SPACE-BASED SOLAR MONITORING AND ALERT SATELLITE SYSTEM (SMASS)

Overview

Space operations, both manned and unmanned, are in constant jeopardy of mission degradation or failure due to the impacts of space weather (i.e., variability of the near-Earth and interplanetary space environment). The primary driver of the interplanetary space weather affecting earth is the Sun's varying emission of electromagnetic radiation and solar wind plasma (i.e., an ionized gas consisting of protons, electrons, and other heavy, energetic particles ejected from the Sun's outer atmosphere (corona) at a mean velocity of 400-500 km/sec with a mean density of 5 particles per cubic centimeter).[1] Galactic cosmic radiation contributes only 5-10 percent of the total radiation, and thus, is not a major driver of space weather from the earth's perspective.[2] Near-Earth space weather (i.e., within the Earth-Moon orbital system) is primarily the resultant of the Sun's electromagnetic radiation and plasma interactions with the Earth's intrinsic geomagnetic field. The variability of space weather is closely tied to the 27 day rotation period of the Sun and the Sun's approximate 11-year sunspot cycle. During solar maximum (i.e., time of maximum sunspot activity and associated solar flare eruptions), the magnitude of the variability can become quite large, producing extremely hazardous space environmental conditions (figure 1).

Space weather can impact space operations by inducing spacecraft charging, orbital drag variations, and hazardous ionizing radiation effects on spacecraft and astronauts. For example, the Jupiter Pioneer spacecraft encountered severe space weather in the Jovian radiation belts which nearly destroyed many on-board systems.[3] Closer to home, the geostationary Earth orbiting ATS-6 satellite, launched in 1974, recorded static surface potentials (spacecraft charging) as high as 20,000 volts due to severe space weather.[4] Common satellite anomalies induced by space weather include computer processing errors, loss of satellite contact, satellite shut-down, and loss of satellite orientation due to the radiation and energetic particle import on star navigation sensors. Satellite orbits can rapidly decay due to satellite drag resulting from space weather induced higher atmospheric density. Narrow-beam tracking radars can temporarily lose fixes on the spacecraft due to these unexpected orbital changes. Often times the drag requires orbital adjustment to keep the satellite in a usable orbit.[5]

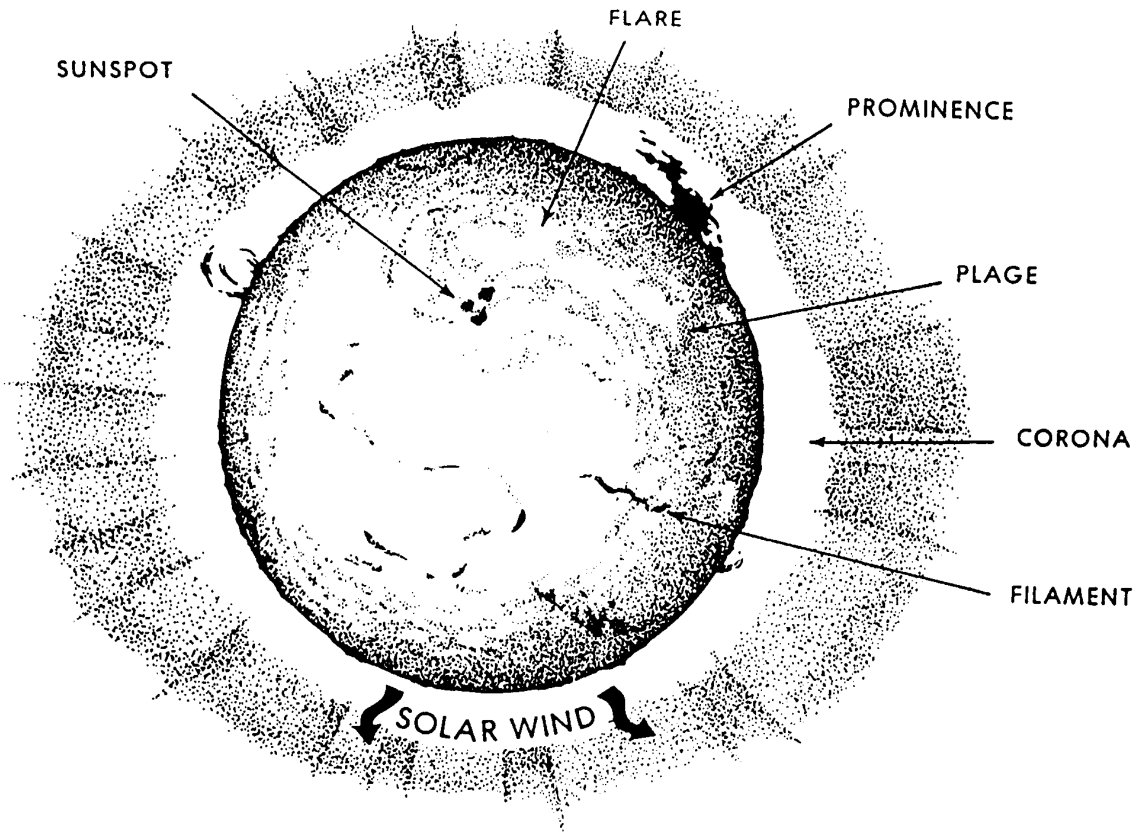

Figure 1. Principal features of the active Sun. The region marked as a flare denotes a highly concentrated, explosive release of energy which appears as a sudden, short-lived brightening of a localized area in the Sun's chromosphere.[6]

