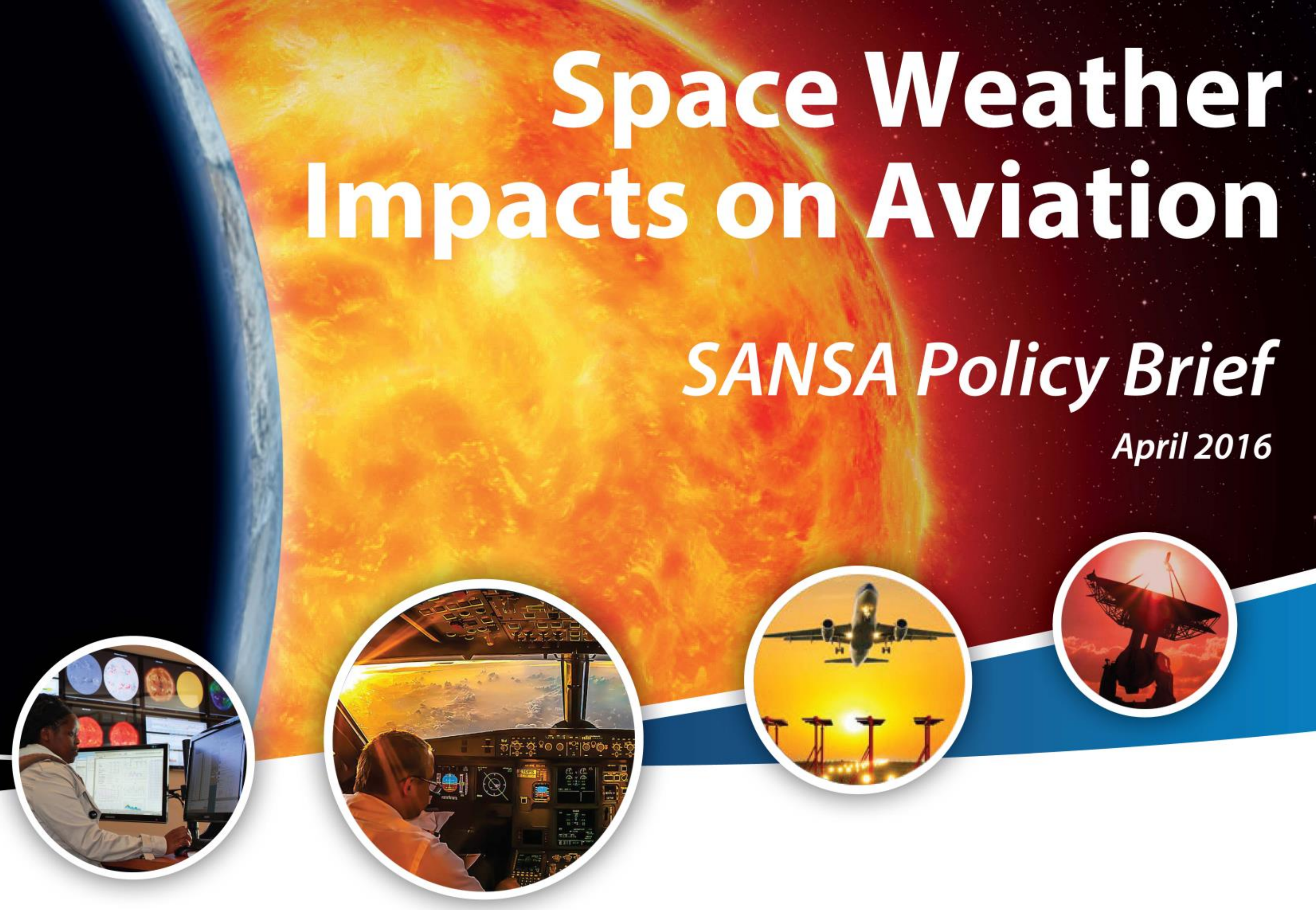
Space Weather Impacts on Aviation

SANSA Policy Brief

April 2016



Executive Summary

This policy brief addresses the need to raise awareness of the impacts caused by space weather on the aviation sector. The main recommendation put forward is that South Africa should align itself with international standards for the provision and access to space weather information in order to meet the International Civil Aviation Organisation (ICAO) recommendations by 2017, and to protect the vulnerable areas within the aviation sector. An additional seven recommendations are included which would assist South Africa in developing capabilities, strategies and action plans around space weather and its impact on the aviation sector in South Africa.

