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Reply on RC2

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Author comment on "Evaporation over a glacial lake in Antarctica" by Elena Shevnina et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2021-218-AC2, 2021

General comment:

Anonymous Referee #2 noticed that the manuscript is based on “the absolutely unique database”. However, he/she suggested “a major refocusing of the paper that needs to be done in addition to correcting some aspects of the methodology and improving the analyses”. We implemented most relevant suggestions given by the Anonymous Referee #2 that greatly contributed to the improvement of the manuscript. We agree that the dataset allows us to explore several topics, nevertheless, in our study, we focused on the uncertainties inherent in various methods applied in the estimation of evaporation. We believe that this topic is only first in a series of the research based on this dataset. The manuscript allows partial publication of the hydrological data collected on the glacial lakes located in East Antarctica. Our next case study will be focused on Lake Glubokoe (the Schimacher oasis), and it will be based on the dataset collected during December, 2019 - February 2020.

Detailed comments:

Further, we follow the comments of the Referee in answering them point-by-point:

1) The paper needs to be refocused on its main theme (evaporation from a lake in Antarctica) and avoid repetition.

This study is among other papers focusing on the water budget and thermal regime of lakes located in Antarctica (Shevnina and Kourzeneva, 2017; Shevina et al., 2018; Shevnina et al., 2021). This study is particularly aimed to understand which method is the best in estimation of one of the terms in the water budget of the lake (evaporation). It is a reason why we did not pay much attention to the evaporation itself particularly in the Introduction.

Introduction: too much emphasis on glacial lakes, but not enough on evaporation itself. What is known about evaporation from water bodies at very high latitudes?

We revised the Introduction and now less attention is paid to the glacial lakes themself. We extended the description of the methods applied to evaluate the evaporation, and the case studies direct to evaluation of the evaporation of lakes located in very high-latitudes. We did not find many of them, and they are described in the Discussion in order to place our results into the framework of what is already known in this topic.

ERA5: I understand that ERA5 is not a good tool for estimating lake evaporation in Antarctica (not a huge surprise, let's be honest), but I think it is given too much emphasis in the paper. To be honest, we have never considered the ERA5 as "a tool for estimating lake evaporation" because of the difference in "a spatial footprint". Including the ERA5 data only shows the magnitude of difference between the evaporation over the liquid water (which is a lot stored in the glacial lakes spreaded over the continental ice-sheet and shelf) and snow/ice covered surface (as it is supposed in ERA5 within this region). In the revised version of the manuscript, we shortened the discussion on the ERA5 data in whole text, and finally placed them in the section of the Discussion. We also add the new figure allowing us to extend the explanation.

The following text was included: "Seasonal presence of the liquid water (ie. in lakes and iced "swamps") over the ice/snow covered land surface affects the surface-atmosphere moisture exchange. A proper description of the land cover is a crucial element of numerical weather predictions (NWPs) and climate models, where the overall characteristics of the land cover are represented by surfaces covered by ground, whether vegetation, urban infrastructure, water (including lakes), bare soil or other. Then, various parameterization schemes (models) are applied to describe the surface-atmosphere exchange (Viterbo, 2002). Lakes have been recently included in the surface schemes of many NWPs (Salgado and Le Moinge, 2010; Dutra et. al., 2010) with known external parameters (location, mean depth) available from the Global Lake Database, GLDB (Kourzeneva, 2010;Kourzeneva et al., 2012). The information on only a few glacial lakes is included in the newest GLDBv3 version, and not any lakes found in Antarctica (Toptunova et al., 2019). Over 65 thousand glacial lakes have been detected over the East Antarctic coast via satellite remote sensing in austral summer 2017, and most of them have spread over the ice shelf (Stokes et al., 2019). For example, the total area of the glacial lakes in vicinity of the Schirmacher oasis was over 72 km2 in January 2017 (Fig. 7), two largest glacial lakes are of the similar size as the Schirmacher oasis itself. Such amount of the liquid water may contribute to the additional source of the uncertainties inherent in the estimations of the regional evaporation after the NWPs. Estimates on evaporation are also available from climate and NWP models and atmospheric reanalyses. The most recent global atmospheric reanalysis is ERA5 of the European Centre for Medium-Range Weather Forecasts (Copernicus Climate Change Service, https://climate.copernicus.eu/, last access 09.07.2021; Hersbach et al., 2020). As other reanalyses, ERA5 does not assimilate any evaporation observations, but evaporation is based on 12 h accumulated NWP forecasts applying the bulk aerodynamic method. The results naturally depend on the presentation of the Earth surface in ERA5, and in the Dronning Maud Land, the surface type is ice and snow with no lake. Therefore the estimate of the evaporation does not include evaporation from liquid water surface. We estimated the daily evaporation also from the ERA5, and the results suggest that the evaporation during summer (DJF) 2017–2018 was 0.6 mm day-1. It is only one fifth of the evaporation estimated with the direct EC method."

