

DYNAMICAL DOWNSCALING OF PRECIPITATION – PART II: COMPARISON WITH RAIN GAUGE AND HYDROLOGICAL DATA

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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. Firstly, 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). Probability of false alarms (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 inland in N-Iceland. Secondly, model output is used as input to the WaSiM hydrological model to calculate and compare the runoff with observed runoff from six watersheds in Iceland. It is found that model results compare favourably with observations.

INTRODUCTION

The 6-hourly ERA40 re-analysis of the ECMWF have been dynamically

downscaled for the period 1961–2006 using the numerical model MM5 (Grell et al., 1995). The modelling approach is described in detail in Rögnvaldsson et al. (2007, 2008).

Climatological downscaling of precipitation is of use for hydrological purposes. The MM5 model, using a similar setup 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 would both like to be able to predict precipitation, their interests lie on different timescales.

In this paper we use output from the MM5 model as input to the WaSiM hydrological model (Jasper et al., 2002) for the same six watersheds as used for validation purposes by Rögnvaldsson et al. (2007) and compare the simulated discharge with observed discharge. We also 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 for a forecaster. We therefore set out to making 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. The work should shed a light on which aspects need improving. Increased understanding of the limitations of the simulations on a short timescale will also be beneficial for their use in hydrological purposes.

This paper begins with a short description of rain gauge data used in this study and how simulated precipitation compares to observations. Following is a comparison of modelled discharge to observed discharge 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 twice per day on the chosen synoptic stations, at 09 and 18 UTC. The MM5 output was saved every 6 hours, at 00, 06, 12 and 18. The shortest comparison period is therefore 24 hours (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 km². Therefore we do not expect the simula-

tions 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

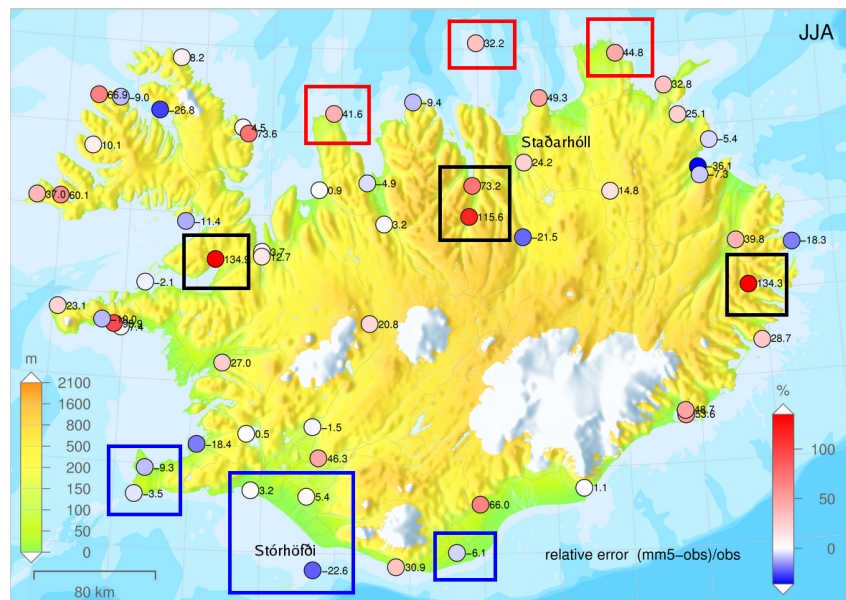


Figure 1: A topographic map of Iceland showing relative difference between simulated and observed accumulated precipitation, $(mm5-obs)/obs$. Each coloured circle corresponds to a synoptic weather station. Station names are included at the stations referred to in this paper. The colour of the circle denotes the relative error in the simulations (colourbar to the right) for the summer months June, July and August (JJA). 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.

behaves differently in N- and S-Iceland for stations in flat land (minimal effect of non-resolved orography). For stations on flat land in the South, the simulations and observations are in an overall reasonable agreement (see stations in blue boxes in Fig. 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 (red boxes in Fig. 1). This is particularly true in northerly flow. For stations situated in orography that is obviously not resolved by the model (black boxes in Fig. 1), the somewhat expected result of huge relative errors is clearly visible.

