Madden-Julian Oscillation and the Global Ocean: Local and Remote Forcing

Eric C. J. Oliver
Keith R. Thompson

DALHOUSIE UNIVERSITY

Department of Oceanography
Dalhousie University, Halifax, Canada

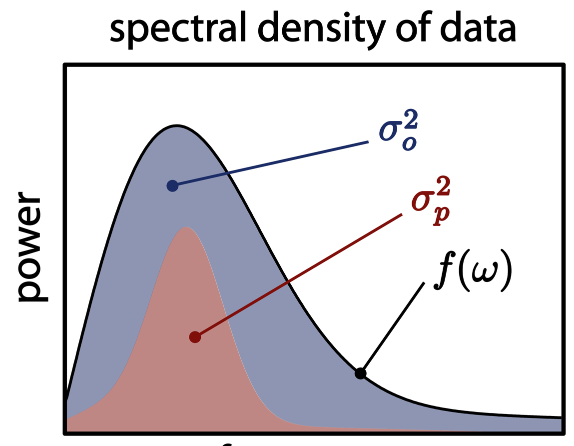
1 Introduction

- There is growing interest in extending the range of weather forecasts and ultimately developing a seamless prediction capability that bridges both weather and climate.
- The main prospect for predictability on intraseasonal timescales is the Madden-Julian Oscillation (MJO). Understanding the dynamics of the MJO, its interactions with the extratropics and its coupling with the ocean has been an active research topic in recent years. In this context, there is an important role for empirical studies which use statistical techniques to explore the relationship between the MJO and global distributions of atmospheric and oceanic variables.
- In this study, we first examined the global connections between variability in sea level height and the MJO. A statistical metric to quantify this connection was developed and its spatial distribution was mapped (Section 2).
- Next, three regions are identified for which the connection is strong: Equatorial Pacific and Coastal Americas, Northeast Indian Ocean, the Gulf of Carpentaria. In each region, the physical mechanisms relating to the MJO-sea level relationship are examined using a combination of statistical and dynamical tools (Section 3).

2 MJO and Global Ocean Variability

- Data:
  - MJO: Daily bivariate MJO index which consist of the first two principal components of the combined tropical OLR and zonal wind fields after removing seasonal and interannual variability [1].
  - Sea Level: Weekly values of sea level anomaly are available globally on a 1/4° grid which we take over the period from 14 October 1992 to 12 May 2007 [2]. These data are high-pass filtered with a cutoff period of 120 days in order to remove interannual variability.

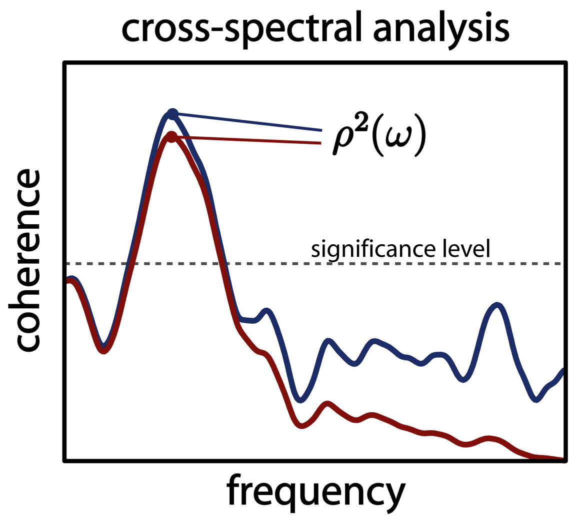
spectral density of data



- The area under the curves represent the variance of the observed sea level (blue) and that predicted by the MJO (red).
- The ratio represents the proportion of variance predicted by the MJO [3]:

$$\bar{\kappa}^2 = \frac{\int \rho^2(\omega) f(\omega) d\omega}{\int f(\omega) d\omega} = \frac{\sigma_p^2}{\sigma_o^2}$$

cross-spectral analysis



- The calculation of coherence (blue) is modified by adding a small constant to the power spectra of the MJO indices in order to reduce the coherence at high frequencies (red) where there is almost no energy in the MJO.
- This is allows us to avoid choosing an arbitrary range of "MJO frequencies".

