

Reply to reviewers' comments.

Dear Editor,

5 We would like to thank the two reviewers for their detailed comments that helped us improve the text, tables and figures of our manuscript. We have taken into account their remarks in the revised version that is provided, together with a point by point answer to comments.

10 We also would like to stress here that, following one comment from Dr. Stenni, we have identified a mistake in our ice core chronology due to a wrong first year (2007 instead of 2006). We deeply thank Dr. Stenni for identifying this issue and have therefore corrected our initial chronologies, repeated all calculations and corrected results in all figures as well as in the numbers provided in the text. This correction only has minor implications on our key findings.

Reply to comments from Dr. Elizabeth Isaksson

15

The reviewer comments are displayed in italics, followed by our answers.

20 *The paper present and discuss the data from a 22 m deep ice core covering 60 years drilled from a coastal site in Adélie Land, an area well known for the strong katabatic winds. The ice core data are discussed in relation to outputs from a high resolution atmospheric general circulation model including water isotopes. Because of the specific meteorological conditions with strong winds the dating of this ice core has been a big challenge- and that is one reason for the lack of such data from this particular region. However, because of the proximity to Dumont d'Urville, various other glaciological and meteorology data has been collected here for several decades. Thus, there are some valuable scientific background data that are helpful for both dating and interpretation of this ice core.*

25

We thank Dr. Isaksson for her appreciation of the new data.

30 *A major part of the paper focuses on the dating of the core- something that is important for this particular site for the reasons just mentioned. The authors do a thorough job describing the procedure in great details, and verifying the traditional dating with model output. I find this to be an important scientific contribution because dating is something that is usually regarded as a method and thus do not receive too much attention.*

We share the concern for the importance of chronologies. Please note that the chronology has been partly corrected (see above), without any consequence for the key findings of our analyses.

The main conclusion in the paper is that one core can indeed accurately capture major annual anomalies and multi-decadal variations. During recent years there has been lots more focus on ice core data from coastal regions in Antarctica and therefore the results from the drill site presented here is highly interesting. It is important to collect field data also from “difficult” areas for validation of models so I feel that this paper is a very important contribution, and also an inspiration for such work. Although the paper is presenting valuable data there are a few issues to consider before it is accepted.

10 We again thank Dr. Isaksson and have carefully considered the 4 main points of comments.

1. It is very important to have field data for validation of models but it is also crucial that the field data are of good quality. There are a number of pieces of information missing in the manuscript in order for the reader to make this judgement. Not much data on the general glaciology and meteorology are provided- and the available information is not collected in one place which makes it harder for the reader. It could be good to collect the information that exists in a separate chapter - “area description”-in the beginning of the paper. For instance, the wind direction and wind speed information (chapter 5.3.1.) should be appearing in the general introduction because this is such fundamental information for all interpretation.

20 In order to provide more information about the general meteorological context (wind characteristics), but also to keep the manuscript concise, we have added a brief description of the site characteristics upfront in the introduction. Wind direction and wind speed characteristics at DDU have been explicitly added (cf p. 3 l. 13-16): “These features lead to dominant southerly (160 plus or minus 20°) intense katabatic winds (Wendler et al., 1997). During summer open sea conditions, a reverse pattern of wind direction can occur, associated with sea breezes. At Dumont d’Urville station (hereafter DDU), Périard and Pettré (1993) reported an average wind speed of 10 m s⁻¹, as well as events when wind speeds exceed 20 m s⁻¹ during several days (with an observed local maximum wind speed at 90 m s⁻¹).”

2. Information about spatial distribution of accumulation is missing in the paper. A single ice core and its regional representativeness is always an issue for discussion. A first step is to look at the snow layers using GPR (see recommendations in Eisen et al. 2008). In chapter 2.1 GPR measurements are briefly mentioned, and seem to have been collected at the time of the core drilling. Then one might wonder why that is not included here? When this core in addition comes from an areas so affected by katabatic winds this definitely has to be paid more attention to. Also, I think it is necessary to include some more information about the stake data for the same reason. As a reader I am not entirely convinced that the good agreement with major annual anomalies and multi-decadal variations is not pure coincidence.

We agree with Dr. Isaksson that providing information on the variability of accumulation in an area so much exposed to katabatic winds is critical. We therefore expanded the discussion section with respect to information available from stake data, and reported what existing lines for information with respect to the variability of accumulation in the region. (Section 4.3, p.15 l.22-25):

5 “Indeed, the mean accumulation given by the stake located at D10 is 25.6 cm w.e y^{-1} and the standard deviation of mean accumulation values from the 14 stakes located within the first 10 km is 12.0 cm w.e y^{-1} . A high variability reaching tens of millimeter over few meters was also reported by Genthon et al. (2007) and Favier et al. (2011) over an ablation site located 4 km from D10.”

10 We also expanded the description of processes (distribution of the precipitation and wind driven erosion or deposition) affecting the signal in the SIC1 core.

3. There is no information about ice layers and potential effect of melting.

In our initial manuscript, we provided information on negative summer temperature at the sampling site during a year that appears to be representative of average summer conditions (-5°C). In response to the request to provide more information, we have again expanded Section 4.3 to explicitly address the issue of potential melting and refreezing. For this purpose, we refer to the analysis of small refreezing ice layers from the stake network of the Glacioclim observatory and report precipitation events recorded at D10 during the Glacioclim campaigns. Based on this evidence, we conclude that liquid precipitation, melting and refreezing processes have very limited impacts in this region (Section 4.3 p.15 l.31- p.16, l.7):

20 “However, refreezing of precipitation or melting in this region does not seem to be enough significant to be counted as noise. Indeed, 2.5-m snow cores were collected every 0.5 km from the 156-km stake network of Glacioclim observatory. These surface cores were used for density measurements but also for a quick stratigraphy analysis. Small refreezing ice layers exceeding 2 mm can have been identified. It was found that these layers were found the same depth. At D10 and around, only one event of very large refreezing was observed, following a high precipitation event between December, the 31th of 25 2014 and January, the 01st of 2014. At D10, accumulated thickness of ice layers within the first 2.5 m of ice exceeded 25 cm w.e. and ice layer were sometimes 5 to 6 cm thick. However, this event only occurred once over the last 60 years according to the observations made at the Meteo-France station. In order to confirm this point, over the last 10 years, we only observed one ice layer thicker than 3 mm at D10. Indeed, a 3 cm thick ice layer was observed at 60 cm in the surface core collected in 2008-2009. As a consequence, melting and liquid precipitation occur at D10, but the effect on percolation is limited.”

30

4. The paper is generally heavy to read and it looks like the text is based on a thesis with different chapters. I suggest the authors try to re-organize- and maybe also shorten it a bit. Dating is a main aspect of this paper as it is written now so maybe that should be reflected in the title?

We apologize for the fact that the manuscript does not easily read. The first author of the manuscript is a PhD student and she was eager to share with readers the diversity of investigations that she has conducted: the text is not based on a thesis, but the manuscript will be part of a PhD thesis scheduled for 2018. We have done our best to reduce some paragraphs that were not necessary (deleting a few sentences) but have also added information to answer to the comments of the reviewers.

Tables and figures

Table 2. Specify % for r and p

The correlation coefficient r and the p-value are dimensionless and are not expressed in %.

Table 3. Use capital letters for READER and ECHAM as in other tables. Specify % for r and p, unit for slope

We used capital letters for READER and ECHAM as in other tables and added the unit for the slope.

Figure 2. Spelling of DMS is not English

Figure 2. We corrected Dimethyl sulfure (DMS) to Methansulfonic acid (MSA).

Figure 3. Different colors are needed- hard to distinguish between the ones chosen.

Figure 3. We changed the colours of the test horizons to make the figure more readable.

Figure 7. Poor color choice also for this figure. Add labels and units for y-axes. Very difficult to distinguish the different information from one another in the lower panel.

Figure 7. The y-axis label and its unit are written on the left side of the figure as for other graphics. We hope that the editorial setting will allow this figure to be printed in a larger format so that to enhance readability.

Figure 8. This figure would benefit from being re-drawn. Labels should be better placed. Legends need to be bigger. All the "d18O" in the Figure caption should be changed to the right format.

Figure 8. We re-drew the Figure using cityscape lines for all the plots. As for the previous figure, the y-axis label is the same for all the plots and therefore, has been placed to the right side of the Figure. We made the legends bigger.

Minor issues

There are a number of language problems, typos etc. for the authors to take care of. Here is a small selection - but there are many more.

p. 5 line 23. A slight rewrite to remove at least one of the three "cleaned"

p. 5 line 27. Remove a single "e"

p. 9 line 4-9. There are many very long sentences in the paper that makes it hard to read. Here is one of many examples.

p. 10 line 5. long term. . . ? Uncomplete sentence

p. 11 line 5. Should be "links"

5 p. 11 line 32. Should be "the period"

p. 12 line 8. Should be cha

We corrected all these minor issues (omission or orthography mistakes) and shortened sentences that were difficult to read.

10

Reply to comments from Barbara Stenni

The paper by Goursaud and co-authors is presenting a new isotopic and snow accumulation rate records obtained from an ice core drilled in the Adelie Land coastal area (in the proximity of the French Dumont d'Urville station) in a site which is characterized by a relatively high snow accumulation rate (about 220 mm w.eq. yr-1) and covering the 1947-2006 period. The paper is much focused on the dating issues and on the comparison with the data simulated from the high resolution atmospheric general circulation ECHAM5-wiso model ($\delta^{18}O$ as well as precipitation) and with the regional atmospheric model MAR. The authors also suggest a method to improve the dating considering particular isotopic signature in the inter-annual variability of ECHAM5-wiso isotopic data. The obtained results suggest that also a single ice core from a coastal area can capture the main climatic signals although a multi-core approach should be desirable in order to reduce the stratigraphic noise which is unavoidable. The paper is interesting, the data are well presented and I have found the reading quite smooth although some parts could be reduced a little (e.g. paragraph 3.1.3). I recommend its publication after the authors have been considered to the following comments.

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25 We thank Dr B. Stenni for her interest and her recommendations.

Page 2, line 3: ice core chronology: the period covered by the core should be 1947- 2006 rather than 2007, in fact the drilling has been carried out in January 2007, so the topmost snow layers should at maximum be referred to the year 2006. Please, check this in the whole manuscript, as well as in the tables, figures and related captions. I did not understand if this is just a refuse or a real mistake.

30 We thank Dr B. Stenni for having directed us toward a dating mistake. Indeed, we had made a mistake when copying/pasting the resampled $\delta^{18}O$ and had shifted all to one year. So the initial S1C1 chronology was dated from 1947 to 2007 instead of 1946-2006. Therefore, in the following of the study, the selected period for all the climatic records was also the period 1947-

2007. We have corrected our data (cf. Supplementary Material), and re-processed all the statistical calculations. The main changes are the lack of significant correlation analysis results between $\delta^{18}\text{O}$ from the SIC1 core (1st dating) and the DDU near surface temperature at the annual scale, and lack of significant correlation analysis results between $\delta^{18}\text{O}$ from the SIC1 core (1st dating) and the SAM or the Niño index. Changes were made in the body of the paper, in the tables (Tables 2 and 3) and in the Supplementary Material. We also revised the alternative dating, based on the comparison between $\delta^{18}\text{O}$ from the SIC1 core and $\delta^{18}\text{O}$ outputs simulated by ECHAM5-wiso. Instead of one-year shift, this alternative dating had two-year shift compared to the first one. Details from the choice of the added/deleted identified annual layer is detailed in Section 4.1.

Page 3, line 3: the reference Ahmed is not correct! Please change into "PAGES 2k Consortium, 2013". Page 3, line 5: the reference Jones et al., in press. ... is published.

Done

Page 3, line 26: please add here Schlosser et al., 2008 (Neumayer station data) as well as Stenni et al., 2016 (TC).

Done

Page 4, line 6: delete the "."

Done

Page 4, lines 25-27: the sentence "Data obtained. ... context." is not clear at all. Please explain what do you mean.

To make it clear, the sentence was rewritten (p.5, l.3-6):

"Data obtained during 3 days at 25 cm depth show a mean value of -5.0 °C. At DDU and Dome C, July 2007 temperatures were close to the climatological average conditions from the period 1995-2015. As a result, our punctual measurements from summer 2007 are assumed to be representative of average summer conditions."

Page 4, line 31: please change the Laboratory of Glaciology into LGGE, already defined before.

Done

Page 5, lines 13-14: the citations Delmas and Pourchet (1977) and Magand et al (??) (2009) are lacking in the Reference.

Done

Page 5, line 21: why not shown? May you consider to have a figure on this in the Supplement?

Both 1955±1 AD and 1965±1 AD peaks are shown in Figure 2. To make this more explicit, Figure 2 is now called at the end of the sentence (red vertical lines, Fig. 2).

Page 5, line 27: delete “e” and add “the”. The method is the “CO₂/H₂O equilibration method”. Please add.

The “CO₂/H₂O equilibration method” was detailed for the δ¹⁸O measurements.

Page 5, line 28: add ± before 0.05 and after ‰ add (1 sigma).

5 Done

Page 5, line 29: I would not refer to the figure 2 here but rather in the result section.

Following the resolution of the δ¹⁸O measurements, instead of referring to Figure 2, we now refer to Table S1 from the Supplementary Material (p.6, 1.4-5):

10 “The accuracy of each measurement is ±0.05 ‰ (1σ) (Table S1 Supplementary Material).”

Page 6, line 10: delete “in” after Antarctic sites and add “the”.

Done

15 Page 6, line 29: add “from” before the Nimbus Page 7, line 25: the citation Bintanja (2000) is lacking in the Reference.

Done

Page 7, lines 27-29, line 31: the citations Kessler (1969), Lin et al. (1983), Meyers et al. (1992), Levkov et al. (1992), Morcrette (2002) and Galle et al. (2013) are lacking in the Reference.

20 Done

Page 8, line 4: the authors refer here to one year DDU record of precipitation. Are these data available? Are these the same data cited later on in the text (paragraph 3.3.1)? Please, explain better. Perhaps the data could be added in the Supplement?

25 The only δ¹⁸O measurements at DDU were those communicated by Jean Jouzel. Not to confuse the reader, we deleted the sentence here and presented these data only in Section 3.3.1 (p.10, l. 22-25), as previously written.

Page 9, line 1: paragraph 3.1.3: I suggest to reduce a little this paragraph by using a table or a figure. ...

As suggested, the new Table 1 details the occurrence of species not showing a summer peak for an identified summer (data missing in summer, peaks not identified at all, or 2 or 3 peaks appearing for the same year). As a result, the text paragraph

30 has been shortened.

Page 10, line 20: add a space between “calculated” and “from”.

Done

Line 10, line 28: less depleted values Different seasonal pattern: the mean $\delta^{18}O$ at SIC1 is -18.9‰ not very far from -18 at DDU considering the difference in elevation. I mean the results seems consistent, obviously less depleted than DC. ...

Then regarding the difference with Dome C it's not surprising but I cannot comment on the different seasonal pattern if all the data (DDU) are not provided as a figure ...

- 5 In our discussion of seasonal patterns, we referred to the timing of the maxima, which are reported in the text for DDU and Dome C: “the highest values in March (-10.0 ‰) and November (-11.5 ‰)” (p.10, l.25), and “...with maximum values in December-January” for Dome C (p.10, l.31). We agree that the comparison between the few data points from DDU and SIC1 is not conclusive (quite similar mean levels, and impossibility to conclude about the average seasonal cycle from just one year of sampling at DDU).

10

Moreover, considering the large inter-annual variability of Antarctic climate and the only less than 1-year record at DDU I do not think that it is appropriate to discuss about different seasonal patterns.

- 15 We have been very explicit about the limits to such comparisons:” This comparison is of course limited by the short dataset available for DDU and the fact that these measurements were not performed for the same time period.”

Page 10, line 29: Stenni et al., 2016, now published (to be changed also in the Reference).

Done

- 20 Page 11, line 9: when comparing SIC1 site with Law Dome you have to consider the extremely different snow accumulation rate between the two sites. Please add something about this.

We have added explicitly a comparison of differences in accumulation rates between the SIC1 site and Law Dome (p.11, l.11-12):

- 25 “Note that the annual accumulation rate at Law Dome (64 cm. w.e. y^{-1}) is ~3 times higher than in the SIC1 core (21.9 cm. w.e. y^{-1}).”

Also add the Johnsen (1977) citation about post-depositional effects.

Done

- 30 Page 11, 13-22: please refer to the appropriate figures, 4 and 5, in the text otherwise it is not easy to follow.

Done

Page 11, line 23: delete “accumulation” after $\delta^{18}O$ or an “and” is lacking? Please, correct.

Done

Page 11, line 33: at Dome C we used daily values or monthly values and obtained a slope 0.49‰°C. Not sure what you have used here, please explain.

