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Challenges for precipitation estimation in mountainous regions

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Abstract. Deriving quantitative precipitation information from weather radar data is a difficult task in mountainous regions. All operational Norwegian weather radars suffer from some degree of beam blockage. Also the new weather radars planned along the west coast will suffer from blocked sectors. A range-dependent gauge adjustment compensating for the effect of the VRP does not perform properly for these radars. The gauge adjustment method implemented in Norway makes therefore use of all precipitation stations, including the climate stations, to derive mean monthly adjustment surfaces of adjustment factors. The precipitation estimates are corrected separately for each of the radars, before the data is merged to a composite image. The spatial gauge adjustment performs well under average conditions, since it accounts for the seasonal variation of the VRP. During situations with ducting or extreme rainfall, however, the accuracy could be improved by removing errors related to beam blockage and anomalous propagation before the gauge adjustment. We have developed the software to derive beam propagation from radiosonde profiles. The model is used to determine the degree of beam blockage, but it might also be useful in identifying anaprop noise.

1 Introduction

The Norwegian weather radar network is operated by the Norwegian Meteorological Institute (met.no). Today, it consists of two C-band Doppler radars located at Asker near Oslo, and at Hægebostad near Kristiansand (Fig. 1). The Oslo radar is located at an elevation of 458 m. It is an Ericsson radar with EWIS software. The Hægebostad radar was installed in 1999, and is located at an elevation of 631 m. It is a Gematronik radar with RAVIS and Rainbow software. The current scanning protocol makes use of a total of 12 elevation angles ranging from 0.5° to 15.5°. Two new radars have been installed in July 2002 and are now under testing. They are located in the community of Rissa close to Trondheim (616 m) and in the community of Bømlo, on an island close to Bergen (104 m). The approximate locations of further planned radars are also shown in Fig. 1. No data is available for the Bømlo and Rissa radars yet, but first results from the beam propagation model indicate that the Bømlo radar will be severely blocked in some eastern sectors under average refractive conditions. The degree of beam blockage will increase in situations where temperature- and moisture profiles close to the sea surface cause anomalous propagation. Figure 2 shows the elevation of the radar beam's lower edge under normal refractive conditions.

An example from the Oslo radar shows that the patterns of beam blockage and uncorrected radar precipitation estimates (Crochet and Gjertsen, 2000) match well (Fig. 3). The uncorrected precipitation accumulations decrease also with distance from the radar due to the VRP. The influence of the VRP is well known and documented (e.g. Joss, 1998). The strongest decrease is visible in winter when precipitation is shallow (Koistinen and Saltikoff, 1999).

2 Gauge adjustment

Corrected precipitation estimates are routinely derived for the radars Oslo and Hægebostad. The NORDRAD PseudoCAPPI product is used as input. The PseudoCAPPI image is build at an elevation of 500 m above the radar site. The spatial resolutions of the reflectivity products are 2 × 2 km for the Oslo radar and 1 × 1 km for the Hægebostad radar, the sampling interval is 15 minutes. The system of projection is polar-stereographic (60°, 0° E). The radar reflectivity factor Z is transformed into an uncorrected estimate of precipitation intensity using the standard $Z-R$ relationship with $a = 200$ and $b = 1.6$ and accumulated.

The gauge adjustment method is described in Gjertsen (2002). It is a spatial correction method similar to the methods described by Brandes (1975), Koistinen and Puhakka (1981), and Michelson et al. (2000). A surface of adjustment factors is derived by applying a 3-dimensional curve

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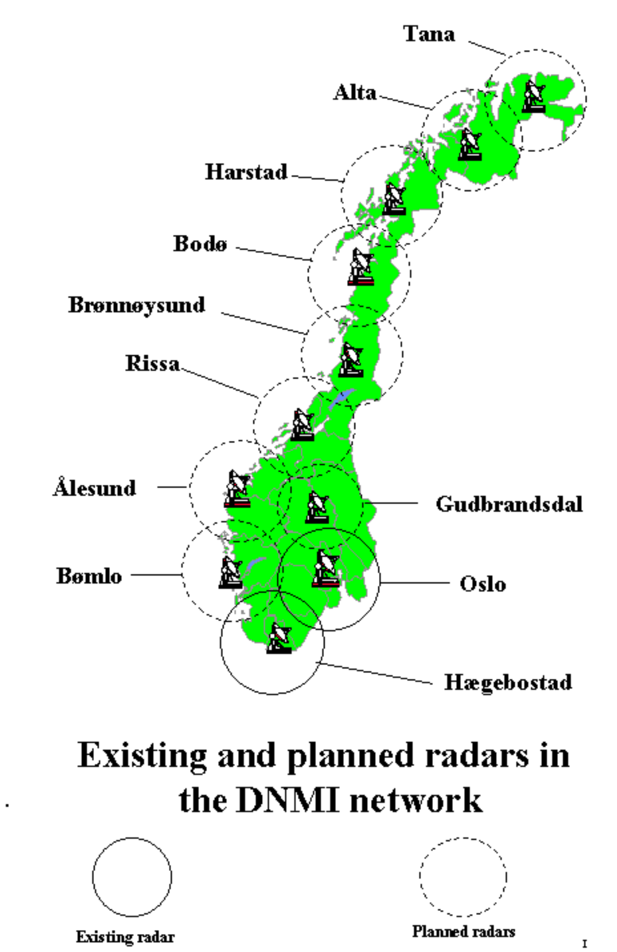

