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The First Hurricane Track determined by Meteorological Satellite

JAMES C. SADLER, Lt. Col., USAF

Chief, Satellite Meteorology Branch, Atmospheric Circulations Laboratory, Air Force Cambridge Research Laboratories, Bedford, U.S.A.

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ABSTRACT. The most fascinating aspect of Tropical Meteorology is the formation and movement of tropical storms. Meteorological satellites show promise of being an ideal observational tool to study the life history of such storms. An example is shown of the TIROS I surveillance and tracking of a tropical storm during a six-day period as it developed in the Arabian Sea from a depression to hurricane intensity, moved WNW onto the Arabian Coast and dissipated over the mountains of SW Arabia. The influence of the 40,000 ft circulation as a possible 'trigger' to development is noted. A comparison is given between the storm path as determined from satellite observations and as determined by conventional post analysis.

1. Introduction

The purpose of this paper is to demonstrate the utility of meteorological satellites in tropical meteorology and in particular their utility for the surveillance and tracking of tropical storms.

During mid-May 1960 TIROS I was obtaining data on the SW-NE leg of its orbital path between latitudes 5° and 40°N. From 13-19 May, photographs were obtained of a tropical storm in the Arabian Sea as it developed to hurricane force, moved onto the Arabian Coast, and dissipated over the mountains of SW Arabia. These data represent the first tracking of a hurricane by a meteorological satellite.

Excellent land marks, usually the south coast of Arabia, are contained in the picture sequences so that the earth location accuracy of picture contents is on the order of 30 nautical miles (Glaser 1960).

The conventional post-analysis of the storm track which is used for comparison purposes is as published by the Indian Meteorological Service (India met. Dep. 1960).

2. General Synoptic Discussion

Figs. 1 through 7 are the surface streamline analyses for the period 13—19 May. Streamline analyses for the 10,000 ft and 40,000-ft levels for 14 and 17 May are shown in Figs. 8—11.

A low level east-west trough system extends from the southern Bay of Bengal across South India through the southern portion of the Arabian Sea and into the Gulf of Aden. This trough is more pronounced at 10,000 ft than at the surface. Two cyclonic cells exist in the trough, one just north of Ceylon and the other in the Arabian Sea. The westerlies to the south of this trough represent the advance of the summer monsoon into southern India.

During this period the depression near Ceylon remained essentially stationary with no development. The depression in the Arabian Sea began deepening on the 14th and after development moved WNW onto the Arabian Coast. This is the storm of particular interest for this discussion.

The moderate number of ship reports available in the Arabian Sea and North Indian Ocean permit a reliable analysis of the low level circulation but are not sufficient for an adequate positioning and tracking of the storm, nor are they adequate to permit an evaluation of the strength of the storm. The best indication of the storm intensity with the data shown, is given by the surface chart of 18 May (Fig. 6). One ship, to the east of the storm, reports fifty knot winds and several ships to the south and east show a strong circulation of thirty knots to well below the equator, a distance of over 1000 miles. A better indication of storm intensity is obtained from the daily storm bulletins issued by the Indian Meteorological Service, since it is probable that these bulletins were based on more information than that contained in the routinely distributed ship observations. These bulletins are quoted :

13 May 1960—"Ships' observations from the Arabian Sea are meagre. The deep depression in the southeast Arabian Sea was centred at 0830 hrs. I.S.T. within one degree of Lat. 12·5° North and Long. 66·5° East."

14 May 1960—"The deep depression in the Arabian Sea was centred at 0830 hrs. I.S.T. within 1° of Lat. 14·5°N and Long. 64·5°E. It may intensify and move northwest."

15 May 1960—"Yesterday's deep depression in the Arabian Sea concentrated into a cyclonic storm of small extent and was centred at 0830 hrs. I.S.T. within one degree of Lat. 15·5°N and Long. 62°E. It is likely to move westnorthwestwards."

16 May 1960—"Ships' observations in Arabian Sea are scanty, but it is believed that yesterday's cyclonic storm of small extent in the Arabian Sea is centred at 0830 hrs. I.S.T. today with one degree of Lat. 16·5°N and Long. 60°E. It is likely to move westnorthwest."

17 May 1960—"The cyclonic storm in the west central Arabian Sea has become severe and has a core of hurricane winds. Latest available ships' observations indicate that the severe cyclonic storm is centred at 0830 hrs. I.S.T. within half a degree of Lat. 14°N and Long. 59·5°E with estimated central pressure of 975 mbs. It is likely to move westsouthwestwards."

18 May 1960—"The severe cyclonic storm with a core of hurricane winds, in the west central Arabian Sea, is centred at 0830 hrs. I.S.T. today within one degree of Lat.14·5°N and Long. 57°E. It is likely to move westwards."

19 May 1960—"Ships' observations from the west central Arabian Sea are meagre but it is believed that the severe cyclonic storm is centred at 0830 hrs. I.S.T. within one degree of Lat. 14°N and Long. 56.5°E with estimated central pressure of 990 mbs. It is likely to weaken while moving westwards and cross Arabian coast within one hundred and fifty kilometers of Riyan."

20 May 1960—"Observations from the east coast of Arabia and ships' observations from west Arabian Sea are practically absent. But it is believed that the cyclonic storm in the west Arabian Sea has weakened and moved away westwards as a low pressure wave."

3. Discussion of Satellite Observations

The satellite orbits are shown in each surface streamline chart as solid lines oriented SW-NE extending from the point of equator crossing to the north edge of the chart. The camera pointed to the right of and back along orbit as indicated by the dashed line with arrow pointing to the SW. As an aid to picture orientation, look toward the horizon, when visible, then a line from the picture center perpendicular to the horizon points towards the SW. The area covered by each photograph of the wide angle camera is approximately 700 miles on a side when pointing vertically. The estimated storm center is denoted by a small circle on each photograph.

13 May 1960—Selected photographs from two successive orbits (Fig. 1) show clouds associated with three systems of interest. Fig. 12 is a view of the east central coast of India and shows isolated thunderstorms along the convergence line. Fig. 13 depicts the cloud system associated with the cyclonic cell between Ceylon and southeast coast of India and Fig. 14 is the cloud system of the cyclonic cell in the Arabian Sea. The cloud patterns of these two cells are very similar in that both are of the "blob" type and have little, if any, vortex spiral structure. This could well be the typical pattern of a weak dormant cell, of the depression stage, imbedded in a tropical trough.

