Observation of snowfall and super-cooled liquid clouds with active and passive remote sensing instruments

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TOSCA – campaign

- TOSCA = Towards an Optimal estimation based Snowfall Characterization Algorithm (funded by the German Science Foundation DFG)
- Deployment of several active and passive remote sensing instruments together with in-situ measurements during winter 2008/2009 at an Alpine site:
- Environmental Research Station 'Schneefernerhaus' (UFS) at 2650 m.a.s.l., 47° 25.0'N, 10° 58.9'E (~300m below the Zugspitze summit)
- Dataset: Total of 1218 h of snowfall (i.e. 25% of the campaign time) and ground temperatures below -5°C (*Löhnert et al., submitted to BAMS*).

Active Sensors:

- **35.5 GHz Cloudradar** (MIRA36)
- **24.1 GHz MicroRainRadar** (MRR)
- **Ceilometer**

Passive Microwave Radiometers:

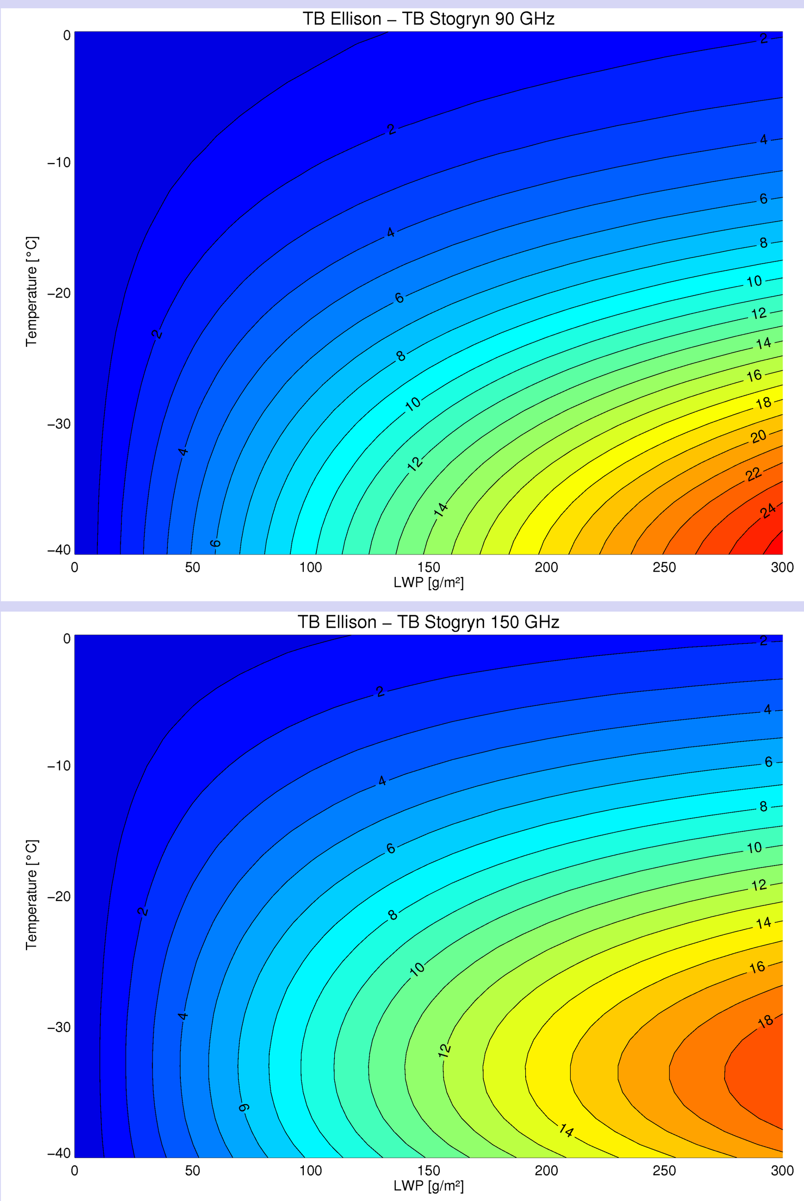
- **HATPRO (22-58 GHz):** T/q-profile, liquid water path (LWP), integr. water vapor (IWV)
- **DPR (90/150 GHz):** sensitive to snow scattering; polarized receiver @150 GHz

In-situ instruments:

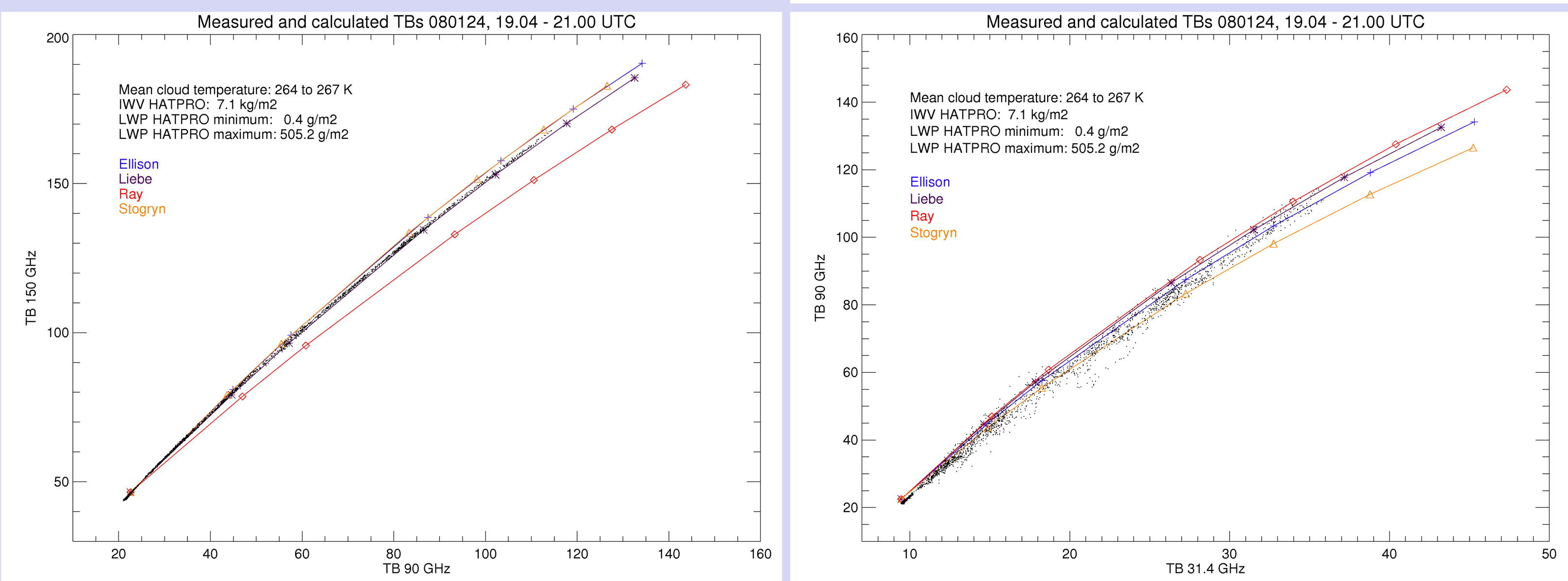
- **2D-Video disdrometer** (2DVD): particle size, shape, fall speed (from two cameras)

Refractive index of super-cooled water

- Accurate models of the **refractive index (RI) of super-cooled liquid water (SLW)** in the MW are essential for SLW retrievals.
- Currently there are almost no laboratory measurements available at temperatures below 0°C => **RI-models have to extrapolate towards lower temperatures!**
- Snow clouds have been observed to contain SLW up to 400 gm^{-2}.
- Uncertainties between different RI-models increase towards lower temperatures and larger liquid water path (LWP).

