Forty-Year Sea Level Pressure and Sunspots

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Abstract

The 40-½ years of mean montly sea level pressure maps based on the Historical Map Series have been typed according to numerical indices that indicate to what extent each particular monthly map resembles a typical or normal winter or summer map on one hand, or a typical spring or fall map on the other hand. These indices are easily determined from the average pressure of certain key areas and are quite effective in separating the winter from the summer months and the spring months from the fall months. The persistence in these indices and their relation to the sunspot cycle has been investigated.

1. Introduction

In 1947 the writer (BRIER 1947) in reporting upon an investigation of the pressure data from the HISTORICAL DAILY MAP SERIES (1943—44) found indications that there had been a considerable decrease in the total mass of air over the Norther Hemisphere between 1899 and 1939. The trend toward lower surface pressure was most pronounced in the higher latitudes and a further investigation (BRIER 1948) disclosed that the trend existed in all months of the year. AHLMANN (1948), KINCER (1946) and others have reported that during this same period there seemed to be a general warming of the Northern Hemisphere, particularly in the higher latitudes and in the winter months. Because of general interest in the question of recent climatic fluctuations and the suggestion of WILLETT (1949) that irregular solar activity is the most probable cause of climatic fluctuations, it was decided to examine the variations in the pressure data in relation to known solar effects, such as the seasonal change in the position of the sun, and to other possible effects that might be associated with an index of solar activity such as sunspots.

2. The Seasonal Changes

Regarding the seasonal changes in the distribution of pressure, there are two well-known and established facts. First, in the Northern Hemisphere winter there is an excess of air relative to the summer. This is shown by the annual cycle of monthly values of the average sea level pressure north of Latitude 20° N when plotted for each month from January, 1899 to June, 1939, in Figure 1. These data are based on the series of MEAN MONTHLY PRESSURE MAPS (1946 b) for the period. Since they are based on reduced sea-level pressures rather than on actual station pressures they do not represent the best possible estimate of the total mass of air. However, some computations made by the author indicate that the