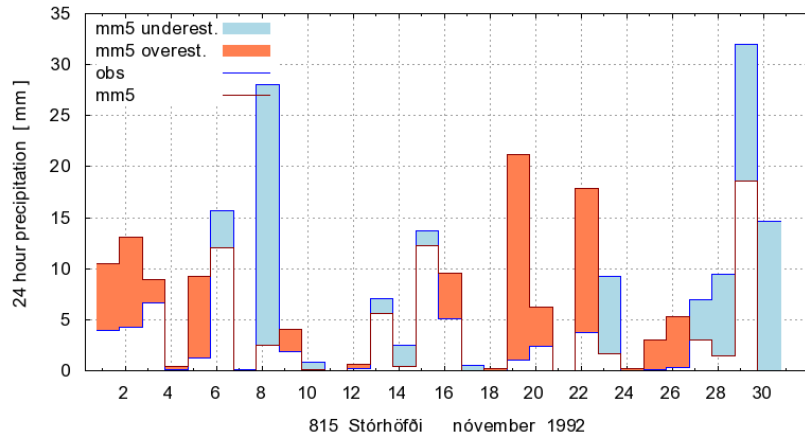


Figure 2: Data from Stórhöfði, S-Iceland, accumulated 24 hour precipitation [mm] (observed and simulated) for November 1992. Blue colour denotes the amount of mm5 underestimation and red denotes the mm5 overestimation.

The 24 hour precipitation amounts (observed and simulated) for November 1992 at Stórhöfði, S-Iceland, is shown in Fig. 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 hours (from 18 to 18) where there is some precipitation in the simulations ($r_{mm5} > 0.1$) but the observations are dry ($r_{obs} \leq 0.1$). Figure 3 shows the percentage of events that fall into the false alarm category on each of the stations during the winter months December, January and February (DJF). Comparison with maps from the other seasons (not shown) reveals that there is increased probability of false alarms in winter, most notably for inland areas in N-Iceland. In Fig. 4 all false alarm events at Staðarhóll have been categorized according to wind direction. We see that most of the precipitation during false alarm events is associated with southerly winds.

A "missing" event is defined as a 24 hour period where the simulations are dry ($r_{mm5} \leq 0.1$) but the observations are wet ($r_{obs} > 0.1$). Figure 5 shows the percentage of missing events during the summer months (JJA) at each of the observation stations. There is higher probability of missing events during summer than in winter (map not shown). In Fig. 6 the precipitation during missing

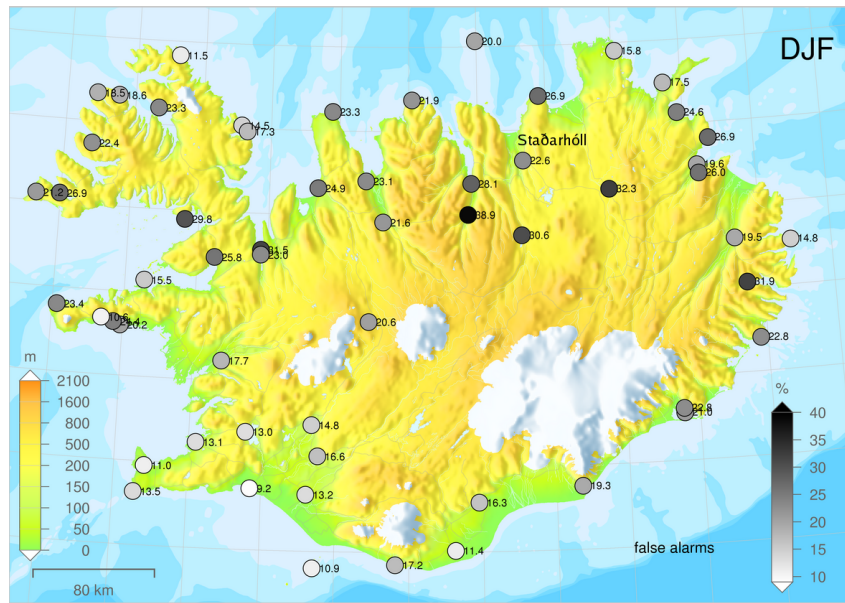


Figure 3: Ratio [%] of "false alarms" (mm5 wet, obs dry) during winter (DJF).

