Mausam, (1992), **43**, 4, 395-398

551.515 : 551.501.79(267.37)

Evolution of two troughs in the tropical Indian Ocean and their characteristic features

M. S. SINGH* and B. LAKSHMANASWAMY

Meteorological Office, New Delhi

(Received 25 April 1989)

सार—उष्ण कटिबन्धीय हिन्द महासागर के जलवायु विज्ञान मानचित्रावली (भाग I और II) जोकि हस्तेनरथ और लैम्ब (1979) द्वारा तैयार की गयी, की सहायता से उष्णकटिबंधीय हिन्द महासागर में दोहरी द्रोणी विधियों के विकास और अभिलाक्षणिक विशेषताओं का अध्ययन किया गया। इस बात की पुष्टि की गई कि यहां पर दो द्रोणी (उत्तरी गोलार्ध भूमध्यवर्ती द्रोणी और दक्षिणी गोलार्ध भूमध्यवर्ती द्रोणी) इस क्षेत्र (दक्षिण एशियाई भू–संहति सहित) में साल भर रहते हैं, एक उत्तरी गोलार्द्ध और दूसरा दक्षिणी दोनों की प्रकृति प्रवासी है और कदाचित मूल उष्मीय है। दो द्रोणियों के अभिसारी क्षेत्रों में अत्याधिक मेघमयता है। अपने क्रमिक ग्रीष्म ऋतुओं के दौरान इन द्रोणी प्रणालियों के प्रवास उत्तर और पश्चिम में हिन्द महासागर के आस–पास दक्षिण एशियाई/अफ्रीकी भू संहतियों के बृहत्त उष्मन से संबंधित दिखाई पड़ते हैं।

ABSTRACT. Evolution and characteristic features of double trough systems in the tropical Indian Ocean have been studied with the help of *Climatological Atlas (Part I and II) of the Tropical Indian Ocean* (Hastenrath and Lamb 1979). It is confirmed that there are two troughs (Northern Hemisphere Equatorial Trough and Southern Hemisphere Equatorial Trough) in this region (including south Asian landmass) all the year round, one in northern hemisphere and the other in southern. Both are migratory in nature and, perhaps, thermal in origin. In the convergent zones of the two troughs, there is extensive cloudiness. The migration of these trough systems during their respective summer seasons appear to be related to the extensive heating of the south Asian/African land masses surrounding the Indian Ocean in north and west.

Key words — Thermal trough, International Indian Ocean Expedition (IIOE), NHET, SHET.

1. Introduction

Occurrence of two trough systems, one in north and the other in south tropical Indian Ocean throughout the year was noticed during the International Indian Ocean Expedition (IIOE) in 1963-64 (Raman 1965). Satellite observations have since confirmed their occurrence all the year round of which the northern one reaches the extreme position of 25°-27°N latitude over India during SW monsoon season. The development of these double troughs in this area has been alluded to the existence of a belt of westerlies along and near the equator in the Indian Ocean (Saha 1970) in between the two trade wind belts (NE'ly, SE'ly). The meeting zones of these two trades with equatorial westerlies gives rise to the two troughs. An attempt has been made in this paper to study the evolution, seasonal movement and characteristics of the double trough system from climatological stand point.

Hastenrath and Lamb (1979) have published a detailed Climatological Atlas (in two parts) of the tropical Indian Ocean for 60 years' (1911-1970) ships observations including almost 4.5 million sets of data. Part I of this atlas contains surface winds and their derivatives like convergence/divergence, vorticity and distribution of cloudiness, precipitation etc and part II, the thermal aspects. Our study draws extensively from this atlas.

2. Discussion

(*i*) *Differing characteristic of the two troughs*

In the monthly mean charts one trough (in the summer hemisphere) appears as an elongated low pressure area around which dominant trade wind turns cyclonically when crossing the equator while the other (in the winter hemisphere) is more or less a meeting zone of the two trades, generating a series of cyclonic vortices. The trough alongwhich the trades turn (to cross the equator) is nearer the equator than the one where the two trades meet. The former is well marked, while the latter is a meandering one with a series of embedded cyclonic vortices. In the transition months of April and October to November, weak turning of trades is observed.

