

Review to: “Atmospheric ^{10}Be from Talos Dome (East Antarctic) ice core records geomagnetic dipole intensity from 170 to 270 ka BP”

Comments from reviewer are in black / answers to the comments are in blue / suggested modified sections are in orange, with the specific modifications in **bold**

Review 1:

The manuscript presents a new ice core record from Talos Dome, Antarctica, covering the period from 170 to 270 ka BP. This ^{10}Be record is highly significant and provides valuable insights into geomagnetic field variations, including one well-defined global excursion and several others of moderate intensity. The study is thorough, containing extensive information on ^{10}Be measurements, as well as climate proxies and ion concentrations, which are used to assess postdepositional effects and accurately estimate the ^{10}Be flux. The resulting signal is consistent with data from the Dome Fuji ice core, sediment archives, and global production reconstructions based on the VADM stack.

We thank the reviewer for their comments, the time dedicated to review, and the very valuable feedbacks they suggested.

It is important to clarify the reference background to which the results are reported. Discuss the possible options in a single section, and rather than reporting multiple values for one event, decide on one reference value. For example, the background, 1.36, 1.44 or 1.56×10^5 at $\text{cm}^{-2} \text{a}^{-1}$, is over which period, mean, or estimated over the running mean, before or after excluding the identified ^{10}Be minima? (Lines 280 to 293, 349 to 350)

Answer

We acknowledge that our discussion on the background Lines 280 to 293 is not clear enough. We want to clarify that the values reported lines 349 and 350 refer to the mean values, including the flux during the geomagnetic excursions. A clear definition of the background Lines 280 to 293 would have prevented this lack of clarity. Following the suggestion made by the reviewer, we add a section in the Result section dedicated to defining the background value “4.3. ^{10}Be background flux”, in addition to subsections “4.1 ^{10}Be concentration and flux” and “4.2. ^{10}Be minima”. Lines 280-293 we presented to options to define the background, using either a fixed baseline or the mean value on the minimum-removed profile. Although it would have been beneficial to define a clear background value, neither our profile nor our understanding of the polar bias allows to do so. We therefore prefer to highlight this limitation, further work being necessary to refine this question. We also clarify this point in the new 4.3 section.

Revision:

L243: “**4.1. ^{10}Be concentration and flux**”

L263: “**4.2. ^{10}Be minima**”

L280: “**4.3. ^{10}Be background flux**”

After removing the 52 identified ^{10}Be minima, rolling averages can be calculated to smooth the record and obtain the first-order variations, which are likely to result. Test 1 ka, 3ka and 5 ka rolling averages

(Figure S1) illustrate the trade-off between noise reduction and signal preservation. Given the mean resolution of our record (300 a) we selected a 3 ka rolling average as a practical compromise. This choice provides stable background trends while preserving the amplitude of GDM-related variations. The resulting 3-ka averaged ^{10}Be flux record can be compared to geomagnetic reconstructions, including the Dome Fuji ice core data (Figure 4, Horiuchi et al., 2016), authigenic $^{10}\text{Be}/^9\text{Be}$ records from marine sediment cores (Figure 5, Simon et al., 2016) and ^{10}Be production (Figure 5, Poluianov et al., 2016) calculated from RPI-based VADM (Channell et al., 2009). Flux enhancement during geomagnetic excursions or events depends strongly on the choice of background taken as reference. **When discussing paleomagnetism, the background should be defined as the ^{10}Be profile without minima.** Here, we consider either the full 170–270 ka BP interval ^{10}Be flux mean average ($(1.36 \pm 0.26) \times 10^5$ at $\text{cm}^{-2} \text{a}^{-1}$) or a fixed baseline of 1.1×10^5 at $\text{cm}^{-2} \text{a}^{-1}$ as **background**. The latter could be considered as representative of the long-term background ^{10}Be flux, which is close to the minimum values the 3 ka rolling average around 178 ka BP and 223 ka BP. Depending on the chosen baseline, the flux enhancement factors during specific events are as follows: for the 190 ka BP event (IBE), the ^{10}Be flux is 1.59 or 2.08 times the background; for the 205–215 ka BP event (PFE), the increase is 1.24 or 1.62 on average; and for the 240 ka BP event (ME), the peak flux reaches 1.25 or 1.63 times the reference value. **It is evident that defining a clear background value would have been preferable; however, this was not possible due to the limitations inherent in our profile and our understanding of the polar bias. We therefore advocate the necessity of having this dual scenario, mean or fixed values, with further work being necessary to refine this question.**

L 349: “For the period 170–270 ka BP, the mean 3 ka rolling ^{10}Be flux in TALDICE, **including the background and the geomagnetic events**, is 1.44×10^5 at $\text{cm}^{-2} \text{a}^{-1}$, which slightly increases to 1.56×10^5 at $\text{cm}^{-2} \text{a}^{-1}$ when the identified ^{10}Be minima are excluded.”

Line 80: Several geomagnetic excursions are reported (Figure 1), but the caption reads three. It would be beneficial to provide a table, either in the main text or in the Supplementary Material, listing the records plotted, including their references. Additional columns could indicate which excursion is recorded and, potentially, the corresponding age. I assume the authors already have this information, as the studies are discussed in Section 2.

Answer:

We thank the reviewer for this suggestion. A Table has been added in supplementary.

Revision:

L121: “Figure 1: map of sites recording at least one of the geomagnetic excursions discussed in this paper: the **IBE and PFE** excursions (triangles), IBE alone (stars), or PFE alone (circle). **The references are listed in Table S1.**”

Table S1: list of studies reporting at the IBE, PFE, and IBE and PFE excursions

Excursions recorded	Latitude	Longitude	Type of archive	Archive name	Source
IBE	43.48	-112.53	Volcano	site E at the Idaho National Engineering Laboratory INEL	Champion et al., 1988
PFE	43.78	-121.53	Sediment	Pringle falls	Herrero-Bervera et al.1989; 1994
IBE PFE	-1.64	159.22	Sediment	Ontong Java plateau ERDC 113p	Taux & Wu, 1990
IBE PFE	0	155.87	Sediment	Ontong Java plateau ERDC 89p	Taux & Wu, 1990
IBE	-3.09	-110.53	Sediment	ODP Sites 848	Valet & Meynadier, 1993
IBE	2.99	-110.5	Sediment	ODP Sites 851	Valet & Meynadier, 1993

IBE	1.01	136.96	Sediment	West Caroline Basin, western equatorial Pacific NP5	Yamazaki & Ioka, 1994
IBE	2	135	Sediment	West Caroline Basin, western equatorial Pacific NGC16	Yamazaki & Ioka, 1994
IBE	4.13	136.27	Sediment	West Caroline Basin, western equatorial Pacific NGC29	Yamazaki & Ioka, 1994
IBE	2	138.01	Sediment	West Caroline Basin, western equatorial Pacific NP7	Yamazaki & Ioka, 1994
IBE	3.8	141.48	Sediment	NP35	Yamazaki et al., 1995
IBE	1.22	160.57	Sediment	NGC36	Yamazaki et al., 1995
IBE	-14.99	175.17	Sediment	NGC38	Yamazaki et al., 1995
IBE	43.52	-30.4	Sediment	SU9008	Weeks et al., 1995
IBE	7.78	77.5	Sediment	KET82-51	Guyodo & Valet 1996
IBE	4.73	103.58	Sediment	DED87-07	Guyodo & Valet 1996
IBE	-2.55	91.33	Sediment	MD84-629	Guyodo & Valet 1996
IBE	-1.42	90.32	Sediment	MD85-668	Guyodo & Valet, 1996
IBE	-1.52	90.7	Sediment	MD85-669	Guyodo & Valet, 1996
IBE	-8.38	112.57	Sediment	MD85-674	Guyodo & Valet, 1996
IBE	9.9	121.53	Sediment	ODP 768A	Guyodo & Valet, 1996
IBE	10.75	121.57	Sediment	ODP 769B	Guyodo & Valet, 1996
IBE	39.37	-26.61	Sediment	SU-92-17	Lehman et al., 1996
IBE	37.79	-27.23	Sediment	SU-92-18	Lehman et al., 1996
IBE	37.3	-27.09	Sediment	SU-92-19	Lehman et al., 1996
IBE	44.68	168.23	Sediment	ODP Site 884	Roberts et al., 1997
IBE PFE	60.4	-23.6	Sediment	ODP Site 983	Channell et al., 1997; Knudsen et al., 2008; Christl et al., 2010
IBE	32.97	-76.28	Sediment	ODP Site 1061	ODP Leg 172 Scientific Party 1998
IBE PFE	32.98	-76.23	Sediment	ODP Site 1062	ODP Leg 172 Scientific Party 1998
IBE PFE	33.68	-57.62	Sediment	ODP Site 1063	ODP Leg 172 Scientific Party 1998; Knudsen et al., 2008; Christl et al., 2010; Channell et al., 2012
IBE	58.21	-48.37	Sediment	HU90-013-013P	Stoner et al., 1998
IBE	61.07	-24.02	Sediment	ODP Site 984	Channell et al., 1999
IBE	-19.7	246.5	Seafloor	East Pacific Rise (EPR)	Gee et al., 2000
IBE	-19.4	246.5	Seafloor	East Pacific Rise (EPR)	Gee et al., 2000
IBE PFE	53.6	108.3	Sediment	Lake Baikal	Oda et al., 2002; Demory et al., 2004
IBE	55.5	-14.7	Sediment	ODP Site 980	Channell & Raymo, 2003
IBE PFE	-40.9	9.9	Sediment	ODP Site 1089	Stoner et al., 2003
IBE PFE	37.8	-10.6	Sediment	MD95-2042	Thouveny et al., 2004; Carcaillet et al., 2004
IBE PFE	40.58	-9.87	Sediment	MD95-2040	Thouveny et al., 2004; Carcaillet et al., 2004
IBE PFE	62.67	-37.46	Sediment	ODP Site 919	Channell et al., 2006
IBE	58.93	-47.12	Sediment	MD99-2242	Laj et al., 2006
IBE	59.08	-31.47	Sediment	MD99-2247	Laj et al., 2006
IBE	19.58	117.63	Sediment	ODP Site 1145	Laj et al., 2006
IBE	16.45	116.27	Sediment	ODP Site 1146	Laj et al., 2006
IBE PFE	57.19	-47.13	Sediment	JPC-18	Evans et al., 2007
IBE PFE	47.6	-57.58	Sediment	JPC-19	Evans et al., 2007
IBE	32.77	130.28	Volcano	Unzen Volcano	Shibuya et al., 2007
IBE PFE	35.6	-106.75	Volcano	Albuquerque Volcanoes, NM	Singer et al., 2008
IBE	-50.2	-45.7	Sediment	IODP Site U1302/03	Channell et al., 2014
IBE	58.24	-45.64	Sediment	IODP Site U1306	Channell et al., 2014
IBE PFE	-10.53	147.22	Sediment	MD05-2930	Simon et al., 2016
IBE PFE	-2.51	144.32	Sediment	MD05-2920	Simon et al., 2016
IBE	-77.5	39.4	Ice core	Dome F	Horiuchi et al., 2016
IBE	2.77	-110.57	Sediment	ODP Site 851	Valet et al., 2020
IBE	39.08	-127.78	Sediment	ODP 1021	Valet et al., 2024

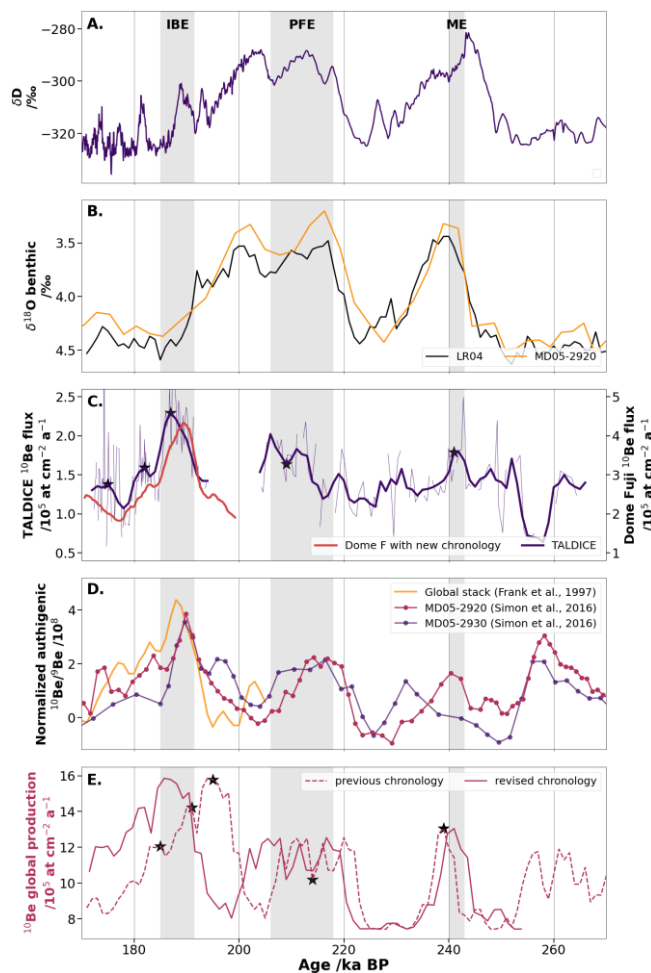
From a point a view of the geomagnetic field, the authors discussed variations derived from the PISO-1500 RPI stack. A global model of IBE exists, though outdated, and built with limited, hemispherically-constrained sediment records (Lanci et al. 2008, doi: 10.1016/j.pepi.2008.06.004), the dynamics of IBE can be compared with the TALDICE record. As well as with the global stacks of Frank et al., 1997 ([https://doi.org/10.1016/S0012-821X\(97\)00070-8](https://doi.org/10.1016/S0012-821X(97)00070-8))

Answer:

We thank the reviewer for completing our discussion with these records. We have added the global ^{10}Be stack to our Figure 5 (Frank et al., 1997), as the data are available. We also now discuss the comparison with this global record as well as the model from Lanci et al. (2008).

