

Design Documentation

Australian Actuaries Climate Index

November 2018

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1. Introduction

The Australian Actuaries Climate Index (AACI) has been developed to measure whether the frequency of extreme weather conditions is changing over time. It is designed to provide an easy to interpret and valuable metric for actuaries, policy decision-makers and the general public to refer to when monitoring changes in climate[1]. Tim Andrews, Principal at Finity Consulting, led the team who collated the index

The AACI includes a series of component indices and a composite index.

- The component indices show changes in the frequency of extreme levels of each of temperature (high and low), rainfall, drought, wind, and sea level.
- The composite index combines the measures of high temperature, rainfall and sea level into a single index.

Actuaries specialise in understanding risk and this index has been designed to have some correlation with risk. This has been done through the selection of climate metrics that are indicators of risk and also through the focus on the 'extreme' tail of the metric distributions.

In the future, the intention is for additional indices measuring specific risk attributes to be developed by looking at the relationship between the data on extremes and historical risk data e.g.

- Risk of damage to property.
- Risk of damage to health.
- Risk of excessive energy demands.

2. Reference Period

A reference period of 1981 to 2010 has been used as a base from which to measure change, and data from this period has been used to determine a reference value for each metric. The index measure for each component represents the change between current conditions and the reference period value. We have chosen a relatively recent reference period to provide a contemporary view of how the extremes are changing.

Results are produced for each season, such that autumn is compared to previous autumns, summer is compared to previous summers, etc.

3. Individual Component Indices

There are six individual indices available which have been chosen for the impact and risk they pose to people and the economy. The data used for the indices is available from the Bureau of Meteorology (BoM) and described in Section 6. The indices are described in Table 1.

[1] The Actuaries Climate Index™ (ACI) has been developed in North America with a similar objective. http://actuariesclimateindex.org/home/

Table 1 – Components of Index

Component	Description
High Temperature	Frequency of maximum and minimum temperatures above the 99th percentile.
Low Temperature	Frequency of maximum and minimum temperatures above the 1st percentile.
Precipitation	Frequency of rainfall over five consecutive rainfall above the 99th percentile.
Wind	Frequency of daily wind speed above the 99th percentile.
Consecutive Dry Days	Seasonal maximum consecutive dry days.
Sea Level	Seasonal maximum sea level.

3.1.1 Temperature

For the high temperature, the AACI measures the change in the proportion of days in a month on which the maximum and minimum temperatures exceed the 99th percentile of the reference period distribution for the relevant day. The results for the maximum and minimum temperatures are then averaged.

The low temperature measure is calculated using a similar process by looking at the frequency above the 1st percentile.

Both the high and low temperature components therefore record if there is a warming in temperature.

3.1.2 Precipitation

Extreme precipitation over short periods is a key driver of flood and storm damage. The rainfall component of the index focuses on extreme rainfall over a consecutive 5-day window.

3.1.3 Wind

During severe wind weather events such as storms and cyclones, it is the maximum wind gusts that are likely to lead to higher risk and damage. The wind metric measures the monthly frequency of daily maximum wind gust above the 99th percentile.

3.1.4 Consecutive Dry Days

Consecutive dry days is included in the index as an indication of drought conditions. It is defined as the number of consecutive days with less than 1mm of rain up to a maximum of 365 days. The cap is included for practical purposes and has no material impact on the index.

3.1.5 Sea Level

The sea level measure tracks movements in the monthly maximum observed sea level, an important risk factor for coastal inundation. This measure uses sea level movements relative to land. Using this measure doesn't allow for land movements which can be caused by a mixture of climate and non-climate (tectonic movements) related factors, but this is the most readily available measure and is measured accurately by tide gauges.

4. The AACI

The headline AACI combines three of the individual component indices:

- High Temperature
- Precipitation and
- Sea Level.

The other individual metrics were excluded from the composite index for the following reasons:

- Low Temperature – to ensure that temperature was not overweighted in the composite, noting that High temperature is included.
- Wind - due to inconsistencies in the way wind data has been measured during the 1981-2010 reference period, which coincides with when the anemometers were upgraded (typically around 1995). The website shows wind gust data, but only for the period post installation of cup anemometers.
- Consecutive Dry Days - The drought measure was excluded as it shows a strong inverse correlation with the rainfall measure.

5. Calculation of Exceedance Thresholds

The measures for temperature, precipitation and wind track the frequency of events that are in excess of calculated exceedance thresholds. These thresholds represent the 99th percentile of events observed over the base period.

These 99th percentile thresholds are calculated for each day of the year during the base period. The calculation process is described through an example:

- Using 6 March as an example, we use all daily maximum temperature values for 6 March between 1981 and 2010. In order to increase the available data, we also take the observations for the five days before and after. This gives 330 days. From that data we take the temperature on the 4th warmest of the 330 days as the 99th percentile.
- The index then tracks the proportion of temperature values in a month that exceed the baseline.

