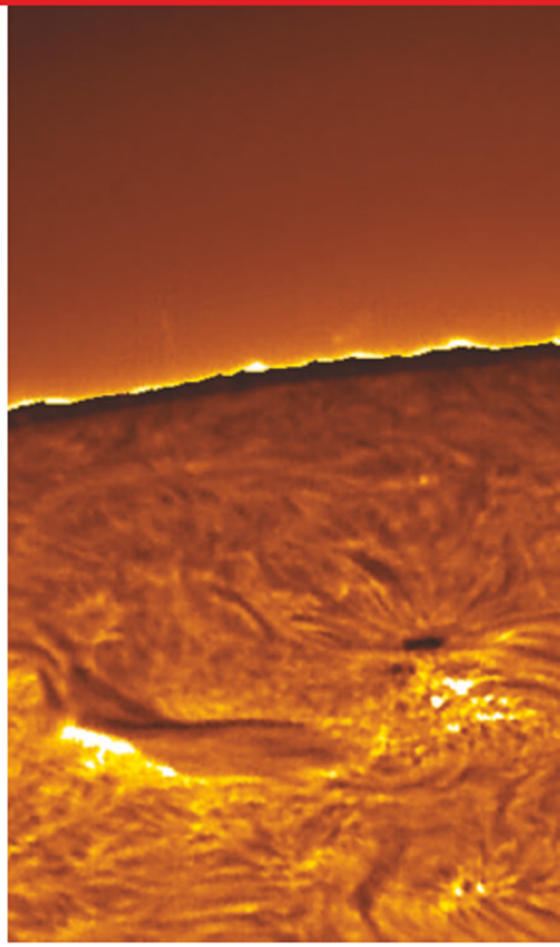


THE DARK SIDE OF THE SUN

The Sun occasionally hurls streams of particles towards Earth, where they can wreak havoc with satellites. Predicting these solar storms is hard, but some physicists believe we're about to face the biggest bout of solar flares in years. Stuart Clark reports.

Halloween is supposed to be a time of weird phenomena and spooky events. But by any standards what happened in late October 2003 was unusual. Telecommunications around the world were disrupted, half of NASA's satellites malfunctioned, 50,000 people in Sweden were left without electricity, and the global airline industry lost millions of dollars.

The link between these events was not supernatural, it was something far more familiar: the Sun. The chaos was caused as our star went through one of the more active moments in its 11-year cycle. And according to some predictions, what happened that October is nothing compared with what is going to occur in five or six years' time.

"Solar activity in the next cycle could be more of a problem than ever," warns Peter Gilman, a physicist at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. And it's not just satellites and telecommunications that face problems. Some researchers claim that the Sun's behaviour affects Earth's atmosphere — in particular influencing cloud formation. This claim has attracted global-warming sceptics, who argue that the Sun has greater influence than human activities on our changing climate.

The Sun's 11-year cycle is driven by its magnetic field, and generates a flow of charged particles known as the solar wind. At the quieter parts of the cycle, activity is fairly low and the solar wind is reasonably uniform. But at the 'solar maximum', sunspots — dark patches caused by the magnetic field twisting at the surface — appear on the Sun's face. Huge solar flares explode above these spots causing turbulence in the solar wind and sending streams of charged particles hurtling through space.

The most recent solar cycle was fairly moderate when measured by the number of sunspots (see graphic). Yet in late October 2003, three years after the cycle's peak, two monstrous sunspots appeared, each more than ten times the diameter of Earth. Both were in a state of almost constant eruption, spewing out billions of tonnes of electrically charged particles.

These were the particles that caused such havoc when they hit Earth's atmosphere. The global maritime emergency call system blacked-out, contact was lost with expeditions on Mount Everest, and the accuracy of the global positioning system was impaired. As well as NASA's satellite malfunctions, the Japanese lost contact with one of their weather satellites altogether. The cost to the airline industry arose as planes were re-routed to lower altitudes, congesting the airways and burning more fuel.

