Why HF and SATCOM are Complementary

Overview

Safe, efficient air travel requires reliable communications. In order to provide reliable communications for aircraft operating beyond the range of ground-based VHF radio, the effects of solar weather must be understood and accounted for when designing the complement of communication systems deployed on aircraft for long range communications.

Historically, HF has been recognized as the long range communication system by default. However, technology now provides alternate solutions, satellite communications (Inmarsat and Iridium specifically for aeronautical use) which have also been recognized by regulatory authorities for use in long range communications. Just as the satellite navigation community initially supported satellite navigation as sole means for navigation, some satellite communication proponents similarly support satellite communication as sole means for long range communication. Material in subsequent sections of this paper support a position that HF and L-band SATCOM are complementary and provides background information on signal propagation, identifies transient environmental events which can impact communication (and navigation) and provides a summary description of the event characteristics as well as their impact on HF and SATCOM. The material provided is not intended to delve into detailed technical analysis, rather it provides high level summary information leaving the reader to research any in-depth information that they desire.

To date there have been more studies pertaining to satellite navigation impacts of solar or space weather than satellite communication; however, due to the RF spectrum similarities between these systems those satellite navigation studies do contain data that is relevant for Inmarsat or Iridium satellite communication systems.

Electromagnetic Propagation Modes

There are two fundamental modes of electromagnetic (radio wave) propagation; Line of Sight (LoS) and Beyond Line of Sight (BLoS). Propagation characteristics for all electromagnetic transmissions vary with frequency and environmental conditions; see Figure 1 for atmospheric windows. LoS propagation occurs when there is a direct, straight-line path between transmitter and receiver antennas. BLoS propagation, for HF and lower frequencies, does not have a direct, straight-line path between transmitter and receiver antennas. BLoS can occur either through groundwave following the curvature of the earth or skywave which "skips" off one of the ionosphere layers (D, E or F). Figure 2 shows ionospheric effects on radio wave propagation modes.

HF Propagation

HF communications signals can occur with both LoS and BLoS propagation modes. LoS signal propagation is minimally affected by ionospheric conditions as the aircraft is flying in the troposphere, well below the ionosphere; however, certain space weather conditions can impact the troposphere and LoS communications. Groundwave signal propagation is not impacted by ionospheric conditions but it is impacted by the conductivity of the specific path over the earth (rocky terrain, sand, earth, fresh water, salt water, etc.). HF BLoS signal propagation is impacted by ionospheric absorption and reflection conditions which vary with space weather conditions.

SATCOM Propagation

L-band satellite communications signals, including Inmarsat and Iridium, operate with LoS propagation mode, a direct path between the satellite antenna and either a ground station or an aircraft antenna. The satellite link path passes through both the troposphere and the ionosphere which, as noted previously, are both affected by space weather.
Figure 1: Atmospheric Windows in Radio Wave Propagation (Source: NASA)

Figure 2: Ionosphere’s Role in Radio Wave Propagation
Space Weather

Ever since the invention of the telegraph and radio, disruptions that could be associated with solar activities have been observed. The various disciplines that have studied these phenomena have been collected into the discipline of heliophysics, as the science of space weather. Space weather refers to a collection of dynamic conditions in the space environment near the Earth. These include all conditions and events:

- On the sun (solar activities),
- Propagated by the solar winds,
- In near-Earth space,
- In the magnetosphere,
- In the thermosphere, and
- In Earth’s upper atmosphere (ionosphere).

These dynamic conditions each have some impact on electromagnetic propagation. The solar activities associated with these conditions include:

- Solar flares,
- Solar prominences,
- Coronal holes, and
- Coronal mass ejections.

