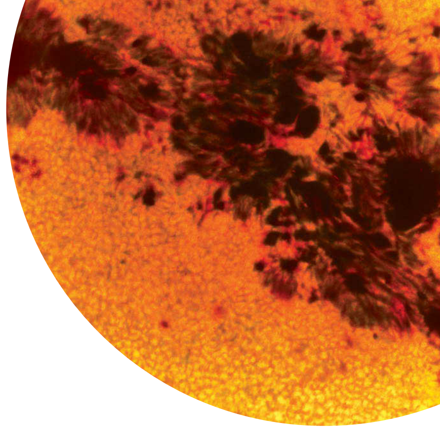
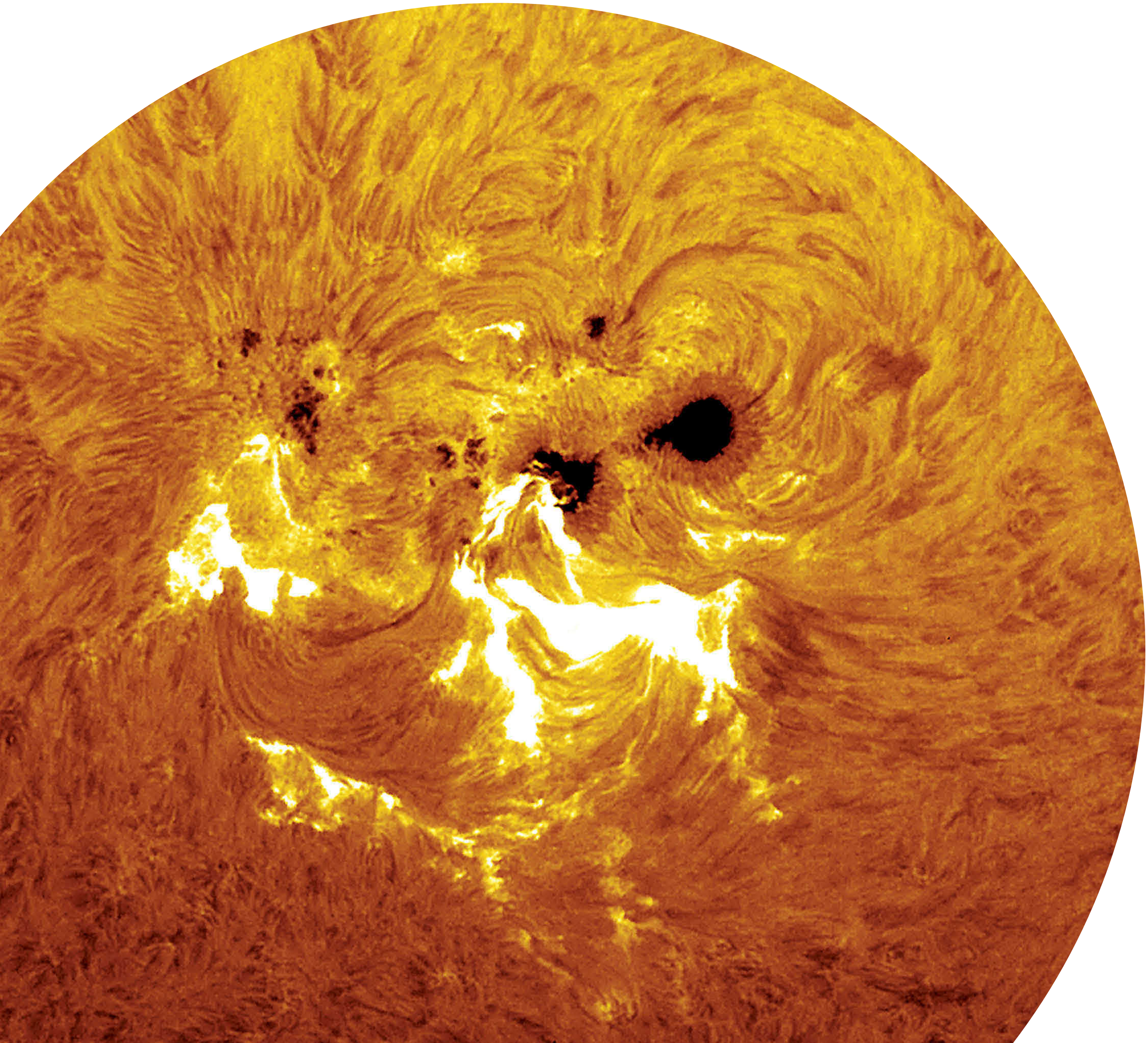
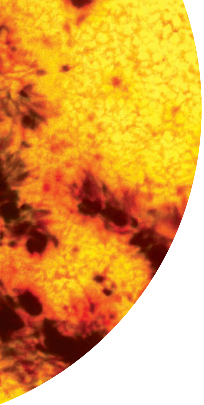