We also used daily data to compute the correlation between precipitation $\delta^{18}\text{O}$ and temperature at Dome C. We specified it as follows (p.11, l.33 – p.12 l.2):

“At Dome C, over 3 years, daily precipitation $\delta^{18}\text{O}$ displays a significant positive correlation with daily AWS near surface air temperature, with a slope of 0.49 ‰ per °C ($r=0.79$ and $p=3.2\text{E-}109$).”

Page 12, line 1: please check the reported statistical values. Also there seem to be a typo error

We thank Dr Stenni for identifying a mistake in the reported p-value. The new values will be found in p.12, l.1-2: “with a slope of 0.49 ‰ per °C ($r=0.79$ and $p=3.2\text{E-}109$)”

Page 12, line 2-3: at Dome C we considered daily values, so we did not exclude the seasonal cycle. We also obtained a higher slope (1.4) if considering the only 3 annual values, but its significance is low since it is calculated on 3 years only.

Here, on the other hand, you are considering inter-annual variability.

We agree that the $\delta^{18}\text{O}$ -temperature slope at Dome C is quite variable depending on the considered time scale, and that the inter-annual variability is relevant for the comparison with results from the SIC1 core.

Page 12, line 14: rather than metamorphism I would say exchanges between surface snow and water vapour.

We have reformulated the expression (p.12, l.10): “isotopic exchanges between surface snow and water vapour in-between snowfall events”.

Page 12, line 26: the first reported values ($r=-0.48$ and $p=8.0\text{E-}3$) seem significant. Please, check.

We have checked the correlation coefficient and the p-value. Indeed, they are significant. However the correlation coefficient is too low to assume a trend.

We have rewritten “Weak but significant decreasing long-term trends appear in both the SIC1 record and the model outputs” ($r=-0.38$ and $p=4.0\text{E-}2$ and $r=-0.48$ and $p=8.4\text{E-}3$ respectively).” (p.12, l.21-22).

Page 13, line 21-22: in Antarctica this problem was nicely shown by Frezzotti et al, 2007 JGR. Also for snow accumulation rate values as those found by the authors for this Adelie Land site SIC1 and also considering the wind effects (see comment by E. Isaksson)!

We have informed the reader of this feature in the introduction. We have first given more information about the winds (cf p. 3 l. 13-16): “These features lead to dominant southerly (160 plus or minus 20°) intense katabatic winds (Wendler et al., 1997). During summer open sea conditions, a reverse pattern of wind direction can occur, associated with sea breezes. At

Dumont d'Urville station (hereafter DDU), Périard and Pettré (1993) reported an average wind speed of 10 m s^{-1} , as well as events when wind speeds exceed 20 m s^{-1} during several days (with an observed local maximum wind speed at 90 m s^{-1}).

We have also reported *Frezzotti et al., 2007* in the introduction to report this previous study which show the impact of the high variability in accumulation (due to wind-driven deposition and erosion processes in this region) over ice core records.

5 (p.3, l.17-20): "The resulting high spatial variability in accumulation challenges the climatic interpretation of a single ice core record, especially for accumulation rates lower than $20 \text{ cm w.e. y}^{-1}$ (Frezzotti et al., 2007)."

Page 13, line 27: add "scale" after "horizontal".

Done.

10

Page 14, line 15: the year should be 1986 and not 1985.

Done

Page 15, line 7: add a space between "the" and "period".

15 Done

Page 15, line 10: what do you mean by "climatic deposition signal" . . . not clear.

When writing "climatic deposition signal", we meant that the signal represented the synoptic climatic. Changes towards this meaning were made (p.15, l.2): "This finding shows that the nudged ECHAM5-wiso simulation is able to capture almost
20 40% of the inter-annual average accumulation variance, and that there is a clear synoptic climatic deposition (and not only local deposition) in the stake accumulation record".

Page 16, line 3: why "his"?

It was a typing error.

25

Page 16, line 6-7: comparison with the ECHAM5-wiso output BUT with which chronology?

It was originally with the first one. But it has changed since we had to correct it. But we should not have referred to this correlation since the climatic signal has been shown thanks to the comparison of the model with the stake data (cf. last correction). Therefore, it was corrected (p.16, l.12-13): "to confirm our hypothesis that there is a significant climatic signal
30 in $\delta^{18}\text{O}$ from this single core, as suggested by the comparison of the average stake area record with the ECHAM5-wiso output."

Page 16, line 9: contradictory: may you explain better?

Our initial formulation was confusing and we have removed this sentence.

Page 16, line 20: Stenni et al., 2016.

Done

5 Page 16, line 21: see also the conclusions by Schlosser et al., 2016 (ACP) about the inter-annual difference.

We have cited this manuscript that is indeed relevant for our work (p. 16, l.28):

“These model results suggest that processes other than local temperature play a key role in local $\delta^{18}\text{O}$ seasonal cycle and inter-annual variability, as suggested by Schlosser et al. (2016).”

10 Page 16, line 28: if I am not wrong, this statement “but a significant and weaker correlation between $\delta^{18}\text{O}$ from the SIC1 core and simulated by ECHAM5- wiso” depends on the age scale considered, isn't it?

After correcting the chronology and reprocessing the statistical calculations, we have revised our statements to (p.17, l.4-7)

“a high and significant correlation between inter-annual variations in temperature from the READER database and ECHAM5-wiso simulated near surface air temperature ($r=0.91$ and $p=2.2\text{E-}12$) but no significant correlation between inter-annual variations in $\delta^{18}\text{O}$ from the SIC1 core (from the first dating) and simulated by ECHAM5-wiso.”

15

Page 17, line 10: this adjective “coherent” seems in contradiction with what you have just said few lines before.

We deleted this adjective.

20 Page 18, line 4: change sake into stake

Done

Page 18, line 7: please consider that the difference in the snow accumulation rate (and wind action) at the different sites and their effects on the diffusion effects and so on the smaller amplitude of the seasonal isotopic cycle. See comment before.

25 We completed this sentence by the following (p.18, l.17): “But note that the accumulation rate is site-dependent.”

Page 18, line 10-12: the sentence “We stress ... relationship.” seems not valid if I consider δ core and Techam. May you check?

30 The underestimation of the inter-annual variability in $\delta^{18}\text{O}$ by ECHAM5-wiso explains its underestimation of the strength of the slope $\delta^{18}\text{O}$ -temperature. Indeed, in table 4, the slopes for the period 1979-2006 are weaker for $\delta^{18}\text{O}$ extracted from the model than estimated using data from SIC1 and READER. (See table below).

Resolution	Source of the temperature	Source of the $\delta^{18}\text{O}$	Slope	r	p
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annual	ECHAM	ECHAM	0.29	0.39	3.8E-2
annual	READER database	S1C1,2	0.42	0.48	1.0E-2

5 *Page 18, line 17: I would also add that precipitation sampling at DDU would be desirable.*

We have added that not only vapour isotopic composition measurements at DDU were needed, but also precipitation ones (p.18, 1.25-27): "...obtaining continuous vapour and precipitation isotopic composition measurements at DDU will offer the possibility of a direct comparison with atmospheric transport pathways, and with aerosol chemical data."

10 *Page 18, line 34: the reference Ahmed is not correct! Please change into "PAGES 2k Consortium, 2013". And also Jones et al. is published.*

Done

Page 19, line 5: please specify what is PSA2.

15 We have given its definition (p.19 1.15-16): "PSA2 (associated with the tropical heating anomalies in the Pacific)"

References: some are not completed (Jones et al, Lemeur submitted, Masson Delmotte et al., 2008 the authors list is not completed) and some must be changed from discussion to final accepted papers (Ritter, Schlosser). Please, make a careful check.

20 Done

Table 1. The precipitation column is not only precipitation (ok for ECHAM) but in the case of the core data is accumulation. What is μ ? I suppose average. ...

μ is indeed our notation for the mean value. It has been specified in the legend.

25 Indeed, ECHAM5-wiso simulates precipitation values, but we have accumulation data for the S1C1 core. It has been clarified in the label and in the legend.

Table 2: be careful about the year 2007 (the period covered by the core). ... see my comment above (page 2, line 3).

All tables and figures were corrected.

30

Table 3: something is lacking in the first column: You should have 1956-2006 (annual and decadal) and then the same for 1979-2006.

We readjusted the content of the first column to be placed at the top of each cell.

Why you did not discuss in the text the relationship between Techam and $\delta^{18}\text{O}$ SIC11 and SIC12, if I am not wrong? (see my comment above Page 18, line 10-12).

Relationships using the two chronologies were recalculated. the statistical analysis of linear correlation between READER data and SIC1 d18O leads to no significant result using the first chronology, while it appears significant (but weak) with the revised chronology, and, in this case, with a slope close to the one expected from a Rayleigh distillation (Table 4). So we completed as follows (p. 16 1.22-23):

“We note that over the period 1979-2006, although the $\delta^{18}\text{O}$ -temperature relationship from the fist chronology is not significant, the relationship from the second one is significant but weak, with a slope close to the Rayleigh distillation.”

10 *Figure 1: add “hatched area” in the caption after “Passive Microwave Data”.*

We added “hatched area” after “Passive Microwave Data” as suggested.

Figure 2: in the caption: you do not have dimethylsulfure data but MSA data!! I would also make the labels larger than they are.

15 It was a mistake to write “Dimethyl... (DMS)”, and this has been corrected to MSA. Also the figure was re-drawn regarding the corrected alternative chronology.

Figure 4: the different lines are not distinguishable. Also in this case I would use larger labels. In the caption: resampled data: specify with which step. The annual mean is calculated by the annual layer dating? Specify.

20 We have re-drawn this figure, removing the resampled data, which were not distinguishable with the raw data. The annual mean values are based from the resampled data and the accumulation data from the annual layer counting. This information is now provided in the legend.

Figure 5: Also in this case I would use larger labels. In the caption, some typos. ...

25 Larger labels were drawn.

Figure 6: I had some difficulty in comparing the values referring to the red (cityscape) and the blue lines.

All data were draw using cityscape lines.

30 *Moreover, check also here the correct period covered by the core. The first year is 2006, the accumulation record seems OK but for the $\delta^{18}\text{O}$ why you have a value for 2007? Here the dimensions of the different labels are OK.*

Done

Figure 7: Also in this case I would use larger labels. Figure 8: Also in this case I would use larger labels. Also here the first $\delta^{18}\text{O}$ seems to be 2007. ... To be checked.

Done

Author'changes in manuscript

- 5 In this part, we summarize the main corrections implemented in the revised manuscript. After reporting the general corrections which have impacts through all the manuscript, we mention corrections which are specific to each section.

General corrections:

- Some sentences were shortened or deleted to make the manuscript shorter.
- Omissions were corrected.
- 10 - Some reformulations were made.
- We had made a mistake when copying/pasting the resampled $\delta^{18}\text{O}$ versus year and had shifted all dates by one year for both $\delta^{18}\text{O}$ and accumulation data. So the chronology was reported to range from 1947 to 2007 instead of 1946-2006. Therefore, we first changed through all the paper the covered period by the SIC1 core. Then, in the following of the study, the selected period for all the climatic records was also the period 1947-2007. We thus have corrected
- 15 our data (cf. Supplementary Material), and re-processed all the statistical calculations. The main changes were the absence of significant correlation between $\delta^{18}\text{O}$ from the SIC1 core (1st dating) and the DDU near surface temperature at the inter-annual scale, and the absence of any significant correlation between $\delta^{18}\text{O}$ from the SIC1 core (1st dating) and the SAM or the Niño index. Changes were made in the body of the paper, in the tables (tables 2 and 3) and in the Supplementary Material. Also we have changed the alternative dating (based on the comparison
- 20 between $\delta^{18}\text{O}$ from the SIC1 core and $\delta^{18}\text{O}$ outputs simulated by ECHAM5-wiso). Instead of one-year shift, this alternative dating had two-year shift compared to the first one. Details from the choice of the added/deleted identified annual layer is detailed in Section 4.1.

Title page: The affiliation associated with LSCE was corrected as it is now part of Université Paris Saclay.

- 25 **Abstract:** We changed information linked to the dating which has been corrected:

- The covered period by the SIC1 core: 1946-2006
- The correlation between the $\delta^{18}\text{O}$ core from SIC1 and the DDU near surface temperature which is now significant at the annual scale anymore, but only at the decadal scale.
- The alternative dating is now shifted of 2 years.
- 30 - We also reformulated some expressions.

1. **Introduction:** The paragraph describing the meteorology of the Adélie Land was completed in order to give useful information, e.g. wind direction and speed wind linked with wind-driven deposition.

2. Material and method

5 2.1 Field work and ice core sampling

We reformulated the sentence linked to the comparison of the firm temperature at DDU with summer Dome C and DDU temperatures over the period 1995-2015.

2.5 Atmospheric simulations

A number of references had been omitted in the bibliography. The list of references has been updated.

10

3. Results

3.1.3 Combining layer counting with absolute age horizons

Details associated with equivocal annual layer identification was deleted and reported in a table (Table 1).

3.2 Record of accumulation variability and comparison with stake measurements

15 Statistical values and spectral analyses of the SIC1 accumulation record were corrected (still because of the dating mistake)

3.3 Record of $\delta^{18}\text{O}$

3.3.1 Other sources of information for $\delta^{18}\text{O}$ regional variability

As for accumulation records, statistical values and spectral analyses of $\delta^{18}\text{O}$ from the SIC1 core were corrected (still because of the dating mistake)

20

3.4 Model-data comparison

3.4.1 Comparison between the ECHAM5-wiso and the SIC1 data

Statistical values between ECHAM5-wiso outputs and SIC1 records were corrected.

4. Discussion

25 4.1 An alternative age scale can improve the model-data comparison for $\delta^{18}\text{O}$

The identification of summer layers leading to the establishment of the chronology was updated considering a corrected alternative dating, based on 2-year shift compared to the initial chronology.

Correlations using the corrected alternative dating were updated too.

4.2 Processes causing non-climatic noise

30 More information about the representativeness of the spatial accumulation around the SIC1 site was given, based on stake records. We mentioned the high variability of accumulation in the region.

Also, a brief discussion about refreezing, melting and liquid precipitation has been added.

4.4 $\delta^{18}\text{O}$ -temperature relationship

All correlations using the SIC1 records (from both dating) were corrected.

5. Conclusions and perspectives

Relationships between SAM and el Nino index with $\delta^{18}\text{O}$ from the SIC1 core were recalculated and found to be insignificant.

5

A sixty year ice-core record of regional climate from Adélie Land, coastal Antarctica

5 S.Goursaud^{1,2}, V. Masson-Delmotte¹, V. Favier^{2,3}, S. Preunkert^{2,3}, M. Fily^{3,2}, H. Gallée^{2,3}, B. Jourdain^{2,3}, M. Legrand^{2,3}, O. Magand^{2,3}, B. Minster¹, M. Werner⁴

1 LSCE (UMR CEA-CNRS-UVSQ 8212-IPSL), [Université Paris Saclay](https://www.ipsl.fr/), Gif-sur-Yvette, France

2 Univ. Grenoble Alpes, Laboratoire de Glaciologie et Géophysique de l'Environnement (LGGE), 38041 Grenoble, France

10 3 CNRS, Laboratoire de Glaciologie et Géophysique de l'Environnement (LGGE), 38041 Grenoble, France

4 Alfred Wegener Institute for Polar and Marine Research (AWI), Bremerhaven, Germany

15

Correspondence to: Sentia Goursaud (sentia.goursaud@lscce.ipsl.fr)

Abstract. . A 22.4 m-long shallow firn core was extracted during the 2006/2007 field season from coastal Adélie Land. Annual layer counting based on sub-annual analyses of $\delta^{18}\text{O}$ and major chemical components was combined with 5 reference years associated with nuclear tests and non-retreat of summer sea ice to build the initial ice core chronology (19467-20067), stressing uncertain counting for 8 years. We focus here on the resulting $\delta^{18}\text{O}$ and accumulation records. With an average value of 21.89 ± 6.98 cm w.e. y^{-1} , local accumulation shows multi-decadal variations, peaking in the 1980s, but no long-term trend. Similar results are obtained for $\delta^{18}\text{O}$, also characterized by a remarkably low (-2.6%) and variable amplitude of the seasonal cycle. The ice core records are compared with regional temperature and stake area accumulation measurements, variations in sea ice extent, and outputs from ~~two models nudged to ERA atmospheric reanalyses~~: a high resolution atmospheric general circulation model (AGCM) including stable water isotopes (ECHAM5-wiso) and a regional atmospheric model (MAR), ~~both nudged to ERA atmospheric reanalyses~~. A significant linear correlation is identified between decadal variations in $\delta^{18}\text{O}$ and regional temperature data, ~~especially in winter~~. No significant relationship appears ~~neither~~ with regional sea-ice extent ~~nor with Dumont d'Urville wind speed~~. The model-data comparison highlights the inadequacy of ECHAM5-wiso simulations prior to 1979, possibly due to the lack of data assimilation to constrain atmospheric reanalyses. Systematic biases are identified in the ECHAM5-wiso simulation, such as an over-estimation of the mean accumulation rate and its inter-annual variability, a strong cold bias, and an under-estimation of the mean $\delta^{18}\text{O}$ value and its inter-annual variability. As a result, relationships between simulated $\delta^{18}\text{O}$ and temperature are weaker than observed. Such systematic precipitation and temperature biases are not displayed by MAR, suggesting that the model resolution plays a key role along the Antarctic ice sheet coastal topography. Inter-annual variations in ECHAM5-wiso temperature and precipitation accurately capture signals from meteorological data and stake observations, and are used to refine the initial ice core chronology within 24 years. After this adjustment, remarkable positive (negative) $\delta^{18}\text{O}$ anomalies are identified in the ice core record and the ECHAM5-wiso simulation, respectively in 1986 and 2002 (1998-99). Despite uncertainties associated with post-deposition processes and signal-to-noise issues in one single coastal ice core record, we conclude that the SIC1one single ice core can correctly capture major annual anomalies in $\delta^{18}\text{O}$ as well as multi-decadal variations. These findings highlight the importance of improving the network of coastal high resolution ice core records, and stress the skills and limitations of atmospheric models for accumulation and $\delta^{18}\text{O}$ in coastal Antarctic areas, particularly important for the overall East Antarctic ice sheet mass balance.

