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SEASONAL SEA SURFACE TEMPERATURE VARIATIONS IN THE PERSIAN GULF AS RECORDED BY NIMBUS 2 HRIR

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GREENBELT, MARYLAND

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ABSTRACT

Nimbus 2 High Resolution Infrared Radiometer (HRIR) observations over the Persian Gulf have been analyzed for cloud-free nights from June to November 1966. The relative spatial and temporal distribution of the observed mean equivalent blackbody temperature data is in agreement with historical seasonal surface ship data. The sea surface temperature spatial distribution as observed by the satellite radiometer was seen to respond to the prevailing surface winds. These results show that satellite radiometric observations can be used to discover large scale air-sea interaction features.

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INTRODUCTION

Observations of sea surface temperature offer many clues to the oceanographer and meteorologist about the nature of the air-sea interaction processes taking place over the oceans. The conventional methods of observing sea surface temperature are limited by the number of observations that can be obtained over any large area. The inclusion of radiometers on meteorological satellites has provided a means of monitoring the surface temperature of large bodies of water of over extended periods (Warnecke, et al. 1969, Smith et al. 1970). This report discusses satellite measurements of sea surface temperature that were made over the Persian Gulf during the Summer and Fall of 1966.

This Persian Gulf was selected as the site for this study because its size and the associated climatological conditions lend themselves to an investigation such as this one which had the objective of further evaluating the usefulness of satellite radiometer observations in oceanographic research. It will be shown that the satellite observations do show variations in space and time of the sea surface temperature that are in overall agreement with previous observations made by conventional means and also offer some new insight as to the nature of the circulations within this body of water.

INSTRUMENTATION AND DATA ANALYSIS

The observations used in this study came from the Nimbus 2 High Resolution Infrared Radiometer (HRIR). This instrument monitors the emitted terrestrial radiation in the narrow atmospheric "window" between 3.4-4.2 μ where the absorption by atmospheric gases such as H_2O, CO_2, and O_3 is relatively small, and, as a result, the radiances observed by the radiometer can be used to infer land and sea surface temperatures in cloud-free atmospheres. The spatial resolution of the instrument is 8 kilometers of the subsatellite point. Details concerning the operation and construction of this instrument are available in the Nimbus 2 User's Guide (Goddard Space Flight Center, 1966).

The orbits from which observations were obtained and analyzed in detail were selected by examining HRIR imagery from the Persian Gulf area in the form of photofacsimile film strips. Only orbits in which clouds were not observable in the film strips were used. In view of the fact that this area is relatively cloud free, observations from 25 orbits during the period extending from June through November 1966 were examined. The data from these orbits were computationally reduced to multi-resolutional mercator grid-print maps (See Goddard Space Flight Center, 1966) on a 1:2 million map scale. The grid intersections on these maps are spaced approximately 25 kilometers apart and the observation recorded at each intersection represents the average of all observations observed in a 0.25° latitude-longitude square around each intersection. Typically, about 10-15 observations or scan spots were used in producing the average observation at each intersection. Each individual observation or average was in the form of an equivalent blackbody temperature representing the radiance observed by the radiometer in the 3.4-4.2 μ spectral region.

The emphasis in this study was on relative variations in space and time of sea surface temperature. Sufficient averaging was done to reduce as much as possible errors resulting from instrument noise and variations in atmospheric attenuation over the Persian Gulf area. In the latter instance, as will be discussed later, the magnitude of the atmospheric attenuation was calculated by utilizing the equation of radiative transfer along with a knowledge of the vertical distribution of the absorbing gases.

DISCUSSION OF RESULTS

Fig. 1 shows the mean equivalent blackbody temperatures observed in the northern and southern portions of the Persian Gulf during the period extending from June to Nov. 1966. The means plotted here were an average of all the observations in a one degree latitude-longitude square situated in the center of the northern and southern portions of the Gulf (see Fig. 3), i.e., no observations of the shoreline were included in the mean. Approximately 250 values constitute the means at each point used in constructing the two curves shown in Fig. 1. It can be noted in Fig. 1 that the southern part of the Persian Gulf is consistently warmer than the northern part. The mean difference is 1.3C. This observation is in agreement with similar historical sea surface temperature data for this region that indicates a 1.7C difference (Dubach, 1964).

