SOLMAG: AN OPERATIONAL SYSTEM FOR PREDICTION OF SOLAR AND GEOMAGNETIC INDICES

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Introduction

The European Space Operations Centre (ESOC) requires predictions of solar and geomagnetic activity levels on time-scales ranging from days to years. The forecasts are used in long-term mission planning and in day-to-day management of operational spacecraft. An important application is orbital prediction, where an atmospheric model is used to compute air density in order to estimate the atmospheric drag on the spacecraft. In the atmospheric model solar and geomagnetic activity are parameterised in terms of the solar 10.7 cm radio flux (F10.7) and the *ap* index respectively.

The Geomagnetism Group of the British Geological Survey has carried out work under contract to ESOC to investigate forecasting techniques. Two methods have been developed for forecasting solar and geomagnetic activity: In the first method medium to long-term (months to years) predictions are made by a software package called SOLMAG; in the second method short to medium term (up to 27 days) predictions are made by a software package called PDFLAP. This paper gives examples of both types of prediction.

Note: In the plots presented here both sunspot numbers and values of the F10.7 radio flux are used to illustrate solar activity, and the *aa* and the *ap* indices are used to illustrate geomagnetic activity. The two pairs of activity parameters are closely related; sunspot and *aa* index data are available over a much longer period of time than values of the F10.7 flux and the *ap* index.

Long-Term Variability of Solar and Geomagnetic Activity

The medium and long-term prediction method implemented in the SOLMAG software is an adaptation of the technique due to McNish and Lincoln (1949), similar to that used by Holland and Vaughan (1984). The procedure for forecasting sunspot numbers in cycle 22 (the present sunspot

