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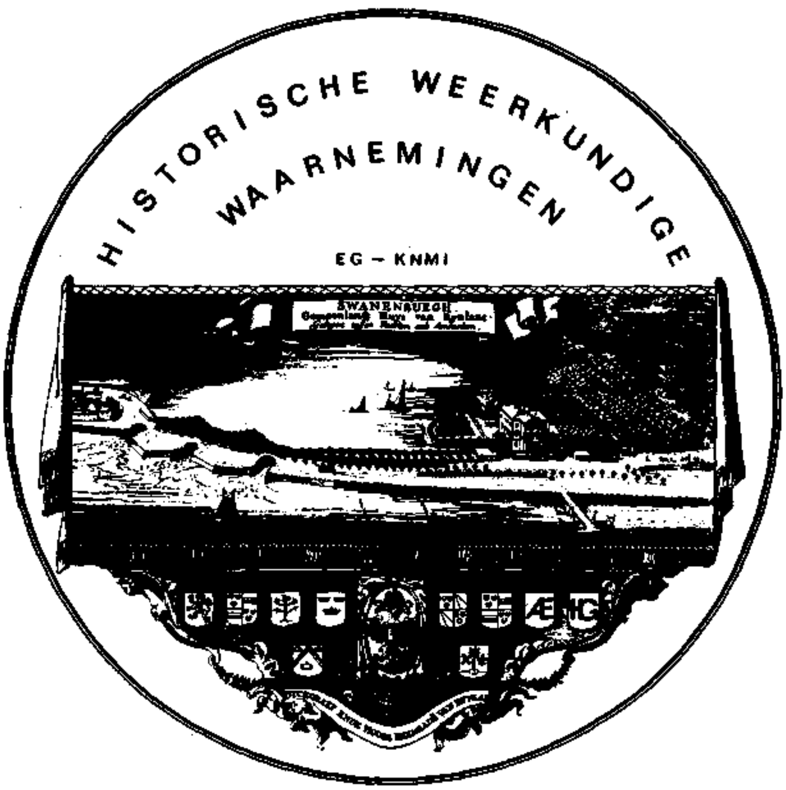

DEEL IV

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Nicolaus Cruquius (1678-1754) and his meteorological observations

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NICOLAUS CRUQUIUS

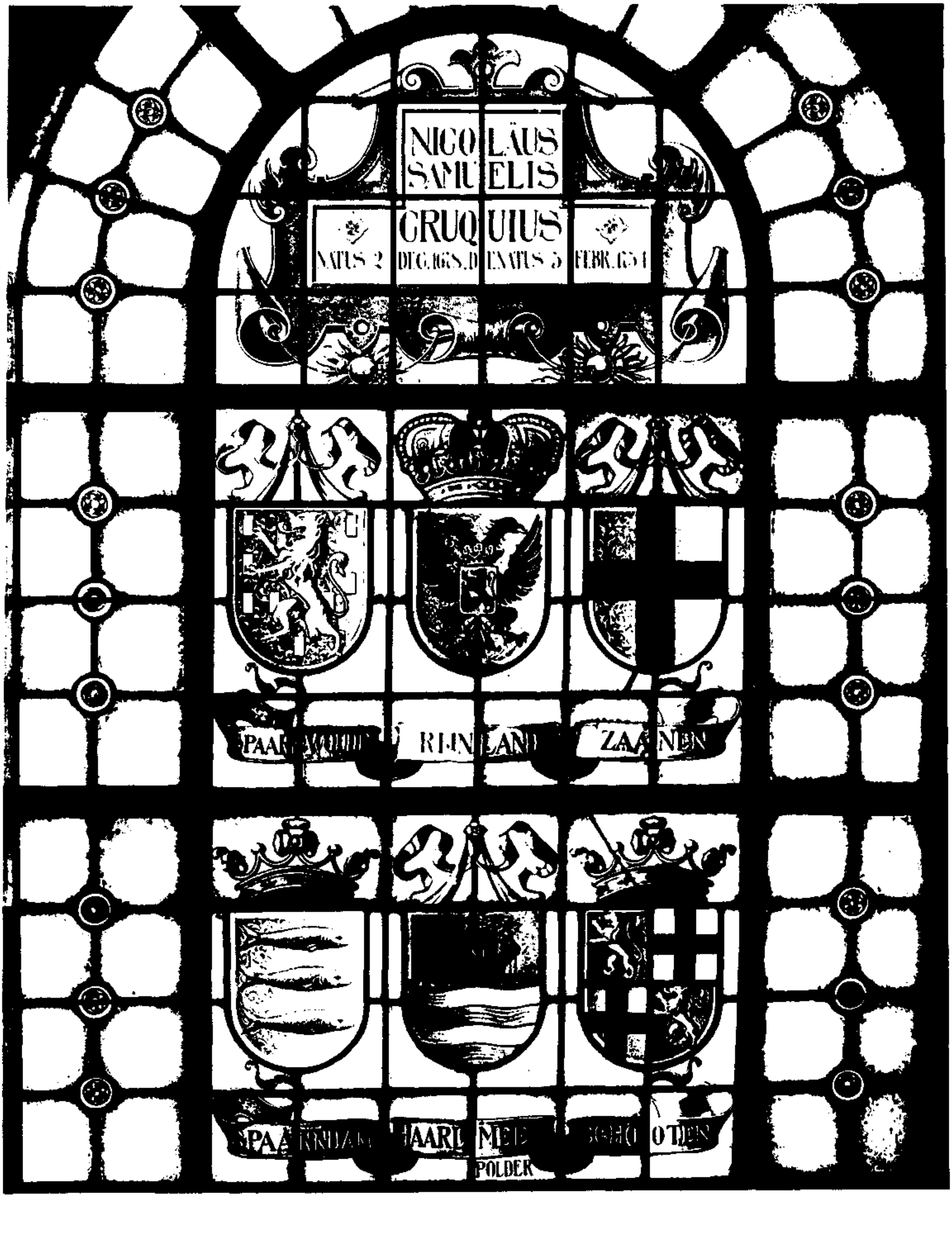
1678 - 1754

AND HIS

METEOROLOGICAL OBSERVATIONS

Memorial window above the grave of Nicolaus Cruquius
in the church of Spaarndam.

photograph: G. Jansen, Honselersdijk


NICOLÄUS SAMUELIS
CRUQUIUS
NATUS 2 DEC. 1678. DENATUS 5 FEBR. 1754
SPAARNWOUDE
RIJNLAND
ZAANEN
SPAARNDAM
HAARLEMMER POLDER
SCHOOTEN

Preface

In 1981 the European Community launched a number of Climatological research projects under the title "Reconstitution of Past Climates". The contribution of this programme by the Royal Netherlands Meteorological Institute (KNMI) consists of a project on historical weather observations.

The emphasis has lain on studying observations made in the Netherlands with early instruments before the foundation of the KNMI in 1854. The wealth of meteorological data dating from that era in Dutch archives owes its existence to the immense contemporary interest in the weather. Although these data have not yet been fully catalogued, it proved possible to feed various series of measurements into a computer.

The longest unbroken series of observations is that made at Zwanenburg House between 1735 and 1861, although measurements had been taken earlier in Delft, Leiden, Rijnsburg and Spaarndam. Nicolaus Cruquius (1678-1754), a cartographer and hydraulic engineer, coordinated these observations and indeed made many of them himself. The daily summaries which have survived of the detailed observations ascribed to Cruquius, cover the period between 1706 and 1734. His measurements date from a time when virtually no weather observations were made.
As they are very comprehensive they are of great significance for a reconstruction of the climate.

Until recently little was known about Cruquius and his meteorological background. The only publication containing biographical information is "De kaart van Delfland" (1977), written by C. Postma of the Delfland district water control board. Although this publication stresses Cruquius' work in the fields of cartography and hydraulic engineering, it nevertheless provided very important information on which to base the present report.

Ample attention has been devoted to Cruquius, because of his importance in achieving recognition in the Netherlands for meteorology as a legitimate scientific activity and because he may be regarded as a forerunner of C.H.D. Buys Ballot (1817-1890), founder of the KNMI. Cruquius was responsible for numerous meteorological discoveries, perhaps one of the most important being that he was the first to present weather data graphically. Until recently this innovation was ascribed to Petrus van Musschenbroek (1692-1761).

Furthermore, Cruquius' correspondence with the Royal Society was of major significance for the weather observation methods employed in the eighteenth century Netherlands. His letters to the Royal Society, which were in an obscure form of Latin, have been translated by Mr. M.J. Moir, formerly a translator at the Ministry of Foreign Affairs, and are appended to the present report. It goes without saying that we are grateful to Mr. Moir for this and other assistance with translations from Latin.

We also thank Mrs. H. Bannatyne and Mrs. Y. van Rees - Rosenberg of the Ministry of Foreign Affairs and Prof. A. Crowe for the English translation of our manuscript.

The greater part of the report is devoted to a compilation of the temperature measurements taken by Cruquius. Although we lack sufficient data to convert these reliably into 24 hour averages, the compilation did produce a reconstruction of mean monthly temperatures for Delft/Rijnsburg over the period between 1706 and 1734. In order to link on this series to the familiar De Bilt series extending backwards to 1735 (Labrijn, 1945), both series were compared with an overlapping part of the Central England series from 1723 to 1834 (Manley, 1974). The Delft/Rijnsburg series appears to be very reliable and is eminently suitable for detailed climatological research over the early eighteenth century.

We are very grateful to Dr. T.A. Buishand and Prof. C.J.E. Schuurmans for their useful advice and comments.

KNMI De Bilt, January 1985. *Aryan van Engelen,*
Harry Geurts

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NICOLAUS CRUQUIUS (1678-1754) AND HIS METEOROLOGICAL OBSERVATIONS

1 Introduction

Nicolaus Samuelis Cruquius, who was born in 1678 on the island of Vlieland and died at Spaarndam in 1754, is in many respects one of the pioneers of meteorology. He was among the first in the world to make and record meteorological observations systematically (1). His measurements of precipitation, humidity and evaporation are the earliest in the Netherlands and his temperature and humidity readings constitute one of the oldest series of the world. He was the first to draw graphs of his measurements and he introduced symbols which may be regarded as the forerunners of those used in today's weather maps (2). A self-willed and difficult man, he was never rendered the esteem due to him for his work. He demonstrated the importance of meteorological observations and set a precedent by trying to obtain financial assistance for such work from the States of Holland (3). The present report seeks to show his importance for meteorology and to publish the temperature series in an easily comprehensible form.

2 Biography (4)

Shortly after Cruquius was born on the island of Vlieland in 1678, his family moved to Delft, where his father, Samuel Cruquius, was sexton, schoolmaster, mathematician and examiner for the Dutch East India Company.
In Delft Nicolaus probably lived in his parents' house "In den Regenboogh" (Under the Rainbow) on the eastern side of the Werversdijk and in a house outside the St. Joris or Watersloot Gate at the end of the Binnenwatersloot.
Nicolaus died on 5 February 1754 and was buried in the Reformed Protestant Church in Spaarndam. A memorial window bearing his name and the arms of the Rijnland district overlooks the grave. It was restored in 1913.

His mother, Veronica, the daughter of Jacob van der Meer, was considered insane and was nursed at home. The family further consisted of his brothers, Jacob and Dirk, and two sisters, Lucia and Aafjen. Since both his brothers died young, Samuel and Nicolaus had to care for the family for many years.

His tomb bears an inscription most of which - remarkably - was executed two years before his death. Probably his health was failing even then.

I. D. VOGEL. W. V.D. ZYP K. MEEST.
TER EER EN OPHEF DER HOOGE BEDUIDEN
VAN 'T BOVENSTAANDE KERKGLAS.
VERTOONENDE 'T
WEL. ED. COLL. VAN HEEREN DYKG. EN HO. HEEM-
RADEN VAN RHYNL. MET DESZELFS INSTELDER
GRAAF WILLEM VAN HOLLAND ROOMS KONING
5 JDUS OCT. A° 1255 INDICTIE 14.
WIENS XVI^E AFSTAMMEL. EN NANEEF. DIENAAR
VAN HAARE WEL EDELHEDE EN VAN DEN LANDEN
WAS
NICOLAUS SAMUELIS CRUQUIUS
GEADMITTEERD LANDMETER
CANDIDATUS MEDICINAE.
EXAMINATEUR DER O.I. STUURL. TE DELFT.
LID VAN DE KONINKL. SOC. DER WETENS. TE LOND.
LID VAN 'T KONST-GENOOTSP. TE HAARLEM.
TOEZIENDER VAN RHYNLAND.
SCHOUT TE SPAARNDAM.
NATUS 2 DEC. 1678 DENATUS 5 FEB. 1754
NAAM-ZIN-SPREUK
NEMINEM SCIENTIA CRUCIAT.
NOOYT SCHAADCONST.
W. DEN HENGST. IN COMP. FECIT 1752 PRINC. GET. 5.15.25.

Fig. 2 Inscription on Nicolaus Cruquius' tomb in the church in Spaarndam

The spelling of his name is also worthy of note. The present report consistently uses "Nicolaus Cruquius", as it appears on his tombstone.

A number of important documents contain other variations, however, spelling the forename as Nicolaas or Nicolaes and his surname as Kruikius or Krukius.

Fig. 3 The Cruquius family arms from the map of Delfland, 1712.

3 Education and career (4)

Nicolaus Cruquius trained as a surveyor and, after passing his examinations in 1698, was appointed as such by the provincial States of Holland. He was particularly gifted as a topographer and spent a great deal of his life compiling geographical maps. He made a number of important recommendations in the field of hydraulic engineering and constantly showed his concern for the future of water management in the Netherlands. As controversy surrounded his views of the factors causing rivers to silt up and the water level to rise, he tried to substantiate them by making observations, among the most important being his meteorological readings.

In 1716 he began his studies at the University of Leiden, attending lectures by Herman Boerhaave (1668-1738) among others. It was probably during this period that he acquired the knowledge of meteorology that he later needed.
While at Leiden, he came into contact with the Royal Society through his weather observations, and was elected a member of it in 1723.

In 1725 he succeeded his father as a member of the trainee pilots committee of the Delft Section of the East India Company. He had to conduct oral and written examinations, a process in which his knowledge of meteorology was undoubtedly an asset. His last post, from 1733 onwards, was that of "supervisor" of the Spaarndam dike and its locks and sluices. He was probably bored with this repetitive work in a subordinate position and expressed his inventiveness by giving advice on hydraulic engineering: for example, he devised a plan to drain the Haarlemmer lake.

He was succeeded as supervisor after his death in 1754 by Jan Noppen (1706-1764) who inititated the series of weather observations from Zwanenburg House in 1734 (5).

4 Graphs, maps and hydraulic engineering

The surveyor from Delft developed into a cartographer and hydraulic engineer. He was a master of the art of charting topographical and hydrographic maps and presenting data, including his meteorological observations, in graphic form: his earliest published graph, dating from 1723, gives a comprehensive survey of daily observations which he made in Leiden (supplement VI) (6). On this diagram he used a curve to represent atmospheric pressure and arrows and dots for the direction and velocity of the wind. He also used symbols to denote rain, snow, hail, fog, thunder and cloud.

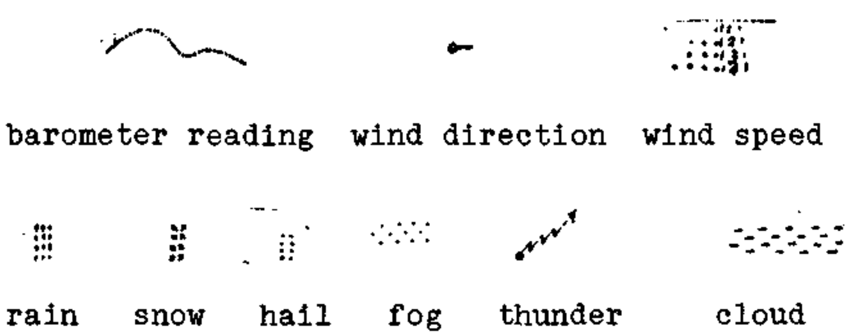


Fig. 4a Symbols used by Cruquius to represent various weather conditions (6)

These symbols may be regarded as prototypes of the ones found on today's weather maps.

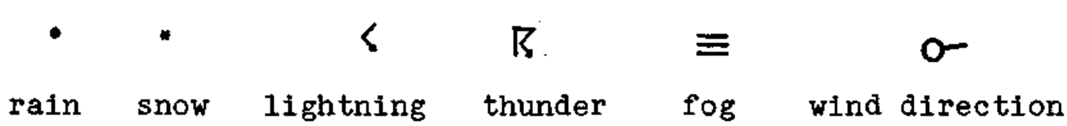


Fig. 4b Symbols used in contemporary weather maps.

The graphic presentation of meteorological data seems to have been invented by Cruquius. His original notebooks contain elementary and clearly experimental examples, the earliest dating from 1721.

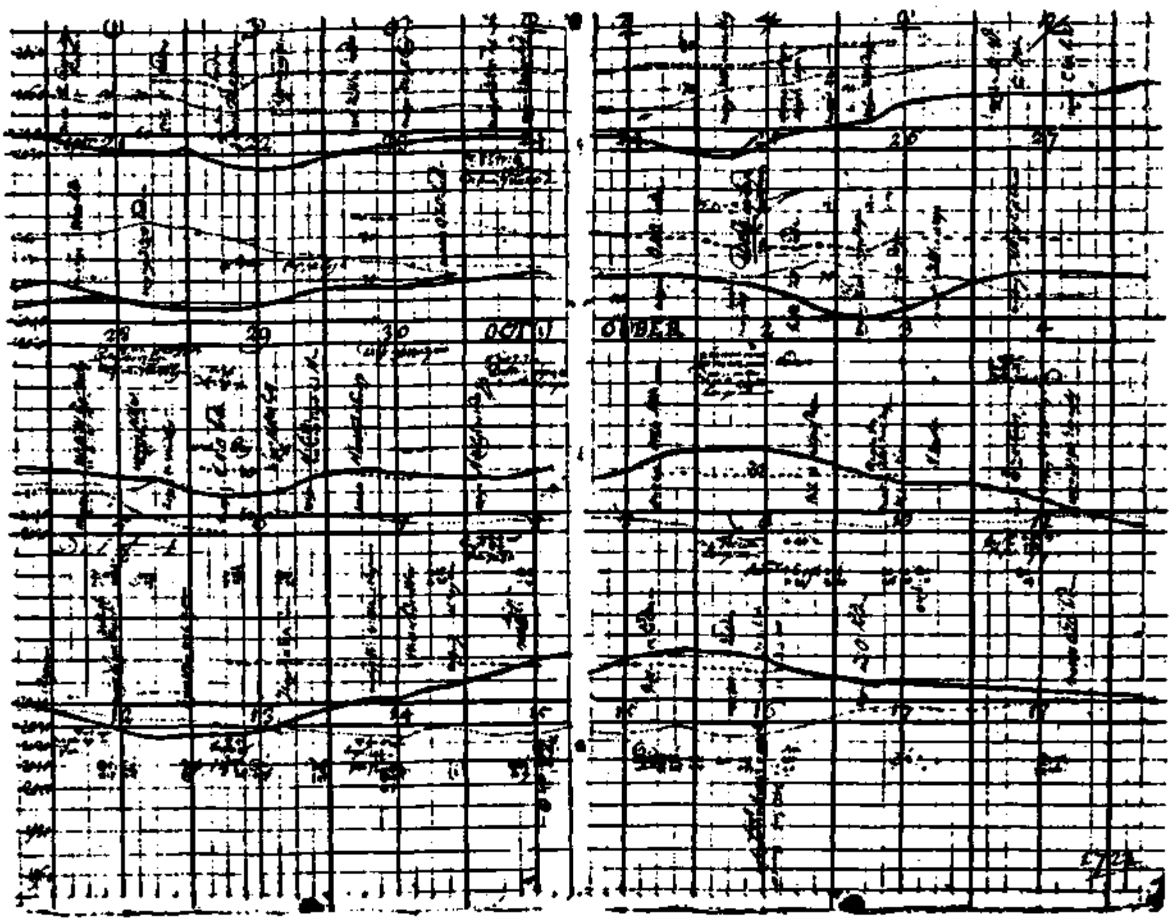


Fig. 5 Graphs of weather observations (Delft, Leiden, 1722) by Nicolaus Cruquius, showing the rudiments of his later graphics (1).

He also wrote to the Royal Society explaining his graphs and pointing out that he had spent a great deal of time developing methods of presenting meteorological data. He had finally arrived at the method submitted to them, which made the observations perceivable at a glance (supplement II). It is striking that even then Cruquius was so conscious of the advantages of graphic presentation. The form in which Petrus van Musschenbroek presented his readings taken in Utrecht in 1728 closely resembles the drawings made by Cruquius in the early 1720s.

Cruquius' fame as a cartographer rests primarily on his map in 25 parts of Delfland (4). He accepted this extensive and difficult commission in 1701 and embarked on it together with his brother Jacob. The latter's early death in 1706 was not the only setback Cruquius experienced. The work did not progress rapidly enough for the governors of the water control board, with the result that Cruquius came under a certain amount of pressure. In 1708 two engravers were employed to work at his house. Three more were appointed later and disputes arose about wages and working conditions. Cruquius and his father obviously disdained the engravers who had to work from 6 in the morning to 10 at night, whereas 10 hours was regarded as a working day of "an ordinary kind". No payment was made for overtime. The meals provided by the Cruquius family for the engravers were poor. The latter had to take their breaks outdoors and sometimes grew numb in the hail or snow, while Cruquius sat smoking his pipe by the warm fire.

The employees were only allowed inside when there was a heavy frost.

Despite all the problems a very successful map of Delfland appeared in 1713 and was to achieve wide circulation (9). In the years that followed Cruquius drew numerous maps which often served to support his recommendations in the sphere of hydraulic engineering.

In 1722 he devised a scheme to dig a drainage canal between The Hague and Scheveningen which could relieve the Delfland and Schieland polders of surplus water and facilitate cleansing The Hague's canals (10). His plans to reinforce the sea wall along the coast of Holland revealed his knowledge of water management and expressed his concern about the future (11). The quantity of water discharged by rivers into the sea was steadily decreasing. The River IJssel, for example, poured sand into "the huge insatiable pool of the Zuyder Zee"; the mouth of the Rhine was choked at Katwijk and the Lek had "lost its power because the Rhine had dried up at Schenkenkrans". As insufficient river water was discharged less sand was carried into the sea and fewer dunes were formed. Cruquius even predicted that the flow of river water into the sea would cease completely. The rivers would then rise so high that they would flood the dikes with dire consequences. He foresaw this as the end of the world and voiced his fears in highly emotional terms.

"The devastation will exceed that caused by the Cimberse Deluvie. Our greatest cities, our most beautiful palaces

and farms, our most fertile gardens and fields will be as most wretched pools of desolation" (11).

He regarded the steady rise in the levels of the seabed and the beds of rivers and inland waterways, caused by sediment, as another of the Netherlands' increasing drainage problems. His most important proposal was to create a second outlet for the River Maas by digging a channel through the Hook of Holland. Although he defended this plan in every possible way it encountered much opposition and was rejected. More than a century later the channel was dug as part of a plan devised by Pieter Calland (4).

5 Meteorological observations

5.1 Introduction

"Whereas the applicant has long demonstrated a natural inclination for observing the changes to which the atmosphere is subject and has so abundantly proven his experience therein that we cannot doubt that he, with God's blessing, and assisted by humble observers under his direction, would be able to gather the observations necessary for the said work - which would be of great value - and to compare them with one another" (12).

Jacobus Wittichius
Willem J. 's Gravesande
Leiden, 24 February 1727

The quotation comes from the report on Cruquius' application to the States of Holland which 's Gravesande (1688-1742) and Wittichius (1677-1739), professors at Leiden, made to the States' Standing Committee (Gecommitteerde Raden (supplement VIII) (12). The substance of the application may also be found in a letter of 14 October 1725 from Cruquius to Professor Johan Lulofs (13). He requested financial assistance on a monthly basis to take meteorological and hydrographic readings. Cruquius referred to the long series of observations he had already made. An estimate of the costs of the proposed activities was appended to the request under the following title: "Provisional estimate of costs required monthly - which may be increased or reduced as the occasion demands - to determine the height and depth of the land in relation to the level of the waters which surround and traverse Holland" (13).

He estimated the total at Fl. 450 a month, a large sum for the time, of which Fl. 10 was for weather observations. These were described as follows: "Carriage costs to and from for the aforesaid forty observers among whom should be four or five who shall observe changes in weather and wind by means of weatherglasses and instruments to that end".

