SURFACE CIRCULATION FEATURES IN THE BAY OF BENGAL AS SEEN IN ERTS IMAGERY

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ABSTRACT

Multispectral scanner data obtained from the Earth Resources Technology Satellite (ERTS) for 14 and 15 September 1972 over the Bay of Bengal show interesting circulation features. Imagery from 0.5–0.6 μm and 0.6–0.7 μm channels show some sediment transport in the Bay along the relatively shallow part of the coastline. A very sharp boundary in the reflectance of the water delineates an area with very little sediment and without any clouds. The absence of clouds can be attributed to relatively cooler water at the surface, inhibiting the growth of low-level convective clouds. An intense tropical storm that crossed the coast over this area on 10 September 1972 mixed the upper layers of the Bay causing a net cooling effect at the surface. Some circulation features in the western section of the Bay can be deduced from ERTS imagery These indicate a counter-clockwise circulation from the head of the Bay of Bengal to 17°N and a clockwise circulation south of 17°N. This is in agreement with the mean monthly circulation patterns published by the U. S. Naval Oceanographic Office.

INTRODUCTION

The oceans cover about seventy percent of the Earth's surface and are subjected to heating, cooling, evaporation, Earth's rotation, winds, tides and pollution. These parameters make the oceans restless and keep them moving. Ocean currents play a major part in transporting heat (energy) from one place to another; they provide rich fishing grounds, and often cause economic and natural disasters by contributing either directly or indirectly to weather patterns such as tropical storms and droughts. Yet these ocean currents and their day to day variations often are poorly understood because of insufficient observations.

With the advent of the Space Age in the early 60's, it became easier to observe some ocean circulation features from the pictures obtained from space (Badgley, 1969; Stevenson, 1969). Major circulation features could be inferred qualitatively from these pictures. Another dimension was added to this information when infrared (IR) radiation measurements from environmental satellites became available. Thermal boundaries could be detected in the IR data and thus could be used to locate surface currents when the skies were relatively cloud free. A number of studies (Warnecke et al., 1968 & 1971; Curtis and Rao 1969; Rao et al., 1971) have shown the potential of such IR data for monitoring major ocean currents. The spatial resolution of those IR radiometers was about 8 kilometres; thus only thermal circulation features with dimensions larger than the resolution could be observed. One of the recent satellites, NOAA-2, carries a Very High Resolution Radiometer (VHRR) with a spatial resolution of about 1 km. The information from this instrument shows detailed thermal features that have never before been observed over such large areas and at such frequent intervals (Strong and DeRycke, 1973).

DATA SOURCE

Another satellite system, NASA's Earth Resources Technology Satellite 1 (ERTS-1), was launched on 23 July 1972. ERTS has been providing very useful information for oceanography, agriculture, geology, hydrology, and other environmental disciplines. An Earth-pointing, stabilized spacecraft in a nearly-polar sun-synchronous orbit at an altitude of 925 km, has a period of 104 minutes and crosses the Equator at approximately 0930 local sun time. Its sensors are capable of very high spatial resolution (about 100 metres). However, the same point on Earth is viewed by the satellite only once in 18 days over most areas; in the polar regions viewing is more frequent.

The ERTS-1 satellite carries a Return Beam Vidicon (RBV) multispectral camera and a Multispectral Scanner (MSS). A complete description of the instruments can be found in the NASA ERTS Data User's Hand Book (1972). The MSS has four channels in the following spectral intervals: Band 4, 0.5–0.6 μm; Band 5, 0.6–0.7 μm; Band 6, 0.7–0.8 μm; and Band 7, 0.8–1.1 μm. The MSS gathers data by viewing the surface of Earth simultaneously in these four bands through a single optical system. The scan width is 185 km and the instantaneous field of view is a square 110 m on a side. The scan is generated by an oscillating mirror in the optical system. Scanned data are transmitted to the ground station and images are recreated for each spectral interval; these data also can be combined to produce colour images.

DATA PRESENTATION AND INTERPRETATION

ERTS-1 MSS data for 14 and 15 September 1972 are used in this study of conditions over the western Bay of Bengal. Pictures in each of the four spectral bands have 10% overlap between successive pictures along a given orbit. The montages shown in Figs. 1, 2, 3, and 4 were produced by cropping each picture. Each montage represents the original data as it came from the satellite. In all four figures the centre of each frame is located by latitude-longitude and the corresponding spectral bands are indicated. Clouds appear to be white and cloudfree areas appear darker. Information at 0.5–0.6 μm generally corresponds to the green-yellow part of the spectrum; 0.6–0.7 μm to the orange–red; 0.7–0.8 μm from red to near–IR; and 0.8–1.1 μm to near–IR portion.

