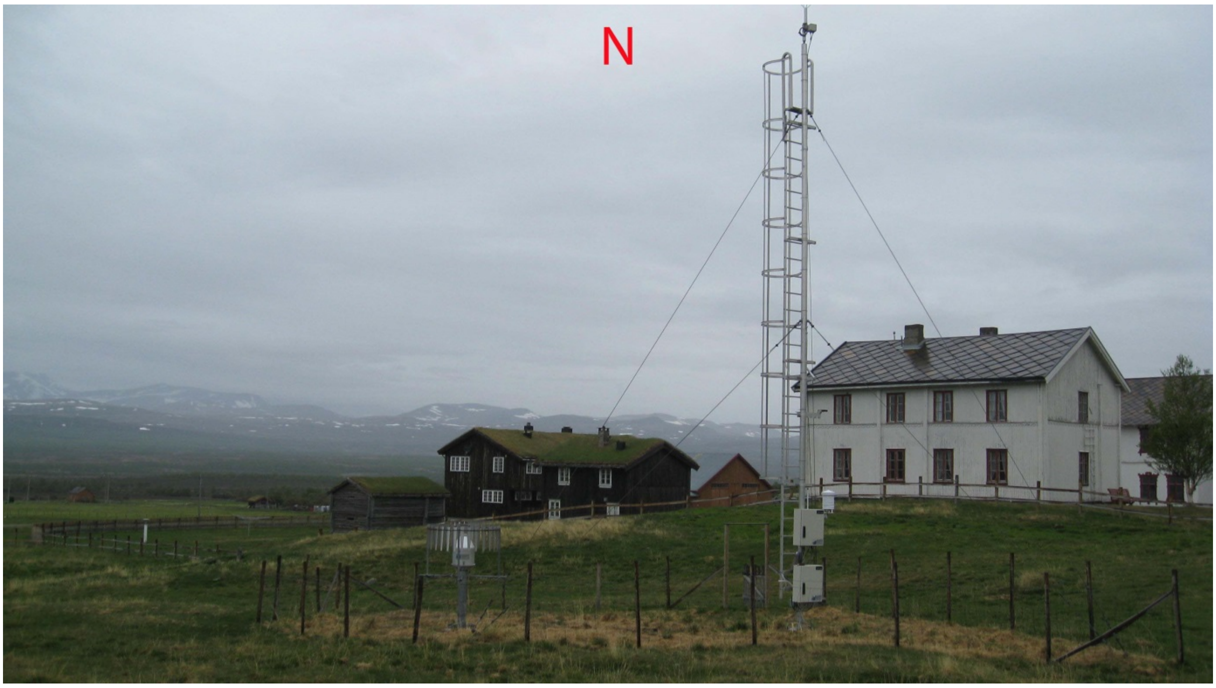
Norwegian Meteorological Institute
*150 years

No. 12/2016
ISSN 2387-4201 Climate

MET report



Homogenization of daily precipitation in Norway

Elin Lundstad

Meteorologisk institutt
Meteorological Institute
Org.no 971274042
post@met.no

Oslo
P.O. Box 43 Blindern
0313 Oslo, Norway
T. +47 22 96 30 00

Bergen
Allégaten 70
5007 Bergen, Norway
T. +47 55 23 66 00

Tromsø
P.O. Box 6314, Langnes
9293 Tromsø, Norway
T. +47 77 62 13 00

www.met.no

Abstract

Title Homogenisation of daily precipitation in Norway	Date 2016-05-31
Section Climate data and spatial analysis section	**Report no.** No. 12/2016
Author(s) Elin Lundstad	**Classification** ● Free ○ Restricted
Client(s) Statkraft	**Client's reference** Gastón Santisteban-Martinez

Abstract

When assessing trends and variability of climatic time series it is necessary to ensure that these only represent a climate signal, and that the series not are influenced by external factors such as station relocations, instrumentation changes and changes in the surroundings. To check this, the series should undergo a homogenization analysis, where such inhomogeneities are identified and adjusted. This report presents such an analysis for five Norwegian precipitation series applying three different homogenization software's with different time resolution; HOMER, MASH and RHtests_dlyPrcp. HOMER is applied to detect homogeneity breaks for annually series, while MASH 3.03 is applied to adjust these breaks in monthly time series, and RHtests_dlyPrcp is applied to adjust these breaks in daily time series.

Five precipitation series representing different energy consumption regions in Norway are successfully homogenized; Fokstua, Sauda, Takle, Mo i Rana and Bardufoss. The study show that HOMER, MASH 3.03 and RHtests_dlyPrcp are strong tools and well suited for such analyses. The three different methods show both agreements and differences in the results. Much of the differences lay in challenges with raw data, E.g. Mo i Rana.

Keywords

Daily Homogenization, Homer, MASH 3.03, RHtests_dlyPrcp, homogeneity

Disiplinary signature

Responsible signature

Table of contents

Innhold

1 - Introduction

Homogeneous time series of weather elements are essential for studies of climatic fluctuations and changes. When analysing trends and variability of climatic time series will the accuracy and consistency of the underlying observations be of extreme importance. A homogenous representation of climate only exists when variations in the time series are only results of variations in weather and climate (Easterling et al, 1996). Changes in the technical and/or environmental conditions such as relocations, change in instruments and sensors, change of observers, change of observing practices, new buildings etc. at observation stations might seriously affect the measurements in such a way that sudden shifts (homogeneity breaks) in the time series will be introduced. Other conditions such as land use changes, urban development and changes in vegetation and built environment introduce trends in the time series that might deviate from the regional climate characteristics. Analysing and correcting for such external influences to achieve homogeneous climatic time series is therefore necessary before making an assessment of climatic change.

This report presents the results for homogeneity analyses of daily precipitation series for five locations in Norway having different measurement challenges: This study is a part of the MIST-2 project, which is collaboration between Statkraft and MET. The aim of this study is to develop adjustment/homogenization procedures to use daily resolution data to generate high quality time series of precipitation.

Hydrological department at Statkraft delivers hydrological and meteorological forecasts on long and short term for operational use and hydrological analyses for investment and rehabilitation purposes. Long series of reliable precipitation and temperature records are essential for hydrological modelling and climate changes monitoring. Time series inhomogeneities may hide the true climatic signal and patterns, and thus potentially bias the conclusions of climate and hydrological analysis and forecast. Consistent and homogenous historical data will thus provide a better background for energy management and production optimization.

The homogeneity if climatological time series have traditionally been analysed on annual, seasonal and occasionally on monthly data. Such analyses have been a focus by climatologists in particularly the last two-three decades (Peterson et al, 1998, Venema 2012). The analyses usually take a *relative homogenization approach* assuming that neighbouring stations are exposed to the same climate signal and thus differences between such stations can be used to detect inhomogeneities, e.g. by using the well-known double-mass principle plotting the cumulative sum of the candidate series with one or more accumulated neighbouring series (Buishand, 1982).

Identification and adjustment of inhomogeneities in daily precipitation data sets have been carried out in some countries in the world using a very different approach (Mekis and Hogg, 1999). It is done little so far in Europe. There has been some theory and application development (Szentimrey, 2014 & Mestre et al, 2011 & Della-Marta and Wanner, 2006), but no analysis or completed studies with good results. It is only in Canada and the United States it has been systematized and operationalized (Vincent, 2002; Easterling et al, 1996 and Wang, 2010).

From Canada, we know that the method has not been completely reliable because the number of neighboring stations has been inadequately combined with the local characteristics of precipitation. The method employed for precipitation do not rely on the availability of neighbour stations, but rather use the station history files for identifying the precise dates for known instrument changes. This method removes discontinuities resulting from network-wide or systematic changes but not individual station discontinuities caused by local site alterations (Peterson et. al., 1998). Work continues on the expansion of the Canadian adjusted daily precipitation database. The research environment around Lucie A. Vincent, from the Climate Research Branch, Meteorological Service of Canada, has done more work on this topic (Vincent, 2002 & 2005). We apply a later developed Canadian method, Rhtest, (Wang et al, 2010) in this study.

Homogenisation of precipitation in Norway

In Scandinavia large achievements was done in terms of homogenizing Nordic climate series in the 1990'ies, much inspired by the development of the SNHT method (Alexandersson, 1986) at SMHI. Homogenization of precipitation (monthly) is done once in Norway and then with the SNHT tests (Hanssen-Bauer and Førland, 1994).

That study of 165 Norwegian precipitation series showed that 70% of the series were inhomogeneous (ibid). The most frequent reasons for inhomogeneities in Norwegian precipitation series were relocation of the gauges (47%), changes in buildings and vegetation in the environments of the gauges (18%), and installation of windshields (9%,). Changes in the gauge's height above the ground are usually so small that they have little effect on the measurements, except in areas with much drifting snow. New observer is given as a reason (3 %) of the inhomogeneities. Figure 1 shows the reason or breaks in the homogenization analysis by Hanssen-Bauer and Førland (1994).

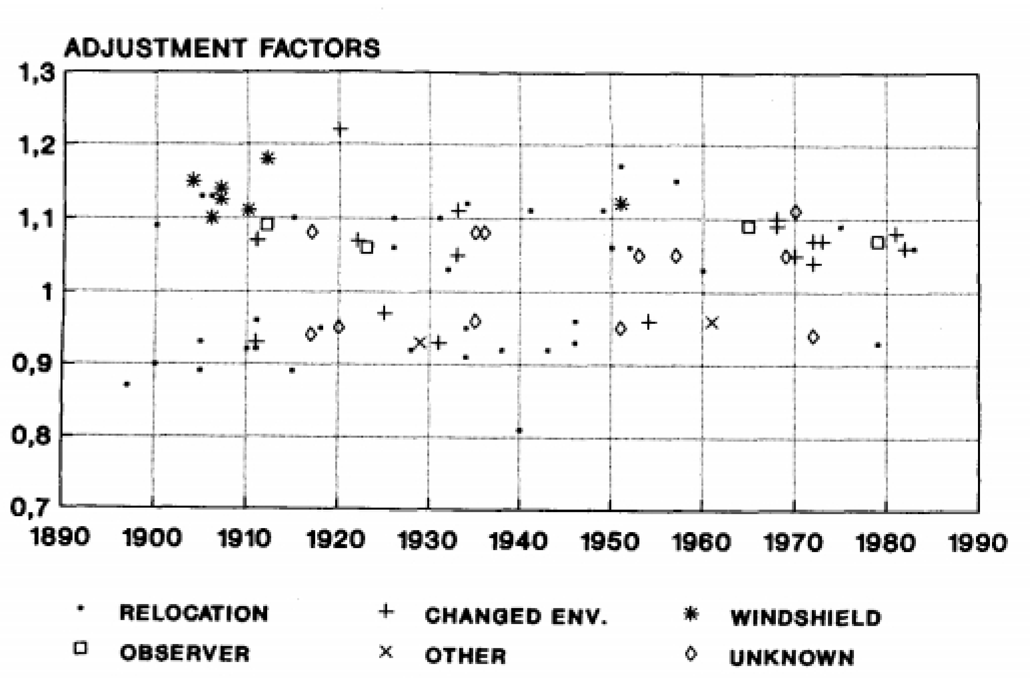


Figure 1: Adjustment factors plotted against time for 79 inhomogeneities (Hanssen-Bauer and Førland, 1994).

This analysis was done more than 20 years ago and since then the precipitation observation network has undergone large changes with respect to both network design and developments in precipitation measurement technology. The largest change has been the automation and the reduction in number of stations from ~>700 -> ~530. The automation started in the late 80s, but really took momentum in the 90s leading to changes in the Norwegian Meteorological precipitation gauge network. The development are not yet completed, but much has been done and now there are relatively few manual precipitation gauge stations (<300) left. This must be seen in relation to the change in society, e.g. what was previously carried out by people on small farms at remote places in Norway is now done by automatic data loggers. Figure 2 shows a photo from a typical precipitation station in the last century. The observer and his daughter beside the precipitation gauge at the farm Selseng in Sogn (in Western Norway). The number of such small farms is rapidly decreasing, and many of them are no longer having permanent residents. (This station is later used in this analysis below Takle network: 55730 Sogndal-Selseng.)

Figure 2: An old Norwegian precipitation gauge with the observers (Station Selseng, 1939).

When a precipitation gauge is installed today, it is common to use an automatic rain gauge, like the Geonor gauge (fig. 3) and preferably on public area with access to electricity. There have been more than 1200 rain gauges in Norway (1896-1990), which the Norwegian Meteorological Institute (MET) has been responsible for.

It is always usual for the precipitation measurements to be underestimated due to wind effects, wetting and evaporation losses (Mekis & Vincent, 2007). It is a scientifically proven truth. That scientific debate we will not go into in this report.


Figure 3: Geonor precipitation gauge.

As a part of the international effort to provide homogenous climate data series will the Norwegian Meteorological institute continue to test and adapt tools for homogeneity analysis of climate time series on different time resolutions. This report describes an analysis testing a method for homogenization of daily precipitation. It is continuation of a similar report about daily homogenization of temperature in MIST-2-project (Lundstad & Tveito, 2016). That previous report presented a complete homogenization procedure for daily temperature series based on the break detection method SPLIDHOM (Mestre et al., 2011).

This report gives an overview of the methods, and the results of applying recommended method at the locations of interest for Statkraft. The report present a complete homogenization procedure for daily precipitation series based on the break detection method RHtestprep (Wang et al., 2012). The first section of the report describes the theoretical history and background. Section 2 briefly reviews the method and procedure for change point detection. Section 3 describes the 5 locations in this study. Section 4 reports the results of the analyses of five homogenized precipitation time series during the period 1930 until 2014 at five locations in Norway. We complete this report with some concluding remarks in section 6. These time series are accessible through the eKlima portal (http://eklima.met.no).

2 - Background

Precipitation is one of the most important climate variables. There are some statistical challenges for homogenization of daily precipitation. Some of them we will look at here:

- The normality assumption is not valid for daily precipitation data.
- Daily precipitation is not a continuous variable. Therefore, the most common approach to modeling daily precipitation has been to use models that describe the occurrence (nonoccurrence) process and to describe the distribution of the nonzero amounts independently (Woolhiser 1992; Katz and Perlange 1993, 1996; Wang and Cho 1997; among others). In a data homogenization context, the precipitation occurrence process can be represented by the frequency of precipitation occurrence (or nonoccurrence).
- The precipitation parameter has the extremely high spatial variability and the non-continuity of daily precipitation can make it unrealistic to find a suitable reference series for use in homogenization of daily precipitation series.

For precipitation, both seasonal and annual test results are used in addition to the metadata, to state if and when there is an inhomogeneity. The noise level is larger for monthly and seasonal testing; therefore, many inhomogeneities are easier to detect using annual values. As with temperature, the adjustment values for precipitation may vary throughout the year (Hanssen-Bauer *et al*., 1994; Hanssen-Bauer *et al*., 1996). In Norway there are three major reasons for such variability: (i) the effect of inhomogeneities on rain and snow is quite different (Førland *et al*., 1996). For example, a change in wind speed of 1.0 m/s implies a change in gauge catch of 10% for snow, but has a small effect on catch efficiency for rainfall (Førland, 1994). Thus, changes in the environment around the gauge will lead to different adjustment factors for rain and snow; (ii) in mountainous areas, the orographic enhancement varies substantially throughout the year. Accordingly, the adjustment factor for relocation will be different for different seasons. (iii) Finally, in areas where drifting snow is a serious problem, the effect of relocation on the catch efficiency of snow and rain may even be opposite (Nordli *et al*., 1996). Precipitation measurements exhibit large cold season biases due to under-catch in windy conditions. These uncertainties affect water balance calculations, snowpack monitoring and calibration of remote sensing algorithms and land surface models. More accurate data would improve the ability to predict future changes in water resources and mountain hazards in snow-dominated regions (Wolff et al., 2014). Currently a very few statistical methods for homogenization of daily climate data for temperature and precipitation are available. Homogenization methods on a daily basis are scarce and often disregard uncertainties accompanying the break adjustment.

Identification and adjustment of inhomogeneities in daily precipitation data sets have been carried out in some countries in the world using a very different approach (Mekis and Hogg, 1999). It is only in Canada and the United States it has been systematized and operationalized (Easterling, 1996, Vincent, 1998 and Wang, 2008). In the mid-1990s, the first generation *Adjusted Precipitation for Canada - Daily (APC1-Daily)* dataset was prepared to provide a more accurate estimate of the precipitation amount and for the analysis of climate trends (Mekis and Hogg, 1999). There are some academic studies in this field from Europe, but actually it is only theoretical method development and there are no results yet (ibid, Mestre et al., 2011 and Szentimrey, 2013).

However, most methods are primarily designed for and applied to annual or monthly time series and mostly only adjust the mean state of the time series. Since many climate research studies are recently focusing on changes in extreme events the need for quality controlled, homogenized data on a sub-monthly scale is steadily growing. For series of monthly or annual relative frequency (i.e., count divided by the total number of observations in the month or year) or a logistic transformation of the count series (Wang, 2006), normality is not a big concern (Wang et al., 2010).

In this study analyses of annual and seasonal values are carried out in addition to the daily homogenization. For the annual analysis, we used HOMER and for the seasonally analysis we used MASHv3.03. These methods are described in detail in the previous report (Lundstad & Tveito, 2016). So we do not go more closely into the methodology of these programs/applications here.

In this study 3 homogenization methods have been applied:

(i) RHtest_prec, developed by Wang & Feng from the Climate Research Division, Atmospheric Science and Technology Directorate, Toronto, Ontario, Canada (published online 2009).

(ii) MASH, (Version MASHv3.03), initially developed in the Hungarian Meteorological Service by *Szentimrey* (1994, 1999, 2013); and,

(iii) HOMER developed in the framework of COST Action ES0601 (Mestre, 2013 & www.homogenisation.org).

3 - Methods and approach

During the last few decades a number of algorithms for testing homogeneity of climate data series have been developed and applied. This chapter gives a detailed descriptions of the methods applied in this study. There are a number of change point detection methods that have been developed (Wang et al. 2007; Wang 2003, 2008a, b; Vincent 1998; Alexandersson 1986). In statistical analysis, change point detection tries to identify times when the probability distribution of a stochastic process or time series changes. In general the problem concerns both detecting whether or not a change has occurred, or whether several changes might have occurred, and identifying the date of such changes. However, most of the commonly used methods assume that the data are normally distributed, and those that do not need the normality assumption, such as nonparametric methods (see Reeves et al. 2007) or empirical likelihood-based methods, are at most comparable with a method based on normality assumption if the data can be transformed to approximate a normal distribution well. However, the normality assumption is invalid for daily precipitation data, which is one of the most important climate variables. Apart from its departure from normality, daily precipitation is not a continuous variable. Therefore, the most common approach to modeling daily precipitation has been to use models that describe the occurrence (nonoccurrence) process and to describe the distribution of the nonzero amounts independently (Woolhiser 1992; Katz and Perlange 1993, 1996; Wang and Cho 1997; among others).

This method removes discontinuities resulting from network-wide or systematic changes but not individual station discontinuities caused by local site alterations. Daily rainfall and snowfall are therefore adjusted specifically for inhomogeneities caused by precipitation gauge changes and by changes in observing procedures. These absolute inhomogeneities typically occur in the data series of most stations in a region at roughly the same time, and can usually be verified through the station history files. Precipitation data sets have been assessed and adjusted for 5 Norwegians stations which are relatively evenly distributed across the country, and which cover the period 1930–2015 as much as possible.

For homogenization of daily precipitation data series, it is essential to model the occurrence process and the nonzero amounts separately. Otherwise, estimates of adjustments needed for nonzero amounts would be biased; in particular, adding an adjustment value to all days, including days of zero precipitation, will make all days of reported zero precipitation disappear from the series or will result in negative daily precipitation amounts.

The method is applicable to other two-phase regression-model settings. This study also proposes methods for adjustment of shifts in nonzero daily precipitation and other series of positive values; one of which can also be used for Gaussian data with slight modification.

The methods that have been applied, based on recommendations of the COST HOME action are HOMER. It is two others methods which is used and that is MASH and RHtests_dlyPrcp.

HomeR

In the period 2007-2011 the COST Action ES0601 HOME (www.homogenisation.org) was devoted to evaluate the performance of homogenization methods used in climatology and produce software that would be a synthesis of the best aspects of some of the most efficient methods. HOMER (HOMogenizaton softwarE in R) is software for homogenizing essential climate variables at monthly and annual time scales.

HOMER has been constructed exploiting the best characteristics of some other state-of-the-art homogenization methods, i.e., PRODIGE, ACMANT, CLIMATOL, and the recently developed joint-segmentation method (*cghseg*). HOMER is based on the methodology of optimal segmentation with dynamic programming, the application of a network-wide two-factor model both for detection and correction, and some new techniques in the coordination of detection processes from multi-annual to monthly scales. HOMER's approach to the final homogenization results is iterative. It is an interactive method that takes advantage of metadata.

Homogenization using HomeR: Homer is better described in the report (MET report 6/2016; Homogenization of daily mean temperature in Norway) HomeR operates only with a correction factor for a year on the precipitation parameter and here we use a multiplicative correction (comp. temperature: Additive correction). Precipitation is a cumulative parameter. The result can e.g. show us an amplitude = -0.13. This means that annually precipitation has decreased by 13%. This is the first step of the homogenization: Annual analyze of the time series for the five selected station. In HomeR we use a candidate station and reference stations.

MASH v3.03

The MASH method was developed in the Hungarian Meteorological Service (see References). The MASH procedure was developed originally for homogenization of monthly series. It is a relative method and depending on the distribution of examined meteorological element additive (e.g. temperature) or multiplicative (e.g. precipitation) model can be applied. In the earlier program system MASHv2.03 the following subjects were elaborated for monthly series: series comparison, break point (change-point) and outlier detection, correction of series, missing data complementing, automatic usage of meta data and last but not least a verification procedure to evaluate the homogenization results.

It is a relative homogeneity test procedure that does not assume the reference series are homogeneous. Possible break points and shifts can be detected and adjusted through mutual comparisons of series within the same climatic area. The candidate series is chosen from the available time series and the remaining series are considered as reference series. The role of series changes step by step in the course of the procedure. Depending on the climatic elements, additive or multiplicative models are applied (Szentimrey, 2014). In this survey, MASH v3.03 is used to the homogenization of seasonal and monthly data series and hence in order to compare results with the annual and the daily homogenization.

RHtests_dlyPrcp

The RHtests_dlyPrcp software package is specifically designed for homogenization of daily precipitation data time series. The program is developed by Xiaolan L. Wang and Yang Feng from the Climate Research Division, Atmospheric Science and Technology Directorate Science and Technology Branch, Environment Canada inToronto, Ontario, Canada (Wang et al., 2010). They belong to a second generation of Canadian working with homogenization, continuing the work of Lucie Vincent. They have developed the new technique for the detection and adjustment of shifts in daily precipitation. In addition, to making the RHtests_dlyPrcp software package, they have made 5 versions of the similar software for homogenization of temperature on monthly or annual solution: RHtestsV1-5. With pioner applications by Solow (1987) and Peterson and Easterling (1995) and reformulated by Lund and Reeves (2002).

It is essential for homogenization of daily precipitation data series to test the nonzero precipitation amount series and the frequency series of precipitation occurrence (or nonoccurrence), separately. The transPMFred algorithm is used to test the series of nonzero daily precipitation (which are non-Gaussian and positive), and the existing PMFred algorithm can be used to test the frequency series. The software package RHtests_dlyPrcp that contains a set of functions for use in detection and adjustment of shifts in nonzero daily precipitation amounts has been developed and has been made available online (http://cccma.seos.uvic.ca/ETCCDMI/software.shtml).

It works as follows (Wang et al., 2010):

1. The main idea of the proposed change point detection procedure is to first seek an appropriate transformation, the assumptions of normality, constant variance, single change point, and piecewise linearity. The change point detection is then performed on the transformed data. λ is called a transformation parameter.

2. When one or more of the identified change points is determined to be insignificant and hence is deleted from the list of change points, the best λ value for the series with the new list of change points being accounted for is sought; then, the statistical significance of the retained change points is re-estimated using the new transformed series (with the new best λ value).

3. After identifying all significant change points, we now wish to adjust the precipitation data series to diminish all significant artificial shifts (i.e., to homogenize the precipitation data series). However, homogenization of daily precipitation series is a very challenging task. This includes an iterative procedure to detect multiple breakpoints and the new statistics account for important aspects as serial autocorrelation. Because nonzero daily precipitation data are positive and typically highly skewed, we recommend using the Box–Cox power transformation (Box and Cox 1964), which is defined as follows: For a response $Y_i > 0_i$

$$h(Y_i * \lambda) = \begin{cases} Y\frac{\lambda}{i} - 1/\lambda & \lambda \neq 0 \\ \log Y\, i & \lambda = 0 \end{cases}$$

The Box-Cox transformation is necessary, because daily precipitation amounts are not normally distributed. Since daily precipitation is highly variable both spatially and temporally (it could be raining in this side of the street, but not the other side), it is hardly possible to find a suitable reference series (except in the case of parallel measurements). Thus, this software does not use any reference series. Since daily precipitation is not a continuous process, discontinuities in the occurrence frequency of precipitation might exist and should be dealt with first to avoid complicating the homogenization of daily precipitation data time series.

The Box–Cox power transformation procedure is integrated into the PMFred algorithm (which is based on the common trend two-phase regression model) to make it applicable for detecting change points in non-Gaussian data series, such as nonzero daily precipitation amounts or wind speeds or dew point depression data (which are all nonnegative and non-Gaussian).

This is a useful data transformation technique used to stabilize variance, make the data more normal distribution-like, and improve the validity of measures of association such as the Pearson correlation between variables and for other data stabilization procedures. The transformation procedure is also applicable to the two-phase regression model that allows the trend to change at the time of mean shift (Lund and Reeves 2002).

4 - Locations and networks

The procedure for homogeneity testing followed the relative principle of comparing a candidate series (the series to be tested) against reference series. Traditionally the reference might be series from one or more neighbouring stations. This is done for the annual and seasonal homogeneity analysis. This chapter describes the data; metadata and the locations of the daily precipitation series analysed in this study. Subsequent paragraphs will describe more about the candidate station, especially for the daily homogenization. The main homogenization procedure is to find the breaks in the time series (section 4).

Statkraft and the Norwegian Meteorological institute have jointly selected 5 different stations which are measuring precipitation. The choice of meteorological stations used in this analysis is based on that it is qualitatively good and technical interesting stations and the use of long time series which is representative for Statkraft's energy production needs. E.g. Fokstua has very useful meteorological observations for the water power industry. The station has also been moved a few times (a few meter sometimes or 1 km another time) and the weather are changing fast here: Rain, not rain or snow? It is useful for both to have a homogeneous precipitation time series here. In this report we have selected one meteorological station in the analysis from each geographical region in Norway. The selected meteorological stations are listed in table 1, and their locations are shown as red squares in figure 4.

As HOMER and MASH depends on a network of highly correlated neighbor time series representing the same climatological features reference networks for each candidate station are established. The networks used in HOMER and MASH will be presented later in the chapter. The application used to the daily homogenization; RHtests_dlyPrcp, do not use network (only the one candidate station) for the homogenization analysis.

Precipitation is an irregular parameter. Occasionally it may be the best to look at seasonal and trend components in the precipitation series. Short term fluctuations in the series which are neither systematic nor predictable may be present. In a highly irregular series, these fluctuations can dominate movements, which will mask the trend and seasonality. In this situation, a multiplicative model is usually appropriate (HOMER & MASH). In many time series, the amplitude of both the seasonal and the irregular variations increase as the level of the trend rises (section 2).

Table 1: List of regions and the candidate precipitation series in the study.

