



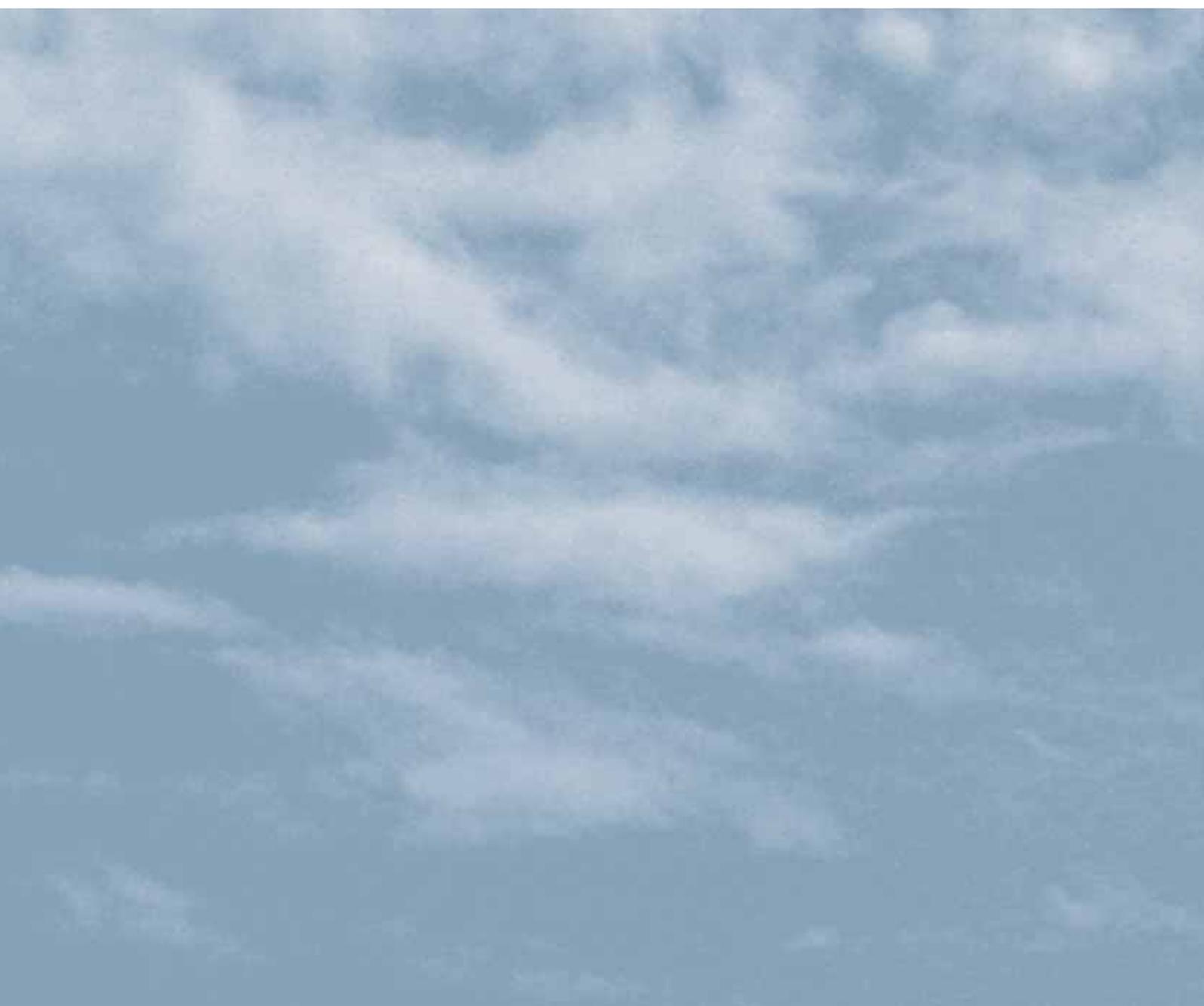
Australian Government

Bureau of Meteorology

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

Bureau of Meteorology response to recommendations of the Independent Peer Review Panel

15 February 2012



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Introduction

This document constitutes the formal response of the Bureau of Meteorology (the Bureau) to the recommendations of the Independent Peer Review of the Australian Climate Observations Reference Network – Surface Air Temperature (ACORN-SAT) data-set and methods (the Review). The Review took place in Melbourne over the period 8–12 August 2011.

