# DYNAMICAL DOWNSCALING OF PRECIPITATION – PART I: COMPARISON WITH GLACIOLOGICAL 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. The simulated precipitation is compared to estimates derived from mass balance measurements on the Icelandic ice caps. It is found that the simulated precipitation compares favourably with the observed winter balance, in particular for Hofsjökull, where corrections to take liquid precipitation and / or winter ablation into account have been made, and for the comparatively high altitude outlet glaciers Dyngjujökull and Brúarjökull, where such corrections are relatively unimportant.

## INTRODUCTION

The geographical distribution of precipitation in Iceland is poorly known but very important for hydrological applications, both in general and particularly in the context of climate change. Therefore, an extensive task carried out in the recent VO project (Jóhannesson et al., 2007) was concerned with modelling of precipitation and a compilation of precipitation data sets on a regular grid covering the whole country. These data sets provide the opportunity to model river runoff and glacier mass balance both in the current climate and also in a hypothetical future climate based on the CE / VO climate change scenarios.

The climate of Iceland is largely governed by the interaction of orography and extra-tropical cyclones, both of which can be described quite accurately by present day atmospheric models. As a result, dynamical downscaling of the climate, using physical models, gives valuable information about precipitation distribution, especially in the data-sparse highlands.

In this paper we compare dynamical downscaling of large-scale meteorological fields provided by the ERA40 reanalysis (Uppala et al., 2005) to precipitation estimates derived from mass balance measurements on the Icelandic ice caps. The dynamical downscaling is done by using the mesoscale MM5 model (Grell et al., 1995).

This paper begins with a description of the model approach, followed by comparison of the model results to data and concluding remarks.

## MODELLING WITH THE MM5 MODEL

The idea of using limited area models (LAMs) for regional climate simulations was introduced by Dickinson et al. (1989) and refined by Giorgi (1990). One of the benefits of such an approach is that it is relatively inexpensive in terms of computer resources used for simulations of the atmospheric flow at relatively high spatial and temporal resolutions. As resolution is increased, processes governed by the interaction of the large scale flow and topography become better resolved by the models. One drawback of this approach which is not present in global climate models is that the simulations are dependent on the lateral boundary conditions. These can constrain the model dynamics and hence affect the results (*e.g.* Warner et al., 1997). To minimize the constraining effects of the boundary conditions, Qian et al. (2003) suggested consecutive short term integration, overlapping in time as to minimize the effects of spin-up, instead of a single long term integration. Other investigators (*e.g.* Giorgi and Mearns, 1999) opt for longer integration times, emphasising the importance of the model to be free to develop its own internal circulations. Liang et al. (2004) used this approach when simulating precipitation over the U.S. during 1982–2002 using the MM5-based regional climate model CMM5.

Several case studies investigating orographic forcing of precipitation have been made in recent years. Chiao et al. (2004) used the MM5 model at a 5 km horizontal resolution to simulate a heavy precipitation event during MAP IOP–2B. The precipitation was satisfactorily reproduced by the model although the total amount of precipitation was slightly higher than measured by rain-gauges. Buzzi et al. (1998) simulated a 1994 flooding event in northwestern Italy. The role of orography was found to be crucial in determining the precipitation distribution and amount.

Atmospheric flow over Iceland was simulated for the period January 1961 through June 2006 using version 3–7–3 of the PSU/NCAR MM5 mesoscale model (Grell et al., 1995). The domain used is $123 \times 95$ points, centered at

64° N and 19.5° W, with a horizontal resolution of 8 km. There are 23 vertical levels with the model top at 100 hPa and model output is every 6 hours. The domain setup is shown in Figure 1. The MM5 model was used with initial and lateral boundaries from the ERA40 re-analysis project to 1999. After that date, operational analysis, from the ECMWF were used. The ERA40 data were interpolated from a horizontal grid of 1.125° to 0.5° prior to being applied to the MM5 modelling system. The modelling approach differs from that used by Bromwich et al. (2005). Instead of applying many short term (*i.e.* on the order of days) simulations and frequently updating the initial conditions, the model was run over a period of approximately six months with only lateral boundary conditions updated every six hours. This was made possible by taking advantage of the OSU land surface model (Chen and Dudhia, 2001).

