



Australian Climate Observations Reference Network

**Surface Air Temperature
(ACORN-SAT)**

**Report of the Technical Advisory Forum
June 2015**

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Cover image: Clouds over Canberra (Leanne Chow and Department of the Environment)

12 June 2015

The Hon Bob Baldwin MP
Parliamentary Secretary to the Minister for the Environment
Parliament House
CANBERRA ACT 2600

Dear Parliamentary Secretary

It is with great pleasure that I enclose a copy of the first annual report on Australian Climate Observations Reference Network Surface Air Temperature (ACORN-SAT) dataset. I have transmitted the report in parallel to Dr Rob Vertessy, Director of the Bureau of Meteorology, for the implementation of our recommendations.

Thank you for appointing the Forum to review and provide advice on the ACORN-SAT dataset. This dataset represents an important source of information on the climate trends affecting Australia. The Forum believes that its recommendations will ensure that independent scientific expertise is available to the Bureau of Meteorology in managing and improving the dataset.

The Forum is pleased to inform you of the progress made in reviewing the dataset's operation and to provide advice on its future development. In the report, the Forum considered three aspects of the ACORN-SAT dataset as required by our terms of reference:

- the extent of the public availability of the ACORN-SAT information
- developments since the 2011 Independent Peer Review of the Bureau's data and analysis methods
- the scientific integrity and robustness of the Australian climate record and the homogenisation process.

Our report concludes that ACORN-SAT is a complex and well-maintained dataset that has some scope for further improvements. To this end, the report presents recommendations to boost the transparency of the dataset and increase its usefulness in informing decision-making.

The Forum now looks forward to working with the Bureau of Meteorology in implementing the report's recommendations.

I would like to note our thanks for the support of the Department of the Environment in the development of the report. We also record our appreciation of staff from the Bureau of Meteorology in providing information and answering questions on the dataset.

Yours sincerely



Dr Ron Sandland AM FTSE

Chair, ACORN-SAT Technical Advisory Forum

On behalf of: Emeritus Professor Bob Vincent (Vice Chair), Dr Phillip Gould,
Dr John Henstridge, Ms Susan Linacre, Professor Michael Martin, Professor Patty Solomon,
Professor Terry Speed

12 June 2015

Dr Rob Vertessy
Director of Meteorology and CEO
Bureau of Meteorology
Level 3, 14 Childers Street,
GPO Box 2334
CANBERRA ACT 2600

Dear Dr Vertessy

It is with pleasure that I enclose the Technical Advisory Forum's first annual report on Australian Climate Observations Reference Network Surface Air Temperature (ACORN-SAT) dataset. I have also provided a copy of the report to the Parliamentary Secretary to the Minister for the Environment, the Hon Bob Baldwin MP.

The ACORN-SAT dataset represents an important source of information on the climate trends affecting Australia. The Forum believes that its recommendations will ensure that independent scientific expertise is available to the Bureau of Meteorology in managing and improving the dataset.

In the report, the Forum considered three aspects of the ACORN-SAT dataset as required by our Terms of Reference:

- the extent of the public availability of the ACORN-SAT information
- developments since the 2011 Independent Peer Review of the Bureau's data and analysis methods
- the scientific integrity and robustness of the Australian climate record and the homogenisation process.

Our report concludes that ACORN-SAT is a complex and well-maintained dataset that has some scope for further improvements. To this end, the report presents recommendations to boost the transparency of the dataset and increase its usefulness in informing decision-making.

I would like to extend the Forum's thanks to the Bureau staff who provided information and knowledgeably answered our questions on the dataset.

The Forum looks forward to working with the Bureau on implementing our recommendations over the next three years.

Yours sincerely



Dr Ron Sandland AM FTSE
Chair, ACORN-SAT Technical Advisory Forum

On behalf of: Emeritus Professor Bob Vincent (Vice Chair), Dr Phillip Gould,
Dr John Henstridge, Ms Susan Linacre, Professor Michael Martin, Professor Patty Solomon,
Professor Terry Speed

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Executive summary

The Bureau of Meteorology has collected daily temperature records in Australia for more than 100 years. Due to improvements in technology and observation methods, very few weather stations collect daily temperatures in exactly the same way as they did a century ago. Observing practices change, thermometers change, stations move from one location to another and new weather stations are installed. All these changes affect the historical temperature record. The Bureau, like other weather monitoring institutions around the world, faces the complex challenge of analysing temperature trends from a historical record that is affected by these changes. This is done by a process known as homogenisation that is designed to remove artificial systematic errors or artefacts in the raw data.

The Australian Climate Observations Reference Network—Surface Air Temperature (ACORN-SAT) is the Bureau's long-term homogenised dataset of Australian daily temperatures covering the period from 1910 to the present. In light of the importance of the integrity of this dataset in understanding long-term climate trends affecting Australia, the Bureau initiated an independent peer review of ACORN-SAT dataset in 2011. The peer review expressed overall confidence in the Bureau's practices and considered its practices as among the best in the world. One of the recommendations of the peer review was for the Bureau to establish a Technical Advisory Forum to review and provide advice on the ongoing development and operation of the dataset.

The Technical Advisory Forum (the Forum) was established by the Parliamentary Secretary to the Minister of the Environment for a three-year period to annually review the development and operation of ACORN-SAT and to provide advice and recommendations on further developments.

This is the first annual report of the Forum. As per its Terms of Reference, the Forum considered three aspects of ACORN-SAT:

- The extent of the public availability of the ACORN-SAT information;
- Developments since the 2011 Independent Peer Review of the Bureau's data and analysis methods; and
- The scientific integrity and robustness of the Australian climate record and the homogenisation process

It should be noted that the Forum restricted its discussions to the Terms of Reference and issues that stemmed directly from them. It did not address broader issues of global climate change.

The first meeting of the Forum was held over a single day but this was preceded by significant preparation time and detailed follow-up discussions. The discussion that took place on that day and subsequently should be seen as establishing an agenda for continuous improvement consistent with the Bureau’s philosophy. The Forum also notes that Bureau staff demonstrated a strong commitment to answering the questions raised during its deliberations.

The Forum is generally satisfied with the Bureau’s commitment to continuous improvement and their approach to the methodological development and operation of the ACORN-SAT dataset. In particular, the Forum notes the approach adopted by the Bureau in implementing the recommendations of the 2011 peer review and its commitment to transparency and information provision.

The Forum concludes that ACORN-SAT is a complex and well-maintained dataset. In fulfilling its role of providing advice on the ongoing development and operation of ACORN-SAT, the Forum also concludes that there is scope for improvements that can boost the transparency of the dataset and increase its usefulness as a decision-making tool.

The Forum recognises that homogenisation plays an essential role in eliminating artificial non-climate systematic errors in temperature observations so that a meaningful and consistent set of records can be maintained over time. There is a need to adjust the historical temperature record to account for site changes, changes in measurement practices and identifiable errors in measurement. The Forum considers that the analyses conducted by the Bureau reflect good practice in addressing the problem of how to adjust the raw temperature series for systematic errors. To this end, the Forum supports the need for the Bureau’s homogenisation process to incorporate both metadata-based adjustments and adjustments based on the statistical detection of atypical observations. In the opinion of the Forum members, unsolicited submissions received from the public did not offer a justification for contesting the overall need for homogenisation or the scientific integrity of the Bureau’s climate records.

The Forum notes that the Bureau is recognised internationally for its expertise in methodological approaches to homogenisation. The Forum has made five recommendations to support and inform the Bureau’s approach to continuously improve the ACORN-SAT dataset. Each of the five recommendations is grouped thematically and contains a number of sub-elements. The recommendations predominantly address two key aspects of ACORN-SAT, namely:

- a) improving the clarity and accessibility of information provision—in particular, explaining the uncertainty that is inherent to both raw and homogenised datasets, and
- b) refining some of the Bureau’s data handling and statistical methods through appropriate statistical standardisation procedures, sensitivity analyses, and alternative data fitting approaches.

The Forum considers that its recommendations will deliver improvements to the management and communication of the ACORN-SAT dataset. It is not currently possible to determine whether the improvements recommended by the Forum will result in an increased or decreased warming trend as reflected in the ACORN-SAT dataset.

It is important to note that the Forum has a duration of three years. All five recommendations made by the Forum should be addressed by the Bureau over the three year period. However, the issues that should be given highest priority are marked with one or two asterisks. Those with two asterisks are the most important. Further recommendations may be made at future Forum meetings. Obviously addressing these recommendations will require resourcing and the Forum recognises that the Bureau's ability to address them will be subject to resource availability.

The Forum expects that the progress made towards implementing its recommendations as well as discussion of the need for additional recommendations should be matters for consideration at the next Forum meeting in 2016.

