STP-11 Keynote Talk

SPACE WEATHER: A Personal View

J. H. Allen (SCOSTEP) and

L.J. Lanzerotti (Bell Labs and Lucent Technology)

Joe Allen: Version of 2006/02/26 – Work in Progress (updating & correcting)

This "shorter talk", co-authored with Lou Lanzerotti, was prepared as a Keynote Address for SCOSTEP's 11th Quadrennial STP Symposium held during March 2006 in Rio de Janeiro, Brazil. It is a composite of slides selected from earlier PowerPoint talks with a few new slides added about historical information and to describe recent (2005) solar activity and its consequences. The figures were selected from a number of talks given over some 35 years on different aspects of the topic of "Space Weather", several prepared with colleagues. About 10% of the slides in the "longer talk" version are my collected old working slides prepared from viewgraph transparencies (most are not included in the **"Shorter Space Weather Keynote Talk").** These slides were scanned and merged with the bulleted outline in the "Long Version".

The **"Long Version"** is too long to be given as a single talk. It numbers over 130 slides. It has been on-line at the SCOSTEP website since about 2001(but does not contain the newer, slides added here). However, I can select pertinent segments for focused presentations, while making the full set available on CD if someone requests it in that format. For example, this shorter talk began by moving figures about recent anomaly events to the start of the long presentation, adding historical and update slides, and presented in a 42-slide version at the **STP-11 Symposium** in the Keynote talk on **"Space Weather" (Allen & Lanzerotti).**

I understand that the SCOSTEP Secretariat will arrange to put all STP-11 Keynote Talks onto the SCOSTEP website so they may be accessed electronically. However, from past experience, I know that this can create too large a selection of slides to be successfully downloaded by direct computer connection for many users who access the website. It is my hope that all the STP-11 Keynote talks will be copied onto a CD and made available to anyone who wants a copy (Please contact the SCOSTEP Secretariat with your request). If you have a problem in obtaining this talk, please contact **Joe.H.Allen@noaa.gov** with your request and I will try to send them to you on a CD.

Many talented young scientists who worked for me when I directed the Solar-Terrestrial Physics Division of NGDC (and before) made contributions of figures. Where possible, they are acknowledged in these electronic "yellow notes", but some slides are included without attribution. Either I don't remember the source, or they were taken from resources made available on the WWW by generous PI's or extracted from program CD-ROMs. Some sources of figures and information asked to remain anonymous and I respect their wishes.

I especially acknowledge Daniel C. Wilkinson (NGDC/STPD) who created the "SAM" (Spacecraft Anomaly Manager) software and NGDC satellite anomaly data base in the early 1980's.. He developed a PC-based presentation of solar telescope images to display the impressive solar events of March 1989. These were published on the first CD-ROM produced by Joe H. Allen and staff for the National Geophysical Data Center/WDC-A for STP (Boulder, Colorado). Dan also contributed many of the other data displays used here. We co-authored several papers from which some of these figures are taken (see references below).

Marsha Korose (USAF-OSA) sent a PowerPoint briefing from which some slides were taken.

Dan Baker (LASP) shared several images from our joint papers, and Dan Moorer (now at Ball Brothers) made a composite about the Brazilsat failure (in 2000) while he was finishing his PhD and job hunting just before graduation.

Henry Garrett (JPL) generously shared figures and information from his collection.

I appreciate the efforts of many people who correspond regularly with me by e-mail about the topic of Satellite Anomalies. If I have said something in error in what follows, they are not to blame; but I welcome the opportunity to make corrections, so please let me know. This informal group is my "ANOM" list of contacts and they are very cooperative. I try to keep their names private to avoid Spam or other problems. Sometimes local e-mail systems refuse to accept messages with attachments sent to such large groups of people (a typical Spam precaution) and will not transmit my messages. In such cases, I send a warning e-mail to their IT office and then delete that member name from my list. Some countries have responded expeditiously to my requests for these ANOM Messages to be accepted and to get someone returned to the ANOM list.

Some anonymous persons have given information about satellite problems that can not be acknowledged directly, but they should be thanked too. Probably I have missed someone who should be mentioned. That's the trouble with working on a subject for over 30 years, memory begins to blur.

I must stop making these notes before finishing all the slides in the long set, but may return to them and continue the process as time and inclination permit in the future now that I have retired from serving as SCOSTEP Scientific Secretary (effective March 2006). Many of the figures and much of the information for this shorter talk and the longer one comes from the paper **"Solar-Terrestrial Activity Affecting Systems in Space and On Earth"**, J.H. Allen and D.C. Wilkinson, pp 75-107, in **"Solar-Terrestrial Predictions – IV: Proceedings of a Workshop at Ottawa, Canada, May 18-22, 1992"**, edited by J. Hruska, M.A. Shea, D.F. Smart, and G. Heckman. The longer talk (without the updated events through 2005) is available currently on the SCOSTEP website.

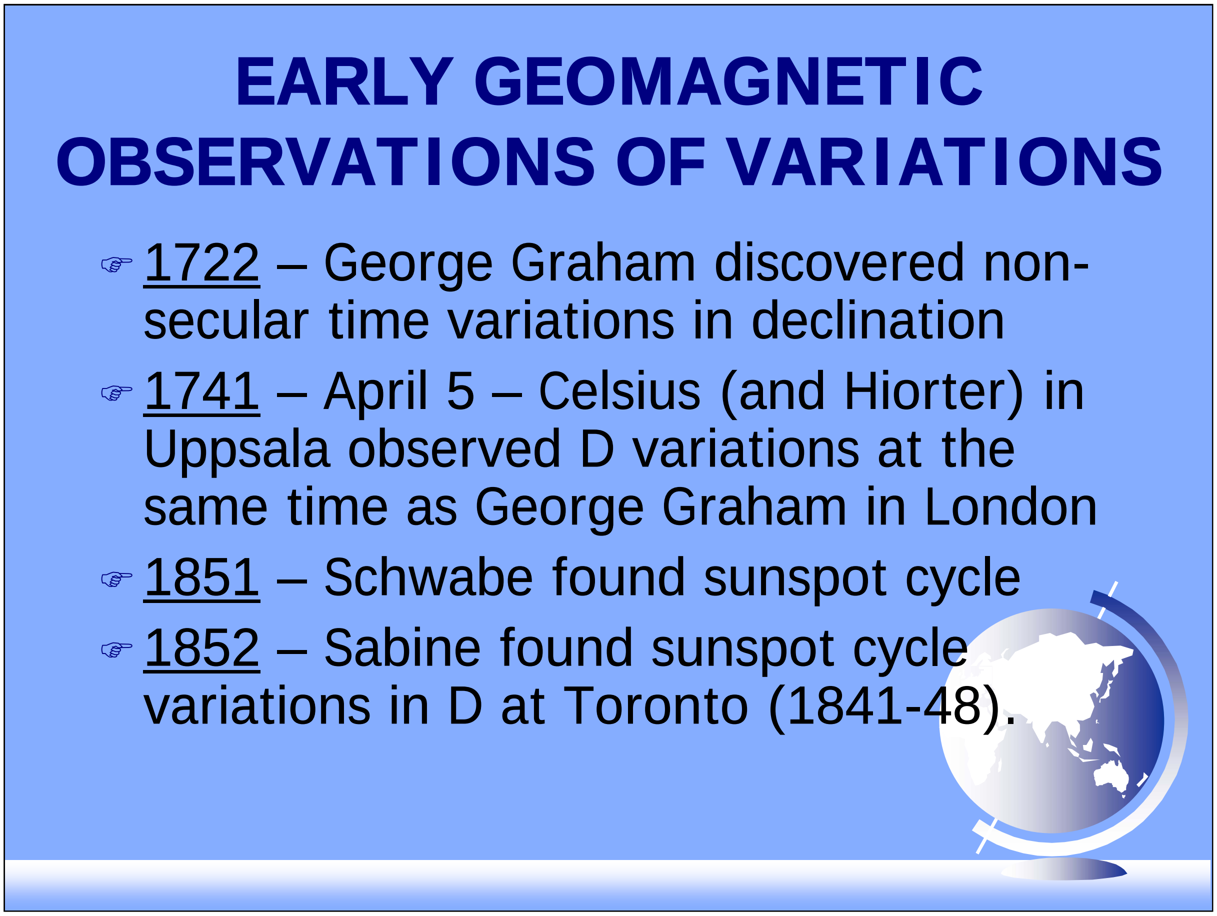
Joe Haskell Allen, 2006/03/07

SPACE WEATHER: A PERSONAL VIEW

Joe H. Allen and Louis J. Lanzerotti

- "Space Weather" as a subject of intellectual interest has a long history. No certain beginning is postulated here. Naked eye recordings of sunspots by Chinese observers looking through clouds of dust could take its origin far back in time. Some might reference the beginning as Galileo's sunspot observations and their description to a credulous public as blemishes on the solar surface. However, for cause-and-effect associations, one must skip forward to the mid-1800's and early 1900's. Development of transportation and communications technology in industrializing nations led to the association of electrical malfunctions in railroad telegraph equipment with the occurrence of aurora and an increase in sunspots with geomagnetic activity. Carrington's records of the large sunspot group in August-September 1859, and his naked eye sighting of the great white-light solar flare followed some 15 hours later by auroral displays and a great geomagnetic storm with all its consequences provided an early appreciation of the impact of space weather on technological society. At that time, skeptics questioned the association of events on the Sun with effects at Earth, just as some involved in aerospace applications in the 1970's and 1980's rejected the idea that satellite malfunctions could be associated with solar activity. Today "Space Weather" has assumed a reputable status although some still claim the subject is given more credit for satellite problems than it deserves. In this presentation, the first author (who is stepping down after this meeting from his role in SCOSTEP to become more completely retired) gives a highly personal overview of the types of solar activity that affect objects in space and ground-based technology, of the mechanisms of satellite anomalies, and of a few unanswered questions that remain for current students to explore.

This abstract was published by the Brazilian LOC for the STP-11 conference. It is included here for completeness. We do not expect anyone to be able to read this small text in the environment of an auditorium presentation, but believe that it contains an explanation of the viewpoint behind this presentation.



Historical notes excerpted from "GEOMAGNETISM" by S. Chapman and J. Bartels:

Some of the earliest observations related to what we now call "Space Weather" were made by talented university professors, their students, and early instrument makers who were fascinated with the behavior of magnetized needles left free to oscillate in the Earth's changing field. George Graham, a talented instrument maker in London and careful observer, was the first to record and circulate information about non-secular time variations in geomagnetic declination. He carefully noted the sometimes agitated state of his balanced magnetic needle and whether or not the changes might be due to local motions of magnetic materials in or near his "observatory".

In Uppsala, Prof. Celsius and his talented student Hiorter were also making systematic observations of the motions of a disturbed magnetic needle that was free to oscillate in a horizontal plane. Celsius wrote to Graham and proposed coordinated magnetic observations for a period of time that included the great magnetic storm of 5 April 1741. Through correspondence about the event, they established that substantially the same type and relative magnitude of oscillations were observed at both locations at about the same time. Also, Hiorter noted that there was substantial red aurora to the far south of Uppsala. Graham didn't mention aurora, possibly because daylight obscured his view.

In 1851 Schwabe discovered the sunspot cycle and described it widely among scientists and instrument makers. A year later (1852), Sabine found the sunspot cycle displayed in D-variations recorded at the Toronto Magnetic Observatory from 1841-1848.

These were some of the early observations, about a century apart, of what we now call elements of space weather.

HIORTER'S OBSERVATIONS

1741 – 1 March – First observed aurora south of Uppsala and great motion of the magnetic needle.

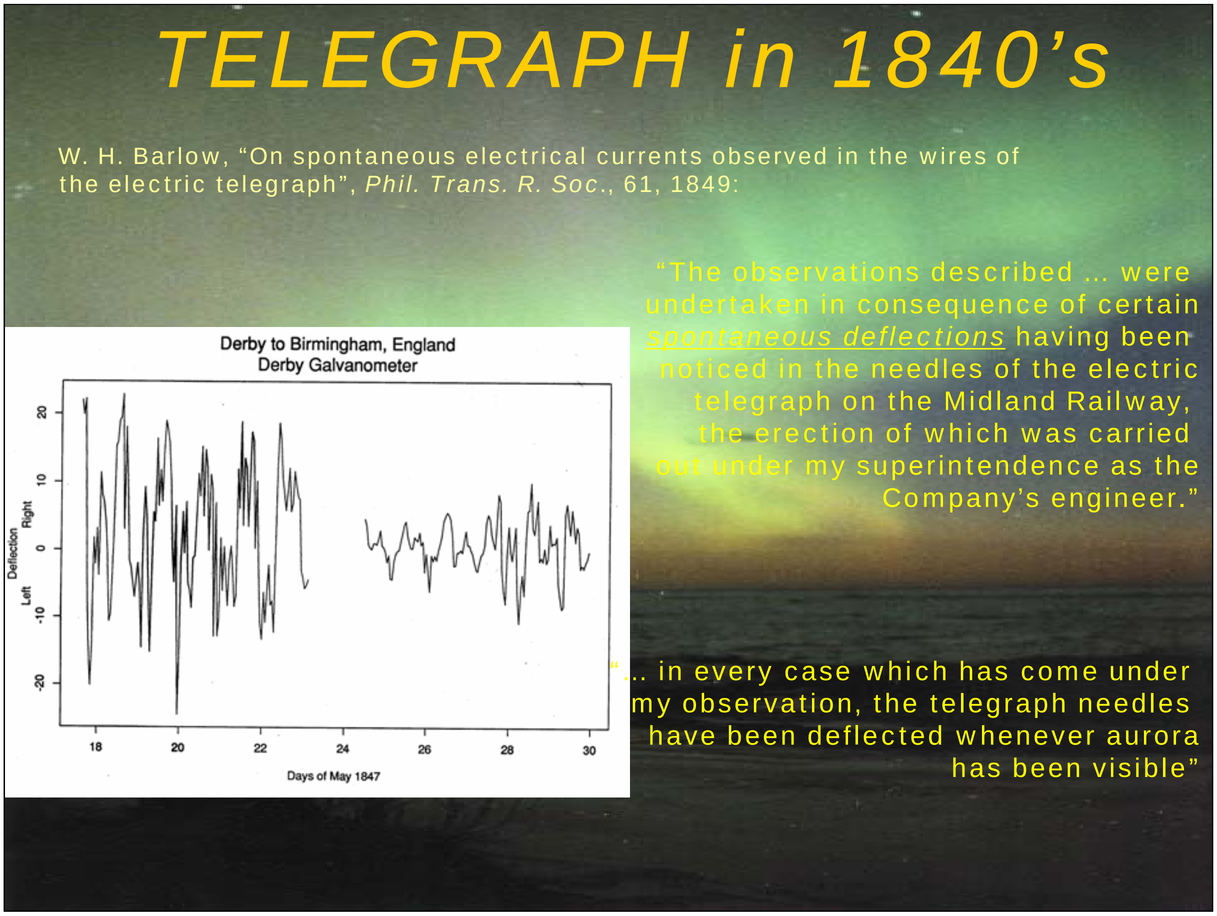
1741 – 5 April – Simultaneous aurora and needle motion seen at Uppsala and similar magnetic changes confirmed at London.

1747 – "A motion of the magnetic needle has been found which deserves the attention and wonder of everyone. Who could have thought that the *northern lights* would have a connection and a sympathy with the magnet, and that these … within a few minutes cause considerable oscillations of the magnetic needle through whole degrees?"

Relations between Professors and their students seem not to have changed much in some aspects over the centuries since Celsius and Hiorter observed magnetic phenomena together. On 1 March 1741. Hiorter first reported observing aurora south of Uppsala and great motion of the magnetic needle at the same time. When he told Prof. Celsius about this observation, the professor is reputed to have said something to the effect of "Yes, I myself have observed this before but didn't mention it because I didn't want to bias your observations."

On 5 April 1741 (still within a few weeks of equinox when most magnetic storms are recorded), the simultaneous aurora and needle motions mentioned in the previous slide were observed at Uppsala and the same needle motions seen at London.

In 1747, Hiroter wrote the statement quoted here as taken from Chapman & Bartels "Geomagnetism".

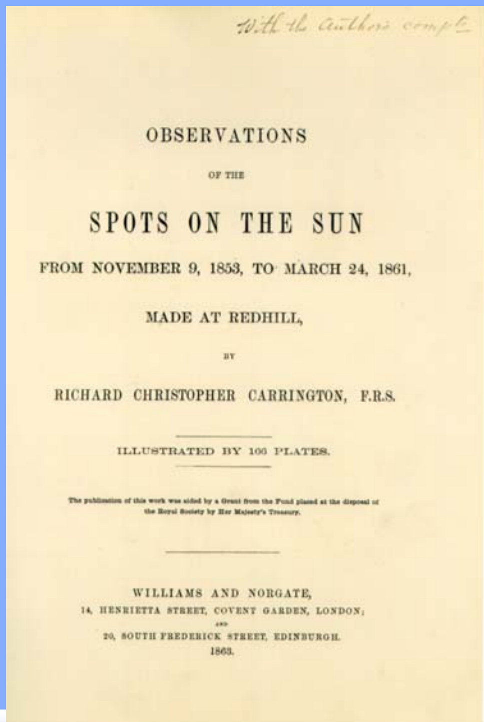


If we jump ahead almost a century, new electrical means of communication had begun to spread through the industrialized world in Europe and the Americas.

The quotes and figure given here were published by W.H. Barlow, Company Engineer for the Midland Railway. He described the appearance of spontaneous electrical currents (induced) on the telegraph wires and appearing sometimes as dangerous "sparks" on the early telegraph operator's keys. Several such effects on technology were described at STP-11 by David Boteler in his talk on the effects of superstorms. It was not unusual for a telegraph operator to receive a serious shock or to be burned at his work and sometimes nearby papers were set afire during such events.

The notice taken by Barlow that such events were seen when aurora was visible was another early perception of phenomena involving space weather.

Discovery of a Solar Flare



OBSERVATIONS

OF THE

SPOTS ON THE SUN

FROM NOVEMBER 9, 1853, TO MARCH 24, 1861,

MADE AT REDHILL,

BY

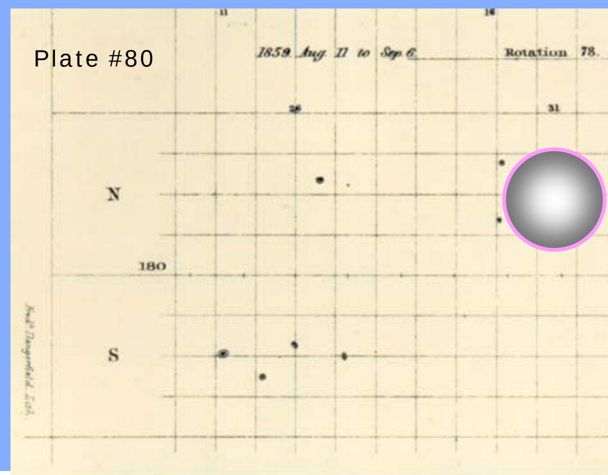
RICHARD CHRISTOPHER CARRINGTON, F.R.S.

