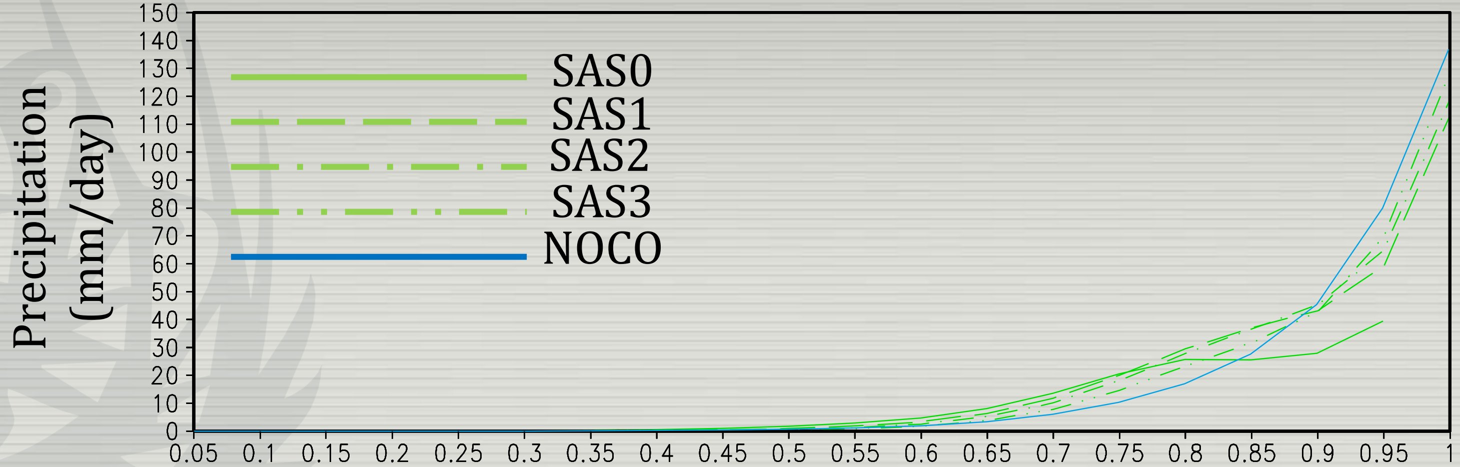
Poster session (Daehyun Kim)

Issues

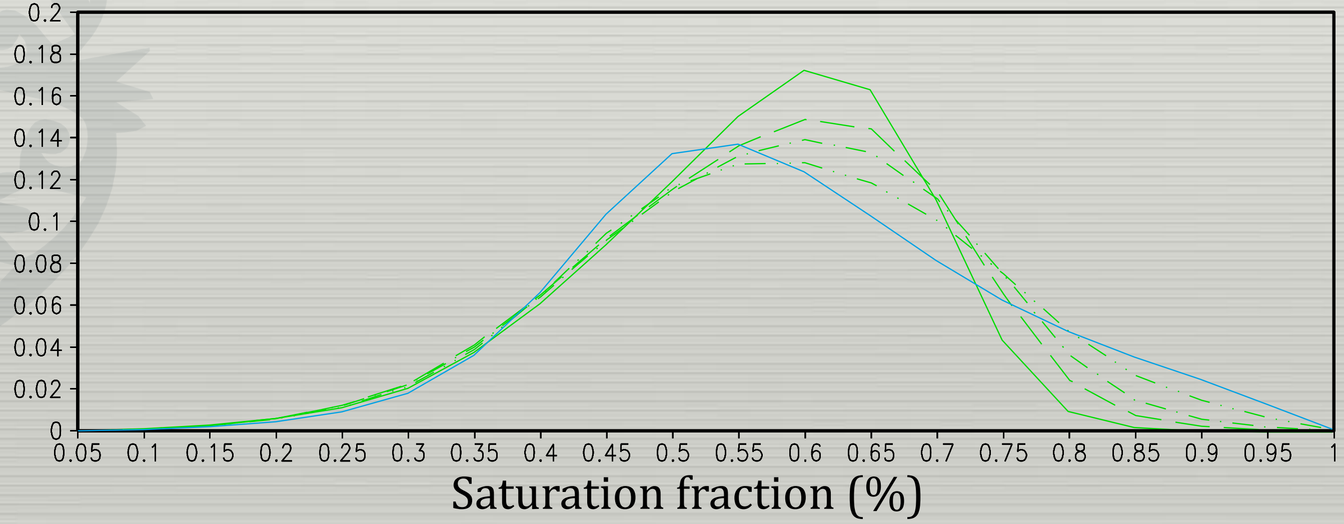
- We don’t fully understand why we have different MJOs in different models
  - Process-oriented diagnostics (MJO TF)
- What is going on, at least in the model?
  - MJO mechanism study
- Better MJO is not necessarily accompanied by better mean state
  - Systematic relation between biases
  - Do we need air-sea coupling?

Process-oriented diagnostics

Precipitation vs. Saturation fraction

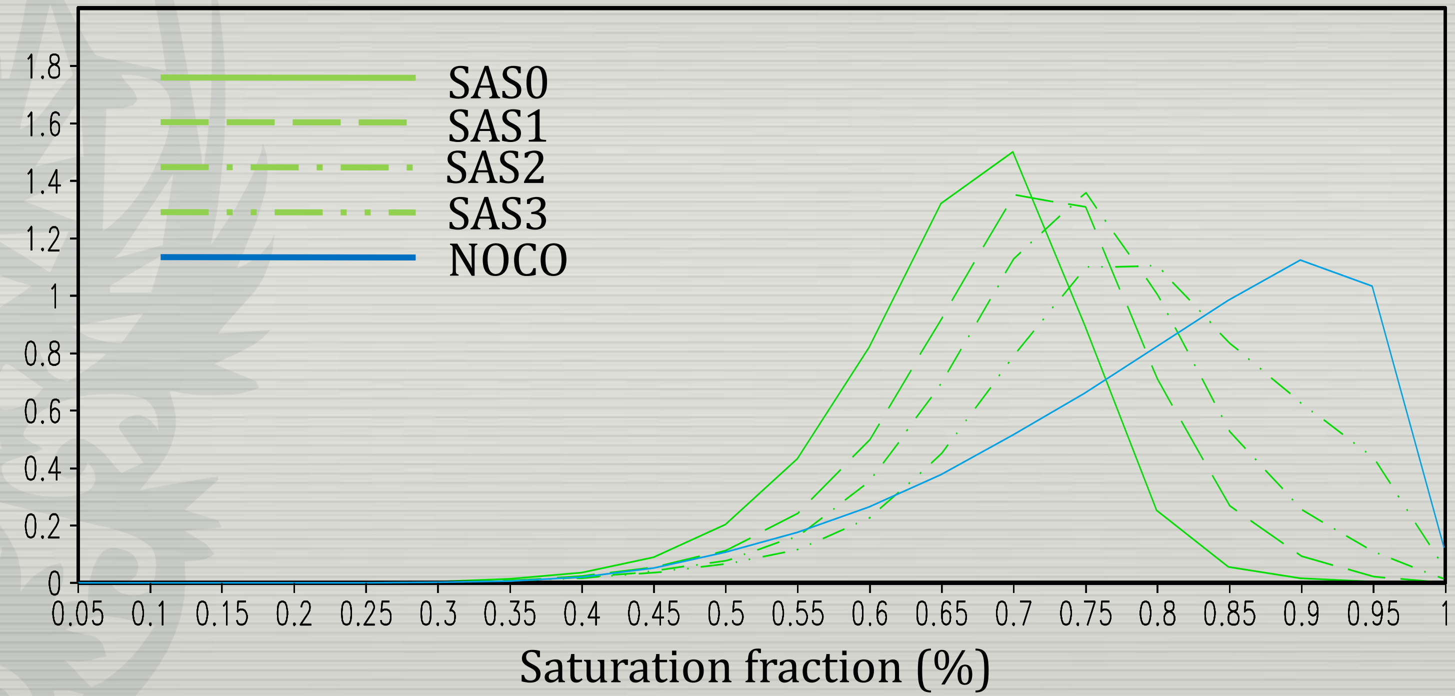


PDF of saturation fraction



Process-oriented diagnostics

PDF-weighted precipitation vs. Saturation fraction



Strong MJO model has more contribution from heavy precipitation for total precipitation