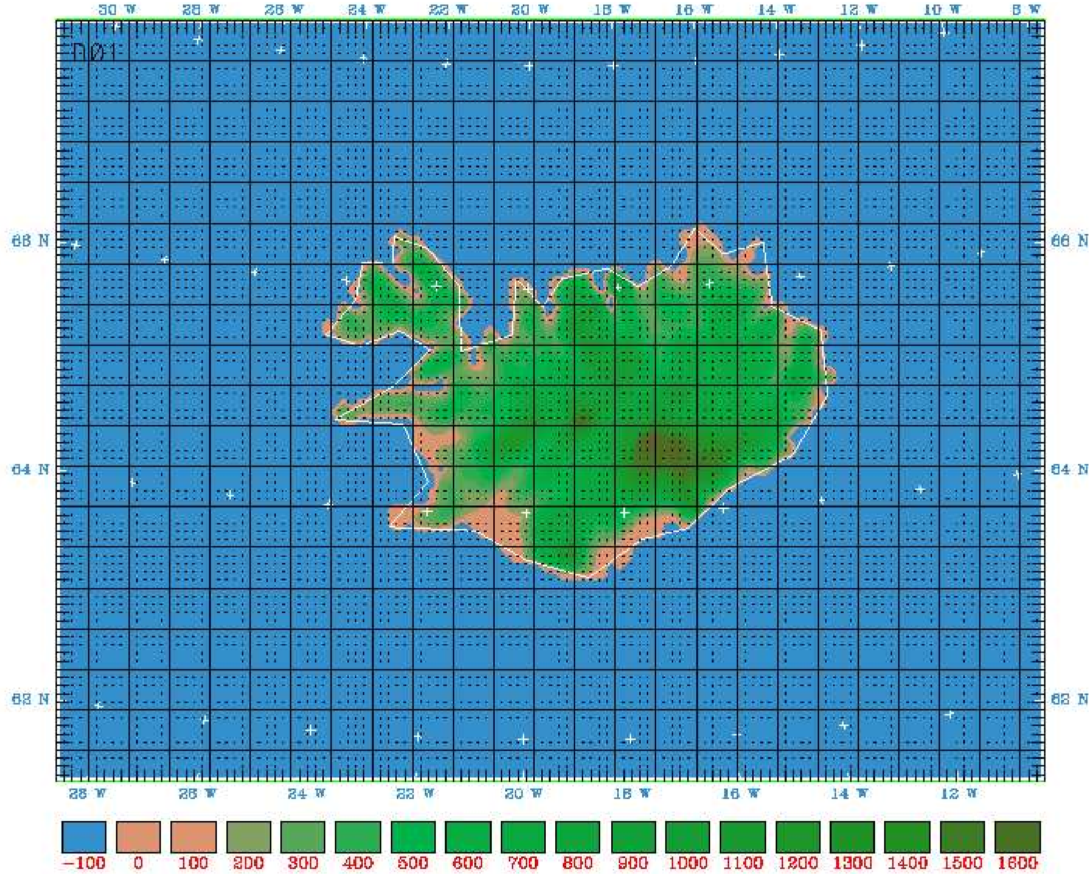

**Figure 1:** Domain setup of the MM5 model, horizontal grid size is 8 km.

## VERIFICATION OF SIMULATED PRECIPITATION

Rögnvaldsson et al. (2007) simulated atmospheric flow over Iceland for the period September 1987 through June 2003 using version 3–5–3 of MM5 driven by initial and boundary data from the ECMWF. The simulated precipitation was compared with two types of indirect precipitation observations. Firstly, winter balance on two large outlet glaciers in SE-Iceland and on two large ice caps in central Iceland. Secondly, model output was used as input to the WaSiM hydrological model to calculate and compare the simulated runoff with observed runoff from six watersheds in Iceland for the water years 1987–2002. Model precipitation compared favourably with both types of validation data.

## COMPARISON WITH GLACIOLOGICAL DATA

The spatial variability of the mass balance on large ice masses, such as Vatnajökull and Langjökull ice caps, can be mapped given data along several profiles extending over the elevation range of the ice caps. Mass balance has been observed on parts of Vatnajökull ice cap in SE-Iceland since 1991 (Björnsson et al., 1998) and from 1996 on Langjökull ice cap, central Iceland (Björnsson et al., 2002) (see location map on Fig. 2). Here, we use measurements of (accumulated) winter mass balance, expressed in terms of liquid water equivalents. Björnsson et al. (1998) estimated the uncertainty of the areal integrals of the mass balance to be a minimum of 15%. Due to surging of the Dyngjujökull glacier in 1998–2000, the uncertainty is considerably greater for this period and the following winter (Pálsson et al., 2002a). As yet unpublished data for the past few winters are from Björnsson and Pálsson[1]. The ice caps and typical locations of the mass balance stakes are depicted in Figure 2.

