Exploring Key Processes in Modeling the Madden-Julian Oscillation (MJO)

A Joint YOTC / MJO Task Force and GEWEX GASS Global Model Evaluation Project

Component I: Climate Simulations

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Bin Guan[1,2], and Participating Modeling Groups

Acknowledgments:

NSF/Climate & Large-scale Dynamics

Vertical Structure and Diabatic Processes of the MJO: *Global Model Evaluation Project*

MJO Task Force/YOTC and GASS

WCRP MJO TF THORPEX WWRP GASS GEWEX YOTC

http://yotc.ucar.edu/mjo/vertical-structure-and-diabatic-processes-mjo

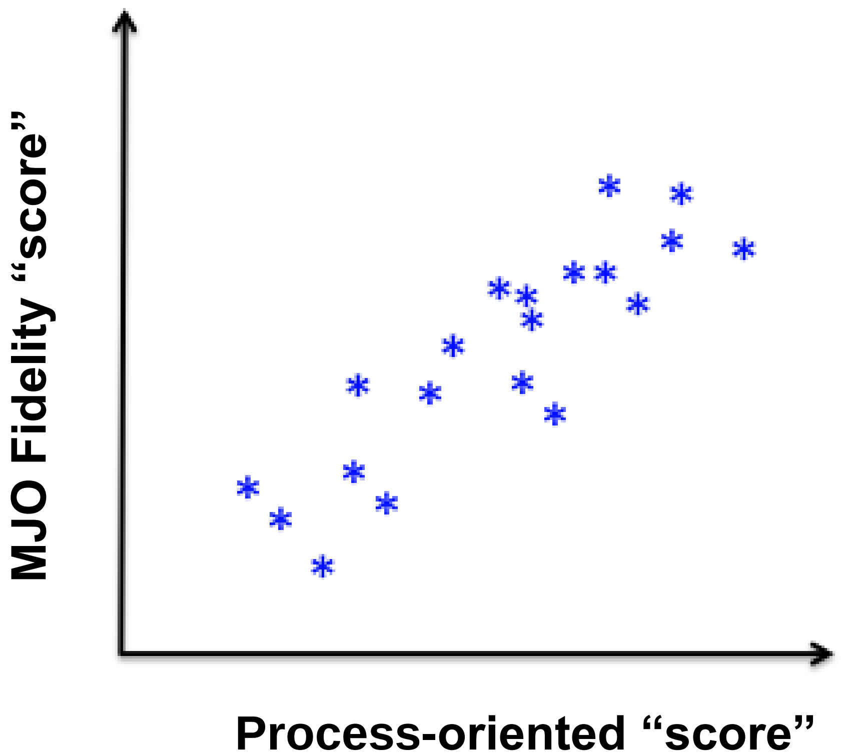
Model Experiment	Science Focus	Exp. POC
I. **20 Yr Climatological Simulations** (1991-2010 if AGCM) 6-hr, Global Output Vertical Structure, Physical Tendencies	Model MJO Fidelity Vertical structure Multi-scale Interactions: (e.g., TCs, Monsoon, ENSO)	**UCLA/JPL** X. Jiang D. Waliser
II. **2-Day MJO Hindcasts** YOTC MJO Cases E & F (winter 2009)* Time Step, Indo-Pacific Domain Output Very Detailed Physical/Model Processes	Heat and moisture budgets Model Physics Evaluation (e.g. Convection/Cloud/BL) *Short range Degradation*	**Met Office** P. Xavier J. Petch
III. **20-Day MJO Hindcasts** YOTC MJO Cases E & F (winter 2009)* 3-hr, Global Output Elements of I & II	MJO Forecast Skill State Evolution/Degradation Elements of I & II	**NCAS/Walker in.** N. Klingaman S. Woolnough

*DYNAMO Case TBD

Commitments: About 30 Modeling Groups with AGCM and/or CGCM

Met Office JPL UCLA National Centre for Atmospheric Science NATURAL ENVIRONMENT RESEARCH COUNCIL

Primary Goal of the Climate Simulation Component



Participating GCMs for Climate Simulation Component (Experiment I)

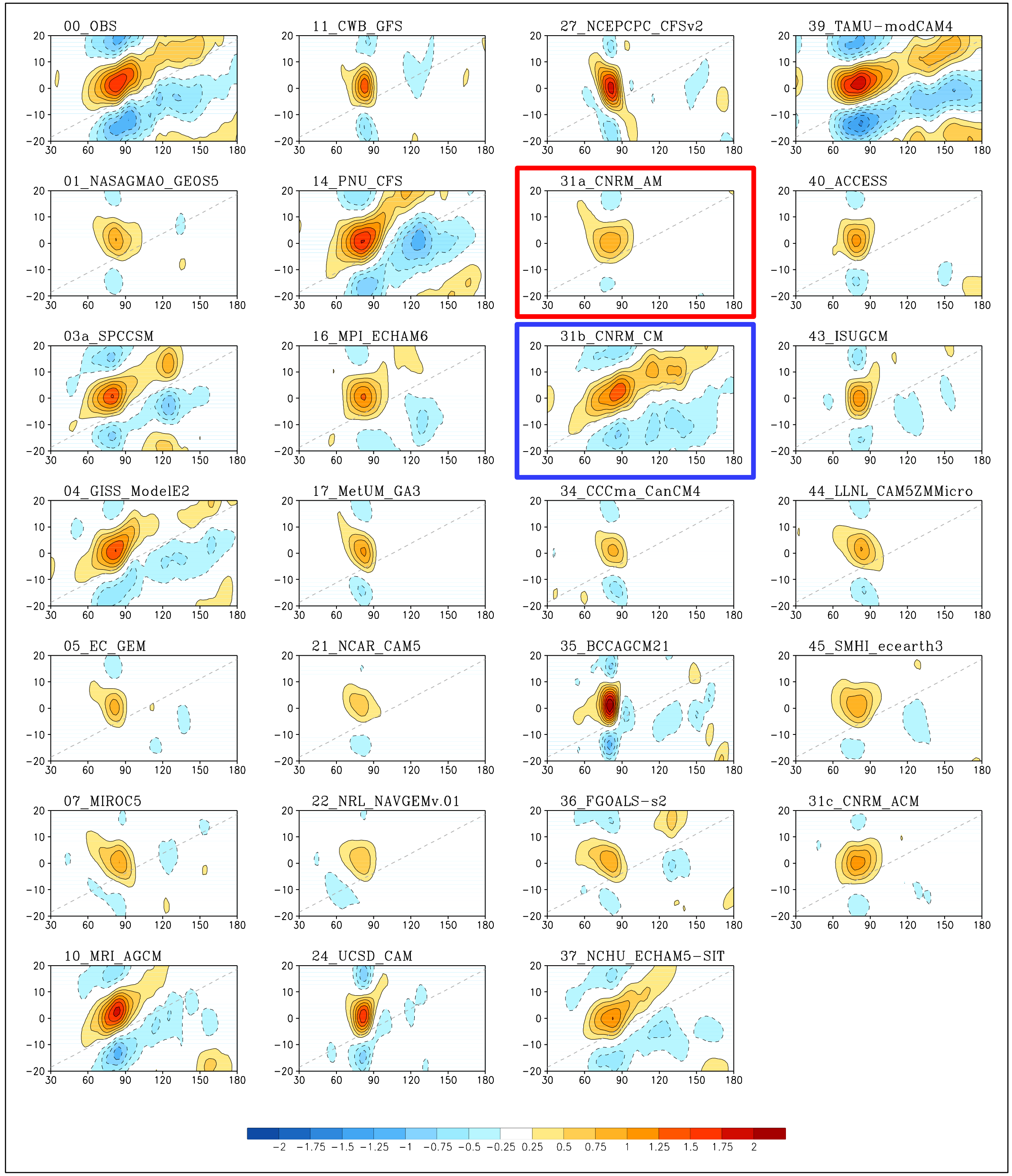
	Model	Horizontal Resolution	Vertical Resolution	Cumulus Scheme	Notes
1	01_NASAGMAO_GEOS5	0.625° lon x 0.5° lat	72	RAS (RAS; Moorthi & Suarez 1992)	
2	03a_SPCCSM (CAM3 + POP)	T42 (~2.8°)	30	**Super-parameterization** (Khairoutdinov & Randall 2003)	
3	03b_SPCAMP_AMIP	T42	30	(Khairoutdinov & Randall 2001)	1986-2003
4	04_GISS_ModelE2	2.75° lon x 2.2° lat	40	Kim et al. (2012), Del Geino et al. (2012)	
5	05_EC_GEM	~1.4°	64	Kain and Fritsch 1990)	
6	07_MIROC	T85 (~1.5°)	40	Chikira scheme (Chikira and Sugiyama 2010)	AMIP SST 1986-2005
7	10_MRI-GCM	T159	48	(Pan and Randall 1998)	
8	11_CWB_GFS	T119 (~1°)	40	(RAS; Moorthi & Suarez 1992)	
9	14_PNU_CFSv1	T62 (~2°)	64	(RAS; Moorthi & Suarez 1992)	
10	16_MPI_ECHAM6 (ECHAM6 + MPIOM)	T63 (~2°)	47	(Tiedtke 1989; Nordeng 1994)	
11	17_MetUM_GA3	1.875° lon x 1.25° lat	85	Gregory and Rowntree (1990)	
12	21_NCAR_CAM5	T42 (~ 2.8°)	30	(Zhang & McFarlane 1995)	
13	22_NRL_NAVGEMv.01	T359 (37km)	42	(Hong and Pan 1996; Han and Pan 2011)	
14	24_UCSD_CAM	T42 (~ 2.8°)	30	(Zhang & McFarlane 1995)	
15	27_NCEPCPC_CFSv2	T126 (~ 1°)	64	(Hong & Pan 1998)	
16	31a_CNRM_AM	T127 (~1.4°)	31	Bougeault (1985)	
17	31b_CNRM_CM (CNRM_AM+ NEMO)				
18	31c_CNRM_ACM				
19	34_CCCma_CanCM4	T63(?)	35(?)	(Zhang & McFarlane 1995)	
20	35_BCCAGCM2.1	T42 (~2.8 deg)	26	(Wu et al 2011)	
21	36_FGOALS2.0-s	R42 (2.8°lonx1.6°lat)	26	(Tiedtke 1989; Nordeng 1994)	
22	37_NCHU_ECHAM5-SIT	T63	31	(Tiedtke 1989; Nordeng 1994)	
23	37b_NCHU_AGCM				
24	39_TAMU_Modi-CAM4 (CCSM4)	2.5 ° lon x 1.9 ° lat	26	(Zhang & McFarlane 1995)	Idealized tilted vertical heating
25	40_ACCESS (modified METUM)	1.875° lon x 1.25° lat	85	(Gregory and Rowntree 1990)	
26	43_ISUGCM	T42 (~ 2.8°)	18	(Zhang & McFarlane 1995)	
27	44_LLNL_CAM5ZMMicro	T42 (~ 2.8°)	30	(Zhang & McFarlane 1995)	
28	45_SMHI_ecearth3	T255(80km)	91	IFS cy36r4	

