SHORT COMMUNICATION

Instrumental pressure observations from the close of the 17th century: Leiden (The Netherlands)

(Instrumental 17th century pressure observations)

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ABSTRACT

We present a series of daily pressure readings taken 1697-1698 in Leiden (Netherlands) by W. Senguerdius. The readings were reviewed, converted to modern units, and reduced to 0°C. The 2-yr series runs parallel with the Paris 1665-1713 and Londen 1697-1708 pressure series. Although the series covers a time span of 23 months only, it can be regarded as a useful addition to the very few pressure series that extend back into the 17th century.

KEY WORDS: early instrumental data; sea level pressure; data bases, historical climatology; Europe

The increased interest in climate change and variability has created a demand for more empirical data about past climate. The understanding that paleodata are capable to answer only part of the questions raised, has lead to a rehabilitation of historical data of high temporal resolution. One track in the reconstruction of the past climate on basis of high temporal resolution data, is the recovery and digitation of pre-1854 semi-instrumental (i.e. wind) and weather observations from ships. The first comprehensive attempts in that direction (García-Herrera *et al.*, 2005; Woodruff *et al.*, 2005), has resulted in databases of good spatial coverage of wind direction and wind force data over the world's oceans 1750-1854, which penetrates well in the era of poor global coverage over land. The second track is the recovery or revisiting of the earliest instrumental land station data of temperature and in particular of pressure that exists in the world, hence of data that are taken in the early 18th century or even in the 17th century. Attempts in that direction has resulted in the accessibility of pressure data taken by William Derham in Upmister (20 km ENE of central London) Feb 1697- Dec 1708, which together with the earlier recovered pressure data recorded by Louis Morin 1665-1713 from Paris (Legrand and LeGoff, 1992) provides insight in the atmospheric circulation over Europe for the 11 years that the series overlap (Slonosky *et al.*, 2001).

Against this background, we present here another systematic pressure series that extends into the 17th century. The observations are taken in Leiden, a town 35 km SW of Amsterdam and situated at 10 km distance of the North Sea coast. The series is daily and covers the 23-month period Feb 1697-Dec 1698. Its existence implies an independent third station in the 17th century pressure network over Europe. The location of Leiden (52°9'N, 4°30'E) with respect to Paris and London is optimal for circulation studies, as the three stations form an almost regular triangle with sides of about 400 km.

The readings were taken by Wolferd Senguerd (1646-1724), since 1675 professor in natural philosophy at the in 1575 founded Leiden University, in a house in Leiden whose exact location is unknown. In total, two barometers and four thermometers were operated. Half of the instruments were in a room at the north of the building, the others in a south-facing room. The south-facing room was mostly closed; the instruments in the north-facing room were placed near a door that was regularly opened. The motivation behind this was the idea at the time that the motions in liquids in the instruments were partly determined by their exposure to the open air (Geurts and Van Engelen, 1992). Both rooms were probably at ground level. This implies that the instruments were at about 2 m above mean sea level. The observations ran from 1 Feb 1697 till 31 Dec 1698. The meteorological readings consist of pressure, temperature, wind direction, wind strength, and weather. The routine observation time refers probably to the morning, as additional observations took place in the afternoon or the evening. The observations, together with a scientific introduction, were published in Latin in a scientific treatise under Senguerd's Latinized name Senguerdius (1699).

The pressure, in old-style Rhineland inches divided into 12 lines (1 Rhineland inch equals 26.1518 mm; one line 2.18 mm), was recorded from two mercury stick barometers, indicated by Senguerdius as Barometer A and B. From 1 May 1698 onward, only the readings Barometer A were published. The reported values were given in integer values of lines, indicating a truncation error of 1.09 mm at most. Apart from an obvious misprinting in the pressure for Barometer A (on 27 March 1698), no larger differences between A and B occur than 2 Rhineland lines (4.36 mm). These 2 Rhineland line differences happen for only 7 days in the series, all of them before July 1697; for all other days the difference mount to 1 line at most (23% of the days). No correction to height, temperature or gravity was applied to the data.

