Hot questions of temperature bias

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An unseen measurement bias has been identified in global records of sea surface temperature. The discrepancy will need correction, but will not affect conclusions about an overall warming trend.

In a recent issue of *Nature*, Thompson *et al.*[1] take a fresh look at the global temperature record throughout the twentieth century, which is both a central test of climate models and prima facie evidence for man-made global warming. After filtering out large-scale natural effects, they uncover a large discontinuity in the data in 1945, and trace its source to a change in the instrumental bias in the sea surface temperature (SST) record that occurred around that time, and has not previously been adjusted. But how did this discrepancy come about? And how does it affect the credibility of the temperature record and, by extension, models of global warming in general?

In answering the first question, it is important to realize that SST and land-temperature observations are very different. The network of measuring stations on land is relatively fixed, not tending to wander in space. At a given station, thermometers are continually and reproducibly calibrated to give a continuous, benchmarked record. Changes at individual stations that might affect the measurements — if a station is moved, for example, or if the surrounding environment changes — can be corrected. Discovering additional unexpected biases in land temperatures would mean finding systematic changes in the whole observing system. Given the attention paid to these issues in, for example, the four assessment reports of the Intergovernmental Panel on Climate Change (IPCC) over the past two decades[2], as well as in the US Climate Change Science Program's final report on temperature trends in the lower atmosphere[3], it is generally accepted that such a development is highly unlikely. The records represent a best possible estimate of the changes in land-surface temperatures.

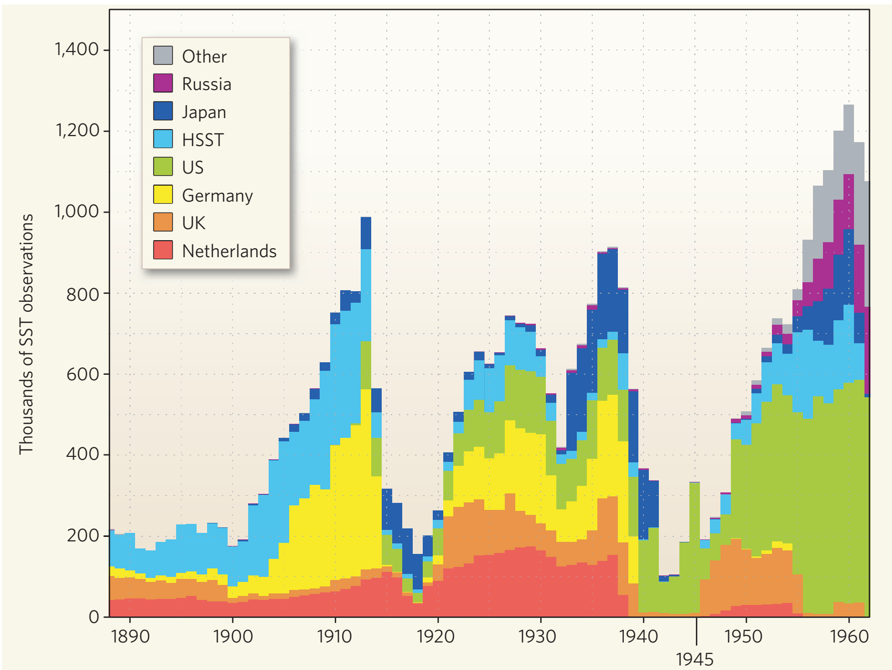

Figure 1 Flying the flag. Sea surface temperature (SST) records from the International Comprehensive Ocean–Atmosphere Data Set[15,16], together with Historical Sea Surface Temperature (HSST) project data[17], demonstrate a wide range of national origins — and, presumably, a similar range of slightly differing measurement protocols. Thompson *et al.*[1] identify a shift in the SST record in 1945 with the resumption of a significant programme of measurement by the United Kingdom at the end of the Second World War.

For the oceans, the situation is different. Until the 1970s, SST observations were made entirely from ships. (After 1970, temperatures were also measured using moored and drifting buoys and, from the early 1980s, using satellites.) Different ships used different measurement methods over the years, each of which potentially had different biases. Some measurements were made by lowering uninsulated buckets over the ship's side; these tend to produce colder temperatures, owing to the effects of evaporation once the bucket has left the water. Other measurements were taken at the inlet for the intake of water to cool the ship's engine; these are likely to be biased towards warmer temperatures because of heating from the engine-room.

