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OCEANOGRAPHIC APPLICATIONS OF COLOR-ENHANCED SATELLITE IMAGERIES

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ABSTRACT

Black and white infrared imageries obtained from satellites over the oceans were transformed into color presentations.

Investigations in different regions (Persian Gulf, Arabian Coast, Somali Coast and the Northwest Coast of Australia) revealed that temperature gradients and temperature differences of two degrees Celsius can be displayed by the color process from the imageries. This data display can be used for a rapid analysis of information obtained with an APT station.

CONTENTS

OCEANOGRAPHIC APPLICATIONS OF COLOR-ENHANCED SATELLITE IMAGERIES

I. INTRODUCTION

Future expeditions during the International Decade of Oceanic Exploration (IDOE) will be in areas where upwelling occurs. The planning for these expeditions includes the use of Automatic Picture Transmission (APT)-type stations in the areas of the expeditions to obtain the Direct Readout Infrared (DRIR) information from satellites and then to convert the data into useable form by means of a near real-time processing procedure. One means of realizing this goal is to interpret satellite imagery telemetered from space and received by a ground station. This paper presents the results of detailed analysis of black and white imagery obtained from satellites. The densities in the black and white imageries were transformed into color presentations. The investigations were made for regions where concurrent sea surface temperature analysis has been performed, such as the Persian Gulf (Szekielda, et al., 1970), the Somali Coast (Szekielda, 1970) and the northwest coast of Australia.

II. DESCRIPTION OF EQUIPMENT

The equipment used in the color interpretation technique described in this paper was the Spatial Data Systems, Datacolor Densitometer, Model 702-12, located at Navy Weapons Engineering Support Activity Detachment (FAMOS), Suitland, Maryland. This equipment consists of (1) a light box to back-light film positives of satellite photographs, (2) a precision monochrome television camera to convert the transmitted light to an electrical video signal, (3) an analyzer that separates the shades of gray or voltage levels in the video signal into 12 colors and encodes the levels into color television signals and (4) a color television monitor for reproduction of the transparency in the original black and white or in the color analysis. The 12 colors which the equipment is capable of producing are white, dark blue, light blue, dark green, light green, olive, brown, gold, red, magenta, violet and black. The gray scale in satellite infrared imageries is transformed into colors from white (cold) to black (warm) with increasing temperatures indicated by the color steps enumerated above.

III. ANALYSIS AND INTERPRETATION

A. Persian Gulf

The Persian Gulf has a well-pronounced seasonal temperature variation which is reflected in the historical mean values shown in Figure 1. During the summer months the highest temperatures reach 33 C whereas during winter the mean value is 22 C. However, the maximum temperature which has been reported is 36 C and the observed minimum has been 13 C. Therefore, the Persian Gulf is an excellent area for the investigation of the capability of sensing temperatures from space platforms.

Szekielda, Salomonson and Allison (1970) showed that seasonal changes in sea surface temperatures (SST) could be monitored by the Nimbus 2 satellite, reporting a mean difference of 1.3 C between the southern and northern portions of the Gulf.

Figure 2 shows an example of the Nimbus 2 HRIR black and white imagery.

In Figure 3, the same imagery as Figure 2 was used to produce the three color analyses of the northern Arabian Sea. In Figure 3(a) it is shown that the southern part of the Persian Gulf is warmer than the northern part. This is well illustrated by the black area in the photograph. Figure 3(b) was enhanced to show in more detail the distribution of warm water in the northern Arabian Sea. Filtering out the colors in the red spectrum produced the photograph in Figure 3(c). The blue shades are representative of the distribution of warm water in the Persian Gulf and along the Arabian Coast. The warm water along the Arabian Coast is not coming from the Persian Gulf since the outflow from the Gulf lies at depths between 100 m and 200 m. An explanation for the presence of the warm water is the heating of this water mass at the end of the southwest monsoon period when upwelling and vertical mixing are reduced by diminishing winds.

For a comparison between the color representation of temperature structures and the analysis of digitized data, Figure 4 shows the temperature distribution obtained from the same orbit as the photographs in Figure 3 but derived from computer-produced grid print maps. The southern area shows a separated warm water pocket with temperatures above 34 C. The high temperature can be explained by the system of currents and the bottom topography in this area. The topography in the southern portion is flat so that the entire incoming solar energy will be accumulated in a relatively thin layer.

This study illustrates that with proper color enhancement, temperature differences of two degrees Celsius can be easily recognized. Significant temperature structures can therefore be obtained if the skies are cloud-free.

B. Australian Coast

Detailed investigations of the temperature distribution along the northwest coast of Australia using Nimbus 2 HRIR data are under way. However, no conclusive summary of this work can be given at this time.

