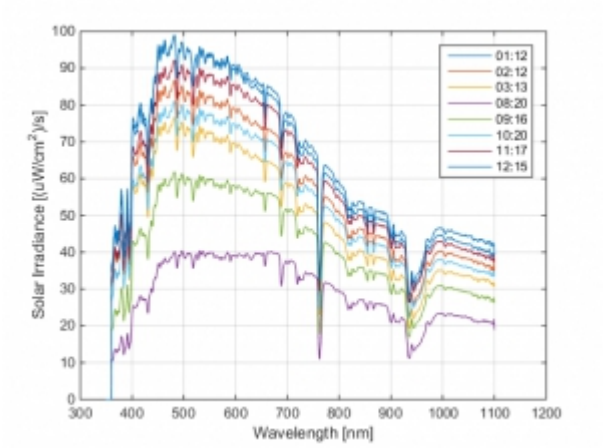
Solar Irradiance and Solar UV Field Measurements



The Sun is the primary source of energy on Earth. Radiation from the sun strikes the Earth's atmosphere and begins to be absorbed by air particles and gases, while the remaining energy reaches the Earth's surface. Earth absorbs much of this radiation, and reflects and emits radiation as well. Even small changes to the equilibrium of this energy system is believed capable of causing intense changes to Earth's climate.

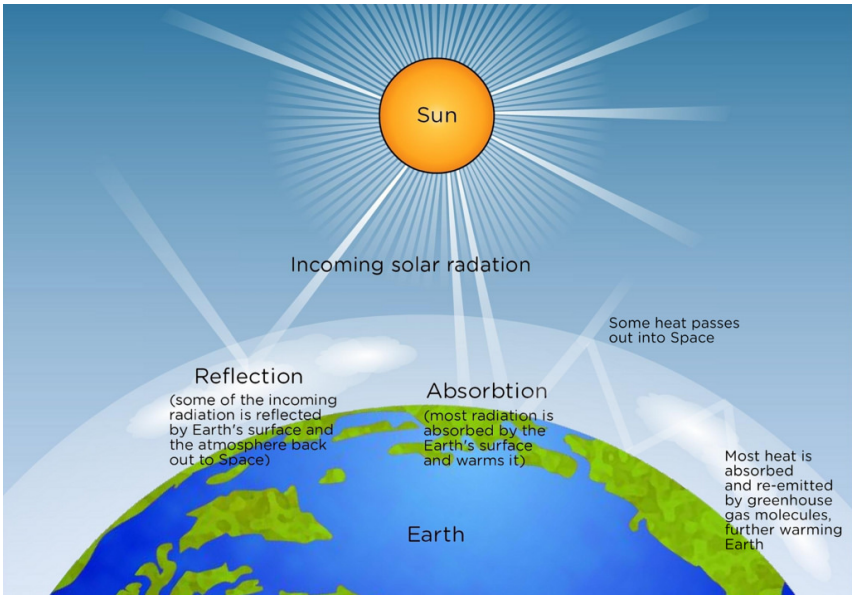
Solar Irradiance data is a critical component of climate and environmental study, but solar radiation can affect many other areas of life on Earth, from agriculture and health to technology and manufacturing. Researchers and scientists from academia and industry need access to reliable, repeatable solar characterization data. For solar spectra collection and solar characterization systems, trust Avantes, the world leader in the manufacture and design of optical spectroscopy equipment.

Defining Solar Irradiance

Total solar irradiance is defined as the sum of solar energy, over all wavelengths, per meter squared at the point of incidence upon the Earth's outer atmosphere. This total solar irradiance is approximately 1,360.8 Watts per meter squared, But we know that the Sun's energy is not a homogenous constant. Rather the sun's energy fluctuates slightly as it emits radiation across the entire electromagnetic spectrum. This spectrum includes what we characterize as visible light as well as Ultraviolet and Infrared radiation.

A solar spectra measurement differs from the total solar irradiance in that it gives an intensity measurement for each wavelength. The characterization of the full spectrum of sunlight provides important data points for researchers. As the sun's energy passes through the layers of Earth's atmosphere, a portion of that energy is reflected, scattered or absorbed by gases, water vapor, or airborne particulates. This scattering is what gives the sky its blue appearance. The shorter wavelengths, like those in the blue range, are scattered more than longer wavelengths.

