Taking Australia's temperature?

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The Australian Bureau of Meteorology provides two Australia wide temperature data sets that are the results of extensive adjustments. This analysis looks at three possible problems in the procedures that have been followed to arrive at the adjusted temperature time series. Analysis shows a systematic shift by using daily minimum and maximum temperatures and more importantly a location dependant distortion where averaging of minimum and maximum temperatures does not always represent the mean for the day. Further the problems resulting from the urban heat island effect have been ignored. The final conclusion is that the BOM temperature time series need to be re-worked. This analysis may have relevance to temperature analysis elsewhere.

1. Introduction

The Australian Bureau of Meteorology (BOM) provides two Australia wide temperature data sets that are the results of extensive adjustments (ACORN-Sat and High Quality). This analysis looks at possible problems in the procedures that have been followed to arrive at the adjusted temperature time series.

Three possible sources of systematic error will be examined in this paper:

- Is there a systematic error from using minimum and maximum temperatures as there are transitory temperature variations of only a matter of minutes?
- Is there a location dependant difference when averaging minimum and maximum readings compared to a mean value calculated from readings throughout a 24 hour day? and
- Is there an observable urban heat island effect and has it been properly treated in adjustments to the Australian temperatures?

The BOM on its website (http://www.bom.gov.au/australia/index.shtml) provides an extensive data base including daily minimum and maximum temperatures and temperatures recorded every 30 minutes through the 24 hour day at a large number of locations. The average of the daily minimum and maximum temperatures are used as the basis for the adjusted mean temperature series.

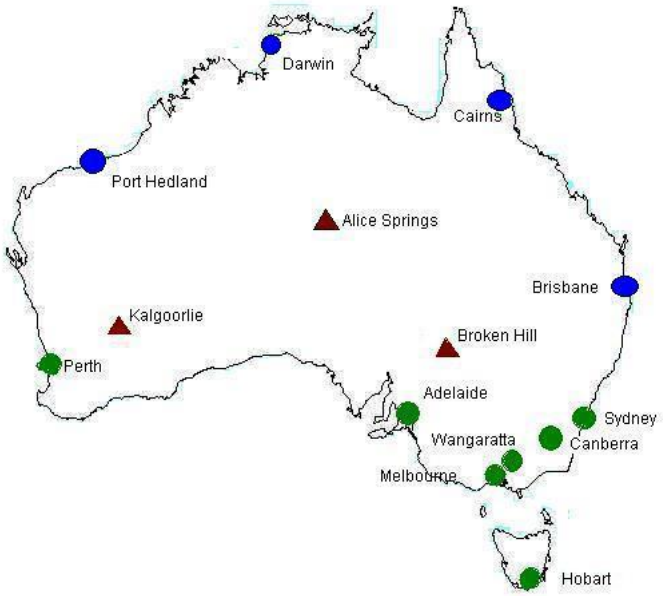


Figure 1: *Locations for temperature measurements divided into north (**blue**), central continental (**brown**) and south (**green**) regions.*

14 locations around Australia have been selected for analysis. The locations are shown in Figure 1. Data has been accumulated for up to 100 days from March to June 2013 along with 4 of these locations having data for June and December 2012. For each day 48 temperature measurements spaced 30 minutes apart and the minimum and maximum temperature were recorded from automatic weather stations. Figure 2 shows the average of the 30 minute frequency readings for 101 days from March to June for Cairns and Alice Springs. The figures show errors on the mean, not standard deviations. The data for all 14 sites divided into north, central continental and south regions are shown in the Appendix.

The measurements at Alice Springs and Cairns are a perfect illustration that the mean is not always the average of minimum and maximum temperatures when calculated from 30 minute frequency readings (Figure 2). The average of the minimum and maximum temperatures for Alice Springs is 0.01 +/- 0.06 above the average of all 48 30 minute readings while for Cairns it is 0.55 +/- 0.04 above the average of all 48 30 minute readings.

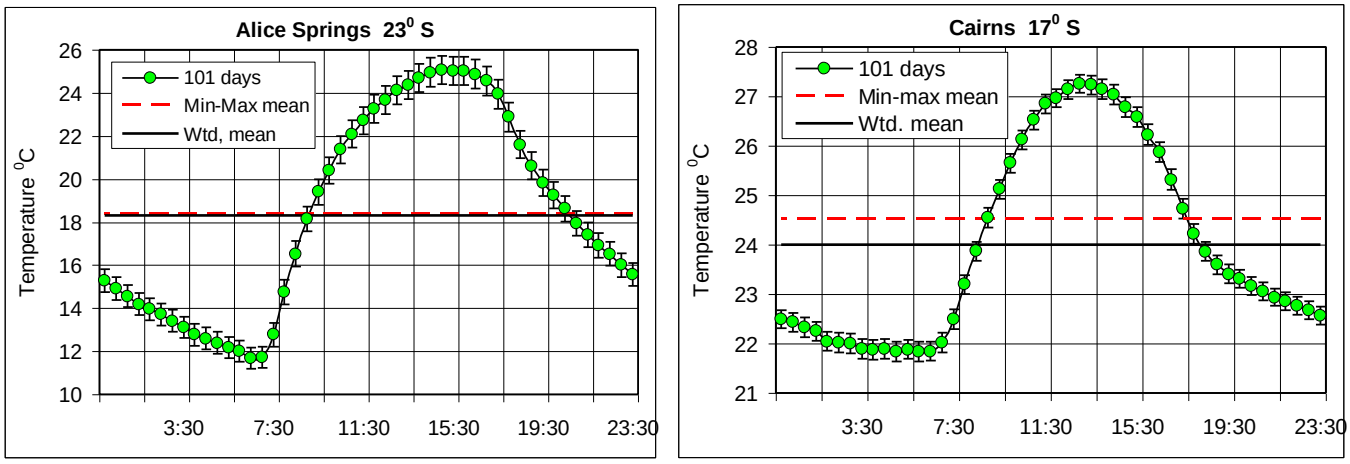


Figure 2: *Temperatures measured at 30 minute intervals through a 24 hour day. The sample is for 101 days from March to June and the standard errors of the mean not the standard deviations are shown. The difference for (Tmin + Tmax)/2 - Tmean is 0.01 +/- 0.06 for Alice Springs and 0.55 +/- 0.04 for Cairns. Note that the minimum and maximum temperatures are taken from the 30 minute spaced readings.*

2. Systematic errors from the minimum and maximum temperature recordings

The minimum and maximum temperatures that are reported by the BOM are a result of readings from automatic weather stations. This gives a record of the minimum temperature for the day, generally occurring between midnight and sunrise, between 6.00 am and 8.00 am local time. This can be seen in Figure 2. The maximum temperature generally occurs in the afternoon.

