Chapter 26

Constancy, Thy Name Isn't the Sun

In This Chapter

- Is the solar constant constant?
- The solar constant and the sunspot cycle
- Measuring the solar constant from space
- The Sun is very round, but equatorial bright features can fool you
- The Sun and the Earth's weather

Astronomy is such an old science that it has wonderful and sometimes colorful names left over from long ago. "Sunspots," after all, just look like spots on the Sun. And they really are. "Planetary nebulae," on the other hand, don't have anything to do with planets. They are really the way the Sun and stars like it will wind up. But over 200 years ago, the first fuzzy glimpse of one looked like the fuzzy glimpses of the planet Uranus that had just been discovered. So "planetary nebulae" they were, and "planetary nebulae" they remain.

Perhaps we have a similar story with the "solar constant." Though we have long assumed that the Sun, on which we rely for our very lives, is constant, measurements made during the space age have shown us that it isn't quite so.

The Solar Parameter?

The Sun radiates astonishing amounts of energy each second. The result of nuclear fusion in its core radiates up through 71 percent of its body and then bubbles up as convection through the outer 29 percent. Once it reaches the surface, it heats the gas. That gas radiates the energy that we see, with most of the energy falling in the visible part of the spectrum.

Some of the Sun's energy comes in other parts of the spectrum than the visible. Those other parts are known to be very variable. The amount of radio flux from the Sun shows flares and other activity, and can easily be observed with radio telescopes on Earth. To study the ultraviolet, x-rays, and gamma rays, we have to observe from space, but we know that those parts of the solar spectrum also vary violently. Still, the bulk of the solar radiation is in the visible, and that appears to be pretty constant, at least during our lifetimes.

The Earth's atmosphere absorbs some of the solar radiation, and the Earth's atmosphere is variable. To find out what the Sun emits, we have to either correct our measurements for the effects of the atmosphere or go above the atmosphere. Both methods have been tried.

The solar constant is the amount of solar radiation received by each square meter of a perpendicular square facing the Sun at the top of the Earth's atmosphere, corrected to an Earth-Sun distance of 1 astronomical unit, the average distance from Earth to the Sun.

At All Altitudes

Charles Greeley Abbot, the fifth Secretary of the Astrophysical Observatory of the Smithsonian Institution, famously devoted his life to measuring the solar constant. Abbot was born in 1872 and lived to the age of 101, making measurements and publishing scientific papers right up to the end. His measurements spanned many sunspot cycles and a long period of time. Abbot started his measurements in 1895, when he was hired by the first director, Samuel Pierpont Langley, to make solar measurements. Langley, and Abbot with him, used a device—a *bolometer*—that allowed incoming radiation to heat up a cavity. They measured the temperature of the cavity electrically, since the resistivity of many metals depends sensitively on temperature. They hoped to follow changes in incoming radiation by following the electrical changes. Note that since they were basically measuring the heat from

Sun Words

Bolometer comes from the Greek word *boli,* which means "beam of light."

the Sun, their measurement included all incoming solar radiation, though, of course, the parts absorbed by the atmosphere never got through to their instruments. Still, the bolometer measured solar infrared radiation, and Langley was a pioneer in the study of the infrared.

Langley and Abbot worked hard to account for Earth's atmosphere. To eliminate as much of it as possible, Langley took a bolometer to the top of the tallest mountain in California: Mt. Whitney. Langley and Abbot also launched bolometers on balloons. Langley and then Abbot ran a Smithsonian measurement program from 1902 until 1960. During that period, the latest re-evaluation of the Smithsonian results were that 1,353 watts fell on each square meter. In the old British units, that is equivalent to about 2 calories per square centimeter per minute. Abbot reported variations of as much as 10 percent. However, newer reevaluations of his data showed that no variations were ever really found, to an accuracy of 1 percent. Abbot had hoped to use the measurement of variations to help improve weather forecasts. He strongly believed that Earth's weather depended on the amount of energy from the Sun. That link never worked out.

Fun Sun Facts

Charles Greeley Abbot lived so long that people forgot that he was still alive. When Soviet scientists tried to name a crater on the back side of the Moon after him, following their first map of the far side, they ran afoul of the International Astronomical Union's rules against naming craters after living people. An exception was made.