Revision:

Modified figure 5:



L510: “During IBE, the TALDICE ^{10}Be flux record closely follows variations in oceanic authigenic $^{10}\text{Be}/^9\text{Be}$ from a global compilation (Frank et al., 1997) (Figure 5). In particular, the timing, duration, and stepped structure of the collapse and subsequent recovery of the GDM are consistent between the ice cores and marine records (Figure 5). For instance, the ≈ 7 ka plateau of elevated ^{10}Be flux observed in TALDICE has also been observed in Dome F ice core (Horiuchi et al., 2016) and is in agreement with oceanic records (Knudsen et al., 2008). Besides, the good overall agreement

between the TALDICE and Dome F records with global geomagnetic field model of the IBE (Lanci et al., 2008) further supports the global record of Antarctic ice cores.

Because of this broad **global** agreement, a comparison of ^{10}Be production calculated from RPI-based VADM and authigenic $^{10}\text{Be}/^9\text{Be}$ with ice core ^{10}Be fluxes is possible.”

General comment on using brackets when reporting ages and standard deviation on the age? Why? If it is the journal rule ok, otherwise the text will be cleaner without, and removing them improves readability in my opinion (throughout the whole text). The same comment applies to the values of the $^{10}\text{Be}/^9\text{Be}$ ratio, ^{10}Be half-life (e.g., line 187), and all other numbers in brackets.

Answer:

We thank the reviewer for this comment. However, we prefer to follow the IUPAC writing (https://old.iupac.org/publications/books/gbook/green_book_2ed.pdf, page 83) when reporting values as: *(value ± std) unit*.

Revision:

No modification

Minor comments and questions:

Line 30: Add a reference for the first sentence. E.g., Bono et al., 2022 (doi: 10.1029/2022GL100898)

We modified accordingly

Line 34: the geodynamo

We modified accordingly

Line 38: I wouldn't say 'occasionally conflicting', rather 'with high uncertainties'

We modified accordingly

Line 46: Add 'e.g.', in front of references, as these are examples.

We modified accordingly

Line 47: decreases in plural and (recovery) in the brackets in singular. I understood what the sentence says, but it can be clearer.

We clarified this sentence.

Revision:

L47: “In both excursions and full reversals, the dipole moment decreases prior to the VGP migration, while the recovery of field intensity occurs after the return to a stable polarity state, either in the original or in the reversed polarity”

Line 48: (ref)?

Sorry for the mistake. We should have added the reference.

Revision:

L47: “In both excursions and full reversals, **the dipole moment decreases prior to the VGP migration, while the recovery of field intensity occurs after the return to a stable polarity state, either in the original or in the reversed polarity (Valet et al., 2005; Laj et al., 2006).**”

Line 49: another word for migration?

We prefer to remain consistent and use VGP migration

Line 51: We don't know if the IBE is probably the strongest. By which criteria? It is probably among the strongest.

We thank the reviewer for raising this lack of precision. We now clarify this referring to geomagnetic intensity reconstruction.

Revision:

L51: “The Iceland Basin Excursion (IBE, naming and dating of the event is discussed in section 2.1), dated to approximately 190 ka BP, is probably the strongest excursion during the Bruhnes chron (< 780 ka BP) **based on GDM intensity reconstruction (Simon et al., 2016)**”

Line 53: reduction in % with respect to what? Present-day values?

We thank the reviewer for raising this lack of precision. We now clarify this referring to the background value.

Revision:

L53: “**Dipole intensity reduction has been estimated between 70 % (Yamamoto et al., 2010) and 80 % (Simon et al., 2020) relative to the pre-event background dipole moment.**”

Line 59: Better make two sentences. It is produced in the atmosphere ... ^{10}Be mainly results ...

We have now separated the two blocks.

Revision:

L59: “**Atmospheric ^{10}Be mainly results from spallation reactions between galactic cosmic rays and atmospheric oxygen and nitrogen atoms (Poluianov et al., 2016). Between 60 and 66 % of its atmospheric production occurs in the stratosphere (Golubenko et al., 2022; Poluianov et al., 2016; Zheng et al., 2024)**”

Line 59: too many brackets: .. in the stratosphere, from 60% to 66% (refs)

We corrected this as mentioned in the preceding answer.

Line 64: remove the comma before that

We modified accordingly

Line 65: studies = records

We modified accordingly

Line 73: avoid double brackets, e.g., ... events such as the Laschamps, ~41 ka BP (ref) and

We modified accordingly

Line 74: The Pringle Falls also named Mamaku or Jamaica? As written so far, Pringle Falls and Mamaku are two separate events?

We thank the reviewer for raising this inconsistency. We agree with the reviewer on this point, although it is also true that this inconsistency is present in the literature. We now refer to the section 2, that discusses the names of these excursions.

Revision:

L74: “respectively the IBE and the **two** Pringle Falls **excursions** also named Mamaku or Jamaica (**see section 2 for a literature review on the naming of the events**),”

Line 77: add reference for the sedimentary, as it is given for the other record used for comparison from Dome Fuji.

We added the references.

Revision:

L77: “(Horiuchi et al., 2016; Simon et al., 2016; Frank et al., 1997)”

Line 111: Stoner et al., 1998 is not in the References

We thank you for this attention.

Line 113: remove ‘on’

We modified accordingly

Line 125: an RPI

We modified accordingly

Line 338: PISO-1500

We modified accordingly

Line 141/142: Reference only once, as it is the same.

We modified accordingly

Line 155: Section name: 'Material, methods and chronology', as the chronology is a Subsection in this Section

We modified accordingly

Line 165/175: Only suggestion: Can these long links be removed from the main text and added in the Acknowledgment section, where the institutes and facilities are listed anyway again?

We modified accordingly

Line 167/168: repetition with Line 178 about the cutting/melting.

We thank the reviewer for raising this point. We removed the second mention

Line 173: ... developed by Raisbeck et al., 2006 and Baroni et al., 2011. Cite without the brackets, and avoid repetition.

We modified accordingly

Line 177: remove 'the' in front of the number of samples. The number is introduced for the first time here.

We modified accordingly

Line 177: Why is the standard deviation reported like this? If it is important to report that this is one standard deviation, then: $121 \pm 10 \text{ g}$ (1σ).

We modified accordingly

Line 184: in a crucible

We modified accordingly

Line 187: The ratio is unitless, right? On this line, and the rest of the text

Indeed, the ratio is unitless, which is why we wrote at at^{-1}

Line 198: then shared for analysis ..., Please clarify whether 'shared' means that different measurements were performed in different laboratories, or that the same measurements were carried out on the same samples for inter-laboratory comparison.

We thank the reviewer for pointing out this ambiguity. The text has been revised to clarify that the samples were distributed among the laboratories to accelerate the analytical work. Each laboratory analyzed a distinct subset of samples, and no inter-laboratory comparison was performed.

Revision:

L198: "The discrete samples were then **distributed** for analysis among four different **laboratories for analysis**: University of Florence (Italy), BAS (Cambridge, United-Kingdom), IGE (ex-LGGE, Grenoble, France), and AWI (Bremerhaven, Germany). **No inter-laboratory comparison was performed, and each laboratory analyzed a distinct subset of samples.**"

Line 200: What is MSA?

We thank the reviewer for raising this point. We now clarify that MSA is methane sulfonic acid

Line 209: The AICC2023 chronology (Bouchet et al., 2023) was used to date

We modified accordingly

Line 210: Make a new sentence 'The mean snow accumulation is 5.5 cm a⁻¹', and move it to Line 212 after the range of accumulation rates is listed, and before the sentence starting with 'On average, ...'

We modified accordingly

Revision:

L210: "The AICC2023 chronology (Bouchet et al., 2023) was used to date the ice, spanning from (172.3 ± 1.9) ka BP to (275.7 ± 1.8) ka BP. Our record covers several transitions from glacial to interglacial periods, from Marine Isotope Stage (MIS) 6.4 to 8.4 (Railsback et al., 2015). **Therefore, the annual snow accumulation rate, provided by the AICC2023 chronology, ranges between (4.3 ± 0.8) cm a⁻¹ and (8.1 ± 1.5) cm a⁻¹ with a mean value of 5.5 cm a⁻¹.** On average, the ≈20 cm resolution corresponds to ≈300 years (min = 60 a; max = 1,375 a)."

Line 233: Maybe not refer to Figure 5 here because the figure comes much later.

We corrected this mistake and changed it to Figure 1.

Line 240: moving is more commonly used than rolling

We agree that the term 'moving average' is more commonly used. In our case, however, the averaging window is defined in time (3 ka) rather than by a fixed number of data points, due to irregular sampling. This results in a variable number of samples within each window, for which the term 'rolling average' is more appropriate.

Line 234: Why 0.2 in Eq. 1?

We thank the reviewer for pointing this lack of precision. The coefficient 0.2 in Equation 1 corresponds to the ±20 % relative uncertainty on snow accumulation rates associated with the AICC2023 chronology. We have clarified this explicitly in the text to avoid any ambiguity.

Revision:

L234: "Rather than applying the full absolute uncertainty of the accumulation rate, **we use the 20 % accumulation rate uncertainty from AICC2023 as a relative uncertainty (0.2) applied to deviations from the mean accumulation rate**"

Line 235: The paragraph starting here should be moved later when the comparison is discussed

We understand the reviewer's suggestion to move this paragraph closer to the comparison section. However, this paragraph does not present a comparison itself, but describes a methodological update applied to the Dome Fuji ¹⁰Be record prior to any comparison. Specifically, we recalculated the ¹⁰Be flux using the updated DF2021 chronology and associated accumulation rates. We therefore consider

it more appropriate to keep this description in the Methods section, as it documents how the external dataset was processed before comparison with the TALDICE record. Nevertheless, to improve clarity, we have slightly rephrased the paragraph to emphasize that it describes a methodological update of the Dome Fuji record rather than the comparison itself.

Revision:

L235: “Prior to comparison with the TALDICE record, the Dome Fuji ^{10}Be fluxes (Horiuchi et al., 2016) were recalculated using the more recent accumulation rate.”

Line 240: the sentence to be clearer, e.g., ‘3 ka rolling average of the standard deviation’. Suggestion: These ^{10}Be minima were identified when the concentration fell below the mean minus one standard deviation, both calculated using a 3 ka moving window. (If this correctly explains how the minima were identified)

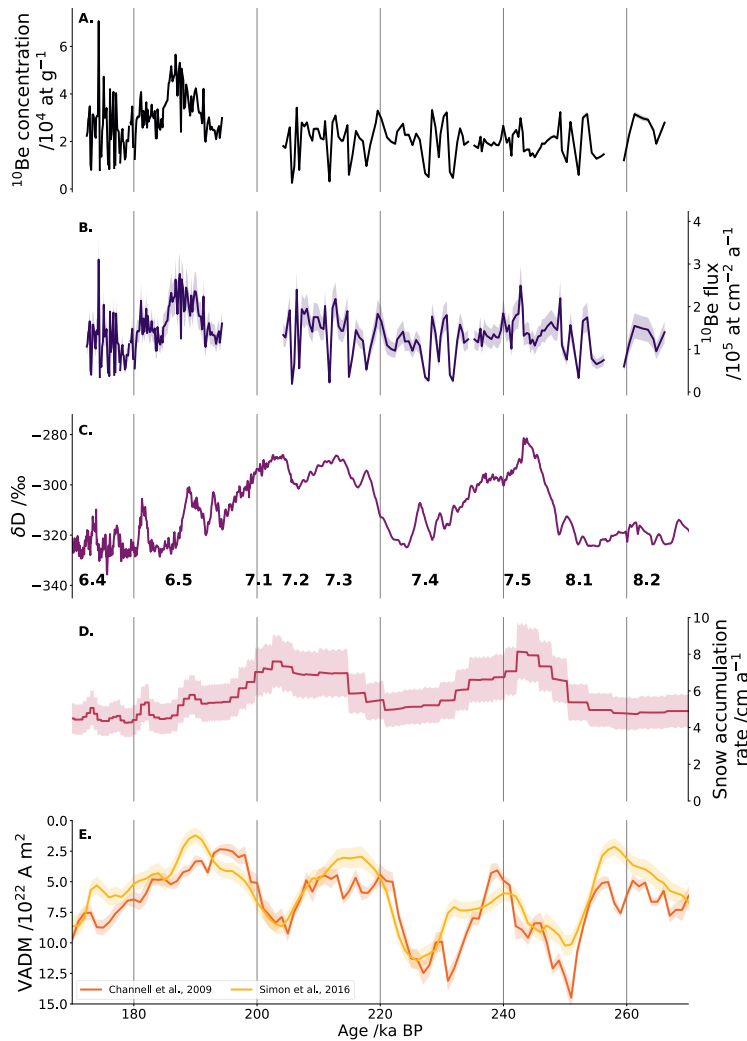
We thank the reviewer for this rephrasing and modified accordingly.

Line 280: rolling again? If you decide to change it in the first place, change it accordingly

No modification to be consistent

Line 245: Add the MIS periods mentioned here on top of Fig. 2?

We thank the reviewer for this suggestion and we modified accordingly



Line 246: Refer to Fig. 2D

We thank the reviewer for this suggestion and we modified accordingly

Line 281: Testing 1 ka, 3 ka ...

We modified accordingly

Line 284: To avoid figure reference and citation together. Suggestion: 'The resulting 3-ka averaged ^{10}Be flux record can be compared to geomagnetic reconstructions, including the Dome Fuji ice core data (Horiuchi et al., 2016) in Figure 4, and authigenic $^{10}\text{Be}/^9\text{Be}$ records from marine sediment cores (Simon et al., 2016), and the ^{10}Be production (Poluianov et al., 2016) calculated from RPI-based VADM (Channell et al., 2009) in Figure 5.

We modified accordingly

Line 288: too many brackets

We modified accordingly

Revision:

L288: “Here, we consider either the full 170–270 ka BP interval ^{10}Be flux mean average of $(1.36 \pm 0.26) \times 10^5$ at $\text{cm}^{-2} \text{a}^{-1}$ or a fixed baseline of 1.1×10^5 at $\text{cm}^{-2} \text{a}^{-1}$ as reference values.”

Line 289: After the discussion on the baseline, decide on one and report the enhancement factors with respect to the selected one. Maybe also add the enhancement with respect to the present-day values?

As said in one previous answer we conserve the discussion with the two scenario. We add, as a general idea, the contemporary flow value.