The Review makes 31 recommendations regarding the future management of the ACORN-SAT data-set. These relate to the Bureau's observation practices, station selection methodology, data homogenisation process, data analysis methods and approaches to communication with the public and technical peers.

Overall, the Bureau **agrees in full** with 28 of the recommendations, and **agrees in part** with the remaining three recommendations. Several of the recommendations will be implemented ahead of a planned public release of the ACORN-SAT data-set in late March 2012. Some of the recommendations will be investigated but can only be implemented if funding for them can be secured. In a few cases, the recommendations may take several years to implement.

The Bureau wishes to record its sincere appreciation to the Review Panel. In our view, the Review was conducted with a high degree of professionalism and yielded very productive insights and valuable guidance. We are confident that the Review process will enable the Bureau to enhance the robustness and utility value of the ACORN-SAT data-set. We also hope that it will engender public confidence in the quality of the Australian climate record.

Note

This response is the final in a series of eight documents that are part of the Review. Six reports were submitted to the Review Panel, including:

- Report 1 – guidance document
- Report 2 – organisational, data and network context
- Report 3a – methods of dataset development
- Report 3b – sensitivity of Australian temperature variability and trends to analysis methods and observations networks
- Report 4 – surface temperature observing methods
- Report 5 – station catalogue.

The Report of the Independent Peer Review Panel and this Response are the final two documents in the series. All eight Review documents are available from the Bureau's website.

Responses to recommendations

A. The observation practices employed by the Bureau of Meteorology for surface air temperature measurements

A1. Reduce the formal inspection tolerance on ACORN-SAT temperature sensors significantly below the present ± 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 ± 0.2 °C encouraged by the World Meteorological Organization (WMO).

Agreed. The recommendation to reduce the temperature tolerance for ACORN-SAT station sensors will be added to the Bureau's Observing System Rolling Review of Requirements. As a first step, an assessment of the costs of implementing this change will be made.

A2. Analyse and document the likely influence of any of the historical ± 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.

Agreed. The Bureau will undertake a number of *Monte Carlo* simulations using probability distribution functions of observed statistics to gauge potential sensitivities to instrument differences and instrument drift. This analysis will be guided by past thermometer verification results available through the Bureau metadata database SitesDB.

In addition, the Bureau will investigate the ability of the homogeneity detection method to detect typical measurement errors. Results described previously indicated that non-random errors as small as 0.3°C are detectable at the station level, but the robustness of this result will be confirmed.

An analysis of the results of existing instrument tolerance checks was also carried out. This found that tolerance checks, which are carried out six-monthly at most ACORN-SAT stations, were within 0.2 °C in 90% of cases for automatic temperature probes, 99% of cases for mercury maximum thermometers and 96% of cases for alcohol minimum thermometers.

These results give us a high level of confidence that measurement errors of sufficient size to have a material effect on data over a period of months or longer are rare.

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 develops a strategy to make cost-effective investments in redundancy to ensure the continuing resilience of the ACORN-SAT network.

Agreed. The Bureau will undertake a study to assess and cost various options for enhancing the resilience of the ACORN-SAT observation network. System redundancy will be introduced gradually over a ten-year period at a rate that is dependent on available funding.

A4. The Review Panel noted that most but not all of the possible historical monthly temperature records are digitised, and that some daily ACORN-SAT data remain 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.

