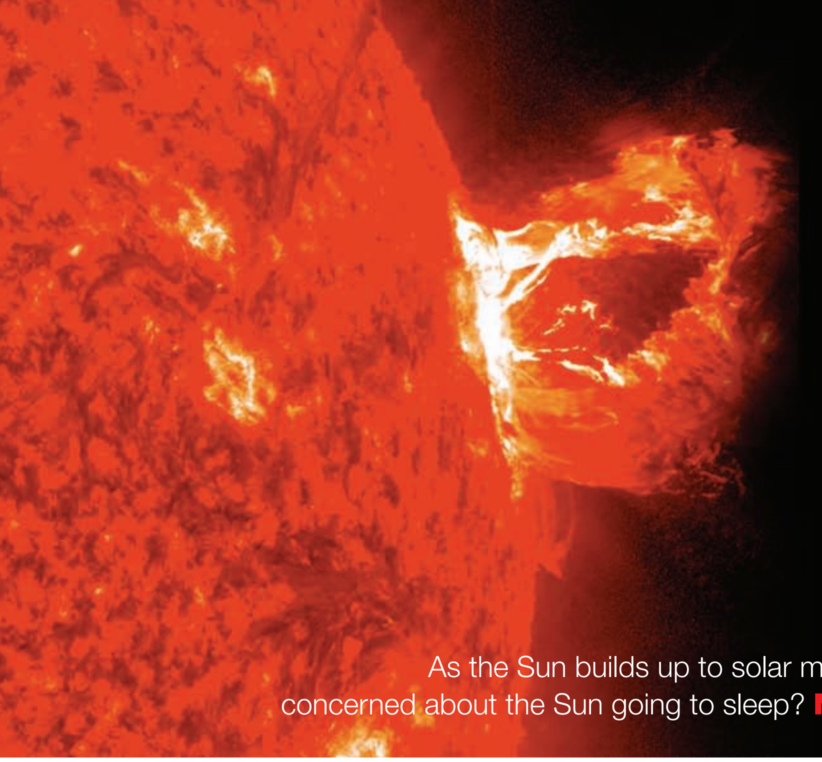
Is the Sun headed for hibernation?

As the Sun builds up to solar maximum towards the end of the year, why are we so concerned about the Sun going to sleep? **Nicola Guttridge** dons her sunglasses to find out.



▲ A massive solar flare that erupted on 17 April, captured by the Solar Dynamics Observatory. Image: NASA/SDO/AIA.

In March there came news of a massive solar storm heading to Earth that had the potential to wreak havoc on our planet. In April, NASA's Solar Dynamics Observatory captured incredible images of a solar flare erupting from the limb of the Sun - a beautiful arcing jet of superheated plasma. Such reports suggest a very active Sun, but this is not actually the case - the Sun is currently the quietest it has been for approximately 100 years.

Solar activity affects us a great deal. Luckily, the aforementioned solar storm passed by without much effect, but the periodic fluctuations the Sun experiences have adverse effects on our communications systems and satellites, can disrupt our national grid and are dangerous to the health of astronauts and even frequent flyers. In fact, space weather is of such concern that, for the first time, the UK government has included it on the National Risk Assessment for 2011/12.

