Australian Government
Bureau of Meteorology

The Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT) data set

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1. Introduction and goals

Long-term, high-quality data sets are very important in monitoring climate change and variability. It is also important that the data are homogeneous, in order to be confident that any changes in the data are representative of changes in the broader climate.

Two homogenised data sets have previously been in operational use in Australia: an annual set beginning in 1910 (Della-Marta et al., 2004) and a daily set starting in 1957 (Trewin, 2001).

The new Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT) data set is a new data set which contains daily data from 1910 onwards, and will replace both of the earlier data sets in the Bureau of Meteorology's operational analyses. The data have been homogenised at the daily timescale, and form what is believed to be the world's first national-scale data set of this type.

Major advantages of the new data set include:

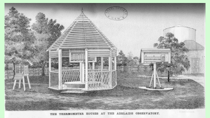
- The availability of data for the full 1910-2011 period.
- The possibility of century-scale analyses of variability and change in temperature extremes.
- Greatly improved documentation of the data set and adjustment process.

The ACORN-SAT site at Rutherglen, northern Victoria

2. The Australian temperature observation network through history

The first instrumental temperature observations in Australia occurred shortly after the beginning of permanent European settlement in 1788, but it was not until the middle of the 19th century that systematic, long-term observations began to be taken. Observation standards differed considerably between states and it was not until the Bureau of Meteorology was established as a federal organisation in 1908 that consistent standards were applied nationally. The Stevenson screen was adopted as a national standard around this time.

Observations covered many parts of Australia by 1930, although coverage of remoter areas was still sparse, particularly in the Northern Territory and central Australia. Coverage of these areas improved after 1950 (although the total number of stations did not change greatly), with stations opening in a number of key locations. However, the network in many parts of the country is still sparse compared with many other developed countries, with numerous stations more than 100 kilometres from their nearest neighbour.



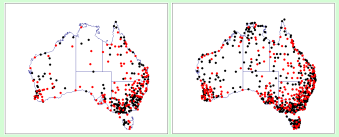
The Adelaide Observatory circa 1900, with a Stevenson screen (left), large thermometer house (centre) and Glaisher stand (right).

Historically, observations have been made using manually read liquid-in-glass thermometers, but since the early 1990s, automated probes have become increasingly important and now make up about 70% of the network. Unlike many other countries, Australia retained the same screen type when automated probes were introduced.

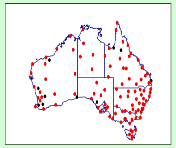
Until recently, only very limited digitised daily data were available prior to 1957. There has been a major digitisation program over the last decade and there are now more than 60 sites with daily data available in 1910 or earlier.

3. Data availability and the ACORN-SAT network

There are about 1600 stations in Australia which have observed temperature at some point in their history. 770 of these are currently operating, but only 132 of these have more than 50 years of available data (this total can be augmented, to some extent, by composites). Most of the more densely populated areas have at least some available data from 1910 onwards, but some key stations in remote areas did not open until the 1940s or 1950s, such as Oodnadatta (1940), Birdsville (1954) and Giles (1956).



The Australian temperature network in 1930 (left) and 2010 (right). Stations in red have 40 years or more of observations.



The ACORN-SAT station network. Black indicates sites not in previous high-quality networks.

The ACORN-SAT data set contains daily maximum and minimum temperature data from 112 stations, selected from the best long-term records available. The data set starts in 1910 (earlier data were not considered because of the lack of standardisation of instrument shelters), with 60 stations having data for the full 1910-2011 period.

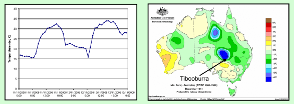
4. Data quality control in the ACORN-SAT data set

The Bureau of Meteorology currently operates a comprehensive quality-control system for incoming climate data. The current system, however, has only been in operational use since 2008, with less effective systems in use prior to that. (In particular, it is only in the last 10 years that computing improvements have made it feasible to carry out spatial cross-validation on a routine basis.) The ACORN-SAT data therefore underwent an independent quality-control process, with the aim of giving the whole data set, as far as possible, a level of quality control similar to that in operational use post-2008.

