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The Environmental Impact of Solar Variability

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Introduction

Amid all of our activities and discussions here on planet Earth we human beings tend to take our neighboring star the Sun very much for granted. We assume without further reflection that the Sun's energy production rate is absolutely constant. Until the mid-1970's this view prevailed even among astronomers. Research of the last decade, however, clearly shows that the Solar Constant, strictly speaking, is not constant.

The Sun is classified by astronomers as a rather ordinary Main Sequence star of spectral type G2V, that is a moderate size "dwarf" of moderate temperature. The Sun is not classified as a variable star; indeed most Main Sequence stars (which constitute about 90% of all stars) are not variable in a meaningful sense of the term. Nevertheless research coming to light since the mid-1970's reveals slight variations in the Sun which may have highly significant environmental impact. Commenting on a modest recent decline in solar energy production physicist Richard Willson of the Jet Propulsion Laboratory recently said:

> This is a very small change in the total energy output of the Sun, but [it] has great potential significance for the Earth's fragile ecosystem.[1]

There are several different factors which cause the received amount of solar radiation to vary. Some of these are extrinsic, that is, variations in solar energy levels caused externally. Included in these are long-term cyclical changes in the eccentricity of the Earth's orbit, gradual shifts in the date of perihelion, long-term cyclical changes in the orientation of the Earth's rotation axis (precession), and somewhat unpredictable changes in the Earth's albedo. There are also intrinsic changes in the energy production of the Sun itself.

Extrinsic Variability

We shall consider the extrinsic factors first. The shape of the Earth's orbit slowly varies from nearly circular to moderately eccentric (e=0.067) and back again in a period of about 93,000 years. When eccentricity is near zero the Earth's orbital velocity is nearly constant, and the seasons are of essentially equal length. For ten thousand or more years on either side of maximum eccentricity, however, the Earth's distance from the Sun and the amount of heat received vary considerably. The portion of the Earth's orbit then which is nearest the Sun is traversed rather rapidly, and orbital velocity is significantly diminished in the more remote portion of the orbit. The result is a rather brief time of high insolation near perihelion, and a prolonged time of cooling near the time of aphelion. The net result tends to make for cooler weather overall and shorter growing seasons in temperate climates.

During the last few thousand years we have been favored with a nearly circular orbit and nearly equal seasons. (Eccentricity at the beginning of 1982 was 0.01672.) Looking ahead to coming millenia, however, this value will be slowly but steadily increasing, with significant climatological impact. At maximum eccentricity the Earth's distance from the Sun will vary by slightly more than 20 million km compared with the almost exactly 5 million km difference between perihelion and aphelion experienced today. That four-fold difference will have an adverse effect on temperate climates. It is worthy of note that evidence of the 93,000 year cycle has been observed in temperature data obtained from oxygen 16/oxygen 18 ratios in radiolaria in sediment cores from ocean floors. (Core containing up to as many as 460,000 annual layers have been recovered in recent years, yielding important Pleistocene temperature data.)

One should also understand that the date (or perhaps one should say longitude) of perihelion slowly shifts; the whole cycle is about 50,000 years long. With perihelion now occurring on January 2, the northern hemisphere (where most of the world's food is grown) has had somewhat shorter winters and long summers in historical times, but this too is slowly changing. It will bring a shortening of the growing season in temperate climates, particularly in the northern hemisphere. Evidence for this cycle can also be seen in temperatures recorded in ocean floor sediments.

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There is also the 25,800 year precession cycle involving the shifting of the orientation of the Earth's poles, and a long-term variation in the obliquity (or tilt) of the rotational axis to the plane of the orbit. These also may have some effect upon climate; the precessional cycle does seem to be present in the temperature data based on ocean floor sediments.

Another extrinsic factor affecting the amount of received solar energy is the overall albedo (reflectivity) of the Earth. The higher the Earth's albedo due to cloudiness, ice and snow cover, haze, smog, etc., the more solar energy is reflected immediately back into space, and the cooler it is on the surface of the planet. Albedo is usually expressed as a decimal fraction of the total incoming solar radiation. While there are more complex formulae which might be used to indicate the relation of albedo changes to temperature, we shall use a simplified formula

$$T = 392\,[(1-A)/r^2]^{1/4}$$

where T = mean temperature (in Kelvin) for the illuminated hemisphere on the planet or satellite
A = albedo
r = distance of object from the Sun expressed in Astronomical Units (i.e., units of the mean Earth-Sun distance)

This simplified formula is reasonably accurate for slowly rotating bodies like the Moon and Mercury which lack atmospheres. In the case of rapidly rotating objects like the Earth it gives too high a value because the illuminated side does not have time to get fully heated, and considerable heat loss occurs on the night-time side. Furthermore the Earth's vast oceans (covering 70.8% of the planet) constitute a heat sink which greatly minimizes diurnal temperature variations. The Earth's moderately dense atmosphere also transports heat and complicates the actual temperature patterns.

Since, however, we are not trying to predict exact temperatures for particular places on Earth, but only trying to assess the general impact of albedo changes on global temperatures, the above formula will serve well to show the approximate temperature change for a given change in albedo.