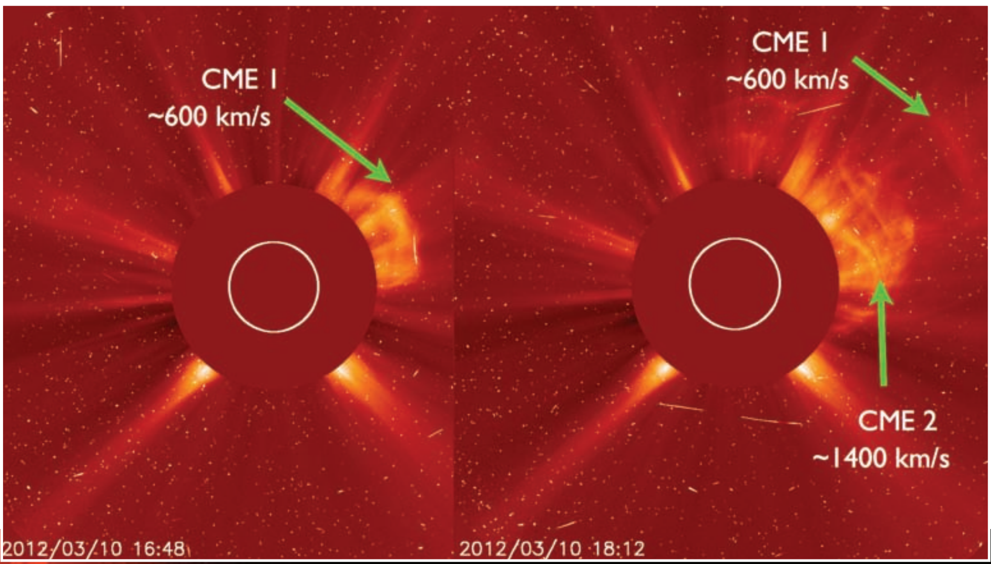
Our reliance on the Sun means that understanding its behaviour is a pressing concern. What is happening in the Sun and what does this mean for the future of its solar cycle?

The heartbeat of the Sun

The activity of the Sun is a complex mix of long-term and short-term behaviour. The solar cycle is "the heartbeat of the Sun, and as such presents the fundamental workings of our local star," explains Dr Lucie Green of University College London's Mullard Space Science Laboratory. "We need to understand the solar cycle to understand how our Sun operates."

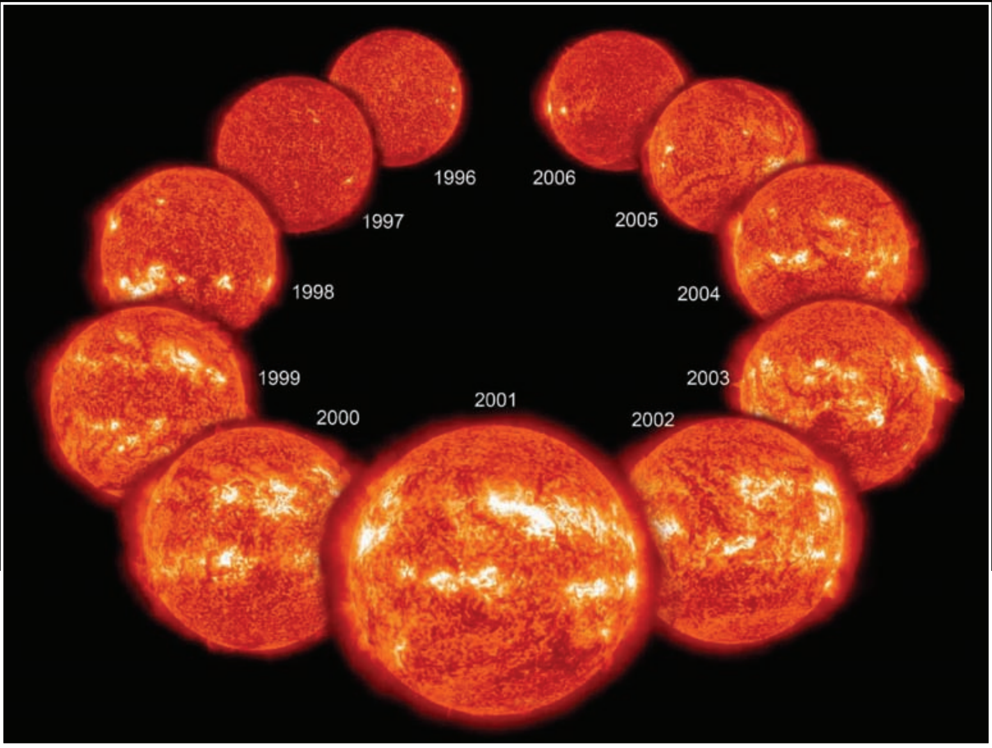
The Sun goes through a pattern of activity approximately every 11 years known as the Schwabe cycle, in which its activity gradually climbs towards a maximum and then descends again.

