Modelling the Madden-Julian Oscillation

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Outline

- History of modelling of the MJO
- Challenges of Modelling the MJO
- Two examples process studies
  - Sensitivity to convective entrainment
  - Role of air-sea coupling
- High resolution modelling of the MJO
- MJO in sub-seasonal prediction systems
- Summary

History of modelling the MJO

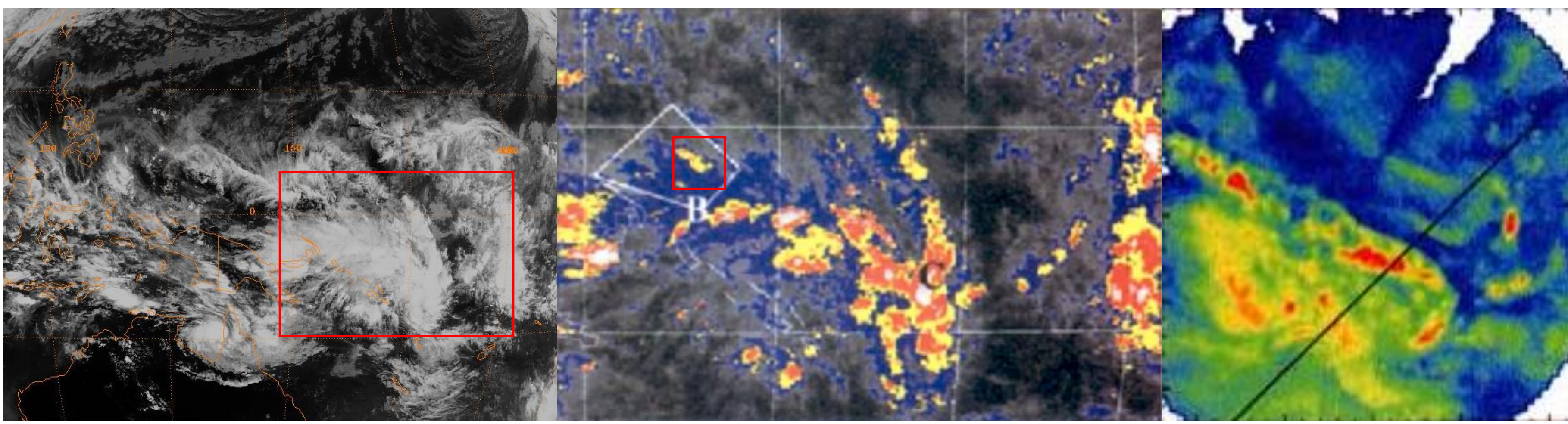
- A faithful representation of the MJO in weather and climate models is a long-standing challenge in Atmospheric Modelling
- Slingo et al. (*Clim. Dyn,* 1996) analyzed 15 GCMs contributing to the first AMIP experiment and found
  - most models were not able to capture one or more essential feature of the MJO, its:
    - period,
    - amplitude, or
    - eastward propagation
  - however they note that the best models tended to have
    - convection schemes closed on buoyancy rather than moisture convergence
    - A better representation of the mean state precipitation

History of modelling the MJO

- Lin et al. (*J. Climate*, 2006) diagnose 14 models from CMIP3 and found
  - Most models (12 out of 14) have less than half the observed MJO variance
  - are unable to capture the eastward propagation of the MJO
  - However they note that the two best performing models have closures or trigger functions that depend on moisture convergence
- Hung et al, (*J.* Climate, 2013) compare CMIP5 models to CMIP3 and found a general overall improvement
  - Improved MJO variance
  - Improved relationship between eastward and westward power
  - However the argue only one in 20 models was able to simulate a realistic eastward propagation of the MJO

Challenges of modelling the MJO

- The MJO relies on an interaction between the planetary scale tropical dynamics and atmospheric convection
- Convection is organized across many scales from the planetary scale of the MJO to mesoscale systems and individual clouds
- We rely on convective (and other) parametrizations to represent these smaller scales and "trust" they will interact with the dynamics on the large-scales in the correct way



~6000km ~2000km ~200km

Multiscale organization in the MJO, from Chen et al. (JAS, 1996; centre) and Rickenbach and Rutledge (JAS, 1998; right)

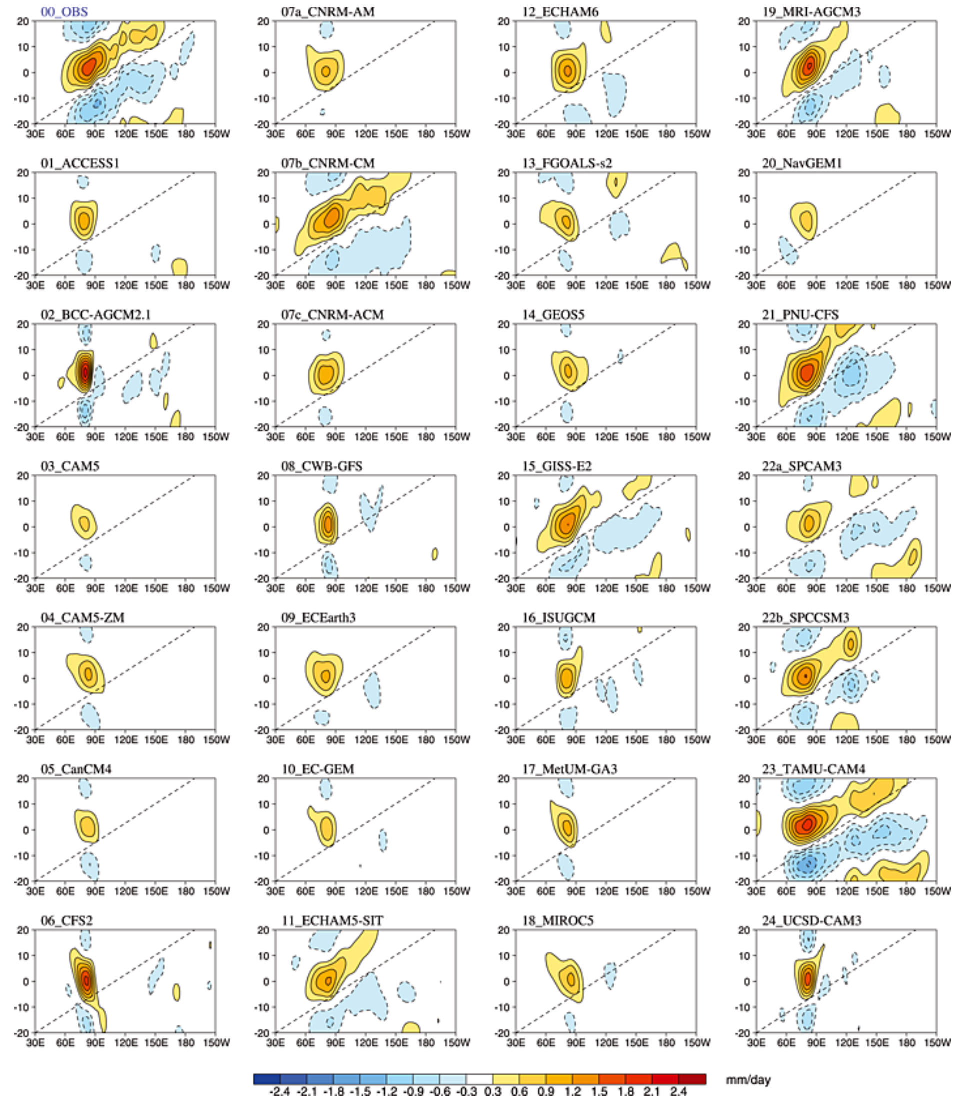
Aspects of convection which may be important

- Whilst the interaction between the convection and the large-scale dynamics is fundamental to the MJO, the details of the key important characteristics of convection for the MJO are still unknown; a number have been suggested, e.g.
    - the stratiform heating (e.g. Chang and Lim, 1988; Fu and Wang 2009) and its impact on wave speeds and growth
    - the role of shallow heating (e.g. Wu 2003, Li et al 2009) and the moistening by the associated circulation
    - the role of moistening directly by shallow convection (e.g. Woolnough et al. 2010)
    - the sensitivity of convection to environmental humidity (e.g. Hannah and Maloney 2011)
- Its is likely that no signal aspect on its own will determine the quality of the MJO simulation

Current status of the MJO modelling

- Jiang et al. (JGR, 2015) compared a 27 simulations from 24 models as part of an intercomparison project to explore the relationship between the MJO simulation and modelled diabatic processes
- About ¼ of models capture an eastward propagating signal,

OBS



Time longitude regression of intraseasonal precipitation against a base point in the Indian Ocean (Jiang et al, 2015)

