

CLEAR AND BRIGHT

WITH A CHANCE OF SUNSPOTS AND MAGNETIC STORMS

Because of our increasing reliance on satellite-driven technology and far-flung power grids, the Sun and its magnetism can wreak havoc on society in a matter of hours. New computer models and observing tools developed at NCAR are sharpening scientists' views of the vast forces shaping magnetism on and above the Sun's surface. These tools also help point the way toward prediction of solar storms, as well as the strength and timing of the Sun's 11-year cycle.

For centuries, the ebb and flow of weather has engaged the predictive efforts of soothsayers, folklorists, and—more recently—scientists. In the late 20th century, the notion of solar weather prediction joined its earthbound counterpart as a scientific goal. As the threats of solar activity to a burgeoning array of vulnerable technology became clear, solar weather prediction became both more critical and more plausible. So what features tell us most about when, where, and how powerfully the next solar storm will assail satellites, mobile phones, or electrical grids?



Mausumi Dikpati leads an effort to predict the timing and intensity of solar cycles.

The vast solar corona, the outermost part of the Sun's atmosphere, holds key clues. It's the launching pad for energized particles that can trigger geomagnetic storms in Earth's atmosphere. Research

on the corona has been part of NCAR since 1961, when the new center absorbed the pioneering High Altitude Observatory.

There's now fresh momentum to HAO's work on solar processes in the corona and other promising regions. New computer models, observations, and a groundbreaking NCAR instrument may yield critical insights into the 11-year cycle of sunspots, the mechanisms that lead to giant eruptions known as coronal mass ejections, and the behavior of magnetic fields.

WILL THE NEXT SOLAR CYCLE BE ON TIME?

Scientists for generations have speculated about the mysterious mechanisms that drive sunspots. These regions of concentrated magnetic fields at the Sun's surface can cause powerful solar storms, known



as coronal mass ejections, that sometimes buffet Earth's atmosphere. But why does sunspot activity tend to ebb and flow in cycles of about 11 years?

Equipped with a groundbreaking computer model, NCAR scientists and colleagues may be closing in on some important clues. The key to the 11-year cycle, they believe, has to do with a current of plasma, or electrified gas, that circulates between the Sun's equator and its poles.

If this proves to be the case, the finding could lead to better predictions of upcoming solar cycles. For example, the team forecasts that the next one, known as cycle 24, will begin in late 2007 or early 2008—or at least six months late—because of a deceleration of the plasma circulation.

Scientists for years have known about this current of plasma, or the meridional flow, which moves at a pace of around 72 kilometers per hour (45 miles per hour) near the surface. But they had not previously connected it to sunspot activity. The meridional flow appears to act as a sort of conveyor belt by slowly transporting remnant magnetic signatures of the sunspots of previous cycles from the Sun's surface to the interior. Inside the Sun, the remnants give rise to a new generation of magnetic fields that produce new sunspots at the surface.

"In our model, we can show how physical processes relate the surface signatures of solar magnetic fields from old cycles to that of the new



AT FIRST

THE CASE OF THE MISSING SUNSPOTS

*I*t wasn't big news when sunspot activity diminished between roughly 1645 and 1715. Astronomers of the day took note of the spots that did occur, but the overall lack of activity didn't stand out until the discipline itself grew older. In the 1880s, German astronomer **Gustav Spörer** took a closer look at the 1645–1715 sunspot drought. He concluded that it was more than just the result of a small number of observers in a still-young discipline. A few years later, E.W. Maunder carried out further study on the mysterious minimum. In 1976, NCAR scientist John Eddy labeled the period the Maunder Minimum and named an earlier minimum, from about 1420 to 1570, for Spörer. The two periods fall within a regional cooldown in Earth's climate known as the Little Ice Age. Today, researchers continue to explore and debate the extent to which variations in the Sun affect climate on Earth.



