Remote Sensing of Sea Surface Temperature

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A thorough knowledge of the distribution of sea surface temperature over large areas is important in the geophysical and marine sciences. This enables one to understand certain atmospheric and oceanic processes, in the detection and monitoring of ocean currents, upwelling zones, and other circulation systems. Unfortunately, a true and complete picture of the sea surface temperature distribution has not been available due to observational difficulties. Sea surface temperature charts that are available now are based on commercial ship reports and on data from research cruises. Comprehensive survey of this feature by means of sensors carried in aircraft, ships, or any other similar platforms would be time-consuming and is frequently impractical. An earth satellite in a near-polar orbit can best provide useful information about the sea surface temperature.

After the launch of several TIROS and Nimbus satellites containing different radiometers, it has been shown, that it is possible to measure the sea surface temperature distributions under relatively clear sky conditions. The observed temperature distributions are very complex and difficult to interpret in the absence of any "ground truth" information. In the future every effort should be made to obtain sufficient concurrent surface observations in order to successfully compare and interpret the data.

**Description of the Experiment**

Examples discussed here are for the Nimbus II period. This satellite carried on board several television cameras, a medium resolution radiometer (MRR), and a high resolution infrared radiometer (HIIR). The Nimbus II User's Guide gives a complete description of the instrumentation. The data under consideration was obtained from the HRIR radiometer. It contains a lead telluride photoconductive cell radiatively cooled to approximately 750 C and measures the radiation in the 3.5-4.1 micron region. The energy received at the satellite after correcting for the atmospheric attenuation is proportional to the temperature of the radiative surface. The radiometer has an instantaneous field of view of approximately one half degree, which means that from an altitude of 1100 km (500 n.m.), if the radiometer looks straight down at the surface, the area viewed is approximately 7 km (5 n.m.) in diameter. This type of geometry associated with the scanning mechanism of the polar-orbiting radiometer provides a global coverage twice a day.

The HRIR data are read out at the Data Acquisition Station and then transmitted to the Goddard Space Flight Center (GSFC), where it is displayed on a photograph recorder. A continuous strip picture is then produced on a 70 mm film. The information is displayed as a gray scale picture with ten steps of gray and is arranged in a format such that clouds and cold regions are shown white (less radiant energy reaching the radiometer) and clear and warmer regions are shown dark (more radiant energy reaching the radiometer). This method of pictorial display is very useful for qualitative interpretation of the radiation data.

**Data Analyses and Interpretation**

Figure 1 is an example of the gray scale display of the Nimbus II HRIR data showing the north wall of the Gulf Stream and almost the entire east coast of the United States. Warncke et al., Greaves et al., and Rao have already shown the utilization of the HRIR data for locating these current boundaries. The present example is for 0500 GMT, November 15, 1966. The dark areas correspond to warm regions and the white are associated with cold areas. Features like the Florida Peninsula, Chesapeake Bay, and Long Island are clearly visible. The dark area south-east of Chesapeake Bay is the Gulf Stream. The white area south and east of it is a cloud system associated with a low pressure center and cold front over the Atlantic. This gray scale format is useful for display but cannot be meaningfully used in any quantitative studies.

For this purpose, digitized HRIR data are useful and the output is available in the form of maps in several different projections and map scales. These maps are NASA computer produced and they take into account the calibration information of the radiometer and the geographical location.

One such example is shown in figure 2. It shows the digitized HRIR data for the same orbit as discussed above (2H8B, November 15, 1966, 0500 GMT) on a Mercator map projection at a scale of 1 to 1 million at the equator. In this scale there are eight grid intervals between each degree of longitude and eight grid intervals near the equator for each degree latitude. The number of grid intervals increases with increasing latitude. On the average, there are about three observations in each grid interval in this particular map, and the average of the observations within every grid interval is printed at each grid location.

The isotherms are drawn at 29 K intervals. Temperatures greater than 290° K are shown by dotted areas and less than 280° K by striped areas. These temperatures represent equivalent blackbody temperatures and should not be confused with the actual surface temperatures. The most striking feature is the strong gradient in temperature along the north wall of the Gulf Stream between 35 N-37 N and 71 W-73 W. The other interesting feature is the display of many small centers of high and low temperatures throughout the region. The evidence available at present, such as aircraft and ship observations, does not support the existence of such cellular pattern. It seems unlikely that
all of this fine structure is noise in the data; therefore, some are probably depicting the real thermal structure of the surface. Some of the possible explanations for the patterns are (1) clouds partially influencing the field of view of the radiometer, (2) a variable distribution of different radiation absorbing constituents of the atmosphere existing between the satellite and the surface, or perhaps (3) differences in the emissivities of the radiating surfaces due to impurities like monolayered slicks and other organic and inorganic surface variables. Preliminary examination of some aircraft data and ship data have shown the existence of temperature variations over short distances, but the amplitudes of these variations are considerably lower than those observed in the satellite data. Until frequently observed surface observations are available, no definite conclusions can be reached.

