TRENDS IN SPACECRAFT ANOMALIES

Daniel C. Wilkinson

National Oceanic and Atmospheric Administration
National Geophysical Data Center
Solar-Terrestrial Physics Division
Boulder, Colorado 80303

SPACECRAFT CHARGING TECHNOLOGY CONFERENCE

Naval Postgraduate School
Monterey, California

October 31, 1989 - November 3, 1989

ABSTRACT

NOAA's National Geophysical Data Center maintains a data base of anomalous spacecraft behavior attributed to environmental interactions. One of the uses of these data base has been to identify 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 difficult without on-board environmental monitors. Statistically verified anomaly trends can provide a good reference point to begin analysis of a spacecraft's susceptibility to environmental conditions. The data base currently contains over 3000 anomaly reports from 7 countries.

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. Those responsibilities include the GOES (Geosynchronous Operational Environmental Satellite) series of weather and space environment monitoring satellites and the lower altitude, polar orbiting NOAA satellites. Long and productive spacecraft lifetimes are of major importance to NOAA.

NOAA also operates a system of 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 near space environment.

Data on spacecraft anomalies is maintained at the Solar-Terrestrial Physics Division of NGDC. Date, time, location, and other pertinent information about the anomaly are included. These events range from minor operational problems to permanent spacecraft failures. The data base currently contains over 3000 anomalies spanning 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.

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 their anomalies and forward the result 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 (1977) 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 distribution, 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 methods are used to analyze the following trends with the help of public domain software (Gustafson, 1983).

BACKGROUND

When an earthquake devastates a major highway during rush hour it attracts a great deal of attention. Those who are tasked with maintaining highways are concerned with the safety of existing structures. Highway engineers become concerned with upgrading specifications on future projects. The end result is that attention is focused on techniques to improve the reliability of structures subjected to the trauma of earthquakes.

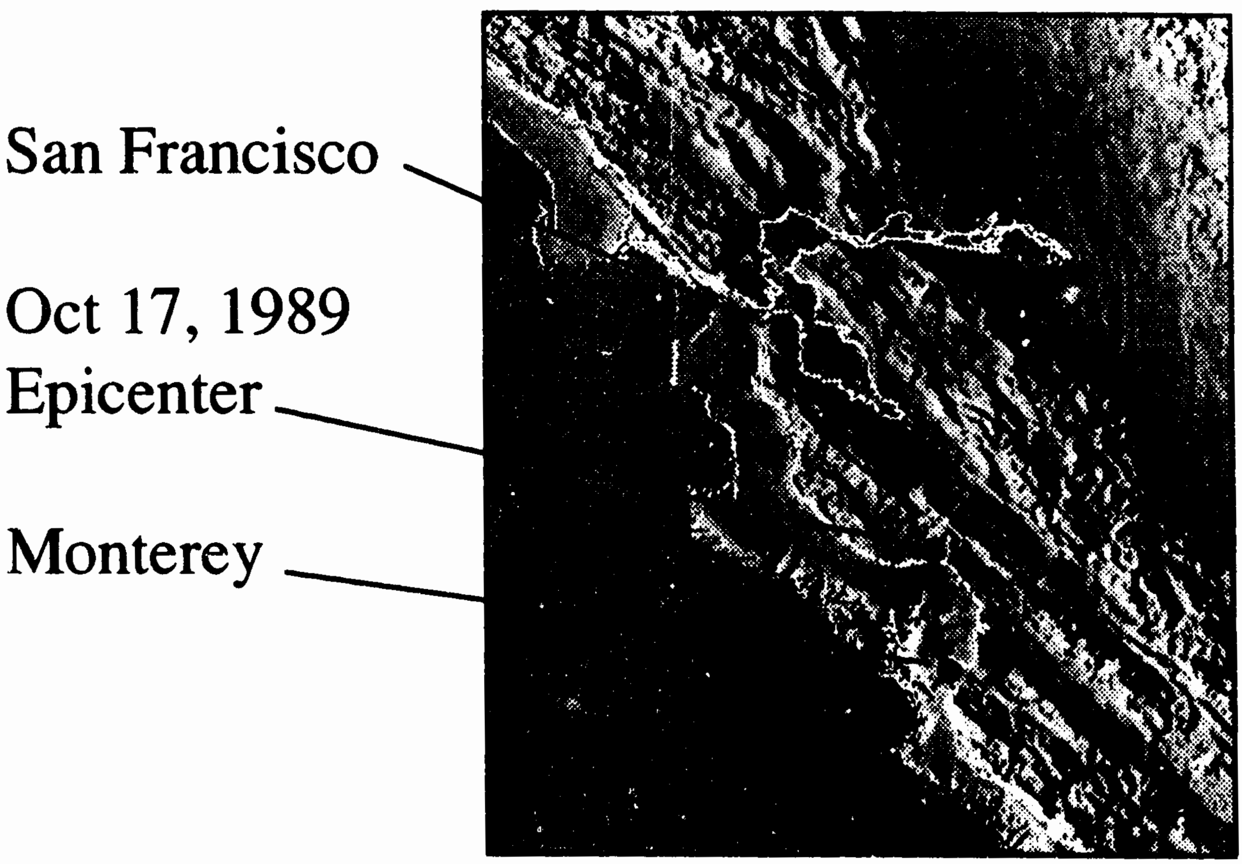
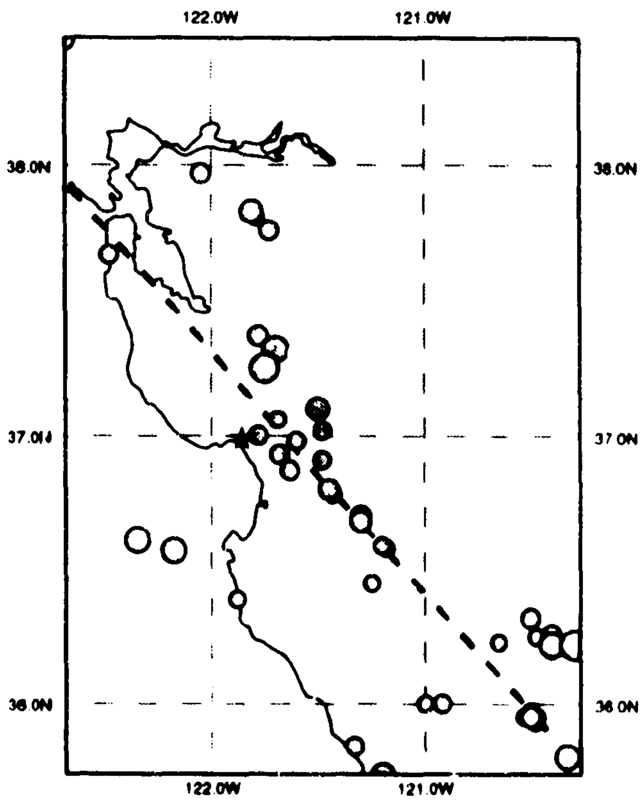