We know that every element in the periodic table absorbs light at a particular wavelength. Each element has a unique spectral signature like a fingerprint allowing scientists to identify materials with spectral analysis. Measuring the spectral irradiance of the Sun's light tells us about the chemical makeup of Earth's atmosphere

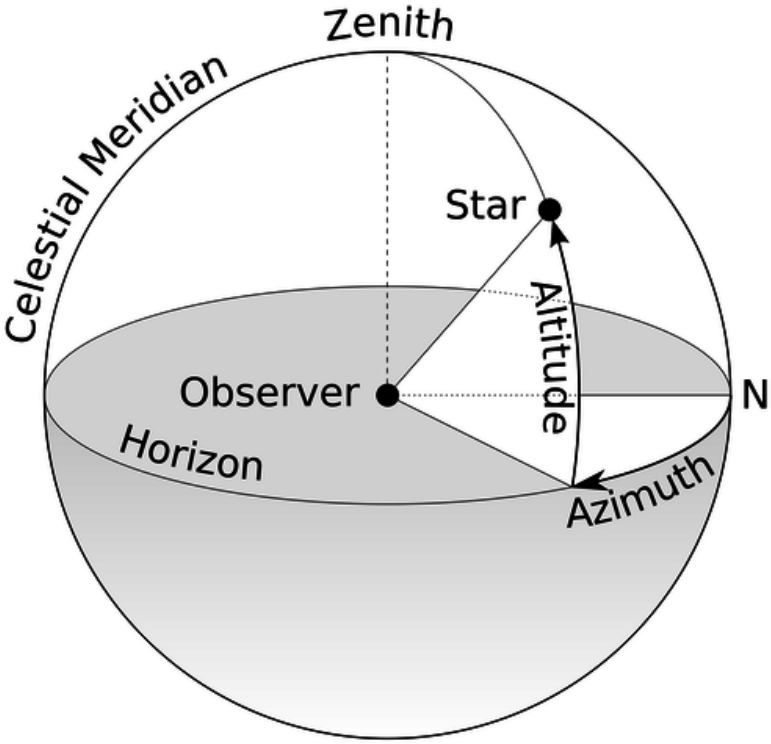


and aids in predicting how the climate will respond to changes in Earth's energy system.

Measurement Parameters

There are many factors that affect the behavior and characteristics of light from the sun as observed on Earth. The sun's energy does fluctuate, and solar storms and other phenomena can affect solar output. Air pollution, water vapor, and cloud coverage can also affect the quality of light reaching the Earth due to absorption and light scattering.

Also, solar position is a dominant factor in solar irradiance measurements. Parameters such as season, time of day, and the observer's geographic location affect solar measurements. The Sun's radiation is strongest near the equator during summer when the Earth's tilt brings the observer's hemisphere closest to the sun, and at noon when the sun is closest to its zenith. At this point the energy from the sun has the least distance to travel through atmosphere. At sea level, this is referred to as 1 atmosphere (1 atm). When measurements are taken at other latitudes, or other times of day, the angle of the sun will affect solar irradiance. The amount of atmosphere that energy must travel through before reaching the point of observation is called the air mass index. This is expressed in ratio to the constant 1 atm so that for most latitudes of North American the Air Mass index is considered to be approximately 1.5 atm.



Capturing Solar Spectra

The state of Colorado in the U.S. Rocky Mountains boasts a healthy solar research community because the mile-high altitude is an advantage for solar measurement applications. Avantes engineers at the U.S. offices near Boulder, CO took advantage of the location at 1,626 m above sea level to perform some solar irradiance tests recently. The higher altitude gives the Boulder, Colorado region a noon-time air mass index slightly lower than the majority of the United States. Colorado also averages nearly 300 days of sunshine per year.

Over a series of days, Avantes engineers gathered broadband spectra of global horizontal irradiance using the Avantes cosine corrector (CC-UV/VIS) to compensate for solar zenith angle and any other inherent sampling geometry. The cosine corrector was coupled to the Avantes AvaSpec-ULS2048x16-USB2 spectrometer using a solarization resistant FC/PC 400µm core UV fiber.

The Avantes AvaSpec-ULS2048x16 was calibrated for irradiance using a NIST traceable source over the range from 300-1100 nm. After such calibration, the spectrometer was used to collect solar spectra using a laptop running AvaSoft 8.6.1.0 in Absolute Irradiance mode.

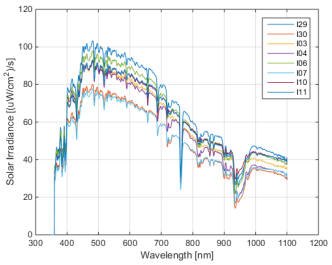
Avantes engineers set up the monitoring station in the same geographic location for each series of solar irradiance spectra measurements. In the first series, measurements were taken at roughly the same time of day over the course of several days. Additional atmospheric data was collected for reference.

Avantes Offices Location

- Longitude&Latitude 39°57'46.1"N 105°07'24.0"W
- Elevation: 5,335' a.s.l. (1,626 m)

Solar Spectra Data

In the second series of measurements, spectra data was collected hourly throughout the course of the workday. The same geographic location was used throughout sampling process. Hourly atmospheric data was also collected for reference.

