Projected changes in temperature and heating degree-days for Melbourne, 2003-2007

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A report for GasNet

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Executive summary

GasNet is a gas supply company operating in Victoria. Gas demand was significantly lower in 1999 and 2001 due to exceptionally warm winters. GasNet asked CSIRO to make an investigation of Melbourne temperature trends, and to project the underlying trend for 2003-2007 both in terms of average temperature and an index of demand called heating degree-days (HDD). We have estimated a range of trends that allow for warming due to enhancement of the greenhouse effect and increased urbanisation.

Melbourne's mean temperature has increased from 1950 to 2000 by about 1.0°C. Maximum temperature has increased by 0.35°C and the minimum has increased by 1.6°C. Contributions to this warming include a regional (non-urban) warming trend, which may be related to enhanced greenhouse climate change, and a residual warming trend partly due to increasing urbanisation.

Climate models indicate a warming of 0.03 to 0.20°C for the Melbourne region by the year 2007 relative to 2000 due to the enhanced greenhouse effect. If the recent rate of rise in minimum temperature due to increased urbanisation continues, then the greenhouse plus urbanisation warming is 0.09 to 0.26°C by 2007.

In order to compute HDD, projected warming needs to be added to a baseline temperature for the year 2000. This baseline is 15.88°C with a range of 15.68 to 16.09°C. Allowing for projected greenhouse and urbanisation warming gives a range of 15.96 to 16.13ºC by 2007 relative to the mid-point of the baseline in 2000, and a range of 15.76 to 16.35ºC allowing for baseline uncertainty.

The baseline HDD for the year 2000 is 1175 with a range of 1125 to 1227. Allowing for projected greenhouse and urbanisation warming gives a range of 1111 to 1154 by 2007 relative to the mid-point of the baseline in 2000, and a range of 1061 to 1205 allowing for baseline uncertainty. The midpoint in 2007 is 1132, which is very close to that based on simple extrapolation of the linear trend from 1965-2000.

1. Introduction

GasNet is a gas supply company operating in Victoria. It supplies gas to Melbourne, which corresponds to about 85% of total Victorian demand. VENCorp, the independent forecaster for the gas industry, recently concluded that a significant warming trend has affected Melbourne since 1950. On this basis they believe that the gas demand forecast for the period 2003-2007 should be amended to a value below the average of the past 20 years.

GasNet asked CSIRO to make a more detailed investigation of Melbourne temperature trends, and to project the underlying temperature trend for 2003-2007. They specified that the projection should include greenhouse warming, urbanisation effects and other climatic factors. They also wanted this to be converted into a gas demand projection, expressed in units of heating degree-days (HDD: the annual accumulation of daily mean temperatures below 18.0°C).

2. Temperature data

Quality controlled daily maximum and minimum temperature data used in this report were provided by the National Climate Centre (NCC) of the Bureau of Meteorology. The data for the Melbourne weather station covered the period 1860 to 2000. In addition, monthly-average temperatures on a grid covering Australia (resolution = 100 km) were also provided by NCC for the period 1950 to 2000. This gridded data set is based on rural observations only, and therefore excludes urbanisation effects on temperature in major cities.

3. Method

Our analysis of trends in Melbourne temperature has been split into two tasks that include the effects of natural variability, greenhouse warming and urbanisation.

1. Assess trends in Victoria-wide temperature from 1950-2000 based on the rural gridded data set. This tells us the component of broad-scale temperature variations due to natural variability and greenhouse warming, excluding urbanisation effects.
2. From the rural gridded data set, extract data for the grid-point nearest to Melbourne. This grid-point has no urban influence since it is interpolated from surrounding rural sites, so it effectively gives us a non-urbanised Melbourne temperature record. Comparison of the 1950-2000 grid-point data for Melbourne with the data from the Melbourne weather station tells us the component of the Melbourne trend due to urbanisation.

In order to project Melbourne temperatures for 2003-2007, we need to estimate the effect of greenhouse warming and urbanisation, assuming no change in natural temperature variability (which is not easily predictable). This is done as follows:

1. Define the baseline temperature for the year 2000 for projecting temperatures due to greenhouse warming and urbanisation
2. Estimate the range of potential greenhouse warming for 2003-2007 based on results published by the Intergovernmental Panel on Climate Change (IPCC, 2001) and CSIRO's (2001) regional warming projections for Australia
3. Include the urbanisation effect on temperature for 2003 to 2007 as estimated from the historical record
4. Convert the projected temperature trends to HDD trends.

4. Observed temperature changes

According to the Bureau of Meteorology, the Australian average temperature from 1950 to 2000 increased by 0.85ºC. The average maximum increased by 0.63ºC while the average minimum increased 1.05ºC. Trends in the number of extreme temperatures have been investigated by Collins *et al*. (2000) from 1957 to 1996. They defined hot days with maximum temperatures over 35ºC, cold nights with minimum values below 5ºC, cold days with maximum temperatures below 15ºC and hot nights with minimum values above 20ºC. The annual number of hot days and nights has increased by 0.16 and 0.26 days per year, respectively. The annual number of cold days and nights has decreased by 0.12 and 0.24 days per year, respectively. For areas affected by frost, Collins *et al*. (2000) found that the annual number of frost days declined by an average of 5.6 from 1957 to 1996 and the average length of the frost season shortened by around 24 days.

4.1 Victorian temperature changes

According to the Bureau of Meteorology, the Victorian warming trends are slightly lower than the all-Australian trends. From 1950-2000, Victorian average maximum temperature increased by 0.53ºC, average minimum temperature increased by 0.33ºC and the state-wide mean temperature increased by 0.43ºC (Figure 1). This is a measure of regional-scale temperature variations due to natural variability and possible greenhouse warming, excluding urbanisation effects. Unlike the general pattern for Australia, Victorian maximum temperatures have risen faster than minimum temperatures.

4.2 Melbourne temperature changes

Maximum, minimum and mean temperatures at the Melbourne weather station have increased since 1860 (Figure 2). Maximum temperatures increased steadily from about 1890. Minimum temperatures increased slowly from 1870 to 1920, fell slightly from 1920 to 1950, and then increased rapidly by about 1.5^{o}C from 1950 to 1980 with little change since. Consequently, Melbourne's mean temperature has increased slowly from 1890 to 1920 and increased rapidly by about 1.0^{o}C from 1950 to 2000 (Figure 3). Over the past 50 years, maximum temperatures have increased by 0.35^{o}C and minimum temperatures have increased by 1.6^{o}C. This warming reflects natural variability, greenhouse warming and urbanisation.

Using daily temperature data from 1860-2000, in the number of annual heating degree days (HDD) below 18^{o}C have been computed for Melbourne (Figure 4). There is strong year-to-year variability, but a steady decrease in HDD is evident from 1950 to 2000 due to higher temperatures . The 11-year running mean shows that the HDD has dropped from about 1500 in 1950 to about 1200 in 2000, i.e. a 20% decrease in 50 years.

