Tech Tips
Space Weather and Marine Navigation

By Bill Whitney

All sailors are aware of the weather and its impact on their comfort and safety. Terrestrial weather imposes limits on most of our nautical pursuits, and can, at its worst, pose a real threat to our lives and property. However when studied by knowledgeable meteorologists, its impact can be forecast and action taken to mitigate whatever it may bring our way.

We live in the lower level of the atmosphere called the troposphere. Tropospheric weather is the weather that we can watch develop. It's up close and personal. It affects what we wear, where we go, and our heating bill; even what we eat. However, there is another aspect of the weather that we give very little thought to, that is more important to our lives than we realize. As you probably guessed from the title above, I'm referring to space weather, the cumulative sum of storms, calms and other disturbances that occur on the sun and in the ionospheric layers of the atmosphere above us, and which can impact our electronic systems.

Ionosphere

The Ionosphere is part of Earth's upper atmosphere, between approximately 50 and 400 miles above us, where extreme ultraviolet (EUV) and X-ray radiation from the sun ionize the atoms and molecules in the high altitude gasses, creating an ion-rich layer of the atmosphere. The ionosphere is important because it reflects and modifies radio waves used for communication and navigation.

The atmospheric atoms and molecules are impacted by the high energy the EUV and X-ray photons deliver from the sun. The amount of energy (photon flux) at EUV and X-ray wavelengths varies by nearly a factor of ten over the 11 year solar cycle. The density of the ionosphere changes accordingly. Other solar phenomena, such as solar flares (sunspots), changes in the solar wind, and geomagnetic storms also effect the charging of the ionosphere. Since the largest amount of ionization is caused by solar radiation, the night-side of the earth, and the pole pointed away from the sun (depending on the season) have much less ionization than the day-side of the earth, and the pole pointing towards the sun.

This means that as the sun's activity changes, so does our ionosphere, and with these changes the performance of our electronic devices, which carry electronic data through the ionosphere, will change.

Space Weather and GPS Systems

The use of satellite radio navigation systems, like the Global Positioning System (GPS), has grown dramatically in the last decade. GPS receivers are now in nearly every cell phone and in many automobiles, boats, trucks, and any equipment that moves and needs precision location measurements.

There are several ways in which space weather impacts GPS function. GPS radio signals travel from the satellite to the receiver on the ground, passing through the Earth's ionosphere. The charged plasma of the ionosphere bends the path of the GPS radio signal similar to the way a lens bends the path of light. In the absence of space weather, GPS systems compensate for the "average" or "quiet" ionosphere, using a model to calculate its effect on the accuracy of the positioning information. But when the ionosphere is disturbed by a space weather event, the models are no longer accurate and the receivers are unable to calculate an accurate position based on the satellites overhead.

In calm conditions, GPS systems can provide position information with an accuracy of 3 feet or less. During a severe space weather storm, these errors can increase to 100 yards or more.

Since radio waves are affected by the presence of electrons, the more electrons in the path of the wave, the more the radio signal will be affected. The change in the path and velocity of radio waves in the ionosphere has a big impact on the accuracy of satellite navigation systems.

A geomagnetic storm is a major disturbance of Earth's magnetosphere that occurs when there is a very efficient exchange of energy from the solar wind into the space environment surrounding Earth. Geomagnetic storms create large disturbances in the ionosphere. The currents and energy introduced by the storm enhance the ionosphere and increase the total number of ionospheric electrons. GPS systems cannot correctly model this dynamic enhancement and errors are introduced into the position calculations. This usually occurs at high latitudes, though major storms can produce enhancements in the ionosphere large enough to impact mid-latitudes.

During storms, the currents in the ionosphere, and the energetic particles that precipitate into the ionosphere add energy in the form of heat that can increase the density and distribution of density in the upper atmosphere, causing extra drag on satellites in low-earth orbit. The local heating also creates strong horizontal variations in the ionospheric density that can modify the path of radio signals and create errors in the positioning information provided by GPS. While the storms can create beautiful aurora, they can also disrupt navigation systems and create harmful geomagnetic-induced currents in the power grid and pipelines.

Smaller scale electric field fluctuations that may cause GPS signal to waiver are called ionospheric scintillations, and are not associated with space weather storms, but are simply part of the natural day-night cycle of the equatorial ionosphere. Severe scintillation conditions can prevent a GPS receiver from locking on to the signal and can make it impossible to calculate a position. Less severe scintillation conditions can reduce the accuracy and the confidence of positioning results. Scintillation is more prevalent at low and high latitudes; mid-latitudes, such as the United States, experience scintillation much less frequently. Scintillation is a strong function of local time, season, geomagnetic activity, and solar cycle.

The lesson here is that under "normal" atmospheric and solar conditions that have been studied and modeled for years, our electronic aids to navigation, such as GPS, will work reliably and with acceptable accuracy. Unfortunately, the sun is not always "normal". Solar events have a significant impact on our ionosphere that can and do put it outside the normal parameters that in many cases cannot be corrected for. Most of these abnormal events are not effectively communicated to the user communities. If you put blind faith in what your GPS or GPS integrated chart plotter is telling you, you need to reassess your navigation practices, or at least increase your insurance coverage!