Progress in Modelling in the Madden-Julian Oscillation

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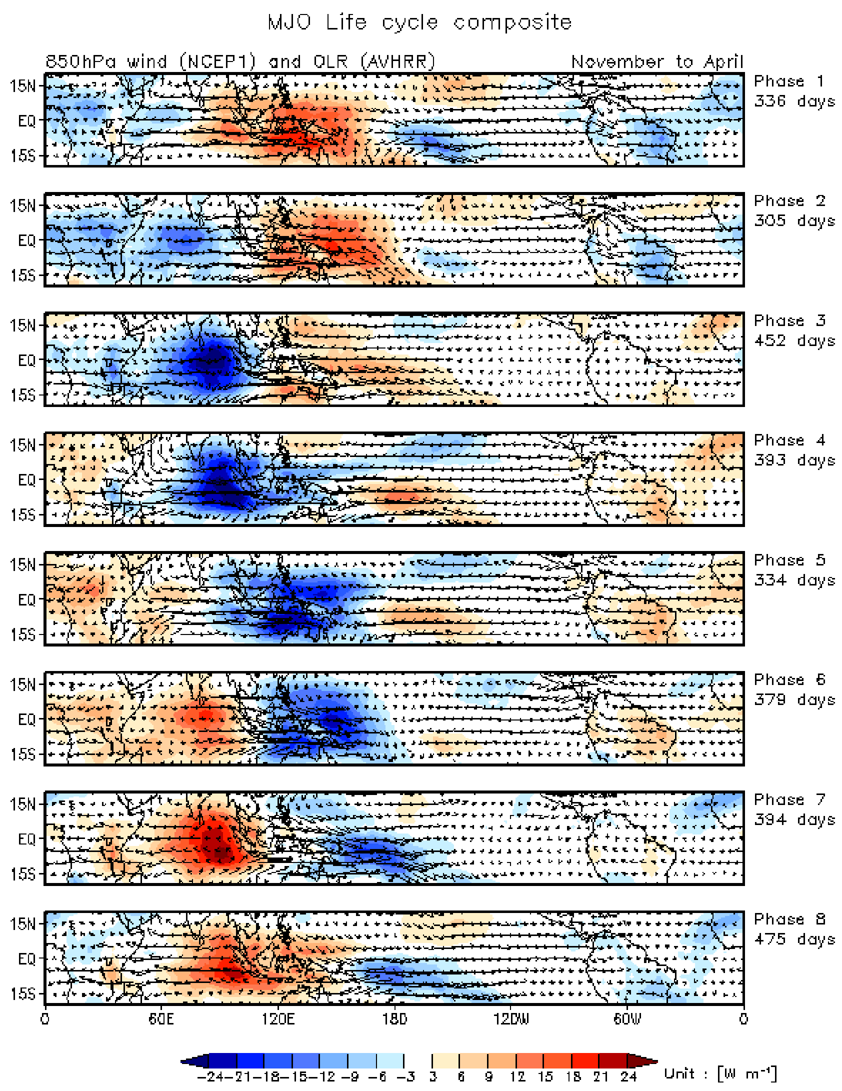
Outline

- Introduction
- The Madden-Julian Oscillation in a cloud-system resolving model
- The Madden-Julian Oscillation in a climate model
  - Sensitivity to the representation of convection
  - Sensitivity to ocean-coupling
- Future work

Introduction

- The Madden-Julian Oscillation (MJO) is the dominant mode of subseasonal variability in the tropics
  - The dominant mode of subseasonal tropical variability of convection
  - Explains 30-50% of the intraseasonal (20-100days) variance in convection over the tropical Indian and western Pacific oceans
- Eastward propagating signal (in convection and winds)
  - period of about 40days
  - wavelength of ~10,000km

Introduction



- Winter (Nov-Apr) composite of OLR and 850hPa winds
  - based on the multivariate index of Wheeler and Hendon (2004)
- Convective signal develops in Indian Ocean propagate eastwards and decays in the Central Pacific
- Low-level westerly anomalies behind the convection and easterlies ahead

Figure taken from US Clivar MJO WG Diagnostics Page
http://climate.snu.ac.kr/mjo_diagnostics/index.htm

Introduction

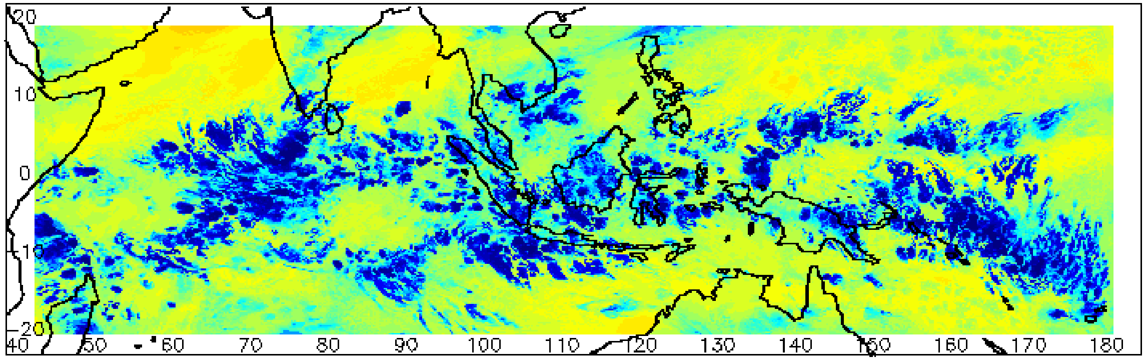
- MJO exerts pronounced influences on global climate and weather systems (e.g. Lau and Waliser 2005; Zhang 2005)
- MJO represents a primary sources of predictability on subseasonal time scales (e.g., Waliser 2005; Gottschalck et al. 2010)
- Current GCMs exhibit limited capability in representing this prominent tropical variability mode (e.g., Slingo et al. 1996; Slingo et al. 2005; Lin et al. 2006; Kim et al. 2009).
- The fundamental physics of the MJO are still elusive; coupling between the convection is key, other important aspects include
    - Sensitivity of convection to environmental humidity
    - Coupling with the ocean
    - Vertical structure of the convective heating profile
    - Radiative feedbacks

Simulation of the MJO in a cloud-system resolving model

Simulation of an MJO event from April 2009 (YOTC event D, Waliser et al (2012) in Met Office UM as part of the *Cascade* project

- Limited Area Model over Tropical Indian Ocean and West Pacific, lateral BCs from ECMWF YoTC analysis
- Horizontal Resolution from 1.5-40km
- With parametrized convection at 12km and 40km
- With explicit convection at 4km and 12km resolution
    - With conventional UM Boundary Layer Scheme in vertical
    - With Smagorinsky type mixing in the vertical

Holloway, Woolnough, and Lister, *J. Atmos. Sci.*, submitted August 2012

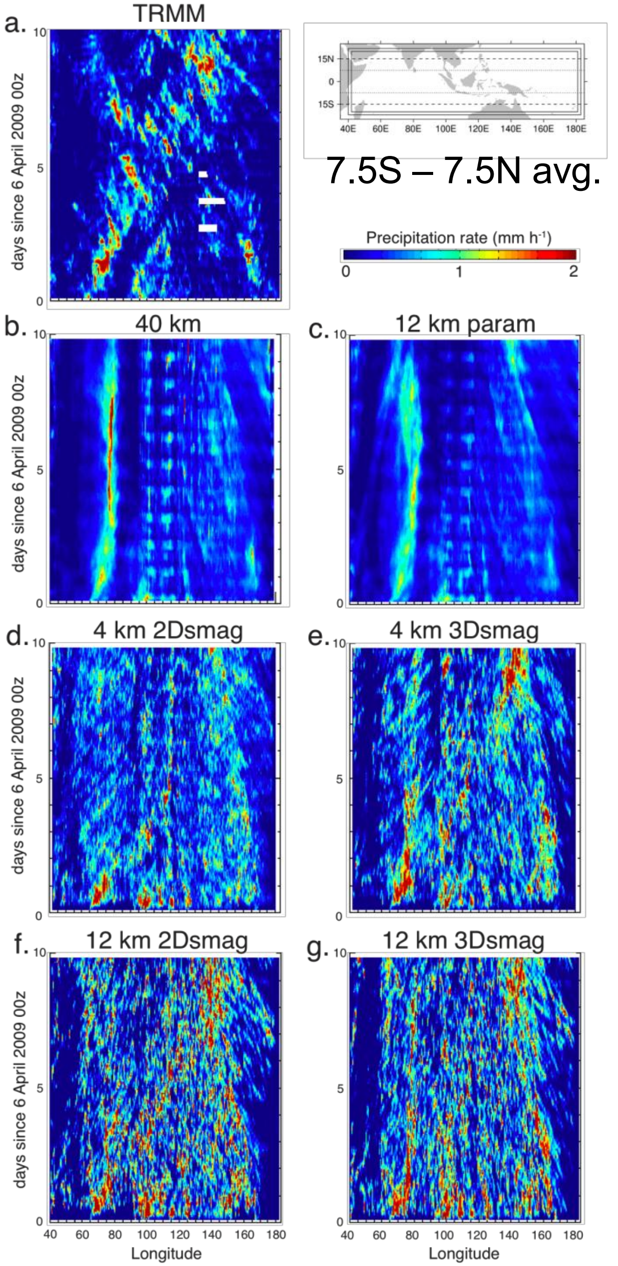


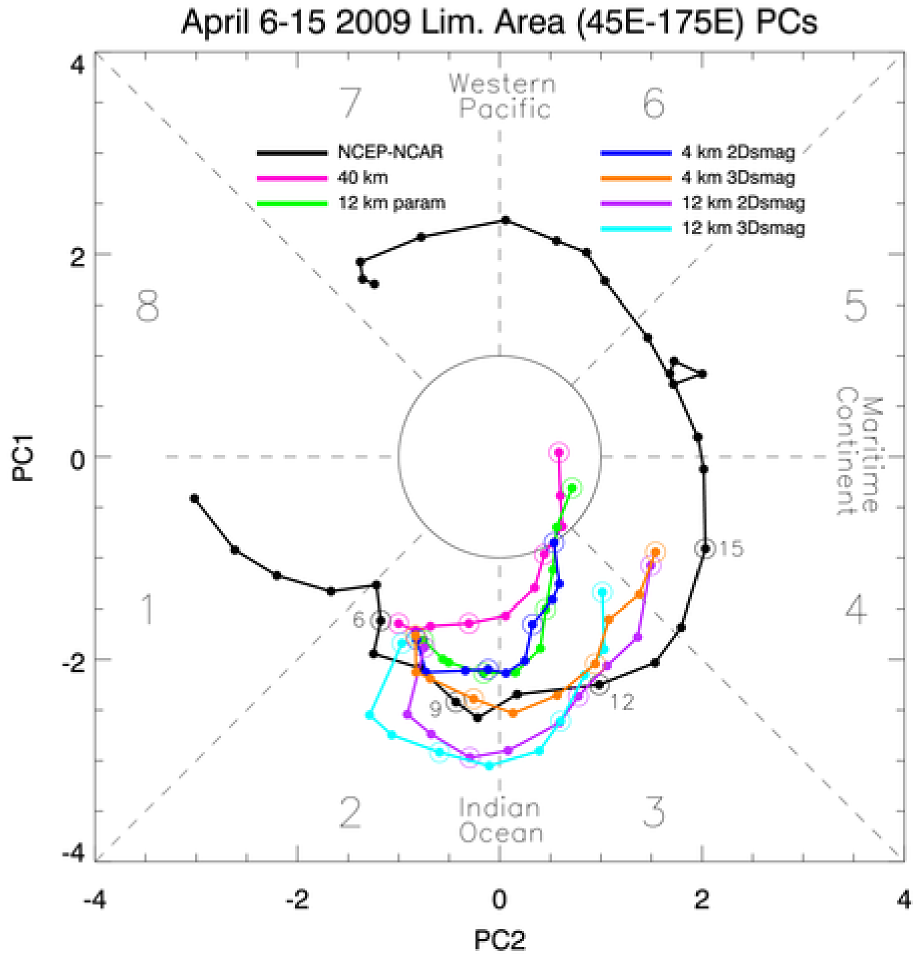
Simulation of the MJO in a cloud-system resolving model