"The cycle is a magnetic cycle and results in an ebb and flow of solar activity," says Green. Phenomena such as solar flares, sunspots, coronal mass ejections, the solar wind and sunspots are indicators of observable solar activity, all of which are thought to be driven by energy released from the solar magnetic field. During a solar cycle maximum these phenomena are all increased, and are decreased during a minimum – in the case of sunspots, to near-zero levels.



▶ Two giant coronal mass ejections were released from the Sun during March. The Sun is blocked out by a coronagraph, while the speckles on the image are cosmic ray hits. Image: SOHO (NASA/ESA).

▶ **Eleven years in the life of the Sun, spanning most of solar cycle 23, as it progressed from solar minimum (upper left) to maximum conditions and back to minimum (upper right) again, seen as a collage of ten full-disc images of the lower corona. Image: NASA.**



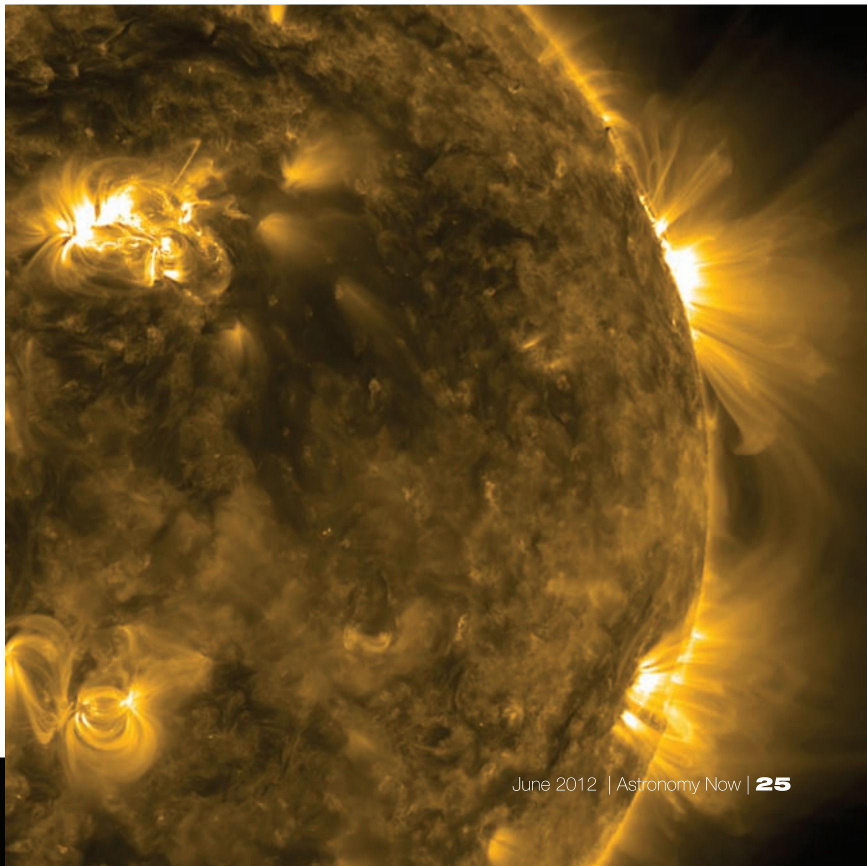
This magnetic cycle is thought to be caused by an internal dynamo process and solar flows – processes used by the Sun to generate and maintain its magnetic field. This magnetic field is key to much of the solar behaviour and features we experience. For example, sunspots are caused by areas of magnetic activity so intense that they inhibit convection, meaning that they are significantly cooler than their surroundings and appear as black marks on the solar surface. They are where magnetic loops puncture the Sun's surface. Sunspots appear in magnetically-opposite pairs at high latitudes, and migrate towards the equator as the cycle progresses. One way to think of sunspots is to imagine a large horseshoe magnet buried underneath the surface of the Sun - one sunspot represents 'north' magnetic polarity, and one 'south'. During each Schwabe cycle, flows on the Sun's surface carry magnetic fields from mid-latitude sunspots up to the solar poles, causing a polarity flip as north-pointing flows are carried to the south solar pole, and vice versa. It therefore takes 22 years – or two Schwabe cycles – for the Sun to return to its initial magnetic state.

