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Investigation of rain induced depolarization by means of a physically based simulator

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Abstract

A physically based simulator is applied in this work to investigate the depolarization induced by rain along Earth-space links, and specifically to shed light on the impact of different precipitation types (stratiform/convective) and of the axial ratio selected to model the drop oblateness. To this aim, we employ rain maps derived from an S-band weather radar as input to the simulator. Results indicate that the Cross Polar Discrimination (XPD) depends more on the drop axial ratio than on the type of precipitation event, and, more in general, they give a hint of the usefulness of the proposed simulator to isolate and investigate the contribution of the different atmospheric constituents to the overall XPD.

1. Introduction

Depolarization is one of the detrimental effects induced by rain on Earth-to-satellite links operating at frequencies above the 10 GHz, especially when considering systems aiming to increase the link capacity by simultaneously exploiting two orthogonal polarizations. Depolarization occurs when an electromagnetic wave crosses the troposphere in presence of rain drops and/or ice particles, due to their anisotropy [1]. The few depolarization data available show quite a marked spread in the Co-Polar Attenuation – Cross Polar Discrimination (CPA-XPD) plane [1], which existing models can hardly catch. A simulator has been under development at Politecnico di Milano, aiming at clarifying the contribution of different constituents (rain, melting layer, ice clouds) on the overall XPD [2]. Prior contributions have shown the preliminarily application of the simulator using as input synthetic rain cells [3]. This paper extends the investigation of rain induced depolarization by providing as input to the simulator a much more realistic meteorological environment, which is extracted from a large set of weather radar derived rain maps [4].

2. XPD model and meteorological input

2.1 The XPD simulator

The depolarization simulator has been already described in [2-3], to which the reader is addressed for more details. We report here a brief summary to point out its main features. While in [2-3] a synthetic rain layer was generated based on single exponentially shaped rain cells, in this contribution, we have used as input to the simulator real rain events derived from the research weather radar installed at Spino d'Adda experimental station. Such maps provide the rain rate at ground level, while the rain height is assumed to coincide with mean 0 °C level of the local site of interest.

The simulator allows to characterize the hydrometeor population in terms of particle size distribution, shape, axial ratio, water temperature and falling velocity, which is assumed to be constant up to the top rain layer. Knowing the link configuration, i.e. frequency and elevation angle, scattering coefficients are calculated using the T-matrix method [5] from which, in turn, the specific propagation constants (attenuation and propagation) are obtained as a function of the rain rate for each pixel of the map crossing the link. Afterwards, overall rain induced attenuation and phase rotation are obtained by integrating the effects along the whole Earth-to-satellite link.

2.2 The NPC database

The events analyzed in this work belong to the NPC (Nastri Pioggia Cartesianizzata) database, a collection of rain events affecting the Padana Valley, recorded between 1988 and 1992 by means of the research weather radar installed at Spino d'Adda experimental station. The ensemble of the radar derived maps were proven to be statistically representative of the rainfall process of the region [6]. Rain maps consist of 160×160 pixels, each of which has 0.5 km×0.5 km spatial resolution (coverage area = 80 km×80 km around Spino d'Adda).

Among all, we have selected two opposite rain events: a stratiform one, collected in winter (January), and a convective one, recorded during the summer (August).

2.3 Modelling assumptions

All the computations are performed for circularly polarized waves. The link operation has been tuned to the frequency of 49.5 GHz, with an elevation angle of 37.7 deg., according to the ITALSAT experiment [1].

The rain heights ($h_{R,Jan}$ = 1.928 km and $h_{R,Aug}$ = 3.975 km) are set to coincide with the mean monthly 0 °C isotherm height as derived from the ERA-40 database [7].

The drop size distribution has been derived from the Marshall and Palmer relation, an assumption typically considered to be valid in temperate regions [8], and, moreover, it has been assumed not to vary throughout the whole rain map (Longitudinal Homogeneity Medium [1]). Oblate spheroids are particularly suited to represent raindrops [9,10] and they have been chosen in the simulations. Their axial ratios have been set to the diameter dependent relations present in literature [9-12], which are the result of theoretical investigations and experimental observations. Finally, all hydrometeors are supposed to lie along the vertical direction (Principal Planes Model [1]).
Table 1 summarizes the assumptions made in the simulations.

Table 1. Parameters used in the simulations.

PARAMETER	SETTING
0 °C isotherm height	1.928 km (stratiform) 3.975 km (convective)
Particle Size Distribution	Marshall and Palmer
Axial ratio	See Figure 3
Frequency	49.5 GHz
Elevation angle	37.7 °
Polarization	Circular

4. Investigation of rain induced depolarization

4.1 Stratiform rain event

The first event consists of 342 maps of stratiform rain collected on the 20th January of 1992. A sample map is reported in Figure 1. This kind of rain presents a large coverage in the radar observation area, whereas the rain intensity is quite limited and is characterized by a limited spatial variability.