The main space weather hazard to human life is the ionizing radiation resulting from exposure to high energy particles. These energetic particles may come from distant stars and galaxies (galactic cosmic radiation); they may be found trapped in planetary radiation belts, such as the Earth's Van Allen radiation belts; or they may be ejected into space by the Sun in the solar wind or more rapidly by solar flare eruptions (figure 2). To put the space weather radiation hazard to human life in perspective, at geostationary orbit, with only 0.1 gm/cm^2 of aluminum shielding thickness, the predicted radiation dose (REM) for one year continuous exposure, with minimum-moderate solar activity, is estimated to be about 3,000,000; using 5.0 gm/cm^2 of aluminum shielding, the REM for one year continuous exposure would be reduced to about 550.[7] (Note: REM = dose

(RAD) x Relative Biological Effectiveness (RBE) of particular ionizing radiation.)[8] Although drastically reduced by shielding, 550 REM for a sample population would cause radiation sickness and about 50 percent deaths.[9] Astronauts protected with only a spacesuit during normal-length extra-vehicular activity at geostationary altitude could receive about 0.43 REM per day under minimum to moderate solar activity conditions, which is sufficient to damage the eyes and other vital organs.[10] Under high solar activity, and most importantly during large solar flare occurrences, daily REM values could be a thousand-fold higher and probably lethal.[11] In comparison, an earth-bound person would have an estimated total yearly radiation dosage in the range of 0.17 to 2.6 REM; the daily dosage would be approximately 4.7×10^{-4} to 7.1×10^{-3} REM (2 to 3 orders of magnitude less than the astronauts daily dosage in our example).[12]

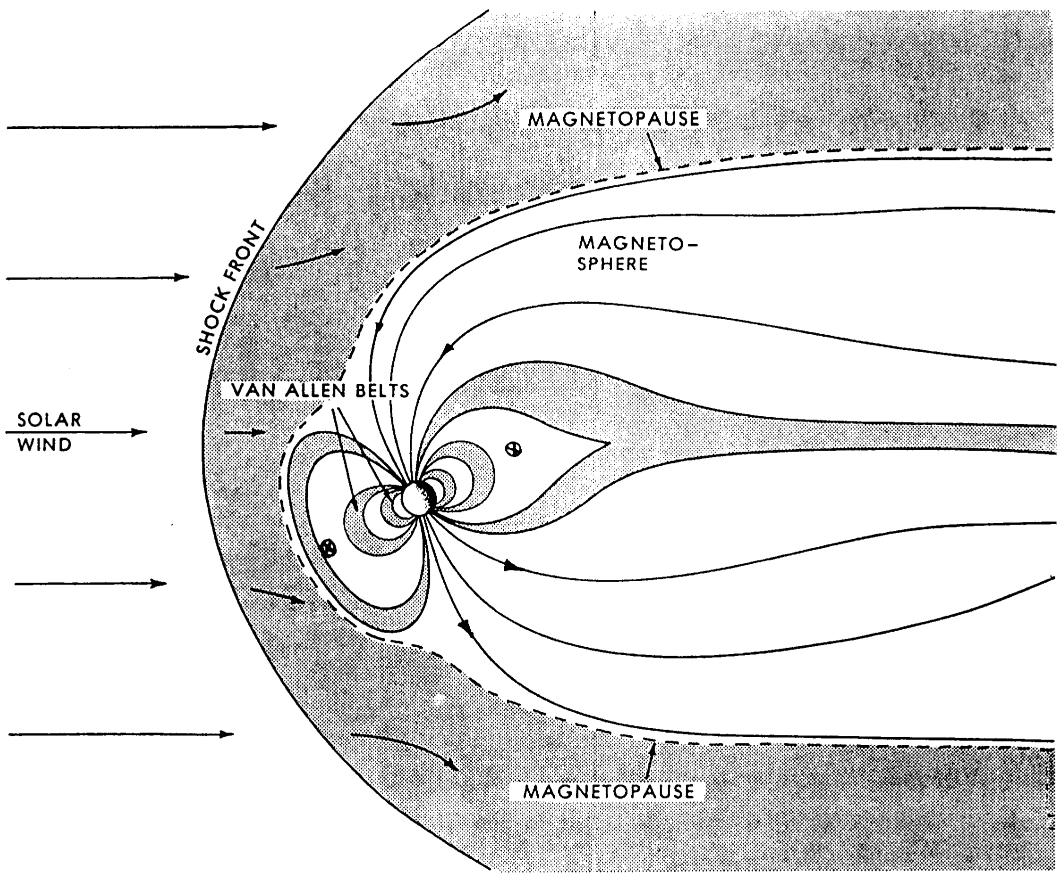

Figure 2. Qualitative picture of the bow shock and magnetospheric boundaries formed by the solar wind interaction with the Earth's intrinsic magnetic field. (Geostationary satellite altitudes are marked by the circled "X").[13]

