Evaluation of GMS-derived sea surface temperature in the southern hemisphere

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Ten-day mean sea surface temperature (SST), derived from the Japanese Geostationary Meteorological Satellite (GMS) infrared radiation data, have been evaluated seasonally around Australia using buoy and ship data archived by the Australian Bureau of Meteorology for 1979 and 1980. The overall average success rate of the SST acquisition from the satellite is found to be 75 per cent; the maximum and the minimum rates are 86 per cent (October 1979) and 57 per cent (April 1980) respectively. It is shown that an objective analysis scheme can provide useful SST data for the residual 25 per cent of grid-points rejected mainly due to cloudiness.

The accuracy of the GMS-derived ten-day mean SST was verified against data from drifting buoys and conventional ships, yielding a mean temperature difference of −1.2° to +1.3°C with a root mean square (RMS) difference of 0.8° to 1.5°C. With the exception of July, the satellite estimates for 1980 were in good agreement with shipborne measurements, that is both the mean temperature and the RMS differences were less than 1.1°C.

Introduction

Global monitoring of the oceans from satellites has long been desired by the oceanographic and meteorological communities. Above all, sea surface temperature (SST) is one of the principal and readily available elements that is being obtained from satellites in space using remote sensing techniques, and has been given attention in view of its importance in the air-sea interaction problem.

Since 1978 the Japan Meteorological Satellite Center ( JMSC) has routinely produced ten-day mean SST from the visible and infrared spin scan radiometer (VISSR) data of the Japanese Geostationary Meteorological Satellite (GMS). The measurements have been calculated by a fully automated processing and objective analysis method over the oceans of both hemispheres within the GMS coverage region (50°N – 49°S; 90°E – 171°W) at grid-points one degree latitude and longitude apart. The fundamental algorithm of the SST derivation has been adapted from the global operational sea surface temperature computation (GOSTCOMP) of the NOAA series of polar orbiting satellites (Brower et al. 1976). The geostationary algorithms have been obtained by modification of the GOSTCOMP formulations.

VISSR scans cloudy areas as well as cloud-free areas. Clouds introduce noise during the derivation of SST from space. The GMS infrared radiometer measures radiation in the range 10.5 to 12.5 μm, which is one of the most transparent regions — the so-called 'atmospheric window'. However, it is well known that atmospheric attenuation would still be encountered, arising primarily from water vapour in the atmosphere.

In order to obtain more accurate SST from satellites using infrared data, the following problems should be solved:
• elimination of the effect of cloud contamination;
• correction for atmospheric attenuation.

For the elimination of cloud contamination, a statistical histogram analysis method has been introduced. The correction for atmospheric attenuation can be estimated from an empirical relationship using climatological precipitable water.

Many scientists have investigated the accuracy of satellite-observed SST. As far as the GOSSTCOMP products are concerned, Brower et al. (1976) have examined the accuracy with the use of a global daily mean temperature difference and a root mean square (RMS) deviation from data supplied by ship reports, and Barnett et al. (1979) have undertaken an evaluation of the difference between satellite and actual observations with airborne expendable bathythermographs (AXBTs) in the central Pacific Ocean. Concerning the GMS SST produced by methods similar to GOSSTCOMP, Abe (1981a, b) and Nagasaka (1982) have studied the accuracy of the GMS-derived ten-day mean SST in the northern hemisphere by comparing them with conventional ship measurements. On the other hand, the evaluation of the accuracy of the GMS SST in the southern hemisphere has not yet been carried out.

This article briefly summarises the general description of the GMS ten-day mean SST derivation, and describes the seasonal evaluation of the products using drifting buoy and conventional

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ship observations around Australia during 1979 and 1980.