Figure 5 shows the black-body temperature (T_{BB}) distribution for August based on a composite of two orbits, and one analysis for September. Both charts show the temperature decrease in the southwest direction, although the temperatures are somewhat cooler in August. The area covered by temperatures below 22 C in the August composites may represent a region where upwelling occurs. No reports of upwelling along the Australian Coast are available so that it probably does not have the importance of other known areas of upwelling (i.e., Somali Coast, Northwest Coast of Africa, etc.).

Temperature fluctuations in a region where the most cloud-free orbits were obtained with Nimbus 2 have been observed from May to September. The region studied is illustrated in Figure 5. Figure 6 shows the mean T_{BB} values for this region. Each point is based on approximately 300 measurements (single "scan spots"), therefore the data are significant enough to give a resolution better than one degree Celsius. A temperature minimum was found in August. At that time the colder water was detected farther southeast which was visible in the infrared imageries after color enhancement. During May warming of the water masses along the east coast of Australia is indicated.

Figure 7 shows two orbits along the west coast of Australia analyzed with the color densitometer. The analysis of these orbits shows warmer water which is probably transported along the coast from the northeast. An interesting feature is the separated warm water areas which appear in the color enhancement as purple. A more detailed satellite data analysis should give an explanation for the building of these separated warm zones.

C. Somali Coast

Studies using Nimbus 2 and Nimbus 3 HRIR data have shown a very complicated SST structure along the Somali Coast and in the Gulf of Aden. During the southwest monsoon, strong upwelling appears along the Somali Coast, the development of which could be observed with infrared measurements from satellites over a period of six months.

A generalized diagram of temperature distribution during the upwelling period is shown in Figure 8, as constructed from ship observations. Near Ras Hafran, temperatures below 16 C were observed. This cold water has its origin at a depth of about 200 meters and transports high concentrations of nutrients to the surface.

Figure 9 shows the color analysis of an orbit obtained with Nimbus 4 THIR during daytime on June 25, 1970. Two different color enhancements were tried. In Figure 9(a) the temperature pattern in the Gulf of Aden was selected. Temperatures were found to be higher in the middle of the Gulf than in the adjacent sea. This agrees with the results obtained with Nimbus 1 (Allison and Kennedy, 1967), Nimbus 2 and Nimbus 3 (Szekielda, 1970). In Figure 9(b) the upwelling area along the Somali Coast was enhanced in the Nimbus 4 imagery to show the cold water as blue-green. With this analysis cold water along the Arabian Coast is also detectable. The temperature distribution along the Somali Coast shows that cold water is also found far from the upwelling region. This cold water is transported in an anticyclonic movement away from the coast.

The Nimbus 2 data show a very sharp temperature gradient at the exit of the Gulf of Aden, which was confirmed by ship measurements. An analysis of T_{BB} for September 11, 1966 is shown in Figure 10. The temperature variation outside the Gulf of Aden is between 24 C and 31 C. The corresponding analyzed infrared imagery is given in Figure 11. The sharp temperature gradient is recognizable in the area by the color change from brown to red.

IV. CONCLUSIONS

These investigations show that the color densitometer does afford the capability to interpret black and white satellite imageries in detail sufficient for oceanographic application. It is apparent from this study that temperature differences as small as 2 C can be detected. With ground stations strategically located, research vessels can be directed immediately to regions of upwelling if cloud-free conditions occur. As long as an APT station provides similar quality in the pictorial data display, the equipment could be used for a rapid data analysis of real-time satellite readout.

ACKNOWLEDGEMENT

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Szekielda, K.-H., V. V. Salomonson and L. J. Allison (1970): Seasonal sea surface temperature variations in the Persian Gulf as recorded by Nimbus 2 HRIR. NASA X-651-70-416.

