Global Warming -the forest from the trees

Waugh's Australian Almanac | **Climate, Indeed!** | Year 1859

'Climate, indeed, is a subject upon which the most extravagant and unreasonable statements are made. Not only do many men, even of much scientific information, imagine that within the short scope of their own recollection they can detect a permanent change in weather or some other phenomenon, which would involve a connected change over all the regions of the earth, but they even assert that man's muscular strength and mental ingenuity can effect such changes. The clearing away of trees they say will render a climate dry; extensive reservoirs of water may increase the moistures of the atmosphere...'

Source: Jevons, William Stanley 1859. 'Some data concerning the climate of Australia and New Zealand' p.79 in: ***Waugh's Australian Almanac for the year 1859****, James William Waugh, Sydney.*

Sydney Observatory.

William Stanley Jevons.

Weather Station, Sydney.

CLIMATE, INDEED!

The year 2009 marks the 150th anniversary of the publication of the first comprehensive climate of Australia as well as the first full year of weather data at Sydney's Observatory Hill. Written by a remarkable Englishman who went on to become one of the founders of mathematical economics, William Stanley Jevons' "Climate" represented an early example of thinking about Australia as a single continental landmass subject to natural forces that recognise nothing of political boundaries. Among the contributions he made to Australian arts and sciences during his brief stint of less than five years in the colony of New South Wales, the young Jevons wrote regular weather reports for "Empire" - the Sydney newspaper of Henry Parkes, the later-day father of Australian Federation.

Nevertheless, Jevons was a man of his times, and in the extract from his "Climate" quoted above, we hear voiced, perhaps for the first time in Australia, more than a hint of scepticism about the possibilities that human endeavour and economic activity might have the potential to alter the very climate of the Earth. Jevons was perhaps Australia's first "Climate Change Sceptic".

CASE STUDY

In this Case Study, we ask the questions:

Is climate change real or a figment of the imagination?
What is the evidence that our planet is warming?

We use some of the statistical techniques pioneered by Jevons and his near contemporaries, to examine one aspect of the science of meteorology; the measurement of day-to-day local air temperature, the way in which temperature data is compiled and the way it is presented in order for inferences to be drawn about long term trends in climate. The emphasis will be on the skills of graphical presentation applied particularly to data sets derived from select meteorological stations in eastern Australia.

STRUCTURE

The Case Study is organised in three parts:

1. **This document - "Global warming – the forest from the trees" downloadable from**
   http://www.blueplanet.nsw.edu.au/templates/blue_content.aspx?pageID=543

2. **The Appendices document (pdf file) downloadable from**
   http://www.blueplanet.nsw.edu.au/templates/blue_content.aspx?pageID=543

3. **Data Spreadsheets - (Excel® files) downloadable from**
   http://www.blueplanet.nsw.edu.au/templates/blue_content.aspx?pageID=542

It is possible to complete the main Activities and Questions within this document without reference to the supporting Appendices and the Excel® spreadsheets; these addenda are given to enable completion of the Extension Activities and Questions, and a deeper exploration of the techniques referred to in the case study.

CURRICULUM LINKS

This case study was written for high school students within the NSW curriculum. Each individual page within the body of the text is designed to be a stand-alone page usually centred on an activity or set of questions.

Although the case study primarily addresses the **NSW Stage 6 Advanced Mathematics Draft Syllabus,** specifically the content of the Preliminary Year topic ***PMA6 Data Analysis,*** many of its activities can be used in other areas of the curriculum, namely in **Stage 5 Science**, **Stage 5 Geography** and **Stage 6 Earth and Environmental Science.**

At the end of this document, the connections of individual pages of the case study to areas of the curriculum are listed in two tables

- Guidelines for use of the case study within the Stage 6 Advanced Mathematics Draft Syllabus Topic PMA6 - Data Analysis
  (see page 22)
- Guidelines for use of the case study in other areas of the NSW curriculum; Stage 5 Science, Stage 5 Geography and Stage 6 Earth and Environmental Science
  (see page 23)

REFFERENCES

A full bibliography acknowledging all published writings and web pages referred to in this case study is listed on ***pages 20-21*** of this document.

ACKNOWLEDGEMENT

The concepts underpinning this case study and most of the data were drawn from the pages of the Australian Bureau of Meteorology (BOM) website (http://www.bom.gov.au/) and its supporting documents. The painstaking efforts of numerous staff and amateur enthusiasts down the decades and across the breadth of Australia have contributed to the massive body of weather records upon which we are now all so dependent.

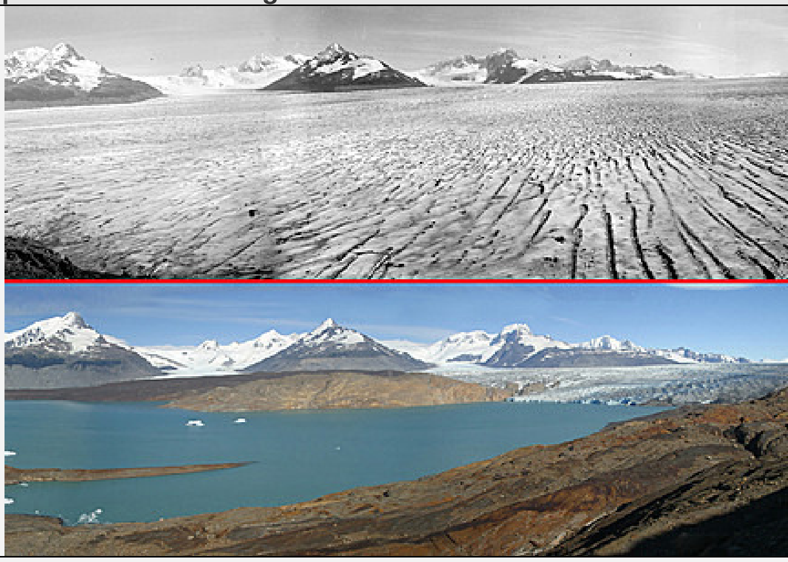
CASE STUDY: Global Warming – the forest from the trees

1. A picture is worth a thousand words?

ACTIVITY:

Examine the two photos published by the Green Peace organisation on its website (Green Peace 2009).

Upsala Glacier in Patagonia: 1928 vs 2004



Greenpeace (2009)

Now examine the two photos of the same glacier published by NASA on its website (NASA (2009).

Upsala Glacier in Patagonia: 2001 vs 2004

January 2001 Image ISS001-E-5318	
January 2004 Image ISS008-E-11807	

NASA (2009)

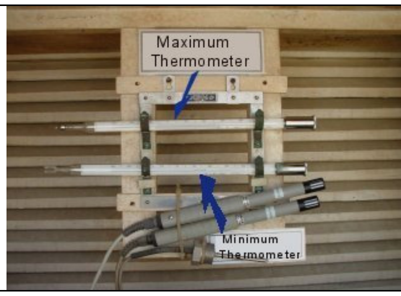
QUESTIONS:

1. *What do these pictures suggest about changes occurring in the Upsala Glacier?*
2. *Describe any differences in the kind of message you obtain from viewing each of the two picture sets.*

CASE STUDY: Global Warming – the forest from the trees

2. Long term temperature records.

Canberra Airport is one of about 370 land surface meteorological stations in Australia useful for national climate monitoring purposes. It has been recording daily maximum and minimum temperatures in a Stevenson Screen since 1939, the year the Second World War broke out. As you would expect of the nation's capital, the meteorological station at the airport is of high quality and has been reliably recording the daily weather for 68 years. In all that time, there have been only 19 days on which an accurate measurement of the maximum daily air temperature failed to be taken. Canberra airport is one of the 100 or so meteorological stations comprising "**Australia's Reference Climate Stations Network (RCS)**" selected for high quality monitoring of the long term climate.

		
Canberra airport met station (*BOM, 2009 a*)	**A Stevenson Screen** (*Wikipedia, 2009*)	**Maximum and minimum** thermometers inside a Screen

ACTIVITY: The quality of the meteorological network

Examine the information in Table 1 then answer the questions below.

Table 1: The location and characteristics of six meteorological stations in eastern Australia (*BOM, 2009b*)

	Wagga	Canberra	Sydney	Newcastle	Charleville	Boulia
BOM No.	072150	070014	066062	061055	044021	038003
WMO No.	94910	94926	94768	94774	94510	94333
Latitude	-35.16	-35.30	-33.86	-32.92	-26.41	-22.91
Longitude	147.46	149.20	151.21	151.80	146.26	139.90
Purpose of station	RCS, Synoptic	RCS, Synoptic	Synoptic only	Synoptic only	RCS, Synoptic	Synoptic only
Altitude (m)	212 m	578 m	39 m	33 m	303 m	162 m
Year opened	1941	1939	1858	1862	1942	1886
Completeness of temperature record (%)	99.8	99.9	99.9	-	99.4	96.8
Days missed	37	19	16	-	136	949
Quality rank *	2	-	3	2	2	3

* Quality of records ranked on a scale of 1 to 5 with rank 1 being very good, 5 being very poor (*Della-Marta et al., 2004)*

QUESTIONS:

1. Which of the six stations in this Table is the most northerly?
2. Which station has the longest record of daily temperature readings?
3. Which of these stations has the largest amount of missing data in the temperature record?

EXTENSION (based on Appendix 1 in the separate Appendices document):

*1. Of the 18 meteorological stations detailed in **Appendix 1 (a),** which are likely to have temperature records influenced by an "Urban Heat Island" effect?*
*2. Based on the information in **Appendix 1 (a),** what is the purpose of a "synoptic" met station?*
*3. On the basis of the information provided in **Appendix 1(b)**, can you suggest a reason why the Sydney meteorological station at Observatory Hill is not included in the Reference Climate Station (RCS) network?*

3. Measuring the daily maximum and minimum air temperature.

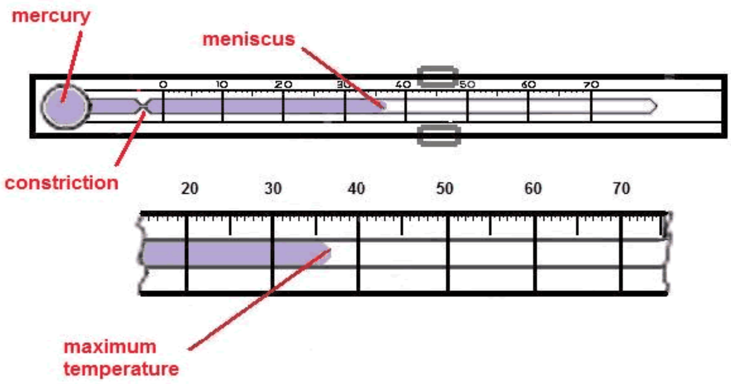
Air temperatures over land are usually measured at a height of between 1.2 and 2.0 m above ground in a Stevenson Screen. Liquid-in-glass thermometers are the traditional instruments used. For measuring maximum temperatures, the liquid is usually mercury. Minimum thermometers, on the other hand, usually contain alcohol because it freezes at a lower temperature (-130 ^{0}C) than does mercury (-38.3 ^{0}C). When the bulb of a thermometer is heated, the liquid expands and is forced up the fine bore of the tube, and when the bulb is cooled the liquid tends to contract down the bore.

