Synoptic messages to extend climate data records

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Abstract. Synoptic messages (SYNOP) exchanged internationally for operational weather forecasting are regularly used to extend validated (quality controlled) daily climate time series to the present day, despite differences in measuring intervals and lack of validation. Here we focus on the effect of this on derived climate indices of extremes in Europe. Validated time series are taken from the European Climate Assessment & Dataset (ECA&D). Validated data and SYNOP over the period 01 April 1982 to 31 December 2004 are compared. The distribution of the difference series of validated data and SYNOP is skewed. Generally, minimum temperatures are lower or equal in the validated series, while maximum temperatures are higher or equal. This is at least partly due to the 24-hour (validated data) versus 12-hour (SYNOP) measuring intervals. The precipitation results are dependent on the difference between the measuring intervals of both time series. Time series of indices of extremes exhibit a non-climatic inhomogeneity for several indices when SYNOP are used to extend the validated series, leading to spurious trends.

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The sizes of the trends in pure validated and pure SYNOP series are generally in good agreement, but the absolute values of the indices show an offset. Accepting a trend error of 10%, the averaged winter minimum and maximum temperature and the number of tropical nights (minimum temperature $> 20°C$) in summer allow only a very small fraction of SYNOP in the extended series (about 5–10%), while for the other indices studied here a larger fraction can be used (up to 50%).

1. Introduction

Main synoptic messages (SYNOP) are meteorological reports at 00, 06, 12 and 18 UTC that are exchanged internationally between National Meteorological Services (NMSs) in near-real-time through the Global Telecommunication System (GTS) [World Meteorological Organization, 2007], although reports might also be sent at other hours (e.g. 3-hourly). Not all parameters are sent at all hours, but usually at least one value is available each day. Although initialization of weather forecast models is the main application of this dataset, SYNOP are being increasingly used for climate research.

Unlike SYNOP, daily time series in climatological databases undergo an extensive validation process at most of the national institutes responsible for their networks. Validation usually consists of quality control procedures, but can also include homogeneity corrections and/or filling in of missing values. The exact validation procedures will vary between institutes. Because validation takes time, these series are usually not available over large regions for the most recent time period. SYNOP can then be used to extend the climatological time series to the present time. An additional reason for using SYNOP is that validated climatological time series are not always freely available, while SYNOP are.

Several climatological datasets, either daily or monthly, use the messages sent through the GTS system for the recent part of the station series or even for complete series. For example, the GISS (Goddard Institute for Space Studies) Surface Temperature Analysis [Hansen et al, 2010] uses the monthly GTS messages (CLIMAT) as their principal source to update their dataset, and the Global Historical Climatology Network (GHCN)-Daily uses SYNOP when no other data are available for a certain station [GHCN-Daily, 2009].

Also gridded datasets such as the precipitation dataset APHRODITE [Yatagai et al, 2009] and the Global Precipitation Climatology Centre (GPCC) [Rudolf and Schneider, 2005; Rudolf et al, 2011] use SYNOP as one of their input data sources. Reanalysis products such as ERA-40 (and the current ERA-Interim) [Uppala et al, 2005] and the NCEP/NCAR reanalysis [Kalnay et al, 1996] use SYNOP as their principal input as well. Therefore almost any study that makes use of these datasets will indirectly use SYNOP data.

The European Climate Assessment & Dataset (ECA&D) project [Klein Tank et al, 2002; Klok and Klein Tank, 2008] uses SYNOP for the most recent part of the daily time series to extend the station records until the present time. These SYNOP values are subsequently replaced when validated data become available. A few providers (10%) in ECA&D provide validated series every month, but most of them send these series only once a year or even only once every few years. Therefore, up to ten years of the most recent data in ECA&D can be drawn from SYNOP. More information on ECA&D, the blending process and quality control procedures can be found on the website http://eca.knmi.nl and in ECA&D Project team [2010].

For this study we have compared validated data and SYNOP for an overlapping time period. The aim of this study is to assess the differences between the two data sources and to determine what biases are introduced when the validated data are extended with SYNOP in climate change research, in particular when assessing the changes in indices of extremes derived from daily series. Section 2 describes the data and the method used in this study. The results are given in Sect. 3 and we end with a conclusion in Sect. 4.

2. Data & Method

2.1. SYNOP

We have retrieved SYNOP in BUFR format [WMO, 2001] from the Meteorological Archival and Retrieval System (MARS archive) at the European Centre for Medium-Range Weather Forecasts [ECMWF, 2006]. For this study we use only daily minimum temperature, daily maximum temperature and daily precipitation sums. The reason is that most indices of extremes are based on these variables [Zhang et al, 2011].

In Europe, SYNOP usually reports the minimum and maximum temperature over the last 12 hours only at 6 UTC or 18 UTC. Therefore we concentrate on these hours only (as done in ECA&D). SYNOP has a code for the minimum and maximum temperature over the last 24 hours, but this is not often recorded by the stations. Minimum temperature is provided at 6 UTC (BUFR code 12015) and the maximum temperature is given at 18 UTC (BUFR code 12014). Because the analysis is for Europe, the SYNOP minimum temperature that we used is the night-time minimum temperature (between 18 UTC of the previous day and 6 UTC), while the SYNOP maximum temperature used is the day-time maximum temperature (between 6 UTC and 18 UTC). This might result in some days not having the correct minimum and/or maximum temperature recorded when that value falls outside the 12-hour measuring interval (see Sect. 2.4).

SYNOP precipitation amount is provided for the last 12 hours at both 6 and 18 UTC (BUFR code 13022) which has been converted to 24-hour sums. Here we used three possibilities. Firstly, we added for each day the 18 UTC value of the previous day to the 6 UTC value of the current day. This provided us with 24-hour sums between 6 UTC of the previous day to 6 UTC of the current day (hereafter SYNOP RR1). Secondly, we determined the 24-hour sums between 6 UTC of the current day to 6 UTC of the next day (hereafter SYNOP RR2), and finally we added the 6 UTC and the 18 UTC values of the same day together, giving 24-hour sums from 18 UTC of the previous day to 18 UTC of the current day (hereafter SYNOP RR3). If at least one 12-hour value is missing, the corresponding 24-hour sum is also set to missing.

Below 1 mm, SYNOP precipitation is recorded in units of 0.1 mm. Above 0.9 mm, values are rounded off to the nearest integer. For example, 0.7 mm is recorded as 0.7 mm, while 1.4 mm is recorded as 1 mm. Values are rounded off at both 6 UTC and 18 UTC. The precision of temperature values is 0.1 °C regardless of their value.

2.2. Validated data

The data provided by participants of the ECA&D project, mainly national meteorological and hydrological services, for stations throughout Europe are referred to as validated data. These validated series underwent a quality control procedure and sometimes infilling of missing values using other sources (e.g. radar or neighboring stations) at the home institutions of the participants before they were sent to ECA&D. The precise quality control procedures are not always known, especially for the more distant past. The collected metadata at ECA&D shows that it is not the same between participants. It is also possible that the procedure changed over time. The measuring intervals of the validated series are all 24-hour periods, but the exact interval varies with station and parameter. Validated daily data are, therefore, the daily data that can be downloaded or requested from some national meteorological institutes.

2.3. Additional quality control

Both the validated data and SYNOP underwent a basic quality control procedure as part of this study. Suspect data was flagged and not taken into account.

