Possible Relationships Between Solar Activity and Atmospheric Constituents

ROBERT G. ROOSEN
Goddard Space Flight Center, New Mexico Station
and
RONALD J. ANGIONE
San Diego State University

The large body of data on solar variations and atmospheric constituents collected between 1902 and 1953 by the Astrophysical Observatory of the Smithsonian Institution (APO) is examined. Short-term variations in amounts of atmospheric aerosols and water vapor due to seasonal changes, volcanic activity, air pollution, and frontal activity are discussed. Preliminary evidence indicates that increased solar activity is at times associated with a decrease in attenuation due to airborne particulates.

In 1902 a series of observations was begun at the Smithsonian Institution's Astrophysical Observatory, generally called the APO. The purpose for these observations was to make daily determinations of the solar constant and correlate variations in the observed values with variations in rainfall, temperature, and other meteorological phenomena.

Until about 1920, the so-called "long method" was used in which the result was fundamentally dependent on daily spectrobolometric determinations of the transmission of Earth's atmosphere at over 40 places in the solar spectrum covering a wavelength range from about 0.35 to 2.5 μm. In succeeding years the work came to rely on a "short method" based on tables using pyranometric and pyrheliometric observations along with observed values of precipitable water vapor to estimate the effective atmospheric transmission over the entire wavelength region. This method was regularly checked by the spectrobolometric long method. Observations were continued from 1920 to 1955 on a full-time basis at sites in both the northern and southern hemispheres.

The techniques used and results obtained are extensively documented in the *Annals of the Astrophysical Observatory* (Abbot, 1908, 1913; Abbot, Aldrich, and Fowle, 1932; Abbot, Fowle, and Aldrich, 1922; Abbot, Aldrich, and Hoover, 1942; Aldrich and Hoover, 1954), hereinafter referred to as *Annals*. Other interesting summaries and descriptions of the work were also written by Abbot (1929, 1963). The *Annals* report long-method spectrobolometric determinations of atmospheric transmission at various sites for over 3500 days, and short-method results for over 10 000 days. The sheer bulk of the observational results gives some idea of the crusading nature of this program as well as the problems of scale that arose with data reduction and correlation analyses. When we consider that the program was carried out entirely without the aid of electronic computers, a project of such magnitude appears in retrospect to be impossible.

Nevertheless the work was performed and we have been left with a legacy of measurements of solar and atmospheric parameters completely unparalleled in terms of accuracy, homogeneity, quantity, and historical baseline. Application of modern computing equipment and techniques to this body of data will be of value in answering many of the questions raised at this symposium.

It is not our intention here to rediscuss relations between solar activity, weather, and climate already documented in great detail by Dr. Abbot. But we would like to make two points concerning their relevance.

First, the APO's final mean value for the solar constant (Aldrich and Hoover, 1952) agrees to within one-tenth of one percent with the value adopted by NASA in 1971 based on the most modern available equipment and techniques, including aircraft and rocket observations (Thekaekara, 1971).

Second, based on his analyses of solar variations and the water levels of the Great Lakes, Abbot (1963) has predicted that a great drought will occur in this country beginning in the year 1975. Elsewhere in these proceedings Dr. Roberts discusses predictions of such a drought made in the last few years. Dr. Abbot's prediction was first published in the year 1938.

SHORT-TERM VARIATIONS IN ATMOSPHERIC CONSTITUENTS

Before discussing possible relationships between solar activity and atmospheric constituents, we would like to give an idea of the size of the variations that occur naturally. We should point out that because these results are from solar observations, all of the work reported here was done when the Sun was not obscured by clouds, producing a rather obvious selection effect.

Figure 1 shows the annual variation in atmospheric transmission at 0.4 and 1.6 μm as measured at the APO in Washington, D.C., during the period from 1902 to 1907. Because these wavelengths were chosen to avoid molecular absorption bands, essentially all of the variations can be ascribed to variations in the amount of particulate matter (that is, aerosols) in the atmosphere.

People are often surprised to learn that any variations occur at all. A surprisingly large amount of photometric work has been based on the assumption of constancy. It is plain from figure 1 that monthly means yield only a slightly better idea of the true situation. The curves shown here are sine curves fit by the method of least squares. They serve to demonstrate our conclusion that, in general, atmospheric transmission tends toward a maximum in midwinter and a minimum in midsummer (Roosen, Angione, and Klemcke, 1973).

