Space Climate

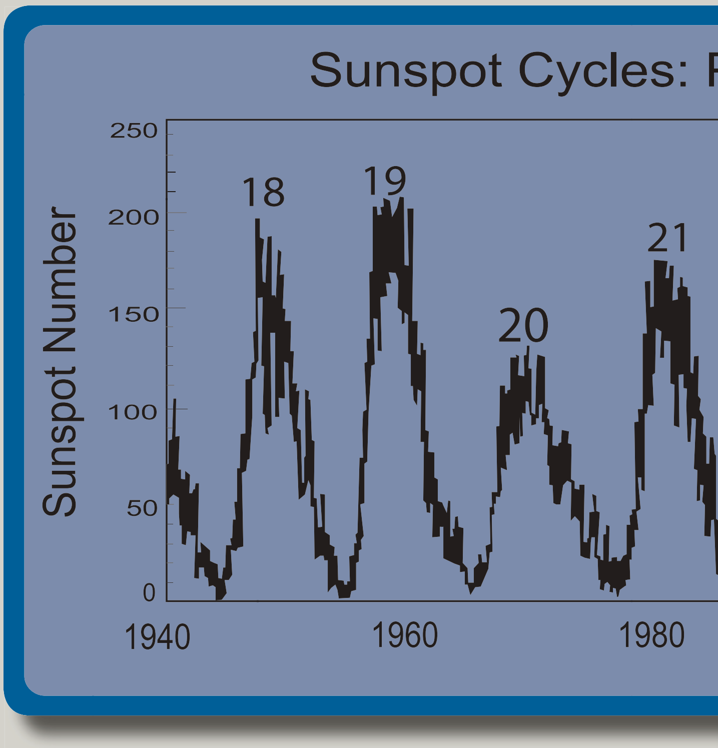
and the Military Decision Making Process in Solar Cycle 24

By CPT Stacy Godshall

1. Introduction

January 2008 was the beginning of a new solar cycle called solar cycle 24. In this new 11 year cycle, as with all solar cycles, the sun will have an increase in magnetic activity until the maximum is reached in about 2012 or 2013, and then decrease until about 2019 when minimum will be reached. This type of dynamic activity in the sun has been visibly manifested for centuries in the number of sunspots on the sun, with the maximum of the cycle corresponding to the maximum of the number of sunspots. The maximum of solar cycle 24 will possibly have a peak 30-50 percent greater than the peak of solar cycle 23 as depicted in Figure 1 [Dikpati, et al, 2006; Phillips and Hathaway, 2006], and thus it will possibly be an intense cycle for geomagnetic storms.

As mentioned, these cycles have been the object of study for scientists for centuries. What has not occurred in centuries past however is the analysis of the solar cycle and its impact on military operations. This is obvious since no military operations have needed to incorporate the solar cycle and its dynamics into planning since it generally had no effect on operations. Times have changed and the military has extensively utilized Space assets in operations for approximately the last twenty years. Thus for two solar cycles, specifically cycles 22 and 23, we have incorporated Space weather into mission analysis. Weather in general has had significant impact on operations since warfare began; either benefiting one force or the other. The following are just a few examples of such operational impacts created by weather conditions. In 1915, German forces use of poison gas and wind blew the chemicals back onto German lines and destroyed four Prussian regiments. In 1944, the D-Day weather forecast was for conditions favorable to air, sea and ground operations together — a rare event. In 1966, U.S. Army material replacement cycle in Vietnam speeded up from eight years to two years due to tropic moisture's degradation of wood, cloth and electronics. In 1990, Desert Storm Diurnal



