Structure of an Oceanic Near-Equatorial Trough Deduced from Research Aircraft Traverses[1]

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ABSTRACT

Opinions differ on the nature of near-equatorial troughs and their associated weather. Two research aircraft traversed a South Indian Ocean near-equatorial trough on 2 February 1964. Their detailed observations support earlier, large-scale studies which postulated that trough lines above 5° latitude coincide with maximum sea-surface temperature and relatively fine weather.

1. Introduction

Over the tropical oceans, surface near-equatorial troughs are apparently linked to the axes of maximum sea-surface temperature (Riehl, 1954; Raman, 1967; Ramage, 1968). Observations of mean sea-level pressure and sea-surface temperature made on research vessels, and monsoonal influences on trough movement, lend statistical and climatological support to this idea (Ramage, 1974). In his study of eastern North Pacific summer weather patterns, Sadler (1964) noted that the weather satellite cloud photographs "have shown the area between the convergence lines to be one of minimum cloudiness . . . more or less centered . . . about the . . . trough line. The trough is, in fact, likely to be clear or to contain only scattered clouds except for the concentrated cloudiness associated with the tropical cyclones travelling along the trough." Sadler pointed out that the earlier observations by Alpert (1945, 1946) and Simpson (1947) were in agreement with this view. Thus a consistent, if crude picture emerges. The trough is a heat trough coinciding with a sea-surface temperature maximum which in turn is maintained and enhanced by insolation through relatively clear skies. However, this is not the picture seen by most meteorologists and most numerical modelers, whose views are better represented by Balogun (1973)—"the ITCZ marks the boundary between the N.E. trades and the low level cross equatorial flow. It is a narrow band about 2°–3° latitude wide extending east and west and comprising lines of active meso-scale cumulus convection." In other words, the trough line and bad weather coincide. These apparently contrary views may reflect the detail and care with which different investigators have studied the phenomenon.

In February 1964, while participating in the meteorological program of the International Indian Ocean Expedition, two DC-6 aircraft of the U. S. Weather Bureau Research Flight Facility (Friedman *et al.*, 1969a and b) traversed a near-equatorial trough in the South Indian Ocean. In the remainder of this paper, observations made on these flights are described and analyzed.

2. Case study

The two DC-6 aircraft of the Research Flight Facility were equipped to measure flight-level winds, pressure and radar altitude (and consequently D-value), air temperature, and two moisture parameters—liquid water content and absolute humidity. All the data were recorded on magnetic tape and spot values were printed out at 10-second intervals. The moisture parameters were recorded in digital count units. However, since no calibration curves were available for the individual measuring systems, the digital counts could not be expressed in meteorological units. Cameras made time-lapse movies of clouds, from the nose with 16-mm color film, and from right and left sides using 35-mm black and white film; scope presentation of horizontally and vertically scanning weather radars were photographed at 16–20 s intervals.

a. Data

On 2 February 1964, both aircraft flew the same course, one (A) at 500 mb, the other (B) at 945 mb from Gan Island (00° 41′S, 73° 09′E) to Mauritius (20° 18′S, 57° 30′E) (Fig. 1). Between 12 and 16S, southbound along about 60E, they traversed the South

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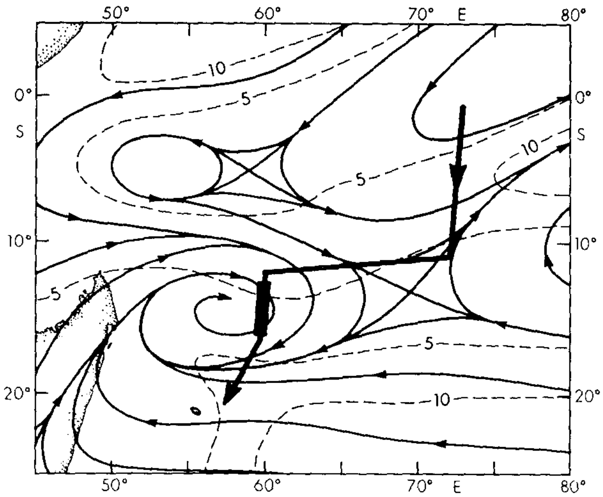

FIG. 1. Lower tropospheric circulation (surface winds from ships, gradient level winds from stations) for 1200 GMT 2 February 1964. Streamlines full, isotachs (m s^{-1}) dashed. The track of the two RFF planes is shown by a thick full line, made thicker over that portion of the track for which a detailed study (Table 1) was made.

