

Interactive comment on “Linking pollen deposition, snow accumulation and isotopic composition on the Alto dell’Ortles glacier (South Tyrol, Italy) for sub-seasonal dating of a firn temperate core” by Daniela Festi et al.

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Authors: We thank the reviewer for his comments and suggestions.

Referee #1: With the manuscript, the authors try to improve their dating method for ice cores in their previous study (Festi et al., 2015, Journal of Glaciology) to achieve core analyses at sub-seasonal time resolution. They also attempted to argue the accuracy of the new dating method in comparison with time change of surface level calculated at the drilling site by a mass balance model. In addition, they tried to interpret the profile of D values of the core based on their detailed chronology established. The

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challenge for high resolution analysis is highly evaluated. However, due to a lack of in-situ observation data, it is difficult to judge the argument in this manuscript.

Authors: It is unclear which in-situ observation data the reviewer refers to. In this study, we actually make use of a combined pollen, meteorological and dD data dataset that is unique at such altitude in the European Alps. Daily monitoring of pollen deposition over glaciers would be highly desirable but it is unfeasible for logistic and economic reasons.

Referee #1: Also, it seems like that the argument is based only on good results obtained by statistical analysis using the SPSS software. The authors should consider more what the data mean and what statistical techniques mean.

Authors: The argument is based on solid and widely used statistical methods, whose use is mandatory considering the large amount of in-situ observation data used in this study. On the other hand, converging independent evidence from palynological methods and from glacier mass balance modelling is extremely unlikely a mere artefact or coincidence (e.g. correlation of pollen and Eismodel results has a correlation coefficient $r^2=0.99$). We would appreciate further and more specific indications by the reviewer, to improve our paper.

Referee #1: The novelty alone cannot warrant publication of this manuscript. Therefore, I recommend the manuscript not to be published.

Authors: We respectfully argue that the method and the interdisciplinary approach are unprecedented and show a very high potential in combining pollen with mass balance models. We believe this paper makes an important contribution to ice core science by i) providing a new high-resolution dating tool, ii) creating a bridge between biology and physical ice core science, iii) process understanding, and iii) inspiring researchers to replicate and develop new methods. We have now emphasized these aspects also within the text.

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Referee #1: Section 3.1. High resolution pollen-based timescale: the depth-to-day method P3, L11: Is the sampling interval of 10 cm appropriate for the sub-seasonal time resolution? The authors need to show its grounds.

Authors: The sampling interval is appropriate as demonstrated by the fact that it allowed a sub-seasonal time resolution. This was already illustrated in previously published papers (Gabrielli et al 2010, Festi et al 2015, Kirchgorg 2016)

Referee #1: P3, L25: The authors mentioned that the onset of flowering may differ by several days. How about the peak season and the end of the season? I think those factors also influence the daily changes of airborne pollen concentration and assemblage.

Authors: The peak in the airborne concentration of a pollen type in the air during the flowering season (above called "peak season") might also differ by a few days each year. However, this is irrelevant for the method because we compare only the presence of the airborne concentration of pollen types. The end of the season also affects the daily assemblage. These differences are taken into account by comparing the ice assemblages with all the monitoring years available and by adding the uncertainty to the date determined.

Referee #1: P3, L32: How long does each 10 cm sample accumulate (accumulation time frame)? I wonder if the authors can compare similarity between daily data from Solda and core samples because of the different time scales.

Authors: There is no homogeneous snow accumulation on Alpine glaciers, as precipitation regimes are not constant throughout the year. The point of the paper is indeed to determine the time period encompassed between different samples, which is virtually always different. Changes to the manuscript: We now specify in section 4.1 that the uncertainty gives an indication of the number of days encompassed by a sample.

Referee #1: P4, L6: Does the transportation of airborne pollen depend on the species?

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I wonder if the pollen composition may be kept until pollen deposition on the glacier.