(*ii*) *Sea surface temperature and troughs*

Description of sea surface temperature distribution is restricted to four cardinal months of January, April, July and October. It is seen that the two roughs are

*Present address : C/36, DDA Flats, Saket, New Delhi.

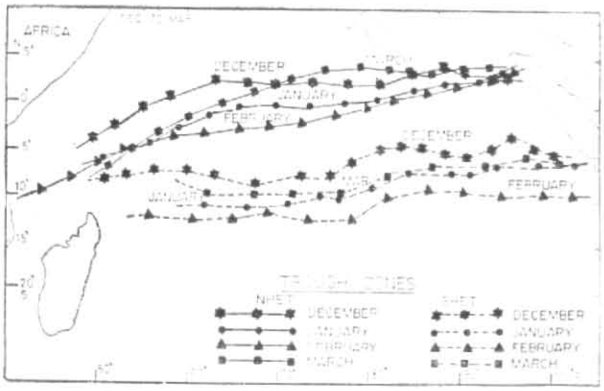


Fig. 1. Trough zones (December-March)

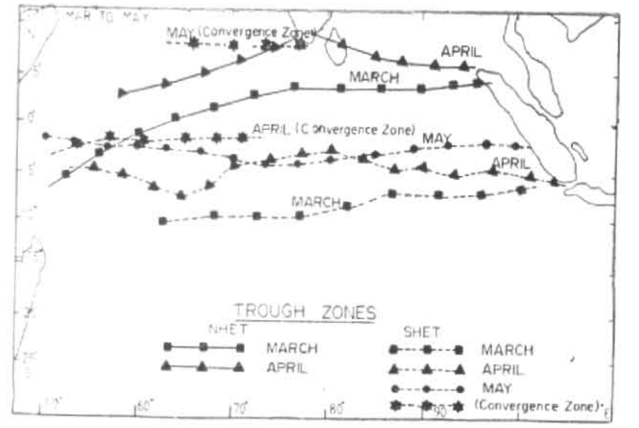


Fig. 2. Trough zones (March-May)

located in a zone of relatively warmer temperatures in the ocean, *i.e.*, 28°C in January, July and October and 29°C in April. Only in July, it extends up to 26°C isotherm in the western part of the equatorial Indian Ocean (west of 60°E). They are also located in the region where there is net oceanic heat gain, *i.e.*, where ocean is getting heated. Thus the thermal origin of these troughs seems to be a strong possibility (Raman 1965).

(iii) Divergence, relative vorticity and cloudiness

Part I of the atlas contains the distribution of convergence/divergence ($\times 10^{-6}$ sec^{-1}), relative vorticity ($\times 10^{-6}$ sec^{-1}) and cloudiness (in tenths) which includes satellite data up to 1970. The convergence/divergence distribution indicates that both troughs are associated with predominantly convergent areas. The trough in the southern Indian Ocean in January, April and October shows high degree of convergence ($\approx -5 \times 10^{-6}$ sec^{-1}). In July it is near the equator and hence the value of convergence is small. The value of convergence is low in the northern trough in April and October. The same is the case with relative vorticity. The distribution of total clouding is in conformity with this picture. Average clouding associated with the troughs in all these months (January, April, July and October) is between 5 and 7 tenths and they seem to be extensive both to the south and north of the troughs. This discrepancy may be due to the averaging process in the shifting trough zone, thus we can say that there are two troughs in the tropical Indian Ocean and adjoining areas of land (*i.e.*, monsoon trough) all the year round which are convergent and extensive clouding prevails over and along them. They are located over warm ocean (temperature 27°-29° C) which indicates that they could be thermal in origin.

