Authors' Response:

We thank the Reviewer for the comments and suggestions. In the text below, we outline our response in blue.

Anonymous Referee #1

Overall: This paper provides an analysis of a new dataset stemming from the Roosevelt Island Climate Evolution ice core. The authors identify how well this ice core compares with ERA-Int data, approximate the regional temperature and precipitation variability, and how well it compares with other proxy data in West Antarctica and portions of the western Ross Ice Shelf. The authors note an finding of a 'Ross Sea dipole' where there are periods of opposite relationships between the eastern and the western Ross Ice Shelf.
I think the paper holds promise, and certainly this new dataset needs to be presented and discussed widely. However, I find concern in interpreting the Ross Sea dipole to the SAM.

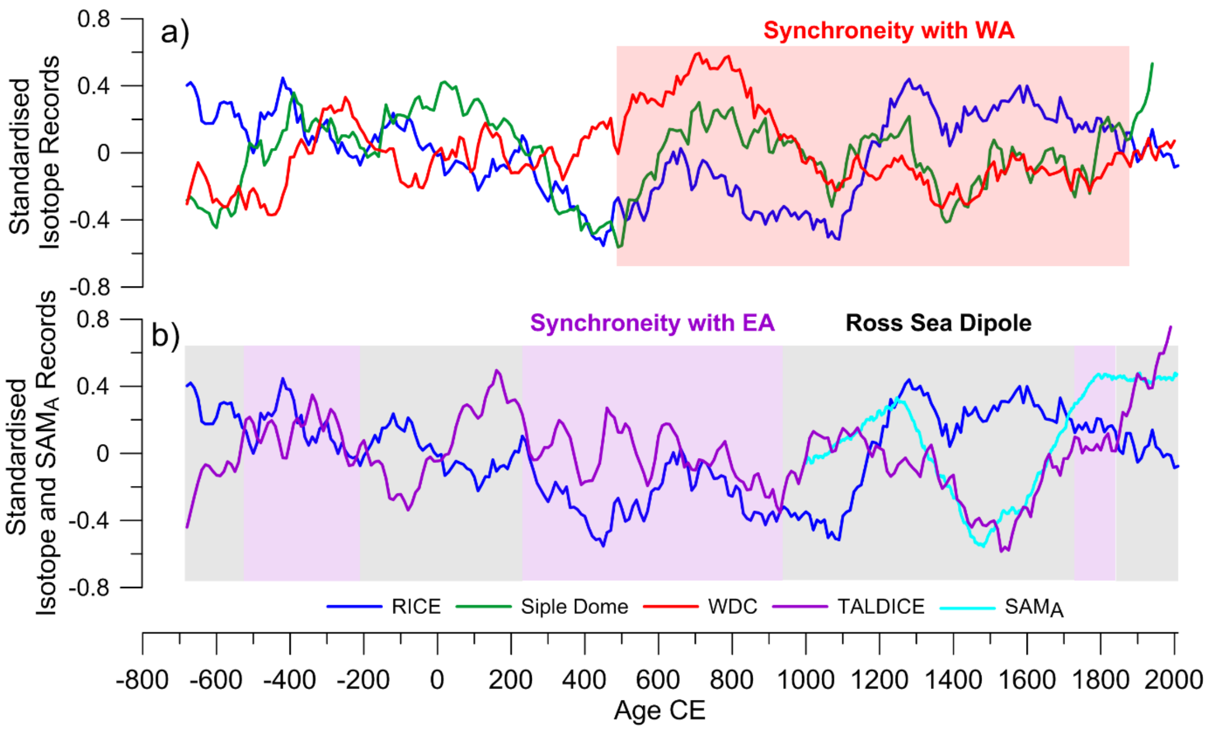
The authors base the SAM connection with the Ross Sea dipole from one paper, Marshall and Thompson (2016), presumably Fig. 2b in this paper. This figure from Marshall and Thompson (2016) indeed shows opposite patterns of heat flux across the eastern and western Ross Ice shelf associated with the SAM. However, I'm not sure that this can easily be implied as consistent with the results from the anti-phase relationships observed in the proxy data presented in the paper, for a few reasons:

a) The relationships in the Marshall and Thompson (2016) paper were based on daily data, and the authors note that the heat flux relationships with the SAM are much weaker when integrated over time periods more than a week. It is therefore really hard to know if they still exist on annual mean data (let alone data that are smoothed with 200-year moving averages!). This dipole pattern with the SAM and the heat flux is also found in reanalysis data since 1979, which certainly can't tell us much about its persistence on timescales back more than 100 years.
b) Even if there were a dipole pattern associated with the SAM that persisted, there clearly isn't a dipole pattern with temperature and the SAM (Fig. 3b of Marshall and Thompson (2016) and many other works, including Marshall (2007), Thompson and Solomon (2002) etc.). In terms of temperature, the SAM exerts the same-sign relationship across the entire Ross Ice shelf, and West Antarctica and East Antarctica. For precipitation / accumulation, there may be more of a dipole like structure (this is nearly impossible to verify with observations or reanalyses), but so many local factors influence precipitation / accumulation that it is hard to say how robust any Ross Sea dipole pattern is.
c) Climate connections with the ASL, whether from ENSO or the SAM, show dipole patterns on much larger scales, with differences (in temperature, precipitation, winds, etc) occurring between the Antarctic Peninsula / eastern West Antarctica and the Ross Sea (Ice Shelf) / western West Antarctica. I don't know fully how a dipole pattern across just the Ross Ice Shelf, from annual mean data or longer, could be related to these much larger-scale climate patterns, at least based on observations and contemporary reanalyses.

I therefore found the climate connections and their interpretation with the RICE data to be far too simplistic and an incorrect interpretation of one figure from Marshall and Thompson (2016). The authors need to revise this portion of the paper and better justify / support the pattern in relationship to the SAM, or simply not make claims that it is consistent with the SAM.

Our hypothesis that the Ross Sea Dipole might be, at least in part, an expression of the regional influence of the SAM, is based on a range of observations, with the principal evidence derived from the comparison of the 1,000 year-long SAM reconstruction (SAM_A) by Abram et al. 2014. During the most negative phase of the SAM_A, we observe cooler (warmer) conditions in the western (eastern) Ross Sea (Figure 6). We further investigate this relationship by comparing detrended isotope records from RICE, Siple Dome, WDC and TALDICE, smoothed with a 200 year moving average (Revised Figure 8). Please note that in the revised Fig.8 we use an updated from Severi et al, 2012 age scale for TALDICE. The original and revised Figure 8 identified time periods dominated by opposing temperature trends in the eastern / western Ross Sea. Instead of time periods of known and hypothesised past negative and positive SAM time periods, we have modified the figure to show the SAM_A reconstruction smoothed with a 200 year running mean. This replaces frames used in the original figure, which identified the the two periods of prolonged positive and negative SAM phasing as recorded in the SAM_A record. The revised figure illustrates the relationship between SAM_A and the phasing / occurrence of the Ross Sea Dipole. In the manuscript, we explore a possible mechanism to explain the influence of the SAM on the spatial temperature pattern influenced by the heat flux pattern observed by Marshall and Thompson (2016) and as noted by Reviewer 1, the influence of the SAM producing a dipole in the meridional heat flux across the Ross Ice Shelf can be observed in the ERAi data for the 1979-2012 time period. This suggests that the SAM - dipole heat flux relationship remained robust despite changes in the phasing of ENSO and the IPO. Marshall and Thompson (2016) find that this dipole is not apparent in temperature. We don't necessarily see this contradicting our hypothesis as on short time periods other drivers, in particular sea ice conditions have a strong, perhaps masking influence. But if changes in heat flux and meridional winds persist over longer time periods, we would expect those changes to lead to changes in sea ice extent, temperature and snow accumulation in the Ross Sea.

However, we agree with Reviewer 1 that we did not provide sufficient evidence to suggest a causality. For this reason, we have revised the manuscript to remove statements suggesting causality and instead only note the co-variance between the SAM_A record and the reconstructed spatial temperature pattern.



