National Committee for Space Science

Decadal Plan

AUSTRALIAN SPACE SCIENCE PLAN 2007-2017

SPACE WEATHER AND INDUSTRY

For information:

Industrial Space Weather Working Group**: Intended to identify the ways in which Space Weather is important to Australian Industry, assess the costs, and then to develop plans to mitigate them.**

Expected outcomes **are statements and examples of how Space Weather effects are important to Australian Industry, what the costs are, and how to mitigate them.**

DRAFT 2 (2 June 2006)

What is space weather?

Most people are familiar with the effect of weather on their lives. Often this is relatively minor - determining what to wear and where to go; but on occasions, it is dramatic and costly as major events inflict severe damage and even loss of life.

Unseen and unknown to most people, there is another form of weather - space weather - which is of great importance to many modern technologies. And like ordinary weather, space weather constantly produces low-level effects on human technology; interspersed with occasional dramatic events.

Space weather refers to conditions on the Sun and in the solar atmosphere that can influence the performance and reliability of space-borne and ground-based technological systems.

The Sun is a huge generator of power (4×10^{20} megawatts) and is the main source of space weather. Its output varies over a period of about 11 years with sudden explosive bursts of energy over periods of minutes to days. Currently solar activity is moving from a minimum in early 2007 to a maximum in 2009-10 waning to the next minimum in 2017. The increasing importance of space weather for a technical society together with ever-present solar activity means that space weather disturbances have a higher profile than in the past and a potentially greater impact on modern industry.

The Sun-Earth Environment and Space Weather

The Sun-Earth environment is the region of space extending from the surface of the Sun out to, and including, the Earth's upper atmosphere and magnetic field. It is a harsh environment dominated by electromagnetic radiation and electrically charged particles from the Sun. It is subject to dramatic and violent change as events on the Sun blast streams of radiation and energetic particles towards the Earth.

Space weather results from changes in the speed or density of the solar wind, a continuous stream of charged particles flowing from the Sun past the Earth and into interplanetary space. This flow distorts the Earth's magnetic field, compressing it in the direction of the Sun and stretching it out in the anti-Sun direction. Fluctuations in the flow of solar wind cause variations in the strength and direction of the magnetic field measured near the surface of the Earth and inject energetic particles into the radiation belts through which many satellites pass. Large abrupt changes in this dynamic medium are called geomagnetic storms.

The coupling of the solar wind with the geomagnetic field also causes the Earth's ionosphere (the electrified layers of the upper atmosphere) to be severely disturbed by streams of charged particles. This degrades the ionospheric "mirror" that reflects High Frequency (HF) radio signals back to the Earth allowing cheap and convenient communication over a wide range of distances.

Space Weather Effects

Space weather events have the potential to significantly and detrimentally affect our access to space based (i.e. satellite) services, and may also severely degrade ground based and airborne electronic services. Australia is strongly reliant on access to space based services for telecommunications, positioning and timing information and remote sensing imagery among others. These services contribute to Australia's national security, environmental integrity and to our standard of living. There are strong government, community and business interests that must be served by these services.

Examples of activities and systems affected by space weather include:

- satellite operations, satellite communications, data and information collection, surveillance and land management, weather imaging and data,
- aviation, communications, staff exposure to space radiation, especially on polar routes,
- navigation and timing systems, loss of lock and tracking giving poorer accuracy
- general electrical control systems, railway, transport and traffic control,
- high-frequency (short wave) communications, degraded signal strength, interference
- short-wave broadcasting,
- surveillance radars for customs, immigration and defence, impairment or possible blinding
- geophysical exploration, spurious or contaminated geomagnetic data
- electricity power grid distribution, transformer burn-out or possible tripping of parts of grid
- long pipeline corrosion, excessive currents giving rise to costly corrosion
- insurance of systems affected by space conditions.

Nearly all these examples are related to industrial processes, products or services. Under severe space weather conditions, systems can be degraded sometimes to the point of failure, with costly results. In many cases forewarning of storms can be accommodated within operational parameters or can be protected by the design of the system.

Intense space weather events are triggered by the explosive release of energy stored in the Sun's magnetic fields. A strong burst of electromagnetic and "cosmic" radiation reaches Earth within 9-30 minutes, with the potential to disrupt the services outlined above. The explosion also results in a shock wave that reaches the Earth about 24 hours later, and this can give rise to disruptions of our public and industrial infrastructure possibly with economic consequences. At present there is little warning of these events, forecasts are limited in their accuracy and a predetermined response plan is necessary to allow the impact to be managed in an effective manner.