14 May 1960—Fig. 15 is a view of the Arabian Sea cell a day later. Increased storm circulation is evidenced by the beginning of the spiral vortex cloud pattern. The storm center is estimated by utilizing the curvature of the spiral bands and the overall appearance of the cloud mass.

The extensive east-west cloud system some 300 miles south of the storm center (Area A of Fig. 15) is associated with the area of convergence produced by the confluence of the southwesterly equatorial flow and the westerly flow from Somaliland (Fig. 2).

16 May 1960—No TIROS observations were obtained in the storm area on 15 May. Fig. 16 is a view of the storm at 0915 Z, 16 May. The storm has further intensified and is probably of hurricane intensity as evidenced by the low level spiral inflow pattern and more so by the extensive cirrus shield radiating out ahead of the storm (Area B of Fig. 16). The principal cirrus bands are radiating from the left front quadrant of the storm from a direction of 110°. This direction agrees well with the 40,000 ft winds of 120° reported from Aden at 0000Z. The dark area near the center of the cloud mass could be the eye and from a summary inspection would perhaps be interpreted as such.Here it is interpreted as an area between the spiral rain bands near the center for the following reasons : (*a*) the size and shape and in particular the elongated portion towards the northwest which is more than fifty miles in length; (*b*) the original photograph shows a circular shaped pattern around the estimated center which is slightly brighter than the surroundings, and (*c*) the most predominant reason is the orientation and radius of curvature of the low spiral bands which are more compatible with an eye located as shown.

17 May 1960—Fig. 17 is another excellent view of the entire hurricane. The center is estimated by inspection. The elongated dark area near the center is interpreted as a break in the clouds between bands. The cirrus shield preceding the storm is too near the horizon to be identified but is reported by all stations to the west along the Arabian coast (Fig. 5).

18 May 1960—The relatively poor photograph (Fig. 18) of storm on this date reveals very little detail of the storm circulation. The center is estimated by inspection. The storm has just moved inland with hurricane force. A ship some 150 miles east of the center reported winds of fifty knots at 1200Z (Fig. 6).

19 May 1960—Fig. 19 is a view of the dissipating storm over the rugged terrain of southwest Arabia. Note the almost complete absence of clouds in the mouth of the Gulf of Aden which was the area covered by the issued storm bulletin for this date.

Storm Track—Two plots of the hurricane track are shown in Fig. 20. The solid line is the track as determined from satellite observations and the dashed line is the published (India met. Dep. 1960) track as determined from conventional observations.

The accuracy of the storm fix determined by satellite observations is on the order of one degree. Much of this uncertainty is due to the difficulty of recognizing or determining the storm center from the photographs and some is attributed to the inherent distortion and position errors of the TIROS I system (Glaser 1960). Considering this accuracy and the normal one degree accuracy claimed from conventional data, the two tracks are quite comparable during the storm development period of 14 to 17 May. The more accurate positioning, by satellite observations, on 17, 18 and 19 May shows a normal path and allows for the logical dissipation over the rugged terrain of southern Arabia. The positions as determined from conventional data, in addition to the consequences of erroneous hurricane warnings, produced for historical purposes, a very rare hurricane which dissipated over a tropical ocean far removed from a cold air source.

4. Storm Development

Good fixes of tropical storms by conventional data and aircraft reconnaissance have an extreme geographical bias. The same bias, perhaps to a lesser degree, exists in the determination of the time and location of storm intensification, since many storms intensify to hurricane force in areas of very sparse conventional data and beyond the range of normal aircraft reconnaissance. Satellite observations will reduce, and eventually eliminate, this bias. These increased observations of the time and location of the storm development will aid in the search for, and understanding of, the "trigger" necessary for development. Recent studies of tropical storm development have looked to the circulation of the upper troposphere for the "trigger" mechanism (Ramage 1959, Riehl 1948, Alaka 1961 and Koteswaram and George 1957).

A qualitative interpretation of the satellite observations indicates that the Arabian Sea storm had developed to hurricane intensity prior to the observation on 16 May. The circulation patterns in the lower troposphere show very little change during this period of interest (Figs. 8 and 9). The upper troposphere pattern, however, underwent a radical change. The 40,000-ft circulation pattern on 14 May (Fig. 10) was rather normal. The sub-tropical ridge line was oriented east-west near 17° North with predominant zonal flow on either side. By 16 May a sharp trough had developed in the westerlies over Northwest India and by 17 May this trough had intensified and penetrated into southern India (Fig. 11). The storm developed to hurricane intensity some 15 degrees west of this intensifying trough which is in agreement with the model as proposed by Ramage (1959).

Of equal importance to the understanding of the development process will be the opportunity afforded by the satellite observations to study the numerous tropical vortices which do not develop to the advanced storm or hurricane stage. One ideal geographical area for such surveillance is the Eastern North Pacific. Numerous vortices propagate westward during the summer season, from the region of Central America. The westward track of these vortices ranges from a rapid recurvature into Southern Mexico to a long trek into the mid and western Pacific, but only on rare occasions do any develop to hurricane intensity east of 180° longitude. Fig. 21 is a view of a weak vortex located near 15°N, 120°W. It is embedded in easterly flow and has no subsequent history of further development. Note the difference in cloud structure when compared to the two depressions embedded in a trough system (Figs. 13 and 14).

5. Conclusions

1. Meteorological satellites are ideal platforms for observing the tropical atmosphere. Disturbances, within this homogenous air mass, covering the spectrum from convergence lines to hurricanes are mirrored in the cloud patterns.

2. The stage of development and a "rough" estimate of the intensity of tropical storms can be deduced from the satellite photographs.

3. The hurricane eye, in many cases, will not be detectable by satellite photography due to an overlying thick cirrus shield and/or cloud debris within the eye. In such cases, a good approximation to the center position can be obtained by utilizing the curvature of the low level cloud spirals outside the main cloud mass similar to the method of utilizing the radar rain band spirals within the main cloud mass as reported by Senn, Hiser and Bourret (1957).