Temperature values are suspect when the value is higher than 60°C or lower than -90°C. Repetitive values for 5 days in a row or more are also disregarded. Furthermore, the temperature should be in the interval determined by the long term average (determined over the whole study period) plus or minus 5 standard deviations (calculated for a 5 day window centered on each calender day). More maximum temperature data (up to 1%) are flagged as suspect compared to minimum temperature (up to 0.1%).

For precipitation it was checked that the amount was equal to or higher than 0 mm, but less than 300 mm. The amount should not be repetitive for 10 days in a row if the amount is larger than 1.0 mm or repetitive for 5 days if the amount is larger than 5.0 mm. The amount of precipitation data flagged as suspect is less than 0.1%.

For all variables it is possible to overrule the quality control flag with a manual flag, for example in cases where more than 300 mm of precipitation indeed occurred on one day.

2.4. 12 hours vs 24 hours measuring periods

Sections 2.1 and 2.2 indicate that there is a difference in measuring intervals for temperature between validated data and SYNOP. The first is measured over 24 hours while the latter is measured over 12 hours. For the Dutch station De Bilt we have access to hourly data. Therefore we use this station as a case study for the differences in measuring intervals.

This sub-daily data from De Bilt gives us the hourly interval for which the minimum and maximum temperatures are observed. The fraction of days for both winter (DJF) and summer (JJA) is determined for which daily minimum and maximum temperatures are within the 18 – 6 UTC and 6 – 18 UTC intervals. This exercise has been undertaken for three time periods covering 01 April 1982 – 31 December 2004 to see if these fractions are changing over time.

Table 1 shows the resulting fractions. The fraction of days that the minimum temperature is recorded outside the 12-hour SYNOP measuring interval of 18 – 6 UTC is much larger in winter than in summer (∼45% vs ∼7%). This means that in winter for ∼45% of days the true minimum temperature is not recorded by SYNOP. Also for maximum temperature, the fraction outside the 6 – 18 UTC window is much larger in winter than in summer (∼29% vs ∼13%). This result for station De Bilt indicates that differences in measuring interval are indeed potential reasons for the differences between validated data and SYNOP. No significant change over time in these percentages is seen for station De Bilt.

In most of northern Europe in winter, 6 UTC is before sunrise, so even with a regular diurnal cycle the chances that the minimum temperature will occur after 6 UTC is quite high. We do not have hourly data for a Mediterranean station, but we would expect lower percentages of minimum and maximum temperatures to be reported outside the two SYNOP 12-hour periods.

2.5. Selecting validated and SYNOP station pairs

We selected 106 stations that have validated daily series available for public download from the ECA&D website, have known measuring intervals for minimum temperature, maximum temperature and precipitation, and report SYNOP from the same location (Fig. 1 and Table 2). We have assumed that stations having a maximum distance of 2.5 km between the validated series location and the SYNOP location, and a height difference of less than 50 m are in fact the same station. The available metadata such as WMO numbers and coordinates are not complete or precise enough to use only these to determine if the stations are identical. Even for a station for which the WMO number is known in ECA&D, the difference with the coordinates of the SYNOP station with the same WMO number can be significant. The majority of the selected pairs do have a location difference of less then 2.5 km with 75% less than 1 km. The period analyzed is 01 April 1982 to 31 December 2004 for which we have validated data as well as SYNOP.

The precipitation measuring intervals of the validated data do not necessarily coincide with the 24-hour intervals for SYNOP. The first option in a general comparison for precipitation is to use the SYNOP measuring interval closest to the validated one. Therefore the SYNOP measuring interval will differ from station to station. If the measuring interval of the validated series is from midnight to midnight, we have chosen SYNOP RR2 for the comparison. The three other options in the comparison are to use the same SYNOP measuring interval for all stations (subsequently RR1, RR2 and RR3). This has been done because in every-day practice, it is not always known what the measuring period of the validated series is (here we limited the selection to only those stations for which this is known).

The measuring intervals for a few selected stations from different areas of Europe are shown in Fig. 2 with the coordinates given in Table 2 (with bold station names). The available metadata, including measuring periods, for all stations can be found on the ECA&D website (http://eca.knmi.nl/dailydata/countryquery.php). Although ECA&D is continuously updating the metadata, the types of thermometers and precipitation gauges and changes in measuring periods or instrumentation are only known for a very small percentage of all the available stations at present.

3. Results

3.1. Daily values: temperature

To determine if SYNOP can be used to reliably extend climate data records we have analyzed the daily differences between the validated data and SYNOP. We assumed that the validated data and SYNOP are determined from the same station and instrument, so in principle, the values should be the same with possibly a (small) spread around zero due to errors from the conversion from Kelvin to degrees Celsius (SYNOP in the MARS archive is stored in Kelvin) and rounding differences.

Examples of a histogram of the temperature difference series are shown in Fig. 3 for station Bodø VI in Norway, but this general picture is valid for almost all stations. The histograms show the fraction of all days in the difference series belonging to a certain temperature difference bin. About 35% of days have a difference between -0.05 and $0.05°C$. The other days show that the minimum temperature in SYNOP is generally higher than the validated value and that the maximum temperature in SYNOP is generally lower than the validated value. This effect is also visible in the time series of the daily differences given in Fig. 4. This result is what one would expect when the values for SYNOP are determined over 12-hour intervals whereas the validated data are for 24-hour intervals, see Sect. 2.4. The few outliers in this figure are most likely erroneous values that are not flagged by our basic quality control checks.

For each station, the standard deviation (stdev) of the difference series is determined per year. Fig. 5 shows box plots of the median and the 5, 25, 75 and 95 percentile values for the stdev at all 106 stations used in this study. The average over all the years of the median values of the stdev in winter is 1.26°C for minimum temperature and 1.21°C for maximum temperature. In summer this average is 0.60°C for minimum temperature and 0.88°C for maximum temperature. It is thus clear that the stdev is smaller in summer than in winter. This can partly be explained by the 12-hour vs 24-hour measuring periods for SYNOP and validated data (see Sect. 2.4). The diurnal cycle is less regular in winter and therefore we expect this effect to be larger for winter than for summer as is shown in Table 1.

Besides differences in measuring intervals, missing values can also affect the comparison of validated data and SYNOP. In the study period SYNOP has much more missing values than the validated data. The percentage of missing values per year of the 106 stations is given as a box plot in Fig. 6. Although the median of the percentage of missing values decreases in more recent years, the spread becomes larger. The average over all stations is around a few percent to 10% missing values per season, but it can increase to 50% or even 100% for specific stations in a specific season. Especially, summer 1990 and, less pronounced, winter 1992 have a large number of missing values in SYNOP. According to WMO (pers. comm.) there were no code changes around summer 1990 that could influence the exchange of these messages. ECMWF (pers. comm.) is also not aware of technical or archival problems at the MARS archive. Reductions during these two seasons are also unrelated to political changes in Europe during these seasons. For validated data almost all stations have none or very few missing values.

3.2. Daily values: precipitation

We have argued that for a meaningful comparison it is important to use SYNOP precipitation with the measuring interval as close as possible to the validated one. As an illustration, Figure 7 shows for station Bodø VI the effect of using SYNOP RR1 and RR3 on the daily differences. SYNOP RR1 is the same as the measuring interval of the validated series. In this figure it is clearly seen that by using SYNOP RR1 the spread in the differences between validated data and SYNOP is much smaller than by using SYNOP RR3. No seasonal cycle is seen in the difference series of precipitation data.

