Q# refer to questions by the reviewers, **A#** refer to our replies to the corresponding question, **line number** mentioned in our replies refer to the revised version of manuscript.

Boxho et al. "Quantifying Southern Hemisphere dust sources during the Last Glacial-Interglacial Transition using rare earth elements in the EPICA Dome C ice core"
Reviewed by Austin Carter

This paper presents a high-resolution record of source contributions to embedded dust within the EPICA Dome C (EDC) ice core, specifically focused across the time interval of 33.7-2.9 kyr BP. The authors apply a statistical model previously developed by Vanderstraeten et al., 2023 to a large dataset of discrete rare earth elemental (REE) concentrations of ice core dust from EDC as reported in Gabrielli et al., 2010. The previously published dataset contains nearly 300 sections of ice from EDC which have been acid leached using 1% HNO3 and individually characterized for REE concentrations. Subsequently, the model in Vanderstraeten et al., 2023 includes a database of REE concentrations for a variety of samples from potential sources within the Southern Hemisphere. After making the EDC leached REE data comparable to total REE concentration using element-specific enrichment factors, the authors then modeled various combinations of sources that would result in the most closely matched data for each ice core dust sample. In this way, source contributions are effectively unmixed from the dust.

The authors show that before 14.5 kyr BP high-latitude PSAs (Patagonia + New Zealand) dominate the EDC ice core dust record and are stable. After 14.5 kyr BP, there is more heterogeneity in PSA contributions with periods of greater low-latitude PSA contributions (Australia, South Africa, and Puna-Altiplano Plateau). These changes are attributed to both hydrological changes in Patagonia and its corresponding shelf exposure as well as regional source dynamics at low-latitude sources. Candidly, I found the latter to be a bit hard to follow in its current organization. Lastly, when compared with EDML, the EDC record's PSA contributions over time are broadly similar with subtle differences owing to their geographic positioning. Overall, I enjoyed reading and learning more about this statistical application, and I find it very clever and interesting; however, I have some comments on clarity and the inherent limitations in the methods that I believe merit additional discussion in the paper after which I believe it would have my full support. I hope the following suggestions can help improve the manuscript:

We would like to warmly thank Austin Carter for the time and effort he dedicated to this review. In what follows, we did our best to accommodate his remarks and comments.

Q1: L17: The authors frequently refer to their record as "continuous." However, it is my understanding that the EDC REE dataset from Gabrielli et al., 2010 used for this study is not continuous. Instead, these measurements were on discrete sections of ice. If this is correct, then I do not think it's valid to describe the paper's results as continuous, and this should be edited for clarity.

A1: We agree with the reviewer and modify the text accordingly.

Q2: L34-52: The opening paragraph of the introduction parallels that of the opening paragraph of Vanderstraeten et al., 2023 very closely with regard to sentence structure and reference order etc. While I recognize the parallel logic between the papers, it would be nice to differentiate this manuscript's introductory paragraph a bit.

A2: We rewrote the introduction focusing more on the advances made in Vanderstraeten et al., 2023 in terms of dust provenancing and the relevance of studying EDC ice core. We believe that this new introduction is distinct enough from our previous work. Here is the new introduction:

"Antarctic ice cores preserve long-range atmospheric dust at high temporal resolution and provide a unique window into past changes in continental aridity, atmospheric circulation, and Earth system feedbacks during major climate transitions (Lambert et al., 2008; Grousset and Biscaye, 2005). Variations in dust flux and composition recorded in these archives have been central to our understanding of glacial–interglacial climate dynamics, particularly through the role of mineral dust in Southern Ocean iron fertilization and its impact on

atmospheric CO_2 concentrations (Martínez-García et al., 2014; Lambert et al., 2015, 2021). However, translating Antarctic dust records into quantitative constraints on past climate processes requires robust reconstructions of dust provenance and an understanding of how source-specific emissions respond to climatic and geomorphological change.

Geochemical fingerprinting of dust and sediments from Potential Source Area (PSA) upwind of Antarctica has therefore been a central component of dust provenance studies. Southern South America (SSA), Southern Africa (SAF), Australia (AUS), New Zealand (NZ), and ice-free regions of Antarctica have been identified as the dominant Southern Hemisphere PSAs (e.g., Grousset and Biscaye, 2005; Delmonte et al., 2010; Gili et al., 2017). While radiogenic isotope systems such as Sr–Nd and Pb have been widely used to trace dust sources, their application is limited by the relatively large sample masses required, which restricts temporal resolution—particularly at remote, high-elevation sites such as EPICA Dome C (EDC), where dust fluxes are low and decrease by up to a factor of ~25 from glacial to interglacial conditions (Delmonte et al., 2008; Delmonte et al., 2017). In addition, overlapping isotopic signatures among PSAs and the effects of dust mixing during transport complicate quantitative source ap-portionment (Gaiero et al., 2004; Delmonte et al., 2020).

Rare Earth Element patterns (i.e., the concentrations of the lanthanide series) offer a promising complementary approach to overcome these limitations. Because the full lanthanide series captures multi-dimensional geochemical information, REE patterns provide greater discriminatory power than elemental ratios alone, while requiring substantially smaller sample sizes and thus enabling higher temporal resolution. Previous applications of REE measurements in Antarctic ice cores achieved multi-decadal resolution but were limited in their ability to quantitatively resolve mixed dust sources (e.g., Gabrielli et al., 2010; Wegner et al., 2012). Recently, Vanderstraeten et al., (2023) introduced a novel statistical apportionment framework based on REE pattern fitting, producing the first quantitative, decadal- to centennial-scale reconstruction of dust provenance at EPICA Dronning Maud Land (EDML) across the Last Glacial–Interglacial Transition (LGIT).

That study revealed pronounced and time-dependent changes in dust source contributions to East Antarctica. During the Last Glacial Maximum, dust reaching EDML was dominated by high-latitude sources, particularly Patagonia and New Zealand, consistent with enhanced glaciogenic sediment production, expanded continental shelves, and strong Southern Westerly Winds. During deglaciation and the early Holocene, contributions from lower-latitude PSAs such as Southern Africa, Australia, and the Puna–Altiplano Plateau increased as high-latitude dust emissions declined. Beyond documenting changing provenance, Vanderstraeten et al., (2023) suggested that distinct physical mechanisms controlled dust delivery at distinct stages of the LGIT. During Heinrich Stadial 1, reductions in dust flux occurred without major provenance changes pointing to en-hanced atmospheric wet scavenging as the main driver of dust flux reduction. In contrast, the shift from high-to- low latitude sources after ~14.5 kyr BP likely reflects geomorphological thresholds in Patagonia. These include sea-level rise and the submergence of continental shelf, as well as and a major hydrological reorganization of Patagonian rivers (Delmonte et al., 2017; Davies et al., 2020; Thorndycraft et al., 2019). Together, these processes would have reduced the volume of sediment available to aeolian deflation (Vanderstraeten et al., 2023; Delmonte et al. 2017).

While EDML provides a sensitive record of dust provenance changes in the Atlantic sector of East Antarctica, it remains unclear to what extent these source shifts are representative of the broader East Antarctic Plateau. EPICA Dome C, located further inland and at higher elevation, receives lower dust fluxes and integrates longer atmospheric transport pathways, making it particularly sensitive to changes in large-scale circulation and dust residence time. EDC has played a central role in reconstructions of Southern Hemisphere dust variability and climate coupling, yet quantitative, high-resolution provenance across the LGIT remain limited at this site due to analytical challenges associated with low dust concentrations. Here, we apply the REE-based statistical provenance framework developed for EDML to the EPICA Dome C dust dataset of Gabrielli et al., (2010).Our study aims at (1) establishing a quantitative record of dust provenance in EDC throughout the LGIT and particularly during the Holocene, (2) confronting and validating the EDC results from our REE pattern-based model against Sr-Nd isotopic data published in the literature, (3) examining shifts in dust provenance at EDC in relation to regional climatic changes and (4) contrasting this new EDC provenance with the coeval record in EDML in the Atlantic sector of the Antarctic continent to assess spatial variability of dust deposition across East Antarctica during the LGIT."

Q3: L69: It would be useful to elaborate or define what is meant by "REE patterns" here.

A3: We agree and made the appropriate changes in the text in lines. Added text in lines 56: “i.e., the concentrations of the lanthanoid series”

Q4: L121-124: The first limitation when applying the DEPOT statistical model lies in the ability to compare acid-leached REE concentration data with other REE concentration data from PSAs. There is a possibility for preferential leaching of LREE (La, Ce, Pr, Nd) during a 1% HNO3 leach as shown in Gabrielli et al., 2010. Hence the need to apply enrichment factors to translate data from acid-leached to its potential total concentration form, which I think is handled well in the manuscript. However, the readers are left to assume that all of the PSA data are in total REE concentration form. Can you confirm this? Or are enrichment factors also applied to these data in their respective studies? I think some added clarity and its importance for direct comparisons would be valuable and would strengthen the paper’s methods.

A4: We thank the reviewer for this comment. We confirm that all the REE patterns from the PSA database were measured after full digestion, as total REE concentration. The correction factor (*cf*) are used solely to convert the REE concentration measured in EDC dust after partial dissolution into total REE concentration. Those “*cf*” values were measured in Gabrielli *et al.,* (2010).

