SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 106, NUMBER 22
(End of Volume)

Roebling Fund

SOLAR CYCLES

BY

H. H. CLAYTON

(Publication 3870)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
MARCH 5, 1947

SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 106, NUMBER 22
(End of Volume)

Roebling Fund

SOLAR CYCLES

BY
H. H. CLAYTON

(Publication 3870)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
MARCH 5, 1947

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

Roebling Fund

SOLAR CYCLES

By H. H. CLAYTON[1]

It is a generally accepted fact that certain terrestrial conditions such as auroras, magnetic character numbers, ionization of the upper atmosphere, and earth currents vary in close relation to the sunspot period of about 11 years.

There is also a semiannual period in these conditions with maxima at or near the equinoxes. Two suggestions have been made in explanation of this semiannual period. One is that the sunspots are more directly pointing toward the earth at the equinoxes. The equator of the sun is inclined about 7 degrees to the plane of the earth's orbit, so that spots in the southern hemisphere are directed more nearly toward the earth in spring, and spots in the northern hemisphere are directed more nearly toward the earth in autumn. Another view is that the earth produces tides in the solar atmosphere which result in a slight increase in sunspots at the time of the equinoxes. Evidence of a semiannual period in sunspot areas was presented by Henryk Arctowski[2] in 1916. He found two small maxima in sunspot areas, one near the spring equinox and the other near the autumn equinox. This research was followed by an investigation of Dr. L. A. Bauer[3] in 1924. He found a small semiannual oscillation in sunspots of an amplitude of about two spots with maxima in March and October, corresponding with similar oscillations in the atmospheric electrical potential gradient at Ebro, in earth currents, in the annual frequency of auroras, and in magnetic character numbers, all of which are known to be intimately associated with changes in sunspot numbers.

Since the first arrangement and publication of sunspot numbers in tables, by R. Wolf in 1859, there has been speculation and research concerning the question as to whether the planets in their revolutions around the sun might not be the origin of sunspot changes.[4]

---

[1] Published posthumously. The author died October 27, 1946.

[2] Mem. Soc. Spettroscopisiti, vol. 5, pp. 98-99, 1916.

[3] Terrestrial Magnetism and Atmospheric Electricity, vol. 29, pp. 23-28, 161-186, 1924.

[4] Wolf, R., Compt. Rend. Acad. Sci. Paris, vol. 48, p. 231, 1859; De la Rue, W., Stewart, B., and Loewy B., Proc. Roy. Soc. London, vol. 20, pp. 210-218, 1872; Birkeland, Kr., Recherches sur les taches du soleil et leur origine, Skrift. Vidensk., vol. 1, Christiania, 1899; Brown, E. W., A possible explanation

The arguments of Prof. Arthur Schuster in regard to the possibility of small tides in the solar atmosphere, published in the Proceedings of the Royal Society of London in 1911, interested me, and I undertook a research on the subject, using more than a hundred years of sunspot observations, namely, from 1837 to 1938. The results of my studies are plotted in figure 1 and compared with the results of Arctowski.

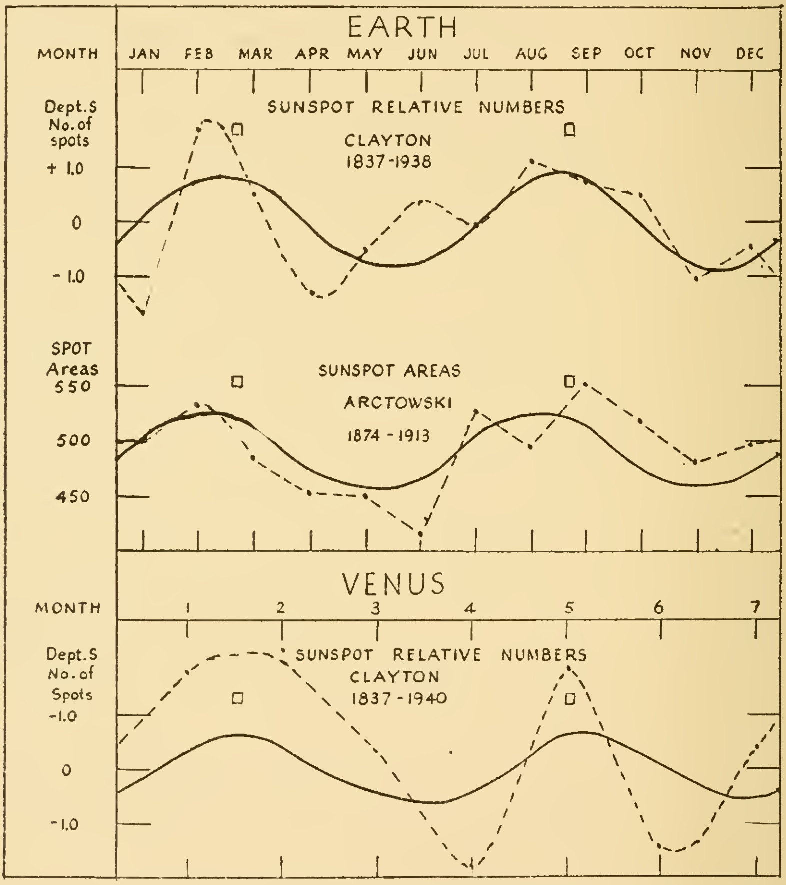

Fig. 1.—Variations in the number and area of sunspots during sidereal revolution of the earth and Venus. Small squares show positions when exerting greatest precessional pulls on the sun.

of the sunspot period, Monthly Notices, Roy. Astron. Soc., vol. 60, pp. 599-606, 1900; Pocock, R. J., The relative numbers and areas of sunspots east and west of the central meridian during the years 1902-1917, Monthly Notices, Roy. Astron. Soc., vol. 79, p. 54, November 1918; Schuster, A., The influence of the planets on the formation of sunspots, Proc. Roy. Soc. London, vol. 85, pp. 309-323, 1911.

