

# CALIBRATION OF REFLECTIVITY OBSERVATIONS FROM THE WEATHER RADAR NETWORK OF CYPRUS AGAINST GPM DUAL-FREQUENCY PRECIPITATION RADAR

*Eleni Loulli<sup>1,2</sup>, Johannes Bühl<sup>3</sup>, Silas Michaelides<sup>1</sup>, Athanasios Loukas<sup>4</sup>, and Diofantos G. Hadjimitsis<sup>1,2</sup>*

<sup>1</sup> ERATOSTHENES Centre of Excellence, Limassol, Cyprus

<sup>2</sup> Department of Civil Engineering and Geomatics, Cyprus University of Technology, Limassol, Cyprus

<sup>3</sup> Leibniz Institute for Tropospheric Research (TROPOS), Leipzig, Germany

<sup>4</sup> School of Rural and Surveying Engineering, Aristotle University of Thessaloniki, Thessaloniki, Greece

## ABSTRACT

This paper analyses polarimetric weather radar data to explore their potential for comprehensive and reliable precipitation and thus, drought monitoring in Cyprus. Reflectivity measurements from the two ground-based Xband dual-polarization radars of the Department of Meteorology of the Republic of Cyprus are compared with measurements obtained from the Dual-Frequency Precipitation Radar (DPR) onboard NASA's Global Precipitation Measurement (GPM) mission in order to calibrate the ground-based reflectivity. The comparison is done using a volume matching method that allows us to associate the datasets both in space and time. To correct the attenuation, we examine a Z-A relationship approach and the forward gate-by-gate attenuation correction based on an iterative approach with scalable constraints. Preliminary results show a significant underestimation of the groundbased reflectivity, as well as a notable impact of attenuation that leads to a major source of error for rainfall estimation.

**Index Terms**— X-band polarimetric weather radar, GPM DPR Ku-band, volume matching, attenuation correction

## 1. INTRODUCTION

Cyprus is characterized by a semi-arid climate and faces frequent and extensive droughts that have negative impacts on agricultural production, the ecosystem, and the economy [1]–[3]. Existing research on drought events in Cyprus relies on in-situ data, mainly temperature and precipitation measurements at meteorological stations, and water levels at the main reservoirs [4]–[6].

Polarimetric weather radars can provide a range of additional information on precipitation-generating processes and can improve quantitative precipitation

estimation [7]. This paper analyzes a 6-year dataset of polarimetric measurements from the two X-band dual-polarization radars of the Department of Meteorology of the Republic of Cyprus to explore this research opportunity.

## 2. DATA

Ground radars and satellite precipitation radars measure reflectivity in three dimensions and can thus be used for direct comparison of such observations [8] [9].

This study uses reflectivity measurements from the DualFrequency Precipitation Radar (DPR) onboard NASA's Global Precipitation Measurement (GPM) mission to calibrate the two X-band dual-polarization radars of the Department of Meteorology of the Republic of Cyprus. GPM is constantly validated with a consistent calibration accuracy of 1 dB [10] and has been suggested by several authors as a reasonable reference for the calibration of ground-based radars [9], [11], [12].

We exploit the Ku-band of the DPR, which has a spatial resolution of 5 km, 245 km swath width and 125 m vertical resolution. The ground-based radars are located in Rizoelia, Larnaca district (LCA), and Nata, Paphos district (PFO), providing a full coverage of the island. Their scanning strategy includes eight (8) different plan position indicator (PPI) with elevation angles between 0.5° and 30°. Their azimuthal resolution is 1° and their maximum range is 150 km and 250km, for October 2017 to September 2020 and October 2020 to September 2023, respectively. Since we do not have any engineering records considering radar calibration and maintenance, the range change is important to note. We consider this change in the analysis of our results, as it depicts a radar maintenance that might have led to radar calibration changes.

### 3. METHODOLOGY

To compare and calibrate the reflectivity measurements of the satellite- and ground-based radars, they must be associated in both space and time. To spatially associate the datasets, we follow the volume matching method (VMM) of [13] as modified by [9]. The VMM averages the reflectivities from the ground and satellite-based radars at the positions where the satellite radar beam intersects with the ground radar

979-8-3503-6032-5/24/\$31.00 ©2024 IEEE  
 elevation sweeps. Satellite radar reflectivities are vertically averaged along the beam, whereas ground radar reflectivities are horizontally averaged along the range-azimuth plane and within the satellite radar footprint. To reduce the standard deviation of the reflectivity difference ( $\Delta Z$ ) distribution and improve the statistical agreement between the ground-based radars and GPM, we apply the iterative procedure that was suggested by [14] and as applied by [15]. The methodology is applied separately to LCA and PFO measurements with and without attenuation correction. The total number of matched datasets (matchups) was 47 and 51 for LCA and PFO, respectively.

In the case of attenuation correction, we compare the method applied in [15] that uses a Z-A relationship derived from Tmatrix calculations, with the forward gate-by-gate attenuation correction based on the iterative approach of [16] and [17]. The latter is developed using the Open Source Software *wradlib* and combines different constraints (i.e. constraints for maximum corrected reflectivity and maximum path integrated attenuation PIA) and their corresponding threshold values. Comparing with the satellite data, we follow an iterative approach throughout the 6-year time series in order to decide which constraints lead to an acceptable tradeoff between attenuation correction and robustness (Figure 1).

