ART. XLI.—*On the Periodicity of the Rainfall in the United States in relation to the Periodicity of the Solar Spots*; by Professor JOHN BROCKLESBY, of Trinity College, Hartford, Ct.

THE researches of scientists, especially of late, lead to the conclusion that there is an intimate connection, more or less marked, between the solar disturbances and various terrestrial phenomena. Thus, upon comparing the mean daily range of the magnetic declination, and also the number of auroras observed each year, with the extent of the spots on the solar disk, a striking correspondence is observed in the curves which respectively represent these phenomena. A periodicity in the cyclones of the Indian Ocean and West Indies corresponding with that of the sun-spot area is asserted by Mr. J. N. Lockyer to have been established by Mr. C. Meldrum, Director of the Meteorological Observatory at Mauritius, and it is claimed by Mr. Meldrum and others that the variation in the annual rainfall conforms also to the sun-spot cycle of about eleven years. Various investigations likewise point to the inference that changes in the annual temperature of the atmosphere occur in cycles of ten or eleven years, coincident with those of the solar commotions.

It is proposed in this paper to discuss the alleged connection between the variations in the annual rainfall and the variations in the extent of the solar spots, as regards this continent, so far as we have data for the same.

At the meeting of the British Association last year, Mr. Meldrum, in a paper on the "Periodicity of Cyclones and Rainfall in connection with the Sun-spot Periodicity," remarked as follows: "With the help of the researches of Mr. Lockyer, Mr. Symons and Dr. Jelinek of Vienna, I have now examined ninety-three tables of rainfall for various parts of the world, and I find that, scarcely without exception, more rain falls in maxima than in minima sun-spot years. So far as observations go, Europe, Africa, America, and Australia give very favorable results. Asia is represented, however, only by three stations, and France, which affords as yet only five stations, is the only European country which presents results opposed to the theory."

From the comparatively small number of the tables of rainfall which Mr. Meldrum gives, and from his silence upon the subject, we may, I think, safely conclude that he did not consult Mr. Charles A. Schott's elaborate article on the "Rainfall in the United States," published by the Smithsonian Institution, a work which embraces abstracts of records of aqueous precipitation from about twenty-two hundred stations. The investigations, therefore, of Mr. Meldrum, so far as this country is concerned, may be regarded as incomplete.

As the following discussion is based upon Mr. Schott's tables, it may not be amiss to state briefly in what manner they have been so constructed and arranged that the variations in the annual rainfall throughout the United States admit of ready comparison with the changes in the extent of the solar spots.

From the whole number of stations whose mean annual rainfalls are respectively recorded, Mr. Schott selects one hundred and seven, which, on account of their extent of record, involve the smallest probable errors in their average rainfalls; and he then ascertains the ratio of each annual rainfall to the average yearly rainfall for every one of these stations. The period of record of these stations extends, with greater or less intervals, from 1799 to 1867.

To free these ratios from accidental irregularities and to exhibit the nature of the fluctuations from year to year more distinctly, the author unites them in groups, formed of stations where the annual rainfall appears subject to the same laws. Group I is composed of stations on the Atlantic sea board, extending from Maine to Virginia. Group II comprises the State of New York, and adjacent parts of Canada, New Hampshire, Massachusetts and Vermont; group III includes parts

of Iowa, Minnesota, Illinois and Wisconsin; group IV embraces the Ohio Valley, Ohio, Illinois, Indiana, Kentucky and part of Missouri; group V is formed of the Indian Territory and Arkansas; group VI comprises Louisiana, Alabama and West Florida; group VII comprehends the sea-coast from Virginia to Florida, and group VIII includes the sea-coast of California.

In these groups the percentage of the mean amount of rainfall is tabulated for each year of observation, the longest period of record extending from 1804 to 1867.

From the data thus afforded curves are constructed which present to the eye the annual fluctuations of the rainfall over the vast region embraced by these groups. Mr. Schott speaks briefly of the connection between the solar disturbances and the rainfall, stating that the rain curve for 1837-8 shows a decided minimum in precipitation, when there was a marked maximum of solar activity; but that the two phenomena lead to an opposite conclusion about the epoch of 1855-6; a minimum of rainfall then occurring with a minimum extent of sun-spot area. He does not enter into any detailed investigation of this supposed connection.

Under these circumstances, it appears, therefore, desirable, in order to detect what connection, if any, exists between the fluctuations of the annual rainfall and the variations in the extent of the solar spots, that these phenomena should be compared either year by year, or by groups of years; and this it is now proposed to do.