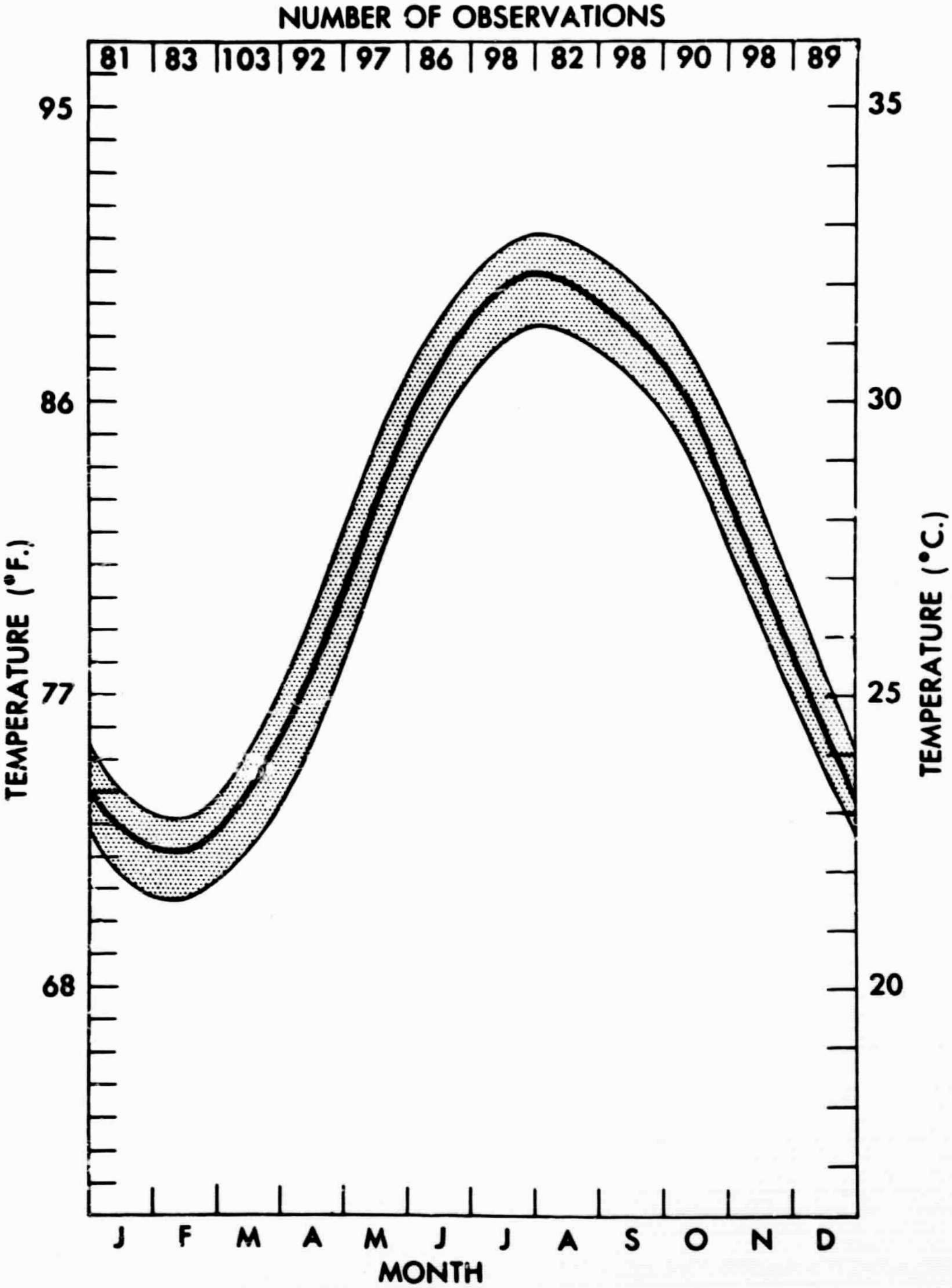

Figure 1. Seasonal Temperature Change in the Persian Gulf Based on Historical Data (After LaViolette and Mason, 1967)