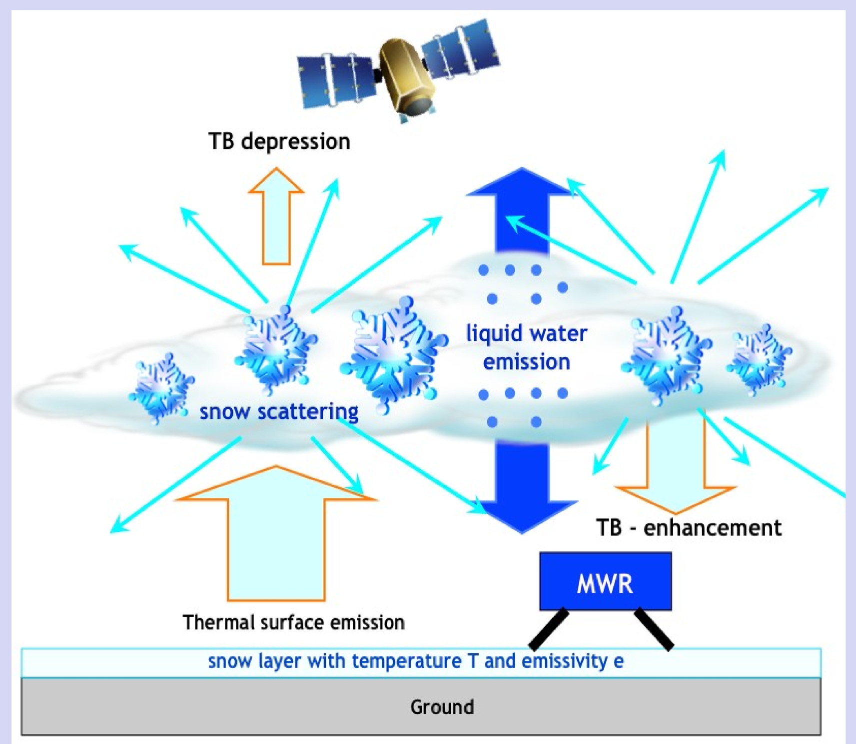


Right: Brightness temperature (TB) differences between two different RI-models as function of LWP and temperature for 90 GHz (upper) and 150 GHz (lower).

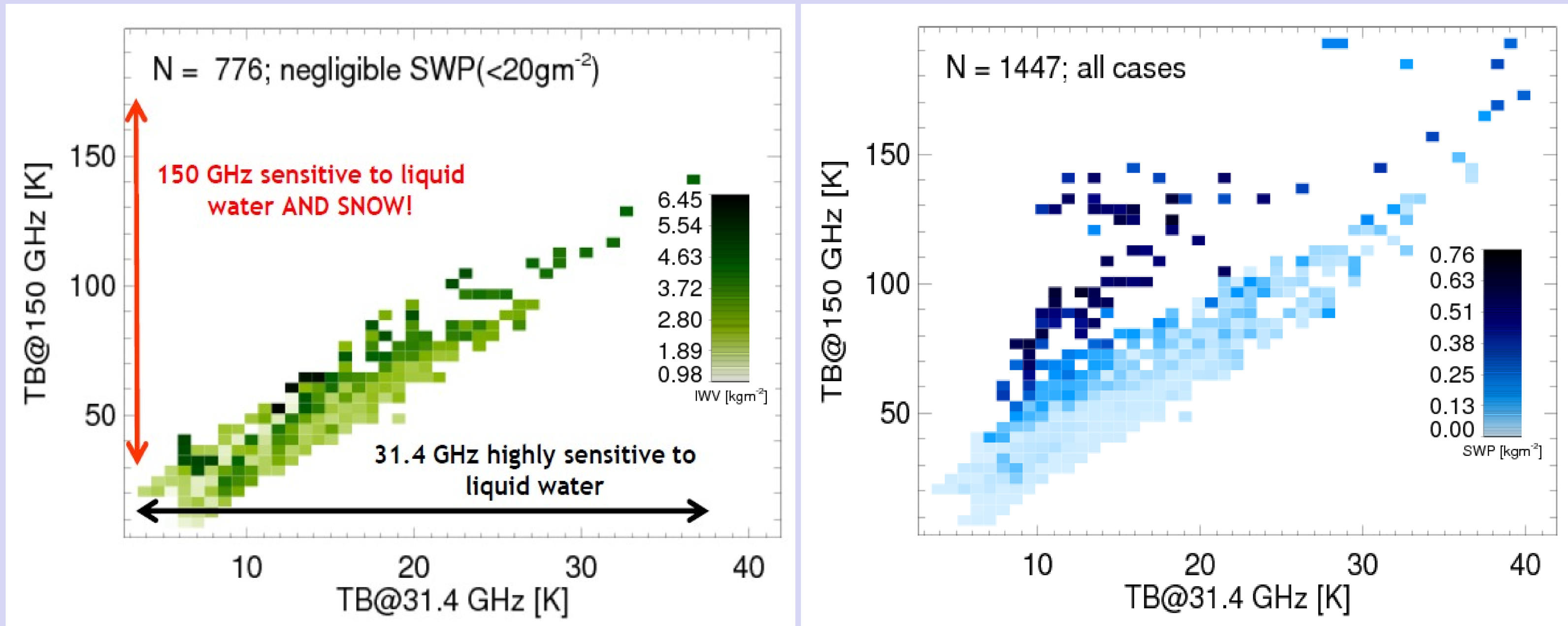


Thin single layer clouds are identified by ceilometer and cloudradar; Scatterplots of measured TB (black dots) are shown for 150/90 GHz (left) and 90/31.4 GHz (right). The colored lines represent the possible TB-range based on the different RI-models: Ellison2006, Liebe1991/93, Ray1972, Stogryn1995.

