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Intraseasonal Oscillation in the Tropical Indian Ocean

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ABSTRACT

The features of the intraseasonal oscillation (ISO) of the tropical Indian Ocean are studied using several sources of observational data. It is shown that there are intraseasonal oscillations in the tropical Indian Ocean, but their periods vary with latitude: the major period is about 20–30 days in the equatorial region, about 30–50 days at 10°N/10°S latitude and 60–90 days at 20°N/20°S latitude. The intensity of the ISO increases with latitude but the speed of the westward propagation of the ISO decreases with latitude. The intensity and propagation speed of the ISO have clear interannual variation features. The atmospheric intraseasonal oscillation over the tropical Indian Ocean is also analyzed and compared with the oceanic intraseasonal oscillation. It is shown that the major period is in the range 30–60 days and the intensity and period of the atmospheric ISO decrease with latitude slightly. The zonal propagation of the atmospheric ISO also has some differences with the oceanic ISO. It is necessary to study the relationship between the atmospheric ISO and oceanic ISO in the tropical Indian Ocean deeply.

Key words: intraseasonal oscillation, tyopical Indian ocean, atmospheric ISO, oceanic ISO

1. Introduction

The intraseasonal oscillation (ISO or Madden-Julian Oscillation, MJO) in the tropical atmosphere has been studied extensively, including its existence, structure, evolution and propagation (Madden and Julian, 1971; Murakami, et al., 1984; Lau and Lau, 1986; Knuston and Weickmann, 1987; Li, 1991; Madden and Julian, 1994; Li, 2004). In recent years, the impacts of the tropical ISO on the monsoon activity and the occurrence of El Niño events were also investigated (Lau and Chan, 1988; Kindle and Phoebus, 1995; Lau and Yang, 1996; Li and Li, 1997; Li et al., 2001; Long and Li, 2002). These studies and results demonstrate the importance of the atmospheric ISO in the climate system.

The intraseasonal oscillation in the tropical ocean has also been revealed in some studies, but most of these are theoretical analyses or numerical simulations (Hirst and Lau, 1990; Li and Liao, 1996; Wang and Xie, 1998; Li and Yu, 2001), where the observational analysis is inadequate, particularly in the Indian Ocean (Sengupta et al., 2001; Brandt et al., 2003). It can be said that until now, the understanding on the activity and pattern of the ISO in the tropical Indian Ocean is not very good.

In this study, we would like to reveal the features and pattern of the activities of the ISO in the tropical Indian Ocean through an observational analysis, using various data sources. A simple comparison with the ISO in the atmosphere over the tropical Indian Ocean is also performed.

2. Data used in this study

In order to reveal the intraseasonal oscillation in the tropical Indian Ocean and its features, we used the following three datasets:

(1) TOPEX/Poseidon SSH (sea surface height) data. The data have a $0.25° \times 0.25°$ horizontal resolution and a 10-day temporal resolution during 22 October 1992–6 August 2001, taken in the region (30.125°S–30.125°N, 29.875°–110.125°E).

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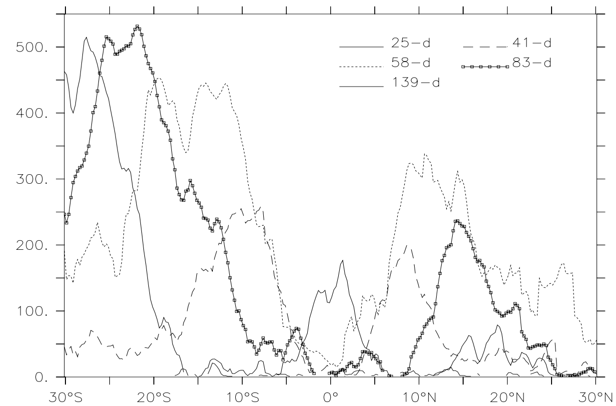

Fig. 1. The zonal averaged intensity variations of various oscillation modes with latitude for the SSH.