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. Continuous monitoring of the space environment allows for early warning, forecasting and prediction of space weather events that could lead to technological and infrastructure failure. 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. 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. It is important to note that space weather is a global phenomenon with regional impact.

Ground based support and aircraft are vulnerable to space weather impacts, primarily in four key areas: communication, navigation, aircraft avionics and radiation exposure. ICAO has recognised the need for the adoption of procedures related to mitigating space weather impacts. During the 2014 Montreal Meeting of the ICAO Meteorology Division a recommendation was passed for

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the development of provisions for information concerning space weather. Included in the recommendation was the requirement that space weather information be integrated into global air traffic environment information systems. ICAO recommended that all aviation providers and users become familiar with the impacts of space weather on the aviation sector and requested that pertinent space weather information be filed with all flight plans by 2017.
Given SANSA's global positioning in the space weather community and the expertise developed over the past five years running a fully operational space weather centre, SANSA is in a position to collaborate with the aviation sector and government, and to develop the necessary space weather capability that addresses the nation's requirements.

Space weather describes events that happen in space, which can disrupt modern technologies such as GPS, power grids, avionics, navigation and communication systems.

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, as well as 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 service.

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, communication 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].

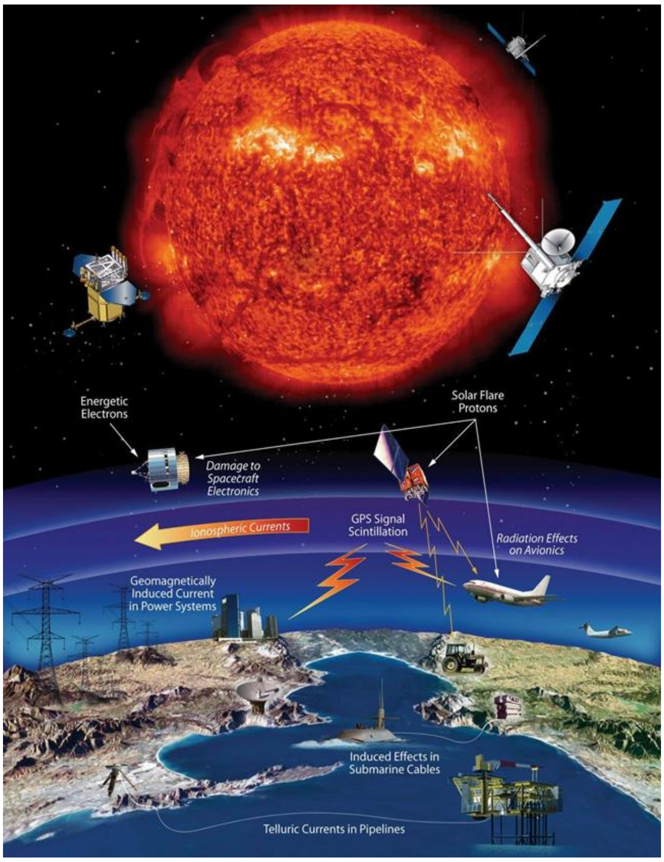

Figure 1: Space weather can influence the performance and reliability of numerous technological systems that society depends on daily.