The tally of splotches on our sun tells us what it's up to. It's a pity no one can agree how to count them, says Brian Owens

Spot of bother





EVERY lunchtime, Gustav Holmberg leaves his desk at Lund University in Sweden to take part in a scientific ritual that stretches back to Galileo's time.

Back at his flat, the historian of science sets up a modest telescope and, taking due care not to burn his eyes, points it directly at the sun. He spends 5 minutes or so counting, and uploads a number to a server in Belgium. There, it is automatically combined with similar numbers from some 90 other observers around the globe, two-thirds of them amateurs like himself.

Satellite engineers use this number, updated daily, to predict how the sun's future activity will affect their spacecraft. Climate scientists use it to pick out the sun's long-term effects on Earth's climate. Electricity companies use it to anticipate solar storms that could affect their grids. It is the international sunspot number: the world's oldest continuous data series, and one of its most important. "It is probably, apart from the Dow Jones index, the most used time series ever," says Leif Svalgaard, a solar physicist at Stanford University in California.

But there is a problem. There is not one sunspot number, but two.

In the past couple of decades, a rival series has revealed the existence of mysterious blemishes in the official sunspot record that cast doubt on its accuracy. That is embarrassing for the scientists involved and problematic for those who rely on the record's accuracy. What to do?

Sunspots are dark splotches that mark cooler patches on the solar surface. They correlate with areas of intense magnetic activity that are breeding grounds for violent outbursts of matter and radiation from our star. If it weren't for the protective hull of Earth's atmosphere and magnetic field, these solar flares and coronal mass ejections would rapidly fry life on our planet.

Observers peering through the first telescopes in the early 1600s were blissfully unaware of all this when they started to systematically record dark spots on the solar surface. Many at the time rejected the idea that God's celestial orb could be anything less than perfect, and assumed these blotches must be shadows of other bodies orbiting the sun. It was Galileo who championed the view that they were features on the sun itself.

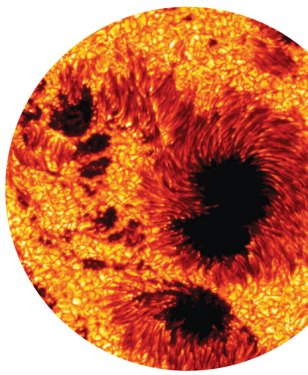
In the 1840s, the Swiss astronomer Rudolf Wolf took observations of sunspots to a new level. He diligently recorded his own measurements each day, and delved into the piecemeal records of earlier astronomers to extend the series of observations back to 1700. In the years before that, the sun was going through a prolonged period of unusually low activity known today as the Maunder minimum, and Wolf felt there were too few reliable records to look further back.

Counting sunspots is not as easy as it sounds. Sunspots tend to cluster together in groups, and individual spots within a group can be difficult to discern. To take account of these uncountable spots, Wolf came up with a formula to calculate the "relative sunspot number", which he defined as 10 times the number of sunspot groups, plus the number of clearly distinguishable individual spots. Since different observers with different telescopes tended to count slightly different numbers of sunspots, Wolf used overlapping periods to assign correction factors to the numbers from each new observer, and so ensure these numbers were consistent with his own.