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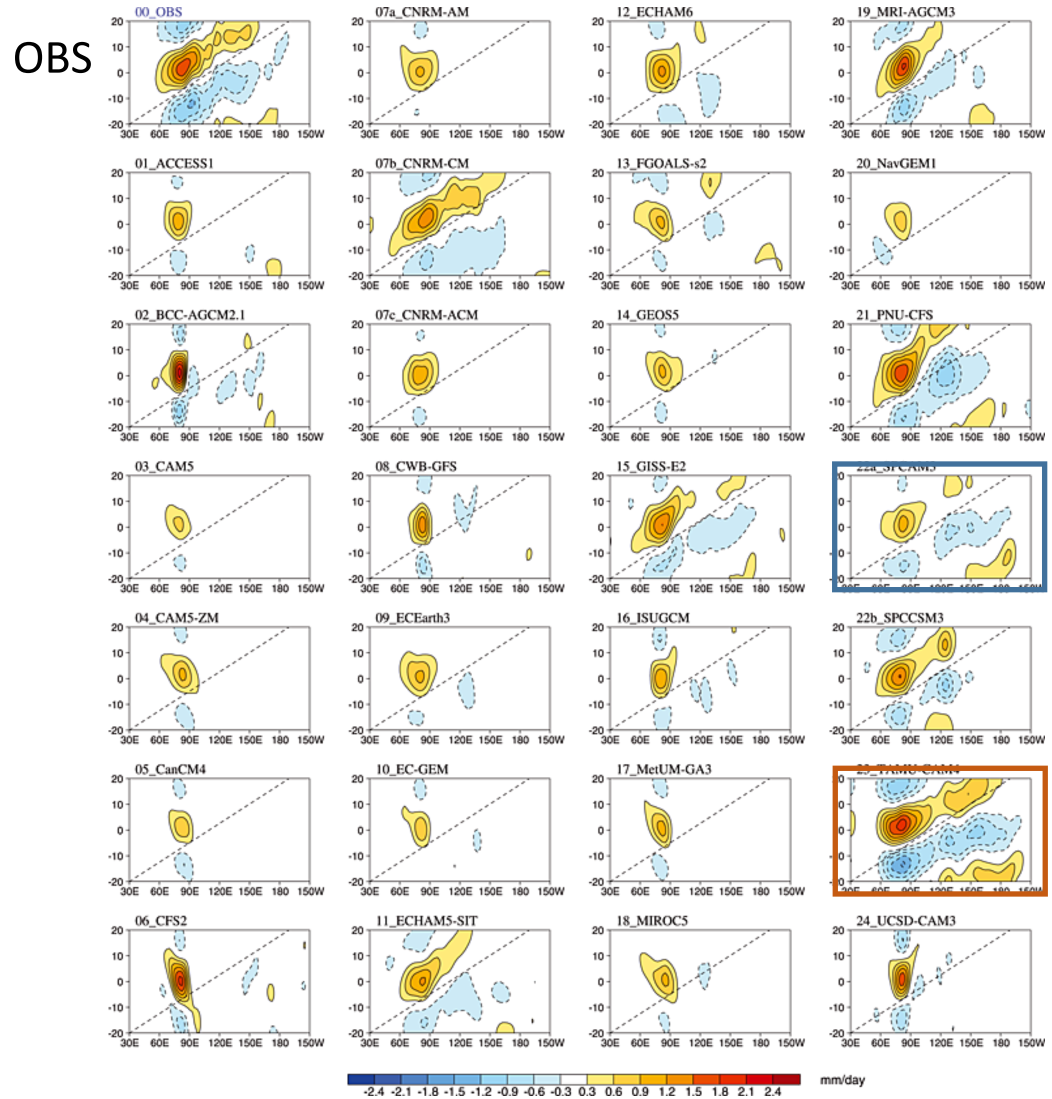
  - "super parametrized" CAM
  - TAMUCAM in which the vertical profile of heating is imposed as a function of MJO phase



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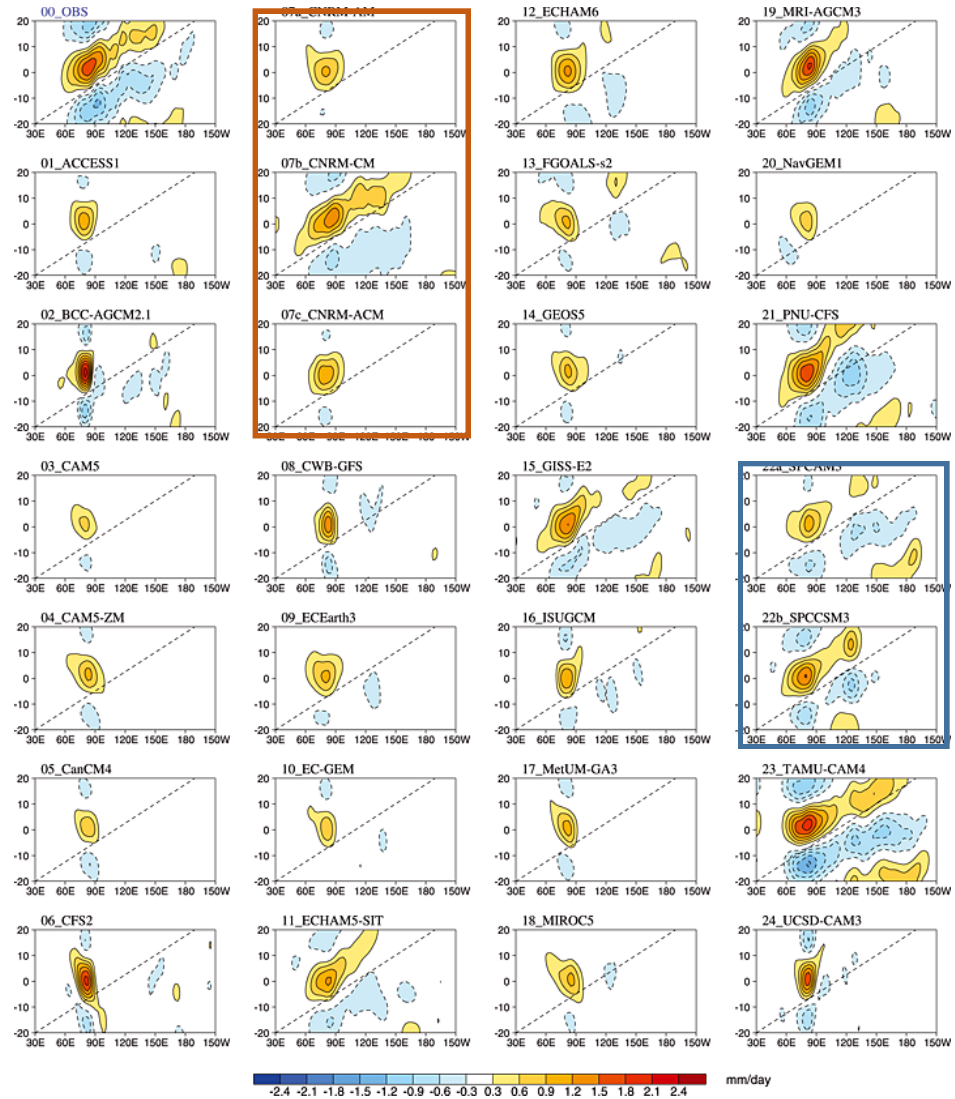
- Sensitivity to air-sea interaction

OBS



Time longitude regression of intraseasonal precipitation against a base point in the Indian Ocean (Jiang et al, 2015)

Current status of the MJO modelling

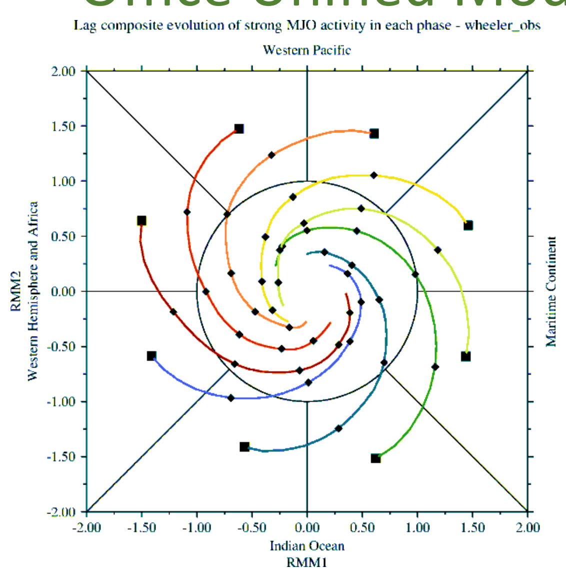
- Jiang et al (2015) found no systematic relationship between MJO fidelitity and
  - the basic state
  - The partitioning of convection between large-scale and convective rain (this is different from convective and stratiform rain)
  - The vertical profile of diabatic heating
- Jiang et al (2015) did find relationships between MJO fidelity
  - the relationship between precipitation and relative humidity suggesting a dependence of the sensitivity of convection to humidity
  - The gross-moist stability, a measure of how efficient convection and the resulting circulation is at removing moist-static energy from the column (this does depend indirectly on the vertical profile of heating)

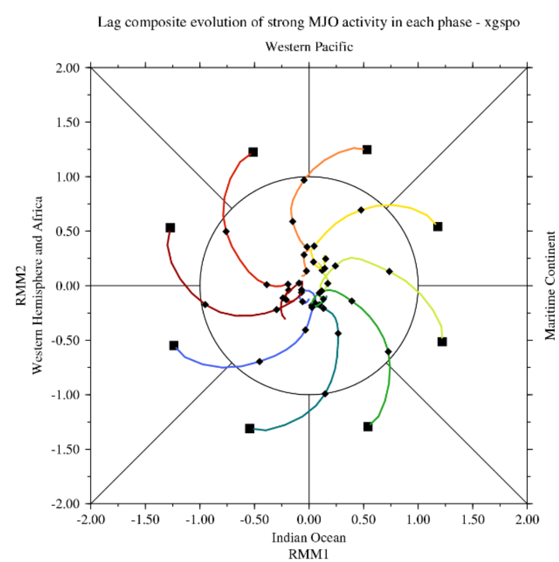
Current status of the MJO modelling

- A number of studies looking at the relationship between MJO fidelity and aspects of the representation of convection have been performed
- Either in large model intercomparison projects or perturbing some aspect of the model physics rather than comparing different models
- However these studies do not always draw the same conclusions
- Relationships between gross properties of the model (e.g. the normalized gross moist stability) and MJO fidelity are often not directly relatable to the formulation of physical parametrizations

Sensitivity to convective entrainment

- A number of studies have shown improved simulation of the MJO by increasing the sensitivity of convection to environmental humidity (e.g. Tokioka et al, 1988; Bechtold et al, 2008; Neale et al, 2008; Hirons et al, 2012a,b; Klingaman and Woolnough 2014a)
- Klingaman and Woolnough explore the sensitivity to convective entrainment rate for convection in the Met Office Unified Model

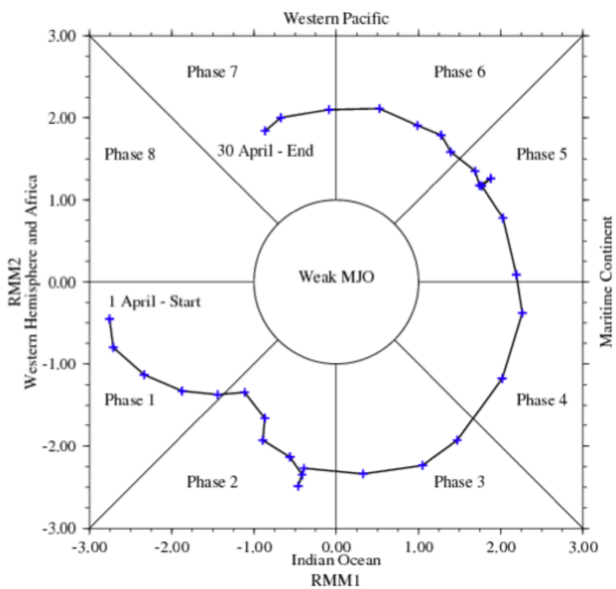




Composite evolution of the MJO in Wheeler-Hendon Phase Space. Observations (right) and the standard configuration of the Met Office UM at GA2.0 (left)