Keywords.

Water isotopes, ice sheet mass balance, decadal climate variability, model evaluation

1. Introduction

Deep ice cores from coastal Antarctic areas are crucial to retrieve highly resolved, multi-millennial records, a priority of the International Partnership for Ice Core Science within the Past Global Changes 2k project- (Consortium, 2013). Obtaining highly resolved records spanning ~~first~~ the last decades is therefore a pre-requisite to identify the potential of a given site.

5 Moreover, climate variability of the last decades in Antarctica remain poorly documented and understood (e.g. Jones et al, 2016), ~~despite the wealth of information provided by firm and ice cores~~. This is particularly the case in coastal Antarctic areas, which play a key role for the overall Antarctic mass balance (Agosta et al., 2013; Palerme et al., 2016), with relevance for global sea level (Church et al., 2013). Finally, field data are needed to assess the validity of climate models for multi-decadal variability and change in coastal Antarctic temperature and mass balance (Krinner et al., 2007).

10 Here, we focus on coastal Adélie Land (Fig. 1), an area where regional climate is marked by the interplay of katabatic winds accelerating downslope from Antarctic interior to the coast (Périard and Pettré, 1993), a large seasonal variations in sea-ice extent (König-Langlo et al., 1998; Simmonds and Jacka, 1995) and its proximity to the circumpolar storm track (Jones and Simmonds, 1993). These features lead to dominant southerly (160 plus or minus 20°) intense katabatic winds (Wendler et al., 1997). During summer open sea conditions, a reverse pattern of wind direction can occur, associated with sea breezes. At
15 Dumont d'Urville station (hereafter DDU), Périard and Pettré (1993) reported an average wind speed of 10 m s⁻¹, as well as events when wind speeds exceed 20 m s⁻¹ during several days (with an observed local maximum wind speed at 90 m s⁻¹). The region is therefore marked by sastrugi formed by snow erosion and redeposition, The resulting high spatial variability in accumulation challenges the climatic interpretation of a single ice core record, especially for accumulation rates lower than 20 cm w.e. y⁻¹ (Frezzotti et al., 2007). The knowledge of Adélie Land climate variability therefore requires a spatial network
20 of field data. (Périard and Pettré, 1993), accelerating downslope from Antaretic interior to the coast, a feature known as “the home of the blizzard” (Mawson, 1915), with large seasonal variations in sea-ice extent (König-Langlo et al., 1998; Simmonds and Jacka, 1995) and its proximity to the circumpolar storm track (Jones and Simmonds, 1993).

Multi-decadal climate variability in this region is documented since 1958 from Dumont d'Urville (hereafter DDU) meteorological measurements, and since 1979 from sea ice remote sensing. So far, a few ice cores were drilled near DDU,
25 ~~and~~but none was dated (Jean Jouzel, personal communication), preventing any comparison of the ice core records with meteorological measurements.

In the framework of the International TASTE-IDEA / VANISH programs (Trans-Antarctic Scientific Traverse Expeditions - Ice Divide of East Antarctica), a 22.4 m-long shallow firn core (named SIC1) was extracted in January 2007 from the Adélie Land sector (67.71 °S, 139.83 °E, 279 m a.s.l.) (Fig. 1). The core was collected close to a stake network which provides
30 records of accumulation spatio-temporal variability from 1971 to 2015 (Favier et al., 2013).

Following the classical approach for other coastal Antarctica areas, the chronology of the SIC1 core is established through the annual layer counting of seasonal cycles in chemical species, water isotopes records and absolute horizons (e.g. Graf et al., 1991; Mulvaney et al., 2002). This task was feasible thanks to a multi-year aerosol monitoring at sub-seasonal scale at

DDU providing detailed information on the seasonal cycle of aerosols ~~in relationship with their underlying sources and transport pathways~~. However, no such monitoring is ~~yet~~ available for precipitation isotopic composition at this site. Indeed, very few multi-year direct records of snowfall isotopic composition are available from Antarctica (Fujita and Abe, 2006; Landais et al., 2012; Schlosser et al., 2016; Stenni et al., 2016). And emerging records of water vapour isotopic composition only span one month (Casado et al., 2016; Ritter et al., 2016). We therefore investigated seasonal variations in precipitation isotopic composition from a simulation performed with the isotopically enabled ECHAM5-wiso atmospheric general circulation model (Roeckner et al., 2003; Werner et al., 2011) nudged to ERA40 (Uppala et al., 2005) and ERA-interim atmospheric reanalyses (Dee et al., 2011). This high-resolution model was chosen due to its good skills with respect to the present-day spatial distribution of water stable isotopes and mass balance in Antarctica (Masson-Delmotte et al., 2008; Werner et al., 2011). The 50 year long simulation is used to identify uncertainties associated with annual layer counting based on the seasonal cycle in precipitation $\delta^{18}\text{O}$. Vice-versa, the ice core record and the stake area network will allow assessing the skills of this simulation in coastal Adélie Land. This model-data is further expanded through investigation of recent mass balance and temperature variations from the regional atmospheric model MAR (Gallée and Schayes, 1994). Section 2 describes the material and methods underlying this study, including our new measurements, the methodology for the annual layer counting, as well as the regional instrumental (near surface air temperature, wind speed and stake area measurements) and remote sensing (sea-ice extent) datasets, the simulations performed with these two atmospheric models. . Section 3 reports our results. In section 4, we discuss our new ice core records, and compare $\delta^{18}\text{O}$ and accumulation records with local to regional climate information as well as atmospheric model outputs. We summarize our main findings and suggest future research directions in our conclusions (Section 5).

20 **2. Material and method**

Here, we briefly describe the ice core sampling, the chemical and isotopic analyses, the density measurements and the dating methodology. We then introduce the regional climate datasets used for statistical analyses, as well as the atmospheric simulations used for model-data comparisons.

2.1 Field work and ice core sampling

25 The field campaign was conducted from the 16th to the 26th of January 2007 in Adélie Land by a French joint LGGE (Laboratoire de Glaciologie et Géophysique de l'Environnement) and IPEV (Institut Français Polaire Paul-Emile Victor) expedition. Several shallow firn cores were drilled along a transect between the Italian-French Cap Prud'Homme station, at sea level, and D47 point, located around 1600 m a.s.l. and approximately 100 km from the coast. This round-trip traverse was part of the ANR-VANISH (*Vulnerability of the Antarctic Ice-Sheet*) and IPEV-TASTE-IDEA (*Trans-Antarctic Scientific Traverses Expeditions – Ice Divide of East Antarctica*) scientific programs. The scientific aim of the programs was

to obtain new firn core records and ground-penetrating radar measurements to improve the knowledge of coastal East Antarctic accumulation.

The present paper is focused on one ice core drilled at the S1C1 site (66.71 °S, 139.83 °E, 279 m a.s.l.), the closest sampling site to the coast and the French Dumont-D'Urville station (Fig. 1). At this site, the measured temperature of the firn was -

5 13.1 ± 0.5 °C at 10 m-depth. Data obtained during 3 days at 25 cm depth show a mean value of -5.0 °C. At DDU and Dome C, July 2007 temperatures were close to the climatological average conditions from the period 1995-2015. As a result, our punctual measurements from summer 2007 are assumed to be representative of average summer conditions. ~~assumed to be representative of climatological average summer conditions, based on summer 2007 DDU and Dome C temperatures in a multi-decadal context.~~ Such negative near surface air summer temperature ensures preservation of snow signals (e.g. water
10 stable isotopes, chemical species).

A portable solar powered electromechanical drilling system was used to extract the 22.4 m long and 58 mm diameter firn core (Ginot et al., 2002; Lemeur, submitted; Verfaillie et al., 2012). The recovered core pieces were sealed in polyethylene bags in the field, stored in clean isothermal boxes and transported in frozen state to the cold-room facilities of the Laboratory of Glaciology (LGGE) ~~in Grenoble, France~~. Sample preparation for chemical measurements was performed under clean-
15 room laboratory conditions. After stratigraphic observations and measurements of bulk density, the firn core was divided in two half cores. One half was dedicated to radioactivity measurements and the other half was analysed in ionic chromatography and mass spectrometry (Section 2.2). Sub-annual resolution sampling and gross beta radioactivity and gamma spectrometry for bomb test markers allowed to build the S1C1 firn core chronology (Section 2.3).

2.2 Measurements

20 Discrete density values were calculated based on snow sample volume and mass measurements with a 50 cm resolution, from the surface to 22.4 meters depth. The resulting values range from 400 to 700 kg m⁻³ (Table S2 Supplementary Material). Accounting for measurement difficulties due to weak cohesion of snow in the first few meters, and considering measurement errors, the associated uncertainties are ±20-25 kg m⁻³ (± 4%) from the surface to 7 meters depth, and ±15 kg m⁻³ (± 2%) from 7 to 22.4 meters. Hereafter, density values are used to convert snow depths into water equivalent depths.

25 Firn core sections were processed for artificial radioactivity measurements by low-level (i) beta counting and (ii) gamma spectrometry, with a continuous sampling every 50 cm from the surface to 22.4 m-depth. Using a method developed by Delmas and Pourchet (1977) and improved by Magand (2009), snow samples (100-200 g) were melted, weighed, acidified and filtered on ion exchange paper, on which radionuclides of interest (⁹⁰Sr, ¹³⁷Cs, ²⁴¹Am – daughter of ²⁴¹Pu) were trapped. All steps were realized in the LGGE clean room laboratory to prevent any contamination. After drying (in an oven at 60 °C),
30 these filters were first analysed by a beta gas-proportional counting system (gross beta measurement) to determine the presence of beta emitters peak(s) corresponding to nuclear weapons global fallout of the 1950s and the 1960s. In a second step, very low level gamma spectrometry (coaxial germanium detector) measurements were performed on the filters to

determine activities of ^{137}Cs and ^{241}Am . Both 1955±1 AD and 1965±1 AD peaks were clearly identified in the SIC1 core, respectively at 19.5-20.0 m and 16.5-17.0 m-depth (not shown).

Along the SIC1 core, each 5 cm sample was analysed for ~~ions concentrations~~ and the oxygen isotopic ratio. The firm pieces dedicated to the ion analysis were ~~decontaminated/cleaned~~ under a clean air bench located in a cold room (-15 °C) using a pre-cleaned electric plane tool on which the ice is slid (Preunkert and Legrand, 2013). A total of 427 subsamples were obtained ~~along the 22.4 m SIC core, with a 5 cm sample resolution.~~ Concentrations of cations (Na^+ and NH_4^+), and anions (Cl^- , NO_3^- , SO_4^{2-} , and methanesulfonate, hereafter MSA), were analysed by ion chromatography (IC) equipped with a CS12 and an AS11 separator column, respectively. Finally, ~~e~~-the oxygen isotopic ratio analysis was processed using the equilibration method on a Finnigan MAT252, using two different internal water standards calibrated to SMOW/SLAP international scales. The accuracy of each measurement is 0.05 ‰ (1 σ) (Table S1 Supplementary Material). (Fig. 2).

2.3 Methodology for layer counting

As shown by Jourdain and Legrand (2002), all ions exhibit a summer maximum at DDU, as also found for different Antarctic coastal stations for nitrate (Wagenbach et al., 1998b), ammonium (Legrand et al., 1998), MSA and sulfate (Minikin et al., 1998). The sodium seasonal pattern at DDU (maximum in summer) is reversed compared to those observed at other coastal Antarctic sites (e.g. Halley and Neumayer), ~~where the largest concentrations occur in winter~~, a feature already discussed by Wagenbach et al. (1998a).

The outstanding summer maximum of sea-salt concentrations only detected at DDU is related to its location on a small island, immediately surrounded by open-ocean from December to February. With the aim to use the seasonality of sulfate and MSA produced by dimethyl sulfonic acid emitted in summer by marine phytoplankton, we have calculated the non-sea-salt sulfate concentrations in the SIC1 core. Wagenbach et al. (1998a) showed that at coastal Antarctic sites in, sea-salt aerosol exhibits a strong depletion of atmospheric sulfate in winter due to precipitation of mirabilite ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$) on the sea-ice surface (Wagenbach et al., 1998a). In order to quantify non-sea-salt (nss) SO_4^{2-} contribution, different sulfate to sodium ratio should be defined for summer (0.25, i.e. the reference seawater value) and winter (0.13 derived by Jourdain and Legrand (2002) for DDU):

$$[\text{nssSO}_4^{2-}]_{\text{summer}} = [\text{SO}_4^{2-}] - 0.25 [\text{Na}^+] \quad (1)$$

$$[\text{nssSO}_4^{2-}]_{\text{winter}} = [\text{SO}_4^{2-}] - 0.13 [\text{Na}^+] \quad (2)$$

Note that the volcanic horizons related to the eruptions of Mt Agung (1963) and Pinatubo (1991) are not detected in the nss SO_4^{2-} profile. Legrand and Wagenbach (1999) explained this feature by the fact that, in coastal Antarctica, the volcanic perturbation remained weak with respect to the year-to-year variability of marine biogenic sulphate. While the relationship between concentrations in snow and in simultaneously sampled air remains poor for all compounds (Wolff et al., 1998), there is a general seasonal coincidence of the maxima. Annual layer counting is therefore based on our assessment of the concurrence of synchronous maximum values for Na^+ , MSA, SO_4^{2-} , NH_4^+ , NO_3^- and $\delta^{18}\text{O}$ to objectively identify summer

horizons. The combination of information on annual layer counting as well as absolute age markers used to build the SIC1 age scale is described in Section 3.1 (Results).

2.4 Regional climate records

We extracted DDU monthly near surface air temperature data spanning the period 1958-2007 from the READER data-set (<https://legacy.bas.ac.uk/met/READER/>) (Turner et al., 2004). We also calculated annual mean values of wind speed spanning the period 1950-2007 (with gaps in years 1953-1955) at DDU (P. Pettré, pers. comm.). Finally, we extracted the average sea ice concentration the Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data (<http://nsidc.org/data/nsidc-0051>) and focused on the region situated between 90 °E and 150 °E (Center, 1996). We used these datasets to perform linear regression analysis ~~to explore relationships~~ with the SIC1 $\delta^{18}\text{O}$ and accumulation records.

2.5 Atmospheric simulations

In this manuscript, we refer to two simulations, one by the ~~global-atmospheric-model~~AGCM ECHAM5-wiso and one by the regional atmospheric model MAR.

~~The atmospheric general circulation model (AGCM)~~ ECHAM5 (Roeckner et al., 2003) has been equipped with stable-water isotopes (Werner et al., 2011). This model, named ECHAM5-wiso, leads to realistic simulations when evaluated against observations of isotopic composition in precipitation and water vapour on a global scale. More specifically, the simulated distribution of annual mean precipitation isotopic composition over Antarctica is in good agreement with the spatial isotopic dataset compiled from snow and ice core data (Masson-Delmotte et al., 2008).

In addition to the most common water stable isotope H_2^{16}O , H_2^{18}O and HDO were implemented into the hydrological cycle of ECHAM5-wiso, in an analogous manner than in the previous model releases of ECHAM3 (Hoffmann et al., 1998) and ECHAM4 (Werner et al., 2001). Each water phase (vapour, cloud liquid and cloud ice) being transported independently in ECHAM5-wiso contains its isotopic counterpart, implemented in the model code. Equilibrium and kinetic fractionation processes are taken into account during any phase change of a water mass.

