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A reconstruction of radiocarbon production and total solar irradiance from the Holocene ^{14}C and CO_2 records: implications of data and model uncertainties

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Past atmospheric CO_2 concentrations reconstructed from polar ice cores [Monnin et al., 2004] combined with its $\Delta^{14}C$ signature as conserved in tree-rings [Reimer et al., 2009] provide important information both on the cycling of carbon as well as the production of radiocarbon in the atmosphere. As the ^{14}C production rate (Q) is modulated by changes in the strength of the magnetic field enclosed in solar wind, it serves as a valuable proxy for past changes in solar activity.

Using the Bern3D-LPX, a fully featured Earth System Model of Intermediate Complexity (EMIC) with a 3D ocean and a dynamic vegetation model component, we perform transient carbon-cycle simulations spanning the past 21 kyr. By solving the atmospheric ^{14}C budget, the radiocarbon production rate over the Holocene is reconstructed. Applying different deglacial forcings, as well as a control-simulation with constant climate, the sensitivity of Q to carbon-cycle changes is discussed. The error in the terrestrial ^{14}C record is translated into an uncertainty in Q using a Monte-Carlo approach. In addition, uncertainties in the global carbon inventory, GPP and air-sea gas-exchange are taken into account. The estimated modern (1950-2005) production rate of 1.55 ± 0.20 atoms/cm^2/s is close to a recent theoretical calculations by Kovaltsov et al. (2012) yielding a modern production rate of 1.64 atoms/cm^2/s but considerably lower than the estimated 2 atoms/cm^2/s by Masarik and Beer (2009).

The newly produced production rate record is then interpreted as a proxy for solar activity changes in the past 10 kyrs. To do so, we use published results from particle simulations [Masarik and Beer, 1999] together with the latest reconstruction of the geomagnetic dipole moment [Knudsen et al., 2008] to calculate the past history of the so-called solar modulation potential (Φ). The ^{14}C based Φ is extended to 2005 A.D. with instrumental data [Usoskin et al., 2011].

In a subsequent step, Φ is translated into past total solar irradiance (TSI) using a recently published Φ-TSI relationship [Steinhilber et al., 2009]. Our TSI record shows, besides recent solar grand solar minimas like the Maunder Minumum (MM), numerous centennial-scale variations with deviations from the long-term mean of only approx. 0.5 W/m^2, while the millennial-scale trend in TSI is even smaller. The frequency-spectrum of TSI reveals well known solar periodicities of different length. Finally, our radiocarbon-based TSI record is fed back into Bern3D-LPX in order model past changes in surfaces atmospheric temperature (SAT) caused by solar variations, leading to relatively low transient SAT excursions of less than 0.1 K.

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