Effect of the 1997/98 El Niño on Chlorophyll *a* Variability Along the Southern Coasts of Java and Sumatra

BY R. DWI SUSANTO AND JOHN MARRA

The 1997/1998 El Niño Southern Oscillation (ENSO) was detected through observation of satellite-derived ocean color data (expressed as chlorophyll *a*) in the Indonesian seas. In addition to ENSO, other forcings may influence chlorophyll *a* concentrations in the Indonesian seas, such as tides (Ffield and Gordon, 1996; Susanto et al., 2000), the Madden-Julian Oscillation (MJO) (Madden and Julian, 1994), Kelvin and Rossby waves (Arief and Murray, 1996; Sprintall et al., 2000), monsoons (Asanuma et al., 2003; Moore et al., 2003; Susanto et al., submitted), and the Indian Ocean Dipole (IOD) (Saji et al., 1999; Webster et al., 1999). Because of its longitudinal extent (90° to 141°E), the Indonesian seas contain a significant part of the tropical ocean productivity. The majority of the ocean's productivity occurs within the tropics along the equatorial band of 10°N to 10°S (Longhurst, 1993). The Indonesian seas are also a center of biological diversity (Veron, 1995). They are one of the regions in the world that exhibits high variability in ocean color (Yoder and Kennelly, 2003). And, the Indonesian seas are the sites of important fisheries, such as off the Halmahera coast (western Pacific warm pool region; Lehodey et al., 1997) and in the upwelling region in the eastern tropical Indian Ocean along the southern coasts of Java and Sumatra.

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UPWELLING REGION ALONG THE SOUTHERN COASTS OF JAVA AND SUMATRA

During the southeast monsoon (April to October), southeasterly wind from Australia generates upwelling, bringing cooler waters and increased nutrients to the surface along the southern coasts of Java and Sumatra. Conditions are reversed during the northwest monsoon (October to April). Coastally trapped Kelvin waves, generated along the equatorial Indian Ocean during the monsoon transitions (April and October), also affect upwelling and downwelling processes (Arief and Murray, 1996; Clarke and Liu, 1993; Sprintall et al., 2000). Understanding spatial and temporal variability of upwelling and satellite-derived chlorophyll *a* data in this region is important for coastal fisheries. Susanto et al. (2001a,b) concluded that the southern coasts of Java and Sumatra exhibit the largest sea-surface-temperature variability and sea-surface-height anomaly, and the strongest winds, all of which are associated with monsoons and ENSO. These sea-surface characteristics indicate that the upwelling center south of Java and Sumatra extended northwestward along the western Sumatra coast and persisted through the El Niño of November 1997. Chlorophyll *a* and, perhaps, fish catch in this region also respond to ENSO, as modulated by the monsoons.

We have investigated the spatial and temporal variability of chlorophyll *a* along the south coasts of Java and Sumatra from September 1997 to December 2003 using data derived from the Sea-viewing Wide-field-of-view Sensor (SeaWiFS) onboard the *Seastar* satellite (Patt et al., 2003). During the southeast monsoon, chlorophyll *a* concentration along the coasts of Java and Sumatra is higher than during the northwest monsoon (Figure 1). In the southeastern part of Java and Bali, high chlorophyll *a* concentration spreads out over more