Lucky escape

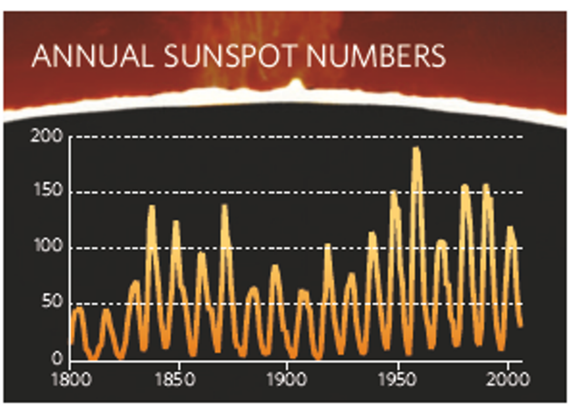
The sunspots bombarded Earth, on and off, for two weeks as the Sun's rotation carried them across its face. On 4 November, as the second sunspot was about to be lost from sight, it let loose another tremendous explosion. Solar physicists calculated that it was one of the largest solar flares in recorded history[1]. By sheer luck it exploded into deep space, catching Earth only in the side wash. Those who saw it breathed a sigh of relief and wondered what the damage might have been if such a flare had exploded facing Earth. If the latest prediction comes true for the next solar cycle, we may yet find out.

Predicting the timing and strength of such solar eruptions is clearly important, but it is hampered by the fact that scientists know relatively little about the Sun's inner workings. So to coincide with the start of the next solar cycle, the largest coordinated study of the Sun will be launched next year. Known as the International Heliophysical Year (IHY), the initiative hopes to build awareness of the Sun's possible influence on Earth's climate and to bring researchers from different disciplines together to study solar activity.

Currently, the Sun is at a solar minimum, and most predictions suggest that the next solar maximum in five or six years' time will be weak. But the most recent forecast, the first to be based on a completely physical model of the Sun, suggests otherwise.

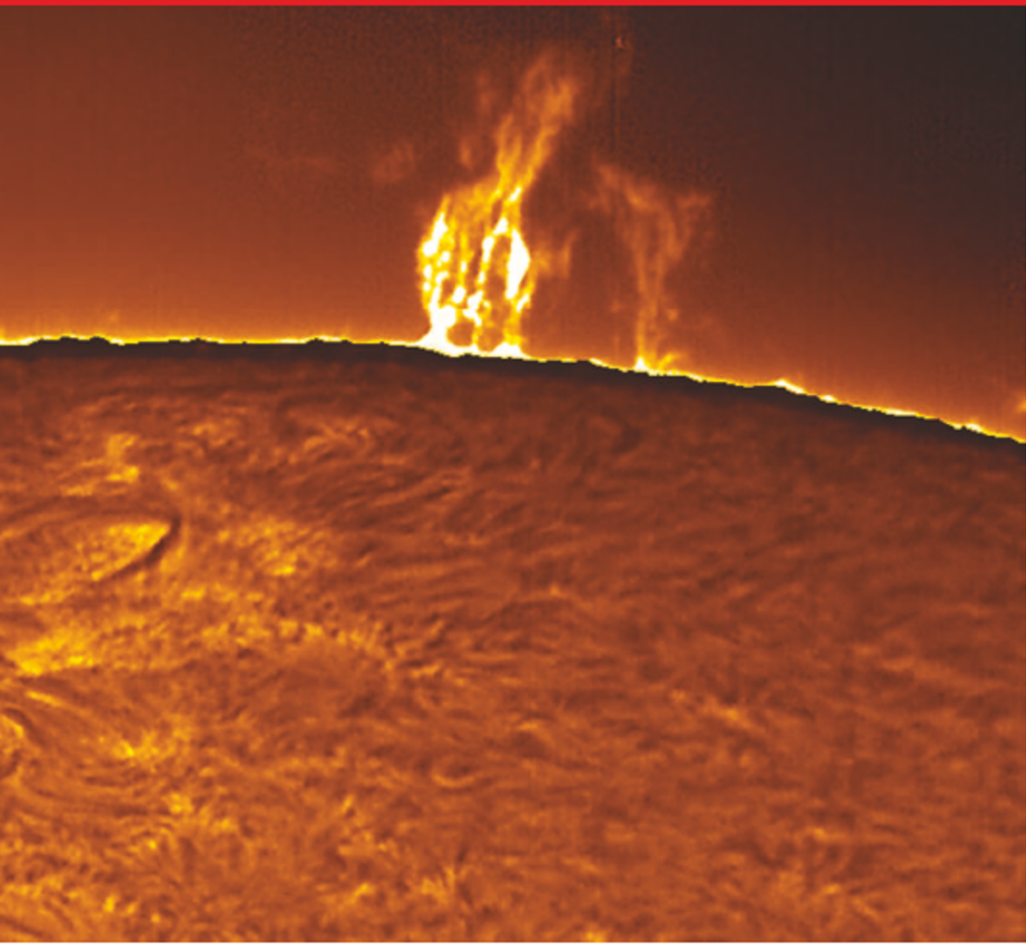
This forecast has been generated by Mausumi Dikpati and her team at the NCAR[2]. They have developed a computer simulation that mixes the Sun's internal magnetic dynamo with theories about how solar plasma circulates near the surface. And they have reached a sobering conclusion. "We expect between 30% and 50% more sunspots and solar activity than the cycle just ending," says Gilman, who is a member of Dikpati's team.