Q5: L129: While I recognize the term Dust Sources (DS) was previously adopted in Vanderstraeten et al., 2023, I do think it can be slightly misleading. From my understanding, these are not unique sources, rather these are individual samples of dust, loess, sediment, and/or soil that make up a Potential Source Area (PSA). The text would benefit from some clarity on that and additional descriptions here. The confusion is made clear when we take Patagonia, for example. The authors describe 39 Dust Sources that make up the Patagonia PSA. To me this implies, 39 unique regions, but I only count 19 markers on Fig. S2 for Patagonia. This is likely because multiple samples come from similar sites, which therefore would not necessarily be a different dust source.

A5: We thank the reviewer for pointing out a potential source of confusion regarding the terminology “Dust Sources (DS)”. Our intention is to retain the terminology introduced in Vanderstraeten *et al.*, (2023) for consistency with the existing database; however, we acknowledge that the term “Dust Source” may be misleading without clarification. DS refer to individual aeolian dust (or sediment/soil) samples collected within a given PSA, and do not systematically represent distinct or independent geographic source regions. This is the case for example, for DS from Bahia Blanca (39°S), Puerto Madryn (42.7°S), Trelew (43.15°S) and Puerto San Julian (49°S) which represent aeolian dust samples collected at the same site during different seasons in 1997, 1998 and 1999 (see Gaiero *et al.,* 2004; Gili *et al.,* 2017 - for details). Although the composition of those sample is broadly similar across seasons, including multiple sample allows us to cover the regional variability of dust composition transported through those areas (predominately via westerly winds). To clarify this point, we modified:

- the description of the sample in Table S1 to clear specify the season and year when needed ;

- the section 2 in lines 130 by adding the following text:

“Following Vanderstraeten et al., (2023), “Dust Sources” (DS) refer to individual samples collected within a given PSA. Multiple DS may originate from the same sampling location when samples were collected during different seasons (see Table S1).”

Gaiero, D. M., Depetris, P. J., Probst, J.-L., Bidart, S. M., and Leleyter, L.: The signature of river- and wind-borne materials exported from Patagonia to the southern latitudes: a view from REEs and implications for paleoclimatic interpretations, Earth and Planetary Science Letters, 219, 357–376, https://doi.org/10.1016/S0012-821X(03)00686-1, 2004.

Gili, S., Gaiero, D. M., Goldstein, S. L., Chemale, F., Jweda, J., Kaplan, M. R., Becchio, R. A., and Koester, E.: Glacial/interglacial changes of Southern Hemisphere wind circulation from the geochemistry of South American dust, Earth and Planetary Science Letters, 469, 98–109, https://doi.org/10.1016/j.epsl.2017.04.007, 2017.

Q6: L127-133: The second and most important limitation in this approach is related to the quantity of data in the PSA database. Because the goal is to compare all samples in the PSA database individually to the ice core samples, PSAs that have a greater quantity of REE concentrations might have a bias. Perhaps this is less of an issue after taking the median of each PSA-specific PDF, but it is hard to know without seeing an example. I made a pie chart showing the distribution of the PSAs below. Australia makes up nearly half of the database, which I'm concerned that the % contributions might be biased heavily as a result.

A6: We thank the reviewer for raising this point regarding the unequal number of samples among PSAs. We explicitly tested the sensitivity of our results to the size of the PSA-specific REE database. For Australia, model results were first obtained using 51 REE pattern (mostly from Darling Basin and Lake Eyre) and were then recomputed after adding additional regions (e.g., Murray Basin; Marx and Kamber, 2010), for a total of 107 REE patterns. This more than twofold increase in the number of Dust Sources did not lead to any significant change in the inferred Australian contribution.

A similar sensitivity test was performed for New Zealand, where model outputs based first only on 6 REE patterns (Marx *et al.,* 2005) were compared with results obtained after adding 19 additional patterns from Koffman *et al.,* (2021). Despite this fourfold increase in the number of samples, the inferred New Zealand contribution remained essentially unchanged. These tests indicate that our approach is not strongly biased by the number of samples per PSA, but rather by the distinctiveness and variability of the regional REE signatures. Once the characteristic range of a PSA is adequately captured in the database, adding further samples within this range has a limited impact.

Q7: Additionally, based on Pb isotopic data for both EDC ice core dust and PSAs, Gili et al., 2016 argues against significant glacial and interglacial Australian contributions to the EDC dust record, yet this paper's finding suggests otherwise. If there is no bias in the DEPOT model, then the findings showing large influences from Australia are interesting and worth discussing further in that regard. While I agree with L366-355, importantly this study's findings with respect to Australia are not fully consistent with those in Gili et al., 2016.

A7: As discussed in A6, we are confident that our algorithm is not biaised by the large number of dust sources representing AUS. Regarding Gili *et al.,* (2016) (Fig. 3), it should be noted that the isotopic Pb domains defined for the various PSA are heavily overlapping with one another (more so than in Sr-Nd systems), preventing in our view, any solid quantification or appreciation of the contribution of AUS. More recent studies by de Deccker *et al.,* (2019, 2020) have re-evaluated the role of AUS as a dust source during modern and Late Quaternary times showing that Australian dust likely reached certain sectors of Antarctica, such as Taldice and Taylor Glacier, predominantly during interglacial periods. Modelling studies (Albani *et al.,* 2012; Krinner *et al.,* 2010; Li *et al.,* 2008) also showed that AUS modern dust prevails over the Pacific SO and towards western coastal regions of Antarctica. Looking at ensembles of air-mass back-trajectories, Neff and Bertler, (2015) have demonstrated that modern dust from Australia can reach EDC. We agree that the discussion regarding the Australian contribution to Antarctica which has been largely debated in the literature, probably merits further discussion in the present paper.

We added this text in lines 401-417: "*Although Gili et al., (2016) dismissed AUS as a major Antarctic dust source, later studies re-evaluated its role, suggesting Australian dust reached TALDICE and Taylor Glacier mainly during interglacials (de Deckker et al., 2019, 2020). Modeling and back-trajectory analyses further indicate that modern Australian dust dominates over the Pacific Southern Ocean and western Antarctic coasts and can reach EDC (Albani et al., 2012; Krinner et al., 2010; Li et al., 2008; Neff and Bertler, 2015).*"

Albani, S., Delmonte, B., Maggi, V., Baroni, C., Petit, J.-R., Stenni, B., Mazzola, C., and Frezzotti, M.: Interpreting last glacial to Holocene dust changes at Talos Dome (East Antarctica): implications for atmospheric variations from regional to hemispheric scales, Clim. Past, 8, 741–750, https://doi.org/10.5194/cp-8-741-2012, 2012.

De Deckker, P.: An evaluation of Australia as a major source of dust, Earth-Science Reviews, 194, 536–567, https://doi.org/10.1016/j.earscirev.2019.01.008, 2019.

De Deckker, P.: Airborne dust traffic from Australia in modern and Late Quaternary times, Global and Planetary Change, 184, 103056, https://doi.org/10.1016/j.gloplacha.2019.103056, 2020.

Krinner, G., Petit, J.-R., and Delmonte, B.: Altitude of atmospheric tracer transport towards Antarctica inpresent and glacial climate, Quaternary Science Reviews, 29, 274–284, https://doi.org/10.1016/j.quascirev.2009.06.020, 2010.

Li, F., Ginoux, P., and Ramaswamy, V.: Distribution, transport, and deposition of mineral dust in the Southern Ocean and Antarctica: Contribution of major sources, J. Geophys. Res., 113, 2007JD009190, https://doi.org/10.1029/2007JD009190, 2008.

Neff, P.D., and Bertler, N.A.N.: Trajectory modeling of modern dust transport to the Southern Ocean and Antarctica. JGR Atmospheres 120, 9303–9322, https://doi.org/10.1002/2015JD023304, 2015.

Q8: Similarly, I believe the Antarctic PSA might be discounted too easily and quickly despite it being argued as a plausible contributor during the Holocene at EDC in Gabrielli et al. 2010 from which the REE dataset originates. Additionally, Delmonte et al., 2013 highlights how the measured EDC ice core dust for the Holocene are geochemically similar in Sr-Nd isotope composition to Antarctic PSAs. However, the PSA database contains only 5 samples from the McMurdo Dry Valleys to represent the Antarctic continent (though only 4 are reported in Table S2). Because there are so few available samples, it seems inherently less likely that there will be enough trends to compare to and, thus, less likely they will make up a significant portion of the EDC ice core dust in the statistical model. Part of this issue may also be a result of limited measured Antarctic PSAs for REE concentrations within the literature. Some added caution here would be valuable and perhaps the inclusion of dust size might be useful as well.

A8: We thank the reviewer for this thoughtful comment and agree that the potential contribution of Antarctica deserves careful consideration, although ice-free regions represent only ~2% of the modern Antarctic surface. Among these regions, the McMurdo area is the largest, the closest to EDC (~1700 km), and includes the active McMurdo Volcanic Group along West Antarctic Rift System. It therefore represents the most relevant Antarctic dust source region for our study. Other coastal ice-free areas (e.g., Bunger Hills, Vestfold Hills, Larsemann Hills) are smaller, more distant from EDC (>2000 km), and, to the best of our knowledge, are not yet been geochemically characterized in terms of REE.