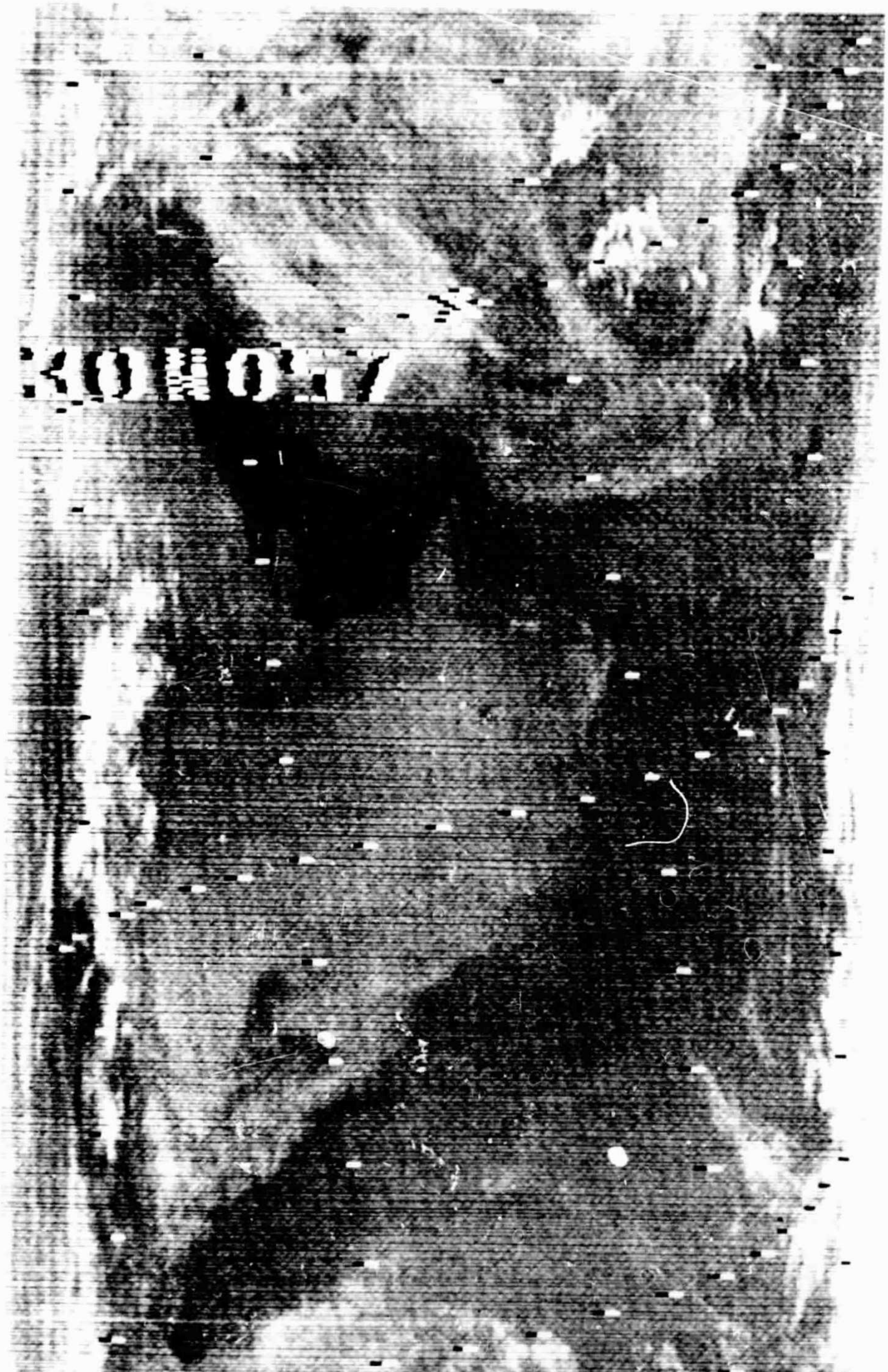

Figure 2. Nimbus 2 HRIR Imagery, Orbit 1804, 27 September 1966, Over Arabia and Iran

(a) (b) (c)

Figure 3. Color Analysis from Nimbus 2 HRIR Imagery over the Northern Arabian Sea, 27 September 1966 (for Explanation, See Text)

