Response of the Tropical Pacific Ocean to the Madden Julian Oscillation

Xu Zhang, PhD Student
Nanjing University, Dalhousie University
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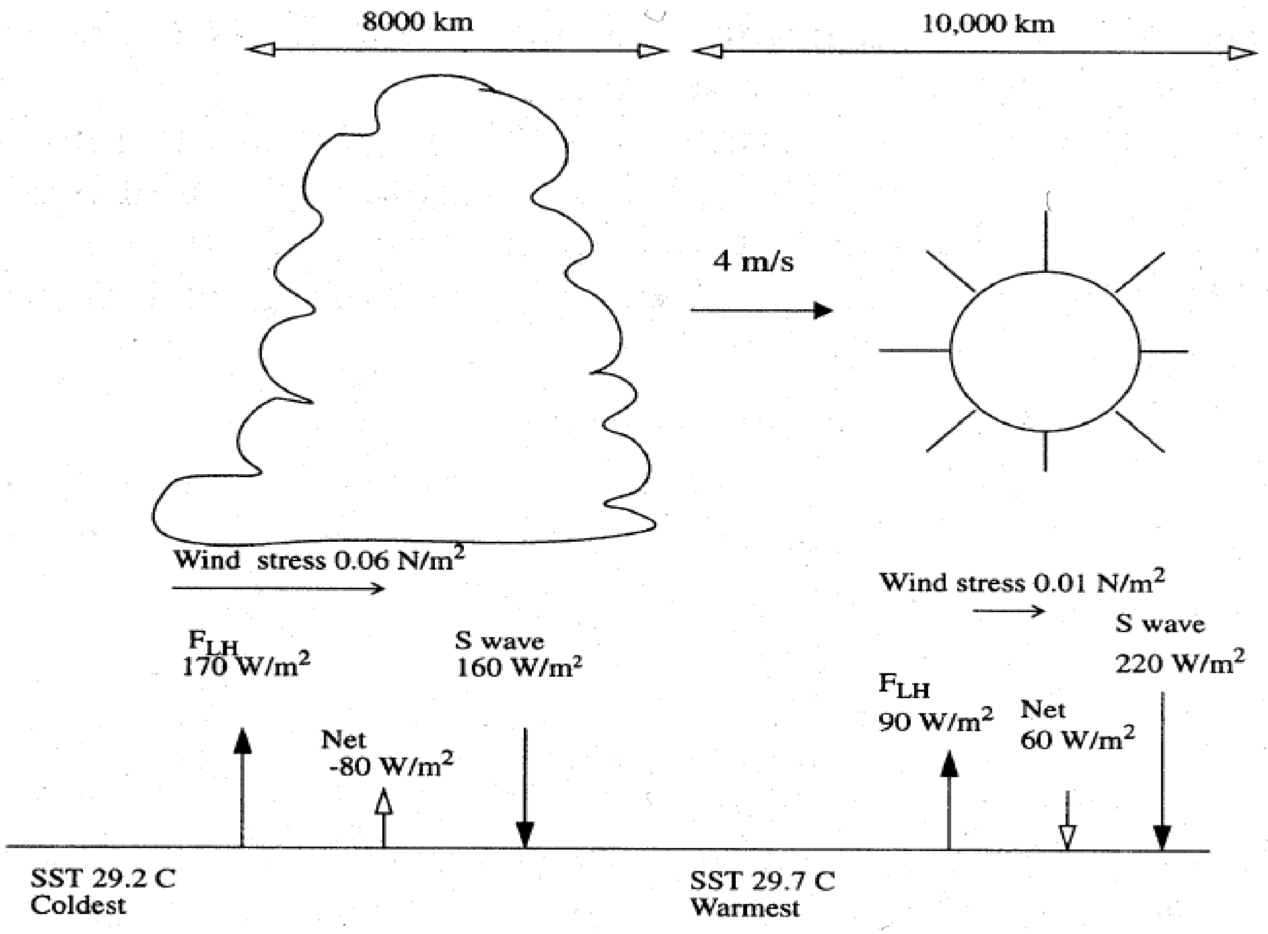
Outline

- MJO and Associated Ocean Forcing
- Physics of the Ocean Response
- ➢ Mixing
- ➢ Jets
- ➢ Waves

  → Focus on Kelvin waves
- Relationship between MJO and ENSO
- Modelling
- Possible Thesis Themes

