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A COMPARISON OF SURFACES TEMPERATURES FROM HCMM INFRARED DATA WITH FIELD MEASUREMENTS

N83-14555

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October 1982
Final Report

Prepared for

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

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FOREWORD

This report by the Office of Geosciences Programs of the Research Triangle Institute, Research Triangle Park, North Carolina, presents the results of a study on the comparison of HCMM infrared data with field data to establish the absolute and relative accuracy of these data. The study was performed for the National Aeronautics and Space Administration, Goddard Space Flight Center, under Contract No. NAS5-26442. The author wishes to acknowledge the assistance of Mr. Bobby W. Crissman.

PREFACE

HCMM surface temperatures were compared to field data obtained in the Mississippi River in the vicinity of St. Louis, Mo., and in the oceans in the vicinity of the Nantucket Shoals and in the eastern Gulf of Mexico. It was found that, on the average, the difference between the HCMM surface temperature corrected for atmospheric attenuation and the _in situ_ temperature at the same location was -4.6°C. Previous calibration results (Bohse et al., 1979) indicated that the difference was +5.2°C. As a result of that study, the HCMM data were adjusted so that they were 5.2°C lower. The results of this study suggest that that adjustment was made in error, so that 5.2°C must now be added to the HCMM surface temperatures to obtain the correct value.

However, the results of this study also indicated that there may have indeed been a calibration problem for the HCMM infrared radiometer in the first few months after launch, but that after June 1978, the problem may have no longer existed. However, due to the limited amount of data processed for this study, the time extent or nature of the calibration problem could not be conclusively determined. It was noted that two case studies in June 1978 (i.e., two orbits on different days) had digital count values corresponding to an _in situ_ temperature of about 25°C that were, on the average, 14 counts higher than the digital count value corresponding to about the same _in situ_ temperature value for all remaining orbits studied (most of which were in the period after June 1978). The 14 counts correspond to a temperature difference of about 5.0°C. Since the previous calibration was made using data for May and June of 1978, the HCMM radiometer may have had a calibration problem at that time, and the HCMM surface temperatures may have been 5.2°C too high.

Calibrated and atmospherically corrected HCMM surface temperature data were compared with the ocean surface data. Fifty-seven data pairs were compared over the temperature range from 10° to 25°C. The RMSD was ± 1.0°C and the linear correlation coefficient was 0.97. These values are consistent with values found by other investigators (McClain, 1980; and Maul, 1981) for other satellite infrared radiometers, and they are probably very near the geophysical limit of accuracy of the present generation of infrared radiometers.

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1.0 Introduction

The satellite for the Heat Capacity Mapping Mission (HCMM) was launched on 26 April 1978. The HCMM satellite gathered data in support of studies to determine the feasibility of using infrared temperature data to compute the thermal inertia from the earth's surface. The data were obtained at 12-hour intervals at times when the temperatures were at maximum or at minimum. The satellite was in sun-synchronous orbit with nominal ascending equator-crossing time of 2:00 p.m. Local Standard Time (LST) to provide north midlatitude crossing times of 1:30 p.m. and 2:30 a.m. LST.

The radiometer on the HCMM satellite had a geometric instantaneous field of view of 0.83 milliradians (ground resolution of 0.5 kilometers at nadir), and covered a wide swath on the ground so that the selected areas received repeated coverage within the 12-hour period. The radiometer had two channels: one channel for reflected radiation from the 0.5 to 1.1 micrometer waveband; and the other channel for the infrared radiation from the 10.5 to 12.5 micrometer band.

Soon after launch of the satellite, a comparison of HCMM ground temperatures and selected *in situ* data suggested that there had been a change in the calibration of the thermal channel (Bohse et al., 1979). Data from five satellite passes in May and June were used in the analysis. The results suggested that the HCMM infrared temperatures were 5.2°C too large. The decision was made to offset the prelaunch calibration values by -5.2°C in order to force agreement between the satellite data and the surface measurements. This offset was applied to all standard processed HCMM data.

However, after the offset had been made and the newly calibrated HCMM data distributed to the user community, results derived by the HCMM user community suggested that the infrared ground temperatures were, in some cases, too low. A documented comparison between the HCMM infrared ground temperatures and *in situ* data had not been accomplished since the offset had been applied. It is the purpose of this study to compare the HCMM infrared temperatures with *in situ* data to establish a measure of the absolute and relative accuracy of the HCMM infrared data. (The relative accuracy is a measure of how well the HCMM infrared data described the spatial variation of temperature.) This study will describe the results of a comparison of HCMM infrared temperatures with *in situ* data from the Mississippi River in the St. Louis, Mo., area and with sea-surface temperatures collected in the Nantucket Shoals and Gulf of Mexico regions.

2.0 Methodology

2.1 Processing HCMM Ground Temperatures

The HCMM data were processed to remove the extraneous influence of the atmosphere and to calibrate the infrared measurements. The signal from the ground reaching the radiometer was influenced by absorption and radiation in the atmosphere by water vapor and carbon dioxide. In order to obtain the precise value of the ground temperature, the influence of the atmosphere was accounted for. The procedure that was used to account for atmosphere attenuation and to calibrate the data is described below.

The radiation received by the satellite, N_s, can be determined through the radiative transfer equation:

$$N_s = \int_{\lambda} \phi_\lambda \tau_\lambda R_\lambda d\lambda + \int_{\lambda} \phi_\lambda \int_{\tau_\lambda} R'_\lambda d\tau_\lambda d\lambda \quad , \qquad (1)$$

where λ is the wavelength, ϕ_λ is the spectral response, τ_λ is the transmissivity, R_λ is the blackbody radiation from the surface, R'_λ is the blackbody radiation from the atmosphere. Letting

$$\bar{\tau} = \int_{\lambda} \tau_\lambda d\lambda \Big/ \int_{\lambda} d\lambda \quad , \qquad (2)$$

and defining

$$N_o \equiv \int_{\lambda} \phi_\lambda R_\lambda d\lambda \qquad (3)$$

and

$$\delta N \equiv \int_{\lambda} \phi_\lambda \int_{\tau_\lambda} R'_\lambda d\tau_\lambda d\lambda \quad , \qquad (4)$$

where N_o is the blackbody radiation emitted at the surface in the spectral interval, and δN is the increment of radiation emitted by the atmosphere and received by the satellite in the spectral interval, then the following approximation is made

$$\bar{N}_s \sim \bar{\tau} N_o + \delta N \quad . \qquad (5)$$

Assuming that δN is invariant in a small area (i.e., the air mass characteristics do not change markedly over a small area), then differentiating Equation (5) gives

$$\frac{dN_s}{dN_o} = \bar{\tau} \quad . \tag{6}$$

Equation (6) states that the gradient of (temperature or) radiation emitted from the ground would be reduced due to atmospheric absorption.