Figure 1 Methodology for the set of constraints for attenuation correction

### 4. PRELIMINARY RESULTS

Preliminary results of reflectivity comparison without attenuation correction at LCA show a mean offset of -15.96 dB for the range of 150 km and -14.06 dB for the range of 250 km (Figure 2). Considering PFO, the reflectivity comparison without attenuation correction results in a mean offset of -16.17 dB for the range of 150 km and -9 dB for the range of 250 km (Figure 3) for LCA and PFO respectively.

The reflectivity attenuation correction using the Z-A relationship as applied in [15] with an initial set of constraints shows an impact on the final offset estimation (Figure 4 and Figure 5). This set of constraints results in a slightly higher mean standard deviation of the reflectivity difference ( $\Delta Z$ ) distribution. It is anticipated that the examination of further sets of constraints using the forward gate-by-gate attenuation correction method will result in a more suitable attenuation correction for the weather radar

IGARSS 2024

network of Cyprus.

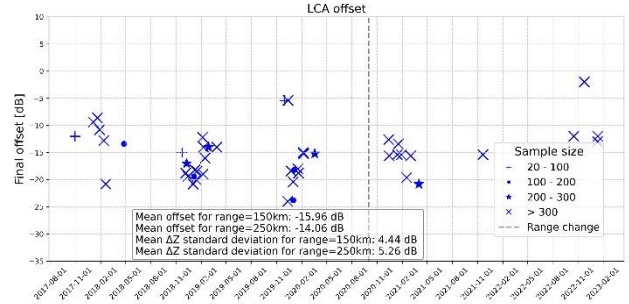


Figure 2 LCA offset without attenuation correction

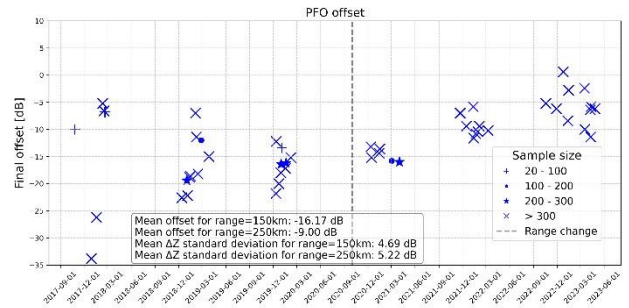


Figure 3 PFO offset without attenuation correction

Figure 4 LCA offset with attenuation correction

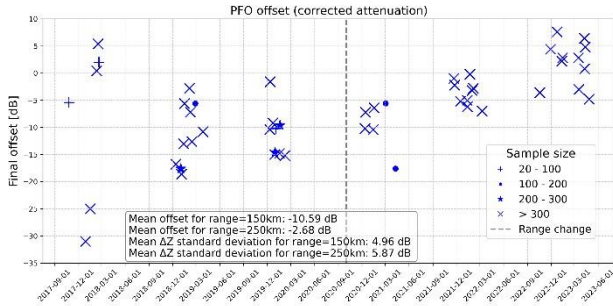


Figure 5 PFO offset with attenuation correction

## 5. FUTURE WORK

Future work includes the exploitation of the simulation measurements at the two ground radars to overcome the attenuation inaccuracies, and the investigation of methods that use specific attenuation to retrieve rainfall rates at the ground-based radars [18], [19]. The rainfall retrieval methods will be evaluated against satellite-based rainfall rates, as well as measurements at rain gauges. The overall outcome is expected to become an accurate and reliable dataset that will contribute to the development of an automated method for the estimation of the precipitation budget over the area of Cyprus.

## 6. ACKNOWLEDGEMENTS

The authors acknowledge the ‘EXCELSIOR’: ERATOSTHENES: EXcellence Research Centre for Earth Surveillance and Space-Based Monitoring of the Environment H2020 Widespread Teaming project (www.excelsior2020.eu). The ‘EXCELSIOR’ project has received funding from the European Union’s Horizon 2020 research and innovation programme under Grant Agreement No 857510, from the Government of the Republic of Cyprus through the Directorate General for the European Programmes, Coordination and Development and the Cyprus University of Technology.

The authors acknowledge also the Department of Meteorology of the Republic of Cyprus for the provision of the XBAND radar datasets.

