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Metadata for the Norwegian Meteorological Station Network 1866-1956

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Abstract

From its start in 1866 to the end of 1956 the observations by the Norwegian Meteorological institute were stored in paper protocols. From 1957, however, new data were stored electronically, and additional data added year by year. Also, some data before 1956 were digitised. During the first two decades of the 21st century the effort of digitising older data than 1957 increased much by the establishment of a project called HistKlim. The longest and most homogenous time series had priority. This effort has made it possible to use the long-term series of daily station data in climate research.

The present report gives general metadata on the network of stations. It presents information of the instructions that were given to the observers and how the instructions varied through time. Formulae and procedures for the calculation of daily and monthly mean values are also given.

Keywords

Station network, metadata, observations, digitization, HistKlim

Disiplinary signature

Responsible signature

Samandrag

I perioden 1866 til 1956 skjedde det mange endringar på dei meteorologiske stasjonane når det galdt instrumentering. I tillegg vart observasjonsprogrammet endra ein del, og også dei prosedyrane som låg til grunn for observeringa vart endra. Somme av desse endringane har konsekvensar for tolkinga av dataa frå perioden. Døme på det er omgrepet døgnnedbør som ikkje var heilt klårt definert den fyrste tida. Og når det gjeld temperatur kan enno ulike definisjonar av temperaturdøgnet skape problem for bruken av data.

I 1961 fekk Meteorologisk institutt si fyrste datamaskin. Det gjorde det mogleg å digitalisere observasjonane som inntil no berre var lagra på papir. Observatørane på vêr og klima-stasjonane samla observasjonane sine i protokollar som vart sende inn til instituttet ved slutten av kvar månad. På nedbørstasjonane vart observasjonane sende inn kvar veke på såkalla «ukekort». Der vart dataa kontrollerte og eventuelle synlege feil retta. Instituttet makta å digitalisere tilbake i tid. For dei fleste stasjonane vart digitaliseringa starta med året 1957, men for dei arktiske stasjonane var det 1956.

Det var likevel ein stor hemsko å måtte avgrense seg til desse årstala om ein ville bruke datamaskinar i arbeidet. Etter som tida gjekk, sette ein i gang med vidare digitalisering, fyrst til 1954 og så til 1951. Nokre få stasjonar vart òg digitaliserte tilbake til 1931 som var starten på ein normalperiode.

Fyrst på 2000-talet vart HistKlim-prosjektet sett i gang med det føremålet å digitalisere lange tidsseriar. Det var eit internt prosjekt på instituttet der studentar kunne få sommarjobb. Prosjektet vara i fleire år, og dermed vart det digitalisert i eit heilt anna omfang enn tidlegare. Det er rett å seia at prosjektet sette standardar for korleis avleidde data skulle reknast ut. Eksempel på det er døgn- og månadsmiddel for temperatur. Det kom også eksterne midlar til digitalisering frå Statkraft Særleg galdt det nedbør. Elles bør det nemnast at Olav P. Amundgård, observatør på Lesja, gjorde ein stor frivillig innsats ved å digitalisere lange seriar etter eit spesielt opplegg.

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1 General information

[Ingress]

1.1 The start of standardized observations

Already in the year 1860 a certain observational standard was introduced for meteorological observations by the Norwegian State Telegraph. The institution established five stations along the coast of southern Norway. All of them came into operation from 1st of January 1861. These were Sandøysund, Mandal, Skudeneshavn, Ålesund and Kristiansund, and in 1864 a station inland in Norway was also established, i.e. Dombås. With the foundation the Norwegian Meteorological Institute (MET Norway) the 1st of December 1866, the administration of the stations was transformed from the State Telegraph to MET Norway. It led to a further standardization of the instruments and the observational procedures. But those standards shifted with time, mainly because of technical improvements and progress in meteorology.

Figure 1. Dombås meteorological station (photo MET Norway 21. June 1946). On this farm the measurements were started in 1864 by the Norwegian State Telegraph. It was the first station located inland. The present station at Dombås lies only 300 m from the old site (Høgåsen et al. 2021).

1.2 Digitization

MET Norway bought its first computer already in 1961. This computer was utilized for the digitizing of observations back to 1957; for the Arctic stations even back to 1956. This means that all daily observations are available in our database from 1957 onwards. Later the institute now and then was able to digitize daily values for earlier years for selected stations. However, the digitization activity was mostly concentrated on monthly values. These were statistical data calculated manually, for example temperature and precipitation standard normals for the periods 1901-1930 and 1931-1960 had high priority.

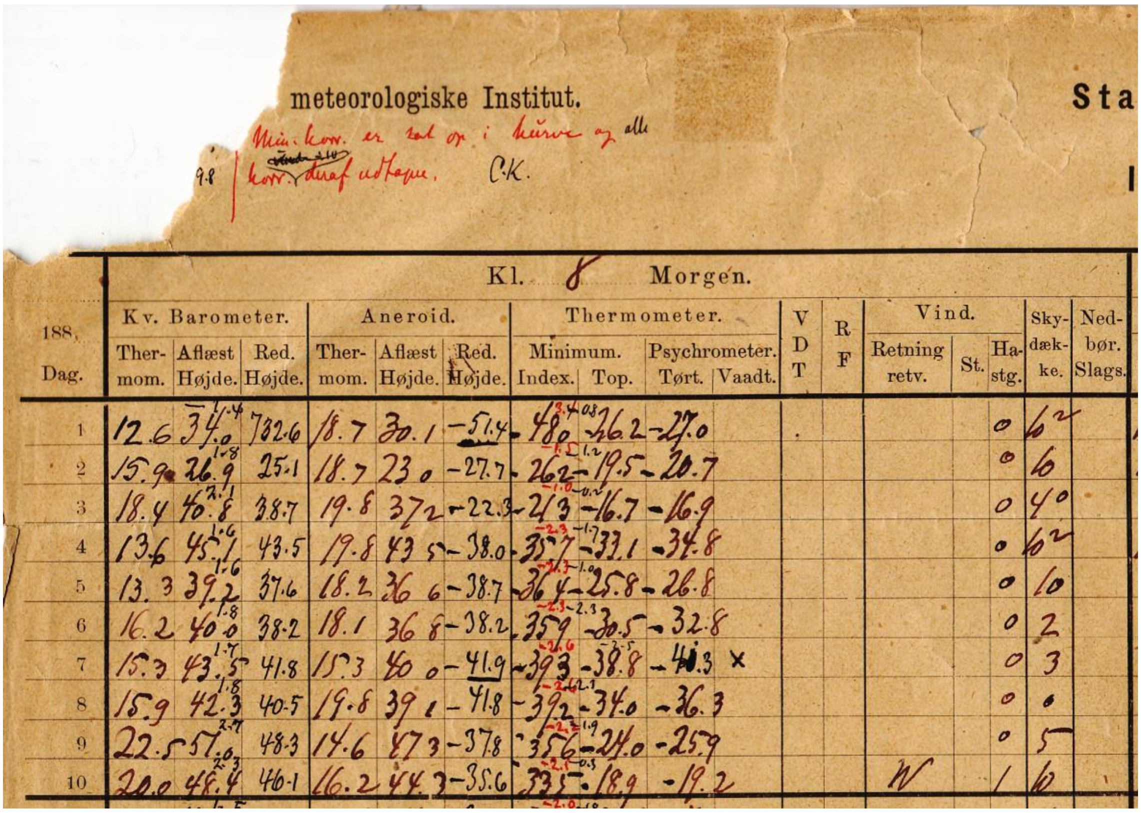

Figure 2. Station protocol for the Karasjok (Kárášjohka) station for January 1886 with the national minimum temperature extreme record of -51.4°C. The whole series is digitized.

