

Response to Referee 2

The referee comments are shown in black and are numbered sequentially as [R2-#1], [R2-#2], etc. Our responses are shown in blue.

We thank the referee for the positive and constructive comments. Several comments overlap with those of Referee 1, and the corresponding revisions have been implemented consistently. The main revisions include (1) additional evaluation of the chronology and temporal resolution through age-based ice-core comparisons and clarification of the volcanic-sulfate detection and resolution; and (2) a new analysis of post-eruption $\delta^{18}\text{O}$ and snow-accumulation responses.

[R2-#1] RC2: 'Comment on egusphere-2026-3602', Giulia Sinnl, 03 Sep 2026

Hamamoto et al. present an excellent contribution to the field of ice-core science and paleoclimatology in terms of a very detailed chronology at sub-annual precision for the period 1871-2020 CE, adding a considerable pre-satellite interval to the previously established SE1 chronology from the same site. By dating the climatic signal of the ice core SE-Dome II in great detail, the authors enable a semi-independent validation of the seasonality of other proxies (e.g. H₂O₂ and volcanic sulfate), as well as enabling the site-specific assessment of models of precipitation. The scientific quality of the study is high, with plenty of evidence provided of the results and the methods. The general presentation of the work is clear and well-structured, with a good logical flow between sections.

We thank the referee for the positive assessment of our manuscript and for the constructive comments.

I find myself in agreement with the comments by the other referee (A. Svensson) and I encourage the authors to address those comments carefully. In particular: ([R2-#2] to [R2-#4])

[R2-#2] What is the reason behind the correction factor 1.209 (L165)?

The factor 1.209 corrects the underestimation of precipitation by ECHAM6-wiso at SE-Dome. As shown in our Figure 1, SE-Dome lies within a steep spatial precipitation gradient in southeast Greenland. We therefore attribute the mismatch primarily to the model's difficulty resolving this strong local precipitation gradient. Our analysis cannot determine whether ECHAM6-wiso has a systematic precipitation bias across Greenland, so we treat this factor as a site-specific correction. The correction is required for the SNOWISO experiment because underestimated accumulation would produce an unrealistically thin simulated snowpack and thereby bias isotope diffusion. More

ice-core-based accumulation records, particularly along steep precipitation gradients in high-accumulation regions, would help evaluate such regional model biases.

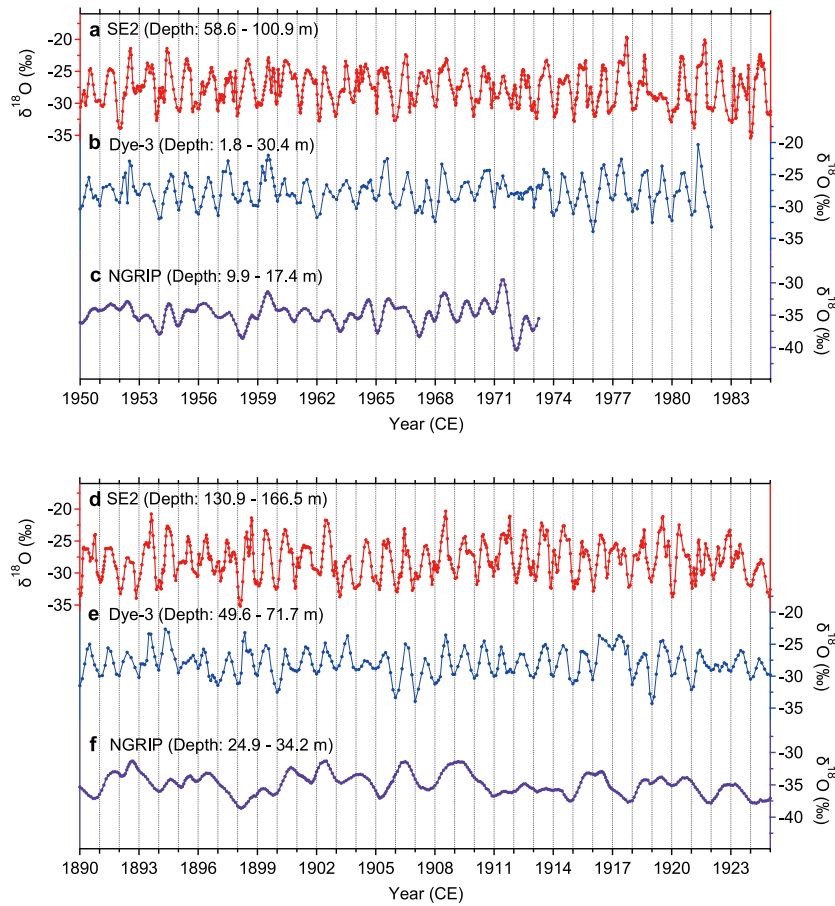
We will revise the sentences in L165–167, as follow:

“To correct the underestimation of precipitation by ECHAM6-wiso at SE-Dome, which would otherwise underestimate snow-core length and associated isotope diffusion, modeled precipitation was scaled by a constant factor of 1.209 derived from the regression slope between observed annual accumulation and modeled precipitation over 1991–2019. The bias likely reflects the difficulty of resolving the steep spatial precipitation gradient around SE-Dome.”

[R2-#3] Why is figure 6 is on a depth scale, instead of an age scale? I understand that you want to demonstrate the quality of the dataset and compare the overall properties of $\delta 18\text{O}$ at the different sites, but I cannot help but think that NGRIP covers almost your entire age interval at those depths (1880s to 1930s), while Dye-3 only covers 1940s to 1950s. The data from SE2, on the other hand, is from 2000-2010CE. The climate was surely different during these decades. I would suggest to perform the same statistics (variability, how many multi-month peaks there are in a year) and plot figure 6 on a uniform age interval.

We chose a depth axis for Fig. 6 because we wanted to compare signal preservation at similar burial depths. The depth-based and age-based comparisons have advantages and limitations. A same-depth comparison is appropriate for evaluating how differences in accumulation rate affect annual-layer thickness and the preservation of multi-month signals at comparable burial depths. In contrast, a same-age comparison allows direct comparison over the same climatic interval, but the corresponding layers occur at substantially different depths because the cores were drilled in different years and have different accumulation rates. This depth difference can lead to different degrees of post-depositional diffusion and vapor exchange.

To address your comment and referee #1's comment (**[R1-#10]**), we also prepared same-age comparisons. Because burial depth is a key limitation of this approach, we compared two calendar intervals representing substantially different depth ranges. Beyond illustrating temporal-resolution differences, this figure reveals interesting similarities between the Dye-3 and SE2 cores (e.g., 1971-1974, 1952-1954, 1918-1925). We will add these new comparisons to the Appendix, which provide a complementary assessment of temporal resolution across the cores. We retain the depth-based comparison in Fig. 6 and have clarified the rationale in Sect. 3.2.1.



“new Figure A2”. Age-based comparison of $\delta^{18}\text{O}$ variability in the SE2, Dye-3, and NGRIP ice cores at two depth ranges. Panels (a–c) show the overlapping records available for the three cores, and panels (d–f) show an older interval during 1890–1924 CE. The corresponding depth ranges are indicated in each panel. Because the cores were drilled at different times and have different accumulation rates, layers of similar calendar age occur at substantially different depths. The uppermost depths differ because the publicly available datasets begin at different depths.