Outline of the GMS ten-day mean SST derivation

A flow diagram for the GMS SST derivation and processing is shown in Fig. 1. The SST derivation system is made up of daily processing and ten-day mean processing. Daily retrieval is effected from an analysis of the brightness temperature histogram within a one degree square of latitude and longitude. The histogram comprises data that are accumulated from six-hourly VISSR infrared observations, enabling diurnal variations to be considered.

If a square in a sea area with a uniform temperature field is cloud-free, the histogram shape would show a Gaussian distribution, and the representative temperature of the area is the mode of the distribution, Tm (Smith et al. 1970). If a histogram has a Gaussian distribution, the mean temperature Tm can be expressed as

\[
T_m = \frac{(T_3 - T_1) \ln (F_1/F_2) + (T_1 - T_2) \ln (F_1/F_3)}{2 (T_3 - T_1) \ln (F_1/F_2) + 2 (T_1 - T_2) \ln (F_1/F_3)}
\]

where Ti and Fi are the temperature and frequency of the i-th class respectively (Brower et al. 1976). In this analysis three classes will be used, i.e. (T1, F1), (T2, F2) and (T3, F3).

Ordinarily, clouds would also be present in the square area. However, in general, cloud top temperature is colder than sea surface temperature.

Fig. 1 Flow diagram for GMS SST derivation processing system.

Therefore, the cold side of the distribution must be affected by cloud contamination. It would be expected then that the warmer side should be unaffected by clouds, thus the mean temperature Tm can be determined by Eqn 1.

The spectral region of the GMS infrared radiometer channel is 10.5 to 12.5 μm. Because the radiant energy emitted from the sea surface in this region is attenuated principally by the water vapour in the atmosphere, it must be corrected for this atmospheric attenuation. In the GMS system, the correction for atmospheric attenuation, DT, has been estimated from an empirical relation using the solar angle, the brightness temperature, and the climatological precipitable water (Inoue 1979). The coefficients of the correction are determined by the regression method using the following relationships

\[
DT = T_s - T_{bb} \quad \ldots \quad 2
\]

\[
W = \frac{\sum W \Delta P}{\sum \Delta P} \quad \ldots \quad 3
\]

where Ts and Tbb are an actual observed SST and brightness temperature, W is the measured precipitable water that is calculated from radiosonde observations, and Q is the mean mixing ratio between two different pressure layers ΔP. These coefficients use the same values in all months. The daily retrieval, Tr, is calculated by

\[
T_r = T_m + DT \quad \ldots \quad 4
\]

As a matter of course, the daily retrievals are not successful in the square areas where the amount of cloud is excessive. Nevertheless, since cloudiness variability in space and time is very high, the probability of having cloud-free square areas increases over an observing period of several days. Arguably, the heat capacity of sea water is so large that the sea surface temperature might not change significantly during a ten-day period. By taking advantage of these characteristics, the mean SST for the ten days could be derived using the time composite method. Unfortunately, data histograms compiled for areas of uniform or partial cloud layers would yield the same shape, e.g. the Gaussian distribution. Therefore, before calculating the mean SST, such daily retrievals that may be in error because of this ambiguity must be identified by comparing them to a reference or First Guess SST (FGSST) and a thermal surface gradient and then removed. The FGSST is the previous ten-day mean SST derived from the GMS. This is called the Static Control Check.

The absolute value of the ten-day mean SST is determined from the weighted retrievals that have passed the Static Control Check. This is the time composite processing (TCP) procedure. Furthermore, the ten-day mean SST obtained from the TCP
is checked against adjacent grid-point SST tendencies around the search area, and anomalous data are rejected. The associated search area is inferred from the thermal surface horizontal gradients. This test is called the Dynamic Control Check.

Finally, rejected grid-point SST data are estimated from the good quality neighbourhood SST measurements within the search area and the FG SST, using an objective analysis technique (Brower et al. 1976; Abe et al. 1979). This is named the Quality Control and Final Merge Processing procedure. In this way, a complete field of grid-point SST data can be produced. These satellite-derived SST data become the following ten-day FG SST field (Fig. 1). Figure 2 is an example of the GMS-derived ten-day mean SST isotherm chart.

