

SORCE

Solar Radiation and Climate Experiment



Science Writers' Guide



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Solar Radiation and Climate Experiment (SORCE)

Quick Reference Guide

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SORCE Related Publications

- SORCE Fact Sheet, Publication #FS-2002-12-052-GSFC
- SORCE Brochure, Publication #NP-2002-9-482-GSFC
- SORCE Lithograph, Publication #LG-2002-10-058-GSFC

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SORCE Web Sites for More Information:

SORCE (Solar Radiation and Climate Experiment): <http://lasp.colorado.edu/sorce/>
SORCE Reference Article: <http://earthobservatory.nasa.gov/Library/SORCE/>

The 4 instruments onboard SORCE are the Total Irradiance Monitor (TIM), the Spectral Irradiance Monitor (SIM), the Solar Stellar Irradiance Comparison Experiment (SOLSTICE), and the Extreme Ultraviolet Photometer System (XPS). TIM, SIM, and SOLSTICE will measure solar irradiance and the solar spectrum to help scientists understand the Sun's role in climate change. The XPS will measure high-energy radiation from the Sun.

SORCE Instrument Web Sites:

Total Irradiance Monitor (TIM)
Spectral Irradiance Monitor (SIM)
Solar Stellar Irradiance Comparison Experiments (SOLSTICE)
XUV Photometer System (XPS)

All instrument web pages are found at the web site of the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado: <http://lasp.colorado.edu/sorce/>



SORCE Science Objectives

The primary goal of the NASA Earth Observing System's (EOS) Solar Radiation and Climate Experiment (SORCE) is to enable solar-terrestrial studies by providing precise daily measurements of the Total Solar Irradiance (TSI) and the Spectral Solar Irradiance (SSI) at wavelengths extending from the ultraviolet to the near infrared. The following lists the SORCE science objectives:

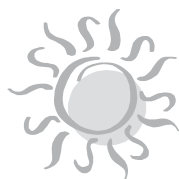
- SORCE observations will improve our understanding of how and why changes in the Sun's energy occur and how it affects our atmosphere and climate. This knowledge can be used to estimate past and future solar behavior and climate response.
- SORCE will make precise and accurate measurements of the TSI. These measurements will be connected with previous TSI measurements to continue a long-term record of solar influences on the Earth. SORCE will measure TSI with an absolute accuracy of 0.01% and with a long-term relative accuracy of 0.001% per year.
- SORCE will make precise measurements of the visible and near infrared SSI suitable for future climate studies. SORCE will obtain daily measurements of the SSI from 300 to 2000 nanometers (nm) (a billionth of a meter), an absolute accuracy of 0.03%, and a precision and relative accuracy of better than 0.01% per year.
- SORCE will make daily measurements of the solar ultraviolet irradiance from 120 to 300 nm with a spectral resolution of 1 nm. It will achieve this measurement with an absolute accuracy of better than 5% and with a long-term relative accuracy of 0.5% per year.

Total Solar Irradiance (TSI) is the total energy per unit area per unit time, or the total power density, contained in all of the Sun's emitted electromagnetic radiation. TSI is the Sun's total power in watts divided by the area of a sphere centered on the Sun and with Earth's approximately circular orbit lying on the sphere's surface. SSI is the power density in each particular band of wavelengths (e.g. ultraviolet, visible, infrared or other wavelengths).

The Earth Observing System (EOS) is the centerpiece of NASA's Earth Science Enterprise (ESE). It consists of a science component and a data system supporting a coordinated series of polar-orbiting and low inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans.

The science objectives of the EOS program are to provide global observations and improve the scientific understanding of the hydrologic cycle, land cover change and global productivity, climate variability and change, natural hazards, and atmospheric chemistry and dynamics.

SORCE is a joint partnership between NASA and the University of Colorado's Laboratory for Atmospheric and Space Physics (LASP) in Boulder, Colorado. NASA's Goddard Space Flight Center provided management oversight and engineering support to this principal investigator led mission. Scientists and engineers at LASP designed, built, calibrated, and tested the four science instruments on SORCE. The spacecraft carrying and accommodating the instruments was developed by Orbital Sciences Corporation in Dulles, Virginia. The Mission Operations Center and the Science Operations Center are both operated at LASP.



SORCE Instruments

The SORCE satellite consists of a spacecraft and four instruments provided by NASA. The four instruments onboard were designed and built by the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado in Boulder. They are the Total Irradiance Monitor (TIM), the Spectral Irradiance Monitor (SIM), two identical Solar Stellar Irradiance Comparison Experiments (SOLSTICE), and the XUV Photometer System (XPS). TIM, SIM, and SOLSTICE will measure solar irradiance and the solar spectrum to help scientists understand the Sun's role in climate change. The XPS will measure high-energy radiation from the Sun.

What and Where SORCE Will Measure	
<p>Measurement: Energy emitted by the Sun Instrument Used: TIM Focus: All levels of atmosphere/ocean, since this is TOTAL energy (includes all wavelengths) Contact: Greg Kopp, LASP/CU</p>	<p>Measurement: Solar ultraviolet irradiance from 120 to 320 nm daily Instrument Used: SOLSTICE Focus: Stratospheric ozone layer Contact: Bill McClintock, LASP/CU</p>
<p>Measurement: Solar spectrum in ultraviolet, visible, and near infrared wavelengths Instrument Used: SIM Focus: Tropospheric water vapor, clouds, & oceans Contact: Jerry Harder, LASP/CU</p>	<p>Measurement: The Sun's corona and transition zone by monitoring solar radiation in extreme ultraviolet and low-energy x-ray wavelengths Instrument Used: XPS Focus: Mesosphere and thermosphere Contact: Tom Woods, LASP/CU</p>

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 these variations to changes in the climate. The new readings will also help improve climate models.

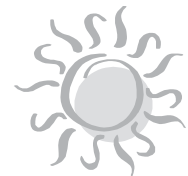
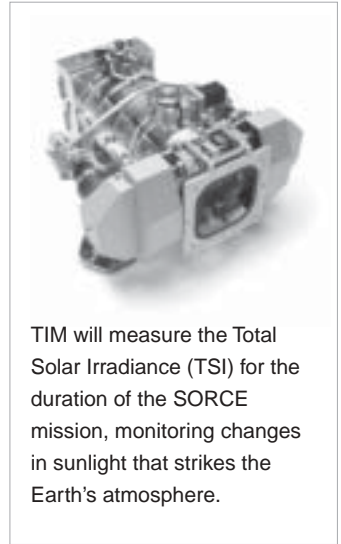
Using a new development that incorporates improvements and state-of-the-art technologies and takes full advantages of new materials and modern electronics, TIM measures TSI to an absolute accuracy of 100 parts per million (ppm). Four times daily, TIM will report the total amount of the Sun's energy that reaches the top of the Earth's atmosphere.