Fig. 1 shows a large cloudfree area over the western part of the Bay of Bangal. The western boundary of the dark and grey area is very sharp in the 0.5–0.6 μm band and not so well defined in the 0.6–0.7 μm band. The southern end of this line of contrast is diffuse. No subsidiary information for this period is available over the centre of the Bay. The East Coast of India is about 40 km west of the sharp boundary and is easily seen through gaps in the clouds in the 0.6–0.7 μm band. The coastline is even more well marked in Fig. 2 because of the high contrast between land and water in the two near–IR spectral bands. The dark area in Fig. 1 is cloudfree and is so indicated in all the bands. The suppression of low-level convection is an indication of relatively cool water at the ocean surface. There will be further discussion of this when the circulation features are discussed. A grey area between cloud clusters is visible (in Fig. 1) between the coastline and the cloudfree area. Charnell and Maul (1973) have shown that, the 0.5–0.6 μm channel has more penetration in water than the 0.6-0.7 μm channel and that there is essentially no penetration in the two near-IR channels. Thus the near–IR data portray only surface characteristics. Using this reasoning, one could conclude that the grey area in the visible bands is probably sediment suspended in the upper few metres of the waters of the Bay. The boundary becomes diffuse to the south, suggesting dispersion or settling of the sediment to greater depths.

Fig. 3 and 4 for the next day, 15 September 1972, show the area just southwest of where it appeared on 14 September. The coastline is visible in all four bands. Again grey areas over the ocean in the 0.5–0.6 μm channel indicate the presence of suspended sediment. A sharp NW to SE boundary can be seen in the 0.5–0.6 μm channel and a faint indication in the 0.6–0.7 μm channel. In the other two channels, the boundary is not visible. One can also notice some sediment plumes in the grey areas along the coastline; these indicate northeastward movement of the surface water. The sharp boundary in Fig. 3 is probably the southern limit of suspended matter; the northern boundary appears in Fig. 1. The features visible in Figs. 1–4 could be attributed to any one of, or combination of events over the area.

On 10 September 1972, a tropical storm crossed the east coast of India at about 18°N (the area shown in Fig. 1), and by 14 September was located over north–central India. A series of pictures of the storm taken by the ESSA–9 satellite on 10th through 15th September are shown in Fig. 5. Corresponding 0000 GMT surface synoptic charts for 11 through 15 September 1972 are shown in Fig. 6. The storm was moderately severe and heavy rains occurred over vast areas in the vicinity of the storm. The suspended matter visible in Figs. 1 and 3 is probably sediment transported into the Bay of Bengal by rivers swollen by rainfall from this storm. Inferences about any surface circulation features based on the information presented above were deferred until the bathymetry of the region was examined. Fig. 7 shows the steep gradient of bottom topography within 50 to 60 km of the shore. Depth increases from 180 to 1830 metres fathoms over a distance of less than 50 km.

Some circulation features can be inferred from these data. Figs. 1 and 2 show a relatively cloudfree area over the north Bay of Bengal, indicating cooler water at the surface. The rain water associated with the tropical storm of 10 September or the cool bottom water brought to the surface by strong mixing caused by the high winds of the tropical storm may be the sources of the cool surface water. Fig. 1 also reveals that the circulation in this part of the Bay of Bengal is counterclockwise and that the cooler mass of water is being transported southeastward. The sharp turbidity boundary between the cool water over the deep basin and the shelf water is in good agreement with the narrow zone in the bathymetry where the depth changes from 180 to 1,830 metres. The suspended matter is transported southward along the shelf; at about 18°N the transport changes to southeastward and eastward thus marking the southern boundary of the counterclockwise circulation. The surface synoptic charts for this period (Fig. 6) show very weak winds over the area.

A close examination of data in the 0.6–0.7 μm band (Fig. 3) reveals sediment plumes oriented towards northeast along the coastline between 17° and 18°N, and a very sharp west-east boundary between water with suspended sediment and relatively clear water (noticeable in the 0.5–0.6 μm band). Unlike conditions shown in Fig. 1, for 14 September, where there are few low–level convective clouds over the clear water area, a fair amount of such clouds appear over this area on 15 September (Fig. 3), indicating no appreciable temperature difference between the two different water masses. The surface charts show winds with a southerly component over this area. Combining all these features, one can conclude that the surface circulation in the Bay is towards north along the coast between 15°N and 17°N and moves towards east between 17°N and 17.5°N; this is indicated by the sharp boundary visible in Fig. 3. From the combined information contained in Figs. 1 and 3, one can surmise that between 17°N and 18°N, there is a region of confluence and the flow is towards east at the surface. Since no satellite data are available over the other parts of the Bay during this period a total reconstruction of the surface circulation features is not possible.

