SPACE WEATHER SUPPORT FOR COMMUNICATIONS

Overview

Ionospheric variability (space weather) significantly impacts ground and space-based communications. In essence, the electrically charged particles of the ionosphere (i.e., the partially ionized portion of the atmosphere starting at about 40 nautical miles (nm) above the Earth's surface) can attenuate, totally absorb, reflect, change direction of propagation, and change the phase and amplitude of radio waves. The magnitude of the impact is dependent on ionospheric space weather conditions resulting from: (1) the variability of the solar radiation entering the upper atmosphere (primarily extreme ultraviolet (EUV)); (2) the solar plasma entering the Earth's magnetic field; (3) the gravitational atmospheric tides produced by the Sun and the Moon; and (4) the vertical swelling of the atmosphere due to the daytime heating of the Sun.

Space weather in the ionosphere becomes more intense and hazardous during solar flare activity. Sudden ionospheric disturbances (SID), ionospheric storms, polar-cap absorption (PCA), and geomagnetically induced storms are forms of space weather resulting from solar flare activity. During these conditions, enhanced levels of energetic particles and EUV enter the ionosphere, increasing atmospheric neutral and electron density through particle injection and photoionization. Depending on the intensity of the variability induced, the resulting space weather could significantly impact radiowave propagation, causing intermittent or a complete blackout of communications, radar, and navigation, primarily in the polar regions and high-to-middle latitudes.

Ionospheric space weather can also be induced by the tilt of the earth's geomagnetic field. This tilt produces anomalous regions in the South Atlantic and over Southeast Asia where energetic particle interactions are occurring with neutral particles at a much lower altitude resulting in increased radio propagation effects.

Ionospheric scintillation, another form of space weather, can cause fluctuations in the phase and amplitude of radio wave propagation. This space weather phenomena causes outages on satellite-to-ground or satellite-to-aircraft transmissions over the frequency range of VHF to L-band, especially in the equatorial belt (+/- 20 degrees latitude). Fleet Satellite Communications (FLTSATCOM), Air Force Satellite Communications (AFSATCOM), and Navstar Global Positioning System (GPS) are especially vulnerable to this form of space weather (figure 1).