Agreed. Further digitisation and imaging at ACORN-SAT sites will be undertaken, at a rate that can be sustained by available funding. Our overall target will be to digitise records for an additional ten stations over a five-year period, but we will seek funding opportunities to exceed this target.

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.

Agreed in part. Crowd-sourcing offers potential to assist the Bureau in addressing the digitisation challenge. The Bureau is concerned about the highly technical nature of the task and the criticality of maintaining good quality control, and is therefore of the view that crowd-sourcing could be problematic if not very carefully managed. We will give consideration to the inclusion of crowd-sourcing in our future digitisation strategy.

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.

Agreed. Wherever practical, the Bureau will provide information for all station adjustments (as transfer functions in tabular format), cumulative adjustments at the station level, the data for detected inhomogeneities and all supporting metadata. This will be provided in digital form. Summaries of the adjustments will be prepared and available to the public. Site metadata available in electronic format for the ACORN-SAT stations will be made available for viewing in a report or processed format. We will assess how to improve access to the paper metadata records not currently available in digital form.

B. The methodology used to select stations for the ACORN-SAT data-set

B1. The Bureau should clearly define, document and observe objective criteria for selecting stations for, and excluding stations from, the ACORN-SAT network.

Agreed. The selection of sites for the ACORN-SAT was largely objective, chiefly driven by data availability, record length, spatial distribution and coverage of the entire network and data quality as described in Report 3a to the Independent Peer Review. The final ACORN-SAT report will detail this selection process in full detail. The selection of

sites was made to optimise the elements listed above (quality, quantity, spatial distribution and length). This is largely an objective but also a heuristic process that will vary in terms of achievable optimisation across individual sub-regions.

The homogenisation process is an iterative one; with the initial quantile-based adjustments further tested through the spatial intercomparison. This entails looking for spatial homogeneity in the data, including the spatial homogeneity of climate variability and change. This process of iterative quality control will be applied in real-time to the ACORN-SAT data-set, even after release into operations. Hence, the ACORN-SAT data-set will be 'live' when operational.

We note that, at the time of the Review, a small number of ACORN-SAT sites in the 'Review version' of the data-set were flagged for re-evaluation through the iterative process described above. Hence they were removed from the spatial analysis pending re-evaluation of the inhomogeneities and applied corrections. We expect that these station level issues/errors will be largely resolved for the final ACORN-SAT data-set. If any individual site does not pass final review, the reasons for its omission from ACORN-SAT will be clearly described, justified and documented.

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.

Agreed. Options for augmenting ACORN-SAT network coverage in remote, data-sparse regions of Australia will be assessed and costed. Eventual expansion of the network will depend on the availability of funding.

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.

Agreed. This requirement is largely covered in the current version of the Bureau's Observational Change Consultation Protocol, but it is essential this be promulgated, implemented and adhered to. The Bureau will reinforce its planning and governance processes concerned with observing systems to ensure that the special requirements of ACORN-SAT stations are met. The Bureau will give special regard to the 'relative weight' of each station in terms of its influence on the national average temperature. Stations that have a large proportional impact on the national average temperature (by virtue of their isolation) will receive most attention when considering station closures and operational changes.

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.

Agreed. The Bureau will assess the viability of each ACORN-SAT station with a view to identifying possible future disruptions to the supply and quality of surface air temperature data. The assessment, to be completed by July 2013, will also propose strategies for mitigating disruptions, including the timely establishment of overlapping observation sites.

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.

Agreed. The Bureau has re-established the National Climate Centre – Observations and Engineering Branch Coordination Group and regular monthly meetings between the Assistant Directors of Observations, Climate Information Services and Climate and Water Data. The ACORN-SAT network will be added as a standing item at these meetings, with reports to Assistant Directors provided on a quarterly basis.

C. The approach and methodologies applied to these data to ensure the homogeneity of the data-set

C1. A list of adjustments made as a result of the process of homogenisation should be assembled, maintained and made publicly available, along with the adjusted temperature series. Such a list will need to include the rationale for each adjustment.