In fact, Cruquius was undertaking a scheme in 1725 comparable to that of Christophorus Henricus Diedericus Buys Ballot (1817-1890), who applied to the Ministry of Home Affairs in 1852 for help in setting up the K.N.M.I. Unlike Buys Ballot, however, Cruquius was dismissed empty-handed. Although the Leiden professors' report to the standing committee was very positive and the committee in turn made a favourable recommendation to the States no decision was taken and nothing more was heard of the application. This was highly regrettable, for Cruquius' plan was intended to safeguard Holland against floods. Its implementation at that time might have improved the Netherlands' water management system and spared the country several disasters.

The application was probably the first validation of meteorological observations in the Netherlands. It is notable that Cruquius placed so much emphasis on their social relevance, and his correspondence with the Royal Society also underlined their importance for shipping (supplement II).

A persistent man, Cruquius was undeterred by the States' rejection of his request. Far from it, in fact: he devoted more and more time to his observations, recieving a great deal of encouragement from James Jurin of the Royal Society in London. Cruquius felt greatly honoured to be recognised as a member of this prestigious scientific body. His correspondence with the Society contains significant details of his readings (supplements II, III, IV and V), and shows, for example, that a thermometer was sent to him from England in 1725 (supplement III). It arrived in pieces, however, and a new one was sent in October of the same year. He installed it in Rijnsburg where he had inherited from his father two pieces of land with the buildings on them. The property to the east of Schoolsteeg in Rijnsburg was known as "The Farm or Orchard of Rijnsburg" and consisted of a house, a pavilion, a farm, a stable and an orchard (4). As Samuel Cruquius had owned it since 1719, it was probably he who began to take meteorological measurements there in 1720. The fact that he did take readings can be seen from a manuscript in Nicolaus Cruquius' handwriting noting that certain observations on the deviation of the compass were made by his father (1).

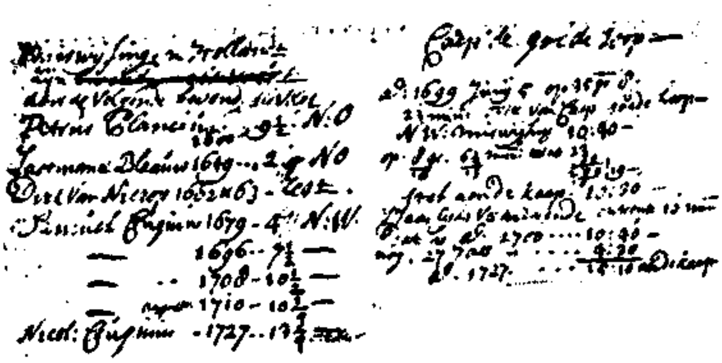


Fig. 6 Part of a manuscript by Nicolaus Cruquius including some observations made by his father, Samuel (1).

The table which Nicolaus Cruquius sent to the Royal Society contains observations at Rijnsburg between 1720 and 1723 (supplement VI) (6). At that time Cruquius was living in Delft and had been taking measurements there since 1705, probably assisted by relatives or servants as observations were made in different places simultaneously.

Measurements were also made in Leiden, probably by Cruquius himself while studying at the University. He compiled large graphs of the Leiden data from 1723, 1724 and 1725 (supplements V and VI). The observations after 1727 were probably made in Rijnsburg rather than Delft, an assumption which is supported by a statistical analysis of the series. Moreover, from 1727 onwards the form of the observation records changes and several readings are registered every day.
Cruquius moved to Rijnsburg in 1729 and lived there until 1733. He then settled in Spaarndam where he was appointed as dike supervisor. He continued to make observations until his death in 1754. Of these only the daily data from 1740 and 1741 have been preserved, plus several tables analysing data.

As there is no apparant change in the Delft-Rijnsburg series (1706-1734) in 1733, the observations there were probably continued by a relative or a servant who may have been involved previously. The full series, containing virtually all the daily readings for an uninterrupted period, ranges from December 1705 to December 1734. Only a few odd days and the whole year 1728 are missing.

5.2 Types of weather observed

Cruquius began his observations on 19 December 1705 with atmospheric pressure alone; from 29 December he measured the temperature and from 13 January 1706 took readings of the speed and direction of the wind. The wind readings ceased in 1709 and resumed in 1725.

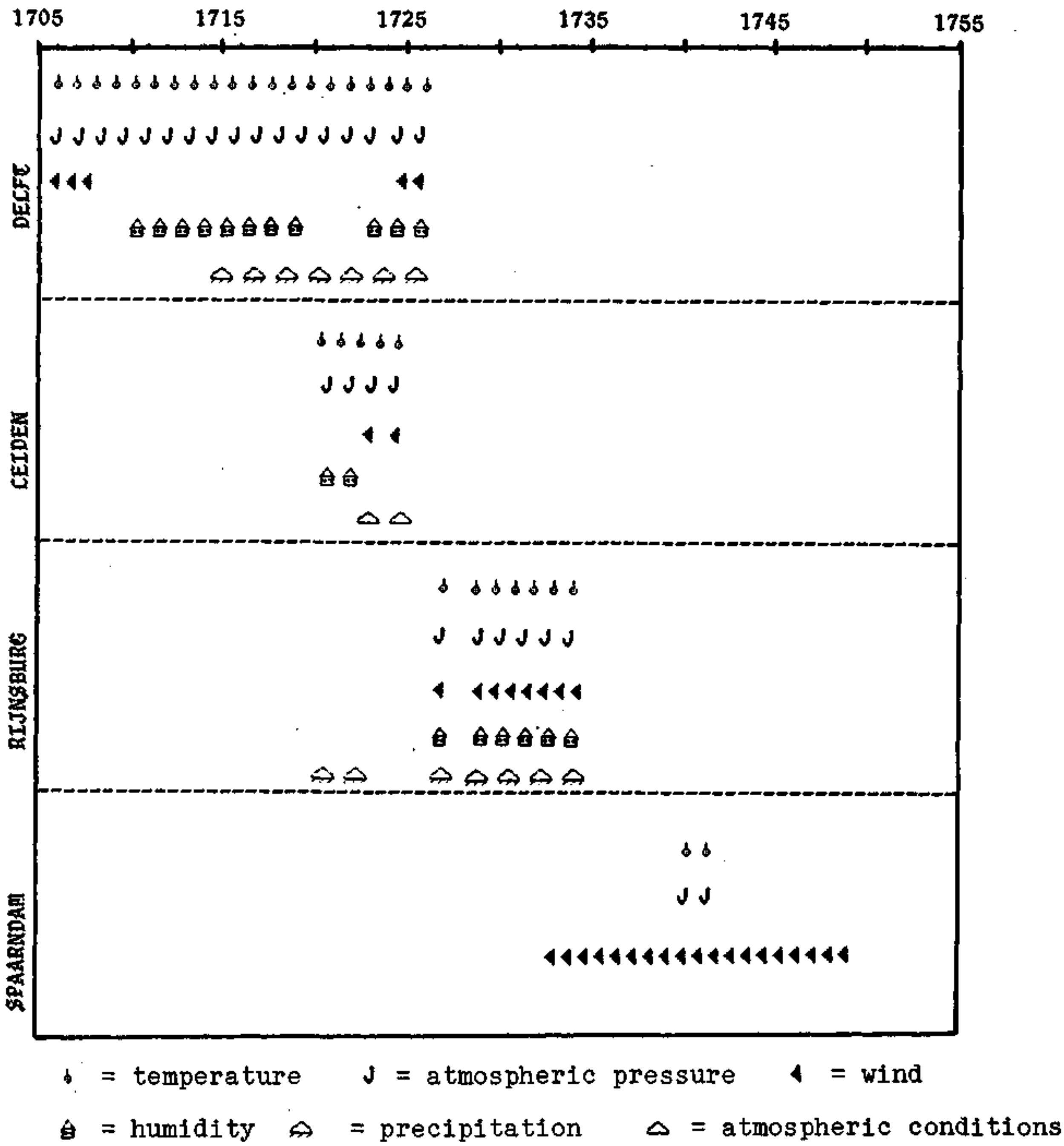


Fig. 7 Summary of the surviving observations made by Cruquius.

5.2 a Atmospheric pressure

The first observations Cruquius recorded were barometer readings. We do not know what type of instrument he used. Atmospheric pressure is recorded in "Pounds troy, Amsterdam weight, and pennyweight" over a surface of one square Rhineland foot (one pound troy = 0,494 kg; one square Rhineland foot = = 0,098562 m^2) (14).

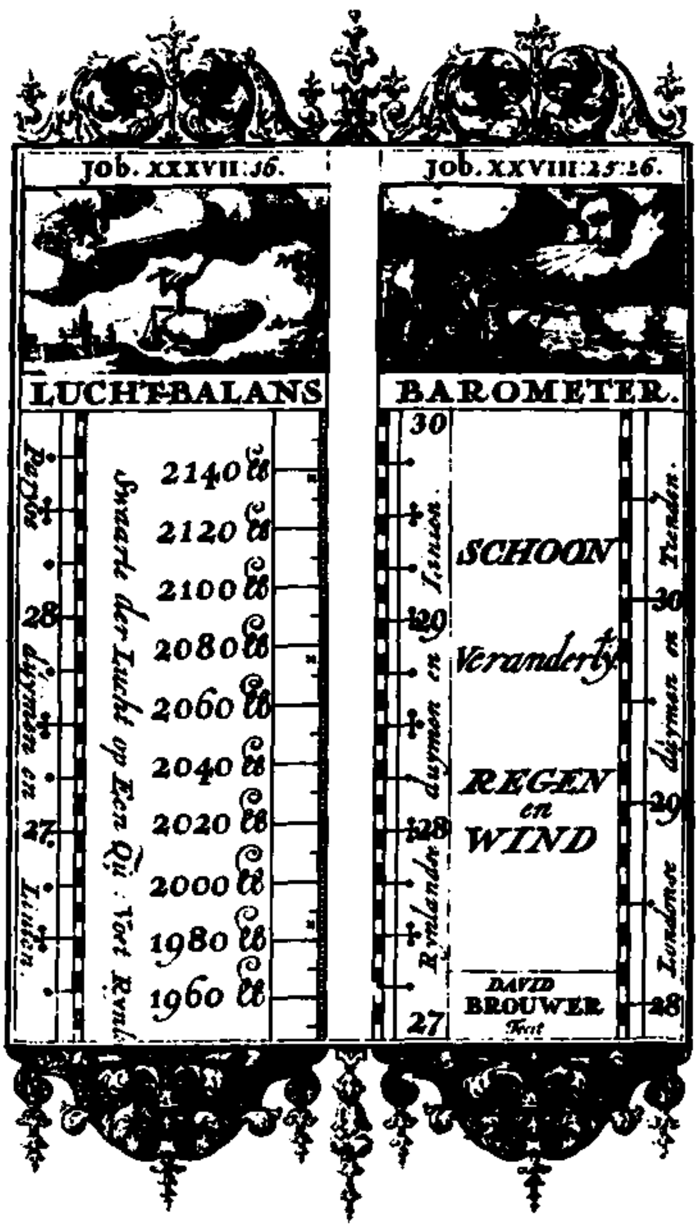


Fig. 8 Barometer scale used by Cruquius showing the comparison of Paris, Rhineland and London inches (16).

5.2 b Temperature

The most important element in Cruquius' series is temperature. He first noted the thermometer reading on 29 December 1705, and probably recorded the temperature or had it recorded virtually every day from then until shortly before his death in 1754. His temperature readings between 1706 and 1734 have been preserved almost in their entirety (1). However, their accuracy should not be taken for granted. Until mid-October 1725 Cruquius must have used a thermometer designed by himself with his own thermometer scale, the Cruquius scale. He called it an air thermometer.

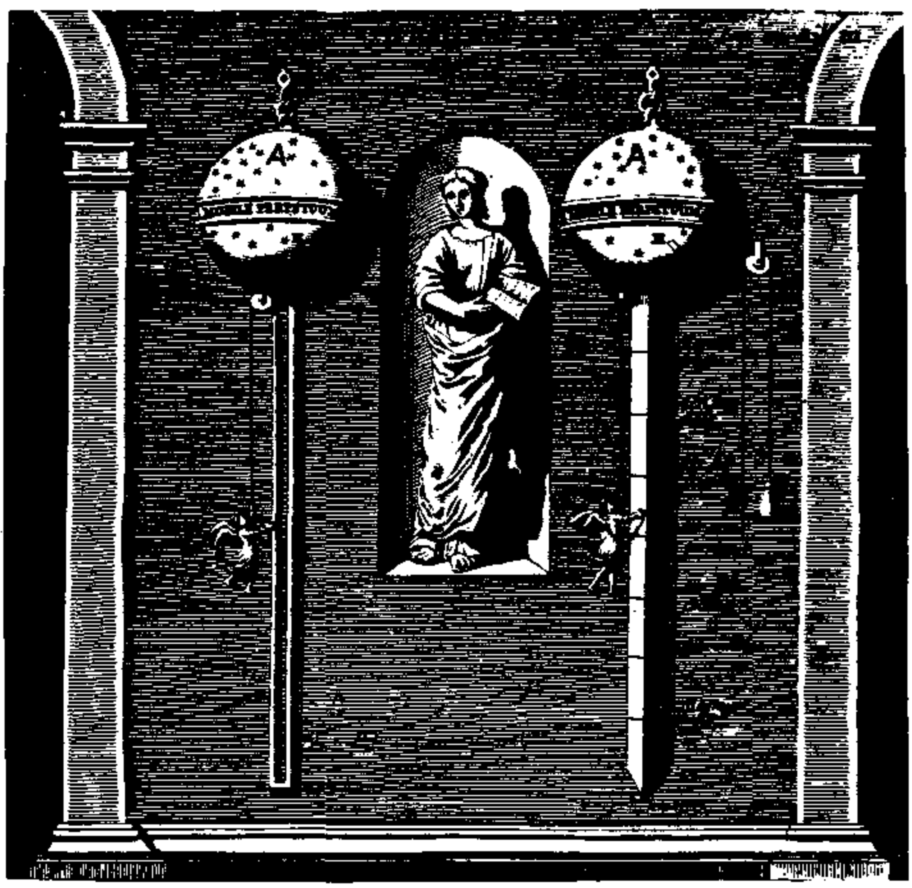


Fig. 9 Air thermometer by Otto von Guericke (1602-1686) dating from c. 1672.

Such instruments constructed by the Dutch Cornelis Drebbel (1572-1634), for example, were widely known in the 17th century.

Otto von Guericke's thermometer, illustrated in Figure 9, worked in the same way as Drebbel's. A U-tube, partly filled with water or alcohol, is situated beneath globe A, which is filled with air. The water in the open-mouthed side of the tube supports a float attached to a string which runs over a pulley. The other end of the string is attached to the figure of an angel whose finger indicates the temperature on the scale. When heated, the air in the globe expands causing the water level in the sealed tube to drop and that in the open tube to rise, thus lifting the float. The angel moves down accordingly. Cruquius used a similar thermometer, probably without the decorative angel. It was calibrated such that 1070° on the Cruquius scale was equivalent to the freezing point of pure water, and 1510° Cruquius equalled the boiling point (5).

He probably determined the scale on the basis of a long series of experimental observations, setting 1000° at the lowest point he had measured between 1706 and 1725 (1000° Cruquius is equivalent to 3,36°F). The instrument itself probably bore a different scale. His publication about the observations in Spaardam from 1733 to 1758 refers to "the height of the thermometer, the degree of warmth, or the quantity of parts of heat above 400 in the air indoors" (16).

He may have installed the thermometer indoors during his years in Spaarndam. In any event he also had an outdoor thermometer at that time measuring the temperature in degrees Fahrenheit.

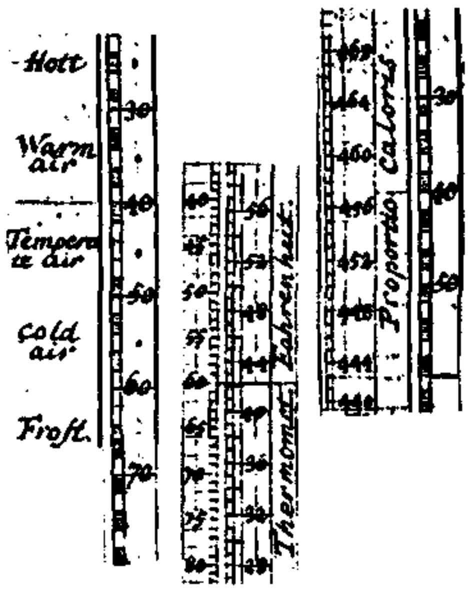


Fig. 10 Temperature scales used by Cruquius in his graphs.

One of his notebooks contains a survey of monthly temperature averages from 1706 to 1725, referring to the "parts of heat" scale, which was equivalent to ten times the Fahrenheit scale (1). The new thermometer which arrived from England in 1725 enabled Cruquius to convert his scale into that of the Royal Society. However he did not use this scale for a long time, because of the introduction in Europe of the definitive Fahrenheit scale. Probably in 1728 he converted all his temperature readings he had made since 1705, into the scale of Fahrenheit.

It is these calculations which have survived and which now serve as the most important source for his work.

The notebooks listing the daily observations from the period between 1705 and 1727 also contain all the remaining data on atmospheric pressure, wind and humidity (1). The original notebooks recording the readings on Cruquius' own scale have been lost. However, the scale may be found in the article on Cruquius' observations published in the Philosophical Transactions (6).

Jan Hendrik van Swinden (1746-1823) catalogued 16th and 17th century temperature scales and included the Cruquius scale in his well-known "comparative table of XXVII thermometers" (19).

Figure 11 shows part of this table comparing the Cruquius scale to several others. Cruquius also used the Royal Society scale, according to which the colder the air is, the higher the temperature (Figure 10).

All these scales - except for Cruquius' own - can be found in his letter of 31 January 1726 to the Royal Society (supplement V) with which he enclosed a graph showing all his daily observations for the previous year. Cruquius had no further contact with the Royal Society. In any event its archives contain no subsequent letters from him. He continued his observations without interruption, however, probably using the thermometer he had obtained from England.

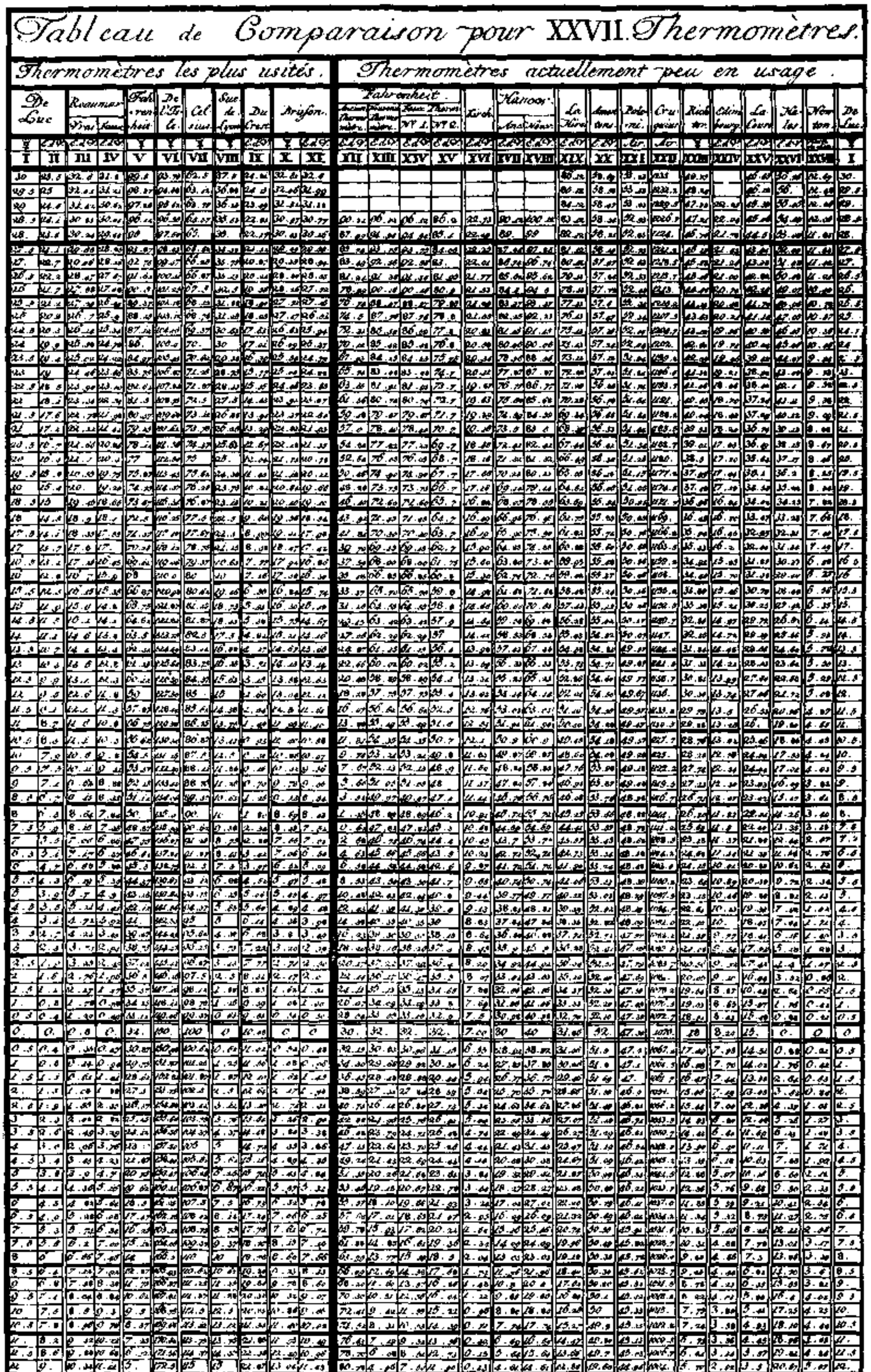


Fig. 11 Part of the "Comparative table of XXVII thermometer scales" by Jean Henri van Swinden (19).

5.2 c *Humidity*

Cruquius took humidity readings from 8 January 1710 using an instrument consisting of a sponge soaked in ammonium chloride which was placed on scales (supplement VI) (6). These are believed to be the earliest humidity measurements taken in the Netherlands. Later, he used the familiar "weather house" in which figures of a man and woman are caused to move by atmospheric humidity. He interpreted their position in terms of degrees of their rotation and recorded these readings (16). It thus appears that a weather house - where the man appears in bad weather and the woman in fine weather - is more than two centuries old.

De Graden van de HYGROMETER, by andere genaamt NOTIOMETER, *binnens Huys waargenomen*, vertonende *de meer en minder vogtigheyt van de Lugt*, eenigſints na reden van het groter of kleynder getal, naar uitwijſing van 't gemeene over-al wel bekende *Weerhuysje*, den geheelen ommeloop van 't Mannetje of Wijfje, na des zelfs verdeling 4 maal 12 of 48, de 2 omlopen 96, de middelſtanden, het meeſte, het minſte en verſchillen als voren.

Maand.	Midd. Vogt	het vogtigſte den	het vogtigſte Graad	het droogſte den	het droogſte Graad	verſchil
JAN.	122	24	146	13	115	31
FEB.	123	2	131	27	116	15
MAR.	108	3	120	29	78	42
APR.	81	4. 5.	92	9	69	23
MAJ.	66	7	84	30	45	39
JUN.	24	6. 7.	44	15	6	38

Fig. 12 Humidity readings from the weather house, one of the hygrometers used by Cruquius.

5.2 d Precipitation and Evaporation

Cruquius was also probably the first person in the Netherlands to measure precipitation (20). He gauged the "level or quantity of water fallen from the sky" with great precision and attempted to limit evaporation as much as possible (16).

> ***Maandelijkſe Hoogte, of Quantiteyt van 't gevallen*** **HEMEL-WATER, op een effen, Waterpas leggende, rondom beſloten Vlakte, in tiende Deelen van Rhijnlandſche Linien; de meeſte Regen die in ieder Maand geduurende een Etmaal is gevallen; als mede het getal der Dagen die gepaſſeert zijn ſonder eenig Hemel-Water, Regen, Hagel, Sneeuw, Dauw en Rijp; beloopt te Spaarndam $33\frac{1}{8}$ Duym.**

Fig. 13 Heading above Cruquius' table of precipitation measurements (16).

Little is known about the instrument he used for this purpose although the text in Figure 13 does give an idea of the method he used to determine the quantity of precipitation in Spaarndam and probably in Delft and Rijnsburg as well. The first readings of this kind were taken in 1715 and the table published in the Philosphical Transactions shows monthly precipitation totals for Delft between 1715 and 1723 (5).

