# Chapter 2

## Measuring Temperature

## The 160 Year Thermometer-based Record

*Estimating Global Temperature*

This chapter deals with some of the problems encountered when trying to assemble a collection of measurements from around the world into something called "global mean temperature." As noted in the introduction to this book, when referring to global mean temperature, we mean the average near-ground air temperature for the entire year, over the entire earth – as measured by existing sensors[1]. In this chapter we show that this number is nothing more than an *estimate* of global temperature, made by using a collection of instruments – from different times and different countries – that are not necessarily calibrated to one another, and definitely not all that accurate. There is a real question of what needs to be done to be able to legitimately combine this variety of instrumentation to create a single number.

Many locations around the world have had thermometers in place for at least a century-and-a-half. Of course, they've likely changed the actual instruments from time-to-time as old ones are broken, or become worn out. That sort of thing can cause problems, because instruments have changed and improved. Around the globe, some instruments are older, some are newer, and some have been in place much longer than others. What do we do about these differences? Mostly we just lump them together.

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[1] Some climatologists are trying to assemble a new type of global mean temperature in which they calculate the average air temperature around the globe throughout the depth of the troposphere. But there is very little long term historical information about the average troposphere temperature, so we will stick with the standard definition based on the classic surface data. It is the definition that allows us to talk about how the global temperature is changing.

Many recording sites are located in places that have anomalous temperature patterns, such as those in mountain valleys, or along sea shores. Some sites have been poorly located in the shelter of buildings. Do we include any of those as representative of global mean temperature variation? Do we keep adding new sites into the long term record once they become established? And what about cities? Many scientific studies have shown that cities are generally warmer than the surrounding countryside – sometimes a lot warmer. This warmth is not an atmospheric phenomenon, but an artifact of the activity in the cities. Problems such as these are continually being addressed by climatologists as they attempt to produce graphs like the one shown in Figure 2.1. Unfortunately, there has been only partial success in this regard.

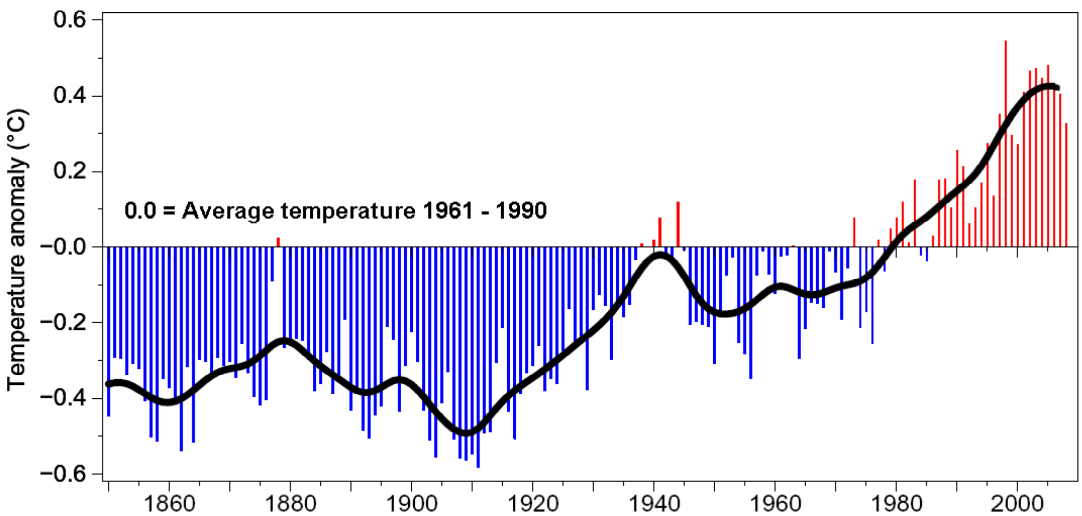


Figure 2.1. Average global temperature as measured in-situ at weather/climate stations around the world for the period 1850 – 2008 ( IPCC, 2001).[2] The lowest temperatures during the Little Ice Age would all be below the lowest level shown on this chart. The black line represents a "smoothed" curve, made by averaging the surrounding years with the current year (called a five-point running mean) to remove some of the "spikiness," and reveal the general trend. (same as Fig. 1.6 in Chapter 1)

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[2] IPCC, 2001. *Climate Change 2001: The Scientific Basis*, Intergovernmental Panel on Climate Change, Working Group 3, third assessment report (editor: J T Houghton). Global temperatures after the year 2000 were added to the 2001 graph from yearly IPCC reports.