The systematic behaviour of the minimum and maximum temperatures and the 30 minute frequency readings can be examined by looking at Tmin(24 hours) – Tmin(30 minute frequency) and Tmax(24 hours) – Tmax(30 minute frequency). The results are shown in Figure 3. There are obvious systematic excursions with the 24 hour minimum readings being equal to or below the 30 minute minimum and the 24 hour maximum readings being equal to or above the 30 minute maximum readings.

However these results in Figure 3 are not surprising as temperatures will vary within a 30 minute interval. Further, there is more variation in the maximum temperature that may well be due to gusts of warm air whereas the minimum is clearly not subject to cold winds to the same extent. Note that there are a number of large differences of as much as 2 ^{0}C and a few measurements that may not have had a quality control check.

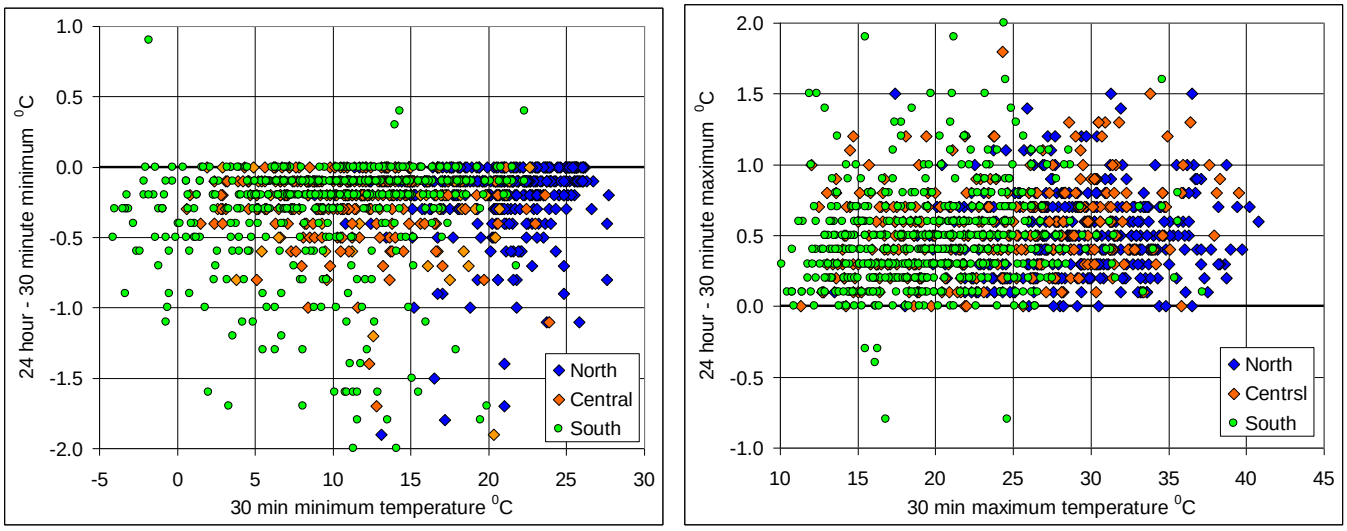


Figure 3: *Minimum or maximum temperature differences for the 24 hour and 30 minute measurements as a function of the maximum or minimum 30 minute temperature measurement.*

There is evidence of a systematic error in Figure 3 that is more obvious in Figure 4 and detailed in Table 1.

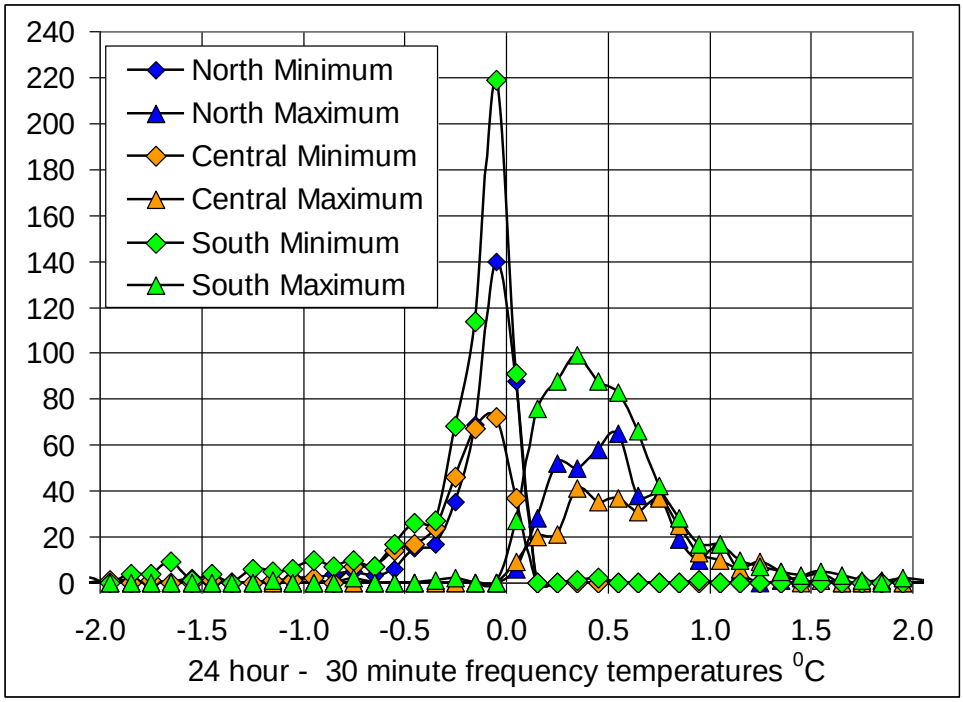


Figure 4: *Maximum or minimum temperature differences for 24 hour thermometer temperatures and 30 minute temperature measurements*

This bias is not unexpected as an extreme might occur in the 30 minute interval between regular measurements.

