Researchers study fluctuations in solar radiation

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The Sun is the Earth's principal source of energy and climate driver. Yet sometimes it sends more light to the Earth than other times. Astronomers working with Natalie Krivova at the Max Planck Institute for Solar

System Research in Göttingen take these fluctuations in solar radiation into account in their models to find out whether they contribute to global warming or counteract it.

I actually need just two things for my work," says Natalie Krivova, with a laugh, "a computer and time." That's surprising, as Natalie Krivova is an astronomer and focuses on the celestial body that is most crucial for life on Earth: the Sun. "Nevertheless, I've rarely ever looked through a telescope." The researcher works in a small office at the Max Planck Institute for Solar System Research in Göttingen. On the wall hangs a whiteboard. Krivova has drawn a smiling sun on it with a green felt-tip marker. The Sun is her passion.

Natural scientists have been observing this star for more than 400 years, since Galileo Galilei developed the first powerful telescope. Since that time, mankind has learned a lot about the gigantic, hot, gaseous balloon. Some details, however, are still unclear. It was previously believed that the intensity of solar emitted radiation did not vary with time, and this was dubbed the solar constant. But now we know better: the radiant intensity of the Sun fluctuates – and this is significant for planet Earth, for life here is dependent on solar radiation.

And with the discussion surrounding climate change, the topic of solar radiation has gained additional significance in recent years. The question is whether the Sun, too, plays a role in the slow process of global warming – and if so, to what extent – or whether diminishing solar activity may even counteract anthropogenic climate change.

Climate models must account for solar activity

Natalie Krivova and her colleagues want to help answer this question. On their computers, they have developed physical computational models that simulate changes in solar activity over many centuries. This is crucial for climate researchers: "If I want to find out how severely the climate will change as a result of the emission of greenhouse gases, then of course I have to be able to assess all of the influences correctly," says Krivova. "And as the Earth's main source of energy, the Sun just happens to be the most important natural influencing factor." No climate model can deliver reliable data if the solar activity isn't computed correctly, she says.

Of course scientists today know the most important solar activity characteristics. Where solar light is vertically incident, around 1,360 watts of power strike one square meter of the Earth's atmosphere. This value, which is calculated across all wavelengths of light, from ultraviolet to infrared, is called total solar irradiance (TSI). However, just how much energy reaches the Earth's surface – on the continents and the ocean surface – depends on the wavelength of the solar light. Ultraviolet light, for example, is almost entirely absorbed in the upper layers of the atmosphere. It is therefore important to consider wavelengths individually.

The intensity of the solar radiation fluctuates over an approximately 11-year cycle. This up and down coincides with the increased occurrence and disappearance of sunspots – dark spots on the Sun. The largest ones are visible from Earth with the naked eye. Chinese scientists even described sunspots many centuries ago. German pharmacist and amateur astronomer Samuel Heinrich Schwabe was the first to study them systematically, starting in 1843. However, it wasn't until the 1970s, when satellites were sent into space with measuring instruments on board, that astronomers noticed that the Sun's radiant flux also changes with the sunspot cycle. Solar radiative flux is highest at the peak of the 11-year cycle, when particularly many sunspots are visible. Today, we know that the TSI increases by about one watt at this time. During a sunspot minimum, in contrast, hardly any spots can be seen. Radiant flux decreases during this period.

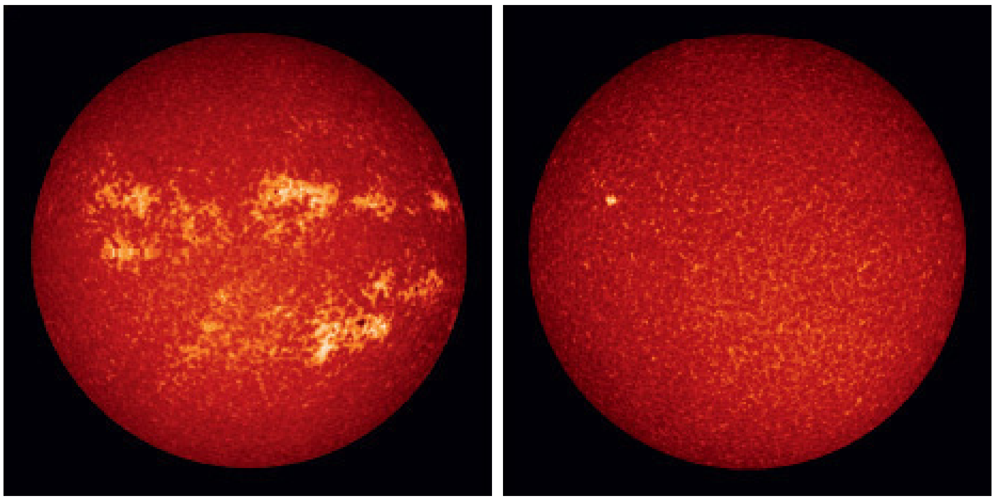
Long-term trends besides the 11-year cycle

