REFERENCE

SOLAR RADIATION AND CLIMATE EXPERIMENT (SORCE)

Without the Sun, the Earth would be no more than a frozen rock stranded in space. The Sun warms the Earth and makes life possible. Its energy generates clouds, cleanses our water, produces plants, keeps animals and humans warm, and drives ocean currents and thunderstorms. Despite the Sun's importance, scientists have only begun to study it with high precision in recent decades. Prior to 1979, in fact, astronomers and Earth scientists did not even have accurate data on the total amount of energy from the Sun that reaches the Earth's outermost atmosphere. Variable absorption of sunlight by clouds and aerosols prevented researchers from accurately measuring solar radiation before it strikes the Earth's atmosphere.

Energy from the Sun makes life on Earth possible. Solar energy also drives the Earth's climate, and slight variations in solar radiance could offset (or increase) global warming. (Photograph courtesy Philip Greenspun)

The launch of the Nimbus-7 satellite in 1978 changed all that. It enabled us for the first time to detect sunlight without interference from the atmosphere. The Earth Radiation Budget (ERB) instrument on the satellite measured levels of solar radiation just before it strikes the Earth's atmsophere. Through subsequent satellite missions, scientists have gathered a wealth of information on the Sun and the solar energy that drives our world's climate system.

> "WITH THE DATA FROM SORCE, RESEARCHERS WILL BE ABLE TO FOLLOW HOW THE SUN AFFECTS OUR CLIMATE NOW AND IN THE FUTURE."

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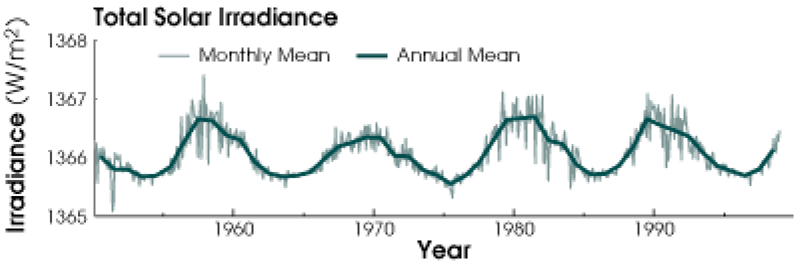
Today researchers know that roughly 1,368 watts per square meter (W/m^2) of solar energy on average illuminates the outermost atmosphere of the Earth. They know that the Earth absorbs about only 70 percent of this total solar irradiance (TSI), and the rest is reflected into space. Perhaps most intriguing, researchers have affirmed that the TSI doesn't stay constant, but varies slightly with sunspots and solar weather activity. In particular, by analyzing satellite data, scientists have observed a correlation between the Sun's output of energy and the 11-year sunspot cycle, which physicists have known of since Galileo's time. These data show that TSI varies just as regularly as the sunspot activity over this 11-year period, rising and falling 1.4 W/m^2 through the course of the cycle (0.1 percent of the TSI). There are also longer-term trends in solar weather activity that last anywhere from years to centuries to millennia and may have an impact on global warming.



The total energy emitted by the Sun varies on an 11-year cycle. Even greater variation occurs at shorter time scales as sunspot groups form and dissipate. At longer time scales the Sun may undergo other cycles. By monitoring these changes in the Sun, scientists hope to better understand its role in changing the Earth's climate. (Graph adapted from Goddard Institute for Space Studies Data and Images: Solar Irradiance)

Due to technological barriers and a limited amount of data, however, scientist's understanding of the Sun-Earth system continues to be incomplete. They are unable to predict fluctuations in TSI due to 11-year and long-term solar cycles, and scientists do not yet have accurate enough measurements to determine the trend from one cycle to the next with sufficient precision. In fact, the TSI is currently known to within an accuracy of a few Watts per square meter, which is greater than the entire fluctuation of the TSI over one 11-year solar cycle. Additionally, scientists haven't pinned down what proportion of solar energy is

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absorbed by the land or atmosphere. They also do not have complete measurements of the energy variation for the distinct wavelengths of incoming solar radiation. These different wavelengths affect the various components of the Earth’s atmosphere, land, and ocean in different ways.

In 2003, Earth scientists will move a step closer to a full understanding of the Sun’s energy output with the launch of the Solar Radiation and Climate Experiment (SORCE) satellite. SORCE will be equipped with four instruments that will measure variations in solar radiation much more accurately than anything now in use and observe some of the spectral properties of solar radiation for the first time. Robert Cahalan of NASA Goddard Space Flight Center serves as SORCE Project Scientist, and the four instruments are being built at the University of Colorado under the direction of Gary Rottman, SORCE Principal Investigator, with participation by an international team of scientists. SORCE will be launched in January 2003 from Kennedy Space Center on a Pegasus XL launch vehicle provided by Orbital Sciences Corporation. With data from NASA’s SORCE mission, researchers should be able to follow how the Sun affects our climate now and in the future.

next: Earth’s Energy Balance

Solar Radiation and Climate Experiment (SORCE)

Earth’s Energy Balance

For the past quarter century, Earth scientists have been trying to get a handle on how much solar energy illuminates the Earth and what happens to the energy once it penetrates the atmosphere. To date they estimate that roughly 1,368 W/m^2, averaged over the globe and over several years, strikes the outermost atmosphere at the Earth. This is called the “Total Solar Irradiance,” or TSI. TSI depends only on the total energy per second produced by the Sun (its absolute luminosity) and the distance from the Sun to the Earth, 93 million miles or 150 million kilometers.

Though sunlight may appear white and nondescript, it consists of electromagnetic waves that have a wide

> “The absorption of solar energy heats up our planet’s surface and atmosphere and makes life on Earth possible.”