**Ship and buoy observed ten-day mean SST**

In order to evaluate the satellite-derived ten-day mean SST, a standard ten-day mean SST should be provided. The Meteorological Information Services Section of the Australian Bureau of Meteorology (ABOM) has operationally archived the validated observed data that are reported by conventional ships and buoys. To measure the standard ten-day mean SST for each grid-point, all available data located in squares of one degree of latitude and longitude during ten days are assembled from the archived data. The question of the reliability of these observations must be carefully addressed before they can be used in any SST verification scheme. The
following procedures are applied to the observations at all grid-points so as to remove any anomalous data.

Gross error check
A ship and buoy reported SST value of more than \([2SD]^\circ C\) difference from the climatological ten-day mean SST is rejected (SD: standard deviation for climatological monthly mean SST). The standard deviations used here have been calculated and published by the US Navy (1981). The climatological monthly mean SST field was calculated for the GMS coverage region at each one degree latitude and longitude square from in-situ ship measurements. The climatological ten-day mean SST has been estimated by interpolation from the monthly SST.

Statistical check
Detailed statistical information for each grid-point is calculated for a ten-day period for the measurements that have passed the gross error check, e.g., the number of accepted reports, the maximum, the minimum, the mean, and the standard deviation. These statistical data are referred to in the next procedure.

Comparison with monthly mean analysis SST chart
Finally, every grid-point mean SST is compared with a composite surface temperature analysis chart issued monthly by the National Meteorological Analysis Centre of ABOM by screening out in-situ ship observations. If the difference between the calculated ten-day mean SST and the monthly mean analysis SST exceeds \([2SD]^\circ C\), the grid-point data are excluded. In cases where the numbers of measurements are few or the standard deviation is large, the conditions of acceptability of the mean data are more stringent.

Evaluation of the GMS SST
A seasonal evaluation of the ten-day mean SST measured by the GMS has been summarised in the region (10°S — 49°S; 100°E — 179°E) during 1979 and 1980. The seasonal representative months of the SST data are based on 11 to 20 January, 11 to 20 April, 1 to 10 July and 11 to 20 October.

Acquisition
The acquisition rates of the satellite SST measurements were examined to ascertain the acceptance rate of all data after all check procedures have been applied, and the result is shown in Table 1. The average availability of good quality SST is 75 per cent; the maximum and minimum rates are 86 per cent (October 1979) and 57 per cent (April 1980) respectively. From spring through summer in particular, the acceptability appears to be higher than the annual average. Figure 3 shows the geographic distribution of the final stage of the SST data at each grid-point. The symbols \(\times\), \(-\), \(+\), and BLANK denote a grid-point that has no retrieval, is rejected at Static Control Check, is rejected at Dynamic Control Check, or is accepted, respectively. On the whole, higher availability of good quality SST data (BLANK) is found in the mid-latitude (15°S — 35°S) zone, but significant seasonal variations of this distribution are not evident.

Accuracy
The GMS SST is an area/time mean measurement, whereas ship/buoy SST is a point instantaneous measurement of the same physical system. Furthermore, the satellite only measures the brightness temperature of the upper few microns of sea water, ship/buoy measurements are of a greater depth (\(-10\) cm). That the temperature obtained from these two measurements should be different — but very similar — is not surprising. As noted by Bernstein (1982), ship — and to a lesser extent buoy — observations have been used to construct the basic global SST data sets and must be interpreted as the standard against which other SST measurements are to be compared. In this paper the ‘accuracy’ of GMS SST data is determined by comparison with the SST fields derived from drifting buoys and ship data.

