THE THREE TO THREE-AND-ONE-HALF YEAR PERIODIC PRESSURE OSCILLATION IN THE FREE ATMOSPHERE

By FRANZ BAUR

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Through employment of the periodogram analysis, which permits a clearer comprehension and a more nearly correct conclusion as to the physical reality of the existing periods, rather than through the usual methods for the disclosure of meteorological periods, I have in an earlier study [1] brought out the fact that along with other real periods of pressure fluctuation in Bavaria a period of about three years also occurs which has every appearance of reality. The progress of the investigation, which will be published in another place, revealed also similar periods in the pressure oscillations of other regions. The question now arises as to what the physical conditions are that produce this three to three and one-half year period. It is important to the solution of the question to gain a clear conception as to whether this oscillation is a result of periodical density (temperature) oscillations of the lower atmospheric strata, or one evolved through thermal or purely dynamic processes in the upper strata. A contribution toward the solution of these conditions forms the subject of the following investigation.

The observational material.—Annual pressure means based on suitable computations will be found in the table at the end of the paper. The pressure means for the various altitudes above Lindenberg are computed from the annual surface pressure means, the annual temperatures of the individual upper strata and the mean relative humidity. These observational results were given me in very excellent manner by Prof. J. Reger, Lindenberg. The material is not strictly homogeneous; as only in the years 1914–1916 were the mean annual temperatures computed from three daily ascents, and in the remaining years from the early ascents only. Furthermore there is involved in the pressure means computed from the temperatures the small defect that the pressure was not determined for each single ascent, and the annual mean computed therefrom, but that the annual pressure mean was derived from the annual temperature mean. Nevertheless the magnitude of this error in annual mean falls below 0.1 mm. Hg. The pressures at the surface are the means of the three hours 7 a. m., 2 p. m., and 9 p. m. In order to ascertain to what extent the results are conditioned by fortuitous values, pressure observations at a few high-altitude stations and their base stations were used for comparison. The annual mean pressures at four Bavarian lowland stations are from the above-mentioned work,[2] and those for high Peissenberg and for the Zugspitze for the respective years are from the German Meteorological Yearbooks for Bavaria. The annual mean pressures for Zurich and for Säntis were kindly given me by the Swiss Central Meteorological Institute.

The analysis.—As observations at Lindenberg are available from 1906 to 1920 only, the analysis could cover only a 16-year period. But this entire period was used because as a multiple of 3.2 it permitted the expectation that a period lying very probably between three and three and one-half years would be revealed, and because, moreover, 16 years are even multiples of 8 and 3.2 years, in proximity to which also probably lie the actual periods of pressure oscillation.[3] A complete periodogram-analysis naturally can not carry through with only 16 ordinates but nevertheless the Fourier analysis of 16 equidistant values beyond the 3.2 year period under investigation yields the amplitudes of six more periods than can be exhibited for comparison. That among these are some which closely approximate the existing real periods is of advantage for the accuracy of the results; as in the computation of periodic phenomena by means of the Fourier analysis it is especially important that the series of years analyzed should be as nearly as practicable a multiple of the existing periods.

To facilitate the computation of the Fourier coefficients I have formulated the following scheme and utilized it in the present investigation.[4] (See scheme below.)

Results.—The amplitudes derived are assembled in the table at the end of the paper. It will be seen that in nine pressure analyses the amplitudes of the 3.2-year period in seven cases showed the largest value and also in seven cases the amplitude is greater than one and one-half times the total of the arithmetical means of the amplitude derived from each analysis. By themselves the analyses of series of observations derived from only 16 yearly means warrant no conclusion as to the reality of the periodicity; but as the existence of this period has already been shown to be very probable, through the investigation before mentioned, which covers a longer term of years, the evident maximum of the amplitudes of the 3.2-year periods shown by the pressure analyses in the present paper may be interpreted as a new confirmation of the existence of about a three-year pressure oscillation.