The impact from space weather can be extensive and compensating for this impact is a challenge. Space weather exhibits terrestrial weather-like variations with the severity differing under different conditions from minor solar storms that are relatively common to extremely large superstorms that occur less often. It is important to be ready to deal with any type of severity and the possible impacts. Although the Sun is a nearly constant source of optical and near-infrared radiation, there is significant variability during storm periods at Extreme Ultra-Violet (EUV), X-ray and radio wavelengths. The extent and directionality of this variability is what determines the impact on Earth [2,3].

Space weather monitoring is essential for the improved understanding and forewarning of solar events that could lead to severe space weather on Earth. Although impending space weather cannot be halted, constant monitoring allows for industries that may be affected to go on standby and provides important scientific information to utilise in making necessary decisions [3].

Space weather predictions and forecasts are useful capabilities which, depending on the accuracy, could affect the way space weather impacts are mitigated. Currently, it is extremely difficult to forecast earth directed solar events, such as solar flares and geomagnetic storms. However, research has provided techniques that are constantly improving our ability to forecast these events. For example, the arrival time of Coronal Mass Ejections (CMEs) can be forecast with an arrival time accuracy of approximately 6 – 8 hours. Global space weather teams are working together to improve the accuracy of forecasts and predictions of arrival times and impact severity. Appropriate instrumentation, such as the STEREO satellites, that enable the monitoring of the far side of the Sun, and the ACE satellite, are essential for providing this operational capability [2,3].

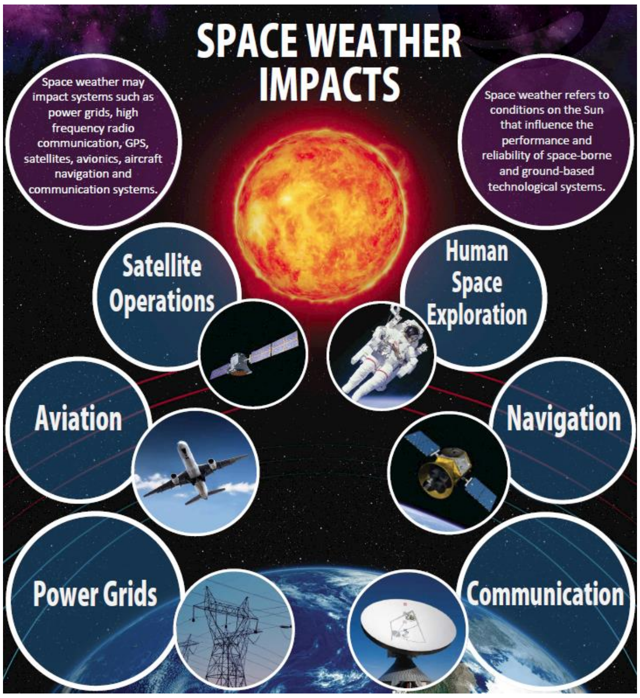

Figure 2: Aviation, as discussed in this policy brief, is just one of several sectors that are vulnerable to the impacts of space weather.

Space Weather Impacts on Aviation and South Africa's Vulnerability

The aviation sector is vulnerable to space weather impacts, primarily in four key areas, communication, navigation, aircraft avionics and radiation exposure. Communication links are essential to airline operations since aircraft must maintain continuous contact with ground control centres. When flying over oceans and polar regions these links are provided either by satellite communications or by High-Frequency (HF) radio that bounces radio waves over long distances off the ionosphere. This form of communication is used in disaster situations when other communication systems are down and is an essential backup communication method for passenger aircraft. Space weather emanating from a number of solar conditions can cause ionospheric storms, resulting in rapidly fluctuating HF signals and unexpected propagation paths. During severe solar storms complete blackouts in HF communication are possible as well as disruption to satellite communication. The loss or degradation of HF and satellite communication signals is an area of vulnerability for South African aviation [6,7].

Space weather can impact GPS signals, which can affect aviation navigation systems.