A maximum thermometer has a constriction just above the bore. If the temperature rises the mercury expands past the constriction, but when the temperature falls the mercury is prevented from receding to the bulb due to the constriction. Thus the mercury in the stem remains at its maximum point of expansion, fixing the position of the highest temperature reached.

A minimum thermometer contains a small dumbbell shaped glass index. When the temperature falls the index is drawn along with the alcohol as it retreats down the bore. After the lowest temperature is reached and the temperature starts to rise again, the alcohol rises in the bore but flows past the index leaving its position fixed. The minimum temperature is read at the upper edge of the stranded index.

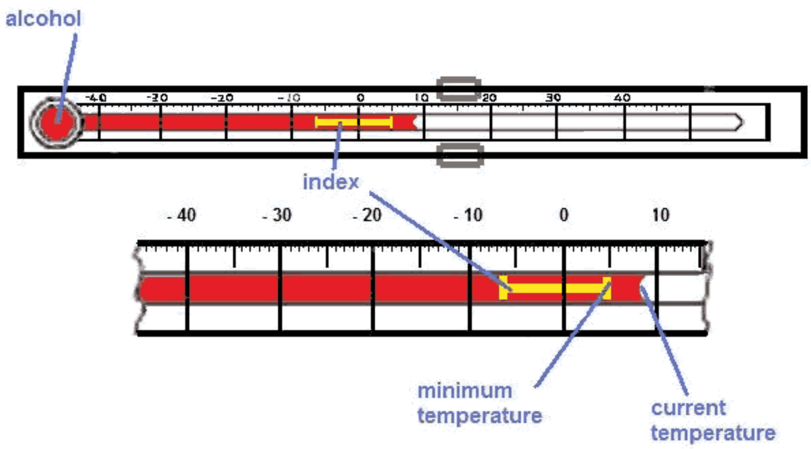
Maximum thermometer

In a maximum thermometer, the mercury thread breaks at the constriction as the temperature falls. To re-set the thermometer, it should be held bulb downwards and shaken until the mercury has been returned to the bulb-side of the constriction.



Minimum Thermometer

In a minimum thermometer, the index is drawn by surface tension back to the minimum position as the temperature falls. The thermometer can be reset by tilting it bulb end upwards, so as to allow the upper edge of the index to rejoin the surface of the alcohol. It must be ensured that bubbles do not form in the alcohol



QUESTIONS:

1. Assuming it is 9 am and that the two thermometers shown above have not been reset since 9 am yesterday, determine:
(a) the highest temperature reached during the last 24 hours;
(b) the lowest temperature reached during the last 24 hours;
(c) the current 9 am temperature.

2. *Do these temperatures seem reasonable? Why? – Perhaps one or other of the thermometers is in error; perhaps they need to be checked (see* ***Appendix 2*** *in the separate* **Appendices**).

4. Different ways of presenting the same data.

Table 2 lists the mean maximum and mean minimum temperature for each year from 1940 to 2008 at Canberra airport, calculated from the monthly statistics of the maximum temperature and minimum temperature measured by thermometer each day. The values are drawn from the Australian Bureau of Meteorology's climate data online monthly statistics and have not been subject to quality control adjustments *(BOM, 2009 b).*

Table 2: Canberra temperature data (1940-2008); unadjusted annual means calculated from the recorded raw monthly maximums and the raw monthly minimums *(BOM, 2009 b).*

The mean maximum temperature and mean minimum temperature (in degrees Celsius) for each year from 1940 to 2008 for Canberra Airport Met Station (World Meteorological Organisation station number = 94926)
Location: -35.3049, 149.2014.

Year	Max	Min	Year	Max	Min	Year	Max	Min	Year	Max	Min
1940	20.9	6.2	1960	18.7	5.8	1980	21.0	7.1	2000	19.8	6.9
1941	19.7	5.6	1961	19.4	5.9	1981	19.9	7.7	2001	20.7	6.6
1942	19.8	7.2	1962	18.9	5.6	1982	21.2	6.5	2002	21.0	6.7
1943	18.1	6.9	1963	19.2	6.4	1983	19.4	7.7	2003	20.3	7.4
1944	20.4	6.5	1964	18.9	6.1	1984	18.8	5.7	2004	21.1	7.0
1945	19.4	7.1	1965	20.2	5.7	1985	19.6	6.2	2005	21.0	7.3
1946	19.7	6.9	1966	18.7	5.9	1986	19.4	6.2	2006	21.8	7.0
1947	19.6	6.7	1967	20.2	6.1	1987	20.0	6.1	2007	21.2	8.3
1948	18.6	5.4	1968	19.7	6.8	1988	20.1	7.6	2008	20.4	7.1
1949	18.7	5.4	1969	19.2	6.3	1989	18.9	7.2			
1950	19.0	6.8	1970	18.7	5.8	1990	19.7	7.3			
1951	19.5	5.6	1971	19.1	5.7	1991	20.3	7.2			
1952	18.7	6.4	1972	20.1	5.6	1992	18.4	6.5			
1953	19.3	5.2	1973	19.9	7.7	1993	19.6	6.6			
1954	19.7	5.7	1974	18.7	6.5	1994	20.4	6.0			
1955	18.7	6.4	1975	19.4	6.8	1995	19.0	6.9			
1956	17.9	5.8	1976	19.0	6.1	1996	19.1	6.2			
1957	20.4	4.6	1977	20.0	6.3	1997	21.0	6.5			
1958	19.1	6.8	1978	19.0	6.8	1998	20.5	7.5			
1959	19.5	6.3	1979	20.5	6.6	1999	19.9	6.5			

When presented in this way it is not easy to see the forest for the trees; the mind gets swamped in the detail and finds it hard to detect any overall trends or changes. The human mind is better able to grasp a graphical presentation.

A graph is a portrait of the data; not one iota of the information need be lost, yet our focus shifts to the image as a whole not to each individual pixel (unless we so choose). The 'rules' for creating a graph are similar to those for painting a portrait – truthfulness of content, balance of composition, use of space, and stand-alone titles and labelling.

ACTIVITY: Graphing the Canberra airport temperature data

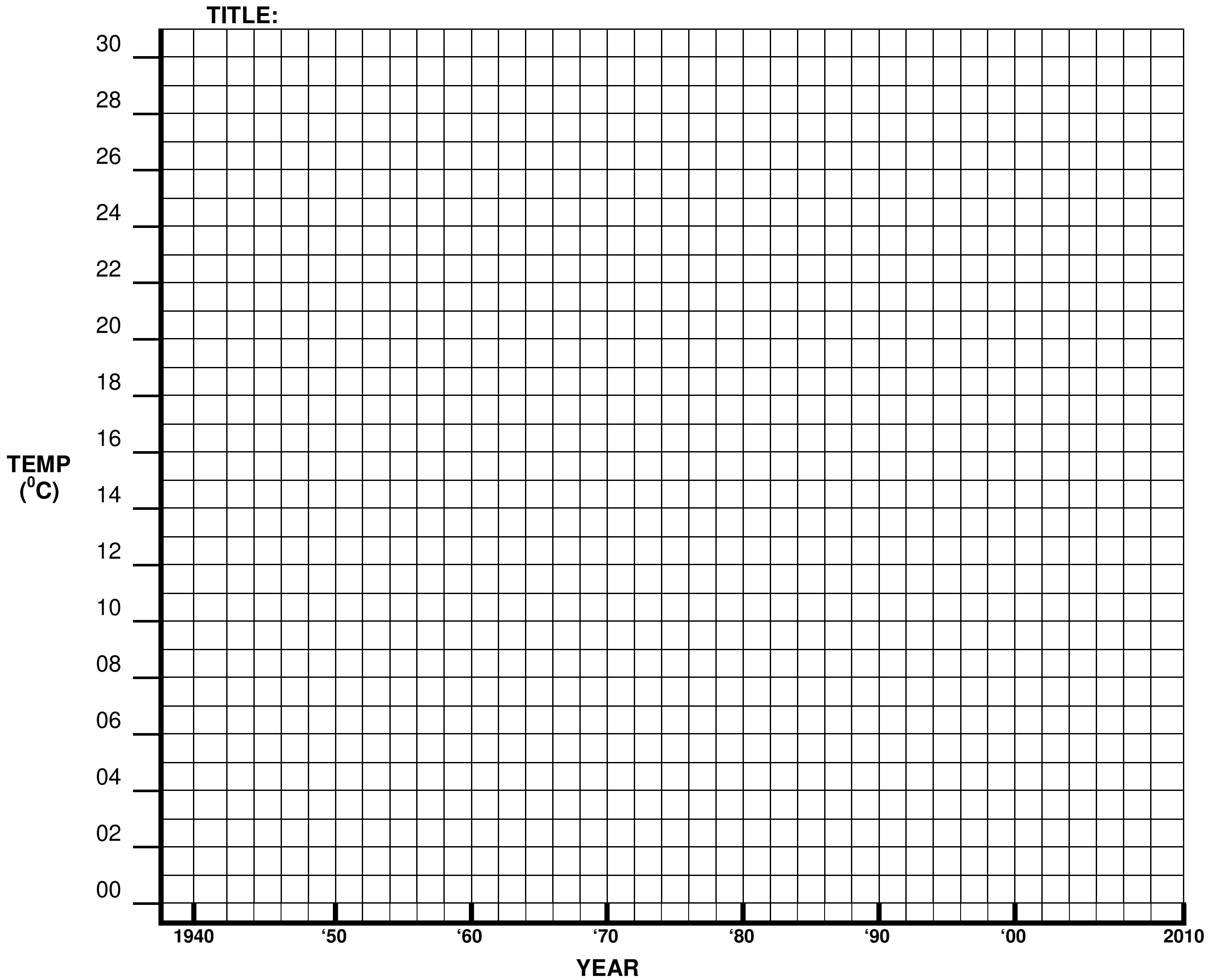
Using the data presented in the table above, graph the trend in maximum and minimum temperatures at Canberra airport over the last 68 years. You may choose to print a copy of the graph template presented **on the next page** to do this. Alternatively, you may choose to use a computer to prepare the graph using Microsoft Excel$_{(R)}$ or some other graph-making software (an Excel$_{(R)}$ file of the above data and is available for down-loading from http://www.blueplanet.nsw.edu.au/templates/blue_content.aspx?pageID=542) which contains all the Excel$_{(R)}$files used in this case Study).