The dotted curves show the observed numbers and the continuous curve shows the values computed from them by harmonic analysis. The maxima for the earth come very near the points when the earth is at its greatest distance above and below the plane of the sun's equator, as shown by the small squares in the diagram. In like manner the averages for the planet Venus show maxima near the points of greatest distance above and below the plane of the sun's equator.

Recently I made a renewed study of this subject in which the revolutions of Mercury were included. Because of the shorter period of Mercury, this study required the use of daily observations of sunspots, for which data from Zurich were available for the years 1917 to 1944. The means gave evidence of a compound period and hence were analyzed by a Fourier series into periods a_1 and a_2, etc. The results for a_2 are

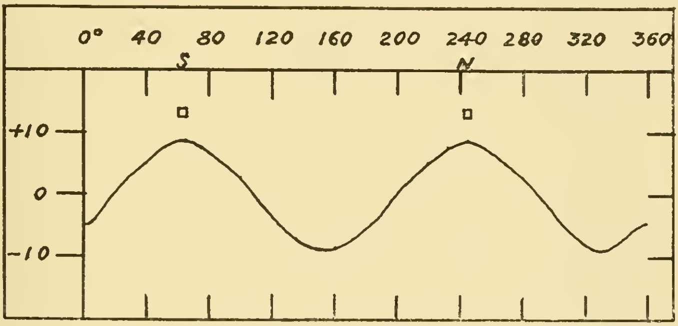

FIG. 2.—Averages of daily sunspot numbers, 1917-1944, in periods of 87.97 days. The letters N and S indicate the points where the planet was at its greatest distance north and south of the solar equator.

shown in figure 2. The plot shows an oscillation in sunspot numbers corresponding with a half-period revolution of Mercury. Maxima occurred at the times when Mercury was at its greatest distance south and at the times when Mercury was at its greatest distance north of the sun's equator. See the letters S and N in figure 2. The results for the three planets are so consistent that accidental coincidence with the requirements of the hypothesis seems impossible.

Another finding by Arctowski was that, when the sunspot areas given in the publications of the Greenwich Observatory were submitted to analysis, the oscillation in sunspot areas in the northern and southern hemispheres of the sun were in opposite phase. When the earth was south of the sun's equator there was an excess in the sunspot areas of the southern hemisphere, but when the earth was north of the sun's equator there was an excess in the areas north of the equator. It seemed worth while to extend this research to recent observations of sunspot areas. Data for this purpose were found in the measurements of sunspot areas made at the United States Naval Observatory and published in the Monthly Weather Review for the years 1927-1945. These data were averaged in periods of 365.25 days, and the means were subjected to harmonic analysis in a Fourier series extending down to harmonics of the annual period of one-fortieth of a year.

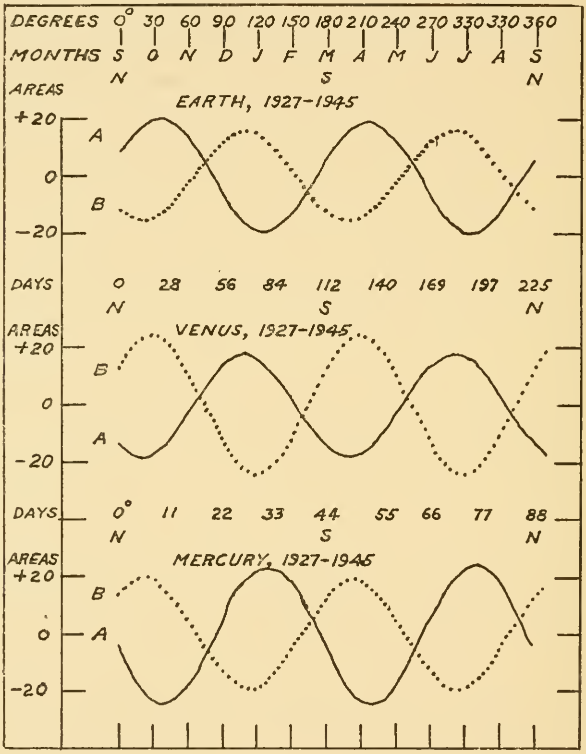

FIG. 3.—Oscillations in sunspot areas in the northern and southern hemispheres of the sun for half the period of revolution of each of three planets, Earth, Venus, and Mercury. The continuous curve, A, shows oscillations in the northern hemisphere of the sun. The dotted curve, B, shows oscillations in the southern hemisphere. These are sine curves computed by harmonic analysis from the observed data. The letters N and S indicate the points where the planets were at their greatest distance north and south of the solar equator. The data on sunspot areas were taken from the reports of the U. S. Naval Observatory, Washington, D. C., for the years 1927-1945.

The spot areas are measured in millionths of the total area of the sun's disk. Taking as a starting point the date when the earth was at its greatest distance north of the equator, the position of the maximum spot area in the northern hemisphere for the full annual period was at 300° with an amplitude of 20 spot areas. For the southern hemisphere it was at 345° with an amplitude of 23 spot areas. That is, both maxima occurred when the earth was near perihelion. For the half-year period, however, plotted in figure 3, the oscillations were in opposite phase in the two hemispheres of the sun.