Two pronounced maxima are apparent in the curves of Fig. 1. One maximum occurred early in June followed by a rapid temperature drop occurring between 15 and 17 June. The second and more broad maximum occurred in mid-September 1966. The first maximum occurred during a period of light winds that was followed by a period of relatively strong northwesterly and northerly winds. Fig. 2 shows the average wind speed at Muharraq plotted versus time. The average was composed of the observations taken at 00, 06, 12, and 18 hours and compiled by the British Meteorological Office. Observations at Dahran and Sharjah corroborate the wind observations at Muharraq (for locations See Fig. 3). The period of light winds over the Gulf during the first half of June permitted the strong heating of the surface waters of the Gulf and produced the relatively high temperatures observed by the HRIR. With the onset of the strong winds beginning on the 14th of June, more vertical mixing of the waters occurred. Furthermore, the radiometer observes only the first few microns of "skin" of the sea surface. As a result, the radiometer may observe cooler temperatures produced by increased evaporation. The broad maximum in September is caused by the continued heating of the summer accompanied by a general decrease in the average wind speed between June and September that results in a reduction of wind-induced vertical mixing.

In examining the equivalent blackbody temperatures or radiances observed by a satellite radiometer, the attenuating effect of the intervening atmosphere should be kept in mind when using these observations to estimate the temperature of a radiating surface, such as the sea surface considered here that is situated below the atmosphere. A very reasonable correction can be computed by utilizing the equation of radiative transfer in conjunction with a knowledge of the vertical distribution of the major absorbing gases (CO_2, O_3, and H_2O) and the temperature. A computer program has been developed by Kunde (1967) to perform this task. This program was used here to estimate the magnitude of effect of the atmosphere on observations made over the Persian Gulf, and to subsequently validate the magnitude of observed temperature changes or differences. Radiosonde observations from Muharraq were obtained for two dates (10 June and 17 June, 1966) that occurred just prior to and just after a large change in equivalent blackbody temperature observed by the Nimbus 2 HRIR over the Persian Gulf. These radiosonde observations provided a knowledge of the vertical distribution of temperature and water vapor. A climatological vertical distribution for ozone was used as obtained from Hanel, Bandeen, and Conrath (1963).

The computed atmospheric correction on 10 June was 2.2C and was 2.8C on 17 June. The difference in these atmospheric corrections is 0.6C. The observed change in equivalent blackbody temperature between the 10th and 17th of June was approximately 5.5C on the northern part and 3 degrees on the southern part of the Gulf. One can conclude, since the relative change in atmospheric conditions was small, that a large change in the Persian Gulf surface temperature was conclusively observed. A more accurate estimate of the magnitude of this change can be made after applying the aforementioned corrections to the satellite-observed temperatures. In general, the clear sky atmospheric conditions do not vary much over the Persian Gulf. Therefore, the relative temperature changes of 1K or larger shown in Fig. 1 can be considered to be reliable. These results also indicate that satellite radiometer observations can be used to observe temporal variations in sea surface temperatures over many other bodies of water of oceanographic interest.

As pointed out in the beginning, normally we find relatively lower temperatures in the northern part of the Gulf. Mean values from all reported salinities indicated that the highest runoff from the Euphrates and Tigris is during June. Since the influence of the outflowing water is limited to the coast, colder water in the northern part can be explained only by transport of cooler water from deeper horizons to the surface, or more pronounced cooling by evaporation. The directional frequencies of the winds over this area show that the major component lies between west and northwest during the whole year. These observations further support the conclusion that cooling by evaporation and intense vertical mixing can be expected in the northern part of the Gulf. An analysis from ship observations of currents indicates that two separated cyclonic eddies exist in the Persian Gulf (Fig. 3). From the sea surface temperatures derived by the satellite, we can conclude that the position of the boundary between the two gyres is not persistent. This was indicated by the shift of the isotherms whose positions depend upon the wind stress. An estimate of the response time for the shifting of an isotherm to the wind can be given with four orbits shown in Fig. 4. After the wind had increased on June 14 (see Fig. 2), cold water was detected in the northern portion. This water with temperatures below 29C was found also on June 16, 17 and 26. One day had elapsed from the onset of the increased wind speed and the appearance of cold upwelled water. The southward shifting of the 29C isoline is a very good indicator for the oceanic response to atmospheric forcing. Reduced wind speed during June 25 produced again a shifting back to the North.