Table 1: 24 hour minimum and maximum readings - 30 minute frequency readings

	North		Central continental		South	
Temperature extremes	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax
Number	370	386	291	299	596	656
24 hour value – 30 minute value	-0.15	0.47	-0.25	0.54	-0.22	0.44
Standard Deviation	0.14	0.25	0.20	0.30	0.22	0.29
Error	0.01	0.01	0.01	0.02	0.01	0.01

The effect that these systematic errors have on the mean temperature is given in Table 2 and shown in Figure 5.

Table 2: (Tmin + Tmax)/2 difference for 24 hour readings - 30 minute frequency readings

	Latitude ^{0}S	Longitude ^{0}E	24 hour value – 30 minute value ^{0}C	+/- Error ^{0}C
North				
Darwin	12	131	0.17	0.02
Cairns	17	146	0.12	0.02
Port Hedland	20	119	0.14	0.02
Brisbane	27	153	0.16	0.02
Mean difference			**0.15**	**0.01**
Central continental				
Alice Springs	24	134	0.18	0.02
Kalgoorlie	31	121	0.11	0.02
Broken Hill	32	142	0.16	0.02
Mean difference			**0.14**	**0.01**
South				
Perth	32	116	0.14	0.02
Sydney	34	151	0.20	0.02
Adelaide	34.9	139	0.09	0.02
Canberra	35.3	149	0.10	0.03
Wangaratta	36	146	0.09	0.02
Melbourne	38	145	0.11	0.02
Hobart	43	147	0.08	0.02
Mean difference			**0.11**	**0.01**

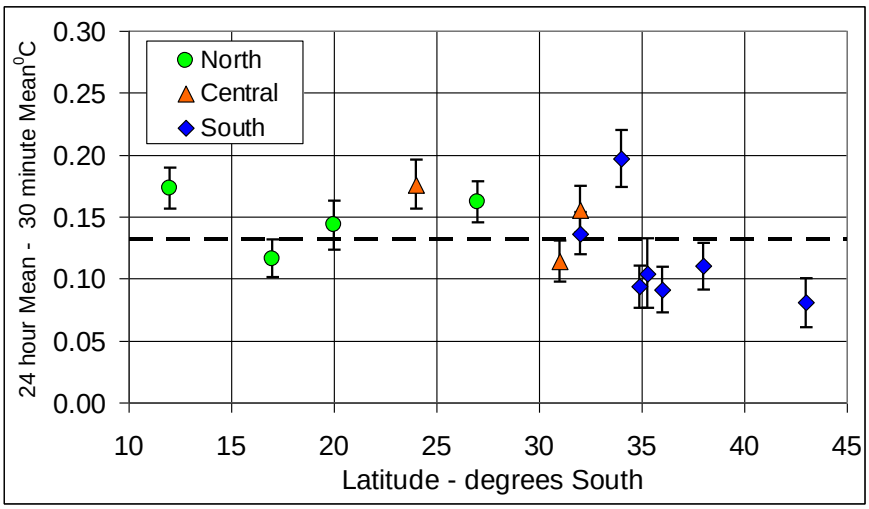


Figure 5*: Location differences of (Tmin + Tmax)/2 for 24 hour readings - 30 minute frequency readings. The overall difference is 0.13 +/- 0.01 ^{0}C.*

The average systematic error from the use of 24 hour thermometer readings is an increase in mean temperature of 0.13 +/- 0.01 ^{0}C.

This systematic error is a consequence of the "one-way" temperature recording where, for example, a 10 minute 1^{0}C fluctuation increasing temperature would give a 0.5^{0}C increase in the average of minimum and maximum "mean" temperature rather than the properly weighted 0.01^{0}C change.

3. A: Comparison of averaging minimum and maximum temperatures and the mean value

A comparison of the average of the mean of 48 measurements throughout the day with the minimum and maximum temperatures from the 48 measurements has been made at 14 locations using 30 minute frequency data. The results of the analysis of mean temperatures are presented in Table 3 and Figure 6. The analysis shows an overestimate of the mean temperature from averaging minimum and maximum temperatures. The variations in temperature difference are a function of latitude and longitude. For this analysis the locations

have been grouped as north, central continental and south. The map of Australia (Figure 1) shows the locations selected for the temperature analysis.

Table 3: Temperature differences derived from 30 minute frequency readings.

	Latitude ^{0}S	Longitude ^{0}E	Number of days	(Tmin & Tmax)/2 – Tmean ^{0}C	
				Difference	+/- Error
North					
Darwin	12	131	101	0.54	0.04
Cairns	17	146	101	0.55	0.04
Port Hedland	20	119	101	0.58	0.05
Brisbane	27	153	101	0.68	0.05
Mean			**404**	**0.58**	**0.02**
Central continental					
Alice Springs	24	134	101	0.01	0.06
Kalgoorlie	31	121	100	0.33	0.07
Broken Hill	32	142	101	0.11	0.07
Mean			**302**	**0.14**	**0.04**
South					
Perth	32	116	101	0.51	0.06
Sydney	34	151	109	0.60	0.06
Adelaide	34.9	139	62	0.42	0.06
Canberra	35.3	149	98	0.55	0.07
Wangaratta	36	146	101	0.67	0.07
Melbourne	38	145	107	0.42	0.06
Hobart	43	147	101	0.57	0.05
Mean			**679**	**0.53**	**0.02**