These solar activities are influenced by sunspot conditions and the number of active sunspots, which recur on the “solar cycle” (11 years on average), in the photosphere of the sun. Refer to the following NASA website for additional information and further references:

https://www.nasa.gov/mission_pages/sunearth/spaceweather/index.html#q2

Solar Activities

Solar Flares

Solar flares, intense bursts of radiation produced by the release of magnetic energy associated with sunspots, are the solar system’s largest explosive events. Solar flares can last from minutes to hours and release photons and radiation across most wavelengths of the electromagnetic spectrum which temporarily alter the characteristics of the Earth’s atmosphere, impacting radio wave propagation. The specific distribution profile of wavelengths for each event is of interest in studies of the impacts on communication, navigation, and surveillance avionics systems.

Solar flares are monitored using both x-ray and optical detectors. Sunspot areas which exhibit solar flares also accelerate particles (electrons, protons, and heavier particles). The specific amount of particle acceleration can lead to coronal mass ejections.
Coronal Mass Ejections (CME)

The outer solar atmosphere, the corona, is structured by strong magnetic fields. Where these fields are closed, often above sunspot groups, the confined solar atmosphere can suddenly and violently release bubbles of gas and magnetic fields called coronal mass ejections. A large CME can contain a billion tons of matter that can be accelerated to several million miles per hour in a spectacular explosion. Solar material streams out through the interplanetary medium, impacting any planet or spacecraft in its path. These explosions of particles and electromagnetic field fluctuations interact with the Earth’s atmosphere and magnetic field and can have biological and electrical affects. CMEs are sometimes associated with flares but can occur independently.

Solar Prominences

A solar prominence (also known as a filament when viewed against the solar disk) is a large, bright feature extending outward from the Sun’s surface. Prominences are anchored to the Sun’s surface in the photosphere, and extend outwards into the Sun’s hot outer atmosphere, called the corona. A prominence forms over timescales of about a day, and stable prominences may persist in the corona for several months, looping hundreds of thousands of miles into space. Scientists are still researching how and why prominences are formed.

The red-glowing looped material is plasma, a hot gas comprised of electrically charged hydrogen and helium. The prominence plasma flows along a tangled and twisted structure of magnetic fields generated by the sun’s internal dynamo. When this magnetic field structure becomes unstable and bursts outward, an erupting prominence with effects similar to a CME occurs releasing the plasma.

Coronal Holes

Coronal holes are variable solar features that can last for weeks to months. They are large, dark areas (representing regions of lower coronal density) when the sun is viewed in EUV or x-ray wavelengths, sometimes as large as a quarter of the sun’s surface. These holes are rooted in large cells of unipolar magnetic fields on the sun’s surface; their field lines extend far out into the solar system. These open field lines allow a continuous outflow of ions as a high-speed solar wind. Coronal holes tend to be most numerous in the years following solar maximum.

Solar Activity Measurements

Space weather scientists have developed three broad storm classifications of space weather that are created by the solar activities described above. Each storm classification impacts the Earth, with biological and electronic system impacts. These three broad storm classifications are geomagnetic storms, solar radiation storms, and radio blackouts. Within each of these classifications there are five categories defined by the effects caused by a storm of that category.

The following three tables, one for each of the three storm classifications, based on National Oceanic and Atmospheric Administration (NOAA) data:

- Identify the five effects categories,
- Briefly describe impacts and
- Provide a measure of the frequency of occurrence.

For our purposes, these three storm classifications are the focus of our evaluation of HF and L-band SATCOM communication systems impacts. Note however that the impacts occur on all communication, navigation, and surveillance systems based on the frequency dependencies of the events. In the highest magnitude events, there are impacts on ground-based systems including electrical power generation and distribution grids. Due to the scaling of impacts based on the magnitude of the solar storms, emphasis has been placed on detection and notification in order to minimize impacts through mitigation preparations similar to activities around hurricanes and typhoons. For aviation the mitigations may include altering routes to
avoid impacted areas; however, for the most serious events, flight cancellations may be indicated due to likelihood of radiation effects on passengers and crew combined with the severity of impacts on electronic systems.

Table 4, following the three NOAA-based tables, summarizes each of the previous three tables in a single table for the effects and impacts solely to HF and L-band SATCOM, removing unrelated information.

