What is the temperature of the earth's surface?

Estimates of the past and present temperatures of the earth's surface are highly politically charged. The International Panel on Climate Change's (IPCC) 0.85 ^{o}C estimate of industrial epoch warming is for the long term change (1880-2012); its uncertainty - 0.20 ^{o}C with 90% confidence - is due to difficulties in separating the centennial scale change from short term fluctuations. But the IPCC numbers are only valid if the basic measurements are accurate enough, so how accurate are they? A new paper in Climate Dynamics concludes that with 90% confidence the true global monthly temperature lies in the range -0.109 ^{o}C to 0.127 ^{o}C of the reported values and that the long term change can be estimated to nearly the same level of accuracy: small enough to justify the IPCC's conclusions.

In order to quantify climate change, centennial length records are needed. Over this period, the accuracy debate has almost exclusively focused on potential human bias. For example, thermometers change with technology and often, so do their exact locations. Such changes are dealt with by numerous comparisons. To start with, absolute biases are eliminated by only using station anomalies. These are differences between the actual temperatures and the long term averages for the station itself (taking into account the annual cycle). However, the anomalies may still be biased, for example, when an initially rural site is later urbanized: the "heat island effect". In this case, comparisons are made with neighbouring rural stations and potentially biased contributions are weighted accordingly.

While there is no question that many adjustments are required, there is no absolute truth for validating them. This has allowed climate skeptics to regularly accuse scientists of selectively correcting the data to exaggerate the warming. Indeed, a new breed of "lukewarmers" have accepted that there is some warming, but claim that it is too small to worry much about. The problem for the lukewarmers is that other independent data sources – such as satellite measurements - show nearly identical overall trends so that we can be confident that human induced biases must be small. But how small?

Ironically, the spotlight on human biases turns out to be misplaced. The *Climate Dynamics* paper shows that there are two much more important sources of error that have virtually escaped attention: the unexpected long term consequences of missing data and biases arising when thousands of sparsely distributed measurements from the oceans and continents are combined to produce a single globally averaged value. Neither of these problems is human in the usual sense: they are consequences of huge variations in atmospheric temperature arising from "whirls" ranging in size from millimeters to the size of the planet evolving over time scales from milliseconds to the age of the earth. While a modern home thermometer can tell us the temperature in our backyard every few minutes with an accuracy of a tenth of a degree, but how to estimate the temperature of a city? Of a country? Of the whole earth? We don't have thermometers everywhere, so how do we infer averages over large areas, and how accurate is our result?

The *Climate Dynamics* paper was able to quantify this by using six disparate monthly and globally averaged temperature series since 1880 and by using techniques from nonlinear geophysics. The missing data problem is easy to understand: since 1880, for monthly temperatures on 500km sized grid boxes, over half had no data, implying a large uncertainty in the global estimates. Here, the new element was the recognition that this would effect the accuracy over long periods: years and decades. The resolution effect is more subtle: when point-like data are "massaged" onto regular grids, there are often insufficient data to adequately average them to their nominal values (e.g. 500 km and one month). Whereas missing data turned out to be the main source of error for time scales less than a decade or so, the resolution effect dominated the uncertainties at the centennial scales that are relevant for industrial epoch warming. In comparison, standard human errors were negligible for periods of months and longer.

Overall, it was found that with 90% confidence, we may estimate the temperature change since 1880 to within 0.108 ^{o}C of the true change. This is less than 13% of the IPCC estimated warming: measurement errors are too small to alter the conclusion that we are living through a period of huge warming and that it is occurring at an unprecedentedly rapid rate.

Lovejoy, S. (2017), How accurately do we know the temperature of the surface of the earth? , *Clim. Dyn.*, doi:10.1007/s00382-017-3561-9.

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