Mass balance on Hofsjökull ice cap has been observed at sites along profile HN (*cf.* Fig. 2) since 1987 and along profiles HSV and HSA since 1988 (Sigurðsson et al., 2004). In our model configuration the maximum elevation of the Hofsjökull ice cap is approximately 1540 metres, *i.e.* more than 250 metres lower than in reality. Hence, we use area-integrated data from an elevation range of approximately 1450–1650 metres along the three profiles HN, HSV and HSA (Jóhannesson et al., 2006). The winter balance on Hofsjökull has been modelled to estimate the amount of precipitation that falls as rain and ablation that may take place during the winter season. These estimates have been added to the measured winter balance to produce estimates of total precipitation at the measurement sites. This correction has not been carried out for Vatnajökull and Langjökull. The amount of liquid precipitation and winter ablation, therefore, has to be implicitly considered when comparison is made between precipitation simulated by MM5 and the glaciological measurements

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[1] Helgi Björnsson and Finnur Pálsson, Institute of Earth Sciences and Science Institute, University of Iceland, personal communication.

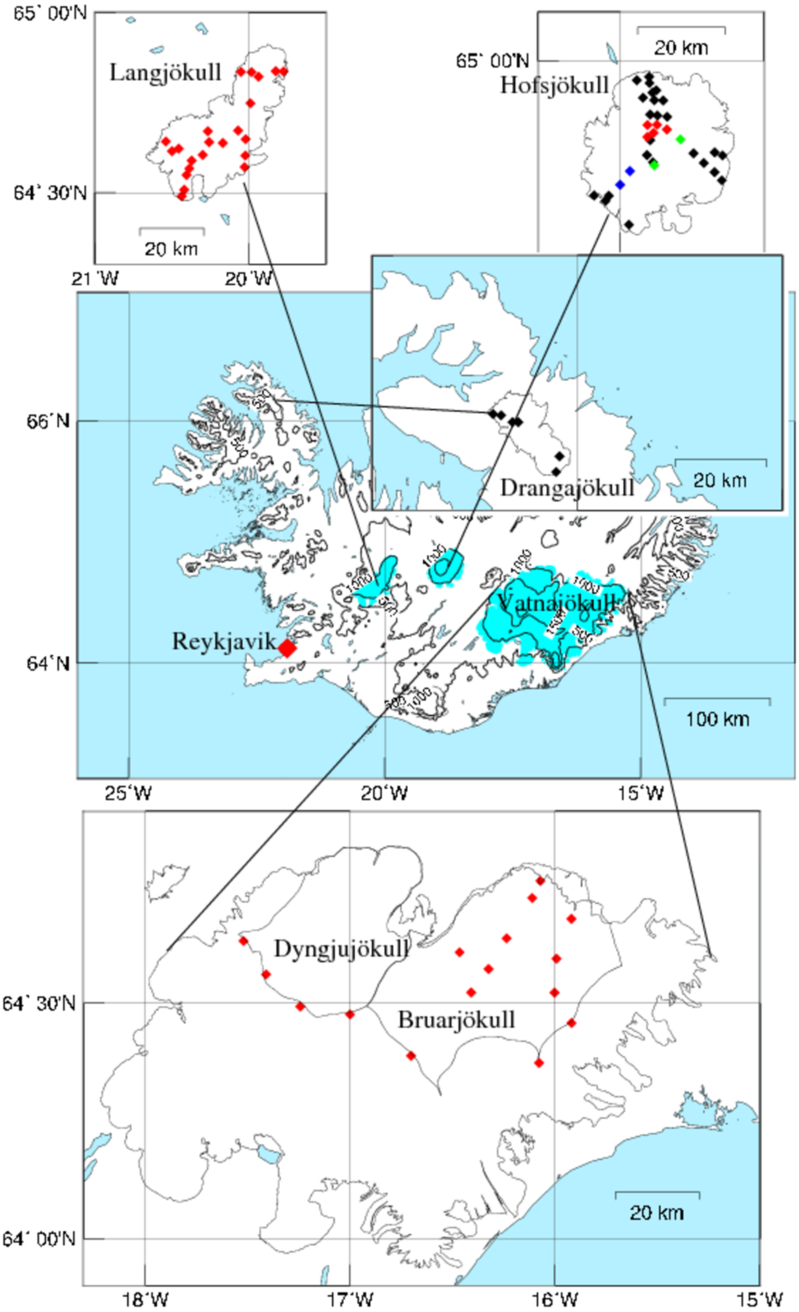

**Figure 2:** Overview of the six ice caps and glaciers used for validation purposes, dots indicate a typical location of observation sites. Red dots on Hofsjökull glacier are along profiles HN (N-part), blue dots along profile HSV (SW-part) and green dots along profile HSA (SE-part), observations at locations shown in black at Hofsjökull have not been used in this study. Drangajökull is split up in two regions, NW- and SE-part (*cf.* Table 1).

for Vatnajökull and Langjökull as discussed below.