One watt – that sounds negligible, but the impact on the Earth is apparently considerable. In the 17th century, there was a particularly cold period in Europe that is now known as the Little Ice Age. Dutch artist Hendrick Avercamp captured winter impressions in his well-known paintings – ice skaters, villages enveloped in snow. At that time, rivers froze over until well into spring. In the mountains, the snow didn't melt, even in summer. In historical astronomical records, hardly any sunspots are mentioned for this period. Accordingly, the solar activity at that time is likely to have been very low for several decades.

So there isn't just the 11-year cycle, but also a long-term trend that may change the climate on Earth over longer periods. For instance, astronomers have found indications that, over the course of the past 300 to 400 years, radiative flux may have increased by roughly another one watt. The exact figure isn't yet known.

Interestingly, during the solar cycle, radiative flux doesn't fluctuate with the same amplitude across the entire solar spectrum. More than 50 percent of the variation in the radiative flux comes from the ultraviolet range. And for a long time, this wasn't taken into account in solar and climate models. In the atmosphere, the ultraviolet radiation reacts with ozone molecules, thus governing the ozone balance. In addition, it reacts with nitrogen and many other molecules. "We don't know exactly how these reactions change over the course of the solar cycle," says Natalie Krivova. "But there are indications that reactions take place in the atmosphere that further increase the effect of the solar irradiance," says Krivova.

That is why Krivova's model SATIRE (Spectral And Total Irradiance Reconstruction) also takes the fluctuations in the UV light into account. "Although the UV light makes up just 8 percent of the total solar irradiance," she says, "the fluctuations are considerable, and if the effect of the UV changes amplifies solar influence on the atmosphere, we have to account for this in our models."



The Sun at the peak (left) and at a minimum of its activity: The Kodaikanal Observatory in India photographed our star in 1928 (left) and 1933. The images show the intensity in the calcium II line of the optical spectrum. Credit: Kodaikanal Observatory, India

In order for models describing natural phenomena such as climate change and solar radiation to reflect reality accurately and make reliable forecasts for the future, they have to be fed with measurement data from the past. Simulating the sea level requires level measurements, simulating solar activity, radiation measurements and many other solar observations from satellites.

Isotope measurements serve as substitute data

However, the researchers have a fundamental problem with the data situation. The physical reconstructions have to cover long periods: if you want to know how the climate and Sun will change in the coming decades and centuries, then you also need data that covers long periods of time – centuries, or better yet, millennia. But we have reliable measurements for only a few decades to feed into the models.

The data that Natalie Krivova feeds into her models goes back to 1974, and the sunspot counts, back to Galileo Galilei. But then? If there are no actual measurements, researchers rely on substitute data, known as proxies. That's what Natalie Krivova does, as well. The astronomer uses measurements of the heavy carbon isotope 14C, or of the beryllium isotope 10Be, as proxies. These two radioactive isotopes are produced in the atmosphere by bombardment with high-energy cosmic particles, 14C, for example, when a nitrogen isotope decays. 14C is incorporated into the global carbon cycle after a few years by plants absorbing it as carbon. Plants always absorb 14C in a proportion corresponding to that in the air. The 14C uptake ends when the plant dies. Then its proportion decreases, for instance in the wood of a dead tree, due to the radioactive decay of the isotope – in the case of 14C, with a half-life of 5,730 years.

From the 14C content of wood samples today, it is possible to calculate the 14C concentration in the atmosphere at the time the carbon was incorporated into the wood. To do this, researchers must know the age of the sample. This can be determined based on the characteristic growth rings found in tree trunks, for which there are now complete profiles that go far back.

