FINDING THE TRUE TEMPERATURE OF THE OCEAN SURFACE

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INTRODUCTION

Sea Surface Temperature (SST) observations made by merchant ships provide important information on changes in the world climate. The methods used to make the observations vary from ship to ship and over time. In order to identify the true temperature of the ocean surface, and how it is changing, we need to isolate and remove any effects due to different instruments being used in different regions and at different times.

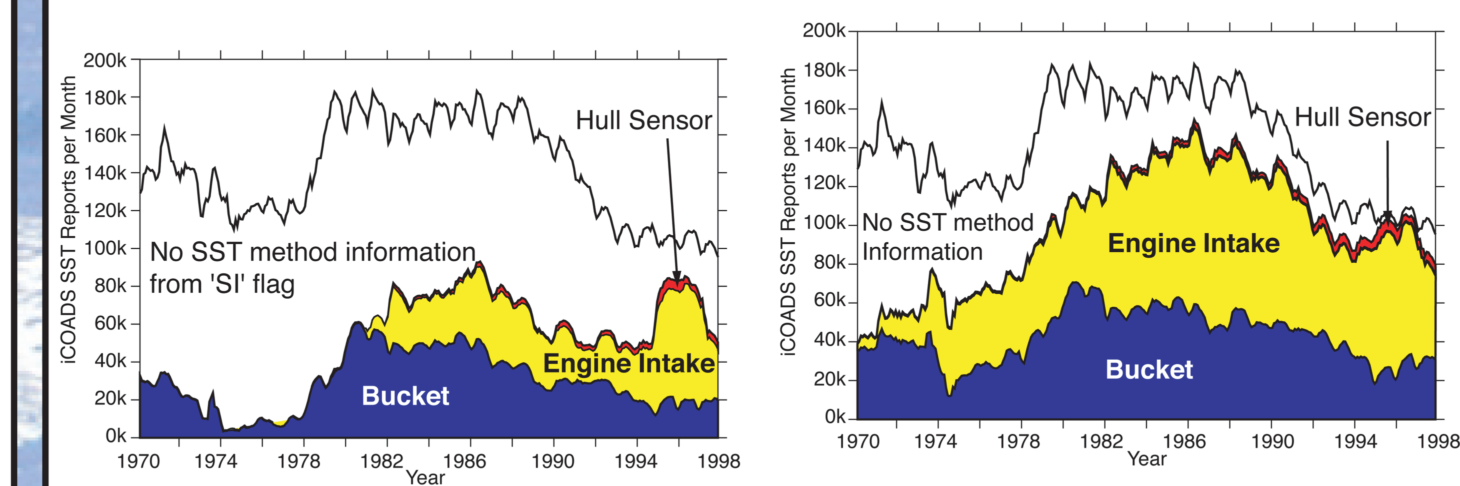
Each year about 7000 ships make weather reports which are collated in the International - Comprehensive Ocean-Atmosphere Dataset (I-COADS, Diaz et al. 2002). We have analysed SST reports for the period from 1970 to 1997.

Stage 1: Identify Measurement Methods

We need to identify the methods of measurement for as many I-COADS SST reports as possible. The two main methods of measurement in recent years are the bucket and the engine intake (with a smaller number of hull sensor reports). The bucket method simply records the temperature of a sample of seawater collected in a bucket and measured with a thermometer. The engine intake SST is a report of the temperature of the pumped seawater used to cool the ships engines.

The photo shows examples of the SST insulated rubber buckets currently supplied by (left to right) the Met. Services of the UK, the Netherlands and Germany.

I-COADS contains a flag which gives the method of measurement for many of the reports (left figure). However there exists another source of information about measurement methods, the World Meteorological Organisation (WMO) "List of Selected, Supplementary and Auxiliary Ships", e.g. WMO (1994). Using this external metadata source we can identify the instrument used by a particular ship at a particular time and therefore, if an I-COADS report contains an identifiable callsign, we can ascribe a measurement method to the report. The figure on the right shows the number of reports with known SST measurement methods from the combined sources of information.



For historical reasons the I-COADS flag does not identify SST reports made using engine intake thermometers in the early period so use of the WMO metadata allows comparisons of bucket and engine intake SST to be extended back in time.

Stage 2: The Physical Model

The aim is to compare co-located SST reports made using different methods to determine whether there are biases in the data. A dataset of paired bucket (SST_{bu}) and engine intake (SST_{eri}) SSTs is assembled where the two reports are within 50 km and taken at the same reporting hour.

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.

$$SST_{bu} - SST_{eri} = \alpha\,(T_{air} - SST_{eri}) + \beta$$

T_{air} is the air temperature and α and β are empirical constants which we will estimate. Using night-time data avoids problems due to the solar radiation contamination of day-time air temperatures.

