4.14 FINDING THE TRUE TEMPERATURE OF THE OCEAN SURFACE

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1. INTRODUCTION

Observations of Sea Surface Temperature (SST) made by merchant ships have been analysed to identify random errors and biases which depend on how the measurement was made.

Routine meteorological reports from merchant ships are collated in the International - Comprehensive Ocean-Atmosphere Dataset (I-COADS, Woodruff et al. 1998). We have analysed reports from 1970 to 1997 using metadata from the World Meteorological Organisation "List of Selected, Supplementary and Auxiliary Ships" to give additional information on the methods of measurement for each ship report.

2. SST MEASUREMENT METHODS

The characteristics of the SST data will depend on how the measurements were made. Most of the SST measurements in the period 1970 to 1997 were made using either a bucket and thermometer or by reporting the temperature of the engine intake cooling water. A smaller number of reports were made using hull sensors which are thought to be more accurate. I-COADS contains a metadata flag giving the method of measurements for some of the reports. Information from the SST Indicator "SI" flag is plotted in Figure 1a which shows that prior to 1981 only a subset of SST reports from buckets can be positively identified. However we can also appeal to external metadata contained in the World Meteorological Organisation (WMO) Report No. 47 the "List of Selected, Supplementary and Auxiliary Ships" which gives methods of measurements for many of the ships. WMO Report No. 47 is available in annual files in digital form since 1973 and was published most years in paper form since 1954 (e.g. WMO 1994). The method of measurement can be associated with individual reports using the ship callsign. Figure 1b shows the combined information from both sources, the SI flag and WMO Report No. 47. Using all the available metadata gives a much larger subset of data for analysis and allows the comparison of bucket and engine intake SST extending further back in time.

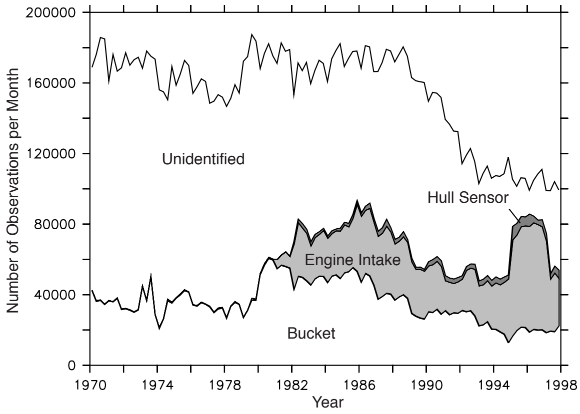

Figure 1a: Number of ship reports by measurement type identified from the COADS "SI" indicator between 1970 and 1997.

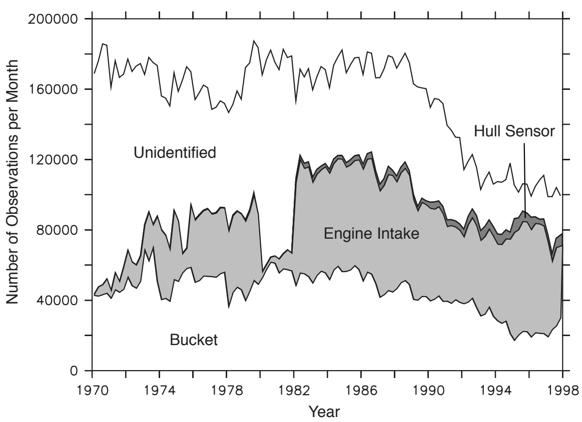

Figure 1b: Number of ship reports by measurement type identified from a combination of the COADS "SI" indicator and WMO Report No. 47 between 1970 and 1997.

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3. RANDOM ERRORS IN SST

The random errors in the dataset were estimated using a method based on that of Kent et al. (1999). They used the semivariogram method to separate random and spatial variability in a dataset of paired ship reports. Squared SST differences were regressed against ship separation to give an estimate of variability at zero separation. We here adapt their method by using a General Linear Model (GLM, McCullagh and Nelder, 1989) with a gamma function error distribution instead of a least-squares regression. The gamma function has a longer tail than the normal distribution (assumed when fitting with least squares) and therefore better fits the distribution of squared differences. Kent et al. (1999) found that their analysis was affected by a small number of outliers: use of the GLM avoids this problem.