Fig. 5 shows four nighttime orbits in September showing the T_{BB} distribution in the Gulf during the second warming period. The southern shallow region shows the persistence of the warmer water masses with T_{BB} values 34C that have been characterized by the shading.

The current system contributes to the heat accumulation in the Southern Gulf. The incoming water from the Gulf of Oman compensates the excess of evaporation over precipitation in the Persian Gulf and flows along the Iranian coast where it turns cyclonically along the Trucial coast. As this occurs the water is warmed in this shallow region and flows eastward back out into the currents along the Iranian Coast.

CONCLUSIONS

This oceanographic study of sea surface temperature patterns has shown that seasonal temperature changes and short term anomalies can be detected by high resolution radiometric observations from satellite altitudes. These observations have also been used to infer the nature of the circulation patterns that exist in the Persian Gulf. If care is taken to avoid cloud contamination and other sources of error, observations from satellite radiometers can be used to monitor sea surface temperature variations in many other areas of the world. It is expected that these observations should enable the oceanographic and meteorological communities to explore in more detail oceanographic circulation characteristics and their effect on the general circulation of the ocean-atmosphere system.

ACKNOWLEDGEMENT

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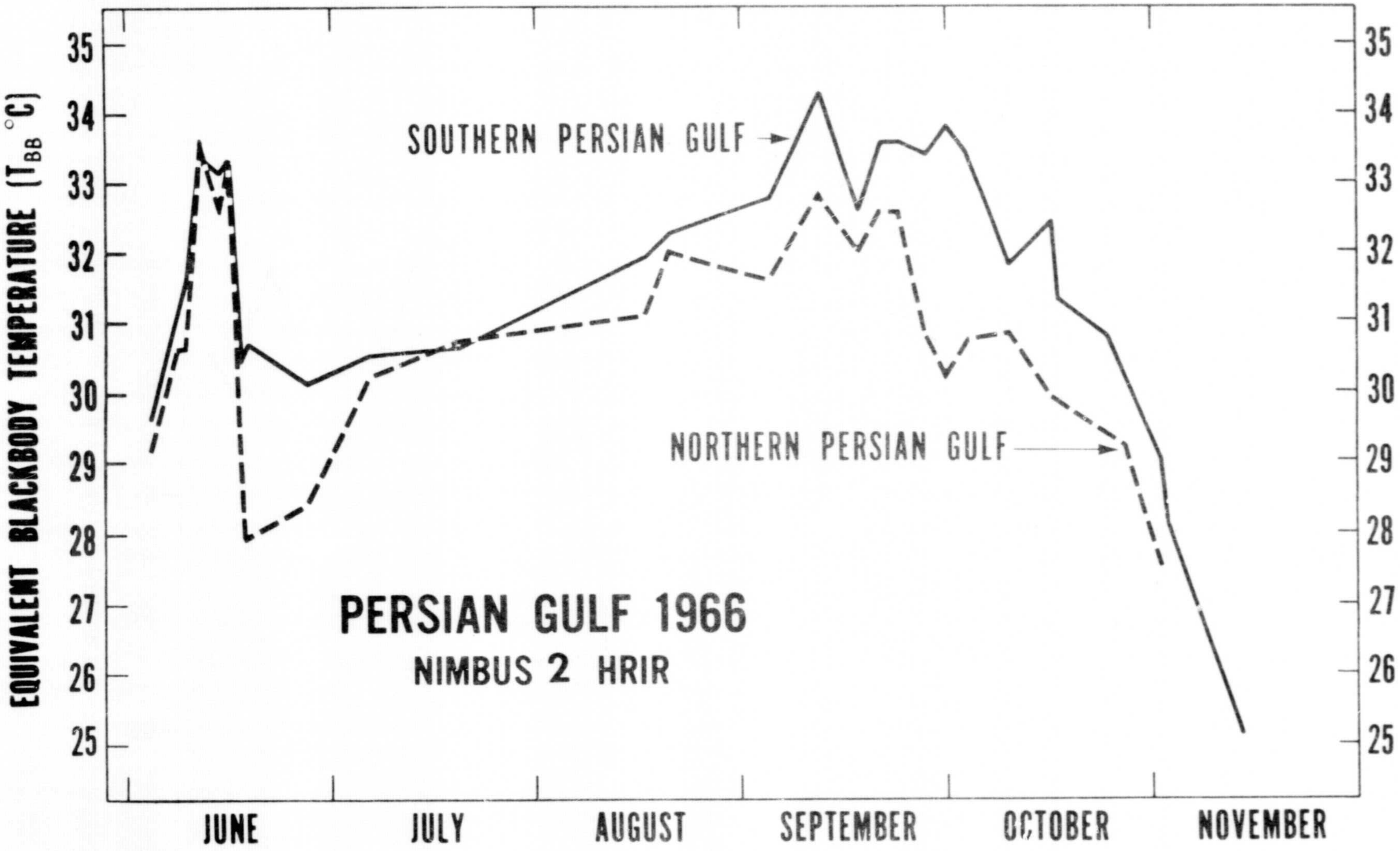