*Thermometer measurements*

Most of us are familiar with thermometers.  Until recent times, about the only kind of thermometer in common use was that using a narrow glass column with some sort of colored liquid inside (e.g., mercury, alcohol, etc) whose volume changes with the changing temperature.  The height of the liquid in the tube changes proportionately.  This type of instrument is still used in many places around the world today, but there are other types of thermometer used more frequently now.  For example, there are so-called bi-metal thermometers.  In this application, a spring is made from two thin strips of different metals (like steel and copper)  fused together.  The two metals expand and contract differently and the spring will coil, or uncoil, by an amount that depends on the ambient temperature.  There are digital thermometers which work because a thermo-resistor changes its resistance at different temperatures.  A small computer chip converts the resistance to a temperature value according to a built-in equation.  There are many other types, but no matter which type instrument is used we're all pretty familiar with the concept of the thermometer and what it measures.  Simple enough, right?


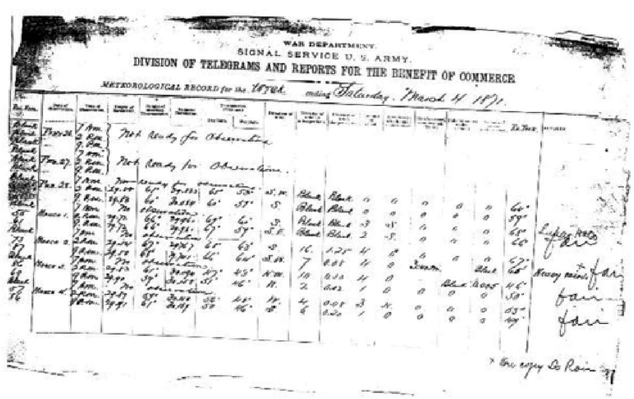
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Figure 2.2.  (left) Young weather observer at Granger, Utah, 1930 –  (right) An early United States Army Signal Service weather data report from the first week of observations in Memphis, Tennessee in 1871. Notice temperatures recorded in whole degrees (not tenths).

One topic that most people don't spend much time worrying about is the accuracy of these measurements. In case you've ever wondered how accurate thermometers are, the answer is, "not very." Some are fairly accurate (±1$^{o}$F), but a good average for the largest percentage is more like ±2$^{o}$F (±1$^{o}$C) at room temperature, *or more*. In plain English, this means that at a temperature of around 70 $^{o}$F, the actual temperature could be anywhere between 68$^{o}$F – 72$^{o}$F. According to statisticians, this isn't as bad a problem as it at first might seem, because when climatologists collect observations from several thousand sites around the globe and average them all together, they assume that these errors will all "wash out" in the average. That is, they assume the "pluses" in some instruments will mostly cancel the "minuses" from others, if the sample is big enough. Statistically, that's a pretty good assumption. If this assumption is correct, the overall averaged error is probably less than ± 0.2 $^{o}$C. But one confounding variable in this mix is that not all instruments are of the same quality. Different instruments, poorly sited instruments, etc., make the statistical exercise questionable. A 2009 report by Anthony Watts[3] looks at U.S. surface temperature records – purportedly some of the most accurate in the world – and finds major problems. Using NOAA's Climate Reference Network five point rating scale[4] (where Class 1 represents the best and Class 5 the worst) to rate 948 of the long term, temperature recording stations. The results are shown in figure 2.3. Notice that more than 2/3 of the sites evaluated can claim accuracies no better that 2$^{o}$C,

[3] Watts, A., 2009: Is the U.S. Surface Temperature Record Reliable? Downloaded from website: http://wattsupwiththat.files.wordpress.com/2009/05/surfacestationsreport_spring09.pdf
[4] NOAA's Climate Reference Network (CRN) Site Information Handbook can be found at: http://www1.ncdc.noaa.gov/pub/data/uscrn/documentation/program/X030FullDocumentD0.pdf

while 8% are no better than 5°C.  So not only are the instruments inaccurate, but there is a substantial variation in the magnitude of the inaccuracy.

