Author comments to the Major Revision Review by Editor and Anonymous Referee #1 on the manuscript

Extending and understanding the South West Western Australian rainfall record using a snowfall reconstruction from Law Dome, East Antarctica

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We thank the Editor and the Reviewer for the time they have spent reading and reviewing it. We respond to each of the suggestions for revision below. The reviewer's suggestions are shown in **bold text**, replies are shown in normal text, text from the original manuscript is shown in green, revisions of the Major Revision are shown in red, and proposed changes for the reconsideration to the manuscript are shown in blue.

Editor's comment:

When I looked at your track changed version, it seemed that the scale of changes you had made was rather small and not really commensurate with what the two reviewers requested (both asked for major revisions). Reviewer 1 has looked at the paper again and confirms exactly this opinion. I noted in my previous editorial comment that your response did not answer the referee's request (point 3) about stationarity, and asked you to address this - but you did not. In view of this please prepare a further version of the manuscript, paying particular attention to the three points that the reviewer has emphasised. Once these are addressed, I will consider it worthwhile to ask the reviewers to spend time on the paper again. Thank you for acting on this.

We thank the editor for these comments. We acknowledge that we could have explored the role of stationarity in further depth. In response to the comments by the editor and the reviewer, we have made further revisions to the manuscript. Most significantly, we have extended our statistical analysis of the robustness of the reconstruction and we have used the climate model simulations to explore the stability of the teleconnection between Law Dome and South West Western Australian precipitation. We offer a point-by-point response to the reviewers' comments below and attach a revised version of the manuscript.

Reviewer's comments:

1 For the mechanism that could explain the link between precipitation in SWWA and snowfall at Law Dome (point 1 in the comments), the authors mention the 'variations in meridional circulation south of Australia' without additional explanation. I could live with that as they refer to a previous paper but this is still very short. I am surprised that such a role of meridional circulation is not clearly mentioned in the introduction when discussing the processes influencing precipitation in SWWA or at Law Dome. By contrast, if I interpret well the figure 1 in the response (Figure S5) the 'Correlation between precipitation at Law Dome and Southern Hemisphere mean sea level pressure' displays a zonal structure with clear change in zonal winds but the meridional variations are not obvious to me. This is consistent with the sentence stating that 'the strength and position of southern hemisphere westerlies dominate changes in coastal Antarctica snowfall.' I am thus wondering if the justification implies a meridional change in zonal flow rather than the meridional circulation itself and more information on this would be very useful for the reader.

We thank the reviewer for this comment. We have added more sentences in the Introduction starting at Line 80 to provide more information on the mechanism.

Lines 80–94: "~~at the DSS site (66.7697°S,112.8069°E,1370m elevation) (Roberts et al., 2015).~~ Connections between mid-latitude climate and that of coastal East Antarctica have been reported for some time (Goodwin et al., 2004; van Ommen and Morgan, 2010). The strength and position of the southern hemisphere westerlies are important for coastal Antarctic snowfall rates, especially for cyclonically driven locations such as Law Dome, East Antarctica (Bromwich, 1988). The specific relationship between SWWA and snowfall recorded in the Dome Summit South (DSS) ice core from Law Dome was reported by van Ommen and Morgan (2010) who found a statistically significant anticorrelation between winter (JJA) mean SWWA regional rainfall and Law Dome snow accumulation. This link, which accounts for up to 40% of the shared variance on interannual to decadal timescales is associated with simultaneous anomalous northward flow of relatively cool, dry air to SWWA and southward flow of relatively warm, dry air to the Law Dome region. This teleconnection pattern is characterised by a broadly zonal wave three pattern in 500 hPa geopotential field. The northward flow to SWWA, while bringing showers to the southern coast, is distinct from the higher rainfall patterns which bring prefrontal rain from north/north-westerly directions (van Ommen and Morgan, 2010). More recently, this work has been extended using a longer 2035-year accumulation record from the Law Dome core (Roberts et al., 2015). As with the earlier accumulation record, this was dated by determining annual layers in the seasonally varying water stable isotope ratios and trace ions from multiple ice cores drilled at the DSS site (66.7697°S, 112.8069°E, 1370 m elevation) (Roberts et al., 2015). Taken together, the relationship between SWWA rainfall and DSS snowfall and the"