CASE STUDY: Global Warming – the forest from the trees

4(a) Template for graphing Canberra airport temperature data

Canberra airport raw unadjusted temperature data (1940-2008)

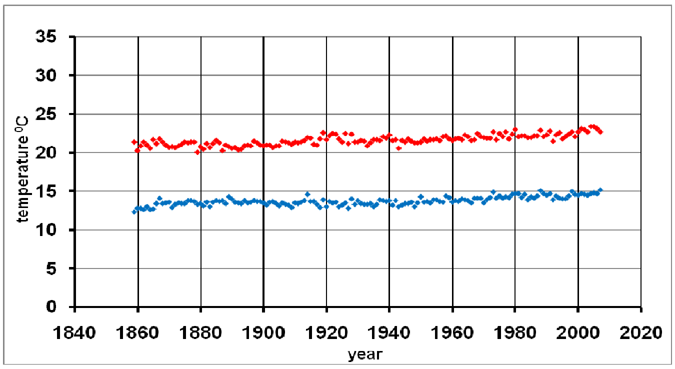
Year	Max	Min	Year	Max	Min	Year	Max	Min	Year	Max	Min	Year	Max	Min	Year	Max	Min	Year	Max	Min
1940	20.9	6.2	1950	19.0	6.8	1960	18.7	5.8	1970	18.7	5.8	1980	21.0	7.1	1990	19.7	7.3	2000	19.8	6.9
1941	19.7	5.6	1951	19.5	5.6	1961	19.4	5.9	1971	19.1	5.7	1981	19.9	7.7	1991	20.3	7.2	2001	20.7	6.6
1942	19.8	7.2	1952	18.7	6.4	1962	18.9	5.6	1972	20.1	5.6	1982	21.2	6.5	1992	18.4	6.5	2002	21.0	6.7
1943	18.1	6.9	1953	19.3	5.2	1963	19.2	6.4	1973	19.9	7.7	1983	19.4	7.7	1993	19.6	6.6	2003	20.3	7.4
1944	20.4	6.5	1954	19.7	5.7	1964	18.9	6.1	1974	18.7	6.5	1984	18.8	5.7	1994	20.4	6.0	2004	21.1	7.0
1945	19.4	7.1	1955	18.7	6.4	1965	20.2	5.7	1975	19.4	6.8	1985	19.6	6.2	1995	19.0	6.9	2005	21.0	7.3
1946	19.7	6.9	1956	17.9	5.8	1966	18.7	5.9	1976	19.0	6.1	1986	19.4	6.2	1996	19.1	6.2	2006	21.8	7.0
1947	19.6	6.7	1957	20.4	4.6	1967	20.2	6.1	1977	20.0	6.3	1987	20.0	6.1	1997	21.0	6.5	2007	21.2	8.3
1948	18.6	5.4	1958	19.1	6.8	1968	19.7	6.8	1978	19.0	6.8	1988	20.1	7.6	1998	20.5	7.5	2008	20.4	7.1
1949	18.7	5.4	1959	19.5	6.3	1969	19.2	6.3	1979	20.5	6.6	1989	18.9	7.2	1999	19.9	6.5			



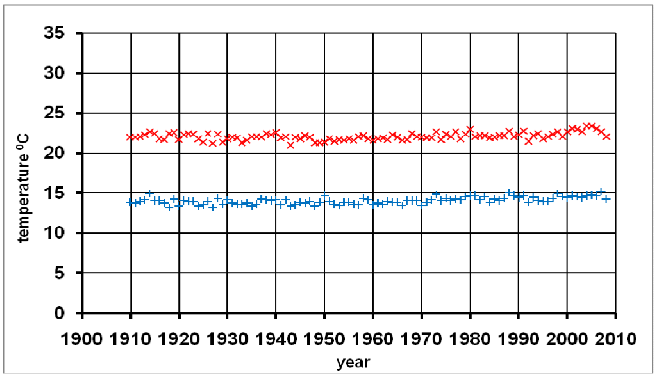
5. Long term trends in temperature data from different sites.

ACTIVITY: Comparing long term trends

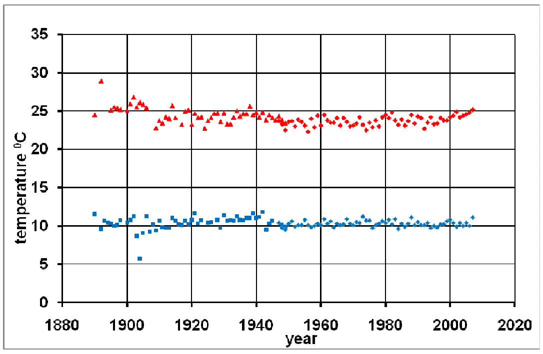
Examine the graphs below which show the trends in values of the annual means of the monthly statistics for the daily **maximum** and **minimum** temperature across the years at three met stations in NSW and Qld. The values on the left hand side are drawn from the Bureau of Meteorology's "Climate Data Online" monthly statistics (*BOM, 2009 b*) and have not been subject to quality control adjustments. The values on the right hand side are drawn from the "Australia's High Quality Climate Change Data" and have been subject to quality control adjustment (*BOM, 2009 c*). For a detailed description of how the High Quality Datasets are obtained from the raw data see **Appendices 3, 4(a), 4(b)** and **4(c)** in the separate **Appendices** document.



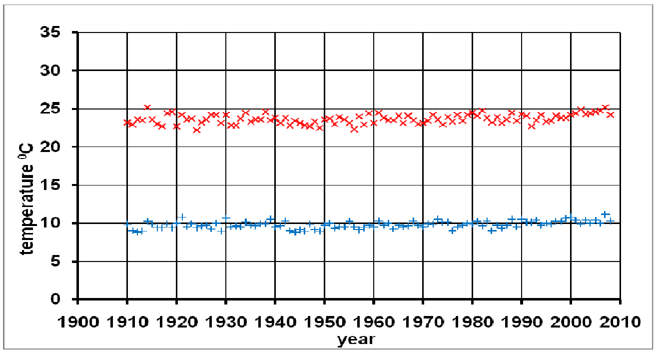
Sydney, 1859-2007 – Unadjusted Annual Temperatures



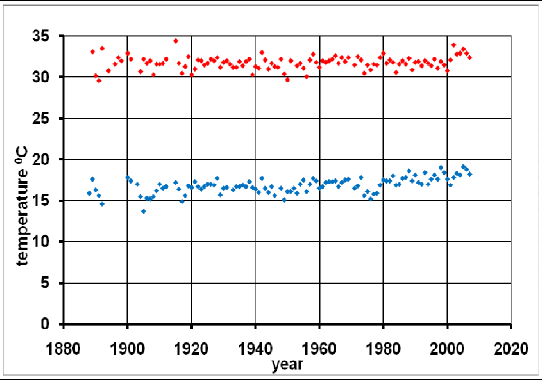
Sydney– Adjusted "High Quality" Temperature Dataset



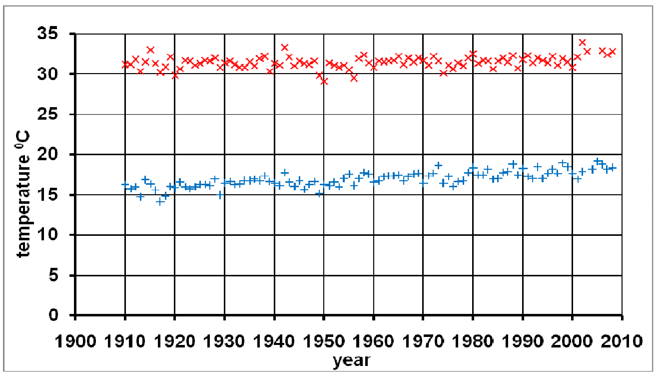
Mildura, 1890-2007 – Unadjusted Annual Temperatures



Mildura– Adjusted "High Quality" Temperature Dataset



Boulia, 1889-2007 – Unadjusted Annual Temperatures



Boulia – Adjusted "High Quality" Temperature Dataset

Note: Red data points are the annual mean maximums. **Blue data points** are the annual mean minimums.

QUESTIONS:

1. *Based on a quick overview of these graphs, which of the three locations is 'hottest' on average?*
2. *Based on a quick overview of these graphs, do you think there has been any overall change in temperatures over the years? Explain your answer.*

EXTENSION

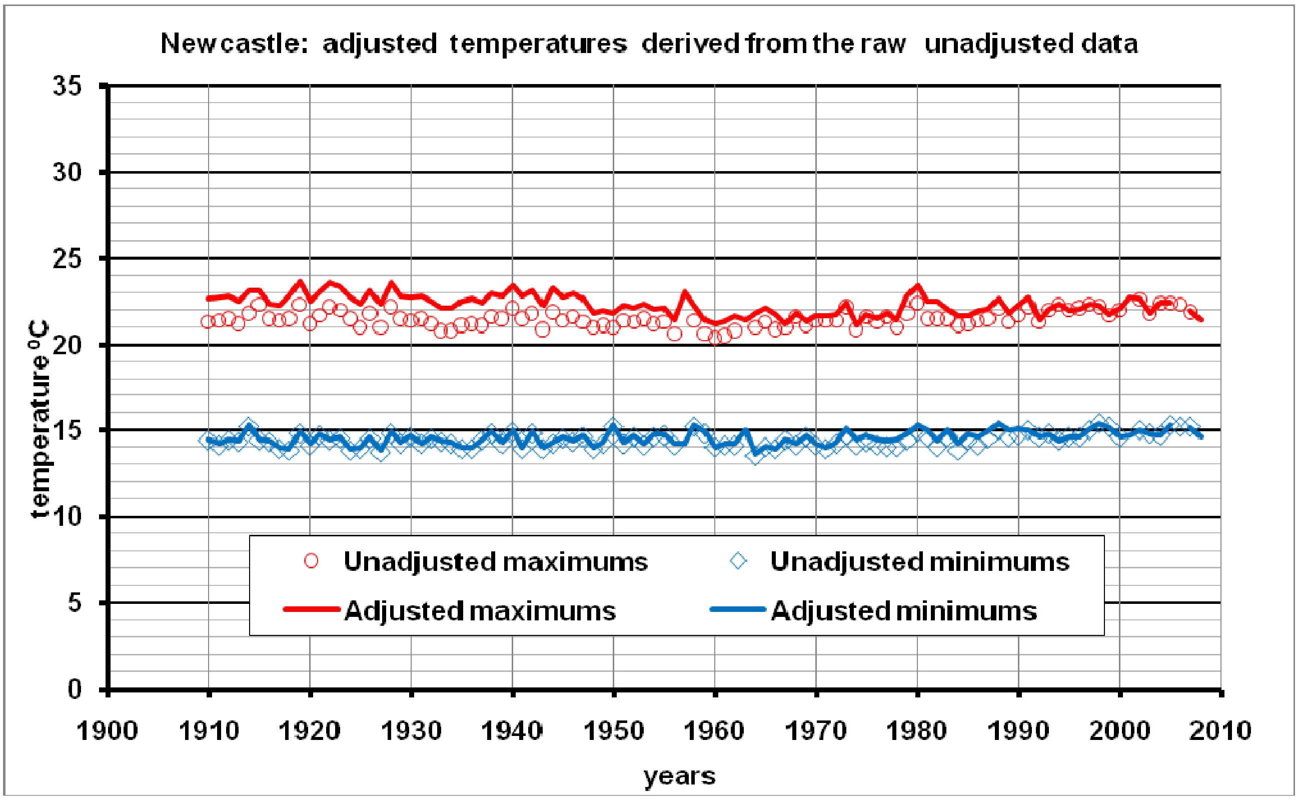
1. *Based on the information in **Appendix 3** in the separate **Appendices** document, can you suggest a reason why the "High Quality Data Set" does not include data before 1910?*

6. A graphical analysis of the long term temperature data for Newcastle.

Nobbys' Signal Station (BOM No. 061055) in Newcastle provides the Central Coast of NSW with its nearest long term temperature record apart from the one at Sydney Observatory. Over the next few pages we will use this temperature record in order to examine the way our perception of long term trends in climate are influenced by different forms of data treatment and graphical presentation and to improve our skills in drawing scientific inferences from such datasets.

