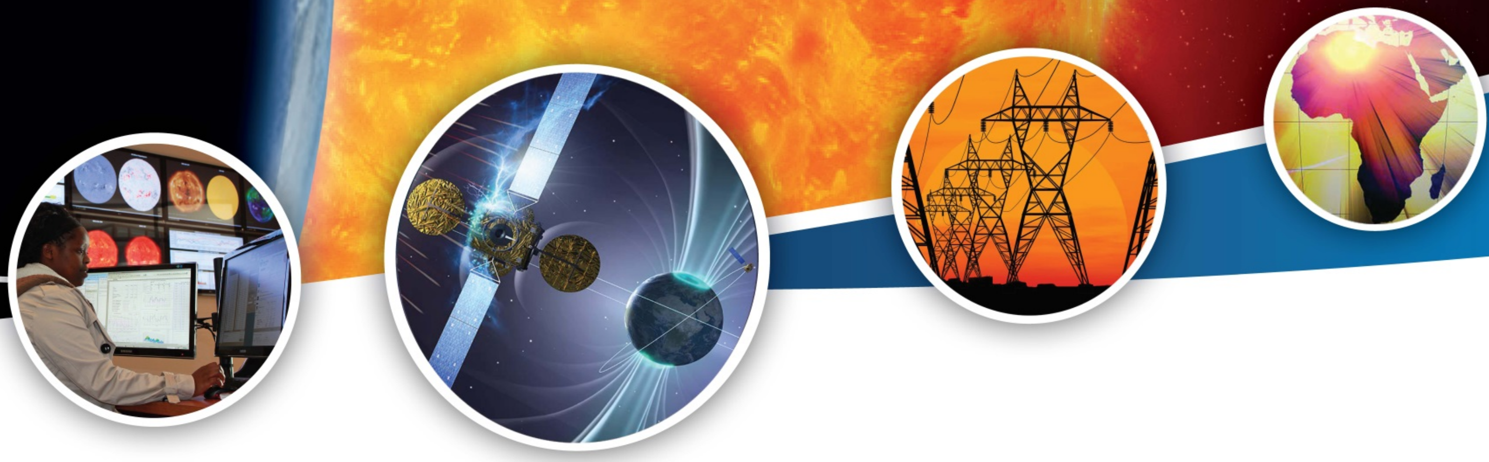
Economic Impact of Space Weather

SANSA Policy Brief

April 2017



Executive Summary

This policy brief addresses the need to raise awareness of the economic impacts that can arise from space weather events and the national risk that space weather presents to South Africa. The main recommendation put forward is that South Africa should identify extreme space weather events as a potential risk to the economy and critical infrastructure, and therefore appropriate recognition, understanding and capability development is required in order to ensure adequate preparedness. Nine recommendations are included which would assist South Africa in developing capabilities, strategies, action and mitigation plans in order to manage the national risk presented by the space environment.

Due to the increasingly interconnected and interdependent technological systems of modern society space weather can negatively impact numerous sectors, leading to a cascade of operational failures. Research has shown that the defence, communications, navigation, aviation, and energy sectors are most vulnerable to space weather effects. Research has also shown that space weather is a global phenomenon with regional impact. The South African National Space Agency (SANSA) operates the Space Weather Regional Warning Centre for Africa, under the International Space Environment Service (ISES), which aims to coordinate global space weather activities. The SANSA Space Weather Centre was established in 2010 with the mandate to (i) develop space weather capabilities within South Africa, (ii) improve the understanding and awareness of space weather within Africa, and (iii) provide a space weather operational service to government, industry and the public.

The field of space weather is growing rapidly, with new discoveries and continuous developments in forecasting and prediction capabilities which improve almost daily. There are still many unknowns and a rigorous assessment of the economic impact resulting from a severe solar storm is a work in progress. Some analysis has been done on the impacts resulting from Geomagnetically Induced Currents (GICs), however, to a large extent the evidence is still anecdotal. This policy brief describes the possible economic impacts, and presents likely scenarios as well as discussion points around the risk that South Africa may be exposed to from space weather.

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Given SANSA's global positioning in the space weather community and the expertise developed over the past six years running a fully operational space weather centre, SANSA is in a position to collaborate with government to identify the national risk exposure, and to build the necessary space weather capability that addresses the nation's requirements and allows for the management of this risk.

Space weather is a national risk that could endanger the economy. Governments in several countries, including the USA and UK, have recently listed space weather on the National Risk Register.