The primary natural sources of atmospheric aerosols are usually considered to be hydrocarbons from trees and plants (Went, 1966), windblown dust, sea spray, volcanoes, and forest fires (Hidy and Brock, 1971). To these we can add manmade effects such as smoke from slash-and-

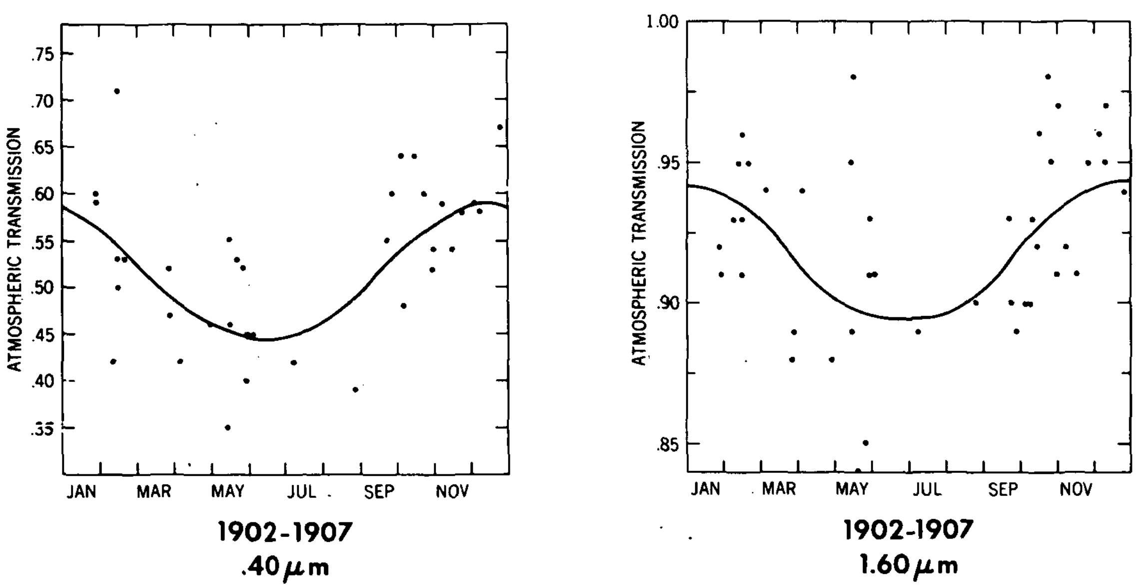

FIGURE 1.—Observations of atmospheric transmission at Washington, D.C.

burn agriculture and other air pollution (Hidy and Brock, 1971). Determining the makeup of the atmospheric aerosol burden at any given place and time is an excruciatingly complex problem, but the results that we will show here are almost certainly due only to naturally produced aerosols.

Large perturbations can occur with the eruption of some volcanoes. An eruption such as that of Mount Agung in 1963 can inject many cubic kilometers of dust into the stratosphere, which could drive the observed values of atmospheric transmission off the bottoms of graphs like figure 1.

Figure 2 shows observed values of atmospheric precipitable water vapor for sites on mountain tops in both the northern and southern hemispheres. Daily and seasonal variations are once again strongly apparent. Variations in atmospheric total ozone are not unlike those shown here for aerosols and water vapor, except that the maximum tends to occur in the spring, at least in the northern hemisphere. We will not show any results for ozone here because we are not satisfied with our reductions yet, but the APO data do contain substantial amounts of information on ozone.

The general question of energy balance in the atmosphere on any given day is very difficult, but the effects of the variations that we have shown here are very likely at the level of tens of percent. The large majority of these variations are almost certainly due to changes in the weather, but it is necessary to have a quantitative idea of the scatter involved before discussing correlations involving changes of only a few percent in long-term averages.

CORRELATION WITH SOLAR ACTIVITY

In large part the previous remarks were meant to give an idea of the caution that we feel in approaching our subject. We spent more than 3 yr writing our paper that merely describes some of the variations in atmospheric constituents (Roosen, Angione, and Klemcke, 1973). In contrast we have spent only 6 months addressing the question of correlations with solar activity.