The simulated winter precipitation at Hofsjökull ice cap is in good agreement with observations (*cf.* Fig. 3) over the northern part of the ice cap (HN,

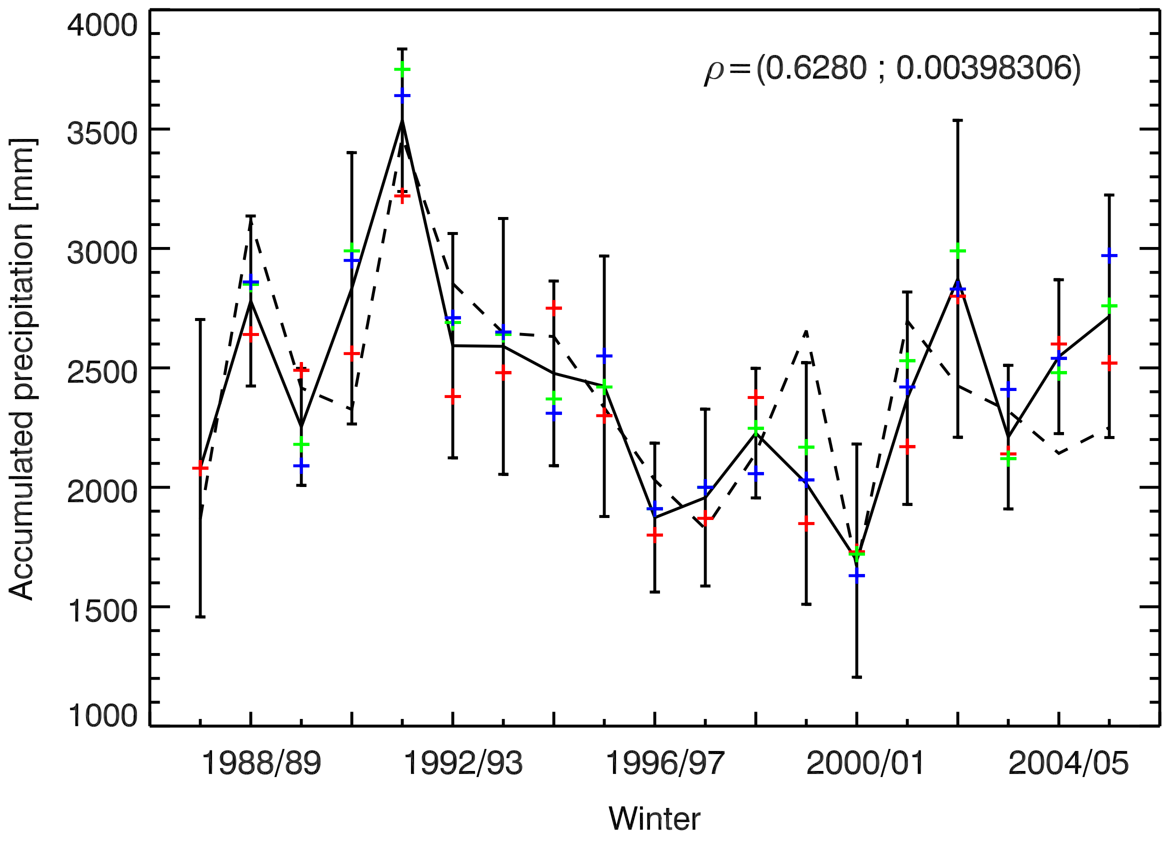

**Figure 3:** Estimated mean accumulated winter precipitation [mm] along profiles HN (N-part), HSA (SE-part) and HSV (SW-part) at altitudes between 1450 and 1650 metres (solid line, Jóhannesson et al., 2006). Dashed line represents simulated precipitation by MM5 (nine point average) at Hofsjökull ice cap. Red, green and blue crosses represent mean winter balance values at stakes along profiles HN, HSA and HSV respectively within the altitude interval 1440–1680 metres (*cf.* Fig. 2). Error bars indicate the standard deviation of the observations. Observed values from individual snow stakes are from Sigurðsson et al. (2004), Sigurðsson and Sigurðsson (1998) and Sigurðsson and Thorsteinsson (personal communication).