Figure 8 shows histograms of the difference series for precipitation for station Bodø VI using SYNOP RR1, RR2 and RR3. Here it is also clear that SYNOP RR1 performs better for Bodø VI than SYNOP RR2 or RR3 in terms of the width of the distributions and the fraction of days with difference between -0.05 and 0.05 mm.

3.3. Indices of extremes

To study the effect of SYNOP and its possible bias on trends in indices of extremes, we calculated indices based on series of daily minimum temperature, maximum temperature and precipitation amount for both validated data and SYNOP. The descriptions of the indices of extremes used are given in Table 3. For an index to be calculated we required that at least 73 days in a season have non-missing data, e.g. about 80% completeness. If a day for a certain station had a missing value in SYNOP that day was removed from the validated data and the other way around. In this study we compare stations on a station-by-station basis and we are not interested in the exact values of the indices, but only in the behavior of trends in the series with or without SYNOP. Therefore the requirement of at least 73 days and excluding days in the validated data or SYNOP when that day was missing in the other series are justified.

In the second step, we required that at least 18 years of valid index data were present, e.g. 80% completeness, for a trend to be calculated. About 80% to 90% of the 106 stations passed these checks, depending on the index. For each station we determined the trend in the validated index and SYNOP index by fitting a linear regression to the data. The trends in the validated data and SYNOP were compared on a station-by-station basis for exactly the same years per station, and for winter and summer separately.

In Europe there are hardly any summer days and tropical nights in winter, nor frost days and ice days in summer. Therefore these indices in those seasons are not taken into account here. For the precipitation indices we used SYNOP RR2 for all stations.

To determine the effect of SYNOP on the validated index series extended with SYNOP (hereafter blended series) in winter and summer, we have determined the trend in the indices of the blended series by increasing the amount of SYNOP from 1 year until the blended series consist of 50% SYNOP in steps of 1 year. The SYNOP part is always the most recent part of the blended series. For each station we have determined the ratio between the trend in the blended series and the trend in the validated series. The medians of these station ratios are shown in Fig. 9a for winter and in Fig. 9b for summer per index as a function of the amount of SYNOP in the blended series. The solid horizontal line (with a ratio of 1) indicates where the trends in the validated series and blended series are equal. As an example, the dotted lines indicate an error of 5% (assuming the trend in the validated series is the correct one) and the dashed lines an error of 10%. The figure shows that for a certain error in the trends of the blended series different fractions of SYNOP are allowed per index. For the indices TN and TX in winter and TR in summer (see Table 3 for descriptions of the indices) only a very small fraction of SYNOP (5–10%) can be used before the difference between the trends in the validated and blended series exceeds the bounds above, while for the other indices studied here a larger fraction of SYNOP can be used (up to 50%).

As mentioned before, the SYNOP minimum and maximum temperatures are recorded in 12-hour intervals while the validated temperatures are determined over 24-hour intervals. This means that the SYNOP minimum (maximum) temperature is higher (lower) or equal to the true minimum (maximum) temperature recorded in the validated series. While the trend in SYNOP indices may be similar to the trend in the validated series, the trend in the blended series will be different due to the offset in the absolute values of the indices. This results in a jump or inhomogeneity in the blended index series which changes the size of the trend. This is illustrated for ice days (ID) in winter in Fig. 10 for station Falsterbo in Sweden.

Fig. 10a shows that the index based on SYNOP alone has a slightly larger trend for this station and a bias towards higher values compared to the validated index. As a result, SYNOP gives more or an equal number of ice days compared to the validated indices.

Combining validated indices and SYNOP indices means that we introduce an inhomogeneity in the series for ID *and* in the trend in this series. This is schematically represented in the solid lines of Figs. 10b and c where the trend in the validated data is depicted before 1994 (Fig. 10b) or 2000 (Fig. 10c) and the trend in SYNOP afterwards. Recalculating the trend over the blended indices series gives the dashed lines, considerably underestimating both trends of Fig. 10a for the indices based on validated data and SYNOP alone. A reason is that the trend in the last part of the time series is different than the trend in the earlier part, even for totally SYNOP or totally validated series.

4. Conclusion

We have studied the influence of SYNOP on climate change indices when these data series are combined with validated data series. One of the main results is that it is in general impossible to recreate the exact minimum temperature and maximum temperature from the available SYNOP series. Temperatures from SYNOP are often provided for only one 12-hour period each day, while the validated data are determined over 24-hour periods. This means that if the real extreme falls outside the 12-hour SYNOP period, the SYNOP value will be too high (minimum temperature) or too low (maximum temperature) compared to the real extreme in the validated data. Also precipitation is not reproducible from SYNOP due to the rounding off to 0.1 mm until 0.9 mm of precipitation and to whole millimeter values for precipitation above 0.9 mm, and due to differences in recording intervals.

Combining SYNOP with validated data is further complicated by insufficiently precise coordinates and missing metadata such as WMO numbers. Therefore we have assumed that nearby SYNOP and validated stations are actually the same physical station and the observations, most likely, from the same instruments.

In addition, SYNOP has on average a much higher percentage of missing values than validated data. This complicates the analysis of indices of extremes where usually a strict requirement for non-missing values is used.

We have compared the size of the trends in several indices of extremes for validated series and blended series (validated series extended with SYNOP). Although the trends in validated index series and SYNOP index series might be comparable, there is usually an offset present in the index values (partly) due to the 12-hour versus 24-hour measuring intervals. Extending validated series with SYNOP then introduces a jump in the index series which will influence the size of the trend. For the indices studied here, this effect is strongest for the seasonal averaged minimum and maximum temperature in winter and the number of tropical nights in summer.

Accepting a certain error in the trend in the blended series and assuming the trend in the validated series represents the truth, a maximum amount of SYNOP can be used per series. Clearly, the offset in the indices and the corresponding change in trends should be taken into account when analyzing trends over a region where part of the data originates from validated series and another part from SYNOP.

This study has been done for the European area only. Additional studies are needed to determine the influence of SYNOP in other parts of the world.

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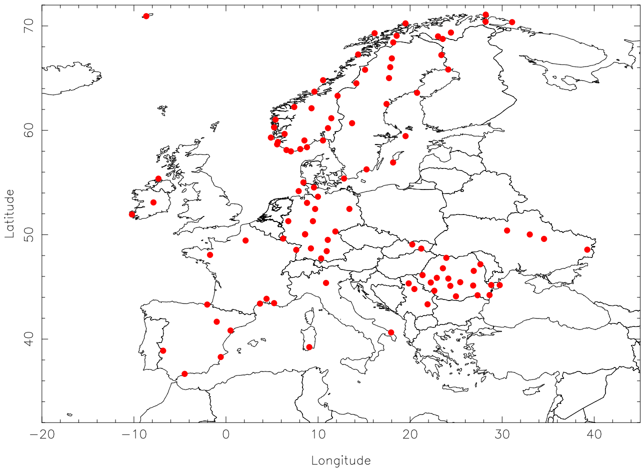

Figure 1. Location of the 106 selected stations.