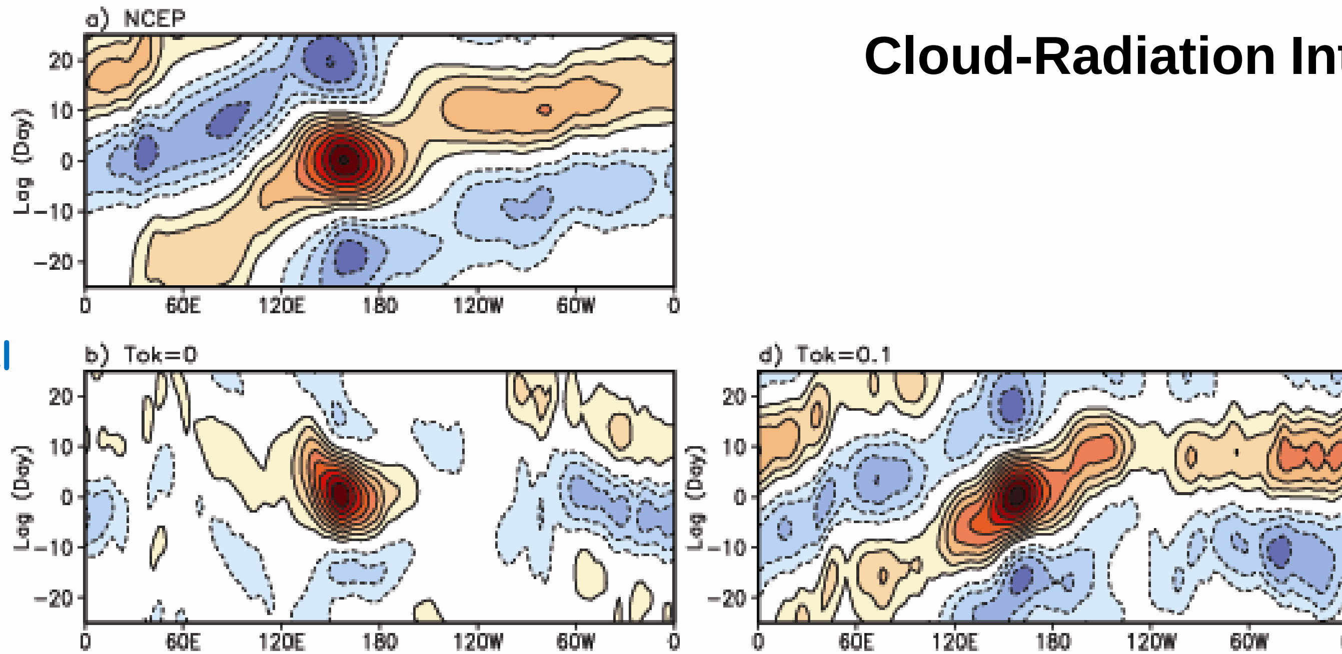
MJO mechanism study

➢ **Experimental Design**

	Tok=0	Tok=0	Tok=0.1	Tok=0.1
Trigger	X	X	O	O
Evaporation **(WISHE)**	interactive	climatology prescribed (from Tok=0)	interactive	climatology prescribed (from Tok=0.1)
Net radiative heating **(Cloud-radiation interaction)**	interactive	climatology prescribed (from Tok=0)	interactive	climatology prescribed (from Tok=0.1)
Surface wind stress **(Frictional-CISK)**	interactive	climatology prescribed 20S-20N only (from Tok=0)	interactive	climatology prescribed 20S-20N only (from Tok=0.1)

*SNUGCM, AMIP, period: 1997-2004

Cloud-Radiation Interaction



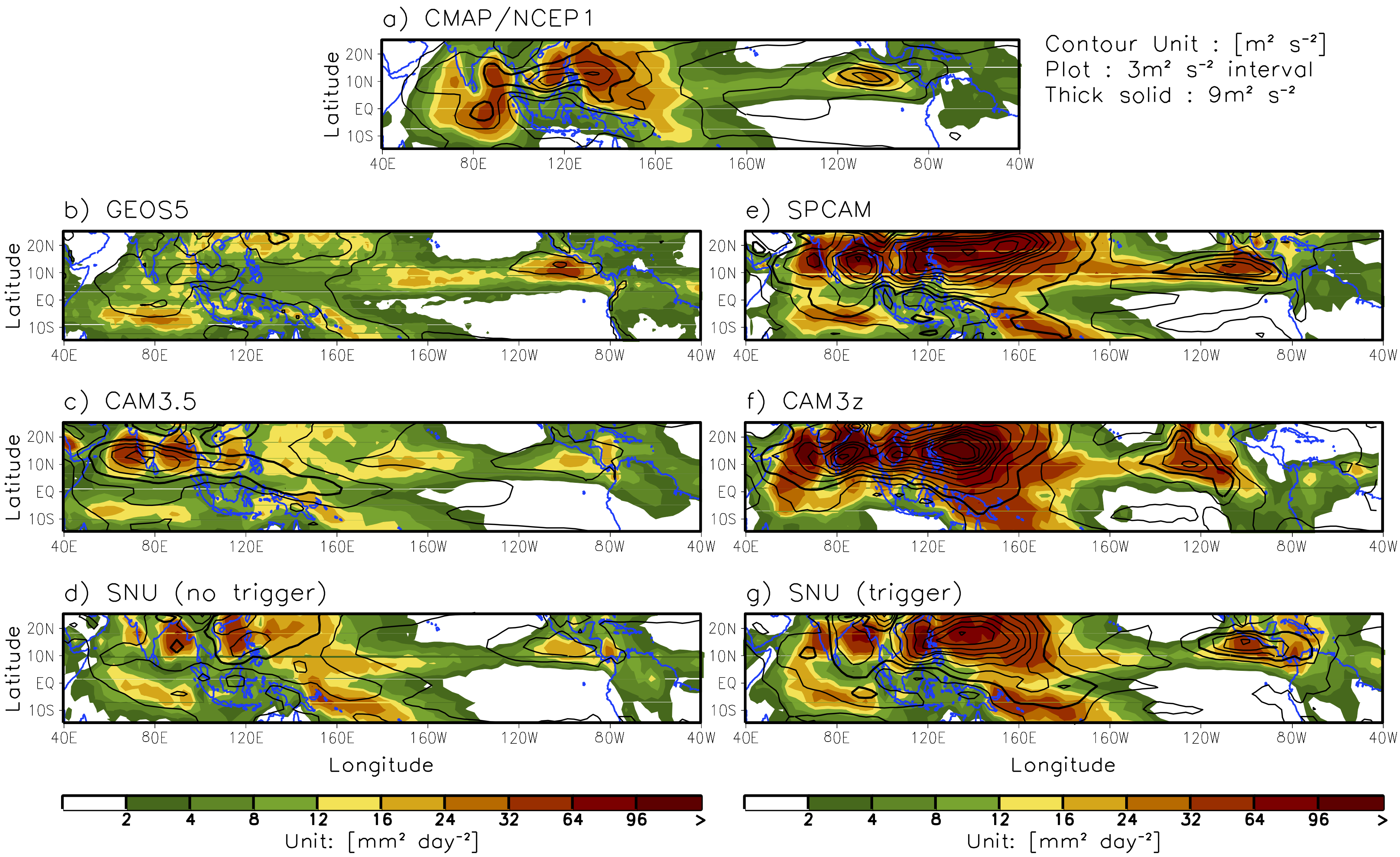
Worse model (Tok=0)

Better model (Tok=0.1)

November-April lag-longitude diagram of 10°N-10°S averaged intraseasonal 850 hPa zonal wind anomalies correlated against intraseasonal precipitation at the west Pacific (155-160°E, 5°N-5°S averaged) reference point.

