

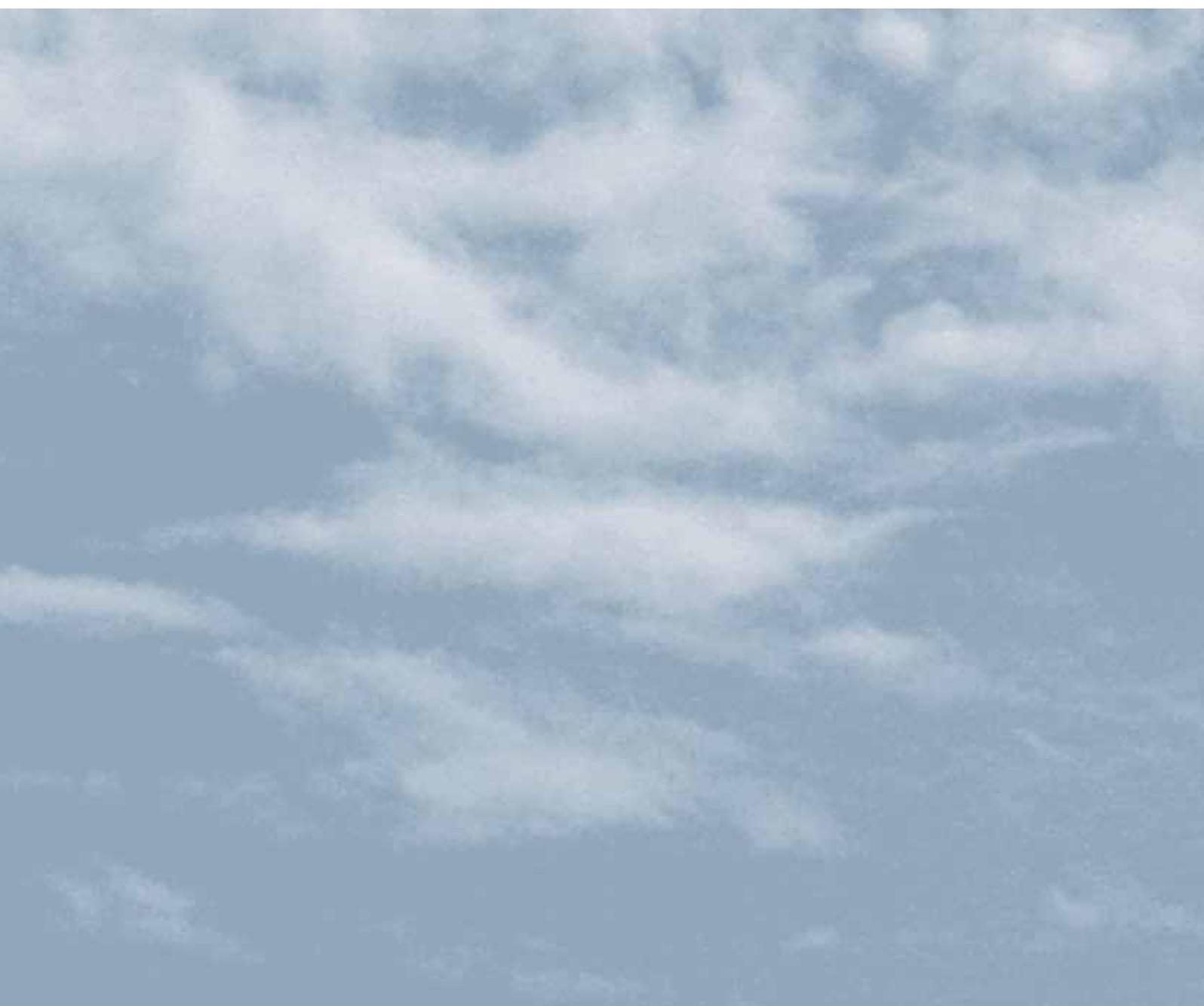


**Australian Government**

**Bureau of Meteorology**

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

Report of the Independent Peer Review Panel  
4 September 2011



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# Independent Peer Review of the ACORN-SAT Data-set

Dr Rob Vertessy  
Deputy Director, Climate and Water  
Bureau of Meteorology  
GPO Box 1289  
MELBOURNE 3001

Dear Dr Vertessy,

We have pleasure in providing you with the report of the Independent Peer Review of the ACORN-SAT data-set.

Our report is based on extensive documentation including the very detailed resource material provided to the Review Panel by your staff - for which we express our appreciation. We appreciate also the patience of your staff during our intensive questioning of them as we worked through the review week (7 to 12 August 2011).

Although we have been kindly assisted by your staff in these ways, we take full responsibility ourselves for the findings we have made.