A precision aperture behind one of four shutters on TIM accurately determines the area over which sunlight is collected, absorbing nearly all of the Sun's energy as heat. This heat is then measured. The ratio of power to area provides an extremely accurate TSI measurement.

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Spectral Irradiance Monitor (SIM) Instrument Scientist:

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The Spectral Irradiance Monitor (SIM) will measure the solar spectrum in ultraviolet, visible, and near infrared wavelengths.

Solar Stellar Comparison Experiment (SOLSTICE) Instrument Scientist:

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There are actually two independent SOLSTICE instruments onboard SORCE, referred to as SOLSTICE A and SOLSTICE B.

Understanding the wavelength-dependent changes in the Sun's energy is of primary importance for long-term climate change studies. 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, aircraft, and Earth-viewing satellites they also may be able to see 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 will also aid in efforts to detect exactly how much of the Sun's energy is reflected by industrial aerosols and clouds.

SIM is a newly developed "prism spectrometer" that will make the first continuous record of the top-of-the-atmosphere SSI in the visible and near infrared bands of the spectrum. The wavelength coverage is primarily from the 300 to 2000 nanometer (nm) range, with an additional channel to cover 200 to 300 nm, and thereby overlap with the observations of SOLSTICE. SIM's range includes the peak of the solar spectrum. The total energy carried by all the visible and infrared wavelengths measured by SIM (from 300 to 2000 nm) adds up to more than 90% of the TSI.

SIM will measure the SSI 4 times per day throughout the SORCE mission. 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 five separate detectors. These detectors, called photodiodes measure the specific wavelengths of light between ultraviolet radiation and near infrared radiation.

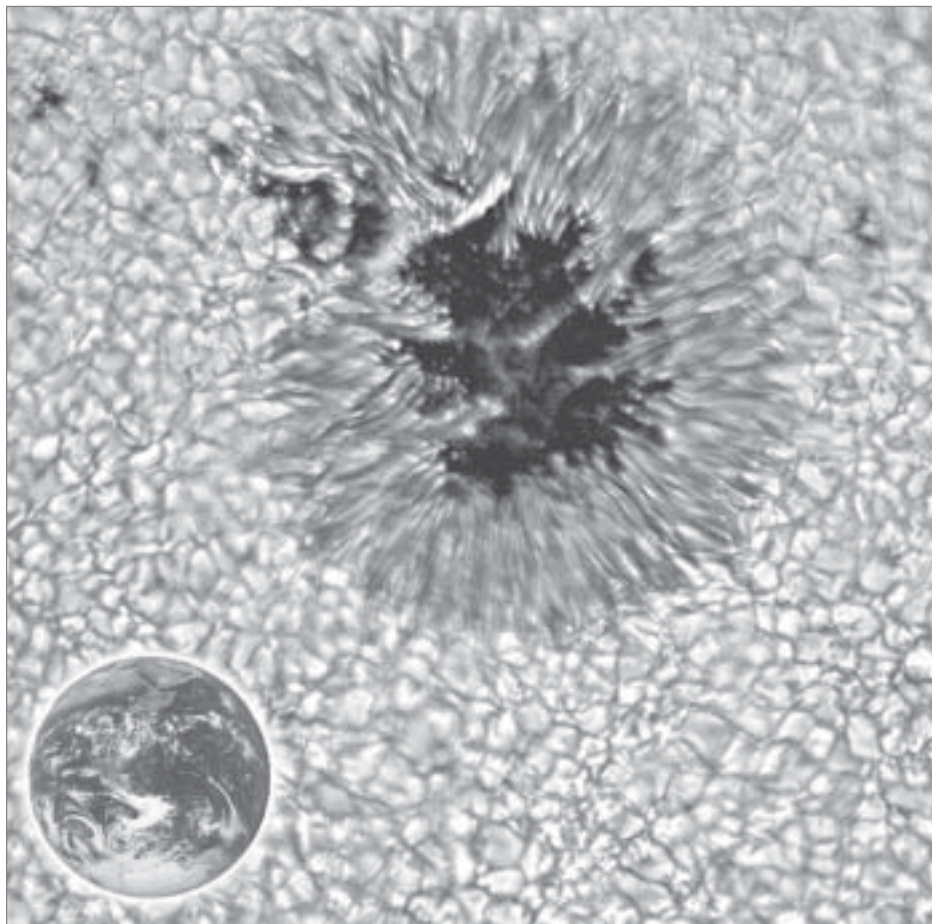
There are two SOLSTICE instruments onboard SORCE that will measure solar ultraviolet SSI from 115 to 320 nm daily.

This SOLSTICE is a follow-up to the very successful SOLSTICE launched aboard the Upper Atmospheric Research Satellite (UARS) in 1991. That instrument observes the Sun and 18 bright, blue early-type stars using similar optics and detectors. Observing the very same stars as the UARS SOLSTICE, the SORCE SOLSTICE will make measurements with greatly improved accuracy and stability. The SOLSTICE on SORCE will continue to monitor ultraviolet radiation well after the UARS satellite is no longer operational.

By looking at the 18 bright blue stars and comparing them to the Sun, scientists can calibrate the SOLSTICE instrument. As SORCE passes through the night-time portion of its orbit, SOLSTICE will measure the ultraviolet radiation coming from these selected blue stars. These stars emit spectra that have significant energy in the ultraviolet range measured by SOLSTICE and that are known to be constant in time. So if SOLSTICE's measurements of these blue 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.

The XPS measures the solar soft x-ray (XUV) SSI from 1 to 34 nm and the bright hydrogen emission at 121.6 nm (H I Lyman- α). The solar XUV radiation is emitted from the hot, highly variable corona on the Sun, and these high-energy photons are a primary energy source for heating and ionizing Earth's upper atmosphere. The XPS is the most sensitive to solar flare events as the solar XUV radiation often changes by a factor of 2 to 10 or more during these flares.

Studies of the SSI of solar XUV radiation began in the 1950s with space-based experiments, but the knowledge of the solar XUV irradiance, both in absolute magnitude and variability, has been questionable due largely to the very limited number of observations. With the launch of the Solar and Heliospheric Observatory (SOHO) in 1995, Student Nitric Oxide Explorer (SNOE) in 1998, and Thermosphere-Ionosphere-Mesosphere-Energetics-Dynamics (TIMED) spacecraft in 2001, there is now a continuous data set of the solar XUV irradiance. With this history, significant advances in the understanding of the solar XUV irradiance have begun. The SORCE XPS, which evolved from earlier versions flown on SNOE and TIMED, will continue these SUV irradiance measurements with improvements to accuracy, spectral image, and temporal change.



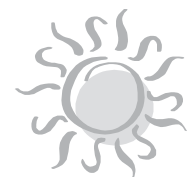
This image depicts a close-up of a typical sunspot with Earth in the lower left inserted to show size comparison. [Image courtesy: Vacuum Tower Telescope (VTT) of the Kiepenheuer Institute of Solar Physics]

Extreme Ultraviolet Photometer System (XPS) Instrument Scientist:

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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.

