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TRENDS IN ENVIRONMENTALLY INDUCED SPACECRAFT ANOMALIES

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ABSTRACT

The Spacecraft Anomaly Data Base maintained at NOAA's National Geophysical Data Center has been useful in identifying trends in anomaly occurrence. Trends alone do not provide quantitative testimony to a spacecraft's reliability, but they do indicate areas that command closer study. An in-depth analysis of a specific anomaly can be expensive and difficult without access to the spacecraft. Statistically verified anomaly trends can provide a good reference point to begin anomaly analysis.

Many spacecraft experience an increase in anomalies during the period of several days centered on the solar equinox, a period that is also correlated with sun eclipse at geostationary altitude and an increase in major geomagnetic storms.

Increased anomaly occurrence can also be seen during the local time interval between midnight and dawn. This local time interval represents a region in Earth's near space that experiences an enhancement in electron plasma density due to a migration from the magnetotail during or following a geomagnetic substorm.

THE SPACECRAFT ANOMALY DATA BASE

The National Oceanic & Atmospheric Administration (NOAA) is the main U.S. civilian agency responsible for the operation of monitoring spacecraft. Its responsibilities include the (GOES)* series of geostationary weather and space environment monitoring satellites and the lower altitude, polar orbiting NOAA/TIROS satellites. Long and productive spacecraft lifetimes are of major importance to NOAA.

NOAA also operates a system of national data centers. The National Geophysical Data Center (NGDC) in Boulder, Colorado has responsibility for collecting, archiving, analyzing, and disseminating solar-terrestrial data and information. NGDC, under the auspices of World Data Center A for Solar Terrestrial Physics, services a worldwide interest in data and information about the origin of solar activity, the transfer of energy from the Sun to Earth, and its effects in interplanetary and near-Earth space. In line with these services, NGDC has made a deliberate effort to apply these data resources to the problem of spacecraft interaction with the the near space environment.

A data base of spacecraft anomalies is maintained at the Solar-Terrestrial Physics Division of NGDC in Boulder, Colorado. It includes the date, time, location, and other pertinent information about incidents of spacecraft operational irregularity due to the environment. These events range from minor operational problems which can be easily corrected to permanent spacecraft failures. It currently contains 2779 anomalies from 1971 to the present with contributions from seven countries: Australia, Canada, Germany, India, Japan, United Kingdom, and the United States. Data suppliers are asked to provide the anomaly type and diagnosis.

*Geostationary Operational Environmental Satellite

The data base is maintained on an IBM compatible personal computer. To facilitate access to the information, software has been written to perform a full range of functions for managing and displaying the contents. Satellite users can use the Spacecraft Anomaly Manager (SAM) software to create a data base containing only their anomalies and forward the data to NGDC on floppy disk for inclusion in the archive. In order to preserve confidentiality, when necessary, spacecraft may be identified by aliases.

SAM also includes two important functions to test anomaly collections for environmental relationships. Histograms of local time and seasonal frequency show distinct patterns for spacecraft susceptible to static charge build-up and subsequent discharge. The current version of the software does not perform statistical validation but the user may convert the data to a standard ASCII file that can be uploaded to any computer and processed by user supplied software.

STATISTICAL METHODS

Grajek and McPherson (ref. 1) point out the value of using statistical methods for analyzing apparent trends in anomaly occurrence. The Chi-square test for randomness can determine the probability that a given histogram, or one with similar deviations from the mean, could occur randomly.

The Pearson Product-moment Correlation Coefficient can determine both the strength of a correlation and the probability of error in establishing a correlation where none exists. A coefficient of 1 indicates perfect correlation, 0 indicates no correlation, and -1 indicates perfect anticorrelation.

These two methods were used to analyze each of the following histograms with the help of public domain software (ref. 2). The results are reported in the discussions that follow.

SEASONAL TRENDS

Figure 1 shows the basic definition of 'seasonal'. The histogram displays the apparent solar declination on the 15th of each month in whole degrees . The cartoon shows the sun-earth geometry that causes a variety of environmental effects on spacecraft in near-Earth-space. This distribution is used to test for seasonal correlations in the anomaly data.