Scheme for analysis of an empirically derived function in sine curves by means of 16 equidistant ordinates:

		y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8
	y_{16}	y_{15}	y_{14}	y_{13}	y_{12}	y_{11}	y_{10}	y_9	
Difference:		u_1	u_2	u_3	u_4	u_5	u_6	u_7	
Sum:	v_0	v_1	v_2	v_3	v_4	v_5	v_6	v_7	v_8

Sine member

	u_1	u_2	u_3	u_4	U'_1	U'_2
	u_7	u_6	u_5		U'_3	
Sum	U_1	U_2	U_3	U_4	U''_1	U''_2
Difference	U'_1	U'_2	U'_3		U'''_1	

	1—7		2—6		3—5		4
Sin. 22½°×	U_1				$-U_3$		
Sin. 45°×		U_2	U''_1			U_2	
Sin. 67½°×	U_3				U_1		
Sin. 90°×		U_4		U''_2		U_4-	U'''_1
Sum, column 1							
Sum, column 2							
Sum	$8a_1$		$8a_2$		$8a_3$		$8a_4$
Difference	$8a_7$		$8a_6$		$8a_5$		

Cosine member

	v_0	v_1	v_2	v_3	v_4	V_0	V_1	V_2	V'''_0	V'''_1
	v_8	v_7	v_6	v_5		V_4	V_3		V'''_2	
Sum	V_0	V_1	V_2	V_3	V_4	V'''_0	V'''_1	V'''_2	W_0	W_1
Difference	V'_0	V'_1	V'_2	V'_3		V''_0	V''_1		W_2	

	0—8		1—7		2—6		3—5		4
Sin. 22½°×				V'_3				V'_1	
Sin. 45°×			V'_2			V'''_1	$-V'_2$		
Sin. 67½°×				V'_1				$-V'_3$	
Sin. 90°×	W_0	W_1	V'_0		V''_0		V'_0		W_2
Sum, column 1									
Sum, column 2									
Sum	$16b_0$		$8b_1$		$8b_2$		$8b_3$		$8b_4$
Difference	$16b_8$		$8b_7$		$8b_6$		$8b_5$		

[1] F. Baur, Mehrjährige periodische Schwankungen des Niederschlags und des Luftdrucks im rechtsrheinischen Bayern (Deutsches Meteorol. Jahrbuch für Bayern 1922, Anhang D.)

[2] Loc. cit. Seite D. 7, Tabelle 2.

[3] Loc. cit. Seite D 4 und D 5.

[4] (Cf. F. Baur, Meteorol. Zeitschr. 1922, S 289, und 1923, S 91.)

Then the amplitude is $r_\gamma = \sqrt{a^2_\gamma + b^2_\gamma}$, the phase $\varphi_\gamma = \text{arc tg}\ \frac{8b_\gamma}{8a_\gamma}$.

For disclosure of possible underlying errors in the computation of coefficients one may appropriately employ the following proof:

1. $[(8a_1 + 8a_7) \cdot \sin. 22\tfrac{1}{2}° + (8a_2 + 8a_6) \cdot \sin. 45° + (8a_3 + 8a_5) \cdot \sin. 67\tfrac{1}{2}° + 8a_4] : 4 = u_1.$
2. $[(8a_1 - 8a_7 + 8a_3 - 8a_5) \cdot \sin. 45° + (8a_2 - 8a_6)] : 4 = u_2.$
3. $\Sigma 8 \cdot b_\gamma = 8 \cdot v_0.$
4. $[(8b_3 - 8b_5) \cdot \sin. 22\tfrac{1}{2}° + (8b_2 - 8b_6) \cdot \sin. 45° + (8b_1 - 8b_7) \cdot \sin. 67\tfrac{1}{2}° + (8b_0 - 8b_8)] : 4 = v_1.$

From the well-known formula for the pressure change at the surface

$$\Delta P = p\Delta\frac{P}{p} - \frac{Pgh}{RT^2}\Delta T$$

we have, if $\Delta T = O$, the "assumed value" of the amplitude of the 3.2-year pressure oscillation in the higher levels,

$$\Delta p = \Delta P\frac{p}{P}$$

in which ΔP indicates the amplitude at the surface, p *and* P *the (16-year) mean of the pressure aloft and at the* surface. Then we obtain:

