Emerging Risk Landscape

Title: Space Weather

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Date : January 7, 2022

Emerging Risks

Extreme emerging risks are risks that are considered greater than the ability of a single organization to cope with or risks that requires a State level response. Extreme risks such as pandemics, solar storms, multiple and severe weather events, mass cyber-attacks, volcanoes with global impact, large scale terrorist attacks and emerging technologies come in a variety of discrete, linked, compound and cascading [1] events. [2]. For example, different parts of the world are experiencing certain effects of climate change, including high and low temperature extremes and heavy precipitation events. These trends are expected to continue and rise in intensify[3], likely resulting in more severe and frequent climate discrete events (e.g., droughts, sea level rise,), compound disasters (e.g., extreme rainfall combined with coastal flooding), and cascading events (e.g., landslide following wildfires),[4].

Moreover, The likelihood that these events manifest over a short period of time is very low. But the downstream, knock-on consequences and the range of triggered, linked and compound risks and cascading consequences they set in motion is complex. These risks tend to cause similar consequences such as global travel disruptions, or a failure of a nations electric power distribution systems, with knock-on effects on food, energy, transportation and medical supply chains. For example, a large solar storm causing a prolonged failure of a nations electricity transmission system would inevitably have repercussions for a wide range of businesses and services, from disruptions to energy supplies, water processing, traffic control and logistical systems, in addition to potential failure of global positioning systems (GPS), and even parts of the finance sector that relies heavily on millions of electronic transactions on a daily basis.

[1] Susan L. Cutter , Compound, Cascading, or Complex Disasters: What's in a Name?(accessed July 28, 2021)

[2] ***Linked Risks***; are risks that have the same cause; for example in 2010, the same meteorological weather anomaly over Russia sparked extreme heat and persistent wildfires in Russia as well as heavy rainfall fuelling heavy flooding in Pakistan. ***Compound risks*** are risks that have independent causes but their effects join together in a certain risk context and amplify the consequence(s) For example, the ongoing Corona-virus and recent European floods in U.K., Germany , Netherlands and other parts of Europe. ***Cascading events*** occur when a primary risk triggers primary, secondary and higher order consequences that snowball

[3] " Europe floods: Rescuers race to find survivors as hundreds remain missing ". BBC NEWS. JULY 2021"(accessed July 28, 2021)

[4] "Special Report of the Intergovernmental Panel on Climate Change, Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation."' (accessed July 28, 2020)

SPACE WEATHER AS AN EMERGING RISK

Space Weather, [5]. [6] events such as Coronal Mass Ejections (CMEs), Solar Energetic Particle Events (SEP), Solar Radio Bursts, and Solar Flares[7] , are naturally occurring phenomena, and a global threat with the potential of affecting many regions and countries simultaneously. These events [8] cause rapid change in Earth's magnetic field inducing electric fields that can damage a country's power grid and telecommunication systems and the critical infrastructure underpinning a country's security and economic vitality. The U.K met [9] office describes space weather as: *"changing environmental conditions in near-Earth space. Magnetic fields, radiation, particles and matter, which have been ejected from the Sun, can interact with the Earth's upper atmosphere and surrounding magnetic field to produce a variety of effects " .*

Space weather events have the potential to cause major socio-economic disruptions and loss of life; and they have a high probability of occurring during a human lifespan, but not frequently. Space weather is a known emerging risk but also can be seen as a Black Swan risk, because of the the fact that our experience of space weather events is novel. We simply do not know with a high degree of confidence the range of *probable* events that might occur in space triggered by the Sun, which have a direct effect on Earth. Furthermore, many, if not all of the mechanisms that happen locally on the Sun's disk, and internally are unknown, and all current models trying to explain why violent bursts occur on the Sun are all hypothesis leading to possible reason(s), but all these potential explanations remain in the realm of *conjecture*.

Historically, the Carringtonr[10] event in 1859, named after the British astronomer who first witnessed the solar activity, was the most severe space weather event recorded. The Carrington event was a CME that caused global disruption to telegraph systems around the world. Moreover, in 1989 , a geomagnetic storm caused by a CME caused Quebec's power grid to collapse within seconds, affecting several million people for nine hours. In 2003, space weather caused an hour-long power outage across Sweden and also South Africa. Likewise, On 23 July, 2012 [11], a powerful coronal mass ejection (CME) tore through Earth's orbit. Fortunately, it narrowly missed Earth. Scientists estimated[12]that the strength of the event was two or three times stronger than the Carrington event[13] , which caused damaging currents in telegraph wires around the world. A 2013 study estimated that the U.S. would have suffered between $600 billion and$ 2.6 trillion in damages, particularly to electrical infrastructure, such as power grid, if this CME had been directed toward Earth. In the same way, according to space weather on April 19, 2021, an M-class solar flare erupted causing a shortwave radio blackout over the Pacific Ocean.