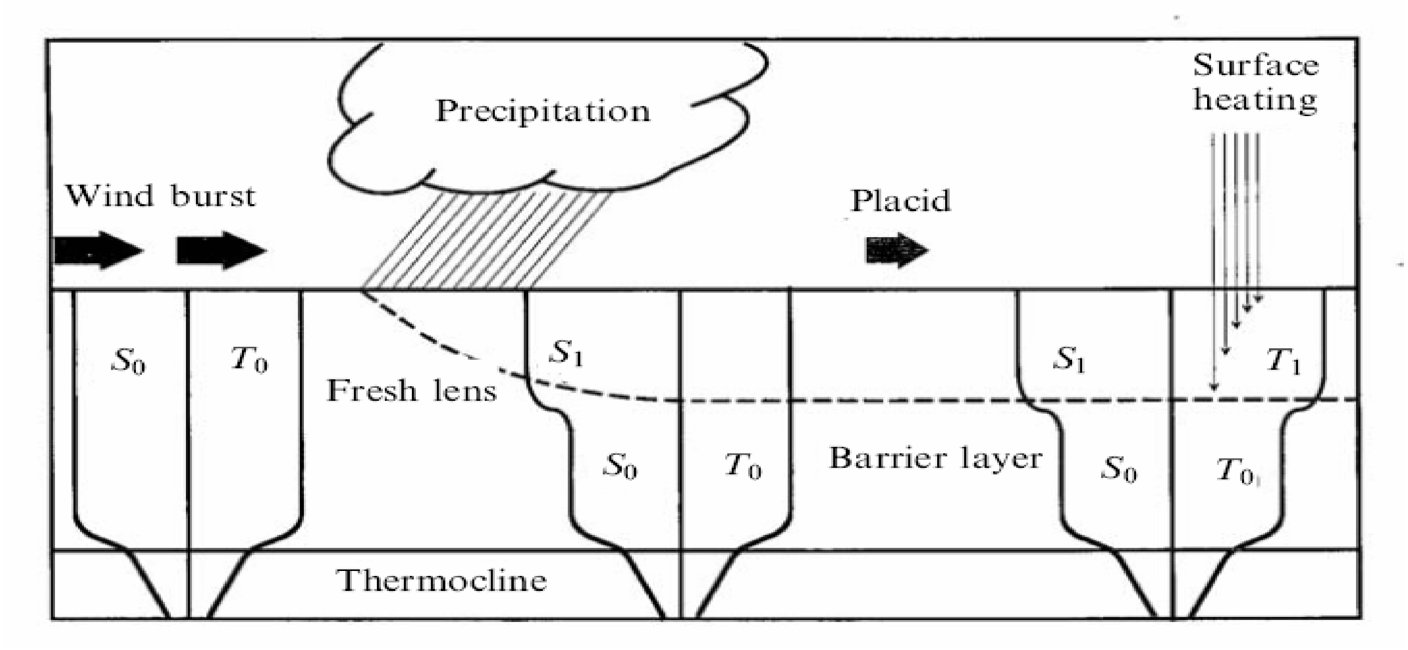
MJO and Associated Ocean Forcing

- MJO: dominant mode of intra-seasonal tropical atmospheric variability; eastward propagation with phase speeds ~ 5 ms^{-1}.
- Changes in surface fluxes associated with MJO force ocean through dynamic and thermal processes:
- Wind bursts (speed u): enhance evaporation (u); generate equatorial jets and waves (u^2); enhance mixing and entrainment (u^3).
- Heat fluxes and precipitation: surface latent and short-wave radiative fluxes have strong signatures as MJO events pass across given region.



Typical magnitudes of surface fluxes and SST variations associated with MJO, and their phase relationship to convective anomaly (*from Shinoda et al.1998).*

Complexity of Equatorial Upper Ocean Mixing: the Barrier Layer



- Barrier layer prevents entrainment cooling from below deep thermocline. *Local* ocean response to heat and momemtum fluxes is concentrated in a thin surface layer and hence enhanced.

Equatorial Zonal Jets

- Typical two-layer current structure*:*
  - Westward upper layer
  - Eastward deeper layer
- Three-layer structure during westerly wind bursts *(e.g*. *Hisard et al. 1970):*
  - Surface to 60m: eastward (an example of Yoshida Jet)
  - 60-175m: westward
  - Deeper than 175 m: eastward (Equatorial Undercurrent)
- Such surface jets can advect SST at the eastern edge of warm pool. May be relevant to the initiation of El Niño through nonlinear mechanisms.

