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Solar signal in records and simulations of past climates

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Abstract. Simulations with a fully coupled Climate System Model are used to show that a temporal fingerprint of solar influence on climate can be isolated. Smaller, rather than larger amplitudes of solar irradiance changes over the past Millennium generate a climate response in better agreement with proxy-based climate reconstructions.

1. Summary

The sun is the fundamental driver of the climate system. Radiative and dynamic processes in the Earth's atmosphere and other components (oceans, land surface, cryosphere) coupled into the climate system are continuously attempting to establish a radiative balance over the globe. In the absence of changes in the solar input and the overall composition of the atmosphere, the climate system could approach an equilibrium around which internal natural variability is occurring. However, the input from the sun is not constant. Variations happen from the shortest (minutes) to the longest (age of the solar system) time scales, and thus climate is in a constant state of adjustment. To establish a physical understanding of how these changes affect Earth, it is fundamental to identify and measure the response of the whole system to these changes. Depending on what time scales are being considered, it is important to focus on the relevant processes that dominate the solar forcing as well as the climate's response.

Solar variations are not the only factor that can disturb the radiative balance of the planet. There are, for example, natural variations caused by explosive volcanism (short time scales) and changes in the Earth's orbit around the sun (longer time scales) that alter the amount of sunlight received over the planet. On geologic time scales, the changes in position of continents and mountain ranges are also affecting how energy is distributed and balanced. In most recent times, changes to the atmospheric composition and the Earths surface have been the result of human activity, imposing a large forcing on the energy balance of the planet. One of the most important challenges to the natural sciences is currently to detect and quantify the effect of our own influence on the climate system. In order to do this, we need to first understand what natural variations are occurring at the same time. Only when we can identify and subtract the natural effects can we isolate the human influence.

The natural forcing from solar irradiance changes is still being considered a large uncertainty when evaluating the climate before and after the industrial revolution (IPCC 2001). Although significant irradiance changes

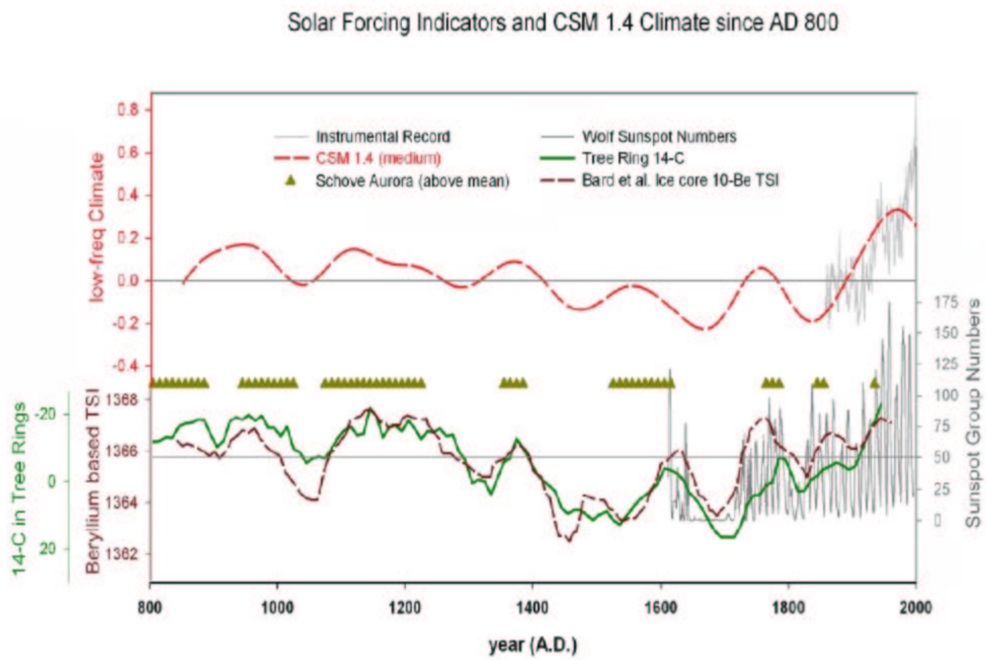

Fig. 1. Solar Forcing Indicators and NCAR-CSM 1.4 simulation with full forcing. ~207-year DeVries band component of the global surface temperature in a fully forced climate simulation is compared to sunspot observations (group sunspot numbers), the radio-nucleides of ^{10}Beryllium and ^{14}Carbon, as well as indications of observed increased aurora activity at high northern latitudes (triangles).

have recently been questioned (Foukal 2002), there still seems to be a distinct signal in climate time series that closely resembles the statistics of solar proxy records (Eddy 1976). Because instrumental records are very short, we often have to resort to indirect information in order to improve the statistics of recognizing potential links between the forcing and the corresponding climate response. Various proxy-archives are currently being used to establish estimates of how the sun has changed, and how climate might have responded to it.

After a short summary of the various ways of reconstructing past solar activity, a comparison between solar forcing and climate response records is shown. In order to circumvent separation problems of what forcing was responsible for which climate variations, the choice was made to focus on a particular frequency band that is very typical in essentially all solar records, but hardly of consideration for other natural external forcings: the ~207-year DeVries cycle. This particular frequency band can be found in essentially all long term proxy records of solar activity, and thus, even when not knowing what exact magnitude of changes in irradiance have to be associated with it, this *pacemaker* can be used for the search of a potential *temporal solar fingerprint*. Additionally, for the climate change debate, this more long term perspective provides a very valuable way for evaluating fundamental questions on climate variability at the multi-decadal to centennial time scales. It is exactly this component of natural forcing influence that might be important to understand when we analyze *trends* in the climate system. A discrete wavelet technique (Oh et al. 2003) is used to focus the DeVries band. Decompositions are presented for proxy records as well as two 1150-year long, transient simulations with the coupled NCAR Climate System Model (CSM) (Ammann et al. 2005), a coupled Atmosphere-Ocean General Circulation Model that does not require flux corrections. The solar forcing used in the simulations was based on the Antarctic ^{10}Beryllium record published by Bard et al. (2000). A clear ~207-year DeVries cycle is present in the forcing, and a key question is to verify if the climate model responds in a recognizable way to a relatively small irradiance change. Note, we focus on a long term forcing equivallent to 0.25% in terms of Total Solar Irradiance (TSI) between the Maunder Minimum and the present.

Figure 1 compares this ~207-year low-frequency component of the model output (top) with various proxy records of solar variability (bottom section). The comparison shows that the climate response in the NCAR-CSM to the solar forcing (Figure 1, ^{10}Be curve) is apparent. Comparing the model output to proxy-based climate reconstructions then confirms that the climate system indeed exhibits variations that can be associated with solar activity changes. By establishing which parts of the evolving climate history are directly associated with solar forcing, it is immediately obvious that solar forcing is only one among other factors that influence climate, the other prominent forcing factor being explosive volcanism. Finally, using these results combined with some studies employing an Energy Balance Model, an indirect best guess of the magnitude of the low-frequency solar irradiance changes over the past millennium is attempted. It is shown that the tradiational solar forcing with a TSI scaling of 0.25% back to the Maunder Minimum results in a climate response very much in phase with independent, proxy-based climate reconstructions, but that the magnitude is somewhat too large, by a fraction up to a factor of about 2. It is thus concluded that solar irradiance changes are an important factor in modulating climate on the century time scales, but that smaller, rather than larger magnitudes of TSI changes are probably enough to explain the climate of the recent past.

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