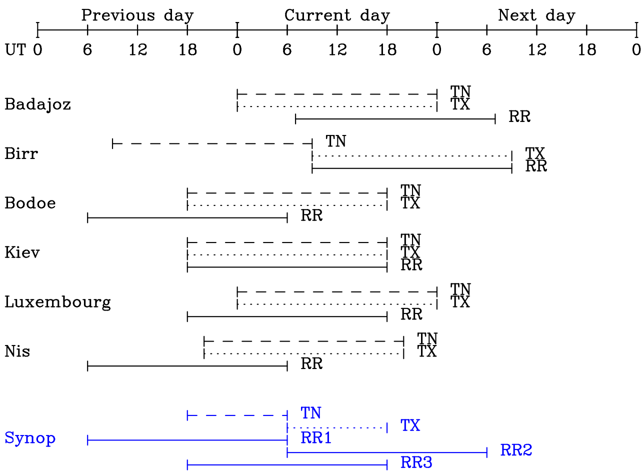

Figure 2. The measuring intervals of the validated data (black) and SYNOP (blue). TN means minimum temperature, TX means maximum temperature and RR means precipitation. These stations are given in Table 2 with bold station names.

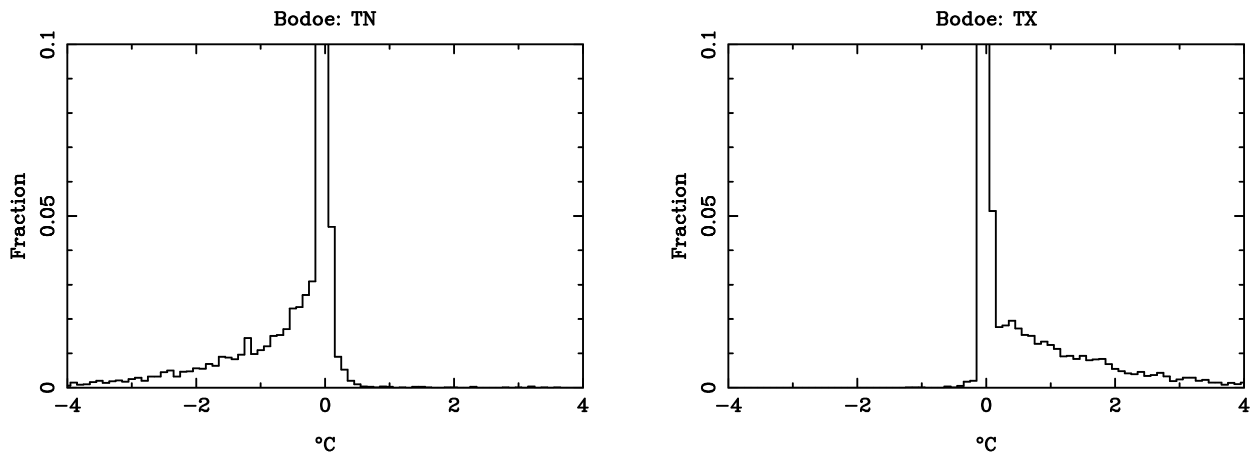

Figure 3. Daily temperature differences for station Bodø between validated data and SYNOP shown as histograms. The maximum fraction at ∼0°C is 0.35 for minimum and maximum temperature.

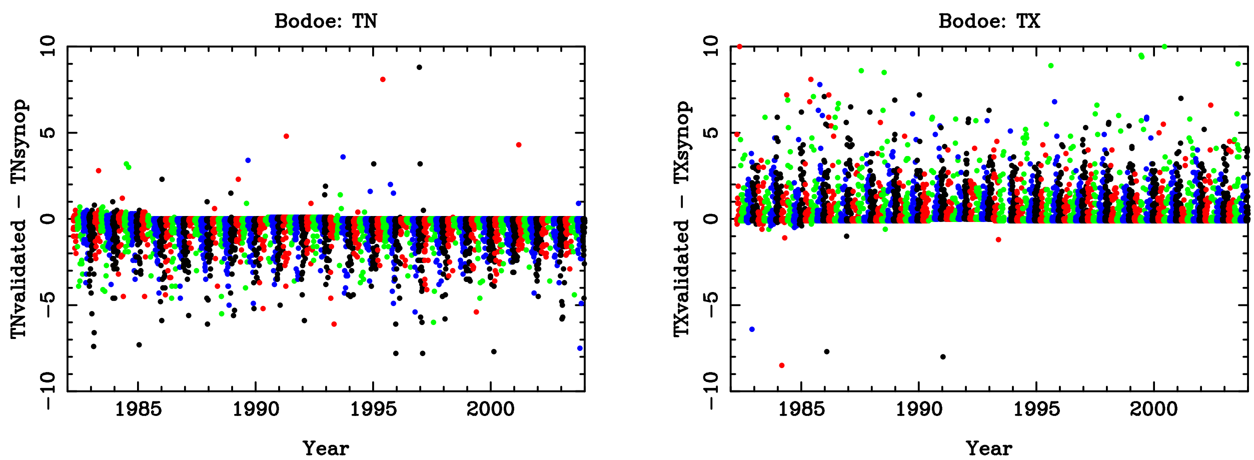

Figure 4. Daily temperature differences for station Bodø between validated data and SYNOP shown as a function of time. Black points are winter days (DJF), red points are spring days (MAM), green points are summer days (JJA) and blue points are autumn days (SON). Units are °C.