Revision:

L289: “Depending on the chosen baseline, the flux enhancement factors during specific events are as follows: for the 190 ka BP event (IBE), the ^{10}Be flux is 1.59 or 2.08 times the background; for the 205–215 ka BP event (PFE), the increase is 1.24 or 1.62 on average; and for the 240 ka BP event (ME), the peak flux reaches 1.25 or 1.63 times the reference value. **As a general idea, the flux enhancement factor for IBE represents 1.5 times the modern value of c. 1.64×10^5 at $\text{cm}^{-2} \text{a}^{-1}$ at Dome C (Jouzel et al., 2026).**”

Line 340: running median.

To be consistent with the naming rolling mean average, we prefer to use the rolling median naming.

Line 340: ‘similar to’ not ‘similar than’. rolling mean average? Suggestion: ‘During glacial periods, the median method results in ^{10}Be fluxes similar to those obtained using a running mean (Figure S2).’

We thank you for raising this mistake.

“Rolling mean average” allows to clarify between the different types of averages. To be consistent, we have now modified all mentions of “rolling mean” to “rolling mean average”.

Line 341: I thought the running median and mean are both calculated on the minima identification results, or not? The sentence is confusing

We thank the reviewer for raising this lack of clarity. The median is calculated based on the total ^{10}Be signal, including ^{10}Be minima. Raisbeck et al., (2006) suggested that the median should be used to consider the effect of extrema. In Figure S2, both the mean, including minima, and the no-minima mean are presented.

Considering the minima for calculating the mean slightly increase the ^{10}Be flux. The difference between the median and the no-minima mean is lower than the difference between the mean and the no-minima mean. Nevertheless, the median value is still 6 % lower than the no-minima mean value. Therefore, we argue that the no-minima is a more robust method for investigating the VADM. We modified the sentences to better explain this point.

Revision:

L341: “However, the median method results in similar ^{10}Be fluxes to those based on a rolling mean average (Figure S2). On average, the method based on minima identification results in +10 % ^{10}Be flux compared to the median method (Figure S2).”

Line 353: ... age models, AICC2023 for TALDICE (Bouchet et al., 2023) and the Dome Fuji DFO-2006 chronology (Kawamura et al., 2007).

We modified accordingly

Line 359: over which period?

We thank the reviewer for raising this lack of clarity.

Revision:

L341: “While the mean ^{10}Be flux in TALDICE is 1.56×10^5 at $\text{cm}^{-2} \text{a}^{-1}$ **over 170–190 ka BP** (accounting for the minima)”

Line 363: ... over the last millennium, between 1000 and 1885 CE, where the ...; and only 'CE' not 'a CE'

We modified accordingly

Line 366: remove brackets around Supplementary material, separate with a comma.

We modified accordingly

Line 367: remove brackets of the citation, separate with a comma.

We modified accordingly

Line 368: list the solar minima intervals

We thank the reviewer for this suggestion, which we integrated in the paper.

Revision:

L368: “with the occurrence of solar minima during this interval (**Wolf, 1280 – 1350 CE; Spörer, 1420 – 1570 CE; Maunder 1645 – 1715 CE; Dalton 1790 – 1830 CE, Steinhilber et al., 2012).**”

Line 384: ... in an Antarctic ice core over the period from 170 to 270 ka BP.

We thank the reviewer for raising this lack of clarity. We wanted to be more general to remind the different flux enhancement of different excursions over the Bruhnes chron.

Revision:

L384: “stands out as one of the most prominent geomagnetic events **during the Bruhnes chron (Simon et al., 2016)**”

Line 385-389: needs to make clear that this interpretation is based on ^{10}Be ,

We thank the reviewer for the suggestion and we clarified this.

Revision:

L385: “Such ¹⁰Be-based enhancement factors place IBE among the strongest known geomagnetic excursions of the last 1 Ma, comparable to the Laschamps event as measured in ¹⁰Be in East Antarctic cores (Raisbeck et al., 2017) or authigenic ¹⁰Be from oceanic cores (Simon et al., 2020), with no equivalent recorded between 200 and 800 ka BP (Cauquoin, 2013), and approaching the amplitude of the Bruhnes–Matuyama transition (Raisbeck et al., 2006; Simon et al., 2020).”

Line 386: It is difficult to say ‘slightly higher’ because it depends a lot on the reference background, as the authors already discussed. I agree with ‘comparable’.

We modified accordingly

Line 407: (Figure 4) not (Figures 2, 4 and 5)

We modified accordingly

Line 410: mirrors? I would use another verb. ‘Mirrors’ as ‘reflects’ in terms of slow decrease during the M/B reversal and rapid decrease in excursions, or as ‘reproduces, resembles’, the same behavior? My understanding is the first one, but it could be misinterpreted

We thank the reviewer for pointing out this potential ambiguity. We originally used ‘mirrors’ in the sense of a temporal mirror image (i.e., opposite asymmetry), but we agree that this wording could be misinterpreted. The sentence has been revised to explicitly describe the time-reversed relationship between excursion and reversal intensity patterns

Revision:

L410: “Interestingly, this asymmetric pattern is **opposite, in a temporal sense, to that** observed for polarity reversals (e.g., Valet and Meynadier, 1993; Valet et al., 2005): **reversals are characterized by** a slow decrease of the dipole moment in the initial polarity followed by an abrupt recovery of the dipole moment in the new opposite polarity. After long and intensive debates (Kok and Tauxe, 1996; Mazaud, 1996; Meynadier et al., 1998; Meynadier and Valet, 1996), the hypothesis was recently tested on authigenic ¹⁰Be/⁹Be records reconstructed from sediment cores (Simon et al., 2018; Valet et al., 2024, 2025) which suggested that the asymmetric patterns were not convincingly reproduced for any of the reversals of the last 4 Ma.”

Line 415-417: Great point!

Thank you

Line 418: remove the four brackets in this line, and in the paragraph

We thank the reviewer for this comment. However, as mentioned earlier we prefer to follow the IUPAC writing (https://old.iupac.org/publications/books/gbook/green_book_2ed.pdf, page 83) when reporting values as: *(value ± std) unit*.

Line 422, 1) the ages come with large uncertainties, 2) do we expect excursions to occur at the same time globally, considering the geomagnetic field dynamics?

We agree that age estimates associated with geomagnetic excursions carry large uncertainties, which are explicitly reported in the manuscript. In addition, excursions related to a collapse of the geomagnetic dipole moment are expected to be globally synchronous. This is supported by cosmogenic

nuclide records showing coherent ^{10}Be increases in both Greenland and Antarctic ice cores. We have clarified this point in the text and now emphasize that the dispersion of reported ages likely reflects the prolonged duration of the event and chronological uncertainties rather than true diachronism of the geomagnetic signal.

Revision:

L418: “Regarding the timing, the IBE flux maximum forms a plateau between (192.07 ± 1.41) ka BP and (185.56 ± 1.44) ka BP, suggesting a ≈ 7 ka interval of extremely low magnetic field strength. This age is in general agreement with previous estimates from sedimentary and volcanic archives. For instance, the age aligns well with the K–Ar dating of transitional lava flows from the Snake River Plain at (188 ± 8) ka BP (Champion et al., 1988), and with excursion ages inferred from high-resolution marine sediment cores in the Ontong Java Plateau (≈ 190 ka BP; Tauxe and Wu, 1990) and the eastern equatorial Pacific (Valet and Meynadier, 1993). It is also consistent with authigenic $^{10}\text{Be}/^9\text{Be}$ records from Portuguese margin cores (Carcaillet et al., 2004). Slightly older ages, such as the (197 ± 17) ka BP have been reported though for the Unzen lava flow in Japan (Shibuya et al., 2007). **It should be noted that age uncertainties associated with both volcanic and sedimentary records are large, often of the same order as the reported differences between archives. Moreover, geomagnetic excursions associated with a collapse of the geomagnetic dipole moment are expected to be globally synchronous, as supported by cosmogenic nuclide records showing coherent ^{10}Be increases in both Greenland and Antarctic ice cores (Raisbeck et al., 2017). In this context, the spread in reported ages likely reflects the prolonged duration of the event, as indicated by the ≈ 7 ka plateau in ^{10}Be flux, which complicates the definition of a single “event age”, combined with age uncertainties, rather than a true diachronism of the geomagnetic signal.”**

Line 449: in agreement with PISO-1500 variations

We modified accordingly

Line 450: Isn't it the case that for excursions, i.e., enhancements, the only variations that should be interpreted are those in the flux, not in the concentration? What does it mean if the others are not expressed in the concentration?

We agree that for geomagnetic excursions, variations in ^{10}Be flux are generally the most appropriate to interpret in terms of geomagnetic field intensity, whereas concentrations can be strongly affected by accumulation changes. This is precisely why we explicitly discuss the fact that the PFE and ME are only expressed in the flux record and not clearly in concentrations. We consider whether such signals could result from accumulation-related artifacts or age-model effects, and argue that this is unlikely based on (i) the occurrence of these events during interstadial periods with high accumulation rates, (ii) the partial control of ^{10}Be concentrations by climate proxies (Na^+), and (iii) the robustness of the AICC2023 chronology over this interval. We have clarified this reasoning in the text.

Revision:

L450: “**Variations in ^{10}Be flux are more directly representative of changes in cosmogenic production, unlike ^{10}Be concentrations which are strongly modulated by snow accumulation. In this context, it is noteworthy that, unlike the IBE, the PFE and ME are not clearly expressed in ^{10}Be concentrations, and only emerge in the ^{10}Be flux (i.e., once considering snow accumulation rate variations and considering ^{10}Be minima). This raises the possibility of whether these low-amplitude signals could be artifacts**

related to accumulation-rate variations or age-model uncertainties. Nevertheless, both events occur during interstadial periods (MIS 7.3 for PFE and MIS 7.5 for ME) marked by elevated accumulation rates, approximately 8 cm a^{-1} (Figure 2), thus supporting the consideration of snow accumulation rate variations. This is further corroborated by the correlation between the concentrations of Na^+ and ^{10}Be ($R^2 = 0.23$, after the removal of the minima, Figure S3) which indicates that about 23 % of ^{10}Be concentration is explained by climate-driven variations in ^{10}Be deposition. Moreover, the robustness of the AICC2023 chronology over this interval, supported by a dense network of chronostratigraphic markers (Bouchet et al., 2023), strengthens the reliability of the flux signals. While confirmation from additional ice cores is required, the present evidence supports the occurrence of two distinct moderate geomagnetic excursions (PFE and ME), enriching the geomagnetic field history during MIS 7. **This observation further emphasizes that relying solely on ^{10}Be concentrations may lead to biased interpretations of ^{10}Be production when glacial and interglacial periods alternate, and that both ^{10}Be concentrations and snow accumulation rates should be reported to allow robust geomagnetic interpretations.”**

Line 463: interstadial stages of MIS 7 (7.1 for IBE, ..), Line 400: interglacial MIS 7.1? I believe my confusion here comes because I don't have expertise in paleo(climatology). Please explain: interstadial vs interglacial in terms of short/long, warm/cold, between/within glacial period. I think it is important to know the climate conditions when these excursions happened.

We thank the reviewer for pointing out that the distinction between interstadial and interglacial terminology may not be obvious outside the paleoclimate community. In ice core and marine isotope stratigraphy, MIS 7 is a complex stage composed of several relatively warm substages (7.1, 7.3, 7.5), commonly referred to as interstadials rather than full interglacials. We have clarified this terminology in the manuscript to better explain the climatic context in which these excursions occurred.

Revision:

L463: “In particular, the occurrence of the three excursions during **warm interstadial substages** of MIS 7 (7.1 for IBE, 7.3 for PFE, and 7.5 for ME), **i.e. relatively warm intervals within MIS7**, raises the question of a climate-dependent polar bias.”

Line 509: add the age of the Mid-Pleistocene Transition

We thank the reviewer for raising this point, which is included.

Revision:

L509: “Mid-Plesitocene Transition **(1.2 – 0.9 Ma, Fischer et al., 2013; Parrenin et al., 2017; Wolff et al., 2022)**”

Line 511: Using the VADM reconstruction PISO-1500 (Channell et al., 2009)

We modified accordingly

Line 520: This study presents a high-resolution ^{10}Be flux record from the East Antarctic TALDICE ice core, covering the interval from 170 to 270 ka BP, and evaluates the reliability of ^{10}Be as a paleomagnetic proxy and as a tool for synchronizing the chronologies of different proxy archives. (or something along these lines, so the three following points are summarized, not only the first two)

We modified accordingly

Line 545: .. offer great possibility for cross-checking the chronologies ...

We modified accordingly

Feedback on the figures:

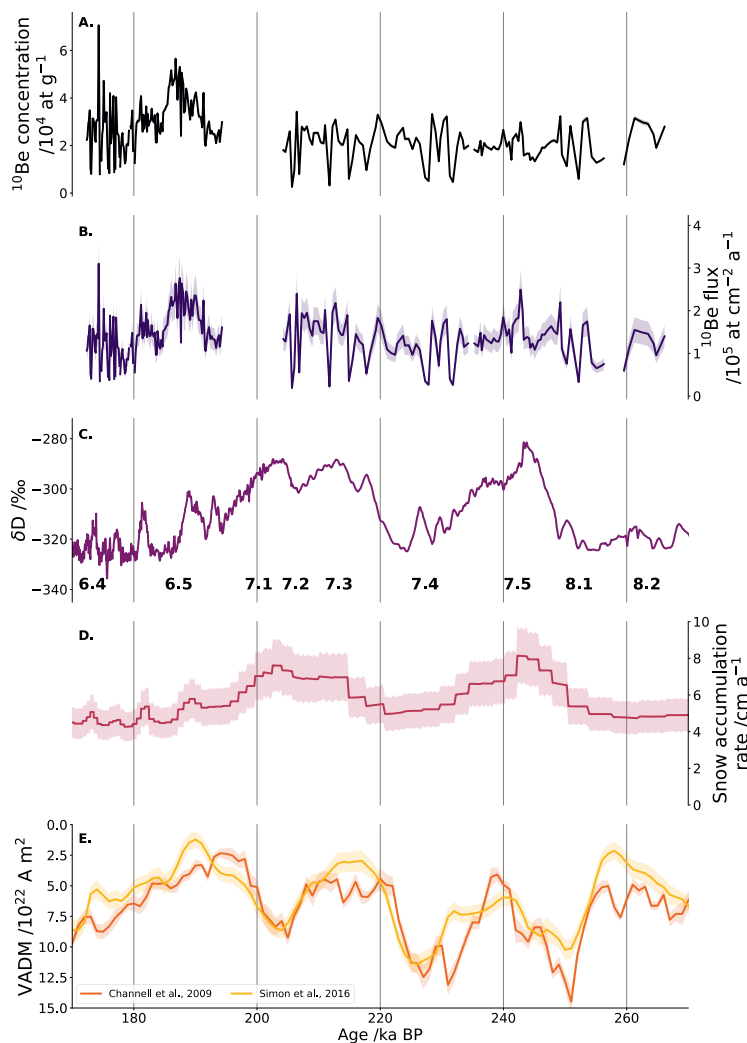
Figure 1: Capital letter in the caption. Expand the caption. The three excursions, which one?