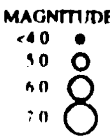
Figure 1

The historical record of earthquakes is an important part of the analysis (Figure 2). The first questions asked after an event like this are: What is the history of this type of event? Has this happened before? Can we expect it to happen again? Where? How soon? How often? What is the track record of similar structures in similar events? None of these questions could be adequately answered if someone had not undertaken the responsibility of long term record keeping. It is though such record keeping that trends appear, trends such as the clustering of earthquakes along the San Andreas fault or the susceptibility of certain civil engineering techniques.

LOMA PRIETA EARTHQUAKE M = 7.1 OCTOBER 17, 1989

The Loma Prieta, California earthquake was located at 37.053N 121.851W by the USGS in Golden, CO. This location is shown by the star on this map. The epicenter of the event was near the northern end of the Southern Santa Cruz Mountains segment of the San Andreas Fault (SSCMS). Preliminary aftershock locations clearly indicate that the event ruptured that segment of the fault. This segment may have had similar events during 1838, 1865, and 1890. The probability of an event of this size on this segment between 1988 and 2018 was estimated as 30% in a recent report by the USGS. This probability was not well constrained, but it was the highest probability determined for major faults in the bay area. The San Francisco Peninsula segment of the fault adjoins the SSCMS to the north. This segment has the second highest probability of experiencing a large event in the next 30 years.





BERKELEY EVENTS M >= 5 1911-1984

Figure 2

Interest in the environmental effects on spacecraft, like earthquakes, follows the large events. Most people who have an interest in such effects can point to a single event or series of events that piqued that interest. The event could have been the catastrophic failure of a major mission component or the sudden increase in the rate of occurrence of otherwise benign anomalies.