For the 1,000-meter level above Lindenberg $\frac{674.2}{750.6} \cdot 1.021 = 0.917$

For the 2,000-meter level above Lindenberg $\frac{595.4}{750.6} \cdot 1.021 = 0.810$

For the 3,000-meter level above Lindenberg $\frac{524.5}{750.6} \cdot 1.021 = 0.713$

For the Zugspitze $\frac{528.8}{676.6} \cdot 0.743 = 0.581$

For the Säntis $\frac{561.9}{719.3} \cdot 0.634 = 0.495$

The fact that the amplitudes of the 3.2-year periods in all the higher strata are not less than the assumed *value shows incontestably that the 3.2-year period pres*sure oscillations are based upon the periodic procedure aloft; the fact that throughout they are even greater than the assumed value and that their absolute values increase from the 1,000 to the 3,000 meter level above Lindenberg and from the high Peissenberg to the Zugspitze have their sufficient explanation in the results of the analysis of the annual mean temperature at 3,000 meters above Lindenberg and on the Zugspitze. The 3.2-year period in temperature is clearly shown aloft, and, indeed, the temperature maximum nearly coincides with the maximum pressure. The phase difference resulting from the computation (Zugspitze, 11° 19′, Lindenberg, 3,000 m., 25° 20′) may have its cause in the simultaneous existence of still other real periods that are not present in the temperature, or vice versa; and, moreover, at Lindenberg the lack of homogeneity of the data exercised a limited influence in the way of an apparent phase disarrangement. The nearly simultaneous temperature increase with pressure increase at the 3,000-meter level permits the assumption that the periodic pressure oscillation is not a pure dynamic effect but that the pressure increase may be ascribed to a cold inflow in the stratosphere combined with warming of the troposphere; the oscillation, that is to say, can be traced to the periodic displacement of the equatorial front.

Noteworthy also is the quite uniform increase over Lindenberg of phase relations with altitude. The maximum pressure occurs about 9 days earlier at the 3,000-meter level than at *the 2,000-meter level and* 9 days earlier at the latter than at 1,000 meters. There is perhaps reason to question the reality of these phase shiftings as the computations were made from annual means

