A Test of an Apparent Response of the Lower Atmosphere to Solar Corpuscular Radiation

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ABSTRACT

A test of an apparent association between solar corpuscular radiation (measured by planetary-scale geomagnetic disturbance) and the subsequent behavior of the sea-level pressure distribution is carried out with completely new and independent data. The new results corroborate the earlier findings which indicated increased persistence in the pressure distribution during the first week and decreased persistence during the second to third week following large geomagnetic disturbances.

1. Introduction

The possibility of an association between solar disturbance and the subsequent behavior of the sea-level pressure distribution was proposed by the author in a series of papers dating back more than 15 years (Shapiro, 1956; 1959). The evidence, statistical in nature, concerned a relationship between solar corpuscular radiation (measured by large-scale, large-amplitude geomagnetic disturbance) and subsequent changes in the persistence of the sea-level pressure distribution over two separate and independent middle-latitude regions. These early studies made use of large data samples taken from the Historical Sea-Level Map Series and the results were subjected to a number of tests for consistency and statistical significance. The essence of these results is shown in Fig. 1 which is reproduced from the earlier papers. This figure shows the average behavior of a measure of persistence ($\bar{r}_i$) before and after day 0, defined as an increase in one day in the International Magnetic Character Figure C_i equal to or greater than 1.0. During the period of time for which the data were available for these studies (1 January 1899–31 May 1945 for the North American region; 1 January 1899–31 December 1938 for the European region) the average frequency of such events was about one per month. The three-day mean persistence correlation r_k for any time k is a measure of the degree of resemblance between the three-day mean pressure distribution on days k, $k+1$ and $k+2$ with that on days $k+3$, $k+4$ and $k+5$. The horizontal dashed lines in Fig. 1 indicate levels of statistical significance.

Direct comparison of the simultaneous behavior of the North American and European persistence correlations (Shapiro, 1959) shows that they are independent. Therefore, in view of the generally similar behavior of the three-day mean persistence correlations over North America and Europe after large geomagnetic disturbance, these results indicate the existence of a solar-weather effect. The precise nature of the effect is not clearly evident, except that there is a tendency for a significant increase in persistence during the first week after a large geomagnetic disturbance and a tendency toward a minimum of persistence during the second to third week. Attempts to clarify the relationship by means of mathematical model experiments (Berkofsky and Shapiro, 1961, 1968) have not been successful because the model which was used did not possess sufficient sensitivity. However, in view of the time that has elapsed since the statistical studies were carried out, it was felt appropriate to attempt to reproduce the early results with new data. Such an attempt was recently made and reported (Shapiro, 1971).

The new data consist of sea-level pressures and 700-mb heights on a diamond-shaped grid of latitude-longitude intersections covering much of the Northern Hemisphere. The data which were kindly made available by the Extended Forecast Division of the National Weather Service (NOAA), extended from 1 January 1947 to 31 December 1970. During this period there were 272 geomagnetic disturbances with one-day increases of C_i equal to or greater than 1.0. Although this number of key days is only about one-half of that available for the earlier North American study it was felt to be sufficient to test the earlier results. Unfortunately, the results of this test were inconclusive. The behavior of the European persistence correlations for the new data sample showed no similarity to the original European results. However, the behavior of the North American persistence correlations for the new data (especially at 700 mb) did resemble the earlier results insofar as the correlations were high during the first week after day 0 and low during the second to third week. During the discussion following the presentation of these new results, J. Namias suggested that the lack