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range of wavelengths. One can separate these wavelengths by simply holding up a prism to sunlight, which causes light rays of shorter wavelengths to bend at larger angles. The various purples, blues, greens, yellows, and reds that emerge from the prism represent all the wavelengths of light that are visible to the human eye, which only detects wavelengths between 400 and 700 nanometers (billionths of a meter). The visible spectrum, however, accounts for just under half of the Sun's total energy. Much of the Sun's energy is made up of ultraviolet (UV) radiation, which has shorter wavelengths (higher energy levels) than visible light and extends off of the purple end of the visible spectrum. An even larger amount of this invisible energy can be found in the longer infrared wavelengths (lower energy levels) of light that extend off the opposite end of the visible spectrum.

The Sun emits light in a very wide range of wavelengths—from radio waves, through visible light, to x-rays. The most familiar example is the visible spectrum revealed in a rainbow, but all the colors of the rainbow occur in a relatively narrow band of wavelengths. In addition to visible light, infrared and ultraviolet light also play a role in the Earth's climate. (Photograph courtesy Philip Greenspun)

Not all of this light is absorbed by the Earth. Roughly 30 percent of the total solar energy that strikes the Earth is reflected back into space by clouds, atmospheric aerosols, snow, ice, desert sand, rooftops, and even ocean surf. The remaining 70 percent of the TSI is absorbed by the land, ocean, and atmosphere. In addition, different layers of the Earth and atmosphere tend to absorb different wavelengths of light. Only one percent of the TSI, mostly in the form of UV radiation, is absorbed by the upper atmosphere, mainly by stratospheric ozone. Twenty to 24 percent of the TSI and a majority of the near infrared radiation is absorbed in the lower atmosphere (troposphere),

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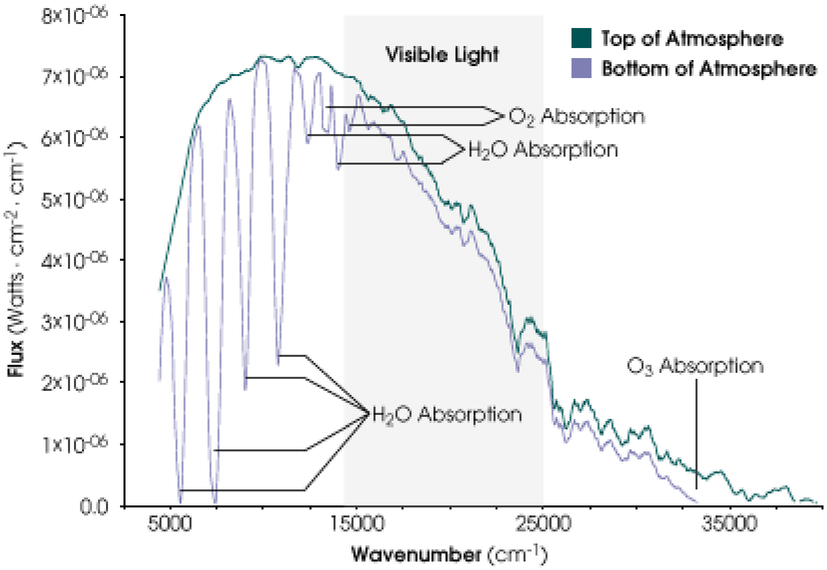
mainly by water vapor, trace gases, clouds, and darker aerosols. The remaining 46 to 50 percent of predominately visible light penetrates the atmosphere and is taken in by the land and the oceans.



Solar radiation is not emitted in a smooth continuum. Superheated atoms in the Sun, particularly Hydrogen and Helium, absorb radiation in distinct wavelengths. These absorption bands are visible as dips in the green line in the graph above, which represents the spectrum of sunlight that arrives at the top of the Earth's atmosphere. Additionally, gas molecules absorb radiation in the Earth's atmosphere, further reducing the radiation at the surface. The blue line represents the spectrum of radiation arriving at the surface of the Earth on a clear day in the tropics, based on an atmospheric model. (Graph by Robert Simmon, based on model data from the NASA GSFC Laboratory for Atmospheres)

The absorption of solar energy heats up our planet's surface and atmosphere and makes life on Earth possible. But the energy does not stay bound up in the Earth's environment forever. If it did, then the Earth would be as hot as the Sun. Instead, as the rocks, the air, and the sea warm, they emit thermal radiation (heat). This thermal radiation, which is largely in the form of long-wave infrared light, eventually finds its way out into space, leaving the Earth and allowing it to cool. For the Earth to remain at a stable temperature, the amount of longwave radiation streaming from the Earth must be equal to the total amount of absorbed radiation from the Sun.

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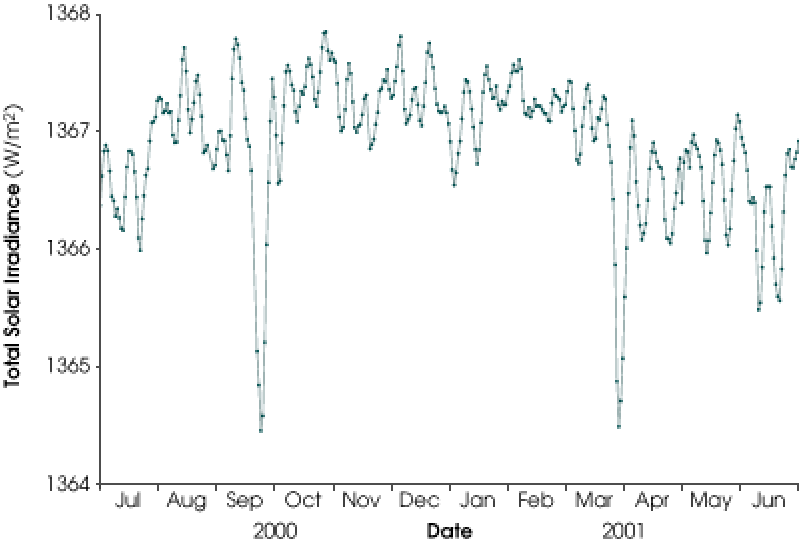
Solar Variability

If that were all there was to the Earth’s radiative balance, scientists studying the Sun would have probably long since moved on to another climate-related problem. Analyzing the Sun and its affects on climate, however, is further complicated by the fact that the amount of radiation arriving from the Sun is not constant. It varies from the average value of the TSI—1,368 W/m^2—on a daily basis.



