A new 94 GHz radar/radiometer suitable for studying cloud edges

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1. The Instrument

The instrument combines a FMCW 94 GHz **radar** with a 89 GHz **radiometer**, both receiving over the **same antenna** (Fig. 1). Vertical **resolutions** up to **5 m** are possible. The calibration **accuracy** is **0.5 dB** and was evaluated by two cross checks: (i) a metal sphere reflector; and (ii) a comparison to a collocated 35 GHz pulsed radar (JOYRAD-35; Fig.2). In both cases the agreement was within 0.5 dB.

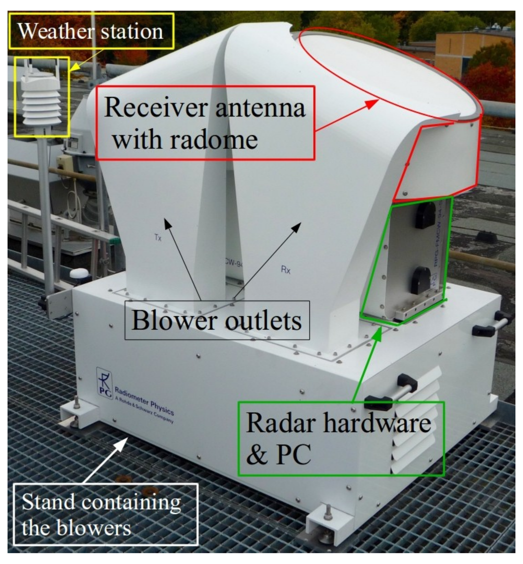

Table 1: Sensitivity of JOYRAD-94 when observing with up to 5 m vertical resolution.

Range [km]	Sensitivity [dBZ]
0.1 – 0.4	(-67) - (-52)
0.4 – 1.2	(-54) - (-46)
1.2 – 3.0	(-48) - (-41)
3.0 – 12.0	(-44) - (-30)

Fig. 1: JOYRAD-94 at Jülich Observatory for Cloud Evolution (JOYCE).

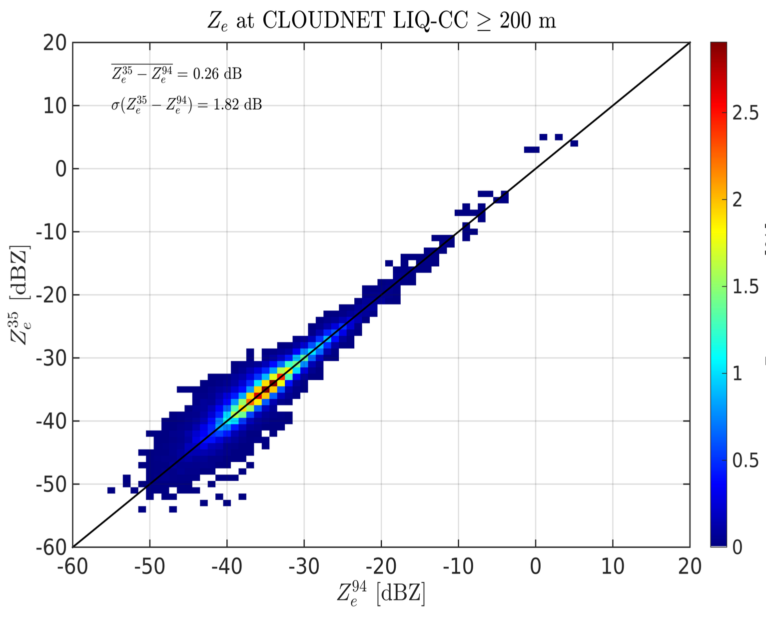

Fig. 2: Reflectivity comparison to JOYRAD-35 collocated 5 m next to JOYRAD-94. Considered were only single-layer liquid clouds after [1].

2. Retrieving the Liquid Water Path at 89 GHz

Using multi-variant regression, we derived liquid water path (**LWP**) retrievals of second order for (i) brightness temperatures (BT) measured at 89 GHz; (ii) BT89 with additional information on the integrated water vapor (IWV) with a random uncertainty of +-2 kg/m² (Fig. 3); and (iii) BTs at 7 frequencies ranging from 22 to 31 GHz. The latter is a common frequency range for observing LWP and will be used as a reference. The model study revealed the following **uncertainties**: (i) 44 g/m², (ii) **15 g/m²**, and (iii) 25 g/m².

