U.S. Senate Committee on Homeland Security and Government Affairs
Roundtable: Perspectives on Protecting the Electric Grid from an Electromagnetic Pulse or Geomagnetic Disturbance
Statement by Dr. Justin Kasper (University of Michigan)

Introduction

Chairman Johnson, Ranking Member Peters, and members of the Committee, thank you for this opportunity to discuss what we know about the solar origin of geomagnetic disturbances (GMD) and how we can improve our ability to predict their occurrence.

The most famous example of a solar GMD began on September 1, 1859, when an intense solar flare produced a visible white flash directly observed by the astronomer Carrington. Just 18 hours later material from the solar atmosphere released after the flare slammed into Earth at about three million miles an hour. Earth was engulfed in a magnetic tsunami from the Sun that sent compasses spinning, brought the Northern lights down into the Caribbean, and set telegraph lines sparking, rendering them inoperable for days. We might not rely on telegraph today but our power lines are equally susceptible. The potential nation-wide and even world-wide loss of power due to a Carrington-level event and the resulting economic and societal impact are why we are here today.

The risk is real and unfortunately the Carrington event was not unique. On July 23, 2012 a spacecraft operating on the other side of the Sun was immersed in a similar eruption that would have hit Earth square on if it had happened nine days sooner. Multiple researchers estimate the probability of a similar event happening in any decade at between 3 and 10 percent. I would like to stress that in addition to these extreme events, smaller but more frequent GMDs are estimated to cause an average of $10 billion in damage each year. Address the major GMDs and we can also protect us from these smaller events.

What can we do about this? Right now telescopes detect an eruption at the Sun and we make a forecast by simulating its expansion into space, but we do not have confirmation of a threat to Earth until it reaches the NOAA DSCOVR spacecraft floating one percent of the way towards the Sun. Any warning is better than none, but an extreme event would get from the spacecraft to Earth in less than ten minutes. This is not enough time to assess the risk and recommend action. We need spacecraft closer to the Sun providing earlier warning of Earth directed events and their properties, better models of these eruptions and regional forecasts of GMD. Most importantly we need leadership with a mandate to coordinate and direct the research and operational components of space weather that are spread over multiple agencies.

Overview

My written testimony is organized to address the following three questions.

1. How do public and private sectors evaluate the likelihood and magnitude of these events?
2. Is there ongoing research to help us better understand the solar phenomena that lead to space weather impacts on Earth?
3. How can current National Oceanic and Atmospheric Administration (NOAA) and/or National Aeronautics and Space Administration (NASA) programs improve GMD forecasting, mitigation, coordination, and response efforts?

1. How do public and private sectors evaluate the likelihood and magnitude of these events?

Evaluating the likelihood and magnitude of the most severe GMDs is challenging because the detailed record of direct observations only extends back half a century to the start of the space age, and because we are still in the early phases of understanding what aspects of a solar eruption and the Earth determine the severity of the resulting GMD. We are also still learning about the impacts of GMDs. For example an extreme space weather event in August 1972 known for its speed and intense particle radiation, did not generate a particularly large global GMD, but did produce a magnetic disturbance in Asia so strong that it spontaneously detonated dozens of sea mines south of Hai Phong, North Vietnam on 4 August 1972.[1] Within the research community the most accepted estimates of the probability of an extreme GMD are based on an analysis of the occurrence rate of historical GMDs as a function of severity, fit to a statistical model, and then evaluated at the extreme.[2] Quoting the Riley et al. (2018) study,

> Based on these results, our best estimate for the probability of another extreme geomagnetic event comparable to the Carrington event occurring within the next 10 years is 10.3% with 95% confidence intervals (CI) in the range [0.9,18.7] for a power-law distribution, but only 3.0% with 95% CI [0.6,9.0] for a log-normal distribution (see also Riley and Love 2017). Our results, however, depend on: (1) how an extreme event is defined; (2) the statistical model used to describe how the events are distributed in intensity; (3) the techniques used to infer the model parameters; and (4) the data and duration used for the analysis.

Thus depending on assumptions about the distribution of events the probability of an extreme Carrington level event within the next ten years ranges from 3% to 10%.