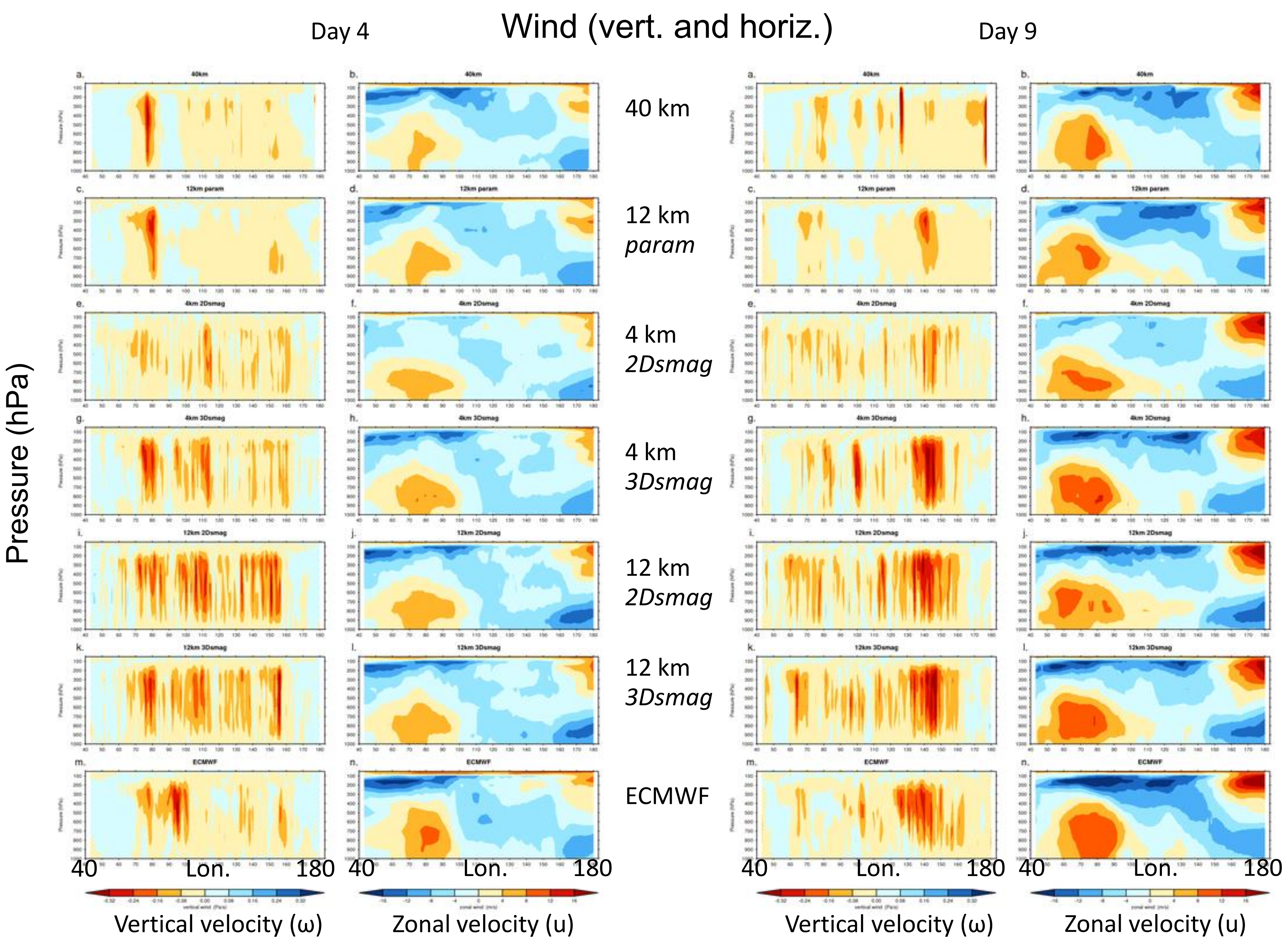
	4 km *2Dsmag*	4 km *3Dsmag*	12 km *2Dsmag*	12 km *3Dsmag*	12 km *param*	40 km
Convection nearly all parameterized					✔	✔
Convection nearly all explicit	✔	✔	✔	✔		
Horizontal Smagorinsky subgrid mixing	✔	✔	✔	✔		
Vertical boundary layer scheme mixing	✔		✔		✔	✔
Vertical Smagorinsky subgrid mixing		✔		✔		
Vertical levels	70	70	38	38	38	38

Smagorinsky-Lilly subgrid-scale mixing based on local stability and wind shear (flow-dependent), mixing length = 0.1 * horiz. grid size

Simulation of the MJO in a cloud-system resolving model



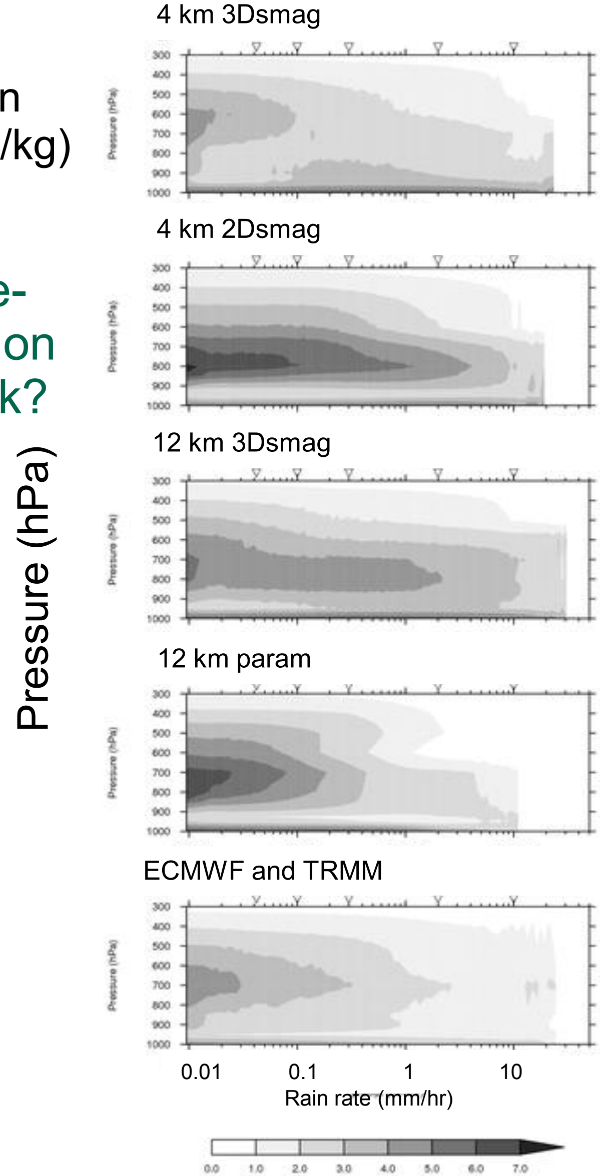



Wind (vert. and horiz.)
Day 4
Day 9
Pressure (hPa)
40 km
12 km *param*
4 km *2Dsmag*
4 km *3Dsmag*
12 km *2Dsmag*
12 km *3Dsmag*
ECMWF
40
Lon.
180
Vertical velocity (ω)
Zonal velocity (u)

Simulation of the MJO in a cloud-system resolving model

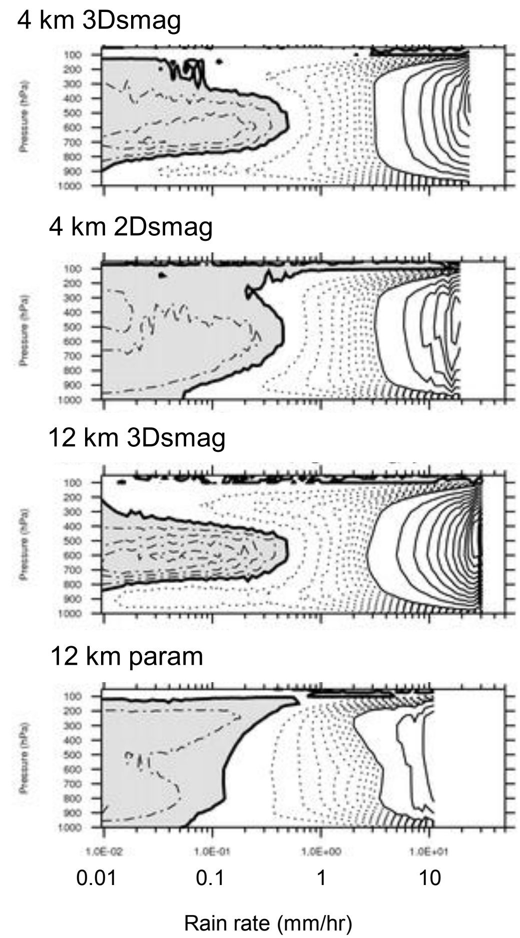
Saturation deficit (g/kg)

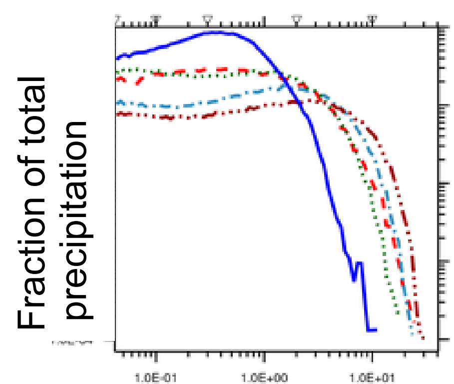
Better moisture-convection feedback?



Vertical velocity (Pa/s) (downward shaded)

More explicit low-level ascent in light rain regions?





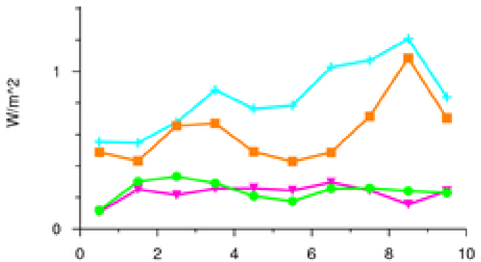
12 km *param* model has too much light rain, not enough heavy rain, preferred rate ~10 mm/day (0.4 mm/h)