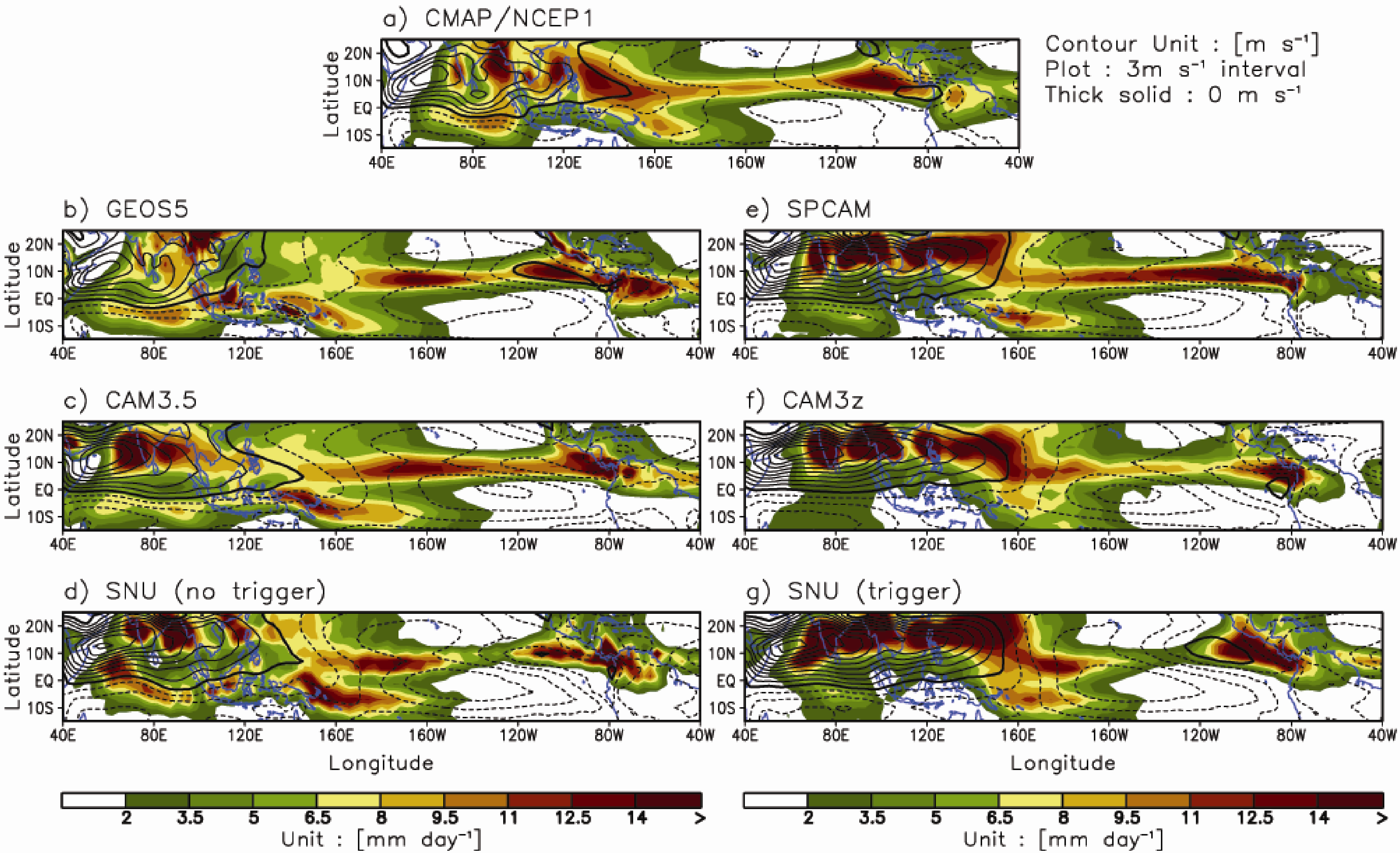
Summer

Subseasonal (20-100day) variability



Summer

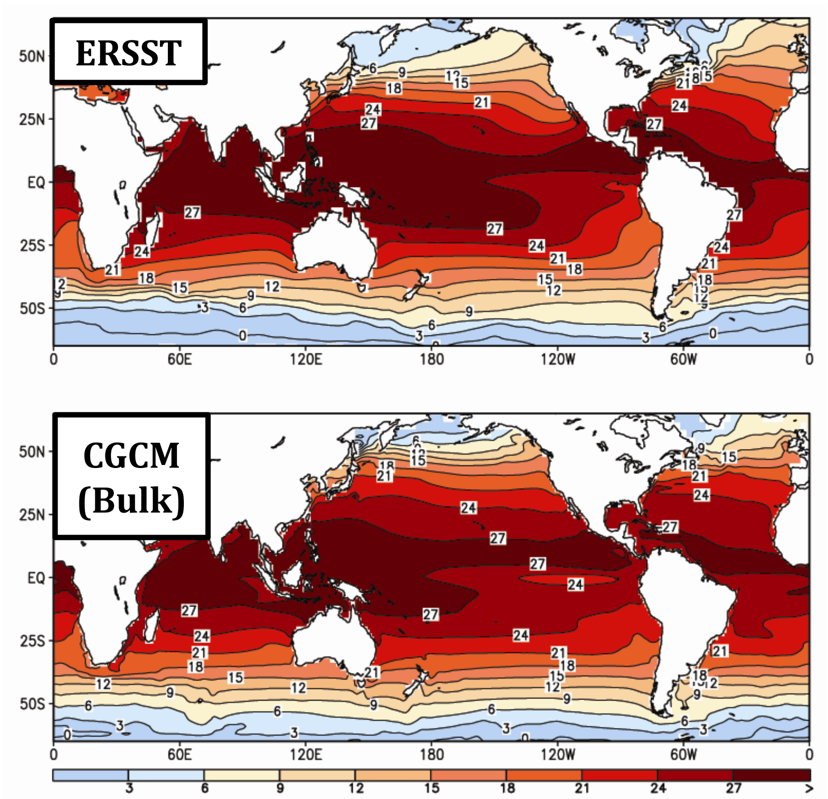
Mean precipitation/U850

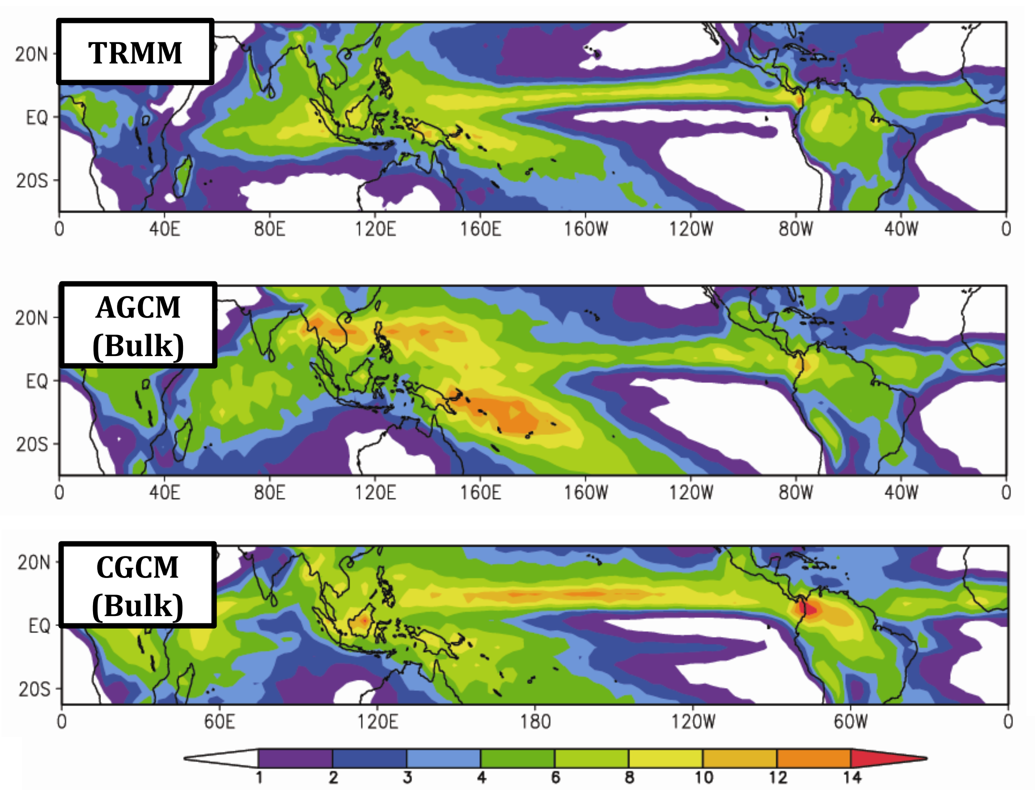


Do we need air-sea coupling?

SST

Precipitation





*CGCM : 6 year average
after 1 year spin-up

Summary

- Progress
  - We have understood what is important and what is unimportant in MJO simulation capability of GCM
  - We have known how to improve GCMs to have better MJO simulation capability
- Issues
  - We need more understanding on why GCMs have different capabilities to simulate the MJO
  - Better MJO model shows systematic bias which is not well understood

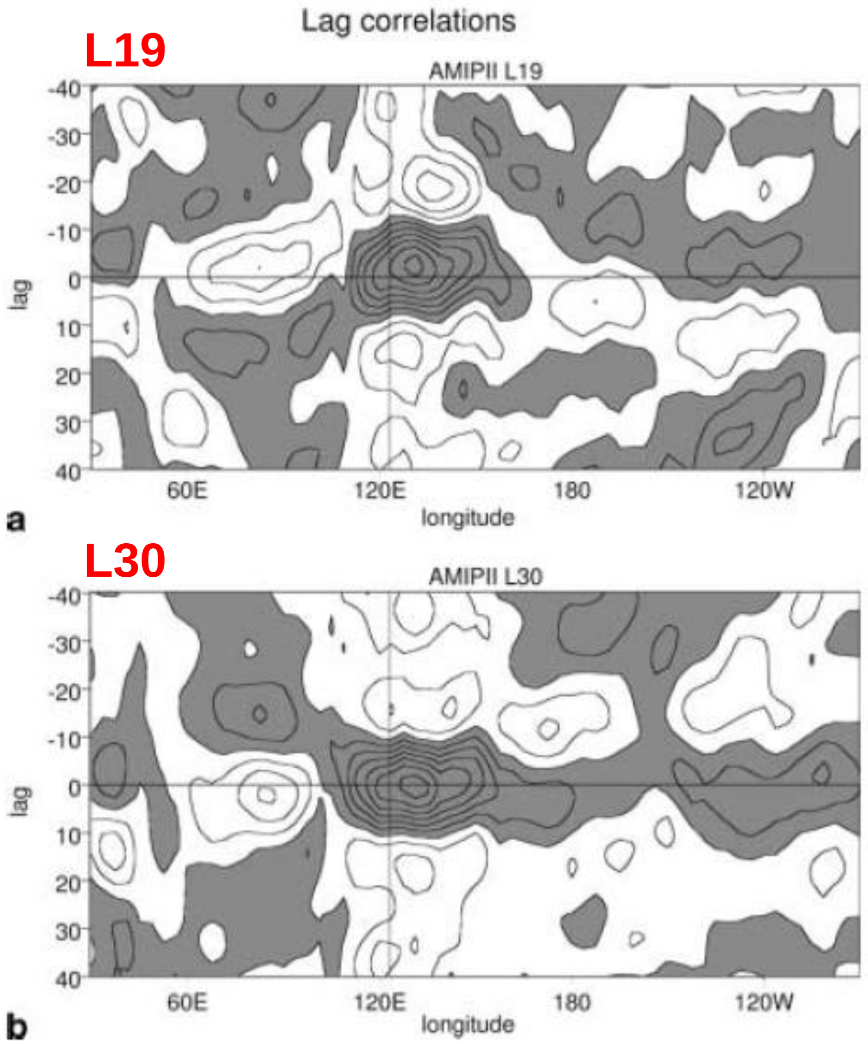
Thank you!