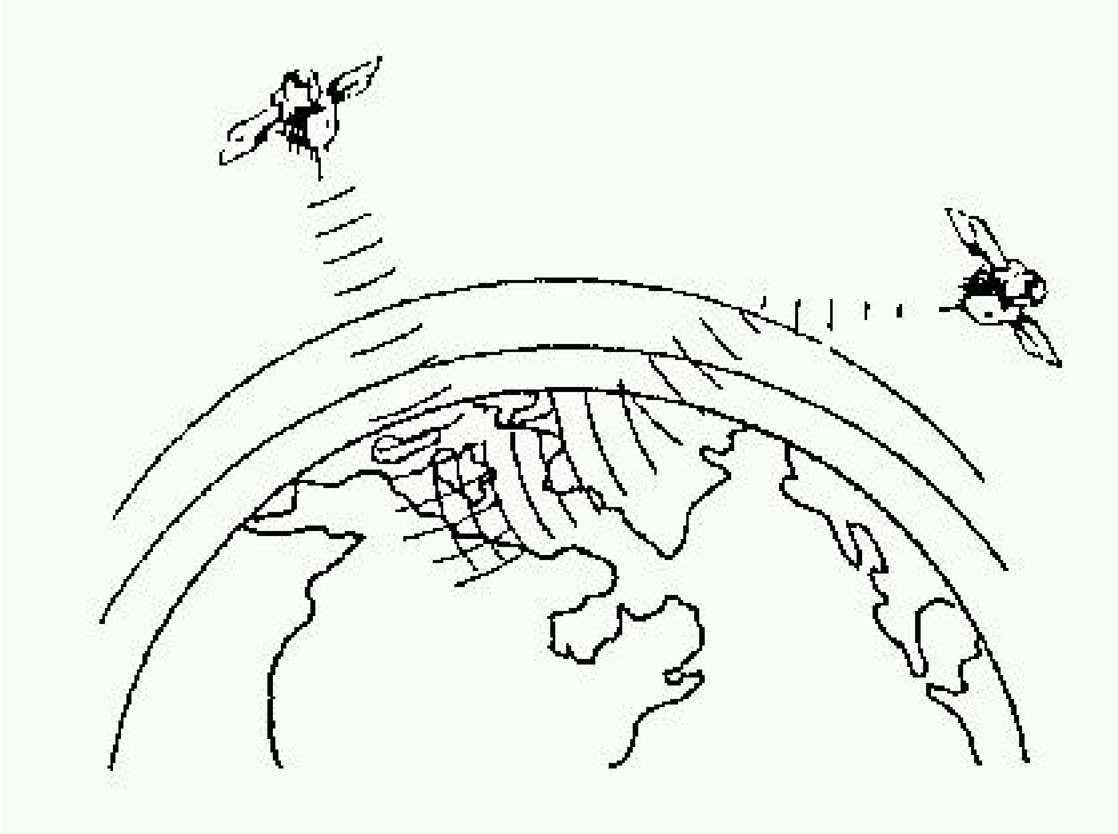

Figure 1. Depiction of ionospheric scintillation affect on GPS satellite transmissions.

Our current capability to provide ionospheric space weather observations, accurate forecasts of space weather conditions, and timely hazard alert warnings is limited. Key factors causing the limitation are: (1) current ionospheric sensing capability; (2) density and frequency of ionospheric observations; (3) sophistication and accuracy of ionospheric models; and (4) current scientific understanding of the physics of the ionosphere-thermosphere-magnetosphere coupling mechanisms. To improve our ionospheric space weather support capability, especially to tactical and satellite communications, our ability to frequently measure the ionosphere vertically and spatially must be significantly enhanced.

The Need For Ionospheric Mapping

To achieve this enhancement, daily, consistent in time and space, worldwide ionospheric mapping capability is required. This capability can be obtained through the following architecture: (1) installation of ionospheric sounders and other ionospheric sensing devices on department of defense (DoD) global satellite constellations, such as the GPS (altitude of 11,000 nm) (figure 2), and on global commercial constellations (such as the future IRIDIUM system being developed commercially by Motorola) and others in planning or development; (2) installation of ionospheric sounders and sensors on dedicated or host satellites flying in lower circular, equatorial orbits (critical for equatorial scintillation identification and forecasts) between 20 degrees latitude north and south at an altitude of about 400 nm; (3) continued installation of ionospheric sounders and sensors on polar orbiting satellites such as the Defense Meteorological Satellite Program (DMSP); and (4) expansion of ground based ionospheric vertical sounder networks (United States' and other nations'). The data collected from the satellite-based sounders will be down-linked to an operational center, such as the Air Force Space Forecast Center, Falcon AFB, Colorado, for processing and coupling with ground-based ionospheric sounding data to develop a daily, global, vertical electron density profile structure for the entire ionosphere. The other ionospheric sensors in the proposed package will collect additional ionospheric data to include: (1) ultraviolet images of auroral zone and airglow spectra; (2) *insitu* particle counts; (3) kinetic temperature measurements of ions and electrons; and (4) measurements of plasma irregularities. This proposed data collection and distribution architecture parallels the ideas presented in the SPACECAST 2020 White Paper, "Global View." (U), June 1994.