Agreed. The Bureau will provide information for all station adjustments (as transfer functions in tabular format), cumulative adjustments at the station level, the date of detected inhomogeneities and all supporting metadata that is practical. This will be provided in digital form. Summaries of the adjustments will be prepared and made available to the public.

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 homogenise the ACORN-SAT data, should be made publicly available. An important preparatory step could be for key personnel to conduct code walk-throughs to members of the ACORN-SAT team.

Agreed. The computer codes underpinning the ACORN-SAT data-sets will be made publicly available once they are adequately documented. The Bureau will invest effort in improving documentation on the code so that others can more readily understand it.

C3. Both the raw and the homogenised ACORN-SAT data-sets should be analysed with the same gridding and trend analysis method, to identify the effects of the data homogenisation.

Agreed. This analysis is completed and will be reported in the ACORN-SAT science paper as well as the update to ACORN-SAT Report 3a.

C4. The Bureau should better clarify whether or not there were 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 were addressed. This is significant because tests based on comparing neighbouring station records usually cannot detect network-wide changes.

Agreed. ACORN-SAT Report 3a does address this issue in part and further analysis was carried out since which will be documented in the update to this report and the science paper that follows. For the time being, we note that the principal network-wide changes that occurred are:

- A change in observation times in 1964 from midnight to 0900 at Bureau-staffed stations (about 30% of the total ACORN-SAT network). An analysis based on recent one-minute data found that this had the potential to significantly impact on mean minimum temperatures at stations outside the tropics, and all such stations were checked for any evidence of previously undetected inhomogeneities in 1964, using only non-Bureau-staffed stations as reference stations. This analysis found that in most cases any inhomogeneities arising from this cause were already detected through statistical methods and no further adjustments were necessary.
- The introduction of automatic weather stations (AWSs) into the network and in particular the switchover to AWSs as the primary instrument at Bureau-staffed sites on 1 November 1996. In many cases, as noted in Report 3a, the introduction of an AWS was accompanied by a site change, which was dealt with through the regular homogenisation procedure. An analysis of sites that introduced AWSs without a site change, using only manual stations as reference stations, found no evidence of any systematic inhomogeneity in temperatures arising from AWS introduction.

- The change from imperial to metric measurements on 1 September 1972. Previous work undertaken by the Bureau identified laboratory tests and other evidence suggesting no significant impact, and comparisons with other data (such as low level radiosonde data and Australian region sea-surface temperatures) were inconclusive. It is not proposed to carry out any adjustments in this case, but the issue will be discussed in the updated Report 3a and science paper to follow.

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.

Agreed. The Bureau undertook a sensitivity analysis as recommended and will report on the findings in the update to ACORN-SAT Report 3a. A sensitivity analysis was carried out for various adjustments at stations that were identified as having anomalous trends in either means or extremes. As a result of this, a number of reference series for some adjustments were identified as being inhomogeneous, and the adjustments were thus repeated with a revised set of reference stations and/or a revised time period over which transfer functions were developed. A small number of new adjustments were also made as a result of this process.

C6. The Panel notes the intention of the Bureau to consider 'infilling' 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 infilled data should be flagged and maintained separately from the original.

Agreed. There appears to be a little confusion about this issue. At this stage, the Bureau only intends to publish and disseminate the ACORN-SAT data-set without infilling (i.e. as a composite and homogenised data-set). Should an infilled data product be published, the Bureau will clearly identify it as such and keep it separate from the core ACORN-SAT data-set.

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.

Agreed. Since the Review, the research team has undertaken various additional analyses aimed at understanding this issue. The analyses were conducted in concert with other Review recommendations, including the investigation of network-wide, systematic inhomogeneities and the sensitivity of transfer functions to various different reference stations.