Daily variation in solar output is due to the passage of sunspots across the face of the Sun as the Sun rotates on its axis about once a month. These daily changes can be even larger than the variation during the 11-year solar cycle. However, such short-term variation has little effect on climate. The graph above shows total solar irradiance on a daily basis. The plot is based on data collected by the ACRIM III instrument, which is currently in orbit. (Graph by Robert Simmon, based on data from ACRIM III)

Variations in TSI are due to a balance between decreases caused by sunspots and increases caused by bright areas called faculae which surround sunspots. Sunspots are dark blotches on the Sun in which magnetic forces are very strong, and these forces block the hot solar plasma, and as a result sunspots are cooler and darker than their surroundings. Faculae, which appear as bright blotches on the surface of the Sun, put out more radiation than normal and increase the solar irradiance. They too are the result of magnetic storms, and their numbers increase and decrease in concert with sunspots. On the whole, the effects of the faculae tend to beat out those of the sunspots. So that, although solar energy reaching the

> “ANALYZING THE SUN AND ITS EFFECTS ON CLIMATE IS COMPLICATED BY THE FACT THAT THE AMOUNT OF RADIATION ARRIVING FROM THE SUN IS NOT CONSTANT.”

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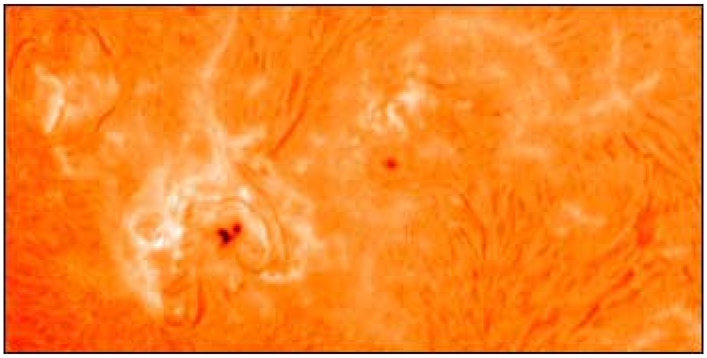
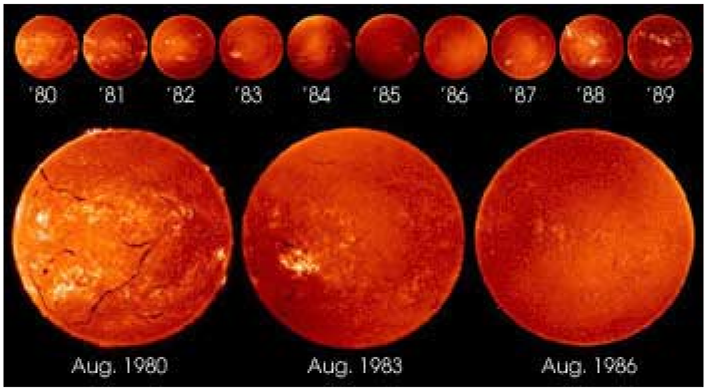
Earth decreases when the portion of the Sun's surface that faces the Earth happens to be rife with spots and faculae, the total energy averaged over a full 30-day solar rotation actually increases. Therefore the TSI is larger during the portion of the 11 year cycle when there are more sunspots, even though the individual spots themselves cause a decrease in TSI when facing Earth.

Outgoing Heat Radiation



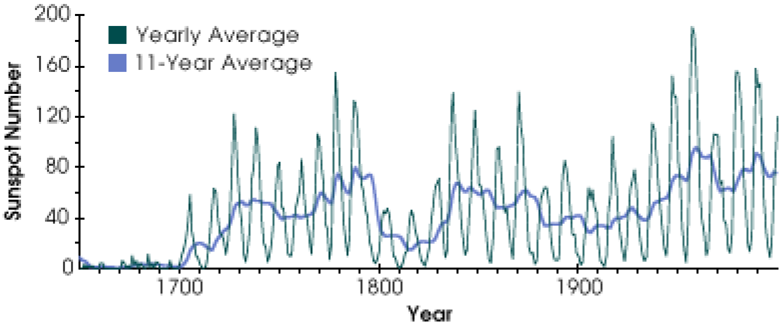
The bright regions on the Sun that surround sunspots are called faculae. Although sunspots reduce the amount of energy radiated from the Sun, the faculae associated with them increase the radiated energy even more, so that overall, the total amount of energy emitted by the Sun increases during periods of high sunspot activity. (Image courtesy Big Bear Solar Observatory)

The number of sunspots visible from the Earth not only changes from day to day, but also in cycles that can last from decades to centuries to millennia. The most well-known and well-analyzed of these cycles is the 11-year sunspot cycle. Over the course of 11 years, the yearly average number of sunspots and faculae slowly increases and then return to normal levels before rising again for the subsequent cycle. The change in the Sun's yearly average total irradiance during an 11-year cycle is on the order of 0.1 percent or 1.4 watts per square meter.



The 11-year solar cycle is manifested by the appearance and disappearance of large numbers of sunspots on the Sun's surface. The image series above shows the Sun at a wavelength of 656.3 nm, where Hydrogen emission just above the Sun's visible surface reveals increased energy coming from faculae. One image was taken every year from 1980 to 1989. 1980 was near a solar maximum and the Sun was active, while 1986 was near the minimum, and the Sun's surface was almost featureless. (Image adapted from *The Sun: a pictorial Introduction* by P. Charbonneau and O.R. White)

Another trend scientists have picked up on appears to span several centuries. Late 17th century astronomers observed that no sunspots existed on the Sun's surface during the time period from 1650 to 1715 AD. This lack of solar activity, which some scientists attribute to a low point in a multiple-century-long cycle, may have been partly responsible for the Little Ice Age in Europe. During this period, winters in Europe were much longer and colder than they are today. Modern scientists believe that since this minimum in solar energy output, there has been a slow increase in the overall sunspots and solar energy throughout each subsequent 11-year cycle.