### Table 1: NOAA Radio Blackout Scales

<table>
<thead>
<tr>
<th>Description of Impact on System</th>
<th>S, S,M*</th>
<th>Avg. Freq</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HF Radio</strong>: Complete HF blackout over entire sunlit portion of the Earth lasting several hours.**</td>
<td>R5 Extreme 2x10^{-3}</td>
<td>&lt;1 per cycle</td>
</tr>
<tr>
<td><strong>Navigation</strong>: Position awareness loss due to non-GNSS navigation and L-band signal outages over entire sunlit portion of the Earth lasting several hours. Increased GNSS positioning errors on sunlit portion of the Earth lasting several hours, possible spread of problem into night side.</td>
<td>R4 Severe 1x10^{-3}</td>
<td>8 per cycle</td>
</tr>
<tr>
<td><strong>HF Radio</strong>: HF blackout on most of the sunlit portion of the Earth for 1-2 hours. <strong>Navigation</strong>: Increased position errors due to non-GNSS navigation signal outages in sunlit portion of the Earth for 1-2 hours. Minor GNSS and L-band disruptions possible in sunlit portions of the Earth.</td>
<td>R3 Strong 1x10^{-4}</td>
<td>175 per cycle</td>
</tr>
<tr>
<td><strong>HF Radio</strong>: Wide area HF blackout for ~1 hour on sunlit portion of the Earth. <strong>Navigation</strong>: Non-GNSS navigation and L-band signal degradation for ~1 hour.</td>
<td>R2 Moderate 5x10^{-5}</td>
<td>350 per cycle</td>
</tr>
<tr>
<td><strong>HF Radio</strong>: Limited HF blackout for tens of minutes on sunlit portion of the Earth. <strong>Navigation</strong>: Non-GNSS navigation and L-band signal degradation for tens of minutes.</td>
<td>R1 Minor 1x10^{-5}</td>
<td>2000 per cycle</td>
</tr>
</tbody>
</table>

*GOES X-ray peak brightness by flux in the 0.1-0.8 nm range, in W-m^{-2}. Other physical measures also considered.

**Other frequencies may also be affected by these conditions.
Table 2: NOAA Geomagnetic Storm Impacts

<table>
<thead>
<tr>
<th>Description of Impact on System</th>
<th>S&lt;sub&gt;s&lt;/sub&gt;, S&lt;sub&gt;s,M&lt;/sub&gt;*</th>
<th>Avg. Freq</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power systems</strong>: Widespread voltage control problems &amp; protective system problems occur, some grid systems blackout or collapse. Transformers may be damaged. <strong>Spacecraft operations</strong>: Extensive surface charging, increased drag, problems with orientation, uplink/downlink and tracking satellites may occur. <strong>Other systems</strong>: Pipeline currents up to hundreds of Amps, HF propagation not possible for 1-2 days, multi-day GNSS and L-band degradation, aurora may be seen to 40° geomagnetic latitude.</td>
<td>G5 Extreme Kp = 9</td>
<td>4 days per cycle</td>
</tr>
<tr>
<td><strong>Power systems</strong>: Potential widespread voltage control problems &amp; some protective systems mistakenly remove key assets from the grid. <strong>Spacecraft operations</strong>: Possible surface charging and tracking problems, increased drag, corrections for some orientation problems. <strong>Other systems</strong>: Induced pipeline currents impact protection mechanisms, sporadic HF propagation, multi-hour GNSS and L-band degradation; aurora may be seen to 45° geomagnetic latitude.</td>
<td>G4 Severe Kp = 8</td>
<td>60 days per cycle</td>
</tr>
<tr>
<td><strong>Power systems</strong>: May require voltage corrections, false alarms on some protection mechanisms. <strong>Spacecraft operations</strong>: Possible surface charging on satellite components, increased drag for LEO, corrections for some orientation problems. <strong>Other systems</strong>: Intermittent GNSS, L-band and HF propagation may occur; aurora may be seen to 50° geomagnetic latitude.</td>
<td>G3 Strong Kp = 7</td>
<td>130 days per cycle</td>
</tr>
<tr>
<td><strong>Power systems</strong>: High latitude power systems may trip voltage alarms, transformers may be damaged by long duration storms. <strong>Spacecraft operations</strong>: Possible corrective actions for orientation problems, possible changes in drag affect orbit predictions. <strong>Other systems</strong>: Possible HF propagation fades at higher latitudes; aurora may be seen to 55° geomagnetic latitude.</td>
<td>G2 Moderate Kp = 6</td>
<td>360 days per cycle</td>
</tr>
<tr>
<td><strong>Power systems</strong>: Possible weak power grid fluctuations. <strong>Spacecraft operations</strong>: Possible minor impacts on satellite control. <strong>Other systems</strong>: Migratory animals affected, aurora commonly seen to 55° geomagnetic latitude.</td>
<td>G1 Minor Kp = 5</td>
<td>900 days per cycle</td>
</tr>
</tbody>
</table>

