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The occurrence and characteristics of grand solar minima and maxima during the Holocene epoch

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Observations of the Sun since 1610 AD show that the activity level of the Sun varies from the Maunder Minimum (1645–1715), when sunspots almost completely vanished from the solar surface, to the enhanced activity level since the middle of the 20th century. Maunder Minimum-like periods are believed to represent a special state of the solar dynamo and they pose a challenge for solar dynamo theory and models, in part because the current models do not agree on the frequency and nature of this phenomenon. Similarly, the models do not robustly address whether grand minima represent regular or random characteristics of the solar dynamo.

Information on solar variations prior to 1610 relies on past production rates of cosmogenic nuclides, such as 10Be and 14C. Cosmogenic nuclides are produced in the atmosphere by interactions of galactic cosmic ray particles from space with atmospheric elements, such as N and O. Their production rates are inversely correlated with solar magnetic activity and the geomagnetic field intensity due to the non-linear shielding effect of the solar magnetic field and the geomagnetic dipole field.

In this study, we use the IntCal13 14C and the GRIP 10Be records to calculate the solar modulation potential for the overlapping time period that approximately span the last 8000 years. Based on the solar modulation potential, we study the occurrence and characteristics of grand minima and grand maxima. In our approach, a period is only defined as a grand minimum or maximum if it can be identified as such in both reconstructions (14C and 10Be) based on Gaussian statistics. Based on this approach, we identify 19 grand minima and 15 grand maxima for the period spanning the last 8000 years. We also investigate whether the occurrence of these grand minima and grand maxima is best understood as a stochastic or non-stochastic process using waiting time distribution analysis. Furthermore, wavelet analyses of the solar modulation potential reconstructions reveal that the 22-year Hale cycle weakens during grand minimum episodes, whereas it's more pronounced during grand maximum periods. Such observations may serve as an important guide for solar dynamo models, and, in turn, improve our understanding of the processes underlying solar variability.