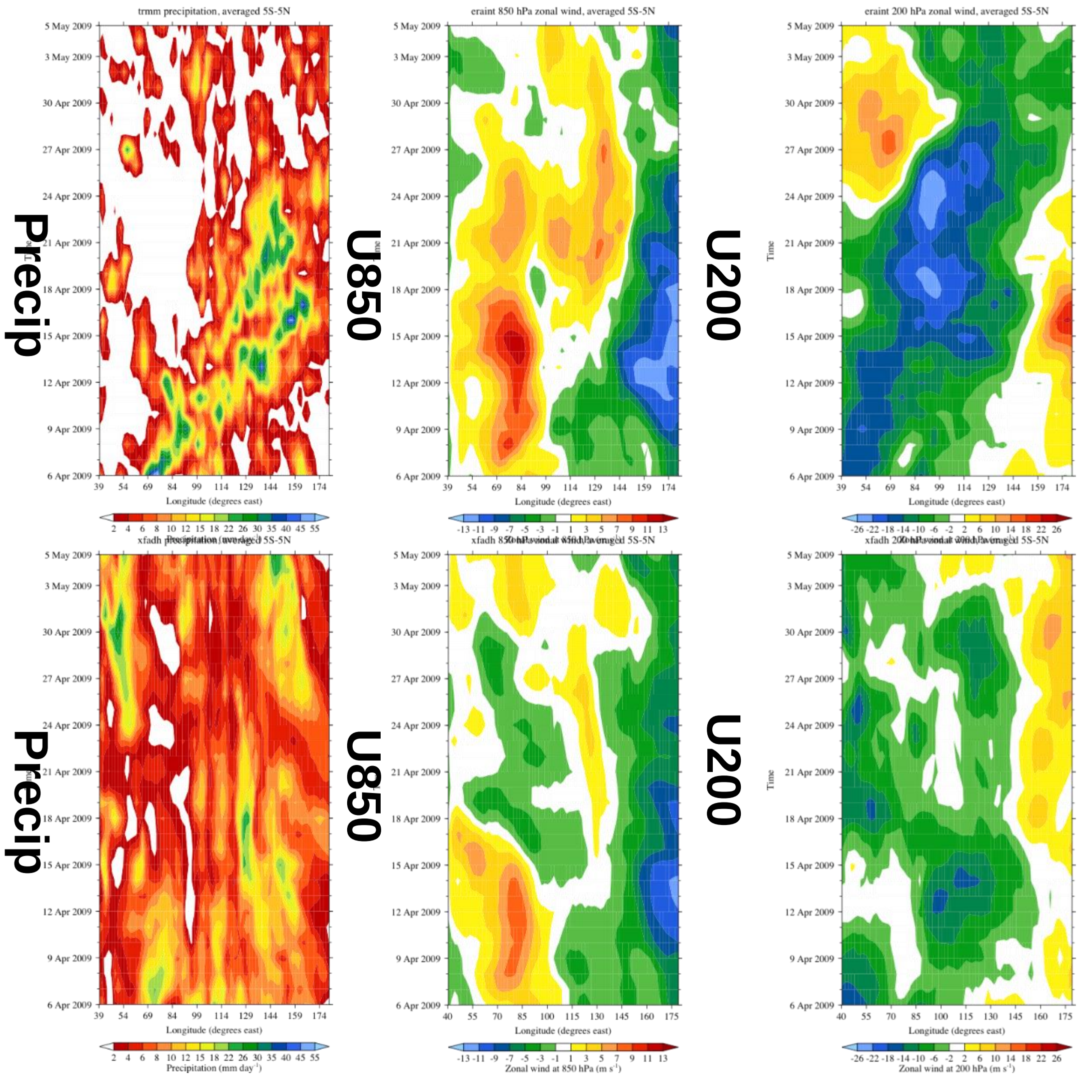
Sensitivity to convective entrainment

Intially explore the sensitivity to convective entrainment in hindcast experiments



Observed propagation of April 2009 event in MJO phase space

Observations



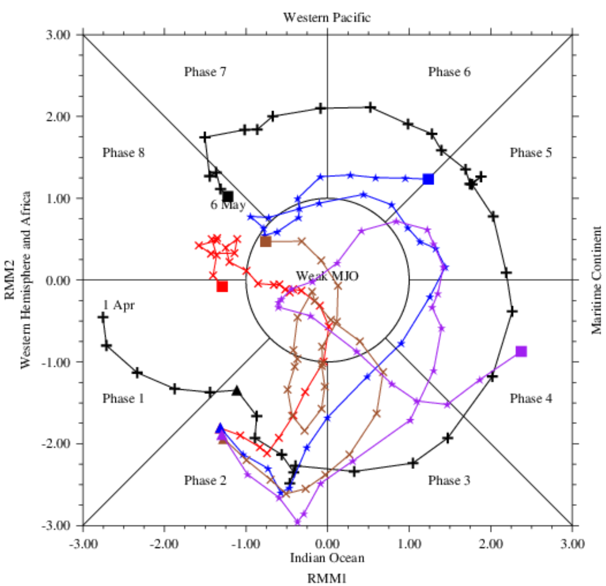
A-CTL

Control Entrainment

Model

Sensitivity to convective entrainment

Increase the entrainment (and detrainment) rate for deep and mid-level convection by 50%



Propagation of April 2009 event in MJO phase space

Black: Observations

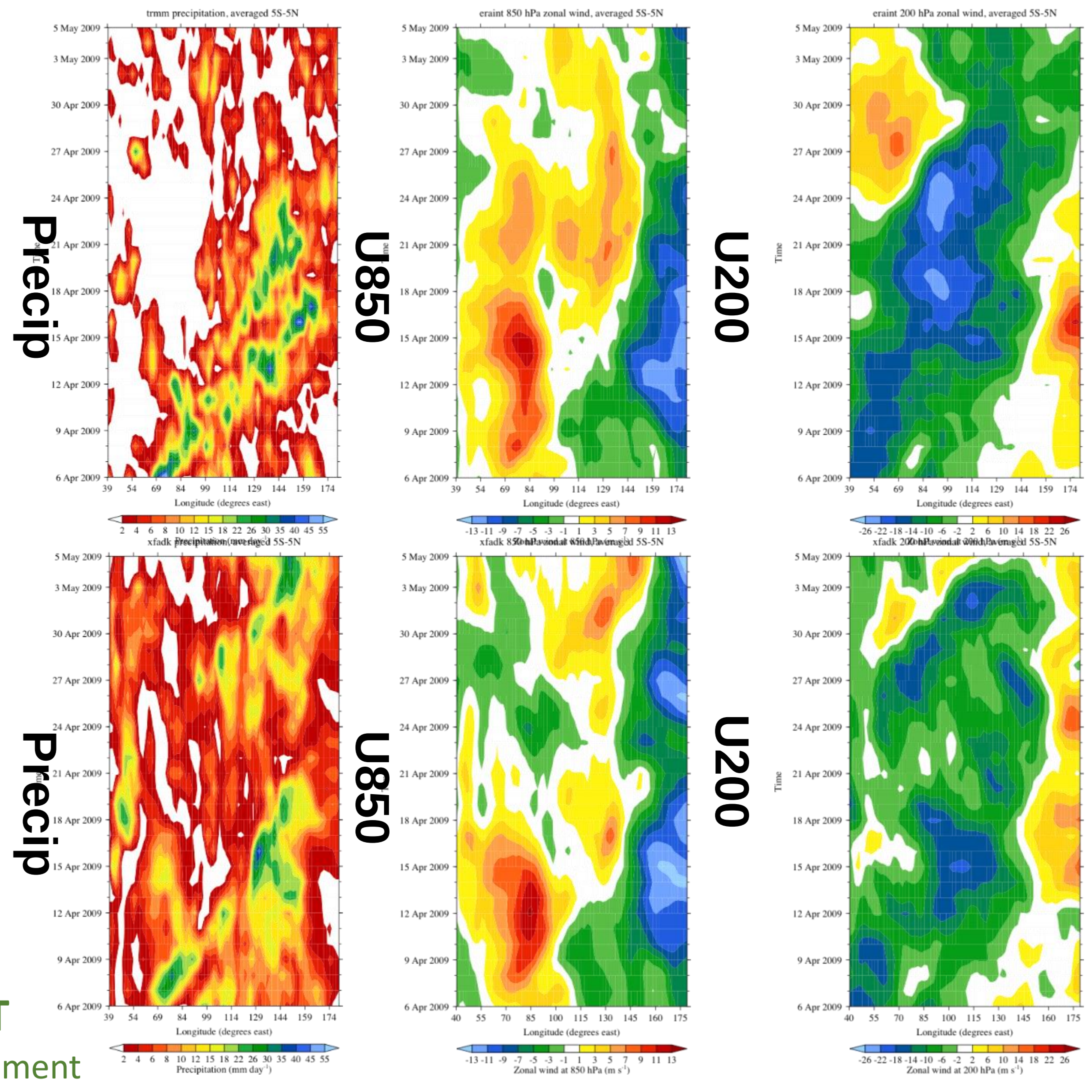
Red: A-CTL

Blue: A-ENT

Brown : A-CTL (No CMT)

Purple: A-ENT (No CMT)