For the satellite infrared data, the digital counts, C, are related to radiation received by the satellite by a simple linear relationship; i.e.,

$$N_s = a\,C + b \quad , \tag{7}$$

where a and b are parameters derived from the satellite calibration data. For the HCMM satellite, a = 1.0 and b = 118.214 (HCMM User's Guide, 1980). In order to correct for the atmospheric absorption, the following inversion procedure was used. Equation (6) was differentiated:

$$\frac{dN_s}{dC} = a \quad . \tag{8}$$

This differential equation was written in the following form:

$$\frac{dN_o}{dC}\,\frac{dN_s}{dN_o} = a \quad . \tag{9}$$

Substitution of Equation (8) into Equation (9) and integration gave:

$$N_o = a'C + b' \quad , \tag{10}$$

where $a' = a/\bar{\tau}$. The new intercept term, b', may be expressed as a function of the old intercept term, b, by combining Equations (5), (7), and (10):

$$b' = (b - \delta N)\bar{\tau}^{-1} \quad . \tag{11}$$

Equation (10) gives the radiation emitted at the surface which is directly related to the ground temperature. The ground temperature was derived through the inversion of the Planck function:

$$T_g = \lambda_o[\ln(\lambda_1/N_o - 1.0)]^{-1} \quad , \qquad (12)$$

where T_g is the ground temperature, λ_o = 1251.159, and λ_1 = 14421.587.

The mean transmissivity was determined by calculating the optical path for water vapor using upper air data at various upper air weather stations. For the studies performed in the St. Louis area, the upper air weather station at Salem, Illinois, was used; for the Gulf of Mexico area, the Key West, Florida, station; and for the Nantucket Shoals region, the Chatham, Massachusetts, station. The optical path for carbon dioxide was calculated assuming that the carbon dioxide distribution was thoroughly mixed in the atmosphere with the mixing ratio of 0.5 grams per kilogram (Haltener and Martin, 1957). The optical path for carbon dioxide and water vapor were used to develop the mean transmissivity in the thermal wavelength band of the HCMM from data presented by Wyatt et al. (1964a, 1964b). The corrected intercept term, b', may be computed using Equation (11). However, because of the controversial 5.2°C error in the HCMM-derived temperatures (see the HCMM User's Guide, 1980), it was decided to use an alternative approach to determine the intercept term b'. For each area and for each time period, one _in situ_ temperature value was used to derive a value of surface radiation through the Planck function in the wavelength band utilized by the HCMM. The derived value of the surface radiation was matched with the HCMM digital count located in that region. These two values were combined in Equation (10) to determine the intercept term b'. By referencing the HCMM digital count to the _in situ_ temperature, the procedure accounted for the calibration and a portion of the atmospheric effect.

2.2 Geographical Location of HCMM Data

A conformal mapping procedure was used to locate the HCMM data in space. A Mercator projection of the region of interest was developed which will hereafter be referred to as the base map. A contour analysis of the HCMM digital counts for either the IR or the visible data was developed. The area of HCMM analysis was always selected to be larger than the area covered by the base map. The analysis of the digital counts will hereafter be referred to as the analysis map.

The coordinates of identifiable points such as bends in the river, confluences of rivers, edges of lakes, etc., on the base and analysis maps were determined relative to a fixed origin. The origin in the analysis map was not the same for each case study. Coordinates were determined as distances from the origin. Matrices of the two sets of corresponding coordinates were created, and the equation relating the two coordinate systems was established; i.e.,

$$A \cdot Z = B \ , \tag{13}$$

$$A = \begin{matrix} x_1, y_1, 1 \\ x_2, y_2, 1 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ x_n, y_n, 1 \end{matrix} \ , \qquad B = \begin{matrix} a_1, b_1, 1 \\ a_2, b_2, 1 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ a_n, b_n, 1 \end{matrix} \ , \tag{14}$$

where (x_i, y_i) are the coordinates of the points $i = 1,2,\ldots,n$ in the analysis map, (a_i, b_i) are the coordinates of corresponding points $i = 1,2,\ldots,n$ in the base map, and Z is an unknown transform matrix which relates the two sets of coordinates. If the transform matrix is determined, then the HCMM data can be projected into the base map.

In order to determine the transform matrix, the transpose matrix of A, A^T, was computed, and both sides of Equation (13) were multiplied by the transpose of A:

$$(A^T \cdot A) \cdot Z = A^T \cdot B \cdot \tag{15}$$

The transform matrix Z was determined by first computing the inversion matrix of the product of the transpose of A times A and multiplying both sides of the Equation (15) by the inversion matrix:

$$Z = (A^T \cdot A)^{-1} \cdot (A^T \cdot B) \quad . \tag{16}$$

In the analysis map, each data value (digital count, for example), V_k, has a corresponding grid point (x_k, y_k). Each coordinate in the analysis map was postmultiplied by the transform matrix to determine a coordinate (a_k, b_k) in the base map. If the computed coordinate fell outside of the domain defined by the base map, the coordinate and the associated HCMM data value were discarded. However, if the coordinates fell within the domain of the base map, the HCMM data value was stored in an array $F_{i,j}$. The array $F_{i,j}$ corresponded to the base map, and the i,j locations were determined by knowing the length scale and defining the i and/or j grid spacing of the base map. The array then became

$$F_{i,j} = F_{i,j} + V_k \quad , \qquad (17)$$

where initially

$$F_{i,j} = 0 \quad . \qquad (18)$$

The procedure stored all HCMM data values, having transformed coordinates which fell within a certain ρ-neighborhood of a grid point within the $F_{i,j}$ array, at the grid point. Therefore, some grid points had more than one HCMM data value. An array, $C_{i,j}$, was determined which accounted for the number of HCMM data values stored in each i,j location. Upon completion of the mapping, the average HCMM data value was determined in the array:

$$\bar{F}_{i,j} = F_{i,j}/C_{i,j} \quad , \quad C_{i,j} \neq 0 \quad . \qquad (19)$$