Introduction

Space weather refers to the conditions in space; on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems. Space weather is a consequence of the behaviour of the Sun, the nature of Earth's magnetic field and atmosphere, and the Earth's location in the solar system. The Sun is the driver of space weather, therefore, monitoring solar events is a key component in providing a space weather forecasting and prediction service.

Figure 1: Space weather can disrupt modern technologies such as GPS, power grids, avionics, navigation and communication systems.

The importance of developing capabilities, strategies and action plans around space weather lies in the global trend for dependence on technological systems for economic vitality and national security. Space weather can disrupt these technological systems, including satellite and airline operations, communications networks, navigation systems, and the electric power grid. As global economies and individual nations become ever more dependent on these technologies, space weather poses an increasing risk to infrastructure and the economy[1,2].

Space weather has become a hot topic on a global scale both scientifically, as the need rises for an increased research focus and the development of prediction tools becomes essential, and operationally, as the prediction and forecast of space weather events and their impacts becomes an essential mitigation method. It is important to note that while extreme space weather events are a low probability high impact scenario, research has shown that continuing degradation as a result of a number of smaller impacts is often where the vulnerability lies. In addition, space weather events are a global phenomenon with regional impact, and therefore, it is important for South Africa, as a country with an increasing dependence on technology, to understand the applicable risks associated with space weather and develop a degree of preparedness. Several countries have recognised space weather as a source of national risk, such as the United States where the White House has issued an executive order from the President, for government agencies to coordinate the preparedness for severe space weather[3], and the United Kingdom where space weather has been listed on the national risk register as a potential major disaster with far reaching consequences[4]. Several insurance companies have also investigated the loss aspects related to space weather and are currently debating the liability aspects of space weather storms[5,6,7].

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In South Africa, SANSA has been developing a capability in space weather research, applications and operations. This capability allows the country to put measures in place to investigate, understand, and operationalise the risk and mitigation required with respect to the potential impact from space weather storms. This policy brief aims to put forward recommendations to assist decision-makers in understanding the potential economic risk, and what steps could be taken in this regard.

Economic Impact of Space Weather relevant to South Africa

Documented evidence of the economic impact resulting from severe space weather is limited, however, there are many studies currently underway. It is only in recent years that the consequences of this kind of risk have been recognised, and attempts made to measure and record the vulnerability associated with it[5,6]. Where there are known sources of information pertaining to South Africa these are quoted in this document, however, in some cases international studies are used to surmise the potential risk for South Africa.

Energy

The energy sector is affected by adverse space weather through Geomagnetically Induced Currents (GICs) that arise from geomagnetic storms resulting from extreme solar activity. Globally, there are many studies underway on the impact of GICs on national power networks, and traditionally it has been thought that only high-latitude regions are affected[8,9]. However, recent evidence from the so called Halloween Storm of 2003, indicate that mid-latitude regions may also be affected[10]. Space weather research is currently being undertaken regarding the risk to the South African power network and the development of modelling capability for South Africa[11,12].

Calculating the exact loss that could incur as a result of GICs is a challenging task, as the damage is not always instantaneous and the impact is far reaching given the nation's dependence on reliable electrical power. The calculation for the economic impact resulting from GICs needs to include a loss of income to the power utility, the cost of replacing damaged transformers, the cost of generating electricity through other means, and the loss of income from mines and other revenue generating industries. The downstream impact to the health, aviation, education, financial and security sectors is also significant and would need to be factored in.

Figure 2: Damage to a large power transformer in South Africa due to the effects of a space weather storm which gave rise to GICs.

As an example, in 1996 Oak Ridge National Laboratories in the USA estimated that the potential economic costs to the GDP, from a wide-spread power blackout in the North-Eastern USA as a result of GICs, could be on the order of USD 3-6 billion[13]. Assuming that South Africa has a GDP of 1/100 that of the USA, and that the 1996 costs should be multiplied by 10 due to inflation, this would give an estimate of R 300-600 million as a consequence of a wide-spread power blackout due to a severe space weather (geomagnetic) storm. The estimates of the economic impact for the USA range from USD 10 billion to an estimate of USD 1 trillion to USD 2 trillion (2008 estimates) during the first year alone for the societal and economic costs of a "severe geomagnetic storm scenario" with recovery times of 4 to 10 years[3]. Scaling this to an estimate for South Africa (smaller GDP, smaller population, inflation rate since 2008) these numbers could be translated to ZAR 1 trillion to ZAR 2 trillion (2016) during the first year alone for the societal and economic costs of a "severe geomagnetic storm scenario" with recovery times of 4 to 10 years. While these examples only provide approximate costs of the impact they do illustrate the potential risk to the economy resulting from a space weather storm.