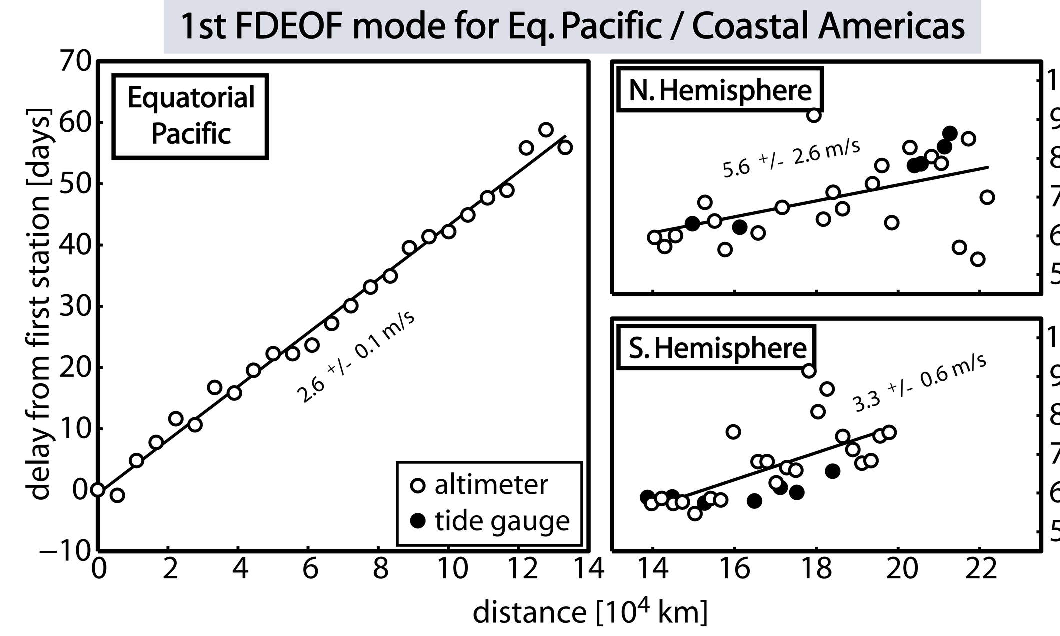
3 Regional Connections: Local and Remote Forcing by the MJO

- Three regions are examined using frequency-dependent EOF (FDEOF) analysis. The frequency is chosen based on the peak in coherence between a set of sea level time series and the MJO.
- In each case a peak in coherence with the MJO occurs ~75 days and the forcing is shown to be a combination of local and remote effects - with different dynamics in each region.