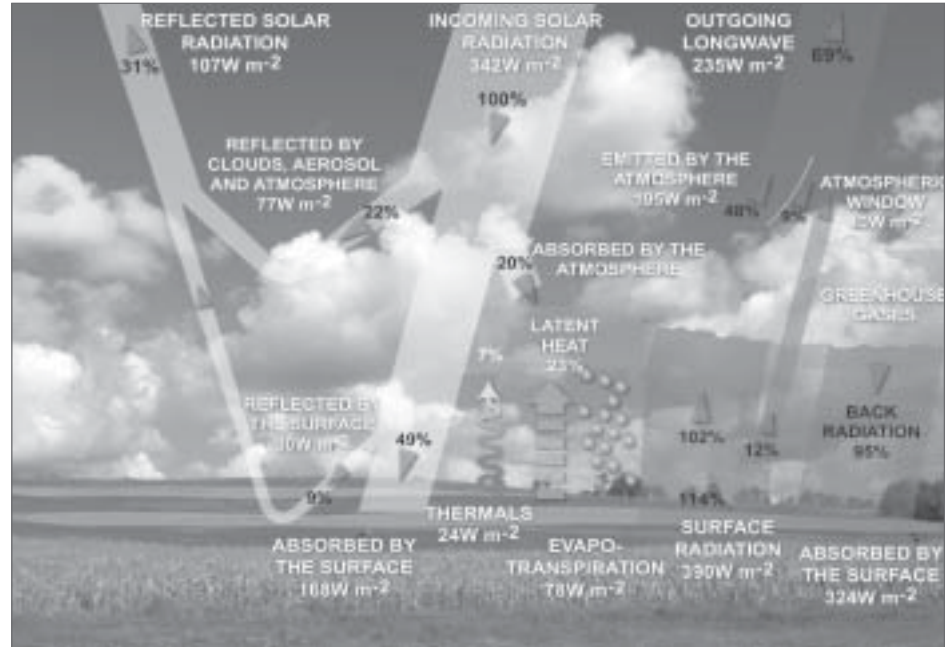




Galileo Galilei (1564-1642).

Galileo made his first telescope in 1609. He was among the first to make detailed observations of sunspots through the telescope.

SORCE Will Measure Earth's Total Solar Irradiance



The diagram above illustrates the radiation balance of the Earth showing how much solar energy is received and how it is redistributed—either reflected back into space or absorbed by the planet to warm the Earth. Approximately 20-25% of the total solar irradiance is absorbed by atmospheric water vapor, clouds, and ozone, impacting convection, cloud formation and latent heating via processes that are strongly wavelength dependent. (Diagram credit: Jeffrey T. Kiehl and Kevin Trenberth)

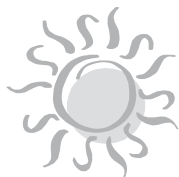
SORCE Research Profiles

The SORCE Satellite

To further understand the influence of the Sun on the Earth system, NASA will launch the SORCE satellite in early 2003. SORCE is a key component of NASA's Earth Observing System (EOS) program.

The small free-flying satellite will carry four scientific instruments to measure the solar radiation incident at the top of the Earth's atmosphere. This research is critical to studies of the Sun, its effect on Earth, and its influence on humankind.

The Sun is the dominant energy source for the entire Earth system, and solar radiation is one of the key climate system variables. Measuring and understanding the total energy output from the Sun, or Total Solar Irradiance (TSI), and Spectral Solar Irradiance (SSI) will tell researchers how the Sun's total radiant energy varies, and specifically how the energy is changing in those wavelengths of the Sun's spectrum that affect major components of Earth's climate. For thousands of years scientists have been studying and learning about our Sun. Preliminary models of the TSI data based on very early observations (such as sunspot darkening) compare favorably with current TSI observations. This trans-



lates to a better understanding of the Earth's energy balance. For example, ozone is especially sensitive to changes in the Sun's ultraviolet radiation, and both observations and models show a close relationship of its concentrations to solar irradiance.

The spectral measurements identify the Sun's light by characterizing the Sun's energy and emissions in the form of color or wavelengths. Using the most advanced equipment available, data obtained by *SORCE* will be used to model the Sun's output and to explain and predict the effect of the Sun's radiation on the Earth's atmosphere and climate.

SORCE will continue a history of TSI measurements with greatly improved accuracy. Monitoring TSI using electrical substitution radiometers (ESRs) from the vantage point of space began with the launch of the *Nimbus 7* satellite in November 1978. This was soon followed by an Active Cavity Radiometer Irradiance Monitor (ACRIM) instrument on the *Solar Maximum Mission* and by the *Earth Radiation Budget Experiment*. More recently, second and third ACRIM instruments have been launched, in addition to the launch of two instruments on the *NASA/European Space Agency Solar Heliospheric Observatory*. The various data sets are in basic agreement and show conclusively that variations of TSI track the passage of sunspots across the Sun's surface with an amplitude of about 0.2%, and that long-term solar cycle variations are on the order 0.1%. *SORCE* will continue these important TSI observations, and will further improve their accuracy to the order of +/- 0.01%, and will provide more extensive and detailed information on variations in the Sun's wavelength spectrum.

Four Areas *SORCE* Will Study:

- Earth's Energy Balance
- Changes In the Sun (Solar Variability)
- Connection Between the Sun and Global Warming
- Uncertainties in Solar Measurements

Why *SORCE* Will Look at the Earth's Energy Balance

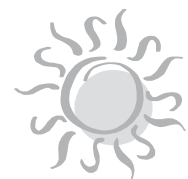
For the past quarter century, Earth scientists have been trying to get a handle on how much solar energy illuminates the Earth and what happens to the energy once it penetrates the atmosphere.

Solar energy entering the Earth's atmosphere is measured in watts per meter squared, or the amount of heat associated with a square meter area. To understand this concept, if a flashlight with a one watt bulb casts light that covers a square meter, then the energy emitted would be one watt per meter squared.

To date scientists estimate that roughly 1,368 watts per meter squared (W/m^2) of energy from the Sun averaged over the globe and over several years, strikes the Earth's outer-



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.

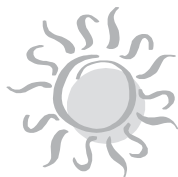




How Large is the Sun?

The Sun is some 333,400 times more massive than Earth and contains 99.86% of the mass of the entire solar system. It is held together by gravitational attraction, producing immense pressure and temperature at its core (more than a billion times that of the atmosphere on Earth, with a density about 160 times that of water).

