In a recent article, Hastenrath (2002) raised a concern about the use of the term “dipole” to describe climate variabilities in the Atlantic and tropical Indian Oceans. Here we affirm the terminology of the “Indian Ocean Dipole (IOD)” we coined to describe the ocean–atmosphere coupled mode in the tropical Indian Ocean by demonstrating its physical existence.

DETECTION OF THE IOD.

Inspired by the anomalous summer conditions in Asia during 1994 (e.g., Behera et al. 1999; Vinayachandran et al. 1999), Saji et al. (1999) discovered the existence of an east–west sea surface temperature (SST) anomaly dipole in the tropical Indian Ocean. They showed that this dipole is coupled to the zonal wind anomalies in the central Indian Ocean, suggesting the Bjerknes-type of air–sea interaction as in the tropical Pacific. After introducing the Dipole Mode Index (DMI), based on the east–west difference in the SST anomalies, they identified six major positive IOD events during the period of 1958–99. The composite pictures of those six events (1961, 1967, 1972, 1982, 1994, and 1997) demonstrated that the air–sea coupled IOD phenomenon evolves during boreal spring, matures in fall, and decays in winter (cf. Figs. 2 and 3 in Saji et al. 1999).

IOD’S APPEARANCE IN THE STATISTICAL ANALYSES. Despite the remarkable presence of IOD events, the dipole pattern appears as the second dominant mode in the SST anomalies in conventional statistical analysis such as the empirical orthogonal function (EOF) method. It is rare for climate dynamists to discuss the second mode of variability. This is why some had difficulties in understanding the new concept of the IOD. The dominant EOF mode is a basinwide SST monopole that has a high correlation (~0.85) with the Niño-3 (5°N–5°S, 90°–150°W) index when the latter leads the former by 4 months. Thus, the dominant Indian Ocean SST variability is caused by the external forcing related to the El Niño–Southern Oscillation (ENSO). The wavelet spectra of the SST anomalies in the raw data of the eastern (10°S–0°, 90°–110°E) and western (10°S–10°N, 50°–70°E) poles show apparently uncorrelated behavior (Fig. 2, upper panels) because of the masking effect of the dominant EOF mode (Behera et al. 2003). However, we recover a remarkable seesaw during IOD events in the SST variability of the two poles after removing the external ENSO effect (Fig. 2, lower panels; Fig. 3). Another way to capture the dipole behavior is to calculate the zonal difference of SST anomalies as in Saji et al. (1999). This important aspect of the tropical Indian Ocean variability as discovered by Saji et al. (1999) was missed unfortunately in earlier studies (e.g., Hastenrath et al. 1993). In contrast, other major oscillatory modes such as the Southern Oscillation and the North Atlantic Oscillation appear as the first dominant mode; the statistical dominance allows a negative correlation between the poles for those two modes even in the raw data.
FIG. 1. (a) Normalized indices of IOD, based on the anomalies of SST (SSTDMI), zonal wind (UDMI), OLR (OLRDMI), and sea level pressure (SLPDMI). Niño-3 index from the eastern Pacific is shown for reference. SSTDMI is a difference between the western (10°S–10°N, 50°–70°E) and eastern (10°S–equator, 90°–120°E) Indian Ocean. Similarly, SLPDMI is a difference between (13°–9°S, 96°–100°E) and (9°–5°S, 52°–56°E) and OLRDMI is a difference between (5°S–5°N, 70°–80°E) and (10°S–equator, 90°–100°E). The UDMI is obtained by taking an area-average in the central equatorial region (5°S–5°N, 70°–90°E). (b) The index for sea surface height and sea level anomalies from the eastern (EI) and western (WI) boxes of the tropical Indian Ocean. The domains for these boxes are the same as in the SSTDMI.