4. Storm center fixes by satellite can be superior to those by conventional means even over regions containing a relatively large number of ship and land reports.

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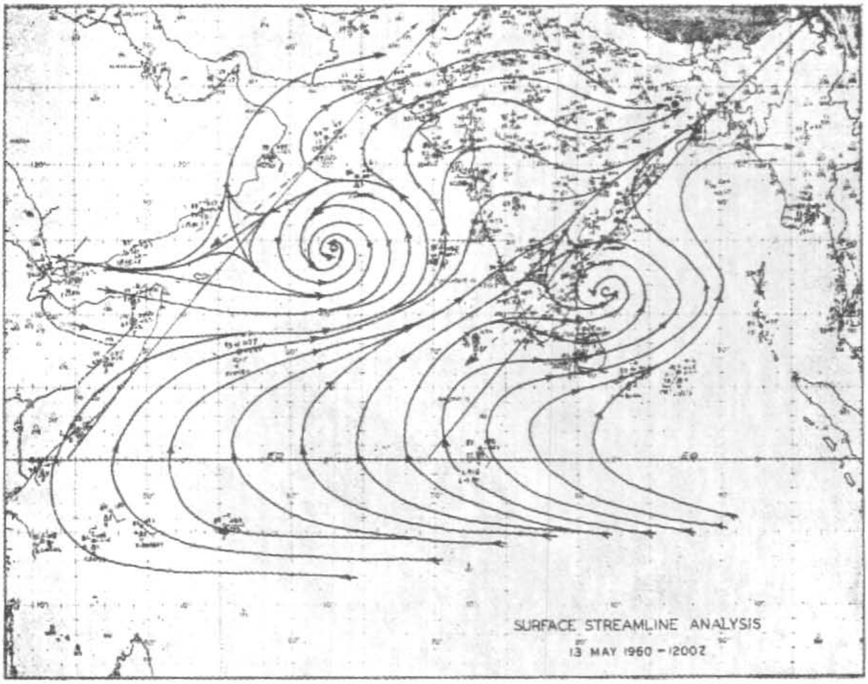

