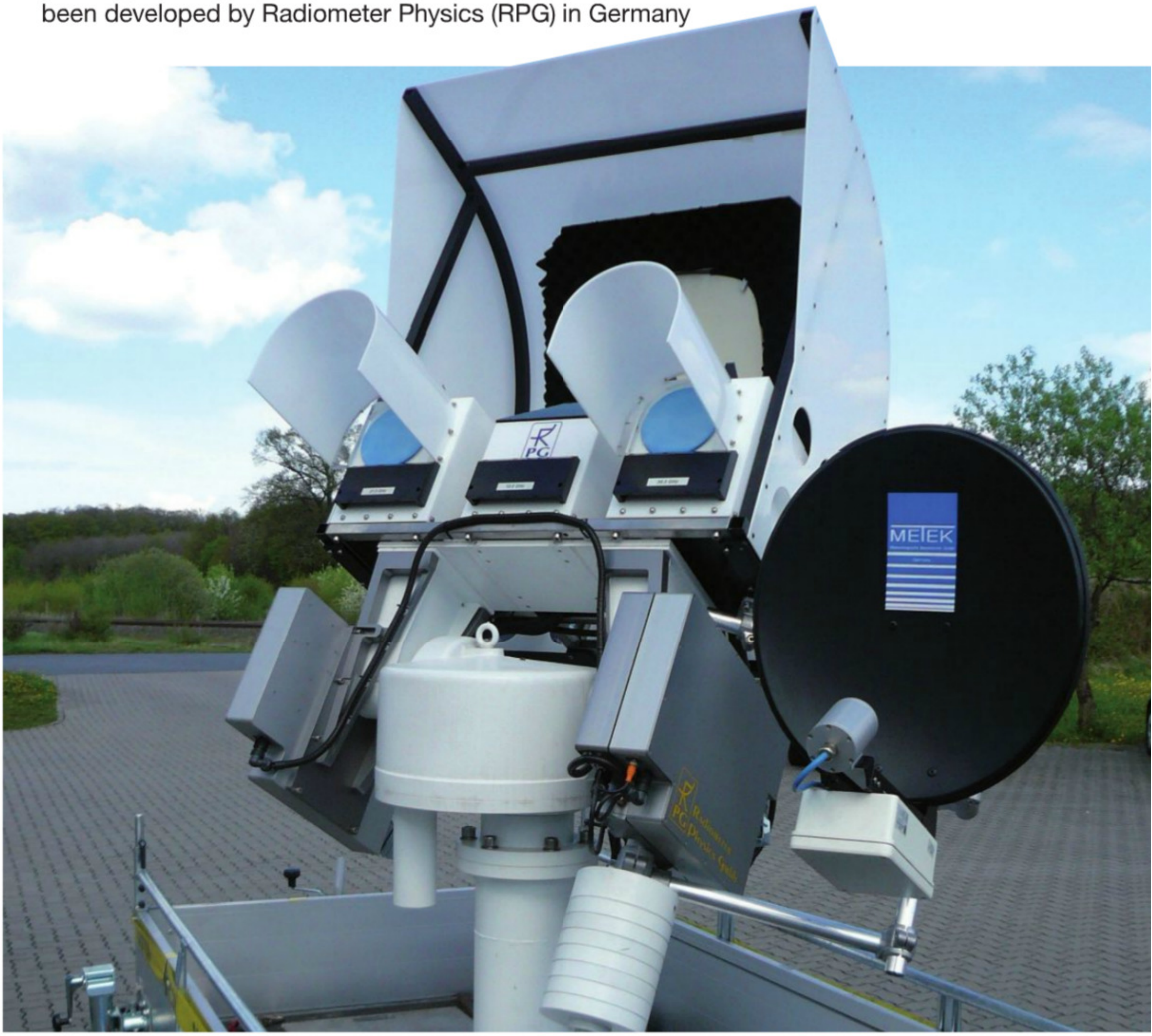
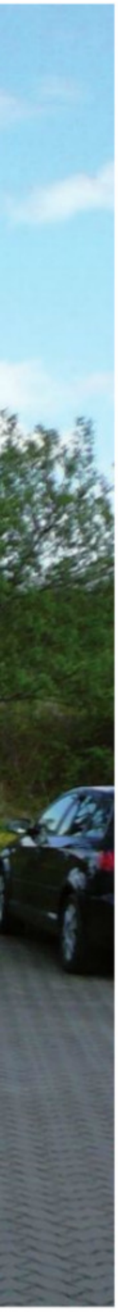
by Dr Harald Czekala

RADIANT RAIN

Observation of rain with dual-polarization radiometers

A next-generation dual-polarization scanning microwave radiometer has been developed by Radiometer Physics (RPG) in Germany





"Usually, the emission of gases and also by small-cloud droplets is unpolarized"

The estimation of cloud-liquid water with ground-based microwave radiometers has a long tradition in meteorology. For more than four decades, this remote sensing technique was established, from theoretical background to instrument technology, with good success in the retrieval of integrated water vapor (IWV) and liquid water path (LWP) in the earth's atmosphere.