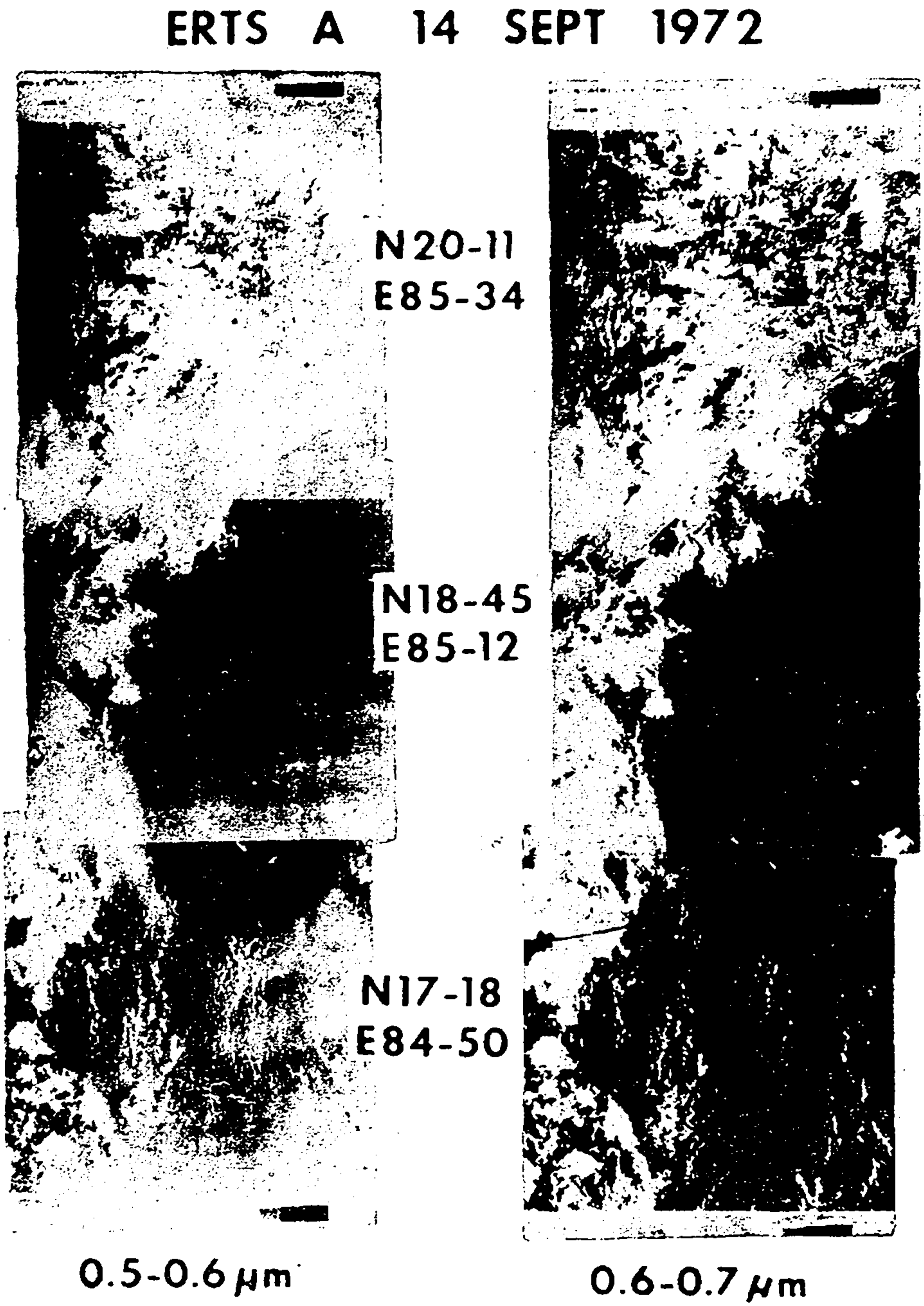

Fig. 1. Montanges of ERTS imagery in the 0.5–0.6 μm and 0.6–0.7 μm bands for 14 September 1972. Latitude-longitude values correspond to the centre of each frame.