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<tr>
<td>Rejected at static check*</td>
<td>304</td>
<td>289</td>
<td>471</td>
<td>911</td>
<td>170</td>
<td>643</td>
<td>199</td>
<td>249</td>
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<tr>
<td></td>
<td>13%</td>
<td>12%</td>
<td>19%</td>
<td>38%</td>
<td>07%</td>
<td>27%</td>
<td>08%</td>
<td>10%</td>
</tr>
<tr>
<td>Rejected at dynamic check</td>
<td>252</td>
<td>226</td>
<td>300</td>
<td>129</td>
<td>201</td>
<td>105</td>
<td>151</td>
<td>181</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>09%</td>
<td>12%</td>
<td>05%</td>
<td>08%</td>
<td>04%</td>
<td>06%</td>
<td>07%</td>
</tr>
<tr>
<td>Good quality (accepted)</td>
<td>1861</td>
<td>1902</td>
<td>1646</td>
<td>1377</td>
<td>2046</td>
<td>1669</td>
<td>2067</td>
<td>1987</td>
</tr>
<tr>
<td></td>
<td>77%</td>
<td>79%</td>
<td>68%</td>
<td>57%</td>
<td>57%</td>
<td>69%</td>
<td>86%</td>
<td>82%</td>
</tr>
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</table>

*Including ‘no retrieval’ (see Fig. 3: ‘X’)
Average good quality SST = 75%
Number of land grid-points = 783
Number of sea grid-points = 2417
Comparison with drifting buoy observations.

The correlation of satellite-based and drifting buoy observed fields has been investigated. Buoy measurements are known to have precision that is high and superior to that of conventional ship observations, and so are useful as 'sea truth' data (e.g. Bernstein 1982). Fortunately the number of reports from buoys in the Australian region during this period was relatively high due to the favourable survival rate of the First Global GARP Experiment (FGGE) buoys. It is unfortunate that the observations concentrated on the mid-latitude (15°S - 35°S) zone, and were scarce in the tropical region.

Figure 4 shows the differences between the satellite SST and the buoy SST as geographically located fields for the years 1979-1980. The distribution of the deviations from the concurrent buoy data does not have an obvious geographical tendency. On the other hand, the magnitude of the fields of the differences between them depends on season and year.

A summary of the statistics for mean temperature difference and RMS deviation between the two estimates is shown in Table 2. The classification 'A' shown in Table 2 represents all the satellite derived SST including the grid-point data estimated by an objective analysis method; classification 'B' represents the satellite-observed SST data that have passed all Control Checks. The GMS SST data show closer agreement to the buoy observations during 1980 than in 1979. Only during July was a negative mean temperature difference found (i.e. the satellite-derived SST was lower than the buoy-measured SST). Inclusion of SST data estimated by an objective analysis method does not appear to affect the accuracy significantly (see classification A of Table 2).

Table 2(a). Seasonal comparison of GMS-derived SST with buoy-observed SST for 1979. Classification 'A': all satellite-derived SST including grid-point data estimated by an objective analysis method; 'B': good quality SST measured by satellite.

<table>
<thead>
<tr>
<th>Date</th>
<th>11-20 Jan</th>
<th>11-20 Apr</th>
<th>01-10 Jul</th>
<th>11-20 Oct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of grid-points for buoy reports (Total)</td>
<td>42</td>
<td>48</td>
<td>79</td>
<td>83</td>
</tr>
<tr>
<td>(Reject)</td>
<td>6</td>
<td>4</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>Classification</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>No. of comparisons</td>
<td>36</td>
<td>29</td>
<td>44</td>
<td>24</td>
</tr>
<tr>
<td>Satellite Mean temp. diff.</td>
<td>+0.93</td>
<td>+1.00</td>
<td>+0.83</td>
<td>+0.90</td>
</tr>
<tr>
<td>minus Standard deviation</td>
<td>0.81</td>
<td>0.88</td>
<td>0.82</td>
<td>0.80</td>
</tr>
<tr>
<td>buoy (°C) Root mean square diff.</td>
<td>1.23</td>
<td>1.30</td>
<td>1.17</td>
<td>1.20</td>
</tr>
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</table>

Table 2(b). Same as for Table 2(a) but for 1980.