ILLUSTRATED BY 166 PLATES.

The publication of this work was aided by a Grant from the Fund placed at the disposal of the Royal Society by Her Majesty's Treasury.

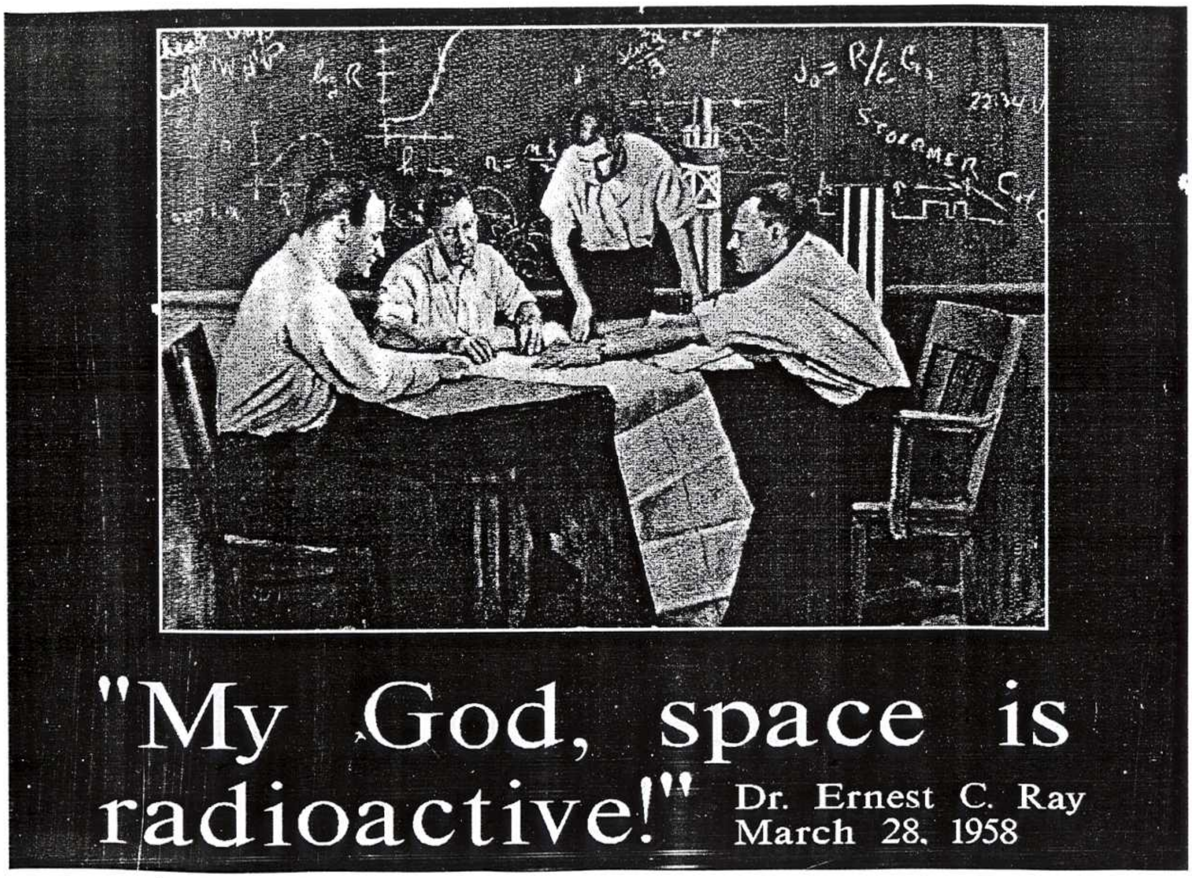
WILLIAMS AND NORGATE,
14, HENRIETTA STREET, COVENT GARDEN, LONDON;
AND
20, SOUTH FREDERICK STREET, EDINBURGH.
1863.

"The observation of this very splendid group on September 1st [1859] has had some notoriety. ... I ... witnessed a singular outbreak of light which lasted about 5 minutes, and moved sensibly over the contour of the spot ...."



The great superstorm of September 1859 was the consequence of the Coronal Mass Ejection (CME) associated with the intense white-light solar flare observed directly by Richard Carrington and described by him along with others from many years of observations in his report published in 1863 by the Royal Society. His statement about the "notoriety" attendant on the event and its consequences was probably a reference to the extravagant newspaper and tabloid articles that shocked the public with the claim that a transient event on the Sun could have many serious consequences at Earth.

This storm still is the subject of special issues of journals and many interesting speculative papers about the consequences today if such a great storm and particle event happened while our many satellites are in orbit, airliners are flying over the polar cap and at high altitudes, astronauts are orbiting in the International Space Station (ISS) or shuttles, and ground-based communication and power distribution systems are all vulnerable.



Joe Allen:

According to Herb Sauer, he was a PhD candidate at the University of Iowa at the time this picture was staged. Herb said he was the first one to look at the analog chart record of returned Geiger counter values from the University of Iowa experiment on the USA's first successful satellite, **Explorer-2**. He saw the regular pattern of off-scale periods and commented that they had to be a result of system saturation when the satellite was in critical high counting regions; they were not a loss of signal due to bad transmissions. The pattern was simply too regular for any other explanation. Later others looked at the records again and agreed. Over the auroral zone and through the region of the South Atlantic Anomaly, the sensor was exposed to so much radiation that it saturated and the counts went off-scale.

A similar experience with off-scale analog chart records of the proton sensors on GOES satellites on 29-30 September 1989, was not at first recognized as a "real signal". No activity had been observed on the Earth-facing solar surface. However, finally it was realized that a massive event must have erupted from a large active region that had just rotated over the west limb of the Sun a few days before. Earth was only in the fringe volume of the proton event and it was massive.

This scene shown here is a photograph of a painting that was a recreation involving the top persons from the University of Iowa Physics Department who worked on the Geiger-counter experiment. From the left end of the table, going clockwise, they are: Carl McIlwane, James Van Allen, George Ludwig, and Ernest Ray. They posed for a commissioned painting of the scene. This image is from a photograph of the painting. The painting was given to Mrs. Mary Ray by NSF. Joe Allen found a film copy of the photograph in NGDC archives many years ago and often uses it in such presentations.

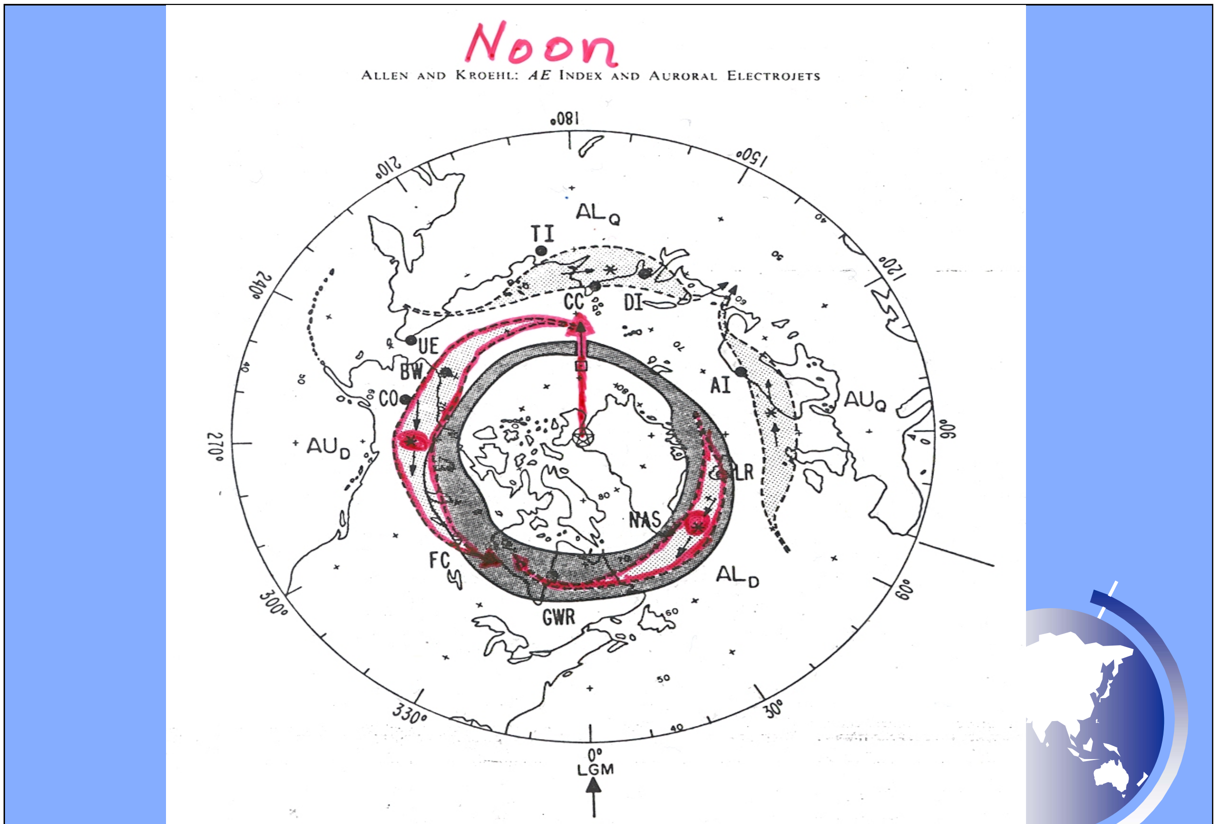


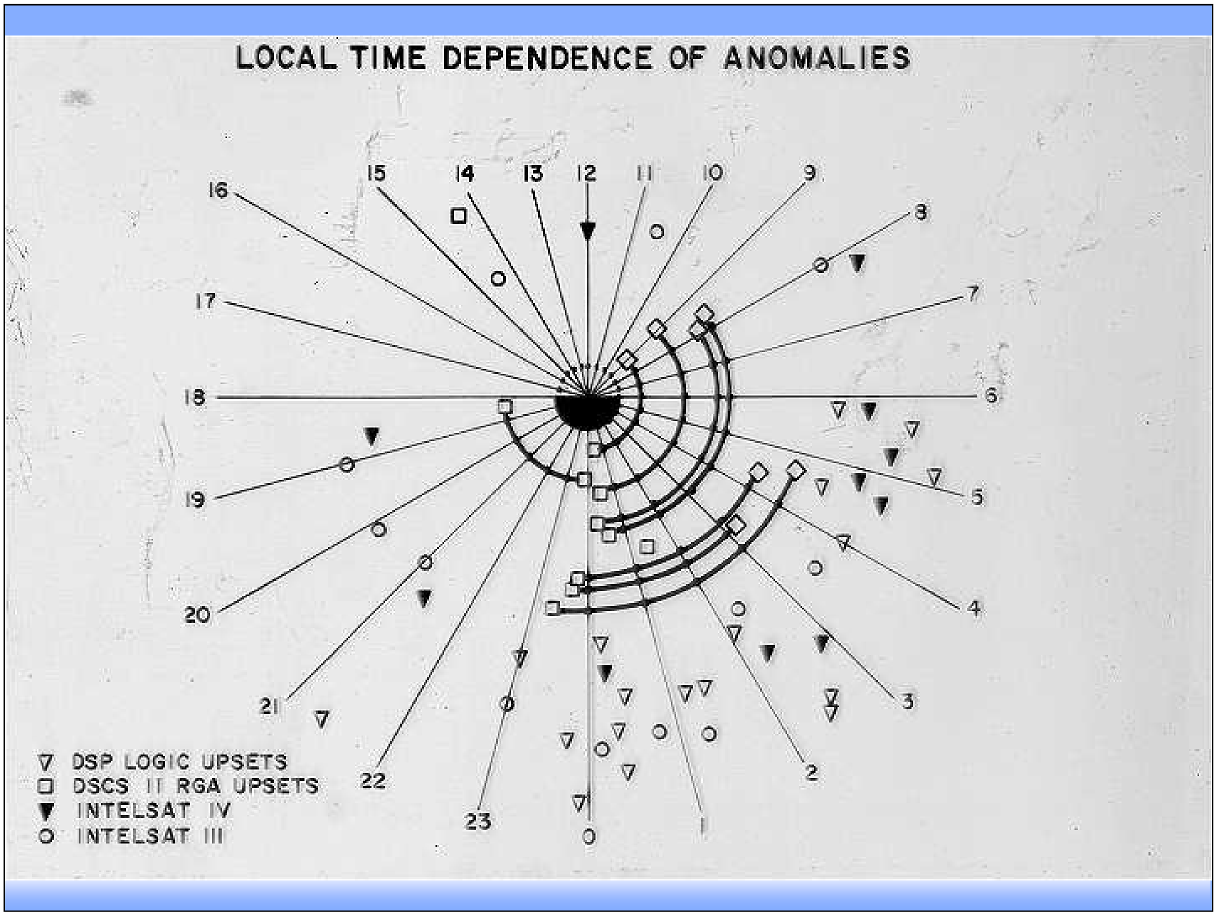
Fig. 8. Map of the Fel'dshteyn corrected auroral oval and composite ionospheric current system regions which produced AL and AU for quiet times (AL_Q, AU_Q) and disturbed times (AL_D, AU_D). The map displays the regions at the time corresponding to LGM on the 0° geomagnetic meridian (0430 UT). An asterisk marks the average location within each current region where the most frequent occurrence of maximum H deviations produced corresponding AU and AL indices.

Joe Allen:

In working on the derivation of the Auroral Electrojet Magnetic Activity Index (AE) in 1970-71, I noted the regular shift of the local time of provision of extreme values of the disturbed H-component at auroral zone observatories. The extreme negative H perturbation was most often recorded by the observatory near 65° geomagnetic latitude and located in the midnight-to-dawn sector around 03:30 Magnetic Local Time (MLT). The extreme positive H perturbation was most often recorded by a comparable auroral zone observatory located near the sunset meridian near 18:00 MLT. Using the first year delta-H data for AE indices produced by my project at NGDC, I built a database of regional loci of observatories providing the quiet and disturbed extremes in the auroral zone. I copied a graph of the observed auroral zone (the "Fel'shteyn Oval") from Syun Akasofu's book on Geomagnetic Substorms, and overlaid it with the regions of overhead current flow that would produce the consistent quiet-time and disturbed-time H-perturbation patterns seen when producing the AE components AU and AL indices. The arrow-shaped regions are widest at that time zone of the most frequent extreme values.

The original sandwich of map and auroral zone/current region overlay were on viewgraph transparencies pinned together so the overlay could be rotated around the map as the "Earth turned". This figure is frozen on the time of Geomagnetic Midnight (about 04:30 UT) when the line from the Sun across the polar cap passes through the off-center geomagnetic pole. At this time, I expected to find the most frequent extreme negative delta-H recorded at Narssarssuaq, Greenland, although sometimes the extremes could be spread from Fort Churchill Canada as far around as Abisko, Sweden. The extreme positive delta-H most often occurred at College, Alaska. By working definition, a "disturbed time" was when the hourly average AE index was 50 nT or greater.

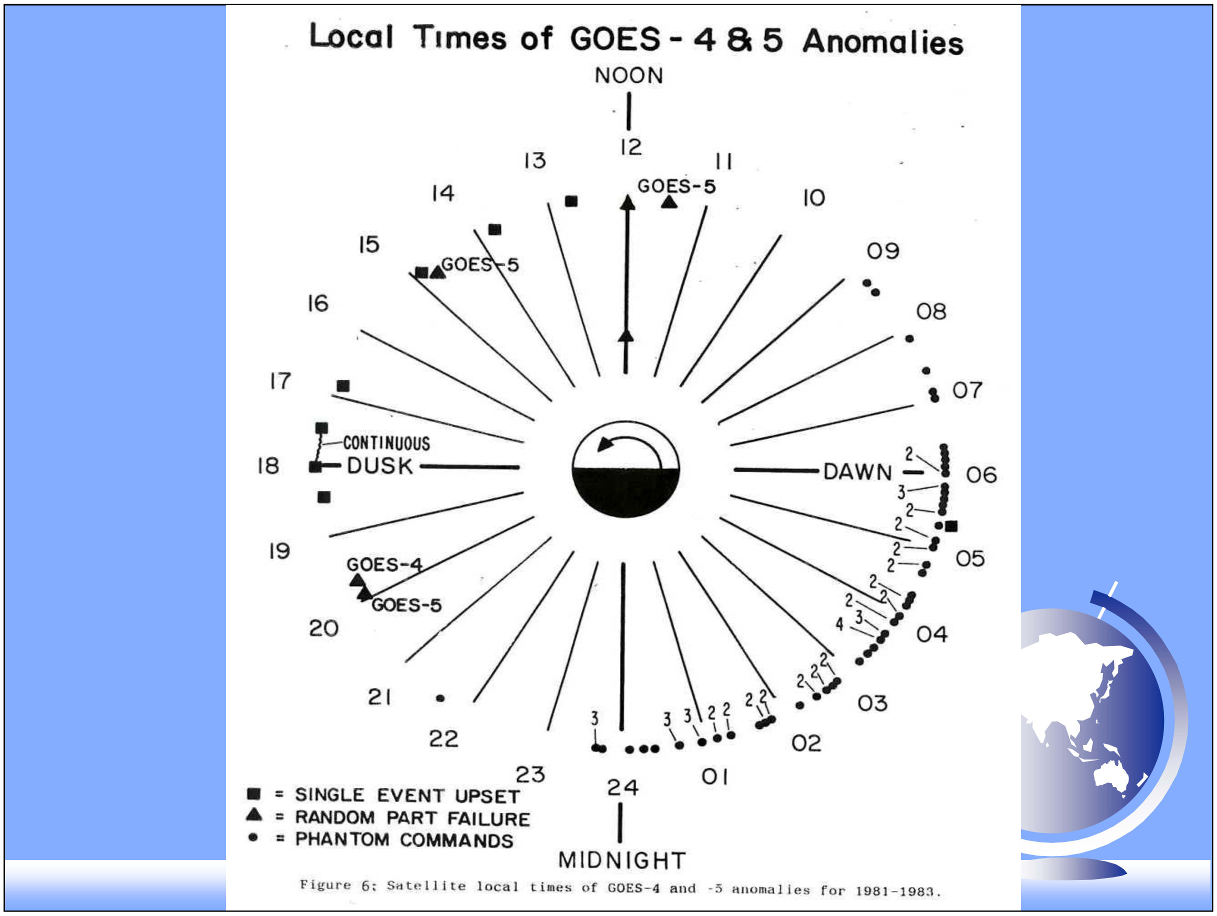
In August 1972, Wayne Lejeune (then a UCLA graduate student working part-time for TRW) brought in a clock-diagram map of GEO satellite anomalies as shown in the next slide. it was the same size as my map of auroral electrojet regions; so when he showed it to me, I brought out his map (printed on a rotating plastic disc pinned on a map of AE-observatories in the N. hemisphere) and overlaid the two. Clearly the zone of most frequent serious satellite anomalies at GEO altitude in the equatorial plane was the same longitude sector as the current system feeding the westward auroral electrojet (i.e. the field-aligned electrons that cause the negative H extremes when they move from W to E overhead in the auroral zone – recall that current direction is opposite to electron motion). It seemed likely that the same conditions in the equatorial plane at 6.6 Re that caused the satellite Phantom Command (PC) anomalies were also related to the field-aligned currents feeding the westward auroral electrojet in the polar ionosphere. This was in August 1972. Wayne went back to California to participate in a series of satellite tests in a plasma chamber that simulated the substorm conditions in space. TRW sponsored a study by DeForest, Rostoker, and McPherron that established a relationship between GEO satellite anomalies and injected electrons from the magnetotail. This report is almost impossible for an outsider to obtain.