At the core, the temperature is 16 million degrees Kelvin (K), which is sufficient to sustain thermonuclear fusion reactions. The released energy prevents the collapse of the Sun and keeps it in gaseous form. The total energy radiated is 383 billion trillion kilowatts, which is equivalent to the energy generated by 100 billion tons of TNT exploding each second. TSI is the Sun's total power in watts divided by the area of a sphere centered on the Sun and with Earth's approximately circular orbit lying on the sphere's surface.



most atmosphere. 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 range of wavelengths (from radio waves, through visible light, to x-rays). 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 nm. The visible spectrum, however, accounts for just under half of the Sun's total energy. In addition to visible light, infrared and ultraviolet light also play a role in the Earth's climate.

Some of the Sun's energy is made up of ultraviolet (UV) radiation, which has shorter wavelengths (higher energy photons) than visible light and extends off of the purple end of the visible spectrum. A larger amount of this invisible energy can be found in the longer infrared wavelengths (lower energy photons) of light that extend off the opposite end of the visible spectrum.

Not all of this light is absorbed by the Earth. Roughly 30% 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% of the TSI is absorbed by the land, ocean, and atmosphere. In addition, different layers of the atmosphere and the Earth tend to absorb different wavelengths of light.

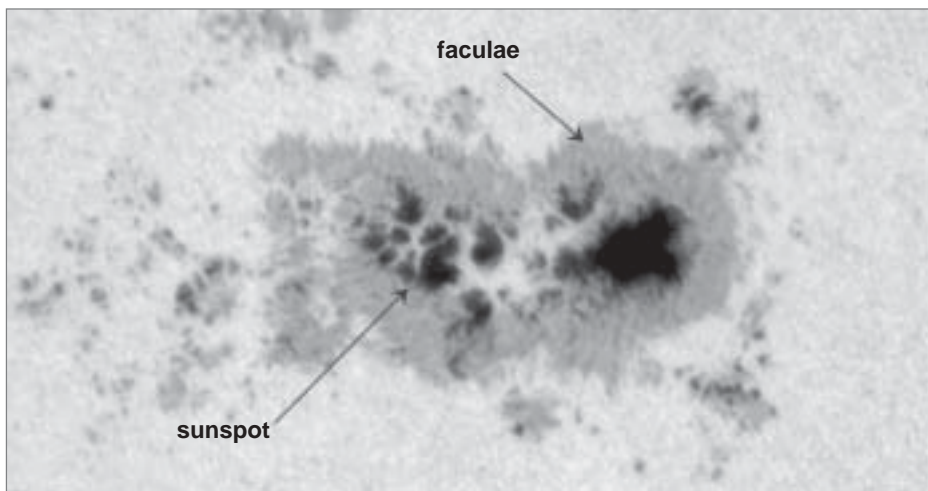
Only one percent of the TSI, mostly in the form of UV radiation, is absorbed by the upper atmosphere, mainly by stratospheric ozone. 20 to 25% of the TSI and a majority of the near infrared radiation is absorbed in the lower atmosphere (troposphere), mainly by water vapor, trace gases, clouds, and darker aerosols. The remaining 45 to 50% of predominantly visible light penetrates the atmosphere and is taken in by the land and the oceans.

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.

Why SORCE Will Study Changes in the Sun (Solar Variability)

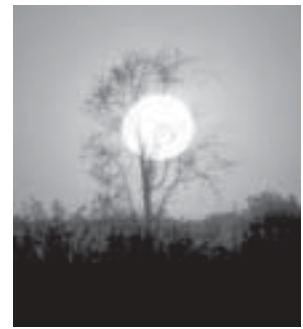
The Sun and its effect on climate is complicated because the amount of radiation arriving on Earth is not constant. It varies from the average value of the Total Solar Irradiance (TSI)— $1,368 \text{ W/m}^2$ —on a daily basis.

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 and size increase and decrease in concert with sunspots. On the whole, the effects of the faculae tend to beat out those of the sunspots. So, although solar energy reaching the 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.



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 re-

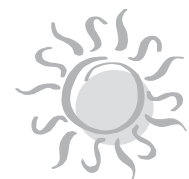


How Many Earths Would Fit Inside the Sun?

Imagine a round fish-bowl (as the Sun) and a bunch of marbles (one marble as the Earth). Now imagine that the diameter of the fish bowl (the Sun) was 100 times larger than the diameter of the each marble (Earth). That way, 100 marbles (Earths) would stretch end to end across the fish bowl (the Sun).

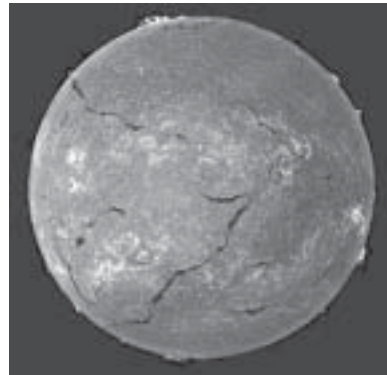
So how many marbles (Earths) fit in the fishbowl? As it turns out, marbles can be stretched across the fish bowl in three directions, up/down, in/out and left/right, and everywhere in between. To fill the bowl, we would require $100 \times 100 \times 100 = 1,000,000$ marbles. So, about one million Earths would fit inside the Sun.

Information Credit: Jonathan Keohane and Jim Lochner for Ask a High-Energy Astronomer

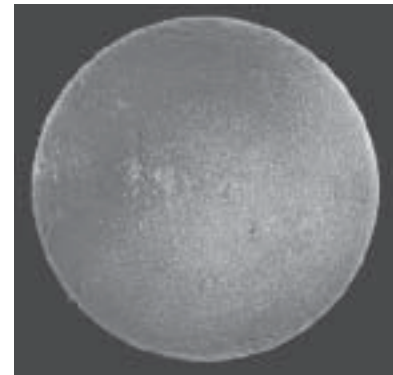




turns to normal levels before rising again for the subsequent cycle. The change in the Sun's yearly average total irradiance during an 11-year cycle is on the order of 0.1% or 1.4 watts per square meter.



1980

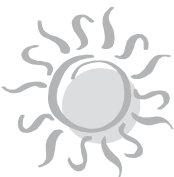


1986

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.*)