After the average values were computed, a gravitationally weighted interpolation model was used to compute a data value at each i,j location where $C_{i,j} = 0$ (i.e., at each i,j location in the array $F_{i,j}$ where HCMM data values were not mapped from the analysis map because coordinates near or corresponding to the specific i,j location did not exist).

Errors in location of the satellite data occurred because it was not possible to locate precisely geographical features in the analysis map. Generally, a number of estimates were attempted until one was found that yielded the best geographic positioning. Even so, positioning errors as large as 3 km are noted in some of the analyses.

3.0 In Situ Data

3.1 Nantucket Shoals and Gulf of Mexico Regions

The *in situ* observations of sea-surface temperature in the Nantucket Shoals region used in this study were acquired by the Woods Hole Oceanographic Institution (Limeburner, Beardsley, and Esaias, 1980). Biological and hydrographic data were obtained by Woods Hole in the vicinity of the Nantucket Shoals in the period of May 1978 to May 1979. During that period, a number of transects were accomplished during each cruise; essentially, the same transects were accomplished for each cruise. Figure 1 shows the position of the stations chosen from those available from which data were acquired for use in this study. The stations having a north-south orientation will hereafter be referred to as the N-S transect; and those with a west-east orientation, the W-E transect.

The *in situ* data used in the Gulf of Mexico were acquired by the Research Triangle Institute as a part of the data acquisition for the Department of Energy's Ocean Thermal Energy program (Starr and Maul, 1982). Biological, ocean color, and hydrographic data were collected for the period of 27 March through 1 April 1979. Figure 3 shows the position of the transect from which data were acquired on 27 March 1979 and used in this study. Table 1 gives the dates, specific locations, *in situ* surface temperature, corresponding HCMM digital count at the location of the surface temperature, and mean transmissivity for each case study. These data were used in the calibration procedure.

In both the Nantucket Shoals and the Gulf of Mexico programs, standard calibration procedures were used to maintain the temperature probe. The results of the calibration analyses indicated a potential error in the *in situ* sea-surface temperature data of less than 0.5°C (average error was about ± 0.3°C).

The upper air data necessary to calculate the atmospheric transmissivity were acquired from the National Weather Service upper air station at Chatham, Massachusetts, and at Key West, Florida, for the Nantucket Shoals and for the Gulf of Mexico case studies, respectively. Chatham is roughly 50 km from the Nantucket Shoals, and Key West is roughly 400 km from the center position of the transect used in the Gulf of Mexico.

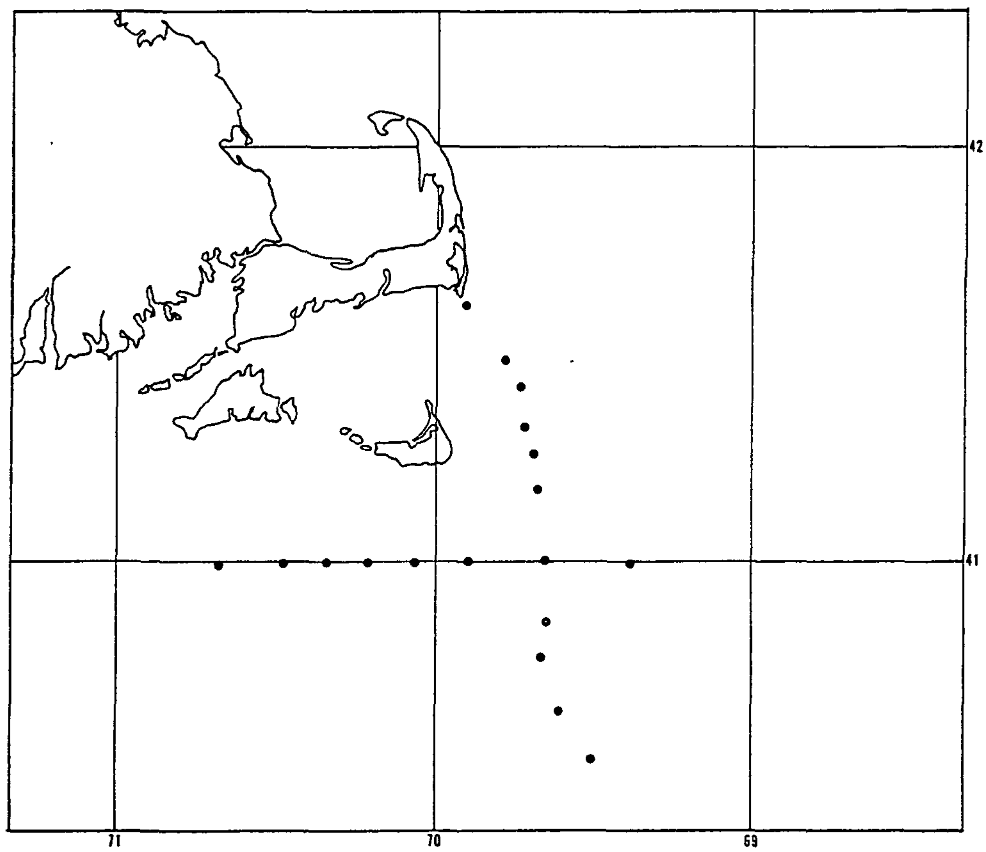

Figure 1. Map showing positions where in situ sea-surface temperatures were obtained for the Nantucket Shoals study.

