Author's Response

We thank the Reviewer for their constructive comments regarding our manuscript. Our responses to specific comments are shown below in blue.

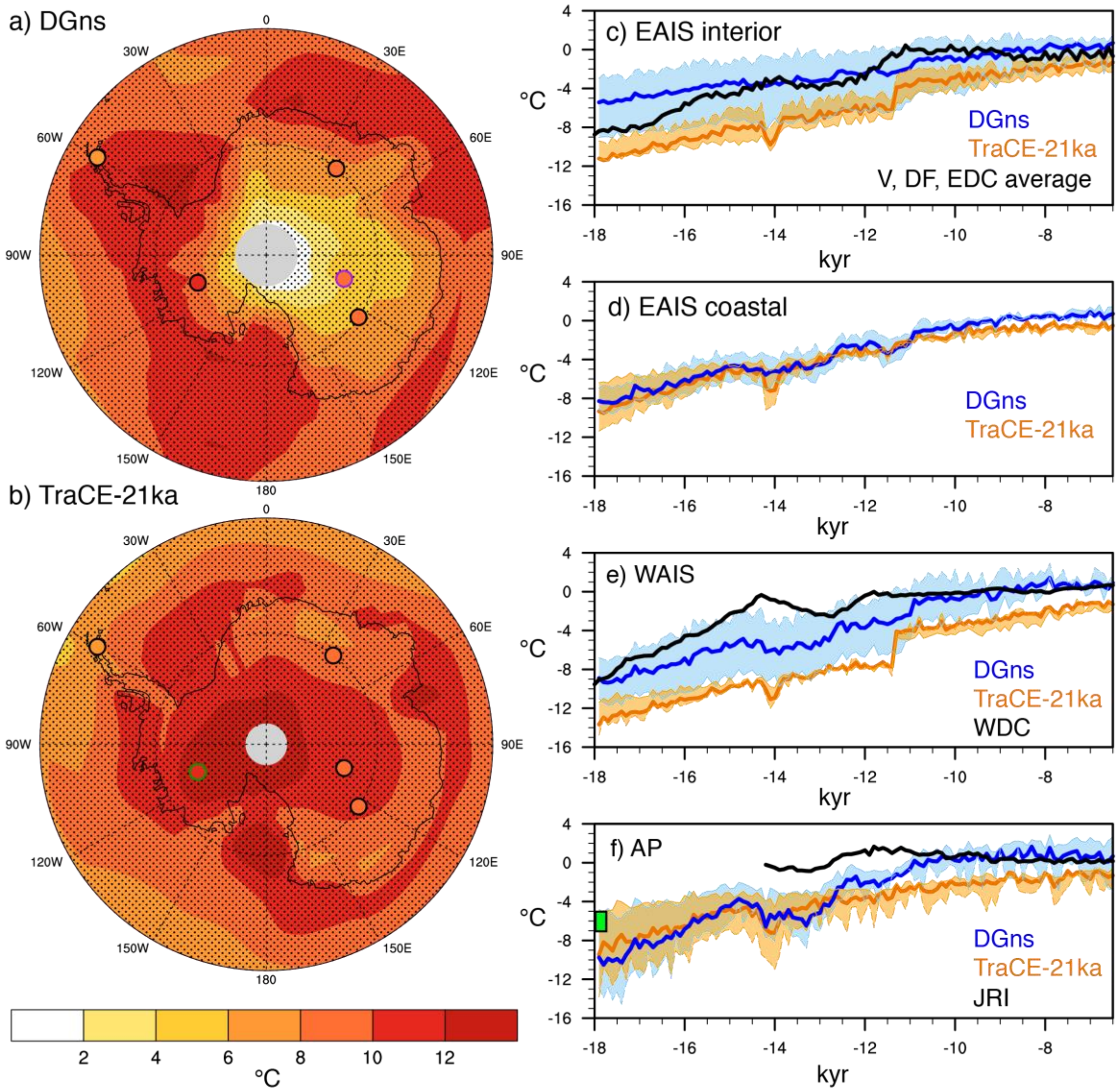
This manuscript analyzed published transient simulations of the last deglaciation with a focus on regional conditions in Antarctic and Southern Ocean. The authors compared modeled temperature, accumulation rate and sea ice with available proxy estimates. Using model simulations, the authors also explored changes in variables and relationships that could impact ice-sheet mass balance. The manuscript is well-written. The topic may interest readers of Climate of the Past. But, I hope the following questions and comments will be addressed.

