House of Commons Select Committee on Science and Technology: Inquiry into scientific advice and evidence in emergencies

Submission from the Royal Astronomical Society

1. With more than 3500 Fellows, the Royal Astronomical Society (RAS) is the leading UK body representing the interests of astronomers, space scientists and geophysicists (including specialists in solar-terrestrial physics).

2. As such, the Society is very much interested in two aspects of this inquiry, namely the Icelandic volcanic ash eruptions in 2010 and the potential emergency situations that could arise from future solar storms.

3. The submission on the Icelandic volcanic ash eruptions will be submitted separately by the British Geophysical Association, the Joint Association of the RAS and the Geological Society.

Executive summary

4. Solar storms or space weather events originate from Coronal Mass Ejections (CMEs), where a large amount of material is ejected from the outer atmosphere of the Sun, and phenomena associated with them. When CME material reaches the Earth, it creates fluctuations in the terrestrial magnetic field and affects a number of natural and artificial systems.

5. Space weather events are relatively common, with their frequency increasing at times of higher solar activity such the forthcoming solar maximum expected between 2012 and 2014. The majority of these events are minor, but larger scale events occur, such as those in 1989 and 2003. The events of 1859 and 1921 were larger still and similar sized storms are anticipated to occur at some point in the future.

6. The RAS notes that space weather events can have a great impact on many areas of civil and military life, including satellites, navigation systems, communications, IT infrastructure including both computer chips and Wi-Fi systems and electrical power grids. In the most severe cases power distribution systems can be seriously damaged at great cost to a national and even the global economy.

7. The RAS further notes that the preparedness of the UK Government for such events remains uncoordinated although progress has been made in recent years by a number of public sector departments and agencies. The Society recommends that these efforts continue and that Government departments are made aware of the impact that a space weather event could have on their 'core business.' On an international level, the UK should invest more heavily in the European Space Agency (ESA) Space Situational Awareness (SSA) programme which considers this at a European level.

Solar storms: What are the potential hazards and risks and how were they identified?

8. The section of the RAS submission sets out the nature and potential impact of solar storms.

9. ‘Solar storms’ are a popular name for what is generally now called ‘space weather’. This describes severe disturbances of the upper atmosphere and near-space environments, most of which are caused by violent events on the Sun.

10. The most important events in this context are coronal mass ejections (CMEs) which are large bodies of ionized matter (plasma) ejected into interplanetary space when magnetic structures in the outer solar atmosphere (the corona) become unstable.

11. If CMEs encounter the Earth they can greatly enhance the electric currents that naturally flow in space around our planet and thereby create fluctuations in the Earth’s magnetic field (magnetic storms).

12. These fluctuations induce electric fields below the surface of the Earth, driving additional current into power grids and affecting their operation. There is significant scientific evidence that the performance of power grids around the world varies with space weather conditions.

13. This is mostly a minor problem, but the strongest CMEs can trigger violent magnetic storms that can damage power grids as happened in March 1989 (when Quebec suffered a power blackout) and in October 2003 (when Sweden was affected in the same way). The 1989 event also damaged UK power systems and the level of space weather protection on the National Grid was raised.

14. The last decade has seen major advances in this area, with the threat from inclement space weather now understood to be global rather than just confined to high latitudes. There is also strong evidence that two severe space weather events in September 1859 and May 1921 would have been much more dangerous to modern power grids (had they existed) than the storms of 1989 and 2003.

15. The magnetic storms created by CMEs also generate profound changes in the density, temperature, composition and wind systems of the upper atmosphere (here defined as more than 100 km above the surface of the Earth). These changes affect radio waves passing through the upper atmosphere – a process used by many civil and military technologies including satellite communications, satellite navigation (GPS), high frequency radio communications, over-the-horizon radars, space-based radars used for earth observation and security surveillance and ground-based radars used to track space objects.

16. In normal conditions these systems mitigate the impact of space weather through choice of radio frequency or by applying correction factors. During a space weather event it becomes much more difficult to determine these - at worst the radio signals can become unstable and the technology can fail. For example, GPS is vulnerable, as demonstrated by problems experienced in the US during the October 2003 space weather event.

17. The other major solar source of severe space weather is ‘solar energetic particle events’, sometimes called solar radiation storms. These are intense bursts of charged particles produced by events in the solar atmosphere, especially the shock waves generated by CMEs. This particle radiation can damage electronics and power systems in spacecraft. The energetic particles can pass through computer chips, changing their digital state, thereby corrupting data and on-board software. This can disrupt the operation of the spacecraft, something that may take several days of work by ground controllers to put right.