In the 1990s and in the 2000s the digitization was organized in projects, the largest and most well-known was HistKlim. It had its highest activity during summer with the engagement of students. It also set the standards for which weather elements should be digitized, and how they should be stored in the climate database, cf. chapter 2 on metadata.

1.3 Observation times

From the start of the institute most stations observed in local time, except some telegraph station that observed in Christiania time (ChT), which is local time for Christiania (Oslo). From 1 January 1895 Central European Time (CET) was adopted as official time in Norway, but the practice of observing in local time was not changed. The only difference was that the few telegraph stations that before 1895 had observed according to ChT now changed to CET, but the difference between them is only 17 minutes: CET = ChT + 17 minutes. This difference is considered to be too small for giving attention.

The stations that had observed in local time should continue to do so, but as CET grew more and more common, it seems like some stations changed from local time to CET without reporting it to the institute. But from 1 July 1919 all observers were instructed to report on CET (Birkeland 1936: p. 8).

Since 1 July 1949 MET Norway's standard observation times have been at 06, 12 and 18 UTC (Universal Time Coordinated). Both before and after this, some stations have had slightly different observation times. The most common deviation occurred in the morning observation, which often was delayed one hour. The observation times for each station are listed in the yearbooks and for digitized stations they are stored as additional information of original observation times. The timeseries are stored on the standard observation times using UTC in MET Norway's two databases. The oldest one is Klimadatavarehuset (KDVH) or the Climate Data Warehouse. This is in the process of being replaced by the Observation Data Archive (ODA) as of 2022. For the old data the accuracy stored in the database is no better than the nearest hour. One should also remember that for telegraph stations the observations had to be taken at least 15 minutes before the official time to complete the weather telegram in due time. The history of observations hours is shown in Table 1.

Table 1. The history of observation hours. The official observation time have been in Local Time (LT), Christiania time (ChT) and in Central European Time (CET). In the database the nearest hour of observations is shown in Universal Time Coordinated (UTC). For stations that observed in LT the nearest hour in UTC varies with the longitudinal coordinate of the station.

Period (from – to)	Official obs. hours	Nearest hour
1866.12 – 1919.06	08, 14, 20 LT	**08, 14, 20** UTC west of 7°30' E
1866.12 – 1919.06	08, 14, 20 LT	**07, 13, 19** UTC 7°30' W - 22°30' E
1866.12 – 1919.06	08, 14, 20 LT	**06, 12, 18** UTC east of 22°30' E
1866.12 – 1919.06	08, 14, 20 ChT	**07, 13, 19** UTC
1919.07 – 1920.06	08, 14, 20 CET	**07, 13, 19** UTC
1920.07 – 1948.12	08, 14, 19 CET	**07, 13, 18** UTC
1949.01 – 1949.06	08, 13, 19 CET	**07, 12, 18** UTC
1949.07 – present	07, 13, 19 CET	**06, 12, 18** UTC

For the year 1916 the so-called summer-time was introduced in Norway, table 2. This has led to some uncertainty of the real observation hours. When it was introduced, the observers were asked by a letter to take the observations one hour later for avoiding a real change (Harbitz, 1963). During the WWII summer time was also introduced, but in most cases the real observation time can be seen from the observation protocols. Under the German occupation real observation times could also be changed for some stations. Since 1980 Norway has had summer-time each year. Therefore, the observers have gotten more familiar with adjusting for summer-time, so it is not considered to be a major problem.

Table 2 Summer-time in Norway, when it begins and stops each year. Since 1980 summer- time has been introduced each year lasting from late March to late October. There was also summer time in Norway in the period 1959-1965. In the latest years the summer-time has been coordinated by EU. It should last from the last Sunday in March to the last Saturday in October.

From	To
22 May 1916	30 Sep. 1916
11 August 1940	1 Nov. 1942
29 March 1943	4 Oct. 1943
3 April 1944	2 Oct. 1944
2 April 1945	1 Oct. 1945
After 1959: Late March	After 1959: Late October

2 Metadata for each weather element

2.1 Cloud cover

When observations started at the telegraph stations in 1861 the observers should assess how much of the sky that was covered by clouds. The scale used had four categories Category 1 was used if ¼ of the sky was covered, whereas 4 was used if the whole sky was covered. The observers should also take into account the cloud density (Harbitz, 1963). If the clouds were thin, the fraction should be reduced according to how much light could pass through the clouds. If for example, the whole sky was covered by thin cirrus clouds the assessment should be 1, not 4.

In the instruction to the observers from 1867 it is written that the cloud cover should be assessed with numbers from 0 to 10 where 0 is clear sky and 10 are totally overcast. However, also at this time the observers had to consider the density of the clouds: “One should think that the clouds should be gathered in the sky at a usual degree of density. It should be assessed how many tenths of the sky the clouds then would cover”.

At the congress of the International Meteorological Organization (IMO) in 1874 it was decided that the total cloud cover should be observed as the fraction of the sky that was covered by clouds. This should be done without regard to the cloud’s thickness, so this was a new compared to the earlier procedure. The response by MET Norway came in 1875 with a letter to the observers. The density of the clouds should be assessed by a number written in uppercase. For example, if 3 tenths of the sky was cover with very thin clouds the notation should be 3^0, whereas if the clouds were extraordinary thick the notation should be 3^2, and if the clouds were of ordinary thickness the notation should be only 3. However, according to Harbitz, (1963) old observers continued with the old procedure until the end of the 1880s. The uppercase number has not been stored in the databases.

The scale for observation of cloud cover changed from 1 January 1949 according to new guidelines from the World Meteorological Organisation (WMO). Now the observers should assess the cloud cover with numbers from 0 to 8, where 0 is clear sky and 8 is overcast. To obtain homogeneity in MET Norway’s databases observations before 1949 are converted to fractions of 8 (oktas), eqn (1).

$$N_8 = \frac{8}{10} N_{10} \qquad (1)$$

, where N_8 is cloud cover in parts of eight, and N_{10} is parts of ten.

For clear sky, half overcast and overcast it is obvious that the conversion should be 0, 4 and 8 respectively. It is also a rule that if there are clouds in the sky one should not use 0, and 8 should never be used if one sees blue sky somewhere. Therefore, it is also obvious that N_{10}=1 is converted to N_8=1, and N_{10}=9 to N_8=7.

Table 3. Conversion of cloud cover observed in fractions of ten (N_{10}) to fractions of eight (N_8). Frq shows how large parts of observations of the N_{10}-scale are converted into the N_8-scale for the respective cloud classes, see text for further explanation.