<table>
<thead>
<tr>
<th>Date</th>
<th>11-20 Jan</th>
<th>11-20 Apr</th>
<th>01-10 Jul</th>
<th>11-20 Oct</th>
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<tbody>
<tr>
<td>Number of grid-points for buoy reports (Total)</td>
<td>63</td>
<td>48</td>
<td>37</td>
<td>10</td>
</tr>
<tr>
<td>(Reject)</td>
<td>6</td>
<td>13</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Classification</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>No. of comparisons</td>
<td>57</td>
<td>43</td>
<td>35</td>
<td>14</td>
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<tr>
<td>Satellite Mean temp. diff.</td>
<td>+0.75</td>
<td>+0.74</td>
<td>+1.24</td>
<td>+1.21</td>
</tr>
<tr>
<td>minus Standard deviation</td>
<td>0.86</td>
<td>0.78</td>
<td>0.53</td>
<td>0.42</td>
</tr>
<tr>
<td>buoy (°C) Root mean square diff.</td>
<td>1.14</td>
<td>1.08</td>
<td>1.35</td>
<td>1.28</td>
</tr>
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</table>
Fig. 3(a) Seasonal geographical distribution patterns of GMS SST data acceptance/rejection fields for 1979.

'X': no retrieval, '-': rejected at Static Control Check, '+': rejected at Dynamic Control Check.

'BLANK': accepted (good quality).

11-20 January 1979

11-20 April 1979
Fig. 3(b) Same as Fig. 3(a) but for 1980.

11–20 January 1980

11–20 April 1980
Fig. 4(a) Seasonal geographical distribution patterns of the difference, DS (°C) between GMS-derived SST and buoy SST for 1979 (referring to classification 'B' of Table 2).

'\(D\)': \(3.5 < DS \leq 4.5\)  'C': \(2.5 < DS \leq 3.5\)

'B': \(1.5 < DS \leq 2.5\)  'A': \(0.5 < DS \leq 1.5\)

'O': \(-0.5 < DS \leq 0.5\)  '1': \(-1.5 < DS \leq -0.5\)

'2': \(-2.5 < DS \leq -1.5\)  '3': \(-3.5 < DS \leq -2.5\)

11–20 January 1979

11–20 April 1979
Abe: GMS-derived sea surface temperature

1–10 July 1979

11–20 October 1979
Fig. 4(b) Same as Fig. 4(a) but for 1980.

11–20 January 1980

11–20 April 1980
Abe: GMS-derived sea surface temperature

1–10 July 1980

11–20 October 1980
Table 3 lists the climatological anomalies calculated for the classification B SST (GMS and buoy) observations. The correlation coefficients for 1980 take higher values than for 1979.

**Comparison with shipborne observations**

Some reports from merchant or fishing ships are of questionable reliability, but these are the most widely available data source providing large-scale SST fields (e.g. Bernstein 1982). The accuracy of the satellite-derived SST was evaluated after the matching procedure had been applied to all available ships, buoys, and other in-situ SST measurements.

Figure 5 illustrates the geographical magnitude distribution fields between the satellite and shipborne observations of the SST. The magnitude of the deviations from the shipborne SST has a strong seasonal and yearly dependence. However, the distribution field of the discrepancy of GMS SST from the collocated ship data does not reveal a geographical tendency. The statistical results are tabulated in Table 4.

The differences between satellite and ship determination of SST are smaller in 1980 than in 1979. Only during July was a negative mean temperature difference obtained. When estimated SST data from an objective analysis scheme are included, the satellite-derived SST data still show good accuracy, with the mean temperature difference ranging from −1.12° to +1.06°C and the RMS error 0.88° to 1.52°C.

