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Gridded climatological precipitation in Iceland
A case study in the Kárahnjúkar area

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Abstract

The 30-year mean monthly and annual gridded precipitation amounts are estimated for the period 1971-2000. This information is then used to derive the 50-year mean annual gridded precipitation amounts for the period 1941-1990.

1) Introduction

The 30-year mean monthly and annual gridded precipitation amounts are estimated for the period 1971-2000. First, a statistical model evaluates the relationships between precipitation and the topographic and atmospheric features. These relationships are used to produce a first map. Then, the residuals between the observed and estimated precipitation are interpolated and added to the first map. A last adjustment is performed using recent information from the period 1999-2001. Finally, the 50-year mean annual gridded precipitation amounts are estimated for the period 1941-1990 by simple scaling of the 30-year mean annual precipitation.

2) The data

Four datasets are defined, one for the 30-year period 1971-2000, two for the 3-year period 1999-2001, and one for the 50-year period 1941-1990.

For the 30 year period (1971-2000), the stations having at least 24 years of observation are used, between 70 and 75 station in total for each month (table 1 and appendix 1). For the 3-year period (1999-2001), only the stations with all 3 years of observation are used. The total number of stations for this period varies from 123 to 131 (table 2). Then, a second network is defined, as similar as possible as the one used for the period 1971-2000, (table 3). For the 50-year period (1941-1990), the selected stations must have at least 44 years of observation and belong to the (1971-2000) network as well, 21 stations in total.

Table 1: number of stations for the period 1971-2000

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
74	73	72	71	74	74	70	71	71	75	72	72

Table 2: maximum number of available stations for the period 1999-2001

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
126	127	124	123	124	129	127	128	128	131	128	125

Table 3: number of stations used in the second network for the period 1999-2001

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
69	68	67	67	68	69	66	67	66	70	68	66

3) Statistical model

The statistical relationship between precipitation and the topographic and atmospheric features is assessed through a multiple linear regression (MLR):

$$R_i(T) = a_{0,T} + \sum_{j=1}^{4} a_{j,T}\, p_{i,j} \tag{1}$$

Where

$R_i(T)$: mean monthly precipitation for month T and spatial location i

$a_{j,T}$: regression coefficients

$p_{i,j}$: predictors describing the atmospheric and topographic features around the point i, considering a spacing of 1km and an averaging window of 8 km for the topographic predictors (see appendix 2):

$p_{i,1}$: Mean specific humidity in g/kg from the NCEP-NCAR Reanalysis, see [1]

$p_{i,2}$: z_i, the smooth elevation around the site i

$p_{i,3}$: smooth topographic gradient in x direction

$p_{i,4}$: smooth topographic gradient in y direction

In the past years, several studies have described the statistical links between precipitation and topographic information, see [2], [3], [4] and [5] for instance and the combined effect of topographic and atmospheric features, see [6]. In Iceland, the preliminary study of [7] has also stressed the existence of a statistical relationship between topography and precipitation.

4) Calibration of the statistical model for the period 1971-2000

The model (1) is calibrated for various regions (see appendix 3) where the data enable the identification of a robust relationship, which is then applied to larger areas. For the overlapping regions, the mean of the different estimates is taken.
The regions were defined by merging together several topographic domains identified by applying the method of the watershed transform to the local maxima, see [8] (for instance). This calibration is made individually for each month (see appendix 4).

5) Mapping procedure

The model (1) is used to produce a first map $\hat{R}_i(T)$. Then, the residuals of the regression:

$$\varepsilon_i(T) = R_i(T) - \hat{R}_i(T) \tag{2}$$

are interpolated using a spline in tension, see [9], and added to $\hat{R}_i(T)$:

$$R^*{}_i(T) = \hat{R}_i(T) + \hat{\varepsilon}_i(T) \tag{3}$$

6) Adjustment procedure for the 1971-2000 period

The maps derived for the period 1971-2000 are based on a ground network of about 70 stations. Consequently, the uncertainty of such maps may be high over the highlands and the mountainous regions because of a lack of information. An adjustment procedure based on information from the period 1999-2001 is defined as follows:

First of all, two sets of mean monthly precipitation maps are produced for the period 1999-2001 following the steps defined in sections 4) and 5) with the two networks defined in section 2.

The maps derived with the dense network are the reference, $R_i^{ref}(T,_{1999-2001})$ used to assess the quality of the maps derived with the sparse network, $R_i^*(T,_{1999-2001})$, and assumed to be of similar quality than the maps for the period 1971-2000.

For each month T and each grid point i, a scaling coefficient is defined as follows:

$$\alpha_i(T,_{1999-2001}) = \frac{R_i^{ref}(T,_{1999-2001})}{R_i^{*}(T,_{1999-2001})} \quad (4)$$

with the constraint:

$$\alpha_i(T,_{1999-2001}) = \begin{cases} 0.5 & if < 0,5 \\ 1.25 & if > 1.25 \end{cases}$$

and $\alpha_i(T,_{1999-2001}) = 1$ over the Vatnajökull ice cap for Z > 800m.

This constraint is defined arbitrarily in order to limit the sampling problems between the two periods 1971-2000 and 1999-2001. A visual inspection of these coefficients reveals that the regions around the ground network are not affected by the adjustment ($\alpha_i(T,_{1999-2001}) \approx 1$ as expected), and the areas the most subject to an adjustment ($\alpha_i(T,_{1999-2001}) \neq 1$) are those poorly instrumented (see appendix 5).

Then, the 30-year mean monthly gridded precipitation amounts $R_i^{*}(T,_{1971-2000})$ are scaled as follows:

$$R_i^{scaled}(T,_{1971-2000}) = \alpha_i\,(T,_{1999-2001})R_i^{*}(T,_{1971-2000}) \quad (5)$$

Finally, a last adjustment is made in order to make sure that the grid points having an observation for the period 1971-2000 match that observation. The residuals between the scaled gridded values and the observations are computed, interpolated and added :

$$\varepsilon_i(T,_{1971-2000}) = R_i(T,_{1971-2000}) - R_i^{scaled}(T,_{1971-2000}) \quad (6)$$

and

$$R_i^{adjusted}(T,_{1971-2000}) = R_i^{scaled}(T,_{1971-2000}) + \hat{\varepsilon}_i\,(T,_{1971-2000}) \quad (7)$$

The 30-year mean annual gridded precipitation, $R_i^{adjusted}(_{1971-2000})$, is simply derived as the sum of the 12 monthly estimates $R_i^{adjusted}(T,_{1971-2000})$.

The adjusted monthly and annual precipitation maps for the period 1971-2000 are given in appendix 6.

7) Adjustment procedure for the 1941-1990 period

In this section, an attempt to derive the 50-year mean annual gridded precipitation for the period 1941-1990 is presented. It is based on an adjustment of the mean annual gridded precipitation estimated for the period 1971-2000. First of all, a common network of stations in operation during both periods is defined, 21 stations in use for more than 43 years for the period 1941-1990 and for more than 23 years for the period 1971-2000. For each station i belonging to the common network, a scaling coefficient is defined as follows:

$$\lambda_i = \frac{R_i\left(_{1941-1990}\right)}{R_i\left(_{1971-2000}\right)} \tag{8}$$

where $R_i\left(_{1971-2000}\right)$ and $R_i\left(_{1971-2000}\right)$ are the mean annual precipitation estimates calculated from the observations.

A visual inspection (appendix 7) shows that the ratio λ_i is quite stationary over Iceland and lower than one, except for 2 stations believed to be outliers and for which the value exceeds 1. The mean value, m_λ , is computed over Iceland with the constraint $\lambda_i \leq 1$. It is used as a scaling coefficient to derive the 50-year mean annual gridded precipitation by adjustment of the 30-year mean annual gridded precipitation:

$$R_i^{adjusted}\left(_{1941-1990}\right) = m_\lambda R_i^{adjusted}\left(_{1971-2000}\right) \tag{9}$$

with m_λ=0.96

The idea lying behind this procedure is the following:
The network of stations available for the 50-year period is too sparse to apply the procedure defined in sections 4) and 5). It is thus assumed that the spatial variability of the mean annual precipitation over the 50-year period is basically the same as the one estimated for the 30-year period. A simple adjustment between the two periods is applied in order to take into account the average discrepancy in the magnitude of the amounts between the two series.

The adjusted annual precipitation map for the period 1941-1990 is presented in appendix 8.

8) Conclusion

Within the limits of the information provided by the ground precipitation network, the proposed method attempts to map the amount of precipitation by exploring the statistical relationships between precipitation and topographic as well as atmospheric features. It is observed that these relationships are usually quite strong when long-term averages are considered. The result obtained by application of this technique is a map that displays considerably more information than a map derived by a simple interpolation procedure.

Acknowledgements

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References

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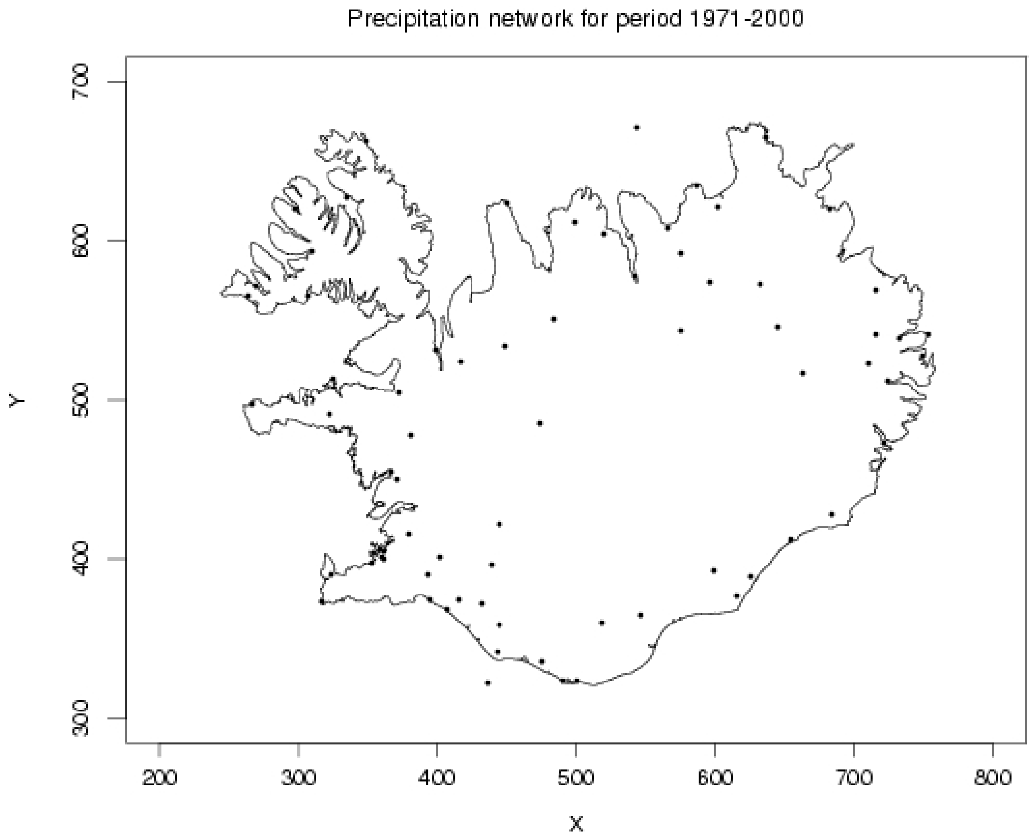
[8]: Roerdink, Jos B.T.M and A. Meijster, 2001: The watershed transform: Definitions, algorithms and parallelization strategies. Fundamenta Informaticae (41), 187-228.