Electrical power is of critical importance to modern economies, and is particularly vulnerable to space weather.

Security

The security sector can be significantly affected by adverse space weather, with the extent of the risk dependent on the systems in use. Key elements of any military operation are being able to navigate and communicate effectively. The former requires magnetic compasses and GPS systems while the latter requires effective radio and satellite communications which can be affected by space weather. While there are no economic studies concluded in this area, it is possible to reason that a complete communications blackout, which is entirely possible as a consequence of a space weather storm, could be a critical safety of life concern. The military are heavily dependent on HF communications, and could be rendered inoperable for days as a result of a space weather storm. The downstream consequence of this could be isolated troops, delayed campaigns and exercises, and the lack of a backup in the event of a disaster. It is not possible to put a cost to the loss to military operations, and the risk to lives.

Figure 3: HF radio and satellite communications can be severely affected by space weather; resulting in communication blackouts.

Health

The health sector is also vulnerable to the impacts of space weather. For example, at aviation altitudes, radiation is always present due to galactic cosmic rays, however, this background radiation has a minimal health impact on passengers and crew. During severe space weather storms, a substantial amount of additional radiation is present at aviation altitudes resulting in an increased accumulative dose which is a health risk to both passengers and crew[5,6]. The loss of national power which may occur during a severe space weather storm can significantly impact health infrastructure such as water supply, food safety, medical care system, and emergency services. In extreme emergency situations, a lack of communication and a disruption to power services resulting from severe space weather can result in the loss of lives (for example: inability to access chronic medication, or medical services). Although the economic impact to the health sector has not been fully quantified, the overall ability of space weather storms to disrupt the medical care system and affect public health has been listed as one of the top 10 sectors affected in an indirect impact scenario risk listing for sectors within the United States[6].

SANSA aims to provide the right information to the right people in the right format at the right time to facilitate and enable the right decisions.

Communication and Navigation

The communications and navigation sector depend on satellite systems which orbit Earth. Global Navigation Satellite Systems (GNSS) are particularly vulnerable to space weather storms. GNSS services are utilised for positioning, navigation, and timing, and as such play an important role in our daily lives and most sectors including safety of life applications. The loss of GNSS during a severe space weather storm would have devastating social and economic repercussions [14].

GNSS are used to ensure the accuracy of car navigation systems as well as for ship and aircraft navigation. The unavailability of GNSS can also affect the financial sector; including banking and the stock market. The day to day economic activities such as business operations which are dependent on information technology and GNSS timing (e.g. internet for carrying out ordering and banking transactions between two parties, data streaming etc.) can be interrupted by space weather storms. These space weather vulnerabilities can also be applied to any augmentation system (such as the wide area augmentation system, WAAS, used for aviation landing systems) and any industrial application that requires time or timing with appropriate accuracy, stability and reliability in order to operate (such as telecommunication networks, mobile data communication and national power generation and distribution)[14]. Global insurance companies are currently debating the risk liability of a loss occurring due to a GNSS outage. GNSS satellites are typically not insured as satellites are only insured up to the pre-launch phase, however, the current debate is centred on the down-stream impact of the outage[6]. At this stage there is no quantification of the economic impact that this may have, although the consequences of an outage given the dependence on this technology in many sectors could be dire.

Transport

The impact of space weather storms on the transportation sector has been considered with respect to aviation, rail, and maritime. Within aviation the impact from a space weather storm could result in the re-routing or grounding of flights, damage to avionic systems, the unavailability of communication systems, inaccuracies introduced in navigational aids, and degradation in the accuracy of landing systems. In extreme cases, airports and other transportation hubs may need to be closed for extended periods of time causing huge inconveniences and economic implications for passengers and airline companies[6,14].

Figure 4: Space weather could potentially create huge disturbances in the transport, aviation and navigation sectors.

The SANSA 2015/2016 Policy Brief entitled "Space Weather Impacts on Aviation" deals exclusively with the potential impact of adverse space weather on the aviation sector[15]. Although SANSA's focus has been mainly on the aviation sector impacts, the rail and maritime sectors also have vulnerabilities that are introduced due to adverse space weather. Rail transport depends on power, communications and GNSS for positioning and timing, and anomalies have been observed in signalling systems during geomagnetic storms[16]. There is limited available literature on the impacts on rail, however, it is well known that the extent of the vulnerabilities will differ from country to country depending on the approach to operations and the system architectures. GICs can be induced on any long length of earthed electrical conducting material during a solar storm, and therefore, rail networks are susceptible to disruption caused by space weather induced GICs[14,17].

