SPACE WEATHER APPLICATIONS OF GEOMAGNETIC OBSERVATORY DATA

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SUMMARY

Solar maximum is expected between late 2012 and early 2014. Space weather impacts on worldwide technological infrastructures are therefore likely to be at their greatest at this time. These infrastructures include power grids, pipelines, railways, communications, satellite operations, high latitude air travel and global navigation satellite systems. For example, severe magnetic storms in March 1989 and October 2003, near the peaks of previous solar cycles, were particularly significant in causing problems for a wide variety of technologies. Further back in time, severe storms in September 1859 and May 1921 are known to have been a problem for the more rudimentary technologies of the time. In this paper we review examples of these impacts, what scientific research and measurement is underway, or is still needed, and how the geomagnetic observatory community can best contribute to the ongoing efforts in developing new space weather data products. Throughout, the need for near to real-time observatory data and products to help space weather forecasters and to serve industry and government is emphasised. We also discuss how industry perceives the space weather hazard, using examples from the electrical power industry, concerned with the risk to high voltage transformers and the safe and uninterrupted distribution of electrical power.

1. INTRODUCTION

Space weather can be defined as disturbances in the solar wind that can affect Earth’s space, atmosphere and surface environments and that can disrupt technologies. The Sun has a magnetic activity cycle, as measured by sunspots, of approximately eleven years. Solar magnetic activity takes the form of coronal mass ejections (CMEs) and coronal holes. CMEs (see Figure 1) are particularly significant for ‘bad’ space weather, when they are Earth-directed. A CME is a plasma cloud threaded by magnetic fields that is ejected from the Sun with speeds from a few hundred to a few thousand kilometers per hour. Its impact on the Earth’s magnetosphere (see Figure 2) depends on whether the magnetic field in the CME is southwards pointing. In a southward configuration magnetic reconnection on the dayside of the Earth, between the magnetic fields of the CME and the magnetosphere, allows the energy and plasma of the CME to enter the magnetosphere. This boosts current systems within the magnetosphere (Figure 2), resulting in geomagnetic storms when the ring current is strengthened. Geomagnetic sub-storms occur when the magnetospheric convection that is controlled by the solar wind concentrates magnetic flux in the magnetotail. This gives rise to intermittent current discharge through field aligned currents connecting the energized magnetotail to the auroral ionosphere. CMEs should be distinguished from solar flares. The latter produces intense X-ray and EUV emissions and can give rise to radiation storms in space. However, CMEs are the driver of geomagnetic activity, for example as measured by ground-based geomagnetic observatories.

2. IMPACTS

The consequences of space weather, besides the visible aurora borealis and aurora australis, are largely impacts on technologies we rely on, for example communication, travel, navigation and power. Examples of such impacts, and an indication of some of the underlying physical causes, tied to space weather, are shown in Figure 3. One of the issues for the modern world and its exposure to space weather is the interconnectedness of many of these technologies and their reliance on uninterrupted electrical power. This is a concern for many governments at the present time.

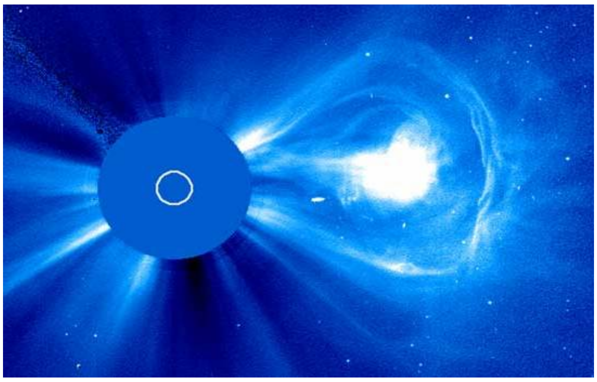

Figure 1 –A coronal mass ejection illuminated by sunlight from behind an occulting disk (blue). To scale the visible Sun is indicated by the white circle. The image is from the SOHO spacecraft, courtesy of SOHO/LASCO consortium. SOHO is a project of international cooperation between ESA and NASA. See soho.nascom.nasa.gov.

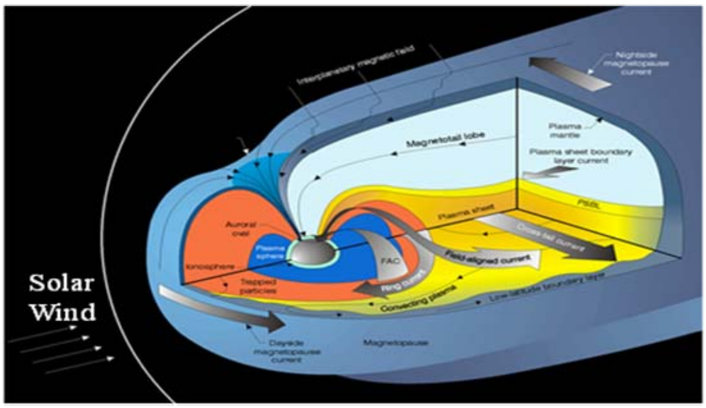

Figure 2 –A cartoon showing the major current systems of the magnetosphere (grey arrows) and major particle populations (colour). The solar wind, containing CMEs, impinges from bottom left. Figure courtesy of NASA.