[9]: Smith, W.H.F., and P. Wessel, 1990: Gridding with continuous curvature splines in tension. Geophysics, 15 (3) 293-305.

Appendix 1

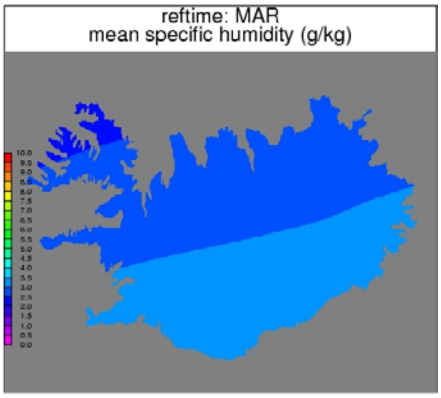
The precipitation network
period 1971-2000

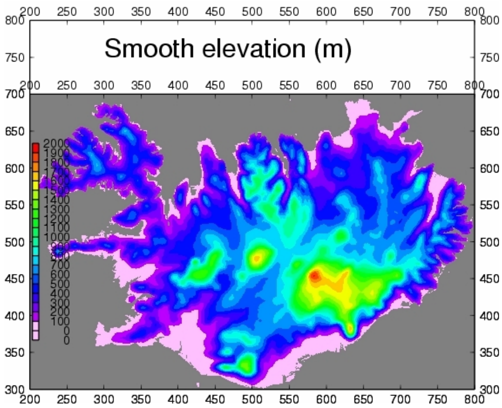


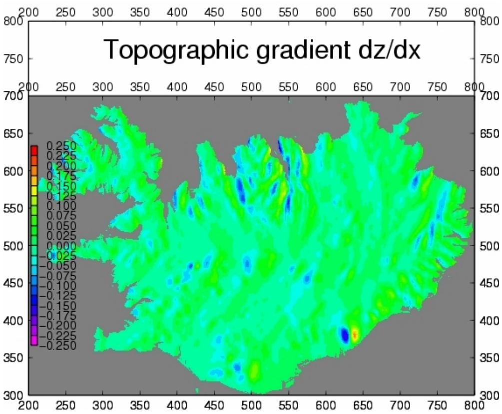
Precipitation network for period 1971-2000
700
600
500
400
300
Y
200
300
400
500
600
700
800
X

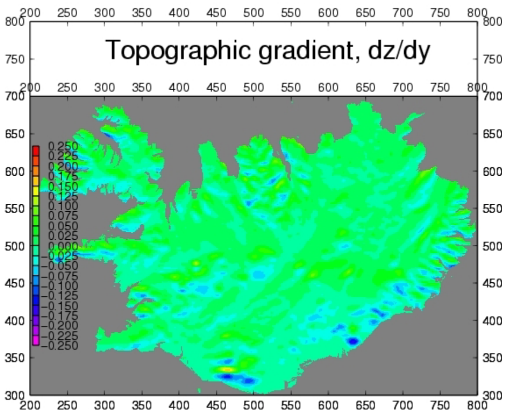
Appendix 2

The predictors
(1 km spatial resolution, 8 km smoothing window)


reftime: MAR
mean specific humidity (g/kg)

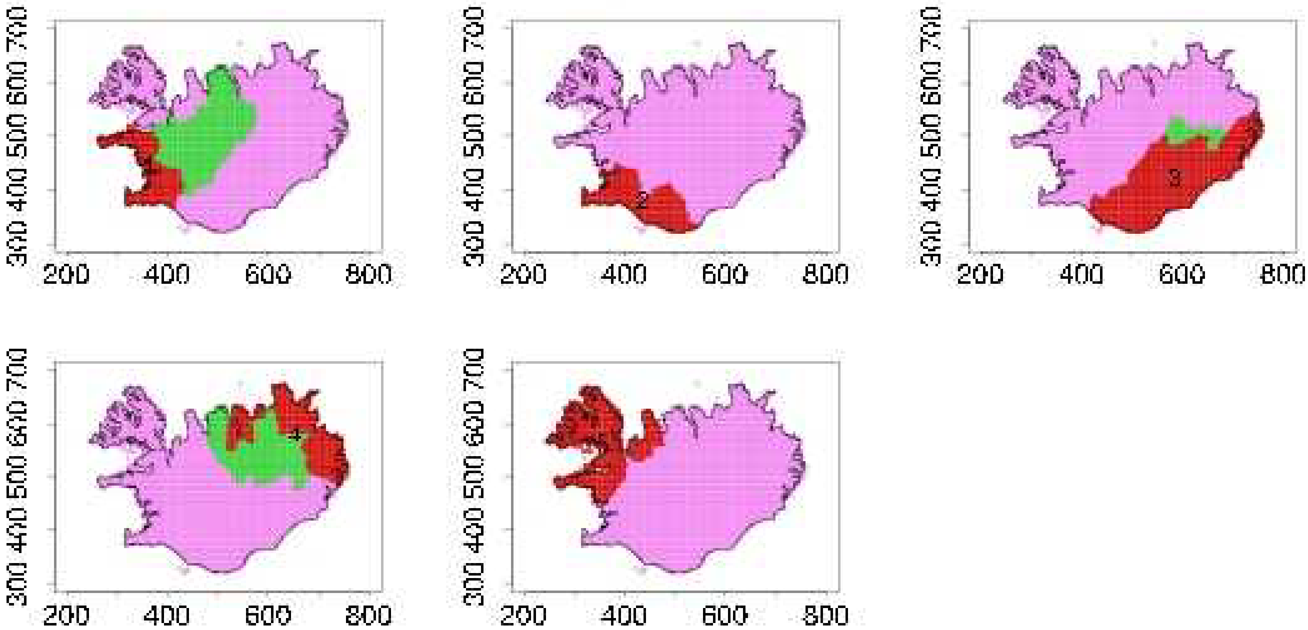

Smooth elevation (m)


Topographic gradient dz/dx


Topographic gradient, dz/dy

Appendix 3

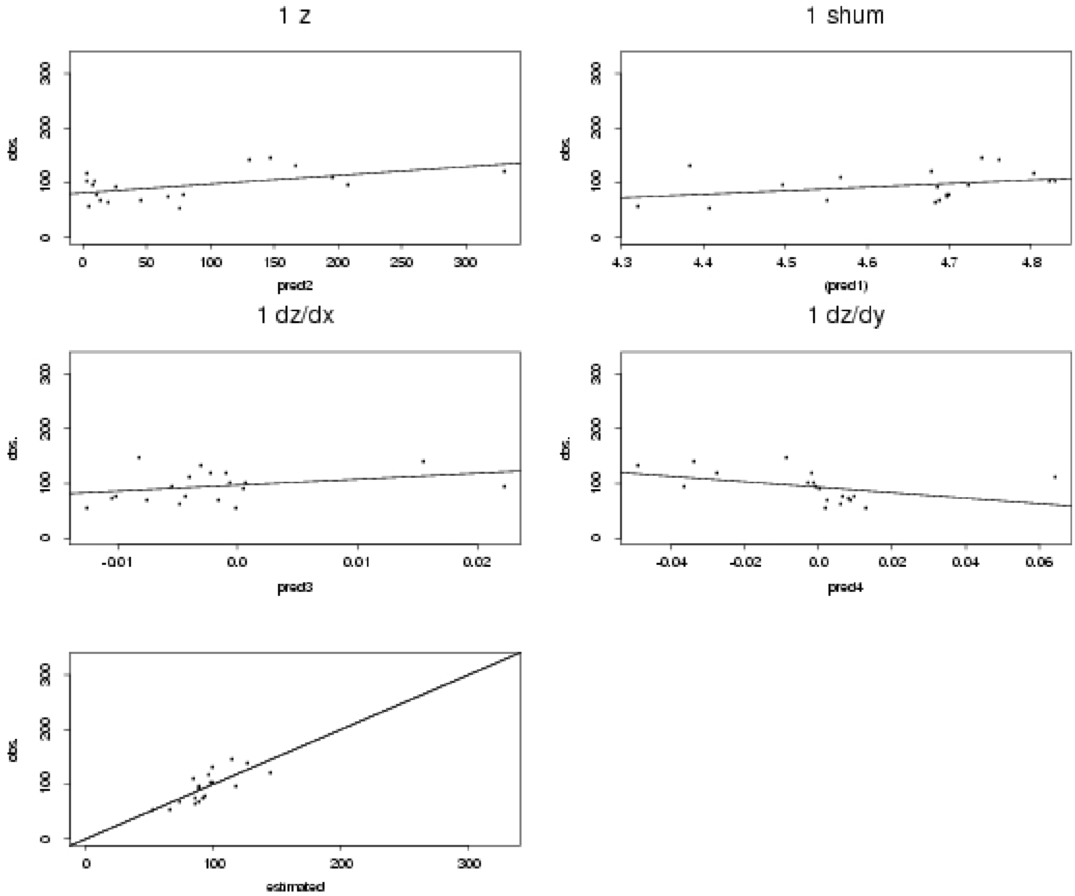
The different regions of application of the statistical model



The different regions defined to calibrate the statistical model (red), and to apply it (red and green)

Appendix 4

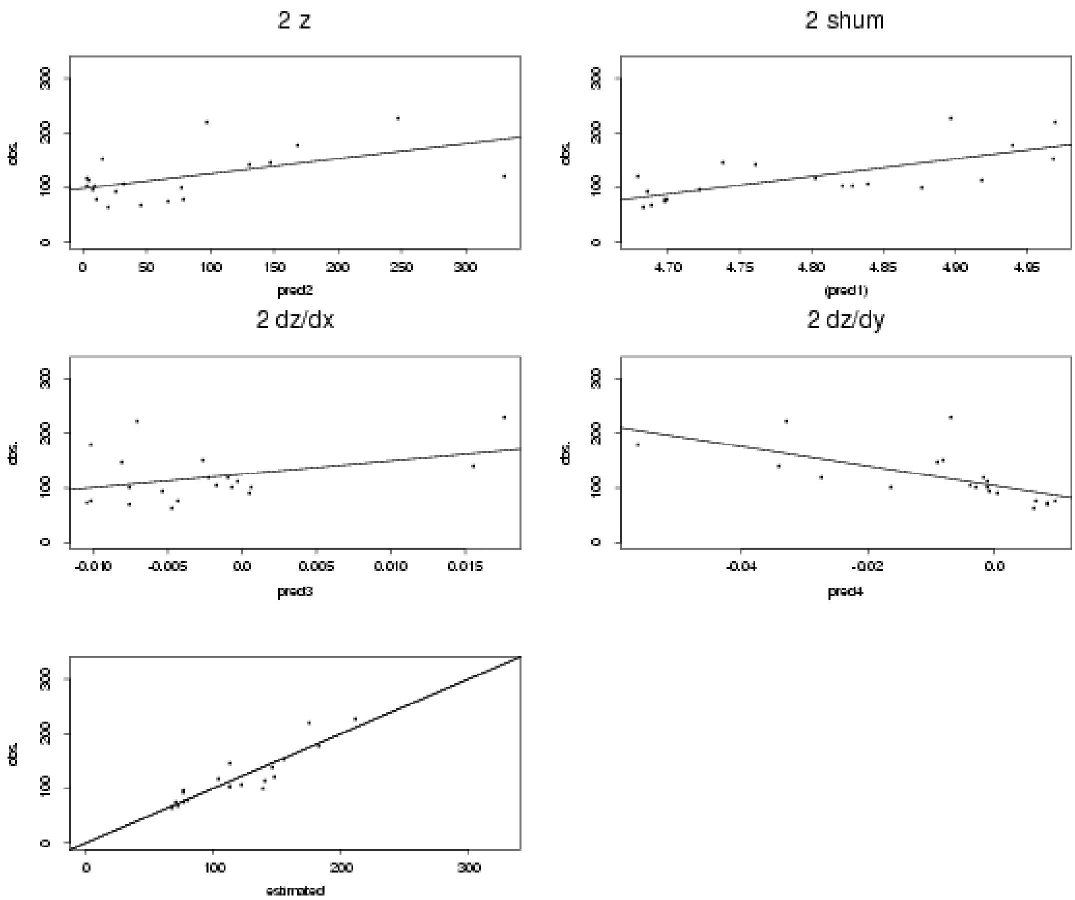
Example of calibration of the statistical model
September (1971-2000)