Fun Sun Facts

Abbot traveled to observe total solar eclipses in North Carolina in 1900, Sumatra in 1901, a South Pacific island in 1908, and Bolivia in 1919. To assess the effect of Earth's atmosphere on the solar constant, he carried out his measurements of the solar constant from Washington, D.C., at sea level; Mt. Wilson, California, at an altitude of 1,742 m (5,715 ft.); and at Mt. Whitney, California, at an altitude of 4,418 m (14,495 ft.). His balloons went even higher.

Is the Sun Going Away?

Since the solar constant is defined as the rate at which sunlight hits a defined region at the top of Earth's atmosphere, it makes sense to go to the top of our atmosphere to measure it. Once we could get satellites into space, this type of measurement became possible.

A pioneering instrument to measure the solar constant from space was on the Solar Maximum Mission in the 1980s. To get all the solar radiation, or irradiance, the light was made to enter a cavity, where it was trapped. Because a device that measures radiation is a radiometer, the device was called the Active Cavity Radiometer Irradiance Monitor (ACRIM). The technical name for the solar constant is now Total Solar Irradiance (TSI).

The Solar Scoop

The original ACRIM, which we can call ACRIM I, was launched on Solar Maximum Mission in 1980. ACRIM II was on the Upper Atmosphere Research Satellite (UARS), launched in 1991. ACRIM III is on a devoted ACRIMSAT mission and was launched in 1999. The satellite wasn't pointing properly at the Sun at first, but it was saved.

ACRIM was built and controlled by Richard Willson at Caltech's Jet Propulsion Laboratory in Pasadena, and it was the first solar-constant instrument able to measure to better than a tenth of a percent. As the data came in, slight variations were seen on that level. Some big dips occurred that corresponded to big sunspots on the face of the Sun. So the longstanding question as to whether sunspots blocked enough solar energy to be detected in the overall solar irradiance was finally answered.

Fun Sun Facts

The cavity of ACRIM has mirror-like black surfaces that reflect incoming light in a way that it doesn't get out. A total of 99.99998 percent of the Sun's incoming energy in the wavelength band from 1,800 Å in the ultraviolet to 30 microns in the infrared are absorbed.

As the months passed, a general downward trend became visible in the solar constant. This downward trend was in addition to the day-to-day variations. From Solar Maximum Mission's launch in 1980 until it malfunctioned in 1984, the average solar constant had dropped more than a tenth of a percent. That rate of decay of incoming sunlight can't go on at that rate without severe consequences! In not many centuries, the Sun would become faint, Earth would become very cold, and our descendents would all die.

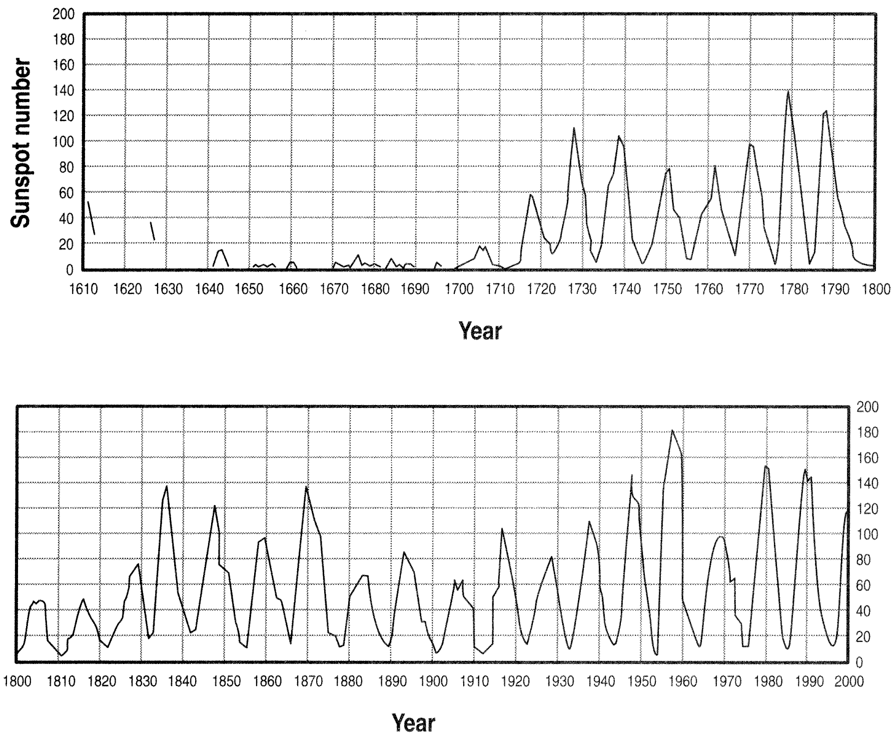
Data from ACRIM and ACRIM II showing the change in the sun's brightness over about two decades. The graph shows that, after a period from launch in 1980 through 1984 when the data weren't precise, the solar constant—the amount of energy received by a square meter of the top of the Earth's atmosphere each second—was falling. Fortunately, it began to rise in 1987, reaching a peak in 1990–91, the next maximum of the solar-activity cycle. Our hope for saving the Earth had to be in the sunspot cycle. Perhaps the solar constant was linked to it. But SMM was spinning out of control, and we had no accurate monitor. Fortunately, SMM was saved, and so was the Earth. When SMM was spun down and ACRIM started working again, the solar constant continued to decline for another year or so. In fact, the instrument was working better than ever, with increased stability of the spacecraft leading to less variation reported.