[14].

According to a 2013 report by Lloyd's of London , the report predicts that a Carrington–level solar storm is almost inevitable in the future. The risk of an extreme geomagnetic storm becomes

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[5]"Parliamentary Office of Science and Technology, Space weather, ,POSTnote 361, July 2010" (accessed July 28, 2021)

[6]" Extreme Solar Particle Storms: The Hostile Sun, Edited by Fusa Miyake, Ilya Usoskin, Stepan Poluianov, IOP publishing, Bristol UK, 2020." (accessed July 28, 2021)

[7]"Space Weather, The Classification of X-ray Solar Flares" (accessed July 28, 2021)

[8] " NASA: The Day the Sun Brought Darkness' '(accessed July 28, 2021)

[9] " Space Weather' '(accessed July 28, 2021)

[10] " A Super Solar Flare, NASA Science News, 6 May 2008, nasa.science.gov , ' '(accessed July 28, 2021)

[11] "Near Miss: The Solar Superstorm of July 2012 " (accessed July 28, 2021)

[12] " Solar Storm Risk to the North American Electric Grid " (accessed July 28, 2021)

[13]James L. Green, Scott Boardsen , Duration and extent of the great auroral storm of 1859

[14]"J. P. Eastwood, E. Biffis M. A. Hapgood,L. Green,M. M. Bisi, R. D. Bentley, R . Wicks, L. A. McKinnell, M. Gibbs, and C. Burnett, The Economic Impact of Space Weather: Where Do We Stand?: The Economic Impact of Space Weather", (accessed August 02, 2021)