The McMurdo Dry Valleys (Miers, Victoria, Alatna, and Taylor) have a complex geological and depositional history (Diaz et al., 2020). Low-elevation valleys (i.e, Miers and Victoria) were submerged during the LGM, whereas higher-elevation valleys (i.e., Alatna and Taylor) have remained ice-free since the Miocene and have accumulated substantial atmospheric material from distal sources, especially during glacial periods where dust loading were 25 times higher than during interglacials. As a result, dust emitted from Alatna and Taylor valley displays REE signatures strongly influenced by deposition from Australia, Patagonia, New Zealand (Diaz *et al.,* 2020). Including these valleys therefore introduces the risk of conflating distal and local Antarctic signals, potentially leading to an overestimation of the Antarctic contribution. For this reason, we focused on Miers and Victoria valleys, which became exposed in the late Pleistocene, when Antarctic dust inputs were proportionally more relevant to investigate (as they potentially represent a larger fraction of total deposition to EAP).

To better represent the variability of these two valleys, we expanded the Antarctic PSA dataset by adding 32 individual geochemical patterns from Diaz *et al.,* (2020), replacing the four valley-averaged patterns previously used. This substantially improves the representation of McMurdo sources in the DEEPOT dust source database. We re-ran the provenance model for EDC using this expanded dataset, and the results are now presented in Fig. 1 of the revised manuscript. After those improvements, the Antarctic signal increase - especially in the Holocene which is in line with the deglaciation timing of those valley - but overall it remains secondary and does not modify the trends of the other PSA. These new simulations confirm that, our provenance patterns are robust, supporting the internal consistency of the model.

To adjust our isotopic calculations to include Antarctic dust source, we used the Sr-Nd isotopic data from Blakowski *et al.,* (2016). More precisely, we have selected the Sr-Nd values of the fine fractions (<5 microns) from regolith and glacial drift rocks or sediments recommanded by Blakowski *et al*., (2016) as the most representative of the McMurdo Dry Valley. Figure 2 (and new Figure S5) and its caption have been modified accordingly.

Added text (lines 430-437) section 4.4: "*Local antarctic dust from the McMurdo dry valley is only detected after 13kyr BP which is consistent with the deglaciation timing of the low-elevation valleys included in the DS database (Diaz et al., 2020). In contrast, higher-elevation valleys in McMurdo regions have remained ice-free since the Miocene and have accumulated substantial atmospheric material from distal sources - especially during glacial periods. As a result, those areas display REE patterns are strongly influenced by deposition from Australia, Patagonia, New Zealand (Diaz et al., 2020). In order to avoid the risk of conflating distal and local Antarctic signals potentially leading to overestimation of the Antarctic contribution, we excluded those high-elevation areas from the DS database. Furthermore, dust transport from ice-free coastal areas to EDC have been shown very limited (Delmonte et al., 2013).*"

Q9: Along the same lines, Coppo et al., 2022 argues that the activation of S-CWA is a plausible dominant PSA to the East Antarctic Plateau during the LGM; however, this paper's findings suggest it is not a dominant contributor during any time across the LGIT. This is an interesting difference and may also be related to its limited quantity (n=5) in the PSA database. All of these above points, especially when in contrast to papers that are heavily cited in the text, central-western Argentina are worth noting/discussing further.

A9: We interpret the results of Coppo *et al.,* (2022) somewhat differently. While they highlight that the Sr–Nd isotopic composition of EAP dust during the LGM is almost identical to that of CWA, they also emphasize that this signal is not uniquely diagnostic and may reflect mixing ["*either from southern central-western Argentina or from a combination of Patagonia/Tierra del Fuego and southern Puna in the PAP. Our results favor this second scenario…"*]. For Holocene dust, Coppo *et al.,* (2022) report more dispersed isotopic signal, indicative of a more complex and variable source mixture, in which CWA may contribute mainly as part of a Patagonian–CWA end member. However, its relative contribution remains poorly constrained, and additional inputs from the Puna–Altiplano region and Australia are also proposed. Overall, the cautious interpretation of Coppo *et al.,* 2022 illustrates the limitations of relying solely on isotopic tracers for dust provenance.

In this context, we consider that our REE-based approach provides additional and more specific constraints on the contribution of CWA to EAP dust. Central-western Argentina displays distinctive REE patterns, notably characterized by negative Nd and Ho anomalies (Fig. S2 of [Vanderstraeten *et al.,* (2023)]), which would be expected to leave a clear imprint in the EDC record if CWA were a major contributor. The absence of such features and the consistently low modeled CWA contribution therefore suggest that CWA was not a dominant long-range dust source to EDC. CWA were also absent from our EDML provenance record which is the closest and directly down-wind from South Southern America sources.

Regarding the limited number of CWA dust source (DS) samples, we included all available <5 µm fine-fraction samples (n=5) reported by Gili et al., (2017), which, to the best of our knowledge, remains the only study providing REE data for fine-grained materials from CWA. Although the CWA dataset is limited, it currently represents the most comprehensive REE characterization of this region and cover with 3 REE patterns the South CWA.

To evaluate the sensitivity of our results to grain-size effects, we performed additional runs including REE data from the <63 µm fraction reported by Gili *et al.,* (2017), adding 5 REE patterns from CWA.

While this broader fraction is much less representative of long-range transported dust, its inclusion provides a useful test of model behavior for EDC and EDML ice core. These runs produced minor Holocene CWA contributions at EDC but no corresponding signal at EDML, despite EDML being geographically closer and directly downwind from South American dust sources. This spatial inconsistency, together with the well-established dominance of the <5 µm fraction in Antarctic ice core, supports our decision to restrict the provenance analysis to fine-fraction data in CWA. We therefore conclude that inclusion of coarser fractions does not provide a physically consistent or robust constraint on CWA contributions to Antarctic dust.

Added text in section 4.2 (line 305-316):

« Although CWA has been proposed as an important PSA in southern South America (Gili et al., 2017), it is notably absent from our EDC provenance record. A similar absence was observed in the EDML record (Vanderstraeten et al., 2023), despite this site being the closest to, and directly downwind of, SSA. The distinctive REE patterns of CWA, characterized by pronounced negative LREE and HREE anomalies, would be expected to produce a clear imprint if CWA were a major contributor to either ice core. The CWA "hypothesis" is based on isotopic evidence; however, the strong overlap between the isotopic signatures of CWA (εNd ≈ −4 to 0; $^{87}Sr/^{86}Sr \approx 0.707$–$0.712$; Gili et al., 2017) and those of Patagonia, the S-Puna, the Darling Basin, and southeastern Australia complicates the clear discrimination of these sources. Taken together, these lines of evidence suggest that CWA is unlikely to represent a major dust source in the EDC and EDML records. »

Q10: I agree with the principle of modeling Sr-Nd isotope compositions and comparing it to established data as a fidelity check for the DEPOT algorithm and thank the authors for exploring this; however, I have some concerns in the way this is currently presented in the manuscript. First, the measured Sr-Nd isotope compositions of samples are described as coming from dust in ice cores as reported in previous studies; however, the Iso Early Holocene category appears to consist predominantly of dust from modern snow pits on Berkner Island (not from ice cores; Bory et al., 2010). Furthermore, in the text Early Holocene is classified as 11.7-7.5 kyr BP, but these Berkner Island data do not represent that time interval. The dust described in Bory et al., 2010 span a two-year period from 2002-2003. Therefore, I do not think these are relevant and should be removed.

A10: We thank the reviewer for this careful observation and agree that the Berkner Island samples reported by Bory *et al.,* (2010) represent modern snow pit material (2002–2003) and therefore do not correspond to the Early Holocene time interval (11.7–7.5 kyr BP) as defined in our study. We acknowledge that was misleading and have changed to "Iso Holocene". It is important to note that this "Iso Holocene" dataset is not solely compose of Berkner Island dataset but also from Talos Dome, Taylor glacier and Taylor Dome that also showed a much wider variability than LGM data (Table S5).

We consider however the Berkner are important to keep as they currently represent one of the very few Sr-Nd isotopic measurements of East Antarctic atmospheric dust available to be directly comparable with our modeled results for low-dust conditions typical of Holocene. They therefore provide an important reference for evaluating the performance of the DEEPOT algorithm under modern-like climatic conditions. We have revised the caption and Figure 2 to clearly distinguish these data as modern reference samples.

We emphasize that this change improves the temporal consistency of the comparison without affecting the main conclusions of the Sr–Nd fidelity test.

Q11: Second, after removing the Berkner Island data, I would not necessarily agree that there is close agreement between the modeled EDC Sr-Nd isotope compositions and the literature measured Sr-Nd isotope compositions of dust from Dome C and Taylor Glacier. For East Antarctic sites during the Holocene, εNd values of ice core dust are generally below 0 but not lower than -10 and for 87Sr/86Sr range approximately between 0.707 and 0.715. While the modeled Holocene data do capture a wider range than the modeled LGM data (as expected), the modeled Holocene data appears to extend beyond what would be expected from measured ice core dust, which merits some explanation.

