

## Validation of numerical simulations of precipitation in complex terrain at high temporal resolution

Teitur Arason, Ólafur Rögnvaldsson and Haraldur Ólafsson

### ABSTRACT

Atmospheric flow over Iceland has been simulated for the period January 1961 to July 2006, using the mesoscale MM5 model driven by initial and boundary data from the ECMWF. A systematic comparison of results to observed precipitation has been carried out. Undercatchment of solid precipitation is dealt with by looking only at days when precipitation is presumably liquid or by considering the occurrence and non-occurrence of precipitation. Away from non-resolved orography, the long term means (months, years) of observed and simulated precipitation are often in reasonable agreement. This is partly due to a compensation of the errors on a shorter timescale (days). The probability of false alarms (the model predicts precipitation, but none is observed) is highest in N Iceland, particularly during winter. The probability of missing precipitation events (precipitation observed but none is predicted by the model) is highest in the summer and on the lee side of Iceland in southerly flows.

**Key words** | dynamical downscaling, Iceland, MM5, QPF, rain gauge data, validation

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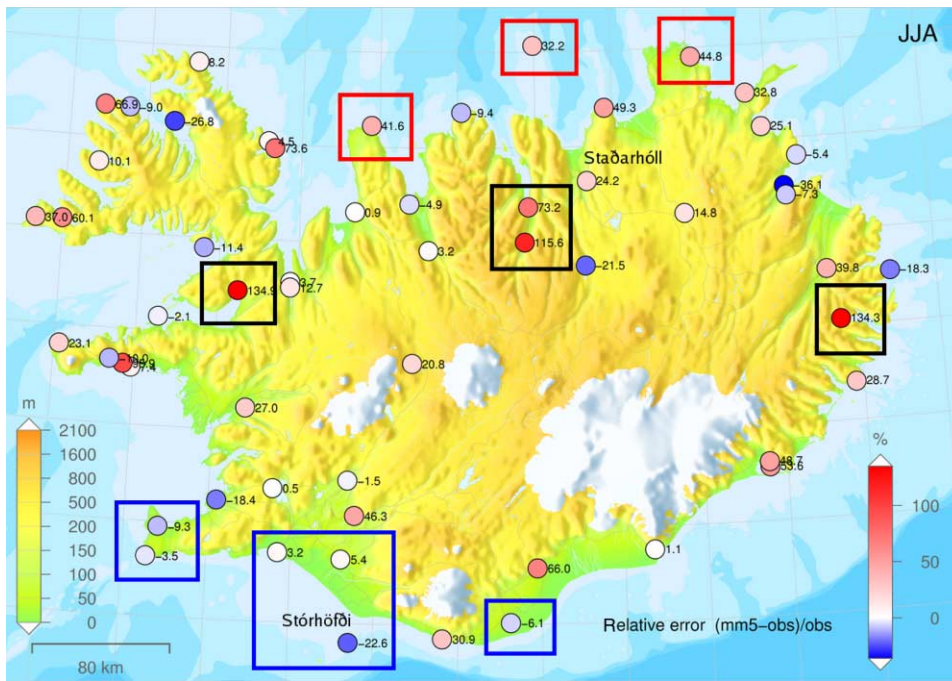
### INTRODUCTION

The 6-hourly ERA40 re-analysis (Uppala *et al.* 2005) of the ECMWF (European Centre for Medium-Range Weather Forecasts) has been dynamically downscaled for the period 1961–2006 using the numerical model MM5 (Grell *et al.* 1995) run at 8 km horizontal resolution on a  $123 \times 95$ -point grid with 23 vertical levels. The model set-up included the Grell cumulus scheme (Grell *et al.* 1995), the Reisner2 microphysics scheme (Thompson *et al.* 2004) and the MRF (Hong & Pan 1996) planetary boundary layer (PBL) scheme. The modelling approach is described in greater detail in Rögnvaldsson *et al.* (2007a) and Rögnvaldsson & Ólafsson (2008).