Region	Stnr	Station Name	Time period	Relocations (>100 m)	Breaks	Masl	Municipality
Eastern Mountain Norway	16610	FOKSTUA	1923-2014	1	8	973	Dovre
Southern-Western Norway	46610	SAUDA	1930-2014	1	0	5	Sauda
Western Norway	52860	TAKLE	1950-2014	1	1	38	Gulen
Northern Norway	79480	MO I RANA	1935-2014	3	0	41	Rana
Northern Norway	89350	BARDUFOSS	1946-2014	0	0	76	Målselv

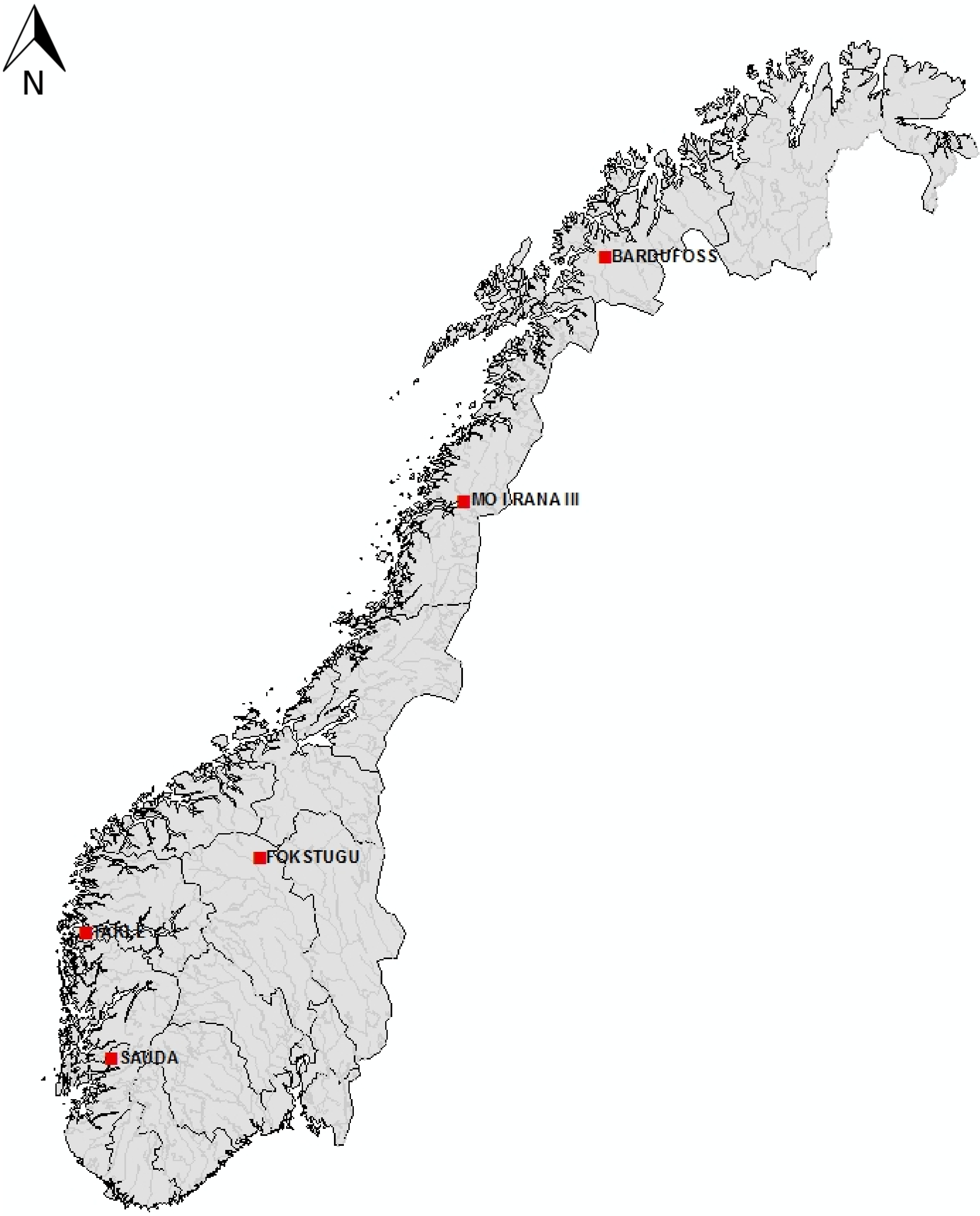


Figure 4: Map of the locations used in this analysis.

I. Fokstua

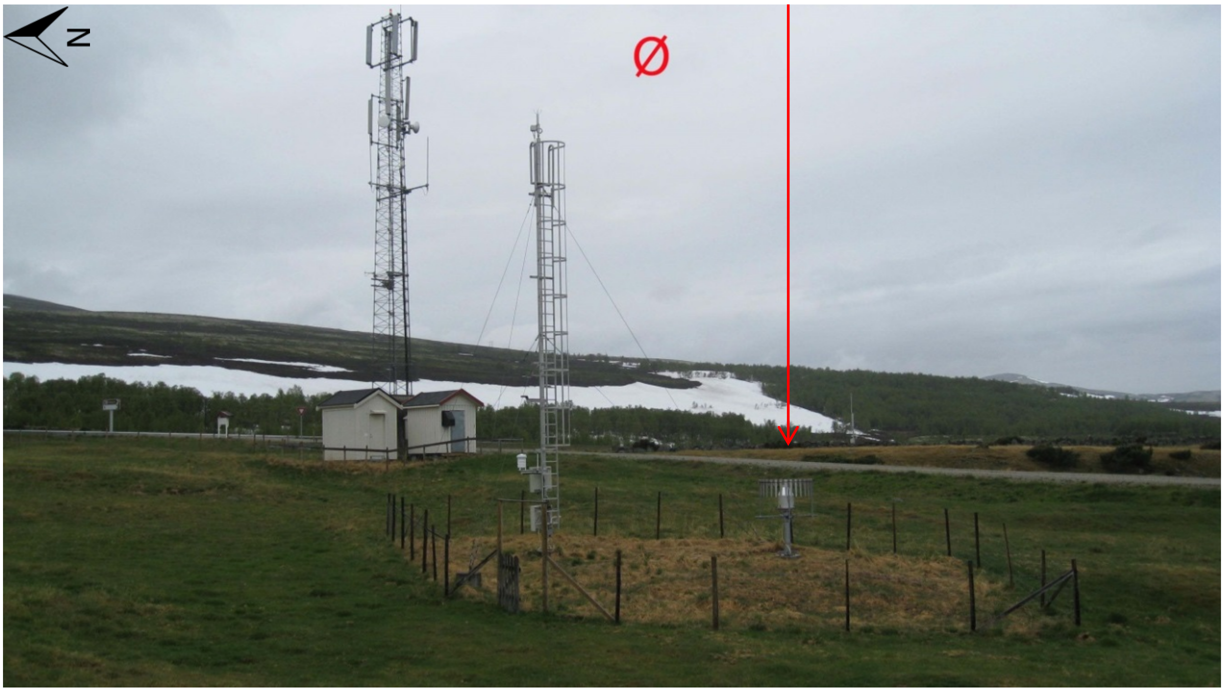


Figure 5: Picture of 16610 Fokstua met station. The geonor T-200 precipitation gauge is marked with the red arrow.

16610 Fokstua

Fokstua (or Fokstugu) station is located at Dovrefjell, between Dombås and Hjerkinn. The station is situated on the eastern side of a large plain, Fokstugumyri, and about 25 m higher than the marsh. On the NW and SE side of Fokstugumyri it is high mountains that reach 400-600 meters over the station level. Dovrefjell is the mountain range in central Norway that forms a natural barrier between Eastern Norway and Trøndelag. The highest mountains are in the NNW direction about 10 km from the station. Snøhetta is the highest mountain at Dovrefjell (2286 masl). As the station is situated in the high mountains, the weather conditions might be rough. The station is exposed to strong winds and drifting snow in the winter season, and this affects the precipitation measurements.

The Fokstua meteorological station is operated by the Norwegian Meteorological institute and started to operate in March 1923. It was relocated in May 1968 about 1 km SE from the railway station. From 1st June 1968: *16610 Fokstua II* started to operate at the current location. Since then the instruments are relocated at the site a couple of times (less than 20 m), e.g. 1980 & 2002, because of the drifting snow in the winter (fig.7). In 2007, the station was renewed (automation). The new station is shown in the photo above (fig. 5).

The map in fig. 6 shows the move <1 km SE of the station in May 1968 from the railway station to the mountain farm. The environment and surroundings are almost the same at the two places. The new station is at 973 m a.s.l (>20 m). There are almost no changes in the nature of these 90 years. It is characterized as a mountainous area with little vegetation (some mountain birch and marsh). The only thing that may have changed over the last 50 years is the road (E6); wider asphalt road and increased traffic on the road is only a few meter from the station (<20 m). It is thus unlikely that traffic affects meteorological measurements.

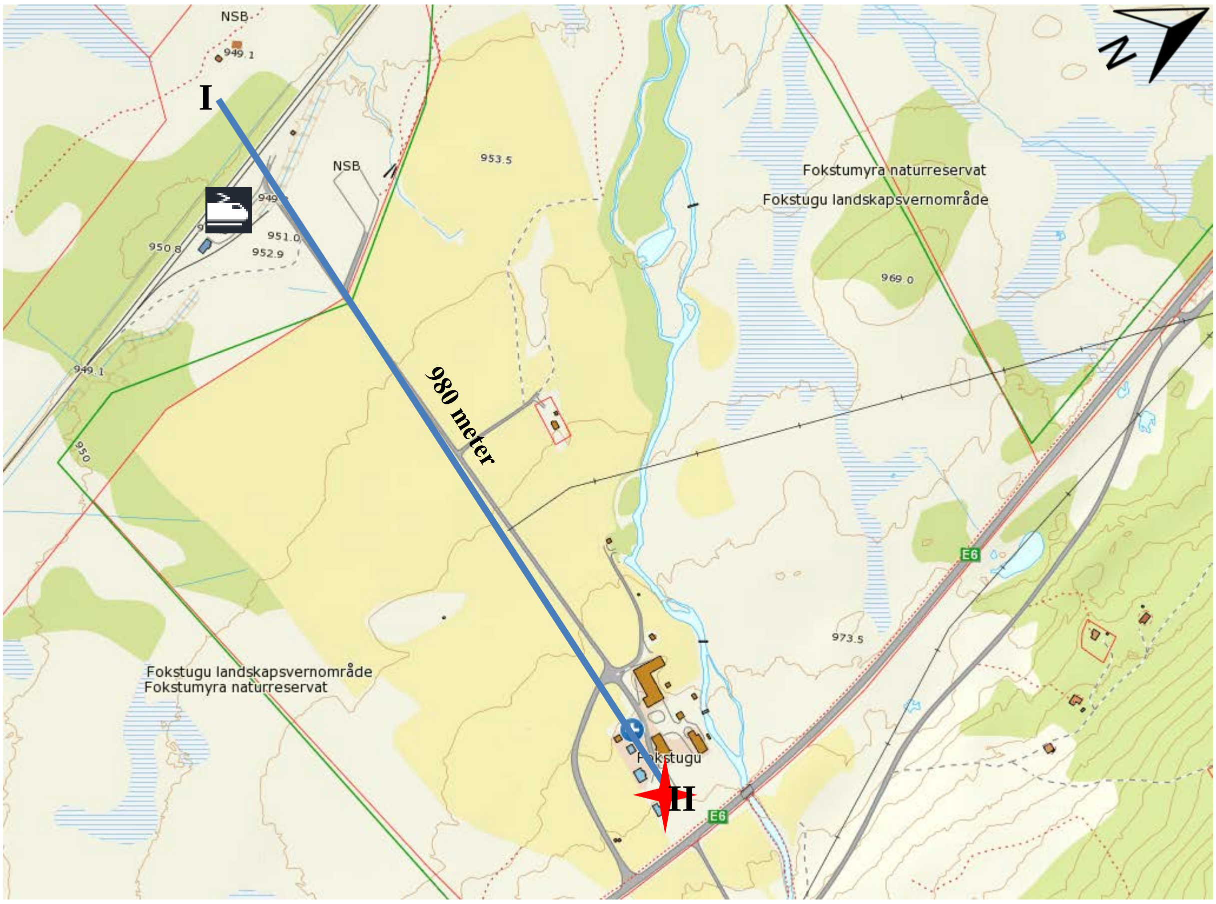


Figure 6: The map shows the relocation in 1968 between the stations Fokstua I & II: Ca 1 km.

Figure 7: Picture of the old instruments at Fokstua II from 1981. The instruments are placed near the house (9 m) between 1968 and 2002.

Fokstua network

The Fokstua network consists of 13 series including the candidate series at Fokstua. Table 2 shows the series in the network, including the original series from which they are merged. The locations of the series are shown in figure 8. The stations are mostly located near the Dovre mountain area and/or down the valleys: Gudbrandsdalen in S, Folldal/Rondane in the E, Vågå area in W and Sunndalsfjella and Sunndal (NW). Table 3 shows the correlation between the series in the network. The stations in the network are not so highly correlated. This is because of the windy weather at Fokstua which influences the precipitation and the weather (wind direction) changing fast in the mountain there. So it may be difficult to replicate that in the network. It is the best stations in the area which is used in the analysis.

Table 2: Series in the Fokstua network (breaks from HOMER).

Analysed series	Name	LAT/LON	MASL	Period	Nr of original series	Breaks	Original series	Time coverage original series
9160	Folldal	62’ 4 36 °E 9’35 48 °N	694	1923-2015	**2**	**1**	9100 Folldal	1.1.1923-1.7.2006
							9160 Folldal-Fredheim	1.1.2011-u.t.
14550	Preststulen	61’ 31 12 °E 9’0 15 °N	823	1950-2015	**1**		14550 Preststulen	1.9.1950-u.t.
14580	Vågåmo	61’31 26 °E 9’3 16 °N	371	1949-2011	**2**		14600 Vågåmo-Klones	1.1.1949-31.12.1976
							1458o Vågåmo-Nordgrind	1.10.1979-31.7.2011
14711	Grov-Solhaug	61’29 17 °E 9’0 28 °N	811	1954-2015	**2**	**1**	14710 Grov	1.9.1950-31.8.1999
							14711 Grov-Solhaug	1.9.1999-u.t.
16240	Tolstadåsen	61’29 39 °E 9’13 48 °N	656	1955-2005	**1**		16240 Tolstadåsen	1.8.1955-30.11.2005
16270	Høvringen	61’ 32 2 °E 9’16 58 °N	935	1972-2015	**2**	**1**	16270 Høvringen	1.6.1972-1.9.2013
							16271 Høvringen II	26.9.2013- u.t.
16560	Dombås	62’2 34°E 9’4 7 °N	638	1923-2015	**4**	**3**	16550 Dombås II	1.1.1923-1.6.1972
							16540 Dombås-Kirkenær	15.6.1972-1.6.1976
							16740 Kjøremsgrende	1.7.1976-31.8.2006
							16560 Dombås-Nordigard	31.8.2006-u.t.
16610	Fokstua	62’4 4 °E 9’10 18°N	973	1923-2015	**2**	**3**	16600 Fokstua	1.3.1923-31.5.1968
							16610 Fokstua II	1.6.1968-u.t.
16790	Lesja	62’3 48 °E 8’33 5 °N	551	1967-2015	**2**		16830 Lesja-Norderhus	1.9.1967-30.4.1971
							16790 Lesja-Svanborg	1.6.1975-u.t.
61550	Verma	62’12 18 °E 8’1 51°N	247	1923-2015	**1**		61550 Verma	1.1.1923-30.4.2009
61630	Bjorli	62’9 18 °E 8’7 11°N	579	1955-2015	**4**	**2**	61770 Lesjaskog N	1.9.1955-31.8.1976
							61770 Lesjaskog VS	1.10.1976-30.11.2000
							61770 Lesjaskog VS II	1.4.2001-31.7.2008
							61630 Bjorli	22.10.2010-u.t.
63530	Hafsås	62’18 20 °E 8’35 11 °N	698	1977-2015	**1**		63530 Hafsås	1.10.1977-u.t.
63580	Angårdsvatn	62’24 9 °E 9’7 4 °N	596	1965-2015	**1**		63580 Angårdsvatn	1.7.1965- u.t.

Table 3: Correlation with the neighbor stations.

Meteorological station	Correlation
16560 Dombås	0.809
16790 Lesja	0.788
14711 Grov	0.742
14550 Preststulen	0.736
61630 Bjorli	0.652
9160 Folldal	0.650

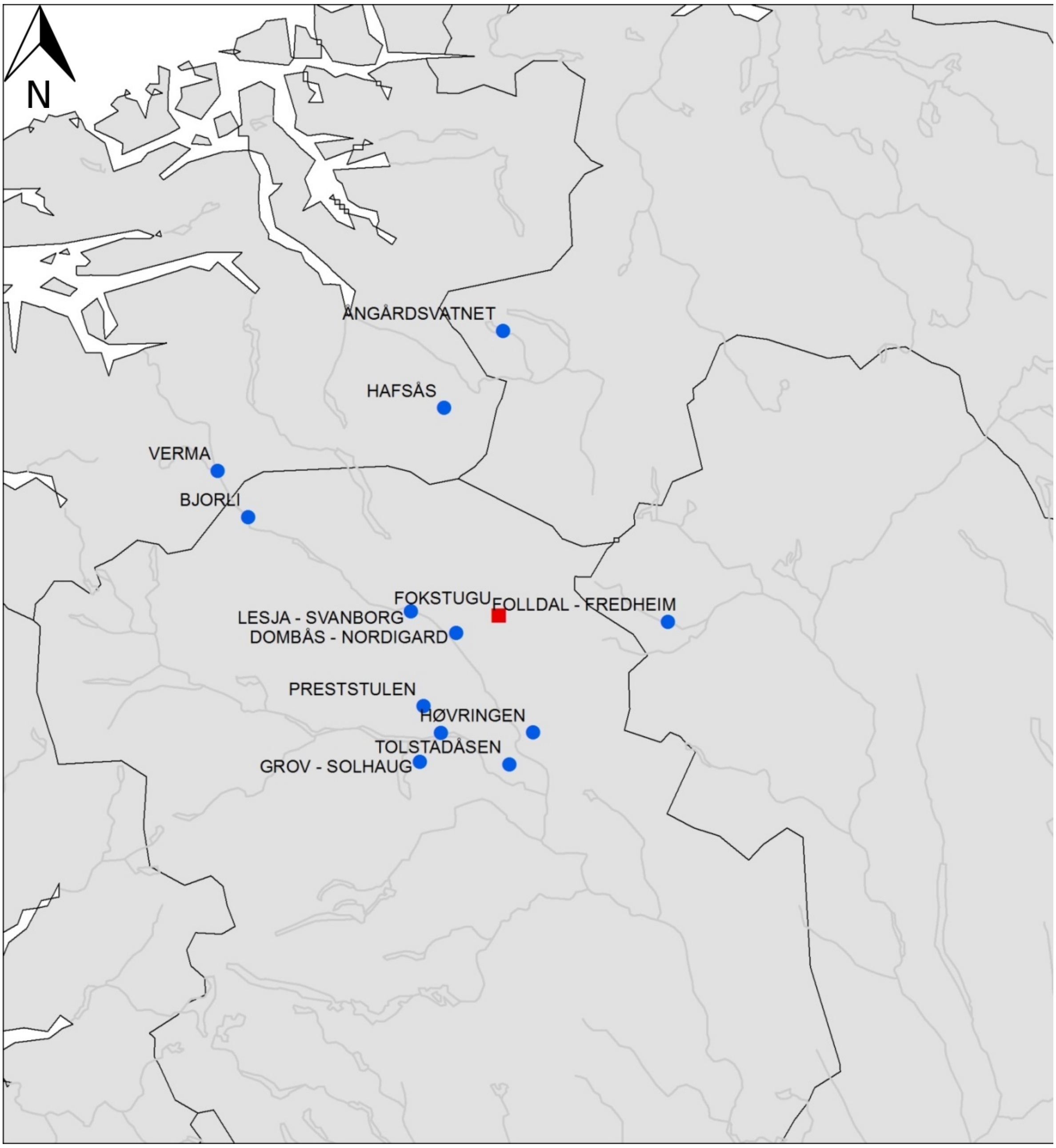


Figure 8: Map of the locations of the stations in the Fokstua network.

II. Sauda

Figure 9: Picture of 46610 Sauda meteorological station. The geonor T-200 precipitation gauge is marked with the red arrow.

Sauda is a town in Sauda municipality in Rogaland County. The village, which is also the administrative centre of the municipality, is located in a river valley at the northern end of the Saudafjorden. A large part of the industrial harbour area of Sauda is built on reclaimed land that was once underwater in the fjord.

Sauda received "town status" in 1998. The town has a population of 4,253. Sauda was originally (as with many Norwegian towns/cities) an old farming village. The village survived on agriculture and the timber industry throughout the last millennium. Due to its proximity to many nearby waterfalls, several mills were built for pulp and paper. Over time, Sauda grew up as industrialization began, especially at the start of the 1900s. Zinc mining in the late-1800s grew up. Sauda Smelteverk has been the main factory in the town. It was a plant for producing manganese alloys from 1915. The smelting plant in Sauda is Northern Europe's largest of its kind.

46610 Sauda

The station is near the harbor in the town, on grounds of Elkem Saudefallene (fig. 9 & 10). Near the station it is a lawn (about 10m wide) between the parking and the smelter and a road. Around the station it is open, without any shielding from houses or trees. Distance to the fjord and mouth of the river is about 100 meters. A river runs close to where the instruments are and river flows out 300 m from the station. Sauda is surrounded by mountains on all sides, with an average altitude of about 1000 m a.s.l. The highest mountain is approximately 1600 m (Kyrkjenuten). Some heights near the station are only 2-400 meters.

This explains some of the weather conditions in Sauda. This allows the temperature of the winter probably is slightly higher than the area in general. In the summer it may be a bit lower? The precipitation is representative of the district. It is more precipitation in this area than on the coast, because the mountains it will increase precipitation. Most of the precipitation will probably come in the southwest and follow Saudafjord inward. In the west and northwest will probably the mountains shield for any precipitation. The station sits in Saudafjord with several valleys meet in the inlet end (fig. 11).

The station history folder and the inspection reports contain many notes. It is given increasingly descriptions that measuring equipment is kept dust coated and turns black here. The instructions from the inspector (DNMI) are every time to cleaned and painted the instruments white. There are inspection regularly every second year. There has been considerable pollution in the area due to the factories. We still think not that this will or had affected the measurement of precipitation.

Figure 10: Aerial photo (a) & map (b) of the location of 46610 Sauda: Automation in 2008: New AWS.

Sauda network

The Sauda network consists of 14 series including the candidate series from Sauda. Table 4 shows the series in the network, including the original series from which they are merged. The locations of the series are shown in figure 9. Sauda is furthest inside in the Boknafjorden, which has many fjords branching off from it (including Saudafjorden). The stations are mostly located in this area near Boknafjorden. There are some stations a little higher up the hillside farther inland, e.g. Røldal. Table 5 shows the correlation between the series in the network. All stations are highly correlated, fulfilling the criterion in HOMER of ρ>0.8. Hellandsbygd is the nearest meteorological station with the same type of weather conditions and precipitation (see ch. Results), but it is not the best station to compare with, because it has gaps in the time series.

Table 4. Series in the Sauda network (breaks from HOMER).

Analysed series	Name	LAT/LON	MASL	Period	Nr of original series	Breaks	Original series	Time coverage original series
45350	Lysebotn	59’ 1 59 °E 6’23 16 °N	5	1896-2015	**1**	**3**	45350 Lysebotn	1.1.1896-u.t.
45600	Bjørheim	59’2 47 °E 6’0 43 °N	64	1952-2014	**1**	**1**	45600 Bjørheim i Ryfylke	1.9.1950-u.t.
45870	Fister	59’5 45 °E 6’1 18 °N	30	1950-2015	**3**	**2**	45900 Fister	1.1.1950-1.9.1991
							45880 Fister-Tønnevik	1.6.1992-31.7.2007
							45870 Fister-Sigmundstad	29.5.2007-u.t.
46150	Sand	59’17 15 °E 6’9 56 °N	25	1933-2015	**2**	**2**	46140 Sand i Ryfylke	1.1.1933-31.12.1956
							46150 Sand i Ryfylke II	1.1.1957-u.t.
46300	Suldalsvatn	59’21 11 °E 6’29 7 °N	333	1895-2015	**1**	**1**	46300 Suldalsvatn	1.7.1895-u.t.
46400	Nesflaten	59’23 23 °E 6’29 31 °N	72	1968-2013	**2**		46400 Nesflaten	1.1.1968-31.1.2001
							46400 Nesflaten II	1.1.2005-31.12.2013
46450	Røldal	59’23 19 °E 6’12 35 °N	393	1902-2015	**1**	**1**	46450 Røldal	1.7.1902-u.t.
46590	Sauda	59’23 19°E 6’12 35 °N	5	1928-2015	**2**	**1**	46610 Sauda	1.4.1928-31.7.1932
							46610 Sauda	1.9.1932-u.t.
46700	Hellandsbygd	59’24 42 °E 6’18 43°N	255	1940-2015	**2**	**1**	46700 Hellandsbygd	1.1.1940-31.12.1952
							46700 Hellandsbygd	1.1.2005-u.t.
46850	Hundseid	59’20 0 °E 5’35 50 °N	159	1936-2015	**1**		46850 Hundseid i Vikedal	1.10.1936- u.t.
46910	Nedre Vats	59’17 18 °E 5’27 1 °N	64	1969-2011	**1**	**2**	46910 Nedre Vats	1.2.1969-31.12.2011
47500	Etne	59’23 56 °E 5’34 45°N	35	1895-2014	**1**	**1**	47500 Etne	1.7.1895-31.12.2014
47820	Eikemo	59’30 56 °E 6’10 1 °N	178	1962-2015	**1**		47820 Eikemo	1.1.1962-u.t.
47890	Opstveit	59’30 53 °E 6’0 35 °N	38	1968-2015	**1**		63580 Angårdsvatn	1.1.1969- u.t.

Table 5: Correlation with the neighbor stations from the HOMER the annual analyzes.

Meteorological station	Correlation
46700 Hellandsbygd	0.964
46910 Nedre Vats	0.963
46850 Hundseid	0.957
46450 Røldal	0.954
47500 Etne	0.954
46150 Sand	0.953
46300 Suldalsvatn	0.923
47890 Opstveit	0.915
47820 Eikemo	0.913
45870 Fister	0.897
45350 Lysebotn	0.889
45600 Bjørheim	0.876
45600 Nesflaten	0.823

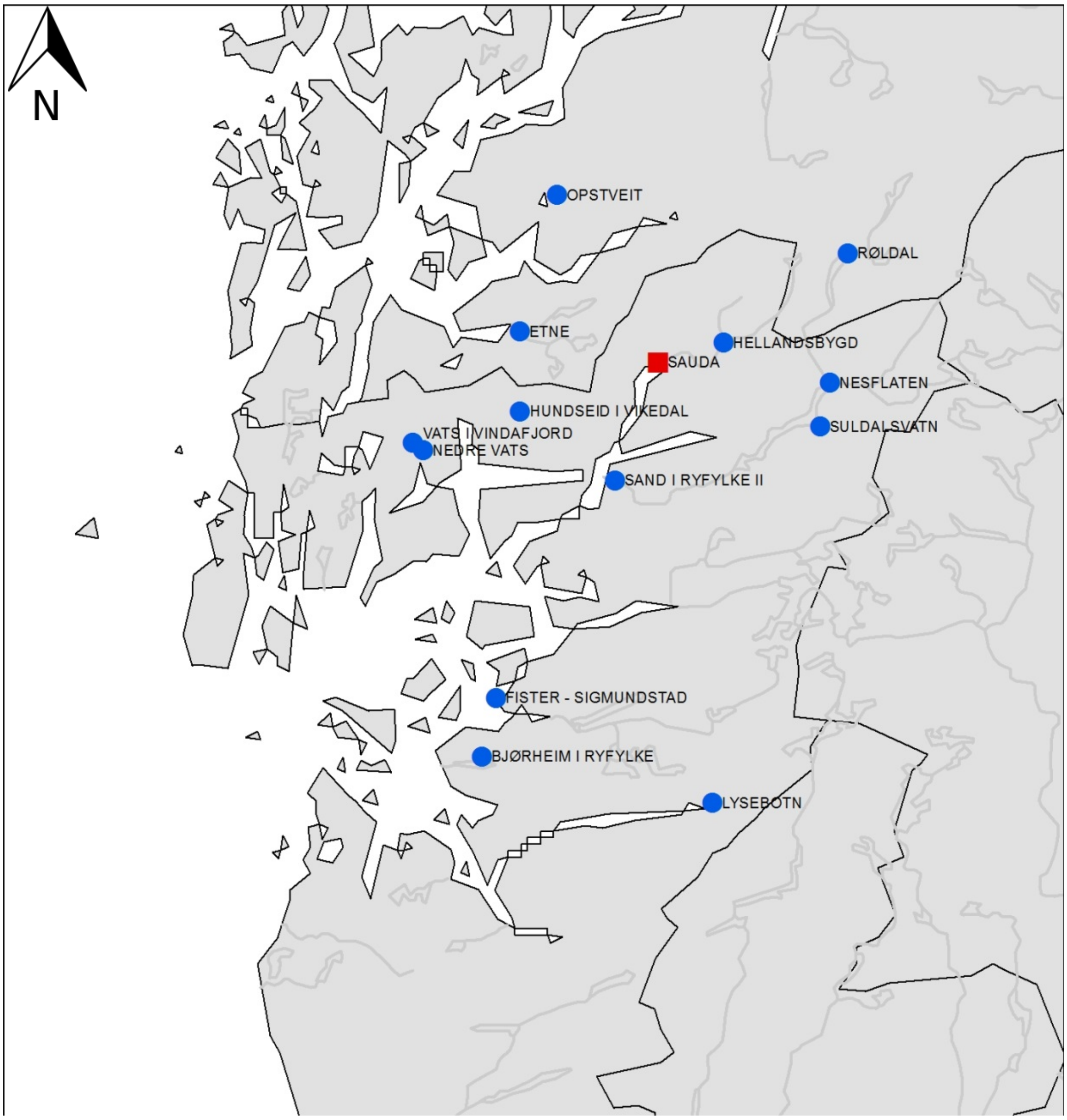


Figure 11: Map of the locations of the stations in the Sauda network.

