Meteorology. — *On a period of 5.25 years in rainfall, temperature and pressure.* By H. J. DE BOER. (Communicated by Prof. E. VAN EVERDINGEN.)

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A periodicity of just over five years in the North and East component of wind direction and in the airpressure over the British Isles, investigated by BROOKS [1]), and the fact that the winters of 1924, 1929 and 1934 were cold in the Netherlands [2]) led to the detection and investigation of a period of 5.25 years in and around the region of the Northern Atlantic Ocean.

Suppose we compare the departures from normal of the seasonal means of some meteorological element during two different series of the same length in years. If there is periodicity in the deviations, the positive correlation between the corresponding values in two series of years will be maximum, when the difference of time $\triangle$ between the beginning of the two series is an even multiple of half the period; the negative correlation will be maximum when the difference of time $\triangle$ is an odd multiple of half the period.

For the determination of the period we take successive values of $\triangle$ and calculate for each value the correlation coefficient. So we get in the curve for the correlation coefficients many maxima and minima indicating even and odd multiples of half the period respectively. The distance in time between two successive maxima or minima is of the order of the length of one period. Thus we can easily compute how many periods correspond to each maximum. From each maximum and each minimum we can calculate the length of the period. Then we may consider the arithmetic mean of all the calculated lengths to be the length of the supposed period.

In order to avoid the elaborate computation of the correlation coefficients, we introduce a new quantity, "the sign coefficient". When comparing two series of departures from the mean, we note a plus sign for two corresponding deviations of the same sign. When the corresponding deviations are opposite in sign, we note a minus sign. We note the value 0 when at least one of the deviations is zero. Now the sign coefficient is the quotient obtained when the difference between the number of plus signs and the number of minus signs is divided by the total number of figures, the zero values included.

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1) C. E. P. BROOKS, the Meteorological Magazine, **72**, 204 (1937).

2) S. W. VISSER, Hemel en Dampkring, **36**, 13 (1938).

Dr. S. W. VISSER has calculated the correlation between 50 sign coefficients in the interval 1901—1937 and the 50 corresponding correlation coefficients. The correlation coefficient proved to be 0.82.

This shows that we may use the sign coefficient as a good approximation of the correlation coefficient, except when the deviations are very small.

The above-mentioned scheme has been applied at first to the seasonal temperature deviations at De Bilt for the interval from 1849 to 1938. We have only used the winter deviations after elimination of the 27-month period [3]) and have started from a value of $\triangle$ of 20 years; then we have taken $\triangle$ equal to 21 years and so on up to 70 years. Thus we have found maxima at $\triangle$ values of 21.0, 25.4, 31.5, 36.6, 42.9, 47.2, 53.2, 63.7 and 67.7 years, evidently corresponding to 4, 5, 6, 7, 8, 9, 10, 12 and 13 periods. From these maxima, the mean length of the period has been calculated to be 5.25 years. The same result we deduced from the minima, which we found at 23.8, 27.7, 34.7, 40.0, 44.7, 49.5, 55.4 and 65.2 years, corresponding to $4\frac{1}{2}$, $5\frac{1}{2}$, $6\frac{1}{2}$, $7\frac{1}{2}$, $8\frac{1}{2}$, $9\frac{1}{2}$, $10\frac{1}{2}$ and $12\frac{1}{2}$ periods. These data too gave us a mean length of the period of 5.25 years. (See figure 1.)