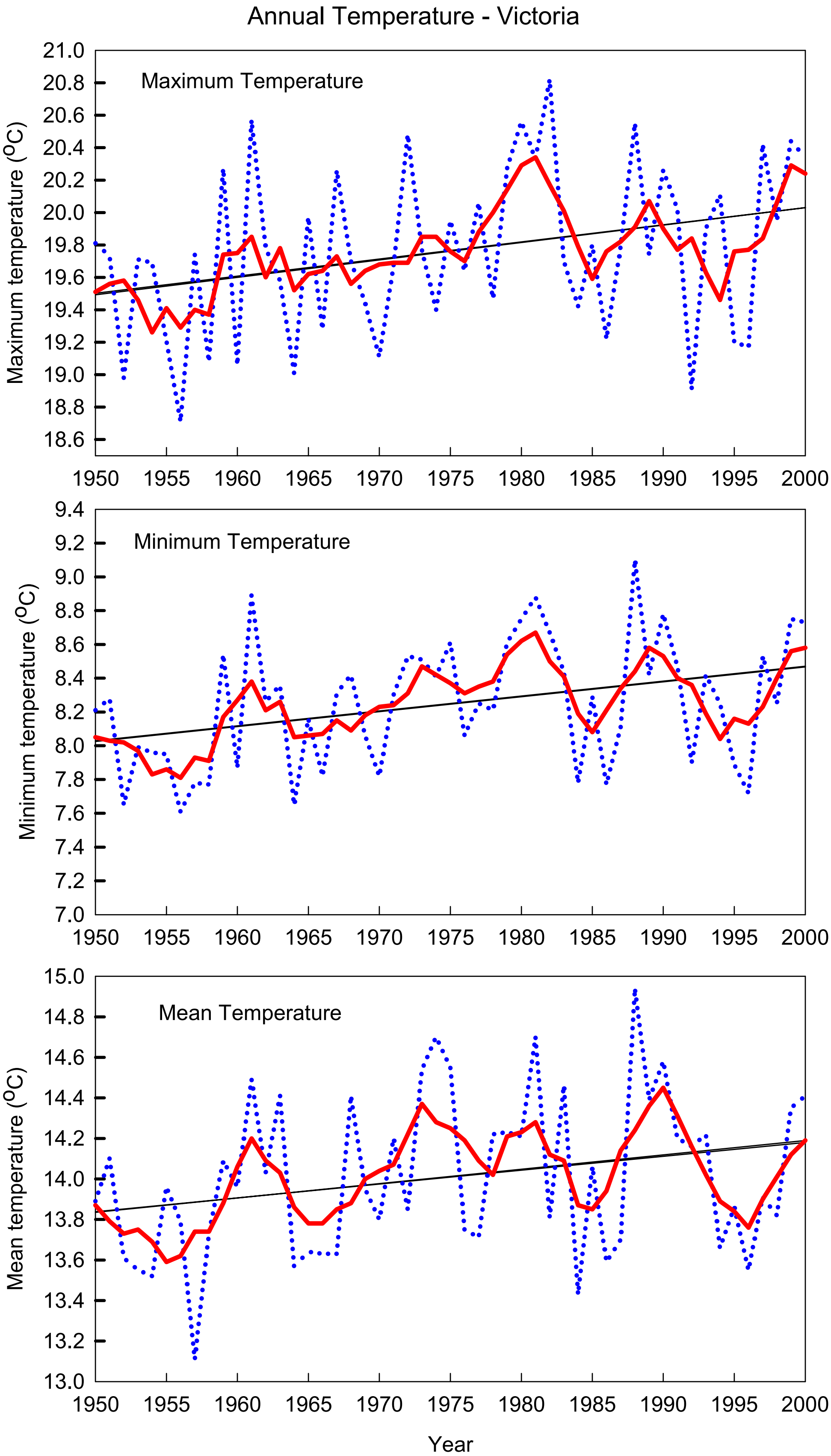

Figure 1. Annual maximum, minimum and mean temperatures for Victoria from 1950 to 2000 using the rural gridded data. The solid line is a 5-year running mean and a linear trend line has been fitted. (Source: Bureau of Meteorology).

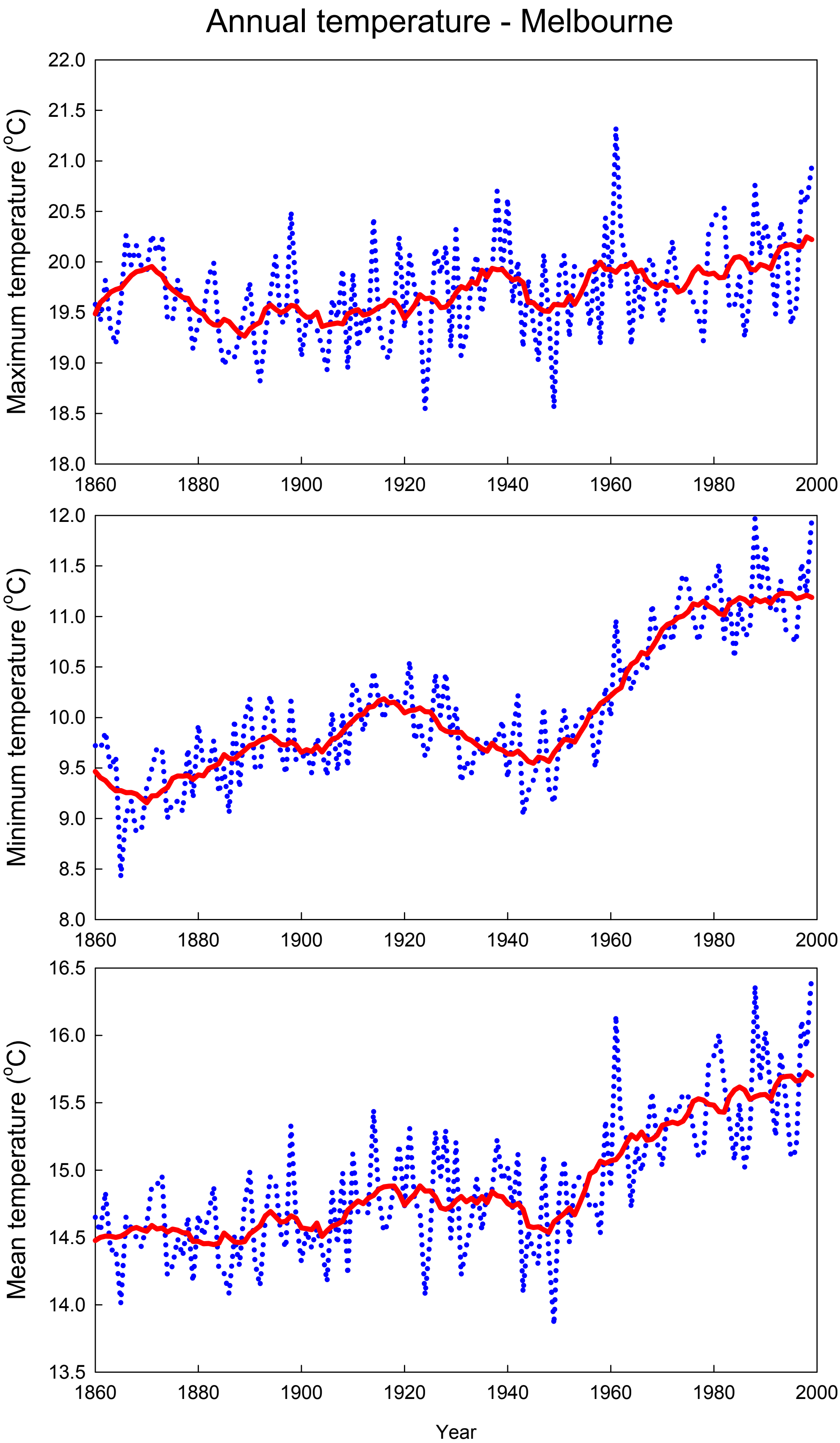

Figure 2. Annual maximum, minimum and mean temperatures for Melbourne from 1860 to 2000 (Source: Bureau of Meteorology). The solid line is an 11-year running mean.