MJO Fidelity

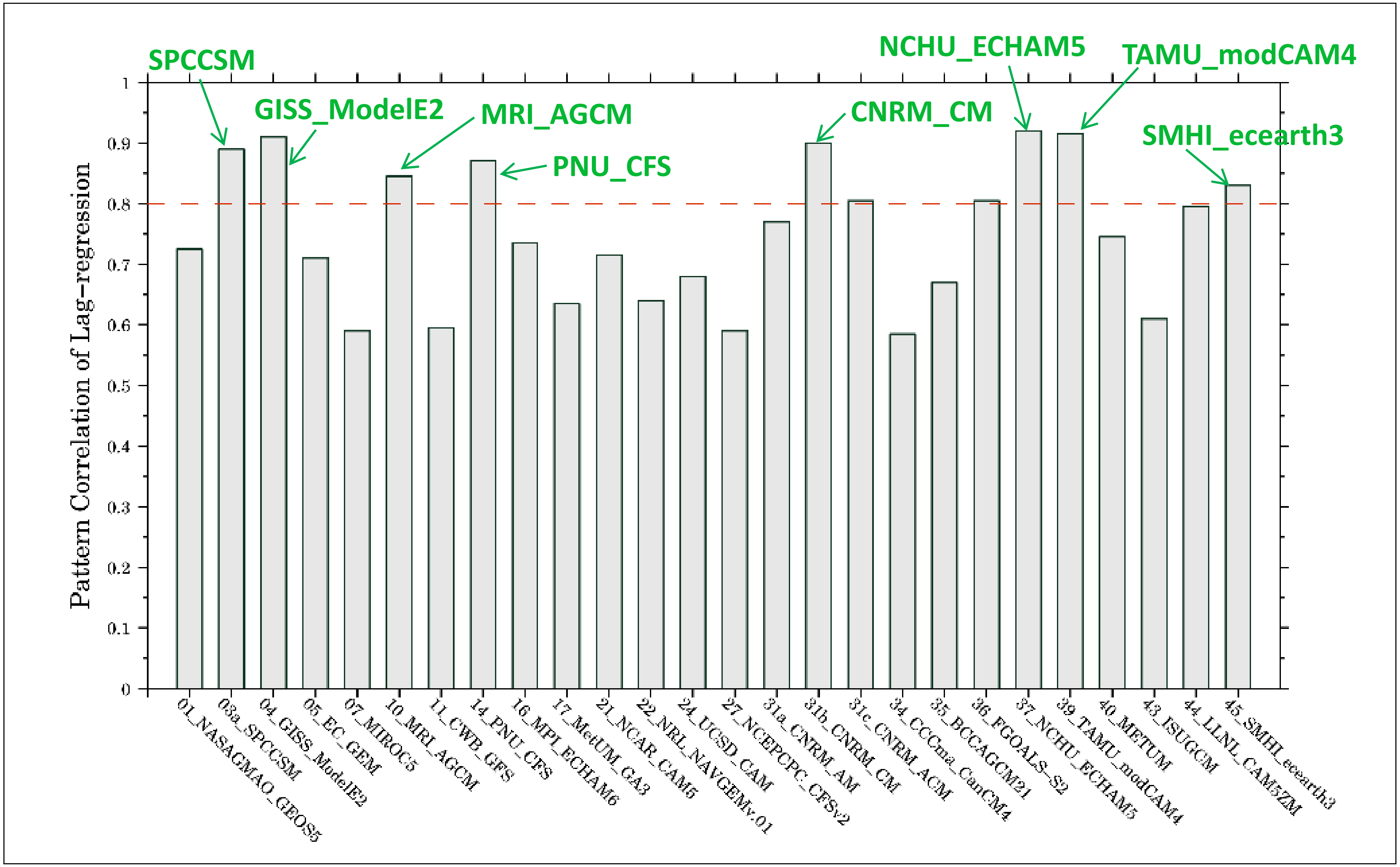
Lag-regression of rainfall with Indian Ocean (70-90°E; 5°S-5°N) base point

20-100-day filtered

dash line – 5 m/s



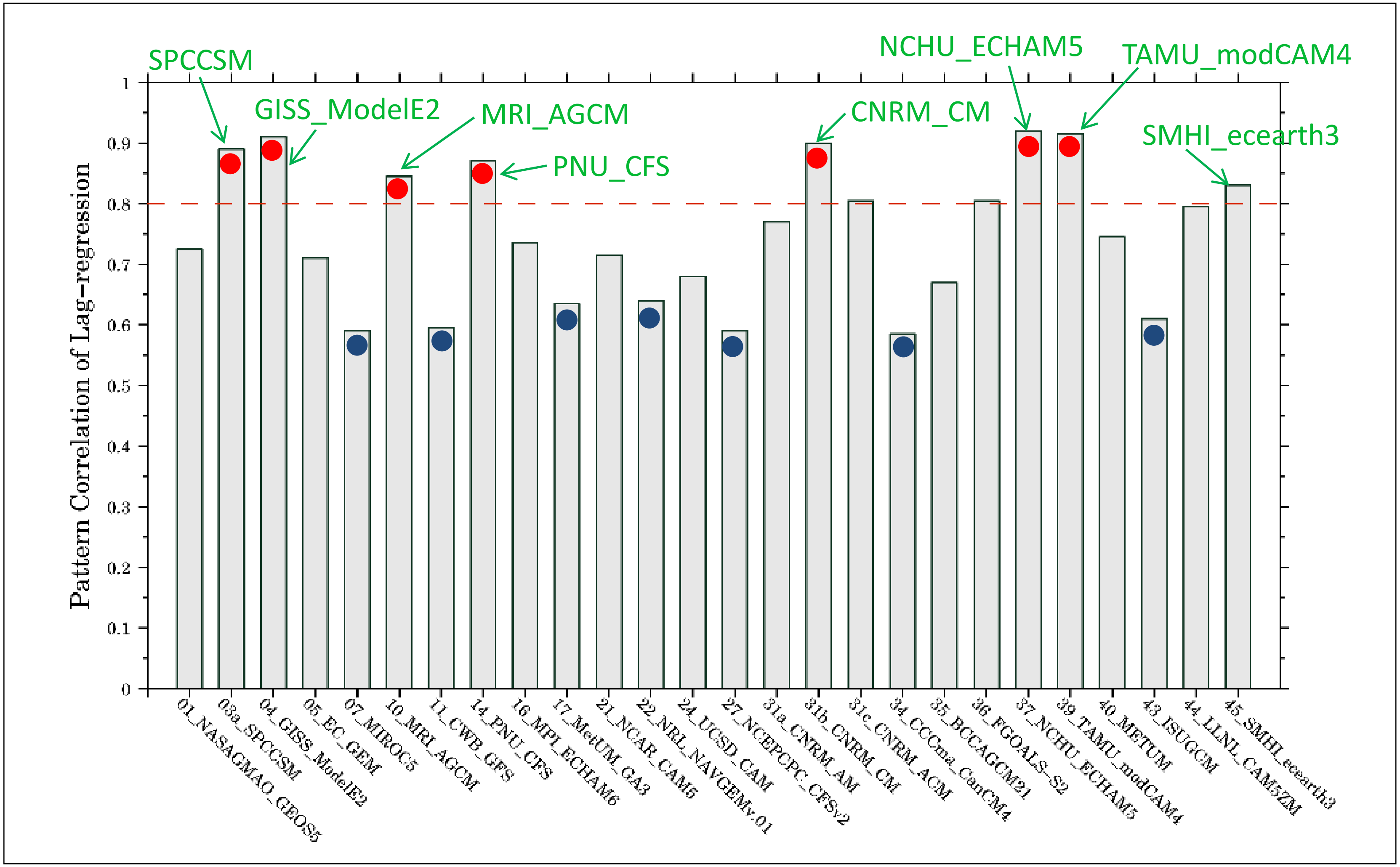
MJO Skill Score by Rainfall Hovmöller Diagram
(Indian Ocean & western Pacific averaged)



