Precipitation Modeling in Complex and Data Sparse Terrain

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ABSTRACT

The monthly precipitation in Iceland during a period of twelve months is estimated in two ways:

- By high-resolution calculations with the numerical model MM5 driven by boundaries from the ECMWF reanalysis.
- By a statistical model that calculates precipitation values on a regular grid from observations.

Both methods agree on the basic pattern of the precipitation but in some cases the spatially average difference is as much as 100%. The linear regression model is computationally inexpensive and can be run at a very high resolution with low cost. Consequently, it can be run to show patterns attributed to small scale topography. The numerical simulations give on the other hand more valuable information in data sparse mountainous regions. The linear model serves to validate the numerical simulations for downscaling of future general circulation scenarios.

1. Introduction

The purpose of this work is to map precipitation in Iceland in present climate. Two different methods have been employed for this purpose. First we applied a statistical model (SMOD) that is based on observed precipitation and a number of topographical predictors (Crochet 2002). Secondly we have used a limited area atmospheric model, MM5 (Wang et al 2001), that solves the primitive equations. One of the reasons that the precipitation is simulated with a limited area atmospheric model is to obtain a dataset for the current climate for comparison with downscaling of future climate scenarios.

2. Model description

2.1. Statistical model

The model evaluates the statistical relationship between monthly precipitation and the topographic features in the vicinity of a raingauge network of about 100 stations by using a multiple linear regression. The relationship is then applied respectively on a 2 km (not shown) and 8 km resolution grids to produce precipitation maps. The influence of topography on precipitation has been explored in the past by many authors for mapping purposes, see e.g. Benichou & Breton (1987) and Wotling, Bouvier, Danloux & Fritsh (2000). The statistical model used here is as follows:

$$R_i(T) = a_{0,T} + \sum_{j=1}^{7} a_{j,T} P_{i,j} \qquad i = 1, \ldots, n$$

where

$R_i(T)$: precipitation accumulated over a period of one month at location i.
$a_{j,T}$: regression coefficients estimated separately each month for various regions.
$p_{i,j}$: predictors for the site i:
$p_{i,1}$: x coordinate (in Lambert Conformal).
$p_{i,2}$: y coordinate (in Lambert Conformal).
$p_{i,3}$: shortest distance to the ocean in km.
$p_{i,4}$: average elevation (in meters) within 5 km from i.
$p_{i,5}$: average slope orientation (in degrees) within 5 km from i.
$p_{i,6}$: average steepness of hill slope (in %) within 5 km from i.
$p_{i,7}$: standard deviation of the elevation within 5 km from i.

2.2. MM5

The PSU/NCAR MM5 model is a state of the art non-hydrostatic limited area model. It solves the pressure, three dimensional momentum and thermodynamical equations that describe the atmosphere using finite difference methods. The equations are integrated in time on an Arakawa-Lamb B grid using a second-order leapfrog scheme. Some terms, like the fast moving sound waves, are handled using a time-splitting scheme. In this study, the turbulent boundary layer is parameterized according to Hong-Pan (Hong & Pan 1996) and cloud physics and precipitation processes according to Grell (Grell, Dudhia & Stauffer 1995) and Reisner2 (Reisner, Rassmussen & Bruintjes 1998), respectively.

The initial and boundary condition that drive the model are from the European Centre for Medium-Range Weather Forecasts (ECMWF).

3. Model results

Comparison between MM5 and SMOD indicates that MM5 overestimates the precipitation compared to SMOD in most parts of Iceland and in most seasons. This can be seen in Figure 1. A considerable difference is seen between S- and N-Iceland in the fall (SON), see Figure 2. At 8 km horizontal resolution both models show similar accumulated precipitation amounts in the south but MM5 has about double the SMOD precipitation in N-Iceland. The models estimations are in general similar in SW-Iceland for all seasons, the MM5 being about 5–25% higher than SMOD. It is worth noting the large seasonality in SE-Iceland, the winter and spring months being considerably wetter in MM5 than in SMOD, whilst the opposite is true for the summer and autumn months. NE-Iceland shows in general the largest difference between the two models, MM5 simulating double the precipitation of SMOD. When SMOD is run with a 2 km resolution the difference between NW- and NE-Iceland becomes less destinct, see Figure 1.

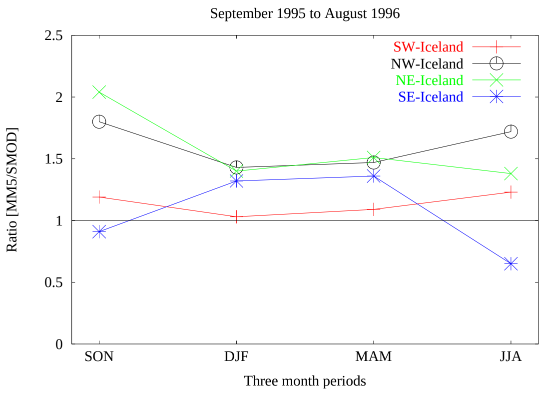

Figure 1: *Comparison between simulated precipitation by MM5 (at 8 km resolution) and SMOD (at 2 km resolution). The vertical axis shows the ratio between MM5 and SMOD and the horizontal axis shows the three month periods over which the precipitation was accumulated.*