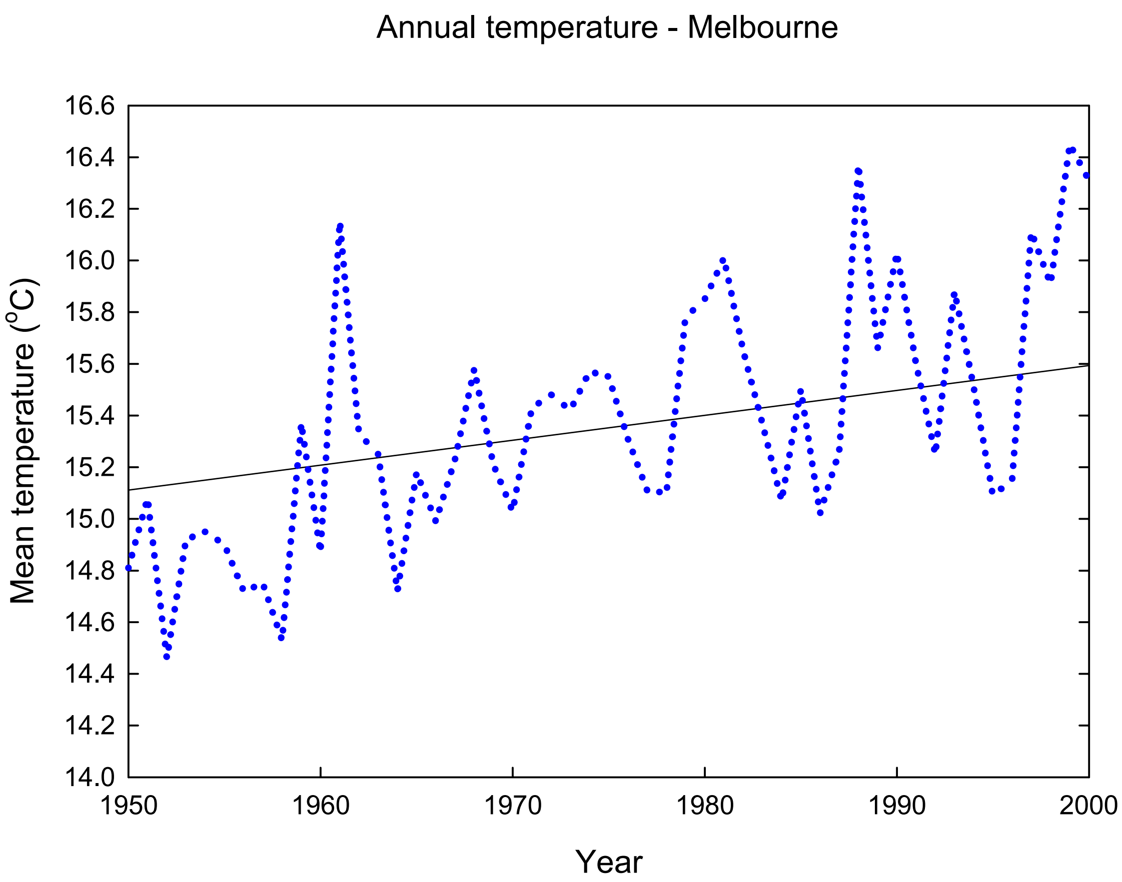

Figure 3. Annual mean temperature for Melbourne from 1950 to 2000 (Source: Bureau of Meteorology). A linear trend line is shown.

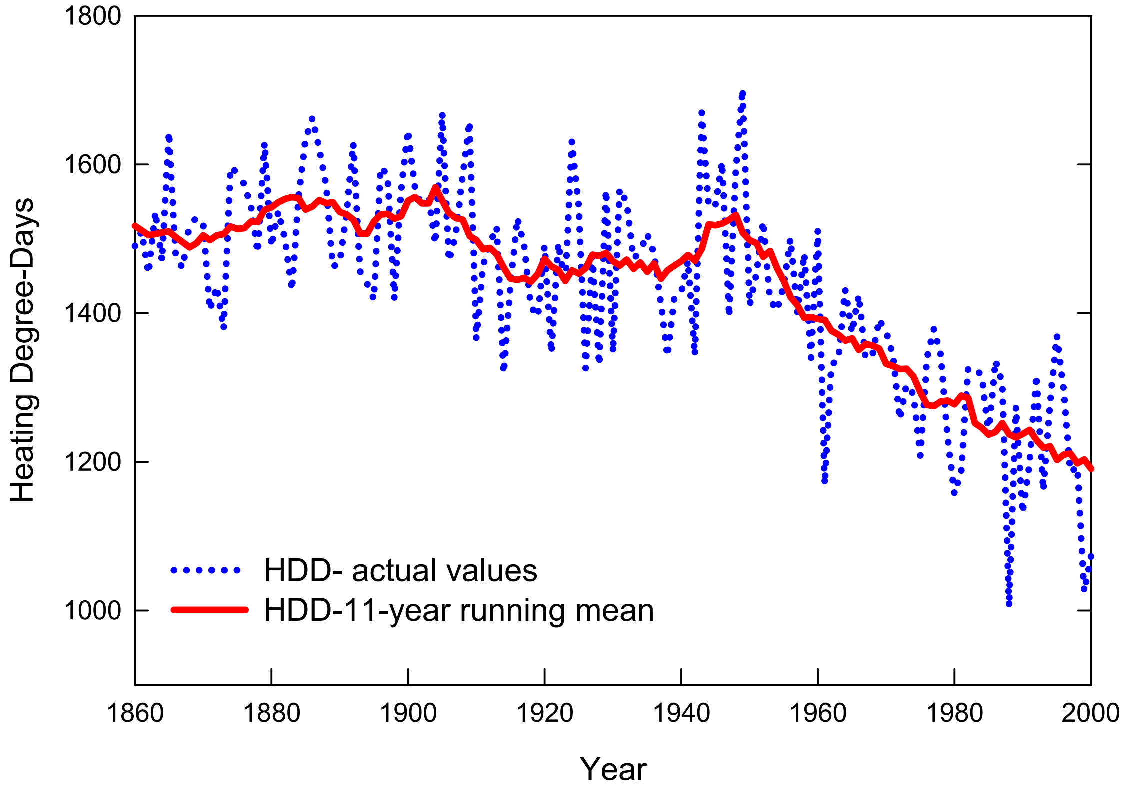

Figure 4: Annual heating degree-days below 18°C for Melbourne from 1860 to 2000.