- Any questions?

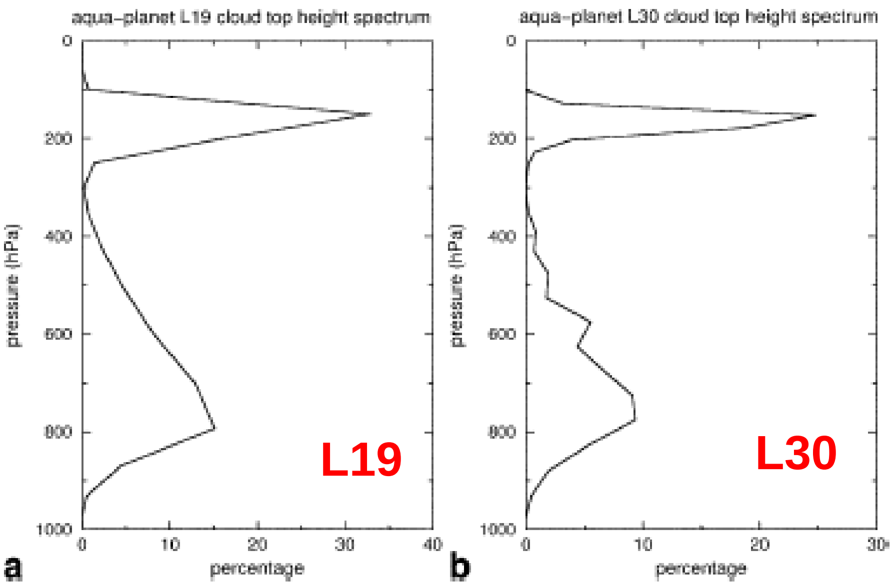
Resolution

- Horizontal: Rajendran et al. 2008; Liu et al. 2009
- Hypothesis: resolve small scale phenomena → improve MJO simulation
- Vertical: Inness et al. 2001; Jia et al. 2008
- Hypothesis: be able to represent cumulus congestus → improve MJO simulation

Lag correlation diagram
(convective precip vs. 200hPa VP)

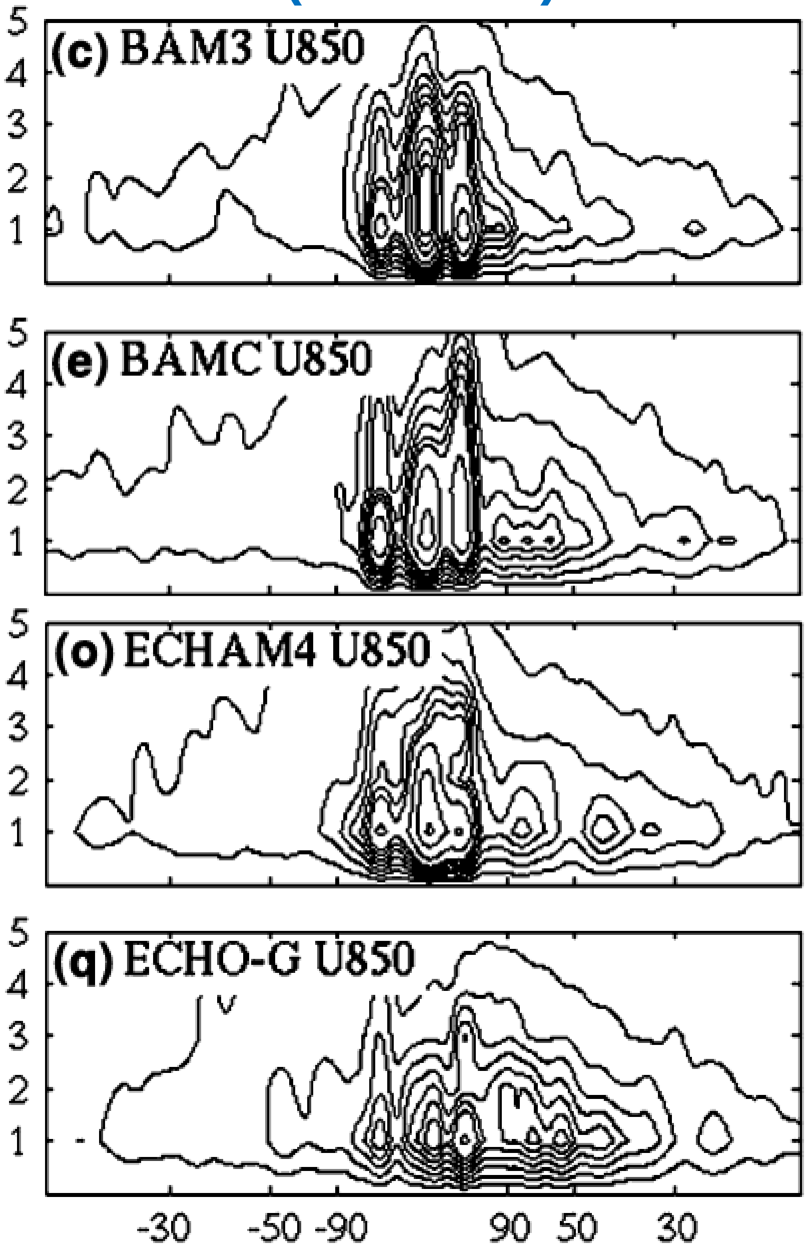


Cloud top height spectrum



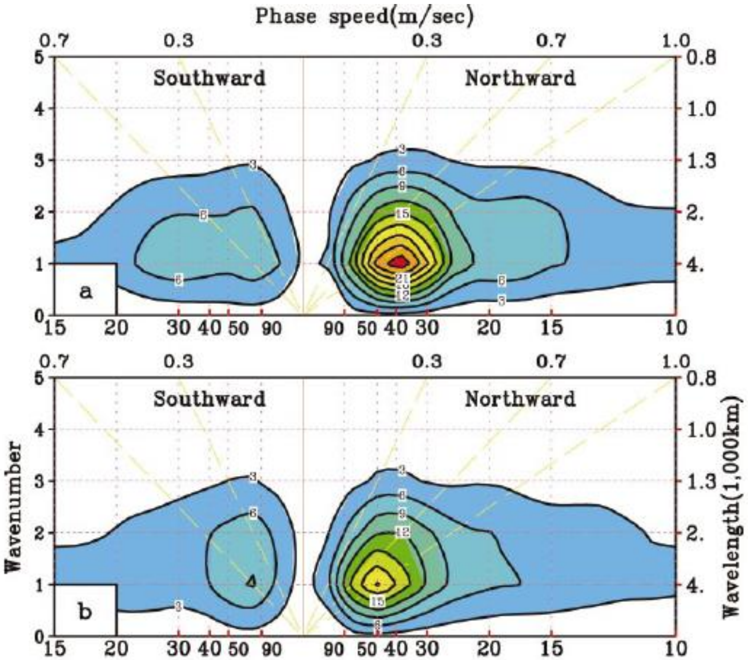
Inness et al. 2001, HadAM3

Space-time power spectra (Eastward)



Zhang et al. 2006, BAM, GFS03, CAM3, ECHAM4

Space-time power spectra (Northward)



Fu and Wang 2004, ECHAM4

Coupling to Ocean

- Waliser et al. 1999; Hendon 2000; Kemball-Cook et al. 2002; Inness and Slingo 2003; Fu and Wang 2004; Sperber et al. 2005; Marshall et al. 2008

- Hypothesis: realistic representation of air-sea coupled process → improve MJO simulation

Strong MJO models show..

- Excessive summer monsoon
- Why?
- Is coupling to ocean helpful?

