29 January 2025
Dear Editor and Reviewer,

Thank you for your thoughtful review, comments, and suggestions. We are happy to answer your questions and provide more information.

The following pages contain comments that appear exactly as they were received. Our responses are inserted next to each comment in blue text. Thank you again for taking time to review our manuscript.

Sincerely,
Svetlana Stuefer and Kesley Stockert on behalf of the coauthors

22 Dec 2024
Editor decision: Publish subject to minor revisions (review by editor)
by Andrea Popp

Dear Kelsey Stockert and co-authors,

We finally received the comments from the two reviewers. While the reviewers acknowledge the improvements you made, referee#2 has highlighted remaining issues that need to be addressed before the manuscript can proceed.

Please clarify and expand particularly on the reviewer's points regarding 1) the variability in snow sublimation across sites and years, considering site characteristics and meteorological conditions,

Response 1: We appreciate the Editor's assessment of the manuscript and comments on improvements. We hope that the bolded text in this response makes clear how our revisions and clarifications address your request.

The variability in snow sublimation across sites and years is expanded in section 4.1 by clarifying and revising following sentences to address the ***variability in sublimation across sites and years****: Lines 243–248 "Broadly, tundra site sublimation rates increase from US-ICh (ridge) to US-ICs (valley bottom) to US-ICt (mid-slope). At the lowland boreal sites, sublimation rates are greatest at US-BZS (black spruce) and lowest at US-BZB (bog). There is high interannual variability in sublimation rates (Figure 4). The most extreme range at US-ICs measures a nearly 40 mm year^{-1} difference of sublimated water between 2015 and 2021. The relative inter-site rates between sites variability in sublimation rates within tundra and lowland boreal forest snow classes is lower than interannual variability (Figure 4)."*

Section 4.3 tests the statistical significance of the variability in snow sublimation across sites and ***site characteristics*** *in*

1) *Figure 5 shows that "… the lowland boreal bog (US-BZB) measures significantly lower cumulative annual sublimation rates than the lowland boreal black spruce (US-BZS, p value = 0.03) and the tussock tundra (US-ICt, p value = 0.04). The remaining sites do not measure significantly different cumulative annual sublimation from each other."*
2) *Figure 6 shows another boxplot that "pools sites with trees (US-BZS) and without trees (US-BZB, US-BZF, US-ICh, US-ICs, and US-ICt)…[and] demonstrates that sublimation rates are significantly different between sites with trees and without trees (p value = 0.02), a finding that is masked by the small site-to-site variation evaluated in Figure 5.*

Section 4.4 contains results for correlations (Table 5) and single and multiple linear regressions (Table 6) to evaluate the effects ***meteorological conditions*** *have on sublimation rates/variability.*

2) the use of datasets in statistical analyses to ensure the methods clearly state which datasets were used and for what purposes,

Response 2: Section 3.3 was re-written to clarify the use of the data and methods (Lines 190–206). Most notably the addition of Lines 214–220: "data are summarized at different time scales: hourly, daily, monthly, and annual. Reporting daily rates is valuable for comparison with findings from other studies in the literature (Section 5.3). Correlations and regressions with meteorological variables are conducted using the hourly and daily data because these relationships are stronger at finer temporal resolutions. In contrast, regressions with environmental variables, namely snow cover duration, SWE, and solid precipitation, are meaningful (and available) only at the annual scale. ANOVA tests are applied to annual data to provide a clearer understanding of the impacts of sublimation over entire winters; and avoid the limitations of daily rates, which fail to capture the substantial difference in the snow class's snow cover duration (see specifics of differences in Section 4.2.1)."

and 3) a discussion of correlations at different temporal resolutions (hourly vs. daily) and their implications.

Response 3: A discussion was added to Section 4.4 (Lines 308–311): "All variables, except for net radiation and relative humidity, exhibit stronger correlations with daily summaries, likely due to reduced noise compared to the hourly data. However, the reduced statistical power for net radiation at the daily scale may result from the loss of meaningful information caused by aggregation daytime and nighttime values. It is unclear why relative humidity has weaker correlations at the daily scale at the tundra sites."

Furthermore, additions to Section 5.2 (Lines 373–378): "The lowland boreal sites exhibit stronger relationships with meteorological variables than the tundra sites; the largest differences are associated with higher wind speeds and lower relative humidity (Table 5). The markedly higher winter wind speeds at the tundra sites (Table 1) may cause those EC sensors to capture a smaller proportion of total sublimation compared to the lowland boreal sites (see Section 5.1 discussion on underestimates during blowing snow events), and potentially affect the relationship between sublimation rates and wind speed and comparison across sites."

Please revise the manuscript to address all comments of referee#2. If you choose not to implement specific suggestions, provide a clear justification in your response letter.

Thank you for addressing these points. I look forward to your updated submission.