Quality-control checking applied to the data set included:

- Spatial intercomparison of observations at daily and monthly timescales.
- Internal consistency of maximum and minimum temperatures with each other, and with available fixed-hour observations.
- Checks for 'spikes' and excessively rapid variations in high-resolution data (where available).
- Comparison of newly digitised daily data with previously published monthly means.

Once flagged by the automated checks, observations were subject to follow-up investigations, involving data from other stations and fixed hours, and other elements (e.g. terrestrial minima) where available. The effectiveness of this was determined by the available supporting data (e.g. data at hours other than 0900 and 1500 were mostly not digitised before 1987). As a result of this process, about 18,000 observations (0.3% of the total) were flagged as suspect.

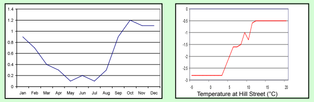


Some issues found by quality-control checks – a downward 'spike' in temperature (probable instrument fault) on 12 November 2008 at Nuriootpa (left) and a persistent instrument fault resulting in anomalously low monthly temperatures at Tibooburra in 1931-32 (right)

5. Homogenisation – detection and adjustment

The detection of inhomogeneities in climate time series is a well-explored problem with numerous techniques in use (Venema et al., 2012). In the ACORN-SAT data set, detection was carried out using a combination of available metadata and a statistical technique using pairwise comparisons of time series between neighbouring sites and the Standard Normal Homogeneity Test (Alexandersson, 1986). The statistical technique used for detection is closely based on that used in the development of a homogenised temperature data set for the United States (Menne and Williams, 2009).

Adjustment of data to remove inhomogeneities is a less explored field, although one in which there have been a number of recent developments. Historically, adjustment has often been carried out by applying a uniform annual adjustment (or, at best, a uniform monthly adjustment). However, in many cases the size of inhomogeneities varies seasonally or according to weather type; in particular, in many cases minimum temperature inhomogeneities are greatest on clear, calm nights, which in Australian climates are often the coldest nights.



Temperature differences (°C) between inland (airport) and coastal (Hill Street) sites 5 km apart at Port Macquarie during 1995-2003 overlap period – (left) mean monthly maximum temperature, (right) winter daily minimum temperature.

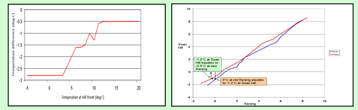
Failing to account for such daily and seasonal variability in inhomogeneities has the potential to produce adjusted time series which are homogeneous in the annual mean but remain inhomogeneous in the seasonal cycle and/or the occurrence of extremes. A number of techniques have been developed to address this (e.g. Della-Marta and Wanner 2006; Mestre et al., 2011), but none have previously been applied to year-round data in a national-scale data set.

6. The percentile-matching (PM) algorithm

The percentile-matching (PM) algorithm was developed to make adjustments for inhomogeneities in the ACORN-SAT data set.

The simplest case is where a composite record is being created from two records which overlap (for example, where the original site continues when a new site is opened). For each of the 12 3-month periods (January-March, February-April, etc.), during the overlap period, the 5th, 10th, …, 95th percentile points of the frequency distribution of daily temperature anomalies are calculated at each station and reconverted to temperature values by adding the monthly normal of the central month, then these percentile points are used as fixed points in a transfer function. Constant differences are assumed below the 5th percentile and above the 95th percentile.

Where no overlap is available, a two-stage process was used, using transfer functions between the candidate station and a reference station for a period (normally 5 years) before the inhomogeneity, and between the candidate and reference station for a similar period after the inhomogeneity. The final adjusted value was then calculated as the median of the estimates using each of the 10 best-correlated reference stations (with a minimum correlation of 0.6), if available.



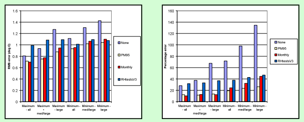
(Left) Example of a single-station transfer function, expressed as differences from the original station. (Right) Example of a two-step homogenisation at Kerang using a reference station (Swan Hill).