Motivations

- MJO WG developed diagnostics that makes it possible to diagnose the MJO in order to assess simulation and track the improvement (e.g. amplitude): We can say confidently whether one model simulates the MJO and another doesn't but we need diagnostics that provide insight as to why

- Need to develop diagnostics that focus on physical processes of relevance to the MJO so as to deepen understanding of simulation and promote improved simulation

- If MJO WG developed a thermometer that can measure body temperature of sick person, now MJO TF aims for develop stethoscope to diagnose the reason for the symptom

Two possible ways of development

- Semi-empirical way
  - try lots of approaches, using multiple simulations that have wimpy and strong MJO/ISV, and then focus in on those that are obviously consistent across the spectrum of simulations (e.g. common features in strong-MJO models)

- Objective way (from theory)
  - test some (many?) diagnostics from theory and select some of them which are proved in our application to fulfill the requirements

Existing (suggested) diagnostics

- **Precipitation vs. Saturation fraction** (originally Bretherton et al 2004; Zhu et al. 2009, Theyer-Calder and Randall 2009; Maloney et al. 2010) bin rainfall into sat frac bins

- **Composite/bin based on precipitation** (Thayer-Calder and Randall 2009, Kim et al. 2009, Zhu et al. 2009, Neale ??)
  - relative humidity, temperature, specific humidity, diabatic heating, moistening, cloud liquid/ice water, convergence, changes in PW, etc.

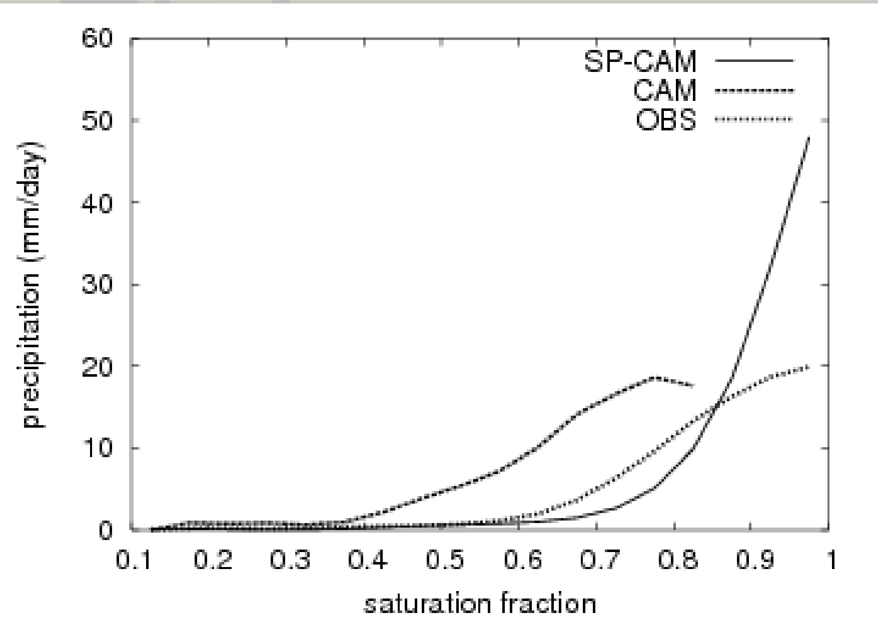
- **Composite based on MJO index** (doesn't work if no MJO; Maloney et al. 2010, Tian et al. 2010, Jiang et al. 2010, Ling and Zhang 2010)
  - Maloney et al.: moist static energy budget : horizontal/vertical advection, surface flux, radiative heating
  - Tian et al.: temperature and specific humidity anomaly
  - Jiang et al.: cloud liquid/ice water
  - Ling and Zhang : diabatic heating

↓ **complexity**

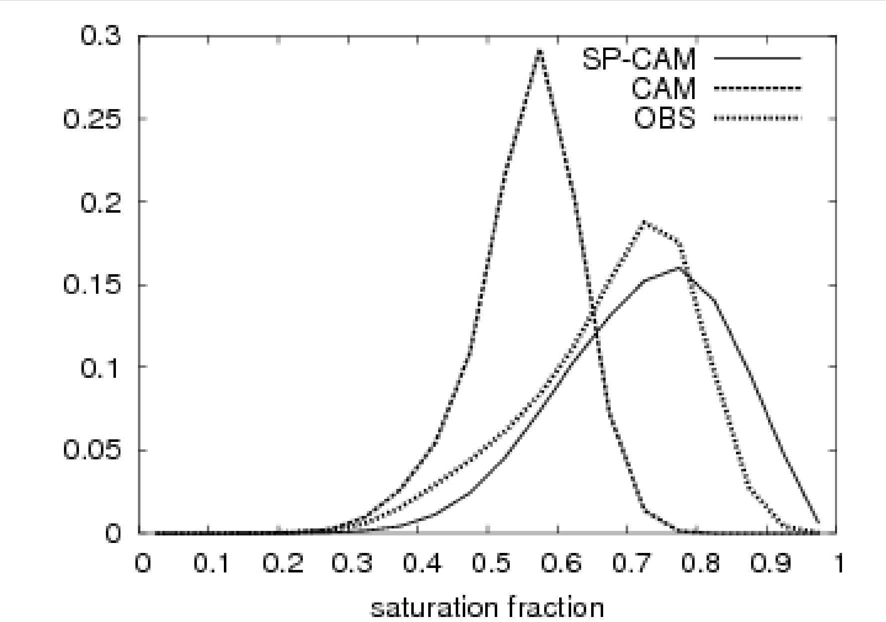
Sat. Frac. vs. PRCP

- Raymond
- Bretherton et al (2004)
- Neelin, Peters

Precipitation vs. Saturation fraction

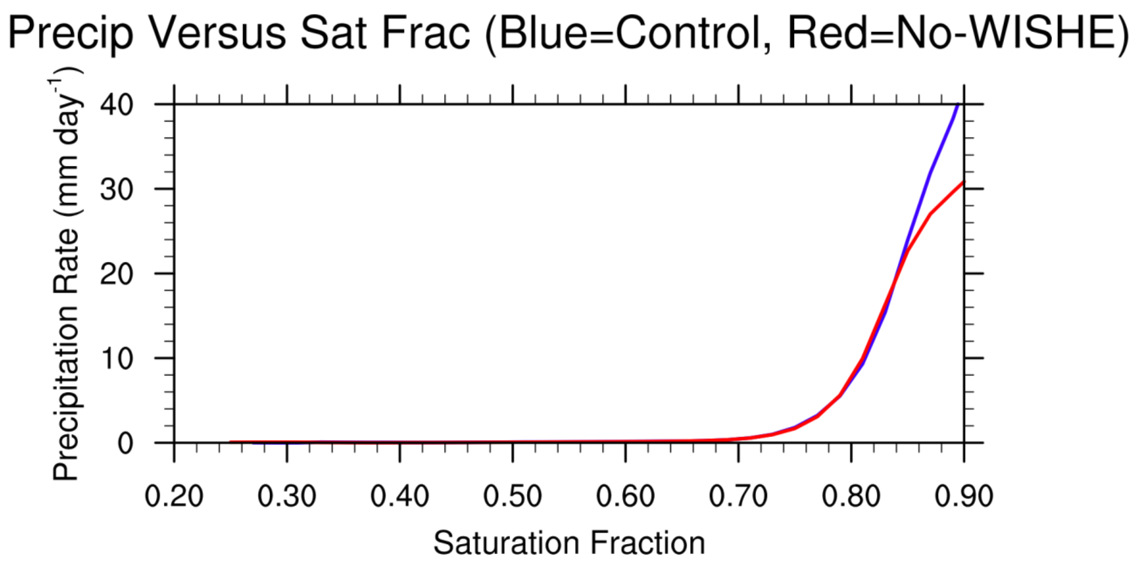


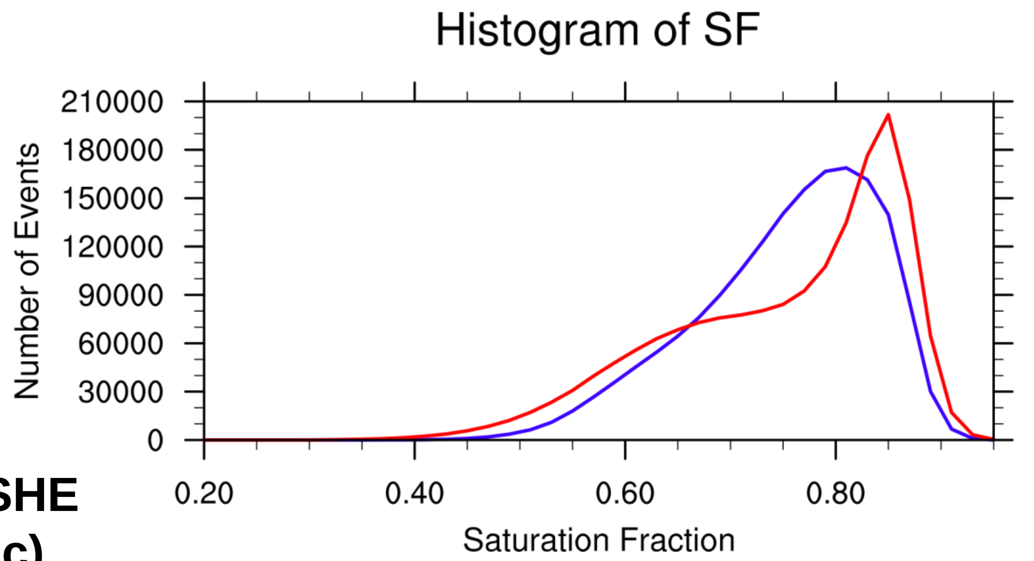
PDF of saturation fraction



CAM vs. SPCAM (Zhu et al. 2009)

