PREDICTION OF METEOSAT ANOMALIES BASED ON SPACE WEATHER

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ABSTRACT

A non-linear classification method of the high energy electron flux measured on board the European Space Agency, Meteosat, is used to investigate the correlation and the predictability of spacecraft anomalies. A characteristic time for the build-up of the process leading to an anomaly is shown to be of about four days. However, it is not clear yet to what extend this time scale is related to the anomaly mechanism or to the associated magnetospheric processes. Moreover, the result of the study suggests that not only the time integrated flux of energetic electrons has an influence on the anomaly occurrence but also the time variation of the flux over several days.

Key words: Spacecraft anomaly; Space weather; Meteosat.

1. INTRODUCTION

The spacecraft operational anomalies can be due to the energetic electron environment via two major mechanisms: surface charging and internal charging. Surface charging results from the build-up of electrostatic charges on material surfaces exposed to the plasma. Strong electric fields may be created at some location of the surface especially if the surface is nonhomogeneous or has a complicated geometry. This may result in breakdown of the electrostatic configuration accompanied by powerful current transients that are induced or conducted into sensitive electronics. The electrostatic distribution equilibrium on spacecraft surfaces following change in the space environment is usually reached on a time scale of the order of 10^{-3} second to 1 minute depending on the conductivity of the surface. The most significant environmental parameters are the sunlit area, the energy distribution of the electron population and the total plasma density.

In the internal charging process, the charge build-up occurs behind spacecraft surfaces, e.g., within dielectric coating material and is due to electrons with energy sufficient to penetrate the typical thickness of the spacecraft surfaces, i.e., energy of the order of 100 keV to 1 MeV. The resulting electrostatic field in some location can be very large if the electric conductivity is too low to allow a rapid leakage of the charge deposited by the penetrating electrons. This may lead to transients phenomena, pulses or sparks. The time scale for the build-up of the electrostatic configurations until a breakdown occurs can be several days.

For both mechanisms, the charging processes are rather well understood and quantitative modelling of them feasible. However, the process by which the equilibrium, or quasi-equilibrium, of the electrostatic configuration breaks down is still not completely understood and is a matter of debate. As a consequence, criteria for the protection of systems against electrostatic breakdown are largely empirical. From the space environment point of view the situation is not better elucidated. The plasma parameters relevant both to surface and internal charging may vary by orders of magnitude in geosynchronous orbit on time scales much smaller than a day. Furthermore, several type of plasma populations (e.g., relativistic electrons and cold magnetospheric plasma) may be involved simultaneously in the electrostatic breakdown process. As a matter of fact, there are currently no self-consistent model fully accounting for the dynamics of the whole charged particle environment suspected to be involved in the generation of spacecraft anomalies.

Given the complexity of the parameters and mechanisms possibly involved in the anomaly generation processes the possibility to unambiguously identify the detail of the process leading to it is very exceptional. Therefore, the most convincing studies of spacecraft anomalies are mainly of a statistical nature. In the last decades there have been several studies indicating correlation between spacecraft anomalies and large negative surface charging (cf *Lauriente and Gaudet* [1994] for a review). As a consequence, spacecraft designers now include specifications to control surface charging either by grounding or by a judicious choice of surface materials that charge moderately even in severe environments. Recently, however, there has been evidence of correlation of some operational anomalies with enhanced flux of very high energy electrons, i.e. with energy of the order of a few MeV. Studies relying on dedicated spacecraft experiments, e.g. CRRES, SCATHA, have led to the most reliable proofs of the existence in space of internal charging induced anomalies [*Violet and Frederikson*, 1993; *Koons and Gorney*, 1991]. However, the design of these spacecraft was purposely far less conservative than the one of the commercial satellites. Conversely, studies involving commercial satellites are often limited by the lack of information on the environment and therefore suffer from a poor statistics. In order to overcome part of these difficulties, *Wrenn* [1997] studied the correlation of anomalies observed on a commercial geosynchronous satellite with particle measurements provided by other spacecraft, e.g. GOES-7, at the same orbit. This study gave further evidence of the existence of internal charging induced anomalies on commercial spacecraft, but statistics were still poor.