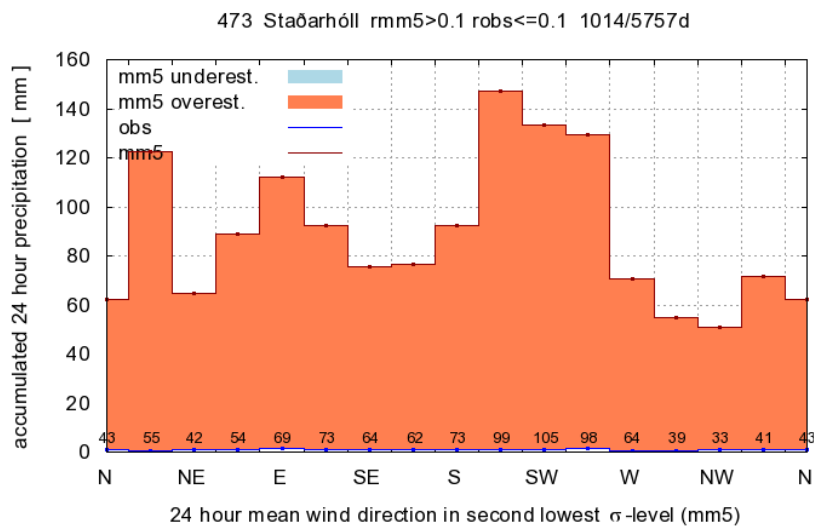


Figure 4: All "false alarm" events from Staðarhóll, NE-Iceland. The horizontal axis shows bins for 16 wind directions. The vertical axis shows the accumulated precipitation in each bin.

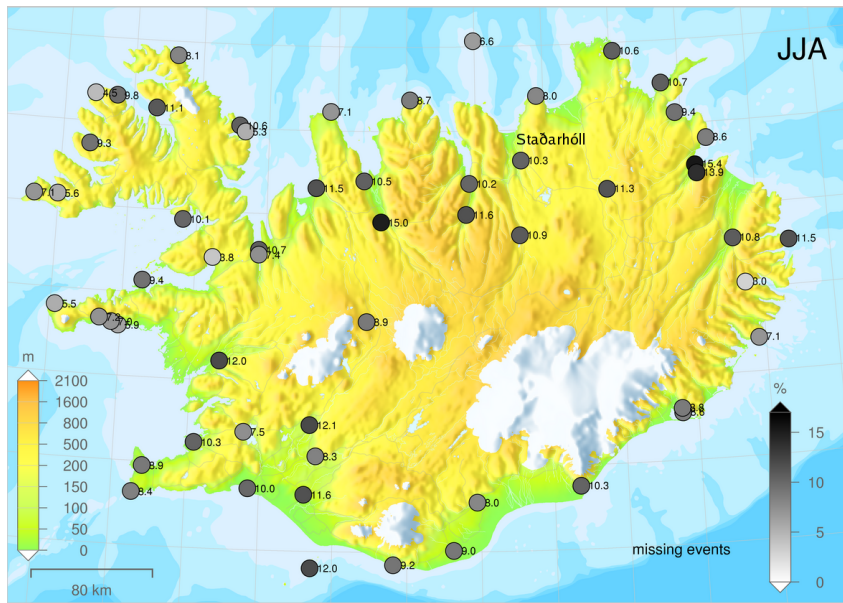


Figure 5: Ratio [%] of "missing" events (mm5 dry, obs wet) during summer (JJA).

