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Impact of RFI on C-Band weather radars and techniques for detection, prediction and mitigation

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Weather radars are essential components for understanding and predicting weather, however, their performance is increasingly compromised by radio frequency interference (RFI) from a variety of sources. This interference can significantly degrade the quality of radar products, affecting data accuracy and the reliability of weather forecasts. In this paper, a review of the impact of RFI on C-Band weather radars is presented, exploring its prejudicial effects and current techniques for its detection and prediction. The challenges associated with RFI mitigation and the need to develop innovative solutions to ensure the continued reliable operation of these critical systems are discussed.

Keywords: Weather Radar, C-Band, radio frequency interference, RFI, RFI detection, RFI prediction, RFI mitigation, ghost echoes, loss of sensitivity, degradation of radar product quality, spectrum monitoring, pattern analysis, prediction models

Radio Frequency Interference Conference (RFI2024)
14-18 October 2024
Bariloche, Argentina

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PoS(RFI2024)060

1. RFI effects on C-Band weather radars:

Appearance of ghost echoes: False echoes are generated in radar images, making it difficult to distinguish between real precipitation and interference signals. [1–5].

Loss of sensitivity: Reduces radar sensitivity, limiting the detection of weather events [1].

Degradation of product quality: Introduces noise and distortion into radar images, making them difficult to interpret and analyze [1] [2] [6].

2. Some approaches to RFI detection and prediction:

Spectrum monitoring: Allows identification of sources of interference and their location. National regulatory entities have systems and mechanisms for constant monitoring, for example, the *Sistema Nacional de Comprobación Técnica de Emisiones* (SNCTE) in Argentina, made up of 6 technical verification centers, 20 remote stations, and 24 mobile units [7].

Pattern analysis: Analysis of radar echo patterns can reveal the presence of RFI, as interfering echoes often exhibit distinctive characteristics. Based on this information, filtering and digital signal processing techniques can be applied [1]. In [4], an RFI detection algorithm is presented that combines the measurement of normalized standard deviation of received power (STD) and signal quality index (SQI) to identify the presence of RFI interference in radar signals. This algorithm is implemented using a simple hardware setup, called "RHunt" (short for RLAN Hunter), consisting of a commercial WiFi receiver connected to a Raspberry Pi. This device is permanently connected to the radar receiver chain, allowing continuous monitoring for the presence of RFI. A high STD value indicates an abrupt change in the received power, which, based on pattern analysis, can be associated with the presence of external interference sources. However, the algorithm is not limited to measuring STD, but also considers the SQI value. The combination of high STD and low SQI is identified as a reliable indicator of external WiFi interference. Other approaches are based on studying the effect of RFI on Doppler velocity [8]; Synchronization and detection of OFDM frames IEEE 802.11/802.11a to obtain MAC sublayer information [9, 10]; identification of signals under the IEE 802.11a standard by locating the preamble of each frame [11].

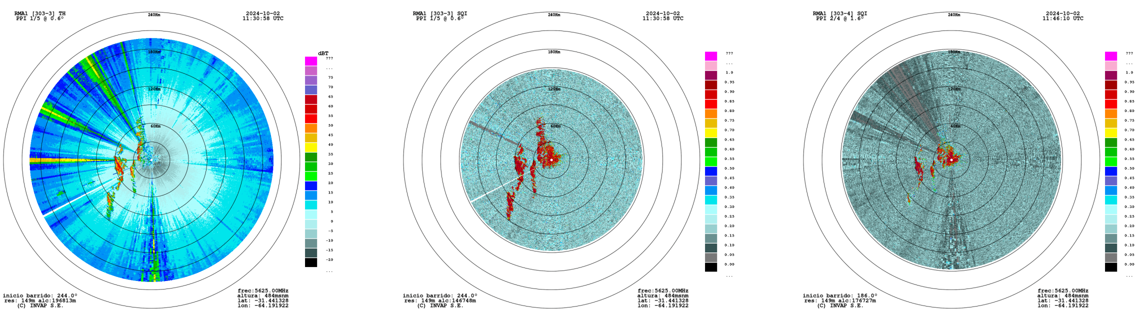
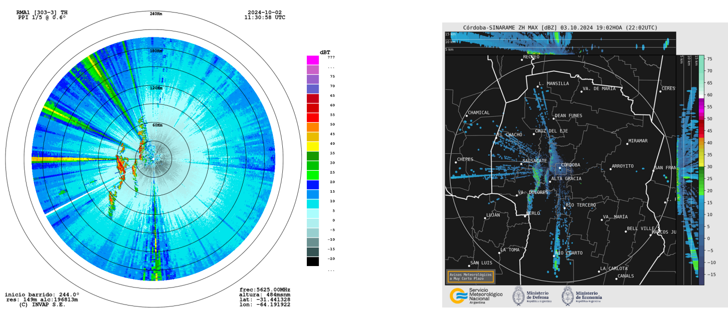


Figure 1: **(a)** Uncorrected reflectivity [dBT] **(b)** and **(c)** Low SQI directly linked to RFI detected at various azimuth and elevation angles.