Figure 2 shows a time series of random error estimates for all data (solid line) and also separately for reports from buckets and engine intakes. Estimates were calculated for each 5° region for each month where there was enough data. These estimates are then averaged to give a global error estimate for each month. The most significant variation is the difference in quality between engine intakes (dotted line) and bucket reports (dashed line). Engine intake reports typically contain nearly 50% more scatter than bucket SST reports. There is however some evidence that engine intake reports are improving in quality, the average engine intake SST error in the 1970s is 1.8°C, in the 1990s it has decreased to 1.5°C.

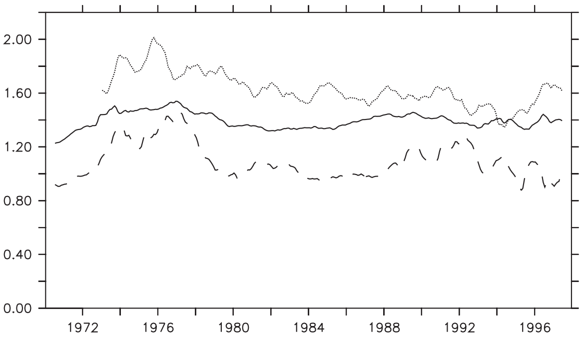

Figure 2: Random error estimates for SST (°C) calculated monthly for period 1970 to 1997. Solid line (centre) is for all data, long-dashed line (bottom) for SST from buckets and dotted line (top) for SST from engine intakes. A 12-month running box filter has been applied to the monthly estimates.

Figure 3 shows how the error estimates for all SST reports vary globally. Large errors can be seen in high variability regions such as the Gulf Stream and Kuroshio. This suggests that the semivariogram method may not be effective at removing all of the spatial variability in these regions. Better error estimates could possibly be achieved by allowing the spatial variability to vary directionally, but this has not been done in this study. The larger errors in the Pacific compared with the Atlantic are due to the distribution of measurement types, there are more reports from engine intakes in the Pacific than in the Atlantic and Figure 2 shows that this will lead to larger errors in SST.

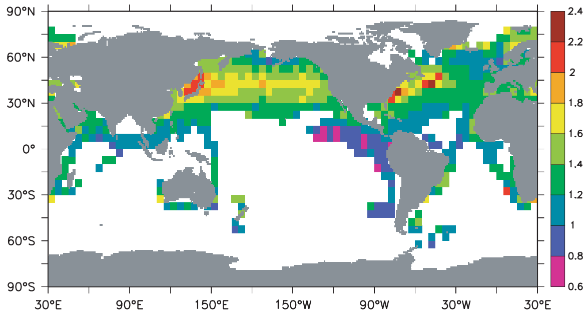

Figure 3: Random error estimates for SST (°C) averaged over period 1970 to 1997.

4. ANALYSIS OF BIAS IN SST

The possibility of bias in the SST reports has been investigated using co-located data pairs. Co-locations are defined as the same reporting hour and within 50 km. Based on the literature (e.g. James and Fox 1972) we assume a model where the bucket SST is affected by air-sea heat fluxes and the engine intake SST contains a bias. In the simplest case we analyse night-time data at moderate wind speed only and represent the air-sea heat flux by the air-sea temperature difference:

$$\underbrace{SST_{bu} - SST_{eri}}_{y} = \alpha\underbrace{\left(T_{air} - SST_{eri}\right)}_{x} + \beta \qquad (1)$$

where SST_{bu} is the bucket SST, SST_{eri} the engine intake SST, T_{air} is the air temperature and α and β are empirical constants. In order to determine α and β by linear orthogonal regression the random errors in the dependent variable (y: SST_{bu} - SST_{eri}) and those in the independent variable (x: T_{air} - SST_{eri}) must be equal and uncorrelated. The errors are not equal; the error in night-time air temperature is smaller than that in bucket SST. In addition the errors are also correlated as SST_{eri} appears as part of both the dependent and independent variable. We must therefore transform the data so that the errors are equal and uncorrelated. This can be achieved by transforming the data using an error correlation matrix:

$$\begin{bmatrix} \sigma_{air}^2 + \sigma_{eri}^2 & \sigma_{eri}^2 \\ \sigma_{eri}^2 & \sigma_{bu}^2 + \sigma_{eri}^2 \end{bmatrix} \qquad (2)$$

where σ_{air} is the random error in the air temperature measurement, σ_{eri} the random error in the engine intake SST and σ_{bu} is the random error in the bucket SST. The diagonal elements are the random error in x and y and the off-diagonal elements are the correlation between them which, in this simple case, is the random error in the engine intake SST. These error estimates are those derived from semivariogram analyses as described in Section 3. Once the data have been transformed, a linear orthogonal regression can be performed and the resulting regression parameters transformed back to give estimates for the model parameters α and β.

Results from a North Atlantic subset of January data are shown in Figure 4. Figure 4a shows the bucket minus engine intake SST plotted against the air minus sea temperature difference. The dashed line is the line of equality and data falling on or near this line cannot be distinguished from errors in the engine intake SST (which appears on both axes). Much of the data is contaminated by these errors as we know that the random error in engine intake SST is large (see Figure 2). The same data is shown in Figure 4b following transformation using the error correlation matrix. The errors in the transformed data shown in Figure 4b are equal and uncorrelated. An orthogonal linear regression has been performed and the upper and lower limits of the regression line are shown. The regression parameters are then transformed back into the physical space and shown as the solid lines in Figure 4a. An estimate of the uncertainty in the regression has been made by repeating the calculation with different values for the error estimates (equation 2). The elements of the covariance matrix were adjusted to the limits of their error range to give

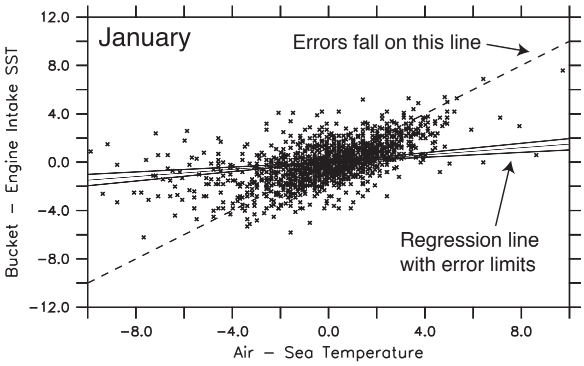

Figure 4a: Bucket - engine intake SST plotted against air-sea temperature difference. Dashed line indicates the contribution of errors in the engine intake SST. Solid lines are the regression (from Figure 4b) and its estimated uncertainty allowing for errors and correlations in the data.

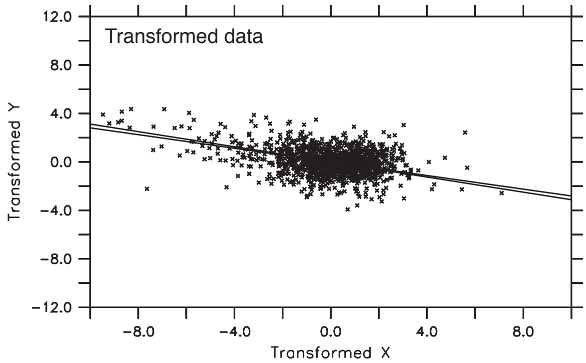

Figure 4b: Data as in Figure 4a after transformation into a data space where errors are equal and uncorrelated. The solid lines are the range of uncertainty in an orthogonal linear regression of the data.

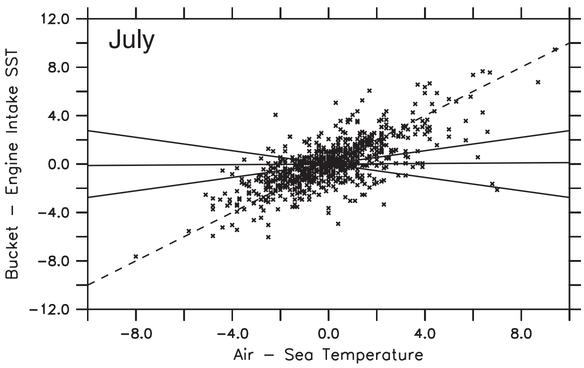

Figure 4c: As Figure 4a but for July.

