J. mar. biol. Ass. India, 1972, **14** (2): 545-554

INDIAN OCEAN FRONTS CAUSED BY INTRUSION OF ANTARCTIC AIR*

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ABSTRACT

Linear weather disturbances frequently occur over the tropical Indian Ocean and are usually identified by convergence of the opposing airstreams and by cyclonic activity. The associated weather is concentrated along 'lines' or narrow zones lying either along or across the general windflow. Intrusion of Antarctic Air into the Indian Ocean produces such disturbances in either half of the region—the Trough Lines of the Southwest Monsoon in the Northern Hemisphere and the Meridional Fronts of the South Indian Ocean.

Cold fronts from high latitudes south of Madagascar are sometimes swept along the East African coastline into the tropical airstream. Within the tropics they undergo considerable modification and are transformed into dynamic fronts as distinct from the cold fronts of the high latitudes. They are recognised as discontinuities in the windfield with equatorward bulges in the isobaric patterns. On an average three or four Trough Lines reach the Ceylon area each year. Their characteristics and their influence on the Ceylon weather are examined in this paper.

The Meridional Fronts of the South Indian Ocean are the boundary zones between successive high pressure cells of the sub-tropical anticyclonic belt of the Southern Hemisphere. They develop as a result of convergence of the tropical airstream moving southwards behind one particular cell with Antarctic Air induced northwards ahead of the succeeding cell. Convergence does not arise purely from any concentration of temperature gradients. Consequently, these fronts appear like the usual tropical convergence zones rather than the high latitude cold fronts. They move regularly from West to East across the ocean. Some interesting cases are discussed in this paper.

INTRODUCTION

LINEAR weather disturbances occur frequently over the tropical Indian Ocean Region and are usually identified by convergence of the opposing airstreams and by cyclonic vorticity. The associated weather is concentrated along 'lines' or narrow zones lying either along the general windflow as shear lines between two opposing windstreams or across or transverse to the main windflow. Two of these linear disturbances which occur over the Indian Ocean are caused by the intrusion of Antarctic Air into this region—the Trough Lines of the Southwest Monsoon in the Northern Hemisphere and the Meridional Fronts of the South Indian Ocean.

TROUGHS IN THE WESTERLIES

The Trough lines in the westerlies are discontinuity zones which lie transverse to the general windflow. They travel from west to east across the North Indian

* Presented at the 'Symposium on Indian Ocean and Adjacent Seas—Their Origin, Science and Resources' held by the Marine Biological Association of India at Cochin from January 12 to 18, 1971.

Ocean along with the main current. The distance between successive troughs varies considerably. It is very short at times, as in Figure 1, where the second and third zones of the series are only 08° apart. At other times there are instances without even a single trough across the entire North Indian Ocean. There is, thus, no evidence of a persistent travelling wave in these low latitudes and these troughs are not associated with the wave systems of the middle latitude westerlies.

Their origin has been traced by Forsdyke (1944) to cold fronts from the high latitudes of the Southern Hemisphere. During the outflow of mass from the winter to the summer hemisphere, cold fronts developing in the high southern latitudes south of Madagascar and the Mozambique Channel are, under suitable conditions, swept along the East African coastline into the tropical westerly airstream of the Northern Hemisphere. It has often been possible to follow their paths from the cold-front stage right up to the Ceylon area.

Within the tropics they undergo considerable modification and are transformed into dynamic fronts as distinct from the cold fronts of the temperate latitudes. They are recognized as discontinuities in the windfield, particularly with respect to wind direction,and appear as equatorward bulges in the isobaric pattern. These troughs are shallow, hardly extending beyond a kilometre or two vertically. Their north-south extent is also limited.