Region 1, september 1971-2000:

Top left: linear regression between monthly averaged precipitation and smooth elevation
Top right: linear regression between monthly averaged precipitation and specific humidity
Center left: linear regression between monthly averaged precipitation and smooth topographic gradient in the x-direction
Middle right: linear regression between monthly averaged precipitation and smooth topographic gradient in the y-direction

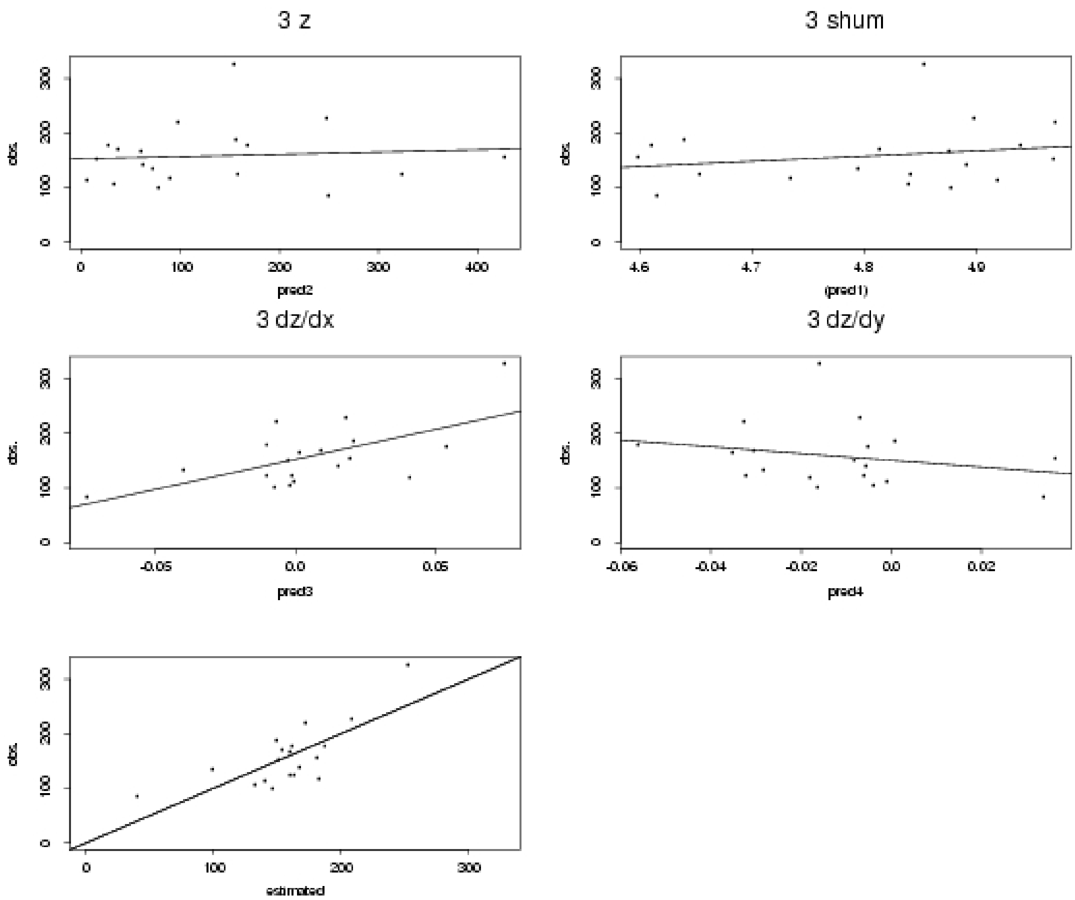
Bottom left: multiple linear regression (MLR) between monthly averaged precipitation and the 4 predictors.
Scatter plot between estimated (abcissa) and observed (ordinate) precipitation



Region 2, september 1971-2000:

Top left: linear regression between monthly averaged precipitation and smooth elevation
Top right: linear regression between monthly averaged precipitation and specific humidity
Center left: linear regression between monthly averaged precipitation and smooth topographic gradient in the x-direction
Middle right: linear regression between monthly averaged precipitation and smooth topographic gradient in the y-direction

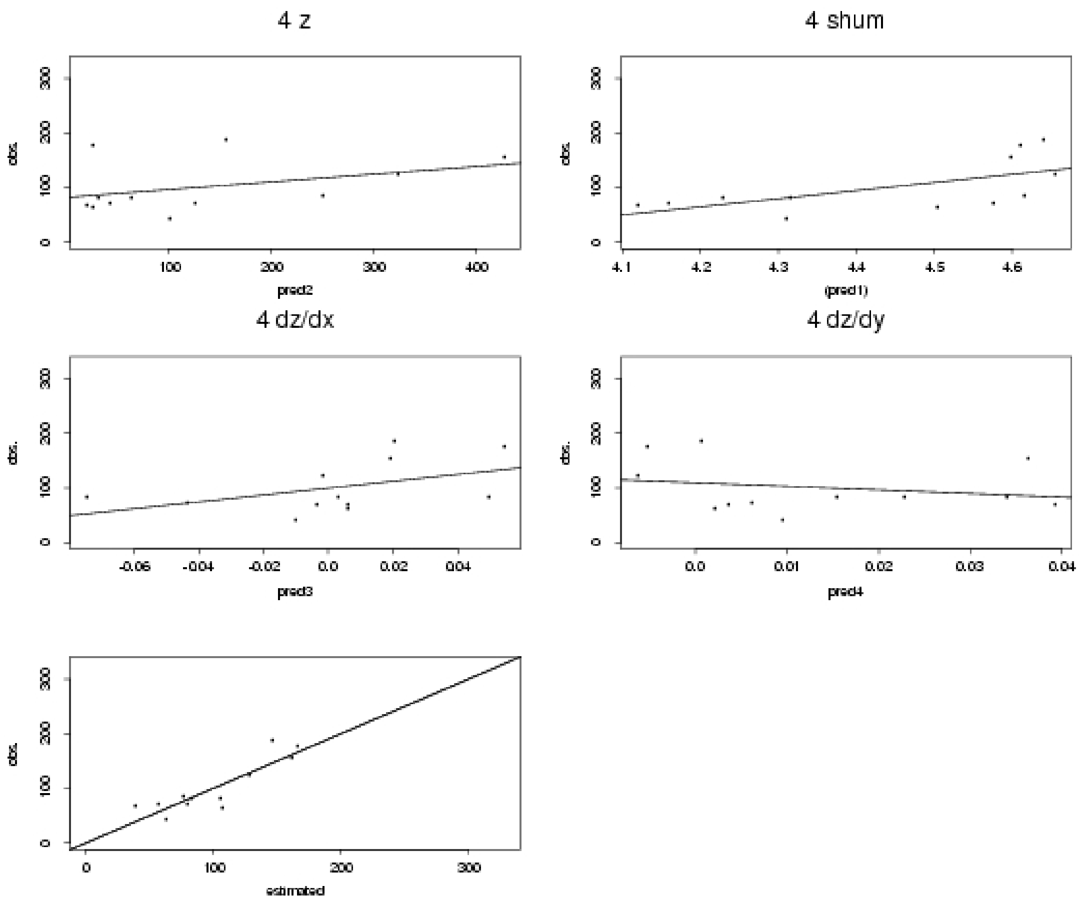
Bottom left: multiple linear regression (MLR) between monthly averaged precipitation and the 4 predictors.
Scatter plot between estimated (abcissa) and observed (ordinate) precipitation



Region 3, september 1971-2000:

Top left: linear regression between monthly averaged precipitation and smooth elevation
Top right: linear regression between monthly averaged precipitation and specific humidity
Center left: linear regression between monthly averaged precipitation and smooth topographic gradient in the x-direction
Middle right: linear regression between monthly averaged precipitation and smooth topographic gradient in the y-direction

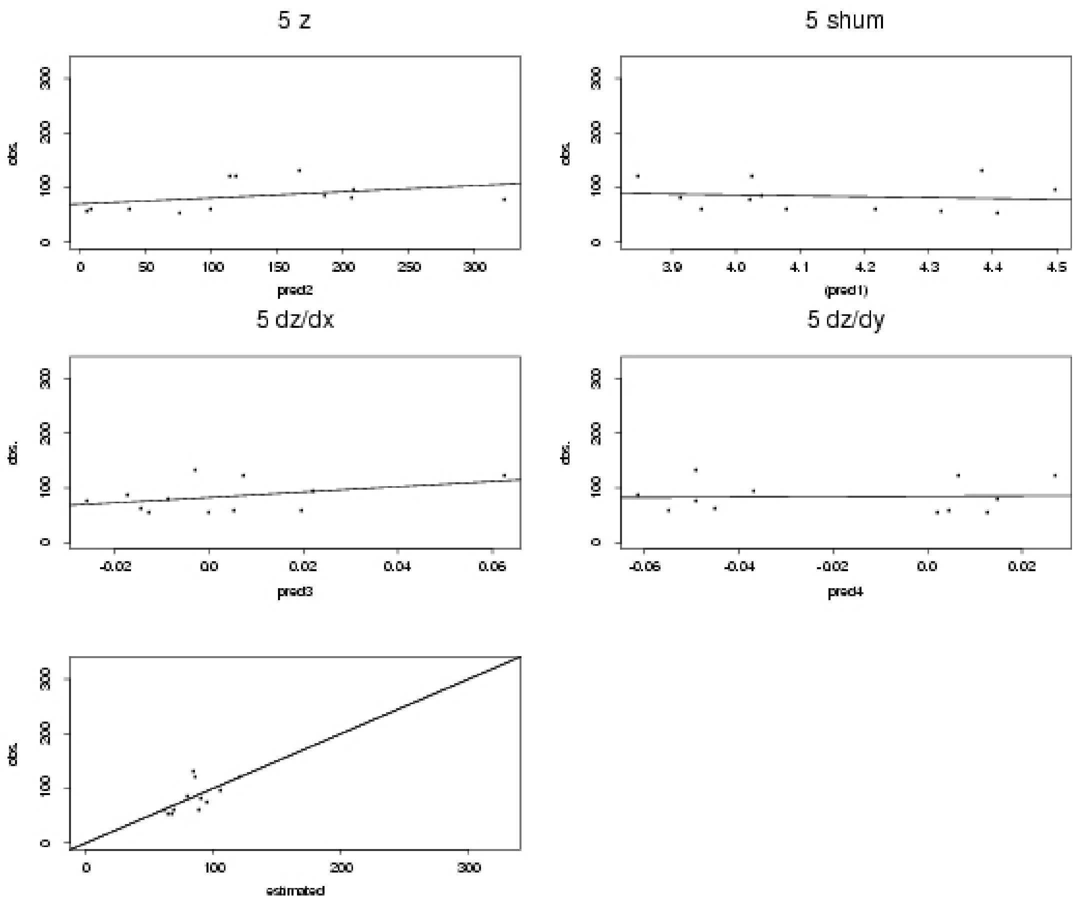
Bottom left: multiple linear regression (MLR) between monthly averaged precipitation and the 4 predictors.
Scatter plot between estimated (abcissa) and observed (ordinate) precipitation



