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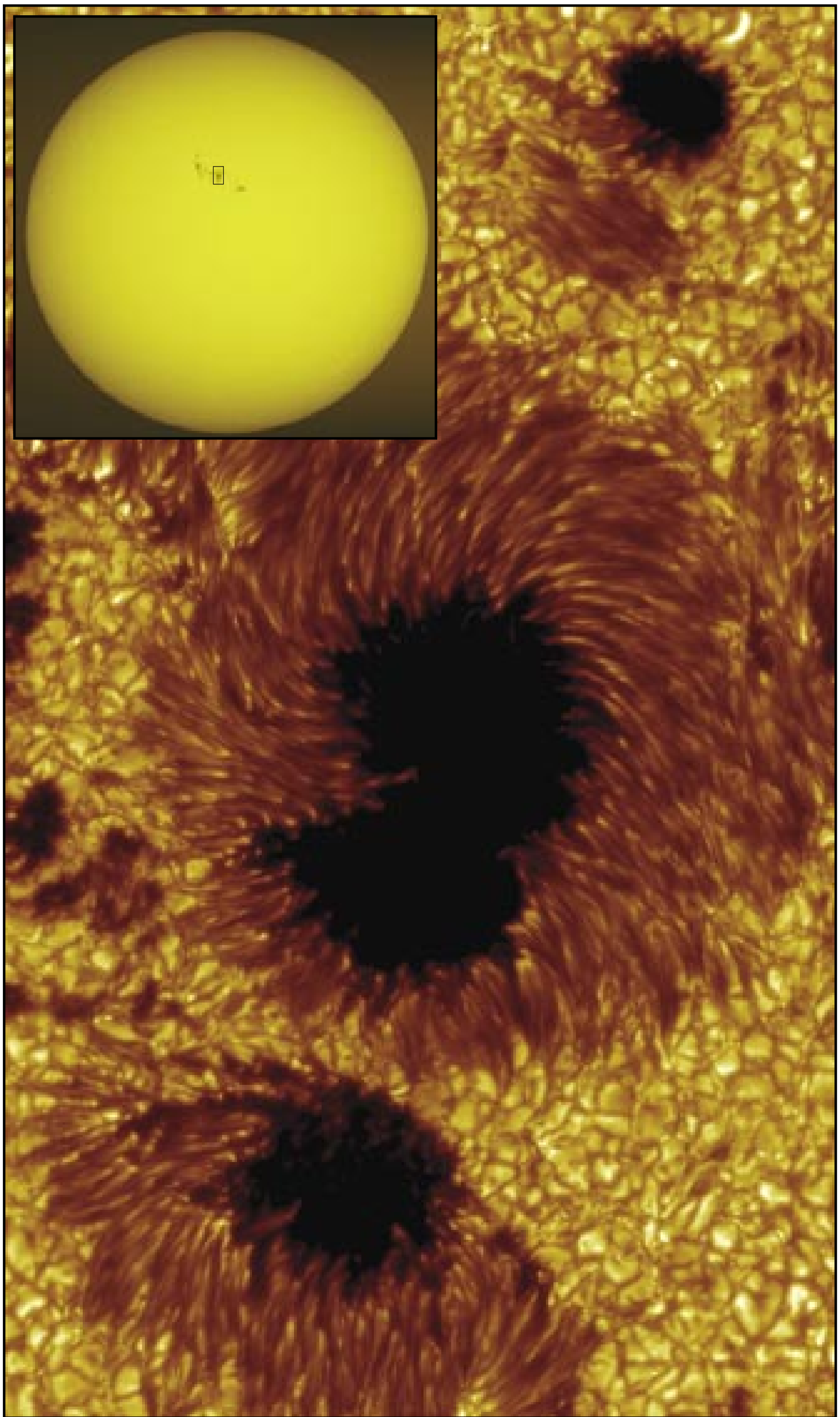


"Everybody agrees that the Sun drives the Earth's climate system", says Juerg Beer, but "until recently, almost no-one believed that the Sun had anything to do with climate change." In this NewsLetter Juerg beer discusses *Solar Variability and Climate Change* while Ulrike Lohmann and Martin Wild discuss the issue of *Solar Dimming* – the reduction of solar radiation at the Earth's surface due to increasing emissions of aerosols from human activity. A related Science Feature reports on aspects of ACE-Asia, focussing particularly on the impacts of soot and considering whether mitigating soot emissions can help mitigate global warming.