SURFACE STREAMLINE ANALYSIS
13 MAY 1960 – 1200Z

Fig. 1

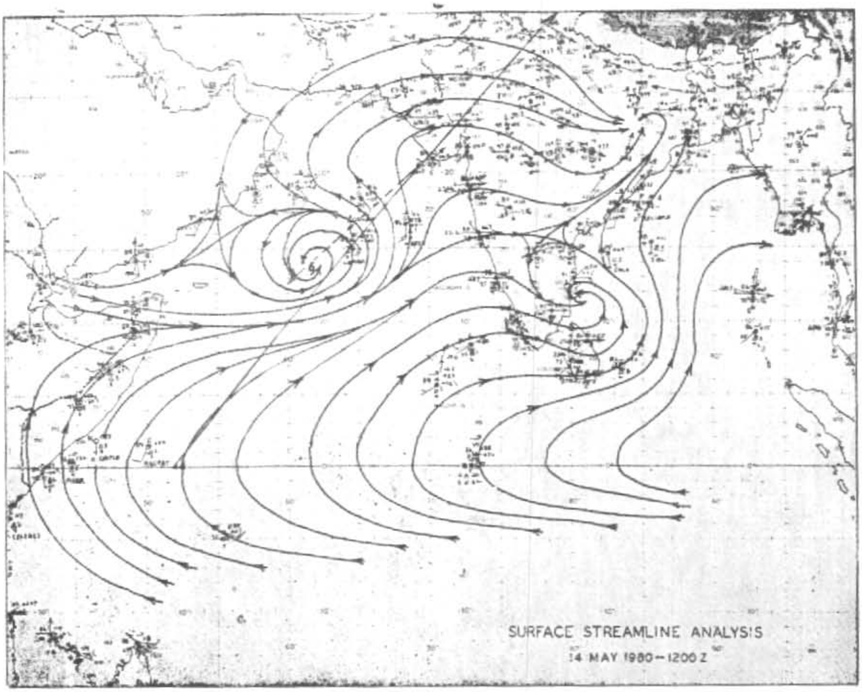

SURFACE STREAMLINE ANALYSIS
14 MAY 1960 – 1200 Z

Fig. 2

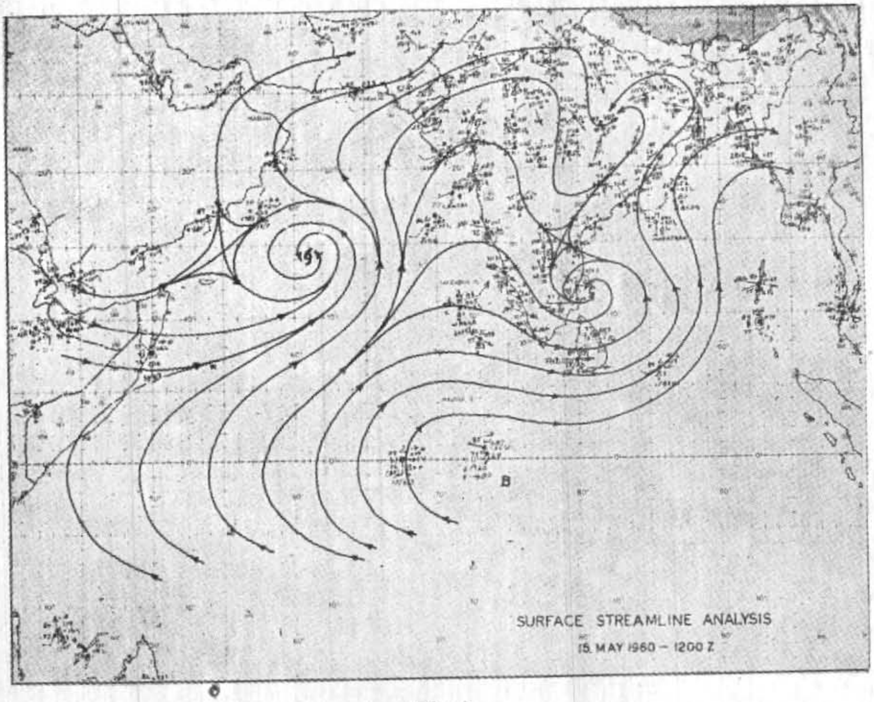

SURFACE STREAMLINE ANALYSIS
15 MAY 1960 – 1200 Z

Fig. 3

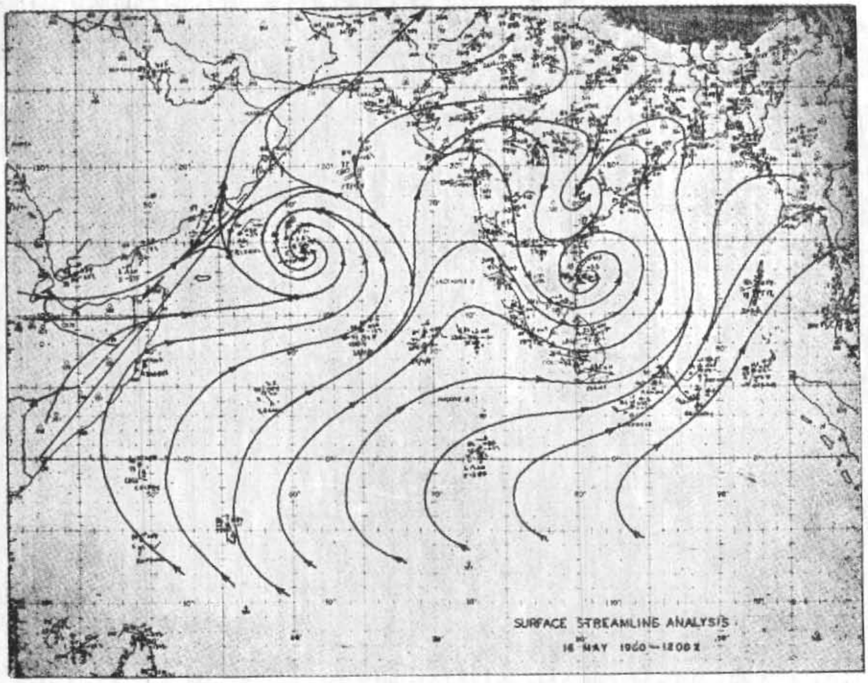
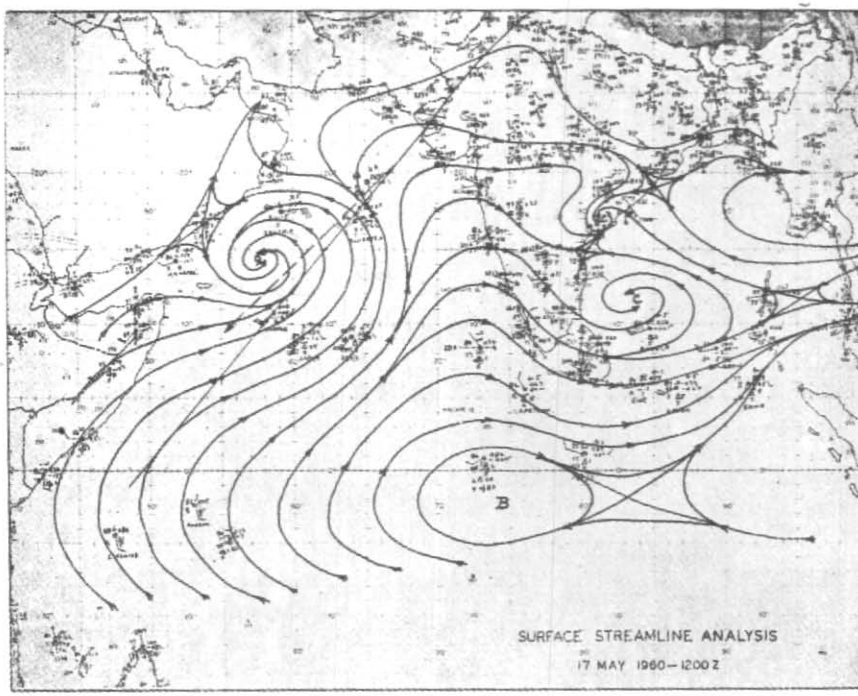

SURFACE STREAMLINE ANALYSIS
16 MAY 1960 – 1200 Z

Fig. 4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17 MAY 1960—1200 Z

Fig. 5

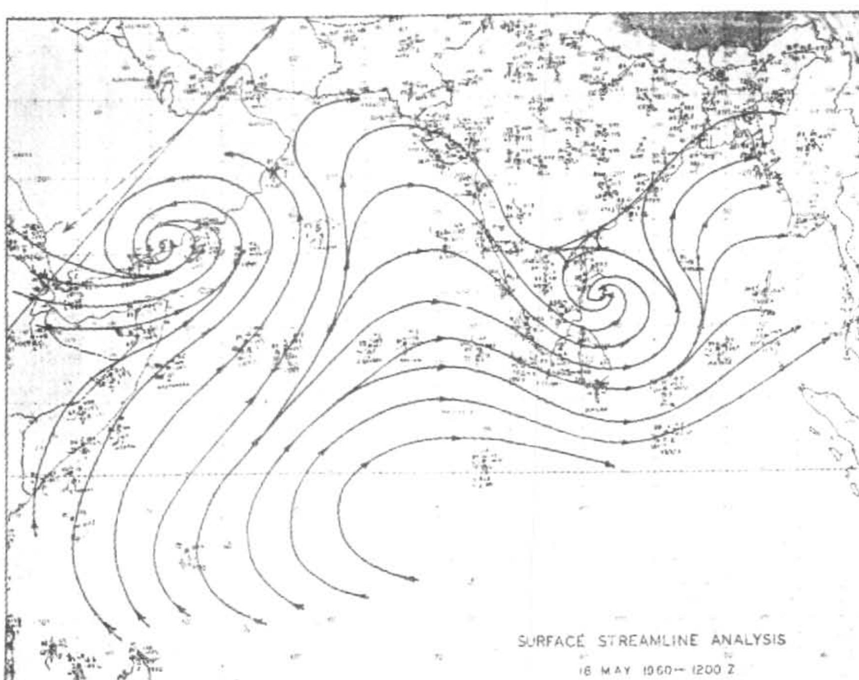
SURFACE STREAMLINE ANALYSIS
18 MAY 1960—1200 Z