Our report is framed closely around the terms of reference provided for our review. Even so, the Panel emphasises that the terms of reference have not constrained us from investigating and commenting on any other issues we considered could be relevant

We have been pleased that the skills and experiences of the different Panel Members have been so complementary. With our diverse professional backgrounds and international experiences we have been able to explore many different aspects of the ACORN-SAT system. As a result, our review has investigated a wide range of technical, scientific, statistical and management aspects of the developing ACORN-SAT project.

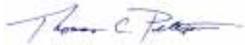
Although the principal purpose of the independent peer review was to evaluate the Bureau's approach to the ACORN-SAT data-set and to make an assessment of the overall level of confidence that can be placed in the climate trends that may be inferred from the data-set, we have also taken the opportunity to make a number of specific recommendations for action. We would not wish these recommendations for change to be misinterpreted as undermining our overall positive assessment of the data-set. Rather, the recommendations are practical suggestions to further improve what will become a valuable national and international asset when it is launched.

We commend the report to you and trust it will be of value to the Bureau as the project proceeds.

Yours sincerely



Ken Matthews AO  
Chair  
4 September 2011



Thomas Peterson PhD  
Panel Member



Xiaolan Wang PhD  
Panel Member



David Wratt PhD  
Panel Member

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# 1. Introduction

## “What’s past is prologue” – William Shakespeare, *The Tempest*

Historical weather observations can provide valuable insights into climate change. Unfortunately, there are very few weather stations in the world today that observe daily maximum and minimum temperatures in exactly the same way that they did a century ago. Thermometers change; the shelters that house the thermometers change; observing practices, such as the time of day the thermometers were read, change; and the stations themselves are moved or old ones closed down while new ones are opened. All of these changes impact the historical record.

A large and growing body of scientific analysis has assessed ways to address these and other difficulties in creating an accurate national temperature time series. Australian scientists have been in the forefront of this work for decades and have collaborated with scientists around the world. The World Meteorological Organization (WMO) has helped foster some of this collaboration, but the WMO does not yet provide clear guidance on all the best practices to use when moving from station data with non-climatic artefacts in them to a large area-averaged time series which faithfully reflects the actual climatic variability and change. Therefore, the Bureau of Meteorology asked the Panel to review their processes and procedures (see Appendix 1 for the Terms of Reference).

The Australian Climate Observations Reference Network-Surface Air Temperature (ACORN-SAT) is a long-term data-set of Australian daily air temperature, covering the period from 1910 to the present. Its purpose is to provide the best possible data-set for analyses of variability and change of temperature in Australia. This includes analyses

of annual and seasonal mean temperatures as well as extremes derived from daily observations. Much of the motivation for this data-set is producing an Australian average temperature assessment but the data-set must also have fidelity on sub-national regional scales, that is, analyses that involve averaging data from several stations in a particular area.

The Panel’s review, therefore, focuses on whether the processes and practices of creating ACORN-SAT produced a data-set that meets these needs. Achieving that goal is more than just data processing. The ACORN-SAT derived trends are so important to so many people that the data-set must be created with the highest possible level of transparency. Furthermore, tests need to be run and documented to assess whether the data are indeed free of systematic non-climatic influences. There is no single best way to produce national temperature time series against which to compare ACORN-SAT but there are aspects of the process which can be compared to widely accepted international best practices. In addition to assessing ACORN-SAT, the Panel has made recommendations that have the potential to improve the fidelity of the data, the transparency of the data-set creation process, and to document the robustness of the data-set.

The Bureau of Meteorology asked the Panel to specifically address five aspects: observing practices, station selection, data homogenisation, calculation of trends, and overall confidence in ACORN-SAT. The Panel specifically added communications and transparency to this list and organized the report around these criteria. But to help see these parts as a unified whole, the report starts with a summary of the Panel’s key findings.

## 2. High Level Findings of the Panel

The following are the Panel's highest level findings. More specific and detailed findings are in the respective sections of the report.

1. The Panel affirms the considerable national and international value of the ACORN-SAT data-set and encourages the Bureau to consider the data-set an important long-term national asset.
2. The Panel is satisfied, overall, with the methodologies used by the Bureau to date in its development of the ACORN-SAT data-set given the purposes for which it is intended. This is the key finding of the review Panel.
3. The Panel encourages the Bureau to improve the public transparency of ACORN-SAT arrangements. This will not only build public confidence in the data-set but should assist the Bureau in its continuous improvement efforts and its responsiveness to data users.
4. The Panel also encourages the Bureau to more systematically document the processes used, and to be used, in the development and operations of ACORN-SAT. Some aspects of current arrangements for measurement, curation and analysis are non-transparent even internally, and are therefore subject to significant "key persons risk", as well as a risk of inconsistency over time.
5. While the Panel is broadly satisfied with the ACORN-SAT network coverage, it is concerned that network coverage in some of the more remote areas of Australia is sparse. Targeted investments in a small number of additional sites in remote Australia would likely be a good investment, particularly for improved regional temperature trend analysis.
6. Completing the development of the ACORN-SAT network and data-set and sustaining it into the long term will continue to raise a number of challenging research questions. The Panel suggests that the Bureau consider internal management arrangements that more effectively integrate service delivery functions with the necessary research capacity.
7. Effective completion and operation of the network into the future will also require good coordination of efforts within the Bureau. The Panel has observed occasional deficiencies in internal coordination and suggests that the Bureau design measures to improve internal liaison arrangements to address this issue.