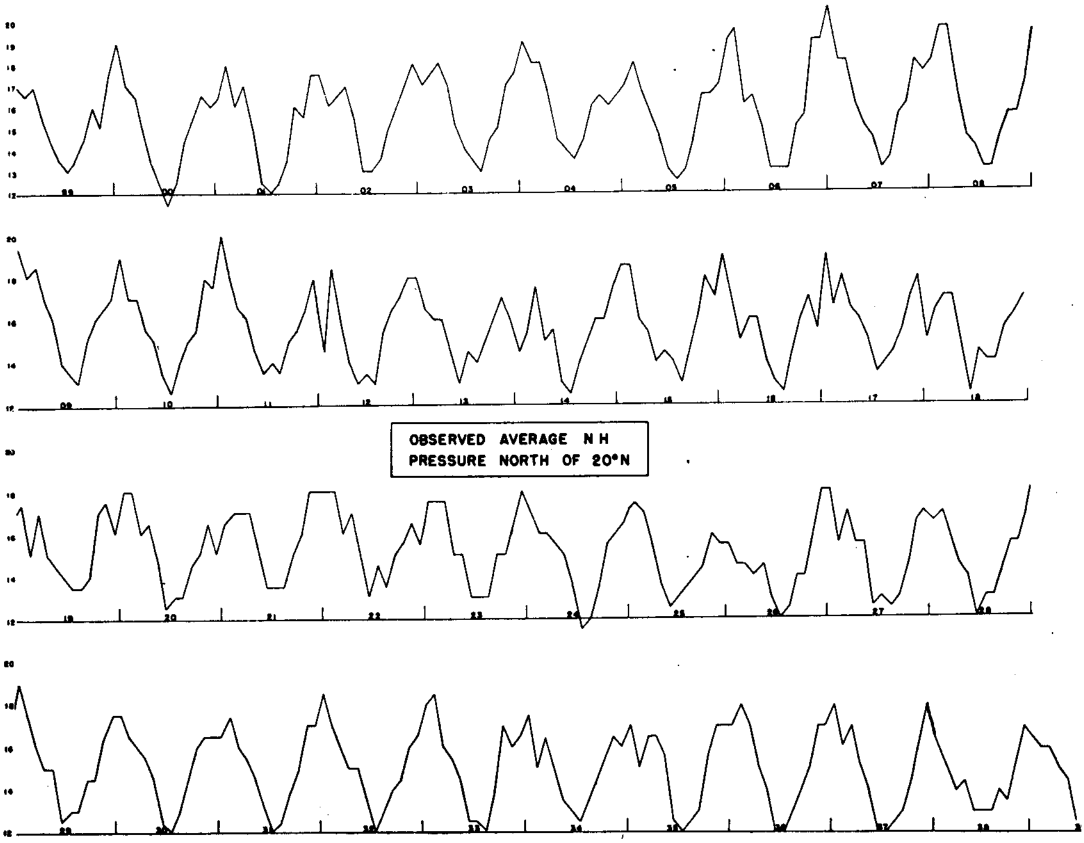

Fig. 1. Monthly values of the average sea-level pressure (in mb minus 1,000) north of latitude 20° N for the period 1899 to 1939. Numbers along the abscissa are years (without the first two numbers) plotted in the middle of the year.

effect of the artificial reduction to sea level is not a serious one for the purpose of this study and the qualitative picture given by Figure 1 is essentially correct.

The second well-known fact is that the relative distribution of air over the land and water surfaces of the hemisphere is, in general, opposite in winter and summer. This difference, a seasonal effect, is illustrated in Figure 2, which shows the normal difference in pressure between January and July. This map was obtained from the Normal Weather Maps (1946 a) which also were based on the 40 ½ years of sea-level pressure data. An additional chart, Figure 3, shows the difference in pressure between October and April and indicates that for most of the hemisphere the seasonal march of pressure is not symmetric to January and July.

3. Computation of Indices

Since Figure 2 indicates that the average difference in pressure between January and July is of greater magnitude, and of opposite sign, in some regions than in others, it would seem reasonable to suppose that a few critical or "key" areas could be chosen from which numerical pressure indices could be computed that would show a good discrimination between individual months of January and July. The author has shown (Brier, 1948) how monthly mean pressure maps might be typed or classified according to a few simple pressure indices chosen on the basis of areas showing maximum monthly change in surface pressure. An index, say W, might thus be computed for each of 486 months in the series, indicating whether a particular map was more like a winter map or a summer map. A

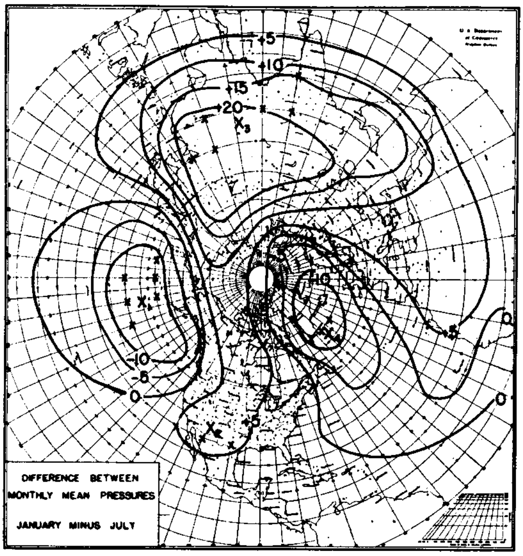

Fig. 2. Isopleths of difference in normal sea level pressure in mbs. between January and July for the Northern Hemisphere.

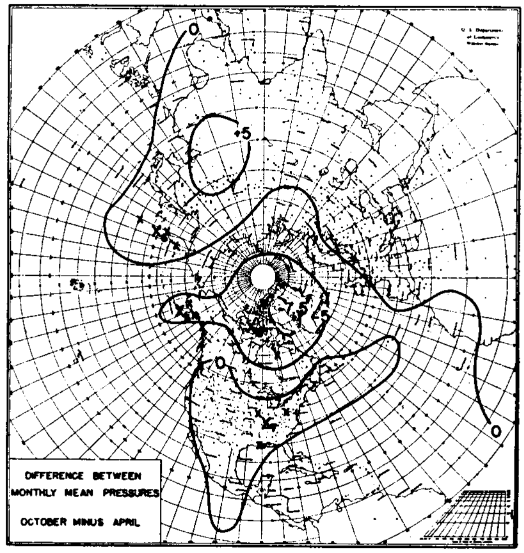

Figure 3. The difference in normal sea level pressure between October and April for the Northern Hemisphere.

statistical analysis of such an index might disclose interesting facts. Likewise, since Figure 3 indicates differences between October and April on the average, it would appear possible to determine another index V which would indicate the extent to which a particular monthly map resembled a spring map compared with a fall map.