A11: We thank the reviewer for this careful assessment. To complement our A10 reply, it is important to add that some data points from the Taylor Dome reach -13.5 in εNd and 0.716 for $^{87}Sr/^{86}Sr$ values, i.e., highlighting that the isotopic measurements exhibits quite a large variability despite their scarcity (even when Berkner Island dataset is not considered). We believe that the wider range displayed by the modeled Holocene and LGM data primarily reflects the much higher temporal resolution of the REE-based record compared to the sparse isotopic dataset. The REE record provides "quasi-continuous" information, allowing the model to capture short-term variability and transient source-mixing events that are not resolved by the limited number of available isotope measurements. In contrast, Sr–Nd data are available for only a few discrete time intervals, which likely represent time-averaged conditions and may underestimate the full natural variability of dust sources. As a result, some modeled values extend beyond the currently documented isotopic range. Additional high-resolution Sr–Nd records would be required to more fully evaluate the modeled variability. Importantly, despite this broader spread, the modeled isotopic fields remain centered within the range of observed values, supporting the overall consistency of the DEEPOT results.

We have added clarification in the revised manuscript (in section 4.1 in lines 282-286) to emphasize that the apparent mismatch partly reflects differences in temporal resolution and data availability, rather than a systematic bias in the model.

Added text in lines 261-273: "*The broader range of the modeled LGM and Holocene (relative to the measurements) primarily reflects the much higher temporal resolution of the REE-based record compared to the sparse isotopic dataset. The isotopic data, compiled from different sites and only available only for discrete time intervals likely represent time-averaged conditions and therefore underestimate the variability of dust sources. In contrast, the quasi-continuous REE record enables the model to resolve short-term variability and transient source-mixing events. Despite those limitations, our modeled isotopic compositions generally agree with those measured in EDC (and with other East Antarctic dust records) during both glacial and interglacial intervals supporting the robustness of our DEEPOT algorithm and reinforcing the interpretation that a distinctive shift in dust provenance occurred over the LGIT.*"

Q12: Similarly, the modeled LGM measurements span a wider range than would be expected for MIS 2 samples, which based on the literature should be tightly clustered around εNd of -1 or -2 and 87Sr/86Sr of ~709. Furthermore, when looking at the PSA % contributions during the LGM, all PSAs appear relatively stable and with a consistent mix of sources, I would expect a much tighter modeled cluster as a result. Why might be the modeled data result in these wider ranges?

A12: We thank the reviewer for this comment. As in **A11**, the broader range of modeled LGM isotopic values primarily reflects the contrast between the high temporal resolution of the REE-based modeling and the limited number of available Sr–Nd measurements for MIS 2. The isotopic data currently available for the LGM represent only a small number of discrete samples and likely reflect time-averaged conditions, resulting in a tightly clustered signature in the literature. In contrast, our model is constrained by tens of REE data points spanning the MIS3/LGM, allowing it to resolve shorter-term variations in source mixing.

Although the relative dust source contributions during the LGM appear comparatively stable over, they are not constant. As shown in Fig. 3, the Patagonian contribution varies between approximately 50% and 95% during this period. Given the strong contrast in Sr–Nd compositions between Patagonia and other PSA, even moderate changes in mixing proportions can lead to significant shifts in modeled isotopic values as illustrated in Fig. 2. This sensitivity, combined with the higher temporal resolution of our dataset, explains why the modeled LGM isotopic fields display a wider range than the currently available measurements. We have clarified this point in the revised manuscript.

Q13: Lastly, I think part of the difficulty in deciphering Figure 2 is that there are multiple goals rooted in several comparisons (i.e., comparing time interval changes, modeled vs. measured data, and PSAs).

Perhaps this could be split into multiple figures or panels. One could focus on directly comparing modeled vs. measured data and one on just comparing modeled data to PSAs.

A13: We agree with the reviewer. We have now separated this overly complex figure in several panels separating the different periods of time. Figure 2 now shows only LGM and Holocene while Figure S5 shows four panels illustrating end of MIS3, HS1, ACR and YD.

Q14: Section 4.3. This section is packed with useful information but does struggle a bit in its structure. The opening paragraph provides three processes to explain the variability across the Holocene. As a reader, I expected the subsequent paragraphs to be focused on a discussion of these processes in greater detail, but that was not necessarily the case. The next paragraph (L315-334) feels very results heavy and compares the record broadly to other papers. Then, the following paragraphs are subdivided into PSA-specific discussions, which are very detailed but also hyper-focused. I think this section would be greatly improved by a slight restructuring and including a broader discussion of the glacial-eustatic and hydrological feedbacks that connect the regional source dynamics.

A14: We agree with the reviewer on this point. Section 4.3 has now been divided into two sections: Section 4.3, which addresses the drivers of variability after 14.5 kyr BP, and Section 4.4, which focuses on regional responses to glacial–interglacial transitions. Glacial-eustatic and hydrological feedbacks are discussed in detail at the end of Section 4.5, following the EDML/EDC comparison that establishes a pan-Antarctic dust signal.

Q# refer to questions by the reviewers, **A#** refer to our replies to the corresponding question, **line number** mentioned in our replies refer to the revised version of manuscript.

Review of Boxho et al, CP
Dec. 30, 2025 by Bess Koffman

This paper applies a previously developed statistical 'unmixing' model to a previously published rare earth element (REE) dataset from the EPICA Dome C ice core in Antarctica to infer changing dust source contributions over time. In general, I think this is a worthwhile exercise with the potential to clarify broad interpretations about changing dust provenance during climate transitions, and their causes. Following major revisions, it should be appropriate for publication in *Climate of the Past*.

We thank the reviewer for this positive overall assessment and for recognizing the potential of our approach to clarify changes in dust provenance across climate transitions. While our study indeed builds on previously published REE measurements from the EDC ice core, we would like to emphasize the fact that our quantitative statistical unmixing framework opens a whole new perspective to this unique REE dataset, offering an unprecedented interpretation of dust source variability through time.

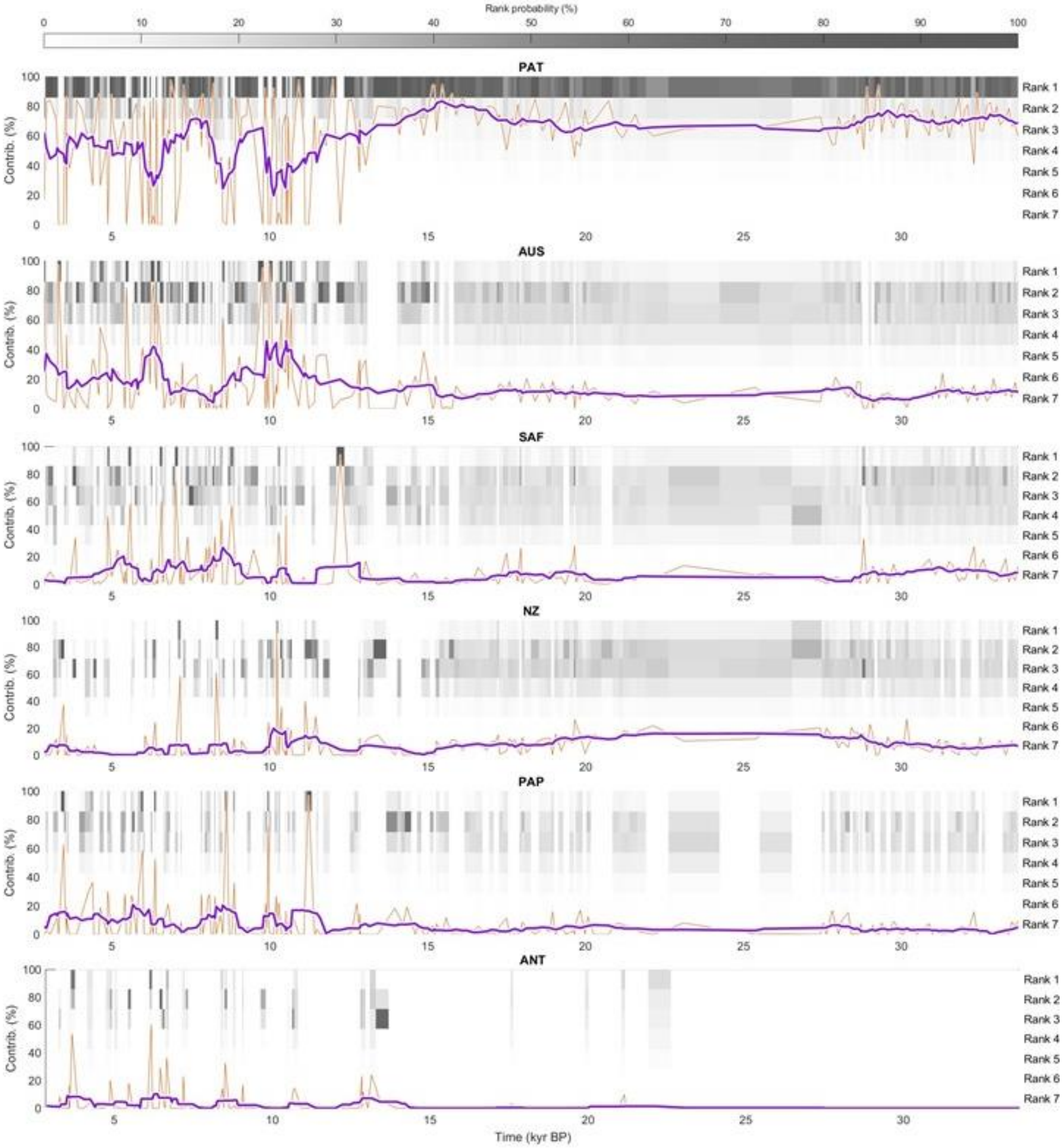
We are grateful to Dr. Bess Koffman for the time and care devoted to this review. Below, we have addressed each comment in detail and describe how we revised the manuscript accordingly to clarify the novelty, scope, and implications of our work.