Temperature was recorded with three gas thermometers and, from 1 April 1697 onward, additionally from a liquid alcohol thermometer. The liquid thermometer was called by Senguerdius Thermometer C, the air thermometers as Thermometer A, B, and D. The temperatures are reported in integer values of an unknown unit that differ among the thermometers. All temperatures units refer to an inverted scale (cold=high value). The relative response of the thermometers to temperature rise was determined by us from a regression of the daily temperature readings of liquid Thermometer C with those of air Thermometers A,B,D. In the regression analysis, the pressure of Barometer A was also included to account for the barometric dependency of the air thermometers. The absolute values of the responses of the thermometers to 1°C rise were obtained by comparing the temperature difference between July and December 1698 as recorded by Thermometer C with our estimation of its real difference (see below). The result shows that the scales of the thermometers in the south room (1°C≅ 2.9 units averaged over the two thermometers) is about 1.5 times coarser than for the thermometers in the north room (1°C≅ 4.7 units). The reason for this difference is unclear. See Table I for details of the instruments and the operations.

The simultaneous presence of temperature and pressure readings opens the possibility to reduce the pressures to 0°C. The readings of Thermometer C are the most logical choice for this, as a liquid thermometer is barometrically independent and as a liquid thermometer is more likely to remain stable over the 2-yr period than an air thermometer. Because the Feb-March 1697 readings of Thermometer C are missing, readings from at least one of the three air thermometers have to be invoked for these two months.

A proper reduction of the pressures to 0°C requires an assessment of the quality and stability of the various thermometers. No parallel readings in the Netherlands are available to serve for this purpose. However, the Netherlands is in the fortunate circumstances to have administrative records from 1634 onward about the transportation via the barge-canal between the cities of Leiden and Haarlem. These include accurate records of the days when the traffic was interrupted because of freezing of the canal (denoted here as canal freezing days). These days represents a physical proxy to temperature, which correlates well with the Dutch DJF winter temperatures (De Vries, 1977; Van den Dool *et al.*, 1978). Here we tested the quality of the Senguerdius thermometers with use of the number of canal freezing days stratified by month (Buisman and Van Engelen, 2005; De Kraker, pers. comm), by investigating whether the sign of the trends from 1697 to 1698 for the individual winter months are consistent with the monthly mean thermometer data of Senguerdius. The underlying assumption behind this approach is that a month with more freezing days was accompanied with lower air temperature in Leiden, which seems reasonable as the canal passes through Senguerdius's town. Table II presents the result of the comparison. It shows consistency between the canal data and the monthly mean temperatures of Thermometers B and C, but inconsistency with Thermometer A. For instance, Dec 1697 (10 canal freezing days) was apparently colder than Dec 1698 (no canal freezing), consistent with B (6 units higher on its [inverted] temperature scale) and with C (11 units higher), but inconsistent with A (9 units lower). This result is supported by the high correlation between C and B (0.98) compared with their correlations with A (0.77 with C and 0.75 with B). As D covers only 1698, we chose C augmented with B as the best choice for deriving the temperatures for the pressure reductions to 0°C.

The translation of the old units to Celsius requires the determination of a scale and a zero point, both for Thermometers B and C. Linear multiple regression analysis between the daily temperature observations of Thermometers C against Thermometer B and the reported pressure *P* (in mm) of Barometer A yields the following conversion formula between the temperature readings *T*:

$$T_C(\text{Seng. unit(C)}) = 1.23\ T_B(\text{Seng. unit (B)}) - 1.38\ P(\text{mm}) + 1041, \quad (1)$$

where the index refers to the thermometer and Seng. unit to the unit that is applied by Senguerdius in that thermometer. We verified that liquid thermometer C is barometrically independent, as it should be. We estimated the Celsius equivalent to the Senguerdius unit of Thermometer C from the mean July minus mean December 1698 temperatures (57.4 units), assuming the real difference to be 11°C, which is 1.5°C below the 1971-2000 normal value. The motivation for introducing the below-normal July-Dec value is that the number of canal freezing days (nil) indicates for 1698 a mild December (De Vries, 1977; Buisman and Van Engelen, 2005; De Kraker, pers. comm.), whereas documentary data indicate a cool 1698 summer in the Low Countries (Van Engelen *et al.*, 2001). The zero point of the scale was obtained from a comparison of the median of Senguerdius's temperature distribution at days where he reported snowfall (12 days in total) with that of the hours with snow in De Bilt 1991-1995 (ww codes 71-75 only). This indicates that the 149 Seng. units on Thermometer C corresponds to -1.3°C, so that

$$T(°\text{C}) = -\ 0.19\ (T_C(\text{Seng. unit(C)}) - 149) - 1.3 \quad (2)$$

The credibility of this conversion was checked by comparing the 1697/98 DJF temperature observed by Senguerdius (-1.27°C) with the estimate from the canal freezing days (-1.3±0.7°C, see Van den Dool *et al.*, 1977). These numbers compare surprisingly well, although two partly compensating effects may spoil the Senguerdius data: the fact that his thermometers are indoor, and the fact that he observed in the mornings only. We estimate from modern data of the synoptic station at Valkenburg airport, situated 6 km W of Leiden, that this may cause the Senguerdius winter temperature to be too high by 1.0°C at most. We note however that this potential bias is largely compensated by our estimation procedure of the zero point, in which Senguerdius indoor temperature was calibrated with the modern outdoor temperature during snowfall.