The USAF Air Weather Service has been providing solar observations and space weather forecasts and hazard alert warnings to support department of defense(DoD) space operators and users since 1962. The support effort is excellent, but the overall capability to provide timely and accurate space weather forecasts is limited. This limitation is caused by: (1) predominately earth-based observational access to the sun; (2) current sophistication of space weather sensor technology and its associated data processing and analysis, and by (3) overall scientific understanding of solar dynamics and interplanetary space physics. For example, influx of solar plasma and electromagnetic radiation into the near-earth space environment can cause the Earth's magnetosphere to go into geomagnetic storming conditions. Geomagnetic storms can severely degrade the radiowave propagation characteristics of the ionosphere, resulting in black-out of communications, radar, and navigation. Current forecast accuracy for predicting geomagnetic storms is in the range of 20 to 40 percent.[14] Forecast accuracy for geomagnetic storm prediction could reach the 80 to 100 percent range with more accurate and timely observations of incoming solar plasma and electromagnetic radiation.[15]

The Need For SMASS

On Earth, accurate and timely weather support provides resource protection and force enhancement for the warfighter; the same holds true in space. If humans expect to effectively and safely operate, and eventually live in the space environment, then significant improvements in space weather support capability are needed. The most beneficial enhancements will involve: (1) continuous observation of the Sun using the entire electromagnetic spectrum; (2) accurate and timely measurement of earth-bound solar electromagnetic radiation and plasma; and (3) rapid processing, analyzing, and disseminating of alerts, warnings, and accurate forecasts of space weather impacts to near-Earth and interplanetary space operations.[16] To achieve the capability enhancements just described, this paper proposes the development and operational employment of a space-based, solar monitoring and alert satellite system (SMASS) to be developed and operated jointly by DoD, National Aeronautics and Space Administration (NASA), and National Oceanic and Atmospheric Administration (NOAA). Other nations may also desire to participate in the SMASS program.[17]

The proposed SMASS will consist of one, potentially up to three satellites, placed in a deep space Earth-orbit ahead of the Earth's magnetosphere bow shock, possibly near the Earth-Sun libration point in a halo orbit (L1, about 220 earth radii out toward the sun (Figure 3)).[18] Direct and continuous optical observation of the Sun as well as continuous measurement of the Sun's emitted electromagnetic radiation and solar wind plasma will be made possible by the proposed satellite system. Some key functions and data collection by the satellite system will include the following: (1) multispectral electro-optical images of the Sun; (2) on-board sunspot mapping and analysis; (3) on-board solar interplanetary magnetic field mapping; and (4) solar flare monitoring and alert capability. The solar flare alert function will include an immediate alert notification communications system, the capability to determine the solar flare's location on the solar disk, and the capability to measure the magnitude of the solar mass and electromagnetic radiation