Joe Allen:

After the comments on the previous two slides were written, a colleague from my Satellite Anomalies group talked to me about the October 2000, S-RAMP meeting in Sapporo, Japan. While discussing early days of "Space Weather" studies, I mentioned having seen a figure like the one in this slide. My colleague thought the description sounded familiar and found this in his collection (as a negative). He scanned it and e-mailed it to me for use in this presentation (in 2002). I believe this to be a later version of the one I first saw in August 1972, and that more anomalies on other satellites have been added.

The slide shows the distribution in satellite local time of anomalies on different craft. Most are clustered in the midnight to dawn sector. I suspect that they were associated with injection of thermal electrons from the magnetotail during geomagnetic storms or auroral substorms. Anomaly events near noon and in the evening hours are more likely due to encounters with energetic protons. Joe Fennel (Aerospace Corp.) told me that preparation of the original anomaly map was the first job he undertook after being hired.



Joe Allen:

This slide was prepared by Dan Wilkinson in 1984-85 to show the location in orbit of different types of anomalies experienced by NOAA's Geostationary Operational Environmental Satellites (GOES) –4 and –5.

Phantom Commands are clearly clustered in the midnight to dawn sector. Identification of the type of satellite anomaly is often difficult and usually can only be inferred, so it is helpful to have a record of the time and location in orbit of anomalies of each type and for GEO, MEO and LEO satellites. Often the hardest to obtain are for LEO satellites (e.g. usually polar orbiters) because they are not typically tracked on a continuous basis.

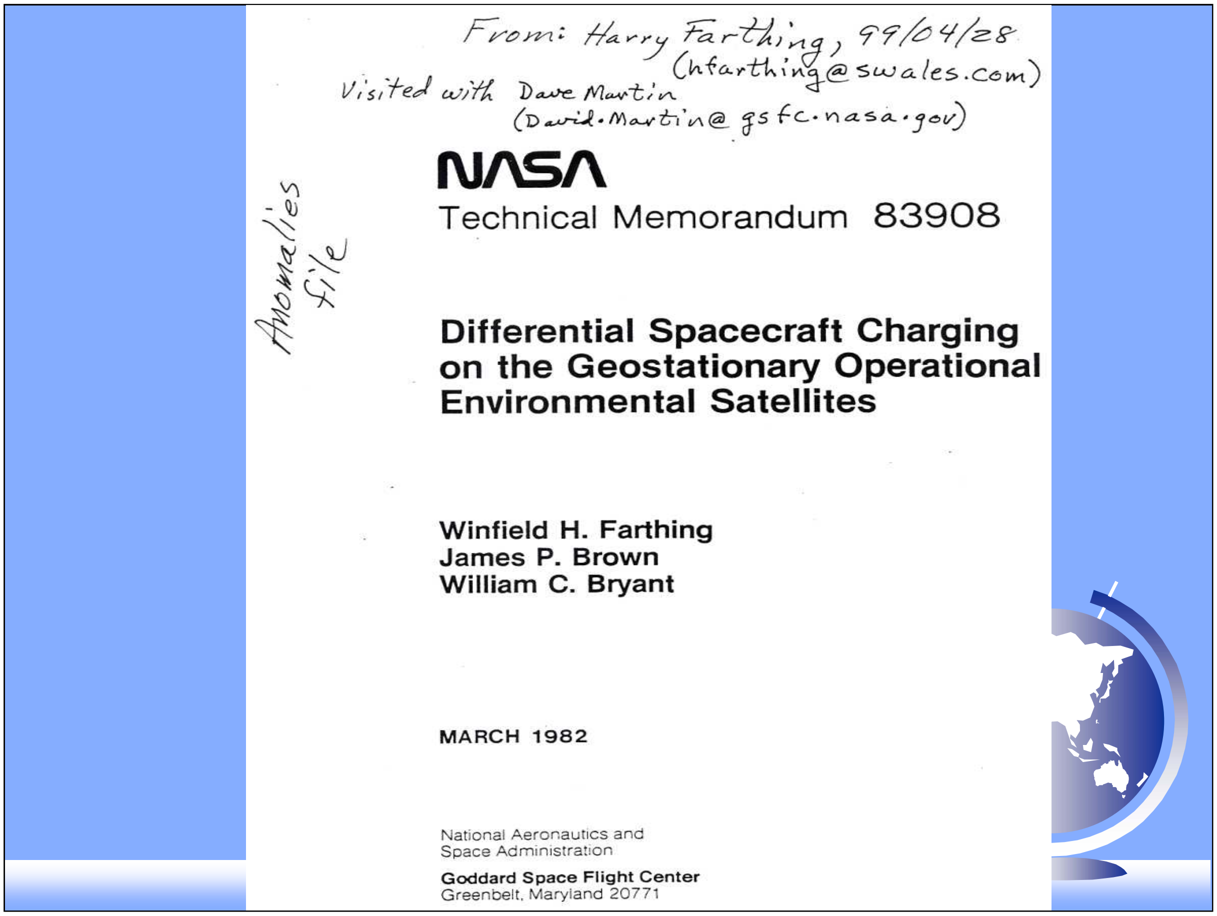
Single Event Upsets (SEU) are "penetration" events in which high energy charged particles (protons, alphas, or heavier ions) enter a chip and "burn" a destructive track or deposit charge that changes the contents of chip memory.

Random Part Failures (RPF) are those rarer events when a component on a satellite fails and, if the satellite is to keep operating, its controllers must switch operations to a redundant component if one exists.

The figure in this slide mimics the one for USAF DSCS satellites shown to Joe Allen in August 1972 by Wayne Lejeune (TRW) during a visit to Boulder. A sudden catastrophic failure of a satellite when Wayne was in Boulder resulted in call from California to check out conditions. This was during the event that NASA later called the "Anomalously Large Proton Event", although it later was fitted into a relatively continuous spectrum of event amplitudes as the activity of 1989, 1991, 2000, and 2003 was tracked and added to the accumulated data record.

Wayne came to Joe Allen's office at NGDC and showed him a clock-face diagram of DSCS satellite anomalies. It looked much like the GOES plot seen here. As described earlier, that display fit nicely over the map of N. hemisphere auroral zone magnetic observatories from whose records we derived the AE and related indices. The main region of anomalies from just before midnight around to the dawn meridian was the same as the overlay longitude zone in which the most extreme AL deviations were recorded, I.e. the Western Auroral Electrojet zone.

Later when we looked into near-Earth space conditions during the times of the Phantom Command anomalies, we noticed that they clustered mainly during lower-amplitude geomagnetic storms that most frequently happened seasonally during the weeks around spring and fall equinox.



From: Harry Farthing, 99/04/28
(hfarthing@swales.com)
Visited with Dave Martin
(David.Martin@gsfc.nasa.gov)

Anomalies file

NASA
Technical Memorandum 83908

Differential Spacecraft Charging on the Geostationary Operational Environmental Satellites

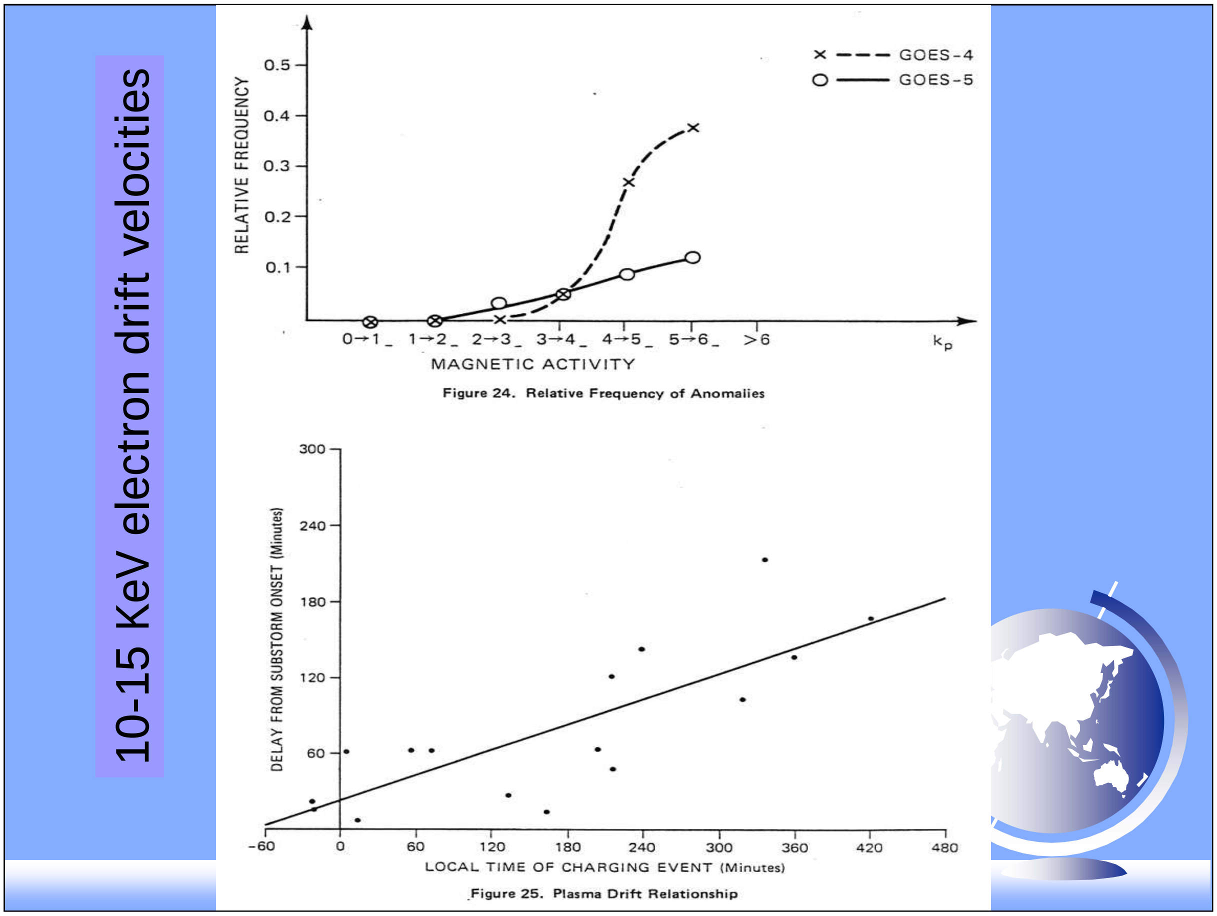
Winfield H. Farthing
James P. Brown
William C. Bryant

MARCH 1982

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

Joe Allen:

In March 1982, Harry Farthing (NASA GSFC) and others published the in-house NASA Tech Memo shown here. In it they clearly showed the cause of PC anomalies on GEO satellites using NOAA GOES-4 and –5 early operational histories to be due to satellite exposure to thermal electrons injected around midnight from the magnetotail (see next slide) and either encountering the GOES near midnight or else drifting eastward to overtake them in the night sector around to the dawn meridian.

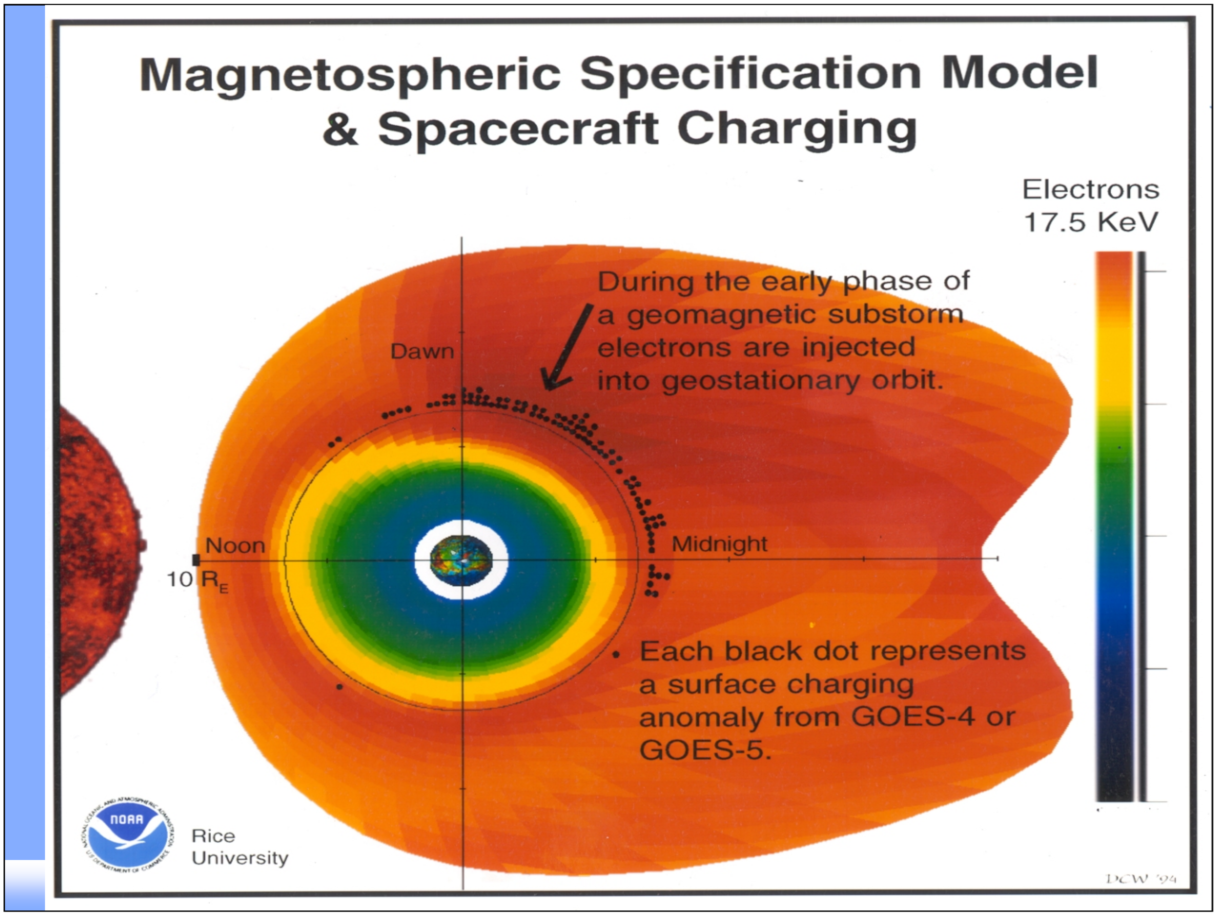


Joe Allen:

Some of the first GOES-4 and –5 anomalies shown earlier in the clock-diagram plot by Wilkinson were used by Farthing in his study. Changes in the satellite design were incorporated into GOES-5 after the history of GOES-4 was studied and they noted the exponential rise in frequency of anomalies with rising Kp index. The result is shown in the upper panel of this slide. As the Kp-Ap magnetic activity index increased, the GOES-4 anomaly relative frequency rate rose rapidly. However, the design changes introduced into GOES-5 produced a satellite that experienced more anomalies with rising magnetic activity, but at only a linear rate of increase.

In 1979 at the IUGG meeting in Canberra, Australia, I reported on the distribution of the increase in satellite anomalies taken from the SAM database prepared by Dan Wilkinson. It showed a doubling of the probability of occurrence for Kp >= 3. At the time of this talk, there was criticism that such Kp events were “too small” and “happen too often” to be the cause of GEO satellite anomalies. However, the Farthing results in this report clearly show the rise in anomaly relative frequency starting about Kp = 2+ to 3-.

Harry selected several isolated substorms during the anomaly record period that could be associated with anomalies by using the AE index (we then produced AE at NGDC in Boulder). Harry took the time of substorm peak as To for the start of particle injection from the magnetotail around the midnight meridian. He took the anomaly time, Ta, and computed the difference dT = Ta – To. He then plotted these differences against the local time of each anomaly event. The result, in the lower panel, is a remarkably linear distribution of difference points. GOES satellites near midnight when an isolated injection happened were impacted at the moment of injection (isolated substorm onset in AE). As the satellites were located further from midnight toward the dawn meridian, the anomaly time delay after injection increased linearly. The slope corresponded to the drift velocity of 10 to 15 KeV electrons that were injected in the equatorial plane near midnight and drifted toward dawn under the influence of $V \times B$ forces.



Joe Allen:

In summer 1995, Prof. John Freeman (Rice University) visited with NGDC STP Division staff and gave us on-line access to the new Rice Magnetospheric Specification Model. Dan Wilkinson combined the Rice model with the 10-year old clock diagram display of GOES' anomalies and produced this figure. It shows in the equatorial plane cross section the early phase of electron injection during a substorm and the drifting toward dawn meridian superposed on the map of anomaly events.

My First Reference to “Space Weather”

In October 1985, the STP Division of NOAA-NGDC held a conference on Space Environment Effects on Satellites. Some major accomplishments were:
(1) Proof that NASA’s TDRSS-1 had anomalies from protons & alphas;
(2) I first used phrase “Space Weather”.
(3) Proved Philco-Ford had problems caused by environmental disturbances.