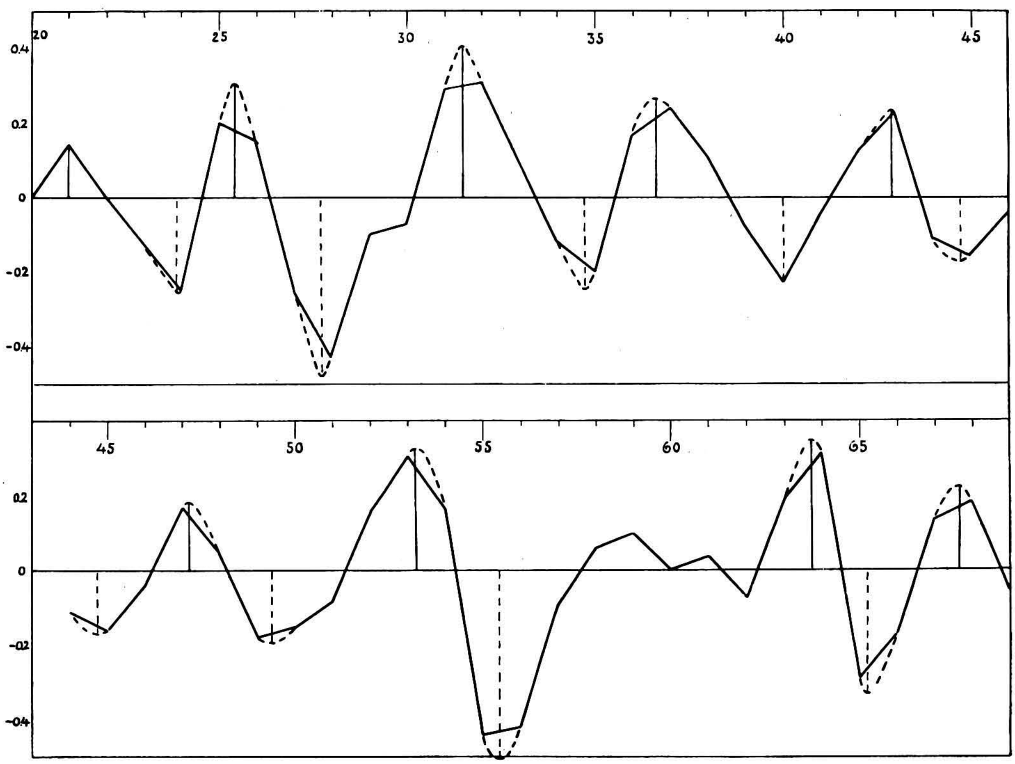

Fig. 1. Sign coefficients of temperature at De Bilt.

In order to show the stability of the 5.25-year period in the temperature

[3]) S. W. VISSER, Proc. Royal Acad. Amsterdam, **40**, 513 (1937).

of De Bilt, the deviations for the four seasons corrected for the 27-month period have been arranged in cycles of 21 years duration and we have determined the mean for each cycle. The stability of the maximum during the interval from 1849 to 1938 is satisfactory (table 1).

TABLE 1. Stability of the 5.25 year period in the temperature of De Bilt (degrees C.)

1849—1869	0.8	−0.6	−0.1	−0.9	−0.8	0.4	−0.3	−0.3	0.3	0.4	−0.2
	0.4	0.4	0.5	**1.4**	1.0	0.0	0.4	−0.3	−0.0	−0.4	
1870—1890	0.2	−0.1	−0.4	−0.3	−0.4	−0.1	−0.1	0.7	−0.8	0.1	0.1
	0.1	0.6	−0.0	**1.0**	−0.1	−0.1	−0.0	0.5	**−0.8**	−0.2	
1891—1911	−0.5	−0.3	−0.6	−0.8	−0.0	−0.2	−0.1	0.4	−0.8	0.4	0.2
	0.0	−0.0	**0.8**	0.4	−0.2	−0.8	−0.1	0.6	0.3	0.0	
1912—1932	−0.2	0.1	0.3	−0.3	0.6	−1.1	−1.4	0.3	0.1	0.4	0.2
	0.8	**1.3**	−0.7	−0.4	0.1	0.8	0.5	−0.3	0.2	−0.6	
1849—1937	0.2	−0.1	−0.1	−0.5	−0.2	−0.3	−0.5	0.4	−0.1	0.3	0.1
	0.4	**0.6**	**0.1**	0.6	0.2	0.0	0.2	0.1	−0.1	−0.3	

It seemed worth while to apply this method also to precipitation at De Bilt. We used for precipitation the four seasonal deviations after elimination of the 27-month period and we took values for $\triangle$ of 20, 20¼, 20½, 20¾, and so on up to 70 years. Again we found a period of 5.25 years. Here the stability of the minima in the various 21 season cycles is satisfactory, though to a smaller degree than with the maximum in the case of temperature during the interval from 1849 to 1938 (table 2).

TABLE 2. Stability of the 5 25 year period in rainfall of De Bilt (mm).