Space weather events of sufficient size to impact economic activity occur relatively infrequently - a few times every 5 to 10 years in recent experience although they may be spread throughout the 11-year solar cycle. However, when they occur, they are worldwide in nature. Since many space technology assets providing global services are controlled off-shore, the impact on Australia can be strongly influenced by decisions taken overseas. As a consequence, Australia must have the knowledge and capability to plan alternative strategies in the event of significant, if infrequent, worldwide and/or national disruption.

Technological Impacts

Services delivered by satellite, or at least with the assistance of a space craft, are increasing year by year. Our past has been forged from terrestrial processes but our future is bound to the management of the solar system and in particular to the Sun-Earth relationship. Fleets of satellites in the space environment will be a vital part of that management.

However, satellites are particularly vulnerable to large space weather events. Their internal control and power supplies may be seriously and permanently damaged, and complete loss of operational satellites has happened, and is regarded as a serious ongoing risk by overseas agencies. Increasingly, Australia's national infrastructure is inescapably and fundamentally dependent upon external space data delivered as both services and products. Satellite transmissions control many process including credit card transactions, stock exchange activities, telephone networks, as well as many aspects of aircraft and terrestrial navigation and electrical power grids. Much of the Bureau of Meteorology's weather data is sourced from satellites. A sudden reduction or loss of any of these services as a result of a space weather event would immediately impact many Australians. The industrial and social impact could be significant.

Telecommunications and information technology fields are likewise vulnerable to space weather. Australia, like all modern societies, relies heavily on space systems (ref 4) for communications and resource information (meteorological, geophysical prospecting, navigation, and remote sensing). There are high costs and high risks associated with the consequences of space weather events, as insurance companies recognise (ref 5). Numerous satellites have already failed or been degraded by disturbances in the space environment. Space and terrestrial communications, paging systems, and remote sensing devices have been disrupted or terminated during space weather events.

The effects of space disturbances on space or ground systems can have significant consequences. In Australia, GNSS (Global Navigation Satellite Systems) services, navigation data, satellite usage, short wave communication, surveillance radar and mining surveys have failed or been severely degraded during intense space disturbances. Reports documenting other major impacts include the collapse of the electrical grid system in Quebec, disruptions to power distribution systems in Scandinavia and New Zealand, loss of light aircraft communications in Australia, degradation of satellite communications over Pacific and Indian Oceans, cosmic rays causing altitude dependent affects on computers in the US and failures of railway speed controls in Germany. In many cases there have been major costs associated with such events and yet, in general, the connection with space weather is not appreciated until after the event. Had the space weather effects been appreciated and taken into account, the costs would have been considerably reduced.

Satellite derived navigation systems such as GPS or Galileo are becoming an indispensable feature of Australian industry and society. Trucks, trains, taxis, and tractors and other agricultural and mining systems, for example, are increasingly using them to increase productivity. Car navigation, location based services, precision agriculture and machine control for mining operations all require accurate and reliable position location data now or in the future. There is an unquantified risk that a significant space weather event will result in losses of capital equipment and productivity if space weather conditions are not accurately predicted and distributed.

Communications systems, both satellite and HF radio, are the mainstay of public safety or emergency situations and can be degraded or disrupted by space weather. HF communications are especially vulnerable. HF supports Defence, maritime services, airlines and general aviation (particularly in remote areas), Police, Customs, Australian Antarctic operations, State Government Agencies (Water Authorities, Fire Brigades and Emergency Services), and rural medical services.

It is now widely recognized that airline passengers and crew are subject to measurable radiation exposure due to the cosmic radiation that continually bombards the upper atmosphere from space. As a result, France has regulated against excess radiation exposure to staff on airline flights, and this is under close scrutiny elsewhere in Europe (ref 6) and the USA. In recent years, some intense space weather events have resulted in large increases in solar cosmic ray flux, and, as reported in the 'radiation dose at aircraft altitudes' sessions of the Asia Oceania Geosciences Society annual conference held in Singapore in June 2005, it appears likely that the maximum allowable dose during pregnancy (particularly during the first trimester) could be reached in individual events. During the October/November 2003 space weather storms, the US Federal Aviation Authority issued alerts of increased radiation dosage over polar routes and flights over the polar cap were modified to reduce this risk. While the relatively low latitudes of continental Australia mean that this is a low risk for domestic air travel, it is of concern for all international air travel over the Antarctic or Arctic and has the potential to seriously impact the economics of international air travel.