MJO Skill Score by Rainfall Hovmöller Diagram

(Indian Ocean & western Pacific averaged)

● Top 25% models ● Bottom 25% models

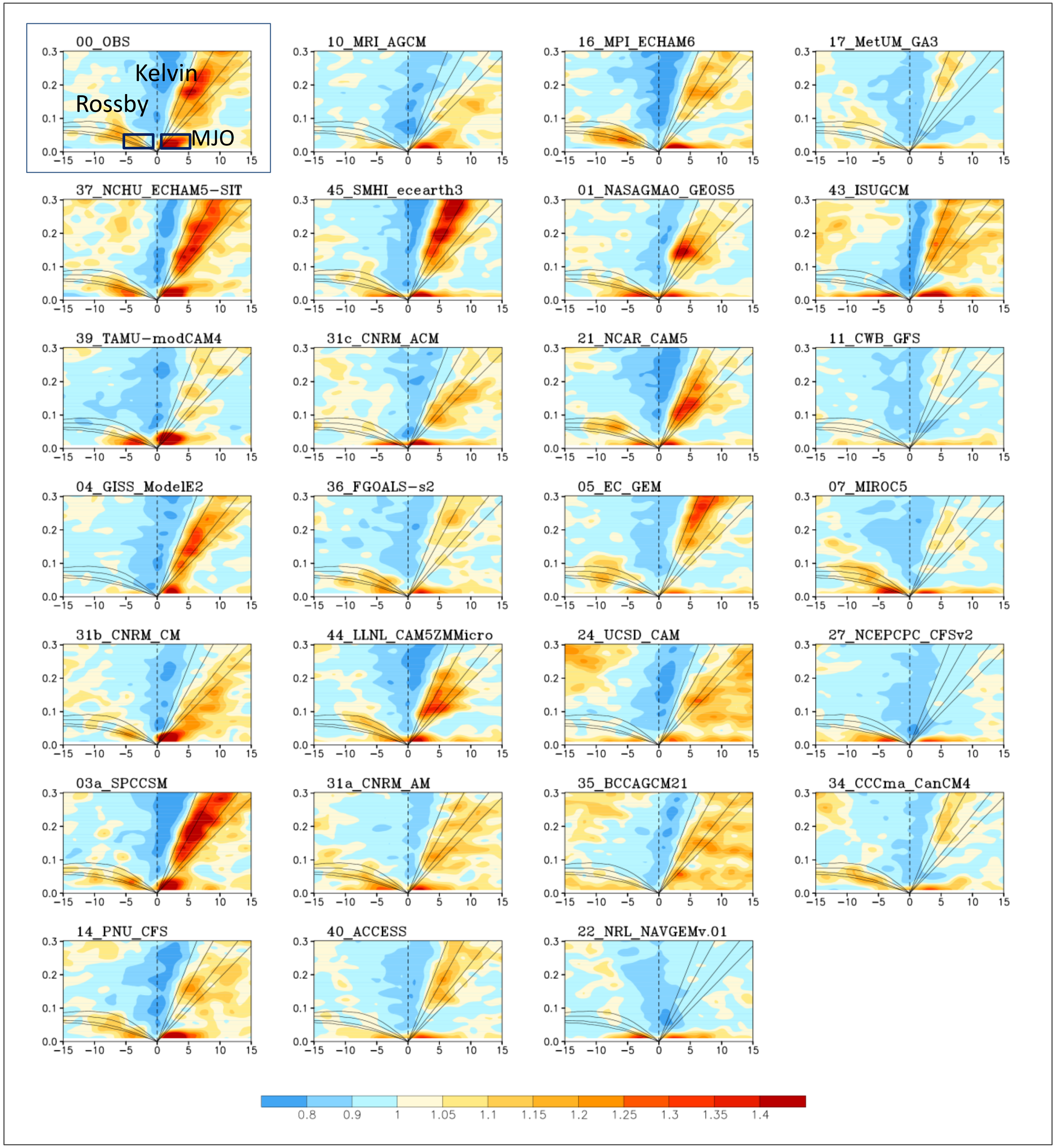


Wavenumber-Frequency Spectra (Nov-Apr)