Previous studies (Rögnvaldsson *et al.* 2004, 2007a; Bromwich *et al.* 2005) have shown the combination of the Grell cumulus scheme, the Reisner2 microphysics scheme and the MRF PBL scheme to be a reliable set-up for

simulating precipitation over Iceland at 8 km resolution. Rögnvaldsson & Ólafsson (2002) also tested the sensitivity of simulated precipitation to the number of vertical levels (23 vs. 40) and to the size of the simulation domain. They found that the simulated precipitation is neither sensitive to domain size nor vertical resolution.

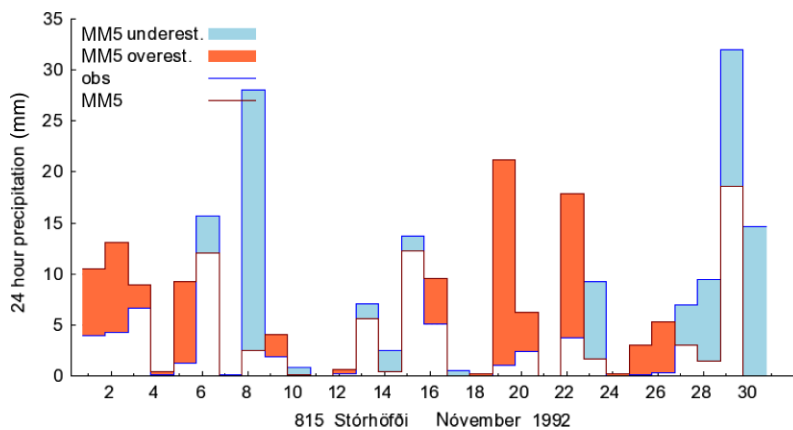
The 8 km grid size is a compromise between resolution and available computer resources. Simulation time is roughly proportional to the increase in horizontal resolution to the power of three. Hence, a 1 km grid would take 512 times longer to simulate than an 8 km grid. The issue of computational resources is one reason to simulate precipitation using a simpler and faster model. Crochet *et al.* (2007) used a linear model of orographic precipitation that included airflow dynamics, condensed water advection and downslope evaporation to simulate precipitation over