Correlations are usually performed with time averaged scalar values of environmental parameters. Attempt to identify dynamics feature of the environment can be performed with the so-called superposed epoch analysis [*Rodgers*, 1991; *Rodgers et al.*, this proceedings]. However, this technique provides only qualitative information. Alternatively, a technique based on the classification of the environment data can provide quantitative information of the correlation between spacecraft anomalies and dynamics feature of the environment. This technique has been earlier applied and indicated that time varying feature of the environment may play a significant role in the anomaly process [*López and Hilgers*, 1997]. However, the conditions of applications were very harsh since the anomaly data set was very small (40 events) and the environmental data were measured on a spacecraft remote from Meteosat. The purpose of the present study is to investigate further the correlation of space environment dynamics features with spacecraft anomaly in more favourable conditions, i.e. using a much larger data set and environmental data measured on the same spacecraft.

2. ENVIRONMENTAL AND ANOMALY DATA

The anomaly data set used for this study corresponds to about 500 anomalies affecting Meteosat spacecraft. The data of the high energy electron environment (from 43 to 300 keV) are provided by an onboard monitor, SEM-2, supplied by Mullard Space Science Laboratory under contract to ESTEC. The flux over the investigated period of time is displayed in the top panel of Figure 1. The vertical lines in the upper panel indicate the day when one or more anomalies occur. The main daily electron flux is displayed in the lower panel. The variation of the electron flux appears clearly in the Figure. It is however hard to find any quantitative correlation between the environmental data and the set of anomalies by visual inspection for such a low time resolution. Even on a more expanded time scale as in Figure 2, no obvious features appear to be characteristic to the environment preceding an anomaly occurrence. Therefore, statistical methods are required.

In Figure 3, the histogram of the daily averaged flux for a day preceding an anomaly (dashed line) or a non-anomaly (solid line) is displayed. It appears that the anomalies roughly tend to occur when the flux is high but still many anomalies appear to occur at rather low flux level. The description of the environment can be further detailed by taking into account the change of the environment from one day to the other. To this end, pattern classification techniques as described below can be very powerful.

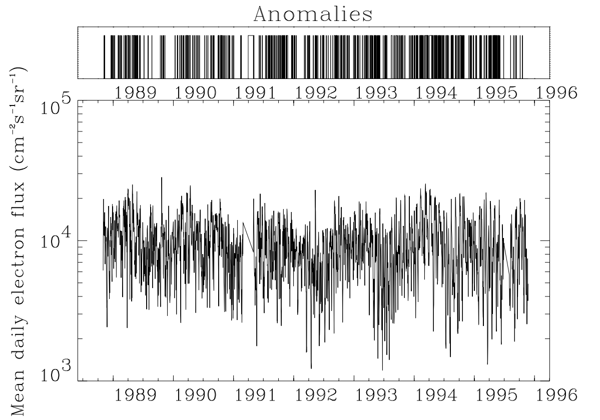

Figure 1. Time series of the daily averaged electron flux (lower panel) and occurrence of Meteosat anomalies (upper panel).

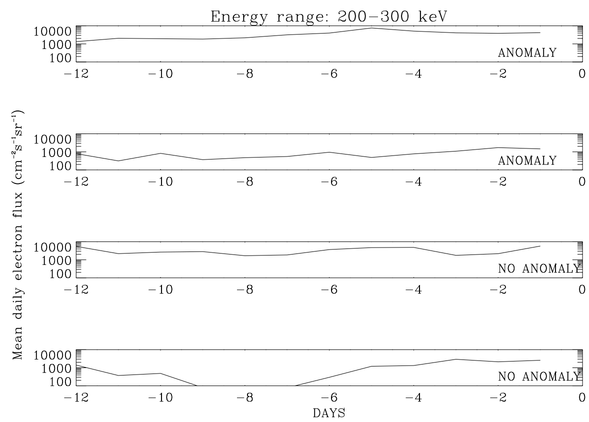

Figure 2. Segment of time series preceding a day with anomalies at date 0 (upper two panels) or a day without anomaly at date 0 (lower two panels).