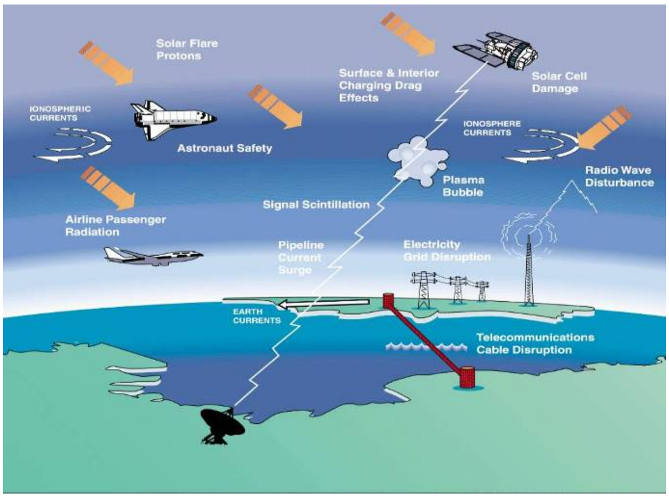

Figure 3 –Examples of space weather impacts on technology. Figure courtesy of Louis J Lanzerotti, New Jersey Institute of Technology.

3. SCIENTIFIC RESEARCH

Research into space weather, its causes and impacts, continues in many countries, particularly, but not exclusively, in countries at higher latitudes where the space weather impact is generally greater. Of particular concern are geomagnetically induced currents (GIC), that are a result of geomagnetic storm variations inducing an electric field in the conducting Earth, which in turn drives GIC through grounded networks, such as electrical transmission systems. Documented power grid impacts from GIC have been noted in places such as Sweden, USA, Canada, South Africa and the UK, indicating the range of (magnetic) latitudes where systems may be affected.

As just one example of current worldwide research in this area, in Figure 4 we show the impact of a hypothetical‘extreme’ event on the UK power grid. Here we have scaled the magnetic variations actually measured during the ‘Halloween Storm’ of October 2003. In order to estimate how big the GIC would be in the earth wire of each transformer in the UK grid, a detailed, geological map-based model of shallow surface conductivity was derived (Beamish and White, 2012). Magnetic variations were interpolated across the British Isles using the technique of ‘spherical elementary current systems’ (Amm, 1997), from magnetic measurements made across northern Europe. The UK National Grid company is considering the impact of these large GIC on transformers, together with government advisors.

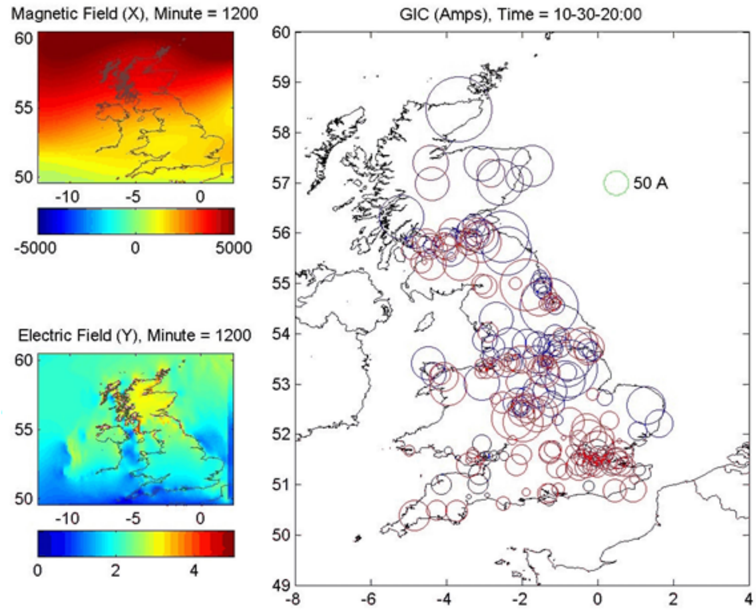

Figure 4 –Interpolated magnetic field variations (top left), calculated surface electric field (bottom left) and estimated GIC at major transformer nodes in the UK grid (main Figure: scale is 50 A) at one instant (20:00UT) on 30th October 2003, scaled to represent a 1 in 100 to 1 in 200 year event. Red (blue) denotes current flow into (out of) the grid from (into) the ground.

Of course, estimating what constitutes an extreme event is difficult, not least because the continuous geomagnetic record is only around 150 years old (depending on location and observatory) and has been digital since only about 1980. Nevertheless studies such as those by Riley (2012), Love (2012) and Thomson *et al.* (2011) have recently attempted to address this question. The latter study was used to provide the scaling factor for the example shown in Figure 4.

