

First experiences of operational use of a dual-polarisation weather radar in Finland

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Abstract

Many national weather services are taking dual-polarization radars in operational use, after three decades of use in research. In Finland, two systems are already running operationally, and the data are integrated as part of the national weather service infrastructure. This gives new possibilities for applications, but also sets new demands for measurement design. Our solution has been to alternate measurements optimized for dual-polarization with another set of measurements optimized for the best quality of Doppler velocity data. This paper describes the design of the new measurement schedule. Our experience after the first year of usage is illustrated with case studies in weather situations typical for Finnish climate.

Configuring the measurements of the dual-polarization radar differs from the conventional radars. In the present type of signal processors used by FMI, time-domain processing has to be used for dual-polarization parameters. Thus, velocity de-aliasing with random phase and the most advanced clutter-cancellation methods are not available for this mode.

The FMI radar network consists of eight C-band Doppler radars, installed 1993-2005. The three oldest ones of these radars have been upgraded during years 2009-2010, and the new equipment is capable for dual-polarization measurements.

This paper describes design and implementation of the new measurements for the dual-polarization radars, what are the needs and commitments guiding the design, and finally, what kind of information we get from the atmosphere using these measurements.

The Finnish radar data are used in general weather analysis, weather services for aviation, road maintenance and media, as well as in some hydrological and NWP applications. The users' needs are different and sometimes contradictory.

Based on the requirements and limitations, a measurement task schedule was designed to consist of twelve PPI scans and two RHI scans, to be repeated every 5, 7.5 or 15 minutes. The set includes scans in Dual-polarization mode and in conventional mode. Additionally "bird bath" measurements to calibrate the ZDR are made once every 15 minutes.

Pictures of different parameters and products in the different weather cases show that dual polarization reveals properties of precipitation event not seen from conventional radar data. The first applications are there, but we forecast, that just like for Doppler data, only after years of routine measurements and active use of the existing tools, the most advanced new methods and needs will be found.

1. Introduction

Dual-polarisation weather radars have been used in research and in tests for more than 30 years (SELIGA and BRINGI, 1976; BRINGI and CHANDRASEKAR, 2001). European national weather services are currently acquiring their first dual-polarisation radars; in 2009, these comprised approximately 15 of them out of the total of 180 weather radars, and dual-polarisation is becoming the new standard requirement for operational weather radars (TABARY et al., 2009; HOLLEMAN, 2009).

The FMI radar network consists of eight C-band Doppler radars. Almost all of Finland – apart from the northernmost Lapland - is within radar coverage, provided data are collected out to the maximum measurement range of 250 km (SALTIKOFF et al., 2009).

The configuration procedures for bringing dual-polarisation radar measurements into the production process differ from those for conventional radars. In the present type of signal processors used at FMI, time-domain processing has to be used for the dual-polarisation parameters. Thus, velocity de-aliasing with random phase and the most advanced clutter-cancellation methods are not available in this mode (VAISALA, 2009).

This paper describes the design and implementation of the new measurements for the dual-polarisation radars, including the needs and commitments guiding the design; and finally, what kind of information of atmospheric structures and processes are extractable from these measurements.

2. Demands and requirements

Since the new radars have to be part of the existing weather service infrastructure, the new measurements

have to be specifically designed so that all existing services can continue at the same operational level as before. The use of radar data for various applications is extensive and versatile (e.g., FMI delivers every day 1700 different products based on measurements with the Vantaa radar) many of the present products are based on national or international composites; hence the measurement intervals, ranges and quality must fit to the existing network.

Anyone planning the task schedule of operational weather radar, meets usually two dilemmas: so called Doppelp dilemma makes one to choose between large unambiguous range or large unambiguous velocity interval. So called resolution dilemma makes one to choose between vertical resolution (many elevations) or time resolution (frequently repeated volume scans).

Acquiring several parameters brings a new dilemma: while reasonable quality of reflectivity measurements can be achieved with 16 or 32 samples to be processed together, more samples would be needed for good quality of Doppler and dual-polarization measurements. We made tests and noticed biggest differences in RhoHV. Still we compromised to 32 samples.

Another challenge rises with the current implementation of signal processing of dual-polarisation parameters: a time-domain processing is needed for the dual-polarisation parameters, while frequency-domain processing is preferred for the best Doppler velocity estimates. Scanning with horizontal polarisation and random phase (RPHASE) processing enables to use high PRFs without usual problems of 2nd trip echoes (i.e., an echo from a given pulse that is not received until after the transmission of the next pulse), and to get good quality mean Doppler velocity.