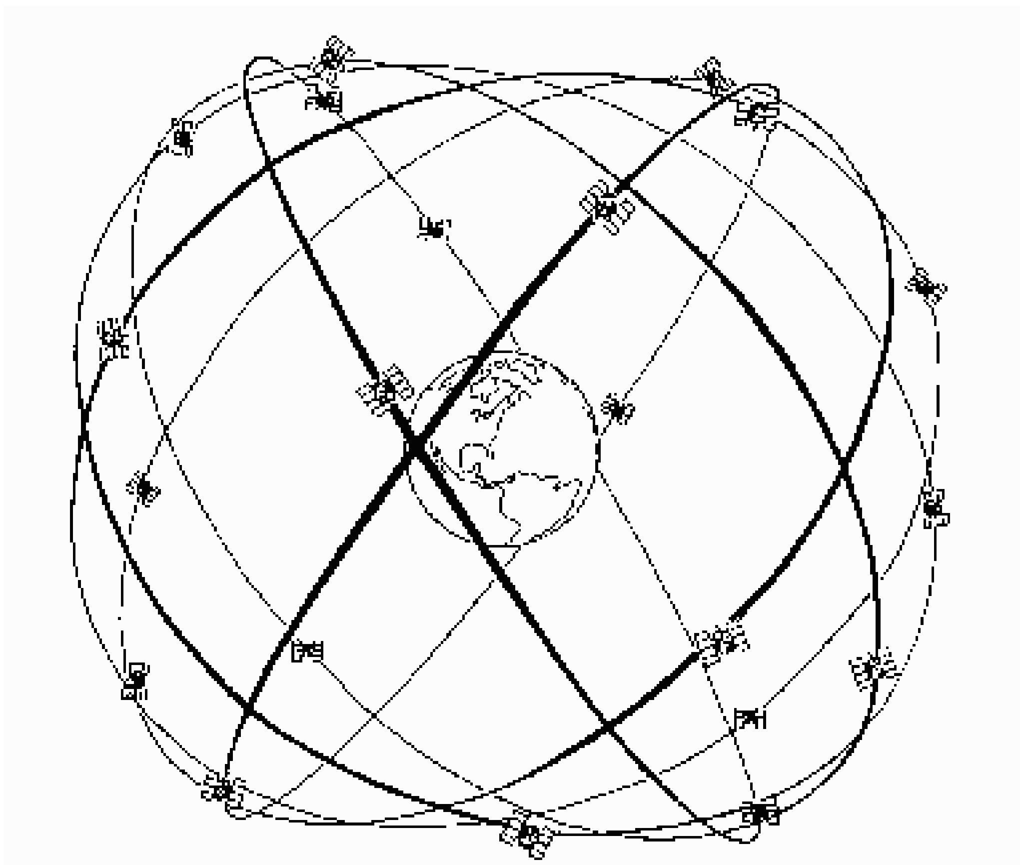

Figure 2. NAVSTAR Global Positioning System constellation.

The frequently replenished ionospheric data obtained from the worldwide mapping capability will significantly improve the timeliness and accuracy of: (1) space weather alerts and warnings; (2) radio frequency propagation forecasts; (3) radio direction finding activities (potentially by an order of magnitude); (4) order of battle assessments; and (5) forecasts for ionospheric scintillation outages affecting satellite communications. Study of the data can bring new insight into the space weather physics, leading to improvement in ionospheric and thermospheric forecast models. Accurate space weather forecasts will greatly assist satellite operators and users in their efforts to improve operational efficiency of their space systems. Current ionospheric forecast accuracies are estimated to generally range between 40-60 percent; daily global mapping of the ionosphere can potentially increase the forecast accuracy range to 80-100 percent.

The Capability and Its Relevance

The GPS constellation consists of 24 satellites in circular orbits just under 11,000 nm above the Earth's surface. Four satellites are in each of the six orbital planes, each plane inclined 55 degrees to the equatorial plane and separated by 60 degrees in right ascension. The replenishment requirements for the GPS constellation with the resultant periodic launches will provide the opportunity to include an ionospheric measurement capability on future production satellites.

The IRIDIUM system, designed to provide worldwide cellular phone access, is still under production; initial launch is expected within the next two or three years. The constellation is projected to contain 66 LightSats (i.e., small, light-weight satellites). Attaching ionospheric sounding devices on this system and other similar systems will significantly increase observation rate and enhance global ionospheric mapping capability.