Precip vs. Saturation Fraction





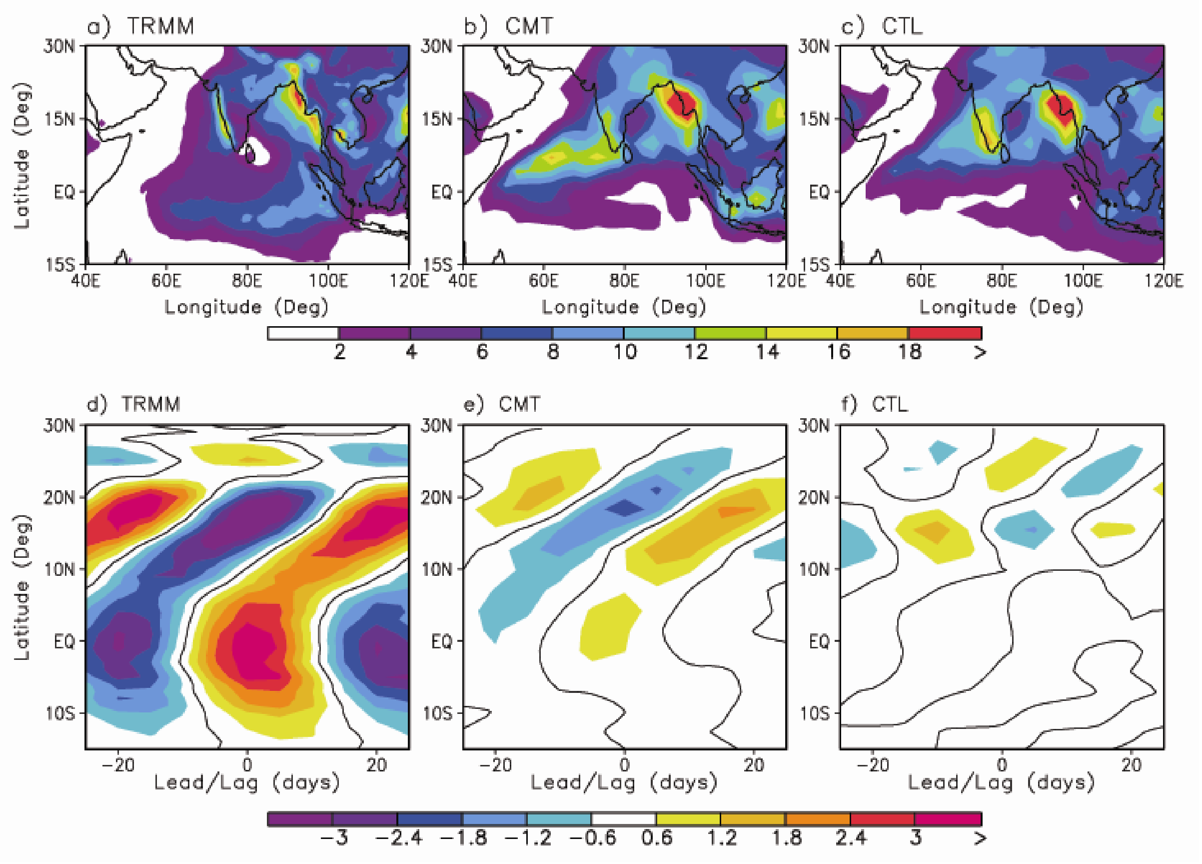
No WISHE vs. WISHE (aqua CAM3.1, Eric)

Characteristics of PRCP vs. Sat. Frac. and PDF of Sat. Frac. in different models and its relationship to simulation capability of the MJO

	PRCP vs. Sat. Frac.	PDF of Sat. Frac.
CAM vs. SPCAM (Zhu et al. 2009) 60-180E, 12S-12N Ocean only	• Weak-MJO model can not retain high sat. frac (>0.8) • Strong-MJO model (stronger than obs) produces more rainfall in high sat. frac. regime (>0.85) compared to obs • Strong-MJO model starts to make rain with higher sat. frac.	• Probability of high sat. frac. (~0.8) is higher in strong-MJO model (compared to obs. Again, MJO is stronger than obs in this model)
SAS0 vs. NOCO (SNU, Daehyun) 50-180E, 18S-18N Ocean + Land	• Weak-MJO model can not retain high sat. frac (>0.95) •Strong-MJO model produce more rainfall in high sat. frac. (>0.9) regime • Strong-MJO model starts to make rain with higher sat. frac.	• Probability of high sat. frac. (~0.8) is higher in strong-MJO model
No WISHE vs. WISHE (aqua CAM3.1, Eric) Tropics (aqua planet) Ocean only	• Strong-MJO model produce more rainfall in high sat. frac. (>0.85) regime	

Is your MJO same as mine?

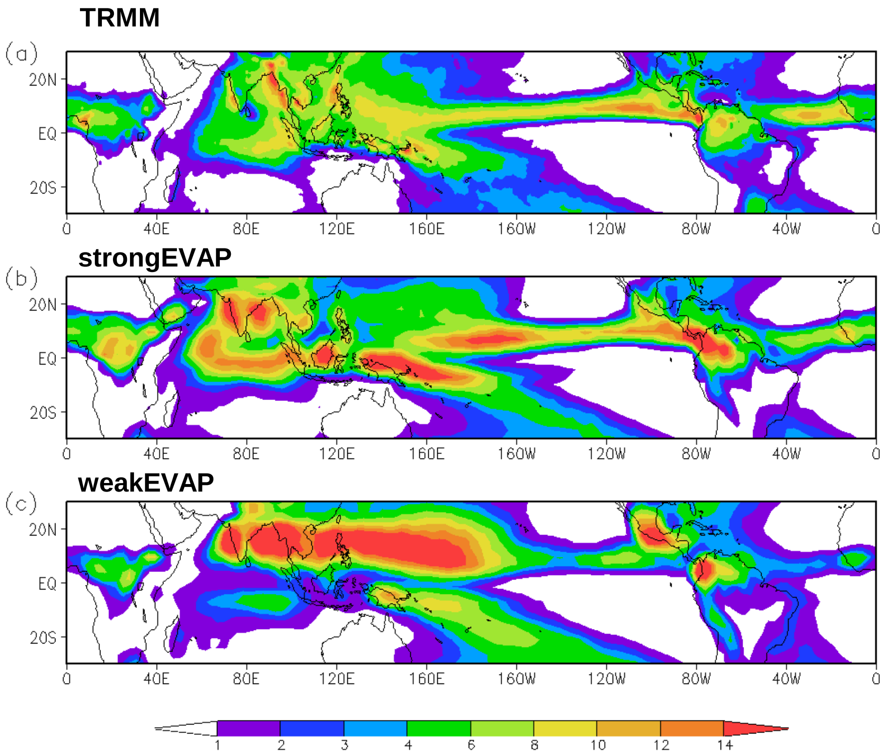
Impact of CMT on northward propagation of ISO