Recommendations

RECOMMENDATION 1:

The Forum recommends that the Bureau continue to improve its communications related to the ACORN-SAT dataset by:

- a. Expediting the Bureau’s current work on developing uncertainty measures¹ in closer consultation with the statistical community. The Forum recommends the Bureau seek to better understand the sources of uncertainty and to include estimates of statistical variation such as standard errors in reporting estimated and predicted outcomes, including:
 - quantifying the uncertainty for both raw and adjusted data;
 - prioritising the provision of explicit standard errors or confidence intervals, which should further inform the Bureau’s understanding and reporting of trends in all temperature series maintained by the Bureau;
 - examining the robustness of analyses to spatial variation; and
 - articulating the effect of correcting for systematic errors on the standard error of resulting estimates. **
- b. Developing a clearer articulation of the purpose for the ACORN-SAT exercise to enhance public understanding of the program, and communicating processes for developing and using ACORN-SAT in a way that is appropriately clear, broad and supported by graphics and data summaries. In particular, the central focus on the Australian annual mean temperature anomaly² as the primary end point of the ACORN-SAT exercise should be reconsidered and a broader narrative around including regional effects should be developed. **
- c. Avoiding jargon in explaining statistical uncertainty that could mean different things in scientific language versus common usage. The Bureau should carefully define or use alternative words without common connotations that are different to the scientific use. *
- d. Maintaining on its website links to journals databases where the public can access peer-reviewed, published research relating to climate science and the ACORN-SAT dataset, and providing example case studies or evidence of other climate analyses by the Bureau and independent bodies that use the ACORN-SAT data. Where such literature can only be accessed by payment of a fee, this should be indicated next to the relevant web link.
- e. Reducing the potential for confusion between temperature series that measure fundamentally different physical quantities (e.g. satellite temperatures are different to air temperatures near the ground) by clarifying the differences between different types of measurements in public statements regarding other datasets. **

1. Such measures could include standard deviations for recorded temperature measurements or standard errors for derived measures such as homogenised temperatures. The development of such measures could allow the development of confidence bands for both raw and homogenised temperature series to properly represent the statistical properties of these measurements.

2. A temperature anomaly is the deviation of a specific temperature value from a long-term (usually 30-year) climatological mean reference value.

RECOMMENDATION 2:

The Forum recommends that the Bureau continue to improve the accessibility of ACORN-SAT data and information by adopting the following:

- a. Utilising a universal text-based format such as CSV for providing both raw and adjusted data.*
- b. Providing the CSV files for the 112 ACORN-SAT stations that contain time series of maximum and minimum temperature records together with the relative contribution (such as a relative weighting or similar) to the Australian average temperature record. This provision should be accompanied by advice consistent with the reconsideration of the Australian annual mean temperature anomaly as a central output of analyses supported by the ACORN-SAT dataset.*
- c. Consolidating all downloads of raw and adjusted data using links on a single web-page.*
- d. Improving the usability of the website for downloading data (both raw and adjusted) to allow downloads of bundled data by year rather than by site, and if possible, the option to download all data with appropriate warnings about file size and potential download costs.*
- e. Releasing the Python computer code for ACORN-SAT as a downloadable link along with all supporting documentation and listing of the technical requirements for the software. The Bureau should also monitor and gather download statistics to gauge demand for this software.*
- f. Publishing a brief, plain-language (as far as possible) description of the criteria for adjustment and the basis for adjustment itself.*
- g. Adopting an at-cost fee-for-service approach for the provision of custom data, noting that the provision of custom data may impose a substantial resource burden on the Bureau. The Bureau should include a statement on the ACORN-SAT website that while reasonable assistance may be provided by the Bureau, extensive assistance may not be provided without an appropriate cost-recovery charge to be determined by the Bureau’s management. Access to the complete data (i.e. without user-requested customisations) should remain free, consistent with the Australian Government’s Open Government Initiative)*
- h. Providing advice on its website about the necessary level of end-user expertise and resources necessary for reproducing the ACORN-SAT analysis.*
- i. Examining the provision of a robust code that supports a level of automation that allows sensitivity analyses to be reasonably undertaken by independent parties.

RECOMMENDATION 3:

The Forum recommends the Bureau should continue to develop and improve the statistical methods employed in developing the ACORN-SAT dataset by adopting the following:

- a. Developing a work program for engagement with the statistical community on an ongoing basis to ensure that its data analysis methods are leading practice.*
 - i. Refining the choice of data fitting functions and identification of temporal changes in the data used within the statistical methods for the ACORN-SAT dataset.**
 - ii. While it is acknowledged that the quadratic function is one valid fit to the available data, the Forum recommends that the Bureau revisit the use of piecewise linear fits or nonparametric smoothers such as LOWESS for the purposes of data description. The Forum strongly recommends that these fitting methods be investigated for public communication about temperature changes over time. The Forum recommends that the Bureau clearly communicate that all such fitted curves should be interpreted as descriptions of available data and cautions against the use of these forms for forecasting or predicting specific future temperature behaviour.
- b. Where breakpoints are identified by statistical means, the Bureau should seek to apply them at the time value at which they were detected (as opposed to applying them from the beginning of the calendar year) , so that, for example, breakpoints in annual series are attributed to the year, while for daily series, breakpoints would be attributed to a specific day.
- c. Undertaking appropriate sensitivity analyses to demonstrate the extent to which the process of adjustment has a material effect on indicative temperature patterns.*
- d. Incorporating weights within the data-fitting process that reflect the differential uncertainty associated with the measurements from pre-1910 and attempting to undertake regional analyses (e.g. for south-eastern Australia).*

RECOMMENDATION 4:

The Forum recommends that the Bureau continue to improve the access and handling of metadata information by:

- a. Providing links to access metadata information for each station via clickable maps.
- b. Developing a framework for standardising metadata information so that adjustments made on the basis of metadata are seen as both transparent and objective. This development should result in a set of agreed guidelines that support digitisation of metadata.
- c. Examining the feasibility of developing a robust, uniform digital format for metadata.
- d. Examining crowd-sourcing as an option for improving data-gathering processes, with appropriate safeguards for ensuring data integrity.

RECOMMENDATION 5:

- a. The Forum recommends that the Bureau continue to expand the ACORN-SAT dataset and supporting analyses.
- b. The Bureau should augment the ACORN-SAT dataset with other data such as ACORN-RAIN to build a more complete understanding of climate trends in Australia and broaden the public discourse on climate change.
- c. Regional sub-analyses should be undertaken as a means for assessing the sensitivity of ACORN-SAT analyses to regional differences.
- d. Further, the possible availability of pre-1910 data at south-eastern sites may allow for a comparative analysis to be performed for south-eastern Australia to assess whether the inclusion of pre-1910 data is worthwhile in attempting to understand current temperature patterns.



1. Introduction

This is the first annual report containing the findings and recommendations of the Technical Advisory Forum on the Australian Climate Observations Reference Network—Surface Air Temperature (ACORN-SAT) dataset.

Australian Climate Observations Reference Network— Surface Air Temperature

The Australian Climate Observations Reference Network—Surface Air Temperature (ACORN-SAT) is a dataset of national temperature records maintained by the Bureau of Meteorology (the Bureau) which contains long-term, adjusted surface air temperature data from 112 stations across Australia for the last 105 years. Homogenisation, as it is commonly known, is the standard approach in meteorology and climate science that enables weather monitoring institutions to maintain a consistent set of temperature records over time, while eliminating non-climate factors that impact temperature readings. For instance, non-climate related factors include:

- the replacement of thermometers;
- changes in observing practices;
- expansion of the network into remote locations;
- changes in infrastructure surrounding a weather station;
- relocation of weather stations.

The homogenisation adjustment process helps to eliminate artificial systematic errors or artefacts induced by such changes and is a key requirement for compiling and then analysing long-term records of daily maximum and minimum temperatures for any given location. While similar adjusted datasets are maintained by meteorological institutions around the world, ACORN-SAT is the world's first continent-scale homogenised dataset of daily temperatures.

In 2011, the Bureau initiated an independent and detailed peer review of ACORN-SAT to investigate the robustness of its observing practices, station selection, data homogenisation, calculation of trends and overall confidence in ACORN-SAT.

The independent peer review expressed overall confidence in the Bureau's practices and noted that its practices are among the best in the world. The peer review made 31 recommendations to further increase confidence levels and ensure the highest levels of transparency are maintained. Of these recommendations, 18 have been implemented fully (with one under review) and 13 are in the process of being addressed. One of the recommendations was to establish a Technical Advisory Forum to review and advise the Bureau on the ongoing development and operation of ACORN-SAT.

Technical Advisory Forum

The Technical Advisory Forum (the Forum) was established by the Parliamentary Secretary to the Minister of the Environment on 19 January 2015 to annually review the development and operation of ACORN-SAT and to comment on further developments over the years 2015–2017.