The failure of the Visual and Infrared Spin-Scan Radiometer (VISSR) on GOES-4 coincided with the arrival of very energetic protons associated with a large solar flare (Figure 3). What was it about this particular proton event that could cause such a failure? Are proton events of this magnitude common? Have GOES satellites survived similar proton events? Could the 12 hours of enhanced > 2 MeV electron flux cause a charge build-up on internal dielectric materials that discharged when the energetic protons arrived? Or, was it only a coincidence that GOES failed during the proton event? Some of these questions can only be answered if historical information is available about the space environment and the interaction of GOES and similar spacecraft with that environment. Others will never be answered. The failure of GOES-4 prompted the creation of the Spacecraft Anomaly Data Base in the hope that such a historical record would help answer questions about future failures.

SOLAR-TERRESTRIAL ENVIRONMENT
November 1982

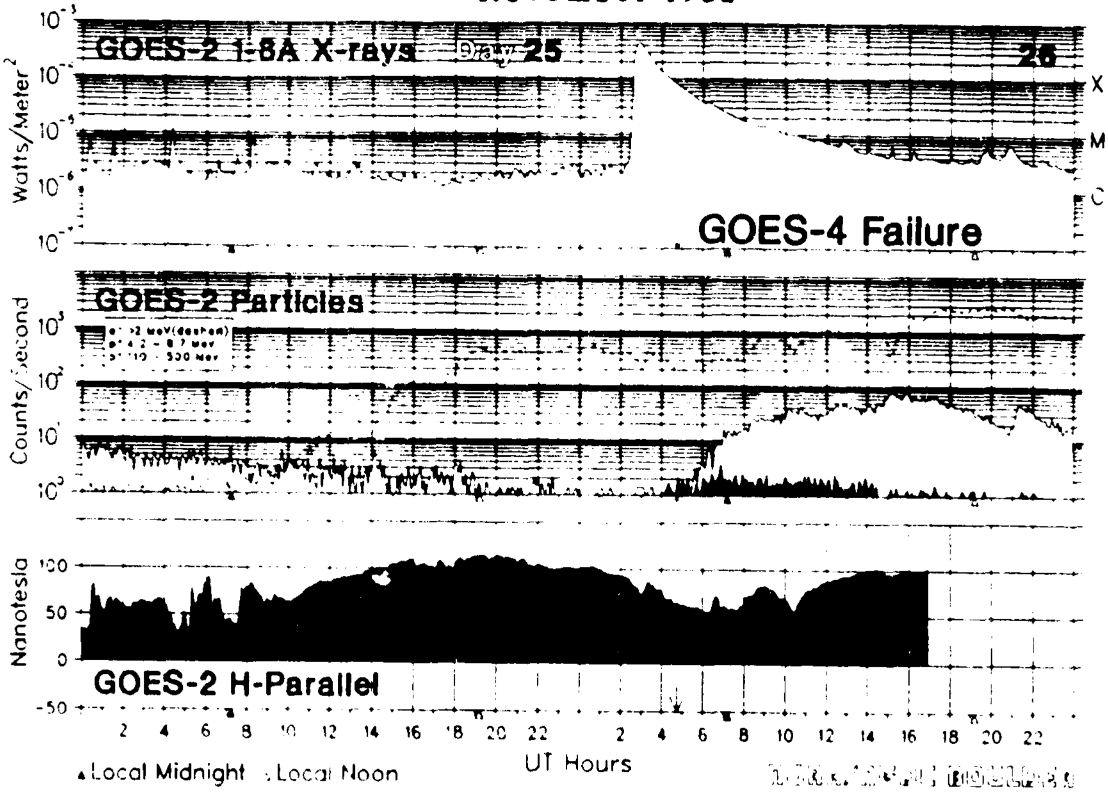


Figure 3

Events like the one displayed in Figure 4 are creating a whole new generation of believers in the potential of the space environment to threaten space operations. This X9 class flare produced protons of such energy that they caused the largest ground level event in 30 years. The proton fluxes caused sensitive electronics to malfunction and solar array output to drop dramatically on many spacecraft. What does the historical record say about the effects of this type of event? Nothing, the last time an event of this magnitude occurred there were no spacecraft.