Fig. 6

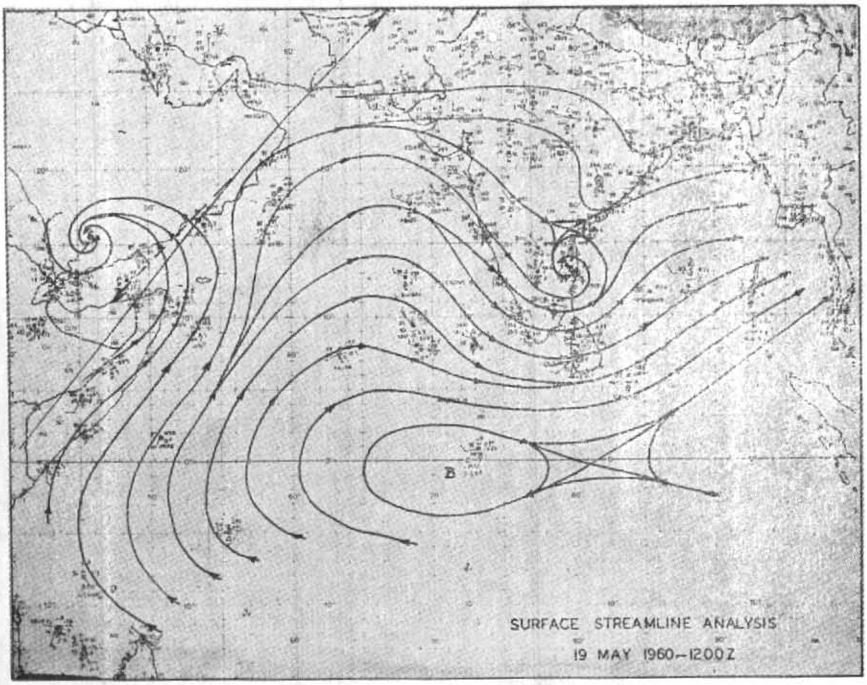
SURFACE STREAMLINE ANALYSIS
19 MAY 1960–1200Z

Fig. 7

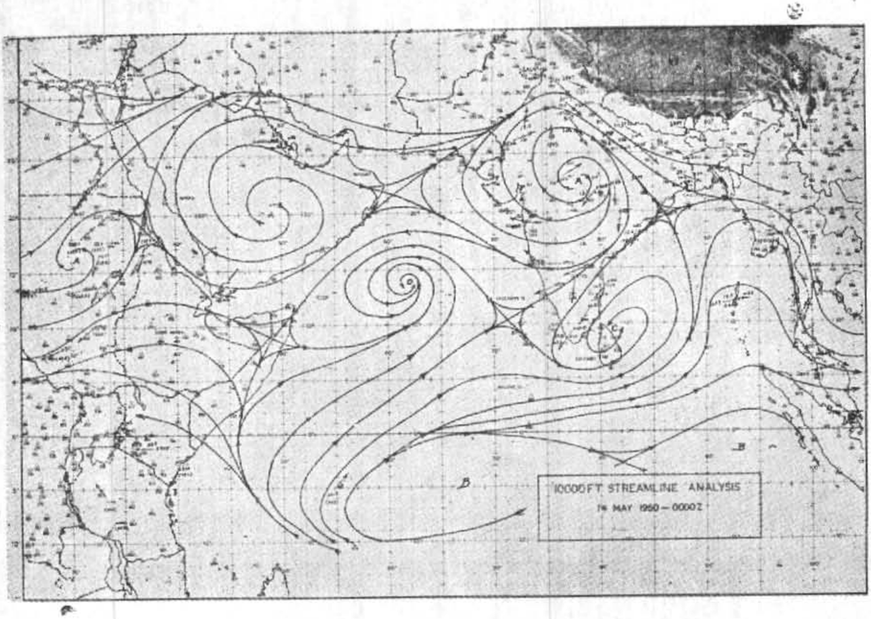
10000 FT STREAMLINE ANALYSIS

Fig. 9

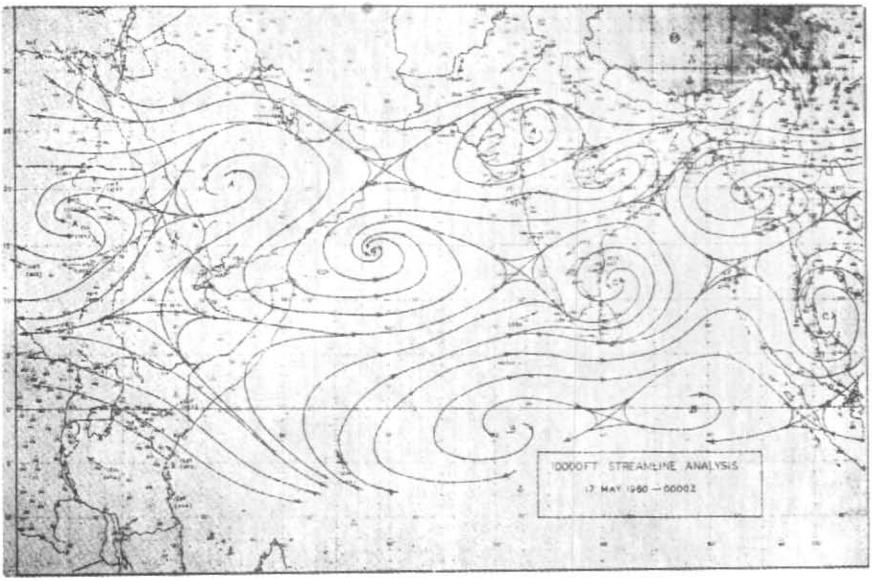
10000 FT STREAMLINE ANALYSIS
17 MAY 1960 — 0000Z

