SPACE PHYSICS

Does the Sun Trigger Outbursts From Earth's Magnetosphere?

Whenever Earth's teardrop-shaped magnetic field swells with an extra-large load of energized particles, everyone from power-system operators to satellite controllers cringes in anticipation. At some point, the magnetosphere will dump this accumulated energy toward Earth in a short, disruptive burst called a substorm, causing auroras to flare, sending damaging currents through power grids, and disrupting satellites. The timing of these substorms is unpredictable, however. When magnetic havoc threatens, all space scientists can say is: Lie low.

They have their hands full, after all, just trying to predict when the turbulent wind of particles blowing out from the sun will energize the magnetic field in a days-long episode called a magnetic storm (*Science*, 1 March, p. 1231). Forecasting when the magnetosphere will dump its energy in sudden substorms is still more difficult, because researchers aren't even sure what triggers them. A dozen different models invoke some process deep within the magnetosphere, but there's no sign of a consensus about what that internal trigger could be. Now a lone researcher is arguing that substorms have an external trigger, located in the solar wind. If so, solar physicists monitoring the solar wind from spacecraft might issue warnings as much as an hour ahead of a substorm's onslaught.

"Until 2 years ago, all theories had substorms being an internal instability," says space physicist Lawrence Lyons of The Aerospace Corp. in Los Angeles. "My interpretation of the available observations is that in fact the external trigger dominates, although that's not proven at this point." Although a few studies had suggested that the solar wind could trigger substorms externally, "these were not considered seriously by the field; they were regarded as oddities." Now, by reevaluating old evidence, Lyons has generated an active debate over the external triggering idea.

Lyons's campaign for external triggering is "very healthy" for the field, says space physicist George Siscoe of Boston University. "It gives, for the first time I think, an opportunity for substorm models to be shaken out and tested quantitatively. If he's right, that's going to throw away a lot of models." It would also open the way for efforts to pinpoint just what change in the solar wind acts as the trigger. And, as Lyons points out, "if you understand the triggering mechanism and can measure it, you can predict [substorms]."

At the moment, all the models, including Lyons's, agree on only one thing—the source of the energy released in a substorm. The magnetosphere is like a balloon that can be inflated by an influx of energy from the solar wind. The solar wind can only blow into the magnetosphere, however, when the magnetic field that accompanies its charged particles points southward, enabling it to couple with Earth's northward field. The coupling unlocks the magnetosphere, allowing gusts of solar wind to inflate its tail and energize its trapped ions and electrons.

The models diverge, however, over what happens after this "growth phase," which loads the magnetosphere with energy. One alternative comes from researchers who have correlated substorms with the behavior of the solar wind, recorded by spacecraft outside the magnetosphere. They have noticed that substorms often seem to strike while the solar wind is blowing with a steady force and orientation. That, they say, implies that something inside the magnetosphere must trigger the substorms. The resulting models invoke some sort of local instability, like a weak spot in a balloon, that lets the stored energy burst Earthward in what is called the expansion phase of a substorm. But pinpointing the location and nature of such an instability has proven difficult, and competing models of an internal trigger have proliferated.

JACK FINCH/PHOTO RESEARCHERS

Substormy skies. Auroras flare when a magnetic substorm dumps energy into the upper atmosphere.

Lyons has made his own study of the published substorm observations and sees a different pattern—one that implies the trigger isn't an inherent weakness in the balloon but a pinprick from outside it. When he re-examined the substorm studies, he found that many of the supposed substorms were not substorms at all, he says. Instead, they were lesser disturbances that were misidentified as substorms based on data from just a single type of monitor, such as ground magnetometers. Substorms identified from enough different kinds of instruments to rule out any ambiguity, says Lyons, always coincided with a change in the solar wind, such as a reorientation of its magnetic field.

"Most, and perhaps all, substorm expansion phases are triggered by" changes in the solar wind, wrote Lyons in the 27 February issue of the weekly geophysics newspaper *Eos*. He proposes that after the growth phase has gone on for at least half an hour, any change in the solar wind that eases up on the push of energy into the magnetosphere—such as a shift in the magnetic field from southward back toward northward—allows the currents and fields in the magnetosphere to snap into a new pattern, triggering the auroras and other manifestations of a substorm.

"Most people are undecided" about the proposal, says Lyons. Some researchers who had already seen hints of external triggering in the data are seconding his claim, however. "There's ample evidence that lots and lots of substorm expansion phases are triggered externally," says Gordon Rostoker of the University of Edmonton in Canada. "I think most of them are triggered externally."

But Lyons's substorm proposal is meeting some head winds as well. In an effort to respond to Lyons's claims, Michael Henderson of Los Alamos National Laboratory and his colleagues searched a half-dozen different sorts of ground-based and satellite records. "We agreed with Lyons that maybe there was something wrong with [earlier analyses], so we scanned through quite a bit of data," says Henderson. But as they report in an upcoming paper in the *Journal of Geophysical Research*, "it seems pretty clear you can get true substorms during steady solar wind conditions," says Henderson, that is, without any apparent external triggering.

Lyons concedes that Henderson may have found two or three good examples that argue against an external trigger, out of the six he reported. "That's the first and only paper, in my opinion, that indicates there may be some substorms that are not [externally] triggered," says Lyons. But even if he has to concede a few cases, he says, "I would be perfectly content if my theory accounts for only half of the substorms. That would be a half more than all the other theories."

–Richard A. Kerr