Impact of the MJO on the Gulf of Carpentaria during the monsoon

Eric C. J. Oliver[1,2] and Keith R. Thompson[2]

[1]*Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Tasmania, Australia*
[2]*Department of Oceanography, Dalhousie University, Halifax, Nova Scotia, Canada*

Introduction

The Madden-Julian Oscillation (MJO) is an atmospheric phenomenon but the associated precipitation, convection, and wind anomalies also interact with the ocean surface. Broad scale patterns of intraseasonal sea level anomalies have been detected worldwide (Fu 2003) and are largely driven by surface wind stress. Oliver and Thompson (2010) found that sea level from many ocean regions, including the equatorial Pacific, the west coast of the American continent, the Gulf of Carpentaria and the northeastern Indian Ocean, have significant correlations with the MJO. Sea level and circulation in the Gulf of Carpentaria have been shown to be related to the MJO during the Australian-Indonesian monsoon season (Oliver and Thompson 2011) and these results are reviewed here as well as a discussion on the predictability of Gulf of Carpentaria sea level.

Data

Six-hourly fields of surface winds were obtained from the NCEP/DOE Reanalysis 2. Hourly time series of sea level were obtained from three tide gauge locations around the Gulf of Carpentaria: Groote Eylandt was obtained from Australian Baseline Sea Level Monitoring Project; Karumba and Weipa were obtained from Maritime Safety Queensland, Queensland Government, Australia. The MJO is characterised using the real-time bivariate index of Wheeler and Hendon (2004) and daily values were obtained from the Government of Australia Bureau of Meteorology

Intraseasonal sea level, wind and MJO variability during the Monsoon

The prevailing winds over the Gulf of Carpentaria are strongly linked to both the local trade winds and the Australian-Indonesian monsoon. The background flow in this region is dominated by the southeasterly trade winds which peak in July. During Austral Summer the Australian-Indonesian monsoon causes reversal of the mean flow and predominantly northwesterly winds (see Forbes and Church (1983)). The Madden-Julian Oscillation has been shown to be strongly related to bursts and breaks (e.g., modulations) of the Australian-Indonesian monsoon (Hendon and Liebmann 1990; Wheeler and McBride 2005).

To examine the relationship between the MJO index and average wind over the Gulf of Carpentaria we calculated the coherence between these two variables as a function of frequency. The coherence reaches a peak for both zonal and meridional wind components over the intraseasonal band, defined as periods between 30 and 90 days (not shown, see Oliver and Thompson (2011) henceforth OT11). Zonal wind has the highest coherence with the MJO (between 0.5 and 0.7 across the intraseasonal band). Directional dependence was explored by looking at the average coherence over the intraseasonal band between the MJO and wind projected onto various wind directions (not shown). The intraseasonal coherence peaks for westerly to northwesterly winds (or easterly to southeasterly). Using a barotropic ocean circulation model (see OT11 for model details) it has been shown that the Gulf responds most strongly to wind in the northerly to northwesterly (or, equivalently, the southerly to southeasterly) direction. Therefore, sea level in the Gulf of Carpentaria is expected to respond strongly to MJO-related wind stress during the monsoon.

The seasonal variation of the spectral properties of the wind and the MJO was explored by calculating evolutionary spectra using 180 day subsets of the wind time series with successive blocks shifted by one day. The seasonal cycle of spectral density was then calculated by averaging across years for each day of the year. The seasonal variation of the northwesterly wind spectrum (Figure 1, left panel) shows that the

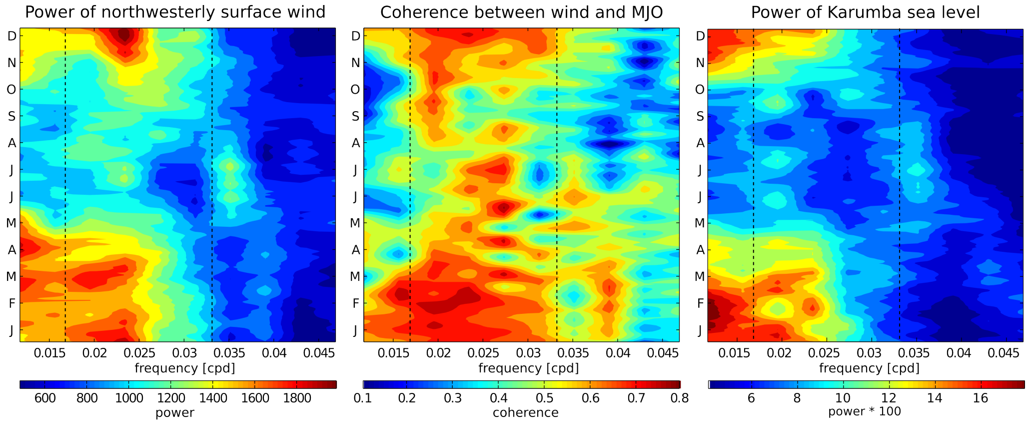

Fig. 1: Seasonal variation of the spectral density of the northwesterly surface wind over the Gulf (left), the coherence between the wind and the MJO index (centre), and the spectral density of observed sea level at Karumba (right). Vertical lines indicate periods of 30 ad 60 days.