Equatorial Waves

- Rossby waves *(Chelton et al.,1996, Science).*
- Tropical Instability waves.
- Kelvin waves.
- Strongest tropical ocean response to MJO often associated with intra-seasonal Kelvin waves.

Kelvin Waves

- Influence current, thermocline depth and sea surface (or dynamic) height. Baroclinic.
- Generated in western Pacific by strong MJO events. Waves propagate into eastern Pacific where surface signature is usually weak or absent.

Phase Speed of Kelvin Waves

- Observed propagation speeds of intra-seasonal Kelvin waves are 2.1-2.8 ms^{-1}. Linear theory predicts 2-3 ms^{-1}. Phase speeds are higher in western equatorial Pacific because of sloping thermocline.
- Phase speeds can be affected by ENSO and nonlinearity, and maybe slightly enhanced by Doppler shift associated with equatorial undercurrent *(Johnson and Mcphaden,1993).*

Frequency of Kelvin Waves

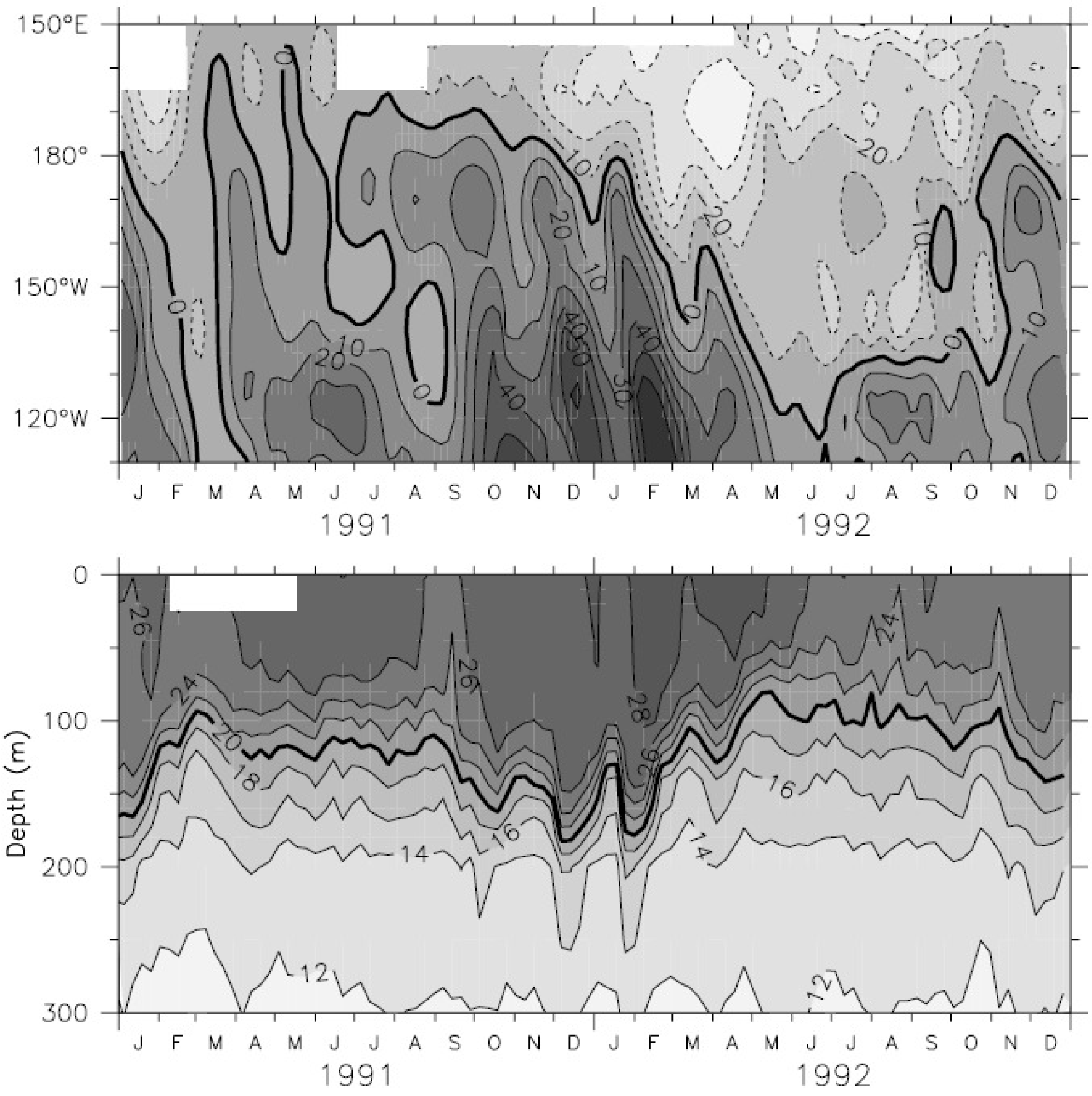
- Dominant periods of intra-seasonal Kelvin waves are 70-90d. Dominant MJO periods are 30-60d. Discrepancy is puzzling.