The last time solar activity occurred



SOURCE: SOLAR INFLUENCES DATA ANALYSIS CENTER

BACKGROUND: WWW.SUNGAZER.NET


WWW.SUNGAZER.NET

Flaring up: the Sun's magnetic field causes a peak in sunspots and solar flares every 11 years.

on this scale was in 1958, when there was little technology in orbit. Now things are very different: Earth is surrounded by thousands of active satellites.

Satellite operators rely on predictions of solar activity to estimate the lifetime of space missions. The solar wind heats Earth's thin upper atmosphere, increasing atmospheric density and causing more drag. Gilman estimates that a 30% increase in activity will almost double the atmospheric density at an altitude of 300 km, affecting low-altitude satellites.

Mission planners looking ahead to 2012 may want to boost their spacecraft to higher orbits, or accept a shorter operational lifetime. Even above 800 km, where satellites are safe from atmospheric drag, other dangers remain. The solar wind can cause a build up in electrical charge, which then short-circuits and burns out sensitive equipment. This is the suspected fate of the Japanese Midori 2 satellite, lost during the 2003 flares. And as more satellites die in orbit, operators have to worry about dodging 'space junk'. In the aftermath of a large solar storm, the change in atmospheric drag can shift the orbit of space debris, endangering active satellites.

The Sun's influence over space hardware is only one aspect of the latest drive to understand the star. The possible effects of the solar cycle on our climate, especially cloud formation, are also receiving a lot of attention. A link between the two was suggested in 1997, when meteorologists Henrik Svensmark and Eigil Friis-Christensen, both at the Danish Meteorology Institute in Copenhagen, analysed weather satellite records for 1979 to 1992. They found that during solar minima, Earth was 3% cloudier than at solar maxima[3]. They also noticed that the influx of high-energy particles reaching Earth from deep space,


M. SVALGAARD

"We must now let Mother Nature tell us who is right." — Leif Svalgaard

phenomena known as cosmic rays, was up to 25% higher at solar minima, hinting that they might seed cloud formation. The pair called their finding a "missing link in solar–climate relationships".

Climate sceptics who argue that human activities are not responsible for global warming have seized on these results. They claim it shows that the Sun is largely responsible for variations in our climate. So convinced are they that last year two Russian sceptics placed a $10,000 bet that global temperatures will show an average fall for 2012–17 — on the assumption that the next solar cycle will be weak[4].

But most proponents of the solar–climate link are proceeding more carefully. "We're not suggesting that all clouds are formed by solar activity, merely that the process might be modulated by solar activity," says Robert Bingham, a physicist at the Rutherford Appleton Laboratory in Didcot, UK. He is part of an international experiment known as CLOUD, or Cosmics Leaving Outdoor Droplets. This will use CERN's particle accelerator on the French–Swiss border to fire charged particles through a chamber holding gases to simulate Earth's atmosphere and determine whether 'clouds' are created.