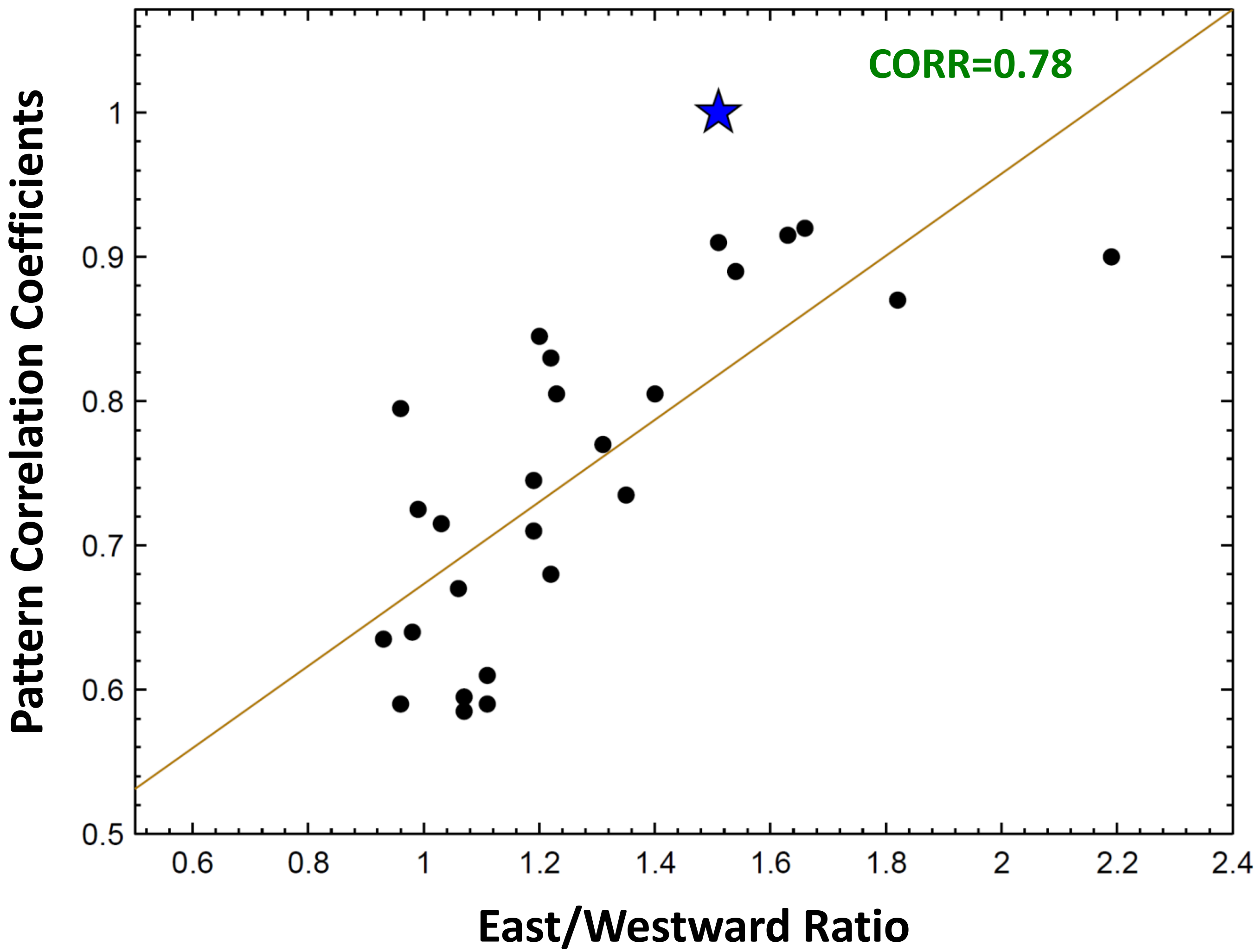
Symmetric

E/W Ratio:
Wave number 1-3;
30-96-day

✓ Kelvin wave & MJO



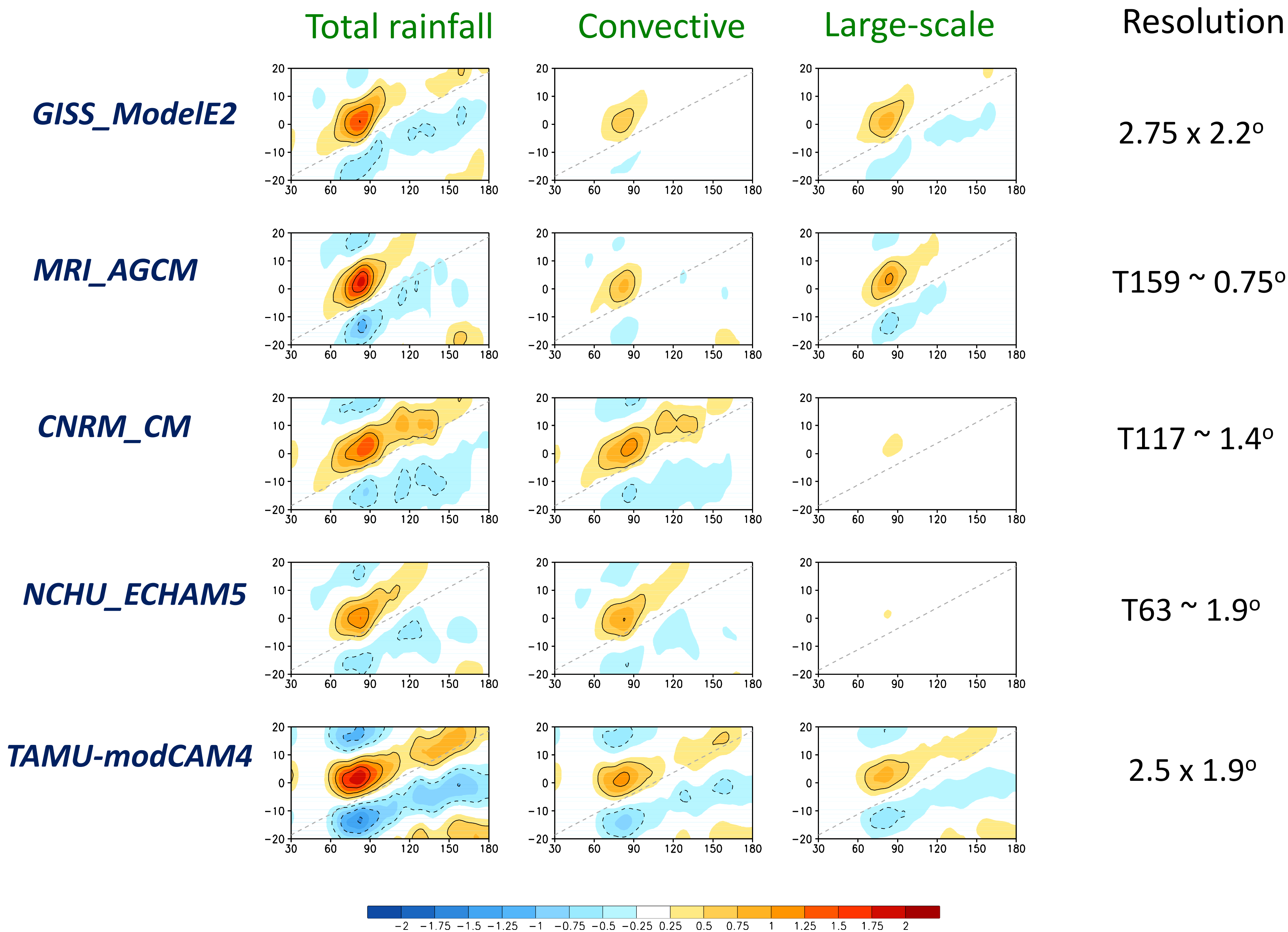
MJO skill by Hovmöller Diagram vs E/W Ratio



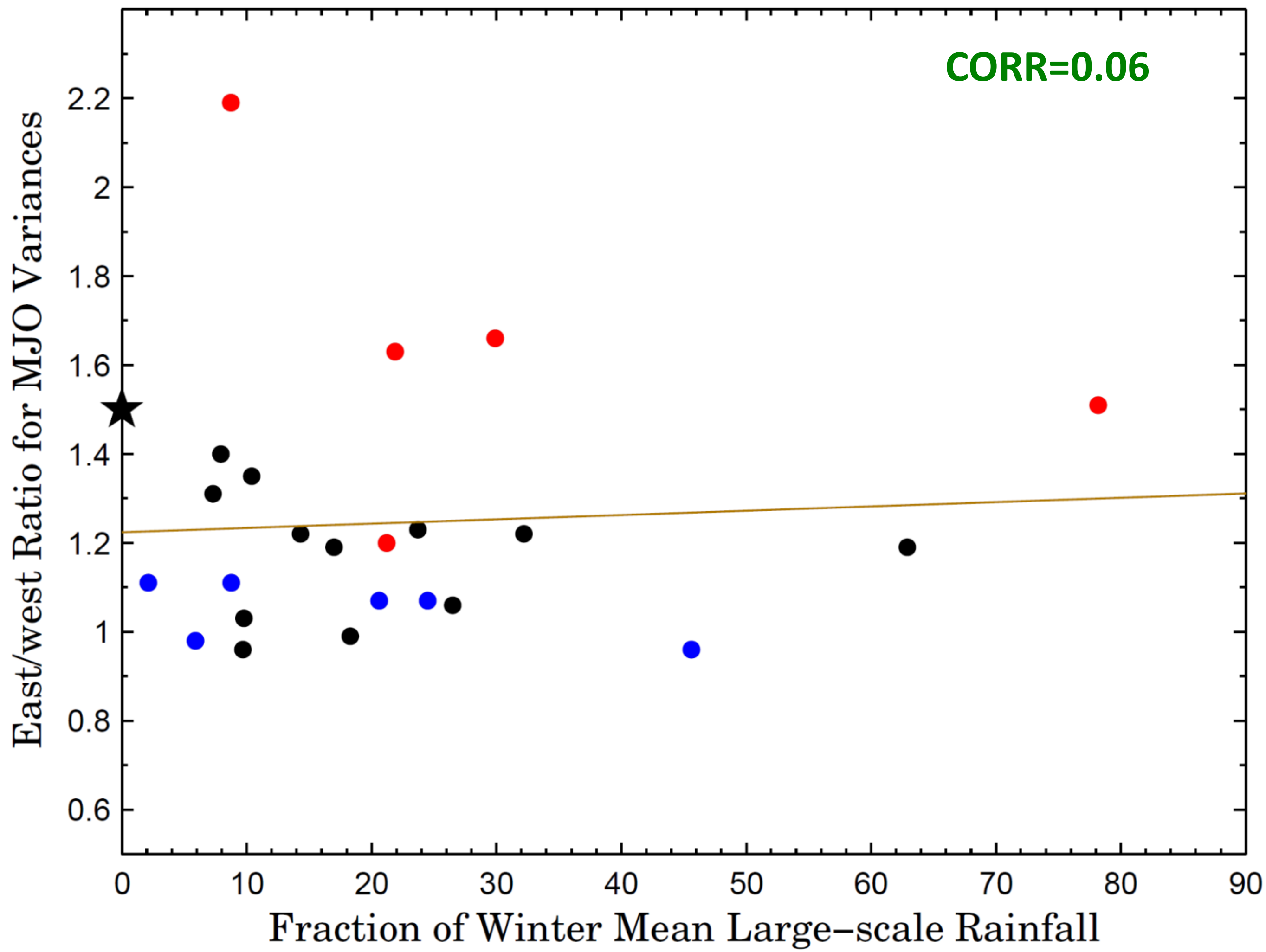
Process-oriented metrics for MJO

- ✓ Large-scale rainfall partition
- ✓ Mean zonal wind over IO/W.Pac warm pool
- ✓ Vertical moisture profiles with rainfall rate
- ✓ Normalized gross moist stability (NGMS)
- ✓ Radiative vs convective heating ratio

Metric I. *Convective vs large-scale rainfall*


Total rainfall
Convective
Large-scale
Resolution
GISS_ModelE2
2.75 x 2.2°
MRI_AGCM
T159 ~ 0.75°
CNRM_CM
T117 ~ 1.4°
NCHU_ECHAM5
T63 ~ 1.9°
TAMU-modCAM4
2.5 x 1.9°
−2 −1.75 −1.5 −1.25 −1 −0.75 −0.5 −0.25 0.25 0.5 0.75 1 1.25 1.5 1.75 2