The solar irradiance over the past 11,000 years

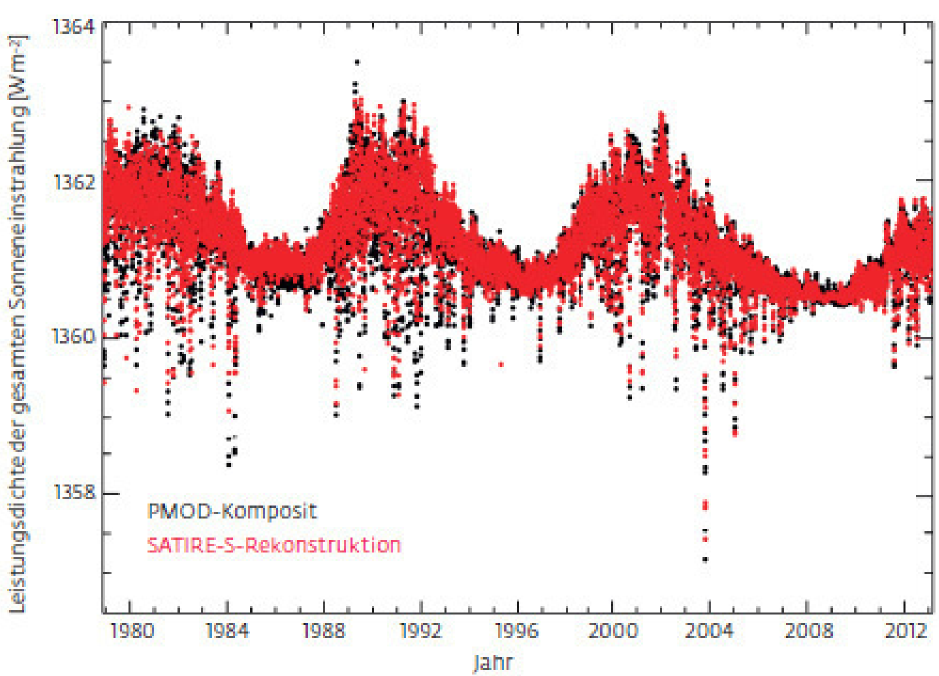
The atmospheric 14C concentration at a given time, as ascertained from tree ring samples, stands in direct relation to how severely the Earth is bombarded with energetic charged particles. The driver of the fluctuations in particle bombardment is the Sun's magnetic field. It acts as a protective shield for the Earth, weakening the flux of high-energy cosmic particles. When the Sun's magnetic field is weaker, the Earth is less well protected. The solar magnetic field is also responsible for the formation of sunspots and the solar irradiance changes. Thus, 14C measurements from tree ring samples can also be used to reconstruct, indirectly, via the strength of the magnetic field, the solar irradiance. In a similar way, the 10Be data can serve as proxy data for the solar irradiance. However, beryllium precipitates out of the atmosphere and eventually falls to the ground. Historical traces of beryllium can be found today, for example, deep in the icy armor of glaciers on Greenland and in the Antarctic.

Together with other researchers, Krivova succeeded, with the aid of these proxies, in computing, in detail, the variability of the solar irradiance for the past 11,000 years since the last ice age. Compared with the models of other research groups, Krivova's simulation tool proved to be very reliable. Climate modelers therefore use it also for those simulations that are included in the Intergovernmental Panel on Climate Change (IPCC) climate report. But it can still be better, Krivova believes. Sunspots and 14C proxies aren't everything – the variability of the solar radiation depends on many factors. Sunspots emerge primarily in regions in which the Sun's magnetic field is particularly strong. Here, the strong magnetic field hinders the heat transfer from the Sun's interior to its outer boundary. Sunspots are thus areas on the Sun's surface where less radiation is emitted, which is why they appear darker.

One would expect the radiative flux of the Sun to decrease when particularly many sunspots occur at the cycle's peak, but the opposite is the case. This is because, simultaneously, during the active phase, many smaller, bright regions appear that are best visible in UV light. The number of these faculae, as they are called – torches – increases much more than that of spots, which compensates for the radiation attenuation in the sunspots.

Unlike sunspots, faculae are not well seen in visible light. Researchers use magnetographs for this, special instruments on satellites that make the changes in the magnetic field clearly visible – and in this way discern not only sunspots, but also faculae, because they also harbor magnetic fields.