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winds prevented Iraq from launching ballistic SCUD's during daytime operations; winds apparently blew chemicals in unsuspected directions. Likewise, Space weather has and will increasingly continue to have an impact on operations. Just in the last two solar cycles, there have been solar flares and other solar dynamic activities which have caused impacts on civilian satellite systems including but not limited to the following: GPS signal scintillation caused by geomagnetic storm induced ionospheric density variations, increased satellite drag, anomalous data readings, and satellite charging effects. Therefore, just as in the past when weather has impacted specific weapon use, timing of operations, or outcome of an operation, we will need to be able to analyze the current weather conditions as well as past statistical data which will enable for the pattern of possible future Space weather conditions and thus a Space weather situational awareness. The military decision making process by way of mission, enemy, terrain and weather, troops and support available, time available, civil consideration (specifically terrain and weather) can incorporate analysis from the past two decades of scientific data to formulate a "Space climate" if you will. In FM 3-0, terrestrial and atmospheric climate is described as "… the prevailing pattern of temperature, wind velocity, and precipitation in a specific area measured over a period of years. Climate is a more predictable phenomenon than weather. It is also better suited to operational-level analysis. Planners typically focus analysis on how climate affects large-scale operations over a geographically diverse area." Therefore, Space climate can also be based on the following pattern during solar cycle 24.

As a solar cycle progresses from minimum to maximum, the dynamics of the solar activity change as well. Geomagnetic storms can occur during almost any part of the cycle and originate from solar activity such as solar flares, coronal mass ejections, and Corotating Interactive Regions of solar wind (regions in which fast and slow solar wind mix to create solar wind shock fronts). However, there is extensive data which shows that such activities and subsequent geomagnetic storms occur at certain times more than others just as hurricanes occur in the Atlantic Ocean at certain times of the year. It is the geomagnetic storms which will have an increased place in the weather portion of the military decision making process and mission analysis of the future. This due to the fact that the in this solar cycle and beyond.

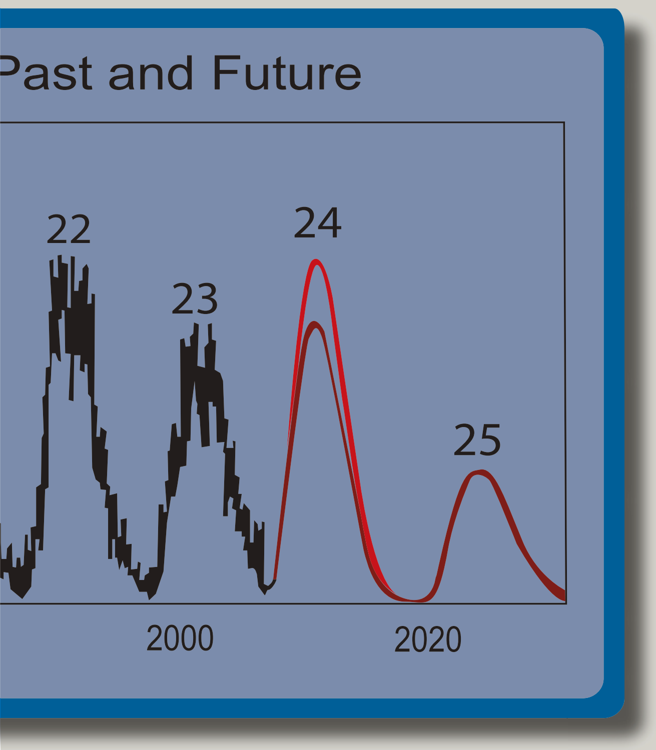

Figure 1: Past sunspot numbers for respective solar cycles and predicted levels for cycles 24 & 25.

