

A MILLENNIUM OF WEATHER, WINDS AND WATER IN THE LOW COUNTRIES

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INTRODUCTION

In 1995 under the auspices of KNMI the first volume of a series of 6 books was published, where in some 4000 pages the weather in the Low Countries (present-day Benelux) for the period 1000 to present is depicted and classified. In the books¹, the course of the weather during both the winter and summer season as well is followed from year to year and placed in a historical context. In summer 2000, Vol. IV, covering the era 1575-1700, will appear which with the non-instrumental period is covered. Vol. V (to be published in 2001) and Vol. VI (2002) will deal with the instrumental period.

The reconstruction of the weather in the Low Countries is based on sources that are related to the area geographically covered by the present Netherlands and neighbouring areas of the southern part of the North Sea; Gt. Britain, Northern districts of France, the downstream basin of the Rhine, Westphalia and Northwest Germany. If relevant, remarkable or extreme weather in Middle Europe or even Northern Italy is also considered.

The major part of the text is devoted to detailed, well-documented, annotated descriptions and analyses of the weather in the past. Numerous compilations and classifications however offer a structured base for further interpretations. Without being complete the following are mentioned: sources per era and per area, climatology per 25 year period, harvest data, ice on major rivers, tree-ring data, classifications of winter and summer temperature, wet and dry seasons, storms and storm surges.

The books are written in the Dutch language and therefore not easily accessible to the international research world. It is for this reason that we present here in a brief overview some of the issues: the historical sources used, pitfalls that threaten dating due to the different types of calendars that were in use and the way the historical evidence could be classified into instrumental winter temperatures.

The most important publications from Volumes I-III are listed in the *References for the Period 763-1575*.

The *appendix 1200-1250* contains an integral translation of the book text for 1248-1249, a table of the seasonal and annual temperatures of the first half of the 13th century, and a list of the most important historical documentary sources for this period.

SOURCES

Sources that provide useful information about the weather in the past can be subdivided into two main categories: the tangible sources and the non tangible sources like toponyms, folk customs, traditions legends and songs. The analyses of the past weather are predominantly based however on tangible sources. These sources yield essentially two types of data: direct, mostly written observational data of the weather and indirect or proxy data, within which the effects of weather and climate are recorded. In judging the liability of the sources it is of importance to be aware of the number of levels of transmission – that can introduce noise - between observer and the historical fact. The evidence of a primary source, as provided by the observer himself or a contemporary, and only slightly transformed by transmission is potentially more reliable than that of a secondary source with a large distance in space or time between the historical fact.

The analyses of the weather in history of the Low Countries are based upon the following types of sources:

Instrumental observational series

Detailed descriptions of the course of the weather in the historical instrumental period (ca. 1700-1850) will be based on the digitised KNMI historical data-set with the more than 2,5 million three times a day readings, carried out at some 12 historical observational stations, of air temperature, pressure, wind-speed and –direction, precipitation, state of the sky and some astronomical observations. Stationdictionaries with comprehensive descriptions of the instruments used, observers, conditions of observations and other relevant metadata have been composed for these and some 125 more other observational locations in the Low Countries². Descriptions from 1900 onwards will originate from the modern KNMI information systems. For the in between period 1850-1900 the ‘not yet digitised’ information from the so-called KNMI Yearbooks serves as the source.

Weather diaries and Weather journals

Weather diaries, offering daily qualitative descriptions of the weather, are popular from the beginning of the 17th century onwards. In the instrumental period they are often mixed with instrumental readings. The oldest weather diary – as far the author knows as – is written by William Merle³ from England, covering the period 1337-1344. Clergyman David Fabricius⁴ (1564-1617) from East Friesland composed the oldest diary from the Low Countries. The Dutch barrister at fiscal law Anthonis Duyck⁵, witnessing prince Maurice and his army, wrote an important daily weather journal with notations for the weather from 1590-1602. Other rich sources are the diaries of Isaac Beeckman⁶, giving the weather from day to day in Zeeland (1612-1615) and the weather observations carried out by the probably oldest weather observatory in the Netherlands at Dordrecht (1627-1637). Fabio Chigi (1599-1667) was papal nuncio at Cologne, Munster and Aachen and became well known as Pope Alexander VII. As an Italian he was fascinated by the cold northern climate and he noted down all frost, ice, snow and rain but paid no attention at all at sunny and warm days. We owe him an inheritance of descriptions of the weather for more than 2600 days⁷.

