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The Swedish weather radar production chain

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1 Introduction

Over the last few years, the way data and products from the Swedish weather radar network (SWERAD) have been generated and mananged has undergone a significant transformation, from distributed to centralized configuration. New systems have been introduced for these purposes, along with a number of quality enhancements. This contribution attempts to summarize these recent developments, and it also indicates future directions.

SWERAD is operated jointly between SMHI and the Swedish Armed Forces, with a common management organization. The network consists of 12 Ericsson C-band Doppler weather radars. National radar coverage remains incomplete; a gap in the north-west still requires filling. The radar technology used has not undergone any significant modification since it was developed in the 1980's, although its Doppler mode is in the process of being extended to the full operational range of 240 km. This paper focusses on how the data is managed and products are generated. SWERAD is centrally located in NORDRAD, so radar products from Norway, Finland, Estonia, and Denmark are indispensible to, and an integral part of, the Swedish production chain.

2 Three different systems, one common file format

SWERAD's central processing is carried out by three seperate systems. Partec II, maintained by Saab Aerotech, is the host system located at each radar site. This system manages the radar and collects and transmits individual polar scans to a centrally-located server running the second-generation NORDRAD software system (N2). This N2-node compiles polar volumes and transmits them to Sigmet IRIS Analysis which generates single-site products. Composites and higher-order products are generated by a second N2-node which also communicates with Finland (FMI) and Norway (met.no). Danish data is added to NORDRAD from Norway, and Estonian data is added from Finland. The BALTEX Radar Data Centre (BRDC) at SMHI acts as a "hot" integration platform, also as a real-time N2-node, and it receives Polish data which are reserved for R&D purposes.

All three systems (Partec II, IRIS, and N2) come from different suppliers, with some commercial constraints, but all three systems have integrated the HDF5 file format using the information model developed in COST 717 (Michelson et al., 2003). This use of HDF5 provides the ability to exchange scan, volume, image, and profile data/products in a harmonized and transparant manner. At the NORDRAD level, this use of HDF5 constitutes an official European standard exchange format since 2004.

3 Polar data

With the exception of a five-minute high-priority 0.5° Doppler scan, all data are acquired with a temporal resolution of 15 minutes. The individual scan files transmitted from each radar are collected by the central N2-node. Partec II has the ability to include hardware error messages in the HDF5 files. If a given scan file contains a hardware error message, then the polar volume will be compiled using all the previous scans from the same acquisition period. The scan containing the error message is stored to enable off-line analysis of the frequency of different errors from different radars. In real-time, radar hardware error messages are automatically extracted from the HDF5 files and e-mailed to our maintenance organization. This procedure is relatively new and is intended to significantly reduce human troubleshooting when hardware errors occur, thereby reducing downtime.

A simple and somewhat arbitrary clutter filter is applied to data from some radars once their volumes are compiled.

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This filter operates in polar space and, based on the statistical properties of ground clutter in normal conditions, selects the value from the lowest clutter-free bin. In moving this new value to its lower position, it is corrected using a vertical reflectivity gradient of 3–5 dB depending on the radar. This procedure is only applied to non-Doppler data, and it is expected to be phased out when the Doppler mode is extended to 240 km. The filtered output volume contains only one reflectivity scan per elevation angle, ie. there is no differentiating between T (total reflectivity, input) and Z (corrected reflectivity, output).

4 Single-site products

Polar volumes are received by IRIS and single-site products are generated from them. The pseudo-CAPPI, with product height 500 m above the radar, 2 km horizontal resolution, 8-bit depth, and gnomonic projection is the standard NORDRAD reflectivity product for exchange. These products are also transmitted to the GTS, in HDF5 format, for use in the European composite generated by the OPERA pilot data hub. Wind profiles (WRWPs) are generated using IRIS' dealiased VVP algorithm and are also exchanged in NORDRAD, and transmitted to the GTS, in BUFR format, for use by the WINPROF CWINDE data hub among others. One-kilometer resolution pseudo-CAPPIs are generated from Doppler volumes with only 120 km maximum range.