We revised the caption as follow:

“Figure 1: Map of sites found in literature recording at least one of the geomagnetic excursions discussed in this paper: the three excursions (IBE, PFE and ME, triangles), IBE alone (stars), or PFE alone (circle). The references are listed in Table S1”

Figure 2 caption: shaded in black? Are these visible? Explain δD . I found the notations for the subfigures in the brackets confusing. It is much clearer to have: A) B) etc, as it is started, then continue for C), D), and add E). Write the name of the RPI stack. Y-axis is reversed. Note the MIS stages at the top

Be concentration uncertainties are small, which is why we cannot see the shaded black areas. We clarified in caption that the uncertainty is $<3.6\%$. MIS has been added.



“Figure 2: A) TALDICE ^{10}Be concentration (10^4 at g^{-1}) with the concentration uncertainty (shaded black, 3.6 % on average). B) ^{10}Be flux (10^5 at $\text{cm}^{-2} \text{a}^{-1}$) with the uncertainty (shaded purple) which accounts for the concentration uncertainty and the variation of the accumulation (see section 4). C) Climate variations are recorded in TALDICE with δD water isotopes (‰; Stenni et al., 2011), from which Marine isotope stage can be listed (6.4 to 8.3; Railsback et al., 2015). D) Snow accumulation rate (cm a^{-1}) is retrieved from the AICC2023 chronology (Bouchet et al., 2023). E) Virtual Axial Dipole Moment (VADM, A m^2) is estimated from Relative Paleointensity (PISO-1500; Channell et al., 2009) (orange) or from authigenic $^{10}\text{Be}/^9\text{Be}$ (Simon et al., 2016). Note that the y-axis is reversed.”

Figure 3: Capital letter in the caption. Shaded orange and grey, do these overlap? In total, they should be 52, or 52 orange only? Note down in the caption which ones are removed in the analysis? List the major ion concentration (...).

We thank the reviewer for these comments. We corrected the caption and clarified the definition and counting of minima, including the fact that minima are identified at the ^{10}Be sampling resolution (≈ 20 cm), so that low-concentration intervals extending over 40 cm are counted as two minima. We also clarified the meaning of the orange and grey shaded areas and corrected the total number of minima retained in the analysis. We also realized that we have made a mistake. Only 40 minima are identified in the section 1470 – 1531 m. The 52 minima mentioned in the previous version included other sections that have been removed from the manuscript, in order to mainly focus on the 170-270 ka BP period. Figure 3 correctly showed the section with the 40 minima. We corrected the section 4.2.

“Figure 3: Minima in ^{10}Be concentration (black line) identified at the measurement resolution (≈ 20 cm) are highlighted by shaded areas. Orange shading indicates ^{10}Be minima that are concomitant with maxima in major ion concentrations, whereas grey shading indicates minima without concomitant major ion maxima. The resolutions are the measurement resolution, i.e. ≈ 20 cm for ^{10}Be . Because minima are defined at the ^{10}Be sampling resolution, a low-concentration interval extending over 40 cm is counted as two distinct minima. Only the 40 minima identified within the 1470–1531 m depth interval (corresponding to 170–270 ka BP) and retained for the present analysis are shown. The major ion (Na^+ , Cl^- , MSA , SO_4^{2-} , Ca^{2+} , Mg^{2+} , NO_3^- , and H^+) concentration profiles are in high resolution (8 cm). Acidity profile (H^+) is calculated from an ionic balance (see section 3.2.2).”

L263: “4.2. ^{10}Be minima

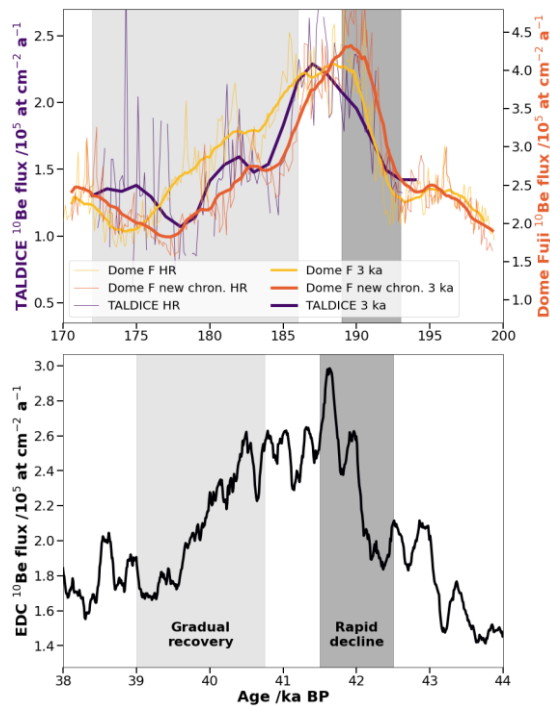
A total of 40 minima in ^{10}Be concentration were identified across the TALDICE record studied in this work, which appear to coincide with maxima in the concentrations of major ions (Figure 3). This association is statistically significant (permutation test’s p -value = 0.0001), though no direct quantitative relationship can be established. The major ions involved originate from a variety of sources, including oceanic sea spray (Na^+ , Cl^- , Mg^{2+} , MSA , SO_4^{2-}), crustal dust (Ca^{2+} , Mg^{2+}), and volcanic (SO_4^{2-}) sources. In addition to ion concentration peaks, many of the ^{10}Be minima are also associated with decreases in the Cl^-/Na^+ ratio which is typically used to study changes in the relative contributions of marine aerosols or alterations in transport processes (Legrand et al., 2017).

To test whether the identified ^{10}Be concentration minima preferentially occur under particular conditions, we compared their distribution against δD and $[\text{Ca}^{2+}]$. Of the 40 minima identified, 31 occurred during glacial intervals ($\delta\text{D} < -300$ ‰), which is proportional to the fraction of the record spent in glacial conditions (77 %). A χ^2 test confirms no significant increase in the number of minima during glacials ($p = 1.00$), and δD values at ^{10}Be minima are statistically indistinguishable from non-

minima levels (Mann-Whitney U test, $p = 0.889$). In contrast, $[Ca^{2+}]$ concentrations are systematically higher at ^{10}Be minima. While median $[Ca^{2+}]$ is only slightly elevated at minima compared to the background (Mann-Whitney U $p = 0.53$), contingency tests using thresholds show strong enrichment: for example, **32 %** of ^{10}Be minima exceed 15 ppb Ca^{2+} compared to **13 %** of the background ($\chi^2 = 8.0$, $p = 0.005$), and **7** ^{10}Be minima exceed 30 ppb compared to only **9** out of **221** non-minima samples ($\chi^2 = 8.4$, $p = 0.005$). This suggests that short-lived ^{10}Be minima preferentially coincide with dust-rich conditions.”

Figure 4: Capital letter in the caption. Which line is purple? .. the snow accumulation rate. Also, rather than the vertical lines showing the x-axis major ticks, add minor x-axis ticks only to the x-axis, and add vertical lines that distinguish the periods of rapid decline and the three-step recovery (and four arrows showing the decline and recoveries). I would suggest adding another panel showing the Laschamps excursion, as there is an extended discussion on it (with similar vertical lines).

We thank the reviewer for these comments. We have revised the Figure 4, now including the Laschamps excursion record from EDC (Raisbeck et al., 2017) and some highlighted areas to better distinguish periods of rapid decline from those of gradual recovery.



“Figure 4: Comparison of Dome Fuji (high resolution and 3 ka rolling mean average, yellow, Horiuchi et al., 2016) and TALDICE (purple, this study) ^{10}Be flux records for IBE. The revised Dome Fuji record is also presented based on chronology revision, which modifies snow accumulation rate (orange, Oyabu et al., 2022). The dark (resp. light) grey shaded area represents the period of rapid decline (resp. slow recovery) of the GDM. For comparison, the same periods can be identified during the Laschamps excursion in the ^{10}Be flux record from EPICA Dome C ice core (Raisbeck et al., 2017)”

Figure 5: Note the IBE, PFE and ME in the figure on top of the grey bars. Denote the subfigures A,B,C... and add these to the main text when referring to the subfigures. The timing of the stars in TALDICE is also different in MD05-2920, but the sediment record wasn’t considered for defining the shifts, right? Are the stars from TALDICE directly applied to the ^{10}Be global production? I found the star around 210 ka very difficult to uniquely identify.

Regarding the stars, we are sorry if having the stars on the MD05-2920 core led to confusion. Indeed, as correctly understood by the reviewer, the stars only enable the alignment of the RPI-based ^{10}Be production record with the TALDICE one. Besides, we agree with the reviewer that the ca. 210 ka BP star is difficult to precisely assign. We clarify in the document the higher uncertainty on this matching.

Revision:

L429-430: “These well-resolved features are also mirrored in ocean sediment records (Black stars in Figure 5) and could serve as valuable tie points for synchronizing paleoclimate archives across different media. **In contrast, the feature tentatively identified around c. 210 ka BP is less well constrained and should be regarded as having a higher uncertainty in its assignment.**”

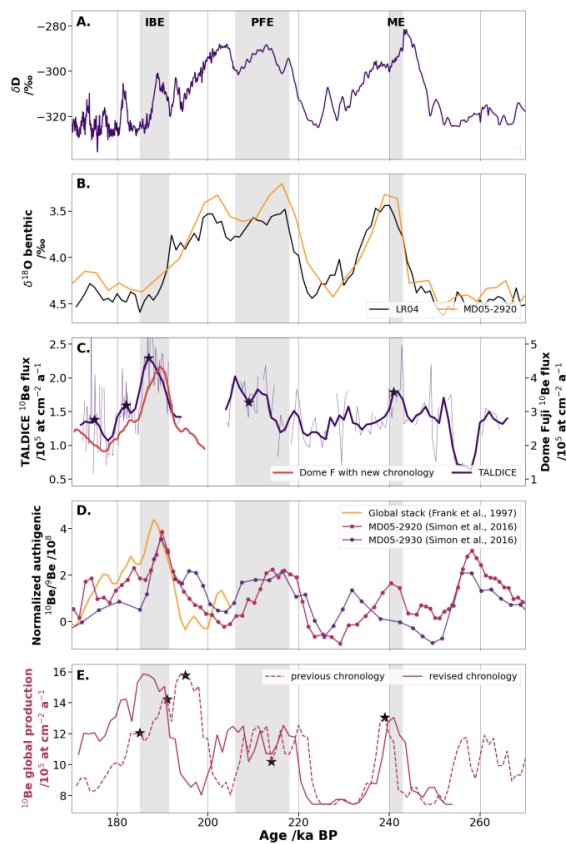


Figure 5: Comparison of ^{10}Be and climate records from ice cores and marine sediments over 170–270 ka BP with: **A.** TALDICE δD (‰), **B.** benthic $\delta^{18}\text{O}$ (‰) from LR04 stack (Lisiecki and Raymo, 2005) and MD05-2920 (Tachikawa et al., 2014), **C.** TALDICE and Dome Fuji ^{10}Be (in purple and red respectively, /at $\text{cm}^{-2} \text{a}^{-1}$), **D.** authigenic $^{10}\text{Be}/^9\text{Be}$ from global stack reconstruction (yellow, Frank et al., 1997), MD05-2920 (red), and MD05-2932 (purple) (Simon et al., 2016), and **E.** the ^{10}Be global production (/at $\text{cm}^{-2} \text{a}^{-1}$; Poluianov et al., 2016) calculated from RPI-based VADM (Channell et al., 2009). Grey bars highlight the main geomagnetic excursions discussed in the text (IBE, PFE, ME). Timing of identifiable geomagnetic features (black stars in TALDICE and RPI-based VADM) is used to obtain a revised chronology of RPI-based VADM used for calculating the ^{10}Be production, **noting though a lower confidence on the star around 210 ka BP.**”

Reviewer 2:

Atmospheric ^{10}Be from Talos Dome (East Antarctic) ice core records geomagnetic dipole intensity from 170 to 270 ka BP by Lamothe et al.

This study presents a long-term ^{10}Be record from the Talos Dome ice core (TALDICE) in East Antarctica, spanning a period from 170 to 270 thousand years before present (ka BP). After removing some potential post-depositional "noise", the 3-kyr smoothed ^{10}Be flux profile appears to faithfully represent the broad variations in the atmospheric ^{10}Be production signal. These variations are likely sufficient to serve as a proxy for relative paleointensity (RPI). The smoothed profile shows the ^{10}Be maxima caused by three geomagnetic dipole moment lows: the Iceland Basin excursion (IBE), the Pringles Fall excursion (PFE), and the Mamaku excursion (ME). The characteristic ^{10}Be variations of the largest low, the IBE, are also evident. These maxima and variations could serve as useful tie-points for paleo-archives. Ice core data is especially valuable for the 200–270 ka interval, for which no data has been published yet. Furthermore, I generally agree with their interpretations and conclusions. However, I have the following concerns, which, in my opinion, should be properly addressed before this work is published in GChron.

1. Earlier studies' findings are disregarded

Comprehensive research on the IBE period (170–200 ka BP) has already been conducted by Horiuchi et al. (2016). They presented unprecedented, high-resolution ^{10}Be data from the Antarctic Dome Fuji (DF) ice core and western equatorial Pacific sediments. They also discovered the following: (i) a 7-kyr plateau of the ^{10}Be maximum at the IBE, (ii) a twofold enhancement in ^{10}Be production (i.e. cosmic ray intensity), (iii) an asymmetric pattern of the ^{10}Be peak that is opposite to that of geomagnetic reversals, and (iv) an apparent age offset of several kyr between the ice core and the marine sediments, mainly due to uncertainty in the chronology of the sediments. I found that all of these findings are confirmed using independent data sets by Lamothe et al. in this preprint. This is truly wonderful. However, this preprint does not refer to the earlier findings. It should properly indicate what is known from the earlier research and what new findings were obtained in this study.