Forecasting radio frequency propagation is similar to weather forecasting in that large volumes of fresh data, collected over vast territorial expanses, are needed daily to provide condition estimates reasonably accurate and sufficiently detailed. The daily worldwide mapping of the ionosphere will provide the needed data to make accurate forecast reports for diurnal, worldwide, terrestrial propagation characteristics of electromagnetic energy in the 3 MHz to 300 MHz frequency range. The data will also enhance the accuracy of radio direction finding activities. With the daily observational picture of the vertical structure and spatial pattern of the ionosphere, significant accuracy can be obtained in locating tactical communications sources by mapping those regions in the ionosphere where certain radio signals in certain frequency ranges are readily refracted by the ionosphere. With this knowledge, tactical radio intercepts can routinely and accurately locate and track enemy (friendly as well) platforms, and thus, significantly improve order of battle assessments. Error ellipses are expected to improve by an order of magnitude through the use of the daily worldwide data.

To enhance the overall global ionospheric mapping and to significantly improve our ability to understand, predict, and exploit equatorial ionospheric scintillation, additional remote sensing of the equatorial ionosphere is needed. Certain regions in the equatorial ionosphere are significantly disturbed to cause electromagnetic amplitude and phase fluctuations (scintillation) on satellite-to-ground or satellite-to-aircraft transmissions. The disturbed regions, called equatorial plasma depletions or bubbles, develop after sunset, drift to the east, and persist well past midnight, resulting in a six to eight hour period of potential intermittent FLTSATCOM/AFSATCOM and GPS outages. To obtain the necessary data, an ionospheric remote sensing satellite, in addition to the GPS or IRIDIUM constellation, is proposed to be flown in a circular orbit between 20 degrees latitude north and south at a lower altitude of about 400 nm; however, a remote sensing package can be flown as an add-on sensor on another satellite if a similar orbit is being used.

Information obtained from the equatorial ionospheric sounding satellite or package will be used to forecast the existence and movement of equatorial scintillation regions. With the real-time, daily measurements of ionospheric parameters, such as temperatures, densities, and plasma irregularities, combined with new scientific insight and model development, highly accurate forecasts of future outage locations can be expected. This predictive capability for equatorial ionospheric disturbance regions will improve the reliability of communications within this region through the use of alternate raypaths or relay to non-disturbed regions. Operational users will finally have the ability to uniquely distinguish ionospheric outages from hardware problems or jamming.

Potential Technologies

Ionospheric modeling will be significantly enhanced with the availability of daily worldwide data. Ionospheric vertical and spatial structure will be more readily apparent which can lead to advances in scientific understanding of coupling mechanisms within the ionosphere, thermosphere, and the magnetosphere. Insertion of daily measurements of the total EUV flux into ionospheric models will also significantly improve model accuracies. (See SPACECAST 2020 White Paper "Space-Based Solar Monitoring and Alert System (U).")

The scientific challenge in understanding ionospheric scintillation is to determine the exact geophysical conditions leading to the onset of plasma depletions at a particular location and time. This challenge relates directly to a major operational FLTSATCOM/ AFSATCOM requirement to issue accurate outage forecasts to operational satellite users dispersed worldwide and operating over a wide range of frequencies. The ability to forecast these C3I outages will overcome a long standing limitation of reliable FLTSATCOM/AFSATCOM in the equatorial region.

A potential exploitation technology can be developed in the twenty-first century once ionospheric variability is understood, globally measured and mapped on a daily basis, and made predictable with a high degree of accuracy. This technology will involve temporarily modifying the ionosphere through insertion of gaseous compounds, such as those containing molecular oxygen (O2), atomic oxygen (O), molecular nitrogen (N2), nitrous oxide (NO), helium (He), and atomic hydrogen (H), at certain altitudes and locations to increase the neutral and electron density of a given region through the natural photochemical reactions initiated by the absorption of EUV radiation (figure 3). This effect, however, can also be enhanced by shooting a high energy laser, microwave, or particle beam (wavelength will be dependent on gaseous compounds used) into the chemical insertion region to accelerate the photoionization and dissociative recombination processes. End result from the chemical insertion will be increased electron density having a jamming effect on the enemy's radio wave propagation capability due to absorption of the wave energy by the charged particles in the enhanced ionosphere. The downside is that your own communications can be affected as well.

