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Madden–Julian Oscillation Enhances Phytoplankton Biomass in the Maritime Continent

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In addition to monsoon-driven rainfall, the Maritime Continent (MC) is subject to heavy precipitation caused by the Madden–Julian Oscillation (MJO), a tropical convection-coupled circulation that propagates eastward from the Indian to the Pacific Ocean. This study shows that riverine runoff from MJO-driven rainfall in the western MC significantly enhances phytoplankton biomass not only in the coastal regions but as far as the nutrient-poor Banda Sea, located 1,000 km downstream of the riverine source. We present observational estimates of the chlorophyll-a concentration in the Banda Sea increasing by 20% over the winter average within an MJO life cycle. The enhancement of phytoplankton in the central Banda Sea is attributed to two coinciding MJO-triggered mechanisms: enhanced sediment loading and eastward advection of waters with high sediment and chlorophyll concentrations. Our results highlight an unexpected effect of MJO-driven rainfall on the downstream oceanic region. This finding has significant implications for the marine food chain and biogeochemical processes in the MC, given the increasing deforestation rate and projections that global warming will intensify both the frequency and strength of MJO-driven rainfall in the MC.

Surrounded by a warm ocean, the Maritime Continent (MC) is a "wet tropical" region characterized by high precipitation and runoff. A quarter of the total annual sediment exported from land to the global ocean comes from the MC[1,2]; this discharge leads to large nutrient flux and enables high productivity in MC coastal and shelf regions (Fig. 1). Terrestrial nutrients, however, are mostly consumed in the shelf waters before reaching the larger area of the open ocean[3]. In deep MC waters such as the Banda Sea, biological processes are linked to changes in the physical environment associated with climate factors. The surface chlorophyll-a (Chl) concentration in the Banda Sea exhibits strong seasonality in response to monsoon climate forcing[4,5]. Wind-induced vertical mixing and upwelling raise the productivity of this region during the southeast monsoon in the boreal summer. During the northwest monsoon in the boreal winter, however, the Banda Sea becomes oligotrophic because the wind induces downwelling and suppresses the entrainment of nutrients from deep water. By contrast, shallow seas such as the Karimata Strait, Java Sea, and Aru Sea are constantly enriched with nutrients.

One of the most prominent meteorological phenomena in the tropics is the eastward-propagating Madden–Julian Oscillation (MJO)[6,7], a subseasonal coupled convection–circulation system with a 30–60-day cycle. Similar to monsoonal forcing, the MJO is characterized by reversals in surface wind direction and distinct wet/dry phases and causes significant fluctuations in surface heat flux, precipitation, and momentum. The precipitation and momentum fluctuations lead to an increase in rainfall, wind-induced surface currents, local entrainment, and ocean surface dynamics during the convection-active phase[8–15]. To date, only a few studies have investigated the effect of the MJO on ocean biology; those few have found that local wind-mixing nutrient entrainment is enhanced in the oceans surrounding the MC[16–20]. However, the biological response to the MJO in island-enclosed waters in the MC has not been investigated. The MC has a relatively complex topography and orography, which complicates interaction of the MJO with the MC[21]. Herein, we report how a distinct process—namely, MJO-driven precipitation and oceanic advection—can greatly affect the Chl concentration in the Banda Sea. This analysis focuses on four extremely strong and long-lasting MJO events during northwest monsoons (December–February) from 2002 to 2010. The MJO phase diagram in Fig. 2 shows that in each of these four events, the

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