Region 4, september 1971-2000:

Top left: linear regression between monthly averaged precipitation and smooth elevation
Top right: linear regression between monthly averaged precipitation and specific humidity
Center left: linear regression between monthly averaged precipitation and smooth topographic gradient in the x-direction
Middle right: linear regression between monthly averaged precipitation and smooth topographic gradient in the y-direction

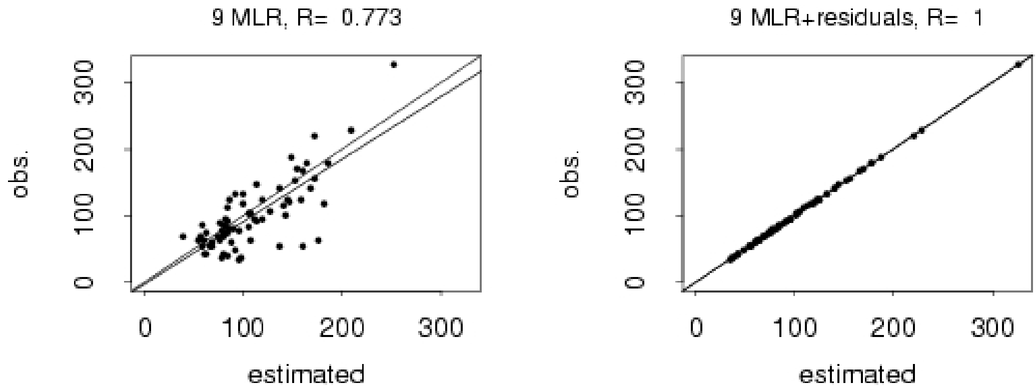
Bottom left: multiple linear regression (MLR) between monthly averaged precipitation and the 4 predictors.
Scatter plot between estimated (abcissa) and observed (ordinate) precipitation



Region 5, september 1971-2000:

Top left: linear regression between monthly averaged precipitation and smooth elevation
Top right: linear regression between monthly averaged precipitation and specific humidity
Center left: linear regression between monthly averaged precipitation and smooth topographic gradient in the x-direction
Middle right: linear regression between monthly averaged precipitation and smooth topographic gradient in the y-direction

Bottom left: multiple linear regression (MLR) between monthly averaged precipitation and the 4 predictors.
Scatter plot between estimated (abcissa) and observed (ordinate) precipitation

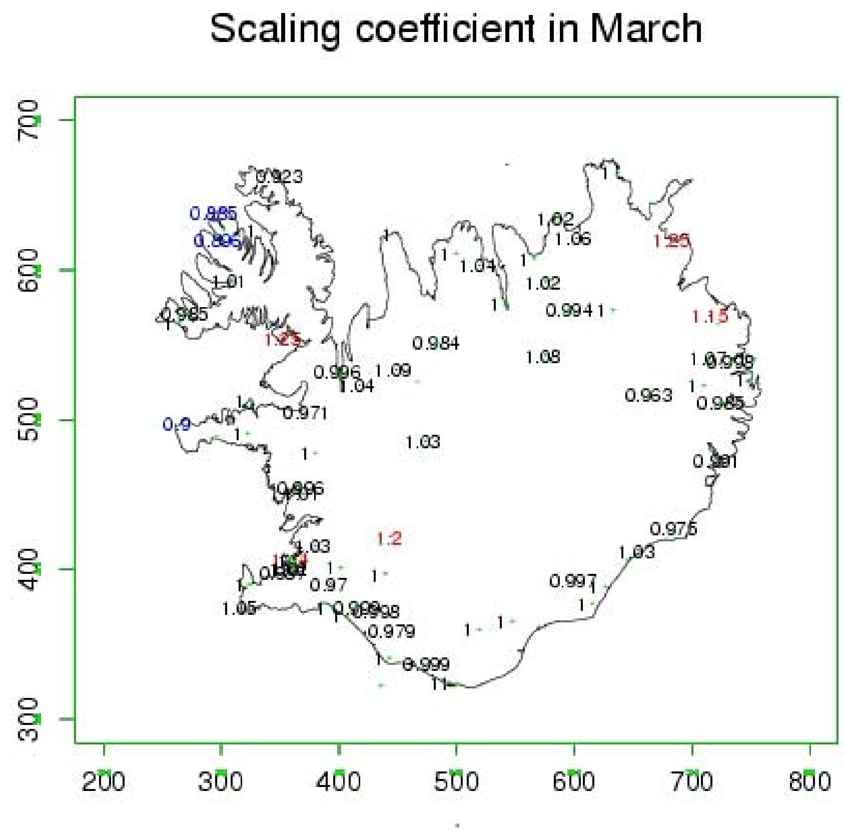


All Iceland, september 1971-2000: Scatter plot between estimated (abcissa) and observed (ordinate) precipitation

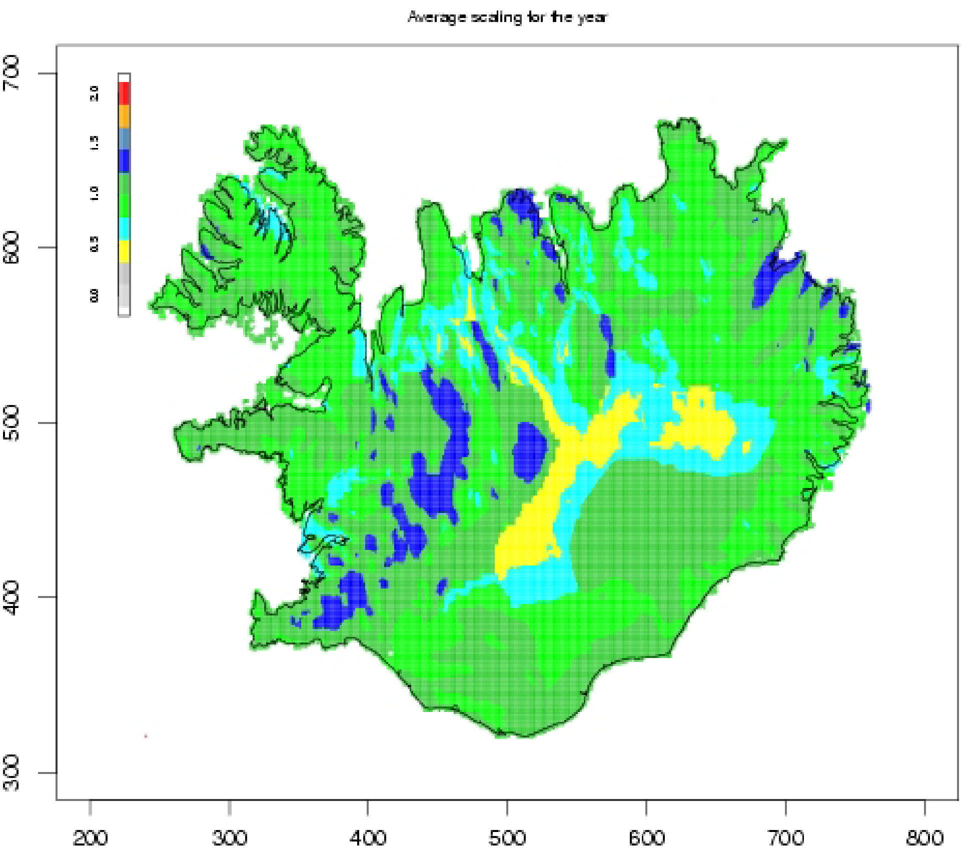
Left: multiple linear regression (MLR) from the 5 different regions.
Right: MLR + interpolated residuals

Appendix 5

Scaling coefficients
Two examples



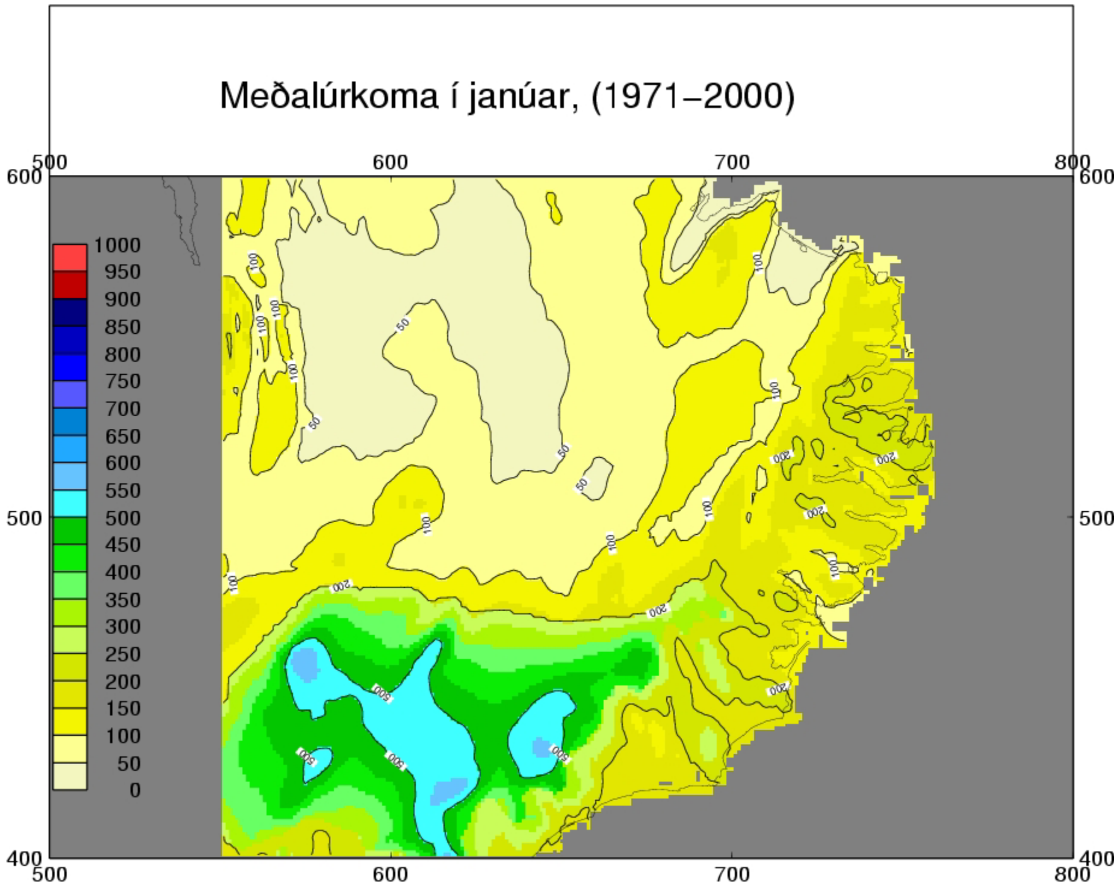
Numerical values of the scaling coefficient for March, at each station site.