This same system was used for over a century by Wolf and his successors in Zurich, with each new observer's results calibrated to an existing reference standard. When the Zurich observatory closed in 1981, the Solar Influences Data Analysis Center (SIDC), based at the Royal Observatory of Belgium in Brussels, took responsibility for compiling the number, known also as the Wolf number in honour of its founder. Since 1951, the US National Oceanic and Atmospheric Administration (NOAA) based in Boulder, Colorado, has compiled a second series using Wolf's formula, using data from different observers, that produces results broadly in agreement.

Both these sunspot series show consistent features over centuries. The sun's activity varies over a roughly 11-year period, rising to a maximum before dropping off again to almost nothing. We're not altogether sure about the cause, but maximum activity always occurs just before a regular flip in the polarity of the sun's magnetic field; the next such flip is expected within months. Not all peaks and troughs are equal. There are extended periods of low activity, such as the Maunder minimum, as well as prolonged periods of high activity. Some solar physicists think we may be entering a long quiet period now.

But how sure can we be? In the 1980s, nearly 100 years after Wolf's death, the seemingly model historical continuity of the sunspot series was seriously called into question. Douglas Hoyt, a solar physicist then working at a company called Research and Data Systems in Greenbelt, Maryland, noticed ›



Eye of the beholder: sunspot counting is open to interpretation

L-R: JACK NEWTON; NOAO/SPL; SCHARMER ET AL. ROYAL SWEDISH ACADEMY OF SCIENCES/SPL that the English astronomer William Herschel had recorded sunspot observations over periods in the early 1800s when Wolf's record implied none had been made. Hoyt concluded that Wolf may have missed records kept in English, and possibly others. Along with Ken Schatten of the NASA Goddard Space Flight Center, also in Greenbelt, he began trawling through museums, libraries and observatory archives around the world, gathering as many historical sunspot observations as he could. In the end, the two dug up about 100,000 observations that Wolf had not used. Many were recorded during the Maunder minimum, extending the series all the way back to Galileo in 1610. "Even so," says Hoyt, "I probably missed some observations myself."

Rival series

These earlier observations counted only groups of sunspots, so the new series, ending in 1995, was directly comparable with that based on Wolf's method only after careful cross-checking and calibration. That turned up a surprise. Although the two series agreed fairly well in some places, in others they differed radically. In some periods before 1885, the new group sunspot number was lower than Wolf's by as much as a half (see diagram, below). Between 1945 and 1995, the Wolf numbers near maximum were consistently higher than the numbers revealed by the group method.

This is a problem. To take one example, the level of solar activity controls the rate at which particles evaporate from the uppermost layers of Earth's atmosphere. These particles exert a tiny, but perceptible drag on spacecraft in low Earth orbit such as the International Space Station. Predictions of solar activity based on sunspots are used to determine what orbit a satellite should be put into, how much fuel it will need, and how long the mission might last – as well as how much it will cost to insure it against loss in a solar storm. The US Air Force has newer Wolf numbers hard-coded into the operational programmes that control its rockets and satellites.

But it is in climate science where the existence of two rival sets of sunspot data has caused the most controversy. By grafting Hoyt and Schatten's series on to longer-term data inferred from tree rings and ice cores, it is possible to argue that solar activity has been steadily increasing, and indeed is higher today than at any time in the past 8000 years. That, rather than our own greenhouse-gas emissions, is the reason why the planet is warming, the argument goes.

For Svalgaard, this is a deeply unsatisfactory situation. "Why can't we provide a number that we can have some confidence in?" he asks. "That is something we as solar physicists should be ashamed of."

A few years back, he decided to do something about it. He wanted to get to the bottom of what was causing the inconsistencies and come up with a single, vetted number that everyone could agree on. He and his colleagues think they are now just about there.