Observations



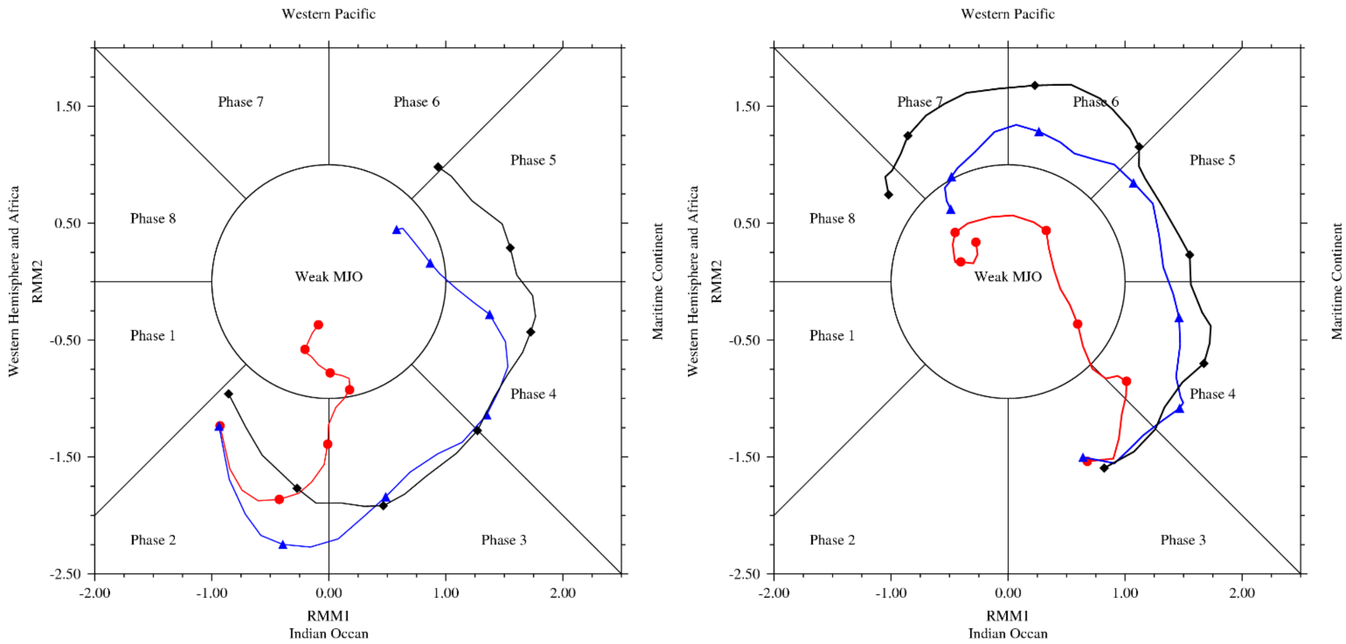
A-ENT

High entrainment Entrainment

Model

Sensitivity to convective entrainment

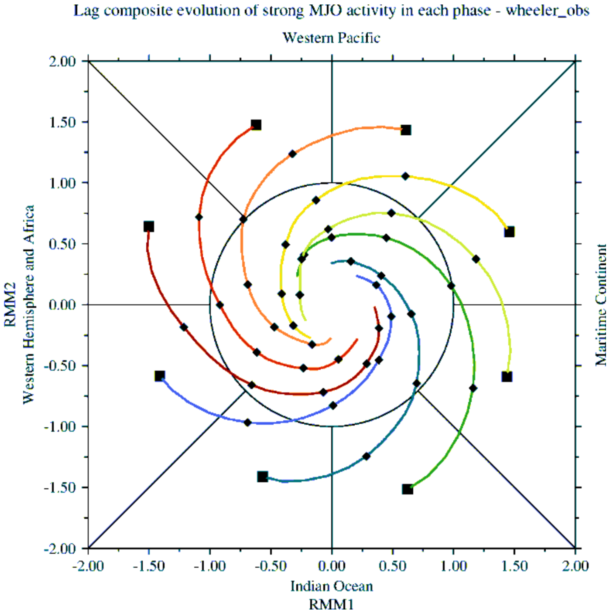
- Repeat for a number of hindcasts

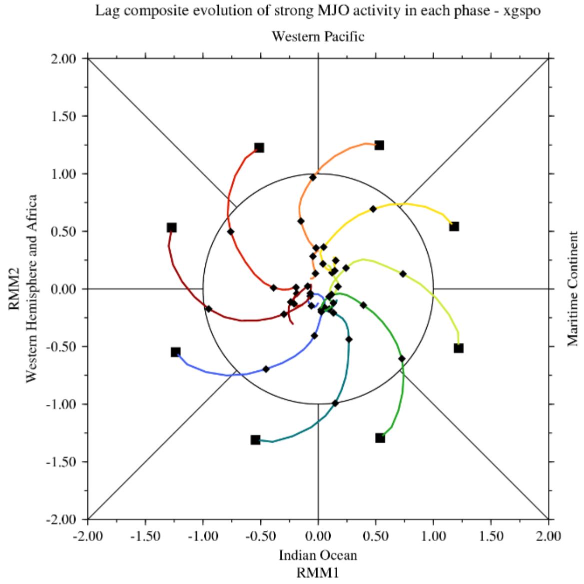


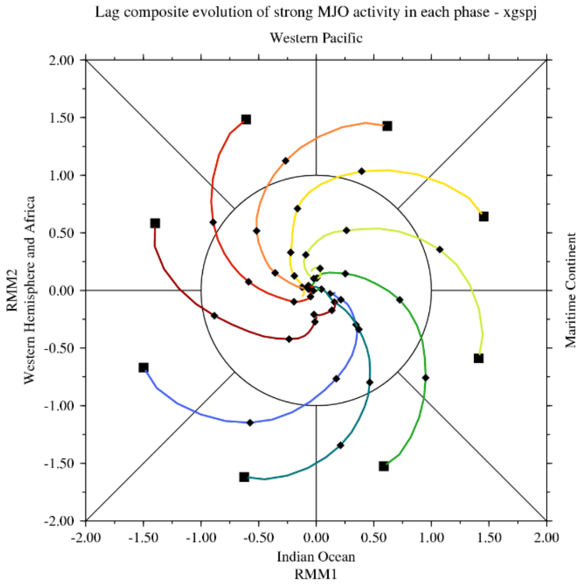
Composite RMM evolution of **observations**, **control hindcasts** , and **high entrainment hindcasts** for 14 strong MJO cases initialized in phase 2 (left) and 10 days later (right). Dots spaced every five days.

Sensitivity to convective entrainment

- Repeat the experiment in the climate model



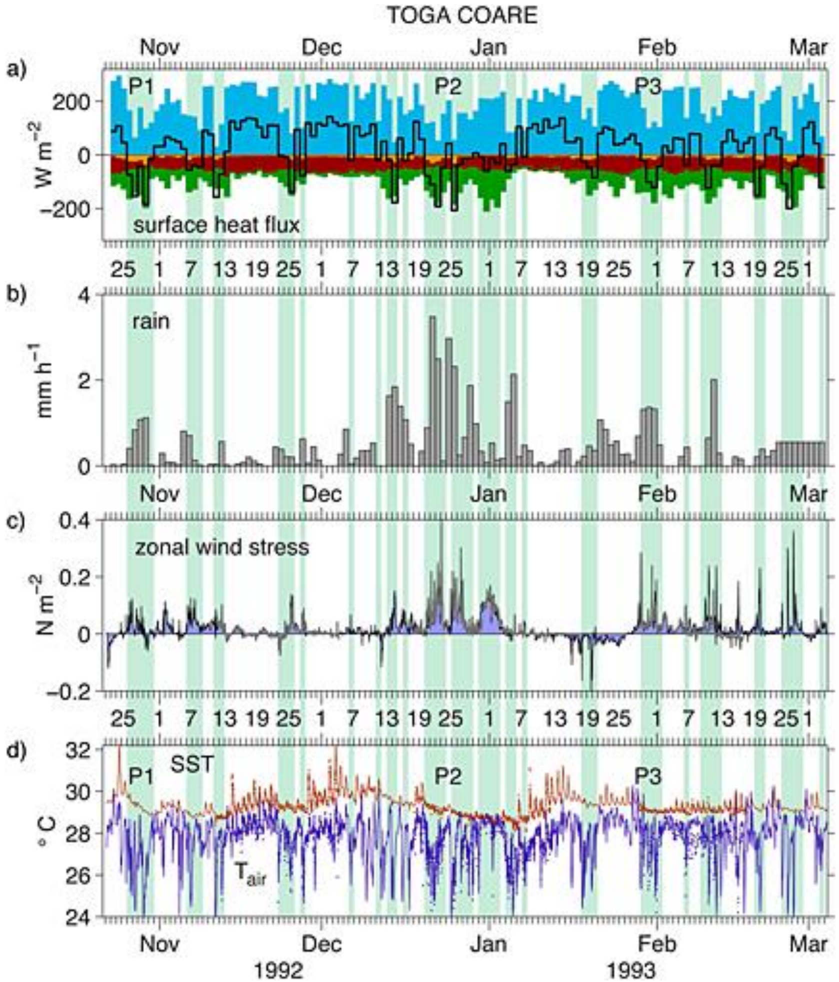




Composite RMM evolution of observations (left),control entrainment climate simulations (middle) and high entrainment climate simulations (right). Dots spaced every five days.