On the basis of Figure 2, four regions were selected where the average pressure was computed for each month of the series. The points selected are shown as crosses on the figure and the areas are labelled X_1, X_2, X_3 and X_4. When the average pressure indices X_1 and X_2 were plotted against each other the points for January fell in the upper left side of the graph and the points for July fell in the lower right hand section. The points for the other months fell in between but with considerable overlap between adjacent months. The means for each month are shown in Figure 4, but the points for the individual months are not reproduced here. Using a graphical regression technique described elsewhere (BRIER, 1946) a series of arbitrary lines Y_1 indicated as curves in Figure 4 were drawn so that all the points had values of Y_1 ranging between 0 and 100. The spacing and curvature of these lines was determined by the data for the individual months which are not plotted here. The values of Y_1 were then read off for each individual month of the 40 year series and plotted against the index X_3 on a chart similar to that shown in Figure 5. Lines Z_1 ranging between 0 and 100 were similarly constructed on this figure as shown. For each month, the value of Z_1 was read off the chart and a final index W was computed by the formula

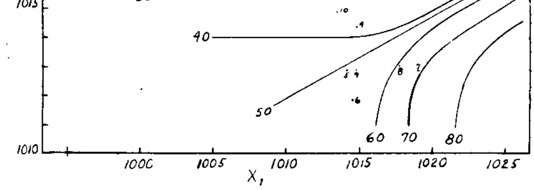

Fig. 4. Scatter diagram showing the separation of the twelve monthly normal maps with respect to variables X_1 and X_2. Months are numbered in order from 1 for January to 12 for December. The curves are indices of resemblance to the July normal chart.

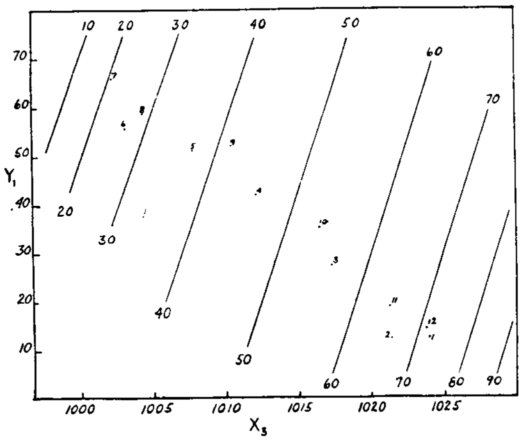

Fig. 5. Scatter diagram showing the separation of the twelve monthly normal maps with respect to variables X_3 and Y_4. The slanting lines are indices of resemblance to the January normal chart. Months are numbered in order from 1 for January to 12 for December.

$$W = \frac{Z_1 - \bar{Z}_1}{\sigma_{z_1}}$$

where $$\bar{Z}_1 = \sum_i^{486} Z_{1i}/486$$

and $$\sigma_{z_1} = \sqrt{\frac{\Sigma\,(Z_{1i} - \bar{Z})^2}{486}}$$

Thus, the index W has been scaled to have a mean of zero and standard deviation of unity. The average values of W for each of the twelve months are shown in Table 2. An attempt was made to use variable X_4, but it was found to contribute no additional discriminating information.

For the spring-fall index, V, the regions chosen are shown in Figure 3. After a little experimentation it was found that the best discrimination was obtained when Y_3 was plotted against Y_4 where

$$Y_3 = X_5 - X_6,$$
$$Y_4 = X_7 - X_8.$$

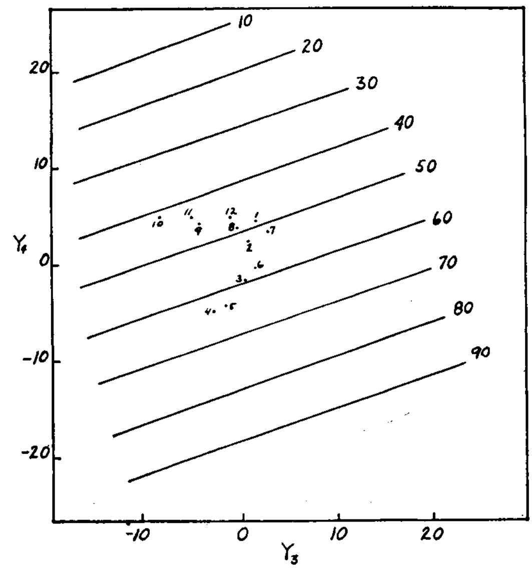

Fig. 6. Scatter diagram showing the separation of the twelve monthly normal maps with respect to variables Y_3 and Y_4. The slanting lines are indices of resemblance to the April normal chart. Months are numbered in order from 1 for January to 12 for December.

