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Temperature change in central Australia: episodic warming

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Abstract

From 1871 to 2024, central Australia experienced distinct warmer and cooler episodes, delineated by breakpoints in mean monthly maximum temperatures (maxima). Early episodes trended cooler; some warmer; later episodes trended warmer. Cooler and warmer components of the maxima both trended warmer in recent years. A system constant of 2.57^{o}C (the difference in episode averages between warmer and cooler components of maxima) was found across the 109 sets of records examined. Changes in Alice Springs maxima from 2001 to 2024 were strongly related to changes in certain oceanic climatic indicators and rainfall. Changes in arid South Australian vegetative cover were related to changes in maxima and changes in rainfall. Monthly changes in components of its vegetative cover were associated with changes in a complex of maxima, rainfall, and different ocean indicators.

Introduction and Methods: ***Expecting the average, knowing the unexpected***

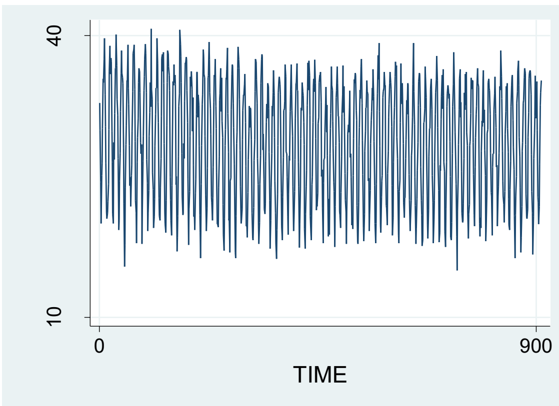
Each day, each month, each year, we expect the temperature to be average, despite its continuing rise and fall, while wanting to know whether it will be, is, and has been hotter or colder than we expected. This difference to the average ("*the unexpected*") is as important to us as the average. When Alice Springs maxima are plotted by month, the difference to the average surges up and down (Fig. 2), different to the structured if ragged maxima (Fig. 1). (Figs. 1 to 5 use Alice Springs Post Office 1887-1953; Fig 6 shows Alice Springs Airport 1941-2024)

When you add these differences together in sequence, you form the Change Plot (Fig. 3), showing how maxima have changed over time, once you've allowed for temperature increase or decrease. A Change Plot depicts what you didn't expect, and have not known, including episode duration and the large difference between each and all warmer and cooler episodes (Fig. 1.4).

In any change plot, all measures in an incline were above average, and below average in any decline, but not increasing nor decreasing significantly within each episode. The peaks and troughs are the sharp breakpoints between warmer and cooler episodes.

Change plots were used to visualise and analyse the interrelationships of maxima, rainfall, vegetation, and oceanic climatic indicators. Regression analysis, ttest, tabulation and chi test were statistical methods employed (Stata: www.stata.com). Alice Springs maxima and the vegetative cover of arid South Australia are used as examples for central Australia.

Monthly temperature and rainfall data were downloaded from Australian Bureau of Meteorology (BOM: www.bom.gov.au/climate/data). Ocean indicators were from BOM and National Oceanographic and Atmospheric Administration (https://www.ncei.noaa.gov/cdo-web/). Vegetative cover data were from Rangelands and Pasture Productivity (https://map.geo-:rapp.org).



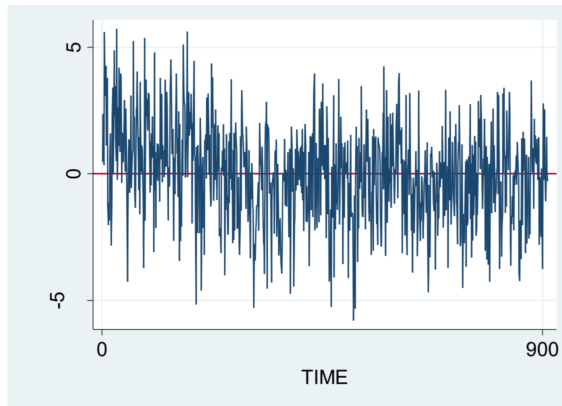
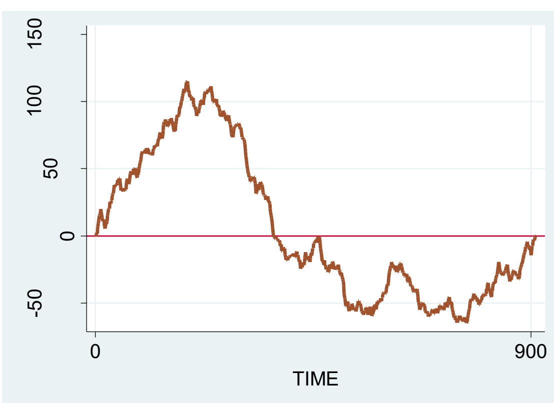