Viewed in that light, the results that we describe in this section should really be considered as a case study. We feel that they are important, but we cannot guarantee that they are truly representative.

We have applied the shotgun approach of taking annual means and then looking for correlations between solar and geomagnetic parameters on the one hand and atmospheric constituents on

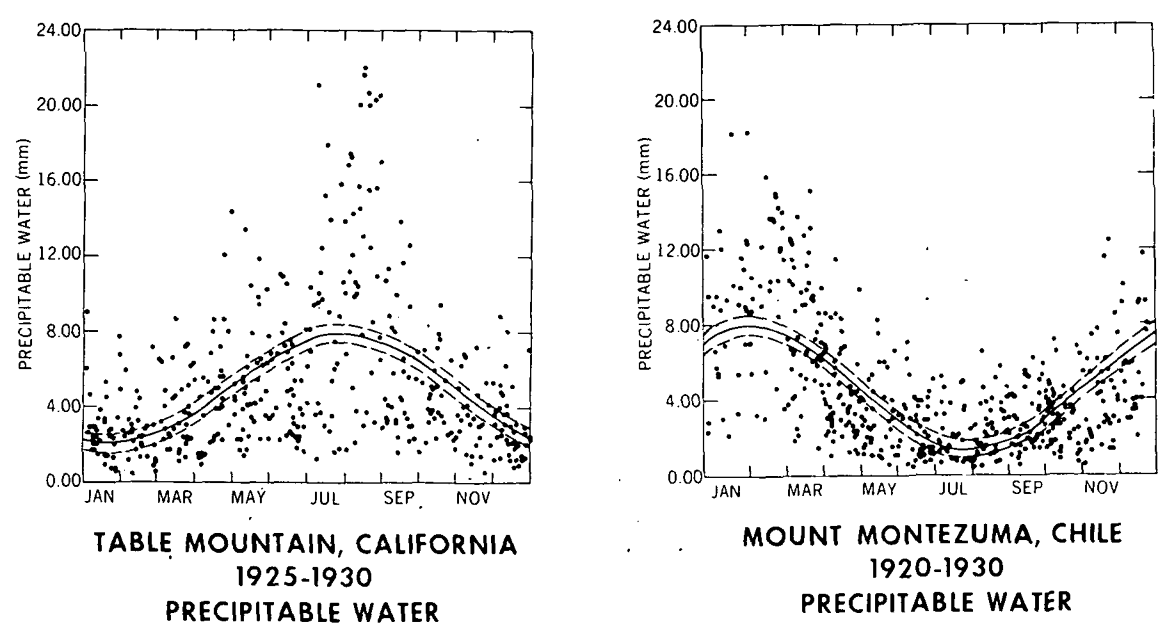

FIGURE 2.—Observations of atmospheric precipitable water vapor at the two main APO sites.

the other. We found a number of intriguing possibilities, the best of which is presented here.

Figure 3 shows the variations with time of annual means of atmospheric precipitable water vapor as observed at the APO's primary mountaintop observatories. The curve at the top shows the annual means of the Zurich sunspot numbers. The correlation between sunspot numbers and precipitable water vapor at Table Mountain is 0.02, which we will call zero for short. The correlation at Mount Montezuma is apparent to the eye; the computer says that it is −0.20.

Figure 4 is a plot of sunspot numbers versus observations at Mount Montezuma, Chile, of solar brightness at an altitude of 30° corrected to mean solar distance. The correlation coefficient between these two quantities is 0.56. The observed brightness certainly seems to increase with increasing solar activity. Because the observed solar brightness depends directly on the amount and size of aerosols in Earth's atmosphere, this figure indicates that increased solar activity is associated with decreased attenuation due to atmospheric aerosols. The only reported effects of volcanic activity are represented by the triangle in the lower left-hand corner of the graph. This point represents the year 1932, during which at least five separate volcanoes erupted in the Chilean Andes. We believe this to be the only year in this study that is significantly affected by volcanic dust.