Holloway, Woolnough, and Lister, *QJRMS*, 2012

Simulation of the MJO in a cloud-system resolving model

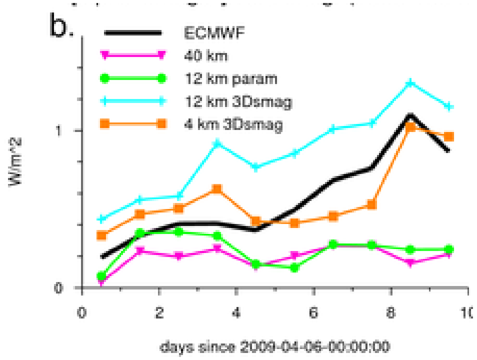
Generation of Eddy APE

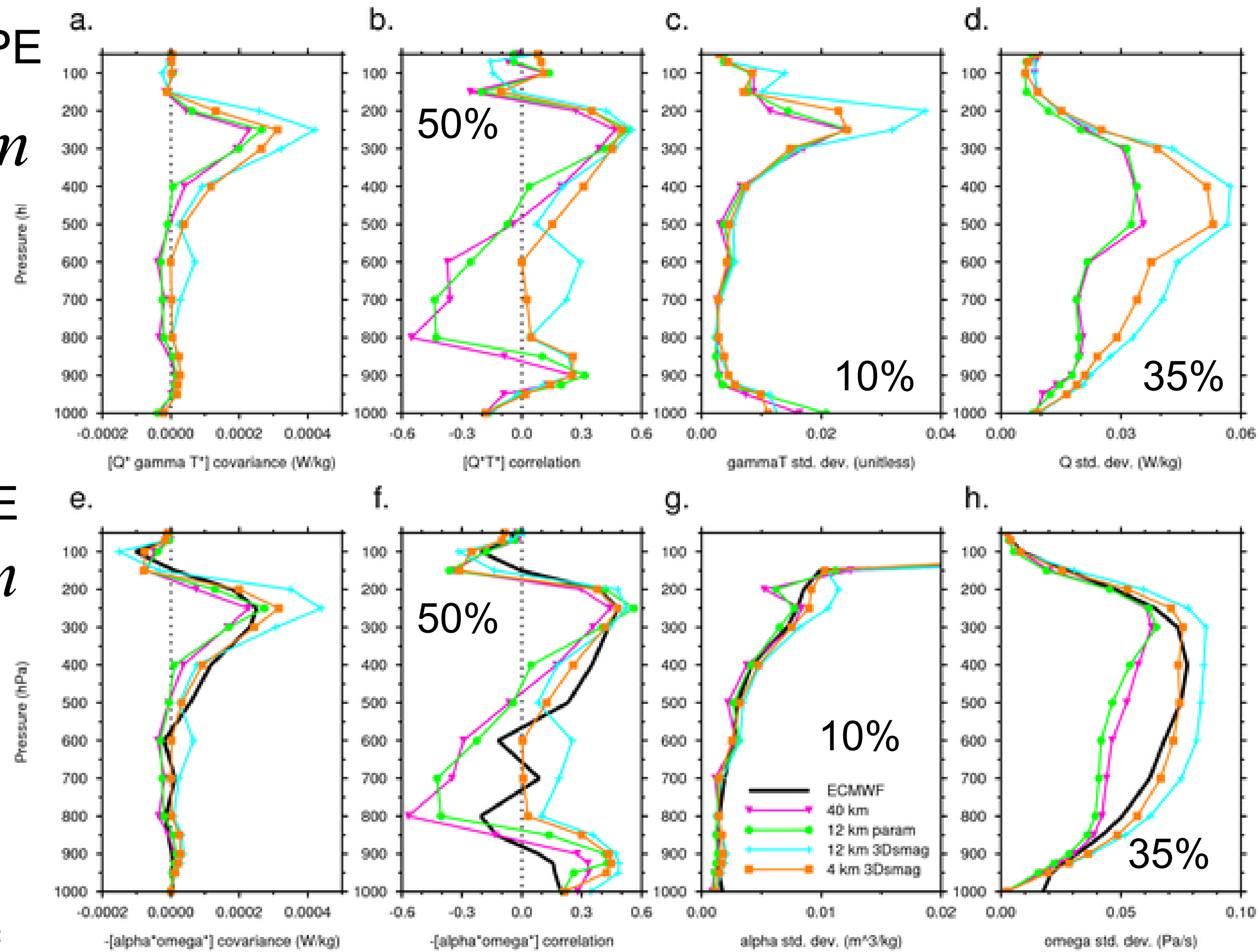
$$G_e = \int \gamma [T^* Q^*] dm$$



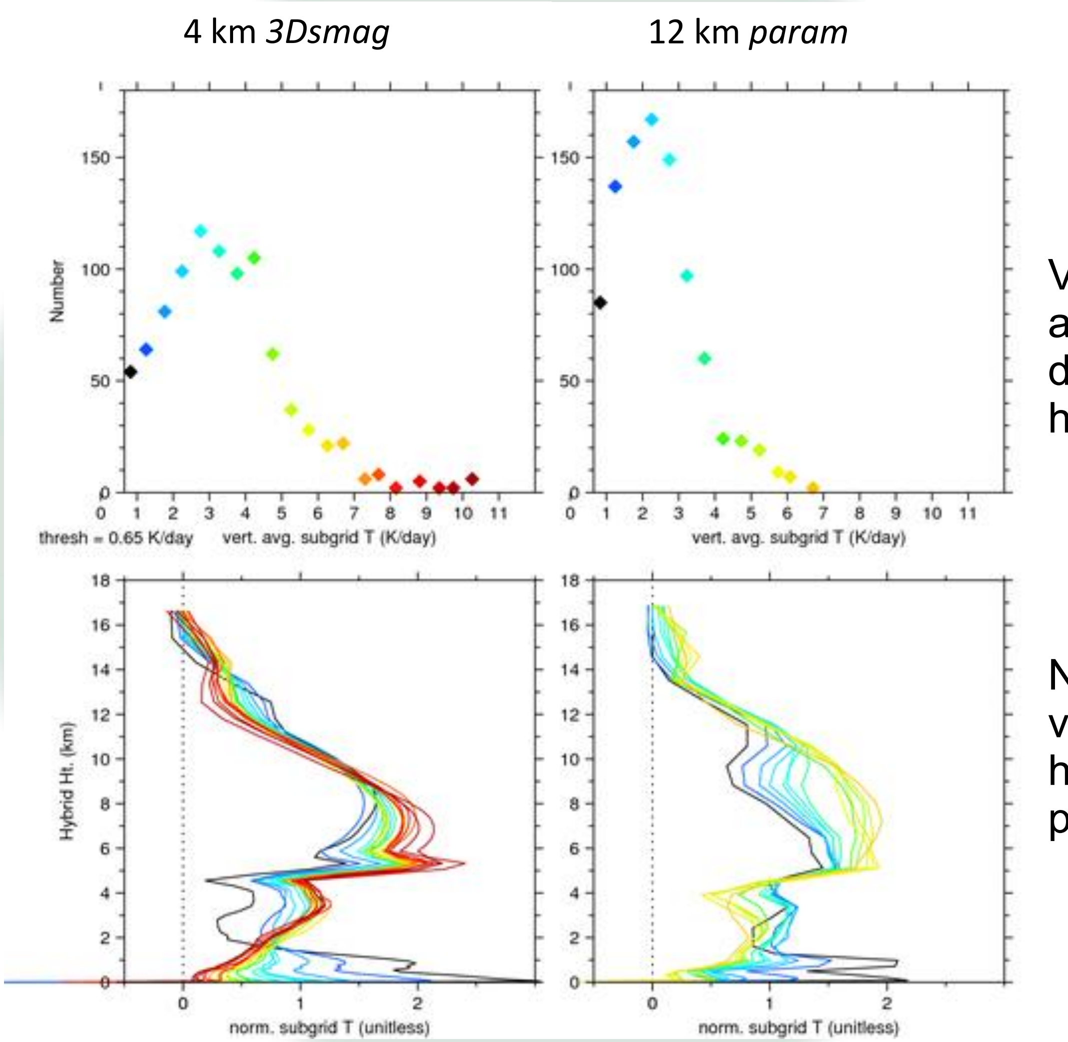
Conversion of APE to KE

$$C_e = -\int [\alpha^* \omega^*] dm$$





Simulation of the MJO in a cloud-system resolving model



Vertically averaged diabatic heating

Normalised vertical heating profiles

Simulation of the MJO in a cloud-system resolving model

Summary

- Explicit convection (vs. parameterized convection) matters more than horizontal resolution per se.

- But you still have to get other parameterizations right (or different), such as subgrid turbulence.

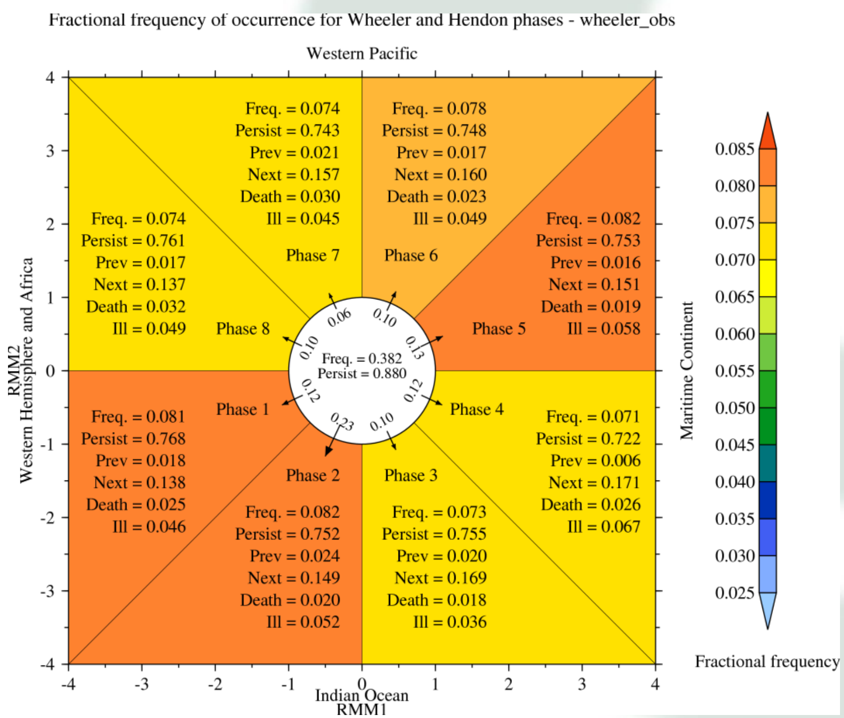
- Explicit convection gives an overall more realistic rainfall distribution, whereas parameterized convection has preferred (light) rain rate.

- The MJO improvements in the explicit convection runs might be related to
  - a better relationship between free-tropospheric humidity and precipitation,
  - changed relationship between precipitation rate and vertical velocity
  - larger generation of APE and conversion of APE to KE,
  - the variations in the vertical profile of diabatic heating

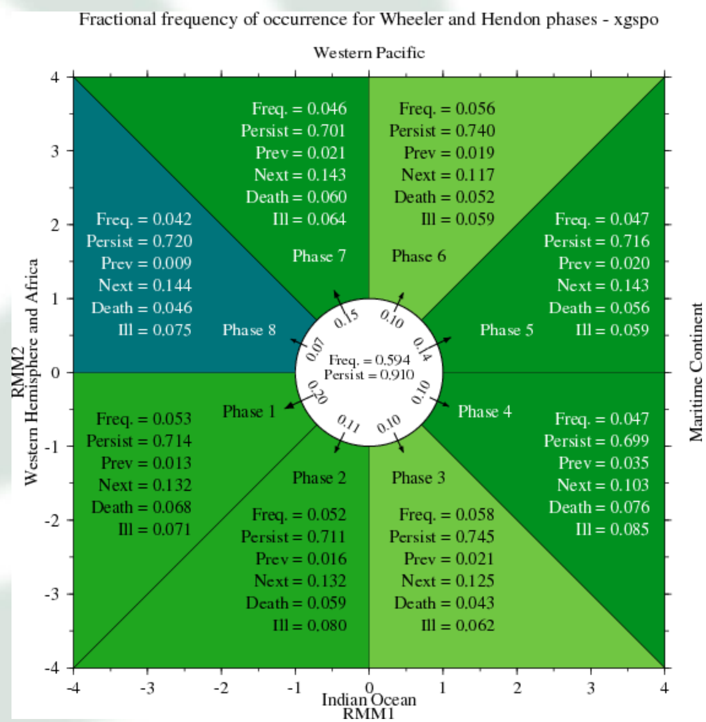
MJO in a climate model: sensitivity to convective entrainment

- MJO simulation in the Met Office UM
  - (GA3.0), N96L85 (~200km resolution)
  - 20 year simulations with climatological SSTs

Observations (1979-2011)



A-CTL

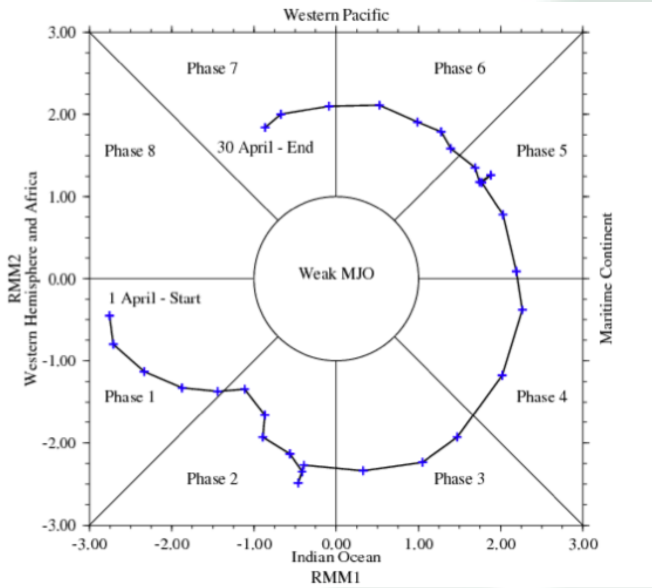


MJO in a climate model: sensitivity to convective entrainment

- Poor MJO simulation in the control run, how can we improve it
- Perform a series of hindcasts varying a (14) number of physical parametrizations, singly and in combination, including
  - Convective Entrainment
  - Convective closure timescale
  - Convective momentum transport
  - …
- Compare two here
  - **A-CTL** the control integration
  - **A-ENT** as the control integration but with the convective entrainment (and mixing detrainment) parameter increased by a factor of 1.5

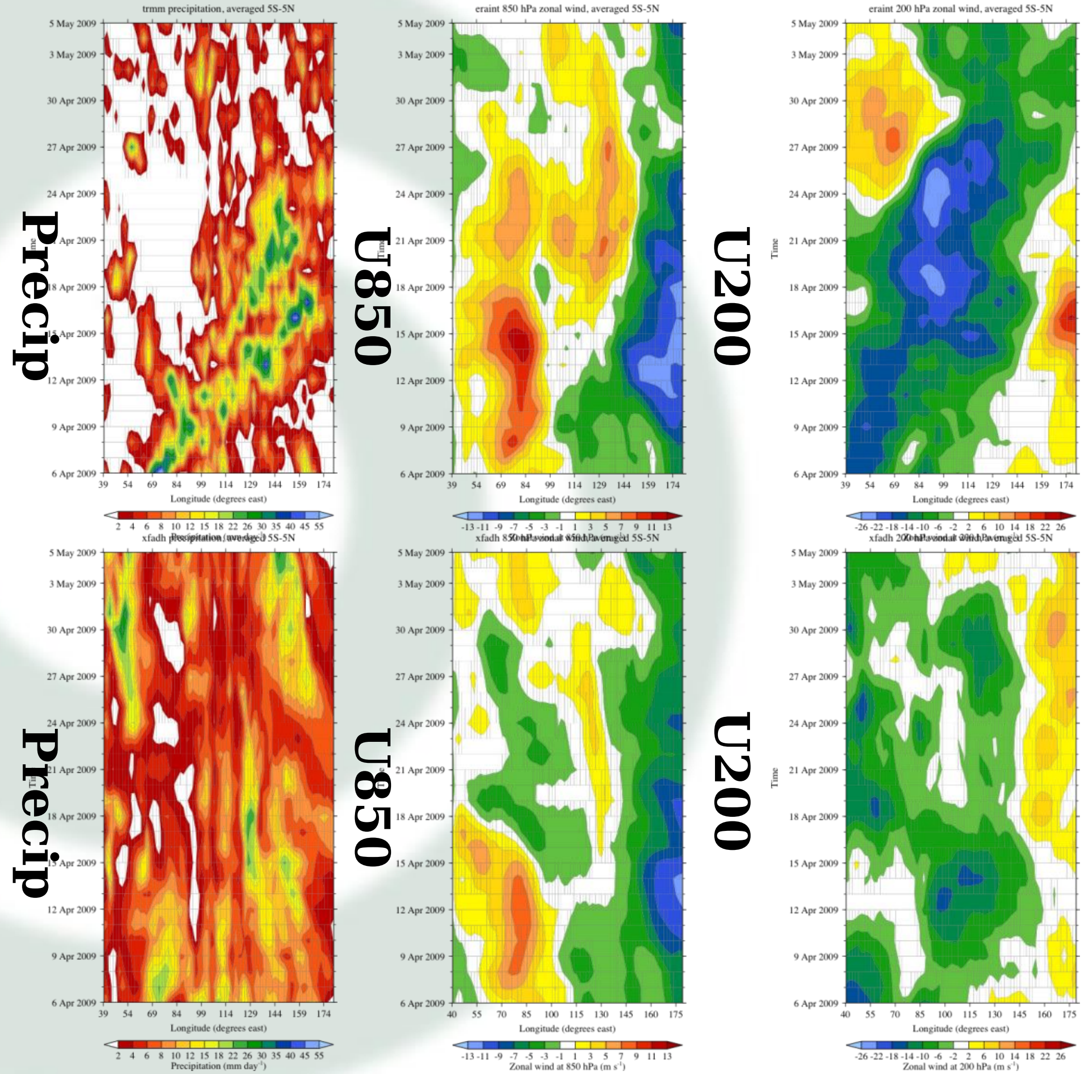
Klingaman and Woolnough, 2012a in prep

MJO in a climate model: sensitivity to convective entrainment



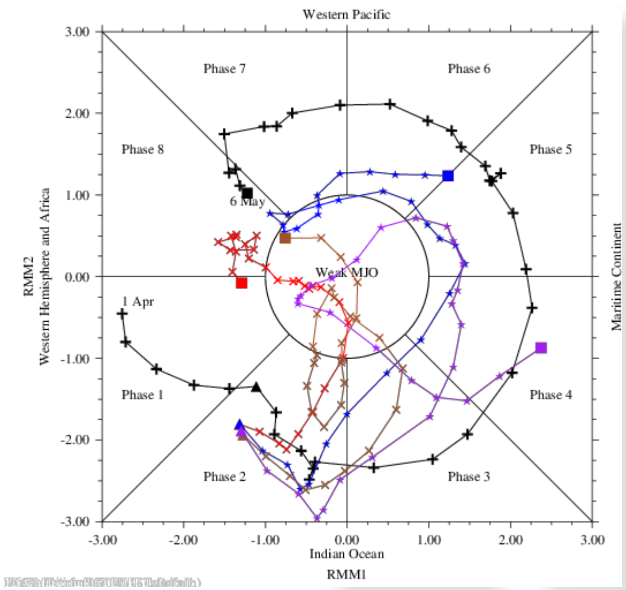
Observed propagation of 6 April event in MJO phase space