Fig. 1 Monthly maxima

Fig. 2 Difference to monthly average



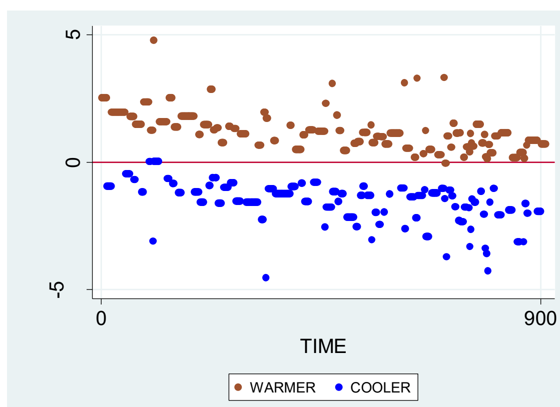


Fig. 3 Change Plot

Fig. 4 Episode Mean Difference to Average

Results:

Seeing temperature change

The numerous short episodes that can be seen in the change plots of Alice Springs Post Office (159 between 1878-1953 – Fig. 3) and Airport (343 between 1941-2024) can be grouped into 28 longer episodes (Fig. 5). These episodes have two features:

- Large episodic oscillations between cooler and warmer episodes
- A distinct fall then rise

The duration of longer oscillations can vary from less than 1 year to decades.

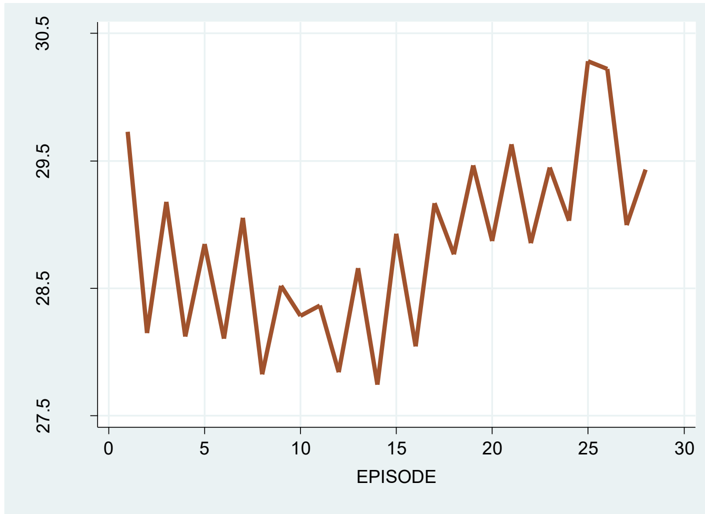


Fig. 5. Longer cooler and warmer episode maxima for Alice Springs 1878 to 2024

These oscillations in maxima were found in all 109 central Australian records examined, together spanning 1871 to 2024. See locations in Appendix.

Warmer and cooler episodes of the maxima oscillate about a constant

Parsing the change plot of monthly maxima for Alice Springs (1941 to 2024) found 172 warmer and 171 cooler episodes. Each mean episode difference to the average is plotted in Fig. 6. The warmer episode means averaged 30.45 ºC lasting 3.1 months; the cooler episode means averaged 27.10 ºC and 2.6 months, compared with general mean of maxima: 28.92ºC.

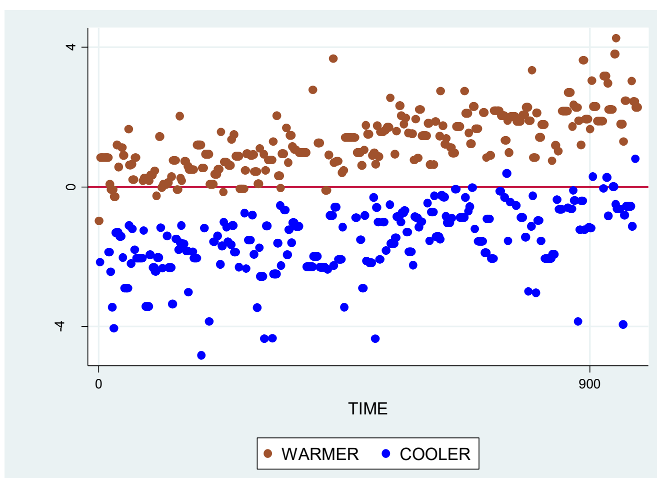


Fig. 6. Episode mean difference to average monthly maxima: Alice Springs 1941 to 2024

The trend in warmer and cooler maxima averaged 0.0128 ºC per warmer episode and 0.0098 ºC for cooler episodes. The maxima had a lower trend of 0.0012 ºC. The decadal change for warmer episodes was 0.266 ºC; 0.198 ºC for cooler episodes, and 0.234 ºC for all maxima. Over the 83 years, the mean episode difference between warmer and cooler episodes of the maxima averaged +2.81 ºC, larger than the total change in maxima (+1.93 ºC). The total change in maxima for Alice Springs 1878-1953 (see Fig. 4) was a cooling of -1.44 ºC.

Falls in maxima were common in records beginning before 1940 (21 of 32 sites) across central Australia. Rises in maxima were observed in all records beginning from 1940. Decadal trend averaged +0.032ºC for records commencing before 1940, and +0.310 ºC for later sets of records.