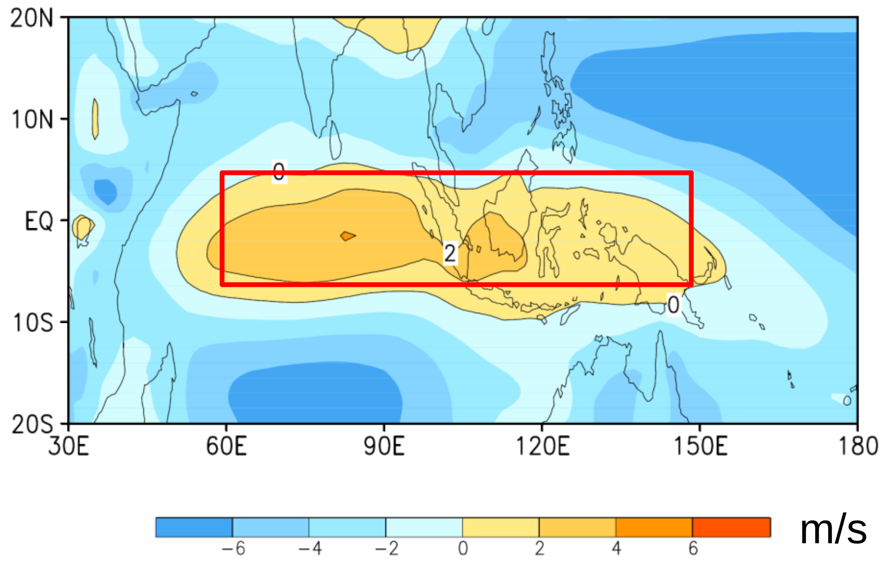
MJO Skill vs Large-scale Rainfall Fraction



Metric II. Mean zonal wind over IO & W. Pacific warm pool

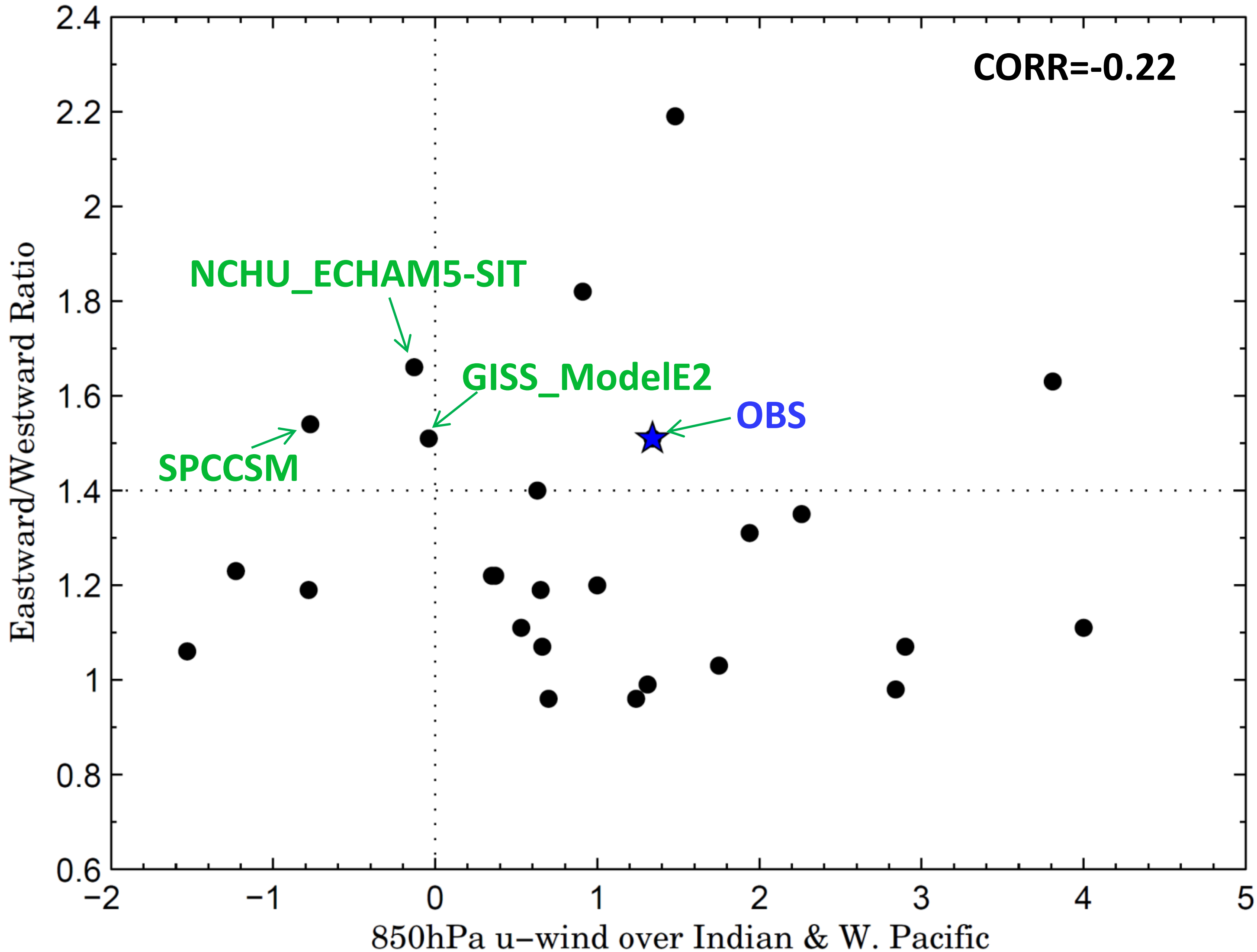
Winter mean u-wind at 850hPa (Nov-Apr)

ERA-Interim

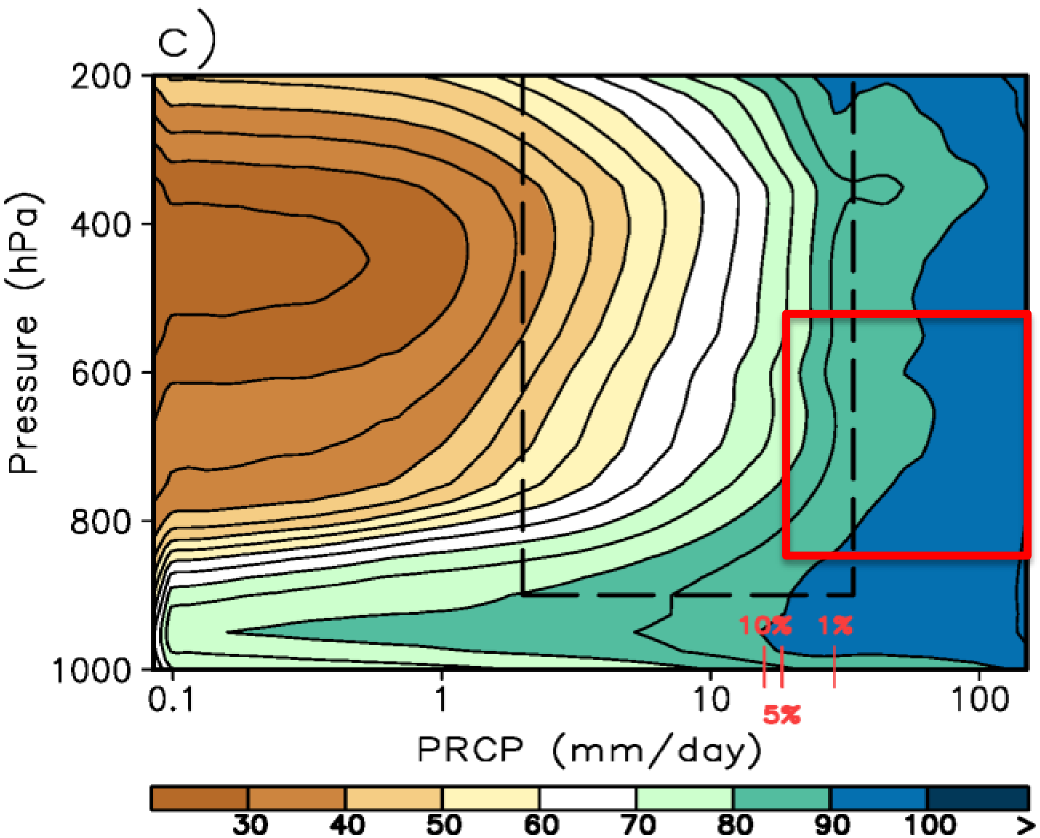


(60-150^{o}E;5^{o}S-5^{o}N)

MJO Fidelity vs winter mean 850hPa u-wind over Indian/W. Pacific (60-150^{o}E;5^{o}S-5^{o}N)