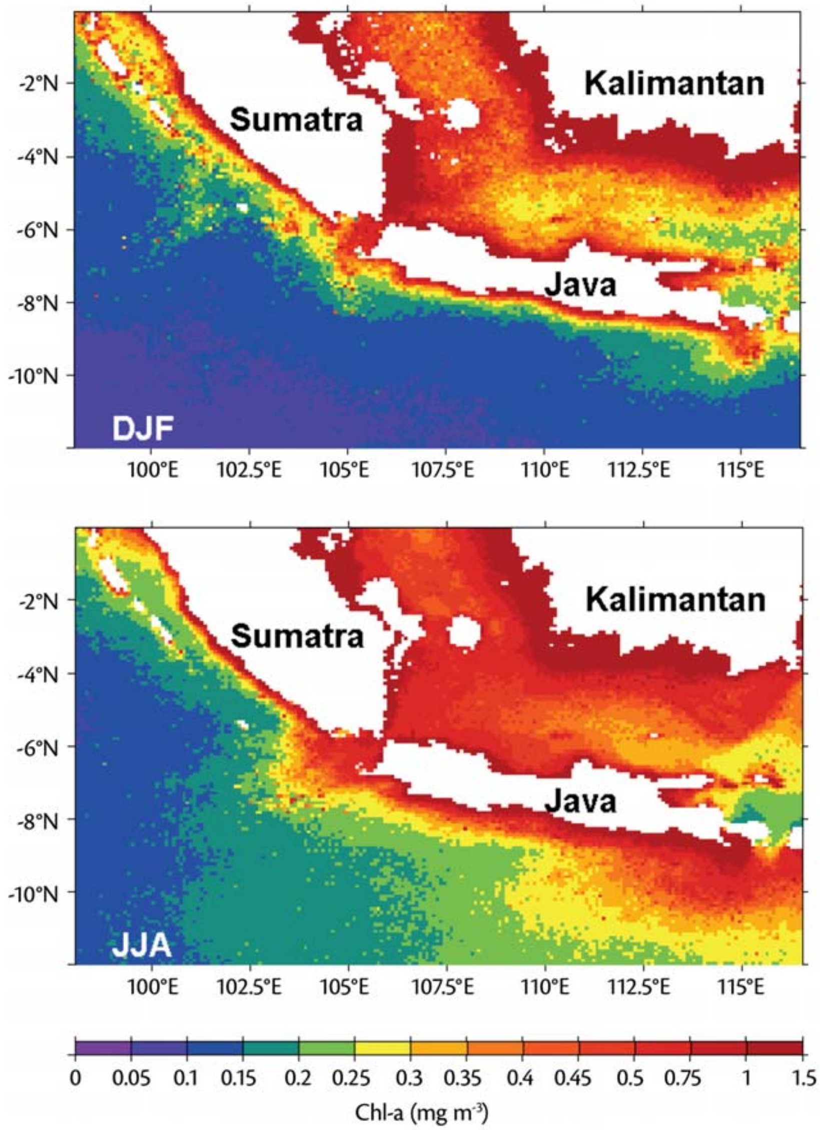

Figure 1. (a) Average chlorophyll *a* concentration derived from *SeaWiFS* from January 1998 to December 2003 during the northwest monsoon (December–February, or DJF). (b) Average chlorophyll *a* concentration during the southeast monsoon (June–August, or JJA). Southeasterly winds from Australia induce upwelling, bringing cooler and higher-nutrient waters to the surface along the south coasts of Java and Sumatra. Hence, chlorophyll *a* concentrations are higher in comparison to those during the northwest monsoon.

than 2° latitude (approximately 220 km) from the coast. Susanto et al. (submitted) concluded that ocean-color variability in the Indonesian region is affected by the monsoons and interannual forcing associated with ENSO and the IOD, particularly in the upwelling region along the coasts of Java and Sumatra, and the Banda Sea. Specifically, the 1997/1998 El Niño/La Niña events coincided with the IOD, producing significant departures from the six-year monthly mean chlorophyll *a* in both magnitude and timing of the seasonal response to the southeast monsoon. During the El Niño, ocean color intensifies in the upwelling region along the southern coasts of Java and Sumatra. The area of increased ocean color extends westward, prolonging the southeast monsoon period.

To understand the temporal variability of chlorophyll *a* along these coasts, we calculated average chlorophyll *a* values from the coast to 200 km offshore (Figure 2). Higher chlorophyll *a* concentration corresponds very well with monsoon-generated upwelling during the southeast monsoon cycle. During the southeast monsoon in a normal year, high chlorophyll *a* extends only to the southern tip of Sumatra. Interannual variability can be clearly seen in Figure 2, as indicated by Niño3.4 and Indian Ocean Dipole indices.

During the peak of the 1997/1998 El Niño, anomalous easterly winds induced strong upwelling, brought cooler water, and lifted the thermocline to depths much shallower than the climatological mean along the coasts of Java and Sumatra (Susanto et al., 2001a,b). This event produced higher chlorophyll *a* concentrations that extended further northwestward along the Sumatra coast (Figure 2).

The average chlorophyll *a* anomaly during the peak of the 1997/98 El Niño (October–December 1997) is shown in Figure 3. Monthly anomalies were computed as departures from the 1998–2003 mean for that month. A higher chlorophyll *a* anomaly was observed in the southeastern part of the region than that further west. Temporal variability of the chlorophyll *a* concentration in the Sunda and Bali Straits are shown in Fig-