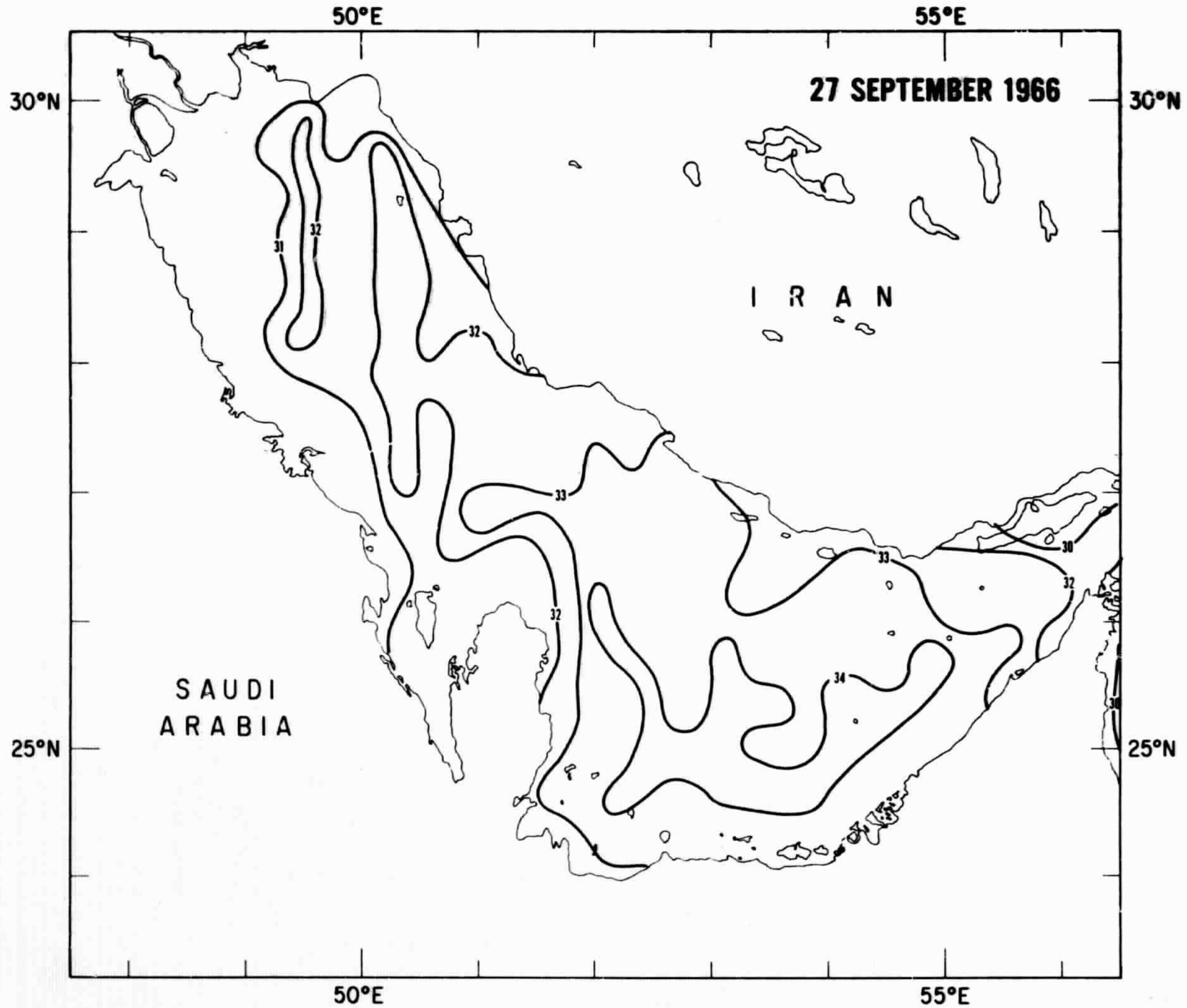

Figure 4. Equivalent Blackbody Temperature Distribution in the Persian Gulf as Obtained with Nimbus 2 HRIR, (Temperatures in Degrees Celsius).