The cover image (coloured for aesthetic effect) shows sunspots on 15 July 2002, during a period of high sunspot activity. As Juerg Beer points out, solar activity (as indicated by sunspot activity) is one driver of climate variations. The image is from the 1 metre solar telescope of the Institute for Solar Physics of the Royal Swedish Academy of Sciences. This telescope (on the Canary Island of La Palma) has provided the most detailed images ever obtained of the Sun and has revealed previously unknown sunspot phenomenae. The inset shows the sunspot group on an image of the entire Sun recorded by the Institute for Solar Physics' finder telescope. The diameter of the sun is around 100 times that of the Earth.

Also in this issue of the Global Change NewsLetter we farewell LUCC – the Land-Use and Cover Change project of IGBP and IHDP. We provide a report from a recent LUCC workshop, a summary of the key findings of LUCC and a vote of thanks. In the centrefold we highlight the Science Plan of the new IGBP-IHDP Global Land Project that will subsume the ongoing research of LUCC into its research framework based on the paradigm of the coupled human-environment land system.

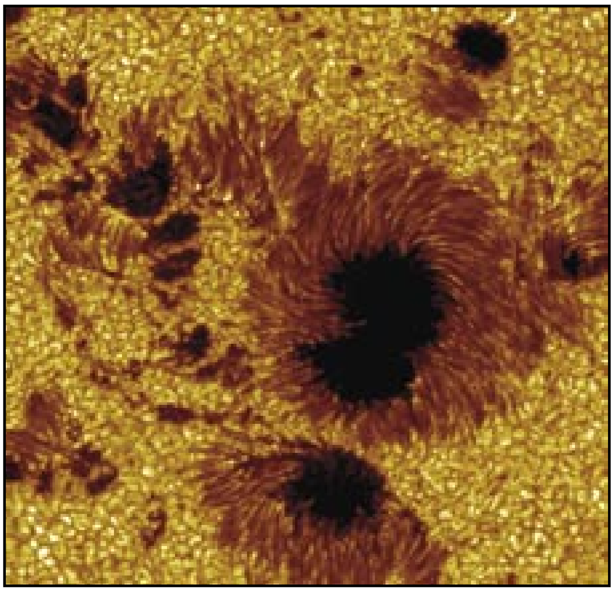
Discussion Forum

Everybody agrees that the Sun drives the Earth's climate system. Every second, the Sun loses around four million tons of weight which are irradiated into space mainly in the form of visible light. One billionth of this power (1,017 W) arrives at the top of the Earth's atmosphere – an amount which corresponds to about 10,000 times humankind's present global consumption. This solar power arriving at the top of the atmosphere is known as the "solar constant" (1,365 W m^{-2}).

Solar Variability and Climate Change

Until recently, almost no-one believed that the Sun had anything to do with climate change. A small number of scientists had tried to test whether the solar constant really is constant. As they were only able to observe the Sun from the surface of the Earth they failed, because absorption of the sunlight crossing the atmosphere fluctuates. It was only in the satellite era that it became possible to continuously monitor the solar constant from outside the Earth's atmosphere. A compilation of several instrumental records clearly shows that the solar constant is indeed not constant [1], but varies with solar activity as indicated by the number of sunspots (Figure 1). However, over an eleven-year cycle the observed change is quite small – only about 0.1%. From these results many people conclude that solar forcing of the climate does occur, but is negligible.

However, in addition to these direct measurements of the solar constant (more appropriately called total solar irradiance – TSI), there are several pieces of indirect evidence proving that the Sun is a variable star and that these variations may well influence climate change. Herein, some aspects of the different mechanisms and amplitude of solar variability are described, together with descriptions of the corresponding sensitivity of the climate system.