(2) AVHRR SST data. The data have a 1.0° × 10° horizontal resolution and a 5-day temporal resolution during 3 January 1990–12 December 2001, taken in the region (30.5°S–28.5°N, 30.5–109.5°E).

(3) Various buoy data in 1991–1992 and 1993–1996.

The National Centers for Environmental Prdiction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data are also used for comparing the atmospheric ISO with the oceanic ISO.

3. Time-space features of the ISO in the tropical Indian Ocean

The analyses based on the SSH data show that there are various oscillation phenomena with different periods in the tropical Indian Ocean. But in these oscillatory variations, the quasi-periodic oscillation with

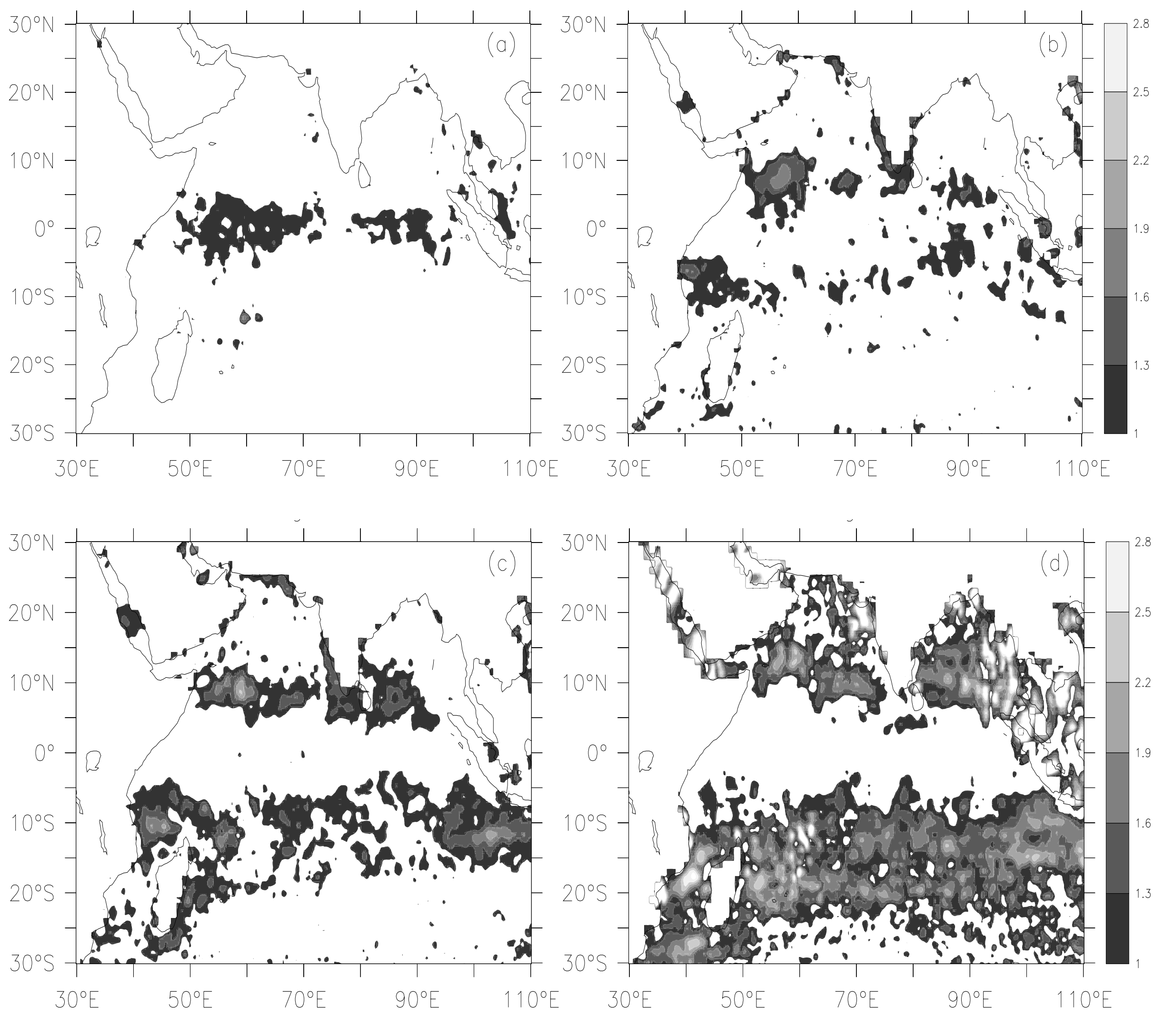

Fig. 2. Distributions of the outstanding levels of intraseasonal oscillation with different periods in the tropical Indian Ocean. (a) 25 days, (b) 35 days, (c) 41 days, and (d) 58 days.