ACTIVITY: The effect of Quality Control adjustment of a data time-series

Long-term sequences of annual temperature means, such as those presented in the graph below, are known as time-series. This graph shows time-series for the period 1910 to 2008 for both the raw data (*BOM, 2009 b*) and for the High Quality (i.e. adjusted) data (*BOM, 2009 c*). Examine carefully the graph below and answer the questions that follow.



QUESTION:

1. *Between 1910 and 1990 which of the two unadjusted time-series (maximum or minimum) required the greater amount of adjustment to produce the High Quality Dataset? What about after 1990?*
2. *According to the 'metadata' (i.e. documentation about the circumstances of measurement) for the Newcastle station, in 1989 the Stevenson Screen containing the thermometers was shifted to a new improved, position (less enclosed by buildings). Based on the above graph, what effect did the poor position of the Screen before 1990 have on the recorded maximum temperatures?*

EXTENSION:

Do you think that the production of a High Quality Temperature Dataset (as shown here for Newcastle and described in detail for Sydney, Mildura and Boulia in ***Appendices 3****,* ***4(a), 4(b) and 4(c)****) is likely to have increased or to have decreased the* <u>*validity*</u> *of any inferences about Global Warming that might be drawn from the long term temperature measurements for these locations? Give reasons for your answer.*

CASE STUDY: Global Warming – the forest from the trees

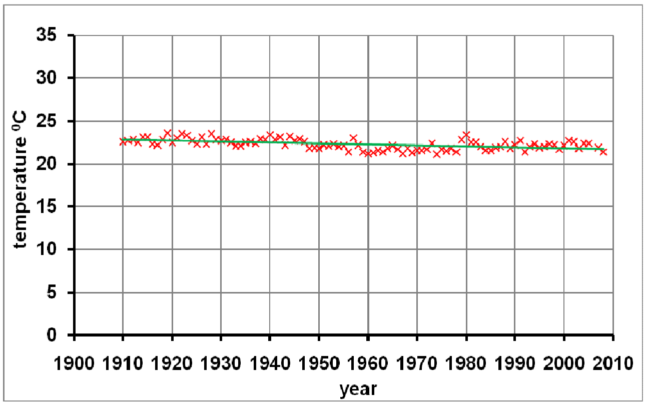
6(a) Effect of a change of scale

The graphs below present the same High Quality Dataset for Newcastle (*BOM, 2009 c*) but in two quite different formats. On the left hand side, the maximum and minimum data are presented on separate graphs (**1(a)** and **1(b)**) with the vertical axis displaying the broad range of temperatures (i.e. from 0^0C to 35^0C) likely to be encountered in the annual mean maxima and minima in eastern Australia. On the right hand side the same two data sets are presented (graphs **2(a)** and **2(b)**) with the vertical axis scaled in each case to a much narrower range of temperatures specific to the particular data being displayed (i.e. 20^0C to 24^0C for the Newcastle annual maximums) and (13^0C to 17^0C for the Newcastle annual minimums).

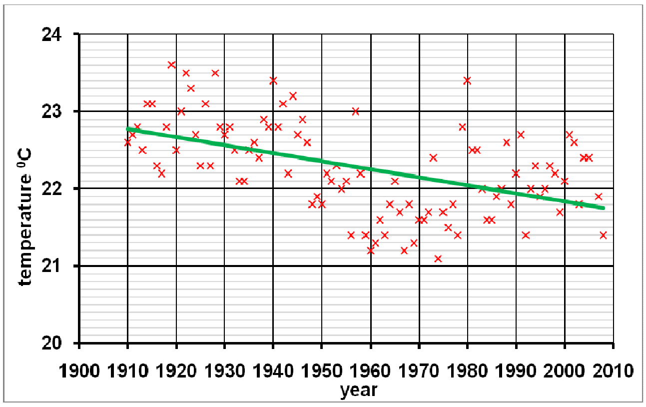
Another new feature of these four graphs is that in each case a 'line of best fit' (achieved by 'least squares linear regression') has been fitted to each set of data. This enables the overall trend in the individual time-series to be observed (see **Appendix 5** in the separate **Appendices** document).

<u>ACTIVITY: The effect on our perceptions produced by a change in the scale of a graph</u>

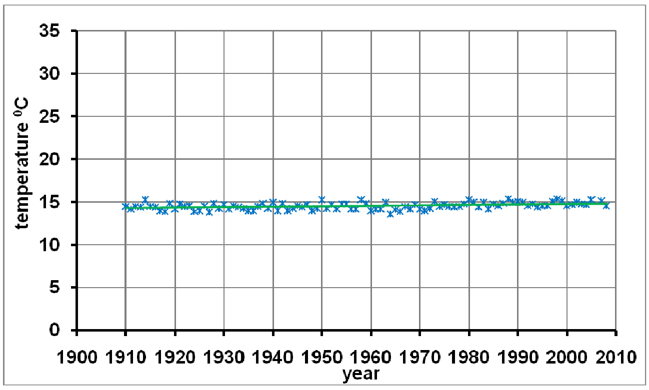
Examine carefully the four graphs below and answer the questions that follow.



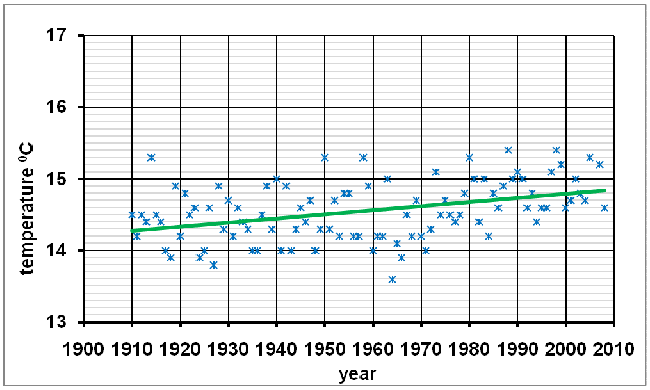
1(a). Adjusted maximums on a scale of 0 – 35 ^{0}C



2(a). Adjusted maximums on a scale of 20 – 24 ^{0}C



1(b). Adjusted minimums on a scale of 0 – 35 ^{0}C



2(b). Adjusted minimums on a scale of 13 – 17^{0}C

<u>QUESTIONS:</u>

1. *Describe the effect on your **perception** of the variability in the datasets, produced by the change in scale of the vertical axis between the graphs on the left and the graphs on the right.*
2. *Describe the effect on your **perception** of the overall trends in the maximum and minimum time-series, produced by the change in scale of the vertical axis.*
3. *Is there any **real** difference in the overall maximum temperatures trends between graph **1(a)** and graph **2(a)**? Explain.*
4. *Does there appear to be a **real** difference in the overall trend over time between maximum and minimum temperatures? Describe the difference.*

6(b) The value of an anomaly

For detecting changes in temperature over time, especially where data from different Stations are to be compared and combined into regional, national or even global averages, meteorologists have found that the actual temperature values are less useful than so called temperature **anomalies.**

At present, the way these anomalies are calculated is like this:

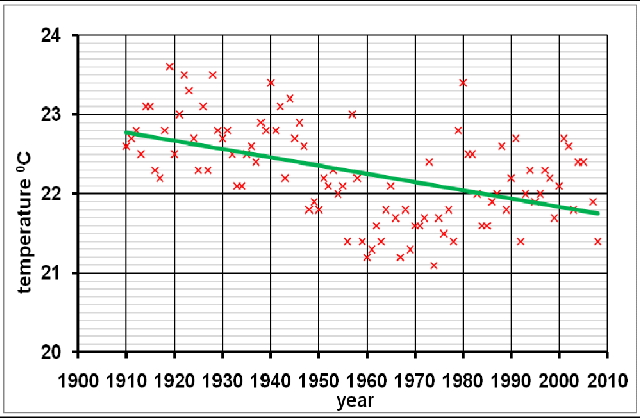
1. For any particular time series (take for example the Newcastle High Quality Annual Maximum Temperature series) we first calculate the mean across the whole 30 year of values for the period 1961 to 1990 This mean value is known as the "*station normal*"
2. We then subtract this 30-year "*station normal*" from each of the individual values in the time series in order to obtain a new time-series such that each element in the time-series is now expressed as a departure (i.e. an anomaly) from the 30 year base period average.

See **Appendix 6** in the separate **Appendices** document for a more detailed explanation of this procedure.

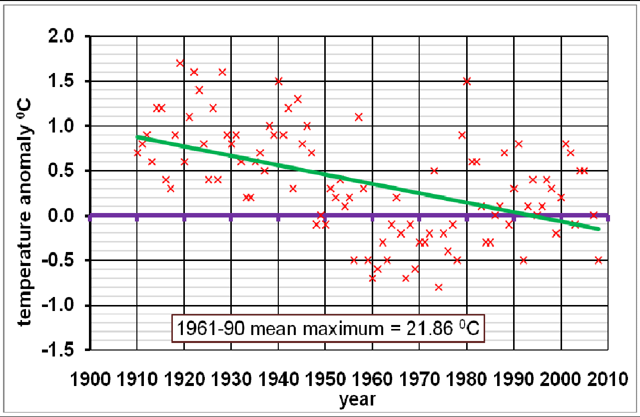
Because it is a period of time with good global data coverage, the period 1961-1990 has been chosen as the current international standard period for these calculations. Meteorological stations on land are often at different elevations, and different countries estimate average monthly temperatures using different methods and formulae. When combining data from different stations, the expression of temperatures as anomalies helps to avoid biases that could result from these problems.

ACTIVITY: The effect of expressing temperature data as anomalies

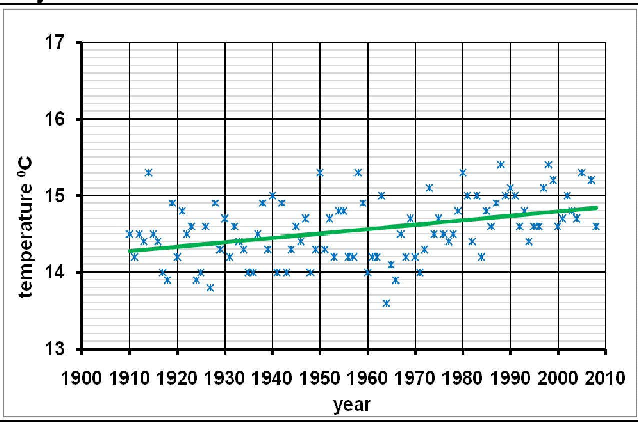
Examine these four graphs of the Newcastle dataset (*BOM, 2009 c*) and answer the questions.



