REVIEW 2

We thank the reviewer for thorough reading and very valuable and constructive comments.

In the following the Reviewer's text is cited in italic fonts, our answers in roman fonts.

Overall comments:

In this paper, the authors reported the vertical structure of atmospheric boundary layer thermodynamics and dynamics, and in particular, turbulence quantities derived from measurements by airborne instruments for a few cases with weakly forced liquid clouds. I recommend the publication of this paper if the following issues can be adequately addressed.

I think the paper can be improved with

1. More meaningful interpretation of the results.

Answer: The Discussion has been completely rewritten. In the revised version, we provide a deeper analysis of the obtained results and provide a comparison of our results and progress with earlier studies of summertime stratocumulus over Arctic sea ice. Also, we stress the differences of Arctic stratocumulus from the subtropical ones.

2. Highlighting the new knowledge from the uniqueness of this dataset and reducing descriptions/discussions of features that have been very well known.

Answer: We agree with the reviewer that the paper would benefit from a better focus on new results. After revision, the description of cases was significantly shortened and the new results relative to previous studies are stressed. We summarize the main new features in the following.

1. Our study presents for the first time (to our knowledge) a case of Arctic stratocumulus with near-zero wind speed, so that the effect of radiative cooling on turbulence is documented separately from other mechanisms of turbulence generation.
2. Also for the first time we present a comparison of the two multi-layer cases which differ by stability in the ABL, namely, stable vs unstable. Previous studies using aircraft data documented only cases with a stably-stratified ABL in the presence of multiple cloud layers. Thus, our study broadens the parameter space in which observations of the ABL turbulence structure in the presence of clouds exist. This is clear from the new Table 2, where our cases are listed together with previously observed ones.
3. Using a mixed-layer model we present the analysis of why the observed turbulent heat flux in the cloud layer is substantially lower than the jump of the net longwave flux at the cloud top (see the Discussion). This was first observed in Arctic clouds by Curry (1986). We clearly show that in shallow mixed layers the maximum of turbulent heat flux is smaller than in thick mixed layers.
4. We stress the difference of the Arctic stratocumulus from the better studied subtropical stratocumulus clouds (see the Discussion). In particular, using the mixed-layer model we show that small latent heat flux at the base of the mixed layer as well as a small total humidity jump at the top of the mixed layer (or even a humidity inversion), as typical for

stratocumulus over Arctic sea ice, leads to much smaller buoyancy forcing in the mixed layer and, consequently, weaker turbulence, as compared to subtropical stratocumulus.

3. More discussions about (a) the uncertainty of the statistics from the slanted legs, especially near cloud boundaries (e.g., cloud top) where the size of a feature may be small and (b) the uncertainty in high-order moments, which are more difficult to obtain than low-order moments. It is critical to describe both bias and variance in the derived quantities if the motivation of this paper is to provide a benchmark for model evaluation/parameterization development.

Answer: As suggested by the reviewer, we added the discussion of the uncertainties of the statistics from slanted legs as well as the uncertainty in higher-order moments. Namely, the following paragraph was added to the Discussions section:

In connection with the above discussion, one should also keep in mind the uncertainty of the observed turbulence statistics. The magnitude of the uncertainty for heat and momentum fluxes obtained from horizontal legs is discussed in Appendix A. Similar to earlier studies (e.g. Curry et al., 1988; Finger and Wendling, 1990; Inoue et al., 2005), the uncertainty is estimated empirically by comparing results from shorter segments of a long horizontal leg. Theoretical estimates of sampling errors due to an insufficient length of flight legs also exist (Lenschow and Stankov, 1986; Lenschow et al., 1994). Based on large Eddy simulation (LES) Petty (2021) showed that there is a good agreement between the empirical and theoretical estimates. However, neither theoretical estimates nor LES account for the horizontal non-turbulent inhomogeneities that exist in nature and complicate the analysis of the observations. It is even harder to obtain theoretical estimates for slanted profiles as statistical properties of turbulence are functions of height within the ABL. Thus, we rely on empirical estimates of the uncertainty also for slanted profiles. So, we can consider the range of the slanted profiles (red hatched regions in Figures 4 and 7) obtained at different positions as a measure of accuracy obtained from these profiles. This is not more than a rough estimate and we expect that especially near the inversion (above $z/h = 0.8$ the measurement errors are large for the slanted profiles but also for the horizontal legs. This hold also for previous aircraft campaigns (Lenschow and Stankov, 1986). In the future, flights should be performed repeating the same profiles and including horizontal flight legs at the same positions to determine the accuracy. Finally, it should be noted that theoretically the uncertainty for third moments is higher than for the second ones. It can be reduced by considering longer averaging intervals, but the drawback of long horizontal legs is that horizontal inhomogeneity starts to affect the results. In case of slanted profiles, it is simply not possible to increase the leg length, as it will either cover a very large height interval or require a very slow ascent or descent, so that the horizontal distance flown during ascent/descent would become too large.

4. The addition of a concise summary of the main characteristics of all cases (maybe using a table).

Answer: Such a table, including also the cases from previous studies has been added (Table 2 in the Discussion section)

Specific comments:

1. *Aren't the markers corresponding to 12 W m^-2 also measured at PS? The authors said the value 'became close to zero for slanted profiles'. Does it mean the mean measured value dropped to close zero or 'mean minus 1 standard deviation' got close to 0?*

Answer: This piece was clarified. We meant that the flux at the lowest flight level was positive (about 10 Wm^{-2}) at the PS location and close to zero in the slanted profiles at that height.

2. In Figs. 5c and 5f (and similar plots), the profiles at PS and flights are quite different. Please reconcile them. For Fig. 5f, the near constant TKE only occur in slanted flights, why? Even for the cloud layer, shouldn't there be height-dependence of TKE? The data from PS seem to suggest a very noisy profile. Please explain.

Answer: A height-constant TKE is typical for convective mixed layers according to previous studies. Close to the ABL top and inversion the increase of TKE according to the horizontal legs is most probably associated with proximity to the region of a jump-like change in wind direction across the ABL top. Horizontal variability of the cloud top height lead to the fact that sometimes the aircraft might have sampled the air from above the ABL top. One should interpret the results close to the ABL top with caution. The discussion of the increase close to the ABL top uncertainty is included in the revised version.

3. In Fig. 5g, if the positive S_w is associated with some surface-driven turbulences, why don't we see a signature in other panels, e.g., Fig. 5d?

Answer: Indeed, the shift from negative to near-zero and even slightly positive values is most pronounced in the vertical profiles of S_w. Nevertheless, one can observe changes also in other profiles. This became more obvious in the revised version of the figure where we use a different vertical coordinate. Clearly, a decrease of sensible heat flux, change in momentum flux, variances and TKE is visible across the cloud base. Also, a jump-like change in wind direction is seen in the subcloud layer in several profiles. This points to a possible weak coupling between the cloud and surface-based mixed layers. To reflect this, the following paragraph was added to the revised manuscript:

Based on the vertical profiles of several turbulence statistics, as well as on the profile of mean wind direction (Fig. 3c) we can conclude that the fully mixed layer associated with the cloud was perhaps weakly coupled to the surface-based mixed layer. As discussed above, this is most obvious in the vertical profile of S_W. The absolute values of other statistics such as H, σ_u, σ_v, TKE, TSH, and TTV also show a slight, yet a clear decrease in the subcloud layer. It is important to note that based on horizontal legs alone it would be harder to observe this. This shows the advantage of considering slanted profiles together with level flights.

4. In Fig. 7b, please be specific of the features that indicate 'low level jets'. There is no clear peak in wind speed in any profiles. This is different from the profiles (T4 and T5) in Fig. 3b.

Answer: Based on the finding that wind speed decreased with height in all profiles on 2 June and assuming that wind speed has to be zero at the height of the roughness length, we concluded that there must be a maximum of wind speed in the boundary layer. Thus, the low-level jet was present. In the revised version, the occurrence of the low-level jet is reported only for those profiles where the maximum of wind speed in the ABL is clearly visible.