Observations



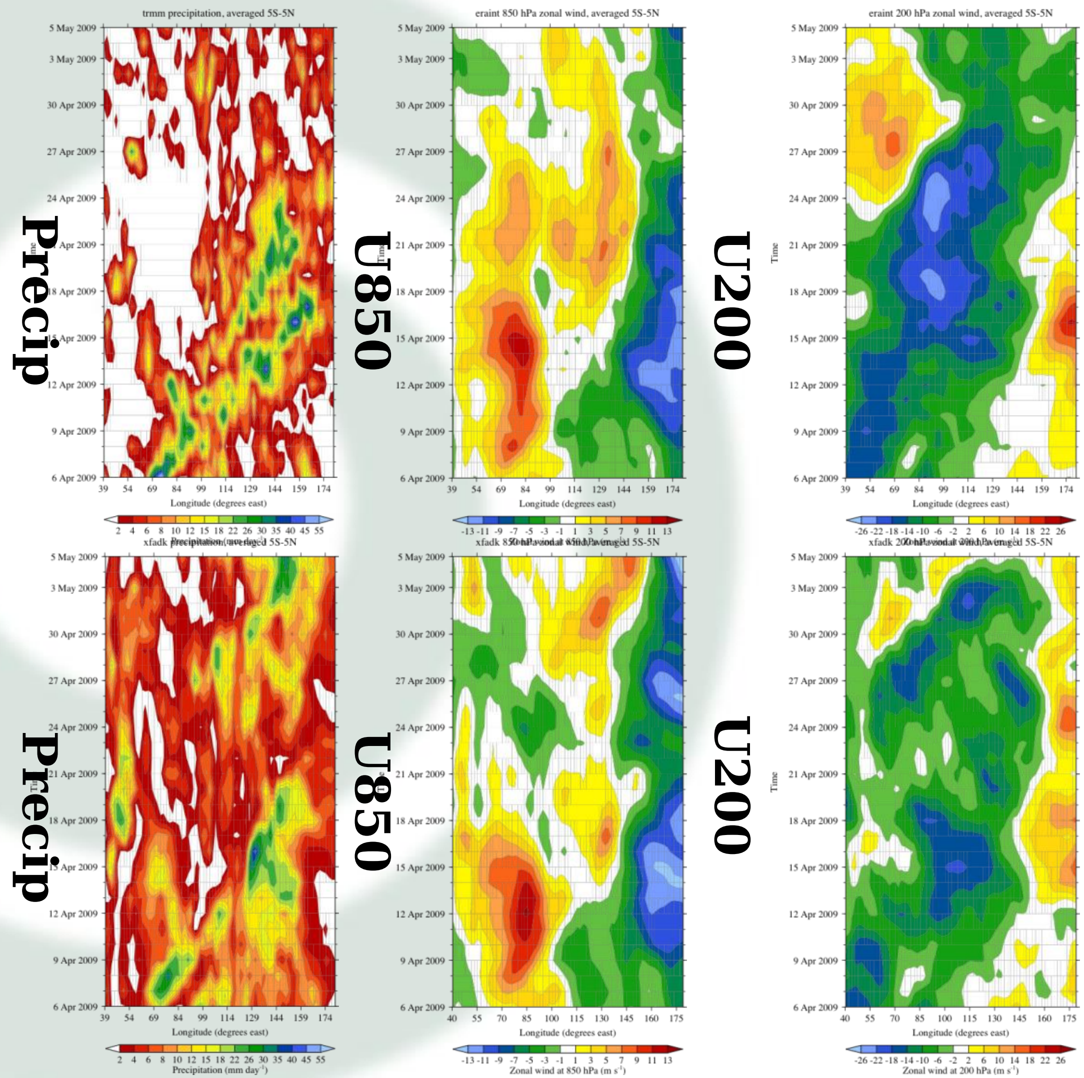
A-CTL

MJO in a climate model: sensitivity to convective entrainment



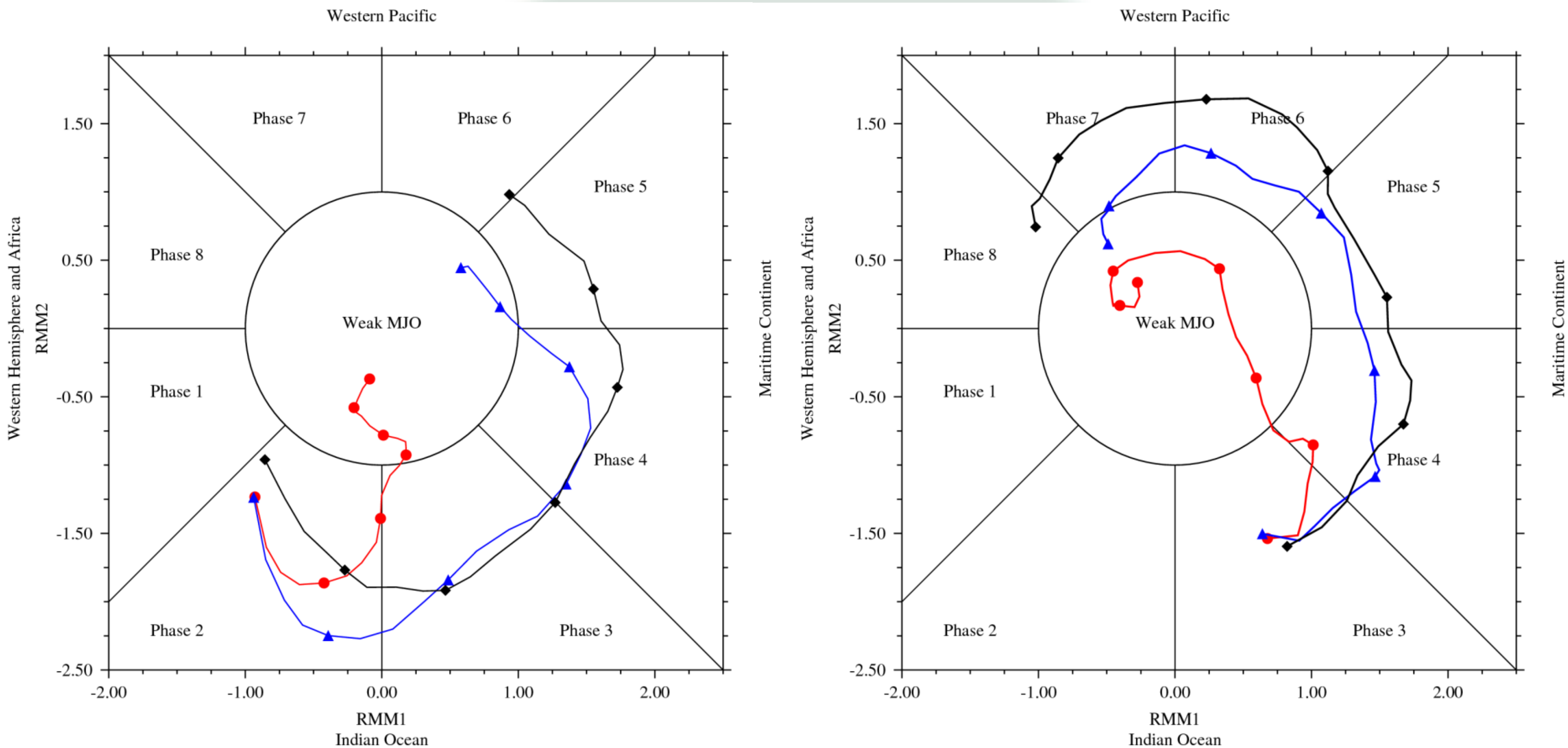
Propagation of 6 April event in MJO phase space
Black: Observations
Red: A-CTL
Blue: A-ENT
Brown : A-CTL (No CMT)
Brown: A-ENT (No CMT)

Observations



A-ENT

MJO in a climate model: sensitivity to convective entrainment



Composite RMM evolution of observations (black), control hindcasts (red) and 1.5x entrainment hindcasts (blue) for 14 strong MJO cases for initialization in phase 2 and 10 days later Dots spaced every five days.

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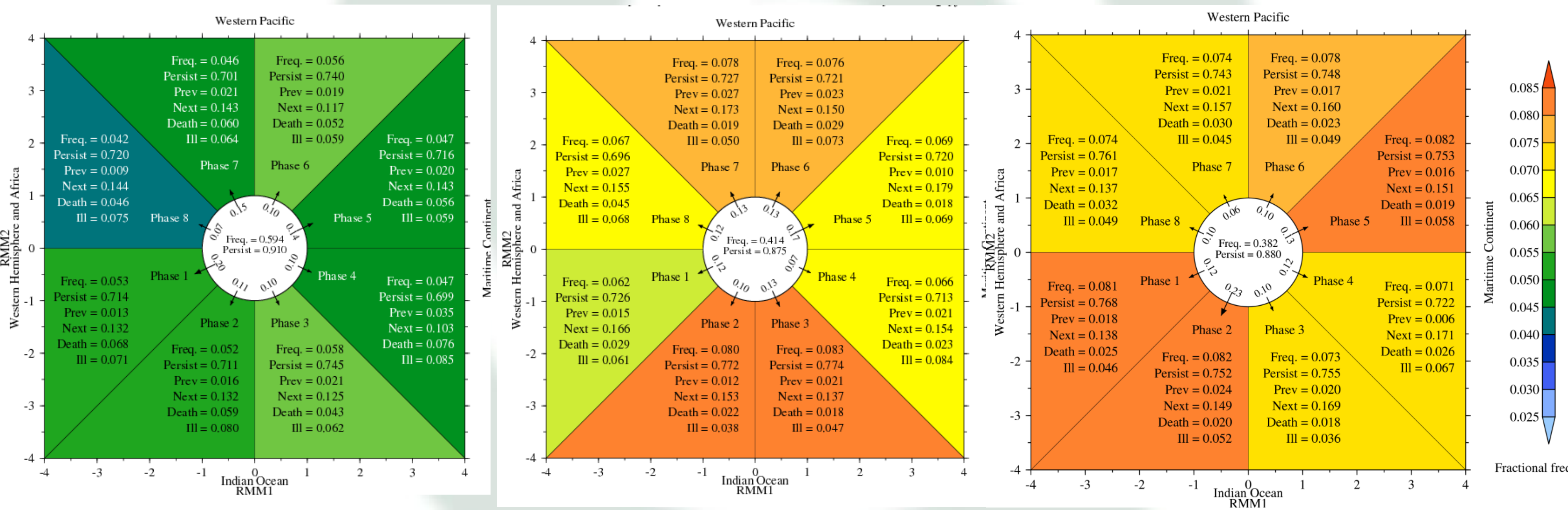
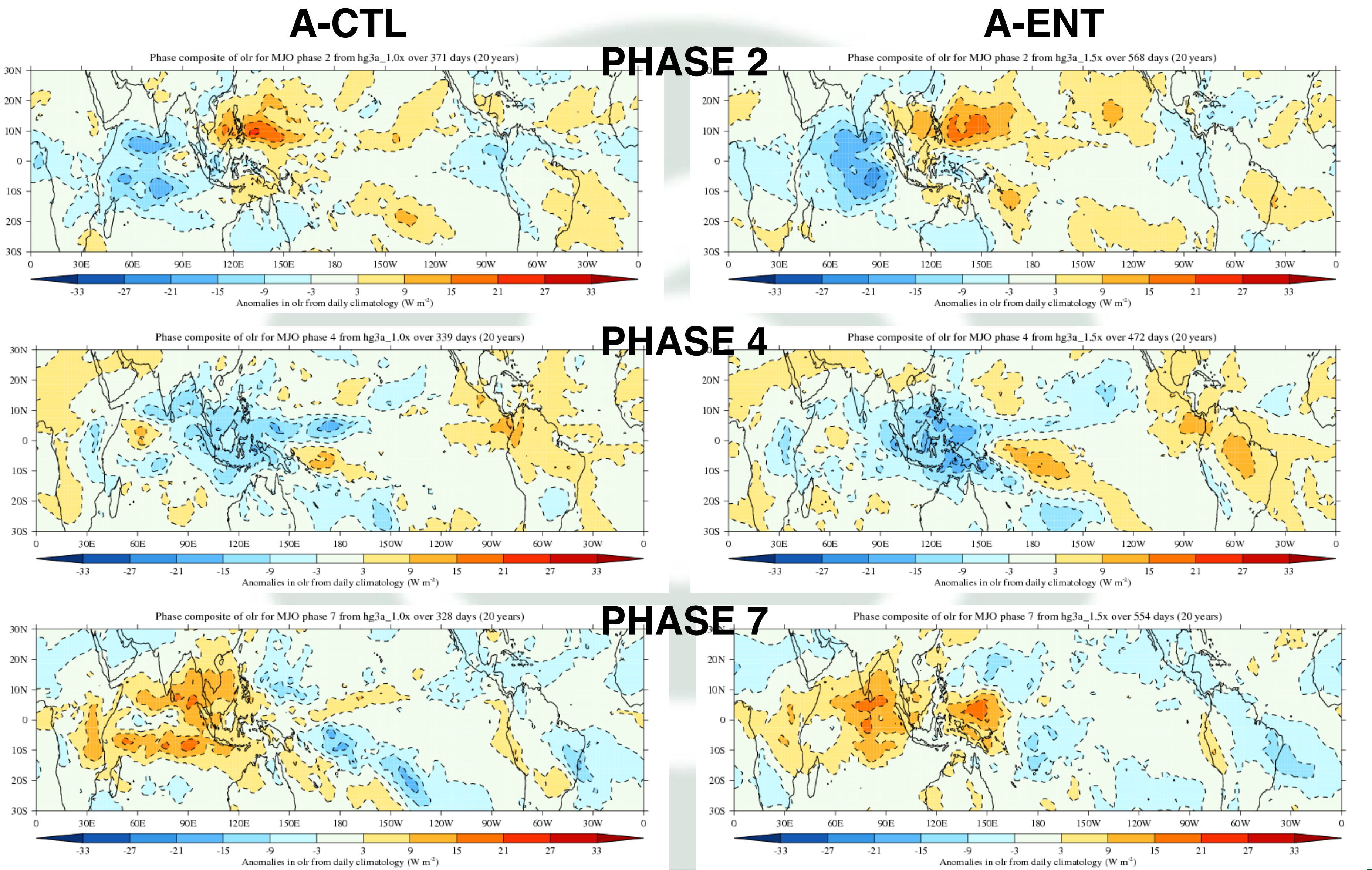
MJO in a climate model: sensitivity to convective entrainment