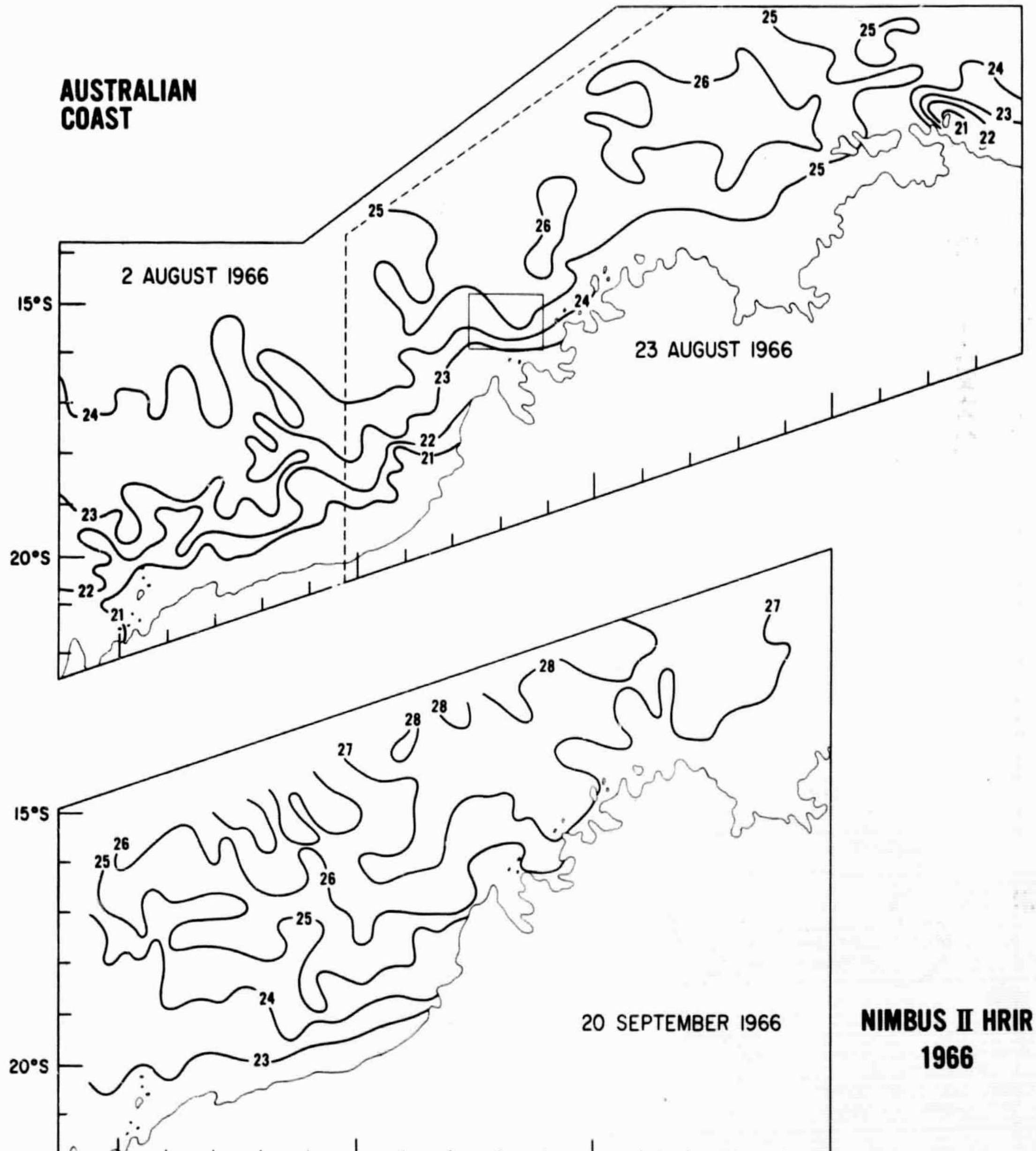

Figure 5. Equivalent Blackbody Temperature distribution along the Northwest Coast of Australia, (Temperatures in degrees Celsius). The rectangle in the upper portion shows the location where the observations in Figure 6 were made.

