# Improved analyses of changes and uncertainties in sea surface temperature measured in situ since the mid-nineteenth century: the HadSST2 data set

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**HadSST2, based on ICOADS data (Worley et al, 2005), provides gridded SST and uncertainty estimates for each month from 1850 to present, on any resolution, and has a wide range of potential applications in climate research.**

### 1. Bias correction and its uncertainty

SST measured before about 1941 is significantly cooler than later SST (Fig 1), owing to the change from sampling water collected using uninsulated buckets to a mixture of insulated buckets and engine cooling water (hereafter ERI).

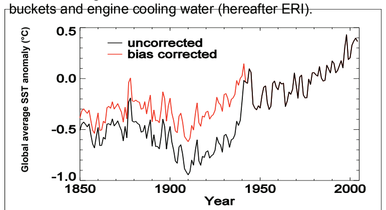


**Fig 1. Global avg corrected and uncorrected SST anomaly, 1850-2004**

We follow the method of Folland and Parker (1995, FP95) to correct these early data, combining information on: ship speed; construction of buckets and models of heat lost from buckets. Ship speeds are known from the literature. Quantities of heat lost from buckets are calculated using thermodynamic models of insulated and uninsulated buckets. Proportions of these buckets are inferred from the fit of corrected SST to NMAT in the tropics. The proportion of canvas buckets and speed of ships increase over time, leading to increased corrections. We have to adjust these corrections to fit the new data base and in recalculating them can vary each input parameter within its uncertainties to generate multiple realisations of the corrections, quantifying their uncertainty (Fig 2).

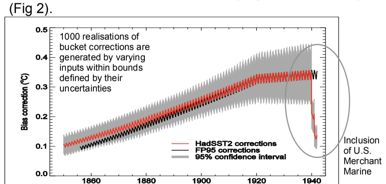


**Fig 2. Global avg bias correction and confidence interval, 1850-1941**

HadSST2 corrections are larger at the start of the record than in FP95. Corrections are greatly reduced between 1939-41 to allow for the inclusion of the newly digitised and now dominant U.S. Merchant Marine data; largely ERI measurements which are warmer than the previously dominant canvas bucket collected data.

### 2. Calculating sampling and measurement uncertainty

The variance of any grid box time series changes with time (Fig 3(a)). Detrending the time series and plotting it with the numbers of obs in each monthly value (Fig 3(b)), we see that the variance in this example is increased when there are few obs relative to well-observed months.

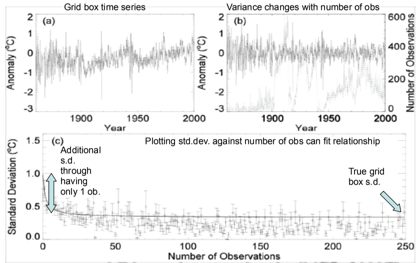


**Fig 3. Fitting the relationship between std. dev. and number of observations**

Binning all the values in the time series according to their constituent numbers of obs and taking the std. dev. of the values in each bin, then plotting those standard deviations against number of obs, a clear relationship can be seen (Fig 3(c)). When there are many observations in the grid box, we can estimate a value for the true detrended grid box std. dev. When there are few observations, this variability is increased by the addition of sampling error. At the extreme left hand end of the curve, we see an estimate of the sampling error which would be incurred through having only one observation in the average. In fact, because the observations also contain random measurement errors, this is an estimate of the combined sampling and measurement error for the grid box.

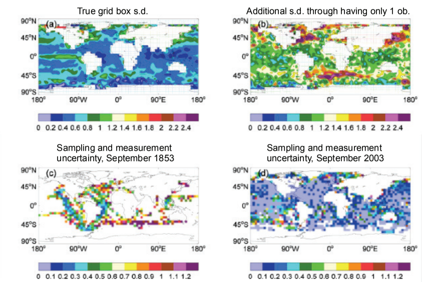


**Fig 4. Partitioning of variance and example sampling/measurement errors (°C)**

We perform this calculation for all grid boxes to obtain fields of true grid box std. dev. and the additional error variability (Fig 4(a) and (b)). To calculate fields of sampling and measurement error in an individual month, we divide Fig 4(b) by the square root of the number of obs in each grid box.