Figure 3 shows the sea surface temperature distribution obtained over the Gulf Stream from an aircraft. The U.S. Bureau of Sport Fisheries and Wildlife, in cooperation with the U.S. Coast Guard, made the flight with an infrared radiation thermometer on November 15, 1966. The flight track is shown by the broken line. There is good agreement in the location of the strong gradient in temperature along the north wall of the Gulf Stream between the aircraft observations and the Nimbus II data. The aircraft data show a fairly uniform field compared to the satellite analysis (figure 2). The shaded areas represent temperatures less than 287° K. The distribution shows a narrow area of temperatures less than 287° K just north of Gulf Stream boundary. The existence of cool ribbons (or streams of water) near the Gulf Stream has been previously observed by many investigators. The presence of the cool ribbon (or ribbons) of water north of the Gulf Stream is not obvious in figure 2. This is due to fine structure that is displayed in the data. However, when a number of cross sections were examined along different longitudes, the filament of cold water is clearly shown. Figure 4 is an example that shows the above mentioned feature at all longitudes that have been examined. All the cross sections show the cold water anomalously just north of the Gulf Stream wall. Occasionally a multiple structure is shown. Since the present purpose of this study is not to seek an answer to the origin and existence of this feature no further comments will be attempted at this time.

The ultimate aim is to use IR radiation data over oceanic regions to obtain the surface temperature distribution over large areas at some frequent interval (e.g., daily or weekly). To achieve this final goal one has to go through several steps of processing and examine the data to eliminate systems noise, clouds and other contaminants and determine the map scale factor or factors that will be useful for any particular study. An examination of the 1.1 million Mercator projection of the HRIR data showed a vast amount of detail in the temperature structure. For many studies, perhaps this fine detail is unnecessary, and a smooth field stream could be obtained by an averaging process. One should remember that clouds can come into the field of view of the radiometer and alter the energy received at the satellite and thus alter the observed temperature. All observations that have been influenced by clouds should be eliminated in the mapping program. It is easy to eliminate the observations in which the clouds fill the field of view completely since the observed temperatures will be lowered depending on the type of cloud cover. A major difficulty will arise when the field of view is not completely filled with clouds. Such observations should be subjectively eliminated.

One of the techniques to eliminate the observations that are influenced by the clouds is either by using the picture information obtained from the satellite or by observing the reflectance values measured in one of the solar channels of the radiometer, (if such a channel is available to measure the reflected solar radiation). This method would be useful during the daytime if the cameras and both the visible and IR sensors were looking at an identical area. The major difficulty to this approach in the case of Nimbus II is that the HRIR information can be used only during the night. The daytime data are unreliable due to their contamination by the reflected solar radiation. So one has to resort to some other techniques to obtain a large scale sea surface temperature distribution.

The first simple method that has been tried is to take the average temperatures over one half degree latitude-longitude grid interval. Again the same data shown in figure 2 have been used for these manipulations. Figure 5 is the sea surface temperature distribution obtained over the Gulf Stream area using the average values. A striking change is the absence of all the cellular patterns noticed in figure 2. The Gulf Stream boundary is still noticeable but the gradient is weaker. The temperatures east of the Gulf Stream area are much lower than the climatological sea surface temperature values, indicating that the influence of clouds are the cause for the low values. With this simple approach and averaging over a small region like one half a degree latitude-longitude, resulted in a smooth temperature field but the influence of the clouds were not eliminated.

The next step was to select the observations that are least contaminated by clouds. Only the highest values of temperatures observed in each one half a degree latitude-longitude box were selected and the analysis performed. The results are shown in figure 6. The basic assumption involved in this technique is that even though clouds persist over large areas, there are always a few breaks in the cloud cover and the radiation from the sea surface would be reaching the radiometer through these holes. The highest values are therefore associated with relatively clear areas. The temperature distribution obtained by this method also is smooth and the temperature gradient along the Gulf Stream boundary is visible. Temperatures east of the Gulf Stream have increased considerably compared to figure 5, indicating that the influence of clouds has been modified. Even over the Gulf Stream area the values are higher than in figure 5. All these facts suggest that cloud contamination has been removed to an appreciable amount in this method of obtaining the sea surface temperature distribution.

