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Reply on RC2

Dieter R. Tetzner et al.

Author comment on "Regional validation of the use of diatoms in ice cores from the Antarctic Peninsula as a Southern Hemisphere westerly wind proxy" by Dieter R. Tetzner et al., Clim. Past Discuss., https://doi.org/10.5194/cp-2021-88-AC2, 2021

Dear Editor,

We appreciate all the comments and suggestions made by the Anonymous Referee #2. We thank for his/her time and consideration. Please find to follow a list of all points raised and our responses to each item.

Reviewers comment #1

Section #1.1

It is mentioned lines 330-335 that established ice core wind proxies such as nssCa, ssNa and nssK present very patchy spatial correlations with annual wind strength across the southern mid-latitudes (figure 3). For this reason, these proxies are mentioned to be of limited interest in this region. However, it appears to be exactly the same for diatom abundances who similarly show very patchy spatial correlations with wind strength (SHIC) and very restricted zones of high correlation (JUR, especially, and SKBL, figure 3).

Response #1.1:

Our results evidence traditional ice core wind and atmospheric circulation proxies present limitations to reproduce the interannual variability of wind strength in the Pacific core of the SHWWs. In particular, these traditional proxies exhibited patchy regions of high-correlation with wind strength outside the core of the SHWWs. Additionally, the locations of most of these regions of high correlation did not fit with their expected sources and were not consistent between sites. Based on the lack of consistency and correlation between each of these proxies and wind strength within the SHWWs, we discard them as potential indicators of wind strength variability in the SHWW. Altogether, our results highlighting these traditional ice core proxies represent the cumulative effect of numerous factors related to atmospheric transport and source conditions, not strictly wind strength in the core of the SHWWs. In parallel, the diatom abundance from high elevation sites in the AP shows a regionally consistent area of high correlation in the core of the SHWWs (Ferrigno ice core in **Allen et al. (2020)** and JUR and SKBL in Figure 3).

The reviewer states that SKBL and JUR exhibit "very restricted zones of high correlation". The restricted appearance of these regions arises from the fact that in Figure 3 we only plotted the regions that exhibited a correlation R>0.6. We only plotted the area of spatial correlation R>0.6 to make Figure 3 less clumped. However, we acknowledge that by presenting the data this way, we have possibly undermined the information we wanted to present.

To address this comment, and following a previous comment from Anonymous Reviewer #1 (comment #15), we have modified Figure 3 and included the whole area of statistically significant correlations ($p<0.05$) for diatom abundance. We have moved the original Figure 3 to supplementary information, where the reader will be able to identify all the areas that exhibited high correlations (R>0.6), regardless of their consistency. Additionally, we have modified the manuscript to specify that the limitations we report from traditional ice core wind and atmospheric circulation proxies are mainly on their capacity to represent wind strength variability within the SHWW.

References

Allen, C. S., Thomas, E. R., Blagbrough, H., Tetzner, D. R., Warren, R. A., Ludlow, E. C., & Bracegirdle, T. J. (2020). Preliminary evidence for the role played by South Westerly wind strength on the marine diatom content of an Antarctic Peninsula Ice Core (1980–2010). Geosciences, 10(3), 87.

Section #1.2

Additionally, for JUR and SKBL, these quadrants of high correlations (QHCs) are outside the main 950 hPa circulation to the ice cores as evidence in Allen et al. (2020). Indeed, back trajectories showed very low density in the 50-60°S band west of 120°W (figure 6, Allen et al., 2020). So one may question how diatom can be sea-sprayed from the NAZ between 120-150°W and then transported to the ice core sites if the air masses reaching the core sites do not sweep the QHCs? Somehow, the correlation between the diatom abundance records and the QHCs might not be causal. One may imagine that changes in wind strength in the QHCs (zonal circulation) also increases the strength of the meridional circulation, which allows a greater diatom deposition in the coastal ice cores. However, nothing proves that there is a transfer of diatoms from the zonal circulation to the meridional circulation (see after with the comment on the diatom assemblages preserved in the ice cores).