Accounts

Useful proxies of the weather are the series of accounts of townships, ship cargos, agriculture, water- and windmills and specially the accounts of river tolls.

In the middle ages and long after that period trade and traffic were hampered by tolls at both overland routes and rivers. Tolls were quite numerous, at least on the continent because they were abolished in England by order of the Magna Carta (1215). They were initiated by

Landlords with the aim of benefitting river trade and were legalised by the so-called *royal stream prerogatives*. The oldest preserved toll accounts⁸ date from the 14th century. They offer us very important information about situations hampering movement as heavy ice, low water levels and extreme weather conditions such as storms. Most important tolls were located along the Rhine (Cologne, Lobith, Arnhem), Meuse (Roermond), IJssel (Zutphen) and the Waal (Nijmegen, Tiel, Zaltbommel). Comparable weather information is hidden in the registers of the ship canal companies. Towboats were popular as public transport in the Low Countries from the 16th century onwards. The economist De Vries⁹ compared the ship canal data with the De Bilt temperatures for the periods 1634-1757 and 1814-1839, yielding a reconstruction of winter-temperatures back to 1634.

In the past centuries a dense network of some 10.000 mills covered the Low Countries. Many of them were water windmills and watermills. A very complete and long series of accounts (1445-1540) with numerous annotations of the weather is found in the archives of the township of Zutphen¹⁰, which exploited the watermills at the small river, the Berkel.

Letters

The majority of the writers of the thousands of letters that were examined considered the topic of weather as quite vulgar and did generally not spend many words on it. There are some notable exceptions however. The letters of Mr. Adriaen van der Goes¹¹ (1619-1686), lawyer at the Court of Holland, are one of the major sources of descriptions of the weather for the period 1659-1673. As a farmer his main interest was in harvests and working the soil. Weather related matters were important to him and he often described them in detail.

Diaries and Journals

Whilst diaries have a personal character predominantly, journals are to be considered as more or less official notes. These contemporaneous witnesses are dominated mostly by the personal or professional interest of the author. Though covering a relatively short period (1491-1498) the diary of Rombout de Doppere (the Brave) registrar of the Minster of St. Donatius¹² (Brugges) gives us very important and quite detailed information about the weather conditions.

Ship journals are well known sources of weather (wind-speed and -direction, state of the sky) information in the past. As The Netherlands developed in the course of the 17th century as the world's most important trading country, thousands of journals were officially kept by their captains, serving for instance the *Verenigde Oostindische Compagnie* (VOC, 1602). Though they are mostly filled with information from far away (West and East Indies, African coasts), less relevant within the context of the climate in the Low Countries, many records reflect the sometimes long periods the ships lay at home, for instance the Dutch isle of Texel waiting for favourable winds or melting of obstructing floating ice in winter times.

Journals of war-vessels offer similar information. Many military journals are available from the sea wars between England and the Netherlands as those from 1652-1654, 1665-1667 and 1672-1674. It is quite probable that a complete and detailed reconstruction of wind and state of the sky, covering the areas of the coasts of Holland and Zeeland and the southern part of the North Sea could be based upon these ship-journals.

Diaries from farmers make mention of early and late frost, snow, dry and wet periods, storms, lightning, wind gusts and hail, all related to the crops, yields and prices. Crop data have a high potential as proxy data.

As many in the 16th and 17th century were inclined to explain the course of the weather by the constellation of sun, moon and stars, their astrometeorological journals can be considered as weather diaries, including the ephemerides. A well-known example is that from Isaac Beekman⁶.

Annals and chronicles

Annals and chronicles are quite simple forms of historiography. Annals originated from Easter tables, long standing tables of Easter dates, illustrated with annotations of various events during the years. Annals and chronicles are quite popular from the Middle Ages onwards. In contrast to the above summarised sources, they generally witness only partly the own observations and experiences of the author. The distinction between both is that annals mostly are anonymous tabular lists of dates and events (earthquakes, storms, comets) and composed by various authors, for own use mainly, whereby chronicles often (but not always) are written by one and the same author, more extensive and narrative and often popular as can be deduced from the many copies and prints. Town chronicles, predominantly from those nearby main rivers offer many weather related events as times of famine, storms, high and low waters and ice.