Stage 3: The Statistics

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 using an error correlation matrix:

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

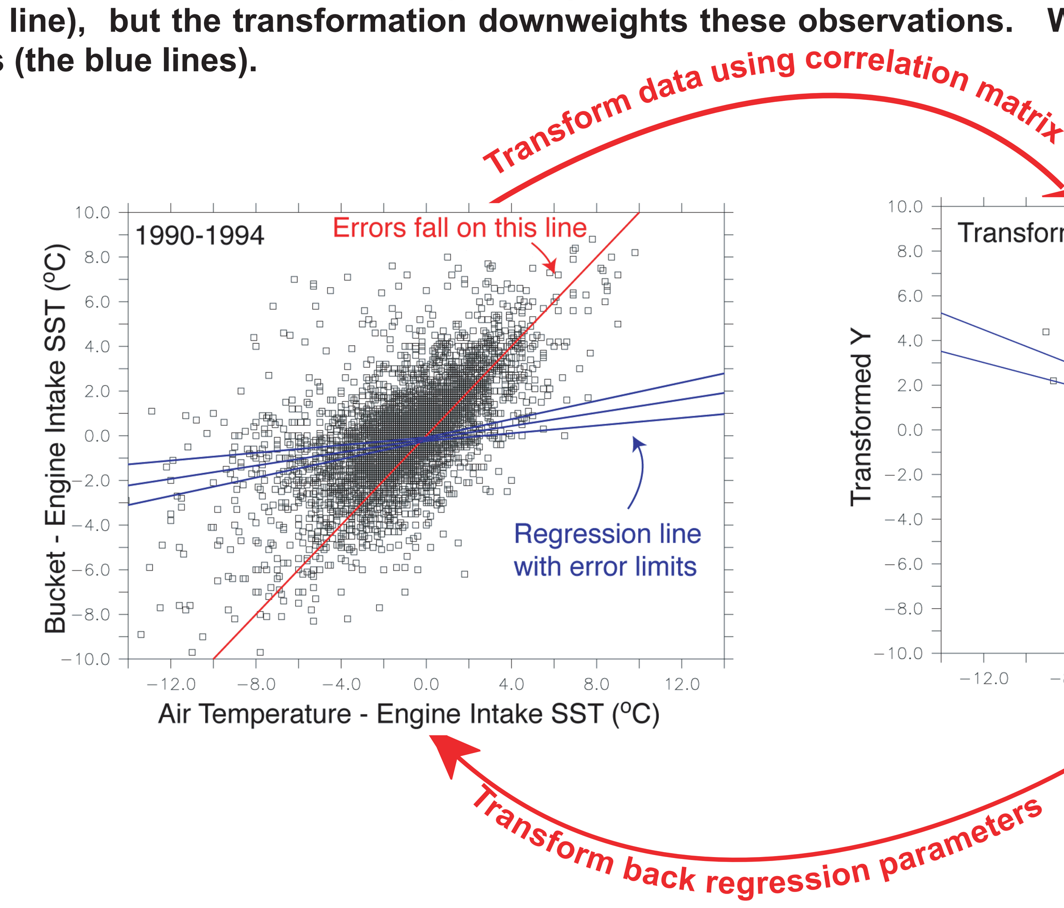
where σ_{air} is the random error in the air temperature measurement, σ_{eri} the random error in SST_{eri} and σ_{bu} is the random error in SST_{bu}. The diagonal elements are the random error in x and y and the off-diagonal elements are the correlation between them which, in this simple case, is the random error in the engine intake SST. The error estimates are derived from semivariogram analyses as described in Poster I-6. Random errors in the engine intake SST are typically about 50% bigger than those in the bucket SST and make up the largest contribution to the error correlation matrix.

Once the data have been transformed, a linear orthogonal regression can be performed. The resulting regression parameters are then transformed back to give estimates for the model parameters α and β.

Example

The figure below shows paired nearly co-incident data from I-COADS for the 5-year period 1990 - 1994. Each pair contains one SST observation made using a bucket and one observation made using an engine intake. At first sight the analysis is dominated by errors in the engine intake SST (clustered around the red line), but the transformation downweights these observations. We can then recover signals from the data which cannot be explained by the errors (the blue lines).