Response #1.2:

The regions of high correlation (R>0.6) between diatom abundance and wind strength (for

JUR and SKBL) are mainly constrained within 55-60°S and 120-150°W. Similarly, the region of high correlation (R>0.6) presented by **Allen et al. (2020**) for the Ferrigno ice core is constrained within 55-60°S and 120-140°W. These quadrants of high correlation lie within the region where 20-40% of the air masses reaching the Ferrigno site potentially entrain marine aerosols **(Allen et al., 2020)**. The reviewer questions how diatoms from the identified region of high correlations can be transported to the ice core sites if the percentage of air masses interacting with this region is so "low" (20-40%).

The reviewer's questionings are based on the 5-day back-trajectory analysis performed by **Allen et al. (2020)** for the Ferrigno ice core site, a site that represents an analogue of the high elevation sites presented in this manuscript **(Thomas and Bracegirdle, 2015)**. In particular, the questioned percentages represent the spatial distribution of air masses reaching high elevation ice core sites. In light of these questionings, it must be highlighted that the percentages presented will inevitably decrease the further away a point is from the final destination (ice core site), as trajectories will be dispersed over a larger area. The closer trajectories are from the final destination, the more channelled they are, increasing the percentages. A percentual reduction with increasing distance indicates that fewer air masses are passing through a unit of surface, not necessarily implying that a considerable number of trajectories are not coming from a large distal region (e.g. our region of high correlation). Another point worth noting is that the back-trajectory analyses presented by **Allen et al. (2020)** are based on 5-day trajectories. Since airmasses do not necessarily move in straight lines, increasing the number of days considered in the back-trajectory analysis would likely increase the percentages of airmasses travelling through distal areas.

The evidence of airmasses passing through the high correlation region enables us to establish causality between wind strength at the QHCs and diatom abundance at the ice core sites. In particular, it has been widely demonstrated that strong winds over the surface of the ocean enhance the production of sea-spray aerosols (including diatoms (**Marks et al., 2019**)) (**Andreas, 1992; Wu, 1993; Andreas et al., 1995; Anguelova et al., 1999; O'Dowd and De Leeuw, 2007**). The enhanced production of sea-sprays is regardless of wind direction. The considerable number of trajectories passing over the high correlation region and their subsequent transport south, following regional atmospheric circulation patterns (**Allen et al., 2020**), establishes a mechanism to link stronger winds (enhanced sea-spray production) with the higher abundance of diatoms in the ice core sites. Thus, supporting a cause-effect relation.

References

Allen, C. S., Thomas, E. R., Blagbrough, H., Tetzner, D. R., Warren, R. A., Ludlow, E. C., & Bracegirdle, T. J. (2020). Preliminary evidence for the role played by South Westerly wind strength on the marine diatom content of an Antarctic Peninsula Ice Core (1980–2010). *Geosciences*, *10*(3), 87.

Andreas, E. L. (1992). Sea spray and the turbulent air□sea heat fluxes. Journal of Geophysical Research: Oceans, 97(C7), 11429-11441.

Andreas, E. L., Edson, J. B., Monahan, E. C., Rouault, M. P., & Smith, S. D. (1995). The spray contribution to net evaporation from the sea: A review of recent progress. Boundary-Layer Meteorology, 72(1), 3-52.

Anguelova, M., Barber Jr, R. P., & Wu, J. (1999). Spume drops produced by the wind tearing of wave crests. Journal of Physical Oceanography, 29(6), 1156-1165.

Marks, R., Górecka, E., McCartney, K., & Borkowski, W. (2019). Rising bubbles as mechanism for scavenging and aerosolization of diatoms. Journal of Aerosol Science, 128, 79-88.

O'Dowd, C. D., & De Leeuw, G. (2007). Marine aerosol production: a review of the current knowledge. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 365(1856), 1753-1774.

Thomas, E. R., & Bracegirdle, T. J. (2015). Precipitation pathways for five new ice core sites in Ellsworth Land, West Antarctica. Climate dynamics, 44(7-8), 2067-2078.

Wu, J. (1993). Production of spume drops by the wind tearing of wave crests: The search for quantification. Journal of Geophysical Research: Oceans, 98(C10), 18221-18227.

Reviewers comment #2

The statistics are based on a small number of data in each ice core. At SKBL, which shows the strongest and largest spatial correlation between diatom abundance and wind strength, it is based on 19 samples. I wonder whether this is statistically significant, especially as the reader is not told how the degrees of freedom for the tests were determined, and what allowance was made for the autocorrelation in the relevant series. This statistical aspect should be presented much more rigorously. See, e.g., Bretherton et al., 1999, The effective number of spatial degrees of freedom of a time-varying field. Journal of Climate, 12, 1990-2009. In the same vein, I did not really get how the series were detrended. Only by subtracting the first order linear trend? But many records do not show any trend. And sometimes mentioned trends are not evident. For example, one really needs the eye of the believer to see any trend in diatom abundance, nssCa, ssNa and MSA in core SKBL, despite what is written line 184.

