

A study of the properties of the Grand Solar Minima throughout the past 13,000 years and the implications for Space Weather.

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The intensity of the cosmic radiation reaching the orbit of Earth is primarily controlled by the strength of the heliomagnetic field, which itself is largely determined by the level of solar activity. The paleo-cosmic ray (PCR) record therefore provides the output from a “cosmic magnetometer”, and a proxy for solar activity in the past. Using ^{10}Be (ice-cores) and ^{14}C (tree rings) data we investigate the wide variations in the PCR and solar activity that have occurred during the past 13,000 years. In particular, we study the occurrence and properties of “Grand Minima”- the periods of very low solar activity similar to the Maunder Minimum (1645-1715) for which solar and geophysical data are available. There was a sequence of five GM between 950-1830CE; there were three similar sequences of similar duration in the preceding millennia; interspersed with intervals of ~ 1000 year essentially devoid of GM. The four sequences of GM correspond to the minima of the 2300 y Hallstatt periodicity. The PCR increases by $\sim 50\%$ during “Grand Solar Minima” and we use the PCR intensity to quantify the relative significance of the Grand Minima in the past. On the basis that the terrestrial and heliospheric consequences of a GM will depend on both the amplitude of the change in PCR intensity, and its duration, we have defined a parameter, the GM index, as the product of the amplitude and duration of a GM. We conclude that there have been 22 GM of geophysical significance equal to, or greater than that of the Wolf GM (1230-1350CE). The Sun is in a “Grand Minimum” condition for $\sim 45\%$ of the time during a GM sequence; and for only $\sim 5\%$ of the time in the intervening 1000y intervals of high solar activity. We discuss the implications of these observations in respect of space weather and climate. In conclusion, we speculate that the sun may now be entering one of its extended periods of high activity which will persist for ~ 1000 y.