Figure 5 is a plot of sunspot numbers versus observed brightness in the part of the sky near to but not including the Sun. These observations were made with a completely separate instrument than that used for the previous figure. The correlation coefficient in this case is −0.51. This figure tells us that scattered light near the Sun decreases with increasing solar activity. The obvious interpretation is similar to that for the solar brightness observations. Namely, increasing solar activity is associated with decreasing amounts of atmospheric particulates.

Figure 6 shows observed precipitable water

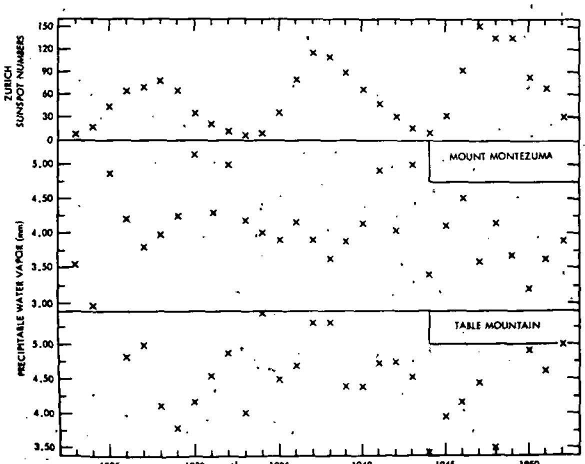

FIGURE 3.—Annual means of precipitable water vapor and sunspot numbers.

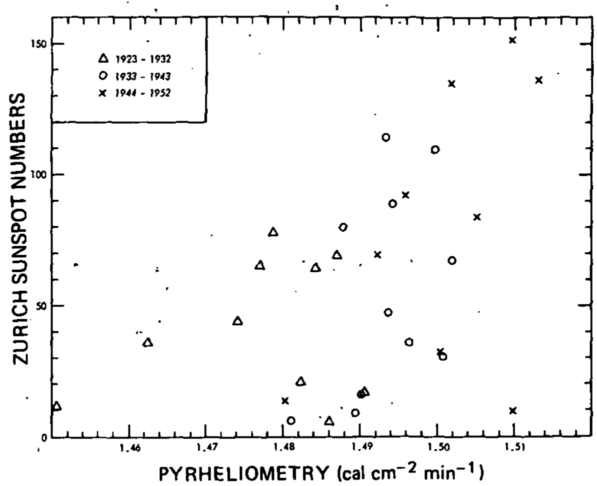

FIGURE 4.—The relation between annual means of direct solar brightness at 30° altitude corrected to mean solar distance and sunspot numbers at Mount Montezuma.

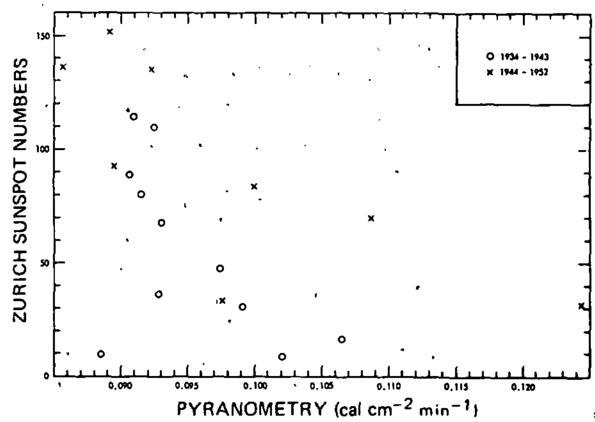

FIGURE 5.—The relation between annual means of scattered light near the Sun at 30° altitude and sunspot numbers at Mount Montezuma.

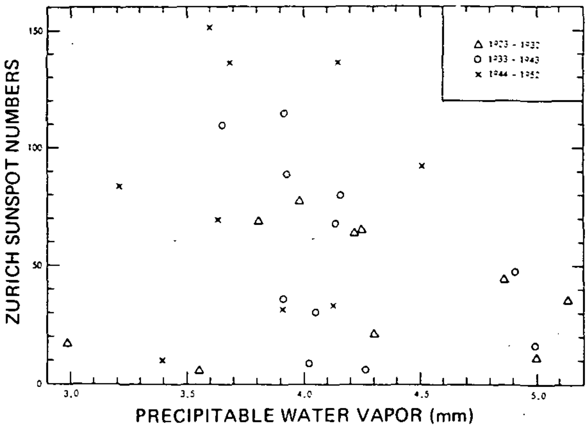

FIGURE 6.—The relation between atmospheric precipitable water vapor and sunspot numbers at Mount Montezuma.

vapor versus sunspot numbers for Mount Montezuma. Remember that the correlation coefficient is −0.20 and that increasing solar activity is associated with decreasing amounts of precipitable water.