1849—1869	−37.1	10.9	−29.6	42.5	− 7.8	− 2.2	−26.5	15.7	0.9	21.0	−11.1
	−17.8	3.4	−28.9	−27.7	−17.0	−30.8	7.0	− 6.9	−33.8	− 1.2	
1870—1890	6.8	4.5	25.6	13.2	11.3	37.7	6.8	4.1	24.7	12.1	13.0
	16.5	21.7	− 1.0	13.0	7.2	−13.6	− 5.0	−17.8	1.0	**−44.5**	
1891—1911	**−43.6**	15.2	20.1	−32.1	10.1	−38.0	−16.7	50.6	− 4.1	−11.7	−19.5
	22.0	−10.5	−18.2	20.1	18.4	− 0.5	8.1	− 2.0	−13.5	−13.7	
1912—1932	− 3.7	32.2	27.6	21.0	− 3.3	−10.0	− 4.4	− 0.6	9.0	7.4	− 1.8
	37.2	56.5	40.6	−16.0	10.5	− 2.2	−27.3	−10.5	−14.1	39.8	
1849—1937	**−23.1**	13.9	9.8	9.2	− 1.0	−20.3	−12.5	15.8	9.2	7.8	− 6.1
	15.6	21.1	− 3.0	− 1.4	7.2	− 5.3	− 1.9	−10.5	−17.8	− 5.0	

Following VISSER's example in the case of the 27-month period in the rainfall, we have investigated the character of the 5.25 year period on and around the Northern Atlantic Ocean. We examined the rainfall for most of the stations from 1876 to 1929 inclusive. The present period of 5.25 years started with the spring of 1938 (March 1st 1938). Harmonic analysis was applied in order to detect some general features of this period. We only used the first two terms of the harmonic analysis.

We found two important features (see table 3):

1. a phase difference combined with a decrease of amplitude on the Atlantic Ocean in the direction of the Gulfstream;
2. a retardation at Thorshavn.

TABLE 3. Harmonic analysis of 5.25-year period on the Atlantic Ocean.

									Maximum in season
1.	Ceara	3.7° N	38.5° W	44.2 sin (x +	125°) +	28.6 sin (2x +	59°)		20.0
2.	Paramaribo	5.8 N	55.3 W	47.6	43	24.0	358		3.7
	Barbados	13.1 N	59.6 W	21.6	42	15.7	321		3.8
3.	Bermuda	32.3 N	64.8 W	14.2	305	16.4	344		9.5
4.	Ponta Delgada	37.7 N	25.7 W	15.7	154	5.9	284		18.3
5.	Valentia	51.9 N	10.2 W	15.4	308	7.6	291		9.3
	Netherlands	52.1 N	5.2 E	7.3	282	5.8	34		10.8
6.	Stykkisholm	65.5 N	22.8 W	10.2	156	7.7	51		18.2
7.	Thorshavn	62.0 N	6.8 W	9.0	30	9.4	224		4.5
8.	Bodö	67.3 N	14.4 E	16.5	75	11.1	154		1.6

Even if we take into account the large yearly rainfall in the neighbourhood of Ceara, the amplitude in this region is larger, which may be explained by the supposition that here the disturbances take their origin. The phase differences are not inconsistent with the hypothesis that the disturbances take a little over eleven years to cross the Ocean from Ceara to Bodö. The travel-time for the 27-month period over the Ocean is six or seven months. So the proportion of the first-mentioned travel-time to the second is as 20 : 1 or the proportion of their velocities is 1 : 20. It is a known fact that the normal proportion of current velocity to wind-velocity in the open Ocean is 1 : 20.

We have calculated from the "Oceanographische en Meteorologische waarnemingen in den Atlantischen Oceaan, Koninklijk Nederlandsch Meteorologisch Instituut, Nr 110" the yearly average of the component of the current-velocity along the direction from Bermuda to Valentia. The yearly average proved to be about 6.8 km in 24 hours. As follows from table 3, the transmission-velocity of the 5.25 year period from Bermuda to Valentia, being 5800 km in 5 years, proved to be 3.2 km in 24 hours.

Also the wind-velocity, averaged over a year, at ships-height above sea-level in the direction of the Gulfstream from Bermuda to Valentia has been calculated. This velocity proved to be 105 km in 24 hours. The travel-time of the 27-month period from Bermuda to Valentia is 2.2 months. Hence the transmission-velocitiy is about 86 km in 24 hours.

The proportion between the yearly average of the current-velocity and the wind-velocity at ships-height above sea-level is 1 : 16, whilst the proportion between the transmission-velocity of the 5.25-year period and the transmission-velocity of the 27-month period is 1 : 26. Considering that the proportion 1 : 20 is only applicable to regions with constant wind direction, such as trade winds, and the real path of the water masses will probably be more curved than that of the air masses, we may consider the result of this rough calculation as satisfactory.

These facts might be explained by supposing that departures from the normal, originating in the neighbourhood of Ceara and showing a periodicity of $5\frac{1}{4}$ years, are transmitted by the water of the Gulfstream, and that other departures with a periodicity of $2\frac{1}{4}$ years are transmitted by the general circulation of air over the Ocean.