On account of the abrupt change in wind, these troughs are associated with convergence and gusty winds, the wind direction shifting sharply from a southwesterly to a northwesterly direction. Large cumulus and cumulonimbus and altostratus accompany the convergence. The resulting rainfall is heavy over the main affected area, causing (what are popularly known as) the surges in the monsoon. Showers commence well ahead of the trough axis and continue inside the trough region but a rapid clearance follows behind the zone. Their activity is often masked by local effects of the area over which they traverse. This is particularly noticeable over land surfaces where orographic effects are prominent. For example, a trough approaching Ceylon from the open sea in the west is active and causes rapid deterioration in the weather over a large part of the Island, particularly in the southwestern areas, and in the adjoining Southeast Arabian Sea area. As it moves inland and reaches the central hills of Ceylon its influence rapidly fades away and its eastward progress is somewhat retarded. Later, it is found to be active again for a few days on the other side of the Island as it moves across the Bay of Bengal.

On an average, three or four Trough Lines reach the Ceylon area each year. An analysis of the synoptic charts during the 30-year period from 1940 to 1969 shows a total of 118 such disturbances affecting the Ceylon weather. Of this total, 41 occurred during the June months, two of them commencing in late May. Twenty-one occurred in July, 32 in August and 24 in September.

A particularly interesting series of troughs moved across Ceylon between 31st May and 28th June in 1949. As many as 10 individual troughs were observed to cross the Island during this period of 29 days and the resulting rainfall was uniformly heavy throughout the southwest quarter of Ceylon. The first of this series was identified as a cold front in the Southwest Indian Ocean. As it moved equatorwards it was followed by 9 other cold fronts. Near the equator, they moved eastwards with the prevailing lower tropospheric westerly winds. Figure 1, which gives the surface synoptic situation at 0600 G.M.T. on 7th June, 1949, shows 3 trough lines lying approximately north-south across the equatorial belt of the Northern Hemisphere. The first has moved well beyond Ceylon to the east and is lying at 95°E. The second is near 70°E and is approaching Ceylon and South India while the third

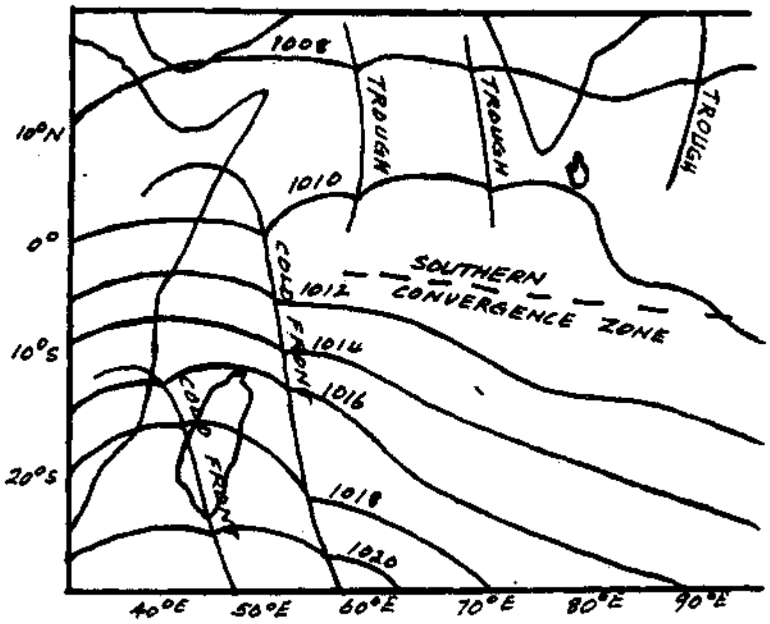

Fig. 1. Synoptic situation at 0600 G.M.T. on 7th June 1949, showing 5 trough lines, 2 of which are still in the cold front stage.

is around 62°E. The fourth and fifth of the series are also seen in the chart off the east coast of Africa. These latter two are still mainly in the cold-front stage.

