Influence of Solar Activity Cycles on Earth's Climate

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Task 1 – Literary Survey on Sun-Earth Connections

WP 100

Technical Note

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Summary

A brief summary of task 1 is given in TN100. For details we refer to the technical notes TN101 (IRF), TN102 (IRF), TN103 (DNSC) and TN104 (IC).

The objective of task 1 is to carry out a "Literature study on Sun-Earth Connection": In TN101 on solar variability; time-scales and causes. In TN102 on solar influences on Earth; proposed mechanisms. In TN103 on signals of climate changes caused by the Sun. In TN104 about modeling of Sun-induced climate variability.

A summary of causes of solar variability, corresponding time-scales and suggested climate changes is presented in Table 1.

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1 Introduction

The objective of task 1, "Literature Survey on Sun-Earth Connection" (WP100), is to establish an initial basis for the study.

In TN101 and TN102 we start from the Sun by describing the causes of solar variability, the time-scales, and how the Sun has been suggested to influence Earth.

In TN 103 on the other hand, we start from Earth and the climate, by describing the found solar signals in climate.

Finally in TN104 various climate models are described.

An extensive database of references has also been produced, which is available at Swedish Institute of Space Physics in Lund.

1.1 Solar Variability (WP 101)

Solar variability originates from solar interior. One aspect of solar variability is linked to solar evolution driven by nuclear conditions in the core. This is a relatively slow process with changes on time-scales of the order of several million years and above for parameters such as mass, radius and luminosity.

Another aspect of solar variability is related to solar magnetic fields generated below the convective zone in the interior. The evolution of magnetic fields results in many manifestations, on time-scales in the range of hours to several hundred even thousand years, such as the well-known sunspot cycle and its longer-period modulations, solar wind structures, and coronal mass ejections.

A third aspect of solar variability deals with periodicities due to orbital conditions such as solar rotation, changes in Earths orbit, or inclination of rotation axis with respect to the ecliptic plane.

Observational techniques are also discribed in this document. We start by discussing helioseismic observations. Studying the waves from solar interior (helioseismology) plays now such an important role for our understanding and even for predicting solar activity. Helioseismic methods have shown us the location of the solar dynamo, the tachocline, a region below the convective zone and above the radiative zone. The new time-scale of solar activity, 1.3 years, was found when studying the conditions at the tachocline. Helioseismic methods have also given us methods to observe the solar activity on the solar far-side, which gives us means to forecast solar activity 7-14 days ahead.

We then also discuss measurements of solar radiation, solar wind, cosmic rays and cosmogenic isotopes.

1.2 Influences of Solar Variability on Earth (WP 102)

There are three solar-related phenomena that may influence the terrestrial environment. First, we have the solar electromagnetic radiation, where clear effects are found on stratospheric ozone generation and subsequent temperature and dynamical impacts.

The second phenomenon is the continuous flow of charged coronal protons and electrons known as the solar wind. Its interaction with the magnetosphere creates magnetic disturbances as well as variations of atmospheric circulation pattern.

The third solar-related phenomenon is the solar wind modulation of galactic cosmic rays, with evidence of an inversely correlation to atmospheric cloud cover. After presenting these phenomena, we describe different methods to analyze solar influences and how to establish adherent significance measures. We describe how the solar influences have been studied with Fourier analysis and wavelet methods. Wavelet methods give a tool to both study frequency of the variability but also how the modes change with time. Description with Principal component analysis (PCA), and artificial neural networks such as self-organizing networks are covered.

1.3 Climate Varibility Correlated to Solar Activity (WP 103)

In WP103 evidences for solar influences on Earth's climate are given.

A clear solar signal is seen in Sea Surface Temperature (SST) (Reid, 1987; Reid, 1991; Reid, 2000). The long-term varibility in SST is in phase with the 80-90 year envelope that modulates the approximately 11-year sunspot cycle.

A positive correlation between the solar activity (solar cycle length (SCL)) and Northern Hemisphere land temperatures was found by Friis-Christensen and Lassen (1991).

Tropospheric temperatures show a very good agrement with changes in reconstructed Total Solar Irradiance (TSI). Although a solar influence on climate is apparent, model studies have indicated that variations in the TSI are too small to explain the observed changes in recent climate. A number of solar amplification mechanisms have been proposed. Mechanisms based on the electromagnetic radiation (TSI) or some component of the UV, the direct influence of the solar wind and the galactic cosmic radiation, which is modulated by the solar wind are described.