Indian Ocean near-equatorial trough to the east of a weak cyclonic vortex center. I have used the trough line as reference axis for all the observations. In the sequence of 10-s Doppler winds measured by the low-flying aircraft, the points of first recorded easterly component and last recorded westerly component were noted. The 32.7 km-long intervening segment, comprising 5 minutes of flying time, was halved to locate the trough line at 14° 27.3′S. Other equal-sized segments were then measured off on either side of the trough segment—five to the north and five to the south and the approximately 30 measurements of each variable by each aircraft in each segment were averaged (Table 1). Aircraft A at 500 mb was about 40 min ahead of aircraft B at 945 mb, thus introducing an unknown but probably small discrepancy. Flight level winds, temperatures and D-values, and wind shear between flight levels are shown in Fig. 2, while Figs. 3 and 4 depict clouds as photographed by the side-viewing cameras at the centers of segments 2, 4, 6 (trough), 8, and 10.

b. Analysis

The trough (*segment #6*). The 945-mb D-values confirm that lowest surface pressure coincided with the trough as determined from the wind distribution. Air was relatively dry in the lower layers (in the absence of horizontal moisture convergence) and relatively unstable up to 500 mb [radiational cooling (see for example, Rodgers and Walshaw, 1966) combined with lack of condensation heating]. *East* of track, a towering cumulus appearing in the right center of Fig. 3(6) displays its southern edge in Fig. 4(6). It produced

TABLE 1. Segment averages of variables measured at 945 mb and 500 mb during N-S traverses of a near-equatorial trough, 2 February 1964.

Segment number	Central latitude	Wind speed (m s^{-1}) and direction			Temperature (°C)		D-value (m)		945–500 mb layer T_v °C	T_v lapse rate °C/100 mb		Moisture (digital count units)			
		945 mb	shear	500 mb	945 mb	500 mb	945 mb	500 mb		945–723 mb	723–500 mb	945 mb Liquid water	945 mb Humidity	500 mb Liquid water	500 mb Humidity
1	12°59.9′S	298°7.7	93°7.2	33°3.8	21.6	−5.7	−4.9	+332.2	12.4	5.4	8.1	897	1836	1820	592
2	13°15.7′S	297°6.5	87°8.3	37°4.2	21.6	−5.1	−4.9	+335.3	12.7	5.3	7.9	902	1839	1819	627
3	13°33.7′S	303°5.6	92°7.0	39°3.6	21.9	−5.4	−4.9	+329.5	12.2	5.4	7.9	903	1846	1813	661
4	13°51.7′S	308°3.3	113°5.3	90°2.3	21.7	−5.1	−2.7	+331.6	12.3	5.5	7.8	901	1844	1807	695
5	14° 9.6′S	329°2.9	108°4.4	67°2.9	21.4	−5.7	−4.6	+329.5	12.2	5.4	8.0	896	1835	1793	651
6	14°27.3′S	364°1.7	106°2.7	71°2.9	22.3	−5.9	−6.1	+326.4	12.4	5.7	8.2	895	1827	1805	719
7	14°44.9′S	20°2.3	134°3.0	87°2.9	22.5	−5.9	−2.7	+327.7	12.1	5.9	8.0	896	1824	1817	672
8	15° 2.7′S	57°3.3	170°4.3	125°4.3	22.4	−5.6	−2.7	+327.7	12.0	5.9	7.9	897	1832	1824	709
9	15°20.7′S	68°3.8	248°4.3	143°3.2	22.3	−5.6	−1.2	+326.4	11.8	5.9	7.8	897	1831	—	666
10	15°38.6′S	80°3.9	242°4.8	194°1.6	22.2	−5.4	+2.1	+329.8	11.8	5.9	7.7	897	1841	—	659
11	15°56.2′S	63°3.3	237°3.9	208°0.7	22.2	−5.8	+2.1	+330.4	11.8	5.9	7.9	899	1837	—	584