Table of annual means, amplitudes, and phases

	Air pressure									Temperature	
	Lindenberg				Bavaria			Switzerland		Lindenberg	
	Surface	1,000 m.	2,000 m.	3,000 m.	On a plain (4 stations)	Higher Peissenberg	Zugspitze	Zurich	Säntis	3,000 m.	Zugspitze
	(122 m.)					(994 m.)	(2,962 m.)	(493 m.)	(2,500 m.)	°C.	°C.
Annual means:											
1905								19.9	62.0		
1906	50.1	73.8	95.1	24.3	28.62	76.6	29.5	19.5	61.9	−6.0	−5.2
1907	50.9	74.4	95.4	24.5	28.97	76.8	29.7	19.7	62.2	−6.3	−5.2
1908	51.8	75.4	96.7	25.9	29.77	77.5	30.2	20.4	62.7	−5.6	−5.1
1909	49.9	73.4	94.5	23.8	27.92	76.0	28.5	18.7	61.0	−6.8	−6.0
1910	49.0	72.9	94.3	23.7	27.12	75.6	28.6	18.0	60.8	−6.1	−5.6
1911	51.5	75.1	96.2	25.3	29.56	77.5	30.2	20.2	63.2	−6.5	−4.6
1912	50.1	73.5	94.5	23.4	28.46	76.3	28.3	18.4	61.8	−7.7	−5.5
1913	51.2	74.7	95.7	24.7	29.39	77.1	29.2	20.0	62.8	−6.7	−5.0
1914	50.4	74.3	95.7	24.9	28.57	76.3	28.6	19.2	62.0	−5.7	−4.8
1915	49.1	72.9	93.9	23.0	26.96	74.8	26.9	17.6	60.4	−7.3	−5.5
1916	48.8	72.8	94.2	23.5	27.10	75.2	27.6	17.9	61.0	−6.2	−4.5
1917	50.6	74.2	95.2	24.3	28.35	76.1	27.8	19.0	61.5	−6.6	−5.3
1918	51.3	75.1	96.3	25.4	29.31	77.3	29.1	20.0	62.7	−6.3	−4.8
1919	49.7	73.3	94.3	23.2	27.73	75.7	26.8	18.5	60.7	−7.5	−6.2
1920	52.4	75.8	97.1	26.4	30.03	78.0	29.9	20.5	63.4	−5.2	−3.3
1921	52.7	76.1	97.2	26.4	30.43	78.4	30.3			−5.3	−3.8
16-year mean	50.6 +700 mm. Hg.	74.2 +600 mm. Hg.	95.4 +500 mm. Hg.	24.5 +500 mm. Hg.	28.64 +700 mm. Hg.	76.6 +600 mm. Hg.	28.8 +500 mm. Hg.	19.3 +700 mm. Hg.	61.9 +500 mm. Hg.		
Amplitudes:											
16-year	0.698	0.595	0.610	0.654	0.626	0.685	0.992	0.511	0.270	0.461	0.326
8-year	0.680	0.554	0.517	0.445	0.699	0.661	0.474	0.542	0.524	0.251	0.419
5.3-year	0.337	0.272	0.201	0.116	0.418	0.272	0.283	0.563	0.369	0.284	0.328
4-year	0.493	0.380	0.380	0.415	0.419	0.381	0.276	0.276	0.213	0.285	0.305
3.2-year	1.021	0.994	1.015	1.038	0.842	0.743	0.772	0.634	0.629	0.575	0.529
2.7-year	0.239	0.298	0.338	0.345	0.252	0.290	0.333	0.140	0.136	0.237	0.212
2.3-year	0.404	0.402	0.426	0.468	0.408	0.403	0.553	0.451	0.706	0.216	0.409
r′=	0.553	0.499	0.498	0.497	0.523	0.491	0.526	0.445	0.406	0.330	0.361
1.5 r′=	0.830	0.749	0.747	0.746	0.785	0.736	0.789	0.668	0.610	0.495	0.542
Phase *of the* 3.2-year *period from* 1.VII, 1921	136° 24′	137° 38′	140° 23′	140° 3′	134° 49′	136° 30′	146° 15′	140° 26′	146° 11′	168° 23′	157° 34′

The boldface amplitudes are the maxima of either analysis. The underlined amplitudes are greater than 1.5 r′, where $r' = \frac{[r]^7}{7}$.

only. These doubts are well justified inasmuch as the true phase shifting is possibly of another magnitude; nevertheless the approach of the extreme of pressure oscillation earlier at the higher levels than at the lower appears to be real, as the phase shifting between Zugspitze and high Peissenberg (with respect to the Bavarian lowland) and between Säntis and Zurich agrees in direction and order of magnitude with that between Lindenberg at 3,000 meters and the surface. It may be seen therefrom how much more precise is the analytical than the customary graphic method for the investigation of periodic processes. In a horizontal direction there results a phase shifting from south to north in such a way that on Säntis (lat. 47° 15′) and on the Zugspitze (lat. 47° 25′) the extreme oscillation occurs about 10 days earlier than at the 3,000-meter level over Lindenberg (lat. 52°). From this result the assumption is permissible that the three to three and one-half year pressure oscillation in central Europe is dependent upon a periodic displacement of the equatorial front.

RAINFALL PROBABILITY DURING THE FIRE SEASON IN WESTERN WASHINGTON AND OREGON[1]

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If forest protective effort were adequate to absolutely prevent and suppress all forest fires, there would be less occasion to study quantitatively the hazards. But the funds are not adequate to give absolute protection. Hence protection has to be skimped in one region to bolster up that in another. The most intelligent distribution of resources in proportion to needs can be made only after some quantitative study of the several factors that go to make up fire danger.

