

Deliverable D2.12: Radar calibration and standardization at Cloudnet stations Herman Russchenberg, Jiapeng Yin

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Cloud Radar Calibration

1. Introduction

Doppler Cloud Radars (DCRs) are widely used to study cloud dynamical and microphysical processes. 15 DCRs are now deployed at (Cloudnet) stations providing data to ACTRIS. To ensure DCR data quality and accuracy, it is important to have standard calibration procedures that can be applied across the ACTRIS network. This will ensure comparability among the different measurements and an adequate estimation of measurement uncertainty.

External radar calibration using trihedral corner reflectors is an established method to retrieve the calibration constant of DCRs. In general, these targets are installed several meters away from radars using a mast or similar equipment to lift them from the ground, to reduce the unwanted echoes. In SIRTA, a trihedral, which is installed on the top of a mast, is used to calibrate the cloud radar at site. However, this approach requires scanning capabilities of the radar that enable it to aim the targets. Therefore, there is an interest in developing new ways of using these calibrators on fixed vertical-pointing instruments, for which scanning is not possible.

Previous experiments have shown that in W-band frequency the radar cross section (RCS) of the UAV is approximately 20 dB below the theoretically expected from a square-trihedral target sized 0.2 m. This encourages the calibration experiment using one unmanned aerial vehicle (UAV). Specifically, we will elevate the square-trihedral corner reflector fixed to a UAV above a scanning radar which is calibrated with a target on a mast, to characterize the reflectivity values of the flying system. Then, using this characterized assembly as a reference to calibrate a different vertical-pointing radar available at site.

Up to now, two cloud radar calibration campaigns have been conducted. An initial calibration campaign was held between 20-24 November 2017 at SIRTA, Palaiseau, France. The follow-up campaign which was carried out in 21- 25 May 2018 at the same location is to further develop the potential calibration techniques for vertical-pointing DCRs. The main objective of these work is to evaluate existing and pioneering techniques for DCR calibration. These techniques make use of the fixed and mobile calibration targets to develop calibration techniques suited for fixed and scanning DCRs.

2. Campaign configuration and basic principle

The recent DCR calibration campaign will be introduced in detail. The following equipment is used in the campaign, as shown in Figure 1.

- (1) A drone and calibrators (sphere and trihedral) provided by TU-Delft and IPSL.
 - a. Square Trihedral Target 1 (ST-D): RCS = 37.8 dBsm. Attached to the UAV.
 - b. Square Trihedral Target 2 (ST-M): RCS = 37.8 dBsm. Attached on top of the 20 m mast.
 - c. 35 cm Diameter Sphere (35-Sph): RCS = -23.4 dBsm
 - d. 18 cm Diameter Sphere (18-Sph): RCS = -36.7 dBsm
- (2) A reference trihedral target provided by IPSL installed on the top of a mast
- (3) Three W-band DCRs

a. BASTA-Mini LATMOS (BML), 95 GHz: BASTA-Mini radar with scanning and frequency tuning capabilities. This radar is already calibrated using a corner reflector mounted on the top of a mast. During the experiment, it will be operated in vertical-pointing direction.

b. RPG U. Granada radar (RPG), 94 GHz: Vertical-pointing radar to be calibrated.

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c. BASTA-Mini Météo-France (BMM)), 95 GHz: BASTA-Mini with scanning capabilities and fixed frequency. It will be located on the top of SIRTA-4, being able to scan the target on the top of a mast (about 20 m in height).



Figure 1: DCR calibration campaign configuration.

Figure 2 summarizes the approach considered for the DCR calibration campaign. It is based on the use of a calibrated radar to retrieve the reflectivity of the UAV + trihedral, and use this ensemble as a valid reference for another vertical-pointing radar calibration (**Hypothesis 3**). Firstly, the BML with scanning capability will be used to retrieve the reflectivity of UAV and UAV + trihedral, to validate the assumption of negligible reflectivity of the UAV compared with that of trihedral (**Hypothesis 1**). Afterward, to ensure that the method can be replicated, both BML and BMM will be used to retrieve the reflectivity of UAV + trihedral. If the result is consistent, then the system can be used to calibrate the vertical-pointing radar. Each value used can and should be retrieved several times (**Hypothesis 2**), as an additional way of assessing the repeatability and uncertainty of the procedure. The detailed preparations are listed as follows:

(1) Time synchronization of radars, GPS box and UAV: UAV flight pattern will incorporate vertical movements of known duration to help to synchronize radar measurements with UAV GPS. At the beginning of each flight, UAV will go to the start position (center of the beam), stay there for 10 seconds, then descend 20 meters for 10 seconds, then return to the start position for another 10 seconds and repeat the descending movement once more. Such movement helps to recognize the starting point of UAV movement.

(2) BML and BMM are configured to point to the trihedral on the top of a mast. This is done to calibrate these scanning radars.

(3) BML and BMM are aimed vertically. In addition, vertical antenna pointing is verified with tools on-site (digital level tool). This should be done before flights.

(4) Aim RPG vertically with tools on-site.

(5) Check that the combination of UAV and trihedral does not saturate RPG radar. If it does, RPG can be calibrated with the UAV using a sphere for RPG. The sphere-based calibration methodology also can be tested on BASTA-radars.

