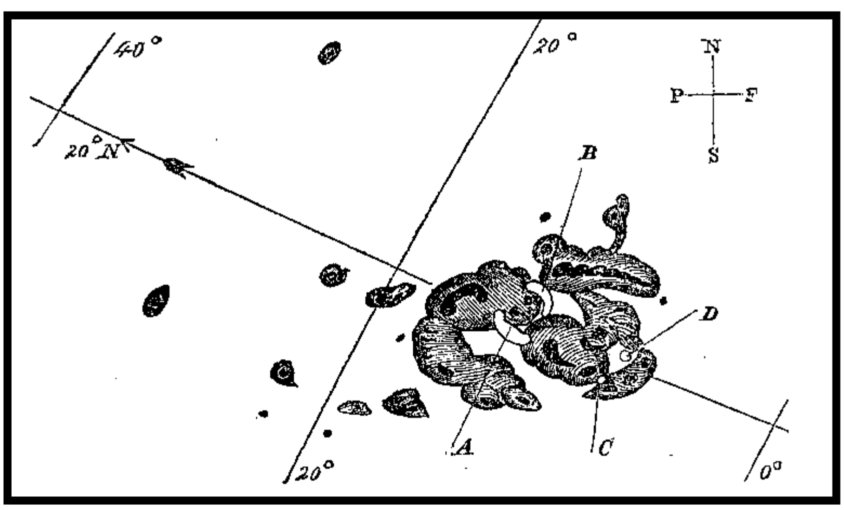
Natural Radio

News, Comments and Letters About Natural Radio

September 2011

On the first of September in 1859, Astronomer Richard Carrington was making his daily observation of sunspots. Solar cycle 10 was heading toward its peak, but as sunspot numbers went it was certainly unremarkable -- similar to our current cycle 24. Suddenly, Carrington saw something quite unusual in the projected image:

> "While engaged in the forenoon of Thursday, September 1, in taking my customary observation of the forms and positions of the solar spots, an appearance was witnessed which I believe to be exceedingly rare. The image of the sun's disk was as usual with me, projected onto a plate of glass coated with a distemper of a pale straw color, and at a distance and under a power which presented a picture of about 11 inches diameter. I had secured diagrams of all the groups and detached spots with the cross-wires used in the observation, when within the area of the great north group (the size of which had previously excited general remark), two patches of intensely bright and white light broke out, in the positions indicated on the appended diagram by the letters a and B, and of the forms of the spaces left white. My first impression was that by some chance a ray of light had penetrated a hole in the screen attached to the object-glass…"



On September 1–2, 1859, the largest ever recorded geomagnetic storm occurred. Auroras were seen around the world, most notably in Cuba and Hawaii; in Rocky Mountains the auroras were so bright that their glow awoke gold miners, who stoked up their campfires and began cooking breakfast because they thought it was morning.

Telegraph systems all over Europe and North America failed or worked erratically. Operators received shocks, with sparks jumping between pieces of apparatus and sometimes between the equipment and the operator. There were reports of papers and even offices catching fire. Some telegraph operators continued to send and receive messages despite having disconnected their equipment from the batteries.

Because of this storm and simultaneous indication observed in the Kew Observatory magnetometer near London recorded by Balfour Stewart, Carrington postulated a solar-terrestrial connection, and the investigation of space weather began.

A little over 150 years have passed since the Carrington Event. Scientists are well aware of the danger that an event of this magnitude presents. In 2008, NASA funded a study by the National Academy of Sciences entitled *Severe Space Weather Events—Understanding Societal and Economic Impacts*. In the 132-page report, researchers summarized what might happen to our modern, high-tech society in the event of a "super solar flare", similar to the Carrington Event, followed by a massive geomagnetic storm.

The report estimates that the economic impact on our economy of such a storm would exceed that of 20 Hurricane Katrinas. The major vulnerability is the electric power grid.

The report continues, "Electric power is modern society's cornerstone technology on which virtually all other infrastructures and services depend." The long transmission lines act like antennas and the induced current flow can actually melt the copper windings of transformers at the heart of many power distribution systems. A large-scale blackout could last a long time, because as the National Academy report notes, "these multi-ton transformers cannot be repaired in the field, and if damaged in this manner they need to be replaced with new units which have lead times of 12 months or more."

Our increasing demand for power in the last 50 years has caused the total length of high-voltage power lines crisscrossing North America to increase by nearly 10 times. Modern networks are sprawling, highly interconnected, and running at near capacity. This is a dangerous situation according to the National Academy of Sciences: "The scale and speed of problems that could occur on [these modern grids] have the potential to impact the power system in ways not previously experienced."

In addition to the catastrophic disruption of the power grid, satellite communications would be disrupted and at worst satellites rendered permanently inoperable. Planes and ships using GPS units for navigation would be without them. Banking, financial and communication networks might go offline, disrupting commerce, transportation and health care. And of course the Internet would be severely affected.