energy is relatively high over the intraseasonal band during Austral Summer which coincides with the Australian-Indonesian monsoon. This time of year also corresponds to relatively high coherence between the wind and the MJO (Figure 1, centre panel) consistent with previous work (Salby and Hendon 1994; Zhang and Dong 2004).

The coherencies between the MJO and the sea level from the Gulf of Carpentaria tide gauges show peaks between 0.6 and 0.7 over intraseasonal time scales (not shown). The seasonal cycle in the spectral density of sea level at the three tide gauges, calculated in the same way as for wind, shows the same cycle as the wind (Figure 1, right panel) indicating the expected sea level-wind-MJO.

Impact of the MJO on sea level and circulation

Sea level and depth-averaged circulation in the Gulf of Carpentaria were predicted from a barotropic numerical ocean model (POM, see OT11 for model details) over the 1979 to 2009 period and the domain is bounded by 120°E, 146°E, 20°S and 3°S. The model slightly underpredicts the observed intraseasonal sea level at the tide gauge locations however the root mean square (RMS) errors between observed and predicted sea levels are lower than the RMS amplitude of the model predictions indicating that the model has some predictive skill. Correlations between observed and predicted sea level, after filtering out variability on time scales longer than 120 days, are generally above 0.7 indicating that the predictions capture the intraseasonal variability well. The model also reproduces the seasonal modulation of intraseasonal sea level variability (e.g., such as that shown in Figure 1, right panel).

The dependence of observed wind and sea level on the MJO was examined by compositing based on its phase. Composites of zonal wind show the passage of a convergence region at the surface associated with the movement of active MJO-related convection over the Maritime Continent. This leads to anomalous easterlies over the Maritime Continent at the equator when the convective centre is over the Indian Ocean (phases 1-3) and anomalous westerlies when it is over the Pacific Ocean (phases 6-7). The Gulf of Carpentaria, just south of the Maritime Continent, experiences anomalous northwesterlies during phases 6-7 with set-up of coastal sea level evident at all three tide gauges and anomalous southeasterlies during phases 1-3 with set-down at all three stations (see arrows in lower left of panels in Figure 2).

The composites of model predicted sea level and depth-averaged current anomalies based on MJO phase are also shown in Figure 2 and are consistent with sea level set-up and set-down respectively. For example, the phase 7 (2) composite of depth averaged currents exhibits a cyclonic (anticyclonic) gyre centred in the Gulf of Carpentaria and strong eastward (westward) flow through the Torres Strait. As the MJO performs a cycle the composites pass through a quiescent state (phase 8), followed by the set-down pattern (phase 1-3), and then another quiescent state (phase 4-5), before returning to the set-up pattern (phases 6-7).