From 1724 onwards the records also contain precipitation samples but this method of notation is unclear and probably inconsistent (1, 15).

Apart from precipitation Cruquius also measured evaporation although how he did so is not clear. In Rijnsburg he gauged the evaporation in the wind. He probably also used, as a measure of evaporation, the water level in a deep well from which no water was lifted during the observation period (supplement VI).

Again Cruquius' evaporation measurements are probably the earliest in the Netherlands. In addition he took numerous readings of water levels inside and outside dikes and sometimes measured the thickness of the ice.

5.2 e Wind

The direction and velocity of the wind were first included in the observations of 13 January 1706 (1). From January 1709, however, these figures no longer appear. In 1729 the observations were considerably expanded and wind direction and force were recorded several times per day. It seems unlikely that Cruquius ceased to take wind measurements in the intervening period; probably he did not transfer them to the records compiled in 1728 when he converted his temperature readings into degrees Fahrenheit. For the first few years he measured wind speed on the scale used by the Royal Society. The conversion may have required so much work that he omitted many of his wind measurements. Petrus van Musschenbroek adapted the Royal Society's wind scale for use in the Netherlands with the following results:

Wind speed	Consequences for the sails of a windmill
1	Cloths can be set on all sails
2	Part of the cloths must be furled on two sails
3	Part of the cloths must be furled on all sails
4	The miller dare not entrust the sails to the wind without cloths

The Van Musschenbroek scale dates from 1728 and a similar one was used by Cruquius until 1734. Thereafter, however, when he was supervisor at Spaardam, he adopted the mill scale, which was probably introduced by Jan Noppen. This had 17 graduations, the wind speed being estimated from the speed of windmill sails.

This scale was used for the meteorological observations made at Zwanenburg until the 19th century.

The tables summarising Cruquius' observations at Spaarndam include lists of monthly wind direction frequencies for the period between 1733 and 1748. He even states the number of hours for which the wind blew from a particular direction (16).

Noppen's windmill wind scale (correlated with the Beaufort scale).

Windmill wind scale	Beaufort scale	Description	Effect on windmill sails
0	0	calm	mills cannot grind
1	1	calm	mills turn, but very little
2	2	light breeze	mills turn gently and continually, and grind
3-4	3	gentle or constant breeze	mills grind at moderate or reasonably brisk rate
5-6	4	moderate breeze	mills grind so briskly that full canvas on sails can be set
7-8	5	fresh breeze	between quarter and a third of the canvas furled; brisk revolution
9-10	6	strong breeze	between half and two thirds of canvas furled
11-12	7	moderate gale	three quarters of canvas furled
13-14	8	storm	no canvas set
15-16	9-10	continuous storm	milling too dangerous
over 16	11-12	hurricane	milling too dangerous

Noppen's windmill scale, which was also used by Cruquius probably dates from c. 1730. It was described in a letter from Johan Christiaan Mohr (1747-1787) to Jan Hendrik van Swinden (20).

5.2 f General weather conditions

The daily entries for the period between 1727 and 1734 contain observations of general weather conditions, such as cloud cover and precipitation (1). All that remains of the later observations in Spaarndam are the daily records of general conditions between February 1740 and April 1741 (15).

The graphs from 1723 and 1725 also contain daily data on atmospheric conditions (supplements V and VI).

Here Cruquius used symbols for cloud and types of precipitation; in his other records he usually employed letters and abbreviations.

The descriptions of the weather for 1727 to 1734 are particularly untidy and unclear. Those from the Spaarndam period, 1740-1741, are much clearer and more detailed.

6. Astronomical observations

Since Cruquius was also deeply interested in astronomy the records of his meteorological observations include astronomical data (1). He assumed a connection between the sun's position and the direction of the wind and believed that this followed a sort of daily course, as witness the heading to one of his tables: "The changes which the sun, in its daily revolution, causes in the direction and strengh of the wind: findings; the monthly wind in the night, morning, afternoon, and evening wind being subtracted, the results may be seen in this table" (16).
He compiled extensive tables of the times of sunrise and sunset which he dedicated to his teacher Herman Boerhaave. He tried to use these to regulate his clock and daily entries in various notebooks state how fast or slow the clock was. He even calculated monthly averages. Cruquius also analysed the position of the stars and made diagrams and drawings of the courses as he perceived them of the planets Jupiter, Mars, Mercury and Saturn.

Symbols in his records indicate the position of the stars and planets virtually every day. A letter to the Royal Society reveals that he supposed that the planets influenced the weather. He said that British, French and Dutch observations of the effects of the sun and moon on the seas and the atmosphere were so far advanced that it would soon be possible to calculate the tidal movements caused by the sun and moon as accurately as the phases of the sun and moon.

It would be extremely valuable to describe accurately atmospheric changes in different parts of the world and the position of the planets at the time those changes occurred. A comparison of these observations over many years would enable natural philosophers to deduce whether, like the tides, meteorological phenomena and particularly atmospheric changes were influenced by the planets (supplement II).

At the time Cruquius wrote this, much interest was focused on astrometeorology, as the combination of astronomy and meteorology is known. Numerous almanacs and popular works on the weather appeared between the Middle Ages and the 18th century. The earliest climatological reviews of meteorological series, which appeared during the 18th century, contained lengthy philosophical reflections as to whether planetary movements influenced meteorological conditions. It is therefore hardly surprising that Cruquius devoted much attention to this question. Throughout the 18th century many scientists found themselves on the wrong track as there proved to be no connection after all. Yet Cruquius was progressive in his ideas, since he pointed to the importance of collecting and collating meteorological observations.

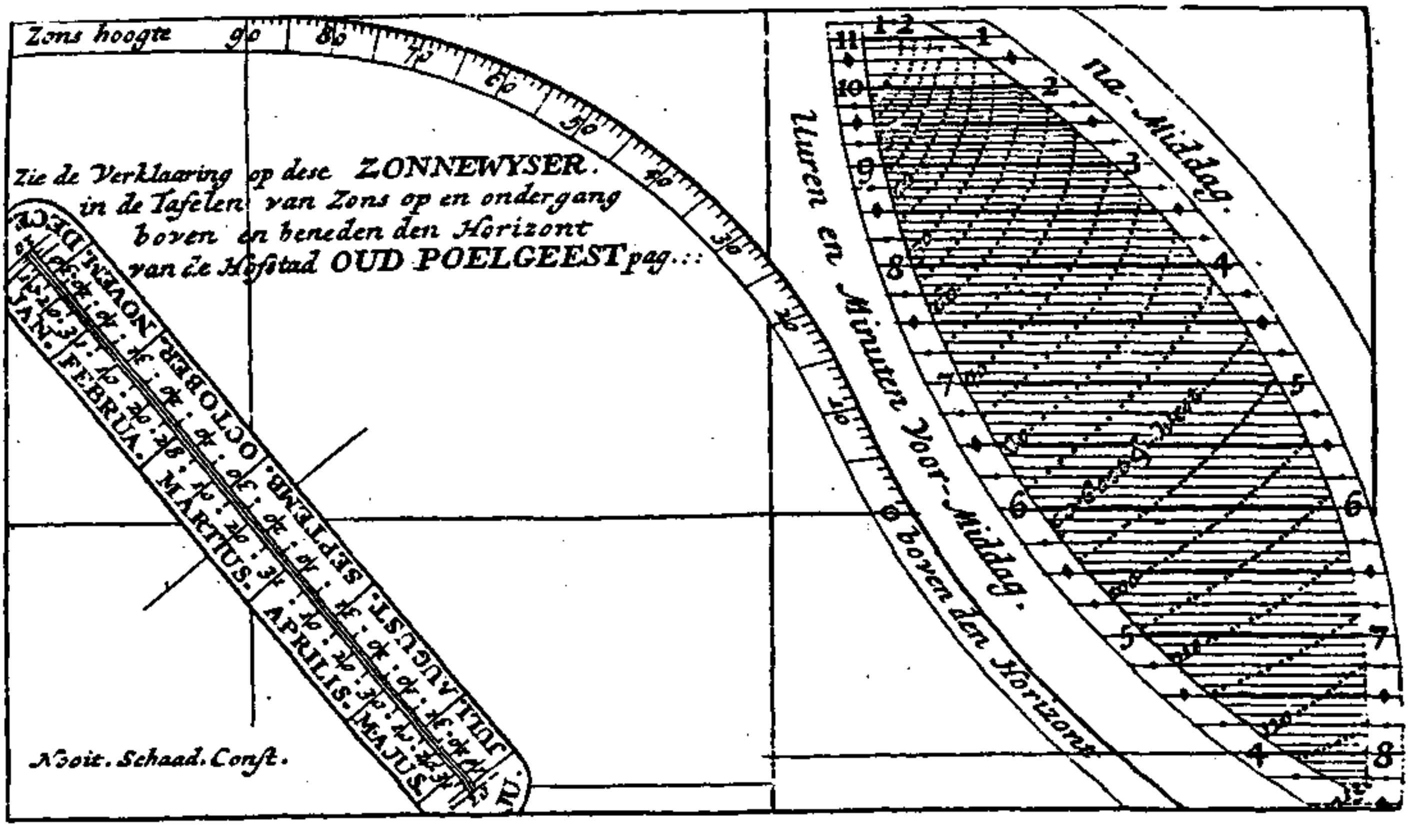


Fig. 14 Sundial designed by Nicolaus Cruquius, probably c. 1735 (16).

7 Compilations of Cruquius' temperature recordings

7.1 Introduction

Series of monthly temperatures have already been reconstructed from the temperature measurements made by Nicolaus Cruquius. Well-known publications include those by Labrijn (20) and Lenke (21).
These reconstructions are based upon monthly averaged values of the temperature which Cruquius himself (1) calculated from his daily observations and contain a number of errors. They cannot therefore be regarded as particularly trustworthy. A more reliable interpretation is now possible since an inventory of the daily recordings is available for the first time.

This inventory will be described in the following sections. Special attention will be given to the methods by which the daily temperature measurements are converted to a reliable series of monthly temperatures for Delft/Rijnsburg over the period 1706-1734.
Reduction of the Delft/Rijnsburg series to conform to the De Bilt series of monthly temperatures (20) covering the period from 1735 to the present time, was made possible by comparing both series with the overlapping series of monthly temperatures for Central England (22).

This report is concluded with a table summarizing the monthly mean temperatures for Delft/Rijnsburg for 1706-1734 which have been reduced to conform to the De Bilt series.

All temperatures in tables and graphs are given in degrees Celsius, mostly rounded off to 0.1 °C, but in some cases to 0.01 °C.

7.2 The collection of temperature observations

The collection of temperature observations, either made by Nicolaus Cruquius himself or made under his supervision, comprise more than 15,500 daily temperatures.

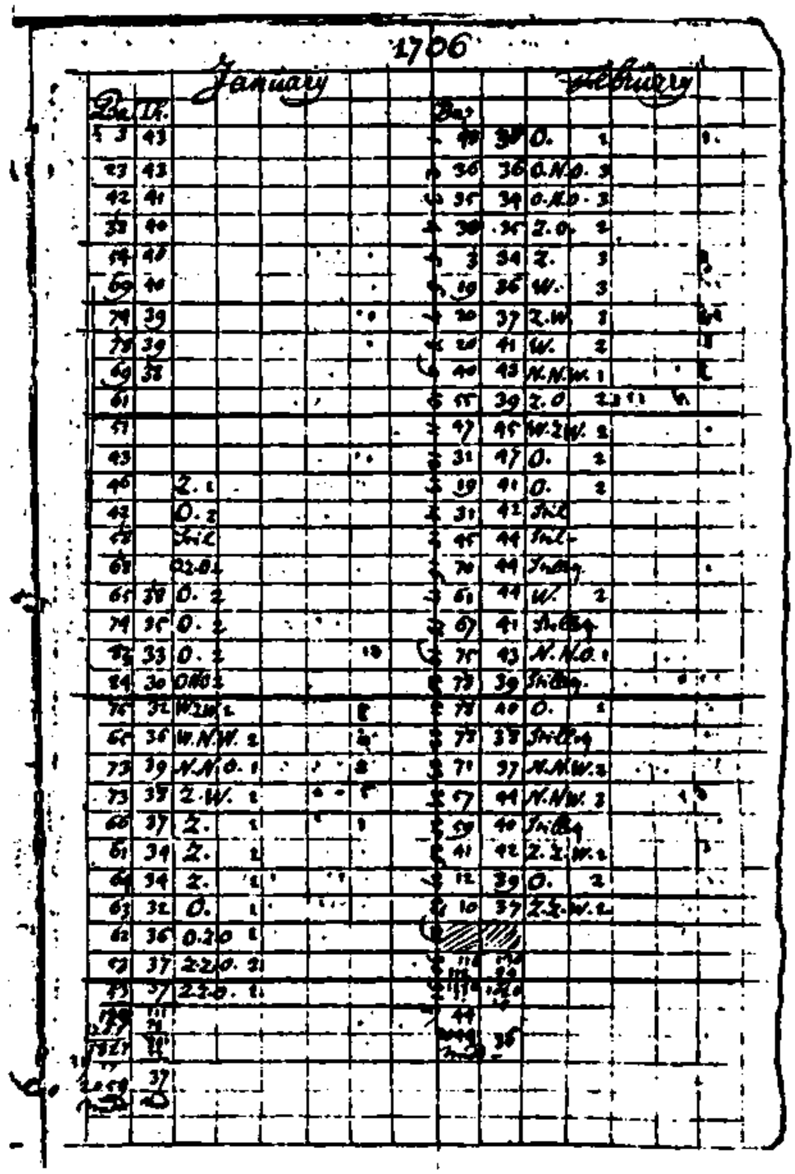


Fig. 15 Log of temperature recordings for January 1706

The data cover the period from January 1706 to December 1734. All the temperature data originate from authentic manuscripts and lists of observations in the possession of the "Hoogheemraadschap" (district water control board) of Rijnland, Leiden (1).

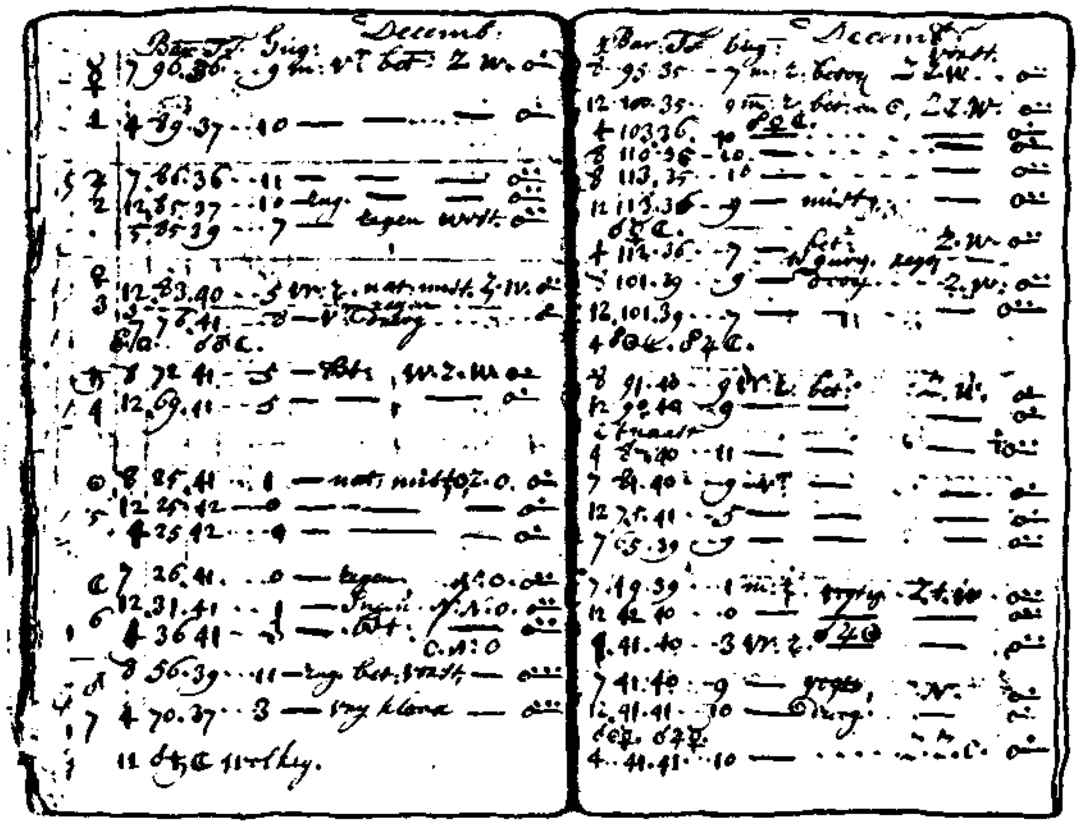


Fig. 16 Log of temperature recordings for December 1734

The data were put onto computer magnetic tape during a three year period from 1981 to 1984. The original authentic notation was retained; no coding or translation was applied. This has the great advantage that access to the original data is always possible during any compilations.

Unfortunately, a homogeneous set of data is not available. Over the period 1706-1727 only the daily (24 hr) temperatures in degrees Fahrenheit are available that Cruquius himself calculated from his original recordings. One or sometimes several daytime temperatures are missing for each month during this period. The temperatures from July to October 1717 are completely missing.
No temperature data at all have been found for the whole of the year 1728. It is not known whether Cruquius made no observations in that year, or whether the logs have been lost. Cruquius made several measurements per day during the period 1729 to 1734 and data are missing for only a few days.

The following section describes where Cruquius made his measurements and what sort of thermometers he used.

7.3 Locations where the observations were made. Types of thermometer and positioning of the thermometers

As indicated in chapter 5, Cruquius recorded temperatures in Delft from 1706 to 1726 and in neighbouring Rijnsburg from 1727 to 1734.

Cruquius used the air thermometer described in chapter 5, at any rate up to 1725.

In that year he received two new thermometers from the Royal Society in London.

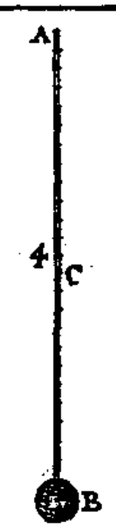


Fig. 4. Is a common Thermometer, to determine the Quantity of the Heat of the Air, or of any Liquor, by the Rarefaction of Spirit of Wine contain'd in the hollow Ball at the Bottom, and its Consequent ascending to the several Divisions on the small Tube.

Fig. 17 An early Hauksbee thermometer. The scale divisions are apparently according to the Royal Society standard (23).

The first was broken in transit. This is apparent from his letter of 25 June to James Jurin (1684-1750), the Secretary of the Royal Society (supplement III). He received his second thermometer shortly afterwards on 7 July (supplement IV). The instrument that Cruquius received was probably a Hauksbee thermometer (fig. 17)

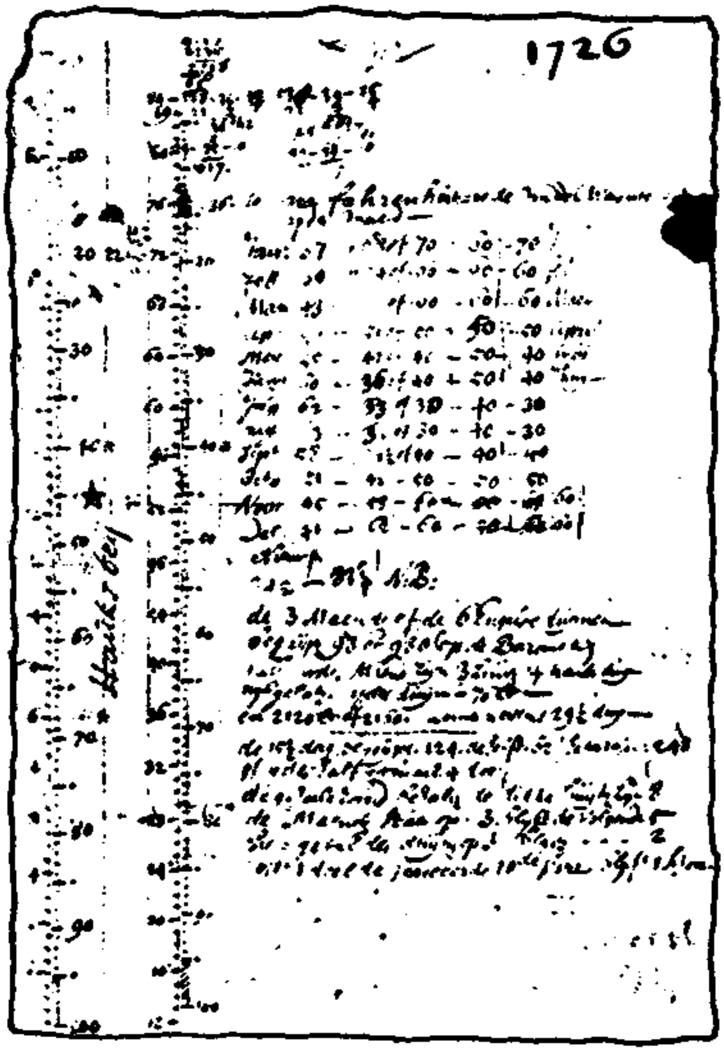


Fig. 18 Page from the log of 1726 with the name "Hauksbeij"

Not only were the Hauksbee thermometers warmly recommended by Jurin in 1723 (24), but written as "Hauksbeij" this name is seen in a sketch made by Cruquius in his log of 1726 (fig. 18).

His replacement thermometer was very certainly not filled with mercury. Altough such thermometers were already made around this time - by Fahrenheit amongst others - it was, if like the first one, filled with another liquid, probably alcohol. This is apparent from a quotation from that letter of 25 June, 1725. Cruquius writes:

".... but I discovered that the thermometer tube was broken and the fluid spilt; in fact the latter had dried up completely, and only the pigment from it was left in the paper and the wood on the box"

The scale on the thermometer was probably divided in units according to those used by the Royal Society (compare fig. 18). This is supported by the fact that Cruquius wrote, also in the letter of 25 June, 1725, that only after he received a new thermometer from the Royal Society would he be able to present them with his temperature recordings in "English thermometer" units.

Indeed Cruquius gave the temperature in both degrees Fahrenheit and units on the Royal Society scale in his graphical summary of his meteorological observations for the year 1725 (supplement V).

Cruquius did not use the English scale in describing his meteorological observations for 1724. Unfortunately no graphical representation can be found for this year. Certainly he mentioned that the temperatures were written down in degrees Fahrenheit. Thus Cruquius must have been able as early as 1725 to convert the temperature measurements, made with his air thermometer, from degrees "Cruquius" to degrees Fahrenheit.

It is not certain if Nicolaus Cruquius actually used his new thermometer as soon as he received it to continue his series of observations. In spite of the fact that he changed the location of his observations from Delft to Rijnsburg in the beginning of 1727, he continued with the same notation in his logs up to the end of 1727: temperatures per 24 hours in degrees Fahrenheit that he had converted from degrees Cruquius.

After a lapse of a year, Cruquius opened a new log in the beginning of 1729. It contained several measurements per 24 hours. He entered the recordings directly in Fahrenheit. It is assumed that these recordings were made with his new thermometer. Probably it was provided with a conversion scale so that the gradations of the Royal Society could be directly read off in degrees Fahrenheit, wich was a scale that had already gained international acceptance in 1729.

Nothing much is known about how the thermometers were positioned. The only indication is to be found in a letter Cruquius wrote to the Royal Society on 31 January, 1726 (supplement V).

Here he stated that the temperature recordings were made in the shade according to the wishes of the Society.

The times at which Cruquius read the thermometer varied a great deal.
More detailed information is given in the following section.

7.4 Observation times

In his *"Invitation for making Meteorological Observations"* (supplement I), James Jurin from the Royal Society in 1723 appealed for meteorological observations to be made not only at least once every day, but also at fixed times (see also (5)). Cruquius was undoubtly aware of this appeal, but he only partially paid heed to it. It appears from his logs from 1729 onwards that he certainly read the thermometer several times daily, but clearly not at fixed times. The times varied greatly from day to day as did the number of observations. Often three were made, one in the morning, one at about mid-day and one in the evening. Sometimes he made only one observation per day, and sometimes as many as five or more. As indicated in chapter 5, only daily temperatures are available for the years prior to 1729. It is not clear upon how many measurements per day they were based, or at what time of the day they were made.