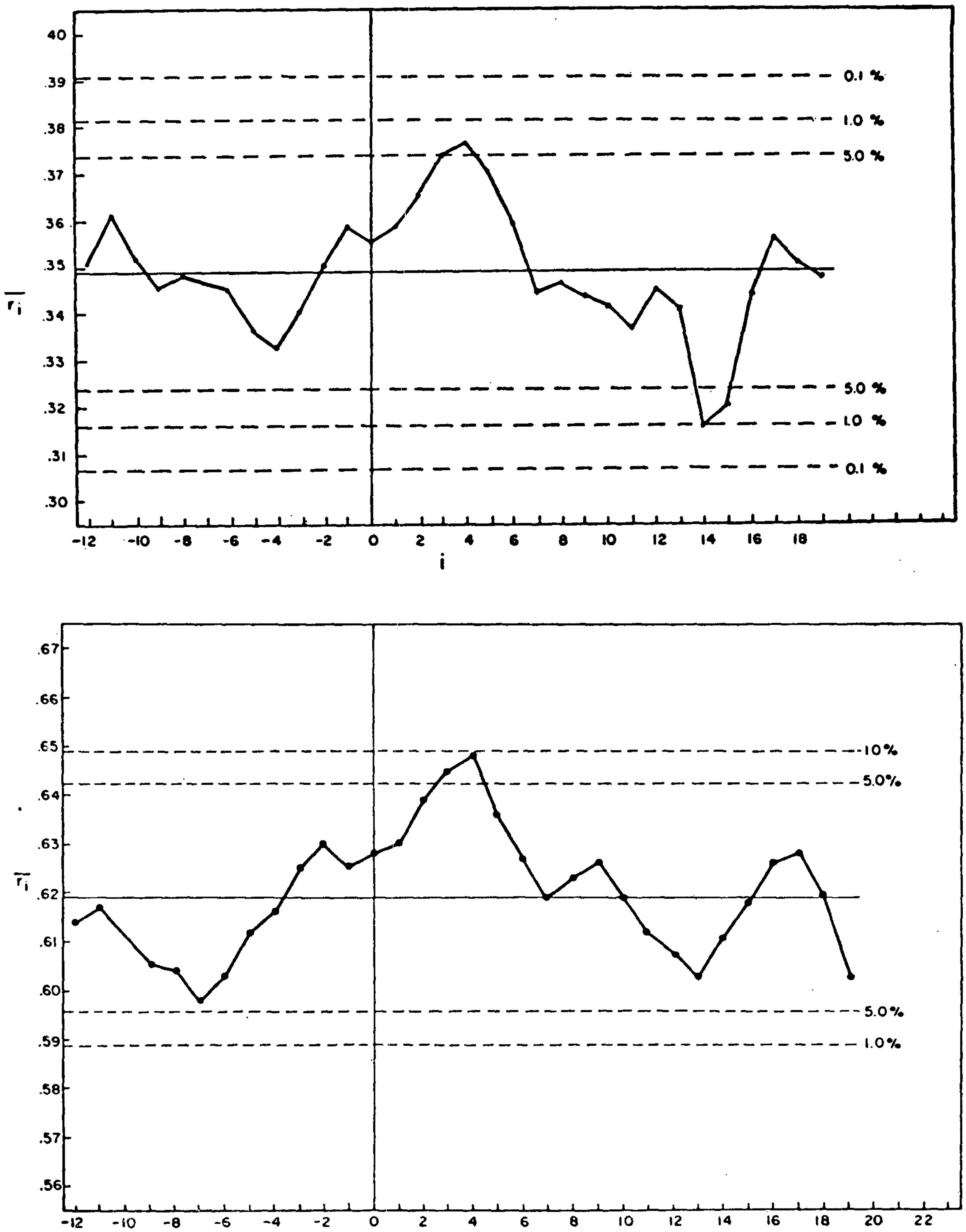

FIG. 1. Average persistence correlations for the 3-day mean sea-level pressure distribution preceding and following large increases in geomagnetic activity. Upper curve refers to the North American region (30–60N, 65–125W); each value represents an average of 564 cases in 47 years of data. Lower curve: European region (35–65N; 30E–30W); each value represents an average of 467 cases in 40 years of data.