Sunspots July 2002. Image from Institute of Solar Physics, Royal Swedish Academy of Sciences. See cover for more details.

In contrast to TSI, changes in the ultra-violet part of the solar spectrum are large, and affect the ozone content in the stratosphere. Model calculations show that these changes can ultimately affect the circulation of the lower atmosphere [2]. While these changes in total and spectral irradiance are caused by processes on the solar surface, models describing the lifetime of the Sun (approximately 10 billion years) show that 4.5 billion years ago when the solar system was created, TSI was lower by about 30%. Since then it has steadily increased, and will continue to do so for about another 4 billion years. A very interesting question is how the Earth System managed to avoid becoming an "ice house"; this is known as the "faint young Sun paradox".

For much shorter – but still quite long – time scales, there is some unique information. The amount of solar radiation arriving at the top of the atmosphere is not only related to the emission from the Sun, but also to the position of the Earth relative to the Sun. As a consequence of the gravitational forces of other planets in our solar system (mainly Jupiter and Saturn), the orbital parameters of the Earth change with periodicities ranging from 100,000–400,000 years (eccentricity), through approximately 40,000 years (tilt angle) to periodicities of around 20,000 years (precession of the Earth's axis). The theory of orbital forcing which was developed to a

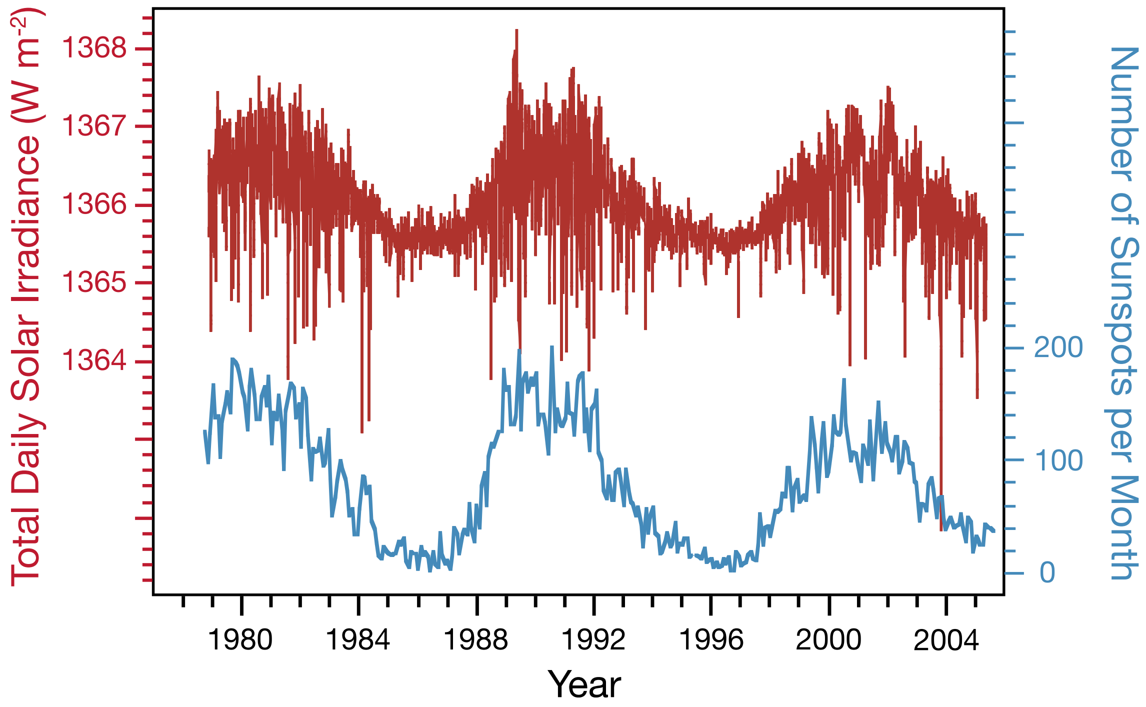


Figure 1. Total solar irradiance (TSI) measured from satellite-based radiometers (daily values) compared with the corresponding number of sunspots per month. TSI data from www.pmodwrc.ch/, sunspots data from sidc.oma.be/index.php3.