The measures for sea levels and consecutive dry days are calculated directly from the data in the manner defined.

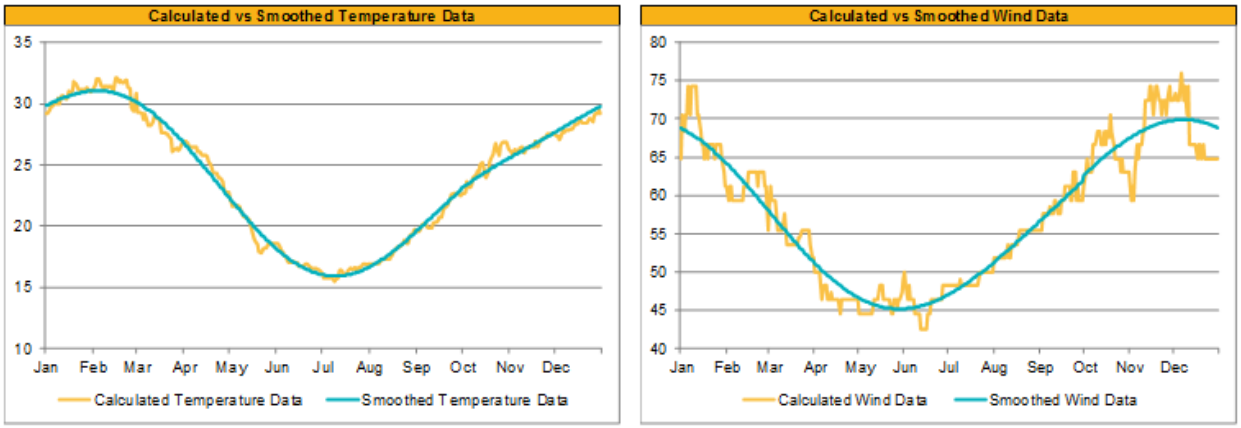
5.1 Smoothing

The one-sided nature of exceedance calculations means that when cut-offs are calculated directly from the data, bias can be introduced by the normal random variability associated with the process. This issue is discussed in *Avoiding Inhomogeneity in Percentile-Based Indices of Temperature Extremes* by Zhang et al (2004). This bias can mean that non-base period metrics appear higher than base period.

We aimed to minimise this bias by fitting smoothed curves (using generalised additive models or GAMs) to the exceedance thresholds before calculating metrics. This adjustment reduced bias from 0.2% to 0.05% when tested on simulated data. The simulated data had similar variability and seasonality as our raw time series, but without any trend over time.

The charts below show examples for temperature and wind. For temperature the curve tended to be straightforward to fit as the variability is limited. Wind was more challenging. In the example shown the assumed wind threshold is well above the observed 30 years of experience in October and below the experience in late November and early December. We have taken the view that variations in the actual experience like these reflect randomness, rather than real differences in the weather conditions.

Figure 1 – Smoothed GAMs to calculate exceedance thresholds



6. Data Sources

Individual weather station data from the BoM was relied on to construct the index. We aimed to ensure the data:

- had history going back to 1981, which is the start of the reference period; and
- was measured consistently over time (or had been homogenised by BoM as discussed below).

Details of the data sources used are provided in Table 2.