Taking Dr. Wolf's table of the relative extent of sun-spots for each year, within the period from 1804 to 1867 inclusive, in which period the yearly percentage of the average rainfall is also given in Mr. Schott's table of territorial groups, two methods of comparison can be employed if we wish to ascertain whether an annual excess of sun-spot area is attended by an excess of annual rainfall, and *vice versa*. The first mode is to take the average of the numbers representing the relative extent of the spots for the period mentioned, viz: from 1804 to 1867, then to note the years in the period that are above or below the average; and next to place the percentage of the mean annual rainfall opposite each year. We can thus detect whether an excess of sun-spot area in any year is marked by an excess of rain and deficiency of the former by a deficiency of the latter, or whether no such law exists. The second method is that adopted by Mr. Meldrum, who makes the comparison by forming quinquennial sets, taking two years on each side of the maximum year for a maximum set, and two on each side of the minimum year for a minimum set; or where this is not possible, a triennial group is formed.

Proceeding by the first method, it is found that the average sun-spot area for the period extending from 1804 to 1867 inclusive is denoted by the number 38. Taking now each year of this period, the year is printed in heavy or light type, according as the number representing its sun-spot area is greater or less than 38; heavy type indicating an excess and light type a deficiency. Each year is then also marked plus or minus from Mr. Schott's table of territorial groups, according as its rainfall is above or below the mean.

This being done, we have the following results. In group I, comprising the seaboard from Maine to Virginia, there are twenty-nine years in which the sun-spot area is above the average. In seventeen of these the rainfall is in excess, in ten below the average, and in two equal to it. In this group there are also thirty-five years when the sun-spot area is below the average. Out of these there are sixteen years when the rainfall is in excess and nineteen years when it is below the mean.

In group II, comprising the State of New York and adjacent parts of Canada, New Hampshire, Massachusetts and Vermont, there are twenty-five maxima sun-spot years. In fifteen of these the annual rainfall is in excess, in nine below the mean, and in one equal to it. There are also in this group seventeen minima sun-spot years, and in these the rainfall is in excess seven times, below the mean eight times, and equal to it twice.

In group IV, a region embracing the Ohio Valley, Ohio, Indiana, Illinois, Kentucky, and part of Missouri, there are twenty-five years of excess of sun-spot area, and in thirteen of these the rainfall is in excess of the mean, in twelve below it, and in one equal to it. There are also in this group twenty-five years when the extent of sun-spots is below the average, and in nine of these the rainfall is above the mean, in fourteen below the mean, and in two equal to it.

The tables of precipitation belonging to these three groups are regarded by Mr. Schott as tolerably trustworthy, and the results of the comparison show a tendency on the whole toward an excess of rain when there is an excess of sun-spot area, and *vice versa*. Yet we meet here with marked anomalies; for in the period from 1818 to 1826 inclusive, which are years of deficiency in solar activity, six annual rainfalls out of the nine are above the mean; and from 1835 to 1840 inclusive, which are years of excess in the sun-spot area, all the annual rainfalls in the three groups are below the average, except in one instance. Moreover, as we see by the table, years of excess and deficiency of rainfall are found as well in the periods when the sun-spot area is above the mean as in those where it is below it.

Passing now to the other territorial groups, the results from which are to be regarded as only rough approximations toward the truth on account of the insufficiency of the stations, we obtain the following results from all these taken together. In the years when the extent of the spots is in excess, the annual rainfall is above the mean thirty-five times, below it thirty-seven times, and equal to it five times. In the years when the sun-spot area is below the mean the rainfall is below the average thirty-two times, above it twenty times, and equal to it six times.

Taking now all the groups which embrace so large a portion of the United States, we obtain the following results in reference to the subject before us:

	Sun-spot area.	Ratio of the excess of rainfall (above the mean) in deficiency.
From 1804 to 1805 (inclusive),*	above the mean,	: 1
" 1806 to 1815	below " "	6 : 4
" 1816 to 1817	above " "	0 : 2
" 1818 to 1826	below " "	6 : 12
" 1827 to 1831	above " "	2 : 4
" 1832 to 1834	below " "	5 : 7
" 1835 to 1840	above " "	6 : 29
" 1841 to 1845	below " "	12 : 19
" 1846 to 1852	above " "	31 : 18
" 1853 to 1857	below " "	8 : 28
" 1858 to 1864	above " "	31 : 15
" 1865 to 1867	below " "	15 : 3

For the reasons already stated, namely, that groups I, II and IV. are only to be regarded as trustworthy, and that the rest give but rough approximations, the above results must be taken with great allowance. As they stand they are full of anomalies, about half the results favoring and the rest contradicting the law which is supposed to exist between the rainfall and the extent of the sun-spot area.

The results obtained by this first method of comparison are exhibited in the annexed table. (Table I.)