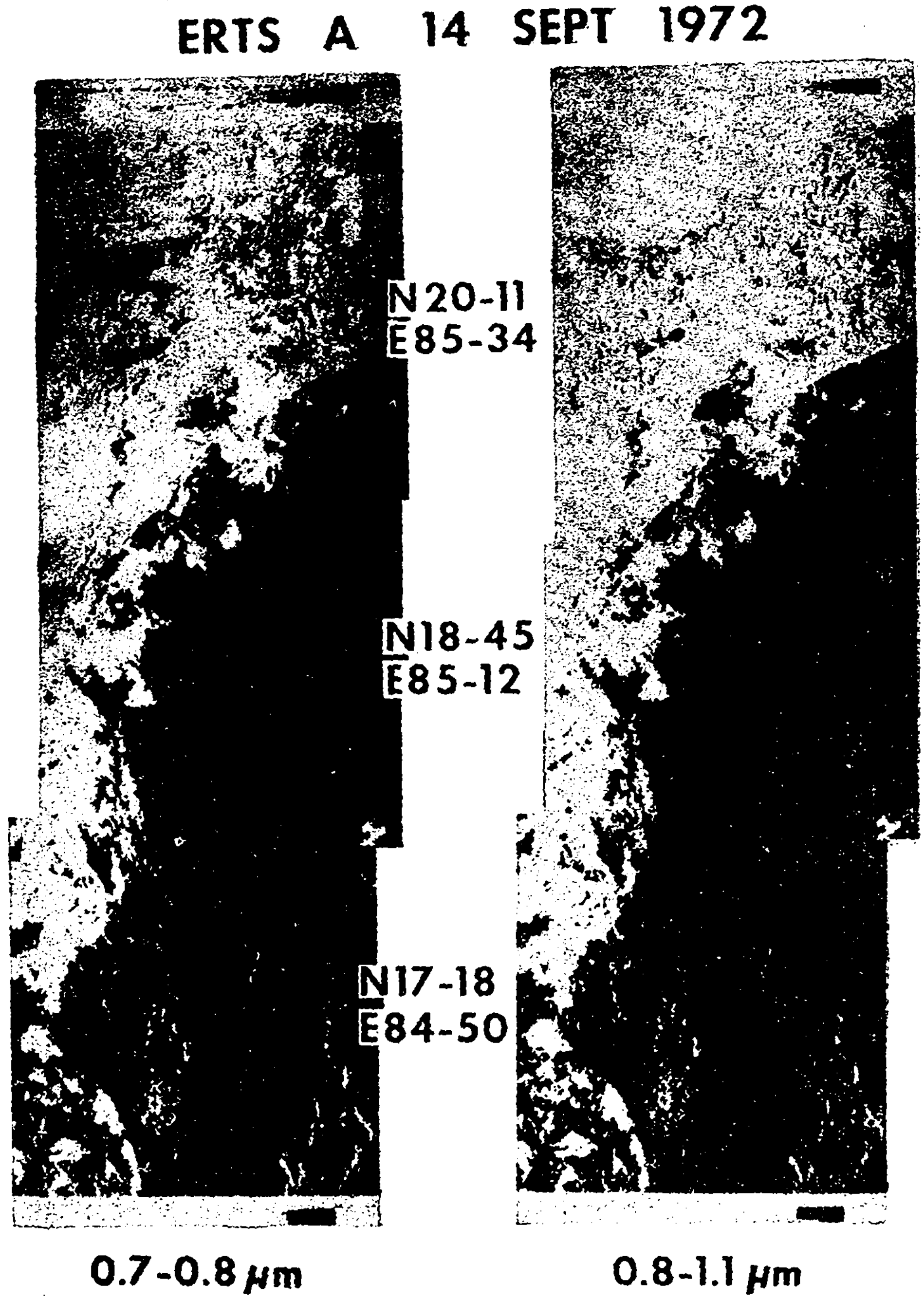

Fig. 2. Montages of ERTS imagery in the 0.7–0.8 μm and 0.8–1.1 μm bands for 14 September 1972. Latitude–longitude values correspond to the centre of each frame.