Figure 7 shows plots of precipitable water vapor versus the astronomical extinction coefficient, which is an indicator of the amount of light removed from the direct solar beam by atmospheric constituents (Roosen, Angione, and Klemcke, 1973). More water vapor leads to a lower observed solar brightness. The strong correlation between precipitable water vapor and atmospheric attenuation shown here points up the possible importance of the fairly weak correlation between atmospheric water vapor and solar activity shown earlier. It is possible that most of the aerosols above Mount Montezuma are hygroscopic and swell in the presence of higher humidity. Hence the observed correlations between solar activity and aerosol scattering may be due in part to a change in the size of the aerosols rather than the total amount.

Analysis of the Table Mountain, California, observations shows correlations between solar brightness, sky brightness, and sunspots that are similar to but not as strong as those found for Mount Montezuma. We believe that the differences between the two sites emphasize the main problem presented by research into the effects of solar activity on Earth's weather and climate—separation of variables.

Table Mountain is located 40 miles east of the Los Angeles basin and is surrounded by pine trees and other vegetation. We have reason to believe that the air above it is filled with dust particles of many different origins, both organic and inorganic. The relationship between solar activity and production of organic aerosols by trees and other plants may well be quite different than that with production of inorganic aerosols. Hence, by observing from a desert site it may well be possible to eliminate some variables and make the problem that much more tractable.

Mount Montezuma certainly meets this criterion. As Dr. Abbot (1929) described it,

> Hardly ever does rain fall near the observatory. It lies in one of the most barren regions of the Earth. Neither tree nor shrub, beast nor bird, snake nor insect, not even the hardiest of desert plants is found here.

CONCLUSION

We have found evidence that (as seen from a high-altitude desert site) increased solar activity is associated with a decrease in attenuation because of airborne particulates. It may also be associated with a decrease in the average amount of water vapor in the air above that particular site. Further, it appears that the results for any particular site are strongly dependent on a great number of variables, only some of which have been isolated.

In any case, we are firmly convinced of one thing: Dr. Abbot and the staff of the APO have presented all of us with a superb body of observational material to help solve the problems of solar variations, weather, and climate.

REFERENCES

Abbot, C. G., 1908, *Ann. Astrophys. Observ. Smithson. Inst.*, **2**.

Abbot, C. G., 1913, *Ann. Astrophys. Observ. Smithson. Inst.*, **3**.

Abbot, C. G., 1929, *The Sun and the Welfare of Man*. Smithsonian Scientific Series, vol. 2, Smithsonian Institution Series, Inc., New York.

Abbot, C. G., 1963, "Solar Variation and Weather," *Smithsonian Misc. Collect.*, **146**(3) [Publication 4545].

Abbot, C. G., L. B. Aldrich, and F. E. Fowle, 1932, *Ann. Astrophys. Observ. Smithson. Inst.*, **5**.

Abbot, C. G., L. B. Aldrich, and W. H. Hoover, 1942, *Ann. Astrophys. Observ. Smithson. Inst.*, **6**.

