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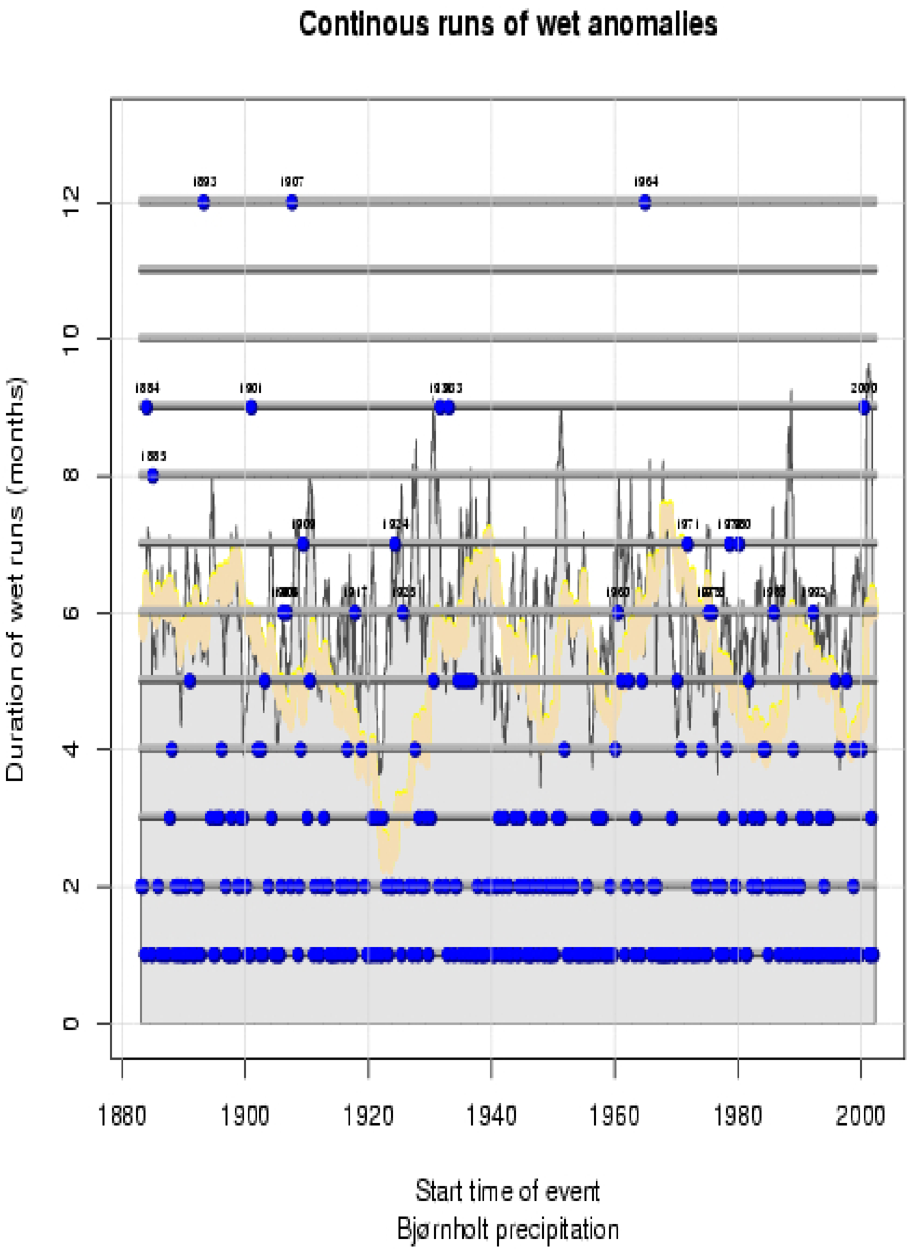
Report 02/03

KLIMA

RegClim:
Regional Climate Development under Global Warming

Past and future trends in the occurrence of wet and dry periods

Rasmus E. Benestad



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ISSN 0805-9918

REPORT NO.
02/03 KLIMA

DATE
2003-02-06

TITLE:

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PROJECT CONTRACTORS:

The Norwegian Research Council (Contract NRC-No 120656/720 RegClim) and The Norwegian Meteorological Institute

SUMMARY:

Analysis of climatic events may encompass extreme value analysis as well as the duration of the events (also referred to as ``runs'') and their timing. This study looks at the duration of continuously wet and dry episodes in terms of monthly values and the time interval between each event from global climate models. The analysis is applied both to monthly observational precipitation records as well as the results from empirical downscaling of monthly precipitation.

The analysis suggests that long-lasting wet runs tend to have longer duration than corresponding dry runs. There are no clear trends in either the duration of these runs or in the time interval between each event. The timing of the long-lasting runs is clustered in time, possibly exhibiting a fractal structure. The timing of these events does not follow a Poisson distribution.

Return values for extreme events were estimated though fits to General Pareto and General Extreme Value distribution. The extreme value analysis for the downscaled results suggests that the return values may increase in the future at some but not all locations in Norway.

KEYWORDS:

Duration of precipitation anomalies Timing of precipitation anomalies Empirical downscaling Extreme value analysis

SIGNATURES:

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Manuscript (2002), **met.no 02/03**, pp. 1–27

Past and future trends in the occurrence of wet and dry periods

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February 20, 2003

ABSTRACT

Analysis of climatic events may encompass extreme value analysis as well as the duration of the events (also referred to as "runs") and their timing. This study looks at the duration of continuously wet and dry episodes in terms of monthly values and the time interval between each event from global climate models. The analysis is applied both to monthly observational precipitation records as well as the results from empirical downscaling of monthly precipitation.

The analysis suggests that long-lasting wet runs tend to have longer duration than corresponding dry runs. There are no clear trends in either the duration of these runs or in the time interval between each event. The timing of the long-lasting runs is clustered in time, possibly exhibiting a fractal structure. The timing of these events does not follow a Poisson distribution.

Return values for extreme events were estimated though fits to General Pareto and General Extreme Value distribution. The extreme value analysis for the downscaled results suggests that the return values may increase in the future at some but not all locations in Norway.

KEY WORDS: Duration of precipitation anomalies Timing of precipitation anomalies Empirical downscaling Extreme value analysis

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TABLE 1. climate stations and time intervals.

Bjørnholt	1883 – 2002
Skjåk	1896 – 2002
Sviland	1895 – 2002
Halden	1882 – 2002
Dunderlandsdalen	1895 – 2002
Namdalseid	1895 – 2002
Tromsø	1931 – 2002

1 Introduction

In 1896, Svante A. Arrhenius (*Arrhenius*, 1896) proposed that atmospheric CO_2 may have a warming effect on Earth's surface. There has been a gradual accumulation of the carbon dioxide concentrations in the atmosphere (*IPCC*, 2001) as well as other so-called "greenhouse gases" since the industrial revolution. This build-up leads to a perturbation in the energy balance between the incoming solar radiation and the infrared radiation emitted from Earth's surface, and there are concerns about the effects of such an energy imbalance on our climate. A climate change has potentially severe consequences for the society, and it is therefore important to be able to forecast future climatic trends. Although the nature of the climate system is chaotic (*Lorenz*, 1967) and its exact trajectory cannot be deterministically predicted years ahead, it may nevertheless be possible to predict the long-term climatic trends, given a systematic change in the boundary conditions. Such predictions are based on coupled atmosphere-ocean general circulation models (AOGCMs), which describe the large-scale dynamics and thermodynamics of the climate systems. The term "climate scenarios" is used henceforth in order to emphasis the fact that these climate models only can forecast plausible climatic trends and that the internal variations are more arbitrary.

Estimations of globally averaged temperature indicate a warming of $\approx 0.6°$C over the past century (*IPCC*, 2001). Although the global aspect of a climate change is important for monitoring purposes and the understanding of our climate, it is the local climate shifts that will have direct effects on our future. It is also on local and regional scales that extreme weather and climate events take place. Therefore, it is important to consider which implications a global warming may have for regional climates.

The climatic evolution of the past may provide some insight into what can be expected in the future. Past trends in precipitation events are presented in this report. Section 2 gives an overview of the methods and the data used in this study and the results are presented in Section 3.

2 Methods & Data

Figure 1 shows the location of the stations used in this study. The monthly precipitation (Table 1) was taken from the Norwegian Meteorological Institutes climatological archive.

The empirical downscaling was based on common EOFs applied to combined fields of 2-meter air temperature [T(2m)] and sea-level pressure. The predictors were taken from NCEP (*Kalnay* et al., 1996) and the region covering 0°E–40°E,55°N–69°N. The climate scenarios were derived from the ECHAM4/OPYC3 GSDIO integration (*Roeckner* et al., 1992; *Oberhuber*, 1993). It is important to keep in mind that the results may be sensitive to the choice of predictor region (*Benestad*, 2001) and that different climate models give different results (*Benestad*, 2002a). The actual downscaling was carried out using a test-version of the clim.pact package (*Benestad*, 2003) for the R data analysis language†. The details of the downscaling strategy are described in *Benestad* (2001, 2002b); *Benestad* et al. (2002); *Benestad* (2002a). The downscaling was applied separately to each of the 12 calendar months (e.g. seasonally stratified analysis).

It is possible to examine the intervals between each event to see if the occurrence of events are random or if they follow certain patterns and to deduce whether there may be any trends in the records. If the probability of occurrence is $p = \lambda x = \nu$, then the probability of k events occurring in a time span with length x can be estimated using a Poisson distribution (*Cameron*, 1960, p.112):

†http://cran.r-project.org/.

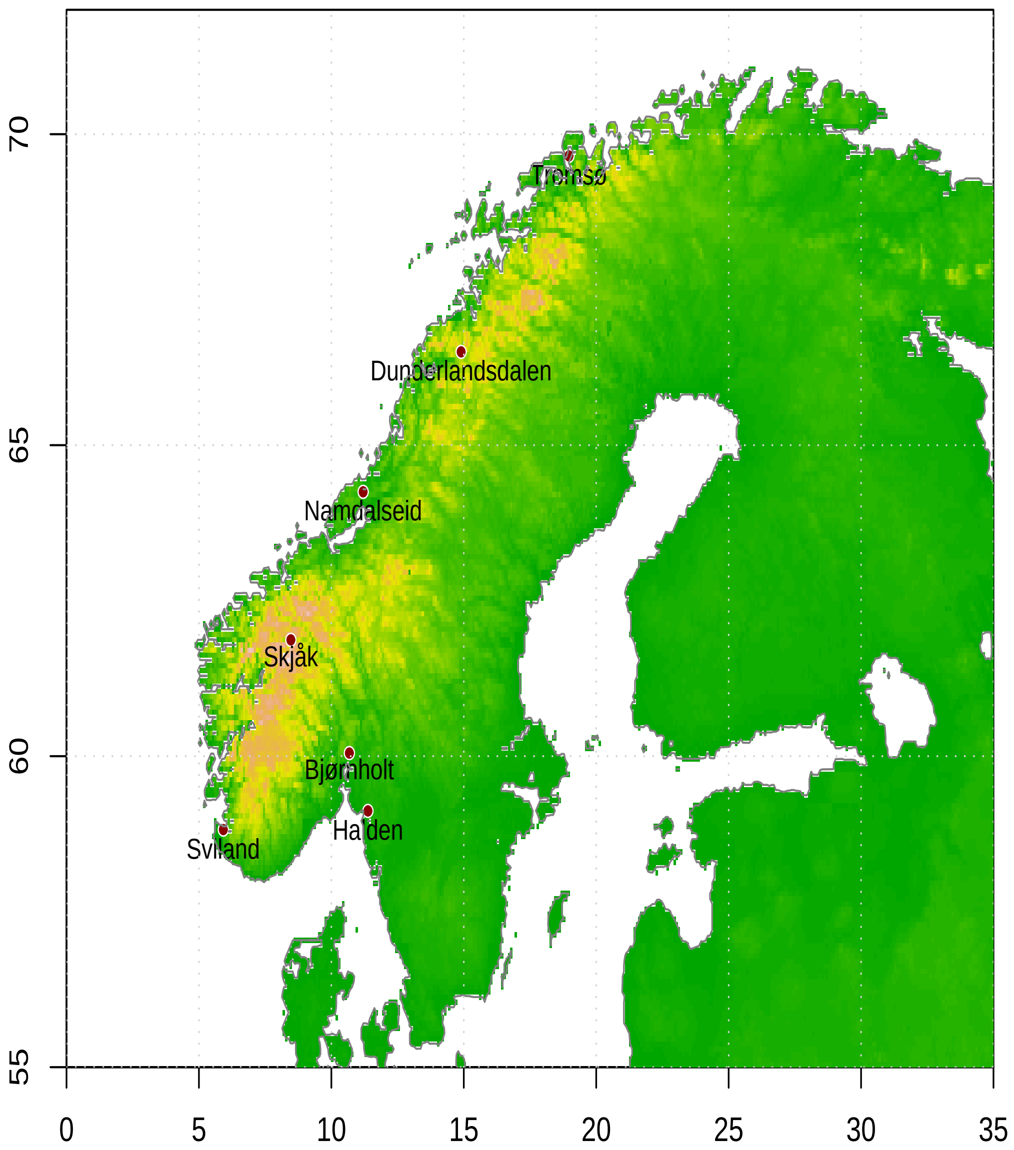


Figure 1. Location of stations.

$$P(k,\nu) = \frac{e^{-\nu} u^k}{k!} \tag{1}$$

where $\nu = \lambda x$, λ is the probability density, and x is taken as the length of the entire data record. A distribution with respect to the time interval between each event ($\tau \sim 1/f$) can be estimated as k/x. The theoretical Poisson distribution can be used to provide a measure for an expected distribution of time intervals, given the assumption that the probability of occurrence is $\sim \lambda x$. The analysis of event-

TABLE 2. The mean precipitation (mm) estimated from the observed and downscaled anomalies for the entire Bjørnholt records. The first row shows the observed 1961–90 climatological means, and the second and third rows show the bias in the anomaly for the entire record. Rows 4–5 give the observed and model-derived standard deviation.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Obs.1961–90 clim.	76	59	71	61	77	91	109	118	128	139	120	89
Obs. anomaly	2	-2	-8	6	-3	-7	0	14	-9	-6	-1	9
Model anomaly	9	18	-2	-8	7	-6	-6	-5	9	1	3	-1
Obs. Stdv.	48	41	43	40	42	49	55	72	64	79	78	60
Model Stdv.	40	34	43	36	36	38	32	38	44	57	52	48

length statistics used a cut-off at 12 months (i.e. only applies to dry/wet runs shorter than 12 months of duration).

An analysis of return periods and values can be carried out using standard extreme value analysis (general extreme value distribution, GEV, or general Pareto distribution, GPD), where standard distribution functions are fitted to the empirical data for the extrapolation of probabilities. The GPD analysis in this study used a threshold value taken as the 90 percentile. This choice for threshold may not always be appropriate, and can lead to a poor fit. Extreme value analysis can also be made using GEV which fits the observed maximum monthly precipitation in each year (1 of 12 months) to a GEV distribution. In this study, the extreme value analysis has been made to the monthly anomalies for the whole year and does not treat the seasons differently from one another. This means that the seasons with the highest variance in the precipitation tend to dominate the analysis.