3. CLASSIFICATION TECHNIQUE

The technique used in this study is summarized by the flow-chart diagram displayed in Figure 4. The environmental data are segments of time series of the daily averaged flux in the energy range 200-300 keV. These segments are first labelled according to whether they are followed by a day with an anomaly (A) or without an anomaly (B). This data set is further divided in two new data sets at random but keeping constant the same proportion of segments A and B in each set. One of the set, the train set, is used to derive a classification rule between segments A and B. To this end a Bayesian method can be used, however, a Learning Vector Quantization (LVQ) technique [*Beale and Jackson* 1990] proved to perform better. Applied on the other set, the test set, the classification rule leads to certain ratios of correctly identified segments A, $\dot{x}_A$ and B, $\dot{x}_B$. A measure of the efficiency of the rule on the test set is provided by the difference between the actual success ratios and the one provided at random but keeping the proportion of A segments and B segments gener-

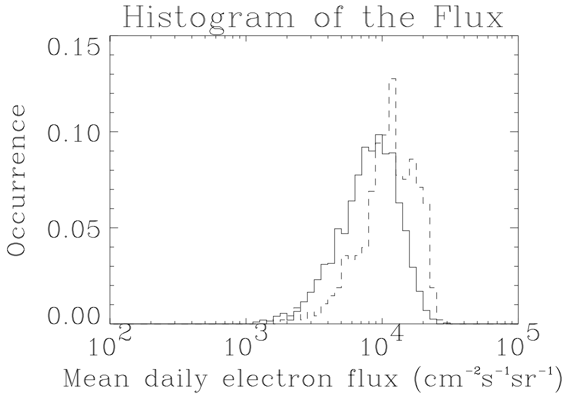

Figure 3. Histogram of the daily averaged flux preceding a day with anomaly (dashed line) or a day without anomaly (solid line).

ated on the train set. This is

$$\chi^2 = \frac{(\dot{x}_A - qn_A)^2}{qn_A} + \frac{(\dot{x}_B - qn_B)^2}{qn_B}$$

with

$$q = \frac{x_A + n_B - x_B}{n_A + n_B}$$

where n_A, x_A, respectively n_B, x_B are the actual number of segments and the one found by the rule on the train set for class A and B respectively. The confidence level Π can be derived from the χ^2 test [cf e.g., *Press et al.*, 1995]. Furthermore, error bars for the different parameters are derived from the variance of the results using 20 different random divisions of the data in train and test sets.

4. RESULTS

In Figure 5 the results of the classification technique using a LVQ algorithm to classify the segments of time series are shown as a function of the window length of the segments. In this Figure, the ratio of success of the classification rule (top panel), the total error (middle panel), and the confidence level (bottom panel) are shown. The classification rule found by the LVQ algorithm appears to be a proof of the existence of a correlation between the environment and the spacecraft anomaly. Furthermore, it provides a quantitative assessment of it and allows thereby to assess the quality of the input data. A striking result is that the best correlations are found for time windows larger than four days. In order to check whether this time effect is purely an accumulation time or whether it reflects some underlying dynamic mechanism, the same classification technique has been applied to the averaged flux over the time window instead of the time series. The result displayed in Figure 6 shows that for this kind of input the correlation is the best when the time window duration is one day.

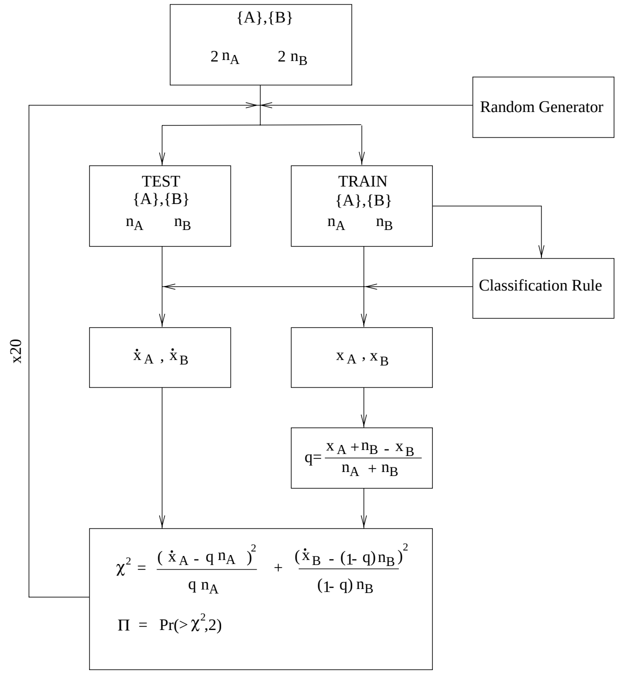

Figure 4. Flow chart of the classification technique. The classification rule can be provided by several means, e.g., a Bayesian classification or a LVQ algorithm.