In what follows now, a discussion is presented on the evolution of these two trough systems (NHET and SHET) through the year over tropical Indian Ocean. It is proposed to discuss upper air characteristics of these troughs in a separate paper.

3. (*i*) *Northern hemisphere winter (December-February)*

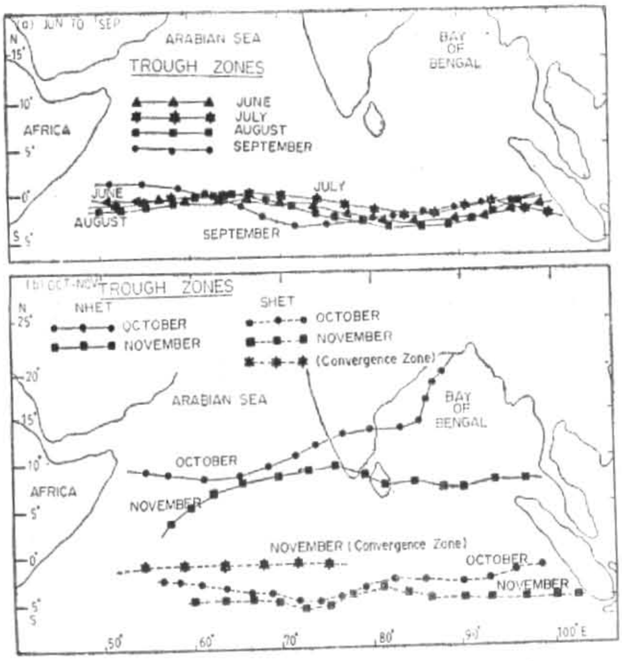
Fig. 1 gives the positions of these troughs from December to March by December the NE'ly trades dominate the surface wind flow both in the Arabian Sea and the Bay of Bengal and these trades cross the equator as NW'ly before finally meeting the SE'ly trades in the south Indian Ocean. As Fig 1 indicates, the trough around which NE'ly trades turn NW'ly in December is roughly along 2-3°N, east of 63°E. To its west, the trough sharply dips southwest reaching up to 5°S at 48°E. In the south Indian Ocean there is another trough between 5° & 10°S. Between 48°E and east African coast, the NE'lies continue up to 5°S and then only slowly turn northerly. Infact, they never turn NW'ly or westerly. Thus in December in the tropical Indian Ocean two troughs are observed one at about 2°N (east of 63°E) and the other between 5°S and 10°S latitudes.

In January and February, both the troughs shift south. In February the northern trough is south of equator to the west of 80°E but still in the northern hemisphere to the east of it. The NE'lies along the African coast too show a tendency to turn NW'ly though much to the south of the equator. The southern trough is now between 10° & 13°S, mostly along 10°S to the east of 80°E and 13°S to the west of it.

(ii) Pre-monsoon season (March-May)

Fig. 1 includes the positions of the two trough zones in March also, just for comparison. It is seen that in March both troughs have registered rapid northward movement. The trough in the north is now at about 4°N at 80°E and its shift is conspicuous in the mid Indian Ocean. The other too is now nearly at the same latitudes as in January.

Fig. 2 shows their position in March, April and May. In April there is a marked change. The south Indian Ocean trough not only shifts further north from its position in March but is also transformed into an active trough all along its length except to the east of 95°E, across which the SE'ly trades turn SW'ly. It is now located roughly along 5°S. The northern trough too undergoes noticeable changes. Firstly, it has shifted much to the north of its position in March (Fig. 2). West of 80°E across this trough N/NE'lies of Arabian Sea/NW Indian Ocean turn NW'ly and finally westerly. But to the east of 80°E it forms a trough across which SW'lies from the south turn S/SE'ly in the western half of the Bay of Bengal (west of 90°E).