Description of weather conditions during the field campaign. Merge into one section, as they are scattered in various sections.

We revised the structure of the manuscript, and now the description of the field experiment is merged with the sub-section presenting the weather conditions.

Appendix: I do not see the relevance in this paper.

The appendix shows the results of the intercalibration between two instruments in order to estimate the instrumental errors inherent in the particular instrument (namely Irgason with the serial number SN1243), which we used during the field campaign. The instrumental error is one of the contributors to the uncertainties inherent in the EC method and due to its importance we would like to maintain the appendix in the manuscript. We explained the relevance in the following text: "Uncertainties in the estimation of evaporation after any method include the instrumental errors associated with the specific instrument. Aubinet et al., (2012) suggest three methods allowing to quantify the uncertainty of the EC method. In this study, we applied the paired tower method to evaluate the instrumental uncertainties of the EC method taking advantage of an intercomparison campaign in Alqueva reservoir, Portugal, during the Autumn 2018. Since the instrumental error does not depend on the region where the instrument will be used, it may be done elsewhere. The relative instrumental error estimated in this intercomparison campaign was 7 % (see the Annex). The uncertainties of the EC method also include the errors due to filtering the measurements to those covered by the footprint area, and there are 18 % of gaps which can be filled with the mean or median values or excluded from further calculations. The large number of filters and corrections that we applied to the EC data allowed us to reduce the errors and uncertainties. Even the EC method itself has some errors and uncertainties but is the most versatile and accurate method to measure the evaporation."

2) Propose complete figures, without repetition and with a good finish.

Figure 1: To be merged with Figure 4. Detail each color code.

We changed Figures 1 and 4 accordingly.

Figure 2: Not helpful, the compass rose in figure 4c does the job.

This plot shows the climatology of wind speed and wind direction in the study area, and we used it to explain how the location of the Irgason measurement site was chosen. Also, we used the data on the wind speed to design the maintenance system for the Irgason in order to sustain local winds. The wind rose in fig. 4c gave the situation for the period of 38 days of the field campaign, and it did not provide the climatology. We would like to keep the figure in the revised version of the manuscript due to its importance for the instrumental set up (good results depend on perfect set-up).

The following text was added to the manuscript: "To plan the field experiment we used 6 hour synoptic observations at the Novo site available from the British Antarctic Survey Dataset (https://www.bas.ac.uk, last access 14.12.2018) covering the period 1998–2016 to calculated the wind direction and frequency of wind speed anomalies over the multi-year means for eight ranges (Fig. 2). The positive anomalies in the wind speed suggest that the observed wind speed is higher than the mean value. In Fig. 2, the prevailing wind direction is ranged from 120 to 140º, and the positive wind speed anomalies are typical for this range. We accounted for these circumstances when choosing the location to deploy the EC measuring systems and to design its maintenance system to sustain the local winds."

Figure 3: Not useful.

The fig. 3 was excluded in the revised text.

Figure 4: add a footprint analysis to show that the retained data is contained on the lake.

We added a footprint analysis to Figure 3 where it is given in a windrose frame. We also provided the explanations in the following text: "The Irgason was settled at the height of 2 meter above the ground, and it allows for footprint lengths less than 200 meter (Fig. 3 c), with only one exception during the whole experiment. This distance is twice less than those between the Irgason and the shore of Lake Zub/Priyadarshini, in east-southeast direction (Fig. 2 c). This condition ensures that the retained data is representative only from the lake and free of contamination from the shores. The height of the Irason allows for a blind zone near the tower, therefore the stones on the lake shore do not affect the fluxes."