Response:

All spatial correlations presented in this manuscript are based on 20-year periods (20 data points per site). Every value reported as statistically significant ($p<0.05$) passed both, one-tail and two-tailed tests. Spatial correlations were calculated using the field correlation tool from the Royal Netherlands Meteorological Institute - KNMI Climate Explorer.

All datasets presented in this manuscript were detrended by subtracting the first order linear trend before calculating correlations. This procedure was conducted regardless of the dataset trends being statistically significant ($p<0.05$). The linear detrending was performed to remove potential trends which could bias the calculation of correlation coefficients. Linear trends are included in the results section to present the datasets that were used for calculating correlations. The original manuscript specifies which trends are statistically significant ($p<0.05$).

No specific allowances were made for the autocorrelation of the datasets. All the raw (sub-annual) MPC, chemical and diatom records obtained from ice cores and wind speed and precipitation reanalyses products were not autocorrelated ($-0.3<R<0.3$) over the time intervals analysed. The raw data of the sea ice cover parameter from reanalysis products exhibited an autocorrelation, possibly due to its strong seasonal cycle.

To address this comment we have modified the manuscript specifying the degrees of freedom for each set of correlations calculated. We also included details about the algorithm we used to obtain the spatial correlations (KNMI Climate explorer). Finally, we specified in the methods section that all datasets were detrended by subtracting the first order linear trend.

Reviewers comment #3

The diatom assemblages appear as important to deal with as the total diatom abundances. They are presented in Tetzner et al. (2021a), which commits the reader to uneasily shuffle between the two manuscripts. It is mentioned lines 237-239 that the QHC regions match with the production zones of the main diatom species preserved in the ice cores. I somehow disagree with that general statement. More specifically, in JUR only S. gracilis (30% of the total diatom assemblages) is produced in the open ocean NAZ. Fragilariopsis cyclindrus is produced within the seasonal sea ice zone, south of 60°S. Fragilariopsis pseudonana occurs in high abundances around the South Shetland Islands. The Cyclotella, Achanthes and Navicula groups (> 50% of the diatom assemblages) represent diatom thriving at the AAP and AS-BS coasts, maybe be at the South American coast. The same interpretations can be drawn for SKBL. This fits quite well with the back-trajectories presented in Allen et al. (2020) with highest density along the 80°W parallel. This suggests that wind strength might not be the only (main?) driver of diatom transport and deposition in coastal ice cores. The wind direction is also very (most?) important.

Response:

Tetzner et al. (2021a) present the main diatom assemblages identified for each ice core site included in this manuscript. The main diatom assemblage identified in JUR and SKBL is composed of two groups of diatoms. These include (1) a group conformed by exclusively marine diatom species, and (2) a group of diatoms that were only possible to identify to Genus level, therefore, not allowing to differentiate between marine (open ocean) and freshwater/brackish species. Among the exclusively marine group (1), there were sea ice affiliated diatoms and open ocean affiliated diatoms (species found within and south of the Antarctic Polar Front). Since the proportion of marine diatoms in (2) is unknown, the proportion of identified marine diatoms (1) is the following: Open ocean diatoms within the NAZ account for at least 65% and 63% of the marine diatoms identified in JUR and SKBL, respectively. In turn, sea ice diatoms account for at the most 35% and 37% of the marine diatoms identified in JUR and SKBL, respectively. These proportions evidence open ocean diatoms within the NAZ account for the majority of marine diatoms present in the high-elevation ice cores. This evidence supports the QHC (55-60°S, 120-150°W) match with the production zone of the main marine diatom species.

To address this comment, we have added a table (**Appendix A – Table A1**) detailing which species are present on each ice core and their correspondent proportion of the main diatom assemblage, as reported in **Tetzner et al. (2021a)**. In this table, we also include the oceanographic zones to which each of these diatom species are affiliated. This new table includes all the necessary information for the reader to understand that among the identified diatoms, diatoms from the NAZ account for the largest proportion of the main diatom assemblage.