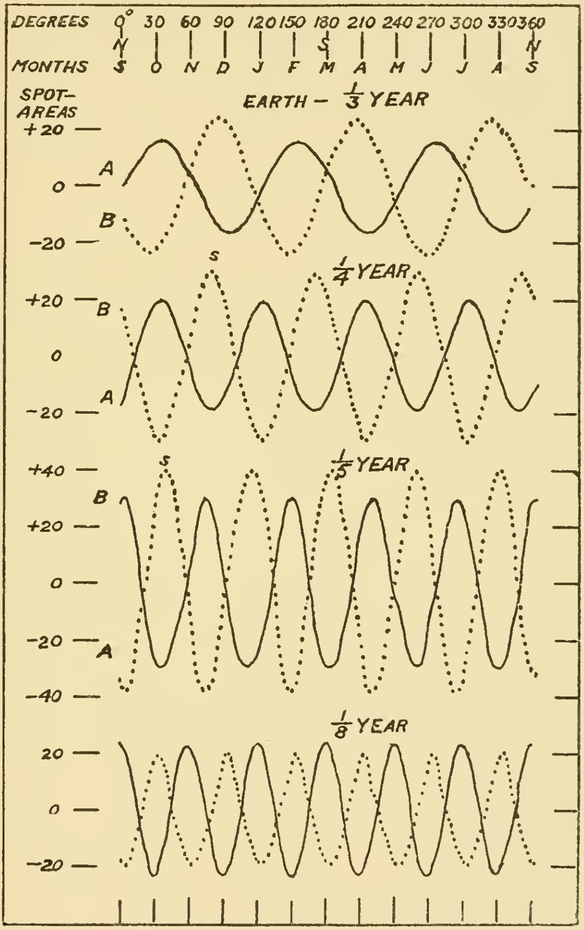

FIG. 4.—Harmonics of the annual period of the earth computed from observations of sunspot areas 1927-1945, averaged in monthly means and analyzed in a Fourier series. The continuous curves, A, show sine curves for the northern hemisphere of the sun. The curves B show sine curves for the southern hemisphere. The data were derived from reports of the U. S. Naval Observatory, Washington, D. C. The letters N and S indicate the points when the earth was at its greatest distance north or south of the solar equator.

This opposition in phase is shown also by most of the shorter harmonics of the yearly period, in many of which the amplitudes of the oscillations were larger than that of the yearly and half-yearly periods. The oscillations in the period of one-third, one-fourth, one-fifth, and one-eighth of a year are plotted in figure 4. This plot shows that the oscillations for the period of one-fourth and one-fifth years were larger than the amplitude of the annual and semiannual period. They show further that in most cases the oscillations in the southern hemisphere are of a larger amplitude than those in the northern hemisphere. It is difficult to interpret the full meaning of these findings, but the most satisfactory hypothesis is that the annual curve results from the nearer approach of the planet to the sun at perihelion, and that the larger oscillation in the southern hemisphere in the half-year period is due to the fact that the planet is then nearer perihelion where the attraction of the sun is greater.

Similar averages of sunspot areas were obtained for the periods of Venus (224.7 days) and of Mercury (87.97 days) and then were subjected to harmonic analysis. The full period of Venus shows a maximum near its perihelion, while the half-year period shows opposing oscillations, as will be seen from figure 3. Opposing oscillations were also found in the periods of one-third, one-fourth, and other harmonics of Venus, but not so strikingly as in the same harmonics of the yearly period of the earth. The inclination of the orbit of Venus to the plane of the sun's equator is only 3°50′ instead of 7°10′ as in the case of the earth.

The orbit of Mercury is inclined 3°23′ to the plane of the sun's equator. In the half period of Mercury the same opposition is found in the oscillations in the northern and southern hemisphere of the sun as was found for the earth and Venus (see fig. 3). But the harmonics of one-third, one-fourth, and one-fifth of the period of Mercury are found in the same phase in both hemispheres. This result may be due to the fact that the orbit of Mercury is more eccentric than that of the other planets, and the oscillations of sunspots are influenced more by the varying distance of the planet from the sun than by the north and south pull when the planet is above and below the plane of the solar equator.

The data for these studies were derived from the table on page xvii of the American Nautical Almanac and from table 36 in "Earth and Sun," by Ellsworth Huntington.[5] Also I was aided in their understanding and proper use by Edgar W. Woolard of the Naval Observatory.

It may be noted that the sunspot changes found in the preceding investigation are small, as were also the changes found by preceding investigators. Perhaps it is for this reason that it is generally believed

[5] Yale Press, 1923.

that planetary influence in producing sunspot changes is so small that if it exists it is negligible.

However, in the course of my investigations I discovered that when two planets acted simultaneously their combined influence was much greater than the sum of the influences of the two planets acting separately. The periods of Venus and the earth are so related that they come back to almost the same positions after a period of 8 years. Also the periods of Mercury are so related to the annual period of the earth that they reappear in a similar pattern each 10 years and come back nearly to the same point after an interval of 20 years. The closest return of Mercury and Venus to the same heliocentric longitude occurs about every 11 years. The three planets Earth, Venus, and Mercury also approach the same place at an average interval of about 11 years.

When the monthly sunspot numbers from 1749 to 1944 are averaged in periods of 8, 10, and 11 years, using approximately the dates when the planets were nearest each other, the amplitude of the oscillations were 15 spots for the period of coincidental influence of Venus and Earth, 35 spots for the period of Mercury and Earth, 65 spots for the period of Mercury and Venus, and 68 spots for the average of the nearest approach of the three planets, Mercury, Venus, and Earth.

The nearest approach of the three planets since the beginning of continuous observations about 1830, was 1870 when the time of arrival of all three planets at their greatest departure south of the plane of the sun's equator differed less than 3 days. The monthly sunspot numbers rose from zero in January 1867 to 176 in May 1870, thus showing the largest oscillation in number of sunspots occurring during the past century. The most logical explanation of the great increase in the number of spots with the coming together of two or more planets is that of resonance. It is said that a band playing while crossing a bridge may set the entire structure in oscillation if the music includes the keynote of the bridge.

Harlan T. Stetson, who suggested the possibility of resonance in his book, "Sunspots and Their Effects," [6] writes on page 183:

> On the basis of any accepted tidal theory one would expect that each planet in turn would raise tides, however slight, in the solar atmosphere approximately equal and opposite. The raising of such tidal waves would immediately set the whole solar atmosphere into oscillation, sending an atmospheric wave around the sun which would travel at a speed that would depend upon the density and the gravitational attraction. Each planet, in turn, would start its own similar oscillation, and the composite tidal wave at any moment would therefore depend upon the positions of the planets with respect to each other.