In his description of his meteorological observations for 1724 (supplement II), Cruquius stated that each day in the graphical summary is divided into three equal eight hour periods. This could possibly be taken to mean that the observation times were analogously divided over the 24 hour period.

The graph of the observations for the year 1725 (supplement V) gives a continuous presentation of the course of the temperature during the 24 hours. From the number of bends in the temperature curve over a daily period, it can be concluded that an average of three readings per day were made but at varying times.

It is not very likely that Cruquius did keep to fixed observation times prior to 1724.
The variance in the daily temperatures from 1706 to 1723 is of the same order of magnitude as that for the period 1724-1734, being 32.6 $^{o}C^{2}$ and 31.2 $^{o}C^{2}$ respectively.
This suggests that the daily temperatures reported by Cruquius prior to 1724 are based upon a number of recordings per day roughly equal to the mostly three per day used from 1724 onwards.

Cruquius' daily observations have been converted to monthly temperatures. The following section describes how the conversions were made.

7.5 Conversion of daily temperatures to monthly temperatures

The observations made several times a day by Cruquius cannot be reliably converted to a series of daily (24 hour) temperatures. For that there is too much uncertainty concerning the regularity and frequency of the times at which he read his thermometer.

A better estimate of monthly temperatures can be made.

A large number of observations (roughly 90) are available for each month, more or less arbitrarily divided over the time.

It is assumed that the arithmetic mean of these values will be representative of the monthly temperature of the month concerned.

Monthly temperatures calculated in this way will be somewhat high since the measurements were nearly always made during the daytime. Other systematic discrepancies might arise for example due to the type of thermometer used, its positioning or by resiting it, and by the way in which it was read.

Nicolaus Cruquius reported all his temperature observations in degrees Fahrenheit and the series of monthly temperatures which we obtain are also in this scale. In order to be able to compare these monthly temperatures with series of monthly temperatures from other locations, it is necessary to convert to the usual Centigrade scale.

The Fahrenheit scale which Cruquius used, certainly deviated from the present standard Fahrenheit scale.

One can only guess the nature and magnitude of the discrepancy.

One Fahrenheit scale that was known in the Netherlands at the beginning of the 18th century, was that of the Amsterdam instrument maker, Daniel Gabriel Fahrenheit himself (1686-1736). The definite calibration of the scale of his mercury thermometer was established round about 1719 (25).
From an exchange of letters between Fahrenheit and the physician Herman Boerhaave (1668-1738) it is possible to deduce the relation between this historical Fahrenheit scale and the modern standard Fahrenheit scale (25).
This is:

$$F_m - 32 = (F_o - 32) \cdot 1.03 \quad \text{or} \quad C = (F_o - 32) \cdot 1.03 \cdot 5/9$$

Where:

F_m = degrees on the modern Fahrenheit scale
F_o = degrees on Fahrenheit's original scale
C = degrees Celsius.

Fahrenheit's thermometer would read roughly 3% too low for temperatures above the freezing point compared to a modern thermometer. Since it is not known which scale Cruquius used, it can not be just assumed that his recorded temperatures should be increased by 3%.
A choice has been made to adopt the standard conversion from Fahrenheit to the Centigrade scale as follows:

$$C = (F_c - 32) \cdot 5/9$$

Where:

F_c = degrees Fahrenheit as given by Cruquius.

The systematically too high deviations in the monthly temperatures due to the temperatures being recorded mainly in the daytime, will then possibly be compensated by systematically too low deviations caused by this scale conversion.

All Cruquius' temperature observations have been converted to a series of monthly temperatures - the Delft/Rijnsburg series - covering the period 1706-1734.

Implausible monthly temperatures present in this series will be considered in the next section.
Inhomogeneities in the Delft/Rijnsburg series are discussed in subsequent sections.

7.6 Implausible monthly temperatures

The monthly temperatures in the Delft/Rijnsburg series have been compared with those in the De Bilt series (20) over the period 1735-1983.

Two suspiciously high values are noticed - July 1719 with a temperature of 22.9 ^{o}C and August 1719 with a temperature of 25.3 ^{o}C. By comparison, the highest July and August monthly temperatures recorded in De Bilt were 20.6 ^{o}C (July 1783) and 19.9 ^{o}C (August 1975). These values were thus considerably exceeded.

If it is assumed that the monthly temperatures for July and August in the Delft/Rijnsburg series from 1706-1734 are independent and normally distributed, then we can apply the van Doornbos slippage test (26) to test the following hypotheses:

H_o: The monthly temperatures for July and August 1719 belong to the populations of July and August monthly temperatures in the Delft/Rijnsburg series over the period 1706-1734.

H_1: The monthly temperatures for July and August 1719 belong to populations with higher mean values than the populations defined in H_o except that the July and August 1719 values are excluded.

If the set of observations y_i $(i=1,2,...,n)$, are placed in ascending order of size, then the test statistic can be calculated by the following formula:

$$t_{max} = \frac{y_n - \bar{y}_{n-1}}{s_{n-1}} \cdot \sqrt{\frac{n-1}{n}}$$

Where:

$\left.\begin{array}{l}\bar{y}_{n-1} = \text{the mean} \\ s_{n-1} = \text{the standard deviation}\end{array}\right\}$ of the $n-1$ observations excl. y_n

For July 1719 this yields:

$t_{max} = 4.0$ and

$P(t_{max} > 4.0) \simeq {}^{n}P(t_\nu > 4.0) \simeq 27 \cdot 0.00025 \simeq 0.00675$

For August 1719 this yields:

$t_{max} = 5.2$ and

$P(t_{max} > 5.2) \simeq 0.00100$

Where t_ν is a Student variable with $\nu = n-2$ degrees of freedom.

Hypothesis H_0 is rejected for both months if a level of significance of $\alpha = 0.05$ is chosen.

The monthly temperatures for July and August 1719 can thus be regarded as outliers. They will not be included in the discussions of monthly temperatures.

The monthly temperatures from May to September 1725 show a remarkable course. They are all one after the other exceptionally low (see supplement IX). August is certainly extremely cold: the temperature, reduced to De Bilt, being 13.5 °C. This is half a degree lower than the coldest known temperature for August in the De Bilt series (August 1956, 14.0 ^{o}C). Compilations of contemporary and independent documents (27,28) describe this part of the summer half-year as continuously very cold, extremely wet and windy, not only in our localities but in England as well.

There are therefore good reasons to believe that the low temperatures that Cruquius recorded in this period can be regarded as representative. They will thus be retained in the compilations of the monthly temperatures in the following sections.

7.7 Comparative series

A suitable method of detecting inhomogeneities and other errors in a series of temperature measurements is to compare it with other, preferably contemporary, series. Such comparative series should have been recorded independently. The locations should not be too far distant, for they should have as nearly as possible the same temperature regimes as the series being considered.
There are three series with contemporary trajectories availabel for the period in which Cruquius made his measurements:

The "Central England" series of monthly temperatures from 1659 to the present. This series is representative for Central England and was compiled by Manley (22).
It should be noted that the monthly temperatures in this series for the period 1707-1722 are mostly based upon the monthly temperatures that Labrijn (20) calculated for Delft and Rijnsburg using Cruquius' observations. The Central England series can only be regarded as an independent comparative series from the beginning of 1723 onwards.

The "Utrecht" series of monthly temperatures for the period 1728-1739, derived by the authors from the daily observations in Utrecht made by Professor Petrus van Musschenbroek (7).

The "Trekvaart" (ship canal) series of winter temperatures for De Bilt. De Vries (29) calculated the winter temperatures in the De Bilt series for the periods 1735-1757 and 1814-1839 with the number of days per winter that the ship canal between Haarlem and Leiden (west Netherlands) was frozen.

In addition, there are some other series that were recorded in The Netherlands in the period 1706-1734. These series have not been used because they are either too short or incomplete, or because the nature and meaning of the observations are not clear. These series are summarised in the table below:

Location	Observer	Period
Leiden	?	1709
Franeker	Andala	1709-1712
Dronrijp	Roucema	1709 and 1716
Breda	Eckhardt	1710-1741
Leiden	Cruquius	1720-1725
Amsterdam	Krighout	1723-1724

The Delft/Rijnsburg series will be reduced to conform to the De Bilt series, compiled by Labrijn (20) from series of monthly temperatures recorded in Zwanenburg, Utrecht and De Bilt for the period 1735-1944. The De Bilt series has now been extended up to the present time (30).

It would appear from research currently being carried out by the authors, that there is room for improvement in this series. Nontheless, since the De Bilt series is recognised as the most important instrumental temperature series in

The Netherlands for climatological research over the last two and a half centuries, it has been decided to reduce the Delft/Rijnsburg series to this series.

There were a number of obvious reasons for choosing the Central England series as the most important independent source of comparative data for testing the Delft/Rijnsburg series for inhomogeneities and to correct it and ultimately to reduce it to the De Bilt series:

The Netherlands and England are close to each other and have temperature regimes that are very similar. Consequently the Central England and the De Bilt series are strongly correlated (see also (31)). It is therefore not surprising that the Delft/Rijnsburg series also shows a good correlation with the Central England series over the period 1723-1734.
The correlation coefficient for the annual temperatures is 0.91
The Central England series has an overlap with both the Delft/Rijnsburg series and the De Bilt series (from 1723 to the present time) that is considerably longer than the overlap of the Utrecht series (1728-1739).
It is rather noticeable that the Utrecht series, which was recorded only 70 km from Delft, has a lower correlation with the Delft/Rijnsburg series, than that of the Central England series over the same period (see table 1).
The Utrecht series appears to be the least reliable of the three.

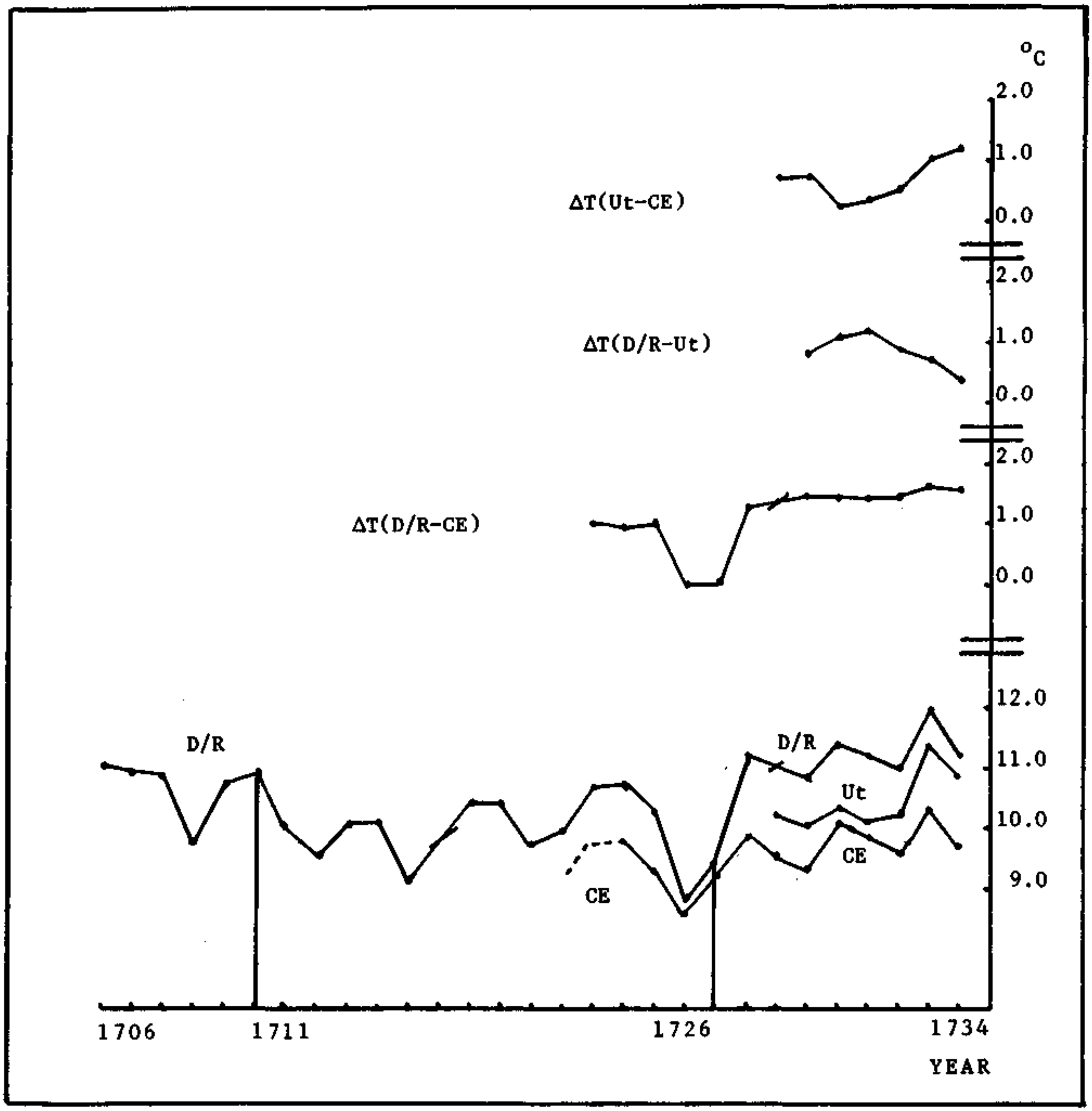


Fig. 19: Annual mean temperatures Delft/Rijnsburg (D/R), Central England (CE) and Utrecht (Ut) series.

SERIES	CE-D/R	Ut-D/R	CE-Ut	
r	0.96	0.89	0.76	
s^2	1.2	2.2	2.9	$°C^2$

$|r| \geq 0.73$ significant at the 5% level (32)

Table 1: Correlation coefficients (r) and residual variances (s^2) of the annual temperatures for the period 1729-1734

Figure 19 gives a graphical representation of the yearly averaged temperatures and the differences between them over the period 1706-1734.

The respective differences between the yearly averaged temperatures of the Utrecht and Delft/Rijnsburg series, and between the Utrecht and the Central England series are very variable. This supports the contention that the Utrecht series is not very suitable as a comparative series. The differences between the Central England series and the Delft/Rijnsburg series are more or less constant, but show a noticeable shift round about 1727. The reason for this must lie in one or both of the series.

The time-course of the yearly temperatures in the Delft/Rijnsburg series makes one suspect that Cruquius recorded temperatures prior to 1727 that were relatively too low. This is not unreasonable since he removed his thermometer from Delft to Rijnsburg in the beginning of 1727.

The Trekvaart series correlates reasonably well with the

Delft/Rijnsburg series. The correlation coefficient over the period 1706-1734 for the winter temperatures amounts to 0.65 (33). However, it provides information only of winter temperatures as seasonal averages (December - February). Its usefulness as a comparative series is therefore restricted.

The following section deals more fully with the similarities and differences between the Delft/Rijnsburg and Central England series. The jump in the Delft/Rijnsburg series that is apparent in 1726/1727 will also be discussed.

7.8 The Delft/Rijnsburg series compared with the Central England series

Table 2 lists the correlation coefficients for each separate month between the Delft/Rijnsburg and Central England series together with their respective standard deviations covering the period 1723-1734.

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
r	0.93	0.82	0.95	0.77	0.89	0.90	0.85	0.89	0.82	0.70	0.75	0.92	
s(D/R)	2.2	1.7	1.6	1.4	1.4	1.4	1.9	1.6	1.3	1.6	2.0	1.8	°C
s(CE)	1.8	1.5	1.4	0.9	1.0	1.1	1.1	0.9	1.2	1.1	1.2	1.7	°C

$|r| \geq 0.60$ significant at the 5% level

Table 2: Correlation coefficients (r) and standard deviations (s()) of the Delft/Rijnsburg series and the Central England series from 1723 to 1734

Not only the yearly temperatures (compare table 1, section 7.7) but also the monthly temperatures show good correlations.
Based upon a theoretical correlation coefficient ρ equal to 0.80, the sample correlation coefficient r will lie between $\simeq 0.40$ and $\simeq 0.95$ wit a 95% probability (e.g. ref(34)).
The correlation coefficients for each month lie within this interval.
It should be noted that in interpreting the correlation coefficients, it is assumed that the temperatures from the Delft/Rijnsburg and Central England series are independent samples of a bivariate and normal distribution.

The monthly temperatures could in fact have a skew or even a bimodal distribution. It is not easy to determine how the calculated correlation coefficients are influenced (35).

It is noticeable that the standard deviations of the Delft/Rijnsburg and Central England series do not show a good agreement for some of the months. In five of the months they differ by as much as 0.5 ^{o}C or more.
It will be shown in the following section that the monthly temperatures in the Delft/Rijnsburg series reveal a jump in 1726/1727. After correcting the monthly temperatures for this jump, it will be seen that the standard deviations will indeed show a good agreement with those of the Central England series.

The presence of a trend can be investigated by means of the Mann-Kendall non-parametric test (36).
The level of correlation between temperature and time (calendar year) can be expressed in Kendalls' rank correlation coefficient τ. The formula for the evaluation of τ is:

$$\tau = \frac{N_c - N_d}{\frac{1}{2} \cdot n \cdot (n-1)}$$

Where:

N_c = number of concordant pairs of observations
N_d = number of discordant pairs of observations
n = total number of pairs of observations

This test is very sensitive for a more or less regularly increasing (decreasing) course of the temperature, and to a somewhat lesser extent sensitive for a stepwise increase (decrease).

The test is carried out on the yearly and seasonally averaged temperatures for the Delft/Rijnsburg series over the period 1706-1734. The value of τ is then calculated for the contemporary annual mean temperatures, recorded in Delft/Rijnsburg and in Central England over the period 1723-1734 (table 3).

PERIOD	YEAR	WIN	SPR	SUM	AUT	*sign. at 5% lev. if:*
$\tau(D/R)_{1706-1734}$	+0.21	+0.08	+0.10	+0.08	+0.20	$\|\tau\| \geq 0.27$
$\tau(D/R)_{1706-1722}$	-0.26					$\|\tau\| \geq 0.37$
$\tau(D/R)_{1723-1734}$	+0.60*					* $\|\tau\| \geq 0.46$
$\tau(CE)_{1723-1734}$	+0.36					$\|\tau\| \geq 0.46$

Table 3: Kendalls' τ between yearly and seasonally averaged temperatures and time (calendar year)

It is noticeable that the rank correlation coefficient has a significant value over the period 1723-1734 for the Delft/Rijnsburg series but not for the Central England series. It is seen in figure 19 (section 7.7) that both series run parallel certainly after 1726/1727 but also apparently before that. A definitely higher value of τ for the Delft/Rijnsburg series should therefore not be attributed to a significant trend, but to the (positive) jump in the yearly temperatures in 1726/1727 discussed previously. This jump also effects the value of τ for the Delft/Rijnsburg series from 1706 to 1734.

Relatively high, but not significantly high, values of τ were found for the annual and autumn temperatures.

No trend in the annual temperatures is visible in figure 19 (section 7.7) during the period 1706-1722, but prior to 1712 they appear to be rather high.
This is illustrated by a negative value of τ during the same period. It is noted that τ is positive for all other periods. It is suspected that another (negative) jump is present in 1711/1712 in the temperature series.

It will be shown in the following section that the jump in 1726/1727 can be seen for almost every month of the year. Further, it will be revealed that a jump in 1711/1712 is likely for a number of months.

Since there is excellent agreement between the Central England series and the Delft/Rijnsburg series, it is possible to correct for the jump in 1726/1727 on the basis of the additional information available in the Central England series.
These corrections will be considered in detail in section 7.10

7.9 Temperature jumps in 1711/1712 and 1726/1727

The statistic S_k^{**} is used for detailed investigation in wich years, in which seasons, and more specifically, in which months temperature jumps appear in the Delft/Rijnsburg series.
This statistic is related to the cumulative deviations of the temperatures over a period of years with respect to the average over the period (37).
Given the independent observations y_i $(i = 1,2,\ldots,n)$, having a common distribution, then S_k^* can be defined as:

$$S_k^* = \sum_{i=1}^{k} (y_i - \bar{y}) \text{ , } k = 1,2,\ldots,n \text{ ; } S_0 = 0$$

And:

$$S_k^{**} = S_k^*/s(y) \text{ , } k = 0,1,\ldots,n$$

Where:

$$s^2(y) = \sum_{i=1}^{n} (y_i - \bar{y})^2/n$$

If S_k^{**} is plotted against the time (in calendar years), it will fluctuate around zero if the series is homogeneous, because no systematic pattern will be expected in the separate values of y_i with respect to their mean value $\bar{y}$.
If a jump in the temperature is present in the series, the S_k^{**} -curve will have a maximum about the point of a negative jump, and a minimum about the point of a positive jump.

A test statistic which indicates a change in temperature level is:

$$Q = \max |S_k^{**}| \ , \ 0 \leq k \leq n$$

High values of Q indicate the presence of a temperature jump. Critical values of this test statistic are given in table 4.

n	$Q/\sqrt{n}$ 90%	$Q/\sqrt{n}$ 95%
10	1.05	1.14
20	1.10	1.22
30	1.12	1.24

Tabel 4: Percentage points of $Q/\sqrt{n}$ taken from (37)

PERIOD	YEAR		WINTER		SPRING		SUMMER		AUTUMN	
	D/R	DB	D/R	DB	D/R	DB	D/R	DB	D/R	DB
$Q/\sqrt{n}$	1.5*	0.7	0.9	0.7	1.0	0.5	0.9	0.8	1.5*	0.8
Year	1726	1965	1726	1970	1726	1961	1726	1966	1726	1961

*$Q/\sqrt{n} \geq 1.23$ significant at the 5% level

Tabel 5: Values of $Q/\sqrt{n}$ and their years of appearance

Table 5 gives the values of $Q/\sqrt{n}$ for the annual and seasonal temperatures of the Delft/Rijnsburg series over the period 1706-1734 apart from the two years 1717 and 1728. For comparison, the values of $Q/\sqrt{n}$ for the De Bilt series are given for an equal number of years; that for 1954-1980. This modern series is considered to be homogeneous.

If the value of $Q/\sqrt{n}$ is based upon a minimum value of s_k^{**}, then it is underlined, otherwise it is based upon a maximum of s_k^{**}.

The corresponding s_k^{**} -curves are shown in figure 20.

The s_k^{**} -curves for the De Bilt temperatures on the one hand and for the Delft/Rijnsburg temperatures on the other hand, show substantially different patterns.

The De Bilt curves fluctuate around zero and exhibit several extremes that do not reach high values or appear regularly.

In contrast the s_k^{**} -curves for Delft/Rijnsburg exhibit only one pronounced minimum in 1726, although it is less pronounced in the winter. In particular the curves for the annual and the autumn temperatures show a less explicit maximum in 1711. Apart from these extremes (1711,1726), the curves do not fluctuate around zero but have a monotonous non-increasing or monotonous non-decreasing character.

Partly on the basis of the characteristics of these curves, it can be concluded that the Delft/Rijnsburg series can not considered to be homogeneous.

The temperatures recorded in Delft up to and including 1726 are too low relative to the temperatures recorded in Rijnsburg from the beginning of 1727. This difference in temperature level is visible in all seasons, but less so in winter.

The temperatures measured in Delft up to and including 1711, particularly during the autumn, appear to be rather too high with respect to subsequent measurements.