The number of sunspots on the Sun's surface is roughly proportional to total solar irradiance. Historical sunspot records give scientists an idea of the amount of energy emitted by the Sun in the past. The above graph shows sunspot data from 1650 to the present. The Maunder Minimum occured from 1650–1700 and may have influenced Europe's little ice age. (The data from this period are not as reliable as the data beginning in 1700, but it is clear that sunspot numbers were higher both before and after the Maunder Minimum.) Since then, sunspot number have risen and fallen in a regular 11-year cycle. An 11-year running average shows only the long-term variation, which shows a rise in total sunspot numbers from 1700 until today. [Graph by Robert Simmon, based on data compiled by John Eddy (1650-1700) and the Solar Influences Data analysis Center (SIDC)]

Lastly, on the time scale of the lifetime of the solar system, measured in billions of years, the Sun is going through the same life and death cycle as any average star. As it uses up its hydrogen fuel, the Sun grows hotter and hotter throughout its lifetime. In a couple of billion years, this gradual heating will melt all the ice on Earth and turn the planet and into a hothouse much like Venus. Since the increase occurs over such an extended period of time, today's instruments cannot even detect year-to-year changes along this cycle. By the time the effects of this warming trend are felt, it's possible humans may have become extinct, or found a way to populate distant planets, and in either case may not still be left on Earth worrying about Earth's demise.

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SOLAR RADIATION AND CLIMATE EXPERIMENT (SORCE)

The Sun and Global Warming

Of the many trends that appear to cause fluctuations in the Sun's energy, those that last decades to centuries are the most likely to have a measurable impact on the Earth's climate in the foreseeable future. Many researchers believe the steady rise in sunspots and faculae since the late seventeenth century may be responsible for as much as half of the 0.6 degrees of global warming over the last 110 years (IPCC, 2001). Since pre-industrial times, it's thought that the Sun has given rise to a global heating similar to that caused by the increase of carbon dioxide in the atmosphere. If the past is any indication of things to come, solar cycles may play a role in future global warming.

Though complex feedbacks between different components of the climate system (clouds, ice, oceans, etc.) make detailed climate predictions difficult and highly uncertain, most scientists predict the release of greenhouse gases from the burning of fossil fuels will continue to block a larger and larger percentage of outgoing thermal radiation emanating from the Earth. According to the 2001 report of the Intergovernmental Panel on Climate Change (IPCC), the resulting imbalance between incoming solar radiation and outgoing thermal radiation will likely cause the Earth to heat up over the next century, possibly melting polar ice caps, causing sea levels to rise, creating violent global weather patterns, and

> "SOLAR CYCLES MAY PLAY A ROLE IN FUTURE GLOBAL WARMING."

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increasing vegetation density (IPCC, 2001).

How the Earth's climate reacts, however, depends on more factors than just greenhouse gases. For instance, some scientists expect that low-level stratocumulus clouds may decrease. Both changes would add to the heating, since an increase in cirrus would trap more infrared, and a decrease of stratocumulous would reflect less sunlight. Such cloud cover changes would intensify global warming. In contrast, an increase of sulfate aerosols created by pollution would likely reflect more sunlight and perhaps also make clouds more reflective, thereby countering global warming especially near pollution sources.

Thick, puffy stratocumulus clouds (left) reflect sunlight and cool the Earth's surface. However, thin cirrus clouds (right) allow most visible light to pass right through them, while blocking thermal radiation, so they warm the Earth. Because of this, how clouds respond to changes in solar energy output is a crucial aspect of the Sun's influence on climate. (Photographs courtesy Dr. Robert Houze, University of Washington Cloud Atlas)

Sunspot cycles may sway global warming either way. If long-term cycles in solar radiation reverse course and the Sun's spots and faculae begin to disappear over the next century, then the Sun could partially counter global warming. On the other hand, if the average number of spots rises, the Sun could serve to warm our planet even more. As to the shorter-term 11-year cycles, they may dampen or amplify the affects of global warming on a year-to-year basis.

The Sun's affect on global warming can mostly be attributed to variations in the near-infrared and visible wavelengths of solar radiation. As previously stated, these types of radiation are absorbed by the lower atmosphere, the oceans, and the land. UV radiation, on the other hand, interacts strongly with the ozone

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layer and the upper atmosphere. Though UV solar radiation makes up a much smaller portion of the TSI than infrared or visible radiation, UV solar radiation tends to change much more dramatically over the course of solar cycles.

The impacts of undulating UV solar radiation may be substantial. Since UV radiation creates ozone in the stratosphere, the oscillation in UV levels can affect the size of the ozone hole. Absorption of UV radiation by the ozone also heats up the stratosphere. Many scientists suspect that changes in stratospheric temperatures may alter weather patterns in the troposphere. Finally, an increase in the amount of UV radiation could impact human health, increasing the incidence of skin cancer, cataracts, and other Sun-exposure-related maladies (please see Ultraviolet Radiation: How it Affects Life on Earth for more details).

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SOLAR RADIATION AND CLIMATE EXPERIMENT (SORCE)

Uncertainties in Solar Measurements

Despite all that scientists have learned about solar irradiance over the past few decades, they are still a long way from forecasting changes in the solar cycles or incorporating these changes into climate models. One of their biggest obstacles has been technology. Because even the smallest shifts in solar energy can affect climate drastically, measurements of solar radiation have to be extremely precise. Instruments in use today still are subject to a great deal of uncertainty.