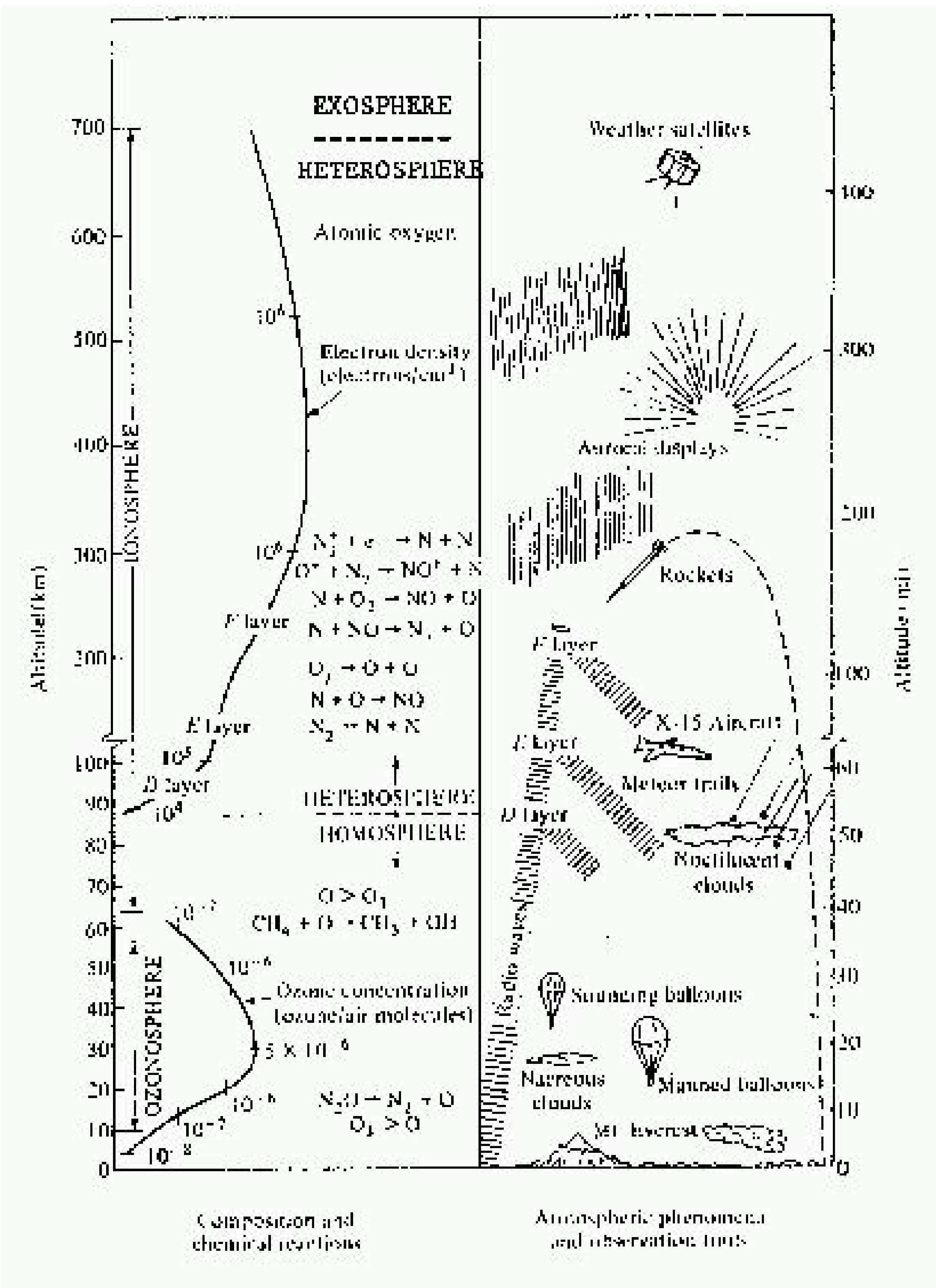

Figure 3. Atmospheric vertical structure, chemical regimes, associated atmospheric phenomena, and weather observation tools.