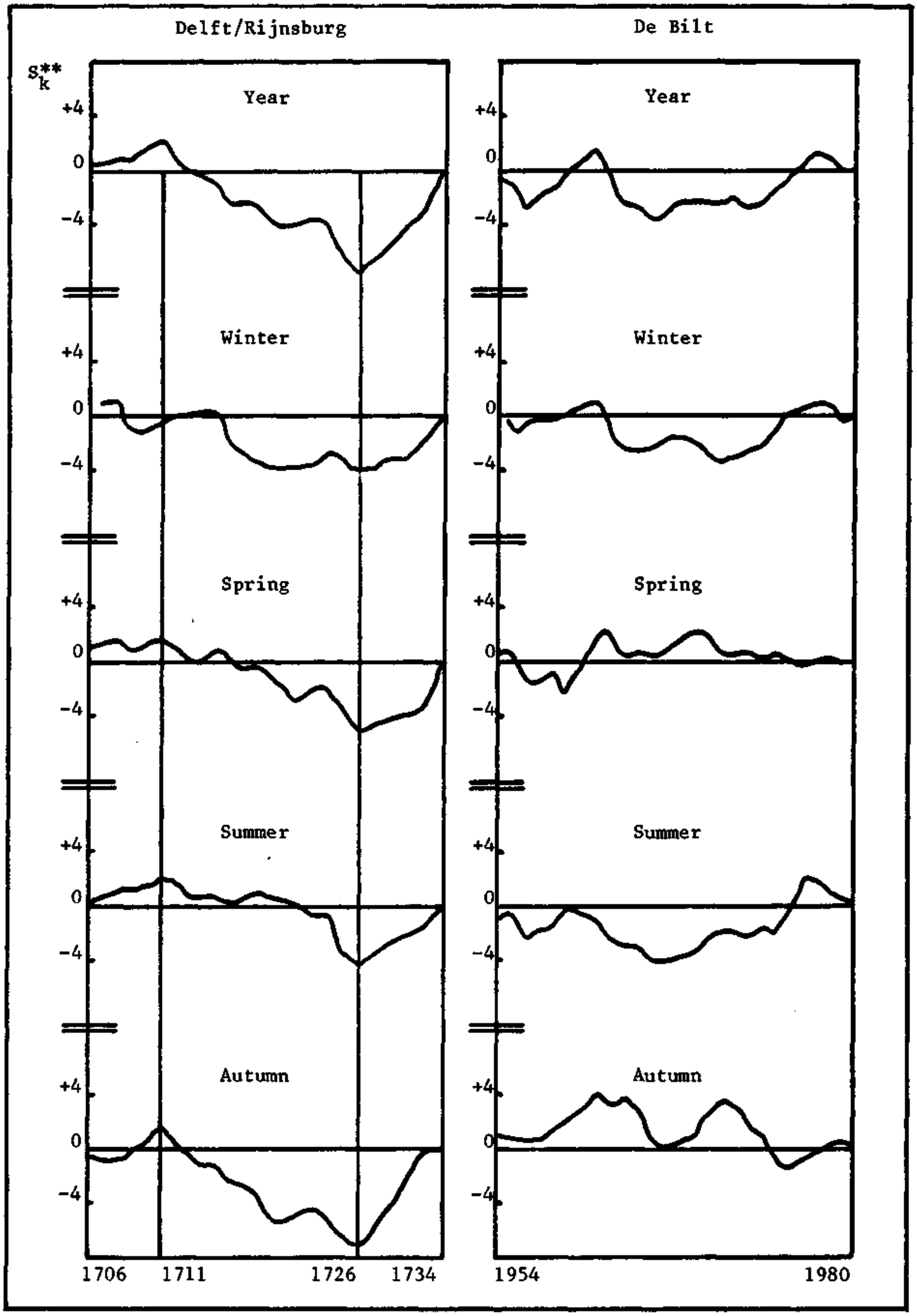


Fig. 20: S_k** -curves for Delft/Rijnsburg (1706-1734 but 1717 and 1728 excluded) and De Bilt (1954-1980)

An analogous picture is given when the s_k^{**} -curves for Delft/Rijnsburg are compared with those for Central England over the period 1723-1734.

Inhomogeneities are not to be deduced in the Central England series either in the annual temperatures or in the seasonal temperatures.

Again the temperatures for Delft/Rijnsburg show a jump in 1726/1727 - a jump which certainly has no climatological foundation since it should also be found in the temperature course for Central England.

s_k^{**} -curves have been plotted for each separate month over the period 1706-1734 of the Delft/Rijnsburg series in order to determine in which months temperature jumps can be demonstrated.

The twelve s_k^{**} -curves can be divided into three groups, each with a particular characteristic.

Representative s_k^{**} -curves for each group are given in figure 21:

Group 1 comprises the curves for January and June. These curves resemble the curves for De Bilt (compare fig. 20) and show no inhomogeneities.

Group 2 concerns April, August, November and December. The curves show a pronounced minimum around 1726 and a maximum around 1711.

Group 3 comprises the curves for the remaining six months. These curves, which have a definite minimum in 1726, are

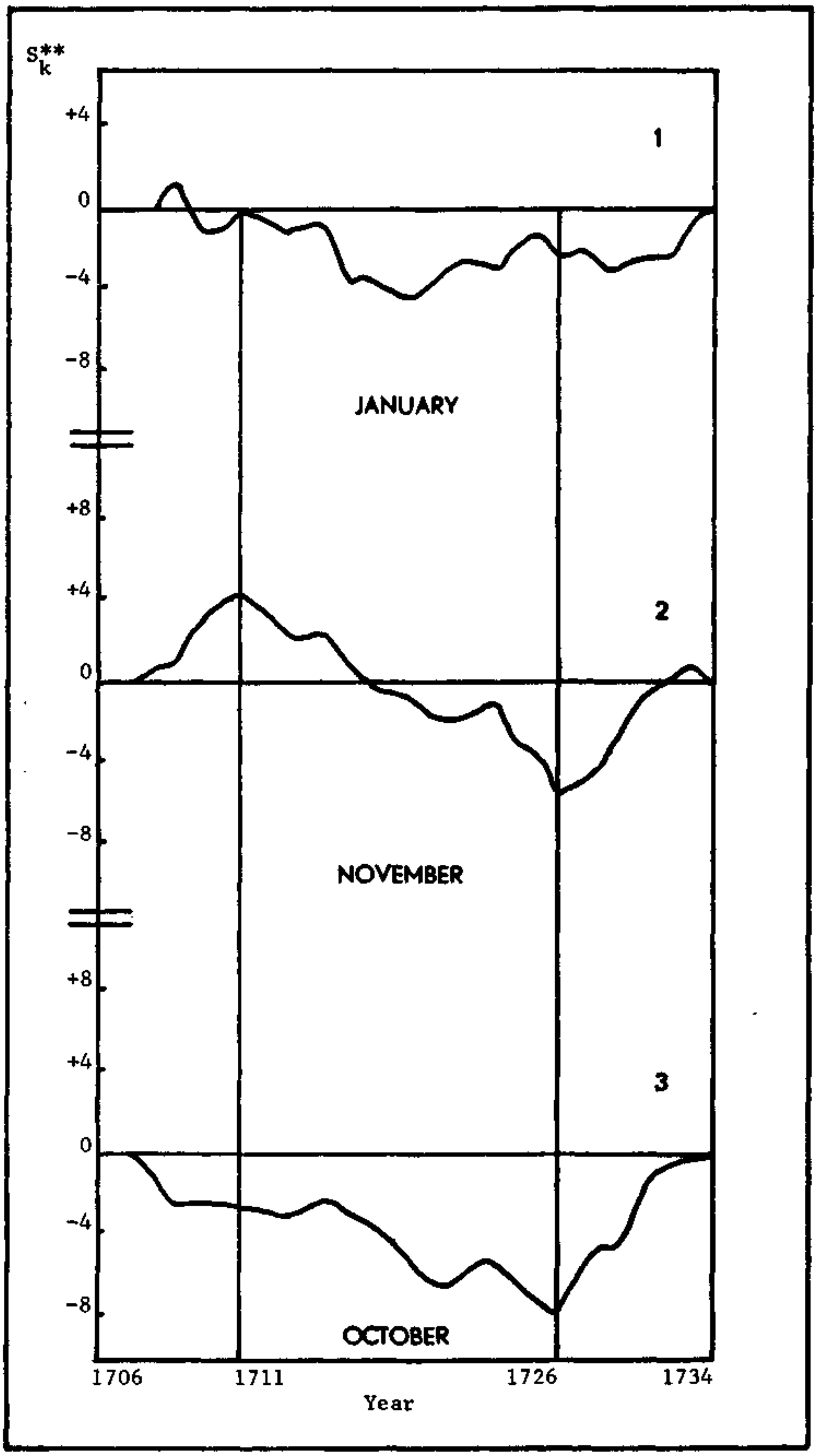


Fig. 21: Representative S_k^{**} -curves for each group 1,2 and 3

comparable with the curves for the seasons (fig. 20).

The values of $Q/\sqrt{n}$ range between $\simeq 0.8$ and $\simeq 1.5$
The variances ($s^2(y)$) for the series of monthly temperatures are generally higher than the variances for the series of seasonal and annual temperatures. As a consequence, the test statistic Q will assume less high values for the monthly temperatures, since: $Q = \max |S_k^*/\sqrt{s^2(y)}|$

It can be deduced from the S_k^{**} -curves for the separate months, that the following jumps are present in the series of monthly temperatures:

- A jump in April, August, November and December in 1711/1712.
- A jump in each month, apart from January and June, in 1726/1727.

The magnitude of the jumps, and the corrections applied to the monthly temperatures in the Delft/Rijnsburg series to make it homogeneous, are discussed in the next section.

7.10 Corrections applied to the monthly temperatures

If a series of temperatures has a jump, then that part of the series prior to the jump, or the part after the jump, has to be corrected by the amount of the difference in temperature level over the jump, in order to make a homogeneous continuity between the two parts of the series.
It can be generally assumed that the more recent part of the series is more reliable than the older part, unless the opposite can be demonstrated on the basis of supporting historical evidence.
Further, corrections do introduce a certain degree of unreliability.
Thus it is desirable to edit the climatological data so that it is contiguous with later data rather than with previous data. In other words, the older part of the series is corrected by using the later part as a reference.
These considerations are used in applying the corrections to Cruquius' temperature measurements.

7.10 a Correcting for the temperature jump in 1711/1712

There are no parallel series available in order to analyse the size of the jump in 1711/1712 in the Delft/Rijnsburg series of monthly temperatures (see also section 7.9).
A criterion for the presence of a jump in the series of temperatures for a certain month, is that the mean temperature over the period 1706-1711 is significantly higher than the mean for 1712-1726 as determined by the Student-t test (e.g. 38).
If this is satisfied, then an estimate of the jump $\hat{Sa}_{1711/1712}$ is taken as the difference in means of the temperatures over the two periods.
The temperatures subsequent to 1726 are not included since a further jump shows in 1726/1727.
Table 6 lists the value of Student's t for each month and, where appropriate, the estimate of the jump $\hat{Sa}$.

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
t	-0.3	+0.7	-0.5	-1.8*	-1.0	-1.4	+0.5	-1.8*	-0.9	+0.4	-3.5*	-2.0*	
$\hat{Sa}$				-1.0				-1.3			-2.2	-1.3	°C

*t ≤ -1.8 significant at the 5% level

Table 6: Values of Students' t and the estimate of the jump $\hat{Sa}$ in 1711/1712

In agreement with what is shown in the s_k^{**} -curves (see section 7.9), a jump is present in the temperature series for the months April, August, November and December.

The monthly temperatures for these four months over the period 1706-1711 are now reduced by the values of the estimates $\hat{Sa}_{1711/1712}$ as given in table 6.

7.10 b Correcting for the temperature jump in 1726/1727

When the value of the jump in 1711/1712 was calculated, there was no alternative but to assume that the true mean temperatures before and after the jump have been remained the same. This certainly need not be the case. The unjustified elimination of an authentic difference in temperature levels, before and after the jump, must be avoided.
It is therefore preferable to relate the size of the jump to the temperature difference with an independent and overlapping series over corresponding times before and after the jump. Such an overlapping series should of course be regarded as representative of the series to be corrected from a climatological point of view.
The Central England series provides reliable supplementary information over the overlapping period 1723-1734 for calculating the heights of the jumps in the monthly temperatures in 1726/1727 (see also sections 7.7 and 7.8).
An estimate of the jump $\widehat{Sap}_{1726/1727}$ for a particular month is obtained as follows:

$$\widehat{Sap}_{1726/1727} = [\bar{T}(CE) - \bar{T}(D/R)]_{1723-1726} - [\bar{T}(CE) - \bar{T}(D/R)]_{1727-1734}$$

Where:

$\bar{T}(CE)$, $\bar{T}(D/R)$ are the mean temperatures for the month in question for the Central England series and the Delft/Rijnsburg series respectively, for the periods 1723-1726 and 1727-1734.

A more refined method than this "means method" is possible by using an (extra) regressor.
This regressor is estimated by means of a linear regression model.
A short description of this model is now given:*

If the following series of independent and normally distributed observations for a particular month are given:

Observations without a jump (Central England):

$$x1_i \ (i = 1,2,\ldots,n1), \text{ prior to the jump}$$

and:

$$x2_i \ (i = 1,2,\ldots,n2), \text{ after the jump}$$

Observations with a jump (Delft/Rijnsburg):

$$y1_i \ (i = 1,2,\ldots,n1), \text{ prior to the jump}$$

and:

$$y2_i \ (i = 1,2,\ldots,n2), \text{ after the jump}$$

Then the following two linear regression equations can be set up:

$$y1_i = a + b \cdot x1_i + \varepsilon1_i \ (i = 1,2,\ldots,n1), \text{ prior to the jump}$$

and:

$$y2_i = a' + b \cdot x2_i + \varepsilon2_i \ (i = 1,2,\ldots,n2), \text{ after the jump}$$

The jump is given by:

$$Sr = a - a'$$

Assuming that the slopes of the regression line before and

**The authors are grateful to Dr. T.A. Buishand for his important contribution to the development of this model* after the jump are the same, then this slope is estimated as follows:

$$\hat{b} = \frac{\sum_{i=1}^{n1} (x1_i - \bar{x}1) \cdot (y1_i - \bar{y}1) + \sum_{i=1}^{n2} (x2_i - \bar{x}2) \cdot (y2_i - \bar{y}2)}{\sum_{i=1}^{n1} (x1_i - \bar{x}1)^2 + \sum_{i=1}^{n2} (x2_i - \bar{x}2)^2}$$

Where:

$\bar{x}1$, $\bar{y}1$ and $\bar{x}2$, $\bar{y}2$ are the means of the observations before and after the time of the jump.

The regression coefficients a and a' can be estimated as follows:

$$\hat{a} = \bar{y}1 - \hat{b} \cdot \bar{x}1$$

and:

$$\hat{a}' = \bar{y}2 - \hat{b} \cdot \bar{x}2$$

The jump is estimated by:

$$\hat{Sr} = \bar{y}1 - \bar{y}2 - \hat{b} \cdot (\bar{x}1 - \bar{x}2)$$

By using a (good) extra regression coefficient (b), it is possible for the regression model to yield a lower variance of the estimate of the jump - and thus a more reliable estimate - than the "means method".

The variance of $\hat{Sr}$ is:

$$Var(\hat{Sr}) = \sigma_\varepsilon^2 \cdot (1/n1 + 1/n2) + var(\hat{b}) \cdot (\bar{x}1 - \bar{x}2)^2$$

Where σ_ε^2 is the variance of the disturbance terms $\varepsilon 1_i$ and $\varepsilon 2_i$

The variance of $\hat{b}$ is given by:

$$\mathrm{Var}(\hat{b}) = \sigma_\varepsilon^2 \,/\, [\sum_{i=1}^{n1} (x1_i - \bar{x}1)^2 + \sum_{i=1}^{n2} (x2_i - \bar{x}2)^2]$$

The variance σ_ε^2 can be estimated by:

$$\hat{\sigma}_\varepsilon^2 = RSS/(n1 + n2 - 3)$$

Where:

$$RSS = \sum_{i=1}^{n1} (y1_i-\bar{y}1)^2 + \sum_{i=1}^{n2} (y2_i-\bar{y}2)^2 - \hat{b}^2 \cdot \sum_{i=1}^{n1} (x1_i-\bar{x}1)^2 - \hat{b}^2 \cdot \sum_{i=1}^{n2} (x2_i-\bar{x}2)^2$$

Estimates of $\mathrm{var}(\hat{b})$ and $\mathrm{var}(\hat{Sr})$ can be obtained by replacing the unknown σ_ε^2 by $\hat{\sigma}_\varepsilon^2$.

The jump in the temperature series has its origin in the relocation of the thermometer from Delft to Rijnsburg. Since both locations lie close to each other, there will be no difference in the temperature regime with regard to that of Central England. It is thus reasonable to assume that the slopes of the regression line before and after the jump should not significantly differ. The number of pairs of observations prior to the jump is too small to test this statistically.

The variances of the jumps ($\hat{Sr}$), calculated by the regression model, are on average 33% lower for each month than those, calculated by the "means method" ($\hat{Sap}$).

For the purposes of comparison, the variances have been determined of the jumps, calculated in an analogous way as the jumps of 1711/1712. A parallel series is thus not used in the calculation. In this case, the variance is formulated as follows:

$$\hat{\mathrm{Var}(Sa)}_{1726/1727} = (1/n1 + 1/n2) \cdot \frac{\sum_{i=1}^{n1} (x1_i - \bar{x}1)^2 + \sum_{i=1}^{n2} (x2_i - \bar{x}2)^2}{n1 + n2 - 2}$$

The monthly temperatures prior to 1712 have not been included in the calculations. It is not certain if, notwithstanding the corrections applied, the linking up of the parts of the series before and after the jump in 1711/1712 is sufficiently homogeneous.

Table 7 lists the estimations of the jump $\hat{Sr}_{1726/1727}$ for each month of the year, calculated with the regression model, together with the corresponding variance var($\hat{Sr}$).
The estimation of the variance var($\hat{Sa}$) is also given for each month.

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
$\hat{Sr}$	0.14	1.05	0.44	0.79	0.48	0.20	1.98	1.10	1.19	1.39	1.84	0.90	°C
Var($\hat{Sr}$)	0.25	0.29	0.09	0.31	0.06	0.12	0.28	0.14	0.07	0.32	0.19	0.07	°C^2
Var($\hat{Sa}$)	0.99	0.57	0.42	0.34	0.30	0.41	0.70	1.09	0.24	0.25	0.35	0.56	°C^2

Table 7: Magnitude ($\hat{Sr}$) and variance (var($\hat{Sr}$), var($\hat{Sa}$)) of the jump in 1726/1727

With the exception of the month of October, var($\hat{Sa}$) is considerably greater than var($\hat{Sr}$).
$\hat{Sr}$ would therefore appear to be the best estimation of the magnitude of the jump.

The jump values for January and June are not significant ($\leq$ 0.2 ^{o}C). The s_k^{**} -curves for these two months (see section 7.9) also exhibit no plausible jump.

For the remaining months all monthly temperatures in the Delft/Rijnsburg series over the period 1706-1726 have been increased by the corresponding jump values of table 7.

Although it is desirable from a climatological point of view to smooth out the values of the jump over the course of the year, this has not been attempted.
These values are too irregular to carry out smoothing in a justified way (see also section 7.13 b).

The Delft/Rijnsburg series can now be considered as homogeneous. However, it is not yet complete; a number of monthly temperatures are still missing. The next section describes how these temperatures are estimated.

7.11 Missing monthly temperatures

After the Delft/Rijnsburg series was corrected for the temperature jumps in 1711/1712 and 1726/1727, two sets of regression equations for each separate month were determined; one with the Central England series from 1723 to 1734, and the other with the Utrecht series from 1729 to 1734.

The missing monthly temperatures in 1717 (July to October inclusive), and new values for the months of July and August 1719 (the original values are considered as outliers - see section 7.6) have been calculated by means of these regression equations from the corresponding values of the Central England series.
It is not known how Manley (22) estimated the temperatures for the months of July and August 1719 in the Central England series, but they appear to agree with the other July and August temperatures in this series.
The missing temperatures in 1717 might have been derived by Manley from Cruquius' measurements, which are now lost, but it seems more likely to us that Manley estimated them, together with the values for July and August 1719, from English observations.

The monthly temperatures for 1728, all of which are missing, are estimated from the Central England series as well as the Utrecht series.
In those months for which both these series have a good

correlation with the Delft/Rijnsburg series, it is found that the two estimates do not significantly differ from each other - the differences being less than 0.3 °C. Exceptions are the months of January to March.

Since the regression equations with the Central England series are based upon a larger number of observations, the estimates from this series are to be preferred.

This preference holds, of course, also for the months for which the Delft/Rijnsburg series correlates better with the Central England series than with the Utrecht series.

Estimates made from the Utrecht series for the months January to March 1728 give considerably higher values, than the estimates from the Central England series. The differences are roughly 1.0 °C. For these first three months of the year the Utrecht series correlates excellently with those of Delft/Rijnsburg. The correlation coefficients are in fact fractionally higher than the correlation coefficients of the Central England series with the Delft/Rijnsburg series.

The winter temperature of 1728, reduced to the De Bilt series, calculated on the basis of the estimates from the Utrecht series (2.2 °C), is in better agreement with the winter temperature of 1728 in the Trekvaart series (4.2 °C) than that calculated from the estimates from the Central England series (1.5 °C). On the basis of these considerations the estimates for the months January to March which are based on the Utrecht series have been chosen.

Table 8 summarizes the estimated monthly temperatures.

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Year 1717							16.9^{e}	17.3^{e}	15.4^{e}	11.8^{e}			°C
Year 1719							19.5^{e}	19.1^{e}					°C
Year 1728	5.7^{u}	4.1^{u}	8.7^{u}	10.1^{e}	14.6^{e}	18.2^{e}	18.5^{e}	17.9^{e}	14.9^{e}	11.5^{e}	9.0^{e}	3.2^{e}	°C

Table 8: Estimates of missing or implausible monthly temperatures made from the Central England series $()^{e}$ and the Utrecht series $()^{u}$

All compilations of the Delft/Rijnsburg series are now completed. In the next section it will be considered whether definite improvements are now apparent in respect to the unedited series.

7.12 Certain evident improvements

Corrections have been applied for inhomogeneities in the Delft/Rijnsburg series and estimates have been made for missing or implausible monthly temperatures. It is now interesting to consider if improvements in the Delft/Rijnsburg series are visible with respect to the comparative series that were used: the Central England series (1723-1734), the De Bilt series (1954-1980) and the Trekvaart series (1706-1734).

The standard deviations for each month of the corrected Delft/Rijnsburg series and the Central England series for the period 1723-1734 are given in table 9.

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
s(D/R)	2.2	1.5	1.6	1.2	1.3	1.5	1.1	1.2	1.0	1.3	1.5	1.8	°C
s(CE)	1.8	1.5	1.4	0.9	1.0	1.1	1.1	0.9	1.2	1.1	1.2	1.7	°C

Table 9: Standard deviations (s()) of the monthly temperatures for Delft/Rijnsburg and Central England from 1723-1734

The standard deviations of both series often differed greatly before the corrections were introduced (compare table 2, section 7.8). There is now good agreement between them.

Table 10 summaries the values of $Q/\sqrt{n}$ for the annual and seasonal temperatures of the corrected Delft/Rijnsburg series over the period 1706-1734 and of the De Bilt series over an almost equally long period: 1954-1980.

PERIOD	YEAR	WINTER	SPRING	SUMMER	AUTUMN
$Q/\sqrt{n}$ $[(D/R)_{1706-1734}]$	<u>0.8</u>	<u>0.7</u>	<u>0.6</u>	<u>0.7</u>	<u>0.5</u>
$Q/\sqrt{n}$ $[(DB)_{1954-1980}]$	<u>0.7</u>	<u>0.7</u>	0.5	<u>0.8</u>	0.8

$Q/\sqrt{n} \geq 1.23$ significant at the 5% level

Table 10: Values of $Q/\sqrt{n}$ for the Delft/Rijnsburg series over the period 1706-1734 and the De Bilt series over the period 1954-1980

In contrast to the values that were obtained without corrections (compare table 5, section 7.9), the values of $Q/\sqrt{n}$ for the Delft/Rijnsburg series are now in good agreement with those for the De Bilt series. Indications of inhomogeneities are not present anymore.

There is only a small improvement in the agreement between the winter temperatures over the period 1706-1734 of the Trekvaart series and the Delft/Rijnsburg series. The correlation coefficient and the residual variance changed from 0.65 and 1.8 $^{o}C^2$ to 0.70 and 1.1 $^{o}C^2$.

The compilations that were carried out have led to a considerably improved and homogeneous Delft/Rijnsburg series.
It is now also useful to extend the De Bilt series further backwards in time with the Delft/Rijnsburg series.
The Delft/Rijnsburg series will have to be reduced to do this.
This compilation is described in the next section.

7.13 Reduction to the De Bilt series

The monthly temperatures in the Delft/Rijnsburg series have to be reduced in order to be able to link on to the De Bilt series which extends from 1735 to the present.
Corrections for systematic differences between both series will be made by reduction. These differences arise from differences in the (micro)climate between the locations where the observations were made, from differences in scales or other properties of the thermometers.
In addition, the monthly averaged "daytime temperatures" of the Delft/Rijnsburg series will be converted to monthly averaged 24 hr. temperatures, representative for De Bilt.

7.13 a The reduction values

The Central England series correlates excellently with both the Delft/Rijnsburg series and the De Bilt series (see also section 7.7). The correlation coefficients between the monthly temperatures of the Central England and corrected Delft/Rijnsburg series over the period 1723-1734 on the one hand, and between the Central England and De Bilt series over the hundred year period 1735-1834 on the other hand, are set out in table 11.