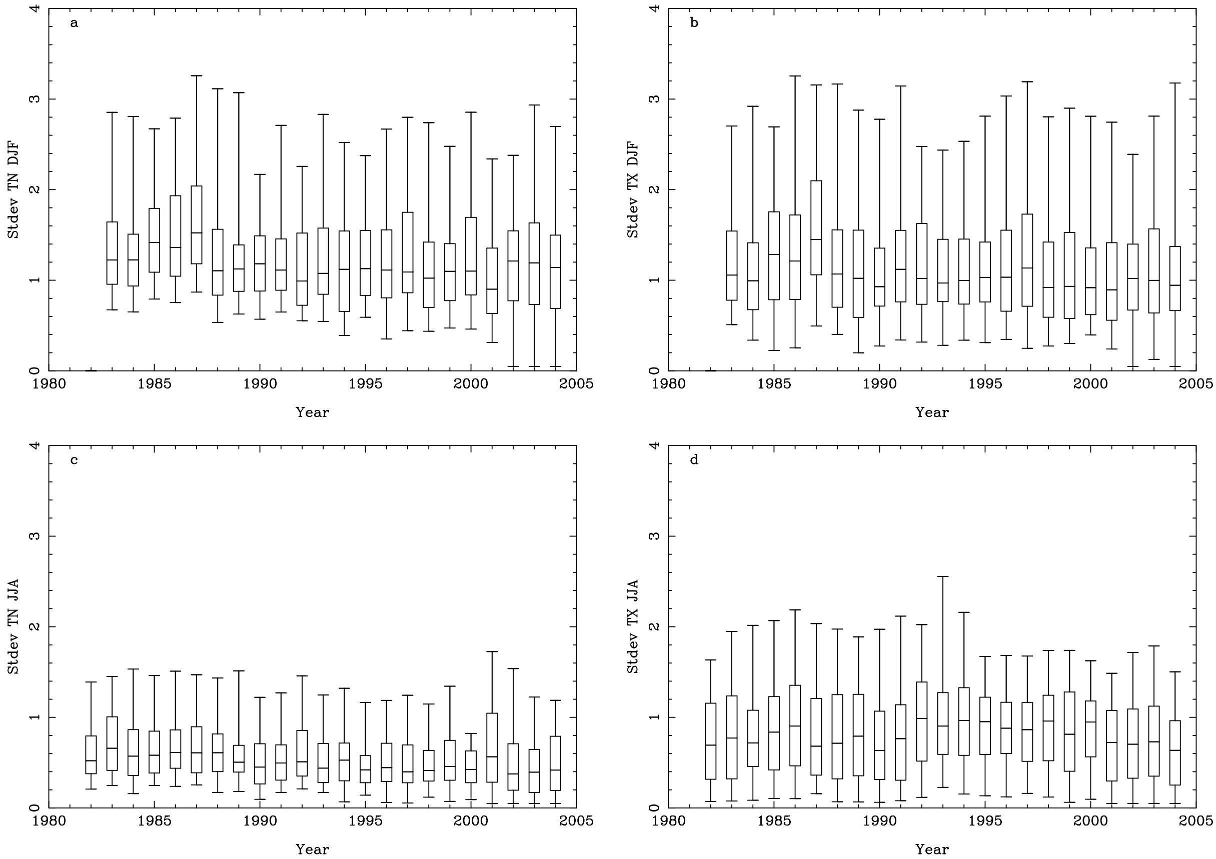

Figure 5. Stdev in °C of the daily difference series between validated data and SYNOP. Shown are the median, 5, 25, 75 and 95 percentiles of the stdev of the 106 stations. (a): Minimum temperature in winter (DJF). (b): Maximum temperature in winter. (c): Minimum temperature in summer (JJA). (d): Maximum temperature in summer.

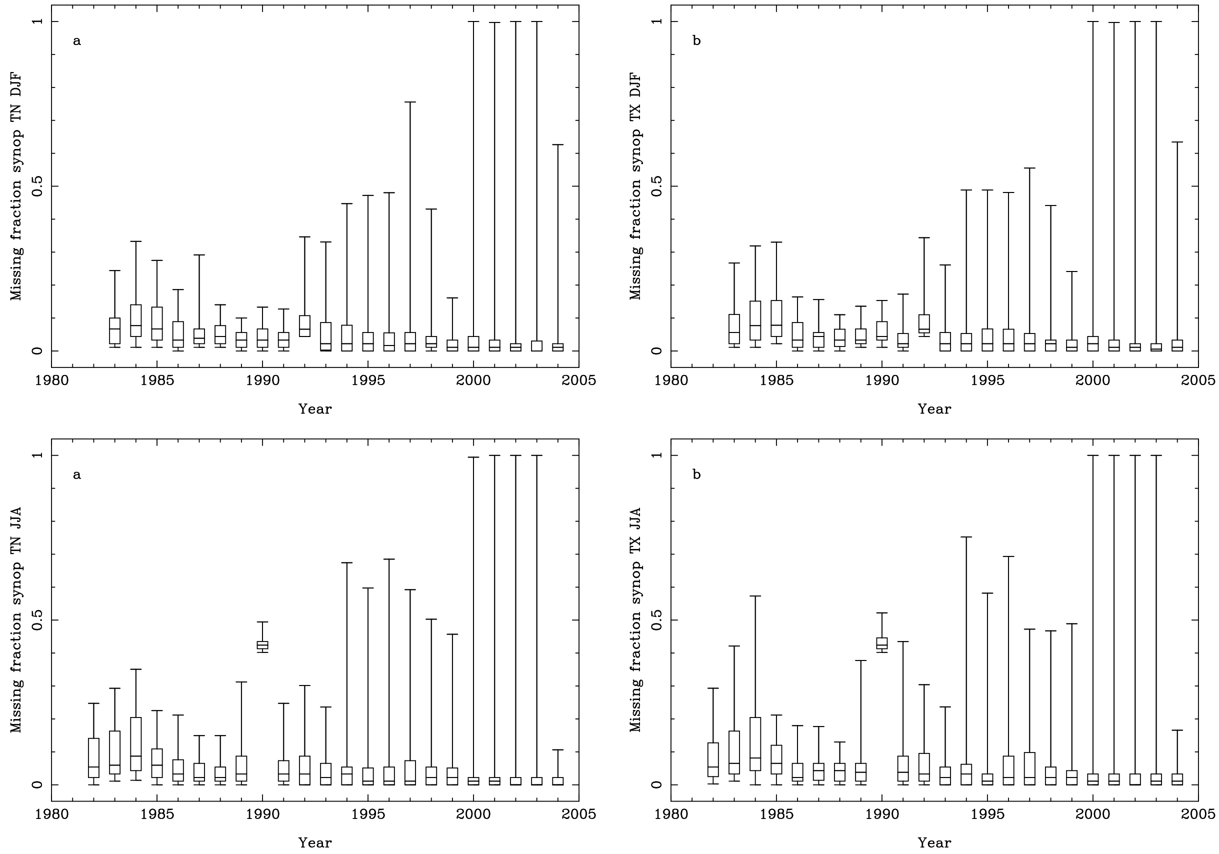

Figure 6. Fraction of missing days in SYNOP. Shown are the median, 5, 25, 75 and 95 percentiles of the fraction of missing days of the 106 stations. (a): Minimum temperature in winter (DJF). (b): Maximum temperature in winter. (c): Minimum temperature in summer (JJA). (d): Maximum temperature in summer.

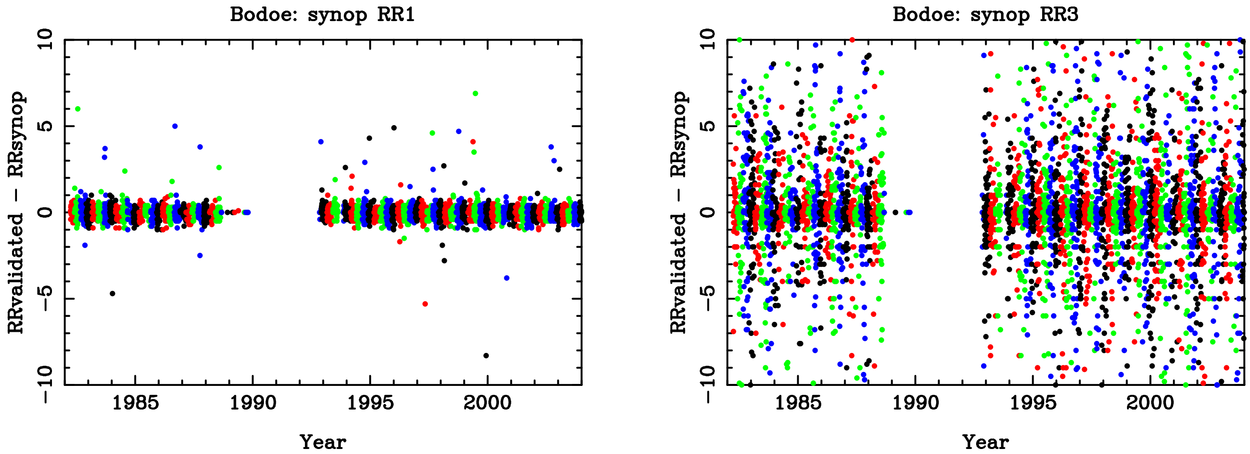

Figure 7. Daily differences for station Bodø between validated data and SYNOP in time. Black points are winter days (DJF), red points are spring days (MAM), green points are summer days (JJA) and blue points are autumn days (SON). Units are mm.