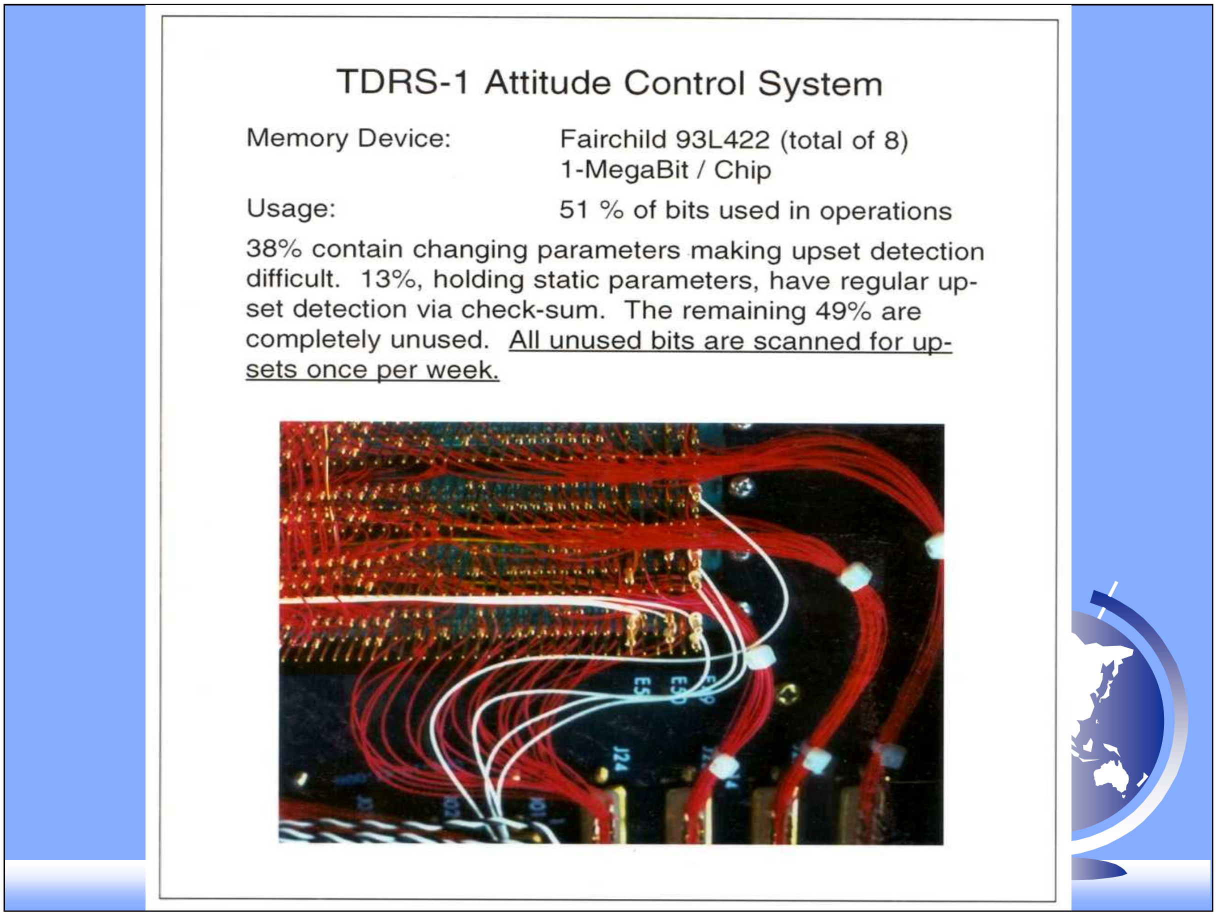
Dan Wilkinson and other young scientists in my STP Division at NOAA’s NGDC organized a conference on Space Environment Effects on Satellites and Other Technology and Humans. It was held in Boulder in October 1985 and was attended by interested participants from government agencies, aerospace industry, communications, and other groups. Perhaps this was a forerunner of the currently popular annual “Space Weather Week” meetings organized by NOAA-SEC.

At this meeting as a result of our cooperation with the contract operators of TDRS-1, the first NASA GEO command and control satellite, it was conclusively shown that components in TDRS-1 (the Fairchild 93L422 memory chip) made it “A flying solid-state cosmic ray detector.” The engineer who made this classification died a few years later in a glider accident. He was a good friend and a hard-working colleague. We memorialized him by creating in SAM a class of “anonymous satellites” that use his initials as an identifier.

The contractor-head of TDRSS operations attended our meeting. He was dismayed by the evidence from TDRS-1 and observed “If this means I have to go back to Washington and tell NASA that they have to design a fix for one satellite already ready to launch and then the next two TDRSS’, it could be worth my job!” Apparently he was successful because design changes were made and the anomalies on TDRSS-2, -3, and –4 were much less frequent than on TDRS-1.

In the concluding discussion, I asked participants what they most wanted in the future. They agreed on four services: (1) Forecasts of disturbed space conditions; (2) Warnings when events started or were detected; (3) On-line images and data showing key parameters of the space environment; and (4) A high-quality archive of accessible data from the GOES Space Environment Monitor (SEM) sensors. I summarized their responses by saying: “Then what you want is for SEL to provide a Space Weather Service”. This was my first (and spontaneous) use of the term <u>“Space Weather”.</u>

One other result from our 1985 meeting that I recall was that an engineer from the satellite manufacturer Philco-Ford (no longer in the satellite-building business) was planning to give a talk on “In-orbit correction of environmentally induced satellite anomalies.” Shortly before our meeting (after the program was printed), I received a call from a Vice-President of the company who told me that their engineer could not attend our meeting. When I asked “Why?”, he said that “Our satellites don’t have environmental anomalies.” I asked whether a change of title would be sufficient to permit the engineer to attend, and pointed out that we would be discussing their satellites because the aerospace communications company that was their major customer planned to be represented in the program and wanted to discuss their operational. The V.-P. became very agreeable and we worked out an acceptable title that was pasted into the programs before the meeting.



Joe Allen:

The susceptible component used in TDRS-1 was the Fairchild 1-Megabit/Chip RAM chip 93L422. Its use in TDRS was not an isolated incident. Another NASA contractor who designed and built the Hubble Space Telescope also used this RAM chip in it. This is reputed to be responsible for the frequent Hubble anomalies when transiting the **South Atlantic Anomaly** (SAA). The SAA is a region where energetic particles penetrate to lower altitude in the upper atmosphere above the Atlantic Ocean in a broad oval area overlapping the east coast of Brazil. The reason for this region of intense radiation at lower altitudes is that the internal geomagnetic field is that of an offset eccentric dipole inside Earth. The dipole is effectively moved away from the center of Earth toward the Pacific Ocean and is inclined at an angle of about 11.5° to the rotational axis. The North Geomagnetic Pole is near Qanaq, Greenland and the magnetic equator dips to the South over the western Atlantic. This offset results in a stronger magnetic field at LEO altitude above the Pacific and the weaker one above the south Atlantic off Brazil. Energetic particles entering the Earth's upper atmosphere during storm and substorm injections from the magnetotail can penetrate more deeply into the SAA than any other non-polar region.

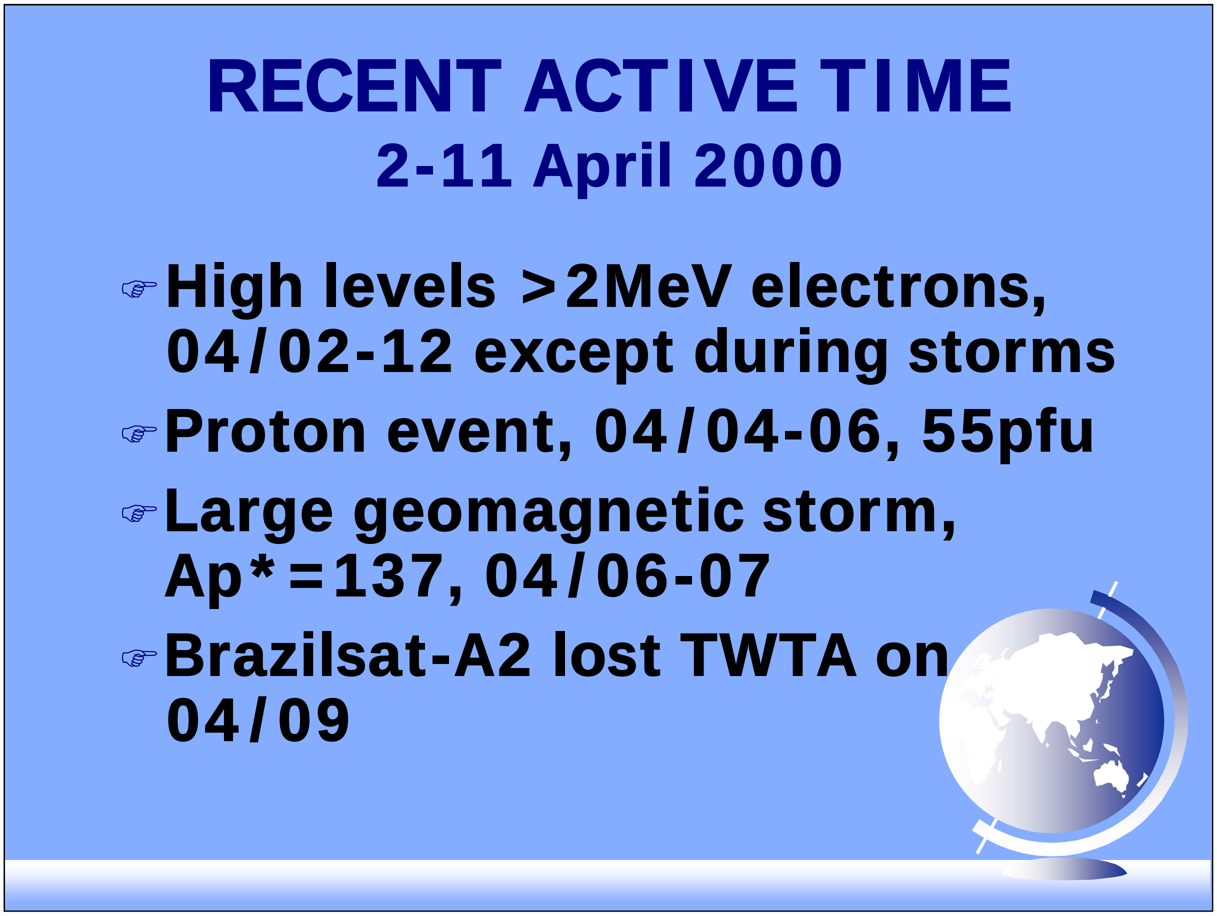
Lest we think that knowledge of the SAA is commonplace and taken into account in satellite design, it should be kept in mind that several LEO satellites launched in 1999 and early 2000 have had anomalies during passage through the SAA. This is especially true during enhanced activity of geomagnetic storms when the SAA may spread and merge with the southern hemisphere auroral electrojet. Even the International Space Station (ISS) experiences anomalies when passing through the SAA several times each day.

Joe Allen:

This collage of newspaper articles about the failure of Galaxy-4 in May 1998, was assembled by Dan Baker and Joe Allen. The disturbed space environment at the time of the outage was described by Baker, Allen, Kanekal, and Reeves in the paper **"Disturbed Space Environment May Have Been Related to Pager Satellite Failure**", EOS, Transactions of the American Geophysical Union, Vol 79, No 40, 6 October 1998.

This event and the high solar activity with consequences at Earth and in geospace were the subject of papers given at sessions of the ISCS Workshop and at the COSPAR General Assembly in summer 1998 in Nagoya, Japan. Also, they were extensively discussed at the meeting of the Western Pacific Regional AGU in Taipei, ROC, just after COSPAR. I traveled from Nagoya to Taipei with Prof. Yuri Galperin (a SCOSTEP Bureau Member) and we enjoyed discussing events involving satellite responses to Space Weather activity. By then the subject was "respectable".

At the WPR-AGU, SCOSTEP's S-RAMP Steering Committee decided to make the period April-May 1998 a **"Special Study Interval"** and to invite concerted analysis of phenomena recorded at that time. This period was the focal topic of many presentations at the **"First S-RAMP Conference"** in Sapporo, Japan during the first week of October 2000. Please see the S-RAMP website (managed by Marissa Rusinek – if it still exists) and Dan Baker's Tutorial PPT presented there.



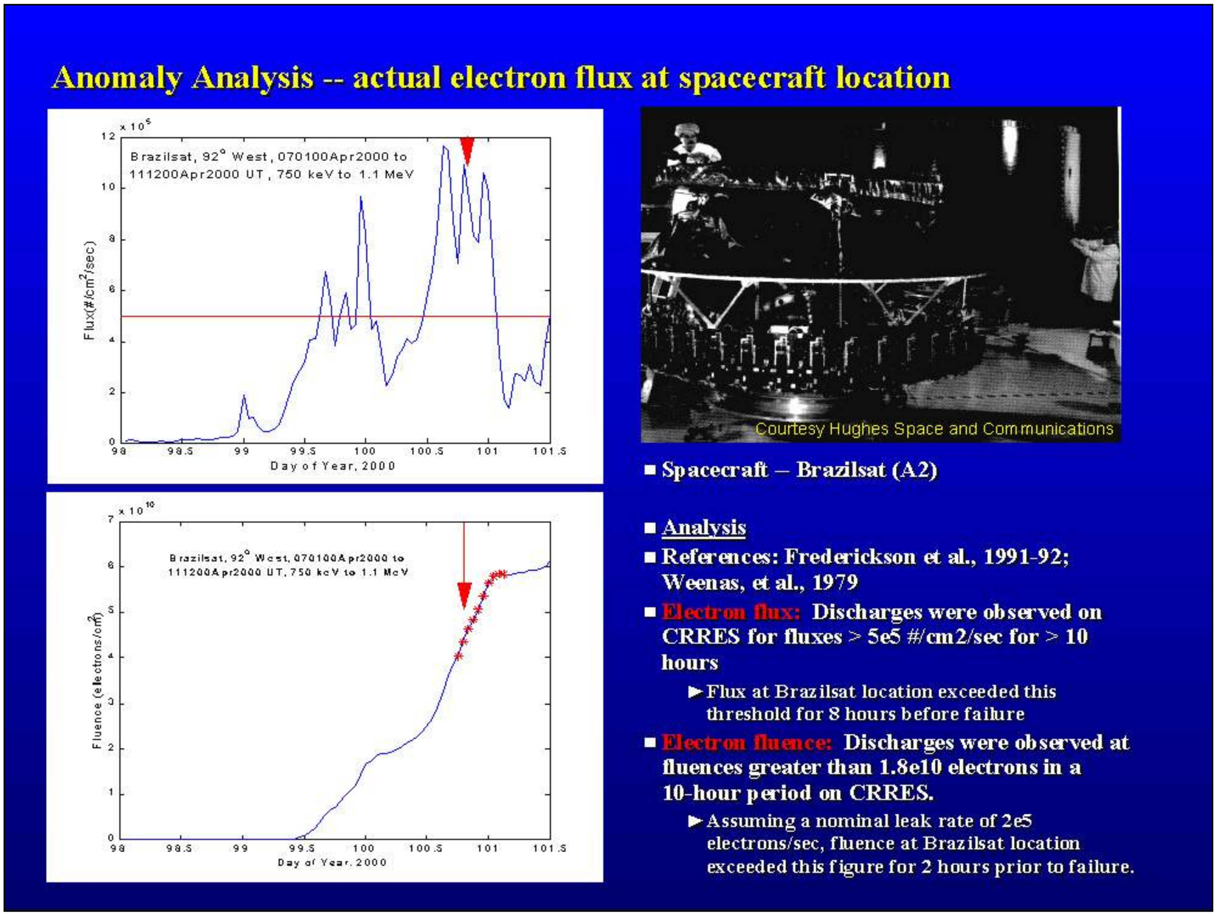
Joe Allen:

According to the maximum 24-hour average of the 3-hourly **ap** magnetic activity indices for this period, the value of **Ap* = 137** was the second largest magnetic storm of this solar cycle (see the Apstar document and list of events at the NGDC/STP website under geomagnetic indices). I introduced the Ap* index in 1976 at the IAGA Scientific Assembly in Seattle to provide an objective rank-order size classification of magnetic storms from 1932 to the present.

Although the >10 MeV proton maximum count (55pfu) from SEC was not particularly high compared to other events, David Evans (SEC) confirmed the event had some of the highest fluxes of auroral energy electrons seen in this solar cycle.

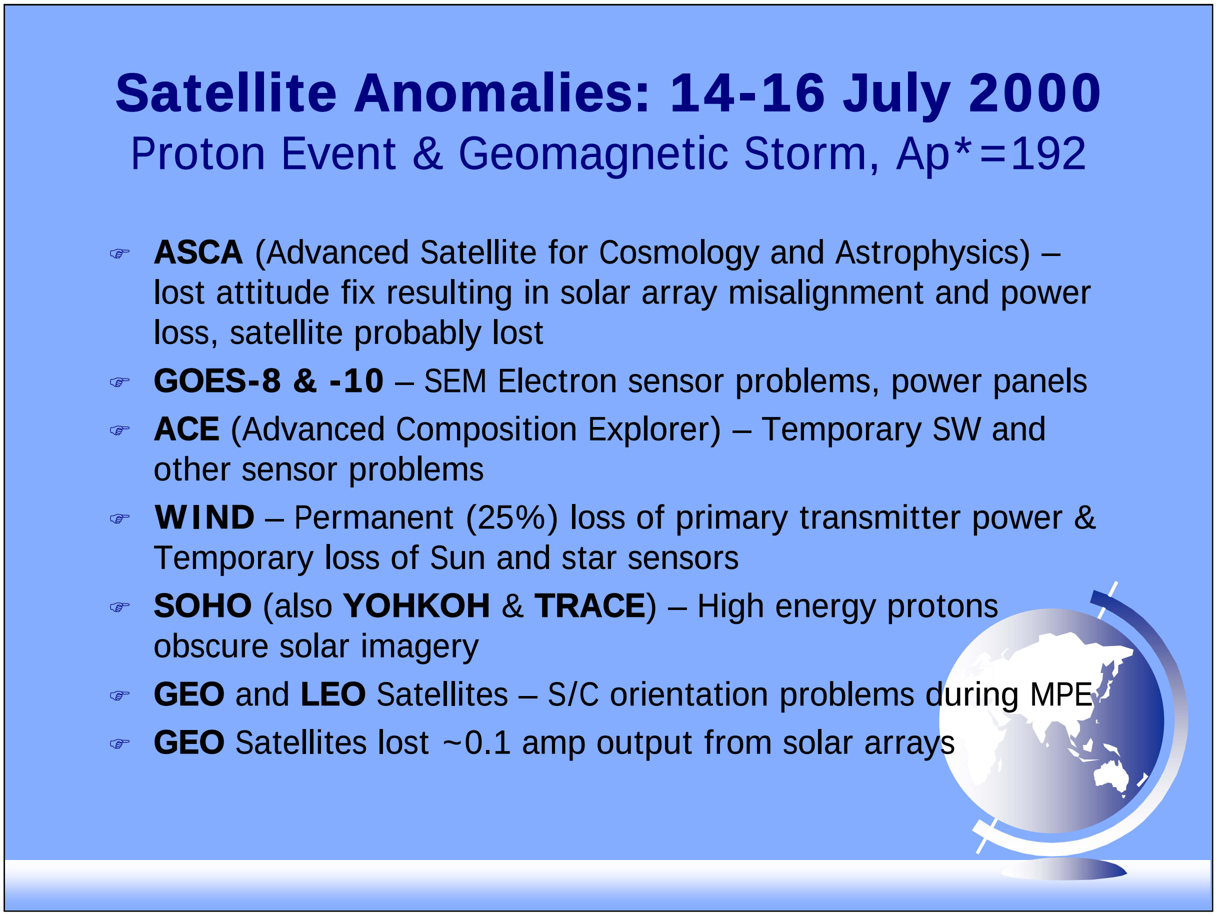
Information about Brazilsat-A2 from L.C.F. de Sousa (EMBRATEL), and later follow-up by Walter Gonzalez

See next slide for modeling by Dan Moorer (LASP).



Joe Allen:

Dan Moorer and Dan Baker (LASP) developed a technique for analysis of space environment conditions at locations where satellite anomalies happen. They use a history of observations under similar environmental conditions as measured by similar spacecraft, and project those observations to the time, location, and conditions when the anomaly event happened. Please contact them for details about this technique which they have reported at the 2000 Chapman Symposium on Space Weather in Clearwater, Florida and the 2000 NATO Workshop on Space Weather in Greece.