The second mode of investigating any relation which may exist between the annual fluctuations in the extent of the solar spots and the variations in the yearly rainfall, consists in forming groups of years, by taking one or two years on each side of the maximum and minimum year of any sun-spot period. As the mean secular period of the spots is about eleven years, quinquennial groups can generally be formed of maximum and minimum years of sun-spot area. When the period is short, triennial groups can be taken. This is the method adopted by Mr. Meldrum and other distinguished meteorologists.

* In 1804 the rainfall equals the mean also.

TABLE I.

Heavy type marks the years when the sun-spot area is above the average, viz. 38. Light type when below. + marks when the rain fall is above the mean. - when below. = when equal.

	Sea coast, Maine to Virginia.	State of N. York, and adjacent parts of Can., N. H., Mass., and Vt.	Parts of Iowa, Minn., Ill. and Wis.	Ohio Valley, Ohio, Ind., Ky., Ill. and part of Mo.	Indian Territory and Arkansas.	Louisiana, Alabama and W. Florida.	Sea coast of Virginia to Florida.	Sea coast of California.				
GROUP.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	+	-		
1804 Max.	=	..	..	..	..	..	..	..	..	0	Total +	Total -
1805	-	..	..	..	..	..	..	..	..	1	..	-1
1806	-	..	..	..	..	..	..	..	..	1	..	..
1807	+	..	..	..	..	..	..	..	1	..	..	..
1808	+	..	..	..	..	..	..	..	1	..	..	..
1809	+	..	..	..	..	..	..	..	1	..	..	..
1810 Min.	-	..	..	..	..	..	..	..	..	1	..	..
1811	-	..	..	..	..	..	..	..	..	1	..	..
1812	+	..	..	..	..	..	..	..	1	..	..	..
1813	+	..	..	..	..	..	..	..	1	..	..	..
1814	+	..	..	..	..	..	..	..	1	..	..	..
1815	-	..	..	..	..	..	..	..	..	1	+6	-4
1816 Max.	-	..	..	..	..	..	..	..	..	1	..	..
1817	-	..	..	..	..	..	..	..	..	1	..	-2
1818	-	..	..	..	..	..	..	..	1	1	..	..
1819	-	..	..	..	..	..	..	..	..	2	..	..
1820	-	..	..	..	..	..	..	..	..	2	..	..
1821	-	..	..	..	..	..	..	..	..	1	..	..
1822	-	..	..	..	..	..	..	..	1	1	..	..
1823 Min.	-	..	..	..	..	..	..	..	1	1	..	..
1824	-	..	..	..	..	..	..	..	1	1	..	..
1825	-	..	..	..	..	..	..	..	1	1	..	..
1826	-	..	..	..	..	..	..	..	1	2	+6	-12
1827	-	+	..	..	..	..	..	..	2	1	..	..
1828	+	+	..	..	..	..	..	..	3	..	..	..
1829	+	+	..	..	..	..	..	..	2	1	..	..
1830 Max.	+	+	..	..	..	..	..	..	2	1	..	..
1831	+	+	..	..	..	..	..	..	3	1	+12	-4
1832	+	+	..	..	..	..	..	..	3	1	..	..
1833 Min.	-	..	..	..	..	..	..	..	1	3	..	..
1834	-	..	..	..	..	..	..	..	1	3	+5	-7
1835	-	..	..	..	..	..	..	..	1	3	..	..
1836	-	..	..	..	..	..	..	..	..	4	..	..
1837 Max.	-	..	..	..	..	..	..	..	..	7	..	..
1838	-	..	..	..	..	..	..	..	1	6	..	..
1839	-	..	..	..	..	..	..	..	1	5	..	..
1840	+	..	..	..	..	..	..	..	3	4	+6	-29
1841	+	=	..	..	..	..	..	..	3	3	..	..
1842	+	+	=	..	..	..	..	..	4	2	..	..
1843 Min.	+	+	=	..	..	..	..	..	3	3	..	..
1844	-	..	..	..	..	..	..	..	..	6	..	..
1845	-	..	..	..	..	..	..	..	2	5	+12	-19
1846	=	..	..	..	..	..	..	..	3	3	..	..
1847	+	..	..	..	..	..	..	..	5	2	..	..
1848 Max.	-	..	..	..	..	..	..	..	4	3	..	..
1849	+	=	..	..	..	..	..	..	4	2	..	..
1850	+	+	+	+	+	-	-	-	5	3	..	..