Figure 1. Variation of mean equivalent blackbody temperatures (°C) for the northern and southern Persian Gulf from June through November 1966.

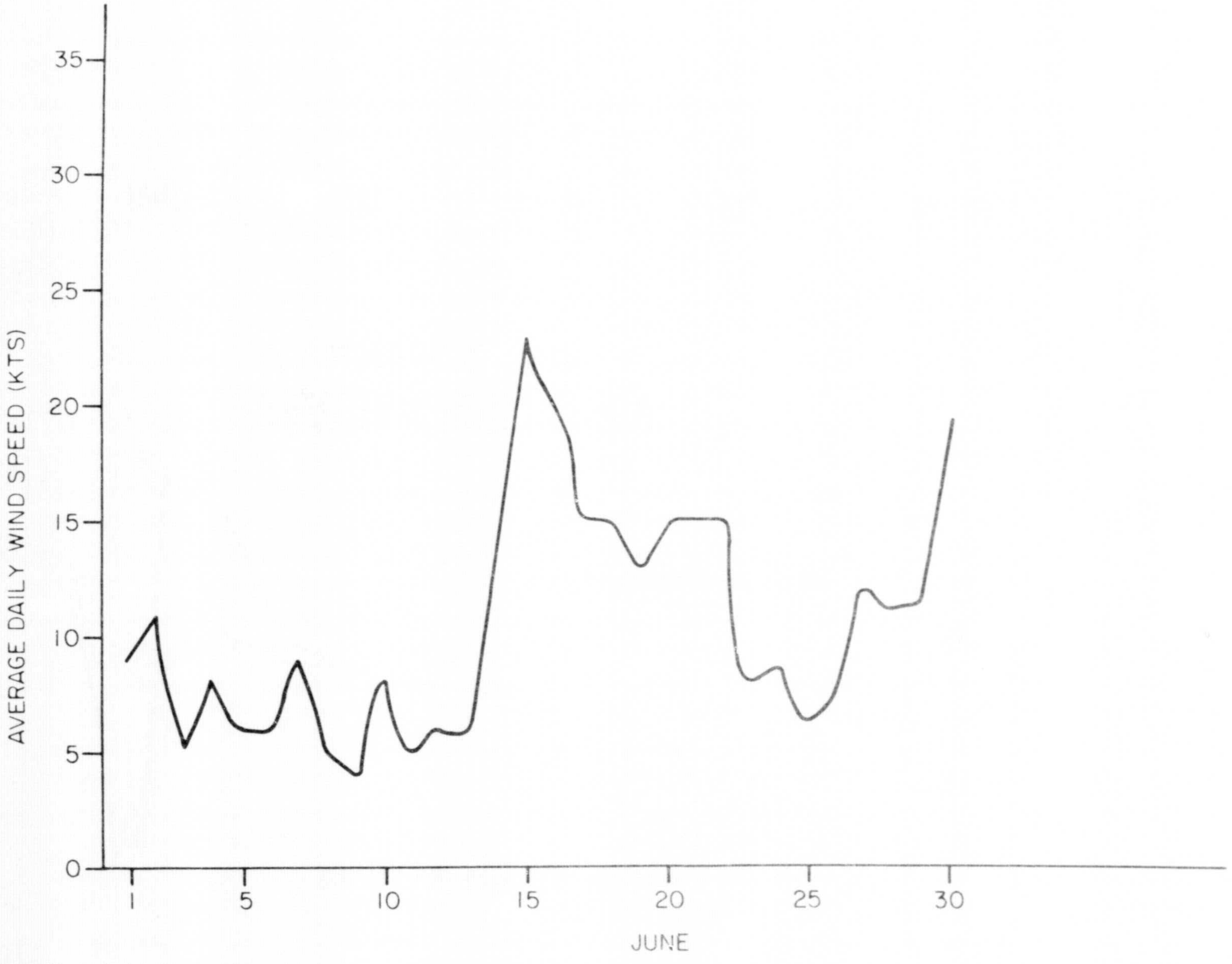

Figure 2. Average wind observations at Muharraq versus calendar day during June 1966.