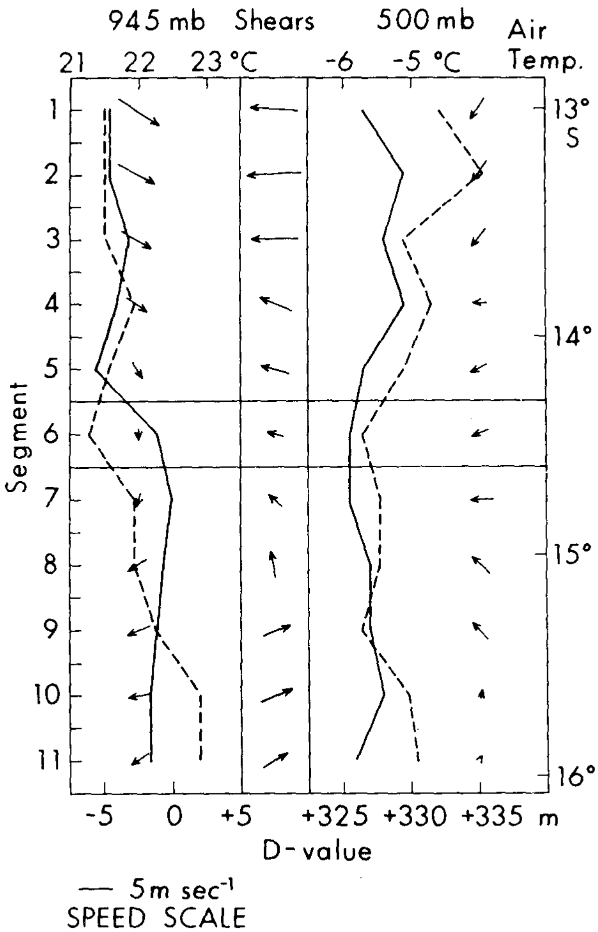

FIG. 2. Segment averages of variables measured at 945 mb and 500 mb during traverses along 60E of a near-equatorial trough, 2 February 1964. Flight-level winds and shear between flight levels labelled in m s^{-1}. Temperatures (°C), full lines; D-values (m), dashed lines.

precipitation echoes to a height of 7 km. *West* of track, incipient convection near the center of Fig. 3(6) developed into a towering cumulus 40 min later [Fig. 4(6)] with an echo top at 3 km. The combination of fine weather and isolated vigorous convection resembles average conditions in the summer monsoon trough of northern India (Ramage, 1971) where the trough line is an axis of relative minimum rainfall and relative maximum thunderstorm frequency.

Although wind shear is smallest at the trough it suggests a southward slope with height of the maximum temperature axis.

North of the trough (*segments #1–5*). The cloud and radarscope pictures agree that the worst weather occurred in segments #3, 4, and 5, a region of relatively large shear, maximum humidity and maximum low-level liquid water content (Table 1), where convective clouds were embedded in sheets of altostratus and nimbostratus from which intermittent rain fell. Precipitation echoes were more extensive than those usually associated with vigorous convection; the tops ranged from 3 to 7 km. Most of the echoes were east of track and made no recognizable pattern, apart from a marked, persistent line extending through the center of segment #5 from 200 km WSW to 110 km ENE. Condensation heating, and radiational cooling restricted by clouds and large moisture content, resulted in a relatively small lapse rate between 945 and 500 mb.

South of the trough (*segments #7–11*). Isolated small precipitation echoes with tops between 2 and 5 km were recorded in every segment. At 945 mb, relatively high temperatures were associated with the largest lower tropospheric lapse rates. Between 723[2] and 500 mb, radiational cooling must have been greater than north of the trough, since skies were predominantly clear and condensation heating largely absent. Therefore, since lapse rates in this layer were about the same to north and south of the trough, the effect of radiational cooling to the south of the trough must have been counteracted by subsidence. Subsidence is also suggested in Fig. 3 (8 and 10) which shows a few cloud tops penetrating a very dry layer and evaporating.

c. Discussion

The distribution of meteorological variables recorded by the research aircraft as they traversed a South Indian Ocean near-equatorial trough accords with the earlier, less detailed observations mentioned in the introduction.

Although sea-surface temperature was not measured, the data suggest that the axes of maximum sea-surface temperature and minimum sea-level pressure nearly coincided. On mean charts, the near-equatorial trough line nearly parallels the upper tropospheric easterlies directly above. Figures 3 and 4 suggests that this may not be fortuitous. The northern part of the trough segment was covered by cirrostratus, part of the layered cloud mass to the north. The edge of the cloud sheet, oriented along the upper tropospheric flow, presumably coincided with a significant radiation discontinuity. The sea surface beneath the cirrostratus would have received less insolation than the surface just to the south, where the trough line was found.