Authors: Given the high correspondence of species found in the ice and at the pollen monitoring station we assume (as already presented within the manuscript and in Festi et al 2015) that the upward transport of all relevant pollen types is equally efficient and does not fractionate the assemblage. To reduce this potential bias we choose the closest and highest pollen monitoring station in the region. For logistic and financial reasons it is not possible to establish a daily pollen monitoring on the Ortles glacier itself. Typically an automatic pollen trap used for daily pollen monitoring requires weekly maintenance (i.e. collect the weekly cylinder on which the pollen is trapped, placing the new cylinder, mechanically recharging the device). Authors, Changes in the manuscript: We added the citation to support species correspondence in section 3.1.

Referee #1: Section 4.1. Pollen based timescale The authors need to explain more what each date indicates. I wonder if pollen deposition and snow fall on the glacier do not necessarily occur at the same time. Once melting occurs, how do the authors think about the date of snow and pollen in the core? For example, significant melting occurred in the summers of 2005 and 2006 based on the model calculation. Then, the surface level of snow was reduced to the level on April 9 and the end of March; respectively, as mentioned on P6 L15-16. Therefore, it should be natural to think the ice core lost those parts when there is no internal accumulation due to refreezing of percolating water as mentioned by the authors on P4 L25 and P6 L14-16. On the other hand, pollen grains should be gathered on the boundary of the removed layer. Therefore, the pollen concentration and composition in the layer are disturbed from the original state.

Authors: Pollen deposition occurs also between snow fall events. This is not a problem for the method as we aim to detect the time period encompassed by the single sample and not to reproduce the date of the single snow event. Once that some melting occurs pollen grains typically remain on the top of the surface layers as also shown by Nakazawa and Suzuki 2008. In years characterized by summer melting, as 2005 and

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2006, the dating pattern points to a hot and dry summer season, while the spring layer remains intact. In this way, even when melting occurs the method provides qualitative climatic information.

Referee #1: Section 4.1. Pollen based timescale. Actually, a thin layer containing mixed spring/summer pollen is observed in the core as mentioned on P6 L8. After all, I wonder if deciding the date at detailed level does not make sense with such melting core.

Authors: The critical point of the component method is that the flowering of the species occurs in continuum. However, in order to detect the seasonality in the snow layers we need to create discrete groups of pollen representing seasons. The components of those groups overlap because, for example, spring species do not all start flowering the same day or finish the same day. The same is valid for early and late summer taxa. Furthermore, there is no "flowering pause" between the seasons (except winter). We prove that the new method is more accurate as it is capable of detecting finer changes in the assemblage in comparison to the previous PCs method. This is a significant improvement on the chronology and allows to derive climatic information.

Referee #1: Showing stratigraphy of the core should be helpful for readers' better understanding.

Changes in the manuscript: We added stratigraphy in the Fig 2 with special regard to the ice lenses.

Section 5.1. Comparison of the pollen and modelled timescales Referee #1: The authors need to discuss the accuracy of layer dating obtained with the EISModel by using observed data, for example, the stake observation or automatic snow depth measurement, event signals of dust storm and volcanic eruption, and etc. Otherwise, the authors cannot insist on the legitimacy of the accuracy of the pollen dating.

Authors: The accuracy of EISModel calculations has now been assessed comparing

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the calculations with mass balance observations carried out in the period from 2009 to 2013 at the study site. Changes in the manuscript: In session 4.2 we added a statement about the accuracy of Eismodel.

Referee #1 The point of argument in the following chapters is unclear. The authors need to revise. Instead of those chapters, the authors should devote pages to the discussion for the concept of dating of snow layers and pollen grains after the post-depositional process, and the accuracy of the pollen dating. The suitable sample thickness for such high resolution time scale should also be discussed. The sampling intervals of 10 cm in this study may be too thick.

Authors: We now expanded the discussion addressing possible post-depositional effects. The sampling resolution is sufficient since we were able to obtain a sub-seasonal timescale and this has been pointed out. Further evidences supporting the fact that the sampling resolution is adequate are exemplified in previously published papers (Gabielli et al 2010, Festi et al 2015, Kirchgorg 2016). Changes in the manuscript: In session 5.1 we expanded the discussion section addressing post depositional effects and dating precision in session as suggested.

