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Some challenges and solutions in operational weather radar applications

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1 Introduction

The development of operational weather radar applications in Europe has been a scientific and socio-economic success story during the past 30 years. During this period national efforts have more and more become an international cooperation promoted e.g. by such activities as COST (Collier (2001),Rossa et al. (2005)) and OPERA Programmes (Huuskonen (2006)). The latter one has 25 participating countries aiming to harmonize European radar data and products. European interaction is also consolidated by the several operational exchange programmes of real time radar data between neighboring countries (e.g. NORDRAD and CERAD). One corner stone in the development of operational applications is supporting research and development driven e.g. in the Research Programmes of the European Union and WMO. A definitely positive decision has also been the establishment of the biennial series of the European Weather Radar Conferences (ERAD) aimed for both scientists and operational staff. The purpose of this presentation is not to give a balanced review of all European operational solutions but only to pick up some of them, following recent developments mostly in Northern Europe. Specific attention is paid to estimation of the probability of detection (POD) of precipitation as a function of range in real time.

2 Examples of recent developments

2.1 Radar based operational processess

During the last 15 years Doppler radar has become one of the standard tools in operational weather applications. The benefits of Doppler capability are crucial e.g. in clutter removal and thus, in quantitative precipitation estimation (QPE), and in the use of wind information e.g. for the purposes of detection and nowcasting (e.g. gust fronts and mesocyclones). The stability of modern radar hardwares and softwares as well as high processing speeds of radar signals and wide bandwidths of telecommunication lines have facilitated full real time operational use of the measured 3D polar volumes of Doppler and reflectivity data. These data are the basis for a plethora of radar products, user interfaces and tailored customer products. For example, FMI delivers on average 1400 individual radar products to the users hourly during the 24 hours of a day. Wired internet and wap-based mobile phone services bring the coloured time series of radar images available to individual persons almost anywhere. It should be noted that real time is not the only important moment in radar applications. An archive of the measured volumetric data with an easy user interface to view and read even several years old data is also becoming an operational tool. Such a system helps much in R&D, climatological applications and in services based on ”old” data, e.g. accidents and insurancies in cases of local severe weather.

In spite of the vast improvement of the infrastructures of radar based services the process is still prone to bottlenecks. First of all, the public sectors of most European countries, including national weather services, have suffered with budgetary cutoffs. As radar systems are quite expensive, an implication can be that old national networks will not be replaced in time with the state of art equipment but become increasingly retarded to meet high quality operational requirements. Limited staff in maintenance and R&D as well as lack of knowledge in systems and meteorology sometimes implicates that a modern radar system has been purchased but the exploitation of it remains incomplete. Figures measuring

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problems in the process are the availability of volumetric data at the site of compositing and user product generation as well as quality and accuracy of the measured data. In optimal cases the average long term availability can exceed 99 % including all maintenance breaks.

2.2 Quality control of the data

Up to these days, in most cases, the users of operational radar products must have accepted the data without any additional information which could indicate the quality or accuracy of the product in general not to speak of pixel by pixel quality indicators. Especially a paying customer is not necessarily satisfied with such a state of art. Luckily the European weather radar community has taken this issue seriously e.g. in COST 717 and OPERA Actions (Michelson et al. (2005),Holleman (2006)). As some kind of operational quality measures will be agreed obviously in near future, it is very important that the logical structures, in other words quality algebra, of such measures are reasonable from the beginning.

In the first workshops of the quality measures a common idea was to find a "universal" quality index for each data pixel, scaled e.g. between the figures 0 and 1. Unfortunately such a single index does not exist as the quality has several dimensions, which are not comparable to each other. The first dimension is the classical accuracy of the measured or estimated quantity i.e. bias and random error, which can be at least estimated as a function of time and space (before and after possible correction steps like a VPR adjustment). The second dimension is the probability of various phenomenal occurrencies in a measurement bin, such as e.g. presence of hail or bright band, birds, insects, sea clutter, severe attenuation, complete beam overshooting. The third dimension is the application i.e. which quantities are used and in which way in the user application and additionally, which are the specific user requirements for the first two dimensions. For example, a hydrologist may define that he applies all radar data grid points in which Z > 20 dBZ, probability of rain is more than 95 % and accuracy of the dBZ pixels is better than 2 dB. Additionally he requires that in the echo free areas the probability of signal loss due to beam overshooting or blocking is less than 10 %. An entomologist studying insect migrations may use the same PseudoCAPPI composite grid as the hydrologist but she may set the quality requirements such that all Z values between -30 dBZ and +20 dBZ are acceptable if their accuracy is better than 10 dBs and the probability of insects or birds is more than 50 %. A more detailed discussion and examples are given in this Conference by Peura et al. (2006).