Fig. 1. The Norwegian weather radar network. Radar sites specified as "planned radars" indicate the approximate locations for new radars. The radius is 180 km. (Map by Oddbjørn Thoresen, Observation Division, met.no)

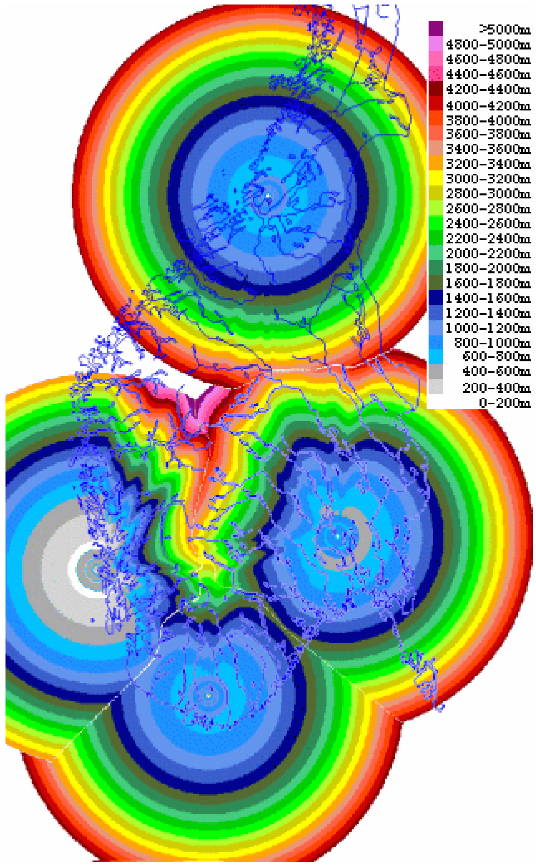

Fig. 2. Result of beam blocking model for radars Oslo, Hægebostad, Bømlo and Rissa (refractive index from standard atmosphere)

fit to the monthly average of the gauge/radar ratio at the gauges. Gauge accumulations are taken from met.no's climate database. Data from the climate stations is available with a delay of about one week. Quality controlled precipitation data is available with a delay of about 2–3 months. The following considerations lead to the present adjustment method:

- The dominating error source is beam blockage, not short term fluctuations of VRP
- The density of synoptic gauges is too low (28 gauges around radar Oslo) to describe the spatial pattern of the adjustment factor in near real time.
- The high density of climate gauges (about 260 around the Oslo radar) can be used to describe the spatial pattern of adjustment factors.
- Observation differences between radar and gauge require long time series for the generation of reliable adjustment factors.
- The gauge data used has undergone the routine quality control. The precipitation measurements from automatic gauges are not always reliable and real-time adjustment may make things worse.

First validations against catchment precipitation data and gauge measurements showed good agreement in summer (Gjertsen and Dahl, 2001), but further validation will be necessary. An example from the Oslo radar is shown in Fig. 4. The spatial adjustment removes the gauge-radar-bias successfully, the correlation is slightly improved and the RMS error is reduced. When polar volumes are available we will analyse the VRP to flag regions where data is missing due to beam overshooting.