References

Allen, C. S., Thomas, E. R., Blagbrough, H., Tetzner, D. R., Warren, R. A., Ludlow, E. C., & Bracegirdle, T. J. (2020). Preliminary evidence for the role played by South Westerly wind strength on the marine diatom content of an Antarctic Peninsula Ice Core (1980–2010). Geosciences, 10(3), 87.

Tetzner, D. R., Thomas, E. R., & Allen, C. S. (2021a). Marine diatoms in ice cores from the Antarctic Peninsula and Ellsworth Land, Antarctica–species diversity and regional variability. The Cryosphere Discussions, 1-32.

Reviewers comment #4

Based on the spatial correlations, this new tool gives an idea of wind strength changes in very small regions of the SWW core. It however gives no information on important aspects of the SWW system, i.e. whether changes in strength are associated to changes in the intensity or the position/expansion of the SWW core, or in the winds' direction that may sweep different regions as shown by the rich diatom assemblages (many coastal and few open ocean diatoms). In conclusion, I wonder whether this is possible to really deconvoluate between wind strength, wind direction and source areas as potential drivers of diatom abundances in ice cores. Not to speak about variable diatom production in different oceanic realms, potential depletion of benthic diatoms from wet rocks, ice, etc….

Response:

This comment includes some points that have been previously addressed. Comments regarding the position and size of the area of spatial correlation have been previously addressed **in response to reviewers comments #1.1 and #1.2**. Comments regarding the diatom assemblage have been previously addressed in **response to reviewers comment #3**.

The reviewer states that the regionally consistent area of spatial correlation between diatom abundance in ice cores and wind strength does not give information about the SHWW system. We disagree with the reviewer's comment. Our results show the diatom abundance in high elevation ice core sites exhibit a high, statistically significant, correlation with wind strength over a large area within the Pacific core of the SHWW (55-60°S, 120-150°W). This relationship establishes a direct link between SHWW intensity and the number of diatoms preserved in ice core layers from high elevation AP sites. Similarly, the main diatom assemblage demonstrates to hold valuable information about the principal diatom source. The current diatom source lies over the NAZ, contributing with a characteristic diatom assemblage to ice core sites. If the core of the SHWW was positioned slightly north (50-55°S) or south (60-65°S), the assemblage would be considerably different. Thus, our results suggest the diatom record preserved in these ice cores hold unique information to track changes in SHWW intensity (through the diatom abundance) and in SHWW migration (through the main diatom assemblage).

Our results are based on the analyses of the wind speed parameter (not wind direction), mainly because the wind speed is the primary factor driving the transfer of diatoms from the oceanic surface to the atmosphere, through sea-spray production processes. These processes occur regardless of the wind direction. However, since the main source of diatoms is located within the core of the SHWW and the strong westerly winds from the core are the most likely to produce sea-sprays, it can be assumed that the wind direction at the source will remain stable in time (westerlies).

Based on the location of the source (NAZ), it can be assumed that there is no considerable variability in the diatom production (**Tetzner et al., 2021a**).

References

Tetzner, D. R., Thomas, E. R., & Allen, C. S. (2021aa). Marine diatoms in ice cores from the Antarctic Peninsula and Ellsworth Land, Antarctica–species diversity and regional variability. The Cryosphere Discussions, 1-32.

Reviewers comment #5

Overall, I am very puzzled about the QHCs localisations in the middle of the Pacific sector of the Southern Ocean, which does not fit with the back-trajectories (Allen et al., 2020) and diatom assemblages preserved in the ice cores (Tetzner et al., 2021a). Some elaborations on these aspects would be welcome.

Response:

The QHCs from high elevation ice cores presented in this manuscript do in fact fit within the back-trajectory region presented by **Allen et al. (2020)** and also coincide with the area of high correlation identified by **Allen et al. (2020)** for the neighbouring Ferrigno ice core (**See response to reviewers comment #1.2**). Likewise, the diatom ecological affiliations obtained for JUR and SKBL support an open ocean source, south (and/or within) the Antarctic Polar Front, as the primary source of diatoms to the ice core sites. Thus, coincident with the oceanographic conditions that prevail in the surroundings of the QHCs (**See response to reviewers comment #3**).