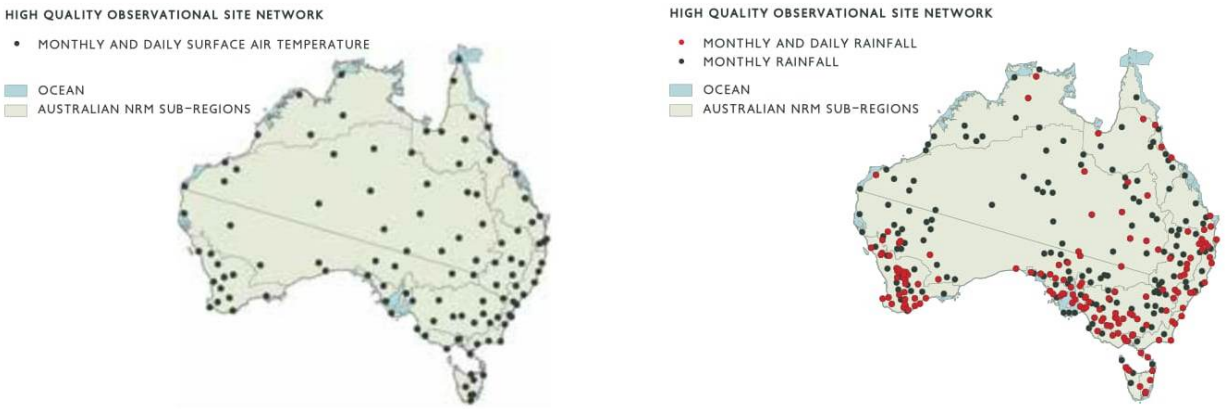
Table 2 – Data sources

Component	Source	Comments
High Temperature	112 ACORN-SAT BoM weather stations	This dataset has been homogenised for accuracy and consistency. There were an adequate number of stations in all of the regions included in our study (minimum of 3).
Low Temperature	112 ACORN-SAT BoM weather stations	As for high temperature.
Precipitation	All BoM weather stations that report on rain	We used all available weather stations (around 2,000) to maximise coverage and average out any inconsistencies.
Wind	38 BoM weather stations	The wind speed data is derived directly from weather station data based only on 38 stations that are thought to provide a reliable time-series, noting that wind data tends to be more uncertain.
Sea Level	Baseline sea level monitoring project	This project has been set up by the BoM in recent years to consistently measure sea levels.

Bureau of Meteorology (BoM)

The BoM has been collecting weather data from all around Australia since its inception in 1906. Some discontinuities and inconsistencies occur due to changes in technology, instruments, location, or environment. However, for certain stations and time series, the BoM has put considerable effort and resources into homogenising the data to ensure consistency through time. This process is widely acknowledged to be state-of-the-art and has been implemented for a subset of the station data. The ACORN-SAT data covers 112 stations across Australia for temperature. The locations of these stations give relatively good coverage across the regions that we are using for the AACI (refer Section 7 for a description of these regions).

Figure 2 – Temperature and Rainfall Site Locations

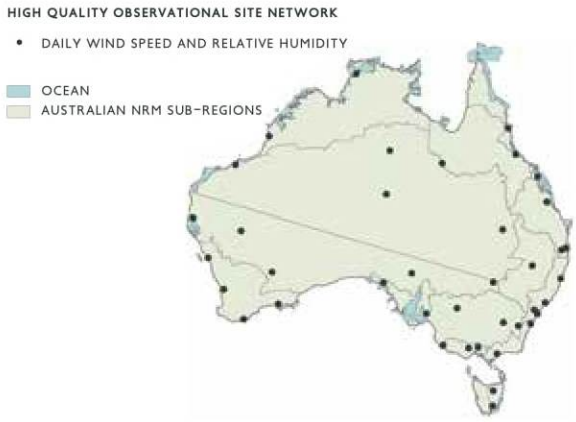


Source: Data Delivery Brochure, *Climate Change in Australia*

The BoM has not carried out this homogenisation process for wind station data. Many sites have issues with discontinuities and change in measurement technology. There are a small number of stations which are viewed by *Climate Change in Australia* (CSIRO and Bureau of Meteorology,

Climate Change in Australia website) to have data that is reliable enough to be used in time series analysis. Using only this subset of 38 stations will ensure that our analysis is as accurate as possible given the limitations. Coverage shown in Figure 3.

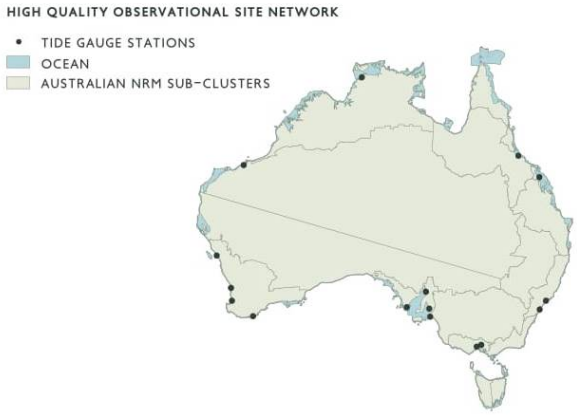
Figure 3 – Wind Speed Site Locations



Source: Data Delivery Brochure, *Climate Change in Australia*

The BoM also publishes data sources relating to sea level rise. The organisation publishes monthly sea levels and statistics from tide gauges, as well as a set of more comprehensive sea level statistics from a smaller number of tide gauges as part of its Baseline Sea Level Monitoring Project. The data is relative to land level.