3 Results

Three 12-months continuously wet periods have been observed at Bjørnholt in 1893 (Figure 2), 1907 and 1964. These events did not coincide with high 12-month running average values (dark grey curve). Hence, high mean-excess values have been due to several short but very wet spells, broken up dry months. The cumulative sum (yellow curve) doesn't indicate that there has been any long-term trend in the historical precipitation. There is also no clear trend in the timing of the wet episodes, however, the occurrence of 2–7 months have an appearance of clustering or fractal structure in time. This kind of clustering or fractal appearance is common to all the precipitation records.

None of the observed dry runs (b) lasted longer than 6 months. The bias in the duration for the wet and dry events is apparently not due to relatively low 1961–90 climatological mean values, from which the anomalies have been defined (Table 2). There is no clear long-term trend in the occurrence of the dry episodes.

Figure 3 shows the same analysis for Skjåk. Again, there is no clear trend in the wet or dry occurrences. The rise in the cumulative sum (yellow curve) towards the end the record indicates a recent trend towards more precipitation. There was a relatively dry period in the beginning of the observational period.

Figures 4–7 show the same analysis for Sviland, Halden, Dunderlandsdalen, Namdalseid, and Tromsø respectively. There is no clear trend in the occurrences in any of these records. The cumulative sums, however, point to more precipitation towards the end in all of these series. The peaks in the 12-month running averages do generally not coincide with 12-month continuous high or low precipitation anomalies. In these records, there are some wet events that are common for some of the stations. The 1964 12-month wet spell can be seen in both Bjørnholt and Halden, but none of the others. There is also a case for which the timing is slightly different: Bjørnholt (1907), Halden (1906). It is important to note that Bjørnholt and Halden are close to each other. Apart from these two events, there is no 12-month episode in more than one station record. This finding suggests that these episodes are local.

An analysis of variance of the empirical downscaling suggests generally high skill (Table 3). The lowest R^2-values were obtained during spring and summer.

Figures 9–14 show the downscaled scenarios corresponding to the locations shown in Figures 2–7. There is no tendency of the wet episodes lasting longer than the dry events in these scenarios. In fact, some of the dry runs at Skjåk (Figure 10) and Sviland (Figure 11) last for 12 months whereas the longest wet spells last 6-months. The long dry events at Skjåk and Sviland appear to be more frequent towards the end of the scenario, however, there are no clear trends. A positive slope in the cumulative sum and

TABLE 3. The estimated proportion of variance (R^2 in %) that the downscaling models can reproduce. Calibration period: 1960–2002.

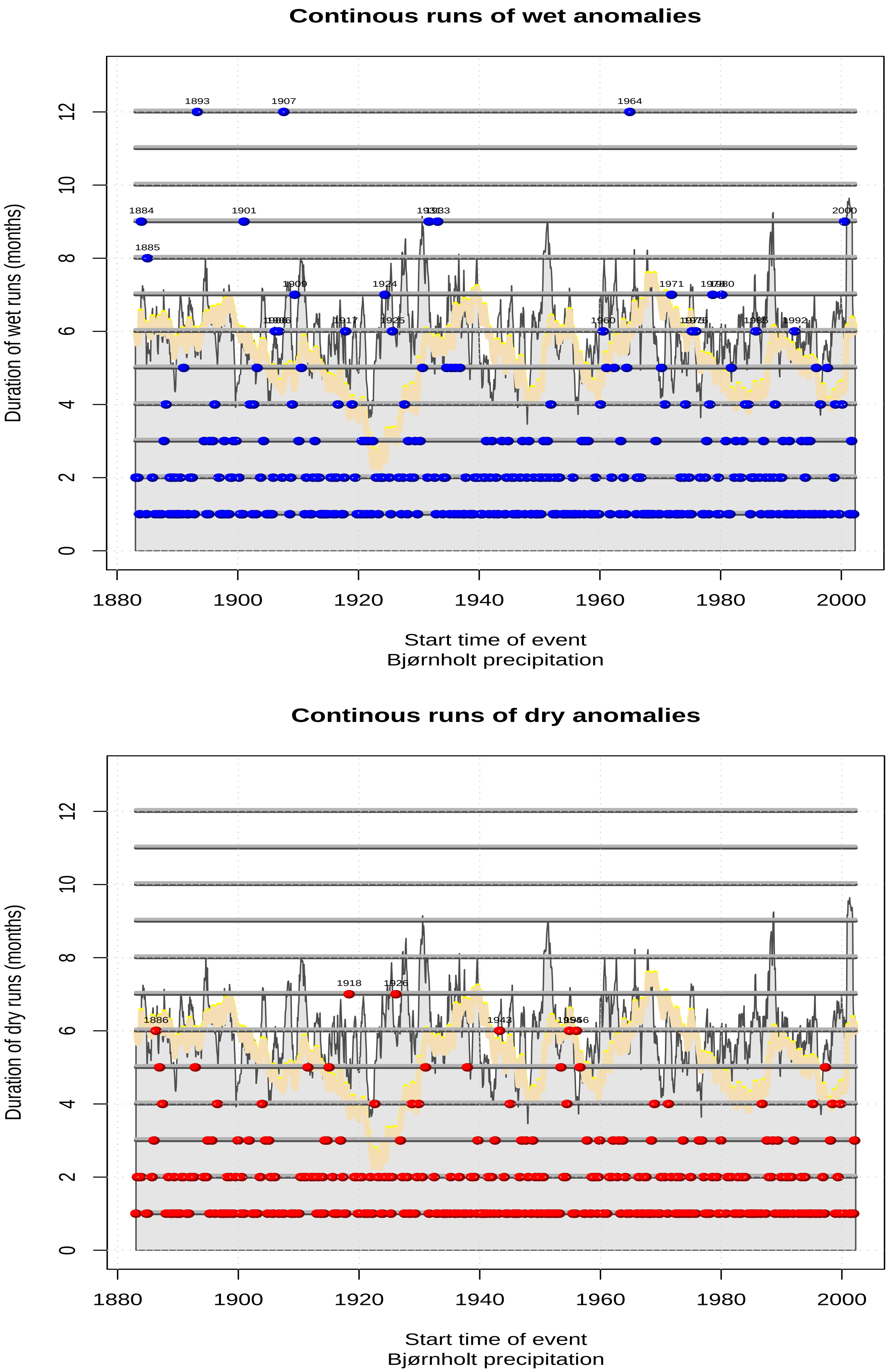
month	Bjørnholt	Skjåk	Sviland	Halden	Dunderlandsdalen	Namdalseid	Tromsø
January	73	70	79	74	80	82	87
February	66	56	87	71	77	82	72
March	63	57	82	82	74	84	61
April	67	8	55	64	57	65	76
May	59	39	57	71	62	67	77
June	56	32	70	44	54	59	48
July	55	59	67	46	42	60	58
August	59	18	64	63	46	56	70
September	54	34	71	58	79	83	66
October	64	36	78	62	84	81	71
November	60	65	81	79	73	72	82
December	68	64	75	80	83	78	78

12-month running mean suggest increased rainfall towards the end.

Figures 16–22 show various statistics associated with the dry and wet spells. Panel (a) shows the observed and downscaled records. Panels (b) and (c) give the frequency of wet and dry events with respect to their duration. The shorter spells are more frequent than the longer spells, as expected and in agreement with the results in Figures 2–14. In general, the downscaled scenarios exhibit similar frequency distributions with respect to the event duration as the observations, although the short wet spells of the scenarios in some locations are more frequent than in the observations. Conversely, the short dry runs appear to be too infrequent in the scenarios.

The statistics for the intervals between the 3-month events are reproduced in panel (d), which shows the frequency distributions of the inter-event interval lengths. Also shown in this plot are the Poisson distributions and the mean inter-event interval lengths. The histograms representing the historical and downscaled scenarios indicate a high proportion of short intervals between the events in line with the time clustering seen in Figures 2–14. Poisson distributed data have a property of which the mean equals the variance: $\mu = \sigma^2$. The mean of the inter-event interval lengths is $\mu = 34.1$ and the variance is $\sigma^2 = 1056$ for Bjørnholt. Hence, these results suggest that the arrivals of these events in general do not follow a Poisson distribution.

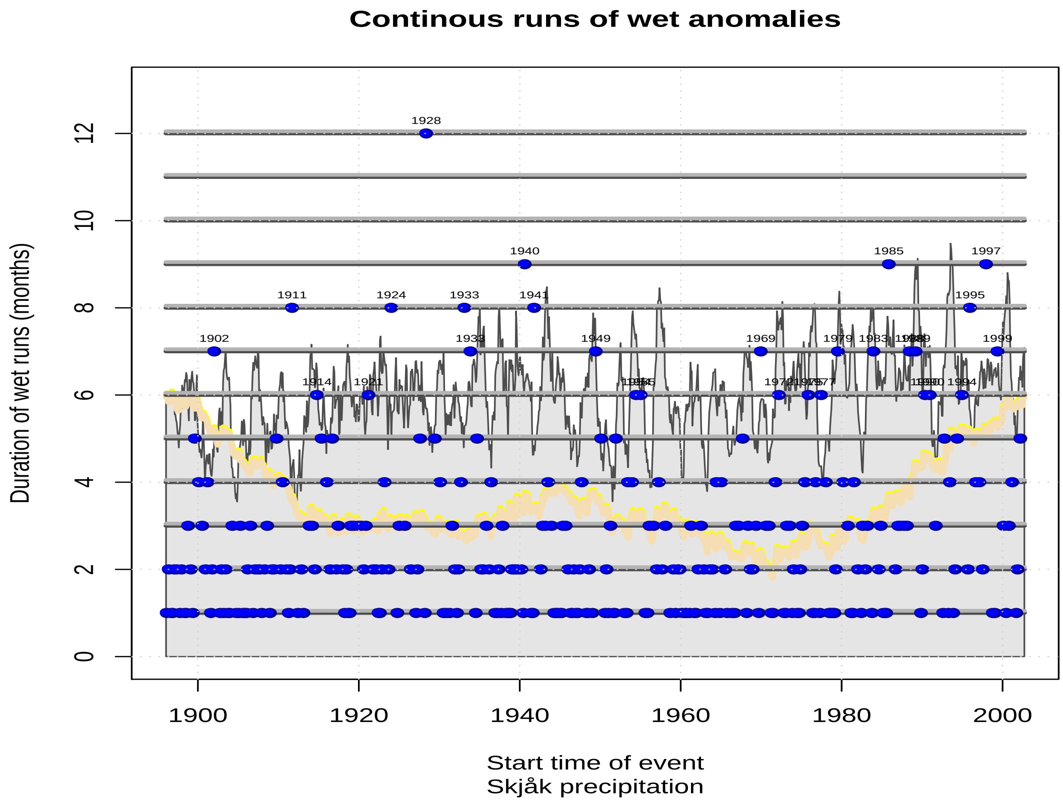
Panels (e) and (f) show the results from extreme value analysis on the monthly precipitation amount. The return value analysis is given in panel (e) and the data fit to the GPD is reproduced in (f). The return value analysis is applied to the observations as well as the scenarios using both GPD and GEV theories. The scenarios have been divided into two sections: 1960–2000 is the control period and 2001–2050 represents the future. The GPD fit is poor for the precipitation at Sviland (Figure 18(f)), Namdalseid (Figure 21(f)), and Tromsø (Figure 22(f)). The reason for bad fit may be inappropriate threshold or due to the fact that the occurrences do not follow a Poisson distribution. In these cases, the GEV is more reliable. In general, the return value curves of the scenarios are very different to the observed curves, and this discrepancy is a major concern when the extremes are the focus of the study. The difference in the return values can to a large extent be accounted for by the empirical downscaling which can account for 8–87 % of the observed variance (Table 3). Such shortcomings can explain the lower return values in general, but not the different shapes in the curves shown in Figure 20 (e). The differences between the control period (blue dashed lines) and the "2001"–"2050" period (red dashed lines) point to an future increase in the return values for most of the locations except Dunderlandsdalen and Namdalseid.



a

b

Figure 2. The timing of wet (a) and dry (b) runs at Bjørnholt are marked with coloured circles along the x-axis. The y-axis indicates the duration of the runs. The dark grey line shows the 12-month running-average and the thick yellow curve shows the cumulated sum of the monthly precipitation after the mean for the whole record has been subtracted.



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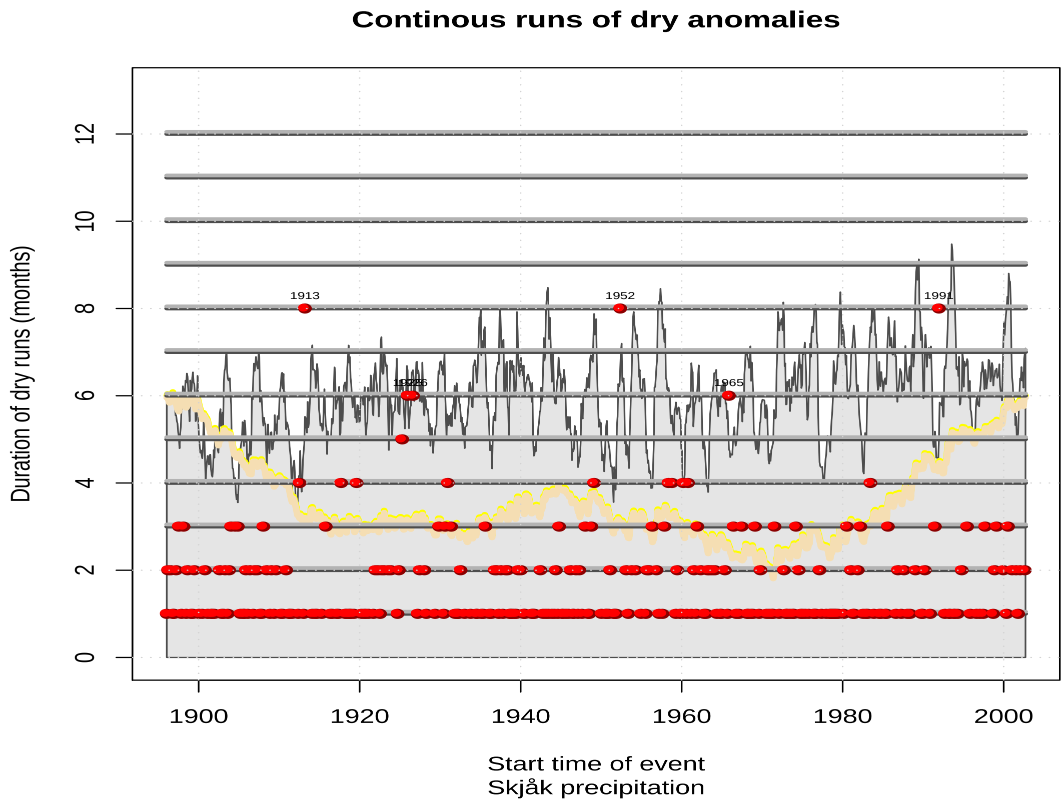

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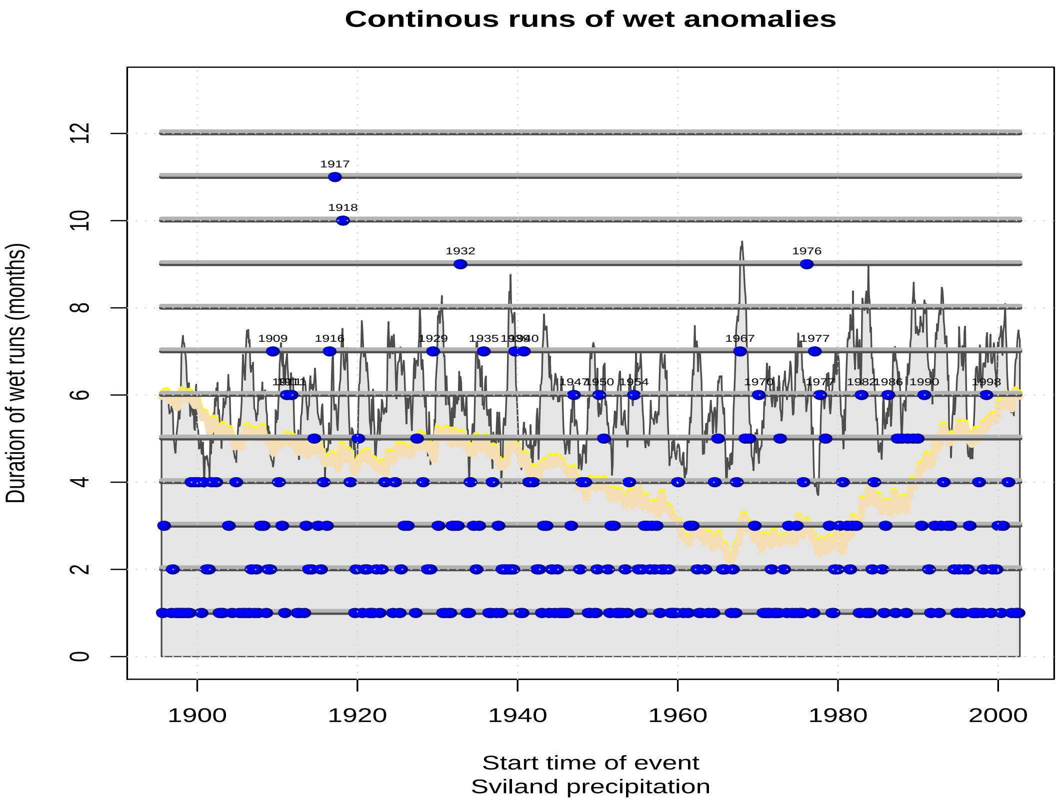
Figure 3. The same as Figure 2 but for Skjåk.