*SSM = Scale, Severity, Measure. Kp values determined every 3 hours but other measures also considered. 
** For specific locations, use geomagnetic latitude to determine likely sightings
### Table 3: NOAA Solar Radiation Storm Scales

<table>
<thead>
<tr>
<th>Description of Impact on System</th>
<th>S, S,M*</th>
<th>Avg. Freq</th>
</tr>
</thead>
</table>
| **Biological:** Unavoidable high radiation hazard to EVA astronauts, high-flying aircraft at high latitudes may expose passengers and crew to radiation risk.***  
**Satellite operations:** Satellites may become useless, memory impacts can cause loss of control, may inject noise into imagery, star-trackers may not locate sources, possible permanent damage to solar panels.  
**Other systems:** Possible complete HF blackout in polar region, extremely difficult navigation due to position errors. | S5 Extreme 10^3 | <1 per cycle** |
| Biological: Unavoidable high radiation hazard to EVA astronauts, high-flying aircraft at high latitudes may expose passengers and crew to radiation risk.***  
**Satellite operations:** May experience memory device problems, noise injection into imagery, star-tracker issues may cause orientation problems, solar panel efficiency degradation possible.  
**Other systems:** Possible HF blackout through polar region, increased navigation errors for multiple days. | S4 Severe 10^4 | 3 per cycle** |
| Biological: Radiation hazard avoidance recommended for EVA astronauts, high-flying aircraft at high latitudes may expose passengers and crew to radiation risk.***  
**Satellite operations:** SEUs, noise injection into imagery, slight solar panel efficiency reduction are likely.  
**Other systems:** Degraded HF propagation through the polar regions and likely navigation errors. | S3 Strong 10^3 | 10 per cycle** |
| Biological: High-flying aircraft at high latitudes may expose passengers and crew to radiation risk.***  
**Satellite operations:** Possible infrequent SEUs.  
**Other systems:** HF propagation effects in polar region, navigation in polar cap vicinity possibly affected. | S2 Moderate 10^2 | 25 per cycle** |
| Biological: None  
**Satellite operations:** None  
**Other systems:** Minor impacts to HF propagation in polar region. | S1 Minor 10 | 50 per cycle** |

*Flux level of ≥ 10 MeV particles (ions) as 5-minute averages, in s⁻¹ ster⁻¹ cm⁻². Other physical measures also considered.