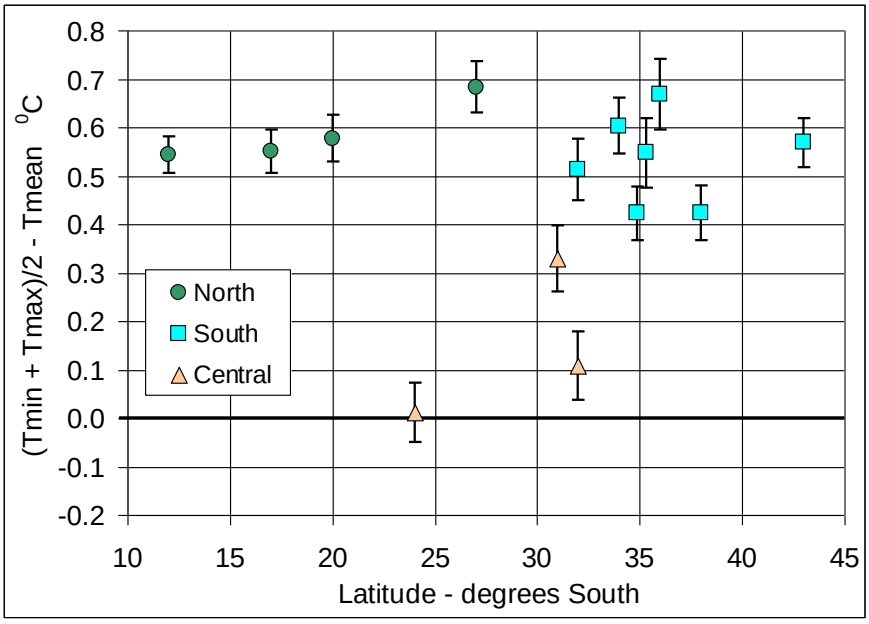


Figure 6: *Temperature differences of (Tmin + Tmax)/2 - Tmean, calculated from 30 minute frequency readings.*

The data and analysis covers up to 100 days of 48 temperature measurements made every 30 minutes. The results indicate significant systematic distortion of the reported mean temperatures.

3 B: Variations throughout the year

Variations in the difference of average of minimum and maximum temperatures from mean temperatures might be expected to occur as the daylight hours are longer in summer than in winter with the extremes being in June and December.

Data for June and December 2012 has been accessed (courtesy of Andrew Miskelly) for Darwin, Alice Springs, Melbourne and Hobart. The analysis results are given in Table 5.

Table 5: Temperature differences comparing the average of Tmin and Tmax with a 24 hour mean.

			Mean (30 minute Tmin & Tmax) – Mean (all 30 minute T) ^{0}C			
	Latitude ^{0}S	Longitude ^{0}E	June 2012 30 days		December 2012 31 days	
			Difference	+/- Error	Difference	+/- Error
Darwin	12	131	0.74	0.08	0.59	0.12
Alice Springs	24	134	0.20	0.08	-0.18	0.17
Melbourne	38	145	0.37	0.09	0.71	0.22
Hobart	43	147	0.34	0.10	0.82	0.15

Two examples of daylight extremes for June and December are shown in Figure 7. In Hobart the range is 9 and 15 hours of daylight and in Darwin 11 and 13 hours of daylight. The sunrise and sunset times are shown in Figure 7.

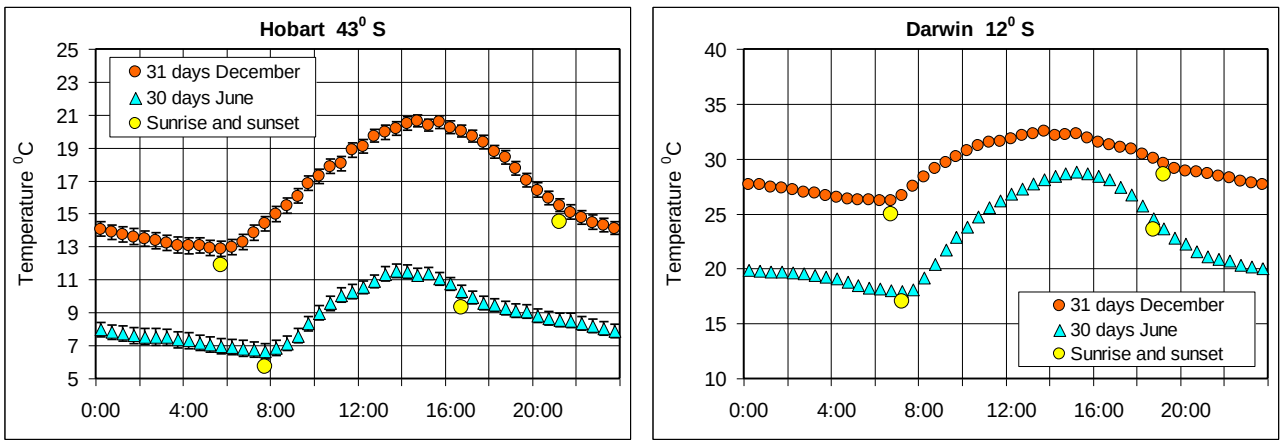


Figure 7: *Temperatures measured at 30 minute intervals through a 24 hour day for June and December 2012. The uncertainties are standard errors of the mean not the standard deviations of the measurements. The yellow points mark sunrise and sunset.*

The results in Table 5 show that the differences of the average of Tmin and Tmax and a 24 hour mean is independent of the length of daylight hours for Darwin and Alice Springs. However there may be a significant monthly variation for Melbourne and Hobart in the south. This can be seen in Figure 8 that shows all the data collected for 2012 and 2013.