- *Kessler et al.(1995)* show Kelvin waves receive energy from zonal winds by integrating along characteristics.

- *Hendon et al.(1998)* suggest waves with periods around 70d are amplified by resonance with “wind patches” propagating eastward at 2.3 m/s associated with lower-frequency component of MJO.

Detection of Kelvin Waves

- Vertical displacements of thermocline depth can reach 60m.
- Clearly evident as sloped bands of high and low values in longitude-time plot of 20□ isothermal depth along equator.
- Many researchers use TAO (Tropical Atmosphere Ocean) array data to detect Kelvin waves.
- Recent work uses altimeter data.

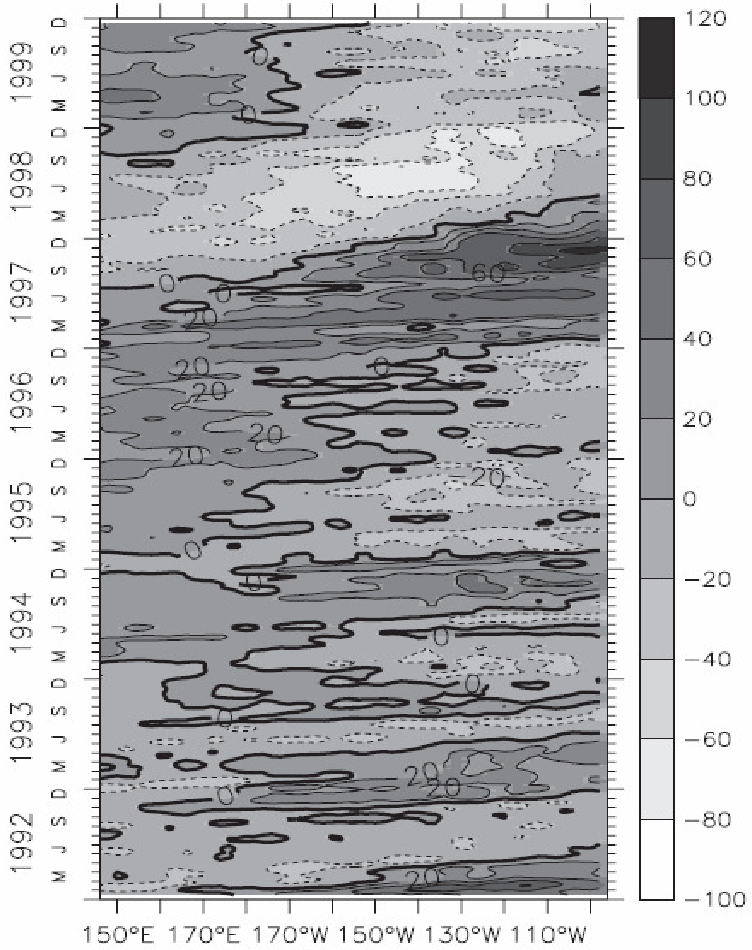


Top:

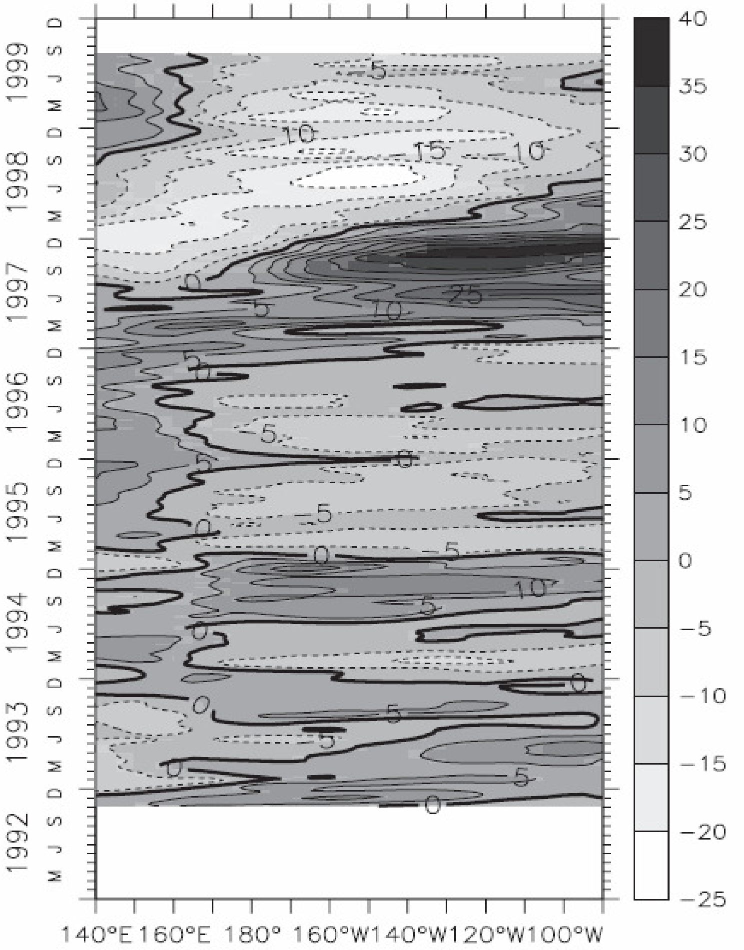
Anomalous depth of 20□ isotherm along equator.

Bottom*:*

Temperature at 0°N,140°W. Thick line denotes 20□ isotherm. Kelvin waves arriving from western Pacific produce sharp downwelling events.



Left: Time-longitude plot of TAO 20□ isothermal depth anomalies (in meters) along equator



Right: TOPEX/Poseidon sea level anomalies (in cm) along equator. Data have been low-pass filtered with a 35-day Hanning filter.

SST Changes Associated with MJO

- Intra-seasonal changes in different regions of equatorial Pacific are controlled by different dominant processes:
  - Western: Local surface heat fluxes (1-D process).
  - Central: Zonal advection by currents and Kelvin waves.
  - Eastern: Vertical advection/entrainment (shallow thermocline).
- Hypothesis for changes in eastern Pacific: Waves deepen equatorial thermocline and increased ML depth decreases effect of upwelling. Thus positive SST anomalies are induced by downwelling Kelvin waves.

Relationship Between MJO-ENSO

- MJO reduces zonal SST gradient in equatorial Pacific:
  - SST reduced in western Pacific by surface cooling.
  - Eastward SST advection at eastern edge of warm pool.
  - Warmer SST in eastern Pacific associated with thermocline depression and reduced effect of upwelling.
- If MJO causes significant reduction in zonal SST gradient, trade wind is relaxed which further reduces zonal SST gradient - a positive feedback.
- If this happens during initial and developing stages of an ENSO warm event, the growth of ENSO may accelerate and its amplitude amplified.

Modelling MJO Response to SST

- Increase in SST east of MJO convective center →
  - Enhances surface latent flux or low-level moisture convergence. Leads to better MJO simulations.
  - Destabilizes atmosphere and enhances eastward MJO propagation. Unclear why eastward propagation speed decreases in some simulations and increases in others.
- By including SST feedback, MJO simulations can improve significantly or slightly, remain unaffected, or even deteriorate.