### 3. Combining uncertainties

Our bias correction uncertainties are independent from our sampling and measurement uncertainties, so to obtain total uncertainty in each grid box, we add them in quadrature. The ratio of bias correction to sampling and measurement uncertainty for September 1938 (Fig 5(d)) shows that they are of comparable size in only a few places and, generally, sampling and measurement errors dominate on the monthly grid box scale.

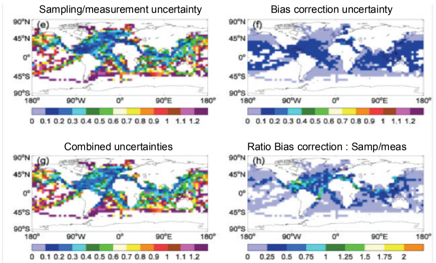


**Fig 5. Combining uncertainties and their relative sizes in September 1938**

### 4. Quantifying the effect on uncertainty of data new to ICOADS

Can we quantify what effect the additional data have had on our uncertainty estimates? Repeating the calculation of sampling and measurement uncertainty for the new and old data bases (Fig 6), we see that the additional data have reduced the estimated errors, as expected

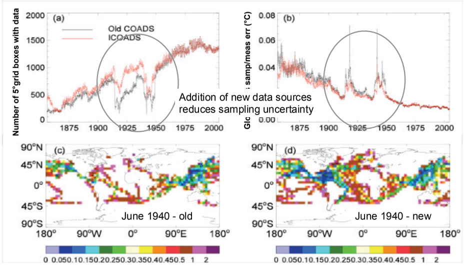


**Fig 6. Effect of recently digitsed data on sampling/measurement errors (°C)**

### 5. Effect on uncertainties on estimates of climate change

Fig 7 shows that the uncertainties are very small compared to the interannual variability in the time series, indicating that we can have considerable confidence in these large-regional averages.

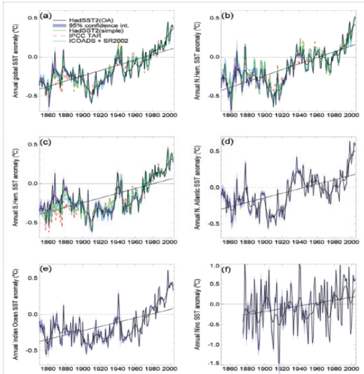

**Fig 7. Large regional averages of SST anomalies from HadSST2, HadSST1 and ICOADS summaries + Smith and Reynolds (2002) bias corrections**

Often, it is tempting to fit a linear trend to the time series, but this provides a poor fit and the resultant uncertainty on the trend comes mostly from the real variability about the trend, rather than the uncertainty in the data. A different way of assessing changes is to smooth the curve using a binomial filter, which results in an overall uncertainty better reflecting that in the data.

| Region | Change from linear trend (°C), 1850-2004 | Change from filtered curve (°C), 1850-2004 |
|---|---|---|
| Globe | 0.52±0.19 | 0.67±0.04 |
| N.Hem. | 0.59±0.20 | 0.71±0.06 |
| S.Hem. | 0.46±0.29 | 0.64±0.07 |

**Table 1. Changes in HadSST2 anomaly, 1850-2004, via two methods**

**Data are available from http://www.hadobs.org.**

Folland and Parker, 1995: Correction of instrumental biases in historical SST data. *Quart. J. Roy. Meteor. Soc.*, 121, 319-367.
Rayner et al, 2005: Improved analyses of changes and uncertainties in sea surface temperature measured *in situ* since the mid-nineteenth century: the new HadSST2 data set, *accepted by J. Climate*.
Worley et al, 2005: ICOADS release 2.1 data and products, *Int. J. Clim.*, 25, 823-842

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