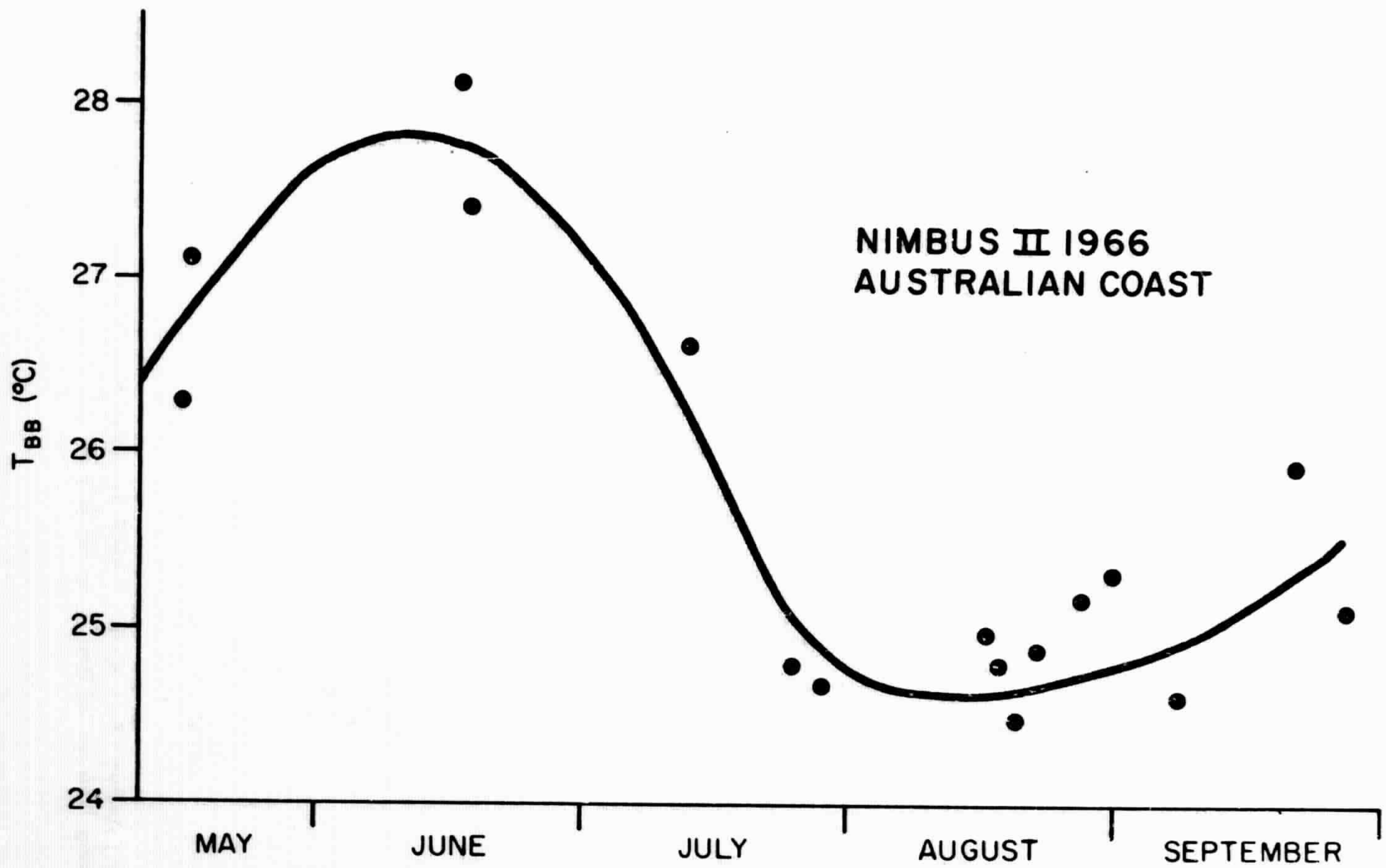

Figure 6. Equivalent Blackbody Temperature Variations at the Northwest Coast of Australia as Observed with Nimbus 2 HRIR During 1966.

(b)

(a)

Figure 7. Color Analysis from Nimbus 2 HRIR Imageries Along the Northwest Coast of Australia During 1966 — (a) May 24 — (b) July 27

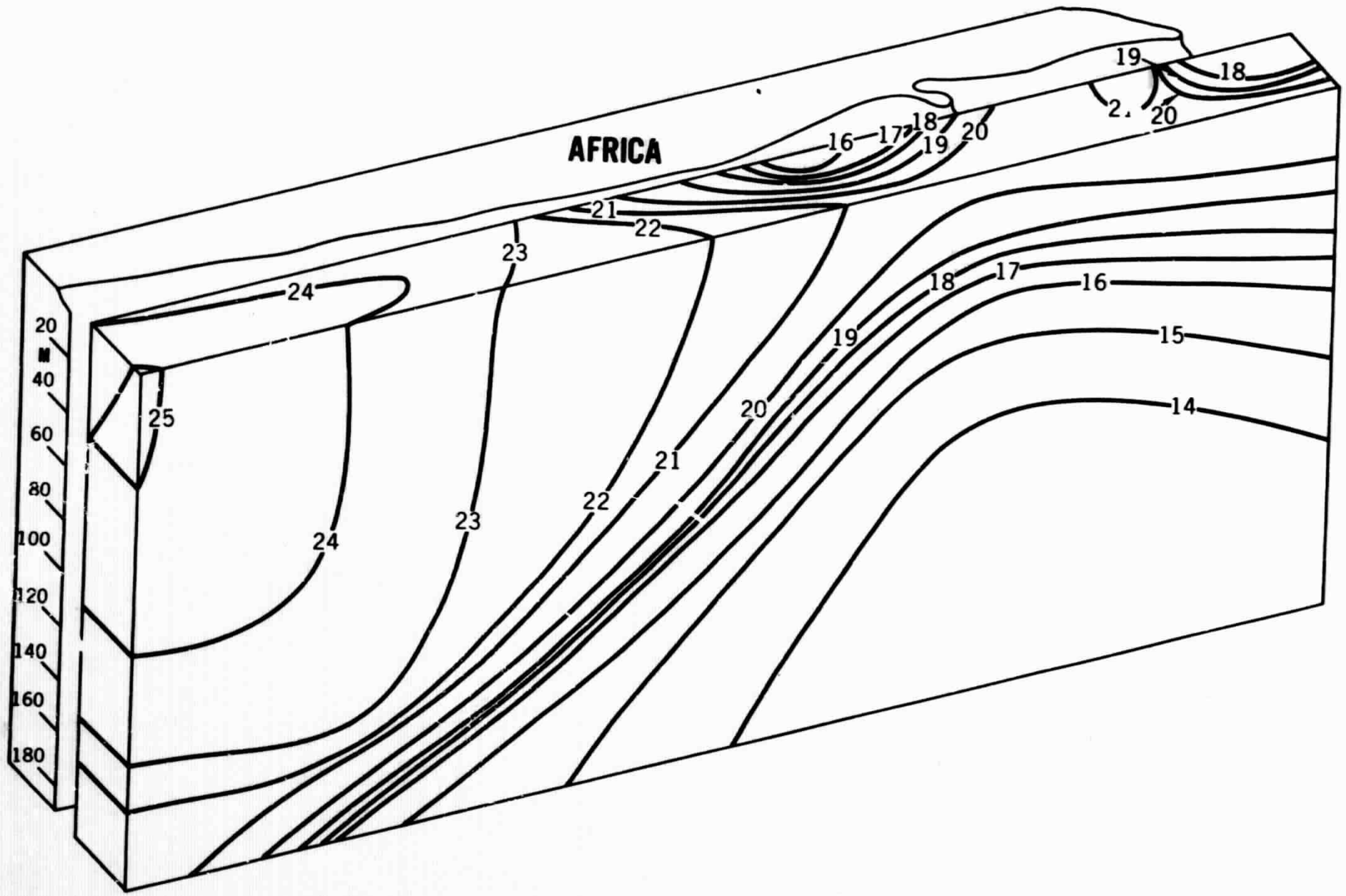

Figure 8. Temperature distribution along the Somali Coast during the Southwest Monsoon. The diagram is based on ship observations.