- Make the entrainment change in the climate model and we get much improved MJO amplitude

A-CTL A-ENT Observations



MJO in a climate model: sensitivity to convective entrainment

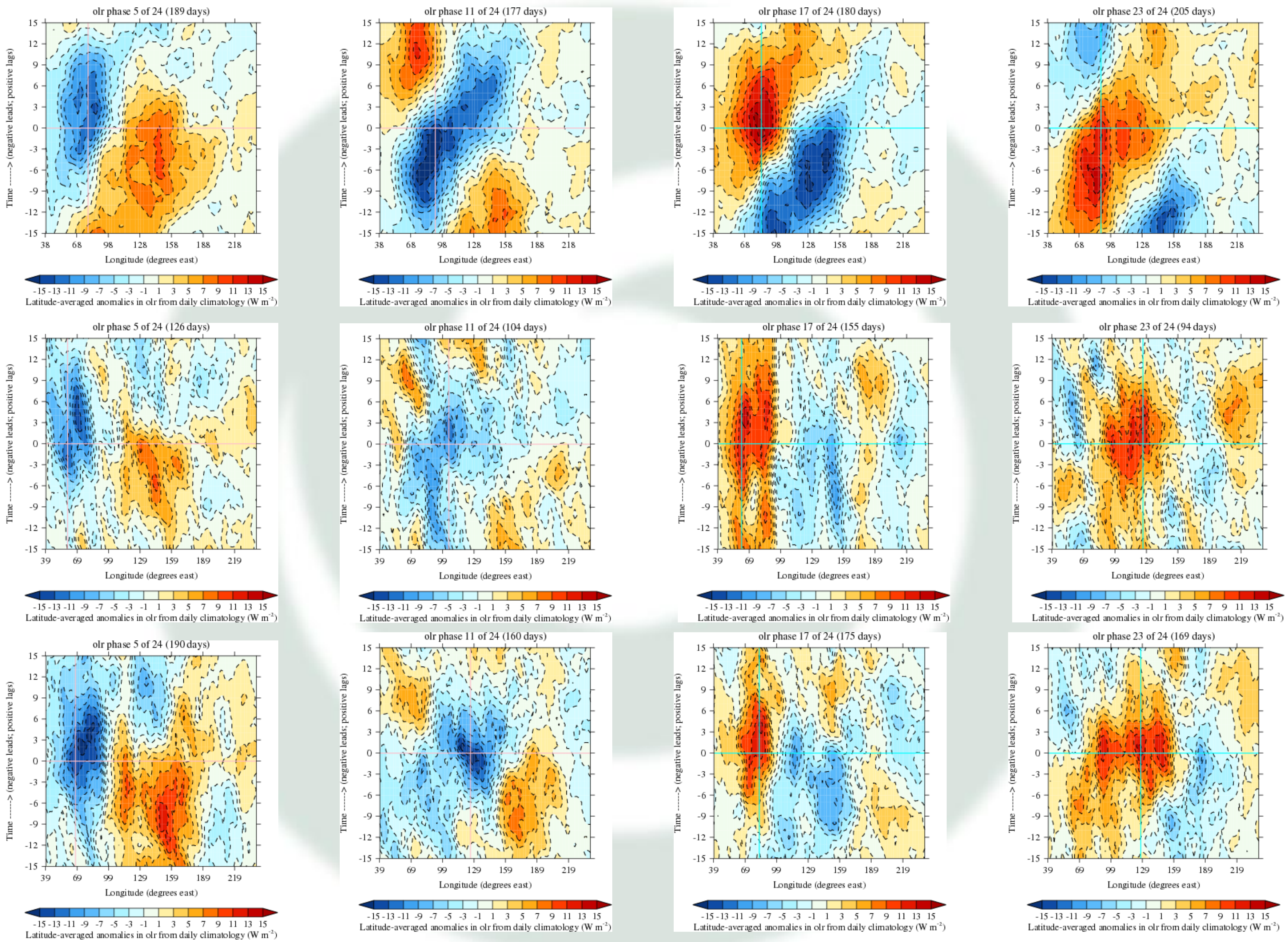


	Phase 2	Phase 4	Phase 6	Phase 8

NOAA

A-CTL

A-ENT



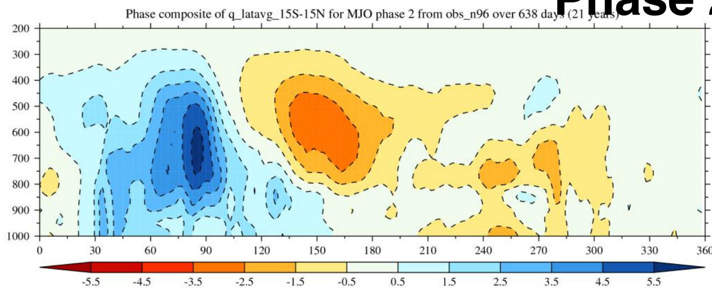
MJO in a climate model: sensitivity to convective entrainment

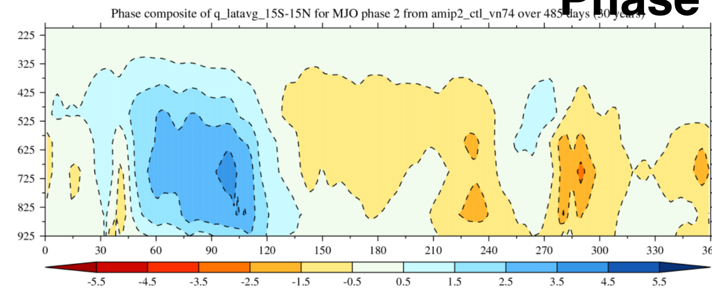
5N-5S q anomalies

ERA-Interim

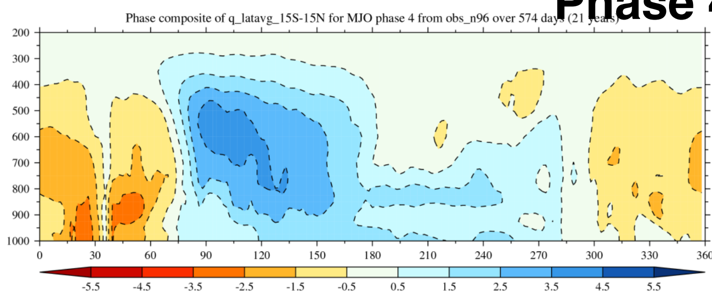
A-CTL

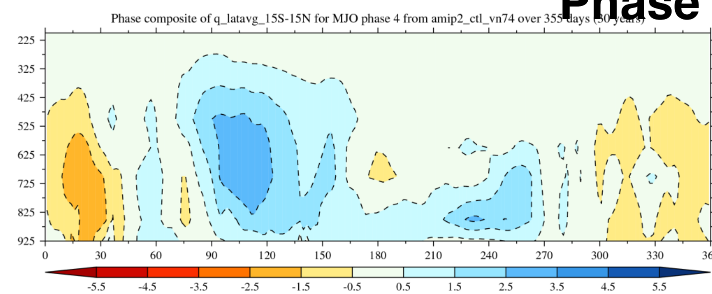
Phase 2



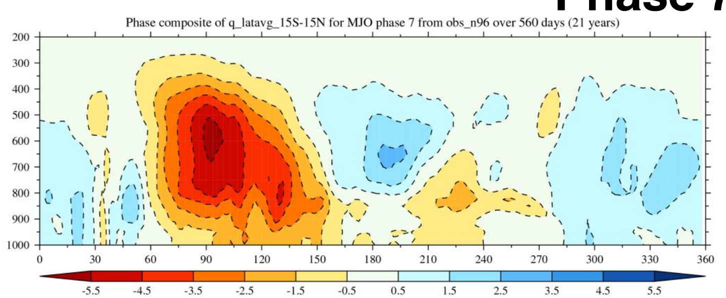


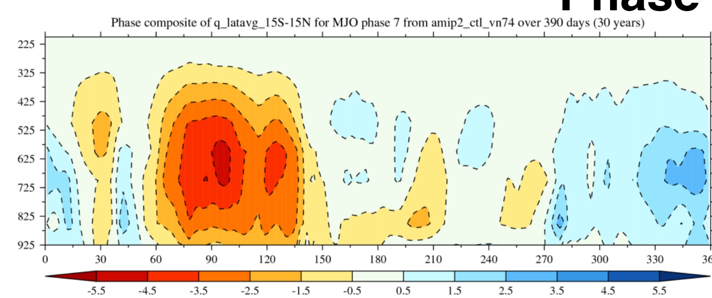
Phase 4





Phase 7





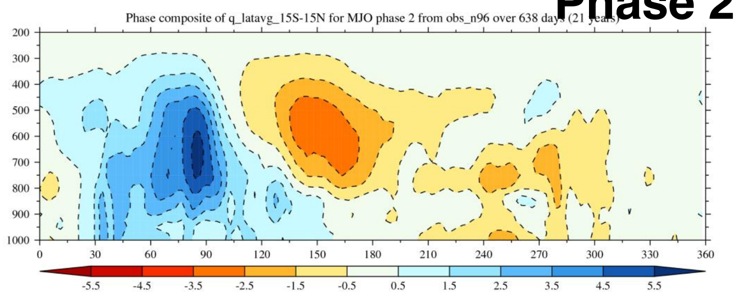
MJO in a climate model: sensitivity to convective entrainment

