Response to Reviewer #2

We thank your for the valuable comments and appreciate the time and effort you dedicated to your feedback. These comments contributed to a significant improvement of our manuscript.

During the review process, we noticed an inaccuracy in the calibration of the hot-wire sensors that warranted a recalibration of the data. The changes are minimal and do not affect the conclusions of this manuscript, but all analysis were performed again with the re-calibrated data. The new data set is currently being in the publication process of PANGAEA and accepted as a data descriptor publication in Nature Scientific Data.

Here is a point-by-point response to the reviewers' comments. We included the original comment in *blue and italics* with the lines referring to the first manuscript. Our response follows in black, and the line numbers refer to the revised version.

General comments

This study examines the characteristics of the Arctic atmospheric boundary layer (ABL), more specifically the surface mixed layer (SML), during the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) campaign, using measurements from a tethered balloon platform including in-situ turbulence measurements. The measured profiles of the turbulence dissipation rate are used to diagnose the depth of the SML. This diagnosis serves as a reference for the evaluation of the bulk Richardson method and the surface flux-based method. I think the most significant result of the study is the determination of a critical bulk Richardson number for the diagnosis of the height of the SML. Furthermore, two typical states of the Arctic ABL were observed and characterized: cloudless situations with a stable and shallow ABL, and cloudy conditions with a mixed ABL. The paper is nicely organized and mostly well written. The presentation is mostly clear. While I think the paper may be acceptable with only minor revisions following the comments below, I think it could be significantly strengthened following the suggestions of the other reviewer.

We thank you for reviewing our paper and appreciate your feedback and comments that improved the quality of our study. We have revised the manuscript considering the comments of both Anonymous referees with the hope that we have addressed all minor and major concerns. Please find the responses to your comments below.

Specific comments

– **L23-L24:** *"… plays an important role as stable stratification hampers the vertical exchange and leads to a near surface warming contribution to Arctic amplification…". This is not clear to me. Wouldn't more stable conditions and reduce vertical exchange lead to surface cooling?*

  Response: This is somewhat misleading, the lapse rate effect describes the additional warming due to the fact that additional heat added to the system (by global warming) is distributed in a smaller volume (due to shallow SMLs) and therefore contributes to surface warming. This mechanism is described in detail by the cited work of Bintanja et al., 2011.

– **L172-L173:** *"For surface temperature, we use observations at the 2 m height". Would this not lead to a significant underestimation of the true surface inversion strength? Please comment on the differences.*
Response: This is a very good point and indeed there is a strengthening of the inversion when the radiative skin temperature is considered. During MOSAiC the air temperature at 2 m height and the skin temperature were measured. We have added a second bulk Richardson number calculated with the skin temperature as surface reference to account for the inversion down to the surface.

"According to the basic concept of the surface bulk Richardson number approach, the lower reference level is the surface where the mean horizontal wind velocity equals zero U ($z = z_0$) and θ_0 is the skin temperature. Since other studies are often based on radiosonde observations only, the temperature at 2 m is then typically used for θ_0, even though this value may differ from the skin temperature, especially for stably stratified conditions with strong surface temperature gradients. To be consistent with other studies, we first use temperature observations at 2 m from the *Met City* tower for θ_0. Then, for comparison, the same analysis is performed using the skin temperature measured during MOSAiC." Lines 196-201

We derived a critical value for both bulk Richardson numbers. The critical values are 0.12 for the reference temperature at 2 m and 0.16 when we use the skin temperature. Either temperature can be used depending on the purpose of the analysis. As skin temperature is not always measured, we concentrated on the standard meteorological parameters that are most likely to be measured during field campaigns. This approach should ensure applicability to other campaigns.

"Applying the same analysis with the skin temperature as θ_0, we derive $Ri_{bc} = 0.16$ (Fig. 6). This difference shows clearly how strongly the derived value for Ri_{bc} depends on the selected surface reference. Furthermore, we can assume that the temperature measured at a height of 2 m on a mast is also significantly more accurate than a corresponding measurement with a radiosonde, which has comparatively large inaccuracies in the lower ranges." Lines 284-287

– **L205:** *"with a less well mixed, neutrally stratified layer below the inversion" What do you mean? To me the sub-cloud layer looks like a rather well-mixed turbulent layer..*
Response: We fully agree and have change the sentence accordingly.

"The first case represents a cloudless ABL with a pronounced surface inversion, and the second case describes a cloudy ABL and the resulting elevated inversion at the cloud top with a well-mixed layer below the inversion." Line 234-236

– **L208:** *"a slightly stably stratified layer". Seems still rather stable to me. Do you mean a "less stably stratified layer"?*
Response: Yes, thank you, we have edited the sentence.

"Cloudless conditions prevailed during a profile observed on 5 March 2020 with a strong surface-based temperature inversion ($\Delta\theta \approx 7$ K within about 40 m) up to 50 m followed by a less stably stratified layer above (Fig. 3a)." Lines 238-239

– **L209-L210:** *"Near the surface, the wind speed increases with height, peaking at about 50 m again and continuing almost constantly until the maximum height of the profile." I find this sentence unclear,*

please reformulate..

Response: We agree and rephrased this sentence.

"The wind velocity *U* increases with height from the surface up to a height of about 50 m, and then remains almost constant up to the maximum height of the profile (Fig. 3b)." Lines 239-241

- **L261:** *"the differences for the two mean case depending..." What do you mean? Please clarify.*
  Response: We referred to the two cases of cloudy and cloudless conditions but we recognize that this was not clear in that sentence. We have rephrased it.
  "While we have derived Ri_{bc} for cloudless and cloudy conditions, the differences for the two typical ABL types are negligible." Lines 293-294

- **Fig. 3:** *The near surface conditions (with strong gradients) are difficult to see. You might want to increase the size of the panels.*
  Response: Yes, that was rather hard to see in the first figure. We have enlarged the size slightly. We hope that this improves readability.

Technical comments

Thank you for your feedback on the language. We have incorporated all the suggested changes and provide the Line numbers below.

- **L23:** *vertical extend --> vertical extent*
  Response: Line 25
- **L203:** *alternates between two cloudless and cloudy --> alternatives between cloudless and cloudy*
  Response: Line 233
- **L214:** *almost linearly increases --> increases almost linearly*
  Response: Line 244
- **L214:** *The new paragraph should start with "The example for vertical stratification under cloudy conditions..."*
  Response: Yes, we agree and have changed this accordingly. Please see Lines 243f.
- **L221:** *decrease almost abruptly --> decrease quite abruptly*
  Response: Line 251
- **L231:** *As it is often --> As is often*
  Response: Line 261
- **L232:** *already begins clearly inside --> already begins inside*
  Response: Line 262
- **L237:** *near surface --> near the surface*
  Response: Line 267
- **L238:** *low values --> lower values*
  Response: Line 268
- **L241:** *turbulence continuously reaches --> turbulence reaches*
  Response: Line 271
- **L280:** *SML height smaller than 150 m --> SML height less than 150 m*
  Response: Line 314
- **L298:** *at the low humidities --> at low humidity values*
  Response: Line 333
- **Fig. 11:** *at surface --> at the surface*
  Response: We have changed this, please see caption of Fig. 11.