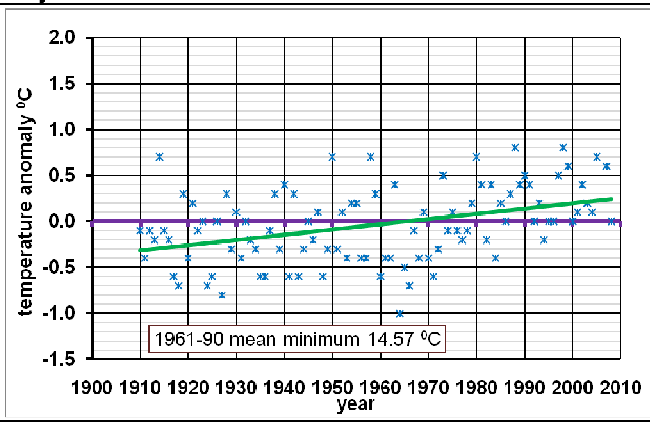
Adjusted maximums - scale 20 – 24 °C



Adjusted maximums as anomalies



Adjusted minimums - scale 13 – 17 °C



Adjusted minimums as anomalies

QUESTIONS:

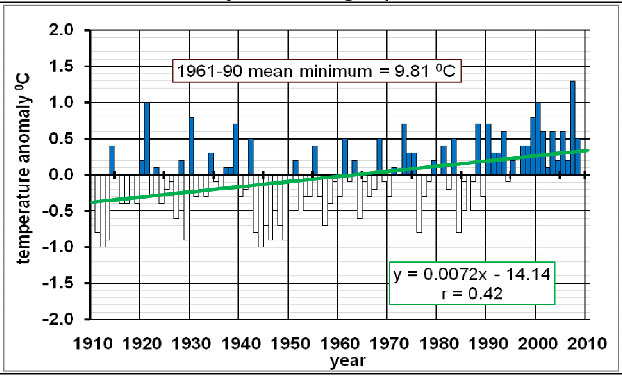
1. *Has the expression of temperatures as anomalies produced any alteration in the general trend of the lines of best fit and in the scatter of data points around the lines of best fit?*
2. *Describe one advantage that has resulted from expressing the Newcastle maximums and minimums as anomalies rather than as actual temperature values.*

7. Comparing temperature anomalies.

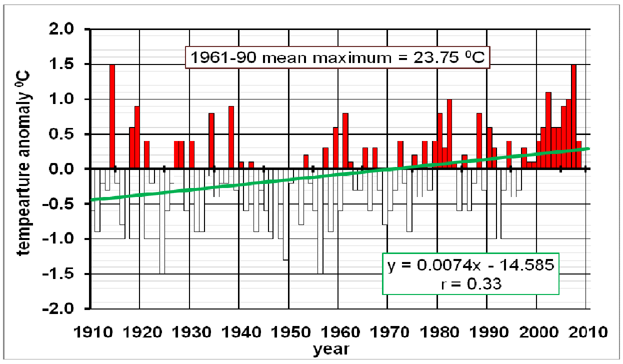
Before (on page 6), we presented the High Quality data for the years 1910 to 2008 for Mildura, Sydney and Boulia (*BOM, 2009 c*) as '**scatter plots'** with the data points displayed on a scale of 0 to 35^0C. In the graphs below the same datasets are presented as '**column graphs'** with the annual temperature values being expressed as anomalies from their 30-year average (1961-1990). The data hasn't changed, only the way of presenting it; making it easier to compare variability and trends and, if required, to combine data sets to obtain regional average data. For those of you who are mathematically inclined, the linear equations (y = mx +c) for the lines of best fit and the correlation coefficients (r) are given to enable you to more precisely compare trends (see **Appendix 5** in the separate **Appendices** document).

ACTIVITY: Comparing trends in temperature anomaly time series

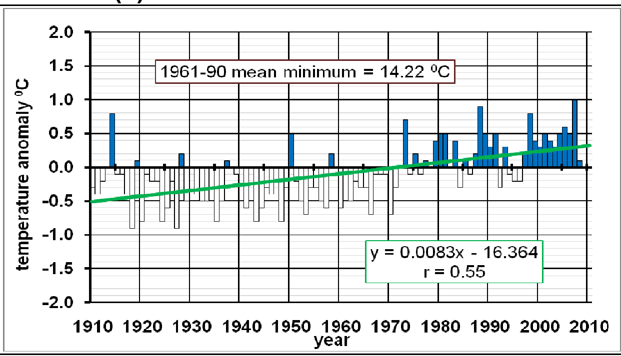
Examine carefully the six graphs below and answer the question that follows.



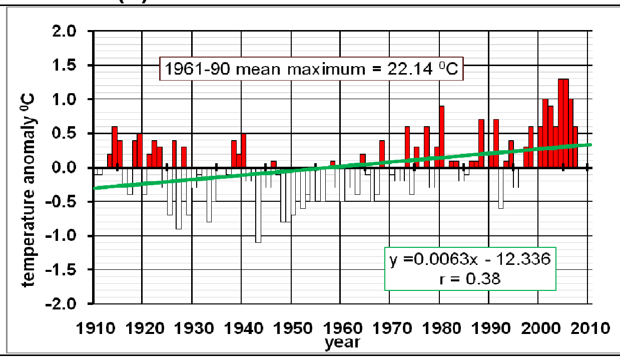
1(a). Mildura minimum anomalies



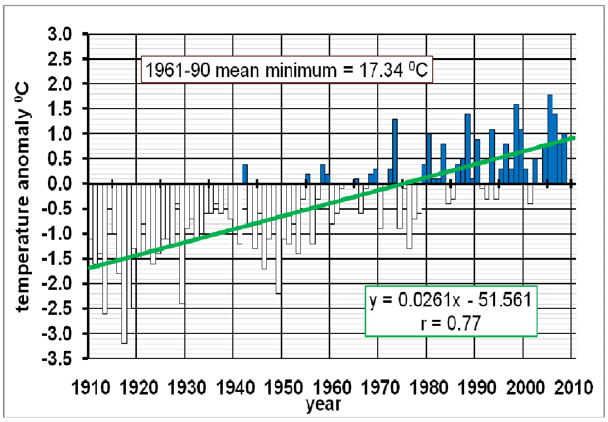
1(b). Mildura maximum anomalies



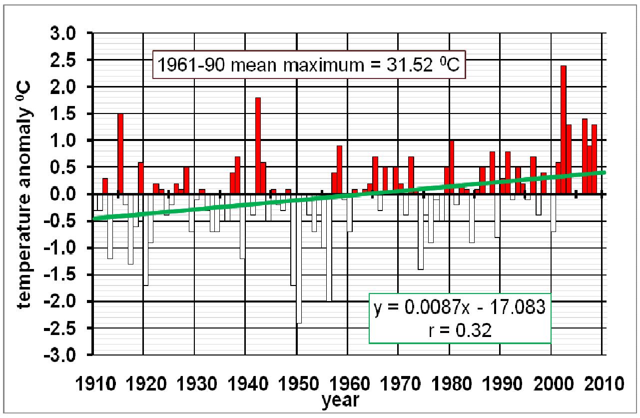
2(a). Sydney minimum anomalies



2(b). Sydney maximum anomalies



3(a). Boulia minimum anomalies



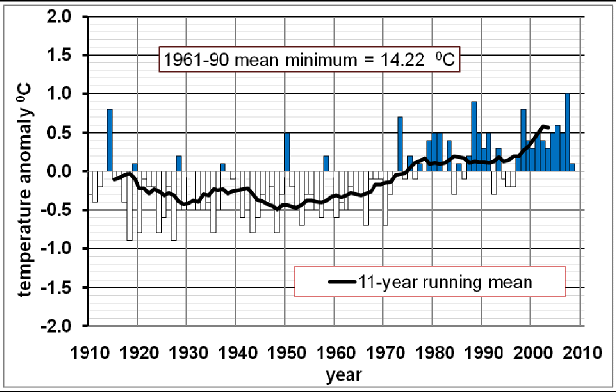
3(b). Boulia maximum anomalies

QUESTION:

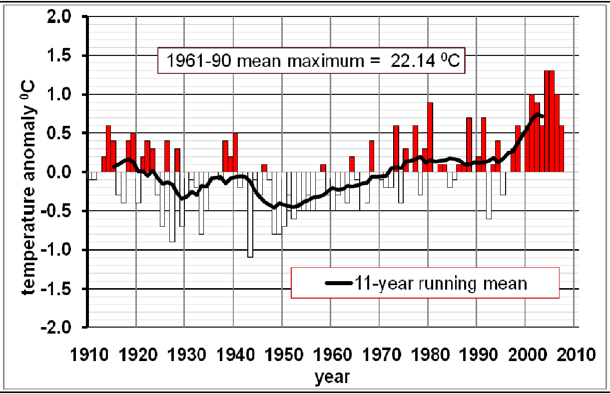
1. *Which of the six time-series above shows the strongest upwards trend in temperatures?*

8. Calculation of the annual mean temperatures from the maxima and minima.

In the two graphs below, we have taken the anomalies for Sydney presented on the previous page but instead of displaying a straight line of best-fit through the data points have chosen instead a different form of trend-line (known as an ‘11-year running mean’) in order to help detect some of the subtlety on the level of about a one decade time-interval in the temperature trends (for more, see **Appendix 7** in the separate **Appendices**).

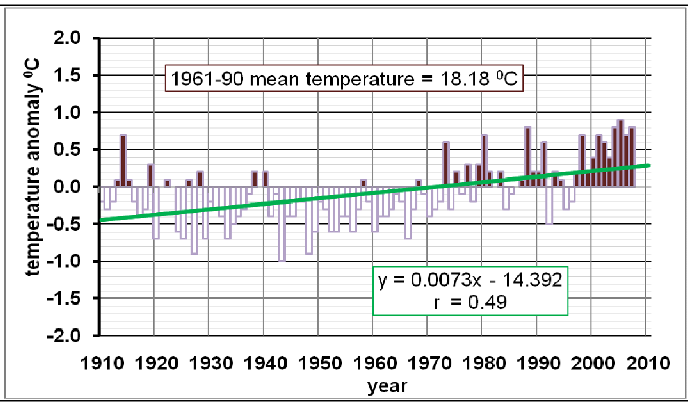


Sydney minimum anomalies.



Sydney maximum anomalies.

One of the features that such an analysis highlights is the dip in temperatures which occurred in the period from about 1940-1960. This is a feature of the data from many meteorological stations and is especially apparent in the maximum temperatures (see for example, Newcastle). Maximum and minimum temperatures behave differently under different synoptic conditions and have been treated separately up until this point. However, when we come to look at climate change on a larger scale such detail can obscure the broader issues. In the graph below, the maximum and minimum anomalies have been combined into one time-series – the mean anomalies. (*BOM, 2009c*)



Sydney mean anomalies

These mean anomalies have been calculated by going back to the original annual maximum and minimum time-series. For each year, the maximum temperature (T_{max}) has been added to the minimum (T_{min}) and then divided by 2 (i.e. $T_{mean} = (T_{max} + T_{min}) /2$). The mean values have been rounded off either down or up, as appropriate, to the nearest decimal point. The anomalies for the mean temperatures have then been calculated in the same way as the anomalies for the maximum and minimum time-series, i.e. to a base of the 1961-1990 average.