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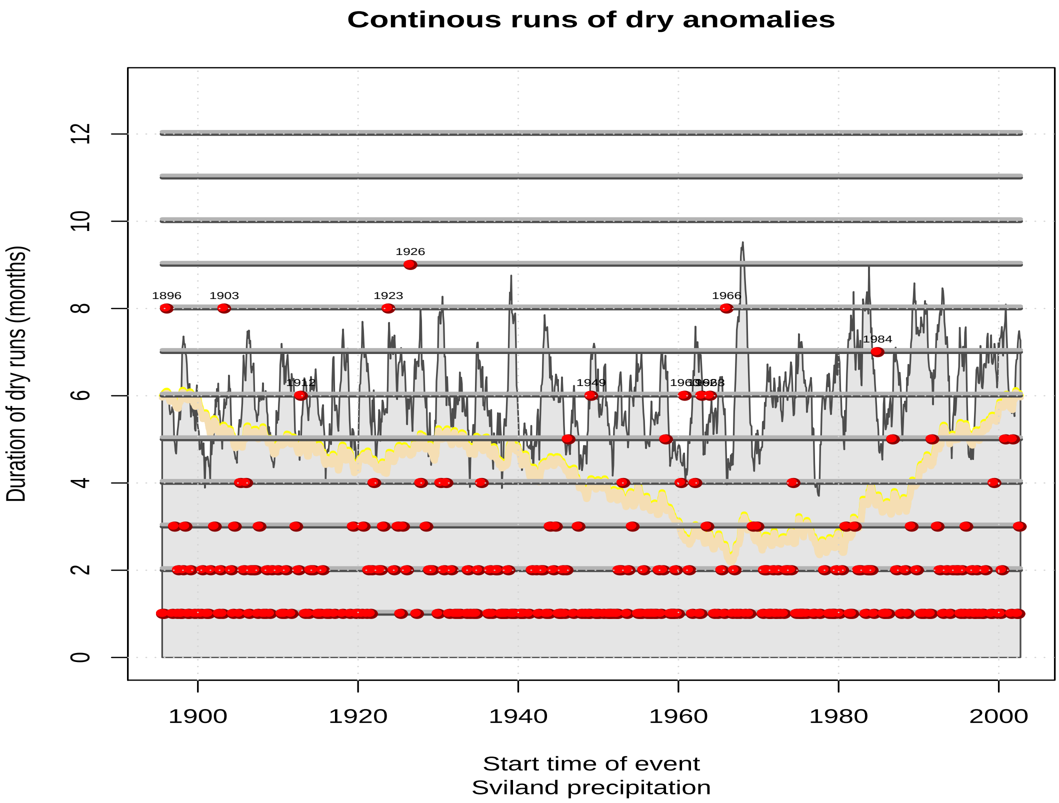

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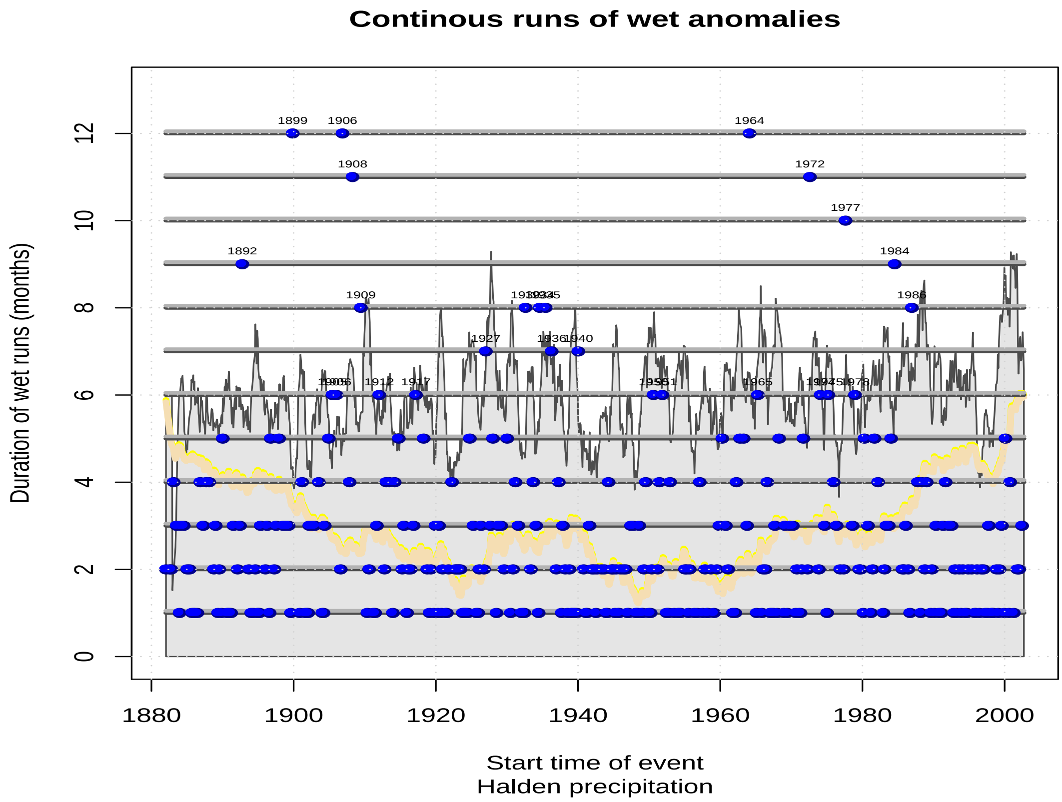
Figure 4. The same as Figure 2 but for Sviland.



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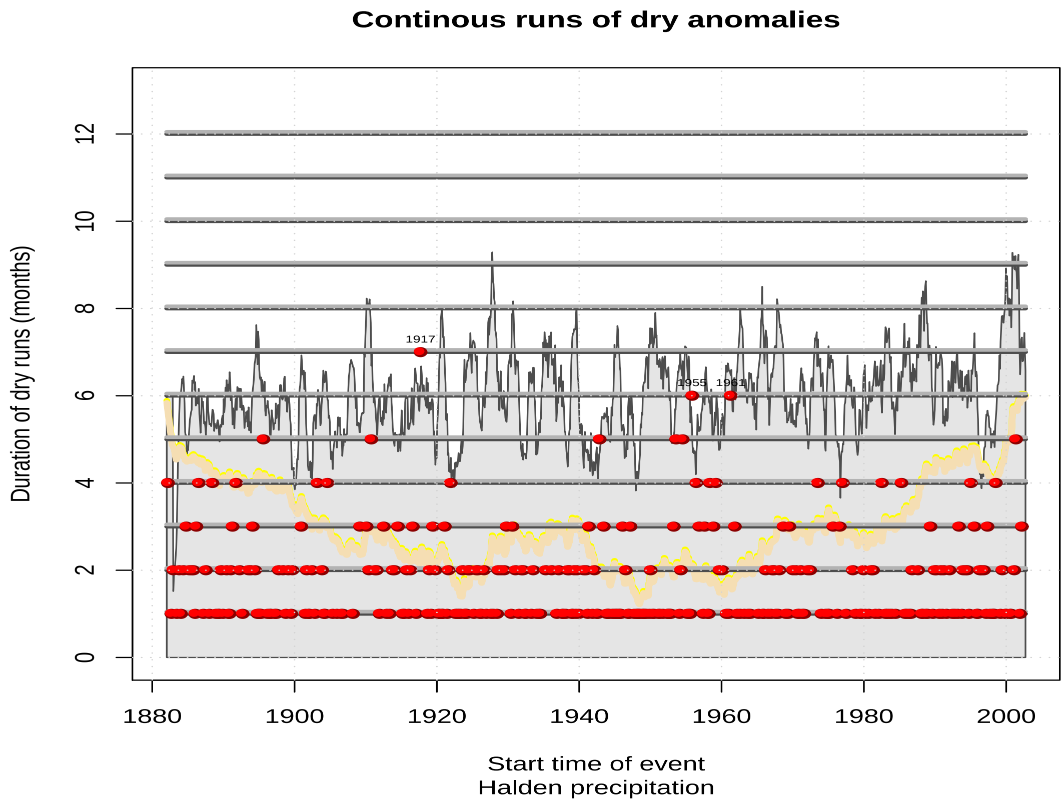

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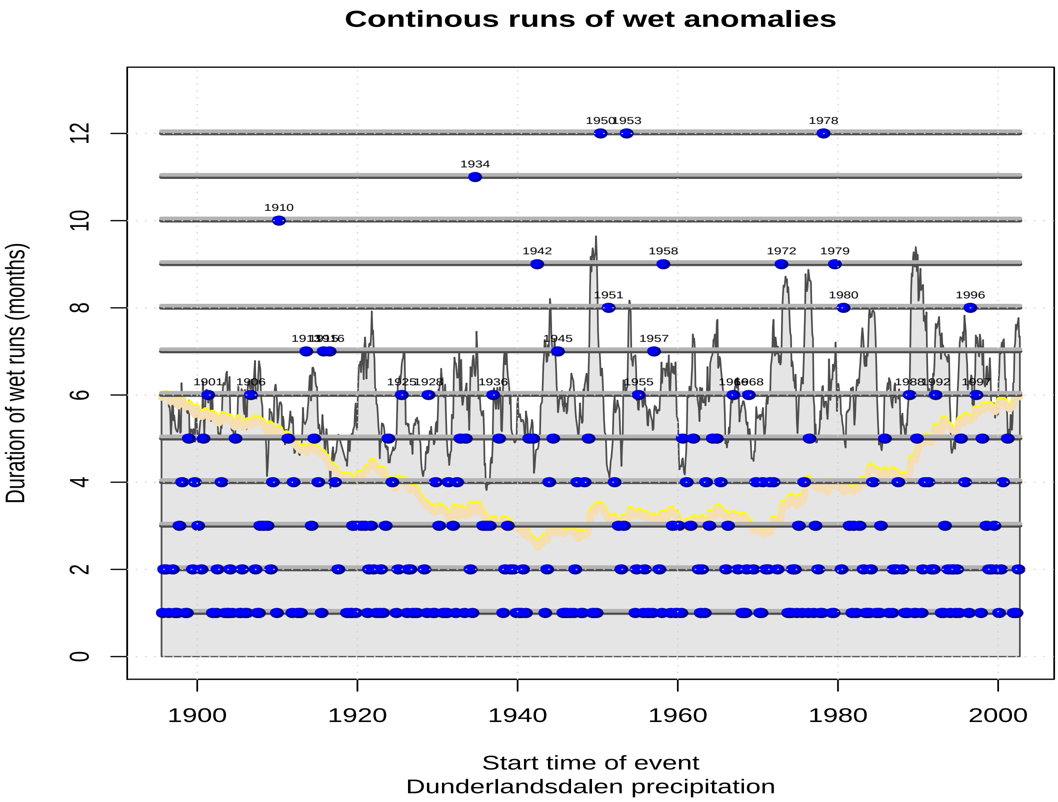
Figure 5. The same as Figure 2 but for Halden.



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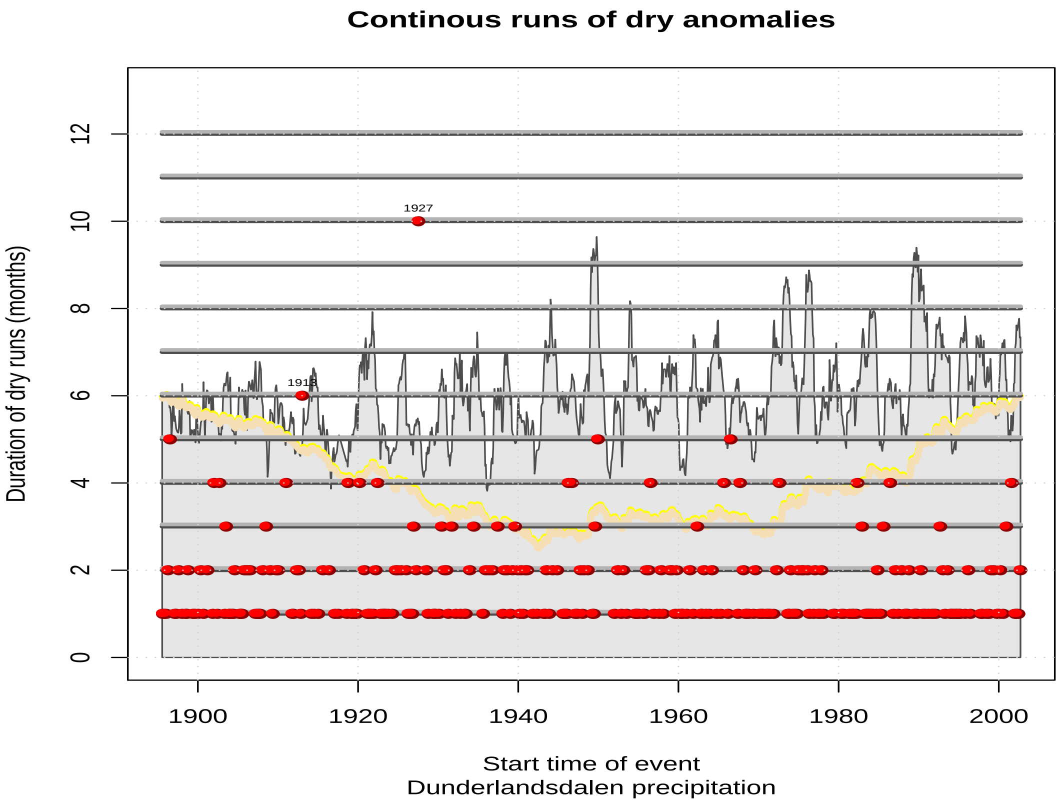

