# Response to Reviewer Comment on “Predictability of summertime diurnal winds over ungauged mountain glaciers”

The authors present a statistical model for deriving the mean diurnal cycle of winds on or near valley glaciers. The model utilizes simple, widely available reanalysis data, making it useful to studies of surface wind speed in glaciated basins. After a first round of reviews, I appreciate the reformulated methodology, and the addition of the discussion section related to where the model may be most applicable on a glacier. Overall, the authors have incorporated the feedback from the first round of reviews well, and present here a stronger manuscript. I have a few, mostly minor outstanding comments and requests for clarification in the methodology and discussion, which are detailed blow.

We thank the reviewer for their positive comments, and for their valuable time.

1. L35-36: “sublimation rates of snow” is conflated with glacier melt here, do you just mean sublimation of glacier ice instead?

We have replaced “snow” with “glacier ice”.

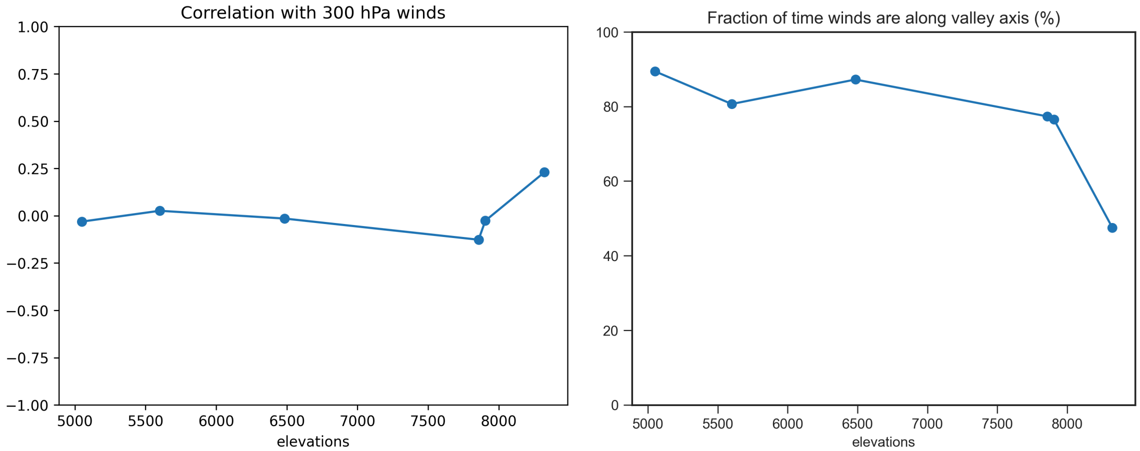
2. L85: Why would you expect to find glacier valley winds at an elevation of 8300+ m? The only terrain on earth at this elevation is exposed and influenced by meso-scale forcing – I don’t think that the processes outlined in your introduction are dictating the wind field here.

Thanks for pointing this out. We agree that the Balcony station may be strongly influenced by the meso-scale forcing.There are four other stations (Bishop, Southcol, Place4 and Weart2) that are on ridges or near glacier headwalls and the same criticism applies to them. However, we kept all of them so as to not reduce the number of stations, which is already low.

This is now mentioned in L86 of the revised manuscript:

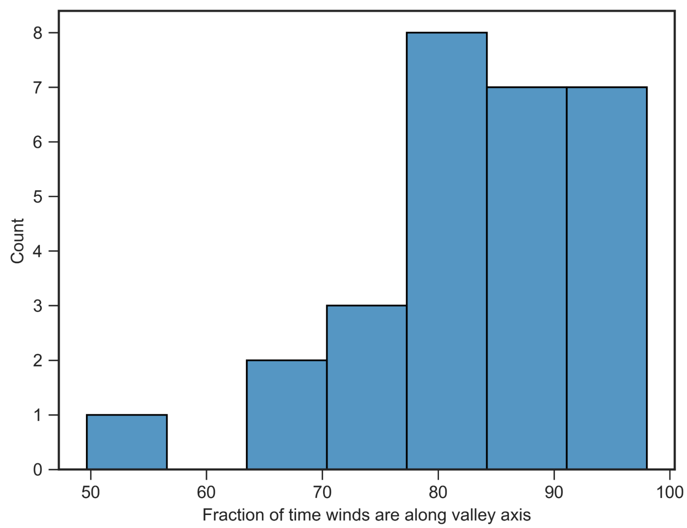
> and the remaining 12 were clean glaciers (Supplementary Table S1). We note that Balcony station may be strongly influenced by the meso-scale forcing.There are four other stations (Bishop, Southcol, Place4 and Weart2) that are on ridges or near glacier headwalls and the same criticism applies to them. However, we kept all of them so as to not reduce the number of stations,

To check that we analyse the correlation between wind-velocity vectors at 300 hPa (~8000m) from ERA5 and that observed in weather stations in Khumbu valley(see plot below). Indeed, there is an increase in the correlation with 300 HPa ERA5 winds at this station, compared to the other stations in the valley. However, the percentage of times when wind directions are within 60 degrees of the valley axis is still significant  (right panel).




3. L120: Can you justify why you assume that the wind direction is always up-glacier or down-glacier? Did you not have observations of wind direction at your stations?

We assume that winds are along the valley axis for all stations, independent of whether they are in up-valley or down-valley direction. For more than 80% of the stations, winds are within 60 degrees of the valley axis for more than 77% of the data period (See figure below).




4. L137: What are “the first differences”?

We have now clarified this in L132-133 of the revised manuscipt:

regression of $T_d$ and its derivative $\frac{d}{dt}T_d$, against $u_d^{obs}$ (Eq. 1). This obtained 28 triplets of best-fit parameters $\{\bar{u}, s, \tau\}$ – one each for each station. Here, the diurnal variation $T_d$ was obtained by decomposing the ERA5L-derived mean diurnal summertime temperature $T$, into its mean and the anomalies. The time derivative $\frac{d}{dt}T_d$ at time step $i$ was approximated as $(T_i - T_{i-1})/\Delta t$, where $T_i$ is temperature at $i$-th time instant and $\Delta t$ is the time step, which is 1 hour.

5. L151: Where do these assumptions come from? For example, that the vertical length scale of turbulence over a glacier is related to the vertical extent of the glacier?

We have modified the text. We search for a suitable length scale (equivalently, slope) from among a large number of candidates by trial-and-error, and do not assume it to be the glacier elevation range. See response to the comment 11 below.

6. L170: It looks like theta is now discussed as being in units of C, but Ta was stated as being in units of K on L155, please reconcile this difference in units in your methodology section.

We have corrected this in the revised manuscript.

7. Section 3.1: I am curious why u¯is predicted purely based on static variables and temperature, and does not take the wind speed from the reanalysis data into consideration. Purely local, valley/glacier winds are unlikely to be resolved by ERA5L, but some effect of mesoscale winds on glacier winds has been observed depending on the location and layout of the glacier. There should be some statement in this section as to why this design decision was made.

Here our limited objective is to predict the diurnal cycle of valley/glacier winds for valleys that are dominated by such winds (Supplementary Fig. S1). Assuming that ERA5 winds are influenced by the large-scale forcing, we exclude them from the set of predictors, and concentrate on the local factors. We agree that on some specific locations or for some specific periods, ERA5 winds may be a good predictor, but for our problem these are exceptions.

8. I also find the new methodology harder to follow than the prior one. Equations 3-6 are not trivially arrived at. A more explicit explanation of the steps taken, and supporting the relationships of variables using prior observational studies, would improve this section.

Thanks for the suggestion. We have modified the section to improve clarity and added justifications for the steps involved.

9. EQ10-12: Given the reported uncertainty ranges, what values do you ultimately use when applying these equations in the LOOVC?