CALENDARS

After the conquest of Rome in the 6th century BC, the Romans introduced the *Roman Republican Calendar*, based, as was usual, on the phases of the moon with a length of 355 days. In order to prevent a shift of the seasons, the Romans introduced the *intercalans*; every two years the last five days of February were replaced by a period of 27 or 28 days. The beginning of the year was decreed on the first of March: the date on which the new consuls started their duties. Calendar and seasons thus got out of step. Advised by the Alexandrian astronomer Sosigenes, Julius Caesar settled affairs in 46 BC; he introduced a corrective intercalans of 67 days, in order to put the seasons in the right place and turned over to the solar calendar with an average length of the year of 365 days and 6 hours. Every four years the 24th of February was doubled as an intercalary day. This was the *Julian Calendar*.

Table 1. From old style to new style

Period	days
700 - 899	+ 4 days
900 - 999	+ 5 days
1000 -1099	+ 6 days
1100 -1299	+ 7 days
1300 -1399	+ 8 days
1400 -1499	+ 9 days
1500 -1582	+ 10 days

In the Julian Calendar the vernal equinox and the winter solstice fell on the 25th of March and the 25th of December respectively. Every century is, according to the Julian Calendar, 18 hours too long. Gradually vernal equinox and solstice shifted forwards in time. As the vernal equinox was needed for the calculation of the date of Eastern the *Council of Nicea* ordered this date to be fixed on the 21st of March. The astronomical vernal equinox did not obey this rule and in the 16th century the real astronomical vernal equinox fell on the 11th of March and the 'legal' equinox was still the 21st of the same month.

In 1563 the *Council of Trent* authorised the pope to carry a reform. Pope Gregorius XIII announced on 24 February 1582 by the *Bull Inter Gravissimas* the *Gregorian Calendar*. The date October 4, 1582 was immediately followed by October 15, to compensate the lag of 10 days between astronomical and formal vernal equinox. Furthermore every four centennials the leap year was abandoned.

The catholic countries accepted this new calendar (*stilus novus*, new style) quite soon but the Protestant countries, on the contrary, kept the old calendar (*stilus vetus*, old stile) sometimes for even more than a century. As a consequence in the Low Countries two

calendars were in use that differed 10 days: an important fact when we have to judge our sources.

In the descriptions of the weather dating from before 1582, the old style is applied consistently, afterwards the new style. The differences (in days) of both styles are listed in table 1.

CLASSIFICATION OF WINTERS

Often historical quantitative evidence can be found of the coldness of the winter season as descriptions of the length of the period of frost or no evidence of frost at all, ice drift on the rivers, days that no toll could be charged.

In the KNMI books the method of IJnsen¹³ is adopted for a quantitative classification of the winter temperatures, based upon the number of frost days (v , $T_{min} < 0^{\circ}\text{C}$), ice days (y , $T_{max} < 0^{\circ}\text{C}$) and very cold days (z , $T_{min} < -10^{\circ}\text{C}$). With these numbers, known for the winter season (November-March) at De Bilt (central Netherlands) from 1850 onwards the so-called *frost index*¹⁴ (V) is calculated as:

$$V = 33 \frac{1}{2} \cdot \left(\frac{v^2}{12100} + \frac{y}{50} + \frac{z}{30} \right)$$

For the instrumental period 1706-1850 only monthly temperatures for De Bilt were available¹⁵ and so it was not possible to calculate directly the frost index. Therefore IJnsen developed a formula for what he called the *winter-number* (H) that characterises the coldness of the winter season, November-March. This formula is based upon T_f : average temperature November-March, T_h : average temperature December-February and T_k : average temperature of the coldest month where:

$$H = 74.88 - 4.61 \cdot T_f - 3.32 \cdot T_h - 2.3 \cdot T_k$$

H was calculated for the period 1707-1990. Over the overlapping period 1851-1990 H and V are functionally related by the equation:

$$V = \exp[5.1592 \cdot \tanh(0.01346 \cdot H)], 0 \leq H \leq 100,$$

with correlation coefficient 0.97. This makes it possible to extend V back from 1850 to 1706.

V has no dimension and ranges from $V=0$: a winter without frost to $V=100$ for the most severe winter. The benefit is that, though calculated from figures for De Bilt, V has the expectance of the regional character of a winter, for an area with corresponding climatological characteristics: the Low Countries.