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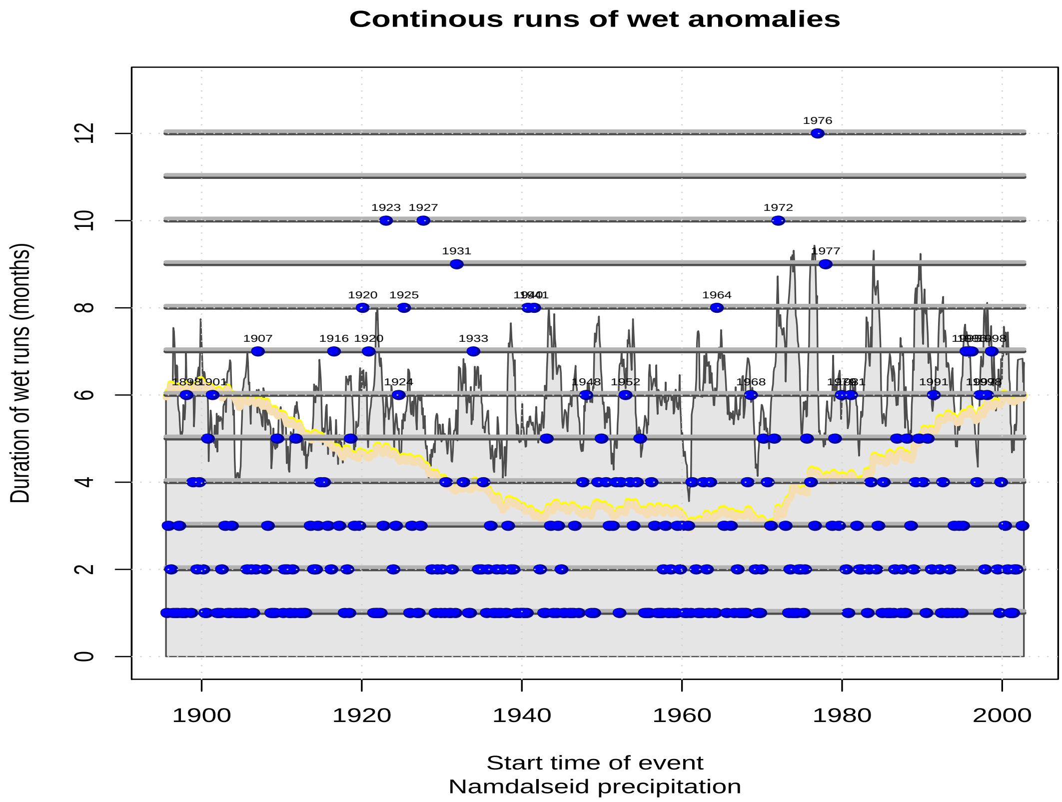
Figure 6. The same as Figure 2 but for Dunderlandsdalen.



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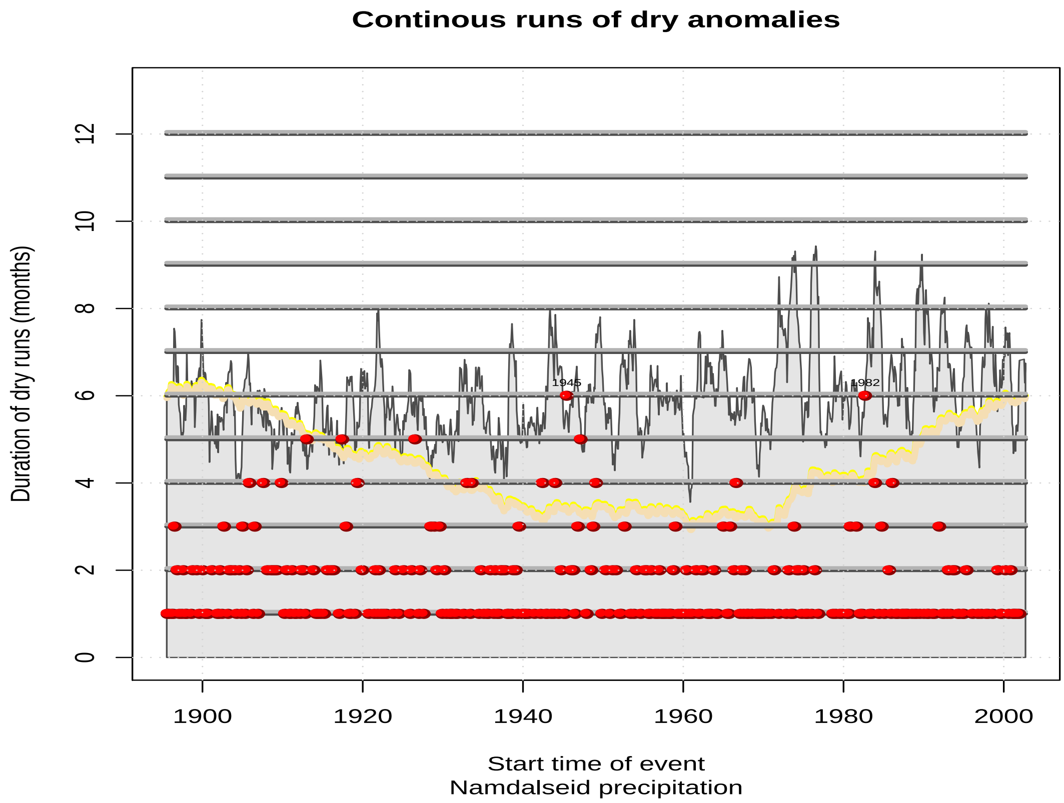

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Figure 7. The same as Figure 2 but for Namdalseid.

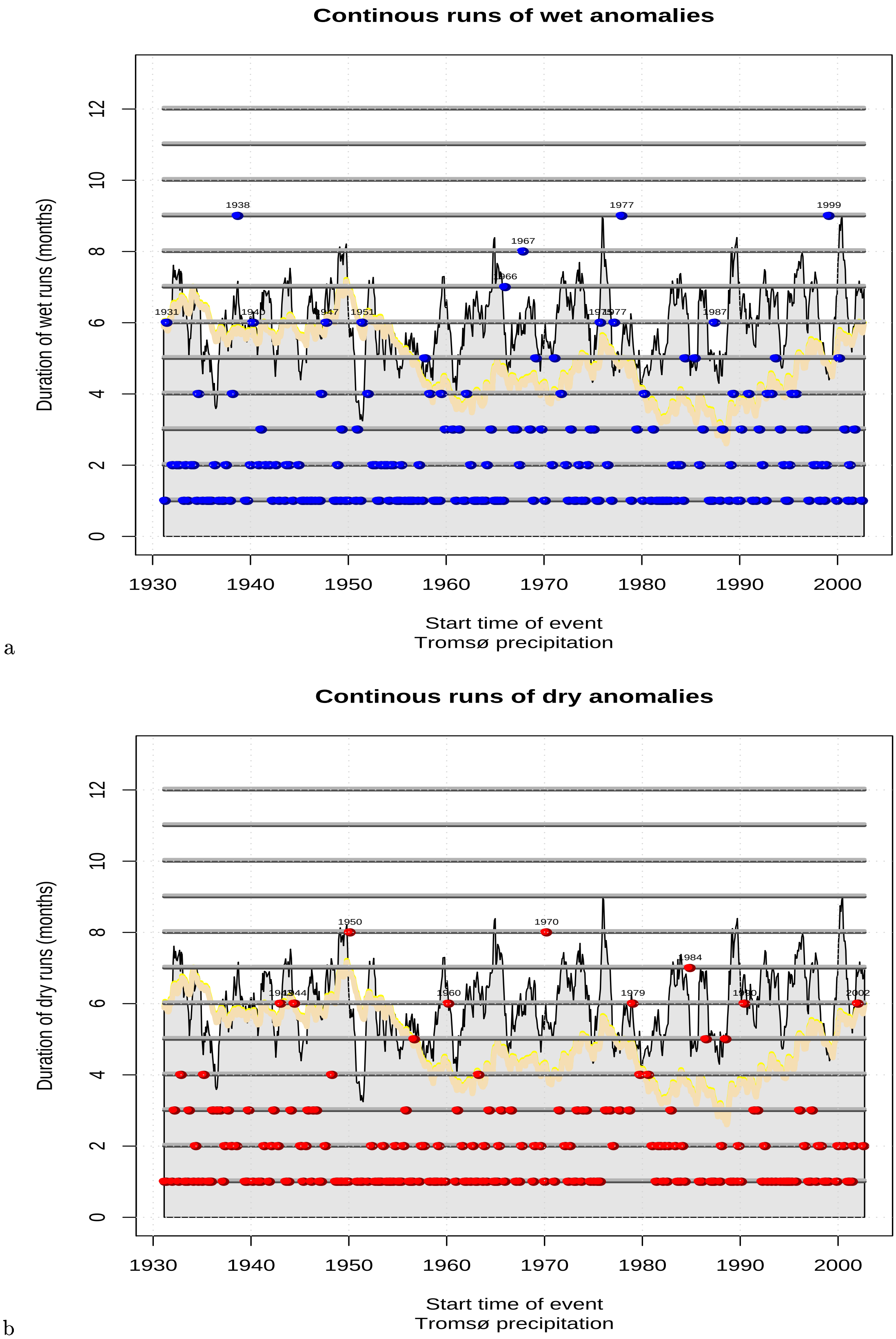
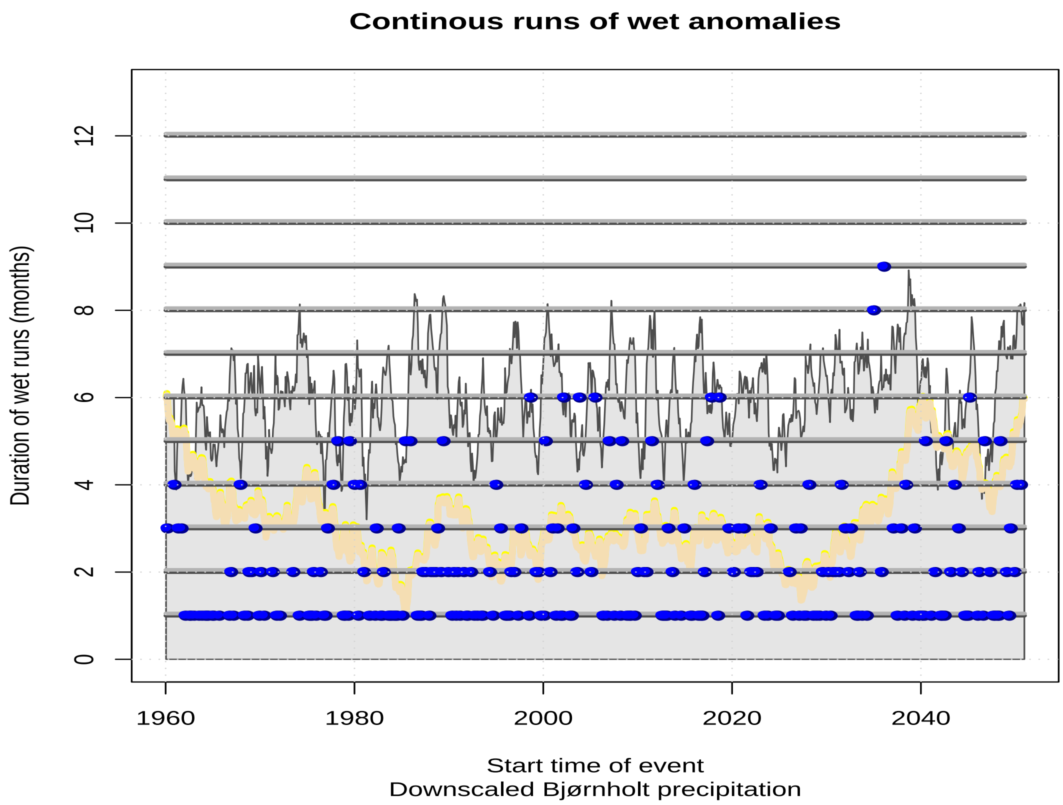


Figure 8. The same as Figure 2 but for Tromsø.



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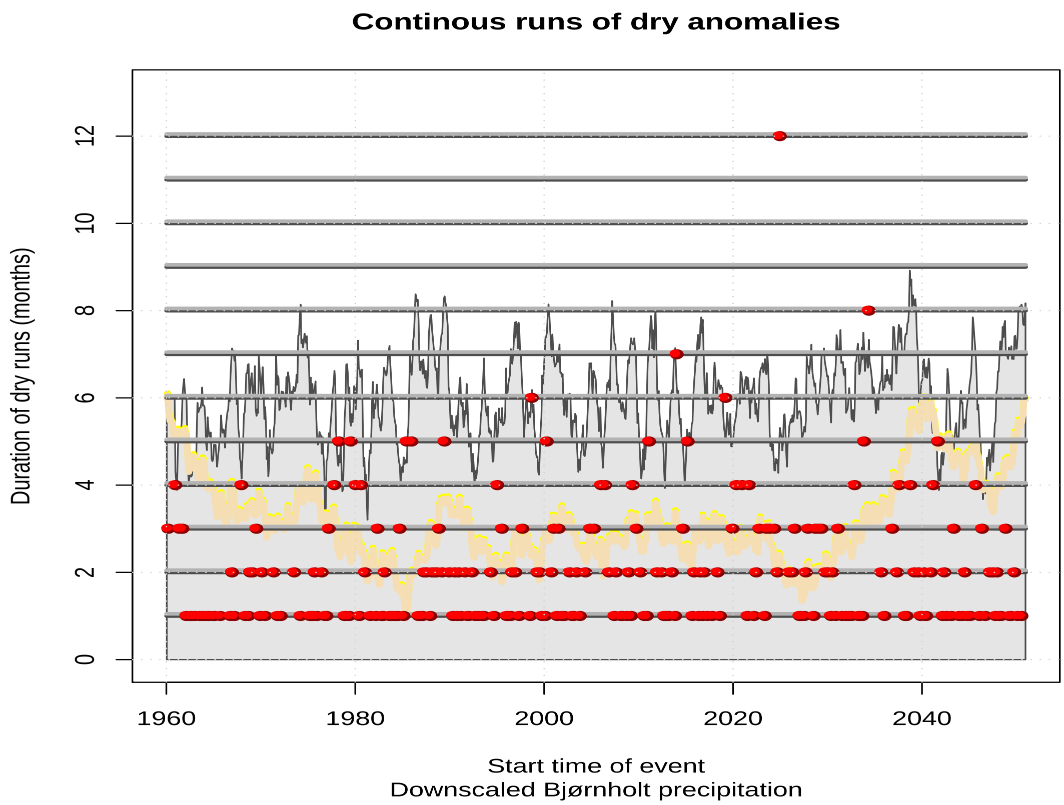