We thank the reviewer for this comment. We agree that our results are in excellent agreement with Horiuchi et al., 2016, which therefore would support more mentions of Horiuchi et al., 2016. We also notice that while many of the results discussed in our work are discussed in Horiuchi et al., 2016 dataset, we propose new elements like the twofold enhancement with respect to polar bias, the influence of marine age model uncertainties on the 3 ka delay, or the different asymmetric patterns between excursions and inversions. We have corrected our manuscript to better show these elements and what was already present and discussed in Horiuchi et al., 2016.

Revision:

L384: "Based on the TALDICE ^{10}Be flux data, a flux enhancement factor of 1.59 to 2.08 is observed, depending on the reference background (see section 4. Results), **similar to the twofold enhancement reported in Dome F (Horiuchi et al., 2016). In comparison, we calculate an enhancement ratio between 1.90 with the ^{10}Be flux calculated with the revised age of Dome Fuji, assuming a background calculated between 170 and 180 ka BP and a low-GDM plateau between 185.5 and 191 ka BP"**

L487: "A systematic time offset between the oceanic and the ice core records is observed (Figures 5, S4.A). **A similar 3 to 4.5 ka offset between oceanic and Dome F ice core records was previously reported by Horiuchi et al., (2016), and interpreted it primarily in terms of magnetic lock-in depth**

associated with post-depositional remanent magnetization acquisition in marine sediments. Our results confirm the existence of a comparable offset using independent marine and ice core datasets, but extend the comparison to ice core ^{10}Be fluxes, which are not affected by magnetization processes. When comparing authigenic $^{10}\text{Be}/^9\text{Be}$ from core MD05-2920 to the TALDICE ^{10}Be flux, the best correlation is obtained when the oceanic record is shifted 3 ka younger ($R^2 = 0.37$, Figure S4), which remains within the uncertainties of the marine core age model (Tachikawa et al., 2014). **Unlike comparisons involving RPI, a phase shift between ice core and oceanic ^{10}Be records cannot be attributed to magnetic lock-in effects. Potential physical causes would instead involve atmospheric or oceanic transport and mixing processes.** Nevertheless, does this 3 ka offset result from age model uncertainties or reflect a physical lag in the system, thereby limiting the possibility to use paleomagnetic events as chronostratigraphic horizons?

A phase shift linked to mixing processes would result in a delayed and attenuated ^{10}Be signal. Although excursion amplitudes are consistent between the two archives (Figure 5), this depends on complex processes that can be involved such as polar bias linked to incomplete atmospheric mixing (Adolphi et al., 2023), oceanic circulation and transport (Jeromson et al., 2025; Savranskaia et al., 2021) and bioturbation in sediments (Raisbeck et al., 1985). Nevertheless, if a physical phase shift occurred, we would expect the ice core signal to lead the oceanic record due to various oceanic mixing effects, thereby resulting in a delayed (and attenuated) marine authigenic $^{10}\text{Be}/^9\text{Be}$ signal.

To investigate the delay, we can examine the cross-correlation between the $^{10}\text{Be}/^9\text{Be}$ from core MD05-2920 and the ^{10}Be flux from TALDICE, **similar to the approach of Horiuchi et al., (2016)**. Such analysis (Figure S4.B) shows the highest correlation when MD05-2920 is shifted by 3 to 3.7 ka earlier. Another approach consists in examining the evolution of the delay between well-defined paleomagnetic events identified in both records (marked with stars in Figure 5). If major changes in oceanic circulation influenced the sedimentation of oceanic ^{10}Be , the lag would vary between glacial and interglacial periods (Savranskaia et al., 2024). However, we observe no variation in the lag across glacial–interglacial variations (Figure S4.C), indicating a consistent phase relationship between atmospheric and authigenic ^{10}Be signals. This approach yields a mean offset of 2.3 ka (Figure S4.C). Taken together, these results suggest that the observed delay is the result of age model uncertainty in the marine core, and that ^{10}Be production events are likely recorded synchronously in both oceanic and ice core archives. This conclusion is consistent with previous findings that suggest a limited reservoir effect and minimal climatic bias in ^{10}Be -based chronologies (Ménabréaz et al., 2012). These findings reinforce the value of ^{10}Be as a reliable synchronizing tool across sediment and ice archives. In the context of the Beyond EPICA project, they emphasize the role of ^{10}Be in refining chronologies and investigating climatic transitions, particularly across complex intervals such as the Mid-Pleistocene Transition (1.2 – 0.9 Ma, Fischer et al., 2013; Parrenin et al., 2017; Wolff et al., 2022).”

L510: **“During IBE, the TALDICE ^{10}Be flux record closely follows variations in oceanic authigenic $^{10}\text{Be}/^9\text{Be}$ from a global compilation (Frank et al., 1997) (Figure 5). In particular, the timing, duration, and stepped structure of the collapse and subsequent recovery of the GDM are consistent between the ice cores and marine records (Figure 5). For instance, the ≈ 7 ka plateau of elevated ^{10}Be flux observed in TALDICE has also been observed in Dome F ice core (Horiuchi et al., 2016) and is in agreement with oceanic records (Knudsen et al., 2008). Besides, the good overall agreement between the TALDICE and Dome F records with global geomagnetic field model of the IBE (Lanci et al., 2008) further supports the global record of Antarctic ice cores.**

Because of this broad **global** agreement, a comparison of ^{10}Be production calculated from RPI-based VADM and authigenic $^{10}\text{Be}/^9\text{Be}$ with ice core ^{10}Be fluxes is possible.”

L406: “The structure of the ^{10}Be flux anomaly during IBE is also noteworthy. **An asymmetric pattern, characterized by a rapid increase in ^{10}Be flux associated with dipole collapse followed by a slow and three-step dipole moment recovery was already identified in the Dome Fuji ice core record by Horiuchi et al., (2016) (Figure 4). Similar asymmetric dynamics have also been reported for the Laschamps excursion in ^{10}Be records from both ice cores (Muscheler et al., 2005; Raisbeck et al., 2017, Figure 4) and sediment cores (Ménabréaz et al., 2012; Simon et al., 2016, 2020).** Interestingly, this asymmetric pattern is **opposite, in a temporal sense, to that observed** for polarity reversals (e.g., Valet and Meynadier, 1993; Valet et al., 2005): **reversals are characterized by** a slow decrease of the dipole moment in the initial polarity followed by an abrupt recovery of the dipole moment in the new opposite polarity. After long and intensive debates (Kok and Tauxe, 1996; Mazaud, 1996; Meynadier et al., 1998; Meynadier and Valet, 1996), the hypothesis was recently tested on authigenic $^{10}\text{Be}/^9\text{Be}$ records reconstructed from sediment cores (Simon et al., 2018; Valet et al., 2024, 2025) which suggested that the asymmetric patterns were not convincingly reproduced for any of the reversals of the last 4 Ma. However, the consistent asymmetry of the dipole moment collapse and recovery observed for Iceland Basin and Laschamps excursions might reveal a fundamental difference between the dynamics of excursions and reversals, and should be carefully considered in future geodynamo modeling efforts.”

2. Ocean ^{10}Be records on the IBE

In addition to the aforementioned concern, it is also strange that only the ice core record was picked up from Horiuchi et al. (2016). The ^{10}Be records from the two marine sediment cores (KR0515-PC4 and KR0515-PC2) remain the highest-resolution ocean records available for the IBE period. I recommend using these records for comparison, at least to discuss the fine features of the ^{10}Be variations in the IBE period.

We thank the reviewer for this suggestion and for highlighting the importance of the KR0515-PC2 and KR0515-PC4 sediment cores presented in Horiuchi et al. (2016), which indeed represent the highest-resolution marine ^{10}Be records available for the IBE interval. In the initial version of the manuscript, we restricted the comparison to oceanic authigenic ^{10}Be records spanning the full 170–270 ka BP interval, which is why the KR cores were not included.

We agree that these records are valuable for discussing the detailed structure of the IBE. We therefore examined the KR0515-PC2 and KR0515-PC4 $^{10}\text{Be}/^9\text{Be}$ records in comparison with TALDICE and with the MD05 sediment cores used in this study. As noted by the reviewer, the KR cores show fine-scale features similar to those observed in other western equatorial Pacific records. However, because these cores originate from the same region and display patterns comparable to the MD records already included, their addition does not significantly alter or clarify the main conclusions regarding the timing, duration, and structure of the IBE.

We have nonetheless revised the manuscript to explicitly discuss the consistency between TALDICE, the MD records, and the KR cores reported by Horiuchi et al. (2016), and we now emphasize that the fine-scale structure of the IBE observed in Antarctic ice cores is also supported by these high-resolution marine sediment records.

Revision:

L480: “The comparison between atmospheric ^{10}Be fluxes from ice cores and authigenic $^{10}\text{Be}/^9\text{Be}$ ratios from marine sediments reveals overall agreement (Figure S4.A), supporting the reliability of both archives in recording geomagnetic events. Previous studies have highlighted the close correspondence between atmospheric and authigenic ^{10}Be records (e.g., Czymzik et al., 2020; Horiuchi et al., 2016). For IBE, high-resolution alignment is observed between ice cores (TALDICE and Dome Fuji, see section

5.3.1) and marine sediment cores (Figure 5). In particular, MD05-2920 (Simon et al., 2016) and KR0515-PC2 (Horiuchi et al., 2016) captures the same three ^{10}Be peaks at 174, 182, and 187 ka BP. PFE is also identified in both MD05-2920 and MD05-2930, while ME is not detected in MD05-2930, likely due to the core's lower temporal resolution (ca. 4 ka around 240 ka BP), which may not resolve the short 2–3 ka duration of the event.”

3. Data processing
The descriptions of the statistical analyses and criteria are sometimes lacking or insufficient. A careless mistake was made when correcting the ^{10}Be flux data of the DF ice core. See the specific comments and questions below for details.

We thank the reviewer for this general comment. We agree that we did not clearly understand the chronology of Dome F which led to mistakes. All points raised regarding the description of statistical criteria and the correction applied to the Dome Fuji ^{10}Be flux have been carefully addressed in the detailed responses to the specific comments below, and the manuscript has been revised accordingly.

Specific comments and questions are as follows:

Lines 162–163. Why is there a sampling gap between 1499 and 1505 m? Please clarify.

We did not sample this section. We clarified this in the manuscript.

Revision:

L162: “The ice core was continuously sampled in sections of 20 cm (when possible) between 1470 m and 1499 m and between 1505 m and 1531 m, **with a non-sampled section between 1499 and 1505 m.**”

Lines 203–204. When the data was merged, did the authors account for the systematic differences (if any) between laboratories? What are the criteria for removing outliers? Please clarify.

We thank the reviewer for this comment. No dedicated inter-laboratory comparison was performed on the TALDICE ice cores. However, all laboratories involved in the ion chromatography analyses followed the same analytical protocols and procedures that were previously applied to the EPICA Dome C and EPICA Dronning Maud Land ice cores. For these EPICA cores, a formal intercomparison exercise was conducted, demonstrating very good agreement between laboratories (Littot et al., 2002). Given the identical analytical conditions and procedures, systematic inter-laboratory offsets are therefore expected to be negligible for the TALDICE samples.

Regarding data screening, outliers were identified and removed following standard quality-control criteria applied to ion chromatography measurements (e.g., values affected by contamination, analytical artifacts, or failing internal consistency checks). These criteria are now clarified in the manuscript.

Revision:

L199: “**No inter-laboratory comparison was performed, and each laboratory analyzed a distinct subset of samples. However, all laboratories followed the same ion chromatography analytical protocols and procedures as those applied to the EPICA Dome C and EPICA Dronning Maud Land ice cores, for which inter-laboratory comparisons demonstrated very good agreement (Littot et al., 2002). Systematic inter-laboratory differences are therefore expected to be negligible for the**

TALDICE dataset. The ions measured by each laboratory on the discrete samples were 5 anions (Cl^- , CH_3SO_3^- (methane sulfonic acid, MSA), F^- , NO_3^- , and SO_4^{2-}) and 5 cations (Na^+ , NH_4^+ , K^+ , Mg^{2+} , and Ca^{2+}). Measurements were made with a mean resolution of 8 cm (maximum 17 cm). Details about blanks and calibrations are reported in Morganti et al. (2007).

The final dataset, obtained by merging the data from the four laboratories, was finally reprocessed by hand, removing outliers resulting from probable contamination events. **Specifically, outliers were removed when values were affected by probable contamination events or analytical artifacts, such as isolated spikes inconsistent with adjacent samples.** In the end, between 1470 and 1531 m, post-processing resulted in the withdrawal of 0 %, 19 %, 3 %, 0 %, 0 %, 2 %, 1 %, 0 %, 0 %, and 0 % of the total sample depths for Na^+ , NH_4^+ , K^+ , Mg^{2+} , Ca^{2+} , Cl^- , MSA, F^- , NO_3^- , and SO_4^{2-} , respectively.”

Lines 214–234. I agree with the authors’ statement that the uncertainty of the raw ^{10}Be flux is overestimated due to the feature of Paleochrono for SAR estimation, which reflects the large prerequisite uncertainty of SAR. However, I have my doubts about the validity of the uncertainty correction for SAR performed here. According to equation 1, if a given SAR value is equal to the mean of all SAR values, then it has no uncertainty. Is that reasonable? All measurements and estimations are subject to some degree of uncertainty.

We thank the reviewer for this important comment and agree that, in a strict sense, all measurements and model-derived quantities, including snow accumulation rates, are associated with non-zero uncertainties, even when their value equals the mean. The issue raised here was also carefully considered during our analysis.

The approach adopted in Equation (1) does not aim to quantify the absolute uncertainty of the ^{10}Be flux at a given time, but rather to estimate the uncertainty associated with *relative variations* of the flux over time. This distinction is essential for the objectives of this study, which focus on identifying and interpreting temporal variations in ^{10}Be flux related to geomagnetic field changes.

If the absolute ^{10}Be flux at a specific time were of interest, propagating the full accumulation-rate uncertainty provided by the Paleochrono framework would indeed be required, as no other constrain currently exists. However, when investigating relative variations, applying the full $\pm 20\%$ accumulation uncertainty uniformly would artificially inflate the uncertainty envelope and obscure meaningful variability.