Augmented navigation systems utilised for aircraft navigation and landing are also susceptible to space weather impacts. An example of such an impact is the large geomagnetic storm of October 2003, when it was reported that the vertical navigation guidance from the US Wide Area Augmentation System (WAAS) was unavailable for approximately 30 hours. Solar radio bursts can also affect the availability of WAAS, for example, the largest recorded burst in December 2006 caused a loss of vertical guidance for 15 minutes. However, it should be noted that in both examples operational integrity was maintained. The increased use of differential and augmented systems for navigation and landing exposes the aviation sector to an increased risk due to space weather events. Global Positioning Systems (GPS) are being utilised with increasing frequency to reduce the separation between aircraft and to make precision approaches for landing. GPS can be affected by space weather through degradation in signals passing through the ionosphere, and through the impact on satellites from high energetic particle bombardment. South Africa’s vulnerability with regards to navigation lies in the use of GPS for navigation and landing, as well as future considerations around adopting augmentation techniques [3,6].

The impact from extreme space weather on avionics electronics arises from an increase in solar energetic particles during a solar particle event. Solar energetic particles can indirectly introduce additional charge into semi-conductor material, thereby increasing the vulnerability of electronic devices to temporary latch-up or permanent failure. The UK Royal Academy of Engineering report[3] estimated that during a solar superstorm the avionic risk could increase by as much as 1 200 times compared to the background risk level. This report also makes the point that more critical avionics, such as engine control, are designed to mitigate component level failure and are therefore more resistant to solar energetic particles. The vulnerability also lies in the ability of secondary heavy charges to change the state of a memory cell, thereby leading to corrupt memory and potential erroneous commands. Research has shown that as aircraft become more "electric" and feature more low cost high power electronics the space weather risk to avionics will increase[3,6].

The fourth primary risk from space weather for the aviation sector is radiation exposure to crew and passengers. The International Commission on Radiological Protection (ICRP) recommends effective dose limits over a 5 year average of 20 millisieverts (mSv) yr^{-1} with no more than 50 mSv in a single year for non-pregnant, occupationally exposed persons, and 1 mSv yr^{-1} for the general public. During an extreme solar event airborne crew and passengers could be exposed to an estimated additional dose of radiation up to 20 mSv at the worst-case. There is no practical way of forecasting this kind of event, or the impact, in time to mitigate effectively, as the high energy particles (which are the primary concern), arrive at the speed of light i.e. within 8 minutes. In addition, the costs associated with grounding aircraft and/or crew, and in diverting to alternative routes are significant. Several studies have been conducted on these effects to assess the most vulnerable scenarios. The primary conclusion of these studies indicate that on-board monitoring of radiation exposure and post-event analysis is required if mitigation and accurate forecasting is to become possible in the future [3,6,8,9,10].

Figure 3: The aviation sector is extremely safety conscious and already has a safety standard into which space weather impacts can be incorporated.

South Africa is less vulnerable to single event radiation dose exposures as polar routes are not generally utilised by South African aviation. However, long term accumulative radiation exposure by crew and frequent flyers may be a relevant risk and should be considered in future studies of space weather impacts on aviation over Africa. The aviation sector is by design extremely safety conscious and sufficient mitigation to extreme space weather can be adopted through the development of standard operating procedures for space weather emergencies.

South Africa should align itself with international standards for the provision and access to space weather information in order to be ready to meet the ICAO recommendations by 2017

The International Civil Aviation Organisation (ICAO) has recognised the need for the adoption of procedures related to mitigating space weather impacts. During the 2014 Montreal Meeting of the ICAO Meteorology Division a recommendation was passed for the development of information, resources and training concerning space weather [11]. The recommendations put forward included that an expert group be tasked with the development of provisions for information on space weather to international air navigation and that this information be integrated into the global air traffic environment information systems.

ICAO recommendation 2/7 lists four main requirements that should be addressed which are[11]:

- Requirements for space weather information services consistent with the draft concept of operations for space weather information services;
- Selection criteria and associated capability for the designation of global and regional space weather centres and the optimum number thereof;
- Appropriate governance and cost recovery arrangements for the provision of space weather information services on a global and regional basis;

- Considerations on the use of space weather information and the various impacts space weather events could have on international air traffic.