**These events last more than 1 day.

***High energy particle (>100 MeV) is a better indicator of human radiation risk.
## Table 4: Solar Storm Effects Summary

<table>
<thead>
<tr>
<th>Classification</th>
<th>Severity, Avg. Freq.</th>
<th>L-band SATCOM Impact</th>
<th>HF Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Geomagnetic storm</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G5 – 4 days / cycle</td>
<td>Satellite orientation problems, impacting performance and satellite tracking may occur. Multi-day signal degradation.</td>
<td>Propagation not possible for 1-2 days.</td>
<td></td>
</tr>
<tr>
<td>G2 – 360 days / cycle</td>
<td>Occasional satellite orientation problems impacting performance, occasional intermittent signal propagation possible.</td>
<td>Possible HF propagation fades at higher latitudes.</td>
<td></td>
</tr>
<tr>
<td>G1 – 900 days / cycle</td>
<td>Possible minor impacts on satellite control but no signal impacts.</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td><strong>Solar Radiation storm</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S5 - &lt; 1 / cycle</td>
<td>Satellites may become useless, memory impacts can cause loss of control, star-trackers may not locate sources, possible permanent damage to solar panels.</td>
<td>Possible multi-day HF band blackout in polar region.</td>
<td></td>
</tr>
<tr>
<td>S4 – 3 / cycle</td>
<td>Memory device problems, star-tracker issues causing orientation problems, solar panel efficiency degradation possible.</td>
<td>Possible multi-day blackout through polar region.</td>
<td></td>
</tr>
<tr>
<td>S3 – 10 / cycle</td>
<td>SEUs, slight solar panel efficiency reduction are likely.</td>
<td>Degraded propagation through the polar regions likely</td>
<td></td>
</tr>
<tr>
<td>S2 – 25 / cycle</td>
<td>Possible infrequent SEUs.</td>
<td>Propagation effects in polar region possibly affected</td>
<td></td>
</tr>
<tr>
<td>S1 – 50 / cycle</td>
<td>None</td>
<td>Minor, short term propagation impacts in polar region.</td>
<td></td>
</tr>
<tr>
<td><strong>Radio Blackout storm</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R5 - &lt; 1 / cycle</td>
<td>Signal outages over entire sunlit portion of the Earth lasting several hours (&gt; 2 hours).*</td>
<td>Complete HF blackout over entire sunlit portion of the Earth lasting several hours.*</td>
<td></td>
</tr>
<tr>
<td>R4 – 8 / cycle</td>
<td>Signal outages in sunlit Earth-side for 1-2 hours.</td>
<td>Blackout most of sunlit Earth-side for 1-2 hours</td>
<td></td>
</tr>
<tr>
<td>R3 – 175 / cycle</td>
<td>Signal degradation for ~1 hour.</td>
<td>Wide area blackout for ~1 hour on sunlit Earth-side.</td>
<td></td>
</tr>
<tr>
<td>R2 – 350 / cycle</td>
<td>Signal degradation for tens of minutes.</td>
<td>Limited blackout for tens of minutes on sunlit portion of the Earth.</td>
<td></td>
</tr>
<tr>
<td>R1 – 2000 / cycle</td>
<td>Signal degradation for brief intervals (minutes).</td>
<td>Minor degradation on sunlit portion of the Earth with occasional loss of contact.</td>
<td></td>
</tr>
</tbody>
</table>

*Broadband RF blackout not restricted to HF and L-band frequencies.
As noted in Tables 1-3 above, the associated impacts for HF and GNSS navigation systems have been studied extensively, while the impacts for modern L-band SATCOM systems are much less studied. However, many of the impacts on the ionosphere identified for GNSS navigation systems produce similar impacts on L-band SATCOM due to the Radio Frequency (RF) spectral similarity with GNSS navigation and augmentation systems. These impacts are those which cause variation in the background noise floor which affect a systems ability to acquire and track the signal of interest in noise. Geostationary satellites have a higher signal than GNSS satellites and Low Earth Orbit (LEO) satellites produce a higher level signal level yet. However, these signal levels are still very small.

Solar weather impacts show frequency dependent impacts from event-to-event based on details related to the particle and electromagnetic field characteristics of the individual event. As such, the impacts on L-band SATCOM are different from those on HF. These impacts not only differ in the type of interaction with the system but they also show geographic location differences, see Figure 3 which depicts some of these impacts for L-band. Table 4 above summarizes the effects on L-band SATCOM and HF allowing easy comparison of the impacts on each system. The following sections briefly describe impacts on L-band SATCOM and HF.
Impacts on L-Band SATCOM

Solar activity impacts on L-Band SATCOM show similar behaviors but differ in magnitude and underlying cause based on the geographic location under consideration. Similar to HF, impacts in low-to-mid latitudes are different from those experienced at high latitudes and in the Polar Regions.

