Deliverable D2.3: Radar calibration and standardization concepts

Herman Russchenberg, Yin Jiapeng

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Cloud Radar Calibration

Background

Climate change is becoming one of the largest challenges of mankind. Clouds play a crucial role in the climate change process. The cloud formation and evolution are the balance between a series of dynamical, radiative and microphysical processes. Cloud particles of sufficient size become falling hydrometeors, such as drizzle drops, raindrops, snow crystals, graupel and hailstones. How to qualitatively identify and quantitatively measure these hydrometers remains a hot topic in current research community because of the direct impact on the public. Moreover, the physical processes behind these hydrometers need to be further explored.

With the advent of cloud radars, one way to quantitatively obtain the information of clouds with high spatial and temporal resolution is provided. There are an increasing number of people involved in the research of cloud radar, and the market for cloud radar is expanding. As of 2015 approximately 12 cloud radars have been installed in Europe as part of the ACTRIS network. In addition, there will be another 10 to 50 new economical cloud radars in Europe up to 2025.

Radar systems are very complex and their calibration is crucial to obtain the sufficient measurement accuracy. Radar calibration aims at characterizing the system properties and its accuracy. The system errors can be estimated by inserting the test signal to the radar system or by using objects with known scattering property. To be specific, radar calibration can be divided into two parts: the internal calibration and the external calibration. For the internal calibration, built-in test equipment should be installed to act as the internal radar calibration loop to monitor the variability of the electronic component inside the radar system. The external calibration, always regarded as end-to-end calibration, involves the measurement of returns from a calibrator with known radar cross section, such as a trihedral or metal sphere. External calibration is able to exercise the full path of transmitter, receiver and antenna, which is necessary to characterize the radar systemic error.

However, nowadays there are no effective calibration methods available. In order to explore the common solution to the problem, a cloud radar calibration workshop was held in University of Cologne on September 28-29, 2015 as part of Task 2.2.2 of ACTRIS-2 WP2. The main goal of the workshop was to initiate and coordinate cloud radar calibration activities across Europe to ensure high quality and intercomparability of the collected datasets. The workshop was also intended to provide an overview of ongoing and planned calibration activities of the different groups, discuss the different aspects and challenges of cloud radar calibration methods, and formulate short-term and long-term calibration goals. This report is the summary of the current and to-be-done methods adopted in radar calibration, which were discussed at this workshop.

Current methods

For a better understanding of current methods, the radar equation for volume scattering is shown below.

$$\overline{P}_r(r_0)=\left(\frac{cT_0}{2}\right)\left[\frac{P_t G_0^2}{\lambda^2(4\pi)^3}\right]\left(\frac{\pi\theta_1\varphi_1}{8\ln 2}\right)L_s\frac{\pi^5|K_w|^2 Z_e(r_0)}{r_0^2} \tag{1}$$

where $\overline{P}_r(r_0)$ is the receiver power in range r_0, *c* is the light velocity, T_0 is the pulse width, λ is the radar wavelength, P_t is the transmitter power, *Ls* is the path loss term, G_0 is the antenna directivity, θ_1 and φ_1 are the conventional 3dB beam widths, $|K_w|^2$ is the water dielectric factor and $Z_e(r_0)$ is the reflectivity factor.

The current calibration methods are mainly divided into sub-system calibration and whole-system calibration, shown in Table 1. For the sub-system calibration, it can be divided into transmitter, receiver and antenna calibration. Moreover, the antenna calibration further includes mechanical properties — antenna pointing, and electromagnetic property — antenna beam pattern. As for the whole-system calibration, it mainly contains tethered balloon calibration, mast target calibration and drone-based calibration. These calibration methods will be discussed in detail in the following sections.

Table 1 ***Current calibration methods.***

Calibration methods	Sub-system calibration	Transmitter
		Receiver
		Antenna pattern
	Whole-system Calibration	Tethered balloon calibration
		Mast target calibration
		Drone-based calibration

Sub-system calibration

The radar system is mainly divided into three parts, specifically transmitter, receiver and antenna. These sub-systems can be used to diagnose the system properties individually or they can be considered as the combinations of two sub-systems. These sub-system calibration methods are regarded as internal calibration which is used mainly to monitor the radar system performance. For some radar system, the radar parameters can be saved in log-files and an email-alert can be generated when a threshold has exceeded its intrinsic value.

Transmitter.

According to the radar equation expressed in (1), it is necessary to characterize the transmit wavelength, transmit pulse width and transmit power. The transmit wavelength is normally determined by measuring the transmit frequency, which can be compensated with the automatic frequency control system. Usually, the measurement of the transmit pulse width and adjustment should be conducted every 1-3 months, according to the discussion in the workshop. As for the monitoring of transmit power, the measurement is conducted by an internal power meter. Additionally, the external measurement of transmit power is necessary to check the accuracy of the internal power meter.

Receiver.

The noise power is useful for receiver calibration. People from the German Meteorological Service (DWD) reported that they used an external noise source to check the internal noise source once every three months to control the consistency. The researchers from the Delft University of Technology proposed using noise measurements to calibrate the offset between two receivers of a polarimetric radar. Specifically, the intrinsic value of the differential reflectivity obtained from the two receivers should be zero. By averaging the noise power of each receiver channel and further subtract these two averaged noise levels, we get the differential reflectivity offset.

Antenna.

Both mechanical and electromagnetic properties should be taken into consideration when dealing with the antenna calibration. Mechanical properties mainly include antenna pointing. Radar mispointing will result in a bad effect on the spectral analysis. For example, the horizontal wind component error will be interpreted as a shift in vertical hydrometer motion for non-zenith pointing radar. There are some methods available to check radar mispointing. For scanning radars, the regular sun scans, inbuilt or external tilt sensor, and external target can be used to calibrate radar pointing. As for zenith pointing radar, the only way is inbuilt or external tilt sensor, whose accuracy is difficult to guarantee.