4.3 Melbourne warming due to urbanisation

Cities tend to provide rougher, warmer and drier surface conditions than rural areas (Oke, 1978). Heating of air over a city can extend up to 600 to 1500 metres above the surface during daytime, and up 100 to 300 metres at night. This is called the urban heat-island effect. It is commonly measured as the difference between urban and rural temperatures at night, when the near-surface effect is strongest.

Recently, a number of studies have dealt with Melbourne's heat island intensity (Torok *et al.,* 2000; Morris *et al*., 2000, 2001). They compared temperatures in Melbourne's Central Business District (CBD) with surrounding non-urban areas. Torok *et al*. (2000) found that Australian towns and cities are likely to have smaller maximum urban heat island effects that those observed in cities in Europe and America for a given population. Morris *et al*. (2001) estimated the maximum heat island intensity for Melbourne based on 20 years data from 1972 to 1991. The maximum intensity was defined as the difference in 6 am (local time) temperature between the CBD and the average of Melbourne Airport, Laverton Airport and Moorabbin Airport. On this basis, the 20-year average heat-island intensity for Melbourne is 1.13°C. The intensity is highest in summer (1.29°C) and lowest in winter (0.98°C).

There has been no study of trends in heat island intensity in Melbourne. However, a number of studies have focused on trends in urban heat island intensity overseas. For example, Magee *et al*. (1999) investigated temperature difference between Fairbanks (urban) and Eielson (rural) in Alaska from 1949 to 1997 and found the heat island effect grew by 0.4°C, with winter experiencing a more significant increase of 1.0°C. Over the 49-year period, the population of Fairbanks grew by more than 500%, while the population of Eielson remained relatively constant.

We have investigated Melbourne heat island intensity and the trend in intensity from 1950 to 2000 since this is the period of steady increase in mean temperature. Our definition of intensity is rather different to that used by Torok *et al.* (2000) and Morris *et al*. (2000, 2001). From the gridded rural temperature data set, we have extracted data for the grid-point nearest Melbourne. This has no urban influence since it is interpolated from surrounding rural sites, so it effectively gives us a non-urbanised Melbourne temperature record. To estimate the component of the Melbourne trend due to urbanisation, we have compared the non-urbanised record with data from the Melbourne weather station (Figure 5).

The net effect on mean temperatures is a city-rural difference of 1.0°C in 1950, increasing to about 1.6°C by 2000. For maximum temperature, the average difference is only 0.1°C with a slight upward trend mainly due to warming in the 1990s. The effect of urbanisation appears most evident in minimum temperature. In 1950 the city's minimum temperature was about 1.9°C higher than surrounding rural sites, increasing to about 3.0°C higher by 2000, i.e. an increase of 1.1°C over 50 years. The 1950-2000 mean minimum temperature difference is about 2.5°C, which is double the 1972-1991 value of 1.13°C found by Morris *et al*. (2001), but we have used different definitions of heat island intensity. Our trend estimates, e.g. 1.1°C over 50 years for minimum temperature, are considered robust because they are less dependent on the definition of heat island intensity.

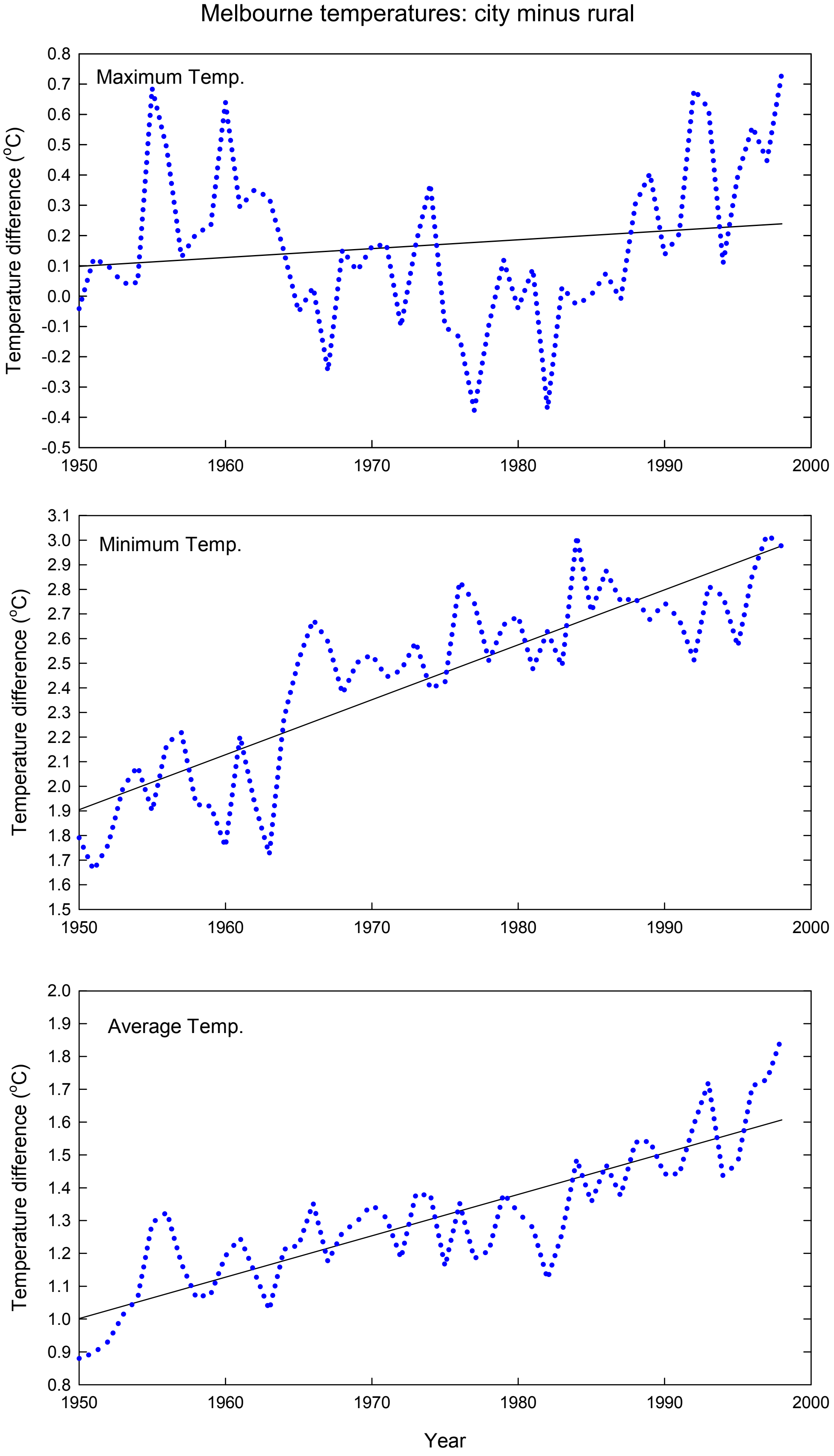

Figure 5: Annual temperature difference between the Melbourne weather station and the non-urbanised Melbourne grid-point data from 1950 to 2000. A linear trend has been fitted.