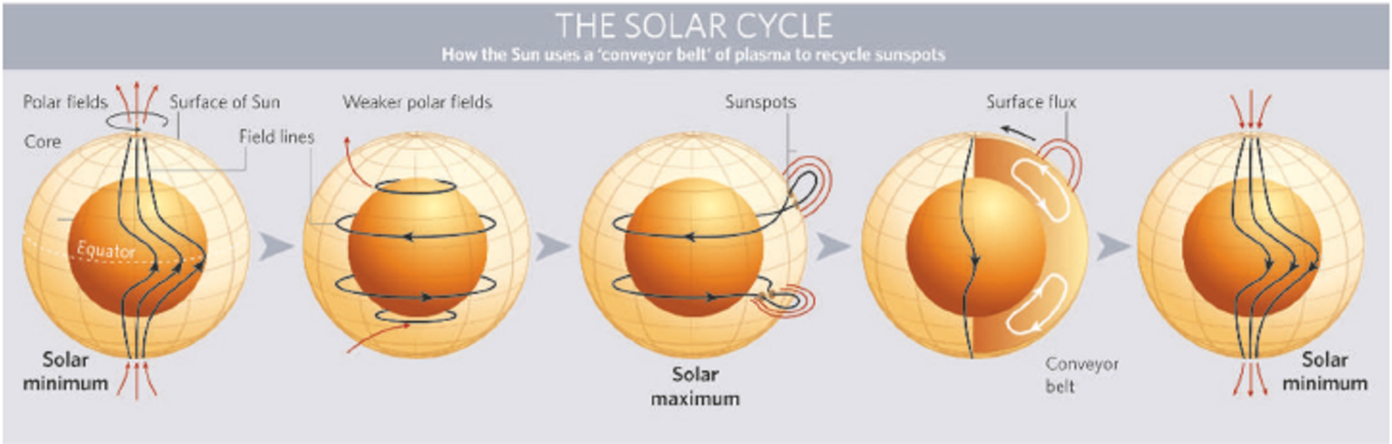
Global network

To take advantage of the next solar cycle more directly, the United Nations is heading an initiative to install radio receivers in all 191 of its member states. For the first time, the upper atmosphere's response to the continual collision of solar radiation would be monitored on a global basis. Although space officially starts at an altitude of about 100 km, scientists know little about this region because it is difficult to study.

The UN project is one of the planned elements in the IHY. Although it has no dedicated research budget, the IHY has initiated a call-for-proposals aimed at making it easier for scientists from any discipline to gain access to solar instruments and data. "We are inviting ideas from the community," says Rutherford's Richard Harrison, the joint UK coordinator for the IHY.

Certainly 2007 will put at scientists' disposal the largest-ever fleet of space missions for studying solar–terrestrial interactions. A dozen spacecraft that track solar activity are already in orbit, and another three should launch this year, including the most sophisticated solar watchdog yet. NASA's Solar Terrestrial Relations Observatory (STEREO) consists of two nearly identical craft that will watch the Sun from different locations, one preceding Earth in its orbit and the other following behind. This will allow them to take stereoscopic images of the Sun and to track the three-dimensional structure of particle eruptions. In this way, STEREO might be able to supply advance notice of the speed and direction of eruptions as they head towards Earth.

Such information should help satellite operators respond to imminent dangers, but for proper planning they will need long-term forecasts of solar activity. Some researchers, such as Harrison, believe that scientists don't yet understand the Sun enough to make meaningful long-term predictions. Certainly, past forecasts have relied on tracking signposts of future solar activity, without worrying too



much about the mechanisms behind them.