We therefore use the $\pm 20\%$ accumulation uncertainty as a relative uncertainty applied to deviations from the mean accumulation rate, which we now explicitly define as a ‘variation uncertainty’. We have clarified this point in the Methods section to avoid ambiguity and to clearly state the scope and limitations of this approach.

Revision:

L228: “In order to avoid artificial inflation of the uncertainty associated with ^{10}Be flux variations, we propose a dedicated uncertainty propagation aimed at tracking relative **changes through time rather than absolute flux values**. Rather than **propagating** the full absolute uncertainty of the snow accumulation rate, we use the 20 % accumulation rate uncertainty from AICC2023 as a relative uncertainty (0.2) applied only to deviations from the mean accumulation rate (Equation 1).

With this formulation, accumulation rates equal to the mean have no associated uncertainty in terms of variability, although they remain subject to absolute uncertainty. This approach therefore does not represent the total uncertainty of the accumulation rate, but rather a ‘variation uncertainty’ that reflects how uncertainty in accumulation affects the amplitude of ^{10}Be flux fluctuations. This corrected uncertainty reflects the fact that variability in ^{10}Be flux is primarily driven by changes in accumulation over time rather than by its absolute range of uncertainty. On average, the corrected uncertainty, used when interpreting ^{10}Be flux variations as in Figure 15, is 22 % (min 0.2 %; max 53 %) lower than the raw uncertainty.”

[we moved one comment to gather with other comments that refer to a similar point]

Lines 239–241, and 280. If the authors used objective statistical criteria, why did they focus only on low values and not high ones? If the reason is related to concurrent peaks of certain ions, why were low ^{10}Be values unrelated to those peaks excluded from the final rolling average? Please clarify.

We thank the reviewer for this comment and for the opportunity to clarify this point. Although objective statistical criteria were used to identify anomalous values, the analysis focused primarily on low ^{10}Be values because they represent the dominant and recurrent feature affecting the rolling-average signal. Sharp and isolated minima are frequent in the ^{10}Be concentration record and can significantly distort the rolling average, particularly when they are related to post-depositional processes rather than to changes in ^{10}Be production.

In contrast, high ^{10}Be values do not display the same behavior. Apart from a single isolated high value at 1473.2 m, very few maxima satisfy the same statistical criteria applied to minima. Applying an equivalent detection procedure to high values identifies only one additional case to 1473.2 m, at 1521.2 m, which corresponds to a broader, multi-sample Gaussian-shaped feature rather than an isolated outlier. Such smooth maxima are unlikely to result from contamination or depositional artifacts and therefore do not significantly bias the rolling average.

For this reason, the analysis focused on identifying and evaluating the origin of low ^{10}Be values. Low values that were not associated with concurrent peaks in major ion concentrations were excluded from the final rolling average because they are interpreted as non-climatic artifacts that disproportionately affect the smoothed signal. In contrast, maxima were retained, as they represent features for which no clear mechanisms can support to discard them.

Revision:

L240: “The outlier analysis was intentionally focused on minima, as low ^{10}Be values are far more frequent and have a strong impact on the rolling average than high values.”

Line 263. Does 52 refer to the number of minima or the number of data points included? In Fig. 3, I see 24 shaded lines that I think represent the minima. So, isn’t the number of minima 24? Please specify.

We thank the reviewer for this comment. We realized that we have made a mistake. Only 40 minima are identified in the section 1470 – 1531 m. The 52 minima mentioned in the previous version included other sections that have been removed from the manuscript, in order to mainly focus on the 170-270 ka BP period. Figure 2 correctly shows the section with the 40 minima. We corrected the new section 4.2. dedicated to ^{10}Be minima and the caption of Figure 3.

Revisions:

“Figure 3: Minima in ^{10}Be concentration (black line) identified at the measurement resolution (≈ 20 cm) are highlighted by shaded areas. Orange shading indicates ^{10}Be minima that are concomitant with maxima in major ion concentrations, whereas grey shading indicates minima without concomitant major ion maxima. The resolutions are the measurement resolution, i.e. ≈ 20 cm for ^{10}Be . Because minima are defined at the ^{10}Be sampling resolution, a low-concentration interval extending over 40 cm is counted as two distinct minima. Only the 40 minima identified within the 1470–1531 m depth interval (corresponding to 170–270 ka BP) and retained for the present analysis are shown. The major ion (Na^+ , Cl^- , MSA , SO_4^{2-} , Ca^{2+} , Mg^{2+} , NO_3^- , and H^+) concentration profiles are in high resolution (8 cm). Acidity profile (H^+) is calculated from an ionic balance (see section 3.2.2).”

L263: “4.2. ^{10}Be minima

A total of **40** minima in ^{10}Be concentration were identified across the TALDICE record studied in this work, which appear to coincide with maxima in the concentrations of major ions (Figure 3). This association is statistically significant (permutation test’s p -value = 0.0001), though no direct quantitative relationship can be established. The major ions involved originate from a variety of sources, including oceanic sea spray (Na^+ , Cl^- , Mg^{2+} , MSA , SO_4^{2-}), crustal dust (Ca^{2+} , Mg^{2+}), and volcanic (SO_4^{2-}) sources. In addition to ion concentration peaks, many of the ^{10}Be minima are also associated with decreases in the Cl^-/Na^+ ratio which is typically used to study changes in the relative contributions of marine aerosols or alterations in transport processes (Legrand et al., 2017).

To test whether the identified ^{10}Be concentration minima preferentially occur under particular conditions, we compared their distribution against δD and $[\text{Ca}^{2+}]$. Of the **40** minima identified, **31** occurred during glacial intervals ($\delta\text{D} < -300$ ‰), which is proportional to the fraction of the record spent in glacial conditions (**77** %). A χ^2 test confirms no significant increase in the number of minima during glacials ($p = \mathbf{1.00}$), and δD values at ^{10}Be minima are statistically indistinguishable from non-minima levels (Mann-Whitney U test, $p = \mathbf{0.889}$). In contrast, $[\text{Ca}^{2+}]$ concentrations are systematically higher at ^{10}Be minima. While median $[\text{Ca}^{2+}]$ is only slightly elevated at minima compared to the background (Mann-Whitney U $p = \mathbf{0.53}$), contingency tests using thresholds show strong enrichment: for example, **32** % of ^{10}Be minima exceed 15 ppb Ca^{2+} compared to **13** % of the background ($\chi^2 = \mathbf{8.0}$, $p = \mathbf{0.005}$), and **7** ^{10}Be minima exceed 30 ppb compared to only **9** out of **221** non-minima samples ($\chi^2 = \mathbf{8.4}$, $p = \mathbf{0.005}$). This suggests that short-lived ^{10}Be minima preferentially coincide with dust-rich conditions.”

Lines 264–265. Please describe the details about the statistical analysis in either the Materials and Methods or the Supplemental Information.

We thank the reviewer for this comment. The statistical tests applied in this section are standard non-parametric methods commonly used to compare distributions and proportions in paleoclimate studies. While the paper is not focused on statistical methodology, we agree that the rationale for using these tests should be made more explicit. We have therefore clarified in the manuscript how each test was applied and what hypothesis it was designed to evaluate. Additional details on the statistical approach are now provided in a new sub-section of the methodology.

Revisions:

L239: “3.4. Statistical analyses

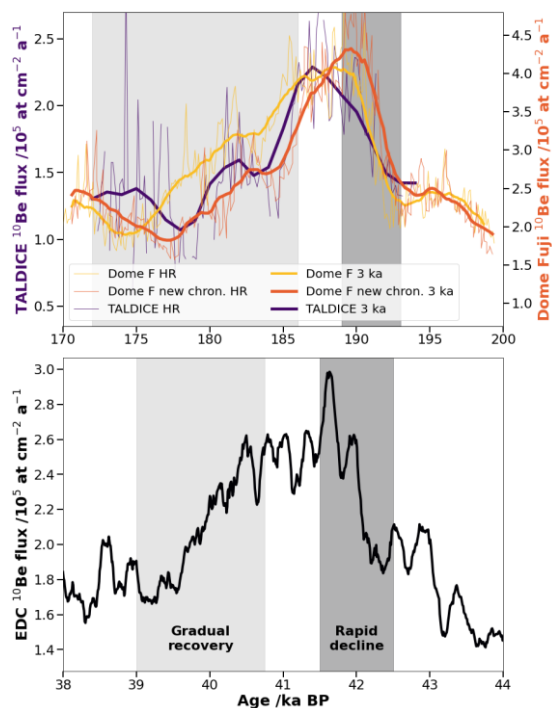
To identify anomalously low ^{10}Be fluxes, which could bias the interpretation of geomagnetic intensity, we applied an objective statistical criterion. These ^{10}Be minima were identified when the concentration fell below the mean minus one standard deviation, both calculated using a 3 ka rolling window. The outlier analysis was intentionally focused on minima, as low ^{10}Be values are far more frequent and have a strong impact on the rolling average than high values.

Statistical analyses were designed to test whether ^{10}Be concentration minima are randomly distributed with respect to climatic and geochemical conditions. A permutation test was used to assess whether the observed coincidence between ^{10}Be minima and major ion concentration peaks could arise by chance. Differences between distributions at minima and non-minima were evaluated using the Mann–Whitney U test, a non-parametric test appropriate for non-Gaussian data. Contingency tables and χ^2 tests were used to test for enrichment of ^{10}Be minima above selected thresholds (e.g., Ca^{2+} concentration), allowing us to assess whether minima preferentially occur under dust-rich conditions.”

Figs. 4 and 5. In these figures, the ^{10}Be flux profile of the DF ice core appears to have been smoothed using a 5-point rolling average or a similar procedure. I recommend showing the data at its original resolution. In any case, the authors should clearly indicate in the captions and text that the profile is smoothed.

We thank the reviewer for this comment. The Dome Fuji ^{10}Be flux record shown in Figures 4 and 5 is indeed smoothed using a 3 ka rolling average to be consistent with other 3 ka-averaged records, improve readability, and facilitate comparison with other records. We have now explicitly stated the smoothing procedure in the figure captions. We now also show the high-resolution DF ^{10}Be flux in Figure 4.

Revisions:



“Figure 4: Comparison of Dome Fuji (high resolution and 3 ka rolling mean average, yellow, Horiuchi et al., 2016) and TALDICE (purple, this study) ¹⁰Be flux records for IBE. The revised Dome Fuji record is also presented based on chronology revision, which modifies snow accumulation rate (orange, Oyabu et al., 2022). The dark (resp. light) grey shaded area represents the period of rapid decline (resp. slow recovery) of the GDM. For comparison, the same periods can be identified during the Laschamps excursion in the ¹⁰Be flux record from EPICA Dome C ice core (Raisbeck et al., 2017)”

Lines 333–335. I understand that the extraction protocol is essentially the same for both EDC in Raisbeck et al. (2006) and TALDICE in the present preprint. However, the appearance of ¹⁰Be anomalies in the deep parts of the two cores is opposite: increasing spikes in the EDC core and minima in the TALDICE core. The authors argue that the minima may be caused by the incorporation of ¹⁰Be into large aggregates that are not released by the extraction protocol. I don't understand how the mechanism keeps only ¹⁰Be and releases other major ions for TALDICE only. What is it? I agree with the authors that future studies are needed to clarify this issue. Nevertheless, some trials using a strong leaching method could support the authors' hypothesis and are not difficult to attempt.

We thank the reviewer for raising this very important point that we now clarify. A key point is that the extraction protocols used in Raisbeck et al. (2006) and in the present study are not identical. In particular, Raisbeck et al. (2006) did not use ion-exchange columns, whereas our protocol involves loading the melted ice sample onto a cation-exchange resin prior to Be purification.

Major ions are measured independently on a separate ice stick, thus being not affected by the ion exchange resin step. In contrast, ¹⁰Be measurements rely on chemical separation steps that may not quantitatively recover Be incorporated into large mineral aggregates or particle-bound phases. Under deep-ice conditions characterized by large grain sizes and enhanced impurity relocation at grain boundaries, ¹⁰Be may become associated with dust or mineral aggregates that are not efficiently released by our extraction protocol, resulting in apparent ¹⁰Be minima despite elevated major ion concentrations.

This difference in analytical treatment provides a plausible explanation for why post-depositional perturbations manifest as ¹⁰Be maxima in EDC but as minima in TALDICE. We agree with the reviewer that further experimental work is needed to directly test this hypothesis, and such investigations, including stronger leaching protocols and inter-method comparisons, are currently underway.

Revisions:

L310: “These ¹⁰Be minima co-occur with sharp maxima in major ion concentrations (e.g., Na⁺, Cl⁻, Ca²⁺), yet the ions originate from diverse sources. This rules out scenarios similar to single-source volcanic fallout (Baroni et al., 2011), terrestrial dust input (Baumgartner et al., 1997), or irregular snow redistribution (Poizat et al., 2024) and extreme atmospheric events such as atmospheric rivers (Wille et al., 2021). Instead, the inverse relationship between ¹⁰Be and major ions suggests a post-depositional control. Spikes in the concentration of major ions have been observed in the deep section of EDC that had been linked to impurities migration in the ice crystal boundaries (Traversi et al., 2009). **Anomalous ¹⁰Be signals were also reported in the deepest parts of the EDC core (>700 ka; >3,100 m) (Raisbeck et al., 2006), documenting ¹⁰Be maxima in EDC rather than minima as in TALDICE. This apparent contrast with TALDICE likely reflects differences in analytical protocols. In particular, the EDC study did not involve ion-exchange resin, unlike the present study. As reported in Kappelt et al. (2025), horizontal migration of Be was proposed to explain these maxima, as “smoothing over several thousands of years does not yield a distribution resembling the expected production signal smoothed by a vertical migration” (Kappelt et al., 2025). Under deep-ice conditions characterized by large grain sizes and enhanced impurity relocation, ¹⁰Be may become incorporated into dust-rich aggregates or**

mineral phases at grain boundaries. Such particle-bound Be may not be quantitatively recovered by the ion-exchange protocol, leading to apparent ^{10}Be minima despite elevated concentrations of major ions. However, it is worth noting that some of the EDC ^{10}Be maxima were also concomitant with spikes in other species, including dust (Raisbeck et al., 2006). Similarly, major ion spikes in EDC were associated with low acidity (Raisbeck et al., 2006), which is different from the high acidity observed in TALDICE.