2 For the point two in my initial comments, the information provided in the response is interesting and the results very convincily prove that the validation is fine if one considers the whole period. It is still important for me to compute the value of the correlation over the period 1900-1971 to see the effect of the trend at the end of the record. I am also still interested in a visual comparison of the time series of precipitation over SWWA and snow accumulation at Law Dome. One option would be to add the reconstruction (which is proportional to snow accumulation at Law Dome if I am right) on Figure S7 or alternatively the time series of observed rainfall on Figure 3 (but this may be less clear on this scale).

We thank the reviewer for this comment. We calculated the correlation over the period 1900–1970 and constructed the linear model. To present these results in context, we extended the analysis to construct a full jackknife ensemble in which all possible pairs of non-overlapping 45-year periods are omitted. This analysis has been incorporated into Table S4.

Although we find that the correlation between Law Dome accumulation and SWWA rainfall is weaker when the period 1971–2015 is omitted, we note that the 95% confidence intervals in the model parameters overlap between all members of the jackknife ensemble. At the 5% probability level, we cannot therefore reject the null hypothesis that the model parameters are unchanged when the period 1971–2015 is omitted. We conclude that there is no evidence to suggest that our model, and therefore our reconstruction, is biased by any post-1970 trend. We have added a corresponding paragraph in supplementary material Lines 54–58: "To further explore whether the relationship between Law Dome accumulation and SWWA rainfall has changed during the current drought, the middle section of Table S4 repeats the jackknife analysis but increases the duration of the period omitted to 45 years. Although we find greater scatter in the values for the correlation coefficient, gradient and intercept, the 95% confidence intervals continue to overlap. We therefore find no evidence to suggest that the relationship between Law Dome accumulation and SWWA rainfall has changed.".

We have added an additional panel on Figure 2 for a visual comparison of the time series of precipitation over SWWA and snow accumulation at Law Dome. We have also added a corresponding sentence in Lines 210–211: "~~The scatter plot for MASK rainfall and DSS snow accumulation is shown in Figure2a.~~ The time series and the scatter plot for SWWA rainfall and DSS snow accumulation are shown in Figure 2a and Figure 2b, respectively. The data show a generally".

3 Still on the stationarity (point 3 in the initial comments), I am wondering why the authors do not provide, at least in their response, a running correlation between precipitation in SWWA and snowfall at Law Dome in the simulations. It is a simple diagnostics. If the value remains high during the whole period, then it is a clear indication that the link is robust and stationary. If it changes a lot between centuries, at least a cautionary note should be added in the discussion.

We thank the reviewer for this comment. We are sorry that we didn't clearly present our response on the running correlation in either the manuscript or the supplementary material. We added Figure S6 in the supplementary material and corresponding sentences in Lines 64–70: "We further explored the link using the SWWA precipitation in the model simulations. To do this, we extract nine CSIRO Mk3L computing cells of the precipitation simulations around SWWA region and nine cells around