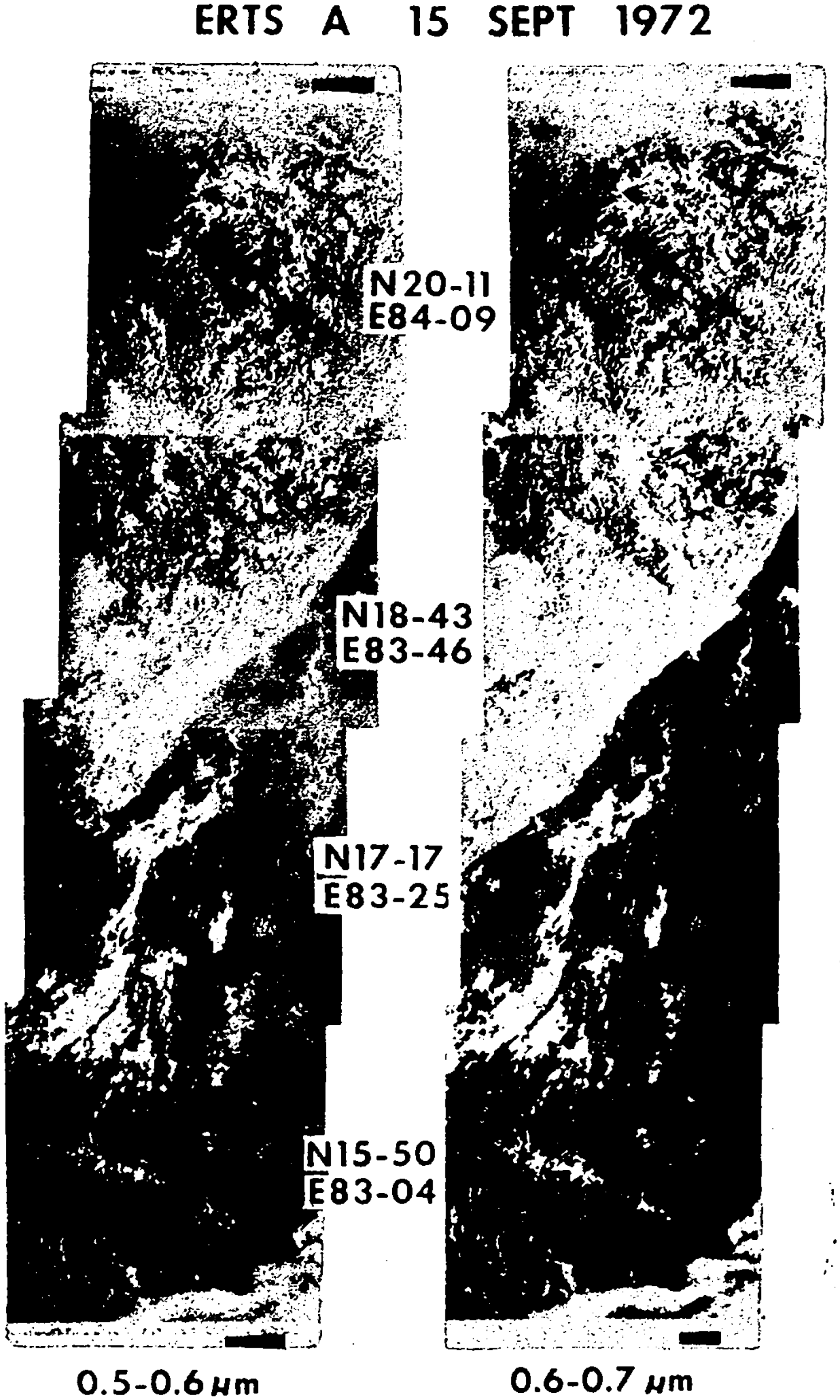

Fig. 3. Montages of ERTS imagery in the 0.5-0.6 μm and 0.6-0.7 μm bands for 15 September 1972. Latitude-longitude values correspond to the centre of each frame.