N_{10}	0	1	2	2	3	3	4	4	5	6	6	7	7	8	8	9	10
Frq	8	8	3	5	5	3	7	1	8	1	7	3	5	5	3	8	8
N_8	0	1	1	2	2	3	3	4	4	4	5	5	6	6	7	7	8

For the other N_{10} values it is not obvious which N_8 values that should be used. The chosen conversion is illustrated by Table 3, for example N_{10}=3 gives N_8=2.4 by eqn (1), so N_{10}=3 lies between 2 and 3 oktas, closer to 2 than 3. If all N_{10}=3 values were converted to N_8=2, the converted observations would have been biased. Therefore, a computer program was developed for the conversion so that 5 out of 8 N_{10}=3 observations were converted to 2 oktas, and 3 out of 8 to 3 oktas, see the second line in Table 3.

2.2 Humidity

The calculation of humidity in the air was from the beginning based on the difference in temperature between dry bulb and wet bulb thermometers, see for example MET Norway (1888, pp 34-45). Later psychrometer observations were also used. From 1908 mechanical hygrometers were introduced, which gradually replaced the wet thermometers or psychrometers (Harbitz 1963). The principle for measurement was the impact humidity has on human hair. Contraction and expansion of the hair in a mechanical hygrometer causes a spring to move a needle on a dial. This kind of hygrometer is therefore often called the torsion hygrometer. The instrument is shown in Fig. 7. The value indicated by the needle was converted to relative humidity (percent of saturated air) by a table for each hygrometer.

Humidity had a low priority in the digitization projects. Therefore, this weather element has been digitized only for a few of the stations, and only for stations equipped with torsion hygrometer.

2.3 Precipitation

2.3.1 Equipment and units

When MET Norway was established the measurement unit for precipitation was decimal lines. In accordance with the definition of one Norwegian foot one decimal line = 3.1374 mm. But already in 1867, the institute replaced the lines with the millimeter scale (Harbitz 1963).

IMO had in 1873 their congress in Vienna, where a standardization of the precipitation equipment was approved. It was decided that the gauge opening should be a quadrat of 225 cm^2 and a loose funnel was used for reducing evaporation during summer. During winter, however, it was recommended to remove the funnel for making a bigger storage room for snow.

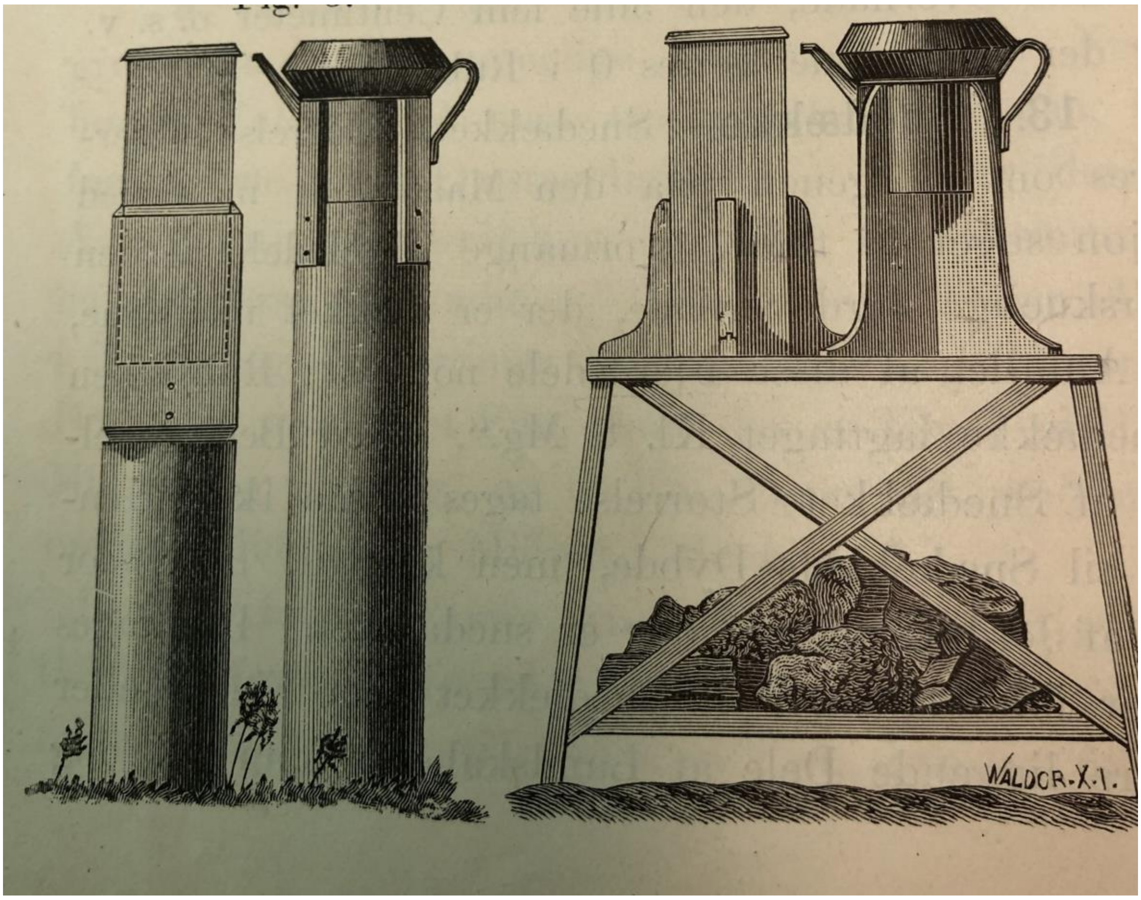

Fig. 3. Two possible arrangements for snow and rain measurements as they were firstly presented in the handbook of 1895 (Met Norway 1895 p. 10). The first snow and rain gauges were without wind screens.

In 1879 the stations got circular rain gauges for the summer season. The funnel was now fastened tight to the walls and there was only a small hole in the middle letting the water into the storage room. Therefore, the rain gauges were more efficient in reducing the evaporation loss from the stored water, Fig. 3

2.3.2 Windscreens and undercatch

In the beginning the stations were not equipped with screens for reduction of undercatch. For snow this undercatch was a big problem at windy places. Undercatch and other measuring errors for the Norwegian precipitation gauge are described in Førland et al. (1996). The institute reduced the undercatch problems from 1906 on by equipping the stations with windscreens of the Nipher type (Hesselberg 1949). The undercatch was reduced so the windscreens worked as intended, Fig. 4. However, this created another problem. The precipitation series were no longer homogenous from the time the stations got their windscreens. Therefore, some old stations remained unchanged keeping their homogeneity.

Fig 4. Precipitation gauge with a Nipher wind screen. There is a passage between the gauge and the screen that lets the snow fall to the ground avoiding filling up the area between the gauge and the screen (photo MET Norway: Lien in Selbu, Trøndelag county)

2.3.3 The concept of daily precipitation

1866-1875: During these years the focus was not on daily precipitation but rather on how much precipitation had fallen during each precipitation event. The general rule was to take the measurement at the morning observation. Another option was to postpone the observation until the rain, eventually the snow, had stopped (Harbitz 1963). Obviously, to wait was the option that cost less effort for the observers, so one is inclined to believe that waiting was widespread.

The measuring procedure of precipitation was confirmed in 1871 (Harbitz 1963): "… the observation should be done no later than the day after a rainy or snowy day, but not if the snow is still falling. In that case one shall wait until the snowfall ends. One may also feel free to observe the rain height at the same time as the other observations." (translated from Danish). Here we see that the observers are encouraged to wait.