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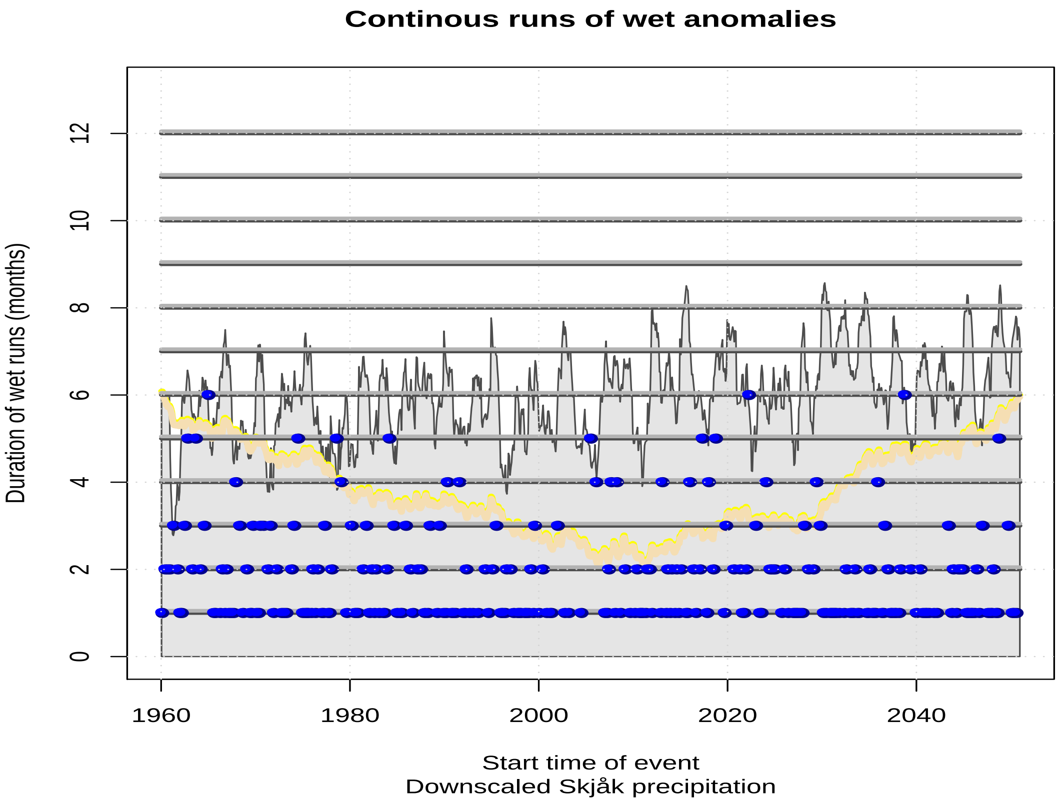
Figure 9. The timing of wet (a) and dry (b) runs downscaled for Bjørnholt are marked with coloured circles along the x-axis. The y-axis indicates the duration of the runs.



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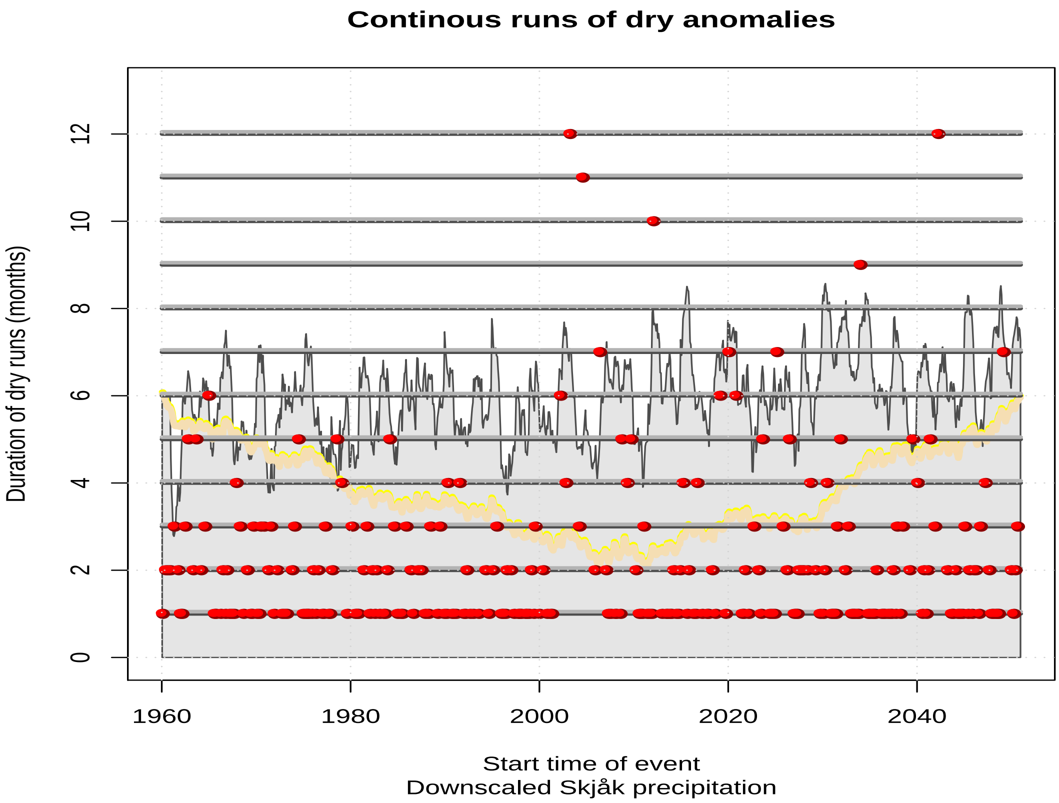

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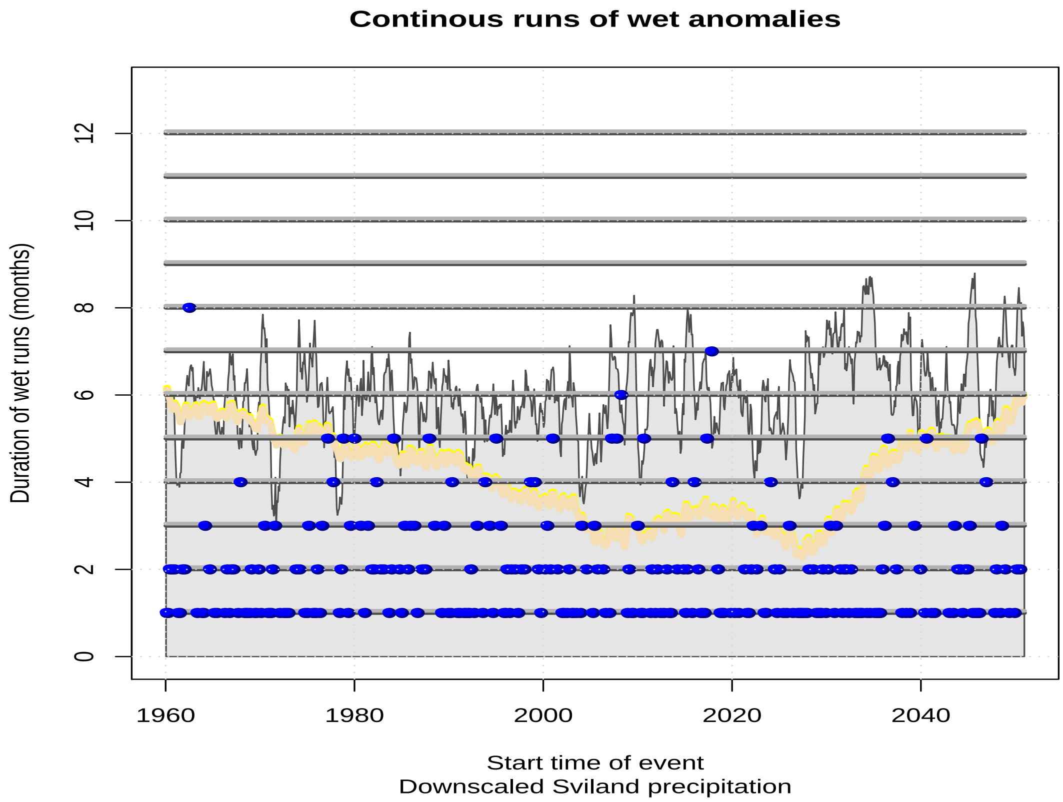
Figure 10. The same as Figure 9 but for Skjåk.



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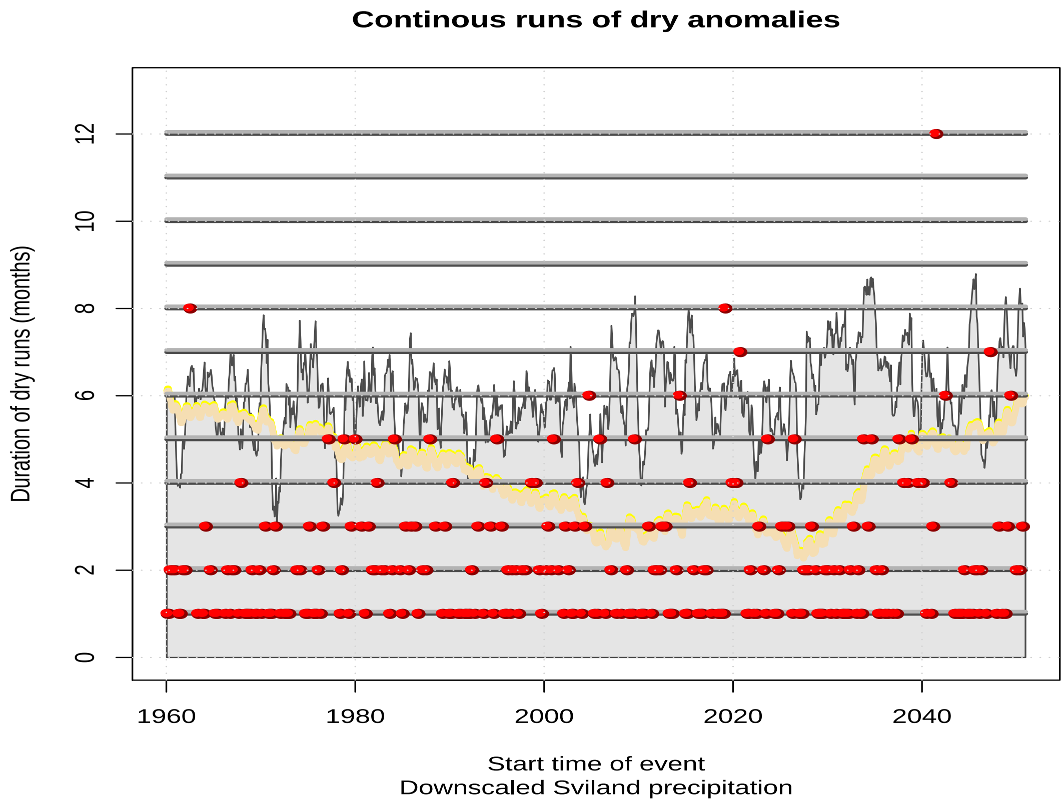

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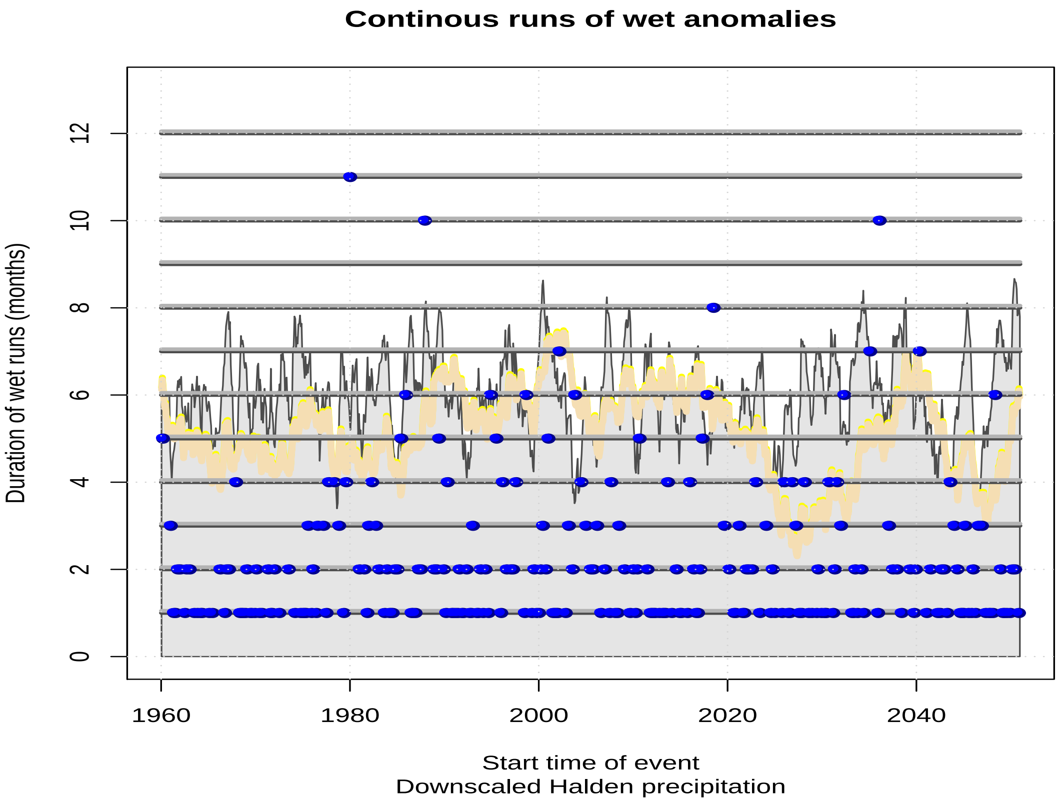
Figure 11. The same as Figure 9 but for Sviland.