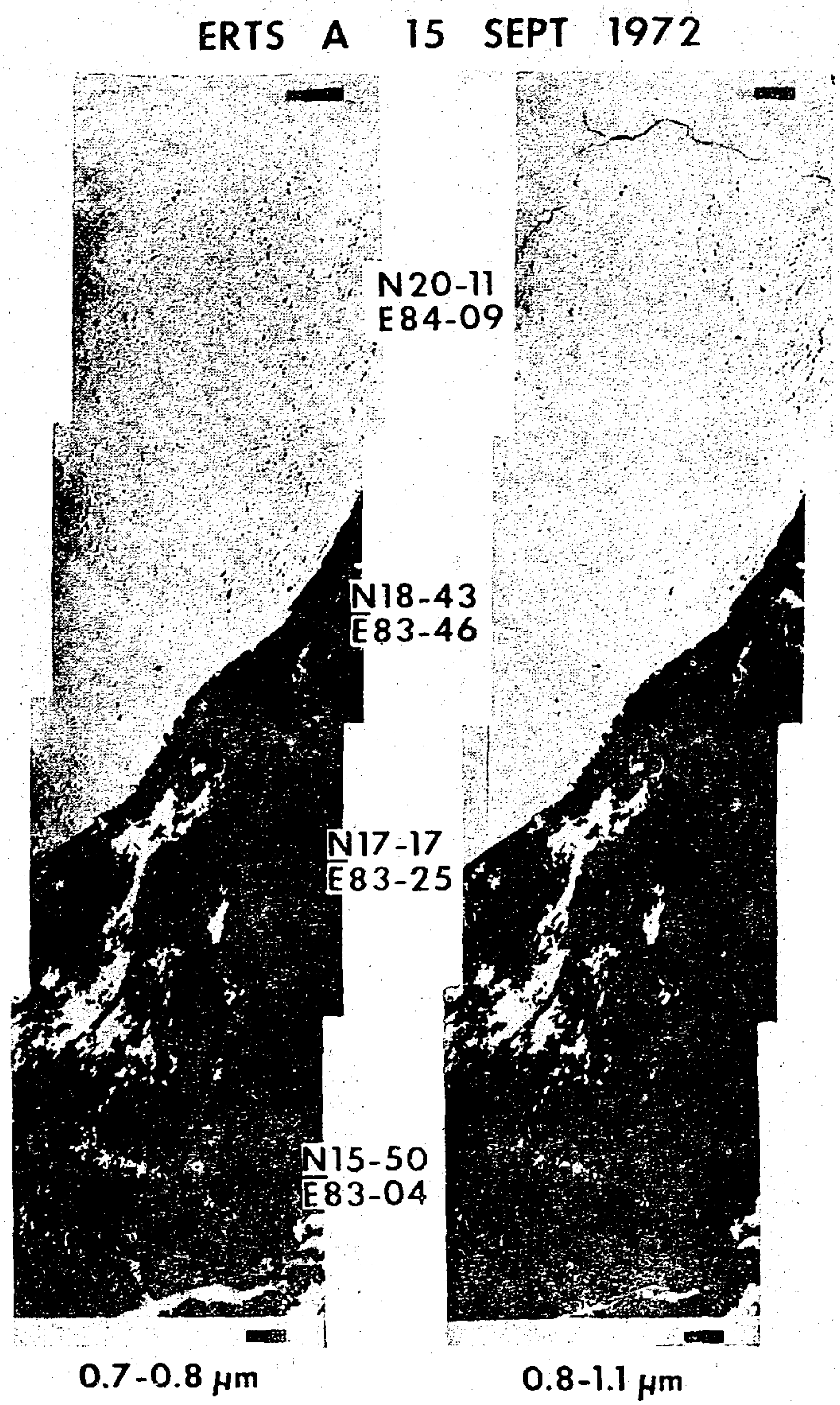

Fig. 4. Montages of ERTS imagery in the 0.7–0.8 μm and 0.8–1.1 μm bands for 15 September 1972. Latitude–longitude values correspond to the centre of each frame.

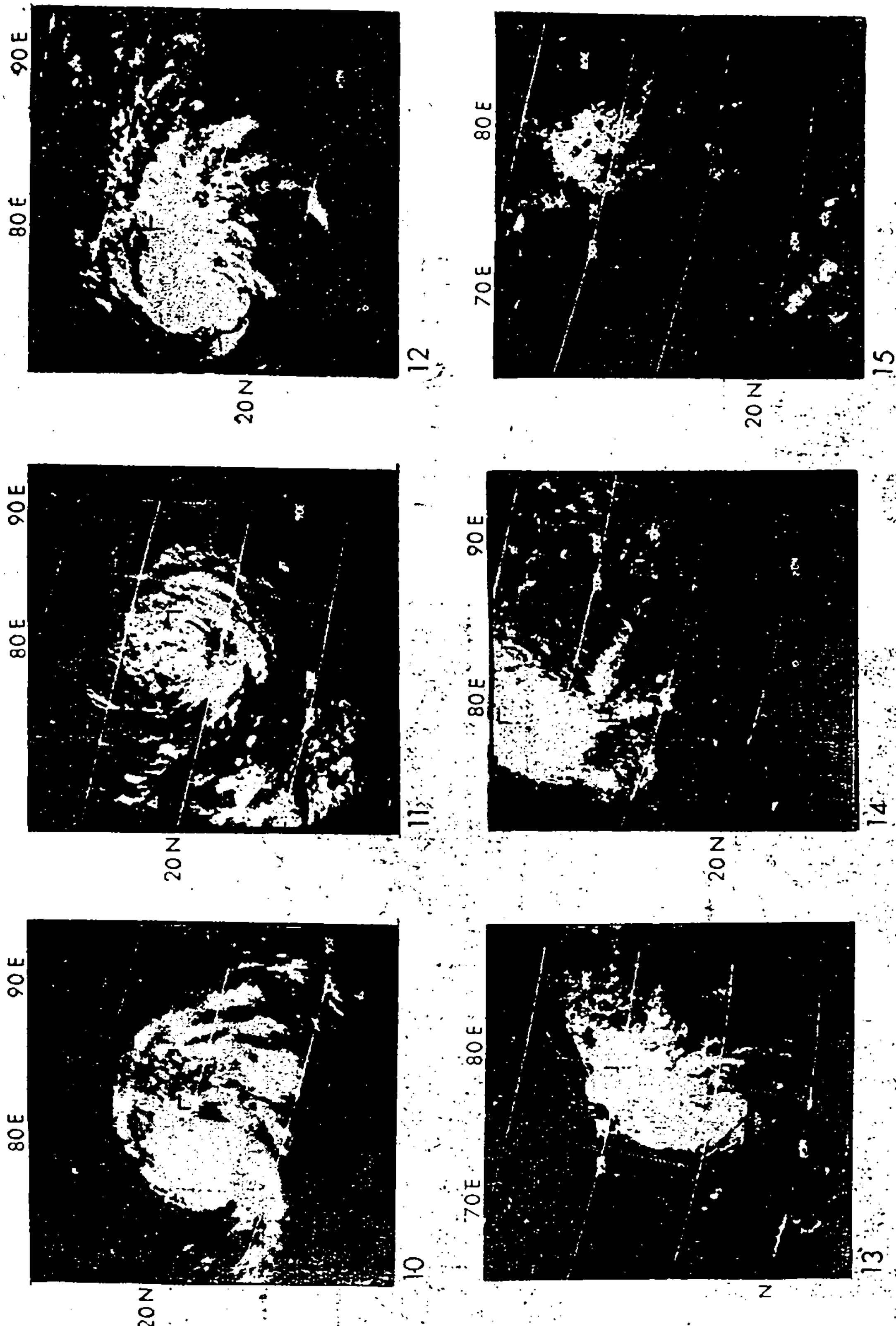

Fig. 5. Imagery obtained from the Advanced Vidicon Camera System on ESSA –9 satellite for the period 10–15 September 1972. The dates are shown at the bottom left hand corner of each picture.