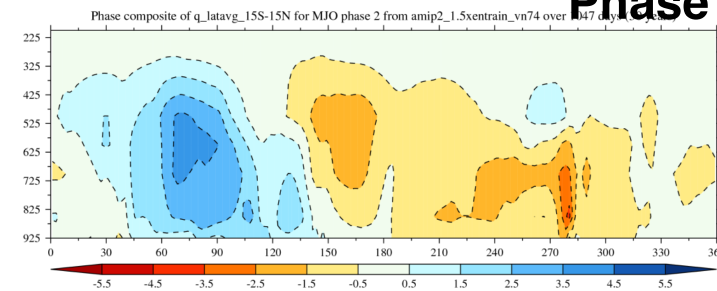
5N-5S q anomalies

ERA-Interim

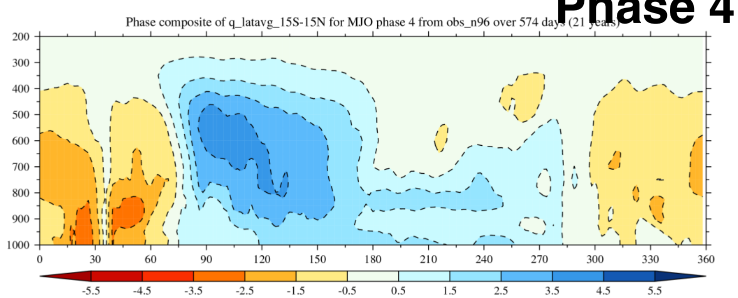
A-ENT

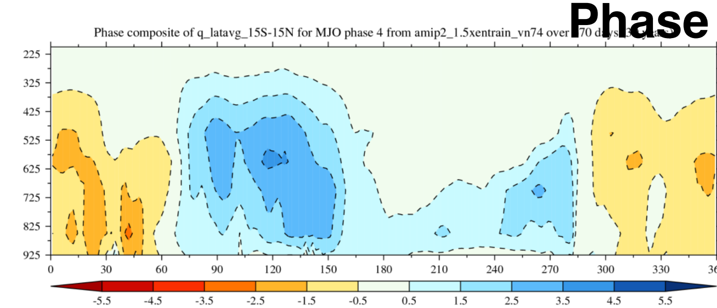
Phase 2



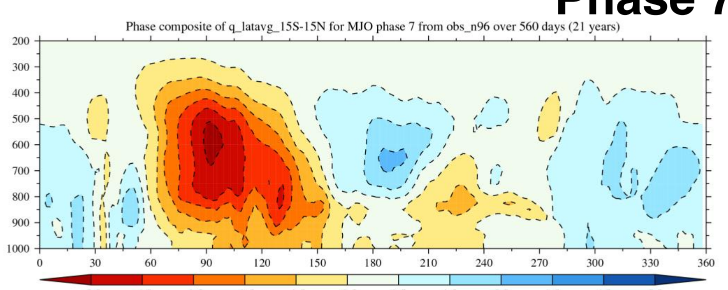


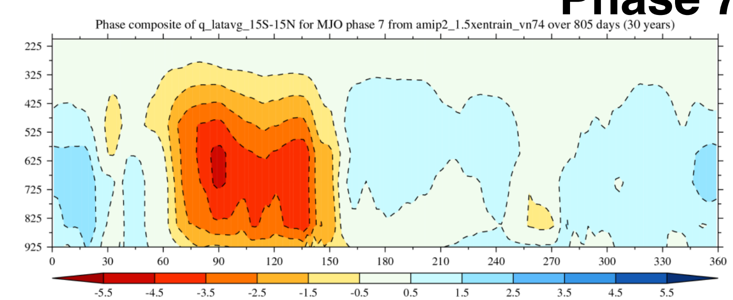
Phase 4





Phase 7

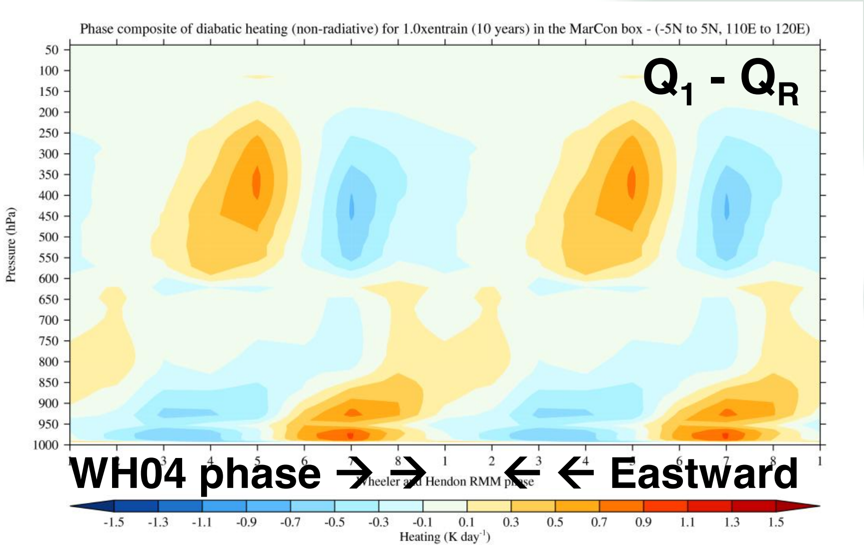


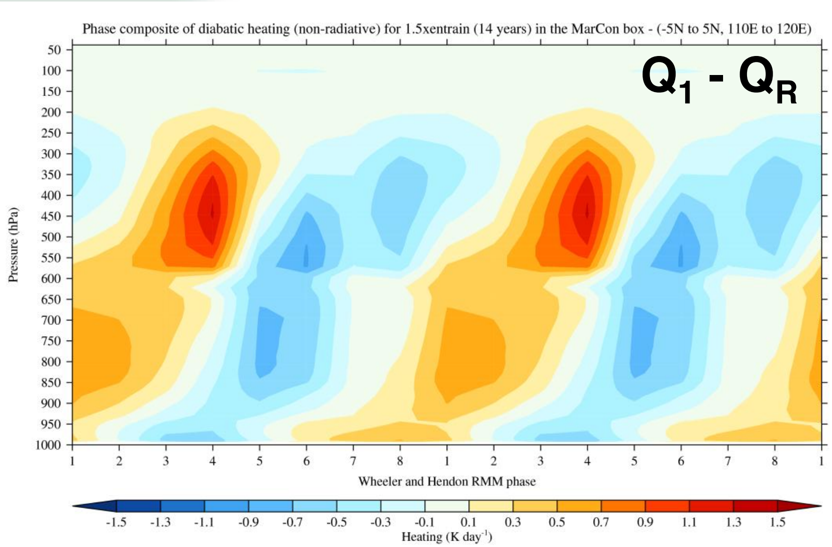


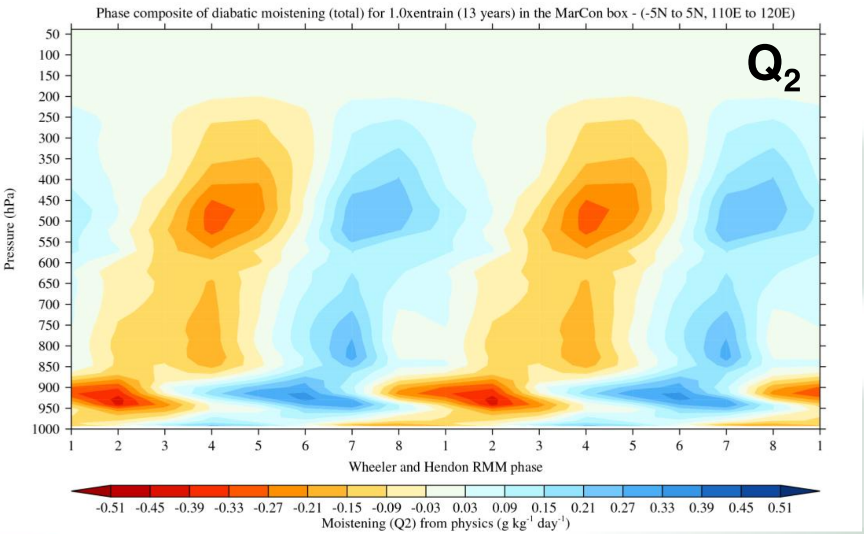
MJO in a climate model: sensitivity to convective entrainment

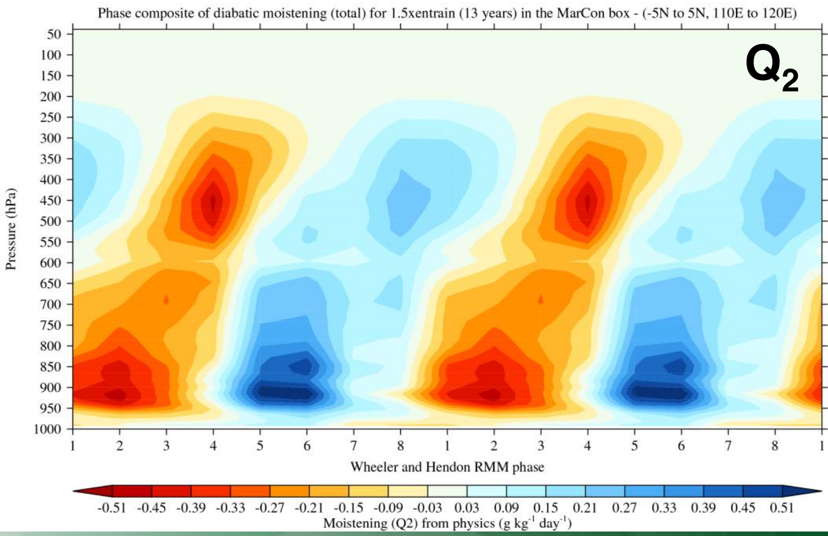
A-CTL

A-ENT







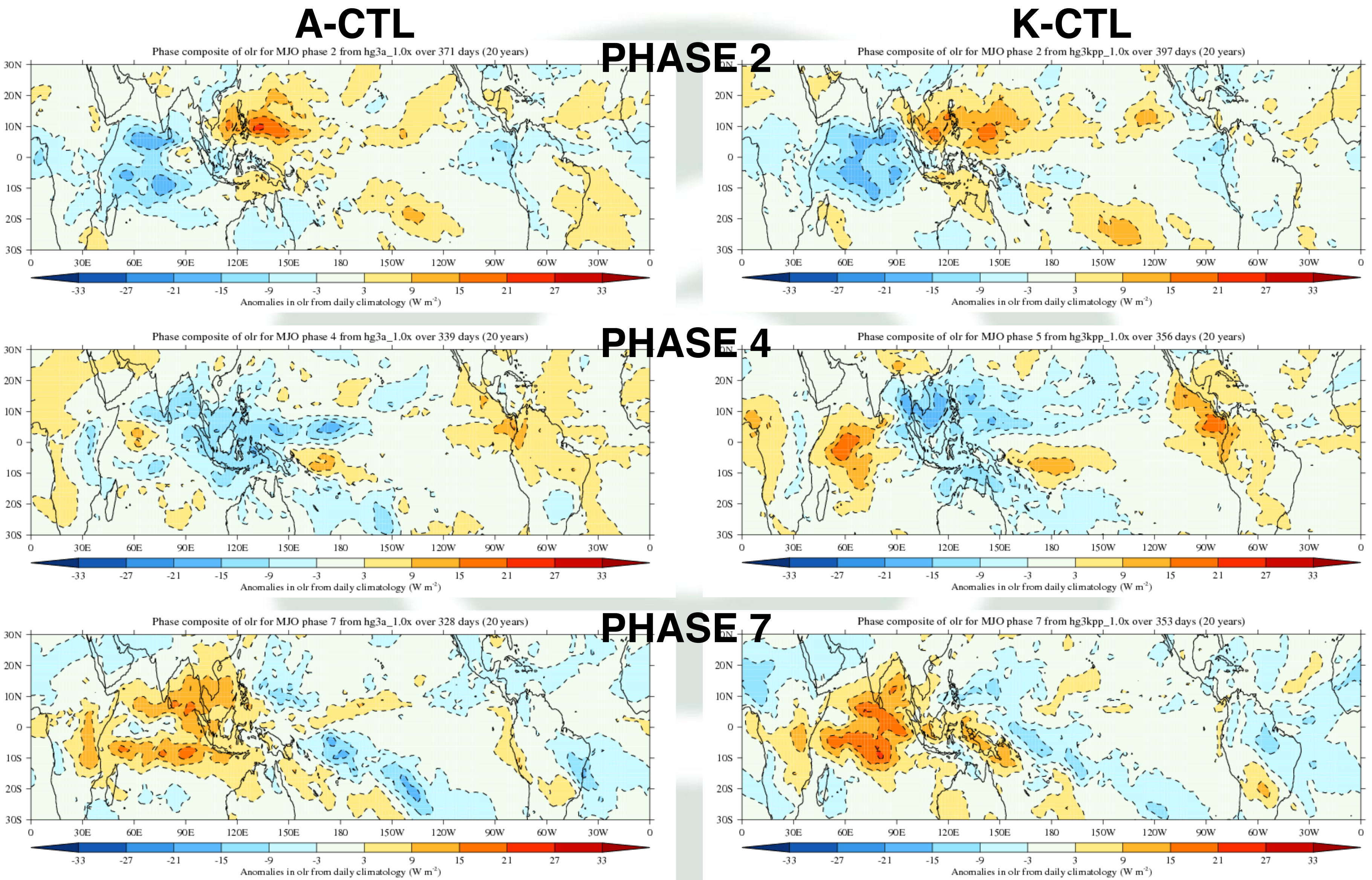


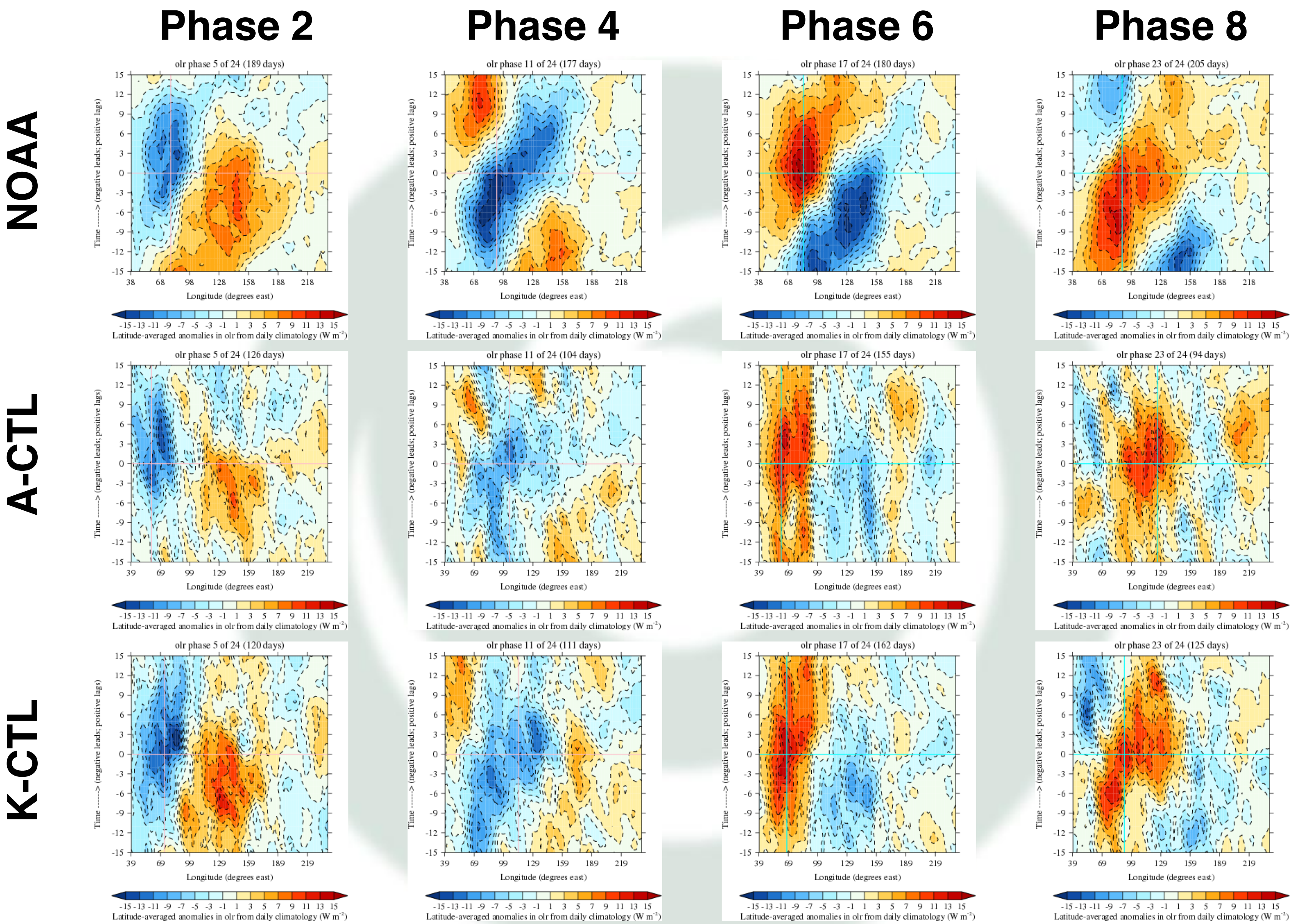
MJO in a climate model: sensitivity to ocean coupling

