APPENDIX 3: A long term temperature dataset for Australia

Measurement of daily Maximum and Minimum Temperature

For the past century, since at least the time when the Commonwealth Bureau of Meteorology was established in 1908, surface air temperature has been measured at meteorological stations in Australia according to fairly standards procedures (*WMO, 2008*).

Thermometers are placed at a height of about 1.5 m above the ground in a Stevenson Screen - a shaded enclosure of prescribed type, which allows a good flow of air across the thermometers but prevents exposure to direct heating by sunlight. In the typical practice, maximum and minimum temperatures for the previous 24 hours are recorded at 9 am local clock time each day. Minimum temperature is recorded against the day of observation, and the maximum temperature against the previous day (*BOM, 2009 g*)

In recent times, many locations have incorporated Automatic Weather Stations (AWS) and these are gradually supplementing or replacing the traditional manual temperature recording methods.

Unadjusted Annual Averages from BOM's "Climate Data Online" Records

Using the raw daily measurements of temperature, each Meteorological Station is able to calculate to varying degrees of accuracy the Mean Daily Maximum Temperature for each calendar month calculated as an average of the daily maximum temperatures for that month. Similarly the Mean Daily Minimum Temperature for a given calendar month is the average of the minimums recorded each day during that month. The accuracy of these estimates varies, of course, depends on the completeness of the data (i.e. the number of missed recording days), the quality of the meteorological station and instrumentation, and the precision of the measurement procedure at each station.

These raw, uncorrected monthly means can be obtained from the Australian Bureau of Meteorology website by the following procedure:

> Open the "Climate Data Online" page at http://www.bom.gov.au/climate/averages/ which provides access to monthly average data for select variables in selected years at selected meteorological station sites.
>
> Chose the required site using the map navigator. After selecting your location you need to select your statistic option. To view **all** statistics change view **from** Main statistics to All available. Scroll across the (element) row you are interested in (e.g. "mean maximum temperature") and hit PLOT.
>
> The data are graphed using all available years. To view data for a particular year use the "Include data for the year: XXXX " option (e.g. 1956) and hit REDRAW. The data are regraphed against the long-term averages; month-by-month data including the annual mean value is displayed underneath.

From these monthly records, the displayed **Annual** Mean Daily Maximum and the **Annual** Mean Daily Minimum temperatures for each calendar year in each location are calculated as the average of the twelve monthly means in the year. It is to be noted that, historically, if in any one month there were missing or erroneous measurements such that less than 24 days of records were available for that month, then the monthly mean values were not calculated for that month; the monthly values were then regarded as missing and the annual means were also regarded as missing for that calendar year.
(*Torok, 1996).*

It may be hard to believe, but since the late 1950s when the Bureau of Meteorology began digitising the historical monthly temperature records (the so called TABS data) for Australia, they have compiled computer records of over 100,000 station-years of monthly temperature

data from almost 1500 stations across the 111 'rainfall districts' into which Australia and its territories are grouped for meteorological purposes. The task of digitising the data of **daily** temperatures measurements taken prior to 1957 is a much more formidable (and expensive) task and has only been undertaken to a limited extent.

For the purposes of this Case Study, it is the Annual Means calculated from these Monthly records that are listed as the "Unadjusted (raw) Data" in the graphical presentations.

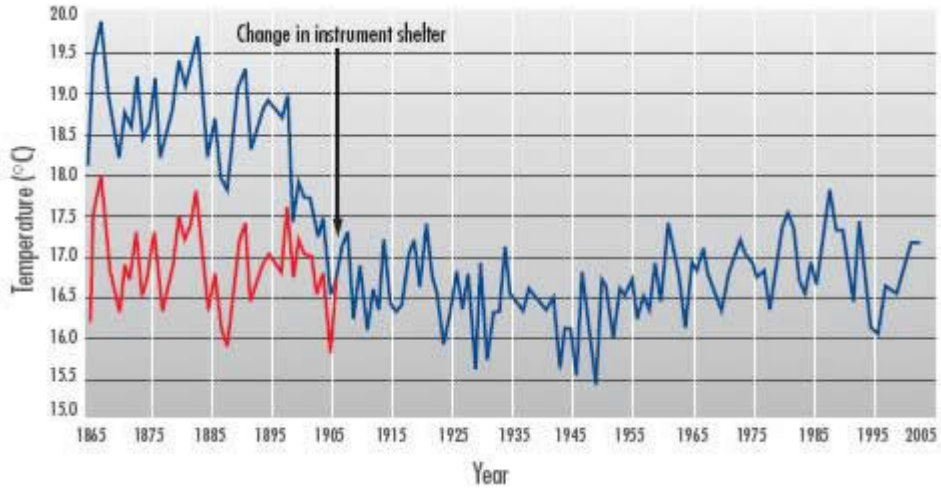
Problems with the Raw Data

The history of systematic recording of surface air temperatures in Australia is less than 150 years; for example systematic measurement of temperature first began in 1855 at Melbourne Regional Office and in 1859 at Sydney's Observatory Hill.