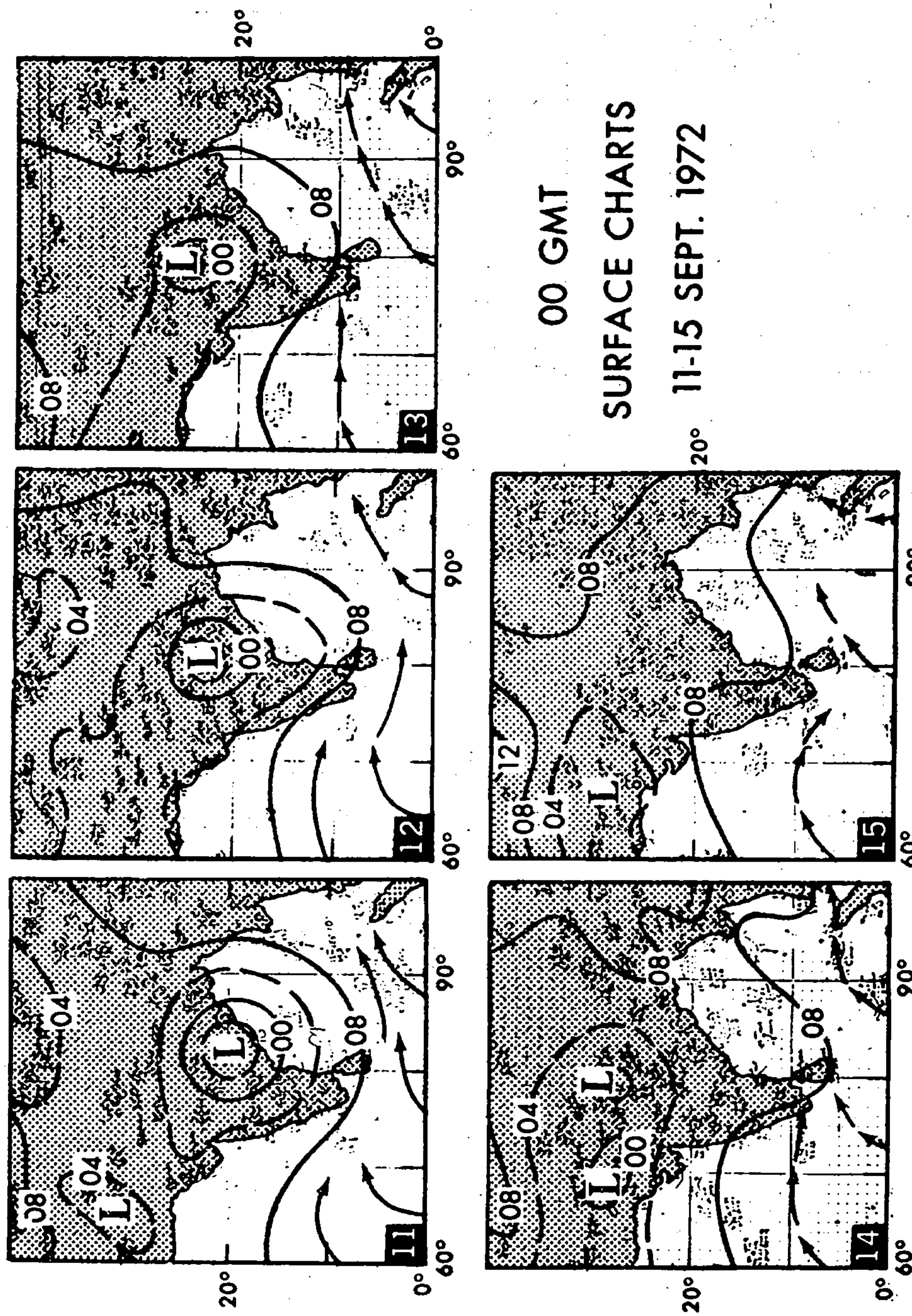

Fig. 6. Surface synoptic charts for 00 GMT for the period 11–15 September 1972.