Averaged scaling coefficient over the 12 months

Appendix 6

30 year averaged precipitation maps for the period 1971-2000
in the Kárahnjúkar area



Meðalúrkoma í janúar, (1971–2000)
1000
950
900
850
800
750
700
650
600
550
500
450
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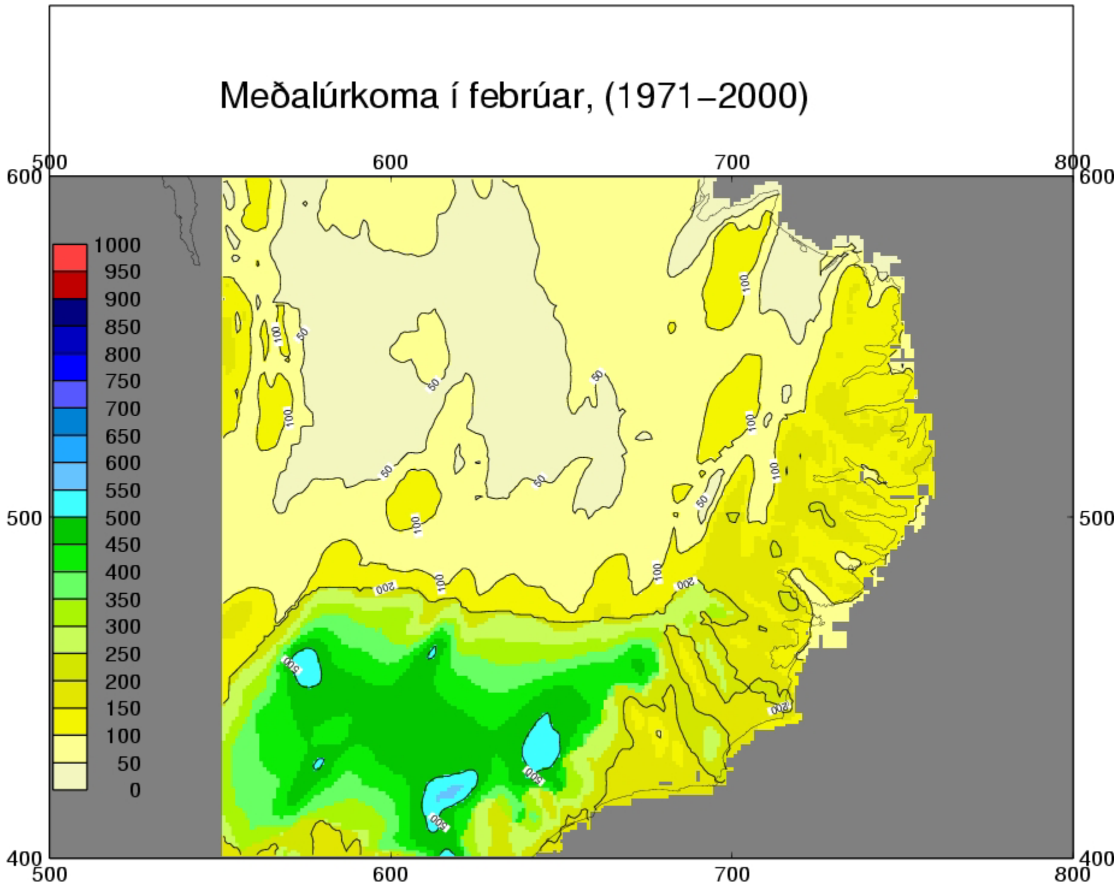
300
250
200
150
100
50
0