1876-1915: Following Harbitz (1963) these rules for observing were changed. From 1 January 1876 the observers at all kinds of stations should observe precipitation at the morning observation. From the same year the precipitation should not be noted on the day the precipitation was observed, but on the previous day. An exception from that rule was if the observers knew that all precipitation had fallen after midnight. Then the precipitation should be noted on the same day as it was observed.

The rules introduced a new concept – precipitation before and after midnight, and "moving" of precipitation to the day before it was observed. The handbook for observers from 1888 (MET Norway 1888) describes in detail how the notation should be done. If the observers followed the rules accurately, daily precipitation can be extracted from the protocols. Also, if the observers did not bother about the "midnight limit", then daily precipitation was directly observed. However, the rules were complicated, so it is doubtful how accurately they were followed.

In 1895 a new station type was introduced, the so-called precipitation station. These stations observed precipitation, snow cover and snow depth every morning as well as precipitation types during three intervals: morning, evening, and night. Norway was then at the start of the development of its hydro power industry but was facing a lacking knowledge of the precipitation climate. The new type of stations soon outnumbered the original ones (the weather stations and the climate stations, see Glossary). Following Harbitz (1963) there were soon 263 of them! Daily precipitation was directly observed from morning to morning and noted on the day measured. The normal observation hour for these stations was at 8 CET.

1916 – present: From now on the precipitation should always be observed at the morning observation and noted on the same day and hour as it was observed. Thus, the concept of daily precipitation was accepted for all stations in the network. The frequency of the observations, however, was increased for most of the weather stations. During the interval from 1919 to 1930 precipitation at the weather stations should be observed three times a day, at the morning, midday, and afternoon observations. From 1931 (or maybe already from the autumn 1930) the midday observation of precipitation was dropped. For climate and precipitation stations the rules were simple during the whole period. They should observe precipitation only once a day, always at the morning observation.

In KDVH the symbols for precipitation was RR_12, RR_24 or RR_X for intervals of 12 hours, 24 hours or an unknown time interval, respectively. There was no RR_6 because the precipitation at midday was added to the evening observation. In the HistKlim project precipitation observations before 1916 from the weather station were noted RR_X. It is disputable whether the interval should be noted as RR_X or RR_24 in the period 1876-1915.

2.4 Air pressure

The first stations in the network measuring pressure had barometers made by the instrument maker Lundh in Oslo (Åstrand, 1866). They were mercury siphon barometers with scales in mm, here denoted mmHg. These barometers are more portable than their counterpart: the cistern barometers. Therefore, the siphon barometers are also called portable barometers. The mmHg scale was used in the meteorological yearbooks until 1 January 1922, when it was changed to hPa, at that time named millibar (mb). By the eqn (2) pressure in mmHg may be converted into hPa. This is done in KDVH and ODA for all data originally observed in mmHg.

$$P_{hPa} = 1.3332 P_{mmHg} \qquad (2)$$

,where the P_{hPa} is the pressure in hPa and P_{mmHg} is the pressure measured in mm.

Before 1891 the observed station pressure, PO, was not reduced to standard density. In the digitization projects this was done before storing the observations in the database. The formula used was a traditional one (Yearbook 1891), formula (3)

$$P_{O\_red} = -P_{O\_u}[a\cos(2\varphi) - bh_s] \qquad (3)$$

, where $PO_{\_red}$ and $PO_{\_u}$ are the pressure reduced and not reduced to standard density, respectively, h_s is the height of the station in m and φ is the latitude, a and b are constants, $a = 2.59 \cdot 10^{-3}$ and $b = 1.96 \cdot 10^{-7}$.

For φ larger than 45˚ cos(2φ) is negative, so the quantity in the bracket is also negative, which means that $PO_{\_red} > PO_{\_u}$. For example, for stations at latitude 60˚ the reduction to standard density amount to 1.3 hPa, whereas it amounts to 2.0 hPa at latitude 70˚ when PO = 1000 hPa.

Pressure observations must be corrected for varying temperature in the mercury of the barometer. Therefore, they are equipped with a thermometer for the observation of the so called “barometric temperature”. The observer had to read both the height of the mercury column of the barometer as well as the barometric temperature. Based on those observations the correct station pressure, PO, was established by use of tables valid for each barometer. However, from the beginning of 1930s to 1956 a labor saving procedure was applied (Harbitz, 1963). The correction was applied for each observation only for the most important stations. For the other stations the correction was performed for the monthly extremes and for the monthly mean of the uncorrected data pressure values. The error of the monthly mean was considered to be so small that it was accepted.

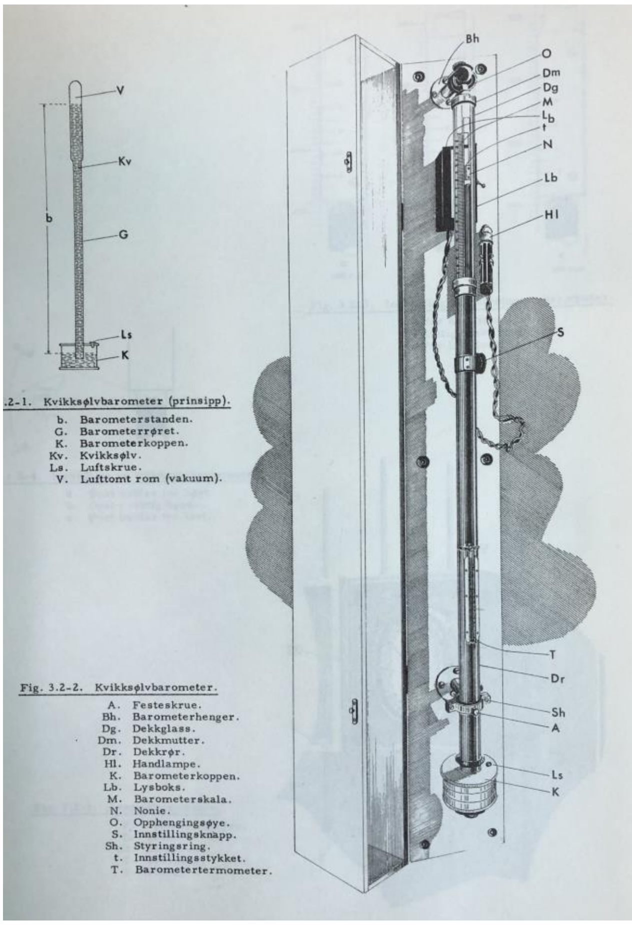

Fig. 5. A cistern barometer used in the Norwegian station network. The drawing is a taken from the observer's manual from 1965 (MET Norway 1965). The upper left figure shows the principle of the cistern barometers, whereas the right figure is a drawing of the actual instrument in use. K = cistern, T = barometric thermometer, M = barometric scale. V = vacuum.

Unfortunately, the correction tables have not been preserved. Therefore, in the HistKlim project the corrections were reconstructed by regression analysis based on the maximum, minimum and mean values. By use of the regression equation the corrected values for each observation were calculated and stored in the database.

For making weather maps the pressure needs to be reduced to sea level. Traditionally this has been done by Laplace's formula (Harbitz 1963; Mohn 1895). Since 1 January 1944 the reduction tables are based on a work by Arnt Eliassen, (Eliassen 1943), see eqn (4), (5) and (6) below.

