

Comment on “The impact of temperature errors on perceived humidity supersaturation” by S. A. Buehler and N. Courcoux

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1. Introduction

[1] Recently, Buehler and Courcoux [2003] presented in this Journal simple Monte Carlo experiments, in order to simulate how temperature errors in the retrieval chain of the 203 GHz water vapor retrieval for the Microwave Limb Sounder, MLS, [Read *et al.*, 2001], propagate into errors of relative humidity over ice, *RHi*. Assuming Gaussian temperature errors with 2 K standard deviation, and a uniform background distribution of *RHi* between 0 and 100%, Buehler and Courcoux [2003] could show that error propagation results in an exponential distribution of *RHi* in the supersaturation range, thereby advancing earlier results obtained by Jensen *et al.* [1999]. Buehler and Courcoux [2003] concluded that “remotely measured *RHi* distributions can be explained, at least partly, by temperature uncertainties”.

[2] While we do not deny the error propagation effect demonstrated by Buehler and Courcoux [2003], we fear that hasty readers could get the wrong impression that (1) high ice supersaturation (say, in excess of *RHi* > 120%) is mainly an instrumental artifact and (2) that the exponential distribution of *RHi* is an artifact. Therefore we believe that we should make some comments in order to place Buehler and Courcoux’s conclusion into a more adequate perspective. We do this by giving some additional information on supersaturation and its statistics.

2. On the Existence of Supersaturation

[3] As Buehler and Courcoux [2003] state, the existence of ice supersaturation in the atmosphere is known since quite a time. In fact, first measurements of ice supersaturation date back to the 1940es (as far as we are aware of, Glückauf [1945], Weickmann [1945], Brewer [1946]). There are now many measurements taken during research flights with quite a variety of techniques that show substantial ice supersaturation (e.g. frostpoint hygrometer, Ovarlez *et al.* [2000]; tunable diode laser, Jensen *et al.* [1998], Vay *et al.* [2000]; capacitive sensors, Helten *et al.* [1998, 1999];

radiosonde, Spichtinger *et al.* [2003]). Some of these techniques directly measure relative humidity, not absolute humidity, so that the error propagation analysis of Buehler and Courcoux [2003] does not apply for all instrument types listed.

[4] Aside from this experimental evidence for widespread existence of ice supersaturation, there is also theoretical evidence. In the cold ($T < -40^{\circ}\text{C}$) layers of the upper troposphere, pure liquid water cannot exist, and ice formation is thought to be mainly via freezing of aqueous solution droplets, e.g. of sulphuric acid solution. These solutions generally need a substantial supercooling (i.e., supersaturation) for freezing (because the formation of the ice lattice is suppressed by the foreign molecules until the concentration of the latter is low enough that ice formation can proceed). Koop *et al.* [2000] have shown that irrespective of the chemical nature of the solution, a supersaturation of more than 40% (increasing almost linearly with decreasing temperature) is necessary for homogeneous nucleation to commence. Ice supersaturated regions become evident to everybody on days when the sky is covered with persistent contrails. Without ice supersaturation the contrails would vanish about 2 min after their formation when the aircraft wake vortices decay [Sussmann and Gierens, 2001].

3. On the Distribution of Supersaturation

[5] The exponential distribution of *RHi* for ice supersaturated regions has not only be found using MLS data [Spichtinger *et al.*, 2002]. It has been shown before [Gierens *et al.*, 1999] using humidity data from the Measurement of ozone by Airbus in-service aircraft, MOZAIC, [Marenco *et al.*, 1998; Helten *et al.*, 1998, 1999]. The hygrometers on the MOZAIC aircraft are capacitive sensors that directly measure relative humidity. Another example is the exponential supersaturation statistics obtained from the recent interhemispheric differences in cirrus properties from anthropogenic emissions (INCA) project [Haag *et al.*, 2003], where a frostpoint mirror was employed. Both instruments suffer much less from temperature errors than the MLS retrieval, because in both instruments the temperature is measured to an accuracy of a few tenths of a K. This shows that the exponential distribution of supersaturation cannot be explained largely by temperature errors.

[6] In our evaluation of MLS humidity data [Spichtinger *et al.*, 2002] we found exponential distributions of supersaturation with slopes varying from one geographical region to another, depending on pressure altitude, and changing from tropospheric to stratospheric air. It is not probable that the variation in the slopes of the exponentials is caused mainly by corresponding geographical variations of the

MLS temperature error, since there are similar slopes in regions with different temperature errors and vice versa. It is more plausible that these variations are brought about by differences of natural temperature fluctuations, which have not been considered by *Buehler and Courcoux* [2003]. Natural temperature fluctuations of Gaussian type also lead to a distribution of supersaturation that can excellently be fitted by an exponential [*Kärcher and Haag*, 2004]. This is an example of a natural mechanism that establishes the exponential distribution of supersaturation. The general nature of processes that lead to exponential distributions of relative humidity has been worked out by *Gierens et al.* [1999]: There must be many independent elementary dynamical and microphysical processes that increase and decrease the number of water molecules in the gas phase of the considered system; these elementary processes, acting as Poisson processes without memory, establish an exponential distribution of relative humidity. Of those processes, vertical air motions leading to temperature fluctuations seem to have the largest impact on the slope of the exponential distribution [*Kärcher and Haag*, 2004]. These authors also showed that a shift of the mean temperature by 20 K only weakly affects the slope of the humidity distribution (cf. blue curves in their Figure 2).

4. Conclusion

[7] We conclude that ice supersaturation does frequently occur in the upper troposphere, and it must reach quite high values for cirrus formation via homogeneous freezing. The exponential distribution of the degree of supersaturation is established by natural processes, in particular by vertical air motions leading to temperature fluctuations. Temperature errors that propagate through the retrieval chain from absolute to relative humidity may be superposed onto the natural temperature fluctuations, and may thus affect the measured humidity distribution, as claimed by *Buehler and Courcoux* [2003]. However, this does not apply for instruments measuring relative humidity directly (e.g. MOZAIC). Anyway, more investigation on these subtle points seems to be necessary.

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