A trough that caused exceptionally heavy rain over the southwest quarter of Ceylon was that of August, 1947. This was a particularly active trough. Its influence was felt from the 8th to 18th, with very heavy rainfall between the 13th and 15th. On the 13th there were 54 stations in the southwest quarter reporting rainfall over 5 inches for the day, 3 of these exceeding 10 inches. On the following day there were as many as 153 falls over 5 inches of which 73 were greater than 10 inches, 7 of them exceeding 15 inches for the 24 hours. Highest falls for the day were 18.80 inches at Watawala, 18.70 inches at Oonoogaloya Estate in Kotmale and 18.00 inches at Luccombe Estate in Maskeliya, all on the exposed southwestern slopes of the central hills. On the 15th there were 73 falls over 5 inches, 16 of them exceeding 10 inches with one over 15 inches.

Meridional Fronts

The sub-tropical anticylonic belt of the South Indian Ocean consists of a series of individual high pressure cells which move in an almost continuous procession from west to east between the southeast coast of Africa and Western Australia. The boundary between each pair of these cells is known as a Meridional Front. These fronts develop as a result of convergence of the tropical airstream moving southwards in the rear of one particular cell with Antarctic Air induced northwards ahead of the succeeding cell. The convergence, however, does not arise from any concentration of temperature gradients. Consequently, these fronts appear more like the usual dynamic tropical convergence zones than the cold fronts of the higher latitudes.

These fronts lie mainly along a north-south direction and move eastwards along with their associated anticyclonic cells. During this eastward displacement their northernmost sections often tend to lag behind, as may be observed in Figs. 2d and 5c. The orientation of this portion is thereby gradually altered from north-south to west-east. It ultimately detaches itself from the main front and appears for some time as a quasi-stationary front lying near the equator and almost parallel to it.

The movements of three of these fronts across the South Indian Ocean are illustrated in Figs. 2a to 5c and are discussed in the following paragraphs.

The synoptic chart at 0001 G.M.T. on 11th May, 1954 (Fig. 2a), shows a Meridional Front with a high pressure cell lying on either side of it. The movement of the front is indicated in the three subsequent charts (Figs. 2b to 2d). Fig. 2b gives the surface synoptic situation 12 hours after that of Fig. 2a while Fig. 2c follows a further 18 hours later. Fig. 2d shows the surface situation at 0001 G.M.T. on 14th May.

Figures 2a to 2c show how the northernmost section gradually lags behind while the main portion moves along with the anticyclonic cells. The final disengagement is shown in Fig. 2d. The abrupt changes in the winds are illustrated in Fig. 2c.

As in the case of the normal convergence zones in the Indian Ocean these fronts are usually associated with large cumulus and cumulonimbus clouds and with altostratus. However, it is difficult to identify these fronts using this criterion owing to the lack of a suitable network of observational stations over this open oceanic surface. The only available observations are from ships which navigate these waters. They are infrequent and, moreover, they do not always appear near fronts at the times of the observations.

The shift in the wind direction is often clearly marked. It generally changes from a northerly or easterly direction to a southerly to easterly one. Changes in wind speed are also common across these boundaries. These changes in wind direction have been found useful in detecting these fronts but, as in the case of cloud and precipitation, one is confronted with the problem of scarcity of data.

The 'troughing' of isobars along the front has been found to be a very useful indication for their identification. The practice adopted has been to follow the isobaric pattern and to place a front in a north-south direction along the approximate position of the isobaric trough. This process has been found to be more than a rough approximation, and has frequently led to the accurate location of the frontal position.

This procedure has the advantage that it does not require observational data from the immediate neighbourhood of the front. If, however, in addition to the troughing of isobars there is observational evidence of frontal-type cloud and precipitation or a clearly marked change in the windfield, the problem becomes much simpler.

