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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Particle backscatter and relative humidity measured across cirrus clouds and comparison with state-of-the-art cirrus modelling" *by* M. Brabec et al.

Anonymous Referee #2

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General comment:

The paper presents a new experimental approach to determine in-cloud and out-of-cloud humidity with respect to ice by combining the balloon-borne new backscatter sonde COBALD and the established frostpoint hygrometer CFH. This is a step forward in measurements of cirrus clouds and their environmnent, since no aircraft is needed which makes the observations much easier. Though no detailed microphysical cirrus properties can be derived from the COBALD-CFH-tandem, the upper tropospheric water vapour budget -a key player in the Earth's climate- can be better estimated with the complementary information of cirrus clouds and relative humidity. The peculiar charm of the tandem is that the instruments are light weight and quite simple (after careful development and calibration).

In addition to the measurements, model simulations are performed for an observed cirrus case to reconcile the measurements and explain out-of-cloud supersaturations and in-cloud non-equilibrium humidities. High resolution COSMO data are used to resolve small scale temperature fluctuations in the simulations, and furthermore the calculated backward trajectories are superposed with temperature fluctuations to reproduce cirrus formation and evolution. It is shown that the model can satisfactorily reproduce one observed cirrus cloud, but difficulties still exist in another case.

Altogether, the paper is fluently written, a pleasure to read and the message of the paper is very clear.

However, I have some comments outlined in the 'Specific Comments' that I recommend to consider before final publication in ACP.

Specific comments:

(arranged in order of appearance in the text)

1. **Abstract line 1-2 (and Page 9568, line 7-9):**
   ' ... determine the partitioning of atmospheric water between the gas phase and the condensed phase in and around cirrus clouds, ... '

   Do you think that it is really possible to determine the condensed phase from the measurements? As far as I can see it is possible to determine the in-cloud and out-of-cloud gas phase from CFH, but deriving the condensed phase from COBALD seems to be problematic. Please comment on that and possibly scale back the statement.

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2. **Abstract, Page 9554, line 22:** Please define NWP.

3. **Page 9555, lines 12-14:**
   'At times surprisingly high supersaturations inside and around cirrus clouds have been measured, as if the nucleation of ice particles or the uptake of water onto the existing ice surfaces were hindered (Peter et al., 2006, and references therein).'

   References of more recent studies as e.g. Krämer et al. (2009), ACP, or Murray et al. (2010), Nature Geosciences, are missing. These studies show high supersaturations both from atmospheric and laboratory observations and give possible explanations of the related processes.

4. **Page 9559, line 17:**
   I am wondering that heterogeneous ice nucleation is not included in the model, nor mentioned at all in the paper, though it is known that initial heterogeneous freezing can influence the formation and microphysical properties of cirrus clouds (see e.g. Spichtinger and Cziczo, 2010, JGR).

   Maybe the upper cloud 'U' (Fig. 1, 3, 5) could have been better reproduced with the model in case heterogeneous freezing would be allow to occur?

   By the way, it would be nice if you could add the RH_{ice} thresholds for homogeneous freezing for the observed cirrus (I estimated 150% at $T \approx 230K$ for 'L' and 170% at $T \approx 205K$ for 'U').

5. **Page 9560, line 20:** Please specify the homogeneous ice nucleation parameterization implemented in the model.

6. **Page 9561, line 4-5:**
   '... , in a mixed phase cloud, the water cloud droplets, the so-called Bergeron-Findeisen effect (Seinfeld and Pandis, 1998). '

   Are mixed phase clouds also implemented in the model? If yes, please describe how.

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7. **Page 9562, line 26-28:**
   ‘ The observed clear-sky supersaturations of 30% are not surprising; for example homogeneous ice nucleation requires more than 45% supersaturation under midlatitude upper tropospheric conditions (Koop et al., 2000).’

   Heterogeneously freezing ice nuclei (IN) are omnipresent in the upper troposphere and in case they are aged and coated with organics or sulfuric acid they can have freezing thresholds between 130% and the homogeneous freezing threshold. This should also be discussed here (see also comment 4.).

8. **Page 9562, line 28ff:**
   The range of RH_{ice} = 50%-130% inside the lower cirrus might be more surprising at first sight, but only detailed cloud modelling can help clarifying whether such non-equilibrium conditions are to be expected (see Sects. 5 and 6).’

   From earlier field, laboratory and modelling studies (see -as examples- the already mentioned papers) it is known that non-equilibrium RH_{ice} exist and are expected from theory. So please rephrase.

9. **Page 9566, line 4:**
   ‘ ... peak-to-peak amplitudes of 1 K ... ’.

   Why you choose 1K as amplitude? Maybe beased on the study of Gary (2006), ACP ?

10. **Page 9566, line 25ff:**
    ‘ ... . the BSR maxima are located below the RH_{ice} maxima (or actually sit close to the transition point of super- to subsaturation), which is likely due to particle sedimentation.’

    Another possible explanation cloud be that no cloud is formed above the observed and thus RH_{ice} is still high, and that inside of the cloud RH_{ice} is already reduced, yes?

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11. **Page 9566, line 25-27:**
' The modeled in-cloud RH_{ice} covers only the range from 80% to 105%, i.e. in the model sub- and supersaturations tend to relax too rapidly. This suggests a delicate interplay between RH_{ice} and $(dT/dt)_{ss}$:...'

    This suggests that the model might produce too many small ice crystals, which brings me back to heterogeneous ice nucleation:
    in case ice formation would be initialized heterogeneously and followed by a homogeneous ice nucleation event, the ice crystal concentrations could be lower than for pure homogeneous ice formation (Spichtinger and Cziczo, 2010, JGR).
    I suggest to discuss that in the paper.

References:

- Gary (2006): Mesoscale temperature fluctuations in the stratosphere, ACP
- Krämer et al. (2009): Ice supersaturations and cirrus cloud crystal numbers, ACP.
- Murray et al. (2010): Heterogeneous nucleation of ice particles on glassy aerosols under cirrus conditions, Nature Geosciences.
- Spichtinger and Cziczo (2010): Impact of heterogeneous ice nuclei on homogeneous freezing events in cirrus clouds, JGR.