### 3. Detailed Findings and Recommendations

#### A. The Observation Practices Employed by the Bureau of Meteorology for Surface Air Temperature Measurements

*The Panel finds that the Bureau's observing practices for the ACORN-SAT network are above average standard with respect to current international practice. Adherence to these observing practices enables determination of multi-decadal national climate trends from the ACORN-SAT observations once they have been quality control checked and homogenised. But there is room for some improvements.*

The Bureau supports and seeks to observe the “Ten principles for long-term sustainable climate monitoring<sup>1</sup>” adopted by the UN Framework Convention on Climate Change and endorsed by the Global Climate Observing System. Practices for the siting, installation and inspection of observing stations follow as closely as possible the standards documented in the *Surface Observations Handbook* (Bureau of Meteorology c. 2011a) and the *Inspections Handbook* (Bureau of Meteorology c. 2011b), and these documents also guide the selection of equipment and the day-to-day operations of measuring and reporting temperatures at the observing sites. However, as identified by the Bureau's 2005 Basic Observing System Study, the surface temperature observation network fails to meet the internationally recommended minimum spatial density through much of inland Australia.

Throughout the period covered by the ACORN-SAT data-set, observing practices have been guided by documented national or international practice. For example Instructions to Country Observers in 1907 states that temperature observations conform to international regulation from British Meteorological Services, and to a lesser extent, USA Weather Bureau

Documents (Commonwealth Meteorology, 1907). A further strength of the observations used in the ACORN-SAT data-set is that throughout the period since 1910 covered by the series the observations have been made from temperature sensors located within standard Stevenson screens<sup>2</sup>. While the designs of these screens have experienced some modifications during the ACORN-SAT period, the Bureau has carried out tests that show the influence of these design changes on temperature measurements has not been material.

The standards documented in the Bureau's “Observations” and “Inspections” handbooks are generally compatible with standards laid out in the World Meteorological Organization's Guide to Meteorological Instruments and Methods of Observation (WMO, 2008). However they are not identical. The WMO Guide states that an acceptable range of error for thermometers (including those used for measuring maximum and minimum temperature) is  $\pm 0.2$  °C. However, throughout the last 100 years, Bureau of Meteorology guidance has allowed for a tolerance of  $\pm 0.5$  °C for field checks of either in-glass or resistance thermometers. This is the primary reason the Panel did not rate the observing practices amongst international best practices.

The Review Panel received advice from Bureau instrumentation specialists that the platinum resistance thermistors presently used for temperature measurements generally perform within a narrower band than these Bureau tolerance limits, and that it would be possible to set tighter tolerances for future operations. The Panel would like to see such a move to tighter tolerances, at least meeting the WMO-suggested  $\pm 0.2$  °C.

<sup>1</sup> The Ten Principles are documented in Appendix 2 of this report.

<sup>2</sup> The Stevenson Screen is a particular type of wooden white louvered instrument shelter, designed to minimise errors caused by radiative heating or cooling of the temperature sensor.

Bureau specialists on quality control and homogenisation of temperature data advised the Review Panel that if the performance of a thermometer at a particular measurement site strayed towards the outer bounds of the inspection tolerance limits, this would be picked up by the quality control and homogenisation analyses, and corrected through homogenisation. Nevertheless, the Panel recommends that analysis should be undertaken and documented to support this contention. This analysis should also examine the influence (if any) of this tolerance on the uncertainty range in both individual station and national multi-decadal temperature trends calculated from the ACORN-SAT temperature series.

In some countries (e.g. US, Canada), the Reference Climate Station Network sites used for producing data-sets similar to ACORN-SAT contain three independent temperature sensors. This provides redundancy should one sensor fail, and also allows a continuous check of whether a sensor is going out of calibration. It would be prudent for the Bureau of Meteorology to adopt a similar procedure, beginning with isolated sites in the more remote areas of Australia which carry a particularly heavy weight within the gridded analysis used to determine the national temperature trends.