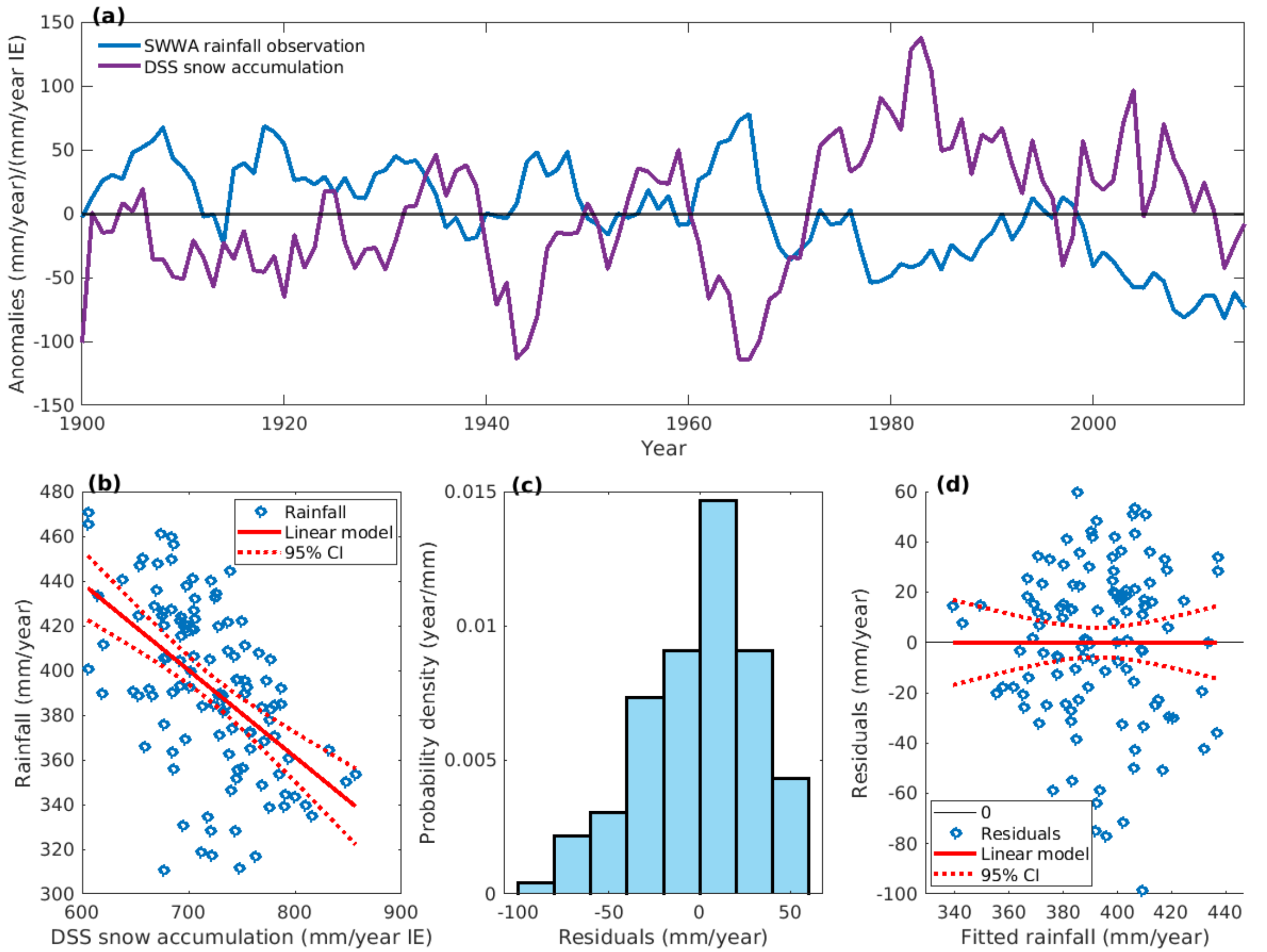
. Table S4. The correlation coefficient between the smoothed ice core record and the mean of the AWAP rainfall in the "MASK" region. The three sections represents the results for a 12–year jackknife, a 45–year jackknife and the full period, respectively. x1 and Intercept are the coefficients for the linear model: Rain = Snow * (x1 $\pm$ 95% CI) + Intercept $\pm$ 95% CI mm/year. The 95% confidence interval (CI) is estimated by multiplying the standard error of the model by 1.96.