Figs. 3(a&b). Trough zones : (a) Jun -Sep, and (b) Oct-Nov

Between these two troughs there is a zone of convergence where the NW/W'ly from the north meet SW/S'ly from the south. This is seen clearly in the west Indian Ocean along about 2°S.

By May, the trough in the north Indian Ocean has disappeared completely as N/NE'ly flow in the Arabian Sea is now replaced by SW/W'lies and the Bay comes under the complete sway of SW'ly monsoon flow.

The southern trough is well marked west of 90°E across which the SE'ly trades turn north to become SW/W'ly monsoon flow. It is located between 2° & 4°S, being farthest south between 70° & 80°E longitudes. As can be seen Fig. 2, it has shown no movement between these longitudes though it shifted north to the west and east of this zone. There is a zone of convergence now in the Arabian Sea at about 8° N across which NW'lies of Arabian Sea meet the monsoon westerlies from south.

(*iii*) *SW monsoon* (*June-September*)

By June the SW monsoon establishes over India the Arabian Sea and the Bay of Bengal and the prevailing winds are SW'lies and the northern trough becomes the well known monsoon trough. Hence in the Indian Ocean we have only the southern trough which is between 1° & 3°S. Fig. 3 (a) gives the position of this trough from June to September. It is seen that in these months the trough is near about equator (roughly between the equator and 3°S) with little movement except in September when it shows a little more oscillation and even crosses the equator west of 60°E. Hence, during the SW monsoon season we have only this trough in the ocean (which is truely the equatorial trough now) located at the equator or just to the south of it.

(*iv*) *Post monsoon season* (*October and November*)

By October, the SW monsoon withdraws from the north and central India and N/NE'lies establish over most parts of Arabian Sea and along the east coast north of Tamil Nadu. Hence the northern trough can be seen over the central and adjoining Bay of Bengal and the south Arabian Sea. The trough in the south Indian Ocean still persists and shifts a little south of its September position. It is now seen between 3° & 5°S.

In November the NHET shifts further south over the Bay and the Arabian Sea across which N/NE'ly trades turn to become NW/W'lies. The southern trough zone still continues along about 5°S but is of attenuated strength. In between the two trough zones, there is a zone of convergence along about 1°S but is not very well marked. In December both the troughs shift further south.

4. Equatorial westerlies and development of twin troughs

Because of the existence of two trough zones simultaneously on the two sides of the equator all the year round, it is obvious that westerlies will be the dominant flow over the equator. But as Fig. 1 indicates, from December to March, it is mostly some northerly flow (NE/N/NW'ly) which prevails over the equator. Similarly, from May to September the equator is dominated by S/SW'ly flow. It is during April, October and November that the flow over equator is westerly east of about 60°E. West of 60°E and up to the African coast it is never westerly. It is either N/NE'ly or S/SW'ly.

The intense heat low over NW India/Pakistan in pre-monsoon months extends to NW Bay by June to form a trough (known as monsoon trough) which attracts the SE'ly trades all the way to the northern limit of the Indian subcontinent. This circulation system typifies the SW monsoon flow. The monsoon trough could be observed to be the displaced equatorial trough (Rao 1976), displaced northwards due to the intense heating of the south Asia in summer. By October, as the heat zone shifts south, this trough also shifts to south Arabian Sea and the central and adjoining south Bay [Fig. 3(b)]. This shift of the northern trough southward continues throughout northern winter (December to February) under the combined effect of intense cooling of Asia and heating in the southern hemisphere, particularly south Africa. The effect of African heating, though not so profound as that of Asia, is nonetheless quite marked and significant. Looking at the configuration of these troughs in the Indian Ocean from November to February (southern summer) and also in March and April, it is noticed that these troughs show a sharp dip towards SW in the western Indian Ocean being farthest south near the African coast. In fact, the western portion of the trough is south of equator right trom December to March being as far south as 12°S latitude in February. This effect extends eastwards also as southern summer season advances. At its peak (in February) it extends even up to the east of 80°E longitude. It is apparent, therefore, that the heating of south Africa though very small in comparison to that of south Asia, causes the marked shift of the troughs to the south of equator in the western Indian Ocean. By contrast, the eastern side the trough always remains north of equator as there is no large landmass there. It may be mentioned that these troughs concide with the warmest temperature belts in the ocean.