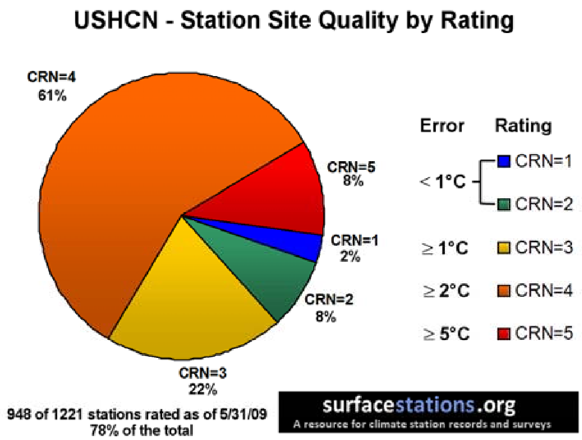


Figure 2.3.  Pie chat showing U.S. surface site observation quality ratings as discussed in text.  Graph is from the website:  www.surfacestations.org.

Another problem in comparing and combining surface observations is the time of day that the observation is taken.  When you're trying to track year-to-year temperature changes, this is critical.  If you decide, for example, to define the average temperature for the day as the average of the 7:00 am and 7:00 pm local time at every location (which is a frequently-used definition), then you're counting on everyone involved to be out at exactly 7:00 am to get their measurement.  If you're looking at historical records, you're counting on the fact that all those people back in the 1800's and 1900's, all around the world, got out early enough to make the morning observation on time, and that each and every one of them managed to get back in time to make the 7:00 pm observation as well. Historically, observers have not only been known to take their measurements early or late, but a large number of observers in the past have even missed days, if they were away from home or busy with other work.  During wars, the missing observations have spanned longer periods than that.  Again, the hope is that all of these sorts of errors might wash out in a large sample.  But will the problems wash out in the case of early, late or missing observations?  Some scientists believe that there might be a slight bias towards later morning and earlier evening observations which might tend to push average temperatures slightly in the warmer direction, but that's just a guess.  Plus, if it's true, it's probably always been true, so the effect would be a relative one and maybe not all that important in the present context – unless, of course, observers have gotten more careful over time.

Another difficulty with the historical network of surface observations concerns the fact that, over the years, some sites that might have been part of the record for many years – or even many decades – might have been shut down or moved, while new sites are frequently added.  So the actual sites where the measurements that make up the climatological average have changed and continue to change.

But changing location isn't the only problem.  There is also an issue that more or less destroys the whole notion of a historical, thermometer-based, *global* temperature.  It has to do with the fact that there are few, if any, historical observations from inhospitable regions of the planet such as deserts, the arctic, the Antarctic, uncivilized areas and nearly none from over the oceans.  In fact, less than 15% of the earth's *surface* is historically represented by long term temperature records.  Does this representativeness problem affect the average?  Of course it does.

Finally, we come to the issue of the so-called urban heat island.  There have been countless documented studies showing that as urban areas increase in size and population, the temperatures in and around the developing areas increase relative to nearby undeveloped areas.  The increase is due to the nature of the urban environment, and all of the heat-producing activities taking place (e.g., warming of houses, driving of cars, hot pavement, etc.). Big cities are the worst. The concrete, asphalt and industry generally combine to drive the urban temperature up as much as 4-5°C relative to the surrounding countryside during the afternoon. And since urban areas are where most people live, it is there where a lot of the historical observations have been taken.