Uniform monthly adjustments were used in a small number of cases (mostly early in the data set) where there were fewer than 3 suitably-correlated reference stations with available data. 'Spikes' (where there were two opposite inhomogeneities 3 years or less apart) were also treated as a special case.

7. Evaluation of the PM algorithm

An evaluation of the PM algorithm was carried out, comparing it with uniform monthly adjustments, the RHtestsV3 algorithm (Wang et al., 2010) and no adjustment at all. This evaluation was carried out using 16 locations where there were two stations with parallel data for periods between 4 and 10 years; the test data series switched from the old to the new station at the start of the overlap period, and the continuation of the old station was used as the verification data set. The 16 locations were characterised, separately for maximum and minimum temperature, as having large (mean annual difference > 0.6°C), medium (mean annual difference > 0.3°C, or seasonal mean differences > 0.3°C in at least two seasons or > 0.5°C in any one season) or small (all others) inter-site differences. Several metrics were used for evaluation, including root-mean-square (RMS) error, number of days above the 90th/below the 10th percentile, and highest/lowest value for each month.

These results indicated that the PM algorithm outperformed other methods for medium and large inhomogeneities, particularly for metrics related to temperature extremes. They also indicated that no adjustment method provided useful skill over the no-change case for small inhomogeneities, which were consequently not, in general, adjusted for in the ACORN-SAT data set.



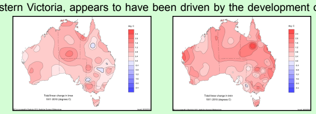
Evaluation of various adjustment techniques: (left) RMS error, (right) accuracy of simulation (%) of number of days with minima below 10th percentile.

A separate evaluation, carried out by using random subsamples of all stations meeting correlation thresholds as reference stations rather than the 10 best-correlated neighbours, found that a correlation of 0.6 was sufficient for a station to be a useful reference station in making adjustments at the candidate station.

8. Some preliminary results from the ACORN-SAT data

The new data set, as was the case for earlier data sets, indicates warming in both maximum and minimum temperatures over the 1910-2011 period almost throughout Australia, with some limited exceptions (one notable one, local cooling of maximum temperatures at Mildura in northwestern Victoria, appears to have been driven by the development of irrigated agriculture in the region).

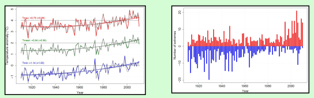
Total estimated warming of nationally averaged temperatures over the 1910-2011 period was 0.75°C for maximum temperatures and 1.14°C for minima, both closely matching results from earlier data sets (Fawcett et al., 2012).



Observed maximum (left) and minimum (right) temperature trends for 1911-2010

A comparison of the adjusted data to raw data indicates that the two match closely after 1960 but the raw data are somewhat warmer before 1960, and especially before 1940. This is most likely due to a number of site moves, particularly during the Second World War when numerous sites moved from town centres to airports.

The new data set also allows century-scale analyses of extremes. One of the first analyses to be carried out indicates that record high values are more likely to have occurred in recent years, and record low values are more likely to have occurred in earlier years.



(Left) Australian temperature anomalies, 1910-2011; (right) temporal locations of record high (red) and low (blue) daily minimum temperatures at ACORN-SAT stations

9. References and further information

References

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Data and further information

The data set and detailed documentation are freely available through the Australian Bureau of Meteorology website at http://www.bom.gov.au/climate/change/acorn-sat/. The Technical Reports below may also be found at this site. Fuller documentation of the data set, and methods used in its development, may be found in:

Fawcett, R.J.B., Trewin, B.C., Braganza, K., Smalley, R.J., Jovanovic, B. and Jones, D.A. 2012. On the sensitivity of Australian temperature trends and variability to analysis methods and observation networks. *CAWCR Technical Report 50*, Centre for Australian Weather and Climate Research, Melbourne, 60 pp.
Trewin, B.C. 2012. A daily homogenized temperature data set for Australia. *Int. J. Climatol.*, published online 13 June 2012.
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