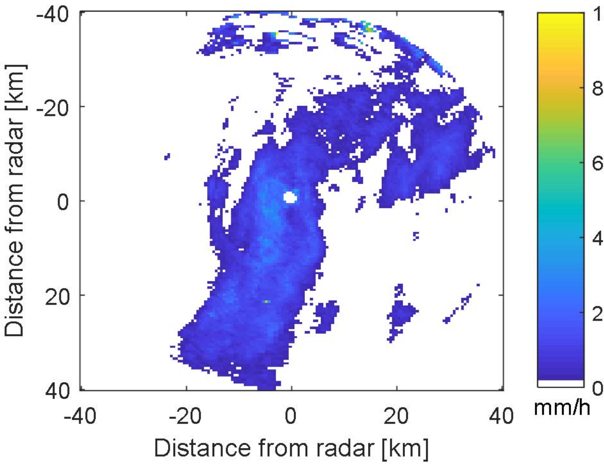

Figure 1. A snapshot of the rainfall rate during the stratiform event.

4.2 Convective rain event

The second event consists of 408 maps of convective precipitation collected on the 22nd August of 1988: a snapshot is provided in Figure 2. Note the differences with respect to the previous map: the rain is locally very intense and is no longer widespread, but concentrated over small regions.

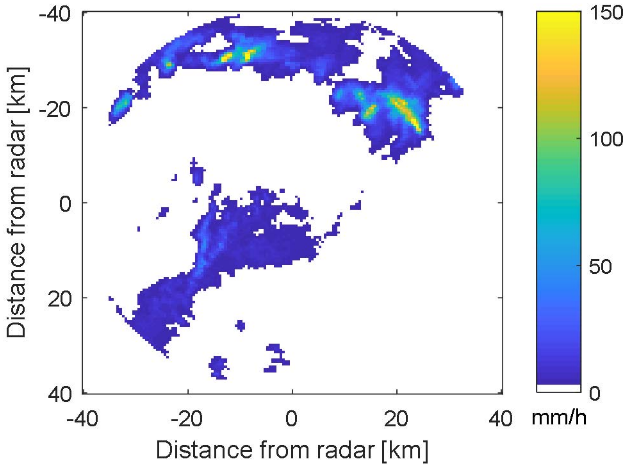

Figure 2. A snapshot of the rainfall rate during the convective event.

5. Discussion of the results

The resulting CPA-XPD scatterplot for the first event is reported in Figure 3 (all maps included): each point corresponds to a different position of the ground station across the whole map. The model included in recommendation ITU-R P. 618-13 is also shown in the picture as reference [13].

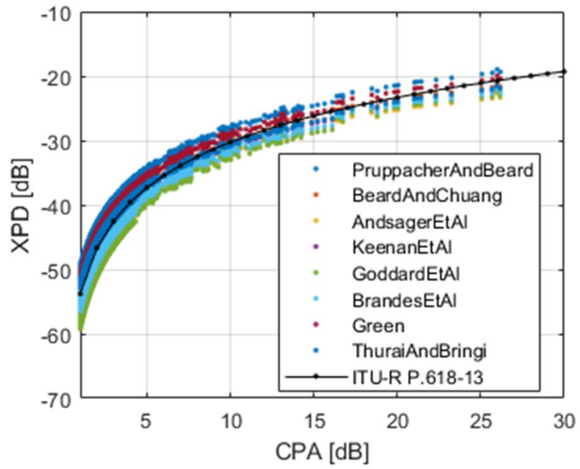

Figure 3. CPA-XPD scatterplot for the stratiform rain event, for different drop axial ratios.

The contribution of the event rain maps is limited: each colored cloud of points represents the simulator output for the specific axial ratio. We observe that all the points for a given axial ratio selection lie along a common strip not wider than 2-3 dB.

The results for the second event are aligned with those obtained from the stratiform event, which indicate that changing the rain event type (and the rain height) does not have a significant impact on the overall XPD variability. This is confirmed by the direct comparison of the stratiform and the convective event in Figure 4, which shows that the points lie on a common strip of possible values, for the same axial ratio. On the other hand, the convective precipitation, as expected, causes higher XPD values, as well as higher CPA values.

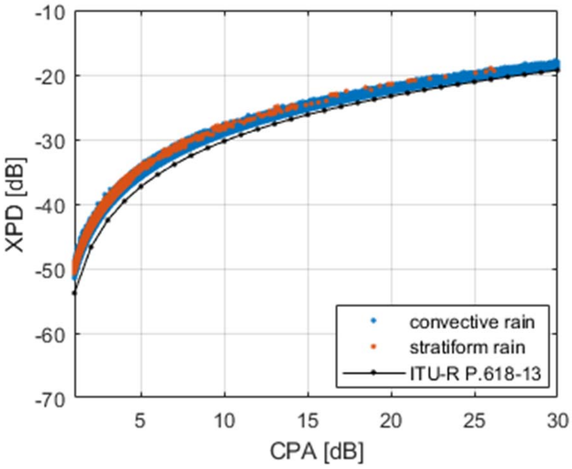

Figure 4. CPA-XPD scatterplot comparison of the stratiform (red) and convective (blue) rain event; Pruppacher and Beard axial ratio