Joe Allen:

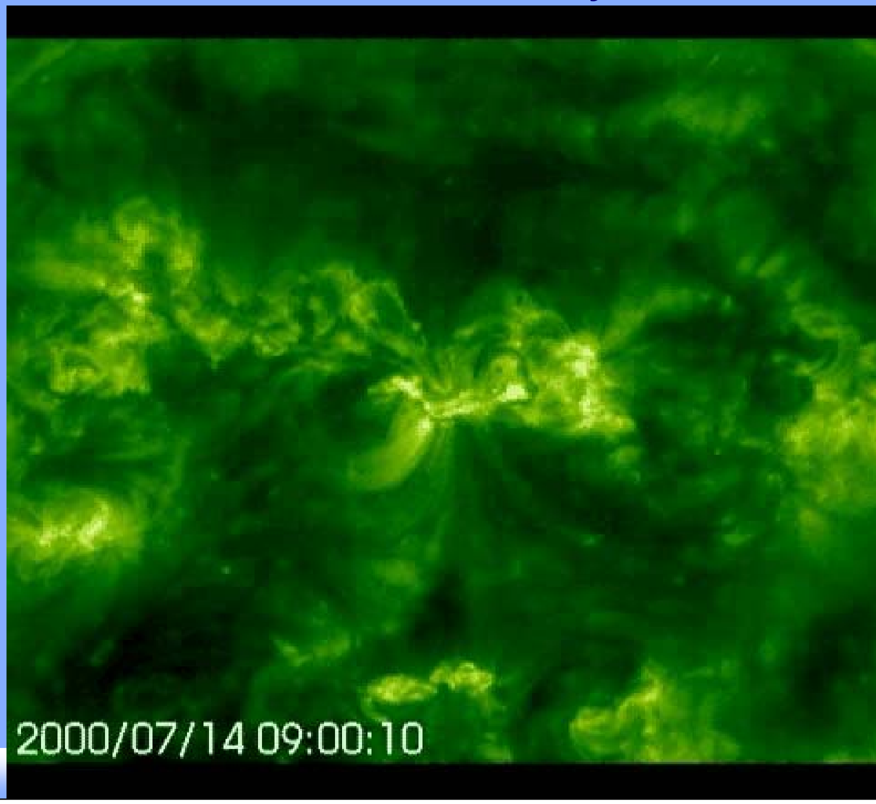
On 14 July 2000, an impressive X5/3B X-ray flare was recorded by NOAA's GOES-8 and -10. Within a few minutes after the flare detection, highly relativistic protons and heavier ions began to arrive at GOES in a very hard-spectrum proton event. Those who looked to the ACE real-time data plots were surprised to see that the solar wind velocity had dropped to background (as if the sensor was turned off). When the stream of very high energy protons arrived at GOES, the high energy electron sensors on both satellites failed, and stayed off for more than 24 hours. Magnetopause Crossing Events for GEO satellites near local noon happened on the 14th and again on the 15th for even longer periods. Data plots for these events are shown on the following slides.

Many interested persons began exchanging e-mail messages early during this disturbed period, and continued over the next several days. At this time, the COSPAR General Assembly was in progress in Warsaw, Poland, and many persons most likely to be concerned and knowledgeable about such events were there. Executives of aerospace companies, satellite operators, and customers of GEO vendor services were busily exchanging e-mail and sharing near-panic experiences. A special session was planned for the Fall 2000 AGU on the event. As Dan Baker has been heard to say, **"It's an ill solar wind that blows no good."**

The list of satellite anomalies given here is incomplete, largely because of vendor concerns for adverse economic impacts.

This "Bastille Day" event and its consequences are an example of the combination of flare, CME particles, relativistic particles, and a major geomagnetic storm.

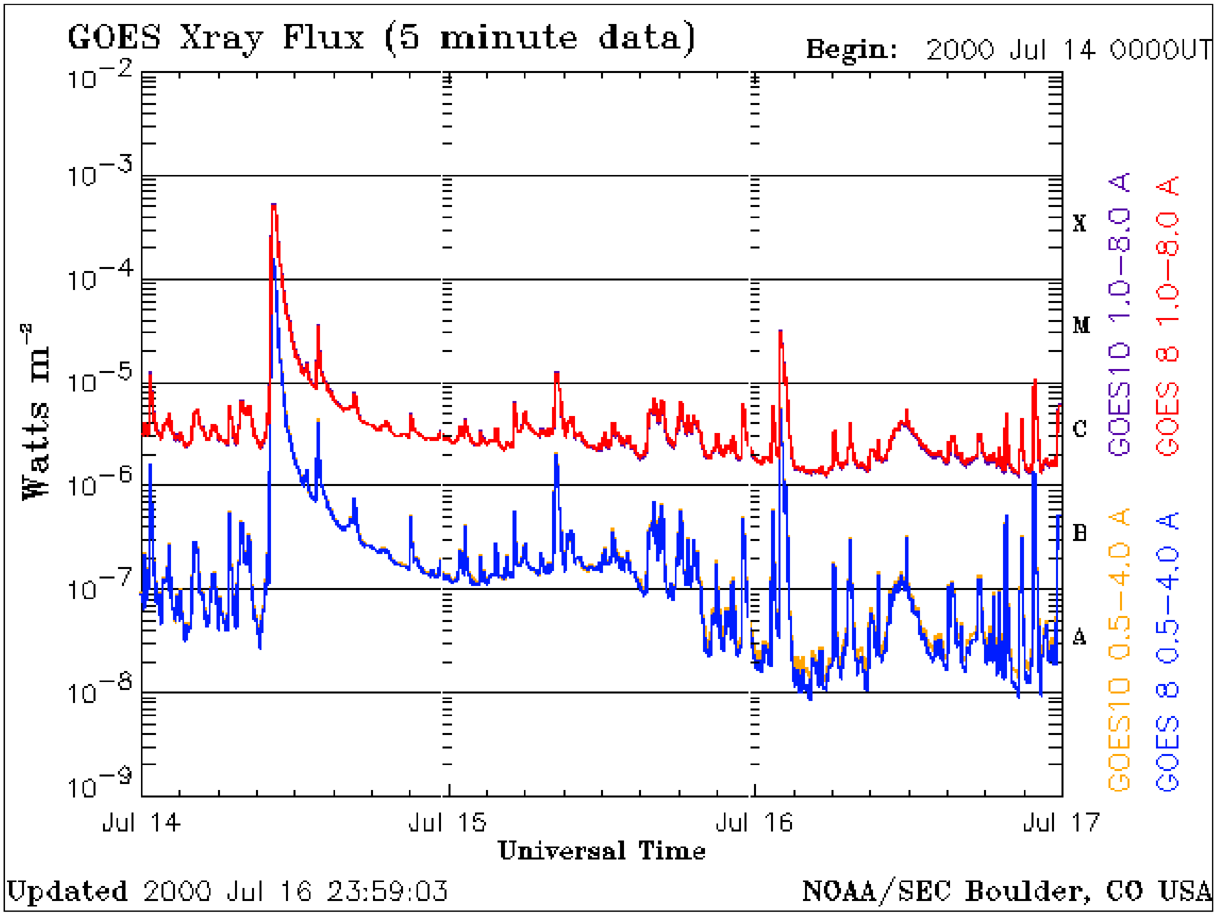
SOHO EIT for 14 July 2000



Joe Allen:

This video clip from the SOHO website shows the X5/3B flare from the Active Region near the center of the frame. The sequence begins at 09:00 UT on the 14th of July (“Bastille Day” event). Minutes before 11:00 UT the first “sparks” in SOHO optics begin to appear from arriving relativistic protons and heavier ions. They passed on Earthward, causing the onset of a SEC GOES “proton event” beginning at 10:45 UT. The magnetopause compression began to register on the GOES magnetometers just before 15:00 UT and the first of two recorded magnetopause compression events began around 18:00 UT on the 14th. The second, longer MPE begins about the same time on the 15th, a combination of the satellites moving into near alignment with the Sun-Earth line and a resurgence of the solar wind pressure on the magnetopause.

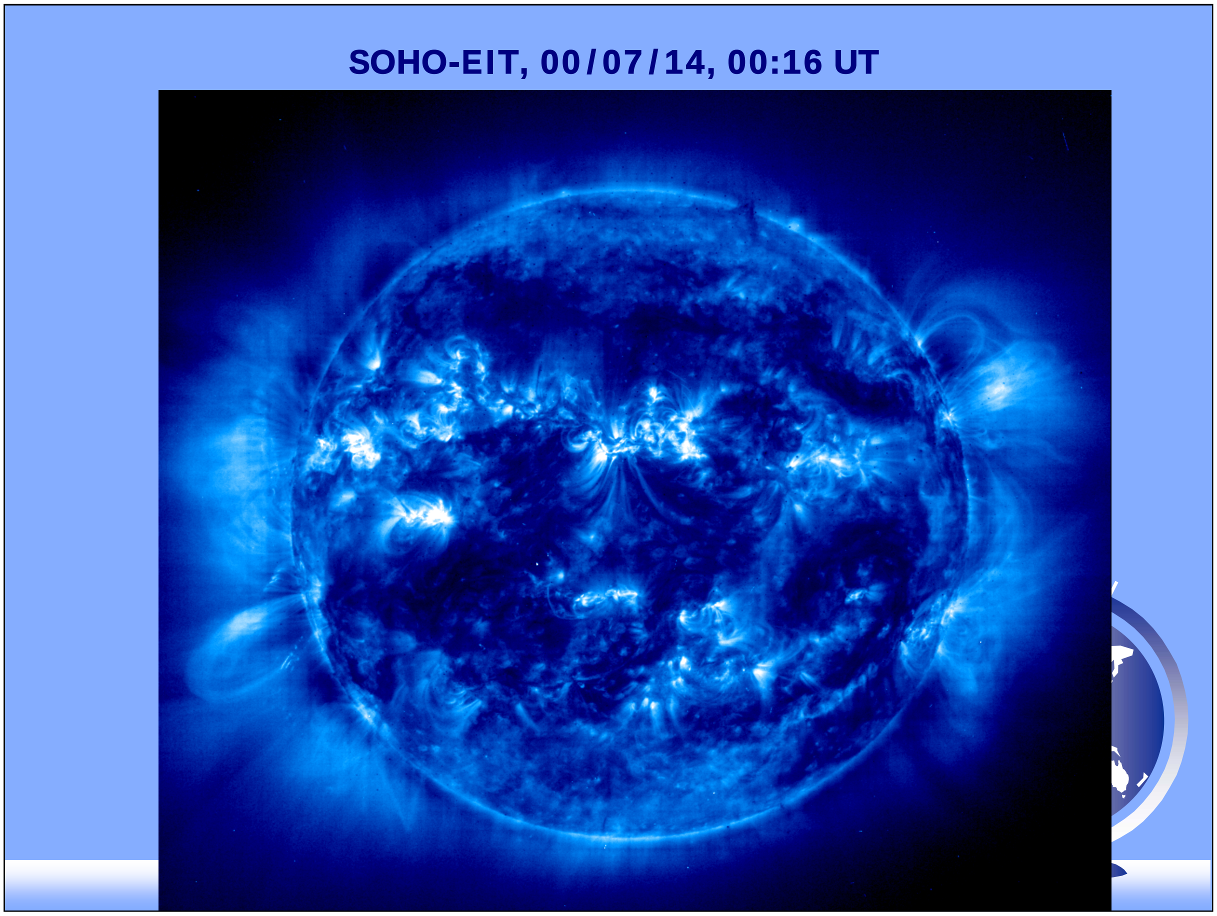
We do not have specific reports of times and positions of commercial or government GEO satellites that experienced anomalies during these events (as of 2000/09/22), but know that many happened.



Joe Allen:

Electromagnetic X-ray radiation from the active region flare arrived at GOES at 10:24 UT on the 14th as reported by NOAA-SEC. This slide shows 5-minute average data from their online real time space weather website.

Satellite sensors and communications between ground and satellites, and from satellite-to-satellite were affected by the ionization of the upper atmosphere by this radiation. It also affected ground-based radio and other communication media.



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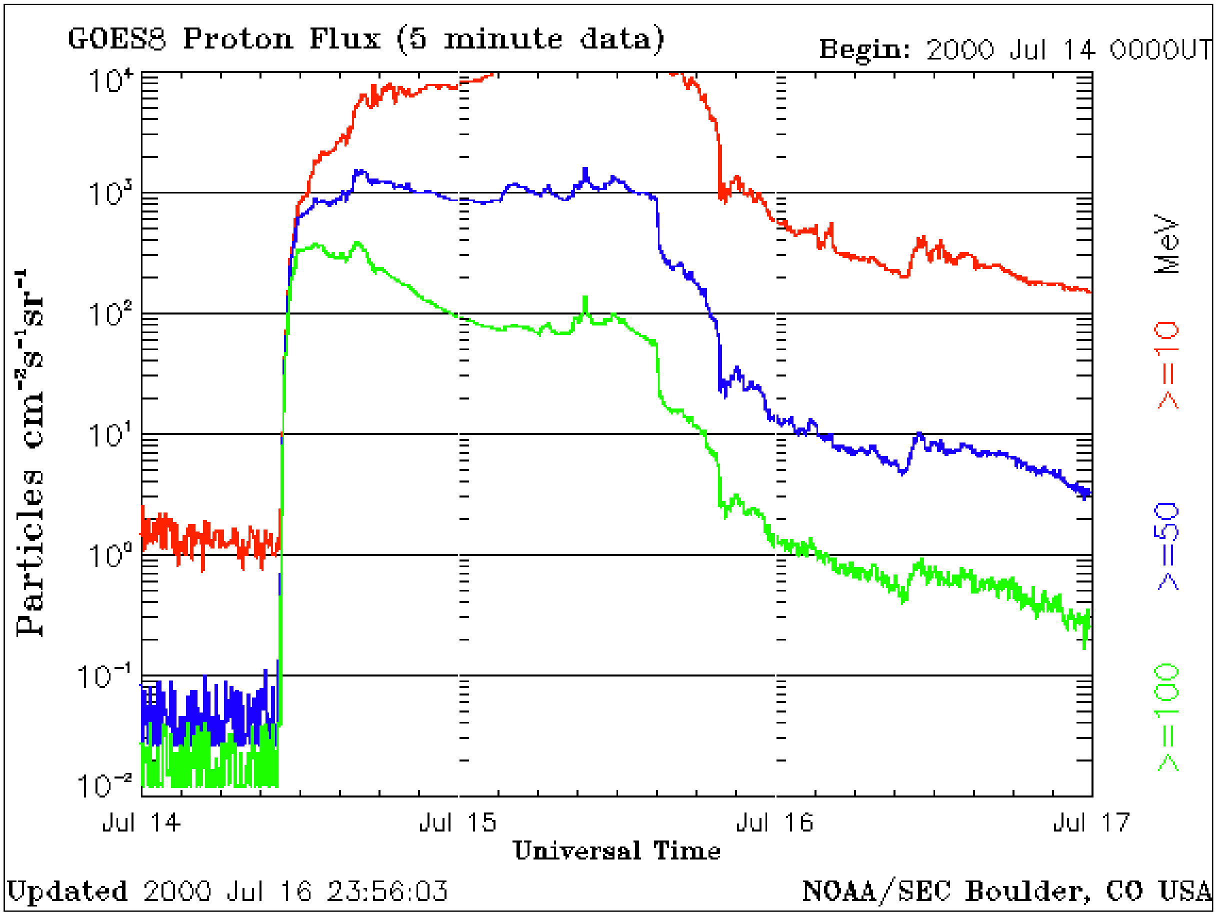
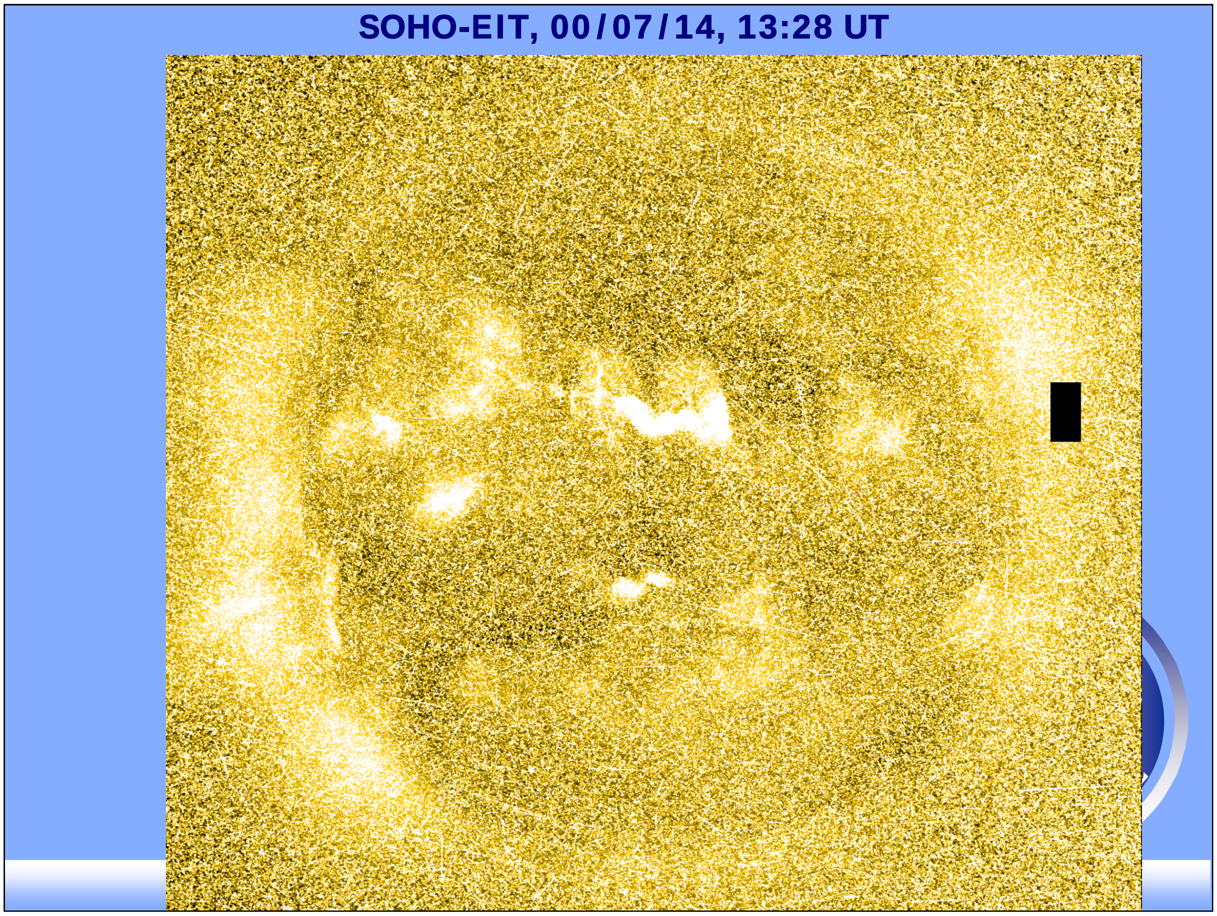


Joe Allen:

All three energetic proton channels are initially at nominal background level at the start of 14 July. They begin to rise essentially simultaneously, a characteristic of a hard spectrum event.