Forum members were chosen for their expertise in disciplines such as atmospheric physics and statistics to specifically provide independent advice on the Bureau’s statistical and data analysis methods. Nominations for Forum Members were made by Australia’s Chief Scientist, the Acting Australian Statistician, the Australian Academy of Science and the Australian Academy of Technological Sciences and Engineering. The members of the Forum are:

Dr Ron Sandland AM FTSE	Chair
Emeritus Professor Bob Vincent FAA	Vice Chair
Dr Phillip Gould	Member
Dr John Henstridge CStat, AStat, AFAIM, QPMR, FSS	Member
Ms Susan Linacre	Member
Professor Michael Martin PFHEA	Member
Professor Patty Solomon	Member
Professor Terry Speed FAA, FRS	Member

The Forum held its first meeting on 26 March 2015. In line with its Terms of Reference, the Forum considered three aspects of ACORN-SAT: the extent of the public availability of the ACORN-SAT information; developments since the 2011 Independent Peer Review of the Bureau’s data and analysis methods; and the scientific integrity and robustness of the Australian climate record and the homogenisation process. The Forum considered a broad range of information and data concerning the management and development of the ACORN-SAT dataset provided by the Bureau as well as unsolicited submissions by some members of the public.

Terms of Reference

1. The extent of the public availability of the ACORN-SAT information including:
 - Raw and adjusted data;
 - Documentation of data methods;
 - Computer code;
 - Adjustments;
 - Metadata;
 - Inputs and outputs of peer review; and
 - Ability to reproduce findings.

2. Developments since the 2011 Independent Peer Review (IPR) of ACORN-SAT data and methods including:
 - ACORN-SAT network, in the context of the Bureau’s Observation strategy
 - Addition of new temperature data, including from individual stations and data post-2010, and whether there is merit in inclusion of pre-1910 data;
 - Progress with metadata to allow independent replication of homogeneity analyses;
 - Progress against the IPR recommendations; and
 - Extent of scientific adoption of data and analyses.

3. The scientific integrity and robustness of the Australian climate record and the homogenisation process including:
 - Compared to raw (unadjusted) data, how does homogenisation affect the overall climate trend for Australia?
 - Compared to other available datasets, how do the trends indicated by ACORN-SAT compare?
 - How does the Bureau’s curation methods compare to other international curation methods?
 - What steps should be taken to document or improve the consistency of decision making for the selection of data periods or stations and of the adjustment methods and decisions?
 - How has the Australian Bureau of Statistics (ABS) assessed ACORN-SAT as part of the Essential Statistical Assets for Australia?

Submissions

The Forum also received over 20 unsolicited submissions from some members of the public about the dataset. Further, the Forum is also aware that there have been an unspecified number of written correspondences from members of the public sent to the Minister for the Environment the Hon Greg Hunt MP, the Parliamentary Secretary the Hon Bon Baldwin MP and the Bureau concerning the ACORN-SAT dataset.

Members of the Technical Advisory Forum were appointed to provide advice on the basis of their formal expertise, and the Terms of Reference do not therefore require the Forum to receive or respond to unsolicited submissions. However, these submissions were provided to all Forum members to ensure that Forum members were aware of concerns raised by some members of the public regarding the Bureau’s management of ACORN-SAT during their deliberations.

The submissions raised some broader concerns about the science of climate change which fall outside the scope of the Terms of Reference for this Forum, and are therefore not addressed in this report (for instance, the validity of climate change and the impartiality of the Bureau in reporting climate trends). However, the Forum is aware of the following issues raised in the submissions:

- The 1910 commencement date for the ACORN-SAT dataset (even though some records are available prior to 1910) and its potential impact on reported climate trends;
- The treatment of claimed cyclical warming and cooling periods in the adjustment process and its impact on reported warming trends;
- The potential effects of site selection (such as from urbanisation) and the later inclusion of stations in warmer regions;
- The treatment of statistical uncertainty associated with both raw and homogenised datasets;
- The ability of individuals to replicate/verify the dataset;
- The justification for adjusting historic temperature records;
- The extent of metadata digitisation and quality assurance in using metadata during the adjustment process;
- The Bureau’s communications concerning homogenisation and overall data provision;
- The statistical methods used in developing the dataset; and
- Comparisons between ACORN-SAT and other datasets.

While the Forum has not sought to specifically respond to each individual submission, it is however aware of the issues identified within them. To this end, the Forum considers that its recommendations for improving the Bureau’s overall communications, statistical methods and data handling, and further regional analysis based on the pre-1910 data will address what it considers to be the most important of these concerns.

Nevertheless, in the opinion of the Forum members, the unsolicited submissions received from the public do not provide evidence or offer a justification for contesting the overall need for homogenisation and the scientific integrity of the Bureau’s climate records.

2. Public availability of the ACORN-SAT information

Raw and adjusted data

The Forum commends the Bureau for its commitment to providing both raw (original measurements) and adjusted data in full for download. Although numerous formats for supplying such data do exist, the Forum recommends that a universal text-based format such as CSV would allow both experts and the public the best access to the data. Currently, data are delivered in CSV format from the links under the page on the Bureau of Meteorology site <http://www.bom.gov.au/climate/data/> (raw data) but the adjusted ACORN-SAT data are delivered as plain text files (.txt) from the ACORN-SAT page <http://www.bom.gov.au/climate/change/acorn-sat/#tabs=Data-&-network> by clicking a map depicting individual stations, after which all years of available maximum and minimum temperature data for selected stations can be accessed by clicking two separate links. Thus to access max and min data for all 112 stations in ACORN-SAT requires 224 select-and-clicks. To then combine the data into a useable format requires significant combining and cleaning. Obtaining the raw data appears to be a time-consuming (but different) process accessed through a different page and supplying data in different formats (CSV and PDF).

While all the data appear to be available, its supply in disparate sections of the website and in a mixture of formats makes access onerous. It would be useful, thus, to supply raw and adjusted data from links on the same page, and in the same, universal, format (CSV). Further, it would be useful to allow downloads of bundled data by year rather than by site, or even to provide a bundle containing all the data (acknowledging that that will be a large download that may incur non-negligible download costs—so warnings to this effect should also be advised on the website).

To this end, the Forum also notes that the ACORN-SAT data are available in a combined format from <http://lab.environment.data.gov.au> (not on the Bureau website itself) with the process of creating this resource described in an article published on the internet at <http://www.semantic-web-journal.net/system/files/swj457.pdf>. The ACORN-SAT data itself can be downloaded from <http://lab.environment.data.gov.au/dumps/release/> as a 130 MB download (ZIP file that expands to 5.3 GB of data files) that provides the data in XML format. At a minimum, links to these resources should be made available on the ACORN-SAT pages on the BOM website. The Forum recommends that CSV files be made available that contain time series of max/min temperature records for all 112 sites together with the averaging weights used to calculate the Australian average temperature record. The weights should be provided at each time value to reflect that they may change over time as new sites became operational. This information should allow users to reconstruct the average min/max temperature anomaly series for both the Australian Water Availability Project (AWAP) and ACORN-SAT data. Such a provision would facilitate end-user efforts to reproduce at least the principal Australian annual mean temperature anomaly.

Raw (original, unadjusted) data from before 1910 can be downloaded for sites at which such data are available and have been digitised. ACORN-SAT data are only available post-1910, by the approaches discussed in the preceding paragraphs.

Documentation on methods

In general, documentation on data methods is available easily within PDF files supplied from the ACORN-SAT page. While expertise is required to properly read and understand these documents, they are easy to access.

Computer code

The Forum notes and commends the transparency offered by access to computer code, which is available (in the language Python) from the Bureau on request. This fact is advised on the ACORN-SAT pages on the Bureau of Meteorology website at <http://www.bom.gov.au/climate/change/acorn-sat/#tabs=Methods&-network=>, referencing the e-mail address Helpdesk.Climate@bom.gov.au. The Python code was developed for broader use outside the Bureau, as the original development of the code for internal use within the Bureau was in Fortran. The Forum recommends that the Python code be made available as a downloadable link rather than by request. It is recommended that the Bureau monitor hit/download statistics to gauge demand for this software.

Access could be further improved by clarifying the technical requirements users need to satisfy in order to use the code. For instance, is it enough to simply have installed Python on any platform (Windows, Mac, Linux, Android, iOS)? The Bureau should supplement links to the code with appropriate supporting documentation and a clear listing of technical requirements to use the software.

Adjustments

Full detail on adjustments is given at <http://www.bom.gov.au/climate/change/acorn-sat/documents/ACORN-SAT-Station-adjustment-summary.pdf>. However, the Forum recommends the use of a more convenient format such as CSV, rather than PDF delivery.

This material provides information on what adjustments have been made. The Forum recommends that the Bureau should also make available to the public a brief, plain-language (as far as possible) description of the criteria for adjustment and the basis for adjustment itself. In this document, terminology such as *anomaly* (which also has a common English usage) and *homogenisation* must be carefully defined to avoid confusion. This document could be used to

address public concerns about the Bureau's rationale for adjusting the raw data, and to counter the perception expressed within unsolicited submissions that the raw data represent 'truth' while adjustments seek to alter that 'truth'.