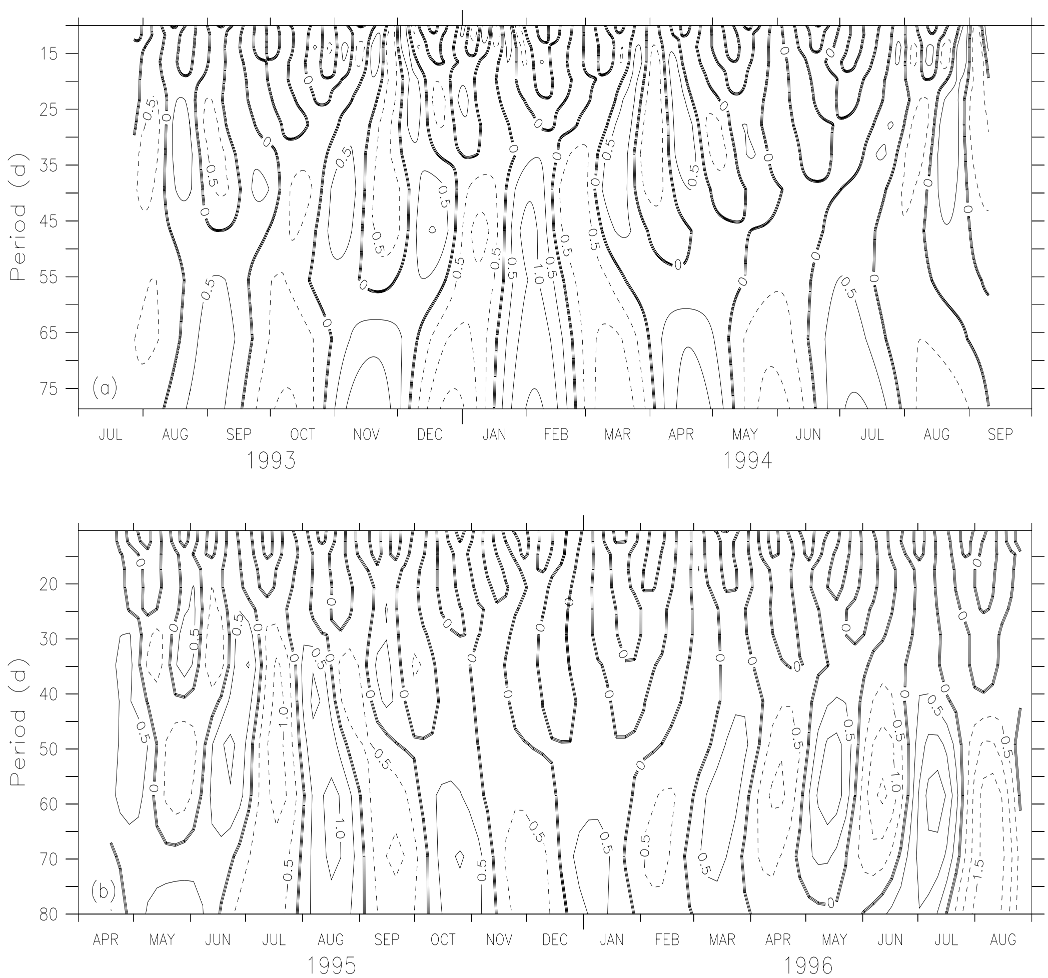

Fig. 3. Wavelet analysis results for the observed Buoy SST with the Buoy at points (a) 2.17°N, 80.5°E; and (b) 7.01°N, 50.08°E.

