How we make our forecasts

To make our high energy electron forecasts we collect the following data:

- ACE satellite data measuring the solar wind
- GOES satellite data measuring particles at geostationary orbit
- A real-time forecast of the Kp index from the Swedish Institute of Space Physics, Lund
- A near real–time forecast of the Kp index from the British Geological Survey

We use the near real time forecast of the Kp index, combined with satellite data from ACE and GOES, to drive our models. Since the forecast of Kp covers a period of 3 hours, we use this as input to our models to simulate the radiation belts for the past 24 hours and provide a forecast for the next 3 hours. The forecast of Kp is updated every hour and the models are re-run to update the radiation belt forecast every hour. The results are then displayed on our public web site.

As a backup, should the ACE data become unavailable or unreliable, we use the near real time Kp index produced by the British Geological Survey from ground based magnetic field measurements to drive our models. In this case we can still provide a forecast, but the forecasting time is reduced by about 1 hour or so.

Two independent models are used to make the forecasts, one at the British Antarctic Survey (BAS), in Cambridge, UK, and the other at the Aerospace Research Laboratory (ONERA) in Toulouse, France. Models at different locations provide a measure of backup, because if one model goes down, or there is a system failure, the other model can continue to provide forecasts. The difficulty is that the two models can give different results, due to differences in the physical processes that are included in each model, differences in way the models are constructed, and differences in the boundary conditions. It is not always easy to show which model is the best. One model may perform better for certain geomagnetic conditions, whereas another may be better for other conditions. We select the model results considered to be the best for a particular set of conditions. The process of improving the models and determining the best results for different conditions is an area of active research for the rest of the project.

We consider the use of two independent models a strength. Independent computer programs are commonly used in aircraft system to ensure safety and reliability. We have adopted the same principle for our space weather forecasting. Furthermore, there are many different types of space weather conditions and only by comparing the results of each model against data for different conditions can we improve our understanding of the physics and evolve the models to make better forecast and prediction. We welcome collaboration with other modelling Groups in this area.

Timescale for SPACECAST forecasts

Since it takes approximately 30-60 minutes for the solar wind to flow from the ACE spacecraft to the boundary of the Earth’s magnetic field one may ask how we can forecast up to 3 hours ahead reliably. However, research shows that it takes approximately 4 hours for information about changes in the solar wind to be transferred to electrons at geostationary orbit [Borovsky et al., 1998]. This additional time delay helps to make our forecast of up to 3 hours ahead more reliable than might be thought at first.

Our method implicitly assumes that the level of activity will not change much over the next three hours. If it changes slowly and the solar wind becomes less geo-effective then activity will generally drop and our forecast will tend to over-estimate the radiation belt flux. However, this will be corrected within one hour. If the solar wind becomes more geo-effective, then we may have under estimated the flux. However, since it takes time to accelerate electrons to high energies and increase the radiation belt flux substantially, typically 1-2 days following a geomagnetic storm; this should not be too much of a problem.

If the solar wind changes rapidly, on a timescale less than an hour or so, then our forecasts will become less reliable. For example, a large coronal mass ejection (CME) can push the outer boundary of the Earth’s magnetic field inside geostationary orbit on a timescale of minutes, totally changing the radiation environment. However, when the solar wind changes rapidly one of the most common features of the outer electron radiation belt is that the electron flux drops rapidly on a timescales of minutes to hours. This is known as a flux drop-out and is the subject of much research. We cannot reproduce these events reliably at present. However, since satellite operators are more interested in high flux, which causes internal charging problems, the omission of these events from our model should not pose too much of a problem. If a flux drop-out occurs then the threat of internal charging is reduced substantially and our forecast will be corrected within one hour.

A key part of the project is to conduct research into flux drop out events, and other processes, and then include these in a later upgrade of our forecasting models.

Reliability of 1 – 3 day warnings

Some space weather forecasting systems provide warnings 1 – 3 days ahead. These warnings are helpful in that they may indicate that a disturbance such as a coronal mass ejection is on its way from the Sun to the Earth, and that it may cause disruption. However, it is not possible to forecast changes in the Earth's radiation belts accurately this far ahead, or to say how geo-effective the disturbance will be. The key word is accuracy.

The problem is that the Earth's radiation belts, and many other types of space weather, depend on how the solar wind and the interplanetary magnetic field vary when they reach the outer boundary of the Earth's magnetic field. Although we can observe a coronal mass ejection and note that one is on its way to the Earth, we cannot measure the direction of the interplanetary magnetic field inside the coronal mass ejection until it reaches the ACE spacecraft, some 200 Earth Radii in front of the Earth. Since it only takes between 30 and 60 minutes for the solar wind to flow from ACE to the Earth, this does not give much time. Since the solar wind can vary rapidly causing rapid changes in the Earth's magnetic field, it is not possible to give a reliable warning more than a few hours ahead and certainly much less than 1 day.

References

Borovsky, J. E., M. F. Thomsen, and R. C. Elphic (1998), The driving of the plasma sheet by the solar wind, J. Geophys. Res., 103, A8, 17,617-17,639.