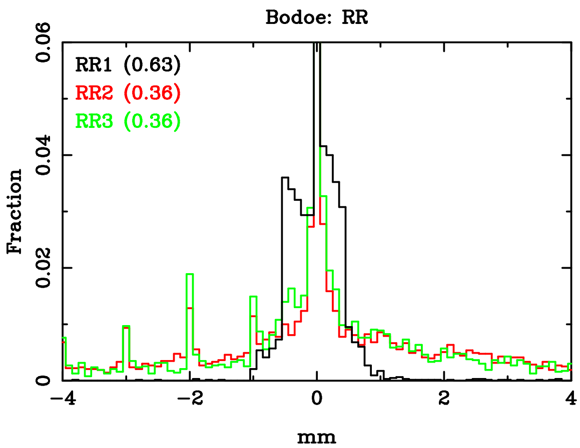

Figure 8. Daily precipitation differences for station Bodø between validated data and SYNOP shown as histograms. The maximum fraction at ∼0 mm is given in parentheses per SYNOP RR flavor.

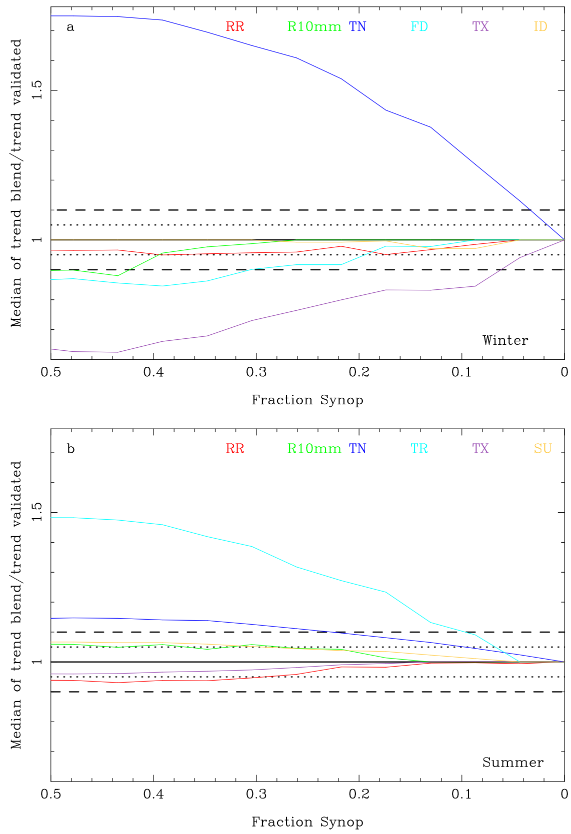

Figure 9. Median of the station ratios of the trend in blended series over trend in validated series versus the fraction of SYNOP in the blended series. The solid line indicates equal trends, the dotted lines indicate an error of 5% (assuming the validated trend is the correct one) and the dashed lines indicate an error of 10%. For indices descriptions, see Table 3. (a): winter, (b): summer

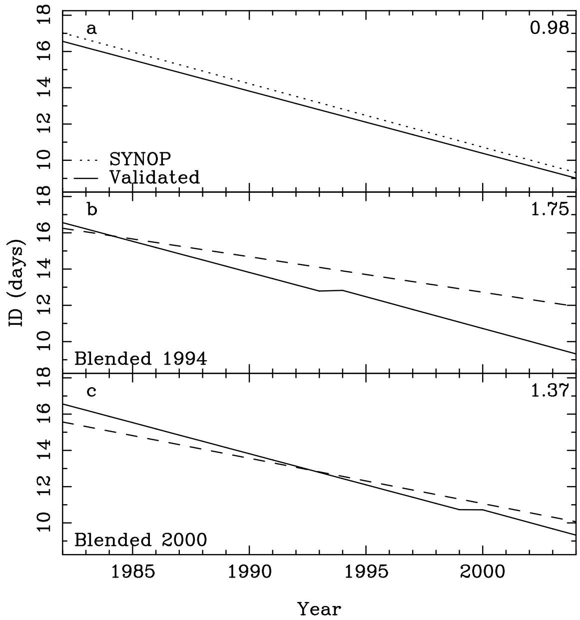

Figure 10. Example of trends in the number of ice days in winter. All lines are based on the real trends determined from the validated and SYNOP data for station Falsterbo in Sweden. (a): validated data (solid) and SYNOP (dotted). (b): Blended series (solid) based on the calculated trends where the validated part since 1994 has been replaced by SYNOP. The corresponding trend in the blended series is shown with the dashed line. (c): Same as (b), but replaced since 2000. The numbers in the top right corner gives the ratio between the trend in the validated index series w.r.t to either the trend in the SYNOP index series ((a)) or the trend in the blended index series ((b) and (c)).

Table 1. Fraction of days in winter and summer that the minimum temperature (TN) or maximum temperature (TX) falls in a specific time window (6 - 18 UTC or 18 - 6 UTC), determined for three time periods for station De Bilt.

	Winter			
	TN 18-6	TN 6-18	TX 18-6	TX 6-18
1982-04-01 – 1988-12-31	0.56	0.44	0.27	0.73
1989-01-01 – 1996-12-31	0.56	0.44	0.32	0.68
1997-01-01 – 2004-12-31	0.54	0.46	0.28	0.72
	Summer			
	TN 18-6	TN 6-18	TX 18-6	TX 6-18
1982-04-01 – 1988-12-31	0.93	0.07	0.12	0.88
1989-01-01 – 1996-12-31	0.93	0.07	0.15	0.85
1997-01-01 – 2004-12-31	0.95	0.05	0.11	0.89

Table 2: Locations of all 106 stations. Station in bold are used in Fig. 2. Lat: Latitude, Lon: Longitude, Elev: station elevation (m), Dist: distance between validated and SYNOP location (km), Hgt: difference between validated and SYNOP elevation (m), WMO: WMO code.

