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Enhancing radar estimates of precipitation over complex terrain using information derived from an orographic precipitation model

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SUMMARY

The objective of this paper is to present a radar-based quantitative precipitation estimation algorithm and assess its quality over the complex terrain of western Iceland. The proposed scheme deals with the treatment of beam blockage, anomalous propagation, vertical profile of reflectivity and includes a radar adjustment technique compensating for range, orographic effects and variations in the Z–R relationship. The quality of the estimated precipitation is remarkably enhanced after post-processing and in reasonably good agreement with what is known about the spatial distribution of precipitation in the studied area from both rain gauge observations and a gridded dataset derived from an orographic precipitation model. The results suggest that this methodology offers a credible solution to obtain an estimate of the distribution of precipitation in mountainous terrain and appears to be of practical value to meteorologists and hydrologists.

Introduction

The Icelandic Meteorological Office (IMO) operates a C-band non-Doppler weather radar located in southwest Iceland. The domain covered by this radar displays a complex topography including several mountain ridges and glaciers of hydrological importance. Until now, this radar has mainly been used qualitatively by weather forecasters to monitor precipitation systems and occasionally to study volcanic eruptions (Lacasse et al., 2004; Vogfjörð et al., 2005; Marzano et al., 2006), but no attempt to produce operational quantitative precipitation estimates (QPE) in real-time has been made. Errors and problems affecting the radar measurements are well known and the literature is abundant on the subject (see for instance Wilson and Brandes, 1979; Zawadzki, 1984; Collier, 1989; Joss and Waldvogel, 1990). These errors include among others the presence of ground clutter and anomalous propagation, partial or total beam occultation by obstacles, partial beam filling, beam overshooting, attenuation, spatio-temporal variation in the drop size distribution and variation in vertical profile of reflectivity (VPR) resulting from micro-physical processes and water phase of hydrometeors. In mountainous terrain and cold environment, some errors are enhanced and the use of radar data becomes more problematic (Bourrel et al., 1994; Joss and Lee, 1995; Borga et al., 2000). In particular, in order to avoid clutter contamination and beam occultation by topographic obstacles, the use of high elevation angles is required and may reduce the operational range of the radar for estimating precipitation at ground level. In addition, orographic effects such as enhancement of precipitation can be significant. Such effects are often concentrated within a shallow layer above the hills, typically in the lowest 1.5 km of the atmosphere (Hill et al., 1981) and are not easy to detect with radars because measurements are often made above the enhancement region in order to avoid clutters from the hill itself (Gray and Seed, 2000), making the measurement aloft unrepresentative of surface precipitation. Despite the sophistication of techniques developed in the past decades for mitigating all known sources of error, radar estimation of precipitation in complex terrain remains a challenge. The goal of this paper is to present the global methodology in development at IMO for making radar-based QPE in an operational environment and assess the quality that can be expected. This framework is intended for general application and is suitable for quantitative precipitation monitoring and hydrological applications. It is designed to deliver QPE that keeps consistency with daily precipitation in average, up to a range of approximately 120 km. Daily precipitation has been used until now in rainfall–runoff modeling (Jónsdóttir and Þórarinsson,

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2004; Rögnvaldsson et al., 2007) and this temporal resolution is compatible with the response time of the main river catchments under monitoring in southern Iceland. The radar-based QPE products are therefore suitable for this type of hydrological applications. The study is organized as follows: Section "Data" describes the data. The radar correction strategy is presented in Section "Radar processing" and addresses the treatment of several error sources mentioned earlier. This strategy consists of four main steps: (a) retrieval of reflectivity measurements (Z) from volume scan data and removal of known sources of errors, (b) conversion into rain-rate (R) and derivation of surface precipitation after VPR correction, (c) range adjustment and enhancement of the radar estimates over complex terrain on a pixel-to-pixel basis, using information derived from an orographic precipitation model and (d) mean field bias adjustment using a rain gauge network to account for temporal variations in the Z–R relationships. Section "Validation" analyses the performance of the correction schemes and Section "Summary and conclusions" concludes the paper.

Data

Radar data

The C-band non-Doppler Ericsson weather radar used in this study is located in southwest Iceland, 64.03°N, 22.64°W, at approximately 3 km from Keflavík airport and approximately 40 km from the city of Reykjavík (Fig. 1). The radar is situated at an elevation of 45 m.a.s.l. The half-power radar beam width is 0.9°. The radar reflectivity data used in this study are polar volumes made from 10 elevation angles (Table 1) every 15 min up to a range of 240 km with a radial resolution of 2-km and an azimuthal resolution of 1°. The radar electronic calibration is usually performed once a year. Blocking and possibly specular reflection due to the presence of the airport buildings in the vicinity are observed to affect several beams pointing toward the south at the lowest two elevation angles. The pixels affected by these problems are mainly located over sea. The analysed period is January 2005 to December 2006. The year 2006 is used to develop the methodology, and the year 2005 is kept for validation.