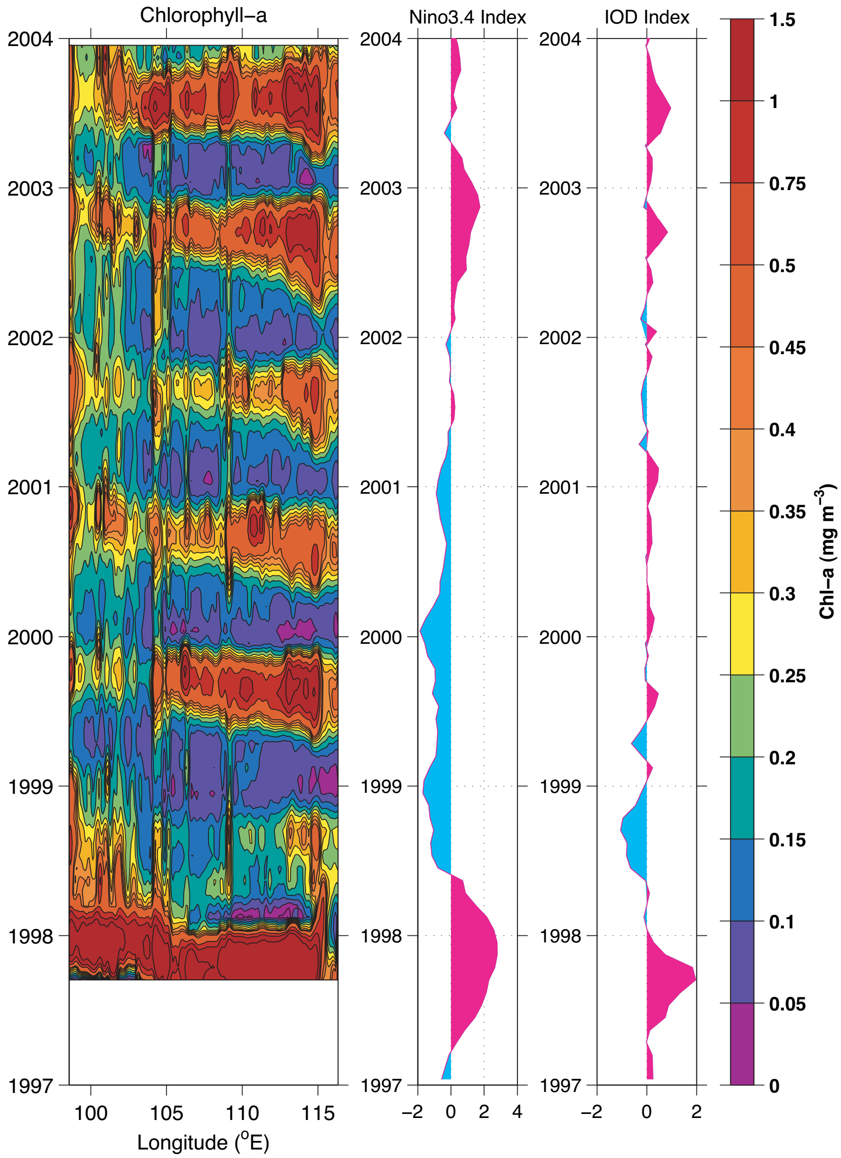

Figure 2. Temporal variability of chlorophyll *a* concentration along the southern coasts of Java and Sumatra (refer to Figure 1 to correlate longitude with the location of these two islands). Higher chlorophyll *a* concentrations are matched very well with the upwelling during the southeast monsoon cycle. Interannual variability associated with the 1997/1998 El Niño, which coincided with Indian Ocean Dipole, produced higher chlorophyll *a* concentrations that extended further north-westward along the Sumatra coast. Note that the increase in ocean color between 2000 and 2003 may signal an increase in the monsoonal winds (Goes et al., 2005). The Niño3.4 index defines an average sea-surface-temperature anomaly within the region 120°W–170°W and 5°N–5°S. The Indian Ocean Dipole index is defined as the difference in sea-surface-temperature anomaly between the tropical western Indian Ocean (50°E–70°E, 10°S–10°N) and the tropical southeastern Indian Ocean (90°E–110°E, 10°S–Equator) (Saji et al., 1999).