Metric III. Sensitivity to vertical Moisture Profile



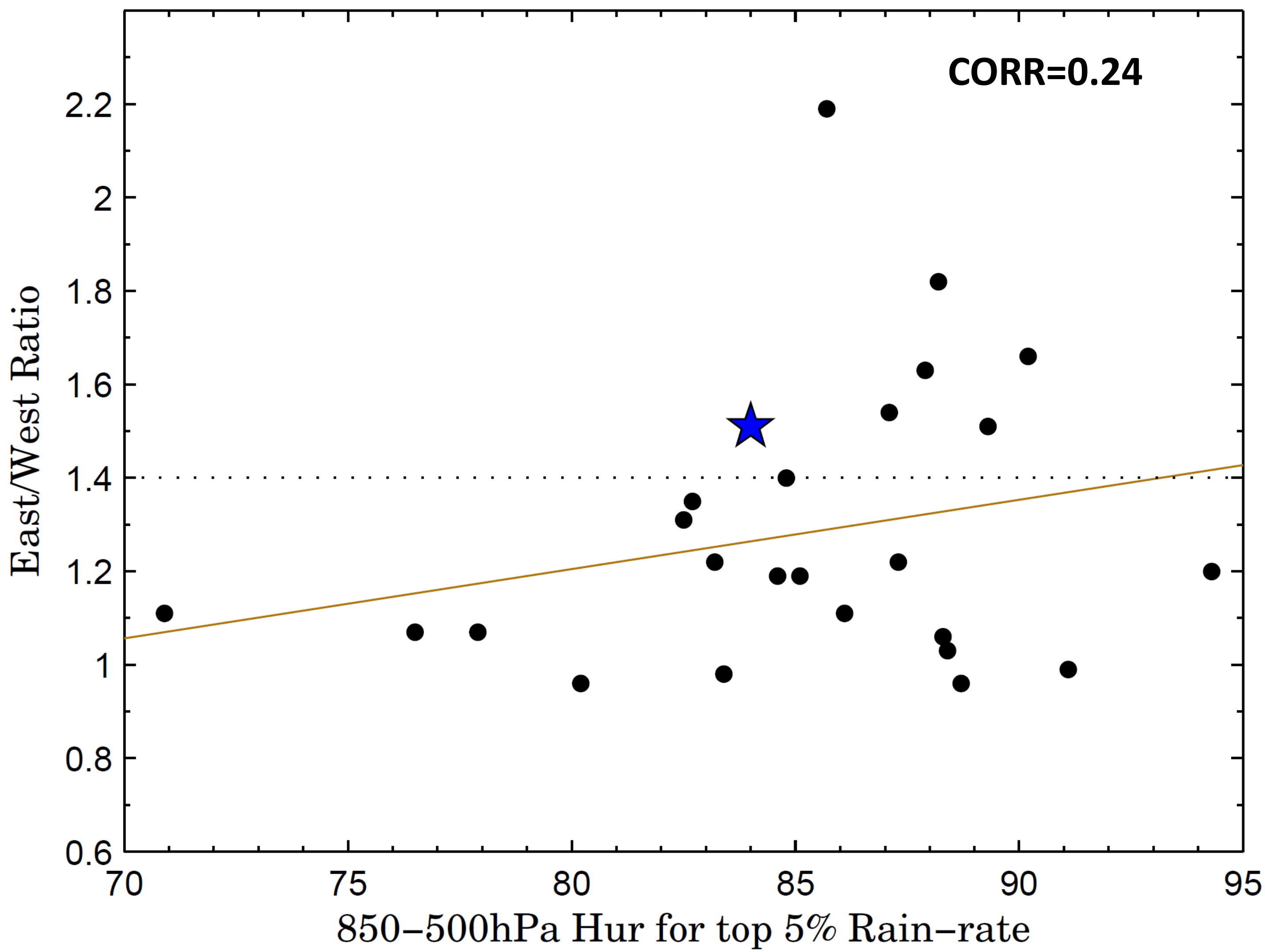
Mass-weighted average of mid-to-lower tropospheric (850-500 hPa) RH for high rain rates (1, 5, and 10%)

(Courtesy of Daehyun Kim)

A correlation of ~0.62 between E/W ratio and RH for 5% rain events based on CMIP3/CMIP5 models.

Kim et al. (2013)

MJO fidelity vs 850-500hPa RH for top 5% Rain Rates



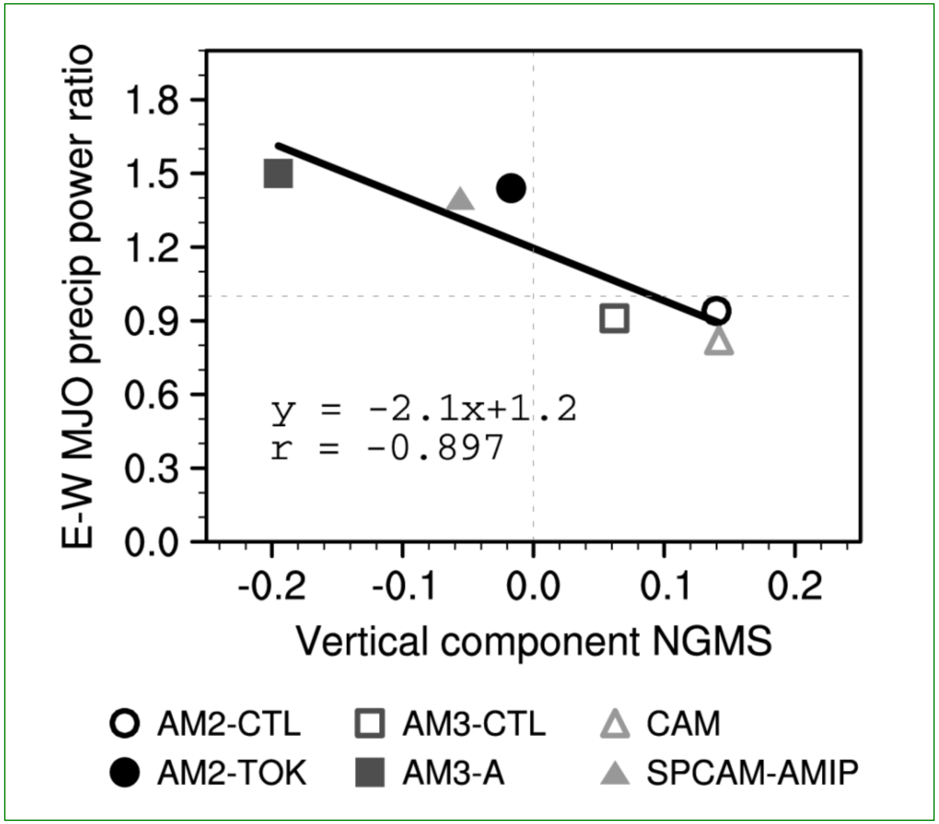
Metric IV. Normalized Gross Moist Stability (NGMS)

(Raymond et al. 2008; Benedict et al. 2013; Maloney et al. 2014)

$$\Gamma_V = -\frac{T_R \langle \omega (\partial s / \partial p) \rangle}{L \langle \nabla \cdot (r\, v) \rangle}$$

s - moist entropy
r - mixing ratio

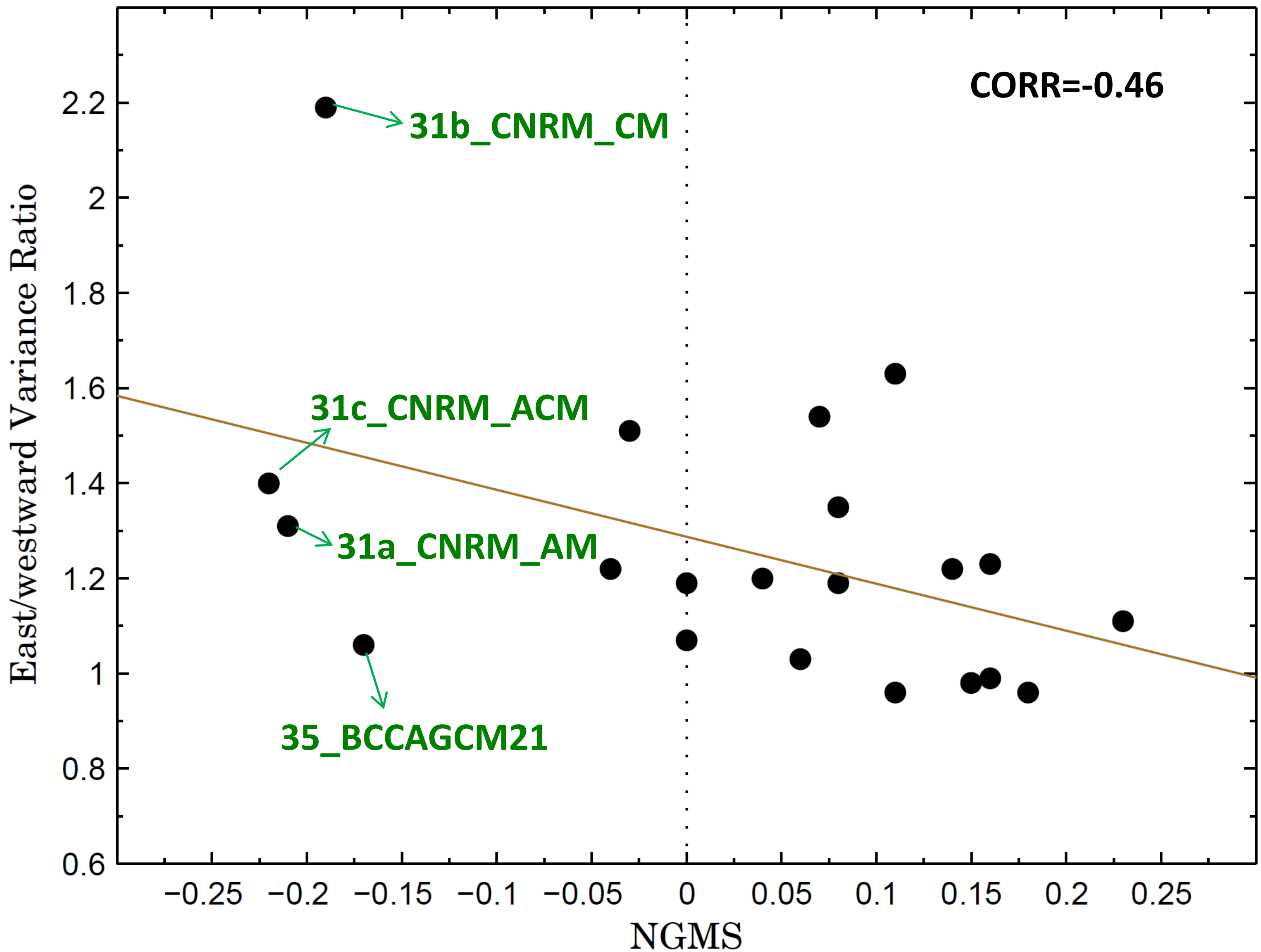
- ✓ Efficiency of convection and associated circulation in discharging column moisture
- ✓ Weak positive or negative GMS is necessary to destabilize the MJO in an idealized "moisture mode" framework (Sobel & Maloney 2013).



