acp-2018-759-RC1
Response to Referee #2

Referee Comment 1: The authors describe the observations and the conditions under which the laminations have been observed, and briefly describe other observations of laminated aerosol and cloud structures.They offer little in the way of explanation for the observed phenomena, however, which seems to me a major shortcoming that should be rectified before publication in Atmospheric Chemistry and Physics.

Author response:

Some proposed explanations for the observed cloud laminations have now been added to the manuscript.

Change to manuscript:

We have added a new Section 5.6 to the manuscript: "Suggested explanations for the laminated phenomena".

New references:

[Beals2015CloudHolography]
Beals, M. J., Fugal, J. P., Shaw, R. A., Lu, J., Spuler, S. M., and Stith, J. L.: Holographic measurements of inhomogeneous cloud mixing at the centimeter scale, Science, 350, 87 – 90, 2015.

[Hocking2001GravityWavesWebsite]
Hocking, W. K.: Buoyancy (gravity) waves in the atmosphere, http://www.physics.uwo.ca/~whocking/p103/grav_wav.html, 2001.

[Mahrt2014StablyStratBoundaryLayers]
Mahrt, L.: Stably Stratified Atmospheric Boundary Layers, Annual Review of Fluid Mechanics, 46, 23–45, 2014

Referee Comment 2: The figures showing range-scaled photocounts on log scales are a little hard to interpret. How deep are the laminations/striations? Are they closer to 10% or 90% of the total backscatter? More quantitative information would help the reader consider the possible roles of cloud vs interstitial aerosol particles.

Author response:

Examining Figure 2, blue curve, gives a few calculable examples. Let's consider by how many percent of the range-scaled photocounts the in-between layers (yellow in Fig 1) drop the signal compared to the values in the layers themselves (red/orange in Fig 1):

One of the "deeper" laminations gives a result of $((10^{9.316} - 10^{8.833})/(10^{9.316}))\times 100\% = 67.11\%$, while the shallower laminations produce results such as $((10^{9.312} - 10^{9.103})/(10^{9.312}))\times 100\% = 38.2\%$.

These are fairly representative values. Therefore the range-corrected signal drops by between about

35% and 70% of maximum local value between layers.

Change to manuscript:

The text in bold is added to the end of the paragraph on Page 2 lines 15-18 : ``Figure 2 shows selected profiles of range-scaled 532 nm photocounts from Fig. 1 as a function of altitude for four consecutive minutes just after 06:40 UTC, each offset by 1x10^0.6 along the x-axis, between the altitudes of 3 to 4 km. There are clearly horizontal coherent structures in the cloud in space (aliased to time by motion over the lidar) at least down to the 7.5m height resolution of the lidar. **The regions between the laminations generally exhibit range-scaled signals between 35 and 70 % lower than the signals in the laminations immediately above and below.''**

Referee Comment 3: To first order, the laminations are reminiscent of the fog striations seen in cold pools under near stable conditions (Stably Stratified Atmospheric Boundary Layers, L. Mahrt, Annual Review of Fluid Mechanics 2014 46:1, 23-45).

Author response:

Thank you for drawing our attention to this publication.

Change to manuscript:

Following Page 5 lines 20-21 "All of the laminated haze layer reports are from aircraft campaigns of short duration, and all excluded from consideration any measurements which included ice crystals and clouds.", we insert a new paragraph:

``In mid-latitude examples of extremely strong atmospheric boundary layer stability, striations of fog may be identified at scales smaller than 1-metre (Mahrt 2014, Fig. 3). These are qualitatively similar to the cloud laminations identified by CRL. Perhaps the two phenomena share similar properties, particularly in terms of the factors which enable the laminations/striations to persist.''

Text referring to Mahrt 2014 is also added to the new Section 5.6 ``Suggested explanations for the laminated phenomena.'' in the response to Reviewer 2 Comment 1, above.

New reference:

[Mahrt2014StablyStratBoundaryLayers]
Mahrt, L.: Stably Stratified Atmospheric Boundary Layers, Annual Review of Fluid Mechanics, 46, 23–45, 2014

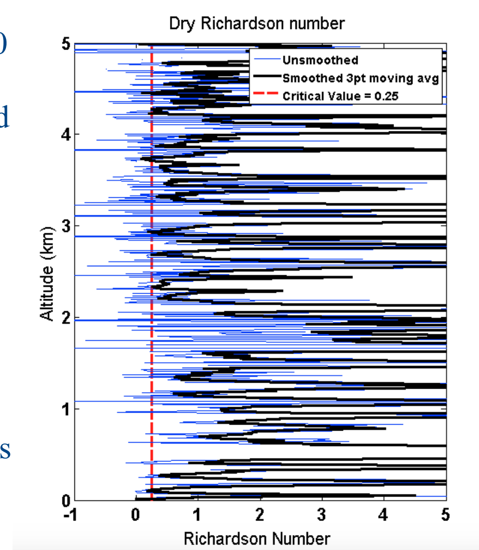
Referee Comment 4: What are the wind conditions here? Wind profiles and Richardson numbers would be a useful addition, and potential temperature profiles would also be more instructive that the included temperature profiles.

Author response:

The twice-daily Eureka radiosondes provide windspeed and direction, and we have calculated potential temperature from the sonde temperature profiles as well. These have been added to Figures 5, 7, and 12, with accompanying text.

