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Editorial

The science of space weather

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This special issue of Annales Geophysicae is devoted to the science of space weather. This subject has become a hot topic in recent years as a result of the growing appreciation that many phenomena in the space environment around the Earth can affect human beings and their technological systems. These phenomena are ultimately driven by activity on the Sun. Thus the science of space weather is deeply concerned with the origins and manifestations of solar activity and with the propagation of solar-originated effects through the heliosphere to locations where human activities take place. This, of course, is predominantly the Earth and the region of space immediately surrounding it. But our exploration of the solar system means that we must also be aware of space weather effects beyond the Earth - both for the robotic probes currently used for exploration and to be ready for human exploration when that is finally realised.

But space weather is not just science. It is concerned with phenomena that can directly affect other human activities, so it is important to understand how the science of space weather can interact with those activities. Many of the people who run technological systems affected by space weather are interested to know about the science and to explore what it can do to help them. But they want good science, e.g. information on the size and frequency of effects. They will then to use this to see if they can design out space weather effects at reasonable cost. If not, they will then see if there are reasonable precautions that they can take in response to reliable estimates of current or future conditions. The key point is that the practical response to space weather must be reasonable - in particular terms of costs.

But to be truly effective that practical response must be underpinned by an understanding of the physical mechanisms of space weather phenomena. For example, our current understanding of dayside reconnection is far from perfect but is sufficient to allow us to be confident in using upstream measurements of the solar wind plasma and magnetic field to provide short-term warnings of geomagnetic activity. In principle, one could base these warnings purely on the statistical relationships between geomagnetic activity and upstream data. But our physical understanding gives us much greater confidence in scope and validity of those warnings. Physical understanding also helps the community to seek financial and political support for space weather applications. It allows us to demonstrate that we really understand the problem and thus that the proposed work is truly worth supporting. Put bluntly, it makes it easier to "sell" space weather to sources of funding.

However, it is equally clear that there remains considerable scope to improve space weather applications by improving our knowledge of the underpinning science. In some cases we need to improve detailed scientific understanding in order to advance existing space weather applications. A prime example would be the provision of advance warnings of geomagnetic activity based on observations of coronal mass ejections (CMEs). Here it is essential to develop the ability to model the propagation of the CME from the Sun to the Earth and thus predict the sign of B_z on arrival at Earth. In other cases we lack physical understanding and thus can develop space weather applications only on a statistical basis. A prime example would be solar proton events. There is, as yet, no scientific consensus on the source region where these particles are accelerated to high energies. Thus it is hard to build a reliable application to predict individual solar proton events. What is possible, of course, is to build statistical models of the cumulative exposure to solar protons over a period of time, e.g. the JPL 91 model of Feynman et al. (1993). These models can then be used to guide the design of systems that must cope with solar proton events. This is essentially a conservative engineering approach and is clearly an excellent way to work round space weather problems while the underpinning scientific knowledge is poor. For example, Fig. 2 shows solar proton induced power losses on ESA's Cluster mission. The solar array design includes a margin for these losses; this was calculated using the JPL 91 model.

This it is important to identify the areas where further scientific research is needed to improve our understanding of space weather. In Europe this has recently been addressed as part of two ESA studies of a European space weather pro-

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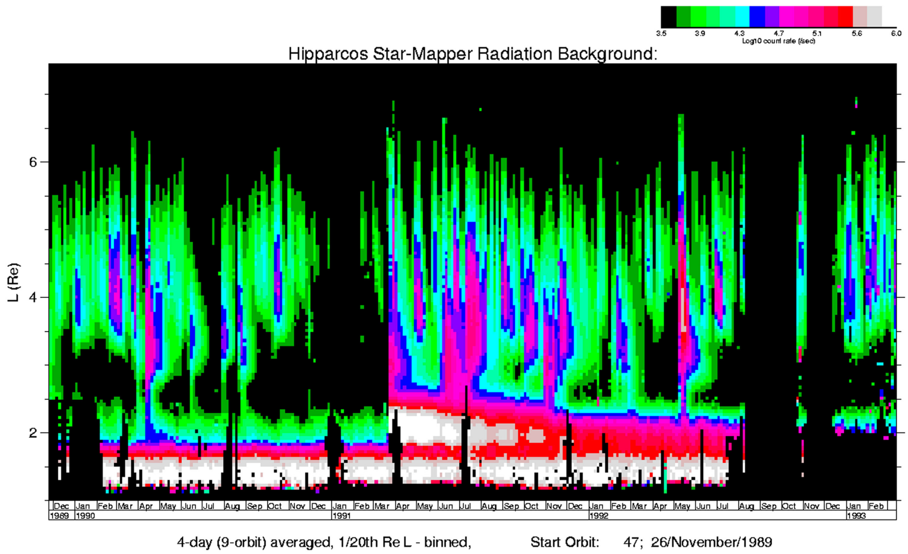

Fig. 1. One key area affected by space weather is other scientific research in space. This figure shows noise induced in the star-mapper on ESA's Hipparcos astronomy mission (Daly et al., 1994). Due to launch problems, Hipparcos ended up on a elliptical orbit through the radiation belts. The radiation background is ordered by the McIwain L parameter. The resulting pattern is similar to that of high-energy electrons in the radiation belt, suggesting that these are the source of that background. Courtesy ESA (E. Daly).