The ECHAM5-wiso model simulation analysed in this study covers the period 1960-2007. ECHAM5-wiso was nudged to atmospheric reanalyses from ERA40 (Uppala et al., 2005) and ERA interim (Dee et al., 2011), which was shown to have good skills for Antarctic precipitation (Wang et al., 2016), surface pressure fields as well as vertical profiles of winds and temperature. The ocean surface boundary conditions (sea-ice included) are prescribed based on ERA40 and ERA interim data. ~~too~~. Isotope values of ocean surface waters are based on a compilation of observational data (Schmidt et al., 2007). The simulation was performed at a T106 resolution (which corresponds to a mean horizontal grid resolution of approx. $1.1^\circ \times 1.1^\circ$). We used the model results at the grid point closest to our site of interest.

The MAR (Modèle Atmosphérique Régional) model is a limited area coupled atmosphere – blowing snow – snow pack model. Atmospheric dynamics are based on the hydrostatic approximation of the primitive equations (Gallée and Schayes, 1994). The vertical coordinate is the normalized pressure. The parameterisation of turbulence in the surface boundary layer

(SBL) takes into account the stabilization effect by the blowing snow flux, as in Gallée et al. (2001)–~~Gallée et al. (2001)~~. Turbulence above the SBL is parametrized using the local E - ε model of Bintanja (2000)–~~Bintanja (2000)~~. Prognostic equations are used to describe five water species (Gallée, 1995): specific humidity, cloud droplets and ice crystals, rain drops and snow particles. A sixth equation is added describing the number of ice crystals. Cloud microphysical parameterisations are based on the studies of ~~Kessler (1969)~~Kessler (1969), Lin et al. (1983)~~Lin et al. (1983)~~, Meyers et al. (1992)~~Meyers et al. (1992)~~ and ~~Levkov et al. (1992)~~Levkov et al. (1992). The radiative transfer through the atmosphere is parameterised as Morcrette (2002)~~in Morcrette (2002)~~. Surface processes in MAR are modelled using the Soil – Ice – Snow – Vegetation – Atmosphere – Transfer (SISVAT) scheme (Gallée et al., 2001). In particular, the snow surface albedo depends on the snow properties (dendricity, sphericity and size of the snow grains). Finally the blowing snow model is described in–Gallée et al. (2013)~~Gallée et al. (2013)~~. MAR is set up over Antarctica with a horizontal resolution of 40 km over 200 x 200 grid points. Lateral forcing and sea surface conditions (SST and sea – ice fraction) are taken from ERA-Interim (Dee et al., 2011). There are 33 levels in the vertical with a high vertical resolution in the low troposphere. The first level is situated at 3 m a.g.l. The simulation was performed from January 1st, 1990, to December 31st, 2010.

Hereafter, we use the ECHAM5-wiso simulation ~~to explore the suitability of local precipitation δ¹⁸O to identify seasonal cycles, as no regional precipitation monitoring data are available, to explore the suitability of precipitation δ¹⁸O to identify seasonal cycles, to circumvent the lack of regional precipitation monitoring data, as the one-year Dumont d'Urville record is too short to allow robust analysis.~~ We then compare the ECHAM5-wiso (δ¹⁸O, temperature and accumulation) and MAR (temperature and accumulation) outputs with our ice core records.

3. Results

3.1 Age scale

3.1.1 Information from ECHAM5-wiso on annual δ¹⁸O cycles

In order to assess whether annual layer counting was possible using ~~a δ¹⁸O seasonal cycle δ¹⁸O variations,~~ we investigate ECHAM5-wiso outputs ~~and the timing of the maximum precipitation δ¹⁸O value for each year, to characterize the seasonal cycle of precipitation δ¹⁸O in Adélie Land, as well as the variability of the timing of the maximum precipitation δ¹⁸O value.~~

The mean simulated precipitation δ¹⁸O seasonal cycle over the period 1979-2006~~7~~ (28~~9~~ years) shows a maximum in December-January, a minimum in May, and an overall amplitude of 4.45 ‰. The timing of the simulated monthly precipitation δ¹⁸O maximum fluctuates from year to year. Out of the 29 years, it was simulated at 80 % during local spring-summer: 7 times in December (i.e. 24 %), 8 times in November (i.e. 28 %) ~~and~~, 8 times in January (i.e. 28 % of the time). However, several occurrences were simulated in autumn: 3 times in March (i.e. 10 %), once in February (i.e. 3 %), and in winter: 2 times in August (i.e. 7 %) (Table S3 Supplementary Material). From this analysis, assuming that the ECHAM5wiso ~~outputs are model is~~ a perfect representation of reality, peak δ¹⁸O has a 80% likelihood to occur in December ~~± 1 month plus~~

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~~or minus one month.~~ If a chronology was purely based on $\delta^{18}\text{O}$, the occurrence of maxima during other seasons may therefore lead to age scale errors of up to 6 months.

3.1.2 Absolute age horizons

Following major nuclear tests in the atmosphere, radioactive debris were injected in the stratosphere in 1953-54 and 1963-64 and reported to be deposited in Antarctic in 1955 and 1965 (± 1 year) (Picciotto and Wilgain, 1963). ~~These two dates are indicated by red vertical lines in Fig. 2., providing absolute dates for two depths in the SIC1 core (red vertical lines, Fig. 2).~~ Aerosol monitoring data from DDU (1991-2015) show an unequivocal fingerprint of rare summers during which the sea-ice retreat was not complete offshore the site; through the absence of sodium maximum. ~~Such events were~~ observed in January 1995 (Jourdain and Legrand, 2002), and more recently in January 2012 and 2013 (Legrand et al., 2016). Prior to the start of DDU atmospheric monitoring in 1991 and to the availability of satellite sea-ice data in January 1979, two other years were characterized by a non-complete sea-ice retreat in summer offshore DDU, namely January 1969 and January 1979 (Patrice Godon, personal communication). ~~These years were used as absolute horizons in the ice core dating (purple vertical lines, Fig. 2).~~ The identification of years 1995, 1969 and 1979 in SIC1 records is indicated by purple vertical lines in Fig. 2. Note that the chemical fingerprint of summer 1969 is equivocal, as it is defined by the absence of a sodium maximum, but coincides with a sulfate maximum, contrary to what is expected.

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3.1.3 Combining layer counting with absolute age horizons

We assessed the concurrence of synchronous maximum values for Na^+ , MSA, SO_4^{2-} , NH_4^+ , NO_3^- and $\delta^{18}\text{O}$ to objectively identify summer horizons, indicated by the vertical continuous black lines in Fig. 2. Only 4 layers showed simultaneous peaks in all species (in 1959, 1966, 1984 and 2001). In the other cases, the determination was equivocal: either data were missing for the depth interval corresponding potentially to summer (~~4 times for MSA and 2 times for $\delta^{18}\text{O}$~~), or peaks were not identified in some of the records (~~4 times for Na^+ , 10 times for MSA, 4 times for the nssSO_4^{2-} , once for NO_3^- , 7 times for NH_4^+ and 25 times for $\delta^{18}\text{O}$~~), or, conversely 2 or 3 peaks appeared (~~9 times for Na^+ , 2 times for MSA, 5 times for the nssSO_4^{2-} , 6 times for the nssSO_4^{2-} , 7 times for NO_3^- , and 5 times for NH_4^+~~). Table 1 reports the number of occurrence of such cases for each species. We note that maxima in NO_3^- and $\delta^{18}\text{O}$ were often delayed with respect to maxima in other species. These two parameters can potentially be affected by diffusion in the firn, due to snow-vapor interactions (Johnsen, 1977; Mulvaney et al., 1998). Mulvaney et al. (1998) also reported that MSA could migrate in the firn. Potential seasonal signals were generally associated with a very low amplitude, especially from 1969 to 1975, or no signal could be discerned. Altogether, nssSO_4^{2-} ,_{winter} seems to be the most reliable species to identify seasonal cycles, as a seasonal pattern appears for every layer.

The remaining difficulty is associated with multiple peaks within one year. This appears for instance in year 1993 (represented in dashed vertical line in Fig. 2), ~~for which~~ double peaks may be associated with year 1993 only, or with two

successive years. Such situations were encountered 8 times (dashed vertical lines in Fig. 2). As a result, we made subjective choices for the identification of annual or sub-annual peaks in order to optimize the coherency with absolute age markers. ~~Indeed, 68 potential annual layers were initially identified, and this result is not compatible with the horizons based on these two sources of information (radionuclide peaks and years without summer sea-ice retreat). We then repeated the annual layer counting, excluded layers for which we had the smallest number of maxima among the species.~~

We found 60 summer peaks represented ~~(solid lines, Fig. 2), in Fig. 2 with solid lines,~~ whereas the initial layers excluded from the final chronology are represented with dashed lines. As a result, the SIC1 ice core spans the period 1946-2007, as displayed in a depth (expressed in meter water equivalent)-age scale (Fig. 3).

3.2 Record of accumulation variability and comparison with stake measurements

Annual accumulation variations were extracted from the SIC1 core by combining density measurements with annual mean layer counting (Fig. 4). The resulting annual accumulation varies between 9.7 and 38.0 cm w.e. y^{-1} , with a mean of 21.98 cm w.e. y^{-1} , and a standard deviation of 6.98 cm w.e. y^{-1} . This value is 154% lower than the annual accumulation of 25.6 cm w.e. y^{-1} (standard deviation of 15.1 cm w.e. y^{-1}) measured between 2004 and 2015 on one stake located closest to the drilling site (Agosta et al., 2012) (Fig. 1b), or 27% lower than ~~the mean value measured nearly at the same location between 1971 and 1991 (mean value of 29.9 cm w.e. y^{-1} and standard deviation of 26.6 cm w.e. y^{-1}), the mean value of 29.9 cm w.e. y^{-1} (standard deviation of 26.6 cm w.e. y^{-1}) measured nearly at the same location between 1971 and 1991.~~ We identified remarkable years as those for which accumulation deviates from the mean value by more than two standard deviations. Remarkable high accumulation rates were ~~thus~~ encountered in 1981, 1983 and in 2001 (at respectively 35.9, 37.3 and 38.0 cm w.e. y^{-1}). ~~No remarkable low accumulation rates were found.~~ For stake accumulation measurements performed at the stake closest to SIC1, the highest values were measured in 1979 and 1981 (75.8 and 73.8 cm w.e. y^{-1}). None of these remarkable years can be found neither in the stake average record nor in the stake data the closest to the SIC1 site. Moreover, small and non-significant linear correlation coefficients are found with the stake average record ~~($r=0.15$ and $p=0.6$), and with the stake data the closest to the SIC1 site ($r=0.38$ and $p=0.2$). There is no significant long term.~~ Spectral analyses performed using the Multi-Taper method (Paillard et al., 1996) reveal significant periodicities of 65 and 8 years (harmonic F-test ≥ 0.94). We also note a periodicity of 12 years, but which is not detected as significant (harmonic F-test=0.8). Decadal variability is characteristic of the high latitudes of the Southern Hemisphere (Yuan and Yonekura, 2011). This motivates filtering using a 13-point binomial filter with bounce end-effects (Fig. 5) , i.e. repeating the first (last) value six times in order to calculate the six first (last) running means ~~(Fig. 5).~~ From this analysis, we observe a slight accumulation increase from the 1950s until the 1980s, with secondary maxima in 1970s and 1990s (Fig. 5). A decrease appears from the 1980s to the 2000s, back to the initial mean level. Finally, the SIC1 core displays an unprecedented accumulation increase from the 1990s to the 2000s. ~~The~~is latter feature is surprising, as recent stake measurements from this area show no increase in mean values ~~observed~~ in 2004-2015 compared with earlier surveys (1971-1991). We therefore remain cautious about the recent accumulation increase inferred from one single ice core record, unless this finding can be supported by other lines of

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evidence. Finally, note that only a 5 year periodicity emerges from spectral analysis of DDU temperature (harmonic F-test=0.99).

3.3.3 Record of $\delta^{18}\text{O}$

With our age scale, each year is documented with 2 to 14 $\delta^{18}\text{O}$ 5 cm measurements, with a mean number of 7 values per year. Hereafter, the $\delta^{18}\text{O}$ record is resampled at this average temporal resolution using the Fourier method (Fig. 4). Annual mean $\delta^{18}\text{O}$ values are then calculated from January to December, for comparison with accumulation and other observational or simulation datasets (Fig. 5).

3.3.1 Other sources of information for $\delta^{18}\text{O}$ regional variability

Very few multi-year direct records of snowfall isotopic composition are available from Antarctica (Fujita and Abe, 2006; Landais et al., 2012; Schlosser et al., 2016), and none in our region of interest. Near SIC1, the single direct observation arises from a collection of 19 samples of precipitation at DDU, spanning the period from February to November of 1977 (*J. Jouzel, pers. comm.*). These data depict a mean $\delta^{18}\text{O}$ value of -18.0 ‰, a standard deviation of 3.9 ‰, with the lowest value in August (~ -27.7 ‰) and the highest values in March (-10.0 ‰) and November (-11.5 ‰). Despite its brevity, this dataset shows less depleted values, a different seasonal pattern (*i.e. maxima do not appear at the same months*), and lower variability than at Dome C, where recent measurements are available for the period 2008-2010 (Schlosser et al., 2016) ranging from -80.6 to -35.5 ‰, with a mean $\delta^{18}\text{O}$ value of -58.0 ‰, a standard deviation of 8.6 ‰ and a ~37 ‰ seasonal cycle, *with maximum values in December-January, as for near surface air temperature. This comparison is of course limited by the short dataset available for DDU and the fact that these measurements were not performed for the same time period, in phase with that of near surface air temperature.* The distribution of $\delta^{18}\text{O}$ data at DDU appears consistent with the range of values observed in a multi-decadal (1982-1996) record of surface snow isotopic composition obtained from the coastal station of Neumayer, with a mean $\delta^{18}\text{O}$ value of -20.6 ‰, and a seasonal amplitude varying from 14.6 to 29.0 ‰ (Schlosser et al., 2008). Finally, the Dumont d'Urville precipitation mean $\delta^{18}\text{O}$ value is also quite close to that of shallow ice cores from Law Dome (66.73 °S, 112.83 °E, 1395 a.s.l.) (Delmotte et al, 2000; Masson-Delmotte et al, 2003), which display a mean value of ~ -21 ‰, and an average seasonal $\delta^{18}\text{O}$ amplitude of ~ 6 ‰, together with a larger inter-annual variability rather in local winter than in local summer.

3.3.2 Record of $\delta^{18}\text{O}$ variability and links with accumulation and regional climate records

The sub-annual record from raw measurements and resampling at an average of 7 points per year displays large year-to-year variations in the amplitude of the seasonal cycle, varying from 0.2 ‰ (in 1980) to 132.5 ‰ (in 2005), with a mean value of 2.5 ‰. The SIC1 record clearly displays a smaller intra-annual range than observed in DDU precipitation (17.7 ‰ for one single year), and an average intra-annual range about twice smaller than shallow ice core records from Law Dome (typically 5 ‰). *Note that the annual accumulation rate at Law Dome (64 cm. w.e. y^{-1}) is ~3 times higher than in the SIC1 core (21.9*

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cm. w.e. y^{-1}). However, ~~Note that however, the~~ confidence in this finding is limited by the resolution of our record as well as by potential post-deposition processes affecting the preservation of the precipitation isotopic composition signal (Johnsen, 1977; Touzeau et al., 2016).

We again identified remarkable years as those deviating from the mean value by more than two standard deviations.

- 5 Remarkable low $\delta^{18}\text{O}$ values were encountered in ~~1967, 1997 and 2005~~ 1996, while ~~no~~ remarkable high $\delta^{18}\text{O}$ values ~~were~~ encountered ~~in 1971, 1985 (highest value), 2001, and 2006~~. The year 1985~~97~~ is marked by the most ~~enriched/depleted~~ annual mean $\delta^{18}\text{O}$ values of the whole series. No long-term trend is observed. Spectral analyses performed using the Multi-Taper method evidence highly significant periodicities of 6 and ~~14~~ 14 years (harmonic F-test > 0.99), close to those identified for accumulation. This former result lead us to use a 13-point binomial filter with bounce end-effects allowing us to explore the
- 10 SIC1 $\delta^{18}\text{O}$ record at the decadal scale and to compare it with accumulation at the same scale. The resulting calculations depict a sharp decrease in the 1950s, with the strongest decadal minimum peaking in 1955. It is followed by a gradual increase, reaching the highest $\delta^{18}\text{O}$ decadal-mean values in ~1982 and ~1992, with secondary maxima in ~1962 and ~1972. A sharp decrease occurs in the 1990s, when mean levels from the 1950s are reached again. There is an anti-phase of the $\delta^{18}\text{O}$ and accumulation smoothed signals in the 1950s and the 2000s, while they appear in phase from the 1970s to 1990s, with
- 15 multi-decadal variations.