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[1] Knipp, D. J., Fraser, B. J., Shea, M. A., and Smart, D. F. (2018). On the little-known consequences of the 4 August 1972ultra-fast coronal mass ejecta: Facts, commentary, and call to action.SpaceWeather,16, 1635–1643.

[2] Riley, P., Baker, D., Liu, Y.D. et al. Space Sci Rev (2018) 214: 21. https://doi-org.proxy.lib.umich.edu/10.1007/s11214-017-0456-3. P. Riley, J.J. Love, Extreme geomagnetic storms: probabilistic forecasts and their uncertainties. Space Weather 15(1), 53–64 (2017)

In order to test these estimates other researchers are trying to increase the number of large events in the record by either looking at ancient records of activity earlier in Earth's history, or by simultaneously monitoring many other starts like our own Sun for large flares.

Large solar flares and coronal mass ejections can produce elevated levels of high energy particle radiation in space, factors of millions or more above typical levels. This level of particle radiation can cause measurable changes in the isotopic and chemical composition of the atmosphere which then are preserved through snowfall in undisturbed ice or ancient tree rings for millennia. Ice core samples in Greenland and Antarctica have been used to search for extreme events in the more distant past, although signals from other events such as major volcanic eruptions have made them hard to interpret. An isotopic analysis of tree rings has found elevated spikes in the level of the isotope Carbon-14 in the years 774 AD and 993 AD which may have been due to extreme solar events.[3]

In addition to calculating the probability of an extreme GMD, there have also been efforts to estimate the cumulative impact of smaller but more frequency GMDs. For example, Zurich Risk Engineering recently published an examination of over 11,000 insurance claims submitted by North American commercial organizations from 2000 through 2010 for equipment losses and related business interruptions associated with damage to, or malfunction of, electrical and electronic equipment.[4] The claims were then correlated with the level of geomagnetic activity. There is a very clear association, with claims up 20% for the top 5% most geomagnetically active days. This amounted to about $2B in claims over a decade seen by this one insurance company due to GMD induced electrical damage. Given that this insurance company only covers 8% of the market this suggests that GMD could be responsible for $2B a year in commercial property damage in the US.

2. Is there ongoing research to help us better understand the solar phenomena that lead to space weather impacts on Earth?

For reasons we do not yet fully understand the corona or extended atmosphere of our Sun is nearly 1000 times hotter than its surface. This million degree atmosphere is unstable and produces supersonic jets of plasma called the solar wind that expand into space and flood the solar system with particles and magnetic fields. Occasionally a highly magnetized region in the corona will erupt into space. These eruptions as called coronal mass ejections (CMEs) and they can produce the high speeds and magnetic fields that cause the most extreme GMDs. Variation in the solar wind over time and as the Sun rotates every 27 days can cause the Earth to be

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[3] F. Miyake, K. Nagaya, K. Masuda, T. Nakamura, A signature of cosmic-ray increase in AD 774–775 from tree rings in Japan. Nature 486(7402), 240–242 (2012). F. Miyake, K. Masuda, T. Nakamura, Another rapid event in the carbon-14 content of tree rings. Nat. Commun. 4, 1748 (2013). F. Miyake, K.Masuda,M. Hakozaki, T. Nakamura, F. Tokanai, K. Kato, K. Kimura, T. Mitsutani, Verification of the cosmic-ray event in AD 993–994 by using a Japanese Hinoki tree. Radiocarbon 56(3), 1189–1194 (2014)

[4] Dobbins, R. and K. Schriiver, Electrical claims and space weather. Measuring the visible effects of an invisible force, June 2015

bathed in changing speed solar wind, which can also trigger smaller GMDs. The Earth is surrounded by the ionosphere, a region of space that contains charged particles and electric and magnetic fields. The ionosphere is surrounded by a region of space controlled by the magnetic field of the Earth, the magnetosphere. The magnetosphere and ionosphere are continually bathed in large fluxes of radiation, energetic particles and mass from the Sun. The conditions and changes in both these regions of space are referred to as space weather. As with terrestrial weather, space weather can often result in severe dynamic events, storms in space, many of which result in severe operational consequences for satellites and our technological infrastructure on the ground. Some of these events have the potential for catastrophic damage. A recent review of all research into the Sun and space weather can be found in the comprehensive 2013 National Academy of Sciences Decadal Strategy for Solar and Space Physics.[5] For a review of the state of the art in space weather research a recent special collection in Space Science Reviews titled "The Scientific Foundation of Space Weather" has a comprehensive review.[6]