	Validated			SYNOP					
Name	Lat	Lon	Elev	Lat	Lon	Elev	Dist	Hgt	WMO
Málaga Airport	+36:40:00	−04:29:17	7.0	+36:40:00	−04:28:59	7.0	0.4	0.0	08482
Alicante El Altet	+38:16:58	−00:34:14	43.0	+38:16:59	−00:33:00	31.0	1.8	12.0	08360
Badajoz Talavera	+38:52:59	−06:49:45	185.0	+38:52:59	−06:49:59	192.0	0.4	7.0	08330
Cagliari	+39:13:59	+09:03:00	21.0	+39:13:59	+09:03:00	5.0	0.0	16.0	16560
Brindisi	+40:37:59	+17:55:59	10.0	+40:38:59	+17:56:59	10.0	2.3	0.0	16320
Tortosa - Observatorio del Ebro	+40:49:14	+00:29:29	44.0	+40:49:00	+00:30:00	50.0	0.8	6.0	08238
Zaragoza Aeropuerto	+41:39:42	−01:00:29	247.0	+41:40:00	−01:00:00	258.0	0.9	11.0	08160
San Sebastián - Igueldo	+43:18:26	−02:02:21	251.0	+43:17:59	−02:01:59	259.0	1.0	8.0	08027
Niš	+43:19:59	+21:53:59	201.0	+43:19:59	+21:53:59	202.0	0.0	1.0	13388
Sète	+43:23:53	+03:41:30	80.0	+43:23:59	+03:42:00	79.0	0.7	1.0	07641
Marignane Airport Marseille	+43:26:30	+05:13:36	5.0	+43:27:00	+05:13:59	32.0	1.1	27.0	07650
Nîmes	+43:51:29	+04:24:24	59.0	+43:51:00	+04:24:00	62.0	1.1	3.0	07645
Roşiorii de Vede	+44:06:00	+24:58:59	102.0	+44:06:00	+24:58:00	103.0	1.3	1.0	15470
Călăraşi	+44:12:00	+27:19:59	18.7	+44:12:00	+27:19:59	20.0	0.0	1.3	15460
Constanţa	+44:13:11	+28:37:47	13.0	+44:12:00	+28:37:59	14.0	2.2	1.0	15480
Drobeta Turnu Severin	+44:37:59	+22:37:59	77.0	+44:37:00	+22:37:00	78.0	2.3	1.0	15410
Belgrade (Observatory)	+44:47:59	+20:28:00	132.0	+44:47:59	+20:28:00	132.0	0.0	0.0	13274
Râmnicu Vâlcea	+45:06:00	+24:22:12	239.0	+45:04:59	+24:22:00	238.0	1.9	1.0	15346
Buzău	+45:07:59	+26:51:00	97.0	+45:07:00	+26:51:00	98.0	1.8	1.0	15350
Sulina	+45:10:00	+29:43:59	3.0	+45:10:00	+29:43:59	4.0	0.0	1.0	15360
Tulcea	+45:10:59	+28:49:00	4.0	+45:10:59	+28:49:00	5.0	0.0	1.0	15335
Novi Sad	+45:19:59	+19:51:00	84.0	+45:19:59	+19:51:00	87.0	0.0	3.0	13168
Verona Villafranca	+45:22:59	+10:52:00	68.0	+45:22:59	+10:52:00	68.0	0.0	0.0	16090
Caransebeş	+45:25:12	+22:15:00	241.0	+45:25:00	+22:15:00	242.0	0.4	1.0	15292
Vârfu Omul	+45:27:00	+25:26:59	2504.0	+45:27:00	+25:26:59	2509.0	0.0	5.0	15280
Sibiu	+45:47:59	+24:08:59	444.0	+45:47:59	+24:08:59	444.0	0.0	0.0	15260

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Table 2 – continued from previous page

Name	Validated Lat	Validated Lon	Validated Elev	SYNOP Lat	SYNOP Lon	SYNOP Elev	Dist	Hgt	WMO
Deva	+45:52:00	+22:53:59	230.0	+45:51:00	+22:52:59	241.0	2.3	11.0	15230
Arad	+46:07:59	+21:21:00	116.6	+46:07:59	+21:21:00	117.0	0.0	0.4	15200
Bacău	+46:31:59	+26:55:00	184.0	+46:31:00	+26:53:59	185.0	2.2	1.0	15150
Cluj Napoca	+46:46:59	+23:34:00	410.0	+46:46:00	+23:34:00	411.0	1.8	1.0	15120
Iaşi	+47:10:00	+27:37:59	102.0	+47:10:00	+27:37:00	103.0	1.3	1.0	15090
Kempten	+47:43:27	+10:20:11	705.0	+47:43:00	+10:19:59	705.0	0.9	0.0	10946
Ocna Şugatag	+47:46:59	+23:55:59	504.0	+47:46:00	+23:55:59	504.0	1.8	0.0	15015
Rennes	+48:04:00	−01:43:59	36.0	+48:04:00	−01:43:59	43.0	0.0	7.0	07130
Augsburg	+48:25:35	+10:56:35	461.0	+48:25:59	+10:55:59	474.0	1.1	13.0	10852
Strasbourg-Entzheim	+48:32:59	+07:37:59	149.0	+48:32:59	+07:37:59	154.0	0.0	5.0	07190
Lugansk	+48:34:00	+39:15:00	59.0	+48:34:00	+39:15:00	62.0	0.0	3.0	34523
Košice	+48:40:00	+21:13:00	230.0	+48:40:00	+21:13:00	231.0	0.0	1.0	11968
Stuttgart/Echterdingen	+48:41:21	+09:13:31	371.0	+48:40:59	+09:13:59	391.0	0.9	20.0	10738
Poprad/Tatry	+49:04:00	+20:13:59	694.0	+49:04:00	+20:15:00	696.0	1.2	2.0	11934
Beauvais-Tillé	+49:26:48	+02:07:41	89.0	+49:27:00	+02:07:59	111.0	0.5	22.0	07055
Nürnberg	+49:30:15	+11:03:24	314.0	+49:30:00	+11:03:00	318.0	0.7	4.0	10763
Poltava	+49:36:00	+34:32:59	160.0	+49:36:00	+34:32:58	160.0	0.0	0.0	33506
Luxembourg Airport	+49:37:48	+06:12:35	376.1	+49:37:00	+06:13:00	376.0	1.6	0.1	06590
Lubny	+50:01:12	+33:00:00	156.0	+50:00:00	+33:01:00	158.0	2.5	2.0	33377
Frankfurt/M-Flughafen	+50:01:59	+08:34:59	112.0	+50:02:59	+08:35:59	113.0	2.2	1.0	10637
Frankfurt	+50:02:47	+08:35:54	112.0	+50:02:59	+08:35:59	113.0	0.4	1.0	10637
Hof	+50:18:47	+11:52:38	565.0	+50:19:00	+11:52:59	568.0	0.6	3.0	10685
Kiev	+50:23:59	+30:31:59	166.0	+50:23:59	+30:34:00	167.0	2.4	1.0	33345
Düsseldorf	+51:17:49	+06:46:11	37.0	+51:17:59	+06:46:00	41.0	0.4	4.0	10400
Kassel	+51:17:52	+09:26:36	231.0	+51:17:59	+09:26:59	231.0	0.5	0.0	10438
Valentia Observatory	+51:56:22	−10:13:19	9.0	+51:55:59	−10:15:00	30.0	2.0	21.0	03953
Hannover	+52:27:56	+09:40:46	55.0	+52:28:00	+09:40:59	59.0	0.3	4.0	10338
Berlin-Tempelhof	+52:28:06	+13:24:14	48.0	+52:28:00	+13:24:00	49.0	0.3	1.0	10384
Bremen	+53:02:47	+08:47:57	4.0	+53:02:59	+08:48:00	5.0	0.4	1.0	10224
Birr	+53:05:25	−07:52:35	70.0	+53:04:59	−07:52:59	70.0	0.9	0.0	03965
Hamburg Fuhlsbüttel	+53:38:05	+09:59:24	11.0	+53:37:59	+09:58:59	15.0	0.5	4.0	10147

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Table 2 – continued from previous page