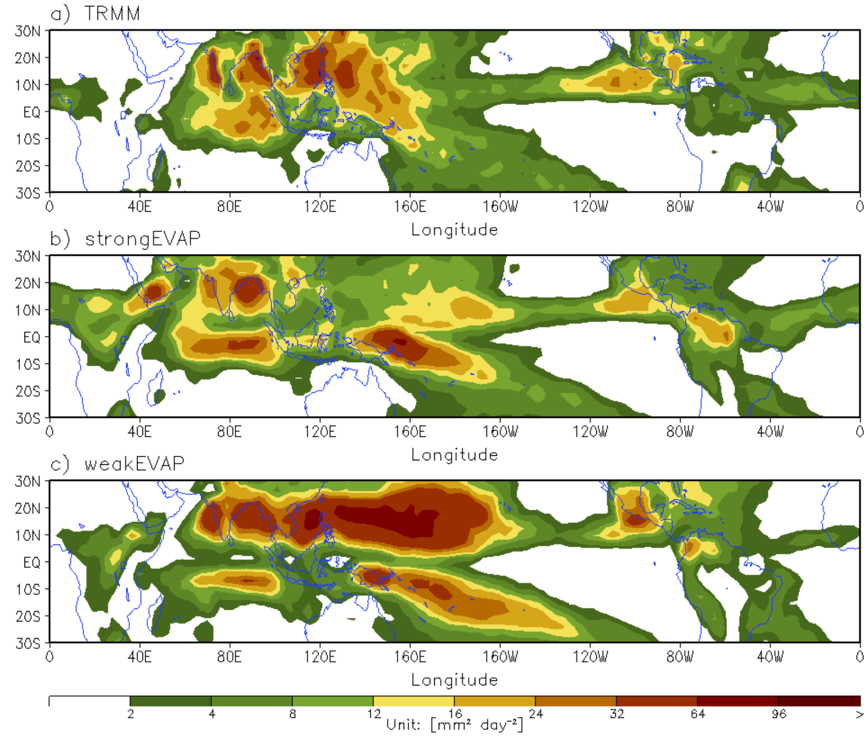
Summer

CAM3.1

Mean precipitation

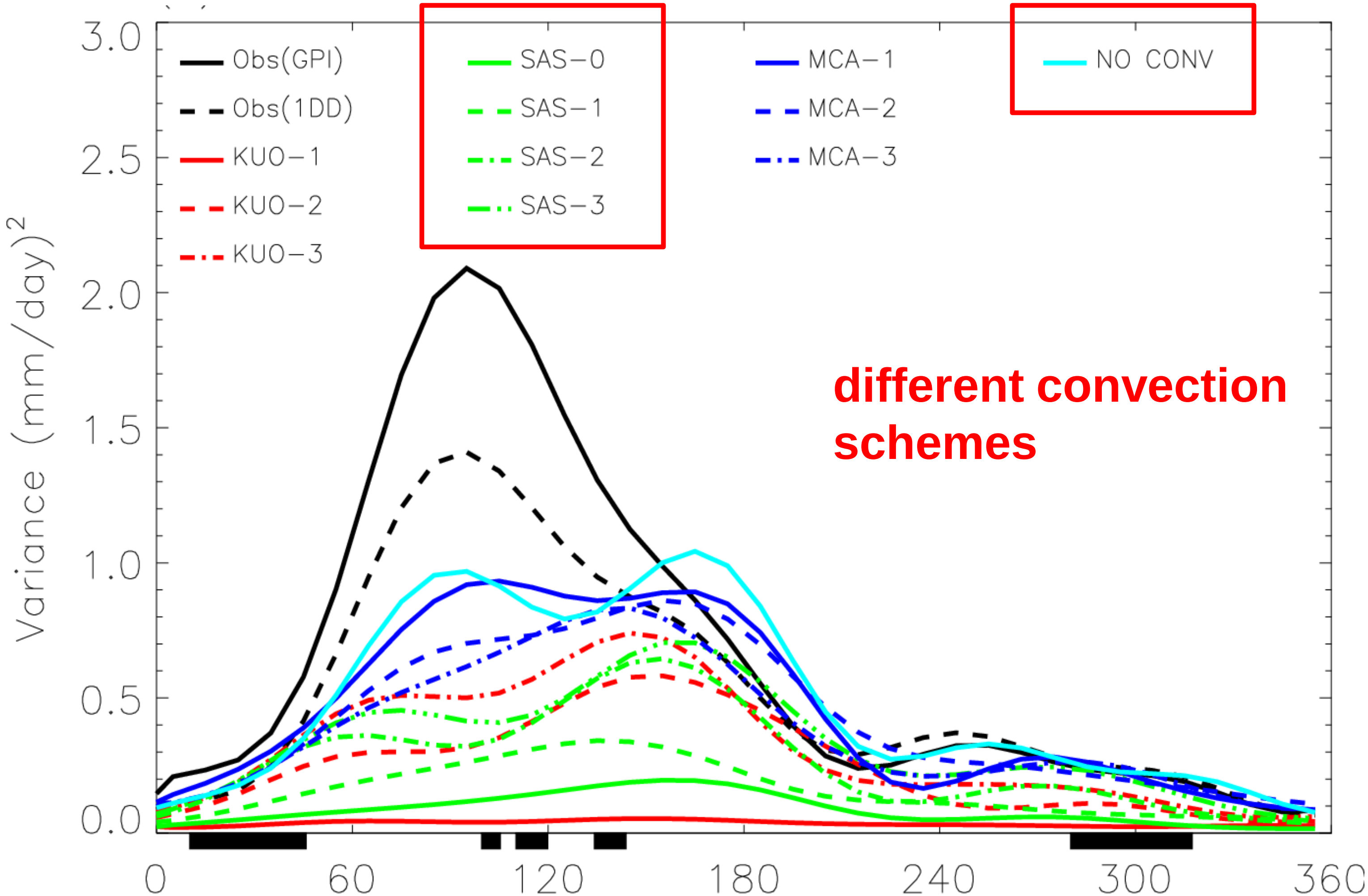


Subseasonal (20-100day) variability



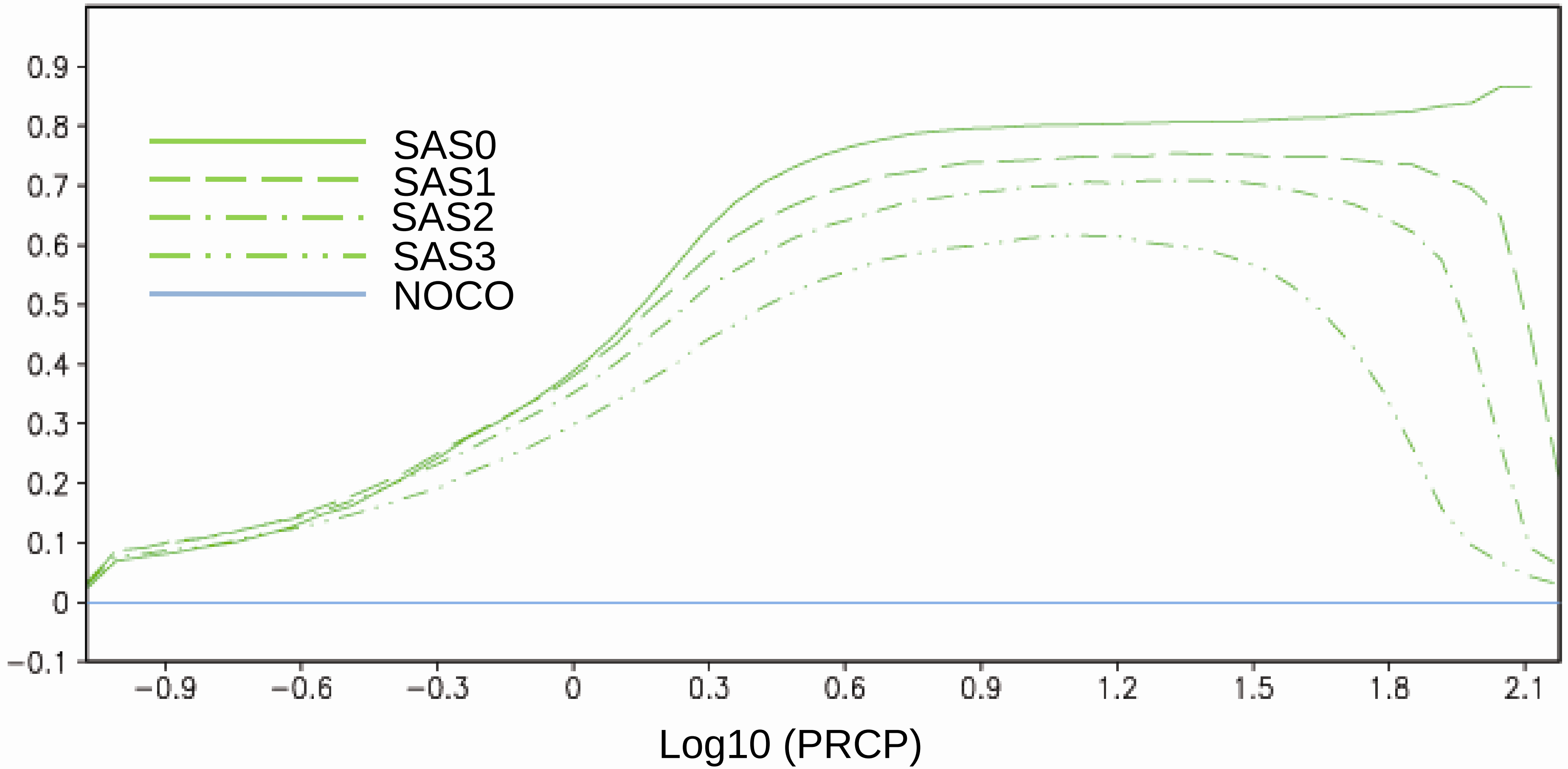
MJO Variance

(eastward wavenumber 1-6, periods 30-70days)