5. P. 16 Lines 4 and 7, what is a profile flight? Do you mean slanted flight?
Answer: corrected to slanted flights

6. In Fig. 9b, why is sigma_w^2 so large near cloud top? Shouldn't they be limited near cloud top (like in Fig. 5d)?
Answer: This figure and the corresponding discussion is now omitted. The first reason is that we needed to shorten the paper and make it more concise. The second reason is that horizontal flight legs were not available for this location. Nevertheless, we agree with the reviewer that one expects a decrease of σ_w^2 close to the ABL top. One possible reason why this was not observed is that each point giving turbulence statistics derived from slanted profiles represents a height range of about 80-100 m.

7. In Fig. 9c, I agree that S_w for T1 is largely negative, but certainly not for T2. Please explain.

Answer: As described above we dropped this figure partly because there were no horizontal legs which would bring more confidence to the results.

8. Is it possible to add a panel for LW cooling rate profile in Figs. 11 and 14?

Answer: In the revised version, the profiles of the net LW flux as well as of the cooling rate are presented in a single figure, namely B1 in the Appendix B.

9. In Fig. 12, if the conditions for all 3 profiles are so similar, why not use the space to show profiles associated with inhomogeneous surface? It would be interesting to see how different they are from the profiles associated more homogeneous surface.

Answer:

We did not include this because of the following reason:

Concerning results of the horizontal flight sections, Polar 6 could not complete the two southern staggered patterns due to icing problems. The southernmost pattern by Polar 5 did not show substantially different results apart from smaller values of heat flux and TKE due to lower wind speed and warmer air temperature. Thus, we concentrate here only on the three northernmost cross-wind staggered legs (Figure 10).

This text is included now also in the paper.

10. In Fig. 12g, why should S_w be so positive near cloud top? The surface-driven eddies should not be able to penetrate the inversion on top of the lower cloud layer anyway.

Answer: The point above the cloud top (above the strong capping inversion) should not be trusted since the turbulence signal is very weak there and nearly all statistics are near zero. Especially S_w should not be trusted because $S_w = \overline{w'^3}/\overline{w'^2}^{3/2}$ and division by a very small number can result in a large value.

11. The discussion section is pretty poorly written. One would expect a rigorous *estimation of uncertainties, connection with other studies, the key insights from the presented research, and so on (although not necessarily all of them) in discussions. Instead, the authors presented a comparison with mixed-layer model calculation without a clear motivation. (Also, I am not sure why only the cloud-top driven case is discussed. The authors said they showed that the cloud top cooling is strongly affecting the turbulence profiles. But most cases they presented were surface driven.)*

Answer: Following the reviewers suggestion, the discussion is completely rewritten. The revised version focuses on a comparison with earlier studies, as well as on insights from mixed-layer modeling in comparison with observations. The usage of the mixed-layer model is now clearly motivated. Uncertainties are also discussed. There is still some focus on the cloud-driven case because, as we stress it, it is, to our knowledge and as follows from Table 2, the first time when a case with low wind speed is presented.

Technical issue:

Please use consistent line types (e.g., why lines for Figs. 11a-11d but dots for Figs. 11e-11f?), variable names (V in Fig. 12b, U_hor in Fig. 15b, but 'wind speed' everywhere else?), and scales (T_sh in Fig. 12j but 1000 T_sh everywhere else?). Also, if different ranges of axes are used for same variable across different cases, please make sure there are common ticks/grid lines for easier comparison across cases.

Answer: in the revised version, the same format is used for all figures. Unfortunately, it is not possible to use the same axis ranges everywhere because the absolute values of some variables, for example of TKE, strongly differs between cases, e.g. because we have cases with stable and unstable conditions. In the stable cases signals are much smaller, nevertheless reasonable but this would not be seen when the axes are the same as in other cases. Using one single range would result in plots which are difficult to comprehend.