Table 1. Values for the mean transmissivity, $\bar{\tau}$, the sea-surface temperature, T_o, and the HCMM digital count corresponding to the sea-surface temperature, C_o, used to determine a' and b' in Equation 10 for the oceanic case studies.

Date	Type of Pass	Location	$\bar{\tau}$	T_o (°C)	C_o
12 July 1978	Night	Nantucket Shoals	0.78	17.5	58
2 Sept 1978	Night	Nantucket Shoals	0.72	16.0	59
24 March 1979	Day	Gulf of Mexico	0.60	24.7	70

3.2 St. Louis Study

For the St. Louis, Mo., case studies, Mississippi River temperatures, which were acquired from the U. S. Army Corps of Engineers, were used to calibrate the HCMM infrared temperatures. Table 2 gives the dates, river temperature, and corresponding HCMM digital count for each case study. The river temperature observations were made near the Chain of Rocks Bridge, which is located near Mosenthein Island immediately north of the central portions of St. Louis (see Figure 2). No estimate of the error in the river temperature observations were available. An error of roughly ± 0.5°C was estimated based on the observed day-to-day variability.

The upper air data from the National Weather Service station at Salem, Illinois, provided the water vapor data to calculate the atmospheric transmissivity necessary to solve the radiative transfer equation and to find the mean transmissivity. Salem, Illinois, is roughly 200 km from St. Louis.

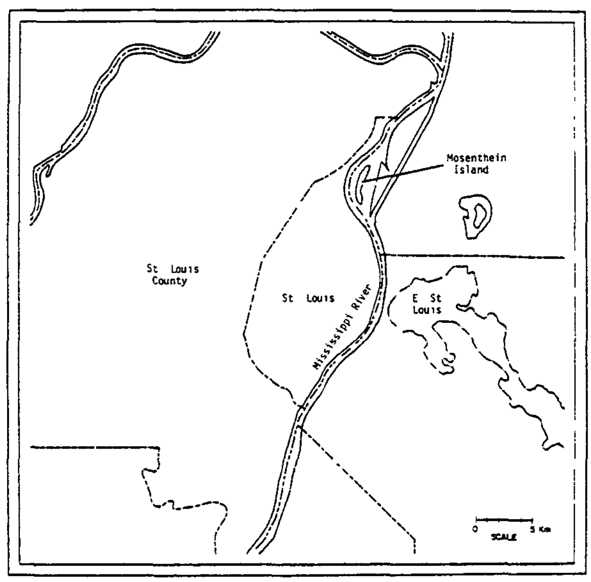

Figure 2. Map identifying regions of interest around the St. Louis, Missouri, area.

Table 2. Values for the mean transmissivity, $\bar{\tau}$, the Mississippi River temperature, T_o, and the digital count corresponding to the Mississippi River temperature, C_o, used to determine the constants a' and b' in Equation 10 for the St. Louis case studies.

Date	Type of Pass	$\bar{\tau}$	T_o (°C)	C_o
9 June 1978	Night	0.80	23.6	65
10 June 1978	Day	0.72	23.3	81
14 June 1978	Night	0.70	23.3	66
26 June 1978	Day	0.62	26.7	84
26 Feb 1979	Day	0.85	2.2	17
27 Sept 1979	Day	0.74	22.2	75

4.0 Calibration Results

Table 3 gives the in situ sea-surface temperature, the HCMM equivalent blackbody temperature at the location of the in situ surface temperature, the atmospheric correction, and the difference between the HCMM surface temperature corrected for atmospheric attenuation and the in situ surface temperature for each of the oceanic case studies. The magnitude of the corrected HCMM surface temperature is, in all cases, less than the in situ surface temperature. The average difference is -4.5°C. Table 4 gives the in situ river temperature, the HCMM surface temperature at the location of the in situ surface temperature, the atmospheric correction, and the difference between the HCMM surface temperature corrected for atmospheric attenuation and the in situ temperature for each of the St. Louis case studies. Again, the magnitude of the corrected HCMM surface temperature is, in all cases, less than the in situ surface temperature. The average difference, in these cases, is -4.6°C. The average difference over all cases is -4.6°C.

Table 5 gives a comparison between the in situ surface temperature, the corresponding HCMM digital count, and the difference between the atmospherically corrected HCMM surface temperature and the in situ surface temperature for those cases when the surface temperature had a value between 22°C and 27°C. For the 10 June and 26 June 1978 cases, the average in situ surface temperature is 25.0°C and the average value of the corresponding HCMM digital count is about 83. For the remaining cases, the average in situ surface temperature is 23.5°C, and the average corresponding HCMM digital count is 69. Essentially, for a difference of 1.5°C between average temperatures, there is an average 14-count difference. It can be shown that, based on equations (7) and (12), there is about a 1.0°C temperature change for an incremental change of about 3 digital counts at around 25°C. Based on the 14-count difference, there should have been roughly a 5.0°C difference between the average in situ temperature rather than the observed value of 1.5°C. Some variation in counts is expected from case to case due to atmospheric attenuating; but for the 10 and 14 June 1978 cases, the atmospheric effect is roughly the same, yet there is a 15-count difference between cases (see Tables 2 and 5). Furthermore, the average value of ΔT--the difference between the atmospherically corrected HCMM surface temperature and in situ surface temperature--for the 10 and 26 June 1978 cases is -2.0°C; whereas for the remaining cases, it is -5.4°C. The HCMM data for 10 and 26 June compare more favorably with the in situ data, implying

Table 3. The in situ sea-surface temperature, T_o, the HCMM equivalent blackbody temperature at the location of the in situ temperature observation, T_{BB}, the atmospheric correction, δT, and the difference, ΔT, as defined by the expression $\Delta T = T_{BB} + \delta T - T_o$.

Date	T_o (°C)	T_{BB} (°C)	δT (°C)	ΔT (°C)
12 July 1978	17.5	10.1	2.3	-5.1
2 Sept 1978	16.0	10.6	1.3	-4.1
24 March 1978	24.7	14.3	6.1	-4.3
			Average	-4.5

Table 4. The *in situ* Mississippi River temperature, T_o, the HCMM equivalent blackbody temperature at the location of the *in situ* temperature, T_{BB}, the atmospheric correction, δT, and the difference, ΔT, as defined by the expression $\Delta T = T_{BB} + \delta T - T_o$.

