

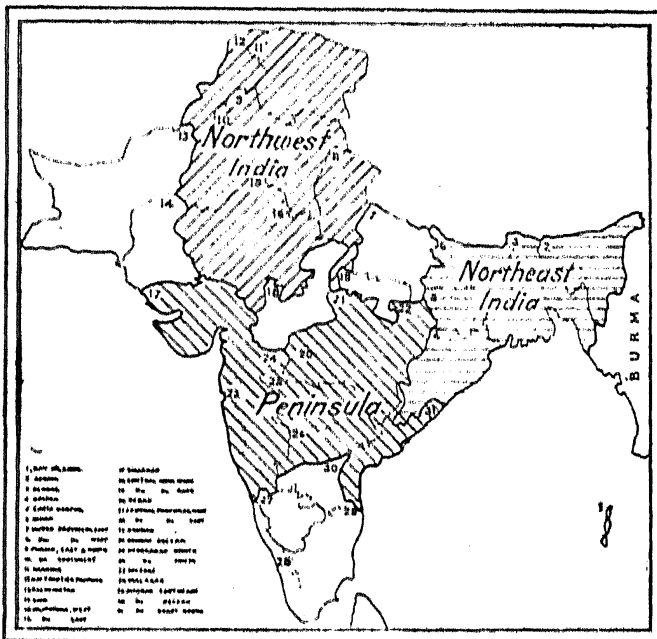
SOLAR RADIATION AND THE INDIAN MONSOON*

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INTRODUCTION

THE S.W. monsoon or summer monsoon is a major event in the agricultural life of India, which has been widely studied. Malurkar¹ has described the day-to-day forecasting of the monsoon over India from its earlier activity in the Indian Ocean. The local distribution of monsoon rainfall² and a forecast of the seasonal rain in various homogeneous divisions of India³ have been studied by Walker. He divided India into three homogeneous rainfall divisions, viz., N.E. India comprising Assam, Bengal, Bihar and Orissa; Peninsula comprising Gujarat, C.P., Konkan, Bombay, Deccan, Hyderabad and north Madras Coast; and N.W. India consisting of the west U.P., Punjab, East and North, Kashmir, N.W.F.P., and Rajputana to which S.W. Punjab has been added on account of its geographical position; but while weighting the mean rainfall with the area of each sub-division to obtain the mean for the whole of N.W. India, only half the weightage is given to S.W. Punjab. The above divisions are referred to in this paper (see Fig. below).



The chief characteristic of the pressure distribution over India during the monsoon† is the trough of low which extends from the S.E. Punjab to the head of the Bay and the concomitant high pressure belt in the Indian Ocean. Hence a study of any feature of the monsoon should be based on this background. The low over Upper Burma is another of the summer low pressure cells.

The monsoon follows closely the movements of the sun both in its advent to the north of the equator and in its retreat thereafter.

The changes occurring in the sun such as sunspots, faculae and flocculi have close relation to changes in the solar radiation outside the atmosphere, particularly to changes in the ultra-violet and blue end of the solar spectrum.⁴ Walker found a correlation coefficient

of +0.59 with a probable error of about a tenth of this value between 42 monthly mean values of sunspot numbers and solar constant.⁵ He also found a correlation of +0.64 between June—August sunspots and synchronous solar constant.⁶

SOME PREVIOUS WORK IN THE FIELD

Walker recorded the effect of sunspots on the annual rainfall of representative stations all over the world.^{5,7} He finds the correlation of sunspots with the total annual rainfall over the plains of India as given by all the stations in existence from 1865 to 1912 to be +0.26. Satakopan's⁸ studies in the Peninsula and N.W. India led him to conclude that "the apparent positive association observed between sunspot numbers and rainfall in India by Walker and others has not been maintained during the recent spot cycles."

Clayton¹ remarks that the centres of high pressure (centres of action) are pushed to higher latitudes with increasing solar activity. They also recede farther from the nearby land areas.

SOURCES OF DATA

The daily values of the solar constant, solar energy in calories per square centimetre per minute outside the terrestrial atmosphere determined at Montezuma, Table Mountain, Mount St. Katherine and Harqua Hala are published in the *Annals of the Astrophysical Observatory of the Smithsonian Institution*. The ten-day and monthly means (preferred and improved preferred values) and their standard deviation from August 1920 to September 1939 are published in Vol. 6 of the *Annals*. The data are given in Table I.

The June to September rainfall departures² from 1875 to 1921 for the Peninsula and N.W. India, and the monthly departures⁹ from 1875 to 1924 for May to October for the Peninsula and N.E. India and for all the months for N.W. India are published in the *Memoirs of India Meteorological Department*. For subsequent years rainfall data for monsoon season as a whole are taken from the "Statement of Actual Rainfall in the Monsoon Season, June to September", issued every year.

