
From the EARTH to the MOON
By JULES VERNE

REFLECTIONS

Early in Jules Verne's prescient novel, *From the Earth to the Moon*, published in 1873, the President of the Baltimore Gun Club presents in a formal address to his colleagues his bold plan to fire a manned projectile to the Moon. "*There is no one among you,*" he begins, "*…who has not seen the Moon, or, at least, heard speak of it.*"

And so it is with the even more familiar Sun, on which we so completely depend for the continuance of life on this planet.

Solar Misbehavior

Throughout human history almost all people have seen the Sun as wholly benevolent and indeed the very emblem of dependability and constancy in its daily pattern of rise and set. This longstanding article of faith was to some degree questioned, however, when in 1609 it was first revealed to the western world (what had long been known in the Orient) that when more closely examined the brilliant face of the Sun was not the perfect, unblemished fire most people had always assumed and indeed wanted it to be, but mottled with a scattering of dark spots of many shapes and sizes that came and went from time to time.

This disturbing realization was made in some ways more palatable when more than 200 years later, in 1843—a delay consistent with Tennyson's later reflection that "*Science moves but slowly, slowly; creeping on from point to point*"—it at last came to light that the total number of sunspots seen in any year was not random but strongly periodic, driven by a cycle of about eleven years, which was not unlike the wholly predictable movements of the planets or the comfortable ticking of a clock.

This seemed to imply that if not constant, the Sun was at least regular. But even this qualified consolation was taken away with the later realization that when examined retrospectively over a longer span of time, the Sun behaved in a less ordered and far less predictable way. During the seventy-year period between about 1645 and 1715, for example, sunspot activity almost disappeared altogether, as had happened not long before that between about 1450 and 1540, and in a dozen other instances sprinkled through the last 10,000 years.

In truth, all that we have ever learned about the Sun confirms that though we might wish it otherwise, ours is a variable and moody star. We now know that the total amount of heat and light released into space from its fiery surface varies from day-to-day and year-to-year: rising when the Sun is more active and falling when its surface is less spotted, through a total range of several tenths of a percent. Solar radiation in the invisible and more energetic components of the spectrum, which have the greatest effect on our upper atmosphere, follows a like variation but through far greater excursions, changing in the ultraviolet by several percent and in the far-ultraviolet and x-ray region by factors of 100 to 1000. We also know that isolated regions on the visible surface of the Sun can for a few minutes erupt in an explosive flash of light accompanied by the release into space of a burst of intense short-wave radiation. And that the Sun pours into space and onto the Earth a nonstop flow of energetic atomic particles in the form of a solar wind that blows in all directions throughout the heliosphere; and often throws out whole pieces of itself in the form of colossal ejections of coronal material, some of them headed our way.

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Solar variability of any kind, gradual or abrupt, alters the amount and nature of the solar energy that reaches the Earth. Moreover, to the best of our knowledge the Sun has been acting this way and doing this to us throughout all of human history, and long before that. Cro-Magnon people could have seen sunspots with their naked eye had they the inclination to look at the dimmed red disk of the Sun when it was near the horizon. Coronal mass ejections repeatedly slammed against the Earth, disrupting its magnetic field and upper atmosphere, throughout the long reigns of the pharaohs; at the time of Christ; and while William Shakespeare was writing plays in London. And although these solar tantrums went long unnoticed, we feel them today and in ever increasing ways.

What Has Changed?

Since prehistoric time what has changed in the age-old Sun-Earth relationship is neither the Sun nor the Earth, but us, through our ever-increasing reliance on technology.

Among the first to sense an immediate effect of sunspots and solar activity—in this case, coronal mass emissions—were early telegraphers in the mid-nineteenth century whose tapped-out dots and dashes were at times garbled in their passage through copper wires that stretched from place to place between wooden poles. The same problem of disruptive electric currents induced by solar-driven magnetic storms was noted at about the same time in the nineteenth century with the use of long communications cables laid down across the sea-floor.

Today, magnetically-induced currents in railroad tracks, in pipelines above and below the surface, and though electrically-conducting soil are a real and growing threat to electric power grids in heavily-populated regions where solar-induced power failures can and have triggered massive blackouts in our interconnected electric power distribution systems, resulting in losses of tens of millions of dollars and more.

Solar-driven changes in the ionosphere, which were previously unrecognized, became a dominant factor in the early 20th century and since, with the advent and ever-wider application of radio waves, affecting early radio broadcasts and other applications of this then emerging technology.

In the world of today solar storms can disturb or interrupt all forms of electronic communication, including essential military, home security, and navigational transmissions and signals sent to and from spacecraft hundreds to millions of miles away. The lifetimes of spacecraft in near-Earth orbits are directly affected by changes in the upper extent and density of the thermosphere, which expands upward with greater solar short-wave radiation, increasing the density of air and hence the amount the spacecraft is slowed by friction at a given altitude. Spacecraft and space equipment in low-Earth orbits are also affected by proximity or passage through the Earth's radiation belts, which are similarly modulated by solar activity. Spacecraft and/or the equipment they carry can be damaged and even put out of operation by highly energetic solar particles. Today commercial and military flight controllers redirect and change the altitude of the flight paths of aircraft to minimize expected exposure to heavy solar particle radiation.