Snow scattering (passive MW)



- Ground, atmosphere and hydrometeors (especially liquid water) emit thermal radiation.
- Snow is a poor emitter at microwave frequencies (MW) but scatters radiation!
- This causes the so called **TB (brightness temperature) – depression,** well known for passive downward looking MW sensors.
- BUT: Is it also possible to measure snow scattering as a **TB-enhancement in ground-based MW measurements**?



Measured TBs at 150 and 31.4 GHz for the whole TOSCA period. Left: Snow-free cases with water vapor content colored; Right: All cases with snow water path colored (estimated with cloud radar).

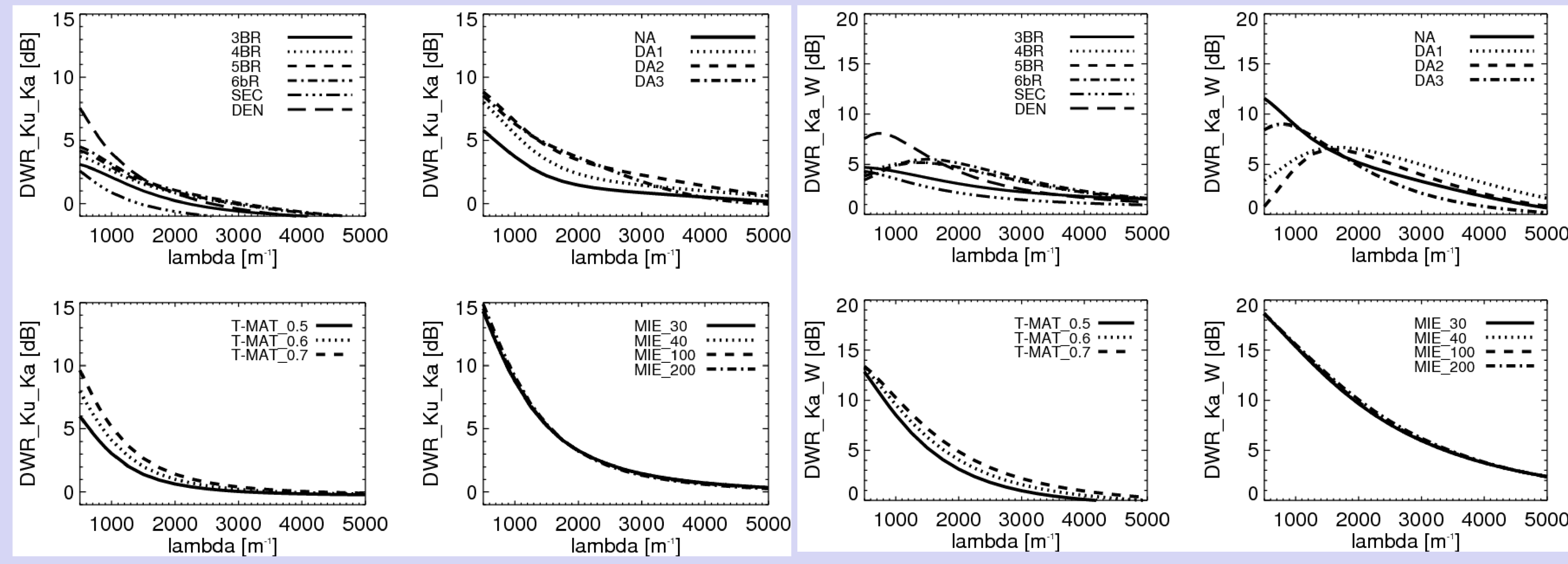
- In **snow-free cases** the signal is dominated by liquid cloud water and water vapor.
- **Additional TB increase at 150 GHz is clearly correlated with SWP**