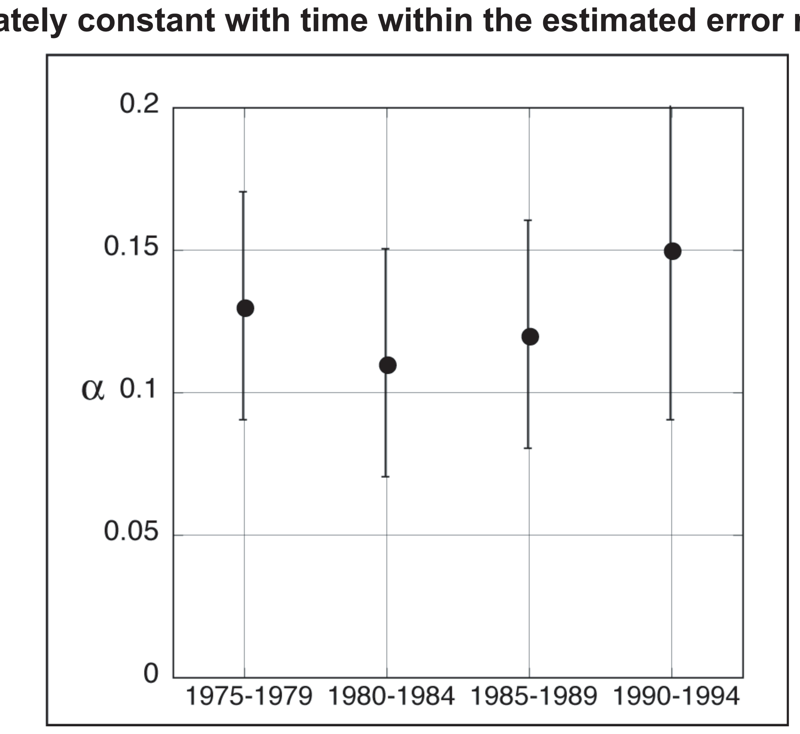
Data falling near to the dashed line cannot be distinguished from noise in SST_{eri} and is down-weighted by the transformation.

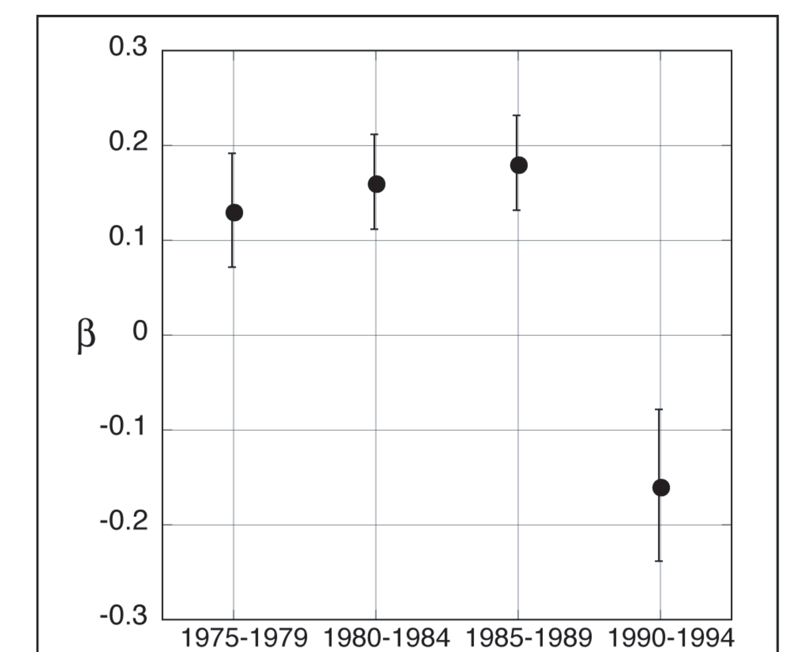


In the transformed space only data points which cannot be explained by errors in the data are significant.

Results

We have analysed data in 5-year intervals from 1975 to 1994. Outside this period there are not enough data to perform the analysis. The results suggest that about 10-15% of the air-sea temperature difference appears as an error in the bucket SST (α in left plot). This proportion remains approximately constant with time within the estimated error range.





The right hand plot shows the estimated intercept (β) and here we do see some significant changes with time. For the period 1975 to 1989 the night-time engine intake SST is warmer than the bucket SST by 0.1 - 0.2 °C. This warm bias is smaller than that found in earlier studies. However in the period 1990 to 1994 we see a cold bias of similar magnitude in the engine intake SST. We might expect the engine intake SST to be on average colder than the buckets as the measurement is taken at greater depth and may be below any shallow warm layer.

These results are interesting and challenge the traditional view that engine intakes are always biased warm and modern buckets are relatively unbiased. However there are many assumptions and simplifications in our model and the random errors are much larger than the signals we are looking for. These results need to be verified using alternative approaches, but should remind us that the VOS are constantly evolving and we cannot assume that the results of older studies will apply to modern data.

More work is needed!

CONCLUSIONS

- Metadata is important for the identification of SST measurement methods as different methods have different random errors and biases.
- Before biases in SST observations can be assessed we need to understand the error structure of the data.
- The bias in the bucket-derived SST observations of order a few tenths °C is climatologically significant.
- Our results suggest that historically there may have been a warm bias in engine intake SST but after about 1990 the engine intakes may be relatively cold compared to the buckets.
- The magnitude of the overall bias will vary with time due to trends in the proportion of reports made by different observing methods.

References:
Diaz, H., C. Folland, T. Manabe, D. Parker, R. Reynolds, and S. Woodruff, 2002: Workshop on Advances in the Use of Historical Marine Climate Data. WMO Bulletin, 51, 377-380.
WMO, 1994: International List of Selected, Supplementary and Auxiliary Ships, WMO Report No. 47, WMO, Geneva, various pagination.