The Forum strongly endorses the view that the raw observations, like almost all measured quantities, are potentially subject to both random and systematic variation and that such statistical variation must be taken into account in analysing the temperature record. Any analysis or presentation of climate data which ignores this feature of the measured raw data is likely to be misleading.

The Forum noted, in particular, a criticism of adjustment made within unsolicited submissions that the Bureau's approach was, essentially, altering the factual record of past observations with a view to using these manipulated values to make predictions of future events. The Forum notes that the Bureau could more effectively address this criticism through the presentation of appropriate sensitivity analyses that demonstrate the extent to which the process of adjustment make a material difference to indicative temperature patterns. For example, a series of analyses could be conducted using a sequence of input parameters (e.g. no adjustment, adjustments made on the basis of metadata alone, homogeneity adjustments using different levels of correlation with nearby sites, etc.) to show the effects of operator choices within the adjustment methodology.

Metadata

Metadata details are supplied for individual sites within the climate data portion of the Bureau's website (<http://www.bom.gov.au/climate/data/index.shtml>). However, accessing individual site metadata is a time-consuming process that involves following successive links for each site (e.g. http://www.bom.gov.au/clim_data/cdio/metadata/pdf/siteinfo/IDCJMD0040.072150.SiteInfo.pdf for the Wagga Wagga site). It would be useful for the Bureau to make access to metadata easier, perhaps by including a metadata link for each station on the clickable maps available at <http://www.bom.gov.au/climate/change/acorn-sat/#tabs=Data-&-network>. The Forum felt that the information provided by metadata contributed to the adjustment process required significant manual operator input, and that reproduction of the ACORN-SAT dataset was unlikely to be able to be automated unless metadata was made available in a uniform, digital format. However, it was acknowledged that site metadata needed to incorporate a wide variety of information, and that identifying a useable uniform format would require further research and development.

It is recommended that the Bureau develop a framework for standardising metadata information so that adjustments made on the basis of metadata are seen as both transparent and objective. This development should result in a set of agreed guidelines that support digitisation of metadata, perhaps through mechanisms such as crowd-sourcing.

Inputs and outputs of peer review

Examples of peer reviewed papers on Bureau climate research are provided at the Methods tab page on the ACORN-SAT sub-site <http://www.bom.gov.au/climate/change/acorn-sat/#tabs=Methods&-network>, although this would not appear to be an exhaustive listing. It would benefit the Bureau within the public discourse to provide example case studies or evidence of other climate analyses by the Bureau and independent bodies that use the ACORN-SAT data. These examples would be likely to improve the public's understanding of broader uses of the dataset (other than simply supporting a headline mean temperature anomaly). The Forum also recommends that the relationship between the ACORN-SAT dataset and temperature data within the Australian Water Availability Project (AWAP) be more clearly explained—particularly in plain language—within the ACORN-SAT website. While material produced and published by the Bureau should be available for free download, links to journal articles published by commercial publishers should be accompanied by appropriate advice that some material may only be accessed after paying a fee, while open-access articles should be flagged as such.

Ability to reproduce findings

The Forum considers that the algorithms and processes used for adjustment and homogenisation are scientifically complex and a reasonably high level of expertise is needed to attempt analysis of the ACORN-SAT data. For this reason the Forum had some queries about the ability to reproduce findings by both experts and members of the public. It would be useful for the Bureau to provide advice about the necessary level of end-user expertise (notwithstanding a likely tendency for end-users to feel qualified to attempt such an analysis). The Forum felt that reproducing the Bureau's ACORN-SAT daily analyses would be a very onerous task, and advice was supplied at the Forum meeting day that, while international groups have provided independent data homogenized at the monthly time-scale, no groups other than the Bureau are known to have attempted to produce or analyse an homogenized daily data set for Australia. One option would be for the Bureau to work with local and international collaborators with the appropriate skill set to broadly assess the ACORN-SAT daily homogenisation methodologies.

The Forum noted that the extent to which the development of the ACORN-SAT dataset from the raw data could be automated was likely to be limited, and that the process might better be described as a supervised process in which the roles of metadata and other information required some level of expertise and operator intervention. The Forum investigated the nature of the operator intervention required and the bases on which such decisions are made and concluded that very detailed instructions from the Bureau are likely to be necessary for an end-user

who wishes to reproduce the ACORN-SAT findings. Some such details are provided in Centre for Australian Weather and Climate Research (CAWCR) technical reports (e.g. use of 40 best-correlated sites for adjustments, thresholds for adjustment, and so on); however, the Forum concluded that it is likely to remain the case that several choices within the adjustment process remain a matter of expert judgment and appropriate disciplinary knowledge.

The Forum recommends that the Bureau work towards providing robust code that supports a level of automation that allows sensitivity analyses to be reasonably undertaken by independent parties. This goal could be pursued through a careful documentation of existing code and feedback from the independent re-analysis recommended in the preceding paragraph. While the Bureau expressed willingness to support end-users who wished to reproduce findings or conduct independent analyses using the ACORN-SAT data, subsequent follow-up on such intentions may have significant resource implications. It is thus recommended that the Bureau limits the amount of assistance it provides end-users and includes a statement on the ACORN-SAT website that while reasonable assistance may be provided by the Bureau, extensive assistance could not be provided without an appropriate at-cost charge. Such limitations are likely to also limit the ability of end-users to replicate ACORN-SAT findings, but the resource implications of offering open-ended support to end-users may be substantial.

3. Developments since the 2011 Peer Review of ACORN-SAT data and methods

The Forum noted that the ACORN-SAT dataset includes post-1910 data from 112 sites. The Forum commends the Bureau for its development of adjustment procedures since the 2011 Independent Peer Review. This development is articulated and explained in the CAWCR Technical Reports 49 and 50 produced jointly by CSIRO and the Bureau of Meteorology. These reports describe, in technical terms, the rationale for and process of adjustment, and describe efforts to use the adjusted data to produce estimates for trend in Australian temperatures. In one sense, Technical Report 49 addresses core questions related to errors, both random and systematic, inherent in the raw observations of Australia’s temperature network. Notably, the details contained in Technical Report 49 have been published in the international peer-reviewed journal *International Journal of Climatology* (Trewin, *Int. J. Climatol*, 2013, vol. 33, pp. 1510–1529). Also, the percentile-matching algorithm developed by Bureau staff as part of the homogenisation process is supported by evidence about similar methodologies from a variety of other fields. The Forum therefore felt that the analyses conducted by the Bureau reflect good practice in addressing the problem of how to adjust the raw temperature series for systematic errors. The Forum has recommendations in two broad areas which the Bureau can explore to improve the use of Australian temperature data.

Purpose

The Forum questioned the focus on communicating Australian annual mean temperature anomaly as the primary endpoint of the ACORN-SAT exercise. Notwithstanding keen public interest in this single number, the richness of the ACORN-SAT dataset provides a broad picture of the Australian temperature experience, as evidenced by the Bureau’s production of spatial maps of Australian temperature. While the Forum acknowledges that the Bureau does provide a range of perspectives on Australian temperature through the ACORN-SAT project, it recommends that the Bureau reconsider its focus on annual mean temperature anomaly in order to broaden public discussion about how temperature is changing both temporally and spatially. For example, the production and dissemination of bar charts such as those below in Figures 3.1 and 3.2 (taken from outside the ACORN-SAT sub-pages: <http://www.bom.gov.au/climate/change/>) as an alternative to reporting a single annual mean temperature anomaly figure may help in informing the public without over-reliance on a single, headline figure of 0.9 degrees (which is itself an estimate that has an associated standard error, and is thus subject to statistical uncertainty in any case).

Looking beyond the single, national mean anomaly, it would be beneficial to establish narratives around both local behavior and more complex but identifiable temporal and spatial patterns than can be described by a single national average measure (e.g. proportion of sites exceeding historical norms on monthly as well as annual bases, identification of sites exhibiting particularly unusual behaviour irrespective of adjustments, and so on).