For the pressure reduction to 0°C, the barometer temperature is needed rather than the outdoor air temperature. Although Thermometers C and B were not in the same room as Barometer A (Table I), it seems that the temperature variability is representative for that in the Barometer-A room. This means that the temperature reduction does not introduce an artificially increased variability in the day-to-day pressure. The fact that our temperature calibration procedure yields a winter temperature close to reality may imply that the barometer temperatures are biased by about 1°C

The actual pressure reduction to 0°C proceeded in four steps: first for Feb and March 1697 the readings of Thermometer C in his Senguerdius units was estimated from the readings Thermometer B and the observed (uncorrected) pressure of Barometer A according to Equation (1); second the temperature in Celsius was determined from the temperature in the Senguerdius units of Thermometer C according to Equation (2); third the pressure expressed mm was converted into hPa by means of multiplication with 1.33322; fourth the pressure was reduced to 0°C using the formula of Kämtz (1832), which was generally used in the 19th century (Können *et al.*, 2003):

$$P(0°)= P(t)\ (1- 1.62\ 10^{-4}\ T(°C)). \qquad (3)$$

The first step in this sequence is only required for Feb and March 1697, as readings from Thermometer C are missing there. Inserting for these months the values obtained via Thermometer B is justified, as the difference between the monthly values averaged over the remaining 21 months in the Senguerdius series between C and B is only 0.27±0.10°C. Note that in the calculation the barometric term in Equation (1) is really needed, as the response of Barometer B to 1°C temperature rise is the same as to a drop of 5 hPa.

Table III show the Senguerdius pressures, together with those of London (Slonosky *et al.*, 2001) and Paris (Legrand and Le Goff, 1992). The Leiden values are much lower than modern climatology. An adjustment of 16.7 hPa is needed to bring the mean of Barometer A to the 1971-2000 normal value of 1015.3 hPa of Valkenburg. This adjustment is large, but not unrealistic: the bias correction required for 17th century London data (9.5 hPa) is of comparable magnitude (Slonosky *et al.*, 2001). Its most likely cause is trapped air in the barometer originating from outgassing of the mercury, which had been neither boiled nor distillated before its use. An accidental trapping of gasses from the atmosphere during the construction of the barometers seems to be less likely, as the average value of the monthly-mean differences of Barometers A and B is negligible (-0.3±0.2 hPa).

Adjusting the mean 1697-1698 pressures to the 1971-2000 normal automatically accounts for systematic corrections (e.g. gravity and height) that are otherwise standard required for pressure readings. We note that for the Senguerdius readings, the gravity correction (+0.6 hPa), height correction (+0.2 hPa), and the time of observation correction (< 0.2 hPa) are very small compared with the adjustment of 16.7 hPa applied here.

The quality of the Senguerdius pressure series was checked by a comparison of its day-to-day standard deviation with that in the Valkenburg data. The comparison is shown in Figure 1. The figure implies that the variability in the Leiden pressures is realistic. Figure 2 shows the complete time series of the daily values of the Senguerdius pressure series.

Figure 3 compares the monthly mean pressures of Leiden, Paris and London for the period under consideration. The difference with Paris in the summer months indicates prevailing westerly airflows, in accordance with the cool character of the 1697 and 1698 summers (Van Engelen *et al.*, 2001). For the 1697/98 winter, the Leiden pressures are higher than Paris, indicating a persistent anomalous circulation pattern over Europe with a dominating eastern component in the airflow over the Netherlands. This anomalous circulation (also found by Slonosky *et al.* (2001) from the London-Paris difference) is consistent with the severity of the 1697/98 winter in the Netherlands, which was not matched till 1709 (Van den Dool *et al.*, 1978). Remarkable is the small London-Paris gradient with respect to Leiden-Paris. This may point toward a N-component in the 1697 and 1698 summers and a S-component in the 1697/98 winter airflow. From Senguerius daily wind observations (not discussed further in this paper) we infer the London data tends to lead here to an overestimation of the N and S wind components. This feature may be a manifestation of a data problem in the London pressures, which could for these years only crudely reduced to 0°C because of lack of associated temperature readings (Slonosky *et al.*, 2001).