Date	T_o (°C)	T_{BB} (°C)	δT (°C)	ΔT* (°C)
9 June 1978	23.6	12.8	2.5	-8.3
10 June 1978	23.3	18.2	3.0	-2.1
14 June 1978	23.3	13.1	4.1	-6.1
26 June 1978	26.7	19.3	5.5	-1.9
26 Feb 1979	2.2	-6.0	1.7	-6.5
27 Sept 1979	22.2	16.2	3.1	-2.9
			Average	-4.6

Table 5. Comparison of the *in situ* surface temperature, T_o, the corresponding HCMM digital count, C_o, and the difference, ΔT, between the HCMM surface temperature corrected for atmospheric attenuation and the *in situ* temperature for only those cases when the *in situ* temperatures was between 22° and 27°C.

Date	Location	T_o	C_o	ΔT
9 June 1978	St. Louis	23.6	65	- 8.3
10 June 1978	St. Louis	23.3	81	- 2.1
14 June 1978	St. Louis	23.3	66	- 6.1
26 June 1978	St. Louis	26.7	84	- 1.9
27 Sept 1979	St. Louis	22.2	75	- 2.9
24 March 1979	Gulf of Mexico	24.7	70	- 4.3

that the imposed correction works well in these cases. Both the 10 and 26 June 1978 cases are daytime cases; however, the 24 March and 27 September 1979 cases are also daytime cases, and yet their corresponding digital count values are closer to the average value of 69 rather than 83, which is for the 10 and 26 June cases. There is, on the average, a one-year difference between the two 1978 case studies when the corresponding digital count was about 83 for an *in situ* temperature of about 25°C and the two 1979 daytime case when the corresponding digital count was about 73 for an *in situ* temperature of about the same value (~ 23.5°C). It is interesting to note that the data used by Bohse et al. (1979) to perform the initial calibration of the HCMM data was collected between 11 May and 19 June 1978; i.e., about the time the large difference between digital count values for roughly the same *in situ* temperature is noted.

5.0 Comparisons With Field Data

The field data collected during Woods Hole's Nantucket Shoals experiment and the Research Triangle Institute's Gulf of Mexico experiment were compared with the HCMM infrared data in order to obtain a measure of the absolute and relative accuracy of the HCMM infrared data. Figure 3 is the analysis of the sea-surface temperature distribution in a portion of the eastern Gulf of Mexico from the HCMM satellite data for 24 March 1979. The analysis was developed using calibrated and atmospherically correct HCMM data in this case as well as all following cases.

The eastern Gulf of Mexico is dominated by a warm water current known as the Loop Current, a part of the Gulf Stream system. In Figure 3, the Loop Current is the water mass having a surface temperature greater than 24°C. The cold water mass (temperatures < 24°C) found generally east of 83°W and north of 23.8°N is the water mass which generally characterizes the West Florida shelf. The cold water mass (< 24°C) centered at around 24°N and 85°W is cold core perturbation imbedded in the Loop Current.

Field data were collected along the transect depicted in Figure 3. Figure 4 gives a comparison between the *in situ* data collected along the transect and HCMM data selected at the points defining station positions along the transect. Even though the field data were obtained 3 to 4 days after the HCMM measurements were made, the agreement is remarkable. The root-mean-square difference (RMSD) between the two surface data sets is ± 0.6°C.

Figure 5 gives the analysis of the HCMM sea-surface temperatures in the Nantucket Shoals region for 12 July 1978. From about the beginning of May to the end of September, when the shelf water becomes stratified, tidal mixing brings cold water from the subsurface to the surface, producing an extensive lens of cold water over the shoals (the region south and east of Cape Cod). Tidal mixing occurs at the other times of the year; however, at those times, the shelf water is homogenously mixed in the vertical so that the temperature contrast is not produced at the surface.

Figure 6 shows the comparison between the HCMM sea-surface temperatures with the field data that was collected along the two transects which are depicted in Figure 1. The agreement between the two data sets is not as good as that for the Gulf of Mexico data set. Even so, there is a strong similarity between the variations delineated in the two data sets. The RMSD in this case is ± 1.2°C.

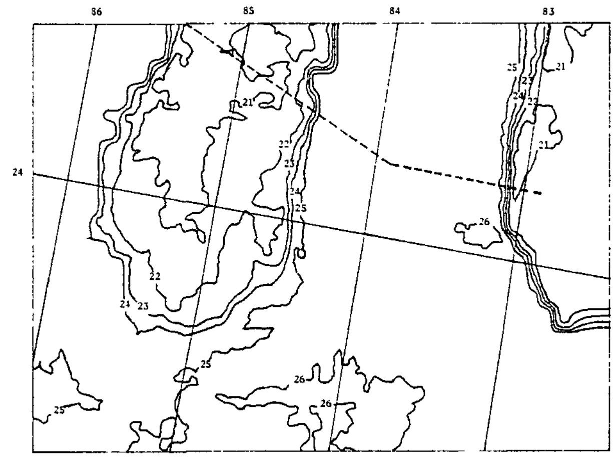

Figure 3. Sea-surface temperature (^{o}C) analysis in portion of the eastern Gulf of Mexico for 24 March 1979 using HCMM infrared data. Dashed line indicates transect along which _in situ_ sea-surface temperature data were collected on 27 March 1979.