3. Concluding remarks

The "ITCZ" as defined by Balogun (see page 754 above) is attracting increasing attention from numerical modelers. Manabe *et al.* (1974), who give extensive references, use a global model with a 250-km grid size to simulate the annual variation of the tropical circulation. In their view, "ITCZ," surface trough, and surface temperature maximum coincide. The model

[2] Approximately the middle of the layer between 945 and 500 mb.

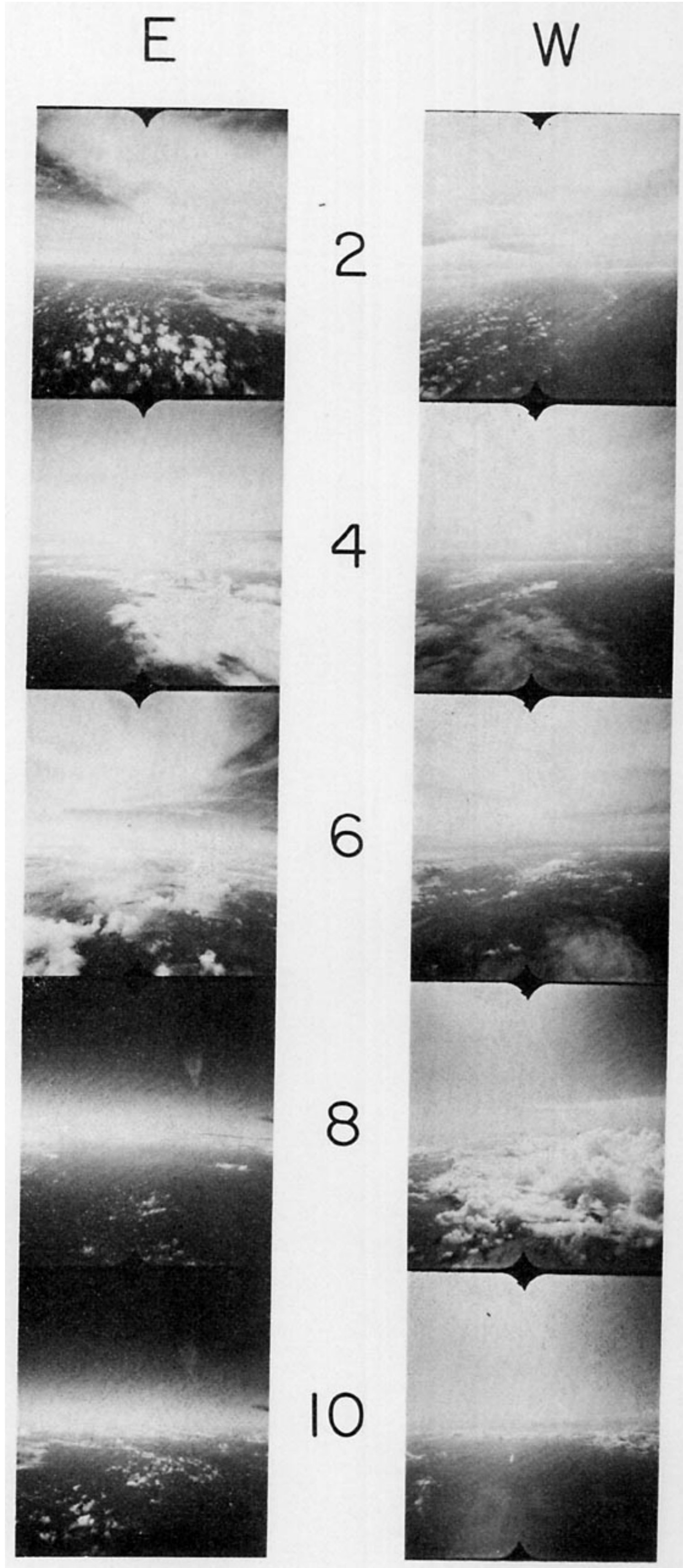

Fig. 3. Photographs taken from aircraft A (500 mb) at the centers of segment 2, 4, 6 (trough), 8, and 10, looking east (left-hand column) and west (right-hand column).