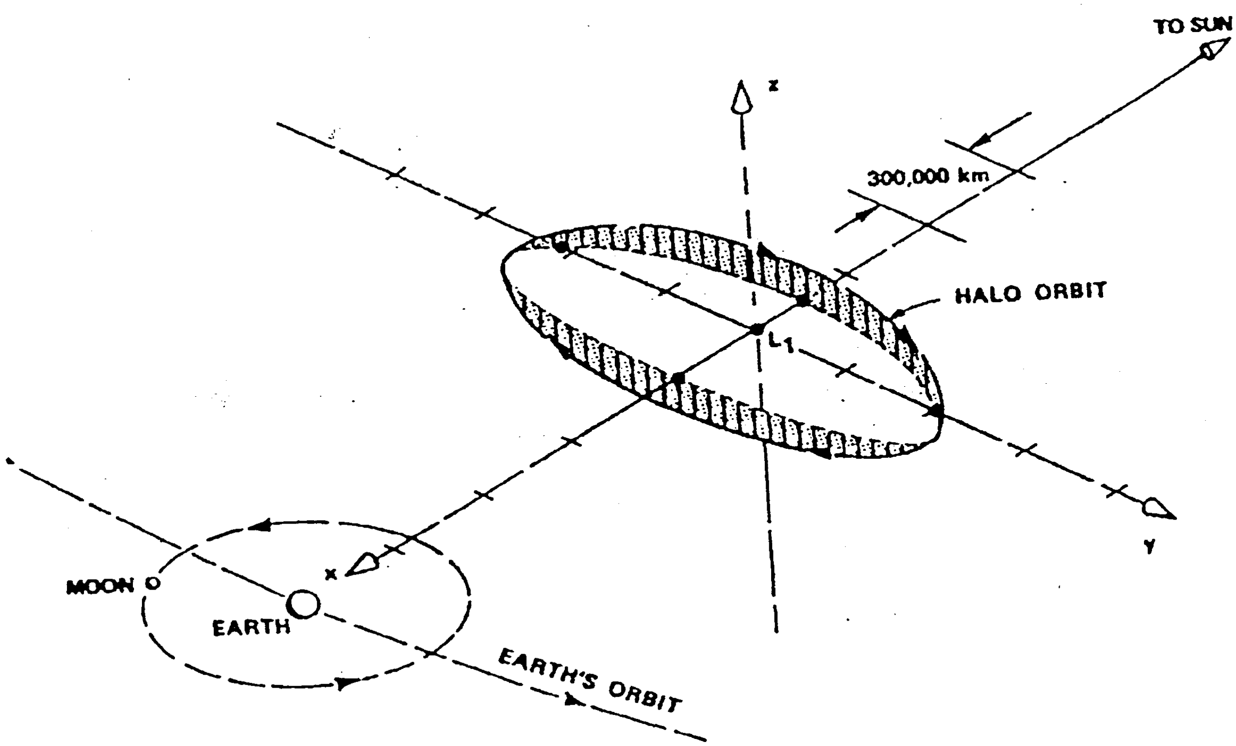

Figure 3. Diagram of a halo orbit around the L1 libration point, located approximately 220 earth radii out toward the Sun.[19]

ejection occurring with the solar flare. Other key functions and data collections by the satellite system will include: (1) plasma particle measurements; (2) direct measurement of the Sun's electromagnetic energy emitted towards Earth to include a direct measurement of the full disk flux in the extreme ultraviolet (EUV) range; and (3) direct broadcast communications capability as well as dedicated transmission links with space operation centers on Earth and in space.[20]

The proposed SMASS can provide a warning lead time of up to three days for solar plasma ejections that will bombard the Earth or spacecraft and stations operating in space.[21] As stated earlier, these solar plasma ejections can be lethal to manned space operations; magnitude of impact is dependent on the operating orbit, the interplanetary space travel and site location, and the physical protection available to the operators in space. The opposite is true for solar electromagnetic radiation traveling at the speed of light. When we see a solar flare, we are already sensing the increased levels of electromagnetic radiation, but more than likely we have not yet measured increased energetic particle-levels. Therefore, forecast lead time for solar electromagnetic radiation, at least from the Earth's perspective, can not be obtained by direct observation. However, increased knowledge of solar dynamics, gained through direct continuous observation of the Sun, can improve solar forecasting to the point that solar electromagnetic radiation bursts of various wavelengths could be predicted prior to occurrence with some useful lead time.

The Capability and Its Relevance

The payload of the SMASS is envisioned to consist of a multispectral optical telescope continuously monitor the Sun's photosphere, chromosphere, and corona. The following physical processes, as a minimum, will be observed and analyzed by on-board processing: (1) explosive solar flare occurrences; (2) mass ejections into the solar wind caused by low observable solar flares, often optically undetected but indicated by rapid changes in key solar disk features, such as disappearing filaments (i.e., large, rope-like areas of condensed gas suspended in the solar atmosphere) and the on-set of active prominences (i.e., another name for filaments seen on the limb of the Sun which have become active areas of solar plasma ejection into the corona, seen as surges, sprays, and loops); (3) sunspot activity and associated magnetic structure; and (4) coronal hole locations from which the solar wind plasma is spirally ejected outward into space along interplanetary magnetic field lines.[22] A bank of sensors will be on-board to measure the energy content of the solar radiation emitted throughout the electromagnetic spectrum. Besides visible wavelengths (optical), the solar radiation measured will predominately include x-rays, infrared, near ultraviolet, extreme ultraviolet and radiowaves. Plasma energetic particle counters will also be part of the payload to determine the magnitude of the solar mass being ejected towards earth (figures 4 and 5).[23]

Measurement of EUV radiation is critical to near-earth space weather forecasts since it is this form of short-wave radiation that photoionizes atomic oxygen above 100 km in the Earth's upper atmosphere, producing charged particles called ions, and, thus, the atmospheric region known as the ionosphere.[24] The energy released by the ionization process produces the temperatures of the thermosphere. Essentially, this flux drives the ionospheric and thermospheric conditions that either allows or disrupts radiowave propagation; it also affects atmospheric density, and thus, satellite drag. EUV radiation cannot be measured directly from Earth; its energy is mostly released in the upper atmosphere. The remaining lower EUV wavelengths, not absorbed by the upper atmosphere, are absorbed by the Earth's ozone layer--a fortunate occurrence, since EUV radiation is lethal to man and many other life forms. Currently, EUV flux estimate is only inferred from a known, but not perfect, correlation with the 2800 MHz solar radio flux (F10.7 cm flux).[25] Thermospheric and ionospheric forecast models will significantly increase in space weather accuracy if direct measurements of EUV are available.[26]