Figure 4 – Tide Gauge Site Locations



Source: Data Delivery Brochure, *Climate Change in Australia*

6.1 Data Cleansing

Additional data cleansing was done to the BoM data to ensure the data feeding into the AACI was as reliable as possible. The key steps of the process are described below:

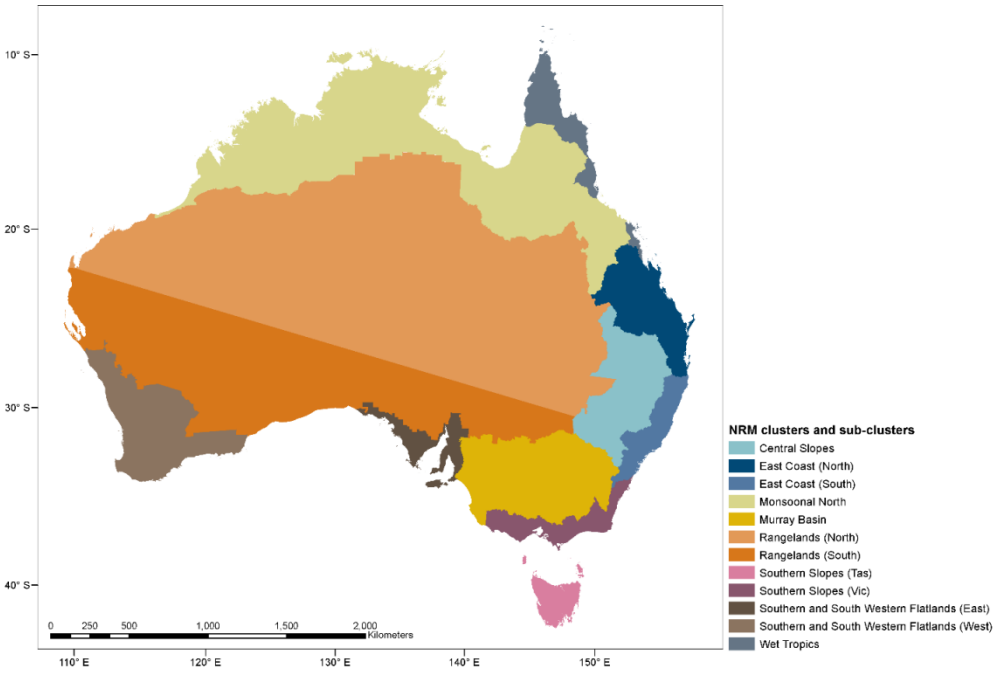
- We eliminated individual data points that were flagged as "suspect" by the BoM.
- Recording stations occasionally have missing data, noting that they can be out of action for (typically) short periods. In order for a station to be included in the analysis it had to exceed certain levels of data availability in both the reference period and post reference period:
  - 20+ days of data per month for the month to be considered valid.
  - For a station to be considered valid, it needs to have been available for at least two-thirds of the time – i.e.
    - 20+ valid months during the base period, for each calendar month.
    - 5+ valid months since the base period, for each calendar month.
    - 8+ valid months in 2017 (intended to determine whether the station is still operational).

7. Regions

Results are available for Australia and for 12 climatologically consistent regions of Australia as shown in Figure 5. These regions are based on CSIRO's 15 sub-clusters used for their 'Climate Change in Australia' data, although we have grouped clusters where there is insufficient data for them to be assessed in isolation.

The CSIRO also do projections of future climate conditions at this region level and project similar metrics to the AACI. Consistency in region definitions means that it will be possible to do a direct comparison of historical observations to their future projections.

Figure 5 – AACI Regions



8. Aggregation of Results

8.1 Geographic Aggregation

All calculations are done at an individual station level and then aggregated to a region level by taking the average of all stations within that region. This is done to ensure extreme observations are not averaged out in the index (which would be the case if we first averaged the station data and then calculated the measures).

Aggregation of the regions to an Australia-wide metric is also done by taking a simple average of the individual regions. This means that less weight is given to larger central Australia where the population is low, and more weight is given to smaller highly populated areas.

8.2 Aggregation of Component Metrics into Index

In order to make the measures comparable, they are standardised using the mean and standard deviation of each measure over the reference period. We subtract the mean from the result and then divide through by the standard deviation. This ratio creates a standardised anomaly, which measures the statistical significance of the change over time relative to the underlying level of variability and importantly allows the different measures to be aggregated into a single index.

To ensure that the index is easy to understand, the AACI uses a simple aggregation method, and takes the simple average of each of the three component measures (once they have been standardised).

$$AACI = mean(HighTemp_{std} + Precip_{std} + SeaLevel_{std})$$

The index is provided at quarterly time periods and updated on a quarterly basis. The primary metric used is a five-year moving average, which smooths some of the volatility and weather cycle impacts from the measure.

References

- The Actuaries Climate Index™ (ACI) has been developed in North America with a similar objective.
- CSIRO and Bureau of Meteorology, Climate Change in Australia website.
- *Avoiding Inhomogeneity in Percentile-Based Indices of Temperature Extremes, Zhang et al, 2004*

About the Actuaries Institute

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