Unexploited treasure: Photos in the calcium II line



The Sun's total radiative flux fluctuates over an 11-year cycle. The SATIRE-S model (red dots) reproduces over 92 percent of measured irradiance variations (black dots). When the short, deep drops in TSI occur, dark spots wander across the Sun's visible surface. Credit: Solar System Research

Krivova feeds her model with the images from the magnetograph, the so-called magnetograms, and the information they contain on the size of the faculae. In this way, together with her doctoral student Kok Leng Yeo, she succeeded in refining the model in such a way that it is currently considered to be the most precise irradiance model available.

But there is one problem: unlike with the sunspots, there is, as yet, no usable faculae data from the time before the satellite era. Magnetograms of sufficient quality have been researched only since the early 1970s, so not yet long enough. Therefore, together with her doctoral student Theodosios Chatzistergos, Krivova wants to take advantage of an as-yet-unexploited treasure: around 100 years ago, astronomers began using a special method to photograph the Sun. They used photo plates that are sensitive only in a certain region of the solar spectrum, in the so-called calcium II line. At this wavelength, faculae are particularly bright.

The network could explain long-term trends

The calcium II photographs haven't yet been thoroughly analyzed. Theodosios Chatzistergos intends to do this – an enormous task. He aims to systematically study 60,000 individual images from three observatories for faculae structures. To do this, he wrote software that automatically detects the faculae areas in the images. By comparing images from three different observatories, he hopes to detect artifacts and image errors. "We hope that this unique faculae data will help us gain an even better understanding of the variability of the solar irradiance," says Krivova.

And then Natalie Krivova has yet another faint hope: in addition to the sunspots and the faculae, there is a third structure on the Sun's surface that influences solar brightness. A fine network of even smaller bright spots that astronomers refer to simply as the network. "We know little about the network," says Krivova. "We suspect that it likewise has a cycle, which is, however, weaker and extended in time compared with the sunspot cycle." Krivova and also other researchers believe that this network contributes to the gradual long-term changes in solar irradiance characterized by extended periods during which there are especially many or few sunspots, such as the Little Ice Age. "Secular change" is the term experts use for this longterm trend – "slow, systematic change."

"The role the network plays in this is still poorly understood – so we hope that, in the calcium II images, we will also be able to recognize and analyze the network." As far as the long-term change in the solar activity is concerned, the Sun is evidently currently in what, from the perspective of Earth's inhabitants, is a very interesting phase. Sunspot counts in the past years indicate that solar activity is on the decline again after 60 very active years. For the coming decades, the researchers expect a decrease in solar activity. Climate change skeptics now claim that this cooling could counterbalance the global warming caused by human emissions of greenhouse gases. But Krivova dismisses this: "Current scientific work and the reports of the IPCC clearly show that greenhouse gases have contributed many times more than the Sun to the change in the Earth's heat balance in the past decades."

UV irradiance to be studied in greater detail

Krivova plans to continue her endeavors to understand the Sun's capricious nature. For her, this also, and especially, includes a more precise investigation of ultraviolet radiation – which, after all, contributes significantly to the variability of solar irradiance. UV irradiance is modulated primarily by the magnetic field in the Sun's upper atmosphere, the chromosphere. The chromosphere floats above the photosphere, which we humans see from Earth as the apparent surface of the gaseous balloon that is the Sun. However, the processes that take place in the chromosphere are so complicated that it is very difficult to incorporate them in models. Now, though, Natalie Krivova aims to embed in her models a sort of calculation module for the chromosphere.

Her working group at the Max Planck Institute for Solar System Research isn't alone with its studies on solar irradiance. She and her colleagues cooperate closely with other groups in the Sun and Heliosphere Department headed by Sami Solanki. This work, in turn, is part of the ROMIC (Role of the Middle atmosphere in Climate) research program, which is sponsored by the Federal Ministry of Education and Research, and in which the middle Earth atmosphere is being studied in greater detail.

Although the weather and the climate on Earth take place in the atmospheric layers near the ground – the troposphere – the processes that take place in the layers above that have a major impact on the troposphere. Even today, researchers don't really understand the processes taking place in the middle atmosphere. Knowledge about the Sun's impact is also fragmentary. Natalie Krivova and her colleagues at the Max Planck Institute for Solar System Research will therefore continue, again and again, to explore uncharted solar territory.

Provided by Max Planck Society

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