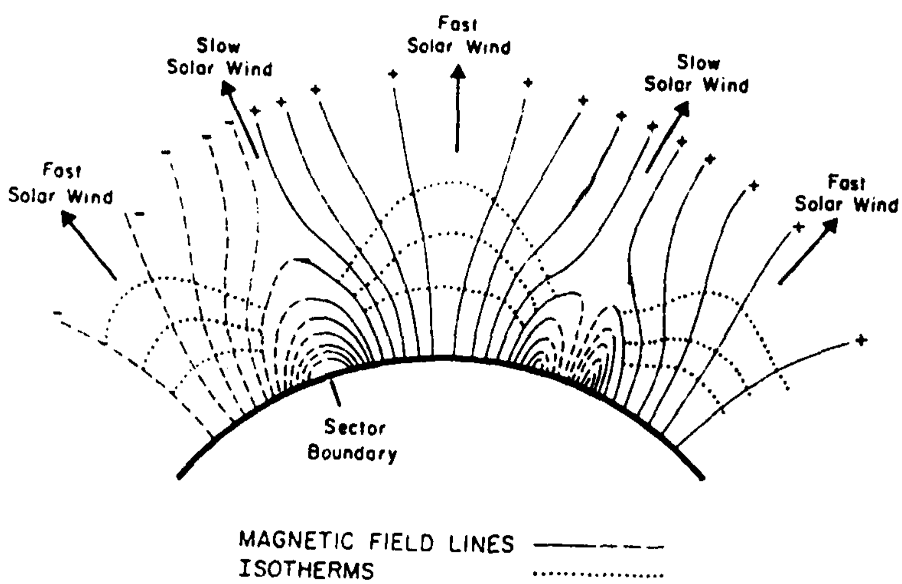

Figure 4. A qualitative sketch of the theoretical coronal structure responsible for high-speed solar wind plasma streams. Magnetic field lines extending outward from the Sun

indicate areas where plasma can flow outward into interplanetary space. Out-flowing regions are called coronal holes.[27]

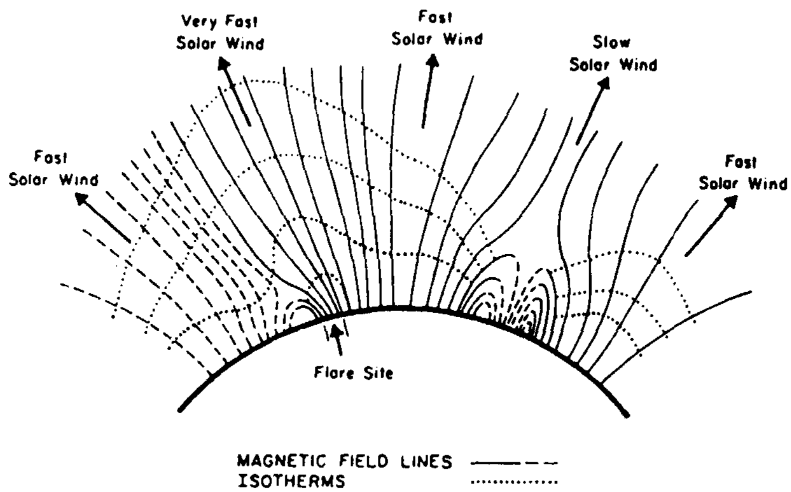

Figure 5. A qualitative sketch of the temporary modification of the coronal structure shown in figure 4 due to flare activity. Diagram assumes the flare was sufficiently energetic to overcome magnetic forces and open a region of the previously closed field lines.[28]

SMASS will have on-board data processing capability, as a minimum, equivalent in capability to the current Cray-system and incorporating the most current computer hardware and software technology available. It is envisioned that the on-board computer can analyze the optical images for critical solar features, and through the use of artificial intelligence schemes, provide high probability forecasts of solar flare eruptions, to include timing and solar disk location, and of coronal hole emission areas for the solar wind. Multispectral, electro-optically-digitized pictures of the Sun as well as on-board analysis products could be transmitted back to a command center, either on Earth or in space, for operational use or further analysis. The radiation and plasma information will be analyzed on-board for alert warning thresholds. Immediate warnings for hazardous increases in flux levels of electromagnetic radiation and plasma as well as associated raw data will be directly broadcasted into space and sent back via direct link to an Earth or space-based operations command center. With the on-board capability to monitor coronal holes, to measure the solar interplanetary magnetic field, and to determine probable areas and timing of solar flares, on-board computer models can generate forecasts (potentially extending out to 72 hours) of solar plasma wind conditions and radiation flux affecting near-Earth space environment and interplanetary space. Forecasts will be directly broadcasted as well as sent back through direct transmission to an operations center on Earth or in space. The operations center will have the flexibility to task the satellite to transmit various combinations of data packages back to the center. Analysis and forecast capability will exist as a redundant capability at the operations center in case of satellite problems.[29]

