VEÐURSTOFA ÍSLANDS

Report
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Comparison between ERA-40 derived precipitation and measured precipitation in Iceland

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1. Introduction

Climatic precipitation maps of Iceland will be made, for the period 1971-2000, using the precipitation modeling approach developed by R. Smith and I. Barstad (2004). Precipitation data from the ECMWF reanalysis, ERA-40, are intended to be used in order to calculate the background precipitation, i.e. the non-orographic precipitation component. A comparison between the ERA-40 precipitation and precipitation measured by the rain gauge network is thus necessary. The goal is to identify how relevant the use of ERA-40 is, in such a context, and to confirm or invalidate this choice.

2. Data

A total of 40 sites were considered in this study (Figure 1). As precipitation is not a part of the primary variables that are reanalysed in the ERA-40 data set, the precipitation was extracted from the ERA-40 prediction runs that are started at 00:00 and 12:00 GMT each day from the reanalysed state of the atmosphere at this point in time. In order to reduce spin-up effects, the initial 12 hours of each prediction run were discarded and a sequence of 12 hourly accumulated precipitation fields was generated from the interval 12 to 24 hours after the start of each prediction run. Daily, monthly and yearly accumulated precipitation was then computed from the 12 hourly accumulated precipitation fields. The grid size of the precipitation fields obtained in this manner is 0.5° in latitude and longitude, which is close to the actual horisontal resolution of the ERA-40 prediction model runs in latitude, but somewhat finer than the model resolution in longitude at the latitude range corresponding to the location of Iceland. The monthly precipitation were estimated at each site with a bilinear interpolation method. The total period under study is 1958-2002, with local variations from station to station depending on the availability of the stations.

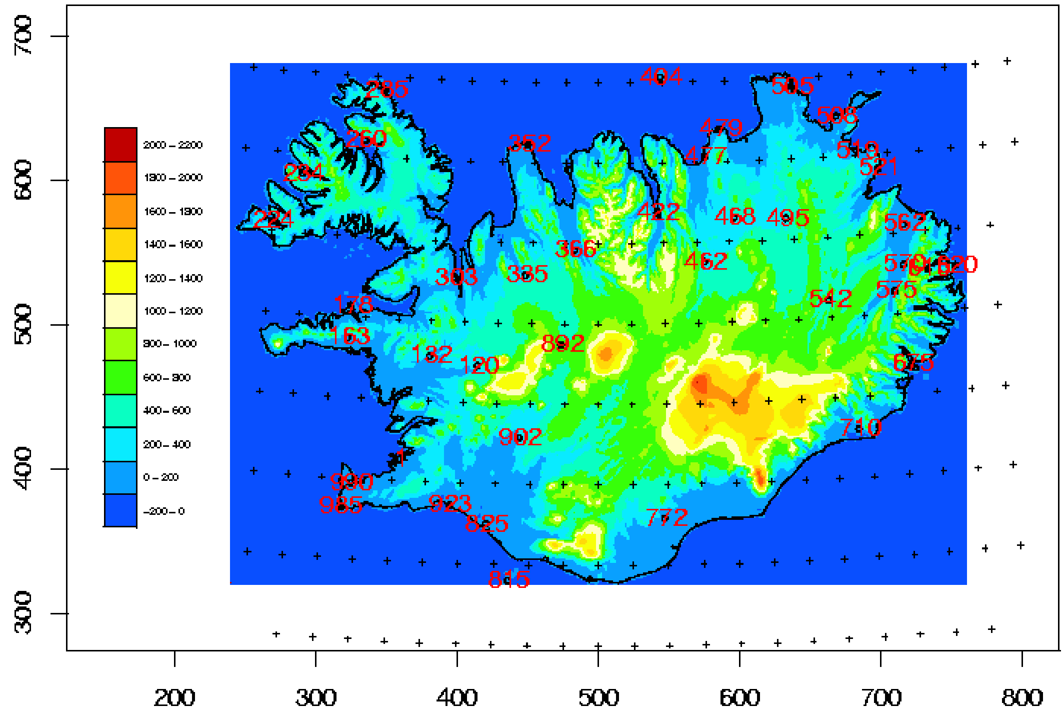

Figure 1: Topography, rain gauge network and ERA-40 mesh (crosses)

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3. Results

In what follows, we will try to analyse and understand possible sources of discrepancy between ERA-40 and the precipitation measurements at the stations. The spring, summer, fall and winter seasons will be denoted respectively by MAM, JJA, SON and DJF.

3.1 Discrepancies related to geographic and topographic features

Time-series of season-averaged monthly precipitation have been made for each site. Some results are presented in Appendix 1. The analysis of these series reveals quite well that both the ERA-40 and measured precipitation data display the same inter-annual variability with the same dry and wet sequences. It is also observed at most sites, that the discrepancies between the two series are quite systematic, and season dependent. Table 1 gives the mean relative difference, MRD=100(ERA-40 - Obs)/ Obs, where Obs is the measured precipitation.

The results of the analysis of these time-series can be divided into three groups, corresponding to the following basic classification:

- For the sites located in **open terrain** (352-404-505-825-902-923-985-990), the two datasets give similar estimates in summer time, except stations 352 and 923. This result shows that in absence of any obvious local conditions, ERA-40 is not biased, and the interpolation procedure gives a good estimation. Station 352, located at the extreme end of a peninsula is most likely exposed to wind, and a systematic difference is observed with ERA-40 in the summer time. Station 923, located south of Bláfjöll mountain range might be exposed to some local convection in the summer time.
For the three other seasons, systematic discrepancies become quite visible at most of these sites, especially in DJF and MAM. If we accept the assumption that they are not related to the interpolation procedure, then the most logical explanation is to assume that the rain gauges underestimate precipitation in the cold months, most likely in relation to the wind-loss of solid precipitation. This assumption is to some extent confirmed by the geographical variations observed in these discrepancies, more marked as we move towards the north and where we expect to have a larger fraction of precipitation as snow (see for instance the stations no. 985-990 on one hand, and 404-505 on the other).

- For the sites located in the vicinity of a complex terrain and subject to **orographic enhancement** such as in the West-Fjords, the Snæfellsnes peninsula, the East-Fjords and the south of Vatnajökull (163-224-285-615-620-675-710-772-815), ERA-40 gives in average less seasonal precipitation, than the measurements, in summer time at least, and depending on the geographical location, during the other seasons as well.

- For the sites located in a **rain-shadow** area (1-120-178-234-260-303-335-366-422-462-468-477-495-519-508-542-562-570-575-892), ERA-40 gives in average more precipitation than the precipitation measurements, in all seasons, and the deviation is also marked in the summer. However, some sites are also subject to a spill-over effect, mainly in the winter, in strong wind conditions. In such cases, the discrepancy is reduced in the winter (stations 234 and 575 could be examples of this).

The number of sites for which ERA-40 is in average larger than the measured precipitation depends on the season (Figure 2). The proportion from highest to lowest is as follows: DJF, MAM, SON, JJA, highlighting the link between underestimation and wind-loss. The relationships are quite linear and the slopes negative. The linear negative slopes indicate an increasing underestimation in the ERA-40 precipitation for stations with the largest observed precipitation. These are the stations with the largest orographic precipitation component, where it is to be expected that the ERA-40 precipitation is too low due to the coarse horisontal resolution of the ERA-40 prediction model landscape.

In order to analyse the inter-annual variability of the season-averaged monthly precipitation without being affected by systematic bias, time series of the precipitation ratio between two consecutive years were made as follows:

For the rain gauge data, Robs(t)=Obs(t)/Obs(t+1) and for ERA-40, Rera40(t)=ERA-40(t)/ERA-40(t+1), where t is the time index of the year. Some results are presented in Appendix 2. One can see the good agreement between the two data sets.

The ratio F(t)=Rera40(t)/Robs(t) is close to 1 most of the time. The average value of this ratio (Table 2) indicates that at most sites, the two data sets display a similar inter-annual variability. The seasonal correlation coefficient between Rera40(t) and Robs(t) is in average close to 0.7 (see Table 3), with some exceptions for sites subject to orographic enhancement. The MAM season contains the largest number of cases where in average, the ratio F(t) exceeds 1.1, mainly in the Eastern half part of Iceland, in the vicinity of complex terrain. For the other seasons, this arises for fewer stations, some of them located in the West fjords. For these stations, the signal related to the orography is not completely removed.

In order to gain more insight into the inter-annual variability of the discrepancies between the two precipitation data sets, Obs was plotted versus ERA-40 and the difference DP=ERA-40 – Obs was also plotted versus Obs, considering directly the monthly values. Some results are presented in Appendices 3 and 4. These results may be summarised as follows:

- For the sites located in open terrain, the direct comparison Obs versus ERA-40 does not display any bias in the summer time, except for stations 352 and 923. For the other seasons, systematic bias are observed, indicating that ERA-40 > Obs. The difference DP does not seem to be proportional to the measured precipitation amount, except the station 352 in DJF.

- For the sites subject to orographic enhancement, ERA-40 gives in average less precipitation than the rain gauge network and the magnitude of the difference is proportional to the measured precipitation amount (negative slope). Stations 479 and 521 can be added to this list, however, the slope is positive for the coldest months (MAM and DJF). Stations 132 can also be added to this list. The slope is negative, but there is no bias in average.

- For the sites located in rain-shadow areas, the direct comparison Obs versus ERA-40 displays systematic bias at all seasons, however the difference between the two datasets does not clearly increase with the precipitation amount, except for a few cases.

- For the sites located in a rain shadow area and subject to a spill-over effect, the majority of the ERA-40 estimates are larger than the rain gauge data, but the largest values are underestimated by ERA-40.

In order to summarize these results, Figures 3 to 5 present Obs versus ERA-40, considering all the stations belonging to a same category together. In open terrain, MRD is ranging from 10% to 80%, in complex terrain where orographic enhancement prevails, MRD is ranging from -5% to 35%, and in rain-shadow areas, MRD is ranging from 90% to 250%.

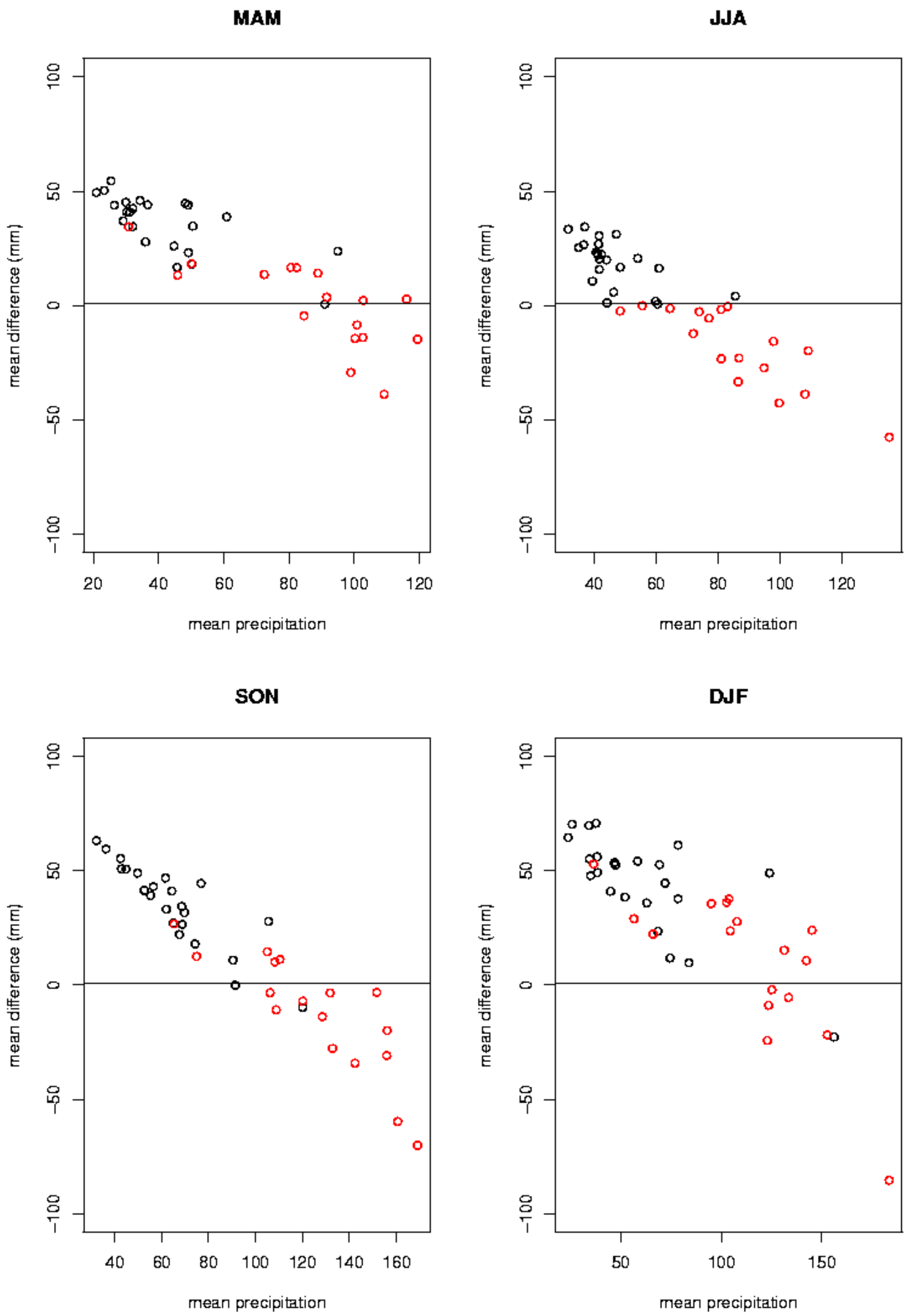


Figure 2: Mean difference ERA-40 – Obs. versus Obs, considering season-averaged monthly precipitation. All stations together. Each point corresponds to a station.
The points marked in red correspond to the sites for which ERA-40 is underestimating precipitation in summer time (JJA)

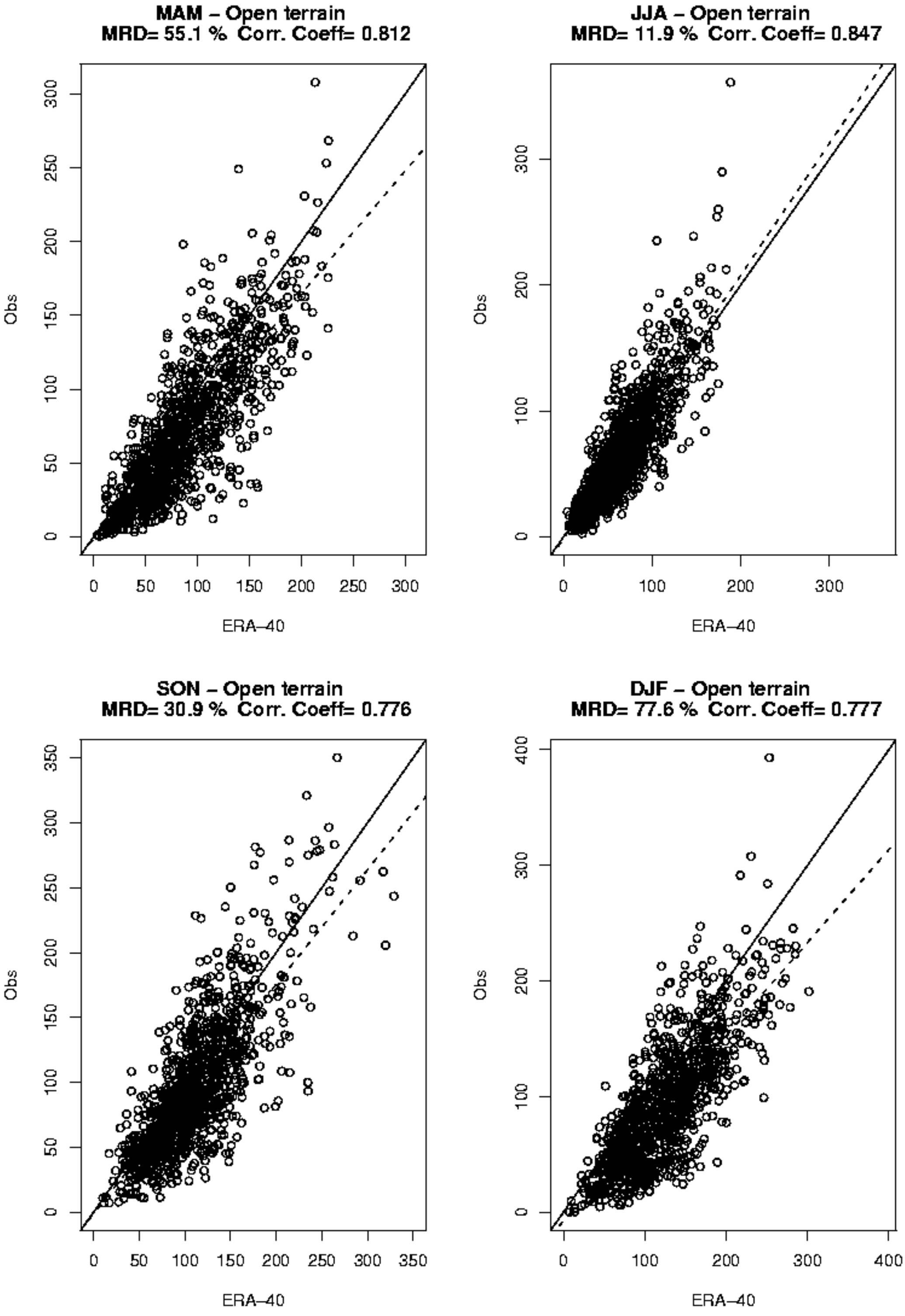


Figure 3: Measured precipitation versus ERA-40 for stations being classified as located in open terrain. The plain line is the 1:1 line, and the dashed line is the regression line. The precipitation is accumulated over 1 month.

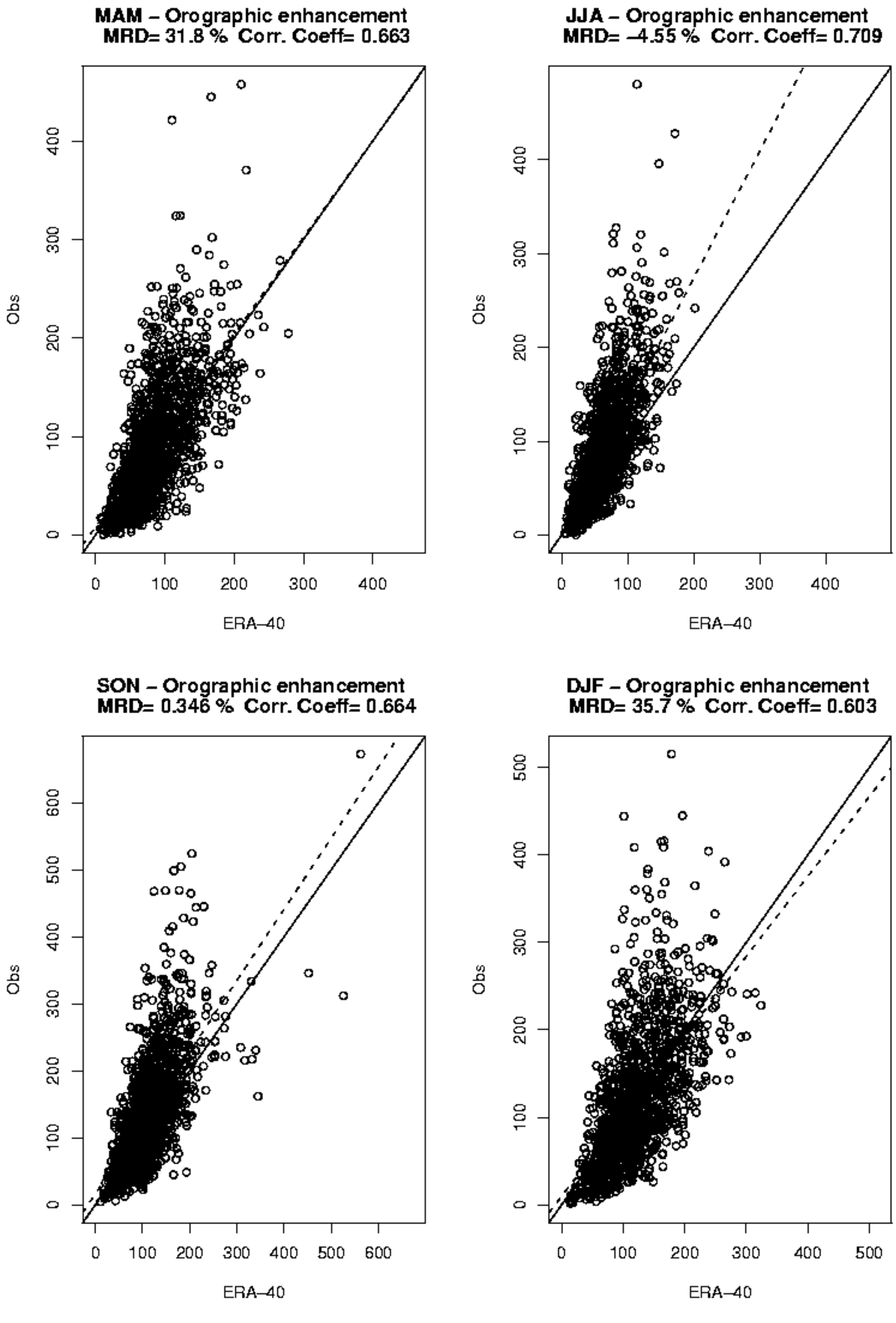


Figure 4: Measured precipitation versus ERA-40 for stations being classified as affected by orographic enhancement. The plain line is the 1:1 line, and the dashed line is the regression line. The precipitation is accumulated over 1 month.

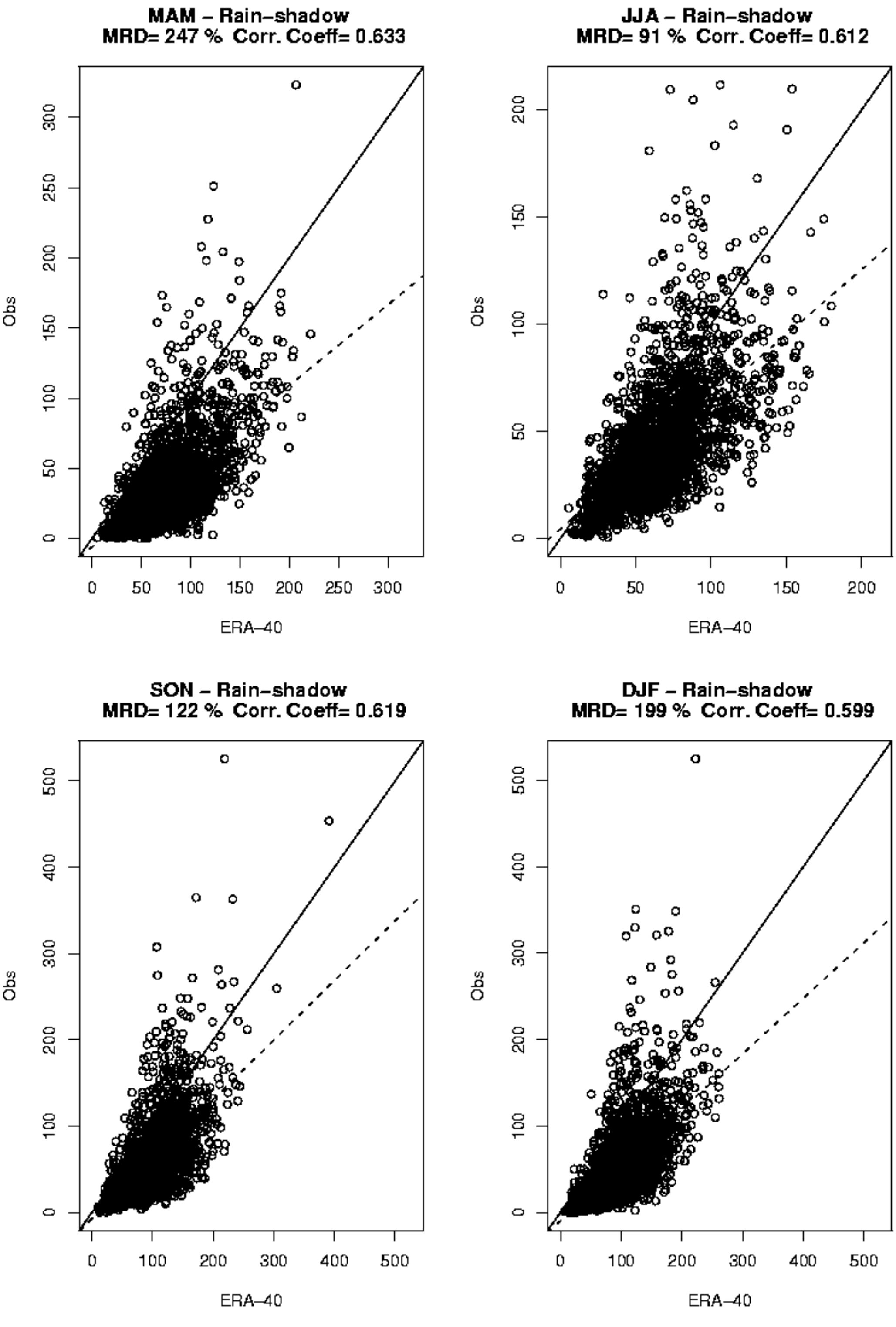


Figure 5: Measured precipitation versus ERA-40 for stations being classified as located in a rain-shadow area. The plain line is the 1:1 line, and the dashed line is the regression line. The precipitation is accumulated over 1 month.

Table 1: Mean relative difference, MRD, in %, calculated with the Season-averaged monthly values

Table 2: Mean ratio E[F(t)], where F(t)=Rera40(t)/Robs(t)

The type is “S” for rain-shadow, “E” for enhancement and “O” for open terrain.