Category C_v	Frost Index V	Definition	Frequency in %	Temp. °C Winter (DJF)	Temp. °C Nov.-March
1	≤ 3.2	Extremely mild	1.0	6.2	6.8
2	3.3-5.7	Very mild	3.8	5.4	5.6
3	5.8-9.7	Mild	11.1	4.3	4.9
4	9.8-16.6	Fairly mild	21.0	3.3	4.2
5	16.7-28.4	Normal	26.2	2.3	3.5
6	28.5-44.3	Cold	21.0	1.2	2.7
7	44.4-73.0	Severe	11.1	-0.1	1.7
8	73.1-82.0	Very severe	3.8	-1.8	0.5
9	≥ 82.1	Extremely severe	1.0	-2.4	0.1

The median of V amounts to 21.51, so that the category 'normal' can be subdivided in the sub categories '5-' for: $[16.7 \leq V \leq 21.5]$ and '5+' for $[21.6 \leq V \leq 28.4]$, respectively 'on the mild side and 'on the cold side'

Table 2. Classification of winters according to IJnsen

Based on the frequency distribution of the frost indices of the 284 winters covering the period 1707-1990, a symmetrical division into 9 categories (1–9), with 5 as centre, is made in which the frost indices are grouped and labelled with a definition.

In table 2, this classification is given together with the expected frequency of occurrence (in %) of the various strengths of winter. To provide thermal information, the expected mean temperature of the climatological winter - the months December, January and February - and the one for the cold season November up to March inclusive for De Bilt are given with each category.

With the help of this classification into categories it is now possible, with the non-instrumental information, to characterise winters. In order to do this a procedure is followed, based on awarding marks to the following three aspects, which are significant for many winters:

- A_t : *thermal aspect*. The whole cold season (November-March) - if possible - is examined, with emphasis on the climatological winter months December, January and February and special emphasis on the coldest month.
- A_d : *aspect of duration*. A measure for duration is the number of days with frost from November till March or a comparable parameter; in many cases it will only be possible to make a rough estimate.
- A_i : *aspect of intensity*. The intensity is low if there are only a few days with frost (or a comparable parameter), high if there are many very cold days. In the instrumental era, intensity is understood to mean the quotient of the frost index and the number of days with a minimum temperature below 0 °C.

With the many uncertainties and the often rough and concise character of the historical evidence in mind, the intervals of the subdivision of the three aspects should be wide. The scoring table (table 3) is derived from the historical evidence of well-known winters from 1850 onwards. The outcomes of the scoring are tested for the period 1901-1987. The sum of the scores for the three aspects in the majority (84%) of the winters exactly equalled the number of the category (C_v) of the winter in concern.

Based on the qualitative historical descriptions of the weather, categories have been estimated independently by Buisman and IJnsen as well. The two series appeared to be very comparable.

Table 3. Estimate of the category of the winter-season by means of aspects

Thermal aspect (A_1)	Points	Frost Index (V)
Very mild	1	≤ 5.0
Mild	2	5.0 – 15.0
Normal	3	15.1 – 30.0
Cold	4	30.1 – 75.0
Very cold	5	≥ 75.0
Aspect of Duration (A_2)	Points	Number of Frost Days (v)
Short	0	≤ 47
Moderate	1	48-88
Long	2	≥ 89
Aspect of Intensity (A_3)	Points	Intensity (V/v)
Low	0	≤ 0.18
Moderate	1	0.19 – 0.55
Strong	2	≥ 0.56

These series were compared with several other series for overlapping periods: generally they showed excellent correlation (correlation coefficients range from 0.79 to 0.98, IJnsen¹⁶). For this reason, the following series contributed to the estimates of the frost indices:

- 1591-1613 Number of days with frost in East Friesland, according to David Fabricius
- 1613-1626 Records of the diary of Isaac Beeckman
- 1621-1650 Number of days with frost and extensive periods with frost per winter in the Kassel series from Hermann van Hessen¹⁷
- 1634-1706 Number of days with ice on the canals Harlem-Amsterdam and Harlem-Leiden
- 1660-1706 Central England monthly temperatures from Manley¹⁸

