DOE/ER04634-1

FINAL REPORT

1. TITLE: Mechanism for the Effects of Variable Solar Activity on the Weather
DE-AC02-78ER04634.A003 (ER-78-S-02-4634)
2. INSTITUTION: Aspen Institute for Humanistic Studies
1229 University Avenue, 2nd Floor
Boulder, Colorado 80302
3. ABSTRACT

MASTER

The goal of the research was to help in identifying the most likely physical mechanisms for the effects of variable solar activity on the weather. The method of attack was largely empirical, and this method was chosen for the following reasons: (1) In order to tap the great pool of scientific talent that may be able to offer sound physical mechanisms, it is necessary to demonstrate that there are some important relationships to explain. (2) If the experiments are carefully designed, they can be useful in eliminating certain mechanisms which seem to have a low probability of success, and picking out the mechanisms which look more promising.

As an example of weeding out a mechanism which had previously been suggested by us, we might mention the cirrus cloud mechanism. The proposed mechanism involved an increase in cirrus cloud cover produced by solar activity. Presumably this increased cloud cover could induce a heating effect and thereby a change in the circulation in the circulation pattern. However, the responses we observe are too immediate to be explained by such a slow acting mechanism. A more reasonable explanation might be thunderstorm modulation by solar activity. This could cause rapid injection of heat into the troposphere.

One of the findings made early in this study was that the hemispheric vorticity area index (VAI) responds to solar activity in the following way: As the plage approaches central meridian the VAI increases for a period of three or more days centered on day "0". Building on this result, we examined the occurrence of thunderstorms in the United States. We found a similar pattern for a 5-day period centered on day "0". We found that the frequency of thunderstorms was about 13% greater than normal. Furthermore, the effect depends critically on the time relationship between the "0" day

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

28

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

and the next solar sector boundary crossing.

It is known that the frequency of sector boundary crossings, particularly of the minus-to-plus type, increases markedly about 4 to 5 days after CMP, 4 1/2 days being the time required for the solar wind to advert from Sun to Earth. It was found in the thunderstorm study that the bulk of the effect occurs with plages where CMP date is followed 4-6 days later by a sector boundary crossing particularly if it is of the minus-to-plus type. In other words, the plages which are capable of affecting the interplanetary magnetic field are also the ones most capable of increasing terrestrial thunderstorm activity.

Thus we have two effects which occur more or less simultaneously, the increase in VAI and the increase in thunderstorm activity, and they both appear to respond to the same solar signal.

4. SCIENTIFIC PERSONNEL

The project has been supervised by Dr. Walter Orr Roberts. In the earlier part of the project he devoted perhaps 5-10% of his time. More recently he has been able to devote more time to this research, perhaps 10-20% of his time over the past year. The detailed meteorological analysis has been done by Mr. Roger H. Olson. He has devoted 75% of his time to the project. In addition, several students have devoted from one-fourth to one-half of their time to the project. One Master's Thesis has been completed by Mr. Steven S. Businger.

5. SCIENTIFIC BACKGROUND

We have coordinated our efforts with various university and other scientists, both overseas and domestic. We have not received financial support from any other government agency. However, our research has been materially aided by use of facilities at the National Center for Atmospheric Research (NCAR).

6. DISCUSSION

We may distinguish between two stages in the solution of the problem we have set out to explore: (1) The first stage, which has been under study for more than 100 years, is a rather shotgun type approach. Many scientists have published a posteriori type empirical studies which seem to indicate that there are indeed some valid relationships between solar

activity and the weather. However, these studies have lacked coherence. Investigators have been led by the data to explore relationships which seem to be non-random, in the hope that such relationships would lead to a cohesive pattern. However, this approach has led to a disappointingly small amount of progress. (2) The second approach, although still empirical, is perhaps more satisfactory because it is of the a priori type. In this case, a statistical analysis is undertaken, not just because the data indicate some interesting correlations exist but because physical reasoning or previous statistical results based on different data indicate that correlation should be expected. In the work covered by this report, we have tried to use the a priori approach whenever possible. For example, in examining thunderstorm occurrence in relation to solar activity, there were several reasons to expect a correlation to exist, particularly when the solar parameter is the central meridian passage date of very active solar plages. (1) The list of solar plages prepared by Prince and Hedeman has earlier been found to correlate with the hemispheric VAI. Thus, it was reasonable to look for a correlation between this list and the occurrence of thunderstorms in North America. (2) Earlier work by Flohn had shown that thunderstorms in Europe increased in frequency for a few days at the time of central meridian passage of large sunspot groups. (3) The quick reaction of the VAI to the passage of plages indicated that a relatively fast-acting energy source is required. The energy fed into the atmosphere by thunderstorms could be such a source. (4) The thunderstorm index to be used in the study consists of a daily count of the stations in the eastern two-thirds of the U.S. which report a thunderstorm. Since the stations are reasonably equally spaced, this index thus becomes a rough measure of the area covered by thunderstorms. Previous studies have shown that an area index of some meteorological parameter is highly useful in identifying a response to a solar signal. For instance, the response of drought in the High Plains to the 22-year solar cycle, according to Mitchell, is shown by the area covered by drought rather than the intensity of drought.