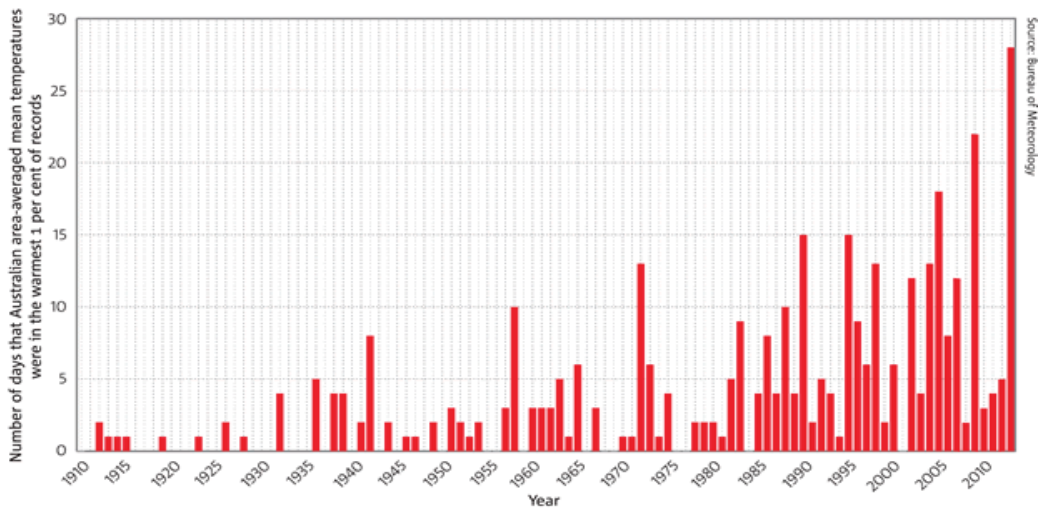
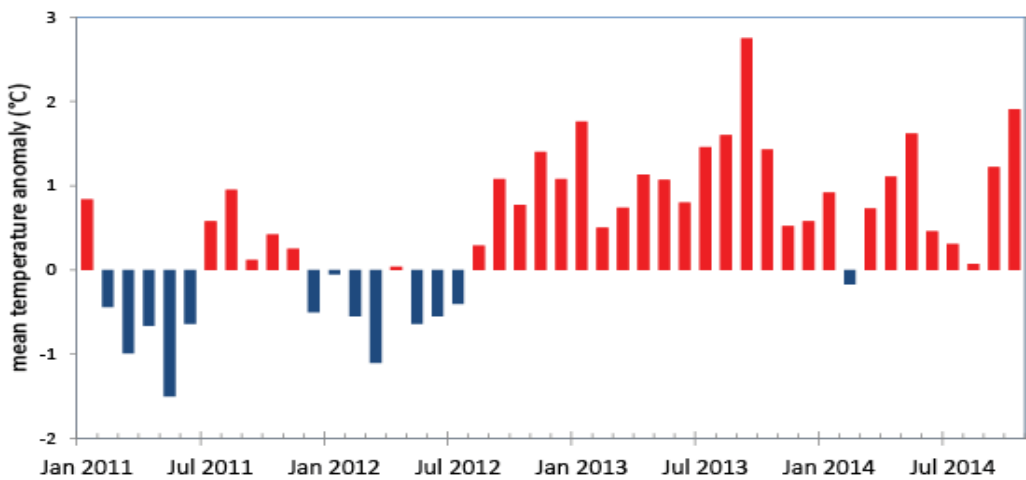


Fig 3.1: Number of days each year where the Australian area-averaged daily mean temperature is above the 99th percentile for the period 1910–2013. The data are calculated from the number of days above the climatological 99th percentile for each month and then aggregated over the year. This metric reflects the spatial extent of extreme heat across the continent and its frequency. Half of these events have occurred in the past 20 years.



© Australian Bureau of Meteorology

Fig 3.2: Estimated Australian mean monthly temperature anomaly for the period January 2011 to November 2014. The anomaly is against the 30-year 1961–1990 long-term average.

The Forum recommends that the Bureau undertake to develop a clearer public understanding of the purpose for the ACORN-SAT exercise, and to communicate this strategy in a way that is appropriately clear, broad and supported by appropriate graphics³ and data summaries.

Quantifying and communicating uncertainty

The technical documentation supporting the ACORN-SAT data construction clearly and effectively targets the problem of correcting systematic errors in raw temperature data, both through systematic effects such as information about site changes (metadata) and structural effects (e.g. time of observation). However, both the raw data and the adjusted data are also affected by measurement error or statistical variation, and thus the estimates of mean temperature anomaly based on each of the raw (unadjusted) data and the ACORN-SAT dataset are also subject to statistical variability.

The Forum noted that investigations of uncertainty form an active area of research both within and outside the Bureau, and that this work is ongoing. The Forum strongly recommends that the Bureau seek to further identify and understand sources of statistical uncertainty and to include standard error estimates or confidence intervals in reporting estimated and predicted outcomes. In particular, for point estimates of mean/min/max temperature anomalies, estimated standard errors should be reported, while graphical representations of mean/min/max temperature behaviour should be augmented with confidence bands. The Forum recognises that multiple sources of statistical variation may impact observations and adjustments, and that quantifying such variation in estimated/predicted outcomes will require methodological development.

A key benefit of the development of appropriate uncertainty measures for both the raw and ACORN-SAT data and derived statistics is that it may allow for at least limited use of pre-1910 data. The Forum felt that with greater uncertainty prevailing in earlier years' measurements, fitting methods used to identify trend patterns within the data should incorporate weights within the fitting process that reflect the differential uncertainty associated with the measurements through time. Such a weighted approach may allow the practical use of earlier data in assessing temporal temperature patterns. While it is acknowledged that the pre-1910 network coverage is sparse, it is likely that pre-1910 data could be included at least in regional analyses (e.g. for south-eastern Australia) to gain a longer historical perspective on Australia's temperature pattern.

3. For example, where a correlation between two temperature series is asserted, it would be more useful to plot the two series using an x-y scatterplot rather than superimposing the series on a time chart. Similarly, plotting deviations between two series measuring the same underlying quantity is generally more effective than over-plotting one on the other. Another useful alternative plot for assessing the coherence of alternative measurement approaches is the so-called Bland-Altman plot (also called the Tukey mean-difference plot) (Altman & Bland, *The Statistician*, 1983, vol 32, pp. 307-317).

Inclusion of uncertainty information *within both analysis and communication of results* is imperative, and the Forum emphasizes that reporting on progress towards quantifying the uncertainty in estimates and prediction should be the key focus of the next Forum meeting, in 2016.

The Forum also noted the importance of communicating clearly the distinction between *statistical* notions of uncertainty (which is what is being discussed here) and the common English usage of the word ‘uncertain’ and how descriptions of ‘uncertainty’ might be interpreted by the public with respect to climate change policy.

The following considerations should be borne in mind by the Bureau in implementing the Forum’s recommendations:

- Uncertainty in each of raw and adjusted cases should be quantified. This notion is important both from an obvious statistical standpoint (as all measurements suffer potential error), but also to correct the erroneous perception that the raw data reflects an objective ‘true’ measurement.
- Robustness of analyses to spatial variation should, in particular, be considered. For example, are results on a sub-regional level consistent with findings at a national level? When providing ‘smooth’ maps of temperature behaviour, are important local features being appropriately reported?
- While the existing focus of investigation has been principally on the removal of systematic errors, what is the effect of removing such artefacts in terms of the standard errors of the resultant estimates? In particular, if the uncertainty is such that overall estimates do not change by a statistically significant amount, does the emphasis placed on correcting systematic errors need rebalancing with more consideration given to identifying uncertainty?
- The interpolation of the adjusted ACORN-SAT data to a grid also introduces spatio-temporal variation into the interpolated dataset. Further, the two-dimensional Barnes successive-correction interpolation method used may not adequately deal with the possible underlying spatial correlation structure. These issues should be fully explored under the Forum’s recommendations concerning uncertainty.

With regard to Term of Reference 2, which concerns development of the ACORN-SAT dataset since the 2011 Independent Peer Review, the Forum felt that the issues of clarity of purpose of the ACORN-SAT project and quantifying uncertainty were key issues for future development in the first year of the Forum.

The Forum considers that the use of technical terms such as ‘anomaly’ and ‘homogenisation’ within documents designed by the Bureau for public consumption affects the effectiveness of public communication about the ACORN-SAT project. While the Forum recognises that these terms have accepted and specific scientific meaning, use of the word ‘anomaly’ causes particular concern, as its common English usage has a feature (atypicality) not shared by the scientific meaning. Thus, the Forum suggests that in publications made available to the public, the Bureau carefully define these terms or seek alternative words without common connotations that vary from their scientific use (e.g. ‘deviation from average’?)

The Forum acknowledges the work of the Bureau in implementing the recommendations of the 2011 Independent Peer Review. The Forum further recognises the continued enhancement of the available data through the digitisation of data available previously only in hard-copy and the maintenance of the observation record through automated weather stations as core to maintaining as complete and current a record of Australian temperature as possible. Progress with updating and digitising metadata is also ongoing, however it remains reliant on manual processes that are time-consuming. The Bureau should investigate the development of a robust, uniform digital format for metadata so that access to approaches such as crowd-sourcing will be available in the future. The Forum notes that undertaking such work may potentially require significant resourcing.

The Bureau provided the Forum with information about specific progress towards the 2011 Independent Peer Review recommendations. This information was provided in summary before the meeting, with further information provided at the Forum meeting. This information has given rise, in particular, to the further recommendations made above concerning public availability of data and code, and the technical recommendations made above.

The Bureau has documented well its own approaches to the analysis of spatio-temporal temperature data, and this information has been made available through the Bureau’s website. It would be useful, however, for the Bureau to maintain on its website links to peer-reviewed, published research in this area, acknowledging that such links will usually be to external sites and to commercial journal sites that may require users to pay fees to access published materials. The maintenance of these links would highlight the Bureau’s engagement with other meteorological agencies and the broader scientific community in research into temperature patterns.