III. Takle

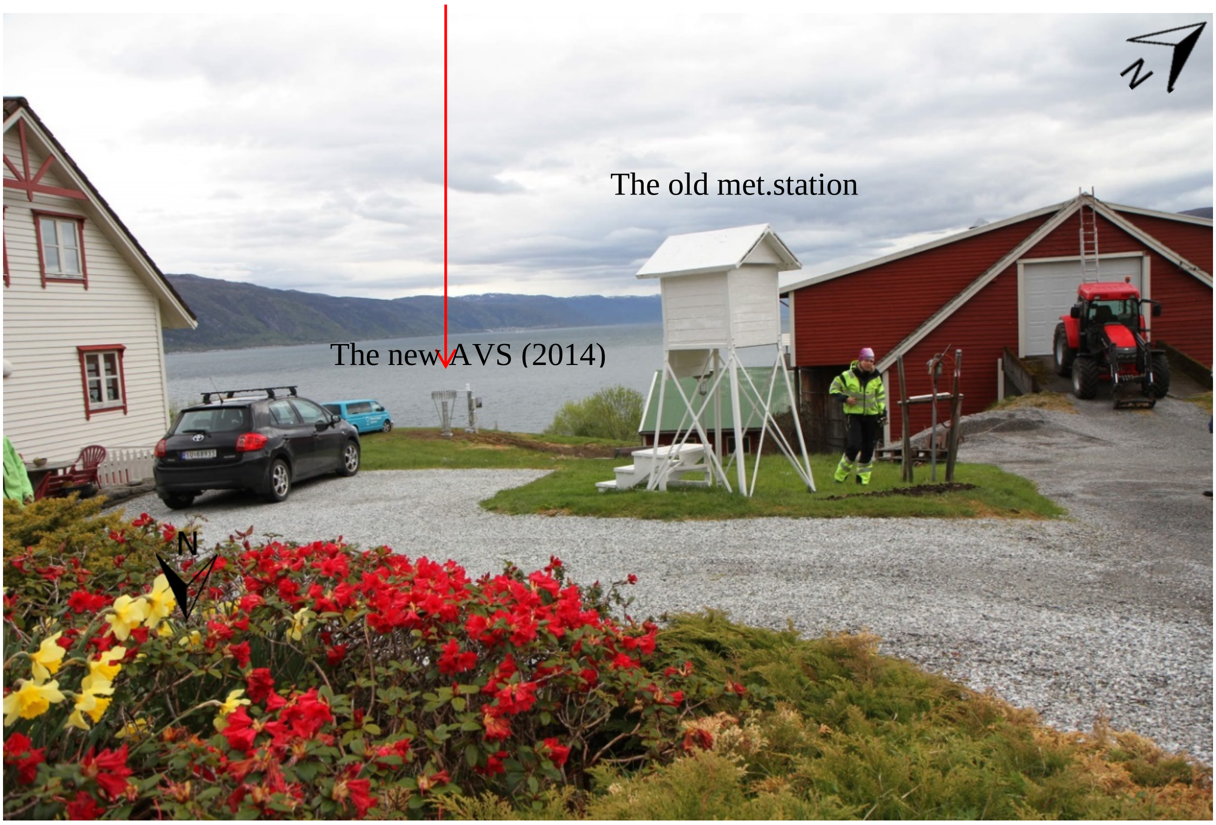


Figure 12: Picture of 52860 Takle met station. The geonor T-200 precipitation gauge is marked with the red arrow: The new AWS from 2014.

Takle is a village at the head of the Sognefjord in Gulen municipality. The village is elongated along the fjord on the east-westerly direction, with settlement 20-30 m a.s.l. The place is situated between the fjord, Søtekollen (557 m a.s.l) and Stølsfjellet (670 m a.s.l.), and it is developed hydropower in the south Takle. Lake is situated 292 m a.s.l. There is a road eastward to Brekke and E 39, and south to Eivindvik via Rutle valley in west or straight south through Takle valley and Austgulfjorden. Bergenshalvøens Power Company, BKK, own Takle power plant and the mean annual production of 5.6 GWh.

52860 Takle

In the village, Takle synoptic weather station (fig. 12) that is currently in use and was created in June 1950. Takle meteorological station is located on the south side of the outer part of the Sognefjord. Around the station there is farmland (fig. 14), with a barn just south of the site. South and west of the station area is the mountain at around 500-700 m. This station measured 184.6 millimeters of precipitation on 27th October 1995. Average yearly rainfall (1961-1990) is 3176 millimeters. The temperature is expected to be representative of the outer Sogn. Regarding precipitation, the local differences, depending on which direction the weather comes from. It will probably be more precipitation on Takle than on the north side of the bay when precipitation coming from the south and southwest. Conversely, when the precipitation coming from the north and northwest. The station is well exposed to precipitation (fig. 13).

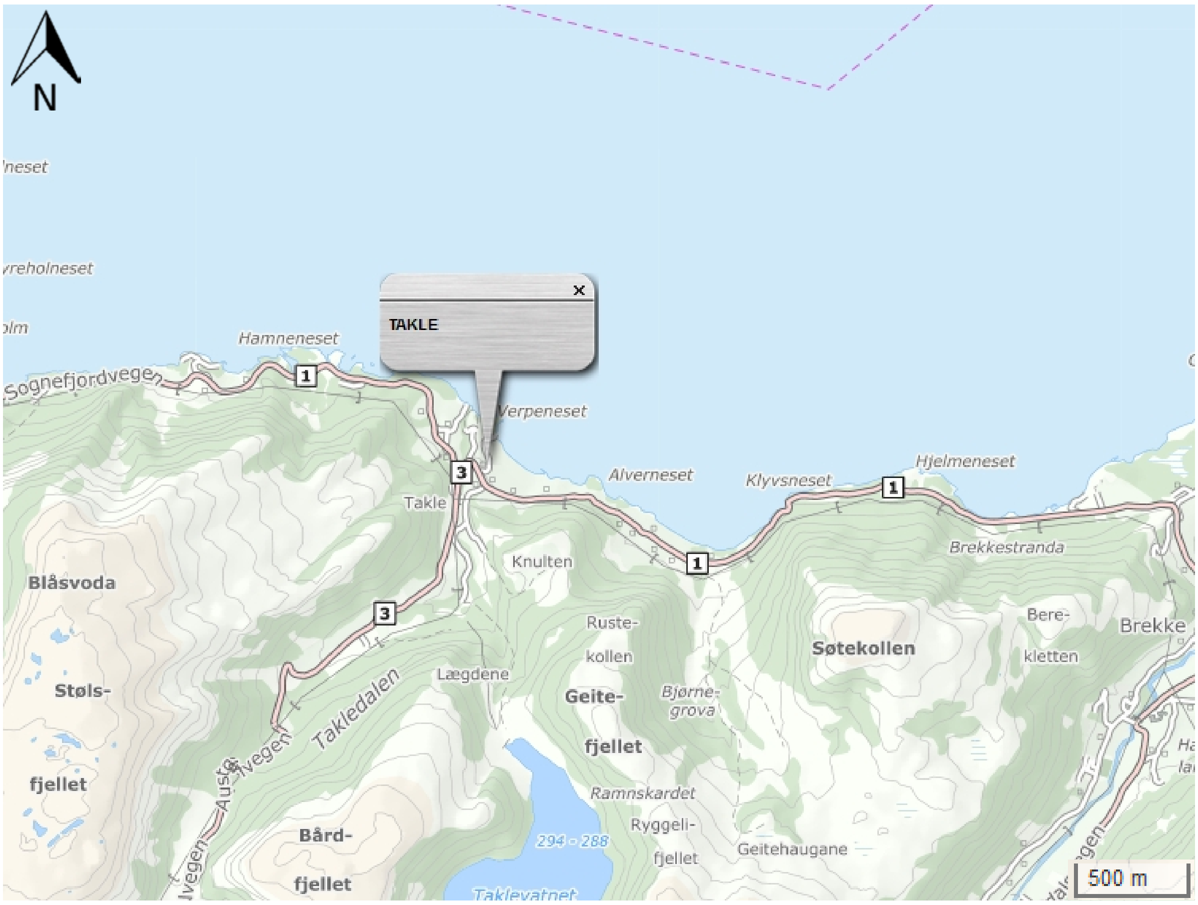


Figure 13: Map from Takle met. Station near the Sognefjorden (Brekke is to the right (E) in the map).

Figure 14: Picture of farm Takle with view against west and Sognefjorden on the right side.

Takle network

The Takle network consists of 19 stations. The 19 precipitation series are all located around the Sognefjord. The Sognefjord or Sognefjorden is the largest and most well-known fjord in Norway and the second longest in the world. Located in Sogn og Fjordane county in Western Norway, it stretches 205 kilometer's inland from the ocean to the small village of Skjolden in the municipality of Luster. The fjord runs through many municipalities and precipitation stations: from 56400 Ytre-Solund in west to 54110 Lærdal in east.

The altitude of the meteorological stations varies between 2 and 241 m a.s.l. Otherwise varies the climate somewhat between mouth of the fjord and head of the fjord. The climate of the inner end of Sognefjorden and its branches are not as wet as on the outer coastline. Lærdal that is situated furthest in the Sognefjord is characterized as a dry place (490 mm per year). Brekke (fig. 13 & 15) holds the record for the highest annual precipitation in Norway (3575 mm per year). The average width of the main branch of the Sognefjord is about 4.5 kilometers. Cliffs surrounding the fjord rise almost sheer from the water to heights of 1,000 meters and more. The mouth of the fjord is surrounded by many islands. Sunnfjord, a smaller inlet little farther north, is also represented in this network (Forde and Sygna). Table 6 shows the series in the network, including the original series from which they are merged. Figure 15 shows the map of the County Sogn og Fjordane and the locations for the stations in the Takle network. Table 7 shows the correlation between the series in the network. It is the geographically nearest station, Brekke that shows the highest correlation (table 7):

Table 6: Series in the Takle network (breaks from HOMER).

Analysed series	Name	LAT/LON	MASL	Period	Nr of original series	Breaks	Original series	Time coverage original series
52310	Modalen III	60’51 37 °E 5’58 40 °N	125	1895-2015	**3**	**3**	52300 Modalen	1.7.1895-31.5.1980
							52290 Modalen II	1.6.1980-30.9.2008
							52310 Modalen III	17.10.2008-u.t.
52600	Haukeland	60’46 5 °E 6’0 43 °N	196	1908-2015	**1**	**3**	52600 Haukeland	1.1.1908-u.t.
52750	Frøyset	60’50 77 °E 5’12 65 °N	13	1895-2015	**1**	**3**	52750 Frøyset	1.7.1895-u.t.
52860	Takle	61’1 63 °E 5’22 88 °N	38	1950-2015	**1**	**1**	52860 Takle	1.7.1950-u.t.
52930	Brekke	60’57 51 °E 5’25 50 °N	240	1939-2015	**1**	**3**	52930 Brekke i Sogn	1.1.1939-u.t.
52990	Ortnevik	61’6 52 °E 6’8 37 °N	4	1973-2015	**1**		52990 Ortnevik	1.1.1973-u.t.
53070	Vik i Sogn	61’4 37 °E 6’34 88 °N	65	1895-2015	**1**	**3**	53070 Vik i Sogn	1.7.1895-u.t.
53101	Vangsnes	61’10 34 °E 6’38 71 °N	49	1921-2015	**1**	**2**	52101 Vangsnes	1.1.1921-u.t.
53130	Fresvik	61’2 28 °E 6’33 38 °N	32	1978-2015	**1**	**1**	53130 Fresvik	1.1.1979-u.t.
54110	Lærdal	61’6 20 °E 7’30 15 °N	2	1869-2015	**4**	**6**	54100 Lærdal	1.8.1869-31.12.1947
							51130 Lærdal-Tønjum	1.6.1948-30.4.1996
							54120 Lærdal-Moldo	31.5.1996-11.9.2008

							54110 Lærdal IV	12.9.2008-u.t.
55730	Sogndal-Selseng	61’20 9°E 6’56 1 °N	421	1895-2015	1	1	55730 Sogndal-Selseng	1.7.1895-u.t.
55780	Leikanger	61’10 81°E 6’51 76 °N	53	1896-1990	1	1	55780 Leikanger	1.1.1896-31.1.1990
							55830 Fjærland	1.1.1921-1.9.1951
							55840 Fjærland-Skarestad	1.1.1952-20.1.2005
55820	Fjærland	61’25 40 °E 6’45 85 °N	3	1921-2015	3	6	55820 Fjærland-Bremuseet	20.11.2005-u.t.
56320	Lavik	61’6 73 °E 5’32 82°N	31	1895-2015	1		56320 Lavik	1.7.1895-u.t.
56400	Ytre-Solund	61’0 41°E 4’40 16 °N	3	1923-2015	2	1	56400 Ytre-Solund	1.2.1923-u.t.
56420	Fureneset	61’10 32 °E 5’1 35 °N	7	1972-2015	1	1	56420 Fureneset	1.9.1972-u.t.
56520	Hovlandsdal	61’13 92 °E 5’26 5 °N	85	1899-2015	1	3	56520 Hovlandsdal	1.9.1899- u.t.
							56800 Gaular	1.7.1895-31.12.1995
56780	Sygna	61’20 61 °E 5’43 60°N	47	1896-2015	2	2	56780 Sygna	1.7.1996- u.t.
							57480 Botnen i Førde	1.7.1895-30.11.1992
57420	Førde	61’27 89 °E 5’56 0 °N	64	1895-2015	2	2	57420 Førde-Tefre	1.12.1992- u.t.

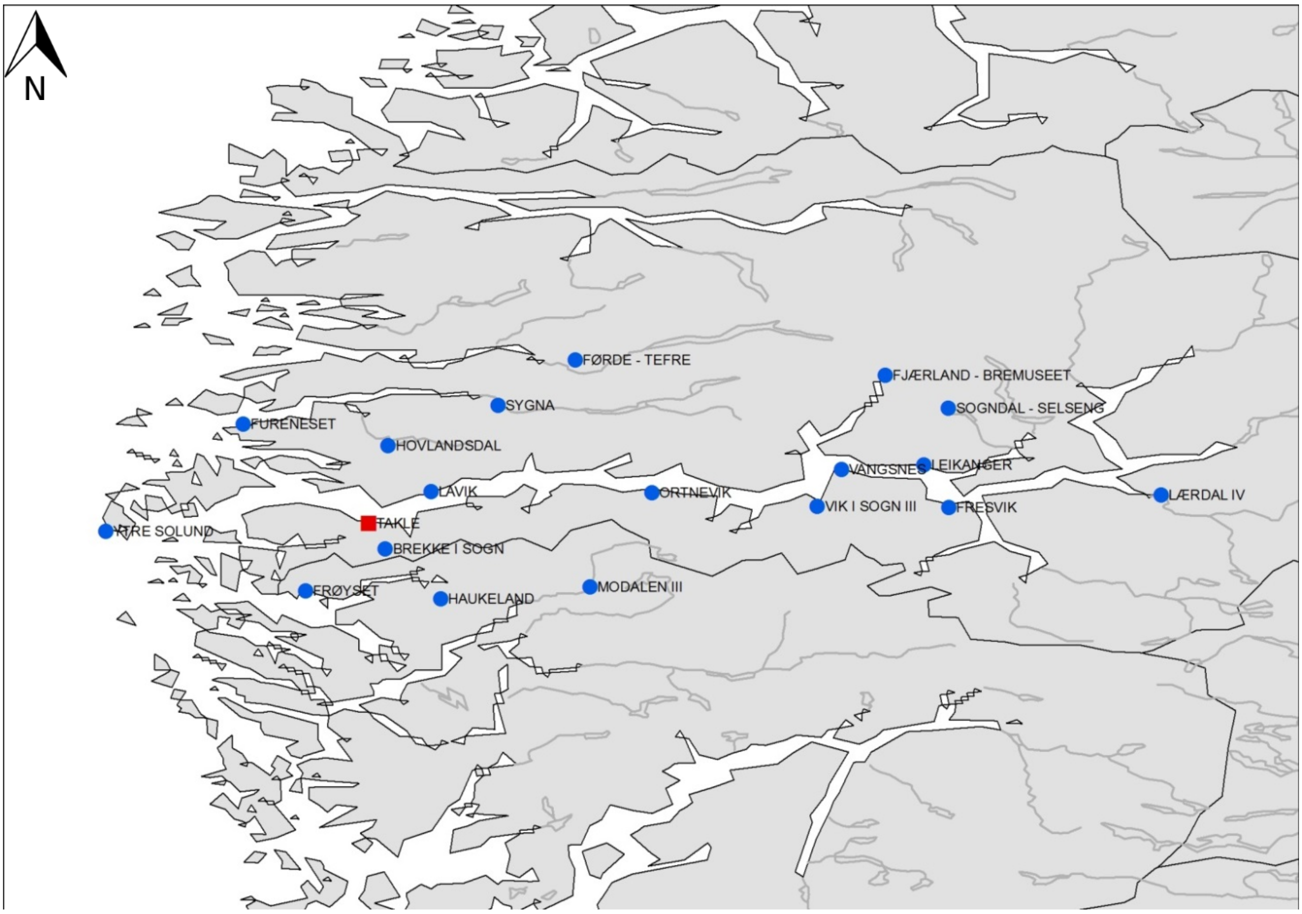


Figure 15: Map of the locations of the stations in the Takle network. Takle is marked red.

Table 7: Correlation in the neighborhood from HOMER, the annual analysis.

Meteorological station	Correlation
52930 Brekke	0.977
52600 Haukeland	0.975
52990 Ortnevik	0.969
52310 Modalen	0.969
56780 Sygna	0.962
55730 Sogndal-Selseng	0.961
56520 Hovlandsdal	0.959
57420 Førde	0.951
53130 Fresvik	0.942
56420 Furuneset	0.937
56320 Lavik	0.937
52750 Frøyset	0.936
53070 Vik I Sogn	0.935
55820 Fjærland	0.930
53101 Vangsnes	0.916
56400 Ytre Solund	0.892
55780 Leikanger	0.856
54110 Lærdal	0.811

IV. Mo i Rana

Mo i Rana is a town and administrative center of the municipality of Rana in Nordland County. It is located 80 km south of the Arctic Circle and in the Helgeland region of Nordland. Population (2013): 18,358. It is the largest town in Helgeland and the second largest (after Bodø) in Nordland. The municipality is rich on iron ores, and water to produce power. This was very important in industry development. Mo i Rana is located at the head of Ranfjorden, just on the southern side of the Saltfjellet Mountains with the Svartisen glacier, Norway's second largest. The river Ranelva meets the Ranfjorden in Mo i Rana. Mo i Rana's climate is usually classified as subarctic (Köppen *Dfc*), with long, cold winters, and short, warm summers. The Norwegian Current (extension of Gulf Stream), follows the coastline of Norway all the way north. The stream has a heavy influence on the climate, helping to keep the temperatures from getting too low in the winter, despite the city being located about 70 kilometers from the coast line. The distance from the coast, however, does give it slightly lower temperatures in the winter than towns nearer the coast. There is much precipitation due to the mountains north of town, often with much snow in winter. The weather can be very unpredictable, and change quickly. The summer is short; July and August are the warmest months. The 24-hr average temperature in July is 13.2 C. This is based on the 1961-1990 base period; recent years have tended to be warmer in this area. Autumn begins in September.

79480 Mo i Rana III

The meteorological station, which measure only precipitation, is situated south-east in the town center in Mo industripark (fig. 16 & 17). It has moved 3 times: 1941, 1946 & 1957 (fig. 18 & 19). Figure 18 shows the old stations and figure 19 is a map which shows the relocations of the four meteorological stations in Mo i Rana.

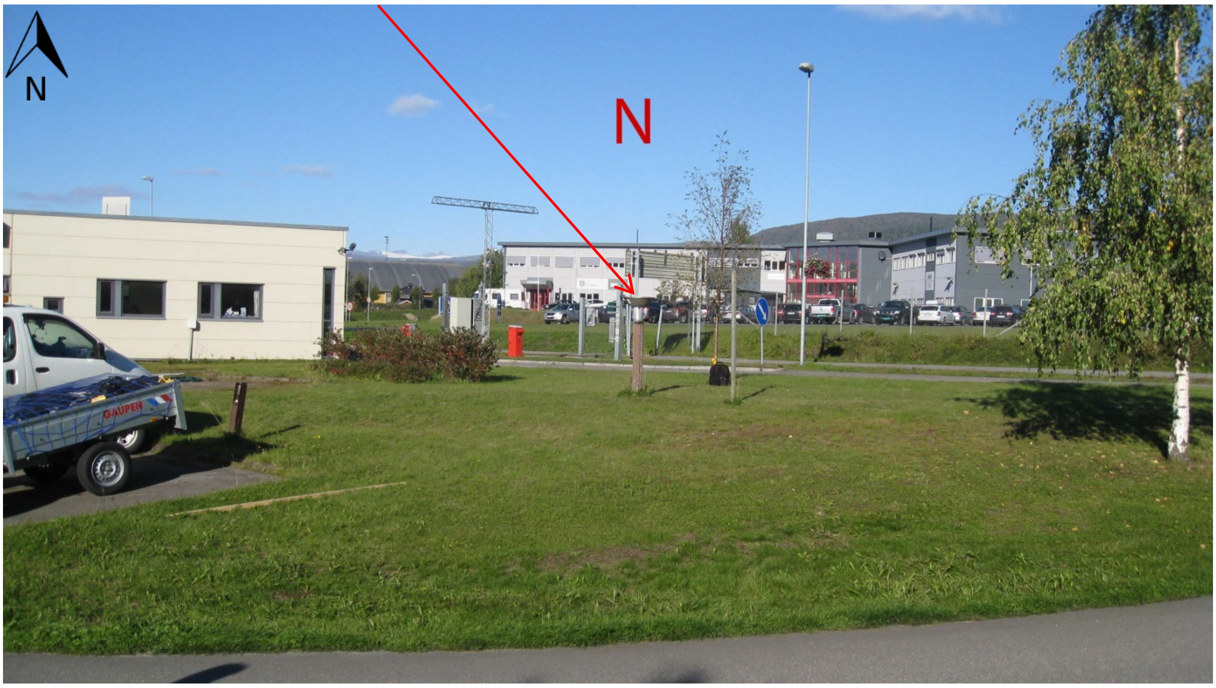


Figure 16: Picture of 79480 Mo i Rana meteorological station. It is a manual precipitation gauge (Swedish type) and marked here with a red arrow.

Figure 17: Aerial photo from Mo i Rana met. station near the town center and Ranfjorden.


*Figure 18: Photo from the 1940s from 2 of the met stations in Mo i Rana. Left: 79510 Mo Rana II (**3**) & Right: 79500 Ytteren (**2**).*

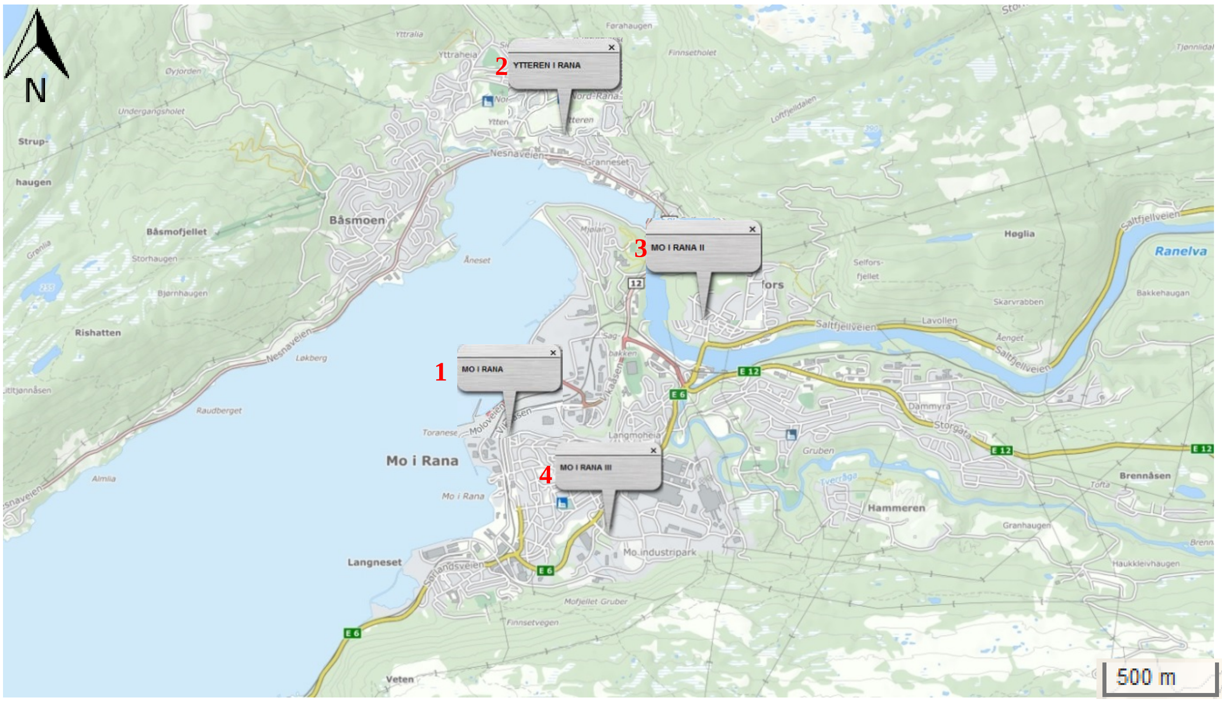


Figure 19: Map of the location of Mo i Rana station.

Mo i Rana network

The Mo i Rana network consists of 12 stations. The meteorological stations are situated around Mo i Rana in Nordland County. This area is called Helgeland and it is the most southerly district in Northern Norway it is located south of the Arctic Circle. It is bordered in the north by the Saltfjellet Mountains and Svartisen glacier, which form a natural border with the Salten district. In the south, Helgeland borders Nord-Trøndelag County. The district covers an area of about 18,832 square kilometers, with nearly 79,000 inhabitants. Helgeland is characterized by pointed mountains and *Strandflaten*, a shallow lowland area, sometimes just above the sea surface. The inland towns, such as Mo and Mosjøen, are situated in valleys.

Table 8 shows the series in the network, including the original series from which they are merged. Figure 20 shows the map of the County Nordland and the locations for the stations in the Mo i Rana network. Table 9 shows the correlation between the series in the network. It is 79650 Nord Rana and 78420 Korgen, which is closest and thus has the highest correlation with Mo i Rana. But both Nord-Rana and Korgen is closed, respectively in 1987 and 1993. So it is really 78350 Bardal, which operates today, that are both closest geographically and statistically in this comparison.

Table 8: Series in the Mo i Rana network (breaks from HOMER).