Richardson numbers (Ri) have not been added to the manuscript. We have calculated Bulk Richardson numbers using radiosonde data, but they are not particularly useful given the scope of this particular paper because the applicability and interpretation of these numbers is nuanced. The issue of turbulence vs. stability could be important, but more specific measurements in this area (e.g. aircraft with a turbulence probe) would be a more appropriate way to study this in detail, in the future.

In general, interpretation of Richardson Numbers smaller than some critical value Rc is that the atmosphere is dynamically unstable and favourable for turbulence, while at values greater than the critical value, it is interpreted to be stably-stratified ("turbulence cannot be sustained", but is also not precluded entirely). The exact Ri values calculated depend on the vertical resolution of the profiles used to make them (Stull 1988, Balsley 2008, Tjernstrom 2009), and so does the value for Rc. Rc can vary from 0.25 (Stull 1988 p. 177) to Rc = 1 or more (Shupe 2017, who uses a minimum cutoff of Ri=1 to guarantee nonturbulence, while still allowing for exceptions of "weak, sporadic" turbulence). The larger Rc values are required for data which is lower resolution and/or smoothed. In our case, if we smooth, or if we choose an inappropriate Rc, we may miss some small patches of instability. This might not be tolerable considering that we are examining laminations at 7.5 m resolution.



As an example, in the figure to the right for 21 March 2017 11:00 UTC, the blue line gives the result at the maximum sonde resolution; the black line gives the result when the windspeed and temperature profiles have been smoothed first by a 3-point moving average filter. We have 238 unsmoothed instances of Ri<1 , and only 139 smoothed instances of Ri<1.

Further, there is a known hysteresis effect in laminar flows, whereby the Richardson Number may begin larger than the critical value (i.e. is stable), then drop below the critical value (there becoming turbulent), and then rise again above the critical value, yet not reaching stability again until a much higher value is reached (Stull 1988 in Brooks 2017). Gravity waves are another example in which turbulence can exist at high Ri. Therefore, interpretation of Ri values we may calculate is also nontrivial.

In order to properly address turbulence/stability, we should also consider whether the dry Ri indicated above are applicable to our situation within clouds. Brooks 2017 advocates the use of such dry Ri (Ri_d; calculated as in Brooks 2017 Eqn 1b, based on Stull 1988 Eqn 5.6.2) only in the case of cloud-free air. They indicate that moist Ri (Ri_m; calculated as detailed in Brooks 2017 Eqn 2, using equations based on Durran&Klemp 1982 Eqn 5) are more appropriate in liquid and mixed phase clouds. To use the latter equations, data contributed from a microwave radiometer or similar is required

- which is far outside the scope of what we can provide for the present manuscript.

Because Richardson Number is a quantity which requires such careful and nuanced calculation and interpretation, the authors did not feel that the current paper was the appropriate place to address into this topic. The Richardson numbers that we calculate at this stage only confound the interpretation of the laminations, while other profiles (wind, temperature, etc) are more straightforward and instructive. To fairly cover the topic of stability would require such space in the paper that it would detract from the main point of the manuscript: the demonstration of laminations within Arctic clouds.

The authors agree that a formal assessment of atmospheric stability in the context of these laminations is an important avenue to pursue in follow-on papers.

New references (just for review response; not required in paper):

[Brooks2017TurbulentSummerBoundaryLayer]
Brooks, I. M., Tjernström, M., Persson, P. O. G., Shupe, M. D., Atkinson, R. A., Canut, G., Birch, C. E., Mauritsen, T., Sedlar, J., and Brooks, B. J.: The turbulent structure of the Arctic summer boundary layer during the Arctic Summer Cloud-Ocean Study, Journal of Geophysical Research: Atmospheres, 112, 9685–9704, 2017.

[Stull1988]
Stull, R. B. (1988). Introduction to Boundary Layer Meteorology (pp. 666). Dordrecht, The Netherlands: Kluwer Academic Publishers.

[Stull2017PracticalMeteorologyBook]
Stull, R.: Practical Meteorology: An Algebra-based Survey of Atmospheric Science, Roland Stull, The University of British Columbia, Vancouver, Canada, 1.02b edn., 2017.

[DurranKlemp1982MoistureBruntVaisala]
Durran, D. R. and Klemp, J. B.: On the Effects of Moisture on the Brunt-Väisälä Frequency, Journal of the Atmospheric Sciences, 39, 2152–2158, 1982.

[Balsley2008GradientRichardsonNumber]
Balsley, B. B., Svensson, G., and Jjernström, M.: On the scale-dependence of the gradient Richardson number in the residual layer, Boundary- Layer Meteorology, 127, 57–72, 2008

[Tjernstrom2009VerticalArcticTropoERA40]
Tjernström, M. and Graversen, R. G.: The vertical structure of the lower Arctic troposphere analysed from observations and the ERA-40 reanalysis, Quarterly Journal of the Royal Meteorological Society, 135, 431–443, 2009.

Change to manuscript:

Figures 5, 7, 12 have been modified to include potential temperature, windspeed, and wind direction plots.

The text fromPage 9 line 30 through Page 10 line 8 (original version numbering), and Page 11 line 9 through Page 11 line 27 (original version numbering), have been changed to address the modified figures.