Station	MAM	JJA	SON	DJF	Type
1	72.5	40.0	61.4	83.9	S
120	99.2	69.9	83.8	57.9	S
132	7.0	1.8	1.9	4.1	E
163	-4.2	-33.7	-18.4	27.9	E
178	83.9	57.5	56.4	80.5	S
224	-6.6	-21.5	-15.9	4.5	E
234	10.1	51.9	6.6	-2.5	S
260	131.6	82.6	59.6	102.5	S
285	22.5	-34.2	-3.4	48.3	E
303	144.8	79.8	75.2	124.3	S
335	235.9	103.1	188.4	247.1	S
352	145.3	29.2	83.3	203.7	O
366	148.0	74.6	133.2	173.8	S
404	48.0	6.0	29.2	65.3	O
422	157.3	118.3	91.6	89.2	S
462	251.3	43.9	146.2	304.6	S
468	194.2	66.6	123.7	178.9	S
477	66.2	11.3	13.3	29.7	S
479	131.6	4.6	48.6	157.3	E
495	264.7	64.6	215.6	332.6	S
505	37.5	-0.7	21.1	40.4	O
508	93.3	20.4	48.4	98.2	S
519	135.9	7.3	42.9	150.1	S
521	49.0	8.9	0.8	55.5	E
542	210.1	65.1	115.6	139.0	S
562	158.4	75.1	67.1	150.6	S
570	100.3	87.3	55.5	63.4	S
575	77.4	56.6	28.4	26.6	S
615	-30.1	-5.4	-35.4	-42.6	E
620	-20.4	-36.8	-34.8	-16.0	E
675	5.9	-19.8	-8.7	-3.4	E
710	-3.5	-23.9	-16.7	-10.5	E
772	-9.8	-41.5	-10.7	9.0	E
815	6.7	-15.5	0.9	19.4	E
825	28.4	6.4	27.1	39.3	O
892	110.3	31.7	74.1	87.8	S
902	20.1	5.4	16.0	31.0	O
923	3.9	-13.3	-1.2	13.9	O
985	22.1	-6.7	12.5	38.2	O
990	23.2	-2.4	15.7	37.4	O

Station	MAM	JJA	SON	DJF
1	1.05	1.03	1.02	1.04
120	1.05	1.05	1.02	1.04
132	1.03	1.02	1.04	1.04
163	1.03	1.03	1.03	1.04
178	1.07	1.04	1.02	1.05
224	1.09	1.08	1.12	1.10
234	1.09	1.13	1.24	1.17
260	1.09	1.08	1.14	1.10
285	1.03	1.14	1.02	1.05
303	1.03	1.06	1.03	1.05
335	1.08	1.07	1.10	1.05
352	1.09	1.03	1.05	1.05
366	1.05	1.07	1.06	1.08
404	1.06	1.04	1.05	1.03
422	1.08	1.07	1.07	1.08
462	1.10	1.08	1.05	1.08
468	1.10	1.06	1.05	1.09
477	1.21	1.07	1.06	1.15
479	1.09	1.05	1.07	1.06
495	1.09	1.05	1.08	1.09
505	1.06	1.05	1.06	1.02
508	1.09	1.09	1.06	1.05
519	1.11	1.05	1.08	1.05
521	1.08	1.14	1.08	1.03
542	1.11	1.07	1.06	1.08
562	1.15	1.16	1.06	1.07
570	1.17	1.11	1.08	1.11
575	1.19	1.09	1.11	1.08
615	1.06	1.15	1.07	1.06
620	1.12	1.10	1.02	1.06
675	1.16	1.09	1.02	1.02
710	1.14	1.07	1.02	1.05
772	1.04	1.02	1.01	1.02
815	1.05	1.03	1.02	1.03
825	1.03	1.01	1.00	1.04
892	1.10	1.04	1.06	1.08
902	1.02	1.04	1.02	1.02
923	1.02	1.03	1.01	1.02
985	1.03	1.03	1.01	1.03
990	1.03	1.03	1.02	1.04

Table 3: Summary statistics for the correlation coefficient between the interannual ratios Rera40(t) and Robs(t)

	MAM	JJA	SON	DJF
min	0.23	0.04	0.41	0.33
25% Quantile	0.59	0.55	0.65	0.58
median	0.74	0.69	0.71	0.73
mean	0.69	0.67	0.72	0.69
75% Quantile	0.78	0.79	0.80	0.83
max	0.90	0.92	0.94	0.95

3.2 Interpretation of the discrepancies

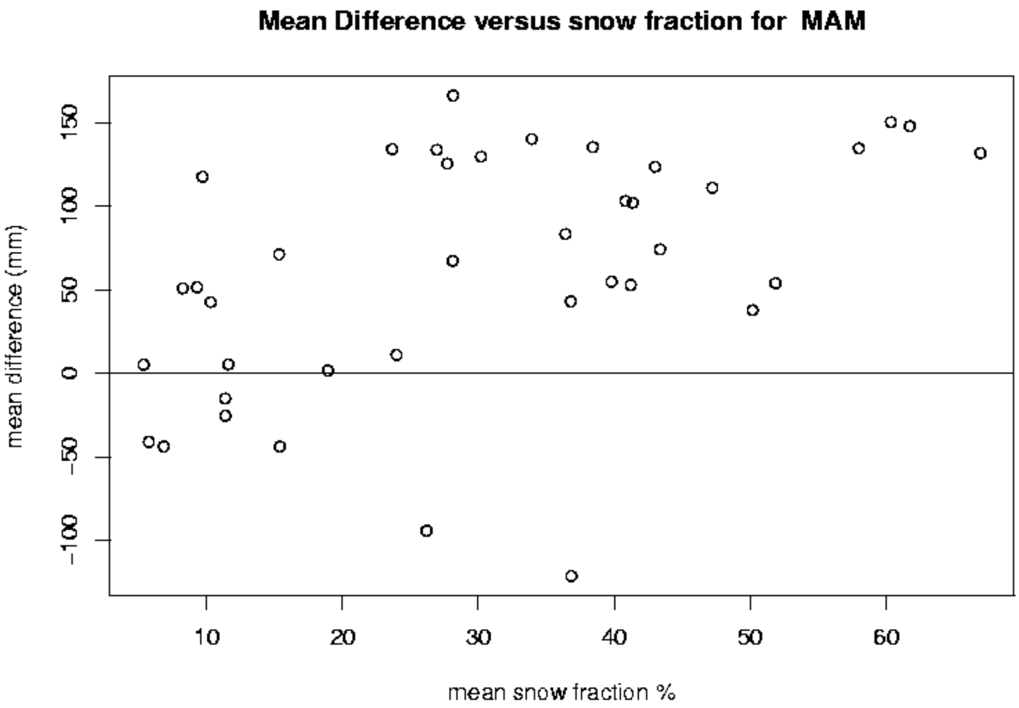
As already indicated in the previous section, the wind and the phase of the precipitation, together with the lack of detail in the ERA-40 model landscape are the most important sources of discrepancy between the two data sets.

A marked link between the magnitude of the discrepancy and the fraction of precipitation falling as snow, is observed at 70% of the sites. Figures 6 to 9 present the relationships between the mean seasonal difference and the mean seasonal snow fraction on one hand, and the mean seasonal precipitation and the mean seasonal snow fraction on the other hand, for all stations together and each season. The difference clearly increases with the snow fraction, and the mean precipitation decreases with the snow fraction. In other words, the largest measured precipitation amounts have a liquid phase, and the lowest ones have a solid phase. This also suggests that our perception of the liquid/solid fraction is biased. Appendix 5, presents various individual examples of the variation of the discrepancy with the snow fraction. The summary of this analysis is as follows:

- For the sites affected by orographic enhancement, the apparent difference between the two data sets is reduced with the increase of snow fraction. In other words, the undercatch of snow at the ground is masked by the orographic enhancement (not captured by ERA-40).

- For the sites located in open terrain and rain-shadow areas, the difference increases with the snow fraction.

For the sites where the wind-speed is measured (21/40), it appears that the magnitude of the discrepancies increases with the mean wind-speed (during days with precipitation), at 17 sites out of 21. The relationships are not always clearly defined, mainly because of the temporal resolution (monthly and seasonal) considered in this study. However, an increase of the discrepancy, interpreted as a wind-loss effect is definitely observed in DJF, and also to some extent in MAM and SON. Station 352 experiences a wind-loss during the summer time as well, as previously suspected. Appendix 6 presents the plots for some representative sites.



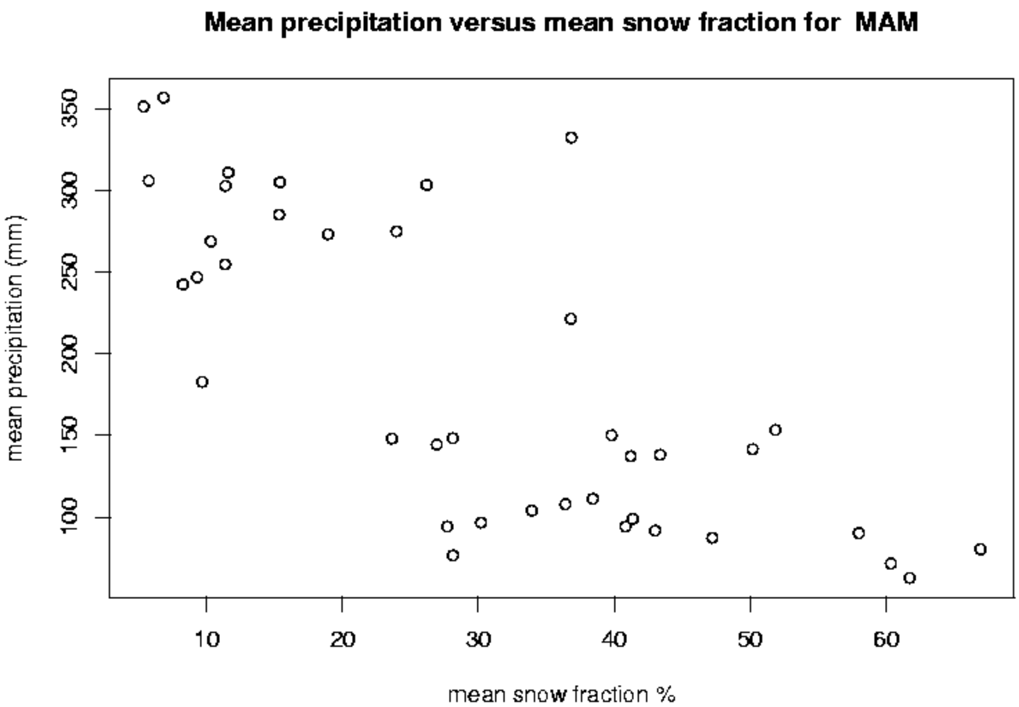
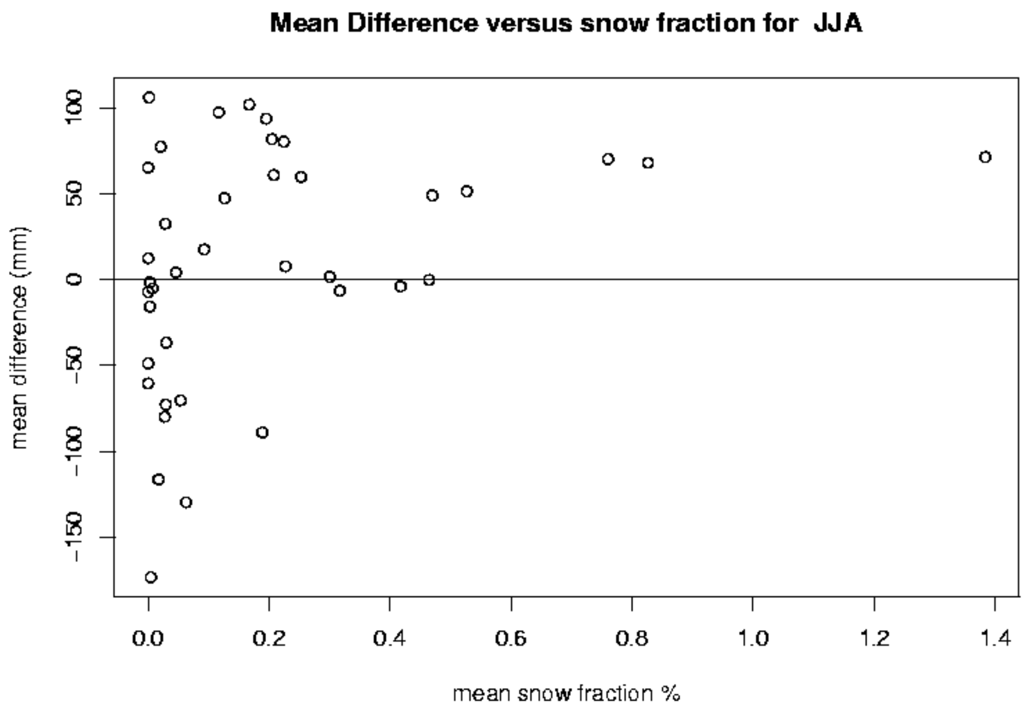


Figure 6: MAM
Up: Mean seasonal difference ERA-40 – Obs (in mm)
versus mean seasonal snow fraction.
Down: Mean seasonal precipitation versus mean seasonal snow fraction.
All stations together. Each point corresponds to a station.



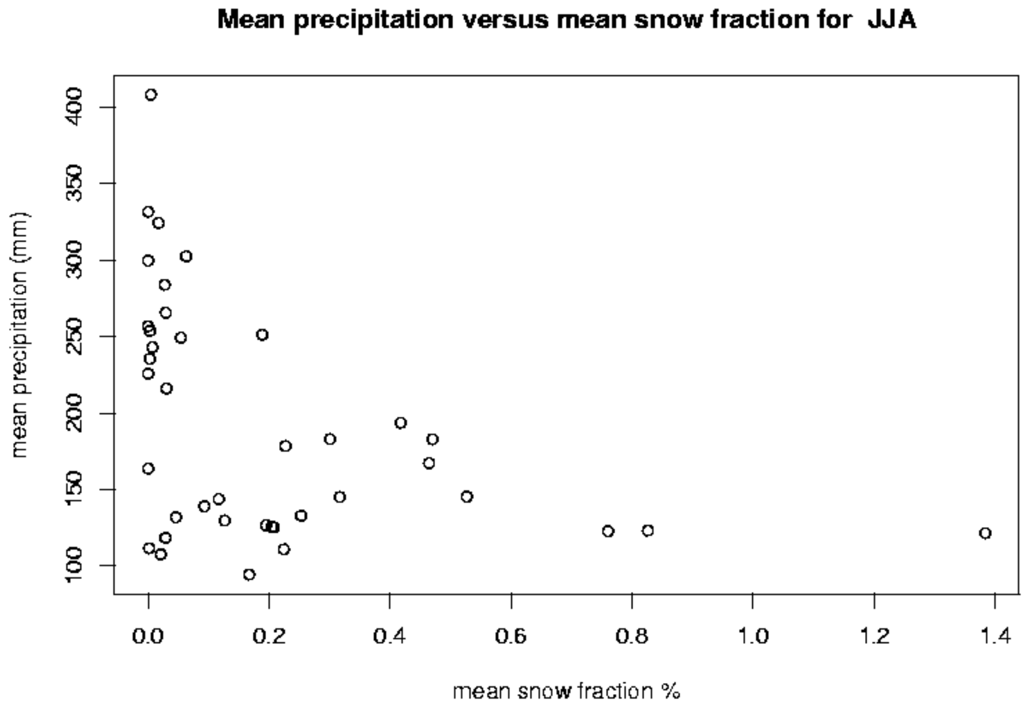


Figure 7: JJA
Up: Mean seasonal difference ERA-40 – Obs (in mm)
versus mean seasonal snow fraction.
Down: Mean seasonal precipitation versus mean seasonal snow fraction.
All stations together. Each point corresponds to a station.

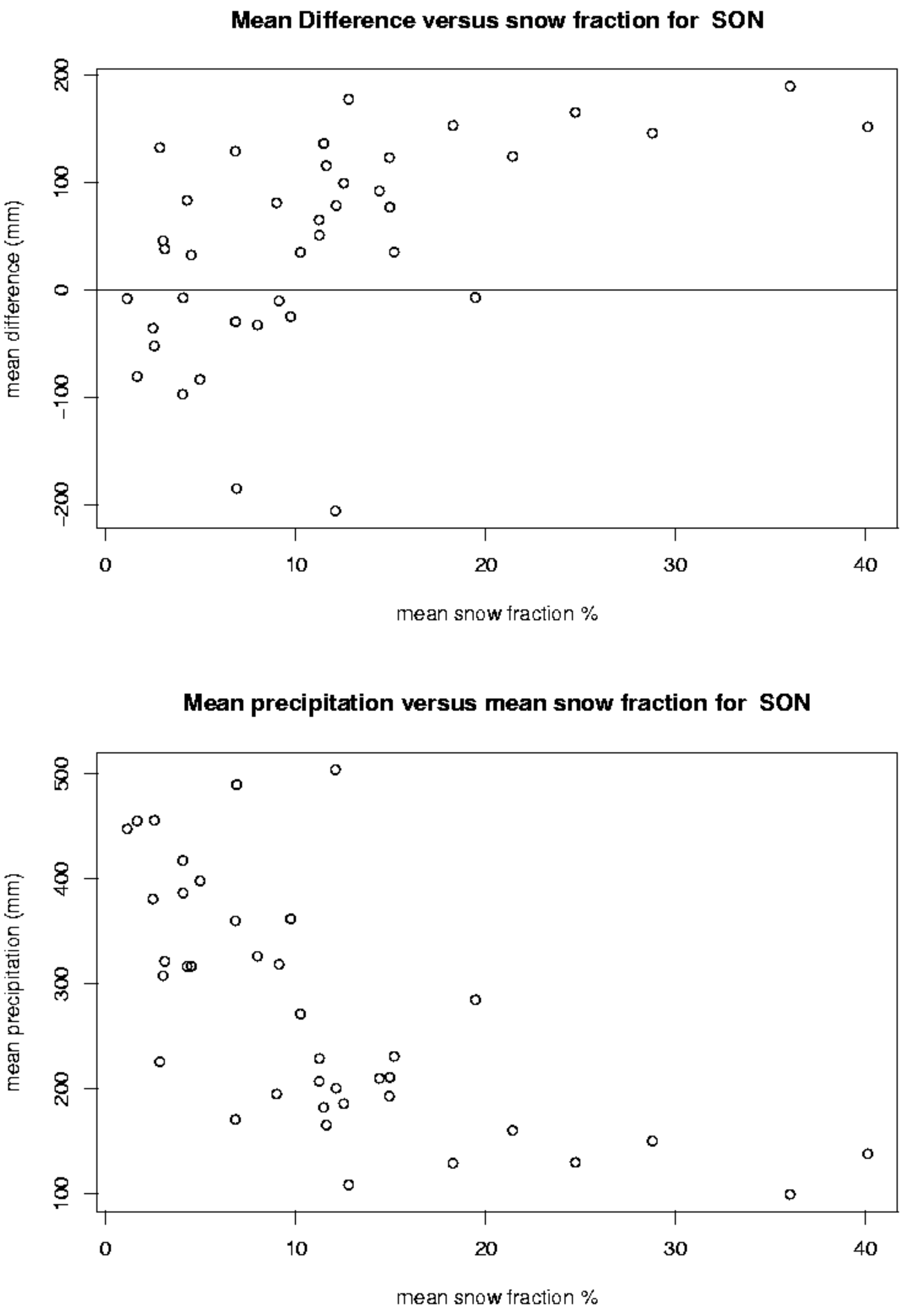


Figure 8: SON
Up: Mean seasonal difference ERA-40 – Obs (in mm)
versus mean seasonal snow fraction.
Down: Mean seasonal precipitation versus mean seasonal snow fraction.
All stations together. Each point corresponds to a station.

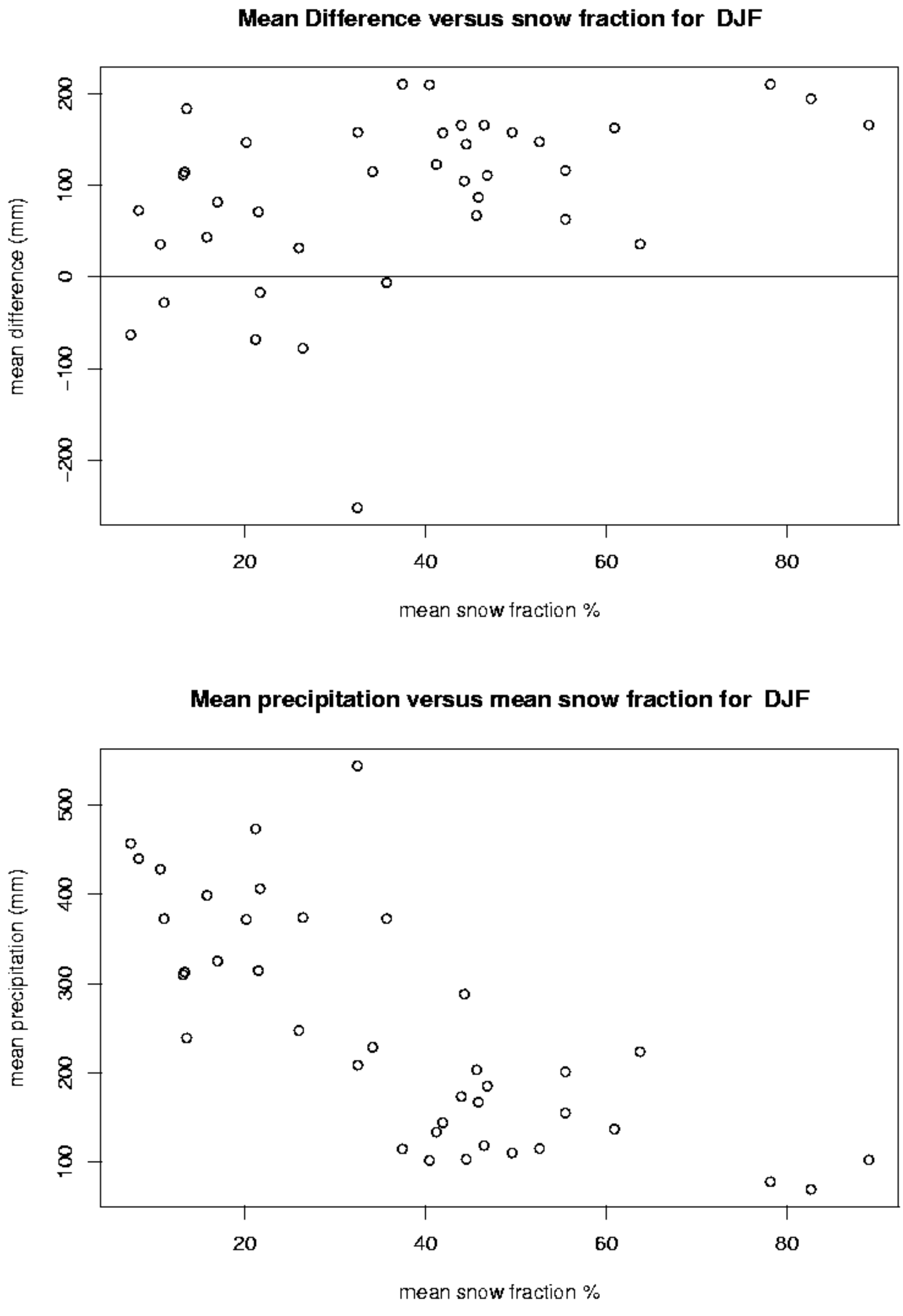


Figure 9: DJF
Up: Mean seasonal difference ERA-40 – Obs (in mm) versus mean seasonal snow fraction.
Down: Mean seasonal precipitation versus mean seasonal snow fraction.
All stations together. Each point corresponds to a station.

4. Summary and conclusions

This study has demonstrated that **ERA-40 captures quite well the inter-annual variability of seasonal precipitation in Iceland**. The discrepancies between the two data sets can usually be explained by several identified sources, affecting either ERA-40 or the rain gauge network. A summary diagram is given in Figure 10. These sources can act individually or combine their effects in order to increase, reduce or mask the discrepancies.

Based on the results obtained in summer time, at sites located in open terrain, we may assume that for the time scales involved in this study (month and season), **errors that are due to the crude horizontal resolution of the ERA-40 model are acceptable**. In general, it appears that the rain gauge network underestimates precipitation, mainly the solid phase, due to wind-loss, although this effect is in many cases masked by counteracting sources of error. This specific source of error appears to be quite marked during the spring and the winter months, and to some extend during fall. For these seasons, **the use of measured precipitation for calculating background precipitation for downscaling purposes could result in a serious underestimation of the actual precipitation reaching the ground.**

The main source of error in the ERA-40 data set is related to the orographic enhancement and rain-shadow effect, which are not well captured by the ECMWF model, as a consequence of its crude horizontal resolution (~50 km). Precisely these aspects may be compensated by the modeling approach of Smith & Barstad (2004). In conclusion, it is **our recommendation to make use of ERA-40 derived precipitation as background precipitation in this model, rather than the measured precipitation. A special attention will have to be given to rain-shadow areas, in the assessment of the Smith and Barstad model.**

A similar study dealing with daily precipitation should be carried out as well, in order to analyse more specifically the behaviour of ERA-40 data set during reported dry days for instance, and vice-versa. Other types of error are most likely affecting the rain gauge data, such as the reading practice and changes in the gauge location or local conditions near the station (urban area, vegetation) over the span of the measurements. The use of ERA-40, as a reference could be an interesting basis for an assessment of such errors.