CORRELATION COEFFICIENTS

The correlation between June to September rainfall of these divisions and the mean solar constant in each of the preceding 12 months, as well as June and June to September of the same year are shown in Table II. These correlation coefficients are based on data for 19 years except for the months of August and September which are based on 20 years' data. The values of the correlation coefficient for different levels of significance and 17 degrees of freedom are taken from Fisher.¹⁰

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† By 'Monsoon' is meant the S.W. monsoon in this paper.

TABLE I
Correlation of Solar Constant with Rainfall in
Various Divisions of India

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1920								1.930	1.947	1.945	1.950	1.953
1921	1.957	1.975	1.949	1.947	1.950	1.939	1.950	1.943	1.950	1.955	1.957	1.952
1922	1.947	1.946	1.936	1.920	1.930	1.918	1.914	1.921	1.917	1.925	1.926	1.924
1923	1.942	1.929	1.932	1.931	1.936	1.929	1.937	1.941	1.948	1.945	1.942	1.941
1924	1.941	1.943	1.945	1.941	1.949	1.949	1.951	1.948	1.948	1.951	1.951	1.953
1925	1.949	1.955	1.940	1.948	1.947	1.948	1.949	1.948	1.949	1.945	1.946	1.948
1926*	1.946	1.941	1.942	1.939	1.941	1.943	1.942	1.944	1.945	1.939	1.936	1.939
1927	1.939	1.945	1.946	1.945	1.942	1.946	1.944	1.944	1.948	1.942	1.947	1.943
1928	1.940	1.942	1.943	1.942	1.942	1.946	1.943	1.943	1.942	1.944	1.947	1.947
1929	1.947	1.942	1.945	1.945	1.944	1.942	1.940	1.940	1.940	1.939	1.942	1.947
1930	1.943	1.944	1.943	1.943	1.948	1.948	1.947	1.947	1.947	1.946	1.948	1.951
1931	1.950	1.949	1.946	1.944	1.948	1.947	1.943	1.948	1.948	1.948	1.948	1.950
1932	1.947	1.945	1.942	1.943	1.941	1.946	1.945	1.944	1.946	1.944	1.944	1.947
1933	1.948	1.948	1.944	1.942	1.940	1.943	1.946	1.946	1.948	1.950	1.950	1.951
1934	1.950	1.946	1.947	1.946	1.946	1.949	1.949	1.948	1.948	1.952	1.950	1.950
1935	1.947	1.945	1.948	1.948	1.947	1.947	1.946	1.949	1.947	1.947	1.950	1.951
1936	1.949	1.949	1.948	1.949	1.947	1.949	1.948	1.945	1.946	1.949	1.951	1.949
1937	1.947	1.948	1.945	1.943	1.944	1.946	1.944	1.947	1.947	1.947	1.948	1.952
1938	1.950	1.949	1.950	1.945	1.944	1.945	1.945	1.945	1.947	1.949	1.951	1.951
1939	1.949	1.948	1.946	1.944	1.946	1.944	1.945	1.943	1.947			
Mean	1.947	1.946	1.945	1.943	1.944	1.943	1.944	1.943	1.945	1.945	1.947	1.947
S.D. .. ..	.004	.005	.004	.005	.005	.007	.008	.007	.007	.006	.007	.007

* Improved preferred means are given from 1926 onwards.

TABLE II
A. Correlation Coefficients

Solar Constant Division	Preceding year												Same year	
	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June to Sept.	
North-east India	+0.17	+0.45	+0.20	+0.47	+0.53	+0.59	+0.49	+0.36	+0.38	+0.11	+0.09	+0.14	+0.33	+0.42
Peninsula ..	+0.34	+0.21	+0.19	+0.20	+0.11	+0.12	+0.28	+0.40	+0.20	+0.21	+0.14	+0.07	+0.22	+0.28
North-west India	-0.21	-0.03	-0.05	+0.02	-0.02	-0.13	-0.07	+0.08	-0.01	+0.17	-0.21	-0.17	-0.16	-0.08

B. Values of the Correlation
Coefficient for Different Levels of Significance

P .	..	.10	.05	.02	.01
C.C.	..	.3887	.4555	.5285	.5751

INFERENCE

Monsoon rain in N.E. India seems to have significant positive correlation with the solar constant of each of the months from September to December of the previous year. The rest of the coefficients do not show any significant relationship at five per cent. level of significance. The consistency of the correlation coefficients and their gradual variation month by month makes it probable that the mode of solar variation during the preceding year influences the subsequent monsoon over India.