A South African study[10] showed significant impact of GICs on power lines over the South African region. It is believed that the impact could be similar for the South African railway systems. While awareness of the risks of space weather on the railway system appear to be limited in general, some countries have started to analyse the vulnerability of their infrastructures which is also important for South Africa.

A study conducted in the UK has identified power, signalling, train traction, GNSS, radio communications and trackside staff as potentially risk areas to adverse space weather on the rail network[5,16]. Another finding from Sweden is that their rail network is subject to an elevated space weather risk due to its location, ground conductivity and the use of DC track circuits [16]. In addition, step-down transformers in rail electrical networks are particularly vulnerable to damage from extreme space weather, and the cost of replacing such transformers as well as down-time and delays in the network contribute to the economic impact for this sector[6].

The maritime sector can be at risk due to a complete loss of power affecting loading and unloading capabilities thereby impacting the import and export trade, as well as the loss of communication signals affecting navigational aids. In some extreme cases, port authorities have had to close national ports as operations have been severely impacted. The economic loss would then be in the loss of trade income, penalties for delays, and the disaster of lost vessels at sea[6]. There is no specific literature available on the economic cost of space weather on the transportation sector, although anecdotal evidence is available on the operational costs associated with airline delays, increased fuel costs due to re-routing, and railway failures[17]. In addition, the costs of transportation disruption can add up significantly when factoring in the impact on trade, and travel, including loss of income, productivity, and the long lead time in recovering from disrupted services.

Interdependencies

The technology that is utilised to drive many applications is interconnected, and this increases the vulnerability due to space weather storms. Susceptibility of today's society to space weather is fast increasing due to an increasing reliance on services provided by vulnerable infrastructure and their interdependencies. The concept of interdependency is evident when looking, for example, at a loss of power for over 10 hours which would affect water supply, communication, banking and finance and just about every other critical infrastructure including government services[18].

Interdependencies between different sectors and infrastructures need to be better understood and assessed to improve the preparedness for extreme space weather. While it is understood that many different areas would be affected by a severe space weather storm that might target one particular sector, owing to the interdependency with other sectors, the extent of the damage could be far reaching.

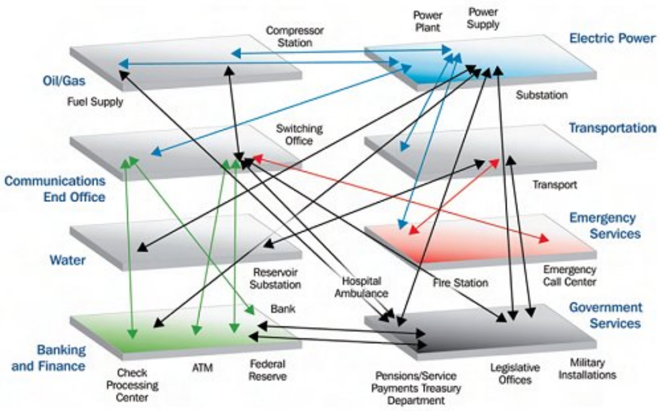

Figure 5: Space weather can lead to a cascade of catastrophic failures of power supply, emergency services, water, satellite communication, transportation, financial, and other essential infrastructure.

Space weather is a global phenomenon with regional impact, and while evidence does exist as to the impact that adverse space weather can have on technology, the quantification of the economic costs are still uncertain. Within South Africa, research is underway as to the extent of the potential impact, and the requirements for forecasting and mitigating that impact. SANSA has recently partnered with a number of UK organisations in a project, funded by the UK Space Agency, to investigate the economic impact of space weather. The results revealed a number of concerns and anecdotal indications of the economic costs associated with loss due to space weather, however, the final results were inconclusive only adding the realisation that this is a sensitive topic to which multidisciplinary experts need to apply their minds[17].

Space Weather in South Africa

Space weather centres have been established around the globe to coordinate space weather activities, and to provide space weather predictions, forecasts and warnings to industry, government and the public. The International Space Environment Service (ISES) is an international body that coordinates space weather related activities through designated Regional Warning Centres. SANSA operates the appointed ISES Space Weather Regional Warning Centre for Africa in Hermanus, Western Cape. The SANSA Space Weather Centre was established in 2010 with the aim to (i) develop space weather capabilities within South Africa, (ii) improve the understanding and awareness of space weather within Africa, and (iii) provide a space weather operational service to the government and industry[19,20].