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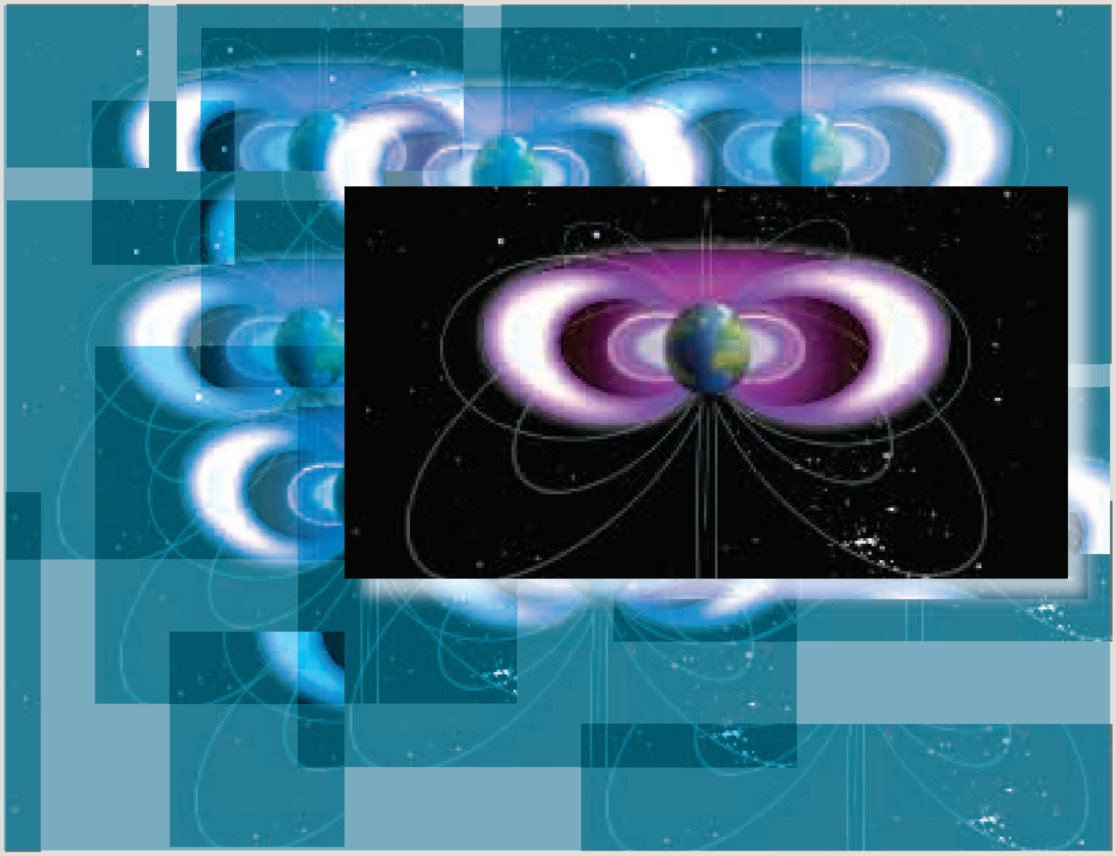
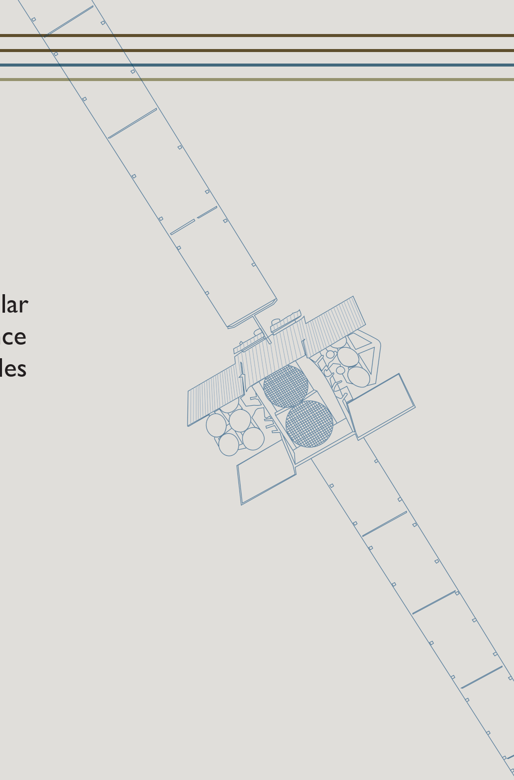