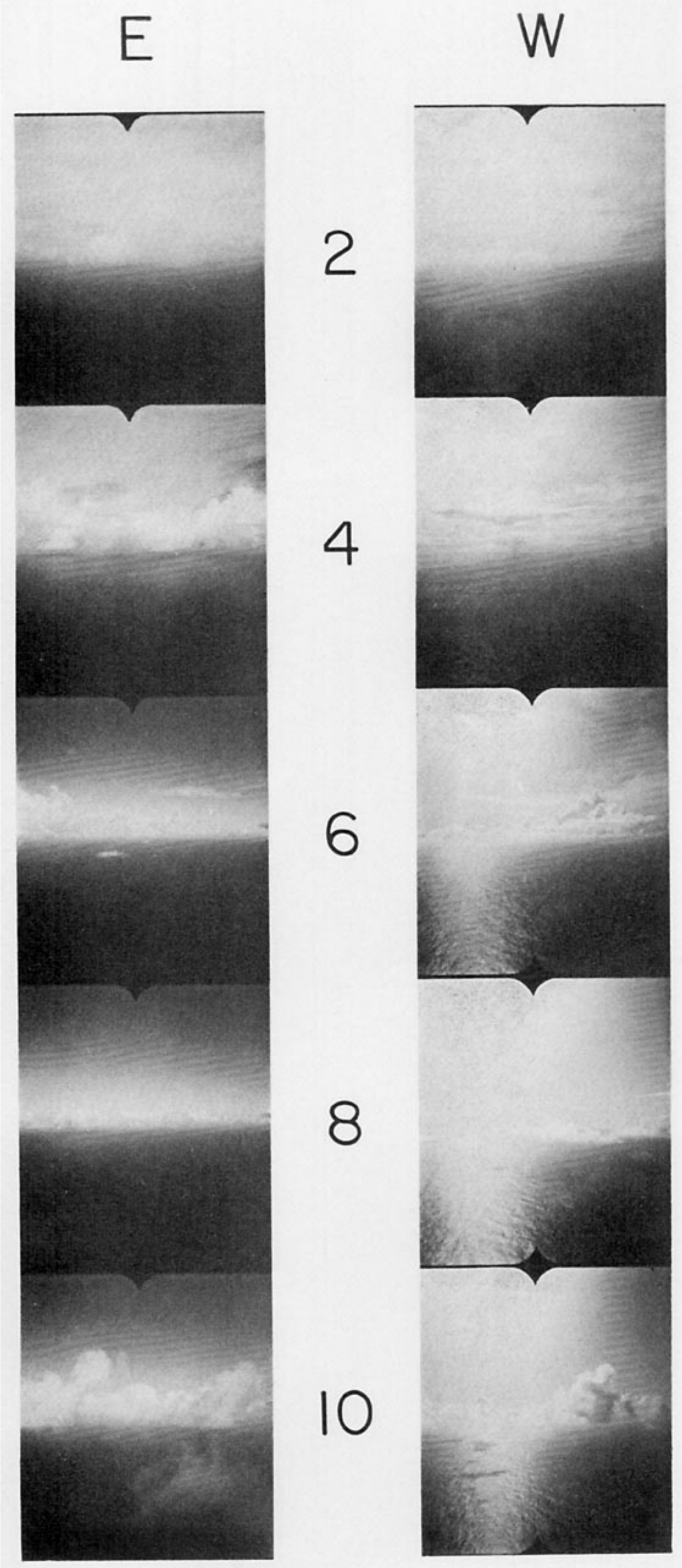

FIG. 4. As in Fig. 3 but from aircraft B (945 mb), taken approximately 40 minutes after the photographs in Fig. 3.

"ITCZ," while meeting their expectations by coinciding with bad weather over the oceans, lets them down by always being north of the rainbelt over Africa. This leads them to seek a meteorological explanation for the difference. In fact, none is needed for the problem is artifically created by the grid size. Over West Africa the trough lies 700–800 km north of the bad weather, a distance resolvable by a 250-km mesh, whereas a usual separation of less than 100 km over the ocean is not resolvable.

Measurements made along a single line can only hint at the distributions of divergence and vorticity, and raise intriguing questions. For example, do the weak vortices usually found in oceanic near-equatorial troughs tend to increase the sea-surface temperature maximum and so decrease the corresponding surface pressure? Perhaps conservation of angular momentum, which prevents surface air from reaching the centers of tropical cyclones, may also function in these weaker systems. Thus in their central regions persistent light variable winds and almost clear skies might lead to significant surface temperature rises as intense insolation heats a thin layer of the ocean.

If multiple simultaneous aircraft traverses of the West Pacific near-equatorial trough can be made in STORMFURY Pacific—1976 (National Oceanic and Atmospheric Administration, 1974), this question may be answered.

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