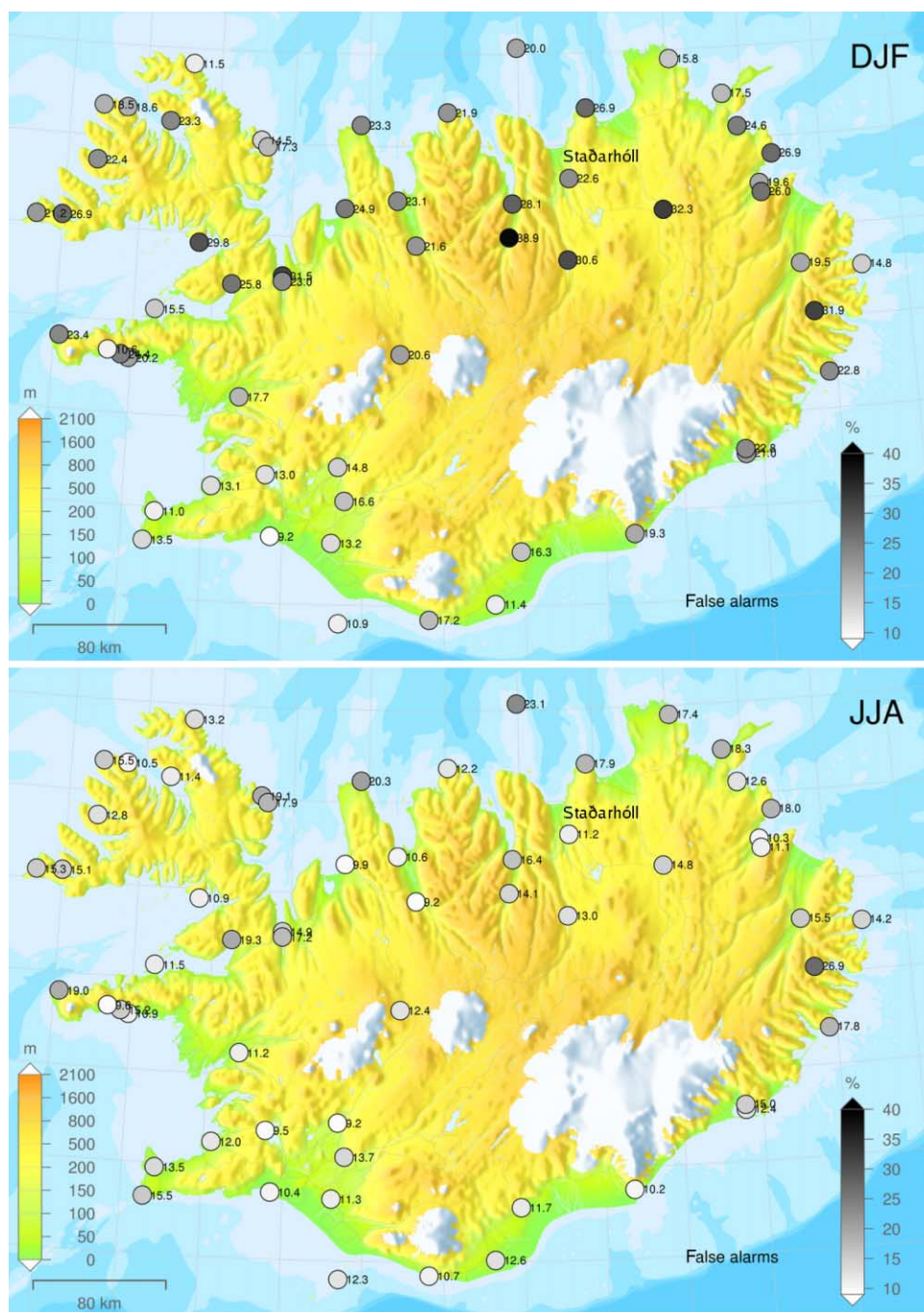
**Figure 1** | A topographic map of Iceland showing relative difference between simulated and observed accumulated precipitation,  $(mm_5 - obs) / obs$ , in June, July and August (JJA). Each coloured circle corresponds to a synoptic weather station. Station names are included at the stations referred to in this paper. The colour of the circle denotes the relative error in the simulations (colourbar to the right). The blue boxes enclose a few stations on flat land in S Iceland where the observations and simulations are in reasonable agreement. The red boxes draw attention to stations in N Iceland where the model overestimates precipitation, despite these stations being on flat land. Stations that have huge overestimation, which is almost certainly due to non-resolved orography, are enclosed in black boxes. The full colour version of all figures in this paper can be accessed by subscribers online at <http://www.iwaponline.com/nh/toc.htm>

Iceland at a 1 km horizontal resolution. The model was forced using the ERA40 dataset for the period 1958–2002. Their results suggested that the linear model did capture the main physical processes governing orographic generation of precipitation in the mountains of Iceland.

Climatological downscaling of precipitation is not only of use for hydrological purposes. The MM5 model, using a similar set-up as used in this study, is in operational use in Iceland for production of short- to medium-range weather forecasts. Although a hydrologist and a weather forecaster



**Figure 2** | Data from Stórhöfði, S Iceland, accumulated 24h precipitation (mm) (observed and simulated) for November 1992. Blue colour denotes the amount of MM5 underestimation and red denotes the MM5 overestimation.



**Figure 3** | Ratio (%) of "false alarms" (mm5 wet, obs dry) during winter (DJF, top) and summer (JJA, bottom).

would both like to be able to predict precipitation, their interests lie on different timescales.

In this paper we evaluate the quality of the simulations by comparing them to rain gauge measurements. This can be done by comparing long term means (months, years) of

simulated and observed precipitation. Such a comparison would be of use to a hydrologist but of somewhat limited value to a forecaster. We therefore set out to make comparisons that would assess strong and weak points of the simulations to aid forecasters. We want to know how

the errors in the simulated precipitation relate to other meteorological factors and if the performance depends on the temporal resolution of the data and geographical location. This work should shed a light on which aspects need improvement. Increased understanding of the limitations of the simulations on a short timescale will also be beneficial to their use in hydrological purposes at all timescales.

In this paper we describe the rain gauge data used in this study and how simulated precipitation compares to observations, followed by discussion and concluding remarks.