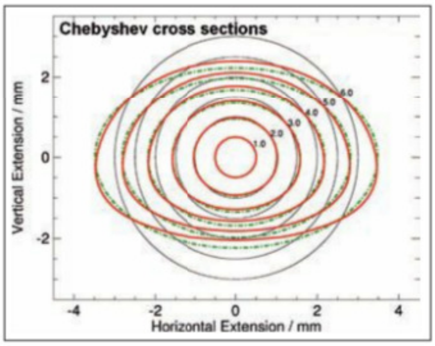
The requirement on the instrument technology is quite demanding. Although the microwave radiometer is, except for the missing active source, very similar to radar technology, the passive microwave radiometers receive the thermal emission of the atmospheric gases (mainly O_2 and H_2O) and liquid drops in the microwave region.

The frequencies under consideration are usually 23.8 and 36.5GHz, with some interest in frequencies as low as 10GHz and up to 90 or 150GHz. This converts to wavelengths in the region of 30mm (10 GHz) to 2mm (150 GHz). The minimal received power levels at the input of the radiometer antenna lead to a demanding signal-to-noise ratio for the low-noise amplifiers in the detection circuits.

For a more convenient handling, the measured microwave intensities are converted into brightness temperature (TB, expresses in Kelvin) by a simple scaling. The radiometer is pointed at black bodies (meaning emissivity equals one inch in the microwave spectral region) with known physical temperature for calibration purposes. Usually, the calibration targets have ambient temperature (290K) and liquid nitrogen temperature (77K). The intensities received during later measurement of the sky are compared to the intensities received by such calibration targets, and based on such a comparison the amount of microwave emission by the atmosphere (and the water drops) is converted into equivalent temperature units.

Frequency selection

The frequency selection for LWP radiometers always follows a common strategy. At least two frequencies are mandatory, with one inside or close to the spectral-emission line of water vapor (which is at 22.235GHz), the other one outside the emission line inside the 'window region' around 36GHz. Liquid water has no pronounced spectral dependence and impacts both frequencies very strongly, and the spectral nature of the gas-phase emission affects the water vapor channel in a much stronger way. This approach allows the discrimination of water vapor (IWV) and liquid-phase water (LWP) as seen in clouds and rain with good overall performance.



Shape of raindrops falling at terminal velocity. Red: precise shape. Green: spheroid approximation. Black: volume sphere

In the past, the favored approach to convert the measured microwave brightness temperatures (TB) into liquid-water path was the exploitation of a very useful and handy relationship. Small cloud droplets (radius less than 0.1mm) are significantly smaller than the observation wavelength in the microwave-frequency window under consideration and thus behave like Rayleigh scattering particles. The amount of emitted black-body radiation is proportional to the water mass of the droplets and independent of their particular size. Twice the amount of cloud water in the field of view of the radiometer yields twice the amount of brightness temperature received by the radiometer.

Unfortunately, this simple relationship only holds for small droplets. In case of precipitation, the raindrops are usually in the range of 0.5-5mm radius, which is already comparable to the observation wavelength. Mie-scattering is the term of the physicists, describing the behavior of electromagnetic waves hitting a spherical body.

