

Response to Reviewer 1

The manuscript was revised following the Specific Comments (SC). Our responses (R) are marked in red below each comment.

1. Does the paper address relevant scientific questions within the scope of HESS?

Yes, unequivocally. The paper tackles the critical challenge of quantifying a fundamental component of the water balance—evaporation—in a sensitive and data-scarce polar environment. This directly aligns with the HESS scope of "physical, chemical, and biological processes within the hydrological cycle" and its emphasis on "the interaction of hydrology with other earth system sciences." Understanding these processes in Antarctica is vital for predicting freshwater availability for research stations, assessing the stability of ice shelves influenced by supraglacial lakes, and modeling regional climate feedbacks.

R1. Thank you!

2. Does the paper present novel concepts, ideas, tools, or data?

Yes, primarily through its novel data. The core novelty is the presentation of rare, direct eddy-covariance measurements of lake evaporation in coastal East Antarctica. This dataset is a significant contribution in itself. The development and validation of a wind dependent parameterization for the bulk transfer coefficient (C_E) specifically for Antarctic lakes is a novel and valuable methodological outcome. While the concepts (EC , bulk method) are established, their application and rigorous validation in this extreme environment provide novel insights.

R2. Thank you!

3. Are substantial conclusions reached?

Yes. The conclusions are robust, significant, and well-supported by the data:

- Direct evaporation rates are quantified (0.3 to 5.0 mm d^{-1}), showing clear dependence on ice cover and wind speed.
- Most combination formulas (Penman, Odrova, etc.) are shown to have severe systematic biases, underestimating evaporation by 27-73%.
- The bulk-aerodynamic method is confirmed to be highly accurate (6-8% bias) but only when using appropriate, site-specific transfer coefficients (e.g., from Arya (1988)), not generic ones.
- Wind speed is identified as the primary driver of short-term evaporation variability, a finding that contrasts with studies in less windy environments (like the Tibetan Plateau in Wang et al. (2019)).

Wang, B., Ma, Y., Ma, W., Su, B., & Dong, X. (2019). Evaluation of ten methods for estimating evaporation in a small high-elevation lake on the Tibetan Plateau. Theoretical and Applied Climatology, 136(3), 1033-1045.

R2.1: We added the following text after line 303: "Our results show that the wind speed is the primary driver for the short-term variation of evaporation, and it contradicts with the

results for the lakes in Tibetan Plateau (Wang et al., 2019) where weather is, however, less windy than in coastal Antarctica”, and on line 569: “Wang, B., Ma, Y., Ma, W., Su, B., Dong, X.: Evaluation of ten methods for estimating evaporation in a small high-elevation lake on the Tibetan Plateau. Theoretical and Applied Climatology, 136(3), 1033-1045, 2019.”

- The authors did not comment on the role of solar radiation which is the main driver of evaporation and needs to be discussed, even they did not directly measure it.

R3. We added the following text after line 360: “The solar radiation is in the beginning of the causal chain of factors controlling ice and snow melt, lake water temperature and evaporation. It is explicitly included in the energy balance method which is among the other indirect methods applied to estimate the evaporation (Finch and Calver, 2008). In this study, however, we focused on indirect methods where the solar radiation is implicitly included in calculations because we did not measure the solar radiation in our experiments. ”

4. Are the scientific methods and assumptions valid and clearly outlined? Yes. The methods are state-of-the-art. The use of EC as a reference is the gold standard. The post-processing pipeline (spike removal, footprint filtering, gap-filling) is clearly described and follows established protocols. The assumptions (e.g., the applicability of Monin-Obukhov similarity theory, the representativeness of point measurements) are standard for such studies and are clearly addressed. The statistical analysis using RMSE and SSC is valid and appropriate.

R4: Thank you!