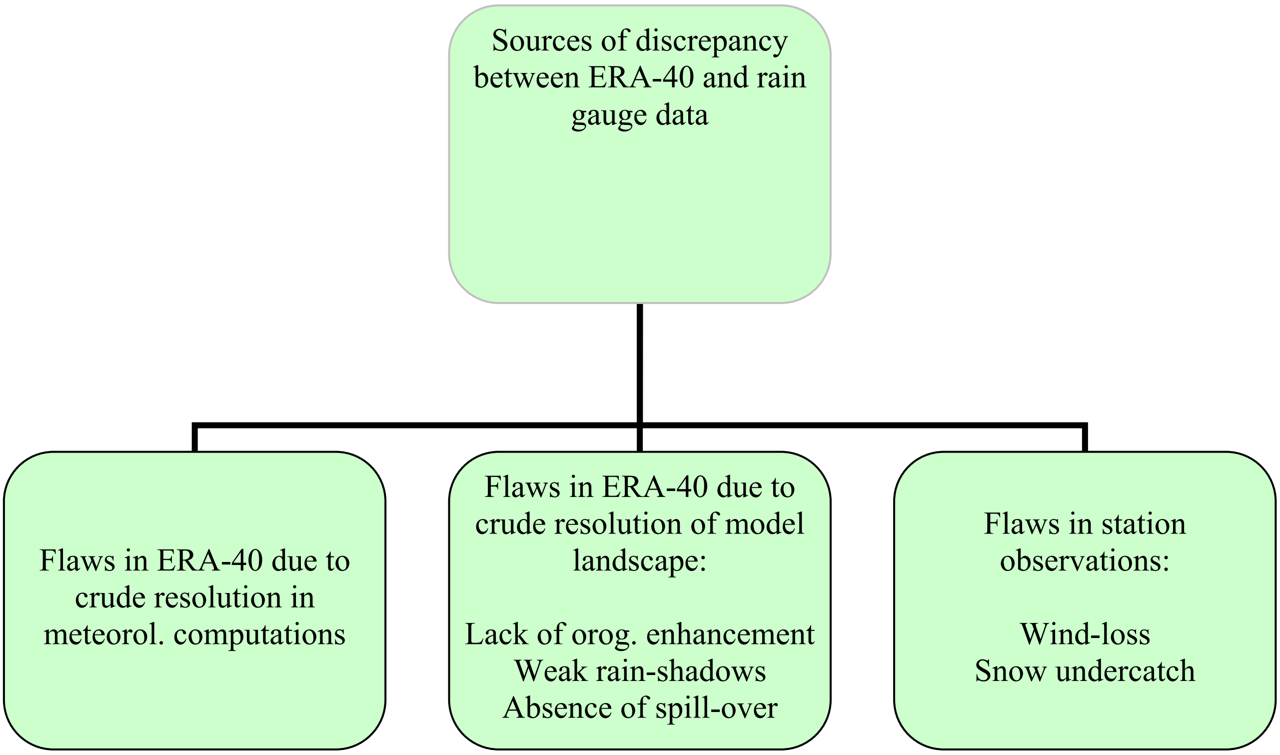


Figure 10: Sources of discrepancy between ERA-40 and precipitation measurements at meteorological stations

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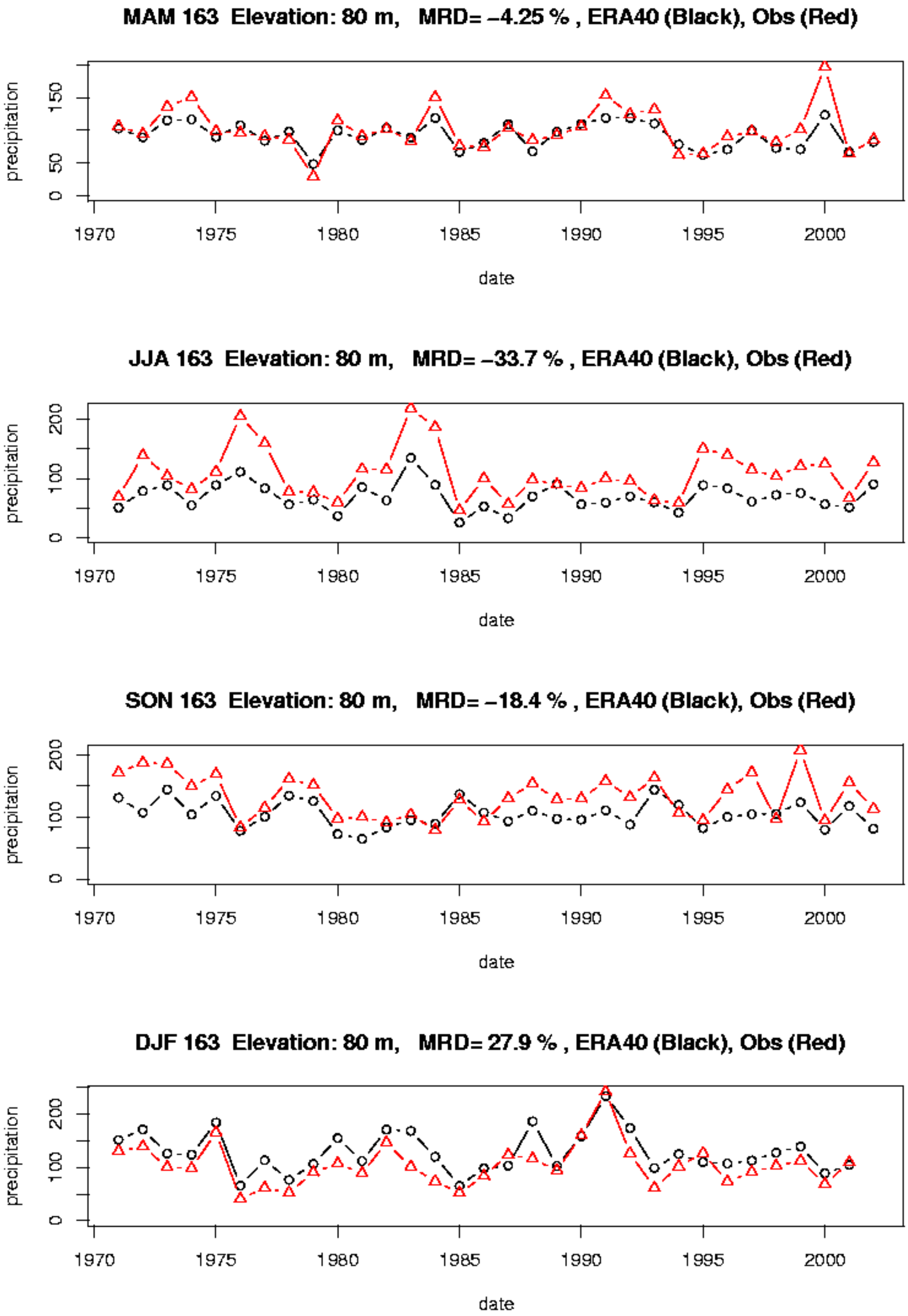
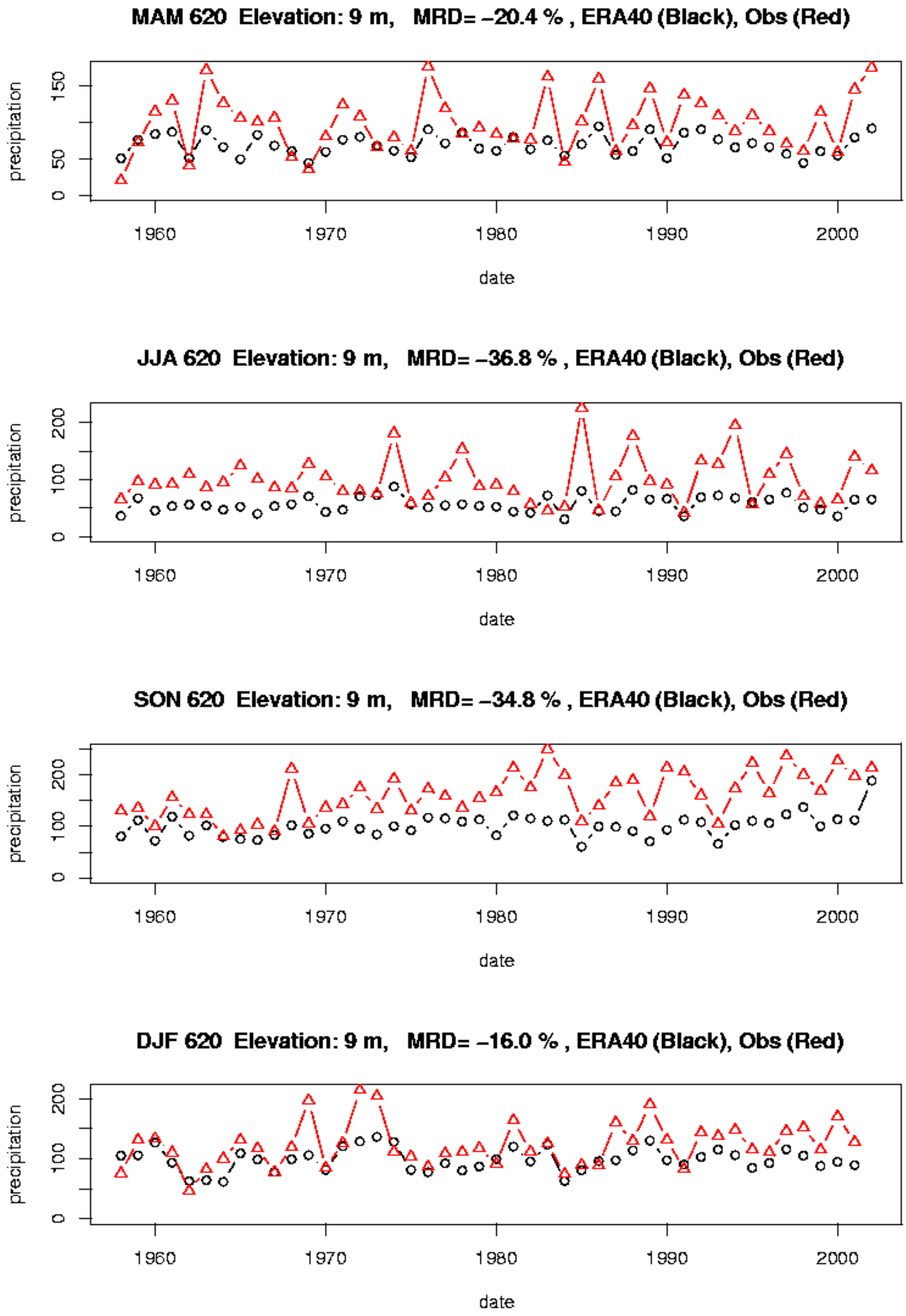
Reference: Smith R.B and I. Barstad. 2004. A linear theory of orographic precipitation, J. Atmos. Sci., Vol. 61 No. 12, 1377-1391

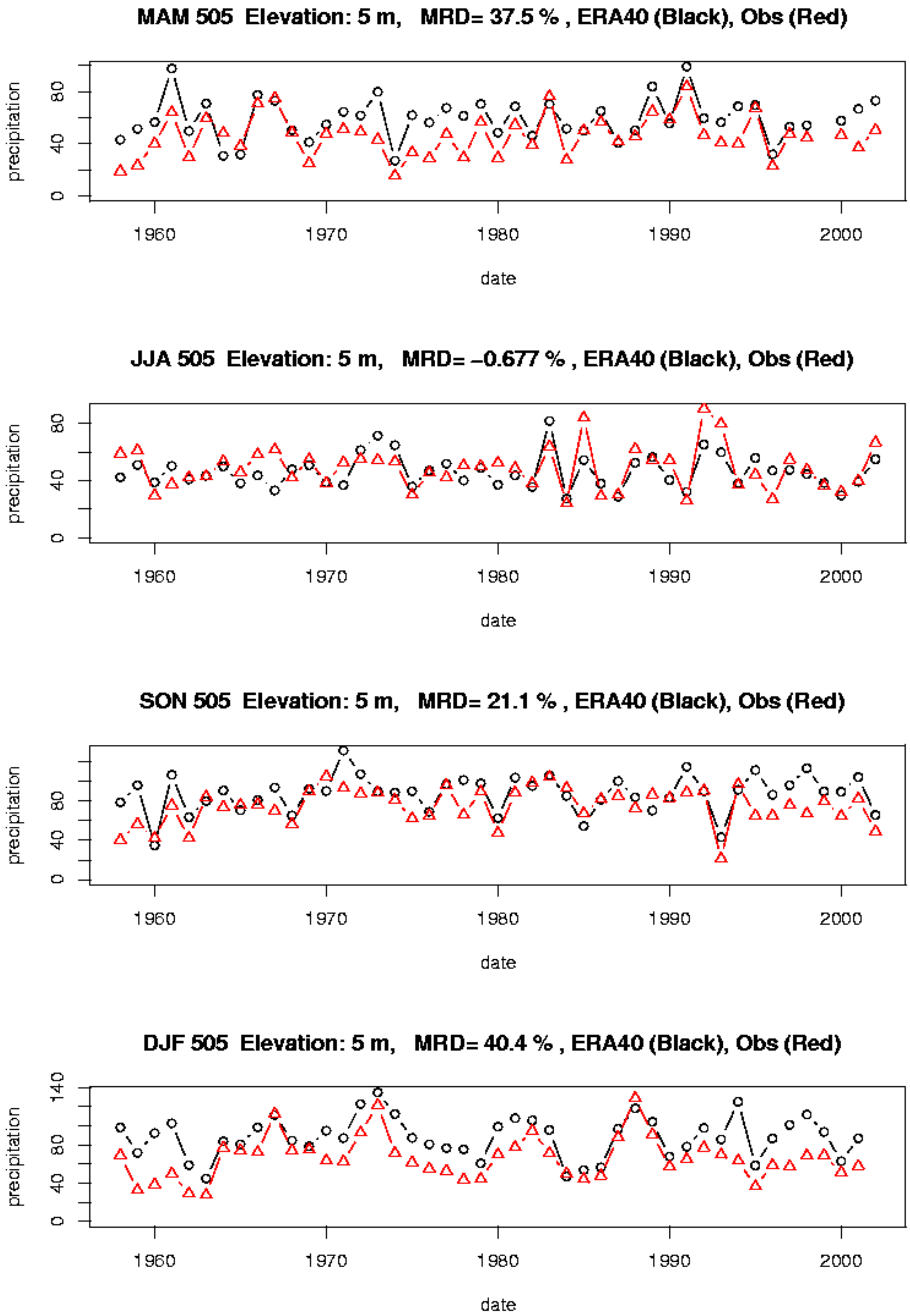
Appendix 1



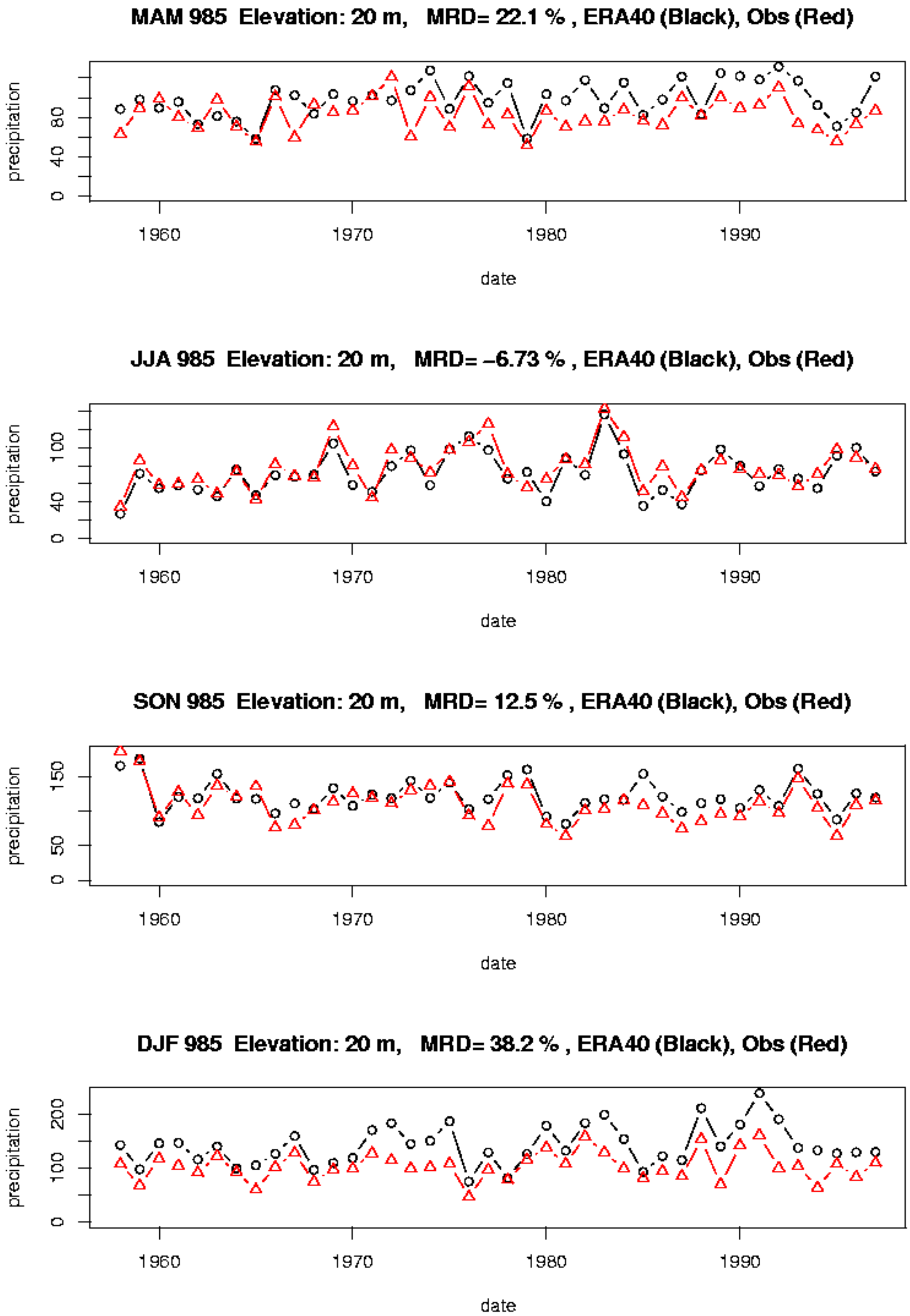
Time-series of the season-averaged monthly precipitation for station no. 163
ERA-40 (black circles) and rain gauge data (red triangles)



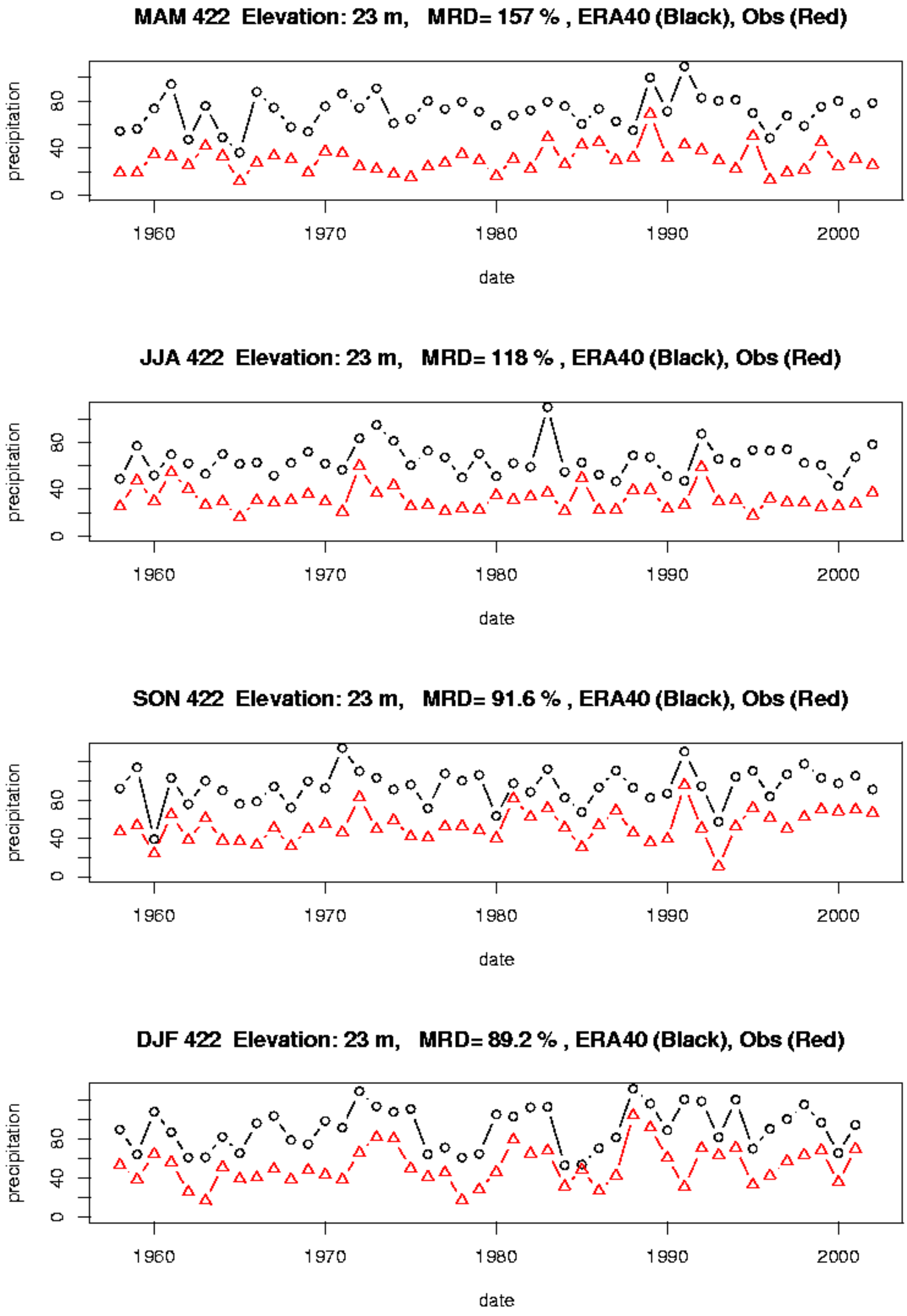
Time-series of the season-averaged monthly precipitation for station no. 620
ERA-40 (black circles) and rain gauge data (red triangles)



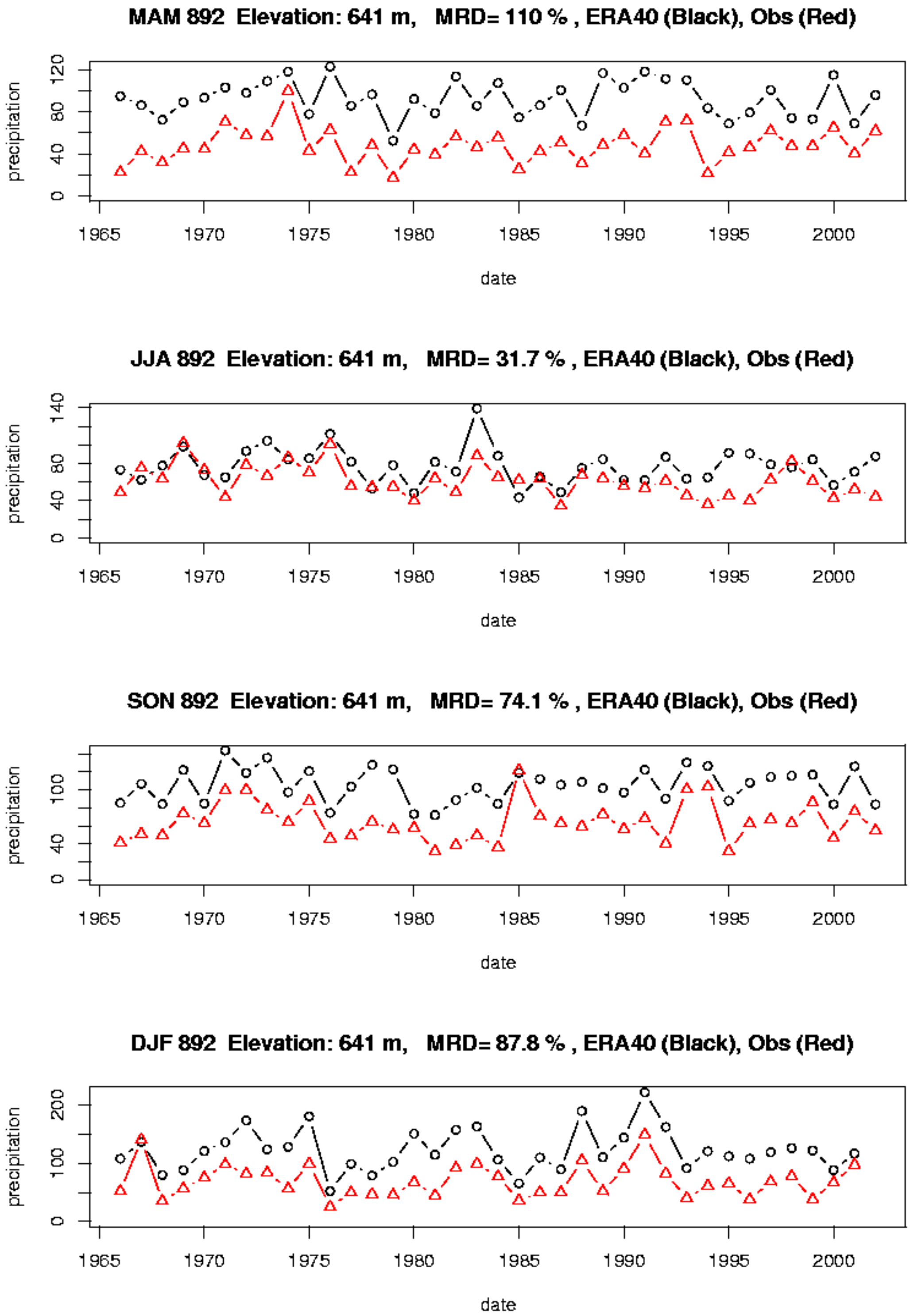
Time-series of the season-averaged monthly precipitation for station no. 505
ERA-40 (black circles) and rain gauge data (red triangles)