SOLAR-TERRESTRIAL ENVIRONMENT
September 1989

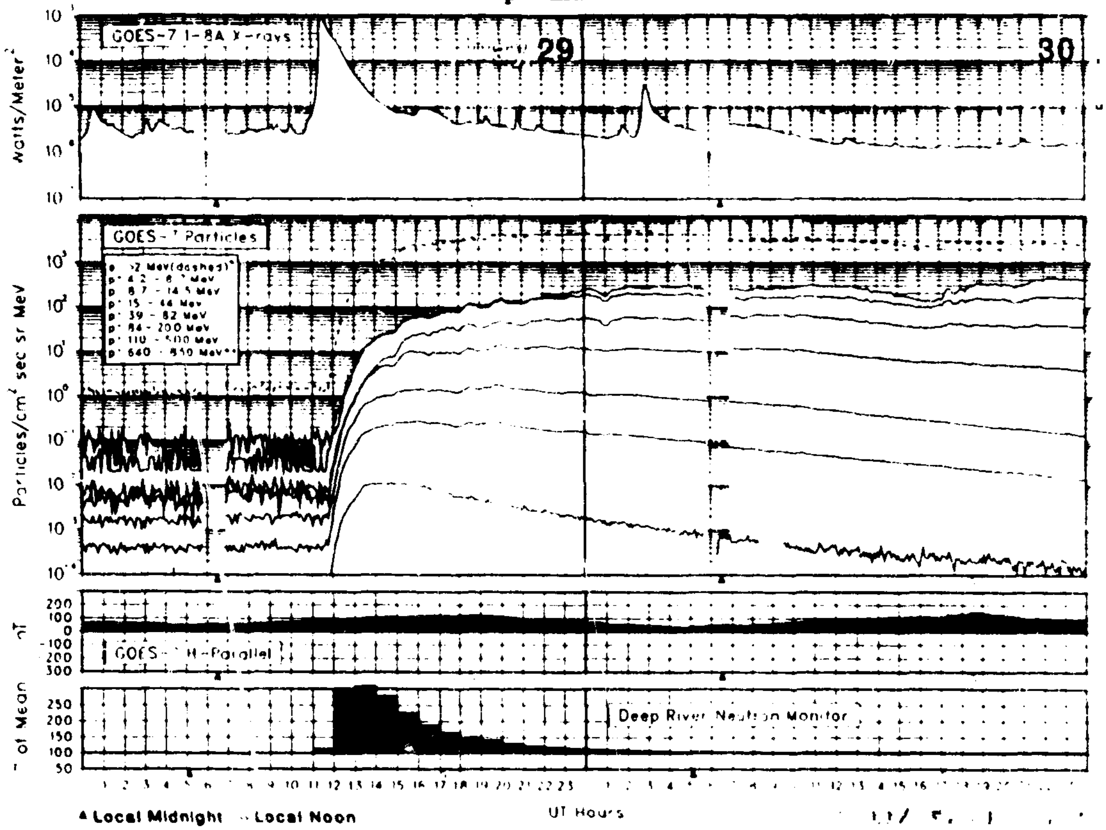


Figure 4

The solar butterfly diagram in Figure 5 is the result of 110 years of continuous, daily observations. The elegant trends of solar activity would not be apparent if observations were made intermittently or only during times of interesting activity. The butterfly diagram was named after the pattern made by the distribution in latitude of sunspot regions over a solar cycle.