We now explore linear relationships between ~~$\delta^{18}\text{O}$ accumulation~~ the SIC1 records and regional climate records (Table 2). No significant linear correlation is identified between annual mean SIC1 $\delta^{18}\text{O}$ and accumulation records from 1947~~6~~ to 2006, but a significant positive linear relationship appears from 1997 to 2006. ~~We a~~ Also ~~note that~~ remarkable years for $\delta^{18}\text{O}$ and accumulation ~~do not~~ coincide.

- 20 There is no ~~linear relationships~~ significant correlation between annual mean SIC1 $\delta^{18}\text{O}$ and ~~regional records of DDU~~ near surface air temperature over the whole available period. At the decadal scale, observe a significant positive correlation, with a slope of 1.49 ‰ per °C. Linear relationships between $\delta^{18}\text{O}$ and near surface air temperature were found in other Antarctic stations. However, a linear correlation appears since 1979, displaying a slope of 1.14 ‰ per °C with the strongest and more significant correlation coefficient during local winter, whereas it is the weakest (and not significant) relationship during
- 25 local summer. At the decadal scale, the correlation between $\delta^{18}\text{O}$ and the near surface air temperature is much stronger, with a linear slope of 1.49 ‰ per °C. At Law Dome, the DE08 ice Australian $\delta^{18}\text{O}$ record displays a weak correlation with Casey near surface air temperature with a slope of -0.31 ‰ per °C ($r=-0.45$ and $p=9.0\text{E-}3$ for the period 1959-1991) (Masson-Delmotte et al., 2003). At Dome C, over 3 years ~~only~~, annual mean and daily precipitation $\delta^{18}\text{O}$ displays a significant correlation with AWS near surface air temperature with a slope of 0.49 ‰ per °C ($r=0.79$ and $p=3.22\text{-}5\text{-E-}14009$).
- 30 By comparison, the $\delta^{18}\text{O}$ -temperature slopes found for SIC1 (Table 3) are particularly high compared with previous results from Law Dome ice cores, and from Dome C precipitation data.

~~No significant relations are detected between annual mean SIC1 $\delta^{18}\text{O}$ and annual mean sea ice concentration in the Adlie land sector, and between annual mean SIC1 $\delta^{18}\text{O}$ and annual mean wind speed over the whole respective available periods.~~

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~~Again, higher correlation coefficients have emerged since 1979 and 2000 for the sea ice concentration in the Adélie Land sector and the wind speed, respectively.~~

~~No significant relations are detected between annual mean SIC1 $\delta^{18}\text{O}$ and annual mean sea ice concentration in the Adélie land sector (Table 3).~~

5 **3.3.4 Model-data comparison**

3.4.1 Comparison between the ECHAM5-wiso and the SIC1 data

This comparison is limited by the fact that we only have one firm core record, and no estimation of the deposition noise. In the future, the latter may be, which can only be estimated from signal-to-noise analyses of multiple ice core records from the same area (Masson-Delmotte et al., 2015). Moreover, recent monitoring of surface snow and surface vapour isotopic composition in polar regions have suggested isotopic exchanges in-between snowfall events (Ritter et al., 2016; Steen-Larsen et al., 2014), in relationship with surface snow metamorphism. Such processes are not accounted for in the atmospheric models, and we can therefore only compare simulated precipitation-weighted $\delta^{18}\text{O}$ with our firm measurements. Similarly, we compare the ECHAM5-wiso model simulated precipitation (or precipitation minus evaporation) with the ice core accumulation data, which may also reflect the impact of wind erosion.

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20 The ECHAM5-wiso simulation produces a large increase in $\delta^{18}\text{O}$ and precipitation after 1979 (not shown). As such increase is not observed in the SIC1 record, we suggest that it may arise from a discontinuity in the ERA reanalyses data used as boundary conditions. Indeed, the lack of sea ice observations prior to the satellite era in the ERA-40 data-set leads to the unrealistic set of climatological sea ice coverage values around Antarctica prior to 1979. This deficit does not exist in the ERA interim data-set, starting from year 1979. Therefore, in the following, the model-data comparison is restricted to the period 1979-2007 (Fig. 6).

The ECHAM5-wiso simulation underestimates the average seasonal amplitude of $\delta^{18}\text{O}$ at the SIC1 grid point by a factor of 2.0, and its inter-annual standard deviation by a factor of 1.4. No strong similarity appears for year-to-year values.

25 ~~Weak but significant decreasing long-term trends appear in both the SIC1 record and the model outputs. Neither the SIC1 record nor the model outputs present any long-term trend~~ ($r=-0.3648$ and $p=5.8.0E-23$ and $r=-0.4338$ and $p=2.24.0E-2$ respectively).

30 By contrast, the model precipitation amount (68.4 ± 11.9 cm w.e. y^{-1}) is much higher than observed (23.1 ± 7.3 cm w.e. y^{-1}) at SIC1 site on the same period. This difference cannot be explained by the impact of sublimation (in average, -4.8 cm w.e. y^{-1} in the simulation). Note that the model may not fully account for the impact of wind erosion, due to missing parameterizations for wind scouring and misrepresentation of small-scale katabatic winds. However, snow accumulation is highly variable in this region, due to the orographic effect on precipitation and to wind scouring. Along the first 50 km of the stake network (Agosta et al., 2012), the mean accumulation rate is estimated at 34.6 cm w.e. y^{-1} between 2004 and 2014. This result confirms that ECHAM5-wiso overestimates the regional accumulation rate. When considering deviations from

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average values (Fig. 6), no similarity emerges between inter-annual variations in the SIC1 record and in the simulation. The simulation captures the observed positive anomalies in 1993. No significant long-term trend is identified from 1979 to 2007 ($r=0.12$ and $p=0.56$ for SIC1 and $r=0.31$ and $p=0.1$ for ECHAM5-wiso).

The model-data mismatch may arise from the topographic effect of the Antarctic ice sheet margin on the distribution of precipitation, and the associated isotopic distillation. The model grid size used here (approx. $1.1^\circ \times 1.1^\circ$, i.e. $110 \times 110 \text{ km}^2$) might also be too coarse for a direct comparison of the simulation results to the SIC1 drill site. Further investigations are needed, and this requires also a regional network of shallow firn core records on the Antarctic ice sheet margin, in order to characterize spatio-temporal variations and signal-to-noise ratios.

In the simulation, we have also explored the $\delta^{18}\text{O}$ -precipitation and the $\delta^{18}\text{O}$ -temperature relationship at the annual scale. A significant linear relationship appears for temperature, with a slope of $0.2932 \text{ ‰ } ^\circ\text{C}^{-1}$ ($r=0.3942$, $p=3.82\cdot 10^{-2}$), therefore much smaller than calculated from the SIC1 core and the DDU temperature data. By contrast, no significant linear relationship is simulated for precipitation ($r=0.1922$, $p=0.342$).

In summary, the ECHAM5-wiso model outputs appear to have a wet and $\delta^{18}\text{O}$ -depleted bias at the SIC1 drill site, overestimate the inter-annual accumulation variability, underestimate the $\delta^{18}\text{O}$ variability and its relationship with surface air temperature, and fail to capture the observed $\delta^{18}\text{O}$ -accumulation relationship.

Our model-data comparison is of course limited by comparing two different data-sets. For the modelling results, we have analysed a pure atmospheric signal (precipitation). ~~In the ice core datasets, we have looked at a signal which is produced by precipitation, but also potentially altered by post-deposition processes such as sublimation, wind scouring and snow metamorphism (which may affect the isotopic signal). The signal recorded in the SIC1 core is produced by precipitation, but also potentially altered by post-deposition processes (such as sublimation, wind scouring and snow metamorphism).~~ Also, the fact of having just one ice core record (also associated with age scale uncertainties) precludes an assessment of the signal-to-noise ratio. Indeed, with similar mean accumulation values, it was shown that 4-5 shallow ice cores may be needed to extract the common climatic signal in North-West Greenland (Masson-Delmotte et al, 2015).

3.4.2 Comparison between the ECHAM5-wiso model and the MAR model

We now investigate the results of the regional model MAR for accumulation. MAR produces a more realistic range of accumulation, with simulated values varying from $12.3 \text{ cm w.e. y}^{-1}$ (in 2006) to $32.4 \text{ cm w.e. y}^{-1}$ (in 1999). At this 40 km horizontal (against 110 km in the ECHAM5-wiso model), the slope of the East Antarctic ice sheet is better represented, a critical aspect for orographic precipitation. However, the inter-annual variability simulated by MAR is very different from that inferred from the SIC1 core compared to ECHAM5-wiso. This result may arise from the nudging technique: while the ECHAM5-wiso model is strongly nudged to reanalyses, the MAR model is only forced by large-scale circulation at the lateral boundaries and layers above 20 km, ~~which allows~~ allowing the model to build its own atmospheric circulation. We conclude that systematic caveats of the ECHAM5-wiso model for coastal Antarctic precipitation amounts may arise from its resolution.

4. Discussion

Here, we propose an alternative ice-core chronology, given the annual layer counting uncertainties. For that purpose, we have screened peak-to-peak relationships between SIC1 record, stake accumulation measurements, and ECHAM5-wiso outputs. We first tried to optimize the match between SIC1 accumulation and stake data. However, the inter-annual standard deviation of SIC1 accumulation is approximately three times lower than calculated from either individual stake records, or from the average stake record. As a result, we could not identify unequivocally remarkable low or high accumulation years as a robust signal. For instance, all stake area data show very low (close to zero) accumulation in years 1972 and 1988, but no such signal can be identified in the SIC1 record. We therefore used the ECHAM5-wiso $\delta^{18}\text{O}$ to test an alternative chronology (Section 4.1). We identified a high similarity between ECHAM5-wiso inter-annual precipitation variability and average stake data (Section 4.2). We then discussed processes that can produce non climatic noise (Section 4.3). After assessing $\delta^{18}\text{O}$ -temperature relationships (Section 4.4), we finally explored the spatial relevance of climatic records from the SIC1 location (Section 4.5).

4.1 An alternative age scale can improve the model-data comparison for $\delta^{18}\text{O}$

The comparison of the most remarkable annual anomalies in the SIC1 and simulated $\delta^{18}\text{O}$ series from ECHAM5-wiso reveals a one year shift: the minimum value is identified in 1997~~6~~ for SIC1 but simulated in 1998, while the 1984~~5~~ maximum value in the SIC1 core may coincide with the simulated maximum value in 1985. Given the uncertainties of age chronology of at least one year and potentially several years (Section 3.1), we reconsidered the annual layer counting to assess whether the SIC1 chronology can be reconciled with the ECHAM-wiso $\delta^{18}\text{O}$ outputs.

~~Indeed, the identification of the summers 1999-2000 and 2000-2001 in our initial chronology (years 2000 and 2001 in Fig.2) are based on equivocal evidence due to multiple peaks in NO_3^- and the lack of a peak in $\delta^{18}\text{O}$. Vice-versa, we could have missed one year between the initial layers associated with the summers 1981-1982 and 1982-1983, where peaks are identified in Na^+ , nssSO_4^{2-} winter, nssSO_4^{2-} summer, NO_3^- and NH_4^+ . Indeed, the identification of the summer 2001-2002 in our initial chronology (year 2002 in Fig.2) is based on equivocal evidence: no peak of MSA, small peaks of both nssSO_4^{2-} winter and nssSO_4^{2-} summer (at a magnitude not systematically counted as a summer). Vice-versa, we could have missed one year between the initial layers associated with the summers 1981-1982 and 1982-1983, where peaks are identified in nssSO_4^{2-} winter, nssSO_4^{2-} summer, NO_3^- and NH_4^+ .~~ We therefore built an alternative depth-age scale (Table S4 Supplementary Material) following these two findings (Fig. 7 and Fig. 8), and discussed the implications for the SIC1 records. Consequently, we have produced new annual mean accumulation and $\delta^{18}\text{O}$ time series, from 1979 to 2007~~6~~, following the same approach (Section 2.3.3).

With this alternative chronology, the resulting mean accumulation does not change, ~~and~~but the inter-annual standard deviation is ~~slightly increased~~ enhanced by 44% ($213.81 \pm 7.49.8$ cm w.e. y^{-1}). It has no impact on $\delta^{18}\text{O}$ or accumulation multi-decadal variations or trends. The resulting accumulation dataset remains non-significantly correlated with the stake

average record and with the closest stake data. ~~The alternative chronology does not improve neither the strength of the $\delta^{18}\text{O}$ -temperature relationship between the SIC1 record and the DDU near surface air temperature time series ($r=0.49$ and $p=1.0\text{E}-2$) (but slightly increases the slope of this relationship with a new value of $1.24\text{‰ }^{\circ}\text{C}^{-1}$), nor the relationship between SIC1 accumulation dataset and the ECHAM5-wiso precipitation output ($r=0.19$ with $p=0.7$ for the initial chronology, and $r=-0.08$ with $p=0.3$ for the alternative chronology).~~ In the alternative chronology, there is still no significant $\delta^{18}\text{O}$ -temperature relationship between the SIC1 record and the DDU near surface air temperature time series, and no relationship between SIC1 accumulation dataset and the ECHAM5-wiso precipitation output at the annual scale. However, it improves (by construction!) the strength of the correlation between the SIC1 $\delta^{18}\text{O}$ and the ECHAM5-wiso $\delta^{18}\text{O}$, from $r=0.1744$ with $p=2.0\text{E}-40.39$ for the initial chronology to $r=0.5764$ with $p=2.01.6\text{E}-32$ for the alternative chronology

10 4.2 Comparison between stake data and ECHAM5-wiso simulation

No significant linear correlation is found neither between the SIC1 accumulation record (whatever chronology is used) and the stake accumulation measurements, nor between the SIC1 accumulation record and the ECHAM5-wiso simulated precipitation. We therefore compared the stake measurements and the ECHAM5-wiso output, with the goal to investigate if there is a common climatic signal (for the period 1979-1991).

- 15 We observe a high and significant correlation between the ECHAM5-wiso simulated precipitation and the average stake record at the inter-annual scale ($r=0.62$ and $p=3.0\text{E}-2$). This finding shows that the nudged ECHAM5-wiso simulation is able to capture almost 40% of the inter-annual average accumulation variance, and that there is a clear climatic deposition signal in the stake accumulation record. We also note that there is a high dispersion in the inter-annual variability of accumulation across the individual stake records, as evidenced by the quartile distribution (Fig. 7). Each stake record is significantly
- 20 correlated with the average stake record (r varies from 0.57 to 0.90, reaching 0.78 for the stake closest to SIC1, $p=3.2\text{E}-5$). However, significant differences are encountered. For instance, the sharp peak in accumulation displayed by the stake closest to SIC1 in 1979 is an outlier and is not recorded in the average stake signal. Similarly, the correlation coefficient between the ECHAM5-wiso simulated precipitation and individual stake records varies from 0.3 to 0.7, stressing potential non-climatic noise in local accumulation data.
- 25 We conclude that the common climatic signal in average stake accumulation time series is related to regional-scale circulation, and is captured by the ECHAM5-wiso simulation. The lack of correlation between the SIC1 accumulation record and both stake records and ECHAM5-wiso precipitation outputs may therefore reflect local non-climatic noise.

4.3 Processes causing non-climatic noise

- The significant correlation between the ECHAM5-wiso precipitation and the stake average accumulation record stresses the
- 30 fact that the inter-annual variability of the average accumulation is dominated by large-scale atmospheric circulation controls on precipitation. Given the spatio-temporal variability of accumulation reported previously, we could not use accumulation information to refine the initial SIC1 chronology, and conclude that the SIC1 accumulation record is probably heavily

affected by non-climatic noise. The significant correlation between the ECHAM5-wiso precipitation and the stake average accumulation record stresses the fact that the inter-annual variability of the average accumulation is dominated by large-scale atmospheric circulation controls on precipitation. However, snow accumulation is spatially variable at the study site (Agosta et al., 2012). Indeed, the mean accumulation given by the stake located at D10 is 25.6 cm w.e y⁻¹ and the standard deviation of mean accumulation values from the 14 stakes located within the first 10 km is 12.0 cm w.e y⁻¹. A high variability reaching tens of millimeters over few meters was also reported by Genthon et al. (2007) and Favier et al. (2011) over an ablation site located 4 km from D10.

This high variability can be associated to wind erosion, wind redistribution, sublimation, occurrence of gravity waves in the katabatic flow, and other processes during or after the precipitation event (Eisen et al., 2008). This leads to very high variability even at very small spatial scales, down to deca-meter scale (Libois et al., 2014), as reflected by the presence of sastrugi (Amory et al., 2015). Local features associated either with the distribution of precipitation or with wind-driven post-deposition erosion or deposition appear dominant for a given stake record, and for the SIC1 record as well.