Then, in 1986 or so, we reached the minimum of the sunspot cycle. We weren't exactly holding our breaths, since it took months and years to be established completely, but the solar constant started going back up again. Finally, we knew that the solar constant merely followed the solar cycle. It goes up and down by about half a percent.

Of course, if the solar constant varies, it isn't really a constant. But, like so many astronomical terms, the term is hallowed by age and usage. We still speak of the solar constant.

Solar Scribblings

Paintings from the seventeenth and eighteenth centuries show ice skating on canals in Holland, something that is now rarely possible. A "Little Ice Age" gripped at least part of Earth. Sunspots were apparently almost completely absent from the Sun for a few decades in the seventeenth and early eighteenth centuries—and people were looking for them. This period, known as the Maunder Minimum, was studied in the twentieth century especially by John A. Eddy. Is there a correlation between the absence of sunspots and the Little Ice Age?



The long-term measurements of sunspots.

(J. Eddy, updated from SIDC)

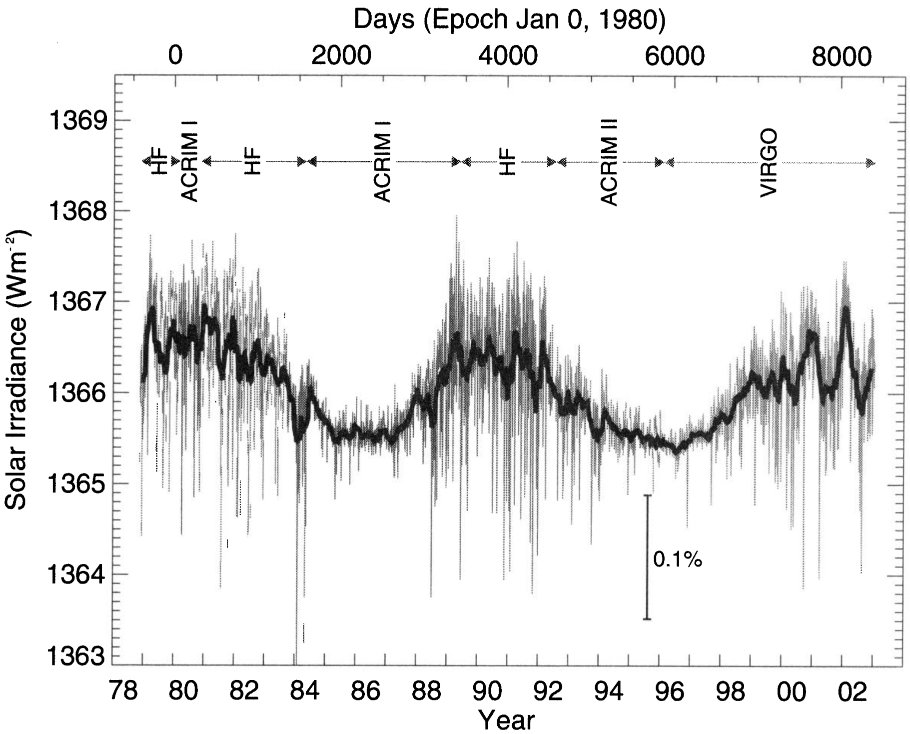
Monitoring Our Lifeline

The Sun is such an important source of energy for us that we continue to monitor it in various ways. Some other spacecraft also carried solar-constant monitors, notably the Nimbus series of weather satellites. The variations that were measured from the different satellites corresponded to each other, though there were—and remain—slight calibration problems. That is, the absolute value measured by one satellite was a steady percent or so different from the absolute value measured by another. This problem remains unresolved.