The paper needs substantial work to be publishable. My main critiques are that 1) the estimates of potential source area (PSA) contributions are presented without uncertainties, making them basically meaningless; 2) differences in interpretation between this study and previous ones are not thoroughly described and supported with evidence; 3) the Younger Dryas is included in the interpretation as if it were a climate event in Antarctica; I find this baffling given the geographical focus of the paper; 4) figures have a range of issues (see comments below); 5) the writing needs major revision with respect to grammar, subject/verb agreement, punctuation, and spelling. In addition, the introductory paragraph follows the structure and citation ordering of the Vanderstraeten et al 2023 study from the same group (thanks to the other reviewer for pointing this out). While I wouldn't call it plagiarism, the similarity is striking. This paragraph should be rewritten and additional citations included.

Q1: Regarding point 1) above: in the paragraph starting on Line 153, analytical uncertainties are discussed, along with their impact on the model outputs, but the uncertainties on the dust provenance estimates from the MC simulations themselves are not given anywhere (unless I missed them somehow). This seems like a simple correction but a very important one. Uncertainties should be incorporated into the text where numerical values are given, as well as into the figures where temporal changes in PSA contributions are indicated (i.e. as colored confidence intervals).
A1: We thank the reviewer for raising this important point. The quantification of the uncertainty of our results captured by the variability between our Monte Carlo (MC) simulations is something we might not have sufficiently reported in the previous version of the manuscript, but the request of the reviewer prompted us to improve this aspect of the study. An important challenge however is to fairly represent these uncertainties. Each Monte Carlo run simulated by our unmixing model yields, a different combination for each time step which do not always include all the sources contributing to the dust sample. This variability results in distributions of the contributions of our PSA across all MC simulations that are generally not gaussian or symmetric and are at times even bimodal. This was already described and illustrated in Fig. S4 of Vanderstraeten *et al.,* (2023) but it implies that the sole reporting of 'uncertainty range' only conveys part of the information regarding the robustness of our simulation and, alone, can even be misleading. To circumvent this limitation and provide a complete picture of our results, we believe they should also be completed by a more qualitive assessment related to the ranking of the PSA. Thus, in the revised manuscript, we now explicitly report the statistical dispersion of the Monte Carlo (MC) outputs associated with the dust provenance estimates. The already reported median (P50) values, used as the main estimate of source contributions, are

associated in Table S2 with the 25th (Q1) and 75th (Q3) percentiles of the probability density function (PDF) derived from the 2000 MC simulations for each PSA at every time step. These percentiles characterize the spread of the PDF and thus provide a quantitative characterization of the variability of the simulated PSA contributions.

In addition, to better illustrate the behavior of the MC simulations in Figure 1, we have also introduced a probabilistic visualization of the source ranking. The grayscale shading represents the probability, across the 2000 MC simulations, that a given PSA occupies a particular rank at each time step (see figure below). Darker shades indicate a higher probability that the source consistently occupies that rank, whereas lighter shades indicate greater variability among the simulations. This representation provides a visual measure of the robustness and dispersion of the MC solutions, highlighting periods when a source is consistently dominant versus intervals when multiple sources compete. We believe this approach conveys the variability inherent to the MC framework while preserving the readability of the figure. This probabilistic representation also highlights the stability of the unmixing solution by showing when a source persistently occupies a given rank across the ensemble of MC simulations, thereby providing an intuitive visualization of the uncertainty and robustness of the inferred dust provenance.



Revised figure 1: Evolution of PSA contributions to EDC ice core between 2.852 to 33.699 yr BP. Median values of PDF distribution are in red while bold purple line denotes the mobile average over 9 steps. Grayscale shading indicates the probability (in %) that the source occupies a given rank in the mixing across the 2000 Monte Carlo simulations (from rank 1 to rank 7).

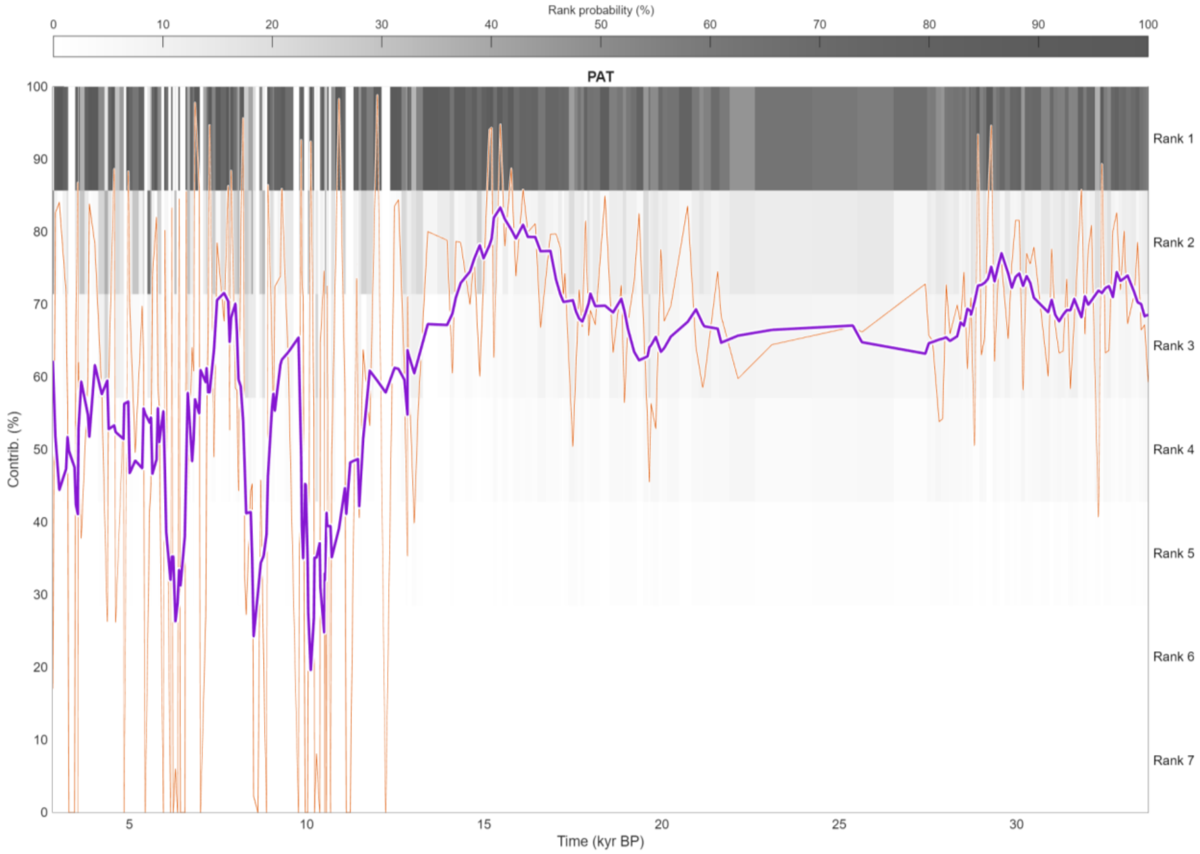


Figure A1: Evolution of PAT contributions to EDC ice core between 2.852 to 33.699 yr BP. Median values of PDF distribution are in red while bold purple line denotes the mobile average over 9 steps. Grayscale shading indicates the probability (in %) that the source occupies a given rank across the 2000 Monte Carlo simulations.

Q2: Regarding point 2) above: there are a number of places where comparisons to prior publications (and their interpretations) are given in a cursory manner, but differences are not fully explored or justified. Considering the volume of published papers on Antarctic dust provenance, this is a place where the present study could really aim to leverage its findings for new insights. One example relates to South American dust sources. The explanation of why the southern Puna and southern Altiplano both contribute dust but not the northern Puna (which is geographically sandwiched between them) needs to be clarified and better justified. This is especially confusing because in Fig. 3a of Gili et al 2017, the REE fields of the northern and southern Puna fully overlap, and their paper includes N Puna as a source. What specific REE ratios support eliminating N Puna as a dust source to EDC? I would also like the authors to reference and/or address the statement in Gili et al 2017 that "REE are less useful for distinguishing sediments from CWA and Puna." The Gili paper highlighted CWA as a more important source than Patagonia, which I don't really see addressed in the present study.