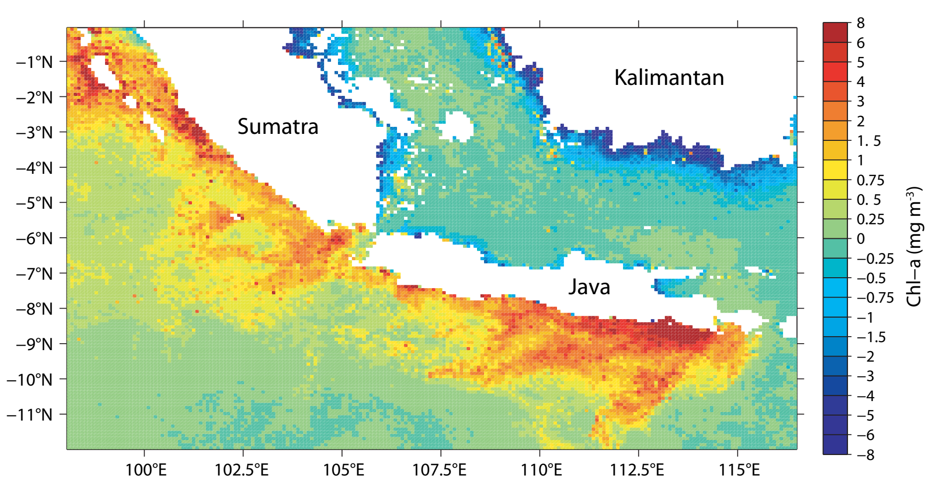

Figure 3. Satellite-derived chlorophyll *a* anomaly during the peak of the 1997/98 El Niño from October to December 1997. Monthly anomalies were computed as departures from the 1998-2003 mean for that month. Anomalous easterly winds during the 1997/98 El Niño coincided with Indian Ocean Dipole (IOD), which generated anomalous upwelling and produced a significant departure of chlorophyll *a* concentrations along the southern coasts of Java and Sumatra.

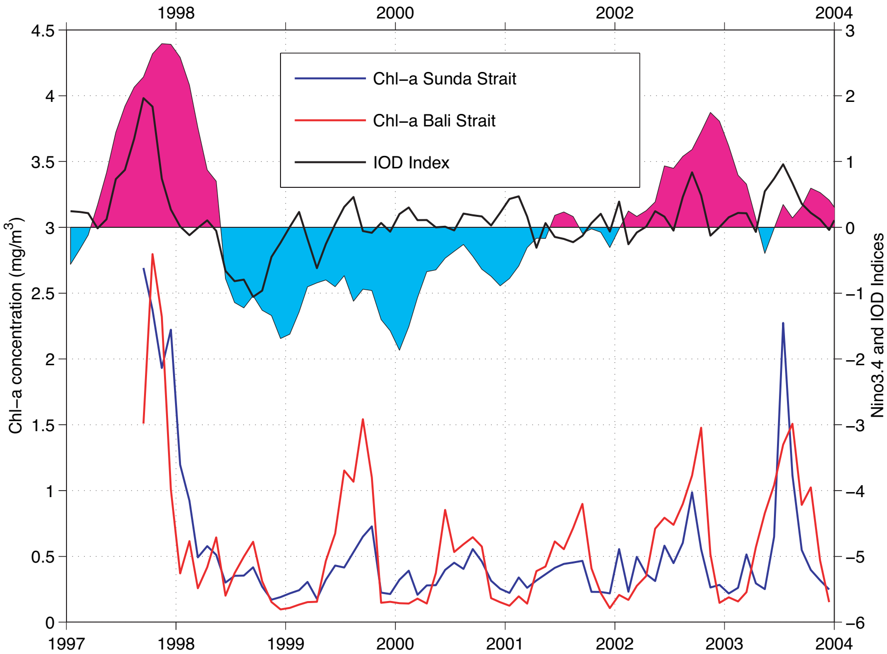

Figure 4. Temporal variability of *SeaWiFS*-derived chlorophyll *a* in the Sunda Strait (blue) and Bali Strait (red), overlain with interannual indices, Niño3.4 index (shaded in magenta and cyan) and Indian Ocean Dipole index (black). The seasonal variability associated with monsoon and interannual variability associated with 1997/1998 El Niño and Indian Ocean Dipole as indicated by the Niño3.4 and IOD indices are clearly seen.

ure 4. Again, clearly seen is the seasonal variability associated with monsoon and interannual variability associated with 1997/1998 El Niño and Indian Ocean Dipole as indicated by the Niño3.4 and IOD indices. The impact of the ENSO cycle on pelagic fish remains to be determined. Catches of small pelagics (e.g., anchovy, sardine) likely follow the temporal variability in chlorophyll *a*.

In summary, the strong 1997/1998 El Niño followed by a La Niña period, which also coincided with an Indian Ocean Dipole event, was associated with higher chlorophyll *a* values in the upwelling region along the southern coasts of Java and Sumatra. Higher chlorophyll *a* values were observed during the southeast monsoon cycle (April–October) than during the northwest monsoon cycle.

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