There are difficulties with the raw data from these long term records arising from irregularities in the procedures of measurement that did not arise from the climate itself but from changes in the instrumentation, the location of the instruments, and so on.

The Bureau of Meteorology's document "The Greenhouse Effect and Climate Change" (*BOM, 2009 f p.23*) expresses the difficulties in the original raw data as follows:

> *"Any change in location, exposure, instrumentation (see Figure below) or observation practice has the potential to create an artificial discontinuity in the climate record of an observation site. For instance, changes in the exposure of instruments, such as through new buildings or growth of trees, can cause apparent differences in temperature and other climatological variables. The changeover from imperial to metric measurement systems may have also induced discontinuities in recorded data. Even slight changes, while hard to detect in day-to-day observations, can create an apparent shift in the observed climate of the site when monthly or annual mean values are calculated. The magnitude of these artificial jumps can be as large as, or larger than, the changes caused by natural variability or changes associated with greenhouse warming. Therefore, they can create spurious trends in the data and make it difficult to detect real climate trends."*



Annual mean temperature series at Cape Otway, Victoria showing the differences between temperatures in the early part of the record, measured using a Glashier stand, and temperatures measured using the current standard instrument shelter, a Stevenson screen. Once the data are corrected for this bias, as shown by the red line, the overall trend tells a remarkably different story. Gaps in the record have

> also been filled by estimating values from comparisons with highly-correlated neighbouring station records.
> *(BOM, 2009 f, p. 25).*

Of the almost 1500 or so digitised Met Station temperature data sets examined by *Torok and Nicholls (1996)*, over half of the stations had less than 40 years of data at that time. In fact when Torok was set the task of assembling a high quality long-term temperature data set for Australia, he was hard pressed to find more than 50 stations that could be regarded as **long term** (i.e. opened prior to 1910) and of **high quality** with respect to site and observer standards:

> ***"Of these, not one had consistent sites or equipment throughout their entire history."***
> *(Torok 1996, Vol 1, p. 37)*

The fact is that it was never going to be possible to assemble an "ideal" set of past temperature data even for as recent a period as one hundred years ago. The "high quality data set for Australia" that *Torok and Nicholls (1996)* were able to compile consisted of data from 145 stations for which a continuous record of 'reasonable' quality data dating back to at least 1910 could be obtained (e.g. Sydney Observatory), together with another 79 stations (e.g. Mildura Airport) for which a 'composite' data set could be obtained by extending the data of limited duration from the principal site with compatible data from a nearby site that covered the missing years.

Australia's High-quality Climate Change Datasets

To detect real changes in the Australian climate and any long term consistent trends, it is critical that we use data that are of the highest quality and that are **homogeneous** through time. The BOM defines a **homogeneous climate record** as:

> "*one in which all observed climate variations are due to the behaviour of the atmosphere, not other influences, such as changes in location, exposure of the observation site, instrumentation type or measuring procedure*" (*BOM, 2009 c*)

Torok and Nicholls (1996) used a variety of objective and subjective techniques to detect non-homogeneous data in the raw data time-series for each location and then to adjust (i.e. correct) the data for each station to give improved data series. This homogeneous high quality dataset of annual mean maximum and minimum temperature series for Australia assembled by *Torok and Nicholls (1996)* was updated in 2004 by *Della-Marta et al (2004)* using additional objective techniques and has been constantly added to and quality-controlled since then. *Della-Marta et al (2004)* reduced the number of sites included in the High Quality Dataset to 133 stations of which 34 were urban (i.e. with a population of at least 10,000 and possibly subject to Urban Heat Island effects) and 99 (now 100) rural stations upon which the detection of any long term climate trends can be reliably based.

The kinds of procedures used to transform the raw temperature data of the type included in the BOM's "Climate Data Online" into the data making up the "Australian High Quality Climate Change Dataset" are described in general terms in the BOM document "The Greenhouse Effect and Climate Change" (*BOM, 2009 f, pp.24-25*) as follows:

> *"A common technique used to correct discontinuities in a climate record involves comparing the series to be homogenised with a highly-correlated homogeneous reference series. The candidate series is then adjusted at the dates of discontinuity so that the difference between the two series remains constant throughout the record. Often, dates of potential discontinuity can be identified using graphical or statistical techniques, or by examining station history information (metadata). In recent times,*

parallel observations over a few years or more are often taken before a change is made at important climate sites. This allows the climate impact of the change to be determined, and the climate record to be adjusted to allow for the change. Often climate trend analyses are based on an average of numerous stations, such as a regional network, to allow random biases at individual stations to cancel each other out, leaving the true climatic signal. This is the approach used for calculating the global mean temperature. No single climate record should be used as evidence for or against global warming. Further improvement to the quality and both spatial and temporal extent of past climate data is taking many forms. This includes 'cleaning up' instrumental data, through a process of 'data rehabilitation', in order to retrieve useful information from data of widely varying quality. A priority is given to continuous long-term records of observations from individual locations."