CASE STUDY: Global Warming – the forest from the trees

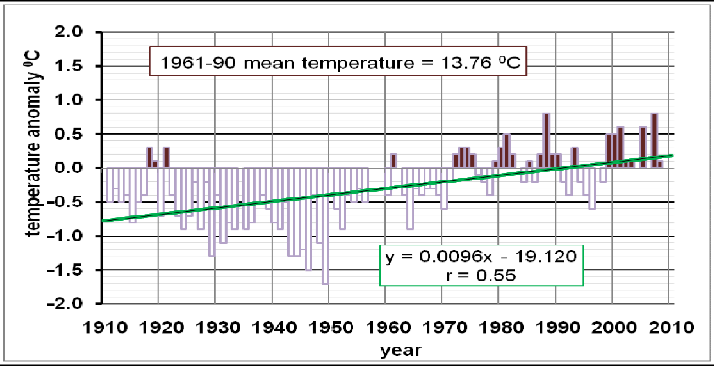
QUESTION:

On the basis of the line of best fit in this graph, has the annual mean temperature for Sydney changed between 1910 and 2008? Increased or decreased? By how much roughly? Try using the linear equation to estimate the average change per decade (per 10 years) that has occurred since 1910.

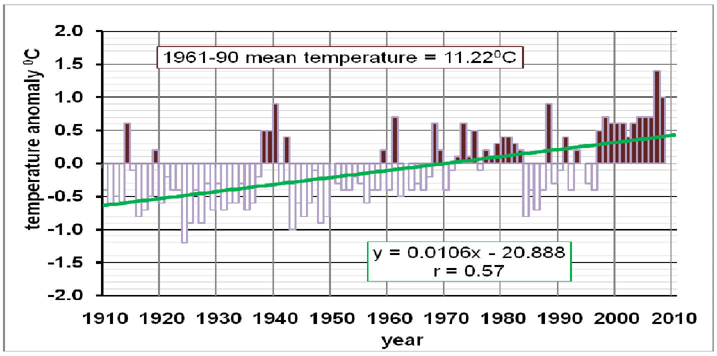
9. Comparison of mean temp anomaly trends for selected rural stations.

ACTIVITY: Comparing linear trends and the goodness of fit to a straight line relationship

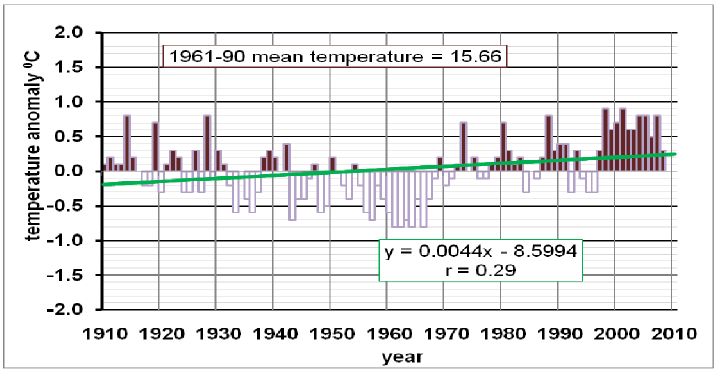
Examine carefully the twelve time-series of mean temperature anomalies from the High Quality Dataset (*BOM, 2009 c*) on the next two pages and then complete the summary table that follows.



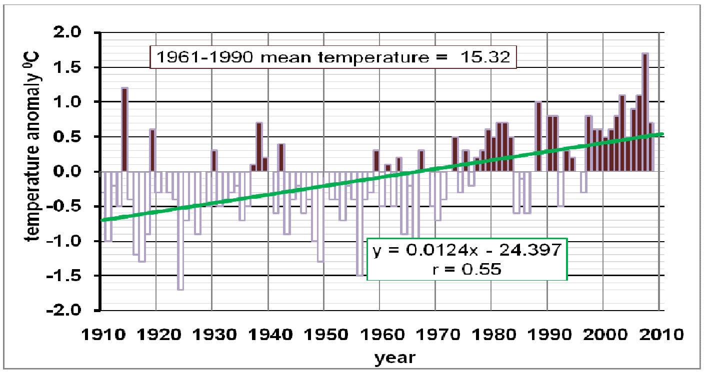
Cape Otway



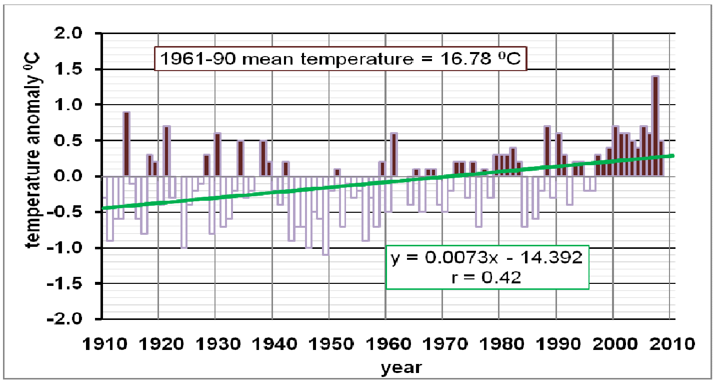
Omeo



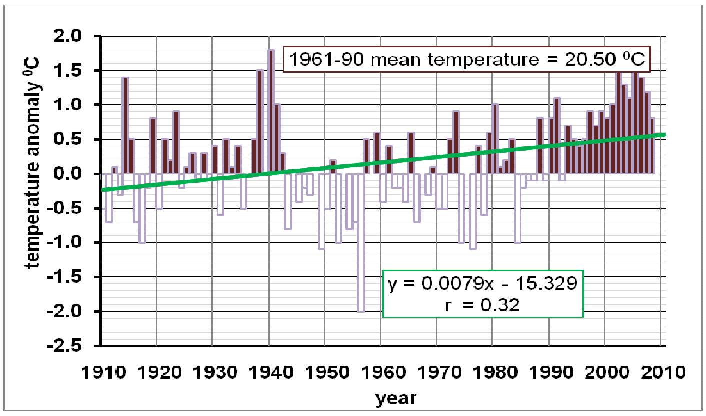
Moruya Heads



Wagga Wagga

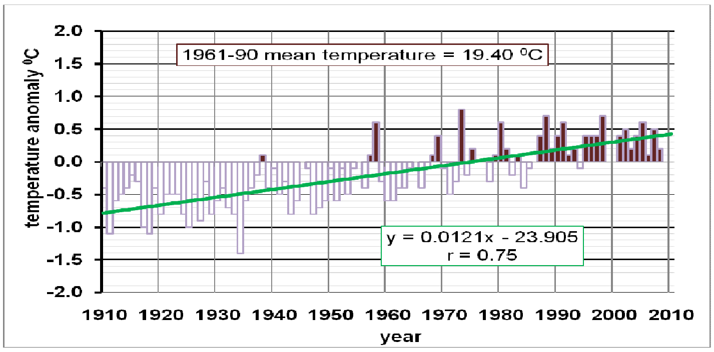


Mildura

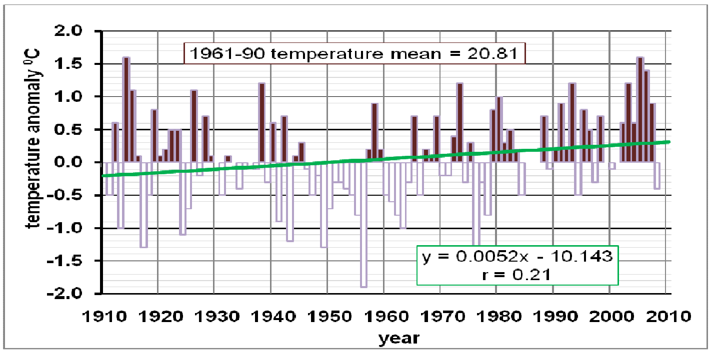


Tibooburra

CASE STUDY: Global Warming – the forest from the trees



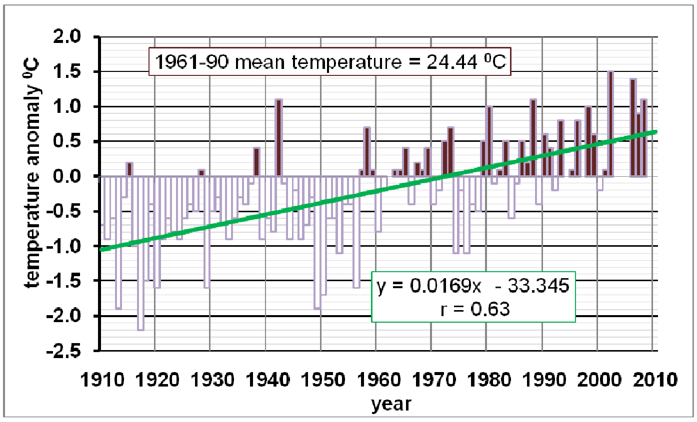
Yamba



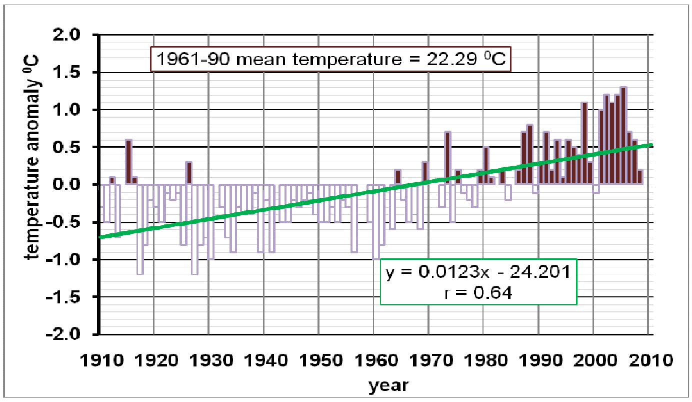
Charleville

CASE STUDY: Global Warming – the forest from the trees

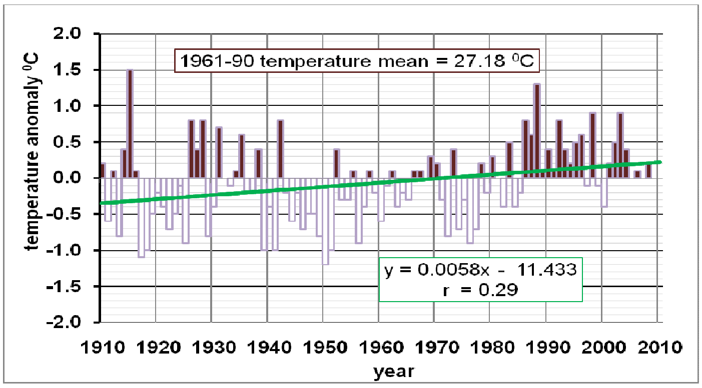
9(b) Comparison continued.