AT THE UNIVERSITIES

ATMOSPHERIC RESEARCH
IN OUTER SPACE

David Charbonneau (Harvard University) was in graduate school in the mid-1990s when astronomers announced the first discovery of a planet outside our solar system. “It was clear that extrasolar planets were going to be a big field of astronomy,” he recalls. “I was very interested in developing new methods of finding them.” Charbonneau pursued his interest while completing his doctorate at Harvard by visiting NCAR and launching a fruitful collaboration with HAO’s Timothy Brown. The two focused on detecting the dimming of light caused when a planet transits, or crosses in front of, its parent star. They broke new scientific ground in 2001 when they used the imaging spectrograph on NASA’s Hubble Space Telescope to detect the first atmosphere on an extrasolar planet. Charbonneau, Brown, and several colleagues recently set up the Trans-Atlantic Exoplanet Survey, a network of small telescopes designed specifically to look for planets orbiting bright stars. In 2004, they detected a Jupiter-sized planet some 500 light years from Earth. Charbonneau expects TrES to lead to new insights into the formation and evolution of planets orbiting other stars by deploying tools such as NASA’s newly launched Spitzer Infrared Space Telescope to determine temperatures, atmospheric compositions, and other properties. “We want to see if most stars like the Sun have systems of planets that are similar to ours,” says Charbonneau.



NCAR’s coronal researchers include (clockwise from top left) Holly Gilbert, Sarah Gibson, David Foster, and Giuliana de Toma.

cycle,” explains NCAR’s Mausumi Dikpati. The model results are consistent with observed solar features, she adds. Dikpati is working with HAO colleagues Giuliana de Toma, Peter Gilman, and Oran White; also on the team is Charles “Nick” Arge (U.S. Air Force).

The team is putting the model through a number of tests. It has already successfully reproduced abnormal elements of cycle 23, when the typical magnetic reversal of the Sun’s north and south poles took place slowly. Now the researchers are working on making additional predictions for cycle 24, including when the peak will occur and how intense it will be.

Ten years from now, Dikpati hopes the model will be able to make some estimates of sunspot count for the next cycle. The model might also help society brace for an extended period of unusual solar activity, such as that during the Little Ice Age, when the number of sunspots dropped dramatically and temperatures cooled in some regions of the globe.

FORECASTING MIGHTY MAGNETIC FORCES

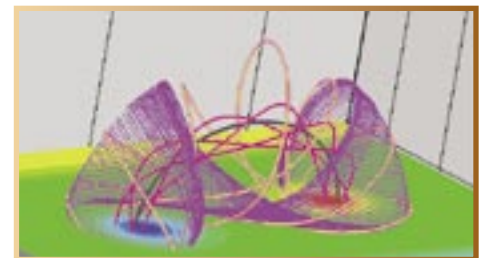
Sunspots get attention in part because they may cause a far larger type of solar disturbance, one that can propagate all the way to Earth’s atmosphere. About once a week when the Sun is relatively quiet and about two or three times a day at the peak of the 11-year solar cycle, a great bundle of plasma escapes from the Sun’s surface. This coronal mass ejection, or CME, accelerates through the corona in only a few hours. If it’s pointed at Earth, it can irradiate astronauts, disable the circuitry in satellites, knock out surface power grids, degrade the accuracy of the Global Positioning System, and paint the high-latitude skies with shimmering auroras.

Forecasts issued by NOAA shortly after a CME emerges from the Sun provide warnings from hours to several days in advance of a potential geomagnetic storm. But will we ever be able to predict one before it erupts? To give society such lead time, scientists will have to learn the precursors of CMEs. They’ll need to illuminate the plasma contortions below the solar surface that give birth to a CME and the coronal magnetic fields that shape its evolution. Spotting a newborn CME is now routine, but viewing the magnetism that lies at its heart—and throughout the surrounding corona—isn’t so easy.

Since 1998, NASA’s Transition Region and Coronal Explorer satellite (TRACE) has parted the curtains somewhat. With a tight focus on small regions, it measures how the magnetic field shapes coronal plasma from the photosphere up through the corona at an exceptionally fine horizontal resolution.

While intrigued by the TRACE images, coronal experts have been tantalized by what is still unseen. The arching structures uncovered by TRACE denote only a few of the corona’s intricately nested magnetic field lines—arches within arches, as it were. To help see these multilayered structures, many coronal specialists have turned to animation. Technology is on their side: desktop computers and software packages are now powerful enough to produce useful animations in short order.

At HAO, Sarah Gibson is using visualization routines based on modeling by colleague Yuhong Fan to see how an idealized twisted tube of magnetic flux—a CME in the making—might appear in observations. She concentrates on a sigmoidal (S-shaped) portion of the twisted field. This zone is the interface between field lines that are firmly tethered to the dense solar surface and those that have a portion suspended in the atmosphere and thus move



The S-shaped magnetic structure above (tightly packed purple lines) could take shape days to weeks before a coronal mass ejection.

more freely. "This is the region where heating is likely to happen during an eruption," says Gibson.