For example, in the 1970s, astronomers recognized that the build up of magnetism at the Sun's poles after the cycle has peaked has a bearing on the strength of the next cycle. Just last year, one of the pioneers of this method, Leif Svalgaard, used the Sun's polar magnetic field to predict that the next solar cycle will be the weakest for a century[5]. Other 'signpost' methods, such as those looking at the amount of 10.7-centimetre radio waves coming from the Sun or the number of bright patches near the Sun's poles, also forecast a weak cycle.

The only signpost method to predict a strong cycle comes from solar physicists David Hathaway and Robert Wilson at NASA's Marshall Space Flight Center in Huntsville, Alabama. In 2004, they noticed that a solar cycle's strength correlates to the number of sunspots two cycles before. Applying that rule of thumb to the next cycle, they have predicted strong activity in 2012 (ref. 6). Dikpati's model agrees with this forecast and, crucially, puts the reason for it on a physical footing.

In the past decade, physicists have discovered a vast conveyor belt of plasma on the Sun that seems to flow from the equator to the poles in each hemisphere at around 30–65 kilometres per hour. Sunspots are typically active for just a few weeks before fading from view, but their magnetic fields linger on. These weak fields are carried by the flow and accumulate at the poles before being submerged below the surface, where they presumably flow back towards the equator[7].

Dikpati's work combines sunspot observations dating back to the 1900s with a computer simulation of the Sun's magnetic dynamo and the conveyor belt (see graphic). In the simulation, the conveyor belt sweeps along old sunspots, submerging them at the poles. During the deep return flow, the Sun's rotation rejuvenates the old magnetic fields, creating new sunspots and fresh areas of solar activity.

It is the only prediction in which every step uses a physics-based computer model, which is why it is being taken seriously by solar physicists. "The solid physics of Dikpati's model is a high hurdle for the other techniques to get over," says Hathaway.

"Mission planners looking to 2012 may want to boost their craft to higher orbits."

Solar memory

The key to Dikpati's forecast is how fast the Sun's conveyor belt runs. The deep return flow is unmeasurable but the model suggests that it is slower than the surface flow, perhaps just 5 kilometres per hour. If so, the return leg of the journey would take a couple of decades. "This shows that the Sun retains a memory of its magnetic field for about 20 years," says Dikpati. So in her model, the Sun's activity is not based solely on the previous cycle's magnetic field but on the interplay with earlier cycles. In contrast, most 'signpost' prediction methods assume that the previous solar cycle immediately kicks off the activity of the next. "It is good for science that the predictions are now diverging," says Svalgaard, although he disagrees with Dikpati's conclusions.

Solar physicists are now waiting to see if this physics-based forecast is right. And they may not have to wait for the peak of activity in six years' time to find out. All methods predict only the average number of sunspots, but records show that large cycles have always begun early and raced to their peak. That means that the telltale signs of a large solar cycle should be evident within just three or four years from now.

"We must now let Mother Nature tell us who is right," says Svalgaard. But Dikpati and her team are refining their model to see whether it can predict features such as an early start. Either way, there will be plenty of sun watchers — from mission planners to climate sceptics — tracking the way the solar wind blows. ■

Stuart Clark is a freelance writer based in Hertfordshire, UK.


NASA/JOHNS HOPKINS UNIV. APPL. PHYS. LAB.

Sun spotters: NASA's twin STEREO satellites will watch the solar weather and give warning of approaching storms.

1. Tsurutani, B. T. *et al. Geophys. Res. Lett.* **32**, L03S09 (2005).
2. Dikpati, M., de Toma, G. & Gilman, P. A. *Geophys. Res. Lett.* **33**, L05102 (2006).
3. Svensmark, H. & Friis-Christensen, E. *J. Atmos. Solar-Terr. Phys.* **59**, 1225–1232 (1997).
4. Giles, J. *Nature* **436**, 897 (2005).
5. Svalgaard, L., Cliver, E. W. & Kamide, Y. *Geophys. Res. Lett.* **32**, L01104 (2005).
6. Hathaway, D. H. & Wilson, R. M. *Solar Phys.* **224**, 5–19 (2004).
7. Hathaway, D. H. *et al. Astrophys. J.* **589**, 665–670 (2003).