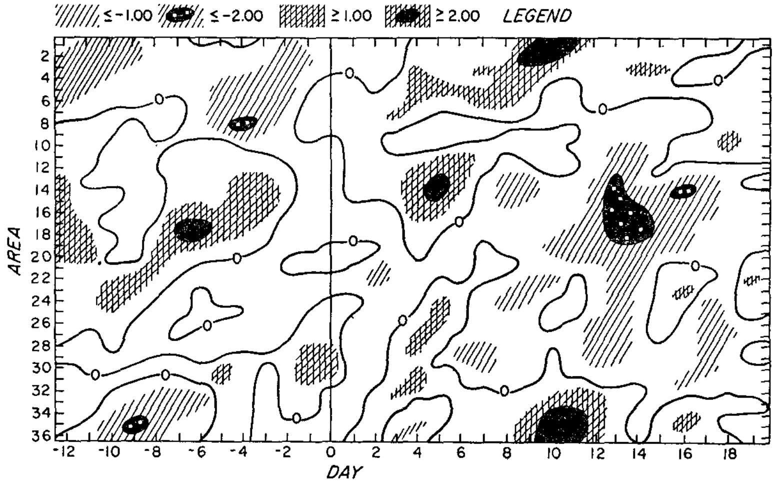

FIG. 2. Magnitude of the departure (in terms of Student's t values) of the daily average 3-day mean persistence correlation from the population mean for each of 36 mid-latitude areas extending around the Northern Hemisphere. Each area extends for 30° of latitude and 60° of longitude. Area 1 (top of diagram) extends from 0–60 W longitude; Area 2 from 10–70W; Area 36 from 350–50W.

of better agreement between the earlier and present results could be due to a shift in the position of one of the quasi-stationary long waves between the time periods of the two studies. Namias' suggestion appeared particularly appropriate in view of the fact that the persistence correlations, as constituted, are confined to specific 60° longitude sectors and would therefore be especially sensitive to such shifts. Since the necessary data were already at hand it was decided to put the suggestion to a test. The purpose of this paper is to present the results of this test.

The test consists of a repetition of the above study with the new data sample but with the 3-day mean persistence correlations computed for a whole set of 36 areas of the same size as the North American and European areas but shifted from each other by 10° of longitude. Each area extends for 30° of latitude (from 30–60N) and 60° of longitude. The area designated as Area 1 extends from 0 to 60W. Area 2 extends from 10 to 70W. Thus, the North American region which extends from 65 to 125W corresponds to Areas 7 and 8, and the European region (330–30W) corresponds to Area 34. If Namias' suggestion is valid we should find some groups of areas in which the behavior of the three-day mean persistence correlations resembles that of the earlier results.

2. Results

Fig. 2 is a plot which contains results comparable to those of Fig. 1, but for each of the 36 areas and with the new sea-level data. The results of Fig. 2, however, are presented in terms of Student's t rather than in terms of the actual departures from the population means of the persistence correlations for each Area. Inasmuch as the population means vary from a high of 0.654 for Area 36 to a low of 0.383 for Area 7, the use of Student's t normalizes the results for each area and permits easy intercomparison among the areas. Hatched areas in Fig. 2 indicate values of Student's t with magnitudes equal to or greater than 1.0 and solid areas contain values equal to or greater than 2.0. Cross-hatching indicates positive values. Fig. 2 shows for each area the magnitude of the departure of the daily average 3-day mean persistence correlation from the population average for the particular area.

It is evident from Fig. 2 that many of the 36 areas show the same pattern of persistence after day 0 that was obtained in the original North American and European results. In particular, those areas surrounding Area 14 and extending from Area 7 to Area 31 show generally high values of persistence around days 4 and 5 and low values around days 13 and 14. In fact, this general pattern is so dominant that the average of the t values for all 36 areas (Fig. 3) shows the highest values

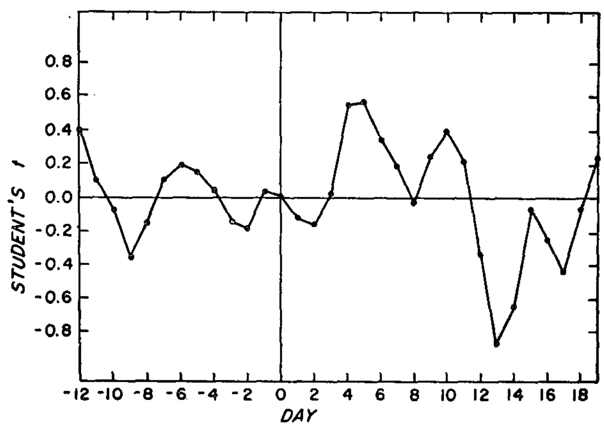

FIG. 3. Average of the 36 Student's t values for each day from Fig. 2.