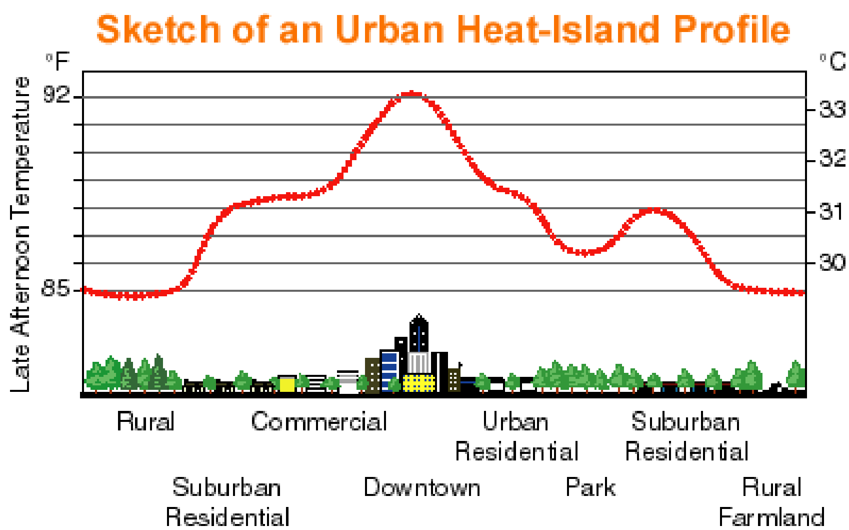


Figure 2.4. Illustrative diagram of the cross-sectional temperature profile associated with a large urban area on a warm summer day. At night, the cooling over the urban area can lag the cooling over the surrounding countryside by another 3-4°C. Diagram from the Lawrence Berkeley National Laboratory's heat island website at: http://eetd.lbl.gov/HeatIsland/HighTemps/ .

Climatologists have attempted to deal with the urban heat island problem over the years by adjusting the final yearly totals by a "best guess" percentage – a fudge factor – for each affected location. However, evidence presented by Kalnay and Cai[5] (2003) indicates that the urban downward-adjustment currently in use (which is based primarily on population and city size), may be too small by a factor of nearly two. If that is true, then the 0.41 °C mean global temperature increase that the earth has experienced over, say, the past 26 years (yes, that's all it's been) may actually be somewhat less than that.

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[5] Kalnay, E. & Cai, M. (2003). Estimating the impact of urbanization and land use on U.S. surface temperature trends: preliminary report. *Nature*, *423*, 528-31.

In fact, there is significant supportive evidence for this notion, at least for this particular period 26 year period. Observations from satellites, combined with those from weather balloons, together provide some of the most accurate measurements of global mean temperature that have ever been available. These observations suggest that global warming during the period 1979 – 2005 may have been only 0.09 - 0.12 $^{o}$C per decade, or 0.23 – 0.30 $^{o}$C total for the entire 26 year period. This range is a very close match to the re-adjustment suggested by Kalnay and Cai. So this problem may have been reduced for recent data and for the future, but it has infested the climatological record from the beginning.

It should be clear from this brief overview that there are serious problems with measuring the global mean temperature. A lot of assumptions have been made, and at least some of them are probably wrong. The so-called increase in "global temperature" that has been recorded, especially in recent years, is small and is easily within the limits of the errors in the data. Decades of warming are in the tenths of a degree Celsius. But what does "tenths of a degree" mean when we know that temperatures are reported to the nearest degree? What does it mean when the errors in measurements can be as high as several degrees in individual sensors? What sense does any of that make?

Of course, some people persist in believing that each year is much warmer than the one before. Many say they can actually feel the difference. They even choose to believe it when the currently accepted global mean temperature measurements used by the IPCC (the official United Nations panel on climate change) show that global warming *is not even happening right now.* This is clearly shown in Figure 2.1. In fact, there has been *n*o global warming over the past eight years, even though atmospheric $CO_2$ levels have continued to climb. We may even be at the beginning of a cooling trend.

Why do people persist in thinking it's getting warmer – in believing that they are actually experiencing it? We (the authors) believe that social psychologists have the answer when they refer to a factor called "confirmation bias." If people have a preconceived notion of what to believe (e.g., that global warming is actually taking place and is dangerous), confirmation bias says that they will have a tendency to look for evidence that confirms their belief and ignore evidence that contradicts it. This bias says that if you believe in global warming, then you'll remember hot summers longer, and dismiss the memories of cold winters after a shorter period of time. In that sort of psychological climate, a naturally recurring warm period over one region of the country may be attributed to global warming. Any natural and expected variation that occurs during these periods may be ascribed to global warming, particularly when the variation is viewed as being a negative one. A study by Wildavsky[6] found that media coverage on the global warming issue supports the viewpoint that warming is severe, dangerous, and human induced. Until recently, that type of story appeared about 10-to-1 over more balanced views, and even now the coverage is heavily biased toward that point of view. So people are constantly bombarded with the message that the earth is getting warmer, and that warming is bad. It's most likely a psychological issue. Think about it. Should anyone really expect to be physically aware of a *decade* that's only 0.09 - 0.12 $^{o}C$ warmer than the previous decade? Would you *really* be able to feel it?

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[6] Wildavsky, A. (1997). *But Is It True?: A Citizen's Guide to Environmental Health and Safety Issues.* Cambridge, MA: Harvard University Press