In order to transmit simultaneously both the horizontally and vertically polarised microwaves, the signal is split into two within the so-called STAR-mode, which decreases the sensitivity of the radar by 3 dB and thus increases the minimum detectable signal. MDS. The sensitivity is also related to the pulse width and thus indirectly to the PRF: shorter pulses must be used with a high PRF, and this limits the sensitivity compared to the use of longer pulses (DOVIK and ZRNIC, 2006). An example of the effect of MDS is seen in case study in Chapter 4.3

Therefore, at FMI we decided to create a hybrid task schedule, which includes scanning combining different PRFs, different pulse widths, different processing modes and use both the STAR mode (simultaneous transmission and reception of H and V polarisations microwave pulses) and also the LDR mode (linear

depolarization mode, during which H polarisation alone is transmitted but both are received).

3. The new measurement schedule

Based on the requirements and limitations described above, a measurement task schedule was designed to consist of twelve PPI scans (Plan Position Indicator; antenna rotating horizontally with elevation angle staying constant for each scan) scans and two RHI (Range-Height Indicator; antenna moving in elevation with azimuth angle staying constant for each scan) scans, to be repeated at least every 15 minutes. Within this 15 min period, the high elevation PPIs (group C) are repeated once, the low-level PPIs with high-quality wind data (group B) twice and the low and middle level measurements with dual-polarisation mode (Group A) three times.

The technical details of the measurement tasks are described in Table 1. The main tasks are repeated every 5 minutes. Data from these tasks are widely used in all precipitation-related products. This group consists of five elevation angles, 0.3 - 9 degrees, aiming at measuring relatively comprehensively the lowest part of the troposphere. The maximum range of 250 km dictates the pulse repetition frequency (PRF) to be 570 Hz, which in turn set the maximum unambiguous Doppler velocity interval to ± 7.6 m/s. Even though this speed interval is too narrow for useful wind measurements, it is good enough for an effective Doppler filtering. The $2 \mu\text{s}$ pulse (longest of the available pulse widths) is used, because it gives the highest sensitivity.

Autocovariance processing, known as Pulse Pair Processing (PPP; Doviak and Zrníc, 2006) is the only processing mode which can be used in this signal processor version to get dual-polarimetric variables, as they are solved in time domain. The saved parameters are radar reflectivity (Z), Doppler velocity (Vd), the width of the Doppler spectrum (W), the signal quality index (SQI), differential reflectivity (ZDR), the normalized co-polar cross-correlation magnitude (RhoHV), the differential phase (PhiDP) and its range derivative (KdP).

The second and third groups use high PRFs and dual-PRF velocity unfolding (Joe and May, 2003). A large PRF has two advantages: the unambiguous velocity range increases and the measurement takes less time. The disadvantage is a smaller unambiguous range. Shorter pulses ($1 \mu\text{s}$ or less) have to be used because of the limits set by maximum average power output of the magnetron transmitter. From these measurements, only the four first parameters (Z, Vd, W and SQI) are saved.

According to Joe and May (2003), dual PRF can be considered *de rigueur* for velocity unfolding with all C-

band data. FMI has used it at higher elevations for years, but at lower elevations the 2nd trip echoes in the higher frequency have spoiled the data. Now with the new generation processors, random phase processing (RPHASE) is used, and the 2nd trips are cancelled at satisfactory level. Every 15 minutes, a set of high elevations are measured. These data are used for extracting wind profiles, cross-sections and cloud tops. The high PRF measurements are used for applications, where quality of wind data is the most important.

In addition to these twelve PPI scans, two RHI scans, southwards and northwards, are scanned. These directions are roughly perpendicular to the coastline at the two first dual-polarisation radars installed in Finland. It is under discussion whether the RHI directions, at least at some of the radars, should rather be parallel to the runway of the nearest airport, or have a dedicated direction with the specific application relevance. Changing the direction according to weather situation would be optimal, but the needed manpower is unfortunately not available.

Group	Processing mode	Azimuth (deg)	Elevation angle (deg)	Pulse width (μ s)	PRF (Hz)	Range (km)	V max (m/s)	Parameters	Polarisation
A	PPP	Full circle	0.3,1.5, 3, 5, 9	2 (long)	570	250	7.6	Full set	H+V
B	RPHASE	Full circle	0.3, 2, 4	1 (short)	1400/1050	100	56	Z, Vd, W and H SQI	
C	RPHASE	Full circle	2,7,11, 15,25,45	1 (short)	1400/1050	100	56	Z, Vd, W and H SQI	
RHI	PPP	0.0,180	0.0-60.0	2 (long)	600	150	8	Full set	H+V

Table 1. Characteristics of the measurements. Group A is repeated 3 times, group B twice, and group C and the RHI once within each 15 minutes slot.