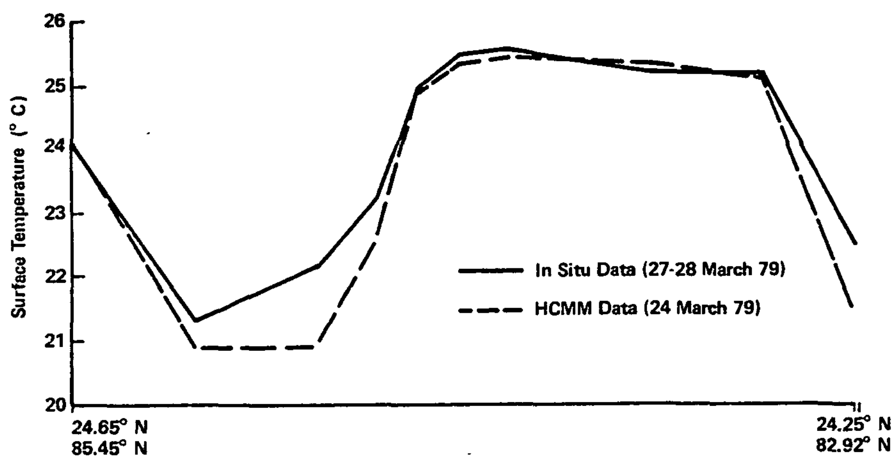

Figure 4. Comparison of in situ and HCMM sea-surface temperatures along the transect in the eastern Gulf of Mexico for the March 1979 case.

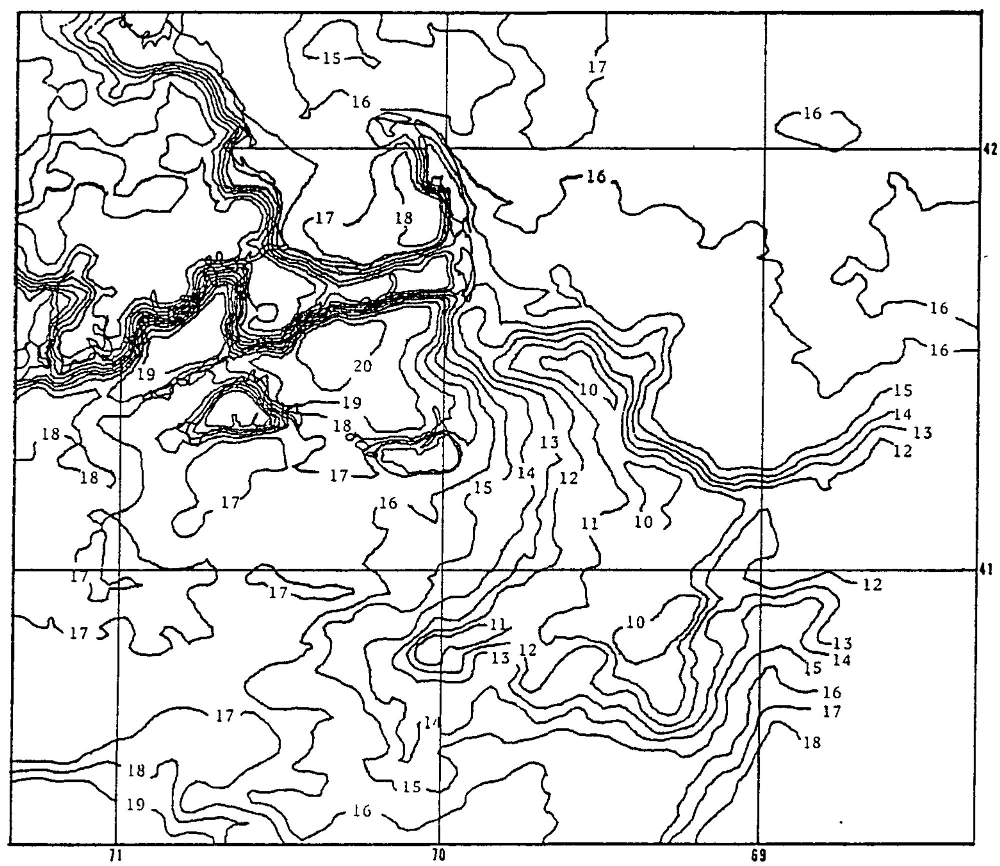

Figure 5. Sea-surface temperature (^{0}C) analysis in the Nantucket Shoals region for 12 July 1978 using HCMM infrared data.

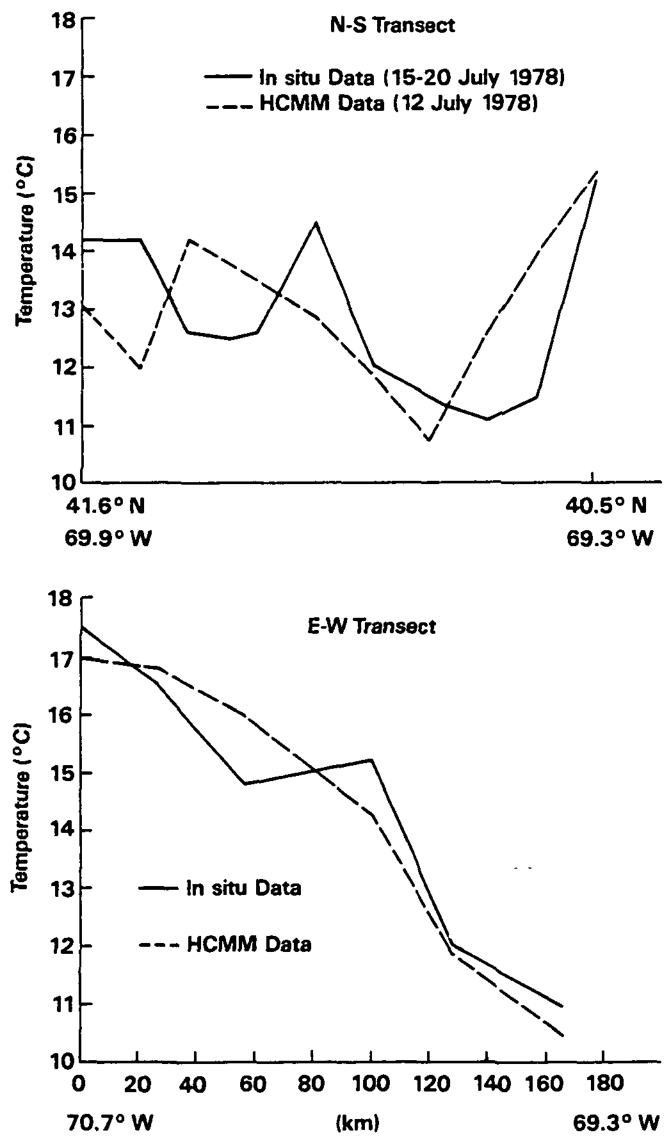

Figure 6. Comparison of in situ and HCMM sea-surface temperatures along the two transects in Figure 1 for the July 1978 case.