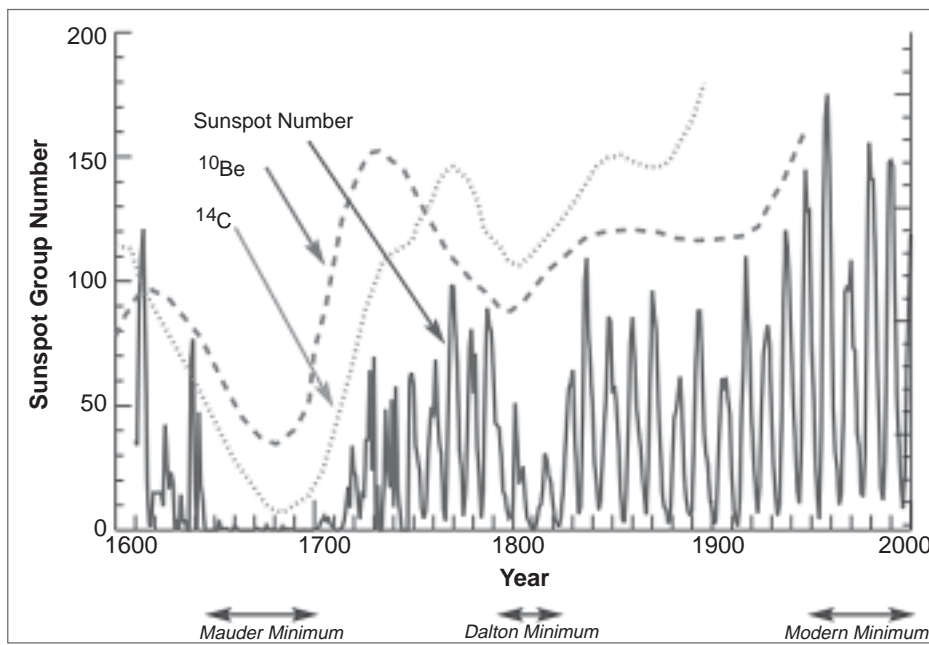
Another trend scientists have noticed appears to span several centuries. Late 17th century astronomers observed that no sunspots existed on the Sun's surface during the time period from 1650 to 1715 AD, now referred to as the Maunder Minimum. This lack of solar activity, which some scientists attribute 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. Some 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.

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 turn our planet into a hothouse, much like Venus.



The Maunder Minimum 1650–1700

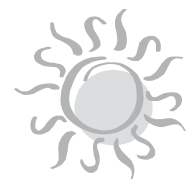
The number of sunspots on the Sun's surface is roughly proportional to total solar irradiance. Historical sunspot records give scientists an idea of the amount of energy emitted by the Sun in the past. The following graph shows sunspot data from 1650 to the present. The Maunder Minimum occurred from 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 numbers 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 Judith Lean, Naval Research Laboratory, derived from work by J. Beer, D. Hoyt, and M. Stuiver)

Studying the Connection Between the Sun and Global Warming

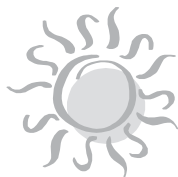
Of the many trends that appear to cause fluctuations in the Sun's energy, those that last decades to centuries are the most likely to have a measurable impact on the Earth's climate in the foreseeable future. Many researchers believe the steady rise in sunspots and faculae since the late seventeenth century may be responsible for as much as half of the 0.6 degrees Celsius (1.08 Fahrenheit) of global warming over the last 110 years (Intergovernmental Panel on Climate Change, 2001). Since pre-industrial times, it is 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.





Layers of the Sun

The photosphere or the Sun's surface is the visible 500-km (310 mile)-thick layer from which most of the Sun's radiation and light finally escape, and it is the place where sunspots are found. Above the photosphere lies the chromosphere ("sphere of color") that may be seen briefly during total solar eclipses as a reddish rim, caused by hot hydrogen atoms, around the Sun. Temperature steadily increases with altitude up to 50,000 degrees Kelvin (89,540 Fahrenheit), while density drops to 100,000 times less than in the photosphere. Above the chromosphere lies the corona ("crown"), extending outward from the Sun in the form of the "solar wind" to the edge of the solar system. The corona is extremely hot—millions of degrees Kelvin (and Fahrenheit).



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 IPCC, the resulting imbalance between incoming solar radiation and outgoing thermal radiation will likely cause the Earth to heat up over the next century.

How the Earth's climate reacts, however, depends on more factors than just greenhouse gases. 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.

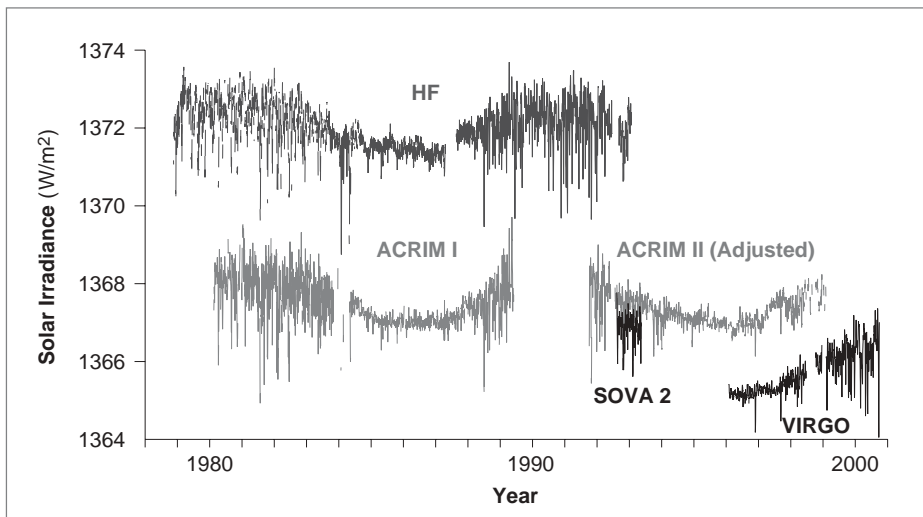
The Sun's affect on global warming can mostly be attributed to variations in the near-infrared and visible wavelengths of solar radiation. These types of radiation are absorbed by the lower atmosphere, the oceans, and the land. UV radiation, on the other hand, interacts strongly with the ozone layer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

Looking at 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.

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



(Graph adapted from C. Fröhlich of the World Radiation Center in Davos, Switzerland.)

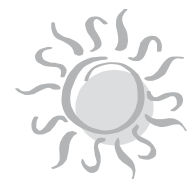


Sun's impact on climate change. The Solar Radiation and Climate Experiment (SORCE) satellite will carry instruments designed to do just that.

The total change in TSI over the 11-year cycle is believed to be 0.1% 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% of the TSI and that the land absorbs 45 to 50%. With solar radiation, a 5% difference is huge. A difference of even 1% would completely throw off climate models of global warming and scientists' understanding of convection (warm, upward moving air currents) in the atmosphere.

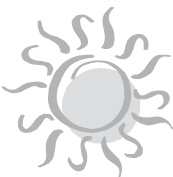
The other big problem scientists face is lack of data. Even in instances when solar energy measurements are accurate, researchers often don't have enough information with which to draw conclusions. Building models to forecast long term trends, in particular, requires a tremendous amount of past data 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





Seasons from the Sun

During the spring equinox, the Sun is directly over the equator, heating both the northern and southern hemispheres equally. The summer solstice in the northern hemisphere occurs on June 21 or 22, when the Sun's rays fall most directly on the Tropic of Cancer at 23.5 degrees north latitude. On September 22 or 23, the autumnal equinox, the Sun's rays are directly on the equator. During the winter solstice in the northern hemisphere, on December 22 or 23, the Sun's rays hit the Tropic of Capricorn directly at 23.5 degrees south latitude.



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.

NASA's Earth Science Enterprise

The purpose of NASA's Earth Science Enterprise is to improve our understanding of the total Earth system and the effects of natural and human-induced changes on the global environment.