For 109 sets of records from 1871 to 2024, the difference between the warmer and cooler shorter episode means centred around a constant: +2.57 ºC (95% CI: 2.53 to 2.61). The varying durations of shorter episodes determined the timing of the larger oscillations, together with varying maxima. The average durations of shorter episodes at any site varied from 2.2 to 5.7 months, with a mean of 3.63.

The oceans influenced maxima

Changes in and over surrounding oceans were related to changes in maxima. For monthly maxima of 4 Alice Springs area sites (Airport, Jervois, Kulgera, Grape Farm) from 2001 to 2024, change in amplitude of the MJO (Δ_MJOAmpl) accounted for 43% of changes in maxima on regression analysis. Including changes in SOI, AO and IOD explained 75% of maxima changes; adding changes in rain raised explanatory power to 90% for changes in monthly maxima:

Δ_maxima ~= +2.25 Δ_MJOAmpl – 0.052 Δ_SOI + 0.67 Δ_AO - 0.95 Δ_IOD -0.048 Δ_rain - 3.393977

*[*Abbreviations*: Δ_parameter: change in a parameter; SOI: Southern Oscillation Index; AO: Antarctic Oscillation; IOD: Indian Ocean Dipole; MJO: Madden-Julian Oscillation - Ampl Amplitude; Phase-Phase; RMM1 -RM1; RMM2 -RM1]*

Maximum temperature changes influenced vegetative cover

Monthly changes in vegetative cover (2001 to 2024) were related to the warmer and cooler episodes when considered with changes in rainfall across central Australia. In one example, the relationships for arid South Australia (see Appendix) were stronger for %green cover and %bare ground than for %non-green cover on regression analysis.

- Δ_Green ~= +1.20*Δ_max +0.38 *Δ_rain +19.1 (R^2 - 0.67)
- Δ_Non-Green ~= +2.80*Δ_max +0.32*Δ_rain +51.7 (R^2 - 0.39)
- Δ_Bare Ground ~= -4.00*Δ_max - 0.75*Δ_rain - 75.5 (R^2 - 0.52)

Maxima and rainfall were for 6 sites (Oodnadatta, Moomba, Woomera, Marree, Yunta, Ceduna).

Maxima, rainfall and the oceans influenced vegetative cover

Changes in vegetative cover of arid South Australia were related to changes in oceanic climatic indicators combined with changes in maxima and rainfall on regression analysis:

- Δ_Green: Δ_[maxima, rain. amplitude of MJO, SOI] (R^2 - 0.85)
- Δ_Non-Green: Δ_[maxima, rain, SOI, IOD] (R^2 - 0.60)
- Δ_Bare Ground: Δ_[maxima, rain, SOI, AO, {Phase, RM2 of MJO}] (R^2 - 0.76)

- Δ_Total Cover: Δ_[maxima, rain, SOI, AO, {Phase, RM2 of MJO}] (R^2 - 0.76)

Discussion, Conclusions and Implications

This study found central Australian maximum temperatures from 1871 to 2024 had structured variability in a binary (warmer/cooler) system with breakpoints delineating episodes. This system may be determined by or interact with oceanic and continental influences, as well as rainfall, from analysis of 2001 to 2024 records. Changes in vegetative cover may be a part of this systemic interaction. The Madden-Julian Oscillation was found to be important in maxima changes, and vegetative cover change.

Changes in maxima were important in vegetative cover changes. Intuitively, the observed large jumps in maxima between cooler and warmer episodes are likely to be important for vegetation. The marked increases over time in both cooler and warmer components of the maxima across central Australia are concerning due to the anticipated manifold effects of global warming, and the likelihood of episodic, extended, widespread large increases in maxima; correlated reduction in rainfall; and consequent widespread falls in vegetative cover.

The widespread cooling from early 1900s may reflect the severe loss of vegetation and soil with the rabbit invasion of eastern Australia and overstocking of its rangeland areas (Barnard 1962, Rolls, 1984; Lunney 1994), with subsequent buildup of airborne particulates, as with "*global dimming*". It is also possible that the limited evidence of warming from the early 1870s to 1890s may reflect the cessation of indigenous burning practices to manage vegetative cover, thereby reducing airborne particulates, as their populations and culture were affected by Europeans from late 1700s and first part of 1800s onwards (Gammage 2012).

Using change plots to visualise and analyse empirically and statistically the dynamics and interrelationships of vegetation, climate and other phenomena opened new ways to understand and quantify Australian rangelands. Change plots remove the cyclic elements of temperature and vegetation that obscure underlying linear change and discontinuities.

Episodicity and episode duration can be included as climate characteristics (Foley 1957, Curran 2023).

The episode mean [*warmer-cooler*] difference is a system constant, in the same sense that each location has a characteristic average rainfall, and differences between wetter and drier episodes centre on constants (Curran 2023), despite varying considerably around that constant from year to year, by month-of-year, and within each day.

Acknowledgements

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