Figure 7 is the analysis of the HCMM sea-surface temperature in the Nantucket Shoals region for 2 September 1978, and Figure 8 gives the comparison of the HCMM surface temperature with those from the field data. The relationship between the two data sets is stronger in this case than in the previous Nantucket Shoals case. This is substantiated by the RMSD which is ± 0.8°C in this case.

All the data shown in Figures 4, 6, and 8 were combined in one overall statistical analysis of the HCMM data. Included in the overall analysis were also surface temperatures chosen at positions where field data were collected in the Nantucket Shoal region that were neither along the N-S transect or the W-E transect. This was done to minimize data gaps over the temperature range for which this analysis was performed. The range was from 10° to 25°C. The analysis (Figure 9) showed that the overall RMSD was ± 1.0°C, and the linear correlation coefficient (R) was a very respectable 0.97. No significant improvement in the correlation coefficient was noted when nonlinear analyses were performed. This implies that the linear expression relating digital counts to the radiation received by the satellite (Equation 7) is an accurate representation of that relationship and that the relative accuracy of the HCMM data is quite good. The overall RMSD found in this case is the same as that found by McClain (1980) using multiple channel data from the NOAA satellites (RMSD = ± 1.1°C) and by Maul (1981) using GOES satellite data (RMSD = ± 1.2°C). Maul (1981) points out that an RMSD of ± 1.0°C or slightly less is probably the geophysical limit of accuracy of the present generation of infrared radiometers.

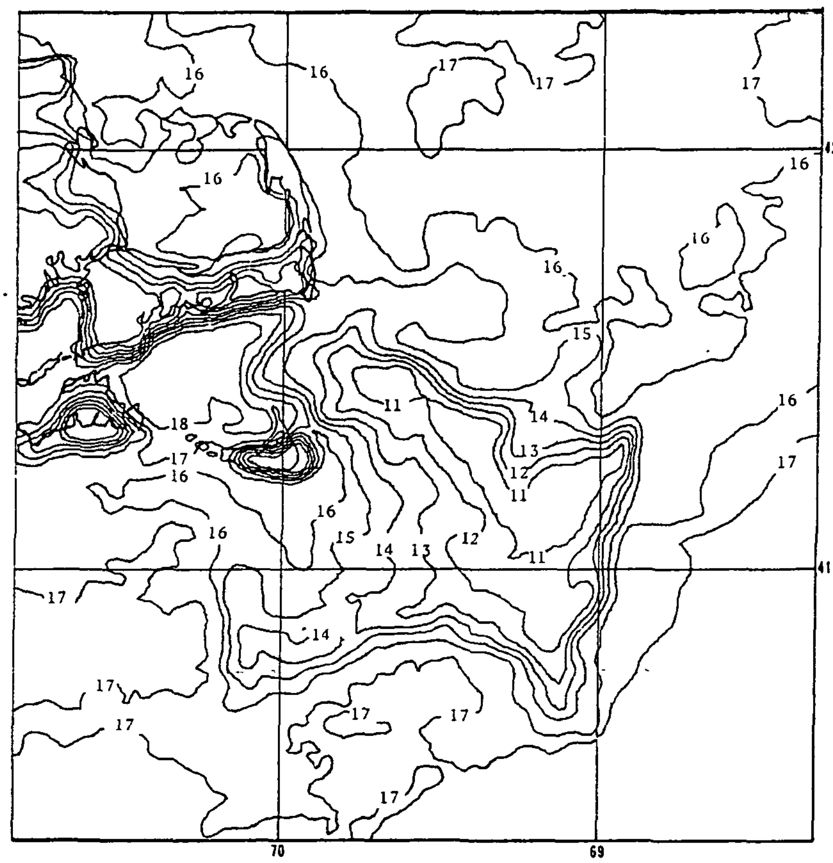

Figure 7. Sea-surface temperature (^{O}C) analysis in the Nantucket Shoals region for 2 September 1978 using HCMM infrared data.

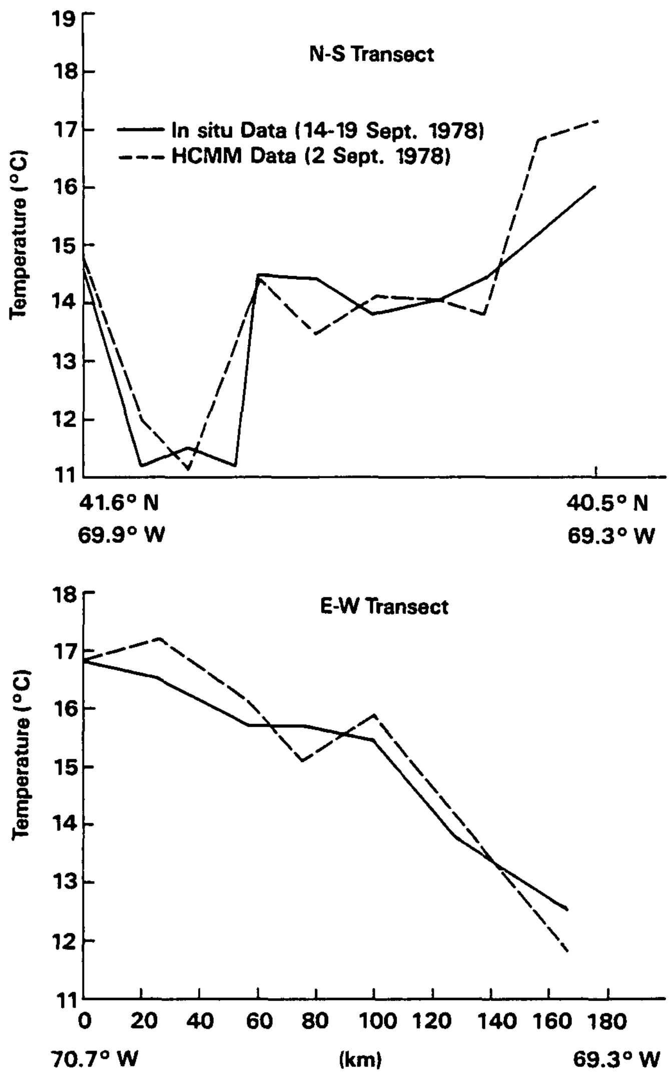

Figure 8. Comparison of in situ and HCMM sea-surface temperatures along the two transects in Figure 1 for the September 1978 case.