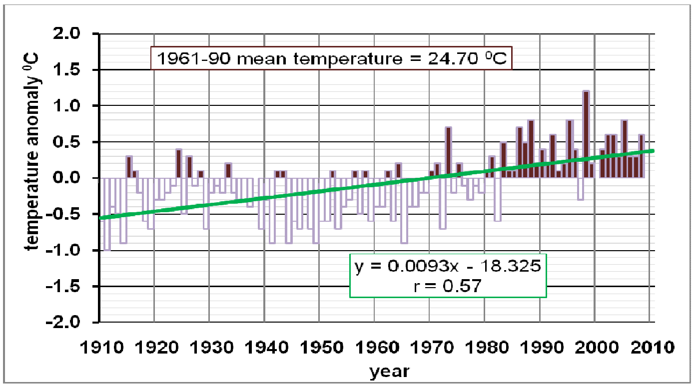
Boulia



Rockhampton



Normanton



Cairns

Now complete the summary table below:

Station	Coefficient of correlation between anomaly and years (r)	Gradient of the line of best fit (°C/year)	Intercept with the y-axis (i.e. T anomaly when x = 1910) (°C)	Predicted T anomaly for when x = 2010 (°C)	Predicted average change per century (1910-2010) (°C)
A. Cape Otway	0.55	0.0096	-0.78	0.18	0.96
C. Omeo	0.57	0.0106	-0.64	0.42	1.06
D. Moruya					
F. Wagga					
G. Mildura					
K. Tibooburra					
L. Yamba					
N. Charleville					
O. Rockhampton					
P. Boulia					
Q. Normanton					
R. Cairns					

QUESTION:

_*In which of the twelve stations does the relationship between time and mean temperature anomaly most conform to a straight line (hint: look for the Station with the highest correlation coefficient and the least amount of scatter of anomalies about the line-of best fit)? What is the predicted average temperature change per century for this Station?*

10. Averaging temperature anomalies for whole regions.

One of the difficulties in attempting to combine the temperature time series from a number of stations to construct an '**average**' time series for a state, nation or indeed the whole globe is that Met Stations are not distributed evenly, nor randomly, across the landspace. They tend to be in clusters, with some regions data rich and others data poor.

Other difficulties include the facts that:

- Met Stations are located with respect to political boundaries and often measure and report differently across them
- while some met stations are located on the plains others partake of the thinner atmosphere of the mountains;
- the Earth consists not only of land but mainly of oceans – surface temperatures are measured very differently across the oceans than on the land;
- finally, the Earth is not flat but spherical.

Australia's Reference Climate Station Network
(*BOM, 2009 d)*

A gridded, spherical earth and its atmosphere
(BOM, 2009 f, p.35)

In this case study, we have adopted a simple 'flat-earth' model - which, nevertheless, goes by the rather imposing title of 'Thiessen Polygons' - to demonstrate how some of these issues are dealt with in combining met data to form State averages (see **Appendix 8** in the separate **Appendices**). On the next page, we compare the results of this analysis with those resulting from the 'Barnes successive correction technique' used by the Australian Bureau of Meteorology to produce digital analyses of temperature change on a regular latitude-longitude grid enabling 'area-weighted averages' for any region for which the user seeks knowledge.

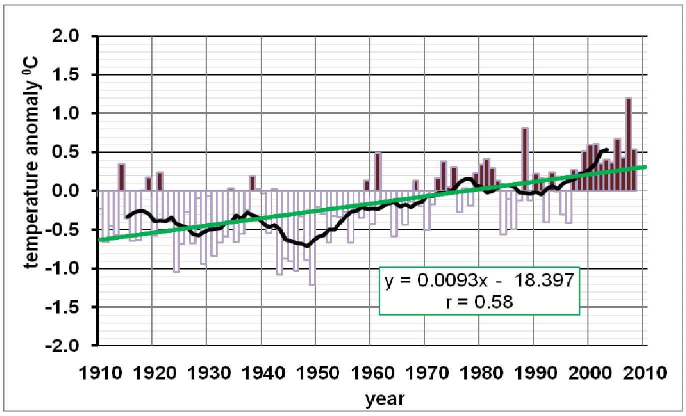
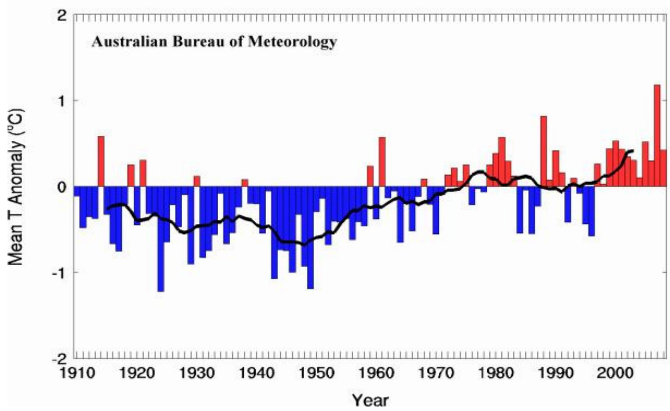
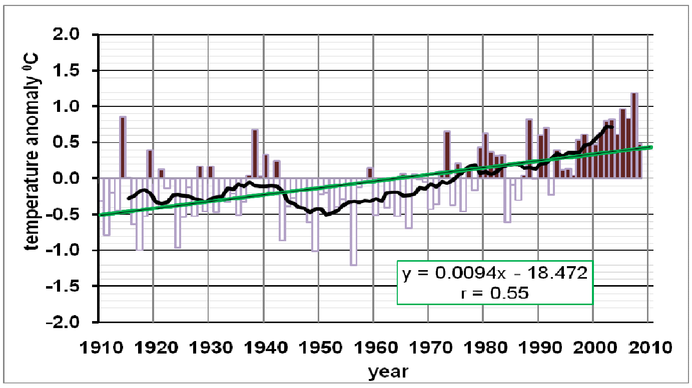
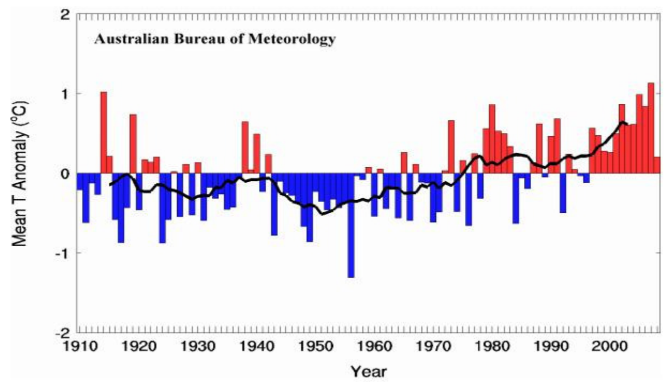
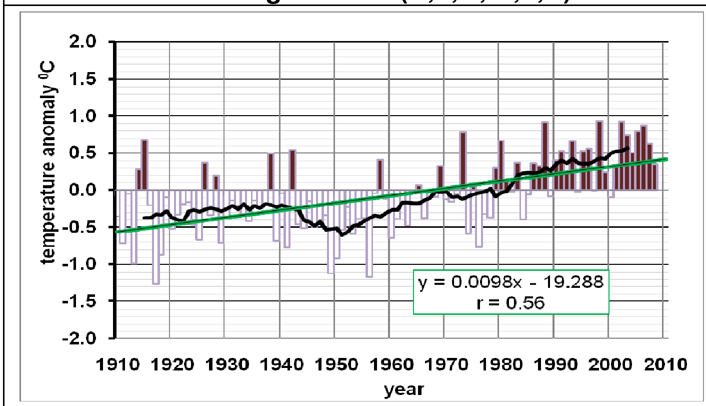
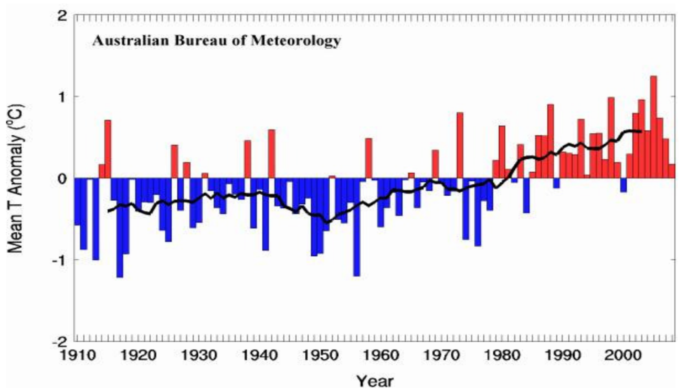
It is beyond the scope of this case-study to delve further into the complex issues involved in choosing between the wide variety of possible different area-averaging techniques for obtaining an objective, replicable and truthful estimate of global warming.

QUESTIONS:

1. *What would be the likely effect on the average temperature for a region of increasing the number of met stations in mountainous areas used in the estimate relative to the number in the plains?*
2. *What do you think would be the effect on the year-to-year variability of the average temperature for a region of including temperatures recorded over the ocean surface along with those recorded over the surface of the land? Explain your answer.*

11. Average temperature anomaly trends in Vic, NSW, QLD.

In the graphs below, the results of the Thiessen Polygons method (see **Appendix 8** in the separate **Appendices**) applied to the mean temperature anomalies of 12 rural stations distributed through the states of Victoria, NSW and Queensland are compared with the Bureau of Meteorology's published regional averages based on the Barnes gridded method applied to the whole High Quality land-based dataset (*BOM, 2009 c*).

'Thiessen Polygon' procedure	BOM's 'Grid-point Averaging' procedure
	
VIC - 4 contributing stations (A,C,F,G)	**VIC - a minimum of 12 contributing stations**
	
NSW - 6 contributing stations (D,F,G, K,L,N)	**NSW - a minimum of 18 contributing stations**
	
QLD – 7 contributing stations (K,L,N,O,P,Q,R)	**QLD - a minimum of 28 contributing stations**

Annual mean temperature anomalies are all calculated relative to the 1961-1990 average for each state. For the BOM data these are 14.1 °C for Victoria, 17.3 for NSW and 23.2 for Queensland.
The 11-year running averages for each time-series shown by black curves.

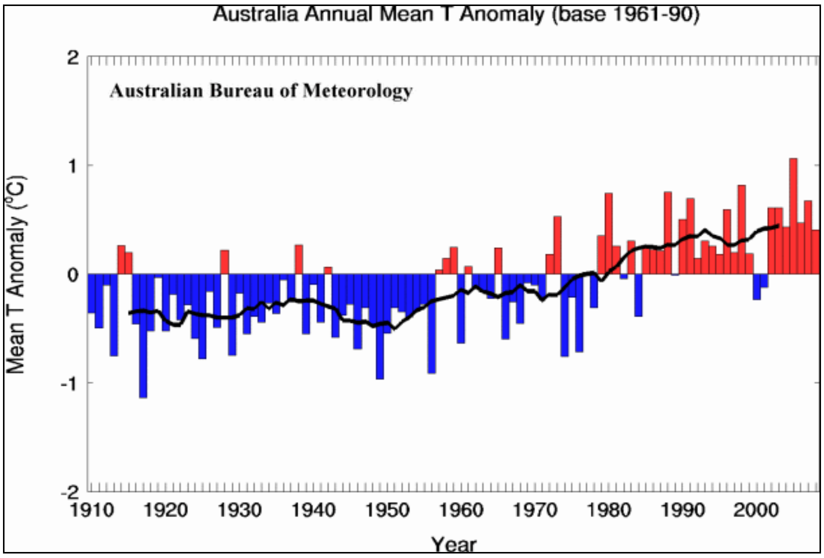
CASE STUDY: Global Warming – the forest from the trees

QUESTION:

*In your opinion, how **sensitive** is the trend in temperatures over the past century to observational errors at individual meteorological stations and to the particular objective methods used to compile the observations into regional trends? What does this suggest to you about the general trend in temperatures over the Australian landscape over the past century?*