red dots, *cf.* Fig. 2), the SE-part (HSA, green dots, *cf.* Fig. 2) and the SW-part (HSV, blue dots, *cf.* Fig. 2). The solid line in Figure 2 shows the average of the observed winter precipitation, corrected to take liquid precipitation and/or winter ablation into account, at altitudes between 1450 and 1650 metres at locations HN, HSA and HSV. The dashed line represents precipitation simulated by MM5 (nine point average) at the location of the ice cap. The simulated precipitation is within one standard deviation of the average observed winter precipitation within this altitude range for sixteen out of nineteen winters during the period (1987–2006). The Spearman's rank correlation is 0.63 with a significance value of 0.004 and the *RMS* error is 49.

Areal integrals of winter balance over the Vatnajökull ice cap as a whole (8100 km$^2$), the Dyngjujökull (1040 km$^2$) and Brúarjökull (1695 km$^2$) outlet glaciers on the north side of the ice cap, and the Langjökull ice cap (925 km$^2$) are compared with simulated wintertime precipitation by the MM5 model in Figure 4. The winter balance is not corrected for to take liquid precipitation

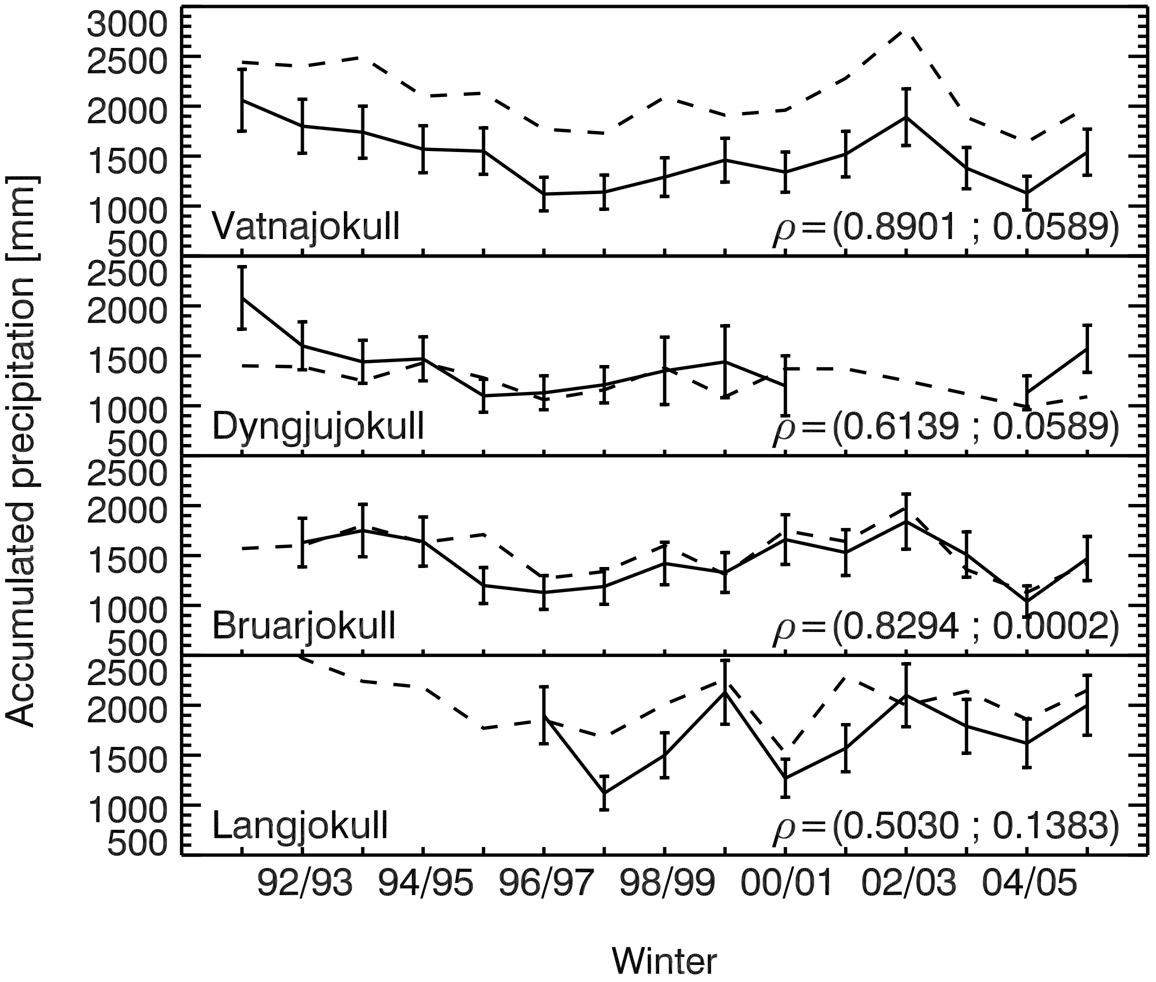

**Figure 4:** Observed accumulated winter balance (solid) and precipitation simulated by MM5 (dashed) for Vatnajökull ice cap as a whole (top), Dyngjujökull (second from top) and Brúarjökull (second from bottom) outlet glaciers and Langjökull ice cap (bottom). Error bars indicate 15% uncertainty of the observations, except for 1998–2001 at Dyngjujökull where it is 25%. Glaciological data for Vatnajökull, Dyngjujökull and Brúarjökull are from Björnsson et al. (1998, 2002) and Pálsson et al. (2002a,b, 2004b,c,d) Data for Langjökull ice cap are from Björnsson et al. (2002) and Pálsson et al. (2004a). As yet unpublished data for the past few winters are from Björnsson and Pálsson.

and/or winter ablation into account as mentioned above. The model shows least skill on Langjökull ice cap ($\rho = 0.50$; 0.14) where it has an $RMS$ error equal to

372, and the greatest skill on Brúarjökull ($\rho = 0.83$; 0.0002) where the $RMS$ error is equal to 171. The correlation for Dyngjujökull is 0.61 with a significance value of 0.06 and the $RMS$ error is equal to 286. The simulated precipitation is within estimated observational error-margins for 10 out of 12 winters for Dyngjujökull, 13 out of 14 for Brúarjökull and 5 out of 10 for Langjökull ice cap. The correlation for Vatnajökull ice cap is 0.89, with a significant