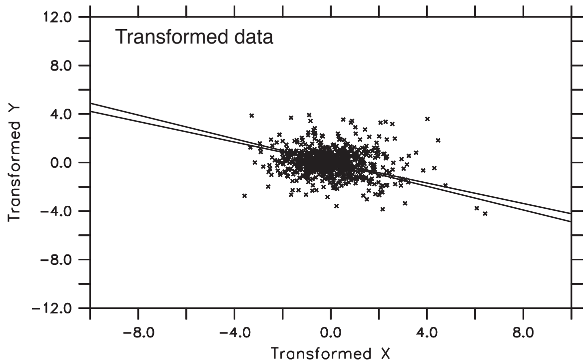

Figure 4d: As Figure 4b but for July.

upper and lower limits for the regression estimate. The uncertainty in the regression itself was also included in the overall uncertainty estimate.

The regression estimate for January shown in Figure 4a is well defined but this was not the case in July (Figure 4c) when there was a smaller range of air-sea temperature difference and little variation away from the dashed line. The transformed data (Figure 4d) shows much less structure than that for January and the resulting regression uncertainty is large (Figure 4c).

Figure 5 shows how the estimates of the regression slope (α, the proportion of the air - sea temperature difference that appears as an error in the bucket SST) and intercept (β, the offset between the bucket and the engine intake SST) vary with month. Outside the summer months (June, July, August) α is 0.2 ± 0.1 (Figure 5a). The estimate of β is not significantly different from zero (Figure 5b)

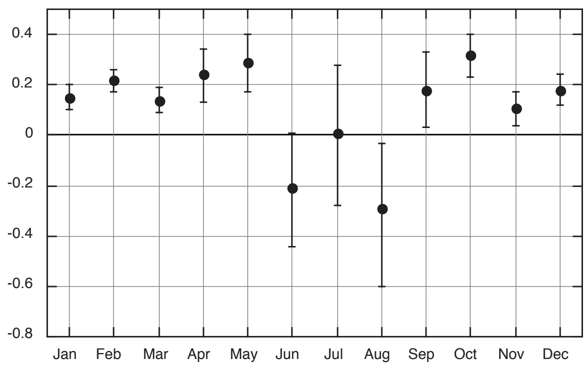

Figure 5a: Monthly variation of slope (α): the relationship between Bucket SST error and the air-sea temperature difference.

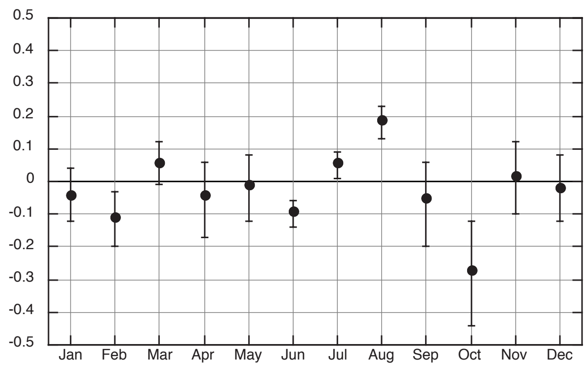

Figure 5b: Monthly variation of intercept (β): the offset in the engine intake SST.

5. CONCLUSIONS

The results suggest that night-time bucket SST may be biased cold. The magnitude of the bias varies with the air-sea temperature difference. If we combine an average North Atlantic air-sea temperature difference of 1.5°C with an fractional error (α) in the SST of 0.2, the bias, on average, is 0.3°C. This is similar to the mean difference between bucket and engine intake SST values found by previous studies. However, once the cold bias in the bucket SST is accounted for, the mean offset between the bucket SST and engine intake SST is close to zero. This contradicts those studies which concluded that engine intake SST is, on average, biased warm due to heating of the water by the ships engines. A supposition for which there was no direct evidence.

This bias in the bucket-derived SST observations of order a few tenths °C is climatologically significant; the magnitude of the effect will vary with time due to trends in the proportion of reports made by different observing methods.

Future work will involve extending the analysis to use more complex models. For example wind speed dependence can be added, or the effect of the heat fluxes on the bucket SST studied. In order to extend the analysis to daytime data the effect of solar radiation on the ship air temperatures needs first to be assessed and removed (Berry et al. 2003).

6. REFERENCES

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