Revised Figure 1: Phasing of multi-decadal and centennial climate variability at RICE, Siple Dome, WDC and TALDICE using detrended, normalised isotope records smoothed with a 200-year moving average. RICE and Siple Dome are compared with a) WDC and b) TALDICE to investigate phase relationships of climate variability in the eastern Ross Sea with West (WDC) and East Antarctica (TALDICE). WA= West Antarctica, EA= East Antarctica. The detrended, normalised SAM_A record (Abram et al. 2014, light blue) has been smoothed with a 200-year moving

average and is shown in panel (b). Shaded periods indicate synchroneity of RICE (and Siple Dome) data with WA (red box) or EA (purple box). Grey shading indicate time periods where RICE (eastern Ross Sea) shows an antiphase relationship (a Ross Sea Dipole) with TALDICE (western Ross Sea).

Minor comments:

Abstract, line 31: change 'Annual' to 'Annular'

Done

Line pg 3: 26: gradient of what, exactly? Just pressure / height, or other fields?

Changed to 'pressure gradient'

Lines pg 3. 30-33: you should specify this is increase in total Antarctic SIE, as there are regional differences.

Pg 3, line 31 - Changed to 'the total Antarctic SIE increase'

Figure 2: the color scale for the correlations is odd. It makes it challenging to see what the magnitude of the correlations are in the top panel. Even if they are significantly different from zero, a small correlation explains very little of the interannual variability and therefore may not be an ideal representation of temperature variability at other regions in West Antarctica or off the Ross Ice Shelf.

The spatial correlation pattern in panel (a), (b), and (c) are shown to highlight and compare the spatial representativeness of records derived from the RICE site (extracted ERAi data) and actual RICE data (δD, snow accumulation). Only correlations significant at >95% are included. While weak correlations can be useful, correlations at r> +0.4 and r< -0.4 are especially distinct with the chosen colour scale changing from red to yellow and from turquoise to blue, respectively. We feel that this colour scheme therefore provides an accessible and clear representation of both the pattern and the strength of the correlation.

Fig 2e, discussion of temp. trends on pg. 6 lines 37-40 and pg. 7 lines 1-7: It is fair to say ERA-Int may not capture the correct trend at the RICE site, but why not compare with observations directly at McMurdo / Scott Base or any of the longer Wisconsin AWS records (Gill , Ferrell, etc.) on the Ross Ice Shelf? These are strongly correlated with the RICE site based on Fig. 2a. I think comparing with NB2014 is helpful, but I think it is a huge oversight to not do any comparisons with direct observations (you could even use the Byrd temperature record here).

There are two principal reasons why we did not use weather station data:

- Records in the vicinity are either short and/or suffer from large data gaps (Margaret, Gill, Ferrell AWS, Siple Station and the original Byrd Station)
- Station records (McMurdo, Scott Base) are at the opposing site of the observed Ross Sea Dipole and the reconstructed Byrd Station record also falls at the margin of the correlation pattern.

However, we agree that it would be useful to show the comparisons. We propose to include the Figure S1 and Table S1 in the supplementary information of the manuscript. For clarity, the comparison in Figure S1 is shown for the raw data covering 1957-2012 and for standardised data for 1957-2012 and 1979-2012. The comparison highlights that while all data sets agree on the occurrence of particularly extreme cold (i.e. 2004, 2010) or warm (i.e. 1980) years, there is large spatial, interannual variability across the data sets. Table S1 shows that for the satellite period (1979-2012), only the correlation between RICE δD and ERAi is statistically significant. If the 1957-2012 time period is considered, the NB2014 reanalysis data set also becomes significant, but only at p<0.1, which is a level not considered in our original manuscript.