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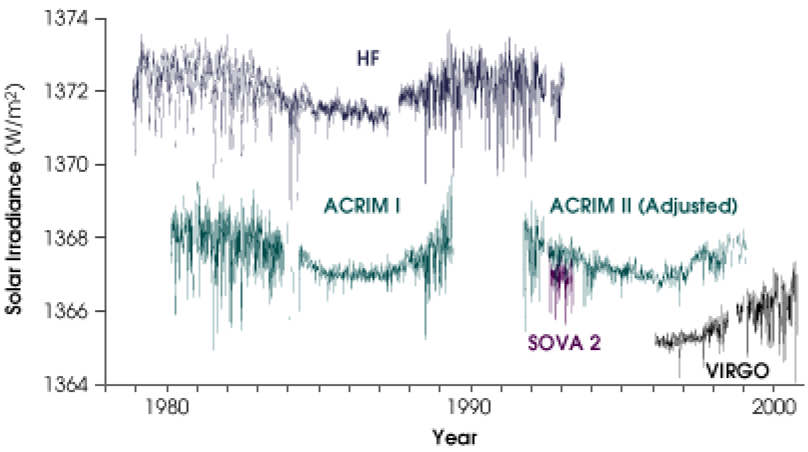

The various sensors agree closely in the timing and amplitude of rapid daily variations due to the passage of individual sunspot groups. The sensors also agree in the amplitude of the 11-year cycle, but disagree significantly in the decadal average level of the TSI—up to 6 watts per square meter. This difference is larger than the total variation in solar irradiance in the past 500 years, so a more accurate assessment is needed to study the Sun's impact on climate change. An upcoming NASA research satellite, the Solar Radiation and Climate Experiment (SORCE), will carry instruments designed to do just that. (Graph adapted from C. Frölich of the World Radiation Center in Davos Switzerland)

The total change in TSI over the 11-year cycle is believed to be 0.1 percent of the Sun's total energy on a yearly average. Individual sunspot events are very accurately reproduced in independent TSI measurements, so that the **relative** accuracy on weekly and 11-year time scales is sufficient to characterize such changes. However, the most accurate estimates of the long-term average TSI are uncertain by several times the amplitude of the 11 year cycle. This large uncertainty in **absolute** calibration of the instruments means that any possible trend from one 11 year cycle to the next, the most important change for global warming, is not known accurately enough to even decide whether the trend is positive, negative, or zero. With such data, scientists have a good approximation of the 11 year cycle, but no real insight into more subtle changes that may occur over many decades and centuries.

Even larger uncertainties exist for measurements of the amount of solar radiation that is absorbed by the Earth's atmosphere, ocean, and land. As of now, researchers know that the atmosphere absorbs between 20 and 25 percent of the TSI and that the land absorbs 45 to 50 percent. With solar radiation, a

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5 percent difference is huge. A difference of even 1 percent would completely throw off climate models of global warming and scientist's understanding of convection (warm, upward moving air currents) in the atmosphere.

The other big problem scientists face is too little data. Even in instances when solar energy measurements are accurate, researchers often don't have enough information with which to draw conclusions. Building models to forecast long term trends, in particular, requires a tremendous amount of past data on those trends. At this time, scientists only have roughly twenty years of satellite data on the Sun —an equivalent of just two 11-year cycles. Most of the data researchers do have on the Sun are for TSI. Relatively very little data have been gathered on the spectral changes in the Sun. Scientists haven't determined with precision how the fluctuations in the Sun's output of visible wavelengths differ from near infrared or from ultraviolet. The dearth of spectral data presents another serious obstacle for climate modelers since distinct wavelengths are absorbed by different components of the Earth's climate system, which react differently with one another as their energy levels change.

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Solar Radiation and Climate Experiment (SORCE)

The SORCE Satellite

To continue to monitor the Sun and to cut down on the uncertainty of solar energy measurements, NASA launched the SORCE satellite on January 25, 2003. The satellite flies at an altitude of 640 km in a 40-degree-inclination orbit around the Earth. On board SORCE are four instruments that will greatly improve the accuracy of the measurements of solar energy. All instruments take readings of the Sun during each of the satellite's 15 daily orbits. The information is transmitted to ground stations at NASA's Wallops Flight Facility in Virginia and a station in Santiago, Chile.

> "On board SORCE are four instruments that will greatly improve the accuracy of measurements of solar energy."

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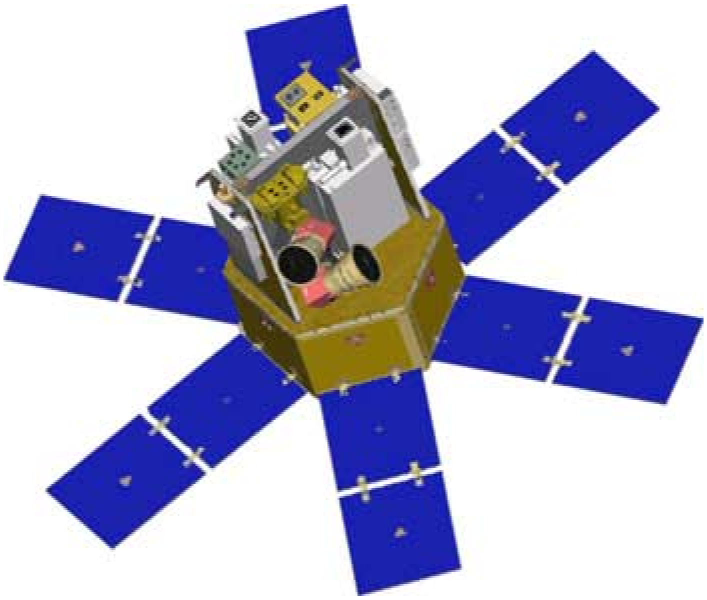