---

[6] McGraw Hill, 1937.

As the sun rotates carrying the atmospheric particles past the point of major attraction, successive pulses would be increasing the amplitude of the waves so long as the period of oscillation of the atmosphere was comparable with the intervals between successive pulses. In this way it is possible that even the slight tide-raising forces of the planets could in the course of time set up a major oscillation in the sun's atmosphere, very much the way in which synchronized footsteps of a regiment may set a steel bridge asway.

I have anchored off my summer place in Maine a forty-foot cabin cruiser. It is of sufficient tonnage so that ordinary movements about the boat do not perceptibly set it in motion. Sometimes, as a matter of amusing experiment, I have stood in the cabin astride the fore-and-aft line and allowed my weight to fall alternately first on one foot and then on the other. Now, the weight of 150 pounds pressing in the floor of a fifteen-ton boat, a foot from the fore-and-aft line, produces of itself no perceptible list. Knowing, however, the natural period of roll of the boat and using this as an interval for alternating the pressure from right to left, I can make the boat roll violently in a very few minutes. It can be stopped equally quickly by reversing my movements, thus making the small force which I can exert oppose the natural roll of the boat.

It is shown in figure 4 that the annual revolution of the earth produces harmonic oscillations of short period. This is true also for the

TABLE 1.—*Length of the harmonic periods in days in Mercury, Venus, and Earth*

Earth	Venus	Mercury	Solar rotation
1/5 = 73.0	1/3 = 74.9	....	....
1/8 = 45.6	1/5 = 44.9	1/2 = 44.0	....
1/10 = 36.5	1/6 = 36.5	....	....
1/12 = 30.4	1/8 = 28.1	1/3 = 29.0	P = 27.36
1/16 = 22.8	1/10 = 22.5	1/4 = 22.0	....
1/20 = 18.2	1/12 = 18.7	1/5 = 17.6	....
1/32 = 11.4	1/20 = 11.2	1/8 = 11.0	....
1/40 = 9.1	1/24 = 9.3	1/10 = 8.8	1/3 = 9.1
1/48 = 7.6	1/30 = 7.5	1/12 = 7.3	1/4 = 6.8
1/64 = 5.6	1/40 = 5.6	1/16 = 5.5	1/5 = 5.5

planets Mercury and Venus. Furthermore, many of the harmonics of the three planets agree closely in length of oscillations, as will be noted in table 1.

The fact that oscillations in sunspots approximately coincide with north and south positions of the planets above or below the plane of the sun's equator led William A. Luby to suggest that the oscillations were of the nature of precessional pulls on an oblate sun similar to the precessional pull of the moon on the oblate earth when the moon is north or south of the earth's equator. If such a force is exerted by the planets on the surface of the equatorial bulge of the sun, there would be a surface current moving toward the north when the planet was on the north side of the equator and moving toward the south when the planet was on the south side of the equator. On such an hypothesis one could explain the opposing oscillations in the northern and southern hemispheres of the sun found by Arctowski and by me. At latitudes 30° to 45° on the sun, matter carried to great heights is falling back toward the surface of the sun. The orbit of all the planets is near the plane of the sun's equator, and if one could assume a precessional pull toward the equator exerted by the planets on this matter, then one could explain the formations of the horizonal rolls on the surface of the sun such as are demanded by the theory of sunspot formation formulated by Bjerkness, and now widely accepted.

Whatever may be the process by which sunspots are generated, the observational data clearly indicate oscillations in the number of sunspots related to the planetary periods in length. Some of these harmonic periods are shown in figure 4, and my analysis of sunspot and terrestrial data strongly indicate short-period oscillations of 4.5, 5.5, 7, 9, and 11 days.[7]

These oscillations increase and decrease in intensity, and the united influence of several planets could easily set the sun's surface into violent agitation. It will be seen from table 1 that periods of 22.5 days, 18.2 days, 11.2 days, and 7.5 days are close to harmonics of the three planets, Earth, Venus, and Mercury, while 9.1 and 5.6 days are close to the harmonics of the solar rotation period and also to harmonics of the planetary periods.

In order to investigate this question in more detail, the dates when the planets were nearest together at the critical heliocentric longitudes mentioned above were taken from British and American Nautical Almanacs from 1830 to 1946. The tabulation of these data in table 2, shows that still another factor enters into the problem of timing these returns. The earth and Venus, for example, approach and pass each other 5 times in 8 years, that is, at intervals of about 9 months, and at the end of 8 years differ only .083 day from coinciding, 13 periods of Venus being that much shorter than 8 periods of the earth.

Table 2 shows that from 1830 to 1886 these planets came closest at intervals of about 8 years when Earth and Venus were south of the solar equator, then in 1886 stepped forward a half year to when Earth and Venus were north of the solar equator. This makes the average lengths of the period somewhat greater than 8 years.

---

[7] See Solar relations to weather, vol. 2, pp. 29-49, 257-260, 268, 368, and 415, 1943.