To address this comment, we have modified Figure 3 to show the wider area of statistically significant correlations (**See response to comment #1.1**). We have also included a table in the Appendix (**Table A1**) to let the reader know which diatoms shape the main diatom assemblage at each ice core site and the aquatic environments that they inhabit.

References

Allen, C. S., Thomas, E. R., Blagbrough, H., Tetzner, D. R., Warren, R. A., Ludlow, E. C., & Bracegirdle, T. J. (2020). Preliminary evidence for the role played by South Westerly wind strength on the marine diatom content of an Antarctic Peninsula Ice Core (1980–2010). Geosciences, 10(3), 87.

Reviewers comment #6

Half of the references in the Introduction are auto-citations. For example, there are many other studies showing the recent warming in AAP based on instrumental data (lines 24-25). Similarly, there are other groups working with climate reanalyses.

Response:

We agree with the reviewers comment. To address this comment, we incorporated additional references in the Introduction section to highlight the valuable work that other research groups have done in this region (Lines 24, 35, 38).

Reviewers comment #7

In Allen et al. (2020), fragments of large diatoms were included in the total diatom content. I could not find this information in Tetzner et al. (2021a) or in the present study. As such, I am unable to evaluate whether the total diatom abundance is robust or not, as one large diatom can form several fragments. And it is impossible to evaluate whether such fragmentation occurs in surface water, during depletion and transport or during precipitation at the ice core site.

Response:

The diatom abundance parameter presented in this manuscript and **Tetzner et al. (2021a)** include all diatom frustules and indistinctive diatom fragments found on each ice core, in line with the results presented by **Allen et al. (2020)**. This information has been recently incorporated in **Tetzner et al. (2021a)** (https://doi.org/10.5194/tc-2021-160-AC1).

Diatom fragments are found on each ice core site presented in this work and are commonly reported in diatom records preserved in Antarctic ice cores (**Burckle et al., 1988a; Burckle et al., 1988b; Budgeon et al., 2012; Delmonte et al., 2017**). The recovery of specimens still articulated in short chains at the bottom of the ice cores presented in this work (**Tetzner et al., 2021a**), evidence the diatoms we find in ice cores are not affected by mechanical fracturing after being deposited. Thus, evidencing fragmentation must occur before diatoms reach the ice core sites, either while transported in the atmosphere, suspended in aquatic environments or after being exposed to sub-aerial environments. This information has been recently incorporated in **Tetzner et al. (2021a)** (https://doi.org/10.5194/tc-2021-160-AC1).

To address this comment, we have modified the manuscript (Lines 124 and 128) to specify that:

"*Diatom counts per sample (n) included all valves, partially obscured valves and diatom fragments identified in each sample*"

and

"*The diatom abundance parameter includes all diatoms and diatom remains identified on each sample, regardless of their potential source*"

References

Allen, C. S., Thomas, E. R., Blagbrough, H., Tetzner, D. R., Warren, R. A., Ludlow, E. C., & Bracegirdle, T. J. (2020). Preliminary evidence for the role played by South Westerly wind strength on the marine diatom content of an Antarctic Peninsula Ice Core (1980–2010). Geosciences, 10(3), 87.

Burckle, L. H., Gayley, R. I., Ram, M., & Petit, J. R. (1988a). Diatoms in Antarctic ice cores: some implications for the glacial history of Antarctica. Geology, 16(4), 326-329.

Burckle, L. H., Gayley, R. I., Ram, M., & Petit, J. R. (1988b). Biogenic particles in Antarctic ice cores and the source of Antarctic dust. Antarctic Journal of the United States, 23(5), 71-72.

Budgeon, A. L., Roberts, D., Gasparon, M., & Adams, N. (2012). Direct evidence of aeolian deposition of marine diatoms to an ice sheet. Antarctic Science, 24(5), 527-535.

Delmonte, B., Paleari, C. I., Andò, S., Garzanti, E., Andersson, P. S., Petit, J. R., ... & Maggi, V. (2017). Causes of dust size variability in central East Antarctica (Dome B): Atmospheric transport from expanded South American sources during Marine Isotope Stage 2. Quaternary Science Reviews, 168, 55-68.

Tetzner, D. R., Thomas, E. R., & Allen, C. S. (2021a). Marine diatoms in ice cores from the Antarctic Peninsula and Ellsworth Land, Antarctica–species diversity and regional variability. The Cryosphere Discussions, 1-32.