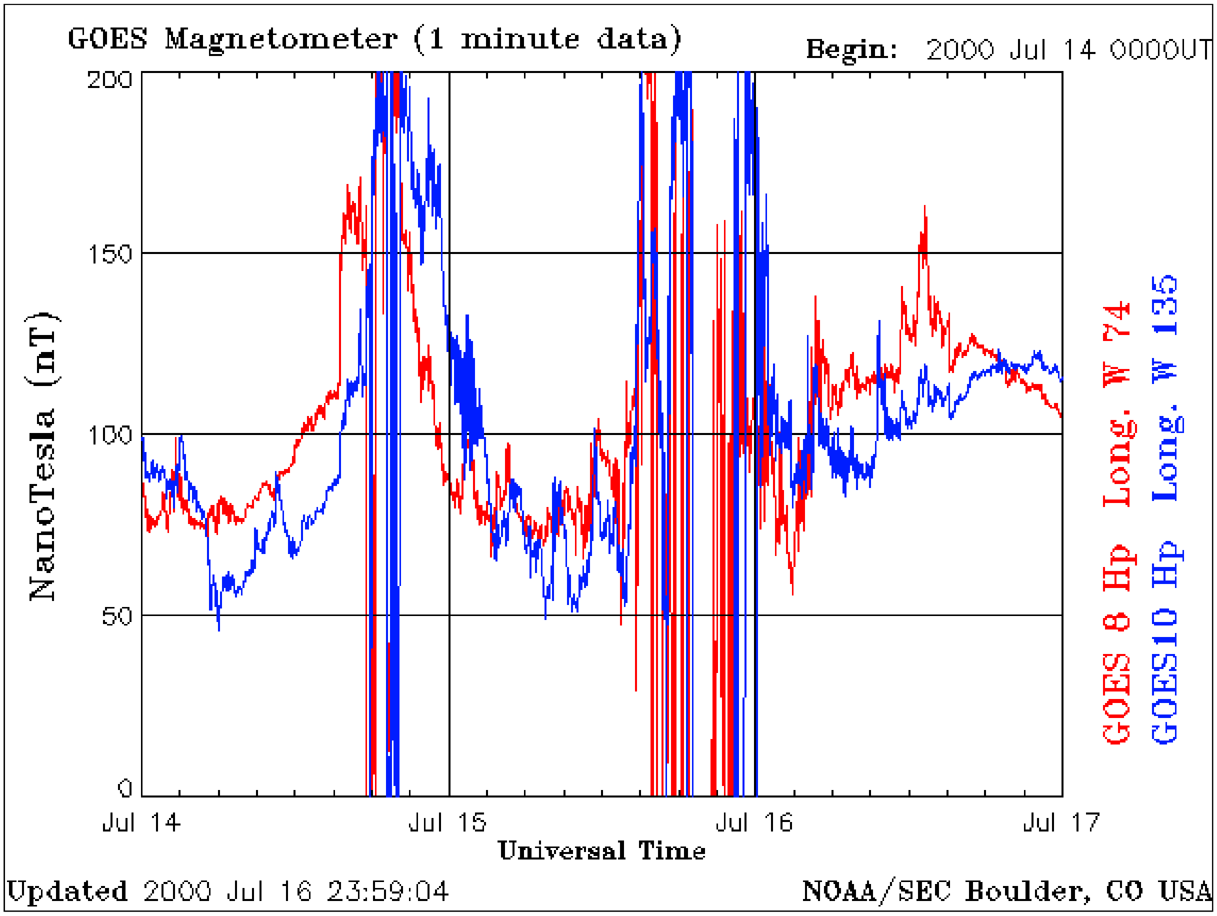


Joe Allen:

When the stream of highly relativistic protons and heavier ions reached SOHO, it produced the noisy image on this slide. The plasma affected optical sensors on ACE, SOHO, YOHKOH, and TRACE. It was as if the "monitor" satellites were among those hit hardest by this event.

One can imagine what must have happened in the optical systems of satellites near Earth that depend on optical systems (star trackers or limb sensors or Sun trackers) to control satellite pointing. Suddenly such systems could not find an object on which to lock their satellite.

Power panels on interplanetary and GEO satellites received a serious dose of short-term radiation.

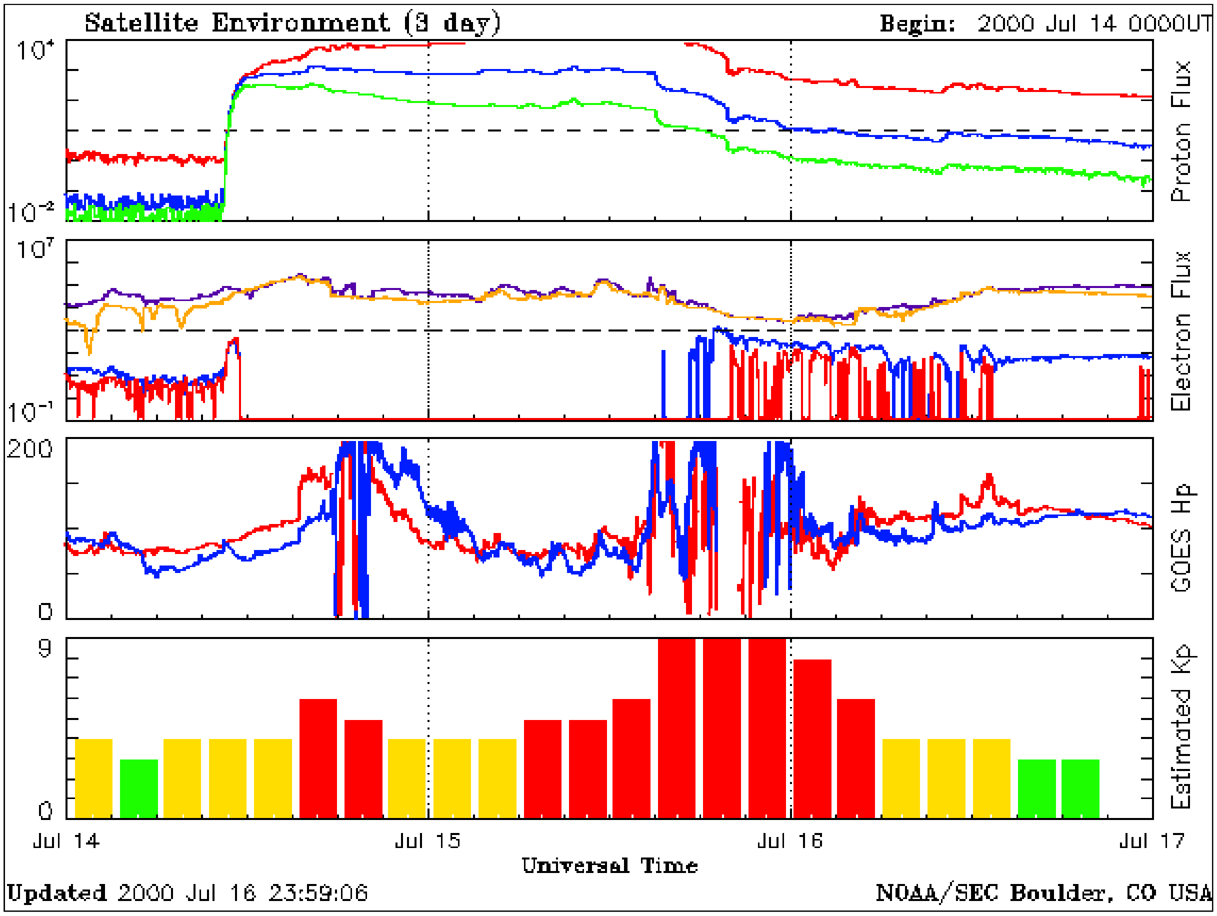


Joe Allen:

Geostationary (GEO) altitude satellites near local noon (i.e. close to the Sun-Earth line) experienced long-lasting Magnetopause Crossing Events (MPE). Those closer to the Earth's dawn or dusk meridians (actually the satellites don't have sunrise or sunset except when passing into or out of eclipse), may pass rapidly outside and then back inside the "flapping" magnetopause which is waving like a flag in the solar wind.

Satellites that use the ambient magnetic field to provide pointing control are apt to become "lost" during the MPE. In order to prevent their going into uncontrolled tumbling, it is usually necessary to have ground-controllers intervene with orientation adjustment commands. A former US Air Force satellite controller who now works for a commercial GEO communications provider told me that "It was the most demanding days of my professional life as we controlled our fleet from ground stations."

Some satellites use magnetic linkages between the body of the spacecraft and the internal "momentum wheel" to despin the satellite and keep it stable. Under disturbed ambient magnetic field conditions, the routine transfer of spin can be impaired (or even reversed). This can be a special problem for Low Earth Orbit (LEO) altitude satellites which may pass through large variable ambient magnetic field regions associated with field-aligned currents between the ring current that expands out to GEO altitude and the ionospheric high latitude auroral electrojet currents at around 100 Km altitude.



Joe Allen:

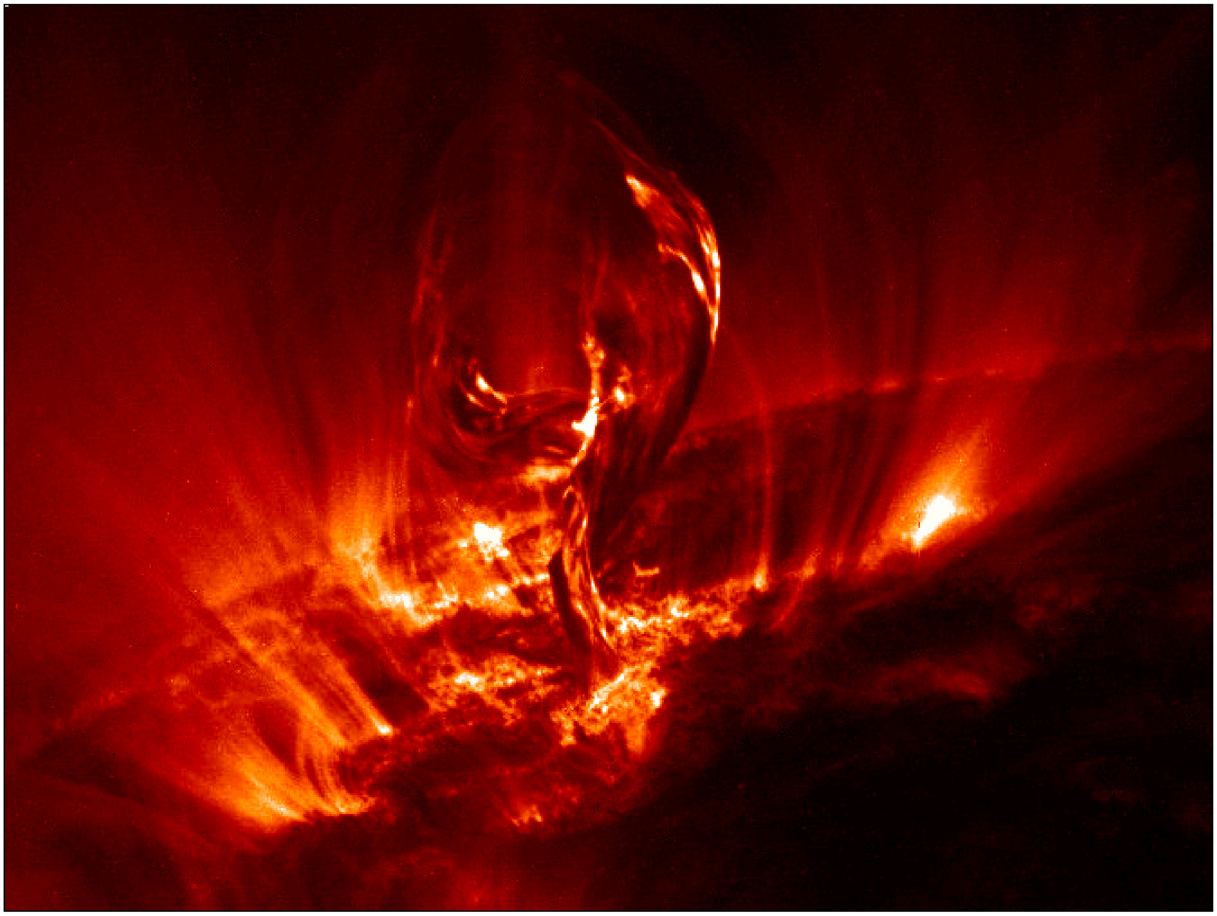
The top three panels of this slide show GOES SEM data during the same three days as the previous slides. The bottom panel shows **"estimated Kp"** indices for each 3-hour interval of the UT day. Failure of the highest energy electron sensors on both satellites is evident soon after onset of the hard-spectrum proton event. Both sensors began to recover some 30 hours later, but continued to be more noisy than before the event and to have other outages.

The large changes recorded in the GOES magnetometer Hp traces (field parallel to the Earth's spin axis) are not noise. As the magnetopause was compressed by the arriving solar wind shock wave, the field at the satellites first increased rapidly to about + 200 nT. Then, as the magnetopause passed inside the altitude of GEO orbits near noon, the external magnetic field was reversed. These SEC plots do not show the negative excursion of Hp because the frame is truncated at Hp=0. As the geomagnetic field at GEO altitude recovered, or the satellites rotated inside the compressed magnetopause, the ambient field returned to large positive values, and variations resumed the typical diurnal pattern. Large pulsations of about 3-hours duration are seen in the Hp traces. About 24 hours later on the 15th, an even longer and better defined MPE happened during the height of the geomagnetic storm.

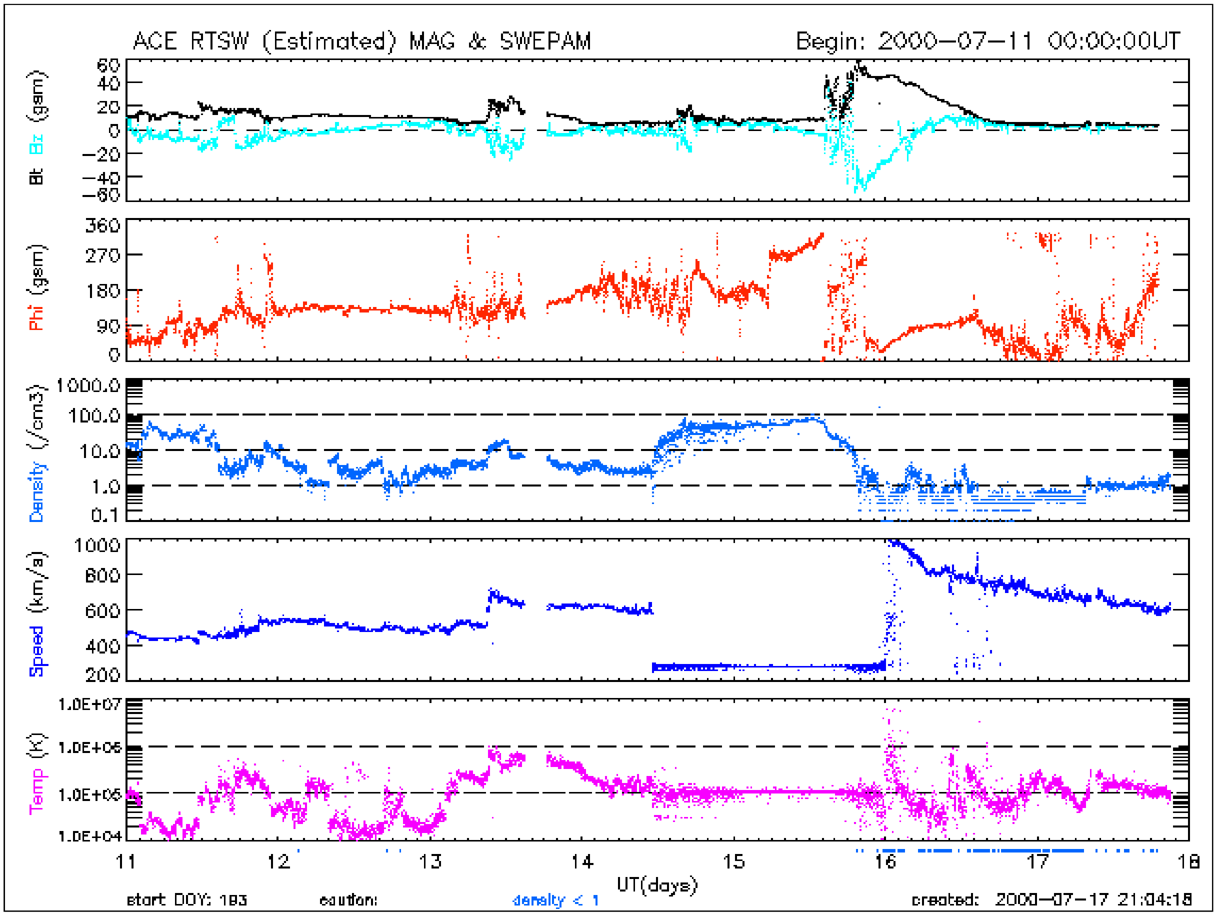
From the global array of ground-based magnetometers, the most disturbed 24 hours of this storm had **Ap*=192**.

This was the second or third largest geomagnetic storm to happen since the "Great Storm" of 13-14 March 1989.

Slide #30 of this STP-11 presentation gives the "Top 10" geomagnetic storms since 1976 (beginning of standard GOES particle data) and the "Bastille Day" storm only rates the 10th spot compared with the others listed there.



This TRACE image was, I believe, taken during the window including the large emissions of mid-July 2000. It does not illustrate a point about Satellite Anomalies, but is a lovely and fantastic image – like something for inclusion in Walt Disney's **"Fantasia"**. It looks as if it could be a cosmic conductor rising from the surface of the Sun, ready to conduct some Wagnerian piece, perhaps the **"Ride of the Valkyries"**.