Solar Butterfly Diagram

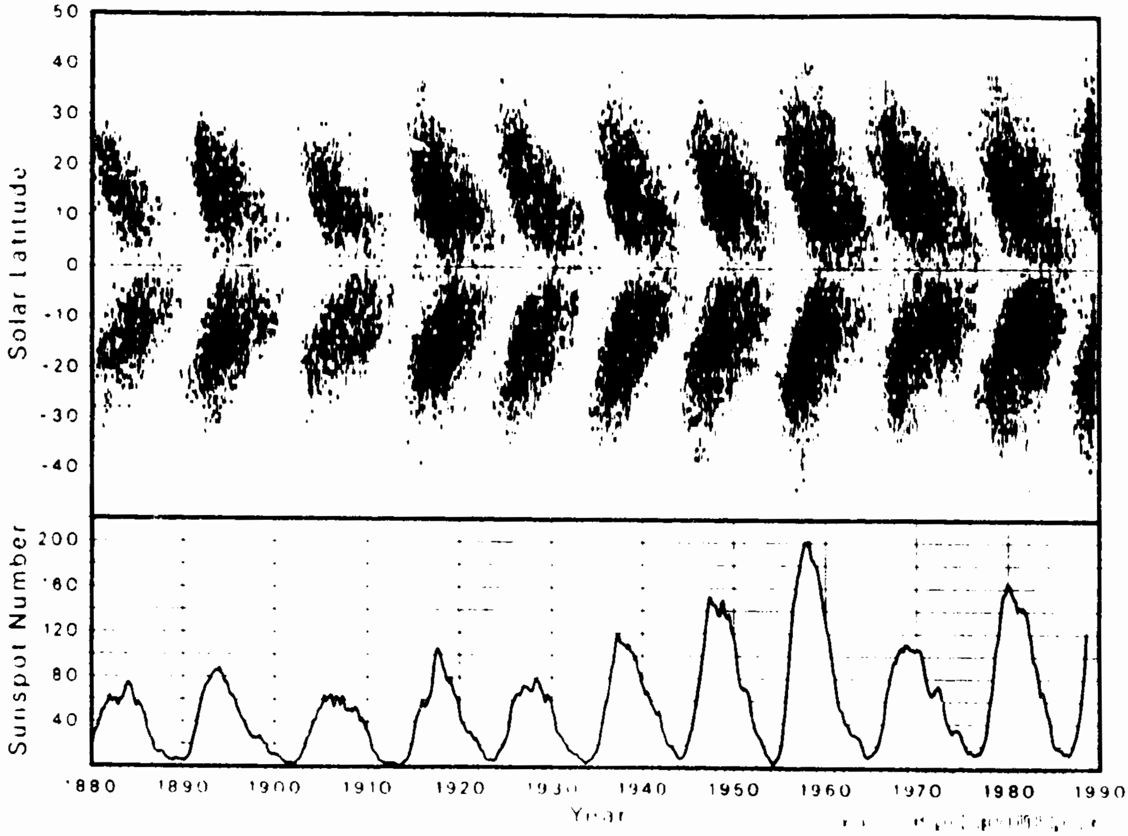


Figure 5

TRENDS IN SPACECRAFT ANOMALIES

The seasonal distribution of the entire anomaly database (Figure 6) shows an increase in the occurrence of anomalies around the spring and fall equinox. To demonstrate what this means in terms of Sun-Earth geometry, the apparent solar declination is plotted in degrees. These data, plotted as the thin line, show the Northern hemisphere tilting towards the Sun twenty-three degrees during summer and away twenty-three degrees during the winter. The thick line is the same data, but the positive declinations are plotted an negative. The symmetry of this relationship allows this modification to be made for the sake of visualization.

At equinox, geostationary satellites experience periods of solar eclipse. During these periods the boiling off of photo-electrons ceases while ambient electrons in the orbital path to continue to accumulate, resulting in abnormal surface charging.

Also, at equinox, geostationary satellites are more in line with the center of the magnetotail and the associated plasma sheet. This result[illegible] spacecraft encountering more plasma region boundaries.

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)