Meðalúrkoma í febrúar, (1971–2000)
1000
950
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850
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750
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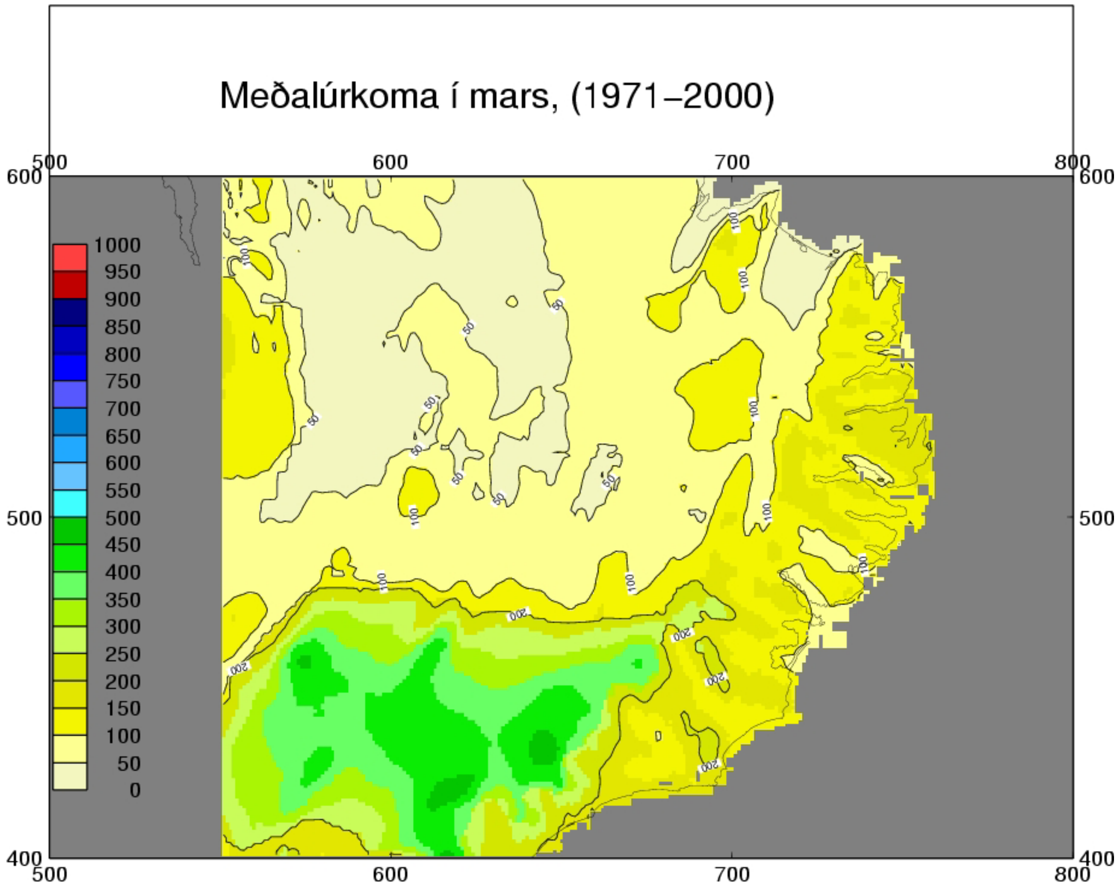
Meðalúrkoma í mars, (1971–2000)
500
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250
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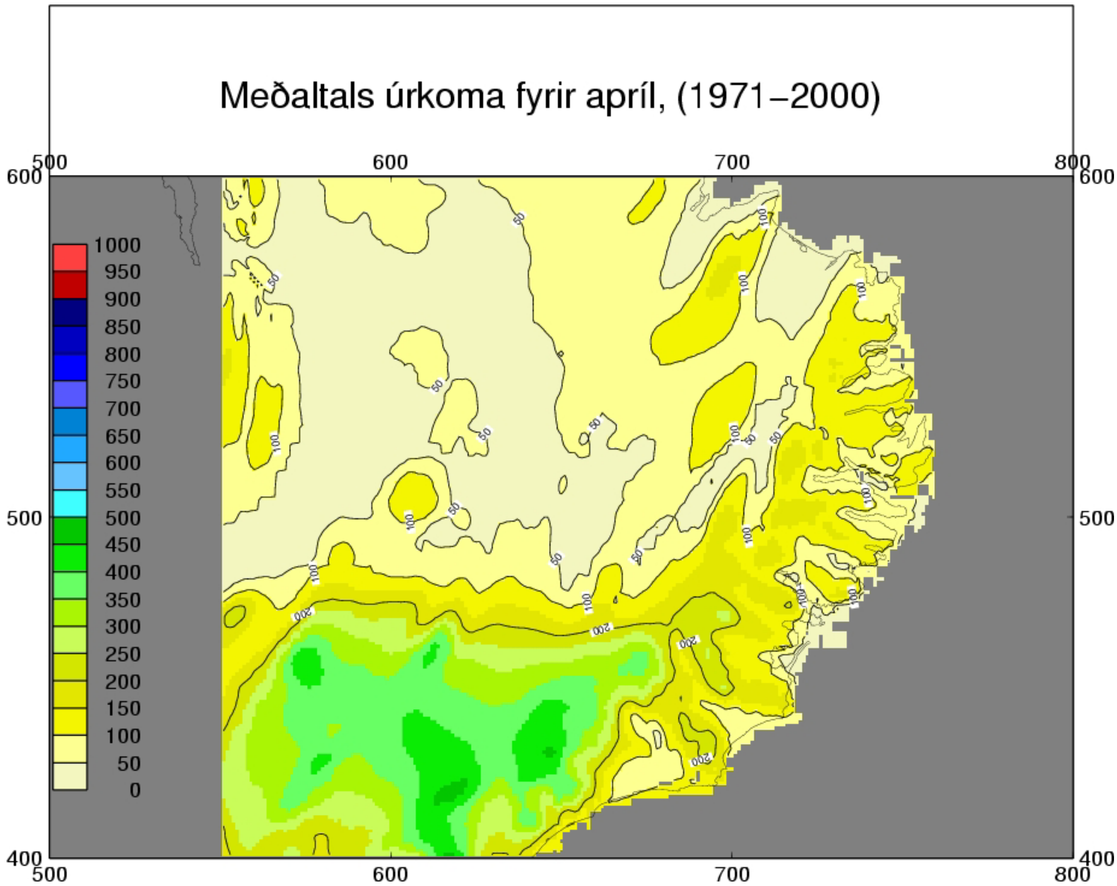
Meðaltals úrkoma fyrir apríl, (1971–2000)
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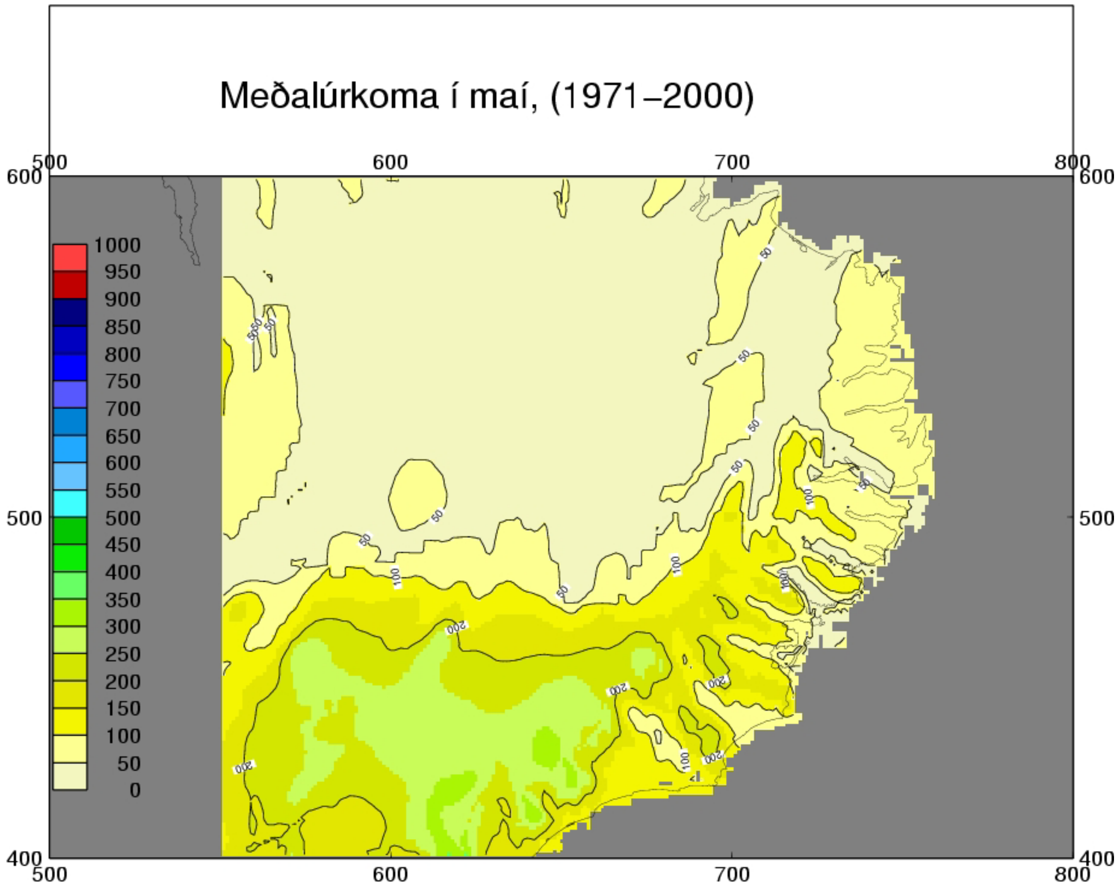
Meðalúrkoma í maí, (1971−2000)
1000
950
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700
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350
300
250
200
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100
50
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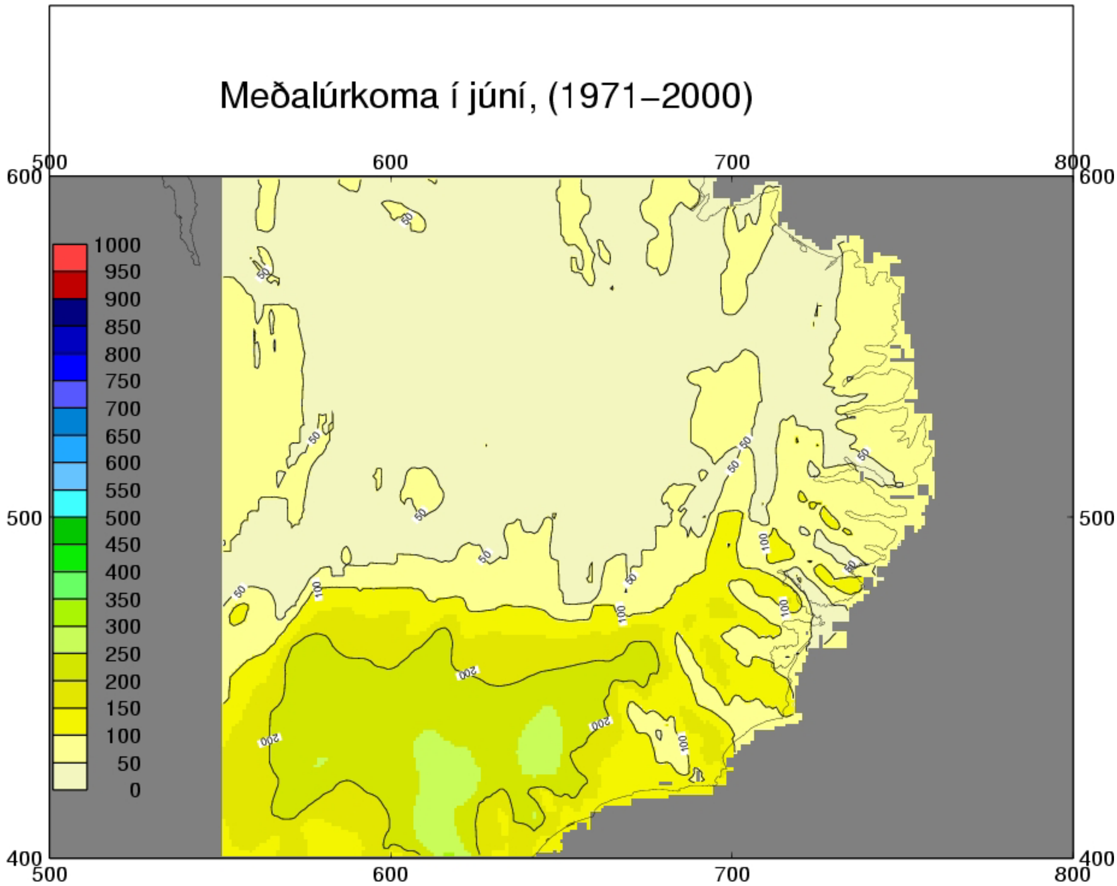
Meðalúrkoma í júní, (1971−2000)
1000
950
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250
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150
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50
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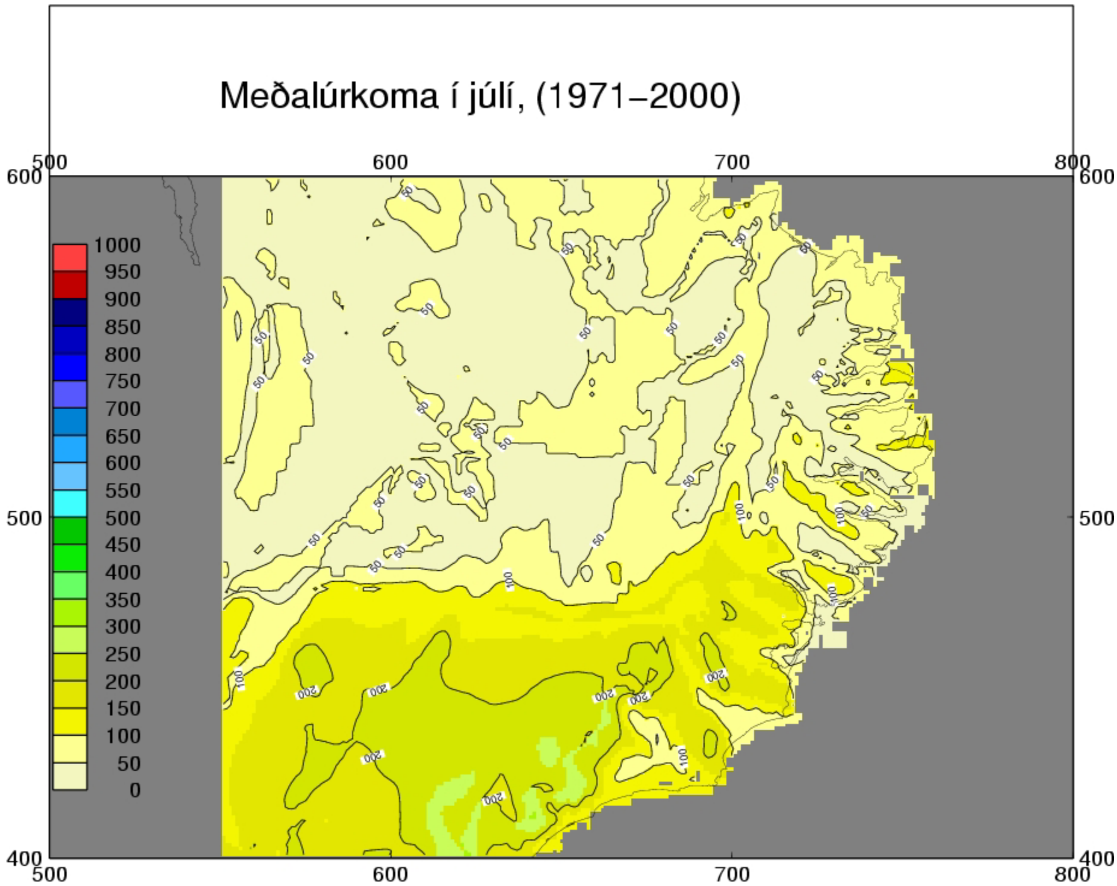
Meðalúrkoma í júlí, (1971−2000)
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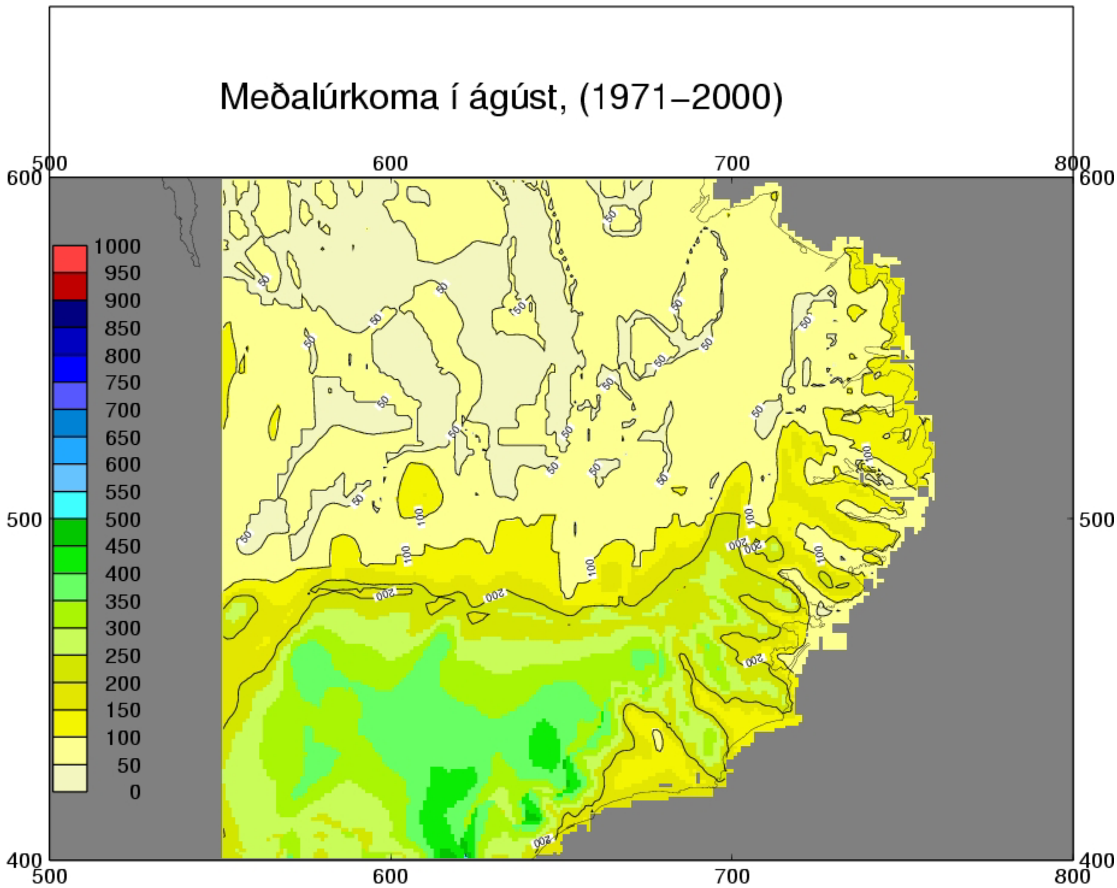
Meðalúrkoma í ágúst, (1971−2000)
1000
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300
250
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150
100
50
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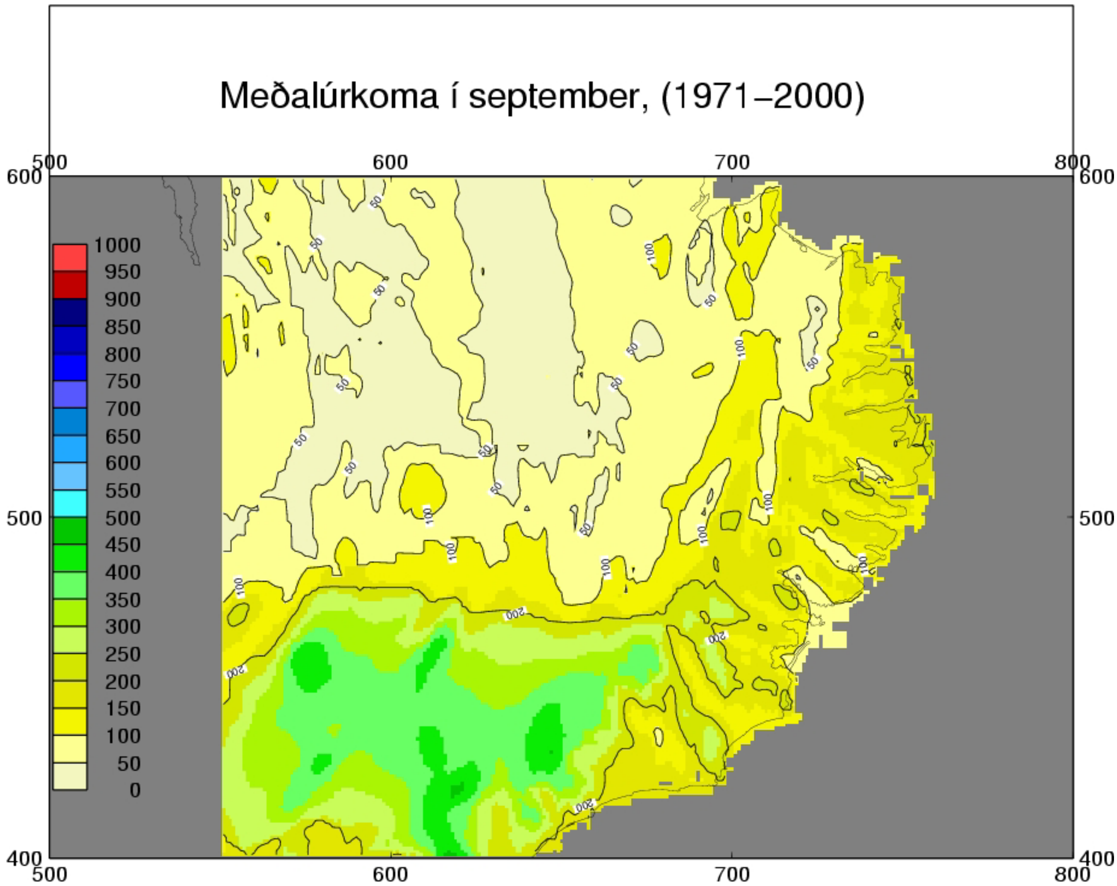
Meðalúrkoma í september, (1971−2000)
500
600
700
800
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1000
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700
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150
100
50
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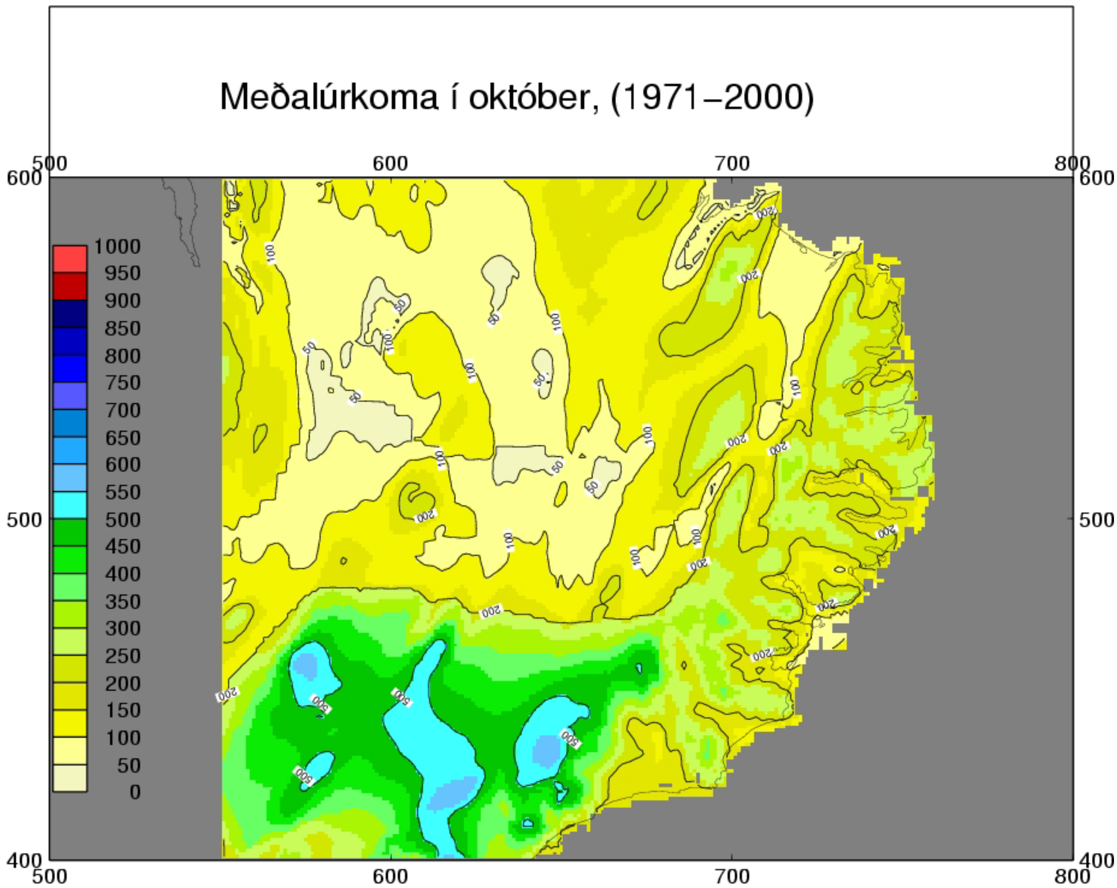
Meðalúrkoma í október, (1971−2000)
500
600
700
800
400
1000
950
900
850
800
750
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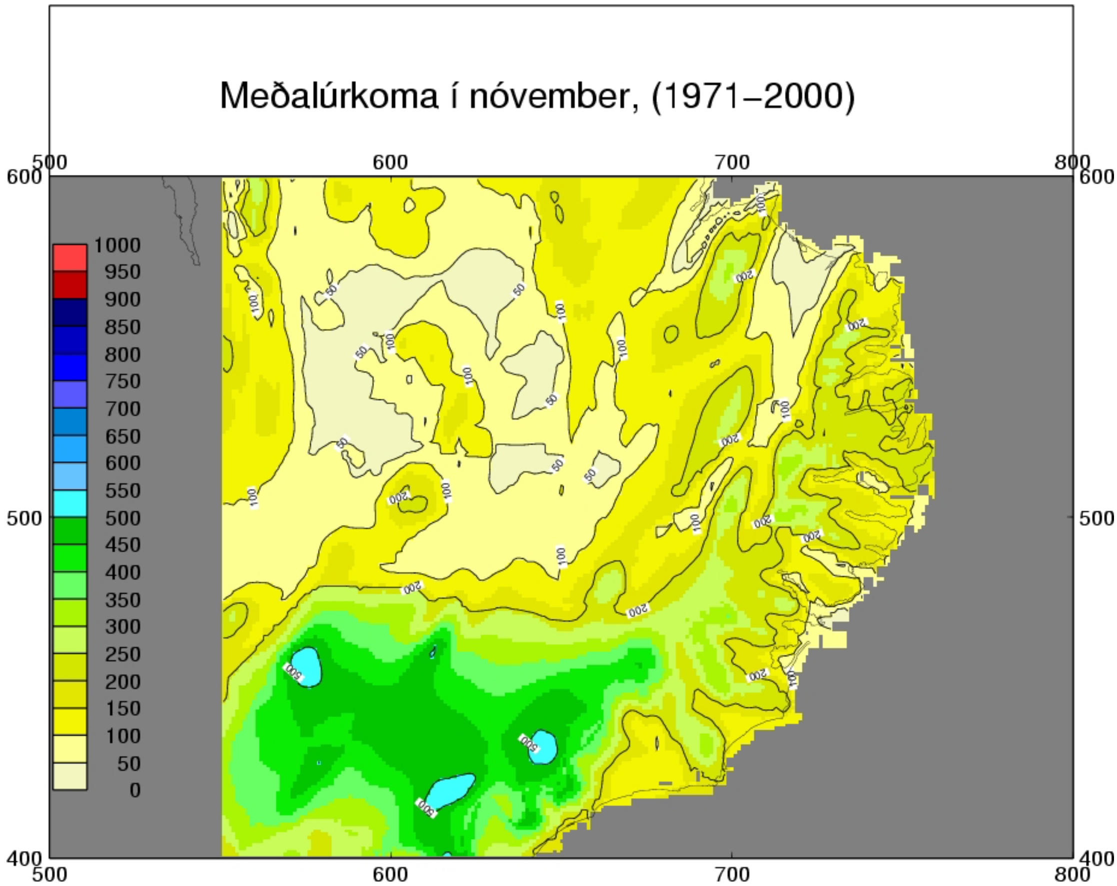
200
150
100
50
0