The homogeneity adjustments were revisited and rechecked multiple times, and all additional analyses recommended by the Review were undertaken. The latest version of the ACORN-SAT data-set shows broad consistency between the pre-1940 data, the ACORN-SAT data-set and the Torok and Nicholls data-set.

Additional analyses were also conducted to determine: 1) the impact of individual stations, 2) the impact of homogenisation, 3) the impact of station selection and 4) the impact of spatial analysis method used to form large area averages. Initial results were already presented to the Independent Peer Review Panel and the final results will be reported in the update to ACORN-SAT Report 3b and science paper to follow.

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 digitised data to the ACORN-SAT data-set. This would enhance the traceability of the data-set and decrease potential confusion among data-set users.

Agreed. The Bureau will establish clear version control arrangements prior to the release of the ACORN-SAT data-sets in early 2012.

D. The methodologies applied in the analysis of temperature trends in the ACORN-SAT data-set

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.

Agreed. The Bureau will undertake a spatial comparison of trends in the ACORN-SAT and Microwave Sounding Unit (MSU) lower troposphere temperatures over the period of MSU observations (from 1979 onwards). Results of this comparison will be reported in the updated ACORN-SAT Report 3b. Based on our preliminary investigations, we expect that the comparison will show similar rates of warming at the surface and aloft.

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.

Agreed. The Bureau will present trends in the ACORN-SAT data as bubble plots (where the diameter represents the magnitude of trend and the colour the sign of trend) and as contour plots which show local area average trends calculated on a regular grid. Further, the presentation of contour plots will be optimised to give the maximum predictive power based on spatial cross-validation following the completion of the final version of the ACORN-SAT data-set. This cross-validation means that the smoothness of contour trend plots is maximised to provide the best fit to the data.

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: 1) town stations versus country stations, 2) airport stations versus non-airport stations, 3) synoptic stations versus daily stations, 4) liquid-in-glass thermometer stations versus electronic thermometer stations and 5) stations that have undergone changes in their daily times of observation versus stations that have not.

Agreed. The Bureau will undertake such an analysis, following the completion of the final version of the ACORN-SAT data-set. It is expected that this analysis will be published in a peer-reviewed scientific paper.

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.

Agreed. The Bureau will include statistical trend uncertainties in the supporting documentation to the final ACORN-SAT data-set. This will define the uncertainty associated with the statistical modelling of trends alone. A full error analysis will not be undertaken at this stage owing to uncertainty about structural errors in the ACORN-SAT data-set

which can never be fully known and the ability to adequately and consistently define these through time. The Bureau will explore this issue in subsequent analyses of the ACORN-SAT data-set. We are of the view that confidence and uncertainty is best assessed through sensitivity analysis (for example, assessing trends across data-sets and time periods) than through a formal and potentially uncertain error propagation approach.

Extensive sensitivity testing was already conducted and the Bureau plans to conduct further research in this area.

D5. The Bureau adopted the practice that monthly mean temperatures are calculated from daily temperature data for months with fewer than ten missing daily values. If nine days at the beginning of a month were missing, there is potential to ignore 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.

Agreed. This issue was largely addressed through the 2007 WMO publication '*The role of climatological normals in a changing climate*' (www.wmo.int/pages/prog/wcp/wcdmp/documents/WCDMPNo61.pdf), which was in part written by a Bureau officer involved in the ACORN-SAT work. The analysis carried out for this publication suggests that the impact of consecutive missing values on potential errors is modest, with ten consecutive missing days in a month having a comparable impact to 13 randomly distributed missing days in a month. The implications of these findings for the ACORN-SAT data-set will be more clearly described and additional sensitivity analysis and justification for decisions supplied.

D6. The Bureau should more actively investigate the possible use of non-instrumental proxy indicators of temperature such as ecological indices or paleoclimatic 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.