Benedict et al. (2013)

(Courtesy of E. Maloney & J. Benedict)

MJO Fidelity vs Normalized Gross Moist Stability (NGMS)

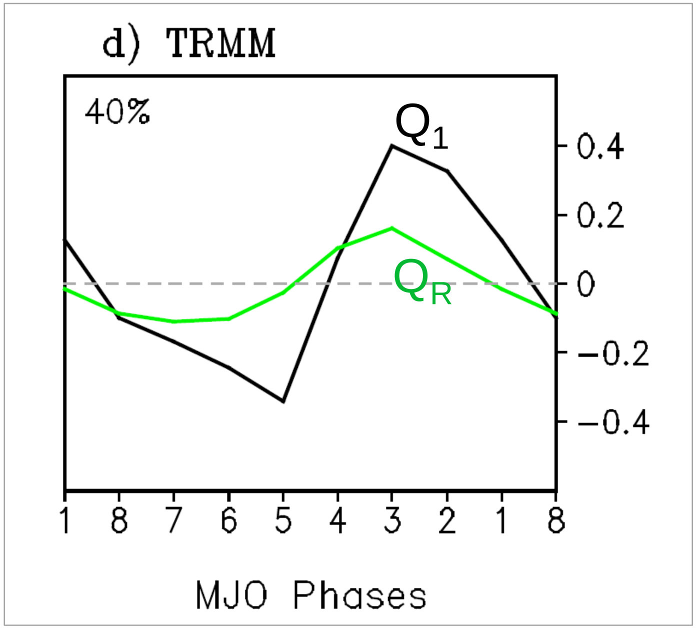


Metric V. Radiative heating for the MJO instability

(Lee et al. 2001; Raymond 2001; Sobel and Gildor 2003; Lin et al 2007; Andersen and Kuang 2012; Jiang et al . 2012)

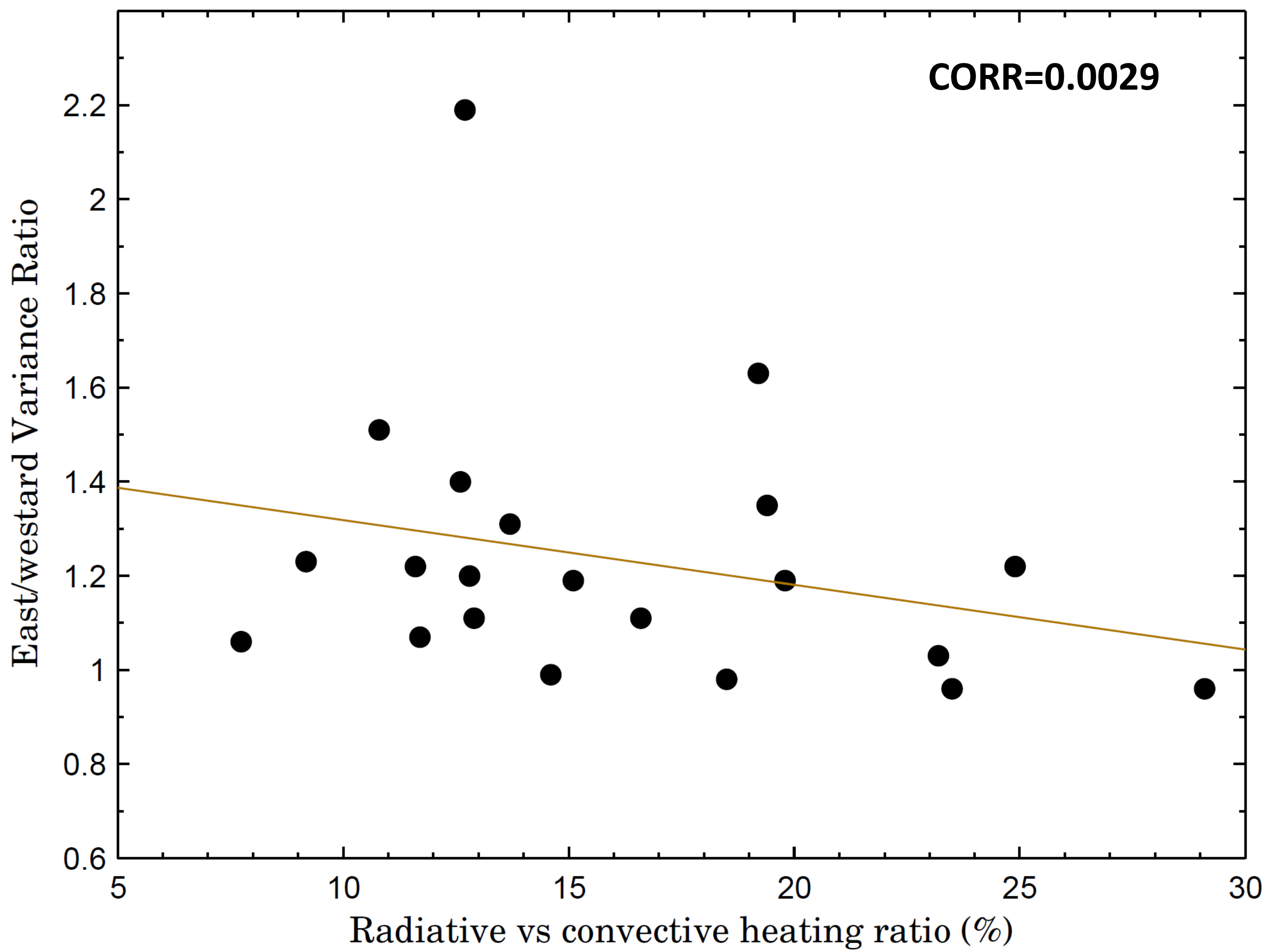
$$\text{Enhancement Factor} = \frac{\langle Q_R \rangle}{\langle Q_1 \rangle}$$

- ✓ "Radiative–convective instability" for the MJO could emerge when this factor exceeds 20% (Lee et al. 2001; Raymond 2001; Lin and Mapes 2004).
- ✓ Enhancement factor of 40% was derived based on TRMM estimate for the MJO peak phase over the Indian Ocean .
- ✓ A factor of 26% in Super-parameterized CAM (Andersen and Kuang, 2012).