The issue of the jump in Wolf's number in 1945 was a strange one. Daily variations in the magnetic field observed at Earth's surface are

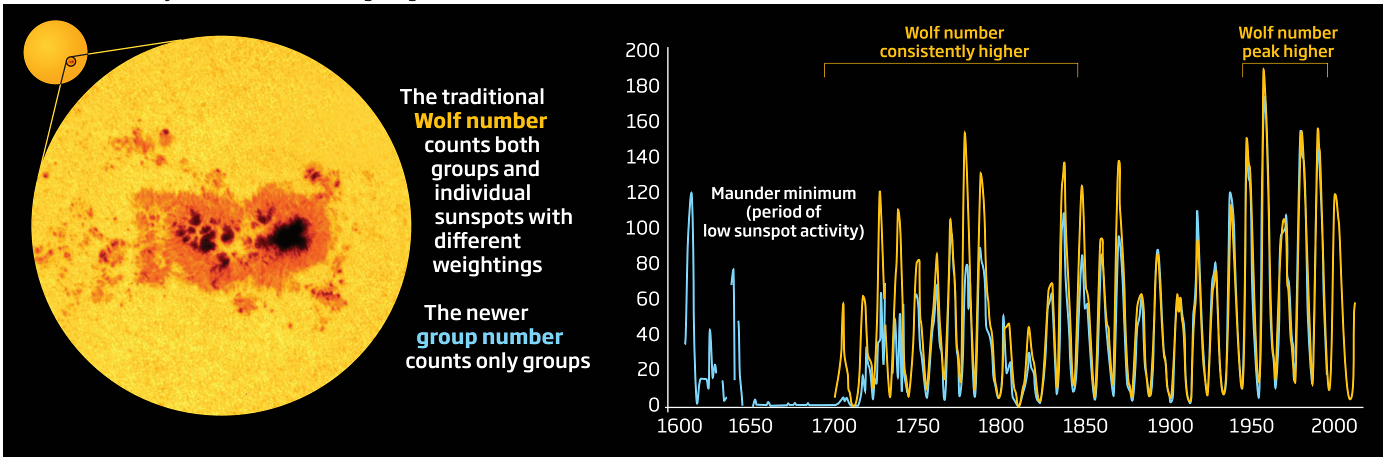
> "In the mid 1940s, the director of the Zurich observatory changed the way sunspots were counted – only he didn't tell anyone"

also influenced by solar activity, and Svalgaard noticed that these did not match up with the sunspot numbers as well as they should have after 1945. Something had gone awry with the counts. It turned out that, sometime after taking over the Zurich observatory in the mid-1940s, its director Max Waldmeier changed the way the sunspots were counted. Because it had become clear that bigger spots represented more magnetic activity, he decided to give them a greater weight. While the smallest ones counted as just one spot, he counted larger ones as many as five times – only he told hardly anyone about it.

One of the few he did tell was Sergio Cortesi at the Specola Solare Ticinese, a small observatory near Locarno in the south of Switzerland that was set up as a twin station to Zurich. Cortesi is still there counting sunspots. After the closure of the Zurich observatory, Locarno became the reference station for the sunspot series, and every new observer's count was referenced to Cortesi's counts, which in turn were calibrated to Waldmeier's. Cortesi had assumed Waldmeier's recalibration was common knowledge, so the blip Waldmeier

Spot the difference

It can be difficult to pick out individual spots on the sun's surface. The two main methods for calculating sunspot numbers have produced results that in some cases differ radically, even after careful weighting and calibration



SOURCE: HOYT & SCHATTEN, 1994/NASA

JAMES REYNOLDS; JOHN EMSLIE/NATIONAL MARITIME MUSEUM, GREENWICH, LONDON

Sunspots have long captivated popular imagination

introduced went uncorrected. The result is that, starting around 1946, the Wolf numbers are about 20 per cent too high.