## RAIN GAUGE DATA

The dynamic downscaling of ECMWF data, using version 3–7–3 of the MM5 model, has been compared to precipitation observations from synoptic stations for the sub-period 1987–2003. Precipitation is measured at 18 UTC. The MM5 output was saved every 6 h, at 00, 06, 12 and 18. The comparison period is therefore 24 h (from 18 to 18). That period will from now on be referred to as an “event” in this paper.

The model output from a grid point can be considered as an area-averaged precipitation over an area of 64 km<sup>2</sup>. Therefore we do not expect the simulations to agree with measurements in areas with topography that is not resolved by the model. When comparing simulated and observed precipitation we must also bear in mind the general problems of precipitation observations. The most significant of these is the large undercatchment of solid precipitation in cold and windy climate, as in Iceland (Førland *et al.* 1996). Undercatchment of solid precipitation is dealt with by looking only at days when precipitation is presumably liquid (summer or temperature criteria) or by considering the occurrence and non-occurrence of precipitation.

## COMPARISON WITH OBSERVED PRECIPITATION

Figure 1 shows the relative error of the simulations, (mm5-obs)/obs, for the summer months June, July and August (JJA). It can be seen that the model behaves differently in N

and S Iceland for stations on flat land (minimal effect of non-resolved orography). For stations on flat land in the south, the simulations and observations are in overall reasonable agreement (see the stations in blue boxes in Figure 1). The model does, however, underestimate precipitation in flows from the SE (not shown). The model overestimates the precipitation for flat land stations in the north (see the red boxes in Figure 1). This is particularly true in northerly flow. For stations situated in orography that is obviously not resolved by the model (see the black boxes in Figure 1), the somewhat expected result of huge relative errors is clearly visible.

The 24 h precipitation amounts (observed and simulated) for November 1992 at Stórhöfði, S Iceland, is shown in Figure 2. The sums of observed and simulated precipitation for this month are almost identical. It is, however, clear that the agreement of the monthly sums is in large part due to compensation of the errors on a daily timescale. We define a “false alarm” event as a period of 24 h (from 18 to 18) where there is some precipitation in the simulations ( $r_{mm5} > 0.1$  mm) but the observations are dry ( $r_{obs} \leq 0.1$  mm). Figure 3, top, shows the percentage of events that fall into the false alarm category at each of the stations during the winter months December, January and February (DJF). Comparison with Figure 3, bottom, showing the false alarm percentage during June, July and August reveals that there is a relatively high probability of false alarms in winter, most notably for inland areas in N Iceland. In Figure 4 all false alarm events at Staðarhóll have been categorized according