large extent by Milutin Milancovic, is unique in the sense that it is the only forcing which can be calculated precisely, not only for the past several million years, but also for the future [3]. The measured $\delta^{18}O$ record of the GRIP ice core (Greenland) indicates the temperature changes during the past 100,000 years, and is plotted here together with the calculated solar insolation (solar radiation reaching the Earth's surface) at 72° N (latitude of the GRIP ice core) during the months July and August (Figure 2). Although the $\delta^{18}O$ record is mainly characterised by the abrupt changes of the so-called Dansgaard-Oeschger events due to changes in the deep-water formation of the North Atlantic, the general long-term trend agrees quite well with insolation changes, except in the past 10,000 years.

The biggest effect of the orbital forcing is the cyclic change between glacial periods and inter-glacial periods over the past 700,000 years, with a periodicity of 100,000 years. This is surprising because the corresponding mean annual change in forcing is very small (~0.2 W m^{-2}). This raises questions regarding the sensitivity of the climate system which are discussed below.

A fundamental problem in assessing the effect of any change in forcing, is the fact that the climate system consists of many components which interact in non-linear ways on very different spatial and temporal scales. Due to positive feedback mechanisms, even very weak but persistent forcing signals can be amplified and lead to strong effects. The sensitivity of the climate system is investigated by means of climate models which are designed to simulate reality [4]. Unfortunately, the closer the climate models approach the complexity of the climate system, the less they are able to simulate orbital forcing effects on time scales of 20,000–100,000 years.

The final issue is the question whether in view of the uncertainty in the forcing and the sensitivity to it, there is any evidence for solar forcing in palaeoclimate records. Clearly on multi-millennial time scales solar forcing is active (Figure 2), and Figure 1 suggests a weak relationship between TSI and solar activity. If true, this offers the possibility to estimate solar irradiance in the past. The sunspot record, which goes back to 1610 when the telescope was invented, clearly shows that the satellite era is characterised by comparatively high solar activity. Periods like the Maunder Minimum (1645–1715) were quite different, with almost no sunspots. This suggests a TSI considerably lower than during the past 30 years. However, we do not yet know how much lower; anything between 0.1% and 1% is possible. But what did the Sun do before 1600?

Using cosmogenic radionuclides such as ^{14}C, ^{10}Be and ^{36}Cl which are produced by the interaction of cosmic rays with the atmosphere, it is possible to reconstruct the solar activity over the past 10,000 years. This gives a first order estimate of solar forcing based on the suggested relationship between