The proposed satellite configuration and orbital location was chosen to provide optimum, continuous support to interplanetary space operations as well as near-Earth space environment. As described, the envisioned satellite system will serve as a direct broadcast beacon for space weather data, advisories, and forecasts. Space weather information will be available to all those in-range of the beacon and who have the capability to access the transmission. The concept is analogous to the key aspects of our nation's severe weather warning system--severe weather detection through the use of the doppler weather radar and area broadcast warning through the use of the National Weather Service's Severe Weather Alert Radio Network. Putting the satellite system in geostationary or low earth orbit would require more satellites to provide continuous coverage of the Sun and will deny the total measurement of the radiation and plasma interacting with the Earth's magnetosphere and ionosphere. Interplanetary space travel will experience degraded warning service due to lack of critical data and restriction in direct beacon access caused by the near-Earth space orbital configurations. Furthermore, solar imaging telescopes in low Earth and geostationary orbits will have to overcome more severe background brightness problems due to the Earth's albedo (reflectance) and aurora than they will in a deep space Earth orbit.[30]

Fielding the proposed satellite system will eventually provide monetary benefit by negating the need for the Earth-based network of solar observatory monitoring and alert facilities currently existing; it will also provide space weather alert protection (as stated earlier, a potential lead time of up to three days for solar plasma bombardment) for space station occupants, interplanetary and near-earth space users and operators. Humans in space will use the warnings to take protective shelter. Special temporary shielding may be employed on the spacecraft or satellite to minimize impact of energetic particles. In the twenty-first century, magnetic force field generation might be possible to protect spacecraft by directing the plasma bombardment away from the spacecraft along outwardly radiating magnetic field lines. Increased space weather warning lead-time can provide space operators and users an opportunity to do alternative communication contingency planning, such as changing raypaths, reverting to different systems less affected, or selectively shutting down systems to avoid electronic damage.

Potential Technologies

Several technologies will need to be developed or upgraded. For example, the development of a satellite-based, multispectral sensor package to monitor the entire solar electromagnetic spectrum will be required. New communications, computer hardware, and software architectures will be needed to: (1) process the data; (2) analyze the data; (3) identify and provide direct broadcast notification of hazardous conditions; and (4) develop and provide forecasts of solar flare occurrences and solar wind plasma conditions. Satellite system protective devices must provide substantial hardening for the satellite so it can withstand the effects of the tremendous electromagnetic radiation and solar plasma bombardment the satellite is trying to measure and analyze. Other additional technological hurdles to overcome will include the: (1) development of a small, high resolution optical telescope suitable for satellite use with the capability of sending electro-optical, digitized pictures of the Sun's atmosphere back to a command center (current solar telescopes are large--tens of feet long); (2) development of a satellite-based, accurate model or artificial intelligence scheme to predict the timing and location of solar flare occurrences; and (3) development of an on-board capability to optically analyze the solar photosphere, chromosphere, and corona for structural features to be used in solar flare and solar wind prediction models.

The envisioned SMASS can be achieved through a phased period of development and employment.[31] During the first phase, the basic satellite data collection system, consisting of a multispectral optical telescope, electromagnetic sensors, and solar wind plasma monitors, will be developed and launched into a deep space orbit. The data collected will be transmitted, without any on-board analysis, back to an Earth-based operations center, such as the current Air Force Space Forecast Center, Falcon AFB, Colorado. Space weather forecasts and advisories will be sent to support space operators and users from the Earth-based operations center. Phase Two of the satellite system evolution will concentrate on the development of the on-board analysis and forecast model capabilities. Development of solar flare and solar wind forecast models as well as schemes to analyze solar atmospheric features (sunspots, flares, plages, disappearing filaments, coronal holes, etc.) are envisioned to use artificial intelligence schemes coupled with solar physics. These models and schemes will require substantial development effort and experimentation using the data acquired from Phase One of the program to ensure a useful level of accuracy can be obtained. Computer miniaturization and increased speed and capacity will be key assets in hardware development to support the on-board analysis and forecast capability. Phase Three of the program will be the launch of the entire SMASS, as envisioned.

The three phased development proposal generally follows the basic information operations architecture phasing outlined in the SPACECAST 2020 White Paper, "Global View." [32] Key similarities include: (1) the development of the capability to collect data and build data bases on earth (Phase I); and (2) the development of the capability to collect and process data on-board the satellite for direct product generation and transmission to the space operators (Phase III). The Phase II development portion of the SMASS differs from the referenced white paper in that it concentrates on using the collected data to develop more accurate solar dynamic models and forecast algorithms for on-board processing envisioned in Phase III. Realistically, the launch of the Phase I data collection solar monitoring system will probably not occur until the Phase II timing of the Global architecture (2001-2010). The actual launch of the envisioned system corresponds to the proposed Phase III (2011-2020 and beyond).