$P_R = P_O e^{\frac{h_p}{Y}}$, where (4)

$Y = \left(C_u + 0.00325 \cdot h_p + 273.2 + t_s\right) \cdot 29.29$ (5)

$C_u = U_m\left(2.5 \cdot 10^{-5} \cdot h_p + 0.10701\right)0.0611213e^{\frac{17.5043t_m}{241.2+t_m}}$ (6)

,where h_p is the altitude of the barometer, t_s and U_m is annual mean values for temperature and relative humidity at the station.

In the database daily and monthly values are given as arithmetic means of PO and PR for the morning, midday, and evening observations.

2.5 Snow cover

The observation of snow cover was introduced in 1895 at the precipitation stations, see paragraph 2.3.3 and MET Norway (1895). The observers were asked to assess how many parts out of four that was covered by snow. If there were no snow zero should be noted, if the ground was fully snow covered 4 should be noted. They were also told not to consider snow in the mountains or in “higher located parts of the terrain” (Danish: høiere liggende Dele av Landskabet).

In a modernized guidebook of MET Norway (1906) the terrain for assessment is given a strict definition. It should be within a zone ± 50 m compared to the level of the station. The scale of 1895 running from 0 to 4 was kept, now with some examples that should help the observers to use the scale correctly. This scale was replaced with a new parameter called “state of ground” around 2009. But state of ground observations are also converted to the old snow cover scale (0-4).

Following Harbitz (1963) the snow cover has been observed on the ordinary stations since 1896. However, by the HistKlim digitization program it was discovered that snow cover was not frequently observed in the beginning.

2.6 Snow depth

Like for snow cover the observation of snow depth was introduced in 1895 at the precipitation stations, see paragraph 2.3.3 and MET Norway (1895). Snow depth was observed in the morning mainly by a stick with a cm scale. No decimals were used.

Following Harbitz (1963), the snow depth has been measured on the weather stations since January 1901. However, the digitization projects have shown that snow depth has been observed earlier at some of the stations, for example at Karasjok from the winter 1897-98. On the other hand, there were only a few of the ordinary stations that had snow depth observations as early as the 1910s. It seems like snow depth was not an important weather element on the ordinary stations, but on the new precipitation stations it was obligatory.

2.7 Temperature

2.7.1 Radiation screens and temperature scales

Norway has a long tradition of temperature observations in wall or window cages either made by wood or metal, Fig 6. This started already with the observations organized by the telegraph authorities in January 1861. In 1875 a standardized metal screen was introduced in the network. Before that year we do not know exactly how the screens were designed, may be the first screens were open structures like the Swedish window shelters (Nordli et al. 1997, Fig. 2a). In the 1930s the window screens were replaced by freestanding screens of the patterns of 1930 and 1933, called MI30 and MI33, respectively. MI30 was a single louvered screen with a "wall" cage placed inside, whereas MI33 had double walls, but not louvered. It was designed for harsh weather conditions. Then in 1946 a Stevenson like screen was introduced, which was of the same type as MI33, but its two side walls were double louvered.

Fig. 6 Left photo: Cages used by the astronomer Sigurd Einbu at the station Brennøygarden in the period 1918-1926. The left box is a wall cage and the right one is a window cage, now at the Einbu museum at Dombås. Right photo: An authentic window cage made of wood at the station Bergen – Pleiestiftelsen in use at the station until it was closed in 1926.

The first thermometers in use (1861-1866) had the Reaumur scale (˚R). In the yearbooks the observations were also printed in ˚R, but in the databases, they are converted to ˚C. The observations were normally carried out at the hours 08, 14 and 20 Local Time. Later there have been changes. The history of the observation times is shown in Ch. 1.3.

2.7.2 Minimum temperature

In the early period of the network the minimum temperature was not recorded, but in the summer and autumn of 1875 the stations were equipped with minimum thermometers. The minimum thermometer was set at the *evening* observation and read at the morning observation, so it was the *night minimum* that was observed. The observations of minimum temperature were often irregular after its introduction in 1875, so therefore it was decided by the HistKlim project not to digitize nightly minimum temperature before 1 January 1876. At high latitudes the day minimum might often be lower than the night minimum, particularly during winter. For example, the midday temperature observation might therefore be lower than the recorded minimum temperature

From 1st January 1894 the observational procedure was changed so that the minimum thermometer was read and set at the morning observation. Thereby a daily minimum temperature was observed from the morning the previous day to the morning the present day. The next change came in 1937 when the minimum thermometer was read and set at the evening observation in addition to the morning observation. However, the institute decided to make a smooth start of the new procedure, so the change did not come into effect immediately. The institute would give the observers some time to adopt the new rule.

From 1st January 1938 the daily minimum temperature was defined from the evening observation the day before to the evening observation the present day. When calculating the monthly mean minimum temperature, the definition of the day turns out to be important. The mean value of the minimum temperatures for the day running from morning to morning are lower than for those running from evening to evening (Nordli, 1997). The reason for that is: in the morning the temperature tends to be closer to its daily minimum value than in the evening. The change of procedure was probably put forward by a resolution at the Warsaw Conference of IMO in 1935: “Extreme thermometers should be read at the morning and evening observations but set only in the evening "(translated from German).