New research capabilities that are posed to transform our understanding of the connection between the Sun and the Earth include the recently launched Parker Solar Probe mission in 2018.[7] This spacecraft will repeatedly plunge into the extended atmosphere of the Sun, collecting the first direct observations of how the corona is heated and the solar wind accelerated, and directly observing coronal mass ejections as they erupt into space.[8] Parker Solar Probe will be joined next year by the Solar Orbiter mission, which will not get as close to the Sun but will image the surface at high resolution. Closer to Earth, the recently launched GOLD mission and the upcoming ICON mission monitor the response of Earth's upper atmosphere to changes in solar input. The community eagerly awaits the completion of the Daniel K. Inouye Solar Telescope (DKIST) solar telescope in 2020 and its unprecedented ability to image activity on the surface of the Sun and in its corona.

3. How can current National Oceanic and Atmospheric Administration (NOAA) and/or National Aeronautics and Space Administration (NASA) programs improve GMD forecasting, mitigation, coordination, and response efforts?

As is often the case, the distribution of work across multiple agencies can hinder progress. In the case of space weather research a major challenge is that it is difficult for NOAA to fund basic research that could translate into operational capability, or to fund the transition of a research product (such as a simulation of a solar eruption, or a model of economic impact) into an operational capability. Similarly NASA and the NSF are well-posed to support cutting edge

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[5] National Research Council. 2013. Solar and Space Physics: A Science for a Technological Society. Washington, DC: The National Academies Press. https://doi.org/10.17226/13060.

[6] The Scientific Foundation of Space Weather, Space Science Reviews (2018), ISSN: 0038-6308 (Print) 1572-9672 (Online).

[7] Fox, N.J., Velli, M.C., Bale, S.D. et al. Space Sci Rev (2016) 204: 7. https://doi.org/10.1007/s11214-015-0211-6

[8] Kasper, J.C., Abiad, R., Austin, G. et al. Space Sci Rev (2016) 204: 131. https://doi.org/10.1007/s11214-015-0206-3

science and technology development, but are generally not in a position to fund the kind of long term monitoring of conditions needed to develop and test forecasting tools. This makes it very difficult for a researcher to develop a new observational capability specifically to improve space weather awareness, or for a modeler or theorist to maintain or extend computer simulations to improve forecasts. One or more agencies must either be given the mandate to foster the transition from research to operations or a managing authority must have the mandate to coordinate this work across agencies.

Our current capability to forecast space weather is decades behind our capability to predict terrestrial weather. This is largely because there are significant aspects of the underlying physics that governs the solar atmosphere and interplanetary space – plasma physics – that we do not sufficiently understand, because our observational view of the connection between the Sun and the Earth is incomplete, and because what we do understand or can predict has not been converted into an operational capability. Over the space age, we have accumulated extensive knowledge of the regions of space surrounding the Earth and the Sun, and the governing physical processes operating in these regions. However, this knowledge, with exceptions, has not fully translated into a systematic operational forecast capability that informs the users of space weather data on timescales sufficient to take appropriate actions, whether for day-to-day operations or to protect against catastrophic events.

What is required is to increase the warning time for when a CME strikes Earth and the probability of it causing a GMD from tens of minutes to at least ten hours for the most extreme events. This would give us time to produce a regional forecast of the resulting GMD and other space weather effects, with sufficient time to make an informed decision whether to take active measures to protect the grid. In order to accomplish this we need (1) new and more capable observations from satellites strategically located to observe the Sun; (2) improved understanding and models that allow us to determine the ambient conditions in the space environment between Sun and Earth and the evolution of CMEs during their transit; (3) improved methods of assimilating the data from the new observations into the models; and (4) improved understanding of the response of the Earth's magnetic field to the impact of a CME to correctly predict the resulting GMD.