Time-series of the season-averaged monthly precipitation for station no. 985
ERA-40 (black circles) and rain gauge data (red triangles)

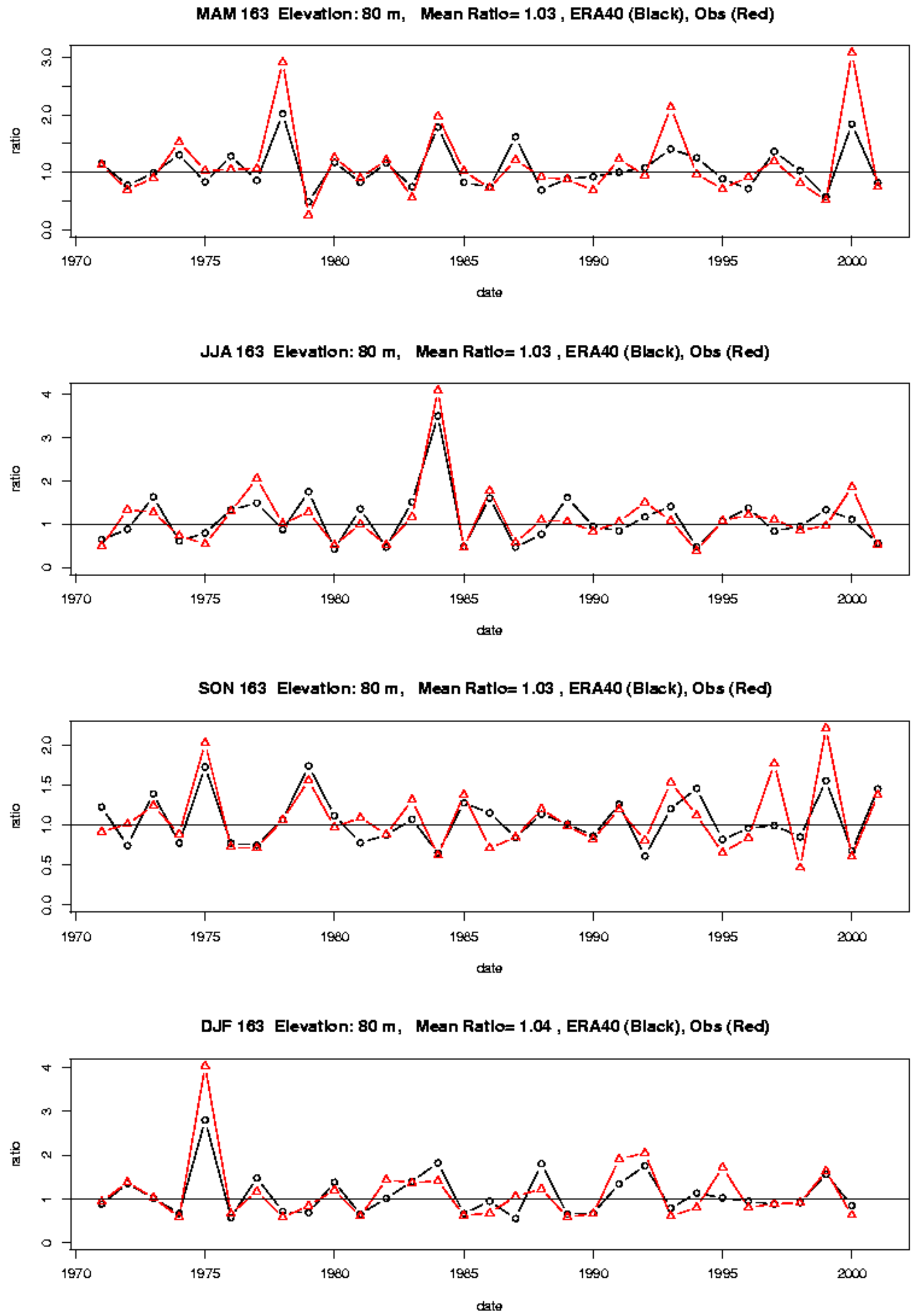


Time-series of the season-averaged monthly precipitation for station no. 422
ERA-40 (black circles) and rain gauge data (red triangles)

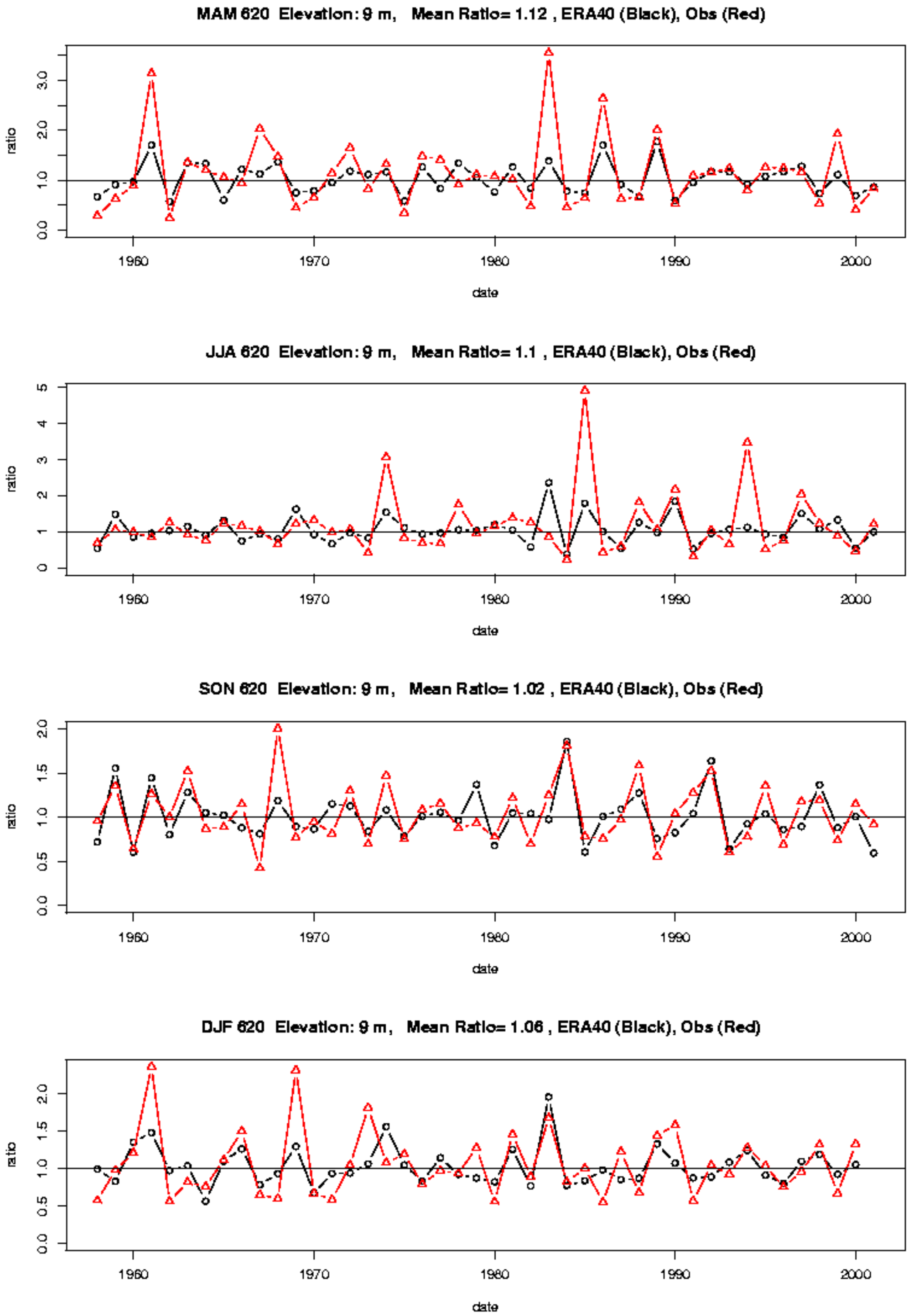


Time-series of the season-averaged monthly precipitation for station no. 892
ERA-40 (black circles) and rain gauge data (red triangles)

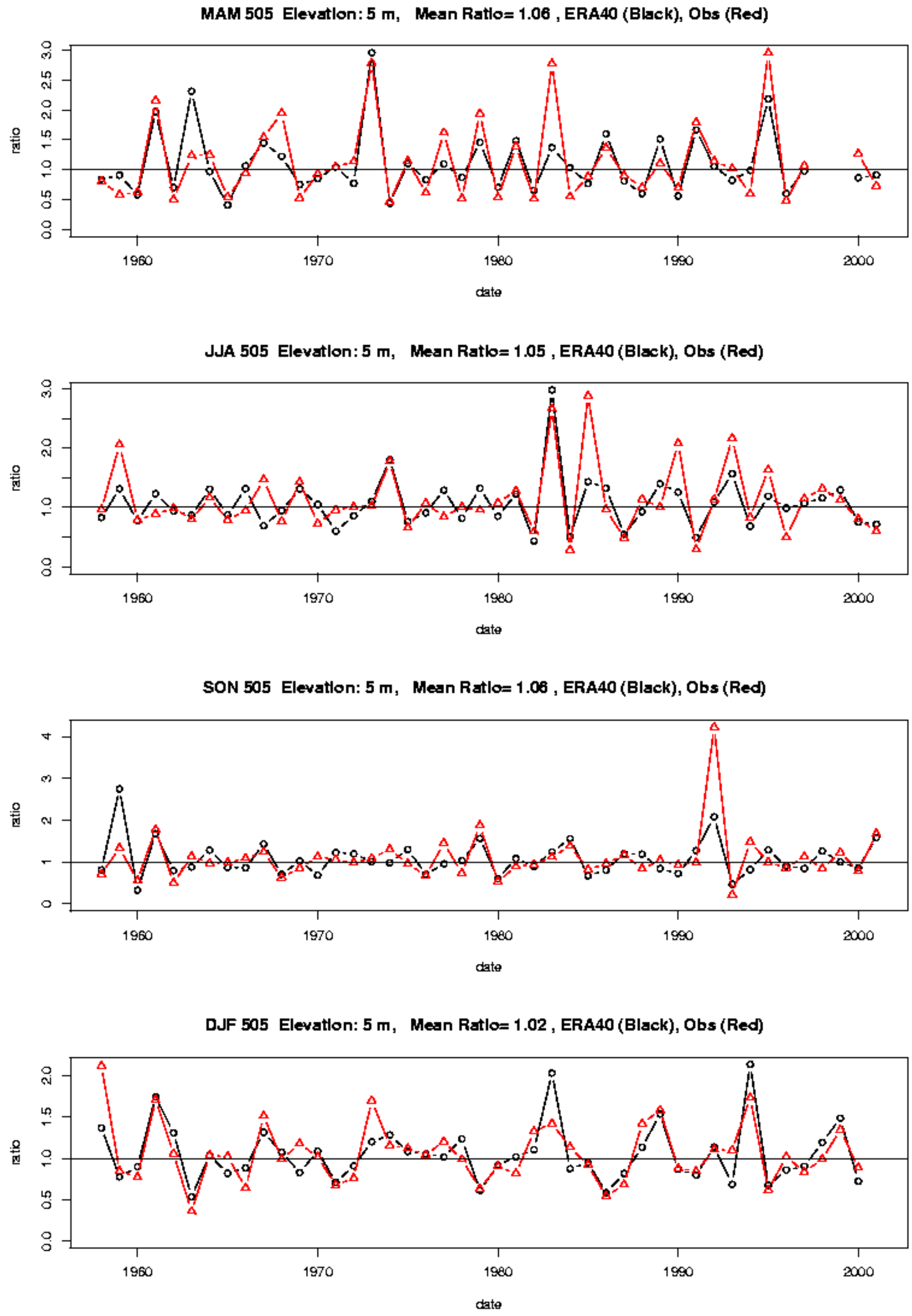
Appendix 2



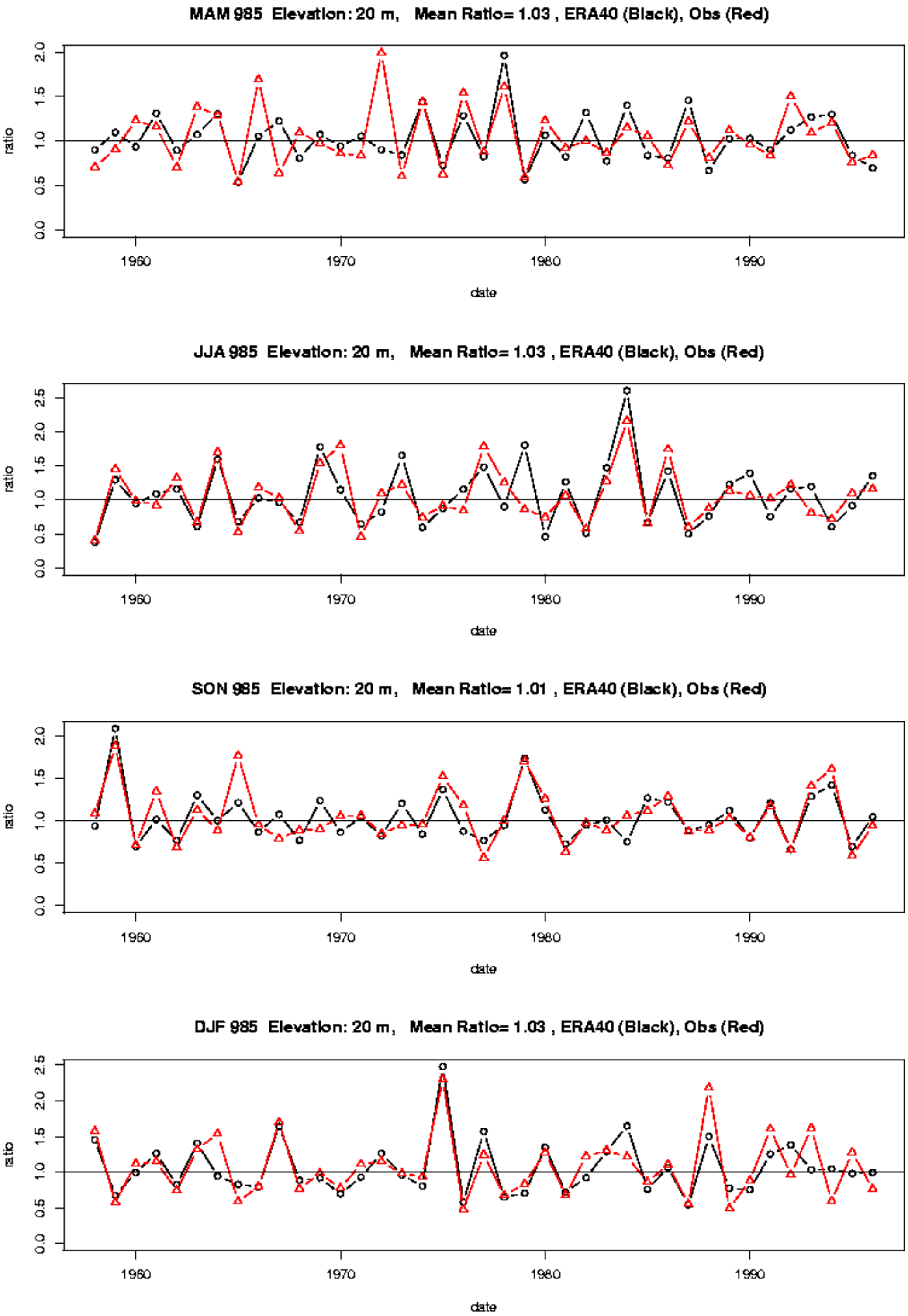
Time-series of the season-averaged monthly precipitation ratio between 2 consecutive years,
for station no. 163
ERA-40 (black circles) and rain gauge data (red triangles)



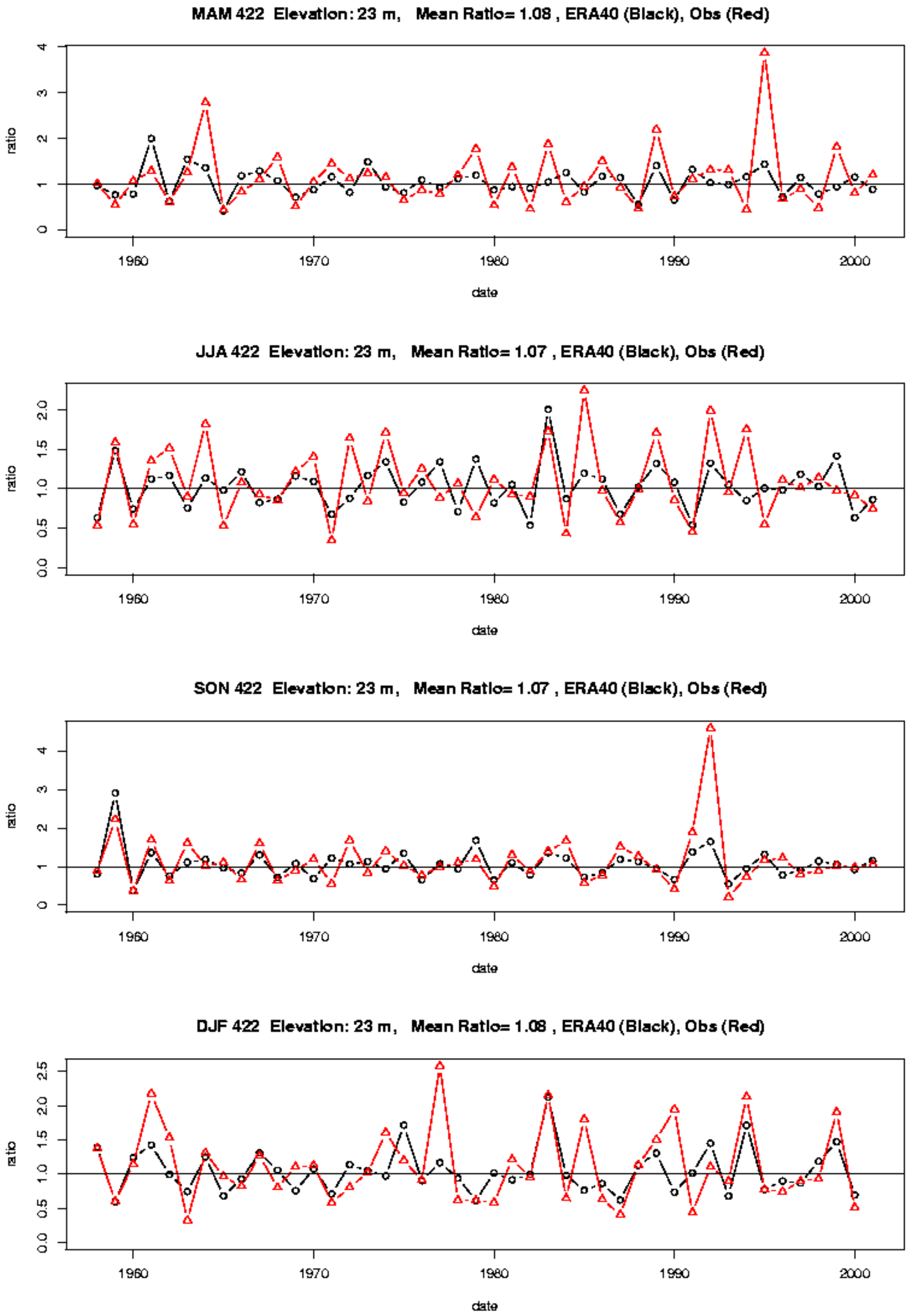
Time-series of the season-averaged monthly precipitation ratio between 2 consecutive years, for station no. 620
ERA-40 (black circles) and rain gauge data (red triangles)



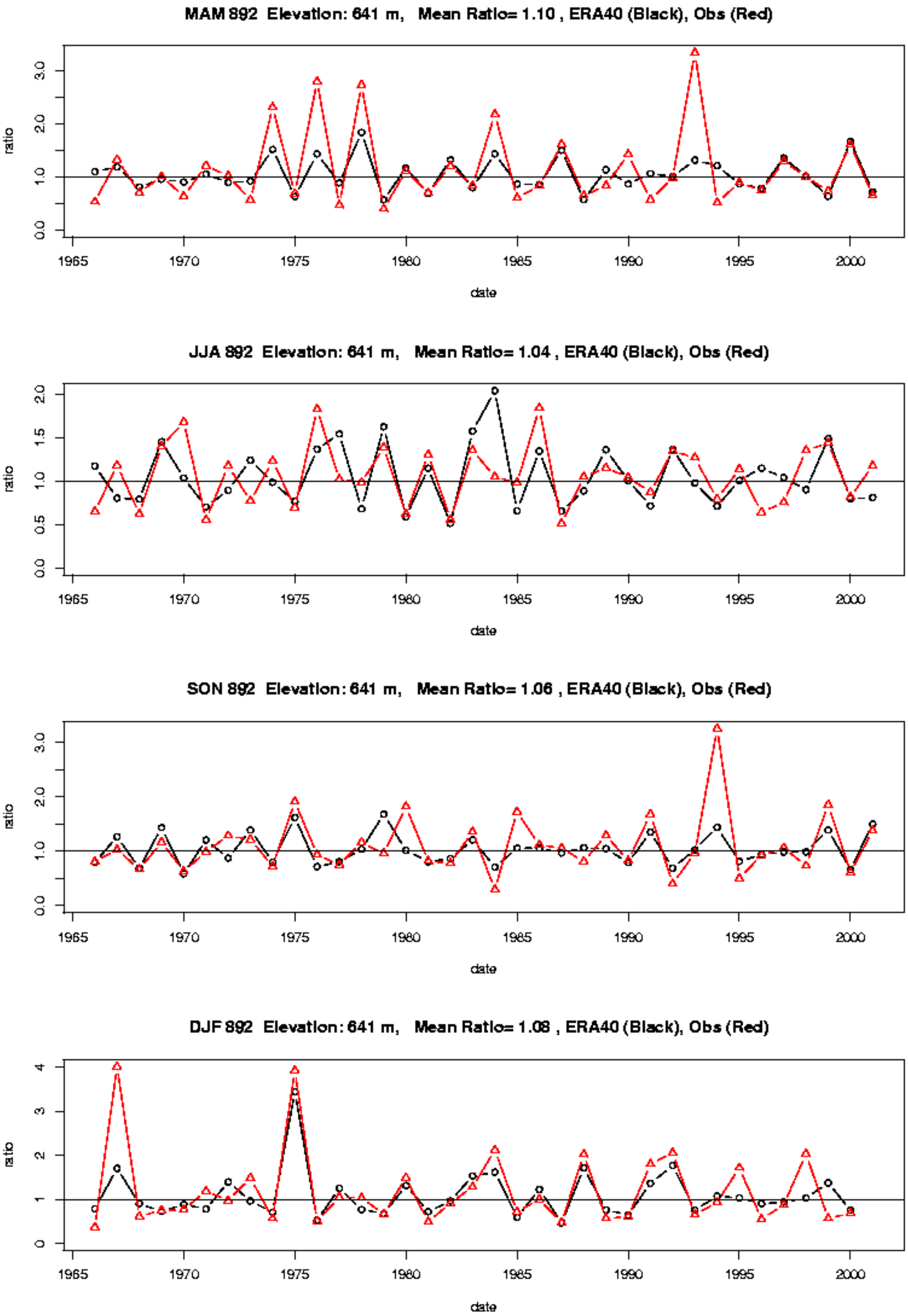
Time-series of the season-averaged monthly precipitation ratio between 2 consecutive years, for station no. 505
ERA-40 (black circles) and rain gauge data (red triangles)



Time-series of the season-averaged monthly precipitation ratio between 2 consecutive years, for station no. 985
ERA-40 (black circles) and rain gauge data (red triangles)