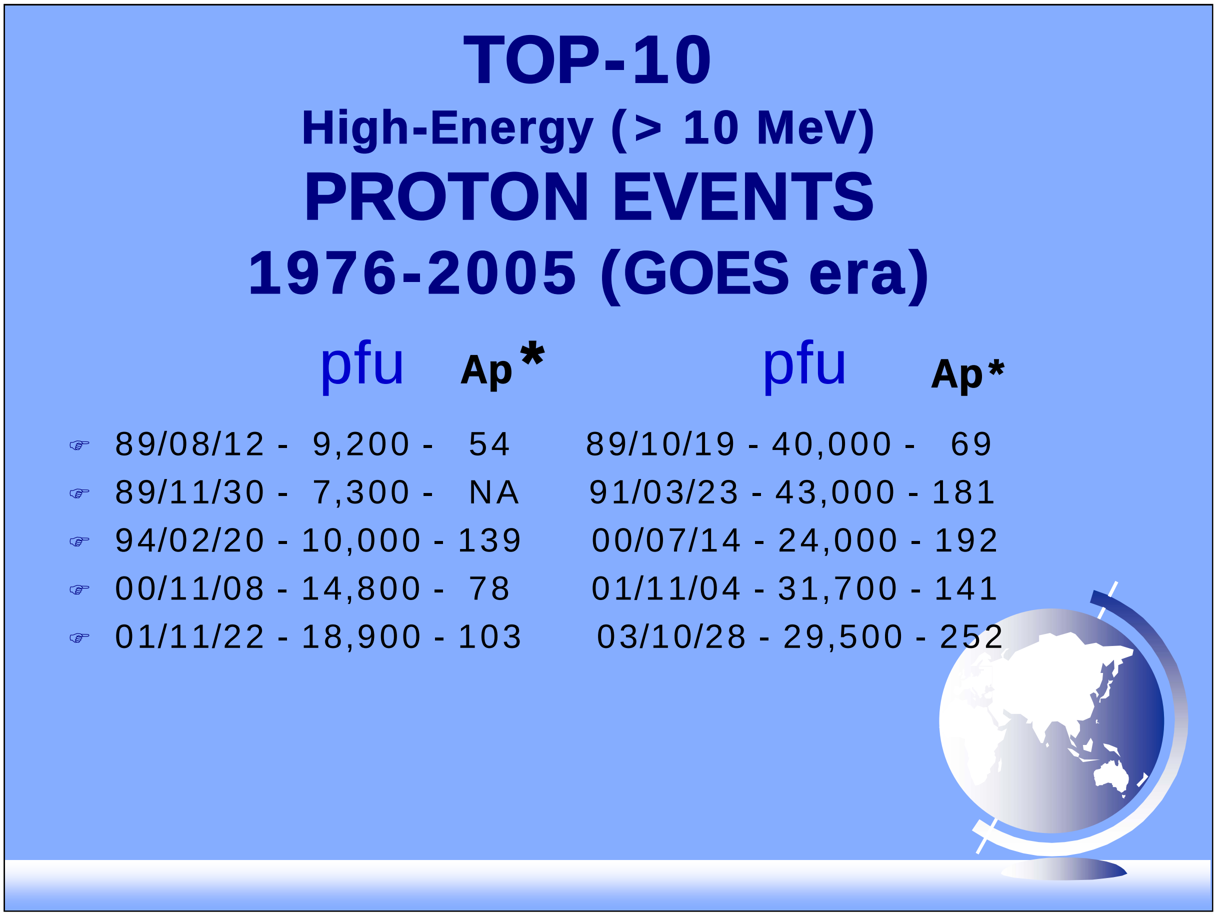
Joe Allen:

ACE monitoring data from interplanetary space around the First Lagrangian Point (the gravity null at L-1) is available from the NASA experimenters in nearly real time via the NOAA SEC Forecast Center website. This is usually the first data at which one looks in order to characterize what is happening in the IMF and SW that may affect Earth.

The “southward turning” of the IMF seen beginning late on the 15th in the top panel is a key characteristic of optimum conditions for merging of the heliospheric and geomagnetic fields when they collide on the Sun-Earth line.

Arrival of the highly relativistic protons and heavier ions already affected ACE sensors almost a day before the southward Bz happened. The outage affected several ACE sensors, but not the magnetometer.

At the “First S-RAMP Conference” (2-6 October 2000) in Sapporo, Japan we were told that **“The ACE Solar Wind sensor did not fail. There was an algorithm failure!”.**



Joe Allen:

NOAA's Space Environment Center (SEC) declares "Proton Events" when the count level of > 10 MeV protons recorded by GOES satellites exceeds a threshold of 10 pfu for 3 successive counts. They tabulate the maximum count attained during the event and it is given in the table. Sometimes there are complications of multiple events within one "event" (see e.g. October 1989).

The following list of the ten largest counts attained was taken from the table on the SEC website. The tabulation of such events can only be taken back to 1976 with the beginning of the SEM sensors on the GOES satellites. Limiting a list to the "top 10" resulted in selecting those for which the maximum attained was >= 7,300 pfu. Lower events may still be significant for satellite impacts. Also, nothing here suggests whether the proton event had a hard or a soft spectrum. In March 1989 the proton event had a peak count of 3,500 pfu. However, its spectrum was relatively soft. The August, September, and October proton events were extremely hard (also true of March 1991 event). Although the 29-30 September 1989 proton event didn't make my "Top 10" list (4,500 pfu), an interesting customer interaction occurred. A physicist at Battelle N.W. research institute called me to talk about "recent conditions". I learned that they were conducting a laboratory experiment to attempt to replicate "Cold Fusion" phenomena. He came back to the lab one morning and had a "EUREKA Moment" when he saw that their chart recorder had gone off-scale during the night. Fortunately I was able to tell him by that time about the very large proton event resulting from an active region already rotated around the west solar limb.

Keep in mind that the SEU and other types of satellite anomalies arising from high energy protons and heavier ions are different from those caused by arcing after either differential surface charge build-up or deep dielectric charging by high-energy electrons. Thus there are significant differences between the proton-event caused anomalies, those from geomagnetic storms and substorms, and those produced by extended exposure to high energy electrons. None of these are the same as the operational anomalies arising from magnetic field changes during Magnetopause Crossing Events at GEO or field-aligned currents and field crossings at LEO. Nor are they the same as anomalies clustered around the time of a GEO satellite entering or exiting eclipse region around equinox or the once-reported seasonally clustered anomalies arising at GEO around the dawn and dusk meridians. The latter turned out to be a case of a large antenna self-shadowing the satellite body and interrupting the thermal boil-off of surface electrons.

Note that even though a major proton event occurs, it does not mean that a major geomagnetic storm will be associated. The converse is also true. Not all large geomagnetic storms are accompanied by big proton events (see next slide).

TOP-10 MAJOR MAGNETIC STORMS: 1976-2005

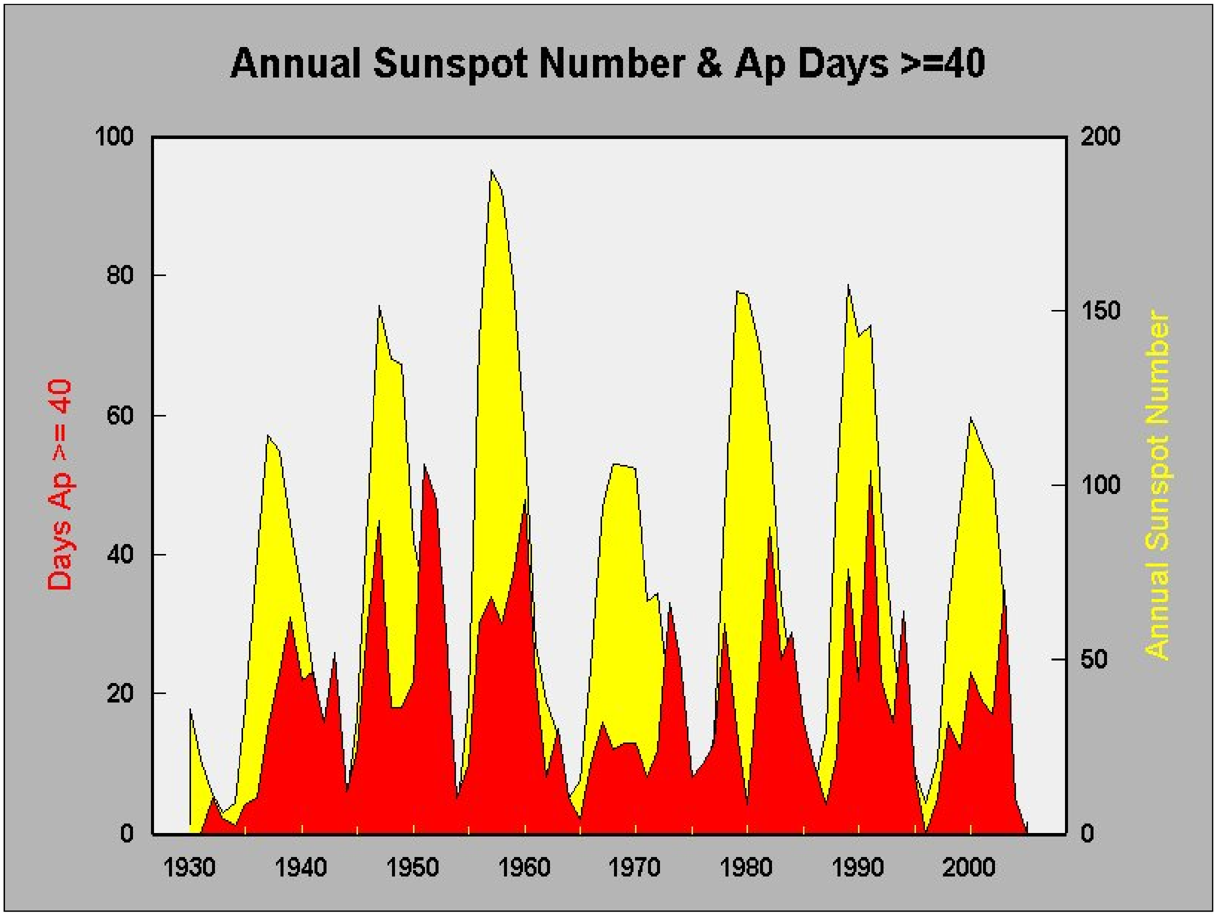
DATE peak 24-hr began	Ap*	peak pfu
☞ 1989/03/13	285	3,500
☞ 2003/10/28	252	29,500
☞ 1982/07/13	229	2,900
☞ 1986/02/08	228	130
☞ 2004/11/07	206	no event
☞ 1982/09/05	201	66
☞ 1991/06/05	196	3,000
☞ 2004/07/26	195	2,086
☞ 1992/05/10	193	4,600
☞ 2000/07/15	192	24,000

Joe Allen:

In 1975, I introduced the Ap* index. It is computed as the 8-point running average of successive 3-hourly ap magnetic activity indices. When the average rises above an arbitrary threshold (usually 40), a major magnetic storm is considered to be in progress. While the running average stays above the threshold, it is considered one storm. After the end of the storm, the most disturbed 24-hour mean is denoted **Ap*** for that storm event. If the most disturbed period begins with the start of a UT-day, then Ap*=Ap. However, about 7/8ths of the most disturbed storm periods don't begin with the UT-day and Ap* for those storms is greater than any regular Ap.

Output from the Ap* tabulation is presented on-line by NGDC/STP sorted first by date and then by size. One can easily search for the larger storms in a particular year or years from 1932 to the present. Using the rank order list gives a means for comparing the relative intensity of different events. The list in this slide was limited to storms from 1976 through 2000, to correspond to the years for which GOES proton event data are available.

These largest geomagnetic storm events are interesting to compare with the Proton Event list (which begins only with GOES), and with Ground Level Event (GLE) lists. The largest geomagnetic storm in this period (3rd largest since 1932) is the "Great Storm" of 13-14 March 1989. It had a relatively modest proton event peak level of 3,500 pfu and as discussed earlier was a very soft-spectrum event. The large storm of November 2004 did not even cause a proton event. It is evident that there is not a 1-to-1 match between geomagnetic storms and proton events.



Joe Allen:

This is a figure that has grown in utility over the last 4 solar cycles since I first prepared it from hand-tabulated values from IAGA Bulletin 22 publications. The yellow trace is of annual values of the smoothed sunspot number from 1930-2004 (we won't know the value for 2005 for a few more months). Data in red are the number of days per year for which the Ap daily average magnetic activity index was 40 or greater. Today these annual numbers quickly can be extracted from computer listing of tables of values, but still it remains a challenge to me to get the figure updated using EXCEL. The rapid drop off at 2005 is not "real" but is an artifact of the plotting package and my limited graphic capabilities.

Immediately obvious is the fact that magnetic storms are distributed differently in time than sunspot numbers. Peaks in storm numbers may happen on the rising side of the sunspot cycle, at maximum, and always on the declining side of the cycle. Some magnetic storm groups during a sunspot cycle are bimodal, some trimodal, and one is essentially unimodal after first reaching an early plateau.

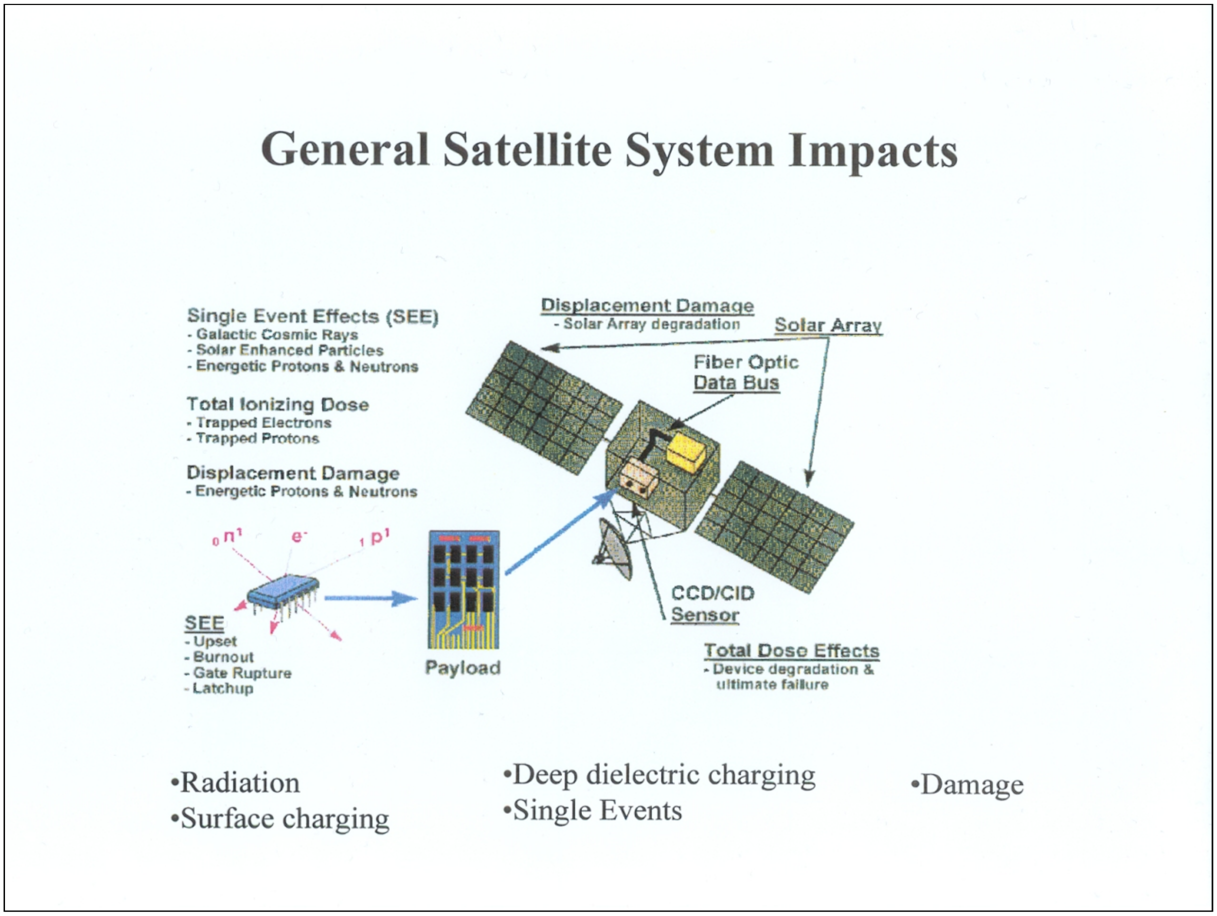
Computing the Ap* indices from the 3-hourly ap values gives fewer events per year (not shown) because some storms last for more than one day but are only one event. However, the Ap* values are greater than any Ap in a given storm about 7/8ths of the time.

Separation of geomagnetic storms at thresholds of 40, 60, 80, and 100 reveals that the larger storms more or less follow the same time distribution as the smaller ones. However, the number of storms having 40<=Ap*<=60 are mainly the result of multi-day recurrent magnetic storms from co-rotating high-velocity solar wind streams. They happen mainly on the declining side of the solar cycle.

Tabulation of the number of satellite anomalies per year shows they generally follow the magnetic storm cycle both from year to year and seasonally within each year. This is not true for the TDRS-1 satellite as explained on another slide.

Joule heating of the upper atmosphere by the currents that produce the magnetic storm variations causes increased satellite drag, which is not considered an "anomaly", but which also may vary along with the anomaly counts for some satellites.

Although GEO satellites seem to give the most clearly seen anomaly patterns associated with geomagnetic storms, it appears that tumbling and other anomaly problems with LEO satellites can happen during passage through the field-aligned current regions, the auroral zone, and the South Atlantic Anomaly.



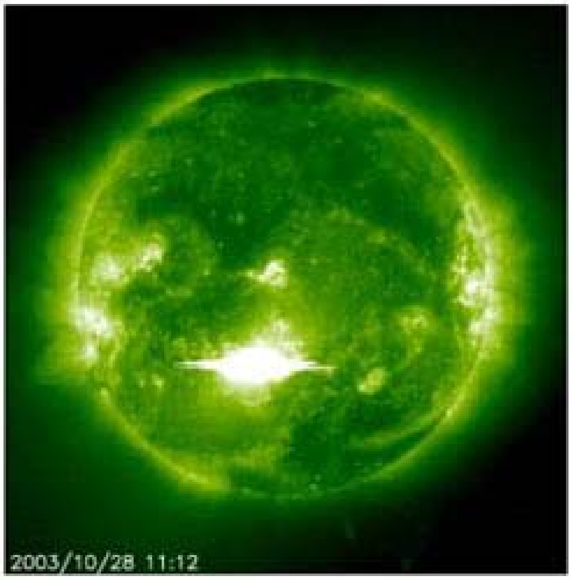
Joe Allen:

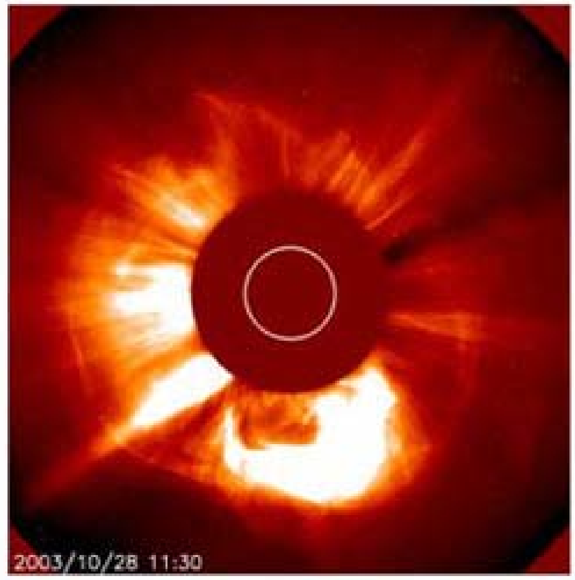
Marsha Korose, USAF-OSA, sent a PowerPoint briefing used to tell senior officers about what disturbed space conditions can do to satellites in orbit. This figure shows several types of damage that can result from different types of solar activity (or galactic cosmic rays).