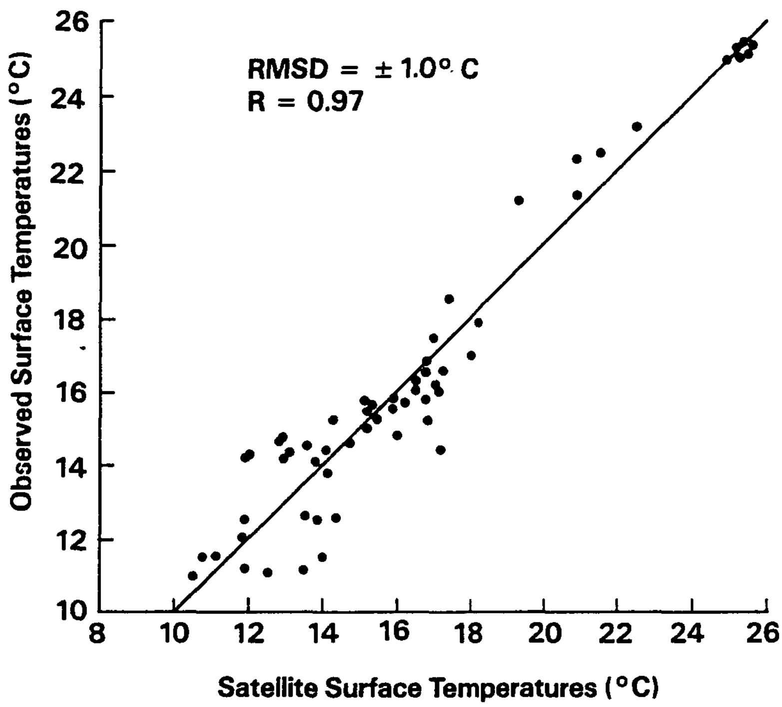

Figure 9. Comparison of in situ and HCMM sea-surface temperatures for all ocean data.

6.0 Discussion of Results

The results of this study indicated that, on the average, the difference between the HCMM surface temperature corrected for atmospheric attenuation and the in situ temperature for the same location was - 4.6°C; i.e., the atmospherically corrected HCMM surface temperature was 4.6°C too low. Though the evidence is not conclusive, it appeared that there may have been a problem with HCMM radiometer calibration in the first few months after launch. Two orbits in June 1978 had digital count values that corresponded to an in situ temperature of 25°C, on the average, 14 counts higher than an average digital count value for the remaining orbits that corresponded to about the same in situ temperature value. Since the remaining orbits covered a period from June 1978 to September 1979, and the 14-count difference was not noted after June 1978, it was assumed that the 14-count difference was a characteristic of the period of the first few months after launch. However, the sample size is too small and the samples too widely separated to determine precisely the time extent of the calibration problem. Some differences are expected due to atmospheric attenuation, but a 15-count difference was noted for two cases having essentially the same atmospheric attenuation. It is interesting to note that a digital count difference of 14 corresponds to a temperature difference of roughly 5.0°C. Furthermore, the HCMM data used by Bohse et al. (1979) for the initial calibration that showed that the HCMM surface temperatures were 5.2°C too high, were collected in May and June 1978. The average difference between the HCMM surface temperature that was corrected for atmospheric attenuation and the in situ surface temperature for the two cases that had a digital count value 14 counts higher than the remaining cases for essentially the same in situ temperature, was - 2.0°C; and that for the remaining cases for the same in situ temperature was - 5.4°C. All this evidence suggests that (1) there was a calibration problem associated with the HCMM radiometer that may have produced atmospherically corrected HCMM surface temperatures that were, on the average, 5.2°C too high; (2) examination of the limited sample size suggested that sometime around June 1978, the faulty operation of the HCMM radiometer may have been corrected on board the satellite, but the exact time was not conclusively determined; and (3) since the raw digital counts for all orbits were processed so as to produce a HCMM surface temperature which was lower by 5.2°C, all HCMM surface temperatures from about July 1978 to at least September 1979 may be 5.2°C too low.

As indicated above, after Bohse et al. determined that the HCMM surface temperatures were 5.2°C too high, all the raw digital data were processed so as to produce a HCMM temperature which was lower by 5.2°C. Since the evidence suggests that this correction may have been erroneously applied to the HCMM data collected after June 1978 and since reprocessing of the raw HCMM data is out of the question, it is recommended that 5.2°C be added to all HCMM surface temperatures, but only after there has been, at least, a limited comparison with in situ data. If the comparison suggests that the HCMM temperature is too low by 3.0°C or more, then the 5.2°C should be added; otherwise, the correction should not be applied.

Calibrated and atmospherically corrected HCMM surface temperatures (hereafter referred to as the corrected temperatures) were compared with field data collected in the ocean shelf regions of the Nantucket Shoals and in the eastern portion of the Gulf of Mexico. There were 57 data points available from the case studies which covered a range from 10° to 25°C. The comparison showed that the root-mean-square difference (RMSD) was ± 1.0°C and that the linear correlations coefficient was 0.97. These values are consistent with values found by McClain (1980) for the radiometer (AVHRR) on the NOAA satellites and by Maul (1981) for the radiometer (VISSR) on the GOES satellite. Maul suggested that an RMSD of ± 1.0°C or slightly less is probably the geophysical limit of accuracy of the present generation of infrared radiometers.

7.0 References

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