Major comments:

1. In general, I feel the authors largely overlooked potential biases and uncertainty in proxy records, including the ice-core temperature and Alkenone- and Mg/Ca-based SSTs. Stable isotopes in ice cores reflect complicated signals in climate system, such as changes in seasonality (Jouzel et al., 2003; Erb et al., 2018), sea-ice content and changes in moisture source regions (Noone and Simmonds, 2004; Holloway et al., 2016), etc. Similarly, marine SST records are also subject to substantial uncertainties (for example, see Tierney and Tingley, (2018) for a discussion of alkenone-based SSTs). The authors should better consider and incorporate these biases and uncertainties in their model-data comparison and related discussion. I suggest the authors further explore possible seasonality biases in ice-core and marine sediment records by comparing modeled seasonal temperatures, in addition to annual mean, with proxy records. They can also test whether water isotopes in ice cores more reflect temperature at condensation level or surface air temperature.

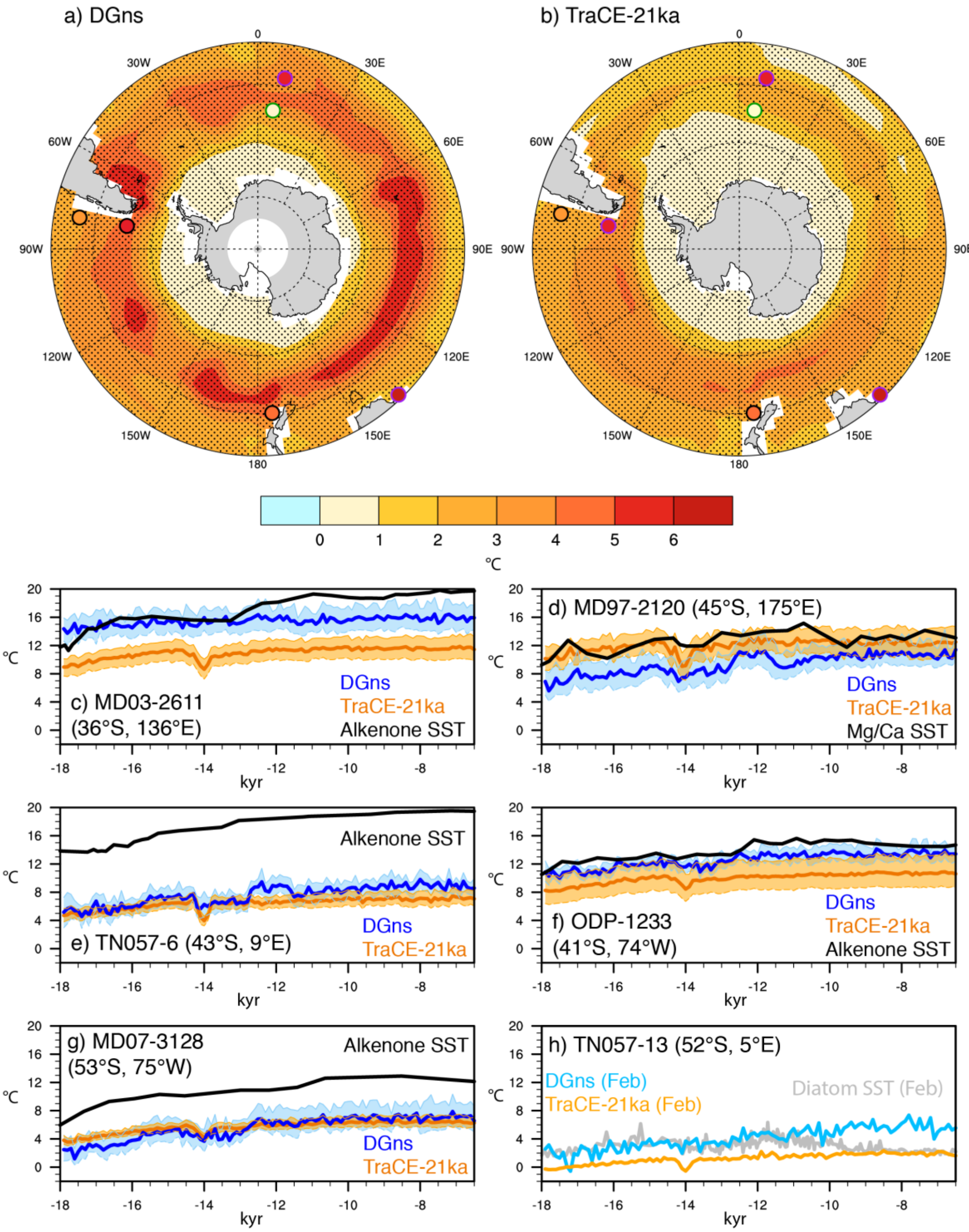
We agree with the reviewer that a discussion of proxy uncertainties and inclusion of seasonal model output is warranted and will make our analysis more robust. We now plan to discuss uncertainties related to ice core and marine SST records in Section 2.2 as well as in the context of our results. Specifically, we will note that the temperature reconstructions of the ice cores can be influenced by the seasonality of precipitation, as explained in Jouzel et al. (2003) and discussed in a climate modelling context in Erb et al. (2018). As such, the ice cores could be reflecting a summer or winter temperature response, rather than an annual mean response. Considering that many of the available Southern Ocean SST reconstructions are alkenone-derived, it is important to explain that in regions of high seasonality, TEX_{86} records can be biased low or high in accordance with the seasonal cycles of the marine archaea that produce GDGTs (Prahl et al., 2010). Seasonal output of both models (austral summer and winter) will therefore be incorporated in the time-series plots of Fig 1, 2 and 5. Additionally, we will explain that changes in the temperatures and locations of the oceanic source region and sea ice concentration contribute to the uncertainty in the ice core temperature reconstructions (Uemura et al., 2012; Holloway et al., 2016). We also note to the Reviewer that this paper is primarily focused on the climate models, which are not isotope-enabled, and as such, analysis of the water isotopes of the ice cores is beyond the scope of this study.