5. Are the results sufficient to support the interpretations and conclusions? Yes. The results are comprehensive and compelling. The data from two different lakes and two summer seasons provide a robust basis for analysis. The figures (timeseries, diurnal cycles, scatter plots) and tables (method comparison, skill scores) effectively present the evidence. The clear gradient of performance across the different methods strongly supports the conclusion that parameterization is key. The finding that wind speed correlates better with evaporation than the vapor pressure deficit is convincingly demonstrated.

R5: Thank you!

6. Is the description of experiments and calculations sufficiently complete to allow reproduction?

Yes. The description of the instrumentation, sensor heights, data processing steps, and equations is excellent. The provision of code and data on Zenodo is a major strength that ensures full reproducibility and aligns with best practices in open science.

R6: Thank you!

7. Do the authors give proper credit and indicate their original contribution? Yes. The introduction and discussion thoroughly contextualize the work within existing literature on polar hydrology and evaporation methods. The authors clearly reference the original sources of the combination formulas they test. Their own original contribution—the unique EC dataset and the

subsequent validation of methods—is clearly stated and forms the central pillar of the paper.

- *Note* while Wang et al. (2019) focused on a different environment, a discussion acknowledging that their finding (mass transfer methods work well) aligns with conclusions from other extreme environments (like high-altitude lakes) could further strengthen the context.

R7: We included the text after line 303 and on line 363: “Our results show that the mass transfer methods work well enough to reproduce the evaporation over the lakes in the Schirmacher oasis, and this aligns with outcomes from the studies focused on the evaporation over the high-altitude lakes of Tibetan Plateau (Wang et al., 2019).”

8. Does the title clearly reflect the contents of the paper?

Yes. The title is accurate, specific, and concise, correctly reflecting the location, subject, and process studied.

R8: Thank you!

9. Does the abstract provide a concise and complete summary?

Yes. The abstract perfectly summarizes the objectives, methods, key results (including quantitative findings), and the main conclusion and recommendation.

R9: Thank you!

10. Is the overall presentation well structured and clear?

Yes. The paper follows a standard and logical structure. The flow is easy to follow, and the argument is built progressively.

R10: Thank you!

11. Is the language fluent and precise?

Yes. The language is clear, formal, and scientific. While there are a few minor grammatical quirks (e.g., "containerizing" on p1), they do not hinder understanding. The manuscript is well-written.

R11: Thank you! We have tried our best to improve the language.

12. Are mathematical formulae, symbols, abbreviations, and units correctly defined and used?

Yes. Formulas are presented clearly. Symbols are defined upon first use (e.g., in the bulk formula on p6). Units are used consistently throughout (mm d^{-1} , ms^{-1} , etc.).

- *Note:* In Table 1, the column "Sum" has units " mm p^{-1} ". This should be clarified to "mm per [33-day] period" to avoid ambiguity.

R12: We corrected the text accordingly.

13. Should any parts of the paper be clarified, reduced, combined, or eliminated?

- Clarify: The distinction between "SSC" and "SSg" in the text and Table 4 should be made consistent.

R13: SSg was the typo, and corrected in the revised version.

- Clarify: The discussion of spray evaporation (p19) references "Eqs 3, 4", but only Eqs. 2 and 3 are presented. This should be corrected.

R13: We corrected the text.

- One needs to guess the applicability of Eqs 2,3, the meaning of the coefficients and the height where the wind speed w_2 is measured should be explicitly stated.

R13: The text was corrected.

- L146: the formula for σ should appear before 'where' in L145.

R13: Corrected.

14. Are the number and quality of references appropriate?

Yes. The reference list is extensive, relevant, and includes key historical works, foundational methodological papers, and recent literature. It appropriately covers the fields of micrometeorology, Antarctic science, and hydrological methods.

R14: Thank you!

15. Is the amount and quality of supplementary material appropriate? Yes, and it is a significant strength. The availability of the raw code and data on Zenodo is exemplary and exceeds typical standards. It ensures full transparency and allows for exact reproduction of the analysis, which is crucial for a validation study like this.