## 7. REFERENCES

- [1] M. P. Papadopoulou *et al.*, “Agricultural water vulnerability under climate change in Cyprus,” *Atmosphere (Basel)*, vol. 11, no. 6, Jun. 2020, doi: 10.3390/atmos11060648.
- [2] M. Markou, C. A. Moraiti, A. Stylianou, and G. Papadavid, “Addressing climate change impacts on agriculture: Adaptation measures for six crops in Cyprus,” *Atmosphere (Basel)*, vol. 11, no. 5, May 2020, doi: 10.3390/ATMOS11050483.
- [3] T. Krauss, C. Mettas, J. Kountouri, C. F. Panagiotou, A. V. Argyriou, and E. Evagorou, “Creating a strong rain danger map for Cyprus,” *SPIE-Intl Soc Optical Eng*, Sep. 2023, p. 32. doi: 10.1117/12.2681731.
- [4] S. Michaelides and S. Pashiardis, “Monitoring Drought in Cyprus during the 2007-2008 Hydrometeorological Year by using the Standardized Precipitation Index (SPI),” 2008.
- [5] S. Pashiardis and S. Michaelides, “Implementation of the Standardized Precipitation Index (SPI) and the Reconnaissance Drought Index (RDI) for Regional Drought Assessment: A case study for Cyprus,” 2008.
- [6] G. Zittis, A. Bruggeman, C. Camera, P. Hadjinicolaou, and J. Lelieveld, “The added value of convection permitting simulations of extreme precipitation events over the eastern Mediterranean,” *Atmos Res*, vol. 191, pp. 20–33, Jul. 2017, doi: 10.1016/j.atmosres.2017.03.002.
- [7] V. Pejčić, J. Soderholm, K. Mühlbauer, V. Louf, and S. Trömel, “Five years calibrated observations from the University of Bonn X-band weather radar (BoXPoL),” *Sci Data*, vol. 9, no. 1, Dec. 2022, doi: 10.1038/s41597-022-01656-0.
- [8] E. N. Anagnostou, C. A. Morales, and T. Dinku, “The use of TRMM precipitation radar observations in determining ground radar calibration biases,” *J Atmos Ocean Technol*, vol. 18, no. 4, pp. 616–628, 2001, doi: 10.1175/1520-0426(2001)018<0616:TUOTPR>2.0.CO;2.
- [9] R. A. Warren *et al.*, “Calibrating ground-based radars against TRMM and GPM,” *J Atmos Ocean Technol*, vol. 35, no. 2, pp. 323–346, Feb. 2018, doi: 10.1175/JTECH-D-17-0128.1.
- [10] K. Toyoshima, H. Masunaga, and F. A. Furuzawa, “Early Evaluation of Ku- and Ka-Band Sensitivities for the Global Precipitation Measurement (GPM) Dual-Frequency Precipitation Radar (DPR),” *SOLA*, vol. 11, no. 0, pp. 14–17, 2015, doi: 10.2151/sola.2015-004.
- [11] V. Pejčić, P. S. Garfias, K. Mühlbauer, S. Trömel, and C. Simmer, “Comparison between precipitation estimates of ground-based weather radar composites and GPM’s DPR rainfall product over Germany,” *Meteorologische Zeitschrift*, vol. 29, no. 6, pp. 451–466, Nov. 2020, doi: 10.1127/METZ/2020/1039.
- [12] S. L. Durden, “Relating GPM Radar Reflectivity Profile Characteristics to Path-Integrated Attenuation,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 56, no. 7, pp. 4065–4074, Jul. 2018, doi: 10.1109/TGRS.2018.2821601.
- [13] M. R. Schwaller and K. Robert Morris, “A ground validation network for the global precipitation

measurement mission,” *J Atmos Ocean Technol*, vol. 28, no. 3, pp. 301–319, Mar. 2011, doi: 10.1175/2010JTECHA1403.1.

- [14] A. Protat, D. Bouniol, E. J. O’Connor, H. K. Baltink, J. Verlinde, and K. Widener, “CloudSat as a global radar calibrator,” *J Atmos Ocean Technol*, vol. 28, no. 3, pp. 445–452, Mar. 2011, doi: 10.1175/2010JTECHA1443.1.
- [15] V. Louf *et al.*, “An integrated approach to weather radar calibration and monitoring using ground clutter and satellite comparisons,” *J Atmos Ocean Technol*, vol. 36, no. 1, pp. 17–39, Jan. 2019, doi: 10.1175/JTECH-D-18-0007.1.
- [16] S. Jacobi and M. Heistermann, “Benchmarking attenuation correction procedures for six years of single-polarized C-band weather radar observations in South-West Germany,” *Geomatics, Natural Hazards and Risk*, vol. 7, no. 6, pp. 1785–1799, Nov. 2016, doi: 10.1080/19475705.2016.1155080.
- [17] S. Krämer and H.-R. Verworn, “Improved radar data processing algorithms for quantitative rainfall estimation in real time,” *Water Science and Technology*, vol. 60, no. 1, pp. 175–184, Jul. 2009, doi: 10.2166/wst.2009.282.
- [18] M. Diederich, A. Ryzhkov, C. Simmer, P. Zhang, and S. Trömel, “Use of specific attenuation for rainfall measurement at X-band radar wavelengths. Part II: Rainfall estimates and comparison with rain gauges,” *J Hydrometeorol*, vol. 16, no. 2, pp. 503–516, 2015, doi: 10.1175/JHM-D-14-0067.1.
- [19] L. Feng *et al.*, “Rain attenuation correction of reflectivity for X-band dual-polarization radar,” *Atmosphere (Basel)*, vol. 7, no. 12, 2016, doi: 10.3390/atmos7120164.