A2: We thank the reviewer for this important comment. We acknowledge that our results differ from previous interpretations/claims and we appreciate the opportunity to clarify those differences. In Gili *et al*., (2017), the Sr-Nd domains of Northern Puna was defined for the first time, and at that time, provided an improved framework for interpreting EDC dust provenance. However, at that same in 2017, isotopic data from Southern western Africa, another important PSA for Antarctic dust, were not available. Subsequent work by Gili *et al.,* (2022) demonstrated that Sr–Nd–Pb isotopes from Namibian coast strongly overlaps with those of Northern Puna – making it difficult to distinguish between those two PSA using isotope alone. Regarding REE systematics, we agree that in Fig 3A of Gili et al., (2017), Southern and Northern Puna domains strongly overlap in Eu*/Eu vs. La/Yb_N space. Indeed, in that two-dimensional representation REE appear less discriminating that isotopes, as stated in Gili et al. (2017). Our approach differs in that we do not rely on bivariate projections but instead we use the full normalized REE pattern (13 elements) in a multidimensional unmixing framework. When considering the complete REE patterns, Northern and Southern Puna show systematic differences (i) with substantially higher Sm value in Southern Puna compared to Northern Puna (ii) (ii) the magnitude of the Eu anomaly and (iii) the enrichment in HREE segment. These differences are not readily visible in two-dimensional plots but become resolvable when the entire REE distribution is used simultaneously. On this basis, the model assigns negligible Northern Puna contributions to both EDC and EDML. We acknowledge, however, that additional sampling in Northern Puna and more generally in other PSA would further strengthen our model, and we now state this explicitly in the revised manuscript in the materials and methods section in lines 153-155: "*As in most provenance studies, the robustness of the unmixing results ultimately depends on the representativeness of the source dataset, and additional sampling would help better capture the natural geochemical variability of the different source areas.*"

We now discuss the Puna-Altiplana Plateau in lines 496-510:

The Puna - Altiplano Plateau emerges as a secondary dust contributor to EDC after 14.5 kyr BP, consistent with its strong sensitivity to aridification and the desiccation of riverbeds, alluvial fans, and paleolake systems. Dust from the South Puna contributes throughout the record, whereas the Southern Altiplano becomes active only after ~11.2 kyr BP (Figure S3), which coincide with the final desiccation of paleolake Coipasa and the establishment of persistent arid conditions (Condom et al., 2004; Blard et al., 2011; Placzek et al., 2006). Although Northern Puna has been suggested in several studies as a major source to EAP (e.g., Gili et al., 2017; Gili et al. 2022; Gaiero et al., 2013), differences in Ce, Sm, Eu and LREE contents allow our algorithm to distinguish between Northern and Southern Puna revealing a clear dominance of South Puna contribution in the EDC. Recently, Pullen et al. (2022) showed that South Puna was an active dust source area during the late Pleistocene and Holocene periods. The combined PAP dust assemblage—comprising a mafic component from the South Puna and a crustal component from the Southern Altiplano—is also consistent with Sr-Nd isotopic compositions of SSA sources and that of the Pampean loess reported by Coppo et al. (2022). Overall, the relatively important contribution of PAP to Est Antarctica during interglacial periods is consistent with previous provenance studies (Gili et al., 2016; 2017; Gaiero et al, 2013; Gili et al., 2022).

Regarding CWA – we addressed that point in our reply to Austin Carter's review (A8).

Q3: Also, a number of studies have treated Tierra del Fuego as its own source area, but the present study seems to ignore it. Is it simply not included, or is TdF being incorporated into the Patagonia PSA? Some discussion is warranted – and ideally, the paper would provide full treatment of TdF as its own source region. A more in-depth discussion of the differences between this study's conclusions and those of Gili et al 2017 is needed, with evidence provided to support the interpretations.

A3: We thank the reviewer for raising this point. In our study, Tierra del Fuego (TdF) is included within the Patagonia. Our REE endmember database incorporates six REE patterns from TdF dust and topsoil compiled from Gili *et al.,* (2017), ensuring that this region is represented in the unmixing model. In our provenance reconstructions, the TdF component is consistently detected but contributes only for a very small fraction of the total dust at both EDC and EDML throughout the studied interval. We therefore do not treat it as a separate source region in the discussion.
We added a mention in line 143-144: "*This dataset (Table S2) includes samples from Southern South America (SSA), subdivided into Patagonia (PAT; 39 dust sources, DS including mainland Patagonia and Tierra del Fuego)…*"

Q4: Regarding point 3) the Younger Dryas is included in the interpretation as if it were a climate event in Antarctica; I find this baffling given the geographical focus of the paper.

A4: We believe the debate about the expression of Younger Dryas in the Southern Hemisphere is out of the scope of the study. We agree that the Younger Dryas is primarily expressed in the Northern Hemisphere as a major cooling event, however it is also evident in the Southern Hemisphere as a distinct climatic interval characterized by relatively mild and generally warmer conditions following the Antarctic Cold Reversal, consistent with the bipolar seesaw framework. In Antarctica, this period is marked by rising $\delta^{18}O$ values in the EDML and EDC record, indicating continued warming. It is also associated with glacier retreat in southern South America (Kaplan *et al.,* 2010). This transition constitutes, in our view, a climatically meaningful phase that is distinct from the ACR.

Q5: figures have a range of issues (see comments below)

A5: We addressed those point below.

Q6: The writing needs major revision with respect to grammar, subject/verb agreement, punctuation, and spelling.

A6: We revised the entire manuscript to correct for grammar, spelling mistakes.

Q7: In addition, the introductory paragraph follows the structure and citation ordering of the Vanderstraeten et al 2023 study from the same group (thanks to the other reviewer for pointing this out). While I wouldn't call it plagiarism, the similarity is striking. This paragraph should be rewritten and additional citations included.

A7: We have rewritten the introduction to address this point.

Minor comments:

Q8: Line 31: "Linking dust composition to eustatic sea level rise" – This isn't new as other studies have highlighted this potential link before. Also, I don't see any evidence presented in this paper that conclusively links dust provenance changes to any specific process in South America such as those described here. Either these connections need to be strengthened, or this sentence should be cut from the abstract.

A8: We agree that the potential link between Antarctic dust provenance and eustatic sea-level rise has been proposed previously, including in our earlier work Vanderstraeten *et al.,* (2023) but also other such Delmonte *et al.* (2017). In the introduction, we aimed at relaying the findings of our previous article on the dust provenance in EDML ice core, not to make a demonstration, we refer the reviewer to Vanderstraeten et al., (2023) on that matter. More generally, our intention here is not to claim novelty for this point, nor to imply a direct and exclusive causal relationship solely based on the EDC record. Rather, the contribution of this study is that the EDC provenance record independently reproduces the same timing, direction, and nature of the provenance shift previously identified at EDML, despite the different geographic setting, transport pathways, and dust flux regimes of the two sites. In Vanderstraeten *et al.,* (2023), the connections between eustatic sea-level rise, continental shelf submergence, and changes in Patagonian dust emissions were examined in detail, taking advantage of the EDML site's location directly downwind of Patagonia and its greater sensitivity to Atlantic-sector dust transport (see Fig. 8 therein). We believe this is not necessary to replicate such a detailed discussion in the current study. We consider it appropriate to frame our EDC results as being consistent with the influence of eustatic sea-level rise and associated postglacial reorganization of river leading to a reduction and re-routing of sediment in Patagonia. We have revised the abstract wording to emphasize replication and consistency across sites rather than asserting a new causal mechanism.

We modified the ending of the abstract to:
"The consistency of the provenance shift recorded at EDC and EDML ice cores points to a common large-scale control, in line with the influence of eustatic sea-level rise and postglacial reorganization of fluvial sediment routing and availability in southern South America."

B. Delmonte, C.I. Paleari, S. Andò, E. Garzanti, P.S. Andersson, J.R. Petit, X. Crosta, B. Narcisi, C. Baroni, M.C. Salvatore, G. Baccolo, V. Maggi Causes of dust size variability in central East Antarctica (Dome B): atmospheric transport from expanded south american sources during marine isotope stage 2 Quat. Sci. Rev., 168 (2017), pp. 55-68, 10.1016/j.quascirev.2017.05.009

Q9: Line 40: this statement deserves a more complete set of citations.

A9: We added extra reference to support this statement.

Q10: Line 88: Remove hyphens in this sentence.

A10: We rewrote this whole section.

Q11: Line 123: Please provide more information on the digested samples: how many were there? At what temporal resolution? Are they evenly distributed throughout the part of the core used for this analysis?

A11: In Gabrielli et al. (2010), two ice samples were digested for REE analysis: one representative glacial sample and one representative interglacial sample. Each sample was digested in triplicate together with two procedural blanks. These measurements were not intended to provide a temporal reconstruction but were used to determine the correction factor (cf_i) between partial and total dissolution of dust particles. The triplicate analyses allowed us to quantify the analytical variability of the correction factor, which we propagate in the Monte Carlo simulations used in the unmixing model. We have clarified this point in the revised manuscript.

Added text in lines 138-139: "*we applied cfi derived from parallel measurements of fully digested EDC samples (three replicates of one glacial and interglacial samples) to obtain total REE concentrations allowing fitting with REE patterns from PSA*"

Q12: Line 127: Where are the citations for these data provided? Are the published PSA data all on digested samples? Needs to be fully described here, as differences in leaching/digestion could lead to discrepancies in the resulting REE concentrations.

A12: As mentioned in line 143, Table S1 regroups all information regarding the REE patterns, including the reference from which they were extracted when appropriate. All REE patterns in our database were verified to be measured after full digestion.

Q13: Line 130: Why is Tierra del Fuego not included?

A13: I refer the reviewer to A3. Briefly, Tierra del Fuego is included in our database within Patagonia.

Q14: Lines 145-146: needs revision.

A14: We thank the reviewed for pointing this out. We revised the sentences in question.