An excellent monitor in recent years has been the Variation of IRradiance and Gravity Oscillations (VIRGO) instrument aboard the Solar and Heliospheric Observatory. It carries two radiometers which, perhaps inevitably differ slightly in their results. One is the DIfferential Absolute RADiometer (DIARAD), run by the Meteorological Institute of Belgium. The other is a set of radiometers from the World Radiation Centre at Davos, Switzerland. (In German, it is the *Physikalische-Meteorologisches Observatorium Davos*, so the parent organization is known as the PMO.) They have operated since early 1986, a few months after the launch of SOHO. The measurements from the two instruments differ by 0.6 to 1.4 watts per square meter out of about 1,368 watts per square meter of solar constant. Thus, the deviation is about 0.1 percent, making the accuracy quite an improvement over the historic solar-constant measures.

NASA has independently monitored the solar constant through a series of detectors each known as an Active Cavity Radiometer Irradiance Monitor (ACRIM). We discussed an earlier ACRIM in Chapter 21 and previously in this chapter. NASA's ACRIMSAT was launched in 2000. NASA's Solar Radiation and Climate Experiment (SORCE) was launched in 2003, also to measure the solar constant very accurately. SORCE measures not only total solar irradiance (the solar constant) but also the solar output in various specific parts of the spectrum, especially as the ultraviolet, whose intensity varies more greatly than the Sun's intensity in the visible.

Occasionally, a solar-constant monitor has been flown on a space shuttle, in order to calibrate the long-term instruments that are in space. After all, the instruments on a rocket or space shuttle can be retrieved so scientists can test them to make sure that their sensitivities haven't drifted during their brief flights. They then know they can trust the calibrations made with these instruments, and compare the results with those from the instruments that have long been in space, to see if the latter's calibrations have changed.



The solar constant, as it has varied, in a unified graph.

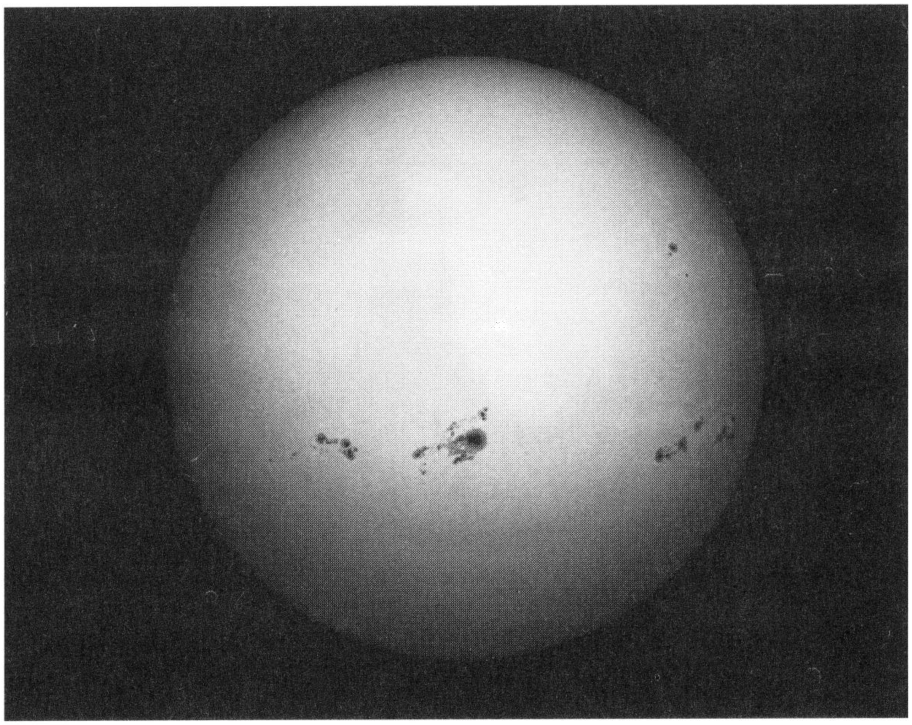
(C. Fröhlich, PMO, and the VIRGO team)

Chiaroscuro

Art historians speak of chiaroscuro, light and dark, on a painting. On the Sun, we also see a sort of chiaroscuro. There are dark regions, the obvious sunspots. But there are light regions as well. They are visible in ordinary light and stand out when you look toward the solar edge instead of toward the disk center. These light regions are called *faculae* (the plural of facula). When seen through filters passing the strong hydrogen or calcium spectral lines, the faculae within the solar limb are seen as plages. They show especially well in the calcium-line filters.