VISSER has computed the correlation coefficients for temperature and precipitation at De Bilt between the values according to the 5.25-year period, calculated from the data in the interval 1849—1937 and the observed data in the interval 1901—1937. The same has been done for the 27-month period (table 4).

TABLE 4. Correlation coefficients between observed and calculated values for the 5.25-year and the 27-month periods.

	Precipitation				Temperature			
	Wi	Spr.	Su	Au	Wi	Spr.	Su	Au
27 month period	+0.020	+0.282	+0.215	+0.323	+0.120	+0.253	—0.013	+0.129
5.25 year period	+0.381	+0.290	+0.177	+0.218	+0.415	+0.195	+0.280	+0.197

Especially for temperature the correlation coefficients for the $5\frac{1}{4}$ year cycle are larger and more stable. This is due to the fact that water is less subject to disturbing influences than air.

Now we will come back to the indication of a retardation at Thorshavn. VISSER found the same result for the 27-month period. The small number of stations available does not permit any definite conclusion, but if the retardation is real in both cases we would be led to the supposition that Thorshavn is not on the mean path of the general circulation and of the Gulfstream between Valencia and Bodö, and that the disturbances reach it only on some return track after intermixing with cold currents from the North.

C. E. P. BROOKS [4]) has found a period of just over five years in airpressure and in the North and East component of wind direction. We will repeat what BROOKS has written about the period of 5.05 years in airpressure and wind direction over the British Isles:

[4]) C. E. P. BROOKS, l.c.

"At Edinburgh the pressure data for the years from 1772—1816 and 1907—1936 showed no evidence of a periodicity of about five years, but the period 1817—1906 showed a periodicity of 5.06 years very clearly." About the N component of wind direction "At London it was 5.09 years from 1715 to 1797, 5.03 years from 1802 to 1887 and again 5.09 years from 1887 onwards. At Edinburgh there were breaks about 1840 and 1860, while at Dublin the length was about 5.0 years from 1726 to 1765 and 5.1 years from 1831 to 1936."

Hence BROOKS has found periods of various lengths at stations at relatively small distances. Moreover, the amplitude of the periodicity was different at various stations. Therefore we have studied the 27-month period and the 5.25 year period in airpressure and in temperature at Edinburgh. We have compared the results with those we found in temperature at Zwanenburg and at De Bilt.

In the first place there was a break about 1842—1843 in the two meteorological elements at the stations mentioned for the 5.25-year period as well as for the 27-month period.

In the second place the two periods were much better developed (i.e. the proportion of the amplitude of the first term to that of the second term of the harmonic analysis is markedly larger after the break, than before). In the third place the two periods in temperature have been better developed in the neighbourhood of the Gulfstream than on the continent, though the amplitude of the first term on the continent is larger than on the coast of the Atlantic Ocean.

Lastly the phase differences in the three cases between the intervals at both sides of the break are in satisfactory mutual agreement except for the 27-month period in airpressure at Edinburgh. Those facts are shown by table 5 (I is the interval 1770—summer 1843, II is the interval autumn 1843—1930, III is the interval 1770—1842 and IV 1843—1930).

TABLE 5. Comparison of harmonic analysis before and after the break ± 1843.

5.25 year period	27 month period
Airpressure Edinburgh	
I $0.22 \sin(x+306°)+0.23 \sin(2x+227°)$	III $0.35 \sin(x+73°)+0.29 \sin(2x+49°)$
II $0.51 \sin(x+98°)+0.07 \sin(2x+278°)$	IV $0.37 \sin(x+190°)+0.49 \sin(2x+198°)$
Temperature Edinburgh	
I $0.09 \sin(x+108°)+0.07 \sin(2x+289°)$	III $0.07 \sin(x+95°)+0.10 \sin(2x+26°)$
II $0.23 \sin(x+215°)+0.06 \sin(2x+150°)$	IV $0.21 \sin(x+135°)+0.09 \sin(2x+40°)$
Temperature De Bilt and Zwanenburg	
I $0.20 \sin(x+81°)+0.17 \sin(2x+178°)$	III $0.12 \sin(x+188°)+0.23 \sin(2x+37°)$
II $0.33 \sin(x+229°)+0.10 \sin(2x+78°)$	IV $0.11 \sin(x+219°)+0.12 \sin(2x+236°)$

In order to show more clearly the break about 1842 which BROOKS has already mentioned, we will take one of the numerical tables of our investigation, namely the 27-month period in airpressure at Edinburgh (table 6).

TABLE 6. The break in the airpressure at Edinburgh.