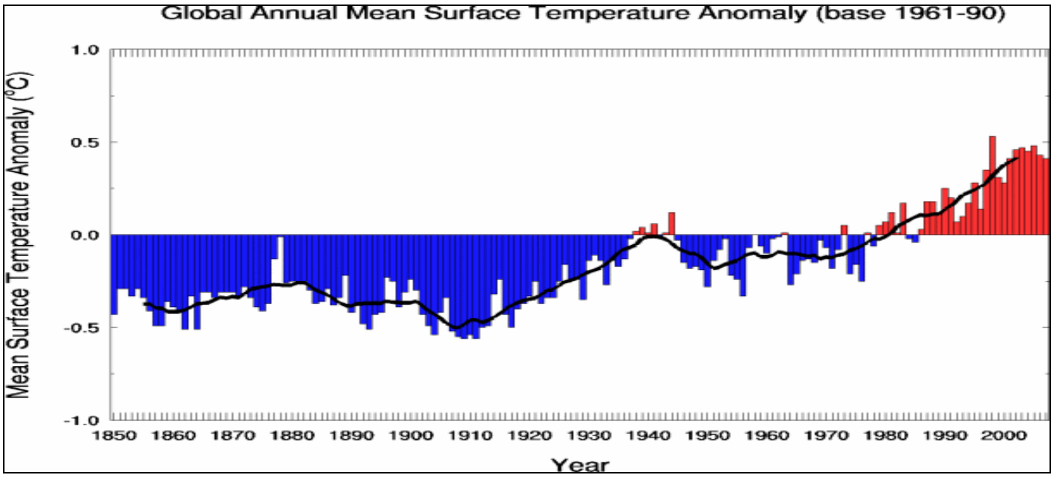
12. Global Warming?

The following is the graph of Annual Mean Temperature Anomalies for the whole of Australia compiled from 100 land-based met stations from 1910 to 2008 inclusive (*BOM, 2009 e*).



Note: The Australian Average Temperature for 1961 -1990 = 21.81 ^{0}C.

Compare the above graph for Australia with the graph below of the Global Mean Surface Temperature Anomaly compiled by the Climatic Research Unit (CRU) in the UK from land (over 4000 met stations) and sea surface temperature measurements over the period 1850 to 2007. The CRU's HadCRUT3v global gridded (5x5 degree resolution) temperature dataset is available from the *CRU (2009)* website. For a description of this dataset and a balanced discussion of the sources of uncertainty in interpretations from it see *Brohan et al. (2005)*.



Note: The Global Average Temperature for 1961-1990 = 13.97 ^{0}C

<u>ACTIVITY: Global Warming"?</u>

> *"Warming of the climate system is unequivocal ... The linear warming trend over the 50 years from 1956 to 2005 (0.13 °C per decade) is nearly twice that for the 100 years from 1906 to 2005...."*
> *(IPCC, 2007 p. 30).*

Write a 2-page essay to evaluate this statement.

13. Postscript – The Newcastle High Quality Dataset.

Earlier in this case study, on pages 7-9, our examination of the temperature data for the Newcastle Meteorological Station revealed a downward linear trend for the High Quality maximum temperature dataset (*BOM, 2009 c*). This was in contrast to the mainly upward trends in both the minimums and maximums that we have been observing for most stations.

Could it be that this dataset is in error; that the data adjustment process for Newcastle was over zealous and that the downward trend is thus a human artefact rather than reflective of the real atmospheric conditions between 1910 and 2008?

Examine the graph on page 7, consult **Appendix 8** in the separate **Appendices** document, and **see what you think.** Remember that despite the objective tests that are brought to bear on the question of discontinuities in the raw temperature data, there is always a significant subjective component in the decision to as to whether an adjustment is required and to what extent.

Use your judgement and see whether you think the Newcastle raw data should be revisited.

How important is this issue and for what purpose is it important? Could it be that Newcastle's heavy industrialisation in 20th Century had a local cooling effect on the maximums? – What could be the mechanism for such a cooling? **What do you think?**

Science can never be left up to robotic computers.

References

Note: The concepts underpinning this case study and most of its analysed data were drawn from the pages of the Australian Bureau of Meteorology (BOM) website (http://www.bom.gov.au/) and its supporting documents.

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CASE STUDY: Global Warming – the forest from the trees

Guidelines for use of the case study within the Stage 6 Advanced Mathematics Draft Syllabus Topic PMA6 - Data Analysis

Case Study		NSW Stage 6 Advanced Mathematics Draft Syllabus	
Page No.	**Page title**	**Page No.**	**Statement**
1-2	"*Global Warming -the forest from the trees*"	6	**2. Rationale** Mathematics is deeply embedded in modern society. From the numeracy skills required to manage personal finances, to making sense of data in various forms, to leading-edge technologies in the Sciences and Engineering **…** The need to interpret the large volumes of data made available through technology draws on skills in logical thought and in checking claims and assumptions in a systematic way **…**The thinking required to enhance further the power and usefulness of technology in real-world applications requires advanced mathematical training. **…**
5-6	"*4. Different ways of presenting the same data*" and supporting Excel® data files	70	PMA6.1: **Types of variables, measures of location and spread (variability), graphical and tabular representations of data**
7	"*5. Long term trends in temperature data from different sites"* and supporting appendices 4, 4(a), 4(b) and 4(c)	72-73	PMA6.2: **Correlation and regression** - constructing scatterplots by hand and with suitable technology - describing patterns (if any) in the scatterplot, and what this indicates about the relationship (or lack of relationship) between the variables - technology (spreadsheets, graphing calculators) should be used to create data displays and to calculate correlation coefficients and trendlines.
8-10	"*6. A graphical analysis of the long term temperature data for Newcastle*" and supporting appendices 5, 6 and 7	72-73	PMA6.2: **Correlation and regression** - constructing scatterplots by hand and with suitable technology - describing patterns (if any) in the scatterplot, and what this indicates about the relationship (or lack of relationship) between the variables - technology (spreadsheets, graphing calculators) should be used to create data displays and to calculate correlation coefficients and trendlines.
11-14	"*7. Comparing temperature anomalies*" and "*8. Calculation of the annual mean temperatures from the maxima and minima*" and "*9. Comparison of mean temp anomaly trends for selected rural stations*"	72-73	PMA6.2: **Correlation and regression** - describing patterns (if any) in the scatterplot, and what this indicates about the relationship (or lack of relationship) between the variables - using a line of best fit to interpolate - Technology (spreadsheets, graphing calculators) should be used to create data displays and to calculate correlation coefficients and trendlines.
15	"*10. Averaging temperature anomalies for whole regions*" and supporting appendix 8	68	**PMA6 Data Analysis** ***Outcomes addressed*** A student: PA1 provides reasoning to support conclusions appropriate to the context PA2 uses algebraic and graphical concepts in the solution of problems involving functions and coordinate geometry PA8 uses concepts and techniques from descriptive statistics to present and interpret data PA12 interprets and uses mathematical language.
16	"11. Average temperature anomaly trends in Vic, NSW, QLD"	68	**PMA6 Data Analysis** ***Outcomes addressed*** A student: PA1 provides reasoning to support conclusions appropriate to the context PA2 uses algebraic and graphical concepts in the solution of problems involving functions and coordinate geometry PA8 uses concepts and techniques from descriptive statistics to present and interpret data PA12 interprets and uses mathematical language.
17-18	"12. Global Warming?" and "13. Postscript – The Newcastle High Quality Dataset" and supporting appendix 9	13	**Objectives Knowledge, understanding and skills** **Students will develop the ability to:** • apply deductive reasoning, and use appropriate language, in the construction of proofs and mathematical arguments • interpret solutions to problems and communicate Mathematics in appropriate forms. **Values and attitudes** **Students will develop:** • appreciation of the scope, usefulness, power and elegance of Mathematics

Guidelines for use of the case study in other areas of the NSW curriculum; Stage 5 Science, Stage 5 Geography and Stage 6 Earth and Environmental Science.

Case Study		NSW Syllabus connections
Page No.	**Page title**	**Stage 5 Science, Stage 5 Geography, and Stage 6 Earth and Environmental Science**
1-2	"*Global Warming - the forest from the trees*"	**Science 5.19:** uses critical thinking skills in evaluating information and drawing conclusions **Geography Stage 5 Focus Area E1 Physical Geography:** climate, weather, climate change, analyse climate data from a variety of sources **Earth and Environmental Science Stage 6 P14:** draws valid conclusions from gathered data and information
3-4	"*Long term Temperature Records*"	**Geography Stage 5 Focus Area E1 Physical Geography:** climate, weather, climate change, analyse climate data from a variety of sources **Earth and Environmental Science Stage 6 P12:** discusses the validity and reliability of data gathered from first-hand investigations and secondary sources, **P13:** identifies appropriate terminology and reporting styles to communicate information and understanding
5-6	"*4. Different ways of presenting the same data*" and supporting Excel® data files	**Science 5.17:** explains trends, patterns and relationships in data and/or information from a variety of sources **Science 5.18:** presenting information **(e), (f)** **Geography 5.3:** selects and uses appropriate written, oral and graphic forms to communicate geographical information **Earth and Environmental Science Stage P13:** identifies appropriate terminology and reporting styles to communicate information and understanding
7	*"5. Long term trends in temperature data from different sites"* and supporting appendices 4, 4(a), 4(b) and 4(c)	**Science 5.18:** presenting information **(e), (f)** **Earth and Environmental Science Stage P13:** identifies appropriate terminology and reporting styles to communicate information and understanding
8-10	"*6. A graphical analysis of the long term temperature data for Newcastle*" and supporting appendices 5, 6 and 7	**Science 5.16 (c):** extract information from column graphs, histograms, divided bar and sector graphs, line graphs, composite graphs, flow diagrams, other texts and audio/visual resources **Geography 5.3:** selects and uses appropriate written, oral and graphic forms to communicate geographical information **Earth and Environmental Science Stage 6 P12:** discusses the validity and reliability of data gathered from first-hand investigations and secondary sources, **P13** identifies appropriate terminology and reporting styles to communicate information and understanding
11-14	"*7. Comparing temperature anomalies*" and "*8. Calculation of the annual mean temperatures from the maxima and minima*" and "*9. Comparison of mean temp anomaly trends for selected rural stations*"	**Science 5.17:** explains trends, patterns and relationships in data and/or information from a variety of sources **Earth and Environmental Science Stage 6 P12:** discusses the validity and reliability of data gathered from first-hand investigations and secondary sources, **P13:** identifies appropriate terminology and reporting styles to communicate information and understanding
15	"*10. Averaging temperature anomalies for whole regions*" and supporting appendix 8	**Earth and Environmental Science Stage 6 P12:** discusses the validity and reliability of data gathered from first-hand investigations and secondary sources,
16	*"11. Average temperature anomaly trends in Vic, NSW, QLD"*	**Science 5.19:** A student uses critical thinking skills in evaluating information and drawing conclusions. **Earth and Environmental Science Stage 6 P14:** draws valid conclusions from gathered data and information
17	*"12. Global Warming?"*	**Earth and Environmental Science Stage 6 P14:** draws valid conclusions from gathered data and information