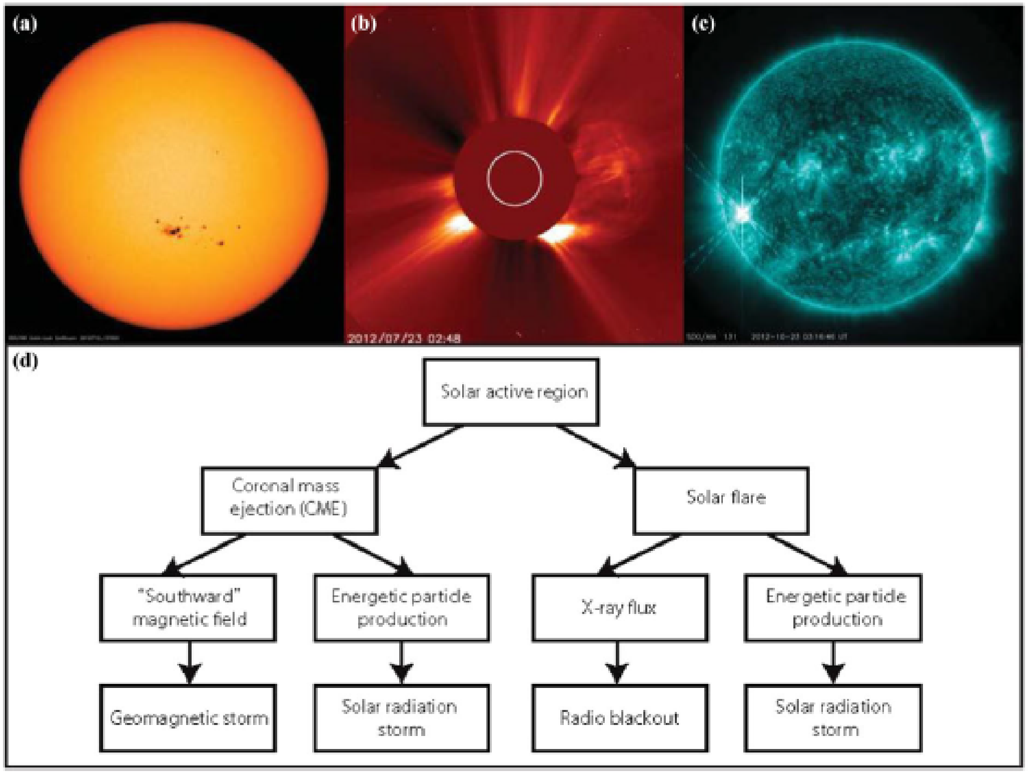

Fig. 1. (a) Image of sunspots on the solar disk from NASA's Solar Dynamics Observatory on July 12, 2012. The grouping of sunspots was associated with active region 1520. (b) CME launched from active region 1520 on July 23, 2012 and observed by the European Space Agency/NASA Solar and Heliospheric Observatory (SOHO) (Image credit ESA/NASA/SOHO). (c) X-class flare observed by NASA's Solar Dynamics Observatory on October 22, 2012 at 131 Angstrom wavelength, which caused an R3 radio blackout (Image credit: NASA/SDO/Goddard). (d) Solar active regions produce CMEs and solar flares, which are subsequently responsible for the three primary categories of space weather as indicated here and in the text.

Figure 1: Source:NASA. Space Weather Events

elevated as the sun approaches the peak of its $11-12$ year solar cycle [15]. The current solar cycle 25 is expected to peak around $2024-2025$, where solar activity will reach its maximum during this solar cycle. Therefore a potential repeat of a Carrington event will have severe economic and societal consequences potentially more disruptive than the ongoing pandemic.

According to NASA the Sun formed about 4.5 billion years ago. Our current experience and data collected on the Sun's activity goes back about only 300 years. For example, data collected on Sun-Spots goes back to 1700 [16]. So we can't say with certainty that our scientific knowledge about the range of phenomena caused by violent bursts on the Sun is complete, and we don't have reliable evidence to draw any valid and cogent conclusions on what might the Sun do next. We know that the Sun's activity is governed by a roughly 11.5 year Sun cycle with **variable intensity**, during which solar flares, and other events occurring on the Sun's disk are at a maximum, roughly, half way through the Sun Cycle, and we also know that there is a potential empirical link between solar system planetary configuration- taking the Sun as the centre, in terms of geometry of planetary positions, velocities, accelerations, and jerks, in relation to the Sun and Earth facing region of the Sun disk, and, particularly the alignment between planets Venus, Earth, and Jupiter[17] in driving

[15] " Overlapping Magnetic Activity Cycles and the Sunspot Number: Forecasting Sunspot Cycle 25 Amplitude' '(accessed July 28, 2021)

[16] " Royal Observatory of Belgium ,Silso, Sun Spot Index and Long Term Solar Observation' '(accessed July 28, 2020)

[17] "Planetary Orbits May Explain Mystery of Sun's 11-Year Cycle' '(accessed August 02 , 2021)

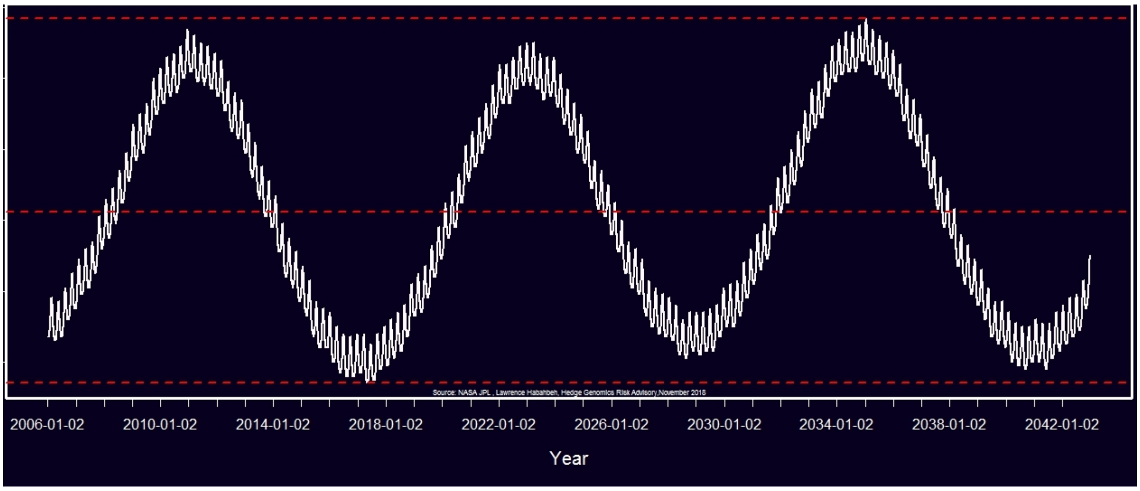

Figure 2: Source: Lawrence Habahbeh. $11 - 12$ Year Solar Cycle

solar flares and CMEs, leading to solar wind and solar energetic particles interacting with Earth's magnetic field, causing a range of complex phenomena (geomagnetic and radiation storm, etc), around, and, on our planet, penetrating down to the lower Earth's atmosphere and surface.