Accurate predictions are one of the keys to preventing damage, and some times our terms and classification systems haven't kept up with new understanding. As Natural Radio observers, we often use the K-index, which dates back to 1932 and is one of the oldest geomagnetic storm classification indices and is the familiar means of characterizing the severity of geomagnetic storms.

When I was researching some of the new trends in prediction I found the following critique of the K-index which is taken from *A Jointly-Commissioned Summary Report of the North American Electric Reliability Corporation and the U.S. Department of Energy's November 2009 Workshop.* (Note that the term dB/dt is the rate of change of the magnetic field, usually measured in nano-Teslas per minute.)

> This index varies over a range from 0 (minimal or no geomagnetic disturbance) to 9 (highest class of geomagnetic disturbance) in threshold steps. This index was derived in an era of paper charts used for recording geomagnetic disturbances at remote observatories and with minimal data communication capability. This approach allowed a simple numerical classification to be collected from multiple observatories to describe not only the local variation in the geomagnetic field but also to develop a global sense of the severity of the storms. NOAA and other agencies around the world primarily focus their geomagnetic storm forecast and alert products on the KIndex.
>
> The design and use of the K-Index has limitations in its application, some of the most important of which are summarized as follows:
>
> - The index saturates at K9 at a low threshold and is not able to indicate levels of severity and intensity that would be important to power system operators. Therefore it blurs intensity and is unable to communicate the extremes of the storm environment.

- The index is only determined once in each 3 hour time block (e.g., eight times per day). Therefore, it also blurs the time-specific details of impulsive disturbances and does not provide sufficiently granular time information to power system operators.

- At U.S. latitudes, the K9 threshold is reached at only a minimum 500 nT variation over a three hour window. This means for slow variations, the dB/dt could be as low at three nT/min, while for very fast and intense variations, the dB/dt is infinite. Therefore the K9 intensity in terms of dB/dt is highly ambiguous.

- The K-Index also cannot be reverse engineered to derive dB/dt from prior storms, therefore it has limited forensic value to provide meaningful comparisons with older storms.

> The K-Index is subject to saturation and widening dB/dt ambiguity at high K levels. It is only areliable indicator of less-severe geomagnetic disturbance levels and periods of very low dB/dt and essentially no GIC. In contrast, the K-Index becomes increasingly ambiguous with respect to the GIC or dB/dt threat as the storm increases in intensity. Additional clarity and granularity of information about these threat levels in intense environments will be vital to improving situational awareness by infrastructure operators that are concerned about GIC. When evaluating the design and performance of power systems, the design challenge is one of countering the severe threats and, for these purposes, a clear definition of the maximum threat environments cannot be readily derived from any historical K-indices. The rate of change of B (or dB/dt in at least a cadence of nT/min) is a reliable proxy for GIC, in that, all other things being equal, the larger the absolute value of the dB/dt the larger the relative levels of GIC. The K-Index cannot be reliably tracked to dB/dt, especially for intense storm levels.

So it will be interesting to see what new method of classifying geomagnetic activity develops. The 2009 report made no suggestions, and there were none apparent in a Google search. But, as models and research progress, it’s inevitable that a more accurate system will emerge.

But as our terminology tries to catch up, understanding and research move ahead. In June, members of US Congress, FEMA, power companies, the United Nations, NASA, NOAA and more, met for the fifth annual Space Weather Enterprise Forum—"SWEF" for short. SWEF was designed to raise awareness of space weather and its effects on society particularly among policy makers and emergency responders.

SWEF believes that their educational mission is key to storm preparedness. Lika Guhathakurta and colleague Dan Baker of the University of Colorado asked in a June 17th New York Times op-ed: "What good are space weather alerts if people don’t understand them and won’t react to them?"

"This is a really exciting time to work as a space weather forecaster," says Antti Pulkkinen, a researcher at the Space Weather Lab. "The emergence of serious physics-based space weather models is putting us in a position to predict if something major will happen."

The computer models are getting so sophisticated, that they can even predict ground currents flowing in the Earth when a geomagnetic storm hits. As mentioned earlier, these currents are deadly to power transformers.

An experimental project named "Solar Shield" led by Pulkkinen hopes to identify the transformers in greatest danger of failing during a given storm. Knowing when and where the currents will develop will allow engineers to disconnect vulnerable transformers from the grid. While this might cause a temporary blackout, the transformer could be re-activated immediately after the storm abated.

Pulkkinen explains how this prediction system works:

"Solar Shield springs into action when we see a coronal mass ejection (CME) billowing away from the sun. Images from SOHO and NASA's twin STEREO spacecraft show us the cloud from as many as three points of view, allowing us to make a 3D model of the CME, and predict when it will arrive."

This data, as well as data from the ACE satellite, such as measurements of the CME's speed, density, and magnetic field are transmitted to Earth and the scientific team at Solar Shield..