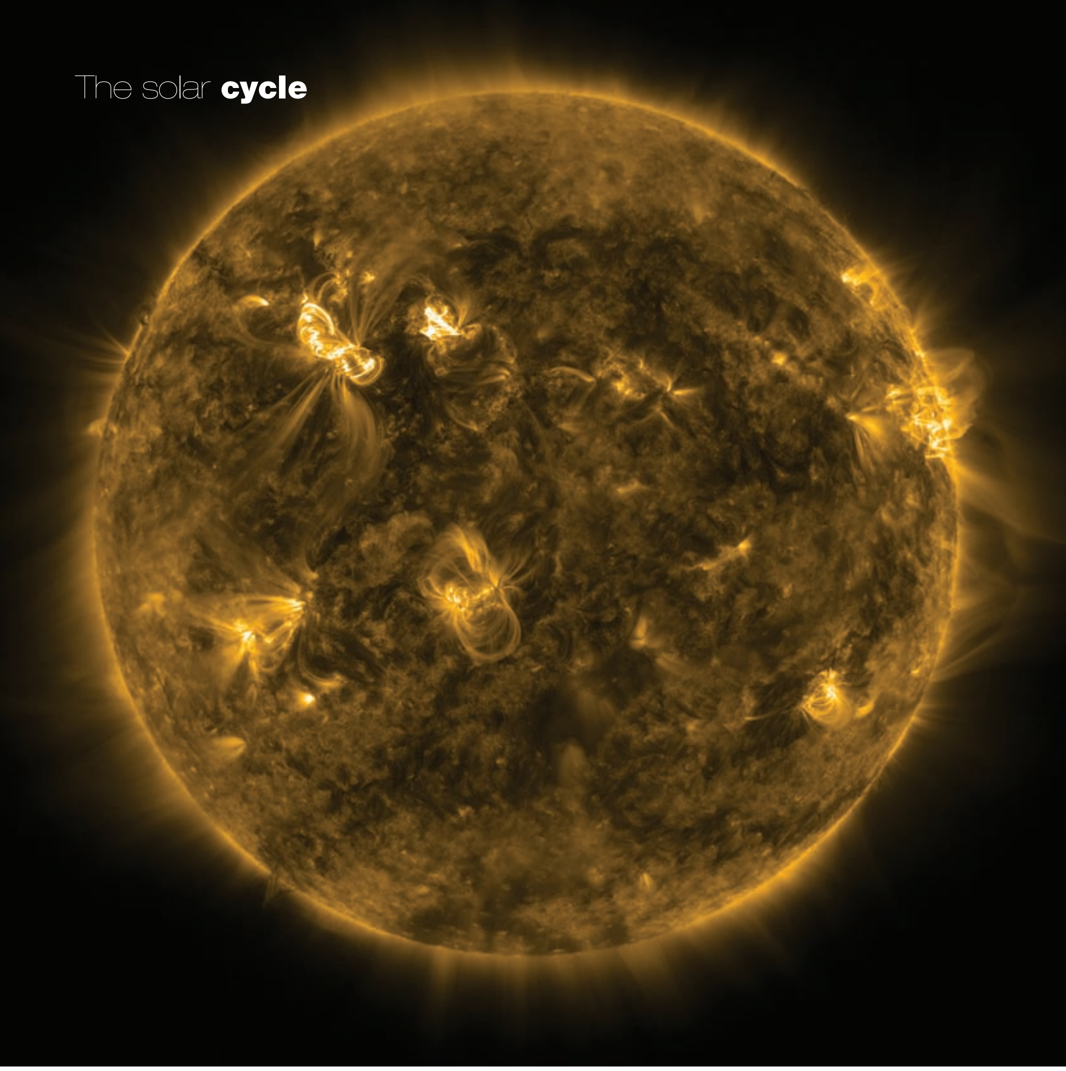
It is thought that the differential rotation of the Sun causes sunspots, amongst other phenomena. As it is composed of gas and plasma, different parts of the Sun rotate at different speeds; parts of the Sun near the poles take 36 days to rotate once, in contrast to 25 days at the equator. This results in the magnetic field lines inside the gaseous body becoming tangled up over a number of cycles, until they eventually reach breaking point and puncture the Sun's surface to cause sunspots, coronal loops and mass ejection events.