These events are present all the time but at low levels that pose little to no risk to well designed technologies and human health. They become a significant risk when violent bursts on the sun lead to severe space weather environments[18] at and near Earth, amplifying the intensity of events that might lead to power grid, satellite and communication systems failures, but that's as far as it goes with our scientific knowledge about solar weather events and their associated effects near and on Earth. Likewise, in terms of the *likelihood* of these events, there is a wealth of scientific evidence that indicates that severe space weather events can occur on time scales of $1 - 10$, $1 - 100$, and $1 - 1000$ years, with increasing impacts. Well documented major events in the previous century including those in 1921[19] , 1956[20] , 1967[21] , 1972 [22] and 1989 [23] . The largest of these events was the event in 1921, where new evidence indicates that it was comparable in severity to the 1859 Carrington event. These events caused significant disruptions to the technologies available in that historical epoch.

Moreover, new data collected over the past decade provide strong scientific evidence for severe space weather over time scales of $1-1000$ years. This evidence comes from "cosmogenic isotopes " [24] measurement of tree rings and ice cores, indicating that severe weather events occurred in 660 BCE, CE $774/775$, CE $993/994$. These isotopes are generated in earth's upper atmosphere when particle radiation from space converts Oxygen, Nitrogen, and Aragon into rare isotopes. These Isotopes fall to earth and some are trapped in tree rings and ice cores. When Earth is exposed to intense radiation as a consequence of severe space weather, the amount of these rare isotopes trapped in tree rings and ice cores also increases, indicating a severe space weather event.

[18] " Summary of space weather worst-case environments (2nd revised edition) RAL Technical Report RAL-TR-2020-005' " (accessed July 28, 2021)

[19] " The great storm of May 1921: An exemplar of a dangerous space weather event' " (accessed July 28, 2021)

[20] " The solar-terrestrial event of 23 February 1956' " (accessed July 28, 2021)

[21] " The May 1967 great storm and radio disruption event: Extreme space weather and extraordinary responses" (accessed July 28, 2021)

[22] " On the little-known consequences of the 4 August 1972 ultra-fast coronal mass ejecta: Facts, commentary, and call to action' " (accessed July 28, 2021)

[23] "A 21st century view of the March 1989 magnetic storm" (accessed July 28, 2021)

[24] "M. LOCKWOOD, WHAT DO COSMOGENIC ISOTOPES TELL US ABOUT PAST SOLAR FORCING OF CLIMATE¿' (accessed July 28, 2021)

Conclusion

Although we have collected an extensive dataset on the sun's activity for the last decades, we still have limited scientific knowledge about space weather risk, limited by current basic scientific understanding of the physics of the sun, and the underlying mechanism(s) responsible for the production of a range of space weather events, in addition to the limited scientific knowledge on the interaction between the interplanetary medium with earth's magnetic field. Therefore, The data set is still insufficient to address open questions related to extreme solar eruptive events such as: ***what is considered an extreme solar event? How strong can an extreme solar event be? How often do they occur? What can be the worst-case scenario for such an event?*** . Finding answers to these pressing questions is crucial for both academic science and practical applications.

For this reason, any statistical estimate of the probability of this **high-uncertainty** risk (*risks where estimating the likelihood is difficult due to lack of a reliable historical record and limited knowledge of the mechanism driving the dynamics of the risk process, in this case the Sun's activity*) occurring over a short period of time is immersed in uncertainty, because any threshold applied to assess the likelihood of occurrence of this type of risk is based on a *central assumption* that a **reasonably accurate estimate of the likelihood** can be generated. Moreover, this limited knowledge and lack of a consensus view on extreme solar eruptive events, their occurrence probability and consequences, renders this type of risk a top priority risk, because it can happen **anytime**.

For the practical management of space weather risk, the best defence is to increase the resilience of essential infrastructure and services in addition to improving the ability to anticipate, prepare for, respond to and recover from these risks by looking at a reasonable range of worst case scenarios based on the most likely trajectory of the primary and secondary linked, and compound risks, and common consequences triggered by these events.