(a)

(b)

Figure 9. Color analysis from Nimbus 4 THIR imagery along the Somali Coast (June 25). The original data were obtained during daytime in June in the 11.5 micron window.

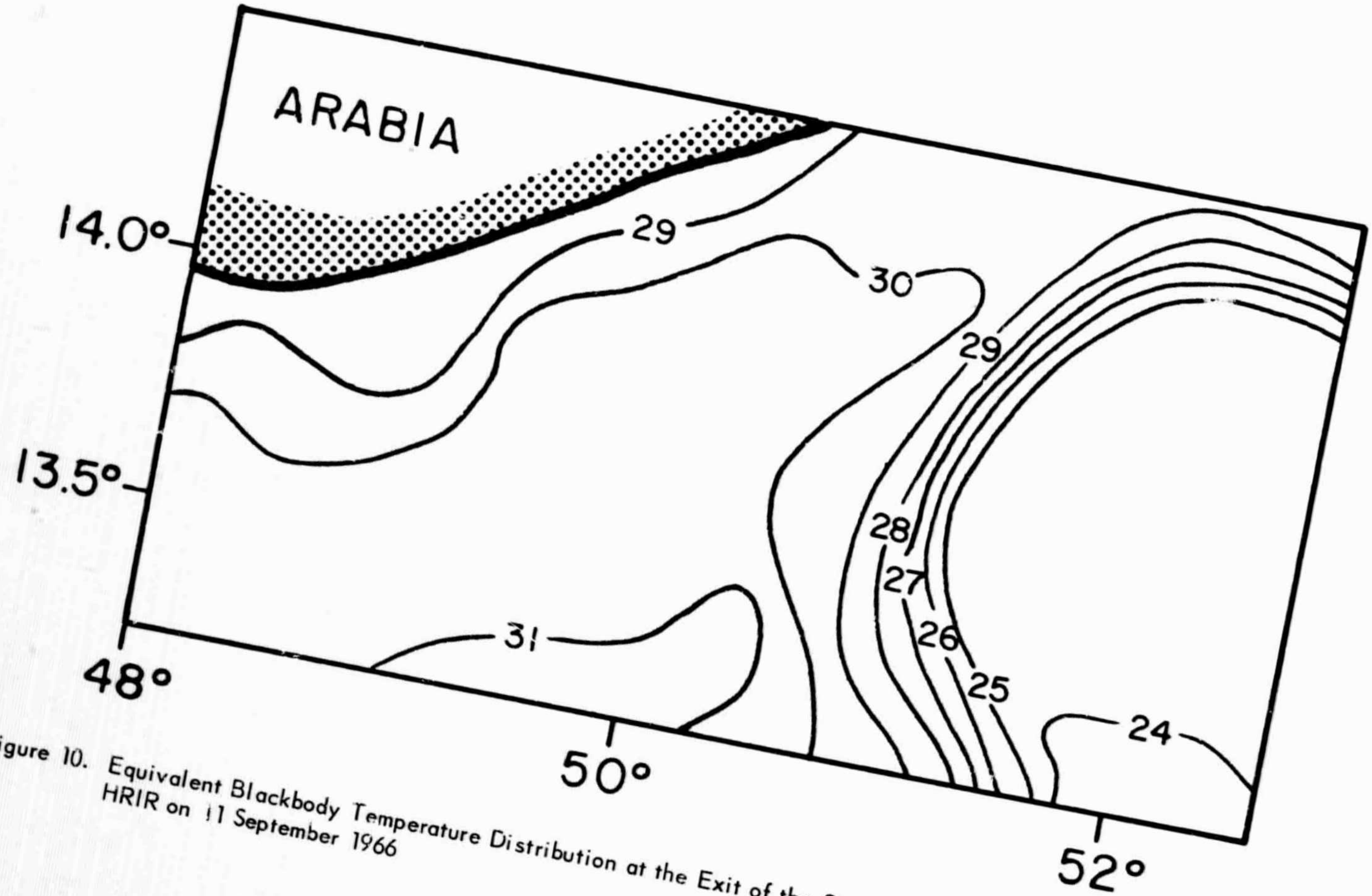

Figure 10. Equivalent Blackbody Temperature Distribution at the Exit of the Gulf of Aden Analyzed from Nimbus 2 HRIR on 11 September 1966

Figure 11. Color Analysis from Nimbus 2 HRIR Imagery at the Exit of the Gulf of Aden during 11 September 1966