It would help in the solution of the problem if each of the factors that go to make up the fire hazard could be measured and rated for each district—even for each tract of land. This is a goal to strive for—to measure and rate the inflammability based upon the amount and character of the combustible material on that tract, to estimate and rate the probability of fire starting, and then to rate the meteorological factors, the probability and local severity of low humidity spells, winds, and the chances of wetting rains, and put these elements together to make a fire danger index rating.

The present report—which is chiefly a set of graphs and maps [The latter not reproduced.—Ed.] aims to set forth in a preliminary way the rating of just one of the factors that contribute to the fire hazard—rainfall probability.

It has always been known that certain parts of this region had more summer rainfall than others, that some valleys were phenomenally dry, others so likely to have summer moisture as to be little worry to the protective agencies. This study was undertaken to find out what the Weather Bureau records might show as to summer rainfall at various points throughout western Oregon and Washington.

The results as presented in the graphs and maps will be of practical use to the protective agencies in getting a picture of one of the big underlying predisposing causes of forest fires, in seeing how much chance of rain they have to count upon in this locality as compared with that locality. They can better meet their opponent in the fire-fighting game if they know what the odds are against them.

It may be appreciated that the weather at any one station may in any one year be absolutely the reverse of the probability; i. e., these percentage chances of rain can not be used as indications of coming weather at any one station in any one period. These probabilities will be dependable over a term of years for a group of stations, just so far as the weather during series of past years is duplicated in the future.

Methods of making this study.—These were suggested by a paper read by Raphael Zon at Madison, Wis., in March, 1924, describing methods of drought prediction in Russia based on probabilities and entitled "Theory of probabilities in relation to climatic cycles as developed in Russia."

The present study consisted of assembling the United States Weather Bureau statistics for the region in such a way as to show how often during a term of years each station has had a good rain, a light rain, or no rain during each 10 days of the fire season. The printed records were used so far as they went, and beyond that the original records in the archives of the Portland and Seattle offices were consulted through the courtesy of Messrs. E. L. Wells and M. B. Summers. The compilation was performed by Mr. Louis Langdell.

All the stations in Western Oregon and Washington were used which had 10 or more years complete summer record. It so happened that there were exactly 50 such stations in each State. The compilation was prepared separately for each 10-day period from June 20 to September 10, which in the case of the last third of July and of August is actually an 11-day period. If a station in any 10-day period had 0.2 inch or more of rain in one or two days it was considered to have had a "wetting rain" or "good rain" in that period. This amount which has been used by other writers,[2] was selected arbitrarily as that which would subdue the forest fire menace for a few days. Recognition is given of the fact that the rate at which a rain falls and the type of cover it falls upon has much to do with its fire-deterrent effect. Ten-day periods which had a trace or more of rain but less than 0.2 inch in any two days were classed as having "light rains." If a station had no rain in a 10-day period it was so classified. The results of all the years, whether it be 10 years or 41, were assembled by 10-day periods for each of the 100 stations, and the percentage of times in each period that each station had "wetting rains," "light rains," or "no rains" calculated. Thus Government Camp, for the period August 1 to 10, in the 25 years of record had wetting rains 7 times, light rains 3 times, and no rain 15 times. This indicates a probability of wetting rains 28 times out of 100, light rains 12 per cent of the time, and no rains 60 chances out of 100.

Presentation of data.—The results of analyzing this great mass of meteorological statistics are assembled in the graphs shown on pages 396–397, one for Washington and one for Oregon. They show for each station what its chances are (based on its history) for a good rain, a light rain, and no rain, all given in percentages, for each of the 10-day periods.

[1] The term "rainfall probability" as here used connotes percentage frequency of rainfall of certain intensities; it should not be confused with results which may be deduced by the methods of the mathematical theory of probability.—Ed.

[2] Gisborne in "Measuring and Forecasting Forest Fire Danger in Northern Idaho" considers that ".20 inches or more in 24 hours is sufficient to eliminate fire danger in northern Idaho."