After Y_3 was plotted against Y_4, the lines Z_2 were drawn as shown in Figure 6. When the individual monthly values of Z_2 were determined from their position on Figure 6 and tabulated they were found to have a slight correlation with index W. In order to have an index independent of W the linear regression of Z_2 on W was determined and a final index V was computed by the formula

$$V = \frac{Z_2 - \bar{Z}_2 + bW}{\sigma_r}$$

where

$$\bar{Z}_2 = \sum_i^{486} Z_{2i}/486$$

and b is the regression of Z_2 on W and σ_r is the standard deviation of the residuals from the regression line. Thus, index V has zero mean and unit standard deviation and is

Table 1. Average values of index W for each month.

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Index W....	1.31	1.01	.41	—.16	—.65	—1.25	—1.61	—1.13	—.41	.28	.88	1.26

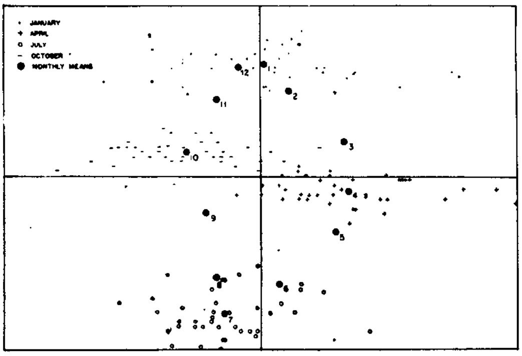

Fig. 7. Scatter diagram showing how the W and V indices separate the January maps from the July maps and the April maps from the October maps. Months are numbered in order from 1 for January to 12 for December.

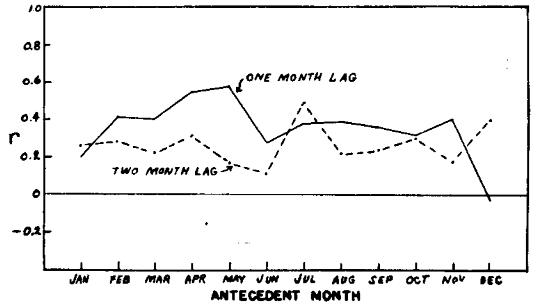

Fig. 8. Auto-correlations of index W for one and two month lags.

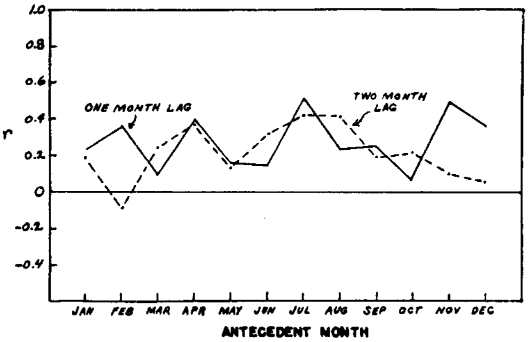

Fig. 9. Auto-correlations of index V for one and two month lags.

uncorrelated with W since it is a residual from the regression line of Z_2 on W.

The effectiveness of these two indices in separating the winter from the summer maps and the spring maps from the fall maps is indicated by Figure 7. On this figure the mean values of W and V are shown for each of the twelve months of the year but the individual monthly values are plotted only for January, April, July and October. If the remaining individual months were shown they would indicate considerable scatter and overlap between adjacent calendar months.

4. Statistical Analysis of the Indices

A number of correlations were computed between W and V and other factors. The persistence in these indices was investigated by computing the one and two month lag auto-correlation for each month of the year. The results of these computations are shown graphically in Figures 8 and 9. The one month lag correlations were highest for W with values greater than 0.50 for April with May and for May with June. The average of the one month lag correlations was 0.35 for W and 0.27 for V. Ordinarily, these would not be considered as very useful for forecasting purposes.