Baumgartner et al. (1997) proposed another mechanism to explain the covariations between ^{10}Be and dust. Indeed, in the deepest and warmest ice of the GRIP core (Greenland), up to 40–50 % of ^{10}Be become dust-bound – higher than the <5 % seen in Holocene ice – due to ice metamorphism. The migration of ^{10}Be and dusts at the ice grain boundaries would result in higher local concentrations and thus favour the adsorption of ^{10}Be onto dust particles. Although such effects are expected to be less pronounced in low-dust Antarctic settings, deeper sections of ice cores, where ice crystals are large, may promote localized enrichment of major ions and ^{10}Be adsorption onto grain-boundary dust, muting the dissolved-phase signal. This mechanism is also in agreement with higher relocations and reactions of dusts in deep TALDICE (Baccolo et al., 2021). The significant connection between ^{10}Be minima occurrence and elevated Ca^{2+} concentrations, particularly above 30 ppb, suggests that extreme, non-atmospheric conditions are the main drivers of these ^{10}Be minima. The absence of a significant relationship with the glacial/interglacial state, as defined by δD , reinforces the idea that these anomalies are not controlled by large-scale atmospheric changes in production or transport, but instead reflect in-ice processes. In this way, **while further experimental work is needed to directly test this hypothesis, including stronger leaching protocols, ion remobilisation associated with ice grain metamorphism, leading to ^{10}Be incorporation into larger mineral aggregates that are not released by our extraction protocol, provides a plausible mechanism for the observed ^{10}Be minima.**

[comment which has been moved is added here]

Lines 236–238. Correcting the previously published ^{10}Be flux data based on the most recent DF chronology (DF2021) is an excellent attempt. However, this preprint incorrectly uses the DF2 depth for SAR estimation (I verified this by recalculating the updated ^{10}Be flux myself.). Since the DF2021 chronology is associated with the DF1 ice core, the equivalent DF1 depth (see Horiuchi et al.'s (2016) supplementary data file) must be used instead of the DF2 depth. Additionally, it appears that the previous chronology (DFO-2006) is still being used for the age model in this preprint (Figs. 4 and 5). To maintain consistency, I recommend that the authors use the DF2021 chronology for the age model of the corrected ^{10}Be flux of DF. As a result, the r-squared values shown in lines 355–356 (and the relevant discussion?) will change.

Lines 363–365. The ^{10}Be record from the DF ice core over the last millennium (Horiuchi et al., 2008) was normalized using the previous nominal value of the ICN ^{10}Be standard. Additionally, the ^{10}Be flux was calculated using an earlier SAR estimation based on the simple empirical relationship between SAR and d^{18}O in surface snowpacks (Satow et al., 1999) (for more details, see Horiuchi et al., 2008). Then, the average of the last millennium's ^{10}Be flux was updated in Horiuchi et al. (2016) using a revised standard value and the formulation of Parrenin et al. (2007) (i.e. using the same methodology as the published ^{10}Be record for the IBE) (see the Supplementary Material of Horiuchi et al. (2016)). Although it is still just about 1.3 times higher, the updated value of 2.07×10^5 at $\text{cm}^{-2} \text{a}^{-1}$ should be compared to the EDC value.

Lines 368–370. As mentioned above, the DF ^{10}Be flux is not twice as high as the EDC ones, but rather, just 1.3 times higher for the last millennium. Therefore, the difference of two times between the DF and TALDICE is not persistent, but has been observed (so far) only during the IBE. Although this seems enigmatic, I agree with the authors that data from other cores is necessary to resolve this issue.

We thank the reviewer for this detailed and very helpful comment. We acknowledge that, in the previous version of the manuscript, the description of the Dome Fuji ^{10}Be flux recalculation was not sufficiently clear and may have led to confusion. We confirm that the revised flux has now been recalculated using the DF1 depth scale consistently associated with the DF2021 chronology (Oyabu et al., 2022). The resulting flux have been corrected accordingly.

We also revised Figures 4 and 5 using the recalculated Dome Fuji flux based on the DF2021 age model. The revised comparison yields an improved agreement between TALDICE and Dome Fuji when using the DF2021 chronology ($R^2 = 0.44$) compared to the older DFO-2006 chronology ($R^2 = 0.37$). The relevant text has been updated accordingly.

Regarding the comparison with last-millennium values, we have substantially modified this discussion. We note that a recent independent compilation combining measurements and atmospheric modelling (Jouzel et al., 2026) confirms that Dome Fuji exhibits systematically higher ^{10}Be fluxes than EPICA Dome C (by 67 %) over the last millennium, supporting the conclusion that the Dome Fuji enhancement is not an artefact of accumulation or standardisation choices. We therefore clarify that the larger Dome Fuji / TALDICE contrast observed during the IBE is specific to that interval, but occurs within a broader context of persistent inter-site differences across East Antarctica. We also now discuss this difference in relationship with climate variations during MIS7, and show that this difference does not differ between glacial and inter-glacial conditions.

Finally, we emphasize that this systematic offset does not affect the interpretation of geomagnetic dipole moment variations, which relies exclusively on relative changes in ^{10}Be flux within each archive.

Revisions:

L 349: “For the period 170–270 ka BP, the mean 3 ka rolling ^{10}Be flux in TALDICE, **including the background and the geomagnetic events**, is 1.44×10^5 at $\text{cm}^{-2} \text{a}^{-1}$, which slightly increases to 1.56×10^5 at $\text{cm}^{-2} \text{a}^{-1}$ when the identified ^{10}Be minima are excluded. For the overlapping period 170–190 ka BP, the TALDICE ^{10}Be flux relative variations are in good agreement with the Dome Fuji (**DF**) record (Horiuchi et al., 2016) (Figure 4). This coherence not only highlights the homogeneous ^{10}Be deposition over East Antarctica, but also indicates that accumulation changes are well captured in both age models, AICC2023 for TALDICE (Bouchet et al., 2023) and the Dome Fuji DFO-2006 chronology (Kawamura et al., 2007). This agreement is further improved when the recent Dome Fuji chronology from Oyabu et al. (2022) is applied ($R^2 = 0.44$, with DF values calculated on TALDICE timestep), compared to the older DFO-2006 chronology ($R^2 = 0.37$). The consistent temporal evolution of ^{10}Be fluxes across these independent ice cores supports the reliability of these datasets for investigating variations in the GDM.

Despite this coherence in temporal evolution, Dome Fuji exhibits systematically higher absolute ^{10}Be fluxes than TALDICE (about 70 % more, Figure 4). While the mean ^{10}Be flux in TALDICE is 1.56×10^5 at $\text{cm}^{-2} \text{a}^{-1}$ **over 170–190 ka BP** (accounting for the minima), the DF ice core shows significantly higher values, reaching 2.74×10^5 at $\text{cm}^{-2} \text{a}^{-1}$ (Horiuchi et al., 2016), or 2.68×10^5 at $\text{cm}^{-2} \text{a}^{-1}$ when recalculated with the revised Dome Fuji chronology (Oyabu et al., 2022). The TALDICE values, however, are consistent with those from other Antarctic sites, such as EDC, which reports mean fluxes of approximately 1.44×10^5 at $\text{cm}^{-2} \text{a}^{-1}$ for the period 200–300 ka BP (Cauquoin, 2013).

This pattern persists over the last millennium, **between 918 and 1893 CE**, the mean ^{10}Be flux was 1.64×10^5 at $\text{cm}^{-2} \text{a}^{-1}$ at Dome C (Jouzel et al., 2026), and approximately twice as high at Dome Fuji (3.08×10^5 at $\text{cm}^{-2} \text{a}^{-1}$, Horiuchi et al., 2008). Although no ^{10}Be measurements are available for the last millennium at Talos Dome, comparison of recent century data shows similar mean fluxes between

Talos Dome (1.49×10^5 at $\text{cm}^{-2} \text{a}^{-1}$, Supplementary Table 1) and Dome C (1.69×10^5 at $\text{cm}^{-2} \text{a}^{-1}$, Jouzel et al., 2026). Independent evidence from the last millennium further indicates that Dome Fuji generally exhibits higher ^{10}Be fluxes than other East Antarctic sites. A recent multi-site compilation and modelling study (Jouzel et al., 2026) reports that measured ^{10}Be fluxes at Dome Fuji exceed those at EPICA Dome C by c. 70 %, consistent with earlier observations. These lower fluxes relative to the last millennium may be the result of the occurrence of solar minima during this interval corresponding to enhanced ^{10}Be production (Wolf, 1280 – 1350 CE; Spörer, 1420 – 1570 CE; Maunder 1645 – 1715 CE; Dalton 1790 – 1830 CE, Bard et al., 2000; Berggren et al., 2009; Horiuchi et al., 2008). These results suggest that persistent differences in ^{10}Be flux over Antarctica likely reflect regional deposition or atmospheric processes rather than artefacts of accumulation estimates or chronological treatment.

Jouzel et al. (2026) further suggest that this persistent contrast reflects regional atmospheric and depositional processes specific to the high-elevation interior of East Antarctica, including a transition from predominantly wet deposition north of 75°S to dry-dominated deposition south of this boundary, as well as enhanced stratosphere-troposphere exchanges over the highest Antarctic domes. While current global aerosol-climate models remain limited in their ability to resolve such sharp spatial gradients over Antarctica (Golubenko et al., 2024; Zheng et al., 2024; Jouzel et al., 2026), these mechanisms provide a physically grounded explanation for the systematically elevated ^{10}Be fluxes observed at Dome Fuji.

Importantly, we find no significant relationship between the Dome Fuji / TALDICE ^{10}Be flux ratio and δD (Spearman test, $p = 0.46$), indicating that differences in ^{10}Be flux over Antarctica is not modulated by glacial-interglacial climate variability. This result implies that the atmospheric and depositional mechanisms responsible for the DF/TALDICE ratio either remain stable through time or compensate one another across climate states. Consequently, while absolute ^{10}Be fluxes may differ between Antarctic sites, their relative temporal variations primarily reflect changes in cosmogenic production. This reinforces the use of Antarctic ice cores as robust records of global ^{10}Be production (modulo hemispheric polar bias; Adolphi et al., 2023) and supports their application to reconstruct variations in the geomagnetic dipole moment.”

Lines 383–393. Horiuchi et al. (2016) clearly described the twofold enhancement of ^{10}Be production for IBE by comparing the high-resolution ^{10}Be flux record from DF with the updated ^{10}Be flux for the past millennium (see above). This earlier work should be referenced appropriately here.

We are sorry for not having been complete. As mentioned earlier in response to the major comment, we now appropriately refer to Horiuchi et al., 2016.

Revisions:

L384: “Based on the TALDICE ^{10}Be flux data, a flux enhancement factor of 1.59 to 2.08 is observed, depending on the reference background (see section 4. Results), similar to the twofold enhancement reported in Dome F (Horiuchi et al., 2016). In comparison, we calculate an enhancement ratio between 1.90 with the ^{10}Be flux calculated with the revised age of Dome Fuji, assuming a background calculated between 170 and 180 ka BP and a low-GDM plateau between 185.5 and 191 ka BP”

Lines 406–417. Horiuchi et al. (2016) clearly pointed out both the asymmetric pattern and its opposite sense to reversals based on the DF record and twin, unprecedented, high-resolution ^{10}Be ocean records from the western equatorial Pacific (This preprint makes no mention of the ocean records, for reasons that are not clear). While it is notable that the authors provide a more comprehensive discussion, they should properly reference the earlier work here.

We are sorry for not having been complete. As mentioned earlier in response to the major comment, we now appropriately refer to Horiuchi et al., 2016.

Revisions:

L406: “The structure of the ^{10}Be flux anomaly during IBE is also noteworthy. **An asymmetric pattern, characterized by a rapid increase in ^{10}Be flux associated with dipole collapse followed by a slow and three-step dipole moment recovery was already identified in the Dome Fuji ice core record by Horiuchi et al., (2016) (Figure 4). Similar asymmetric dynamics have also been reported for the Laschamps excursion in ^{10}Be records from both ice cores (Muscheler et al., 2005; Raisbeck et al., 2017, Figure 4) and sediment cores (Ménabréaz et al., 2012; Simon et al., 2016, 2020).** Interestingly, this asymmetric pattern is **opposite, in a temporal sense, to that observed** for polarity reversals (e.g., Valet and Meynadier, 1993; Valet et al., 2005): **reversals are characterized by** a slow decrease of the dipole moment in the initial polarity followed by an abrupt recovery of the dipole moment in the new opposite polarity. After long and intensive debates (Kok and Tauxe, 1996; Mazaud, 1996; Meynadier et al., 1998; Meynadier and Valet, 1996), the hypothesis was recently tested on authigenic $^{10}\text{Be}/^9\text{Be}$ records reconstructed from sediment cores (Simon et al., 2018; Valet et al., 2024, 2025) which suggested that the asymmetric patterns were not convincingly reproduced for any of the reversals of the last 4 Ma. However, the consistent asymmetry of the dipole moment collapse and recovery observed for Iceland Basin and Laschamps excursions might reveal a fundamental difference between the dynamics of excursions and reversals, and should be carefully considered in future geodynamo modeling efforts.”

L480: “The comparison between atmospheric ^{10}Be fluxes from ice cores and authigenic $^{10}\text{Be}/^9\text{Be}$ ratios from marine sediments reveals overall agreement (Figure S4.A), supporting the reliability of both archives in recording geomagnetic events. Previous studies have highlighted the close correspondence between atmospheric and authigenic ^{10}Be records (e.g., Czymzik et al., 2020; **Horiuchi et al., 2016**). For IBE, high-resolution alignment is observed between ice cores (TALDICE and Dome Fuji, see section 5.3.1) and marine sediment cores (Figure 5). In particular, MD05-2920 (**Simon et al., 2016**) and **KR0515-PC2 (Horiuchi et al., 2016)** captures the same three ^{10}Be peaks at 174, 182, and 187 ka BP. PFE is also identified in both MD05-2920 and MD05-2930, while ME is not detected in MD05-2930, likely due to the core’s lower temporal resolution (ca. 4 ka around 240 ka BP), which may not resolve the short 2–3 ka duration of the event.”