**Summary and conclusions**

Seasonal ten-day mean SST derived from GMS measurements have been compared to in-situ observations around Australia for 1979 and 1980. It was found that good quality SST measurements may be inferred from VISSR infrared radiation data with an average success rate of 75 per cent, and a mean temperature difference of −1.2° to +1.3°C with an RMS difference of 0.8° to 1.5°C. The residual 25 per cent of grid-points may not be useful as SST data for a ten-day period, mainly due to cloudiness. However, this study has indicated that SST data for the rejected grid-points, estimated using an objective technique, can prove useful and reliable for climatological purposes. This method will provide working quantitative measurements in the areas where observations by conventional ships are not available.

By comparison, for GOSSTCOMP products measured by methods basically similar to the GMS system, Brower et al. (1976) have found that the global daily mean temperature difference and RMS error from ship reports ranged from −0.9° to +0.39°C and 1.67° to 2.23°C respectively. Barnett et al. (1979) have carried out an evaluation of temperature differences, using AXBT observations in the central Pacific Ocean, and have found a bias of 1° to 4°C. The GMS SST results appear to be more accurate than those described in the GOSSTCOMP studies. In 1980 (except for the month of July), both the mean temperature and the RMS differences were less than 1.1°C.

 Generally the accuracy of SST measured by satellites has been discussed by comparison with the SST observed by conventional ships or buoys, but it is true that several problems still need to be addressed. Although the selected ship data used in this study were assumed to be correct, any such observation itself has an inherent noise level of 0.5°C (Cogan et al. 1976). In addition, the GMS SST is an area/time mean, whereas ship-observed SST is a point/instantaneous measurement. Furthermore, the brightness temperature measured by satellites represents a skin surface (of few microns thickness) temperature of sea water, while ships measure the temperature of bulk water (>10 cm depth). The former may be lower than the latter by 0.5° to 1.0°C (e.g. Takayama et al. 1982). The results of this investigation for the month of July appear to confirm this situation but the other seasons show an opposite trend.

The GMS ten-day mean SST studies previously examined in the northern hemisphere have yielded exactly the same seasonal trends (Abe 1981a, b). The cause of this effect may probably be attributed to

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<tr>
<td>minus</td>
<td>+1.43</td>
<td>+1.34</td>
<td>+1.04</td>
<td>+1.95</td>
<td>−1.04</td>
<td>−0.40</td>
<td>+1.91</td>
<td>+0.71</td>
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<td>climate (°C)</td>
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<td>Standard</td>
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<td>0.85</td>
<td>0.87</td>
<td>1.00</td>
<td>0.86</td>
<td>0.83</td>
<td>0.72</td>
<td>0.56</td>
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<td>deviation</td>
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<td>Mean temp.</td>
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<tr>
<td>minus</td>
<td>+0.41</td>
<td>+0.55</td>
<td>+0.14</td>
<td>+0.74</td>
<td>+0.19</td>
<td>+0.31</td>
<td>+0.64</td>
<td>−0.03</td>
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<td>climate (°C)</td>
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<tr>
<td>Standard</td>
<td>0.88</td>
<td>1.17</td>
<td>0.72</td>
<td>0.80</td>
<td>0.80</td>
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<tr>
<td>Correlation coefficient*</td>
<td>0.41</td>
<td>0.75</td>
<td>0.50</td>
<td>0.92</td>
<td>0.57</td>
<td>0.84</td>
<td>0.43</td>
<td>0.98</td>
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</table>

*All correlation coefficients are significant at the 5% level.
the coefficients (empirically determined and unchanged through the year) that are applied in the atmospheric correction. The non-uniform monthly number of observations used in calculating the best fit line from which these empirical coefficients were evaluated causes an overestimate in most months and an underestimate around July. Very recently, the coefficients of atmospheric correction for the GMS-2 have been re-calculated by the regression method described previously from the sixteen representative upper air observations in the mid-latitude (14°N-46°N) Pacific Ocean. Using the advanced atmospheric correction, it may be expected that the accuracy of the GMS-2 SST determinations will be more accurate and stable than those from the GMS.