Table 2. Linear Trends in W and V.

Month	Correlation Coefficient		Regression Coefficient	
	W	V	W	V
January	— 0.45	— 0.35	— 0.0068	— 0.029
February	— 0.59	— 0.44	— 0.0090	— 0.032
March	— 0.60	— 0.23	— 0.0058	— 0.016
April	— 0.64	— 0.07	— 0.0079	— 0.004
May	— 0.55	— 0.21	— 0.0071	— 0.015
June	— 0.47	— 0.32	— 0.0072	— 0.019
July	— 0.49	— 0.18	— 0.0119	— 0.009
August	— 0.25	— 0.30	— 0.0046	— 0.017
September	— 0.63	— 0.05	— 0.0065	— 0.002
October	— 0.44	— 0.08	— 0.0051	— 0.005
November	— 0.56	— 0.39	— 0.0072	— 0.033
December	— 0.45	— 0.33	— 0.0084	— 0.023
Annual	— 0.75	— 0.36	— 0.0732	— 0.070

The trends in the indices during the period were investigated by computing the regression on time for each index and for each month. The results, shown in Table 2, indicate that during the 40 years there were pronounced trends in both of these indices and that the sign of the trend was the same in all seasons. Since positive values of W means more winter-like indices, the negative correlations mean that on the average the monthly mean patterns were more like normal winter patterns in the earlier part of the period and more like the normal summer pressure patterns toward the end of the period. The most pronounced trend was during the month of April and Figure 10 shows a plot of the individual values of *W* for the 41 months of April and the regression line on time. This tendency for the maps to show more summer-like patterns during the 40 year period appears to be consistent with the findings of AHLMANN (1948), KINCER (1946) and other investigators reporting a general warming up of the hemisphere during this period. The negative correlations for index *V* are not so easy to interpret but indicate a tendency for the monthly mean pressure patterns to become more like normal fall patterns during the 40 years.

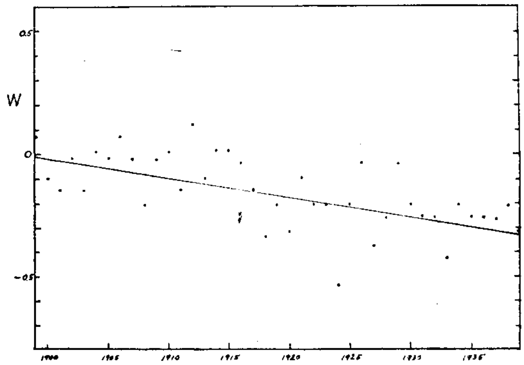

Fig. 10. Time series plot of index *W* for the month of April.

Index *W* was determined on the basis of areas showing the greatest change in pressure from January to July. Since the basic cause of this seasonal change is undoubtedly radiational in character, due to the changing position of the sun relative to the earth, it would seem reasonable to hypothesize that real changes in solar activity might affect the same regions. Therefore, the index *W* was correlated with sunspots (MUNRO 1948) the easiest available measure of solar activity; the results for each of the twelve months are shown by the solid line in Figure 11. Correlations between *V* and sunspots were also computed although there was no a priori reason to expect any relationship. The solid line in Figure 12 shows a graph of these correlations.

For index *W*, all twelve of the correlations turned out negative, ranging in value from — 0.07 to — 0.44. Using the standard test of significance, two of these would be considered significant at the 1 % level and another one at the 5 % level. The algebraic average of the twelve monthly correlations is — 0.26 and on the basis of the *t* test this is a significant departure from zero. For index *V* the situation is quite different. None of the twelve monthly correlations is significant at the 5 % level, and the average of the group does not depart significantly from zero.

Since the analysis indicated a considerable trend in *W* and *V* during the 40-½ year period, the question might be raised as to whether the observed negative correlations between *W* and sunspot numbers might only be the result of a trend in the sunspot numbers opposite the trend in *W*. For example, the trend in *W* during the period might have no physical reality, resulting from some bias in the data introduced by the analysis of the original synoptic maps which were based on less complete data in the earlier years. Since sunspots showed a slight upward trend during the period, a "spurious" correlation between them and *W* would be found even though no physical relationship existed between the two. For this reason the correlations between sunspots and the indices were recomputed after removing the linear trends in *W*, *V* and sunspots. The results are shown graphically by the dashed lines in Figures 11 and 12.

