ATMOSPHERIC CO_2, CARBON ISOTOPES, THE SUN AND CLIMATE CHANGE OVER THE LAST MILLENNIUM

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ABSTRACT

The records of atmospheric CO_2 and of NH surface temperature covering the past millennium hold information on the strength of the sensitivity of the global carbon cycle to climate changes. This sensitivity is defined as the change in atmospheric CO_2 in response to a given change in NH temperature in units of ppm K^{-1}. The magnitude of the sensitivity is estimated for modest (< 1 K) temperature variations from simulations with the Bern Carbon Cycle Climate model driven with solar and volcanic forcing over the last millennium and from simulations with the range of C4MIP models over the industrial periods. The model results are broadly compatible with the data-deduced range.

Cosmogenic isotopes such as radiocarbon (^{14}C) are proxies of solar magnetic activity. The past production of ^{14}C by cosmic rays is estimated from the tree ring ^{14}C record over the late Holocene using a carbon cycle model. Radiocarbon production rates are then converted into estimates of solar magnetic activity by applying a production model for cosmogenic isotopes. The results suggest that the recent activity of the sun was not unusual in the context of the last millennium, in contrast to recent claims.

INTRODUCTION

The ice core atmospheric CO_2 records combined with the proxy records of solar irradiance changes and the range of hemispheric temperature reconstructions covering the past millennium provide an opportunity to evaluate the strength of feedbacks between the carbon cycle and climate and the role of solar-induced climate change. The temperature and CO_2 variations over the past millennium were modest compared to the projected changes for the 21st century. Nevertheless, the proxy records form an important yard stick for coupled carbon cycle-climate models and for evaluating the role of solar forcing.

METHODS

The Bern Carbon Cycle Climate model links an atmospheric energy balance model, the Lund-Potsdam-Jena Dynamic Global Vegetation Model, and the HILDA ocean model. Various model simulations over the past millennium have been performed. The model was driven with solar and volcanic forcing reconstructions and the magnitude of solar forcing has been varied according to different published estimates [*Gerber et al.*, 2003].

A dynamic, 3-dimensional ocean model [*Müller et al.*, 2005] coupled to a simple biosphere model has been used to invert the INTCAL radiocarbon tree ring record for the production of ^{14}C by cosmic rays. The production of ^{14}C is a function of the intensity of the solar magnetic field as described by the solar modulation parameter and the geomagnetic field. The stronger the magnetic field, the stronger the shielding of the atmosphere from the cosmic ray flux, and the smaller the ^{14}C production. The production model of Masarik and Beer has been applied to calculate the solar modulation parameter from the inferred ^{14}C production rates and reconstructed variations in the geomagnetic field [*Muscheler et al*, 2005a,b]. The record was matched with records of solar modulations from neutron and ionisation chamber measurements covering the past 60 years.

RESULTS

The radiocarbon-based reconstruction of solar magnetic activity shows the well-known solar minima during the 15^{th}, 17^{th}, and early 19^{th} century. Solar modulation was higher or equally high than today during three periods of the last millennium. Thus, the present solar magnetic activity is not unusual in the context of the last millennium, in contrast to recent publications.

An approximately linear relationship between the modelled change in NH mean surface temperature and atmospheric CO_2 is found in the Bern CC model in a range of simulations. The average slope that defines the strength of the carbon cycle sensitivity to climate is 12 ppm K^{-1}. This is within the range found for the models participating in the coupled climate-carbon cycle model intercomparison project (C4MIP) for simulations over the industrial period. The strength of the sensitivity depends on several factors including the change in solubility of CO_2 in seawater and the responses of productivity and heterotrophic respiration to temperature and soil water on land.

Atmospheric CO_2 varied by about 6 to 10 ppm over the last millennium (prior to the industrial revolution). Decadally-smoothed Northern Hemisphere temperature was reconstructed to vary between a few tenths of a degree [*Mann et al.*, 1999] and about $0.9^{o}C$ [*Esper et al.*, 2002]. If we accept the ranges of temperature variations reconstructed by *Mann et al.* [1999] and by *Esper et al.* [2002] as equally possible, then a CO_2 concentration range of 6 to 10 ppm constrains the carbon cycle sensitivity to between 5 and 25 ppm K^{-1} (for global mean surface temperature changes of less than ~1 K).

Transient simulations with the Bern CC model and results from the C4MIP models suggest that large solar forcing and solar forcing amplifications and large (> 1K) NH temperature fluctuations are not compatible with the ice core record of atmospheric CO_2 within the framework of current carbon-cycle climate models.

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