Figure 2: The Van Allen Belts include the inner belt, the outer belt, and the slot region between the two. Inner and outer belts are depicted as a cross section of a donut shape around the Earth.

geomagnetic storms (which are produced by the solar activity effects on the Earth's magnetosphere) produce the above mentioned impacts of signal scintillation, satellite drag, anomalous data readings, and satellite charging effects but also cause variations in the Earth's radiation belts (also known as the Van Allen Belts). The Van Allen Belts are regions in which high energy particles become trapped and therefore maintain high concentrations which can also have negative impacts on satellite systems. There are three main regions known as the inner belt, outer belt, and slot region as depicted in Figure 2 (courtesy of UTSA Physics and J. Goldstein).

There are many satellite systems which reside in orbits which typically are not collocated with the Van Allen Belts and thus are not affected by them. The outer Van Allen Belt however changes locations into the slot region [Thorne et al., 2007] and/or has changes in intensity and concentration levels [Iles et al., 2002] during certain types of storms and thus will at those times affect satellite systems that had been previously unaffected. These types of storms can be grouped into what are called geomagnetic superstorms. There is an index which measures the strength of storms known as the Dst index which has a unit of measure of nano Tesla (a Tesla is a unit of magnetic field strength and nano = 10-9). Any storm with a magnitude of Dst greater than 250 nano Tesla is in the superstorm category [Echer,



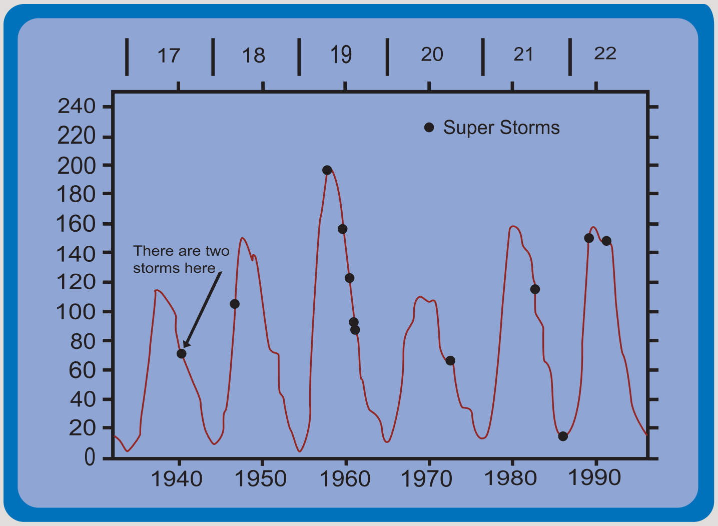


Figure 3: Declining solar cycle phase dependence for superstorm in cycles 17-22.

et al., 2008].

2. Superstorms

There are certain solar events that are the catalyst for geomagnetic storms and are thus the drivers of said storms. There are two types of geomagnetic storms, specifically Corotating Interactive Region driven or Coronal Mass Ejection driven. In a study by a group of physicists lead by Dr. Bell, the number of storms that have this type of strength account for about two percent of all storms and amount to a total of 13 that occurred between 1932 and 1997. In that study, it was determined that superstorms occurred most likely on the declining phase of the cycle from the maximum to the minimum as shown in Figure 3 [Bell et al., 1997]. In addition, that study also determined that superstorms also most likely occur near the equinoxes with most of those occurring near the spring equinox.

Similar statistical data is also available from solar cycle 23 as well. In particular, there were eleven superstorms in total with six of those being in the declining portion of the cycle [Echer et al., 2008].

For most of these storms, it was determined that the solar event combination that caused them was a very fast, full halo (direct line of sight from the sun to the Earth) Coronal Mass Ejection followed by a Coronal Hole Stream [Kataoka & Miyoshi, 2008]. The Coronal Hole Stream is a stream of very fast solar wind. This combination is particularly effective as far as geomagnetic storms are concerned [Kataoka & Miyoshi, 2008].