	Sea coast, Maine to Virginia.	State of N. York, and adjacent parts of Can., N. H., Mass., and Vt.	Parts of Iowa, Minn., Ill. and Wis.	Ohio Valley, Ohio, Ind., Ky., Ill. and part of Mo.	Indian Territory and Arkansas.	Louisiana, Alabama and W. Florida.	Sea coast of Virginia to Florida.	Sea coast of California.				
GROUP.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	+	—	Total +	Total —
1851	+	+	+	+	+	—	—	—	5	3	—	—
1852	+	+	+	—	+	—	—	+	5	2	+31	—18
1853	+	—	—	—	—	—	—	+	2	3	—	—
1854	+	—	—	—	—	—	—	+	2	6	—	—
1855	—	—	—	—	—	—	—	+	1	7	—	—
1856 Min.	—	—	—	—	—	—	—	+	0	7	—	—
1857	+	+	+	—	—	—	—	—	3	5	+8	—28
1858	+	+	+	+	—	—	—	—	4	3	—	—
1859	+	+	—	+	—	+	—	—	5	2	—	—
1860 Max.	+	+	—	+	—	+	—	+	5	3	—	—
1861	+	+	—	+	—	—	+	+	5	1	—	—
1862	+	+	+	—	—	—	+	+	4	2	—	—
1863	+	+	+	—	—	+	—	—	4	2	—	—
1864	+	+	+	—	—	+	—	—	4	2	+31	—15
1865	+	+	+	—	—	+	—	—	4	1	—	—
1866	+	+	+	+	—	+	—	+	6	0	—	—
1867 Min.	+	+	+	—	—	—	+	+	5	2	+15	—3

Proceeding in this manner, maxima and minima sun-spot sets of years are formed from 1808 to 1862 inclusive. Then the sum of the excess or deficiency of the rainfall in respect to its mean, is found for each set of years for the regions comprised in the I, II and IV territorial groups of Mr. Schott's tables. The results obtained are shown in the following table. (Table II.)

In this table we have five maxima sets of years and five minima, as respects the extent of the sun-spots. In the first territorial group, comprising the sea coast from Maine to Virginia, the results in the maxima years conform to the supposed law three times and twice are unconformable. In the minima years they are four times conformable and once unconformable.

In the second territorial group, embracing New York State and the adjacent parts of Canada, Massachusetts and New Hampshire, the results in the maxima years agree with the law twice and disagree twice, and in the minima years they accord with the law twice and are opposed to it once. The observations in this group extend over only four maxima and three minima sets of years.

In the fourth territorial group, comprising the Ohio Valley, Ohio, Indiana, Illinois, Kentucky, and part of Missouri, the observations extend over four maxima and four minima sets

of years. The results in the maxima sets conform to the law twice and twice are unconformable, while in the minima sets of years they are in accordance with it three times and are unfavorable once.

TABLE II.

Sum of the excess or deficiency of the annual rainfalls of the groups as compared with the mean annual rainfall and expressed in the percentage of the latter.

Quinquennial and Trecenal groups of minimum and max- imum years of sun- spot area.	I. Sea coast of Maine to Virginia.	II. State of New York and adjacent parts of Canada, N. H., Mass. and Vt.	IV. Ohio Valley, Ohio, Ind., Ill., Ky., and part of Missouri.	TOTAL.
1808	—·02	----	----	—·02
1809				
1810 minimum				
1811				
1812	—·31	----	----	—·31
1814				
1815				
1816 maximum				
1817	—·30	----	+·22	—·08
1818				
1821				
1822				
1823 minimum	+·27	+·05	—·07	+·25
1824				
1825				
1829				
1830 maximum	—·03	—·11	—·08	—·22
1831				
1832				
1833 minimum				
1834	—·03	—·60	—·55	—1·18
1835				
1836				
1837 maximum				
1838	+·08	—·08	—·04	—·04
1839				
1841				
1842				
1843 minimum	+·06	—·05	+·53	+·54
1844				
1845				
1846				
1847	—·02	+·02	—·14	—·14
1848 maximum				
1849				
1850				
1855	+·41	+·27	+·21	+·89
1856 minimum				
1857				
1858				
1859				
1860 maximum				
1861				
1862				

If we now take the sum of the results, embracing all the three territorial groups, it is seen that in the five maxima sets of years there is an excess of rainfall three times and a deficiency twice, and that in the five minima sets of years there is a deficiency five times, the result being in entire conformity to the supposed law.

Yet amid these results striking anomalies are found, for in the maximum set of years extending from 1814 to 1818, there is a deficiency of 31 per cent of the mean; and from 1835 to 1839, which are maxima years, the three territorial groups all present results below the mean, the first giving $-.03$, the second, $-.60$, and the last $-.55$.

In view of the results obtained from these two modes of investigation, I think we may venture to infer, that so far as trustworthy observations have been made throughout the United States, they point to a connection existing between the variations in the sun-spot area and those of the annual rainfall, the rainfall tending to rise above the mean when the sun-spot area is in excess, and to fall below when there is a deficiency of solar activity.