INFOBOX 2.2

GRAND MINIMA AND MAXIMA OF SOLAR ACTIVITY

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Solar activity depicts a great deal of variability even during the last 400 years of telescopic sunspot observations since 1610 AD (see Figure 2, Chapter 2.5). One can clearly see that there was almost no sunspots during more than a half of a century in 1645–1700 AD. It is important to understand that this lack of sunspots at this time is not due to the lack of sunspot observations. In fact, the Sun was observed by several astronomers already at this time. However, there was little to observe since the solar surface was almost spotless. Some of these early observers wrote weary comments in their notebooks: another year with no sunspots. This period is now known as the Maunder minimum, named after the British astronomer Edward Walter Maunder (1851–1928) (Eddy, 1976). Such a quiet state of the Sun (or another star), when the regular cyclic appearance of sunspots is greatly suppressed for several decades (from 40 to 200 years), is more generally called the **Grand minimum** of activity. Grand minima should not be confused with the normal sunspot minima of the 11-year solar cycle that only last for a couple of years.

Another interesting feature of the Sun in recent times is the very high level of sunspot activity during most of the last century, roughly from the 1930s to the early 2000s. This period is now called the **Modern Grand maximum** of solar activity. Grand maxima are periods when the sunspot cycles attain very high amplitudes. Presently, the Modern Grand maximum is over, and the sunspot activity level of the on-going solar cycle 24 is quite moderate, considerably lower than during the previous cycles forming the Modern Grand maximum.

Since direct sunspot observations only exist for the last 400 years, the occurrence of Grand minima and Grand maxima can be studied only by proxy data, especially the cosmogenic radionuclides ^{14}C and ^{10}Be (see Chapter 2.5). A recent study, using ^{14}C isotopes measured in tree-rings covering the whole Holocene (Figure 1), provides a list of 27 Grand minima and 19 Grand maxima during the last 12 thousand years (Usoskin et al., 2007). Grand minima can

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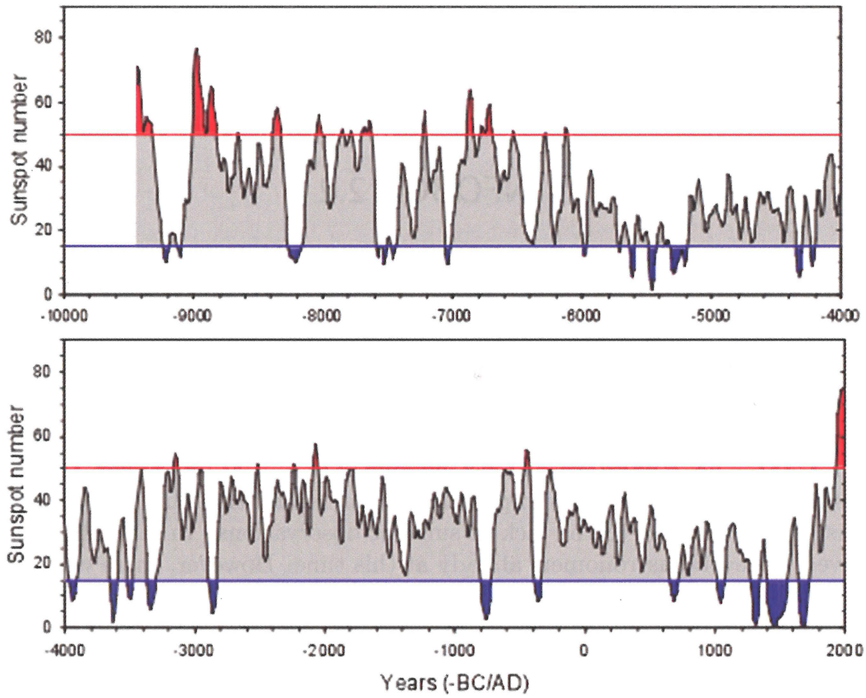

Fig. 1. Sunspot activity reconstructed from ^{14}C data throughout the Holocene. Blue and red areas denote Grand minima and maxima, respectively. The entire series is spread over two panels for better visibility (Modified after Usoskin et al. (2007)).

be robustly defined and form one distinguishable mode of the solar dynamo (Usoskin et al., 2014). They occur irregularly, which implies that these extreme states in the solar dynamo are driven by a chaotic or stochastic rather than a cyclic process. Thus, their occurrence cannot be reliably and deterministically predicted. However, Grand minima tend to cluster in groups of several minima (as, e.g., Oort, Spörer and Maunder minima in 1200–1700 AD) with roughly 200 years in-between, seem as the so-called Suess or deVries cycle. Clusters are separated by intervals of several millennia. Grand minima seem to divide into two types according to their duration: short minima, such as the Maunder minimum, which last 40–90 years and long minima, like the Spörer minimum, which last 100–170 years.

Grand maxima are more uncertain and cannot be unambiguously defined. Also, it is not known if Grand maxima form a separate dynamo mode or if they are an extreme part of the normal sunspot distribution. Grand maxima seem to occur irregularly, and without any apparent clustering or periodicity. Their duration varies between 30 and 80 years. The Modern Grand maximum in the 20^{th} century was an example of this rare but not exceptional form of solar activity.