However, refreezing of Liquid precipitation or melting and subsequent refreezing appear of secondary importance in this region does not seem to be enough significant to be counted as noise. Indeed, 2.5-m snow cores were collected every 0.5 km from the 156-km stake network of the Glacioclim observatory. These surface-shallow cores were used for density measurements but also for a quick and screened for stratigraphic analysis. Small refreezing-ice layers exceeding 2 mm can have been identified. It was found that these layers were found identified at the same depth. At Near D10 and around, only one event of very large refreezing was observed, following one event of a high liquid precipitation event followed by refreezing was observed between December , the 31th, of 2014 and January , the 01st, of 2014. This single event led to At D10, accumulated thickness of ice layers within the first 2.5 m of ice exceeded reaching up to 6 cm of thickness. 25 cm w.e. and ice layer were sometimes 5 to 6 cm thick. According from meteorological monitoring performed at the Météo France DDU station, this is the single such occurrence of a heavy liquid precipitation event since 1957. However, this event only occurred once over the last 60 years according to the observations made at the Meteo France station. From stratigraphic analyses of pits and shallow ice cores at D10, spanning the last , In order to confirm this point, over the last 10-10 years (prior to 2014), we only observed one ice layer thicker than 3 mm at was D10 identified: . Indeed, a 3 cm thick ice layer was observed at 60 cm depth in the surface core collected in 2008-2009. As a consequence, There is therefore evidence for rare occurrence of liquid precipitation, and very limited melting and refreezing of surface snow at D10, with limited percolation effects, when compared to annual accumulation amounts. melting and liquid precipitation occur at D10, but the effect on percolation is limited.

Differences in accumulation estimates from the stake data and from SIC1 may also arise from variations in surface snow density. Indeed, stake height measurements were converted into water equivalent using a spatial estimate of mean density distribution (Agosta et al., 2012). Lastly, his analysis also highlights the limited information which can be extracted from one single ice core. In the future, obtaining several ice cores from this sector will help to quantify the common climatic signal

and better characterize the non-climatic noise, and to confirm our hypothesis that there is a significant climatic signal in $\delta^{18}\text{O}$ from this single core, as suggested by the comparison with the ECHAM5-wiso output.

4.4 $\delta^{18}\text{O}$ -temperature relationship

We now report the various contradictory estimates of the $\delta^{18}\text{O}$ -temperature relationship based on our SIC1 record, instrumental temperature data, and ECHAM5-wiso outputs (Table 43).

~~Correlations and slopes in the $\delta^{18}\text{O}$ -temperature relationship from the data are higher at the decadal scale compared to the annual scale. Correlations and slopes in the $\delta^{18}\text{O}$ -temperature relationship from the data (both chronologies) over the whole available period (1956-2006), are not significant at the annual scale contrary to the decadal scale. It suggests that the $\delta^{18}\text{O}$ -temperature is not stationary through time, and that the calibration established at the inter-annual scale under-estimates the strength of the relationships at the decadal scale.~~

This may arise from non-climatic noise at the inter-annual scale. Moreover, the decadal slopes are stronger than expected from a Rayleigh distillation, possibly resulting from either a decoupling between surface and condensation temperature, or from changes in moisture sources through time.

~~We note that over the period 1979-2006, although the $\delta^{18}\text{O}$ -temperature relationship from the first chronology is not significant, the relationship from the second one is significant but weak, with a slope close to the Rayleigh distillation.~~

The ECHAM5-wiso simulation (Section 2.3.1) shows that the seasonal cycle of $\delta^{18}\text{O}$ is not in phase with the seasonal cycle of temperature. Moreover, the inter-annual variability of $\delta^{18}\text{O}$ simulated in the SIC1 area is maximum in local spring (November), in contrast with the maximum inter-annual variability of DDU temperature, occurring in winter. This finding are also different from Dome C precipitation data (Stenni et al., 2016), showing a larger inter-annual variability of both temperature and $\delta^{18}\text{O}$ during local winter (possibly due to variability in frequency of maritime air mass intrusions). These model results suggest that processes other than local temperature play a key role in local $\delta^{18}\text{O}$ seasonal cycle and inter-annual variability, as suggested by Schlosser et al. (2016).

~~The $\delta^{18}\text{O}$ -temperature relationship within the ECHAM5-wiso model is lower by a factor of 2 to 3 than inferred from the SIC1 records. In the ECHAM5-wiso model, the $\delta^{18}\text{O}$ -temperature relationship is significant (but weak) at the annual scale, and therefore stronger than observed from the SIC1 record. At the decadal scale, as in the data, the correlation is higher. However, the slope is lower (0.63) than in the data, being closer to the Rayleigh distillation.~~ To understand this mismatch between data and simulations, we investigated alternative approaches for the $\delta^{18}\text{O}$ -temperature relationship obtained using annual data through the combination of temperature extracted from the READER database and simulated $\delta^{18}\text{O}$, and the temperature extracted from the ECHAM5-wiso model and SIC1 $\delta^{18}\text{O}$ record (Table 43).

~~We found a high and significant correlation between inter-annual variation in temperature from the READER database and ECHAM5-wiso simulated near surface air temperature ($r=0.91$ and $p=2.2\text{E-}12$) but no significant correlation between inter-annual variations in $\delta^{18}\text{O}$ from the SIC1 core (from the first dating) and simulated by ECHAM5-wiso. We found a high and significant correlation between the temperature from the READER database and ECHAM5-wiso simulated near surface air~~

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~~temperature but a significant and weaker correlation between $\delta^{18}\text{O}$ from the SIC1 core and simulated by ECHAM5-wiso. The variance of the ECHAM5-wiso model result is about twice smaller than in the SIC1 core (inter-annual standard deviation of 0.6 ‰ and 1.8 ‰ for the ECHAM5-wiso model and and 1.8 ‰ in the SIC1 core respectively (Table 24). We conclude that the low simulated $\delta^{18}\text{O}$ -temperature relationship arises from a much smaller variability in the simulated $\delta^{18}\text{O}$ than in the SIC1 record. Also, note that the strength of the correlation coefficient and the magnitude of the slope are higher for ECHAM $\delta^{18}\text{O}$ versus READER temperature than within ECHAM outputs for both annual and decadal time scales. This could be explained by a near surface temperature closer to the condensation temperature in the case of READER compared to ECHAM.~~

So far, we cannot conclude on the cause for such a difference in variance: the ice core record may be affected by post-deposition features that generate noise, or the atmospheric model may not adequately resolve moisture transport pathways driving variability in the precipitation signal. Systematic comparisons between ECHAM5-wiso and results from direct precipitation sampling or from surface water vapour isotopic composition monitoring available will be needed to understand whether this mismatch arises from the atmospheric model or from signal-to-noise issues in one individual ice core record. So far, no such measurements are available in Adélie ~~Land-Land (apart from precipitation data from 1977 reported in our introduction, but in a time period when no sea ice information is available and reanalyses are less reliable). In any case, t.~~ This finding calls for a cautious use of simulated $\delta^{18}\text{O}$ -temperature relationships in coastal areas, before a full assessment of the model skills can be achieved.

4.5 Spatial extent of the representativeness of SIC1 site

We finally take advantage of the coherent framework provided by the ECHAM5-wiso simulation in order to investigate the spatial relevance of the SIC1 site. For that purpose, we have calculated the correlation coefficients of the annual surface air temperature, precipitation amount and $\delta^{18}\text{O}$ between the model output at the SIC1 site and the model outputs for each other Antarctic grid point (cf. Fig. 9). Regarding temperature, SIC1 temperature appears closely related ($r \geq 0.8$) with regional temperature in an approximative ~1000 km from ~120 °E to 150 °E. SIC1 is strongly correlated with regional precipitation amount, although for a much reduced area close to SIC1, within ~500 km. In the model world, SIC1 precipitation-weighted $\delta^{18}\text{O}$ appears only related with regional signals, with the strongest correlation coefficients for a very local area (approximately 100 km width).

5. Conclusions and perspectives

Documenting inter-annual climatic variations in coastal Antarctica is important to characterize natural climate variability, and provide a long-term context for recent changes, beyond the instrumental period. The study of the SIC1 core addresses this challenge.

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The initial chronology of the SIC1 ice core was established combining multi-parameter annual layer counting using major ions and $\delta^{18}\text{O}$, as well as reference horizons, including nuclear test horizons and fingerprints of summers with no sea-ice retreat. The latter approach would not have been feasible without the knowledge provided by long-term aerosol monitoring at DDU. The SIC1 records encompass the period 1946-2006, with equivocal identification of 8 annual years.

5 , and we have provided a clear description of sources of age scale uncertainty.

The mean accumulation rate estimated from the SIC1 record is coherent with information from stake area measurements in Adélie Land. No long-term trend is detected in the stake data (Agosta et al., 2012) and in the SIC1 accumulation record. This robust finding challenges a recent regional modeling study showing a decrease of accumulation in coastal Adélie Land from 1979 to 2010 (Lenaerts et al., 2012). The record is marked by periodicities of 5, 8 and 12 years, and multi-decadal variations, peaking in the 1980s. We are not confident in the signal of higher accumulation rates in the 2000s, because no such signal is detected in the comparison of recent and historical stake measurements. The average stake area record is significantly correlated with results from the ECHAM5-wiso model, but not with the SIC1 record. This finding may arise from post-deposition noise associated with e.g. wind scouring in an area marked by remarkable katabatic winds. The lack of similarity between the SIC1 ice core records and the stake measurements may also arise from the fact that the location of stake measurements may have moved through time (Agosta et al., 2012), and from the correction of height measurements using an average density value along the profile rather than simultaneous measurements of density which were not available.

10 The SIC1 $\delta^{18}\text{O}$ record shows a remarkable small amplitude of the seasonal cycle, when compared to other isotopic datasets from coastal East Antarctica. But note that the accumulation rate is site-dependent. We have evidenced a relationship between inter-annual variations of $\delta^{18}\text{O}$ and accumulation, but stressed that remarkable years are not coincident. Both records display a multi-decadal variability. The SIC1 $\delta^{18}\text{O}$ record is significantly correlated with DDU near surface air temperature only at the decadal scale, with a particularly large slope. We showed stress that the ECHAM5-wiso model strongly underestimates the inter-annual variability in $\delta^{18}\text{O}$ and therefore the strength of the slope of the $\delta^{18}\text{O}$ -temperature relationship. The under-estimation of the inter-annual variance of precipitation $\delta^{18}\text{O}$ by the ECHAM5-wiso model calls for a systematic assessment of the skills of the isotopically enabled atmospheric general circulation models against the whole variety of data regarding the temporal variability (vapour, precipitation and firn isotopic composition using shallow ice core data as well as the few precipitation and vapour measurements). In order to better understand the drivers of isotopic variability in coastal Adélie Land, obtaining continuous vapour isotopic composition measurements at DDU will offer the possibility of a direct comparison with atmospheric transport pathways, and with aerosol chemical data.

25 Implementing water stable isotopes in the regional MAR model is underway. Resolving regional aspects of the atmospheric circulation, especially related to katabatic winds and boundary layer dynamics, may indeed be important to resolve changes in moisture origin at the inter-annual scale. Contrary to the regional MAR model, the ECHAM5-wiso model captures inter-annual variations in Adélie Land accumulation rate (as inferred from the average stake measurements) and remarkable $\delta^{18}\text{O}$ anomalies (as identified in the SIC1 record). Therefore, these variations are driven by large-scale atmospheric circulation.

We have highlighted the fact that model outputs cannot be used in a climate sense prior to 1979, probably due to the lack of sea ice data used in the assimilation systems.

In this manuscript, we have also used the ECHAM5-wiso model outputs to challenge the interpretation of ice core $\delta^{18}\text{O}$ records. First, we have quantified the source of errors associated with the use of seasonal cycle in precipitation $\delta^{18}\text{O}$ to detect summer layers. Second, we have identified the two strongest anomalies in the simulated and SIC1 $\delta^{18}\text{O}$ records, and challenged our initial ice core chronology. None of our key conclusions is affected by the alternative chronology implying a ~~two~~one-year shift, and compatible with the multi-parameter information used for layer counting. Third, we have explored the spatial relevance of precipitation and precipitation $\delta^{18}\text{O}$ outputs at the SIC1 site, and stressed the differences between a large-scale representativeness of temperature (typically, 1000 km), and a smaller-scale representativeness of $\delta^{18}\text{O}$ (typically, 100 km around the SIC1 site). In the future, obtaining a network of shallow ice core records in coastal East Antarctica will be critical to assess signal-to-noise aspects and test the validity of these findings. Obtaining longer records will also allow to better characterize the multi-decadal variability and assess past changes in Antarctic temperature (Consortium, 2013; Jones et al., 2016). Finally, characterizing spatio-temporal variations in deuterium excess will provide a complementary line of information, for the identification of seasonal variations, and for assessing past changes in moisture origin.

Further investigations are finally needed to explore the relationships between large-scale modes of variability ~~such as the Southern Annular Mode (SAM), the Pacific – South American patterns (PSA), such as the Antarctic annular mode, the Pacific – South American patterns;~~ ENSO and climate variability in the Adélie Land sector. Indeed, composite analyses performed from 1979 to 2013 show significant imprints of SAM and PSA2 (~~associated with the tropical heating anomalies in the Pacific~~) on DDU temperature (Marshall and Thompson, 2016), and of La Niña on coastal East-Antarctic climate (Welhouse et al., 2016). ~~No significant relationships emerge with our SIC1 records. During the same time period, SIC1 $\delta^{18}\text{O}$ (using the second dating) is significantly anti-correlated with the SAM index ($r=0.43$ and $p=2E-2$), and significantly correlated with the Niño3.4 index ($r=0.50$ and $p=5.5E-3$). Longer records with multiple ice-cores will allow to test the stability of these teleconnections through time (Yeo and Kim, 2015).~~

We have evidenced a multi-decadal variations in ~~the~~SIC1 ice core records, DDU near surface air temperature and sea-ice extent. Our record, available back to 1947 (therefore 10 years earlier than the instrumental temperature series from DDU) depicts a decadal $\delta^{18}\text{O}$ minimum in the mid-1950s, within the range of subsequent variability. Altogether, these results imply no major climatic reorganization in this sector of East Antarctica prior to the 1970s. It contradicts suggestions for dramatic sea ice contraction in the mid-1950s, based on whaling ship records (Cotte and Guinet, 2007; William, 1997). Given discussions with respect to drivers of penguin demography (Raymond et al., 2015; Southwell et al., 2015), reconciling all sources of information for Adélie Land climate variability prior to the 1970s remains to be achieved.

Author contribution. : V. Favier compared the accumulation data from the SIC1 ice-core with surface accumulation data from stake measurements and designed Figure 1b. M. Fily and O. Magand participated in the TASTE-IDEA/VANISH 2006-2007 summer campaign, and processed density and radionuclides measurements. S. Preunkert performed the chemical

measurements, with support from B. Jourdain. M. Legrand provided insights on aerosol signals and layer counting. B. Minster performed the isotopic measurements. V. Masson-Delmotte designed the study and supervised the analyses of the records. M. Werner performed the simulation of the ECHAM5-wiso model while H. Gallée performed the simulation of the MAR model. S. Goursaud dated the S1C1 ice-core and wrote the manuscript with contributions from all co-authors.

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Tables

5 **Table 1. Occurrence of species not showing a summer peak for a identified summer (data missing in summer, peaks not identified at all, or 2 or 3 peaks appearing for the same year)**

	<u>Data missing</u> <u>in summer</u>	<u>Peaks not</u> <u>identified</u>	<u>2 or 3</u> <u>peaks</u>
<u>Na⁺</u>	<u>0</u>	<u>4</u>	<u>9</u>
<u>MSA</u>	<u>4</u>	<u>10</u>	<u>2</u>
<u>nssSO₄²⁻_{summer}</u>	<u>0</u>	<u>4</u>	<u>5</u>
<u>nssSO₄²⁻_{winter}</u>	<u>0</u>	<u>0</u>	<u>6</u>
<u>NH₄⁺</u>	<u>0</u>	<u>7</u>	<u>5</u>
<u>NO₃⁻</u>	<u>0</u>	<u>1</u>	<u>7</u>
<u>δ¹⁸O</u>	<u>2</u>	<u>25</u>	<u>0</u>

5 Table 2. Statistical analyses : minimum (Min), maximum (Max), mean (μ) and standard deviation (σ) of the precipitation (extracted from ECHAM5-wiso) or the accumulation (from the SIC1 ice core) in cm w.e. y^{-1} , the $\delta^{18}O$ (extracted from ECHAM5-wiso or from the SIC1 ice core) in ‰ and the 2-meter temperature (2m-T, extracted from ECHAM5-wiso or from the READER database) in °C over the different available periods (1946-2007 for the SIC1 ice core and 1956-2007 for the READER database), and over the period 1979-2007.

Table 1. Statistical analyses of the ECHAM5-wiso outputs: precipitation in cm y^{-1} , $\delta^{18}O$ in ‰ and the 2-meter temperature (2m-T) in °C over the 1979-2007 period.