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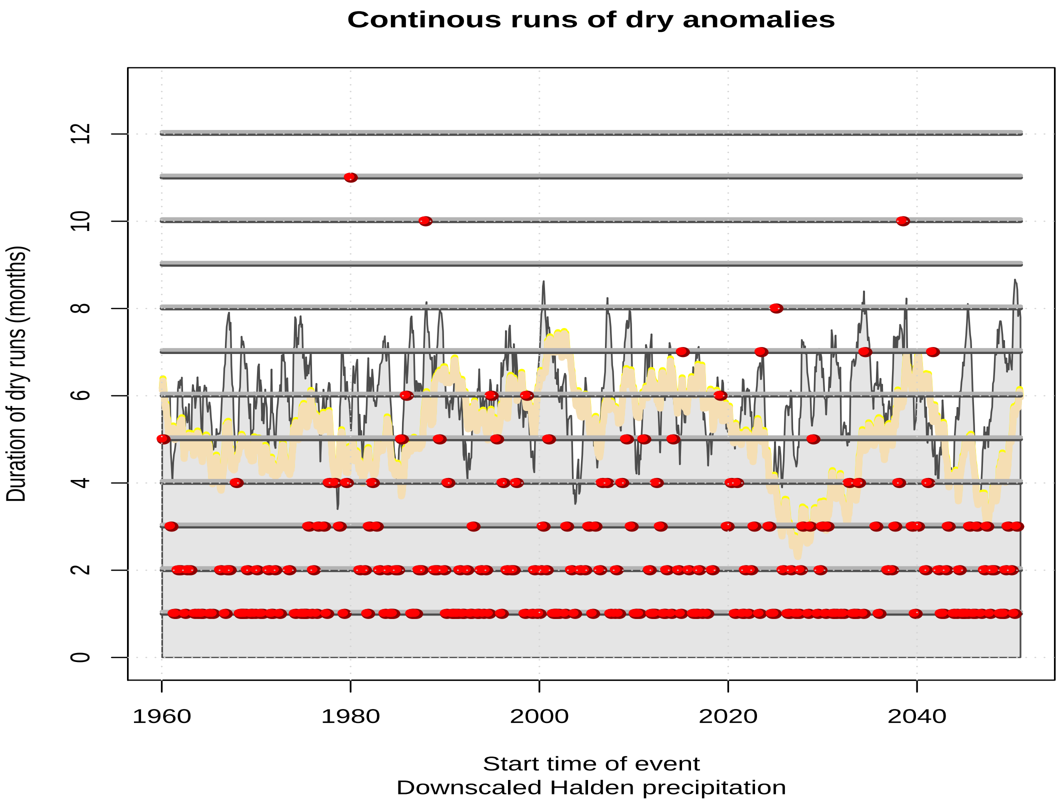

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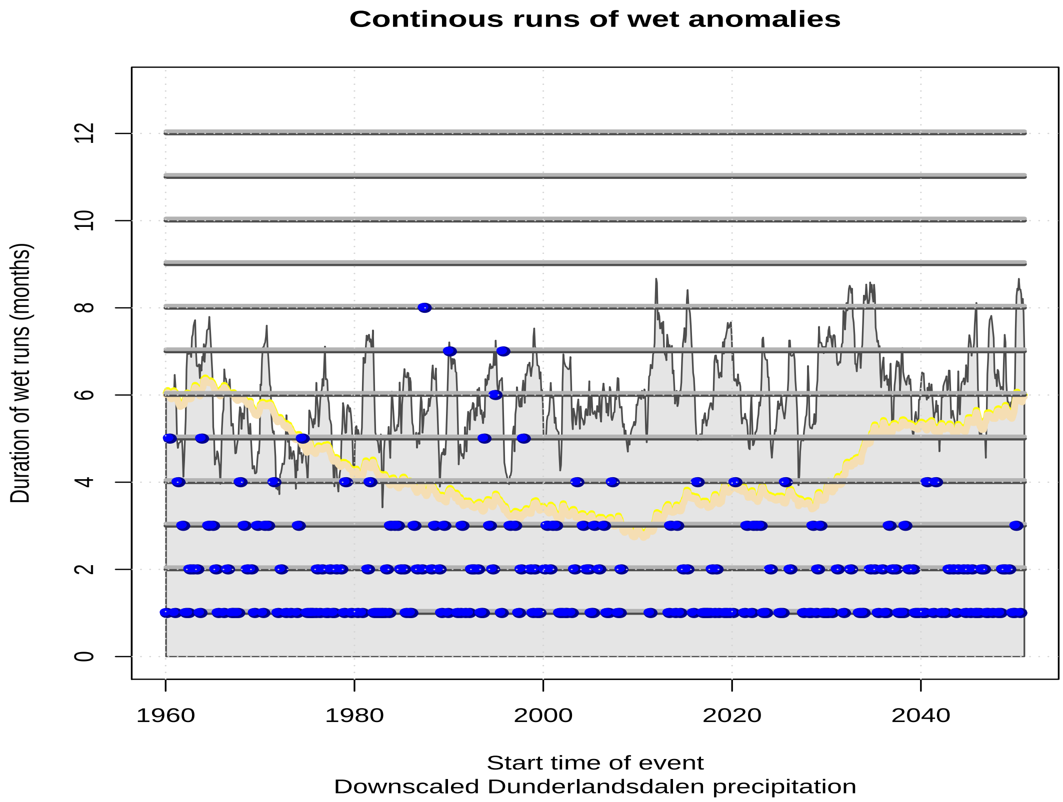
Figure 12. The same as Figure 9 but for Halden.



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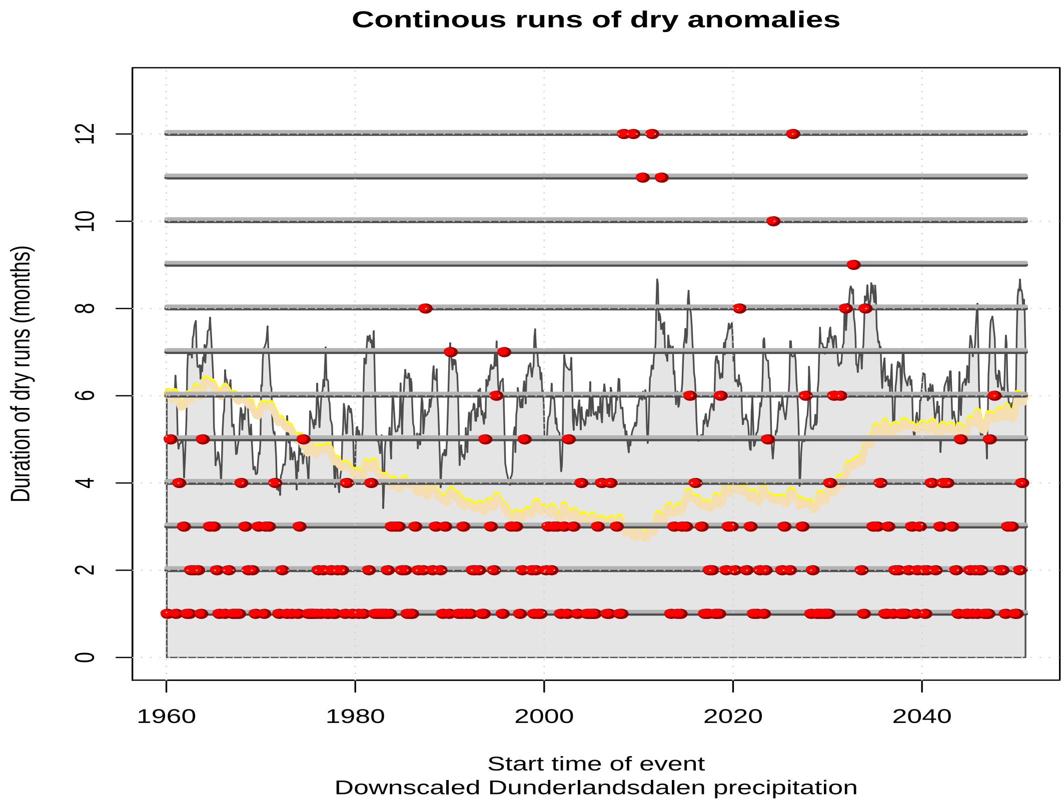

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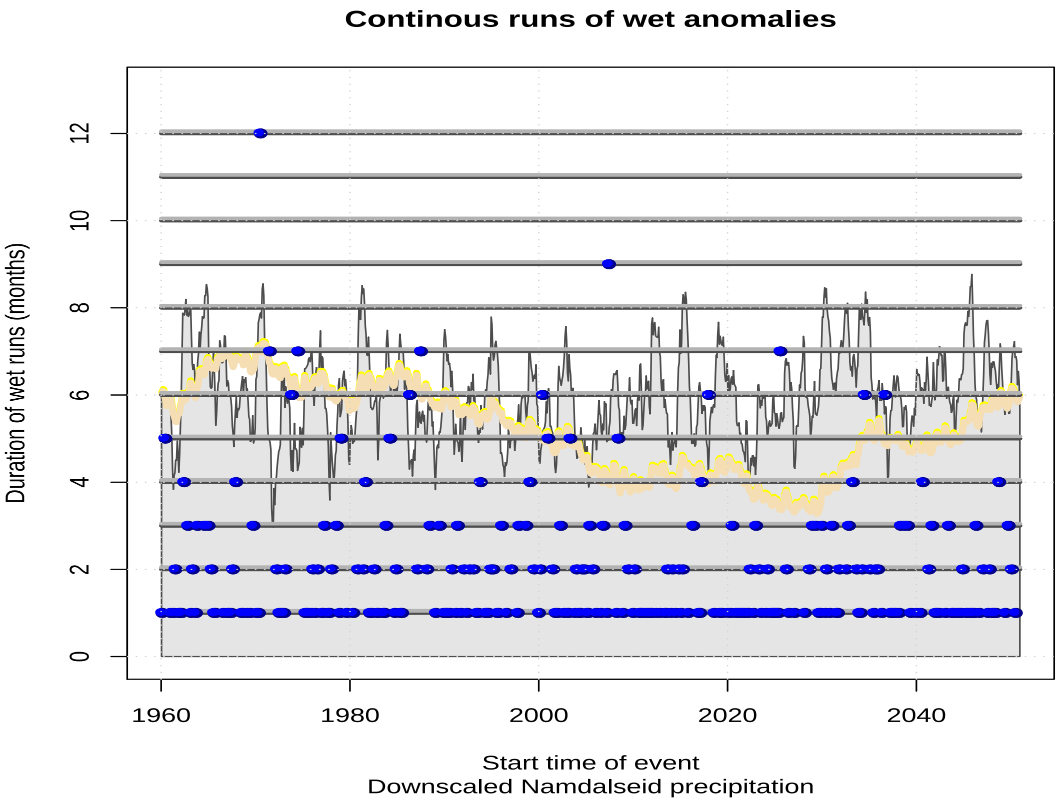
Figure 13. The same as Figure 9 but for Dunderlandsdalen.



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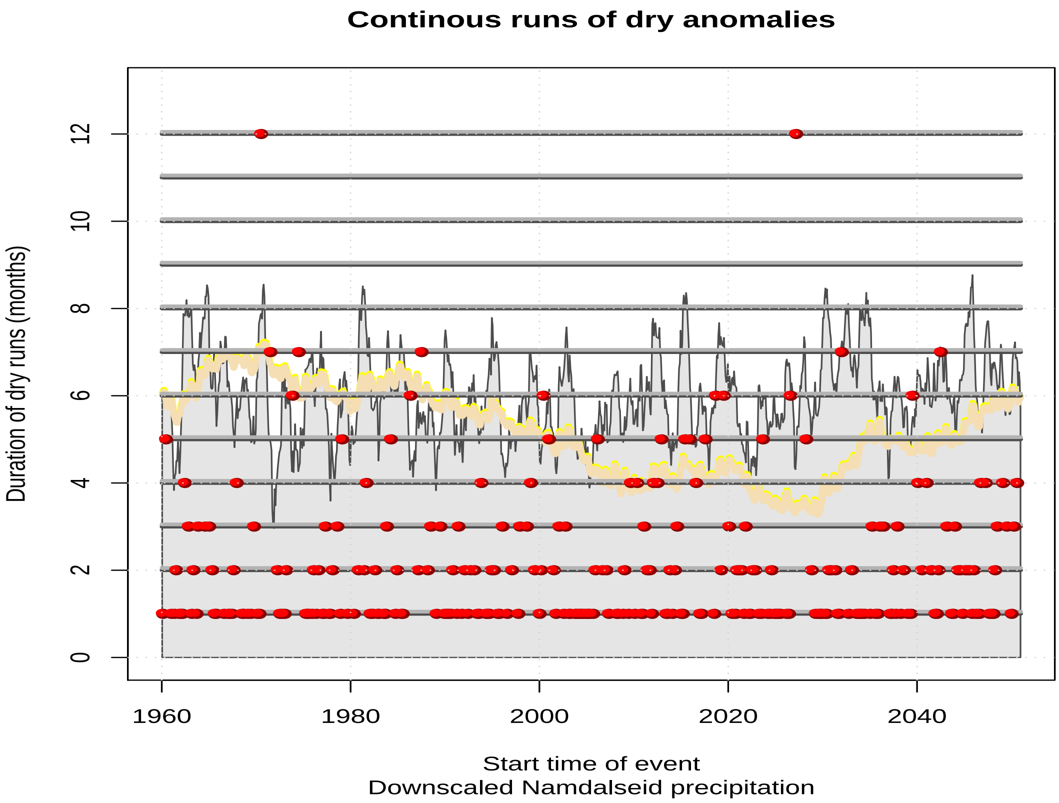

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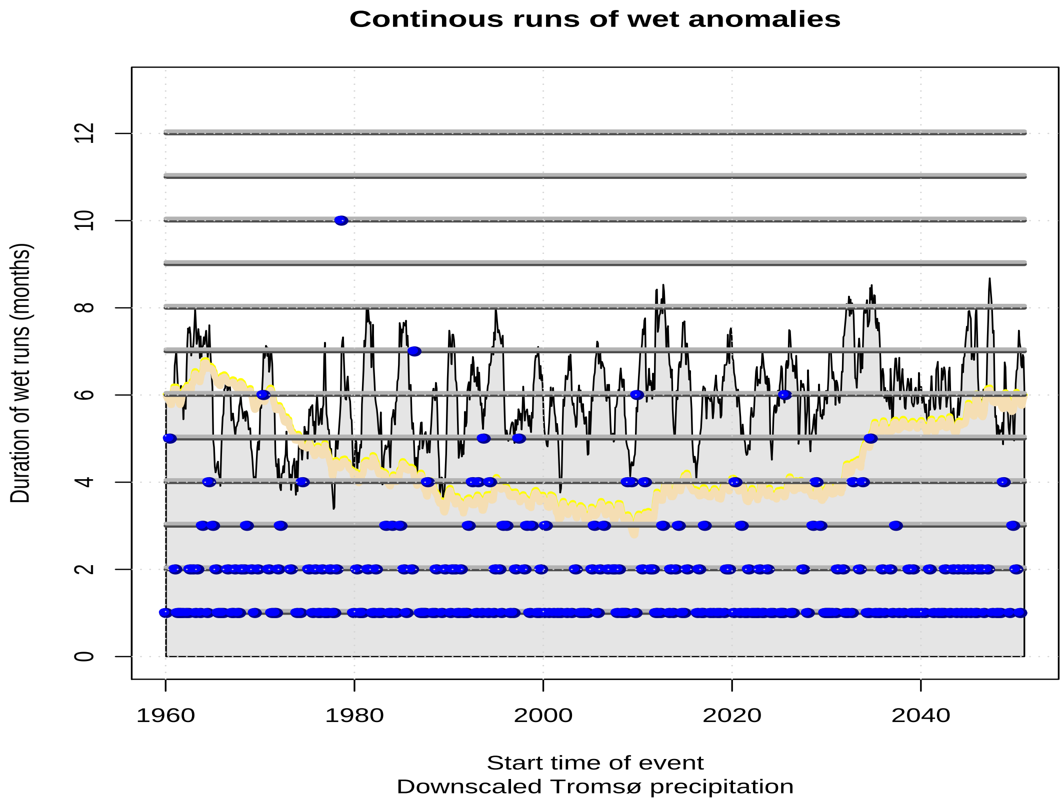
Figure 14. The same as Figure 9 but for Namdalseid.



