Batten down the hatches, solar flare headed this way

Reliable forecasting will ensure that solar storms no longer wreak havoc here on Earth

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"ACTIVE sunspot region 930, currently on the far side of the sun, appears to be growing into a monster. As it rotates Earthside, we expect to see some major flares and coronal mass ejections heading our way. That probably means radio blackouts for people living at lower latitudes, with higher radiation levels and geomagnetic storms at high latitudes. So if you're planning a trans-polar flight in the next couple of weeks, prepare for a longer trip because you could be diverted south."

This report, though fictional, could easily have been broadcast last December, when an unprecedented series of solar storms hurtled towards Earth. That is, if the handful of space weather researchers had seen them coming in time.

In reality, the forecasters weren't concerned about the previously placid sunspot cluster until it rotated into view on 5 December and erupted with an enormous flare. The flare disrupted air traffic control radar in Canada, temporarily shut down the Mars rovers Spirit and Opportunity, and triggered malfunctions in several NASA satellites. When the next storm burst from the cluster a week later, forecasters were able to send out an immediate alert when they spotted the storm, buying enough time for most spacecraft to enter "safe" mode before the worst weather hit. But some, including three of the four spacecraft in the European Space Agency's (ESA) Cluster II mission, did sustain damage. China's *People's Daily* newspaper reported widespread disruption of short-wave radio communications.

So how can we develop a reliable forecasting system for solar storms? The first step is to get more information, says Jack Quinn of the Center for Integrated Space Weather Modelling, a consortium funded by the National Science Foundation and led by Boston University. Whereas terrestrial meteorologists have a network of thousands of ocean buoys, weather balloons, satellites, and other stations constantly feeding them data, space weather researchers are limited to about a dozen measurements at any given time, says Quinn.

To help make up the shortfall, a host of new missions is gearing up to study the sun and its storms in unprecedented detail. And next month NASA and the National Oceanic and Atmospheric Administration (NOAA) will host the first meeting, in Washington DC, for policy makers, researchers and industrialists to emphasise the importance of space weather research to the economy.

And not a moment too soon, says Tom Bogdan, director of NOAA's Space Environment Center in Boulder, Colorado. The December storm was the most powerful ever recorded during a solar minimum, the quietest point in the sun's 11-year cycle, he says. It provided a taste of what is in store during the next solar maximum in 2010 or 2011.

Solar storms consist of flares, coronal mass ejections, or both. Flares are the result of the sun'smagnetic field snapping like a rubber band, releasing energy as photons, which take only 8 minutes to reach Earth. Fast-moving charged particles follow about an hour later. If you think of these brief flares as tornadoes, then coronal mass ejections are "the hurricanes of space weather", says Janet Luhmann, a geophysicist at the University of California, Berkeley. During an ejection, a chunk of the sun's corona, its plasma "atmosphere", can escape, creating a huge cloud of charged particles that can take up to three days to reach Earth.

Solar storms can damage the sensitive electronics of satellites, acting like a mini lightning strike, says Daniel Baker, a space physicist at the University of Colorado in Boulder. Solar flares can also produce bursts of radio noise that can drown out GPS signals (*New Scientist*, 7 October 2006, p 27).

Activities such as deep-sea oil drilling depend on high-precision GPS, while air traffic controllers are using the system more and more. Solar storms can also disrupt radio communications and damage power grids. The bursts of radiation that head towards Earth can endanger astronauts and potentially people on flights over the poles, which are less protected by Earth's magnetic field.

Unfortunately, how these storms form in the sun, travel through space and interact with Earth's magnetic field is still largely a mystery. If we are ever to forecast space weather we'll have to do better. Much of what we already know is down to NASA and ESA's 11-year-old Solar and Heliospheric Observatory (SOHO), which was originally designed to operate for only two years but has been given a stay of execution until at least 2009.

Next year NASA will launch its successor, the Solar Dynamics Observatory. On board SDO will be the Helioseismic and Magnetic Imager, which is designed to track pressure waves inside the sun. These waves form in the interior