TABLE 2.—*Times of arrival of Venus and Earth at their greatest distances above and below the sun's equator*

South			North		
Venus	Earth	Diff., days	Venus	Earth	Diff., days
1830—Mar. 5	Mar. 5	0	1895—Sept. 11	Sept. 7	+4
1838—Mar. 5	Mar. 5	0	1903—Sept. 11	Sept. 7	+4
1846—Mar. 4	Mar. 5	—1	1911—Sept. 10	Sept. 7	+3
1854—Mar. 3	Mar. 5	—2	1919—Sept. 9	Sept. 7	+2
1862—Mar. 2	Mar. 5	—3	1927—Sept. 8	Sept. 7	+1
1870—Mar. 1	Mar. 5	—4	1935—Sept. 7	Sept. 7	0
1878—Mar. 1	Mar. 5	—4	1943—Sept. 7	Sept. 7	0
1886—Feb. 28	Mar. 5	—5	1951—Sept. 6	Sept. 7	—1

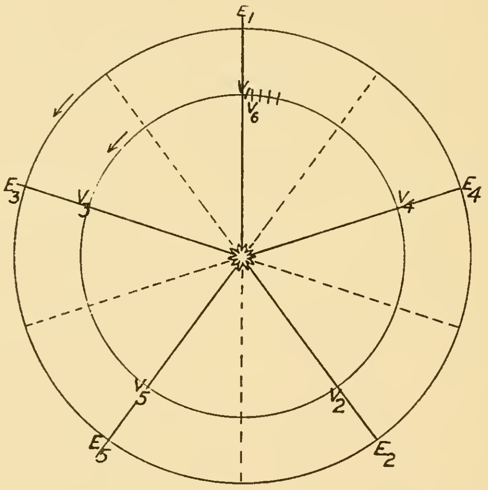

FIG. 5.—Illustrating the revolutions of Venus and Earth. Venus overtakes and passes the earth in about 19 months, as indicated by the letters E_1, E_2, E_3, and E_4. After 8 years they return near to the point E, but about 0.8 day behind E_5. This small difference accumulates, so that after about seven periods of 8 years the planet V is more than halfway back to the earth's position on the opposite side of the sun's equator. The planets then approach a meeting at that point in their orbit. This occurs in about 12 periods of 8 years so that the average length of the period is somewhat greater than 8 years. See table 2.

Figure 5 is intended to illustrate the passing of two planets after intervals of about 19 months and the return of Venus to the point V_6. This difference slowly accumulates after each 8 years and after about 7 periods of 8 years the planet is more than halfway back toward the place where the two planets are on the opposite side of the sun's equator. That is, assuming that the planets coincide in time when at their nearest approach north of the sun's equator, after about 12 periods of 8 years they will coincide in time when farthest south of the sun's equator. This fact is illustrated in table 2, showing the days of nearest approach in time of the two planets when at their greatest distance north and south of the sun's equator. These data were derived from the U. S. Nautical Almanac.

TABLE 3.—*Dates of nearest approach in time of the planets Mercury and Venus when at their greatest distance above and below the sun's equator*

Planets North			Planets South		
Mercury	Venus	Diff., days	Mercury	Venus	Diff., days
1834—Mar. 4	Mar. 6	—2	1836—Dec. 6	Dec. 9	—3
1839—Sept. 17	Sept. 18	—1	1842—June 21	June 24	—3
1845—Apr. 1	Apr. 1	0	1848—Jan. 5	Jan. 7	—2
1850—Oct. 15	Oct. 14	+1	1853—July 20	July 21	—1
1856—Apr. 30	Apr. 27	+3	1859—Feb. 2	Feb. 2	0
1861—Nov. 13	Nov. 10	+3	1864—Aug. 17	Aug. 16	+1
1867—May 29	May 24	+4	1870—Mar. 2	Mar. 1	+1
1872—Dec. 13	Dec. 6	+7	1875—Sept. 15	Sept. 13	+2
1879—Sept. 10	Sept. 13	—3	1881—Mar. 31	Mar. 27	+4
1885—Mar. 25	Mar. 27	—2	1886—Oct. 14	Oct. 10	+4
1890—Oct. 8	Oct. 10	—2	1893—July 12	July 16	—4
1896—Apr. 23	Apr. 23	0	1899—Jan. 26	Jan. 28	—2
1901—Nov. 7	Nov. 6	+1	1904—Aug. 11	Aug. 13	—2
1907—May 23	May 21	+2	1910—Feb. 24	Feb. 25	—1
1912—Dec. 5	Dec. 3	+2	1915—Sept. 10	Sept. 9	+1
1918—June 21	June 17	+4	1921—Mar. 26	Mar. 24	+2
1923 } 1924 } Jan. 4	Dec. 30	+5	1926—Oct. 8	Oct. 6	+2
1930—Oct. 3	Oct. 6	—3	1932—Apr. 23	Apr. 20	+3
1936—Apr. 17	Apr. 19	—2	1937—Nov. 6	Nov. 2	+4
1941—Oct. 31	Nov. 2	—2	1943—May 22	May 17	+5
1947—May 16	May 17	—1	1950—Feb. 18	Feb. 22	—4

The planets Mercury and Venus return to near the same point in about 11 years, Mercury makes 46 revolutions in 11.07910 years, while Venus makes 18 revolutions in 11.07373 years. The difference is .00537 year or 1.96 days. However, on account of this small difference the cycle after about 5 intervals of 11 years steps forward suddenly to a length of more than 12 years and returns closely to its original position after a period of 56.6 years. This makes the average length of the cycle about 11.32 years.

This fact is evident in table 3 where the dates are given of closest approach of the planets to each other at their critical points north and south of the solar equator. Note the alternate intervals.. These data were taken from the British and American Nautical Almanacs and show the computed places from 1834 to 1950.

Another method of approach in studying the movements of the planets is to plot the nearness of approach in time of the planets in pairs when they are at their greatest distance above and below the sun's equator. Such a plot is shown in figure 6 for Mercury and Venus and for Venus and Earth, for the years 1901 to 1933. The peaks in the curve show near approach of the planets, while bottoms show that the planets were far apart. Mercury and Venus show 8 peaks in 11 years while Venus and Earth show 7, so that the peaks are in the same phase only once during each 11 years. The nearest approaches came in 1909, 1919, and 1930. The greatest activity in sunspots came 2 years earlier in each case when the peaks were approaching each other and planetary influence was increasing fastest.