From past experience of satellite failure, power grid burnout, loss of radio communication and GNSS navigation we know that these can be caused by extremes of the space environment. Australia can make an impact on the mitigation and management of these risks.

The costs of space weather

The market affected by space weather includes satellite operators, electric power companies, pipeline operators, commercial airlines. The estimated size of these markets in terms of U.S. dollars is:

Satellite operators	~ $ 775 million
Power companies	~ $ 250 million
Pipeline operators	~ $ 100 million
Commercial airlines	< $ 200 million
Total annualised outlay	< $ 1 300 million

Insurance claims per satellite per year are quoted (Glocer, Welling and Botkin, Space weather forecasting technologies, Univ. Michigan, Proceedings of U.S. Space Weather Week, April 2006) as $ 5.7 million with an estimate of 10-15% of these due to space weather (Balcewicz et al., 2000). Thus the loss due to space weather is about $ 750- 855 000 plus the revenues lost during the outage. A reasonable estimate for outage revenues is $ 230 000 per satellite per year. This leads to an average annual loss per satellite of about $1 million. This does not take into account the national costs involved in loss of defence satellite communications or the outage effects on medical and emergency satellite communications.

The risk to Australian power distribution grid from space weather is much smaller than its counter part in North America. However, the costs to industry are large if an outage is longer than an hour. The costs to power system operators involve not only replacement of damaged equipment but also the loss of revenue from sale of power. The estimate of the costs involved in the March 1989 blackouts in Quebec had a net cost of about $13.2 million, damaged equipment accounting for about $6.5 million. The transformer at the Salem, New Jersey, nuclear generating station, that burnt-out during the March 1989 magnetic disturbance, cost several million dollars to replace. Such expensive units are usually built to order and the delivery time is normally about one year. Unusually, in the Salem case, a replacement transformer was available and delivery and installation took only 6 weeks. Even so, having the transformer out of service restricted the power that could be delivered from the Salem generating station and the purchase of replacement power from neighbouring utilities cost about $17 million, far more than the cost of the transformer. (ref)

During a severe space weather storm, HF communications and incoming radiation can cause expensive aviation re-routing around polar routes. At these latitudes many satellites are below the horizon and HF communications are used to keep in contact with long distance aircraft. Deviation around the polar circle carries extra fuel and landing costs. These are estimated to be about $ 10 000 per aircraft per event.

What Australian space science can do

Given that current and future systems underpinning Australian society are vulnerable to space weather, what can be done to mitigate the effects of space disturbances?

(1) it is vital to know when a disturbance is likely to occur and what its effects will be. This can be met by monitoring the space environment and recognising abnormal conditions before they reach extreme levels. Monitoring space weather variations is a long-term task

(2) Ability to track solar magnetic field structures across the whole surface of the Sun. This requires high resolution and large field of view to pick up magnetic connections between active regions. The temporal resolution must be capable of identifying magnetic reconnections and consequent build-up of critical magnetic sites.

(3) Ability to monitor and track interplanetary structures, especially the magnetic field direction of CMEs. This will need several satellites giving a two-dimensional view of a CME and a method of measuring the overall magnetic field of the CME.

(4) Development of suitable models of the Sun-Earth environment providing reaction to solar active events. These models will need to be fed data from Sun to Earth as the event proceeds and be fast enough to give results in a useable timeframe.

(5) Identification of the most important and/or costly systems that can be affected by space weather events.

(6) Easy access to space weather indicators and predictions of events that might need to be tailored to specific systems. Alerts of impending space weather events need a lead times long enough to allow systems to be placed in a safe mode or reinforced by other, less vulnerable, systems (about one to two days)

(7) Although Australia spans 1/8 of the longitudes of the Earth, space weather requires 24 hour monitoring. It is essential that Australia collaborates with other space weather organisations around the globe to gain access to complete coverage of the sun and space disturbances.

[Are these what industry wants in terms of space science? Are there any other projects or needs that would be valuable in the 10-20 year timeframe?

Monitoring of the Sun, interplanetary space, the Earth's magnetosphere and ionosphere provides the data that leads to improved methods of forecasting space weather.

In promoting the research aspect to the funding agencies, it is equally important to promote the subject to those areas of government, industry and the public most affected by space weather. To this end, a coordinated program of public outreach should be adopted so that knowledge of the space environment can be appreciated and applied in planning future systems.

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