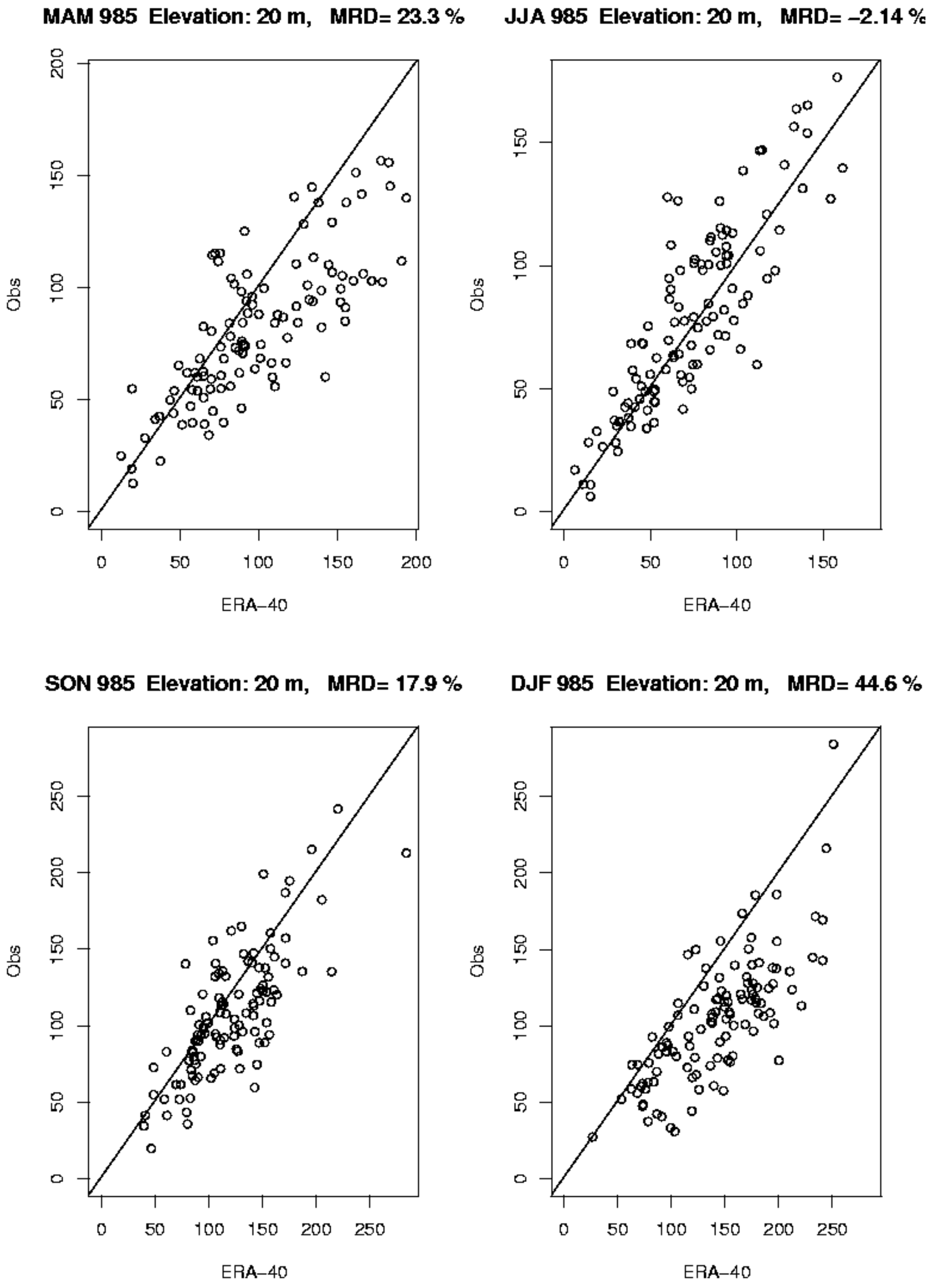


Time-series of the season-averaged monthly precipitation ratio between 2 consecutive years, for station no. 422
ERA-40 (black circles) and rain gauge data (red triangles)

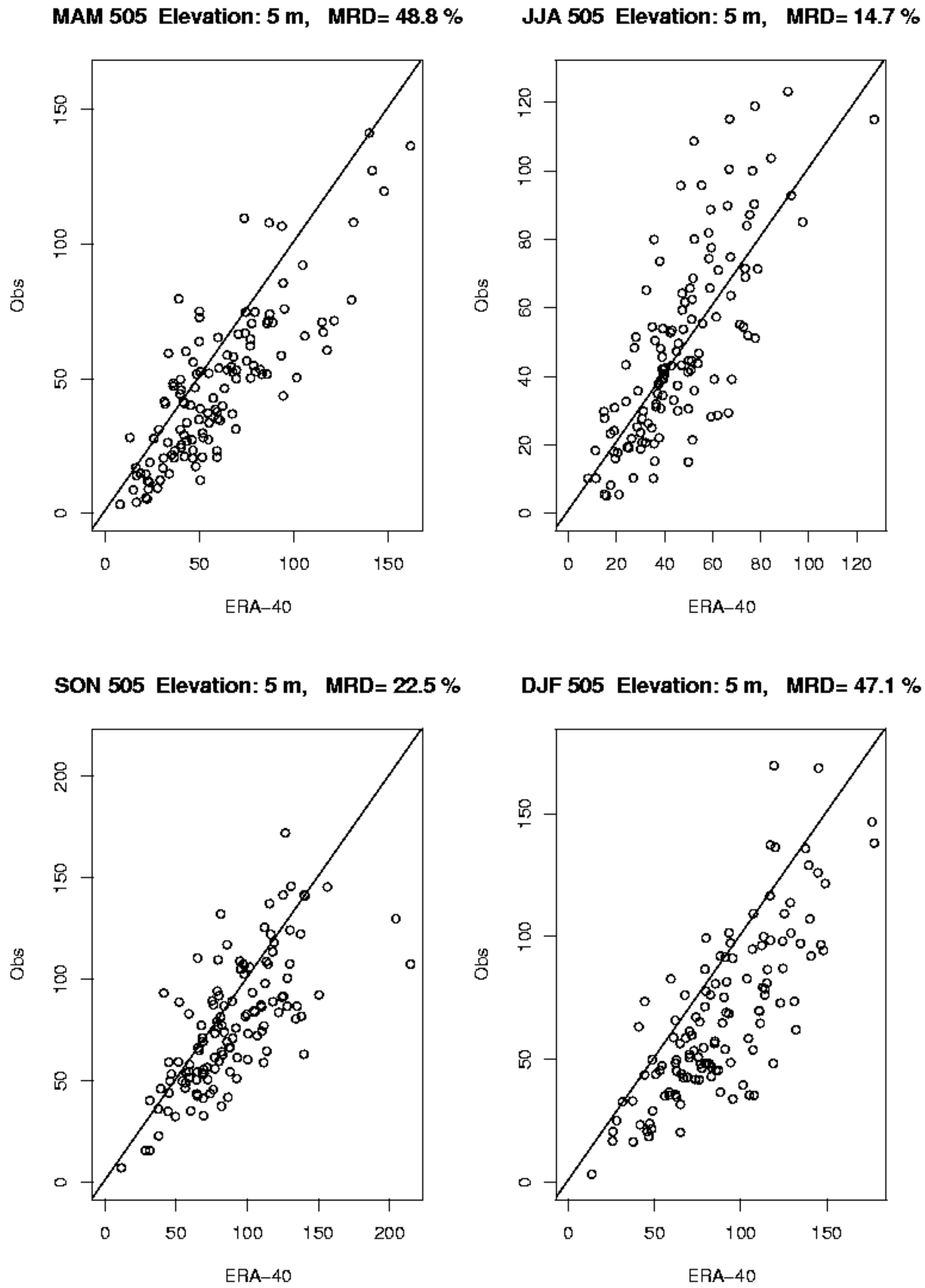


Time-series of the season-averaged monthly precipitation ratio between 2 consecutive years, for station no. 892
ERA-40 (black circles) and rain gauge data (red triangles)

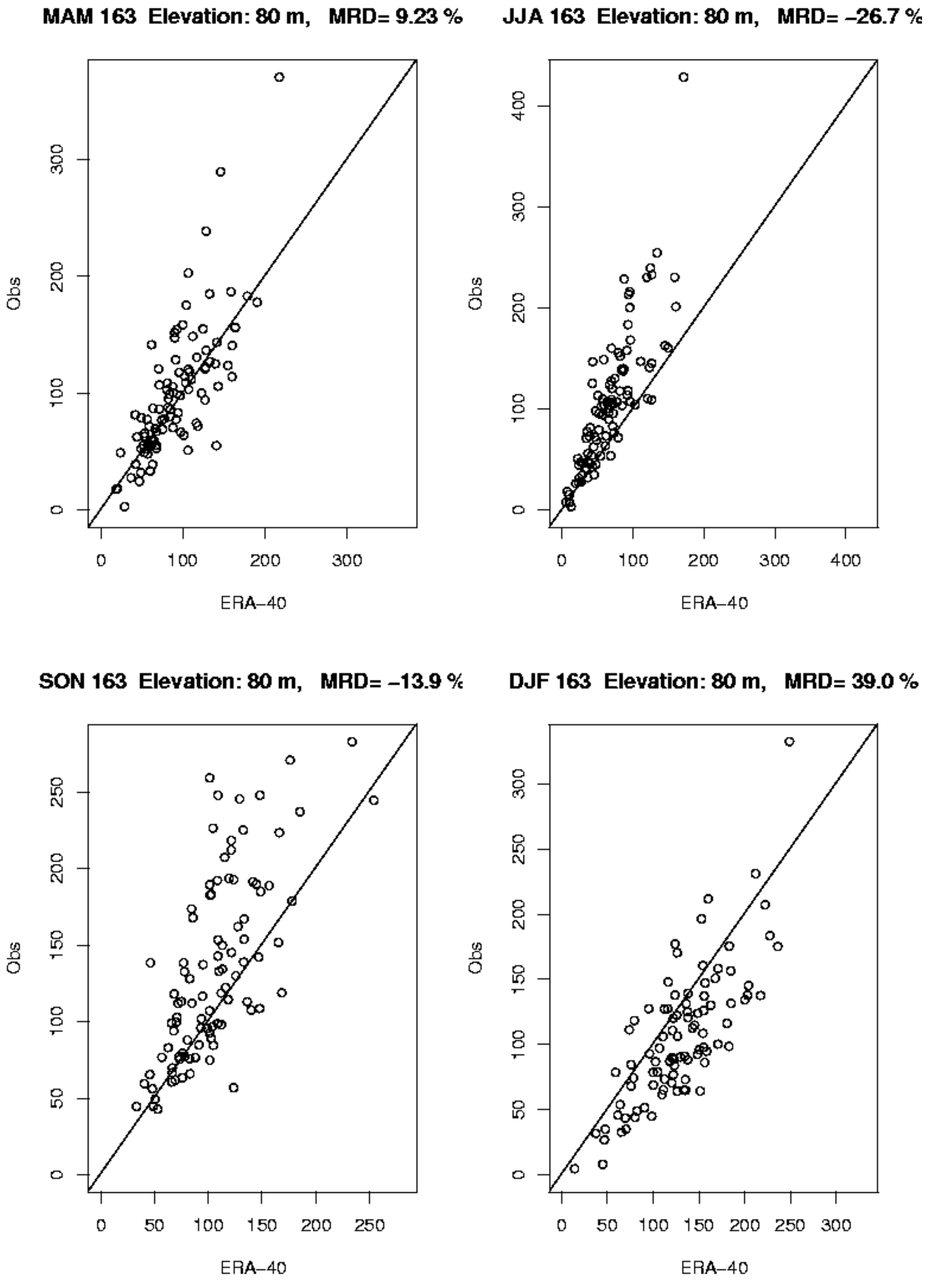
Appendix 3



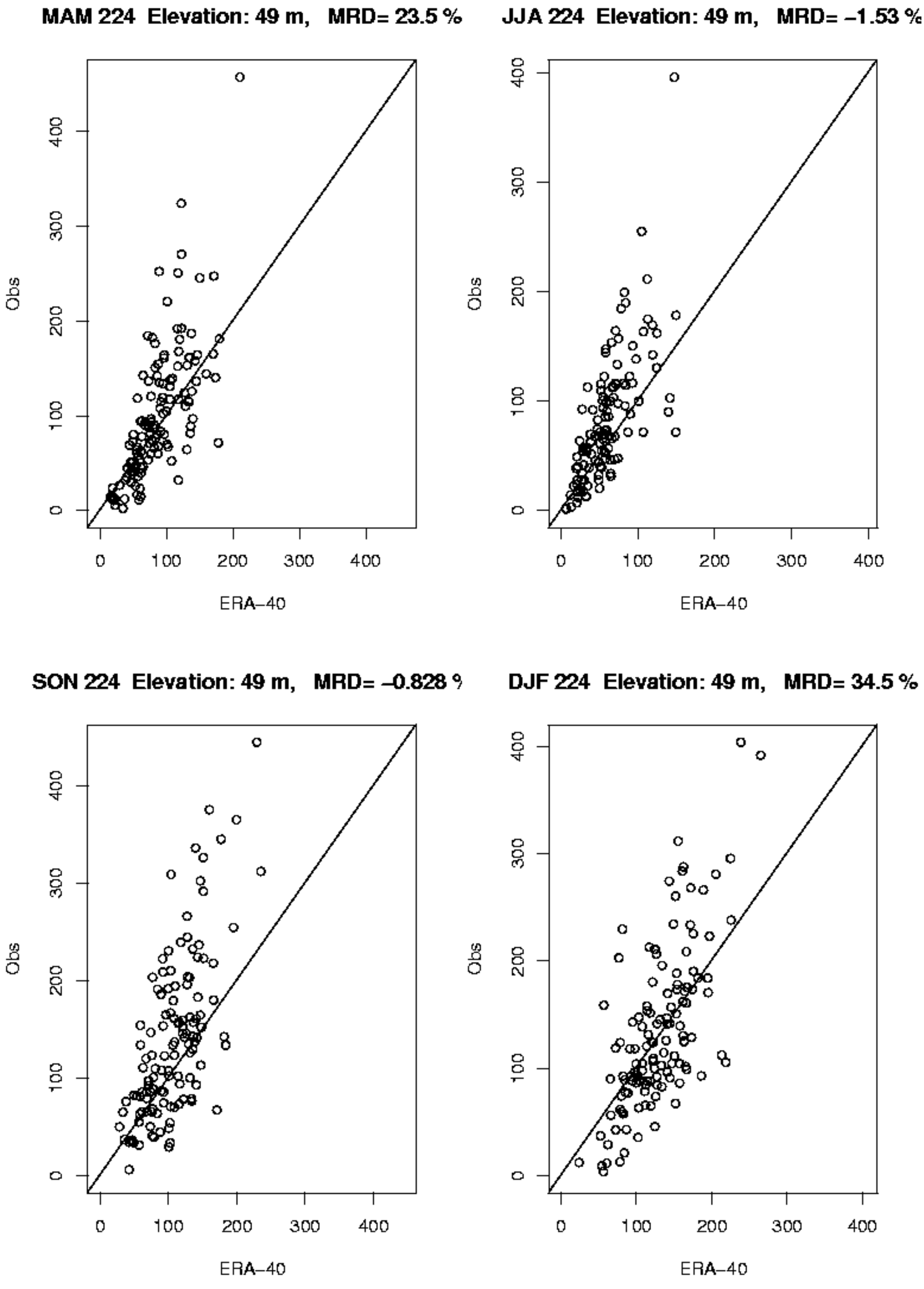
Rain gauge monthly precipitation (Obs) versus ERA-40 precipitation, for station no. 985



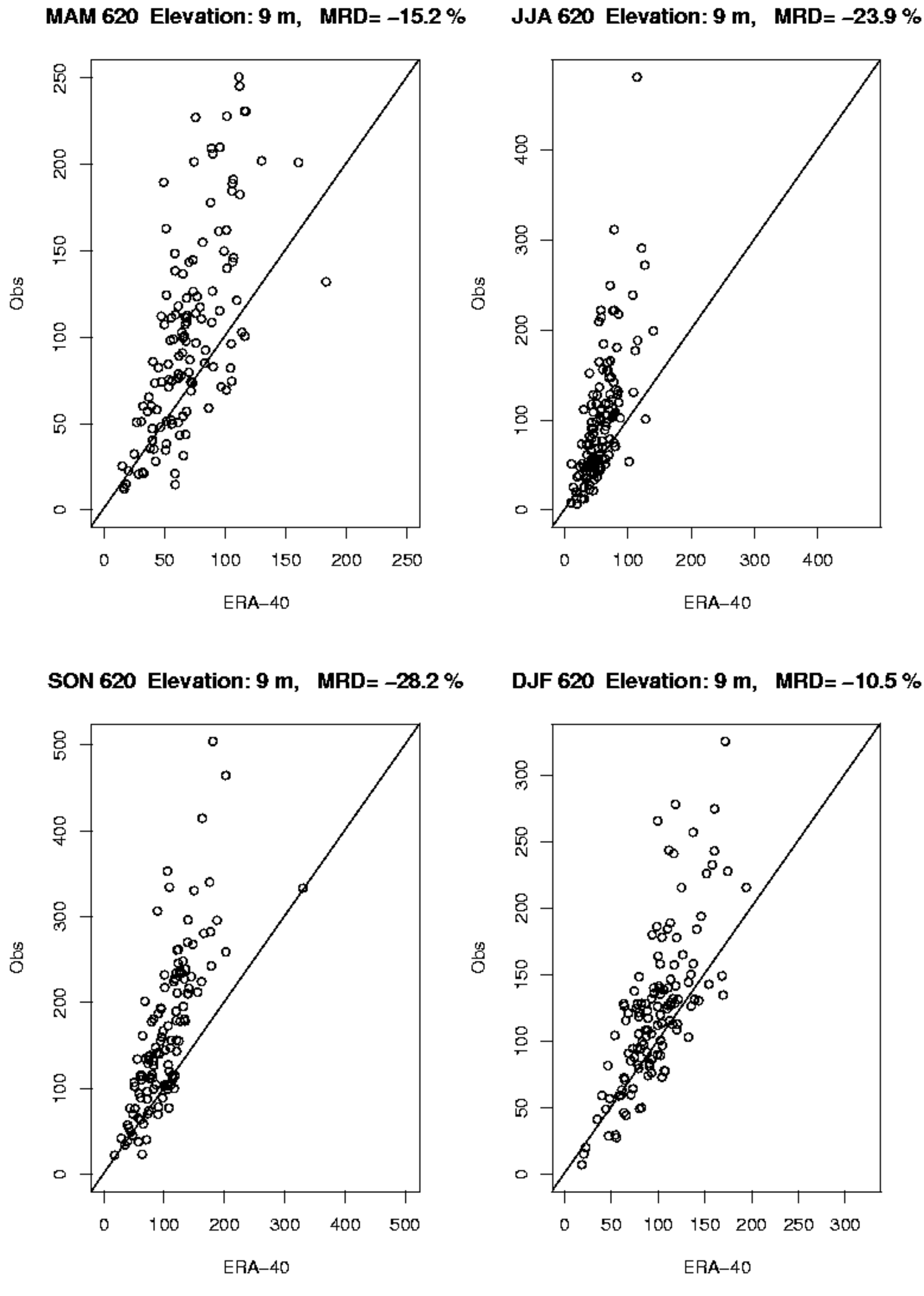
Rain gauge monthly precipitation (Obs) versus ERA-40 precipitation, for station no. 505



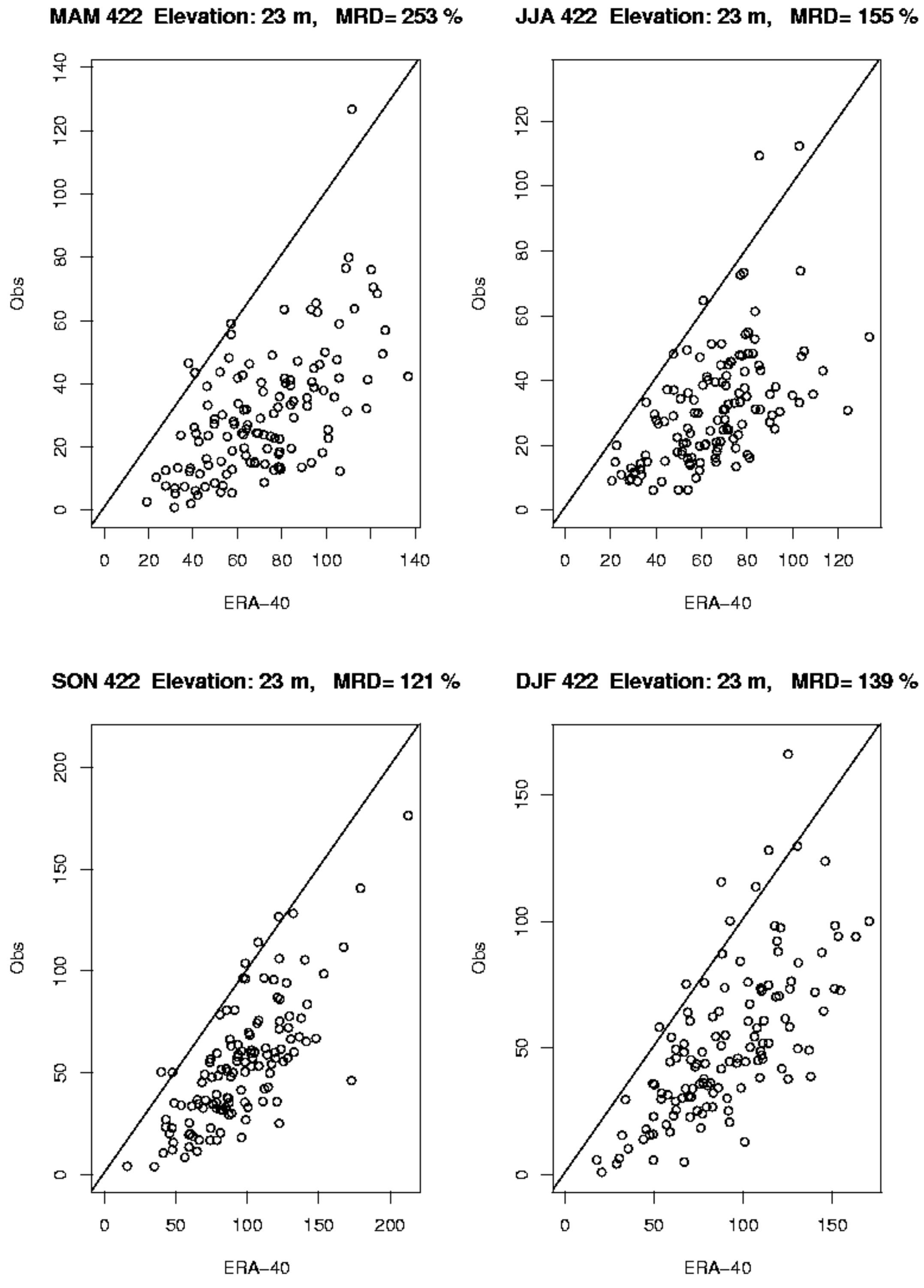
Rain gauge monthly precipitation (Obs) versus ERA-40 precipitation, for station no. 163



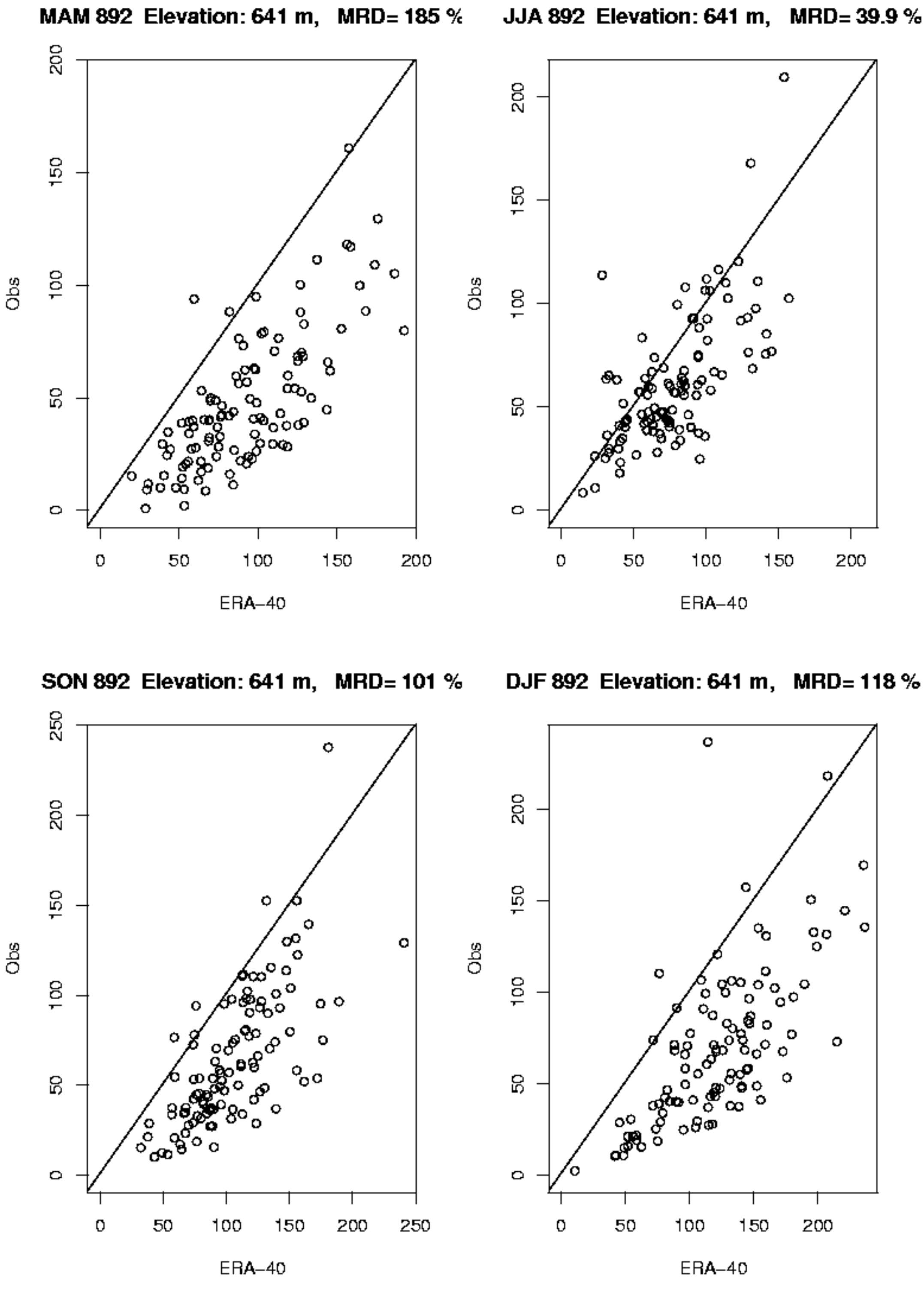
Rain gauge monthly precipitation (Obs) versus ERA-40 precipitation, for station no. 224



Rain gauge monthly precipitation (Obs) versus ERA-40 precipitation, for station no. 620