Best regards,
Andrea Popp

Response to RC2 comment on "Sublimation Measurements of Tundra and Taiga Snowpack in Alaska" by Kelsey Spehlmann, Eugénie Euskirchen, and Svetlana Stuefer.

RC2: 'Comment on tc-2023-153', Anonymous Referee #2, submitted on 20 Dec 2024

General comments:

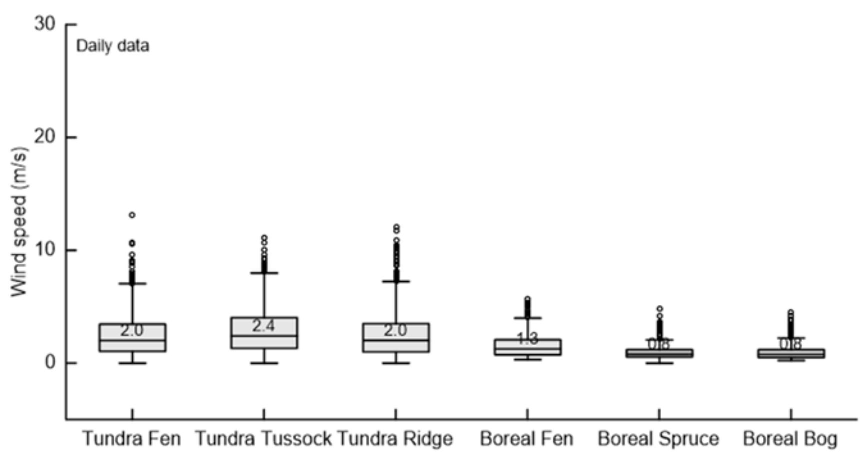
The manuscript has significantly improved compared to the previous version and a few comments and clarification issues remain.

Thank you for your review.

In my previous review comments, the authors were invited to consider additional investigations to assess whether the snow sublimation variability among sites within the same snow class or among years could be related to specific meteorological conditions and site characteristics. In addition to vegetation the six sites are described to have different topographic positions and expositions. The authors did not fully address this point as 1), 2) for SWE, and 3) in the response relate to regressions over the entire study period and combined in lowland boreal forest and tundra. Additional investigations would have also more strongly supported the conclusions on the snow sublimation differences between sites, tree presence, and snow classes.

Response 1: We agree that variability in snow sublimation between sites, tree presence, and snow classes is an important aspect of this paper. An additional analysis for correlations between sublimation and ***specific meteorological variables at individual sites*** *(tundra ridge, tundra tussock, tundra fen, boreal bog, boreal fen, boreal black spruce) was performed during earlier stages of manuscript development and preparation. At that time, we noticed the greater influence of snow-climate conditions over individual site meteorological conditions on sublimation rates in our study sites. This is because sites within the same snow class are located only 0.5 km apart with similar weather conditions, whereas the snow classes are over 600 km and represent distinct climate zones (Arctic Alaska vs Interior Alaska). We added clarification in Lines 221–223.*

Similarly, summary statistics of the wind speed data from individual sites show that difference in wind speed between climate zones is more pronounced than difference between individual sites, i.e. tundra climate is substantially winder than the lowland boreal climate. The wind speed plot provides additional analyses on the difference ***in topographic positions and expositions*** *and supports our approach for aggregating data by snow class during data analysis and synthesis.*



In addition, we clarified (Line 94) that EC towers used in this study were originally established to understand carbon and water cycling in distinct northern ecosystems (rich fen, bog, peat plateau, wet sedge, tussocks, dry heath). These distinct biological and soil criteria were the driving factors for selecting location of the individual sites.

With regards to ***SWE differences between individual EC towers****, there are no corresponding SWE measurements at individual sites. We used SWE measurements available at the nearest location. Furthermore, SWE is only collected as a single end-of-winter measurement and cannot be reduced to evaluate hourly or daily data. Please, also see Response #1 to the Editor.*

In my previous review comment on how the dataset was used in the different statistical analyses, the point was that the results of some statistical analyses, e.g. regressions and correlations with meteorological variables, are presented for hourly and daily data as classes (boreal and tundra), others, e.g. regressions with snow cover duration and analysis of variance, for annual data and distinct sites. The methods should clearly state which type of data sets was used for which statistical analysis and purpose.

Response 2: Section 3.3 was re-written to clarify the use of the data, most notably the addition of Lines 214–223: "… data are summarized at different time scales: hourly, daily, monthly, and annual. Reporting daily rates is valuable for comparison with findings from other studies in the literature (Section 5.3). Correlations and regressions with meteorological variables are conducted using the hourly and daily data because these relationships are stronger at finer temporal resolutions. In contrast, regressions with environmental variables, namely snow cover duration, SWE, and solid precipitation, are meaningful (and available) only at the annual scale. ANOVA tests are applied to annual data to provide a clearer understanding of the impacts of sublimation over entire winters; and avoids the limitations of daily rates, which fail to capture the substantial difference in the snow class's snow cover duration (see specifics of differences in Section 4.2.1). Lastly, most analyses group the data by snow class. This approach reflects the greater influence of snow-climate conditions over individual site meteorological conditions on sublimation rates. Sites within the same snow class are located only 0.5 km apart with similar weather conditions, whereas the snow classes are over 600 km and represent distinct climate zones (Shulski & Wendler, 2007)."