The revised Fig 1 and Fig 5, which include the available seasonal output, are shown below. In consideration of the potential for seasonal bias in the proxy records, the climate models perform relatively well with respect to continental surface temperature. The temperature change observed in the James Ross Island between 18 and 6.5 ka is within the range of seasonal temperature anomalies of both models (we previously said that the models overestimate the temperature change at this site). The temperature changes at WAIS Divide, Epica Dome C, and Dome Fuji are also within the seasonal range of the DG_{ns} simulation (we previously said the DG_{ns} simulation underestimates the temperature change at these sites). Model performance with regard to SST is mixed, with the models generally showing less sea surface warming through the analysed period, with the exception of the highest latitude site in the Atlantic sector, where they overestimate the warming. The best model-proxy agreement is observed in the Pacific sector. Austral summer SSTs of the models generally show better agreement with the proxy reconstructions than the annual mean or austral winter SSTs. We also note that the SST proxy records are temporally sparse, which may also contribute to the model-data mismatch.



Revised Fig. 1: Surface temperature change (°C) as simulated in (a) DG_{ns} and (b) TraCE-21ka for the period of 18 to 6.5 kyr. Ice core locations of the JRI, WDC, DF, V, and EDC sites are marked by open circles, with black outlines indicating a match in warming between the ice core and model simulation (i.e., the ice core temperature change from 18 to 6.5 ka is within the range of seasonal temperature changes of the climate model), and green (purple) outlines indicating an overestimation (underestimation) in warming by the models. For these model-proxy comparisons, we use site-specific model averages of land surface grid cells: JRI (63-65°S, 59-62°W), WDC (77-82°S, 115-109°W), DF (75-79°S, 36-42°E), V (77-82°S, 104-110°E), EDC (73-77°S, 121-127°E). Stippling indicates a difference between decadal output of 18.0-17.5 kyr and 7.0-6.5 kyr that is significant at the