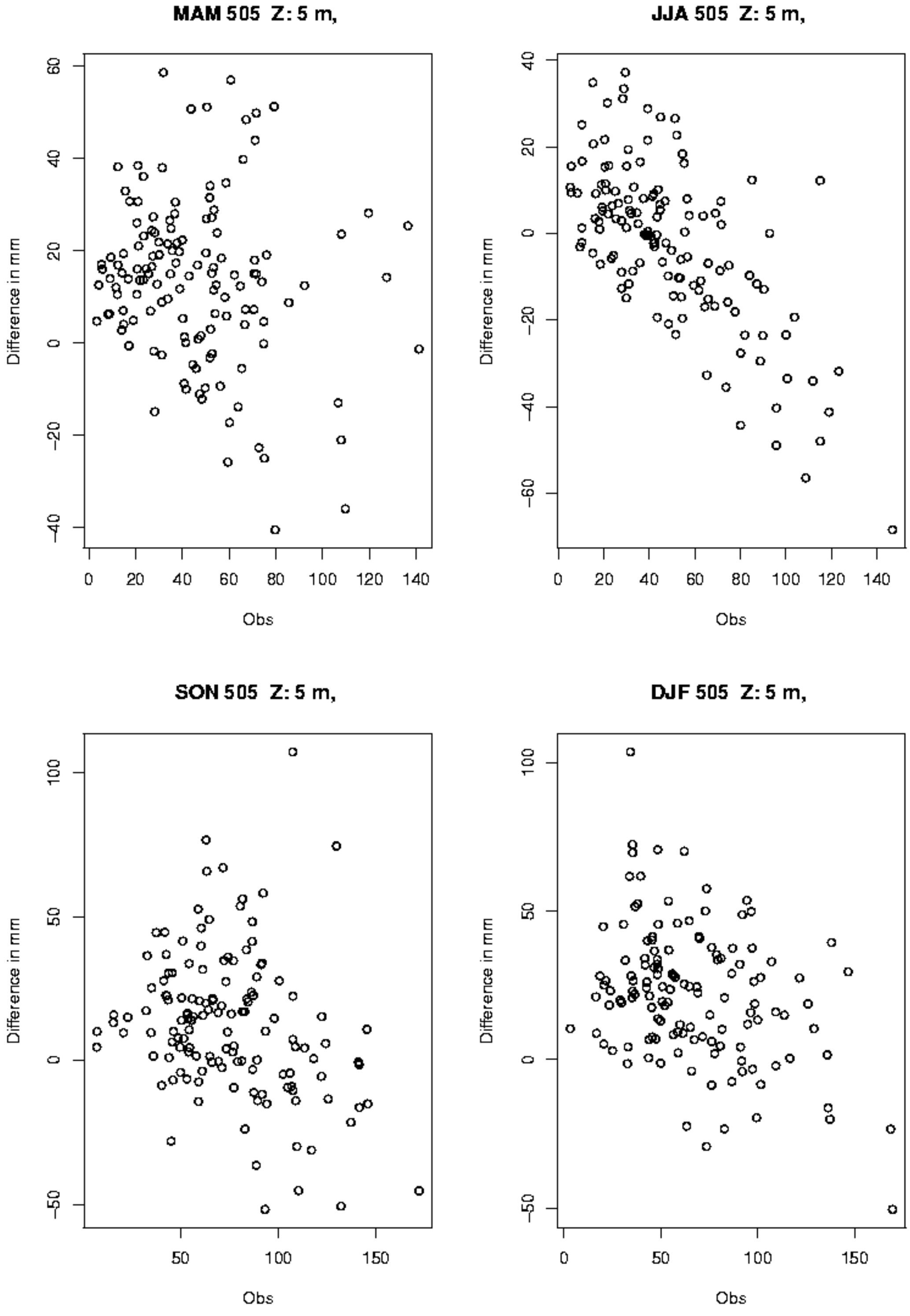


Rain gauge monthly precipitation (Obs) versus ERA-40 precipitation, for station no. 422

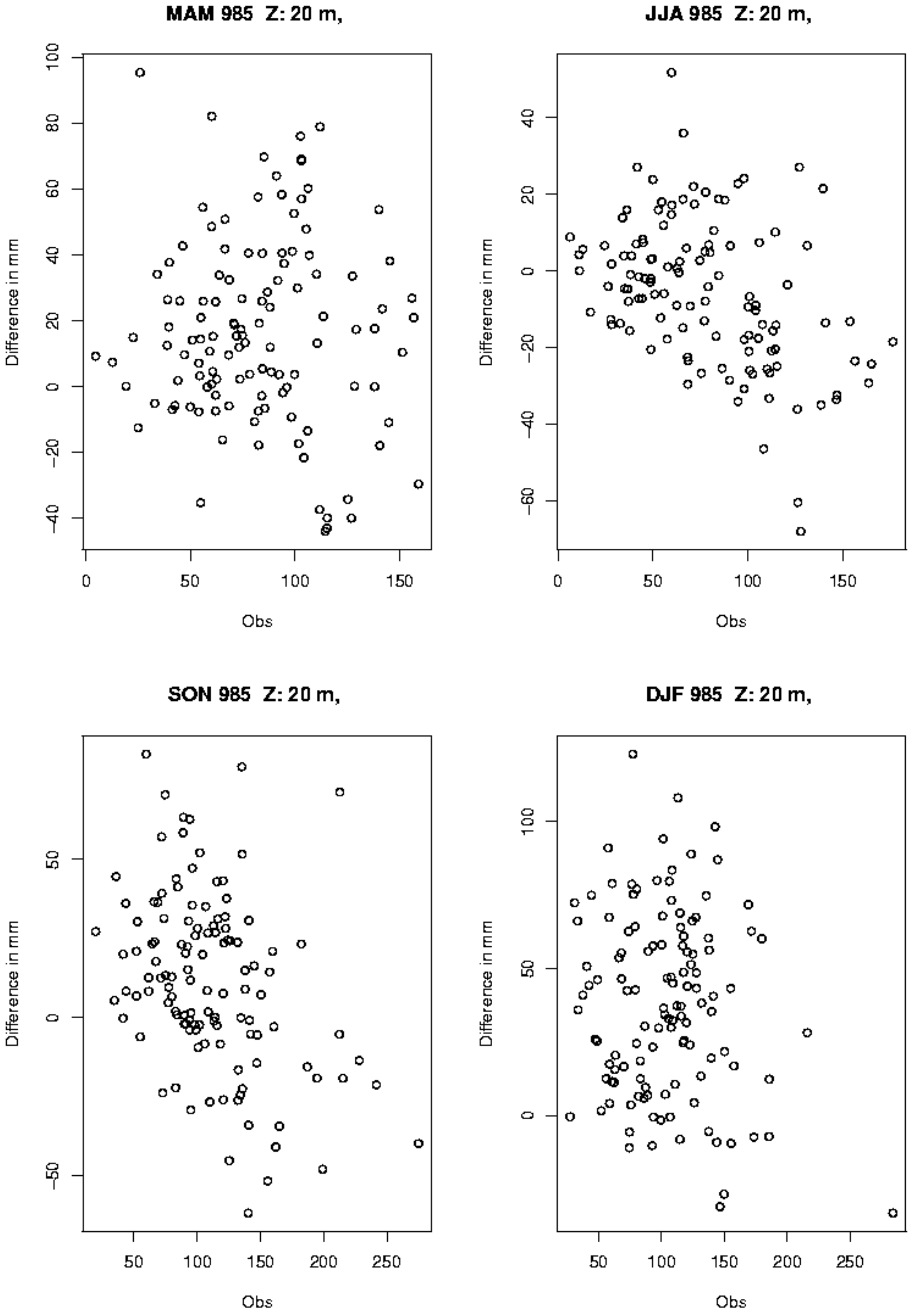


Rain gauge monthly precipitation (Obs) versus ERA-40 precipitation, for station no. 892

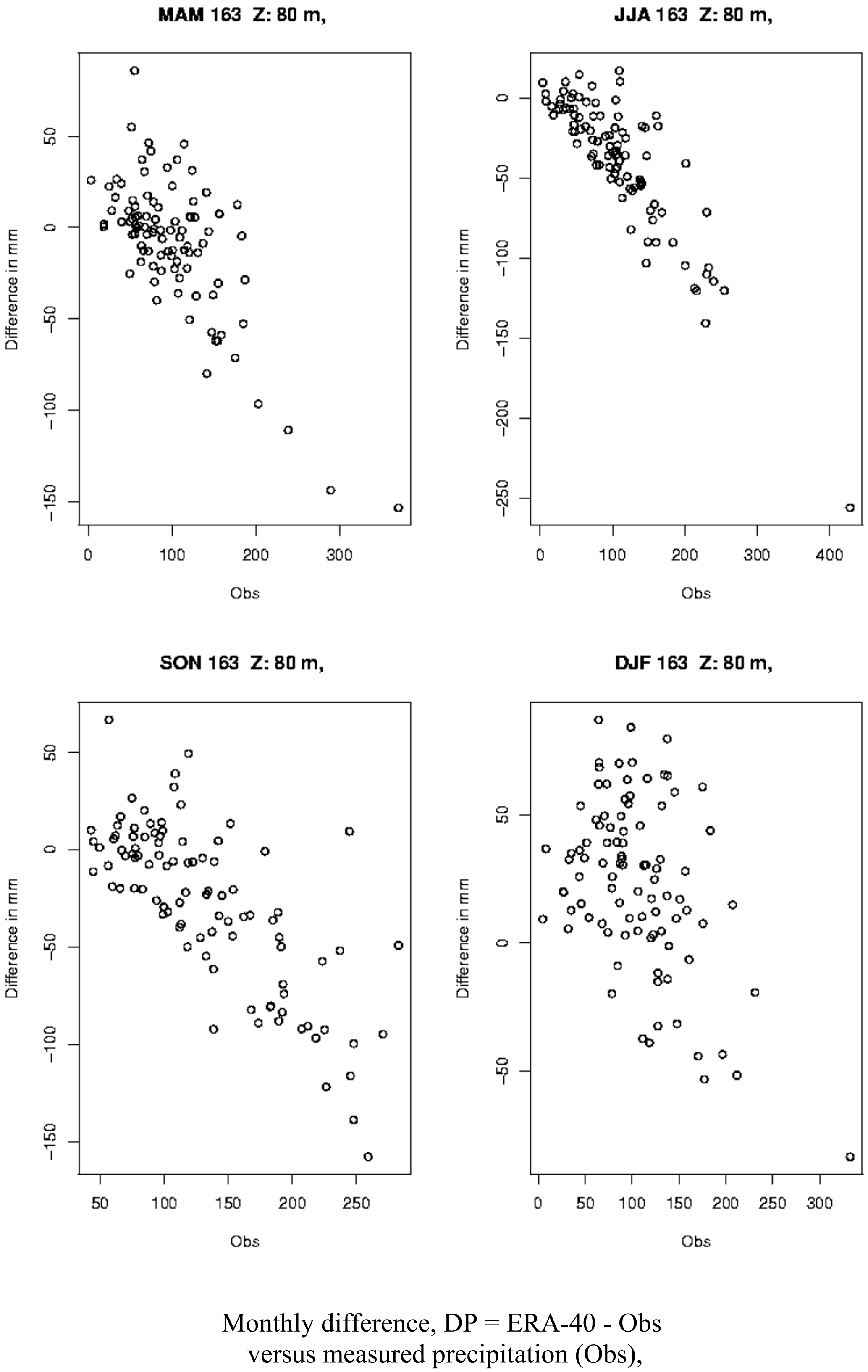
Appendix 4



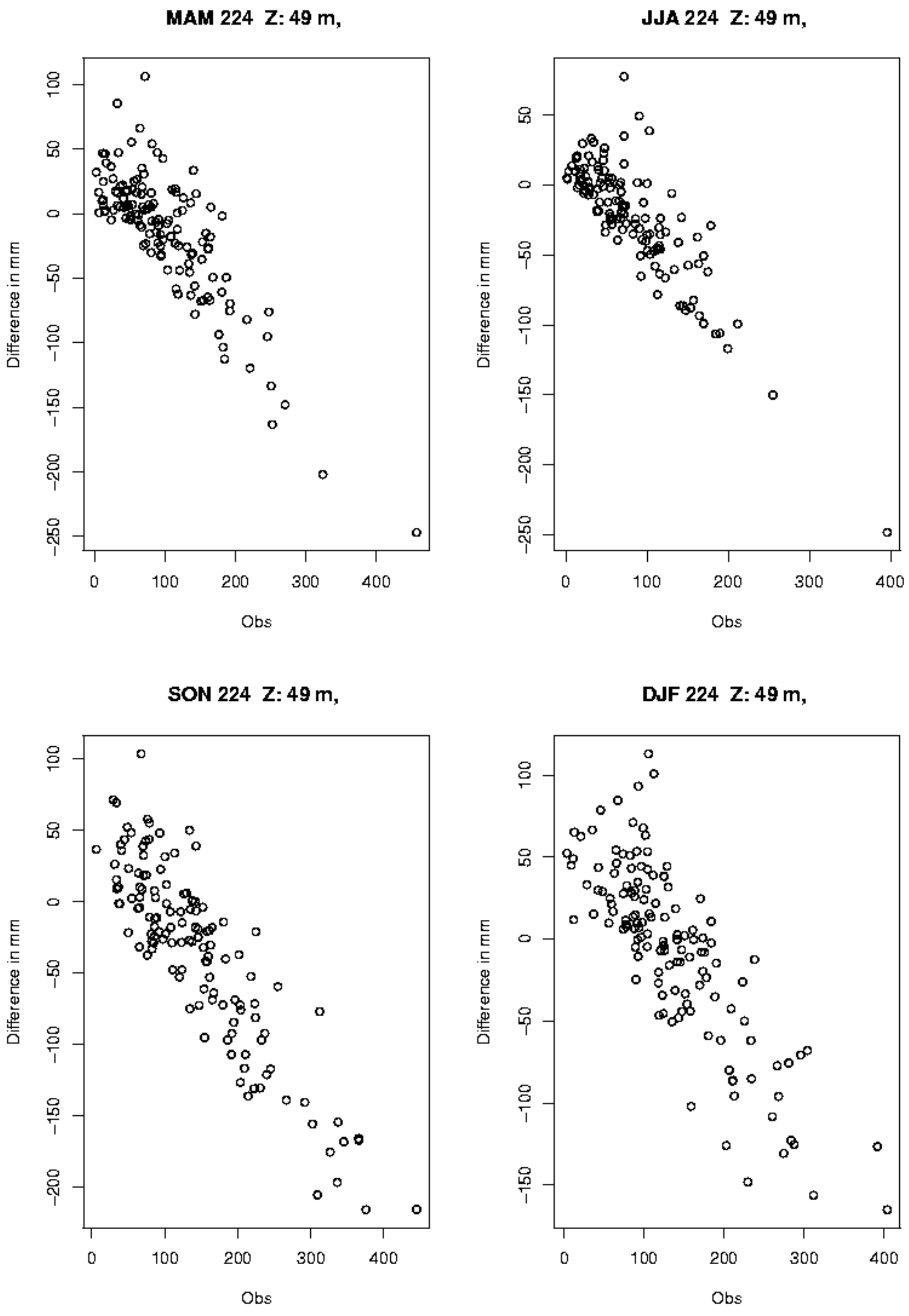
Monthly difference, DP = ERA-40 - Obs
versus measured precipitation (Obs),
for station no. 505.



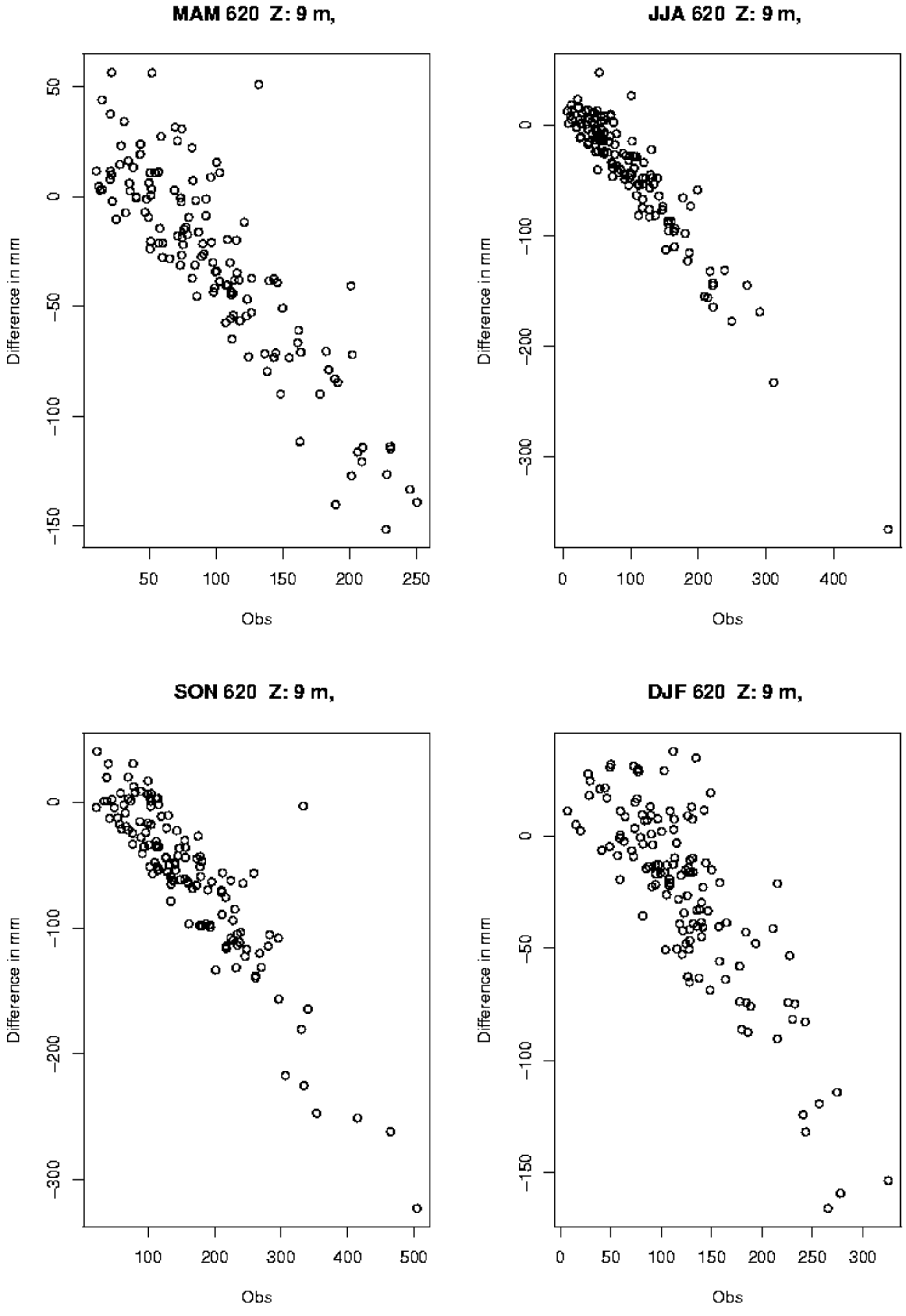
Monthly difference, DP = ERA-40 - Obs
versus measured precipitation (Obs),
for station no. 985



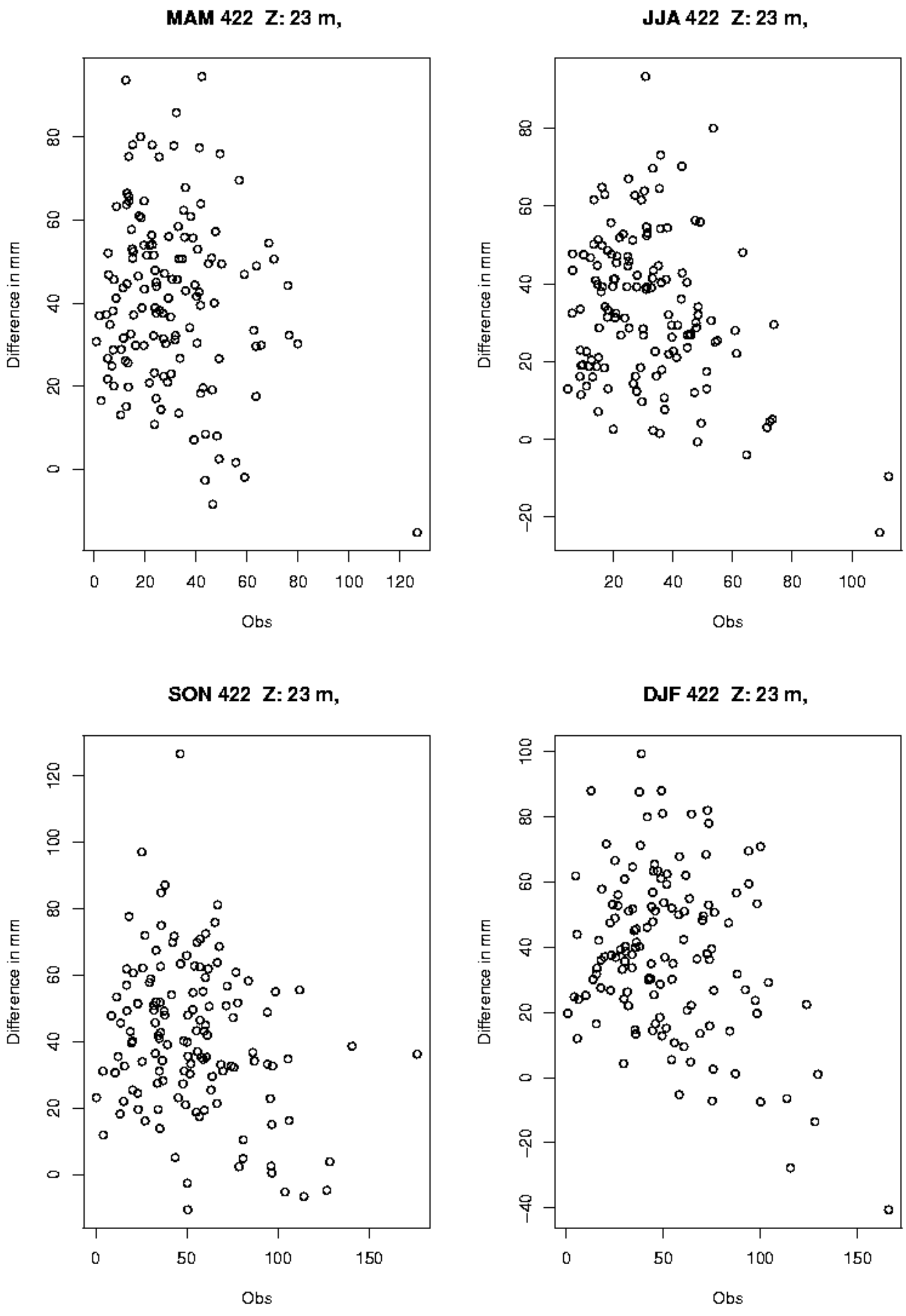
Monthly difference, DP = ERA-40 - Obs
versus measured precipitation (Obs),
for station no. 163



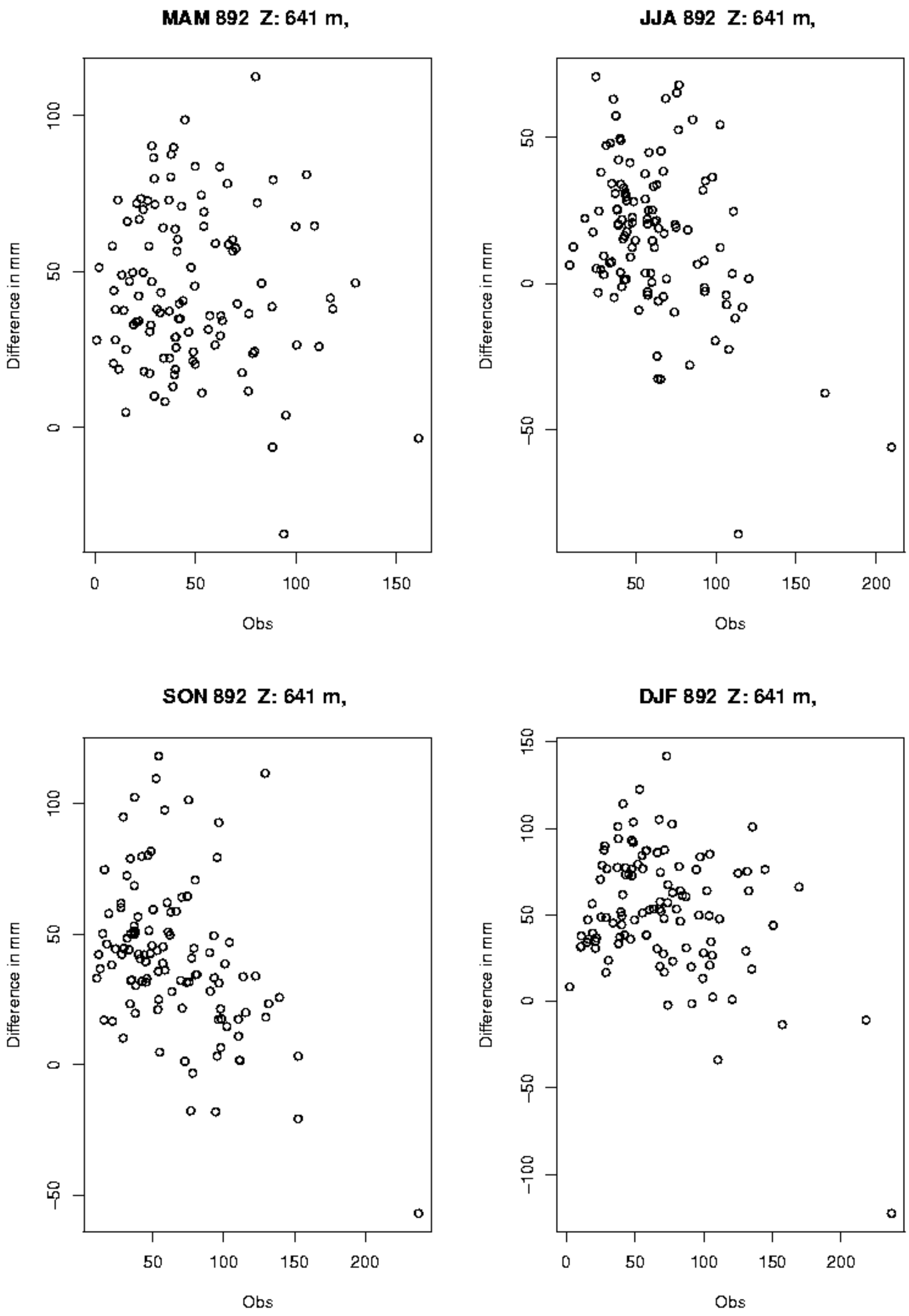
Monthly difference, DP = ERA-40 - Obs
versus measured precipitation (Obs),
for station no. 224