TABLE 1. Average correlation between the 24-year time series of 3-day mean persistence correlations for each of the 36 areas as a function of the separation distance D of each pair of areas.

D (deg. longitude)	Average correlation		Average correlation with seasonal effect removed	
	Sea level	700 mb	Sea level	700 mb
10	0.92	0.91	0.91	0.91
20	0.74	0.74	0.72	0.72
30	0.58	0.58	0.55	0.55
40	0.44	0.45	0.40	0.41
50	0.32	0.33	0.28	0.29
60	0.22	0.22	0.18	0.17
70	0.14	0.14	0.09	0.09
80	0.09	0.09	0.04	0.04
90	0.07	0.07	0.02	0.02
100	0.06	0.06	0.01	0.01
110	0.06	0.05	0.01	0.00
120	0.06	0.04	0.00	0.00
130	0.06	0.04	0.00	−0.01
140	0.06	0.04	0.00	−0.01
150	0.06	0.03	0.00	−0.01
160	0.06	0.03	0.00	−0.02
170	0.06	0.03	0.00	−0.02
180	0.06	0.03	0.00	−0.02

of persistence on days 4 and 5 and the lowest values on days 13 and 14. The resemblance between the average of all 36 areas and the original North American and European results is indeed striking.

The averages shown in Fig. 3 for each day are obtained from the 36 Student's t values for that day. Each set of 36 t values can be treated as a set of 36 numbers and tested for their departures from the population average t value, which is zero. In order to do this we need to estimate the number of degrees of freedom in such a set of 36 numbers. Inasmuch as adjacent areas have 39 out of their 46 grid-point pressures in common, we can expect considerable correlation among nearby areas. Table 1 summarizes the extent of the correlation that exists among the various areas for the entire 24-year data sample. As expected, areas that are separated by only one 10° interval are on the average closely related. The average correlation coefficient between such areas is in excess of 0.9 both for the sea-level and 700-mb data and both with and without removal of the small seasonal effect. However, the interrelationship decreases rapidly with increasing separation and for areas with separations of 6 or more 10° intervals there is essentially complete independence. Thus, at the very least we can assume that among a set of 36 t values comprising an average value in Fig. 3, there are six independent t values with five degrees of freedom. If we assume this minimum of only five degrees of freedom, the values on days 4 and 5 as well as those on days 13 and 14 easily exceed the 5% level of significance. Similar analyses were performed with the 700-mb data and, not unexpectedly, the 700-mb results (which are not shown) are similar to the sea-level results.

3. Conclusions

The results presented here corroborate the earlier findings and imply an association between solar corpuscular radiation and the subsequent behavior of the large-scale tropospheric pressure distribution. Though this result is significant in itself and could have important implications for the large-scale dynamics of the atmosphere, it contains little specific information. Both the earlier and present results indicate that the average magnitude of the tropospheric response to solar disturbances is small since a large data sample is required to minimize the effects of natural variability and yield measurable results. It is likely that a choice of other parameters—not so general as the persistence correlation—would yield results of greater magnitude. A search for such less general parameters and more specific inter-connections should be made. However, it also appears appropriate because of the added confidence supplied by these results to reconsider the use of simulation models to reveal the nature of the effects involved.

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REFERENCES

Berkofsky, L., and R. Shapiro, 1961: A dynamical model for investigation of the downward transfer of energy introduced by upper atmospheric heating. *Planetary Space Sci.*, **7**, 434–444.

——, and ——, 1968: Numerical experiments with a vertically parameterized model designed to study the effects of high-level heating on the large-scale circulation of the lower atmosphere. Environmental Res. Paper No. 294, AFCRL-68-0571, 20 pp.

Shapiro, R., 1956: Further evidence of a solar-weather effect. *J. Meteor.*, **13**, 335–340.

——, 1959: A comparison of the response of the North American and European surface pressure distributions to large geomagnetic disturbances. *J. Meteor.*, **16**, 569–572.

——, 1971: On the response of the lower atmosphere to solar variability. *Proc. Symp. 25: Solar Corpuscular Effects in the Troposphere and Stratosphere*, IUGG, 15th General Assembly, Moscow.