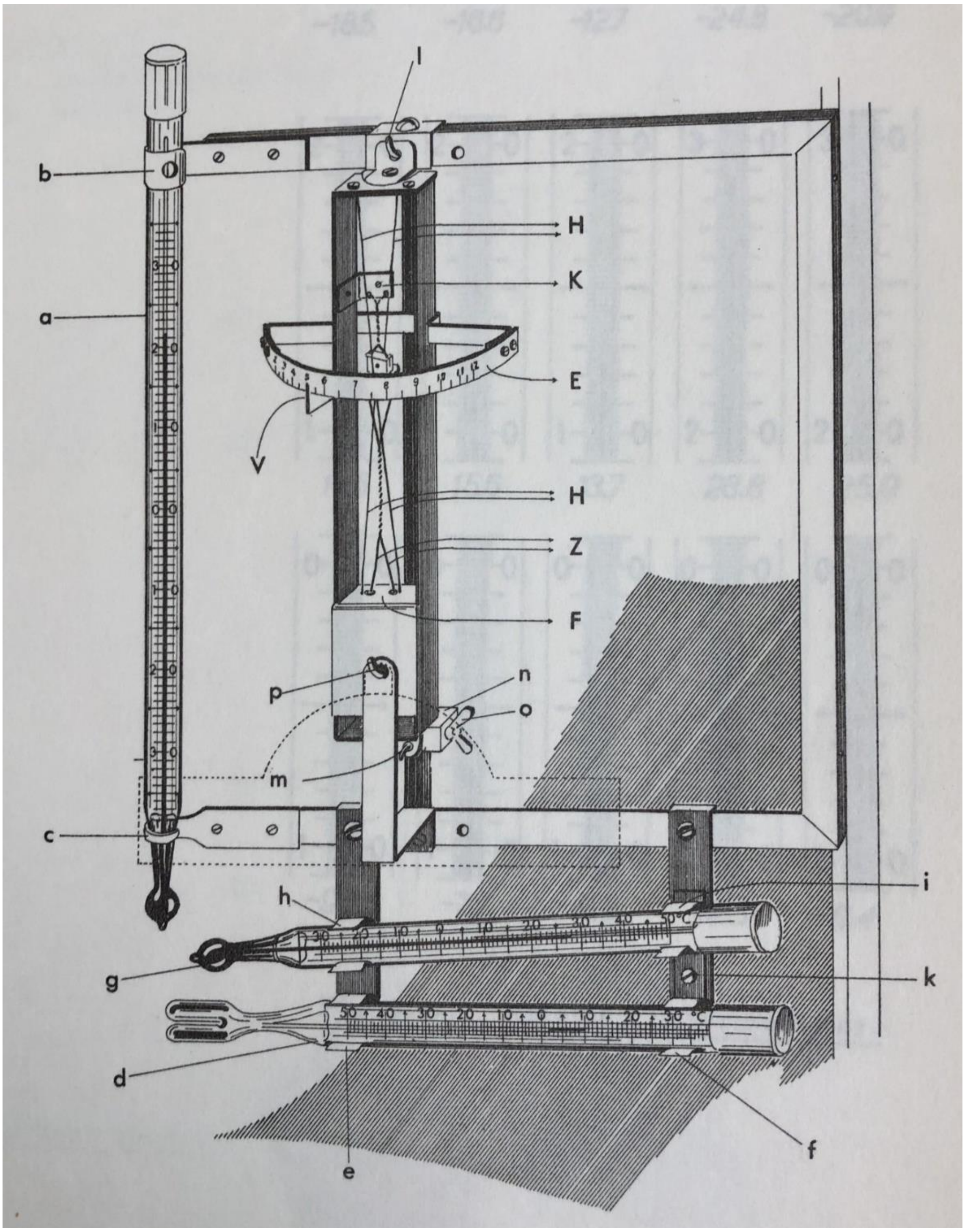

Fig. 7. Thermometers and hygrometer inside the freestanding screen of pattern 1946 (MI46). The horizontal thermometer in the bottom is the minimum thermometer and the thermometer just above with a small angle to its horizontal is the maximum thermometer. The vertical thermometer is the main thermometer at the station, which should be read at every observation. In the middle is the torsion hygrometer (MET Norway 1965).

The minimum thermometers could be rather far off their calibration, but this was not considered being a problem as the corrections were assessed by every observation of minimum temperature. The corrections were found as follows:

1. The actual temperature was read from the main thermometer (glass/mercury) as well as from the minimum thermometer (glass/alcohol), the so-called *top value*.
2. The position of the so-called index was read at the minimum thermometer giving a “raw” uncalibrated minimum value.
3. The difference between the top value from the minimum thermometer and the reading of the main thermometer was calculated. This difference was taken as the correction of the minimum thermometer as the main thermometer was well calibrated.
4. The correction was added to the index value giving the “true” minimum temperature.

In the digitization projects the procedure also followed points 1-3 above but point 4 was different. For each month the median value of all differences, point 3 above, were taken and used as the correction of all index values that month. Often the observers had problems with the observation of the *top value*, so many of the corrections turned out to vary too much for being realistic. The median value can be considered as a robust “mean” value. Therefore, the method used in the digitization projects was found to be better than the traditional method, 1-4, above.

2.7.3 Maximum temperature

The maximum thermometer was uncommon in MET Norway’s network before the 1930’s. The main reason was probably that much focus was laid on monthly mean temperature, where maximum temperature was not included, see Köppen’s formula (eqn 7) below. Unlike for minimum temperature, daily maximum temperature has always been defined from the evening the day before to the evening the present day.

2.7.4 Monthly mean temperature

The meteorological institutes around the world encountered the same problem: how to calculate monthly mean temperature when the observation times were unevenly distributed throughout the day. In particular, the gap during night was problematic. In Norway this was solved by including the mean daily minimum temperature in the calculation together with the mean of the three observations at fixed hours during daytime. These four mean values had to be carefully weighted to achieve a true monthly mean temperature. For this purpose a formula that was introduced in 1888 by Köppen was adopted for use in Norway (Köppen 1888; Birkeland 1936; Høgåsen 1993; Nordli and Tveito 2008; Nordli et al. 2015). It is named Köppen's formula.

$$T_m = \bar{T}_f - k(\bar{T}_f - \bar{T}_n) \qquad (7)$$

, where T_m is the monthly mean temperature and $\bar{T}_n$ is the mean of the daily minimum temperature. The factor k in the formula is called Köppen's constant, for short also called the k-value. The shape of the daily temperature wave affects its value, so it differs by month and place. $\bar{T}_f$ is the monthly mean of the three observations at fixed hours:

$$\bar{T}_f = \tfrac{1}{3}(\bar{T}_{morning} + \bar{T}_{midday} + \bar{T}_{evening}) \qquad (8)$$

The k-values were calculated at some stations where T_m was known directly through the arithmetic mean of hourly observations, which in former time were obtained by thermograph readings, nowadays by automatic loggings. By rearranging Köppen's formula the k-value is given by:

$$k = \frac{\bar{T}_f - \bar{T}_m}{\bar{T}_f - \bar{T}_n} \qquad (9)$$

It turns out that MET Norway is the only meteorological institute that has adopted Köppen's formula for the regular calculation of monthly mean temperature. The quality of the formula has shown to be very satisfying (Birkeland, 1936; Nordli and Tveito, 2008) so it has been kept as the official formula until manual stations were replaced by automatic ones in the 21st century. It appeared for the first time in the yearbook of 1891. Later monthly means for the period 1876-1890 were recalculated by the formula, so its life span amounts to about 130 years!

The success of Köppen's formula also pushed meteorologists at MET Norway to improve monthly mean calculations before 1876, where no minimum thermometer was at the stations. Among them was Nils Føyn, who introduced a Köppen like formula (Føyn 1892; Birkeland 1936: p. 10).

$$T_m = \bar{T}_g + k_g(\bar{T}_{midday} - \bar{T}_g) \qquad (10)$$
$$\bar{T}_g = \tfrac{1}{2}(\bar{T}_{morning} + \bar{T}_{evening}), \qquad (11)$$

Eqn (10) is by Nordli and Tveito (2008) called Føyn's formula, and k_g, defined by eqn (11), is called Føyn's constant. Re-calculation of monthly means by Føyn's and Köppen's formulae was done around 1890. Therefore, the monthly values in the yearbooks will differ from the manual re-calculation from 1890 or those calculated by the HistKlim project.

The $\bar{T}_g$ takes in summer a value near the mean monthly temperature, so the k_g-values in the summer season are almost negligible. In winter the daily temperature wave is almost absent, so k_g at that time is also negligible. Føyn's constant can be found by reformulating (10), when T_m from hourly observations exists for a certain period:

$$k_g = \frac{\bar{T}_m - \bar{T}_g}{\bar{T}_{midday} - \bar{T}_g} \qquad (12)$$

A historic overview on observational procedures that affect Köppen's and Føyn's constants is shown in Table 4. Care must also be taken to the procedures of observation of minimum temperature because they will have impact on the constants.

Table 4. Standard periods, observation times and procedures for the observations that leads to different values of Føyn's and Köppen's constants. The last column shows the formula used and between which observations times the minimum temperature was taken.