Near Term Technologies and Operational Exploitation Opportunities

Currently, Earth-based ionospheric sounders (recorders) can measure and produce excellent vertical profiles of electron density through the lower half of the ionosphere. The upper half of the ionosphere, unfortunately, cannot be measured by the sounder because the signal is either reflected back by the level below the maximum electron concentration or absorbed. To measure the upper half of the ionosphere, satellite-based ionospheric sounders and other sensing devices must be used.

Satellite remote sensing of the ionosphere exists today as a capability, but it is limited in coverage, frequency, type of data collected, and timeliness. Some low-earth orbiting satellites, such as the DMSP (currently two on-orbit), carry ionospheric sensing devices. In the case of the sun-synchronous, polar-orbiting DMSP, a set of four sensors, known as the Ionospheric Plasma Drift and Scintillation Monitor (SSIES), measures plasma parameters such as ion and electron temperatures, densities, and plasma irregularities. The DMSP also carries a Precipitating Electron/Proton Spectrometer (SSJ/4) that detects and analyzes electrons and ions precipitating into the ionosphere producing enhanced auroral displays. This information provides critical knowledge of the state of the polar ionosphere for communications, surveillance, and detection systems such as the Over-The-Horizon radar that propagates energy off, or through the ionosphere.

New upper atmospheric models are under development at various universities and laboratories around the world. As these models develop, they will eventually be incorporated into global circulation models that will have the goal of specifying worldwide ionospheric and thermospheric conditions. The US Air Force's Phillips Laboratory is currently developing a new ionospheric model, known as PRISM, which will eventually be used operationally by the Air Force Space Forecast Center at Falcon AFB, Colorado, to forecast ionospheric space weather. The accuracy of this and other models will be significantly enhanced with daily worldwide mapping data of the upper and lower ionosphere, achieved through space-based ionospheric soundings coupled with Earth-based ionospheric sounder data. The ultimate goal of these models will be to provide more accurately, for example, current and forecasted electron density profiles, atmospheric densities, and auroral disturbance locations. Space operators of communications, radar, and navigation systems as well as operators concerned with predicting satellite orbit already use current and predicted space weather information to more efficiently use their assets; however, the estimated accuracy of the current ionospheric modeling capability is about +/- 25 percent, putting space weather forecast accuracies in the general range of 40-60 percent correct. Daily, worldwide mapping of large volumes of frequently refreshed ionospheric data can reduce modeling error significantly, resulting in potential space weather forecast accuracies in the range if 80-100 percent correct.

The Space Forecast Center provides operational space weather support to DoD space operators and users in the form of bulletins/alerts and forecasts of space weather conditions of the near-Earth space environment. Ionospheric sensing is critical to their capability to provide support. Accuracy of products is degraded due to the lack of near real-time data and worldwide coverage for a given time in space. With a worldwide data base, frequently replenished throughout the day, accuracy of ionospheric space weather products will significantly increase, possibly by an order of magnitude. To take advantage of the increased data availability, from all sources, the Space Forecast Center will need faster and more accurate forecast models (e.g., ionospheric, magnetospheric, thermospheric, solar, satellite drag, etc.) coupled with a high speed, high capacity data processing and product development capability.

The proposed use of the GPS and/or IRIDIUM constellations as well as the launching of an equatorial ionospheric sensor are considered to be a joint-use/dual-use venture among civilian, DoD, and commercial interests. All share similar communication concerns, and oftentimes communications systems are jointly used, thus, all need the same type of information to efficiently use their respective systems. Data collected is expected to be made available for worldwide use unless threat dictates encryption or some type of control. Daily global mapping of the ionosphere will provide significant improvement in the accuracy and timeliness of space weather forecasts, alerts, and warnings for both DoD and civilian space users and operators. The GPS and IRIDIUM constellations provide an access opportunity that must be pursued.