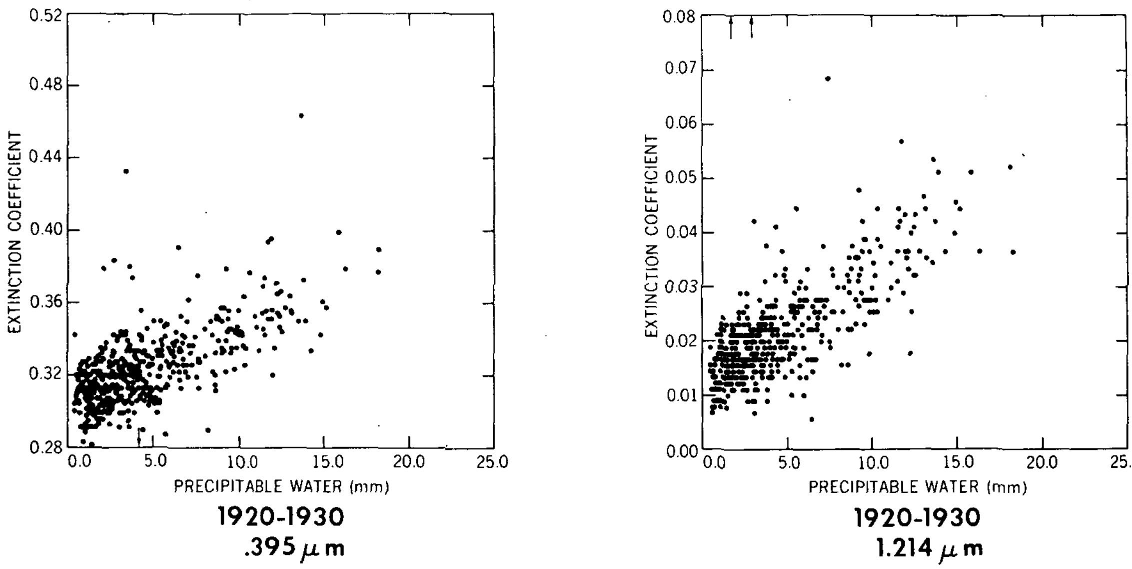

FIGURE 7.—The relation between atmospheric extinction and atmospheric precipitable water vapor at Mount Montezuma. The extinction coefficient

$$k(\lambda) = -2.5 \log T(\lambda)$$

where $T(\lambda)$ is the atmospheric transmission.

Abbot, C. G., F. E. Fowle, and L. B. Aldrich, 1922, *Ann. Astrophys. Observ. Smithson. Inst.*, **4**.

Aldrich, L. B., and W. H. Hoover, 1952, "The Solar Constant," *Science*, **116** (3).

Aldrich, L. B., and W. H. Hoover, 1954, *Ann. Astrophys. Observ. Smithson. Inst.*, **7**.

Hidy, G. M., and J. R. Brock, 1971, "An Assessment of the Global Sources of Tropospheric Aerosols," Proc. 2d Int. Clean Air Cong., H. M. England and W. T. Berry, eds., Academic Press, Inc., New York and London, pp. 1088–1097.

Roosen, R. G., R. J. Angione, and C. H. Klemcke, 1973, "Worldwide Variations in Atmospheric Transmission. 1. Baseline Results From Smithsonian Observations," *Bull. Amer. Meteorol. Soc.*, **54**, pp. 307–316.

Thekaekara, M. P., 1971, *Solar Electromagnetic Radiation*, NASA SP-8005.

Went, F. W., 1966, "On the Nature of Aitken Condensation Nuclei," *Tellus*, **18**, pp. 549–556.

DISCUSSION

LONDON: It is good to hear of the care that was taken in reviewing the Abbot measurements. I wonder if you have an estimate of the probable error of those measurements, and whether you have an estimate of any change in probable error with time as a result of the improvement of the instruments.

ROOSEN: That is one of the reasons that we took 3 yr before we would say anything at all. There were, indeed, changes in the instrumentation. Every effort was made in the spectrobolometry to continue to refer all spectrobolometric observations back to the scale of 1913.

As to the probable error of the spectrobolometric transmission results, my own estimate, from working on the data, is that it is probably better than 1 percent for individual determinations, if you keep in mind the fact that these are done by the so-called Bouger-Langley method of observing the Sun as it rises, and changes in atmospheric transmission during that period are often very hard to eliminate. In terms of the probable error of the individual solar constant observations, I do not think it is appropriate for me to comment. Dr. Abbot, in Smithsonian Publication 4545, said that he felt that the individual solar constant determinations were accurate to about one-half of one percent, and he wished that they were accurate to one-tenth of one percent. I wish that I could do one-tenth as well as he did.

LONDON: Our experience suggests that as the accuracy of the instrument increased, observed variation of the solar constant decreased.

ROOSEN: I would be very pleased to discuss that with you later.