The SORCE satellite carries four instruments to study the Sun. TIM, SIM, and SOLSTICE measure solar irradiance and the solar spectrum to help scientists understand the Sun's role in climate change. The XPS measures high-energy radiation from the Sun. (Image courtesy Solar Radiation and Climate Experiment Project)

Three of the four SORCE instruments will be of direct use to Earth scientists. They are the Total Irradiance Monitor (TIM), the Spectral Irradiance Monitor (SIM), and the Solar Stellar Irradiance Comparison Experiment (SOLSTICE). TIM will accurately determine the TSI by recording the sum of the energy from nearly all the Sun's wavelengths. SIM will measure upper portion of the ultraviolet spectrum (200–400 nm), the full visible range, and the near infrared up to 2000 nm. SOLSTICE will measure the full ultraviolet beginning at 100 nm, and includes the lower half of the ultraviolet region of SIM (200-300 nm). The 200–300 nm portion of ultraviolet measured by both SIM and SOLSTICE overlaps with UV-B (290–320 nm) which causes skin cancer, and is normally blocked from us by the stratosphere's ozone layer. (See Ultraviolet Radiation: How it Affects Life on Earth) Its readings will be of primary importance to understanding the Sun's impact on the stratosphere. A fourth instrument, known as the Extreme Ultraviolet Photometer System (XPS), will be of indirect use to Earth scientists. The instrument will measure very high-energy ultraviolet radiation and lower energy x-ray wavelengths. These readings should yield valuable information about the Sun's

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corona, solar events that impact satellite communications, and the Sun’s effects on the very outermost layers of the Earth’s atmosphere.

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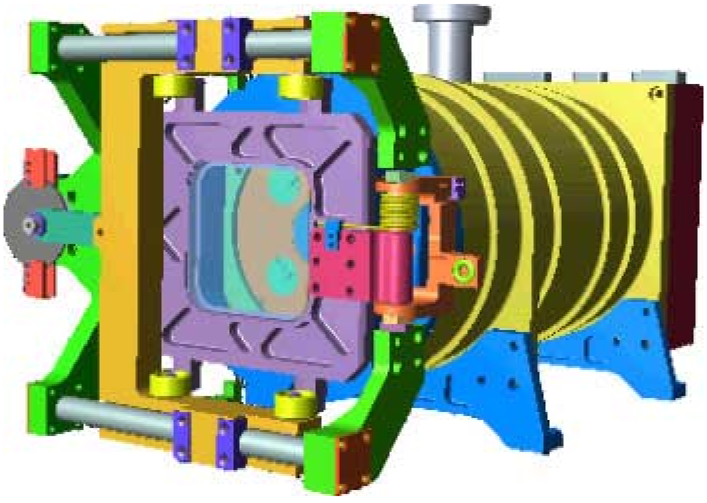
Solar Radiation and Climate Experiment (SORCE)

Total Irradiance Monitor (TIM)

TIM will measure the total amount of radiation coming from the Sun. The sensor uses what is known as an absolute radiometer and houses four cone-shaped cavities. One of the cavities has an oscillating shutter that allows direct sunlight to shine into one of the cones. The material in the cone absorbs nearly all the Sun’s energy and heats up. By measuring the voltage needed to bring this heated cone back to the same temperature as one of the other “reference” cones, which are kept at a constant temperature, the instrument can obtain an extremely accurate reading of the TSI in watts.

> “TIM can obtain an extremely accurate reading of toal solar irradiance.”



The Total Irradiance Monitor (TIM) will measure the energy emitted by the Sun ten times more accurately than previous sensors. (Image courtesy Solar Radiation and Climate Experiment Project)

The electrical substitution radiometer of TIM is similar to that introduced in the ACRIM series, the most accurate being the current ACRIM III on ACRIMSAT. SORCE’s TIM is expected to further increase the accuracy of TSI data by incorporating modern materials and electronics. In particular, it uses phase sensitive processing to achieve a major

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improvement in signal-to-noise. The goal of the TIM instrument team is to measure TSI with 0.01 percent relative standard uncertainty (relation of the measurement to SI units) and characterize sensitivity changes with a relative precision of 0.001 percent per year. Readers interested in procedures and terminology relating to the accuracy and precision of such instruments should refer to "Recommended Practice: Symbols, Term, Units, and Uncertainty Analysis for Radiometric Sensor Calibration", 1998, by Clair Wyatt, Victor Privalsky and Raju Datla, NIST Handbook 152, US Dept of Commerce, Technology Administration, NIST.

The accuracy of TIM’s readings will allow scientists to observe the subtle changes in solar radiation brought on by the sunspot cycles. They will use these numbers to determine just how much the Sun varies on a day-to-day, a month-to-month, and a year-to-year basis and then compare any subtle oscillations to changes in the climate. The new readings will also help improve climate models.

Scientists will be able to confirm the accuracy of the TIM instrument on SORCE by comparing its measurements with those made by an identical instrument carried into space periodically in the bay of the Space Shuttle. (Photograph courtesy NASA Human Spaceflight)

To make sure the instrument continues to make accurate measurements (i.e., to calibrate the instrument), the researchers constructed an identical instrument that will remain on the ground. Once a year they plan to take this identical TIM into orbit on

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the Space Shuttle as part of the “Solar Irradiance Hitchhiker” program. By comparing these measurements with those of the instrument aboard SORCE, the scientists should be able to tell if the SORCE instrument has changed its properties. They can then make the compensating adjustments to the data they receive.