Q15: Line 179: Please omit the dash in this sentence.

A15: We removed the dash.

Q16: Line 187: the time period listed as "Late Holocene" is really more "Middle Holocene," especially considering the cutoff at 2.8 ka. Further, the "Early" and "Middle" portions of the Holocene are commonly distinguished at 8.2 ka. The authors might want to consider this date as the boundary rather than the seemingly arbitrary 7.5 ka.

A16: We agree to change the "Late Holocene" to "Middle Holocene".

Q17: Line 189: remove the word "for"

A17: We made the correction. Thank you.

Q18: Line 199: What does "mafic-like" mean? Can you just use the word "mafic"? Also, LREE stands for "light rare earth elements" not "low". Please correct this.

A18: We changed "mafic-like" for "mafic" and "low REE" for "light REE".

Q19: Paragraph beginning line 201 and throughout: What are the uncertainties on these estimates of PSA contributions? Please give the plus-or-minus values. It's hard to assess how meaningful these numbers are without quantified uncertainties.

A19: Uncertainties associated with the provenance estimates are derived from the Monte Carlo simulations used in the unmixing model (we refer the reviewer to A1). For each individual time step, we report the median contribution together with the 25th and 75th percentiles, which represent the range associated with the model parameters. These values are provided in Table S2.

In the paragraph mentioned by the reviewer, the values correspond to averages calculated over specific time intervals and therefore represent the mean contribution of each PSA across multiple samples. In this context, the variability reflects natural temporal changes in source contributions rather than the uncertainty of a single model estimate. For this reason, we report only the average contributions for these intervals and refer the reader to Table S2 for the uncertainty ranges associated with the individual time steps.

Q20: Line 220: Please capitalize EPICA.

A20: We thank the reviewed for pointing this out. We rewrote it.

Q21: Lines 202 and 223: The listed PSAs have a different order in these two sentences but it is not obvious that they refer to different time periods. Please double-check what is correct and revise as needed.

A21: We thank the reviewed for pointing this out. We rewrote it.

Q22: Line 258: The authors state there is "close agreement" between the measured and modeled Sr-Nd isotope values, but Figure 2 suggests the agreement during certain intervals is better than others. The modeled "iso" symbols appear to be systematically offset to lower 87Sr/86Sr from the measured values in the eNd range of ~ -7 to -12. Then in the LGM interval, the "iso" symbols are tightly clustered in a narrow Sr-Nd range that is also offset to higher 87Sr/86Sr values compared to the bulk of the actual data. The authors need to address the reasons for these discrepancies between the REE-inferred Sr-Nd isotope data and the measured values.

A22: We refer the reviewer to **A11** (in our reply to Austin Carter's review) that also raised this point. Briefly, the broader range of modeled Holocene and LGM values reflects the much higher temporal resolution of the REE-based record compared to the sparse Sr–Nd isotope data. The quasi-continuous REE record captures short-term variability and transient source-mixing events that are not resolved by time-averaged isotopic measurements, causing some modeled values to extend beyond the documented isotopic range. Despite this, modeled fields remain reasonably close to observed values, supporting the consistency of the DEEPOT results. Clarifications emphasizing the role of data resolution and availability have been added to the revised manuscript in section 4.1 lines 347-355.

Q23: Line 261: "Persistence" is misspelled.

A23: We thank the reviewed for pointing this out. We rewrote it.

Q24: Line 283: It might be helpful to the reader to provide some context, e.g. by adding "on the basis of combined Sr-Nd-Pb isotope compositions" to the end of this sentence.

A24: We added this precision to the text.

Q25: Line 284-285: Koffman et al 2021 also estimated the expanded outwash plain area available for dust deflation during the LGM with a sea level lowering of 130 m. Their estimate, at ~75,000 km^2 of exposed continental shelf, is a bit higher than that of Vanderstraeten et al 2023. It might be worth providing both values to give some sense of the range of estimates.

A25: We added this estimation to the text together with ours.

Q26: Line 306: The YD is mentioned here without context. Why is this Northern Hemisphere climate phenomenon relevant to a paper on Antarctic dust provenance? If the paper were focused on interhemispheric climate signals and phasing I could see the logic for highlighting the YD, but otherwise it just seems out of place. I suggest focusing on Southern Hemisphere climate signals such as the ACR in this paper, as this seems more relevant.

A26: We refer the reviewer to our reply A4, above.

Q27: Line 307: The sentence beginning on this line needs grammatical revision.

A27: We thank the reviewed for pointing this out. We rewrote it.

Q28: Line 311: The double angled brackets around "wet scavenging" can be removed.

A28: We thank the reviewed for pointing this out. We change it in the text.

Q29: Line 334: The year for the Speirs article is 2010, not 2001. Further, the direction the winds blow in the McMurdo Dry Valleys, as shown in that article, is generally west-to-east, not east-to-west (see e.g. their figure 4, showing winds from 270 degrees). One must remember that north is "up" toward the coast when looking at maps of Antarctica. Please correct this sentence.

A29: We thank the reviewed for pointing this out. It was a point of Austin Carter's review, so we completely rewrote this section (now split into 4.3 and 4.4) and removed this reference.

Q30: Lines 339-352: It is not possible to evaluate this paragraph given the lack of labeling on Fig. 5

A30: This part is completely rewriting with the creation of the new Figure 5 (*named Figure 4 in new version*).

Q31: Line 353-362: The explanation of why the southern Puna and southern Altiplano both contribute dust but not the northern Puna (which is geographically sandwiched between them) needs to be clarified and better justified. This is especially confusing because in Fig. 3a of Gili et al 2017, the REE fields of the northern and southern Puna fully overlap, and their paper includes N Puna as a source. What specific REE ratios support eliminating N Puna as a dust source to EDC? I would also like the authors to reference and/or address the statement in Gili et al 2017 that "REE are less useful for distinguishing sediments from CWA and Puna.

A31: We refer the reviewer to our reply A2 above, and A9 of Austin Carter's review for a detailed discussion on CWA and Puna.

Q32: Also, a number of studies have treated Tierra del Fuego as its own source area, but the present study seems to ignore it. Is it simply not included, or is TdF being incorporated into the Patagonia

PSA? Some discussion is warranted – and ideally, the paper would provide full treatment of TdF as its own source region.

A32: We refer the reviewer to our reply A3 above.

Q33: And finally, a more in-depth discussion of the differences between this study's conclusions and those of Gili et al 2017 is needed, with evidence provided to support the interpretations.

A33: We refer the reviewer to our reply A2 above.

Q34: Line 384-385: A phrase is repeated

A34: Corrected in the text.

Q35: Line 407: Why are the ACR and YD included together as if they are both climate events in Antarctic ice cores? I suggest removing YD references unless there is clear justification for discussing the YD.

A35: We believe the debate about the expression of Younger Dryas in the Southern Hemisphere is out of the scope of the study. Because we noticed both in EDC in this study and in EDML [Vanderstraeten *et al.,* (2023)] that significant changes in dust sources occurred during this YD period. That is why we maintain this climatic event in our observations, as discussed in *A2 and A26 above*.

Q36: Line 426: remove second use of "dust" in this sentence

A36: We have deleted this in the new version of the article.

Q37: Line 430: "PSA sources" is redundant. Can simply use "PSAs". This sentence also should include citations as this is very detailed information about transport pathways.

A37: Corrected in the new version of the article. We added two references to the sentence in question.

Q38: Line 466-470: This is very arm-wavy given the actual evidence presented in this paper. Suggest removing or toning down the language here.

A38: The interpretation proposed in the section in question is not intended to represent a direct demonstration based solely on EDC data, but rather to place our results in the broader framework of previously proposed mechanisms. In particular, Vanderstraeten et al. (2023) suggested that postglacial geomorphological changes in Patagonia—including continental shelf submergence and drainage reorganizations—played an important role in modulating sediment availability and thus high-latitude dust emissions during the LGIT. The results presented here independently support this interpretation. The temporal evolution of PSA contributions reconstructed at EDC mirrors the pattern previously reported for EDML (Section 4.5; Vanderstraeten et al., 2023). The agreement between these two distant Antarctic sites suggests that the mechanisms controlling the decline of high-latitude dust sources during the LGIT operated at large scale over Antarctica. For this reason, we believe it is appropriate to discuss these processes in the manuscript as a plausible interpretation consistent with both our results and previous studies. To address the reviewer's concern, we have slightly clarified the wording in the revised text to emphasize that these mechanisms represent an interpretation supported by multiple lines of evidence rather than a direct demonstration from the present dataset alone.

Added text in line 644-646: "*Collectively, the patterns observed at both EDC and EDML suggest that eustatic sea-level rise and postglacial hydrological reorganization in Patagonia had broad and long-lasting effects on Antarctic dust composition during the LGIT.*"

Q39: Line 476: The contributions of Patagonia and New Zealand should be given summarily here. If NZ is considered a major source, then it should not be in parentheses.

A39: Corrected in the text.

Q40: Line 488: More evidence would need to be presented to support this statement. I do not believe the paper as written provides clear evidence of any of these processes or feedbacks beyond loose temporal correlation. I would like to see a more robust treatment of the range of potential mechanisms (including robust citations) driving changes in dust delivery to EAIS in order to support a statement such as this.

A40: We refer the reviewer to our replies A8 and A38.