2.3 Quantitative precipitation estimation

Although the history of radar meteorology is full of papers dealing with R(Z)-relations and quantitative precipitation estimation radars can't replace gauges as the standard precipitation measurement tool (Zawadzki (2006). Therefore it is perhaps not surprising how slowly the operational hydrological river models in Europe have started to use radar data as input (Vehviläinen et al. (2005)). At least two main reasons exist to explain this discrepancy. Firstly hydrologists are not used to apply radar data in their education and operational practices and secondly, the accuracy of radar measurements has not been sufficient for them. Operational C band measurements cover typically ranges 0-250 km from a radar. Not until the papers of Zawadzki (1984) and Joss and Waldvogel (1990) were generally accepted it was realised that the main bias in QPE in the European climate is the sampling difference between a radar measurement high above the ground level and the actual precipitation rate at ground. This is a direct implication of the fact that the average vertical reflectivity gradient is negative. Thus, without a proper adjustment of the sampling difference by applying a correction for the effects of the vertical profile of reflectivity, large biases exist in QPE. This is especially valid in mountaineous regions (Germann and Joss (2003)), where reduced visibility due to the topography enhances the effects of the VPR, and in the precipitation of temperate and cold climates (Koistinen et al. (2003a)) where the negative vertical reflectivity gradient is typically larger than in the warm climates. For example in Finland, at the range of 200 km from the radars, the average bias in radar measurements due to the VPR effects in rainfall is -8 dBs and in snowfall -17 dBs. The conclusion is that without a proper VPR adjustment scheme like that by Koistinen et al. (2003b) operational radars are invalid at longer ranges to fulfil the hydrological requirements of QPE.

It is interesting to note that the advocates of dual polarimetric radar systems, which obviously will be the next generation operational systems in very near future, spoke in favour of the polarimetry already 10 years ago using improved accuracy in the QPE as the main reasoning. Unfortunately the typical improvement by 1-2 dBs (if we exclude cases of strong attenuation and hail) is not an impressive figure compared to a VPR bias of e.g. -17 dBs. In this way the advocates actually slowered the acceptance of polarimetry in operational environments. I would like to support the vision that the main reasoning of polarimetry is in the diagnostics of the scattering targets (e.g. snow, sleet, hail, rain, birds, insects, sea and ground clutter), which is very valuable from the point of quality control and products dedicated to display only specific targets.

Another "new" idea in QPE is the use of X band radars. However, they were widely used during the first decades of radar meteorology and have experienced several rebirths since then. For example Juerg Joss considered them seriously in an oral presentation at the end of COST 75 project. Due to occasionally severe attenuation the network should be dense, which will increase investment and maintenance costs although the unit price is much lower than with C band radars. In temperate climates and relatively small regions such networks might work, especially if the applications are local (radar is owned e.g. by a hydropower company), or a wider area is mountaineous ("a radar per valley"). In large and topographically flat European areas C band seems to be a natural solution for the network of a national hydrometeorological service. In any case the sensitivity of C band radars is already sufficient for the detection of e.g. weak snowfall. On the other hand snowfall is often so shallow that in a less dense network wide areas suffer with complete beam overshooting as is described in the next Section. In such environments dense X band networks might help.

3 Precipitation detection range

Any VPR correction method will meet a serius difficulty in the areas of no detectable signal. The longer is the measurement range the larger is the probability that a radar does not detect any precipitation due to total beam overshooting or due to partial beam overshooting and increasing minimum detectable dBZ. Such cases appear as spurious echo free areas in radar measurements. Rapidly decreasing probability of detection (POD) as a function of range (r) is most common in cold climates and in winter when shallow precipitation and weak reflectivities are frequent. In the worst cases moderate snowfall intensities at ground are detectable only to ranges of 50-75 km with a C-band radar. The problem can be severe also in mountaineous regions where beam blocking reduces the visibility and thus, the POD. Although radar meteorologists are well aware of the fact that "invisible" precipitation can exist below the lowest elevation beam, the end users often rely on radar images as a truth up to the nominal measurement range of 250 km shown in the products.

At the Finnish Meteorological Institute we have started to test estimates of POD of ground level precipitation applying three different methods:

(1) The visibility of precipitation (V) can be estimated as a function of range (r) applying the measurement geometry of radar beam, minimum detectable dBZ and high resolution measured vertical profiles of reflectivity (VPR) from the polar radar data at close ranges to each radar. By using Gaussian beam convolution of the VPR at all ranges applying the known lowest elevation angle we obtain a single value for the maximum distance of detection. Probability of precipitation detection at each range is obtained by repeating the convolution procedure for an ensemble of VPRs. The ensemble members can be obtained from the time series of actual measurements in a network of radars, using climatological VPRs or by generating simulated VPRs from the measured VPRs.

(2) The actually observed POD can be quantified at the ranges where overlapping radar pairs measure the same precipitation area with the lowest elevation PPI. The close range radar measures almost at the ground level (which represents well the actual precipitation) diagnosing the area of precipitation A_1 whereas the distant radar detects only part of the precipitating area A_2. The ratio A_2/A_1 is a measure of POD at the average range r, which is the range from the distant radar to the center of the area of comparison.

(3) The observed POD as a function of range can be estimated also from the ratio $f = A_p/A_{np}$ where A_p is the area of precipitation and A_{np} the area of no precipitation in a circular range belt $r_2 - r_1$ from a radar. If the precipitation coverage fraction (f) is horizontally homogeneous the decrease of f as a function of range will measure the quantity $POD(r)$.

When $POD(r)$ is presented as an overlay or underlay component of an operational precipitation product the users immediately recognize at least semi-quantitatively which areas are really non-precipitating and which are spuriously echo free areas, respectively. Real examples how widely $POD(r)$ can vary from day to day will be shown in the presentation.

4 Conclusions

The development of operational radar applications has been rapid during the last 30 years in Europe. In spite of all good achievements weather radar based operational services are far from the state of completeness. Major challenges exist in quantitative measurements, quality control, diagnosis of phenomena (icluding assimilation of radar, satellite and other ground based measurements), nowcasting and user applications. Thus, all international cooperation in radar based services and development should be encouraged.

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