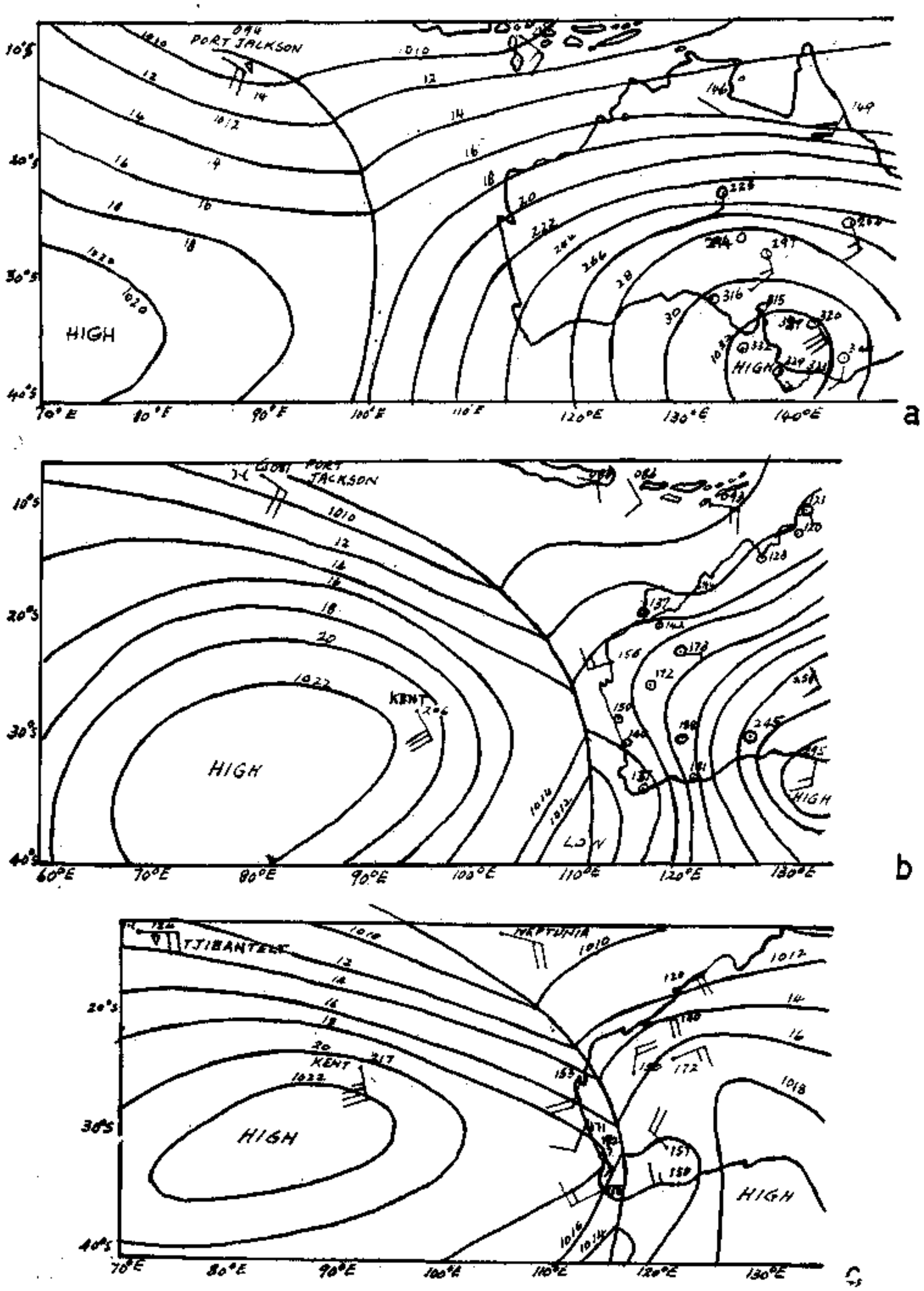

Fig. 2. a. The synoptic situation at 0001 G.M.T. on 11th May 1954, showing a meridional front along 100°E ; b. The position of the meridional front at 1200 G.M.T. on 11th May 1954. It is lying off the west coast of Australia ; c. The chart at 0600 G.M.T. on 12th May 1954. But this time the front had crossed the Australian coast.