4. The scientific integrity and robustness of the Australian climate record and the homogenisation process

The need for adjustment

The Forum endorses the view that there is a need to adjust the historical temperature record to account for site changes, changes in measurement practices, and identifiable errors in measurement. Where metadata indicate that a material change in the temperature pattern is likely (e.g. a physical move from a coastal location to an airport some kilometres inland), such adjustments are clearly appropriate. However, adjustments are also recommended even in the absence of metadata when there is other clear evidence that an observation is an outlier that is inconsistent with other measurements at that location around the same time. Thus, the Forum supports the need for the Bureau's homogenisation process which incorporates both metadata-based adjustments and adjustments based on the statistical detection of atypical observations.

Indeed, the Forum noted that when metadata suggested that a change in temperature pattern could occur, it would be expected that the statistical algorithm would also be likely to detect an atypical observation. Thus, the coincidence of metadata-based adjustments and statistically detected inhomogeneities would act as a consistency check for the statistical algorithm. The Forum recommends that where breakpoints are identified by statistical means, the Bureau should seek to apply them at the specific time at which they are detected, so that, for example, breakpoints in annual series are attributed to the year, while for daily series, breakpoints would be attributed to a specific day.

The effect of homogenisation

The chart below (Fig 4.1) shows the difference in mean temperature anomalies between the homogenised ACORN-SAT and unadjusted AWAP datasets for Australia. Since 1960, there is a noticeable convergence between the raw and adjusted datasets, which most likely reflects the relative increase in the observing station network density over time.

The Forum considers that its own recommendations will deliver improvements to the management and communication of the ACORN-SAT dataset. There is a clear trend increase in both the raw and homogenised temperature data, and the temperature patterns exhibited in a variety of other datasets have a similar character. It is not currently possible to determine whether these improvements will be reflected in an increased or decreased warming trend that has been broadly observed across a range of different datasets.

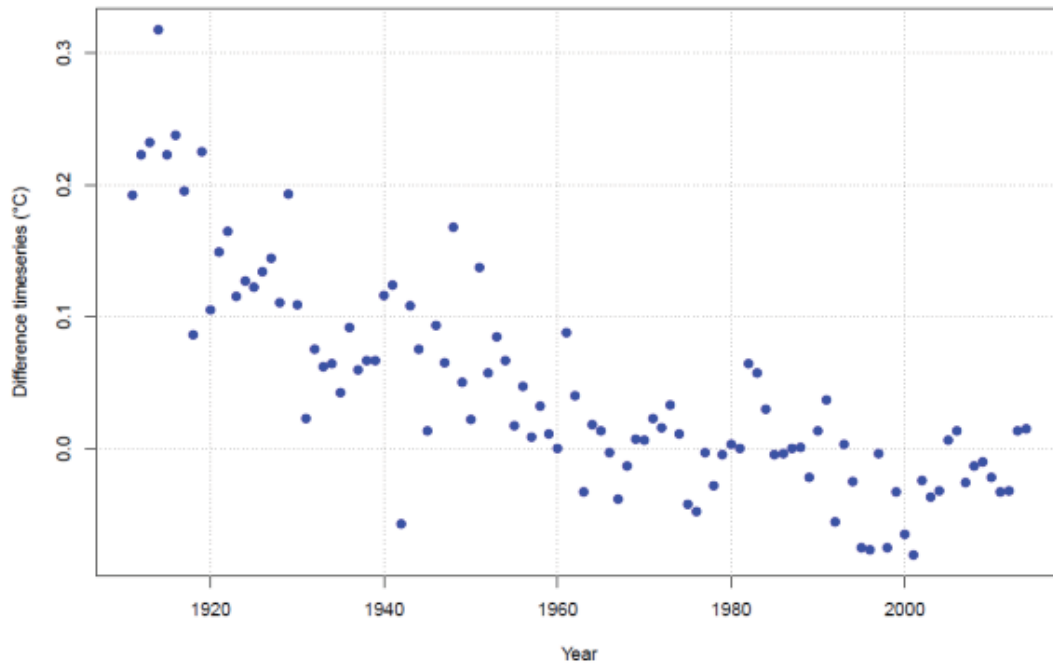


Fig 4.1: Scatter plot of the difference between ACORN-SAT and AWAP mean temperature anomalies (Y axis depicts °C)

Analysis of raw and adjusted data

The Bureau presented the Forum with analyses of the raw and adjusted data that suggested a slight difference in the estimated annual mean temperature anomaly compared to the base period 1961–1990. This difference resulted from descriptive quadratic functions fitted to the raw and adjusted data, respectively. The Forum identified several issues with this approach:

- While it is acknowledged that the quadratic function is a valid fit to the available data, it is inconsistent with the language used by the Bureau to describe the temperature pattern as being essentially flat until a particular time, after which it rises progressively. The language used is consistent with a piecewise linear fit rather than a quadratic, and each of the two forms require only a small number of parameters to be estimated (and hence are similarly parsimonious as descriptions of the data).
- A quadratic fit to these data is purely descriptive and not useful for forecasts of future annual mean temperature anomalies. Further, the extent to which the fit is affected by differential variability between distant past data (e.g. 1910–1930) and present data (e.g. 1990–2014) may be material to the parameter estimates, and hence to the precision of estimates based on the fit (for both raw and adjusted cases).

- The use of a quadratic functional form carries the risk, if (mis)used to project temperatures beyond or before the observation period, of seriously overestimating the change. The Forum strongly recommends that the use of piecewise linear fits or nonparametric smoothers such as LOWESS be revisited by the Bureau. However, the Forum notes that all such fits are best considered only as descriptive curves fit to the available data and should not be interpreted as implying any particular underlying physical model for temperature behaviour beyond the period for which data are available. In particular, the Forum cautions against the explicit use of such fitted curves to generate specific forecasts or predictions of future temperature behaviour.

Within the lifetime of the Forum, the Forum recommends analyses that integrate the ACORN-SAT dataset with other data such as ACORN-RAIN to build a more complete understanding of climate trends in Australia. Certainly, a focus on ‘headline’ figures, such as an estimated annual mean temperature anomaly for the entire country, needs to be broadened in Bureau contributions to the public discourse about climate change, even within considerations of the temperature record but also to features such as rainfall and other climate features, in order to properly understand emerging climate patterns.

Sub-analyses and pre-1910 data

As an interim measure, the Forum felt that regional sub-analyses would be useful tools for assessing the sensitivity of ACORN-SAT analyses to regional differences (e.g. to what extent is a national average anomaly a meaningful and useful concept?) Further, the possible availability of pre-1910 data at south-eastern sites in particular may allow for a comparative analysis to be performed for south-eastern Australia to assess whether the inclusion of pre-1910 data is worthwhile in attempting to understand current temperature patterns. The Forum agreed that the very high statistical variability of early-period data (often related to the limited capacity of equipment available at the time to make precise measurements) was a key factor limiting its usefulness in such data-fitting exercises, again pointing to a strong need to quantify uncertainty in estimation processes throughout ACORN-SAT analyses.

Similarity of trends

The Bureau has made available comparisons of trends estimated using the ACORN-SAT data as well as a variety of other datasets, including satellite data. While the temperature patterns exhibited by all the series have a similar character, they differ in terms of the ‘headline’ estimate of Australian annual mean temperature anomaly. As previously indicated, the Forum recommends

a move away from the strong focus on annual mean temperature anomaly as an output of ACORN-SAT analyses. Notwithstanding this recommendation, a key focus for the Forum in its first year is to reach an understanding about how incorporating standard error estimates or confidence intervals into ACORN-SAT analyses affects the capacity to properly characterise and describe trends in the data with a view to understanding broad temperature patterns. Of course, similar considerations concerning statistical measures of uncertainty are also relevant for other datasets as well, and comparisons of ACORN-SAT analyses with those produced from other datasets will need to take into account such uncertainty measures within each dataset. In saying this, the Forum recognises that the Bureau does not own some of the datasets with which ACORN-SAT is compared, and developing uncertainty measures for those datasets would be the responsibility of owners of those datasets.

Notably, without adequate standard error estimates associated with these quantities (for any of the presented series), it is not possible to assert that these quantities differ by an amount that is statistically significant. Thus, the provision of uncertainty information (typically represented using standard deviations or standard errors) is critical to understanding and reporting the trends of all temperature series. Second, the extent to which each of these series is measuring the same physical phenomenon needs to be very carefully communicated in the Bureau's public statements regarding temperature trends/patterns, as the satellite measurements do not (and are not meant to) measure air temperatures at ground level.