- Compare the experiments **A-CTL** and **A-ENT** to simulations coupled to a high resolution mixed layer model (**K-CTL** and **K-ENT**)
  - KPP mixed layer model
  - 40-200E 30S-30N domain climatological SSTs elsewhere
  - 1m resolution at the surface
  - Coupling every 3 hours
  - 3D seasonally varying heat correction term to maintain climatologicaly SSTs in coupling domain

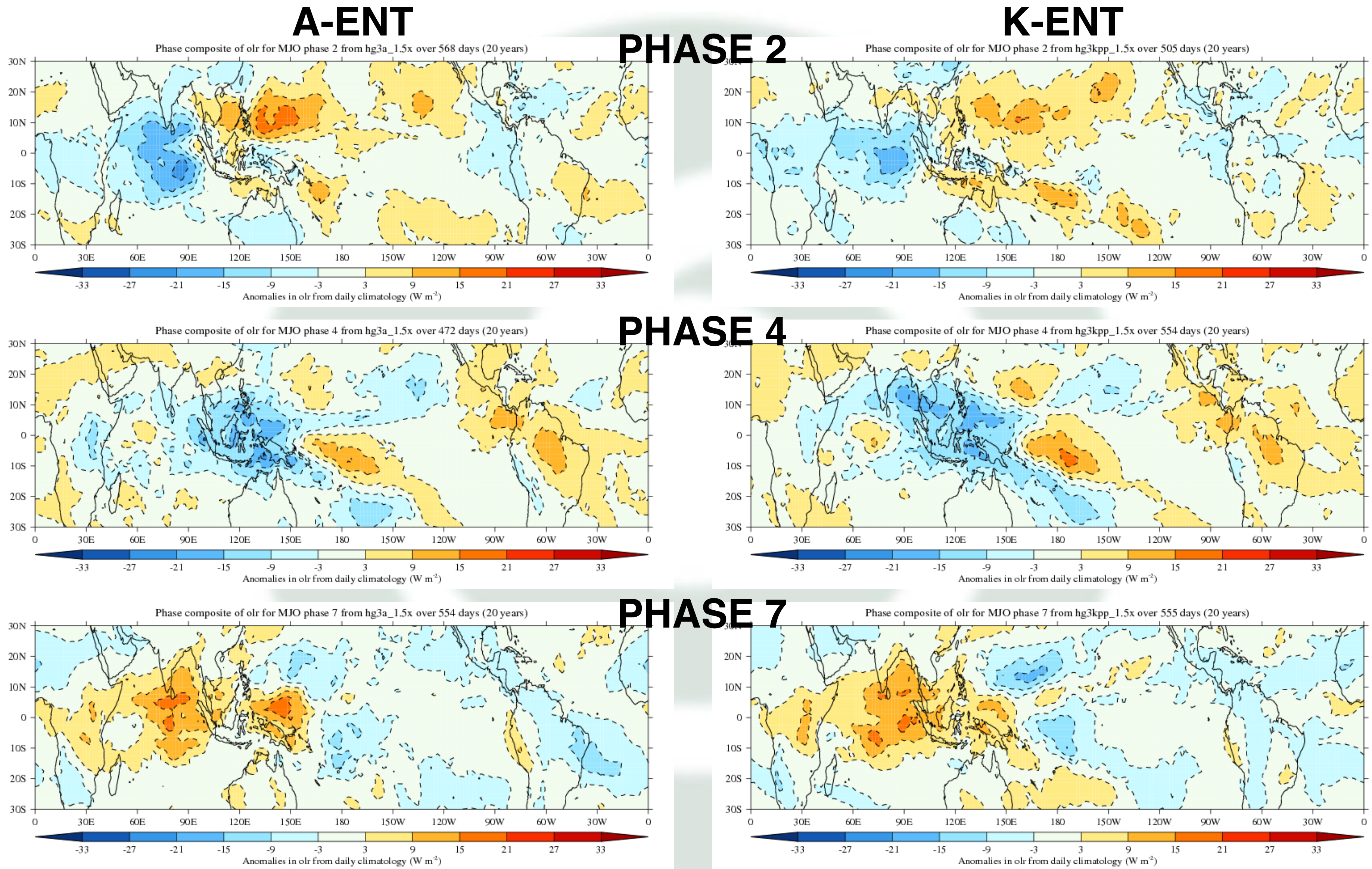
Klingaman and Woolnough, 2012b in prep

MJO in a climate model: sensitivity to ocean coupling




Phase 2
Phase 4
Phase 6
Phase 8
NOAA
A-CTL
K-CTL
olr phase 5 of 24 (189 days)
olr phase 11 of 24 (177 days)
olr phase 17 of 24 (180 days)
olr phase 23 of 24 (205 days)
olr phase 5 of 24 (126 days)
olr phase 11 of 24 (104 days)
olr phase 17 of 24 (155 days)
olr phase 23 of 24 (94 days)
olr phase 5 of 24 (120 days)
olr phase 11 of 24 (111 days)
olr phase 17 of 24 (162 days)
olr phase 23 of 24 (125 days)
Time ------> (negative leads; positive lags)
Longitude (degrees east)
Latitude-averaged anomalies in olr from daily climatology (W m⁻²)

MJO in a climate model: sensitivity to ocean coupling

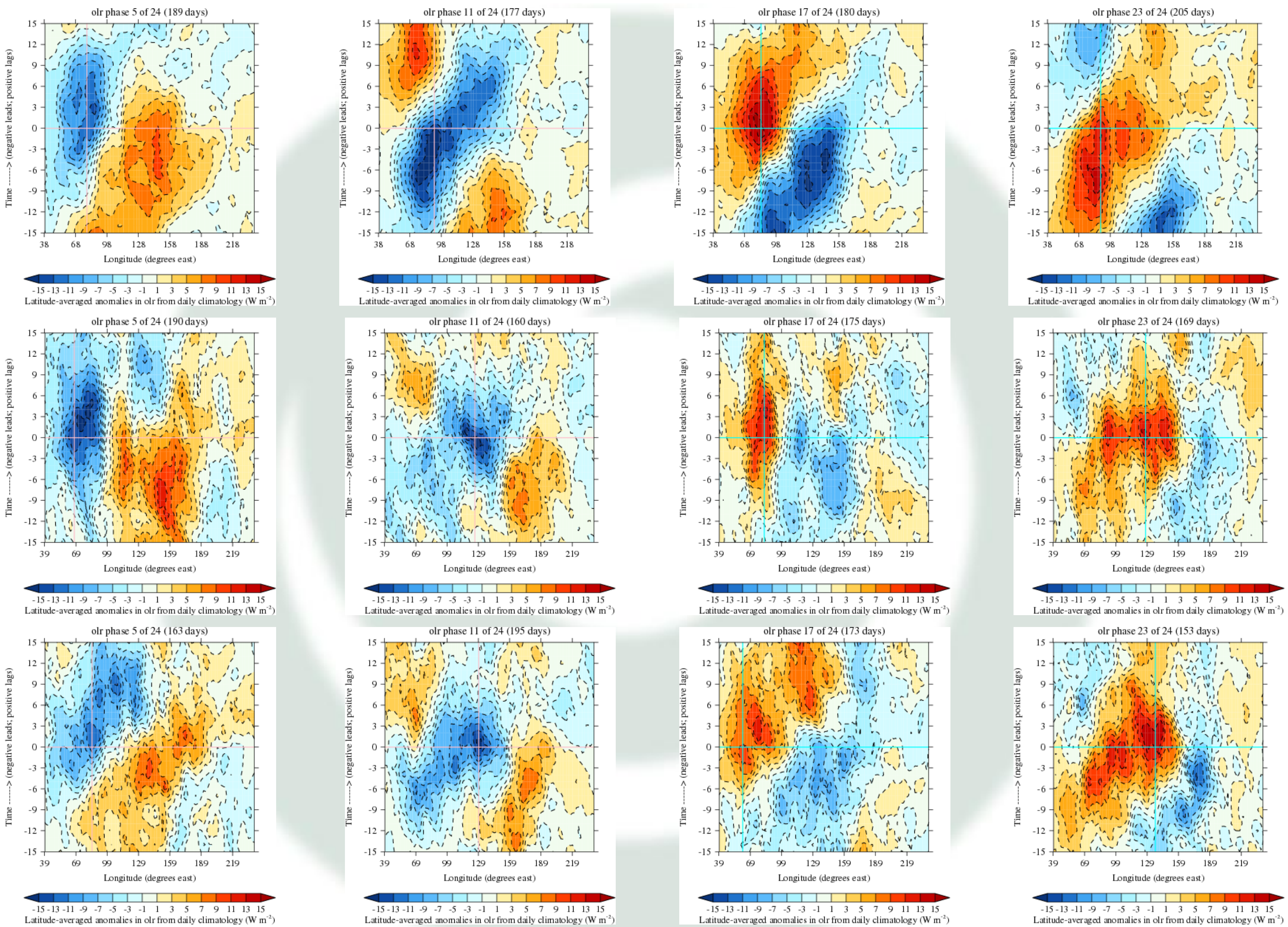


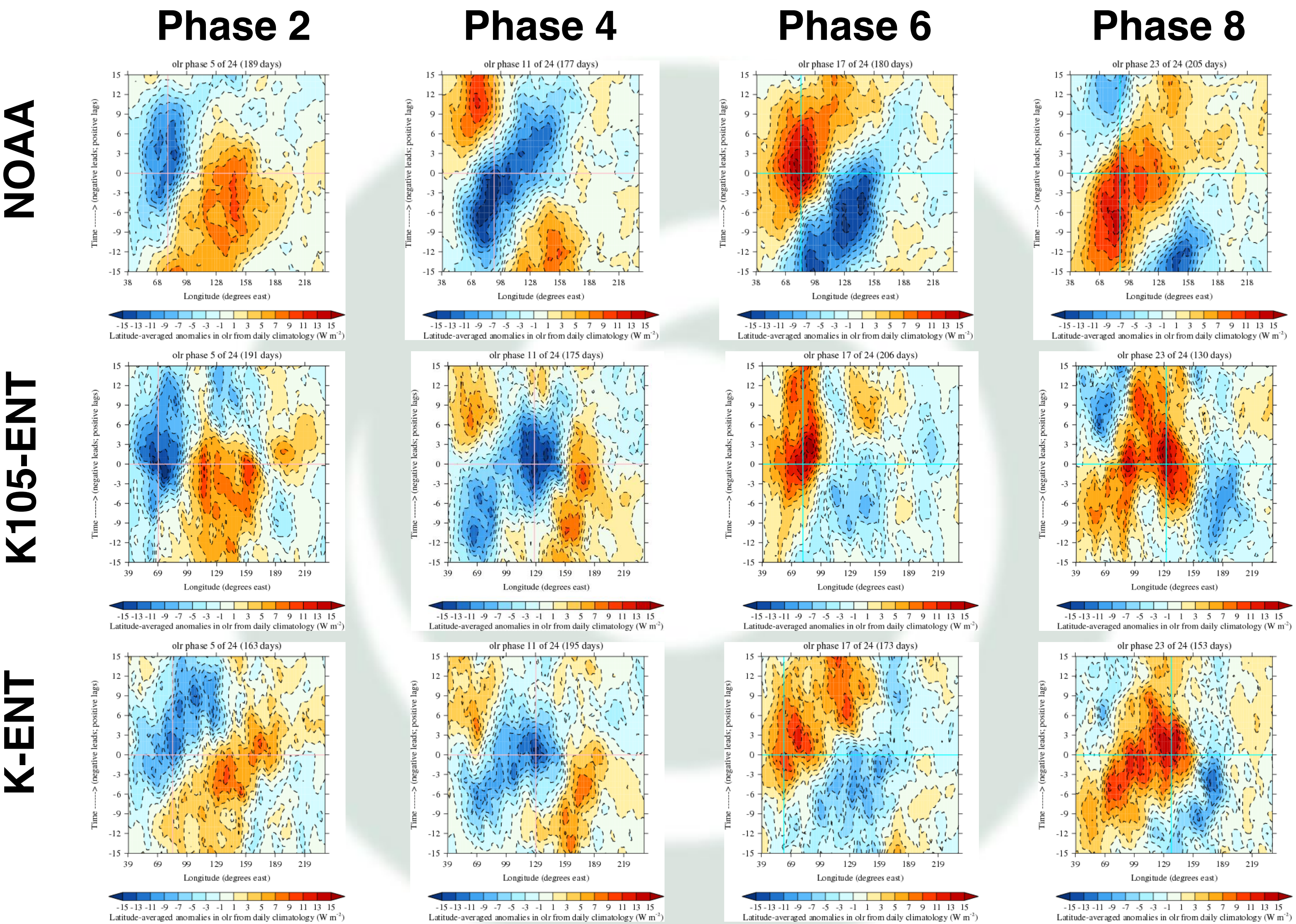
Phase 2 | Phase 4 | Phase 6 | Phase 8

NOAA

A-ENT

K-ENT



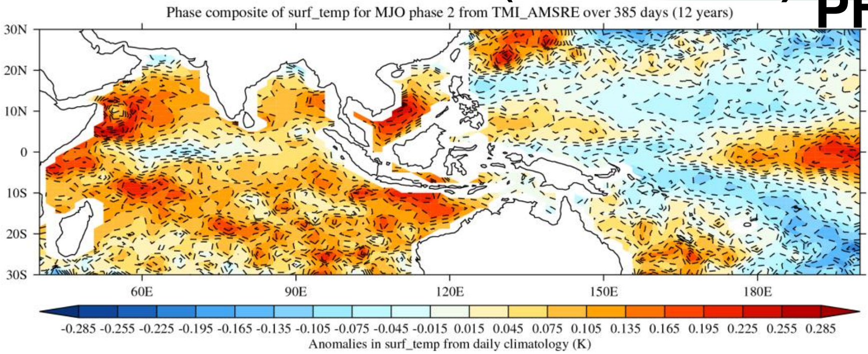

Phase 2
Phase 4
Phase 6
Phase 8
NOAA
K105-ENT
K-ENT
olr phase 5 of 24 (189 days)
olr phase 11 of 24 (177 days)
olr phase 17 of 24 (180 days)
olr phase 23 of 24 (205 days)
olr phase 5 of 24 (191 days)
olr phase 11 of 24 (175 days)
olr phase 17 of 24 (206 days)
olr phase 23 of 24 (130 days)
olr phase 5 of 24 (163 days)
olr phase 11 of 24 (195 days)
olr phase 17 of 24 (173 days)
olr phase 23 of 24 (153 days)
Time ------> (negative leads; positive lags)
Longitude (degrees east)
Latitude-averaged anomalies in olr from daily climatology (W m-2)