3 Topographic correction

The spatial adjustment method performs best where short-term fluctuations of the VRP are small, and where the density of precipitation gauges is high compared to the terrain variations. Near the west coast, where topographic variations are strong, the network of gauges is less dense. Furthermore, for the Bømlo radar, a higher frequency of anaprop conditions can be expected due to the vicinity of the sea surface. There-

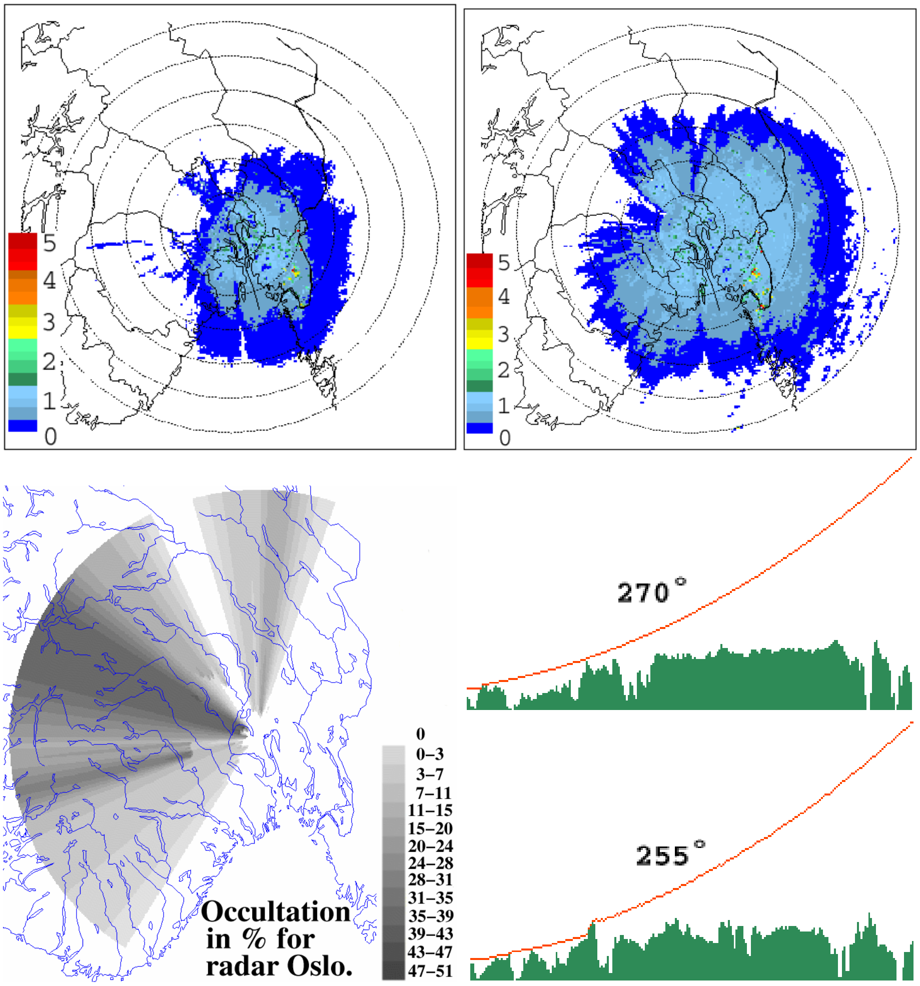

Fig. 3. Mean daily uncorrected radar estimation (a) November 1999 – February 2000, (b) April - June 2000, (c) radar beam blockage, and (d) two-dimensional cuts, for radar Oslo.

fore, we plan to improve the gauge adjustment by integrating correction for beam blockage and anomalous propagation.

The topographic correction is based on a model, which computes the altitude of the highest and lowest effective beam-trace over each radar pixel for each elevation from a numerical model and thus finds the difference between the theoretical and the real volume used to sample each radar pixel. We assume the highest/lowest effective beam trace for each elevation to be elevation angle $\pm 0.45°$ without terrain blockage. A number of beam traces are computed from radiosonde data by the equations

$$\text{curvature} = \frac{1}{6371} + \frac{dN}{dh}\frac{\cos(\alpha)\cdot 10^{-6}}{\text{refractive index}},$$

$$\text{refractive index} = 1 + N \cdot 10^{-6},$$

$$N = \frac{77.6}{T}\left(p + 4810 \cdot \frac{e_v}{T}\right),$$

$$\frac{dN}{dh} = \frac{\Delta N}{\Delta h},$$

where h is the altitude, α is vertical angle, N is refractivity, p is atmospheric pressure, T is temperature and e_v is the partial pressure of water vapour. The beam-trace is computed from curvature by a simple numerical method and used in a distributed model where each pixel is positioned in a cylindrical coordinate system. The topographic data is taken from a map from gtopo30 (US Geo-service), which is converted to UCS-coordinates in 1×1 km. resolution. When a grid point on the topographic map is higher than the computed lowest beam trace for the corresponding radar pixel, the precalculated beam trace closest to the topographic data is used as a new lowest beam trace for that azimuth angle. All parameters produced by the program can be checked by two-dimensional cuts for any azimuth angle out from the radar.