R15: Thank you!

In the revised manuscript, we implemented the modifications following the comments of three reviewers. Also, besides of the modifications suggested by the reviewers, we implemented the following changes:

Fig. 8 became new Fig. 5 and its legend was modified.

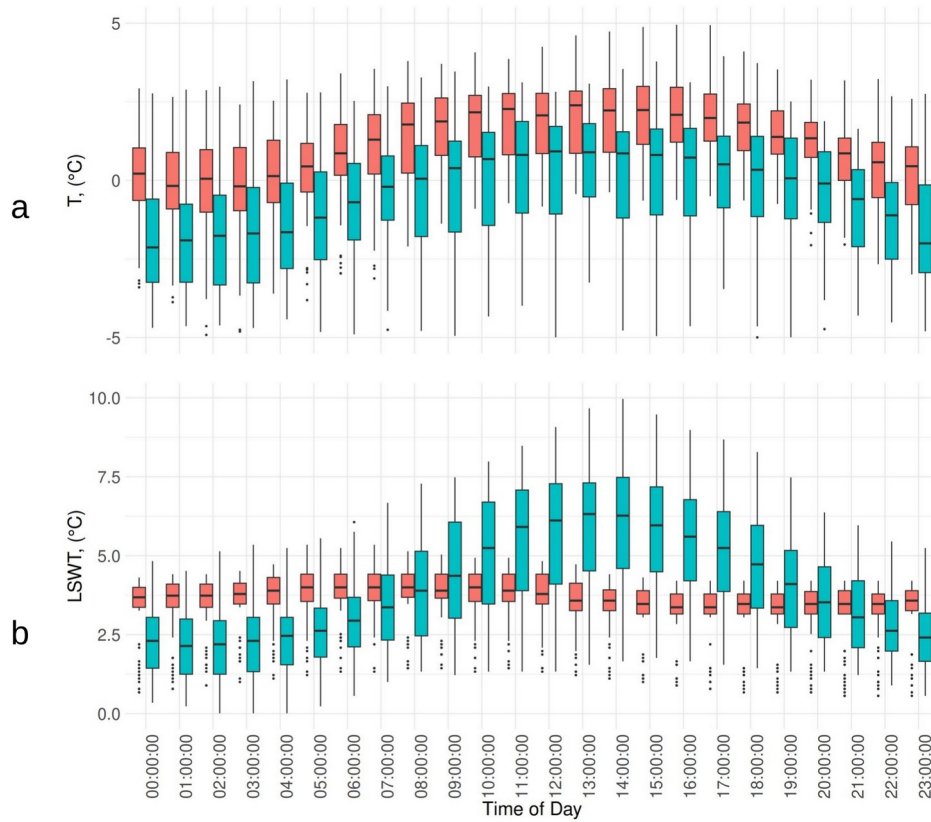


Figure 5. The diurnal cycles of air temperature (a) and the lake surface water temperature (b) measured on Lake Zub/Priyadarshini (light blue) and Lake Glubokoe (coral).

The diurnal cycle of the air temperature is qualitatively similar for both experiments: it reaches the maximum at the mid-day hours and the minimum at midnight. The average temperature was, however, higher in December 2019 – January 2020 (Fig. 5 a, coral boxplots) than in January – February 2018 (Fig. 5 a, light blue boxplots). The diurnal cycle of the LSWT differs for the two lakes: on Lake Zub/Priyadarshini LSWT shows the nighttime (23:00 –02:00) minimums of 3.0 °C and daytime (12:00–14:00) maximums up to 6.0 °C (Fig. 5 b, light blue boxplots), whereas on Lake Glubokoe, the LSWT showed a weaker diurnal cycle, LSWT remaining close to 4.0 °C (Fig. 5 b, coral boxplots).