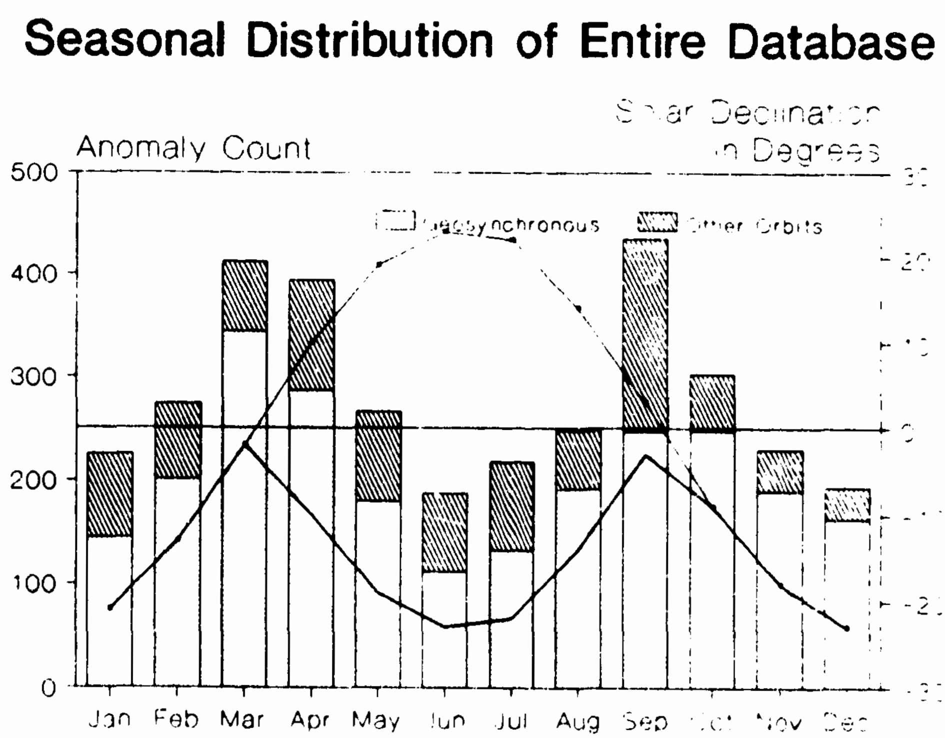


Figure 6

Figure 7 shows the local time distribution of all of anomalies in the data base whose reports have sufficient information for a local time calculation. Local time is used to represent position. Local noon being on the sun side of the Earth and local midnight being on shadow side. The largest trend shows enhanced counts in the midnight to dawn sector. The eclipse intervals occur at local midnight. When charging occurs at midnight the eventual discharge, if any, would occur between midnight and dawn. Local midnight is also where satellites would encounter the plasma enhancements associated with the magnetotail. This is particularly true during magnetic substorms when an injection of energetic electrons would enter geostationary orbit near local midnight and travel towards the dawn sector. This anomaly distribution has a small probability of being random (.00035).

Local Time Distribution - All

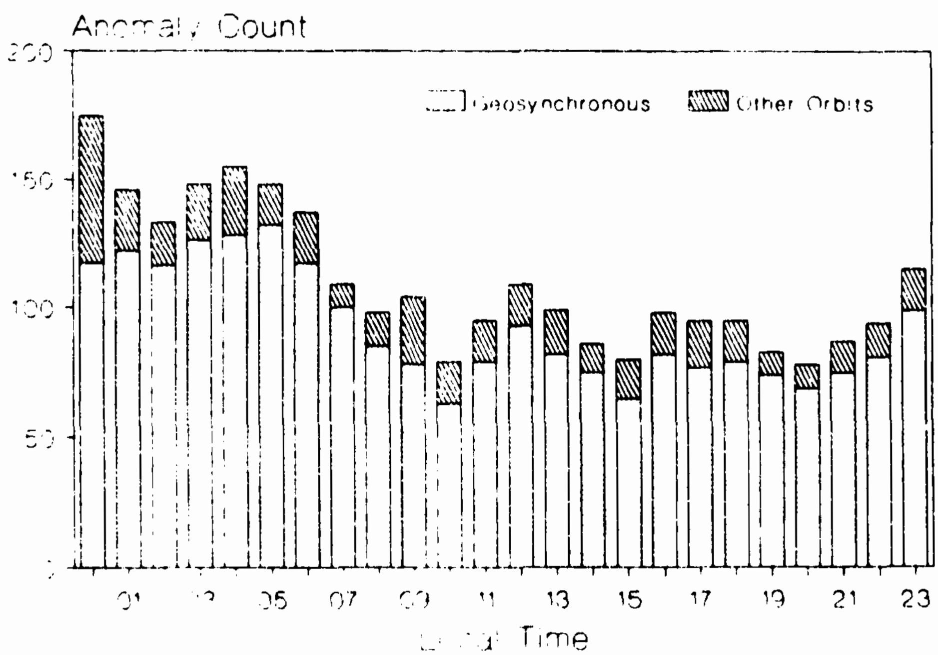


Figure 7

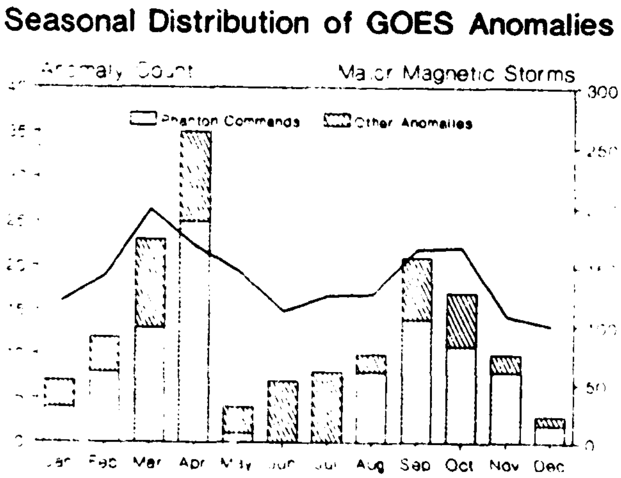
It is obvious from Figures 6 and 7 that the trends are riding on a background of anomaly reports that do not follow the trends. The SAM software's filtering capabilities are used to focus in on specific systems to see which are following the seasonal and local time trends and which are not.