TABLE 4.—*Pattern of about 80 years shown by the approximation in time of the three planets, Mercury, Venus, and Earth (within 30 days), when at their critical positions north and south of the sun's equator*

North of solar equator
Years of nearest approach

1748	1759	1767	1780	1788
1828	1839	1847	1860	1868
1908	1919	1927	1940	1948

South of solar equator
Years of nearest approach

1850	1758	1769	1779	1790
1830	1838	1849	1859	1870
1909	1918	1929	1937	1950

Another way of studying the data is to tabulate the dates since the beginning of sunspot observations when the three planets, Mercury, Venus, and Earth, were nearest to their critical points at the same time. Taking the cases where these planets reached their critical points on the same side of the sun, it is surprising to find that the interval between the occurrences is very irregular, when it is considered that the periods of meeting are derived from three periods, each nearly constant in length. There does appear, however, to be a pattern of about 80 years in the data which is illustrated in table 4.

The groups north and south tend to come in pairs, as for example 1748–1750, 1758–1759, 1767–1769, etc. It is interesting to note that all these pairs were years of high sunspot activity, while the intervals between them were periods of low sunspot activity. This fact will be seen in the plot of sunspot numbers shown in figure 7.

In this plot the smoothed sunspot numbers published at Zurich were used and values were plotted at intervals of 6 months. The first two

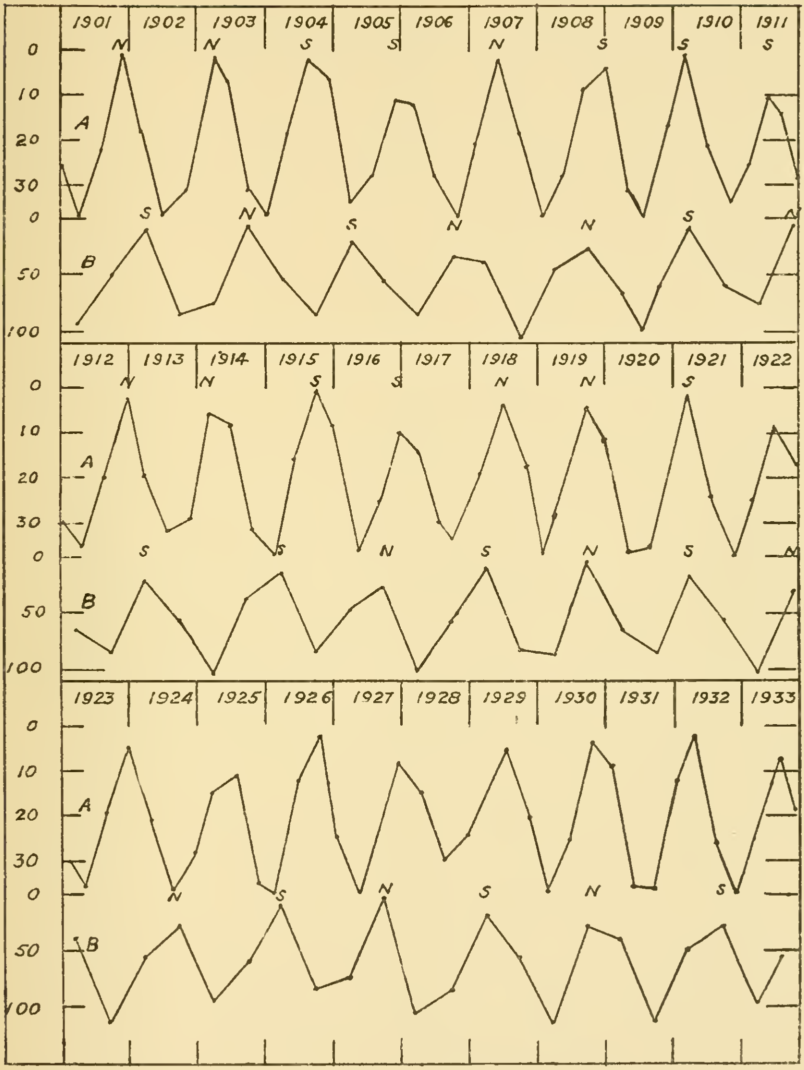

FIG. 6.—Plot of the interval between the dates when the planets Mercury and Venus, and Venus and Earth, are at their greatest distance north and south of the sun's equator. The letter N indicates the times of their meeting north of the equator, and the letter S the times of their meeting south of the equator. Peaks in the curve show approach to simultaneous time in meeting. The curve A is for Venus and Mercury, and curve B for Venus and Earth.