Meðalúrkoma í nóvember, (1971–2000)
500
600
700
800
600
500
400
1000
950
900
850
800
750
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650
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450
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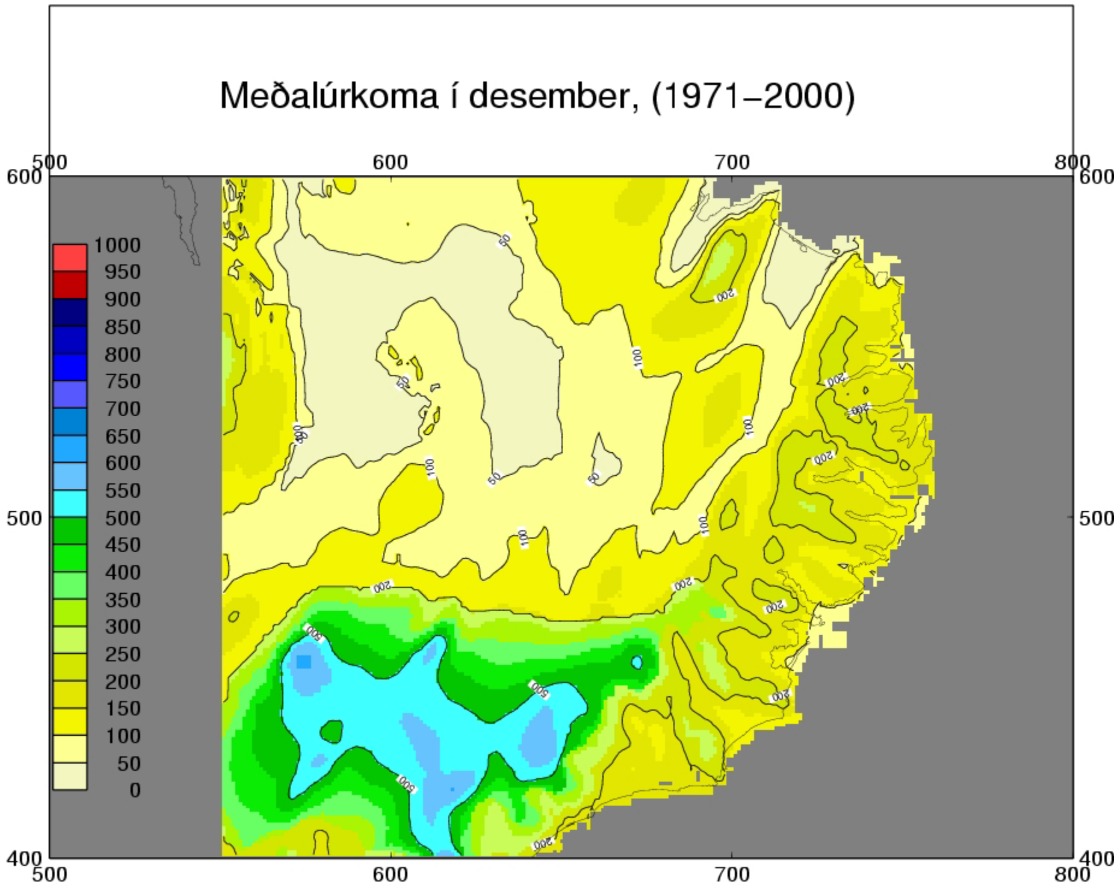
150
100
50
0