Using this formula, and the presently observed albedo of the Earth (0.36), one finds the value T = 350.6 Kelvin, which is about 70 Kelvin higher than observed reality for reasons stated. Since we are concerned with albedo *changes*, the following table will be of interest:

Albedo	**Temperature** (Kelvin)
0.30	358.6
0.32	356.0
0.34	353.3
0.36 (*)	350.6
0.38	347.8
0.40	345.0
0.42	342.1
0.44	339.1
0.46	336.0
0.48	332.9
0.50	329.6
. . .	
0.60	311.7

From the above it is clear even modest changes in the albedo of the Earth can affect mean temperatures significantly, and one would find the same result if a more complicated formula were employed. One wonders how much, if any, albedo has varied over the history of the Earth, and more specifically, how much it may have varied during the present Quarternary Period. Unfortunately we have no information available on this, and until very recently astronomers tended to regard albedos of planets as given and unchanging, something which may not be true of the Earth over a long period of time. During the ice ages, for example, extensive ice and snow cover probably tended to raise albedo somewhat —and lower temperature, making the situation worse. The impact of the pollution of industrial smog has yet to be evaluated, but in time it might lower temperatures.

Violent volcanic eruptions can affect albedo and temperature on a short term basis. After Tembora in Indonesia exploded violently in 1815 ejecting approximately 80 km^3 of ash into the upper atmosphere, cooler than normal temperatures were recorded around the Earth. In New England 1816 was known as "the year without a summer." In Connecticut ice was reported on the fourth of July, and the corn crop was a total failure. While the cause of this cold summer may have involved other factors, the ash from Tambora was probably involved.

In 1883 the volcanic island of Krakatoa, also in Indonesia, similarly exploded with the ejection of about 18 km^3 of material into the atmosphere. Subnormal temperatures and especially red sunsets were recorded in the four years which followed. A relationship seems clear, although other factors may also have been involved.

> From the above its is clear even modest changes in the albedo of the Earth can affect mean temperatures significantly, and one would find the same result if a more complicated formula were employed.

On the other hand, the 1980 May explosion of Mt. St. Helens, involving only 1 km^3 of ejected material, does not appear to have been sufficient to have had a distinct impact upon global temperatures. One wonders what the ejection of about 10 km^3 from a Mexican volcano early in 1982, which produced a high-altitude cloud seen around the world, will do.

It is clear that albedo strongly affects surface temperature. We need an ongoing program to monitor these changes, predict longer-term temperature trends, and advise appropriate crop strategies.

Intrinsic Variability

In addition to extrinsic variability in received solar radiation, there is also increasing evidence of intrinsic solar variation. In other words, strictly speaking, the Solar Constant is not constant.

Evidence for this began to appear in astronomical literature in the mid-1970's, although C.G. Abbott, an early solar investigator, had spoken of it back in 1958.[2] Most astronomers prior to the mid-1970's accepted the view of T. Sterne and N. Dieter[3] that the solar constant did not vary by more than about 0.3% from year to year. (Abbott argued that variations of several percent occurred from time to time and were correlated with specific terrestrial weather events.)

In the mid-1970's photoelectric photometry observations of the four large satellites of Jupiter (Io, Europa, Ganymede, and Callisto) were published indicating that *all* four brightened by 0.02 to 0.05 magnitude between 1973 and 1974.[4] In the same year Saturn's satellite Titan was found to be increasing in brightness by about 0.02 magnitude a year.[5] Commenting on these reports in 1976, David Morrison and Joseph A. Burns declared: "The suggestion of such large secular changes in satellite brightnesses is certainly puzzling and clearly deserving of further study."[6] Indeed! Since it is highly unlikely that internal changes in these five satellites would cause a change in brightnesses in *all* five at the same time, in the same direction, and at essentially the same rate, the obvious cause is a change in the brightness of the Sun, whose light they are all reflecting.

Further studies by G.W. Lockwood and others at Lowell Observatory, beginning back in 1972, sought to evaluate solar change by study of brightness changes in Titan, Uranus, and Neptune. These objects were chosen because there are many nonvariable stars of like-brightness with which they may be compared; direct observations of the Sun itself are very difficult to calibrate and measure because of the total lack of comparison to objects of near-similar brightness.

In 1977 Lockwood reported brightness increases in visible wavelengths for Titan, Uranus, and Neptune for the period 1972-1976 at rates ranging from 0.005 to 0.025 magnitude a year.[7] A second paper of Lockwood in 1978 discussed the photometric variations of Uranus and Neptune for the period 1953-1976. Among his conclusions he stated

> The range of planetary variation is about 2% (0.02 mag), and there is a high degree of correlation between the annual magnitudes of the two planets. . . . Correlated brightness variations of Uranus and Neptune occur on a time scale of years, which is perhaps indicative of a planetary response to the solar cycle. . . .[8]

One wonders what a decline lasting many years or centuries might do to promote glacier formation. The answer is that it might be sufficient to bring on another ice age! This might be especially likely if many of the extrinsic factors already discussed favored a cooling trend.