The trend in the minimum temperature difference can be used as a basis for estimating the change in the urbanisation effect on Melbourne temperatures. However, the abrupt jump in the minimum temperature difference around 1965 is suggestive of a possible change in conditions in the vicinity of the site (and thus a change that need not be part of a general urbanisation trend). Examination of relevant metadata and discussion with the Bureau of Meteorology (B.Trewin, personal communication) failed to identify a clear cause of this abrupt change. Nevertheless, we chose to exclude data from before 1965 for estimating the trend in the effect of urbanisation on minimum temperature. This means that the urbanisation trend may be a conservative estimate. We have also excluded the post-1995 data because the discussion with the Bureau of Meteorology (B.Trewin, personal communication) identified that there may have been a warming of up to 0.5^{o}C possibly associated with the construction of a building near the weather station. The increase in the minimum temperature difference from 1965 to 1995 is 0.49^{o}C, or a trend of 0.016^{o}C per year.

5. Projected trends in temperature and heating degree-days for 2003-2007

5.1 Greenhouse and urban warming trends

The range of greenhouse warming for 2003-2007 is based on results published by the Intergovernmental Panel on Climate Change (IPCC, 2001) and CSIRO's (2001) regional warming projections for Australia. The projected warming for the Melbourne region (Figure 6) has been derived from simulations with nine climate models, in which the level of greenhouse gas concentrations was enhanced. A number of aspects, such as quantifiable uncertainties associated with the range of future emission scenarios, the range of global responses of climate models, and model to model differences in the regional pattern of climate change are considered when producing the projections. Melbourne's projected warming is 0.03 to 0.20^{o}C by 2007. Further details of the projections can be found in CSIRO (2001).

Given the strong evidence of urbanisation affecting Melbourne minimum temperature, evidence of this effect intensifying in recent decades, and an expected future growth in urbanisation (population is expected to grow from 3.4 million in 2000 to 3.7 million in 2007 – Bob Birrell, Monash University, personal communication.), it was considered appropriate that projected temperature trends for Melbourne should allow for a warming trend due to urbanisation. We have assumed that the linear trend in the urban-rural temperature difference from 1965-1995 (identified above) continues at the same rate through to 2007. This warming rate is 0.016°C per year. Since we are assuming no urbanisation effect on maximum temperature, we have applied half of the warming rate for minimum temperature to projected mean temperature (i.e. 0.008^{o}C). When the greenhouse warming and urbanisation effects are combined, the warming for the year 2007 relative to 2000 is 0.09 to 0.26^{o}C.

5.2 Baseline average temperature and heating degree-days for the year 2000

In order to calculate heating degree-days, we need daily temperature data rather than annual-average temperature changes relative to the year 2000. Hence the projected temperature changes need to be added to a baseline average temperature for the year 2000. To get a baseline temperature value, we have fitted a linear trend to observed annual mean temperature data from 1965 to 2000 (Figure 7) and calculated the 90% confidence limits. The end point of the linear trend gives a middle estimate for the year 2000, and the end points of the 90% confidence limits give a range of uncertainty. The middle estimate is 15.68ºC with an uncertainty range of 16.09 to 15.88ºC. These are used as baseline values for projections from 2001 to 2007.

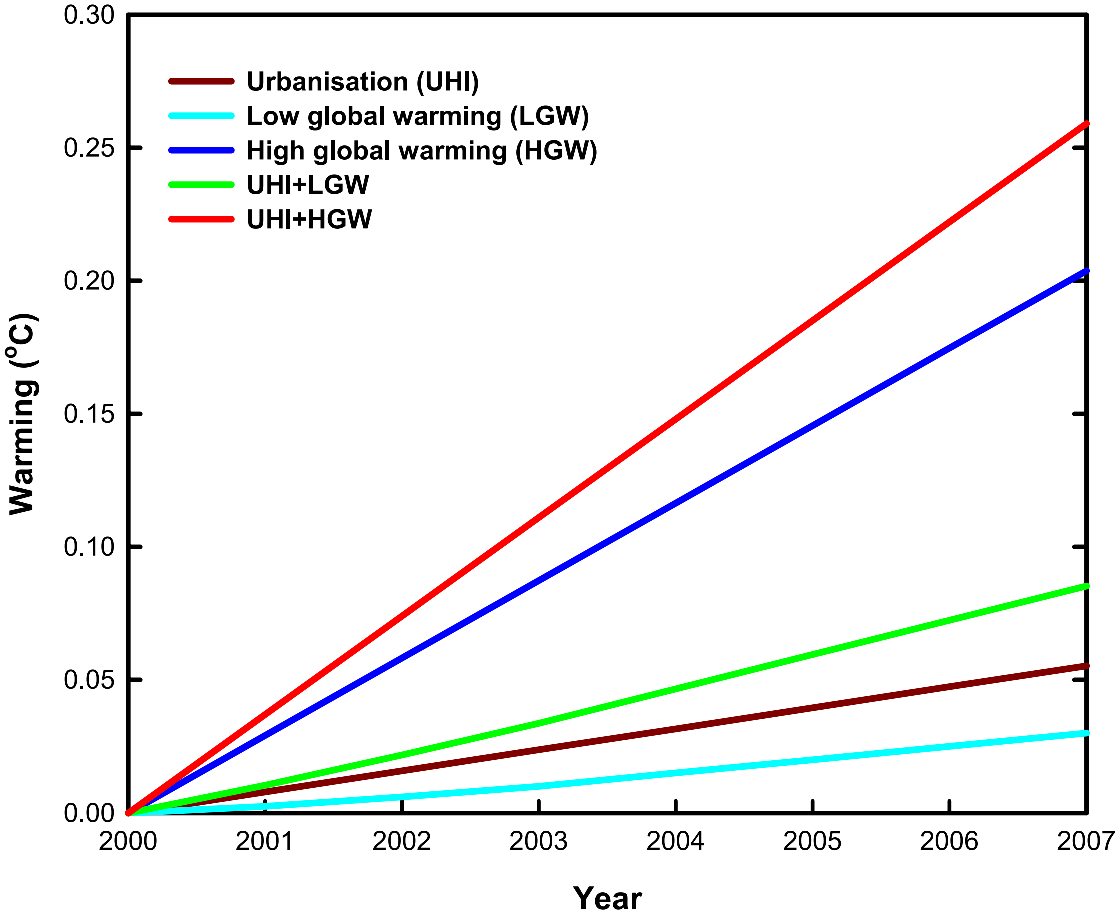

Figure 6: Greenhouse and urbanisation warming trends for Melbourne from 2001 to 2007, relative to the year 2000.

The average temperature values in Figure 7 have been converted into HDDs using the following method. For a given annual average temperature, the difference between this temperature and that of the observed average for 1965-1995 was calculated. This difference was then applied to each of the daily records for 1965-1995, and annual average heating degree-days were calculated for this modified record using the formula:

Daily HDD = [daily average temperature] minus 18	if average temperature is less than 18ºC
Daily HDD = 0	if average temperature is greater than 18ºC
Annual HDD = Sum of daily HDDs divided by 365	

The mean HDD for the year 2000 is 1175 with an uncertainty range of 1125 to 1227 (Figure 8). These are used as baseline values for projections from 2001 to 2007.