Prediction models: RFI prediction models leverage historical data and trend analysis to estimate the probability and intensity of interference in the future, enabling better preparedness and information management. In 2021, the National Meteorological Service of Argentina (SMN) developed an RFI prediction model, analyzing two years of data from the *SINARAME* network (National System of Argentine Meteorological Radars) [12]. This analysis allowed for the statistical characterization of radar sites, identifying patterns and trends of interference. Other models focus on quantifying the effect that RFI has on the estimation of meteorological products [13].

Adaptive cancellation: It involves identifying and canceling specific RFI signals using mathematical models. UIT-R S.734 [14] studies different examples of adaptive cancellation, which are based on the principle of generating an "anti-interference" signal that is identical to the RFI signal but with inverted phase. When this anti-interference signal is added to the received signal, they cancel each other out, eliminating the interference and allowing the desired signal to be recovered. This recommendation [14] reviews the application of these cancellation methods at the baseband, intermediate frequency (IF), and with adaptive filters, specifically applied to Fixed Satellite Service. At the time of the review, while a high level of effectiveness was demonstrated, the limitations in technological development suggested certain complexities and high costs. Currently, the rapid advancement of microprocessors, DSPs, FPGAs, and GPUs allows for the implementation of complex algorithms capable of providing systems with adaptation and environmental tracking capabilities [15]. In the specific case of weather radars, [5] implemented four clutter filtering algorithms for both simulated and real data from the regions of Córdoba and Bariloche; concluding that the adaptive filters presented better estimates with less bias and variance, in addition to having the ability to recover the eliminated samples of the phenomenon.

Digital filtering: Its purpose is to eliminate narrowband or broadband RFI signals through digital filters by employing image processing techniques. The National Meteorological Service in Argentina (SMN) has been collaborating with university researchers and working closely with INVAP S.E. on the development of algorithms to filter pixels affected by non-meteorological echo sources [6]. Essentially, this involves the sequential application of filters that allow for the correction and/or removal of radar pixels associated with reflectivity, maintaining a trade-off relationship (data of interest vs. quality) in the threshold values of each filter's parameters, this approach preserves meteorologically significant reflectivity data while discarding pixels that are heavily compromised due to interference [16]. The implemented filters included: Electromagnetic interference filter, Echo top, Co-Polar correlation coefficient, Isolated echoes, Topographic blockage, Attenuation, and Missing reflectivity [6][16]; details of their operational implementation are discussed in [17]. Additionally, optimizations, improvements, and new filters have been applied [18].



(a) Uncorrected reflectivity [dBT] **(b)** RFI filter ON

Figure 2: Assessment of RFI mitigation using reflectivity measurements

3. Challenges and Future Solutions:

The mitigation of *Radio Frequency Interference* (RFI) in C-band weather radars remains a complex challenge due to the dynamic nature and diversity of interference sources. Innovative solutions are needed that combine advanced detection and prediction techniques with robust signal processing algorithms to ensure the reliable operation of these critical systems. Organizations, agencies, and regulatory bodies worldwide are evaluating the technical aspects, challenges, and possible solutions for the coexistence of weather radars with other technologies. The *European Commission's Joint Research Centre* (EC DG JRC) has initiated a comprehensive study on this topic, presenting preliminary conclusions that qualitatively assess potential options to mitigate the coexistence issue [19]. To determine the feasibility of the proposed solutions, key metrics have been established covering technical, organizational, and economic aspects: technical complexity, organizational complexity, implementation costs, deployment costs, risk of ineffectiveness, and the potential risk that the proposed option may create other unplanned issues. Additionally, the *International Telecommunication Union* (ITU) has reviewed various technical and operational aspects, as well as the principal RFI issues, raising the need to establish protection criteria with the establishment of acceptable minimum threshold values and reference points [20]. Meticulous evaluation of the available options, considering the established key metrics, will allow identifying the most suitable solutions to guarantee the reliable operation of these systems and ensure an interference-free future. New RFI detection and prediction techniques, as well as more robust signal processing algorithms are being explored to improve the effectiveness of mitigation solutions [8]. Collaboration between organizations and entities from different countries is essential to share knowledge, experiences, and resources in the search for effective solutions to the RFI problem. It is necessary to update regulations and standards to guarantee the protection of the electromagnetic spectrum and the harmonious coexistence of weather radars with other technologies. Together, these efforts will ensure that C-band weather radars continue to play a fundamental role in protecting the population, providing accurate and timely information for weather forecasting and critical decision-making.

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