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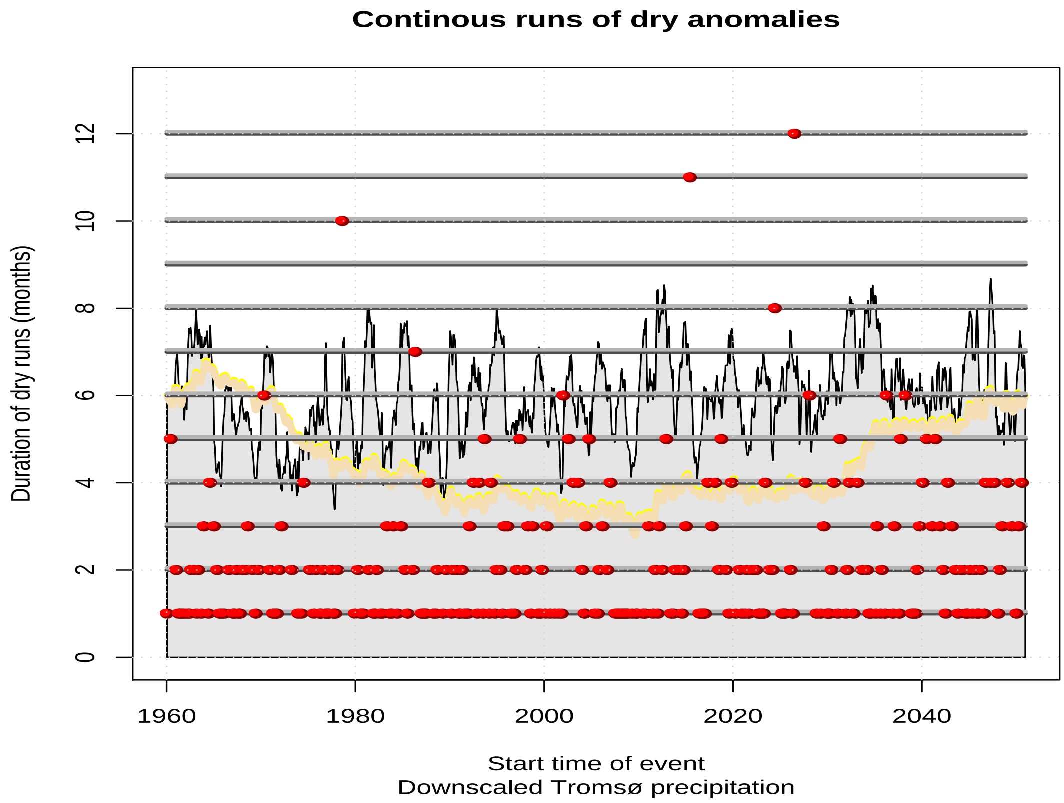

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Figure 15. The same as Figure 9 but for Tromsø.

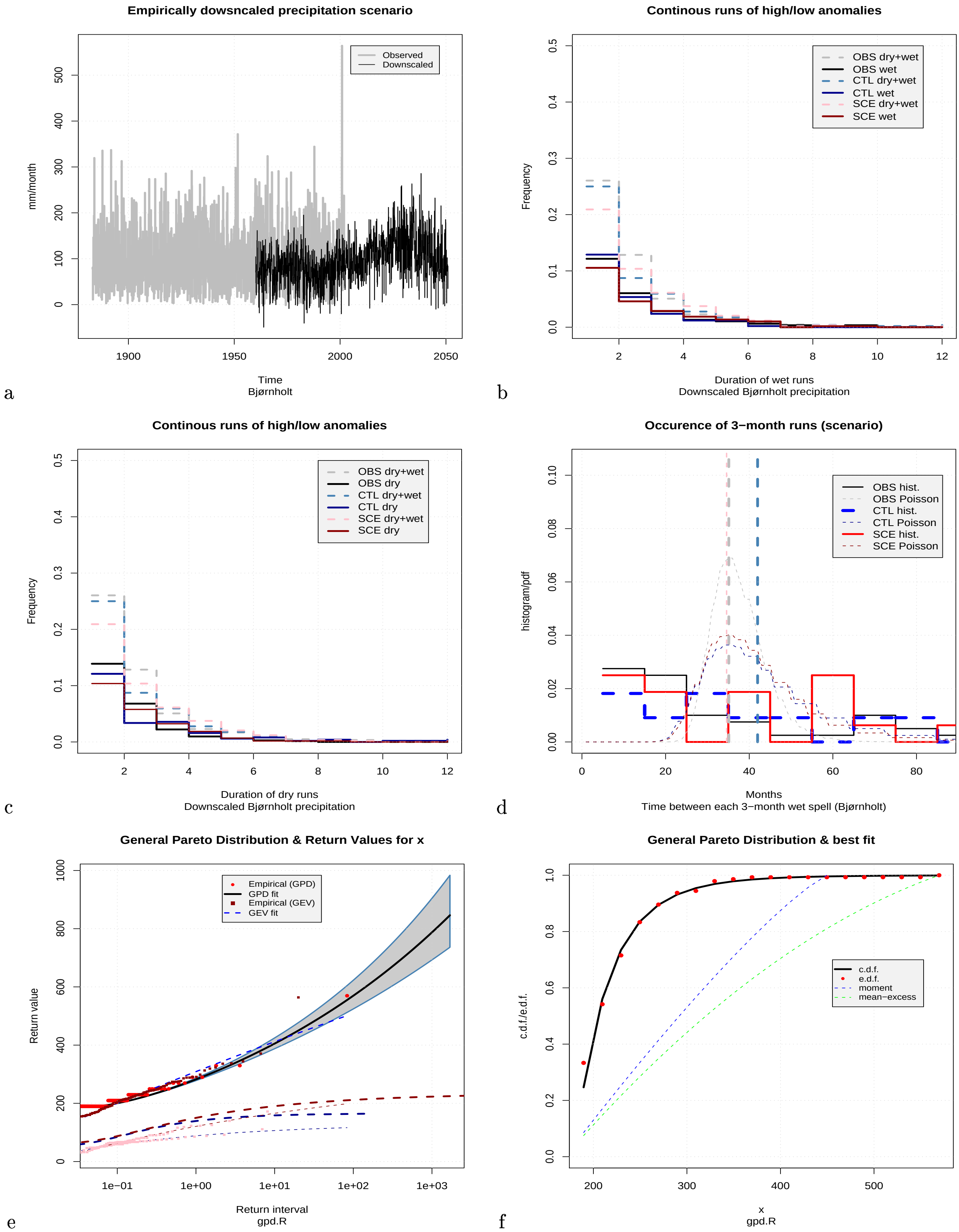

Figure 16. Bjørnholt: (a) the observed and downscaled monthly precipitation; (b–c) frequency distribution of the wet and dry anomalies with respect to their duration; (d) frequency distribution of the inter-event time intervals for the 3-month wet anomalies; (e) return value analysis showing the results for both GPD (thick curves) and GEV (thin lines); and (f) comparison between empirical distribution function (edf) and fitted cumulative distribution function.

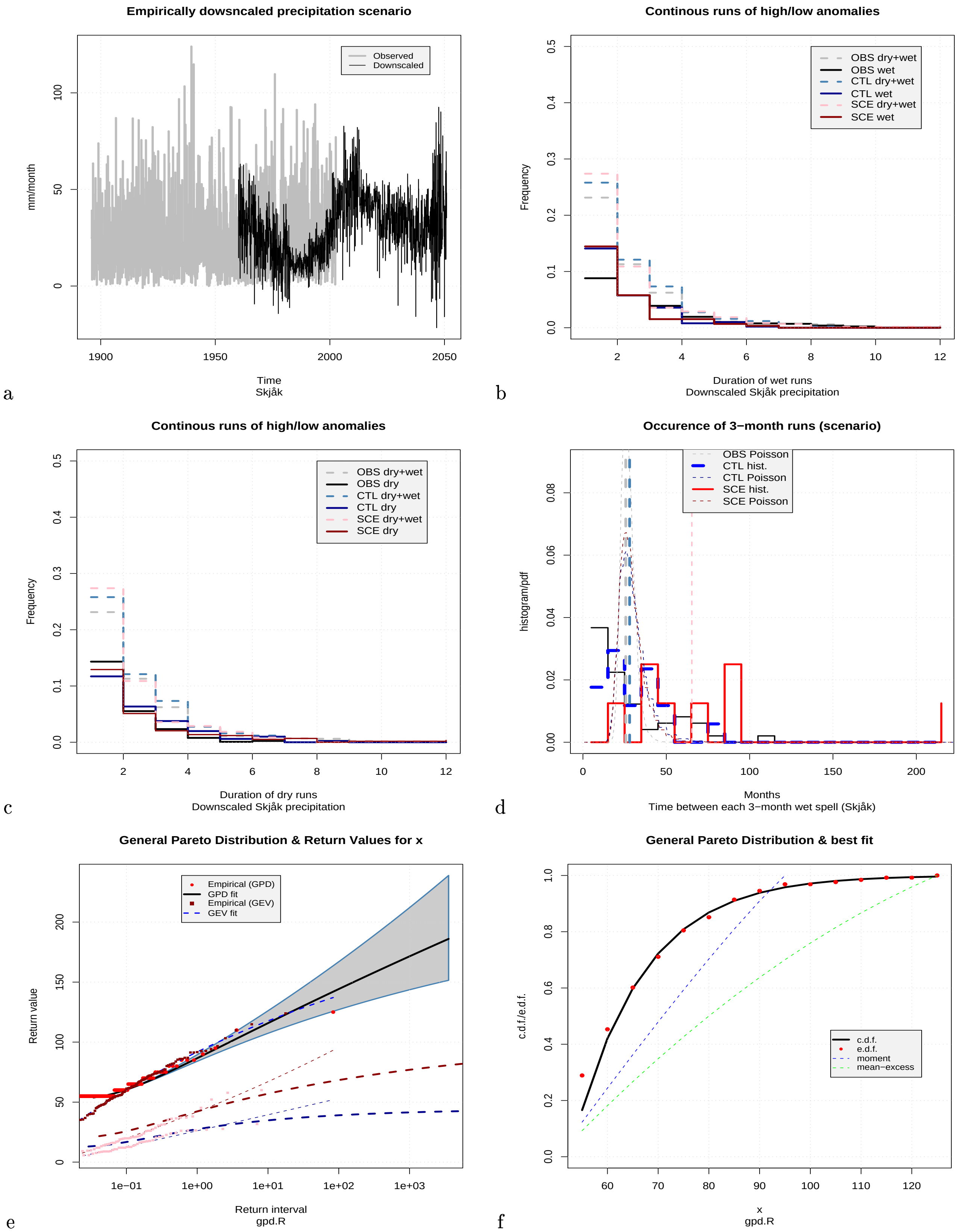

Figure 17. Same as Figure 16, but for Skjåk.

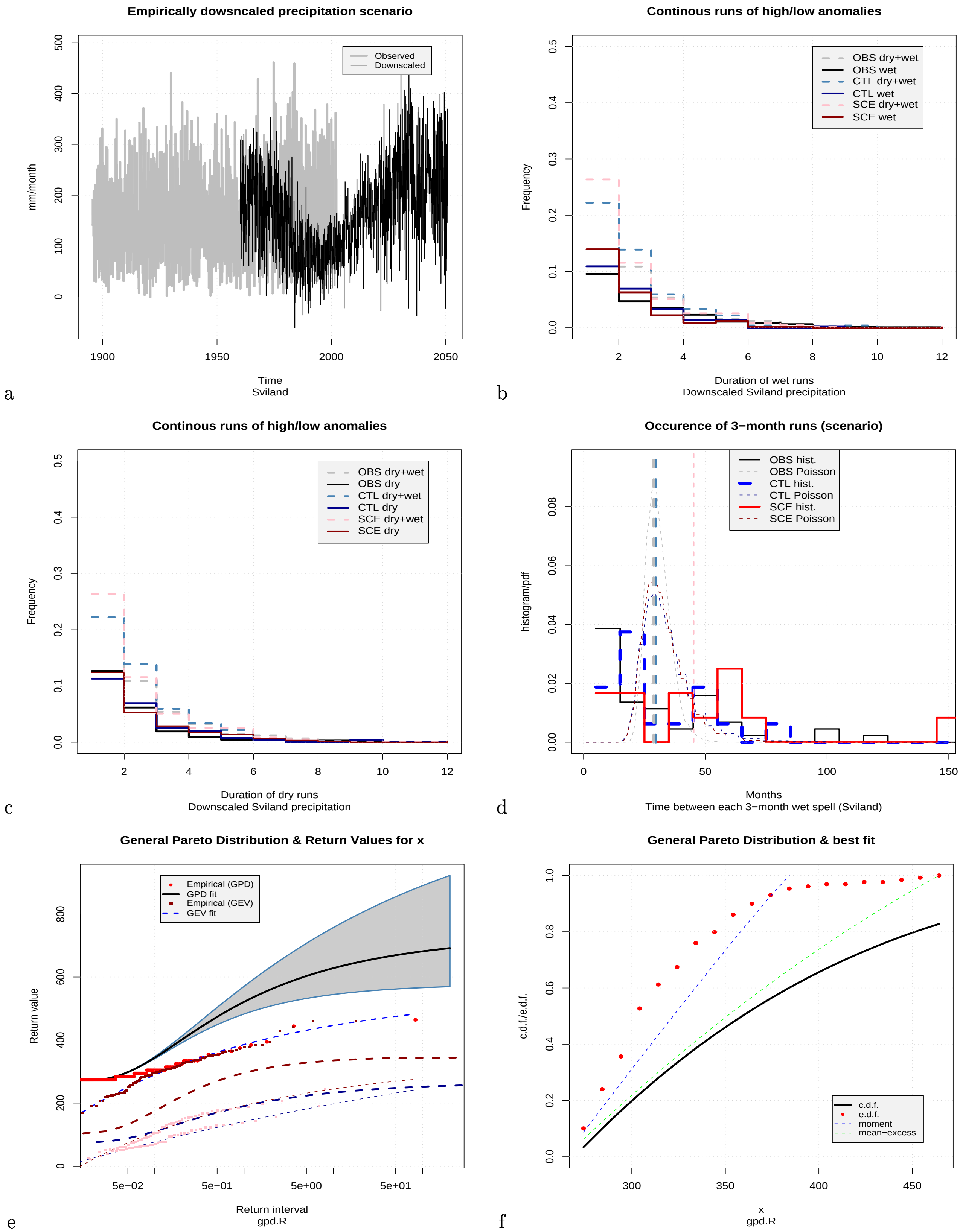

Figure 18. Same as Figure 16, but for Sviland.