The removal of the trends in the series reduced the correlations between *W* and sunspots only one of them (October) remaining significant at the 5 % level. However, 10 of the 12 correlations are of the same sign as before and the average for the group of — 0.10 departs significantly from zero. The fact that the correlations of *W* and sunspots are negative after the trends are removed and that the trend in sunspots is opposite to the trend in *W* strongly suggest that the correlations found between sunspots and *W* presented by the solid line in Figure 11 are not spurious. Furthermore, it is the author's opinion that the trends in index *W* during the period were real and cannot be explained by asserting that insufficient data in the earlier years biased the results in a considerable way. The correlations of sunspots with *V* show essentially the same thing as before the removal of trends, the group average of 0.05 not being

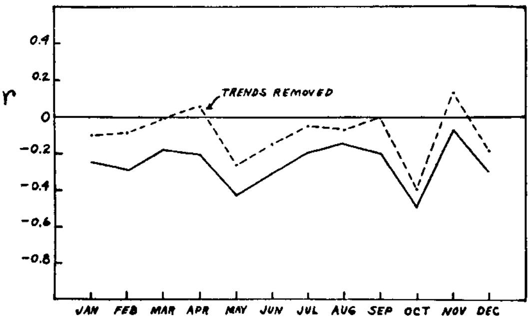

Fig. 11. Correlations of index W with sunspots, before and after removal of the trend during the period.

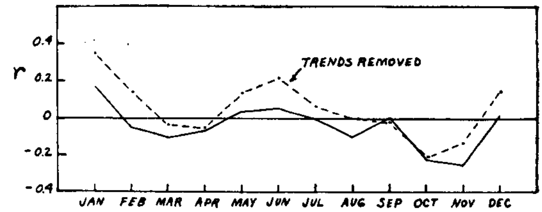

Fig. 12. Correlations of index V with sunspots, before and after removal of the trend during the period.

significant although the January correlation of 0.34 is significant at the 5 % level.

The validity of some of the results reported here might be open to some question due to the fact that some of the points used in determining the indices W and V are located in regions of less reliable data and weather analysis. For example, variable X_2 includes a point located in the mountains of Mexico and another point located in the Pacific off Lower California. This question was investigated by substituting for variable X_2 the mean monthly pressure data for Corpus Christi, Phoenix, and San Diego. The correlations of these stations with variable X_2 averaged 0.92. Likewise, the correlations between variable X_3 and a new variable X_3' which eliminated questionable points located in China and Tibet ranged between 0.87 and 0.94. These changes were too small to have an appreciable effect on the W and V indices and their relationships to the sunspot series, and indicate that the significant correlations reported here cannot be simply explained by the assertion they were produced by faulty data or map analysis.

5. Conclusions

A method of map classification has been developed which can be used to type monthly mean sea-level pressure maps according to the degree to which they resemble a normal winter or summer circulation pattern on one hand and a normal spring or fall map on the other. Index W based on the average pressure of points chosen from three regions measures the resemblance to the January normal map and index V is a measure of the resemblance to the normal spring map.

Indices W and V show considerable persistence from one to two months with auto-correlations ranging from —0.03 to 0.58 for one month lags and from —0.09 to 0.51 for two month lags. Some of these correlations appear to be large and consistent enough to suggest a possible usefulness in long range forecasting.

Both indices show rather consistent negative trends during the period, indicating that the monthly mean patterns were more like summer and fall normal pressure patterns toward the end of the period and more like winter and spring during the earlier part of the period. These results seem to be consistent with the findings of others investigating the climatic flucatuations of the past half-century.

For each month the correlation of index W with sunspots was negative, indicating that periods of high sunspots tended to be associated with summer type patterns, at least so far as these are determined by the distribution of pressure in regions chosen for this study. Since most of the correlations remained negative when the trend was removed from both the sunspots and W series, there appears to be the definite suggestion that part of the variation in the monthly mean sea level pressure patterns during the period 1899 to 1939 was produced by variable solar activity. The correlations are not large enough to indicate that a very substantial portion of variation was solar in origin and they are not high enough to be of much forecasting value, even if they are real. However, the results appear to give some slight supporting evidence to the conclusion reached by WILLETT (1949) that irregular solar activity is responsible for some of the changes in the circulation of the atmosphere.

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