Aviation meteorology is the Swedish user group with the greatest interest in evaluating new radar-based products. In this context it should be noted that the products generated for them are new to them but not new in design or concept. So far, the products implemented on their behalf are:

- Five-minute PPI (dBZ) with 30-minute extrapolated centroid motion vectors overlain.
- Maximum reflectivity with side panels, Doppler mode (120 km), with the radar-based horizontal wind field overlain.
- Cartesian volumes, both Doppler (0.5 km) and non-Doppler (1 km), with 500 m vertical resolution.

These products are generated centrally, but are transferred to a local IRIS Display computer located at SMHI's aviation forecast centre at Stockholm-Arlanda airport. This configuration is being replaced with a central IRIS server which projects Display windows to Linux desktops directly, and to Windows PCs indirectly through the use of a Linux thin client server.

5 Quality-controlled composites

Gnomonic single-site pseudo-CAPPIs are received by the second N2-node and exchanged with FMI and met.no. They are also transformed to polar stereographic projection as a pre-processing step prior to compositing. The original NORDRAD software system was designed to use a rudimentary quality criterion, the height of each input pixel, as the basis for compositing (Andersson, 1992). In N2, this "lowest pixel" algorithm is implemented with higher-resolution input topography from the GTOPO30 database, with the additional difference that virtually any kind of information can be composited. Reflectivity composites are generated using this algorithm, with two-kilometer horizontal resolution and a coverage area which includes all Nordic radars[1].

Recalling the lack of Doppler processing to 240 km in Swedish data, the reflectivity composites suffer from contamination from various non-precipitation sources. A multisource method employing Meteosat IR and near-surface temperature analyses (Michelson and Sunhede, 2004) has been valuable at the BRDC for identification and removal of non-precipitation echoes. A new and simpler procedure has been implemented in the operational processing chain which employs operationally-classified cloud-type products derived from higher-resolution Meteosat-8 data. These cloud-type products have been developed within the EUMETSAT Satellite Application Facility to support Nowcasting and Very Short Range Forecasting applications (NWCSAF) (Derrien and Le Gléau, 2005). These products contain four classes representing cloud-free areas. Radar echoes are removed in areas classified as being cloud-free. This is a convervative procedure, as there are several cloud-type classes which, alone or combined with corresponding quality information, could also potentially be used. Dybbroe et al. (2005) found that the probability of rain in these same classes is less than 2.6% with classified AVHRR data, but no such statistic exists yet for the Meteosat-8 classifications. A preliminary validation of classified vs. observed cloudiness shows, however, an increased overestimation of classified cloudiness with latitude, as a result of confusion between cold cloud-free and low/medium or semi-transparant clouds (Derrien and Le Gléau, 2005). This should lead to lower efficiency of the filter in cold conditions. This filter has been used operationally since March 1, 2006, and experience to date is positive, with only a small penalty in the form of filtered precipitation due to misclassified satellite information.

An positive side-effect of the gauge-adjustment technique, described in the next section, is that it can be used with arbitrary integration periods. This means that it can be applied to individual composites, and this is now done. A "surface reflectivity" composite is thus generated operationally and is available alongside the unadjusted one.

6 Quality-characterized accumulated precipitation

Filtered but unadjusted composites are the basis for a real-time operational implementation of the BALTRAD gauge-

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[1] Publicly-available composites can be viewed at http://www.smhi.se/weather/radar/radar_en.htm

adjustment technique for generating one-hour accumulated precipitation. The original implementation, developed at the BRDC for BALTEX, is presented in Michelson and Koistinen (2000), and its performance is given in Koistinen and Michelson (2002). The original implementation involves the analysis of a fully-spatial adjustment factor which is weighted against a first guess consisting of an adjustment factor as a function of surface distance from the radar. In practise, it has been found that the density of real-time SYNOP observations is so low that the spatial analysis has almost no impact on the final result. So, the real-time implementation uses only the first guess. Fig. 1 shows the arrival of spring as seen through these adjustment factors for the last two weeks of April, 2006. An accumulated precipitation product is illustrated in Fig. 2.