Of the circulation features inferred from this ERTS imagery, some can be compared with the historical circulation features presented by LaViolette (1967) for the months of August and September (Fig. 8). The August circulation shows a counterclockwise gyre at the head of the Bay and southward flow along the northern half of the east coast of India. A confluence zone is shown at 16°N, 88°E. The circulation features for September show a remarkable change along the east coast of India. Northward flow is replaced by a southward surface flow along the east coast except along the southern end of the peninsula. The circulation features over the western Bay of Bengal deduced from Figs. 1 and 3 are in good agreement with August historical patterns, even though the satellite data are for 14 and 15 September 1972. Even a comparison with the September historical data shows a fair agreement over the northern portion of the Bay, indicating the counterclockwise circulation, but shows disagreement with the flow along the southern part of the peninsula. The location of the confluence zone also disagrees with the September historical data. On the basis of information from ERTS imagery it appears that the August-type circulation shown in Fig. 8 prevailed over the Bay of Bengal during the 14 and 15 of September 1972.

CONCLUDING REMARKS

The limited examples of ERTS multispectral imagery presented here show that it is possible to identify, under relatively cloudfree conditions, some oceanic circulation features. Because of the variations in reflectance, transmit-

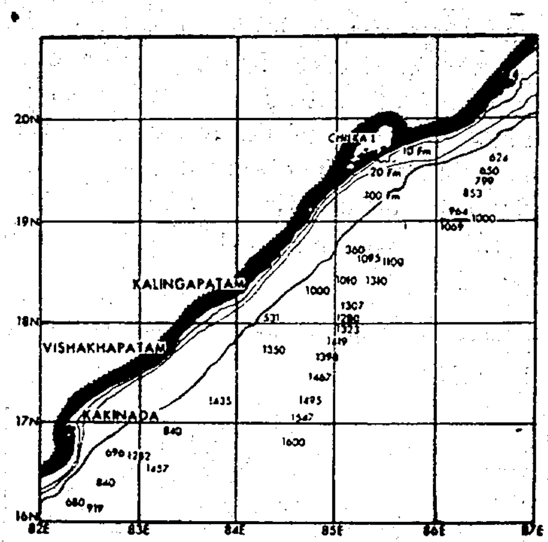

Fig. 7. Bottom topography along the east coast of India. Depths are given in fathoms.

tance, and absorption properties of various water masses and their contents, one can detect the circulation and estimate its horizontal and vertical extent by using the information from bands of the multispectral scanner. Plumes of sediment or suspended material identifiable in these pictures provided a clue to the direction of flow. Even though no thermal infrared observations were available from this satellite, some inferences about surface temperature distribution could be made from the observed cloud type and distribution. A thermal infrared channel is essential for oceanographic studies; data from such a sensor will definitely add an extra dimension of information useful for analysis and interpretation.

Another drawback to the present ERTS obvservations for oceanographic studies is the low frequency of coverage at low and middle latitudes. Coverage, once every eighteen days, will not reveal many of the ocean circulation features and their life cycles. In spite of its drawback, ERTS imagery often does provide sufficient information to permit ready inference of the mechanisms responsible for the observed phenomena. Satellite information combined with surface data coincident in time will provide a more complete picture of various oceanic circulation features.

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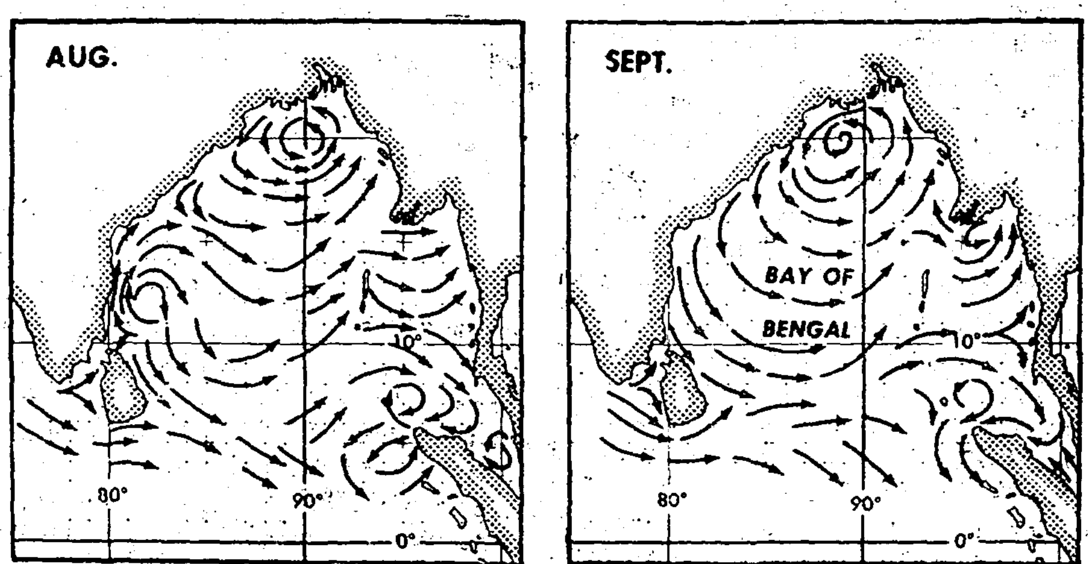

Fig. 8. Surface circulation features over the Bay of Bengal.

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