However, using sunspots as in indicator of solar activity levels does not reveal all about the underlying state of the Sun. "One of the things to remember is that the sun wipes itself just about clean of sunspots every minimum, whatever its underlying state is," explains Mike Lockwood, Professor of space environment physics at the University of Reading. "People tend to think that the Sun returns to the same state every 11 years and that's just wrong - there is an underlying state that sunspots do not tell you about."

The flipping of solar polarity is reflective of this issue. Although outwardly the Sun may appear uniform, the northern and southern hemispheres of the Sun are currently in very different states. The solar magnetic field at each pole flips separately, and there is often a lag between the two swapping polarity. At present, the northern polar field has reversed and is waiting patiently for the southern one to follow suit.

▼ **Solar activity is driven by the Sun's magnetic field, manifest in magnetic loops that stretch out from the Sun like tendrils, filled with glowing plasma in this image seen at ultraviolet wavelengths (171 Angströms). Image: NASA/SDO/AIA.**





▲ The relatively active Sun, as seen on 7 March by the Solar Dynamics Observatory at ultraviolet wavelengths (171 Angströms). The bright knot at top left was the source of a powerful X-ray flare. Image: NASA/SDO/AIA.

Space age waves in the Sun

The start of the space age in the late 1950s has since led to a huge increase in solar research. Up until then, observing the Sun was severely limited by telescopic power and resolution. The field of helioseismology – the study of wave oscillations in the Sun – is relativity young; the development of space-based telescopes enabling us to peer into the Sun's dynamic variable atmosphere has allowed us to expand our observational data and try to understand the solar cycle.

This cycle was first mapped in the early twentieth century by husband-and-wife team Edward and Annie Maunder. The periodic behaviour of solar activity was first noticed in 1843 by German astronomer Samuel Schwabe, whose work was later extrapolated back in time by Swiss astronomer Rudolf Wolf. Wolf reconstructed the solar cycle as far back as Galileo's earliest observations of solar sunspots in the early seventeenth century. However, there are anomalies in the history of the solar cycle. One prominent time period is that spanning 1645 to 1715, during which there was an unexpected paucity of sunspots. This period is now known as the Maunder Minimum, and coincided with the European Little Ice Age. It is thought that we may be approaching a similar solar state in the next few decades, but the effect it may have on our climate is unknown.

Flip-flopping between states

The current solar cycle has been a very quiet one, leading to predictions of incredibly low future levels of activity. However, it is not just this cycle that is showing levels of diminished activity. On top of this 11-year Schwabe cycle is a longer, 'grand' cycle. As well as experiencing a solar cycle minimum or maximum every 11 years or so, the Sun follows a longer-term pattern of similar fluctuating activity, consisting of grand maxima and minima on periodic timescales of roughly 100 to 300 years. During grand maxima, there are greater levels of activity in the corresponding Schwabe cycle maxima. We are currently exiting a grand solar maximum that we have been in since around 1940 - one of the longest maxima of all the cycles on record.

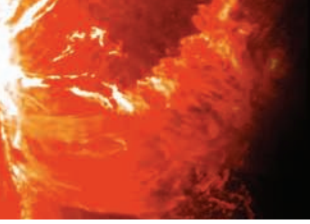
The mechanism behind this longer cycle remains relatively unknown. "We really don't have any idea as to why it does this," says Lockwood. "We can't spot any periodicity, the Sun seems to just chaotically flip-flop between states." From a mix of cosmogenic isotope data, ice records, tree rings and observation, solar researchers have records from a total of 9,300 years of solar activity to work from. In this time, the Sun has endured 24 grand solar maxima, and 30 grand solar minima - but even this is uncertain. "It depends how you define a grand maximum," says Lockwood. "It's like defining when a hill turns into a mountain."