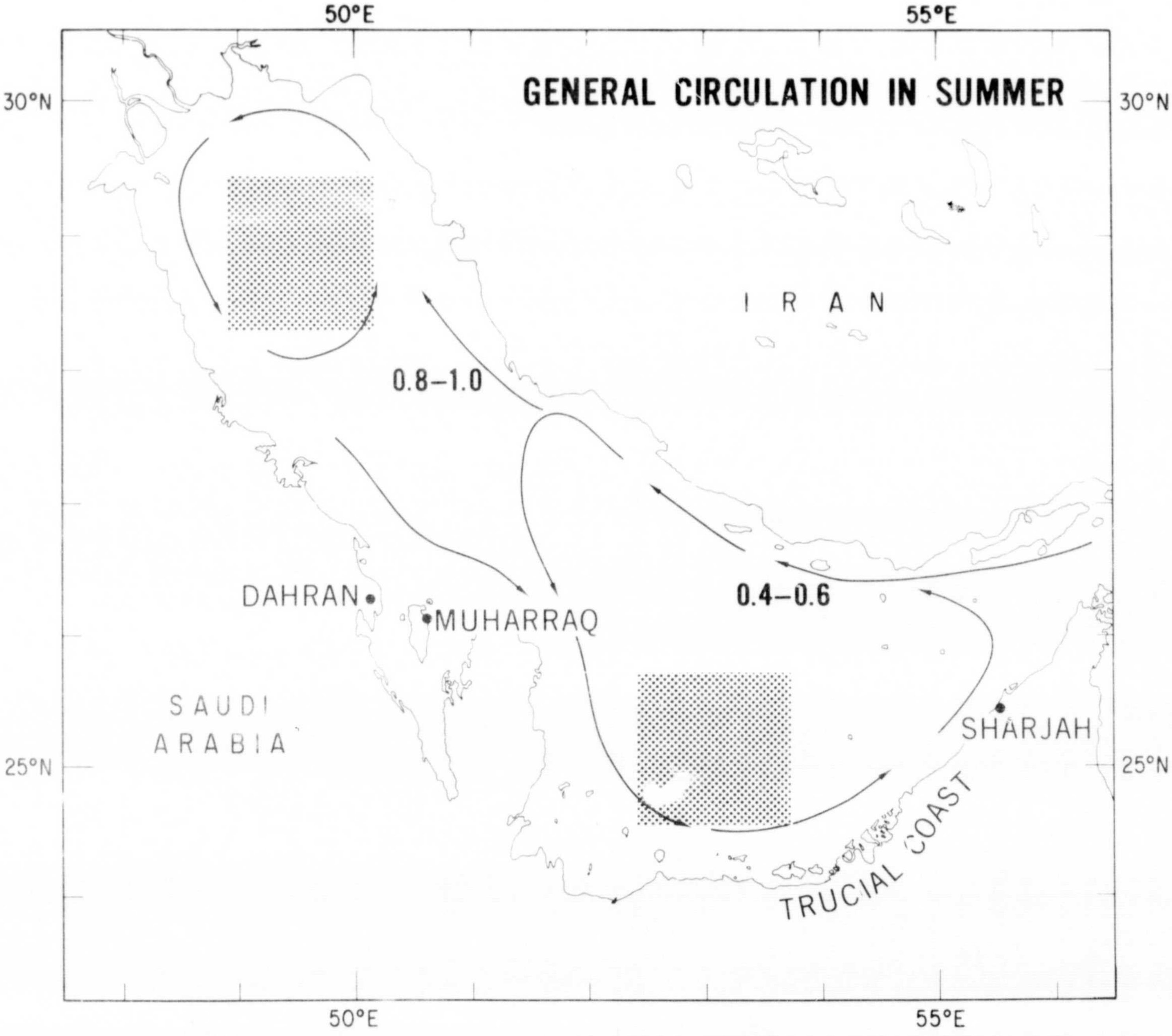

Figure 3. General circulation scheme in the Persian Gulf during summer; speed indicated in knots. Shaded area indicates location where average temperatures were obtained.