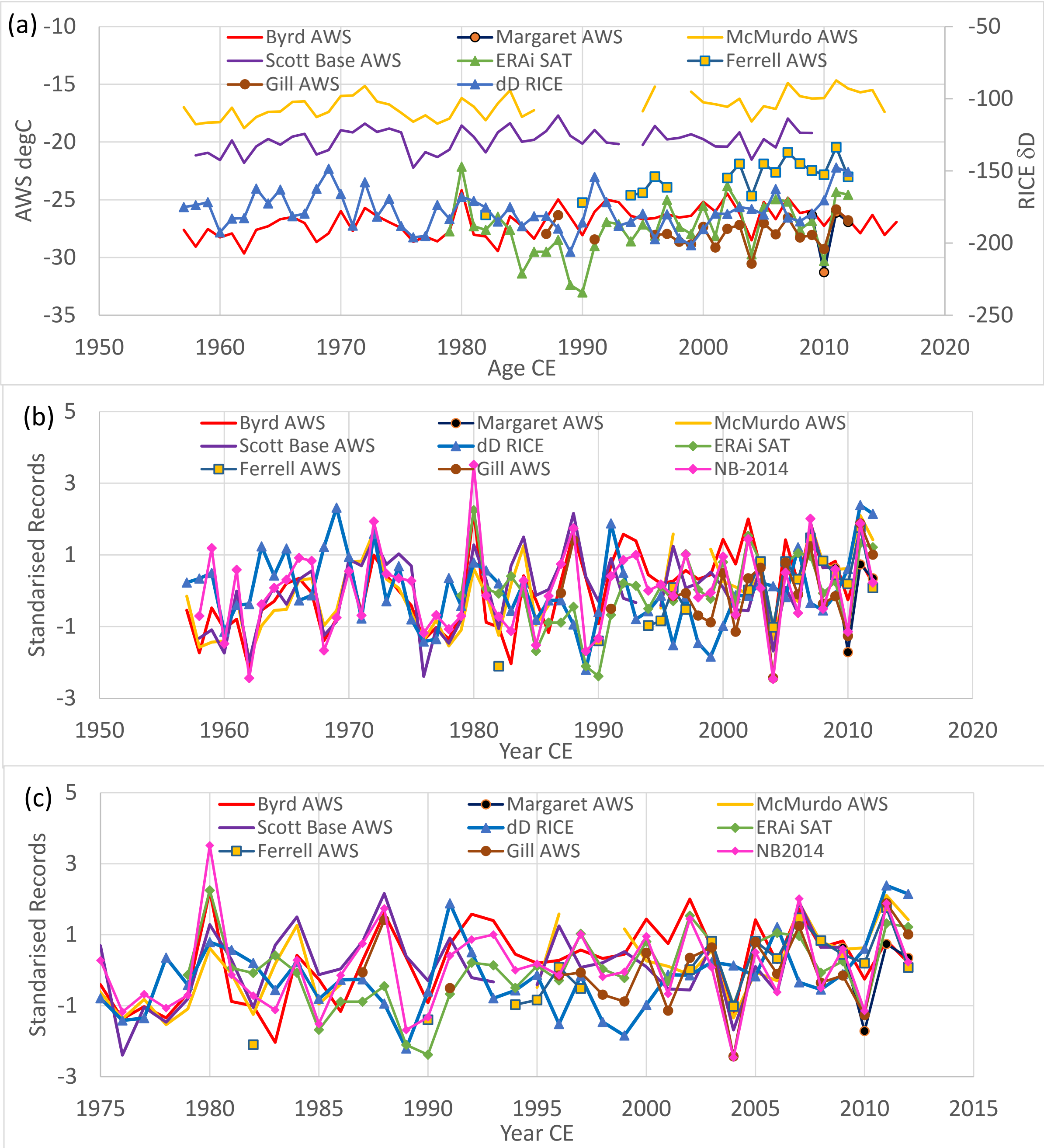


Figure S1: Comparison of temperature data from Antarctic Stations, remote Antarctic Weather Stations (AWS), and reanalysis products with δD RICE data. Origin of the data is referenced in Table R1-1. Panel (a) shows the actual data, panels (b) and (c) show the comparison of the standardised records for the time periods 1957-2012 and 1975-2012, respectively.