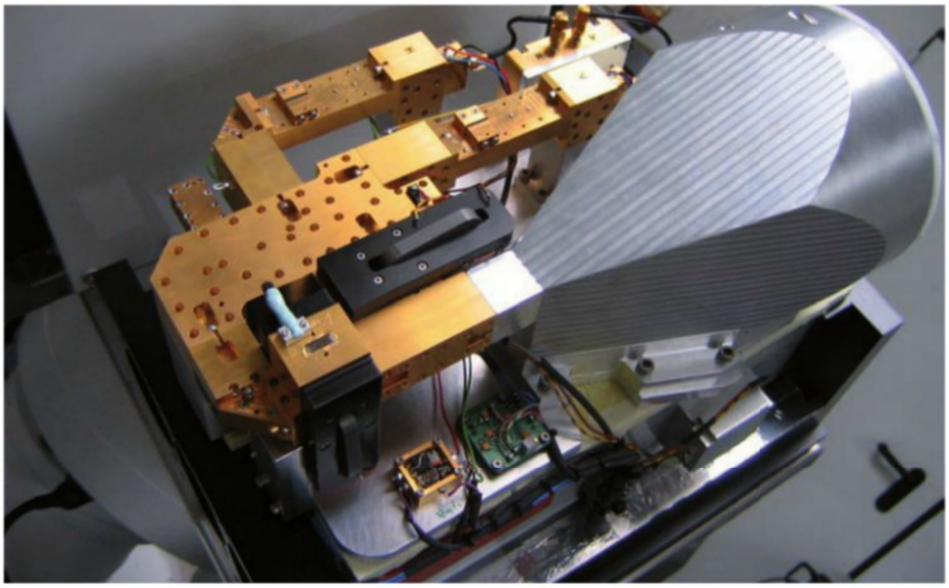
The Lorenz-Mie theory gives different results for the emission-efficiency of raindrops compared with Rayleigh-scattering small-cloud droplets. The same amount of liquid water (say, $1kg/m^2$) will usually produce two or three times more microwave emission than the same water mass in small cloud droplets. The precise numbers can vary and depend on the precise composition of the raindrops' size spectrum.

The fundamental problem of passive-microwave remote sensing in this situation is that the researcher does not have any a-priori knowledge about the cloud microphysical properties by just observing the microwave intensities. Even without observed rain below the cloud and on the surface, there is a good chance of in-cloud rain processes. Without knowledge of the microphysical situation, any retrieval based on the (commonly applied) Rayleigh scattering assumption of small cloud droplets is overestimating the LWP of clouds, if there is rain inside.

Microwave transfer simulation

About 10 years ago, there was an initiative by Harald Czekala and Professor Clemens Simmer at the University of Bonn to fix this problem. Physical theory and computer power advanced and enabled the study of microwave radiative-transfer simulation incorporating the realistic shape of falling raindrops. The shape is, in contrast to common pictures, shows quite often a tear-drop shape, an oblate spheroid, with a more flattened bottom than top. The reasons for the flattening are mainly the drag of wind speed and hydrostatic pressure, balanced by surface tension.

Combining the results of researchers working on the modeling and analysis of precise drop shapes with computer codes developed for simulation of electromagnetic



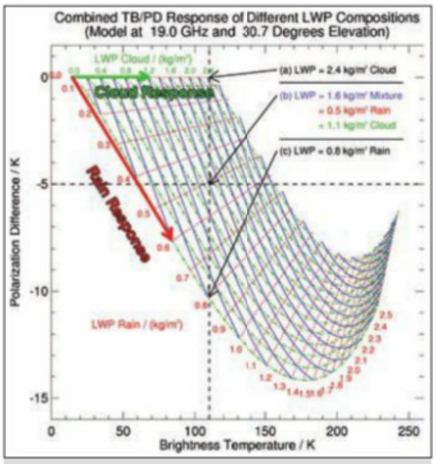
Dual polarization auto-calibration front end receiver from Radiometer

scattering on non-spherical Mie-scattering bodies; and then putting everything together in a dual-polarized passive microwave radiative transfer model, the results showed a possible way to overcome the fundamental remote-sensing problem of rain observation with passive microwave LWP radiometers. Raindrops that are too large to obey the Rayleigh scattering proportionality of water mass and emitted radiation tend to produce a polarization signal in their emitted radiation, which can be used to compensate the lack of information on the microphysical properties inside the cloud or the atmosphere in total.

Usually, the emission of gases and also by small cloud droplets is unpolarized, meaning that two orthogonal linear-polarization receivers on the surface would observe the same brightness temperatures in vertical and horizontal polarized brightness temperature.

Non-spherical raindrops now produce a different emission in the vertically and horizontally polarized TB when observed in an off-nadir viewing geometry (elevation angle usually 25-45°). The PD is non-zero, with values of down to -15 or even -25K (with the minus originating from the definition of PD as a difference of two TB values).