Activity levels during the solar cycle have been linearly falling since 1985. Several independent studies on solar activity performed in 2011 examined solar dynamics, jet streams, sunspots, magnetic field strength and polar activity and all returned results confirming that cycle 25 may display significantly reduced solar activity. After the next maximum, it appears as if our solar cycles will be getting smaller.

"The evolution of this cycle, being so low, is actually on target for a Maunder Minimum in the next 40 years, but there's about an eight percent chance of it happening based on past experience," says Professor Lockwood. "As sure as eggs is eggs there will be another grand minimum unless something dramatic has changed inside the Sun – it's just a question of when."

A complete solar model

Such fluctuations in solar activity are significant as they tell us that something very scientifically interesting is happening underneath the solar surface. However, the incoherent long-term behaviour of the Sun makes predicting future solar activity difficult. This has a huge impact as we rely on the Sun for a great many things, including protection from space events. The solar magnetic field shields us from galactic cosmic rays, and this field strength varies with the solar cycle; the



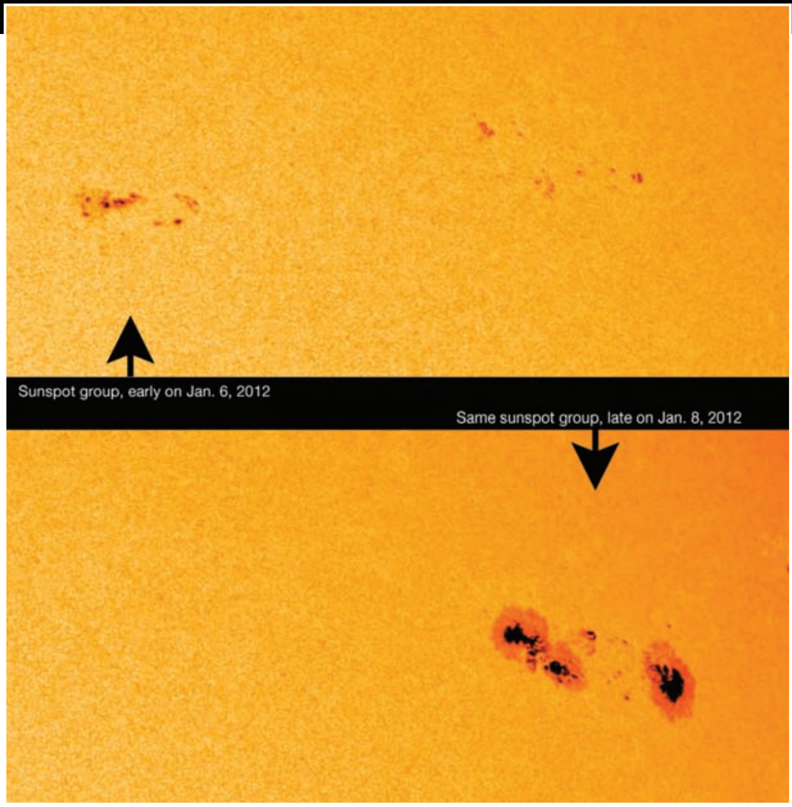
> **"THE SUN GOES THROUGH A PATTERN OF ACTIVITY APPROXIMATELY EVERY 11 YEARS IN WHICH ITS ACTIVITY GRADUALLY CLIMBS TOWARDS A MAXIMUM AND THEN DESCENDS AGAIN."**

lower the field strength, the lesser the protection from cosmic rays. This is important in aviation electronics; currently, all such equipment has a single back-up system that kicks in if a cosmic ray strike disables its primary system. If the frequency and strength of these strikes is increasing, one back-up system may no longer suffice.

