Investigation of super-cooled liquid clouds at the Zugspitze mountain using long-term observations of high frequency passive microwave radiometers

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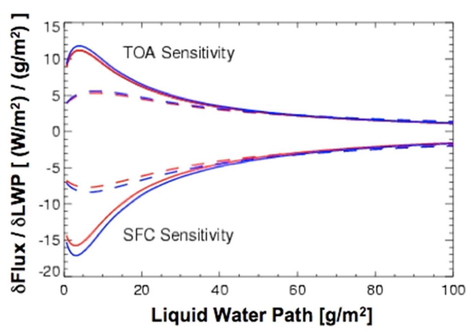
Motivation

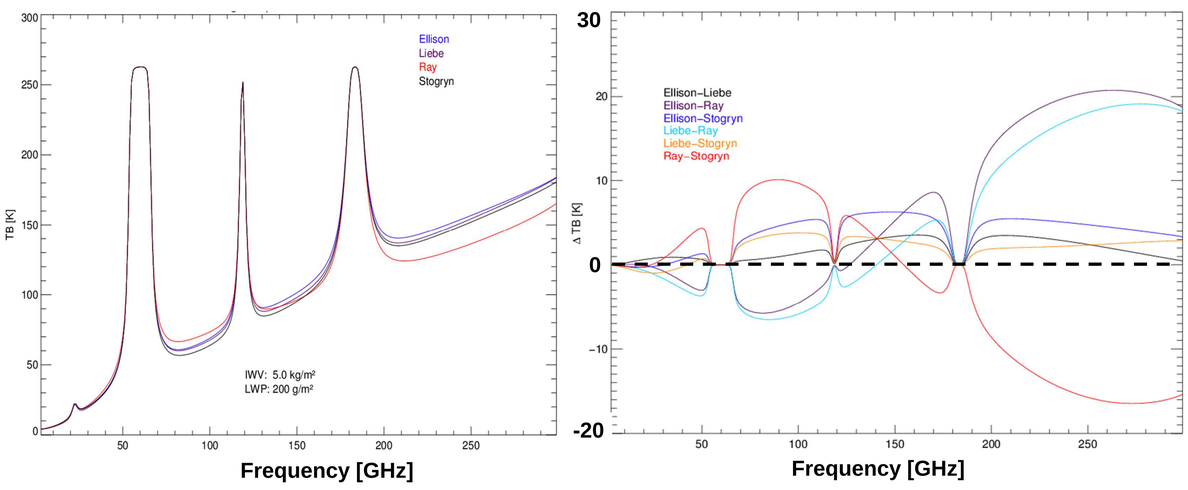
- Liquid water droplets in natural clouds can exist down to -38°C.
- This so called super-cooled liquid water (SLW) plays an essential role in cold cloud microphysics.
- Even small amounts of SLW (<30g/m²) in clouds dramatically change their radiative effect (radiative forcing).
- Passive microwave (MW) retrievals of SLW depend on accurate models of the SLW absorption coefficient.
- Current models are mainly extrapolations based on laboratory data with $T_{water} > 0°C$.



Sensitivity of the shortwave flux at the surface (SFC) and top of atmosphere (TOA) to cloud liquid water path (LWP) (from Turner et al., 2007).

How large are the model discrepancies?

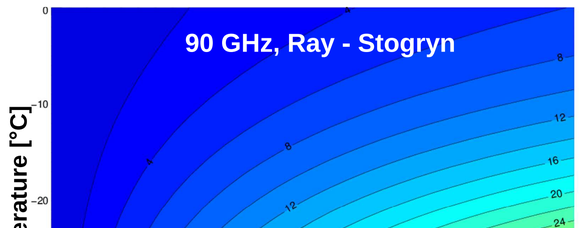
In this study we compared different SLW absorption models: **Ellison (2006), Liebe et al. (1991/93), Ray (1972)** and **Stogryn et al. (1995):**

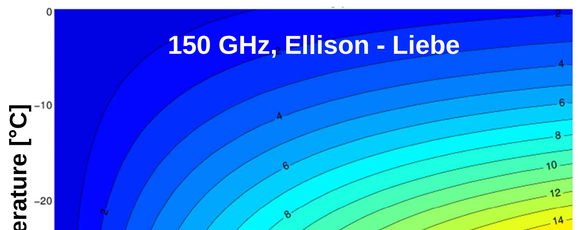


Simulated brightness temperatures (TB) [K] for a ground-based sensor as function of frequency for a cloudy winter atmosphere and different liquid water absorption models (color).

Same as left but only the TB differences [K] between the SLW absorption models are shown.