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
$r(CE\text{-}D/R)_{1723-1734}$	0.92	0.84	0.95	0.76	0.91	0.91	0.84	0.89	0.88	0.72	0.80	0.95
$r(CE\text{-}DB)_{1735-1834}$	0.87	0.84	0.89	0.84	0.78	0.68	0.73	0.72	0.80	0.76	0.68	0.82

95% confidence intervals of r(CE-D/R) and r(CE-DB) if $\rho = 0.80$:
$0.40 \lesssim r(CE\text{-}D/R) \lesssim 0.95$ and $0.70 \lesssim r(CE\text{-}DB) \lesssim 0.85$

Table 11: Correlation coefficients (r()) between the Central England and Delft/Rijnsburg series (1723-1734) and between the Central England and De Bilt series (1735-1834)

Since there is good agreement in the correlation coefficients, the estimate of the reduction value for each month ($\hat{R}r$) has been taken as the difference in temperature level between the Delft/Rijnsburg and De Bilt series with respect to the Central England series over the periods given in table 11. The reduction values are calculated by means of the linear regression model. The method of calculation is thus also analogous to that, applied to the calculation of the jump values $\hat{S}r$ in 1726/1727 (see section 7.10 b).

Table 12 summarizes the reduction values and their variances for each month of the year.

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
$\hat{Rr}$	-2.57	-2.17	-1.79	-1.69	-1.21	-0.87	-1.03	-0.93	-0.93	-2.00	-2.35	-2.95	°C
$Var(\hat{Rr})$	0.21	0.15	0.08	0.07	0.05	0.05	0.08	0.03	0.05	0.10	0.12	0.24	°C^2

Table 12: Estimate ($\hat{Rr}$) and variance ($var(\hat{Rr})$) of the reduction of the Delft/Rijnsburg series to the De Bilt series

It should be noted that one cannot accept without question that the slope of the regression line of the Central England and Delft/Rijnsburg series is equal to the slope of the regression line of the Central England and De Bilt series. This is an important requirement for the regression model. By means of the t-test (39) it can be shown that the slopes for none of the months differ significantly.
This t-test may only be applied if the residual variances of both sets of pairs of observations do not differ significantly either. This is verified by means of an F-test (39). This requirement is satisfied for each month.

The reduction values given in table 12 have a low variance and agree with expectations from a climatological point of view, in showing a fairly regular progression over the course of the year. Smoothing out the reduction values is therefore both possible and meaningful.

The methods used to do this are described in the following sub-section.

7.13 b Smoothing out the reduction values

The 12 reduction values over the year (see table 12, section 7.13 a), given as $\hat{Rr}_i$ ($i = 1,2,\ldots,12$), are calculated from a relatively restricted number of observations. They therefore do not show a completely regular progression over the year.

It would be expected from a climatological point of view that the reduction values would follow a smoother course if a very large number of reliable observations was available.

This "ideal" smooth course can be estimated by means of the so-called "Fourier Analysis" (e.g. (40)).

The progression over the year of the reduction values $\hat{Rr}_i$ can be approximated by the Fourier function:

$$Gn(i) = \sum_{m=0}^{n} [a_m.\cos(m.2.\pi.i/12) + b_m.\sin(m.2.\pi.i/12)]$$
$$(i = 1,2,\ldots,12)$$

Where:

a_m and b_m are constants (the Fourier coefficients)

and the terms:

$a_m.\cos(m.2.\pi.i/12)$ and $b_m.\cos(m.2.\pi.i/12)$ the so-called wave-numbers (Fourier components).

The coefficients a_m and b_m are chosen so that the differences between $Gn(i)$ and $\hat{Rr}_i$ are minimized. The so obtained estimate of $Gn(i)$ will be denoted as $\hat{Gn}_i$. If $n = 6$ then $\hat{Gn}_i = \hat{Rr}_i$

for all months. If n is less than 6 then generally $\hat{Gn}_i$ differs from $\hat{Rr}_i$; the difference increases if n decreases.

In order to do the smoothing, values of $\hat{Gn}_i$ are sought that belong to an optimal value of n. The choice of n should be made as far as possible according to the following criterions:

The residual variance g^2 can be defined as:

$$g^2 = \frac{\sum_{i=1}^{12} (\hat{Rr}_i - \hat{Gn}_i)^2}{12 - (2 \cdot n + 1)} \quad ; \quad (n < 6)$$

Where:

$2.n + 1$ = the number of wave numbers introduced (if $n = 0$ then a single wave number equal to a_0 is introduced).

$12 - (2.n + 1)$ = number of degrees of freedom.

The value of n should be chosen so that the value of g^2 has the same order of magnitude as the values of the variances of $\hat{Rr}_i$, calculated for each month of the year (see table 12, section 7.13 a).

The value of g^2 will more rapidly decrease when the first pairs of wave numbers are introduced than when the last pairs are introduced. There is therefore no point in choosing a greater value of n if g^2 is thereby hardly reduced.

An estimate of in how many of the twelve months the true reduction value Gn_i will fall outside the range $\hat{Rr}_i \pm \sigma(\hat{Rr}_i)$ can be made as follows:

It can be assumed that $\hat{Rr}_i$ is normally distributed with expectation Rr_i and standard deviation $\sigma(\hat{Rr}_i)$.
The probability that Rr_i lies outside the range $\hat{Rr}_i \pm \sigma(\hat{Rr}_i)$ is then equal to $2 \cdot 0.1587 \simeq 0.32$
This is obtained as follows:

$$P\ [Rr_i > \hat{Rr}_i + \sigma(\hat{Rr}_i)] = P\ [(\hat{Rr}_i - Rr_i)/\sigma(\hat{Rr}_i) < -1] =$$
$$P\ [\chi < -1] = 0.1587$$

Where χ is a standard normally distributed variable.
In an analogous way it can be shown that:

$$P\ [Rr_i < \hat{Rr}_i - \sigma(\hat{Rr}_i)] = 0.1587$$

If n is small, then $var(\hat{Gn}_i)$ is also small compared to $\hat{Rr}_i$.
If $\hat{Gn}_i$ is a good approximation to Rr_i, then the probability that $\hat{Gn}_i$ lies outside the interval $\hat{Rr}_i \pm \sigma(\hat{Rr}_i)$ will also be 0.32
Suppose that:

$$z_i = \begin{cases} 1 \text{ if } \hat{Gn}_i \text{ lies outside the range } \hat{Rr}_i \pm \sigma(\hat{Rr}_i) \\ 0 \text{ if this is not the case} \end{cases}$$

Then for the sum z of the twelve z_i's we have:

$$E\ [z] = 12 \cdot E\ [z_i] = 12 \cdot 0.32 \simeq 3.8$$

And:

$$\sigma(z) = \sqrt{12 \cdot 0.32 \cdot (1 - 0.32)} \simeq 1.6$$

A reasonable requirement for smoothing shall be that the

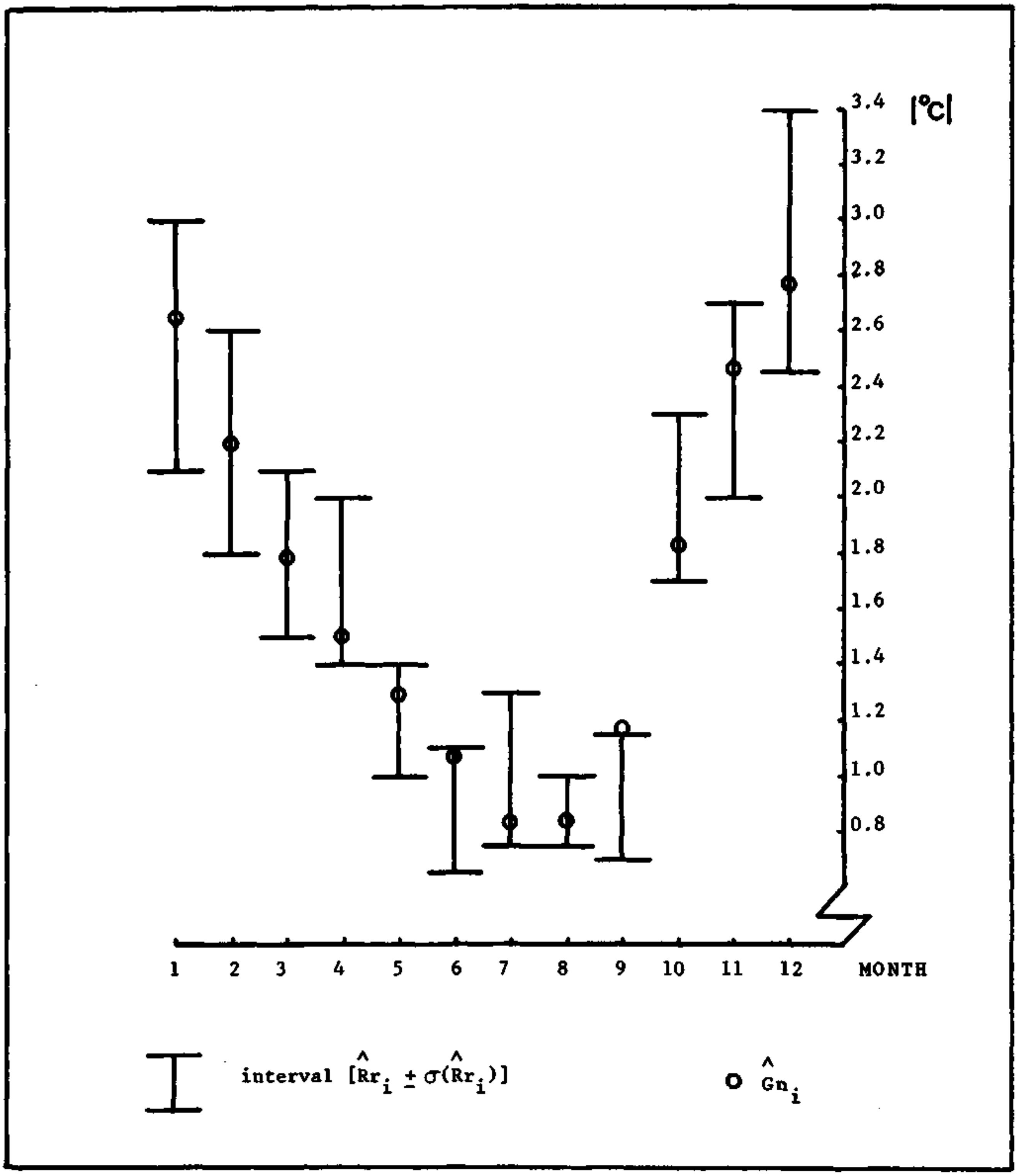


Fig. 22: Annual progression of reduction values $\hat{Gn}_i$

number of values of $\hat{Gn}_i$ lying outside the interval $\hat{Rr}_i \pm \sigma(\hat{Rr}_i)$ should not be greater than $\simeq 3.8 + 1.6 \simeq 5$

On the basis of the above conditions, the most optimal value for n appears to be 2. The value of g^2 would then be 0.04 and $\hat{Gn}_i$ lies outside the interval $\hat{Rr}_i \pm \sigma(\hat{Rr}_i)$ for just one month.

Table 13 gives a summary of the smoothed reduction values $\hat{Gn}_i$ estimated with a Fourier Analysis.

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
$\hat{Gn}_i$	-2.65	-2.23	-1.81	-1.51	-1.29	-1.06	-0.84	-0.83	-1.18	-1.83	-2.47	-2.78	°C

Table 13: Smoothed reduction values ($\hat{Gn}_i$) for the twelve months of the year

The progression of the smoothed reduction values over the year is shown graphically in figure 22.

The monthly temperatures of the Delft/Rijnsburg series over the period 1706-1734 have been decreased by the corresponding reduction values given in table 13 in order to link them to the De Bilt series.
The reduced monthly temperatures are given in supplement IX.

The extend to which these monthly temperatures can be regarded as reliable will be discussed in the following section.

7.14 Estimate of the reliability of the Delft/Rijnsburg series

The recorded temperature for a particular month is the sum of the actual temperature and a disturbance term which arises through errors of measurement:

$$\bar{T}_{recorded} = \bar{T}_{actual} + \Delta_{error}$$

Both the Delft/Rijnsburg series, which is reduced to the De Bilt series, over the period 1723-1734 and the De Bilt series over the period 1951-1980 correlate well with the Central England series.
The correlation coefficients for the separate months over both periods lie in the range ≈ 0.80 to ≈ 0.95
It is reasonable to assume that during the past 280 years, the temperature regime for Central England with respect to that for De Bilt will not have changed very much.
It can therefore be assumed that the variances of the differences of the actual temperatures have also not changed very much. It is possible however that the differences in the recorded temperatures over the course of time will be dominated by errors of measurement that appear either in the Central England temperature recordings, or in those of De Bilt, or in the recordings of both locations.

If it is assumed that the monthly temperatures x_i, y_i $(i = 1,2,\dots,n)$, are independent of the time, then the variances of the recorded differences can be estimated as:

$$var(x_i - y_i) = s^2(x_i) + s^2(y_i) - 2\ r\ s(x_i)\ s(y_i)$$

Table 14 gives the variances of the differences between the monthly temperatures of the Central England series and the Delft/Rijnsburg series, reduced to De Bilt, over the period 1723-1734, and between the Central England series and the De Bilt series over the period 1951-1980.

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
$Var(CE\text{-}D/R)_{1723-1734}$	0.79	0.72	0.26	0.62	0.35	0.42	0.40	0.34	0.30	0.80	0.83	0.30	$^{\circ}C^2$
$Var(CE\text{-}DB)_{1951-1980}$	1.14	1.59	0.41	0.51	0.54	0.31	0.33	0.23	0.26	0.68	0.73	1.43	$^{\circ}C^2$

Table 14: Variances (var()) of the differences between the monthly temperatures of Central England and De Bilt over the periods 1723-1734 and 1951-1980

It can not be concluded from these values that the errors of measurement in the Delft/Rijnsburg series from 1723 to 1734 are larger than the errors of measurement in the De Bilt series from 1951 to 1980.

Conclusions concerning the errors of measurement in the Delft/Rijnsburg series over the period 1706-1722 would be uncertain, since no comparative series is available.
Table 15 lists the standard deviations for each separate month of the Delft/Rijnsburg series over the periods 1706-1722 and 1723-1734 and of the De Bilt series over 1951-1980.

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
$s(D/R)_{1706-1722}$	2.5	1.7	1.4	1.2	1.1	1.3	1.1	1.3	1.0	1.2	1.0	1.5	°C
$s(D/R)_{1723-1734}$	2.2	1.5	1.6	1.2	1.3	1.5	1.1	1.2	1.0	1.2	1.5	1.8	°C
$s(DB)_{1951-1980}$	2.3	2.0*	1.7	1.2	1.1	1.1	1.2	1.2	1.1	1.4	1.4	2.1	°C

*The extremely cold month of Februari 1956 is not included; if included then s(DB) = 2.6 °C

Table 15: Standard deviations (s()) of the Delft/Rijnsburg series and the De Bilt series

The standard deviations of the monthly temperatures of the Delft/Rijnsburg series over the period 1706-1722 are in good agreement with those over the period 1723-1734, and with the standard deviations of the De Bilt series. Only the November and December temperatures in the oldest part of the Delft/Rijnsburg series show somewhat low values.

This good agreement indicates that the Delft/Rijnsburg series prior to 1723 is no less reliable than the part of the series after this year.

Van den Dool et al (33) estimated the root mean square error (i.e. $\sigma(\bar{T}_{actual} - \bar{T}_{recorded})$) of the winter temperatures of the De Bilt series over the period 1735-1847. Their estimate was 0.5 °C.

On the basis of the considerations in this section, the authors consider that the rms error of the separate monthly temperatures in the Delft/Rijnsburg series should certainly be lower, and estimate it to be 0.2 to 0.3 °C.

The conclusion that the Delft/Rijnsburg series is fairly reliable is justified. The series is eminently suitable for detailed climatological research over the early eighteenth century.

S U P P L E M E N T I

An invitation for making Meteorological Observations. By Dr. James Jurin, Royal Society Secretary. No. 379, p. 422. Abridged from the Latin.
from: Philosophical Transactions, vol. XXXII, 1723

Dr. Jurin states that the changes in the weather, especially when great or sudden, have much influence on the health of mankind; for which reason philosophers, even in the 17th century, invented various instruments, by which were ascertained the several degrees and changes in the weight, heat, moisture and elasticity of the atmosphere. They endeavoured also to discover the causes of these changes, adding several observations on the weather, the face of the sky, the winds, and quantity of rain. Were this done more generally, and the observations compared, we should have a still more perfect history of the air. In general, the sudden changes in the weather are chiefly to be attributed to the winds; hence then we should have some means of envincing the cause of the winds, and in particular to determine the truth of falsehood of Dr. Halley's opinion, in No. 181, who thinks that the ascent of the mercury in the barometer is owing to the winds blowing towards the same place from opposite points, thus collecting and accumulating the air; as, on the contrary, that its descent is caused by the winds carrying the air from the same place, towards the opposite parts, and thus exhausting it as were.
Further to improve this part of natural history therefore, Dr. Jurin recommends the curious to mark in their diary, once a day at least, the height of the barometer and thermometer, the course and strength of the wind, the face of the heavens, the rain or snow, as also the observations with the microscope and the magnetical needle.
Dr. J. gives directions for chusing, filling, and using barometers, thermometers, and rain-gauges, etc. He recommends, for the sake of comparison, that all observations be made at the same hour of the day, noting the weight, heat, and moisture of the air, by the barometer, thermometer, and hygrometer; the point of the winds and their strengh, denoting the several degrees by the numbers 1, 2, 3, 4; the face of the heavens, a short account of the weather, with the depth of rain or dissolved snow, in inches or decimals. This last may be easily estimated by means of a funnel, 2 or 3 feet wide, with another vessel to receive the water from it, and a cylindrical measure with a gauge, divided into inches and decimal parts.

The situation of the funnel should be such, that whatever wind blows, no part of the rain may be intercepted, either by the intervention of the house, or any other obstacle. The vessel to be close shut every way, that no water may evaporate, having only a small hole to recieve the water from the funnel above.

At the end of every month and year, let the mean height of the barometer and thermometer in each be subjoined; as also the sum of all the depths of the rain, fallen in the whole month or year, the mean height being found by dividing the sum of all the heights by the number of the days or observations.

Such persons as may be pleased to make the observations, are desired to send copies of them for each year to the secretaries of the Royal Society, that they may be compared with the diary kept in London, by order of the Society, it being proposed, that the comparisons and inferences shall be published every year in the Philosphical Transactions.

S U P P L E M E N T II

Letter of Nicolaus Cruquius to the Royal Society, Leiden, 14 January 1725

Translated from the Latin by M.J. Moir

Most illustrious President!
Most esteemed, noble and
learned Gentlemen!

At the end of last year[1] I submitted to you a Chart of Meteorological Data as a token of the Respect and Esteem in which I hold you. I am delighted that it was so favourably received, and am greatly obliged to you that you saw fit to consider it worthy of inclusion in the published records of your Proceedings.

Moreover, the fact that you deigned to extend membership of your Illustrious Body to one so undeserving and unsuspecting so deeply impressed me that day and night I pondered ceaselessly what I could do to show the depth of my indebtness to you. And all you wish from me - and all I am able to offer - is the fruits of my works - not inconsiderable, it is true - in recording meteorological changes.

Such fruits I gladly offer in the hope that they will not be entirely displeasing to you, and I undertake to put together such meagre offerings year by year, unless you yourselves, having judged them to be without merit, subsequently order me to desist.

Meteorological Phenomena, it is agreed, are produced by various Causes. And that the influence of the Planets is one such cause has been conclusively demonstrated by the work of the great Newton. Nor has it escaped the attention of Natural Philosphers that, depending on their aspects to the Earth and on the different pattern of their conjunctions and oppositions - in other words, their positions - the Heavenly Bodies affect the Earth, the Waters and the Atmosphere in entirely different ways. From which it follows that neither can Meteorological Phenomena be understood apart from the influence of the Planets, nor can such influence be understood without knowledge of Meteorological Phenomena. And indeed, the wisest astronomers[2] of every age have been aware of this.

1) Lat.: Elapso pridie anno = 'when the year ended two days ago'. Cruquius appears to have made a mistake.

2) Lat.: Astrologorum.

But they lacked the instruments that give our favoured Age knowledge of the things that escape our Senses. I refer to Barometers, Thermometers and Hygroscopes. The British, as well as the French and the Dutch, have become so proficient in observing the influences of Sun and Moon on the waters and the atmosphere that it can be expected that it will soon be possible to predict the Tides of the Seas with just as much precision as the appearances of the Sun and Moon. In view of this, I thought it would be extremely useful if both the changes in the atmosphere and the position of the planets at the time of those changes be described as faithfully as possible for different regions of the Earth. And indeed, that is why the positions of the planets in the heavens at any given hour are indicated in the Journal. Accordingly, given a description of Atmospheric Phenomena, together with the exact time that they occur in a given place, it will be an easy matter to relate them to the aspects of the planets. Consequently, after a great number of comparisons over a great many years, Natural Philosophers will be in a position to discover whether meteorological phenomena, and, in particular, movements in the Atmosphere, are, like the Tides of the Seas, under the sway of the Planets. This is, indeed, the sort of thing that was suspected by the great Verulamius in his very full Treatise on the Winds.

The same conclusion is arrived at by the magisterial Newton himself, on the basis of his most valuable discoveries. Although it is undeniable that other Causes play a part, I would argue that the Planets, too, do exert such influence. Indeed, another point of the greatest usefulness follows from this Work, viz. that if one had a record of such observations that faithfully included an indication of time and place for the different parts of the Earth, and were to record the exact position of these places on the Terrestrial Globe and then to compare such observations, one would eventually discover a means of determining the Origins, Progress, Course, Speed, and Demise of Meteors in the Atmosphere. This would be beneficial. For seafaring is governed by movements of the Sea and the Atmosphere, as well as by the winds. And it is in seafaring that the British and Dutch excel and are so successful. And what could be easier than to ascertain from these where and when Warm Weather, Cold Weather, Ice, Thaws, Humidity, Dryness, Clouds, Mists, Rain, Showers, Winds, Storms, Snow, Hail, Thunder, Lightning and Will-o'-the Wisps first arise, whither they proceed, with what force they are borne along, and where they slacken and finally cease?

I dare to warrant that, by drawing a few lines on a geographical map, I can show such things at a glance. I have also discovered a certain mechanical means, making use of proven Hydrostatics, by which it is possible to determine the speed of wind and water and which is of the greatest benefit to seafarers and at the same time very simple. However, I do not yet consider it opportune to discuss it here. Since the practical application of such observations of Natural Science calls not just in the first place for irrefutable Truth, but also for the ease of Simplicity, in order that all things may be presented to the mind for simultaneous consideration, I spent a great deal of time exploring many different avenues of approach. At length I came up with the following carefully arranged Table, which I present as a Contribution[1] on my part: i.e. I dedicate it to You.

1. First entered in the Table you will see the twelve months of last year;
2. Next, in the third row[2], severally, the days of the month;
3. Lastly, too, the spaces for the twenty-four hour period of day and night divided into three equal parts, each of which covers eight hours. Further divisions are avoided[3], to prevent the small chart from being overloaded. But the line can easily be divided into eight parts to indicate the hours.
4. At the times so indicated, small symbols are drawn which indicate by their position the quarter from which the Wind came, with the dots alongside indicating its force, ranging from slight to storm. If an O appears instead of a symbol, this indicates that the Air was extremely tranquil. One dot indicates a gentle breeze, two dots a moderate wind, three a strong one and four one with storm force.
5. The symbols in the second row indicate Sunshine, Darkness[4], Cloud, Rain, Snow, Hail, Thunder, Lightning, etc., and at one place on one occasion a Will-o'-the-Wisp.

1) Lat.: symbolam.

2) Lat.: serie. Without the chart one cannot say whether 'row' or 'column' is meant.

3) Lat.: non divida. I understand this to be an error for 'non divisa'. -Transl.

4) Lat.: obscuritas.

6. In the fourth row the amount of precipitation is shown, the duration being indicated in the small space there. The unit of measure adopted is 1/1000th of an English inch.
7. The fifth row shows the amount of moisture in the air, as indicated by the Hygrometer. The sponge was wetted in the usual way with a solution of Sal Ammoniacus.
8. The thick curve indicates the Barometric reading. The figures on the long horizontal line indicate the levels in tenths of an English inch.
9. The dotted curve shows the temperature in degrees Fahrenheit, the actual readings being entered on the other side of the long horizontal line.