Monthly difference, DP = ERA-40 - Obs
versus measured precipitation (Obs),
for station no. 620

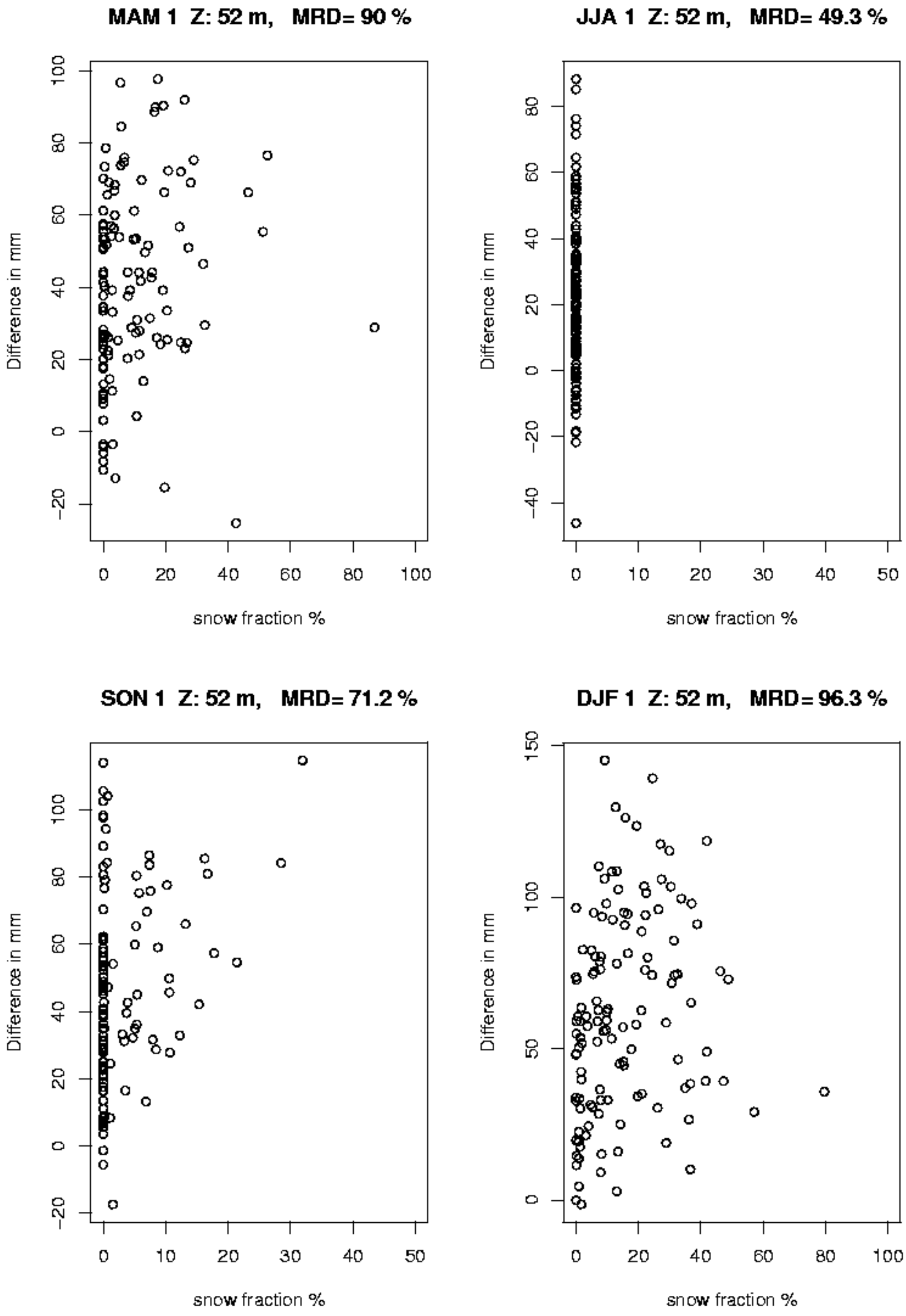


Monthly difference, DP = ERA-40 - Obs
versus measured precipitation (Obs),
for station no. 422

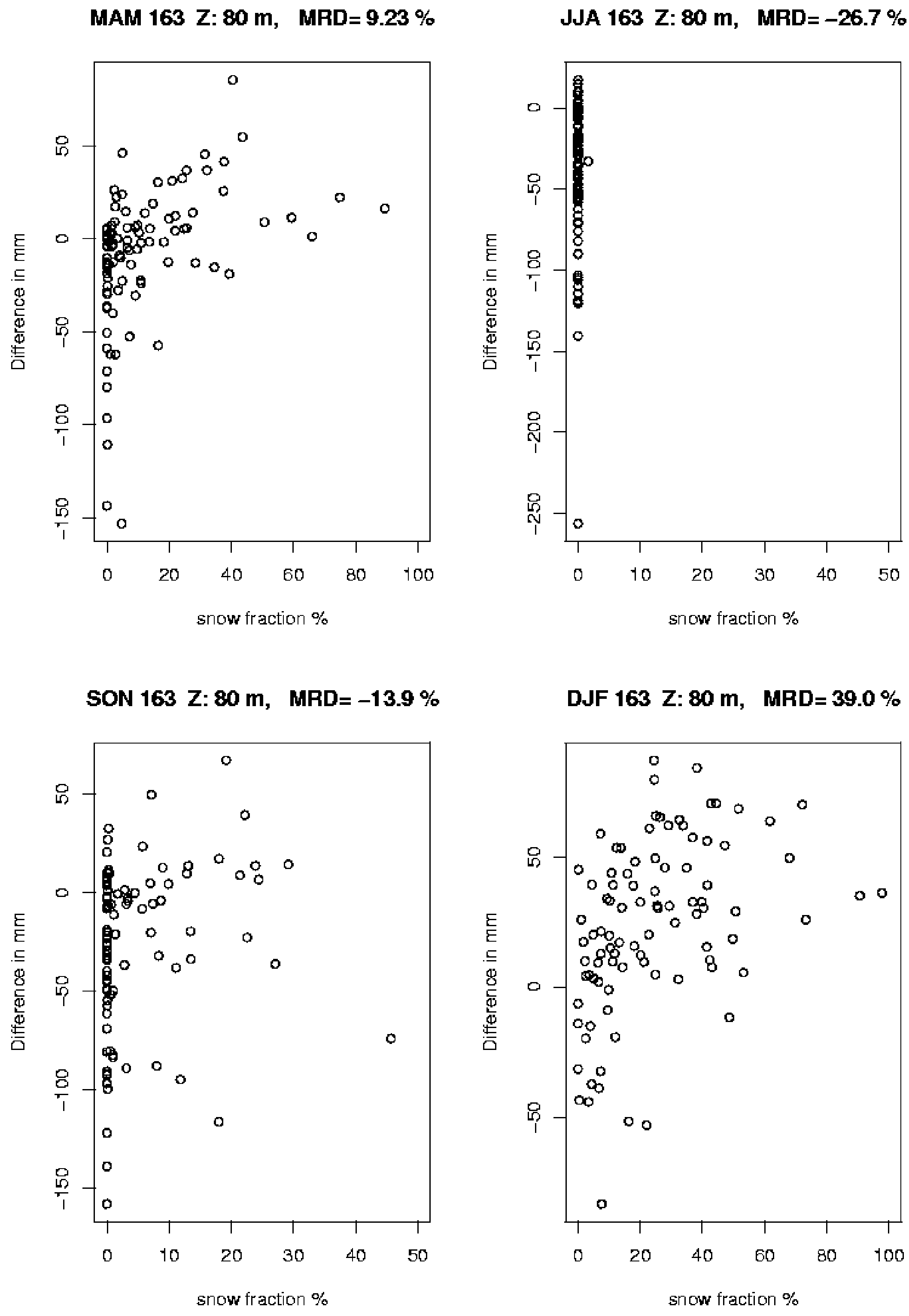


Monthly difference, DP = ERA-40 - Obs
versus measured precipitation (Obs),
for station no. 892

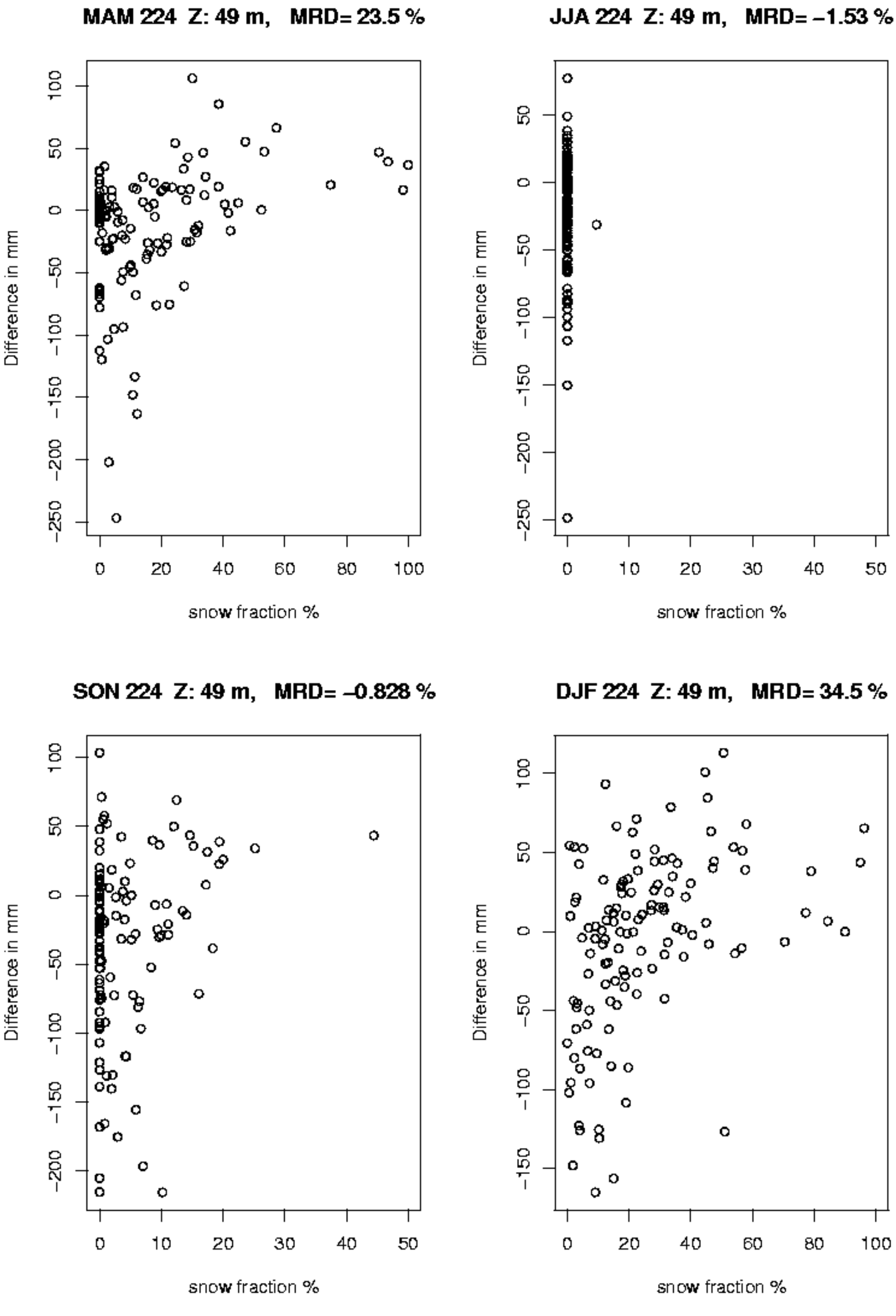
Appendix 5



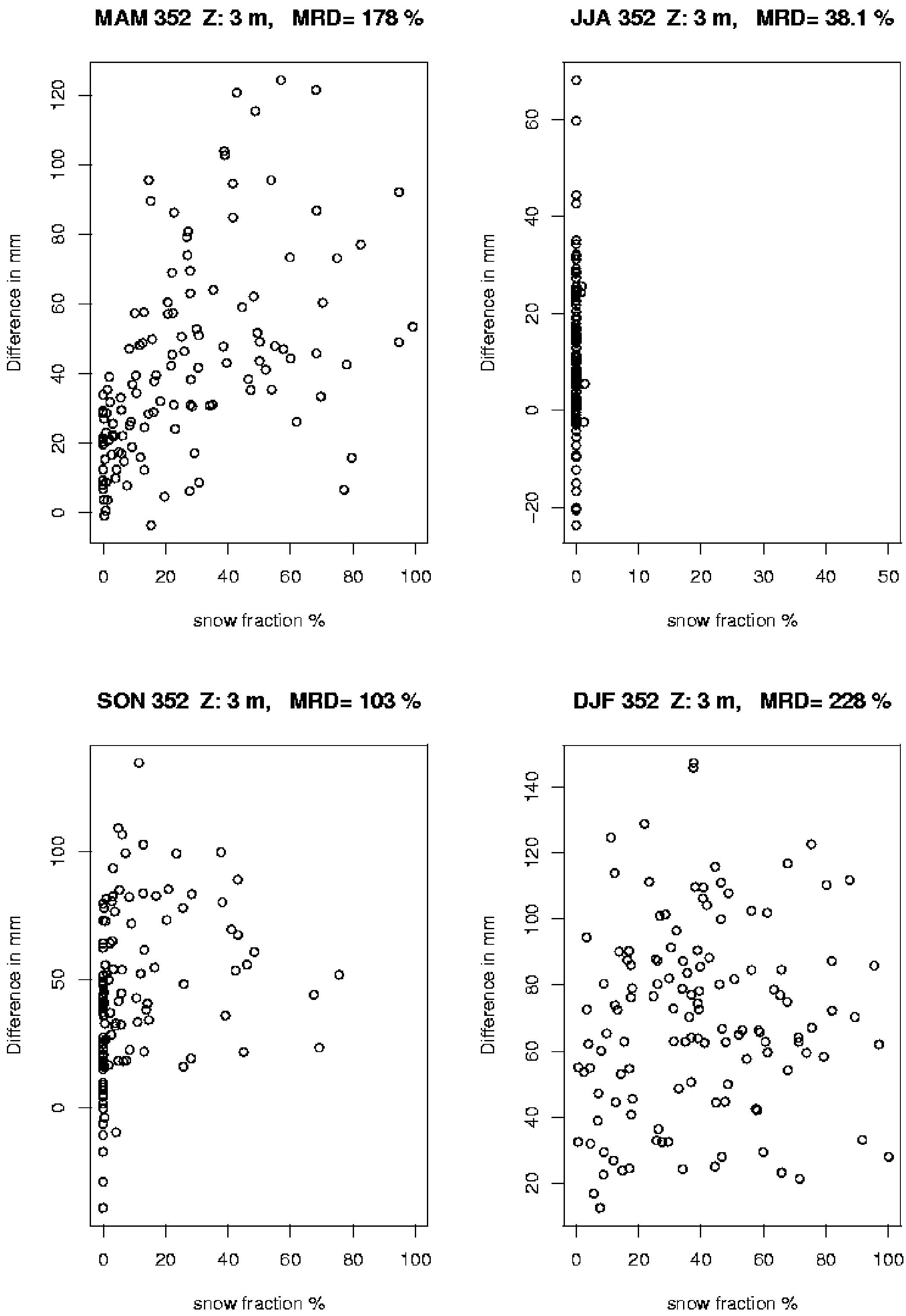
Monthly difference DP (in mm) versus snow fraction, for station no. 1.
DP = ERA-40 - Obs



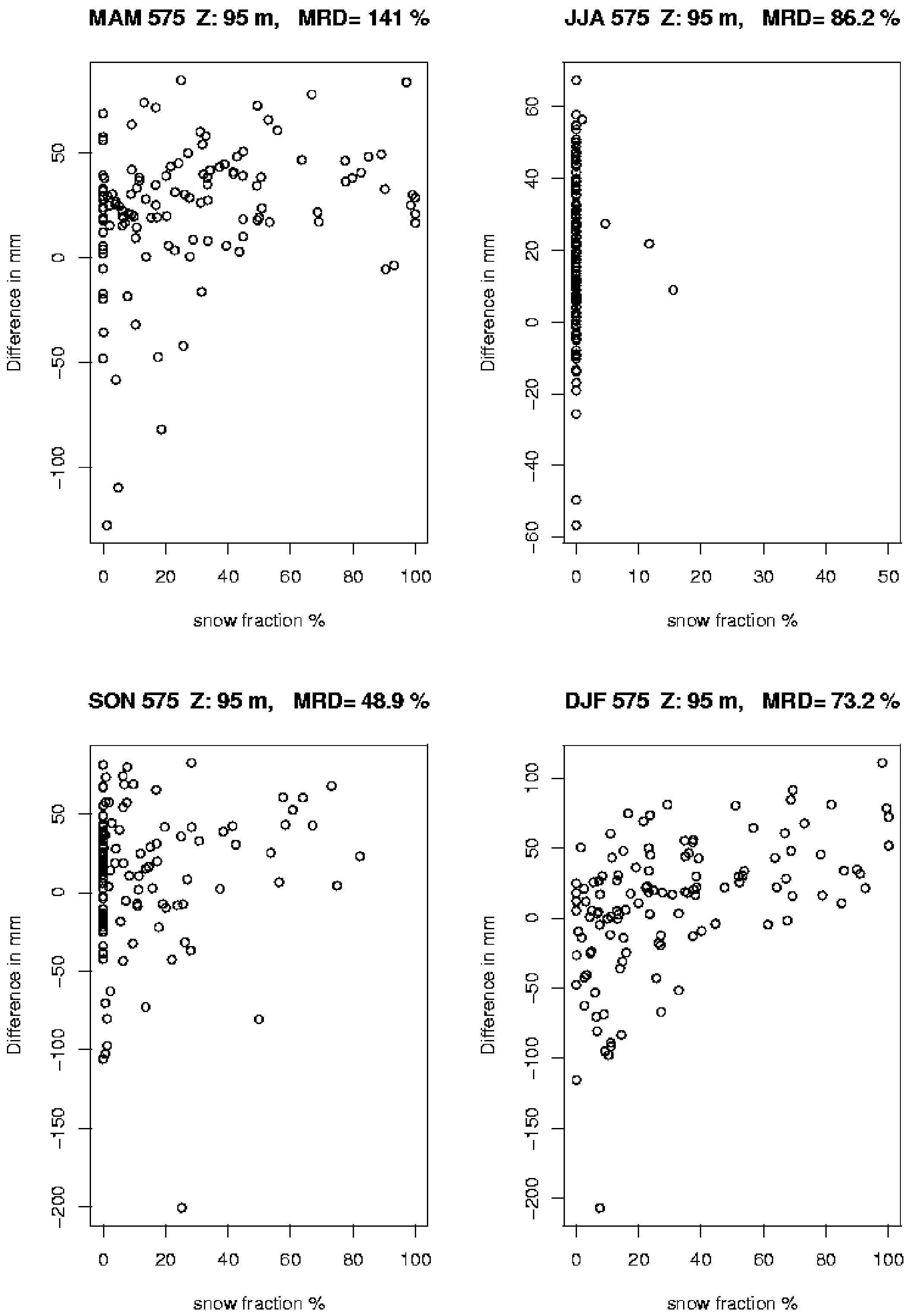
Monthly difference DP (in mm) versus snow fraction, for station no. 163.
DP = ERA-40 - Obs



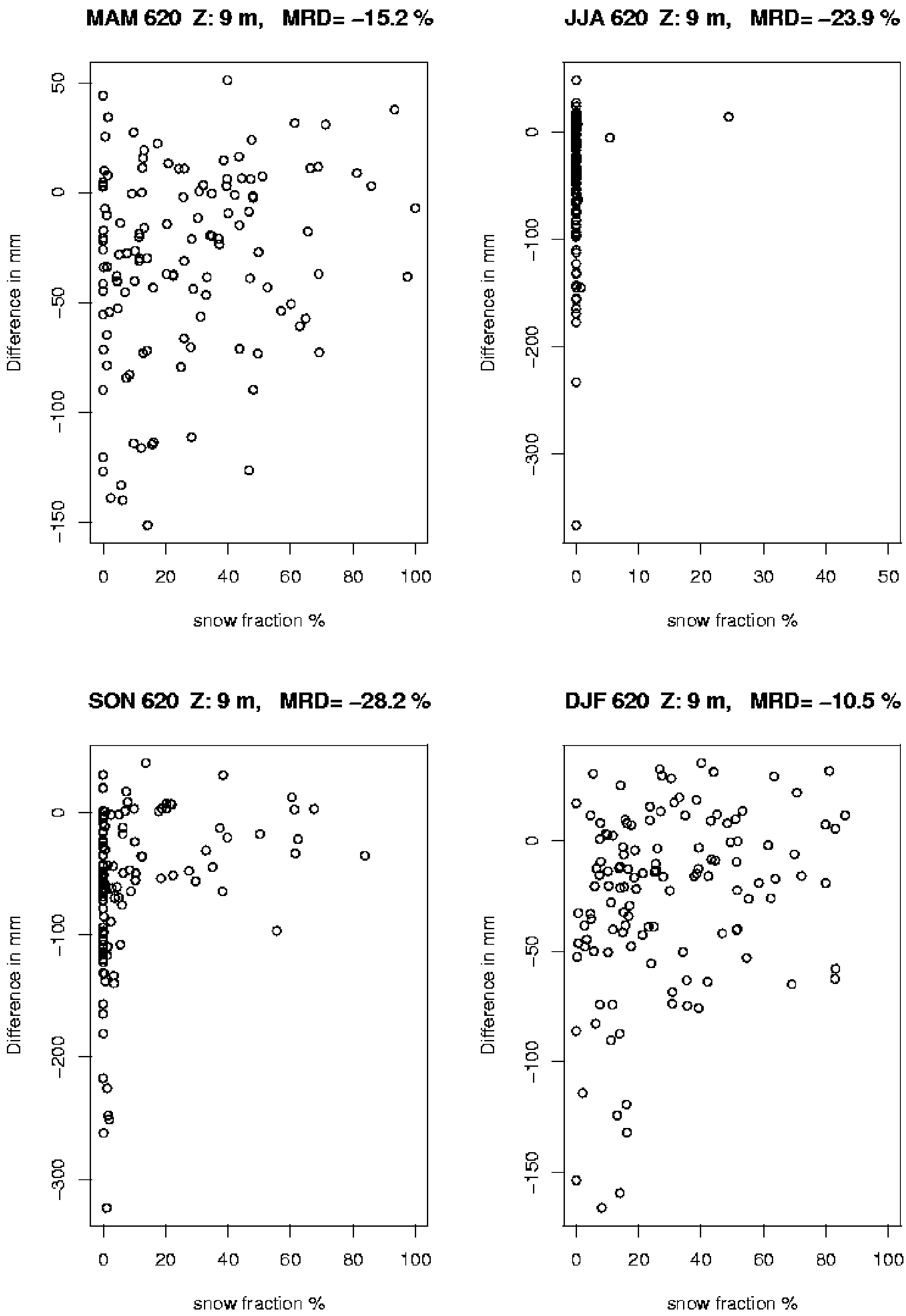
Monthly difference DP (in mm) versus snow fraction, for station no. 224.
DP = ERA-40 - Obs