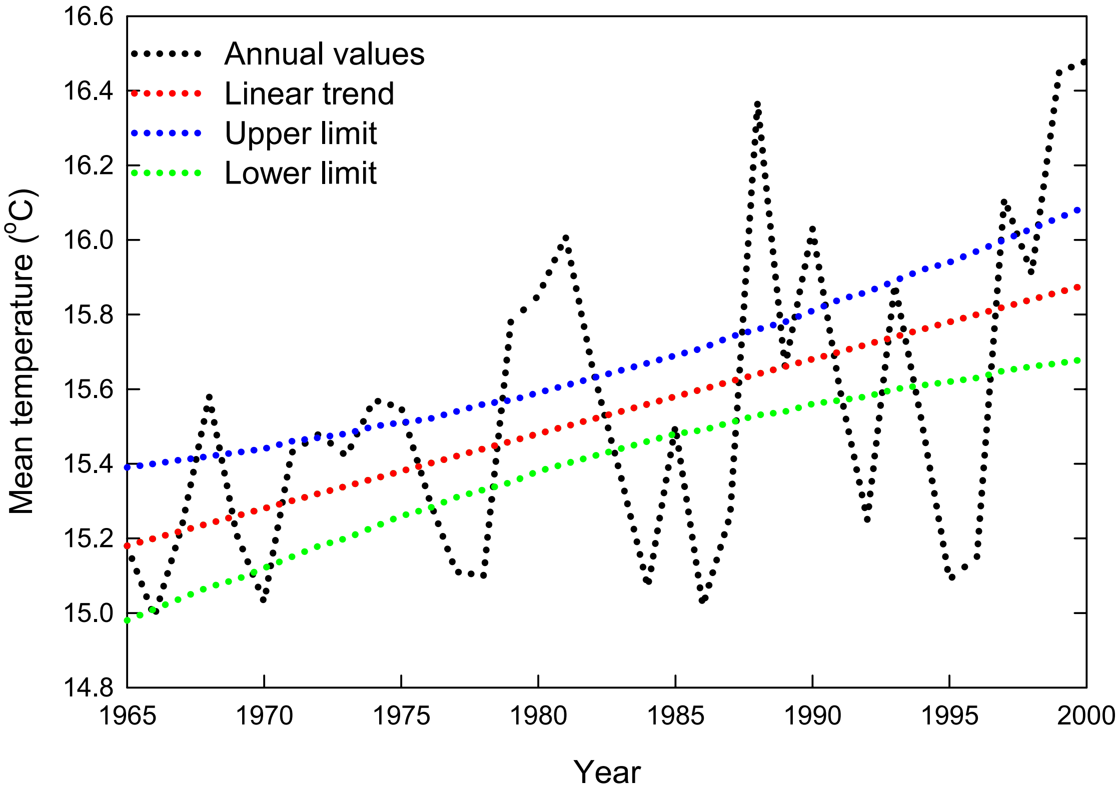

Figure 7. Estimated mean, upper and lower limits of annual temperature for Melbourne from 1965 to 2000. The red line is the linear trend. The blue and the green lines are 90% confidence limits.

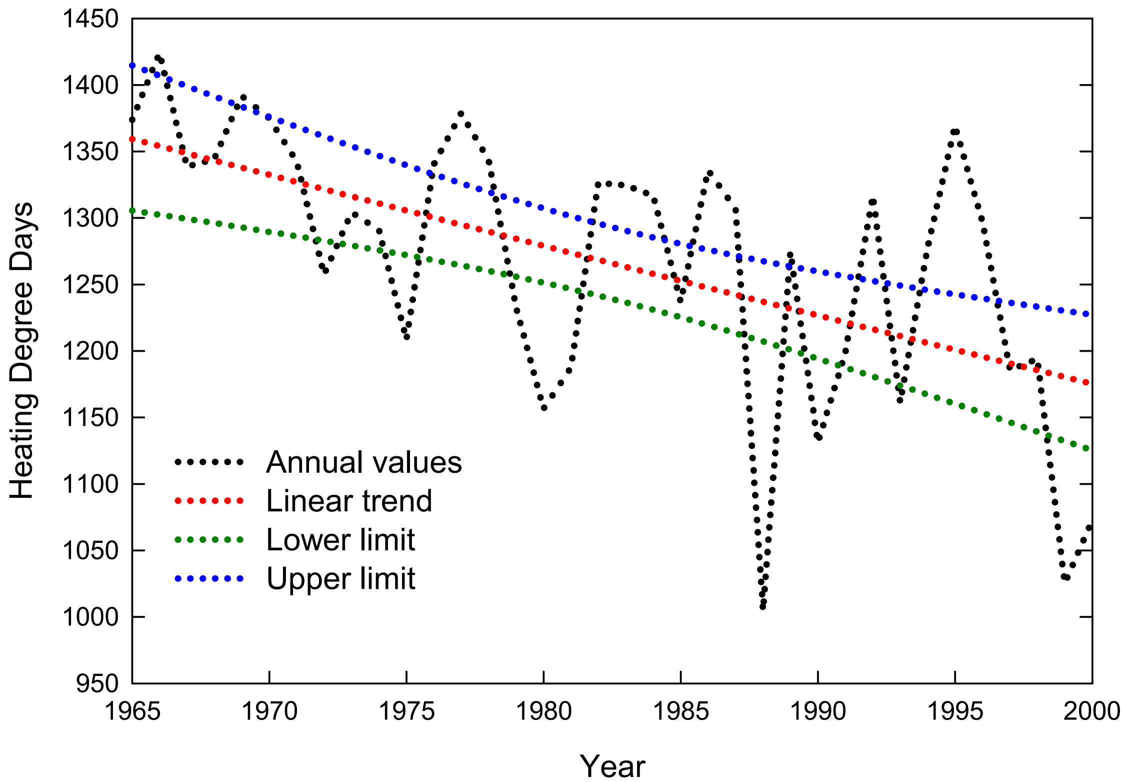

Figure 8. Estimated mean, upper and lower limits of heating degree-days for Melbourne from 1965 to 2000. The red line is a linear trend. The blue and green lines are 90% confidence limits.

5.3 Projected temperatures

Our temperature projections for 2001 to 2007 allow for underlying trends in greenhouse warming and urbanisation, but do not include natural variability, which is mostly chaotic and unpredictable. Natural variability, due to factors like El Niño events, influences year-to-year fluctuations in temperature.

The starting points for the temperature projections are the baseline values for 2000 derived from Figure 7. Projections for 2001 to 2007 are taken from Figure 6. We have also used the high and low global warming estimates for mid cases temperature projections. Projections based on greenhouse warming alone, and greenhouse plus urbanisation warming, are presented separately in Table 1, Figure 9 and Figure 10. The greenhouse-driven temperature in 2007 is 15.65 to 16.35ºC. When urbanisation is included, the average temperature in 2007 is 15.65 to 16.35ºC.

Table 1: Projections of Melbourne annual-mean temperature (°C) based on greenhouse and urban warming.