The Senguerdius series represents a 17th century backward extension by two years of the otherwise almost uninterrupted two-century long Dutch daily pressure series, which starts with a series from 19 December 1705 till 1734 in Delft/Rijnsburg with observations by Cruquius (Van Engelen and Geurts, 1985), after which it continues through the entire 18th and 19th centuries by readings from Zwanenburg and Utrecht/De Bilt. We hope that this article stimulates others to undertake in their national archives a search for very old meteorological readings, particular of pressure and/or wind, to review their contents, and to make them available via the Internet.

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References

Buisman, J., Van Engelen AFV (Ed). 2005. *Duizend jaar weer, wind en water in de Lage Landen Vol 5: 1676-1750* (van Wijnen, Franeker, The Netherlands), p 589 (in press)

De Vries J. 1977. Histoire de Climat et économie: des fait nouveaux, une interpretation différante. *Annales Economis Société Civilations* **32:** 198-227.

García-Herrera, R, Können, GP, Wheeler, DA, Prieto, MR, Jones PD, Koek, FB. 2005. CLIWOC: A climatological database for the world's oceans 1750-1854, *Climatic Change,* submitted

Geurts HAM, Van Engelen, AFV. 1992. Historische Weerkundige waarnemingen, Vol 5, Beschrijving Historische metreeksen. KNMI publication 165-V.

Kämtz LF. 1832. *Lehrbuch der Meteorologie*, Bd II, pp 238-239. Halle. [Available from library KNMI.]

Können GP, Zaiki M, Baede APM, Mikami T, Jones PD, Tsukahara T. 2003. Pre-1872 extension of the Japanese instrumental meteorological observation series back to 1819*, Journal of Climate* **16**: 118-131.

Legrand J-P, Le Goff M. 1992. *Les observations météroloqiques de Louis Morin*. Direction de la Météorologie Nationale, Ministère de l'Equipement et des Transports, monographie No. 6, vol. 1.

Slonosky VC, Jones PD, Davies TD. 2001. Instrumental pressure observations and atmospheric circulation from the 17th and 18th centuries: London and Paris. *International Journal of Climatology,* **21:** 285-298

Senguerdius W. 1699. *Atmospheraerici Aeris*, Lugduni Batavorum, Apud Cournerlium Boutesteyn: Leiden. [Available from library KNMI].

Van den Dool HM, Krijnen HJ, Schuurmans CJE. 1978. Average winter temperatures at de Bilt (The Netherlands): 1634-1977. *Climatic Change,* **1:** 319 - 330.

Van Engelen AFV, Geurts HAM. 1985. Historische Weerkundige waarnemingen, Vol 4, Nicolaus Cruquius (1678-1754) and his meteorological observations. KNMI publication 165-IV.

Van Engelen AFV, Buisman J, IJnsen F. 2001. A millennium of Weather, Winds and Water in the Low Countries. In: *History and Climate: Memories of the future?* (Jones PJ, Ogilvie AEJ, Davies TD, Briffa KR, Eds) Kluwer Academic/ Plenium Publishers, New York, p.101-124.

Woodruff SD, Diaz HF, Worley SJ, Reynolds RW, Lubker SJ. 2005, Early ship observational data and ICOADS, *Climatic Change*, submitted

Figure captions

Fig. 1 Standard deviation of the day-to-day air pressure difference series for each month of Leiden 1697 and 1698, compared with Valkenburg 1971-2000. The Valkenburg values are condensed in boxplots (each of them made up from the 30 values). A boxplot displays the variation of the standard deviation of the day-to-day differences of the Valkenburg 8 GMT air pressures 1971–2000 calculated per month. The lower and upper limits of the box represent the 25th/75th percentiles (quartiles), and the horizontal line in the box represents the 50th percentile (median). The whiskers are drawn to the nearest value not beyond a span of 1.5 interquartile range from the 25th/75th percentiles.

Fig. 2 Daily pressures 1697-1698 in Leiden, bias corrected.

Fig. 3 Leiden, Paris and London monthly pressures 1697-1698, bias-corrected.

Table Captions

Table I. Instruments used by Senguerdius. Dates printed in italics indicate a late start or an early end the instruments readings.