1770—1779	— 0.3	0.3	—10.7	— 6.4	— 1.1	1.0	—14.1	0.9	—11.3
1779—1788	2.5	— 3.9	14.9	0.8	— 4.4	— 0.3	9.2	3.1	5.9
1788—1797	1.5	1.2	— 0.6	0.2	— 4.9	— 8.1	— 2.0	— 9.2	0.2
1797—1806	10.9	— 8.8	—15.7	3.3	— 6.0	6.1	— 7.1	— 6.2	11.4
1806—1815	— 6.8	8.2	— 5.4	— 2.0	— 1.7	4.6	— 0.3	— 3.8	4.0
1815—1824	— 2.9	— 8.3	10.8	— 5.3	— 9.8	1.3	4.6	—11.2	1.0
1824—1833	0.9	1.8	5.5	— 1.2	— 6.3	9.1	11.9	— 5.9	— 4.9
1833—1842	0.7	— 1.7	6.5	— 4.2	—12.7	9.8	— 7.8	4.1	0.5
1842—1851	3.1	— 2.9	1.6	3.1	1.4	— 2.7	— 6.7	— 8.2	— 6.3
1851—1860	2.1	5.8	— 6.6	9.7	4.7	9.9	— 7.5	— 0.1	—11.1
1860—1869	— 1.5	— 5.5	— 4.8	5.4	6.9	3.4	—11.3	4.3	1.7
1869—1878	— 5.1	4.8	9.2	— 1.9	1.1	— 4.0	— 2.9	— 2.7	3.2
1878—1887	12.0	— 7.6	— 4.5	5.4	— 2.3	— 1.5	— 1.6	11.9	7.8
1887—1896	— 3.3	— 1.8	4.1	8.5	6.7	— 3.0	0.3	19.6	4.5
1896—1905	10.5	6.2	0.2	— 3.1	3.4	— 2.9	— 0.8	5.4	10.5
1905—1914	— 0.7	— 7.9	— 8.4	— 1.6	1.4	3.1	6.7	13.0	7.0
1914—1923	— 0.2	— 0.8	— 4.6	7.7	— 2.9	2.1	— 7.3	1.6	6.8
1923—1930	—11.6	— 2.4	— 0.2	—14.3	— 1.6	— 2.8	4.0	9.0	— 5.3

Table 6 contains 18 cycles of nine years duration, each cycle containing the sum of four periods of nine seasons. The feature of the deviations before and after the break is remarkably different.

The mean deviations of the temperature at Edinburgh and at Zwanenburg—De Bilt before and after the break are in very good agreement for the two periods. We will show this in the following table.

TABLE 7. Comparison of the deviations of the temperature at E. and Zw. — De B.

The 5.25-year period at Edinburg and Zwanenburg 1770 — autumn 1843										
E. 0.0	—0.4	0.1	—0.2	0.3	—0.0	—0.0	0.0	—0.4	0.2	—0.1
Zw. 0.2	—0.4	0.1	—0.2	0.6	—0.0	—0.1	0.1	—0.5	0.3	—0.2
E. 0.5	—0.0	—0.5	0.1	0.2	0.1	-0.1	—0.2	0.4	0.3	
Zw. 0.3	—0.5	—0.7	—0.3	0.1	—0.0	0.1	—0.0	0.6	0.5	

TABLE 7 (*Continued*).

The 5.25-year period at Edinburgh and at De Bilt autumn 1843—1930

E. 0.2	—0.0	—0.5	—0.4	—0.3	—0.2	—0.1	—0.1	—0.0	0.2	0.2
d.B. 0.2	—0.1	—0.1	—0.5	—0.2	—0.3	—0.5	0.4	—0.1	0.3	0.1
E. 0.0	0.2	0.0	0.6	0.1	0.0	0.0	0.2	0.1	—0.2	
d.B. 0.4	0.6	0 1	0.6	0.2	0.0	0.2	0.1	—0.1	—0.3	

The 27-month period at Edinburgh and at Zwanenburg 1770—1842

E. 0.2	0.1	—0.1	—0.0	—0.2	0.0	0.1	—0.1	—0.1
Zw. —0.1	0.2	—0.4	—0.3	0.2	0.2	0.3	—0.0	—0.3

The 27-month period at Edingburgh and at De Bilt 1842—1930

E. 0.3	—0.0	—0.1	—0.3	—0.2	0.0	0.1	0.1	0.1
d.B. —0.1	—0.3	—0.0	0.1	—0.1	0.0	0.2	0.0	0.1