The Table, then, shows all this at a glance.[1]

Example:

You wish to know the state of the weather at Leyden at 8 p.m. on the 8th day of December, 1724 (Old Style)*.
Look up December, 8th day and 8 p.m. You will see immediately that:

- the Barometric reading was 28 1/10 inches (and I never encountered a lower one);
- the Thermometer reading was 37°;
- the Hygrometer reading was 80;
- it was rainy, and the amount of rain that fell between 11 a.m. and 9 p.m. was sixty-nine thousands of an inch (069/1000);
- the wind was South-East to South;
- it was force 3**.

Farewell, most illustrious President,
most esteemed, noble and learned Gentlemen!

Your most obedient Servant,

Leyden

Nicolaus Cruquius.

$\frac{3^*}{14}$ January 1725

* *according to the calender old style, the Julian calender. The date differs eleven days from the Gregorian calender, we use nowadays.*

** *Lat.: velocitatis: speed.*

1) *This table is missing.*

SUPPLEMENT III

Letter of Nicolaus Cruquius to the Royal Society, Leiden, 25 June 1725

Translated from the Latin by M.J. Moir

To the most distinguished and most noble Gentleman,
James Jurin,
Secretary of the Royal Society of Great Britain,
Nicoalus Cruquius sends greeting.

How exceedingly pleased I am that my labours have met with the favour of your most illustrious Society! And I am grateful that the Society has seen fit to honour me in the way it has. I hope to forward further Tables, no less complete and equally accurate, at the end of this year. The most noble Richard Poleyus has written to me, enclosing your most recent letter to me. When I read it, I learned of your most illustrious Society's further generosity towards me and of your own personal amity, most distinguished Sir.

I sent someone to fetch the box from the noble Poleyus in my name. I opened it most carefully; but I discoverd that the thermometer tube was broken and the fluid spilt; in fact the latter had dried up completely, and only the pigment from it was left on the paper and the wood of the box. I am so sorry that I am now unable to fulfil the task me by the Society of keeping additional records of the temperature as indicated by the degrees marked on that thermoscope. Should you send another one, do please ensure that it is completely wrapped round in soft wool to prevent the impact of any knock from breaking the glass again.

I shall then see to it that the meteorological readings for the whole of this year's Table are also given in terms of the English thermometer. Indeed, I shall add a conversion table which will enable you without difficulty to convert the readings of my previous tables as well.

If there is any serious service you wish me to perform in this respect, do not hesitate to let me know. I shall most gladly be of whatever I can.

Farewell!

Leyden, $17\frac{25}{6}25$

S U P P L E M E N T   I V

Letter of Nicolaus Cruquius to the Royal Society, Leiden, 13 October 1725

Translated from the Latin by M.J. Moir

To the most distinguished and most noble Gentleman,
Mr. James Jurin
Secretary of the Royal Society of Great Britain,
Nicol. Cruquius sends greeting

Today, a distinguished young man, Mr. Clarck, delivered to me the honourable letter you sent to me on the seventh of July, and with it an undamaged Thermometer. I say this, so that you will not attribute the delay in replying to negligence on my part.

Please accept my thanks, which I offer to your most illustrious President, and to you, Sir, for your fresh gift! I shall use it in accordance with the Society's instructions. I undertake to make observations in keeping with the Julian Calender* and to record the temperature as shown on the thermometer you have sent. In addition to the Tables of my observations, I shall send you a table which will facilitate the conversion of my previous observations to terms of your own Thermometer.

Farewell, from him who holds you in profound respect and is entirely at your service.

Leyden, $\frac{13}{2}$ October 1725.

* *Lat.: ad Periodum Julianam.*

S U P P L E M E N T   V

Letter of Nicolaus Cruquius to the Royal Society, Leiden, 31 January 1726

Translated from the Latin by M.J. Moir

To the most illustrious, most noble,
most esteemed and most distinguished
Gentlemen,
President and Members
of the
Royal Society of London,
Nicolaus Cruquius
(sends greeting)

Herewith the fruits of last year's labour! I pray they may be pleasing to you! You may be sure of my devotion to the task. Once more you have before you, presented in concise form, observations which, if written out in full, would fill a large volume. I have complied with your wishes by recording the temperature of the air, as measured in the shade, in terms of the Thermometer which you sent. Indeed, I have expressed still other data in British terms, to show my profound respect to you. For this reason, then, I shall explain how the present Tables differ from the previous ones.

1. The left-hand side of both tables has a vertical line marked off in London inches and tenths of an inch. Each table covers six months. The horizontal lines drawn from the marks for the tenths enable one to ascertain the Barometric reading for any time of the day.
2. Some of the horizontal lines omitted. This is to make the separation into months clearer. Still, where this is the case, the Barometer and Thermometer readings can easily be supplied analogously. But because of this, too, where the months are seperated, the numerals at the side are also omitted. They may easily be supplied if required, however.
3. In order to make the numerals and figures clearer and more distinct, the symbols for the Winds are entered in the top inch for each month; on the middle line the numerals for the days of the month are entered; and in the bottom inch is enetered the position of the Moon in the Zodiac to within five degrees, the head and tail of the Dragon, and finally the Perigee and Apogee of the Moon.

4. These horizontal lines which indicate the inches and half inches are also used to denote tens of degrees on the English Thermometer; so 1/10 of an inch corresponds to two degrees on that thermometer. The scale is indicated vertically at the right-hand side of the table. In the empty space at the end of February, at the right-hand side of the table, a scale is given for converting English degrees to degrees Fahrenheit.
5. In order that every fifth degree on the Thermometer, or every quarter of an inch, should fit in more conveniently with the Barometer, the Hygrometer weight is always given in figures in the top line for each month. The fifth line below that carries the meteorological legend, whose symbols are explained at the end of the month of February. Then, in the fifth line below that again*, are shown the phases of the Moon: New , Full , Half , followed by the conjunctions ☌ and oppostitions ☍ of the Moon with other. From this it is an easy matter to deduce at once from the known position of the moon in the ecliptic the position of the other planets in the zodiac. Finally, on the bottom line, the amount of rainfall for each day is shown, measured in hundredths of an English inch.
6. The (heavy) vertical lines indicate midnight for any given twenty-four hour period. The shorter, lighter lines further divide a twenty-four hour period into six equal parts, i.e. of four hours each.

May the results of my painstaking labour serve to further our knowledge of meteorological phenomena and all the movements of Nature that depend on them, whose investigations and publication your illustrious Society urges and promotes with such succes. I myself shall do everything I can to carry out your instructions, in order to afford you real evidence of the profound respect in which I hold you. Farewell!

Leyden, 1726

$\frac{31}{20}$ January.

* *Lat.: tertia tali divisura: in a third such division.*

NICOLAUS CRUQUIUS

Leyden

1725

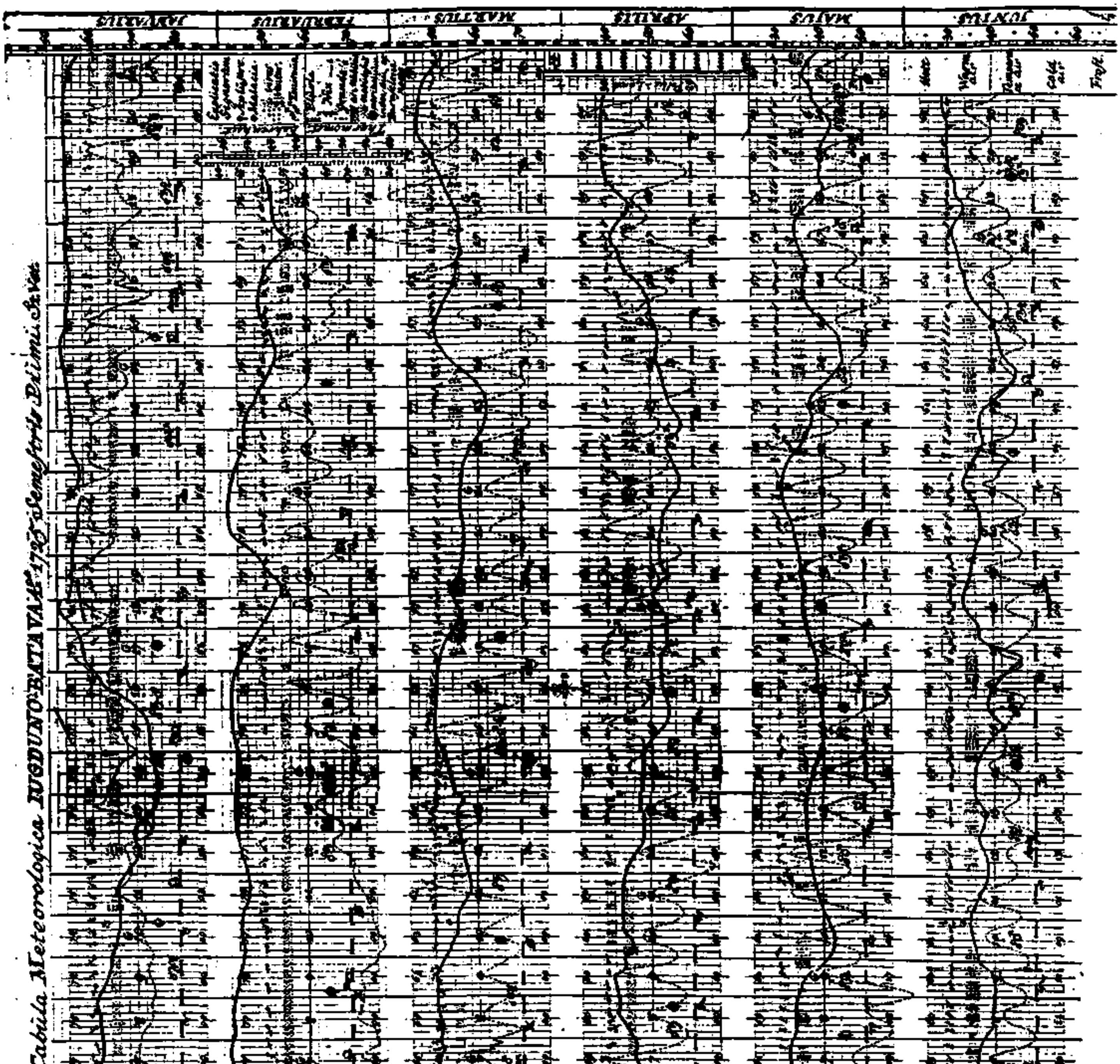
	In: ' ''	''
Janu	29 . 9 . 3	65 . 1
Feb:	30 . 2 =	68 . 2
Mar	29 . 8 . 2	62 . 8
Apr:	29 . 6 . —	51 : 4
May	29 . 6 . 3	45 : 7
June	30 : 6 : 1	43 : 1
July	29 . 8	40 : 2
Aug	29 . 7	41 . 4
Sep	30 : 7 :	46 . 8
Octo:	29 . 8 . 1	54 . — : —
Nov:	30 : 7 : 3	61 : 7
Decr	29 . 5 : 2	65 : 2 : —
	360 : 2 : 3	645 : 6
	30 : — : —	

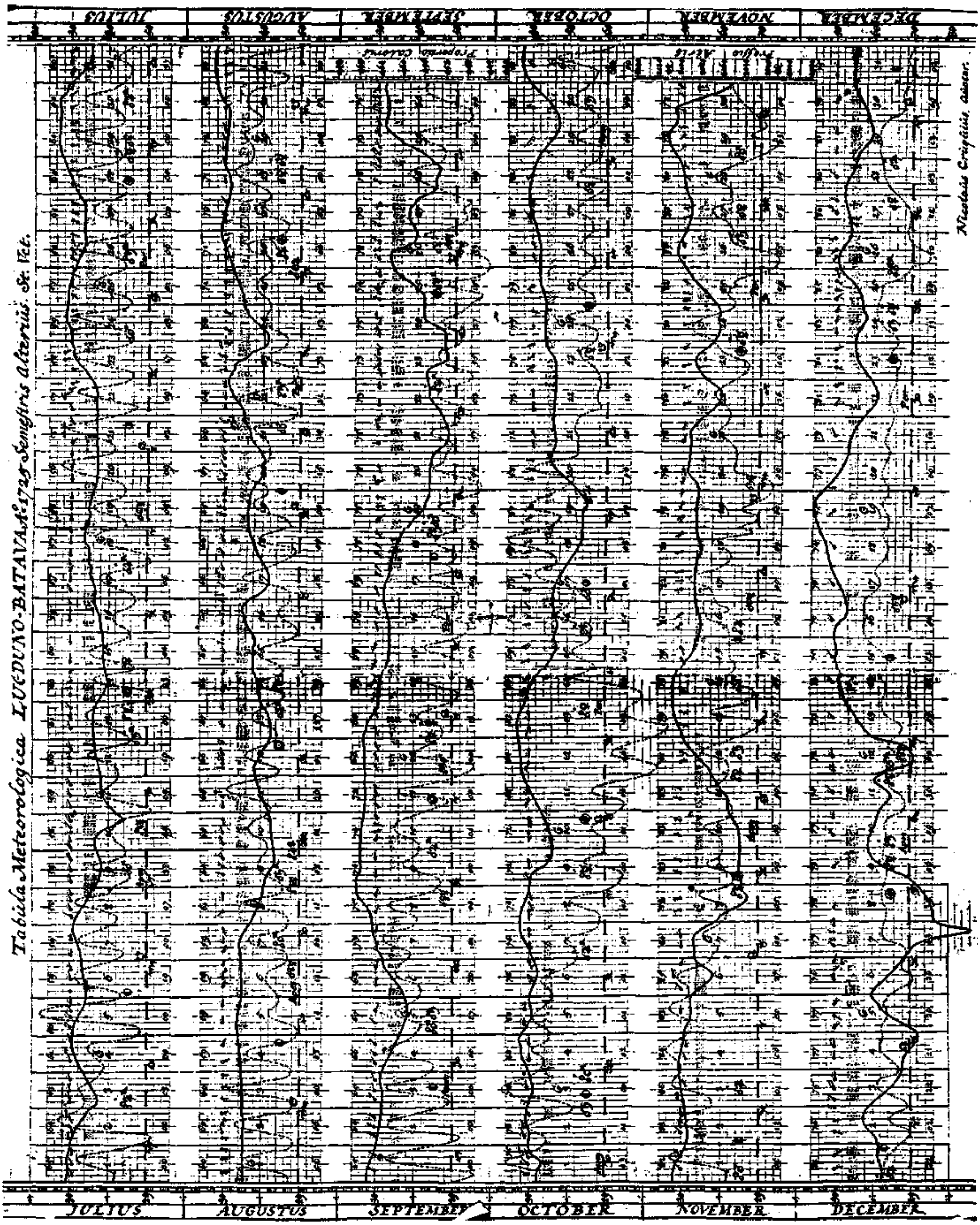
Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Nicolaus Cruquius.

MAS4.

Tabula Meteorologica LUGDUNO-BATAVAE ... Semestris Primi ...




Tabula Meteorologica LUGDUNO-BATAVA A°. 1725 Semestris alterius. St. Vet.
JULIUS
AUGUSTUS
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
Nicolaus Cruquius, auctor.

S U P P L E M E N T V I

11. Careful observations made at Leyden, Delft and the village of Rijnsburg in the year 1723, concerning the average level of the Barometer, the average reading of the Thermometer, and the mean variation of the Hygrometer; concerning the amount of Rain, Dew, Snow, Hail & also concerning the amount of Water which evaporated, and the level of well Water in the Well, from which no Water was drawn throughout the whole year; concerning the variation in time-keeping by the Portable Horloge in each month. To the end that these sure experiments may be of service to students of Natural History, the followers of such pleasures are offered the same by Nicolaus Cruquius, Geometer, R.S.S.

BAROMETER	THERMOMETER	HYGROMETER	
Here I record the Weight of the Atmosphere pressing on an area of one square Rhineland foot. This atmospheric weight is 1,947 Amsterdam lbs. when the barometric reading, in inches, is 27 inches 7 graduations, and 2,094 Amsterdam lbs. when the barometric reading was 29 inches 8 graduations. For such have been the maximum and minimum barometric readings for quite a number of years now.	Here I have entered the atmospheric temperature at the place of observation on the basis of Air becoming rarefied. The lowest temperature observed is marked as 1,000 degrees, pure water freezes at 1,070 degrees and it boils at 1,510 degrees.	Here I have measured the amount of water in the Atmosphere at the place of observation, according to the variation in the weight of the sponge which I fixed to a balance, having forst immersed it in a solution of Sal Ammoniacus.	The amount of Water that evaporated in each month of the year, outdoors, and exposed to the wind. At Rijnsburg.

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Translated from the Latin by M.J. Moir

	lb.	degrees	weight	graduations
January	2Ø51	1076	81	7
February	46	85	80	14
March	35	102	80	33
April	46	109	60	36
May	57	126	57	58
June	53	140	57	57
July	2Ø44	1129	58	37
August	46	141	60	39
September	54	132	61	24
October	55	121	71	15
November	53	104	77	15
December	35	96	79	12
Total	575	1361	821	347
(Illegible)	---			
Average	2048	1113	68	for the whole year; 28 inches 11 grads.

Page 5

Amount of Precipitation from the Sky, to wit; of Rain, Dew, Snow and Hail;

Measured with great care to prevent the slightest loss through evaporation or otherwise

Delft	Rijnsburg
grds. 10ths.	grds. 10ths.
17.9	21.1
25.1	23.8
18.8	28.-
5.5	7.5
4.2	2.7
3.2	4.8
38.6	28.-
41.9	40.2
15.1	14.8
8.2	11.3
30.7	29.7
30.6	40.0
239.8	252.-
20 inches (for the whole year)	2? inches illegible

Level of water in the Well, as measured from the top of the well's side to the surface of the water, at the end of each month. The well was very deep, bubbling and welling up all the way from its sandy bottom, and no water was drawn from it during the whole observation period.

Observation of the fastness or slowness in the timekeeping of a most accurate portable Horologe. So as to show the number of minutes it lost or gained in each month. + indicates fast, ÷ indicates slow. The comparison is with the Sun's course.

	ft. inches	Minutes	
	5 : 4	+ 151	January
	4 : 11	+ 21	February
	5 : 7	÷ 168	March
	6 : 10	÷ 120	April
	8 : 1	÷ 123	May
	9 : 3	÷ 130	June
	9 : 7	÷ 90	July
	9 : 7	+ 133	August
	9 : 9	+ 24	September
	9 : 8	+ 19	October
	9 : 3	+ 266	November
	8 : 2	+ 252	December
	96 : -	+ 866, & ÷ 631	
Average	8 ft.	i.e. + 235	

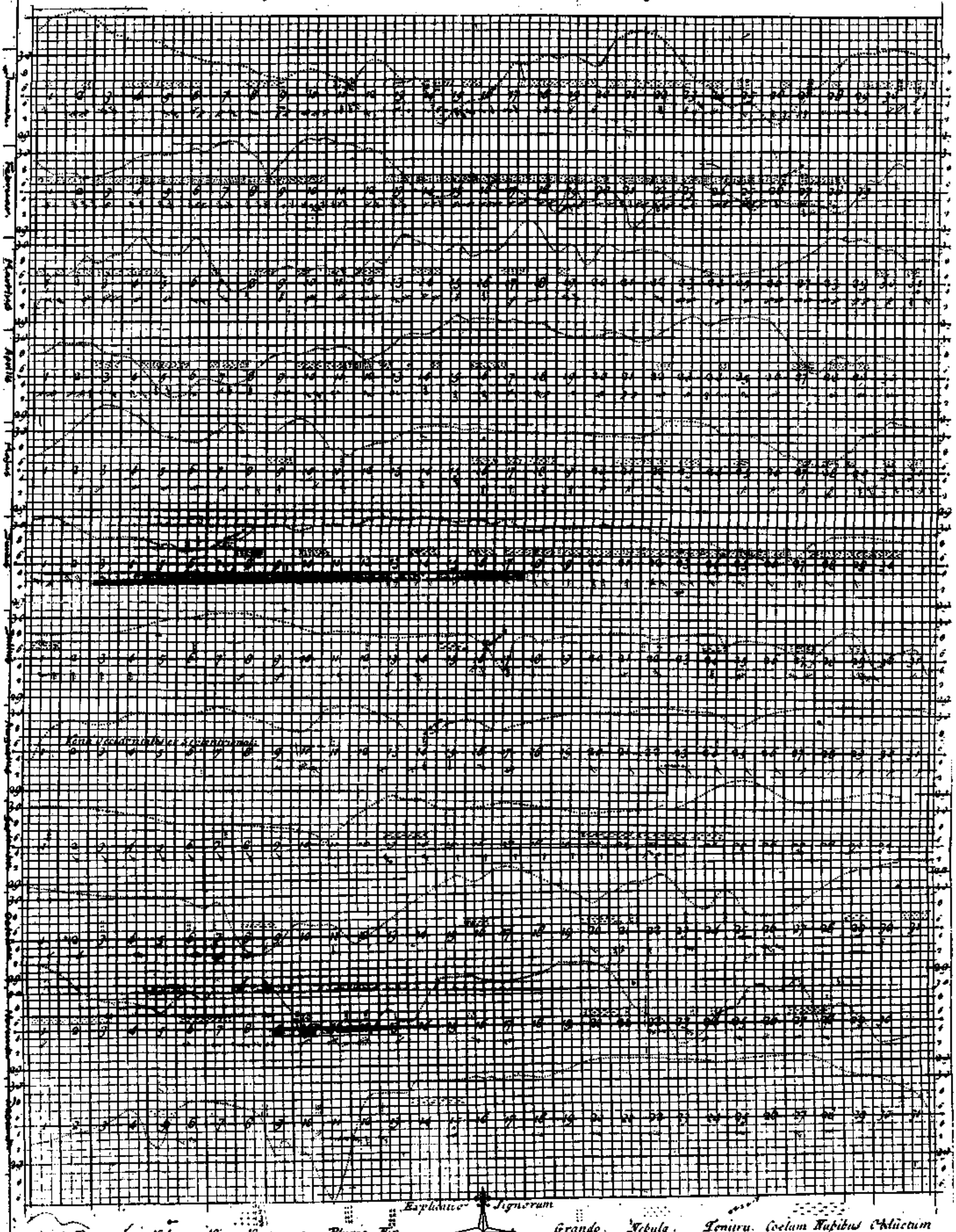
20 minutes fast for each month.

READINGS OBTAINED OVER A NUMBER OF YEARS.