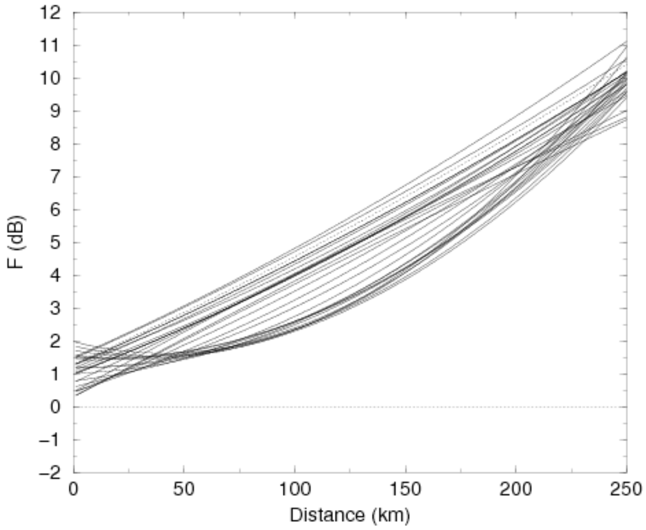

Fig. 1. Operational gauge (G) to radar (R) relations as a function of surface distance. $F = 10 \times \log \frac{G}{R}$ is fitted using a second-order polynomial. April 15–30, 2006.

While the operational accumulated preciptation products represent one-hour accumulations, the adjustment factor is derived only twise per day, at 6 and 18 UTC. The BRDC plays an important role in this process, since the BALTRAD coverage area contains data from more radars and hence more surface observations from SYNOP. A BRDC product is 12-hourly gauge-adjusted precipitation, at these same times, so the adjustment factors derived at these times are automatically available for accumulations derived up to 12 hours after them. Prior to their use, the gauge observations are corrected for systematic errors according to Michelson (2004); this is of particular benefit in winter when gauges are known to significantly underestimate snowfall due to the flow-distortion error caused by wind. Gauge-radar observation pairs influence the operationally-derived adjustment factor for ten days.

This form of quantitative precipitation estimation succeeds in treating the inherent range bias in the radar data, but the method is crude in that it does not take into account differences in precipitation phase, or whether the precipitation is convective or stratiform. Gauge adjustment is more suitably applied after other algorithms, and our long-term goal is to have it at the end of our processing chain following developments outlined in Sec. 7.

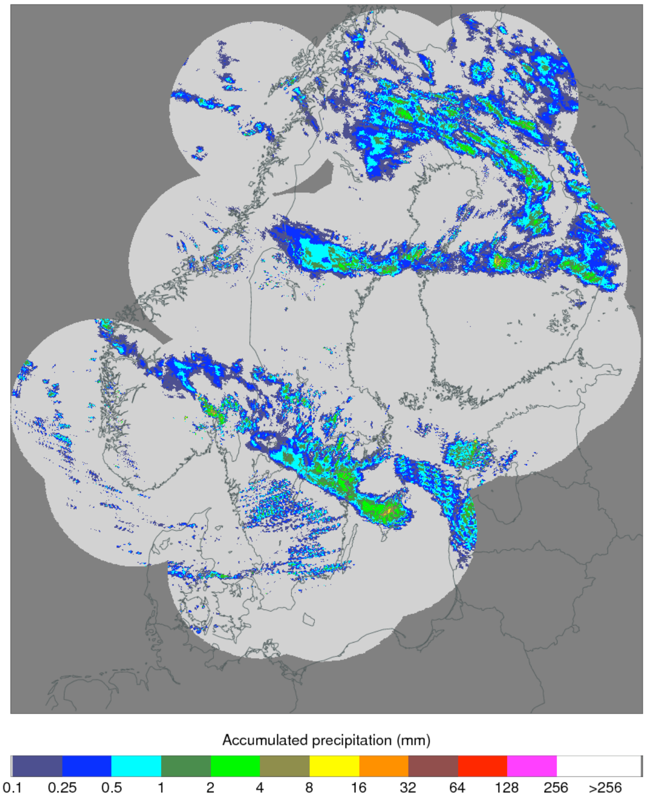

Fig. 2. One-hour gauge-adjusted accumulated precipitation on May 25, 2006, at 9:00 UTC.