In view of the above, it seemed worthwhile to make a study of the thunderstorm area index (TAI) versus the O-dates determined by the Prince-Hedeman plage list. The results are described in the attached DRAFT paper. Briefly, three points emerged from the study: (1) At the time of CMP of the plage, the thunderstorm index summed over a 5-day period centered on O-day, increased by about 13% above average. (2) The effect noted

depends slightly on the degree of activity of the plage. During solar maximum years, when relatively active regions are visible almost every day, it was necessary to establish a threshold level of activity in order to isolate the effect. During solar minimum years no threshold was necessary - the effect was noted with all levels of activity. (3) The effect was strongly dependent on the relationship between the CMP date of the plage and the next solar sector boundary date. Previous work by Diltmer and others has shown that there is a strong statistical relationship between the occurrence of a flaring region at central meridian and the timing of the next SSB. The preferred time is 4-5 days, which is the time required for the solar wind to advect from Sun to Earth. This relationship is stronger if the next SSB is of the minus-to-plus type. In the thunderstorm study we found exactly analogous results. The effect noted was a maximum when the next SSB was of the minus-to-plus type, especially if the delay time was 4-6 days. When the next SSB was of the plus-to-minus type, the effect was found only if the delay time was 4-6 days.

The physical interpretation of the above findings can only be suggested at the present time. It appears that the more active solar plages are able to perturb the interplanetary magnetic field, that influencing the time of the sector boundary crossings at Earth. It appears that these same plages are the ones most likely to cause an increase in thunderstorm activity. Since the plages which have a large magnetic field are also in general the larger and more active regions, this implies that the electro-magnetic and/or particle radiation from the plage is the cause of the increase in both VAI and TAI at the time of CMP of the plage. At the present time, it is difficult to say whether the VAI increase causes the increase in thunderstorms or vice versa. The data used are too crude to allow exact timing.

7. RESULTS

The published results from this research project are shown in the list of publications (Attachment 1). One piece of work which is as yet unpublised but available in DRAFT form is attached as Attachment 2. The number of students who obtained Ph.D. Degrees as a result of this research was zero. However, Mr. Steven S. Businger did receive a Master's Degree, based primarily on work in this project.

8. SUMMARY AND CONCLUSIONS

The past 5-10 years have seen a revived interest in Sun-Weather research. The work reported in here represents a part of the recent advances that have brought this condition into being. The future will very likely see more attempts to expand the horizons of the empirical findings, as well as to find physical models to explain the results.

Chronological List of Publications

1. Olson, R.H., Roberts, W.O., Prince, H.D., and Hedeman, E.R., "Solar Plages and the Vorticity of the Earth's Atmosphere", Nature, Vol. 274, pp 140-142, 1978
2. Gerety, E.J., Olson, R.H., and Roberts, W.O., "Analysis of a Possible Sun-Weather Correlation", Nature, Vol. 272, p 231, 1978.
3. Williams, R.G., "A Study of a Particular Sun-Weather Relation", Geoph. Res., Le#5, p 519, 1978.
4. Williams, R.G., and Gerety, E.J., "Does the Troposphere Respond to Day-To-Day Charges in Solar Magnetic Field?", Nature, Vol. 275, P 200, 1978.
5. Businger, S., "Investigation of Possible Sun-Weather Relationships", NCAR Cooperative Thesis No. 49, 1978
6. Wilcon, J.M., Duffy, P.B., Schatten, K.H., Svalgaard, L., Scherrer, P.H., Roberts, W.O., and Olson, R.H., "Interplanetary Magnetic Field Polarity and the Size of Low-Pressure Troughs Near 180° Longitude", Science, Vol. 204, pp 60-62, 1979.
7. Roberts, W.O., "Introductory Review of Solar Terrestrial Weather and Climate Relationships in Solar-Terrestrial Influences on Weather and Climate", B.M. Mc Cormak and T.A. Seliga, eds. Dr. Reidel, 1979.
8. Olson, R.H., "Comment on 'Stratospheric Temperatures During Solar Cycle 20', by R. S. Quiroz", Jour. Geoph. Res., Vol. 84, C.12. P 7898, 1979.

To Be Published (Draft Copy Attached)

Olson, R.H. and Roberts, W.O., "Solar Control of Thunderstorms in the United States". to be submitted for publication.

Preprint removed