The Fig. 9 and its legend were modified as follows:

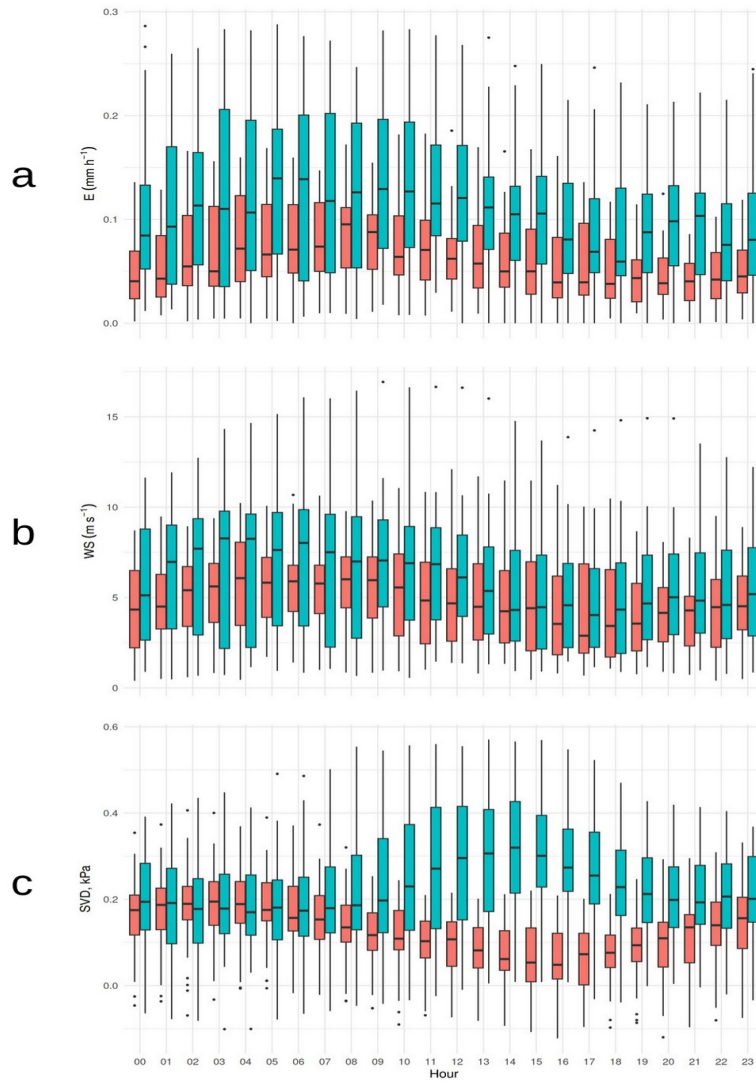


Figure 9. The diurnal cycle of the evaporation (a), wind speed (b) and saturation vapor pressure deficit (c) for two experiments on Lake Zub/Priyadarshini (coral) and Lake Glubokoe (light blue).

The text on lines 213-225 was modified as follows: “The diurnal cycle of evaporation over the lakes depends on the ice cover: the cycle is large during the ice-free stage on Lake Zub/Priyadarshini, and evaporation reaches its maximum (0.2 mm h^{-1}) between 11:00 AM and 01:00 PM (Fig. 9 a, light blue boxes). Its diurnal cycle is similar to the cycle of saturation vapor pressure deficit (Fig. 9 c, light blue boxes). The strongest wind speed was observed at nighttime (03:00 – 04:00 AM) reaching up to 10 m s^{-1} , while wind was often lower at daytime (04:00 – 05:00 PM). The diurnal cycle of evaporation over the partly ice-covered Lake Glubokoe showed maximum (0.15 mm h^{-1}) in the early morning at 06:00–8:00 AM (Fig. 9 a, coral boxes), then reducing to even near-zero values in the late evening hours (09:00 – 11:00 PM) and night. It was in the opposite phase relative to the diurnal cycle of the wind speed, demonstrating that the saturation deficit dominated over wind speed as the primary driver of evaporation (Fig. 9). These different patterns in the diurnal cycle of

evaporation over the lakes reflect the complex interplay of factors (air-water temperature gradient, air humidity, wind speed, solar radiation) that vary throughout the day.”

