Meeting report

Space weather: from mud to magnetopause

The *aurora borealis* appear in records of the ancient Greek civilization and are believed to have inspired the sinuous forms of classical Chinese dragons. Solar activity, in the form of sunspots or disturbances in the chromosphere and corona viewed during eclipses, has been observed since Galileo pioneered the use of the telescope in astronomy. It was not until the twentieth century and the rise of satellite observations, however, that exploration of the near-Earth environment could offer a detailed picture of interplanetary space, the Earth's magnetosphere and radiation belts. This has spanned the gap between the solar and interplanetary physics communities and those studying geomagnetism and the physics of the ionosphere and upper atmosphere.

In parallel, the increasing numbers of satellites for Earth monitoring and communication have led to a gradual awareness of the increased exposure of high-technology human activities to potentially hazardous disturbances in the near-Earth environment driven by transient, highly energetic events of mainly solar origin (Baker, 2000). In response, operational services have begun to emerge with goals to monitor and attempt to predict the highly fluctuating behaviour of electromagnetically active components in the near-Earth environment. This community has adopted the term *space weather* in recognition of the success achieved by operational meteorological services in pooling the expertise of a range of earth science disciplines to produce day-to-day forecasts that bring tangible benefits to many sectors of human activity.

This National Royal Meteorological Society meeting, held on 21 November 2007, was organized by Mike Keil (Met Office). In the first presentation, 'What is Space Weather?' *Juha-Pekka Luntama* (Finnish Meteorological Institute) announced a more formal definition which was recently agreed by the European Cooperation in Science and Technology (COST) Action 724 group for 'Developing the basis for monitoring, modelling and predicting space weather'.

Juha-Pekka's presentation began with the sun, for which the roughly 11-year cycle of sunspots observed and recorded since 1755 is widely used as an activity indicator. At the time of the meeting, the sun showed no sunspots at all as 2007 is a solar minimum period before the onset of Cycle 24! Heat, light and particles stream from the sun in the solar wind, even in quiet conditions, until they encounter the invisible shield of the magnetosphere, the region where the Earth's local magnetic field dominates over that of interplanetary space. Some particles do make their way past this shield, however, especially following solar events, such as flares or coronal mass ejections (CMEs), where they can eventually collect in the Earth's outer radiation belt until they are scattered into the auroral zones of the Earth's upper atmosphere. Extreme ultraviolet radiation from the sun ionizes the relatively tenuous upper atmosphere to form the ionospheric F-region; more energetic soft X-rays penetrate deeper to form ions in the daytime E-region; while hard X-rays form the D-region of the ionosphere, closest to the Earth's surface. As the charged ionosphere reflects and absorbs radio waves, enabling them to bounce round the world, events that lead to disturbances in the ionosphere can have a dramatic impact on communications on a global scale. The D-region is also affected by very high energy particles from outside the solar system, galactic cosmic rays (GCRs) that reach the Earth in larger numbers in the quieter solar wind conditions around solar minimum and can penetrate as far down as the troposphere, ejecting particles that populate the more dangerous inner radiation belt.

GCRs also interested *Giles Harrison* from the University of Reading, as they produce molecular cluster ions throughout the troposphere, even at the surface. Some cluster ions act as precursors in the generation of ultrafine aerosol, from which cloud condensation nuclei (CCN) grow: other cluster ions act to charge atmospheric aerosol particles. As, however, the nonlinear mechanisms by which the cluster ions aggregate to form CCNs are not well understood, it is not currently possible to quantify a direct link between GCR fluxes and cloud formation.

Space Weather is the physical and phenomenological state of natural space environments. The associated discipline aims, through observation, monitoring, analysis and modelling, at understanding and predicting the state of the sun, the interplanetary and planetary environments, and the solar and non-solar driven perturbations that affect them; and also at forecasting and nowcasting the possible impacts on biological and technological systems.

COST Action 724: European Space Weather Portal
http://www.spaceweather.eu

Gareth Jones, from the Met Office, discussed the uncertainties in trying to assemble long-term records of solar irradiance for climate change assessments. Although the UV energy and solar wind that affect space weather can vary significantly, they comprise only a small fraction (1/10,000,000) of the total output from the sun, which has actually varied very little in the satellite era. At present, therefore, the changes in the absorption of sunlight due to changing carbon dioxide amounts appear to affect our climate far more than changes in the sunlight itself.

Alan Aylward from University College London pointed out that although space weather could drive large changes in the upper atmosphere, this thermosphere region actually contains only 1/1,000,000 of the mass of the Earth's atmosphere. Nevertheless, models of the thermosphere and ionosphere show that waves and tides transfer energy up and down through the mesopause and chemical species can also shower out of the upper atmosphere, which suggests that small but persistent effects on very long climate timescales could not be ruled out entirely. *Richard Horne,* of the British Antarctic Survey, looked at the radiation belts and pointed out that wave acceleration is a major, if not dominant, process for accelerating electrons inside the radiation belts, which has redefined our concept of how they are formed (Horne, 2007). The radiation belts are strongly influenced by solar-induced geomagnetic storms and are capable of inflicting serious damage on satellites: the famous Halloween geomagnetic storm of 2003 led to the reporting of anomalies by 30 satellites! The cost of insuring satellites ensures that the insurance industry has a keen interest in space weather.

In the final presentation, *Jean Lilensten* from Laboratoire Planetologie de Grenoble reviewed some of the implications of space weather on human activity in space. As well as satellites, astronauts can be affected by radiation. On occasion, X-ray flares from the sun have produced radiation levels high enough to be instantly fatal to a man in a spacesuit (Lilensten and Bornarel, 2006). Fortunately, astronaut missions so far have been lucky. Another concern was expansion of the thermosphere due to heating in sudden ionospheric disturbances (SIDs) which causes extra drag on manmade objects in low-Earth orbits. As only 6% of Earth-orbiting manmade objects are actually functioning spacecraft with the power to boost their orbits in such situations, many objects change course unpredictably,

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causing problems for ground stations trying to monitor the location of junk, and some even re-enter the Earth's atmosphere to burn up. As a final thought for the meeting, Jean asked, 'If space weather can affect humans, can humans affect space weather?' Global warming of the lower atmosphere is accompanied by a corresponding cooling in the mesosphere and thermosphere that acts to lower the position of the maximum ion density in the ionosphere F-region by the order of 20 km. The mud-to-magnetopause challenge for researchers over the next decade is to couple physical models from the magnetospheric, ionospheric and meteorological communities (general circulation models from the latter commonly cover the Earth's surface up to the mesopause), in order to investigate the transfer of the sun's energy from the solar wind boundary at the magnetopause right down to the surface on which we all live. Who can predict what interesting questions it might reveal!

References

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DOI: 10.1002/wea.269