The NASA Office of Earth Science is pioneering the new interdisciplinary field of research called Earth System Science, born of the recognition that the Earth's land surface, oceans, atmosphere, ice cover, and biota are dynamic and highly interactive.

The Earth Science Enterprise is comprised of an integrated slate of spacecraft and in situ measurement capabilities; data and information management systems to acquire, process, archive, and distribute global data sets; and research to convert data into new knowledge of the Earth system. It is NASA's contribution to the U.S. Global Change Research Program, an interagency effort to understand the processes and patterns of global change.

The centerpiece of the Earth Science Enterprise – the Earth Observing System (EOS), conceived in the 1980s, is a program of multiple spacecraft and interdisciplinary science investigations to provide key information needed to understand global climate change. The Terra satellite, launched in December 1999, was the flagship of EOS. Additional spacecraft have been launched and others are scheduled to fly as part of the EOS program over the next few years.

The overall goal of the EOS program is to advance the understanding of the entire Earth system on a global scale by improving our knowledge of the components of the system, the interactions among them, and how the Earth system is changing. Specific EOS program mission goals are to: (1) create an integrated, scientific observing system emphasizing climate change that enables multi-disciplinary study of the Earth's critical, interrelated processes; (2) develop a comprehensive data and information system, including a data retrieval and processing system; (3) serve the needs of scientists performing an integrated multi-disciplinary study of planet Earth; and (4) acquire and assemble a global database of remote-sensing measurements from space over a decade or more to enable definitive and conclusive studies of the Earth system.

Terra, Aqua (launched in 2002), and Aura (scheduled to launch in 2004) are the three main EOS spacecraft that will support a broad range of scientific investigations. Each of these satellites is designed to operate for a period of at least six years. Additional observations are provided by Landsat 7, launched in April 1999, and several other more spe-

cialized missions. Some of these satellites will be flown in formation to simultaneously or sequentially monitor the same areas, and complement the measurements of the others.

Nearly all U.S.-led EOS missions include international contributions. For example, Terra includes the Canadian instrument Measurements of Pollution in the Troposphere (MOPITT) and the Japanese Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). The Aqua mission includes the Japanese Advanced Microwave Scanning Radiometer (AMSR-E) and the Humidity Sounder for Brazil (HSB). Several U.S. instruments are part of the payloads aboard satellites launched by other countries, including the Russian Meteor 3M, Japanese ADEOS II, and French Jason-1 spacecraft. In addition, numerous agreements have been signed for joint data exchange and distribution, including integration with the EOS Data and Information System (EOSDIS).

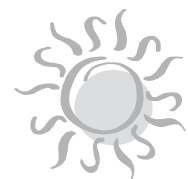
EOS sponsors many interdisciplinary research investigations that use specific Earth science data sets for a broader investigation into the function of Earth systems. Current EOS research spans a wide range of sciences, including atmospheric chemistry, hydrology, land use, and marine ecosystems.

The EOS Project Science Office at Goddard Space Flight Center consists of the Senior Project Scientist as well as project scientists associated with the various EOS missions and the EOSDIS. This office serves as the primary day-to-day interface between the Earth science community and the EOS projects at all NASA centers.

Complementing the EOS missions are a series of small, rapid development Earth System Science Pathfinder (ESSP) missions to study emerging science questions and to use innovative measurement techniques in support of EOS. The New Millennium Program (NMP) is designed to identify, develop, and validate key instrument and spacecraft technologies that can enable new or more cost-effective approaches to conducting science missions in the 21st century.

Data from past and current Earth science missions are captured, processed into useful information, and broadly distributed by the EOSDIS. In addition to EOSDIS, NASA is engaged in a variety of activities to extend the usefulness of Earth science data through a broad range of users such as Regional Earth Science Applications Centers, and the Federation of Earth Science Information Partners.

The intellectual capital behind Earth science missions, and the key to generating new knowledge from them, is vested in an active program of research and analysis. The Earth Science Research and Analysis program funds more than 1,500 scientific research tasks.





Aqua



Aura

Other Earth Science Spacecraft and Instruments

ACRIMSAT

<http://acrim.jpl.nasa.gov/>

A series of U.S. Active Cavity Radiometer Irradiance Monitors (ACRIMs), the latest launched in December of 1999, provides long-term, precise measurements of the total amount of the Sun's energy that falls on our planet's surface, oceans, and atmosphere.

ADEOS II

<http://winds.jpl.nasa.gov/missions/seawinds/seaindex.html>

The Advanced Earth Observing Satellite II (ADEOS II), the successor to the Advanced Earth Observing Satellite (ADEOS) mission, is a joint mission with the National Space Development Agency (NASDA) of Japan. The mission will take an active part in the research of global climate changes and their effect on weather phenomena. It is scheduled for launch no earlier than November 2002.

Aqua

<http://aqua.nasa.gov/> or <http://aqua.gsfc.nasa.gov/>

Aqua was so named because it obtains significant information about the Earth's water cycle, including ocean surface water, snow, ice, water vapor, clouds, precipitation, and soil moisture. Aqua was launched on May 4, 2002.

Aura

<http://aura.gsfc.nasa.gov/>

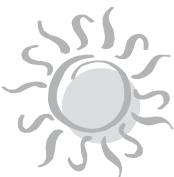
The Aura satellite will focus on measurements of atmospheric trace gases and their transformations. The primary objective of the mission is to study the chemistry and dynamics of the Earth's atmosphere from the ground through the mesosphere. It is scheduled for launch in 2004. (This mission was formerly EOS Chemistry.)

CALIPSO

<http://www-essp3.larc.nasa.gov/picasso.html>

<http://essp.gsfc.nasa.gov/calipso/index.html>

Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) will provide key measurements of aerosol and cloud properties needed to improve climate predictions. CALIPSO will fly in formation with Aqua and CloudSat to obtain coincident observations of radiative fluxes and atmospheric states. This comprehensive set of measurements is essential for accurate quantification of global aerosol and cloud radiative effects. It is scheduled for launch in 2004.



CloudSat

<http://cloudsat.atmos.colostate.edu/>

<http://essp.gsfc.nasa.gov/cloudsat/index.html>

CloudSat's primary goal is to furnish data needed to evaluate and improve the way clouds are parameterized in global models thereby contributing to better predictions of clouds. The new data will increase current understanding of the role that clouds play in climate change, referred to as cloud-climate feedback. It is scheduled for launch in April 2004.



EO-1

<http://eo1.gsfc.nasa.gov/>

One of the key responsibilities of NASA's Earth Science Enterprise is to ensure the continuity of future Landsat data. The New Millennium Program's (NMP) first flight, Earth Observing-1 (EO-1) is validating technologies contributing to the reduction in cost of follow-on Landsat missions. The Hyperion instrument is aboard this spacecraft. It was launched November 21, 2001.