Table II. Comparison of temperatures by Senguerdius (in his units) with the number of canal freezing days for winter months in the Senguerdius series having data in 1697 and 1698.

Table III. Monthly mean pressures 1697-1698 of Leiden from the barometers A and B, monthly mean temperatures of Leiden, and the pressures of London (Slonosky *et al*., 2001) and Paris (Legrand and Le Goff, 1992). To adjust the pressure data to the long-term mean, 16.7 hPa, 9.1 hPa and 0.3 hPh has to be added to the Leiden (Barometer A), London, and Paris data, respectively.

Table I. Instruments used by Senguerdius. Dates printed in italics indicate a late start or an early end of the instruments readings.

	Instruments	Type	Observation Period	Tube length	Temp. Unit
North room	Barometer B	stick	1 Feb 1697 - *30 Apr 1698*	105 cm	--
	Thermometer B	air	1 Feb 1697 - 31 Dec 1698	52 cm	1°C≅ 4.2 unit
	Thermometer C	liquid	*1 Apr 1697* - 31 Dec 1698	41 cm	1°C≅ 5.2 unit
South room	Barometer A	stick	1 Feb 1697 - 31 Dec 1698	127 cm	--
	Thermometer A	air	1 Feb 1697 - 31 Dec 1698	136 cm	1°C≅ 3.7 unit
	Thermometer D	air	*1 Jan 1698* - 31 Dec 1698	220 cm	1°C≅ 2.2 unit

Table II. Comparison of temperatures by Senguerdius (in his units) with the number of canal freezing days for winter months in the Senguerdius series having data in 1697 and 1698.

month	yr	Number of canal freezing days	Thermometers* (Senguerdius's units)			
			B	C (liquid)	A	D
Feb	1697	28 (Jan: 31)	121.8	--	116.2**	--
	1698	21 (Jan: 17)	114.0	148.6	121.1**	108.8
March	1697	6	105.2	--	100.4	--
	1698	12	116.5	141.1	122.6	110.0
Dec	1697	10	112.7	147.0	120.5**	--
	1698	0	106.7	135.9	129.8**	112.7

*High values on all Senguerdius thermometer scales indicate cold

** Difference between 1697 and 1698 data inconsistent with the canal data

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		Leiden			London	Paris
Yr	Mo	P_A(hPa)	P_B (hPa)	T(°C)	P(hPa)	P(hPa)
1697	Feb	1001.0	1000.6	-2.5	1004.5	1012.8
1697	Mar	1005.9	1007.4	2.6	1004.9	1014.4
1697	May	1005.5	1006.4	3.5	1011.9	1015.5
1697	Jun	995.7	997.0	9.2	--	1013.9
1697	Jul	1000.2	1001.5	9.9	1007.1	1014.3
1697	Jun	996.3	995.0	12.2	1010.4	1019.3
1697	Aug	992.8	992.8	11.0	1004.9	--
1697	Sep	995.7	996.0	9.4	1006.3	1016.6
1697	Oct	1001.4	1001.4	5.3	1008.6	1018.5
1697	Nov	1005.4	1005.8	3.1	1012.2	1020.3
1697	Dec	997.7	998.1	-0.9	1002.3	1010.7
1698	Jan	1004.0	1004.1	-1.4	1007.4	1014.9
1698	Feb	998.6	998.6	-1.2	1000.5	1008.2
1698	Mar	1004.4	1004.6	0.2	1010.0	1019.3
1698	May	1001.8	1001.9	4.2	1009.1	1017.5
1698	Jun	997.7	-	5.6	1007.0	1015.8
1698	Jul	997.4	-	10.5	1009.1	1017.4
1698	Jun	991.3	-	12.1	1006.4	1017.5
1698	Aug	994.1	-	10.7	1007.9	1017.6
1698	Sep	990.3	-	9.3	1002.1	1012.8
1698	Oct	991.0	-	6.9	999.9	1011.9
1698	Nov	997.8	-	1.0	1000.2	1012.6
1698	Dec	1004.0	-	1.2	1005.9	1018.9