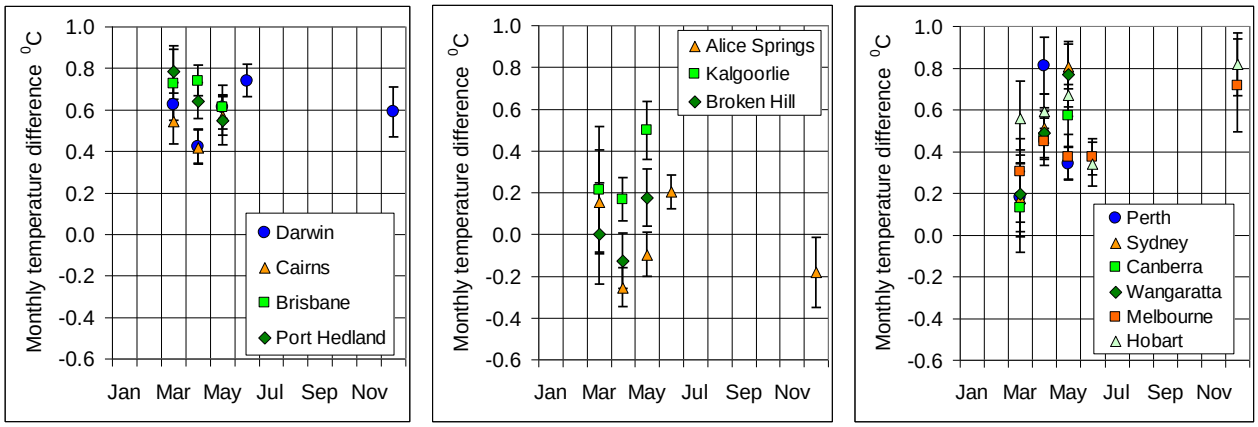


Figure 8: *Monthly temperature differences comparing the average of Tmin and Tmax with a 24 hour mean using the 30 minute temperature measurements.*

These results may apply to the other locations analysed. This is indicated by looking at the variation in temperatures throughout the year.

Figure 9 shows the average monthly temperatures and Table 6 intra year temperature differences for the north, central and south regions derived from the BOM monthly minimum and maximum temperatures for 2012.

Table 6 Temperature variations for 2012 and 2013

Region	2012 maximum – minimum monthly temperatures ^{0}C	Mean (30 minute Tmin & Tmax) – Mean (all 30 minute T) ^{0}C
North	8.7 +/- 3.4	0.61 +/- 0.02
Central	17.4 +/- 2.4	0.05 +/- 0.04
South	12.6 +/- 2.4	0.48 +/- 0.02

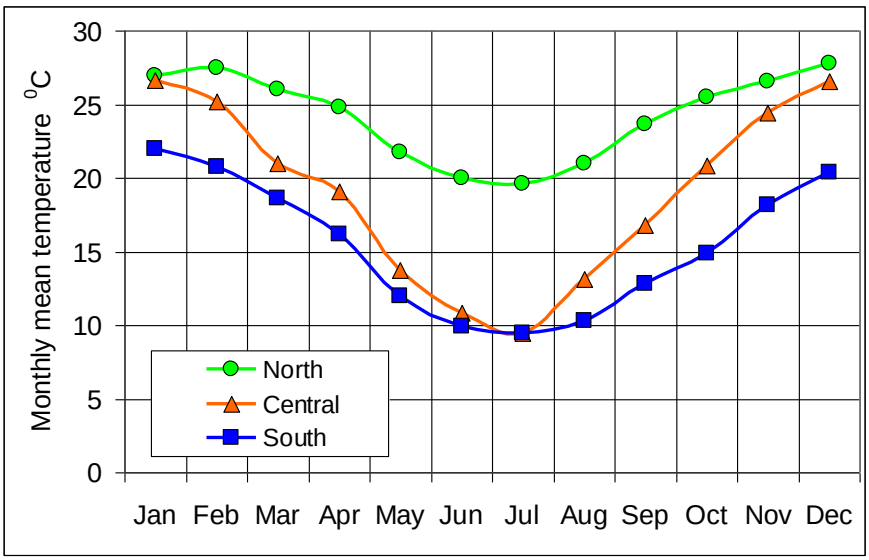


Figure 9: *Monthly mean temperatures derived from the 2012 BOM minimum and maximum temperatures.*

The north and south regions, with higher humidity, have smaller temperature changes than that found in the continental centre (Figure 10). Kalgoorlie however lies in what must be an intermediate region between the central and north and south regions. This can be seen in Figure 10 where Alice Springs and Broken Hill are located in a central minimum humidity area.

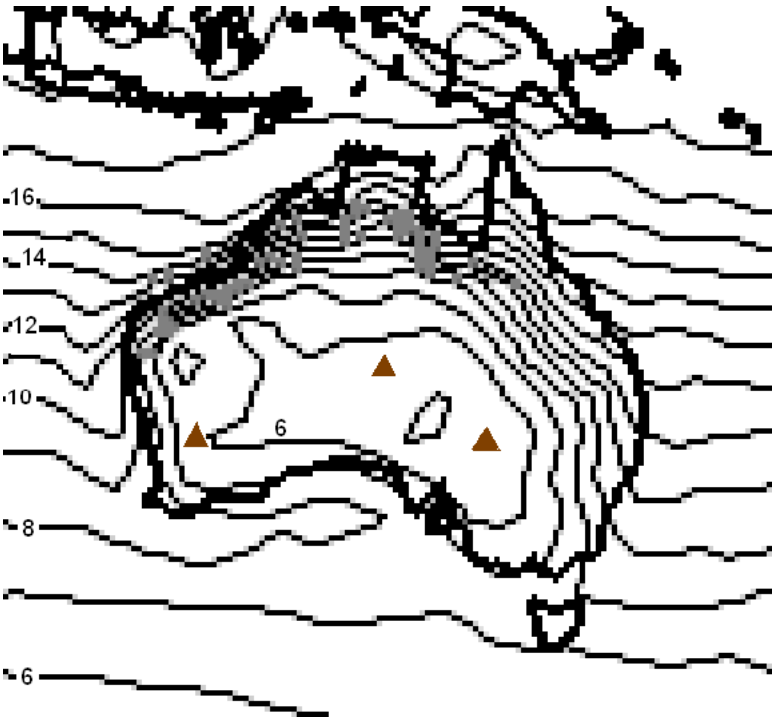


Figure 10: *Contours of annual average specific humidity in gm/kg from 1960 to 2010 (source NCAR). The triangles are the locations (from West to East) of Kalgoorlie, Alice Springs and Broken Hill.*

On the assumption that the measured behaviour in 2012 is applicable to all the other locations analysed, then the results are summarized in Table 6 and Figure 11.