5. CONCLUSION

A method of classification has been used to evaluate quantitatively statistical correlation between the flux of electron in the 200-300 keV energy range and the occurrence of a type of spacecraft anomalies. A characteristic time scale of $\sim$ 4 - 5 days for the build up of the characteristic environment preceding an anomaly has been found. It is not clear yet to what extend this time scale is related to the anomaly mechanism or to the associated magnetospheric processes. However, the study suggests that the anomalies studied above are not purely the result of a charge accumulation process since averaged values of the flux over 4-5 days discriminate less well the anomaly events from ordinary situations. Furthermore, the method provides $\sim$one day ahead forecasting tools of spacecraft anomaly on the basis of time series of the electron environment. This may be useful for forecasting activities of space weather effects on spacecraft or other systems since it is rather easy to automatise and to adapt to any events and time series data.

REFERENCES

Beale, R., T. Jackson, Neural Computing - an Introduction, Adam Hilger., 1990

Koons, H. C. and Gorney, D. J., "Relationship Between Electrostatic Discharges on Spacecraft P78-2 and the Electron Environment," *Journal of Spacecraft and Rockets,* Vol. 28, No. 6, 1991, pp. 683-688.

Lauriente, M. and Gaudet, Environmentally Induced spacecraft anomalies, *Journal of Spacecraft and Rockets,* vol. 31, No. 2, 1994, pp. 153-185.

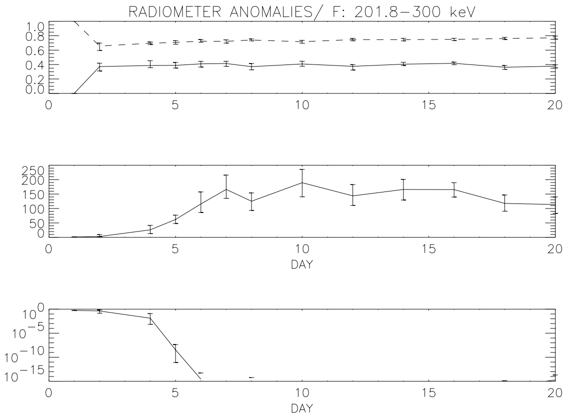

Figure 5. $\dot{x}_A$ (dashed line of upper panel), $\dot{x}_B$ (solid line of upper panel), χ^2 (middle panel), and Π (lower panel) as a function of the window length of the time series.

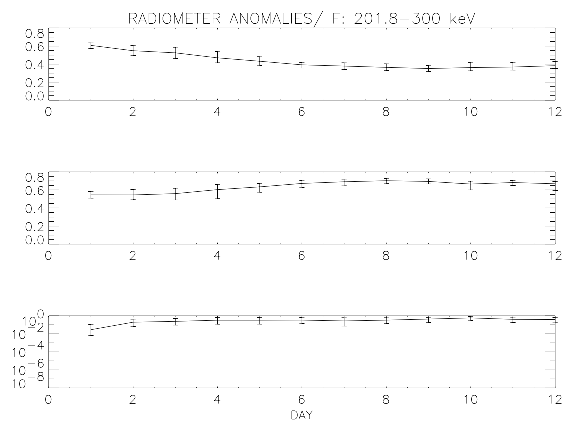

Figure 6. $\dot{x}_B$ (upper panel), $\dot{x}_A$ (middle panel), and Π (lower panel).

López Honrubia, F. J., and A. Hilgers, Some Correlation Techniques for Environmentally Induced Anomalies Analysis, *Journal of Spacecraft and Rockets, 34*, 670, 1997.

Press et al., Numerical Recipes in C, Cambridge Univ. press., 2nd edition, 1995.

Rodgers, Correlation of Meteosat-3 Anomalies with Data from the Space Environmental Monitor, European Space Agency, EWP-1620, June, 1991.

Violet, M. D. and Frederikson, A. R., "Spacecraft Anomalies on the CRRES Satellite Correlated with the Environment and Insulator Samples," *IEEE Transaction on Nuclear Science,* Vol. 40, No 6, 1993, pp 1512-1520.

Wrenn, G., Conclusive Evidence for Internal Dielectric Charging Anomalies on Geosynchronous Communication Spacecraft, *Journal of Spacecraft and Rockets*, Vol 32. No 3, 514-520, 1995.