A. Wave Propagation and the MJO: Remote Forcing of Sea Level along Eastern Boundaries

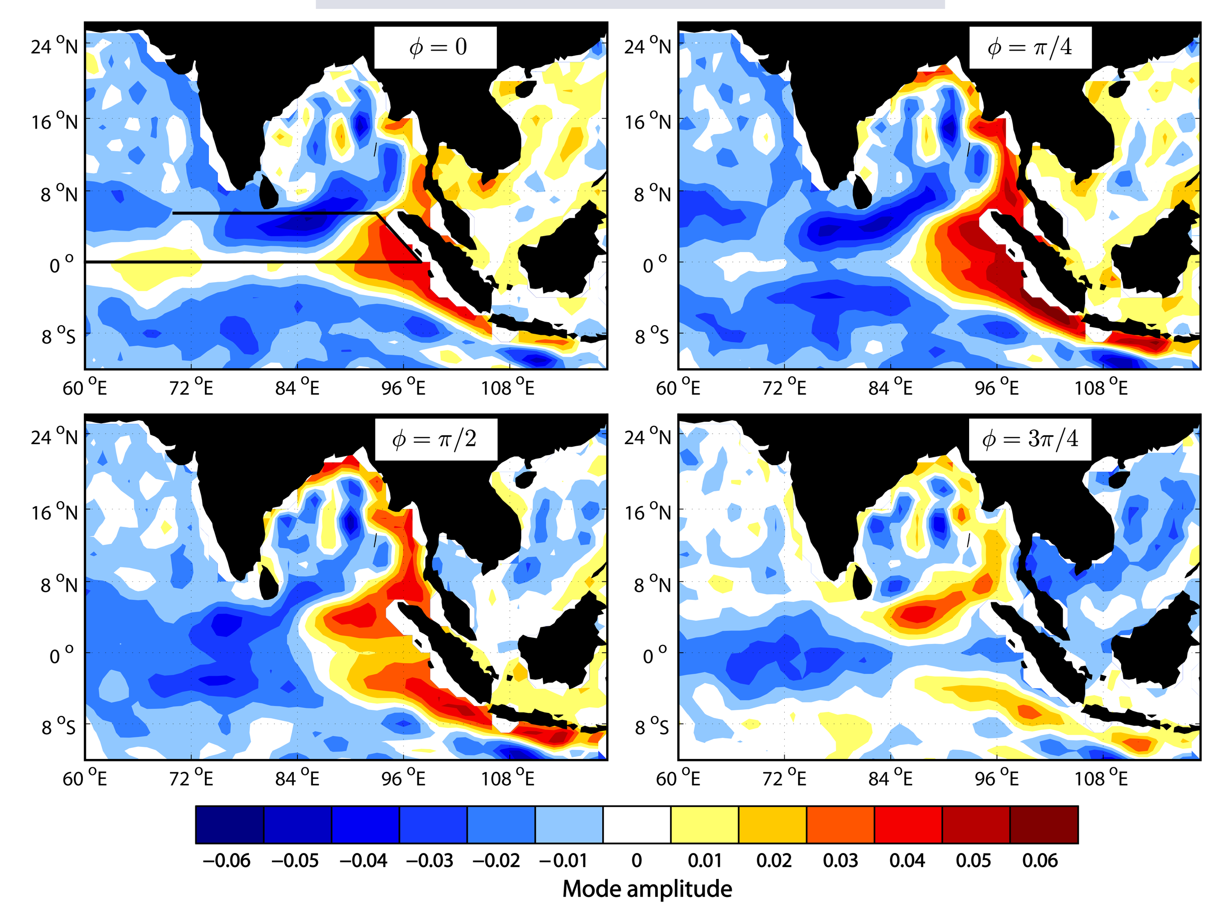
- Sea level time series were chosen along the Equatorial Pacific and Coastal Americas (northern and southern hemisphere). The first FDEOF mode explains 67% of the variance [3].
- Intraseasonal waves propagate along the equator as Kelvin waves (see also [4]) and then poleward along the Americas as coastal trapped waves as far as 37°N and 33°S.

1st FDEOF mode for Eq. Pacific / Coastal Americas



- The first FDEOF mode of sea level in the northeastern Indian Ocean explains 25% of the variance.
- The intraseasonally varying sea level exhibits complex dynamics in this region. Equatorially trapped waves excite energy along the coast of Sumatra which propagates around the Bay of Bengal / India. Furthtermore, Rossby waves are radiated into the basin along 5.5°N [3,5].