Year	Jan.	Feb.	March	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Aver.	Year
	lb.			BAROMETER										12 lb.	
1720	2934	34	38	36	38	42	45	36	50	40	38	23	454	2939	1720
1721	52	42	56	29	29	43	51	46	43	42	32	29	473	39	1721
1722	76	41	32	41	42	45	36	39	50	59	37	32	529	44	1722
1723	51	46	35	46	57	53	44	46	54	55	53	35	575	45	1723
	213	163	161	152	166	183	176	167	197	196	164	147	164		
4	2953	41	35	38	41	46	44	42	40	49	40	20	2942		
	degr.			THERMOMETER										degr.	
1720	1087	89	86	102	126	126	145	138	121	107	91	91	1329	109	1720
1721	90	74	75	112	116	137	136	142	133	110	100	84	1309	109	1721
1722	79	90	97	109	122	134	139	140	135	117	101	90	1353	113	1722
1723	76	85	102	109	126	140	129	141	132	121	104	96	1361	113	1723
	332	338	360	432	492	537	549	561	521	455	396	361	444		
4	83	85	90	108	122	134	137	140	130	114	99	90	111		
	weight			HYGROMETER										weight	
1721	89	82	73	80	69	64	63	68	76	76	89	88	917	76	1721
1722	88	85	76	63	62	62	63	68	70	76	81	88	882	74	1722
1723	81	80	80	60	57	57	58	60	61	71	77	79	821	69	1723
	258	247	229	203	188	183	184	196	207	223	247	255	219		
3	86	82	76	68	63	61	61	65	69	74	82	85	73		
	graduations			Rain, etc. at Delft									inches	grads.	
1715	51	20	36	8	15	18	95	62	36	37	47	15	482	33: 4	1715
1716	19	20	14	7	17	4	48	19	55	57	21	32	343	20: 2	1716
1717	31	15	29	29	31	28	29	18	24	32	29	28	333	27: 9	1717
1718	41	18	6	30	17	17	35	27	14	46	21	25	277	23: 1	1718
1719	33	10	10	11	17	4	12	34	23	25	24	22	235	19: 7	1719
1720	36	34	21	21	15	20	23	55	47	56	25	20	363	30: 3	1720
1721	20	31	27	59	30	34	15	41	27	57	30	48	419	34:11	1721
1722	2	20	25	23	15	22	49	53	25	7	21	53	315	26: 3	1722
1723	18	25	19	5	4	3	29	42	15	8	31	31	230	20:	1723
	191	193	187	193	161	150	345	361	266	325	249	270	241 : 3		
9	21	21	21	21	18	17	38	40	30	36	28	30	26:10		

	Jan.	Feb.	March	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.		
grads.			Rain, etc. at Rijnsburg										inches	grads.
1720	35	16	13	24	29	14	20	48	54	50	39	25	367	30:7 1720
1721	21	29	18	59	35	28	14	47	27	51	32	46	417	34:9 1721
1722	3	20	27	29	28	27	60	64	26	10	21	61	376	31:4 1722
1723	21	24	28	7	3	5	28	40	15	11	30	40	252	21: 1723
	80	89	96	119	95	74	122	199	122	122	122	172	117:8	
	20	22	24	30	24	19	30	50	30	30	30	43	29:5	
grads.			Evaporation at Rijnsburg										inches	grads.
1720	10	10	10	35	44	55	59	56	50	30	10	12	374	30:11 1720
1721	8	9	15	54	47	60	48	42	27	20	22	10	362	30: 2 1721
1722	5	7	20	28	54	54	65	59	34	14	13	13	366	30: 6 1722
1723	7	14	33	36	58	57	37	39	24	15	15	12	347	28:11 1723
	30	40	78	153	203	226	209	196	135	79	60	47	120:6	
	8	10	20	36	51	56	52	49	34	20	15	12	30:2	
ft. inches			Level of Water in the Well										ft.	inches
1720	6:	6:3	6:5	6:7	6:6	8:	8:11	9:	8:3	6:11	5:8	5:5	8[illegible]:	7: 1720
1721	5:6	5:6	4:6	4:2	5:7	7:	8:1	7:9	7:7	6:3	4:6	4:4	70:9	5:11 1721
1722	6:	5:7	5:11	6:1	6:10	7:11	8:	7:10	7:4	7:9	7:3	4:6	81:	6:9 1722
1723	5:4	4:11	5:7	6:10	8:1	9:3	9:7	9:7	9:9	9:8	9:3	8:2	96:	8: 1723
	22:10	22:3	22:5	23:8	27:	32:2	30:7	30:2	32:11	30:7	26:8	22:5	27:8	
	5:8	5:7	5:7	5:11	6:9	8:	8:8	8:6	8:3	7:8	6:8	5:7	6:11	
Minutes			Timekeeping by the portable Horologe											
1722	− 24	− 9	− [illegible]	+ 5	− 38	− 55	− 89	− 78	− 84	− 8	+ 151	+ 246	+&− 402	1722
1723	+ 121	− 1	− 157	− 139	− 222	− 140	− 109	+ 113	+ 4	− 1	+ 246	+ 232	+&− 727	1723
	+ 97	− 8	− 180	− 134	− 190	− 203	− 198	+ 35	− 80	− 9	+ 397	+ 478	+&− 1129	
	+ 45	− 4	− 90	− 67	− 99	− 102	− 99	+ 17	− 40	− 4	+ 199	+ 239	+&− 564	
	Jan.	Feb.	March	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.		

Tabula, praecipue Altitudinem fere Singulis Horis BAROMETRI, totius Anni decursu 1723 Stylo Veteri, digitis Londinensib; ut et parte Pluvias; Plagas, Violentiasque Ventorum; nec non Coeli faciem, Lugduni Observata exhibens.



Explicatio Signorum

Altitudo Barometri. Velum. Vires Ventorum. Pluvia. Nix. Grando. Nebula. Tonitru. Coelum Nubibus Obductum

S U P P L E M E N T   V I I

Requeste van Nicolaas Kruykius Aan de Edele Groot Mog. Heeren Staaten van Hollandt en Westvrieslandt, 20 december 1726 (3)

Aan de Edele Groot Mog. Heeren Staaten van Hollandt en Westvrieslandt.

Requeste van Nicolaas Kruykius.

GEeft met schuldige onderdaanigheyt te kennen Nicolaas Kruyckius, dat hy Suppliant, van jonghs af sich geoeffent hebbende in de konst van Landtmeeterye en observatien van de hooghte van het Landt en van de Wateren, en het geene daar toe verder noodigh is, insonderheyt de wiskunstige Waterpassingen, vervolgens meent in staat te weesen, om een generaal Plan te maaken van de hooghte van de Zee, Rivieren en Binnewateren en constitutie van het Landt, met relatie tot het Water over deese Provintie, vervolgens een vaste Peylnagel te verkiesen, waar na men overal de hooghtens van het Water, Stranden, Dijcken en andere, soo Zee- als Waterkeeringen, soude konnen afmeeten, en van dat alles een Kaarte en Beschryvingh te maaken, die tot een geduurige Standaart of Legger soude konnen dienen.

Dat den Suppliant vertrouwt alle het selve van dienst soude zyn in veele geleegentheeden, om met meerder seekerheyt en dickwils met minder kosten te konnen voorsien tegens de Zee, Rivieren, Ysdammen en Doorbraaken, selfs oock wanneer by oorlogh eenige Inundatien souden moeten gemaackt werden.

Dat hy Suppliant vertrouwt het selve sonder groote kosten en in weynigh jaaren te sullen konnen uytvoeren door Waterpassingen over het geheele Landt en observatien, te doen door Luyden by hem te stellen, op soodanige Plaatsen, Sluysen, Stranden en Waterkeeringen als hy Suppliant, onder een nette Instructie aan haar te geeven, soude noodigh oordeelen en daar uyt sijn geheele Plan te formeeren.

Dat hy Suppliant deese sijne gedachten met eenige Professoren van haar Edele Groot Mog. Universiteyt te Leyden en andere Persoonen van de kunst, oock met eenige Heeren van de Regeeringh, hebbende gecommuniceert, aangemaant is gewerden sijn dienst desweegens aan haar Edele Groot Mog. te presenteeren, om, in gevalle de voorslagh wel opgenomen wierdt, nader gehoort en op alles gedisponeert te werden als U Edele Groot Mog. souden bevinden te behooren.

Onder stondt,

'tWelck doende, &c.

In margine stondt geapostilleert,

DE Staaten van Hollandt en Westvrieslandt vinden goet, dat deese Requeste sal worden gestelt in handen van haar Edele Groot Mog. Gecommitteerde Raaden, omme de selve te examineeren en de Verga-

de-

deringh daar op te dienen van haare confideratien en advis. Actum 20. December 1726.

Onder ftondt,

Ter ordonnantie van de Staaten.

Was geteekent,
Willem Buys.

Lager ftondt geapoftilleert,

DE Staaten van Hollandt en Weftvrieslandt vinden goet, dat van deefe Requefte, als meede van het Advis, Copie fal worden gegeeven aan alle de Heeren Leeden van haar Edele Groot Mog. Vergaderinge, om de confideratien van de Heeren haare Principaalen dien aangaande te verflaan, verder te worden gedifponeert, als na behooren. Actum 27. April 1727.

Onder ftondt,

Ter ordonnantie van de Staaten.

Was geteekent,
Willem Buys.

SUPPLEMENT VIII

Edele Mog. Heeren,

Myn Heeren,

Bericht van de Heeren Professoren te Leyden.

OM te voldoen aan de Ordres van U Edele Mog., vervat in der selver Appointemente, van dato den 10. deeses maandts Februarii, gestelt op de Requeste van Nicolaas Kruykius, raakende het maaken van een exacte Waterstaat deeser Provintie. Na examen van den inhoude van gemelde Requeste, en na dat wy met den Suppliant daar over hebben geconfereert, geeven wy ons selven de eer aan U Edele Mog. toe te laaten komen de volgende Consideratien, inhoudende onse gedachten en gerequireerde advis wegens het maaken van de gemelde Waterstaat.

Sullende deese onse Considenatien, soo als ons de saake voorkomt, moeten raaken twee Pointen, eerstelijck, het Project in sich selve en het met door de executie van dien te wachten. Ten tweeden, de bequaamheyt van den Suppliant, om het selve uyt te voeren, en sulcks soo ten aansien van de kennisse als van de ervaarentheyt.

Wat het Project selfs aangaat, dunckt ons, dat tot een exacte Waterstaat van de Provintie, die van nut soude kunnen zyn en waardigh de attentie van den Souverain, werden vereyscht, het geen genoeghsaam is overeenkomende met het Project van den Suppliant, in generale termen gemeldt in des selfs Requeste aan haar Edele Groot Mog. gepresenteert, en by Appointemente, van dato den 20. December 1726., aan U Edele Mog. gerenvoyeert.

1. Een exact Plan of Kaarte van de Provintie, waar inne niet alleen met de uyterste exactitude moeten werden genoteert de Wateren en Dijcken, maar wel voornamentlijck de Hooghtens en Laaghtens van de besondere Landen en Gronden van alle soo Buyten- als Binnenwateren door de heele Provintie, alles met relatie tot een en de selve vaste Peyl. Oock alle de Watermoolens, met notitie van der selver grootte. Als meede het verschil tusschen de besondere Peylen van de Heemraadtschappen en de voorgemelde vaste Peyl.
2. Een exacte Staat van de Dicktens, Stercktens en Hooghtens van de Stranden, Dijcken, Dammen, Kaaden en andere Watersluytingen.
3. Een Staat van exacte Observatien, geduyrende eenige jaaren na den anderen te maaken, wegens de Zee en alle de Wateren van de Provintie, soo die met de Zee gemeenschap hebben als die van de selve door Dijcken, Dammen en Sluysen zyn afgesondert.

Sullende de Observatien op de Binnenwateren raaken het klimmen en daalen der selve.

Het welck meede plaats moet hebben ten aansien van de Zee, Rivieren en andere Buytenwateren daar meede gemeenschap hebbende, in welcke ter occasie van Ebbe en Vloedt de veranderingen veel meenighvuldiger zyn.

Sullende meede moeten werden geobferveert de veranderingen in de loop van het Water, foo ten aanfien van de directie als van de fnelheyt, als meede de de verdiepingh en de verhoogingh van de Gronden.

4. Een Staat van de veranderingen in de Lucht voorgevallen geduurende den tydt van de waarneemingen omtrent het Water, fulcks ten aanfien van de Winden in haare directie en kraght, van den Reegen, van Koude en Warmte, van de drooghte en vochtigheyt des Luchts, en des felf perfingh.

5. Een overeenbrengingh van alle de voorgemelde obfervatien, foo over befondere faaken als in befondere plaatfen, op een en de felve tydt gemaackt, en fulcks voor alle den tydt dat de voorgemelde Pointen fullen zyn waargenomen.

Een foodanige Waterftaat, gegrondt op obfervatien van eenige jaaren, foude niet alleen zyn van groot nut, maar wy durven feggen, dat het maaken daar van is van de uyterfte noodtfaakelijckheyt. Deefe foude zyn de befte, foo niet de eenighfte, Weghwyfer, die foude kunnen aanwijfen de precautien, om, tot noch toe onvoorfiene, maar door de conftitutie van het Landt te duchten, fwaare ongelucken voor te komen, indien de Provintie daar meede moghte werden gedreyght. De felve foude in onverwachte voorvallen kunnen aantoonen de middelen, om daar uyt te werden geredt, en foude in veele occafien zyn een van de befte Hulpmiddelen, om dit Landt noch een lange reecks van jaaren fijnen natuurlijcken Befitter, het Water, te onthouden.

Wy fouden meenen van de patientie van U Edele Mog. te abufeeren, in gevalle wy hier fouden aanhaalen de befondere gebruycken van het voorgemelde Project. Het nut en de noodtfaakelijckheyt van dien fal ten overvloede blijcken, indien wy boven het voorgemelde generale gebruyck, dat wy hoopen noch verre af te zyn, hier maar melden eenige weynige, doch voornaame Pointen.

1. In de buytengewoone rijfinge van Water, veroorfaackt door Ysdammen of anderfints, fal men aanftondts weeten, waar en hoe het dreygende ongeval moet werden geweert, foo eenighs kan werden voorgekomen, fonder dat men, foo als in voorige tyden meermaalen is gebeurt, op een plaats arbeydt en onkoften doende, door een andere oordt van het Water werde verraft.

2. De meer gemelde Waterftaat aantoonende het onderfcheydt tuffchen de hooghtens, foo van de Buytenwateren op befondere plaatfen als van de Binnenwateren in de befondere Boefems op een en de felve tijdt, en fulcks in het generaal met relatie tot Windt en We'er, &c. en ten opfichte van Ebbe en Vloedt, oock met relatie tot de loop van Son en Maan, foude daar door komen te blijcken, in wat gevallen de uytloofinge van de befondere Boefems, welcke door de hooghte van het Buytenwater werden verhindert,

dert, op andere plaatſen ſoude kunnen werden gevonden.

3. De ſelve Waterſtaat ſoude aantoonen hoe verre door het maalen van de Moolens en openen der Sluyſen het Water in de beſondere Boeſems van het Waterpas komt af te wijcken, door welcke kenniſſe dickmaals geſuppediteert ſouden werden middelen, om de wel gefundeerde klaghten van de Landtlieden voor te komen.

4. Deeſe Waterſtaat ſoude oock doen ontdecken wat door het conſerveeren van groote Plaſſen te duchten ſtaat en wat door het uytdroogen van de ſelve ſoude te vreeſen weeſen: Waar door, ſoo ten aanſien van het een als van het ander, de waare van de gewaande periculen ſouden kunnen werden onderſcheyden.

5. Het nut ſoude oock groot zyn ten aanſien van de vaart in de Rivieren, en voor der ſelver Monden in de Zee, oock in de Zuyder Zee, door de kenniſſe, die deeſe Waterſtaat ſoude geeven van het rijſen en daalen, ſoo ten aanſien van den tijdt als van de ſnelheyt en hooghten der Wateren, van de ſtandtvaſtigheyt van ſommige Gronden en van de veranderingen waar aan andere zijn onderworpen.

6. De rechte kenniſſe van de loop van het Water en des ſelfs kracht, als meede van de werckingh van het ſelve in het verzanden van de Gronden, ſoude dickmaals occaſie geeven tot uytvindingh van middelen, om door leggen van Kribben en andere Wercken in het Water de te vreeſene verzandingen voor te komen, en de noodige door het Water ſelfs te doen uytwercken.

7. Ten laatſten, ſoo, het geen Godt verhoede, het moghte komen te gebeuren, dat deeſe Provintie in die ſtaat wierde gebraght, dat door het Water den Vyandt ſoude moeten werden afgeweert, ſoude de bewuſte Waterſtaat aanſtondts doen ſien waar met de minſte ſchaade de doorſnijdinge ſoude kunnen werden gedaan, en wat precautien ſouden moeten werden genomen, om de inundatie te ſluyten en voor te komen, grooter ſchaade als tot de afweeringh van den Vyandt noodigh ſoude zijn en waar de opſtoppinge van Water ſoude werden vereyſcht, om het Water in de geinundeerde plaatſe te brengen op de noodige hooghte, ſonder de bygeleegene Landen aan onvoorſiene gevaaren bloot te ſtellen.

Overgaande tot het geen de Perſoon van den Suppliant raackt, ſullen wy de eer hebben U Edele Mog. te kennen te geeven, dat wy, met den ſelve hebbende geconfereert, bevonden hebben, dat hy Suppliant wel heeft begreepen waar inne een nutte Waterſtaat moet beſtaan, en ons heeft getoont niet alleen te hebben een volkomen kenniſſe van de middelen door welcke dit groote werck ſoude moeten werden uytgevoert, maar oock de noodige bequaamheyt, om fich te bedienen van de verkortwegen, welcke de particuliere constitutie van de plaatsen kunnen suppediteeren en uyt te vinden het geen noodigh soude kunnen weesen, om de moeyelijckheeden, die in soo een werck sich kunnen opdoen, te boven te komen.

In het particulier ten aansien van de te doene observatien en die over een te brengen, om met een opslagh van het oogh te werden vergeleeken, hebben wy in den Suppliant gevonden een besondere schranderheyt.

De ervaarentheyt van den selven is ons oock bekent, soo in het meeten, in deesen noodigh, als ten opsichte van de observatien hier voor gemeldt: Hebbende den Suppliant seedert lange jaaren een natuurlijcke drift getoont tot het waarneemen van de veranderingen aan welcke de Lucht is onderworpen, en van sijne ervaarentheyt daar inne gegeeven sulcke blijcken, dat wy niet in twijffel kunnen trecken, of den selve soude onder Godes zeegen, geassisteert van eenvoudige Waarneemers, welcke sijne directie souden volgen, in staat zijn, om de besondere observatien, tot het meer gemelde werck noodigh, te versaamelen, en de selve, waar inne het groote nut bestaat, met malkanderen te vergelijcken.

Soo dat wy meenen niet te kunnen nalaaten onse Consideratien met deese getuygenisse te sluyten,

Dat, in gevalle haar Edele Groot Mog. moghten komen te resolveeren tot het doen maaken van de Waterstaat hier voor gemeldt, aangesien dat in de Persoon van den Suppliant zijn saamen gepaart de noodige kennisse en ervaarentheyt, met een natuurlijcke drift tot diergelijcke wercken, sonder welcke drifte de onderneemingh temerair soude zijn, wy ons verseekert houden, dat haar Edele Groot Mog. met moeyte een bequaamer Subject als den Suppliant souden vinden.

Wy hoopen, dat U Edele Mog. ons sullen ten goede duyden, dat wy in een saake van soo groote importantie onse Consideratien niet meer hebben gecontraheert, en ons dien aangaande excuseeren.

Wy beveelen U Edele Mog. in de protectie van den Hemel, en blijven met de uyterste eerbiedt,

Edele Mog. Heeren,

U Edele Mog. onderdanighste en seer gehoorsaame Dienaaren, de Professoren van de Philosophische en Mathematische Faculteyt van haar Edele Groot Mog. Universiteyt.

Leyden den 24. Februarii 1727.

Was geteekent,

Jacobus Wittichius, H.T.R.

W. J. 's Gravesande.

Apostille.

DE Heeren Briell en Boon werden versocht de moeyten op haar te willen neemen, van deesen te examineeren, en haar Edele Mog. te dienen van der

der felver confideratien en advis. Actum den 25. Februarii 1727.

Onfter ftoadt,

Ter ordonnantie van de Gecommitteerden Raaden.

Was geteekent,

Alb. Fabricius.

1727.

S U P P L E M E N T I X

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	WIN	SPR	SUM	AUT	YEAR
1706	0.5	3.2	5.5	8.7	14.6	17.0	17.4	17.3	14.0	11.0	4.4	2.3	-*-	9.6	17.2	9.8	9.7
1707	0.7	4.9	4.7	8.3	12.0	16.8	18.1	15.9	14.9	9.0	6.5	1.9	2.6	8.3	16.9	10.2	9.5
1708	3.9	3.1	5.9	9.5	12.2	14.6	15.4	18.5	15.9	9.2	5.4	0.4	3.0	9.2	16.2	10.2	9.5
1709	-5.1	-0.3	1.1	9.2	11.6	15.3	16.1	16.2	14.5	10.9	7.8	2.5	-1.7	7.3	15.9	11.1	8.3
1710	0.4	1.8	5.6	7.0	13.3	15.0	15.2	16.1	14.7	10.8	7.0	5.5	1.6	8.6	15.4	10.9	9.4
1711	3.2	0.6	5.0	9.8	12.7	16.8	16.0	15.4	14.2	10.6	6.0	3.4	3.1	9.2	16.1	10.3	9.5
1712	-0.1	3.6	4.4	8.8	12.8	16.2	16.7	16.0	14.0	10.9	6.7	2.7	2.3	8.7	16.3	10.5	9.4
1713	-0.9	5.6	4.3	6.4	11.6	13.4	15.0	16.6	14.9	10.6	5.2	2.8	2.5	7.4	15.0	10.2	8.8
1714	1.3	4.4	5.3	9.0	10.8	14.4	18.5	16.1	13.0	11.0	6.3	2.7	2.8	8.4	16.3	10.1	9.4
1715	0.2	4.2	6.1	10.7	12.1	14.5	15.6	14.8	14.1	11.8	7.9	-1.2	2.4	9.6	15.0	11.3	9.2
1716	-5.7	2.2	3.9	10.2	11.8	14.1	16.4	16.8	13.4	9.6	5.2	1.5	-1.6	8.6	15.8	9.4	8.3
1717	1.2	1.4	3.7	8.2	10.7	15.2	16.0	16.5	14.2	10.0	5.2	3.8	1.4	7.5	15.9	9.8	8.8
1718	-1.4	-0.2	4.9	9.4	13.0	16.0	16.2	20.2	16.0	10.2	6.9	3.7	0.7	9.1	17.5	11.0	9.6
1719	0.5	3.1	3.9	6.7	14.0	17.7	18.6	18.3	13.2	9.4	6.7	0.8	2.4	8.2	18.2	9.8	9.4
1720	2.3	3.5	3.4	7.9	12.8	12.5	17.2	15.7	12.4	9.4	5.4	3.9	2.2	8.0	15.1	9.1	8.9
1721	3.0	0.8	1.1	10.0	10.7	15.2	17.1	17.7	15.2	9.9	7.3	2.2	2.6	7.3	16.7	10.8	9.2
1722	0.3	4.5	5.8	9.6	12.0	15.0	17.7	16.7	15.6	11.5	7.5	3.7	2.3	9.1	16.5	11.5	10.0
1723	-0.3	3.2	6.7	9.4	12.9	15.5	15.4	17.1	14.8	12.3	8.4	5.0	2.2	9.7	16.0	11.8	10.0
1724	4.2	4.2	4.1	7.8	12.3	16.6	16.9	18.1	15.1	9.7	3.9	2.1	4.5	8.1	17.2	9.6	9.8
1725	1.7	0.9	3.7	8.2	10.2	11.2	14.7	13.5	12.8	9.3	6.6	2.3	1.6	7.4	13.1	9.5	7.9
1726	-2.4	0.8	2.8	9.0	14.6	16.1	17.4	15.5	15.1	10.5	4.8	0.4	0.2	8.8	16.3	10.1	8.7
1727	2.0	3.2	3.8	7.0	15.1	15.3	16.7	17.5	14.8	11.1	4.6	1.8	1.8	8.6	16.5	10.2	9.4
1728	3.0	1.8	6.9	8.6	13.3	17.1	17.6	17.1	13.7	9.7	6.5	0.4	2.2	9.6	17.3	10.0	9.6
1729	-2.4	1.3	1.9	7.1	11.2	16.3	17.4	17.3	16.4	11.3	6.6	4.8	-0.3	6.7	17.0	11.4	9.1
1730	2.2	3.1	5.2	9.2	12.5	14.2	17.3	17.6	15.1	8.7	8.1	3.1	3.3	9.0	16.4	10.6	9.7
1731	1.2	0.2	4.2	7.0	12.0	15.5	17.0	17.7	15.6	13.0	7.3	3.8	1.5	7.7	16.7	12.0	9.5
1732	0.4	3.7	5.8	9.6	12.2	14.4	16.9	17.1	15.1	10.9	6.1	0.9	2.6	9.2	16.1	10.7	9.4
1733	4.9	4.5	5.7	10.8	11.5	15.2	19.5	17.7	13.3	9.5	6.5	5.9	3.4	9.3	17.5	9.8	10.4
1734	2.3	4.9	7.1	10.2	12.0	15.0	17.5	17.4	14.8	9.5	3.4	2.1	4.3	9.8	16.6	9.2	9.7

Monthly-, seasonal-, and annual means of the airtemperature in °C in Delft/Rijnsburg, reduced to De Bilt

MINIMA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	WIN	SPR	SUM	AUT	YEAR
	-5.7	-0.3	1.1	6.7	10.2	11.2	14.7	13.5	12.4	8.7	3.4	-1.2	-1.7	6.7	13.1	9.1	7.9
	1716	1709	1709	1719	1725	1725	1725	1725	1720	1730	1734	1715	1709	1729	1725	1720	1725
			1721														

MAXIMA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	WIN	SPR	SUM	AUT	YEAR
	4.9	5.6	7.1	10.8	15.1	17.7	19.5	20.2	16.4	13.0	8.4	5.9	4.5	9.8	18.2	12.0	10.4
	1733	1713	1734	1733	1727	1719	1733	1718	1729	1731	1723	1733	1724	1734	1719	1731	1733

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