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# Assessment of refractive index models at super-cooled temperatures and microwave frequencies

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Super-cooled water frequently occurs in the atmosphere and plays an important role in precipitation formation. Laboratory measurements of the refractive index of water at super-cooled temperatures are rather limited in the microwave range. Therefore, refractive index models are mainly based on measurements that were performed at temperatures above 0°C, while the values below 0°C are extrapolations. This implies possible uncertainties in the calculated refractive indices at subfreezing temperatures, which need to be evaluated.

Microwave radiometry from ground and from space is the most accurate technique to derive the liquid water path (LWP). LWP is an important quantity in climate research because the Earth's radiative balance is strongly affected by cloud phase. The radiative properties of clouds are highly sensitive to changes of the liquid water content, especially at low LWP values. The retrieval of LWP from the observed multi-frequency brightness temperatures (TBs) relies on the knowledge of atmospheric radiative transfer (RT) and therefore on the refractive index used to calculate the absorption coefficient.

The microwave radiometers HATPRO and DPR located at the environmental research station "Umweltforschungsstation Schneefernerhaus" (UFS, 2650 m ASL) provide a combination of liquid water sensitive frequencies, which is especially well suited for deriving low LWP values. These measurements are used to evaluate four refractive index models. The high elevation of the UFS leads to low values of integrated water vapor, which makes the liquid water signal more clearly visible. A statistical analysis of the four-year observational dataset demonstrates the high frequency of occurrence of super-cooled liquid water at the site.

The measured TBs at the liquid water sensitive frequencies 31.4 GHz, 90 GHz, and 150 GHz are compared with four sets of calculated TBs for the refractive index models Ellison, Liebe, Ray and Stogryn. For that, a radiative transfer model is used to calculate TBs based on temperature, pressure and humidity profiles taken from numerical weather prediction (NWP) analysis. The base height of the super-cooled cloud is given by ceilometers measurements. Because no independent measurements of LWP are available, the RT calculations are made for a range of LWP values and the resulting TBs are compared by means of frequency combinations. In addition to model-measurement comparisons, the impact of the uncertainty on the derived LWP is presented for both ground and satellite perspective. For the satellite perspective, LWP derived from AMSU (Advanced Microwave Sounding Unit) observations is evaluated with regard to the error due to the refractive index uncertainty.