Near Term Technologies and Operational Exploitation Opportunities

Currently, solar observations are obtained from a network of Earth-based, solar observatory monitoring and alert facilities. The United States Air Force maintains a worldwide alert network of five solar optical observatories and four solar radio telescope observatories to provide continuous monitoring of the Sun for solar flare occurrences. Solar monitoring information is also obtained from several civilian observatories around the world. Solar observations coupled with other key data, such as measurements of the Earth's magnetic field or vertical electron density soundings of the Earth's ionosphere, are fed into the Air Force Space Forecast Center at Falcon AFB, Colorado, for analysis and issuance of space weather advisories and forecasts to military space operators and users. The same information is also sent to the Joint (NOAA) and Air Force Space Environment Services Center (SESC) in Boulder, Colorado. This civilian organization provides similar space weather support to users whose operations depend on knowledge of geophysical conditions near the Earth. These users will include DoD, NASA, and operators of powerline, pipeline, and high frequency communication networks affected by magnetic field disturbances.[33]

Earth-based solar observatories experience decreased observational effectiveness due to cloud cover and to atmospheric attenuation and absorption of the electromagnetic radiation limiting the spectral monitoring capability to two primary optical spectral lines (Hydrogen-alpha and K-line of ionized Calcium) and a few solar radio wave frequencies. The solar observatory effectiveness is also degraded by local radio wave interference, by the observatory's geographic location (especially latitude), and by international politics. For example, the Air Force's Mideast Solar Observatory, now located at San Vito AS, Italy, has a tumultuous history due to international politics. When located in Tehran, Iran, during the fall of the Shah, the solar observatory was taken over by Revolutionary Guards and the commander thrown into prison for a week.[34] Before capture, the commander was able to hide the Hydrogen-alpha filter, thus disabling the optical telescope, and to smuggle the filter out of the country upon his release.[35] The solar observatory was later reestablished in Athens, Greece, but terrorist threats frequently closed the observatory. The current location of the Mideast Solar Observatory has been operational since 1986.[36]

Current space-based solar observational capability is limited to a few geostationary satellites, such as the United States' Geostationary Operational Environmental Satellite (GOES), carrying sensors to monitor x-ray emissions generated by solar flares, charged particle flux, and the magnetic field surrounding the spacecraft.[37] The Advanced TIROS-N (ATN) satellites, which are NOAA's polar-orbiting weather satellites, carry the Space Environment Monitor (SEM) used to measure energetic particles, protons, electrons, and alpha particles in the satellite orbit; direct solar observations, however, are not made.[38] Similarly, the DoD's Defense Meteorological Satellite Program (DMSP) carries a set of sensors to monitor the space weather conditions in the Earth's ionosphere along the satellite's orbit. Items monitored include: (1) plasma parameters; (2) precipitating electrons and ions causing auroral displays; and (3) location, intensity, and spectrum of x-rays being emitted by the Earth's atmosphere. As with the ATN satellites, direct solar observations are not made.[39] A few solar monitoring satellites have been launched in the past, such as NASA's Orbiting Solar Observatories (OSO) in the 1960s and early 1970s, but they were limited in their mission duration and in their electromagnetic spectrum capability, and were designed for scientific exploration and not continuous, operational, solar radiation hazardous alert monitoring.[40]

Promising solar imaging technologies for use on the envisioned solar monitoring and alert satellite system are under development. For example, the Phillips Laboratory Space Physics Division Solar Research Branch, located at Sacramento Peak Solar Observatory in Sunspot, New Mexico, is developing a new sensor package, called the Solar Mass Ejection Imager, that could image the plasma ejection from the Sun, trace it through interplanetary space, and provide accurate forecast of arrival at Earth.[41] The Geophysics Directorate of Phillips Laboratory, located at Hanscom AFB, Massachusetts, is developing a sensor, known as the Autocalibrating Extreme Ultraviolet Spectrometers (ACES PL-202), to measure solar EUV from a near-Earth orbiting satellite to an accuracy of 5 percent.[42] Another promising technology, known as the Solar Disk Sextant (SDS), is being developed through NASA and Yale University with the support of Air Force Office of Scientific Research funding. This technology measures the size and shape of the solar disk oblateness to produce accurate measurements of the solar radius. This information when correlated with other solar dynamic processes could significantly improve solar dynamic models and resulting forecasts of solar activity.[43]

Countermeasure requirements for the proposed space-based, solar monitoring and alert system are expected to be negligible, especially if the satellite system is located in a deep space Earth orbit. However, if they do occur, they will include jamming, input of deceptive information, or satellite destruction**.** This concept is not viewed as a threat that will currently warrant enemy military action. Once the human population has a large permanent residence in the near-Earth space environment, military action could occur, but it is viewed as being unlikely. World-wide agreements are already in-place and have been for years, through the United Nations, to share environmental data. Present day collection of solar data by the civilian and military-owned observatories are routinely made available for world community use. During times of war, data collected by the proposed satellite system can be encrypted or transmitted through secure transmission channels instead of by direct broadcast; this capability will, however, add additional cost to the satellite system.