95% confidence level. (c-e) 100-yr average surface temperature time series (°C) of four regions (EAIS interior: 83°S-75°S, 30°W-165°E; coastal EAIS: 75°S-68°S, 15°W-165°E; WAIS: 83°S-72°S, 165°E-30°W; AP: 72°S-64°S, 64°W-59°W) relative to PI of both model simulations and ice core temperature reconstructions of sites located therein (DG_{ns} in blue, TraCE-21ka in orange, ice cores in black). The colored shading indicates the seasonal range calculated from the 100-yr average austral summer and winter temperature anomalies. For EAIS, the ice core reconstruction is an average of the DF, V and EDC sites. The green box in (f) indicates the LGM temperature anomaly estimated for JRI (6.01±1.0°C; Mulvaney et al., 2012).



Revised Fig 5: Sea surface temperature (SST) change (°C) as simulated in (a) DG_{ns} and (b) TraCE-21ka for the period of 18 to 6.5 kyr. Marine sediment locations are marked by open circles, with black outlines indicating a match in warming between the ice core and model simulation (i.e., the estimated proxy SST change from 18 to

6.5 ka is within the range of seasonal SST changes of the climate model), and green (purple) outlines indicating an overestimation (underestimation) in warming by the models. Stippling indicates a difference between decadal output of 18.0-17.5 kyr and 7.0-6.5 kyr that is significant at the 95% confidence level. (c-h) Time series of 100-yr average mean annual SST from the models and SST proxy reconstructions (°C) at each individual marine sediment core site. The color shading represents the seasonal range calculated from the 100-yr average austral summer and winter temperature anomalies. In panel h, only a seasonal (February) proxy reconstruction is available; therefore, we only show modelled February SSTs from the climate models for this site.

2. Related to the first comment, I suggest the authors provide more details on how ice-core δD is converted to temperature. What temporal temperature-δD slope is used for each proxy records? This could be done in Table 2.

We will add the temporal isotope-temperature slopes to Table 2 for the ice core records. The listed citations in the Table also contain further details regarding the temperature and accumulation reconstructions. We rely on previously published records that are publicly available for download, hence these conversions are not performed as part of our analysis. The revised Table 2, which also includes 2 additional marine sediment core sites and one citation correction (TN057-6), is shown below:

Table 2. Antarctic and Southern Ocean proxy record details.

Record name	*Type*	*Measurement*	*Method*	*Location*	*Reference*
Vostok (V)	Ice core	Temperature anomaly	*δ*D temperature calibration (9.0‰ $°C^{-1}$)	East Antarctica, 78.5°S, 107°E	Lorius et al., 1995; Petit et al., 1999
Dome Fuji (DF)	Ice core	Temperature anomaly	*d* temperature calibration (7.7‰ $°C^{-1}$)	East Antarctica, 77°S, 39°E	Uemura et al., 2012
James Ross Island (JRI)	Ice core	Temperature anomaly	*δ*D temperature calibration (6.7+/-1.3‰ $°C^{-1}$)	Antarctic Peninsula, 64°S, 58°W	Mulvaney et al., 2012
EPICA Dome C (EDC)	Ice core	Temperature anomaly; Accumulation	*δ*D temperature calibration (7.6‰ $°C^{-1}$); Ice flow model	East Antarctica, 75°S, 124°E	Jouzel et al., 2007; Parennin et al., 2007; Stenni et al., 2010
WAIS Divide (WDC)	Ice core	Surface temperature; Accumulation	Water stable isotope record, borehole temperatures and nitrogen isotopes (7.9‰ $°C^{-1}$); Ice flow model	West Antarctica, 79.5°S, 112°W	WAIS Divide Project Members, 2013; Cuffey et al., 2016; Fudge et al., 2016
Core MD03-2611	Marine sediment core	SST	Alkenone-derived	Murray Canyons area, 36°S, 136°E	Calvo et al., 2007
ODP site 1233 core	Marine sediment core	SST	Alkenone-derived	SE Pacific, 41°S, 74°W	Kaiser et al., 2005
Core MD97-2120	Marine sediment core	SST	Mg/Ca-derived	Chatham Rise, 45°S, 175°E	Pankhe et al., 2003
Core TN057-6	Marine sediment core	SST	Alkenone-derived	South Atlantic, 43°S, 9°E	Anderson et al., 2014
Core MD07-3128	Marine sediment core	SST	Alkenone-derived	Magellan Strait, 53°S, 75°W	Caniupan et al., 2011
Core TN057-13	Marine sediment core	Seasonal SST (Feb, Aug)	Diatom-derived	East Atlantic Polar Front, 50°S, 6°E	Nielson et al., 2004; Anderson et al., 2009