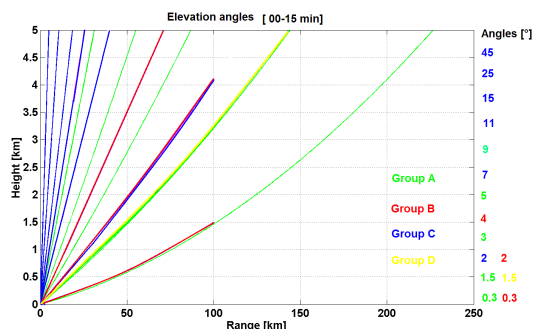


Fig. 1 Elevation angles. Group A (in green) repeated every 5 minutes, group C (in blue) and D (in yellow) repeated every 15 minutes and group B (in purple) repeated in average every 7.5 minutes.

4. Applications: appraising the benefits from the new data retrieved in different weather situations

Case studies can help to shed light on the strengths and weaknesses of the different measurement modes. Three precipitation events in Southern Finland were investigated in detail. The presented cases are not

particularly extreme events, but were selected to represent typical situations in Finland.

The first case illustrates the challenge of precipitation type classification: even though all surface observations show liquid rain, most of the radar measurements are made in snow due to the measurement geometry and the spherical shape of the globe. However, when the radar measures liquid raindrops, in Finland they normally stay liquid, and thus the classification can be used for warnings of extremely dangerous cases, when rain falls on cold surfaces and freezes.

This case also shows features of the vertical structure of the precipitation area, which are not yet completely understood. Several potential explanations are available, but more research is needed to explain which factors are relevant in such a case.

The profiles of wind and reflectivity, shown in association with this case and used by the aviation weather service, set demands for scanning the upper elevations with adequate interval (here 15 minutes).

In the second case, it was possible to detect hail within the precipitation system. Even though it may melt before hitting the ground, it poses a danger to aviation and they can also be seen as indicator of other convection-related severe weather phenomena such as downbursts (e.g. Fu and Guo, 2007).

The short test of the attenuation scheme showed, on average, that the dual-polarisation (PhiDP) based attenuation correction scheme performed equally well as the conventional attenuation correction scheme. Tuning the settings of the correction scheme by comparing to large amount of gauge measurements might improve the results with both methods. However, the major benefits of dual- polarisation are expected to arise especially in extreme cases, because it should be more stable than the conventional ones. For example, occurrence of large hail can lead the conventional methods to overestimate precipitation accumulation, and makes the correction to “explode”. KDP-based methods should manage hail better (Smyth and Illingworth, 1998).

In our procedure, KDP was used to correct reflectivity dBZ, and then dBZ was used to estimate rainfall (RR, in millimetres) in the traditional way. There are several other methods to estimate RR from combinations of dual-polarisation parameters. KDP-based methods are immune to attenuation and calibration errors as well as insensitive to hail, but they do not work in snowfall (Illingworth 2004 p.160). In Finland, snow is measured in every radar volume at least at the highest levels, so the selected method must manage QPE (Quantitative Precipitation Estimation) in snow. A project comparing the different methods is planned for the coming years.

The images of accumulated precipitation associated to this cold front case and used by the hydrological community show the effect of repeating the lowest elevation scans only every 5 minutes. The images of velocity, used in NWP assimilation and convection studies, show the effect of dual-PRF unfolding of Doppler velocities.

In the third convective case, the echoes from non-precipitation targets are correctly identified, but at the moment there is no procedure to “clean“ these echoes from rainfall intensity images. On the other hand, there are also users who are interested in these data for applications such as bird collision risk and insect warnings for agriculture (Leskinen et al., 2009).

The images of cloud tops shown in association with this case and used by the aviation weather service, set demands for scanning the medium and upper elevations with reasonable interval (here 15 minutes).

The pictures in our poster, especially the RHIs, are not as clean and neat as those we have seen from the research community. One of the reasons for this is that in the operational world, one is always in a hurry. This limits the number of samples collected from a same location as well as the angular resolution of the measurements. The RHIs are good for understanding the structure of the atmosphere, but they only present one line across the precipitating system. When dealing with research radars, the operator can focus that cross-line through the most

interesting feature(s), but in an operational network some standards must be created. The PPI volumes are still the most important measurement mode for a network, because map-like products created from them constitute the main tool of many applications.

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