“For comparison, we also plotted the $\delta^{18}\text{O}$ records on a calendar-age axis for two age ranges representing different depths (Fig. A2). In the younger comparison, Dye-3 also preserves intra-annual variability, and SE2 and Dye-3 show broadly similar intra-annual structures during several intervals, for example, 1952–1954 and 1971–1974. Similar structures are also observed around 1918–1925 in the older comparison. At greater depths, however, intra-annual variability is more clearly resolved in SE2 than in Dye-3 and NGRIP (Fig. A2 d-f). Notably, the SE2 layers spanning 1890–1924 CE correspond to depths of 130.9–166.5 m, compared with 49.6–71.7 m in Dye-3 and 24.9–34.2 m in NGRIP, yet SE2 still preserves distinct multi-month variability. This result further supports the preservation of intra-annual $\delta^{18}\text{O}$ signals at the high-accumulation SE-Dome site even at depths exceeding 100 m.”

[R2-#4] Sigl et al (2015) present an analysis of post-eruptive climate in tree-rings: have you thought of presenting a similar analysis using $\delta^{18}\text{O}$ and layer thickness?

As another referee ([R1-#17]) requested the same additional analyses, we performed post-eruption analyses of $\delta^{18}\text{O}$ and snow accumulation for the five volcanic eruptions used in Figs. 12 and 13. Aligning the records to eruption dates left the seasonal phases offset among events, and no clear common response emerged. We therefore also aligned the records to the nss-SO_4^{2-} peaks in SE2, which occur in late spring to summer of the year following each eruption.

The $\delta^{18}\text{O}$ composite shows a minimum around the third post-eruption winter, but the response is weak in individual events and its link to volcanic forcing remains unclear. Seasonal accumulation shows a slightly clearer post-eruptive response, with an increase about 2–9 months after the eruptions. This accumulation increase is consistent with simulated post-eruption circulation changes and therefore potentially reflect a volcanic influence.

We will add the following new figures and a short section after Sect. 3.4.2.

“ 3.4.3 Post-Eruption $\delta^{18}\text{O}$ and Snow Accumulation Responses”

To examine possible climate responses following the five eruptions shown in Figs. 12 and 13, we analyzed $\delta^{18}\text{O}$ and seasonal accumulation using the SE2025iso age scale. Alignment to the reported eruption dates showed no clear common response. Because the interval between eruption and sulfate deposition differs among events (Sect. 3.4.2), we also aligned the records to the nss-SO_4^{2-} peak identified in each SE2 volcanic signal, approximately 10–17 months after the reported eruption dates (Fig. 14). This approach is consistent with previous ice-core-based analyses using volcanic sulfate deposition as an event marker (e.g., Sigl et al., 2015). Anomalies were calculated relative to the mean of the three years preceding each eruption. Individual $\delta^{18}\text{O}$ responses are weak, but the composite shows a pronounced minimum at approximately month +19, corresponding to the second winter after the sulfate peak and approximately the third post-eruption winter (Fig. 14a). This timing is substantially later than the negative precipitation $\delta^{18}\text{O}$ anomalies simulated over Greenland during the first post-eruption winter (Stevenson et al. 2019). Given the small amplitude of the anomaly, its delayed timing, and the weak response in individual events, it is unclear whether the SE2 minimum reflects a volcanic influence.

Seasonal accumulation shows a clearer response. The largest positive anomaly occurs at approximately month –8 relative to the nss-SO_4^{2-} peak, corresponding to approximately 2–9 months after the eruptions (Fig. 14b). This timing is consistent with North Atlantic circulation and precipitation anomalies simulated several months after the Pinatubo eruption (Barnes et al., 2016).

Berdahl et al. (2018) identified 1963–1964 and 1991–1992, coinciding with the Agung and Pinatubo eruption periods, respectively, as periods with an extremely westward Icelandic Low. Such conditions are associated with enhanced moisture transport and precipitation in southeast Greenland, although Berdahl et al. (2018) did not attribute them to volcanic forcing. In comparison, three-year mean accumulation changes after Agung and Pinatubo vary in magnitude and sign among Greenland ice-core sites (Zheng et al., 2023). The five-event SE2 composite therefore resolves a short-lived accumulation increase that is not apparent from multi-year averages. Although the limited number of events prevents attribution to volcanic forcing, the result illustrates the utility of the multi-month chronology for resolving transient climate variability.