On lines 246 – 249 we added the text reads as follows: “We also calculated the transfer coefficient of moisture on the basis of the measurements on Lake Glubokoe following Andreas (1986), Arya (1988) and Fedorovich et al. (1991). The coefficient varied between $1.46 \cdot 10^3$ and $2.10 \cdot 10^3$ depending on the parameterization (Table 2). In Table 2, the transfer coefficients are presented for the measurement heights (different in the two experiments) and, to compare our results, also for the standard height of 10 meters (C_{EN10}).”

We modified the text on lines 319-320: “The evaporation over lakes is often evaluated applying combination formulas, and we found five combination formulas (Penman, 1948; Doorenbos and Pruitt, 1975; Odrova, 1979; Shuttleworth, 1993; and Shevnina et al., 2022) that have been applied over the lakes in Antarctica. ”

We added the text after line 362: “We did not present the estimations of the lake ice cover fraction from the digital images collected in the experiment on Lake Glubokoe, which may be a topic of the next study.”

We added the text after line 349: “Lakes affect formation of fogs: passing of warm and moist air from lakes moves over colder ice covered surfaces cools the air to its dew point, leading to local fog (Gultepe et al., 2003) and precipitation (Su et al., 2020). In the Schirmacher oasis, the fog and “white rainbow” were observed in the early morning on 26 December 2020 (Fig. 12) when the relative humidity was over 95 %, the difference between the temperature of air and the lake water was close to -10°C and wind speed was less than 1.0 ms^{-1} . Such fogs may foster the surface melt, decrease visibility and make danger for the transport operations between the settlements, ice runways and coastal bases.”

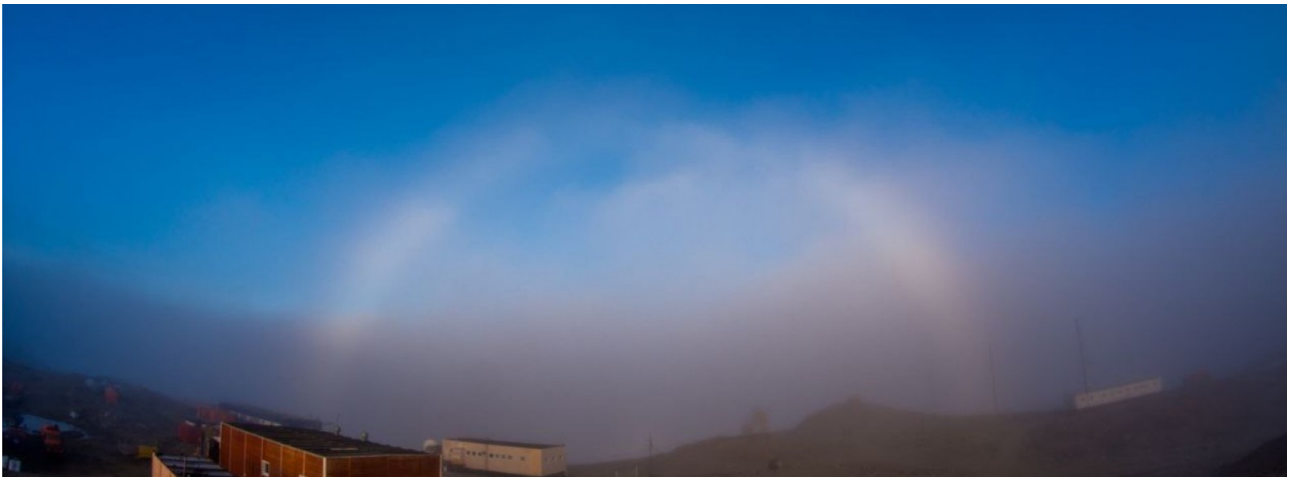


Fig. 12. The fog and “white rainbow” was observed on the early morning 26 December 2020 in the Schirmacher oasis (photo D. Emelyanov).