Such increased risk of cosmic rays may also disturb air travel and affect human health. Frequently flying at high latitudes and altitudes, for example on a commercial aeroplane traversing one of the poles, is already advised against because of the radiation exposure suffered by the passengers. At the current exceptionally low levels of solar activity, the number of times it is possible to safely fly such a route is reduced to below half that of a standard solar state. In a grand minimum, such as the one we are approaching, this may halve yet again. Being able to understand the solar cycle in its entirety will allow us to predict future behaviour in order to mitigate such effects.

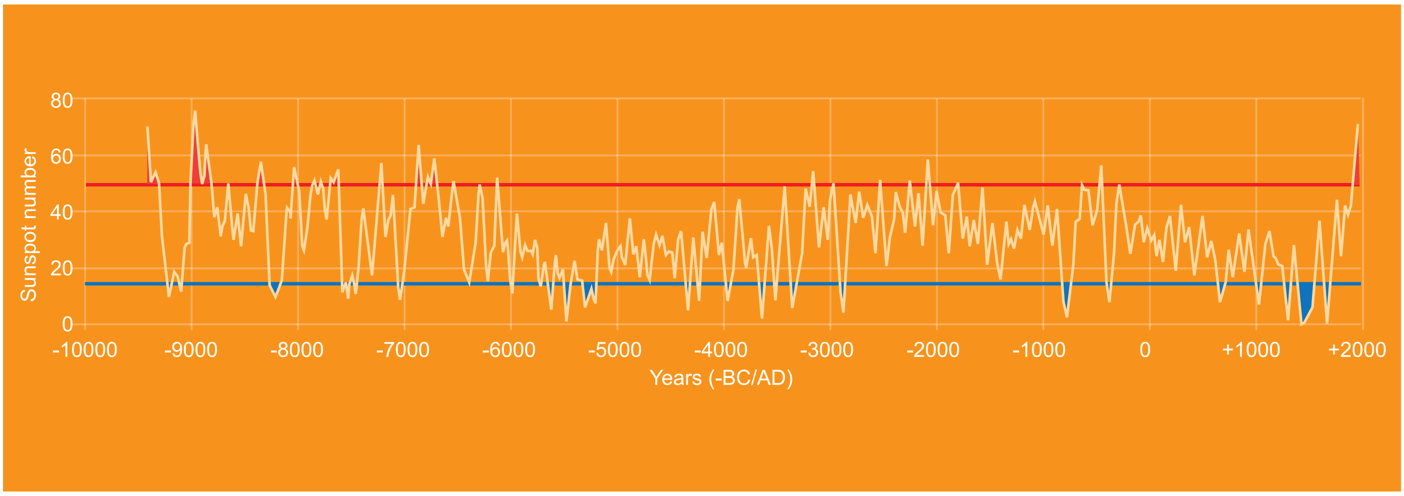
"We don't have a physical predictive model of the solar dynamo," says Lockwood. "We just don't know enough about how it works. As things get quieter we will begin to get clues. We have had 30 years of wonderful data but it's all been in a very active Sun. This past experience needs to go out of the window if the ground rules are changing."

Research into the solar cycle can be compared to the fields of meteorology and climate science. Long-term solar change leads to what can be loosely termed 'space climate change', but our current space weather models are inadequate. The majority of these models are not yet three-dimensional, meaning that predictions about the future of the solar cycle are unreliable. However, this may be remedied if the Sun enters another extended minimum phase, as this will give scientists an invaluable scientific opportunity. "We need to see the Sun under these quieter conditions to understand," says Lockwood. "We'll get to see the other side of the coin and build up a full understanding of how the Sun really works."



▲ Sunspots are intense regions of magnetic activity that prohibit convective flows beneath them, causing them to be cooler than their surroundings. These two sunspot groups evolved rapidly in January. Image: NASA/SDO/AIA.

Nicola Guttridge is an astrophysics graduate and current science communication student.



▲ Estimates of sunspot numbers over the last 12,000 years deduced from carbon-14 in tree rings. Grand minima are below the blue line and grand maxima above the red. The three minima between 1000–2000 AD occurred during the Little Ice Age; the last is the Maunder Minimum. AN graphic by Greg Smye–Rumsby.