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Atmospheric Chemistry and Physics Discussions

Interactive comment on “The Structure of Turbulence and mixed-phase Cloud Microphysics in a Highly Supercooled Altocumulus Cloud” *by* Paul A. Barrett et al.

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We thank the reviewer for the helpful comments and positive response to the paper.

The reviewer comments are in *italics*, author response in plain text, and modified manuscript text in **boldface**.

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1 Minor comments:

Abstract: The turbulence spectrum is observed to have an increasingly negative skewness with distance below cloud top, confirming that longwave radiative cooling from the liquid layer cloud is the source of turbulence kinetic energy. Personally, I would choose the more cautious term suggesting in lieu of the bolder term confirming. I have no doubt that cloud-top radiative cooling is relevant, but without a complete budget of TKE, it is hard to know the relative magnitude of each source.

We agree that the data do not confirm turbulence generated through longwave radiative cooling and agree that "suggests" is more appropriate word for the abstract.

The turbulence spectrum is observed to have an increasingly negative skewness with distance below cloud top, suggesting that longwave radiative cooling from the liquid layer cloud is an important source of turbulence kinetic energy.

Lines 40-41: The GCM simulations are found to have too little cloud in the mid-levels, resulting in a warm bias in sea surface temperatures, The authors might also want to mention Hartmann et al. (1992, J. Climate, see Fig. 22 and Table 1), which suggests that thin, mid-level clouds have little net radiative impact at the top of the atmosphere.

The clouds in the study would indeed be of Type 3 (Hartmann 1992) as they are indeed optically thin, under this definition. We add a caveat and reference to the paper to state that while regional the clouds may have some radiative impact, the global significance of the cloud type is low.

However, optically thin mid-level clouds were shown to be of low global significance by Hartmann et al. (1992).

Lines 74,75: which was predominantly from the south and ranged in strength from 6 m s-1 at the southern end of the flight track to 8 m s-1 in the north. It might also be worth recording the mean vertical wind shear within and near the cloud, because wind shear

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is associated with generation of turbulence.

We add comment that mentions the potential for turbulence generated through shear in these clouds.

There was some degree of wind shear above the cloud containing layer with mean wind direction being close to northwesterly. This shear may have resulted in production of turbulence in the layer below.

Figure 8: On this figure or in its caption, please clarify what the diamond symbols mean, and how the reader is to infer whether the profiles are adiabatic by comparing to the many lines drawn on the figure. The description in Lines 218-224 is also a little unclear to me. E.g., a theoretical adiabatic ascent line is drawn starting at 136 m below cloud top. Was there clear, ascending air observed at this altitude? If not, what does the adiabatic line represent?

Caption refers to Figure 4 for details of symbols. There are observations of updraughts in unsaturated air through the depth of the cloud system to as low as 500 m below the liquid cloud top. We now limit the plot to have 3 adiabatic ascents from three potential cloud bases. Cloud base was visually observed to be non-uniform, in the turbulence mixing- (but therefore not well-mixed) layer. This is supported by the Schmidt observations. The adiabatic ascents are shown to demonstrate that the in-cloud LWC distribution could arise as a result of this variable cloud base - which is in turn driven by the cloud top cooling generated turbulence, rather than by dilution through entrainment either at cloud top or laterally. The figure has been replotted to only show 3 ascents for clarity.

Caption 8 now reads: **LWC profile percentiles relative to CTH for the mixed-phase cloud layer with data from Nevzorov LWC sensor. Theoretical adiabatic ascents are shown, starting from three altitude (see legend for details) which correspond to potential cloud bases (see text for details). Statistics as Fig. 4**

The text has been ammended thus:

Theoretical, undilute adiabatic, LWC profiles were calculated by assuming an ascent of a saturated air parcel from three initial altitudes corresponding to potential cloud bases. The first, from the minimum liquid cloud base at -223 m show that peak observed cloud top LWC values compare well with this theoretical estimate. An ascent from -167 m peaks close to the 75th percentile of cloiud top LWC. A third ascent from -97 m has a peak LWC close to the 50th pecenentile at cloud top. Whilst entrainment of dry air from aloft at the inversion may be non-aero, these calculations demonstrate that he non-uniform cloud base may have contributed to the observed in-cloud variability in LWC at a given level. This suggests a range of turbulent eddies and updraught depths contributed to the overall spectrum of in-cloud liquid water contents.

Fig. 10b: Are the habits of the ice particles photographed by CPI so complex because of aggregation or instead polycrystal formation because of defects (grain boundaries) in the crystals? The text in Lines 256,ÂŰ259 seems to suggest both. Is there a way to distinguish the two?

We have not been able to disentangle the effects of polycrystaline growth from the impact of ice particle aggregation in the CPI imagery. Shadow imaging probe data are also not able to distinguish between the two. It is likely that both processes are active in the cloud. Attempting to quantify the aggregation rate in the clouds based on particle size number concertation etc, was deemed to be too complex and uncertain and so beyond the scope of the work. It may impact the ice production rate estimate to some degree.

Fig. 13: cloud formation through wind shear or gravity wave activity acting at a stable interface in potential temperature Is it possible that the cloud forms from mesoscale or synoptic-scale lifting rather than gravity waves, and that the cloud-top inversion forms later through cloud-top radiative cooling? Is any estimate of large-scale vertical velocity

available?

Following on from the discussion regarding turbulence generation from cloud top cooling in the abstract, we agree, that without a full turbulence budget it is not clear the source of the turbulence, but we also suspect that the wind shear has produced some component of the TKE. There is no estimate of large scale ascent (unless we resort to a reanalysis product), but it is certain that the clouds were in the warm sector of a mid-latitude cyclone, and were experience slow large scale ascent along isentropic surfaces in that region. Mention of large scale ascent has been added to the Figure 13 caption, in line with elsewhere in the text. We suspect the whilst this would produce supersaturation at some stage, the likelihood is that the first liquid clouds were produced when additional uplift from either shear induced wave activity at the top of the warm sector, or gravity wave activity at the same surface resulting from convection in the frontal zones, was present. This cloud would then cool to space and thus begin to produce the turbulence that could maintain the liquid cloud layer, and lead on to ice production.

We agree that the cooling may produce the inversion later on, and have amended the text to say so.

Supersaturation and hence liquid cloud formation in the mid-levels of the troposphere may be achieved through large scale ascent with upwards air motion acentuated through wind shear or gravity wave activity, or convective detrainment at a stable interface (Rauber and Tokay, 1991)

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