A significant contributor to this effect is the interaction of the solar weather with the ionosphere, creating electromagnetic turbulence and non-homogeneity, leading to scintillation in the F-layer. F-layer scintillation affects the L-Band signal by reducing signal-to-noise (SNR), possibly resulting in loss-of-lock, reduced performance tracking of Doppler-shifted signals, and failure to re-acquire lost signals. Amplitude scintillation is quantified using a dimensionless parameter, S4, which ranges between 0 and 1.0. Values less than 0.3 typically indicate minimal or no effect while 0.6 or greater indicates potential for significant degradation. Signal amplitude degradation can range from minor (~3dB) to significant (~20dB) while legacy Iridium systems typically have 15.5 dB of margin.

Low to Mid Latitudes

In the region 10° either side of the geomagnetic equator, solar weather may result in scintillation which can lead to SATCOM signal degradation (decreased signal amplitude) and possible blackout from sunset to near midnight in local areas. Scintillation effects become more prevalent during the peak of the solar cycle (solar maximum). There is also a seasonal dependency correlation.

Mid-latitude operations are typically benign, however, during strong solar weather storms, such as the one in October and November of 2003, several operators reported poor or lost SATCOM. Ground-based GPS receivers also reported difficulty receiving their signals. Measurements of the ionosphere showed severe ionization gradients caused by the high Total Electron Content (TEC).

High Latitudes

In the Polar Regions and high latitudes, ionospheric scintillation also impacts SATCOM; however, the effects are not caused by decreased signal amplitude but by irregular signal phase shifting. Signal polarization variations caused by Faraday rotation effects manifest as similar loss-of-lock, fading, and difficulty in re-acquiring lost signals. These effects may impact today’s modern modulations such as OFDM and others with high symbol constellations more than traditional low data rate modulations.

In addition to signal processing impacts described above, L-Band SATCOM is also affected by solar weather events which can directly impact the satellites. High energy particles and electromagnetic radiation from solar activities:

- Increase orbital drag, potentially causing issues with satellite orientation and orbital dynamics,
- Cause surface charging of the satellite and components, leading to Electro Static Discharge (ESD) upsets of the electronics requiring a reset to regain operation,
- Cause Single Event Upsets in memory and circuitry, and
- Degrade solar panel performance, limiting the power available for transmitters and satellite circuitry.

Impacts on HF

Solar activity impacts on HF show different behaviors based on the geographic location under consideration. Impacts in low-to-mid latitudes are different from those experienced at high latitudes and in the Polar Regions. A significant contributor to this effect is the Earth’s magnetic field and its interaction with the electromagnetic fields and the high-energy particles from the solar activities as they cross the Earth’s magnetic flux lines.
Low to Mid Latitudes

At low-to-mid latitudes, HF communications are impacted by solar weather activity interactions with the magnetosphere and the D, E, and F layers of the ionosphere that produce variations in the absorption and reflection characteristics which form the basis for HF operations. These variations occur on the sunlit side of the Earth and may increase the overall noise floor, cause fading, or total blackout. Disruptions range from dropouts of a few minutes to a few hours depending on the storm category and classification. Many storms only impact a portion of the HF band and effects can be mitigated by appropriate selection of operating frequency. Storms in the “severe” or “extreme” classifications may result in significant drop outs or total blackouts across the entire HF band.

High Latitudes

In the Polar Regions or at high latitudes, HF communications may be adversely impacted with stronger and longer effects due to the dip in the Earth’s magnetic field at the magnetic poles which reduces the polar magnetic field protection below the protection in the mid-latitudes. These solar weather impacts can extend for days during high-energy solar events due to the heavy ionosphere local ionization effects reflecting HF as well as increased local absorption.