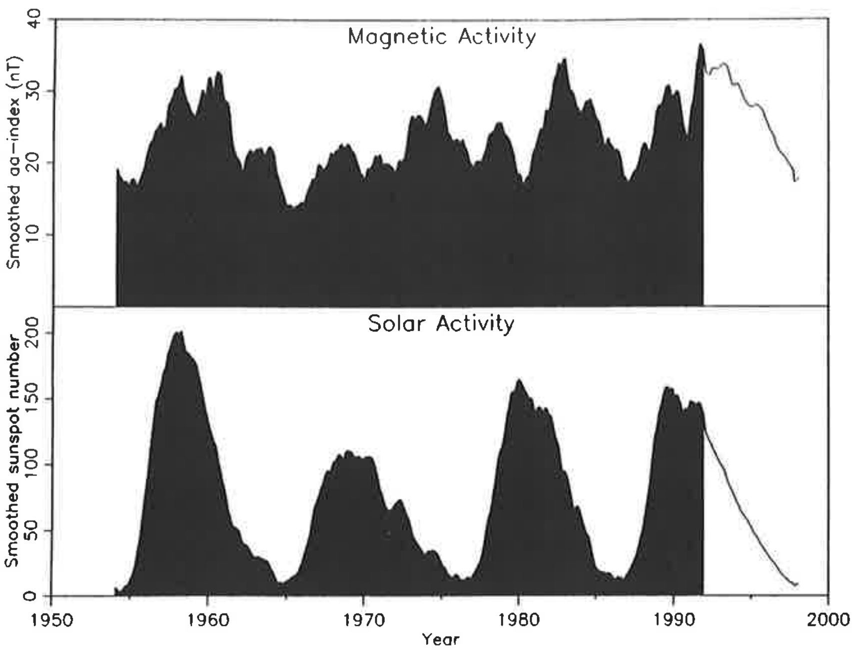

Figure 1 Long-Term Solar and Geomagnetic Activity

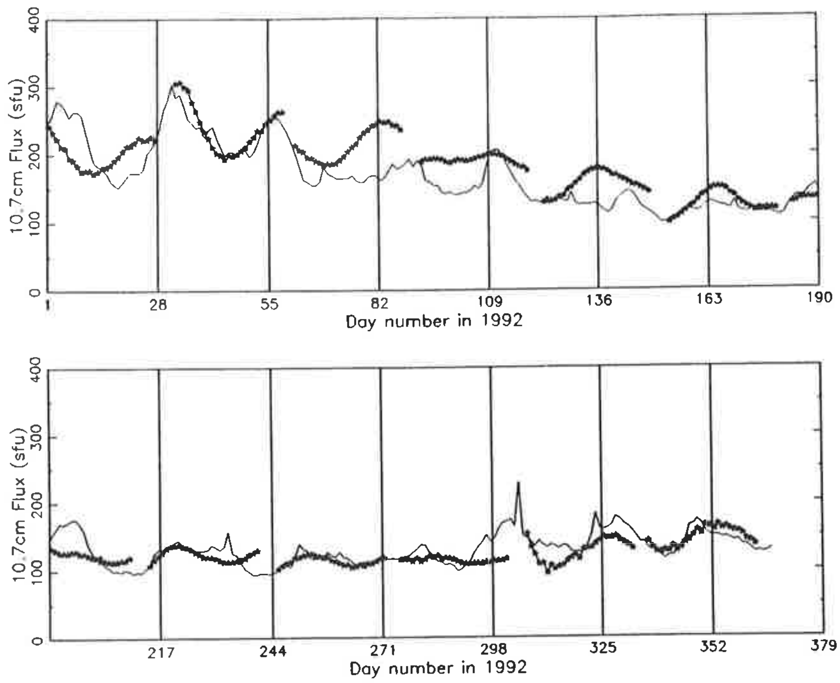

Figure 2 27-Day Forecasts of F10.7 During 1992

cycle) is as follows:

a. calculate the mean period (P), in months, of sunspot cycles 1 to 21;

b. resample each cycle at P+1 points, ie. at the same phase of each cycle;

c. compute a mean cycle based on the resampled values;

d. forecast the departure from the mean cycle for month m of cycle 22, $D_m(22)$, using

$$D_m(22) = \sum k_i D_{m-i}(22)$$

where the k_i, truncated at some value of i, are determined by a least-squares analysis of departures of previous cycles from the mean cycle at the same phase. A similar method is used to predict the geomagnetic *aa* index.

Figure 1 shows smoothed values of the *aa* index and sunspot numbers over recent cycles from 1954-92 (shaded curves), including forecast values for the remainder of cycle 22 (unshaded curves).

Short-Term Variability of Solar and Geomagnetic Activity

The long-term prediction of solar and geomagnetic activity is useful for planning satellite orbits in the months and years before launch. For spacecraft such as ERS-1 and EURECA, which require to be kept in precisely controlled orbits, it is necessary to predict solar and geomagnetic activity in the short to medium-term to plan manoeuvres which keep the spacecraft on track.

The PDFLAP software uses Auto-Regressive Integrated Moving-Average (ARIMA) models of the F10.7 and *Ap* (the daily average of *ap*) time series to predict values up to 27 days ahead. (The sun rotates every 27 days as seen from the Earth and many solar-terrestrial phenomena show a tendency to repeat with this period.) A detailed description of ARIMA modelling is given by Box and Jenkins (1976).

Figure 2 shows 27-day predictions of F10.7 made starting on the first day of each calendar month in 1992 (asterisks). Also shown are the observed values of F10.7 (line). The ARIMA model has 60 coefficients which are recalculated using the previous two years data each time a prediction is made. It can be seen that the model copes well with the general decrease in F10.7 throughout the year. The predictions are less accurate when the tendency for 27-day recurrence of solar activity is changing (eg around day 82) but the model responds to any changes for the next rotation.

Figure 3 is similar to Figure 2, but shows predictions of the *Ap* index. The model used for the prediction is a hybrid model: For predictions up to 4 days ahead an ARIMA model with 4 coefficients is used; for 5-27 days ahead a model with 30