~ 8 - 10 K per 0.1 kgm^{-2} SWP at 150 GHz

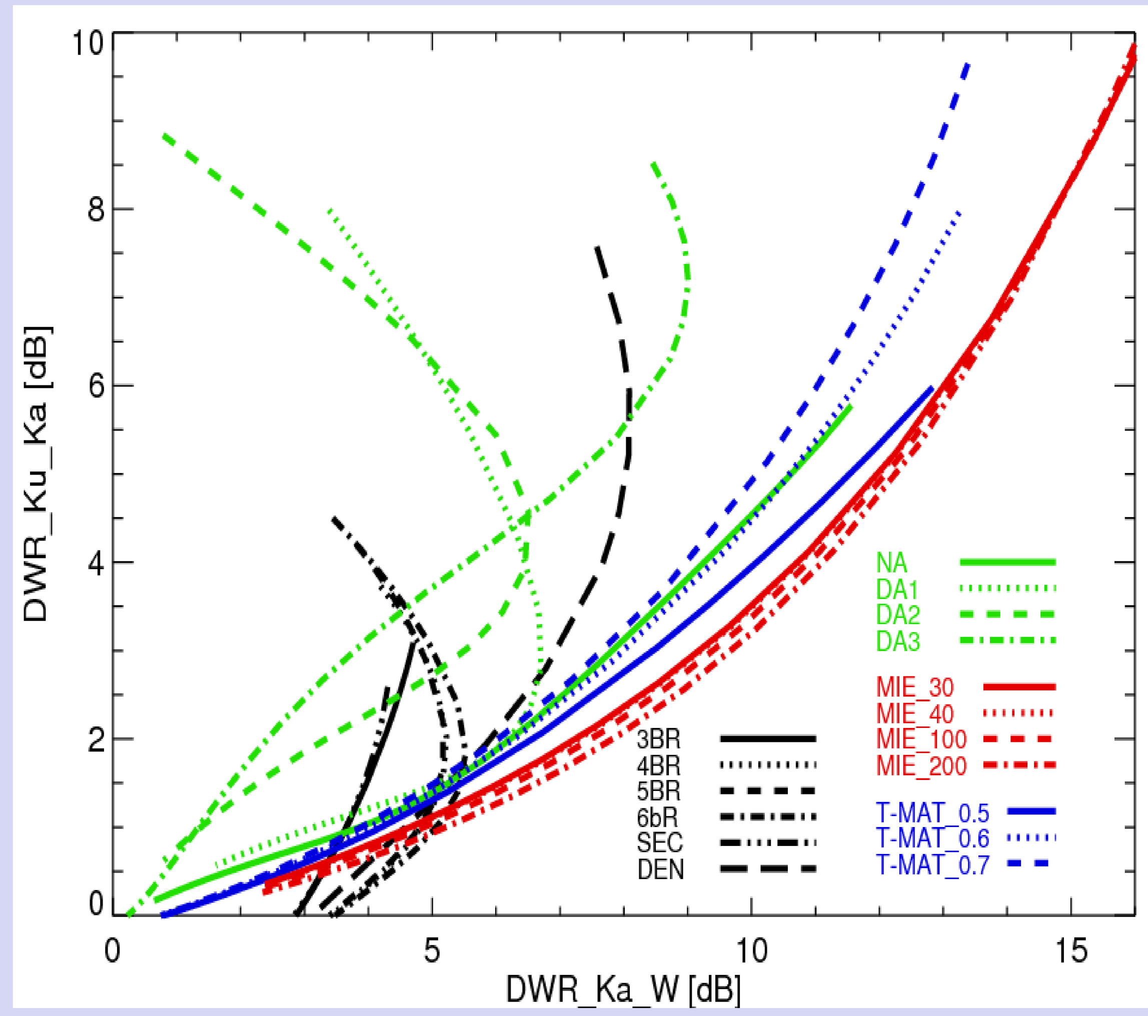
~ 3 - 5 K per 0.1 kgm^{-2} SWP at 90 GHz

Perspective: Triple-frequency radar

- Single-frequency Ze – SWC or Ze – SR relations are found to have large uncertainties due to natural variability in snow size distribution (SSD) and different snow particle habits.
- Using dual-frequency information in form of the logarithmic differences of two Ze measurements (DWR), **the slope parameter lambda of the exponential SSD can be derived with the DWR if the particle habit is known.**



Simulated logarithmic Ze difference or dual wavelength ratio DWR for (left) Ku- and Ka-band (e.g. 13 and 36 GHz) and (right) Ka- and W-band as a function of the slope parameter lambda of the SSD. Simulations use different particle types up to a maximum size of 10 mm: pristine ice particles (upper left), snow aggregates (upper right), ellipsoids (lower left) and soft spheres (lower right) with densities between 30 and 200 kg/m³.



Pristine ice crystals (black lines), from Liu, BAMS, 2008:

Aggregate snowflakes (green lines), from Petty and Huang, JAS, 2010:

Soft spheres and ellipsoids with aspect ratios between 0.5 and 0.7.

- **Radar measurements at Ku-, Ka- and W-band allow to distinguish between different particle types especially if the SSD is dominated by large particles (low lambda range).**
- **This information is expected to lead to a significant improvement of SWC or SR estimates compared to single and dual frequency methods.**

References:

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