20–30-day period is dominant in the equatorial region, and the period of the dominant oscillation will increase as the lafitude increases. In Fig. 1, the intensity variations of various oscillations with latitude are shown. For convenience, the intensity is represented by using the relative ratio of the computed spectrums, which exceeds the 5% significance level at given a certain latitudes in the Indian Ocean. It is clear that the maximum intensity of the oscillation with a 25-day period is at the equator; that with a 41-day period is at 8°N and 8°S that with a 58-day period is at 11°N and 12°S that with an 83-day period is at 14°N and 22°S, and that with a 139-day period is at 18°N and 28°S. The figure not only shows that the period of the dominant oscillation increases as the latitude increases, but also that the intensity of the dominant oscillation increases as the latitude increases; it also shows that the intensity of the low-frequency oscillations is stronger in the Southern Hemisphere.

The distributions of the outstanding levels (significance greater than 95%) for intraseasonal oscillation with different periods in the tropical Indian Ocean are shown in Fig. 2, which are computed by using the TOPEX/Poseidon SSH data. It is shown that the period and intensity of the ISO in the tropical Indian Ocean increase as the latitude increases. And corresponding to the features of the ISO in the tropical Indian Ocean shown in Fig. 1 and the propagation shown below, it is suggested that the ISO in the tropical Indian Ocean off the equator is driven mainly by the Rossby wave, but it may be driven by both the Kelvin wave and the Rossby wave in the equatorial region.

In order to determine further the above-mentioned feature of the ISO in the tropical Indian Ocean, we used the Buoy observational SST data for another analysis. In Fig. 3, as some examples, the wavelet analysis results are shown for the Buoy SST at two Word Ocean Circulation Experiment (WOCE) observing points: ICM7-21 (2.17°N, 80.5°E) and ICM8-6 (7.01°N, 50.08°E), where ICM means Indian Ocean Current Meter. It is

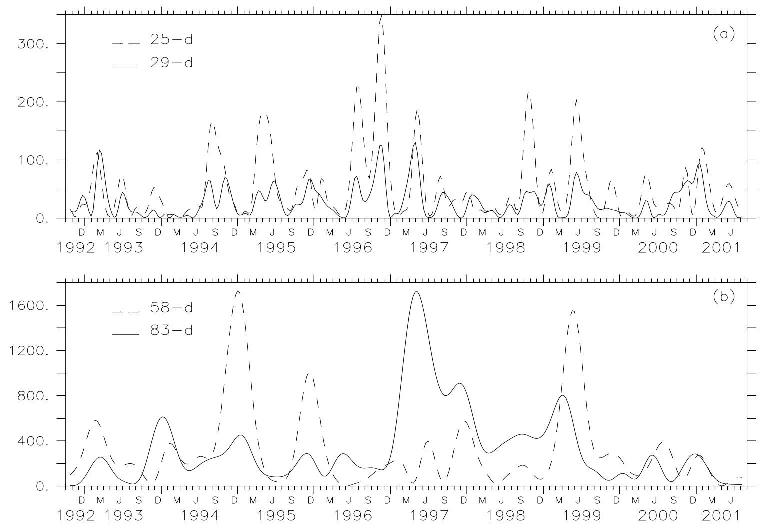

Fig. 4. Temporal variations of the ISO (the wavelet spectrums of the SSH) in (a) region (5°S–5°N, 60–90°E) for the 25- and 29-day modes, and in (b) region (10–20°S, 60–100°E) for the 58- and 83-day modes.