In general, the PD signal is stronger for more flattened (oblate) drop shapes. Fortunately, the raindrops tend to have size dependent flattening due to reduced surface tension, and stronger drag forces at higher terminal fall velocities. Using the right frequency selection, the polarization signal increases at the same time when the raindrops deviate from the Rayleigh scattering theory. The more the raindrop-emission efficiencies deviate from the volume equivalence because of getting too large, the more the non-sphericity (also caused by their size) generates a polarization signal.



Combined brightness temperature (TB) and polarization difference (PD) response of an atmosphere

The method thus uses one size-dependent signal to compensate a size-dependent error in the commonly used LWP retrievals. In addition, the PD signal can be used to not only compensate the distortion in the LWP retrieval, but also give more insight into the cloud microphysical properties.

Passive microwave LWP radiometers

Observing two-dimensionally (TB and PD) instead of one-dimensionally (TB only) opens up a whole new way to look at rain in the atmosphere with passive microwave LWP radiometers. The new dual-polarized technique allows not only a much more precise LWP estimation in rainy situations, but it also yields the partitioning of total LWP into the two classes of cloud-LWP and rain-LWP. Even for clouds with LWP numbers in medium ranges, where the cloud would be considered to be a pure non-raining cloud by today's standard LWP radiometers.

Although this fundamentally new approach was already published back in 2001 by Czekala and co-workers, with backing of the theory by analysis of real radiometer data, it took several years until a practical and operational retrieval technology and a suitable instrument were developed. Alessandro Battaglia and his team at the University of Bonn took up the basic idea, and developed a Bayesian retrieval technique based on the calculation of roughly a million atmospheric profiles, including detailed scattering and emission by non-spherical raindrops.

The corresponding hardware, a dual-polarization scanning microwave radiometer, was developed by Radiometer Physics GmbH (RPG) in Meckenheim, Germany, and delivered in 2007. The ADMIRARI instrument has three frequencies at 10.65, 21.0, and 36.5GHz with dual-polarized direct-detection receivers. Auto-calibration front-end technology is implemented by highly optimized magnetically switched low-loss isolators and noise-injection for two-point calibration while staying pointed on the scene.

The instrument is fully steerable and deployable for field campaigns when mounted on a trailer. Fully developed control software makes the radiometer a turnkey system, making possible low-maintenance 24/7, and un-manned operation of such instruments over long periods.

Since the development of ADMIRARI, several radiometers of this type have been built at RPG. The results gathered by these instruments show that the instrument itself, and the retrieval technique, are mature enough to go operational. ∎

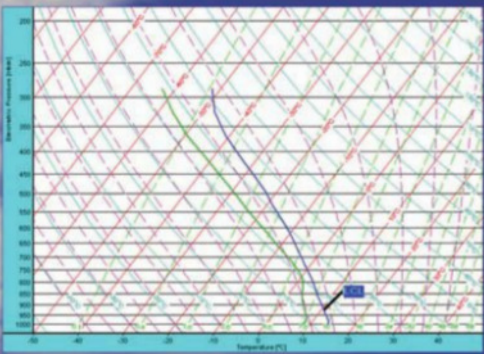
Dr. Harald Czekala is from RPG Radiometer Physics GmbH, based in Meckenheim, Germany

Microwave Radiometers for Weather and Climate

Dual-Polarization Radiometers

Radiometer Physics is the leading supplier of multi-frequency scanning radiometers for geo-physical microwave remote sensing.

- Turn-key systems, fully unattended, operational 24/7
- State-of-the-art auto-calibration receivers
- Designed for automated networks
- Any 4 frequencies above 10.65 GHz on one positioner
- surface measurements (soil-moisture, vegetation)
- ***observation / discrimination of cloud and rain LWP***



Profiling Radiometers

The RPG-HATPRO (Humidity and Temperature PROfiler) is becoming the radiometer of choice for meteorological networks and forecasting systems all around the world.

- 14 chanels (22 to 31 GHz, 51 to 58 GHz)
- Network suitable, control + data flow via internet
- Data formats: netCDF, BUFFR, binary, ASCII, …
- Data products: IWV, LWP, T-profile, RH-profile, stability
- Thermodynamic analysis: Skew-T, tephigram, Stüve, …
- Better boundary layer T-profiling than radio-soundings
- Full-sky scanning (350 directions in less than 5 minutes)
- Ground-based: complementing the satellite view!
- All-weather proof, reliable, robust. Proven.
- Software for interfacing with forecasting (quality flagging, …)
- IR radiometer extensions: single/dual channel, elev. scanning

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