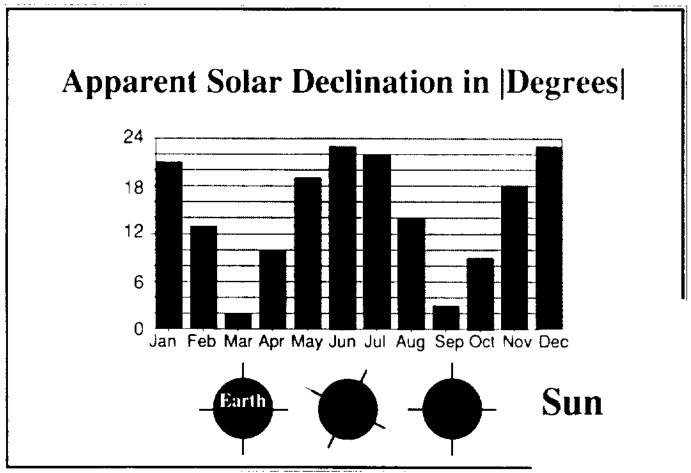

FIGURE 1

One effect of the variation in apparent solar declination on spacecraft is the periods of eclipse that occur at spacecraft in geostationary orbit as shown in figure 2. These periods of earth-shadowing occur at the spring and fall equinox near midnight local time. The periods of darkness cause an interruption in the charge balancing phenomenon that relies on the photoelectric boiling off of electrons. During equinox a spacecraft at geostationary altitude will encounter magnetotail plasma boundaries more often.

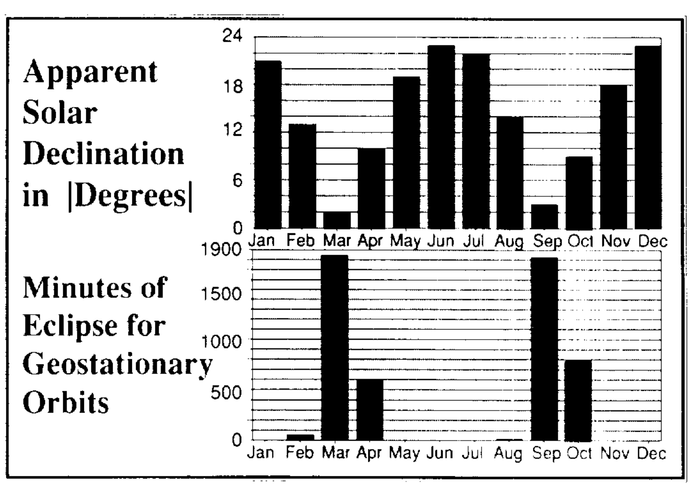

FIGURE 2

The distribution of major magnetic storms is shown in figure 3. It has a very low probability of being random (.00042) and a moderately high anticorrelation to the histogram of declinations (-.89) with a very small probability that the correlation is wrong (.00011).

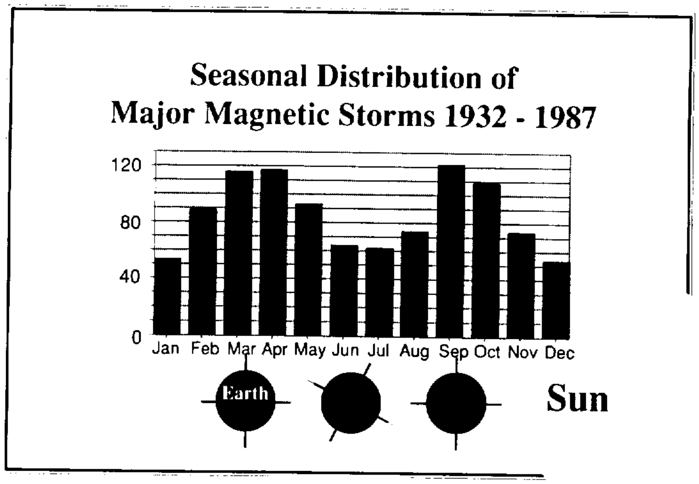

FIGURE 3

Figure 4 displays the seasonal distribution of all 2779 data base anomalies and shows a distinct increase around the spring and fall solar equinoxes. This anomaly distribution has a very low probability of being random (.0000018) and a moderately high anticorrelation to the histogram of declinations (-.86) with a very small probability that the correlation is wrong (.00011).

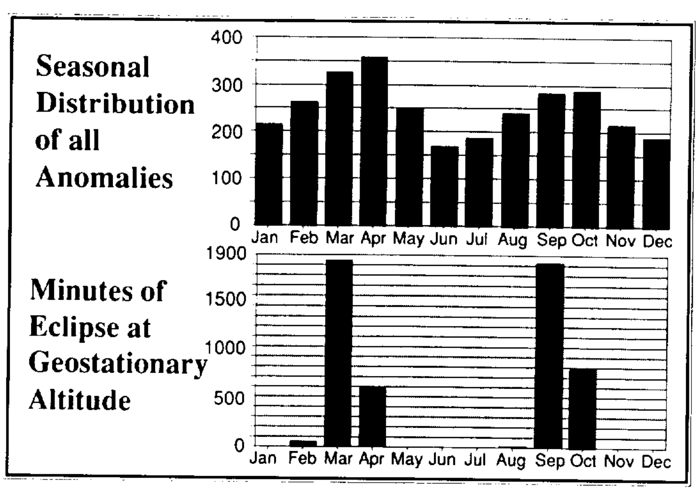

FIGURE 4

The GOES-4 & -5 phantom command anomalies shown in figure 5 are a prime example of a seasonal dependence. The phantom commands have been diagnosed as a surface charging problem which is consistent with the seasonal phenomenon. These charging events have a moderately high anticorrelation to the histogram of declinations (-.72) with a very small probability that the correlation is wrong (.0073)