Fig. 9

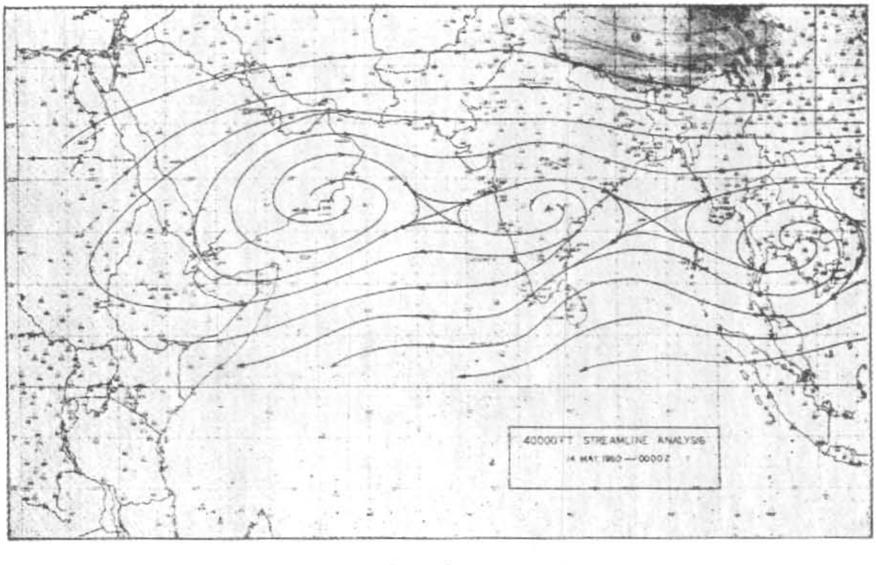
40000 FT STREAMLINE ANALYSIS
14 MAY 1960 — 0000Z

Fig. 10

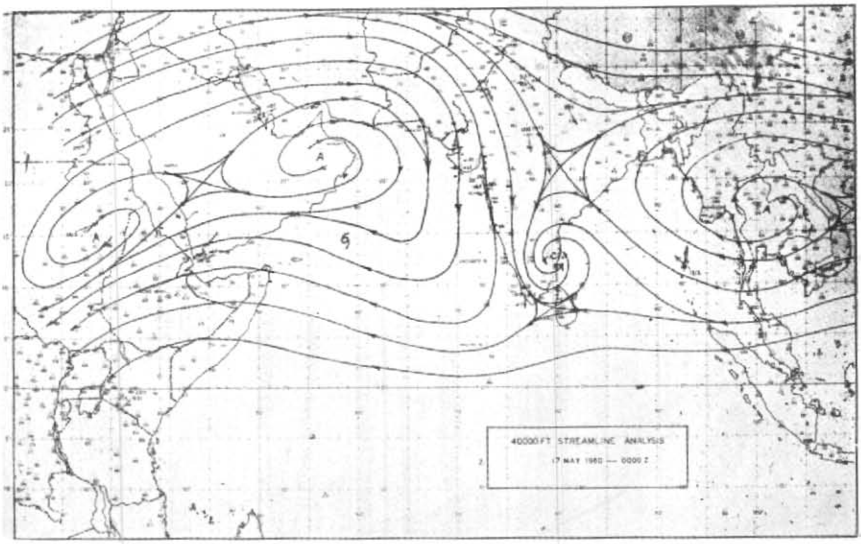

Fig. 11

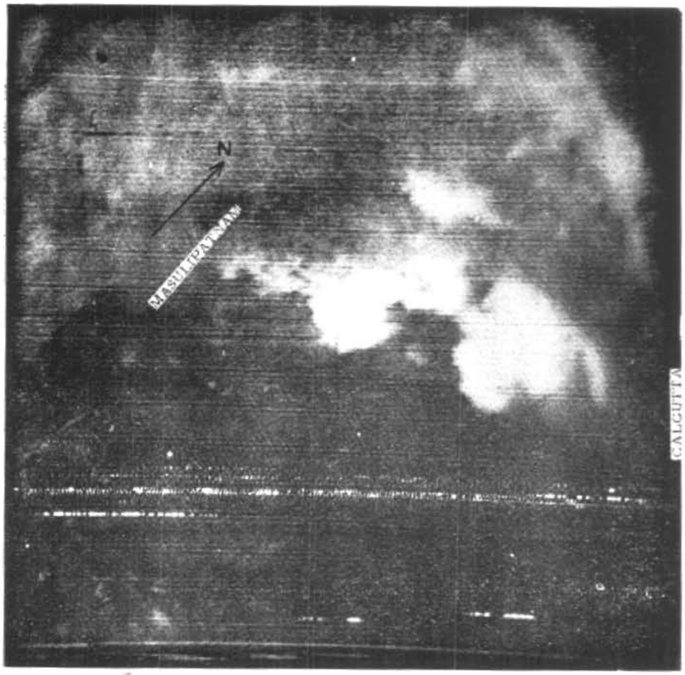

Fig. 12. Isolated thunderstorms along East Coast of India. Orbit 608, Frame 23, 0829 Z, 13 May 1960

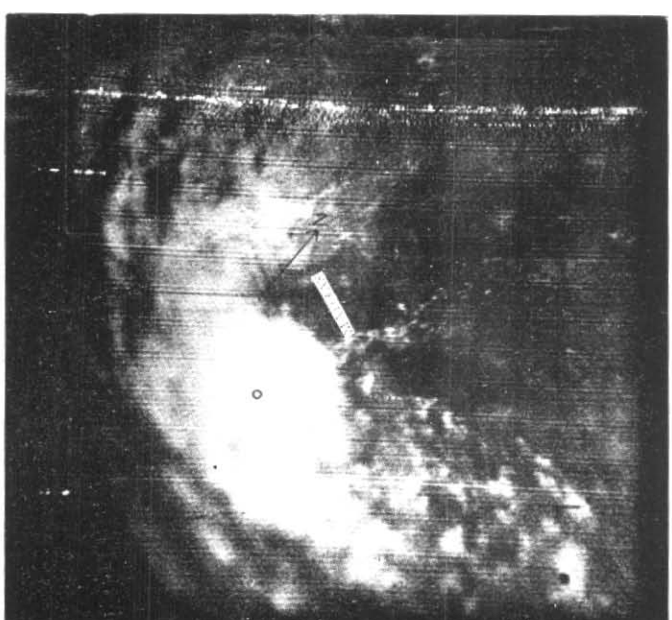

Fig. 13. Cyclonic cell between Ceylon and Southeast Coast of India. Horizon oriented southwest. Orbit 608, Frame 25, 0828 Z, 13 May 1960