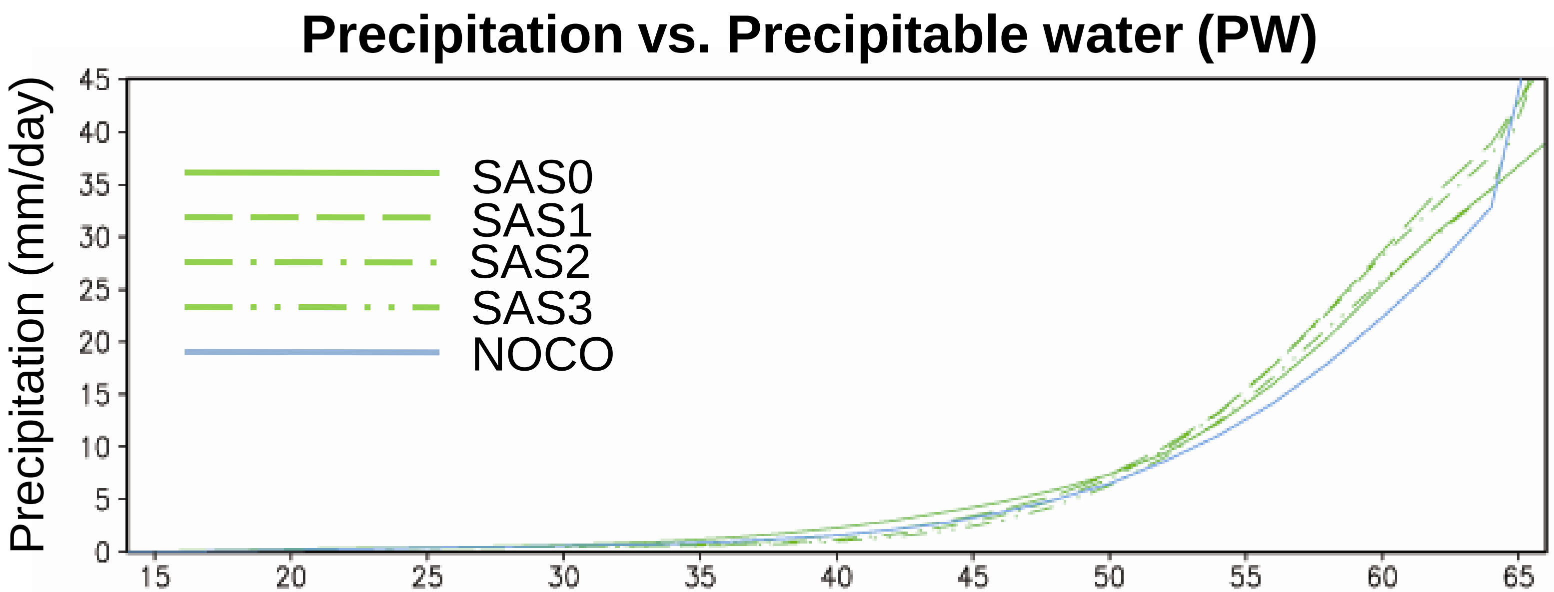


(Lin et al. 2008)

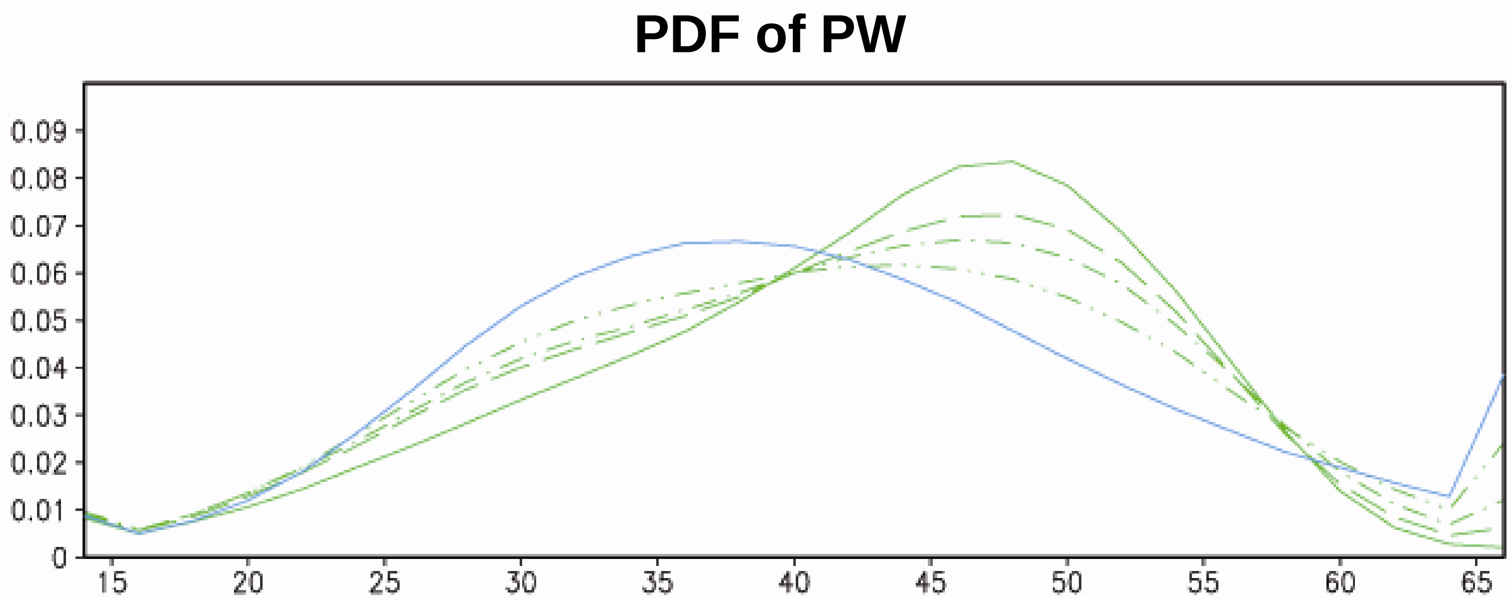
Fraction of convective precipitation to total



Region :
50E-180E
10S-10N



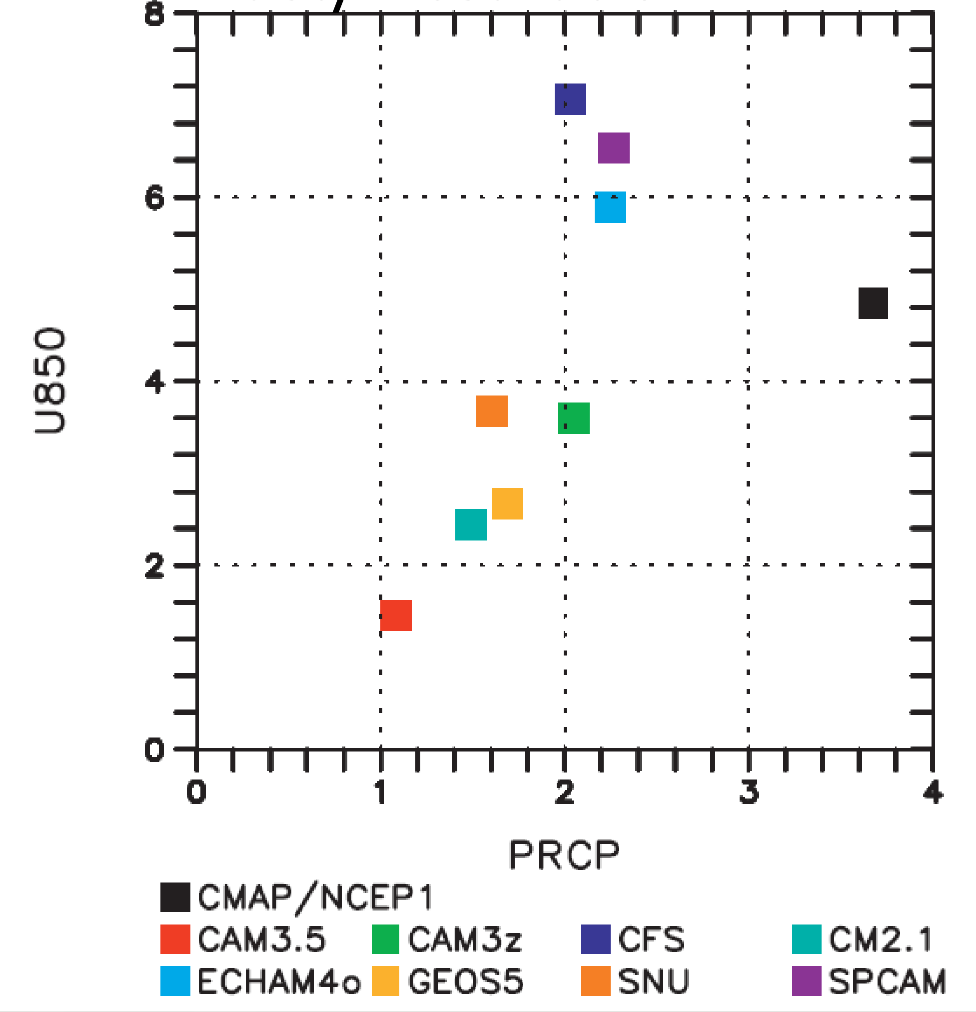
Precipitation vs. Precipitable water (PW)
Precipitation (mm/day)
SAS0
SAS1
SAS2
SAS3
NOCO
0
5
10
15
20
25
30
35
40
45
15
20
25
30
35
40
45
50
55
60
65



PDF of PW
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
15
20
25
30
35
40
45
50
55
60
65

Motivations

East/West ratio



What determines difference between models?

Kim et al. (2009, Fig. 5)