By March when south Asia begins heating, again the vigour of NE'ly trades reduces (as the Asian anticyclone weakens) and so the trough shifts north. This shift continues through April and it reaches over land in May.

In the south Indian Ocean, with the intensification of the Mascarene High, SE'ly trades flowing out of it get attracted by heated south Asia, moves north and turns SW'ly around the southern trough which appears at about 5° south. By June the NHET appears as a full fledged monsoon trough and the SHET moves over to the equator.

Thus, it is seen that the shift of the equatorial trough north and south or appearing on both sides of equator simultaneously in the Indian Ocean is due to the heating and cooling effects of the surrounding continents. It is all the more apparent when we compare the conditions to the west of 90°E with those to the east of it. All changes are prominent in the western part but on the eastern side they are minor. For instance to the east of 90°E the trough zones are not well marked and crossing of the trades not so vigorous as in the west. In fact, to the east of 90°E where land effect is minimal, the trough zones too appear weak.

5. Conclusions

After an analysis of the climatological records of the tropical Indian Ocean (Climatological Atlas by Hastenrath and Lamb) regarding the existence of two equatorial trough zones (NHET & SHET) in this region, the following conclusions can be drawn :

(*i*) From December to March there is a trough in the northern and another in the southern tropical Indian Ocean (Fig. 1). The same is the case in October and November.

(*ii*) From June to September when SW monsoon is active over India there is only one trough in the Indian Ocean located over or just to the south of equator where the SE'ly trades turn to become SW'ly monsoon winds in the north. The trough to the north of equator is now over SE Asia known as monsoon trough.

(*iii*) These troughs are convergent and equatorward side contains zones of extensive cloudiness.

(*iv*) They seem to be thermal in origin and are located over the warmest part of the ocean with temperatures 26°C and above (average 27°-29°C).

(*v*) Both the troughs are migratory, but the northern one shows much greater poleward shift than the southern one. At 80° E it is about 1°S in February and 26°N in July, thus showing a movement of about 27° latitude in a year. The southern one, however, shows a movement of 12°-13° lat. in a year, southernmost position in February and northernmost in July (at 80°E).

(*vi*) The movement of these troughs could be attributed to the pronounced heating effect of the south Asian and African landmasses which surround the Indian Ocean in the north and west. South Asian/north African landmass being extensive and spreading across the whole length of the ocean in north and west shifts both the equatorial troughs to the north in summer, taking the northern one right up to 25°-27°N. The effect of south African landmass seems less prominent. Its effect is felt only in the western parts of these troughs (say, west of 80°E) during southern summer (Nov-Mar). In these months the northern trough crosses equator, gradually reaching its southernmost position in February when its effect is felt up to 80°E. East of 80°E the two troughs remain confined to their respective hemispheres.

References

Das, P.K., 1986, "*Monsoon*". IMD Lectures Published by WMO, Geneva.

Hastenrath, S. and Lamb, P.J., 1979, "*Climatic Atlas of the Indian Ocean*", Part I & Part II, University of Wisconsin Press, USA.

Raman, C.R.V., 1965, "Cyclonic vortices on either side of the equator and their implication", Met. Results of IIOE, pp. 155-163.

Rao, Y.P., 1976, "*Southwest Monsoon*", Met. Monogr. No. 1/1976, India Meteorological Department.

Saha, K.R., 1970, "*Proc. Symp. on Tropical Meteorology*", University of Hawaii, U.S.A.

Sadler, J.C., 1970, "*Proc. Symp. on Tropical Meteorology*", University of Hawaii, U.S.A.