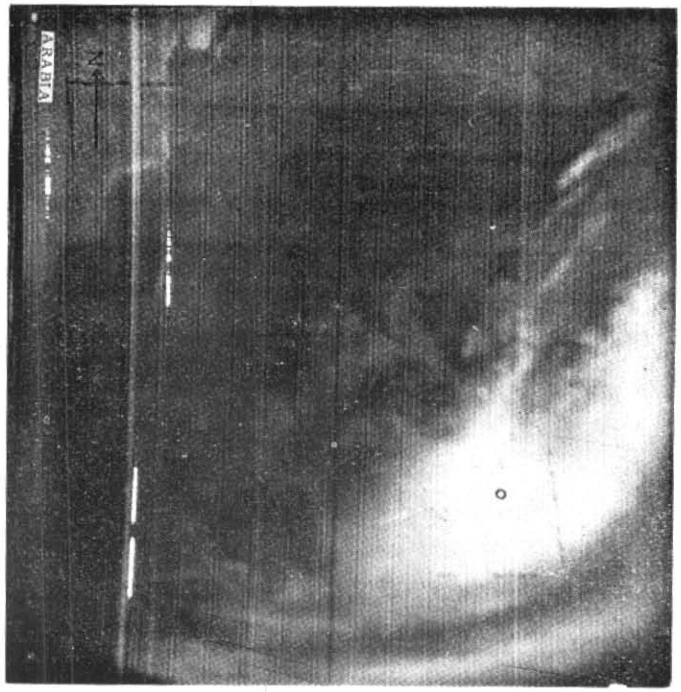

Fig. 14. Cyclonic cell in Arabian Sea. South Arabian Coast visible. Orbit 609, Frame 25, 1017 Z, 13 May 1960

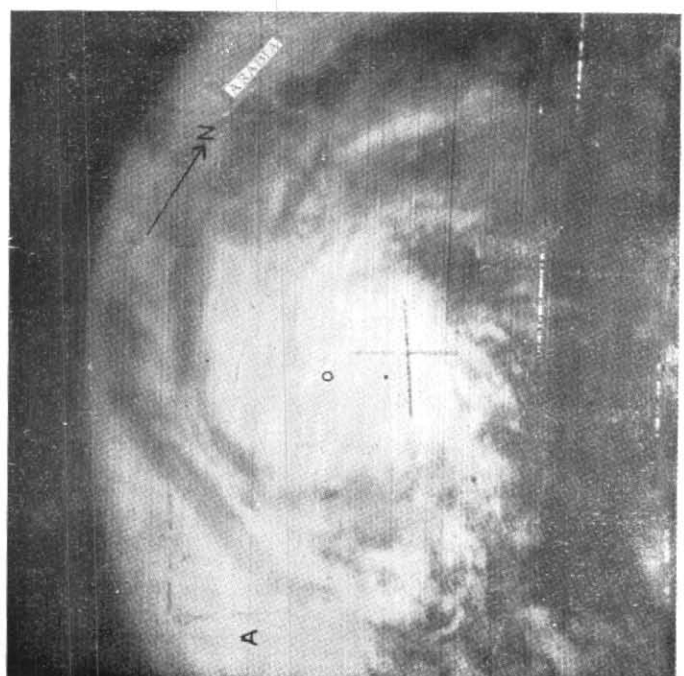

Fig. 15. Tropical storm in Arabian Sea. Horizon oriented southwest, South Arabian Coast in Upper Left. Orbit 623, Frame 25, 0915 Z, 14 May 1960

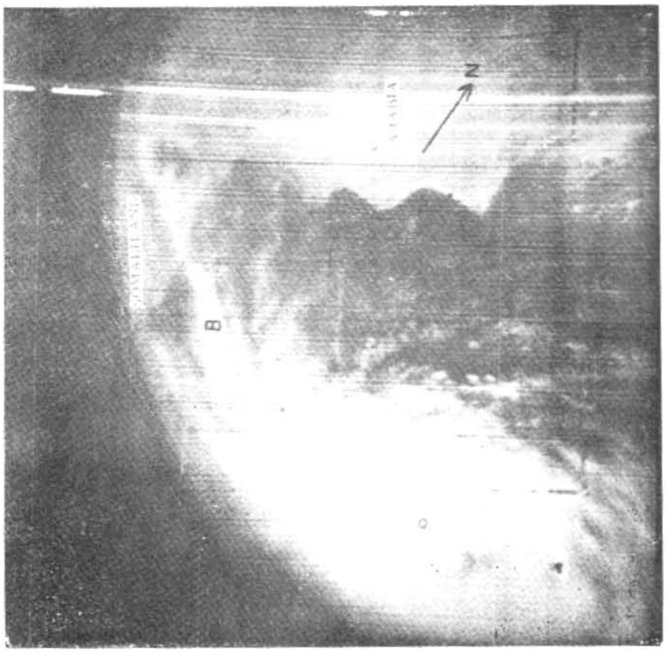

Fig. 16. Hurricane in Arabian Sea. Horizon oriented southwest. South Arabian Coast visible. Orbit 652, Frame 23, 0915 Z, 16 May 1960

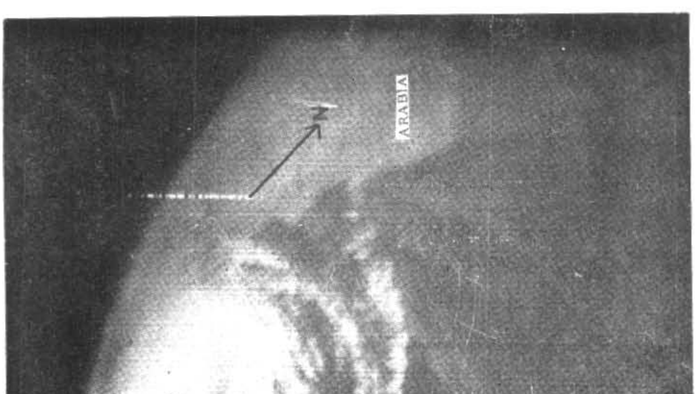

Fig. 17. Hurricane off South Coast of Arabia. Orbit 666. Frame 26, 0820 Z, 17 May 1960