Agreed in part. The potential value of non-instrumental proxy indicators of temperature is evident from the extension of drought analyses (for example) in the United States to the pre-instrumental period. The Bureau will explore external funding opportunities to conduct such investigations. The Bureau is participating in the Australian Research Council-funded linkage project ‘South Eastern Australian Recent Climate History’ (SEARCH) at the University of Melbourne. This aims to develop palaeo, documentary and other methods of reconstructing climate series for the period preceding the ACORN-SAT records. As part of the SEARCH project, a PhD student recently completed an 1850 to 1910 homogenisation of non-standard instrumental temperature records for eastern Australia, with supervision, training and access to records provided through the Bureau. The SEARCH project also recently developed an extended, paleoclimate reconstruction of southeast Australian rainfall from 1800 to the present.

E. Communication and Transparency

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.

Agreed. The Bureau will publish a series of reports and scientific papers to support the launch and subsequent use of the ACORN-SAT data-set. These reports will include:

- public brochure (or similar) providing a non-scientific introduction to the ACORN-SAT data-set
- site catalogue describing each of the ACORN-SAT stations and a summary of site metadata, being an update of Report 5 provided to the Independent Peer Review Panel
- detailed description of the ACORN-SAT data, being an update of Report 3a provided to the Independent Peer Review Panel
- detailed description of the trends and variability in the ACORN-SAT data, being an update of Report 3b provided to the Independent Peer Review Panel
- summary report of temperature observation practices in the Bureau affecting the ACORN-SAT data-set and incorporating much of the information Report 4 provided to the Independent Peer Review Panel
- peer-reviewed scientific paper, being an abbreviated and consolidated summary of the updated Report 3a
- peer-reviewed scientific paper, being an abbreviated and consolidated summary of the updated Report 3b
- other items as deemed necessary by subsequent analysis and feedback.

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.

Agreed in part. The Bureau agrees that a manual based entirely on the experience of the ACORN-SAT process would be useful. However, we believe that the commitment to disclosure and pro-active communication already committed to the ACORN-SAT project will provide adequate information to

the public for the time being (see our response to recommendation E1 for a summary of this commitment). The Bureau will initiate a project to prepare a manual that is intended primarily for internal purposes. This will assist in maintaining corporate knowledge of the procedures used in the development and curation of the ACORN-SAT data-set. This manual will be completed by March 2013. The Bureau does not intend to make this document suitable for general public use.

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.

Agreed. The Bureau will publish a detailed description of the ACORN-SAT data-set and analysis methods in a peer-reviewed international journal of high standing. The Bureau will also publish extended technical reports that will be publicly available.

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.

Agreed. The Bureau agrees that there would be value in enhancing the level of technical dialogue around the ACORN-SAT data-set and methods. The Bureau will hold a technical workshop every two years, starting in March 2014 (two years after the public release of the ACORN-SAT data-set) to review the state of the science and to identify possible improvements to the ACORN-SAT database and analysis methods. The Bureau will ensure that a broad range of experts from outside the agency is inducted into the workshop process.

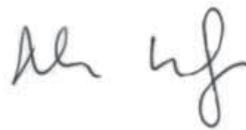
E5. When the ACORN-SAT data-set is released, the release package should include not only technical details of the data-set and the temperature trend estimates derived from the set, but also careful explanation and interpretive commentary about what the data series says about long-term temperature trends in Australia with a particular focus on the differences and reasons for the differences from other data-sets.

Agreed. The release package will include an 'easy-to-read' summary of what the ACORN-SAT data-set shows in terms of temperature trends and will explain differences that exist between it and other long-term climate records of its type. This will be completed by March 2012.

E6. The Review Panel recommends that the Bureau assembles and maintains for publication a thorough list of initiatives it has taken to improve transparency, public accessibility and comprehensibility of the ACORN-SAT data-set.

Agreed. The Bureau will provide such information on the Bureau website by March 2012.

Dr Rob Vertessy



Acting Director of Meteorology
15 February 2012



Australian Government
Bureau of Meteorology

For more information

Visit our website at: www.bom.gov.au