Given the places where these numbers are hard-coded, they can't simply be changed. Because the aim is to ensure the consistency of the series over time, rather than establish an absolute number, Svalgaard's proposal, hammered out with colleagues from the US Air Force Research Laboratory and SIDC among others, is to bump up all the older, pre-1946 numbers by 20 per cent.

The divergent numbers before 1885 were trickier. In compiling the earlier parts of their data series, Hoyt and Schatten had faced the same problem as Wolf: how do you compare sunspot counts from different observers, with different eyesight, different telescopes, and even perhaps different opinions on what constitutes a group of sunspots?

They had handled this in much the same way that Wolf did: by stringing together a daisy chain of overlapping observers, correcting the numbers up or down so that they produced the same average number of sunspots in the time periods when two observers overlapped. The problem with this approach is that if any number is way off-beam errors propagate through the series and accumulate. "It's like the children's game Chinese whispers," says Svalgaard.

Two such errors in particular came to light. The first was in sunspot records kept by the Royal Observatory in Greenwich, UK, from 1874 to 1974. Hoyt and Schatten had used this long-running series to calibrate other observers' data, but comparison with more than 20 other contemporary observers reveals that in its first 20 years the Greenwich series was drifting. Equal sunspot counts do not necessarily represent the same level of solar activity throughout the record.

The second error was in the final multiplier Hoyt and Schatten used to ensure their average sunspot count matched Wolf's. Soon after starting the sunspot series, Wolf became chairman of the Swiss geodetic survey and then director of its weather service. From the 1860s until his death in 1893 he was almost constantly travelling, and continued with his observations not with his large telescope in Zurich, but with a smaller, portable one with which he saw on average 40 per cent fewer sunspot groups. Although Wolf adjusted his own counts to keep the Zurich number constant, Hoyt and Schatten had calibrated to his raw counts.

The upshot is that Hoyt and Schatten's sunspot numbers before 1885 will be revised upwards, to bring them into line with the Wolf number. A meeting is planned for May next year in Locarno to work out precisely how big that correction should be.

Schatten is happy with what has emerged, despite the fact it has highlighted flaws in his work. "Of course, one doesn't like it when the work one does is not perfect," he says, but he thinks the outcome is the right one. A more accurate time series will allow for a better understanding of past solar cycles. "And the past is the key to the present, and the future," says Svalgaard.

Climate controversy

Clearing up its blemishes could give the sunspot record new life, says P. T. Jayachandran, an atmospheric physicist at the University of New Brunswick in Canada. Satellite engineers had been moving away from using sunspot numbers to calculate solar activity, in part because the measurements were considered too unreliable. Instead, they had begun to use direct measurements of solar flux, the radio emissions from the sun. But those flux observations only go back as far as the 1940s. For any view of patterns of solar activity stretching further back in time, these records too had to be calibrated to the sunspot records.

This problem becomes especially acute when it comes to how the sun's activity affects Earth's climate. This becomes more uncertain over longer time periods, says Joanna Haigh, a climate physicist at Imperial College London, partly because there have been "extreme differences in assumptions" about the power output from the sun. With Svalgaard's corrections to the revised sunspot series, it no longer seems that the sun is going through an unusually active phase. In fact, it has been mostly stable for the past few centuries since the Maunder minimum. The argument that the sun, and not human activity, is driving global warming loses one of its supports. Svalgaard is still not so naive as to think this will be the end of the argument. "We expect a grand fight on that front," he says.

With the wrinkles in the earlier data ironed out, we can have a little more confidence in the world's oldest data series. And while plans are afoot to automate the collection of the international sunspot number, for all their imperfections humans remain the most reliable observers. For now, Holmberg will continue delivering his numbers as he always has – methodically, consistently, without fail. As a scientist and a historian, he's proud his hobby can continue to be put to scientific use. "It gives me satisfaction that my data become part of something bigger." ■

Brian Owens is a freelance writer based in St Stephen, New Brunswick, Canada