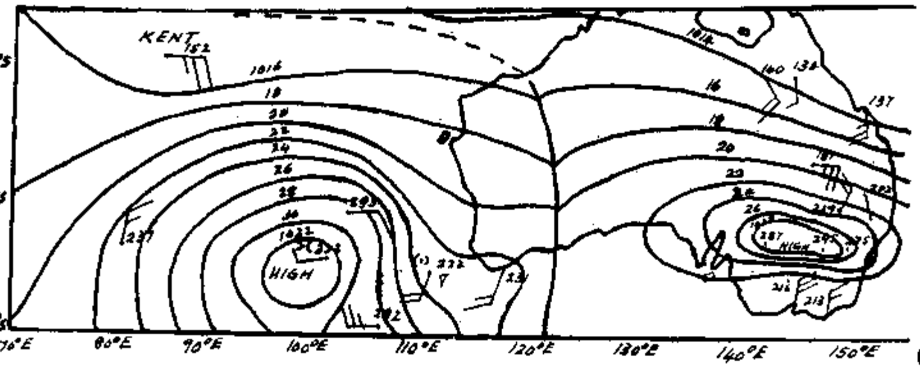

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Fig. 2. d. The synoptic situation at 0001 G.M.T. on 14th May 1954. A portion of the front has broken away.

Figure 3a, which gives the surface synoptic situation 1800 G.M.T. on 20th May, 1954, shows a front that was identified in this manner. The 1016 millibar isobar was found to run somewhat north of Tennant Creek (in Australia) but well to the south of the two ships Hauraki and Urquhart, its distance from each ship being about the same. This resulted in the troughing away from the equator of this isobar eastwards from the Hauraki. Accordingly, a front was placed in the appropriate position of the trough. Reports received six hours later (Fig. 3b) from four ships (Toscana, Avonmoor, Hauraki and Orion) and from Cocos Island indicated rain and showers in this area. Subsequent positions of this front are shown in Figs. 8 to 10. The precipitation recorded at stations in Java, Sumatra, Borneo and Celebes (Figs. 3b to 3d) was due to the influence of one of the Equatorial Convergence Zones which was found to lie slightly to the north of this area at the time.

A centre of low pressure at either end of a Meridional Front would appear as a natural associate of the troughing of the isobars along each end of it. This, in fact, is a common feature of these fronts. It provides another useful criterion for locating these fronts. Thus, if available data show an appreciable decrease in pressure or a wind direction indicating a depressional circulation it would be possible to estimate the central position of the depression by following the isobaric pattern. The position of the front would then be a line through this centre, running practically in a north-south direction.

The surface chart at 1200 G.M.T. on 18th June, 1954 (Fig. 5a), shows showers reported from the ship, British Splendour, and from Cocos Island. The weather and the winds indicated the recent passage of a front over these two positions but these reports gave no information regarding its position east of Cocos. On the other hand, the pressure distribution over Western Australia clearly pointed to the existence of a centre of low pressure off the southwestern tip of the continent. Using this information, the centre was located at approximately 40°S, 112°E and the front was made to pass through this position. Six hours later (Fig. 5b) the front was identified near the west coast of Australia, its presence being confirmed by reports of showers from Onslow and Carnarvon along the northwest coast. The weather at Albany (Fig. 5c) at 0001 G.M.T. on 19th June, 1954, indicated that the front had crossed the extreme southwestern tip of the Australian Continent before midnight of the 18th-19th. Further north it appeared to be lagging behind as shown by the surface winds at Carnarvon and Geraldton. Still further north the showery weather reported by the 'British Splendour' meant that the northernmost portion of this front was very close to this ship, while the fresh northeasterly wind reported from Cocos indicated