To avoid instability as the radius increases, the altitude of two neighbouring grid points in one radius-category must be interpolated to match the location of the centre of the grid points in the next radius-category. This will give a small truncation error in areas with rapid terrain variations. This error can move the indicated blockage one point sideways

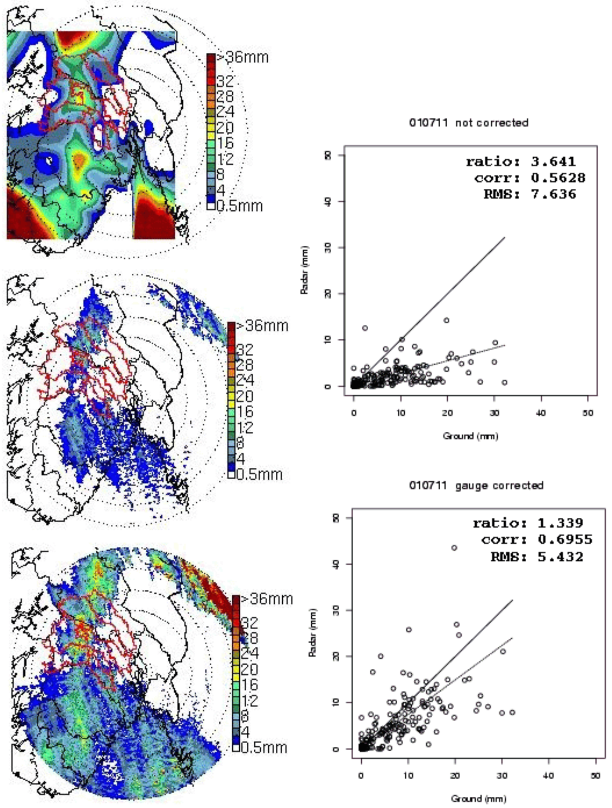

Fig. 4. The effect of gauge adjustment, example from 11 July 2001. The figure shows interpolated gauges (24-h-accumulation for all available gauges), uncorrected radar estimation, adjusted radar estimation and the corresponding scatter plots.

and make peaks of blockage over narrow sectors disappear as radius increases. If a blockage occurs very close to the radar, blockage from one point will spread to a large area on long distances. If the terrain variation within the area covered by one topographic grid point close to the radar is too large, the blockage pattern behind this point will not be correct. This is a problem due to the resolution of the topographic data and we have yet only tried maps with the same resolution as the radar-data files.

We will consider two different methods for producing correction coefficients. The simplest method is a linear correction to the volume used in the radar-equations. This method should be combined with corrections for the radars vertical reflectivity profile to produce a physically based correction for both effects. A more common correction-method is the NEXRAD method (Fulton, 1998), which uses a scheme with empirical correction-factors for predefined classes of occultation (degrees of blockage).

The program can produce correction matrices for each elevation in a set of files with polar volumes. In these matrices, all pixels which should be excluded from the final radar-dataset will be set to zero. This could be used to form a ducting-dependent pseudoCAPPI dataset. This pseudoCAPPI composition is generally not affected by terrain blockage, but the program will change elevation in cases with severe occultation. The method is implemented but is yet not tested.

To find anaprop and beam splitting effects, the program will check the difference in altitude between the endpoints of the different beam traces, identify the highest beam trace which could be said to be in the split (possibly with the use of some threshold-value), exclude all beam traces from this limit and downwards from the calculation of coefficients, and flag 'ducting' on the radar images. The major problem with the method seems to be getting the correct strength and thickness of the ducting layer from our present data sources (radiosonde, HIRLAM), but a severe case of beam splitting has already been modeled by the program from radiosonde data.

4 Summary and discussion

The spatial gauge adjustment method reduces the mean bias between radar estimates and gauge measurements. The method is implemented for the radars Oslo and Hægebostad. New radars located at the Norwegian west coast will require new methods for beam blockage correction and the removal of anaprop echoes. A model deriving beam propagation from actual radiosonde profiles and digital terrain model is now developed.

The most important task for the future will be the integration of the beam propagation model in a correction method combining physical correction with gauge adjustment. For the future we will try to combine height information from the model with polar volumes, find the lowest scan-angle which escapes the duct and analyse whether clutter signals can be identified/removed in specified regions.

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