CGMS-XXVII
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Agenda Item:B.3
USA WP-04

Anomalies from Solar Events in the Coming Solar Maximum

The paper discusses the coming Solar Maximum, predicted to occur around March of 2000, its predicted intensity, and the types of satellite anomalies which the satellite community may expect to see over the next two to four years

B.3 Anomalies from Solar Events in the Coming Solar Maximum

We have begun the steep climb in sunspot activity which heralds the arrival of Solar Maximum, now predicted to occur in around March of the year 2000. Over the next several years the maxima of other types of solar activity will occur as well, such as the maximum of extreme ultraviolet (EUV) flux, energetic proton events, solar flares, and intense geomagnetic storms due to ejecta from the sun. (etc, etc) , culminating in the geomagnetic Storm Maximum which is predicted for 2002. These maxima will be followed by a gentle downslope of activity which continues into the next Solar Minimum. Therefore, the community should be aware that we are entering into a multi-year season of high rates of different types of solar activity which alone or in combination can have multiple deleterious impacts on their systems' operations.

Cycle 23 is expected to have the same level of activity as occurred in the 1988-1991 era. Over the past few months the observed level of sunspot activity appears to have been closer to the lower of predicted levels, but solar activity is now catching up to the prediction.ThisCycleisexpectedtobe Greater societal impacts are expected during this cycle because of the great increase in vulnerable technologies since the last Solar Maximum. Taken alone, the increase in satellites in operation alonerepresents a dramatic increase in the number of systems that can be effected by extreme geomagnetic activity.

Effects That Can Be Expected

The public media have been using generalized terms recently to describe some solar impacts on Earth. Solar Storm generally refers to the explosive release of a large volume of solar material, often called a Coronal Mass Ejection (CME), that can cause a geomagnetic storm at Earth when it arrives in Earth's vicinity two to four days after t leaving the sun. heinitiatingsolarphenomena.The term is sometimes confused with Radiation Storms, which refers to large increase in the number of high energy particles, up to 100,000 times the background level. They are also called Proton Events. These highly energetic particles can arrive at Earth with about one-third the nearlyrelativistic speed of light after being launched shortly after the onset of a major solar flare; warning times for astronauts and satellite operators can be as little as twenty minutes.

Complicating matters is the fact that the term radiation refers to a wide array of energetic particles and other radiative outputs. For example, lower energy electrons and ions are generated in the near-Earth vicinity foundin abundance during geomagnetic storms and cause their own set of characteristic problems for satellite operators. Additionally, the Sun's output in different parts of the spectrum increases, e.g., EUV output increases greatly and causes significant expansion of Earth's atmosphere for several years during solar maximum. Large increases in the X-ray flux produced on the Sun cause havoc with high frequency radio communications when they hit the Earth's ionosphere. Satellite operators need to remember that although the solar phenomena described above may occur separately, the impacts at Earth may be felt simultaneously with compounding effects. For instance atmospheric drag, which was already high because of increased EUV output may increase during a geomagnetic storm due to the deposition of additional heat. from energetic particles produced by the storm precipitating into the atmosphere. It is quite common for the effects of a proton event and a geomagnetic storm to be experienced simultaneously during solar maximum, even through the phenomena which caused them were commenced days apart at the sun. These types of simultaneous, interacting effects can make diagnoseis of satellite anomalies difficult.

Typical effects:

Satellite surface charging: caused by when large numbers of low energy charged particles impacting the surface of the satellite, depositing charge faster than it can bleed away with no way to discharge.. May result in catastrophic rapid discharge.

Satellite deep dielectric charging: caused by when higher energy electrons thatpenetrate deep into the material and building deposit upcharge faster than it can bleed away. May result in breakdown leading to rapid discharge.until it causes a discharge

Atmospheric changes: the uppermost layer of the atmosphere experiences a 700 degree increase in temperature during solar maximum and balloons out to increase density by integer multiples. This heating is caused by multiple effects from geomagnetic storms, but mainly by the increase in solar EUV flux. These changes can cause decreased satellite life due to increased drag. It can also increase the attitude control momentum lower orbiting satellites have to unload. Increased drag can affect along-track positioning knowledge, thereby affecting automatic verification of satellites' position. This movement in the atmosphere also can cause a change in the position of the ionosphere with resultant impact on radio communications.

Magnetic field changes: can be caused by a solar storm's interaction with Earth's magnetic field. A common occurrence is a boundary crossing, when a geosynchronous (typically) satellite crosses from inside to outside the magnetosphere because the Earth's outer magnetic field on the sunward side is pushed inside the orbit of geostationary satellites by the storm. Additionally, some satellites use magnetic torquing to unload momentum and may be affected by field changes.

Navigation effects - GPS signals are affected by the ionosphere. When the ionosphere is different than expected by the receiver, accuracy of position-finding is degraded. Rising bubbles of turbulent ionosphere induce scintillation in signals, and the rapid variation of signal strength and phase can cause difficulties.

Communication effects - Changes in the ionospheric density negatively affect communications in a variety of ways. Increased density in response to sudden solar brightenings can increase HF absorption. Arrival of charged particles from the sun can knock out high-latitude HF communications as the ionosphere reacts. Of more interest to the satellite community are effects like the increased Faraday rotation induced by the greater electron content of the ionosphere near solar maximum; this can rotate a linear polarized signal from a satellite toward an orthogonal orientation with a linearly polarized receiver on the ground. Space-to-ground and ground-to-space signal strengths can scintillate due to bubbles of turbulence in the ionosphere, more prevalent near solar maximum.

Single Event Upsets - caused by galactic cosmic rays or solar proton events can damage satellite solar panels, computer chips

New Data Will Improve Forecasts

Several new data sets have become available to space weather forecasters during recent years. Real time data i are sbeing broadcast from NASA's Advanced Composition Explorer; a Explorerandwitha ground system network composed of international partners allows NOAA to give approximately one hour alerts of geomagnetic storms. Sometime after Solar Max, Solar X-ray Imagers will begin flying on NOAA's GOES satellites to give continuous x-ray imagery of the sun, improving several classes of forecasts, especially warnings of proton events. We will also begin continuously monitoring the Sun's EUV flux with a sensor on the GOES series beginning with GOES N.