Section	Period	Correlation coefficient	x1	Intercept (mm/year)
12-year jackknife analysis	1912–2015	-0.536	-0.385 $\pm$ 0.118	667 $\pm$ 85
	1900–1911 & 1924–2015	-0.513	-0.363 $\pm$ 0.118	651 $\pm$ 85
	1900–1923 & 1936–2015	-0.532	-0.378 $\pm$ 0.117	662 $\pm$ 85
	1900–1935 & 1948–2015	-0.524	-0.405 $\pm$ 0.128	684 $\pm$ 93
	1900–1947 & 1960–2015	-0.545	-0.407 $\pm$ 0.122	685 $\pm$ 88
	1900–1959 & 1972–2015	-0.499	-0.385 $\pm$ 0.130	671 $\pm$ 94
	1900–1971 & 1984–2015	-0.506	-0.427 $\pm$ 0.141	699 $\pm$ 101
	1900–1983 & 1996–2015	-0.492	-0.374 $\pm$ 0.129	662 $\pm$ 92
	1900–1995 & 2008–2015	-0.512	-0.356 $\pm$ 0.116	651 $\pm$ 82
	1900–2007	-0.593	-0.379 $\pm$ 0.098	670 $\pm$ 71
45-year jackknife analysis	1945–2015	-0.511	-0.351 $\pm$ 0.139	635 $\pm$ 103
	1900–1944 & 1990–2015	-0.414	-0.389 $\pm$ 0.202	672 $\pm$ 144
	1900–1925 & 1971–2015	-0.489	-0.403 $\pm$ 0.170	679 $\pm$ 125
	1900–1970	-0.296	-0.193 $\pm$ 0.147	548 $\pm$ 102
Full period	1900–2015	-0.529	-0.389 $\pm$ 0.114	672 $\pm$ 82

Law Dome region. We calculate the mean of each region's nine cells for each member of ensemble and each ensemble mean and perform 6-year smoothing for each series (for consistency), and then calculate the 100-year running correlation (Figure S6). This does not show a strong or sustained correlation. However, this is not surprising, given the mechanism outlined in van Ommen and Morgan (2010). Correlation is essentially connected with periods of enhanced meridional flow which will be less apparent over extended periods in which mix meridional and zonal modes of circulation."

However, we are aware that our last major revision was not clear enough to address this comment. We here add sentences in the manuscript corresponding to the supplementary material Section 5.

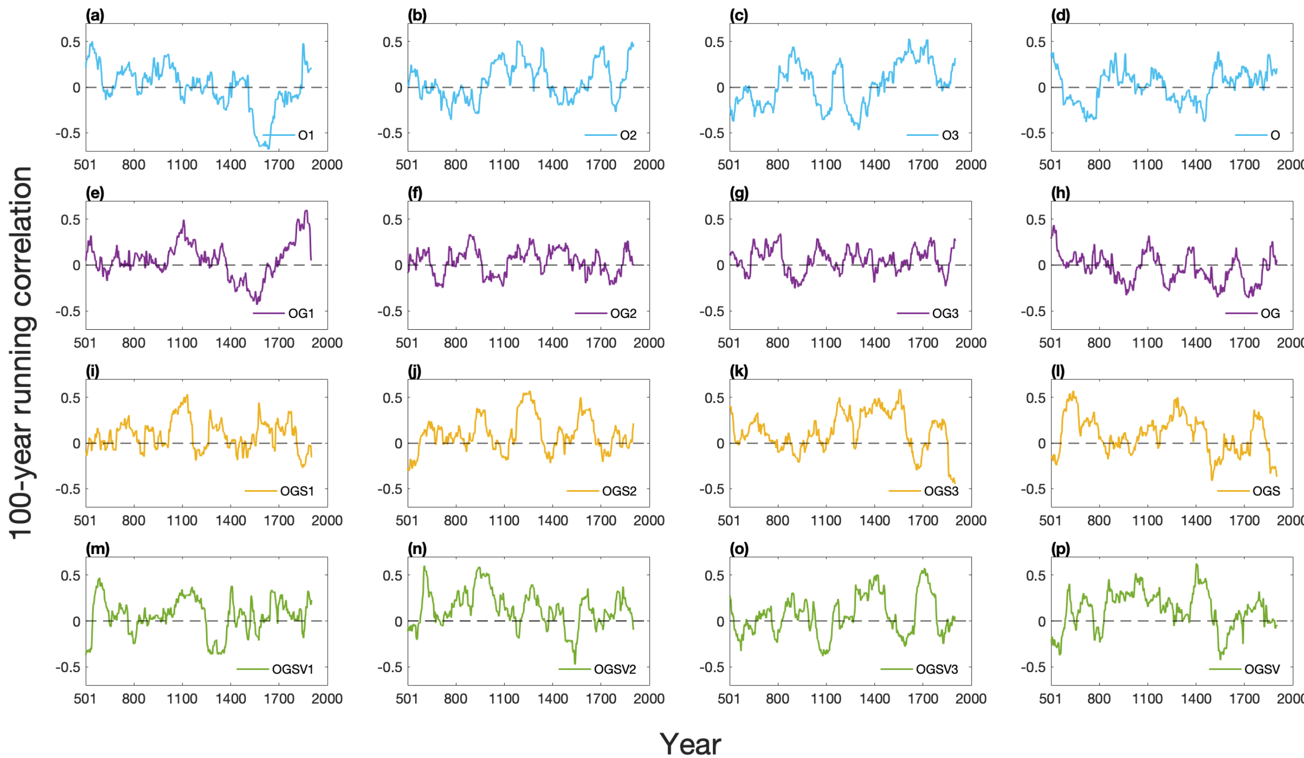
Lines 220–225:"and trend, and is generally symmetric along y = 0. We furthermore assess the robustness of the model in Supplement Section 5. We calculate the autocorrelation length (where the autocorrelation coefficient is equal or below zero) of the SWWA rainfall for the period 1900–2015 CE, and perform a jackknife (modified) analysis. The correlation coefficients of each individual jackknife ensemble member are all consistent with the period 1900–2015 CE (Supplement Table S4), and the 95% confidence intervals for the gradient and intercept are overlapped (Supplement Table S4), showing the statistically