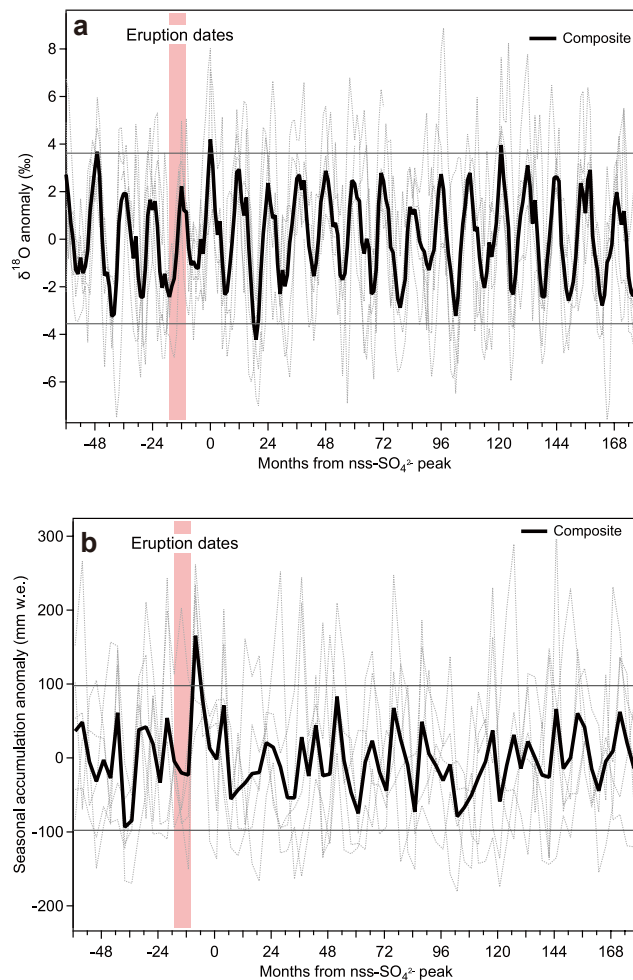


Figure 14. Post-eruptive changes in $\delta^{18}\text{O}$ and seasonal accumulation at SE-Dome aligned to the nss-SO₄²⁻ peak in the SE2 core. (a) Monthly $\delta^{18}\text{O}$ anomalies and (b) seasonally resolved accumulation anomalies for the five eruptions shown in Figs. 12 and 13. Anomalies are calculated relative to the mean over the three years preceding each eruption. Thin lines show individual eruptions, and the

thick black line shows the composite mean. Time zero denotes the nss-SO_4^{2-} peak in SE2. The shaded vertical band indicates the range of eruption dates relative to the sulfate peak. “

References

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- Zheng, M., Adolphi, F., Paleari, C., Tao, Q., Erhardt, T., Christl, M., Wu, M., Lu, Z., Hörhold, M., Chen, P., and Muscheler, R.: Solar, Atmospheric, and Volcanic Impacts on ^{10}Be Depositions in Greenland and Antarctica During the Last 100 Years, *Journal of Geophysical Research: Atmospheres*, 128, 10.1029/2022jd038392, 2023.
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Otherwise, I have a few additional remarks, that I hope you will also consider in your revision: ([R2-#5] to [R2-#8])

[R2-#5] Table 1: do you have correlation data between other ice-core datasets and ERA5/IsoGSM20c during the same time interval? Are the values you obtain for your record better or worse?