Thus, although selected SST observations can be very accurate[4,5], corrections (generally of a few tenths of a degree Celsius) can be necessary depending on how the measurements were taken. Auxiliary information — metadata — about the measurement procedure is often missing, as reporting procedures differ from country to country, and the source of the data was not always recorded. Significant corrections to the global SST record had already been undertaken in response to recognized biases: an upwards movement of the data points before 1942 was a previous attempt to account for a shift from uninsulated-bucket measurements to engine-intake measurements.

Owing to the sparseness of the metadata, Thompson *et al.*[1] use a statistical method to identify where significant biases may occur. First, because short-term variability might mask these biases, they applied a simple filter to the data to remove two sources of significant natural climate variability: the El Niño–Southern Oscillation in the Pacific, and the interplay of land and ocean temperatures in the Northern Hemisphere. What remained were two filtered time series of the global mean temperatures for land and ocean. Comparing the two, several substantial jumps can be seen, but these are mainly the aftermath of large volcanic eruptions that ejected huge amounts of material into the stratosphere, blocking out sunlight: Krakatoa (Indonesia) in 1883, Santa Maria (Guatemala) in 1902, Agung (Indonesia) in 1963–64, El Chichón (Mexico) in 1982, and Pinatubo (Philippines) in 1991. These jumps exist in both the land and ocean data. But one shift remained a puzzle: a significant drop in SSTs from 1945 to 1946 that was not replicated in the land data. This shift is also present, but not as obvious, in the un-filtered data. In an effort to explain this change, Thompson *et al.* looked to the metadata — in particular, to the provenance of SST measurements from around 1945.

Figure 1 hints at the explanation; it shows the total number of SST observations from the various national temperature archives. What's striking is that both the relative fractions and the total numbers of observations vary considerably from year to year. These changes pervade the record, but unsurprisingly the two World Wars (1914–19 and 1939–45) represent the most significant shifts, both in source and in the total number of observations. And here, Thompson *et al.* suggest, we have the clue to the jump exposed in 1945: whereas during the preceding war years, 80% of measurements came from ships flying the US flag, a resumption of UK measurements at the end of the war saw their proportion jump to some 50%. At that time, unlike their American counterparts who took engine-intake measurements, the British relied primarily on uninsulated-bucket measurements.

So, what are the implications? Most immediately, a further correction to the global temperature series will be necessary, albeit of a magnitude yet to be assessed. There are many wider ramifications to consider, but one should be handled directly: should we doubt the rise in global mean temperatures during the twentieth century as a result of this or other hidden, and as yet undiscovered, biases in the record?

The answer is no. According to the filtering of natural variabilities that Thompson and colleagues have done, the only major discontinuity in SSTs is the one in 1945 (although other, insignificant shifts are dotted through the record). The shift from upwards-biased engine-intake measurements to downwards-biased bucket measurements demands a correction; naively speaking, temperatures between 1942 and 1945 would shift downwards by a magnitude of, say, 0.3 °C. Global warming would remain a reality — it would just be a bit more than previously thought.

How does this anticipated correction ripple through to climate models? Global mean surface temperatures are the most widely used data for evaluating the predictive capabilities of models on continental and larger scales[6–8]. They are also crucial for evaluating two other principal uncertainties in climate predictions: the factors forcing climate change (primarily, levels of aerosol particles in the atmosphere) during the twentieth century and thus in the future[6–11]; and the rate of heat uptake from the atmosphere to the ocean (Fig. 1 in ref. 7).

The SST adjustment around 1945 is likely to have far-reaching implications for modelling in this period. One particularly striking example can be found in a figure prominently displayed on page 11 of the 18-page 'Summary for Policymakers'[12] of the IPCC's Fourth Assessment Report, produced last year. In this, the observed decadal mean temperatures of the 1940s — those that contain the anomalous 3–4-year interval dominated by (upwardly biased) US engine-room-intake measurements — are the only ones to lie above model predictions. Although we don't know exactly how the temperature record prior to 1946 will be affected by the awaited correction, it is a safe bet that temperatures in this particular decade will be lower.

The 1940s just happen to fall at the end of what seemed to be a warming trend from the 1910s that was followed by a weak decline in global temperatures into the 1960s. Climate modellers have explained the warming as a response to natural forcings[13], and the cooling as due to an increase in tropospheric aerosols, principally sulphates, as a result of increased economic activity in the decades following the Second World War. This temporarily offset the effects of man-made warming. Data analysts, on the other hand, have considered the maximum in the 1940s to be the expression of a natural fluctuation[14]. In light of the new finding[1], each interpretation will need to be reconsidered — the first of many implications that will need to be explored.

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