The SANSA space weather centre has played an important role in providing space weather predictions and forecasting of related indices as well as communication frequencies in the High-Frequency (HF) band mainly to the defence and energy sector. The centre has also promoted space weather in South Africa and created a public awareness and understanding of space weather and its potential impacts. In addition, SANSA provides space weather bulletins, alerts and warnings, as well as information and interpretation of space weather conditions for specific applications.

The main South African sectors that are vulnerable to the impacts of space weather include the defence, aviation and energy sector which can experience detrimental effects to power grids, High Frequency radio communication, satellites, avionics, aircraft navigation and communication systems and GPS dependent networks. Through the utilisation of specialised knowledge, a large ground based geophysical instrumentation network and global partnerships, SANSA has established an effective space weather team to *provide the right information to the right people in the right format at the right time to facilitate and enable the right decisions*.

Recommendations

South Africa is vulnerable to the impacts of space weather which can affect High Frequency radio communication, power distribution networks, satellites, avionics, navigational aids, and communication systems. Internationally, space weather is being considered a significant risk to the stability of national assets, safety, and security, and in this regard is being considered at a high level in national governments. The economic impact of a space weather event can be catastrophic, and should not be taken lightly. The main recommendation from this policy brief is that South Africa should identify space weather storms as a potential risk that could impact the economy negatively, and therefore appropriate recognition, understanding and capability development is required in order to ensure adequate preparedness. Furthermore, the following recommendations are put forward within this policy brief for consideration:

1. A South African project team, made up of appropriate multidisciplinary expertise, should be established to identify space weather impacts that are applicable to the country and the levels at which a space weather storm becomes a risk for the various sectors;
2. Additional structural and organisational measures should be identified and established to assist

industry in mitigating the risk associated with space weather storms;

3. A space weather severity chart should be developed for South Africa which links to the related sectors that could be affected in the country;
4. Additional observational and modelling capabilities will be required to improve forecasting and prediction techniques as well as for the verification and validation of space weather impact forecasting;
5. Training, education and awareness sessions should be held across the country to educate and create awareness amongst the affected industries;
6. A South African Roadmap should be developed for space weather, detailing the impacts of concern and possible mitigation measures;
7. A study on the global economic impacts should be undertaken to determine and comprehensively assess both direct and indirect losses due to space weather across a diverse range of sectors;
8. Measures should be taken to accurately quantify the technical impact of space weather in a variety of industries (energy, defence, aviation, etc.);
9. Space Weather should be considered a significant risk and entered into the national risk register, with appropriate resources allocated for space weather research and the development of local space weather capability.

Measuring the economic impact of disruption caused by space weather requires multidisciplinary expertise and government and private sector support.

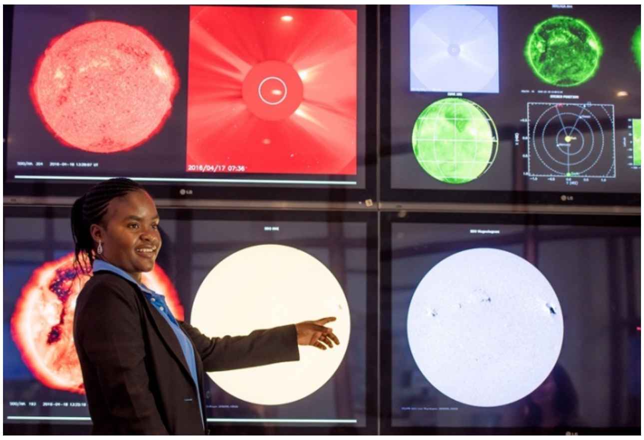

Figure 6: The Sun is the driver of space weather, therefore it is essential to constantly monitor solar activity to assess the potential impact on space and ground based technological systems. SANSA operates the official Space Weather Regional Warning Centre for Africa under International Space Environment Service (ISES).

These recommendations come from an understanding and awareness of the potential impacts of space weather as a national risk to the economy, and have been derived after national and international consultation. The international parties included the International Partnership in Space Programme (IPSP) Economic Impact of Space Weather project team which consisted of four UK institutions, SANSA and the USA Space Weather Prediction Centre[17].

Conclusion

This policy brief is aimed at guiding South Africa towards being in a position to identify, assess and facilitate decision making with respect to space weather impacts in general, and to guide the country in terms of the identification of space weather as a national risk. SANSA is in a position to work together with all the affected sectors, and government, to make provision for a space weather capability that addresses the nation’s requirements, and leads the country towards mitigation measures against this risk. In conclusion, it should be noted that further work will need to be undertaken to assess the likely impacts of space weather that would affect the South African economy. The recommendations put forward in this policy brief would be the first point of consideration.

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