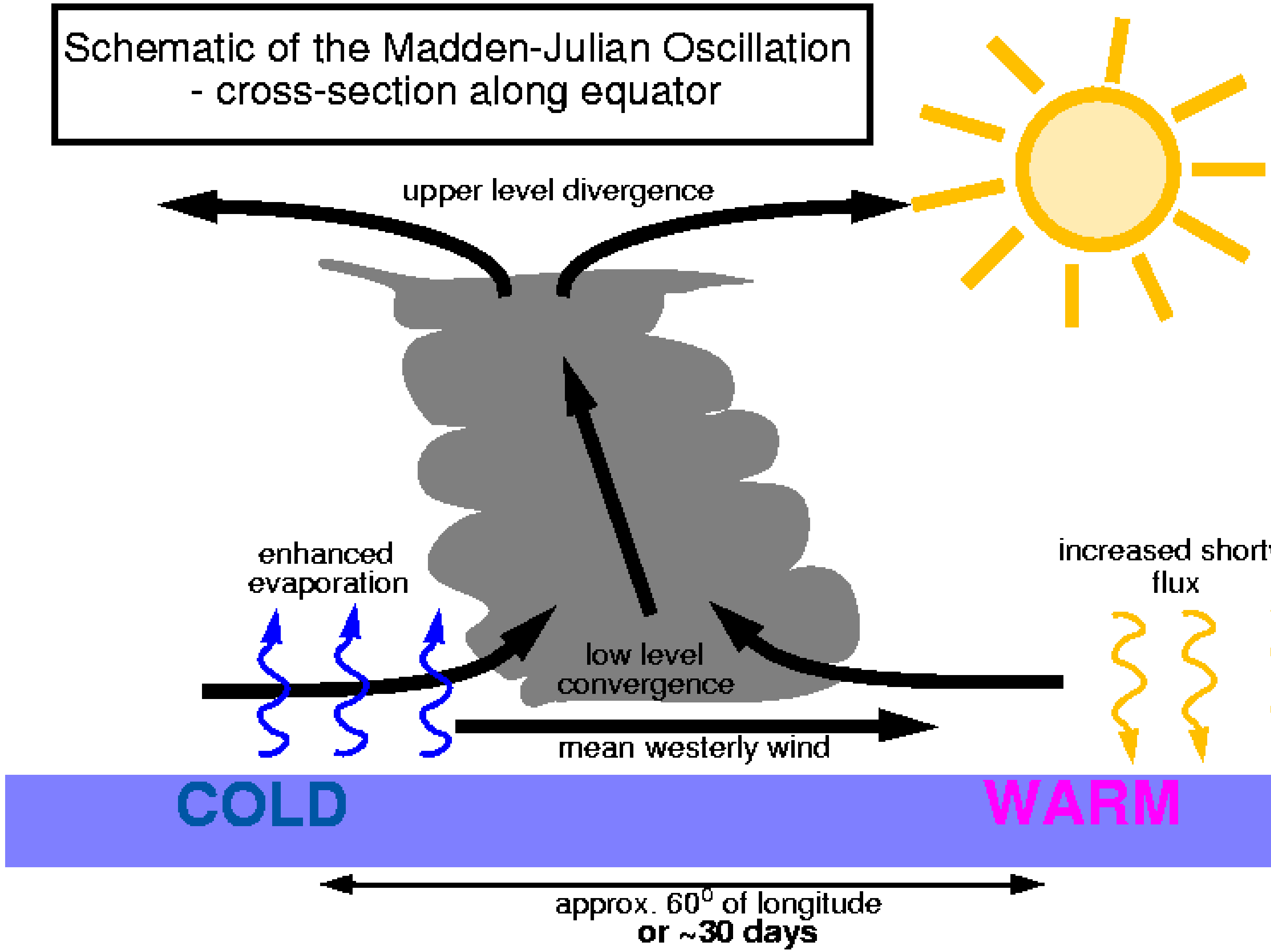
Role of air-sea interaction

- Krishnamurti et al. (JAS, 1988) identified a relationship between the atmospheric and oceanic variability on intraseasonal timescales
- TOGA-COARE field campaign in 1992-3 increased interest in the role of air-sea interaction in the MJO, (Weller and Anderson, JAS, 1996; Hendon and Glick, *J. Clim*., 1997)
- Motivated a number of modelling studies to explore the impact of coupling on the MJO



Daily variations in surface heatflux (a; black), rainfall (b), windstress(c) and SST(d, red) during TOGA-COARE (from de Szoeke et al, *J. Clim, 2015)*

Role of air-sea interaction



After Flatau et al. (*J. Atmos. Sci.,* 1997)

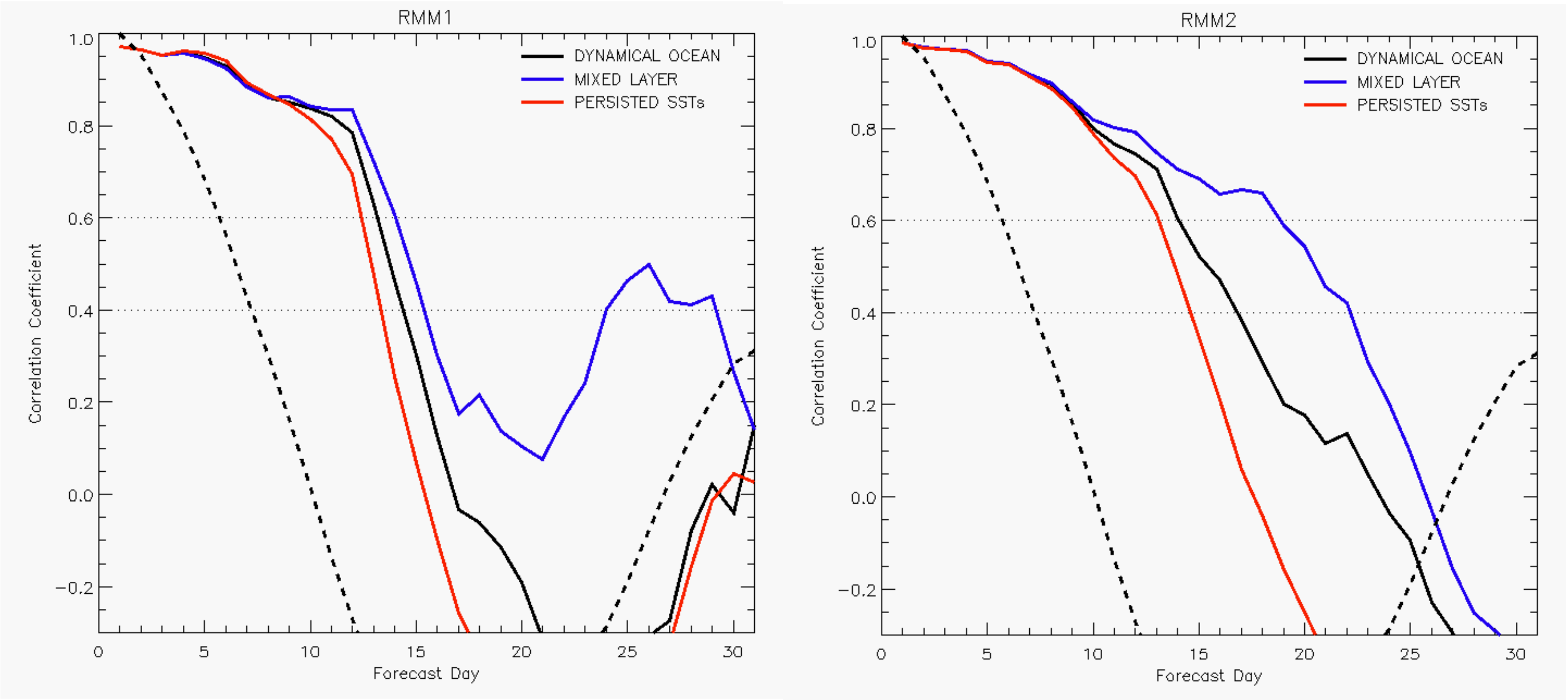
Role of air-sea interaction

- Whilst most modelling studies show coupling improves the representation of the MJO, a number of studies find contradictory results (e.g. Hendon, 2000; Liess et al., 2004; Sperber et al., 2005).
- There a number of plausible explanations
  - Air-sea interaction isn't important for the MJO
  - Errors in the basic state degrade the MJO simulation
  - Poor representation of the air-sea interaction processes in the model
    - either due to a misrepresentation of important processes in the model
    - or errors in the basic state (e.g. surface wind errors, lead to errors in the nature of the coupled feedbacks)
  - An atmosphere only model with no or weak intraseasonal variability may not be able to develop coupled feebacks
- Consensus is that air-sea interaction modifies the properties of the MJO, but is not critical to the existence of the MJO

Role of the diurnal cycle in SST

- During the suppressed phase of the MJO, light winds and clear sky conditions lead to a strong diurnal cycle in SST
- Bernie et al. (*J.* Clim, 2005) showed that to capture these diurnal variations in SST requires
  - at least 3hourly atmosphere ocean coupling,
  - upper-ocean resolution of the order of 1m,
  - and that the impact of neglecting these diurnal variations could lead to an underestimation of the intraseasonal variability in SST.
- Until recently coupled GCMS have typically had upper ocean resolution of the order of 10m
- Woolnough et al. (QJRMS, 2007) demonstrated the impact of poor representation of the diurnal air-sea coupling in a set of hindcasts for TOGA-COARE in the ECMWF monthly forecasting system

Role of the diurnal cycle in SST

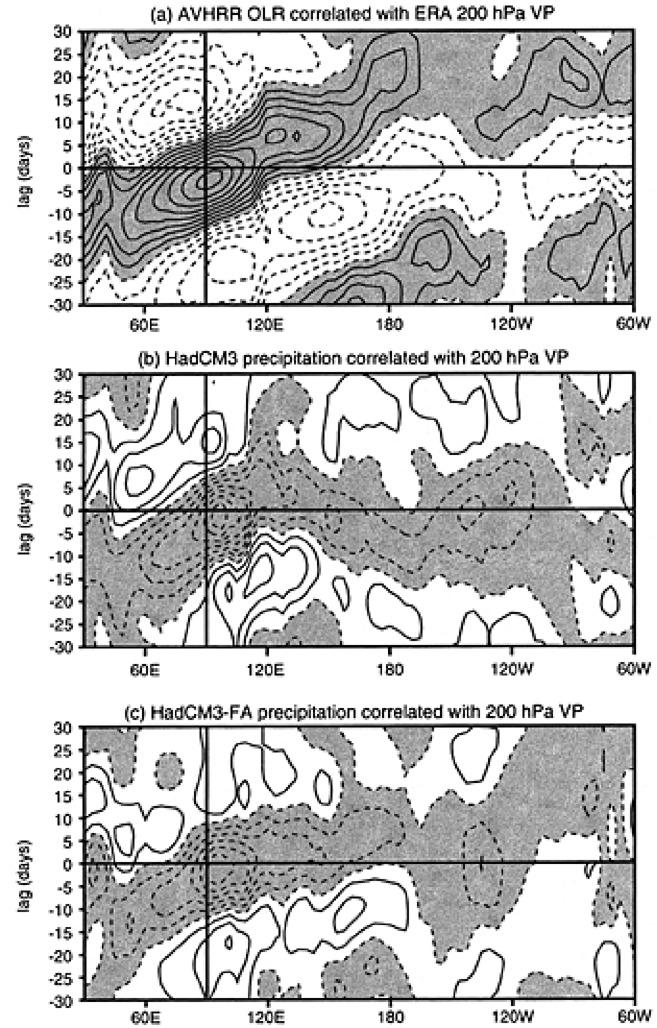


Forecast skill for RMM 1 & 2 of Wheeler Hendon indices for hindcasts initialized during TOGA-COARE in the ECMWF monthly forecasting system with **persisted SSTs**, **a dynamical ocean model with 10m upper layer**, and **a thermodynamic mixed layer model with 1m upper layer**

(from Woolnough et al., QJRMS, 2007)

Role of basic state errors

- Inness et al. (*J. Clim.*, 2013a,b) showed the impact of coupling on the MJO and the impact of basic state errors on the representation of air-sea interaction in the MJO by comparing an atmosphere only simulation and two coupled simulations one with flux correction to correct the basic state



Correlation of 200hPA velocity potential with OLR for observations (top) and with precipitation for control (middle) and flux-corrected (bottom) simulations of HadCM3

