Ground-based remote sensing of snowfall through active and passive sensor synergy

Kneifel, S.[1], U. Löhnert[1], A. Battaglia[2], S. Crewell[1], M. Hagen[4], L. Hirsch[3]

[1] Institute of Geophysics and Meteorology, University of Cologne, Germany, skneifel@meteo.uni-koeln.de

[2] Earth Observation Science, University of Leicester, United Kingdom; [3] Max-Planck Institute for Meteorology, Hamburg, Germany

[4] Institut für Physik der Atmosphäre, Deutsches Zentrum für Luft- und Raumfahrt, Wessling, Germany

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., BAMS, 2010*).

Objectives and Instrumentation

- Snow is the predominant type of precipitation in sub-polar and polar latitudes and plays an important role in the hydrological cycle.
- No single instrument is solely capable of describing the microphysical properties of snow.
- Integrate a number of state-of-the-art remote sensing instruments => final goal: Develop a modular optimal-estimation algorithm and evaluate the potential for deriving columnar snow microphysics.

Active Sensors:

35.5 GHz Cloudradar (MIRA36)

24.1 GHz MicroRainRadar (MRR)

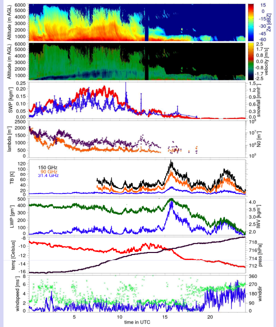
Passive Microwave Radiometers:

HATPRO (22-58 GHz): T/q-profile, liquid water path (LWP), integr. water vapor (IWV)

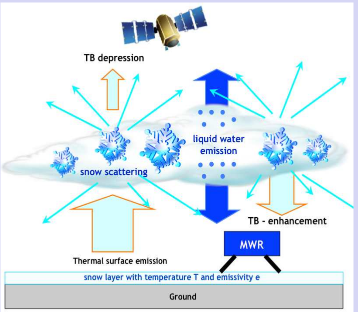
DPR (90/150 GHz): sensitive to snow scattering; polarized receiver @150 GHz

In-situ instruments:

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

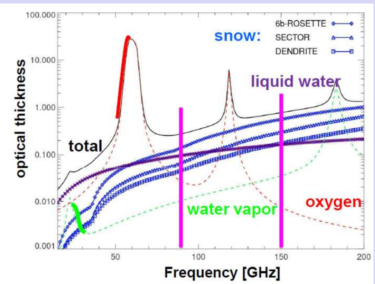


Snow scattering effect



- 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**?

Spectral sensitivity



HATPRO: 7 channels between 22.235 – 31.4 GHz
7 channels between 50.8 – 58.8 GHz
DPR: 90 GHZ and 150 GHz (vertical/horizontal)

Simulated optical thickness for a typical winter atmosphere:

- Oxygen and water vapor show distinct absorption lines/bands.
- Liquid water emission increases continuously with frequency.
- Snow scattering becomes significant only at f > 90 GHz.

HATPRO measures at the wings of the absorption lines, DPR channels measure in atmospheric windows.

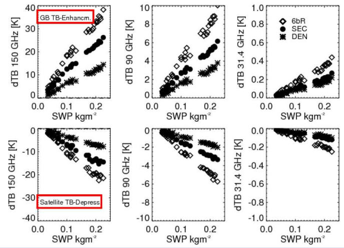
References:

Kneifel, S., U. Löhnert, A. Battaglia, S. Crewell and D. Siebler, Snow scattering signals in ground-based passive microwave radiometer measurements, *J. Geophys. Res.*, accepted.

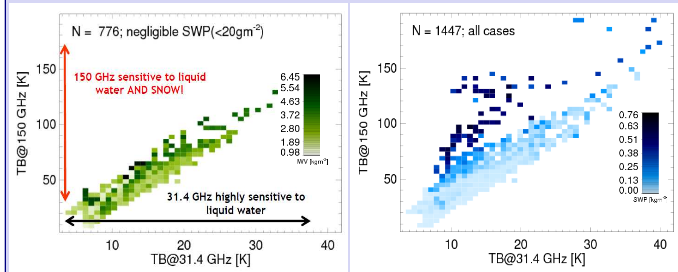
Löhnert, U., S. Kneifel, A. Battaglia, M. Hagen, L. Hirsch and S. Crewell, A multi-sensor approach towards a better understanding of snowfall microphysics: The TOSCA project, *BAMS*, submitted.

Passive MW sensitivities

- Simulations predict TB-enhancement in ground-based passive measurements.
- For the simulated case, the TB-enhancement (upper line) is 2x stronger than the TB-depression (lower line) from a satellite sensor!
- Snow scattering signals are extremely sensitive to snow habit and size distribution (*Kneifel et al., JGR, 2010*).



Radiative Transfer (RT) simulations for different snow habits (symbols) and snow water paths (SWP) for 150, 90 and 31 GHz.



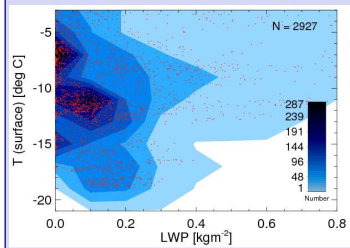
Measured TBs at 150 and 31.4 GHz for the whole TOSCA period. Left: Snow-free cases with water vapor content colored; Right: All cases with snow water path colored (estimated with cloud radar).

- 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**

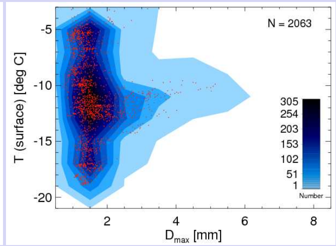
~ 8 - 10 K per 0.1 kgm^{-2} SWP at 150 GHz

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

Statistical snow cloud properties



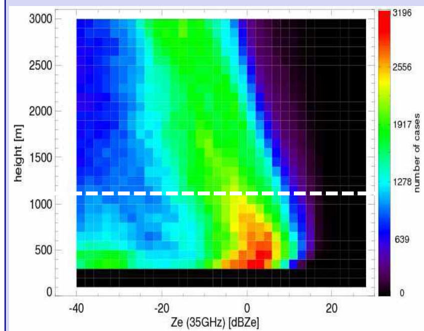
Distribution of liquid water path (LWP) derived from HATPRO for different 2m-temperatures.



Distribution of maximum snow diameter (Dmax) from video disdrometer against 2m-temperature.

- **Liquid water is NOT a simple function of temperature.**
- **High LWP values (up to 0.4 kgm²) were measured even at very cold temperatures (down to -18°C)**

- **Largest aggregates were detected between -10...-15°C. In this so called 'secondary growth region', dendritic crystals dominate and sticking efficiency seems to increase significantly.**



- **Snow clouds @ UFS reveal highest Ze values most frequent (color) in the lowest kilometer.**
- **Those lowest regions are missed by CloudSat**

Distribution of 35.5 GHz radar reflectivity factor with height (abs. number colored). Dashed white line indicates lowest CloudSat height bin.