New references: “Gilson, G.F., Jiskoot, H., Cassano, J.J. *et al.*: The Thermodynamic Structure of Arctic Coastal Fog Occurring During the Melt Season over East Greenland. *Boundary-Layer Meteorol* 168, 443–467, <https://doi.org/10.1007/s10546-018-0357-3>, 2018

Su, D., Wen, L., Gao, X., Leppäranta, M., Song, X., Shi, Q., Kirillin, G.: Effects of the largest lake of the Tibetan plateau on the regional climate. *J Geophys Res: Atmos* 125, e2020JD033396, 2020.”

We modified the text on lines 91-96: “This lake often stayed free of ice during 6–8 weeks during the austral summer (Khare et al., 2008), and it was ice free from 29–31 December 2017 to 8–12 February 2018 and from 22 – 25 December 2019 to 10 – 14 February 2020. Lake Glubokoe is of a maximum depth of 34.5 m (mean of depth is 13.1 m) and the surface area of 147000 m (Loopman et al., 1988). The lake is normally ice-covered year round (Kaup, 2005), but in recent years the lake has been ice free almost every summer (Sharov and Tolstikov, 2020). In February 2018 and 2020 the lake was ice free for two weeks.”

We modified the text on lines 295 – 303: To our best knowledge, the direct (EC) observations on lake evaporation have been done in Antarctica for the lakes in the Schirmacher oasis. Ones, however, can be found for the regions with the polar desert climate, like the high-altitudes lakes located in the Qinghai-Tibet Plateau (36°N, 3194 m asl). Applying two years of observations, Li et al. (2016) found that the evaporation over the ice-free Lake Qinghai reaches up to 12 mm d⁻¹ during wind storms, and days with wind speed stronger than 4 ms⁻¹ contribute up 22 % to annual lake evaporation. Lately, Shi et al. (2024) found that the evaporation over the ice free lake is controlled

by wind based on the EC observations collected in 2014 – 2019. The authors suggested that the ice sublimation takes 23 % of annual evaporation over Lake Qinghai.”

We changed the text on lines 362-370: “The method used in calculation of the evaporation is important for shallow coastal lakes whose volume changes very little over an austral summer (Shevnina and Kourzeneva, 2017). Gopinath et al., (2020) affirm the importance of the summertime evaporation over shallow lakes in the Schirmacher oasis applying the information on water isotope composition. Lake Zub/Priyadarshini is one of such shallow lakes whose water is used to supply the Maitri station and the new Maitri-II site (planned to open in 2029). The lake’s water balance equation includes the precipitation, inlet river runoff (as inflow/positive component) and outlet river runoff, evaporation and water withdrawal (as outflow/negative component). The lake volume is 1032500 m³, and in January-February 2018 it decreased by 40.3 m³, and the discrepancies of the water balance equation was 670.6 m³ (Dhote et al., 2021). The lake evaporation of 58.5 m³ was calculated after Odrova (1979), which underestimated the evaporation for 72 % according to our results. In absolute values it corresponds to 42.1 m³ (58.5 multiplied by 0.72), which represents approximately 6 % of the discrepancy of the water balance equation. It can be reduced by using a better indirect method while calculating the evaporation.”

We added the reference: Gopinath, G., Resmi, T. S., Praveenbabu, M., Pragath, M., Sunil, P. S., Rawat, S.: Isotope hydrochemistry of the lakes in Schirmacher Oasis, East Antarctica. *Indian Journal of Geo Marine Sciences* Vol. 49 (6), 947-953, 2020.

We also try our best to smooth the language of the overall narrative and prepare new supplements with the modified code used for plotting the figures.

Elena Shevnina from behalf of co-authors