Role of air-sea interaction in the MJO

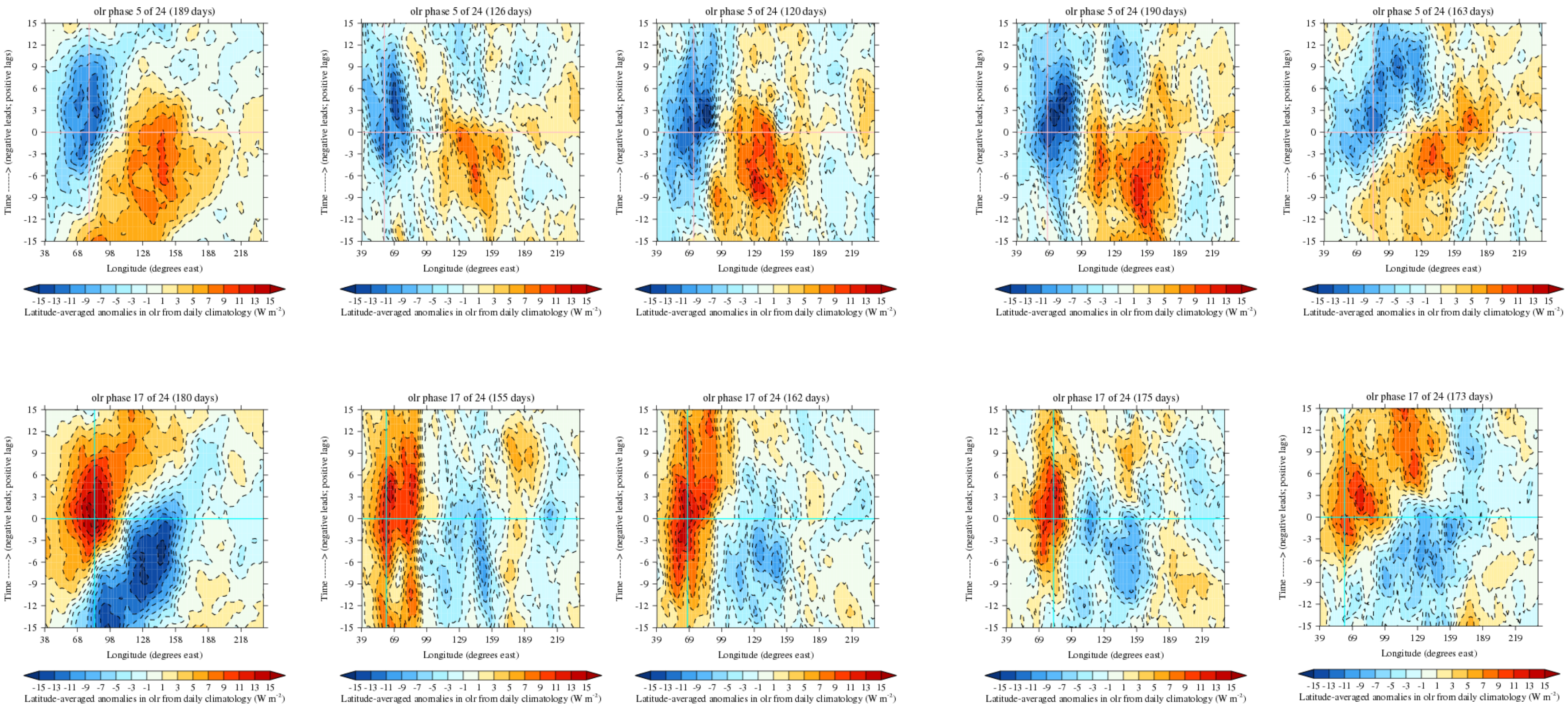
- Klingaman and Woolnough (2014b) explore the impact of air-sea interaction in the MJO using a high vertical resolution thermodynamic mixed layer model coupled to the Met Office UM
  - High resolution allows model to fully capture the diurnal cycle of SST
  - Mixed layer model has prescribed seasonally and depth varying heat and salinity tendencies applied to maintain the basic state
- The compare simulations with high and low entrainment in both coupled and uncoupled frameworks
  - In low entrainment simulations coupling improves amplitude but not propagation
  - In high entrainment simulations coupling improves propagation, but has little effect on amplitude

Role of air-sea interaction in the MJO

Observations | **Control Entrainment** (Atmos, Coupled) | **High Entrainment** (Atmos, Coupled)

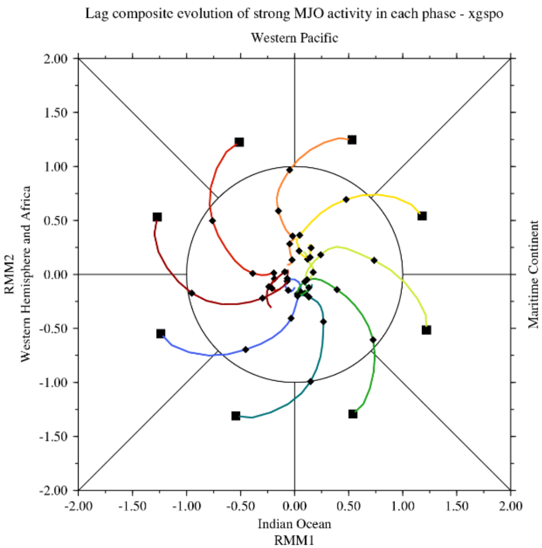
Phase 2

Phase 6

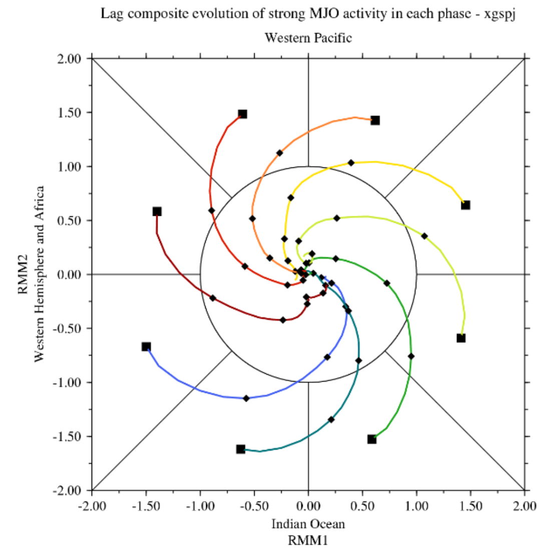


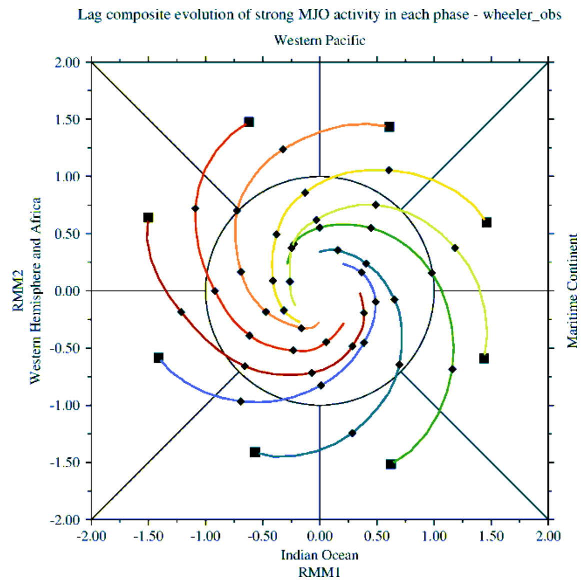
Time longitude composites based on active MJO events in phases 2 &6 for Atmosphere only and mixed-layer coupled simulations with control and high entrainment rates for deep convection from Klingaman and Woolnough (2014)