The GOES phantom command anomalies shown in Figure 8a are a prime example of 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 solar declinations (-.72) with a very small probability that the correlation is wrong (.0073)

The distribution of major magnetic storms shown in Figure 8a 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)

The GOES-4, -5, and -6 "other anomalies" shown in Figure 8a are predominantly telemetry errors that have been diagnosed as Single Event Upsets (SEUs). This anomaly distribution has a good probability of being random (.26) and a weak anticorrelation to solar declination (-.23) with a large probability that the correlation could be wrong (.47). Since galactic cosmic ray fluxes are random in the seasonal context, the statistics validate the SEU diagnosis.

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



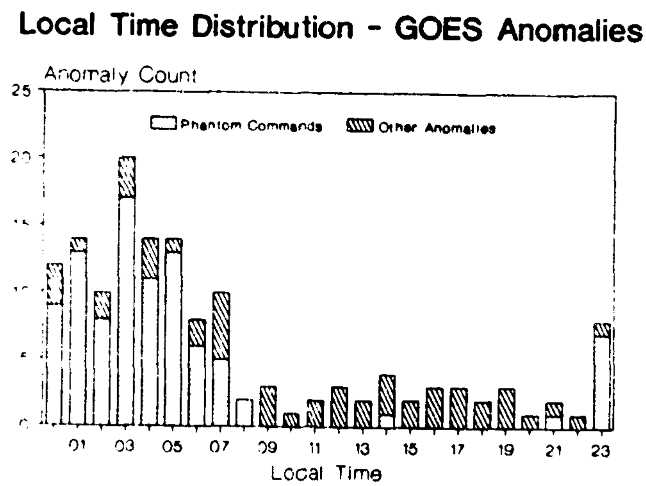
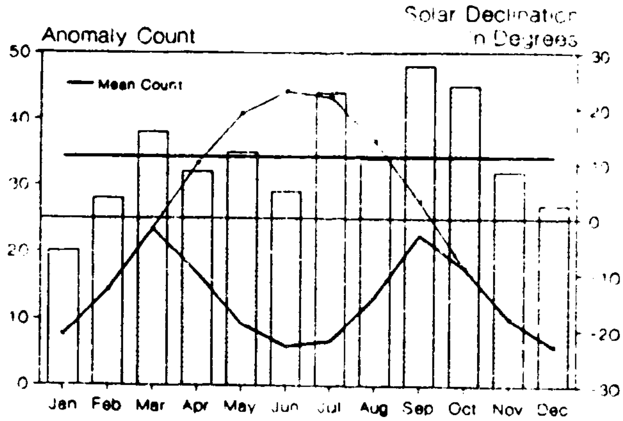


Figure 8a 8b

The TDRS-1 anomalies in Figure 9a 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 solar declination (-.55) with a small probability that the correlation is wrong (.062).

The local time distribution of TDRS-1 anomalies shows no increase of anomaly occurrence during the midnight to dawn local time interval (Figure 9b) and has a very high probability of being random (.97), consistent with SEUs.

Seasonal Distribution of TDRSS Anomalies



Local Time Distribution - TDRSS

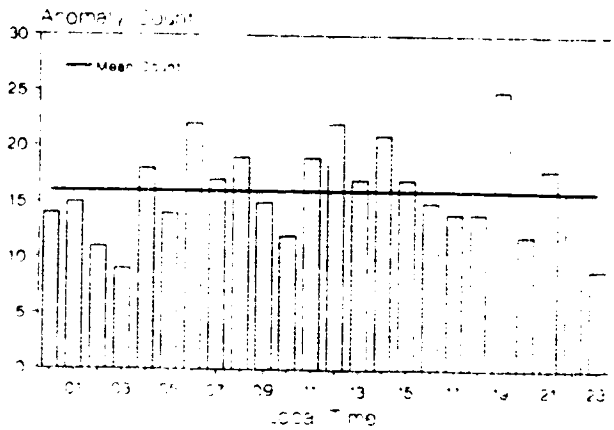
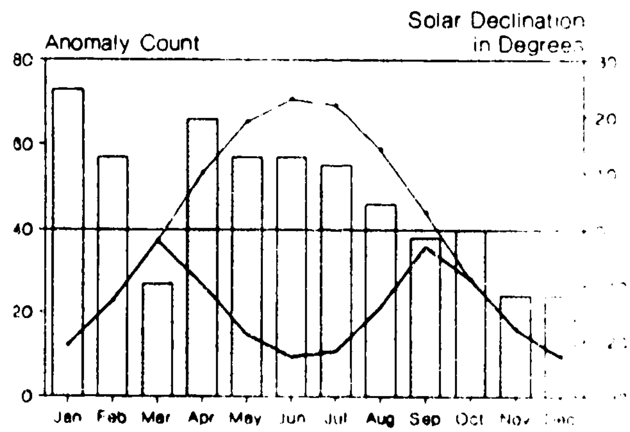


Figure 9a 9b

Not all trends are as straight forward as those concerning GOES and TDRS. The Global Positioning Satellite (GPS) anomalies displayed in Figure 10a and 10b show distinct patterns that do not fit the trends expected for either surface charging or SEU anomalies. The most notable trend is the strong bimodal pattern in the local time chart (Figure 10b). The GPS orbit is inclined 60 deg at 1/2 geosynchronous altitude.