CLASSIFICATION OF SUMMERS

Historical evidence of warmth of the summer is less abundant than of coldness of the winter. In history weather in summer had – in the Low Countries – less impact on society than the weather in the winter season. The witnesses were mostly more interested in summer drought than in summer warmth. Also an observable and distinct thermal level – as icing when temperature drops below °C – is absent. The classification that was developed for summer temperatures (IJnsen^{19,20}) is based on a single parameter – the *summer-number* S , which is, analogous to the winter-number H , a function of the temperature sum (i.e. the monthly temperature times the number of days per month) S_w of the warm season May-September, the temperature sum S_z of the climatological summer (June-August) and the temperature sum of the warmest month S_m :

$$S = 0.0489 \cdot S_w + 0.0670 \cdot S_z + 0.1573 \cdot S_m - 246.2$$

On the basis of the frequency distribution of S , calculated from monthly temperatures at De Bilt for the period 1706-1990, the summers were classified into 9 categories C_s (1-9), with 5 as centre.

Table 4 shows this classification, together with the expected frequency of occurrence (in %).

Category C_s	Summer Number S	Definition	Frequency in %	Temp. °C Summer (DJF)	Temp. °C May-Sept.
1	≤ 13.7	Extremely cool	1.0	14.0	13.1
2	13.8-24.1	Very cool	3.8	14.6	13.6
3	24.2-34.5	Cool	11.1	15.1	14.1
4	34.6-44.8	Fairly cool	21.0	15.6	14.5
5	44.9-55.2	Normal	26.2	16.2	15.0
6	55.3-65.5	Warm	21.0	16.7	15.4
7	65.6-75.9	Fairly warm	11.1	17.3	15.9
8	76.0-86.3	Very warm	3.8	17.8	16.4
9	≥ 86.4	Extremely warm	1.0	18.3	16.8

Table 4. Classification of summers according to IJnsen

For the pre-instrumental period (i.e. before 1706), the category of a summer is estimated directly from documentary evidence. These estimated are supported by estimated based on the following series that were compared with the De Bilt series for the overlapping instrumental period (IJnsen¹⁶):

1354-1836 Data start of grape harvest Beaune and Dijon²¹

1659-1705 Central England monthly temperatures from Manley¹⁸

WINTER AND SUMMER SERIES

All estimates have been combined to continuous series of categories for the pre-instrumental winters and summers that have been coupled to the De Bilt series for the instrumental period. Based on this series a series of annual winter and summer temperatures for De Bilt was calculated for the period 800-present

In the period prior to approximately 1300, evidence is often too scarce to permit a subdivision into 9 categories. For the classification of winters and summers with insufficient data the categories C_w of the winter season were grouped three by three into the three main categories I (*obviously very mild*), II (*about normal*) and III (*obviously very cold*) and the categories C_s of the summer season into the three main categories I (*obviously cool*), II (*about normal*) and III (*obviously warm*).

Figures 1 and 2 show the 25 year means of winter, respectively summer temperature in the Low Countries, expressed as temperatures for De Bilt for the period 800-present. Table 5 contains all annual estimates of the categories C_w and C_s for the same period.

Recently the temperature reconstruction (as LCT: *Low Countries Temperature*) has been analysed and compared with relevant data. It could be concluded that over the period back to the 14th century the LCT reconstruction is consistent with a number of European temperature reconstructions²².