There can be trouble, as well, right here in River City, for solar disturbances can through their impacts on the upper atmosphere disturb many of our common everyday activities, from telephone calls and satellite television to GPS reception and the electronic transfer of information from ATMs, to credit card transactions in stores and restaurants and gasoline pumps.

Acutely vulnerable to drastic changes in solar moods are those manned spaceflights that carry astronauts beyond the protection provided by the Earth's atmosphere and magnetosphere, where they are directly exposed to intense and even fatal particle radiation from major solar flares. This is particularly the case when these brave venturers leave the partial protection of the spacecraft in the course of EVAs, or while on the exposed surfaces of the Moon or Mars. Long voyages to either of these destinations will in addition expose space travelers to a continuous, cumulative dosage of even more energetic galactic cosmic rays, which are also modulated by solar conditions and capable of passing through the spacecraft as though it weren't there.

To detect and monitor significant solar events a fleet of dedicated spacecraft now circle the Earth at various altitudes, serving as a critical outpost of national security. They are there to keep the half of the Sun that is visible to us under continual surveillance, in white light and at wavelengths invisible on the surface of the Earth; as in situ probes to monitor current conditions in near-Earth space; and to serve as distant scouts of what the Sun is sending our way. As important are two dedicated operational centers, manned day and night, where up-to-the minute information from space and the ground are compiled, analyzed, and translated into forecasts and warnings which are made available on the internet in real time to users around the world.

The Sun and Global Warming

The susceptibility of our weather and climate to solar forcing relates directly to another, highly visible issue of current concern around the world. How large a role has the Sun played in the well-documented global warming of the last 50 years, and to what degree could solar changes alter what is expected from an anticipated doubling of greenhouse gases?

Variations in the amount of solar energy received at the top of the atmosphere can through various paths alter meteorological conditions in the lower atmosphere, including the surface temperature of the planet. The degree to which these changes affect land and sea temperatures depends on their magnitude, their persistence, and the relative effect of *competing climate drivers*.

The thermal inertia of the atmosphere and oceans dampens the effect of short term forcing of almost any kind. And on the time scale of days or weeks or months, the impacts of known solar-driven changes are far outweighed by the combined effect of among others, changes in atmospheric circulation and cloudiness; the introduction of volcanic dust and other particulates; and lingering shifts in the interconnected atmosphere-ocean system such as the El Niño effect. On time scales of decades or longer, when the up-and-down effects of these other short-term climate drivers are removed in the averaging process, persistent changes of even a small amount in solar forcing can be recognized. A consistent response to the 11-year solar cycle is found in surface temperature records for both the land and the ocean when these are averaged over large areas and for longer periods of time.

The magnitude of the Sun's impact on global surface temperature was unknown and probably unknowable before it became possible to make highly-precise measurements of the incident solar radiation from above the Earth's atmosphere. What has come from the now 30 years of these measurements is that the total solar radiation varies through limits of about 0.1%, which corresponds to a cyclic change in surface temperature of about 0.1° F.

Possible longer-term, larger-amplitude changes in the Sun's output of energy have been invoked to explain decade-to-century-long trends of warmer or cooler temperatures in climate records of the past—such as the temporal correspondence of the Maunder Minimum in solar activity with the Little Ice Age. Gradual changes in the level of solar activity persisting for 50 to 100 years are indeed readily apparent in both the 400-year record of sunspots and in the much longer tree-ring record of the production of radiocarbon. But the available 30-year sample of measurements of total solar radiation is insufficiently long to allow any meaningful check on whether known longer-term changes in solar activity have been accompanied by concurrent long-term changes in solar radiation. Or whether the amplitude of possible longer term changes in solar radiation might exceed the limits of what characterizes the 11-year modulation.

Nor can a feeling that there might possibly be longer-term, larger solar impacts compete with hard measurements covering almost half a century of an ever-steeper increase in the amount of carbon dioxide in the atmosphere, or mounting evidence that the timing and nature of terrestrial responses, as in Alaska, for example, fit so well what theory predicts for greenhouse warming as opposed to direct solar heating.

As for solar irradiation, the only established fact is that changes that exceed a few tenths of a percent have yet to be found in the limited 30 years of reliable measurements from space. The impact of changes of so small a magnitude on the mean global temperature of the Earth—which have now been observed—are not in the same league with the far larger effects expected from the well-established increase in atmospheric greenhouse gases.

Thus solar forcing of surface temperature is for now relegated to a secondary, second-order effect in terms of its impact on present trends in surface temperature. Any claim that the accelerated global heating of the past 60 years can be attributed to a changing Sun—thus conveniently absolving ourselves of any guilt in the matter—is clearly wishful thinking.

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Much of what is now known in each of the two practical issues just addressed—our increasing susceptibility to solar changes and space weather in the modern world, and the degree to which the Sun has contributed to global warming—has come to light in but the last few decades.

It is fair to say that progress made toward societal application and reliable prediction in the past 30 years exceeds in both cases all that we had accomplished toward this end in the last 300.

It is also true that the principal contributor to these most recent breakthroughs has been our new-found ability to observe and monitor the Sun, solar irradiation, CMEs, the solar wind, the magnetosphere and the upper atmosphere from the vantage point of space. Coupled with the foresight to plan and the dedication to put in place and keep in place, one by one, the spacecraft and space-borne instruments specifically dedicated to that essential and continuing task.