Lines 418–426. The ≈ 7 -kyr plateau of the IBE cosmogenic anomaly is also an important finding by Horiuchi et al. (2016), follows Knudsen et al.’s (2007) suggestion based on their low-resolution data. Both of these earlier works should be properly cited in this paragraph, along with their original age estimations.

We are sorry for not having been complete. As mentioned earlier in response to the major comment, we now appropriately refer to Horiuchi et al., 2016.

Revisions:

L510: “During IBE, the TALDICE ^{10}Be flux record closely follows variations in oceanic authigenic $^{10}\text{Be}/^9\text{Be}$ from a global compilation (Frank et al., 1997) (Figure 5). In particular, the timing, duration, and stepped structure of the collapse and subsequent recovery of the GDM are consistent between the ice cores and marine records (Figure 5). For instance, the ≈ 7 ka plateau of elevated ^{10}Be flux observed in TALDICE has also been observed in Dome F ice core (Horiuchi et al., 2016) and is in agreement with oceanic records (Knudsen et al., 2008). Besides, the good overall agreement

between the TALDICE and Dome F records with global geomagnetic field model of the IBE (Lanci et al., 2008) further supports the global record of Antarctic ice cores.

Lines 427–430. When discussing fine-scale features, the high-resolution ^{10}Be ocean records published by Horiuchi et al. (2016) should not be overlooked, as they remain the highest-resolution ^{10}Be records from marine sediments for the IBE interval.

We are sorry for not having been complete. As mentioned earlier in response to the major comment, we now appropriately refer to Horiuchi et al., 2016.

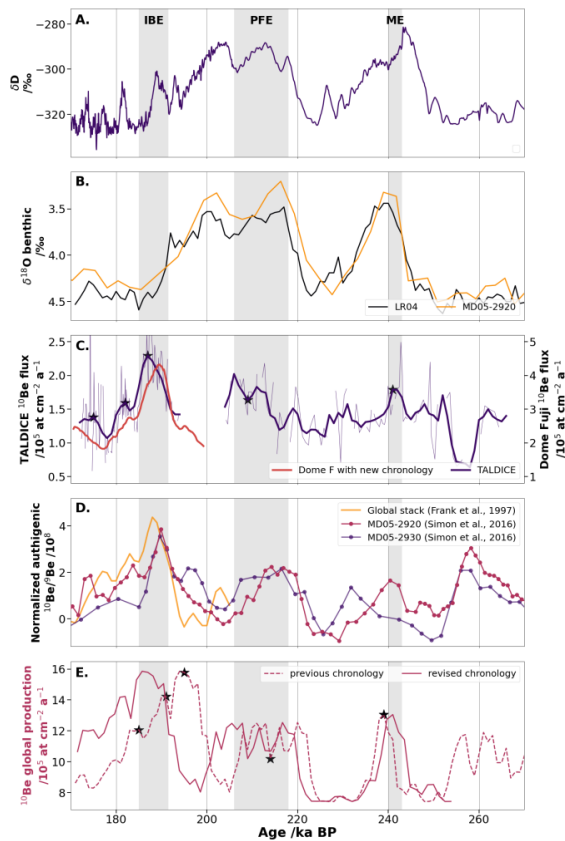
Revisions:

L480: “The comparison between atmospheric ^{10}Be fluxes from ice cores and authigenic $^{10}\text{Be}/^9\text{Be}$ ratios from marine sediments reveals overall agreement (Figure S4.A), supporting the reliability of both archives in recording geomagnetic events. Previous studies have highlighted the close correspondence between atmospheric and authigenic ^{10}Be records (e.g., Czymzik et al., 2020; Horiuchi et al., 2016). For IBE, high-resolution alignment is observed between ice cores (TALDICE and Dome Fuji, see section 5.3.1) and marine sediment cores (Figure 5). In particular, MD05-2920 (Simon et al., 2016) and KR0515-PC2 (Horiuchi et al., 2016) captures the same three ^{10}Be peaks at 174, 182, and 187 ka BP. PFE is also identified in both MD05-2920 and MD05-2930, while ME is not detected in MD05-2930, likely due to the core’s lower temporal resolution (ca. 4 ka around 240 ka BP), which may not resolve the short 2–3 ka duration of the event.”

Fig. 5. In the above discussion, what’s important is not the value itself, but rather the variations in each index. Therefore, MD05-2930 should have a y-axis value of around 5 to 6 $\times 10^8$ at the top, meaning a different y-axis should be used for MD05-2920 and MD05-2930. Otherwise, readers will not be able to effectively compare the ^{10}Be profiles. I also recommend adding data points using symbols for lower-resolution data, such as MD05-2920 and MD05-2930, to clarify the time resolution issue mentioned by the authors on lines 485–486.

We thank the reviewer. We have now normalized the data and add the data points on MD05-2920 and MD05-2930 to better see the differences in resolution.

Revisions:



Line 430 (and Fig. 5) . The criteria for adding the black star in Figure 5 are unclear. A more detailed explanation is necessary to convince audiences of the validity of the tie-point selection.

We agree that the criteria for selecting tie points should be clearly stated. We have revised the text to explicitly describe the criteria used for adding black stars in Figure 5, and we now emphasize that the feature around ca. 210 ka BP is tentative and associated with higher uncertainty, consistent with the comment of Reviewer 1.

Revisions:

L427: “Furthermore, fine-scale features in the IBE record, such as a short-lived recovery at 182 ka BP following a minimum at 183 ka BP, and a subsequent flux minimum around 178 ka BP with recovery by 174 ka BP, are visible in both TALDICE and DF cores as well as in oceanic cores (Figure 4). These well-resolved features are also mirrored in ocean sediment records (Black stars in Figure 5) and could serve as valuable tie points for synchronizing paleoclimate archives across different media. **In contrast, the feature tentatively identified around c. 210 ka BP is less well constrained and should be regarded as having a higher uncertainty in its assignment.**

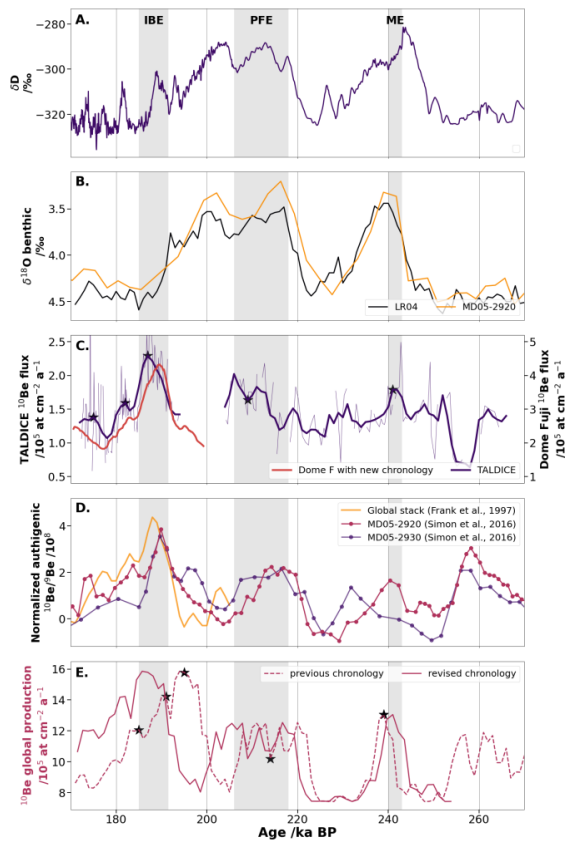


Figure 5: Comparison of ^{10}Be and climate records from ice cores and marine sediments over 170–270 ka BP with: **A.** TALDICE δD (‰), **B.** benthic $\delta^{18}\text{O}$ (‰) from LR04 stack (Lisiecki and Raymo, 2005) and MD05-2920 (Tachikawa et al., 2014), **C.** TALDICE and Dome Fuji ^{10}Be (in purple and red respectively, /at $\text{cm}^{-2} \text{a}^{-1}$), **D.** authigenic $^{10}\text{Be}/^9\text{Be}$ from **global stack reconstruction (yellow, Frank et al., 1997), MD05-2920 (red), and MD05-2930 (purple) (Simon et al., 2016)**, and **E.** the ^{10}Be global production (/at $\text{cm}^{-2} \text{a}^{-1}$; Poluianov et al., 2016) calculated from RPI-based VADM (Channell et al., 2009). Grey bars highlight the main geomagnetic excursions discussed in the text (IBE, PFE, ME). Timing of identifiable geomagnetic features (black stars in TALDICE and RPI-based VADM) is used to obtain a revised chronology of RPI-based VADM used for calculating the ^{10}Be production, **noting though a lower confidence on the star around 210 ka BP.**

Lines 481–484. This type of study has already been conducted by Horiuchi et al. (2016) for IBE. At the very least, this earlier work should be referenced here. Furthermore, their ocean records should also be compared with the ice core records.

We are sorry for not having been complete. As mentioned earlier in response to the major comment, we now appropriately refer to Horiuchi et al., 2016.

Revision:

L480: “The comparison between atmospheric ^{10}Be fluxes from ice cores and authigenic $^{10}\text{Be}/^9\text{Be}$ ratios from marine sediments reveals overall agreement (Figure S4.A), supporting the reliability of both archives in recording geomagnetic events. Previous studies have highlighted the close correspondence between atmospheric and authigenic ^{10}Be records (e.g., Czymzik et al., 2020; **Horiuchi et al., 2016**). For IBE, high-resolution alignment is observed between ice cores (TALDICE and Dome Fuji, see section 5.3.1) and marine sediment cores (Figure 5). In particular, MD05-2920 (**Simon et al., 2016**) and KR0515-PC2 (**Horiuchi et al., 2016**) captures the same three ^{10}Be peaks at 174, 182, and 187 ka BP. PFE

is also identified in both MD05-2920 and MD05-2930, while ME is not detected in MD05-2930, likely due to the core's lower temporal resolution (ca. 4 ka around 240 ka BP), which may not resolve the short 2–3 ka duration of the event.”

Lines 485–486. What is the authors' opinion on the clear maximum observed around 232 ka in the MD05-2930 record? Please clarify.

We thank the reviewer for drawing attention to the specific pattern around ca. 232 ka BP in the MD05-2930 record. We agree that this feature is noticeable. However, it is not observed consistently in other marine records nor in the ice core ^{10}Be fluxes, which prevents a robust attribution at this stage.

Several explanations should be considered, including uncertainties in the marine age model, which could potentially shift this feature toward the age of the Mamaku Excursion, although such a reinterpretation would affect the $\delta^{18}\text{O}$ -based alignment to the LR04 stack. Alternatively, this maximum may reflect local depositional or sedimentary processes, transient perturbations of the authigenic ^{10}Be signal, or changes in sediment circulation or scavenging efficiency.

Given the absence of corroborating evidence from independent archives, we consider this feature as tentative and do not interpret it further. Additional high-resolution marine records would be required to assess its origin and potential geomagnetic significance.

Revision:

L449: “Around 232 ka BP, a maximum in authigenic $^{10}\text{Be}/^9\text{Be}$ in MD05-2930 is observed. However, as this feature is not clearly reproduced in other marine records or in TALDICE ^{10}Be flux, we do not assign a geomagnetic origin to this signal.”

Lines 487–490. Horiuchi et al. (2016) found apparent lags of 3 and 4.5 kyr in the ^{10}Be record of an ice core (DF) compared to two ^{10}Be records from western Pacific sediment cores (KR0515-PC4 and KR0515-PC2) during the IBE period (170–200 ka). They attributed this discrepancy primarily to the uncertainty of the age model for marine sediments. This should be referenced as an earlier study here. Interestingly, an independent examination of this preprint, which used the TALDICE ice core and the MD05-2930 core, yielded a similar result: a lag of 3 kyr. This implies a systematic difference between ice and sediment chronologies (the latter of which essentially relies on marine isotope chronostratigraphy) for this period.

We thank the reviewer for this comment. As answered earlier, we agree that Horiuchi et al. (2016) reported a multi-ka offset between ice core and marine records during the IBE. However, in that study the offset was primarily interpreted in terms of magnetic lock-in depth affecting sedimentary paleomagnetic records, rather than as a consequence of marine age-model uncertainty. We have revised the manuscript to clarify this distinction and to explicitly state how our ice core to marine ^{10}Be comparison, which is not affected by magnetization processes, provides complementary constraints on the origin of the observed offset.

L487: “A systematic time offset between the oceanic and the ice core records is observed (Figures 5, S4.A). A similar 3 to 4.5 ka offset between oceanic and Dome F ice core records was previously reported by Horiuchi et al., (2016), and interpreted it primarily in terms of magnetic lock-in depth associated with post-depositional remanent magnetization acquisition in marine sediments. Our results confirm the existence of a comparable offset using independent marine and ice core datasets, but extend the comparison to ice core ^{10}Be fluxes, which are not affected by magnetization processes. When comparing authigenic $^{10}\text{Be}/^9\text{Be}$ from core MD05-2920 to the TALDICE ^{10}Be flux, the

best correlation is obtained when the oceanic record is shifted 3 ka younger ($R^2 = 0.37$, Figure S4), which remains within the uncertainties of the marine core age model (Tachikawa et al., 2014). **Unlike comparisons involving RPI, a phase shift between ice core and oceanic ^{10}Be records cannot be attributed to magnetic lock-in effects. Potential physical causes would instead involve atmospheric or oceanic transport and mixing processes.** Nevertheless, does this 3 ka offset result from age model uncertainties or reflect a physical lag in the system, thereby limiting the possibility to use paleomagnetic events as chronostratigraphic horizons?"

The following are suggestions for technical corrections:

Line 49. Replace "concomittent" with "concomitant."

Sorry for this mistake we corrected accordingly.

Lines 140–141. Shouldn't it be 210 and 220 ka BP instead of 200 and 215 ka BP? Around 205 ka, there is a local maximum (minimum) of PRI (^{10}Be) in PISO (MD05-2920/2930).

Sorry for this mistake we corrected accordingly.

Line 192. Add $\times 10^4$ to the mean concentration value.

Sorry for this mistake we corrected accordingly.

Line 195. What is "the latter"? Please clarify.

We clarified that we were referring to the discrete samples.

Line 271. I see no data below 1570 m in this preprint. Is it 1520 m instead?

As mentioned in one previous comment, we made a mistake. The previous version included other sections that have been removed from the manuscript, in order to mainly focus on the 170-270 ka BP period.