Period (from – to)	Official obs. hours	Formula, time for T_n registration
1860.01 – 1875.12	08, 14, 20 LT or ChT	Føyn, T_n is not measured
1876.01 – 1893.12	08, 14, 20 LT or ChT	Köppen, T_n, evening - morning
1894.01 – 1920.06	08, 14, 20 LT, or CET	Köppen, T_n, morning - morning
1920.07 – 1937.12	08, 14, 19 CET	Köppen, T_n, morning - morning
1938.01 – 1948.12	08, 14, 19 CET	Köppen, T_n, evening - evening
1949.01 – 1949.06	08, 13, 19 CET	Köppen, T_n, evening - evening
1949.07 – present	07, 13, 19 CET	Köppen, T_n, evening - evening

1860-1875: The $\bar{T}_g$ value in Føyn's formula lies very near the true mean temperature with observation hours 08 and 20 ChT. Therefore $\bar{T}_{midday}$ temperature gives only a minor contribution to the mean value. This might be an advantage because overheating of the wall cage might be larger at midday than in morning and evening. However, a mean of two observations may be less robust for errors than a mean of three (Hestmark and Nordli 2016; Nordli et al. 2015). Føyn's formula was used in the digitization projects when the minimum temperature was lacking.

1876-1893: The night minimum temperature is often higher than daily mean temperature in winter when the sunrise is later than the time for the morning observation. This must be adjusted for by the k-values.

1894.01-1920.06 and 1920.07-1937.12: The daily minimum temperature was defined from morning to morning in the calculation of the monthly means. Thus, the period for the minimum temperature starts in the morning the last day in the previous month and ends in the morning the last day of the actual month, Fig. 8. The time interval for the minimum temperature therefore became far from synchronized with the observation times for the three temperatures at fixed hours. In the digitization projects this was partly adjusted for by a special $\bar{T}_{n\_sp}$ value for use into Köppen's formula:

$$\bar{T}_{n\_sp} = \frac{1}{d}\left(\frac{1}{2}T_{n1} + \sum_{i=2}^{d} T_{ni} + \frac{1}{2}T_{n(d+1)}\right) \qquad (13)$$

, where d is the number of days in the month, T_{n1} is the minimum temperature for the first day in the month, T_{ni} is the minimum temperature at day *i*, and $T_{n(d+1)}$ is the minimum temperature in the first day of next month. By eqn (13) the minimum temperature in Köppen's formula is more centered around the actual month. In the digitization projects this adjustment of T_n is performed, but in the databases, there are still monthly means for the period 1894-1937 without the adjustment. These cannot be changed before new digitization projects are established.

1938-present: Minimum temperature was observed twice a day, in the morning and in the evening and the daily minimum was defined as the lowest one of the two, see above. The definition of the day of minimum temperature was from evening to evening so the interval for minimum temperature was now more synchronic with the observations at fixed hours. This definition was used in the digitization project as well as in earlier manual calculations.

2.7.5 Daily mean temperature

Monthly mean temperature as well as extreme temperatures had been in focus already from the beginning of meteorological observations in Norway, but daily mean temperature had not. One calculated the monthly means of the temperature at fixed hours as well as the minimum temperature if it existed, and then used them in a suitable formula, which expressed the monthly mean temperature. That could be the Köppen's and Føyn's formulae, see above, and the so-called C-formula, which like Føyn's formula used the morning and evening observations. While Føyn had reduced the weight of the midday observation it was totally neglected in the C-formula, eqn (14). Instead, a correction term was introduced, which varied by station and month. The C-formula was not used in the HistKlim-project, which digitized the longest series. Here, the Føyn's formula was used when minimum temperature was lacking. However, in the yearbooks the monthly values before 1876 is calculated by the C-formula. For old, short series monthly means still based on the C-formula might remain in the data bases for the period 1869-1875.

$$T_d = \frac{1}{2}\left(T_{morning} + T_{evening}\right) + C \qquad (14)$$

Many formulae have been used for the calculation of daily mean temperature. However, the standard in the databases is to use Köppen's formula if minimum temperature does exist, if it does not exist, Føyn's formula is used. By using the same formulae for the daily mean as for the monthly mean, the monthly mean is exactly the arithmetic mean of all the daily means within the month.

Summing up: Føyn's formula should be used in the period 1866-1875 and Köppen's formulae from 1876 to present. Köppen's constant takes into account different definitions of the period for the minimum temperature. For the period 1876-1893 it is the night minimum, for the period 1894-1937 it is the daily minimum from morning to morning, and for the period 1938 to present it is the daily minimum from evening to evening. Schematically this is illustrated in Fig. 8.

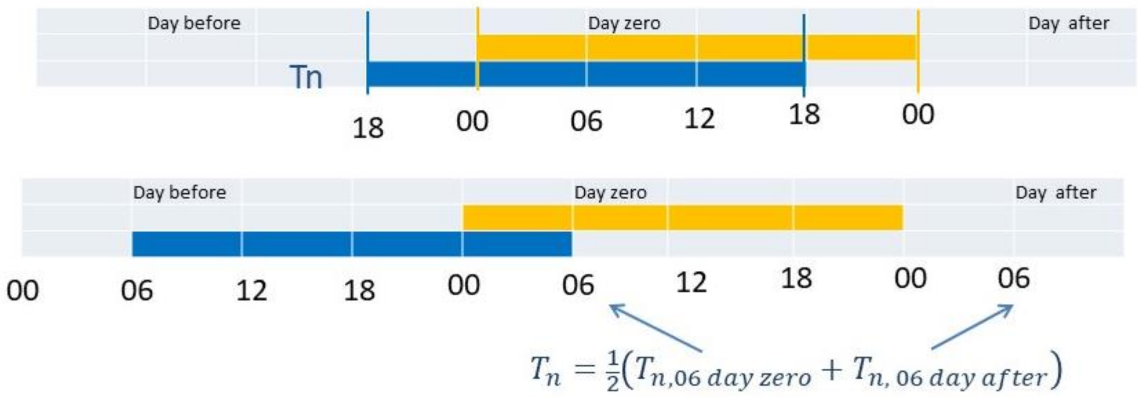

Fig. 8. The actual day is shown in yellow colour, whereas the minimum temperature day is shown in blue colour. The upper panel is for the period 1938-present, and the lower panel for the period 1894-1937.

When morning to morning minimum temperature is used, there is poor overlapping between the actual day and the day for the minimum temperature. Therefore, the minimum temperature is adjusted like in eqn. (15) before it is used in Köppen's formula, see eqn. (7).

$$\bar{T}_{n\_sp} = \frac{1}{2}\left(T_{ni} + T_{n(i+1)}\right) \qquad (15)$$

, where, T_{ni} is the minimum temperature in day *i* and $T_{n(i+1)}$ is the minimum temperature the next day.

2.8 Wind

2.8.1 Wind direction

Most observers used a wind vane for observing the wind direction. The exceptions were some climate stations, which had to assess wind direction without any equipment.

Old private stations often grouped the direction of the wind into 8 classes only. At MET Norway 16 classes were used until 1936. In 1937 the number of classes were increased to 32, and from 1949 the number were further increased to 36 for manual stations. Finally, with the introduction of the automatic stations in the network it was decided that the number of classed should be 360. In the databases all scales are converted to 360 classes, eqn. 16.

$$D_{360} = \frac{360}{n} D_n \qquad (16)$$

, where D_n is the wind direction in a scale of *n* directions. It is the nearest integer of D_{360} that is stored in the databases. This means that all converted data will have some empty classes.