The GOES-4, -5, and -6 telemetry anomalies also shown in figure 5 have been diagnosed as Single Event Upsets (SEUs). This anomaly distribution has a good probability of being random (.26) and a weak anticorrelation to the histogram of declinations (-.23) with a large probability that the correlation is wrong (.47). Since galactic cosmic ray fluxes are random in the seasonal context, the statistics validate the SEU diagnosis made for the GOES telemetry errors.

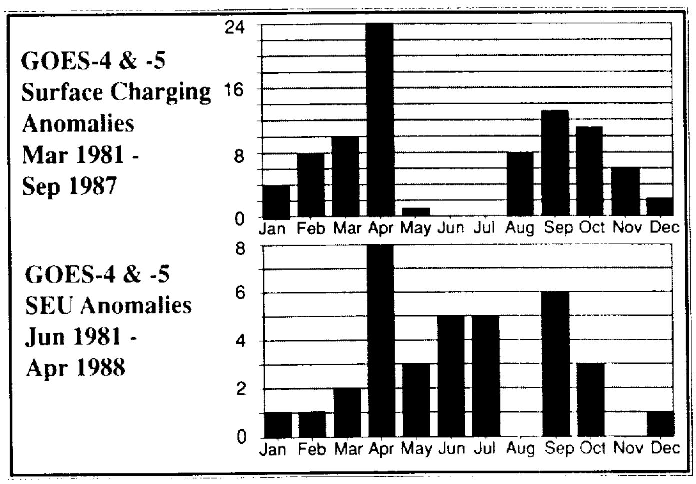

FIGURE 5

Tracking and Data Relay Satellite System (TDRSS-1) anomalies shown in figure 6 show no distinct seasonal variation in anomaly occurrence. This anomaly distribution has a very good probability of being random (.44) and a moderately weak anticorrelation to the histogram of declinations (-.55) with a small probability that the correlation is wrong (.062). However, the TDRSS SEUs show twice the seasonal correlation the GOES SEUs do.

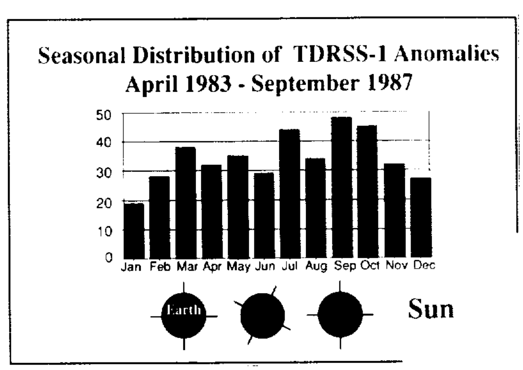

FIGURE 6

LOCAL TIME TRENDS

Figure 7 shows the local time distribution of the 2272 anomalies in the data base that have sufficient information for a local time calculation. This anomaly distribution has a small probability of being random (.00035). There is the expected midnight to dawn bump and two additional bumps, one centered at 12 LT* and one centered at 17 LT. The smaller enhancements may be explained later when a Sun-Vehicle-Earth (SVE) angle calculation is added to the anomaly entries. For specific spacecraft designs there are SVE angles that allow parts of a spacecraft to cast shadows on itself, causing a partial eclipse situation.

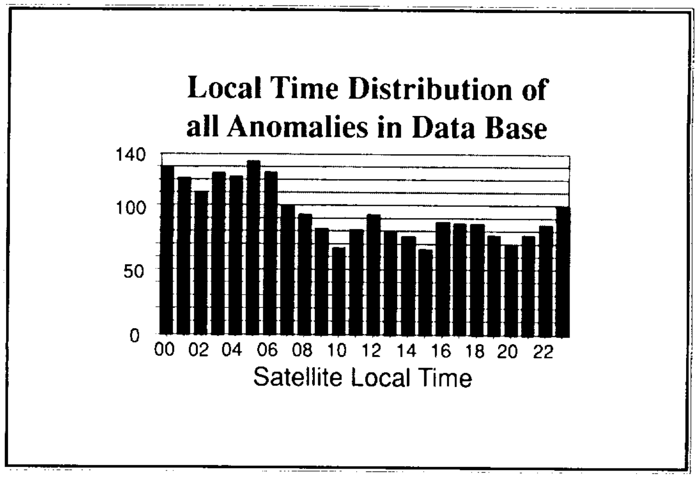

FIGURE 7

In figure 8 the GOES surface charging anomalies show a classic midnight to dawn grouping with a small probability of being random (.0000022). The GOES SEU anomalies show no such grouping and have a very high probability of being random (.94), consistent with SEUs.