Role of air-sea interaction in the MJO



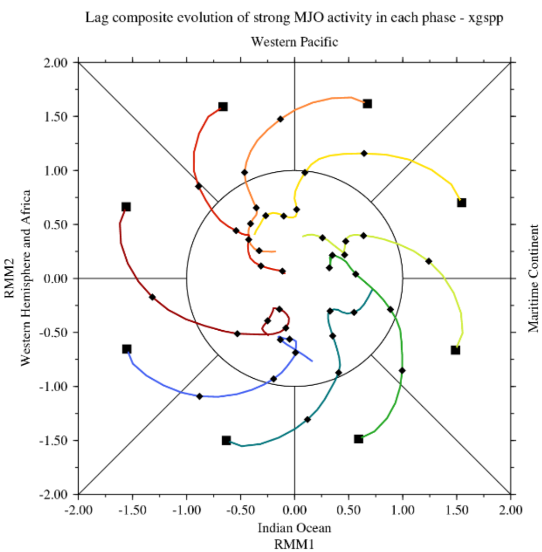
Atmosphere Only



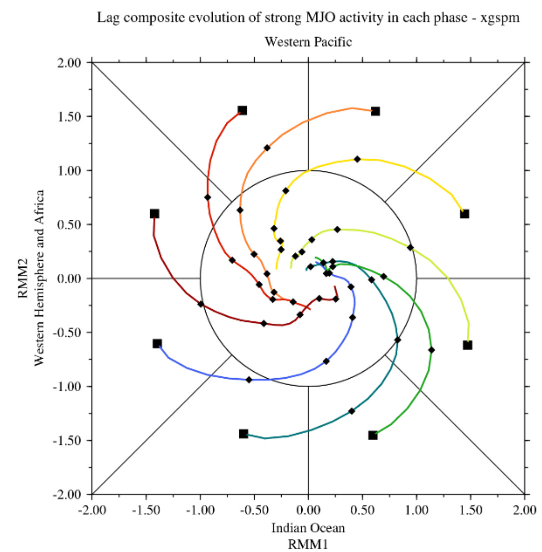


Control Entrainment

High Entrainment



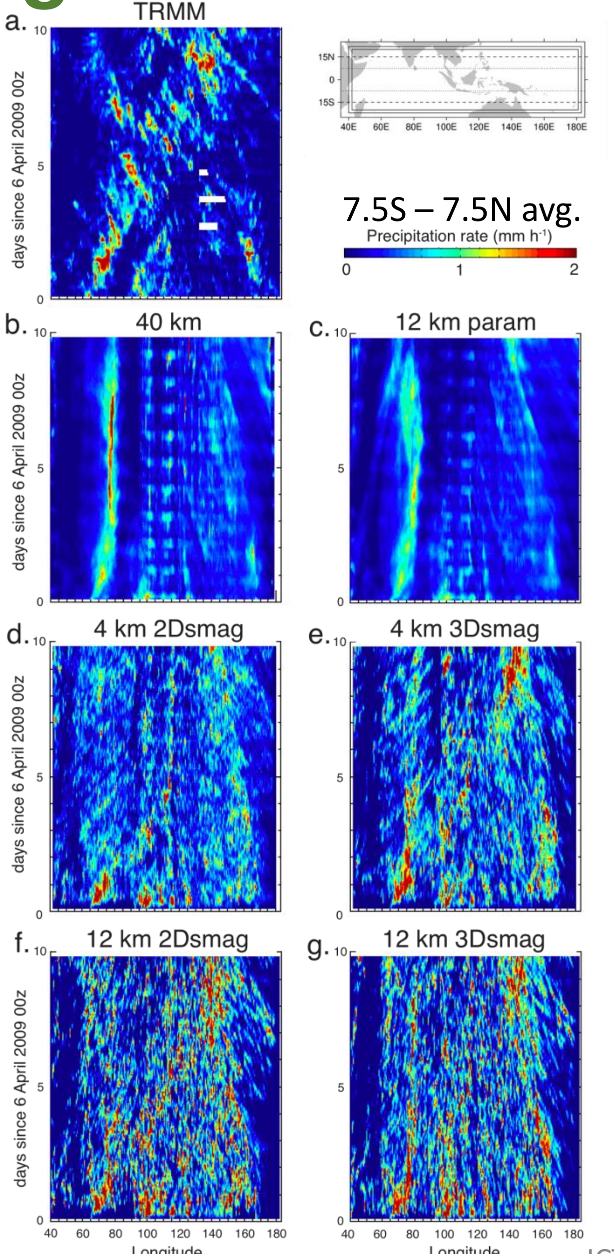
Coupled

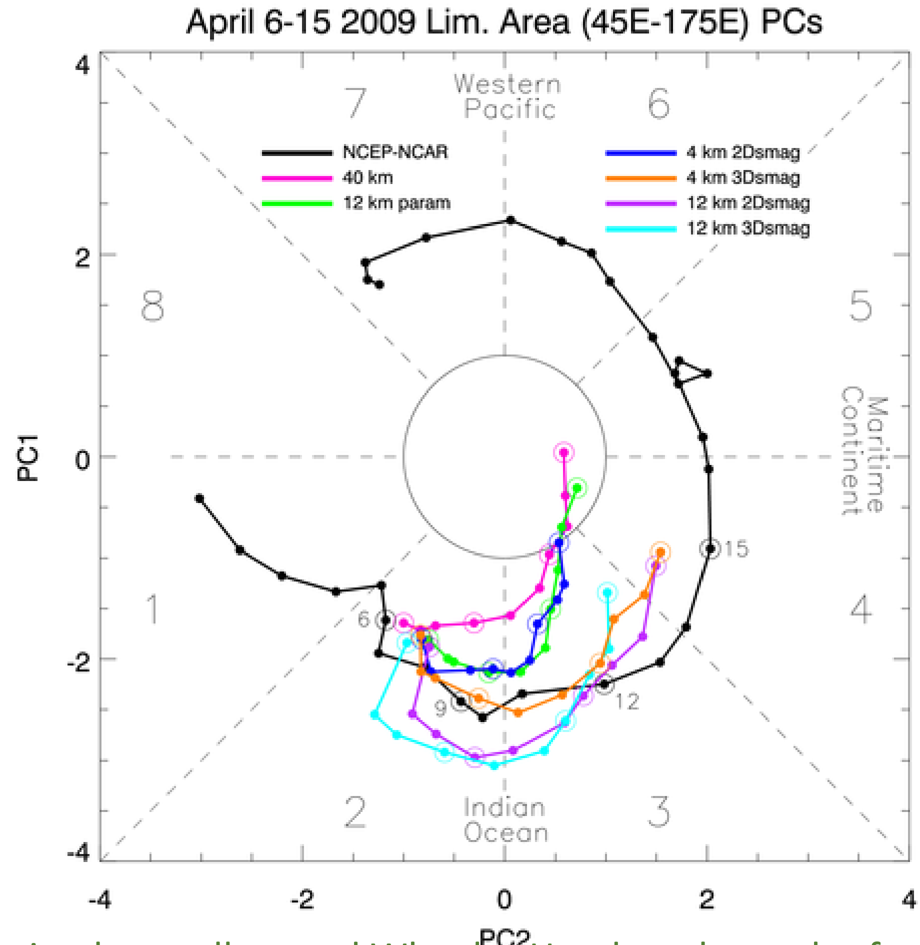


High resolution modelling of the MJO

- Recent advances in computing have allowed simulations of the MJO with an explicit representation of convection, rather than relying on parametrization
  - Globally with (e.g. Muira et al., 2007; Miyakawa et al., 2014)
  - Or regionally (e.g. Holloway et al., 2013)
- Resolution still not cloud resolving, rather cloud permitting
- Generally show improved simulation of the MJO compared to their parametrized convection counterparts
- Still not clear whether improvement
  - relies on the explicit representation of convection and the ability to capture the full range
  - or arises because of improved representation of essentially parametrizable processes (e.g. sensitivity to environmental humidity, vertical profiles of heating)

High resolution modelling of the MJO

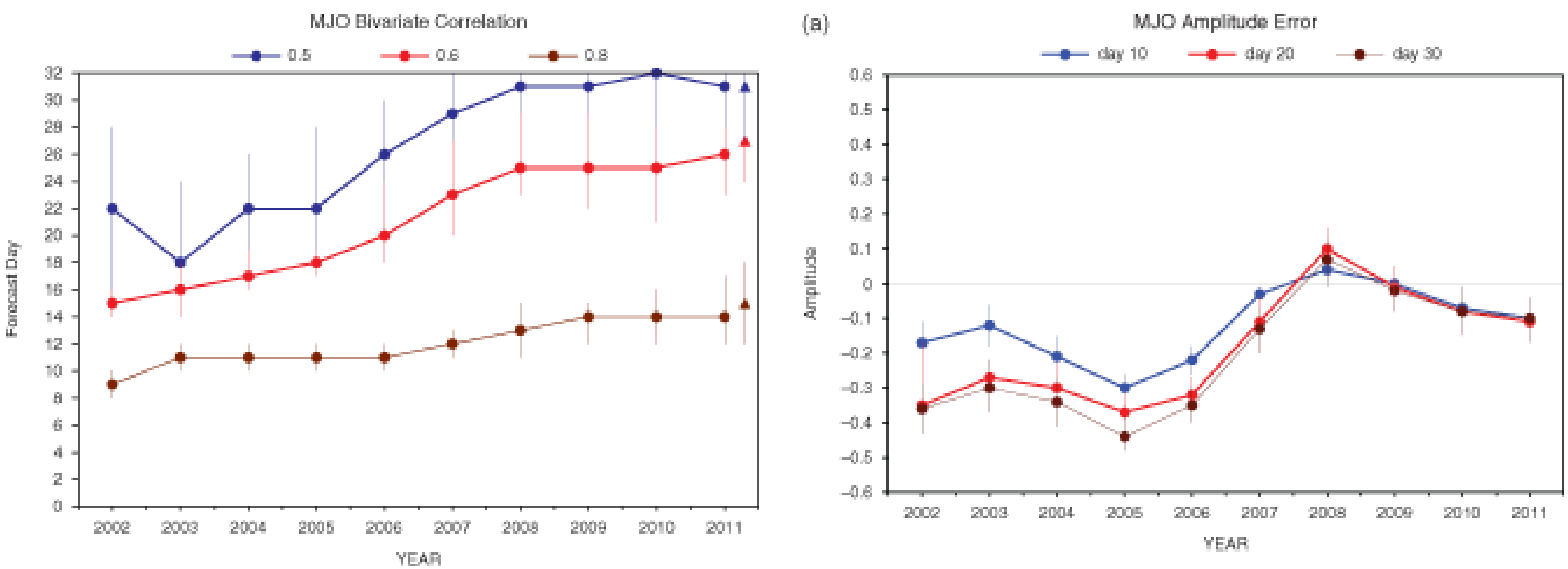




Precpitation hovmollers and Wheeler Hendon phase plot for simulations of the April 2009, MJO event in a both parametrized and explicit convection simulations at a range of resolutions From Holloway et al. (2013)

MJO in sub-seasonal prediction systems

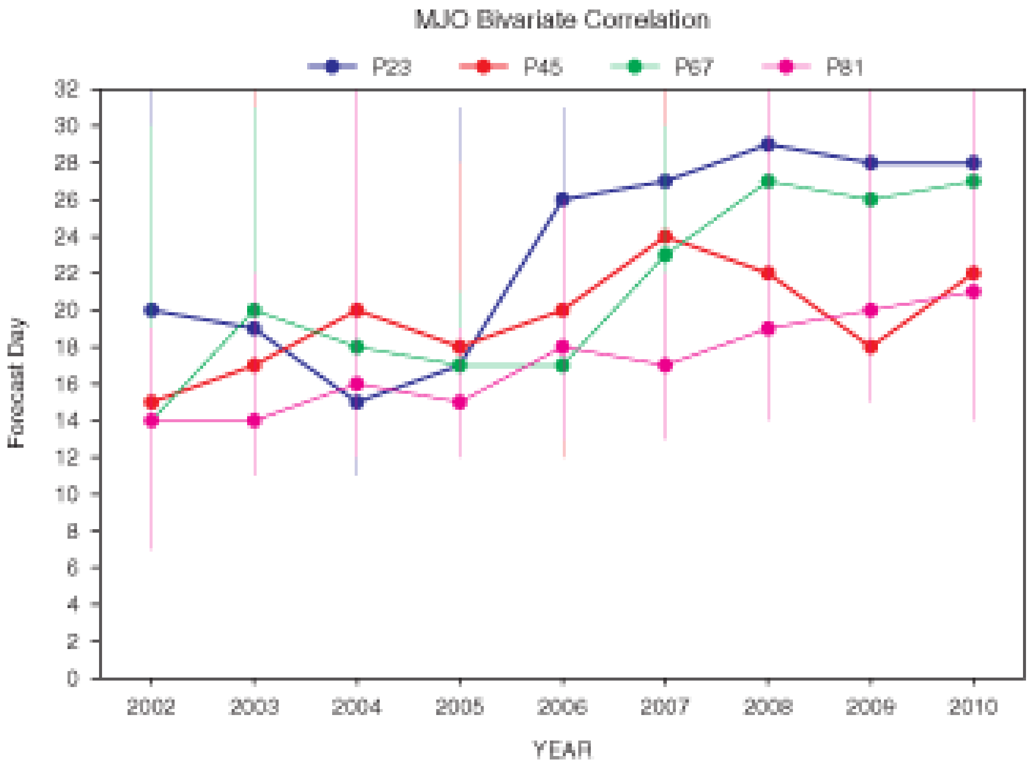
- Despite the difficulties in simulating the MJO in climate models recent progress has been made in MJO prediction in operational prediction systems (e.g. Rashid et al, 2009, Vitart, 2014)



Evolution of the MJO skill in ECMWF monthly forecasts 2002-11. Day at which the MJO bivariate correlation skill falls for the ensemble mean falls below 0.5, 0.6, 0.8, (left) and average amplitude errors at lead times of 10, 20, 30 days (right). From Vitart (*QJRMS*, 2014)