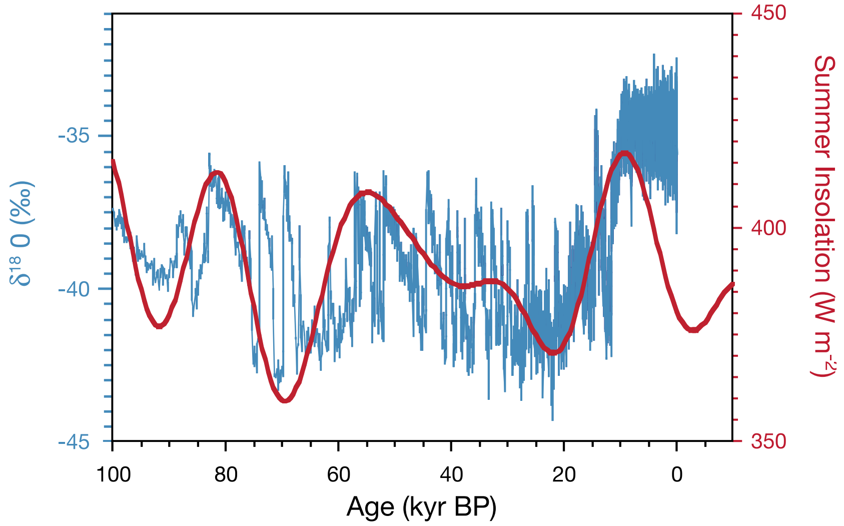


Figure 2. Comparison of the δ18O record from the GRIP ice core (Greenland) indicating climate change over the last 100,000 years ago and the corresponding summer insolation at this site. δ18O data from www.ncdc.noaa.gov/paleo/icecore/greenland/summit/document/gripisot.htm and insolation values calculated with AnalySeries www.ncdc.noaa.gov/paleo/softlib/softlib.html.

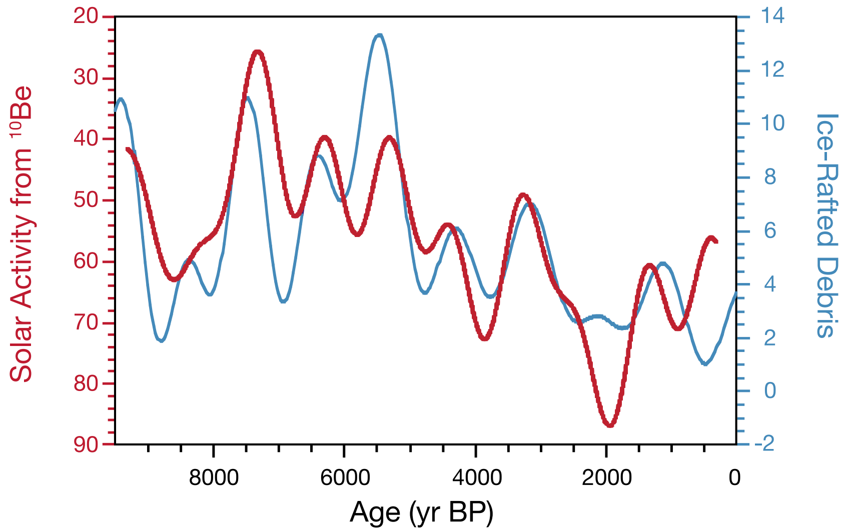


Figure 3. Comparison of ice-rafted debris in North Atlantic sediments (Bond, personal communication) with solar activity derived from ^{10}Be (arbitrary units) (Vonmoos, personal communication). Both records are low-pass filtered with a cut-off frequency of 900 yr^{-1}.

solar activity and solar irradiance [5]. A growing number of high resolution and well-constrained reconstructions of the palaeoclimate during the Holocene, reveal considerable climate changes which point to external forcing. Prior to the industrial era the anthropogenic influence on the climate was probably negligible, so we are basically left with solar and volcanic forcing. The fact that many of the palaeorecords show a relatively high correlation with the reconstructed solar activity, indicates that solar forcing does indeed play an important role.

An example of such correlations is the comparison of ice-rafted debris in the North Atlantic with the solar activity record derived from ^{10}Be in the GRIP ice core (Greenland) [6] (Figure 3). Ice-rafted debris consist of characteristic particles which are picked up by the glaciers moving towards the sea where they break up into icebergs. The origin of some particles is well known: hematite stained grains can be traced back to an area in Greenland, and glass particles originate from volcanic eruptions in Iceland. As the icebergs drift southwards, they slowly melt and release the particles which finally find their way into the sediments. If the climate is generally cold, the icebergs drift further south than during warm periods – as the Titanic experienced in 1912. On longer time scales cold periods with large numbers of ice-rafted debris coincide quite well with periods of low solar activity (high ^{10}Be concentration; Figure 3), as suggested by the direct measurements of total and spectral solar irradiance. Differences arise due to uncertainties in the time scales of the sediment and the ice core, other forcing factors and the non-linear response of the climate system.

Solar forcing is of course just one forcing factor, and understanding climate change requires considering all the different forcing factors. A better knowledge of the natural forcing factors during the industrial era will lead to a better quantification of the anthropogenic forcing, and ultimately to better predictions of the future climate change.

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