The documentation of metadata including site characteristics, instrumentation and setup dates, dates of inspection visits, results of sensor tolerance tests, and visual observations of site conditions, is a vital part of observing processes. While the Bureau has an electronic catalogue of metadata from recent years, significant metadata from earlier periods for some of the ACORN-SAT sites still exists only in paper records. The Review Panel encourages the Bureau to continue its process of moving earlier metadata into electronic form, at least as images of the paper documents, and preferably through digital entry of relevant data. The Bureau has advised that for privacy reasons regarding observers the Bureau cannot make its metadata database publicly available through the internet. However, the Panel considers that for transparency reasons it would be useful if sufficient metadata to allow independent replication of homogeneity analyses for individual ACORN-SAT sites was included within the public ACORN-SAT station catalogue being developed by the Bureau.

**Recommendations:**

The Review Panel recommends that the Bureau of Meteorology should implement the following actions:

- A1 Reduce the formal inspection tolerance on ACORN-SAT temperature sensors significantly below the present  $\pm 0.5$  °C. This future tolerance range should be an achievable value determined by the Bureau's Observation Program, and should be no greater than the  $\pm 0.2$  °C encouraged by the World Meteorological Organization.
- A2 Analyse and document the likely influence if any of the historical  $\pm 0.5$  °C inspection tolerance in temperature sensors, on the uncertainty range in both individual station and national multi-decadal temperature trends calculated from the ACORN-SAT temperature series.
- A3 The Review Panel suggests that the Bureau should give more attention to building redundancy into ACORN-SAT observation stations, particularly stations in remote areas of Australia. This can include redundancy in sensors, loggers, data storage and communications equipment, especially as the inexorable international trend towards automatic weather stations continues. The Panel suggests that the Bureau develop a strategy to make cost-effective investments in redundancy to ensure the continuing resilience of the ACORN-SAT network.
- A4 The Review Panel noted that most but not all of the possible historical monthly temperature records have been digitised, and that some daily ACORN-SAT data remains undigitised. The Panel welcomes the statements they received from Bureau staff that undigitised ACORN-SAT records will be targeted for future digitisation. The residual set of non-digitised data and metadata paper records for ACORN-SAT observation stations should be located as a matter of priority, and imaged. It is important that the digitisation of these remaining paper only daily temperature records then be completed.

- A5 If resources for this task are not available, the Bureau should investigate the feasibility of using crowd-sourcing techniques to accelerate the completion of the ACORN-SAT data digitisation process.
- A6 The Bureau should include sufficient station metadata within the public ACORN-SAT station catalogue currently under development, to allow independent replication of homogeneity analyses for individual ACORN-SAT stations.

## B. The Methodology Used to Select Stations for the ACORN-SAT Data-set

*The Panel finds that the methodology used to select stations from the historical archive for the ACORN-SAT data-set would be appropriate with minor adjustments. The selected network allows confident determination of multi-decadal national temperature trends and variability for Australia. For the future, installation of some further observation sites in remote data-sparse regions in the centre of the country would improve the capability of the ACORN-SAT data-set to robustly indicate sub-national regional trends and variability.*

There are two parts to selection of stations for the ACORN-SAT data-set. The first is the selection of stations from the past for the data-set used for ACORN-SAT analyses of past trends. This selection is necessarily constrained to already existing stations. The second part is the maintenance (and possibly expansion through installation of additional stations) to enable and if possible improve the data-set for scientists to use in future decades to identify national and sub-national temperature trends.

The Panel noted that some stations initially proposed for the ACORN-SAT network were not used in the preliminary trend analyses presented to the Panel. We were advised that the Bureau intends to include some of these stations in its final data-set after some further analysis. It is important to understand why strong spatial variations remain in the trends in some areas after applying an automatic pairwise homogeneity adjustment procedure. Should the further analysis lead to homogeneity adjustments different from those based on the methodology described, the Panel emphasises the importance of documenting the objective basis for these changes. Similarly, should any of these remaining stations not be included in the final data-set, the Panel emphasises the importance of documenting the objective basis for their exclusion.

Bureau staff have undertaken and published studies of the adequacy of digitised historical Australian temperature data for monitoring monthly and daily temperature anomalies and variability (Jones and Trewin 2000, 2002). From this work, and from the spatial analyses provided within the supporting material for our review, the Panel concludes that the methodology used to select historical stations for the ACORN-SAT data-set was adequate to allow robust analyses of nationally-averaged temperature trends and variability. The ability to robustly determine patterns of trend and variability over smaller sub-national areas varies across the country, depending on the density of the selected station network. Estimates of trends in remote central and north-western Australia are very dependent on just a few ACORN-SAT stations.

The Review Panel therefore considers that the ability of future scientists to robustly determine trends and variability in these data-sparse regions could be improved by selecting and / or installing some additional stations. Although the Panel recognises this would involve costs, we encourage the Bureau to consider such an activity, bearing in mind the analysis by Jones and Trewin (2002).