The accuracy of satellite-estimated SST is highly dependent on the correction for atmospheric attenuation occurring primarily due to water vapour in the atmosphere (Brower et al. 1976). A possible explanation of the superior results for correlations (both buoy and ship) during 1980 when compared to those of 1979 may be that the atmospheric state in the later year conformed more closely to the climatological state used in the determination of the empirical correction procedures. It is hoped that the use of precipitable water monitored in real-time will correct this problem.

In spite of the various possible error sources, the results presented in this paper indicate that the absolute ten-day mean SST derived from the GMS can be estimated to at least within 1.5°C for all seasons even if an empirical atmospheric correction, and only a single infrared radiometer, are employed. Higher accuracy (<1.0°C) should be expected routinely if the coefficients of atmospheric correction are updated seasonally (not necessarily daily or monthly) using actual upper air observations.

Acknowledgments
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Table 4(a). Seasonal comparison of satellite-derived SST with ship-observed SST — including buoy-observed SST, for 1979.
Classifications 'A' and 'B' as in Table 2.

<table>
<thead>
<tr>
<th>Date</th>
<th>11-20 Jan</th>
<th>11-20 Apr</th>
<th>01-10 Jul</th>
<th>11-20 Oct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classification</td>
<td>A  B</td>
<td>A  B</td>
<td>A  B</td>
<td>A  B</td>
</tr>
<tr>
<td>No. of comparisons</td>
<td>539 417</td>
<td>454 336</td>
<td>428 394</td>
<td>433 387</td>
</tr>
<tr>
<td>Satellite Mean temp. diff.</td>
<td>+1.06 +1.10</td>
<td>+0.70 +0.72</td>
<td>-1.12 -1.12</td>
<td>+1.03 +1.09</td>
</tr>
<tr>
<td>minus Standard deviation</td>
<td>1.09</td>
<td>1.05</td>
<td>1.07</td>
<td>1.05</td>
</tr>
<tr>
<td>Root mean square diff.</td>
<td>1.52</td>
<td>1.52</td>
<td>1.27</td>
<td>1.27</td>
</tr>
</tbody>
</table>

Table 4(b). Same as Table 4(a) but for 1980.

<table>
<thead>
<tr>
<th>Date</th>
<th>11-20 Jan</th>
<th>11-20 Apr</th>
<th>01-10 Jul</th>
<th>11-20 Oct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classification</td>
<td>A  B</td>
<td>A  B</td>
<td>A  B</td>
<td>A  B</td>
</tr>
<tr>
<td>No. of comparisons</td>
<td>415 330</td>
<td>428 248</td>
<td>423 334</td>
<td>321 286</td>
</tr>
<tr>
<td>Satellite Mean temp. diff.</td>
<td>+0.48 +0.47</td>
<td>+0.73 +0.55</td>
<td>-0.87 -0.89</td>
<td>+0.33 +0.33</td>
</tr>
<tr>
<td>minus Standard deviation</td>
<td>0.96</td>
<td>0.93</td>
<td>1.01</td>
<td>0.94</td>
</tr>
<tr>
<td>Root mean square diff.</td>
<td>1.07</td>
<td>1.05</td>
<td>1.25</td>
<td>1.09</td>
</tr>
</tbody>
</table>


Fig. 5(a) Seasonal geographical distribution patterns of the difference DS (°C) between GMS SST and ship SST — including buoy-observed SST, for 1979 (referring to classification 'B' of Table 2). Symbols as per Fig. 4(a).

11–20 January 1979

11–20 April 1979
1-10 July 1979

11-20 October 1979
Fig. 5(b) Same as Fig. 5(a) but for 1980.

11–20 January 1980

11–20 April 1980
1-10 July 1980

11-20 October 1980
References