Sun Words

Faculae are bright regions on the solar photosphere seen in white light or through certain filters.



The light regions on the solar disk are faculae.

(NSO/AURA)

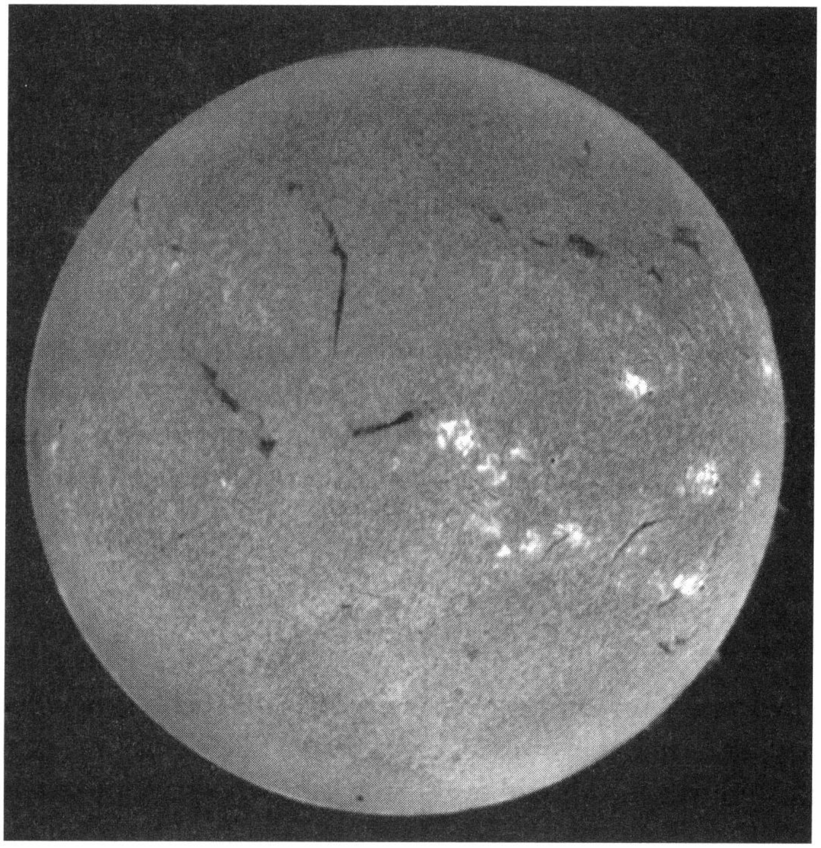
The Solar Scoop

Astronomers can deduce that there is magnetic activity in distant stars by monitoring their spectral lines from ionized calcium, Fraunhofer's H and K. The very central part of these lines are especially bright when there are a lot of plage areas on the stars. Long-term monitoring has shown dozens of stars that have activity cycles like the Sun's, ranging in time from a few years to longer periods.

One of the questions about the solar constant is whether sunspots cause it to drop. Similarly, do faculae cause it to rise? Does some of the energy absorbed in sunspots cause an increase in the number of faculae, compensating or more than compensating? This topic has been an important point of discussion in understanding the role of the solar constant on the Earth.

The faculae correspond to magnetic elements near the Sun's surface. They are visible to some extent in "white light"—that is, integrated visible sunlight—and also show particularly well in the light of ionized calcium. The distribution of faculae and their number change over the solar-activity cycle. The fraction of the Sun that they cover varies by a greater amount than the fraction of the Sun covered by sunspots, so faculae are very important for understanding the variations of the solar constant. Faculae and sunspots are both regions in which the magnetic field limits the amount of energy brought from below by convection. But sunspots are large enough that the area becomes cool and dark. Faculae, on the other hand, are so narrow that light comes into them from their sides, making them relatively bright.

When you look at the Sun through a hydrogen-alpha filter, you don't see the sunspots directly; you see bright active regions around them. As we mentioned briefly in Chapter 2, these active regions are known as plage, from the French word for "beach." (It is pronounced *plahje*, to rhyme with "ah.") Though the plage regions show up only in narrow wavelength bands, perhaps they have some slight effect on the total energy released by the Sun.



The light regions in this view of the Sun, taken through a filter that passes only the H-alpha line from hydrogen, are called plage.

(IfA/U. Hawaii)

Is the Sun Round?