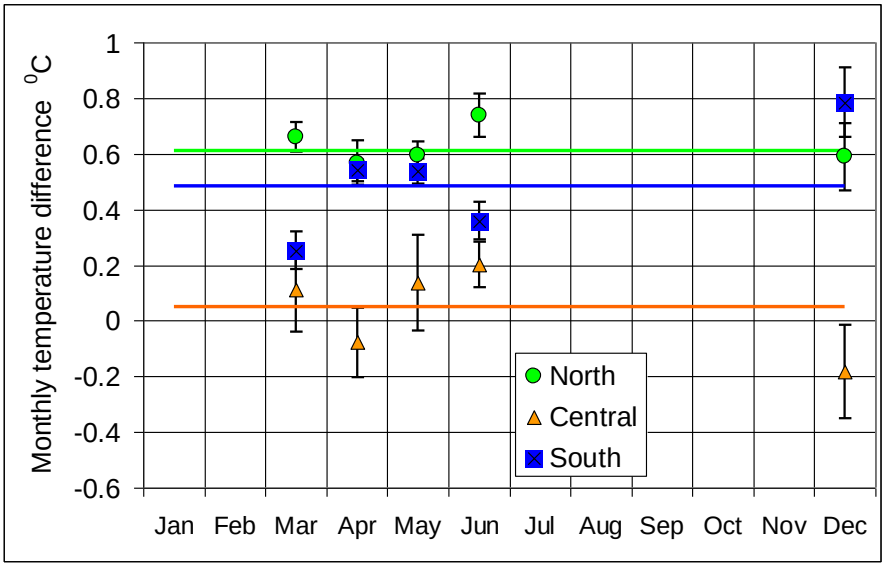


Figure 11: *Temperature differences comparing the average of 24 hour Tmin and Tmax with a 24 hour mean.*

There are systematic errors throughout the year for temperatures measured within Australia.

4. Urban Heat Island Effects

The BOM time series for temperatures do not appear to be any consider the urban heat island effect. In fact the reverse seems to be the case.

An illustration of this (Figure 12) is a comparison of the measurements made at the Melbourne office site of the Bureau of Meteorology with the temperature time series at Laverton some 18 kilometres away. Laverton lies on the same flat plain as the city of Melbourne.

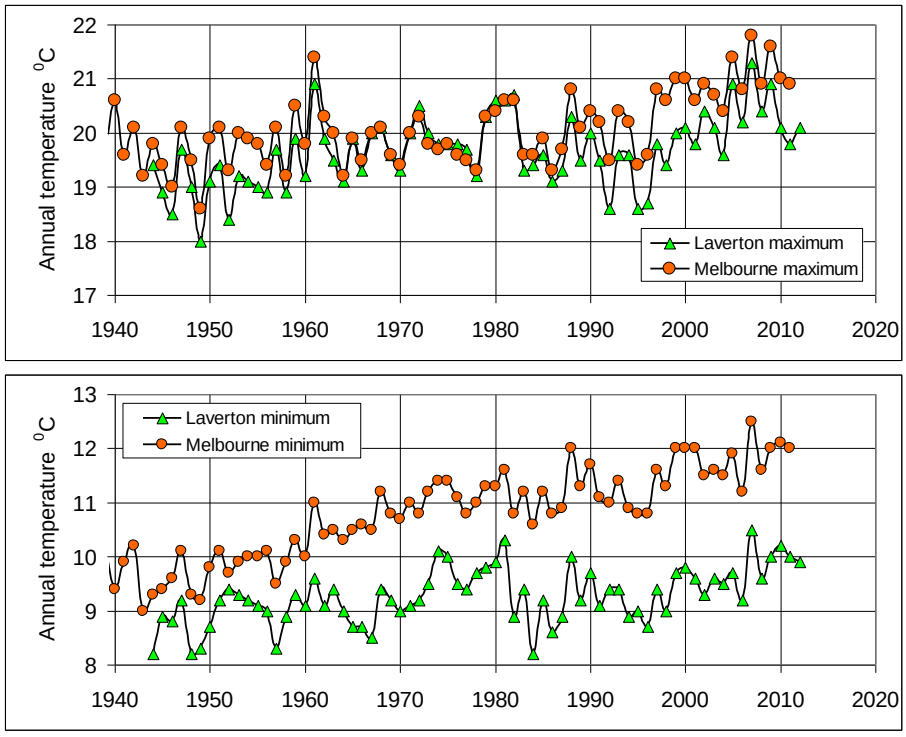


Figure 12: Top) *Maximum and* ***Bottom)*** *minimum annual average temperatures for Laverton airport and the BOM Melbourne office*

The maximum temperatures at the locations differ by an average of 0.4^0C but there is no statistically significant difference in the trend from 1944 to 2011. The two temperature series are strongly correlated with a correlation coefficient of 85% and are a reflection of the constancy of the sun's warming in the mid afternoons

On the other hand for the minimum temperature at Laverton, there is a very significant difference to the Melbourne record in temperature and trend from 1944 to 2011. While there is a modest temperature increase at Laverton of 0.13 +/- 0.03^0C per decade the increase in Melbourne is 0.35 +/- 0.02^0C per decade. There is still a strong correlation with a 77% correlation coefficient but a significant difference in temperature trends.

However the BOM treatment can be seen in the temperature increases made to the original Melbourne observations (Figure13).