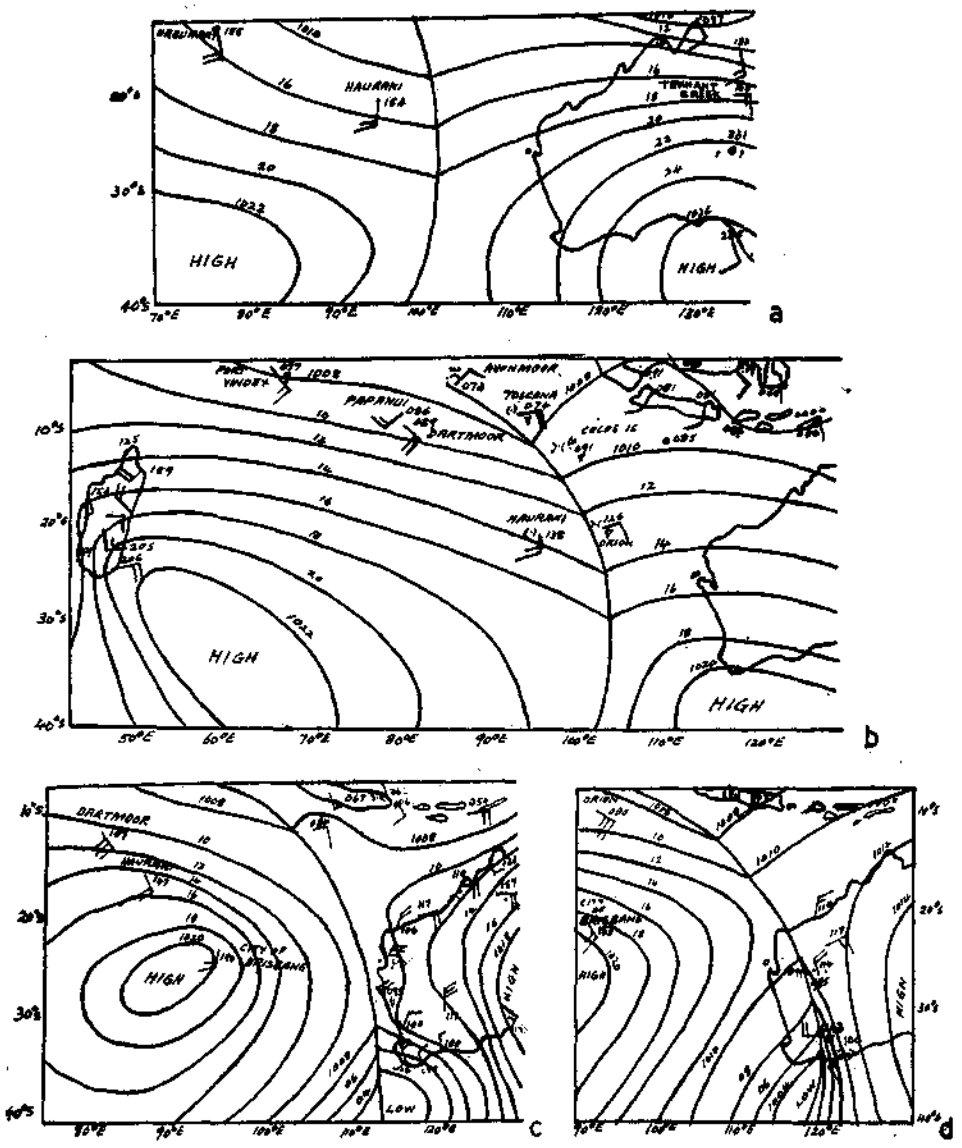

Fig. 3. a. The synoptic situation at 1800 G.M.T. on 20th May 1954. The front was placed in the approximate position as shown ; b. The chart at 0001 G.M.T. on 21st May 1954 with the position of the front clearly indicated ; c. The chart at 0600 G.M.T. on 22nd May 1954 with the front off the west coast of Australia ; and d. The chart at 1200 G.M.T. on 22nd May 1954. The front had crossed the Australian coast by this time.

that at this time the front was situated south of this Island. This was the detached quasi-stationary section of the front.