- While the **sensitivity of the MW channel to SLW increases with frequency²**, also the uncertainty in the absorption models increases with frequency.
- Including high frequency channels (e.g. 90/150 GHz) in SLW retrievals for high sensitivity/accuracy means that also current absorption models must be improved.





Differences between the absorption models increase with frequency, LWP and lower temperatures.

References:

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Liebe et al., 1991: A model for the complex permittivity of water at frequencies below 1 THz, Int. J. Infrared Millimeter Waves, 12(7).

Liebe et al., 1993: Propagation modeling of moist air and suspended water/ice particles at frequencies below 1000 GHz. AGARD, Atmospheric propagation effects through natural and man-made obscurants for visible to mm-wave radiation.

Ray, 1972: Broadband complex refractive indices of ice and water, Appl. Opt., 11(8).

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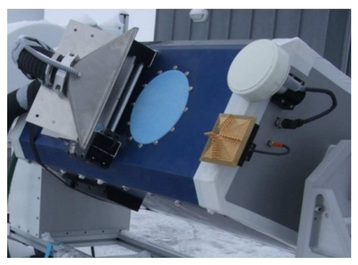
Validation approach using RT simulations and observations

Long-term observations of passive and active MW observations and additional instruments like a ceilometer (Löhnert et al., 2011) from the environmental research station Schneefernerhaus (UFS) at 2650m have been used to select ideal cases (thin single layer clouds) for model - observation comparison of the different SLW absorption models.

Concept:

TB observations, not used for estimate of atmospheric state

HATPRO
22 - 60 GHz



DPR
90 / 150 GHz

Best estimate of the atmospheric state

NWP analysis (COSMO-DE): Vertical profiles: Temperature, Press., Humidity

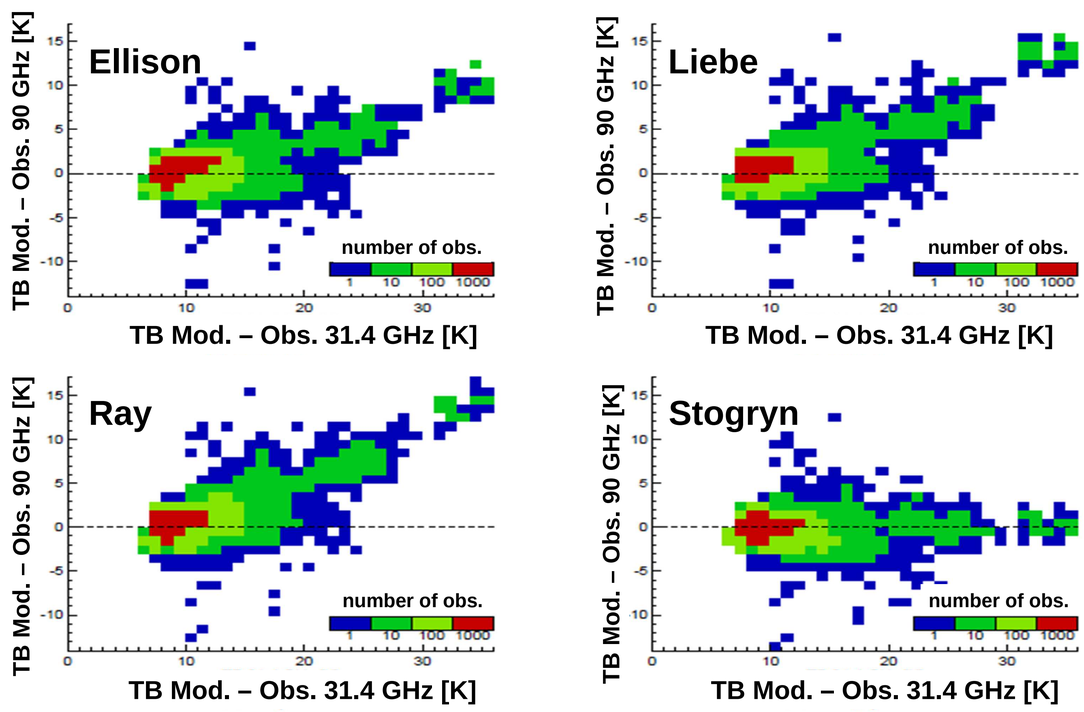
Assume realistic LWP range (e.g. 0 – 200 g/m²)

Ceilometer: Cloud base height

Radiative Transport (RT) applying different SLW absorption models

Comparison of observed TB with simulated TB range (using the four different SLW absorption models)

RT model – observation residuals 31.4 vs. 90 GHz



RT model – observation residuals 31.4 vs. 150 GHz