Figure 1. Winter (DJF) temperatures Low Countries (De Bilt) – 25 year means

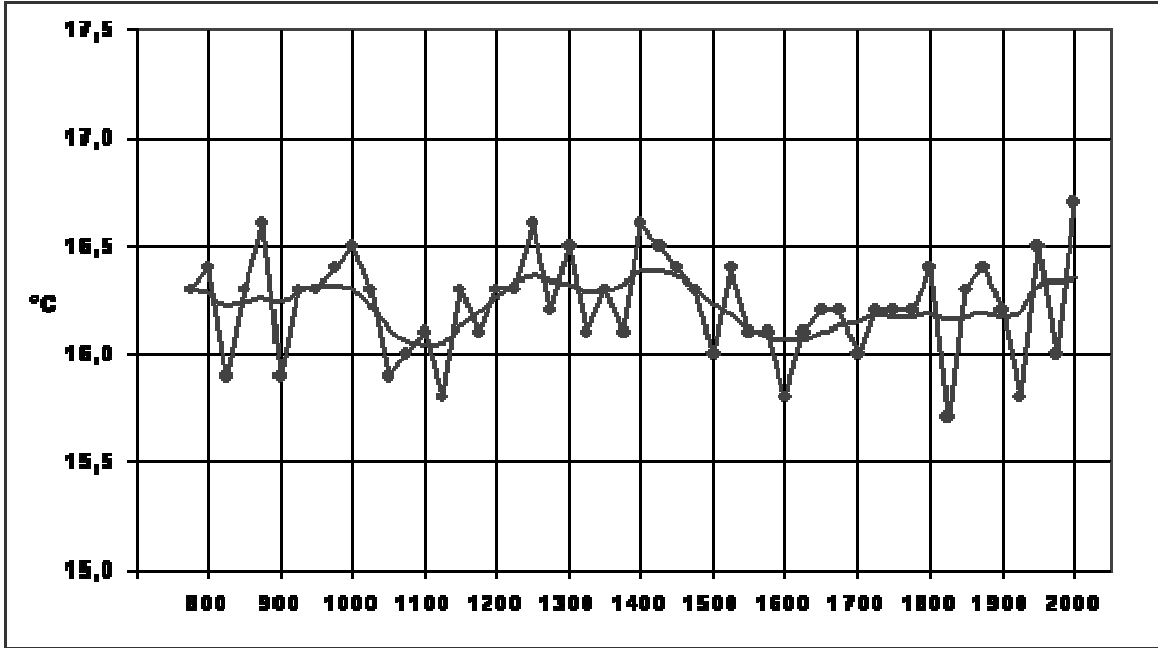
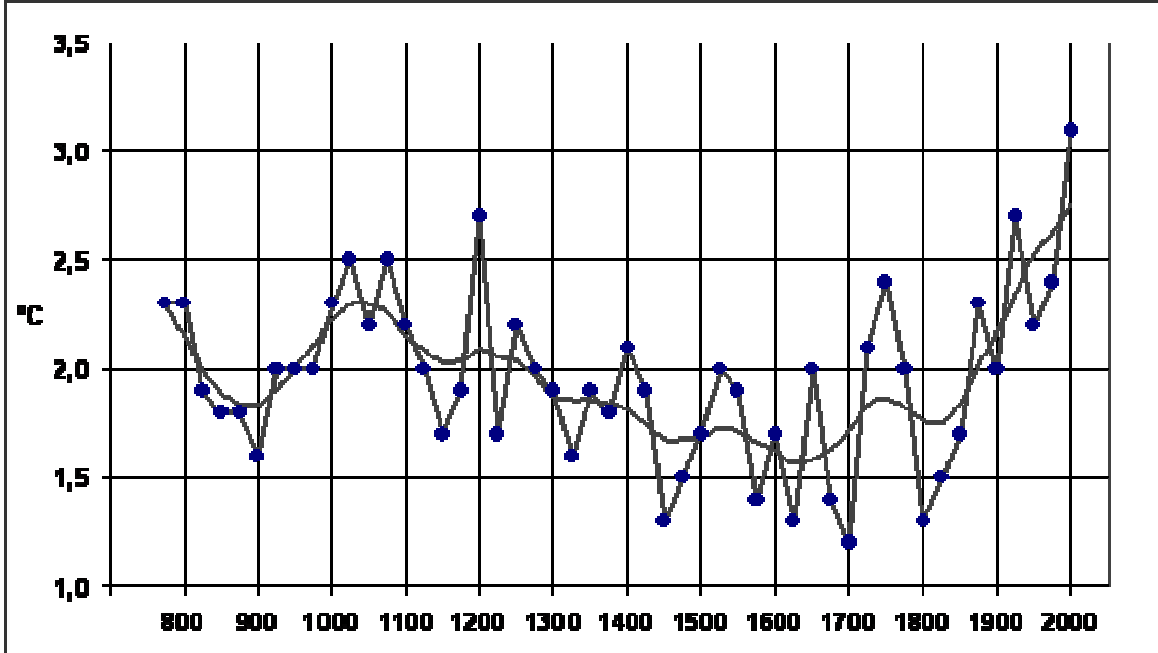


Figure 2. Summer (JJA) temperatures Low Countries (De Bilt) – 25 year means

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