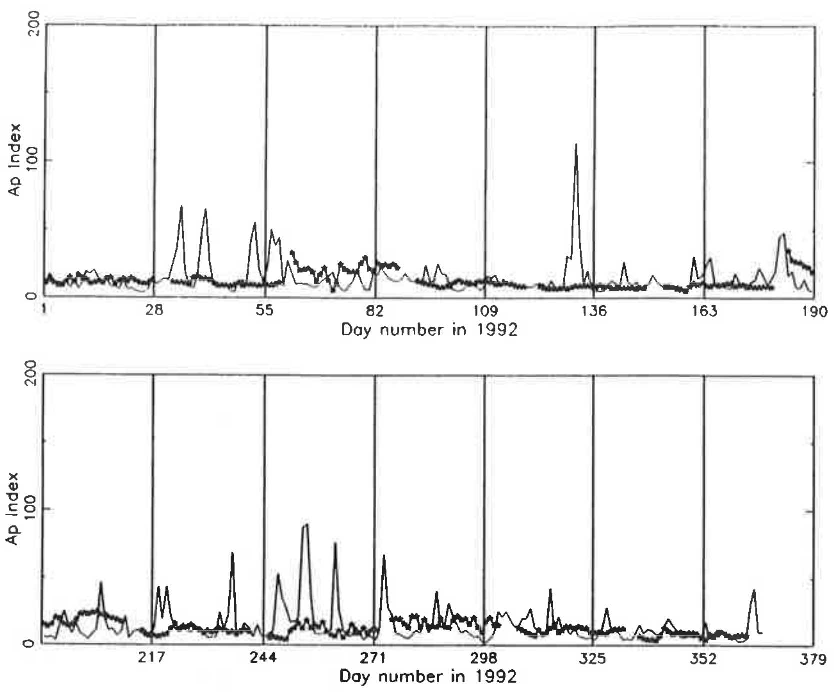

Figure 3 27-Day Forecasts of *Ap* During 1992

coefficients is used. In each case the model coefficients are calculated using the previous six months data. It is clear from this plot that large magnetic storms are not anticipated by the ARIMA method. Thus it is important for planning spacecraft trajectories that monitoring of magnetic activity is carried out in real-time. This service is supplied by the Geomagnetism Group of the British Geological Survey.

The Distribution of Magnetic Storms

The orbits of low-altitude spacecraft (and debris) can be affected dramatically by intense magnetic storms. Figures 4 and 5 show how often intense