Analysed series	Name	LAT/LON	MASL	Period	Nr of original series	Breaks	Original series	Time coverage original series
77850	Susendal	65’12 54 °E 14’9 22 °N	498	1896-2015	**1**	**2**	77850 Susendal	1.1.1896-u.t.
78250	Leirfjord	66’2 24 °E 12’32 44 °N	53	1950-2015	**1**	**1**	78250 Leirfjord	1.1.1950-u.t.
78350	Bardal	66’4 49 °E 13’14 5 °N	39	1972-2015	**1**		78350 Bardal	1.1.1972-u.t.
78420	Korgen	66’3 21 °E 13’29 17 °N	50	1895-1993	**3**	**4**	78400 Korgen	1.7.1895-1.8.1941
							78410 Korgen II	1.8.1942-1.6.1979
							78420 Korgen-Auringsmoen	1.7.1979-18.6.1993
78600	Tustervatn	65’29 23 °E 13’32 23 °N	439	1896-2015	**2**	**3**	78600 Tustervatnet	1.1.1896-31.7.1955
							78610 Tustervatnet II	1.8.1955-u.t.
78770	Famvatnet	65’28 40 °E 14’17 32 °N	510	1969-2015	**1**		78770 Famvatnet	1.1.1969-u.t.
78850	Røssvatn	65’32 46 °E 14’9 47 °N	399	1895-2007	**2**	**1**	78840 Røssvatn	1.7.1895-31.7.1955
							78850 Røssvatn-Heggmo	1.8.1955-31.12.2007
79480	Mo i Rana	66’11 3 °E 14’5 32 °N	41	1935-2015	**4**	**2**	79470 Mo i Rana	1.7.1935-30.6.1941
							79500 Ytteren i Rana	1.1.1942-30.6.1946
							79510 Mo i Rana II	1.8.1946-1.9.1957
							79480 Mo i Rana III	1.10.1957-u.t.
79650	Nord Rana	66’15 0 °E 14’9 36 °N	250	1895-1987	**2**	**1**	79650 Nord Rana	1.7.1895-31.12.1987
79762	Dunderlandsdalen	66 18 16 °E 14’34 2 °N	200	1895-2015	**3**	**2**	79740 Dunderlandsdalen	1.7.1895-4.6.2004
							79762 Dunderlandsdalen-Nyla	1.7.2007-u.t.
80200	Lurøy	66’14 1 °E 13’ 6 44°N	115	1923-2015	**1**		80200 Lurøy	1.1.1923-u.t.
81100	Beiarn	67’0 14 °E 14’20 38 °N	5	1903-2015	**1**	**1**	81100 Beiarn	1.1.1903-31.12.1978

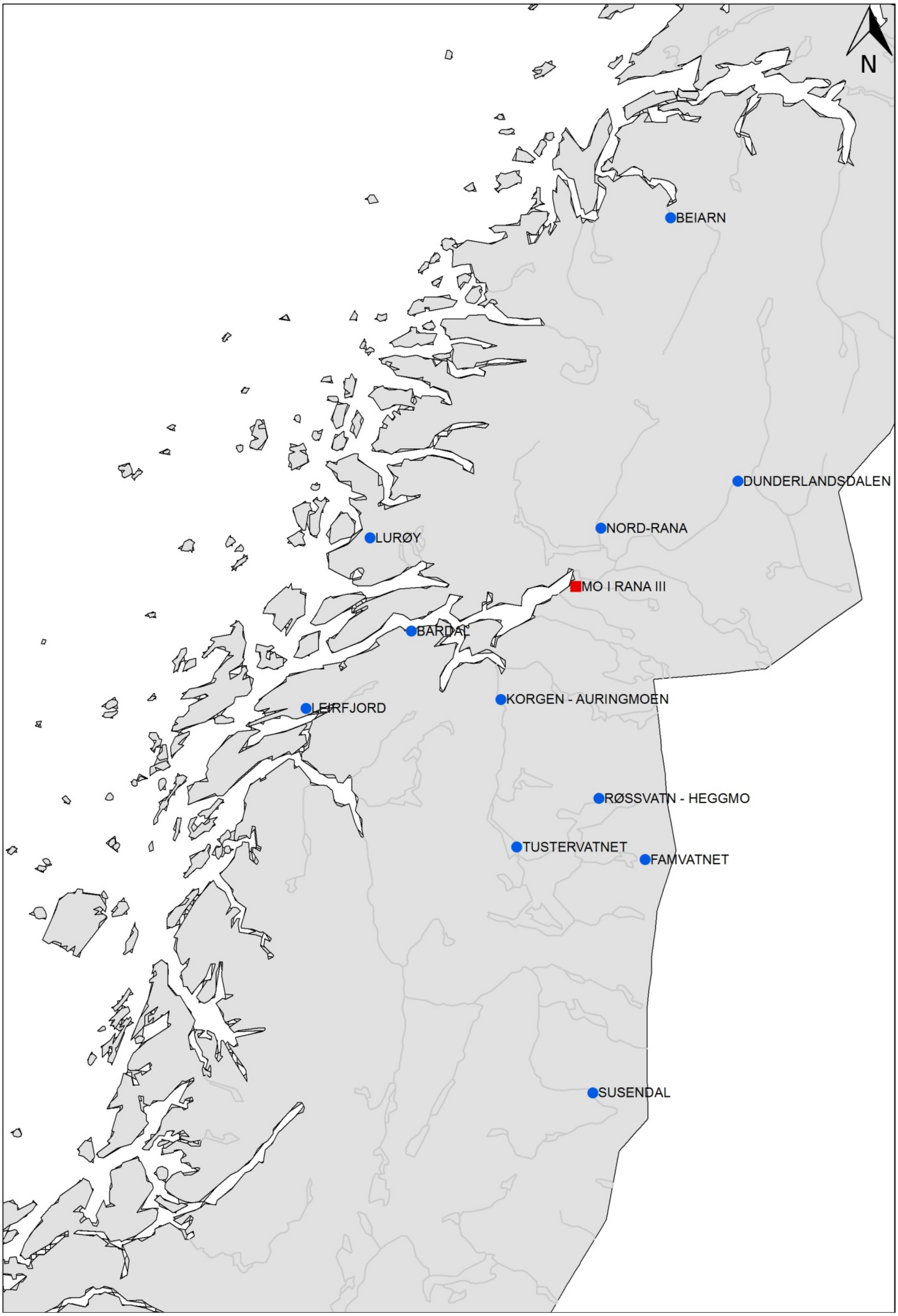


Figure 20: Map of the locations of the stations in the Mo i Rana network. Mo is marked red.

Table 9: Correlation in the neighborhood from HOMER, the annual analysis.

Meteorological station	Correlation
79650 Nord Rana	0.967
78420 Korgen	0.967
78350 Bardal	0.962
78850 Røssvatn	0.961
81100 Beiern	0.946
79762 Dunderlandsdalen	0.937
78600 Tustervatn	0.936
80200 Lurøy	0.935
78250 Leirfjord	0.902
78770 Famvatnet	0.87
77850 Susendal	0.838

V. Bardufoss

Figure 21: The geonor GEONOR T200B (600 mm) precipitation gauge.

Bardufoss is an urban area and commercial center in the municipality of Målselv in Troms County. Bardufoss is located in the Målselvdalen valley near the confluence of the Barduelva and Målselva rivers. It is located about 82 kilometers north of the city of Narvik and about 70 kilometers south of the city of Tromsø. The population is about 2,500. The airport is located between the villages Andselv in N (2 km) and Bardufoss (1 km) (fig. 23). The airport opened in 1938 and is one of the oldest military operating airports in the country.

Although not far from the coast, Bardufoss and Målselvdalen is known for a continental climate, and hence, colder winters (but with less humidity and little wind) compared to the coastal areas. There is a very reliable snow cover in winter, while summer days often are warmer than in Tromsø. There is on average 93 days each winter with daily low -10 °C or colder, and 28 days with low -20 °C or colder. The winter season sees on average 68 days with at least 50 cm snow cover on the ground. Precipitation is fairly moderate, there is on average 75 days/year with at least 3 mm precipitation and 15 days/year with at least 10 mm precipitation (MET).

89350 Bardufoss

The weather station, including the Geonor (fig. 21) is located at the airport in Bardufoss (fig. 22). The weather station at Bardufoss has stood stable at the airport since 1946. It is unfortunately moved a few meters (<20 meters) many times. It is not clear if this has affected the measurements.

Figure 22: The runway at Bardufoss airport (looking to E direction). The geonor T-200 precipitation gauge is marked with the red arrow.

Bardufoss network

The Bardufoss network consists of 11 stations. The meteorological stations are situated around Bardufoss in Troms County. This area is characterized by long distances to the more densely populated areas of the continent and it is wooded terrain (fig. 23). The largest river in Troms (waterflow) is Målselva (in Målselv) is near the station. The entire county is located north of the Arctic Circle and the whole network is located at latitude of nearly 70°N. There are mountains in the area of up to 1,600 meters above sea level. Tromsø (90490) is the northernmost station/area represented and Bardu (88100) is the southernmost station/area in the network.

Table 10 shows the precipitation series in the network, including the original series from which they are merged. Figure 24 shows the map of the County Troms and the locations for the stations in the Bardufoss network. Table 11 shows the correlation between the series in the network. It is 89150 Moen i Målselv and 89800 Øverbygd, which is closest and thus has the highest correlation with Bardufoss. But both Moen i Målselv and Øverbygd is closed, respectively in 1978 and 1996. So it is really 88100 Bones i Bardu, which operates today, that are both closest geographically and statistically in this comparison.

Table 10: Series in the Bardufoss network (breaks from HOMER)

Analysed series	**Name**	**LAT/LON**	**MASL**	**Period**	**Nr of original series**	**Breaks**	**Original series**	**Time coverage original series**
88100	Bones i Bardu	68’23 14 °E 18’8 47 °N	230	1896-2015	**1**	**2**	88100 Bones i Bardu	1.5.1907-u.t.
88660	Botnhamn	69’18 45 °E 17’33 1 °N	6	1967-2015	**2**	**1**	88660 Botnhamn	1.10.1989-u.t.
							88600 Bergsbotn	1.12.1967-30.9.1989
89150	Moen i Målselv	69’4 47 °E 118’22 12 °N	11	1895-1978	**1**	**1**	89150 Moen i Målselv	1.7.1895-31.12.1978
89350	Bardufoss	69’2 4 °E 18’19 34 °N	76	1946-2015	**1**		89350 Bardufoss	1.6.1946- u.t.
89500	Sætermoen	68’30 59 °E 18’12 8 °N	114	1895-2015	**2**		89490 Sætermoen	1.7.1895-1.7.1950
							89500 Sætermoen II	1.9.1952-u.t.
89650	Innset i Bardu	68’23 40 °E 18’29 29 °N	314	1907-2015	**1**	**5**	89650 Innset i Bardu	1.5.1907-u.t.
							Out of service: 1980-2004	
89800	Øverbygd	69’0 38 °E 19’10 5 °N	78	1895-1996	**1**	**1**	89800 Øverbygd	1.7.1895-31.8.1996
89940	Dividalen	68’28 8 °E 19’25 15 °N	204	1912-2015	**2**	**2**	89950 Dividalen	1.1.1912-20.9.2009
							89940 Dividalen II	8.10.2009-u.t.
90200	Storsteinnes i Balsfjord	69’8 52 °E 19’8 11 °N	27	1944-2009	**1**	**1**	90200 Storsteinnes i Balsfjord	1.9.1944-31.12.2009
90450	Tromsø	69’23 31 °E 18’33 43 °N	100	1920-2015	**2**	**1**	90450 Tromsø	1.7.1920-u.t.
90490	Tromsø-Langnes	69’24 21 °E 18’32 52°N	8	1964-2015	**1**	**2**	90490 Tromsø-Langnes	1.10.1964-u.t.

Table 11: Correlation in the neighborhood from HOMER, the annual analysis.

Meteorological station	Correlation
89150 Moen i Målselv	0.96
89800 Øverbygd	0.925
88100 Bones i Bardu	0.914
89650 Innset i Bardu	0.898
90200 Storsteinnes i Balsfjord	0.889
90490 Tromsø-Langnes	0.886
89500 Sætermoen	0.884
90450 Tromsø	0.869
88660 Botnhamn	0.828

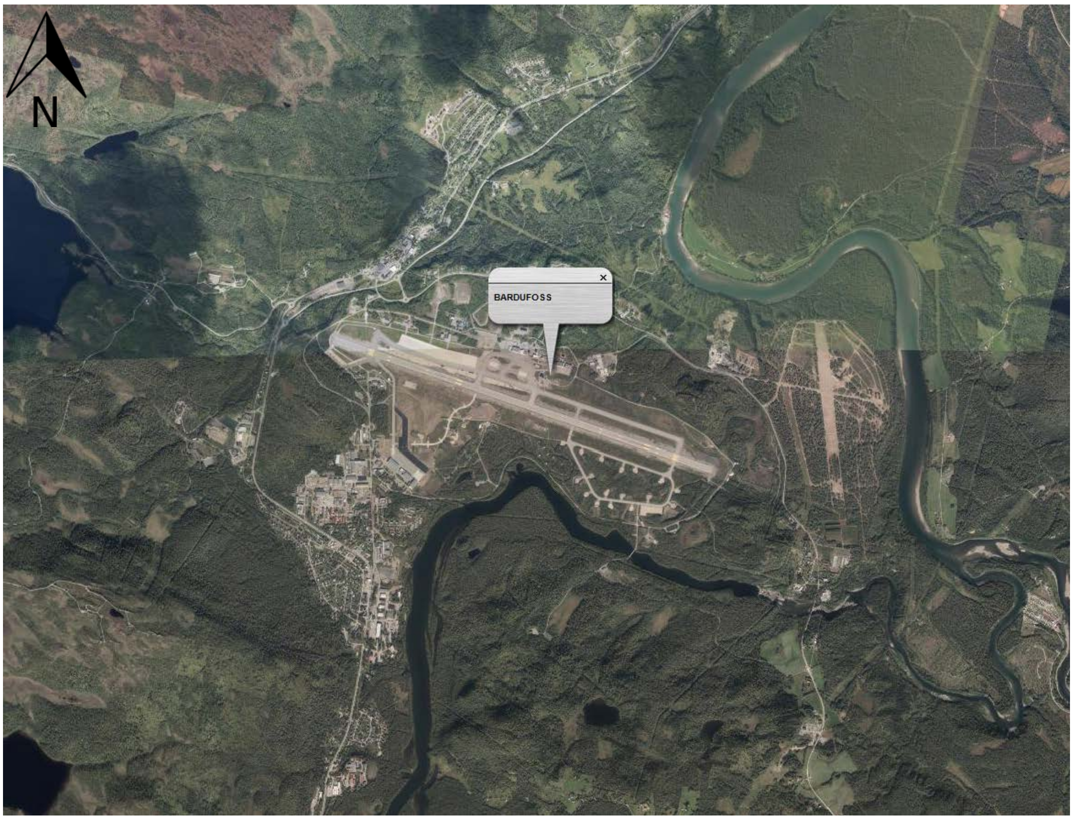


Figure 23: Aerial photo from Bardufoss airport and det met station marked.

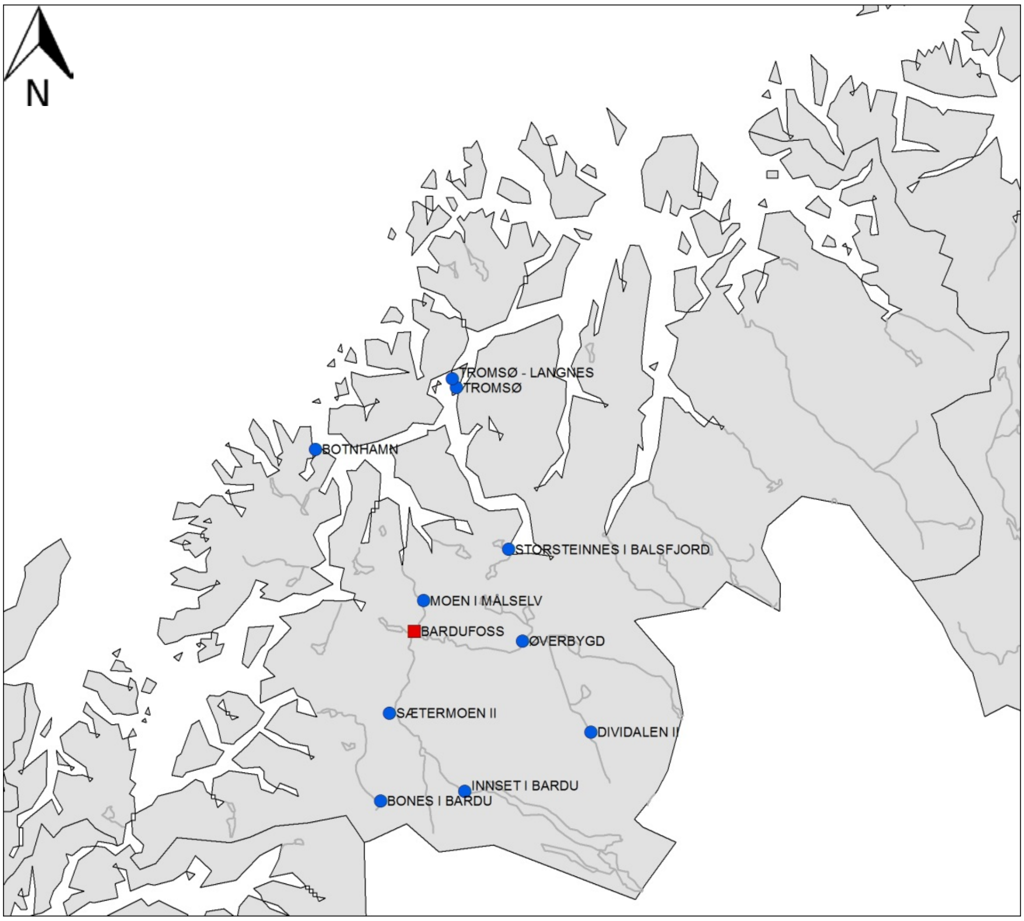


Figure 24: Map of the locations of the stations in the Bardufoss network. Bardufoss is marked red.

5 - Results

Homogenized daily precipitation series for five locations in Norway has been established. The meteorological stations are representive for five major geographical regions in Norway (Fig. 4) and creates an image of the precipitation patterns in Norway: Eastern Norway (Fokstua), Southern Norway (Sauda), Western Norway (Takle), Central Norway (Mo i Rana) and Northern Norway (Bardufoss). The time series have been comprehensively analyzed for inhomogeneities and data errors ensuring a set of station precipitation data which are suitable for the analysis of climate variability and trends.

The methods described in the previous section were applied to assess the homogeneity of the 5 precipitation series (fig. 4) on annual (applying HOMER), seasonal (applying MASH) and daily (applying RHtests_dlyPrcp) scales. The assessment of uncertainties was done statistically, by these methods and subjectively, by comparing the adjustments proposed by the algorithms relating suggested breaks to station metadata, and by taking the result of the bootstrapping into account.

In this section, we present the results from the five Norwegian stations in different precipitation regimes for the period mainly intended to cover the time period from 1 January 1930 to 31 December 2015. All of the 5 precipitation series were found to be homogeneous at the 95% confidence level.

I. Fokstua

The Fokstua precipitation series start in 1923. The annual precipitation varies from year to year between the normal (1961-1990), which is 435 mm per year. The annually mean precipitation has increased almost 10 % during the almost 100 (92) year’s period of observation for Fokstua. The most of the increased precipitation is from the last 35 years (fig. 25 and fig. 28). Dovrefjell and Fokstua is a dry area in Norway with relatively low annual precipitation. The area is characterized by much drifting snow in the winter. This can unfortunately affect precipitation measurements. Figure 26 shows the monthly distribution of precipitation at Fokstua for the normal period (1961-1990). This figure shows that it is most precipitation in the summer.

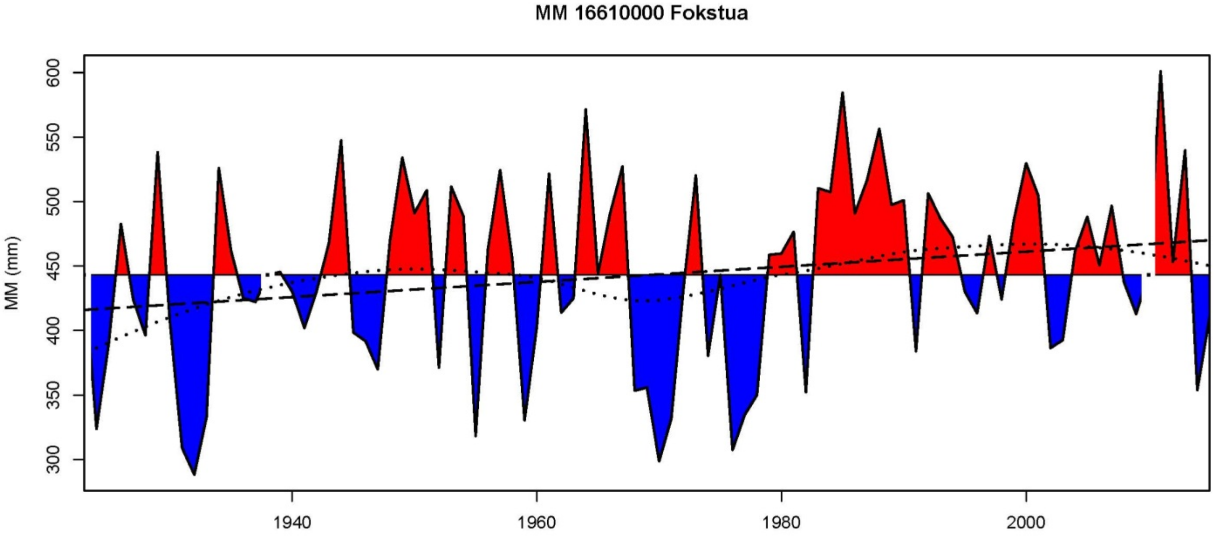


Figure 25: Time series for 16610 Fokstua (1923-2015) (homogenized).

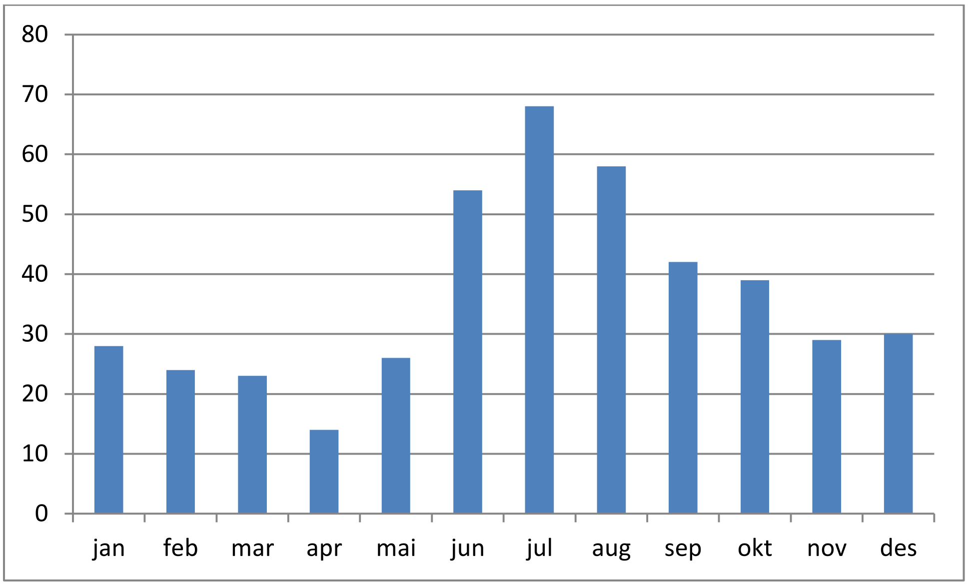


Figure 26: The monthly distribution of precipitation for 16610 Fokstua (1961-90-normal).

Table 12 shows the monthly distribution number of days with precipitation at Fokstua. It is only in the summer it rains less than half the days in the month.

Table 12: Number of days with precipitation at Takle (for the normal period 1961-1990).

Normal per month 1961 - 1990, number of days with precipitation RR>1													
Stnr	jan	feb	mar	apr	mai	jun	jul	aug	sep	okt	nov	des	year
16610	8,9	6,1	6,5	5,0	6,0	9,6	10,8	10,0	9,1	7,9	8,1	8,6	96,6

Annual homogeneity analysis

The homogeneity analysis of annual series with HOMER detected 3 breaks at Fokstua precipitation series (table 13).

The breaks are determined to 1946, 1968 and 2009. All these breaks are supported by metadata: The break in 1946 can be explained with an inspection with leveling of the instruments. The precipitation increased with 12 %. The break in 1968 is the relocation from the railway station and the break in 2009 is the new precipitation gauge: Geonor (table 31; metadata). Both in 1968 and 2009 the precipitation decreased by respectively 9 % and 13 % after the break.

Table 13: Break amplitude shown in ratio, mm & % from HOMER.

Breaks: 3	I: 1946	II: 1968	III: 2009
13 (Year) Average annual rainfall over the period	0.903 443.212	0.783 443.212	0.872 443.212
Break amplitude in ratio & %	0.12 => 12 %	-0.09 => - 9 %	-0.13 => - 13 %

Seasonal homogeneity analysis

The homogeneity testing detected 1 break for the seasonal analyses of homogeneity in the Fokstua precipitation series applying MASH (table 14). This break in 2005 is not so clearly explained by metadata.

Table 14: 1 break at 16610 Fokstua in august 2005 shown in ratio for the time series (1923-2015)

Seasons	Break: 1 - Break amplitude in ratio
1 (DJF):	No Break Points
2 (MAM):	No Break Points
3 (JJA):	2005: 1.05
4 (SON):	No Break Points

In the metadata table (table 15) we can see the different reasons for breaks at the two stations that have been to Fokstua (16600 & 16610). We see the same pattern as in the other networks, that relocations, new instruments and environmental changes are the main reasons for breaks in the time series.

Table 15: Metadata for the homogeneity break at Fokstua

YEAR	MONTH	DATE	Metadata information	Visible as break in our Homogenization
1923	6	30	**Telegraphing weather station** (WMO): 16600 Fokstua	
1933	9	23	Inspection from DNMI: Leakage in the rain gauge => fixing (soldering)	
1938	10	29	Inspection from DNMI: Leakage in the rain gauge => fixing (soldering)	
1942	11	14	Inspection from DNMI: Tight with blowing snow.	
1946	8	5	Inspection from DNMI: Fixing, leveling and painting of the rain gauge.	1946 (HOMER)
1948	8	18	Adjustment of the height and leveling of the rain gauge and straightening the windshield.	
1956	11	21	Renewal of rain gauge: Fixing, leveling and painting.	

1960	6	23	Renewal of rain gauge: Fixing, leveling and painting.	
1960	7	26	Change of observer.	
1961	7	21	Renewal of rain gauge: Fixing, leveling and painting.	RHTest_dlyPrcp
1968	5	31	Relocation: The met.station and the precipitation gauge moved 980 meter SE to the mountain farm from the railway station at Fokstua (**16610 Fokstua II)**	1968 (HOMER & MASH(DJF)) RHTest_dlyPrcp
1969	9	6	Change of rain gauge because of a leakage (Norwegian).	
1971	10	4	Inspection from DNMI: Fixing, leveling and painting of the rain gauge.	RHTest_dlyPrcp
1972	10	27	Inspection from DNMI: Nothing to report.	RHTest_dlyPrcp
1980	9	17	Relocation: Precipitation gauge moved 40 meter NW closer to the houses (fig.7).	
1981	5	5	Change of rain gauge because of a leakage (Norwegian).	
1995	11	15	Modernization of the weather station. Semi automation (computer based, new routines for sending observations. Still Swedish manual precipitation gauge.	
2000	5	29	Inspection from DNMI: Fixing, leveling and painting of the rain gauge.	RHTest_dlyPrcp
2001	5	22	Rain Gauge has bad location. It is too close to houses. This has been complained of in a few decades (since 1980), but nothing is done.	
2002	2	28	Precipitation gauge was moved 20 meters towards SE.	
2007	12	6	Full automation of the station: New precipitation gauge GEONOR T200 (600 mm) (fig. 27)	2009 (HOMER & MASH(DJF)) & RHTest_dlyPrcp

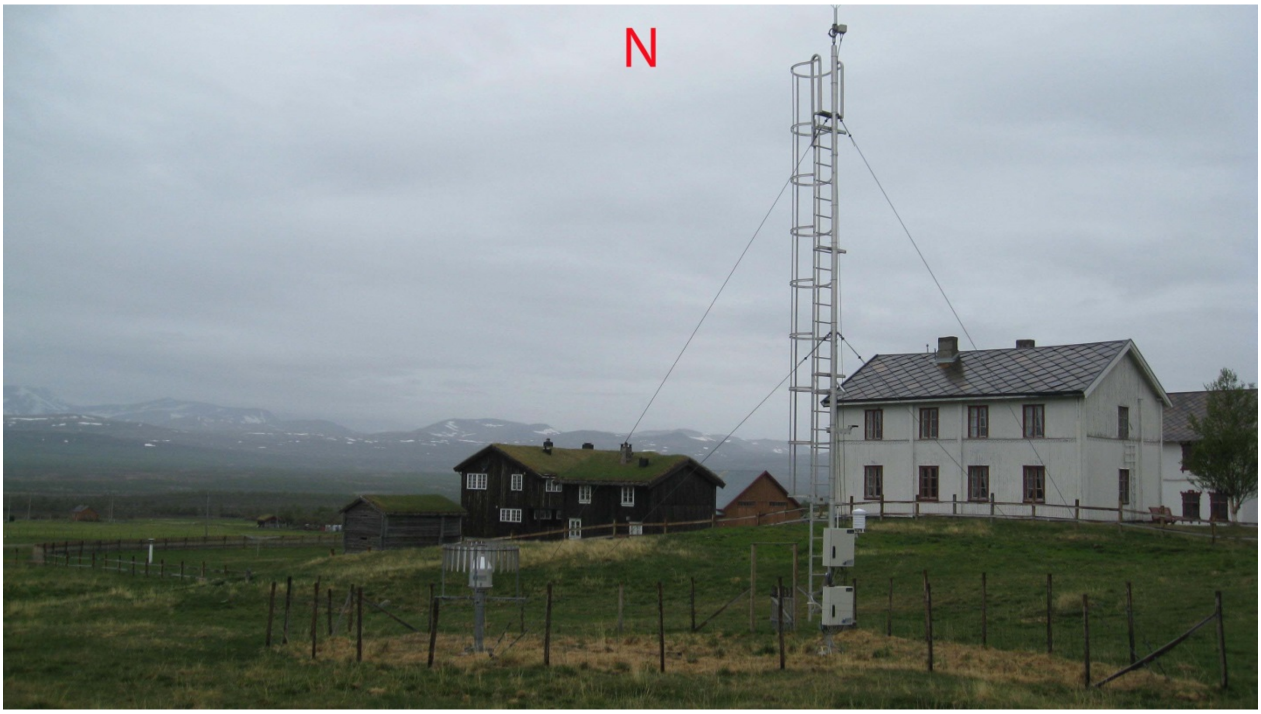


Figure 27: Photo of the" new" meteorological station at Fokstua against the N.

It is a little uncertain which method we should rely on. HOMER gives us 3 breaks in the homogeneity analysis and MASH gives us 1 break. We have to do a thorough investigation of the metadata both for Fokstua and the neighboring stations. MASH has one break in the summer 2005. We choose to exclude this break. When we look at the network for Fokstua (table 2) we can see that both Dombås and Folldal also have a changing point in 2005/2006. These stations were both relocated or renewed in 2005/2006. In the analysis we choose to exclude this break from the result for homogenization breaks at Fokstua (table 14). We choose to rely on the breaks from the annual analysis in 1946, 1968, and 2009. The reasons for the breaks are the instrument adjustment in 1946, the relocation in 1968 which is clear and the change of precipitation gauge in December 2007, which gives the break in 2009. When we look at the distribution of the annual precipitation we can see that there are large variations from year to year at Fokstua. From less than 300 mm to 600 mm per year (see figure 28).