Recent x-ray data show that hot coronal gas can take on a sigmoidal structure a few days to weeks before a CME emerges in the same area. While the relationship isn't guaranteed, and it currently has limited use as a forecasting tool, "the link is definitely intriguing from a scientific point of view," says Gibson. "If we can figure out the science behind the eruptions, we'll be in a much better position for making future forecasts."

A SUN-WIDE GLIMPSE OF CORONAL MAGNETISM

Attempts to observe the solar corona have long been thwarted by the Sun's far-brighter surface, as if someone were trying to decipher a whisper amid a thunderstorm. Eclipses help muffle the visual noise of the solar disk, and filters can artificially block it, but each approach has its limitations.

In early 2004, a handful of NCAR researchers fulfilled a long-sought measurement dream. At the National Solar Observatory in New Mexico, they collected the first-ever data on magnetic fields across the entire solar limb (the slice of the Sun's corona perpendicular to Earth). Animations from their instrument, the Coronal Multichannel Polarimeter (CoMP), reveal turbulent, high-velocity magnetic features spewing outward from the Sun's surface.

"People have measured coronal magnetism before," says HAO's Steven Tomczyk, "but we believe this is the first time it's being done in a time sequence like this, where you can see an evolving structure. I think we're making important steps and demonstrating that this technology works."

Near the Sun's surface—especially in the photosphere, the lowest part of the Sun's atmosphere—magnetism has been traced for over a decade by ground- and space-based

instruments, such as NCAR's Advanced Stokes Polarimeter. These devices infer the magnetic field by measuring several components of visible radiation. The brightness of the polarized light is proportional to the strength of the magnetic field along the line of sight.

But until recently, there was scant hope for using this technique to analyze magnetism in the Sun's corona. Although its temperatures are scorching—as high as a million degrees Celsius (1.8 million Fahrenheit)—the corona is far too thin to yield a strong signal. CoMP capitalizes on a new generation of super-sensitive, low-noise infrared sensors that has made the impossible possible for coronal research. "The technology has only recently come on line," explains HAO software engineer J. Anthony Darnell, who worked closely with Tomczyk and engineer Gregory Card in designing the instrument.

The HAO team also devised a way to measure two wavelength components simultaneously. Earth's atmosphere scatters a continuously varying amount of background light from the brighter disk into the coronal line of sight. The simultaneous measurements in CoMP allow the varying background signal to be accurately removed while preserving the faint coronal signal.

Using a separate instrument based on a somewhat different approach, a team led by HaoSheng Lin (University of Hawaii) began producing maps of the solar corona later in 2004. "There's a little bit of friendly competition," says Lin. However, both groups hope to pair their devices with a larger, yet-to-be-designed telescope on the order of a meter in diameter. "Ultimately," says Tomczyk, "you want to gather more light."

☉ *Web links and updates to this article:*
www.ucar.edu/communications/highlights/2005

The CoMP crew:
Gregory Card,
Anthony Darnell,
and Steven Tomczyk.



AT NCAR

A SOLAR VETERAN'S FORECAST:
INCREASING PROGRESS

One of NCAR's most senior solar researchers, **Thomas Holzer**—who came to NCAR in 1973 to start a program investigating Earth's magnetosphere—believes we are on the verge of critical scientific breakthroughs because of increasingly powerful observing instruments and improvements in solar modeling. "I have a feeling we're going to be making enormous strides over the next ten years," he says. In his role as senior scientist, Holzer is helping to oversee research into such issues as the origins of coronal mass ejections and the generation of magnetic fields. He is especially interested in solar prominences, which may provide insights into the types of coronal mass ejections that can affect Earth's atmosphere. "We're laying the basis for eventually decent space weather forecasting," he says. Meanwhile, several NCAR groups are collaborating on the Whole Atmosphere Community Climate Model (WACCM), which incorporates Sun-driven effects on Earth's upper atmosphere. The time may not be far off, Holzer adds, when scientists will be able to model the entire Sun-Earth system. "It would be my hope that we will eventually have a coupled model all the way from the solar interior to the surface of Earth," he says.