Referee #1: Section 5.2. Melt water effect on the pollen signal. The authors need to clarify more the point of argument in this section. As I have mentioned, I think melting affects the position, concentration and composition of pollen grains and the loss of snow layer. Those post-depositional process should lead to disturb dating of layers in an ice core.

Authors: In this paragraph we now provide the evidence that pollen is not easily transported downwards by melting water in the studied core. For example, it is striking that we do not observe a transport of pollen grains through winter layers (as determined also by stable isotopes) even in years where summer melting did occur. In fact winter layers are markedly depleted in pollen grains providing strong support of the substantial immobility of pollen grains when meltwater percolation occurs. Changes in the

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manuscript: We now better discuss the issue of the possible pollen mixing in 2006 in section 5.1.

Referee #1: P7 L8: Cite original papers. Those were already mentioned in other papers before the study by Gabrielli et al. (2014).

Authors: Gabrielli et al 2014 is an adequate citation as it reports direct and recent observation of the phenomenon. Any further precise indication on proper citations are welcome. Authors: Printer-friendly version

Referee #1: Section 5.3. The potential of pollen for qualitative climatic reconstruction. I wonder if the authors can be more specific in discussing the analysis results by the data obtained because only abstract conception was mentioned here. The studies in Nakazawa and Fujita (2006, *Annals of Glaciology*) and Nakazawa et al. (2015, *Environmental Earth Sciences*) may be useful for the discussion in this chapter.

Authors: We note that data are discussed based on fig 4. This is only an example of how a climatic interpretation of the ice core, based on pollen dating, can be performed. More studies coupling high resolution pollen analyses on longer cores and measured meteorological data series are needed to provide further discussion points. Changes in the manuscripts: We nevertheless expanded the discussion using and citing the suggested papers.

Referee #1: Section 5.4. Application of the pollen based timescale. The authors need to clarify more the point of argument in this section. As the authors noticed, a good correlation between the mean daily temperature and the measured isotopic composition arises from preservation of seasonal variation of the D values. Therefore, the effect of re-evaporation or the stable isotope amount effect seems to be small. However, to reconstruct past temperature, the authors need to analyze the data while considering the smoothing of D values.

Authors: This is certainly a good point. However, this paragraph merely suggests

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a potential use of the pollen timescale and does not suggest any further refinement of the basic interpretation of the dD record and we do not claim any more precise past temperature reconstruction. This topic is therefore not considered within the main scope of this publication.

Referee #1: Section 6. Conclusions. P9 L11: The timing of local flowering of different plant taxa and of the daily changes in airborne pollen concentration should be changed under climate change. How do the authors overcome this problem without airborne pollen data when applying this method to date deeper ice cores?

Authors: This is surely an important point that needs to be addressed when dating a deeper core. relevant. Studies on phenology and historic series of pollen monitoring encompassing the last 35 years show that the shift of the onset and end of the blooming season due to temperature trends are on average around 10 days in Europe (Menzel & Fabian 1999, *Nature*) as well as in the Ortles region (Bortenschlager & Borthenschlager 2007, Grana). We therefore assume that this difference is not particularly relevant for the dating of a deep core as this value is surely smaller than the number of days encompassed in one deep core sample. Changes in the manuscripts: We now address and explained this concept in the conclusion section.

Referee #1: Table 1. The dates in 2005 and 2006 are manifestly inconsistent with the EISModel calculation and the authors' arguments. It needs to be explain more.

Authors: We do not understand this comment as in Table 1 there are no Esimodel calculation. In our opinion Fig 3 shows, both visually and statistically, that 2005 and 2006 are quite consistent. This is also proven by the high correlation coefficient.

Interactive comment on The Cryosphere Discuss., doi:10.5194/tc-2016-221, 2016.

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