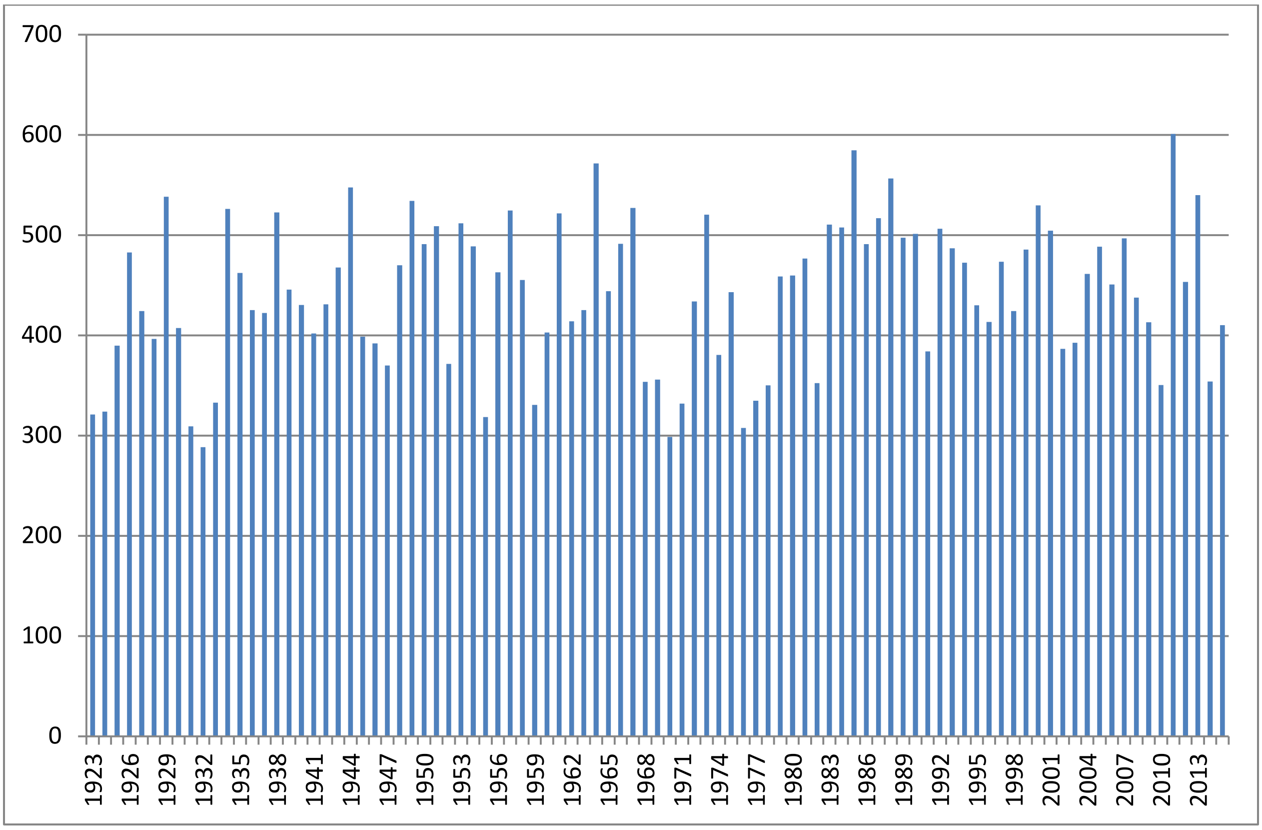


Figure 28: The distribution of the annual precipitation from Fokstua (1923-2015).

Homogenization of daily Precipitation

The RHtests_dlyPrcp program is applied to analyze the homogeneity of the daily precipitation series and the results are shown here:

Table 16: 8 change points in the series is accepted and identified as a homogeneity break.

Type 1	Statistical significant	Date	95 % confidence interval of p-value	Confi dence level	PF_{max} statistic	Nominal confidence level	QM-adjustments
1	Yes	19361120	(1.0000-1.0000)	0.95	37.8938	(17.8503-19.3874)	0.2957
1	Yes	19610702	(1.0000-1.0000)	0.95	108.6266	(17.4264-18.9088)	-0.2507
1	Yes	19680627	(1.0000-1.0000)	0.95	140.3327	(16.0595-17.3654)	-1.0748
1	Yes	19720520	(1.0000-1.0000)	0.95	50.4978	(15.6380-16.8895)	0.1161
1	Yes	19720709	(1.0000-1.0000)	0.95	18.8318	(17.2559-18.7162)	-6.2433
1	Yes	20001101	(1.0000-1.0000)	0.95	29.6503	(17.8223-19.3557)	-0.582
1	Yes	20081006	(1.0000-1.0000)	0.95	44.5811	(16.1115-17.4242)	-0.1711
1	Yes	20100624	(1.0000-1.0000)	0.95	29.2276	(15.9918-17.2890)	0.7133

Eight of these change points is approved of the program as homogeneity breaks for the Fokstua precipitation series (table 32). They are approved of the program as statistically significant. The most of the breaks are supported with metadata (see table 15): 1961, 1968, 1972, 2000 and 2008. Actually, there are only 2 breaks that cannot be confirmed of the metadata: 1936 and 2010. From the annual analysis (HOMER), the seasonal analysis (MASH) and the daily homogenization analysis (RHtests_dlyPrcp) it is clear that there are different number of breaks in the different programs: Respectively 3, 1 or 8 breaks in the precipitation series from Fokstua. In this analyses MASH did not have so many breaks that we had to reject. But we had to reject the break in MASH because of metadata from neighboring stations.

Fokstua station site has been relocated almost 900 meter in May 1968 and RHtests_dlyPrcp found this break as HOMER did. This break is the largest in the analysis (table 16). The mean adjustment for this break (mean of QM-adjustments =-1.0748~10 %) shown in column 8. That means the precipitation has decreased since the break in 1968 (>10 %). HOMER found the same decrease (-12 % in 1968). The RHtests_dlyPrcp recognize 8 breaks and we can found this in the figures 29 and 31.

Figure 29 shows the original precipitation series from Fokstua and the red line is from the the RHtests_dlyPrcp-program and it shows the breaks or the change-point in the time series. Figure 29, 31 and 32 is made of the RHtests_dlyPrcp-program.

Figure 30 shows the original vs. the new adjusted daily homogeneity precipitation series. We can see the original series (red) and we can see the outlines of the adjustments made with RHtests_dlyPrcp in blue. The adjustments are small. These time series are accessible through the eKlima portal (http://eklima.met.no).

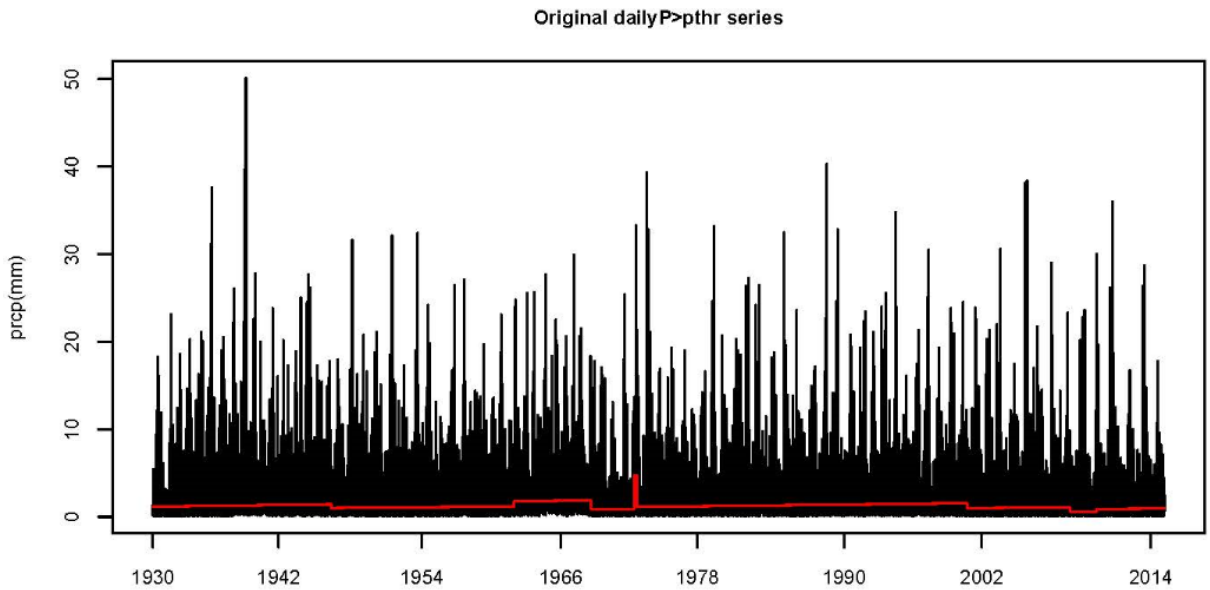


Figure 29: The original time series for 16610 Fokstua (1923-2015) showing the 8 breaks.

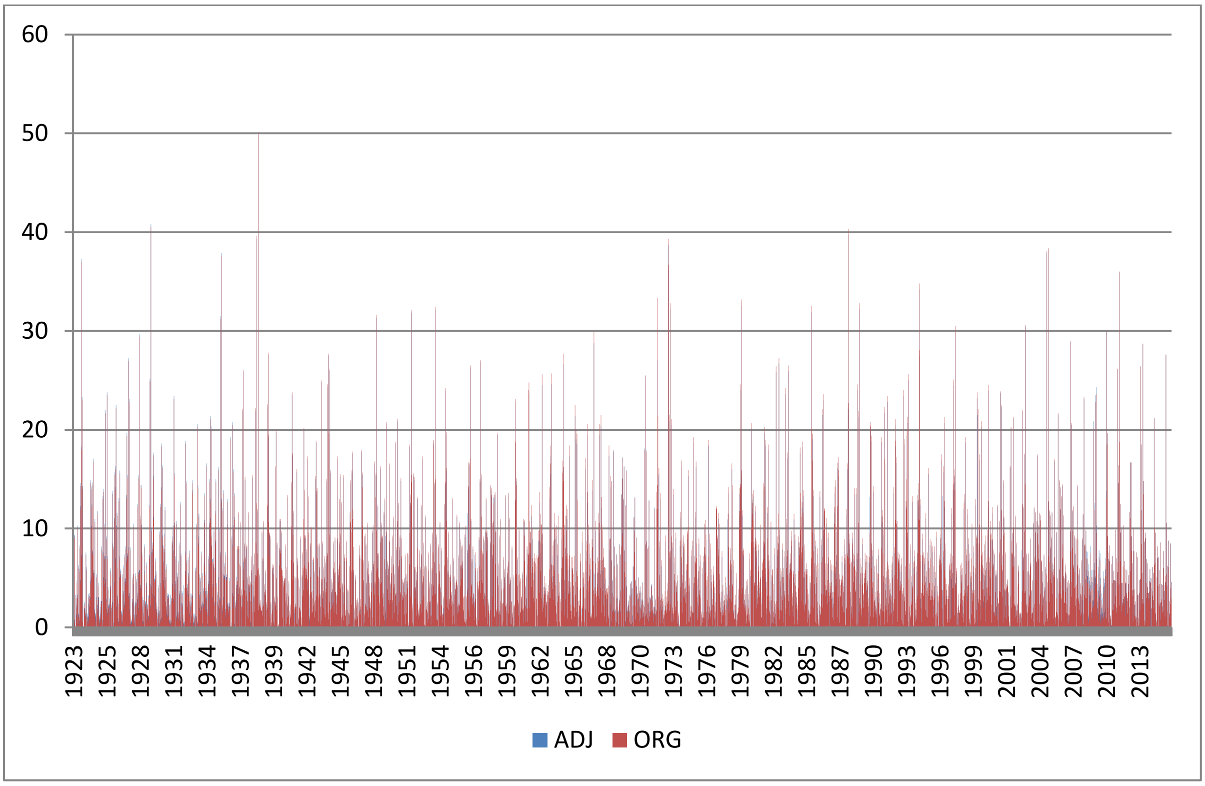


Figure 30: The original and the adjusted precipitation series from 16610 Fokstua after homogenization (with 8 breaks).

Looking at each break we notice that they appear differently. We choose to look at the 1968 break (fig. 31-32). The 1968-break, when the meteorological station was relocated about 900 meters, is the statistically most significant break in the time series. It is observed less precipitation at the new place at Fokstua Fjellstove than the old location. It is about 10 % less precipitation after the relocation in 1968 (fig. 32). The break from 2009 (new precipitation gauge) caused 13 % less precipitation from 2009.

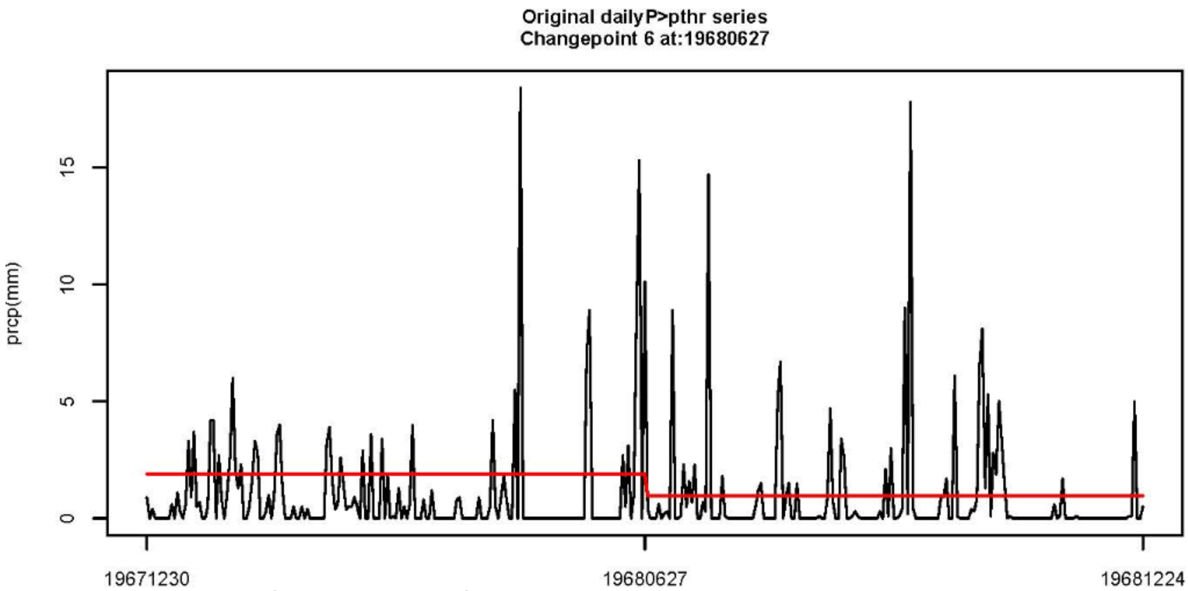


Figure 31: The break from June 1968 from 16610 Fokstua.

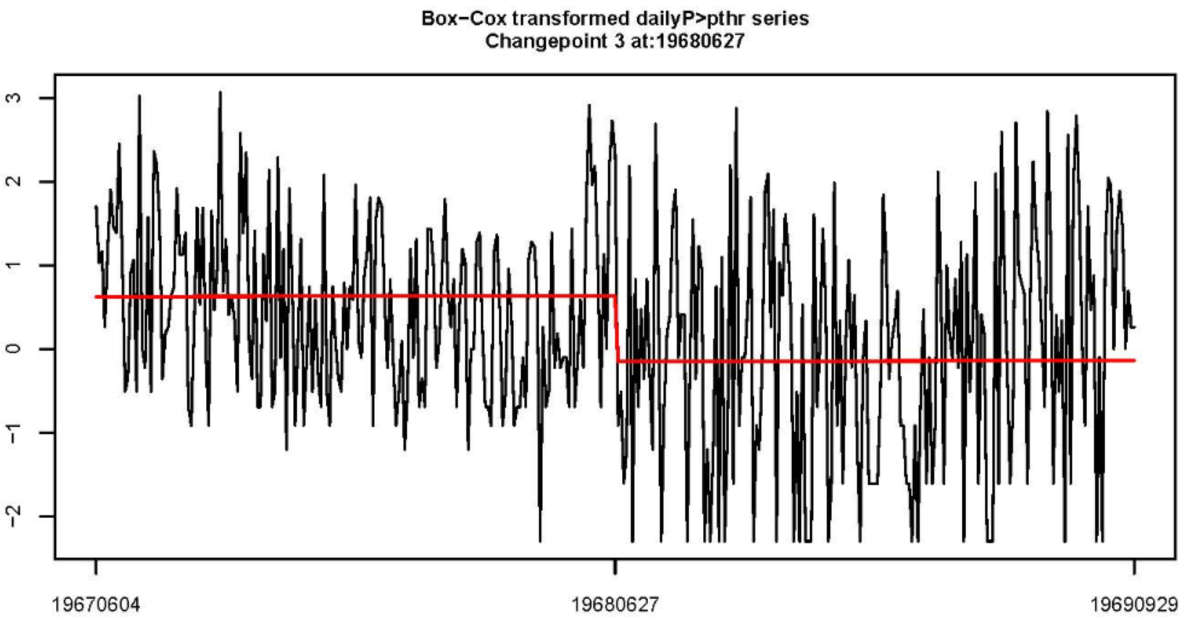


Figure 32: The break in 1968 from 16610 Fokstua shown in Box-cox-regression

II. Sauda

The Sauda precipitation series start in 1928. The annual precipitation varies from year to year around the normal (1961-1990), which is 2201 mm per year. The annual mean precipitation has increased almost 20 % during the almost 90 year's period of observation for Sauda. Most of the increase in the precipitation is from the last 30 years (fig. 33).

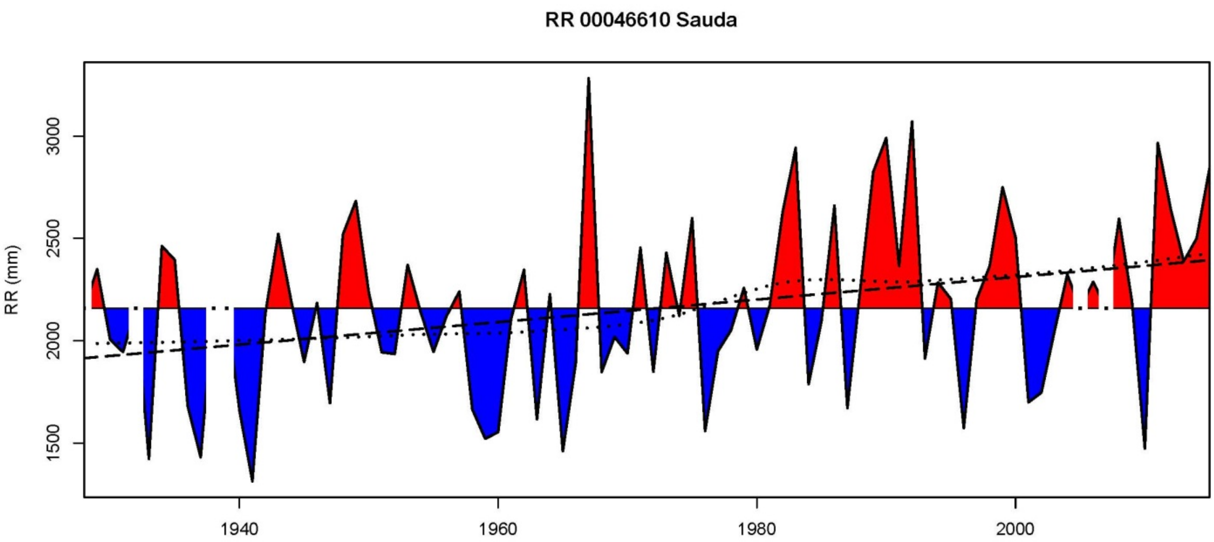


Figure 33: Time series for 46610 Sauda (1928-2015).

Sauda is in the area Ryfylke which in South-Western Norway. This is a wet area with relatively high annual precipitation. The annual mean temperature in Sauda is 6.2 °C. The highest temperature measured in Sauda since measurements began in 1928 was 32.7 ° C in 27

June 1988. Sauda is characterized by a typical western Norwegian coastal climate, but with more distinct differences between seasons than the areas closer to the sea. Autumn and winter gives more precipitation than the normal for Norway, while spring and summer can be hot and dry. The figure 34 shows the monthly distribution of precipitation in Sauda from the normal (1961-1990).

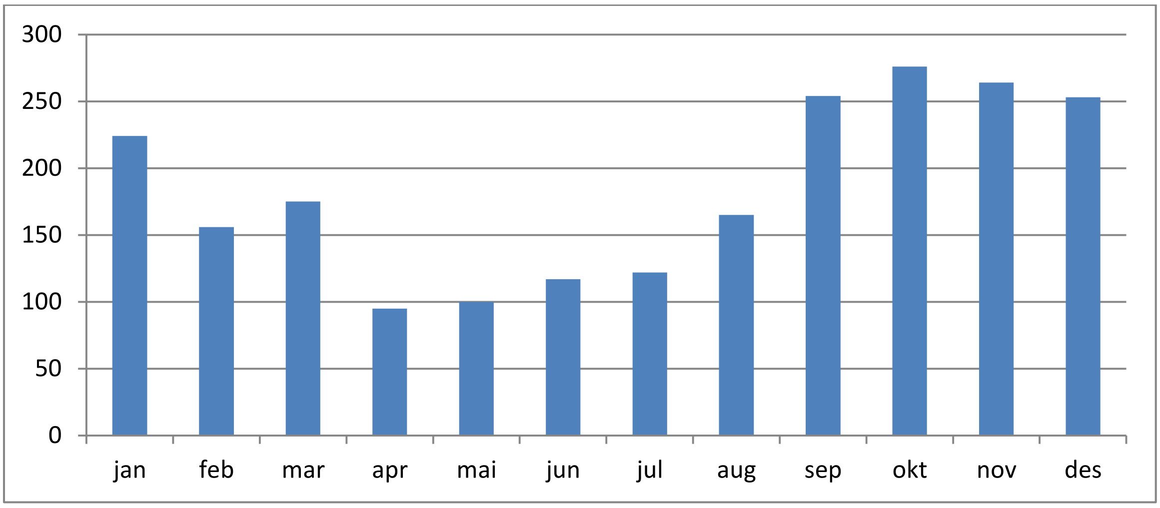


Figure 34: The monthly distribution of precipitation for 46610 Sauda (1961-90-normal).

Table 17 shows the monthly distribution number of days with precipitation at Sauda. In the winter it is the average over half the days every month which possessing precipitation.

Table 17: Number of days with precipitation at Sauda (from the normal 1961-1990).

Normal per month 1961 - 1990, number of days with precipitation RR>1													
Stnr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	Des	Year
46610	16.2	12.0	14.7	11.2	11.6	12.4	12.9	14.7	17.7	18.2	17.9	17.4	176.9

Annual homogeneity analysis

The homogeneity testing detected 1 break for the annual analyze of homogeneity at the Sauda precipitation series with HOMER (table 18). This break is supported by metadata, but it is very small 0.02 mm. See table 20 for metadata-information.

Table 18: Break amplitude shown in ratio, mm & % from HOMER.

Break: I	**2000**	
13 (Year)	0.977 % 2159.178 mm	Average annual rainfall over the period
Break amplitude in ratio	-0.02	The amplitude of the break = 2%

Seasonal homogeneity analysis

The homogeneity testing detected 5 breaks for the seasonal analyzes of homogeneity in the Sauda precipitation series applying MASH program/method (table 19).

Table 19: 2 breaks at 46610 Sauda: In Spring 1958 and in autumn in 2000 shown in ratio scale for the time series (1928-2015).

Season	Breaks: 2 :Break amplitude in ratio
1 (DJF):	No Break Points
2 (MAM):	1958: 1.06/
3 (JJA):	No Break Points
4 (SON):	2000: 1.03

In the metadata table (table 20) we can see the different reasons for breaks at the station in Sauda. We see the same patterns as other meteorological stations, that redecoration and new instrument or relocation are the main reasons for breaks in the time series.

Table 20: Metadata for the homogeneity break at 46610 Sauda.

YEAR	MONTH	DATE	Reason for break	Visible as break in our Homogenization
1928	8	1	New precipitation gauge (Norwegian type)	
1932	6	22	Inspection from DNMI: Precipitation gauge is moved a little farther from a wire fence and raised a few centimeters. CLEANING of the equipment because of the pollution.	
1932	8	1	**Telegraphing weather station** (WMO) (figure 46).	
1941	7	13	Inspection from DNMI: Measuring equipment is dirty and there is too much vegetation. Inspector instructs washing and woodcutting.	
1949	6	15	Inspection from DNMI: Pollution (zink) of the measuring equipment -> Cleaning of the equipment	
1954	9	4	Inspection from DNMI: Pollution (zink) of the measuring equipment -> Cleaning of the equipment	
1957	8	4	Inspection from DNMI: Redecoration of the rain gauge	1958 (MASH)
1963	6	23	New wood post to the precipitation gauge and moved 1 meter E	
1975	10	7	Precipitation gauge moved 10 meter E closer to the house, and more far away from the vegetation and the river. The past 10 years stood in the shade of a poplar tree.	
1988	10	21	Renewal of rain gauge and creation / fixing with larger screws and painting	
1999	8	24	Automation of station: New precipitation gauge GEONOR T200 (600 mm).	2000 (HOMER & MASH)
2007	6	6	Full automation of the whole meteorological station. And it is moved ca. 400 meter in NW-direction from near the fabric, the river mouth on the east side of the river and the fjord in SW to the west side of the river: Storelva and near the road (County-road 520) and the town center in N.	

Figure 35: View of the station area when it became a telegraphing weather station in 1932.

It is a little uncertain which breaks we here can rely on. But it is not so many different breaks to have an opinion about. We have to do a thorough investigation of the metadata both for Sauda and the neighboring stations. The program (MASH) that we use for seasonal testing has sometimes unfortunately a tendency to show too many breaks. It can often treat anomalies as breaks. We have made some variety and ironed some breaks. Then we often can see compensating breaks over two consecutive years. In the analysis we choose to exclude these breaks from the result (table 19). Some of the breaks we disregard because we cannot find any clear reason for the break. Breaks from other stations in the network (table 4), we have also been rejected some breaks. E.g. 1962 (see Eikemo) and 1939 (see Hellandsbygd) in the table. We choose to rely on the breaks in 1958 and 2000 from the seasonal homogeneity analyses. The redecoration in 1958 was so big and the precipitation instruments were so damaged and shabby as a result of much use that it had to be replaced. We accept this as a break. The break in 2000 is supported by the metadata, HOMER and MASH. The automation of the station started in 1999 and the precipitation gauge changes the 24th of august 1999 from a Norwegian manual type to an automatic GEONOR weighting gauge. The change of precipitation gauge is the reason for the break. We see that precipitation has a smoother distribution the last 15 years since the millennium and the automation (figure 36). The station was relocated the 6th of June 2007 to the other side of the river (W) (see figure 10) about 400 meters further W to the other side of the river. We think this relocation is too new to be found in the analyses.

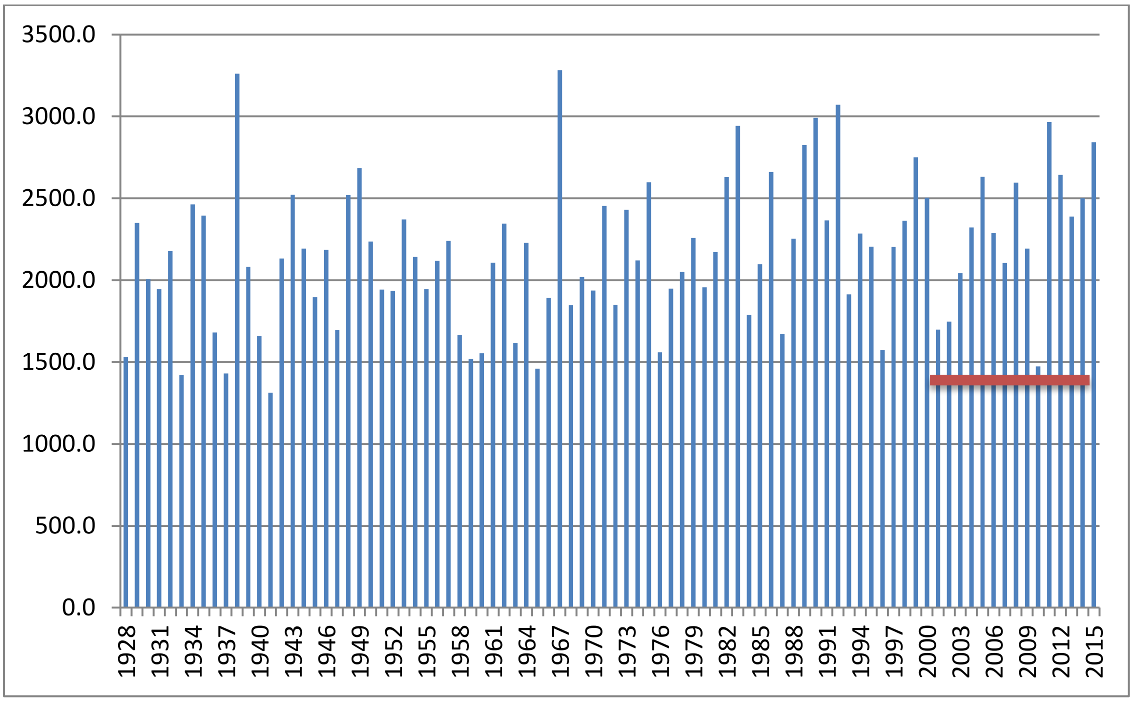


Figure 36: The distribution of the annual precipitation.