Curation

The availability of data for downloading has several aspects that would benefit from further consideration. At present, both raw and adjusted data are available for download from the Bureau website. However, inconsistencies in the format in which the data are available present end-users with considerable work to assemble the entire dataset into a useable format. For instance, the raw data are available in CSV format either through a map-click or text-entry interface, with multiple years of data and metadata details available on the page rendered after an initial single-year selection. However, ACORN-SAT data are available only in raw text through a map-click interface from the ACORN-SAT sub-pages of the BOM site. In each case, maximum and minimum temperature data must be downloaded separately.

Alternatively, through a joint project with CSIRO, the Bureau has developed a linked dataset (through database queries to the BOM site) that is available from the lab.environment.data.gov.au portal, a site external to the BOM site (and not obviously linked from the BOM site). This site allows the download of a 'complete' ACORN-SAT dataset, but in a different format (XML) that

may be difficult for end-users to use without appropriate software. The Forum recognises that the maintenance and provision of the complete ACORN-SAT dataset and the AWAP dataset have resource implications for the Bureau. The data.gov.au portal was created to ‘encourage public access to and reuse of government data by providing it in useful formats under open licences’, and the data available at that site is provided under a [Creative Commons Attribution 3.0 Australia licence](#). Presently, the ACORN-SAT dataset is provided from this portal at the URL <http://data.gov.au/dataset/acorn-sat>, with data accessible either as the complete data or in yearly slices. The Forum noted that although the complete and annual slice data are available from this website, custom data queries are not possible through this portal. However, custom data requests may represent a very resource-intensive activity for the Bureau, and the Forum supports an at-cost fee-for-service approach for the provision of custom data slices to public and external clients. The Forum notes that access to the complete dataset would remain free under the Open Government initiative, so fees would only apply to custom data requests.

The Forum recommends that the data, both raw and adjusted, be made available in a uniform, simplified format, such as CSV, to enable broadest possible access and use.

The 2011 peer review examined the Bureau’s observation practices and approach and methodologies for ensuring homogeneity of the dataset and concluded that they were among international best practice and noted the Bureau’s international leadership in this field. The Forum notes the progress made by the Bureau in implementing the recommendations of the peer review to further improve its curation methods. As noted previously, the Bureau’s staff are active members of the global scientific discourse on methodological approaches to homogenization. Given the findings of the peer review, the Forum did not prioritise further international comparison of the Bureau’s curation methods in this report. However, the Forum will revisit this issue at its next meeting in 2016.

Improving consistency of decision making

The process for identifying appropriate metadata is limited by a lack of comprehensive and consistent historical documentation. Thus, confirming metadata changes remains a task individualised to particular sites. This is a legacy issue rather than a failure in the current system. Widespread structural changes such as metrication and movement to uniform observation time practices have been dealt with sensibly, and where appropriate metadata have been identified, the Bureau response has been appropriate. Crowd-sourcing remains a potentially attractive option for improving data-gathering processes, although quality-control measures would need to be implemented to ensure data integrity.

ACORN-SAT as an essential statistical asset

The ABS has assessed the annual ACORN-SAT dataset as being an essential statistical asset (ESA), with an overall green traffic light assessment. It was given a green light across all of the dimensions (institutional environment, relevance, timeliness, accuracy, coherence, interpretability and accessibility). The ACORN-SAT data was assessed along with the AWAP data and regional sea surface temperature data. The ABS noted the following areas for improvement:

- Key information in the description of the statistic was available from the contributing datasets; however, information about sea levels was lacking;
- There was some variation between data compiled from multiple administrative sources.
- Data quality statements and descriptions of the conceptual limitations were not available for some information.

It is important to recognise that the criteria used by the ABS in assessing ACORN-SAT are different in kind from those implicit in the Forum's Terms of Reference so we simply report the ABS's conclusions above.

Appendix A

Acronyms and abbreviations

ACORN-SAT	Australian Climate Observations Reference Network—Surface Air Temperature
ACORN-RAIN	Australian Climate Observations Reference Network—Rainfall
AWAP	Australian Water Availability Project
CAWCR	Centre for Australian Weather and Climate Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
ESA	Essential Statistical Asset

Appendix B

Technical Advisory Forum communiqué and meeting outcomes

Meeting communiqué issued on 26 March 2015

The Technical Advisory Forum held its first meeting today to advise on part of Australia’s official climate record—the Australian Climate Observations Reference Network Surface Air Temperature (ACORN-SAT) dataset.

Today’s discussions were robust and productive, and the Forum would like to thank the Department of the Environment for managing the Forum’s membership and assisting the Chair. The Forum would also like to thank the Bureau of Meteorology for providing information and answering questions on the ACORN-SAT dataset.

The Technical Advisory Forum was appointed by the Parliamentary Secretary to the Minister for the Environment, the Hon Bob Baldwin MP as an independent advisory body to provide greater transparency and an impartial framework for quality assurance tests and analysis of the Bureau’s datasets.

In line with its Terms of Reference, the Forum discussed three aspects of ACORN-SAT: the extent of the public availability of the ACORN-SAT information; developments since the 2011 Independent Peer Review of the Bureau’s data and analysis methods; and the scientific integrity and robustness of the Australian climate record and the homogenisation process. The Forum considered a broad range of information and data concerning the management and development of the ACORN-SAT dataset provided by the Bureau.

The Forum also received some additional information from members of the public about the dataset. Members of the Technical Advisory Forum were appointed to provide advice on the basis of their formal expertise, and the Terms of Reference do not therefore require the Forum to receive public submissions. However, this additional information was provided to all Forum members to ensure that Forum members were aware of public concerns regarding the Bureau’s management of ACORN-SAT during their deliberations.

The Forum will deliver its report, including detailed recommendations, by June 2015.

ACORN-SAT Technical Advisory Forum

Meeting Minutes

Thursday 26 March 2015

Department of the Environment, John Gorton Building

Attendees: Technical Advisory Forum—Dr Ron Sandland (Chair), Professor Bob Vincent (Vice Chair), Dr Phillip Gould, Dr John Henstridge, Ms Susan Linacre, Professor Michael Martin, Professor Patty Solomon and Professor Terry Speed

Bureau of Meteorology—Dr Rob Vertessy, Mr Graham Hawke, Mr Neil Plummer, Dr David Jones, Dr Karl Braganza, Dr Blair Trewin, Dr Bruce Forgan and Dr Robert Fawcett, Ms Lucy McGarva (Secretariat)

Department of the Environment—Mr David Parker, Mr Brad Archer, Ms Beth Brunoro, Ms Katie Eberle (Secretariat), Mr Jayan Parry (Secretariat) and Ms Anna Summers (Secretariat)

1. Welcome, introductions and purpose of meeting

The Forum Chair, Dr Ron Sandland, introduced members of the Technical Advisory Forum and noted Forum members' responsibilities to address the specific Terms of Reference.

Mr Brad Archer, on behalf of the Department of the Environment, the Minister for the Environment, the Hon Greg Hunt MP, and the Parliamentary Secretary to the Minister for the Environment, the Hon Bob Baldwin MP, thanked members for their participation. Mr Archer emphasised the Department's involvement being support only, and encouraged Forum members to provide independent and frank advice.

Dr Rob Vertessy, on behalf of the Bureau of Meteorology, welcomed Forum members, noted the Forum's independent nature and invited the Forum's open and thorough critique. Dr Vertessy noted the extensive 2011 independent peer review of the ACORN-SAT dataset and methodology, and acknowledged progress on the implementation of the review recommendations.

2. Review of agenda and terms of reference

The Forum Chair outlined the day's agenda and sought member's review of the Terms of Reference. The Terms of Reference were agreed by Forum members (Attachment A).

3. **Presentation: Relevant climate science (Bureau of Meteorology)**

The Bureau made a presentation highlighting the role that homogeneous temperature datasets have in understanding climate, and the role Australian temperature data has in the overall understanding of global temperature changes. The presentation indicated the Bureau's view that homogenisation of temperature records makes no significant difference to the detection and attribution of climate change at the national or global scale.

4. **Presentation: History of Bureau observations and ACORN-SAT (Bureau of Meteorology)**

The Bureau provided an historical overview of the Bureau's climate observational capability, and noted that standardisation of observational practices across Australia occurred around 1910, after the Bureau of Meteorology was formed in 1908.

The Forum was informed that the development of a global network of Reference Climate Stations, of which ACORN-SAT is a contributor, was a request of the World Meteorological Organisation (WMO) in the early 1990s, and that subsequent networks used for long-term climate monitoring have evolved from this.

5. **Presentation and discussion: The scientific integrity and robustness of the Australian temperature record and the homogenisation process (Bureau of Meteorology)**

The Bureau outlined why there is a need for homogenisation of data and identified examples of site changes in the historical record. The Forum actively questioned the Bureau on a number of issues including homogenisation methodologies, its approach for detecting inhomogeneities in historical records and performing adjustments, and presentation of results.

Forum members discussed temporal interpolation techniques, the measurement of spatial means, and comparison of the Bureau's dataset with international datasets. Forum members identified that quantifying uncertainties within the dataset is an important area for future development. The Bureau noted that it has already commenced work in this area.