18. A severe space weather event can then disrupt the space-based infrastructure (e.g. communications, navigation) that many activities in society depend on. If spacecraft are permanently disabled, restoring them requires the construction and launch of replacements. Many everyday activities will be disrupted by the lack of satellite capacity and consequent increases in the market costs for space-based services.

19. Energetic particles from the Sun can also enter the Earth’s atmosphere, where they collide with the nuclei of atoms to produce neutrons. Some of these neutrons can reach the Earth’s surface and raise radiation levels.

20. Like the impact on satellites, this enhanced radiation can disrupt digital systems in aircraft and on the ground. It is important that electronics systems on aircraft are robust against such events, e.g. through the use of at least triply redundant systems.

21. Similar considerations apply to electronic systems used in critical activities on the ground. For example, safety-critical systems must be robust against single event effects where radiation disrupts computer chips (as vendors will advise).

22. In the most severe space weather events the flux of space radiation entering the atmosphere will increase dramatically (e.g. on 23 February 1956 UK scientists observed a 50-fold increase at ground level). In these circumstances there is the possibility that the number of single event effects will be too large to be contained by normal mitigation measures.

23. There is also the prospect of widespread failures in non-critical ground systems. Given the widespread use of computer chips to control all manner of devices, it could cause very significant economic and societal disruption.

24. Another potentially disruptive class of solar events are solar radio bursts. These are intense bursts of natural radio noise produced by events in the solar atmosphere, such as CME launches. They are strong enough to interfere with the low power wireless radio technologies that have been widely adopted over the past decade - including mobile telephones, wireless internet, GPS receivers and short range device control systems. Many scientists are interested to see how much these new technologies are disrupted by the strong radio bursts expected during the forthcoming solar maximum (2012-2014), with some concern that that there is the potential to trigger widespread and highly disruptive simultaneous failures.

25. There are many other solar events that produce space weather effects at Earth, most notably the spectacular explosions termed solar flares. However, these events produce only modest effects at Earth. The Society stresses that these are important for understanding average space weather but less so in respect of the severe conditions that will lead to emergencies that are the aim of the Committee's inquiry.

Solar storms: how does the Government use scientific advice and evidence to identify, prepare for and react to an emergency?

26. Until recently this issue has been addressed separately by different departments and by groups within departments. As a result the RAS believes that the Government's preparedness has become very patchy. Indeed, some Government changes, such as the replacement of the Radio Communications Agency by Ofcom, have inadvertently reduced, and perhaps lost, the technical capability and coordination that underpins preparedness (e.g. the widespread disruption of radio communications that could arise during a severe space weather event).

27. This situation has been very frustrating for members of the solar-terrestrial physics community who wish to transfer relevant knowledge to potential users in government and industry. The situation in the UK has been very unsatisfactory compared to other countries such as Belgium, France, Germany, Spain and the US.

28. The Society acknowledges positive steps taken over the past few years. These include:

    - UK membership of the ESA Space Situational Awareness programme, established in 2009, which focuses European efforts on space hazards and works with the parallel US programme
    - Establishment of the UK Space Agency in April 2010, which should provide better leadership in space activities
    - Work to prepare a National Space Security policy, including protection of assets at risk from space weather
    - Discussions about including space weather hazards in the National Risk Register
    - Recognition of the need for international exchange of space weather data by MOD in its 2006 Defence Technology Strategy
    - Development of the e-LORAN navigation system by the General Lighthouse Authorities. This recognises the need for a navigation system that uses a different technology to GPS and thus provides redundancy in the case that GPS is degraded by natural or human interference (including that from space weather).

29. Thus the RAS welcomes the Government move towards a position where it is much better prepared to address emergencies caused by space weather. It is a work in progress with much to do, but the first steps have been taken. An important aspect of this progress is the opening up of communications between the scientific and policy making communities. This is crucial – the scientific community needs to become more aware of what information is needed by the policy community and vice versa, policy makers need to become aware of the relevant scientific capabilities that exist in the UK. These capabilities are intellectual, physical and computational and are set out in the 'List of potential UK space weather assets' of Rutherford Appleton Laboratory's Professor Mike Hapgood. They include work taking place at universities, public sector research facilities and private sector companies.

30. The recent transfer of Earth-Orientated Solar-Terrestrial Physics (EO-STP) from STFC to NERC is a valuable step towards this goal since the scope of EO-STP includes many aspects of space weather. In particular, EO-STP addresses the effects of space weather that have greatest economic impact, namely those that affect the Earth's surface and upper atmosphere. NERC is experienced in building links between science and the policy community, e.g. through its natural hazards programme. Thus it is well-placed to promote such links for space weather and, indeed, is already working with the scientific community to see how space weather might fit into the natural hazards programme.