Q41: Line 497: I believe "P.B." should be "P.G.," Paolo Gabrielli.

A41: We agree with the reviewer and modify the text.

Figures

Q42: Fig. 1: Please change the x-axis time units to years or thousands of years. Showing time in units of 10,000 years is atypical and not intuitive. This figure would be greatly improved by showing the dust flux in the ice core in addition to the individual PSA contributions. It would also be very helpful to see a d18O or dD record for climate context, particularly to emphasize temperature variations during the deglaciation and to compare to changes in dust deposition and provenance. I also think the "YD" highlighting should be removed, as it does not seem relevant to the study.

A42: We have modified the x-axis time units as suggested.
We prefer not to add the total dust flux, $\delta^{18}O$, and δD records to Figure 1 because these datasets are already presented in Figure S3. Adding these three additional panels would substantially increase the complexity of Figure 1 and risk overloading the figure, reducing its readability. In addition, we provide an estimate of the flux contributions from each PSA to EDC in Figure S2.
Regarding the highlighting of the Younger Dryas (YD), we agree that this climatic event is primarily characteristic of the Northern Hemisphere. However, in our records this interval coincides with marked changes in trends across several source regions. For this reason, we consider it useful to retain the YD marker in the figure, as it helps emphasize these abrupt transitions in dust provenance.

Q43: Fig. 2: In general, I question the "blobs" as currently drawn. The Patagonia field appears far too wide given the data published from this region. The Australia field is missing data from the Northwest Territory and South Australia that would deepen the field to much lower eNd values than what is shown here (e.g. De Deckker 2019). The Southern Puna region has a highly improbable field as drawn; it should be more convex around the available data. The extremely high $^{87}Sr/^{86}Sr$ value included in the NZ field is likely erroneous. I strongly suggest including only data with well-characterized geologic and geomorphic context, in this case, Koffman et al. 2021. In general, I would like to see the actual data points used to generate these "blobs" and the specific citations included for each. This could be a supplementary figure that supports the main text, for instance. But I also think revision of this figure is warranted.

A43: This figure has been completely rearranged according to the insightful comments made by the two reviewers. In particular, we rearranged the Australian domain and considered the reference suggested by the reviewers. The references used to generate these isotopic ranges are as follows: Grousset *et al.*, 1992; Delmonte *et al.*, 2004; Gingele and De Deckker, 2005; De Deckker *et al.*, 2014; Revel-Rolland *et al.*, 2006; Gaiero, 2007; Gili *et al.*, 2017; Gili *et al.*, 2022; Li *et al.*, 2020; Koffman *et al.*, 2021; Blakowski *et al.*, 2014; Diaz *et al.*, 2020. These are mainly fine fractions, where available, and correlate closely with other studies such as Gili *et al.,* (2022).

Q44: Fig. 5: I understand the motivation for this type of comparison, but if the current study aims to draw broader interpretations about the westerlies, or to use proxy records of the westerlies to help interpret the presented dust provenance record, there needs to be appropriate context and breadth of records included. If a figure of this type is to be included, I would also like to see other records from South America and from Antarctic ice cores for context here, as I think it will really strengthen the interpretations and enhance the impact of this work. For instance, you might want to include the NPI (*Nothofagus* to *Poaceae* Index) from Lago Guanaco (Moreno et al. 2010, the Macquarie Island diatom-inferred conductivity record of Saunders et al. 2018, the opal upwelling proxy record of Anderson et al. 2009, the CO2 data and dD data from EPICA Dome C, etc.

In addition, it seems to me that dust flux would be more meaningful to compare to Potrok Aike and these other records. Percent contribution, as currently shown, is a factor of the relative inputs of multiple sources and climate and environmental conditions in those regions, so is less meaningful. It would be better, I think, to scale the total dust flux by the percent from Patagonia and use that in this figure instead (e.g. Patagonia dust flux to EDC). Please also correct the x-axis to be in years or ka, and to match the timescale shown in Fig. 1. Here the (x10^4) is missing so I think the plot is completely uninterpretable as shown. It also needs an x-axis label with units stated. The colored bars are not labeled or described in the caption, but need to be.

A44: We thank the reviewer for the helpful suggestion. We have revised this figure (now Figure 4 in the updated version) by adding several Southern Hemisphere records for comparison. Those includes temperature proxies (δ^{18}O in EDC ice core and Winter Sea-Ice Concentration in marine core PS2090 - Bianchi & Gersonde, 2004*)*, wind intensity indicator (Median Destructive Field MDF in Laguna Potrok Aike - Lisé-Pronovost et al., 2015; diatom-inferred conductivity in Macquarie Island - Saunders et al., 2018) and a fire proxy from Lago Pintito (Patagonia) from Moreno et al., (2021).

These additions allow more meaningful comparisons between the Patagonian contribution to EDC dust deposition and regional climatic and environmental changes in Patagonia and the Southern Ocean. These comparisons are discussed in the revised Section 4.1 (see below).

Added text in lines 475-484: "*Following a pronounced decline after ~14.5 kyr BP, Patagonian contributions reach minimum values around 10 kyr BP (Figure 4). Interestingly, those minima coincide with an early Holocene thermal maximum (11-9 kyr BP) which is clearly expressed in the δ18O record from EDC and more broadly across Antarctica (Masson et al., 2000) as well as in other Southern Hemisphere records (Kilian et al., 2012; Bianchi & Gersonde, 2004). Those climatic conditions likely reduced the thermal gradient between the mid and high latitudes, resulting in persistently weakened wind intensities. Such conditions are recorded at Macquarie Island (sub Antarctic southwest Pacific 54° S - Saunders et al., 2018), in Potrok Aike maar (52° S, Patagonia; Lisé-Pronovost et al., 2015) and in the Southern Ocean south and east of New Zealand (Fletcher et al., 2011). These changes may be linked to a poleward shift of Southern Westly Winds (SWW) belt (Quake and Kaplan, 2017; Moreno et al., 2010). At first glance, those conditions appear unfavorable for dust emissions from Patagonia. However, this interval also corresponds to drier conditions and widespread increase in fire activity in eastern Patagonia (Figure 4 - Moreno et al., 2010; Power et al., 2008; Markgraf et al., 2007). Such conditions likely enhanced dust emissions through vegetation loss and soil destabilization making sediments more susceptible to aeolian deflation upon the return* *of stronger SWW (Dukes et al., 2018; Wagner et al., 2021). After ~8 kyr BP, the strengthening of the SWW coincide with elevated PAT contribution between ~8-7 kyr BP. Apart from a marked drop in PAT contributions between 6-6.5 kyr BP, strong SWW conditions have prevailed since ~5 kyr BP in south Patagonia and correspond to on average PAT contribution of ~50%.*"

Regarding the possibility of comparing the Laguna Potrok Aike wind record with the total dust flux at EDC, we note that the latter is dominated by the two-order-of-magnitude decline occurring between ~18 and 14.5 kyr BP. This large trend overwhelms shorter-term variability and renders a direct comparison with wind proxies difficult to interpret. For this reason, we retain the percentage contribution from Patagonia as the primary metric shown in Figure 4.

-Bianchi, C. & Gersonde, R. Climate evolution at the last deglaciation: the role of the Southern Ocean. *Earth Planet. Sci. Lett.* **228**, 407–424 (2004).

-Lisé-Pronovost, A., St-Onge, G., Gogorza, C., Haberzettl, T., Jouve, G., Francus, P., Ohlendorf, C., Gebhardt, C., and Zolitschka, B.: Rock-magnetic proxies of wind intensity and dust since 51,200 cal BP from lacustrine sediments of Laguna Potrok Aike, southeastern Patagonia, Earth and Planetary Science Letters, 411, 72－86, https://doi.org/10.1016/j.epsl.2014.11.007, 2015.

-Saunders, K. M., Roberts, S. J., Perren, B., Butz, C., Sime, L., Davies, S., Van Nieuwenhuyze, W., Grosjean, M., and Hodgson, D. A.: Holocene dynamics of the Southern Hemisphere westerly winds and possible links to CO2 outgassing, Nature Geosci, 11, 650－655, https://doi.org/10.1038/s41561-018-0186-5, 2018.

-Moreno, P. I., Henríquez, W. I., Pesce, O. H., Henríquez, C. A., Fletcher, M. S., Garreaud, R. D., and Villa-Martínez, R. P.: An early Holocene westerly minimum in the southern mid-latitudes, Quaternary Science Reviews, 251, 106730, https://doi.org/10.1016/j.quascirev.2020.106730, 2021.

Q45: Fig. S2: Please fix the x-axis as in other figures and include appropriate units and labels.

A45: Done.

Q46: Fig. S5: Large y-axis label contains a typo. Actually, this figure is pretty interesting and might be worth adding to the main text once it is revised. I think it provides a nice complement to Fig. 4. I note that the x-axis ages and labeling are distinctly different from the other figures. As mentioned before, figures should all use the same units – either years or kyr.

A46: We transferred this figure to their main text in the new version of the manuscript as Figure 6.

Q47: Table S4 and elsewhere: "Localisation" in English means to make something more localized. It would be better to use the word "Location."

A47: Done.

Q48: All Tables and Figures: Please use decimals for numbers rather than commas.

A48: We agree with the reviewer and modify the text, Figures and Tables accordingly.