Weather radar systems and techniques at different frequencies and polarizations for quantitative precipitation estimation and severe weather monitoring

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Scanning weather radars for severe weather monitoring and quantitative measurements of precipitation have been designed, over five decades, for different frequencies from S to X band and different polarization schemes. The choice of system frequency is determined by a combination of precipitation physics, application priorities, engineering requirements, and often historical precedence and sometimes economics. In fact, aspects like attenuation effects, maximum range of measurements, sensitivity, size of the antenna, and the overall cost of the system are closely related to the radar operating frequency and polarization choices. Radars at S- and C-band at horizontal polarization are used extensively as part of networks of national weather services for long range coverage observations obtained through radar scans at quasi-horizontal elevations. The S-band frequencies (2.700-2.900 GHz), adopted by the NEXRAD network in the US, are mostly not affected by attenuation resulting from precipitation. Exceptions are regions of wet hail or intense squall lines aligned along a radar radial. They are typically expensive, both in terms of purchasing, installation, and maintenance cost, mostly because of the large antennas needed to achieve narrow beams (typically 1-deg beamwidth) and high-power transmitters to cover large areas with high space resolution. The C band (usually 5.600-5.650 GHz) is in general preferred for use in Europe and Canada, representing a good compromise between sensitivity, impact of attenuation and cost of the system, the latter resulting from both lower transmit power and smaller antennas in comparison with S-band systems with the same spatial resolution. X-band frequencies (9.300-9.500 GHz) are adopted because they allow building more sensitive and inexpensive systems (often they are also transportable) but, experiencing higher attenuation, they were originally limited to target short range applications. Conventional, single polarization radars typically adopt a pulsed transmission scheme and the horizontal polarization. Dual-polarization weather radars were introduced by early 1980s.The, dual polarization radars transmit and receive horizontal and vertical polarizations, providing essentially a set of elements of the dual-polarization covariance matrix of precipitation. After two decades of experiments carried out at several research installations, since year 2000 most of weather services have started (or have mostly accomplished) plans to upgrade their radars to dual-polarization to achieve more reliable precipitation estimation and hydrometeor classification. Single and dual polarization share Doppler measurements and reflectivity at horizontal polarization, while other radar variables based both on backscattering and propagation properties, are available for dual polarization radars. Actually, dual polarization techniques have allowed to mitigate the impact of attenuation on radar measurements based on return powers at C- and X- band, whereas advance in processing of differential phase shift to determine robust estimation of its derivative (namely, the specific differential phase shift) which is nearly linearly related to rainfall rate, has determined improvement in obtaining robust quantitative precipitation estimation. Radar networks based on expensive, long-distance radars have been built based on optimizing the number of radar by minimizing region of overlapping. To achieve this goal, density of radar is coarse. Recently, dense networks of small, low cost X-band dual-polarization radars have been pursued by the CASA (Collaborative Adaptive Sensing of the Atmosphere) engineering center. Inexpensiveness of small X-radar systems makes affordable redundancy of radars. On one hand, redundancy has allowed to improve the availability of data in case of heavy precipitation determining high attenuation, and on the other, it has pointed out the benefit of making radars of the network to sense precipitation closer to the ground, avoiding the impact of Earth curvature on systems conceived for long-distance measurements, such as NEXRAD-like S-band systems, that at far distances and with relatively small angles, can miss precipitation.

To plan radar networks, or to study emerging, non conventional, radar applications, it is convenient to build the design process upon extensive data sets of observations available at different bands. Theoretical modeling allowing to build realistic scenarios at target frequencies based on existing datasets (typically at S and C- band) can be conveniently used to define relevant parameters of the new system and to a priori verify its suitability with respect to the goals of target operational applications. This paper provides a comparative study of different scales of networks, and questions and analyzes traditional paradigm such as what polarization and which frequency for different deployments.