"We quickly feed the data into CCMC computers," says Pulkkinen. "Our models predict fields and currents in Earth's upper atmosphere and propagate these currents down to the ground." With less than 30 minutes to go, Solar Shield can issue an alert to utilities with detailed information about GICs (Geomagnetically Induced Currents).

Pulkkinen cautions that Solar Shield is experimental and hasn't been field-tested during a severe geomagnetic storm. A small number of utility companies have installed current monitors at key locations in the power grid to help the team check their predictions and the team is waiting for the inevitable storms as we move up cycle 24 to check their data.

And the data that Solar Shield has to work with just got better. On August 18th, NASA hosted a news briefing in Washington to discuss new discoveries about the structure of solar storms and their impact on earth. The new data comes from NASA's Solar Terrestrial Relations Observatory, or STEREO, spacecraft and other NASA probes.

New processing techniques used on STEREO data allow scientists to see how solar eruptions develop into space storms at the Earth. The storms, called Coronal Mass Ejections, or CMEs, are observed from NASA's twin Solar Terrestrial Relations Observatory spacecraft launched in 2006. STEREO's two observatories orbit the sun, one ahead of Earth and one behind. They will continue to move apart over time. The data now reveals a clear and detailed look at a storm's front from the as it leaves the sun, all the way to Earth, thus reducing uncertainty of its arrival time.

STEREO Program Scientist, Lika Guhathakurta, said, "With STEREO's five telescopes today, we are actually witnessing the Solar Wind, we can see them -- Solar wind and Solar Storm, blowing all the way from Sun to Earth. The clarity these new images provide will improve the observational inputs into space weather models for better forecasting"

The imagery of earlier spacecraft did not clearly show the structure of a solar disturbance as it traveled toward Earth. As a result, forecasters had to make their best estimate of when storms would arrive without knowing the details of how they evolve and grow.

Craig DeForest, a scientist with the Southwest Research Institute in Boulder Colorado said, "We have been drawing pictures of structures like these for several decades. Now that we can see them so far from the sun, we find there is still a lot to learn. For the first time, we've been able to image a Coronal Mass Ejection with a lot of detail and a photometric quality, all the way through its entire life cycle."

The newly released videos from cameras on the STEREO-A spacecraft show detailed features in a large Earth-directed CME in late 2008, from its ejection from the sun's corona through its journey across space, and its intricate collision with the earth's magnetic field three days later. When the data were collected, the spacecrafts were more than 65 million miles away from Earth.

You should definitely go to NASA’s STEREO site and have a look at these movies. We have all imagined the progress of a CME as it was ejected from the sun until it finally collides with earth and makes lots of nice aurora and VLF emissions. Now you can see how it actually happens.

A major problem that the scientists had to overcome was that while CMEs are bright when they leave the sun, as they expand into the void on their earthward journey, the clouds are about one thousand times fainter than the Milky Way. This makes direct imaging of them extremely difficult and new image processing techniques had to be developed to make them visible.

This new data from STEREO can accurately indicate not only the arrival time of the CME, but also its mass. By measuring the brightness of the cloud, the researchers were able to calculate the cloud's gas density throughout the CME as the cloud moved toward earth, and compare it to direct measurements by other NASA spacecraft such as ACE. In the future, with this new technique, forecasters will be able to predict with confidence the size of the cloud about to impact the earth, and where on the sun the material originated.

So, what’s the chance of another storm the size of the Carrington Event? It’s not a matter of “if”, but “when”. The results of an event of this type could be catastrophic without preparation. And the human tendency is to pretend that these rare events won’t ever happen. Why do we build and re-build cities in low-lying areas that are prone to Hurricane surges? Why do we build nuclear plants in low areas that are prone to earthquakes and the often resultant Tsunamis? Hindsight is always 20/20, but at least there are programs like Solar Shield and conferences like SWEF looking at preventive actions for the next big solar storm.

We could live for a while without cell phones and cable TV, but the results of an extended widespread electrical outage would be disastrous. I bought a generator this summer after the second major power outage we had in a year. A few weeks later we had a third. In the 27 years we have lived in this house, these were that first failures that exceeded a couple of hours. The generator runs the sump pumps and keeps me from flooding and keeps the food in the refrigerator from spoiling. It’s not large enough to run the well, so we are without water and consequentially without flush toilets.

Since this happened in the summer, it was really just an inconvenience. In the winter, it could have been a disaster. Those without electricity would be without heat also. In a widespread outage, gas stations would not be able to pump gas so even those with gasoline generators would be without power in a day or two.

Let’s hope our utilities are taking the threat seriously and putting the proper protections into our aging electrical grid to minimize damage.

Fortunately, the new tools we’ve developed with STEREO and other satellites, will give us prediction capabilities far beyond what we’ve had in the past. Let’s just hope that NOAA and NASA don’t lose that funding for these crucial programs due to scientifically ignorant Congressmen with political agendas that deem these programs “wasteful”. Let’s hope that those in Congress who attended the SWEF event this summer will maintain and increase the funding for these important programs.