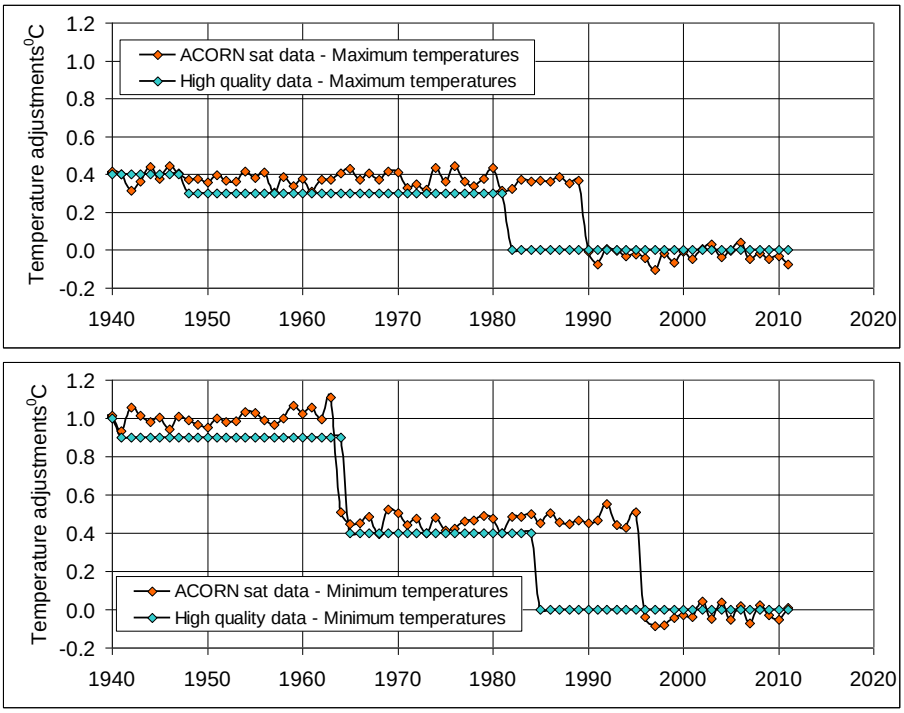


Figure 13: Top) *Maximum and* ***Bottom)*** *minimum BOM adjustments for the BOM Melbourne office temperatures*

The minimum temperatures occur just at or before sunrise when the only sources of heat are carried in the atmosphere or are supplied by land and buildings close to the recording thermometers. The BOM documents the changes in the immediate surroundings of their site at the corner of Victoria and LaTrobe Streets in Melbourne but the adjustment figure above for the minimum temperature shows no hint of urban heating coming from the changes to the surroundings- quite the reverse.

Heat island effects are well known and there is extensive literature even including studies of Melbourne. A good illustration of this effect comes from a paper *Environmental Effects of Increased Carbon Dioxide* by Robinson, Robinson and Soon. (http://www.jpands.org/vol12no3/robinson.pdf)

5. Discussion

There are two systematic distortions that exist in calling the average of the daily minimum and maximum temperatures the mean temperature.

First there is an instrumental systematic shift that arises from the short term, less than 30 minutes, fluctuations in temperature that increase the maximum temperature and decrease the minimum temperature. This shift is present on all sites and is an overestimate of the mean temperature by 0.15 ^{0}C.

Second, there is a more significant shift that arises from the assumption that the mean temperature is the average of the maximum and minimum temperatures. This assumption is clearly wrong. In general there is an overestimate of the temperature. Further the size of the error is a function of location that ranges from 0.0 ^{0}C to 0.8 ^{0}C.

Finally, the presence of the urban heat island effect has been ignored in the BOM High Quality and ACORN sat data sets. Adjustments have been made to the temperature time series that are the opposite of what might be expected. This can be seen by looking at the minimum temperature time series. Indeed the systematic errors found in this analysis are of the same magnitude but in opposition to the BOM adjustments.

6. Conclusion

There is clearly a need to re-examine the reported Australian temperature record in the light of this analysis.

It is likely that the surface temperature for some half of the Australian continent has been overestimated by of order 0.6^{0}C. This can presumably be corrected.

Regional computer models of Australia initialized from the BOM adjusted temperature data will have distortions from overestimated temperatures north and south of the centre of the continent. This will distort the evolving temperatures over Australia or any region within the continent.

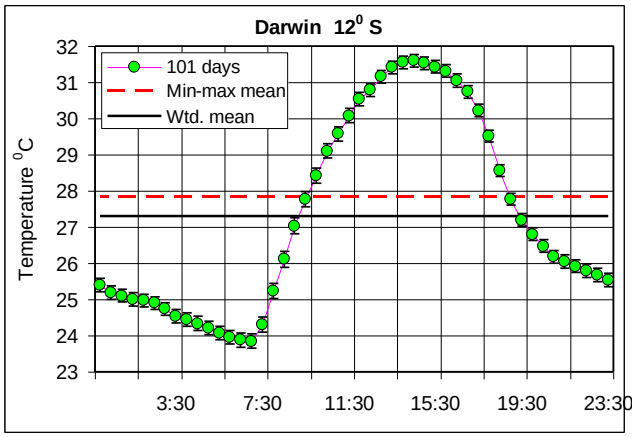
More generally if the mean land temperatures are overstated from averaging minimum and maximum temperatures and the air temperatures over the oceans are mean values obtained in a quite different manner then the blending of the two data sets creates a systematic distortion.

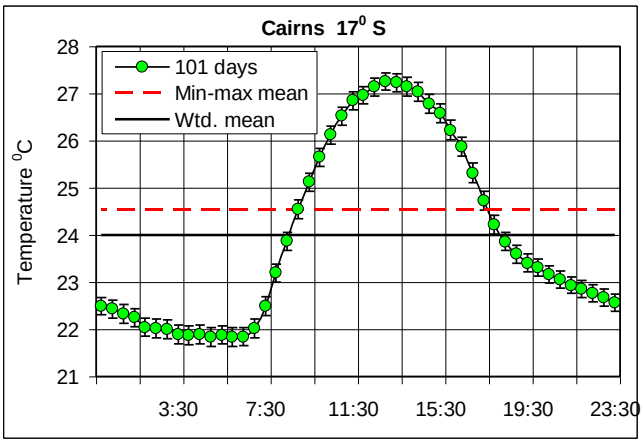
Further regional distortions discussed in this analysis may well be common to the estimation of land temperatures in other countries and in turn give rise to changes in global climate models estimates of temperature.