Table 1
Scanning strategy.

Elevation no.	1	2	3	4	5	6	7	8	9	10
Angle	0.5°	0.9°	1.3°	2.4°	3.5°	4.5°	6°	8°	10°	15°

Rain gauge data

The rain gauge network operated by IMO is made of three different gauge types, a manual type (Hellman) and two automatic types (Geonor and tipping-bucket). The Hellman type gauges are equipped with a wind-shield and used at the synoptic, climate and precipitation stations to record precipitation once or twice a day, at 09UTC and 18UTC. The Geonor type gauges are equipped with a wind-shield but not the tipping-bucket type gauges. Both automatic gauge types record precipitation with a temporal resolution of 10 min. These data have been quality controlled and accumulated over 24 h periods ending at 09UTC each day. Despite the quality control, errors may remain, especially for very light measurements. The reading practice of the different observers and the number of observations made per day (one or two) introduces variations in the minimum observed daily amount at the manual stations which may vary between 0.1 mm/day and 0.5 mm/day. Noise in the automatic rain gauge measurements affect the accuracy of the minimum measured daily precipitation which may vary between approximately 0.1 mm/day and 0.3 mm/day. Measurement errors such as due to wind, wetting and evaporation losses have been corrected according to the methodology proposed by Førland et al. (1996) for the Nordic gauges (see Crochet, 2007). The rain gauge network has been splitted into two subsets, a reference network made of stations delivering observations every day at 09UTC (synoptic and automatic) and a validation network made of (i) precipitation stations whose delivery is usually made once a

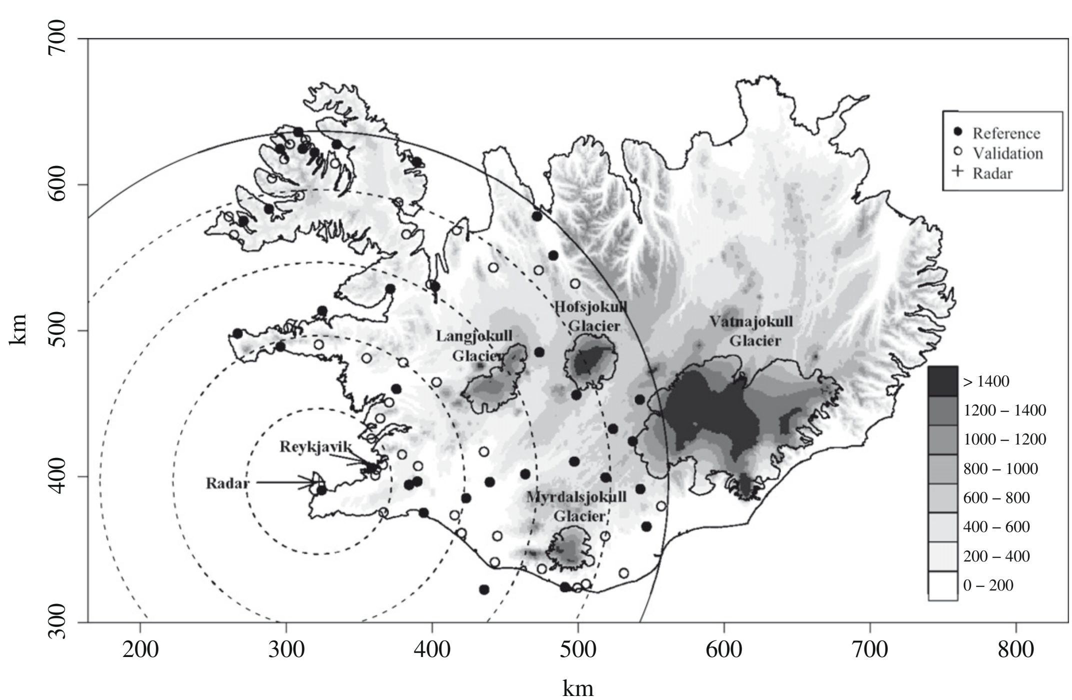

Fig. 1. Topography of Iceland (1-km resolution), rain gauge network used in the radar assessment and range rings at 50, 100, 150, 200 and 240 km from the radar. Filled symbols denote reference stations potentially available for daily adjustment. All reference stations within 160 km range have been used. Open symbols denote stations used for validation.