For the LOOCV analysis we use the best-fit model parameters as given in Eq. 10-12, without incorporating uncertainties. These errorbars are utilised by the Monte-Carlo iterations (Sect 3.3) to estimate uncertainties in the predicted winds,eg, in Fig 6.

We have now clarified that in the main text (L197-200).

> set of RMSEs between the ERA5L products and observations. We do not consider the uncertainties in the predicted model parameters in this LOOCV analysis. Also, we assume the same form of Eqs. 10–12 in each iteration, without repeating the search for the best set of choices for the temperature and slope variables. The present estimates of model performance in this LOOCV protocol are likely to be conservative, as we may not be working with the best model in some of the iterations.

10. Figure 4: The data plotted here looks strikingly similar to that of the earlier manuscript, although the methodology has changed considerably. Is this correct?

The revised method is exactly the same up to section 3.1.2 in both the versions of the manuscript, and the plots are indeed identical.

11. L235: Is the topographic slope mentioned here the mean slope computed within this radius?

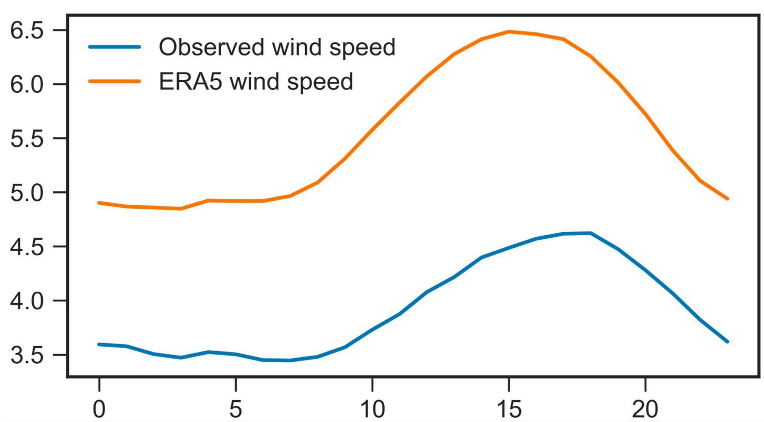
We now clarify this in L236-237 in the revised manuscript.

> The predictor $\sqrt{|\bar{T}|/\varsigma_{10}}$ was found to be the most suitable to estimate model parameter $\bar{u}$ (Fig. 5a), where $|\bar{T}|$ is the absolute value of the mean summertime temperature $\bar{T}$ from ERA5L (Section 2.2), and $\varsigma_{10}$ is the topographic slope of a resampled 10-km resolution DEM using a 3x3 window. A regression between this predictor and the observed best-fit values of $\bar{u}$ yielded

12. L251: Should be "corresponding observed best fit values"

The suggestion is accepted.

13. Figure 6: Can you explain the strange ellipse at the top of the plot formed by some of the ERA5 data? This looks almost like a plotting artifact, given that the rest of the ERA5 data never exceeds 2 m/s.




The observed winds in Schiaparelli Glacier show a good agreement with ERA5 winds, except that there is a time (phase) delay of a few housr (see figure above). Since they both show approximately sinusoidal oscillations with a phase difference, it shows an elliptical pattern.

The prevailing winds in this station located in the southern Patagonia region are westerly (Fig. 17a of Supplementary Fig. S1). This region is known to be impacted by large-scale circulation, such as the southern-hemisphere westerly winds (Gómez-Fontealba et al, 2022).

Additionally, the inset has now been removed, and the caption here should be updated.

Thanks. We have fixed the error in the caption.

14. L265: I strongly support adding the supplementary plot S4 to the main text, since it is one of the only validations performed of the method, and is needed to motivate using the method at other, non-instrumented glaciers. This could be added as a panel to figure 6, for example.

Thanks for the idea. We have accepted the suggestion.