Figure 4 from [Kataoka & Miyoshi, 2008] shows the Coronal Mass Ejection/Coronal Hole Stream event origination at the sun. The image from Solar and Heliospheric Observatory is a visual manifestation of the combination of the fast halo Coronal mass Ejection followed by the Coronal Hole Stream. This imaging is an early warning of a possible superstorm. However, event combinations which include a Corotating Interactive Region driver are not visibly seen and are even more effective at increasing the intensity of the outer Van Allen Belt [Miyoshi & Kataoka, 2006]. This fact that Corotating Interactive Region driven storms are more dangerous was further clarified by observations of the NASA-Air Force Combined Radiation Release and Effects Satellite, which showed the largest intensity increases were indeed occurring in the declining phase of the solar cycle when Corotating Interactive Regions and Coronal Holes Streams dominate the events

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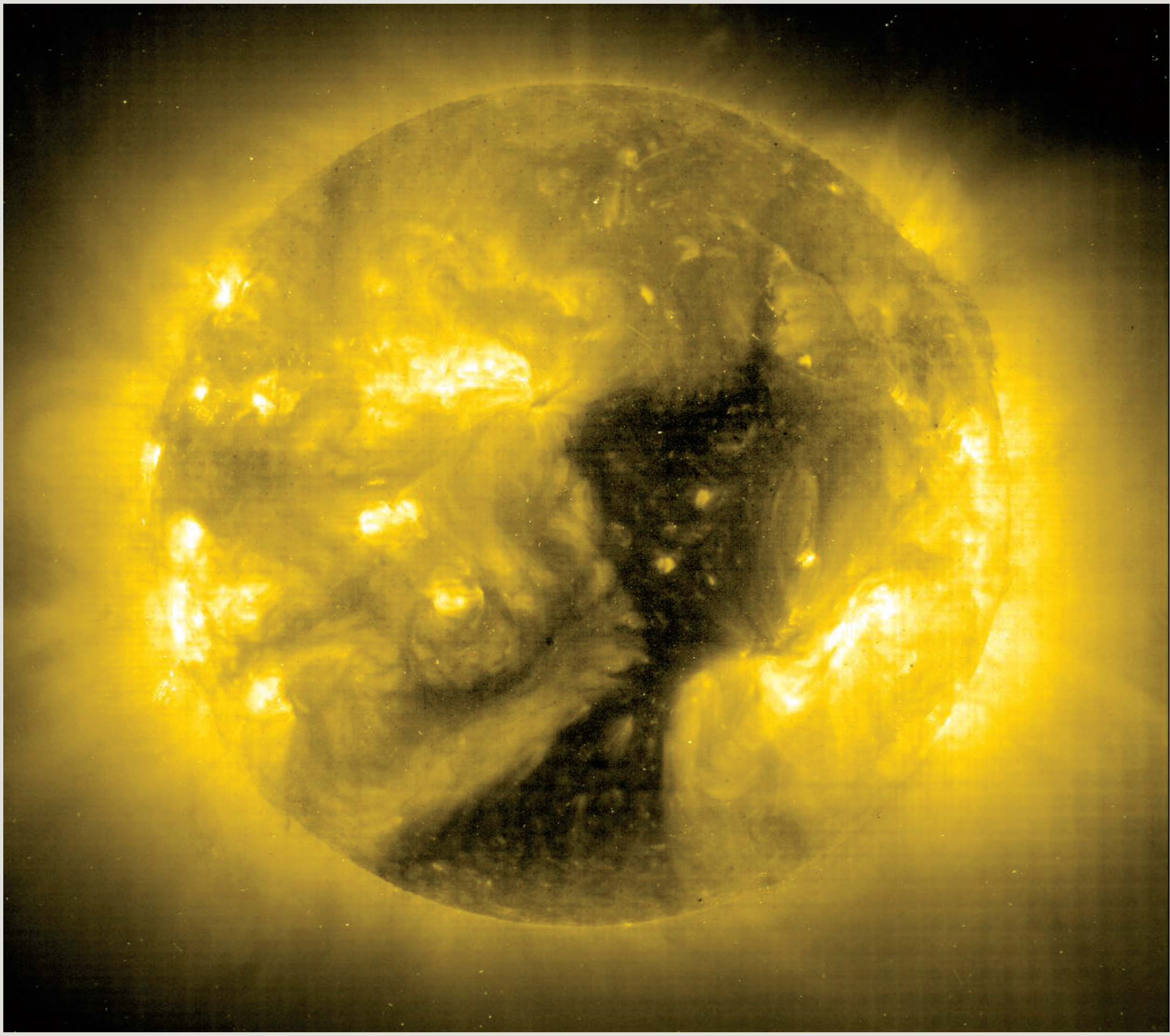