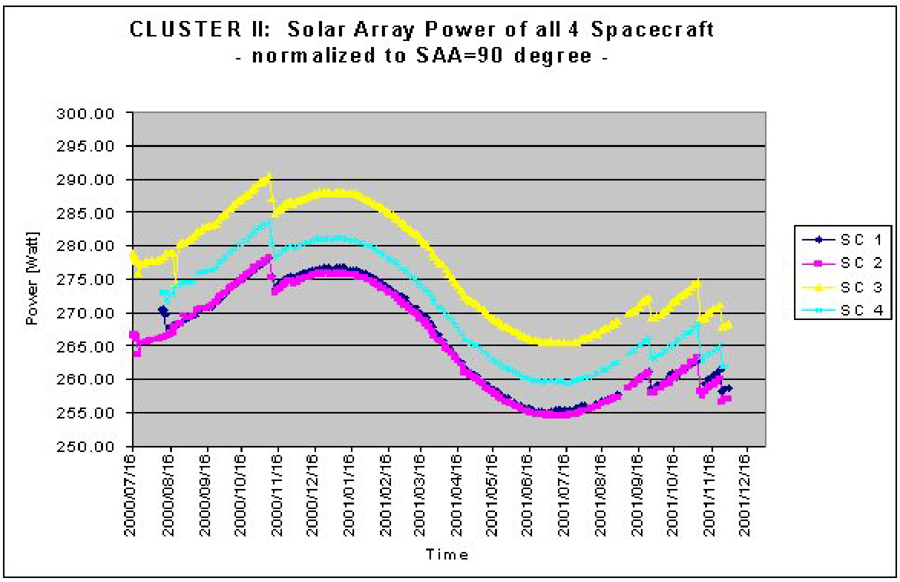

Fig. 2. Solar array power for the 4 Cluster spacecraft. The annual modulation due to the varying Earth-Sun distance was interrupted by abrupt downward steps during a solar proton event in late 2000 and again by 3 events in late 2001. Courtesy ESA (J. Volpp).

gramme (see note at end). While the main focus of the two studies was on applications, they both looked at the science underpinning those applications and discussed the need for further research. They identified a number of key areas in which further work would be very valuable:

- The conditions leading to ejection of material from the Sun
- The propagation of those ejecta, and their embedded magnetic fields, from the Sun to the Earth
- The acceleration of energetic particles both in the heliosphere (solar protons and electrons) and in the radiation belts of the Earth and other planets
- A much deeper understanding of how reconnections works, e.g. to resolve controversies over the location and, in particular, the extent of reconnection regions.
- Magnetospheric dynamics, especially during major storms

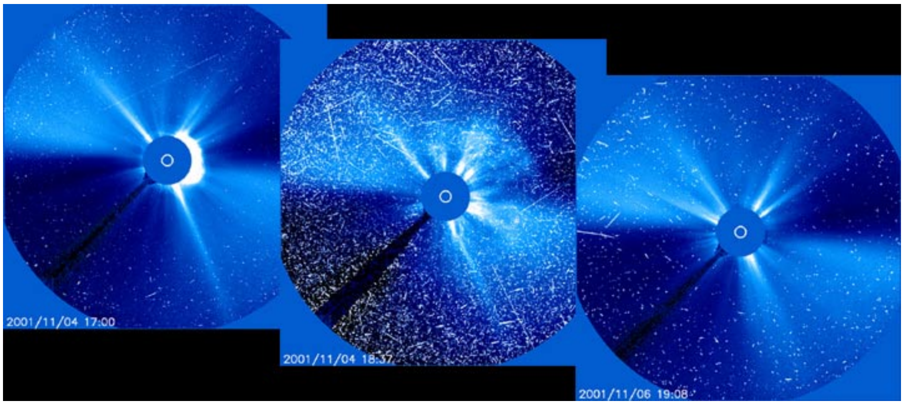

Fig. 3. SOHO has advanced our knowledge of space weather. This series of images from the LASCO coronagraph shows the launch of a CME on the right of the Sun, followed 90 min later by the arrival of solar protons (indicated by the "snowstorm" effect in the middle image). Image courtesy ESA.

– The coupling of the space environment to the neutral atmosphere of the Earth and other solar system bodies

– The size and frequency of extreme space weather events.

These topics lie at the heart of contemporary solar-terrestrial physics and are widely considered to be of great scientific interest independently of the needs to improve space weather services. For example, ESA's recently-selected Solar Orbiter mission is intended to build on the success of SOHO in addressing the first two topics in the list above. Similarly, ESA's Cluster and Ulysses mission are addressing other topics such as magnetospheric dynamics (Cluster) and heliospheric particle acceleration (Ulysses). Furthermore, some of these topics address fundamental problems in the physics of collisionless plasmas and are therefore fundamental issues in our understanding of the physical universe. Thus there is considerable scope for further fundamental research that will also be of great benefit to our understanding of space weather. It is important, indeed essential, for the STP community in Europe to communicate this idea to funding bodies. We must raise the profile of space weather-related research, make decision-makers aware of the importance of particular scientific issues and provide a base on which individual science groups can develop proposals for funding new space weather science.

This special issue is a collection of high-quality papers on a variety of space weather topics including the propagation of solar ejecta from the Sun to the Earth and the behaviour of high-energy electrons in the outer radiation belt. It has its origins in the Space Weather session organised at the 2001 EGS meeting in Nice. Following that meeting a call for papers was issued both to participants in the Nice meeting and to the broader space weather community. As a result we now have a collection of 19 papers giving a broad view of current space weather research.

Note. For information on the ESA space weather studies, see the ESA web site at `http://www.estec.esa.nl/wmwww/wma/spweather/` or the RAL site at `http://www.wdc.rl.ac.uk/SWstudy/`.

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