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

N. Küchler¹, U. Löhnert¹, P. Kollias², S. Kneifel¹

¹Institute for Geophysics und Meteorology, University of Cologne, Germany;
²School of Marine and Atmospheric Sciences, Stony Brook University, USA

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.

<table>
<thead>
<tr>
<th>Range [km]</th>
<th>Sensitivity [dB]</th>
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<tbody>
<tr>
<td>0.1 – 0.4</td>
<td>-67 (-52)</td>
</tr>
<tr>
<td>0.4 – 1.2</td>
<td>-54 (-46)</td>
</tr>
<tr>
<td>1.2 – 3.0</td>
<td>-48 (-41)</td>
</tr>
<tr>
<td>3.0 – 12.0</td>
<td>-40 (-33)</td>
</tr>
</tbody>
</table>

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

2. Retrieving the Liquid Water Path at 89 GHz

Using multi-variate 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.

![LWP retrieval from 89 GHz](image)

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

![LWP retrieval performance](image)

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.

![Simulating Measurements](image)

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 at 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).

![LWP retrieval from 89 GHz](image)

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.

![Doppler spectra](image)

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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nkuech@meteo.uni-koeln.de