value of 0.06 and the $RMS$ error is equal to 388. The relative importance of liquid precipitation and/or winter ablation is greatest for Vatnajökull as a whole because the southern margin of the ice cap reaches near sea level where rain may fall and ablation may take place at any time of the year. The north flowing outlet glaciers from Vatnajökull and Langjökull ice cap do not reach as far down so this problem is less important there. This is presumably the reason why the simulated winter precipitation is approximately 500 mm more than the observed winter balance for the Vatnajökull ice cap as a whole.

Mass-balance measurements at Drangajökull ice cap in NW-Iceland have only been carried out since 2004. Table 1 shows a comparison between simulated and observed winter balance for the mass-balance years 2004–2005 and 2005–2006 (Oddur Sigurðsson, personal communication). The model does not appear to capture the strong observed NW–SE precipitation gradient. The single grid cell values for the SE-part are very close to the observed values but they are too high for the NW-part. The area-averaged values from MM5 are, however, close to mean observed values for the NW-region of the ice cap but too low for the SE-part.

**Table 1:** Accumulated winter balance and simulated wintertime precipitation at Drangajökull, NW-Iceland (*cf.* Fig. 2). Observed winter balance is taken as the mean of stakes above 400 metre altitude in the northwestern (NW) part of the ice cap and in the southeastern (SE) part. Simulated precipitation is both taken as a nine point mean value (lower values) for the nearest grid cells as well as the nearest grid cell value (higher values).

| **Winter** | **$NW_{Obs}$ [mm]** | **$NW_{MM5}$ [mm]** | **$SE_{Obs}$ [mm]** | **$SE_{MM5}$ [mm]** |
|---|---|---|---|---|
| 2004/05 | 1797 (3 pts.) | 2090/2554 | 2675 (2 pts.) | 2072/2603 |
| 2005/06 | 1833 (3 pts.) | 2105/2524 | 2815 (2 pts.) | 2127/2604 |

## CONCLUSIONS

In general, the MM5 model results compare favourably with the observed winter balance, in particular for Hofsjökull, where corrections to take liquid precipitation and/or winter ablation into account have been made, and for the comparatively high altitude outlet glaciers Dyngjujökull and Brúarjökull, where such corrections are relatively unimportant. More extensive comparison of simulated precipitation with glaciological observations needs to be made with corrected mass balance data from all the ice caps.

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