. **Figure 2.** (a) The time series of anomalies for AWAP rainfall in the MASK region and DSS snow accumulation (6-year running averages) for the period 1900–2015 CE. (b) The scatter plot for AWAP rainfall in the MASK region and DSS snow accumulation (6-year running averages) for the period 1900–2015 CE with their linear model and 95% confidence interval. (c) The probability density function histogram for the model residuals. (d) The scatter plot for model residuals and fitted data with their linear fit and 95% confidence interval.

indistinguishable between each individual jackknife ensemble member. Taken together, there is no obvious evidence to reject the linear model. Thus, we use".

Lines 265–273:" ~~over SWWA before the instrument-era.~~ We further validate the rainfall reconstruction in Supplement Section 5. We have found that the temporal stability of large-scale circulation over mid-latitude Australasian and higher latitude Law Dome regions is consistent, indicated by the correlation fields between Law Dome precipitation and mean sea level pressure in each member of the CSIRO Mk3L OGSV ensemble (Supplement Figure S5). This rainfall reconstruction has shown that it is possible to use ice cores to investigate the longer-term context of rainfall variability over SWWA prior to the instrumental era. We should also be aware that the Law Dome—SWWA precipitation correlation is stronger during periods of enhanced (stronger/more frequent) meridional circulation, but weaker during periods of weaker meridional circulation (van Ommen and Morgan, 2010). The robustness of the reconstruction may therefore be reduced during periods of reduced meridional flow between southern Australia and Law Dome (Supplement Section 5). We choose 1850 CE to be the year that separates before and after the"



. **Figure S6.** 100-year running correlation of the CSIRO Mk3L precipitation simulations between SWWA and Law Dome for each member and the each ensemble mean from 501 to 2000.

References

Bromwich, D. H.: Snowfall in high southern latitudes, Reviews of Geophysics, 26, 149–168, 1988.

Goodwin, I., Van Ommen, T., Curran, M., and Mayewski, P.: Mid latitude winter climate variability in the South Indian and southwest Pacific regions since 1300 AD, Climate Dynamics, 22, 783–794, 2004.

Roberts, J., Plummer, C., Vance, T., van Ommen, T., Moy, A., Poynter, S., Treverrow, A., Curran, M., and George, S.: A 2000-year annual record of snow accumulation rates for Law Dome, East Antarctica, Climate of the Past, 11, 697–707, 2015.

van Ommen, T. D. and Morgan, V.: Snowfall increase in coastal East Antarctica linked with southwest Western Australian drought, Nature Geoscience, 3, 267–272, 2010.