Seasonal Distribution of GPS Anomalies



Local Time Distribution - GPS Anomalies

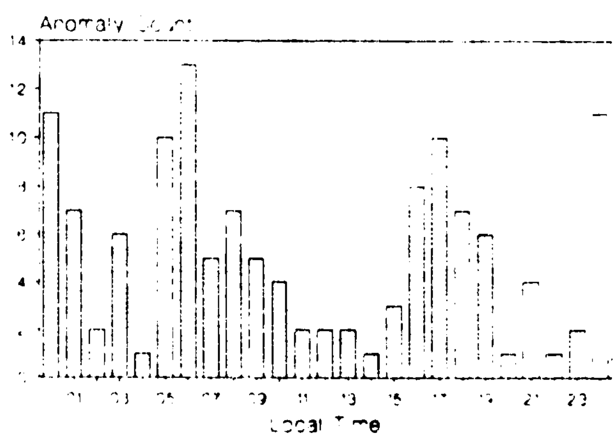


Figure 10a 10b

There are times when a trend in the data can be caused by artificial sources. The SCATHA reports in the data base represent discharge events that were monitored by on-board instrumentation rather than the typical anomaly report. The patterns in Figure 11a and 11b are caused by the incomplete p-ocessing of the SCATHA data. After the first year of operation data were processed only for intervals of specific interest. It is noteworthy, however, that local midnight and fall equinox garnered the most interest.

Seasonal Distribution - Scatha Anomalies

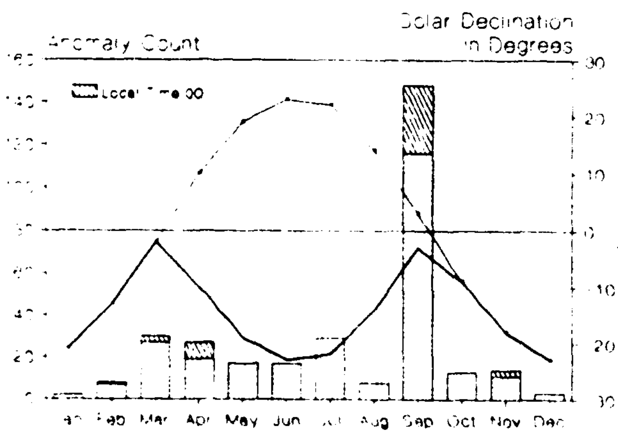
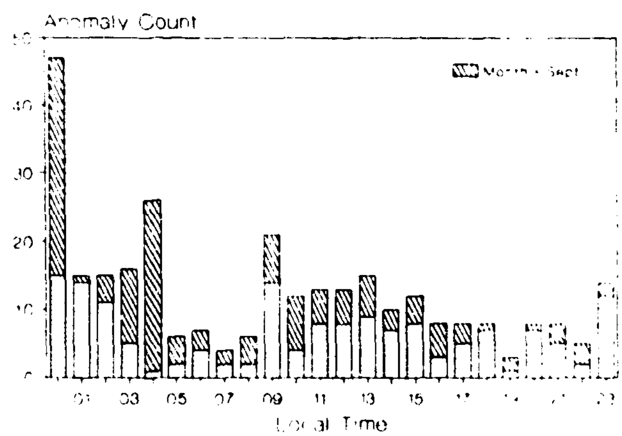


Figure 11a

Local Time Distribution - Scatha



11b

CONCLUSION

The routine reporting and archiving of spacecraft anomalies, like all routine data collection, is not a glamorous task. However, the maintaining of a complete and systematic anomaly history can be a critical part of mission success. Like the solar observations made over the centuries, anomaly archives becomes more valuable as the time base grows.

REFERENCES

1. Grajek, Michael A.; McPherson, Donald A.: Geosynchronous Satellite Operating Anomalies Caused by Interaction with the Local Spacecraft Environment, 1977. NASA NAS3-21048.

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