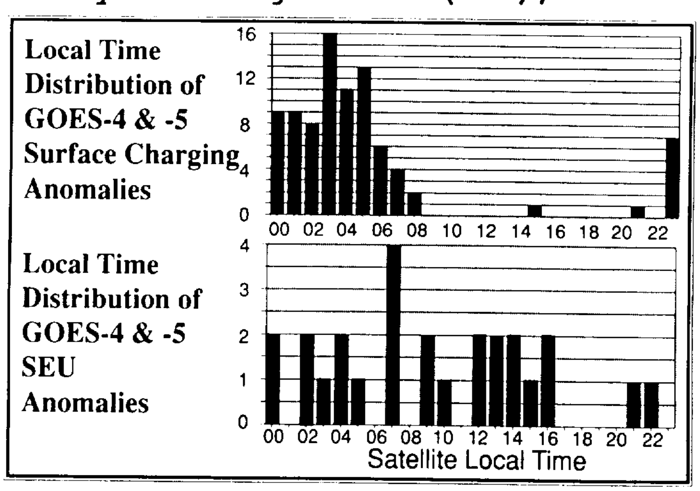

FIGURE 8

*Local Time

Figure 9 shows a clock face plot that distinctly displays the grouping of GOES surface charging anomalies between midnight and dawn. This type of grouping is due to a migration of KeV electrons from the magnetotail during magnetically disturbed periods and illustrates the extremely low probability of randomness (.0000022).

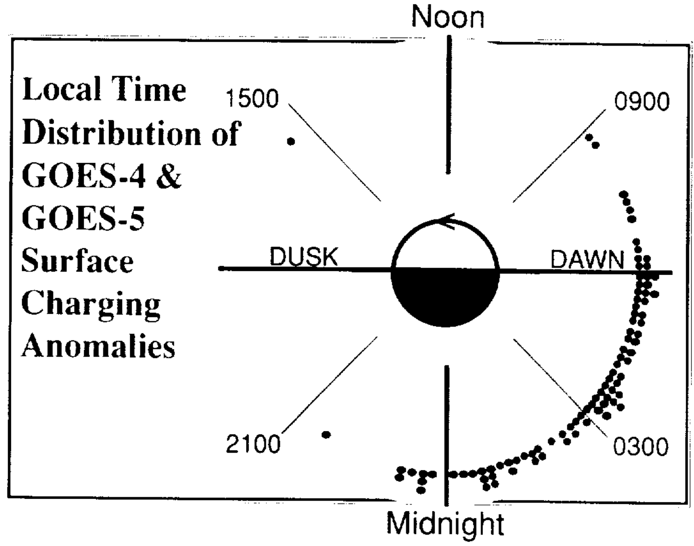

FIGURE 9

TDRSS-1 anomalies show no increase of anomaly occurrence during the midnight to dawn local time interval and have a very high probability of being random (.97), consistent with SEUs.

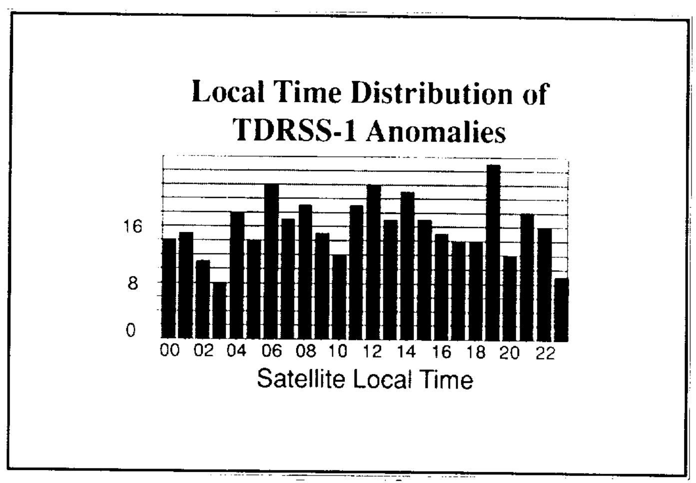

FIGURE 10

CONCLUSION

There is value in studying the trends, or their absence, in populations of spacecraft anomalies. This is only possible if there is a systematic recording of operational spacecraft anomalies and a willingness to merge those records with a common body of data for correlative study. The Spacecraft Anomaly Data Base and software for managing and studying the data are available from NGDC for these purposes.

REFERENCES

1. Grajek, Michael A.; McPherson, Donald A.: Geosynchronous Satellite Operating Anomalies Caused by Interaction with the Local Spacecraft Environment. NASA NAS3-21048.

2. Gustafson, Tracy L.: EPISTAT Statistical Package for the IBM Personal Computer, version 2.1. 1983.