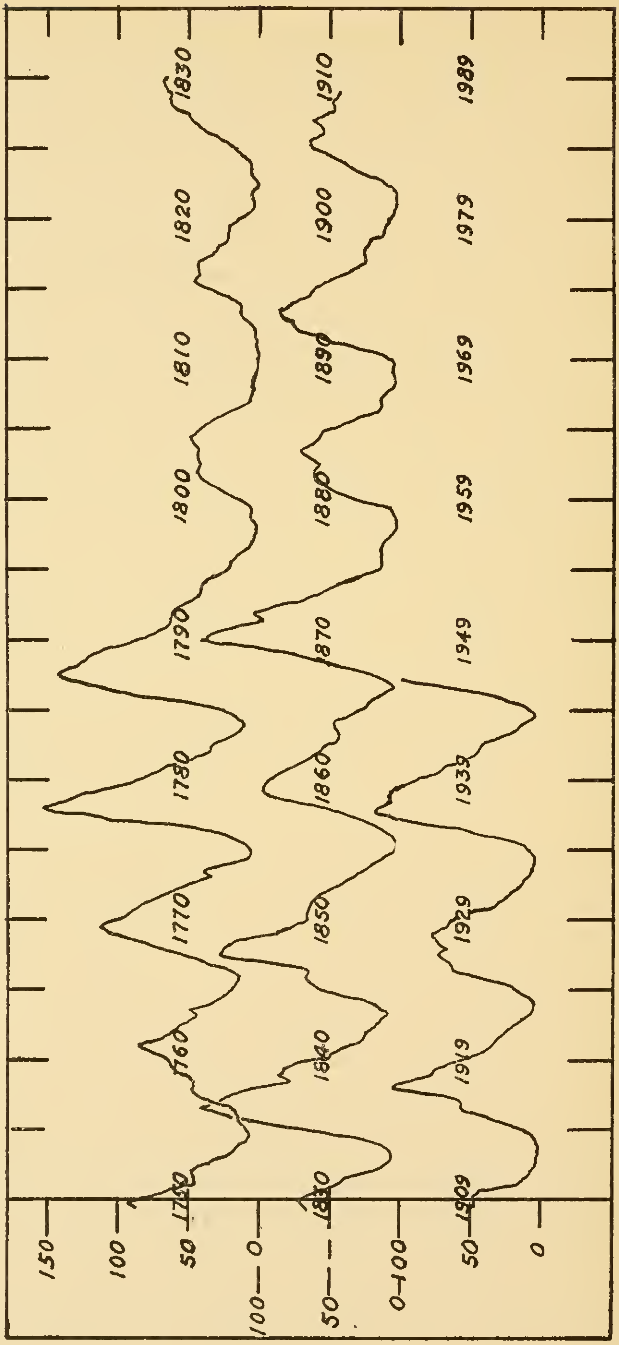

Fig. 7.—Plot of the smoothed sunspot numbers, 1750-1946, reported by the Swiss Federal Observatory at Zurich, showing approximate period of 80 years in sunspots.

curves are separated by an interval of 80 years, while the last two are separated by an interval of 79 years. The shortening of the last interval is warranted by the last row of figures in table 4.

The plot in figure 7 shows that during the first part of the period covered there were large oscillations in sunspots, culminating about the middle of the plot, followed by a long interval of lesser activity. This change may be due to an increase in the intensity of planetary influence as they approach nearer to a simultaneous meeting at their critical points, as indicated in figure 6. The interval separating the three planets was about 12 days in 1788–1790. It was 3 days in 1870 and will be about 9 days in 1951.

After 1785 and again after 1870 the intervals of time separating the planets when at their critical peaks decreased and solar activity also decreased. The present period of solar activity is tending to duplicate the pattern of 1778 to 1790. If this continues there should be a maximum of solar activity in 1947–1948, continuing at a high level through 1950 after which there would follow a long period of relative quietness. It should also be noted that the interval between the maxima is near 10 years when very active and longer when quiet. In closing this consideration of solar activity and planetary relations, I wish to emphasize the fact that these solar periods are irregular in length and amplitude and are not mathematical periods of constant length and amplitude. For this reason they cannot be treated by ordinary statistical methods and forecasts based on that assumption. Such forecasts are subject to failure. This is true whether the sunspot period is considered as a single period, or as a combination of periods.

That the planet Jupiter is also an influence in the formation of sunspots seems evident from the fact that during the past 80 years when Jupiter was north of the solar equator at the time of maxima of sunspots, as in 1854 and 1927, there were an excess of spots in the northern hemisphere. When Jupiter was south of the equator as in 1873 to 1895 at sunspot maxima there was an excess of sunspots in the southern hemisphere of the sun. This excess of spots in the two hemispheres is shown in figure 8. This diagram of excess of spots in the two hemispheres of the sun at successive maxima of spots was published by W. Brunner in the Astronomische Mitteilungen at Zurich, Nr. 144, p. 119, 1944.

Figure 9 shows a plot of the closeness of approach of the planets Mercury and Earth when at their critical points north and south of the solar equator. This pattern tends to repeat itself almost exactly at intervals of 20 years and approximately at intervals of 10 years. The ex-