GRACE

(Gravity Recovery And Climate Experiment)

<http://www.csr.utexas.edu/grace/> or

<http://essp.gsfc.nasa.gov/grace/index.html>

The first of the Pathfinder missions, the Gravity Recovery and Climate Experiment (GRACE) employs a satellite-to-satellite microwave tracking system to measure the Earth's gravity field and its time variability over five years. Such measurements are directly coupled to long-wavelength ocean circulation processes and to the transport of ocean heat to the Earth's poles. It was launched March 17, 2002.



ICESat

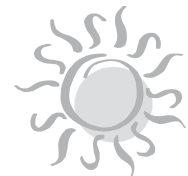
<http://icesat.gsfc.nasa.gov/>

The Ice, Cloud, and Land Elevation Satellite (ICESat) is a small U.S. satellite mission to fly the Geoscience Laser Altimeter System (GLAS) in a near-polar orbit. GLAS will accurately measure the elevation of the Earth's ice sheets, clouds, and land. It was launched January 12, 2003.

Jason-1

<http://topex-www.jpl.nasa.gov/mission/jason-1.html>

Jason-1 is a joint U.S.-France (Centre National d' Etudes Spatiales) oceanography mission designed to monitor global ocean circulation, quantify the tie between the oceans and atmosphere, improve global climate predictions, and monitor events such as El Niño and La Niña and ocean eddies. Jason-1 was launched on December 7, 2001.



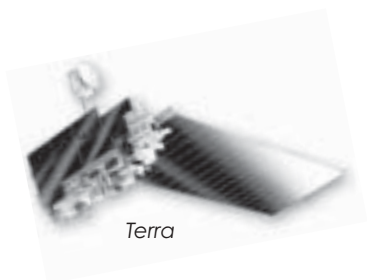


Landsat 7

Landsat 7

<http://landsat.gsfc.nasa.gov/>

Landsat 7 is a U.S. satellite used to acquire remotely sensed images of the Earth's land surface and surrounding coastal regions. The Landsat Program is the longest running enterprise for acquisition of imagery of the Earth from space. The first Landsat satellite was launched in 1972. Landsat 7 was launched on April 15, 1999.



Terra

Meteor 3M/SAGE III

<http://www-sage3.larc.nasa.gov/>

The Stratospheric Aerosol and Gas Experiment 3 (SAGE III) is a fourth generation, satellite-borne instrument and a crucial element in NASA's Earth Observing System (EOS). Its mission is to enhance our understanding of natural and human-derived atmospheric processes by providing accurate long-term measurements of the vertical structure of aerosols, ozone, water vapor, and other important trace gases in the upper troposphere and stratosphere. It was launched December 10, 2001.

QuikScat

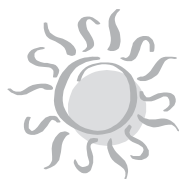
<http://winds.jpl.nasa.gov/missions/quikscat/quikindex.html>

The SeaWinds instrument on the QuikScat mission is a "quick recovery" mission to fill the gap created by the loss of data from the NASA Scatterometer (NSCAT) in June 1997. The SeaWinds instrument is a specialized microwave radar that measures near-surface wind speed and direction under all weather and cloud conditions over the Earth's oceans. QuikScat was launched on June 19, 1999.

Terra

<http://terra.nasa.gov/>

The Terra satellite, launched in December 1999, is the flagship of EOS. It is providing global data on the state of the atmosphere, land, and oceans, as well as their interactions with solar radiation and with one another.



SORCE Quick Reference Guide

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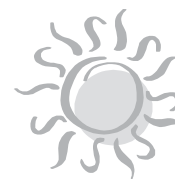
SORCE Program Manager, NASA Headquarters

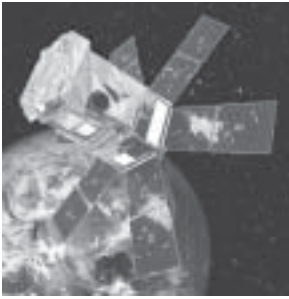
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The Sun's Strange Rotation

The Sun rotates on its axis about once a month. Since it is gaseous, the entire body of the Sun does not rotate at the same speed. The Sun's equator rotates every 25 Earth days, while latitude 70 degrees rotates in 33 days. The Sun's diameter is 109 times greater than the Earth.





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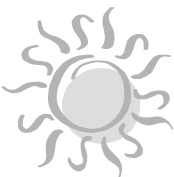
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SORCE Related Publications:

- SORCE Fact Sheet #FS-2002-12-052-GSFC
- SORCE Brochure, Publication #NP-2002-9-482-GSFC
- SORCE Lithograph #LG-2002-10-058-GSFC

To order, contact:

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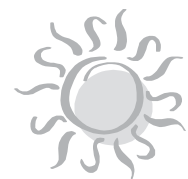
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Related Web Sites

SORCE (Solar Radiation and Climate Experiment): <http://lasp.colorado.edu/sorce/>

SORCE Reference Article: <http://earthobservatory.nasa.gov/Library/SORCE/>

SORCE Instrument Web Sites

Total Irradiance Monitor (TIM), Spectral Irradiance Monitor (SIM), Solar Stellar Irradiance Comparison Experiments (SOLSTICE), and XUV Photometer System (XPS)

All instrument web pages are found at: <http://lasp.colorado.edu/sorce/>

SORCE Science: <http://lasp.colorado.edu/sorce/>

The SOLAR STellar Irradiance Comparison Experiment (SOLSTICE) and Total Irradiance Monitor (TIM) onboard the Solar Radiation and Climate Experiment (SORCE) provide the scientific community with long-term, accurate measurements of the solar ultraviolet (UV), far ultraviolet (FUV), and total irradiance from the Sun.

Destination Earth: <http://www.earth.nasa.gov/>

The web site of NASA's Earth Science Enterprise in Washington, D.C., contains information about the Agency's entire Earth science program. The Science of the Earth System section of the site describes the Agency's major research themes: atmospheric chemistry, hydrological and energy cycle, land cover and land use, ozone, natural hazards and the solid Earth, and climate variability and change. The Missions section provides links to all major spacecraft missions and instruments as well as the Earth Probes program, the New Millennium missions, and commercial remote sensing.

Earth Observatory: <http://www.earthobservatory.nasa.gov>

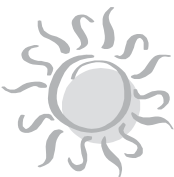
The Earth Observatory presents articles, images, and animations that illustrate the complexities of Earth system science as well as NASA's use of satellite-based and other remote-sensing data to study change on global and regional scales. Updated daily, the Earth Observatory is an information resource for educators, interested lay persons, and media writers.

EOS Project Science Office: <http://eospsso.gsfc.nasa.gov/>

The EOS Project Science Office (EOSPSO) web site presents program information and resources for the entire EOS program. It is appropriate for EOS program scientists and the general public alike.