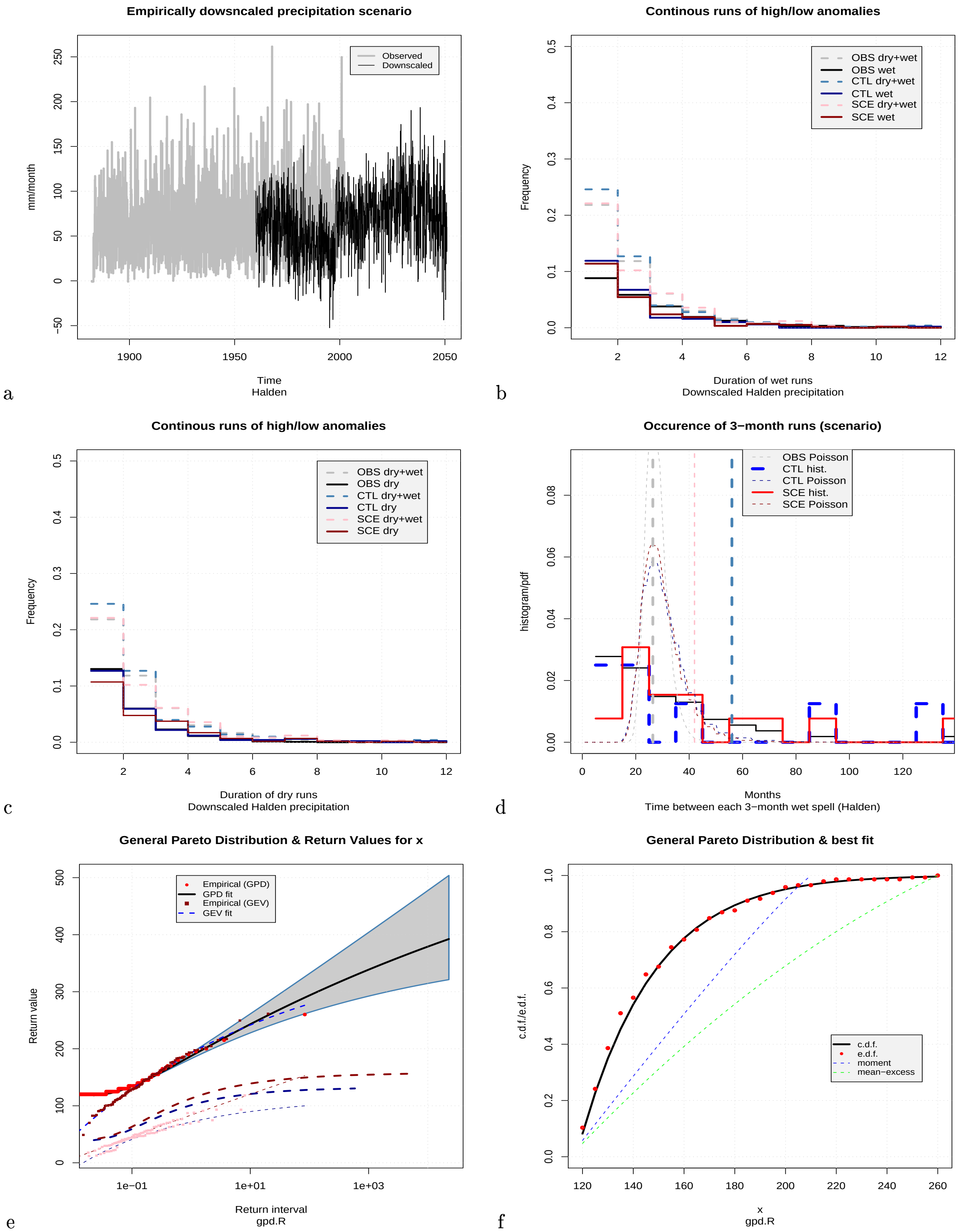

Figure 19. Same as Figure 16, but for Halden.

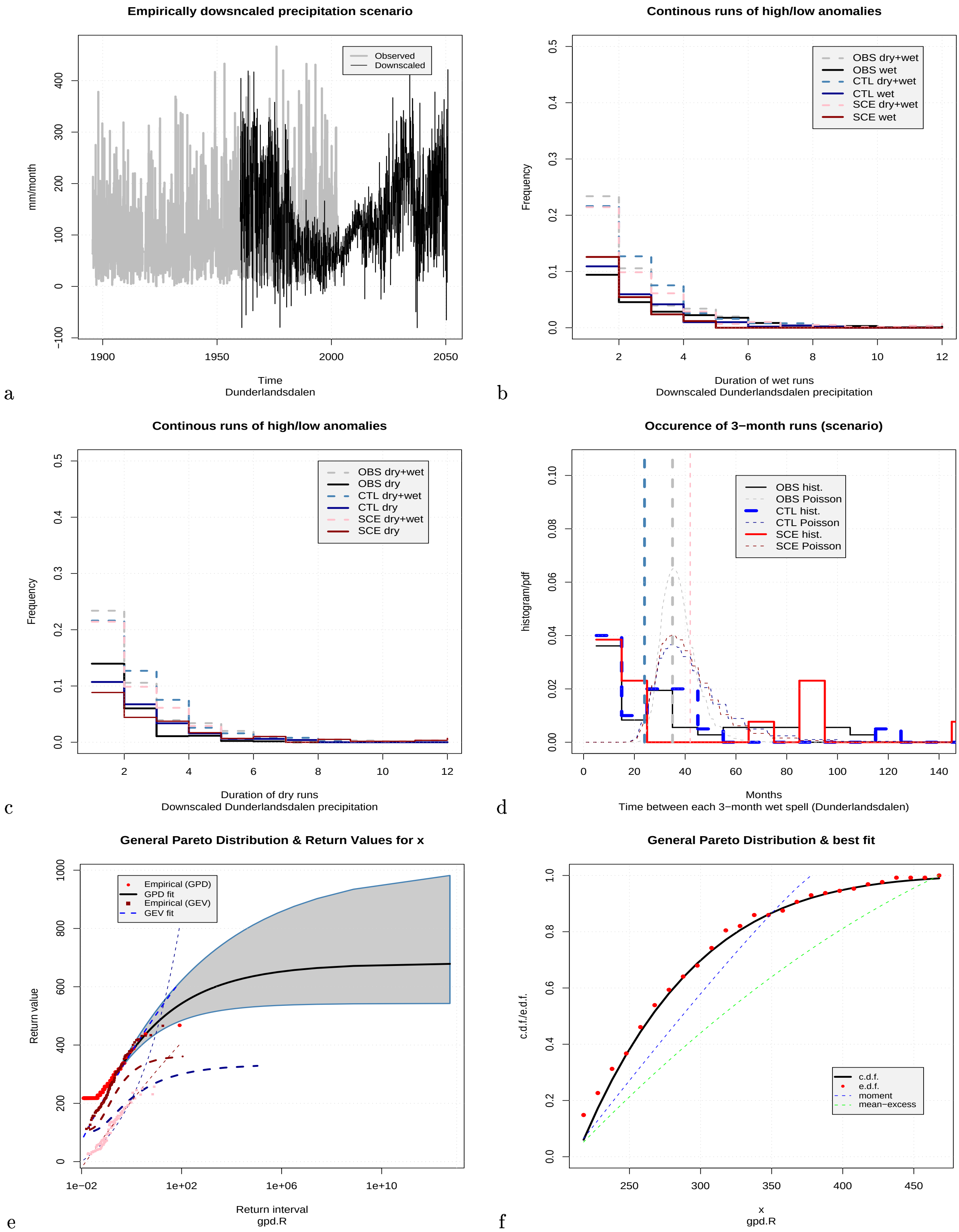

Figure 20. Same as Figure 16, but for Dunderlandsdalen.

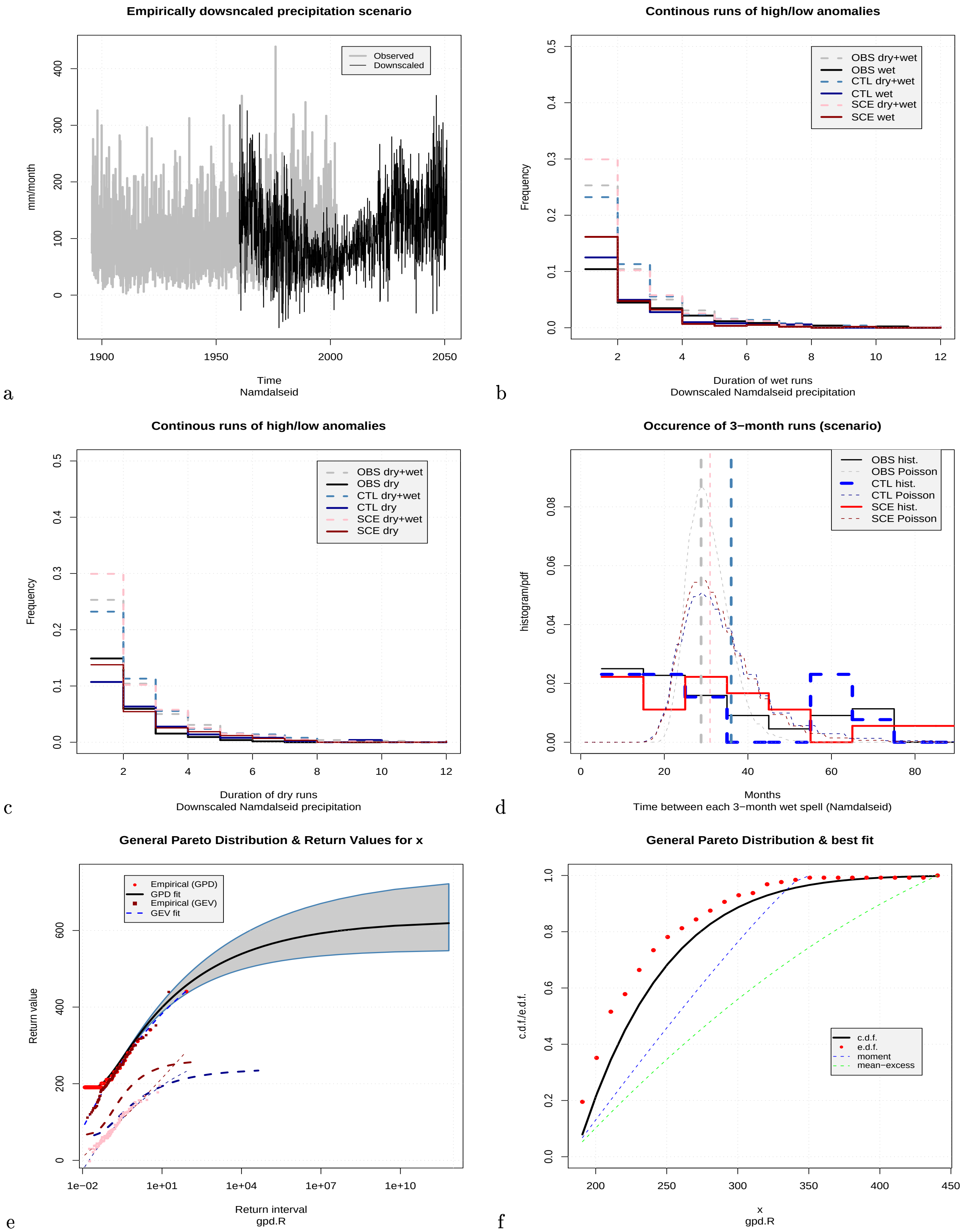

Figure 21. Same as Figure 16, but for Namdalseid.

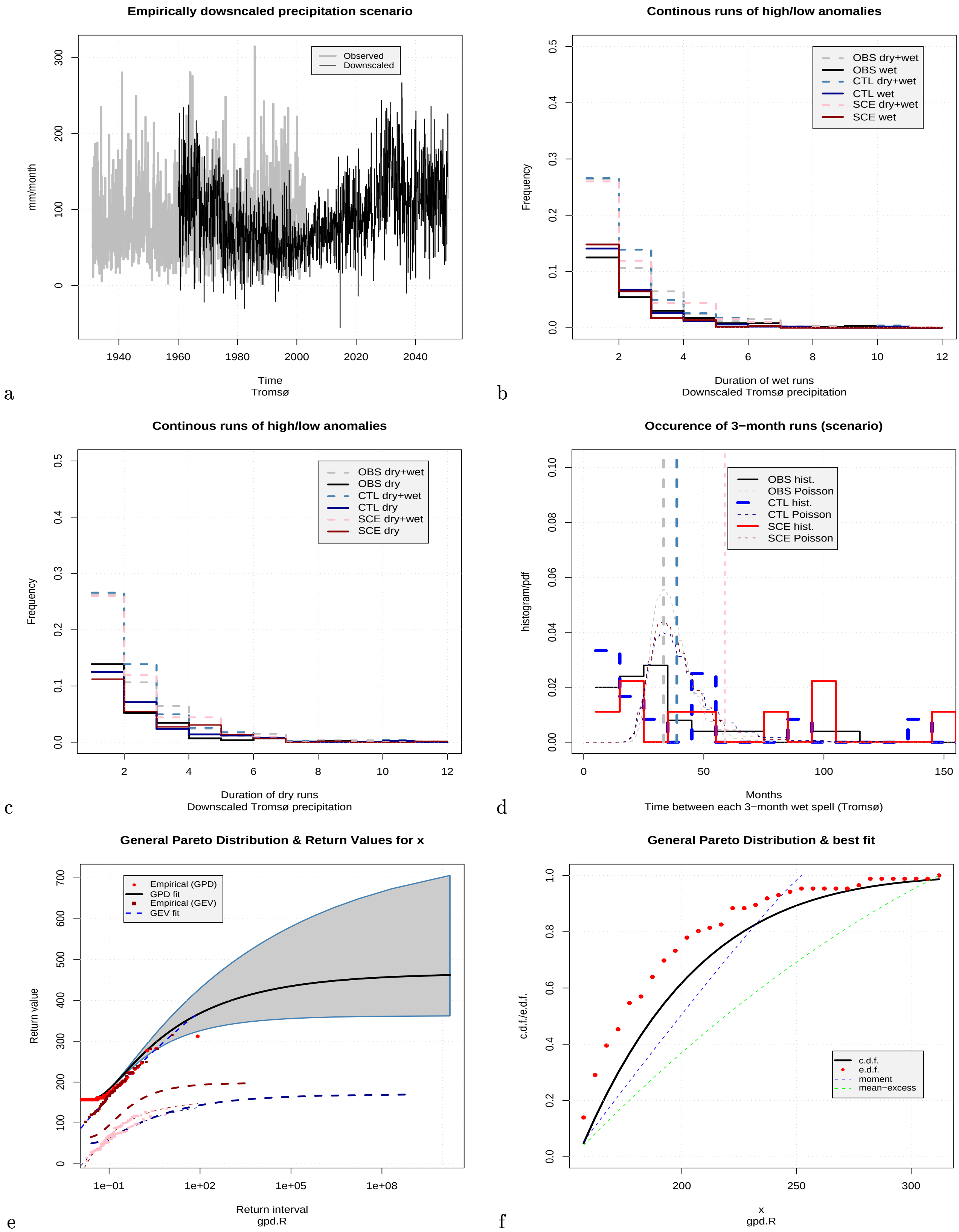

Figure 22. Same as Figure 16, but for Tromsø.

4 Discussion & Conclusions

The apparently longer durations of the longest wet runs cannot be explained in terms of a dry bias in the 1961–90 climatological means. The bias does not disappear if the climatological means are computed for the entire data series. This bias is not found in the downscaled scenarios. The arrival time of the long-lasting wet and dry anomalies are non-Poisson. Since the GPD assumes that the occurrence of events follow a Poisson distribution in time, a GPD may not be appropriate for modelling extreme events whose occurrence does not follow a Poisson distribution. It is possible that the timing of these events has a fractal structure.

The analysis does not find any clear long-term trends in the duration of the runs. There is also no clear long-term trends in the duration of the intervals between the events. It is important to keep in mind that the series used in this study may be too short for providing a good definition of long-term trends associated with rare events. There seems to be, however, a clear trend in the extreme values in the scenarios: higher return values at Bjørnholt, Skjåk, Sviland, and Halden, but no such clear trends at Dunderlandsdalen, Namdalseid. The return values analysis was applied to the whole year, and therefore reflects the seasons with the greatest variance (October–November, Table 2). However, the data samples used for fitting to the extreme value distributions are small and hence the uncertainty is high.

Acknowledgments: This work was done under the Norwegian Regional Climate Development under Global Warming (RegClim) programme, and was supported by the Norwegian Research Council (Contract NRC-No. 120656/720) and the Norwegian Meteorological Institute. The analysis was carried out using the R (*Ellner*, 2001; *Gentleman & Ihaka*, 2000) data processing and analysis language, which is freely available over the Internet (URL http://www.R-project.org/).

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