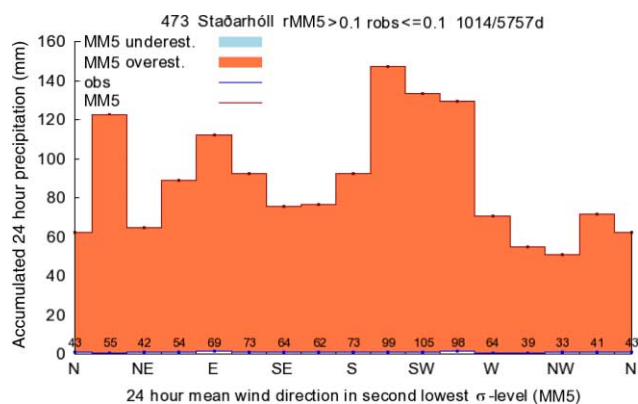
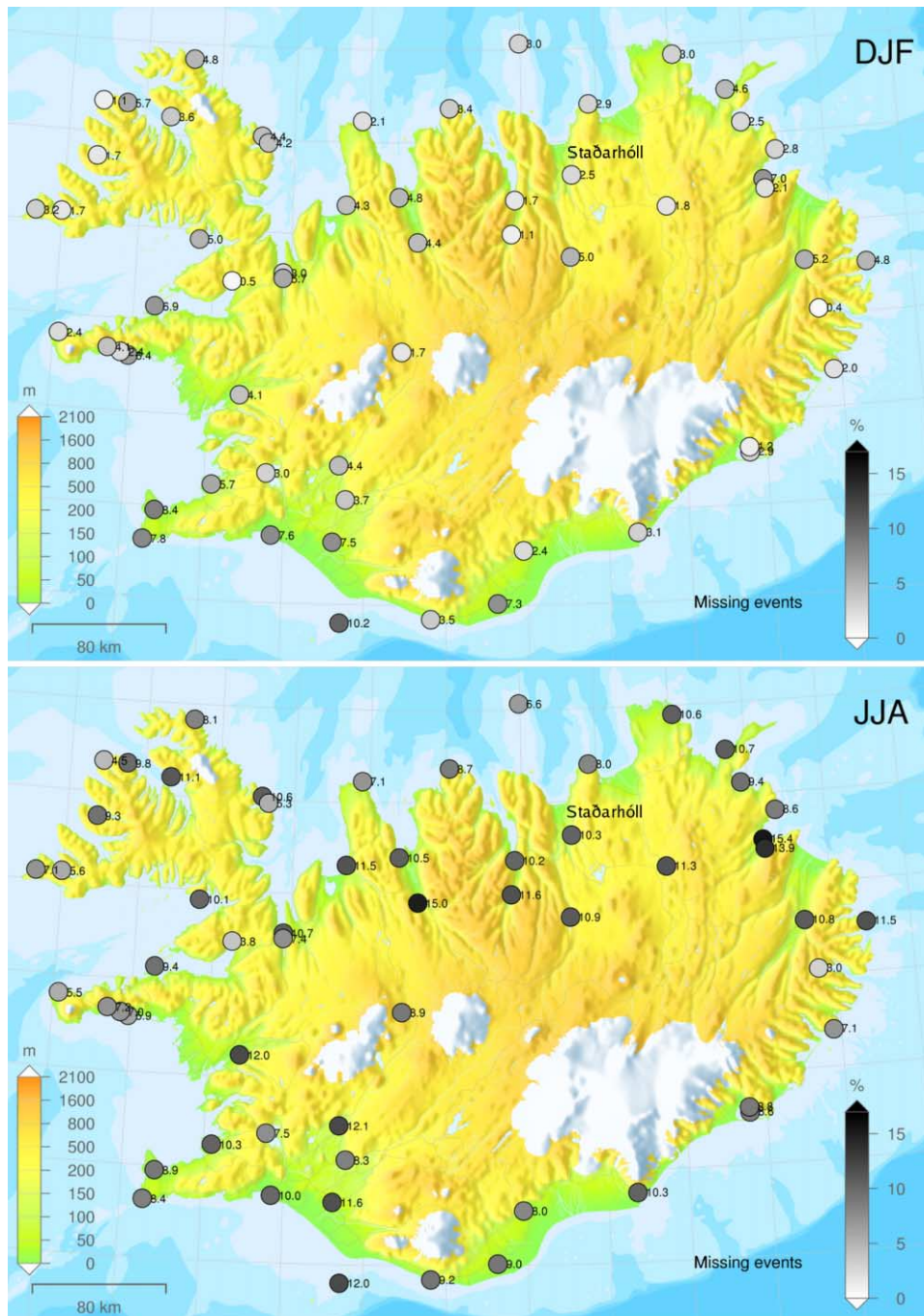


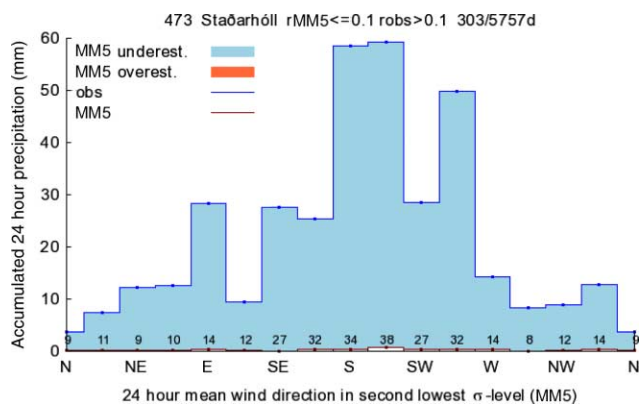
Figure 4 | All “false alarm” events from Staðarhóll, NE Iceland. The horizontal axis shows bins for 16 wind directions. The vertical axis shows the accumulated precipitation in each bin.