Homogenization of daily Precipitation

The RHtests_dlyPrcp program is applied to analyze the homogeneity of the daily precipitation series (table 21):

Table 21: 0 change points in the series is either accepted or identified as a homogeneity break.

Type 1	Statistical significant	QM-adjustments
0	No	**0** change-points in Series

Initially the program identifies 33 change-points in the Sauda precipitation series. Of these, it is worth mentioning some of the change-points, but that was not approved as a break of the program (>0.95).

Table 22: Some of the proposals for change-point from RHtests_dlyPrcp program:

Type 1	Statistical significant	Date	95 % confidence interval of p-value	Confidence level	PF_{max} statistic	Nominal confidence level	QM-adjustments
0	YifD	19491016	(0.9981-0.9981)	0.950	8.3427	(21.2904- 22.6562)	No
0	Yes	19760410	(1.0000-1.0000)	0.950	48.4079	(19.1933- 20.4008)	No
0	YifD	20080331	(0.9999-0.9999)	0.950	16.6323	(19.0237-20.2127)	No
0	YifD	19880705	(0.9922-0.9922)	0.950	5.7544	(19.9410-21.2085)	No

These change-points are not approved of the program because they are seen as not statistically significant. Some of the examples in table 22 are supported with metadata (see table 20): Break in 1949, 1975, 1988 and 2007. It is important to analyze the results, to determine whether or not the smallest shift among all the shifts/change points is still significant. The smallest shift can be determined to be significant if its p-value is larger than the corresponding upper bound, and not to be significant if it is smaller than the lower bound. However, if the p-value is larger than the corresponding upper bound, and 95% uncertainty range, one has to determine subjectively whether or not to take this change point as significant. These change points, we reject as confirmed breaks. We choose to repeat and conclude with the breaks from the seasonal chapter: 1958 & 2000 for 46610 Sauda.

Figure 37 show the “new” daily homogenized precipitation series from Sauda. These time series are accessible through the eKlima portal (http://eklima.met.no).

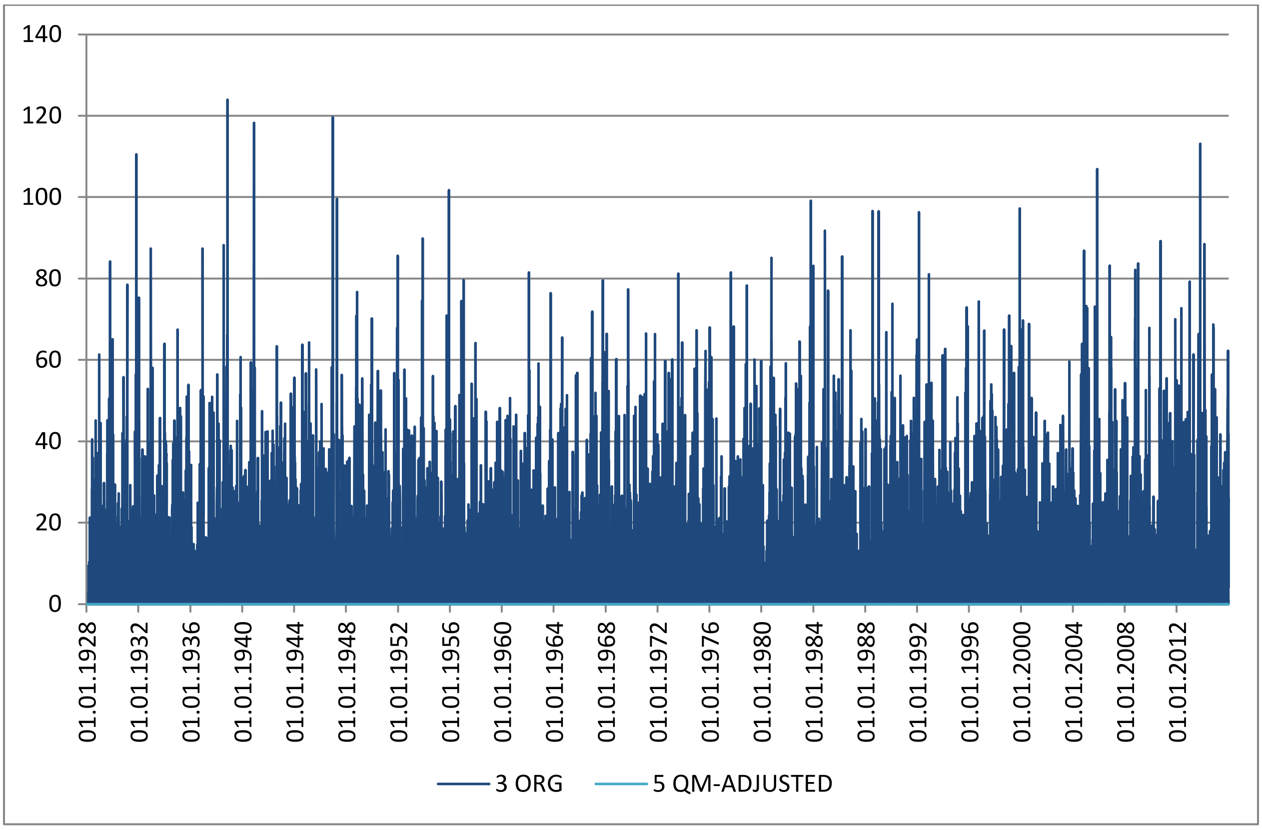


Figure 37: The adjusted precipitation series from 46610 Sauda after homogenization (which is 0).

III. Takle

The Takle precipitation series start in 1950. The annual precipitation varies from year to year around the normal (1961-1990), which is 3179 mm per year. The annual mean precipitation has increased about 15 % during the 65 year observation period. Most of the increase in the precipitation is from the last 30 years (fig. 38).

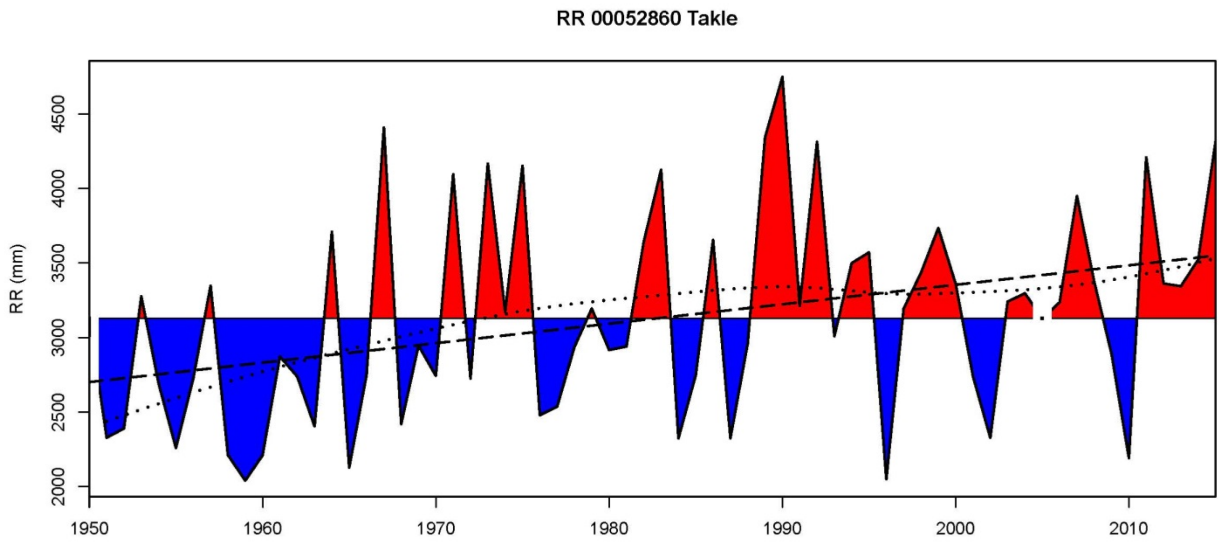


Figure 38: Precipitation series for 52860 Takle (1950-2015).

Takle is located by the Sognefjord in Western Norway. Takle is characterized by a typical western Norwegian coastal climate. This area has some of the highest annual precipitation precipitation. Autumn and winter gives much more precipitation than the normal for Norway. October is the month with most precipitation (>400 mm). Takle is not too far from Brekke. Brekke is the place in Norway, which officially have the highest annual normal precipitation (3575 mm) for the 1961-1990 period. Figure 39 shows the monthly distribution of precipitation in Takle for the normal period (1961-1990).The annual mean temperature at Takle is 6.8 °C. The highest temperature measured at Takle since measurements began in 1950 was 28.8 ° C the 2nd of August 1969. Takle has few days with days less than 0°C.

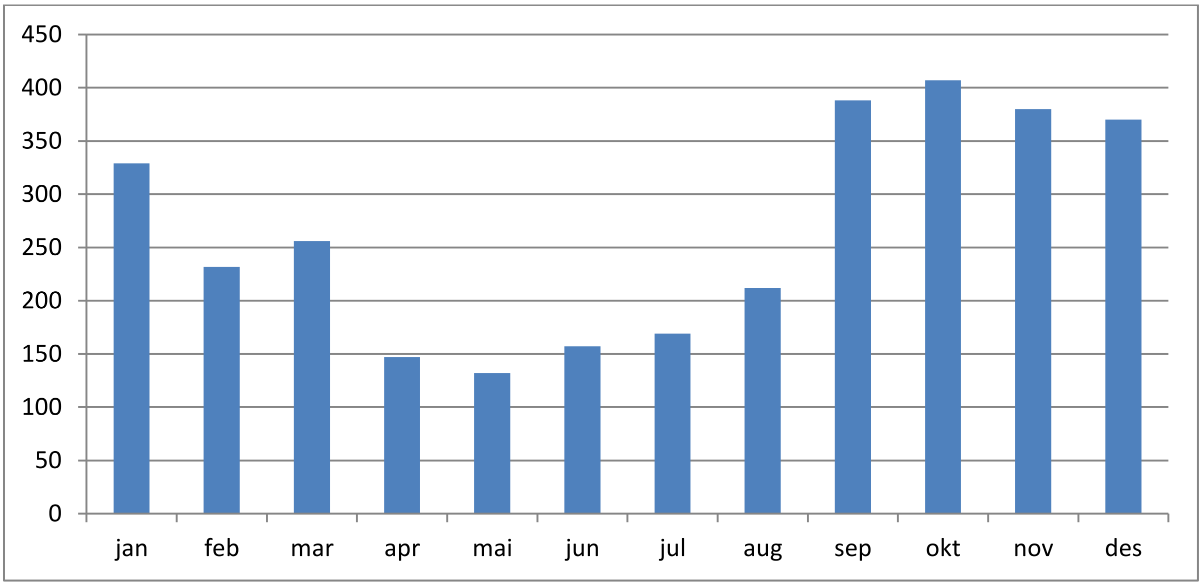


Figure 39: The monthly distribution of precipitation for 52860 Takle (1961-90-normal).

Table 33 shows the monthly distribution number of days with precipitation at Takle. It is only in the summer it rains less than half the days in the month.

Table 23: Number of days with precipitation at Takle (for the normal period 1961-1990).

Normal per month 1961 - 1990, number of days with precipitation RR>1													
Stnr	jan	feb	mar	apr	mai	jun	jul	aug	sep	okt	nov	des	year
52860	18,1	14,4	16,6	13,1	12,8	13,2	14,8	16,0	19,4	20,1	19,1	19,5	197,1

Annual homogeneity analysis

The homogeneity analysis of annual series with HOMER detected one break for the Takle precipitation series (table 24). The break is determined to 1968. The break is supported by metadata, but it is very small 0.02. That means 2 % increase in precipitation in 1968. See table 36 for metadata-information.

Table 24: Break amplitude shown in ratio, mm & % from HOMER.

Break: I	**1968**	
13 (Year)	1.019 % 3127.331mm	Average annual rainfall over the period
Break amplitude in ratio	-0.02	The amplitude of the break = 2%

The correlations between Takle and the other series in the reference network are presented in table 7.

Seasonal homogeneity analysis

The homogeneity testing detected four breaks for the seasonal analysis of homogeneity in the Takle precipitation series applying MASH program/method (table 25).

Table 25: 3 breaks at 52860 Takle: In the winter 1959 and 1968 and spring 1956 shown in ratio scale (correction factor) for the time series (1950-2015).

Seasons	Breaks: 8 (3?) - Break amplitude in ratio
1 (DJF):	1959: 0.94/ 1968: 0.98
2 (MAM):	1956: 0.95/
3 (JJA):	None
4 (SON):	-None

In the metadata table (table 26) we can see the different reasons for breaks at the station at Takle. We see the same pattern as other meteorological stations, that relocations, redecoration and environmental changes are the main reasons for breaks in the time series.

Table 26:Metadata for the homogeneity break at 52860 Takle.

YEAR	MONTH	DATE	Metadata information	Visible as break in our Homogenization
1950	6	1	**Telegraphing weather station** (WMO) (figure 53).	
1956	5	6	Inspection from DNMI: Precipitation gauge found in order, just little redecoration and painting of the measuring equipment.	1956 (MASH (MAM))
1959	10	2	Relocation: Precipitation gauge moved 30 meter S closer to the house (13,5 m) (figure 55).	1959 (MASH (DJF))
1966	6	23	Inspection from DNMI: Reduction and wood cutting of vegetation around the rain gauge before the inspection.	RHTest_dlyPrcp
1970	8	25	Inspection from DNMI: Garage built up and 2 houses near the screen were demolished. Specific date is uncertain, but it happened between 1966 and 1970 (between two inspections.	1968 (HOMER & MASH(DJF))
1980	9	29	Renewal of rain gauge and creation / fixing with larger screws and painting.	
1986	4	2	Change of rain gauge: From Norwegian to Swedish rain gauge.	
1998	9	9	Inspection from DNMI: The wind screen of rain gauge is damaged. It must be replaced = ok.	
2005	7	12	The station upgraded to computer based data delivery (PIO).	
2014	5	9	Full automation of the whole meteorological station. And it is moved ca. 20 meter in N-direction from little farther from the house and barn and nearer the fjord. Change of rain gauge to a Lambrecht-tipping bucket sensor (figure 55).	

The weather station at Central Takle was established the 1st of June 1950 on agricultural area where the meteorological station is located near the Sognefjorden. It is a little uncertain which breaks we here can rely on. We had to do a thorough investigation of the metadata both for Takle and the neighboring stations. The program (MASH), that we use for seasonal testing has a tendency to show too many breaks. It can often treat anomalies as breaks. Then we often can see compensating breaks over two consecutive years. In the analysis we choose to exclude these breaks from the result (table 25). Some of the breaks we disregard because we cannot find any clear reason for the break (e.g. 1960). We choose to rely on the breaks in 1956, 1959 and 1968 from the seasonal homogeneity analyses. The redecoration in 1956 is so prominent in the detection. We accept this as a break. The break in 1959 and 1960 we reject because we see compensating breaks over two consecutive years (as in Sauda). The break in 1968 is supported by the metadata, HOMER and MASH. The building environment around the station has changed with a building of the garage and a demolition of two other houses at the farm. This is the reason for the break. The station is relocated twice (<100 m) (fig. 41), but this does not seem to have had any impact on the precipitation series. When we look at the distribution of the annual precipitation we cannot find any changes in the precipitation pattern at Takle in the observation period (1950-2015) (see figure 40). The automation of the station and change to an automatic sensor, Lambrecht-tipping bucket sensor, happened in May 2014. It is not possible to find that yet in a homogenization analysis or in a statistic tools.

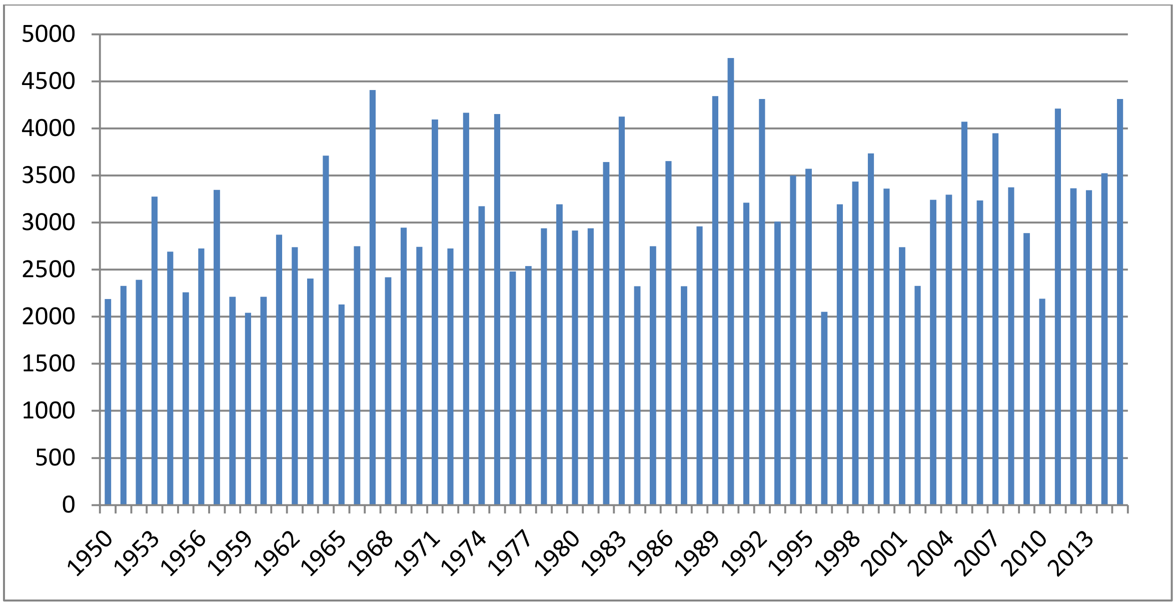


Figure 40: The distribution of the annual precipitation at Takle 1950-2015.

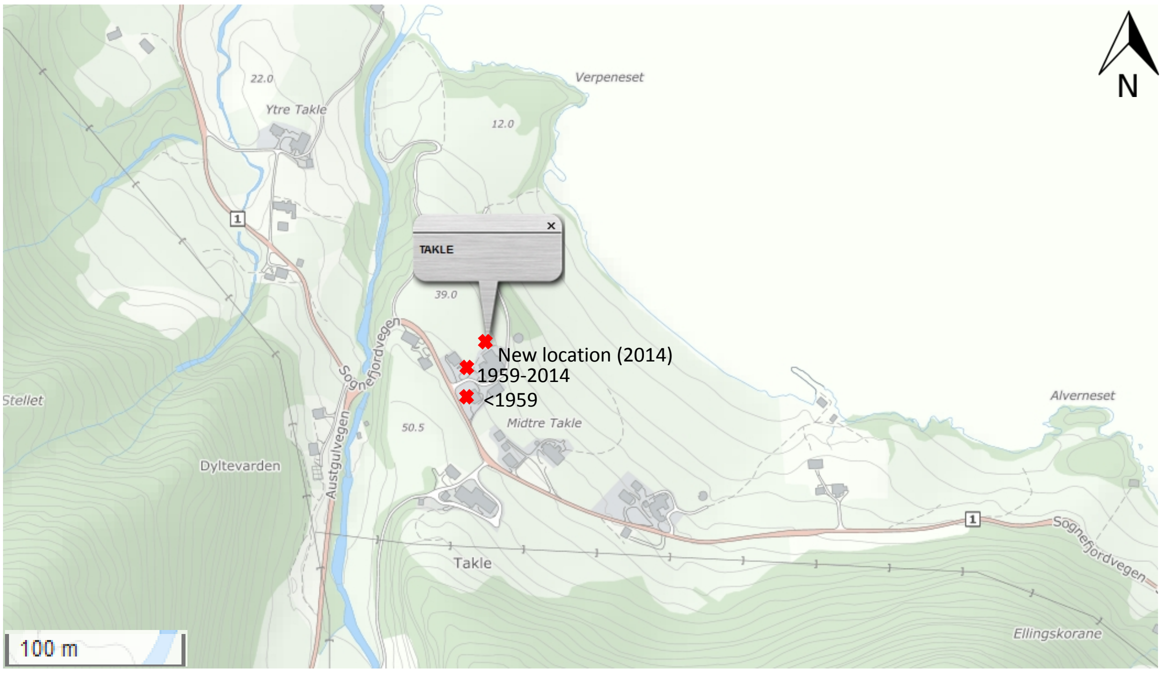


Figure 41: Locations of the precipitation gauges at Takle.

Homogenization of daily Precipitation

The RHtests_dlyPrcp program is applied to analyze the homogeneity of the daily precipitation series. The program identified one homogeneity break in the series (table 27):

Table 27: 1 change-point in the series is accepted and identified as a homogeneity break.

Type 1	Statistical significant	Date	95 % confidence interval of p-value	Confidence level	PF_{max} statistic	Nominal confidence level	QM-adjustments
0	Yes	19660904	(1.0000-1.0000)	0.950	56.9995	(30.3068-32.8227)	1.9542

Initially the program identifies 14 other change-points in the Takle precipitation series. Of these, it is worth mentioning some of the change-points (table 28), but that was not approved as a break of the program (>0.95).

Table 28: Some of the proposals for change-point from RHtests_dlyPrcp program:

Type 1	Statistical significant	Date	95 % confidence interval of p-value	Confidence level	PF_{max} statistic	Nominal confidence level	QM-adjustments
0	YifD	19650407	(0.9893-0.9893)	0.95	9.3253	(19.0898-20.6704)	No
0	Yes	19701025	(1.0000-1.0000)	0.95	35.4273	(19.2196-20.8176)	No
0	YifD	20000112	(0.9965-0.9965)	0.95	8.28	(16.4277-17.6639)	No
0	Yes	20041021	(1.0000-1.0000)	0.95	25.5435	(13.7112-14.6662)	No

These 14 other change-points are not approved of the program as change points because they are seen as not statistically significant. Some of these change points are supported with metadata (see table 26): Break in 1965, 1970, 2000 and 2004. In relation to the discussion from the previous station (Sauda), then there are the same reasons that recur applicable. The software program rejects the change points. The changes are too small and it is rare that inspections itself or transfer to a PC (for the observer) is reason enough to cause a homogeneity break.

From the annual analysis (HOMER), the seasonal analysis (MASH) and the daily homogenization analysis (RHtests_dlyPrcp) it is clear that there is a homogeneity break at Takle in this period. We have rejected many of the proposed breaks of the MASH analysis since it has a habit of showing consecutive compensating breaks. At Takle the demolition of the two other houses and the building of the garage may have influenced the measurements and thus created a homogeneity break: Somewhere between 23.06.1966 and 08.25.1970 has. HOMER and MASH suggested both 1968. RHtests_dlyPrcp use the date: 4.9.1966. So we accept this break.

Figure 42 shows the original precipitation series from Takle and the red line is from the the RHtests_dlyPrcp-program and it shows the break or the change point from 1968. Figure 42 and 44 are made of the RHtests_dlyPrcp-program

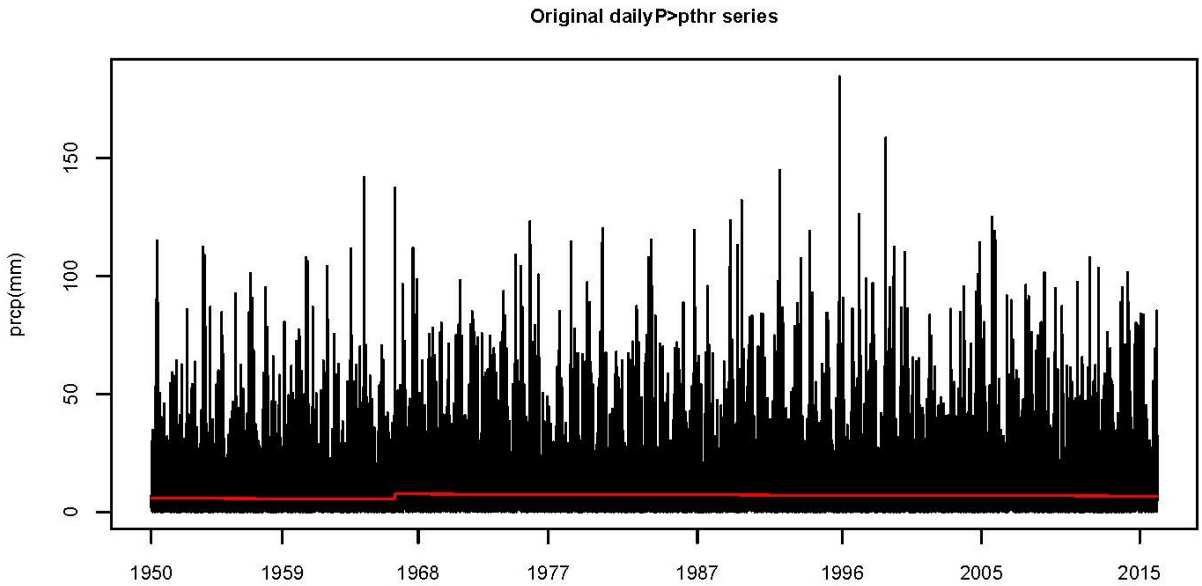


Figure 42: The original time series for 52860 Takle (1950-2015) showing the 1 break.

Figure 43 shows the original vs. the new adjusted daily homogeneity precipitation series. We can see the original series (red) and we can see the outlines of the adjustments made with RHtests_dlyPrcp in blue. The adjustments are clearly from 4.9.1966. The adjustment is not so big, only 2 % increase in the precipitation from 1966. These time series are accessible through the eKlima portal (http://eklima.met.no).

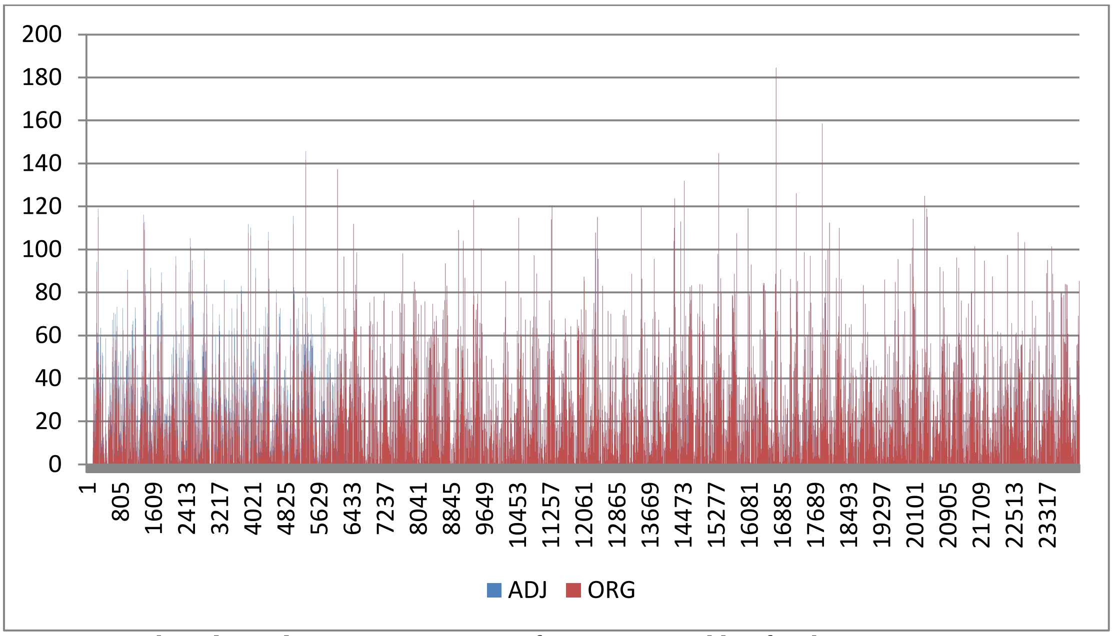


Figure 43: The adjusted precipitation series from 52860 Takle after homogenization.

It is observed more precipitation after the environment change at Takle in the late 1960s. It is around 2 % more precipitation after the settlement was changed between 1966 and 1970 (fig. 41).