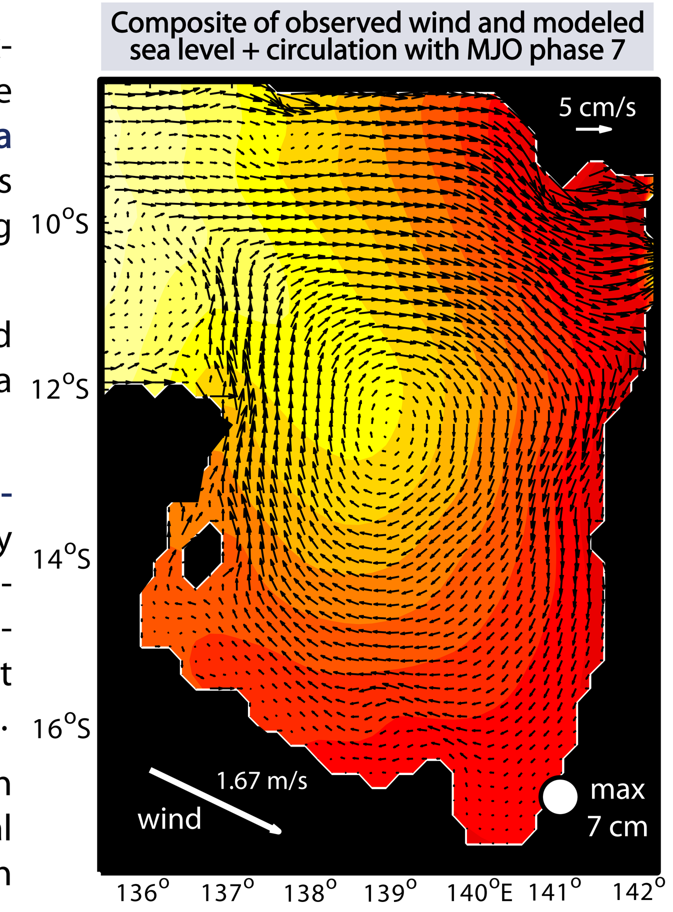
1st FDEOF mode for NE Indian Ocean



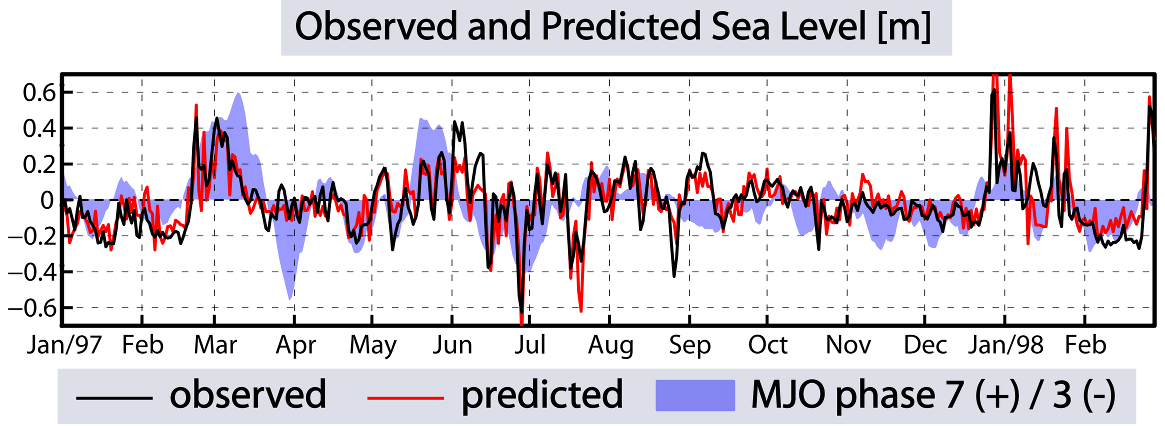
B. Local Wind Forcing: Gulf of Carpentaria

- The first FDEOF mode explains 34% of the variance in the Gulf of Carpentaria region [3]. This Mode is dominated by a standing wave in the Gulf.
- Composites of local wind with MJO phases show a strong connection [6].
- Predictions using a numerical model forced by surface winds (NCEP Reanalysis) match observations and are consistent with simple set-up model.
- Strong seasonality in strength of intraseasonal variability (strongest in Boreal Winter).

Composite of observed wind and modeled sea level + circulation with MJO phase 7



Observed and Predicted Sea Level [m]



- Set-up (set-down) favourable winds occur during MJO phases 6/7 (2/3). This is consistent with the surface zonal wind anomalies associated with the propagating MJO - potential for predictability [6].

4 Conclusions and Future Work

- MJO provides a mechanism for enhancing predictability on intraseasonal timescales (weeks to months).
- We have presented the global distribution of the statistical connection between the MJO and sea level.
- We focused on three regions and physically explained the sea level variability and the connection with the MJO using statistical techniques and a numerical model.
- Further exploration on the physical dynamics and MJO-driven response of the Northeastern Indian Ocean will be performed using a nested global ocean circulation model.

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5 References

[1] Wheeler, M. C., and H. H. Hendon (2004), An all-season real-time multivariate MJO index: Development of an index for monitoring and prediction, Mon. Weather Rev., 132(8), 1917– 1932

[2] AVISO. ``Home: Aviso". http://www.aviso.oceanobs.com/en/home/index.html, March 2010

[3] Oliver, E., and K. Thompson (2010), Madden-Julian Oscillation and sea level: Local and remote forcing, J. Geophys. Res., 115(C1), C01,003.