This does not address the hazard to ground-based, ship or airborne units, nor to humans in orbit or flying at high altitude. It also does not address the effect of space environment disturbances on telecommunications, changes in the geomagnetic field that can disorient satellites, and specific failure modes.

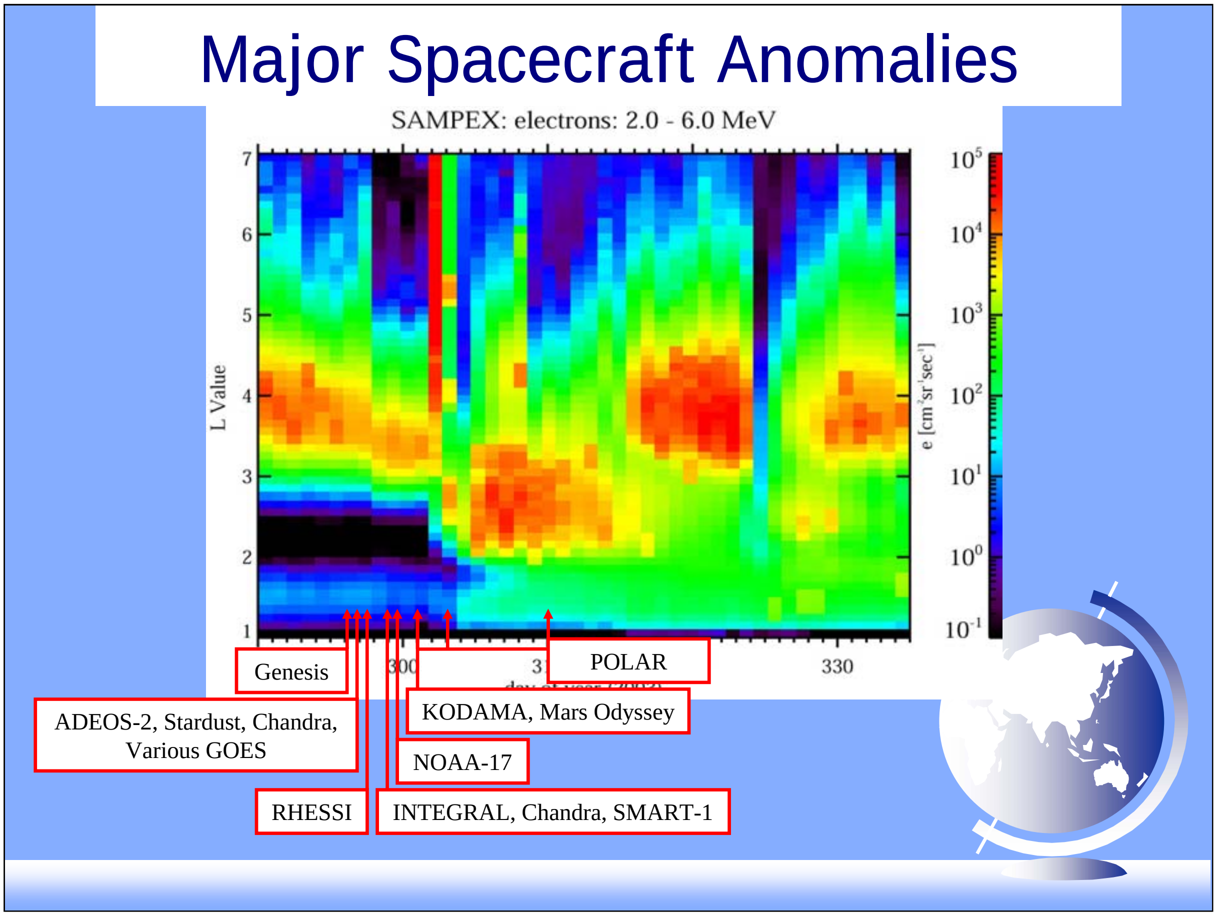
At OSA, Marsha sponsored compilation of listings of satellite anomalies by Harry Koons, et al. (Aerospace Corp.) and they made a very complete report. Harry and others have published a number of publicly available reports on satellite anomalies, spacecraft anomaly reports, and similar topics.

OCTOBER-NOVEMBER 2003
SOHO EIT of X-17 Flare and SOHO LASCO full-halo CME



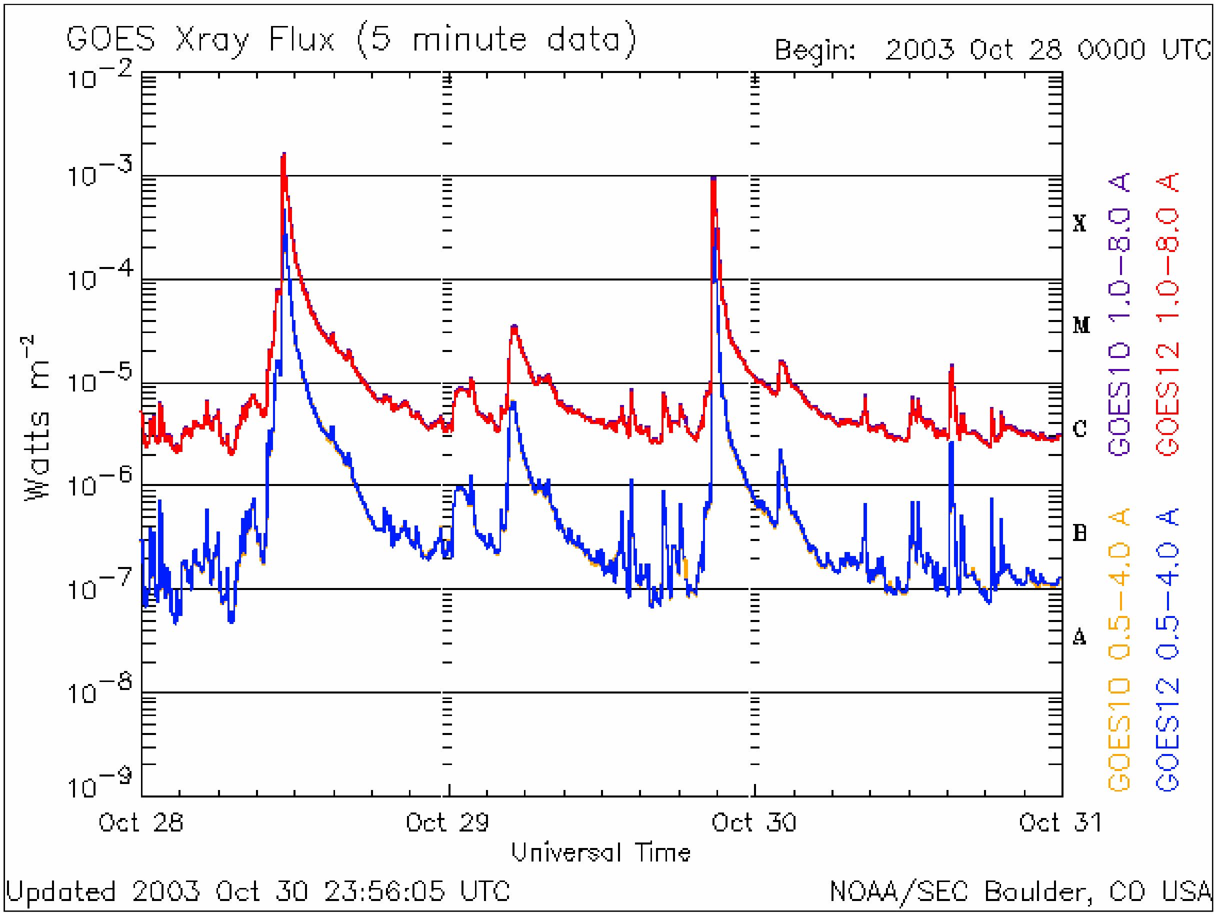


David Webb and Joe Allen collaborated in preparation of a listing of satellite and other anomalies that happened during the highly disturbed "Halloween Storm" and subsequent days in 2003. With encouragement from Lou Lanzerotti, Editor of AGU's "Journal of Space Weather", they prepared a short description of the solar events and geophysical results in space and at Earth. The paper included a table of anomaly events that happened to many different satellites (see following slides) and other technology and to astronauts. These events were discussed enthusiastically a few weeks later at the 2003 Fall AGU in San Francisco (before the paper was published, we had circulated the anomaly list to my ANOM group by e-mail and David receive considerable feedback from several members of the group).



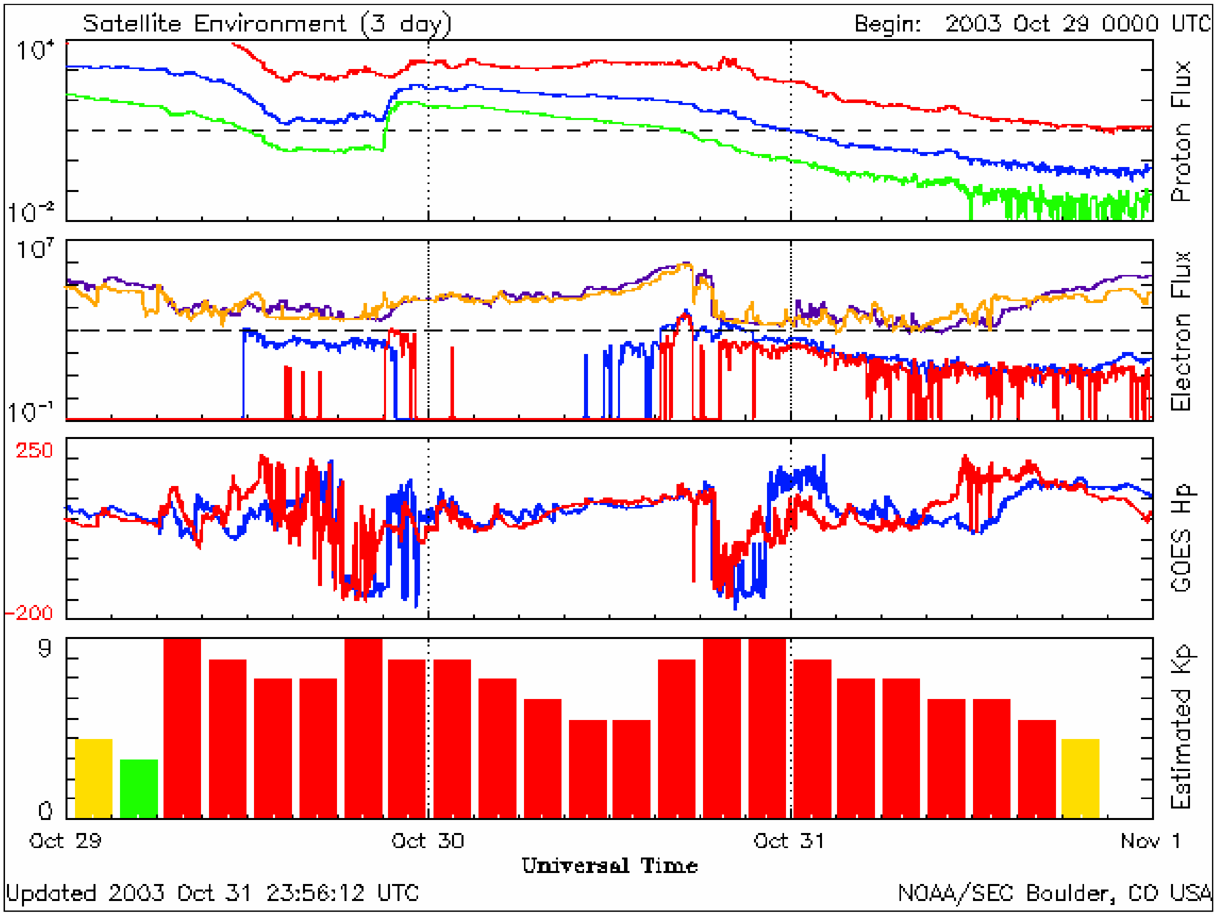
This is a slide prepared by Marissa Rusinek for Dan Baker to use in a talk (I think at AGU). It shows SAMPEX high-energy electron measurements at different altitudes ("L Values") and, as the viewer cycles through it lists some of the key satellites affected by the conditions they encountered.

Note that the "slot" between the inner and outer trapping regions is filled for many days by very high-energy electrons from the peak of this period, but that many satellite anomalies happened well before this change.



These are the familiar on-line traces of the GOES X-ray sensors on the fleet of NOAA satellites. The NOAA Space Environment Center pioneered putting these 5-min average data plots on-line and they have become a standard that is widely used in our community.

Although some make a point that Coronal Mass Ejections (CME) do not have to originate with a solar flare, it is also true that often we see the visible or X-ray record of the electromagnetic signal from a large flare and then this is followed by the arrival at ACE and then at Earth by the energetic particles from the event's CME. These were two of the largest X-ray flares recorded by GOES (although a larger peak was attained a few days later – see Webb & Allen).



The Satellite Environment 3-day plots are often the most useful summary images available from NOAA-SEC. They include energetic proton flux (top panel), energetic electron flux. And the ambient magnetic field at GOES in the direction parallel to Earth's dipole field. If the view draws a zero-level line across the GOES Hp frame, this illustrates the long-duration Magnetopause Crossing Events (MPE) that can so disorient any GEO satellite near local noon that uses the ambient magnetic field for orientation.

Note that a substantial proton event was already in progress before 29 October 2005 as shown by the three traces above the dashed line at 10 pfu. This particular 3-day graph was chosen because it contains the peak hours of the geomagnetic storm for which SEC produces an "Estimated Kp" magnetic activity index.

Selected OCTOBER-NOVEMBER 2003 Events and Anomalies

Major solar flares with CMEs on 22, 28, & 29 Oct 2003
(from Webb & Allen, in SpWx Journal)

23 Oct – Genesis solar wind satellite at L1 entered safe mode – resumed routine 3 Nov
24 Oct – Airlines rerouted polar flights hf-vhf; Midori-2 failed, declared lost; Stardust comet mission safe mode – recovered; Chandra X-ray astronomy halted; GOES-9,10, 12 high bit rate errors, magnetic torquers disabled;
25 Oct – RHESSI solar satellite CPU “rested”;
26 Oct – SMART-1 auto shutdown in lunar transfer orbit (3 eventually reported).

David Webb began compiling anomaly information as the impacts of the large solar activity arrived in near-Earth space. He sent an e-mail copy to me and I added some anomaly effects and made minor corrections. After several iterations and circulating the information to my ANOM list, we began to work on a joint paper for the Journal of Space Weather.

Selected major effects are list here and in the following three slides. Comparisons with the conditions measured by SAMPEX and the GOES SEM sensors as well as reference to the paper can provide insight into the timing of events.

ANOMALIES Continued

26 Oct – Instrument on INTEGRAL safed; Chandra observations halted again;
27 Oct – GOES-8 X-ray sensor turned off, no recovery;
28-30 Oct – ISS astronauts retreated to heavy shielded service module; FAA issued its first radiation dose warning for radiation to passengers above 25,000 feet; Power systems failed in Malmo, Sweden and the Republic of South Africa; NOAA-17 AMSU-A1 lost scanner; ACE and WIND lost plasma observations; GOES e-sensors saturated; CHANDRA halted till 11/01

28-30 Oct Anomalies Continued

KODAMA data relay satellite at GEO went into safe mode with noisy signals; DMSP F14 SSM/T-2 sensor lost data and one microwave sounder; RHESSI had 2 more spontaneous CPU resets; CHIPS computer went offline on 29th and lost contact for 18 hours; Mars Odyssey in safe mode, memory error required cold reboot – MARIE sensor powered off;

28-30 Oct Anomalies Continued

Twin Mars Explorer Rovers en route to Mars entered “Sun Idle” from star tracker hits; SIRTF (trailing Earth) offed science experiments and lost 4 days of operations; CLUSTER satellites processor resets; POLAR out of lock 3 times but recovered; FedSat (Australian LEO) wobbled in orbit and had SEU; INMARSAT’s 9 satellites controllers had to react to momentum wheel speed gains, and CPU outage; NASA E.S.M.O. offed 5.

CONCLUSIONS-1

- Sunspot cycle decline and minimum years are ideal for “killer electrons” at GEO and lower orbit altitudes.
- Sunspot cycle maximum years are ideal for energetic proton and heavier ion events that cause SEUs and sensor optics & power panel degradation. But major solar events can happen anytime.
- Major magnetic storms may happen at any time and cause spectacular effects on satellites, technology and humans but they are most frequent in weeks around equinox.

Some of these conclusions were first included in satellite anomaly talks in the late 1970’s. Others are new to this STP-11 presentation. It has been interesting over the past 35 years to observe how slowly some parts of our community have evolved:

We now share information more openly than before, but much is still concealed because of commercial or other fears;

Helpful individuals within aerospace organizations develop close ties with institutional personnel, but then retire and there isn’t anyone to replace them (happens on both ends).

As lessons are learned about the effects of Space Weather by one generation, another comes along that hasn’t had the experience and must learn again at the expense of programs. As successful scientists and engineers move into management positions, sometimes their attitudes change and they seem to forget important lessons.

Sometimes compartmentalization within an aerospace company can result in the same type of satellite being made by two different groups for different customers and one group will take account of past susceptibility issues while the other seems unaware of basic precautions. Generally, good engineering design based on experience improves future designs.

CONCLUSIONS-2

- Every satellite (or object) in orbit is a probe of the Space Environment.
- The history of satellites should be the basis for our learning what causes operational problems.
- Combining space environment data with satellite histories is necessary.
- Solar Cycle # 23 has been very active. Are we any more ready today?
- What about cycle # 24? Are we going to become better prepared?

After Lou Lanzerotti decided he could not accept the invitation to be the Keynote Speaker on "Space Weather" in Rio at STP-11, the President and Vice-President of SCOSTEP persuaded a reluctant Joe Allen to accept responsibility for preparing and giving the talk. Since I would be the outgoing SCOSTEP Scientific Secretary, this would be the opportunity for my "Swan Song". Lou generously agreed to co-author the talk with me and helped produce the abstract. He copied his AGU Lecture on James Van Allen and his role in Space Weather and sent this to me as a source of material. Because of my serious health problems during December and January, I was unable to interact with Lou concerning the specific content of this talk. I did tell him that I planned to spend most of the time talking about recent solar activity and its impact on technology --- particularly satellites.

Lou should not be held responsible for any mistakes in this presentation. I hope he will not regret having his name associated with it.

I have greatly enjoyed working with SCOSTEP for many years since I was first volunteered by my boss, Alan Shapley, to create the Central Information Office for the International Magnetospheric Study (IMS CIE) in 1976-1979. The scientists and members of SCOSTEP have been a choice group with which to associate these many years. I hope to continue some level of contact with my ANOM list of interested persons.

Joe H. Allen – Rio de Janeiro, STP-11, 10 March 2006