6. **Presentation and discussion: Developments since the 2011 Independent Peer Review of ACORN-SAT Data and methods (Bureau of Meteorology) Note: this presentation and discussion was brought forward in the agenda.**

The Bureau reported on the current status of response to the recommendations of the 2011 Independent Peer Review of the Bureau's ACORN-SAT dataset and methodology, indicating that the majority of recommendations have been implemented in full with significant progress made on all others as resources have allowed. It was noted by Forum members that there are a number of parallel international projects in this space, including the WMO Task Team on Homogenisation and the International Surface Temperature Initiative.

Forum members discussed progress on the recommendations of the 2011 Independent Peer Review, regionalisation of the ACORN-SAT dataset, and sensitivity of adjustments.

7. Presentation and discussion: The extent of public availability of the ACORN-SAT information (Bureau of Meteorology)

The Bureau provided the Forum with data on the availability of ACORN-SAT information, noting that all documentation of the ACORN-SAT dataset and the methods used for its construction and analysis are in the public domain, and documented in peer reviewed publications.

Forum members discussed the availability of data, metadata and code, including the information and data that have been made publicly available since the independent peer-review of ACORN-SAT in 2011/2012 including the take-up of scientific information from the ACORN-SAT website. Forum members also discussed reproducibility and the Bureau’s publicly available information regarding the ACORN-SAT dataset.

8. Presentation and discussion: Future developments of the ACORN-SAT dataset (Bureau of Meteorology)

The Forum members considered priority areas for development of ACORN-SAT including:

1. Developments that could be made to the network
2. Developments that could be made to the ACORN-SAT dataset
3. Developments that could be made in the analysis of ACORN-SAT and derived products.

9. Next steps

The Forum Chair thanked presenters for their preparation, along with the Secretariat and the Department of the Environment for providing support to the Forum.

Forum members agreed to develop a report and recommendations for consideration by the Bureau, in line with the Forum’s terms of reference. Forum members agreed that the report be completed by June 2015.

Meeting closed at 4:30pm.

Appendix C

ACORN-SAT Technical Advisory Forum meeting agenda

Thursday 26 March 2015: 9am to 5pm

**Location: Department of the Environment, John Gorton Building
King Edward Terrace, Parkes**

Attendees: Technical Advisory Forum—Dr Ron Sandland (Chair), Professor Bob Vincent (Vice Chair), Dr Phillip Gould, Dr John Henstridge, Ms Susan Linacre, Professor Michael Martin, Professor Patty Solomon and Professor Terry Speed

Bureau of Meteorology—Dr Rob Vertessy, Mr Graham Hawke, Mr Neil Plummer, Dr David Jones, Dr Karl Braganza, Dr Blair Trewin, Dr Bruce Forgan and Dr Robert Fawcett (Secretariat: Mr Perry Wiles and Ms Lucy McGarva)

Department of the Environment—Mr David Parker, Mr Brad Archer, Ms Beth Brunoro and Ms Katie Eberle, Mr Jayan Parry

No.	Description	Lead	Timing
1.	Welcome, introductions and purpose of meeting a. Opening statement from the Department b. Opening statement from the Bureau	Chair Mr David Parker / Dr Rob Vertessy	9:00–9:25
2.	Review agenda and Terms of Reference	Chair	9:25–9:35
3.	Relevant climate science	Dr Karl Braganza	9:35–9:55
4.	History of Bureau observations and ACORN-SAT	Dr Bruce Forgan and Dr Blair Trewin	9:55–10:15
Morning Tea			10:15–10:45
5.	The scientific integrity and robustness of the Australian temperature record and the homogenisation process (30 min presentation, 45 minute discussion)	Dr Blair Trewin and Dr Robert Fawcett	10:45–12:00
Lunch			12:00–1:00
6.	The extent of the public availability of the ACORN-SAT information (20 minute presentation, 40 minute discussion)	Dr David Jones	1:00–2:00
7.	Developments since the 2011 Independent Peer Review (IPR) of ACORN-SAT data and methods (20 minute presentation, 40 minute discussion)	Dr Blair Trewin	2:00–3:00
Afternoon tea			3:00–3:30
8.	Future development options for ACORN-SAT (20 minute presentation, 40 minute discussion)	Mr Neil Plummer	3:30–4:30
9.	Next steps	Chair	4:30–4:50
10.	Close	Chair	4:50–5:00

Appendix D

ACORN-SAT Technical Advisory Forum member biographies

Dr Ron Sandland AM FTSE (Chair)

Dr Sandland holds a PhD in statistics from the University of New South Wales. His research interests concern applying statistics to solve challenging real problems in areas as diverse as growth of organisms, analysis of mark-recapture experiments, ore-reserve estimation and quality improvement.

He was appointed the Deputy Chief Executive for CSIRO in 1999 and led the Flagship Initiative. This involved six major cross-disciplinary research programs and was aimed at addressing problems of a national priority.

He is an Honorary Life Member of the Statistical society of Australia and is a Fellow of the Australian Academy of Technological Sciences and Engineering (ATSE), and was made a member of the Order of Australia in 2007.

Emeritus Professor Bob Vincent FAA (Vice Chair)

Robert Vincent is Emeritus Professor in the School of Chemistry and Physics at the University of Adelaide. His major expertise is in the area of the atmospheric sciences, with a background in experimental studies of atmospheric processes, including the development of radar hardware, software and data analysis techniques.

He has served on international and national Forums covering Antarctic research and solar-terrestrial physics. His professional standing is recognised by election to the Australian Academy of Science, election as a Fellow of the American Geophysical Union, and as President of the International Council for Science/Scientific Committee for Solar-Terrestrial Physics (SCOSTEP) from 2007–2011.

Dr Phillip Gould

Dr Gould holds a PhD from Monash University specialising in time series econometrics.

He is currently managing the Education and Data Integration Branch within the Australian Bureau of Statistics and has also worked there as a methodologist, managing a team which delivers high quality analytical work for the ABS and external clients. Prior to joining the ABS Dr Gould worked in banking and finance, with a focus on econometric modelling of time series data.

Dr John Henstridge CStat, AStat, AFAIM, QPMR, FSS

Dr Henstridge holds a PhD from the Australian National University and is adjunct Professor at the University of Western Australia. In 1988, he founded Data Analysis Australia which is now the largest private statistical organisation in Australia.

He is a Fellow and Chartered Statistician of the Royal Statistical Society and an Accredited Statistician of the Statistical Society of Australia. He has served as President of both the Statistical Society of Australia's Western Australian branch and of the Geostatistical Association of Australasia and is currently National President of the Statistical Society of Australia.

Ms Susan Linacre

Ms Linacre holds a first class honours degree in Statistics and an Economics degree, both from the Australian National University.

She has spent most of her career at the Australian Bureau of Statistics, where she held a number of senior roles including Deputy Australian Statistician (Social Statistics Group) and First Assistant Statistician (Methodology Division). Ms Linacre has also worked in the UK as head of the Directorate of Methodology and IT in the Office for National Statistics. She is a member of the International Statistical Institute and past President of the International Association of Survey Statisticians.

Professor Michael Martin PFHEA

Professor Martin holds a PhD from the Australian National University where he is currently Professor of Statistics in the Research School of Finance, Actuarial Studies and Applied Statistics and the Centre for Higher Education, Learning & Teaching.

His research interests are applied statistics, statistical theory, statistical education and environmental and occupational health and safety. He also has been deeply involved in the teaching of statistics and has won a number of awards for teaching excellence. He is currently co-chair of the Statistical Education section of the Statistical Society of Australia and is a Principal Fellow of the Higher Education Academy.

Professor Patty Solomon

Professor Solomon holds a PhD in Statistics from the Imperial College of Science and Technology, London, and is currently Professor of Statistical Bioinformatics at the University of Adelaide.

Her research interests include Biostatistics, Bioinformatics, Statistical data mining, Clinical trials and Epidemiology. She has over 100 publications and has been funded by the Australian Research Council and the National Health and Medical Research Council.

Professor Solomon is an elected Member of the International Statistical Institute and is a member of the American Statistical Association, International Society for Clinical Biostatistics, Statistical Society of Australia and the Australian Mathematical Society.

Professor Terry Speed FRS, FAA

Professor Terry Speed holds a PhD from Monash University and is the Professor of Bioinformatics at Walter and Eliza Hall Institute of Medical Research.

He is currently laboratory head in the Bioinformatics division at the Walter and Eliza Hall Institute of Medical Research, in Melbourne, and was head of the division until 31 August 2014. His research interests include the statistical and bioinformatic analysis of microarray, DNA sequence and mass spectrometry data from genetics, genomics, proteomics, and metabolomics.

He has served as President of the Institute of Mathematical Statistics and has been awarded a number of prizes including the Pitman medal in 2002 and the Prime Minister's Prize for Science in 2013.



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