FIGURE 1

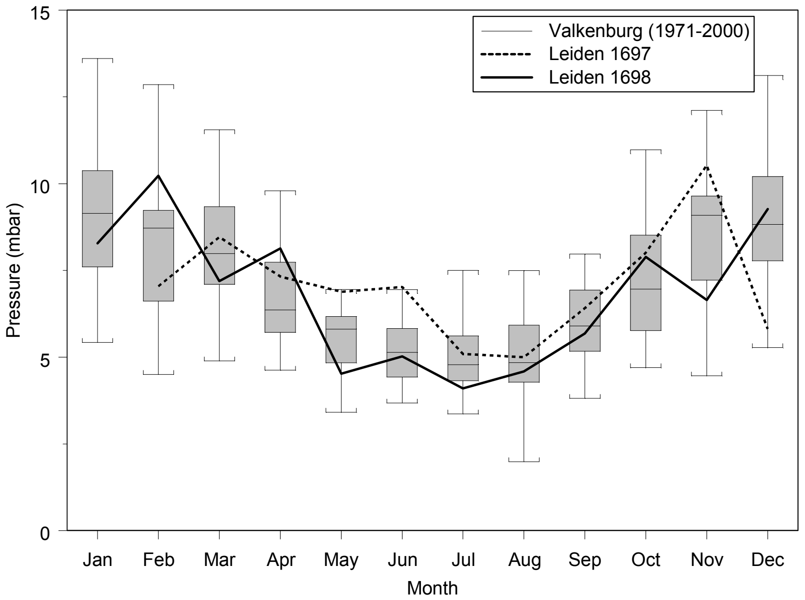

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FIGURE 2

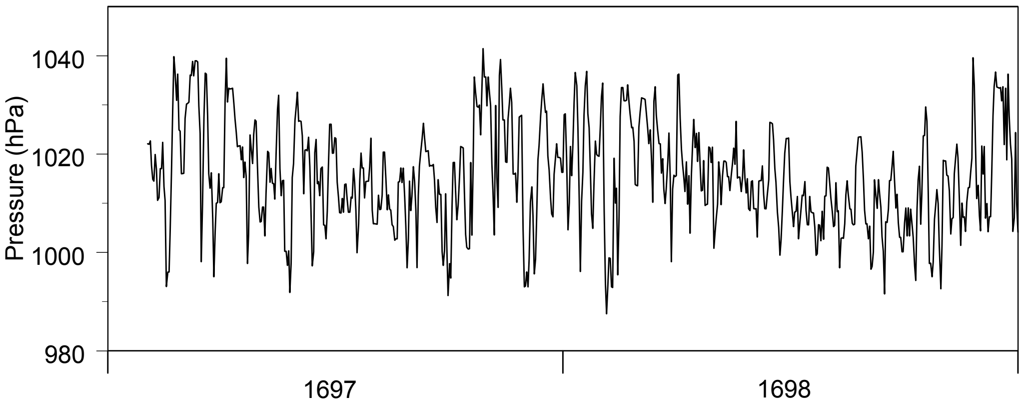

Fig. 2 Daily pressures 1697-1698 in Leiden, bias corrected.

FIGURE 3

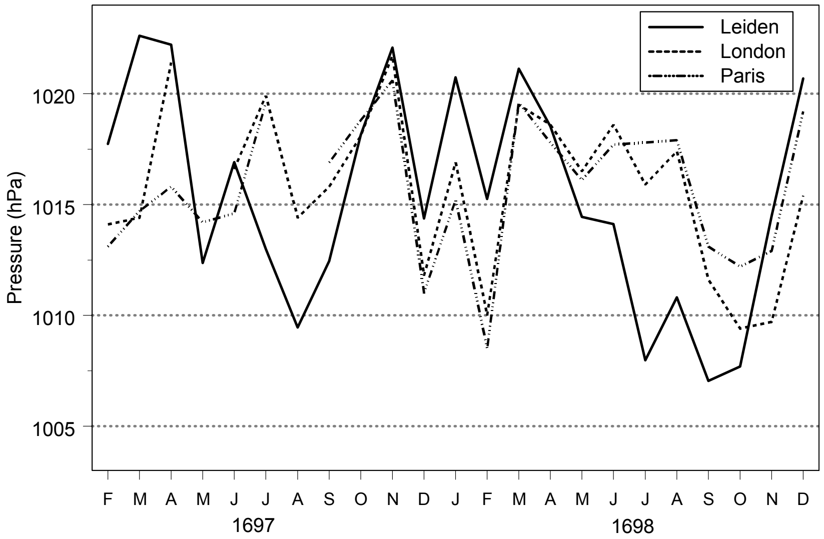

Figure 3. Leiden, Paris and London monthly pressures 1697-1698, bias-corrected.