3. The climate models used in the transient simulations were released more than 10 years ago (e.g., CCSM3 was released in 2004) and were considered outdated. I understand that there are no transient simulations using newer models, but some well-known biases in the models certainly deserves some caveats. For example, CCSM3 simulates much more sea-ice cover in both hemispheres than present-day observation (Yeager et al., 2006). Figure 7 of the authors' manuscript also shows a much more extensive sea-ice cover in the TraCE-21 LGM simulation than proxy estimates. Additionally, CCSM3 has problems simulating jet stream in the Southern Ocean and its response to external forcing (see Rojas et al., 2009). How are these model biases influence model-data comparison and findings in this manuscript?

We agree with the Reviewer that our results need to be discussed in the context of these known model biases. While we do discuss the limitations of the intermediate complexity atmospheric component of LOVECLIM with regard to precipitation, we did not sufficiently address the known biases of CCSM3 or the LOVECLIM ocean component CLIO, as stated in Yeager et al. (2006), Large and Danabasoglu (2006), Roche et al. (2007), and Rojas et al. (2009), among others. This is particularly relevant for our discussion of sea ice and ocean temperatures in sections 3.4, 3.5, and 4.2, and these biases will be detailed in our revised manuscript.

4. For Figure 1a and b, I would like to see temperate changes at individual sites compared with model simulations. One way to do so is to use face color of markers to indicate proxy temperature changes and edge color (e.g., black or no edge) to represent whether model agrees with proxy estimates within uncertainty.

We agree with the Reviewer that this will be useful for readers and plan to revise Fig 1a,b and 2a,b accordingly (see revised Fig 1 above). We now use the outline to represent the model-proxy agreement, but use the circle fill to show the change estimated in the proxy record.

5. The authors are comparing averaged proxy SST in the Southern Ocean with model simulations in Figure 5a. I would suggest them also show model-data comparison at individual core sites, which enables us to see any potential regional difference in proxy estimates and possible divergent behavior from different proxy types (e.g., Leduc et al., 2010).

We agree that comparing the model output to proxy records at individual sites will enhance this analysis. Based on this suggestion, we plan to include a new figure to show seasonal and annual average SSTs of individual sites (see revised Fig 5 above). We will also include two additional sites that were omitted in the original submission, namely, Core MD07-3128 (Caniupan et al., 2011) and Core TN057-13 (Anderson et al. 2009).

Minor comments:

1. Line 92: version T31x3 –> version 3

This has been changed.