To our knowledge, previous comparisons between Greenland ice-core accumulation records and reanalysis precipitation have been largely limited to annual accumulation. Seasonally resolved accumulation is difficult to reconstruct directly from ice cores because it requires a chronology with multiple age constraints within each year. The high accumulation rate at SE-Dome and the multi-month SE2025iso chronology allow such a comparison at SE2. For annual accumulation, Hanna et al. (JGR, 2011) compared shallow ice-core records from several Greenland sites with ECMWF and 20CR reanalyses and obtained mean correlations of $r = 0.53$ and 0.44 , respectively, with substantial

differences among sites. The annual SE2 correlations obtained here ($r = 0.68$ with ERA5) therefore fall within the range reported for other Greenland ice cores. Because the reanalysis products and periods differ, however, these values cannot be directly ranked as better or worse than those from other sites.

We will add this reference and sentence as follows:

“Previous comparisons of Greenland ice-core accumulation with reanalysis precipitation have generally been limited to annual resolution. Hanna et al. (2011) reported mean correlations of $r = 0.53$ for ECMWF and $r = 0.44$ for 20CR across multiple shallow ice-core records, comparable to the annual correlations at SE2 obtained here.”

Reference: Hanna, E., Huybrechts, P., Cappelen, J., Steffen, K., Bales, R. C., Burgess, E., McConnell, J. R., Peder Steffensen, J., Van den Broeke, M., Wake, L., Bigg, G., Griffiths, M., and Savas, D.: Greenland Ice Sheet surface mass balance 1870 to 2010 based on Twentieth Century Reanalysis, and links with global climate forcing, *Journal of Geophysical Research: Atmospheres*, 116, 10.1029/2011jd016387, 2011.

[R2-#6] Figure 12: given the proximity of DYE 3, the reader might wonder why this core is not included (is there no sulphate data out there? I only know of ECM...)

We searched for a published Dye-3 sulfate record suitable for comparison with SE2 but could not find one. We therefore did not include Dye-3 in Fig. 12.

[R2-#7] L 441: I suggest reminding the reader that you used an automated method of detecting sulphate spikes and that this method is the same used by Sigl et al 2013 (albeit with different RM windows). Did you use the same method for the NGRIP sulphate?

We did not independently apply this detection method to the NGRIP sulfate record. The published NGRIP sulfur record was used only for comparison with the SE2 record in Fig. 12.

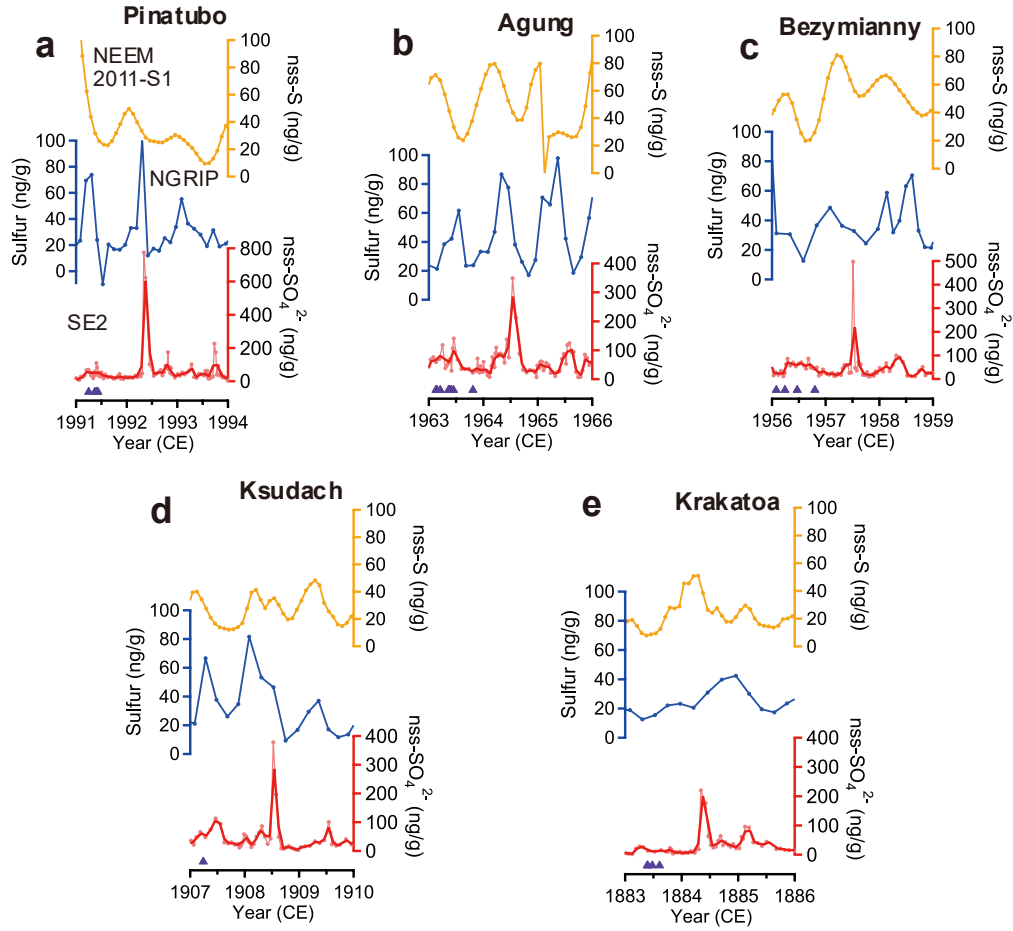
We will revise the text to make this distinction clear as follows:

"Using the detection method described in Sect. 2.6, following the previous studies (Sigl et al., 2013; Traufetter et al., 2004) but with a 21-year running-median window, we detected eight nss-SO₄²⁻ peaks from significant eruptions in the SE2 record, confirming the annual consistency between SE2025iso and NEEM-S1."

[R2-#8] L 455-462: Can you clarify why the sulphate in the NEEM-S1 and NGRIP cores does not show a narrow peak corresponding to the 5 selected eruptions, if they allegedly passed the threshold testing? What is the temporal resolution of these datasets?

We clarify two separate points. First, the threshold detection for NEEM-S1 was performed in the previous study of Sigl et al. (2013), not in the present study. Their detection method was applied to annually averaged nssS data using a 31-year running median and a 3-MAD threshold. Thus, the minimum temporal unit of the detection is one year. For example, around the Krakatoa eruption, the annual mean nssS value is elevated in 1884 (32.7), compared with 16.9 in 1883 and 19.9 in 1885. The threshold test therefore identifies an anomalously high annual value of 1884, but does not determine whether the underlying sulfate deposition formed a narrow intra-annual peak.

Second, we agree that the temporal resolution of the records should be shown more clearly. We will therefore revise Fig. 12 to display the individual data points for the NEEM-S1, NGRIP, and SE2 records, using the same presentation as in Fig. 6. The NEEM-S1 record was measured at high analytical resolution, but the published monthly averages were obtained by assuming uniform snow deposition within each year, without claiming monthly dating precision (Sigl et al., 2013). NEEM-S1 has a mean annual layer thickness of only 0.21 m w.e., and therefore has a lower effective temporal resolution despite the fine analytical sampling. The NGRIP sulfate record was measured at 5-cm depth resolution, corresponding to approximately 4–10 samples per year (Plummer et al., 2012). Our SE2 sulfate data is also 5-cm resolution. Showing the individual data points in the revised Fig. 12 makes these differences in effective temporal resolution.



Revised Fig. 12 (Circles indicate monthly averaged values for NEEM-2011-S1, 5-cm-resolution measurement data for NGRIP and SE2. For SE2, the thick red line shows monthly averages.)

We will add the related sentences in Section 3.4.2 as follows:

“This difference is consistent with the higher effective temporal resolution at the high-accumulation SE-Dome site, where thicker annual layers favor the preservation of short-term signals, as also shown for $\delta^{18}\text{O}$ in Sect. 3.2.1.”