Visible Earth: <http://visibleearth.nasa.gov/>

Visible Earth is a searchable directory of images, visualizations, and animations of the Earth. It features an extensive library of print and broadcast quality images in agriculture, atmosphere, biosphere, cryosphere, human dimensions, hydrosphere, land surface oceans, radiance or imagery, solid earth, and various locations.



Glossary

On-line Glossary of Solar Terms from NASA's Space Environment Center:
<http://www.sec.noaa.gov/info/glossary.html>

Faculae - Bright blotches on the surface of the Sun that put out more radiation than normal and increase the solar irradiance. They are the result of magnetic storms, and their numbers increase and decrease in concert with sunspots.

Infrared - Of or relating to the range of invisible radiation wavelengths from about 700 nanometers, just longer than red in the visible spectrum, to 1 millimeter, on the border of the microwave region.

Irradiance - Radiant energy per unit time per unit area incident on a surface.

Low Inclination Satellite - A satellite flying in an orbital plane that makes a small angle to the equatorial plane of the Earth, usually taken as less than 45 degrees.

Maunder Minimum - During the coldest part of the Little Ice Age, from 1645 to 1715, there is believed to have been a decrease in the total energy output from the Sun, as indicated by little or no sunspot activity. Astronomers of the time observed only about 50 sunspots for a 30-year period as opposed to a more typical 40,000-50,000 spots.

Nanometers (nm) - a billionth of a meter.

Polar Orbiting Satellite - A satellite whose orbital plane is nearly perpendicular to the Earth's equatorial plane, usually taken as less than 45 degrees, and thus crosses the Arctic and the Antarctic regions in each orbit.

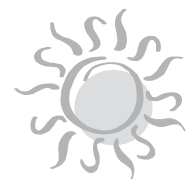
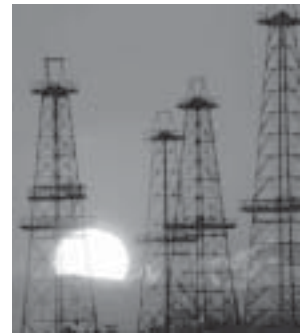
Prism Spectrometer - An instrument that measures energy in visible and near infrared wavelengths of a spectrum (300-2000 nm).

Soft X-ray - Energy from the Sun's corona that reaches the Earth's lower thermosphere at altitudes between 100 and 150 km (62 and 93 miles), at wavelengths of 10-30 nanometers.

Spectral Solar Irradiance (SSI) - Irradiance per unit wavelength, for a particular chosen band of wavelengths.

Solar Ultraviolet Irradiance - The amount of energy in the ultraviolet end of the spectrum from 120 to 300 nm.

Spectral Resolution - The smallest measurable separation between two wavelengths for a given spectrometer.





Sunspots - 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.

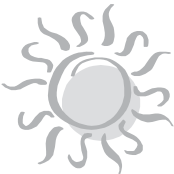
Ultraviolet - Electromagnetic radiation from 4 to 400 nanometers up to the violet edge of the visible wavelengths.

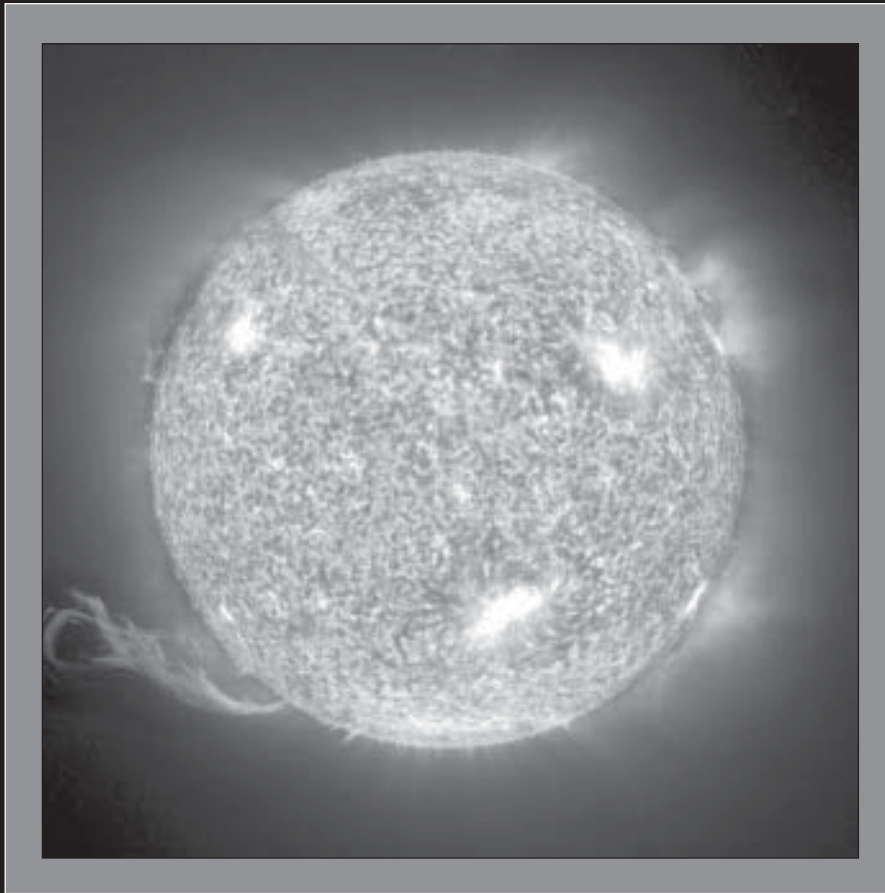
Visible light - Electromagnetic radiation from 400 to 700 nm, which is detectable by the eye.

Wavelength - The distance between one peak or crest of a wave of light, heat, or other energy and the next corresponding peak or crest. (Wavelengths from the Sun range from ultraviolet to infrared.)

Acronyms

AMSR-E	Advanced Microwave Scanning Radiometer instrument on the Aqua satellite
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer instrument on the Terra satellite
EOS	Earth Observing System
EOSDIS	EOS Data and Information System
ESR	Electrical substitution radiometer
FUV	Far Ultraviolet
HSB	Humidity Sounder for Brazil on the Aqua satellite
LASP	Laboratory for Atmospheric and Space Physics, University of Colorado at Boulder
MOPITT	Measurements of Pollution in the Troposphere instrument on the Terra satellite
SIM	Spectral Irradiance Monitor
SNOE	Student Nitric Oxide Explorer satellite
SOLSTICE	Solar Stellar Irradiance Comparison Experiment
SORCE	Solar Radiation and Climate Experiment
TIM	Total Irradiance Monitor
TIMED	Thermosphere-Ionosphere-Mesosphere-Energetics-Dynamics satellite
TSI	Total Solar Irradiance - total energy output from the Sun
UARS	Upper Atmospheric Research Satellite
UV	ultraviolet
XPS	XUV Photometer System
XUV	Solar Soft X-ray





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