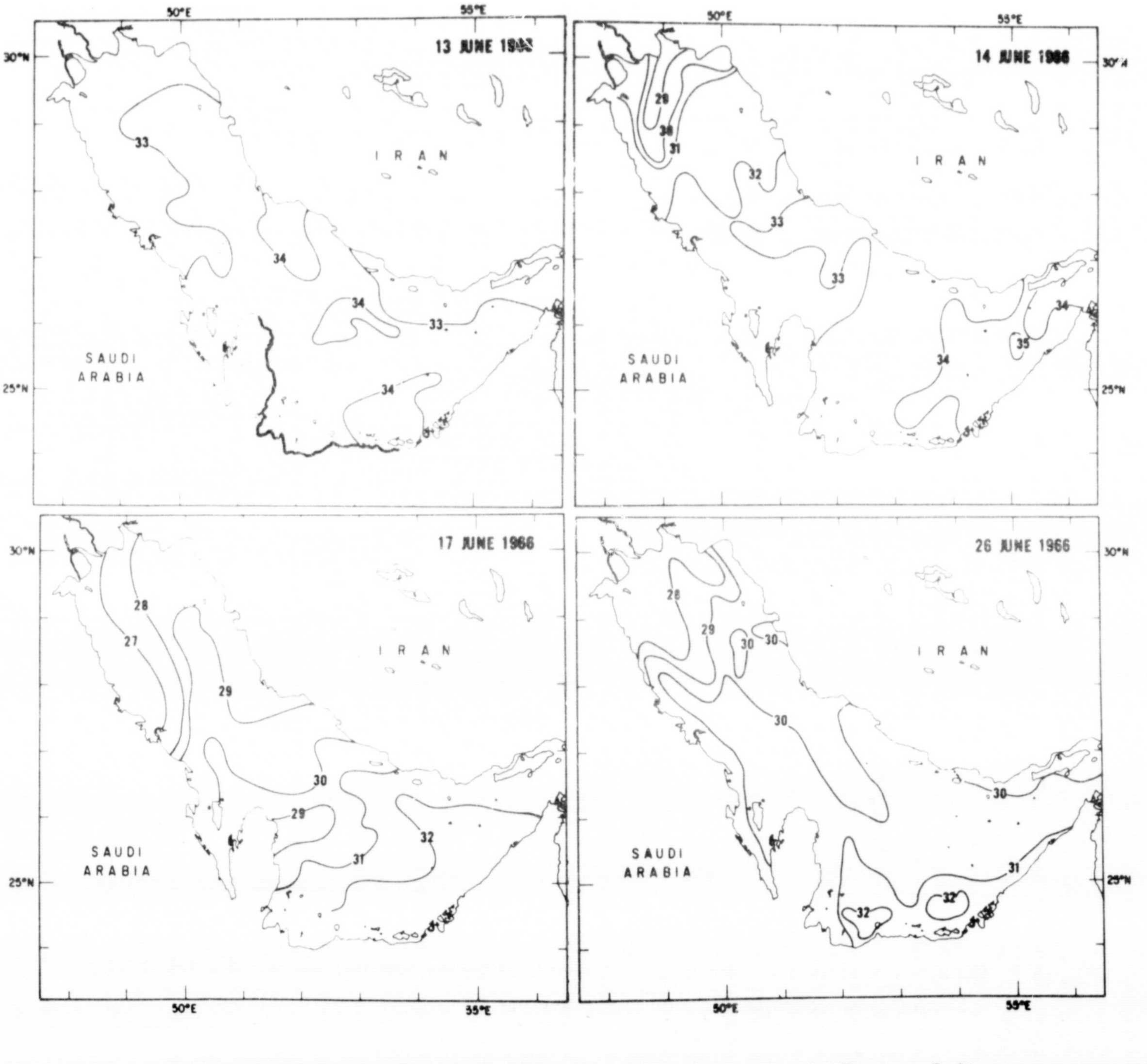

Figure 4. Equivalent blackbody temperature distribution for the Persian Gulf during 13, 14, 17, and 26 June 1966.