**Figure 5** | Ratio (%) of “missing” events (mm5 dry, obs wet) during winter (DJF, top) and summer (JJA, bottom).

to wind direction. We see that much of the precipitation during false alarm events is associated with southerly winds, which are generally not associated with precipitation in this area. A “missing” event is defined as a 24 h period where the simulations are dry ( $r_{\text{mm5}} \leq 0.1$  mm) but the observations

are wet ( $r_{\text{obs}} > 0.1$  mm). **Figure 5**, bottom, shows the percentage of missing precipitation events. It reveals that there is a low probability of missing events in the winter, but much higher in the summer. In **Figure 6**, the precipitation during missing events (precipitation observed, but not



**Figure 6** | Accumulated precipitation for individual wind directions during all “missing” events at Staðarhóll, N Iceland (MM5 dry, obs wet).

simulated) at Staðarhóll has been grouped according to the simulated low-level wind direction. Again, we see that southerly winds (when Staðarhóll is in the lee of Iceland) are the main culprit.

## DISCUSSION

In view of the important uncertainties associated with precipitation processes and the complex nature of precipitation distribution in real flows in the vicinity of mountains, the overall results must be characterized as good. One reason for this must be the fact that most of the precipitation in Iceland is associated with large-scale systems and the precipitation distribution within such systems over complex terrain can indeed be predicted with much greater skill than the distribution of convective precipitation (Dorninger *et al.* 2008). However, it should be kept in mind that some of the results presented in this paper are valid for timescales of several months and errors on the timescale of a passing front are higher. Care should therefore be taken when interpreting the results from Figure 1 in the context of forecasting individual events.

Even though a horizontal resolution of 8 km permits the representation of most of the major mountain ranges, the steepness of the topography is underestimated at many locations. So are the strong precipitation gradients that have been observed (Brynjólfsson & Ólafsson 2009). Simulations of flow in the mountains of SW Iceland have shown that much improvement is to be gained locally when

the horizontal resolution is increased from 8 to 4 km and even from 4 to 2 km (Rögnvaldsson *et al.* 2007b). Similar improvements of the present results through increased resolution can be expected for other parts of Iceland that also have narrow mountain ranges.

Although much of the errors in the simulations can be related to non-resolved orography, this can not easily be done for features such as the overestimation of precipitation away from the mountains in the north and underestimation of precipitation in winds from the southeast over flat land in the southwest. The reasons for these features are unclear. The overestimation of precipitation in the north emanates from cases of both southerly and northerly winds. An overestimation, reminiscent of the southerly flows, can be seen in the MM5 simulations of Schwitalla *et al.* (2008) at some distance downstream of the Black Forest mountain range (cf. Figure 7 in Schwitalla *et al.* 2008). This more distant lee-side problem should be distinguished from the excessive dryness of the model immediately above the lee slopes (Rögnvaldsson *et al.* 2007b; Schwitalla *et al.* 2008). A further analysis of the errors requires precipitation observations with higher temporal resolution and observations of the structure of the vertical profile of the atmosphere, including microphysical properties.

## SUMMARY AND CONCLUSIONS

The numerical model MM5, run at a horizontal resolution of 8 km, has been used to downscale the 6-h analysis of the ECMWF over Iceland. A systematic comparison with observed precipitation for the period 1987–2003 has been presented. The main outcome of this comparison is:

- Away from non-resolved orography, long term (months, years) sums of simulated precipitation are quite correct in the south but too high in the north. This is partly due to compensating errors on a smaller timescale (days).
- The probability of false alarms (the model predicts precipitation, but none is observed) is highest in N Iceland, particularly during winter.
- The probability of missing precipitation events is highest in the summer and on the lee side of Iceland in southerly flows.

- Precipitation is underestimated in southeasterly flows at the SW coast of Iceland and is overestimated at the N coast of Iceland. This cannot only be explained by non-resolved orography.

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