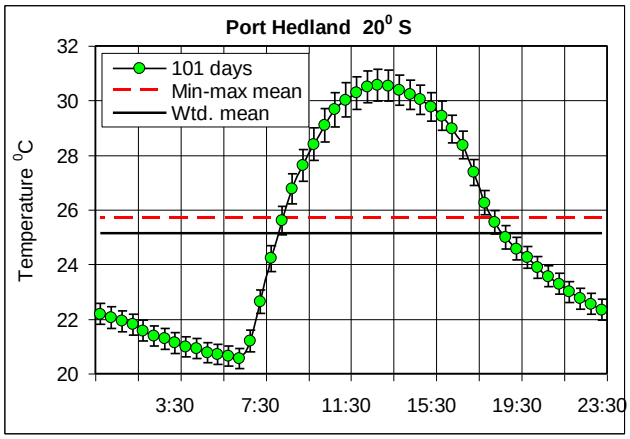
Appendix

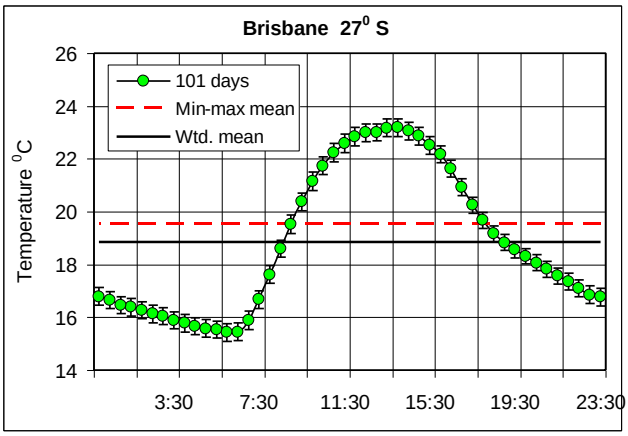
Selected locations show the average of the 30 minute intervals for over 43 days from 18th March to 30th April. The figures show local times and errors on the mean, not standard deviations.

North	Latitude ^{0}S	Longitude ^{0}E	Number of days	**(Tmin & Tmax)/2 – Tmean ^{0}C**
Darwin	12	131	101	0.54 +/- 0.04
Cairns	17	146	101	0.55 +/- 0.04
Port Hedland	20	119	101	0.58 +/- 0.05
Brisbane	27	153	101	0.68 +/- 0.05

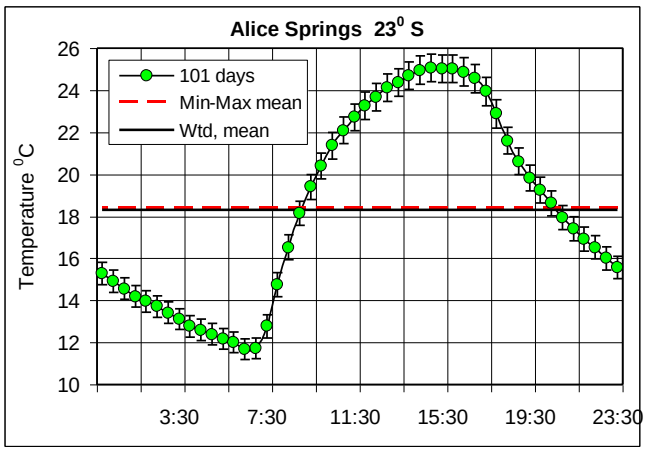


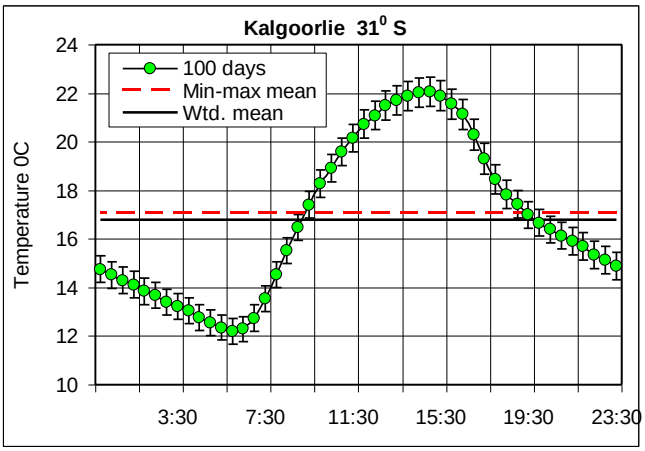


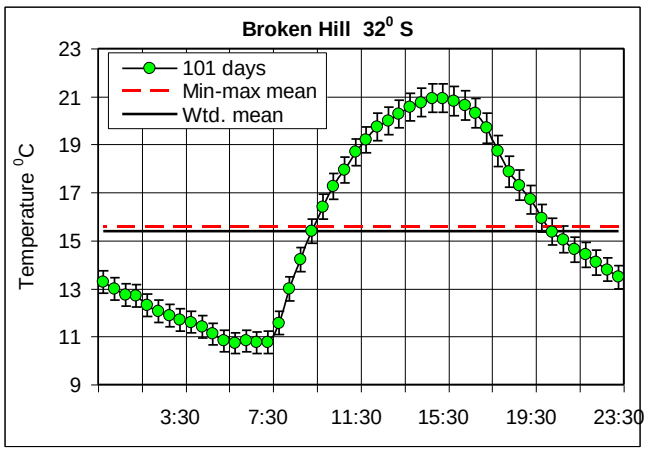




Central	Latitude ^{0}S	Longitude ^{0}E	Number of days	(Tmin & Tmax)/2 – Tmean ^{0}C
Alice Springs	24	134	101	0.01 +/- 0.06
Kalgoorlie	31	121	100	0.33 +/- 0.07
Broken Hill	32	142	101	0.11 +/- 0.07







South	Latitude ^{0}S	Longitude ^{0}E	Number of days	(Tmin & Tmax)/2 – Tmean ^{0}C
Perth	32	116	101	0.51 +/- 0.06
Sydney	34	151	109	0.60 +/- 0.06
Adelaide	34.9	139	62	0.42 +/- 0.06
Canberra	35.3	149	98	0.55 +/- 0.07
Wangaratta	36	146	101	0.67 +/- 0.07
Melbourne	38	145	107	0.42 +/- 0.06
Hobart	43	147	101	0.57 +/- 0.05