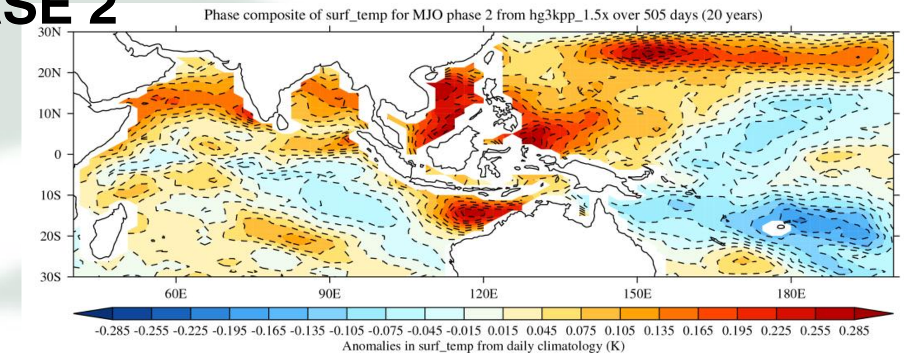
MJO in a climate model: sensitivity to ocean coupling

Observations (TMI AMSRE)

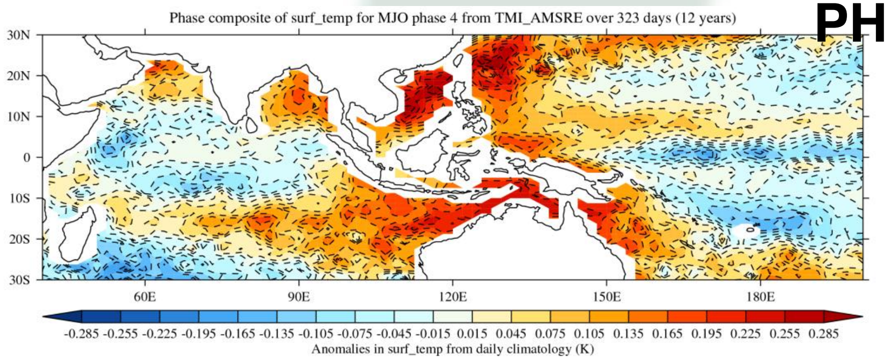
K-ENT

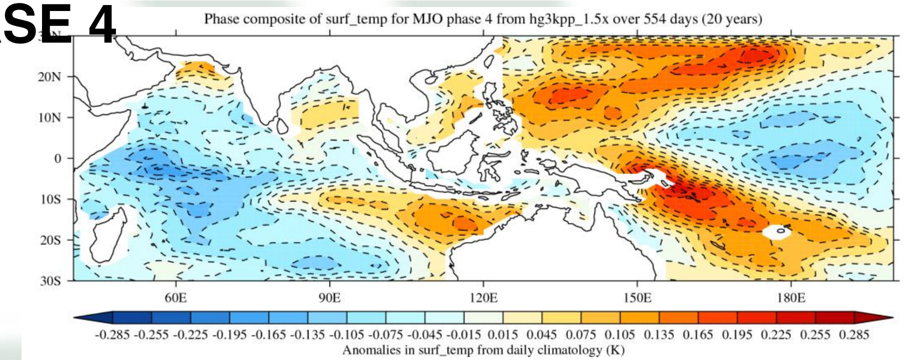
PHASE 2



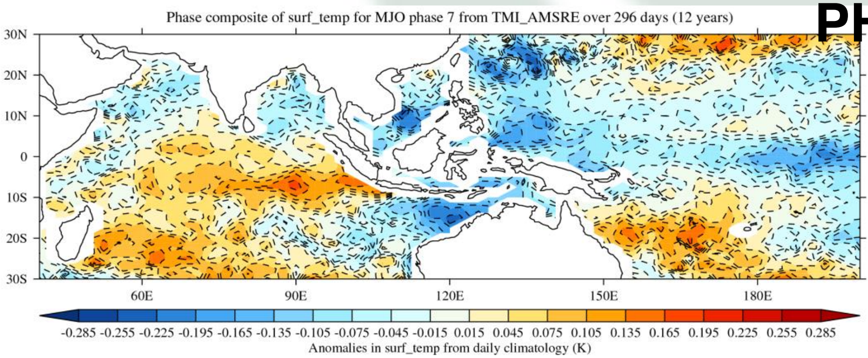


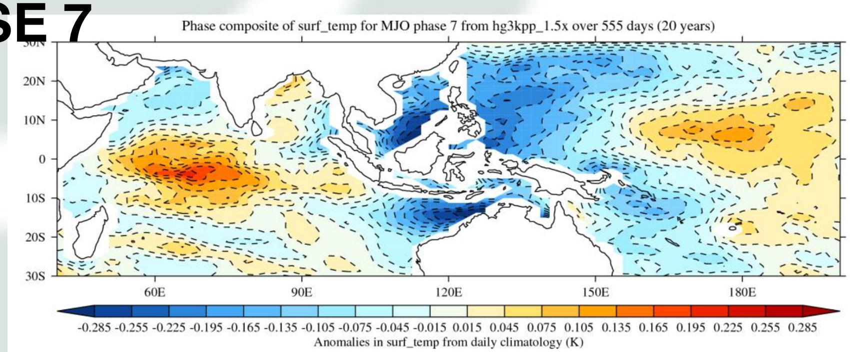
PHASE 4





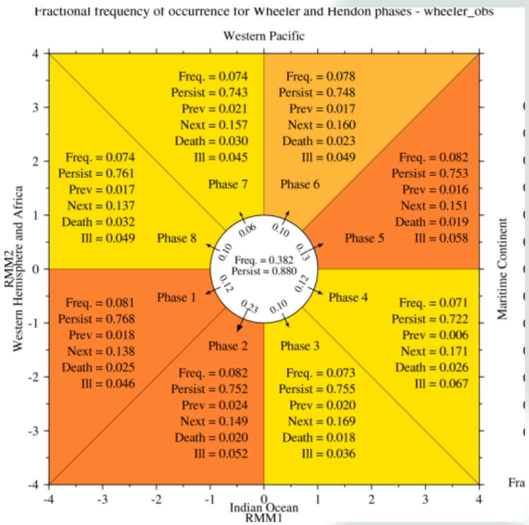
PHASE 7



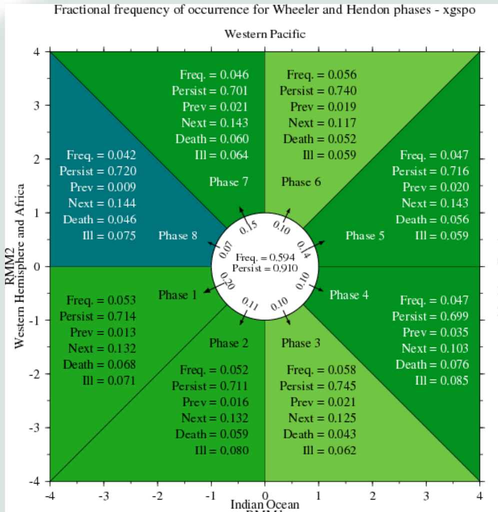


MJO in a climate model: sensitivity to ocean coupling

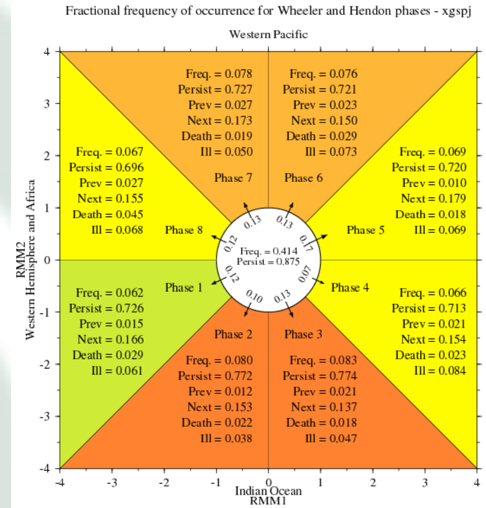
Observations

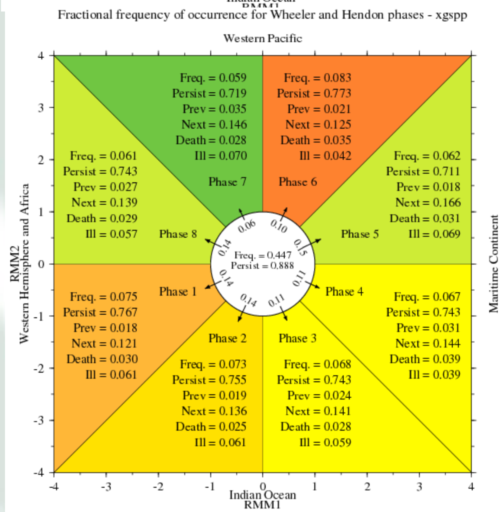


A-CTL

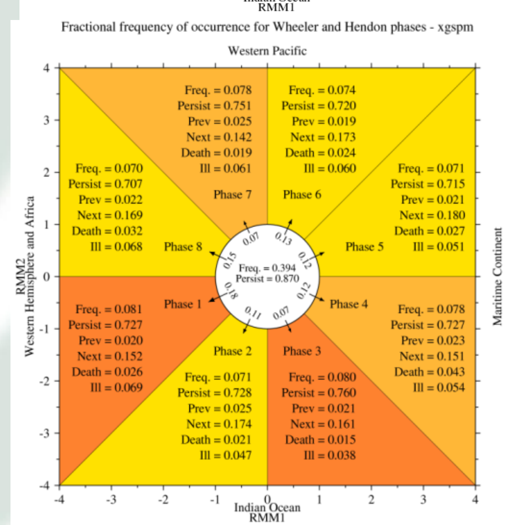


A-ENT





K-CTL



K-ENT

MJO in a climate model

Summary

- Increased entrainment increases MJO amplitude in the model
  - Often found in other studiesthat increased sensitivity to moisture improves MJO simulation
  - Improves horizontal and vertical structure of MJO anomalies
  - Significant changes to diabatic heating and moistening profiles
  - Does not appear to significantly improve propagation
  - Changes to the mean state (not shown)

- Coupling to mixed layer
  - Improves amplitude in control integration but doesn't really improve propagation
  - Marginal changes in amplitude in high entrainment run but significant improvement in propagation, particular from the Indian Ocean to the West Pacific
  - Improvement in propagation depends on coupling in the West Pacific

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

Objectives

- Characterize observed and modelled temperature, moisture, and cloud structures during the MJO life cycle and determine the roles of various heating, moistening and momentum mixing processes.
- Evaluate the ability of current models to hindcast MJO events, and characterize the evolution of the "error" growth in the profiles of moistening, diabatic heating, etc.
- Elucidate key model deficiencies in depicting the MJO physical process evolution, and provide guidance to model development/improvement efforts.
- Based on above analyses, develop more targeted physics/detailed process model studies as well as formulate plans for needed observations (in-situ, airborne, satellite).

	Experiment	Output Data	Science Focus	Leads	No. Models to date
I.	20 year climate simulation (1991-2010)	Global 6 hourly Including vertical profiles of tendencies	MJO fidelity Vertical Structure	UCLA/JPL Xianan Jiang Duane Waliser	20
II.	2 day hindcasts YoTC MJO cases E&F * (Winter 2009)	Detailed time step data on model grid over Indo-Pacfic domain	Evaluation of model physics during different MJO phases	Met Office Prince Xavier Jon Petch	7
III.	20 day hindcasts YoYC MJO cases E&F * (Winter 2009)	Global 3 hourly Including vertical profiles of tendencies	MJO hindcast skill Lead time dependent evolution of diabatic processes	NCAS Nick Klingaman Steve Woolnough	11

* CINDY/DYNAMO Case from Nov 2011 to be performed after preliminary analysis