The two methods discussed earlier provided fairly uniform temperature distribution over a limited area of the sea surface. One of the methods (figure 6) provided the temperature
distribution over relatively cloud-free areas by only accepting the observations that were high over selected regions. These two techniques are simple yet encouraging. Another approach to obtain observations over exclusively clear areas is to consider the temperature distribution in each latitude-longitude box over a given area and come up with a set of rules that will select only the required data. Again November 15, 1966, data over the Gulf Stream is used for this particular study. Figure 7 shows the frequency distribution of temperature in each latitude-longitude box. The idea behind this approach is that the data themselves will provide answers to the nature of the frequency distributions over clear, partly cloudy, and cloudy areas. By looking at the shape of the distribution it is possible to determine more accurately whether there were any clouds over a given area. For example, consider the following four frequency distributions: (1) 36-37N, 77-78W, (2) 36-37N, 75-76 W, (3) 36-37N, 73-74W, and (4) 37-38N, 71-72W. Distribution (1) is over land and a large number of observations are between 273-277° K with a strong peak at 275° K. The shape and narrow span of the curve indicates that almost clear conditions prevailed over this area at that time.

Distribution (2) is over the Atlantic along the east coast of the United States. The distribution is skewed to the left and the range is between 272-292° K with the mode about 286° K. In this particular region the temperature is slowly increasing eastward and so a wide range is indicated in the temperatures. This distribution also reflects predominantly clear conditions.

Distribution (3) is for the Gulf Stream region where a strong temperature gradient exists. Temperatures vary between 271-300° K and the distribution is flat without any significant peak. This is typical for an area where a strong temperature gradient exists. It is difficult to assign any one particular temperature from the distribution as the representative sea surface temperature for that latitude-longitude interval.

Distribution (4) is typical for a region which is partly cloudy. The bimodal distribution indicates that the peak around 279° K is due to cloud contamination and the higher values around 290° K correspond to relatively cloud-free areas. Perhaps the latter peak should be considered as a representative value for that region.

The above are some examples to show that by proper and meaningful statistical manipulations of the radiation data one can eliminate many of the observations with cloud contamination and finally end up with a sea surface temperature distribution which can be used for operational or research work.

Conclusions

The example presented shows that during relatively cloud-free conditions it is possible to observe the sea surface temperature distribution. In spite of many small centers of high and low temperatures throughout the area, it was possible to locate the current boundary and the cross sections along selected longitudes showed ribbons or streams of cool water north of the Gulf Stream. It has been shown that a uniform sea surface temperature distribution over relatively cloud-free areas can be obtained either by subjectively selecting the radiation data over proper grid intervals or by a meaningful statistical screening technique derived from the data itself.

Inadequacy of present surface data from other sources for reference prevented the use of satellite measurements in an absolutely quantitative way. To evaluate this type of satellite information for future use in oceanographic work, sufficient ground truth information must be obtained.

Acknowledgements

The authors would like to thank Mrs. Julia Hart and Mr. Simon Roman for their valuable help in the analyses of the data, Mr. Leonard Hatton for drafting some of the figures, Mr. L. J. Allison of Goddard Space Flight Center for providing the digitized radiation maps, and Mr. T. R. Azarovitz of the Sandy Hook Marine Laboratory for providing the concurrent aircraft thermal mapping.

References


Figure 1. The Gulf Stream from Nimbus II HRIR for orbit 2448, 15 November 1966, 0500 Z. The dark areas are warm and light areas cold.
Figure 2. The Gulf Stream from the analysis of digitized HRIR data from Nimbus II, orbit 2448, 15 November 1966, 0500 Z.
Figure 3. Sea surface temperature measurements over the Gulf Stream from BCF/USCG aircraft for 15 November 1966.
Figure 4. Temperature-latitude cross sections along four longitudes to show the presence of streams of cool water at the surface, north of the Gulf Stream.
Figure 5. Sea surface temperature analysis using the average values in one half degree latitude-longitude box from Nimbus II HRIR data orbit 2448, 15 November 1966, 0500 Z.
Figure 6. Sea surface temperature analysis using only the highest values in one half degree latitude-longitude box from Nimbus II HRIR data orbit 2448, 15 November 1966, 0500Z.
Figure 7. Frequency distribution of temperature over each one degree latitude-longitude box for Nimbus II HRIR data, orbit 2448, 15 November 1966, 0500Z.