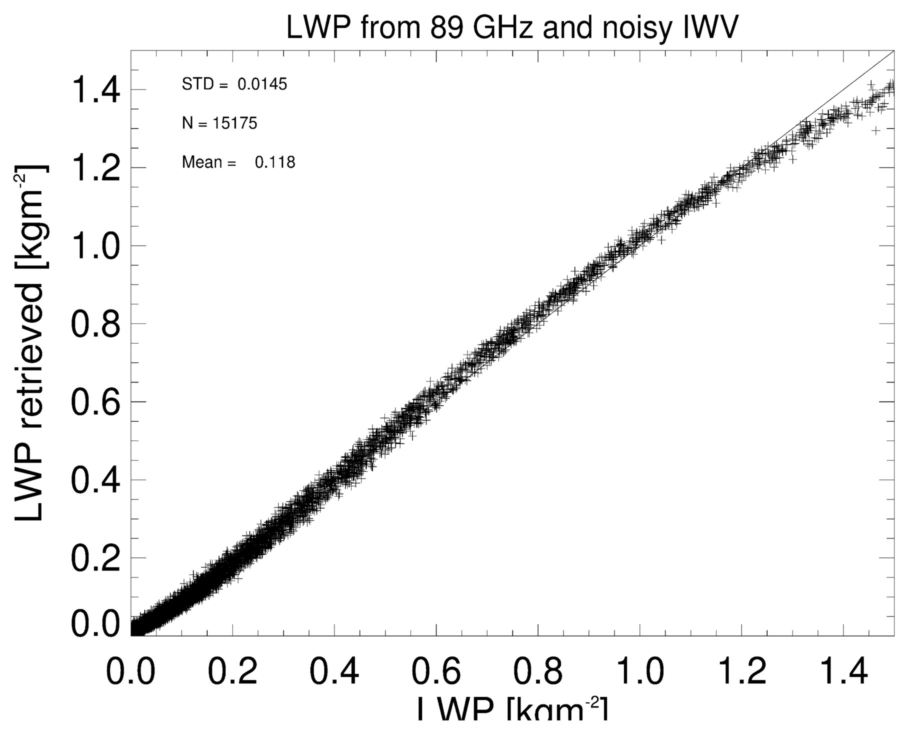

Fig. 3: LWP retrieval performance using BT at 89 GHZ with additional information on IWV

3. Modeling a Cloud and Simulating Measurements

The performance of JOYRAD-94 at **cloud edges**: an **artificial 2D cloud** on a 5 m x 5 m grid was created (Fig. 4). The base was a radiosonde profile with an IWV of 18 kg/m²: (i) a cloud was added using a modified adiabatic approach after [2]; (ii) we added random noise the liquid water content (LWC) profile to create the cloud.

At every horizontal grid point **BT measurements were simulated** at several angles using the Passive and Active Microwave Radiative Transfer Model (PAMTRA) [3]. Frequencies: 22.24, 23.04, 23.84, 25.44, 26.24, 27.84, 31.40 (henceforth: K band), and 89.00 GHz.

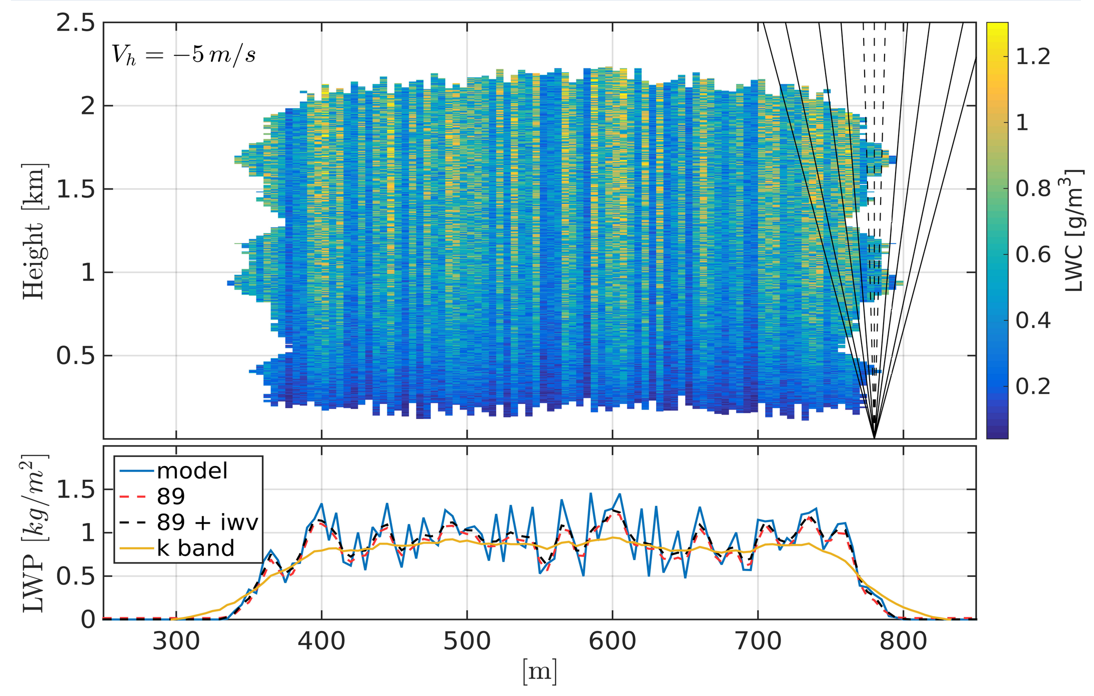

Fig. 4: Top: Modeled cloud. Black lines indicate simulated paths. Bottom: True (model) and retrieved LWPs.