Individual periods show that the precipitation patterns of the models are generally in agreement. The most distinct difference is that the SMOD model produces much less precipitation than MM5 in the mountains in NW-Iceland. Furthermore, it has higher values than MM5 over the northern part of Vatnajökull glacier in SW-Iceland, especially in the fall (SON) and summer (JJA). Another difference is the lack of precipitation over Langjökull

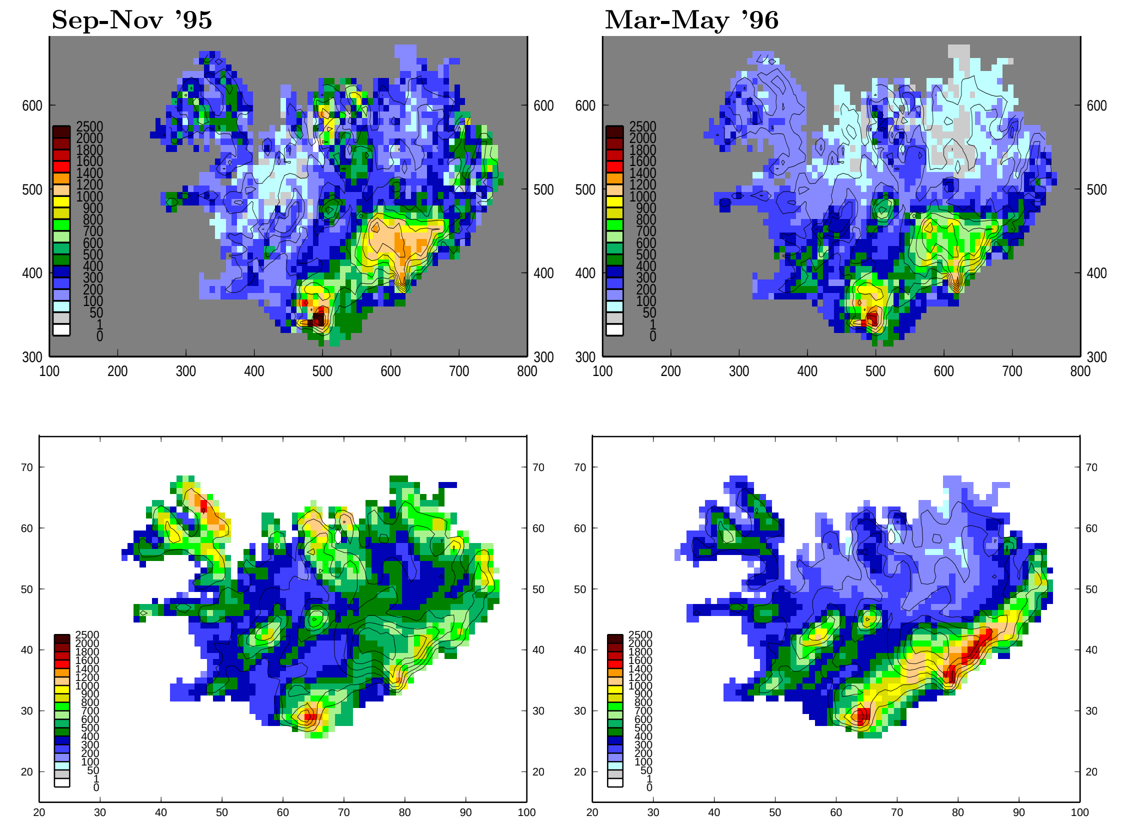

Figure 2: *Accumulated precipitation over Iceland as simulated by SMOD (top) and MM5 (bottom) from September through November 1995 (left) and from March through May 1996 (right).*

glacier (western interior of Iceland) in SMOD compared to MM5. This is interesting as precipitation over Hofsjökull glacier, just east of Langjökull glacier, is in general agreement between both models. This can be seen in Figure 2.

4. Discussion

The results suggest that the statistical relationship between monthly precipitation and the topographical features is quite strong, but the lack of information in the central- and SE-highlands introduces large sampling errors that make the reconstitution of the precipitation field over these areas difficult

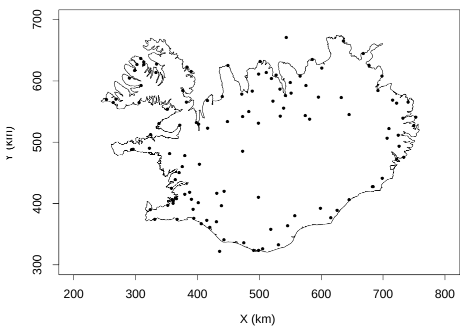

Figure 3: *Map of the raingauge network in Iceland.*

and uncertain. Figure 3 shows the raingauge network in Iceland, most of the stations are at altitudes lower than 200 meters. The data coverage is further sparse in the interior and northern Iceland. Our results can be summarized as follows:

- MM5 simulates in average more precipitation than SMOD. This can presumably to some extend be explained by wind loss of solid precipitation in strong winds. This can be seen by noting that MM5/SMOD ratio is higher in the northern part of Iceland than in the south. We further note the drop in the MM5/SMOD ratio between spring (MAM) and summer (JJA) for SE Iceland, the precipitation falling primarily as rain in the latter period.

- There are more fluctuations in the MM5/SMOD ratio in the mountainous regions. This appears to be related to different precipitation gradients in the mountains in the two models, giving more precipitation increase with altitude in MM5 than in SMOD. The precipitation gradient in mountain slopes is probably sensitive to wind speed (de Vries & Ólafsson 2003). The MM5 model is able to deal with this effect.

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