	Validated			SYNOP					
Name	Lat	Lon	Elev	Lat	Lon	Elev	Dist	Hgt	WMO
Helgoland	+54:10:35	+07:53:35	4.0	+54:10:59	+07:54:00	8.0	0.9	4.0	10015
Schleswig	+54:31:44	+09:32:57	43.0	+54:31:59	+09:33:00	48.0	0.5	5.0	10035
List/Sylt	+55:00:45	+08:24:44	26.0	+55:01:00	+08:24:59	29.0	0.5	3.0	10020
Malin Head	+55:22:18	−07:20:23	21.0	+55:22:00	−07:19:59	21.0	0.7	0.0	03980
Falsterbo	+55:22:48	+12:49:12	5.0	+55:22:59	+12:49:00	5.0	0.4	0.0	02616
Bredåkra	+56:15:35	+15:16:11	58.0	+56:16:00	+15:16:00	58.0	0.8	0.0	02664
Hoburg	+56:55:12	+18:08:59	38.0	+56:55:00	+18:08:58	39.0	0.4	1.0	02680
Lindesnes Fyr	+57:58:59	+07:02:53	13.0	+57:58:59	+07:02:59	13.0	0.1	0.0	01436
Lista Fyr	+58:06:35	+06:34:05	14.0	+58:07:00	+06:34:00	14.0	0.8	0.0	01427
Kjevik	+58:12:01	+08:04:05	12.0	+58:12:00	+08:04:59	17.0	0.9	5.0	01452
Torungen Fyr	+58:22:59	+08:47:30	12.0	+58:23:59	+08:48:00	15.0	1.9	3.0	01465
Obrestad Fyr	+58:39:33	+05:33:19	24.0	+58:38:59	+05:34:00	26.0	1.2	2.0	01412
Sola	+58:53:03	+05:38:12	7.0	+58:52:59	+05:37:59	9.0	0.2	2.0	01415
Færder Fyr	+59:01:36	+10:31:47	6.0	+59:01:59	+10:31:59	8.0	0.8	2.0	01482
Tveitsund	+59:01:37	+08:31:14	252.0	+59:01:59	+08:31:00	252.0	0.7	0.0	01455
Utsira Fyr	+59:18:28	+04:52:41	55.0	+59:17:59	+04:52:59	56.0	0.9	1.0	01403
Svenska Högarna	+59:26:39	+19:30:20	12.0	+59:27:00	+19:30:00	12.0	0.7	0.0	02496
Sauda	+59:38:54	+06:21:47	5.0	+59:38:59	+06:22:00	6.0	0.2	1.0	01424
Gardermoen	+60:12:23	+11:04:49	202.0	+60:12:00	+11:04:59	204.0	0.7	2.0	01384
Bergen/Flesland	+60:17:21	+05:13:35	48.0	+60:16:59	+05:13:59	50.0	0.8	2.0	01311
Malung	+60:40:53	+13:41:58	308.0	+60:40:59	+13:41:59	308.0	0.2	0.0	02410
Takle	+61:01:36	+05:23:05	38.0	+61:01:59	+05:22:59	38.0	0.7	0.0	01319
Rena - Haugedalen	+61:09:33	+11:26:33	240.0	+61:10:00	+11:26:59	240.0	0.9	0.0	01389
Fokstugu	+62:06:51	+09:17:13	972.0	+62:07:00	+09:16:59	974.0	0.3	2.0	01238
Tafjord	+62:14:00	+07:25:00	15.0	+62:13:59	+07:25:00	17.0	0.0	2.0	01218
Sundsvalls Flygplats	+62:31:28	+17:26:27	4.0	+62:31:00	+17:26:59	5.0	1.0	1.0	02366
Storlien-Visjovalen	+63:18:10	+12:07:31	642.0	+63:17:59	+12:07:00	644.0	0.5	2.0	02206
Holmöarna A	+63:35:41	+20:45:23	6.0	+63:36:00	+20:45:00	5.0	0.6	1.0	02288
Ørland	+63:42:01	+09:36:05	10.0	+63:42:00	+09:35:59	7.0	0.1	3.0	01241
Gäddede	+64:30:12	+14:09:34	328.0	+64:30:00	+14:10:00	330.0	0.5	2.0	02222
Nordøyan Fyr	+64:47:52	+10:32:57	33.0	+64:47:59	+10:33:00	33.0	0.2	0.0	01262

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Table 2 – continued from previous page

Name	Validated Lat	Validated Lon	Validated Elev	SYNOP Lat	SYNOP Lon	SYNOP Elev	Dist	Hgt	WMO
Gunnarn	+65:00:26	+17:42:30	280.0	+65:00:00	+17:41:59	283.0	0.9	3.0	02128
Hemavan	+65:47:48	+15:06:15	475.0	+65:49:00	+15:04:59	485.0	2.4	10.0	02104
Haparanda	+65:49:37	+24:08:38	5.0	+65:49:59	+24:08:59	6.0	0.7	1.0	02196
Arjeplog A	+66:03:08	+17:50:35	431.0	+66:02:59	+17:49:59	432.0	0.5	1.0	02124
Kvikkjokk-Arrenjarka	+66:53:15	+18:01:04	314.0	+66:52:59	+18:01:00	315.0	0.5	1.0	02120
Pajala	+67:12:35	+23:23:34	168.0	+67:13:00	+23:23:59	168.0	0.8	0.0	02096
Bodø VI	+67:16:01	+14:21:32	11.0	+67:16:00	+14:22:00	13.0	0.3	2.0	01152
Katterjåkk	+68:25:18	+18:10:10	515.0	+68:25:00	+18:10:00	517.0	0.6	2.0	02020
Sihčjávri	+68:45:19	+23:32:18	382.0	+68:45:00	+23:31:59	382.0	0.6	0.0	01199
Kautokeino	+68:59:48	+23:02:00	307.0	+69:00:00	+23:01:59	307.0	0.4	0.0	01047
Bardufoss	+69:03:32	+18:32:25	76.0	+69:04:00	+18:31:59	79.0	0.9	3.0	01023
Andøya	+69:17:59	+16:08:59	14.0	+69:17:59	+16:07:59	14.0	0.7	0.0	01010
Cuovddatmohkki	+69:22:00	+24:25:59	286.0	+69:21:59	+24:25:59	286.0	0.1	0.0	01057
Torsvåg Fyr	+70:14:44	+19:30:02	21.0	+70:15:00	+19:30:00	24.0	0.5	3.0	01033
Vardø	+70:22:01	+31:05:04	14.0	+70:21:59	+31:06:00	15.0	0.6	1.0	01098
Rustefjelbma	+70:24:01	+28:12:01	10.0	+70:24:00	+28:11:59	11.0	0.0	1.0	01075
Jan Mayen	+70:55:59	−08:40:00	10.0	+70:55:59	−08:39:59	9.0	0.0	1.0	01001
Slettnes Fyr	+71:05:02	+28:13:04	8.0	+71:05:58	+28:13:59	10.0	1.8	2.0	01078

Table 3. Description of the indices of extremes used in this study.

Index	Description
TN	Mean of daily minimum temperature
FD	Number of days with minimum temperature below 0°C (Frost days)
TR	Number of days with minimum temperature above 20°C (Tropical nights)
TX	Mean of daily maximum temperature
ID	Number of days with maximum temperature below 0°C (Ice days)
SU	Number of days with maximum temperature above 25°C (Summer days)
RR	Precipitation sum
R10mm	Number of days with precipitation above 10 mm(Heavy precipitation days)