Electromagnetic propertiesare mainly determined by antenna beam pattern. Radar linear depolarization ratio (LDR), which is important for hydrometer classification, depends on the antenna polarimetric performance. The decomposition of the coherency matrix into non-polarized and fully-polarized parts can be used to correct the unfavourable measurements caused by non-ideal antenna properties.

Whole-system calibration

Calibration drifts due to the gradual degradation of the system performance (antenna gain, radome changes, etc.)cannot be detected by the internal calibration process. For this reason, it may be more practical to evaluate and characterize the radar system as a whole by using the external calibration. Usually, the techniques are based on point targets, such as standard reflectors or metal spheres with known radar cross sections. The specific platform should be well designed to make sure that these standard calibrators are located in the main beam of the antenna pattern. There are mainly two methods available now which presented in the following.

Tethered balloon calibration.

The experiment conducted at the Juelich Observatory for Cloud Evolution (JOYCE) to calibrate a 35-GHz MIRA cloud radar was presented in this workshop. The radar was pointed toward a target which is a plastic sphere with a radius of 10 cm coated with EM shielding spray. The sphere, tethered with 3 lines to reduce oscillations, is lifted to 100 m height using a radiosonde balloon. The experiment is repeated several times to eliminate the uncertainty. The final result of this experiment shows that the reflectivity deviation between the morning and afternoon is 1.2 dB. This may be attributed to attenuation caused by liquid droplets. However, finally, there is no deterministic conclusion of the result.

Mast target calibration.

Additionally, another experiment on the absolute calibration of the BASTA 95-GHz radar was reported in the workshop. The calibration is done using a trihedral corner reflector which is located on a telescopic mast at 20 m height. The experiment took a measurement of relative humidity which is helpful to estimate the attenuation. However, this experiment did not give a certain conclusion on the calibration performance which is validated by a closure experiment. Reflectivity and liquid water closure are successful for the case study of January 6th, 2015, i.e. agreement is found between the vertical profile of in-situ sensor of droplet microphysics and active-passive remote sensing instrument.

Drone-based calibration.

Finally, the last whole-system calibration method discussed is the drone-based calibration, specifically a drone equipped with a hanging metal sphere with a GPS device inside. There are several advantages of this method. Firstly, this method is suitable to all sites. It is easy for a stable drone to bring the metal sphere to any location with the feedback of the GPS information. Secondly, this method is relatively cost-effective. The required equipment is just a drone and a metal sphere. Thirdly, for mobile radars, it is portable to redo the calibration process because it is very convenient to bring the drone and metal sphere to any site. Finally, it provides a possible way to calibrate vertically-pointing cloud radars. Because you can always know the exact location of the drone and metal sphere with the help of GPS devices, you can adjust the flight of the drone to make it outside of the cloud radar main beam while the metal sphere is inside the main beam.

The experiment can be divided into four steps. Firstly, fix the radar antenna pointing to a specific direction and tilt its elevation angle to get rid of the influence of ground clutter. Secondly, let the drone do the specific movement in the antenna far field to make sure that the sphere is in the range of the antenna main beam while the drone is outside of it. Thirdly, keep a record of the receiver power of the sphere as well as its position at the same time and make a selection of these data to get rid of unsatisfactory ones. Finally, by using the position information, we can get the theoretical receiver power and make a comparison with the measured one, resulting in radar system error.

There are some key elements to guarantee the success of this experiment. One is the selection of favourable meteorological conditions, like weather condition which may be clear-air and no winds greater than a few meters per second. Another is the good control of the drone to meet the position requirement of the sphere as well as the drone itself. The Delft University of Technology is going to conduct a drone-based calibration campaign in the spring of 2016.

Summary and outlook

Different aspects of work related to calibration have been performed by the European radar community. In this workshop, researchers came to an agreement that radar calibration is far from mature and there is still a substantial amount of work to be done. In addition, researchers present in the workshop concluded to divide the radar calibration phase into three stages, namely radar system calibration, radar-based secondary target intercomparison and drop-size-distribution-based (DSD-based) indirect intercomparison.

Radar system calibration.

This part mainly concentrates on the radar system itself, not interacting with the radar surroundings. The main contents were described above, including the sub-system calibration and the whole-system calibration. For the whole-system calibration, we want to apply end-to-end calibration, i.e. external calibration. However, there are some problems with current methods. Firstly, there is location limitation, such as radar siting in a high building or tower is difficult to implement the calibration. Secondly, it is not cost-effective to redo the calibration process for mobile radars because a lot of calibration equipment must be transported with the radar. Finally, for vertically pointing cloud radar, it is impossible to calibrate with current methods. Hence, an accessible, cost-effective, portable radar external calibration needs to be explored and adopted.

Radar-based secondary target intercomparison.

The second stage of calibration is the radar-based secondary target intercomparison. Assuming we have two calibrated radars, like one S-band radar and one X-band radar, let them illuminate the same area of precipitation to get their reflectivity respectively. Then one can check whether the two measured reflectivities are consistent or not to obtain the calibration performance.

DSD-based indirect intercomparison.

The third stage will be the DSD-based indirect intercomparison. With disdrometer, we are able to get the drop size distribution of rain, resulting in the theoretical reflectivity. The comparison with the reflectivity obtained from calibrated radar will provide a consistency check.

At the workshop it was agreed that the calibration error should be within 1dB. Regular workshops should be held to discuss the process of calibration. The next cloud radar calibration workshop will be held in the Delft University of Technology in spring of 2016.