In general, Lockwood's data strongly supports the view of C.G. Abbott, and if observations were to be continued over centuries and millenia, quite possibly variations of more than just a few percent might emerge as part of long-term cycles. On the short term there may be a connection with the approximate 11 year visual sunspot cycle, although this is not yet fully established. (The effects of the sunspot cycle on the upper atmosphere, and thus on the weather patterns of the Earth, and upon plant growth have only recently come under scientific study, and a number of significant correlations have been found. To detail these here, however, would make this paper too long.)

What is the effective impact of a 2 percent or 3 percent variation in solar energy upon the Earth? What would be the impact in terms of surface temperature? Again we can consider this in terms of the empirical temperature formula previously discussed,

$$T = 392\,[(1\text{-}A)/r^2]^{1/4}$$

The number "392" in the formula is based on the standard value for the solar constant. If the Sun sometimes varies by 3 percent—to use Abbot's figure—then this figure could be as low as 386.1 or as much as 397.9.

Using the present albedo value, 0.38 in this formula, we find that if solar radiation declines 1½ percent from the mean value, T=342.6 Kelvin instead of the normal of 347.8 Kelvin, a decline of 5.2 degrees. Likewise a rise of 1½ percent above the mean value yields a result T=352.3 Kelvin, an increase of 5.1 degrees. While the formula does not give accurate results for the Earth for reasons mentioned earlier, it does show the *amount of change* fairly well. One wonders what a decline lasting many years or centuries might do to promote glacier formation. The answer is that it might be sufficient to bring on another ice age! This might be especially likely if many of the extrinsic factors already discussed favored a cooling trend.

Environmental Impact

In the light of the foregoing analysis, what is the potential environmental impact of solar variability? In a word, enormous. We cannot afford to take the Sun for granted, nor blindly continue to assume that it is totally invariable. Nor can we be indifferent to the effects of long-term variations in the Earth's orbit or orientation.

Since much of the Earth's grain supply comes from fairly high latitudes, a prolonged decline in received solar radiation—even if short of producing a full-blown ice age—would very seriously endanger the food supply for many of the world's present and projected population. *In agriculture increasingly there is no margin for adversity.*

> The good steward (which God calls us to be) is one who is prudent and prepared, who does not make excessive demands upon the ecosystem, and who leaves the Earth a better place than when he or she found it. Following the example of Joseph in Egypt, we need to set aside in years of plenty for the leaner times which may lie ahead.

A drop of 5 degrees Kelvin (8°F.) caused by a 1½ percent decline in solar radiation, if prolonged, would not only cut food supplies by reducing growing seasons dramatically, but would also increase food demand since in a colder world people would have to eat more to keep warm. They would also be demanding much more in firewood, fossil fuels, and fibers to keep themselves warm. While one does not like to paint a bleak picture—there is no evidence to expect an ice age in the immediate future—there is need for careful monitoring of solar activity and the development of contingency plans in case of a long-term decline. Only with an accumulation of observations over many years can we come to an understanding of the range of solar behavior and gain insight into why the Sun behaves as it does.

It is therefore greatly to be regretted that the Reagan administration is planning to make severe budgetary cuts in the National Oceanic and Atmospheric Administration (NOAA) in fiscal 1983. In the United States NOAA has funded much of the solar-terrestrial relationship research, and this aspect of NOAA's activities, according to present plans, will not just be cut back—it will be totally eliminated.[9] This is a terribly short-sighted move. True environmental stewardship of this planet and sensible planning for meeting future needs will be greatly hindered if we do not monitor solar activity and take into account the reality of solar variability.

The good steward (which God calls us to be) is one who is prudent and prepared, who does not make excessive demands upon the ecosystem, and who leaves the Earth a better place than when he or she found it. Following the example of Joseph in Egypt, we need to set aside in years of plenty for the leaner times which may lie ahead. We need to provide a reserve against times of troubles which sooner or later will surely come.

So far not many of us as individuals—nor any nations to a significant extent—have been doing this kind of contingency planning and stockpiling. Many are too poor to do anything but to struggle with today's problems. But the good steward, however pressed by the needs of today, needs to have a long-term plan, or the future could become a nightmare. Now is time to begin work on long-term preparedness. We cannot take the Sun for granted!

Notes

[1] *The Des Moines Register*, 21 April 1982, p. 1.

[2] *Smithsonian Contributions to Astrophysics 3*, pp. 13-21.

[3] *Smithsonian 3*, pp. 9-12 (1958).

[4] Millis, R.L. and Thompson, D.T., in *Icarus 26*, pp. 408-419.

[5] Jones, T.J. and Morrison, D., *Bulletin of the American Astronomical Society 7*, p. 384 (1975) and Lockwood, G.W., *Astrophysical Journal 192*, L137-L139 (1975) and *Science 190*, pp. 560-562 (1975).

[6] *Jupiter* (ed. by T. Gehrels) p. 998.

[7] *Icarus 32*, pp. 413-430 (1977).

[8] *Icarus 35*, pp. 79-92 (1978).

[9] See the report in *Oceans* (a publication of the Oceanic Society), 1982 no. 3, pp. 54-55.