Modeling Ocean Response to MJO

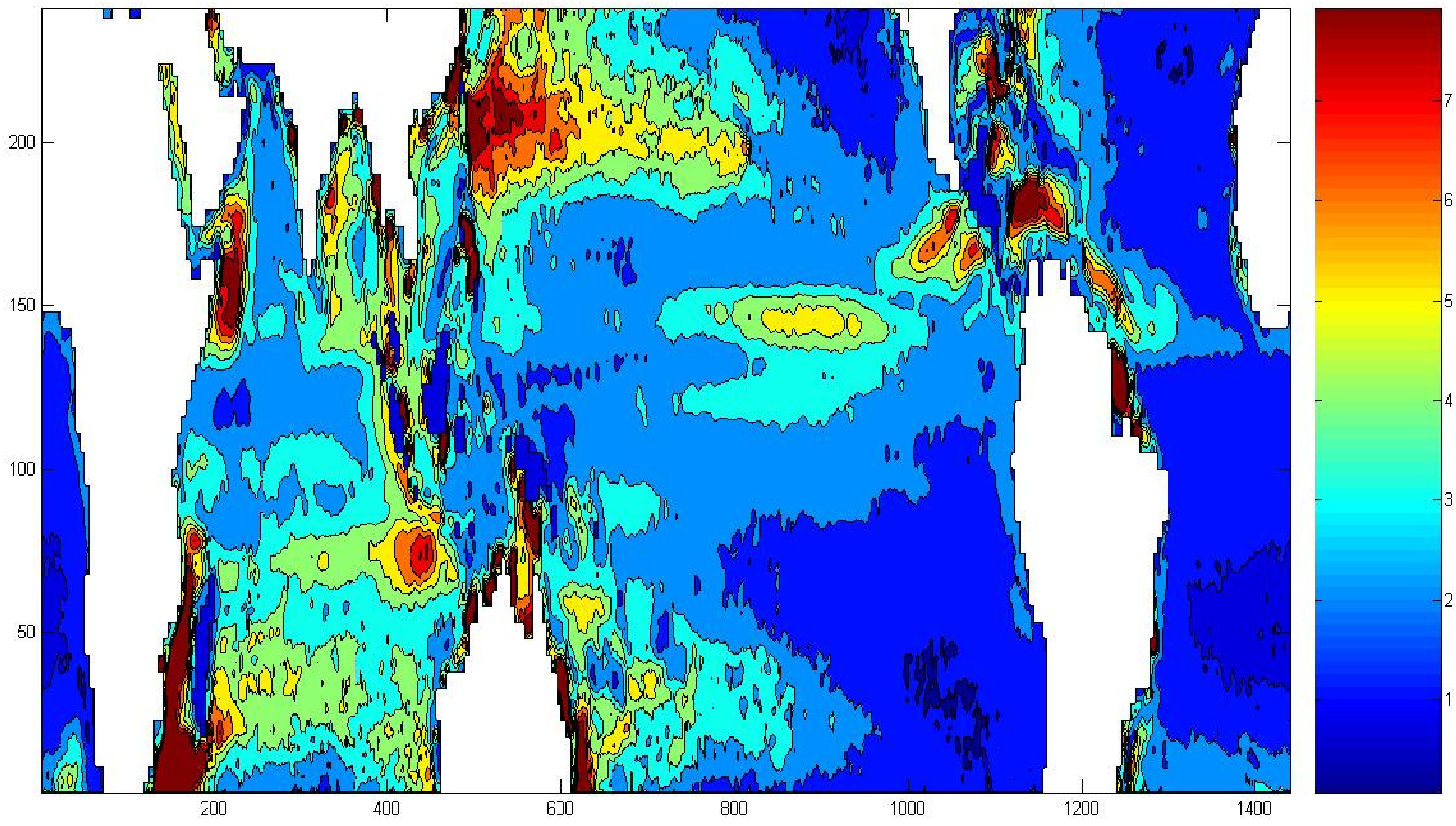
- Models and forcing fields are mostly:
  - Regional (e.g., 30ºS-30ºN), OGCM and reduced gravity models
  - Use idealized forcing (few use realistic forcing)
- Examples: *Waliser et al (2003,2004)*
  - Indo-Pacific domain 30ºS-30ºN, mixed layer, 14 sigma levels, motionless deep layer, 1/3ºx1/2º resolution.
  - Ocean model coupled to advective atmosphere mixed layer model. Inputs are seasonal climatology and canonical composite of MJO anomalies

Possible Thesis Themes

- Focus on tropical Pacific Ocean response to MJO.
- Start by analyzing ocean observations and forcing, e.g.,
  - Sea surface height
  - SST
  - TAO, Argo, …
  - Surface winds, …

  → Wave detection, seasonality, relationship with ENSO
- Ocean simulations
  - Force global ocean model with reanalysis surface fluxes (1990-present), model validation, better understand processes.
- Feedback of ocean response to MJO (coupled model?)

Example: Analysis of Intra-Seasonal Variations of Sea Surface Height



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