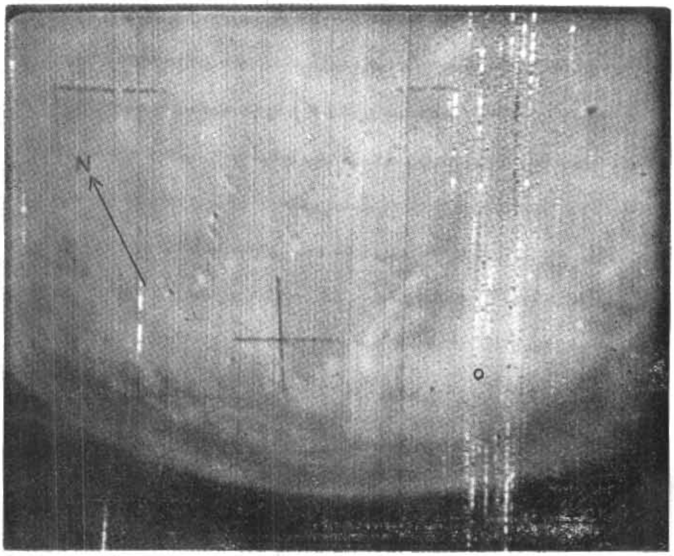

Fig. 18. Hurricane on South Coast of Arabia. Horizon oriented southwest. Orbit 681, Frame 25, 0920 Z, 18 May 1960

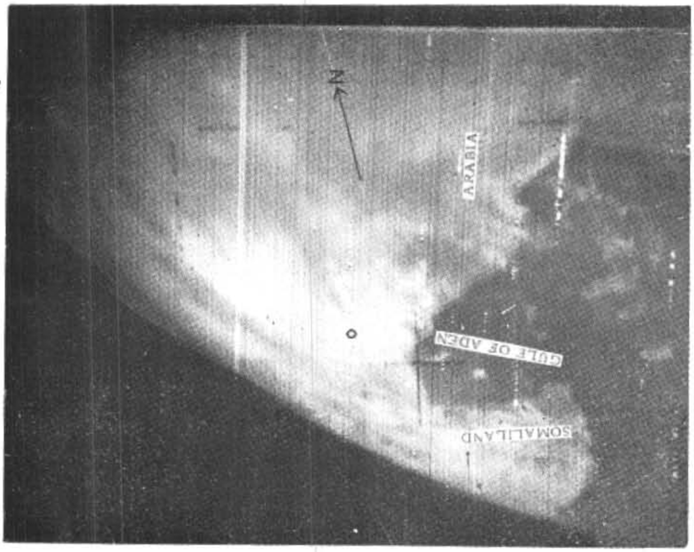

Fig. 19. Hurricane dissipating over mountains of Southwest Arabia. Gulf of Aden and Somaliland visible in Lower Right. Orbit 695, Frame 20, 0850 Z, 19 May 1960

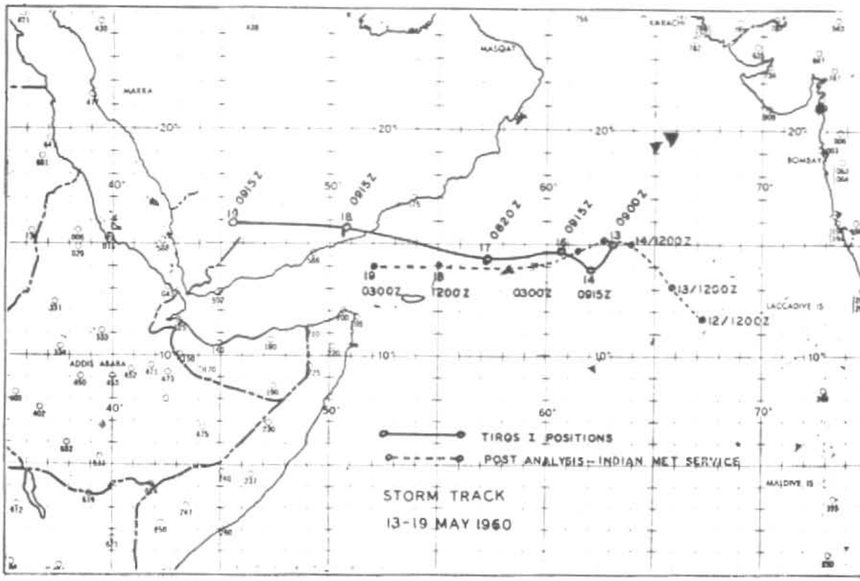

Fig. 20. Comparison of storm tracks determined by TIRCS I and by Conventional Post-Analysis

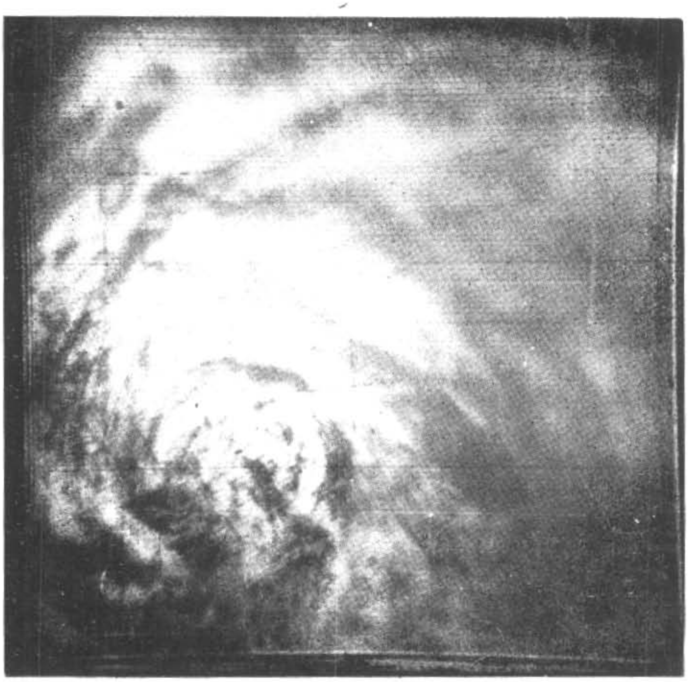

Fig. 21. Weak tropical vortex in Eastern North Pacific Ocean