Year	Greenhouse only			Greenhouse + urbanisation		
	Low	Mid	High	Low	Mid	High
2000	15.68	15.88	16.09	15.68	15.88	16.09
2003	15.69	15.89-15.97	16.18	15.71	15.91-15.99	16.20
2007	15.71	15.91-16.08	16.29	15.77	15.97-16.14	16.35

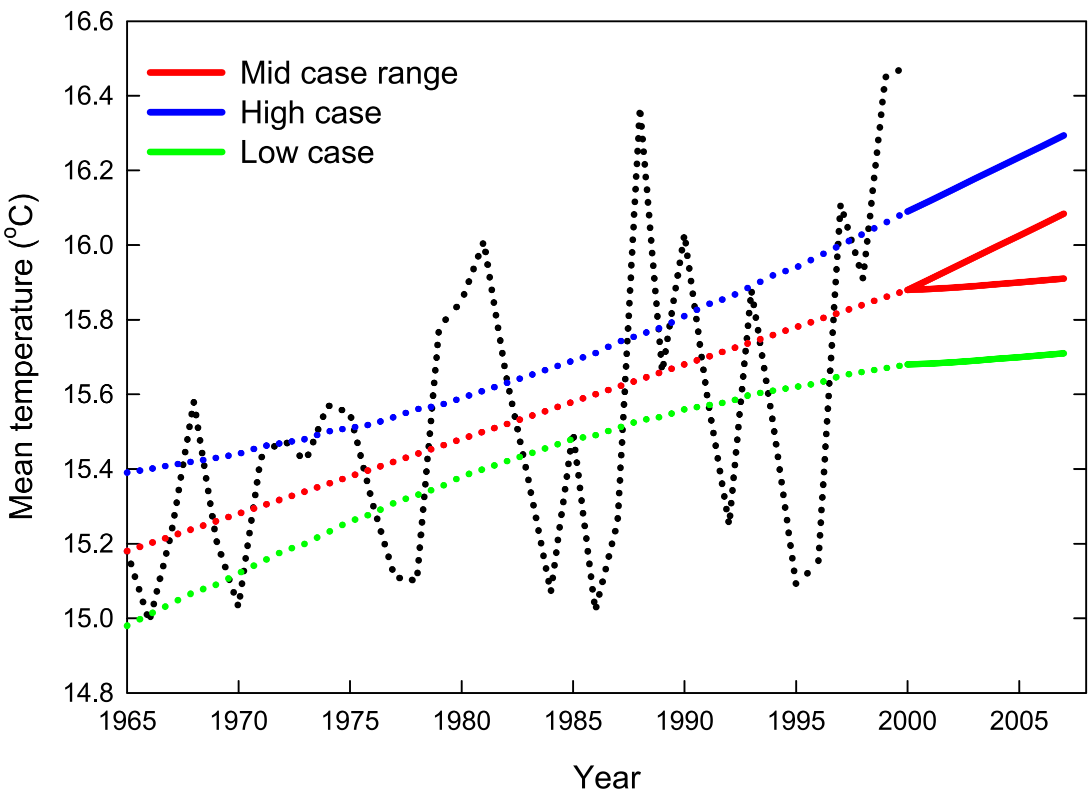

Figure 9. Mid, high and low projections for annual mean temperature from 2001 to 2007 for Melbourne based on greenhouse warming only.

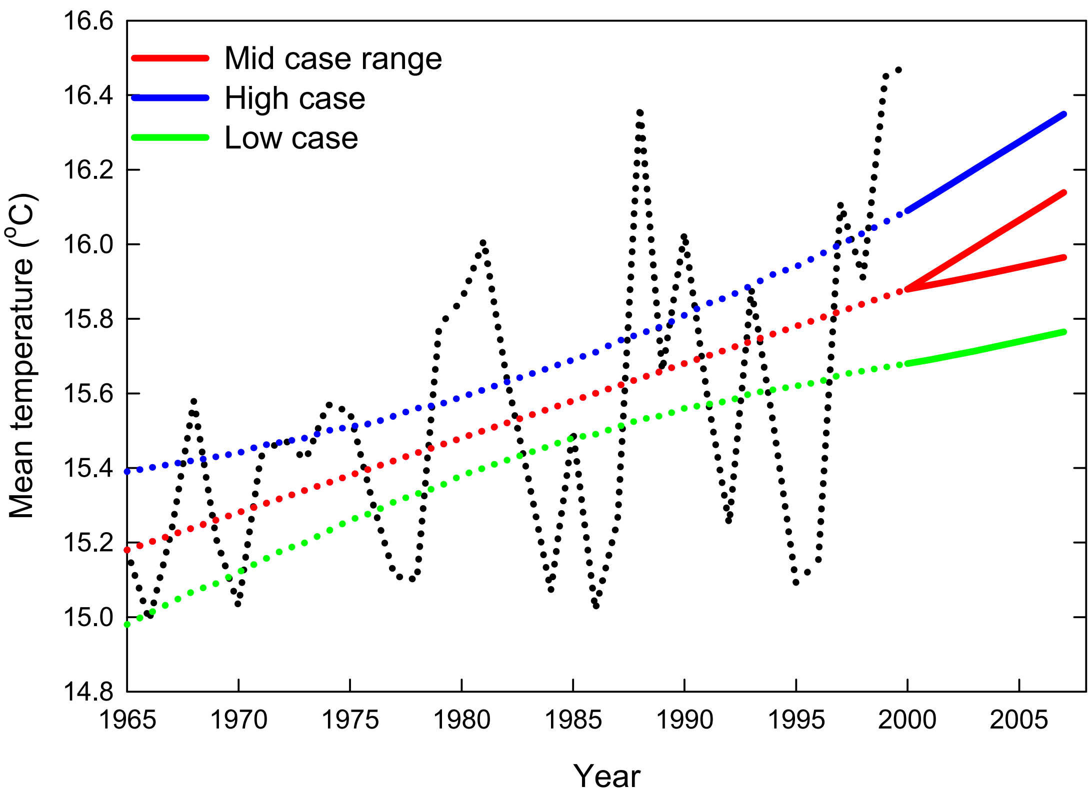

Figure 10. Mid, high and low projections for annual mean temperature from 2001 to 2007 for Melbourne based on greenhouse warming and urbanisation.

5.4 Projected heating degree-days

Using data from Figure 10, heating degree-days can be estimated for 2001 to 2007. The procedure is the same as that used to derive HDDs in Figure 7. Figure 11 and Table 2 show the range of HDD for 2007 lies between 1061 and 1205. The mid-range values lie between 1111 and 1154 with an average value of 1132 by 2007. Notably, the latter figure, obtained from a physically-based approach, is similar to what would have obtained from a simple extrapolation of values based on the linear trend from 1965 to 2000.

Table 2: Projections of Melbourne annual-total heating degree-days based on greenhouse and urban warming.