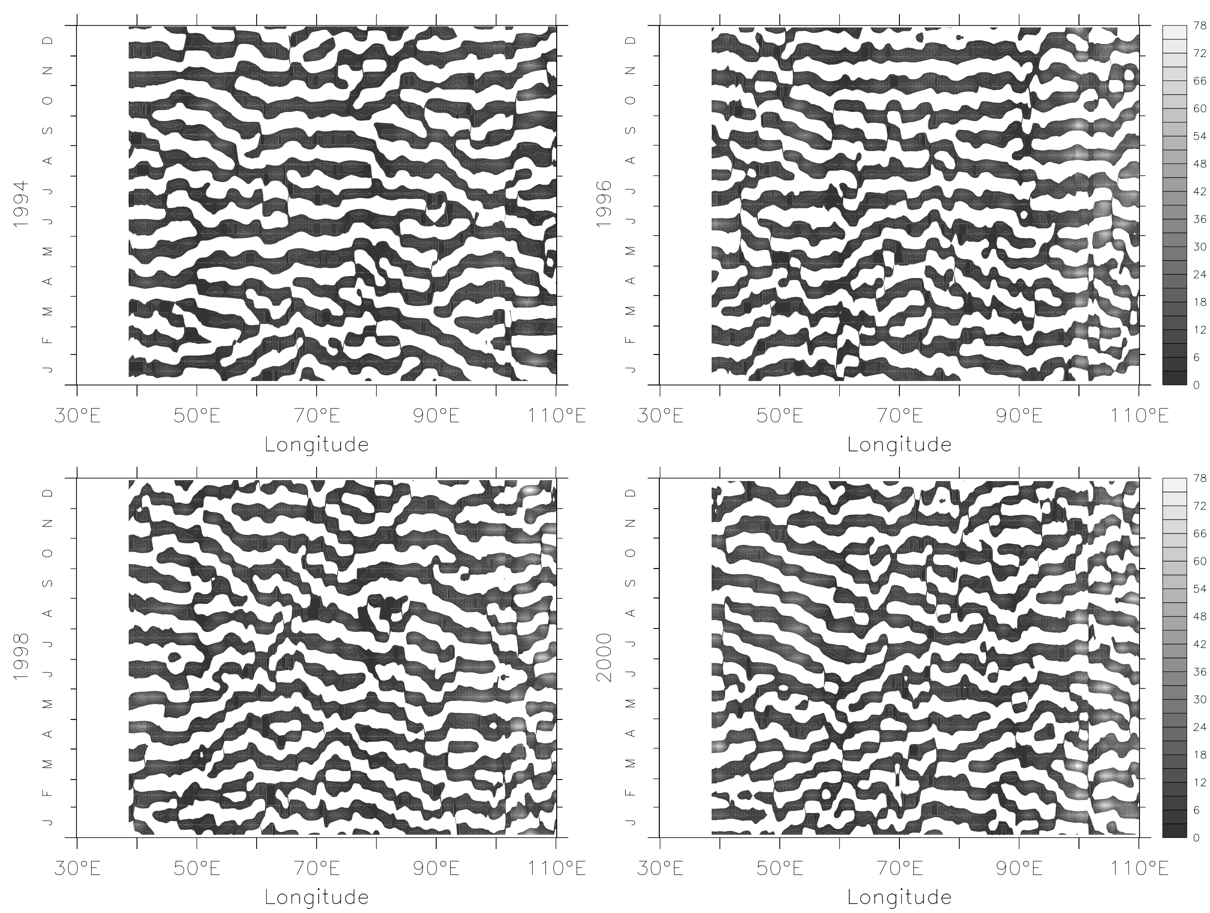

Fig. 5. The time-longitude sections of the SSH along 5°S–5°N for the 25–29-day mode in 1994, 1996, 1998 and 2000.