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Solar Radiation and Climate Experiment (SORCE)

Spectral Irradiance Monitor (SIM)

The SIM instrument will take contiguous spectral readings of the near UV, visible, and near infrared portions of the solar spectrum, from 200 to 2000 nm, which includes the peak of the solar spectrum and together add up to more than 90% of the Total Solar Irradiance. The SIM instrument consists of two solar spectrometers set side by side within one casing. Only one of the spectrometers will be used to take measurements on a daily basis. Sunlight entering this instrument is directed into a prism which then directs different wavelengths of ultraviolet, visible, and near infrared into separate directions. The separate wavelengths of light will then illuminate an array of photodiodes. The photodiodes measure the specific wavelengths of light between low energy ultraviolet (200 nm) radiation and near infrared (2000 nm) radiation. (nm stands for nanometer, which is one one-billionth of a meter.) SIM will measure these wavelengths in intervals that vary in width from 0.25 nm in the ultraviolet to 34 nm in the near infrared. Scientists will be recording measured energy in separate bands of ultraviolet light, violet light, blue light, yellow light, green light, red light, and near infrared light coming from the Sun.

> “SIM WILL BE THE FIRST INSTRUMENT IN ORBIT TO TAKE READINGS OF THE FULL SPECTRUM OF VISIBLE AND NEAR-INFRARED SOLAR RADIATION.”

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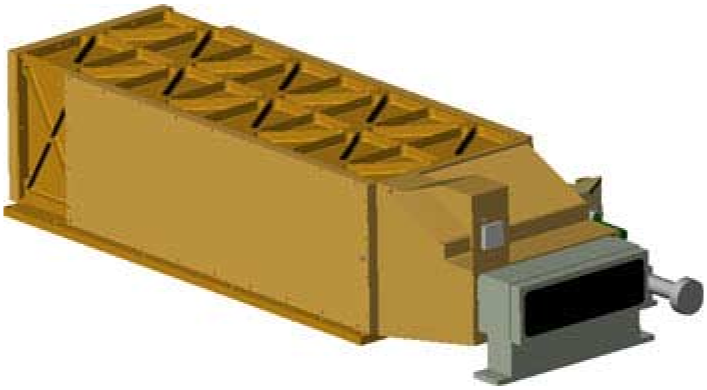

The Spectral Irradiance Monitor (SIM) will measure the solar spectrum in ultraviolet, visible, and near infrared wavelengths. (Image courtesy Solar Radiation and Climate Experiment Project)

SIM will be the first instrument in orbit to take readings of the full spectrum of visible and near-infrared solar radiation. By reviewing data from SIM, scientists may be able to tell how the solar cycles affect both visible and near-infrared wavelengths. Combined with improved measurements by ground and by aircraft, they may be able to discern just how much of this light goes into heating up the lower layers of the Earth's atmosphere and how much goes into the land and oceans. SIM may also aid in efforts to discern exactly how much of the Sun's energy is reflected by industrial aerosols and clouds.

A problem with prism spectrometers is that the glass in the prism can degrade over time. To account for this, the scientists will monitor how well the prism transmits light. Light exiting the first prism will be sent through a slit to create a monochrome (single wavelength) light source. The wavelength is selectable by adjusting the position of the slit. This light source is then directed through a periscope into the second spectrometer. The light is measured before and after it goes into the second prism. If the ratio between the "before" and "after" measurement changes, the scientists will know if the glass is degraded and how this degradation affects the transmission of the light at each selected wavelength. They can then take this information into account when they calibrate the data. To test the entire apparatus, the scientists will open both of the spectrometers simultaneously and compare the data between the two.

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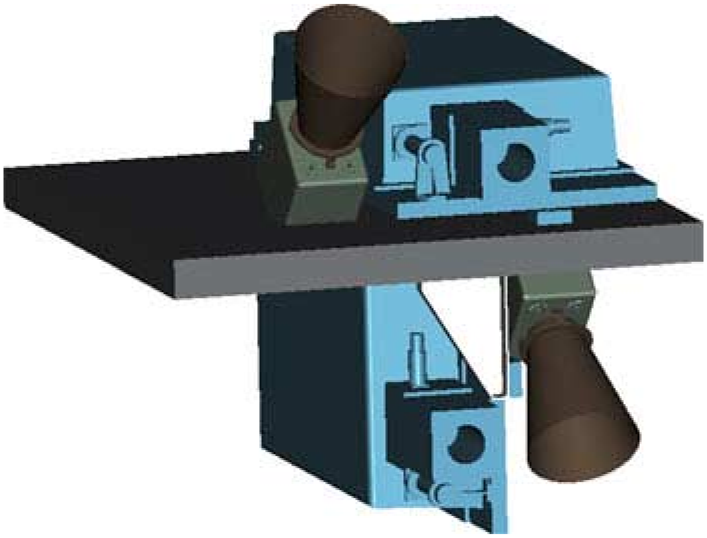
SOLAR RADIATION AND CLIMATE EXPERIMENT (SORCE)

Solar Stellar Comparison Experiment (SOLSTICE)

SOLSTICE will take spectral readings of the ultraviolet energy coming from the Sun. Light from the Sun will enter the instrument and shine on a diffraction grating, which is essentially just a series of very closely spaced slits—many thousands per inch. These slits spread the light into its spectral components much as a prism does. The ultraviolet light is directed towards two arrays of photodetectors similar to the way light from a projector is directed towards a movie screen. One photodetector array measures ultraviolet light in the range of 115 nm to 180 nm at 1-nm to 3-nm increments. The other array will pick up readings for ultraviolet light with near-visible wavelengths from 180 to 320 nm in increments from 0.1 to 2.2 nm. Each of these photodetectors is capable of switching jobs and of measuring the opposing range of wavelengths.



There are actually two independent SOLSTICE instruments onboard SORCE, referred to as SOLSTICE A, and SOLSTICE B, pictured here mounted at right angles to each other, above and below the optical flat, respectively. These can each measure both the F and G band of wavelengths, 115-180 nm and 180-300 nm, respectively, so that if either instrument fails, the other can take up its duties. (Image courtesy Solar Radiation and Climate Experiment Project)

> "WITH SOLSTICE, SCIENTISTS CAN OBSERVE TO WHAT DEGREE SOLAR CYCLES AFFECT THE OZONE LAYER AND THE STRATOSPHERE."