Figure 6a: not useful.

Yes, we agree, and therefore the sub-plot (a) is now excluded from Fig. 6.

Figure 7: add shaded areas indicating +- standard deviation

We finally decided not include the analysis of the intra-daily variability of the meteorological parameters, and therefore Fig. 7 was excluded from the revised version of the manuscript.

In general, there could be more homogeneity in the plots.

We agreed that generally the figures need better presentation, and it is improved in the revised version of the manuscript.

3) Data processing

It is not ok to fill in missing data with medians only, a more robust approach is needed (neural networks, marginal distribution sampling, etc.).

In this study we used two methods to fill those 18% of gaps in the 30 min time-series: by the median and mean values. There is not much difference in the results, and therefore we decided to use the only one value (median) to fill whole gaps, which are 18 % of total data. In further study, we would like to test filling gaps by the average calculated from the neighbouring values. More robust approaches (neural networks, marginal distribution sampling) can be also applied in studies focused only on the uncertainties inherent in the EC measurements, where such details will be good to provide. This is outside this particular study.

4) Bulk transfer approach

What is the impact of strong katabatic winds on lake surface roughness and consequently on CDzN? What justifies the use of a constant value of 0.00181? Consider discussing this with the additional analysis I am recommending (see below).

In general, C_{DzN}depends on the wind speed. Several empirical forms have been developed to quantify the dependence (e.g., Taylor, 2002), but most of the studies have addressed open ocean conditions, where the state of the wave field is not restricted by the distance from the shore. The situation is different over a small lake, where the waves have typically not reached a balance but are still in a growing state with respect to the fetch and wind (except for very weak winds). We therefore considered it better to apply a C_{DzN} value found good for a small lake instead of applying a parameterization developed on the basis of data from open ocean conditions. From the point of view of C_{DzN}, it does not matter whether a strong wind is of katabatic or other origin.

Reference: Taylor, P. K., Air-sea interaction / momentum, heat and vapour fluxes, In: Holton, J. P., Curry, J. A. ja Pyle, J. (Eds.), Encyclopedia of Atmospheric Sciences. Academic Press, London, s. 93-102, 2002.

5) Elaborate 1-2 analyses looking at the processes controlling evaporation, to better value the dataset. Two suggestions:

What is the impact of katabatic winds on evaporation? I understand that this is not your *main study goal, but katabatic winds are there and they definitely play a big role, so they have to be considered!*

We added the analysis on the impact of katabatic winds to the revised version of the manuscript. The following text was included to the subsection of the methods: "To understand the role of the local (katabatic) winds in forcing the evaporation over the lake surface. The katabatic winds blow from the continental interior. Fig. 3 b shows that almost all winds come from a direction that would be the direction of katabatic winds. However, it is not guaranteed that all these winds are entirely of katabatic origin. Some may be driven by a combined effect of the local (katabatic) and synoptic forcing. In this study we distinguished between two groups of days of katabatic and predominantly synoptic forcing by calculating mean values and distributions of the evaporation for both groups of days. Then, the contributions of wind speed, air humidity and surface temperature were related to the temporal variations in the evaporation."

We also extended the section of the results: " The study region is dominated by winds from the southeasterly sector (Fig. 3 b). This corresponds to the katabatic winds, which the Coriolis force has turned left from the direct down-slope direction. To better understand the impact of katabatic winds, we carried out further analyses on the wind conditions in the study region. We calculated the geostrophic wind fields for each day of the study period from the mean sea level pressure fields estimated from the ERA5 reanalysis. The results demonstrated that the geostrophic (synoptic) wind was mostly from the east, i.e., some 45 degrees right from the mean direction of the observed near-surface wind. This deviation angle may partly result from the Ekman turning in the atmospheric boundary layer, which over an ice sheet with a rather small aerodynamic roughness may contribute some 20 degrees, and from the katabatic forcing. In any case, in most cases the observed near-surface winds resulted from the combined effects of synoptic and katabatic forcing, which supported each other, Hence, it is very difficult to robustly distinguish the impact of katabatic forcing on the near-surface winds over the lake.