2.8.2 Wind force

The wind force was observed without instruments at most of the stations, but for observations at lighthouses, where wind force was particularly important, instruments got more and more frequent. Wind force was assessed according to its effects on the nature when no instruments were available. At sea the observers considered how the wind acted on the waves and at inland stations, how tree trunks and twigs moved in the wind.

The first scale of wind force used at MET Norway had 6 classes. In manuals for the observers, it was explained how they should distinguish between the classes (e.g., MET Norway 1888, pp. 66-67). A question immediate arises for the users: how should the classes be converted into wind speed? The first director of MET Norway, Henrik Mohn, answered this question in his text book on Meteorology (Mohn 1903), Table 5.

Table 5. The scale for wind force used from the start of MET Norway to the end of July 1918. The borders (m/s) between the classes are taken from Mohn (1903). The bottom line shows how the classes are converted into m/s in the database. The underlying data for this conversion is unknown to this author. For class 5 the converted data fall outside the interval given by Mohn.

Classes	0	1	2	3	4	5	6
Borders	0-0.5	0.5-5	5-9	9-13	13-17	17-28	>28
Converted	0.1	3.0	5.9	10.0	13.8	16.0	35.0

From August 1918 MET Norway changed to the Beaufort scale. It has 12 classes so it should be more accurate. Experience from the HistKlim project indicate that many observers had difficulties with adopting the new scale. Therefore, during the first months after the change the assessments might be more or less unreliable. In the databases the conversion from the Beaufort classes to the wind speed in m/s was done by eqn. (17).

$$u = 0.836 \cdot \sqrt{B^3} \qquad (17)$$

, where *u* is the wind speed in m/s and *B* is the Beaufort class. The values from the formula are also shown in Table 6.

Table 6. The Beaufort classes converted to wind speed in m/s

Classes	1	2	3	4	5	6	7	8	9	10	11	12
Converted	0.8	2.4	4.3	6.7	9.3	12.3	15.5	18.9	22.6	26.4	30.5	34.8

3 References

Birkeland, B.J., 1936. Mittel und Extreme der Lufttemperatur (Mean and extreme of air temperature). Geofys. Publ. XIV, 155 pp.

Eliassen, A., 1943. The Correction and Reduction of Barometer Readings. Geof. Publ. XIII.

Førland, E.J. (ed), P. Allerup, B. Dahlström, E. Elomaa, T. Jónsson, H. Madsen, J. Perälä, P. Rissanen, H. Vedin and F. Vejen.,1996. Manual for operational correction of Nordic precipitation data, METreport 24/96, MET Norway.

Føyn, N. J., 1892. Neuberechtnung aller Monatsmittel der Reihe 1866-92 (Re-calculation of all monthly averages of the series 1866-92) unpublished.

Harbitz, H., 1963. Oversikt over de offisielle meteorologiske stasjoner og observasjoner i Norge samt over rutine-bearbeidelsen av dem i årene 1866 - 1956. (The Official Meteorological Stations and Observations in Norway and routine publications in the years 1866 - 1956). (No. Technical Report No. 6). Norwegian Meteorological Institute, Oslo.

Hesselberg, Th. 1949. Nedbøren i Norge 1895-1943. I. Middelverdier og maksima. Det norske meteorologiske institutt. Aschehoug & Co.

Hestmark, G., Nordli, Ø., 2016. Jens Esmark's Christiania (Oslo) meteorological observations 1816–1838: the first long-term continuous temperature record from the Norwegian capital homogenized and analysed. Clim Past 12, 2087–2106. https://doi.org/10.5194/cp-12-2087-2016

Høgåsen, S., 1993. Mean temperature in Meteorology. METreport No. 40/1993, MET Norway.

Høgåsen, S., Nordli, Ø., Amundgård O., 2021. Dombås meteorologiske stasjon. METreport No. 9/2021. MET Norway.

Köppen, W., 1888. Über die ableitung wahrer Tagesmittel aus den Beobachtungen um 8h a.m., 2h p.m. und 8h p.m. (On the calculation of true monthly means from the observations at 8h a.m., 2h p.m. and 8h p.m.). Annalen der Hydrographie und Maritimen Meteorologie 16, 341–354.

MET Norway, 1888. Vejledning til udførelser af meteorologiske iagttagelser ved det norske meteorologiske Instituts Stationer. Det norske meteorologiske institutt. Sd-0002 Nordland fylkesarkiv, Bodø https://www.nb.no/items/2b4e6b0a93a1455e3c3d3a42e3b998a2?page=3&searchText=meteorologisk%20institutt%20

MET Norway, 1895. Veiledning til Udførelse af meteorologiske Iagttagelser ved det norske meteorologiske Institutts Regnmaalerstationer. Det norske meteorologiske institutt.

MET Norway, 1965. Handbok for Meteorologiske observatører I.

Mohn, H., 1895. Klimatabeller for Norge. I. Luftens temperatur. Vidensk. Skr. I. Mathem.-naturv. Klasse.
Mohn, H., 1903. Meteorologi. H. Aschehoug & Co, Kristiania (Oslo).

Nordli, Ø., 1997. Adjustment of Norwegian monthly means of daily minimum temperature. METreport No. 06/1997), MET Norway.
Nordli, Ø., Alexandersson, H., Frich, P., Førland, E.J., Heino, R., Jónsson, T., Tuomenvirta, H., Tveito, O.E., 1997. The effect of radiation screens on Nordic time series of mean temperature. Int. J. Climatol. 17, 1667–1681. https://doi.org/10.1002/(SICI)1097-0088(199712)17:15<1667::AID-JOC221>3.0.CO;2-D.
Nordli, Ø., 2008. Om korreksjon av minimumstermometra brukt i Karasjok 1877 – 1900. Den norske kulderekorden frå 1886. METreport No. 19/2008. MET Norway
Nordli, Ø., Hestmark, G., Benestad, R.E., Isaksen, K., 2015. The Oslo temperature series 1837–2012: homogeneity testing and temperature analysis. Int. J. Climatol. 35, 3486–3504. https://doi.org/10.1002/joc.4223
Nordli, Ø., Tveito, O.E., 2008. Calculation of monthly mean temperature by Köppen's formula in the Norwegian station network. METreport No. 18/2008, 13 pp.
Åstrand, J.J., 1866. Meteorologiske iagttagelser paa fem telegrafstationer ved norges kyst (Meteorological observations at five telegraph stations along the coast of Norway). University of Oslo, Christiania (Oslo).

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Glossary

CET – Central European Time = Coordinated Universal Time + 1 hour
ChT – Christiania time = Coordinated Universal Time + 1 hour + 17 minutes
HistKlim – A digitization project for daily data for period 1866-1956
IMO - International Meteorological Organisation
KVDH – Klimadatavarehuset (Climate Data Warehouse)
LT – Local Time
MET Norway – the Norwegian Meteorological institute
Meteorological stations

- Weather station – the observations were telegraphed to the institute at the synoptic times
- Climate station – as the weather station, but not sending observation by the telegraph, often a simplified observation program.
- Precipitation station – only precipitation, precipitation types, snow dept and cover were observed

mmHg – The height of the mercury barometer column in mm, old unite for air pressure.
ODA - The Observed Climate Data Base
WMO – World Meteorological Organisation
UTC – Universal Time Coordinated