6. Conclusions

This contribution investigates the depolarization induced by rain along Earth-to-space links through a physically based simulator which is currently under development at Politecnico di Milano. Results indicate the impact on XPD of different rain types (stratiform/convective) is rather limited, while a higher variability is found as a function of the axial ratio used to model the drop oblateness. These results are only some of the possible outcomes of the XPD simulator, which will be employed to isolate and investigate more in depth the contribution of the different atmospheric constituents to the overall XPD. To this aim, a more complete environment will be provided as input to the simulator [14], to assess also the impact on the XPD of the melting layer [15] and of ice clouds [16], and, in addition, more complex assumptions will be introduced (e.g. drop vibration, drop canting angle, drop size distribution parameters as a function of the rain rate, …) to provide an even more realistic physical characterization of the rain layer.

7. References

1. A. Paraboni, A. Martellucci, C. Capsoni and C. Riva, “The Physical Basis of Atmospheric Depolarization in Slant Paths in the V Band: Theory, Italsat Experiment and Models” *IEEE Transactions on Antennas and Propagation,* **59,** 11, August 2011, pp. 4301-4314, doi:10.1109/TAP.2011.2164207.

2. E. Regonesi, C. Capsoni and C. Riva, “Radio wave depolarization simulator based on the SC EXCELL model” *Antennas and Propagation (EuCAP), 10th European Conference on*, April 2016, pp. 1-3, doi:10.1109/EuCAP.2016.7481245.

3. E. Regonesi, C. Capsoni, R. Nebuloni, C. Riva and L. Luini, “Decrypting XPD-CPA beacon measurements through a physical simulator” *Antennas and Propagation (EuCAP), 11th European Conference on*, March 2017, pp. 3542-3545, doi:10.23919/EuCAP.2017.7928327.

4. L. Luini and C. Capsoni, “MultiEXCELL: a new rain field model for propagation applications”, *IEEE Transactions on Antennas and Propagation*, **59**, 11, 2011, pp. 4286-4300, doi:10.1109/TAP.2011.2164175.

5. M. I. Mishchecko, “Calculation of the amplitude matrix for a nonspehrical particle in a fixed orientation”, *Applied optics*, **39**, 6, February 2000, pp. 1026-1031, doi:10.1364/AO.39.001026.

6. C. Capsoni, M. D’Amico and P. Locatelli, “Statistical properties of rain cells in the Padana Valley”, *Journal of Atmospheric and Oceanic Technology*, **25**, 12, December 2008, pp. 2230-2244, doi:10.1175/2008JTECHA1130.1.

7. S. M. Uppala et al., “The ERA-40 re-analysis” *Quarterly Journal of the Royal Meteorological Society*, **131**, October 2005, pp. 2961–3012, doi:10.1256/qj.04.176.

8. A. Pawlina and M. Binaghi, “Radar rain intensity fields at ground level: New parameters for propagation impairments prediction in temperate regions”, *Proceeding of the 7th URSI Commission F Open Symphosium on Wave Propagation and Remote Sensing*, 1995, pp. 217-220.

9. A. W. Green, “An approximation for the shapes of large raindrops”, *Journal of Applied Meteorology*, **14**, 8, December 1975, pp. 1578-1583, doi:10.1175/1520-0450(1975)014<1578:AAFTSO>2.0.CO;2.

10. H. R. Pruppacher and R. L. Pitter, “A semi-empirical determination of the shape of cloud and rain drops”, *Journal of the atmospheric sciences*, **28**, 1, January 1971, pp. 86-94, doi:10.1175/1520-0469(1971)028<0086:ASEDOT>2.0.CO;2.

11. E. Gorgucci, L. Baldini and V. Chandrasekar, “What is the shape of a raindrop? An answer from radar measurements”, *Journal of the atmospheric sciences*, **63**, 11, November 2006, pp. 3033-3044, doi:10.1175/JAS3781.1.

12. M. Thurai and V. N. Bringi, “Drop Axis Ratios from a 2D Video Disdrometer”, *Journal of Atmospheric and Oceanic Technology*, **22,** 7, July 2005, pp. 966-978, doi:10.1175/JTECH1767.1.

13. “Propagation data and prediction methods required for the design of earth-space telecommunication systems”, ITU-R P.618-13, 2017.

14. L. Luini, “A Comprehensive Methodology to Assess Tropospheric Fade Affecting Earth–Space Communication Systems”, *IEEE Transactions on Antennas and Propagation*, **65**, 7, July 2017, pp. 3654-3663, doi:10.1109/TAP.2017.2700883.

15. M. M. G. D’Amico, A. R. Holt and C. Capsoni, “An anisotropic model of the melting layer”, *Radio Science*, **33**, 3, May-June 1998, pp. 535–552, doi:10.1029/97RS03049.

16. L. Luini and A. Quadri, “Investigation and Modeling of Ice Clouds Affecting Earth-space Communication Systems”, *IEEE Transactions on Antennas and Propagation*, **66**, 1, January 2018, pp. 360-367, doi:10.1109/TAP.2017.2772839.