Within COST 717, issues related to quality control and characterization of weather radar information were comprehensively addressed for the first time at the European level (Michelson et al., 2005). The results have been partly inherited by OPERA, with the aim to arrive at harmonized practises for producing and exchanging quality-related information. A quality framework has been formulated, and one application of it is now being operationally tested at SMHI in dialogue with a quantitative user of radar datasets.

Following the OPERA quality framework, a quality *indicator*[2] field is generated and stored to file as a continuous variable scaled between 0 (lowest) and 1 (highest). An example quality indicator field is illustrated in Fig. 3. Together with the gauge-adjustment coefficients and associated metadata, also written to file, the quality indicator expands to

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[2] In the framework, a quality *indicator* is a product of the radar production chain, whereas a quality *index* is an interpreted variable within a specific application.

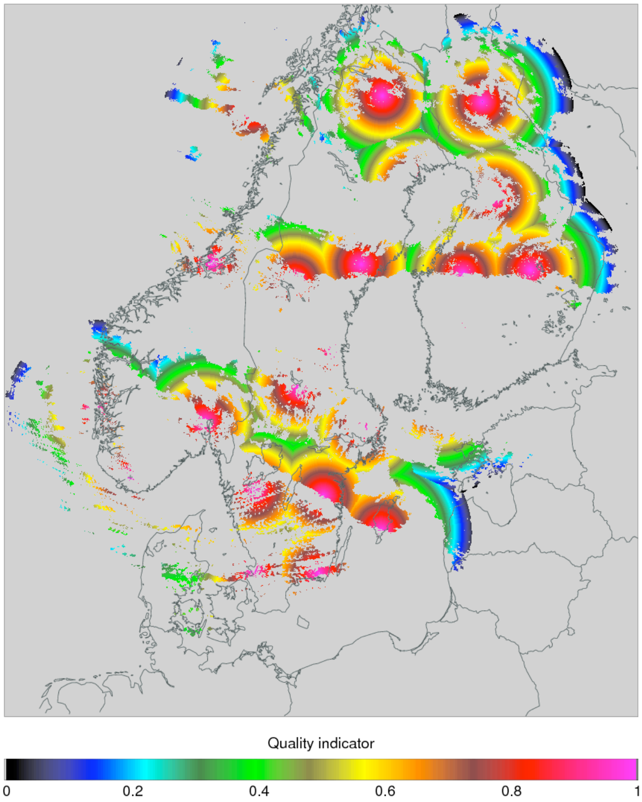

Fig. 3. Quality indicator corresponding to the product illustrated in Fig. 2, where quality ranges from 0 (lowest) to 1 (highest).

constitute the per-pixel average surface distance which was used to perform the gauge adjustment. The availability of this quality indicator and metadata implies that the gauge-adjustment procedure can be reversed completely. More importantly, this information allows the user to formulate criteria for acceptance/rejection/weighting of a given pixel, e.g. based on the adjustment factor or surface distance within the application in question.

It should be noted that this application of the OPERA quality framework is a relatively trivial one, as the framework allows for multiple quality indicators of different dimensions. Nevertheless, the COST 717 information model for use with HDF5 is formulated in such a way as to accomodate this information. It is therefore straightforward to store all data, indicators, and metadata in a harmonized and self-descriptive way.

7 Future developments

Experience has proven that the research collaborations in BALTEX and COST 717, together with the establishment of the BRDC, have been critical in developing the algorithms and software required for enabling the operational implementations of the quality improvements now being used in real time in SWERAD's production chain. Fortunately, the collaboration which was established within the BALTEX Working Group on Radar has led to the official establishment of the NORDMET Radar Applications (NORA) activity, in which commonly-prioritized R&D projects are conducted internationally. Two ongoing projects deal with 1) beam propagation issues and 2) issues related to the vertical profile of reflectivity. Proposals for new NORA projects are accepted by the NORDMET Scientific Committee, and are open for participation by Nordic and non-Nordic groups alike.

It is anticipated that results from NORA projects will be made available in such a way that their efficient operational implementation into national production chains like that in Sweden will be enabled. Results from the beam propagation project are already showing operational potential. In this way, NORDMET has established an organization designed to stimulate interaction between the NORA R&D community and operational networks like NORDRAD, for mutual benefit and, it is hoped, accelerated progress.

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