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Figure 2: Conceptual description of the UAV calibration experiment. Each step requires the successful completion of the previous one to be consistent. Orange boxes are actions that must be performed by the team. Yellow boxes are quantitative outputs, which can be retrieved many times to perform statistical and uncertainty analysis. Blue boxes are the sequence in which the hypotheses previously stated have to be evaluated to guarantee the validity of the method. Without hypothesis 1, 2 and 3 validated, it is not advisable to continue with further actions without evaluating the new possible constraints.

3. Measurement analysis

The preliminary results are provided, while further exploitation of the campaign is currently underway.

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(1) Calibration of BML using trihedral on the top of a mast. 6 experiments are used to quantify the calibration constant errors, and the standard deviation is within 1dB, as shown in Figure 3. The result is promising, however, the deeper analysis of radar constant is necessary to narrow the deviation.



Figure 3. Calibration Constant distribution for 6 iterations of the mast calibration experiment. Each iteration corresponds to a fresh installation of the experimental setup.

(2) UAV characterization in DCRs. The calibration experiment uses the UAV as the aerial platform to carry the calibrator flying over DCRs. It is important to quantify the impact of the UAV because its backscattering is mixed with that of the calibrator. To validate the effectiveness of the proposed calibration technique, it is necessary to assess the backscattering contribution of the UAV. Figure 4 displays the backscattered power of UAV only, UAV + trihedral with absorbing material covering the surface (refer to UAV + absorber TTT), and UAV + trihedral (refer to UAV + TTT).



Figure 4. Backscattered power of UAV only, UAV + absorber TTT and UAV + TTT.

The backscattered power of UAV only and UAV + absorber TTT have comparable results, indicating the good isolation performance of the absorbing material. Compared with the power of UAV only, the one of UAV + TTT has a power 20 dB larger, indicating that Hypothesis 1 holds. However, when the maximum backscattered power is used to calculate the radar constant, we get a value of -181.2dB ± 1dB, around 9 dB deviation from the one obtained by trihedral on the top of a mast. Note that such experiments are

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conducted 4 times, and the 1dB offset is obtained by several measurements. More analysis should be done to solve the radar constant inconsistency problem.

(3) Apart from the trihedral assembled underneath the UAV, the calibration experiment which a sphere is connected to UAV by a line (long enough to separate UAV and sphere in different range bins) is also worth exploring. Such an experiment was done last time but due to the influence of strong wind, it did not work. Repeating the same experiment in a better environmental condition was conducted this time. Two sphere-based calibration campaigns are conducted, and the connecting lines are set to 35m and 50m. Figure 5 displays the backscattered power of UAV+ TTT, UAV only, UAV + sphere (connecting line 35m), and UAV + sphere (connecting line 50m).



Figure 5. Backscattered power of UAV+ TTT, UAV only, spheres.

With the connecting line 50m (corresponding to 4 range resolution in the BML configuration), it's still impossible to separate UAV and sphere in different range bins. In addition, the backscattered power of UAV only and UAV + sphere have similar values, indicating the RCS of sphere is negligible compared with that of UAV. This means that some improvement should be done to make such calibration technique feasible, such as prolonging the connecting line or reducing the RCS difference between UAV and sphere.



(4) RPG radar measurements

Figure 6. Backscattered power of UAV + absorber TTT and UAV + TTT.

In addition to the BML radar calibration, one RPG radar was also calibrated during the campaign. In total, we had 7 flights over RPG radar, which covered all the 3 situations: 1) UAV only; 2) UAV + absorber TTT; 3)

ACTRIS (<u>www.actris.eu</u>) is supported by the European Commission under the Horizon 2020 – Research and Innovation Framework Programme, H2020-INFRAIA-2014-2015, Grant Agreement number: 654109 UAV + TTT. However, 5 of 7 flights failed (the failure is defined as the radar stops working and no data are recorded.). One possibility may be the UAV is too close to the RPG radar and the backscattering echo is too large that the radar protects itself by turning off the measurements, which may also be attributed to saturation. We have only one UAV + absorber TTT and one UAV+TTT measurement at hand, and their results are shown in Figure 6. The maximum power from UAV+TTT is 35.9dB, while that of UAV + absorber TTT is 23.5dB. The 12.4dB difference is because of the absorbing material covering the TTT. More analysis is going to conducted and better experiments for future campaigns are now under consideration.

4. Conclusion and outlook

In this report, 3 calibration techniques are developed to calibrate the Doppler cloud radars (DCRs), namely 1) one trihedral is fixed the top of a mast; 2) UAV + trihedral; 3) UAV + sphere. All the techniques can be used for scanning DCRs, while the later 2 techniques are designed specifically for vertical-pointing radars. The preliminary results show the possibility of calibrating the W-band cloud radars using Technique 2, which shows the standard deviation of BML radar constant within 1dB for several measurements from different days. However, the mismatch of the derived radar constant with Technique 1 (around 9dB) is worthwhile exploring. For Technique 3, the backscattering echoes from UAV and sphere are not so obvious in the radar image because of the short connecting lines. In addition, for the RPG radar calibration, we have only one measurement at hand, which makes it difficult to calculate the standard deviation of radar constant. The frequent measurement failures should be explored and solved for the future calibration experiments.

This work is a also conducted in preparation of the Centre for Cloud Remote Sensing of the ACTRIS research infrastructure to be operational in 2025. The procedures described still need further developed, but will be implemented in the standard procedures for quality control and assurance of cloud profiling in ACTRIS.