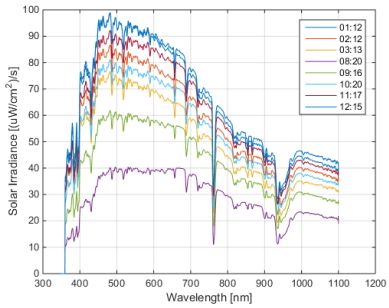


date	time	Spectral Integer	humidity %	visibility mi	pressure in	Zenith angle°	air mass index	GHI record
3/29/17	12:08	49,475.88	66	25	30.09	35.69	1.23	1050.8
3/30/17	12:15	37,307.73	30	50	29.76	35.38	1.23	1051.2
3/31/17	8:35	1,151.90	93	0.1	29.78	58.37	1.9	927.6
4/3/17	12:20	43,968.43	19	50	29.78	34.19	1.21	1052.1
4/4/17	12:01	42,496.18	81	7	29.97	33.60	1.2	1053.2
4/6/17	12:21	46,645.97	29	50	30.19	33.12	1.19	1053.2
4/7/17	12:02	37,169.57	23	50	29.96	32.47	1.18	1054.3
4/10/17	12:15	45,702.08	24	50	30.18	31.52	1.17	1054.9
4/11/17	12:16	45,542.88	17	35	30.16	31.19	1.17	1055.1

Click to See Full Size Spectra Graph

Solar Irradiance Applications-RADIANCE Team

The CU Boulder RADIANCE senior design team in Aerospace Engineering is working to develop low-cost, mass-producible solar irradiance cube satellites to make it easier for researchers to collect solar data and help close gaps in the global irradiance records. These talented, young engineers are preparing the cube satellite for a circumpolar test flight aboard the Arctic Hi-Wind Gondola with the AvaSpec-MINI onboard.



time	date	temp °F	dew point °F	humidity %	pressure in	Zenith angle°
7:51 AM	4/11/17	39.2	17.6	49%	30.2	15.15
8:50 AM	4/11/17	44.6	21.2	34%	30.21	26.36
9:50 AM	4/11/17	50	19.4	30%	30.21	37.32
10:50 AM	4/11/17	55.4	19.4	25%	30.2	47.22
11:49 AM	4/11/17	59	14	17%	30.16	54.79
12:50 PM	4/11/17	62.6	10.4	13%	30.18	58.55
1:47 PM	4/11/17	64.4	10.4	12%	30.14	56.98
2:50 PM	4/11/17	66.2	12.2	12%	30.1	50.30

Click to See Full Size Spectra Graph

The RADIANCE team has been thrilled with the performance of the Mini. The high-powered compact spectrometer is out-performing the team's expectations as they reliably acquire a full spectra measurement ranging from 200-1100 nm at the rate of 1 spectra per minute. To meet the requirements of CubeSat design, the system was built to fit in a package that is roughly the size of lunch box. The AvaSpec-Mini, itself, weighs only 174g and is roughly the size of a deck of cards.

Solar Irradiance- Tartu Observatory, Estonia

Avantes has been a trusted source for solar measurements for more than two decades. The Tartu Observatory, in Tartu, Estonia, contributes to the European Database for UV Climatology and Evaluation (EDUCE). This administrative body maintains a database of solar spectra data and sets standards for data quality control. In 2005 Tartu Observatory installed an Avantes system to provide a continuous backup redundancy UV monitoring system supporting the existing pyranometer and pyrheliometer systems to comply with data handling standards for EDUCE.

Solar Simulators

A solar simulator is a light source that simulates natural sunlight in controllable laboratory testing conditions. Solar simulators are critical in the testing and certification of photovoltaic cells and modules.

The International Electrotechnical Commission and other organizations set standards for solar simulator performance across three parameters: spectral match, spatial non-uniformity, and temporal instability. Each parameter receives a separate letter grade of A,B or C. The quality, and therefore price, of a solar simulator is dependant on the class rating of the light source. The difference of a few points in performance can mean a difference of hundreds of thousands, even millions of dollars in revenue.

These powerful light sources are used in many industries to test solar responsiveness of many materials. They can be used to measure material degradation, to characterize all manner of photoresponsive devices, and to test and rate photovoltaic cells for use in solar panels. The industries that use solar simulators are at risk of significant losses if solar simulator systems are not optimal, and yet these systems, whether continuous or pulsed light, have a finite bulb life which may warrant frequent calibration.

This means that the characterization and regular maintenance of solar simulator light sources is a mission critical technology for many organizations. Avantes offers solar simulator users and manufacturers the AvaSpec-SolarXM spectroradiometer system for easy solar simulator characterization. This ASTM 927-05 compliant calibrated system includes the AvaSpec-ULS2048x16-USB2 spectrometer, fiber optic cables, and a 90° cosine corrector along with a dedicated software application for NIST traceable calibrated measurements. The AvaSpec-SolarXM system is suitable for steady state and pulsed solar systems, and quantifies spectral match according to the A, B, or C classification across six spectral bands.

Avantes, Your Trusted Solar Measurement Source

Avantes has been on the cutting edge of light measuring technology for more than twenty years. Our team has helped thousands find the right solutions to their spectroscopy needs. Our experience in solar irradiance measurements and solar characterization is what sets our service and support apart. Contact our team to discuss your application requirements with a sales engineer or expert distributor today.