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Sea-surface temperature distribution over the Arabian Sea determined from satellite infrared radiation measurements

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ABSTRACT. A composite histogram method is used objectively to derive sea-surface temperature distribution over the Arabian Sea and parts of the Indian Ocean. Nimbus III night-time high resolution infrared data for the first six days in November 1969 were selected to make a set of three-day composite charts. Satellite-derived sea-surface temperature distribution exhibited some thermal structure over the Arabian Sea which was first noticed during the International Indian Ocean Expedition. Over most of the Arabian Sea region, the observed temperature change was about 1 degree Kelvin from one three-day period to the next.

1. Introduction

Operational environmental satellites are now carrying high resolution infrared (IR) radiometers; these are designed primarily to map nighttime cloud cover and to estimate cloud-top heights (Rao 1970). If there are no clouds in the field of view of the satellite, these measurements effectively represent the temperature of Earth's surface. It is now possible by means of a technique developed by Smith *et al.* (1970) to derive global synoptic maps of sea-surface temperatures. A number of articles (Warnecke *et al.* 1971; Rao 1968; Curtis and Rao 1969) have discussed the use of data from IR sensors on satellites for locating thermal boundaries and determining temperatures at the ocean surface. The present paper shows the results of a study over the Arabian Sea and the adjoining Indian Ocean area, using the objective technique of Smith *et al.* (1970).

Knowledge of the distribution of sea-surface temperature over large areas is useful for Earth resources studies environmental research and over the eastern hemisphere, sea-surface temperature is particularly useful for understanding the monsoon circulation. Many of the currently available sea-surface temperature data over the Arabian Sea are based on commercial ship reports along the shipping lanes. Some data also are available from few research cruises and aircraft flights conducted during the International Indian Ocean Expedition (IIOE) period (Miller and Jefferies 1967). These data vary widely in space, time and quality, so a complete distribution cannot be mapped for intervals as short as two or three days. Satellite measurements offer the opportunity to provide complete observational coverage over such periods on a continuous basis.

Several Earth-orbiting satellites have already made possible the measurement of sea-surface temperature under relatively clear sky conditions. The examples presented herein are based on measurements obtained from the Nimbus High Resolution Infrared Radiometer (HRIR) for November 1 through 6, 1969. A complete description of the satellite is given in the *Nimbus III User's Guide* (1969). Only nighttime $3 \cdot 8 \mu m$ HRIR data were considered for obtaining sea-surface temperature because the radiation measured at this wavelength during the day is contaminated with reflected solar radiation. The same technique can be used with currently available $10 \cdot 5$–$12 \cdot 5 \mu m$ radiometer data from the Improved TIROS Operational Satellite (ITOS-1) and National Oceanic and Atmospheric Administration (NOAA-1) satellite.

Mapping sea-surface temperatures by means of these infrared observations requires the ability to discriminate Earth's surface from cloud. One might argue that a single measurement represents either a cloud or a ground temperature on the basis of the magnitude of the observed value. However, it is usually impossible to distinguish the difference between relatively low opaque clouds or high thin clouds and Earth's surface in this manner, because the associated temperature differences may be small and within 10°K of one another.

In the histogram method developed by Smith *et al.* (1970) a large number of observations ob-

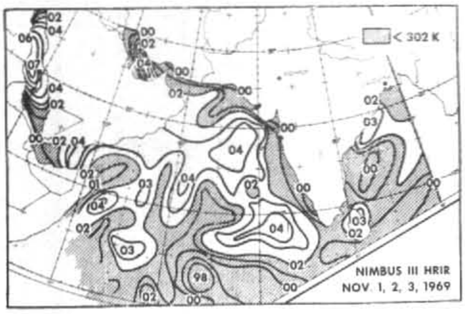

Fig. 1

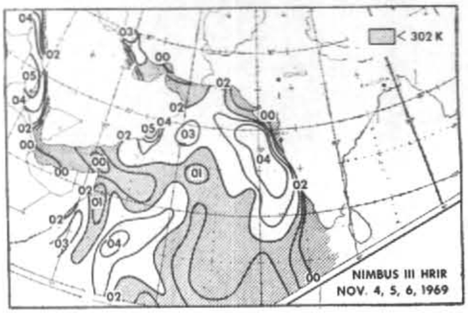

Fig. 2

Three-day composite sea-surface temperature analysis inferred from Nimbus III (nighttime) HRIR data. Isotherms are labelled in degrees Kelvin with the first digit deleted. (Add 300 to values <10; add 200 to values >10.)