		Precipitation (cm w.e. y^{-1})				2m-T (°C)				$\delta^{18}O$ (‰)			
		Min	Max	μ	σ	Min	Max	μ	σ	Min	Max	μ	σ
SIC1	1947-2007	9.47	38.0	21.82	6.9					-23.6	-15.9	-18.9	1.7
	1979-2007	9.7	38.06	23.1	9.8					-23.6	-15.4	-18.76	1.8
READER	1956-2007					-12.26	-8.6	-10.78	1				
	1979-2007					-11.9	-8.6	-10.6	0.7				
ECHAM	1979-2007	52.1	96.6	68.74	12.01	-18.1	-14.8	-16.9	0.8	-22.4	-22.41	-20.8	0.6

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Table 3. Linear relationship between the SIC1 $\delta^{18}\text{O}$ and regional climate records showing the coefficient correlation and the p-value. Note that all data from the SIC1 core are annual averages from the 1st dating.

<u>Period</u>	<u>Resolution</u>	<u>Record</u>	<u>r</u>	<u>p</u>
<u>1946-2006</u>	<u>annual</u>	<u>accumulation</u>	<u>4.4E-3</u>	<u>0.97</u>
<u>1956-2006</u>	<u>annual</u>	<u>READER surface temperature</u>	<u>-0.13</u>	<u>0.35</u>
<u>1956-2006</u>	<u>decadal</u>	<u>READER surface temperature</u>	<u>0.72</u>	<u>2.6E-9</u>
<u>1979-2006</u>	<u>annual</u>	<u>READER surface temperature</u>	<u>-0.15</u>	<u>0.44</u>
<u>1979-2006</u>	<u>annual</u>	<u>sea ice concentration in Adélie Land</u>	<u>0.04</u>	<u>0.82</u>
<u>1950-2006</u>	<u>annual</u>	<u>wind speed</u>	<u>-0.27</u>	<u>6.6E-2</u>
<u>1979-2001</u>	<u>annual</u>	<u>wind speed</u>	<u>-0.47</u>	<u>2.9E-2</u>

Table 2. Linear relationship between the SIC1- $\delta^{18}\text{O}$ and regional climate records showing the coefficient correlation and the p-value.

Period	Resolution	Record	r	p
1997-2007	annual	SIC1-accumulation	0.85	4.0E-3
1956-2007	annual	READER-surface temperature	0.22	0.1
1956-2007	decadal	READER-surface temperature	0.72	2.0E-09
1979-2007	annual	READER-surface temperature	0.44	2.0E-2
	winter	READER-surface temperature	0.43	2.0E-2
	summer	READER-surface temperature	0.21	0.5
1979-2007	annual	sea-ice-concentration in Adélie Land	0.03	0.9
2000-2007	annual	sea-ice-concentration in Adélie Land	0.66	8.0E-2
1950-2007	annual	wind-speed	0.15	0.3
1979-2001	annual	wind-speed	0.43	4.0E-2

Table 4. Linear relationships between temperature and $\delta^{18}\text{O}$ showing the slope, the coefficient correlation and the p-value. The indices associated with "SIC1" indicate the chronology (1, initial; 2, revised).

Period	Resolution	Source of the temperature	Source of the $\delta^{18}\text{O}$	Slope	r	p
<u>1956-2006</u>	<u>annual</u>	<u>READER database</u>	<u>S1C1.1</u>	<u>-0.33</u>	<u>-0.13</u>	<u>0.35</u>
		<u>READER database</u>	<u>S1C1.2</u>	<u>0.36</u>	<u>0.15</u>	<u>0.30</u>
	<u>decadal</u>	<u>READER database</u>	<u>S1C1.1</u>	<u>1.49</u>	<u>0.72</u>	<u>2.6E-9</u>
		<u>READER database</u>	<u>S1C1.2</u>	<u>1.32</u>	<u>0.60</u>	<u>3.2E-6</u>
<u>1979-2006</u>	<u>annual</u>	<u>READER database</u>	<u>S1C1.1</u>	<u>-0.33</u>	<u>-0.15</u>	<u>0.44</u>
		<u>READER database</u>	<u>S1C1.2</u>	<u>0.77</u>	<u>0.31</u>	<u>1.10E-01</u>
	<u>decadal</u>	<u>READER database</u>	<u>S1C1.1</u>	<u>1.82</u>	<u>0.72</u>	<u>1.30E-05</u>
		<u>READER database</u>	<u>S1C1.2</u>	<u>1.38</u>	<u>0.51</u>	<u>5.7E-03</u>
	<u>annual</u>	<u>ECHAM</u>	<u>ECHAM</u>	<u>0.29</u>	<u>0.39</u>	<u>3.8E-2</u>
	<u>decadal</u>	<u>ECHAM</u>	<u>ECHAM</u>			
	<u>annual</u>	<u>READER database</u>	<u>ECHAM</u>	<u>0.42</u>	<u>0.48</u>	<u>1.0E-2</u>
	<u>annual</u>	<u>ECHAM</u>	<u>S1C1.1</u>	<u>-0.37</u>	<u>-0.17</u>	<u>0.40</u>
	<u>annual</u>	<u>ECHAM</u>	<u>S1C1.2</u>	<u>0.58</u>	<u>0.27</u>	<u>0.16</u>

Table 3. Linear relationships between temperature and $\delta^{18}\text{O}$ showing the slope, the coefficient correlation and the p-value. The indices associated with "SIC1" indicate the number of the dating.

Period	Resolution	Temperature	$\delta^{18}\text{O}$	Slope	r	p
1956-2007	annual	reader database	SIC1 ₁	0.36	0.22	0.1
		reader database	SIC1 ₂	0.40	0.24	8.8E-2
	decadal	reader database	SIC1 ₁	1.49	0.72	2.6E-9
		reader database	SIC1 ₂	1.33	0.68	5.0E-8
	annual	reader database	SIC1 ₁	1.14	0.44	2.0E-2
		reader database	SIC1 ₂	1.24	0.49	1.0E-2
1979-2007	decadal	reader database	SIC1 ₁	1.68	0.70	2.2E-5
		reader database	SIC1 ₂	1.31	0.60	5.3E-4
	annual	echam	echam	0.32	0.42	2.2E-2
	annual	reader database	echam	0.43	0.48	8.8E-3
	annual	echam	SIC1 ₁	0.87	0.40	3.3E-2
	annual	echam	SIC1 ₂	1.07	0.50	5.7E-3

Figures.

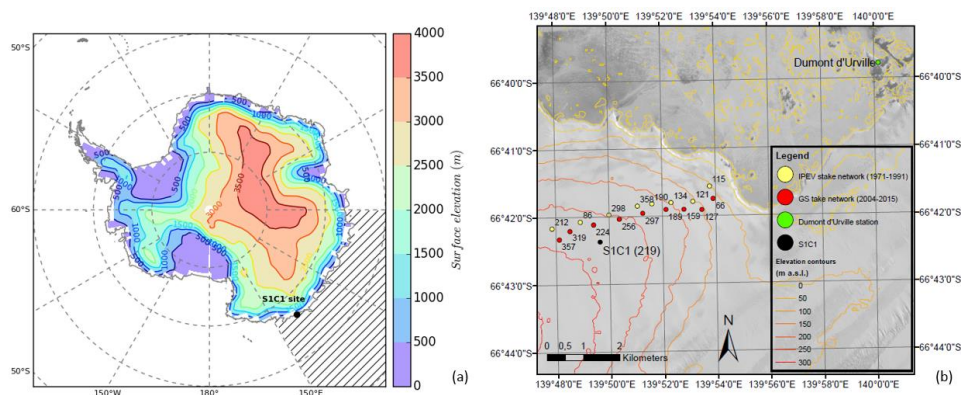


Figure 1: Maps showing the areas of interest with (a) a map of Antarctica representing the local topography (contours), the location of the SIC1 drilling site and the area used to extract regional sea-ice extent from the Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data, and (b) an orientation map showing stake networks around SIC1 drilling site. Data from 1971 to 1991 were measurement by IPEV, whereas data from 2004 to 2015 were measured in the framework of GLACIOCLIM-SAMBA (GS) observatory. Elevation lines are from the digital elevation model of Korona et al. (2009), which was computed from SPOT5 images obtained during the fourth International Polar Year (2007–2009). The SPOT5 image is also included as a background map. Labels are mean accumulation values at each stake computed over the period with measurements.

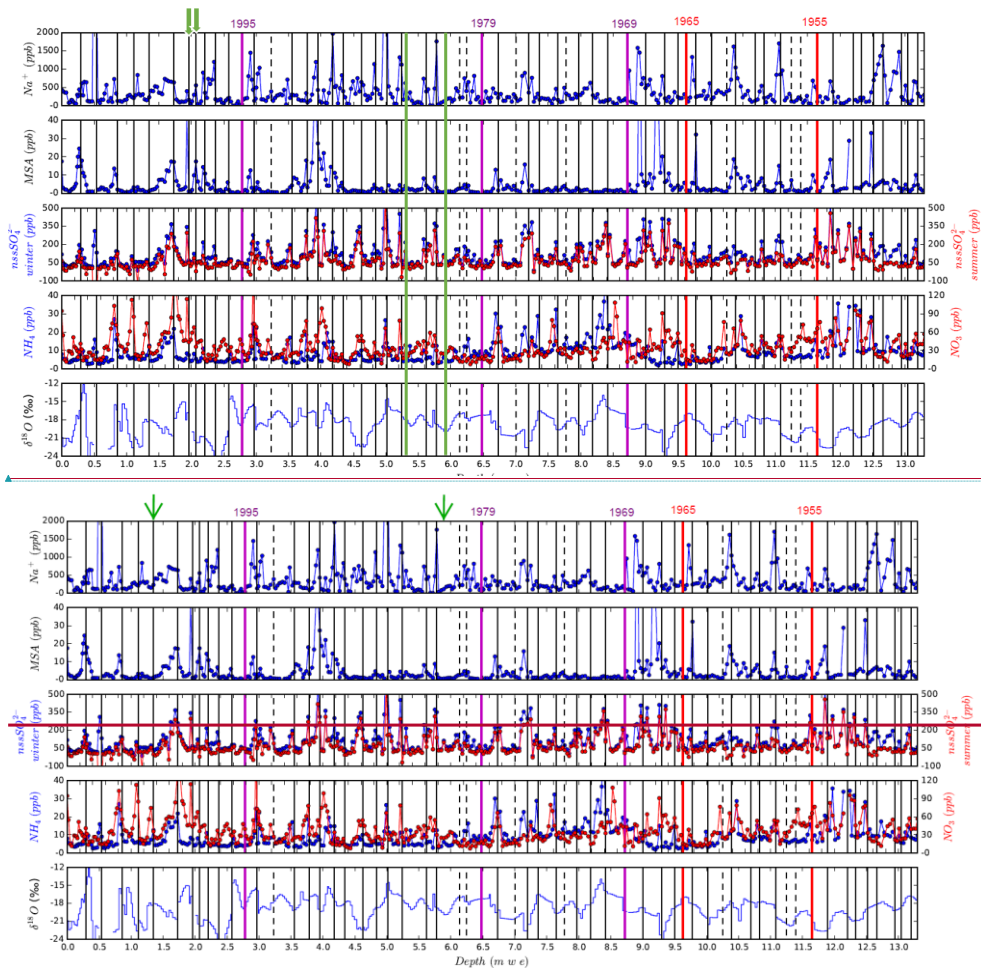


Figure 2: Dating of the S1C1 core based on sodium Na^+ , methanesulfonic acid (MSA) dimethylsulfure (DMS), non-sea-salt sulfate (nssSO_4^{2-}), ammonium NH_4^+ , nitrate (NO_3), and $\delta^{18}\text{O}$. The black lines correspond to the December-January period of each year (solid lines are the layers for which all sources of information are consistent, while dashed lines are the layers for which we have contrasted results from one or more sources of information), the purple lines to the non-full sea-ice retreat horizons and the red lines to the nuclear test horizons. $\delta^{18}\text{O}$ data are shown as horizontal steps because one measurement corresponds to a value

averaged over a 5 cm sample. Green arrows stress the years where changes have been implementing for the second dating (see text for details).

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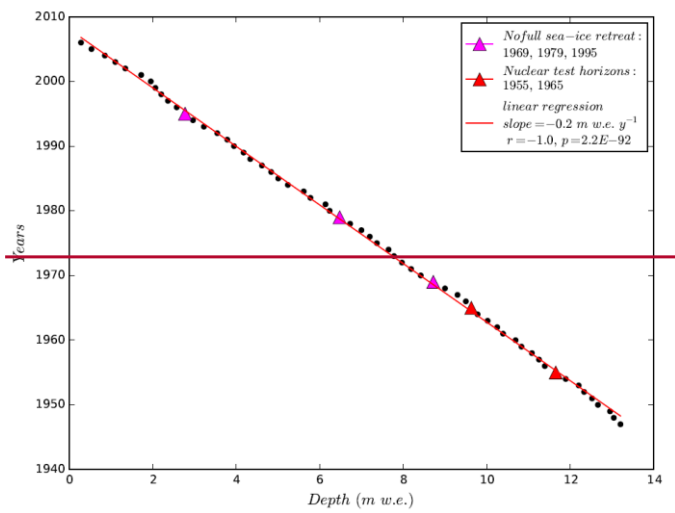
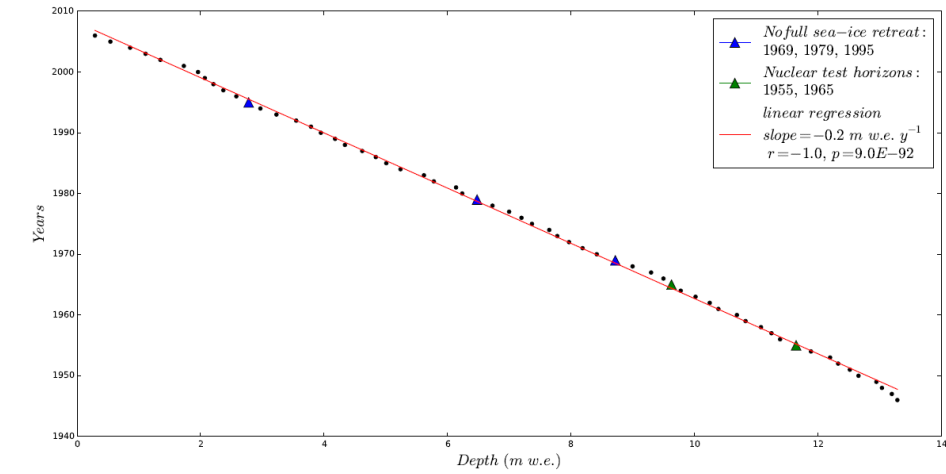
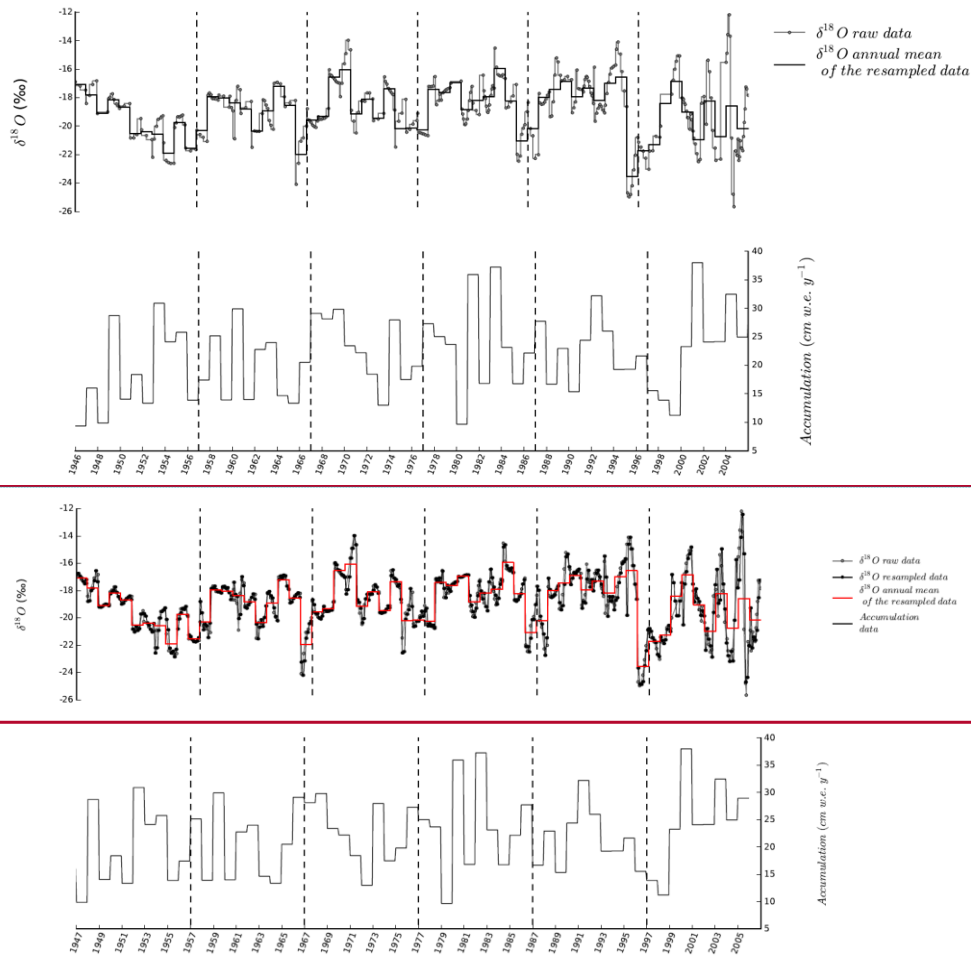
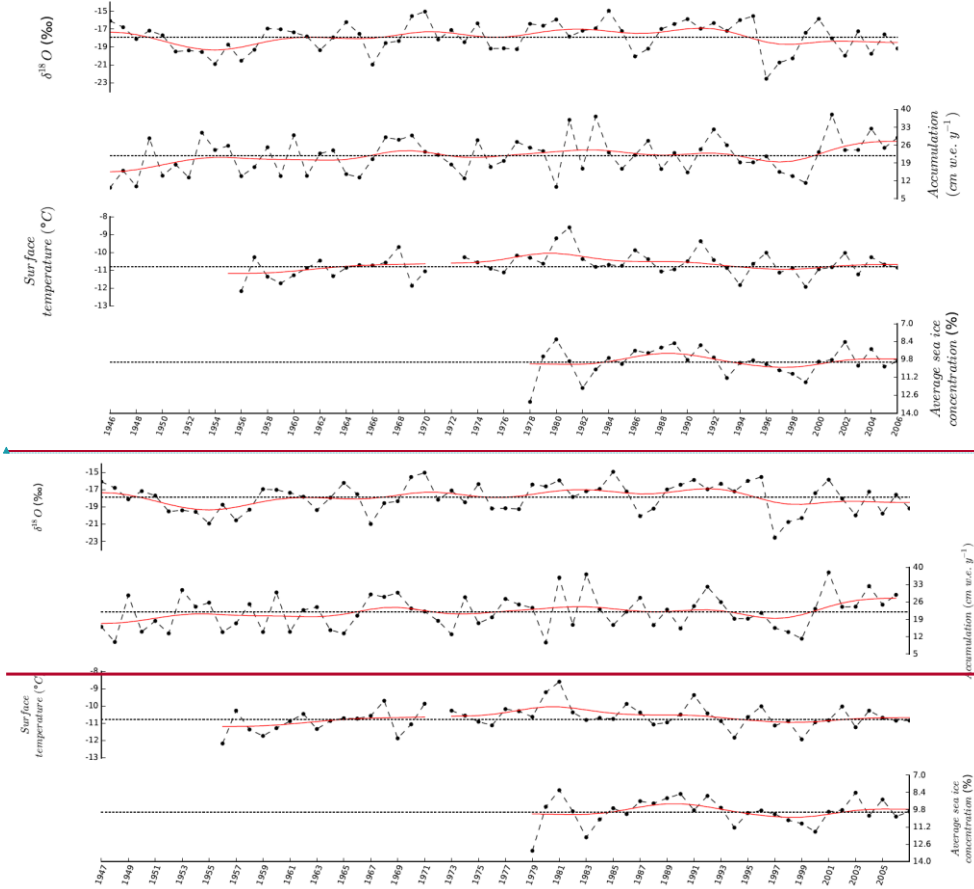