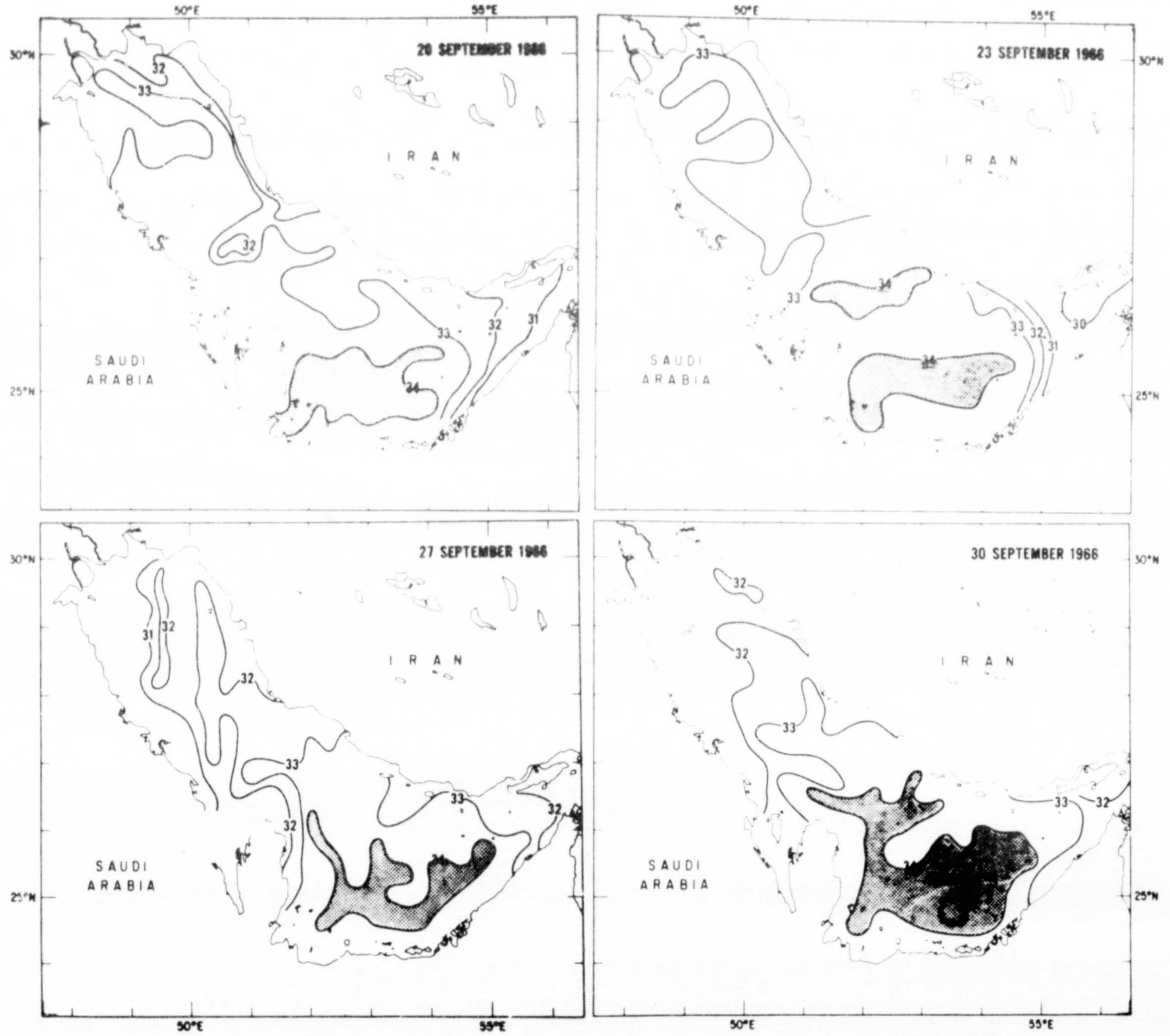

Figure 5. Equivalent blackbody temperature distribution for the northern Persian Gulf during 20, 23, 27, and 30 September 1966.