Year	Greenhouse + urbansiation		
	Low	Mid	High
2000	1125	1175	1227
2003	1097	1147-1167	1218
2007	1061	1111-1154	1205

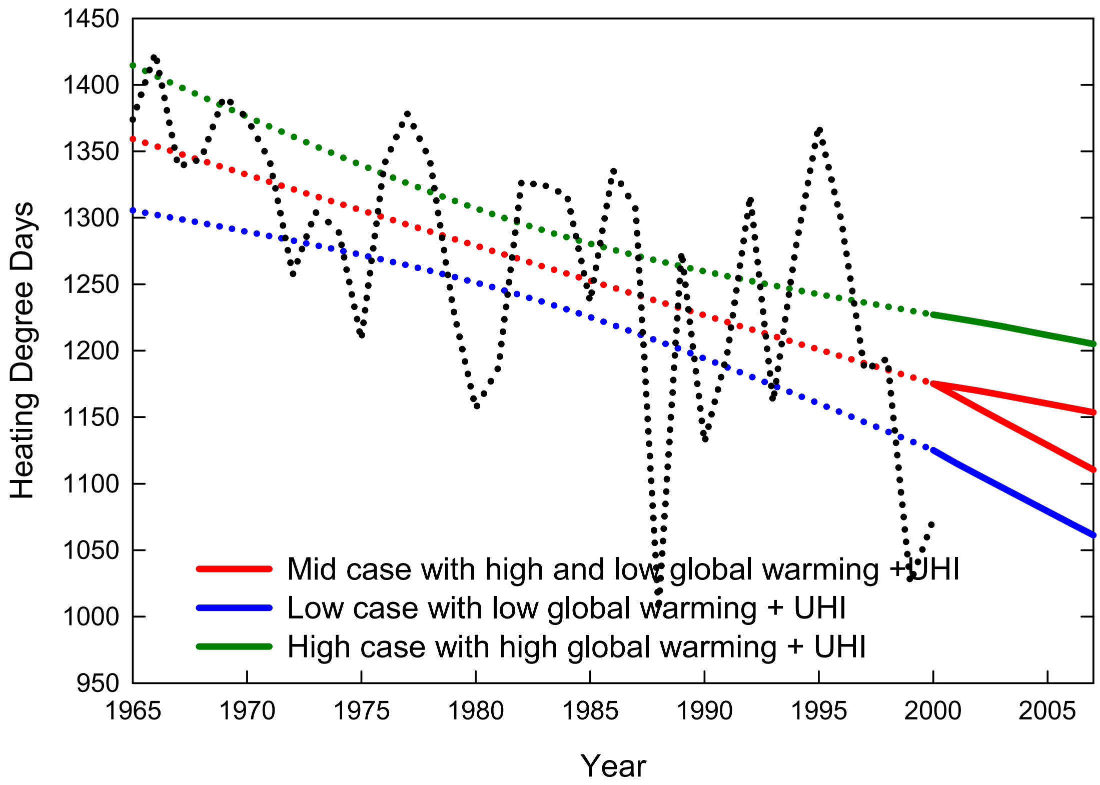

Figure 11. Estimated HDDs from temperature values in Figure 10.

5.5 Uncertainties

In this study, we have quantified uncertainties in the range of baseline annual mean temperatures for the year 2000 and the range of greenhouse warming from 2001 to 2007. Specifically, we have allowed for uncertainties in greenhouse warming associated with future human behaviour and economic and technological change, and differing results from various climate models. However, climate models have insufficient horizontal and vertical resolution to accurately simulate climate over regions as small as Melbourne.

Uncertainty in the urbanisation effect has not been quantified. The trend in urban heat island intensity beyond 2001 is dependent on a number of factors that are not clear at present, e.g. future economic and urban development, energy efficiency and usage, and population growth.

This study addresses underlying trends in temperature due to greenhouse warming and urbanisation. It does not include the influence of natural climatic variability on the year-by-year evolution of temperatures, which represent deviations from underlying trends. Factors associated with natural variability, such as volcanic eruptions, the El Niño-Southern Oscillation, the Antarctic Circumpolar Wave and other chaotic elements of the climate system are not predictable.

6. Conclusions

GasNet asked CSIRO to make an investigation of Melbourne temperature trends, and to project the underlying trend for 2003-2007 both in terms of average temperature and an index of demand called heating degree-days (HDD). We have estimated a range of temperature trends that allow for warming due to enhancement of the greenhouse effect and increased urbanisation.

- Melbourne's mean temperature has increased from 1950 to 2000 by about 1.0°C. Maximum temperature has increased by 0.35°C and minimum has increased by 1.6°C. Contributions to this warming would include a regional (non-urban) warming trend which may be related to enhanced greenhouse climate change, and a residual warming trend partly due to increasing urbanisation.

- The average difference in minimum temperature between Melbourne's urban centre and nearby non-urban sites is 2.5°C. This difference increased by 0.4°C between 1965 and 1995, the period for which the record is considered most reliable. This trend of 0.016°C per year represents growth in the urbanisation effect. The maximum temperature record showed an urban-rural difference of about 0.1°C and a negligible trend.

- Climate models indicate a warming of 0.03 to 0.20°C for the Melbourne region by the year 2007 relative to 2000 due to the enhanced greenhouse effect. If the recent rate of rise in minimum temperature due to increased urbanisation continues, then the greenhouse plus urbanisation warming is 0.09 to 0.26°C by 2007.

- In order to compute HDD, projected warming needs to be added to a baseline temperature for the year 2000. This baseline is 15.88°C with a range of 15.68 to 16.09°C. Allowing for projected greenhouse and urbanisation warming gives a range of 15.96 to 16.13ºC by 2007 relative to the mid-point of the baseline in 2000, and a range of 15.76 to 16.35ºC allowing for baseline uncertainty.

- The baseline HDD for the year 2000 is 1175 with a range of 1125 to 1227. Allowing for projected greenhouse and urbanisation warming gives a range of 1111 to 1154 by 2007 relative to the mid-point of the baseline in 2000, and a range of 1061 to 1205 allowing for baseline uncertainty. The midpoint in 2007 is 1132, which is very close to that based on simple extrapolation of the linear trend from 1965-2000.

7. References

CSIRO, 2001. *Climate Change Projections for Australia*. CSIRO, Atmospheric Research, Aspendale, Victoria, Australia, 8 pp.

Collins, D. A., Della-Marta, P. M., Plummer, N. and Trewin, B. C. 2000. Trends in annual frequencies of extreme temperature events in Australia. *Australian Meteorological Magazine*, **49,** 277-292.

IPCC, 2001. *Climate Change 2001. The Scientific Basis of Climate Change. Summary for Policymakers.* Intergovernmental Panel on Climate Change, Cambridge Uni Press, 20 pp.

Magee, N., Curtis, J. and Wendler, G. 1999. The urban heat island effect at Fairbanks, Alaska. *Theoretical and Applied Climatology*, **64** (1-2), 39-47.

Morris, C. J.G. and Simmonds, I. 2000. Associations between varying magnitudes of the urban heat island and the synoptic climatology in Melbourne, Australia. *International Journal of Climatology*, **20,** 1931-1954.

Morris, C. J.G., Simmonds, I. and Plummer, N. 2001. Quantification of the influences of wind and cloud on the nocturnal urban heat island of a large city. *Journal of Applied Meteorology*, **40**, 169-182.

Oke, T. R. 1987. *Boundary layer climates*. Second Edition. Methuen Inc., New York. 435 pp.

Plummer, N., Salinger, M. J., Nicholls, N., Suppiah, R., Hennessy, K. J., Leighton, R. M., Trewin, B. and Lough, J. M. 1999. Twentieth century trends in climate extremes over the Australian region and New Zealand. *Climatic Change*, **42**, 183-202.

Torok, S. J., Morris, C.J.G., Skinner, C. and Plummer, N. 2001. Urban heat island features of southeast Australian towns. *Australian Meteorological Magazine*, **50**. 1-13.