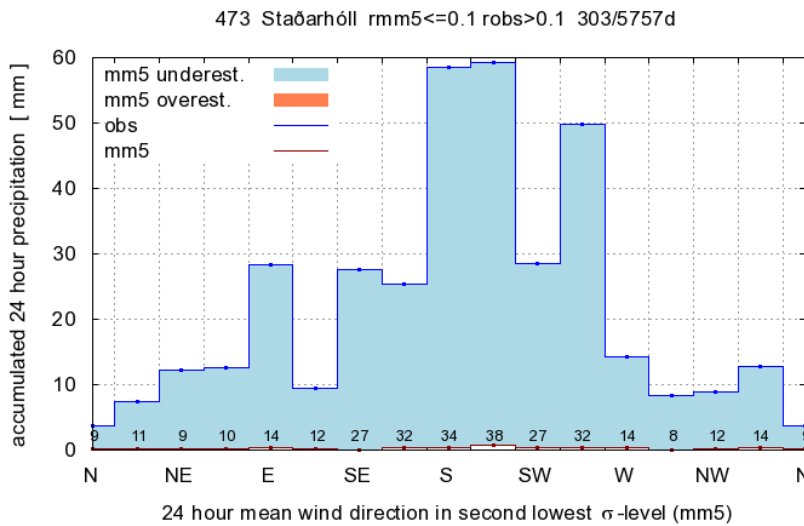


Figure 6: All "missing" events from Staðarhóll, NE-Iceland. Horizontal axis shows bins for 16 wind directions. The vertical axis shows precipitation sum in each bin.

events (only observed precipitation) at Staðarhóll has been grouped into bins of different wind direction and the precipitation in each bin added up. Again we see that southerly winds (lee side) are the main culprit.

COMPARISON WITH HYDROLOGICAL DATA

Several authors have used runoff measurements for validation of precipitation simulated by atmospheric models. Benoit et al. (2000) reported some of the advantages of using one-way coupling of atmospheric and hydrological models, calibrated with observed discharge data, for validation of precipitation calculated by the atmospheric models. They concluded that stream flow records give a better estimate of the precipitation that has fallen over a region than point precipitation measurements, and even though there were uncertainties related to their hydrological model (WATFLOOD), it was sufficiently sensitive to help improve atmospheric models. Jasper and Kaufmann (2003) compared results from WaSiM watershed models that were on one hand driven by meteorological observations and on the other hand driven by data from atmospheric models. They concluded that the hydrological model was sufficiently sensitive to provide substantial information for the validation of atmospheric models.

Jónsdóttir (2008) used the latest output from version 3–7–3 of the MM5 model as input to the WaSiM model for the period 1961–1990 to create a runoff map of Iceland. The difference between measured and modelled discharge was in general found to be less than 5% although larger discrepancies were observed (see Fig. 7). For a full list of stations we refer to Table 2 in Jónsdóttir (2008)). The WaSiM model was not run with a groundwater module. Instead precipitation simulated by MM5 was scaled in order to make the simulated water balance fit the measured water balance for individual watersheds, a detailed description can be found in Section 6 in Jóhannesson et al. (2007) and Jónsdóttir (2008). Therefore, comparison of measured and simulated water balance cannot be directly used for validation of the model-generated precipitation. According to the non-scaled MM5 output for the period 1961–1990, mean precipitation for the whole of Iceland was 1790 mm y^{-1} . After scaling the precipitation, this value was reduced to 1750 mm y^{-1} , *i.e.* by approximately 2%. This difference can, to some extent, be explained by the fact that precipitation falls on porous post-glacial lava in some areas and flows through groundwater aquifers to the ocean without participating in surface runoff. Earlier research (Tómasson, 1982) have estimated this flow to be on the order of $33\text{--}62 \text{ mm y}^{-1}$. This comparison of total accumulated scaled and non-scaled precipitation indicates that MM5 produces comparatively unbiased precipitation estimates when integrated over the