For the future, a proactive management approach will be required for maintaining and in some cases changing the list of stations used in the ACORN-SAT set. For example, the Panel was advised that commercial developments on some airports, and/or rapidly appreciating values of land on which some ACORN-SAT sites are located, may lead to some ACORN-SAT sites becoming untenable in future. Management of the station set requires close communications and collaboration between staff from the Climate Information Program and the Observation Program. This will include consultation over installation or selection of new stations to replace untenable existing stations, and proactive planning for adequate periods of overlapping observations to allow record homogenisation.

The Review Panel understands that consultation and liaison between Climate Information Program and Observation Program staff has waxed and waned over the years, but that improved consultation mechanisms are currently being established. The Panel encourages the Bureau to maintain and in fact strengthen these consultation and liaison arrangements.

**Recommendations:**

The Review Panel recommends that the Bureau of Meteorology should implement the following actions:

- B1 The Bureau should clearly define, document and observe objective criteria for selecting stations for, and excluding stations from, the ACORN-SAT network.
- B2 Develop the investment case for a limited number of additional observation stations in remote (central and north-western) Australia which would further enhance the robustness of ACORN-SAT data for trend analysis work in regional Australia.
- B3 Require that when any area of the Bureau is considering the possibility of observation station closures or operational changes in future years, special consideration be given to the importance of continuity in the ACORN-SAT data series, and custodians of the ACORN-SAT data-set should be consulted before decisions are taken.
- B4 To provide maximum notice of the possibility of the (undesirable) closure of ACORN-SAT observation stations in the future, the Bureau should initiate a study of the viability and continuing long-term availability of the present ACORN-SAT observation sites. This would enable proactive preparations to minimise the negative impacts of such closures, including the timely establishment of overlapping observation stations.
- B5 Maintain and improve mechanisms for consultation and collaboration between Climate Information Program and Observation Program staff, regarding ongoing planning for and operation of the ACORN-SAT network.

**C. The Approach and Methodologies Applied to these Data to Ensure the Homogeneity of the Data-set**

*The Panel finds that the approach and methodologies applied to ensure the homogeneity of the ACORN-SAT data-set are amongst international best practices. Indeed, the Panel considers the Bureau to be at the forefront in this field. Internationally, the ACORN-SAT is the first national-scale homogenized data-set of **daily** minimum and maximum temperatures. It will be very useful for assessing changes in temperature extremes, in addition to changes in mean temperatures.*

Although a few countries are developing a similar data-set (e.g., Canada), none has gone as far as the Bureau has. Documentation of the ACORN-SAT approach would be helpful for other countries to develop a national-scale homogenized daily temperature data-set.

A homogeneous climate record is one that fluctuates and changes only in response to weather and climatic variations. The Bureau's approach to data homogenization consists of the following major steps:

- Comprehensive investigation of available metadata – search for documented changes in the instrumentation, location and environment of observation, and in observing practice, etc., that took place in the period of data record; these changes might introduce non-climatic changes to the temperature records.
- Implementation of a comprehensive suite of quality control checks, to eliminate data errors arising from instrumentation faults, observer/transmission errors, etc. These are typically isolated errors, occurring at one or a few consecutive observing times.
- Detection of systematic non-climatic effects in the temperature data series using statistical tests along with metadata information obtained from the first step above.
- Adjusting the temperature data series to diminish non-climatic changes therein.

The method used for statistical detection of potential non-climatic changes broadly follows the method used by Menne and Williams (2009) in the United States. It is a relative homogeneity testing method, one that is based on comparing “neighbouring” station records (stations that are in the same climate regime, having similar climatic variations). The major underlying statistical test is the Standard Normal Homogeneity Test (Alexandersson, 1986), which is one of the most powerful and commonly used internationally.

The method used to adjust daily temperature data for non-climatic changes is a quantile-matching algorithm. This algorithm adjusts the data to diminish artificially induced changes in the whole distribution of data, not just in the mean. This is necessary for daily data, especially if they are used to analyse extremes, because artificial changes could be regime-dependent. For example, the difference between two sites (before and after a site move) could be larger when it is warm than during cold conditions, or vice versa.

While affirming the national and international value of the ACORN-SAT data-set and the Bureau’s international leadership in this field, the Panel finds that there is room for improvement and we make some specific recommendations.