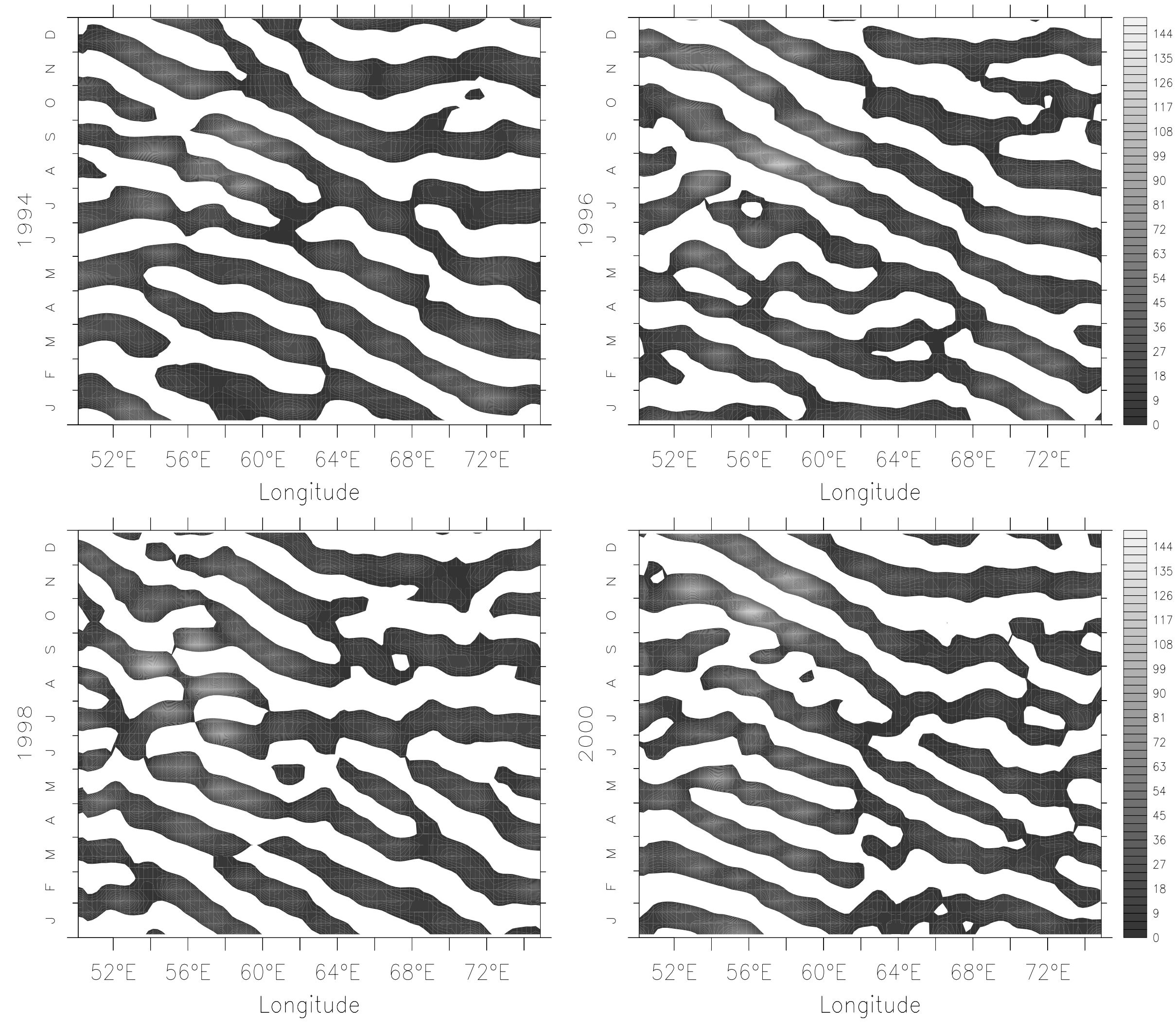

Fig. 6. The time-longitude sections of the SSH along 7°–13°N for the 35–58-day mode in 1994, 1996, 1998 and 2000.

clear that the dominant period at point ICM7-21 is about 30–40 days, and about 50–70 days at point ICM8-6. These results for the SST are similar to those of with that for the SSH variation.

Temporal variations of the wavelet spectrums of the SSH in the tropical Indian Ocean are shown in Fig. 4, in which the ordinate represents the regional mean coefficient of the wavelet spectrum and the intensity of the ISO mode. It is clear that every intraseasonal mode appears to have seasonal and interannual variations. And a quasi-biennial variation seems to be the most obvious for the ISO in the tropical Indian Ocean. The figure is only an example, for other regions and other low-frequency oscillation modes also have clear interannual variations a dominant quasi-biennial variation. In some studies, the quasi-biennial variation and westward propagation of the SST in the South Indian Ocean have been indicated (Xie et al., 2002).