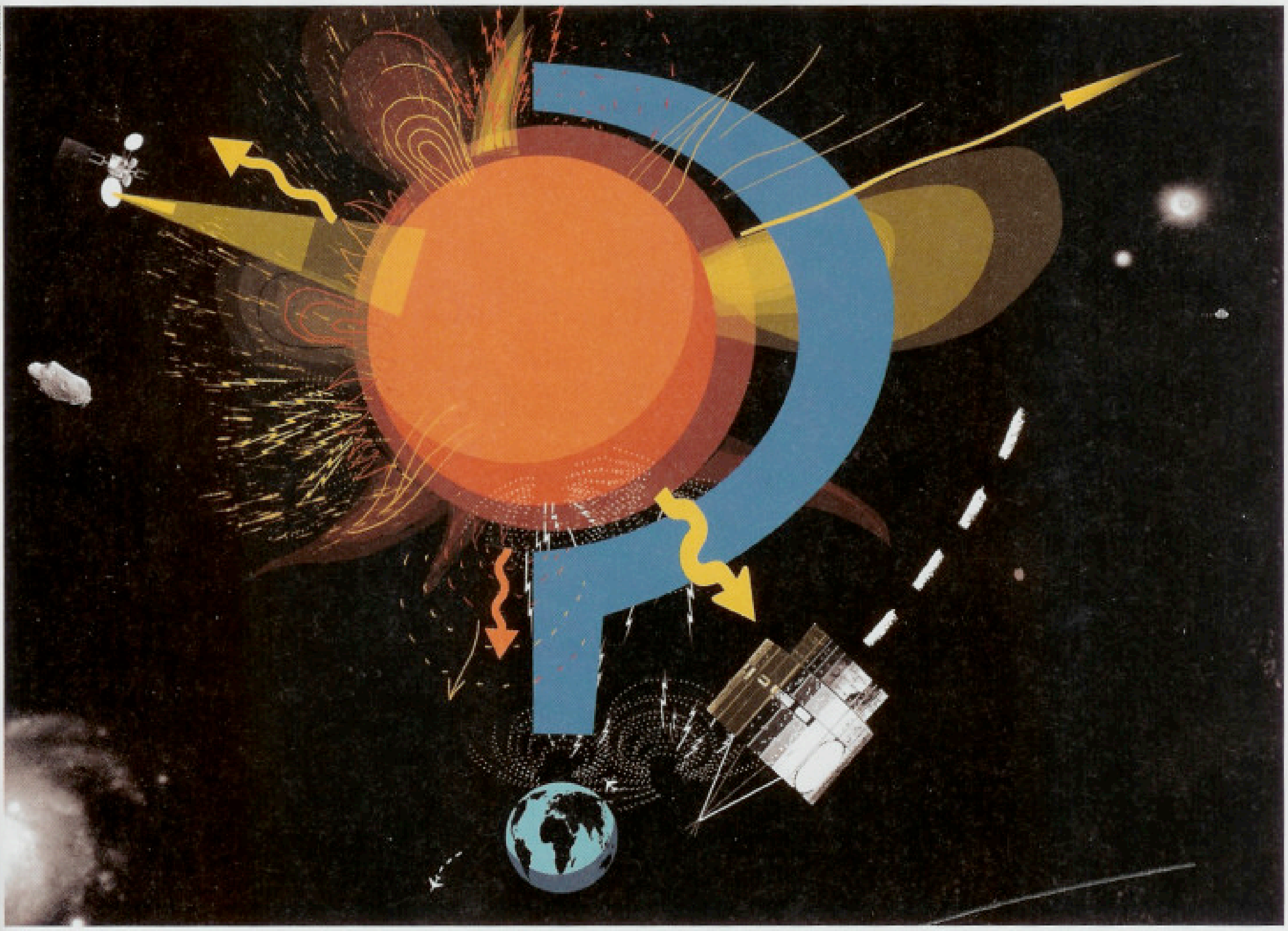
IN FIVE MINUTES THE WEATHER WILL BE...

Insights from solar observatory missions should mean a big leap forward in our understanding of what causes solar flares and coronal mass ejections, but it's not clear when these findings will translate into improved forecasts.

In the meantime, a constellation of space weather instruments is monitoring Earth's magnetic field and upper atmosphere to help forecasters improve "nowcasting", what the space weather is like now. Most are fitted to terrestrial weather satellites, like the ionosphere camera on the Constellation Observing System for Meteorology, Ionosphere and Climate, launched last year. The camera is designed to study the density of charged particles in the ionosphere generated by solar storms to detect when levels are high and could block radio and GPS transmissions.

New techniques are also making better use of the results coming in. The European Space Agency announced this month that it is beginning work on its Space Environment Information System for Operations, which will provide space weather monitoring and short-term forecasting for its missions by aggregating data from NASA, NOAA and ESA satellite instruments.

And scientists are making the best of solar flares disrupting the ionosphere, and therefore GPS. They are exploring ways to use the fluctuations in GPS signals caused by increasing numbers of charged particles in the ionosphere to spot solar flares.



of the sun and ricochet off the surface, causing it to vibrate. If the pressure waves meet the strong magnetic fields that cause solar storms, they change in wavelength, and when they bounce off the sun's surface, cause this area to vibrate at a different rate. From these vibrations, which the imager will measure, scientists can infer when a solar storm starts under the sun's surface and track it as it disappears behind the sun as it rotates. "It's like taking an ultrasound of the sun," says SDO project scientist Dean Pesnell. The imager on board SDO has a higher resolution and wider field of view than its predecessor on SOHO, allowing it to study a larger swathe of the sun in greater detail than ever before. Ultimately, this could allow forecasters to predict storms two weeks in advance, since it takes this long for magnetic fields to emerge from beneath the surface and snap, creating a flare or mass ejection, says Bogdan.

"Solar storms are like a lightning strike on the sensitive electronics of satellites"

While SDO will take a broad view of the sun, the Japanese-led Hinode mission, launched last September, will concentrate on small sections where storms may be forming. Hinode's visible light and ultraviolet telescopes will scan the sun one area at a time. It will coordinate with Hinode's X-ray telescope, which has a view of the whole sun, to help scientists understand the sun's constantly fluctuating magnetic fields.

Also launched late last year, the two spacecraft that make up NASA's Solar Terrestrial Relations Observatory (STEREO) have recently taken up their positions on opposite sides of the Earth: one ahead of Earth in its orbit and the other trailing behind. By studying the sun in stereo, the spacecraft will generate 3D images of coronal mass ejections heading towards Earth. Researchers will be able to compare these with their existing models of the massive storms, to improve their understanding of how and where they are created.

Once these mechanisms are clear, forecasters will have a much better idea of what areas of the sun to watch for signs of a storm brewing, just as meteorologists know what trends signal an impending hurricane, says Jeffrey Hughes of the Center for Integrated Space Weather Modelling. He believes this will take less than a decade. "It took us a while to understand that the energy that powers a hurricane comes from a warm sea surface. And until we understood that's how hurricanes are driven, no one would have thought to go measure the sea temperature." ●