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Influences of Madden–Julian Oscillations on the eastern Indian Ocean and the maritime continent

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ABSTRACT

Oceanic response to Madden–Julian Oscillations (MJOs) is studied with satellite data, mooring observations, and reanalysis products to demonstrate that oceanic intraseasonal variabilities are a direct response to the atmospheric intraseasonal forcing. They propagate eastward to the Sumatran coast and southward along the coast to the southeastern Indian Ocean (SEIO) and the maritime continent, as coastal Kelvin waves. MJOs contribute to about 20% of the intraseasonal variabilities in the SEIO and the maritime continent. In addition, MJOs reduce the annual mean Indonesian Throughflow (ITF) and the associated westward temperature advection. However, MJOs only have slight influences on the peak ITF in boreal summer. The importance of INSTANT data is obvious not only for understanding of ITF but also for improving ocean reanalysis and should eventually lead to improved predictive understanding of phenomena such as MJOs.

1. Introduction

As the major intraseasonal oscillations in the ocean–atmosphere coupled system, Madden–Julian Oscillations (MJOs) have a significant impact on the oceanic variabilities in the tropical Indian Ocean, the maritime continent, and the western Pacific Ocean during their eastward propagation. There have been some previous studies on the MJO influence on the open ocean. For example, in the tropical Pacific Ocean, intraseasonal equatorial Kelvin waves and sea surface temperature (SST) anomalies are attributable to MJO forcing as reported with the TOGA-CORE observations (Kessler et al., 1995;

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Woolnough et al., 2000). In the tropical Indian Ocean, the oceanic intraseasonal variabilities (ISVs) are enhanced due to internal oceanic instabilities and in response to intraseasonal atmospheric forcing (Waliser et al., 2003; Reppin et al., 1999; Sengupta et al., 2001). Schiller and Godfrey (2003) simulated MJO impacts on the oceanic ISVs with an OGCM to conclude that both air–sea heat flux and horizontal advection are important to the mixed layer heat budget in the tropical Indian Ocean. They also highlighted the formation of the barrier layer in the tropical Indian Ocean, mainly due to the heavy precipitation associated with MJOs. Waliser et al. (2003) studied the oceanic response to carefully constructed composite MJOs in the eastern Indian Ocean and the western Pacific Ocean with a layered OGCM. They also emphasized the important role of local heat flux and horizontal advection, especially the meridional advection, in determining SSTs in the eastern tropical Indian Ocean and the western Pacific Ocean. Moreover, they showed that MJOs can lead to low-frequency variations in the Indo-Pacific SSTs. Recently, the MISMO filed experiments (Yoneyama et al., 2008) were conducted to monitor ocean–atmosphere interactions during MJOs. They reported notable oceanic variations in the central Indian Ocean (80.5°E at the equator) associated with the surface winds and precipitation during the observed MJO events, although the physical mechanism for the relations between the oceanic variations and the MJO forcing are still under exploration.

However, in the eastern Indian Ocean off the Sumatran coast and the maritime continent, there are few studies on the oceanic responses to MJO forcing. Actually, the oceanic ISVs in this region are quite energetic. Feng and Wijffels (2002) analyzed satellite altimeter data and attributed the enhanced oceanic ISVs during the second half of the year (boreal summer) to baroclinic instability, which draws most of its energy from the available potential energy associated with the Indonesian Throughflow (ITF). Yu and Potemra (2006) concluded that barotropic and baroclinic instabilities contribute almost equally to the genesis of the oceanic ISVs in the Indo-Australian basin, by analyzing a numerical ocean model. They found that baroclinic instability was sensitive to the warmer and fresher ITF and barotropic instability was attributable to the strong zonal shear between the Eastern Gyral Current and the South Equatorial Current, which is strengthened by the ITF. In addition to the strong dependence on the ITF (Potemra et al., 2002), the oceanic ISVs in the southeastern Indian Ocean (SEIO) also respond to the intraseasonal atmospheric forcing (Sprintall et al., 2000; Iskandar et al., 2006), which is the focus of this study. With satellite data, mooring observations, and reanalysis products, we intend to quantify the contribution of MJO influence to the oceanic ISVs in the eastern Indian Ocean and the maritime continent.

Since the SEIO is the entrance for the ITF to the Indian Ocean, the variations in the SEIO are likely to influence the strength of ITF. There have been many estimations of the mass and heat fluxes by the ITF, based on various observational projects which were conducted at different times (e.g., Godfrey, 1996; Hautala et al., 2001; Meyers et al., 1995; Susanto and Gordon, 2005; Vranes et al., 2002; Gordon, 2001). The range of the ITF flux is not the focus of this study. But it is evident that the ITF flux varies over a wide range, due to both internal (e.g., tides, internal waves, and the diapycnal mixing; Ffield and Gordon, 1992; Hatayama et al., 1996; Hautala et al., 1996) and external processes (such as surface winds and heat fluxes, ENSO, and Indian Ocean Zonal/Dipole mode; Masumoto, 2002; Meyers, 1996; Murtugudde et al., 1998; Wijffels and Meyers, 2004). If MJOs have detectable influence on the SEIO, it is reasonable to assume that they can also have an influence on the variation of ITF. In fact, Waliser et al. (2003) showed that a large part of the ITF variability was attributable to the constructed composite MJOs in a numerical model.

Therefore, the purpose of this study is to present the MJO influence on the oceanic ISVs in the eastern Indian Ocean, the maritime continent, as well as the relation between MJOs and ITF. In Section 2, data and reanalysis products are introduced. The oceanic response to MJOs is discussed in Section 3 and the MJO influence on the ITF is explored in Section 4. The conclusions and discussion are presented in Section 5.

2. Data

The MJO events are defined with an MJO index, which was created by Wheeler and Hendon (2004) with the daily outgoing longwave radiation (OLR) from NOAA polar-orbiting series of satellites (Liebmann and Smith, 1996) and zonal winds at 850 hPa and 200 hPa from daily NCEP reanalysis