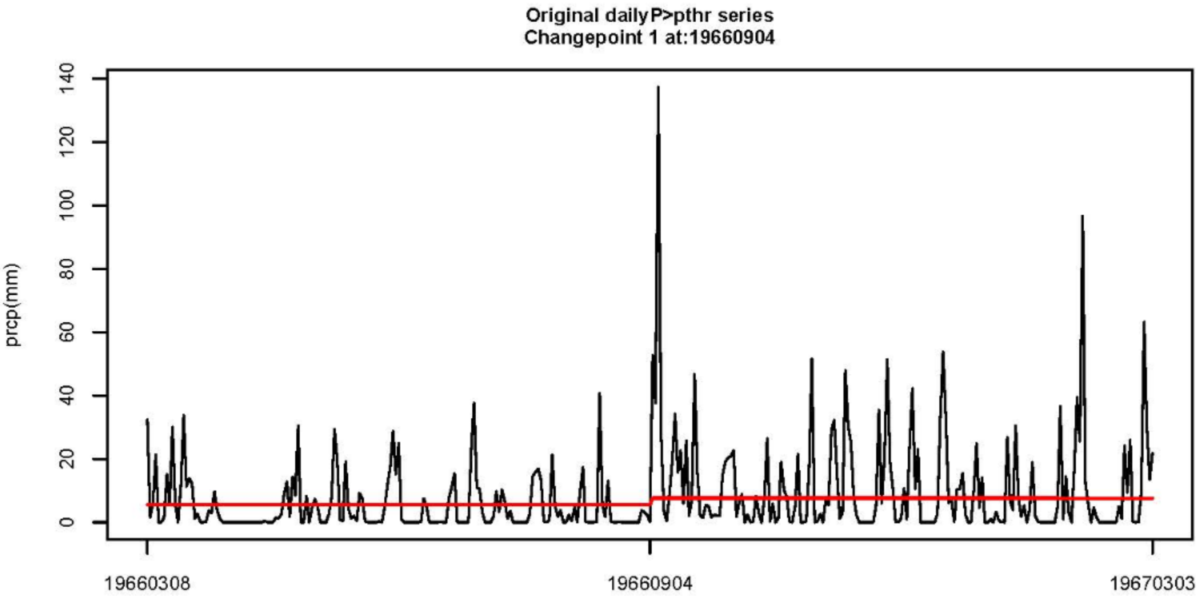


Figure 44: The break from September 1966 from 52860 Takle.

Figure 45 shows the box-cox transformation from 1966-break.

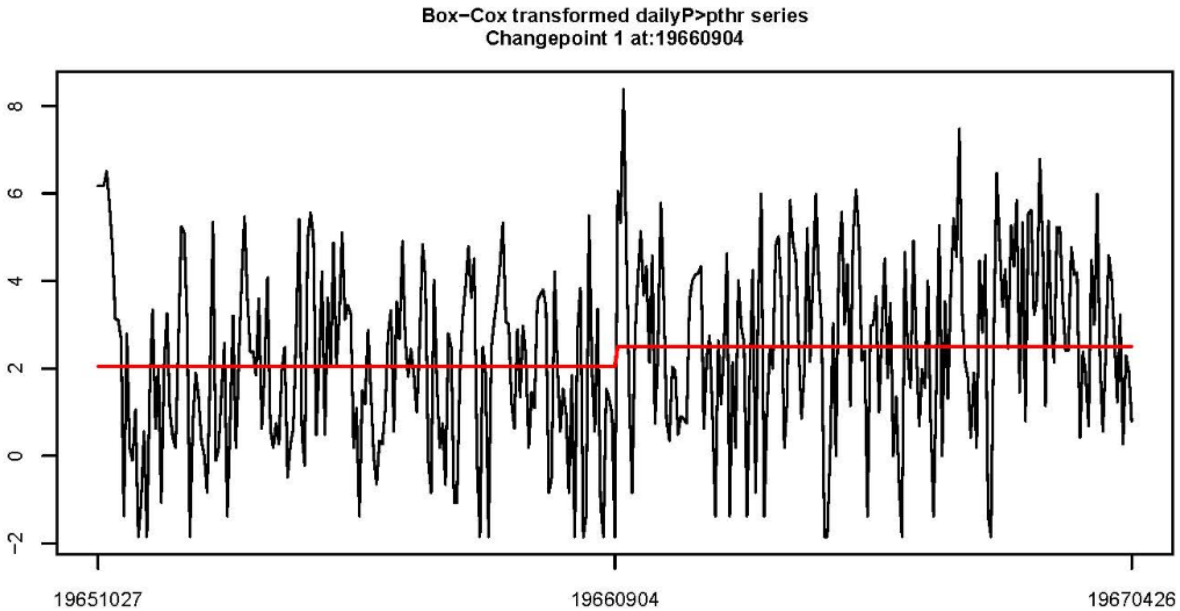


Figure 45: The break in 1966 from 52860 Takle shown in Box-cox-regression.

IV. Mo i Rana

The Mo i Rana precipitation series start in February 1920. Unfortunately the daily data are not digitized before 1935. The annual precipitation varies from year to year around the normal (1961-1990), which is 1431 mm per year. The inter-annual variability is large. It has varied between 750 mm (1960) to 2200 mm (1943). The annual mean precipitation development is almost the same during the 80 year's period of observations for Mo i Rana (called here: Mo). There is little sign of increasing or decreasing trend in the precipitation (fig. 46). The station has moved 3 times (i.e. 4 locations) within a range of less than 5 km on both sides of the Ranfjord (fig. 19). We will see whether this has had an influence on the trend.

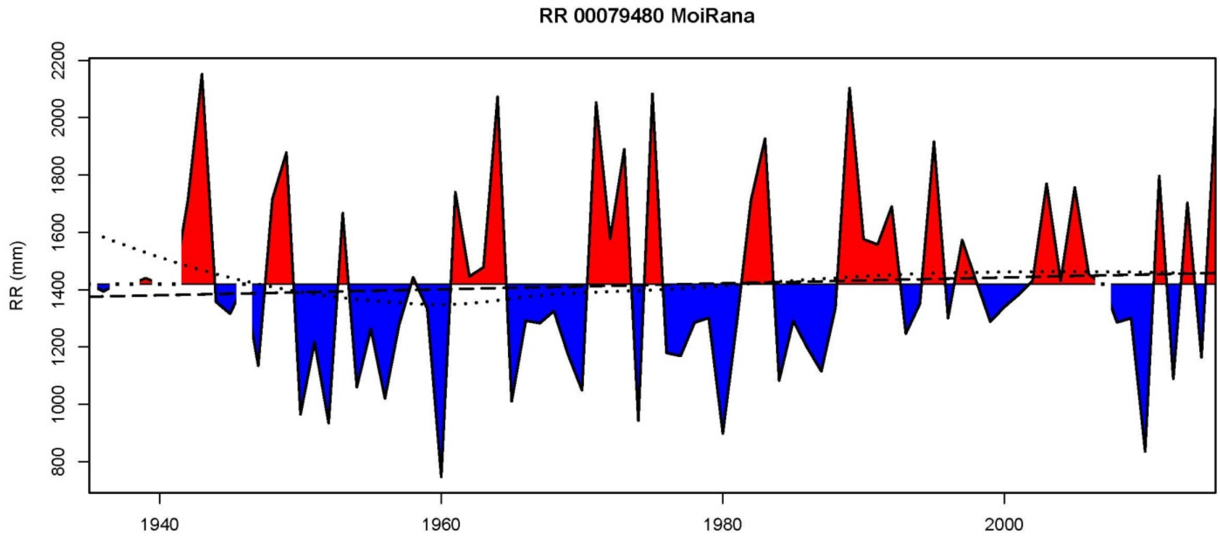


Figure 46: Precipitation series for 79480 Mo i Rana (1935-2015) (4 stations).

Mo is located by the Ranfjorden (fig. 17), just on the southern side of the Saltfjellet mountains with the Svartisen glacier, Norway's second largest. The river Ranelva flows out in the Ranfjorden in Mo. This is a relatively wet area with medium annual precipitation for Norway. The maximum 24 hour precipitation is 123.1 mm from the 26th of August 1971. Mo is characterized by a typical northern Norwegian inland climate with long, cold winters, and short, warm summers. Autumn and winter gives most precipitation. October is the month with most precipitation (>180 mm). The figure 47 shows the monthly distribution of precipitation in Mo for the normal period (1961-1990). The annual mean temperature in Mo is 2.8 °C.

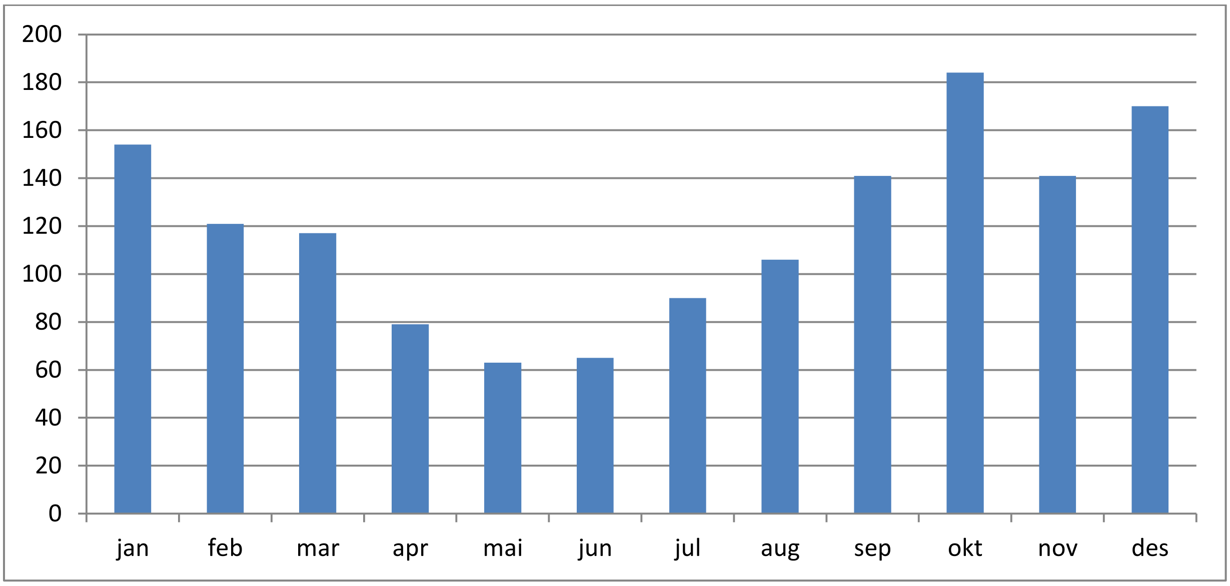


Figure 47: The monthly distribution of precipitation for 79840 Mo i Rana (1961-90-normal).

Table 29 shows the monthly distribution number of days with precipitation in Mo i Rana. It rains less than six months per year in Mo i Rana.

Table 29: Number of days with precipitation in Mo i Rana (for the normal period 1961-1990).

Normal per month 1961 - 1990, number of days with precipitation RR>1													
Stnr	jan	feb	mar	apr	mai	jun	jul	aug	sep	okt	nov	des	år
79480	14,2	13,5	12,5	10,7	9,5	10,4	13,1	13,0	15,8	16,8	14,6	16,7	160,8

Annual homogeneity analysis

The homogeneity testing detected 2 breaks for the annual analysis of homogeneity at the Mo precipitation series with HOMER (table 30). The breaks are in this analysis determined to 1946 and 1957. These breaks are both supported by metadata (table 32) and in these cases it is relocations. The first break in 1946 is a negative break: 14 % less precipitation after 1946. The second break is in 1957 and it is positive. There is an increase in the precipitation after 1957 in Mo, but it is very small: 0.04. That means 4 % increase in precipitation from 1957. See table 44 for metadata-information.

Table 30: Break amplitude shown in ratio, mm & % from HOMER for the 2 breaks.

Break: I	**1968**	
13 (Year)	0.9 % 1419.428mm	Average annual rainfall over the period
Break amplitude in ratio	-0.14	The amplitude of the break = -14%
Break: II	**1957**	
13 (Year)	1.038 % 1419.428 mm	Average annual rainfall over the period
Break amplitude in ratio	0.04	The amplitude of the break = 4%

Seasonal homogeneity analysis

The homogeneity testing detected 5 breaks for the seasonal analyzes of homogeneity in the Mo precipitation series applying MASH program/method (table 31).

Table 31: 5 breaks at 79480 Mo i Rana: 4 in the winter and 1 in the spring shown in ratio scale (correction factor) for the time series (1935-2015).

Seasons	Breaks: 5 - Break amplitude in ratio
1 (DJF):	M1946: 1.04/ M1957: 0.96/ 1983: 1.06/ 2002: 0.95
2 (MAM):	M1941: 1.38/
3 (JJA):	
4 (SON):	

In the metadata table (32) we can see the station history and find the reasons for breaks at the station in Mo i Rana. We see the same pattern as other meteorological stations, that relocations, new instruments, redecoration and environmental changes are the main reasons for breaks in the time series.

Table 32: Metadata for the homogeneity break at Mo i Rana

YEAR	**MONTH**	**DATE**	**Metadata information**	**Visible as break in our Homogenization**
1920	11	1	**79470 Mo i Rana (1. Fig. 62)** Start: 17.6.1935 (digitized)	
1935	6	17	**Telegraphing weather station** (WMO) (fig. 61). End: 1.7.1941	
1941	12	13	Relocation: New meteorological station: **79500 Ytteren i Rana** Precipitation gauge moved 3 km **(2. Fig. 19)** from Mo center in N direction to the area called Ytteren on the other side of the fjord. New observer. End: 9.7.1946	1941 (MASH (MAM))
1946	7	11	Relocation: New meteorological station: **79510 Mo i Rana II** Precipitation gauge moved 2 km in SE direction against the area called Selfors **(3. Fig. 62)**. New observer. End: 31.12.1956	1946 (HOMER & MASH (DJF))
1957	10	7	Relocation: New meteorological station: **79480 Mo i Rana III** Precipitation gauge moved 1,5 km **(4. Fig. 19)**. New observer from Norsk jernverk AS.End as weather station: 1.9.1965.	1957 (HOMER & MASH (DJF))
1959	4	22	The measuring instruments are placed on soil and lawn is sown. The underground is changed from gravel to grass.	
1965	10	25	Change of precipitation gauge and new post. The meteorological station continues with only precipitation measurement.	
1965	11	13	Change in the observations routine (New observation time from 08.00 to 10.30. New observer.	
1982	9	2	Relocation: Precipitation gauge moved 20 meter ESE closer to a path.	
1983	6	10	Change of rain gauge: From Norwegian to Swedish rain gauge.	1983 MASH (DJF)
1992	4	1	New observer (Mo industripark AS)	
2000	8	28	Inspection from DNMI: Relocation: Precipitation gauge will move 500 meter and new observer.	
2002	3	12	Changed observation and submission procedures (sms).	2002 MASH (DJF)

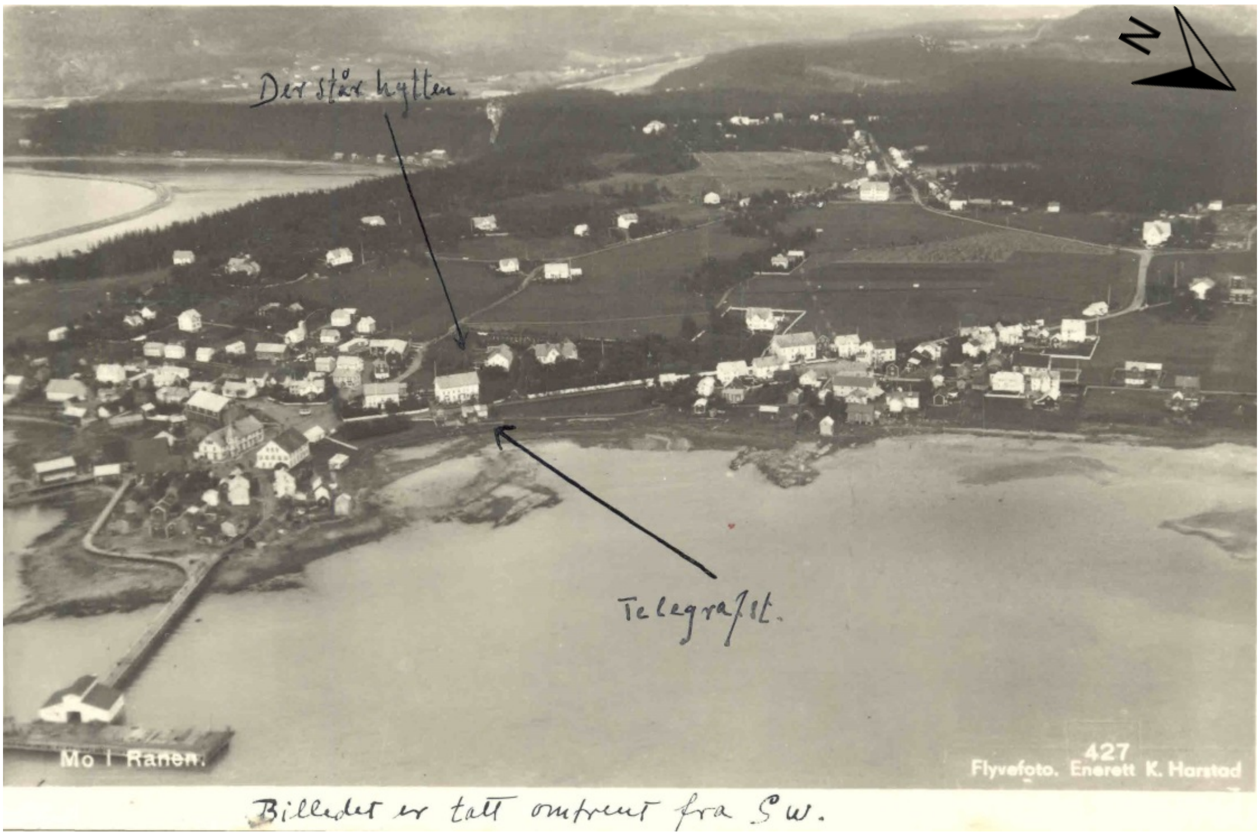


Figure 48: Photo of the first the meteorological station: 79470 Mo i Rana (1920-1941). It became a telegraphing weather station 17 June 1935.

It is a little uncertain which breaks we here can rely on. We have to do a thorough investigation of the metadata both for Mo i Rana and the neighboring stations. Some of the breaks we disregard because we cannot find any clear reason for the break. We choose to rely on the breaks in 1946 and 1957 from the annual and the seasonal homogeneity analyses. Both of these breaks are caused by relocations (2-3 km, fig. 19) and change of observer. So we are confident about these breaks. Figure 48 is a picture form the old station area from the meteorological station in Mo i Rana (79470: 1920-1941). In addition, the breaks in 1941 (MAM), 1983 (DJF) and (2002) are good suggestions from the program that makes the seasonal homogeneity analyses and they are all supported by the metadata. 1941 is relocation of the station 3 km to the other side of the Ranfjord. In1983 the gauge was changed from Norwegian to Swedish precipitation gauge, which we have seen before can be a reason for homogeneity break (Hanssen-Bauer & Førland, 1994). In 2002, the sending procedure of the observations changed. That can also be a logic reason for homogeneity break in the precipitation series because observers need to change observation practices. We accept this as a break in the seasonal analyzes. When we look at the distribution of the annual precipitation we cannot find any changes in the precipitation pattern in Mo in the observation period (1935-2015) (see figure 49).

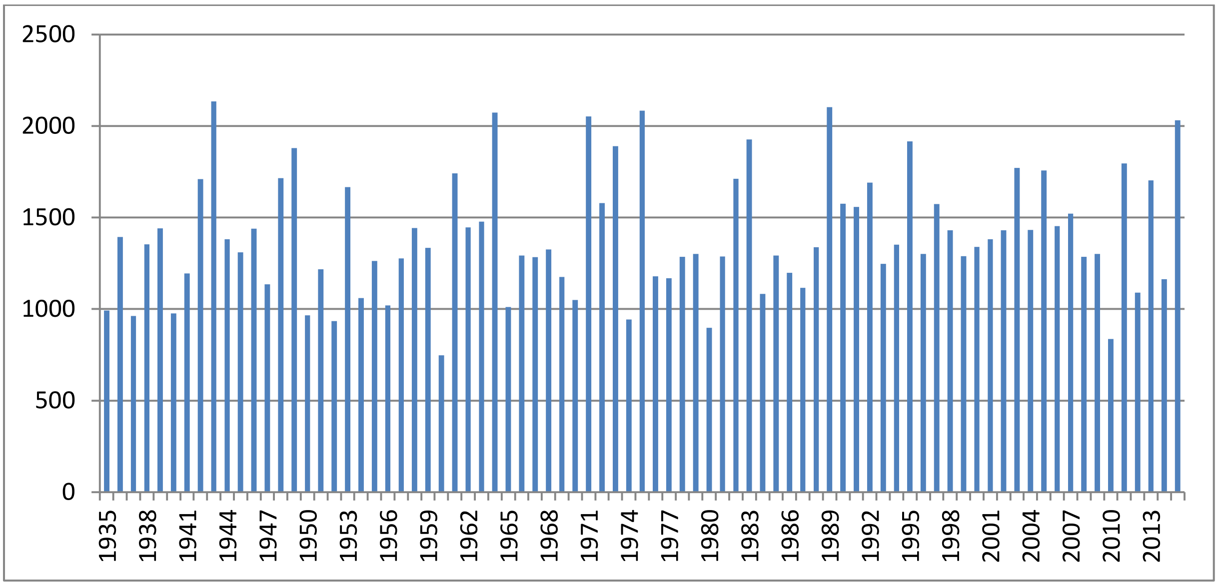


Figure 49: The distribution of the annual precipitation in Mo 1935-2015.

Homogenization of daily Precipitation

The RHtests_dlyPrcp program is applied to analyze the homogeneity of the daily precipitation series (table 33):

Table 33: 0 change points in the series is either accepted or identified as a homogeneity break.

Type 1	Statistical significant	QM-adjustments
0	No	**0** change-points in Series

Initially the program identifies 48 change-points in the Mo precipitation series (table 34). Of these, it is worth mentioning some of the change-points, but that was not approved as a break of the program (>0.95).

Table 34: Some of the proposals for change-point from RHtests_dlyPrcp program:

Type 1	Statistical significant	Date	95 % confidence interval of p-value	Confidence level	PF_{max} statistic	Nominal confidence level	QM-adjustments
0	YifD	19420912	(0.9999-0.9999)	0.95	13.9173	(17.6026-18.8346)	No
0	YifD	19570725	(-0.9968-0.9968)	0.95	8.5467	(-19.2474-20.6323)	No
0	YifD	20020116	(0.9975-0.9975)	0.95	7.5152	(19.9757-21.4265)	No

These change-points are not approved by the program because they are not statistically significant. They are supported by metadata (see table 32): Break in 1941 (1942), 1957 and 2002. In relation to the discussion from the previous stations (Sauda and Takle), then there are the same reasons that recur applicable. The software program rejects the change-points. The changes are too small. There is some relocations here (>= 3 km). Actually this should be seen as breaks, but it is other statistically rules in the daily homogenization than in the annual or the seasonal analysis here. The relocations are not so big and actually it is possible that is not so different daily pattern in the precipitation around the Ranfjorden.
From the annual analysis (HOMER), the seasonal analysis (MASH) and the daily homogenization analysis (RHtests_dlyPrcp) it is clear that there is different number of breaks:

Respectively 2, 5 or 0 breaks in the precipitation series from Mo i Rana. We have as usual rejected many of the proposed breaks of the MASH analysis since it tends to show consecutive compensating breaks.

Mo i Rana has a special meteorological station history. There are 4 stations here. Maybe they have not so different measurements? We know that metadata or pictures do not lie in this case. It is still difficult to figure out the different precipitation conditions in the 4 different locations. It can easily make reflected seasonally and annually. It is large annual variance in Mo (750 -2200 mm). The station is standstill for the last 60 years. Figure 65 show the "new" daily homogenized precipitation series from Mo i Rana. We choose to repeat and conclude with the breaks from the seasonal chapter: 1941, 1946, 1957, 1983 & 2002.

Figure 50 show the original precipitation series. This precipitation series will not be adjusted for the daily resolution.

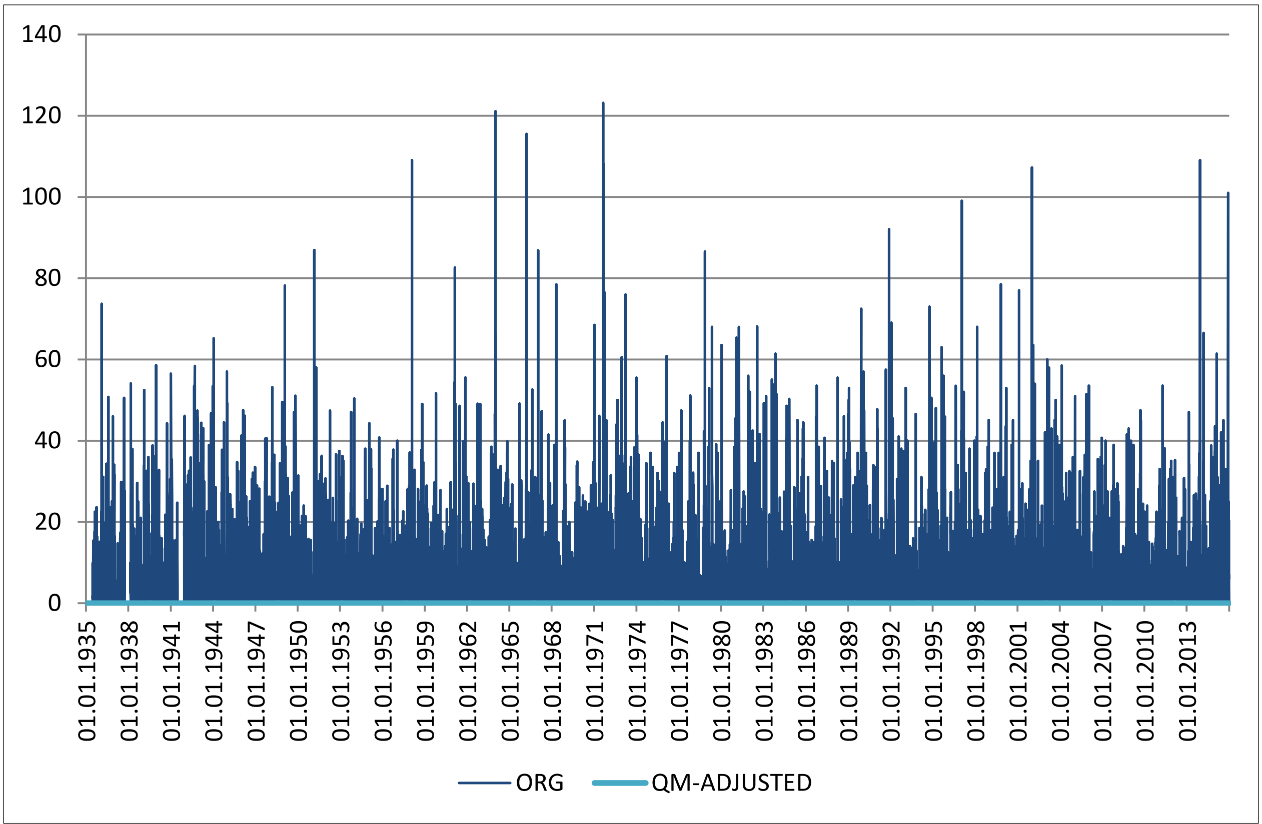


Figure 50: The precipitation series from 79480 Mo i Rana after homogenization (which is 0).

V. Bardufoss

The Bardufoss precipitation series start in July 1946. The annual precipitation varies from year to year around the normal (1961-1990), which is 652 mm per year. There is an increasing trend in the precipitation for Bardufoss the last 70 year (fig. 51). The annual mean precipitation increasing trend is not as visible as for e.g. Sauda and Takle, but it is at around 5% during the 70 year observation period.

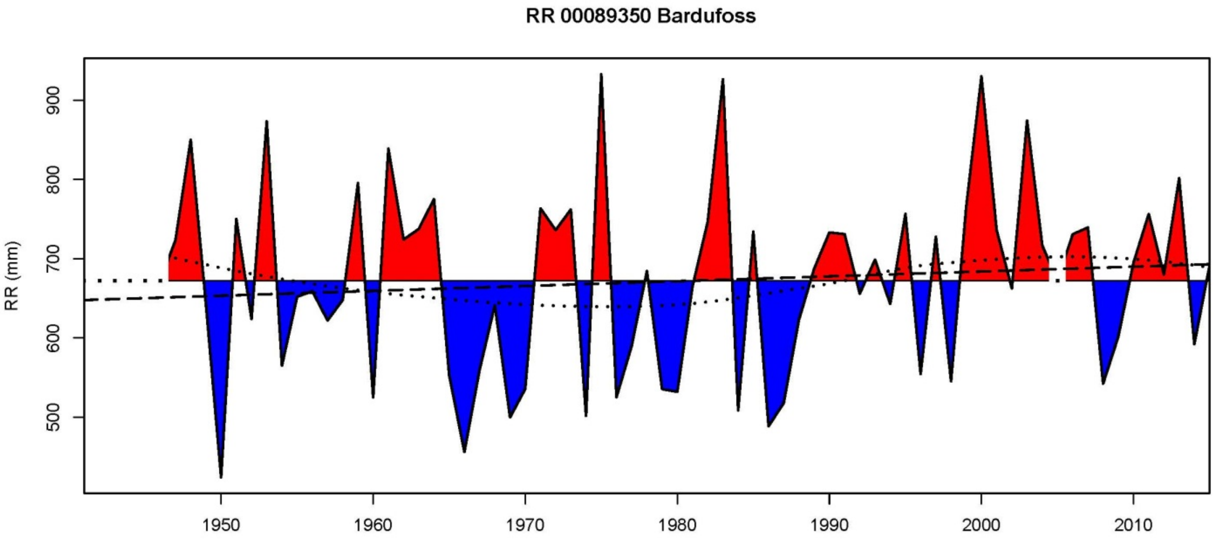


Figure 51: Precipitation series for 89350 Bardufoss (1946-2015).

