A dynamical ocean feedback mechanism for the Madden-Julian Oscillation
Adrian Matthews
Ben Webber, Karen Heywood, David Stevens
School of Environmental Sciences and School of Mathematics
University of East Anglia

International Conference on Southern Hemisphere and Meteorology, 24 April 2012
MJO cycle: rainfall rate
Northern winter (DJF)
MJO cycle: sea surface temperature
Ocean component

SST (°C)

OLR line contours: solid = positive, dotted = negative
Ocean component of the MJO
Thermodynamic

- Slab ocean can interact thermodynamically with atmosphere

Flatau et al., 1997; Shinoda et al., 1998
Ocean component of the MJO
Dynamic?

- Dynamic ocean component = circulation, waves
- There is a dynamic ocean component to ENSO (El Niño – Southern Oscillation)
- Time scale of ocean equatorial waves to cross Pacific ocean is ~6 months – too slow for MJO (1-2 months)
- But
  - Indian Ocean is narrower
  - Do not need an exact match of time scales
- Open questions
  - Is there a dynamical ocean component of the MJO?
  - If there is, is it important?
Ocean component of the MJO
Dynamic?

- Dynamic ocean component = circulation, waves
- There is a dynamic ocean component to ENSO (El Nino – Southern Oscillation)
- Time scale of ocean equatorial waves to cross Pacific ocean is ~6 months – too slow for MJO (1-2 months)
- But
  - Indian Ocean is narrower
  - Do not need an exact match of time scales
- Open questions
  - Is there a dynamical ocean component of the MJO?
  - If there is, is it important?
Satellite altimetry data
Ocean dynamical height

- Merged TOPEX/POSEIDON – Earth Remote Sensing data set
- 0.25 degree grid
- Sea surface height (SSH)
MJO definition
Wheeler and Hendon (2004)

- Phase 1
- Phase 2
- Phase 3
- Phase 4
- Phase 5
- Phase 6
- Phase 7
- Phase 8

Enhanced convection
Suppressed convection
MJO dynamical ocean signal is global
Snapshot in MJO phase 8

SSH anomaly (cm)
Equatorial Kelvin wave in Pacific
MJO phase 2

SSH anomaly (cm)
Equatorial Kelvin wave in Atlantic
MJO phase 3

SSH anomaly (cm)

SST anomaly (°C)
MJO cycle of SSH in Indian Ocean

- Propagation of SSH anomalies difficult to follow
- Mismatching of time scales?

Surface wind (m s$^{-1}$)
SSH anomaly (cm)
MJO cycle
Time lagged from phase 1

Downwelling equatorial Rossby wave

90 days = 2 MJO cycles

SSH anomaly (cm)
SST anomaly (°C)
Hovmöller diagram of MJO cycle
Time lagged from phase 1, Nov-Apr
Averaged 2-4°N and 2-4°S

Positive SST anomaly not driven by fluxes

Downwelling equatorial Rossby wave; $c = -0.8 \text{ m s}^{-1}$

SSH anomaly (cm)

SST anomaly (°C)
Surface flux ($\pm 12 \text{ W m}^{-2}$)
Hovmöller diagram of MJO cycle
Time lagged from phase 1
Averaged 8°S-8°N

Enhanced convection at start of next MJO

OLR anomaly (W m⁻²)
Hovmöller diagram of MJO cycle
Time lagged from phase 1, May-Oct
Averaged 2-4°N and 2-4°S

Positive SST anomaly not driven by fluxes

Downwelling equatorial Rossby wave; $c = -0.7 \text{ m s}^{-1}$
Hovmöller diagram of MJO cycle
Time lagged from phase 1
Averaged 8°S-8°N

Enhanced convection. At start of next MJO?
Schematic of dynamical ocean component of MJO

Local convection in western Indian Ocean generates new MJO event

Westerly winds force downwelling Kelvin waves

~20 days

Downwelling Kelvin wave reflects into downwelling Rossby wave

~35 days

Deepened thermocline leads to reduced entrainment and SST warming

~35 days

Downwelling Rossby wave propagates freely westward across the Indian Ocean
Primary and successive MJ events
A clean natural experiment?

- Ocean dynamics appears to have a role in generation of an MJ event
- Other competing mechanisms
  - Thermodynamical ocean-atmosphere interactions
  - Internal atmospheric dynamics
- “Primary” MJ events
  - No previous MJO activity
  - No apparent trigger (Matthews, 2008)
  - Role of ocean dynamics?
MJ events composited on arrival time of oceanic equatorial Rossby wave

1. Arrival of downwelling oceanic equatorial Rossby wave

2. Causes SST rise in western Indian Ocean

3. Triggers start of primary MJ event
Schematic of triggering of primary MJ event by oceanic equatorial Rossby wave
Model experiments

- Can these ocean-atmosphere interactions be reproduced in a model?
- Linearised ocean general circulation model (GCM)
  - Mean currents are zero
  - Mean potential density stratification independent of horizontal position
Model response to idealised westerly wind burst in Indian Ocean
Conclusions


Webber et al. 2012a QJ Fig. 1
Webber et al 2012a QJ Fig. 6
Webber et al 2012b JClim Fig. 1

Density kg m$^{-3}$