From historical and geological records there are strong indications that the Sun has played an important role in the past climate of the Earth. A history of solar activity is known back in time from the production of cosmogenic nuclides in the atmosphere, e.g.^{14}C and ^{10}Be, by galactic cosmic rays (GCR), the latter being influenced by solar activity. The historical flux of cosmogenic nuclides has been obtained from ice cores and tree-rings, and demonstrates that the solar activity has varied considerably over the past 10 000 years on 10-1000 year time-scales. There is a striking qualitative agreement between cold and warm climatic periods and low and high solar activity. Solar activity was particularly high from 1000-1300 AD, and coincided with a medieval warm period when wine was made from grapes grown in England and the Vikings colonised Greenland. Solar activity

decreased considerably after 1300 AD, a disaster for the Viking settlements on Greenland, and a long cold period followed, referred to as the Little Ice Age. The Medieval Warming/Little Ice Age of the past 1000 years was not an isolated climate event associated with solar activity and appears to be one of a number of warm/cold events that ocurred during the Holocene.

Very interesting evidence emerges from geological indicators where climate, on time-scales of millions of years and longer, is correlated with long-term variations in cosmic ray production. At these time-scales the flux of cosmic rays entering Earth's atmosphere vary due to processes external to our solar system, through the traversing of the galactic spiral arms or the changes in our galaxy's star formation rate. On the very long time-scale of 4.6 billion years a remarkable correlation between the Earth's climate and GCR flux is found. It is seen that in the early period most of the GCR flux is very low as a result of the highly magnetic active young Sun. Later when the Sun is less active the variations in the source of GCR flux, i.e. star formation rate, are clearly seen. In particularly the minimum between one and two billion years ago fits very well with the lack of glaciations on Earth during this period.

1.4 Modeling of Sun-induced Climate Varibility (WP 104)

Modelling of Sun-induced climate variability is covered in this document.

The aim of this report is to review the role of climate modelling in the advancement of understanding of the effects of solar variability on climate. Global Climate Models (GCMs), which are computer simulations of the state of the atmosphere-ocean system and its variability, have become increasingly important as tools of the climate scientist. Using numerical representations of processes involved, GCMs enable studies of complex interactions within climate system, their evolution and sensitivity to internal or external forcing factors.

In this report are considered the fundamental physical and chemical processes that need to be included, how they are represented, some of the approximations made and to what extent GCMs are able to reproduce observed signals of solar variability in the atmosphere.

2 Conclusion

The solar activity varies on time-scales from hours to billions of years. The solar dynamo can produce variability on time-scales from years to several thousands years. Fourier studies of solar activity give certain periods and frequencies. However, wavelet studies show that the periods and frequencies change with time. Certain frequencies come and go. A much more complex picture therefore appears, than a variability on only the 11 year sunspot cycle.

Many are also the mechanisms by which the Sun can influence Earth and the climate. The influences from the variation of the electromagnetic radiation is most often considered. However, a changing solar wind and energetic particles can also influence Earth either directly or indirectly through modulating the cosmic ray flux. Probably many mechanisms influence Earth at the same time.

With this very complex scenario it is not a surprise we detect many solar signals in climate records. Our literature has shown a large number of solar-climate relations. The results of this literary study are summarized in Table 1 with a solar origin of variability, corresponding time-scale, and suggested produced climate change.

Time-scale	**Solar origin**	**Climate change**	**Reference**
$\sim 10^9$ years	Solar evolution and galactic arm transversing	Glaciation periods	Shaviv, 2003 Marcos, 2004
100,000 years	TSI variation due to eccentricity of Earth's orbit	Temperature, ice cores	Berger et al.,1984 Petit et al., 1996
41,000 years	TSI variation due to obliquity in Earth's rotational axis	Temperature, ice cores	-"- -"- -"-
23,000 years	TSI variation due to precession of Earth's rotational axis	Temperature, ice cores	-"- -"- -"-
2,300 years	Solar dynamo modulation of α, ω	Glaciation periods	Denton and Karlen, 1973
205 years	Solar dynamo modulation of α, ω	Temperature, atmospheric circulation, ice cores ^{14}C,^{10}Be	Muscheler et al., 2003 Delmonte et al., 2005
88 years	Solar dynamo modulation of α, ω	Temperature, Precipitation	Hoyt and Schatten, 1997 Fairbridge, 1967
22 years	Solar dynamo main oscillation	Rythm of drought in US	Mitchell et al., 1979
11 years	Solar dynamo main oscillation, meridional circulation speed change (SCL)	Stratosphere T and geopotential height Arctic Oscillation Low cloud coverage Sea surface temperature Land temperature northern hemisphere	Labitzke and Matthes, 2003 Shindell et al., 1999 Svensmark, 1998 Reid, 1987 Friis-Christensen and Lassen, 1991
1.3 years	Solar dynamo bifurcation of ω	Atmosheric circulation? (Geomagnetic activity) (Cosmic rays)	Paularena et al., 1995 Kudela et al., 2002
27 days	Solar rotation	Stratospheric ozone	Williams et al.,2001

Table 1: A summary of processes behind solar variabilities with corresponding time-scales, and correlated climatic variations found in the literature.

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