In addition to the above criteria it is felt that very useful deductions could be made if the isallobaric field is known. This, no doubt, is beyond the scope in such a

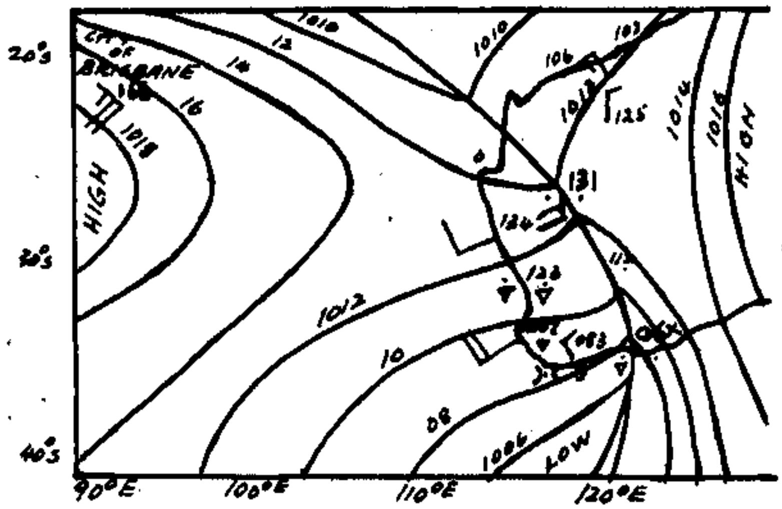

Fig. 4. A subsequent position of the front at 0001 G.M.T. on 23rd May 1954.

vast oceanic region. However, accurate reports of pressure tendencies even from isolated ships in the area could be quite helpful. At present such reports are not available. The practical value of such data could be examined only after reliable estimates become available, at least, fairly regularly.

On account of the extreme paucity of observational data from the South Indian Ocean these fronts are not readily detected. Until other forms of data become available, a careful look-out for the occurrence of one of the following four phenomena from ships' reports would be very helpful—

(i) Development of frontal-type precipitation or, at least, clouds ;

(ii) A discontinuity in the wind direction, which may be accompanied by a significant change in wind speed ;

(iii) The troughing of isobars along a particular direction ; and

(iv) The development of a centre of low pressure.

A concentrated study by a group of this nature should be able to solve some of these problems.