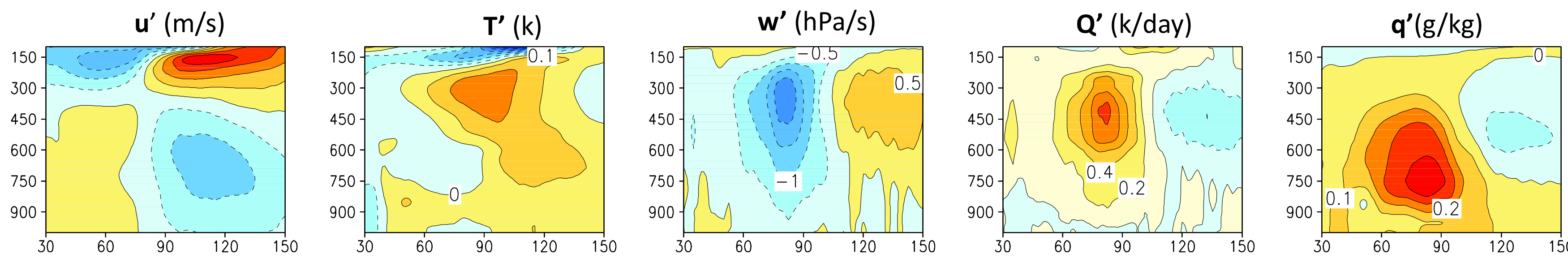
Jiang et al. (2012)

MJO fidelity vs Radiative/Convective heating Ratio

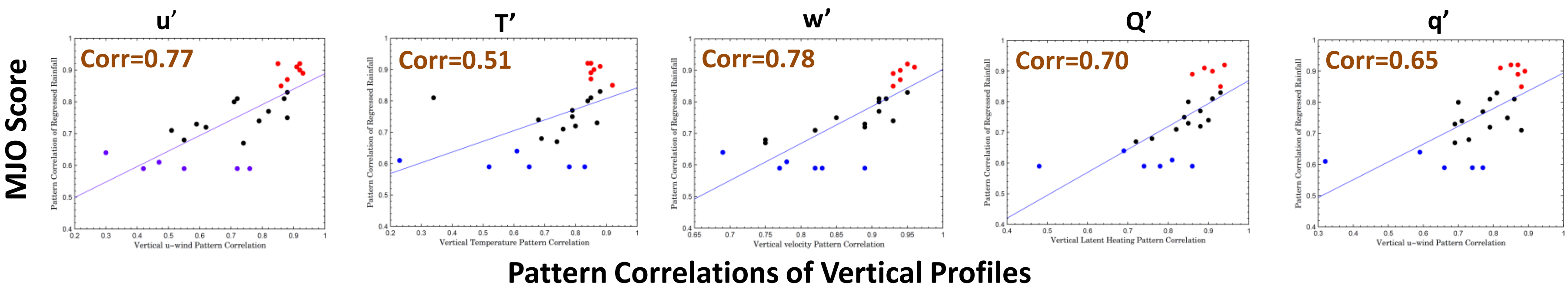


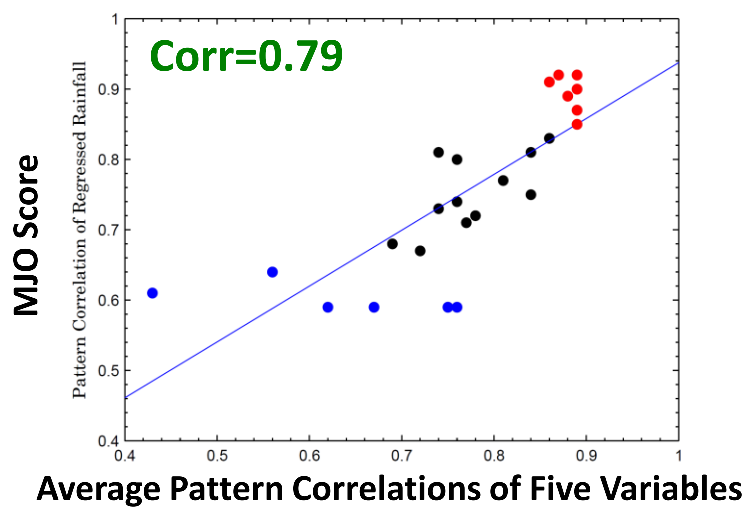
Vertical Structure and MJO Fidelity

Vertical structures of the MJO (ERA-Interim; lag-0 regression)

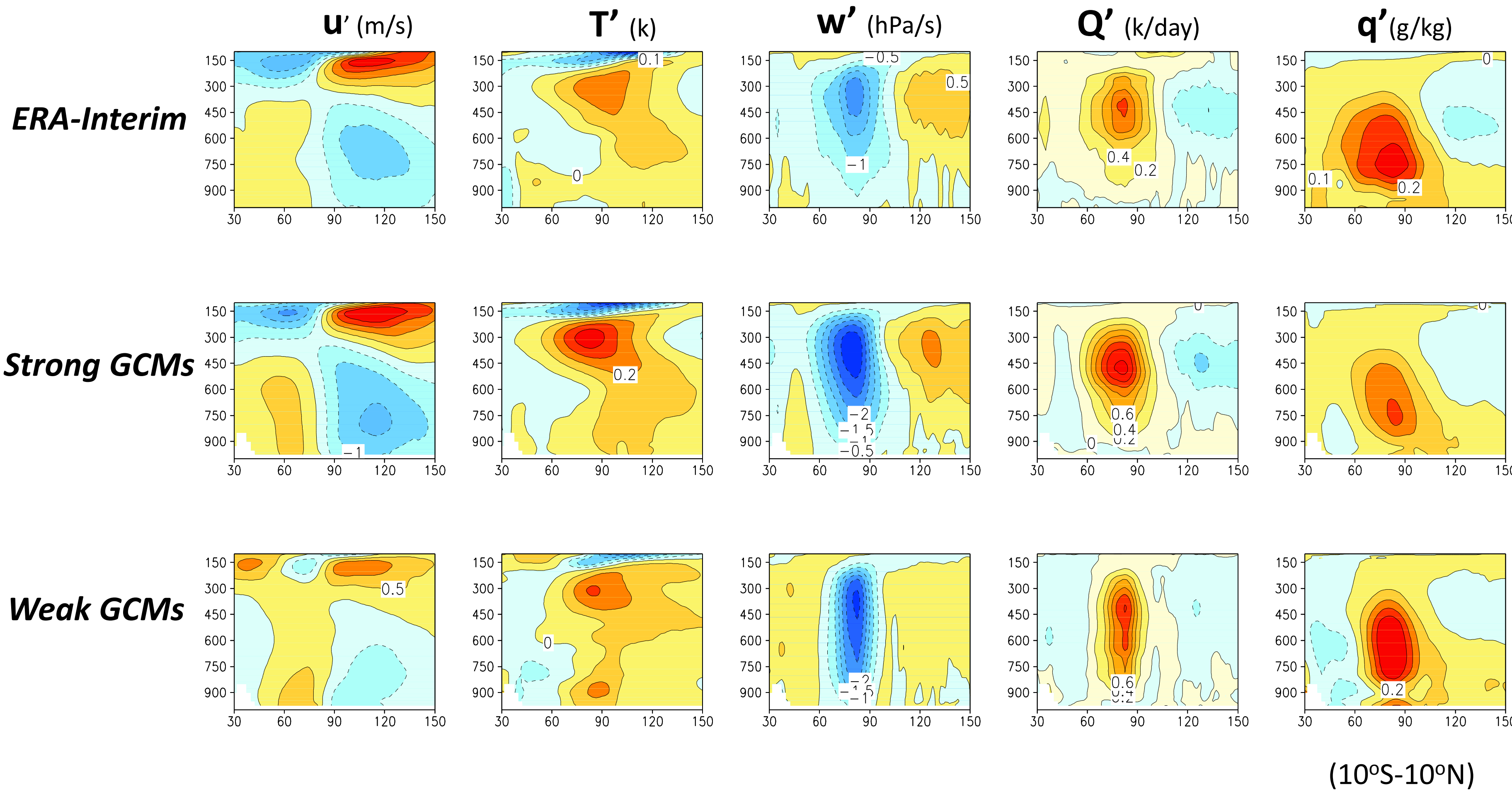


Model Skill in Vertical Structure vs MJO Fidelity





Vertical MJO Structures in Strong and Weak MJO models



Ongoing analyses

- **Comprehensive analyses of moist static energy budget** (e.g., Maloney et al. 2009; Anderson and Kuang 2012)
- **Cumulus Momentum Transport** (CMT; e.g., Tung and Yanai, 2002; Majda and Stachman, 2012; Wang and Liu 2011)
- **Ocean-atmosphere interactive processes** (Fu et al. 2003)
- **Horizontal structure of the MJO**
- ……

Summary

- About ¼ of total 28 GCMs are able to reasonably well capture the observed eastward propagating MJO signals;
- Factors including large-scale rainfall partition, rainfall PDF, vertical relative humidity profiles vs rain-rate, 850hPa u-wind, and surface latent heat flux in a GCM, may not uniquely related to the model fidelity in simulating the MJO;
- Atmosphere-ocean coupling could significantly lead to improved simulation of the MJO;
- Differences in vertical structures of u-wind, T, q, Q, w, associated with the intraseasonal rainfall are noted in "strong" and "weak" GCMs.

Thank you!

For more details of the YOTC/GASS MJO multi-model Project:

http://yotc.ucar.edu/mjo/vertical-structure-and-diabatic-processes-mjo

Suggestions, comments, & collaborations:

Email: xianan@ucla.edu

MJO fidelity vs 850-500hPa RH for (T 5% - B 10%) Rain Rates