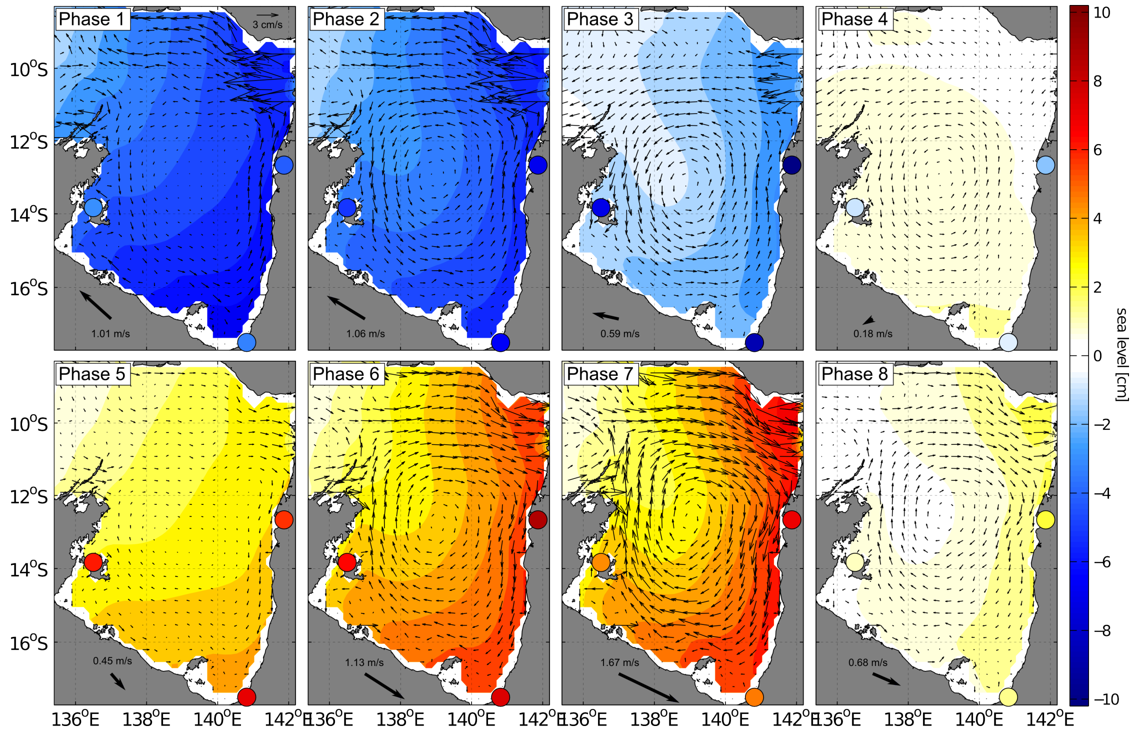

Fig. 2: Composites of sea level (colours), depth-averaged currents (small arrows), and surface wind (large black arrow in lower left of each panel) associated with the eight phases of the MJO index. The coloured circles and contours show the composites of observed and model predicted sea level respectively. A current speed of 3 m/s is indicated in the top right of the first panel.

Predictability

The potential predictability of the MJO-related sea level setup in the Gulf of Carpentaria is now explored using a simple statistical prediction model following Oliver (2012). We relate the sea level series from the Karumba tide gauge (η_t) and the MJO index (first and second components denoted $I_{1,t}$ and $I_{2,t}$ respectively) using a lagged linear regression model

$$\eta_{t+k} = \sum_{d=0}^{D} \beta_{1,d} I_{1,t-d} + \beta_{2,d} I_{2,t-d} + \varepsilon_t$$

where t is a time index, k is a future prediction time, the β are regression coefficients and ε_t is an error term. The model includes $I_{1,t}$ and $I_{2,t}$ at all lags d from 0 to D. In practice the inclusion of so many lags provides an overfit model and in this study we only include lags 0 and 8 days. The model is applied for November through March only, the period for which the MJO-sea level connection is strongest. The model is trained on the first half of the time period and validation statistics are calculated over the second half of the period.

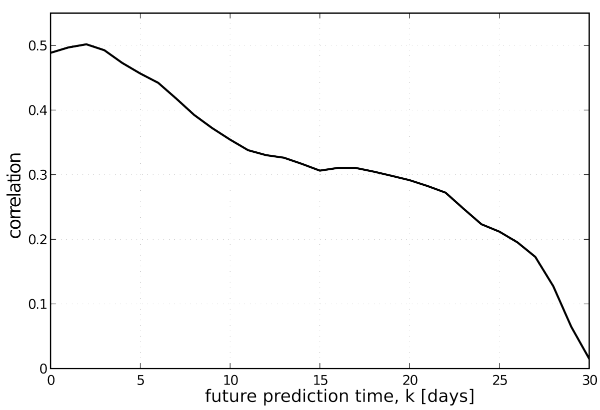

Fig. 3: Potential predictability of sea level at Karumba from the MJO index as measured by the correlation between the sea level series and the lagged linear regression model as a function of future prediction time k.

The correlation between η_t and the statistical model prediction, over the validation period, as a function of future prediction time k is shown in Figure 3. The correlation is ~0.5 instantaneously ($k = 0$ days). The correlation at future prediction times drops slowly, reaching zero at about $k = 30$ days. However, after 20 days the correlation has only dropped by half indicating that in this time period the model can still account for some (~10%) of the variability. These correlation values may seem low but it should be kept in mind that the sea level record was not filtered and so retains variability on time scales outside the intraseasonal band.

Conclusions

We have used a barotropic circulation model to show that intraseasonal sea level and depth-averaged circulation variations in the shallow waters of the Gulf of Carpentaria are dominated by wind setup due to MJO-related surface wind stress. The influence of the wind stress on sea level and circulation is strongest during Austral Summer when the MJO influences the occurrence of bursts and breaks in the Australian-Indonesian monsoon. The sea level signal at the head of the Gulf was shown to be predictable given historical MJO values and predictions of the future MJO index (e.g., Rashid et al. (2011)) may lead to better forecast skill for sea level and circulation in the Gulf of Carpentaria on intraseasonal time scales. Future work may focus on (i) the use of future projections of the MJO index to predict intraseasonal variability in the Gulf of Carpentaria and (ii) an examination of the secondary effects of the intraseasonal variations in the Gulf of Carpentaria (e.g., chlorophyll-a variability).

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