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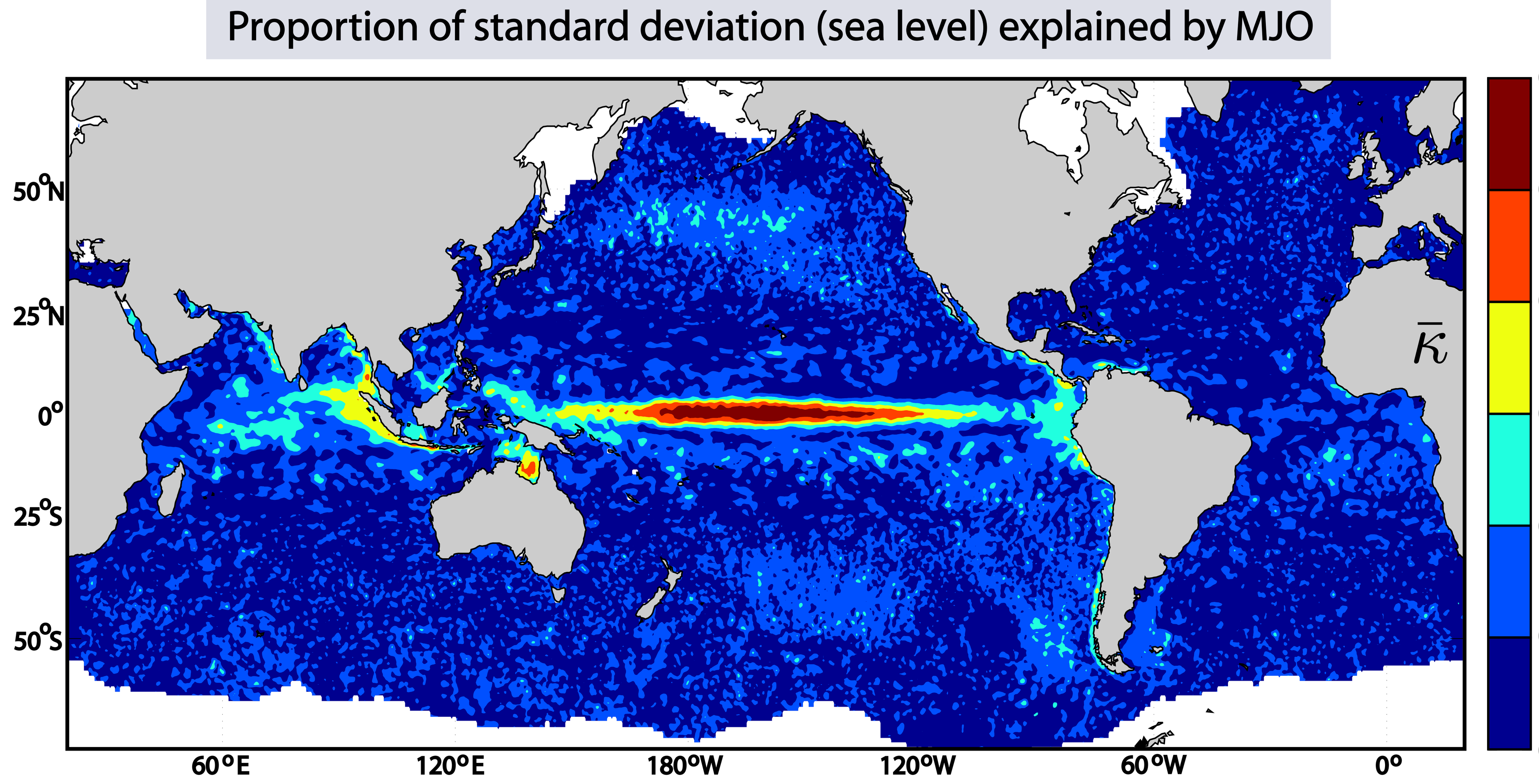
[5] Vialard, J., et al. (2009), Intraseasonal response of the northern Indian Ocean coastal waveguide to the Madden-Julian Oscillation, Geophys. Res. Lett., 36, L14606.

[6] Oliver, E., and K. Thompson (2010), Sea level variability in the Gulf of Carpentaria on intraseasonal to interannual timescales, in progress.

Proportion of standard deviation (sea level) explained by MJO



Standard deviation (sea level) explained by MJO [cm]