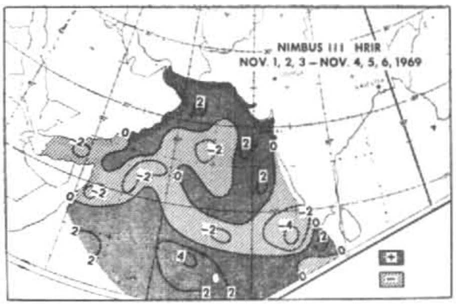

Fig. 3

Sea-surface temperature change over the Arabian Sea derived from Nimbus-II (nighttime) HRIR data during two 3-day periods in November 1969. Temperature changes are given in degrees Kelvin

tained over an area larger than that covered by most clouds, is examined. Using a set of rules (Smith *et al.* 1970), it is possible to derive sea-surface temperatures over most areas that are not completely covered by clouds. The procedure is completely objective and can be executed on a digital computer.

2. Results

Figs. 1 and 2 are three-day composites showing sea-surface temperature distribution over the Arabian Sea and adjoining Indian Ocean. These two figures are parts of the Northern Hemisphere sea-surface temperature maps for 1, 2, 3 November 1969 and 4, 5, 6 November 1969. For large-scale studies of sea-surface temperature as shown in these examples, a grid developed by the National Meteorological Center (NMC) was used. It consists of 64×64 squares over the polar-stereographic projection of each hemisphere; each small grid square is approximately $2\cdot5\times2\cdot5°$ (latiude$\times$longitude) at mid-latitudes. With this grid resolution, there are enough IR observations (approximately 1,024 per grid per day) to define a temperature using the objective technique. Over some areas daily temperatures cannot be derived becuase of persistent cloudiness. But sea-surface temperatures usually can be obtained for such areas by time-compositing, since clouds associated with synoptic systems often dissipate or move out of a region over a three-day period.

These two figures look similar to the one presented by Duing (1970), who used Nimbus II HRIR information for July 1966 for the same area. The analyses in Figs. 1 and 2 show thermal field structure which was lacking in the mean November 1964 surface temperature analysis of the Indian Ocean based on IIOE data (Miller and Jefferies 1967). Also there is a significant difference between the mean temperature distribution shown by Miller and Jefferies and that shown for November in the charts of the Naval Oceanographic Office (1967). In Navy chart there is a very flat thermal distribution over the Arabian Sea, which could be attributed to lack of sufficient ship data for a complete analysis.

In spite of the differences between the structure of the thermal field shown in Figs. 1 and 2, and that of Miller and Jefferies, there are a few areas of good agreement. The low temperatures off the coast of Somali and extreme northern part of Arabian Sea, and another region of relatively low temperatures about 60-65° E between two regions of high temperatures on either side, agree well with the IIOE findings. In general, the satellite-derived temparatures over relatively cloud-free areas seem to be 2°C higher than the temperatures reported by Miller and Jefferies (1967). It should be pointed out that the differences between the two temperatures can be attributed to a number of factors: (1) errors in either or both of the measurements; (2) the fact that the radiation temperatures measured from satellites are most closely related to the surface "skin" temperatures, whereas sea-surface temperatures reported by ships are usually the "subsurface" temperatures, taken at depths to 10 m. Although the two measurements should not be drastically different, significant differences can occur, depending on the wind speed and surface conditions (Saunders 1967).

The warm regions located between 50-55°E and 0-10°N, 60°E and 20°N, 70°E and 20-25°N in Figs. 1 and 2 are probably part of a gyre in the Arabian Sea area. A similar small spiral structure was shown by Duing (1970) in his analysis of Nimbus II HRIR data over the Arabian Sea for July 1966. His analysis of ship data for November 1964 showed a small gyre over the same area; an average diameter size of 450 km was estimated.

Fig. 3 shows the temperature change over the Arabian Sea area from the first period (Nov 1, 2 and 3, 1969) to the second three-day period (Nov 4, 5 and 6, 1969). Except over very small areas the absolute magnitude of the change has been 1°C, the magnitude of change one should expect over large oceanic areas. The larger changes may be due to changes in local cloud conditions. Even in the change chart the gyre over the Arabian Sea can be perceived.

During the monsoon season thermal structures such as these can be related to the monsoonal circulation of the atmosphere (Duing 1970). Recently Saha (1970) related zonal anomalies of sea-surface temperature to the strength of the monsoon circulation. He used mostly climatology and average values over fairly large areas to obtain the anomalies. Small-scale features, such as those shown here and by Duing, will be neglected if only climatological values and a few widely scattered observations are used in temperature analyses.

3. Summary

Multi-day composites of sea-surface temperatures over the Arabian Sea objectively derived from satellite IR data have been presented. Such mapped distributions cannot be obtained from any other platform unless data collected during several days are composited. Some of the thermal structure exhibited in the satellite-derived data agreed well with features of the IIOE analyses derived from less complete coverage by ships and aircraft. Global analyses of sea-surface temperature distribution based on satellite IR data, when available operationally, will be particularly useful over vast areas of the Indian Ocean where conventional observations are few and widely scattered.

As Saha (1970) has shown, such thermal information can be related in a meaningful way to other environmental parameters in understanding the anatomy of the monsoon circulation. Over vast oceanic areas where satellites are the sole source of thermal data, such information should be exploited to the maximum.

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