4. Propagation of the ISO in the tropical Indian Ocean

The propagation of the ISO in the tropical Indian Ocean is also investigated by using the data analyses in this study. The time-longitude sections of the SSH along 5°S–5°N for the 25–29-day mode in 1994, 1996, 1998 and 2000 are given in Fig. 5. It is shown that there are eastward and westward propagations of the ISO in the equatorial Indian Ocean, and the propagation speed of the ISO is quite fast there. The time-longitude sections of the SSH along 7°–13°N for the 35–58-day mode in 1994, 1996, 1998 and 2000 are given in Fig. 6. It is shown that the westward propagation feature of the ISO in the non-equatorial latitudes is very evident; and in the Southern Hemisphere, the ISO of the tropical Indian Ocean has a similar west-

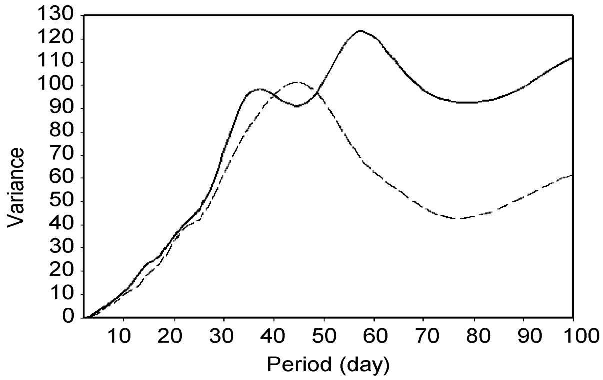

Fig. 7. The wavelet coefficients of the 850 hPa zonal wind anomalies. Solid line: mean in the region (5°S–5°N, 60°–90°E); dashed line: mean in the region (10°–20°N, 60°–90°E).

ward propagation feature to that in the Northern Hemisphere. However, the zonal propagation speed of the ISO of the tropical Indian Ocean in the Northern Hemisphere is greater than that in the Southern Hemisphere.

The data analyses show that there is a slower propagation of the ISO mode from the equator to the higher latitudes in the tropical Indian Ocean, but it is not very evident like the zonal propagation. This is a little different than the result of a hybrid atmosphere-ocean coupled model, where the northward propagation of the ISO in the Indian Ocean is more obvious (Fu et al., 2003).