4. Retrieval Performance and Transient Times

Common radiometers for retrieving the LWP measure in the K band with Half Power Beam Widths (**HPBW**) of about **3.6°** or more ([4], [5]). Such BTs were simulated averaging over several angles (Fig. 4, solid and dashed lines). **JOYRAD-94** has a HPBW of **0.48°** (Fig.4, dashed lines), which leads to **less smoothing** effects in the measurements as can be seen in Fig. 4 (bottom), where the retrieved LWPs are illustrated. Moreover, wider beams lead to larger **transient times** (difference between first cloud signal and cloud at zenith), which are here **up to 10 s at 3.6°** assuming an advection velocity of 5 m/s. With **0.48°** the transient time is **about 1 s**.

Usually clouds are profiled combining **several instruments** having some **distance** to each other [1]. Here, a displacement of 5 m corresponds to a time difference of 1 s leading to **loss of correlation** of up to 20 %, depending on the HPBW of the instruments (Fig. 5).

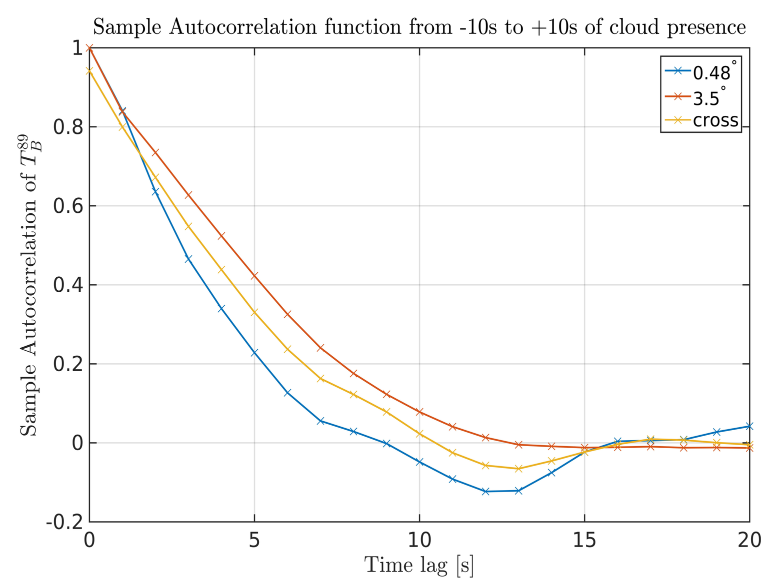

Fig. 5: Autocorrelation and cross-correlation of BTs at 89 GHz for different beam widths.

5. High Vertical Radar Resolution

High vertically resolved Doppler spectra provided **additional information on cloud properties**. Fig. 6 illustrates a comparison of Doppler spectra measured simultaneously by JOYRAD-35 with 30 m resolution and by JOYRAD-94 with **5 m resolution**. Clearly visible is the lagging (shifts to lower velocities) of JOYRAD-35 spectra and mean Doppler velocities.

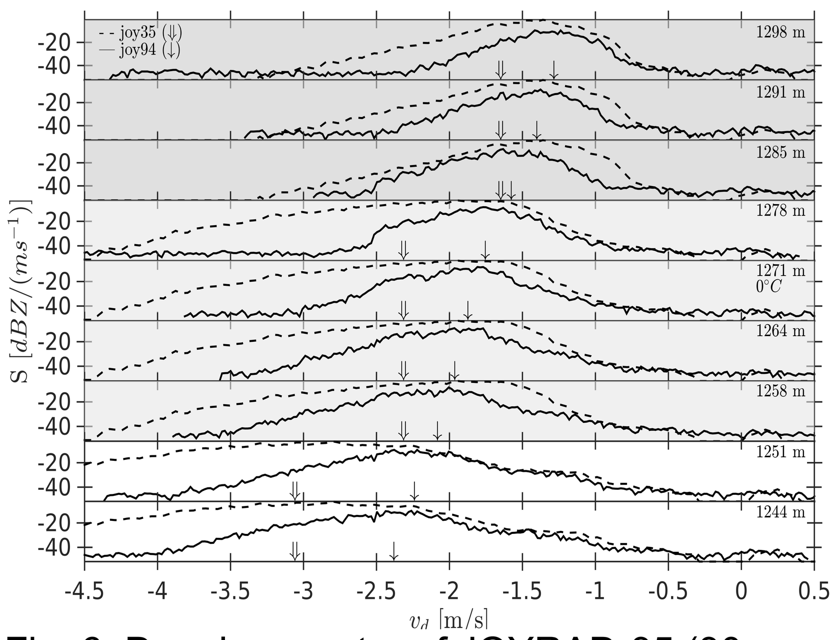

Fig. 6: Doppler spectra of JOYRAD-35 (30 m resolution) and JOYRAD-94 (5 m). Negative velocities indicate movement towards the radar.

6. Summary & Outlook

This preliminary study showed the **benefit of a** radar/radiometer combination with **identical beams**.

The **LWP** can be retrieved from BT measurements at 89 GHz with an **uncertainty of +- 15 g/m²** when knowing the IWV within +- 2 kg/m².

High vertically **resolved spectra** add information on cloud **micro-physics**.

In the next step the model findings will be evaluated with real measurements. Moreover, the model will be sophisticated by including more realistic conditions, such as turbulence.

References

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