IOD’S RELATION WITH ENSO. The IOD evolution is locked to seasons. Thus, it is important to introduce the seasonal stratification in the statistical analysis (Nicholls and Drosdowsky 2000; Allan et al. 2001; Saji and Yamagata 2003a). During the peak season (September–November) of the IOD, the first two dominant EOF modes (for the Indian Ocean north of 15°S) show the east–west dipole patterns (figure not shown). Interestingly, the first EOF mode has a stronger correlation (~0.65) with the IOD as compared to its correlation with the Niño-3 (~0.58). The latter correlation corresponds to a similar correlation (~0.54) between DMI and Niño-3 during this season; one is apt to conclude that IOD events occur as a part of

FIG. 2. Wavelet power spectrum (using the Morlet wavelet) of the SST anomalies (derived from GISST) in (left) eastern and (right) western poles of the IOD. Upper two panels show the spectrum for the whole data and lower two panels show the spectrum when the ENSO effect is removed from the data through a 4-month lagged regression of the Niño-3 index. Shaded is the wavelet power at each period normalized by the global wavelet spectrum. The thick black contour is the 95% significance level.
Table 1. Years of IOD events. The asterisk denotes pure events, i.e., no El Niño (La Niña) during a positive (negative) IOD event.

<table>
<thead>
<tr>
<th>Years of positive IOD</th>
<th>Years of negative IOD</th>
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<tr>
<td>1961*</td>
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<td>1963</td>
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ENSO events because of this high correlation (Allan et al. 2001; Baquero-Bernal et al. 2002). Rather, we claim that it reflects only the fact that one-third of the positive IOD events co-occur with El Niño events. The nonorthogonality of two time series does not necessarily mean that the two phenomena are always connected in a physical space.

We note that the second EOF mode, which is also a dipole, has a significant correlation with DMI (~0.69) but has an insignificant correlation with the Niño-3 (~0.28). This difference in statistical correlation confirms the visual examination of the principal component that shows that the second EOF mode is related to independent occurrences of IOD in certain years such as 1961, 1967, and 1994 (figure not shown).

To investigate such a complex relation, Yamagata et al. (2002) have analyzed the Walker circulation that may connect the Indian Ocean with the Pacific through the atmospheric bridge. As 30% of the IOD events co-occur with ENSO events, a simple correlation analysis is misleading. Therefore, they used appropriate statistical tools like the composite technique and the partial correlation method to extract the distinct nature of the IOD. A positive (negative) IOD event is identified as a pure event when it is not accompanied simultaneously by an El Niño (La Niña) (see Table 1). The presence of the anomalous Walker cell operating only in the Indian Ocean is clearly seen in the pure IOD composite (Fig. 4), thereby confirming the independent occurrence of the pure IOD. To avoid misunderstanding, we repeat that this linear analysis does not exclude completely the possibility that some IODs might be linked with some ENSO events.

The societal benefit of the IOD concept can be appreciated by analyzing its impact on the global climate system. Several recent studies (Ashok et al. 2001; Li and Mu 2001; Behera and Yamagata 2003; Saji and Yamagata 2003b; Guan et al. 2003; Lareef et al. 2003) have shown IOD influences on many parts of the globe such as East Asia, India, Sri Lanka, Australia, and East Africa. Important to note here is that the IOD is also associated with the meridional Hadley circulation changes in the troposphere and influences the monsoon rainfall over India and East Asia (Behera et al. 1999; Ashok et al. 2001; Guan et al. 2003). The unusual hot and dry summer over East Asia including Japan is recently found to be related to the enhanced convective activity over the Indian subcontinent in response to IOD (Guan and Yamagata 2003). Describing this coupled phenomenon as the zonal mode seems to be misleading in this sense.

We believe that the IOD research has raised a new question, and new possibilities for regarding the old
problems and making real advances in the predictability of climate variations originating from the Tropics.

ACKNOWLEDGMENTS. Discussions with H. Hendon, J. McCreary, G. Meyers, H. Nakamura, A. Navarra, G. Philander, H. von Storch, and B. Wang were very helpful in developing the concept of IOD.

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