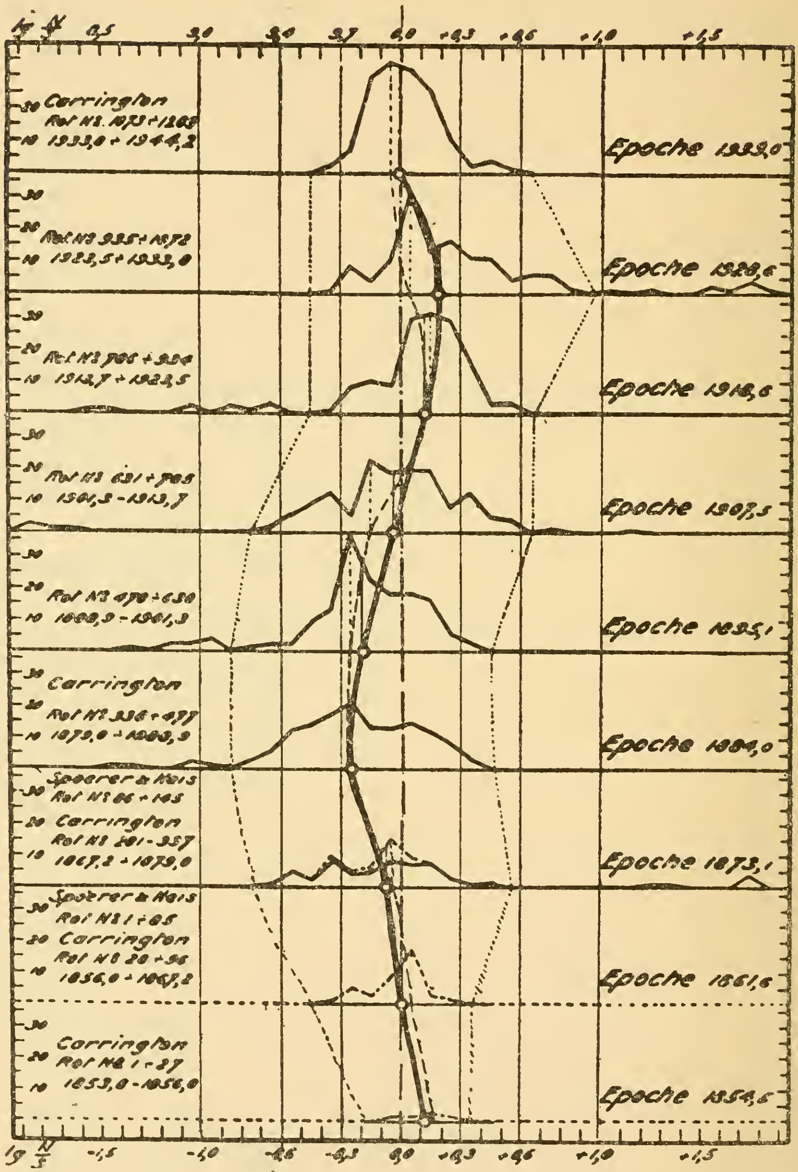

Fig. 8.—Long-period change in excess of spots in northern and southern hemispheres of the sun at time of maxima in sunspots, 1854-1938. (After W. Brunner, Astronomische Mitteilungen Zurich, 1944, Nr. 144, p. 119.)

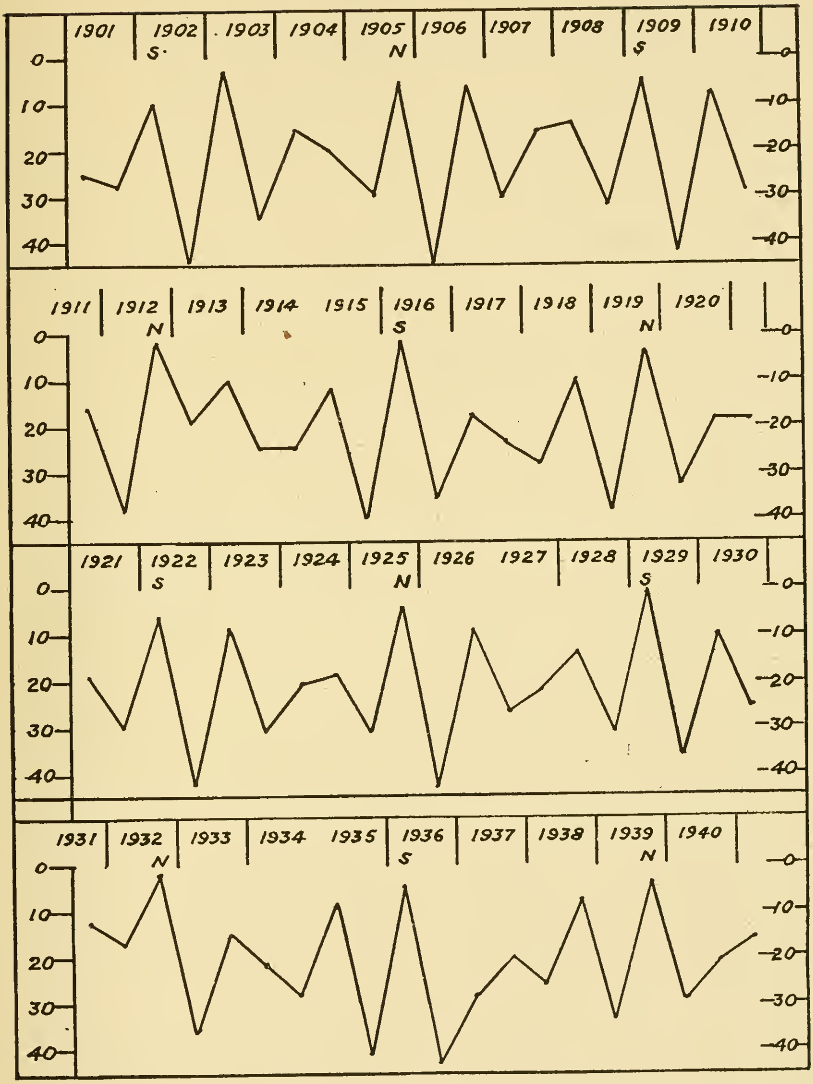

FIG. 9.—Plot of the intervals between the dates when Mercury and Earth were at their greatest distance north or south of the plane of the sun's equator. Peaks in the curve indicate the closeness of approach to simultaneous occurrence. The zero lines indicate no difference. The letters N and S show when the meeting was north or south of the solar equator. Three prominent peaks are found in each 10-year period at intervals of about 40 months.

act interval appears to be in alternate periods of 10.5 and 9.5 years. However, the 20-year period is not exact. After four intervals the nearest approach is 79 years instead of 80 years, so that the average length is 9.87 years rather than 10 years. This period of about 10 years is believed to be the same as that of the 10-year period found in sunspots, although the conjunction and opposition of Jupiter and Saturn is a period of nearly the same length and may contribute to the result.

The results arrived at in this discussion were derived chiefly from the researches of Henryk Arctowski and myself. They depend on two apparent facts:

1. That there are small oscillations in the number and size of sunspots associated with the passage of the planets Earth, Venus, and Mercury through certain critical points in their orbits.

2. These oscillations increase greatly in range when two planets approach their critical points nearly simultaneously. The increase in range follows in the order Venus and Earth, Earth and Mercury, and Mercury and Venus, the last giving the largest range.

3. The range becomes very large when the three planets Mercury, Venus, and Earth reach their critical points nearly simultaneously as in 1870, but more especially if a near approach in the northern hemisphere is followed or preceded within a year or two by a near approach in the southern hemisphere (see table 4).

I see no way of avoiding the logical conclusion that there is a relation between planetary positions and sunspots, unless it can be shown that the findings are erroneous or else some other explanation of them can be found. The findings are not dependent on any theory but on observed facts. I am quite aware that professional astronomers and meteorologists are averse to finding any relations between sunspots and planets, but so were the professional chemists averse to the idea that chemical elements could be changed until the coming of nuclear physics.