However, the geostrophic wind direction was distinctly different, 240 – 350o, in the following days: 6, 8 – 10, 19 and 25 – 27 January. These days were related to transient cyclones centered northwest of the lake or high-pressure centers northeast of the region under the study. During the days, the wind speed over the lake was strongly reduced (Table 7), as the katabatic and synoptic forcing factors opposed each other. The lake surface temperature was higher than usual, but the air temperature was lower. The latter is partly because, during events when the geostrophic and katabatic forcing factors support each other (sector 60 – 130o), the strong wind effectively mixes the atmospheric boundary layer. In stably stratified conditions, which prevail over the ice sheet, vertical mixing results in higher near-surface air temperatures (Vihma et al., 2011). In addition, the adiabatic warming during the downslope flow is a major factor contributing to higher air temperatures (Xu et al., 2021). The impact of adiabatic warming is also seen as lower relative humidity in cases when the geostrophic wind is from the sector 60 – 130o. Related to the compensating effects of air temperature and relative humidity, the specific humidity was not sensitive to the geostrophic wind direction. The effect of the wind speed dominated the effect of the lake surface temperature (which controls e_s in Eq. (3)), and evaporation was strongly reduced when the geostrophic wind was from the sector 60 – 130o (Table 7).

…Table 7 ...

The katabatic wind was a quasi-persistent feature during the study period, and the major changes in the evaporation were driven by changes in the synoptic scale wind direction, which affected the local wind speed."

What is the relationship between lake stratification and evaporation?

Lake Priyadarshini is thermally homogeneous during the ice-free period, and the possible reason for that is the strong katabatic winds allowing mechanical mixing of the whole water body. We add the text as follows: "The lake stays free of ice for almost two summer months from mid-December to mid-February. In this period, the lake has no significant thermal stratification (Sinha and Chatterjee, 2000) "

Specific comments:

L37-38: rephrase 'The authors concluded that over 25%..."

The text is modified as follows: "Estimations of the area for the melting zone in Antarctica are also available from the microwave remote sensors for the summers in the period of 1979/80 - 2005/06, and the melting zone expands over 25 % of the continent at least five times (Picard et al., 2007)."

L57: I disagree, eddy covariance is a direct measure of turbulent water vapor fluxes.

The EC method is a **direct** method providing the estimates of the reference evaporation. We have stressed this circumstance within the whole revised manuscript.

The following text has discussed this circumstance in the Introduction: " Performing the direct measurements of evaporation is difficult, and various methods are applied in the estimations of evaporation over the land surface including lakes. They are generally indirect because they are "point" measurements by an instrument and/or it is calculated from measured meteorological variables (Guidelines, 2008). Some of these methods are expensive and require special instruments and sensors for humidity, wind speed and temperature (Brutsaert, 1982; Finch and Hall, 2001): turbulence measurements (ie. eddy-covariance, EC method), profile measurements (ie. aerodynamic methods) and measurements at two heights (ie. Bowen-ratio based energy-balance methods). Among others, the eddy covariance (EC) method is recognized as most accurate in estimations of the evaporation. This method has been introduced for more than 30 years (Stannard and Rosenberry, 1991; Blanken et al., 2000; Aubinet et al., 2012). The turbulence (EC) measurements are direct measurements of the vertical flux of water vapour occurring over the lake surface. Assuming that the flux at the measurement height is the same as at the surface (or low), the EC measurements are direct measurements of local evaporation over a lake. In this study, we assumed that the point measurement of the EC measuring system was a direct measurement of the lake evaporation."

L64: cite examples.

We have added the references further mentioned in the section with Discussions.

L105: A climatology is usually accomplished over a 30-year period. Also, how can the average incoming solar radiation be so high? How is it calculated?

We removed the term "climatology" from the whole text. Now, we directly mentioned the period, which is used in calculating the statistical values given in Table 1 and further.