The faculae affect not only the solar constant, but also the distribution of solar radiation across the face of the Sun. There are more faculae near the solar equator than there are near the poles. And the number and brightness of faculae vary over the solar-activity cycle.

Some years ago, a Princeton physicist addressed the question of whether the Sun was round—or, really, just how round the Sun is. He set up a device that blocked out most of the Sun and that rotated, with just a little bit of Sun showing around the edge. He detected a slight variation from equator to pole, concluding that the Sun was about 35 km (20 miles) larger (out of a 700,000-km 500,000-mile radius) at the equator. But how could the Sun be bulging like that? (The technical word is *oblate*.)

The physicist's theory was that the Sun had a central region that was rotating rigidly at a high speed—once every four days or so. Only that high speed in the center would account for the observed oblateness at the limb. But such a highly rotating region would cause other effects—notably, an effect on the orbit of Mercury.

The orbit of Mercury is significant because it is a test of Einstein's general theory of relativity, from 1916. The close point of Mercury to the Sun in its elliptical orbit around it is called the perihelion. Once the gravity of the planets is accounted for, the perihelion of Mercury changes by 43 seconds of arc per century. Einstein's theory accounts for that "advance," and the effect has long been considered a test of the theory. But if a rapidly rotating solar core accounted for an advance of Mercury's perihelion by 4 seconds of arc per century, then only 39 seconds would be left, no longer agreeing with Einstein's theory's prediction of 43 seconds of arc. And the physicist happened to have his own theory of gravity that was more general than Einstein's and that could be adjusted to match the effect.

Anyway, solar physicists showed that the presence of faculae near the solar limb meant that the original scientist was measuring an intensity variation but not a size variation. The rotating core just wasn't there. With hindsight, our current helioseismology measurements of the core show that the Sun does not have such a rapidly rotating core. Einstein survives.

The Sun and Weather

Does the Sun change in average brightness over many sunspot cycles, and over centuries? Such changes would have a major effect on climate. The careful measurements of the solar constant now under way should eventually settle this important question.

The Solar Scoop

As one of its major goals, NASA's Living with a Star program tries to find out how solar variability affects life on Earth. It is gathering data to answer the question of whether solar changes affect the details of weather on Earth.

Many people have tried over the past decades to link the Sun and climate. Sometimes a relationship looks good for a long time but then stops working. That effect means that the apparent relationship had been merely a coincidence. Since the 11-year solar cycle is a dominant effect, we have to wait a long time before we go through enough cycles to be sure of a relationship. We aren't even sure if the link between the Maunder minimum and the Little Ice Age of the seventeenth and early eighteenth century is a causal relation or a coincidence.

Some potential links exist between the Sun and Earth's weather. For example, the strength of galactic cosmic rays—energetic particles from beyond the solar system—that hit the top of Earth's atmosphere is linked to the solar cycle. At times of increased solar activity, the solar magnetic field deflects more of these cosmic rays away from the Earth, and the cosmic-ray flux here diminishes. Since the ionization of the atmosphere caused by cosmic rays may lead to the formation of clouds, the decrease in cosmic rays at solar maximum could diminish cloudiness worldwide, which obviously affects weather. Most directly, less cloudiness means more sunlight penetrating to the Earth's surface.

Furthermore, the amount of ultraviolet, which affects things like the ozone layer (which we discuss in the following chapter), is linked to the solar cycle. Some of the spacecraft that monitor the solar constant also carefully monitor the ultraviolet flux that arrives at Earth from the Sun for that and other reasons. In particular, the ultraviolet light from the Sun affects the rate at which ozone is formed and, at different ultraviolet wavelengths, the rate at which it is destroyed. The absorption of ultraviolet radiation by ozone also affects the temperature in the higher levels of our atmosphere. But nobody has ever linked the Sun's radiation, and variations in it, directly to the daily weather or, more particularly, to the weather at particular locations.

The Least You Need to Know

- The solar constant is the amount of energy received by each square meter of the top of Earth's atmosphere each second.
- The solar constant was found to vary by a fraction of a percent through space monitoring.
- The solar constant varies slightly through the solar-activity cycle.
- The solar constant can have a long-term effect on Earth's climate, but no effect on daily weather is known.
- Cosmic rays are affected by the solar-activity cycle and may affect the rate of cloud formation and thus weather.
- The amount of ultraviolet radiation varies by a much greater factor than does the solar constant and may affect weather.