Impacts on Both HF and SATCOM

Some solar weather events produce effects in the ionosphere through photoionization, producing free ions and electrons in the form of a weak plasma that interacts with various frequencies in different ways impacting all layer of the ionosphere. At a given frequency of operation, higher data rate modulation waveforms are more susceptible to effects than lower data rate modulation waveforms.

For those events which impact both HF and L-band SATCOM, these ionospheric differences due to geographic location and frequency, vary the onset and recover times for impacts to HF and L-band SATCOM systems. Some event historical data shows that these differences mean HF may be available when L-band SATCOM is not while other event data shows the opposite.

In September 2015 there was a multi-hour Inmarsat unscheduled loss in the Pacific Ocean Region and communications were handled by HF although the loss may not have been due to solar weather. Future solar weather events associated with the solar maximum portion of the solar cycle are expected to lead to similar operational issues.

During solar events on 7 September 2005, operational data showed SATCOM voice was used as a backup when HF became unreliable and in some cases unable to establish or maintain communications.
Summary

Solar weather activities and their interactions with the Earth’s magnetosphere and Ionosphere result in various magnetic, radiation, and propagation effects that impact people and electronic systems. The extent and magnitude of the effects depend on the classification of the solar weather activity. For the “extreme” severity classifications (G5, S5, or R5), mitigation requires re-routing or cancellation of flights. For many “minor” severity classification events, impacts on systems are minimal and of no concern for people, HF, GNSS, or L-Band SATCOM. For “moderate, strong, or severe” severity classification events, the event characteristics impacting HF are due to changes to the D-layer absorption and F-layer reflection characteristics in the HF band frequencies while those impacting L-Band SATCOM are primarily due to F-layer scintillation induced variations in signal amplitude and phase in L-Band frequencies and Faraday rotation induced variations in signal polarization.

The information on the impacts of solar weather events on the Earth’s ionosphere and magnetosphere presented in this paper indicate that HF and L-Band SATCOM are impacted by changes to different layers of the ionosphere. Research into ionosphere condition and solar weather impacts on HF propagation has been extensively studied but similar research into impacts on L-Band communications has only recently begun. Extrapolation of research related to impact on GPS and WAAS, due to spectral similarities to L-band SATCOM, indicate similar impacts to L-Band communications. Current operational data shows that L-band SATCOM has been available when HF has difficulties and HF has been available when L-band SATCOM has difficulties. Recently there have only been a few solar weather induced issues. It is important to note that the current solar activity level is at a low compared to activity 50-100 years ago and is not indicative of expected performance with traditional solar weather activities.

Solar weather events may impact all portions of the RF spectrum including HF and L-band SATCOM. The information presented in this paper reflects possible impacts; however, each event is unique and the type and magnitude of effects can vary between geographic locations as well as frequencies within and across bands of spectrum. Additionally, recovery times vary based on the specific event frequency and geographic region characteristics. Refer to section 4.1 of ICAO International Airways Volcano Watch Operations Group report [9] for a brief summary of the differences between HF and L-band SATCOM impacts.

Due to the increasingly critical use of satellites for communication and navigation in daily activities, an increased focus on being able to predict these events now provides space weather forecasts used by airlines to routinely evaluate upcoming flights and adjust those flights projected to be impacted by space weather. These activities help mitigate impacts of space weather.

Solar weather event mitigation strategies are in place today however solar weather events can still impact airline operations. Differences in the physical phenomena impacting the D and F layer characteristics supports the position that a robust long range communication system requiring high availability should incorporate spectral diversity. A long range communication system with improved robustness through spectral diversity reduces the number of events requiring mitigation alterations to flight plans.

The aviation navigation community has acknowledged it is not prudent to rely solely on a satellite-based Position, Navigation, and Timing (PNT) solution.

Based on these data points a prudent selection for a long range communication system should include both HF and L-Band SATCOM.
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