Meðalúrkoma í desember, (1971–2000)
500
600
700
800
600
500
400
1000
950
900
850
800
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650
600
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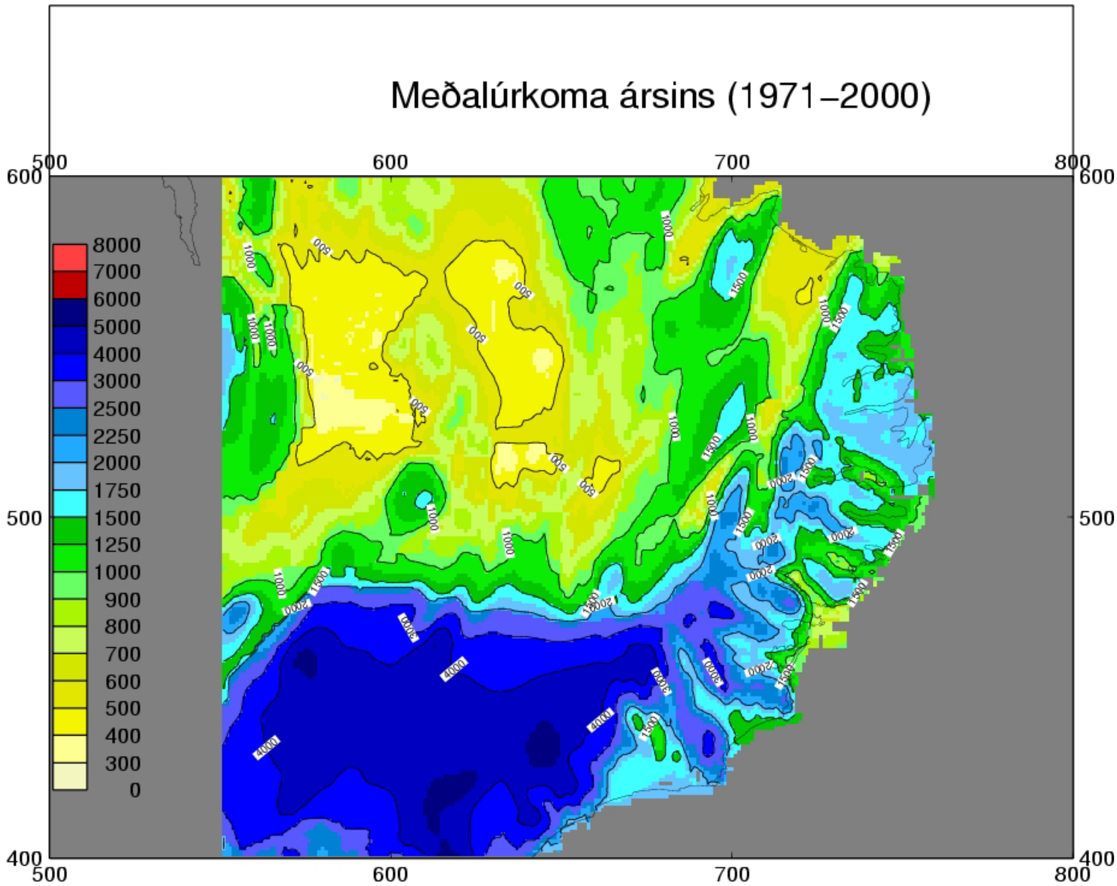
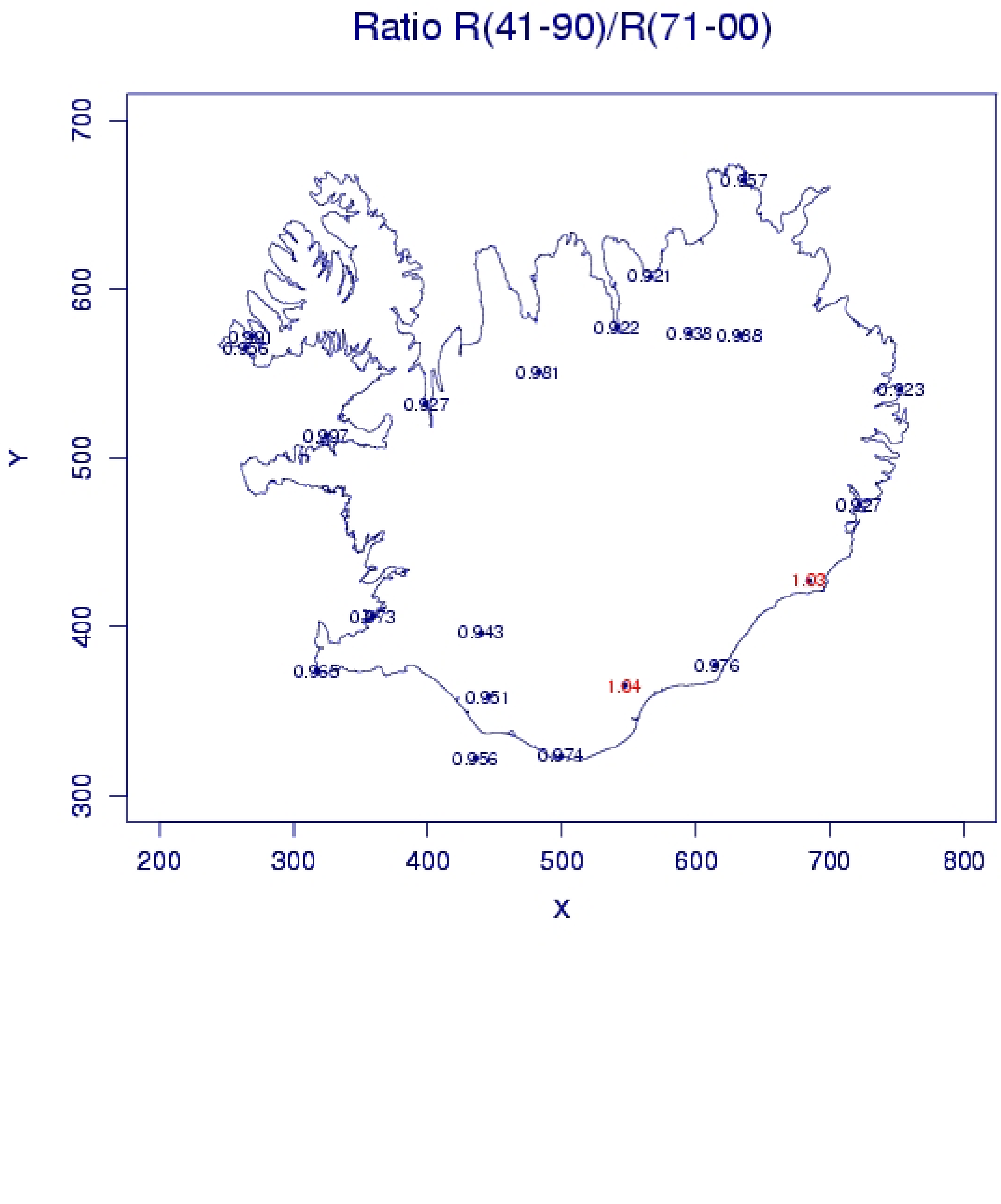
200
150
100
50
0



Meðalúrkoma ársins (1971−2000)
8000
7000
6000
5000
4000
3000
2500
2250
2000
1750
1500
1250
1000
900
800
700
600
500
400
300
0

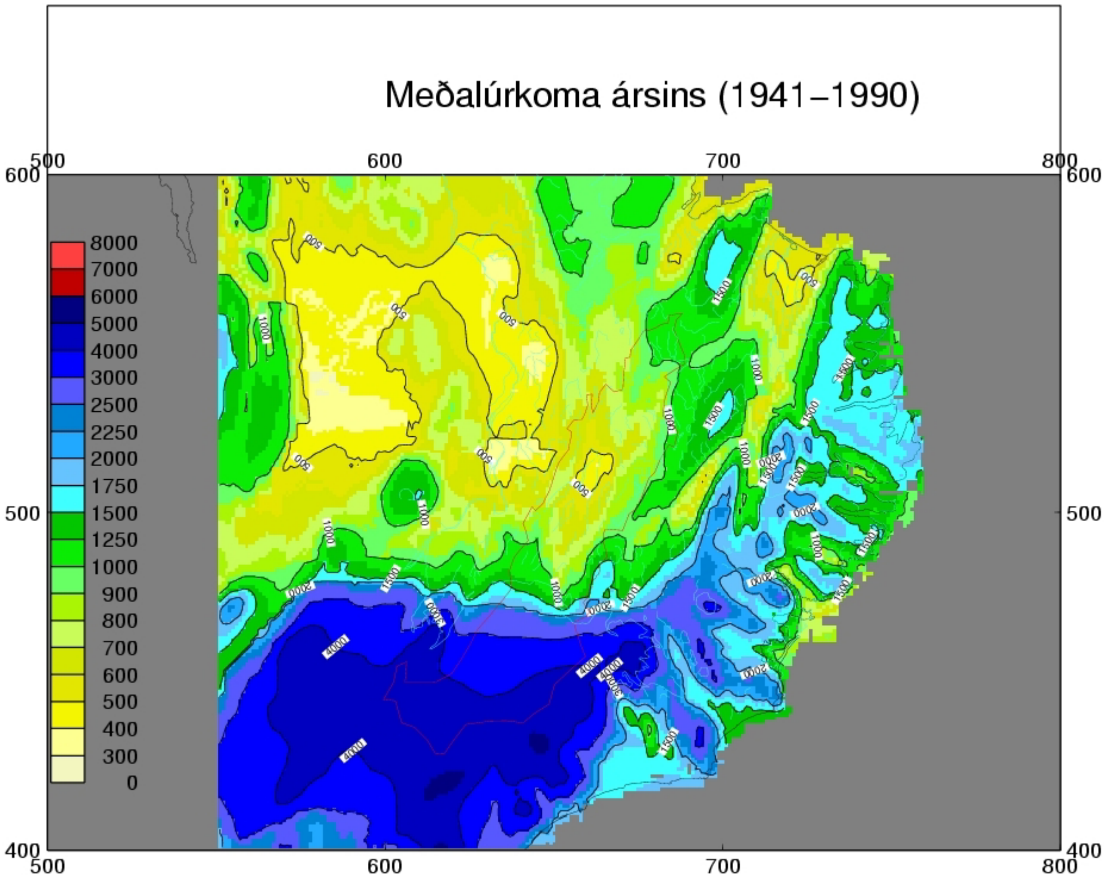
Appendix 7

Precipitation Ratio between 1941-1990 and 1971-2000


Ratio R(41-90)/R(71-00)
Y
X
700
600
500
400
300
200
300
400
500
600
700
800
0.957
0.921
0.922
0.938
0.968
0.981
0.923
0.927
0.997
0.927
1.03
0.943
0.976
1.04
0.965
0.951
0.956
0.974

Appendix 8

50-year mean annual precipitation map
for the period 1941-1990 in the Kárahnjúkar area


Meðalúrkoma ársins (1941−1990)
500
600
700
800
400
8000
7000
6000
5000
4000
3000
2500
2250
2000
1750
1500
1250
1000
900
800
700
600
500
400
300
0