4. THE ROLE OF GEOMAGNETIC OBSERVATORIES

Magnetic observatories provide local measurement of local space weather conditions. At the same time through partnerships like INTERMAGNET (www.intermagnet.org), the International Space Environment Service (www.ises-spaceweather.org) and the World Data Centres for Geomagnetism (Kyoto, Mumbai, Edinburgh), free data exchange between observatories can provide vital data for analysis of space weather activity on the global and regional scale. For space weather research near-real-time magnetic data, often translated into different products (as in the example given in Figure 5), are helpful for situational awareness and for input into models that simulate or predict impact on the environment and technologies. Significant space weather events generate media and public attention, providing an excellent opportunity for geomagnetic observatory scientists to inform and educate. Increasingly, social media such as Twitter and Facebook are used, and alert systems, for example by email or SMS, can attract significant numbers of subscribers.

5. CONCLUSIONS

The potential impact of space weather on technology is growing as technology develops, for example as a consequence of the miniaturization of electrical components. Both public and private sectors of industry should therefore be better aware of the space weather hazard and consider the risk they may be exposed to. Geomagnetism science and technical expertise is in demand from industry to help with risk assessment and the relevance of the data from the worldwide geomagnetic observatory network has probably never been greater. There are therefore many opportunities for institutes operating magnetic observatories to develop local data products, based on their measurements, to address the needs of industry and the public in their countries.

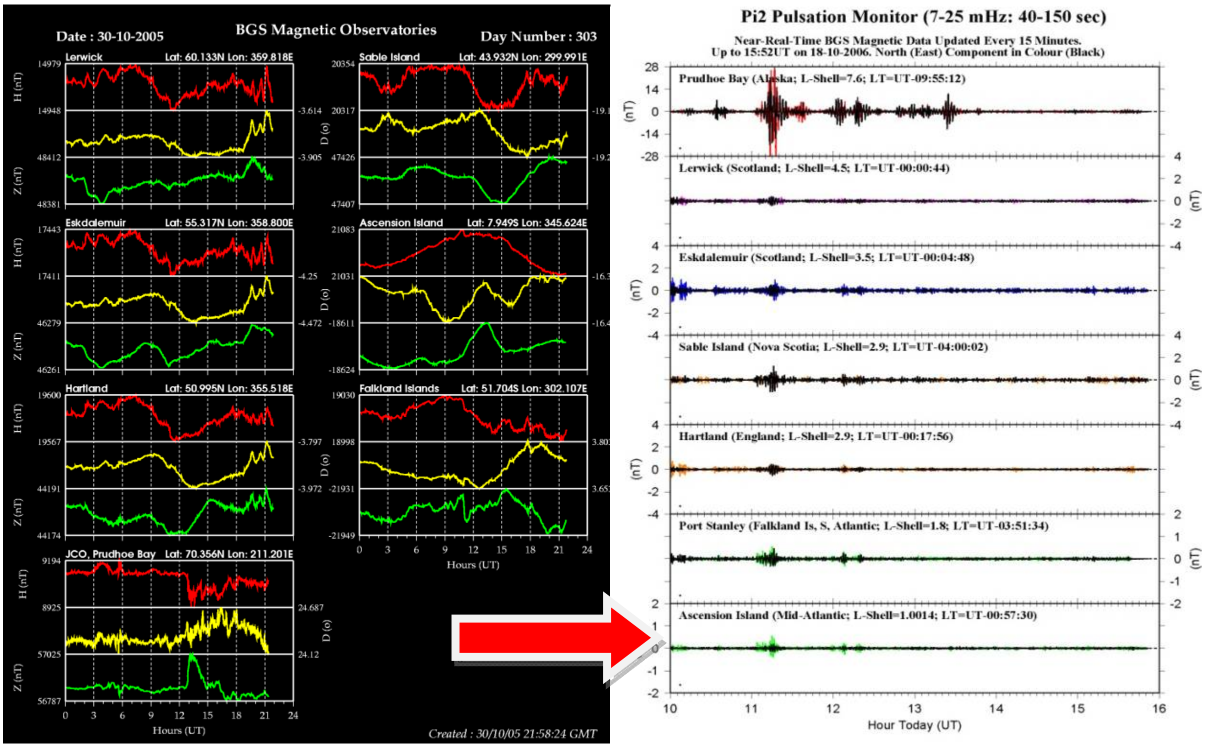

***Figure 5** –Real time observatory magnetograms can be processed to provide monitoring data for different space weather processes. In this Figure magnetograms from seven BGS observatories around the world are filtered to provide a Pi2 real time monitor. Pi2 pulsations indicate substorm activity, which in this case occurs across the world at different latitudes. (Note that two different days are shown simply to illustrate the principle.)*

6. ACKNOWLEDGEMENTS

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