#### **Recommendations:**

The Panel recommends that the Bureau of Meteorology should implement the following actions:

- C1 A list of adjustments made as a result of the process of homogenisation should be assembled and maintained and made publicly available, along with the adjusted temperature series. Such a list will need to include the rationale for each adjustment.
- C2 The computer codes underpinning the ACORN-SAT data-set, including the algorithms and protocols used by the Bureau for data quality control, homogeneity testing, and calculating adjustments to homogenize the ACORN-SAT data, should be made publicly available. An important preparatory step could be for key personnel to conduct code walk throughs for members of the ACORN-SAT team.
- C3 Both the raw and the homogenized ACORN-SAT data-sets should be analysed with the same gridding and trend analysis method, to identify the effects of the data homogenisation.
- C4 The Bureau should better clarify whether or not there have been any network-wide changes in the instrument/observing practices that took place at all stations across large portions of Australia at about the same time. If so, it will be important to demonstrate how these network-wide changes have been addressed. This is important because tests based on comparing neighbouring station records usually cannot detect network-wide changes.
- C5 The Bureau is encouraged to calculate the adjustments using only the best correlated neighbour station record and compare the results with the adjustments calculated using several neighbouring stations. This would better justify one estimate or the other and quantify impacts arising from such choices.
- C6 The Panel notes the intention of the Bureau to consider “in-filling” data gaps in a small number of stations’ data records. The Panel strongly recommends that, if the Bureau proceeds with this work, the processes should be carefully documented, and the in-filled data should be flagged and maintained separately from the original.
- C7 Before public release of the ACORN-SAT data-set the Bureau should determine and document the reasons why the new data-set shows a lower average temperature in the period prior to 1940 than is shown by data derived from the whole network, and by previous international analyses of Australian temperature data.
- C8 Prior to release, the Bureau should establish version control arrangements for the raw and homogenised ACORN-SAT data-sets to accommodate the evolving techniques of data homogenisation and the potential addition of more digitized data to the ACORN-SAT data-set. This would enhance the traceability of the data-set and decrease potential confusion among data-set users.

#### **D. The Methodologies Applied in the Analysis of Temperature Trends in the ACORN-SAT Data-set**

*The Panel finds that the methodologies applied in the analysis of national trends in the ACORN-SAT data-set are appropriate.*

This part of our review addresses the methodologies used to determine trends from ACORN-SAT, not the actual values of the trends nor the underlying data used in calculating the trends.

The first step of Bureau's approach to determining temperature trends is to interpolate monthly station temperature anomalies across the continent to completely fill in a gridded field with grid points approximately every 25 by 25km. The interpolation technique used is the Barnes successive correction method which determines each grid point value using data from multiple stations based on the distance the stations are away from the grid point. The closer the station, the more it is weighted. This process smoothes the data. The successive correction part of the Barnes method prevents too much smoothing as well as the fabrication of structures in the gridded field that are not in the underlying data. While technically no grid point value is produced solely from data from a single station, in practice, where stations are few and far apart, grid point values do primarily rely on the data from just that one nearest station. A key value in using this technique in ACORN-SAT is that the Bureau uses this approach in its other gridded data-sets and maps produced from them for climate monitoring so that creators and users alike are familiar with this level of smoothing. Once the complete monthly gridded fields are created, trends are calculated at each grid point.

The Panel considers that the ACORN-SAT national anomaly temperature series can be relied on to quantify national climate variability and change. The Panel is aware that some remote stations in data-sparse areas make significant contributions to the contoured regional trends. This is why the Panel encourages adding a limited number of stations to the ACORN-SAT data-set in remote areas to improve assessment and monitoring of sub-national regional temperature trends.

The Panel considers the ACORN-SAT national anomaly temperature series can be relied on to quantify national climate variability and change. The Panel is aware that one station, Alice Springs, contributes 7-10% of the signal which is why the Panel encourages adding a limited number of stations in remote areas to improve assessment and monitoring of sub-national regional temperature trends.

One would expect very different techniques would produce somewhat different trends. Yet when the Bureau compared ACORN-SAT's national time series with the Australian portion of several global data-sets, for periods when the data used by the different analyses were similar, the data-sets exhibited essentially the same long-term climate variability and change. This further strengthened the Panel's view that the ACORN-SAT national temperature time series is robust.

However, maps of temperature trends had "bullseyes" patterns apparently associated with individual stations in data sparse regions. The Panel agrees with the conclusion of Easterling et al. (1996) that "care must be taken when using either the adjusted or unadjusted time series for an individual station, and it is our opinion that the optimal use of adjusted climatological time series is in the development of more robust regional analysis."

#### **Recommendations:**

The Panel recommends that the Bureau of Meteorology should implement the following actions:

D1 While the Bureau compared Australian national average ACORN-SAT temperature trends with trends from satellite data, the spatial pattern of trends derived from ACORN-SAT, particularly in data sparse areas, should also be compared to the spatial patterns of trends in satellite temperature observations. The absolute value of the trends may be different, but even satellite-derived temperatures of the lower troposphere produce spatial patterns of trends that commonly agree with the spatial pattern of in situ surface temperature. Comparing these different data-sets therefore has the potential to help identify and quantify potential artefacts in the sub-national ACORN-SAT trend patterns.