2. Line 99 and Table 1: What exact is the resolution of T21? 5.6◦ by 5.6◦?

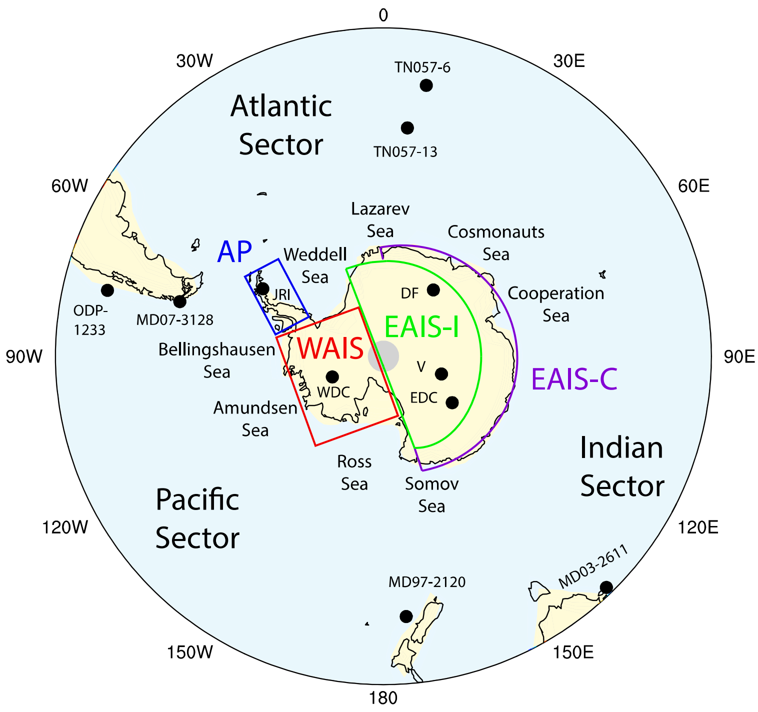
Yes, 5.6° x 5.6°. This has been added to Table 1.

3. Line 162–163: Can you briefly justify the way you divide the Antarctic?

We plan to add the following: Considering differences observed between Antarctic ice core records from East and West Antarctica and between coastal and interior regions, we focus on the following four regions in our analysis: the interior of the East Antarctic ice sheet (EAIS interior; 83°S-75°S, 30°W-165°E), coastal East Antarctica (coastal EAIS; 75°S-68°S, 15°W-165°E), West Antarctica (WAIS; 83°S-72°S, 165°E-30°W), and the Antarctic Peninsula (AP; 72°S-64°S, 64°W-59°W).

4. Figure1: it would be helpful if the authors can plot boxes/sectors for region EAIS interior, EAIS coastal, WAIS and AP.

In order to not distract from the color contours of surface temperature in Fig 1, we plan to add the following figure, which shows each region, ice core site, and marine sediment record site:



View of Antarctica and the Southern Ocean (maximum Latitude of 35°S). The colors indicate the land and ocean mask of the TraCE-21ka simulation (yellow and light blue, respectively). The continental regions, namely, the Antarctic Peninsula (AP), the West Antarctic Ice Sheet (WAIS), the East Antarctic Ice Sheet interior (EAIS-I), and the East Antarctic Ice Sheet coastal region (EAIS-C) are outlined in the colored boxes (blue, red, green, and purple, respectively). The locations of the Antarctic ice core and marine sediment records used in this analysis are indicated by the black dots.

5. Line 197: What is the assumed lapse rate of 1.0degC/100m based upon? I think this is too high. I suggest the authors to calculate the lapse rate in the model or reanalysis (e.g., Mokhov and Akperov, 2006).

We calculated the average polar lapse rate over Antarctica in LOVECLIM for the 18ka time-slice to be 0.54°C/100m, which is in closer agreement with the Mokhov and Akperov (2006) estimation. This sentence will be revised accordingly.

6. Figure 5: Are these time series SST anomalies or absolute SST? If they are SSTA, how are they calculated?

This figure will be divided into two figures, following the Reviewer's suggestions of examining individual sites. In the first, considering the discussion regarding seasonal biases of SST proxy reconstructions, we plan to show the absolute SSTs. In the second figure, in which only the modelled coastal ocean temperatures are shown, we calculate SST anomalies relative to the Preindustrial Era.

7. Line 910–911: "within the range of proxy temperature reconstruction uncertainty of -10% to +30%" Where is the uncertainty range from? Jouzel et al. (2003)? Jouzel et al. (2003) estimated the uncertainty range for eastern Antarctic. How are the uncertainties for WAIS and AP obtained?

Cuffey et al. (2016) and Mulvaney et al. (2012) provide uncertainties for the temperature reconstructions for the WAIS Divide and James Ross Island ice cores, respectively. This will be specified in the text.

References

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