31. Some responsibility for space weather science lies with other bodies:

    - STFC - UK research into the solar sources of space weather and their propagation to Earth
    - UK Space Agency - operations of space-based science instruments such as the UK-led Heliospheric Imager on the NASA STEREO mission
    - EPSRC - research on specialist aspects of space weather, e.g. advanced tools for analysis of solar images, modelling space weather impact on the National Grid
    - MOD - measurement and research programmes linked to specialist interests.

32. The major obstacle to provision of reliable, timely scientific advice and evidence has been the fragmentary nature of governmental activity in this area. Indeed, the past experience of the expert community has been that of "pass the parcel", i.e. when a particular body is asked, the responsibility always lies elsewhere. It is timely to establish a more coordinated approach to space weather as has been done in other countries, notably the US with its National Space Weather Programme, but also our European partners such as Belgium, France and Germany. In all these countries, space weather activities are spread over a number of bodies, including the military but national coordination allows them to work together to deliver effective scientific advice.

33. Another barrier to the provision of scientific advice has been the attitude in some bodies that potentially useful space weather research should be immediately

transitioned to end user funding without any consideration (or funding) of processes to mediate that transition. This has discouraged many scientists from exploring how to apply their research, including as advice to government and industry. Recent developments suggest that this attitude is passing, which is very welcome but it is important that funding mechanisms provide positive encouragement for scientists looking to apply space weather knowledge.

34. The Society recommends the establishment of a process to coordinate UK space weather research activities, perhaps building on and formalizing existing community efforts. NERC and the UK Space Agency should both be major players in this process, but it should operate at RCUK level to ensure that other Research Councils are engaged. It should also build links with public and private sector bodies that are potential users of space weather research outputs.

35. Finally the RAS notes that a crucial aspect of the scientific evidence on space weather is the data produced by scientific instruments monitoring space weather – some based in space and many based on ground. As in meteorology such measurements are an international enterprise with countries making an appropriate contribution but having access to the global set of data.

36. The proposed national coordination on space weather should include the coordination of UK space weather monitoring activities and especially the need to develop funding mechanisms that strike a balance between research needs and user needs for space weather data. It should raise awareness in other government bodies (e.g. MOD, CAA, DECC and DfT), and perhaps industry, of where space weather monitoring is relevant to their core business.

International Coordination

37. Space weather is a global phenomenon. A severe space weather event will affect the whole planet; indeed it will affect the whole of our solar system. The severe event of October 2003, already mentioned above, had profound effects on several deep space missions. The radiation storm within this event blinded navigation sensors on ESA's Mars Express spacecraft, then en route to Mars and destroyed a radiation sensor on NASA's Mars Odyssey spacecraft which was already orbiting the red planet. There is no safe hiding place from a very severe space weather event.

38. It is therefore widely recognised that space weather is a natural topic for international cooperation. Much of this cooperation is now being focused as a major element of Space Situational Awareness (SSA) or knowledge of conditions in space that are relevant to human activities.

39. Both ESA and NASA have established SSA programmes and are looking to space weather as the key area for cooperation but the UK is only weakly linked into this activity. Britain has joined the ESA programme but only at a minimum subscription level. This means that the UK only plays a minor role in and cannot lead the SSA

space weather activities, with limited influence on the evolution of the programme. If this continues, it is likely that other member states will develop capabilities that outstrip those currently available in the UK.

40. For example, ESA recently announced an opportunity to develop a solar imaging instrument for the SSA programme. This would have been a good opportunity to build on UK capabilities, such as those used on the recently launched NASA Solar Dynamics Observatory mission. However, the UK was not able to propose this because of our limited engagement in the relevant ESA programmes. Other opportunities are likely to emerge in the future, but UK experts will be excluded whilst the current funding arrangements continue.

41. It is worth noting that Finland, another country with good space weather skills, has recently (June 2010) joined the SSA programme. Finland had stayed out of the programme at its launch in January 2009, but changed policy when it became clear that the programme offered opportunities to develop their space weather capabilities.

42. The RAS therefore strongly recommends that the UK subscription to the ESA SSA programme should be reviewed and increased as soon as financial conditions allow. We note that the SSA programme operates under the ESA juste-retour rule so that UK expenditure on this programme will feed back to the UK as contracts to UK bodies. Membership would thus help those bodies to expand their space weather skills and thus provide better inputs to government. It would also enable the development of UK-based space weather services that would become part of the growing space export market.