Through the International Space Environment Service (ISES) and the South African Weather Service (SAWS), SANSA is representing South Africa on a number of expert groups that are developing the provisions required to meet this recommendation. It has been recommended that nations be ready to integrate space weather into the aviation sector by 2017.

Figure 5: SANSA operates a wide suite of space monitoring instrumentation which provides valuable space weather data to scientists and forecasters on the state of the space environment.

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. The South African National Space Agency (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 government and industry users.

Figure 4: The SANSA Space Weather Centre provides valuable data, information and interpretation on the impacts of space weather.

The SANSA Space Weather Centre plays 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 sector. The centre is actively involved in promoting space weather in South Africa and creates 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 [4,5].

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.

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 as well as 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

The South African aviation sector is vulnerable to the impacts of space weather which can affect High Frequency radio communication, satellites, avionics, and aircraft navigation and communication systems. Internationally, ICAO is requiring that certain standards be developed to assist air crew and ground support in managing the potential impact from space weather. The main recommendation from this policy brief is that South Africa should align itself with international standards for the provision and access to space weather information in order to be ready to meet the ICAO recommendations by 2017, and to protect the vulnerable areas within aviation systems.

The following recommendations are put forward within this policy brief for consideration:

- A South African user forum, with participation from affected parties within the sector should be established to consider and make provision for space weather impacts on aviation;
- South Africa's Air Traffic Navigation Service (ATNS) should be requested to lead the aviation community in defining and collecting operational data that can be used to assess the different impact areas, and the economic impact arising from space weather mitigation.
- The aviation industry, with the assistance of SANSA, should be requested to clearly define its requirements for space weather information and how these can be incorporated into the operational decision making process.
- SANSA should align itself to deliver space weather information in an internationally agreed upon standardized format as defined by the aviation user requirements, and be given the mandate to assist the aviation sector in fulfilling the ICAO recommendations.
- The Civil Aviation Authority (CAA) should define a minimum set of requirements for incorporating space weather into operational training for aircrew (pilots and cabin crew), dispatchers, meteorologists, and engineers.
- The CAA should mandate that space weather information be received by aviation operators and be included as part of their planning and briefing process. This information must meet a minimum set of standards.
- An annual assessment should be carried out of the service performance within the aviation sector based on space weather events.

These recommendations come from an understanding and awareness of the potential impacts of space weather on the aviation sector, and have been derived after national and international consultation. The international parties consulted included the UK Met Office, the Mullard Space Science Laboratory (MSSL) of the University College London, RAL Space based at the Rutherford Appleton Laboratory in the UK, and the USA Space Weather Prediction Centre.

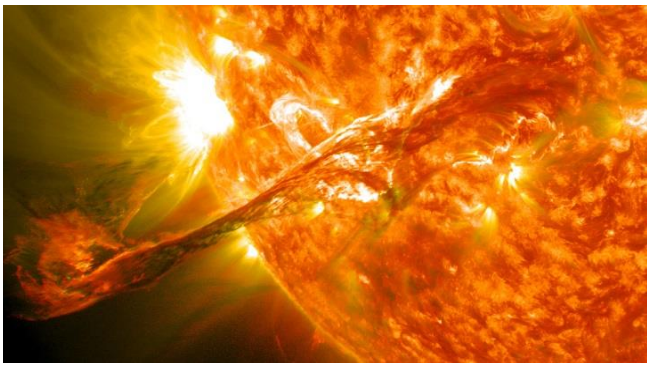

Figure 6: The Sun is the driver of space weather, therefore it is essential to constantly monitor solar activity to assess the potential impact on space and ground based technological systems.

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 on aviation, and the ICAO recommendations. SANSA is in a position to work together with the aviation sector and government, to make provision for a space weather capability that addresses the nation's requirements. 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 aviation sector. The recommendations put forward in this policy brief would be the first point of consideration.

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