- D2 The Bureau should give careful consideration to the best form of visual presentation of temperature trends across the Australian continent. For example, the addition of dots at station locations shaded to indicate each station's trend can help the viewer visually assess whether a particular feature is the function of data from many stations or a single station. If a station only contributes information to part of the period being analysed it would not be an apples to apples comparison to shade that station location with the trend value for a different period. However, simply indicating the location of stations with partial periods would aid in understanding the causes of the spatial patterns of trends. Similarly, "bubble plots", which represent the magnitude of station trends by the size of a circle and the sign of a trend by the colour of the circle, provide a level of information hidden in the Bureau's standard maps. So the Bureau should consider providing this information as well as companion figures.
- D3 The Bureau should compare temperature time series in a variety of subsets of stations versus different subsets, or the network as a whole, to assess and document the robustness of the data with respect to various classes of stations. These comparisons can be across the whole continent or averages of multiple neighbouring station comparisons. Examples of classes of stations that should be compared include (i) town stations versus country stations, (ii) airport stations versus non-airport stations, (iii) synoptic stations versus daily stations, (iv) liquid-in-glass thermometer stations versus electronic thermometer stations, and (v) stations that have undergone changes in their daily times of observation versus stations that have not.
- D4 The Bureau should specify the statistical uncertainty values associated with calculating Australian national temperature trends and make this information readily available whenever trends are discussed. Additionally error bounds or confidence intervals along the time series would be useful.
- D5 The Bureau has adopted the practice that monthly mean temperatures are calculated from daily temperature data for months with fewer than 10 missing daily values. If 9 days at the beginning of a month were missing, there is potential to miss a significant portion of that month's climate signal. The Panel suggests the Bureau revisit this issue by conducting an analysis of the trade offs between decreasing the accuracy of the final analysis by not including as many valid monthly values versus the size of the potential error in a monthly value due to various levels of missing values.
- D6 The Bureau should more actively investigate the possible use of non-instrumental proxy indicators of temperature such as ecological indices or paleo-climatic data to further test and validate the sub-national regional robustness of the ACORN-SAT data-set. This is an example of one of the many research opportunities which will need to be pursued in parallel with the data service delivery functions of the Bureau.

### E. Communications and Transparency

*The Review Panel is convinced that good communications and greater public transparency will be important for the future of the ACORN-SAT data-set. The Panel makes a number of recommendations to improve transparency of specific aspects of the data-set elsewhere in this report. However the Panel considers the communications and transparency issues to be sufficiently important to include the following recommendations which apply to the project as a whole.*

#### **Recommendations:**

The Panel recommends that the Bureau of Meteorology should implement the following actions

- E1 An accessible introductory guide to the ACORN-SAT data-set should be prepared for publication, covering its origins, purpose, functions, operational arrangements, costs, limitations, and international importance. This guide should include a clear explanation of why the ACORN-SAT data-set is needed and how it will improve on the existing network of observation stations.

- E2 For both transparency and internal management purposes, the policies, protocols, procedures and practices for the collection, quality control and adjustment of ACORN-SAT data should be consolidated and kept up to date in a single, binding, program management manual. The contents of the manual should be made available publicly in an accessible form, preferably on the Internet.
- E3 The processes used for network design, data quality control, and data homogenisation in the development of the ACORN-SAT data-set should be published in peer-reviewed journals.
- E4 A Technical Advisory Group should be established to meet approximately annually, to review progress on the development and operation of the ACORN-SAT data-set. The Group should comprise respected external scientists and statisticians, as well as representatives of data users, stakeholders with relevant experience in regional Australia, and representatives from other relevant functional areas of the Bureau. An alternative would be to establish a by-invitation annual technical advisory forum involving respected external scientists, statisticians and stakeholders to provide an opportunity for external comment on the further development of the ACORN-SAT system.
- E5 When the ACORN-SAT data-set is released, the release package should include not only technical details of the data-set and the temperature trend estimates derived from the set, but also careful explanation and interpretive commentary about what the data series says about long-term temperature trends in Australia with a particular focus on the differences and reasons for the differences from other data-sets.
- E6 The Review Panel recommends that the Bureau assemble and maintain for publication a comprehensive list of initiatives it has taken to improve transparency, public accessibility, and comprehensibility of the ACORN-SAT data-set.

## **F. The Overall Level of Confidence that can be Placed in the Temperature Trends that have been Inferred from the ACORN-SAT Data-set**

*Against the background of the above, the Review Panel has a high level of confidence in the national temperature trends that can be inferred from the ACORN-SAT data-set. The Panel's level of confidence in trends in temperature for certain areas of remote Australia (specifically, remote central Australia and north-western Australia) is somewhat lower. This judgement underpins the Panel's several recommendations above about the need for the Bureau to give more attention to observation stations in remote areas of Australia.*

The Panel's overall confidence is derived from its close examination of the Bureau's observation practices, its network selection methodology, its approach to data homogenisation, and its methodologies for the analysis of trends. All of these factors need to be satisfactorily handled before stakeholders can be confident about findings based on the data; a failure in any one of these factors will result in a loss of stakeholders' confidence in the system as a whole.