Figure 4: Coronal hole (seen as the dark area in the lower center of the sun) over central meridian in southern hemisphere with western sector Coronal Mass Ejection. The Coronal Mass Ejection is shown as the bright activity on the right hand side of the sun in this image from the Solar and Heliospheric Observatory.

originating from the sun [Hudson et al., 2007].

3. Conclusions and future work

Changes in the equipment we use to accomplish our mission leads to changes in the military decision making process. These changes lead to the need for incorporation of parts of the analysis that once did not need to be incorporated. Solar activity can lead to geomagnetic storms and changes in the outer Van Allen Belt. The varying intensities of the Van Allen Belts are dependent upon the combination of specific solar events which occur at specific times in the solar cycle. With the combination of a Coronal Mass Ejection or a Corotating Interactive Region followed by a Coronal Hole Stream being one of the most dangerous solar events most likely occurring near the spring equinox of the declining phase of the solar cycle, we must be able to incorporate the possibility of these events occurring into the Space climate aspects of the military decision making process. That is to say, that we must be able

Figure 5: (Artist rendition) Combined Radiation Release and Effects Satellite (NASA-USAF mission) measurements of the outer belts clarified superstorm likelihood during declining phase of solar cycle.

to conduct the military decision making process with the knowledge that near the spring equinoxes from 2013 to 2018, superstorms will most likely occur and thus impact whatever missions are being conducted at the time.

Gaining more understanding of the Space climate is essential to understanding how to conduct both satellite operations and human Space exploration and missions. With this as a motivation several initiatives are under way, or will soon be, to gain that understanding. In particular, the United States Air Force is sponsoring two of these initiatives with one being the High Frequency Active Auroral Research Program. This program is designed to emit High Frequency radio waves into the ionosphere which will in turn stimulate small volumes of the ionosphere. The goal of this ionospheric stimulation is to determine if it will reduce the radiation in that given small volume of the ionosphere. The second of the initiatives is the Demonstration and Science Experiments satellite which is due to launch in 2009. These experiments are designed to measure electron energy levels and Very Low Frequency waves to include those from the High Frequency Active Auroral Research Program for effects on radiation. Lastly, Demonstration and Science Experiments will have an instrument that will measure specific aspects of the slot region. In addition to the U.S. Air Force initiatives, NASA will launch the Radiation Belt Storm Probes in early 2012. The probes are designed to measure changes in Van Allen Belts as a result of solar wind and solar event drivers. Lastly, planning has begun on the NASA Solar Sentinels mission which would help scientists learn to predict solar storms in time to warn astronauts. This mission would also be useful in warning terrestrial-based assets of the likelihood of superstorm induced effects on satellite systems. The proposed locations include one Spacecraft of the sentinel cluster to be at the L3 Lagrange Orbital point on the far side of the sun. The Lagrange Orbital points are stable orbits with one currently occupied by the Solar and Heliospheric Observatory and one will be occupied by the James Webb Space Telescope [Godshall, 2003].

With these tools to gather data, an in depth analysis can be made of the Space climate for operations that may take place

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