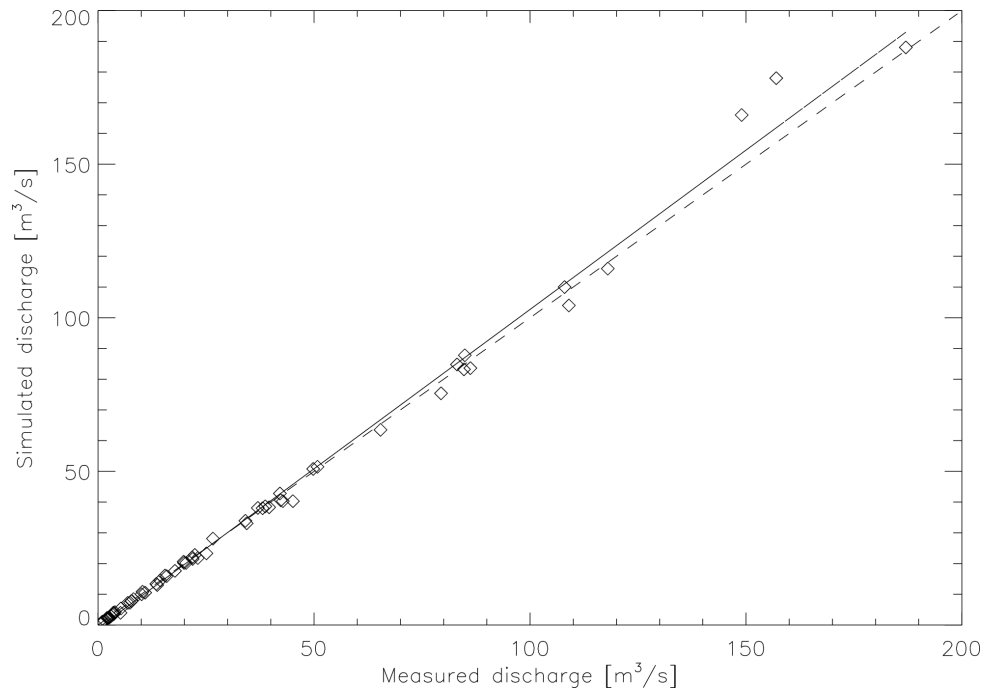


Figure 7: Measured and simulated (WaSiM/MM5) mean discharge [m^3s^{-1}] at the watershed gauges. Dashed line indicates a perfect fit, solid line represents the linear best fit between the measured and simulated discharge.

whole of Iceland.

Table 1 compares observed and modelled discharge from six watersheds that are not much affected by groundwater flow (the same discharge stations as used for validation of an earlier MM5 model version by Rögnvaldsson et al., 2007; *cf.* Table 1 and Fig. 2). Here, un-scaled precipitation is used in the hydrological modelling in order to obtain an independent validation of the precipitation generated by MM5. For four out of six watersheds, the difference in the water balance is reduced when the newer version of the MM5 model is used compared with the results obtained with the earlier model version. The relative difference between the simulated and observed water balance is in the range -8 to 13% , with four of the six values in the range -4 to 5% , indicating a satisfactory performance of the model.

CONCLUSIONS

The numerical model MM5, run at a horizontal resolution of 8 km, has been used to downscale over Iceland the 6-hourly analysis of the ECMWF over a period of 46 years. A systematic comparison with observed precipitation for the sub-period 1987–2003 has been presented as well as comparison of simulated discharge with observed discharge. The main results are:

Table 1: Comparison of observed and simulated discharge [m^3s^{-1}] at six discharge stations using unscaled modelled precipitation from versions 3-5 and 3-7 of the MM5 model. Note that the simulation periods are not the same for the two model versions. Hence, the measured discharge can differ somewhat between the columns corresponding to the two versions. The discharge stations are, respectively; Vatnsdalsá river, Norðurá river, Fossá í Berufirði river, Hvalá river, Fnjóská river and Hamarsá river. The simulation periods are, respectively; 1963–2001, 1971–2001, 1963–2001, 1976–2001, 1976–2001 and 1991–2004.

Station #	MM5 V3-5			MM5 V3-7		
	Q_{meas}	Q_{calc}	Difference	Q_{meas}	Q_{calc}	Difference
45	12.3	13.4	8.9%	10.3	10.8	5.0%
128	29.4	32.2	9.7%	22.4	25.3	13.0%
148	9.1	10.4	14.3%	8.2	7.9	–4.0%
198	26.8	25.4	–5.2%	15.5	15.3	–1.0%
200	48.4	53.9	11.4%	39.6	40.3	2.0%
265	19.6	20.8	6.1%	19.9	18.4	–8.0%

- 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 time scale (days).
- Probability of false alarms (model predicts precipitation, but none is observed) is highest in N-Iceland, particularly during winter.
- Probability of missing precipitation events is highest in the summer inland and on the lee side of Iceland in southerly flows.
- Precipitation is underestimated in SE flows in SW-Iceland but precipitation is overestimated in northerly flows in N-Iceland. This cannot only be explained by non-resolved orography.
- Simulated discharge compares favourably with observed discharge for the majority of observation sites, indicating a satisfactory performance of the model.

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