Figure 3: Depth-age relationship based on the dating of the SIC1 core.



5 Figure 4: Time series of $\delta^{18}\text{O}$ (in ‰) and accumulation (in cm w.e. y^{-1}) extracted from the S1C1 core. Dark green points correspond to the raw data, while pale green points correspond to the resampled data. Finally, the red and black lines correspond to the annual mean of the resampled data and the accumulation data respectively.



5 Figure 5: Comparison of the (resampled) $\delta^{18}\text{O}$ (‰) and the annual accumulation (cm w.e. y⁻¹) from the S1C1 core, with the near surface temperature (in °C) extracted from the READER data base for Dumont d'Urville Station (<https://legacy.bas.ac.uk/met/READER/>) and the Average sea ice concentration extracted between 90°E and 150°E from the Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data (<http://nsidc.org/data/nsidc-0051>). Note that the y-axis of the lowest panel is reversed, to ensure visual coherency between lower sea-ice extent and higher temperatures.

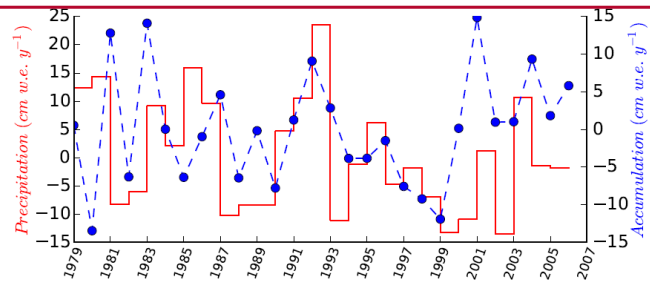
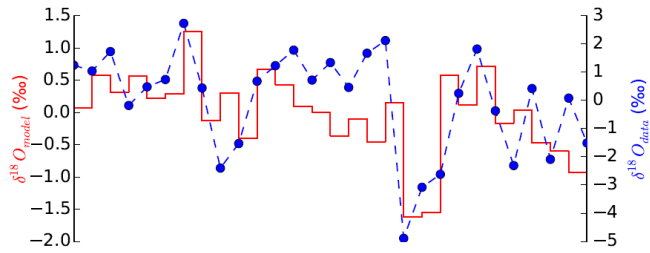
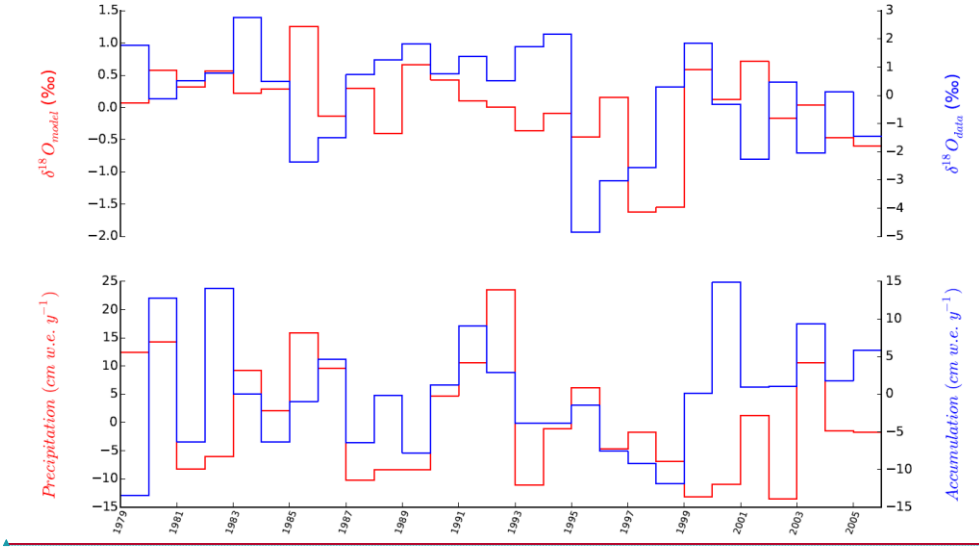
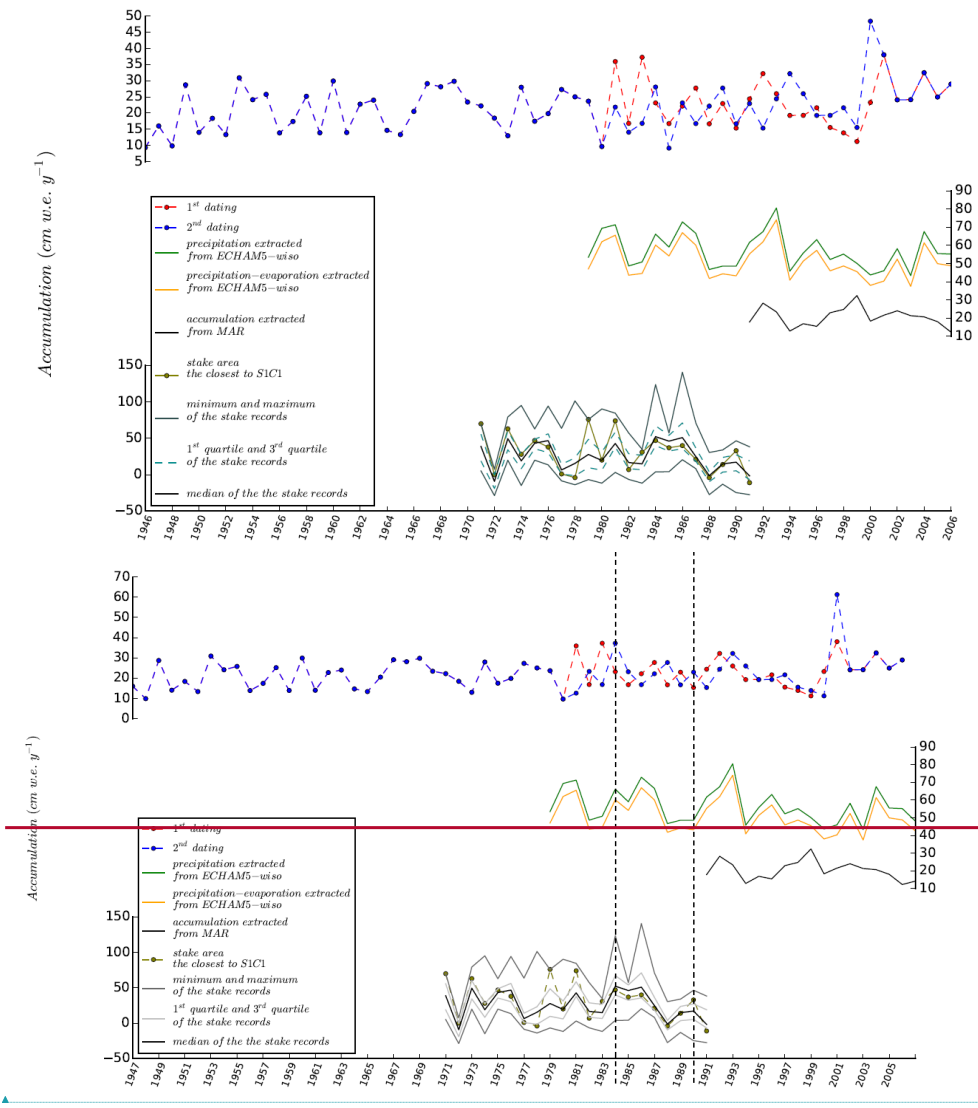


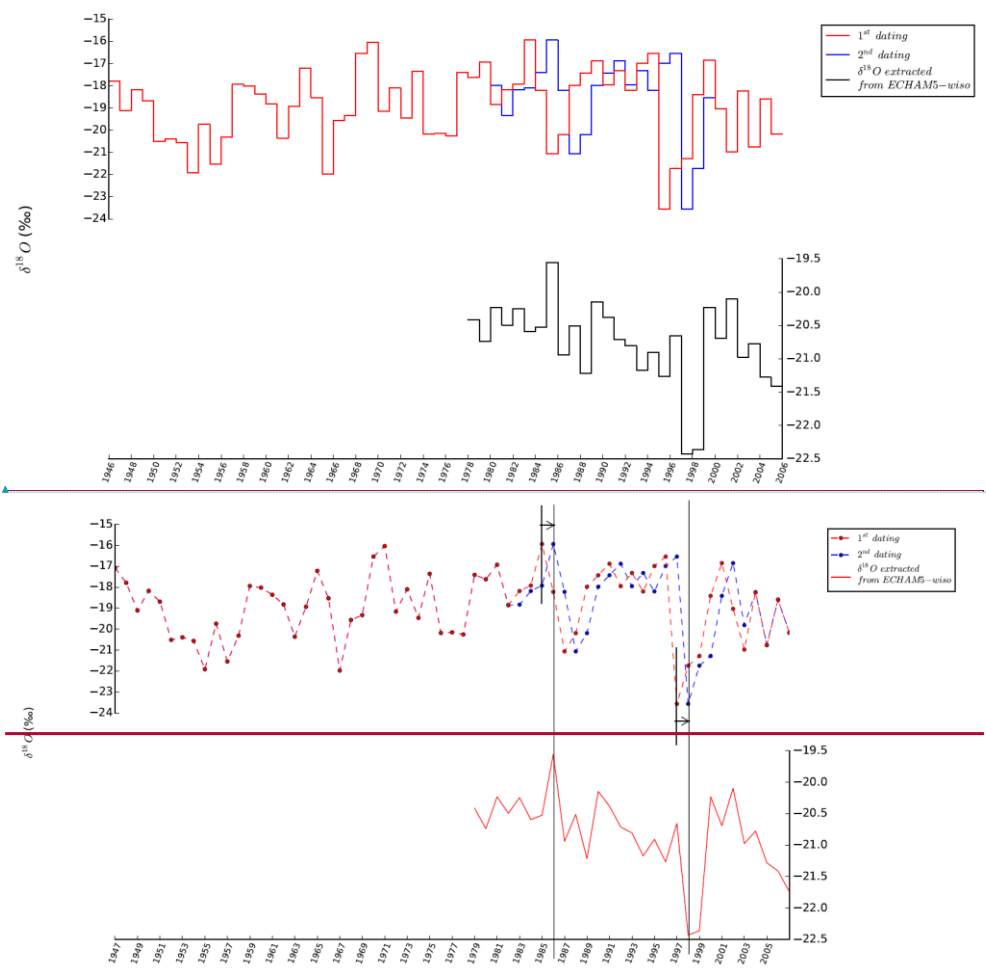
Figure 6: Model-data comparison of the anomalies (annual value minus the 1979-2007 average value) of $\delta^{18}\text{O}$ (‰) and accumulation (cm w.e. y^{-1}). The blue points and dashed lines correspond to the data from the SIC1 core while the red stair steps correspond to the simulations.

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5 Figure 7: Comparison of accumulation data. Top panel: SIC1 reconstruction obtained from the first (red) and second (blue) dating. Note that the accumulation resulting from first dating and second dating overlap over 1947-1980 and 2002-2007 so only one colour line appears. Middle panel: precipitation (green) and precipitation minus evaporation (orange) simulated by ECHAM5-wiso (1979-2007), and accumulation simulated by MAR (1991-2007) (black). Lower panel: distribution of accumulation measurements from stake records, illustrated by minima and maxima (grey lines), first and third quartiles (light grey dashed green lines), median value of stake measurements (black line) and measurements from one single stake, closest to the SIC1 site (solid greendashed grey line). Two dashed vertical lines correspond to years 1984 and 1990.

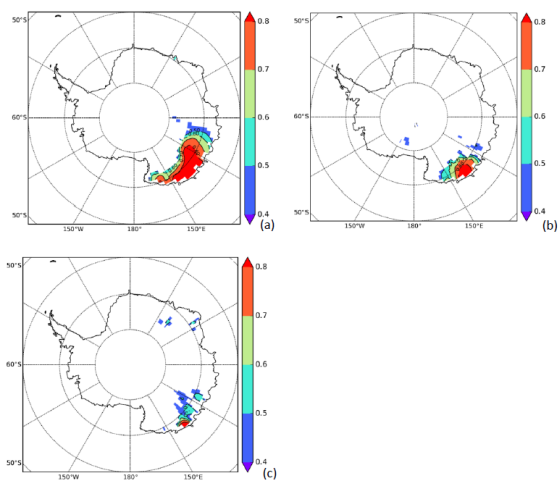


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Figure 8: Comparison of dO18 data. Top panel: annual mean dO18 data from the SIC1 core on the first (red) and second (blue) dating, over 1947-2007. Note that the SIC1 dO18 resulting from first dating and second dating overlap in 1947-1980 and 2002-2007, when only one colour line is displayed. Bottom: annual mean (precipitation-weighted) precipitation dO18 simulated by the ECHAM5-wiso-model. Small vertical black lines and arrows illustrate the shift between the two SIC1 age scales for the years with

the highest and lowest dO18 values of our record. Long vertical lines illustrate the match between the ECHAM5-wiso and SIC1 peaks used to build the second chronology.



5 **Figure 9: Correlation between simulated annual mean 2m-temperature (a), annual precipitation amount (b), precipitation annual mean $\delta^{18}\text{O}$ (c) at the SIC1 site with the same variable at each grid point of the ECHAM5-wiso model for $r>0.4$ and $p<0.03$. Only significant values are represented ($p<0.05$).**