Table S1: Pearson correlation coefficient (r) and significance values (p) for correlations between RICE δD record and relevant observational records from automatic weather stations and reanalysis data. Data for the reconstructed Byrd Station meteorological data (Bromwich et al., 2013) are accessed via the Byrd Polar Research Centre, Polar Meteorological Group, Ohio State University (http://www.polarmet.osu.edu/datasets/Byrd_recon/). Weather station data for Ferrell, Gill, and Margaret AWS are accessed via Antarctic Meteorological Research Center and Automatic Weather Station Project (https://amrc.ssec.wisc.edu). Data for McMurdo Station and Scott Base are accessed via the MET-READER (https://legacy.bas.ac.uk/met/READER/data.html). The number of years of observations represents the total number of years which contain monthly averages for each month of a calendar year. Only years with 12 monthly values are included in the correlation.

Correlation with RICE δD	Location (lat/long)	Elevation (m asl)	Time Period Overlap	No of Years of Observations	r	p-Value
Byrd Station (revised by Bromwich et al.	80.0° S 120.0° W	1515	1957-2012	56	0.05	0.72
Ferrell AWS	77.9° S 170.8° E	45	1982-2012	17	0.30	0.24
Gill AWS	79.9° S 178.6° W	53	1987-2012	20	0.24	0.31
Margaret AWS	80.° S 165.0° W	67	2009-2012	4	0.33	0.67
McMurdo AWS	77.9° S 166.7° E	24	1957-2012	48	0.11	0.46
Scott Base AWS	77.9° S 166.7° E	16	1958-2009	51	0.02	0.90
Siple Station AWS	75.9° S 84.0° W	1054	1982-1992	5	0.02	0.97
NB2014	Extracted for nearest grid point to RICE location 79.39° S / 161.71° W	550	1979-2012	34	0.26	0.14
NB2014	Extracted for nearest grid point to RICE location 79.39° S / 161.71° W		1958-2012	55	**0.23**	**0.09**
ERAi	Extracted for nearest grid point to RICE location 79.39° S / 161.71° W		1979-2012	34	**0.42**	**0.01**

Fig 3, discussion page 7 lines 30-31: ERA-Int could also be different in that it uses a different snow density and/or conversion from precipitation to water equivalent. (something with the microphysics in ERA-Int model).

Agreed. We have added the sentence in line 31: '…and the actual drill site location, as well as differences in assumed snow densities, or different methodologies in the conversion from precipitation to water equivalent units.'

Figure 4: Also not particularly happy about the color scale here for the correlations.

We make the same argument as for Figure 2 above.

Page 7, lines 37-38: It would be more instructive to say that the negative correlation includes regions of the South Pacific, Antarctic Peninsula, and eastern West Antarctica, rather than the

'ASL region' since the ASL varies its location from month to month, and the correlation is not significant across the entire region that the ASL may reside.

Agreed. We have changed the wording accordingly: "A negative correlation is found in the regions of the South Pacific, Antarctic Peninsula and eastern West Antarctica"

Page 9, lines 3-5: The Nino 3.4 and Nino 4 are close (and overlap partially), and are therefore strongly temporally correlated. However PSA1 and PSA2, by design through EOF, are uncorrelated in time and space. I don't think using Nino 4 for PSA2 is a good idea because of this.

Agreed. We have revised the text in the manuscript to refer to the El Niño regions 3.4 and 4 and the resulting Rossby wave propagations.

Page 9, Table 2 ENSO correlations lines 10-15: In addition to differences in the phasing of ENSO and SAM, using annual means for ENSO is also compromising the correlations, since ENSO events wrap around a calendar year (peaking in December often). They are likely stronger on seasonal means; this should be mentioned.

As outlined in our manuscript, we are cautious to use RICE seasonal means because of the variable frequency and intensity of precipitation events which have the potential to lead to seasonal biases. We have added the following sentence on page 9, line 14: 'Correlations using seasonal instead of annual averages might be more suitable to identify a linear relationship between RICE records and ENSO events, which usually peak during the austral summer, in particular December (Turner et al. 2004). However, we refrain from using seasonal means because of the variable frequency and intensity of precipitation events at Roosevelt Island which have the potential to lead to seasonal biases, as outlined in section 4.2."

We will add the following reference: Turner, J.: The El Niño–Southern Oscillation and Antarctica, International Journal of Climatology, 24, 1-31, 10.1002/joc.965, 2004.