The results show that some correlations increase at daily resolution for specific classes and meteorological variables, while they remain low despite the temporal scale for others. These findings should be discussed.

Response 3: Additional discussion was added to Section 4.4 (Lines 308–311): "All variables, except for net radiation and relative humidity, exhibit stronger correlations with daily summaries, likely due to reduced noise compared to the hourly data. However, the reduced statistical power for net radiation at the daily scale may result from the loss of meaningful information caused by aggregation daytime and nighttime values. It is unclear why relative humidity has weaker correlations at the daily scale at the tundra sites."

We also added to the Discussion Section 5.2 (Lines 373–378):"The lowland boreal sites exhibit stronger relationships with meteorological variables than the tundra sites; the largest differences are associated with higher wind speeds and lower relative humidity (Table 5). The markedly higher winter wind speeds *at the tundra sites (Table 1) may cause those EC sensors to capture a smaller proportion of total sublimation compared to the lowland boreal sites (see Section 5.1 discussion on underestimates during blowing snow events), and potentially affect the relationship between sublimation rates and wind speed and comparison across sites."*

Lastly, we elaborated on a point in Section 5.3 (Lines 443–447): "correlation coefficients (Table 5) and linear regressions (Table 6) show that the lowland boreal sites have a substantially higher dependence on relative humidity and wind speed relative to other variables compared with the tundra sites. The relationship between sublimation rates and wind speed is discussed in Section 5.2. However, no hypothesis is proposed for the weak relationship with relative humidity at the tundra sites."

The results of the linear regressions between sublimation rates and single meteorological variables with hourly data are reported in the table but not mentioned in the related section.

Response 4: We revised this sentence to include hourly data. The revised sentence now reads: "Single linear regressions with ***hourly and*** *daily sublimation rates as the response variable show moderate relationships (r2 > 0.1) between air temperature, wind speed, net radiation, vapor pressure deficit, and temperature gradient* ***(Table 6)."***

Differences between hourly and daily results should be all reported and discussed.

Response 5: We revised Lines 323–324: "…the strength of the relationship of meteorological variables generally improves when the time scale is increased to daily summaries (except net radiation)." Please also see the added discussion noted in Response 3.

On the point of multiple linear regression, it is necessary also to show the coefficient of determination values in Table 6 for 1) air temperature and wind speed, 2) vapour pressure deficit (VPD) and wind speed as a result of the stepwise approach for the information completeness.

Response 6: Table 6 was revised to include MLR results for 1) air temperature and winds and 2) VPD and wind speed.

Detailed comments:
Line 100: "occurring as snow" Please specify from and to which month for lowland boreal sites.

Response 7: See Lines 84-85 "Mean daily air temperatures remain below freezing from October to April in tundra sites and from October to March in lowland boreal forest sites (Table 1)" and Lines 276–278 "Snow cover duration at the tundra sites is approximately two months longer than at the lowland boreal sites. On average, snow cover duration is 254 days at tundra sites (mean date of snow onset is ***September 19 and snow melt is June 1****) and 185 days at boreal sites (mean date of snow onset is* ***October 19 and snow melt is April 22****; Table 3)."*

Line 190: Please specify which are the environmental variables and the other water flux.

Response 8: We clarified Section 3.3 (Lines 192–196): "The magnitude of daily, monthly, and annual sublimation rates are calculated for water years with complete records. Mean values, standard deviation, and standard error of the mean are used to compare the variability in sublimation rates between sites (Section 4.1), to compare sublimation with ***environmental conditions (snow cover duration, SWE, solid precipitation****) (Section 4.2.1), and to evaluate sublimation rates with other* ***water fluxes (ET, condensation, and deposition****) (Section 4.2.2).*

Line 191: Please specify what "over time" means, e.g., over the water year with complete records.

Response 9: The sentence in question was removed.

Line 221: Please define snow cover duration with the other environmental variables as it suddenly appears in the results and how snow cover duration, snow onset and melt are calculated.

Response 10: Definition of snow cover duration was added (Line 164): "… snowpack presence ***and snow cover duration*** *are determined from the albedometer installed on the EC towers and from webcam images at the sites."*

Figure 7: Please double-check that the colours used for the three sites are the same as those used in Figure 3.

Response 11: We adjusted the color scheme to be consistent with Figure 3.