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This is not the first SOLSTICE in operation. The first was on the Upper Atmosphere Research Satellite (UARS), which was sent up to measure chemical and physical changes in the Earth's upper atmosphere. The SOLSTICE on SORCE will continue to monitor ultraviolet radiation well after the UARS satellite is taken out of service next year. With SOLSTICE, scientists can observe to what degree solar cycles affect the ozone layer, the ozone hole, and the stratosphere. They can also see if changes in ultraviolet radiation correspond with atmospheric disturbances in the upper troposphere.

The calibration for this instrument is unique. As SORCE passes through the nighttime portion of its orbit, SOLSTICE will measure the ultraviolet radiation coming from certain blue stars. These stars emit spectra that have significant energy in the ultraviolet range measured by SOLSTICE, that are known to be constant in time. So if SOLSTICE's measurements from these stars change over time, then scientists know that the instrument's response has changed. They can then use the knowledge to make adjustments to their data.

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SOLAR RADIATION AND CLIMATE EXPERIMENT (SORCE)

Extreme Ultraviolet Photometer System (XPS)

The XPS instrument will take readings in the "far" ultraviolet, with wavelengths much shorter than seen by SOLSTICE, and down into the "soft" X-ray region. The instrument is essentially an array of 12 thumbtack-sized, identical photodiodes that give off an electrical signal each time x-ray or ultraviolet radiation strikes them. Filters are placed over the diodes to allow the instrument to take readings in 5-10 nm increments. One of the diodes, for instance, will be equipped with a filter that allows only light with 12-20 nm wavelengths to pass through. Another diode is covered by a filter that allows only 17–25 nm wavelengths to pass. Five such filtered diodes together will be used to measure wavelengths between 1-31 nm. A sixth diode will have a filter that screens

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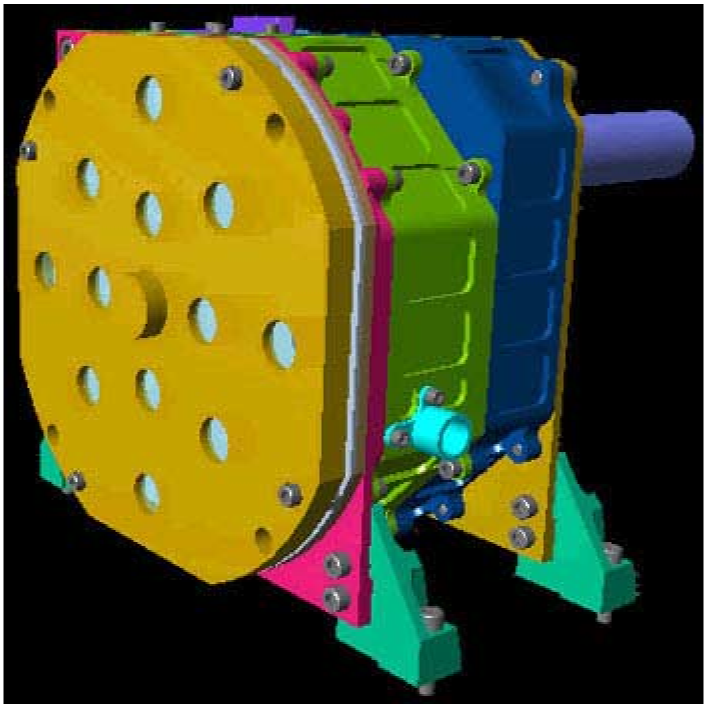
out all but one very specific wavelength at 121.6 nm, known as Lyman-alpha radiation. Lyman-alpha radiation, which is emitted by ionized hydrogen in the Sun's corona, is an especially important wavelength to monitor because it is a very strong emission line coming from a transition to the lowest energy "ground" state of hydrogen, and therefore it makes a good "probe" of the Sun's corona, the solar wind, and even hydrogen flowing into our solar system from elsewhere in the Milky Way Galaxy.



Scientists will use XPS to study the Sun's corona and transition zone by monitoring solar radiation in extreme ultraviolet and low-energy x-ray wavelengths. (Image courtesy Solar Radiation and Climate Experiment Project)

Rarely do these shorter wavelengths penetrate the lower layers of the atmosphere, so they have little effect anywhere below 70 kilometers in altitude where weather develops and life is found. These wavelengths do, however, impact the very outermost regions of the atmosphere such as the mesosphere, the thermosphere, and the ionosphere. Changes in these wavelengths due to solar cycles can affect the chemical composition and the temperature of these regions, which in turn can disrupt satellite operations and radio and satellite communications.

The readings can also give scientists detailed

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information about what goes on in the Sun's atmosphere. The Sun's atmosphere consists of two zones known as the corona and the transition zone. The corona is a cloud of ions that burns at 1 million degrees Celsius, or roughly 200 times hotter than the temperature at the surface of the Sun. Between the Sun and the corona is a transition zone. Though the corona and the transition zone have been studied in increasing detail since the 1970s, their complex variations during the solar cycle are not adequately characterized. SORCE will provide further insight into these fluctuations in the outer solar atmosphere. The 1-31 nm range of XPS is sensitive to changes in the corona, and the Lyman-alpha monitors the transition zone.

Calibration of the XPS will be completed in part by the six diodes that do not take daily measurements. Three of these diodes will not be covered by filters, and they will be used to check on the condition of the silicon window that covers the photodiodes. The three remaining diodes will be covered by filters, and they will take redundant measurements of the Sun once a week. These readings will be compared to those taken daily by the six diodes measuring ultraviolet and x-ray radiation. Finally, sub-orbital flights will be launched once a year with identical XPS photodiodes on board. By contrasting these measurements taken by the sub-orbital flights with those of the instrument aboard SORCE, the scientists should be able to tell if the SORCE instrument's performance has changed. If so, they can then make the compensating adjustments to the data they receive.

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