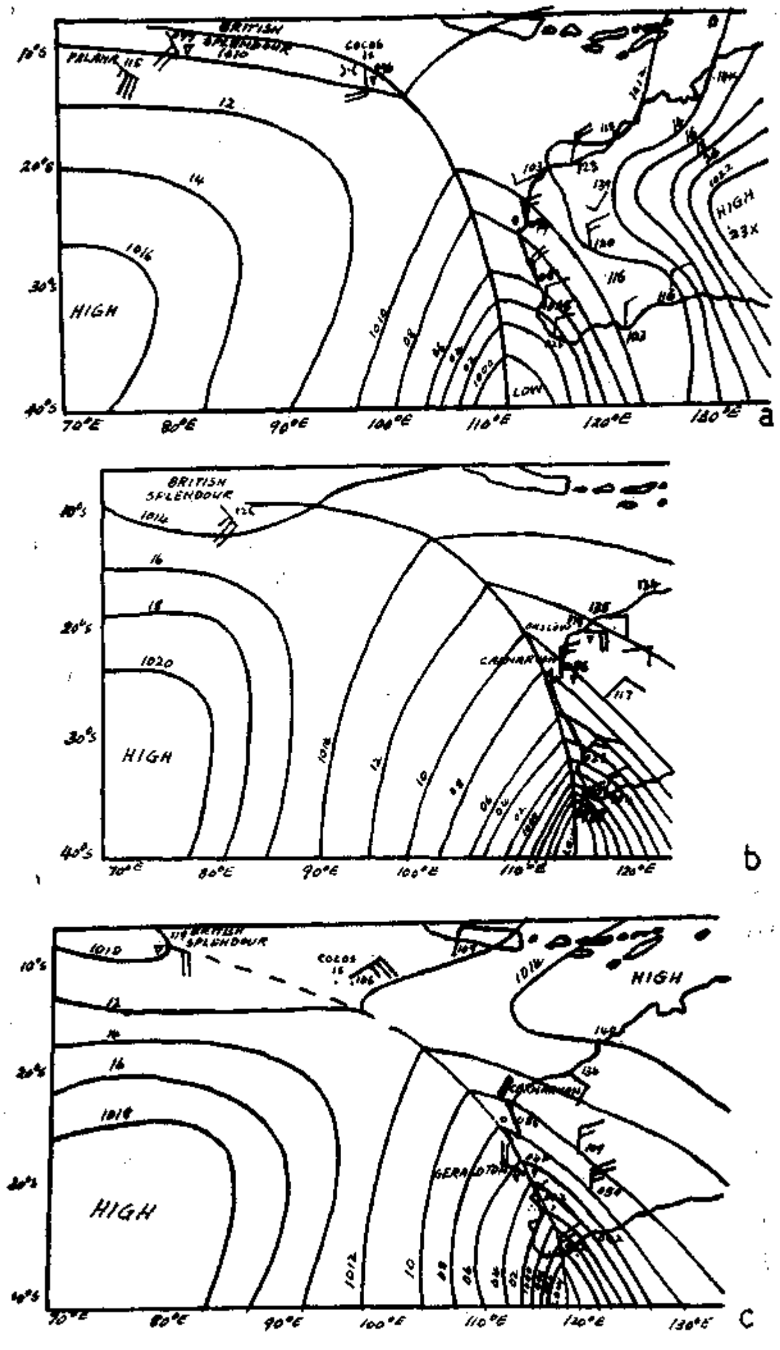

Fig. 5 a. The chart at 1200 G.M.T. on 18th June 1954. A front was placed north of the ship 'British Splendour' and Cocos Island and was made to pass through the estimated position of the centre of low pressure (at approximately 40°S, 112°E) ; b. The synoptic situation at 1800 G.M.T. on 18th June 1954 with the front lying near the Australian coast; and c. The chart at 0001 G.M.T. on 19th June 1954. A portion of the front has broken away.

Reference

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Discussion

N. S. BHASKARA RAO : Upto what latitude equatorward could you trace these fronts ?

G. S. JAYAMAHA : Generally upto about 10°N but sometimes less than that.

N. S. BHASKARA RAO : In which direction do the parts of the fronts north of the High pressure belt move ?

G. S. JAYAMAHA : These remain quasi-stationary for a very short period, not more than 2 or 3 days, and then dissipate away.

K. R. SAHA : Did you utilise any satellite cloud information in your study ?

G. S. JAYAMAHA : The satellite data being received now confirm these. In fact, the cloud film shown here last Wednesday showed some of them quite clearly. My interest in them was initially aroused by the cloud reports received from the Ceylon-based meteorological reconnaisance flights immediately following World War II.

K. R. SAHA : What is the nature of the cold fronts which cross the equator near the coast of East Africa and affect weather north of the equator ? Could you kindly elaborate a little ?

G. S. JAYAMAHA : They appear as dynamic fronts as distinct from the cold fronts of the higher latitudes. By the time they reach the Ceylon area they behave like normal convergence zones. The convergence helps to penetrate the dry layer, which was described by Dr. Ananthakrishnan in his paper, and causes the popularly known ' surges ' in the Southwest Monsoon.

D. R. SIKKA : It would be rather difficult to visualise the penetration of a cold front up to the equator and even across it as suggested by you. The concept of surges in the SE trades affecting the equational weather has been prevalent for some years. We studied day to day satellite cloud pictures during the SW monsoon for five years (1966-70) and found no evidence of any such systematic passages of surges. The nature of equatorial disturbances seems to be very complicated and the data sparsity adds to the problem. What we observe in the satellite pictures is the occasional occurrence of non-equational cloud bands which have an average life duration of 3-4 days and appear to form and decay *in situ* with some lateral compassion. However, no systematic behaviour is noticed as suggested by you.

G. S. JAYAMAHA : By the time they come up to the equator they are no longer cold fronts. Certainly, there is no systematic pasage of these surges. As I mentioned in the paper, only about 2 or 3 of them (on an average) reach us during each Southwest Monsoon Season.