5. Comparison with the ISO in the atmosphere

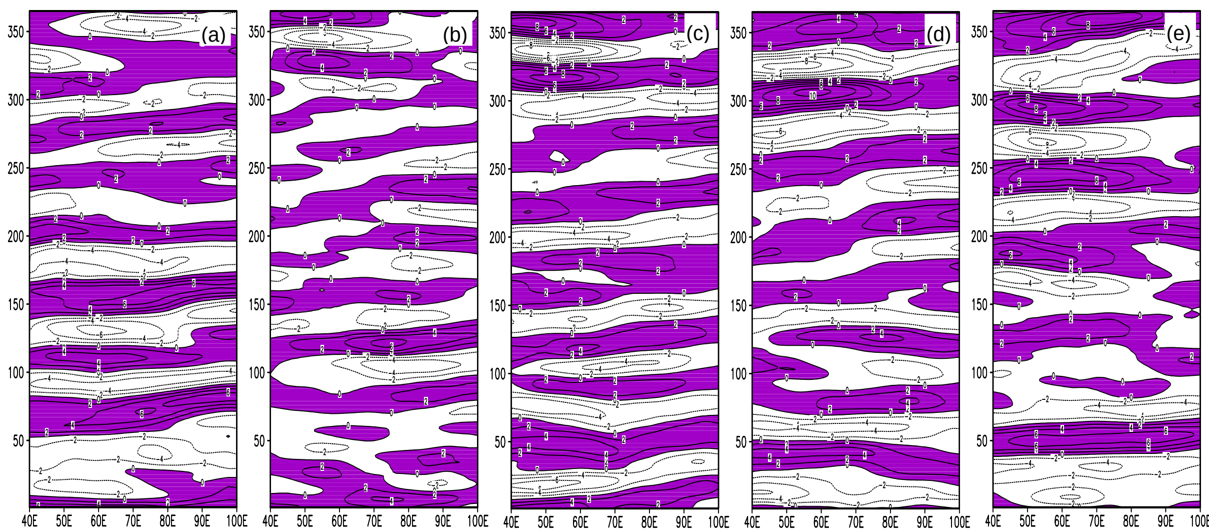

Fig. 8. The time-longitude sections of the ISO for the 200-hPa zonal wind (m s^{-1}) over the equatorial Indian Ocean (5°S–5°N) for (a) 1997, (b) 1998, (c) 1999, (d) 2000, (e) 2001.

The atmospheric ISO in the South Asian monsoon region has been discussed in many studies (Krishnamurti and Subrahmanyan, 1982; Murakami et al., 1986; Chen and Xie, 1988; Lau and Yang, 1996), but a simple discussion will be given here in order to compare the atmospheric ISO with the ISO in the tropical Indian Ocean.

The wavelet coefficients of zonal wind anomalies at 850 hPa in the region (5°S–5°N, 60°–90°E) and in the region (10°–20°N, 60°–90°E) are shown in Fig. 7, in which the wavelet spectrum coefficient is used to represent the intensity of the low frequency atmospheric mode. It can be seen that the strongest mode, with a 60-day period, is over the equatorial Indian Ocean, but there is a strong mode with a 45-day period over the tropical Indian Ocean outside the equator. And the intensity of the low-frequency atmospheric mode over the equator is stronger than the one over the tropical Indian Ocean outside the equator. Obviously, the atmospheric ISO over the tropical Indian Ocean has some differences with the ISO in the tropical Indian Ocean. Yet, in the preceding discussion, we have indicated that both the intensity and the period of the ISO in the tropical Indian Ocean increase with latitude.

The zonal propagation of the atmospheric ISO also has some different features than the oceanic ISO in the tropical Indian Ocean. There is a dominant eastward propagation of the atmospheric ISO over the equatorial region as shown in Fig. 8, in which the time-longitude sections of the filtered 200-hPa zonal wind are shown, but there are both eastward and westward propagations outside the equator.

Corresponding to the comparisons of the ISO in the tropical Indian Ocean with the atmospheric ISO over the tropical Indian Ocean, the different features between the oceanic ISO and the atmospheric ISO are clear but the reasons for the differences are not understood. It is thus necessary to study the air-sea interaction in the tropical Indian Ocean region thoroughly and deeply.

6. Conclusion and discussion

The features of the ISO of the tropical Indian Ocean are studied first by using several observational datasets. The results show that there are intraseasonal oscillations in the tropical Indian Ocean, but their period depends on the latitude: the major period is about 20–30 days at the equator, about 30–50 days at 10°N/10°S and 60–90 days at 20°N/20°S. The intensity of the ISO increases with latitude and the ISO is stronger in the Southern Hemisphere. There are both eastward and westward propagations of the ISO in the equatorial Indian Ocean, which means that the Kelvin and Rossby waves may be a common factor driving the ISO. The westward propagation speed of the ISO decreases with latitude. The intensity and propagation speed of the ISO has a clear interannual variation.

A comparison with a study on the ISO in the tropical Pacific Ocean shows that their fundamental features are similar (Sun and Liu, 1996; Liu and Wang, 1999; Hu and Liu, 2002). The Rossby waves seem to pay an important role in driving the ISO in the tropical Indian/Pacific Ocean outside the equator.

The atmospheric intraseasonal oscillation over the tropical Indian Ocean is also analyzed and compared with the oceanic ISO. It is shown that the major period is about 30–60 days and the intensity and period of the atmospheric ISO decrease with latitude slightly. The zonal propagation of the atmospheric ISO also has some differences with that of the oceanic ISO.

It is also obvious that the relationship and differences between the oceanic ISO and the atmospheric ISO, including the air-sea interaction in the tropical Indian Ocean region, needs to be studied further.

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