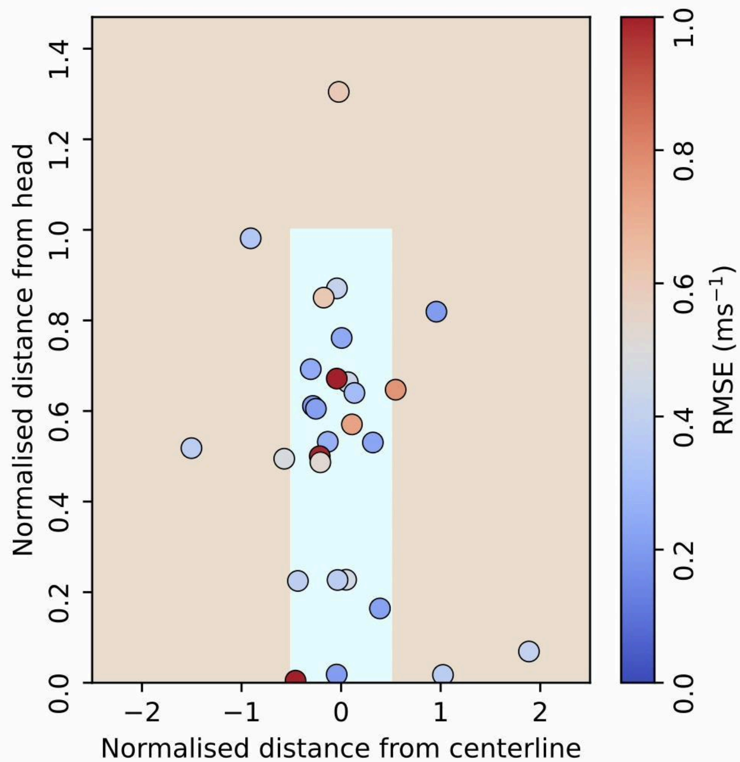
15. Section 5.2.1: Did you limit this time-scale analysis to summer months as well? Or was this now performed over the whole year?

We limit it to the summer months, as do for the rest of the analysis.

16. Section 5.4: I wonder how this method performs at different locations along a glacier? Are your stations biased towards flat locations, for example? It would be helpful to get a sense of how robust the leave-one-out analysis is to different local topographic conditions on a glacier. The new section 5.4 is welcome to discuss how representative the glaciers sampled are, but a similar discussion of how similar/dissimilar the measurement sites are would help a reader understand where along a glacier this method is most applicable.
L483: It looks like (from fig 1b) that some of your stations are near the glacier terminus, did you look at how well the model performs at these stations on the leave-one-out analysis?

Please see the added Supplementary Fig. S9 (pasted below) for the LOOCV performance as a function of the relative station location. No clear spatial pattern for model performance could be seen in our dataset. We have added this point in the revised manuscript (L269):

> diurnal wind speed at the left-out station reasonably well (Supplementary Fig. S4 and Supplementary Table. S3). In comparison to ERA5L, the set of 28 RMSEs of the wind speed predicted for the left-out station by the corresponding calibrated model had two times lower mean (0.87 $ms^{-1}$), three times lower median (0.64 $ms^{-1}$), and three times lower interquartile range (0.42–0.88 $ms^{-1}$). We do not find any clear pattern in the spatial distribution of the RMSE values (Supplementary Fig. S9).




**Supplementary Figure S9 .** The RMSEs in LOOCV (shades of red and blue) of 28 weather stations used in this study, with their relative locations (circles) shown on an idealised glacier (light blue rectangle) of unit length and width (similar to Figure 1b and S8). No clear spatial pattern for model performance could be seen from our dataset.

17. L404: “weather” stations

The suggestion is accepted.

# References

Gómez-Fontealba, C., Flores-Aqueveque, V., & Alfaro, S. C. (2022). Variability of the Southwestern Patagonia (51°S) Winds in the Recent (1980–2020) Period: Implications for Past Wind Reconstructions. *Atmosphere*, *13*(2), 206. https://doi.org/10.3390/atmos13020206