But the confidence of public stakeholders needs always to be nurtured in other ways as well. For that reason the Panel has placed special emphasis in its report on the need for good communications and greater transparency of the development and operations of the ACORN-SAT system. A side benefit of this transparency for the Bureau is that useful suggestions for improvements and refinements to the ACORN-SAT system will almost certainly be made.

Also underpinning the Panel's overall confidence is our assessment of the very high calibre of Bureau staff who are developing the ACORN-SAT system. While this has been an important factor in the success of the project to date, it poses an inherent risk for the future as key members of staff turn over. To manage that risk (as well as to improve transparency) the Panel has made a number of recommendations that procedures and practices should be better documented and a program management manual developed.

The Panel is convinced that, as the world's first national-scale homogenised data-set of daily temperatures, the ACORN-SAT data-set will be of great national and international value. We encourage the Bureau to consider the data-set an important long-term national asset.

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# Appendix 1: Terms of Reference for the Review

1. Review and provide comments on:
  - (a) The observation practices employed by the Bureau of Meteorology for surface air temperature measurements;
  - (b) The methodology used to select stations for the ACORN-SAT data-set;
  - (c) The approach and methodologies applied to these data to ensure the homogeneity of the data-set, with particular emphasis on:
    - i the relocation of sites;
    - ii changes in observation practices;
    - iii changes in instrumentation; and
    - iv urban heat island effects.
  - (d) The methodologies applied in the analysis of trends in the ACORN-SAT data-set; and
  - (e) The overall level of confidence that can be placed in the climate trends that have been inferred from the ACORN-SAT data-set.
2. Provide the Bureau with any additional guidance or comments on the compilation and analysis of climate data time series for use in climate change detection; and
3. Provide a written report on the above actions, by no later than 9 September 2011.

The Panel was also asked to apply an evaluative score to Terms of Reference 1(a) to 1(e), selected from the following table:

Term of Reference	Evaluative score
1a. The observation practices employed by the Bureau of Meteorology for surface air temperature measurements	1. Amongst international best practice 2. Above average standard 3. Average standard 4. Below average standard 5. Well below average standard
1b. The methodology used to select stations for the ACORN-SAT data-set	1. Appropriate 2. Would be appropriate with minor adjustment 3. Inappropriate and requires major adjustment
1c. The approach and methodologies applied to these data to ensure the homogeneity of the data-set	1. Amongst international best practice 2. Above average standard 3. Average standard 4. Below average standard 5. Well below average standard
1d. The methodologies applied in the analysis of trends in the ACORN-SAT data-set	1. Appropriate 2. Would be appropriate with minor adjustment 3. Inappropriate and requires major adjustment
1e. The overall level of confidence that can be placed in the climate trends that have been inferred from the ACORN-SAT data-set	1. Very high confidence 2. High confidence 3. Moderate confidence 4. Low confidence 5. No confidence

## Appendix 2: The Ten Principles for Long-Term Sustainable Climate Monitoring

The following ten principles<sup>3</sup> for effective monitoring systems for climate have been established under the international Global Climate Observing System (GCOS). These Principles were endorsed by the World Meteorological Organization's Commission for Climatology at its 13th Session<sup>4</sup>. They were adopted (in paraphrased form) by the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) through decision 5/CP.5 at COP-5 in November 1999.

1. The impact of new systems or changes to existing systems should be assessed prior to implementation;
2. A suitable period of overlap for new and old observing systems is required;
3. The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e. metadata) should be documented and treated with the same care as the data themselves;
4. The quality and homogeneity of data should be regularly assessed as a part of routine operations;
5. Consideration of the needs for environmental and climate-monitoring products and assessments, such as Intergovernmental Panel on Climate Change (IPCC) assessments, should be integrated into national, regional and global observing priorities;
6. Operation of historically uninterrupted stations and observing systems should be maintained;
7. High priority for additional observations should be focused on data-poor regions, poorly observed parameters, regions sensitive to change, and key measurements with inadequate temporal resolution;
8. Long-term requirements, including appropriate sampling frequencies, should be specified to network designers, operators and instrument engineers at the outset of system design and implementation;
9. The conversion of research observing systems to long-term operations in a carefully-planned manner should be promoted; and
10. Data-management systems that facilitate access, use and interpretation of data and products should be included as essential elements of climate monitoring systems.

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<sup>3</sup> GCOS Climate Monitoring Principles.  
<http://gosc.org/gcos/GCOS-climate-monitoring-principles.htm>.

<sup>4</sup> World Meteorological Organization, 2001: *Commission For Climatology Thirteenth Session. Geneva, 21–30 November 2001. Abridged Final Report With Resolutions And Recommendations.* World Meteorological Organization, Geneva.





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