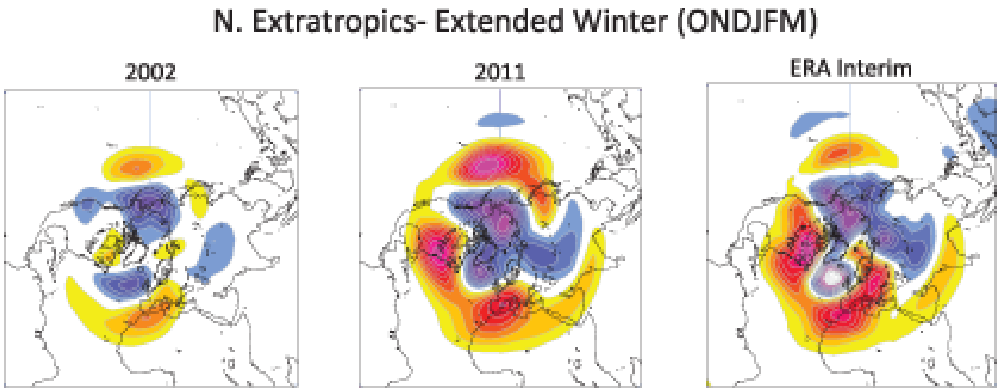
MJO in sub-seasonal prediction systems

- The MJO skill depends on initial phase in the forecasts
  - Higher skill for forecasts initialized in phase 2-3 and 6-7
  - More improvement for phases 2-3 and 6-7



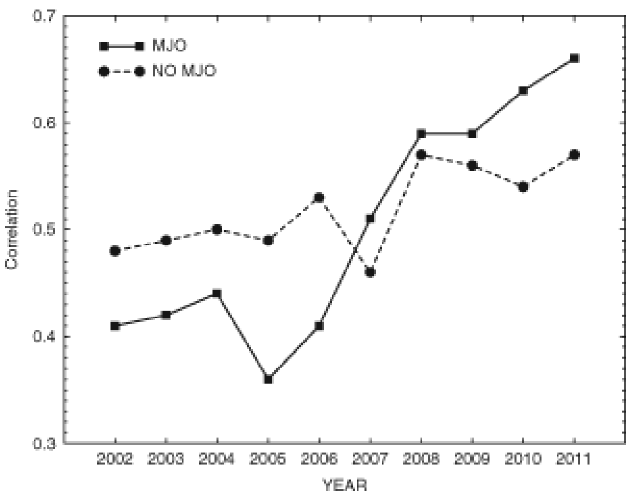
Day at which the MJO bivariate correlation skill falls for the ensemble mean falls below 0.6 for forecasts initialized with a strong MJO in phases 2-3, 4-5,6-7,8-1 (right). From Vitart (*QJRMS*, 2014)

MJO in sub-seasonal prediction systems



Above: Northern hemisphere 500hPa geopotential anomaly 10 days after an active MJO in phase 3 for reforecasts made in 2002 (left), 2011(middle) and from reanalysis (right). From Vitart (*QJRMS*, 2014)

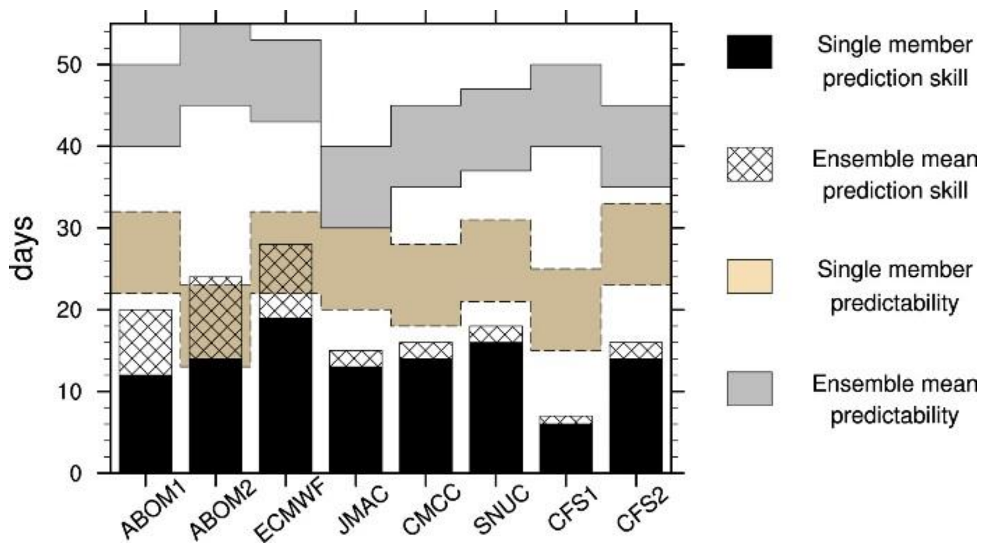
- Errors in amplitude (and possibly propagation speed) have an impact on the teleconnection from the MJO
- Subsequent impact on NAO prediction skill, earlier years have less skill when active MJO in intial conditions compared to later years with higher skill



Left: Evolution of the NAO correlation skill at 19-25 days lead time in ECMWF monthly forecasts 2002-11, for forecasts with or without a strong MJO in the initial lead time From Vitart (*QJRMS*, 2014)

MJO in sub-seasonal prediction systems

- Neena et al (*JAS*, 2014), examine the MJO prediction skill and potential predictability in a comprehensive set of hindcasts
- The find predictive skill based on the time at which the mean square error has the same amplitude as the signal

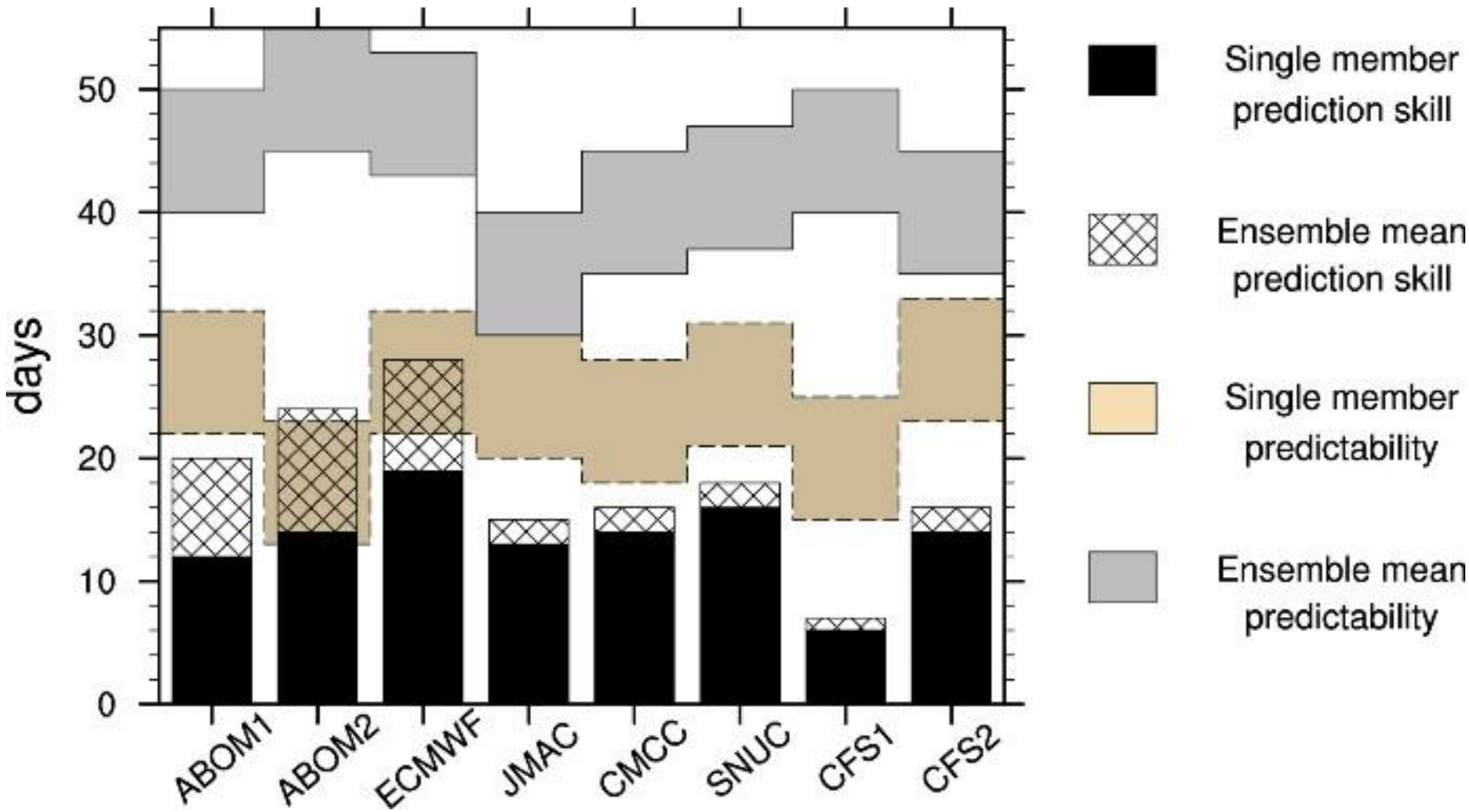


Single member and ensemble mean prediction skill and potential predictability for strong initial MJO conditions from the ISVHE hindcasts (from Neena et al., 2014)

The find skill for strong MJO initial conditions between about 6-18 days for single member skill and 7-27 days for ensemble mean skill

Predictability limits are lower for weak MJO initial conditions and show some phase dependence in some

MJO in sub-seasonal prediction systems



Single member and ensemble mean prediction skill and potential predictability for strong initial MJO conditions from the ISVHE hindcasts (from Neena et al., 2014)

Summary

- Simulating the MJO in climate models remains a long-standing challenge
- The MJO relies on an interaction between the planetary scale dynamics and atmospheric convection and is highly sensitive to the representation of convection in GCMs
  - Sensitivity has been found to a number of aspects of model formulation
  - Modifying convection to be more sensitive to environmental humidity often has a positive impact on the MJO but may degrade other aspects of the simulation
  - High resolution simulations of convection with an explicit representation of convection show improved MJO simulation
- Air sea interaction shown to be important for MJO simulation, but existence of the MJO does not depend on it
- Despite weakness in model MJO simulations operational prediction systems do exhibit useful skill for MJO prediction