Space weather is important to all space users. As we exploit space and establish a continuous human presence in space, the importance of knowing the space weather will be critical to human and hardware survival; this cannot be over-emphasized. Incoming plasma particles ejected into interplanetary space by a solar flare, the most hazardous space weather for mankind, can be as dangerous to one's health and property in outer space as tornadoes are in the midwest United States. As stated earlier, warning lead-time can be achieved for this type of space weather since it can take up to three days for some of the heavier energetic particles to reach the near-Earth space environment. Solar electromagnetic radiation, however, will be essentially sensed at the same time it affects the near-earth space environment since it travels at the speed of light. The tremendous solar data collection capability of the space-based solar monitoring and alert system will substantially increase the space weather support capability far into the twenty-first century.

Notes

[1]Thomas F. Tascione, *Introduction to the Space Environment* (Department of Physics, USAF Academy, CO, 1984), 54.
[2]Ibid., 241.
[3]Ibid., 232.
[4]Ibid.
[5]Ibid., 237-238.
[6]Ibid., 39.
[7]Ibid., 246.
[8]Ibid., 244.
[9]J. B. Cladis, G. T. Davidson, and L. L. Newkirk, *The Trapped Radiation Handbook* (Defense Nuclear Agency, General Electric Company, Santa Barbara, CA, 1977), table reprinted by Thomas F. Tascione, *Introduction to the Space Environment* (Department of Physics, USAF Academy, CO, 1984), 247.
[10]Thomas F. Tascione, *Introduction to the Space Environment* (Department of Physics, USAF Academy, CO, 1984), 246.
[11]Ibid., 242.
[12]Ibid., 244.
[13]Ibid., 113. Taken from L. Berman and J. C. Evans, *Exploring the Cosmos (2nd ed)* (Little, Brown and Co., Boston, MA, 1977).
[14]Richard C. Altrock, astrophysicist, Phillips Laboratory/GPSS, to Lt Col Tamzy J. House, letter, subject: White Paper on Space-Based Solar Monitoring and Alert System (Comments), 10 Mar 94.
[15]Ibid.
[16]Lt Col Tamzy J. House, Technology Concept Paper C116U.
[17]Ibid.
[18]Lt Col T. S. Kelso, AFIT, to Lt Col T. J. House, author, facsimile, subject: L1 Libation Point. Information taken from graphic illustration printed in the *Interavia Space Directory 1991-92*.
[19]Graphic from the *Interavia Space Directory 1991-92* (Provided by Lt Col T.S. Kelso, AFIT).
[20]Lt Col Tamzy J. House, Technology Concept Paper C116U.
[21]B. V. Jackson, R. Gold, and R. C. Altrock, "The Solar Mass Ejection Imager," *Advanced Space Research*, Vol. 11, No. 1, 1991), (1)377-(1)381.
[22]Lt Col Tamzy J. House, Technology Concept Paper C116U.
[23]Ibid.
[24]Thomas F. Tascione, *Introduction to the Space Environment* (Department of Physics, USAF Academy, CO, 1984), 143-146.
[25]Ibid., 146.

[26]Robert E. Huffman, "The New Ultraviolet: Global Space Weather Systems," *Ultraviolet Technology IV,* SPIE-The International Society for Optical Engineering, Vol. 1764, 1992, 154.
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[28]Ibid.
[29]Lt Col Tamzy J. House Technology Concept Paper C116U.
[30]B. V. Jackson, R. Gold, and R. C. Altrock, "The Solar Mass Ejection Imager," *Advanced Space Research*, Vol. 11, No. 1, 1991, (1)377-(1)381.
[31]Col John Warden, ACSC/CC, discussion with Lt Col House during Executive Board review, 15 Mar 1994.
[32]SPACECAST 2020 White Paper, "Global View" (U), May 1994. (TS-SCI) Information extracted is unclassified.
[33]P. Krishna Rao, Susan J. Homes, Ralph K. Anderson, Jay S. Winston, and Paul E. Lehr, editors, *Weather Satellites: Systems, Data, and Environmental Applications* (American Meteorological Society, Boston, 1990), 149.
[34]Lt Col George Davenport, Commander of Mideast Solar Observatory during fall of the Shah in Iran, personal conversation with Lt Col House, future Mideast Solar Observatory commander, San Vito AS, IT, Fall 1985.
[35]Ibid.
[36]Lt Col Tamzy J. House, personal knowledge based on 18 years experience as a USAF Weather Officer, to include providing operational support to space systems while commanding San Vito Solar Observatory, San Vito AS, Italy, 1986-1988.
[37]P. Krishna Rao, Susan J. Homes, Ralph K. Anderson, Jay S. Winston, and Paul E. Lehr, editors, *Weather Satellites: Systems, Data, and Environmental Applications* (American Meteorological Society, Boston, 1990), 130.
[38]Ibid., 118.
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[42]Robert E. Huffman, Phillips Laboratory/GPIM, briefing presented to Air Force Space Experiments Review Board, 23-24 Feb 1994, hard copy, "Autocalibrating Extreme Ultraviolet Spectrometers (ACES PL-202): Geophysics for Military Applications."
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