But the limited nature of the data makes these conclusions only tentative. To study the influence of the mode of solar variation on the monsoon rainfall, a polynomial with a set of constants ($\alpha, \beta, \gamma, \delta$, etc.) may be fitted to the solar radiation data of the year prior to the monsoon. These constants will then represent the variation of the solar energy in that year. They can be used as independent varieties and correlated with the subsequent monsoon rainfall. This technique would bring out the relationship between the trend in the solar energy and the monsoon rains.

Theoretical Consideration of the Influence of the Shift of Centres of Action on Divergence in the Equatorial Region

That atmospheric circulation increases with the increase of solar activity is indicated by the decrease of pressure in the lower and increase in the higher latitudes.^{4b} Simpson¹¹ discusses the change in the cloud amount with increased solar radiation. Actual data regarding the exact proportions of the increase in solar energy utilised for strengthening atmospheric circulation and lost by reflection into space by the consequent increase in cloudiness are not available. The fact that an increased atmospheric circulation is necessary for an increase in the cloud amount perhaps permits the assumption that for any given condition of circulation and cloud amount a small variation in atmospheric circulation would be proportional to the corresponding variation in solar radiation. The probable proportional variation in solar radiation is small—about 0.25 per cent.

Let A represent the total divergence—total amount of air transported—from the regions of excess insolation to the regions of deficit insolation,

s—the mean effect of insolation on divergence over unit area in excess insolation region,
S—insolation, (represented in terms of the solar constant, sunspots, etc.)

l—the difference in latitude between the mean positions of the centres of action and the latitude at which sun is overhead.

Then considering an area of unit breadth between the centres of action in the two hemispheres,

$$A \propto 2 l \cdot s \quad \text{Kls (say)} \quad (1)$$

We may assume that during any given period (loc. cit.)

$$\frac{dA}{dS} \text{ is constant.}$$

and,

$$\frac{ls}{dS} = \text{a constant}^* \text{ (first order}$$

approximation) (2)

$$\therefore \frac{dA}{ds} = \frac{dA}{dS} \cdot \frac{dS}{ds} = \text{Constant, } \lambda \text{ say} \quad (3)$$

Now differentiating (1) with respect to s,

$$\frac{dA}{ds} = Kl + Ks \frac{dl}{ds}$$

This reduces to $\frac{ds}{dl} = \frac{Ks}{Kl - \lambda}$ using relation (3)

$$= \frac{Ks}{\lambda - \lambda} \quad \text{by (1)}$$

$$= \frac{s}{\lambda - \lambda} = K s^2$$

It is evident that

$$\frac{\lambda s}{A} < 1$$

\(\therefore\) Right side reduces to

$$= \frac{K}{A} s^2 \left(1 - \frac{\lambda s}{A}\right)^{-1}$$

$$\text{i.e.} \quad = \frac{K}{A} s^2 \left(1 + \frac{\lambda s}{A} + \frac{\lambda^2 s^2}{A^2} + \dots\right)$$

which reduces to

$$\frac{ds}{dl} = -\mu_2 S^2 - \mu_3 S^3 - \mu_4 S^4 \dots$$

* This is the assumption on which linear correlations are based,

—by (2) and assuming initial values to make the constant of integration vanish.

That is, the change in the divergence over unit area in the region of excess insolation as a result of the latitude shift in the position of the centres of action is to reduce the divergence by a quantity which is proportional to $S^2(1 - \gamma s)^{-1}$.

Therefore the combined effect of the insolation and the shift of the centres of high pressure can be represented by the equation

$$s = a_0 + a_1 S + a_2 S^2 + a_3 S^3 + \dots$$

(upto relevant terms), where a_0, a_1, \dots are necessarily negative.

CONCLUDING REMARKS

Solar variations from September to December have highly significant positive relationship with the subsequent monsoon rainfall in N.E. India. The Correlation Coefficients of October and November mean solar constant with the monsoon rainfall in N.E. India are significant at 2 per cent. and 1 per cent. levels respectively. This part of India is under the direct sweep of the monsoon winds, and hence rainfall there may be taken to be representative of the activity of the monsoon. The above result suggests definite relationship between the solar variations when the sun is south of the equator (the period of the southern monsoon) and the subsequent monsoon current over India. The mode of variation of the solar radiation in the different months of the preceding year seems to have influence on the monsoon. It is also suggested that a curve of higher order may be fitted with better results. Further studies are in progress.

In conclusion, mention may be made of the limitation of even the curvilinear regression. With the shift of the centres of action both in latitude and in longitude the monsoon current also gets shifted, which effect does not come under the purview of the curvilinear regression. Other accidental events, like severe volcanic eruption throwing a lot of dust particles into the stratosphere, have an influence on the incidence of rainfall by increasing the interzonal temperature gradient. The effects of these and similar causes are evidently outside the scope of the regression equation.

I am indebted to Mr. S. L. Malurkar for suggesting the problem and for going through the manuscript.

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