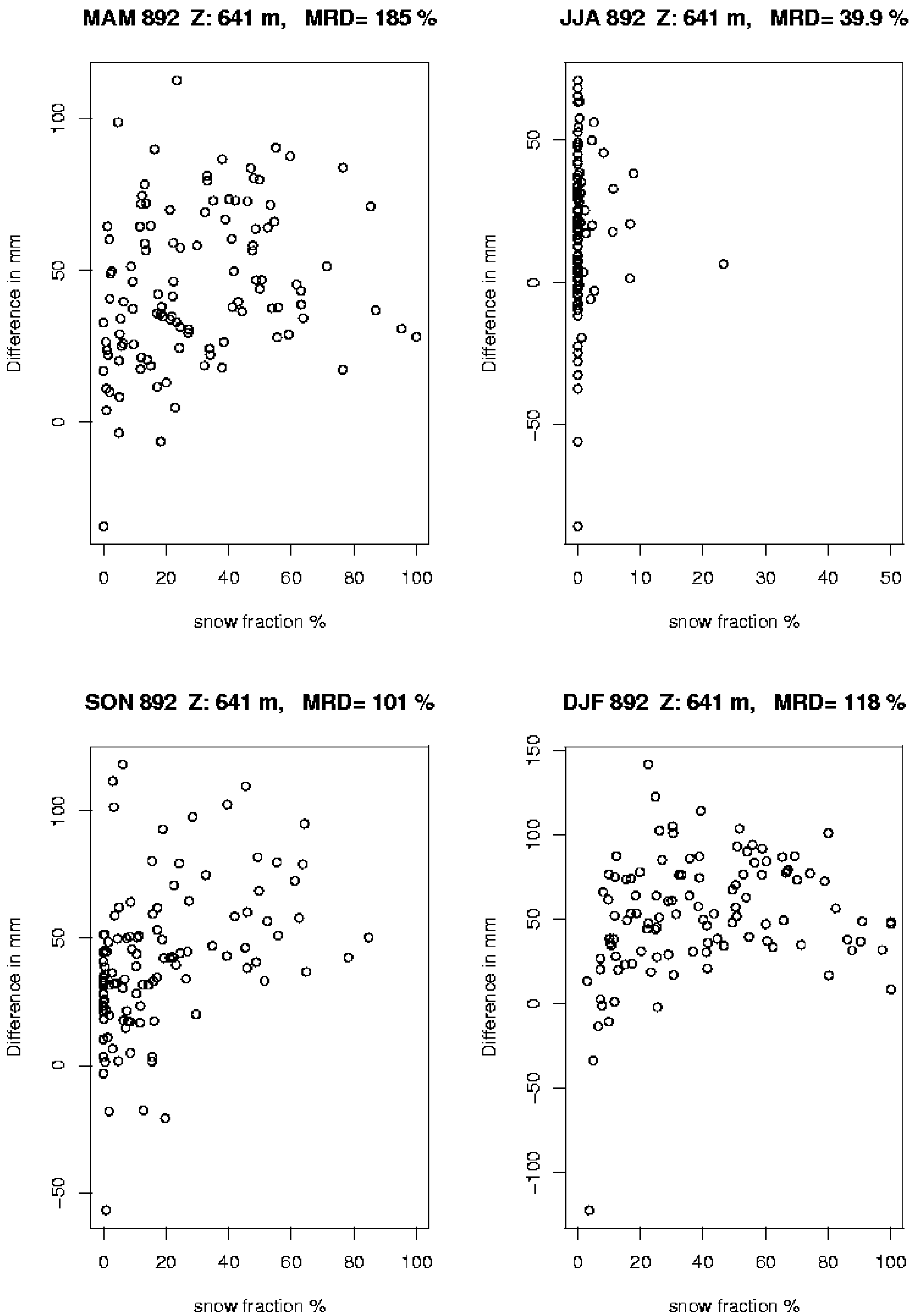
Monthly difference DP (in mm) versus snow fraction, for station no. 352.
DP = ERA-40 - Obs



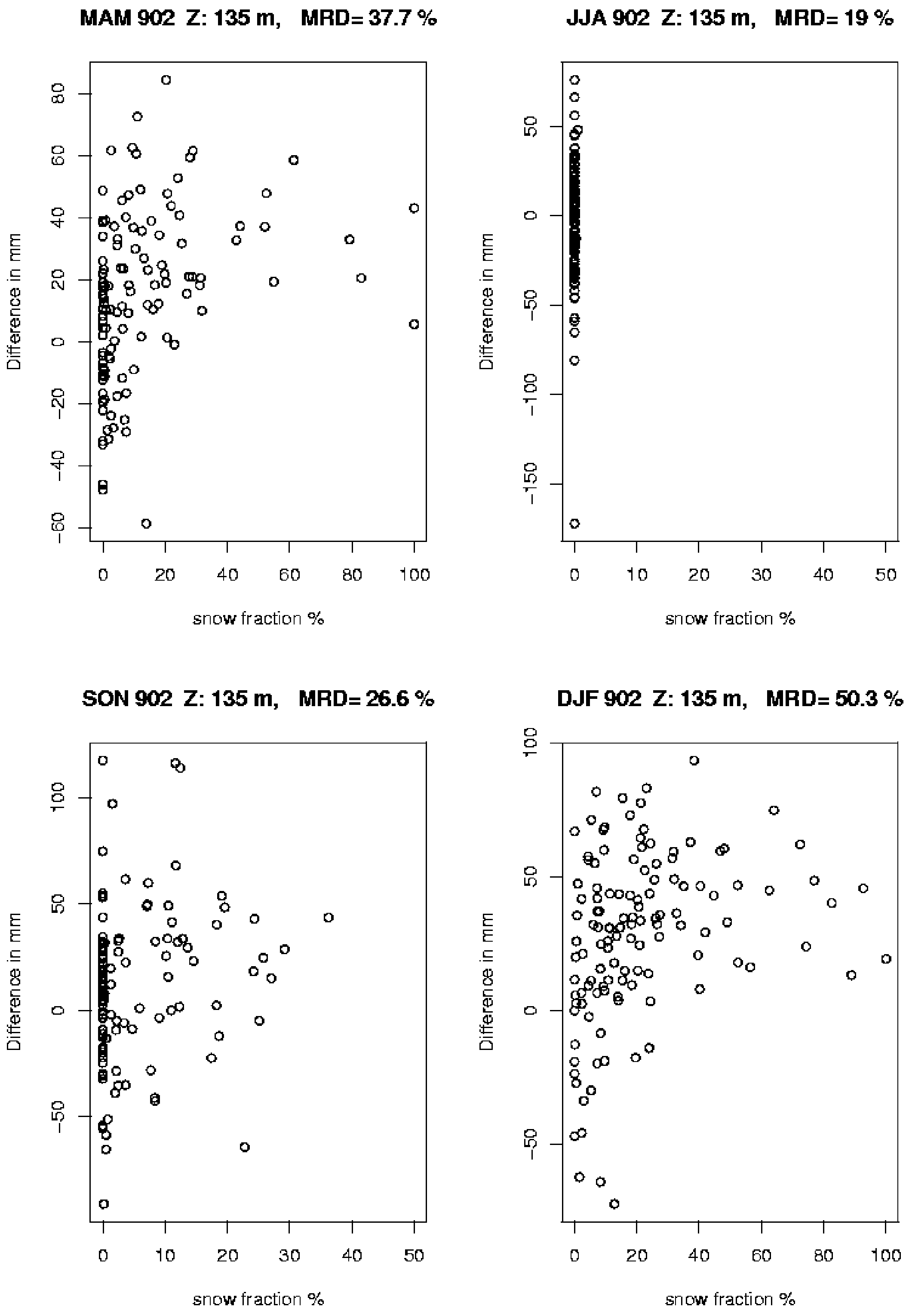
Monthly difference DP (in mm) versus snow fraction, for station no. 575.
DP = ERA-40 - Obs



Monthly difference DP (in mm) versus snow fraction, for station no. 620.
DP = ERA-40 - Obs

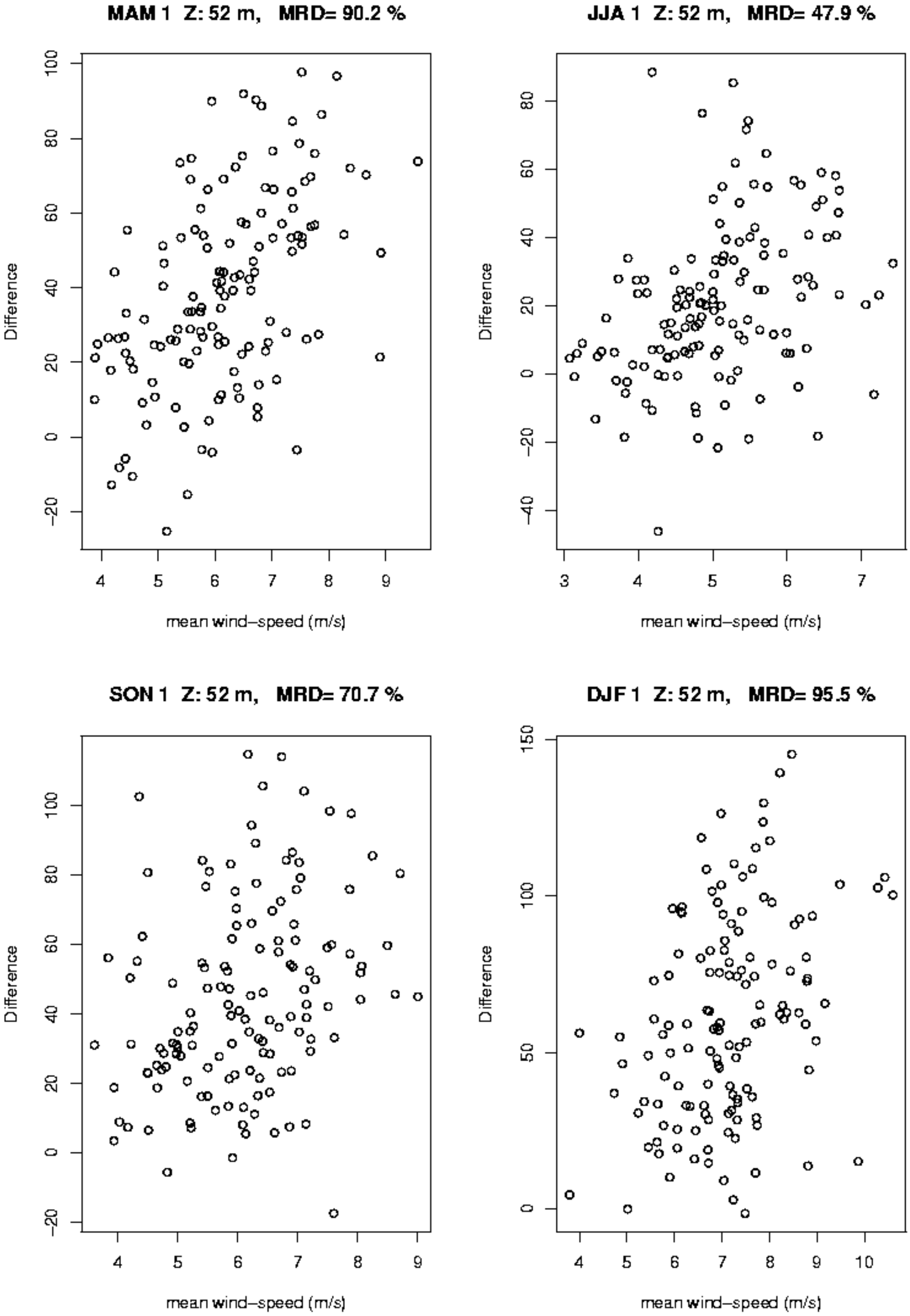


Monthly difference DP (in mm) versus snow fraction, for station no. 892.
DP = ERA-40 - Obs

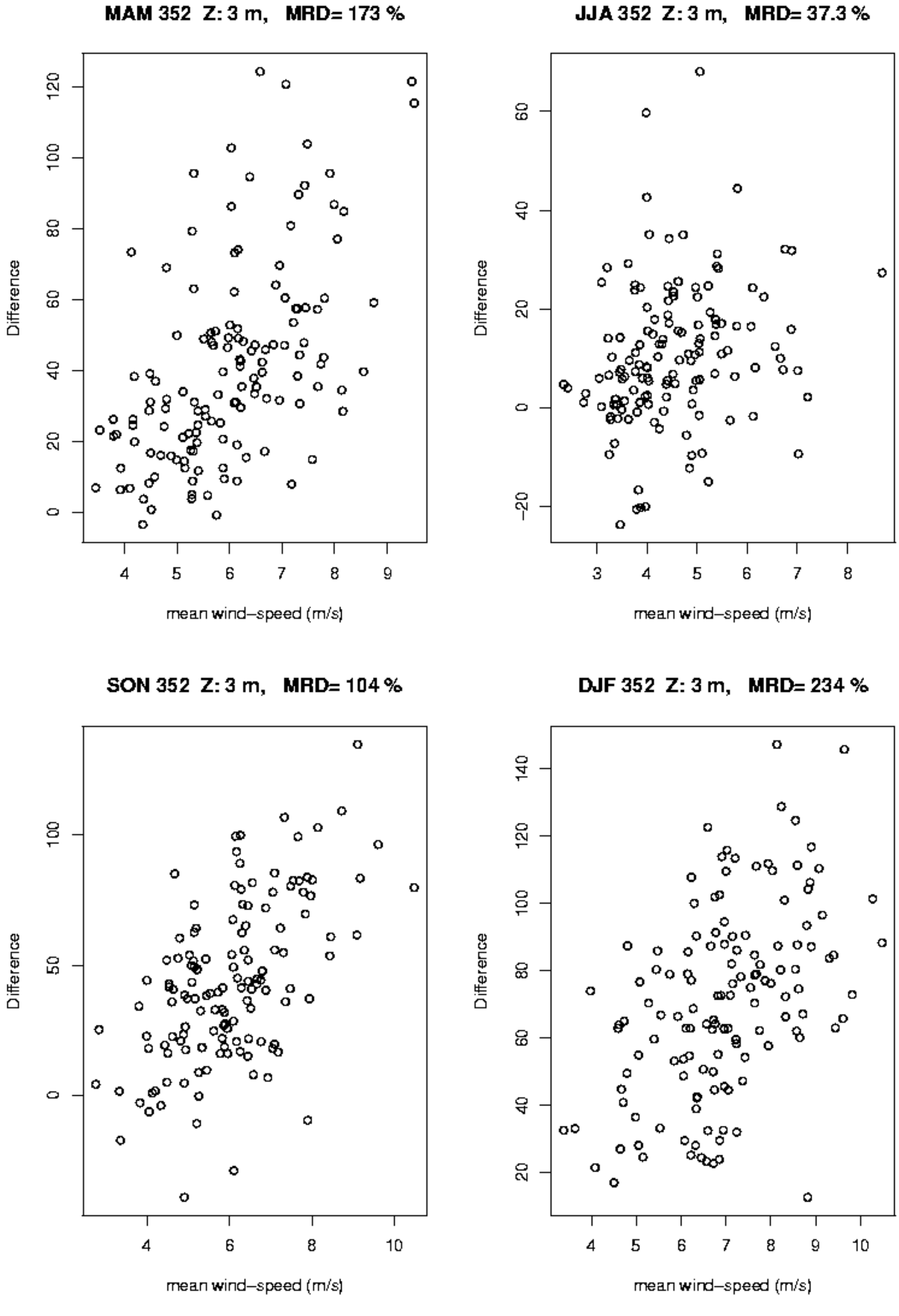


Monthly difference DP (in mm) versus snow fraction, for station no. 902.
DP = ERA-40 - Obs

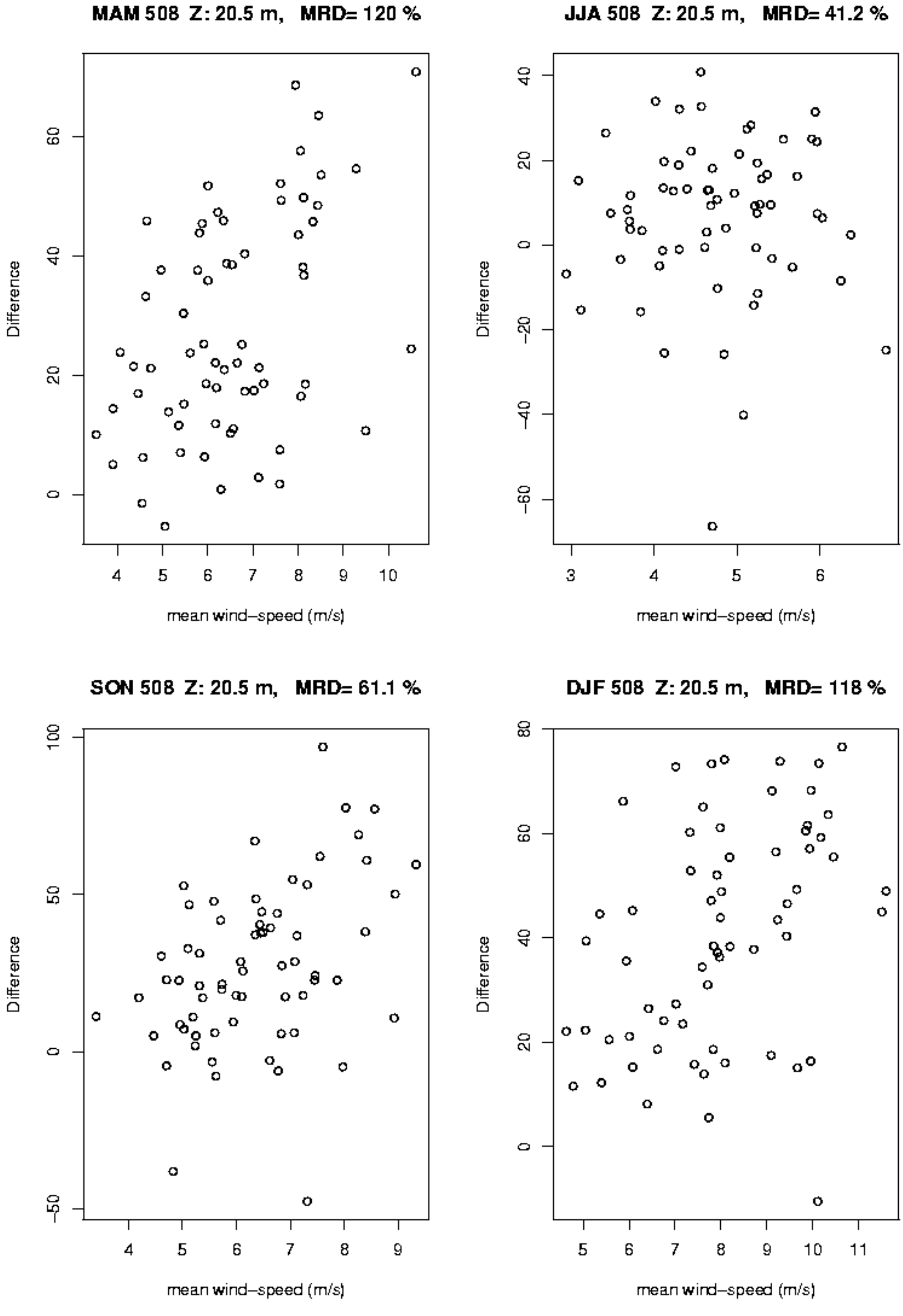
Appendix 6



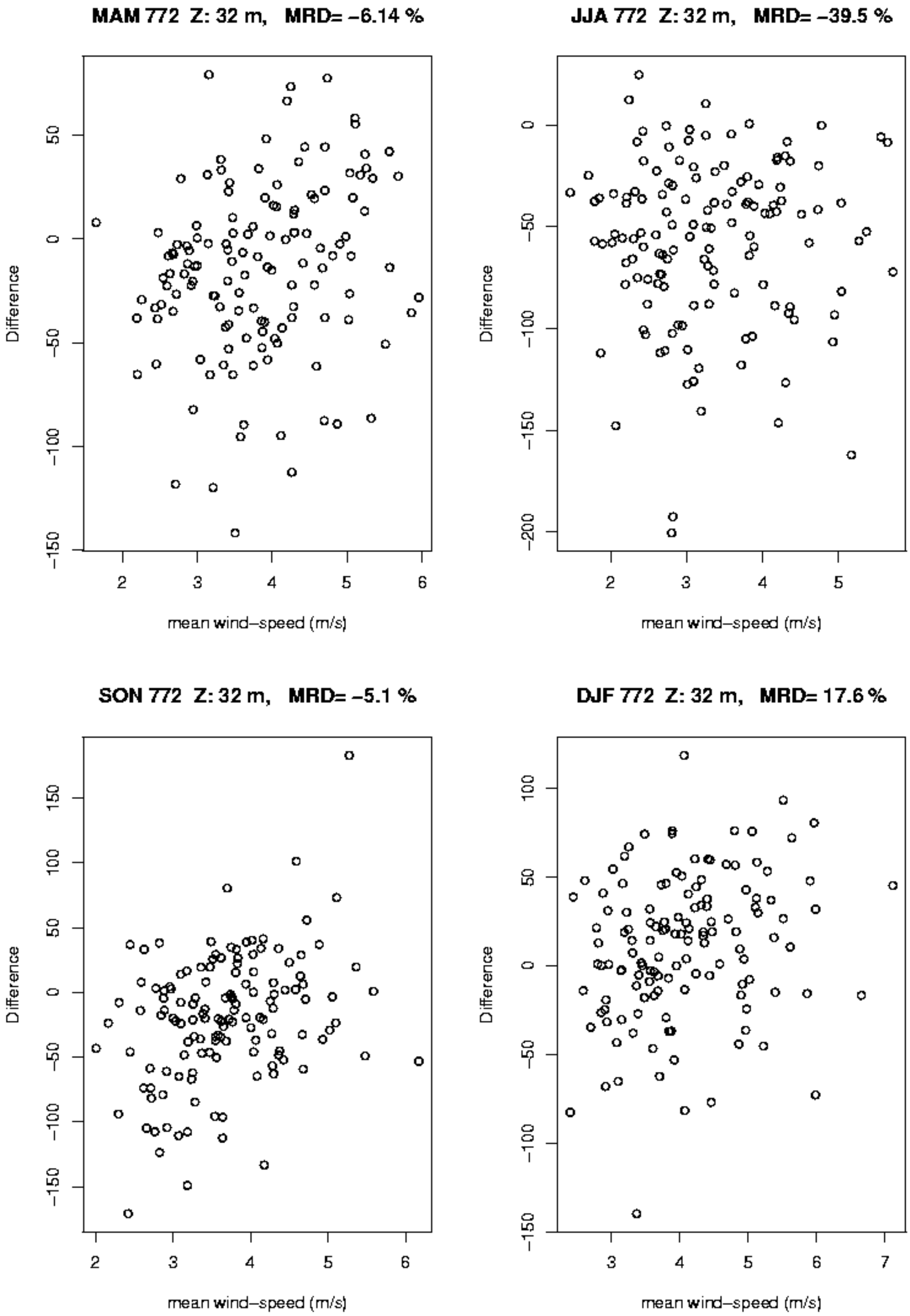
Monthly difference DP (in mm) versus mean wind-speed, for station no. 1.
DP = ERA-40 - Obs



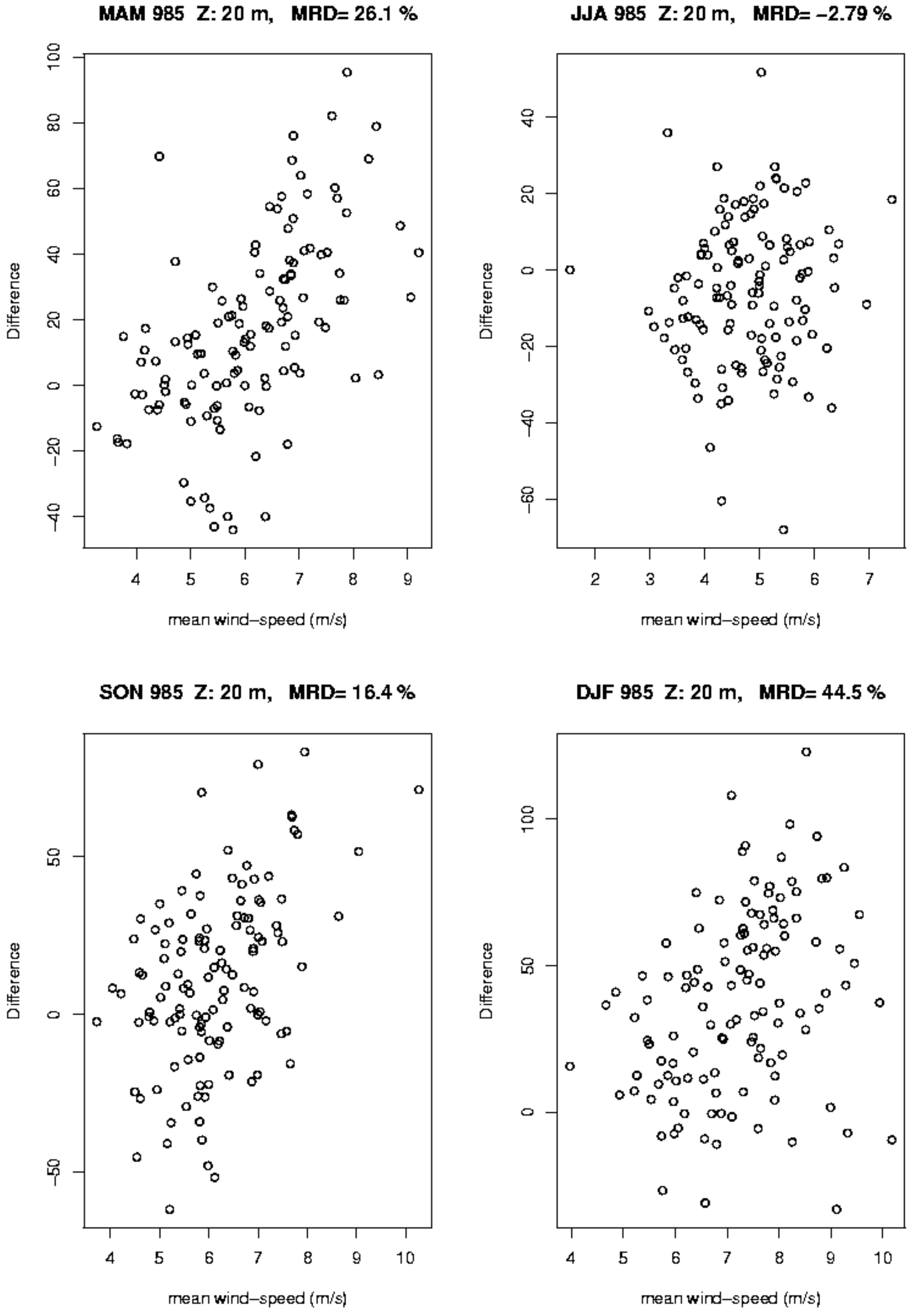
Monthly difference DP (in mm) versus mean wind-speed, for station no. 352.
DP = ERA-40 - Obs



Monthly difference DP (in mm) versus mean wind-speed, for station no. 508.
DP = ERA-40 - Obs



Monthly difference DP (in mm) versus mean wind-speed, for station no. 772.
DP = ERA-40 - Obs



Monthly difference DP (in mm) versus mean wind-speed, for station no. 985.
DP = ERA-40 - Obs