Annual homogeneity analysis

The homogeneity testing detected zero break for the annual analyze of homogeneity at Bardufoss precipitation series with HOMER (table 35).

Table 35: There is no break amplitude from Bardufoss.

Break **0**	Amplitude (1946 - 2015)
13	UNCHANGED REFERENCE PERIOD

Seasonal homogeneity analysis

The homogeneity testing detected **7** breaks for the seasonal analyzes of homogeneity in the Bardufoss precipitation series applying MASH program/method (table 36).

Table 36: 7 breaks at 89350 Bardufoss: 3 in the spring, 1 in the summer and 3 from the autumn shown in ratio scale (correction factor) for the time series (1946-2015).

Seasons	Breaks: X (6?) - Break amplitude in ratio
1 (DJF):	
2 (MAM):	M1954: 1.06/ M1962: 1.03/ M1985: 1.04/
3 (JJA):	M1984: 1.05/
4 (SON):	1961: 1.04/ M1975: 0.96/ M1984: 1.07

In the metadata table (37) we can see the station history and find the reasons for breaks at the station in Bardufoss from this analysis. We see the same pattern as other meteorological stations, that relocations, new instruments, redecoration and environmental changes are the main reasons for breaks in the time series.

Table 37: Metadata for the homogeneity break at 89350

YEAR	**MONTH**	**DATE**	**Metadata information**	**Visible as break in our Homogenization**
1940	7	1	The German creates a weather station.	
1946	3	28	Norwegian rain gauge applied, earlier German, but the observation are missing.	
1946	1	8	**Telegraphing weather station** (WMO): 89350 Bardufoss	
1946	5	31	The precipitation observations start.	
1951	7	20	Inspection from DNMI: Renewal of rain gauge and painting.	
1952	9	25	Relocation: Precipitation gauge moved 40 meter WS.	
1953	6	11	Relocation: Precipitation gauge moved 20 meter NW.	
1953	9	30	Renewal of rain gauge: Fixing, leveling and painting.	
1954	8	14	Relocation: Precipitation gauge moved 115 meter SSE closer to the airport hangar.	MASH (MAM)
1961	12	8	New airport building in NE direction for the precipitation measurements.	MASH (MAM & SON)
1967	7	10	Relocation: Precipitation gauge moved 12 meter E. New height, masl: 78	
1974	11	18	Relocation: Precipitation gauge moved 250 meter W because of new parking.	MASH (SON)
1985	5	31	Relocation: Precipitation gauge moved 200 meter E because of expansion of the airport.	MASH (SON)
1985	6	19	Change of rain gauge: From Norwegian to Swedish rain gauge.	MASH (MAM & JJA)
1997	7	3	Modernization of the weather station. Semi automation (computer based, new routines for sending observations. Still Swedish manual precipitation gauge.	
2016	2	1	New precipitation gauge GEONOR T200 (600 mm).	

Figure 52: Photo from the meteorological station at Bardufoss airport against the E and the mountain Istind. Det picture is taken in February 1987.

It is a little uncertain which method we should rely on. HOMER gives us no breaks in the homogeneity analysis and MASH give us 7 breaks. We have to do a thorough investigation of the metadata both for Bardufoss and the neighboring stations. MASH can often treat anomalies as breaks. Then we often can see compensating breaks over two consecutive years. In the analysis we choose to exclude these breaks from the result (table 36). Some of the breaks we disregard because we cannot find any clear reason for the break. We choose to rely on the breaks in 1954 (MAM), 1975 (SON) and 1984 -> 1985 (2: MAM & JJA) because of small relocations (100-200 meters) and 1962 (1961) (MAM), because of a new airport building NE for the precipitation gauge. 1983 is an instrumental change from Norwegian to Swedish precipitation gauge, a reason for homogeneity break also observed for Mo i Rana (1983 DJF). There have been a lot of small relocations at the Bardufoss airport. Most of them are not visible (less than 100 meters) in the homogeneity analysis as homogeneity breaks. We think that the direction for the relocation is important here if there is break. E.g. relocation of gauge further east provides clearer break. We accept 4 breaks from the seasonal analysis: 1954, 1961/1962, 1975 and 1984/85. Full automation of the station and the shift of the precipitation gauge to an automatic (Geonor), happened in February 2016. It is too recent to be included in the analysis. Figure 52 shows a photograph of a snowy winter in Bardufoss. When we look at the distribution of the annual precipitation we cannot find any changes in the precipitation pattern at Bardufoss in the observation period (1946-2015) (see figure 53).

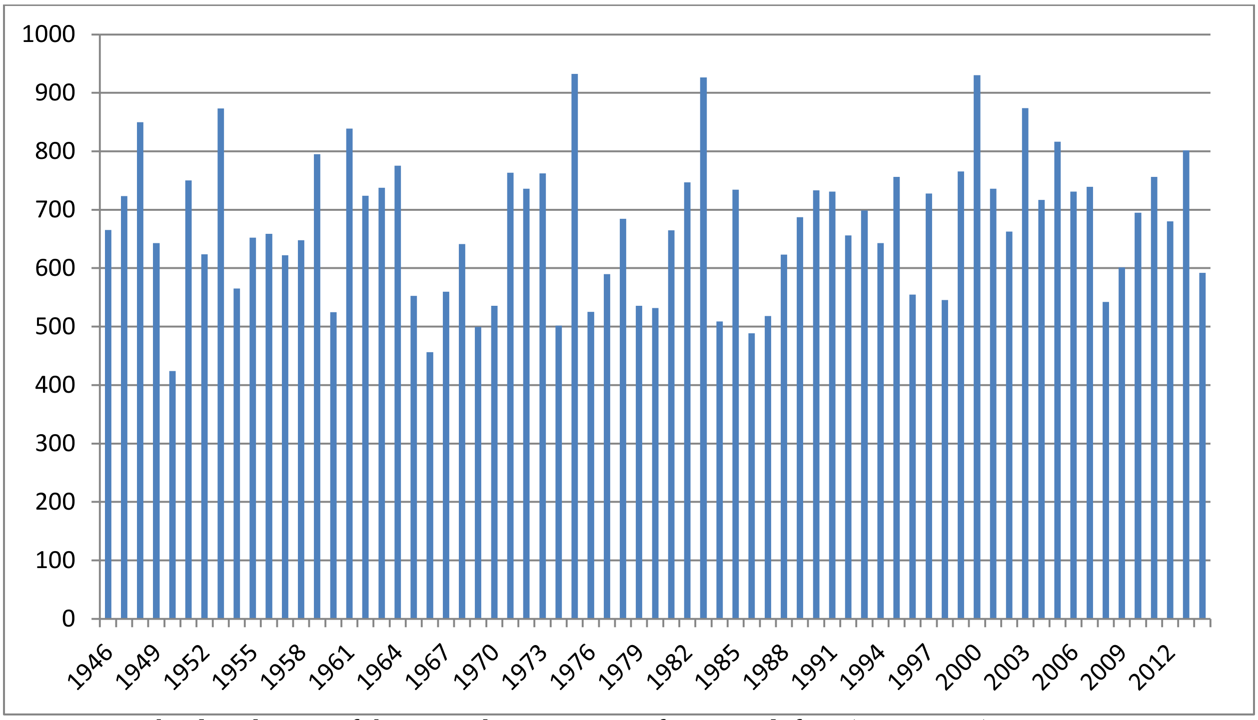


Figure 53: The distribution of the annual precipitation from Bardufoss (1946-2015).

Homogenization of daily Precipitation

The RHtests_dlyPrcp program is applied to analyze the homogeneity of the daily precipitation series and the results are shown here (table 38):

Table 38: 1 change-point in the series is accepted and identified as a homogeneity break.

Type 1	Statistical significant	Date	95 % confidence interval of p-value	Confidence level	PFmax statistic	Nominal confidence level	QM-adjustments
0	Yes	19990716	(1.0000-1.0000)	0.950	32.6056	(23.6856-25.9023)	0.498

Initially the program identifies 14 other change-points in the Bardufoss precipitation series. Of these, it is worth mentioning some of the change-points, but that was not approved as a break of the program (>0.95) (table 39).

Table 39: 2 of the proposals for change-point from RHtests_dlyPrcp program:

Type 1	Statistical significant	Date	95 % confidence interval of p-value	Confidence level	PF_{max} statistic	Nominal confidence level	QM-adjustments
0	YifD	19650407	(0.9893- 0.9893)	0.95	9.3253	(19.0898- 20.6704)	No
0	YifD	20000112	(1.0000-1.0000)	0.95	19.5930	(17.1930- 18.5195)	No
0	YifD	20040816	(0.9874-0.9874)	0.95	8.1872	(14.0801- 15.0767)	No

Only one of these change-points is approved of the program as a homogeneity break for the Bardufoss precipitation series (table 38). These other change-points are not approved of the program because they are seen as not statistically significant. They are not supported with metadata (see table 39). The software program rejects the change-points. The changes are too small. There are several small relocations here (>= 250 meter). The relocations are not so big and actually it is possible that is not so different daily pattern in the precipitation in Målselv.

From the annual analysis (HOMER), the seasonal analysis (MASH) and the daily homogenization analysis (RHtests_dlyPrcp) it is clear that there is different number of breaks: Respectively 0, 7 or 1 break (-s) in the precipitation series from Bardufoss. We have as usual rejected many of the proposed breaks of the MASH analysis since it has a tendency of showing consecutive compensating breaks.

Bardufoss meteorological station site has been on the same place and environment for 70 years at the airport. The relocations (>250 meter) are mostly too small to be counted in the homogeneity analysis (HOMER & RHtests_dlyPrcp). MASH recognizes three of them in the analysis. RHtests_dlyPrcp recognize one break in 1999. We think that can be found in the metadata as the modernization of the weather station. It has led to a positive adjustment in the precipitation series (-0.498). Figure 70 show the "new" daily homogenized precipitation series from Bardufoss with the adjustment (1999) from the Box-cox regression analysis.

Figure 54 show the original precipitation series and the adjustment for the daily homogenization analyze is absent. Figure 54 are made of the RHtests_dlyPrcp and there is this one break with the positive adjustment.

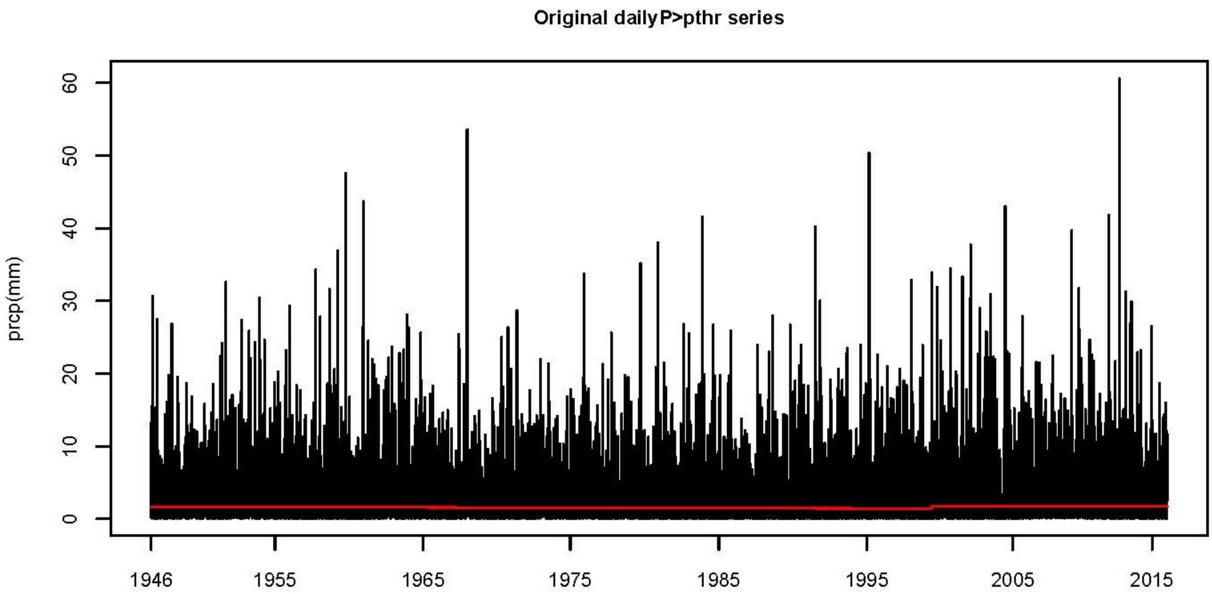


Figure 54: The original time series for 89350 Bardufoss (1946-2015) showing the 1 break.

Figure 55 shows the original vs. the new adjusted daily homogeneity precipitation series. We can see the original series (red) and we can see the outlines of the adjustments made with RHtests_dlyPrcp in blue. The adjustments are clearly from 16.7.1999. The adjustment is not so big, only 0.5 % increase in the precipitation from 1966. These time series are accessible through the eKlima portal (http://eklima.met.no).

It is observed more precipitation after the environment change at Takle in the late 1960s. It is around 2 % more precipitation after the settlement was changed between 1966 and 1970 (fig. 41).

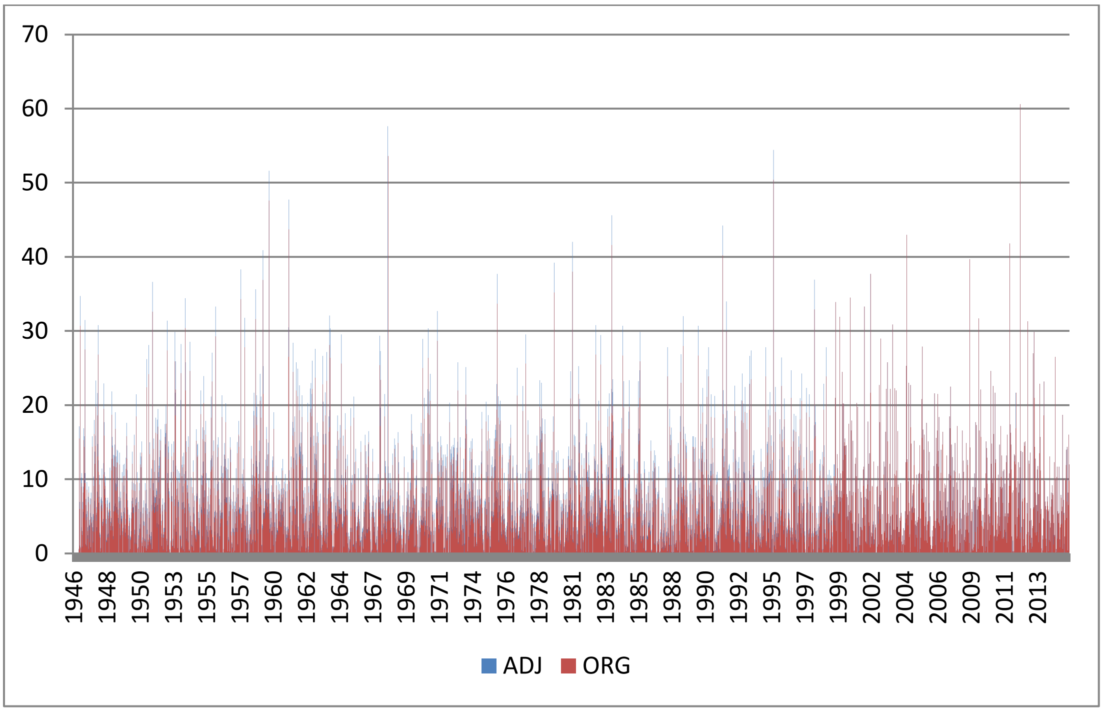


Figure 54: The adjusted precipitation series from 89350 Bardufoss after homogenization.

It is observed more precipitation after the environment change at Bardufoss in the late 1990s. It is around 0.5 % more precipitation after the modernization in the instrument in 1997.

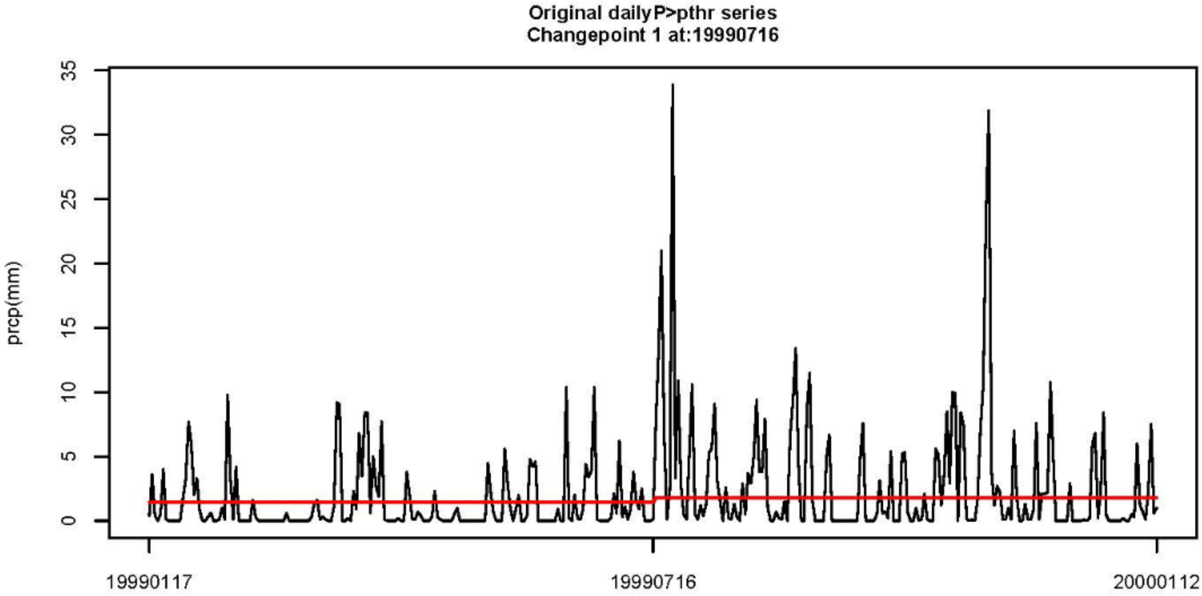


Figure 55: The break from July from 89350 Bardufoss.

Figure 56 shows the box-cox transformation from 1999-break.

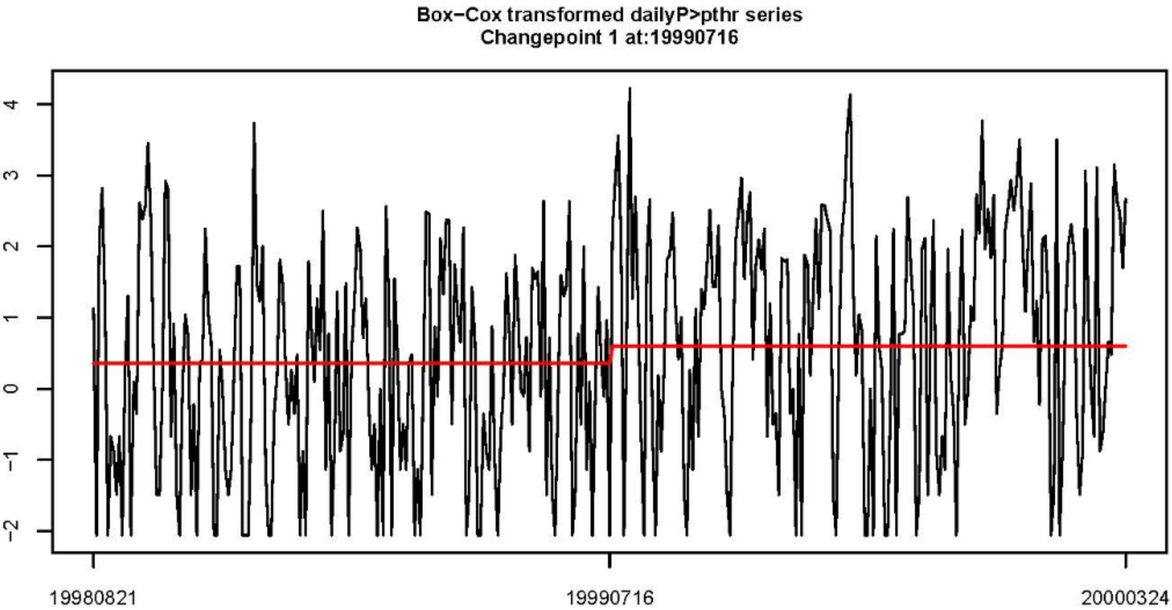


Figure 56: The break in 1966 from 52860 Takle shown in Box-cox-regression.

6 - Conclusions

Homogenized daily mean precipitation series for five locations representing different hydropower production areas have been established (Figure 1). Three different methods are applied in the analysis, hence three completely different applications: HOMER; MASH and RHtests_dlyPrcp. These three different methods are used to investigate different properties of the precipitation series. HOMER is applied to analyze annual series, MASH to analyze seasonal and monthly series. These two methods need reference station networks. RHtests_dlyPrcp applied to analyze the daily series need only one station for the analysis and that is the candidate station. The time period which is analyzed here is from 1923 (1950) to present (2015).

Since three different methods and applications that are used, the results in this analysis will be partly different. Our new homogenized time series is supplied with RHtests_dlyPrcp result. HOMER and MASH results are used for confirmation and validation. The homogenized time series are accessible through the eKlima portal (http://eklima.met.no).

Table 40 shows the distribution of the detected breaks at the 5 candidate stations in the survey.

Table 40: The time series from the candidate stations and the detected breaks

Station	Time series: Homogenized	Detected Breaks		
		RHtest	MASH	HOMER
16610 Fokstua	1923-2015	8	1	3
46610 Sauda	1928-2015	0	3	1
52860 Takle	1950-2015	1	1	1
79480 Mo i Rana	1935-2015	0	5	2
89350 Bardufoss	1946-2015	1	7	0

A homogenized daily precipitation series for Fokstua was established by applying the adjustments obtained by RHtests_dlyPrcp during the 92 year's period the station has been in operation: 1923–2015. In addition, we used HOMER for an annually homogeneity analyses and MASH for a seasonally homogenization.
The daily Fokstua precipitation series was adjusted for eight homogeneity breaks. The seasonal adjustment; autumn: +5 % in 2005. In the annual homogenization it is recognized 3 breaks: 1946 (12 %), 1968 (-9 %) and 2009 (-13 in the precipitation series.

The two long-term series 16600 Fokstua 1 and 16610 Fokstua 2 were successfully merged and corrected for (break: -13%) in 1968. An almost 100 years long homogenized record for Fokstua of daily precipitation was established.

The annual mean precipitation has increased almost 10 % during the almost 92 year's period of observation for Fokstua. The wettest year was 2011 (600,9 mm) and the driest one is 1932 (288,3 mm).

A homogenized daily precipitation series for Sauda was established by applying the adjustments obtained by RHtests_dlyPrcp during the almost 90 year's period the station has been in operation: 1928–2015. In addition, we used HOMER for an annually homogeneity analyses and MASH for a seasonally homogenization. An almost 90 years long homogenized record for Sauda of daily precipitation was established. The analysis of the daily Sauda precipitation series did not show any homogeneity breaks. The seasonal adjustment; spring; -6 % in 1958, +4 % in 1962 and autumn: +3 % in 2000. In the annual homogenization it is -2 % decreased precipitation from the only break in 2000 in the precipitation series.

There is only one station in Sauda, relocated once in 2008, moved then less than 400 meters. The break in the time series (HOMER) in 2000 is caused by the transition to automatic measurement with GEONOR.

The annual mean precipitation has increased around 12 % during the almost 90 year's period of observation for Sauda. The wettest year was 1938 (7430,1 mm) and the driest one is 1928 (1313,1 mm).

A homogenized daily precipitation series for Takle was established by applying the adjustments obtained by RHtests_dlyPrcp during the almost 65 year's period the station has been in operation: 1950–2015. Here are all the methods/applications agree about one break in 1968 (1966) and the metadata can confirm the break with a change in the environment: A new garage near the precipitation gauge was built up and two small houses was demolished.

The daily Takle precipitation series was adjusted for one homogeneity break in 1966. The seasonal adjustment; vinter: 2 % in 1968. In the annual homogenization it is 2 % increased precipitation in the time series.

The annually mean precipitation has increased around 13 % during the 65 year's period of observation for Takle. The wettest year was 1990 (4747.5 mm) and the driest one is 1959 (2040.6 mm).

A homogenized daily precipitation series for Mo i Rana was established by applying the adjustments obtained by RHtests_dlyPrcp during the 80 year's period the precipitation measurement has been done: 1935–2015. In addition, we used HOMER for an annual homogeneity analyses and MASH for a seasonally homogenization.

The daily Mo i Rana precipitation series did not show any homogeneity breaks. The seasonal adjustment; winter: 4 breaks: 1946, 1957 (both respectively 4% decrease), 1983 (6% increase) 2002 (5 % decrease) spring 1941; 1 break: -38 % decreases. In the annual homogenization it is -14 % decreased precipitation from the 1946-break and 4 % increase from the 1957-break in the precipitation series.

The annual mean precipitation has increased roughly 1 % during the 80 year's period of observation for Mo i Rana. The wettest year was 1943 (2135 mm) and the driest one is 1960 (747 mm). There are divergent results between the methods and the results for the number of breaks in Rana. This is unfortunate, but it is however very understandable when we consider the use of the method and statistics in RHtests_dlyPrcp. The change-point test considers the whole time series so uncertain that it chooses to endorse it without breaks. This is described in Wang et al. (2010).

A homogenized daily precipitation series for Bardufoss was established by applying the adjustments obtained by RHtests_dlyPrcp during the almost 70 year's period the station has been in operation: 1950–2015: 1946–2015. In addition, we used HOMER for an annually homogeneity analyses and MASH for a seasonally homogenization.

The daily Bardufoss precipitation series was adjusted for one homogeneity break (1999). The seasonal adjustment; spring: 3 breaks: 1954 (6% decrease), 1962 (3% decrease), 1985 (4% decrease) and autumn: 2 breaks: 1961 (4% decrease), 1975 (4% decrease). In the annual homogenization analyze the conclusion is zero breaks.

The annual mean precipitation has increased about 9 % during the 70 year's period of observation for Bardufoss. The wettest year was 1975 (932.6 mm) and the driest year is 1950 (424.3 mm).

Although HOMER, MASH and RHtests_dlyPrcp might have some uncertainties by identifying false breaks, they are powerful tools in identifying homogeneity breaks in annually, seasonally and daily temperature series when carefully interpreted and compared with station metadata. The results of this study show that the analyses should be extended to homogenize all relevant Norwegian daily precipitation series.

After we have now gone through the 5 locations for this survey we should make a recommendation about which method is best in use for homogenization. We think it is a big difference when we use the high-resolution data and daily homogenization. It makes it difficult finding breaks. We therefore really recommend using monthly, seasonal or annual data series for precipitation (MASH and HOMER). We still think it is worth trying out daily homogenization and RHtests_dlyPrcp.

For homogenization of daily precipitation data series, it is essential to model the occurrence process and the nonzero amounts separately. Otherwise, estimates of adjustments needed for nonzero amounts would be biased; in particular, adding an adjustment value to all days, including days of zero precipitation, will make all days of reported zero precipitation disappear from the series or will result in negative daily precipitation amounts. Changes in measuring device usually would not introduce any sudden change in the reported zero precipitation, unless they are accompanied by a change in the measuring precision (which could affect the frequency of small amounts measured and hence the frequency of reported precipitation occurrence or nonoccurrence) (Wang, 2010). The parameter precipitation in meteorology is multiplicative, and as such it is statistically correct to pursue a Cox-transformation (Vittinghoff, 2012). The expression is called the multiplicative Law of Probability and that is what precipitation is. Two events are said to be independent if the occurrence or non-occurrenceof one does not affect the probability of the other (Wilks, 2011).

Acknowledgements

This study was carried out within the frames of the MIST2-project, a joint initiative between STATKRAFT and MET Norway to develop meteorological and climatological services useful for hydropower and energy production as well for the operational services at MET. I will donate gratitude to Ole Einar Tveito, my boss and he has proof read the whole report. Thank you! Also I will thank Herdis Gjelten Motrøen for training in the MASH method. The project HISTKLIM at MET Norway is acknowledged for having performed the digitalization and quality control of the historical observations from the long time series in this study.

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