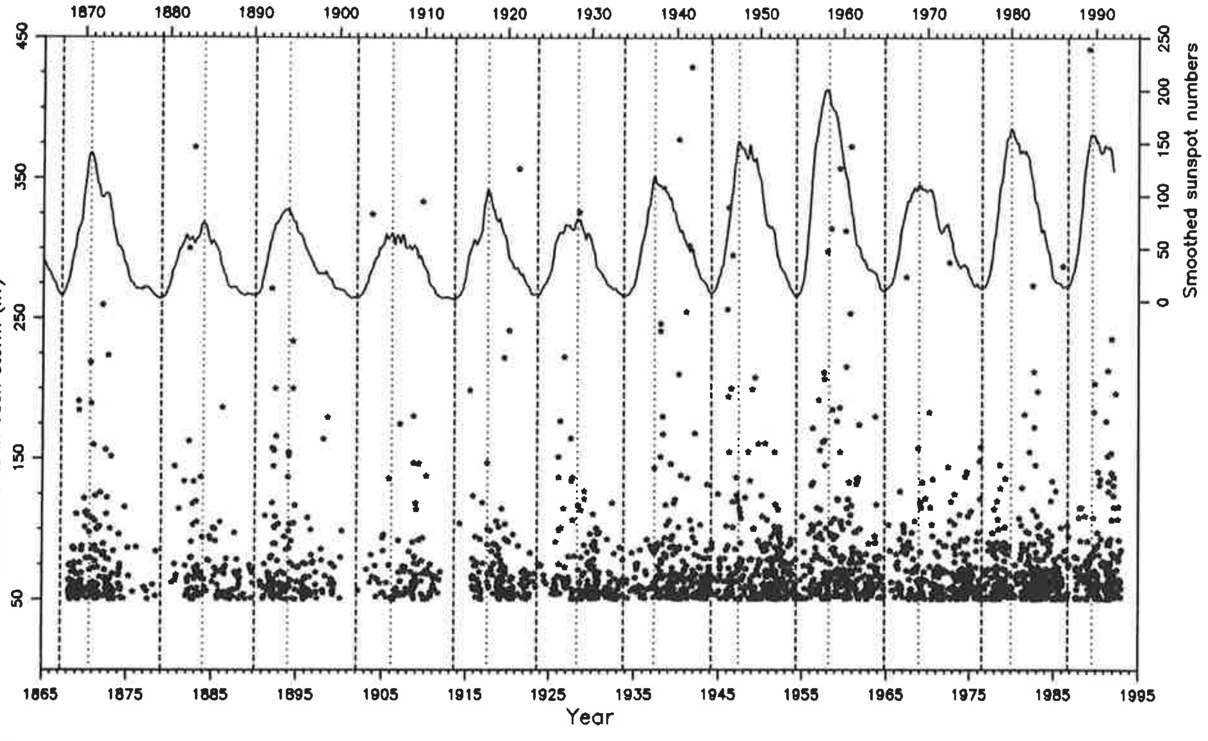

Figure 4 Magnetic Storms with Maximum *Aa* > 50 nT

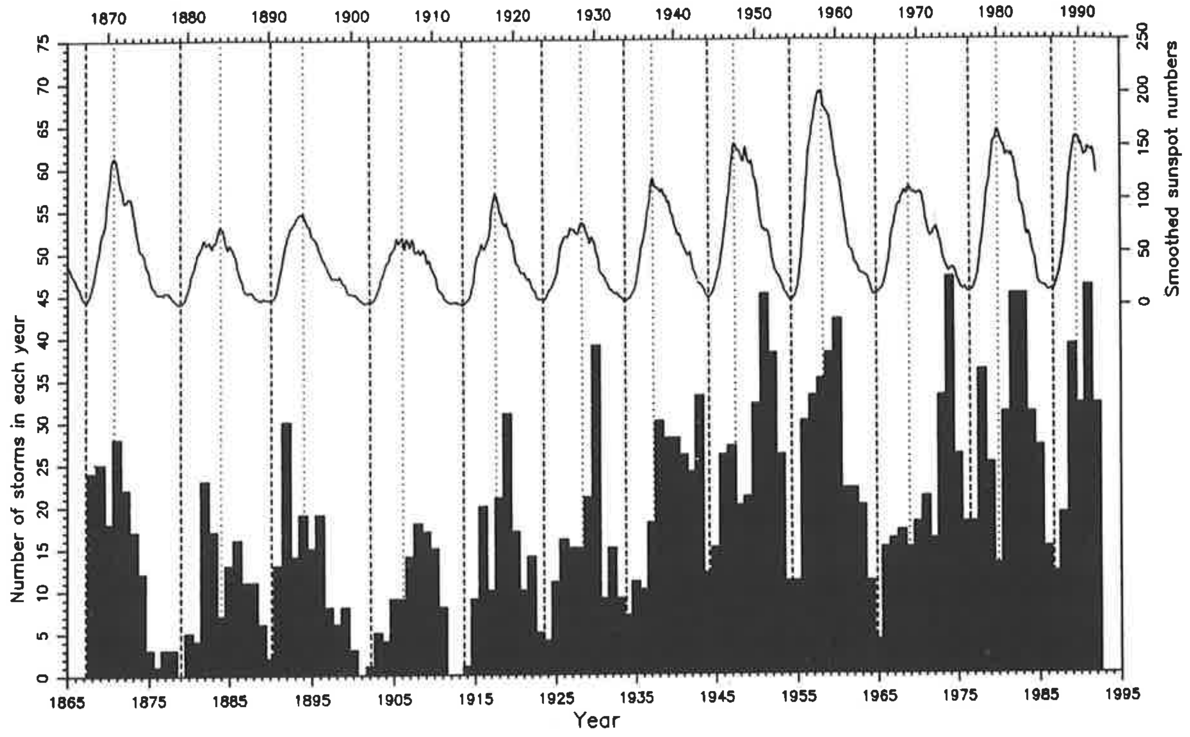

Figure 5 Annual Numbers of Magnetic Storms with $Aa > 50$ nT

magnetic storms occur.

To investigate the distribution in time of magnetic storms an 8-point running mean has been passed through the series of 3-hourly *aa* indices for the 125 years 1868-1992, to generate an index, denoted *Aa* in the plots, representative of a 24-hour period, with 3-hour resolution. For the plots presented here, a storm was said to begin when *Aa* exceeded 50 nT, and to end when *Aa* subsequently fell below 50 nT, and remained below this threshold for at least two 3-hour periods. A total of 2262 storms were found under this definition.

Figure 4 shows the maximum value of *Aa* attained during each of the storms between 1868 and 1992. The smoothed sunspot numbers are also plotted. The dashed vertical lines indicate sunspot minimum and the dotted vertical lines indicate sunspot maximum. There is a slight tendency for the largest magnetic storms to occur during the declining phase of the solar cycle. The most intense magnetic storm was that of 13-14 March 1989.

The number of storms per year are plotted in histogram form in Figure 5. This shows more clearly the distribution of storms in relation to the sunspot cycles. The overall level of geomagnetic activity has increased during the 20th century.

Conclusion

The techniques described here for predicting solar and geomagnetic activity have proved useful in planning spacecraft operations on time-scales of days to years. These techniques could equally be applied to the monitoring of orbits of space debris.

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