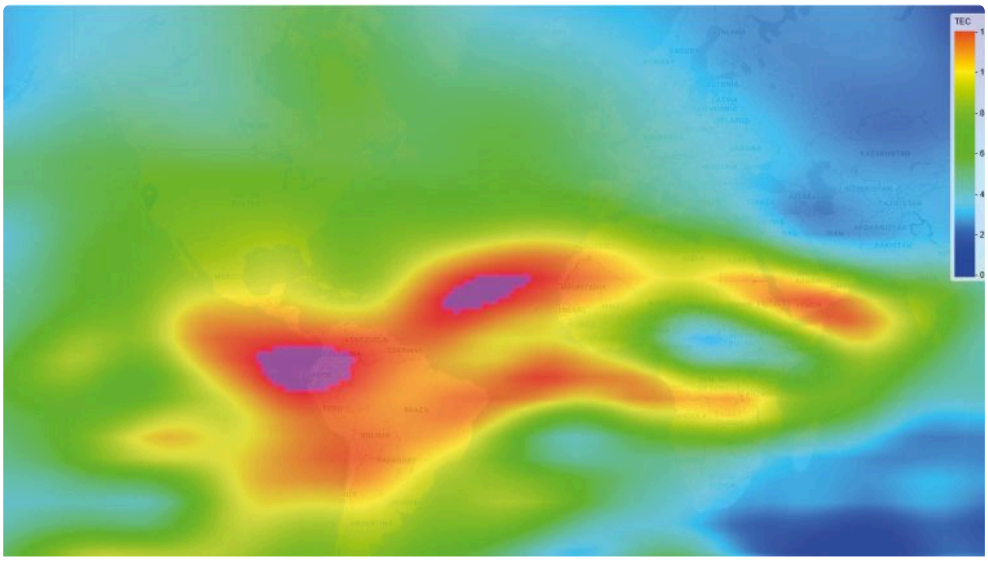


ARTICLE

Signals, scintillation and the solar effect

Mitigating GNSS disruptions as ionospheric disturbances move towards the peak

By Stuart Riley • April 23, 2025

How can geospatial professionals p... the fluctuating GNSS signals caused by the peak in the current solar cycle, which is likely to see an increase in solar storms and ionospheric disturbances?

With the current solar cycle expected to reach its peak this year, the associated solar storms and ionospheric disturbances will increase the likelihood of fluctuating GNSS signals. This article explores how geospatial professionals can proactively plan and prepare for these effects in order to maintain operational resilience and minimize productivity disruptions.

The current Solar Cycle 25 is now in the middle of its 11-year cycle. This means it is expected to reach its maximum this year, with a continued chance of high activity through 2026. The effects are real: in many cases visually stunning (e.g. auroras in lower latitudes), in others potentially troublesome – particularly to those who rely on GNSS for precise positioning and navigation. For geospatial professionals, the increased risk of solar storms and ionospheric disturbances or scintillation equates to a higher likelihood of rapid fluctuations in the strength and quality of GNSS signals. There is the potential for signal loss and complete outages, which needless to say directly affect positioning accuracy.

Thus far, the applications most affected by the current solar cycle include mining and agriculture in the equatorial regions and mining in northern Canada. However, during a large event, lower latitudes can see significant issues that range from longer than normal initialization times to a complete loss of signal. For applications that require precision or semi- and fully autonomous operations, that loss can be highly disruptive. The solar event in May 2024 served as a clear reminder that solar disruptions can impact GNSS operations anywhere in the world, not just in the familiar equatorial and high-latitude regions. And events like this are likely just the beginning.

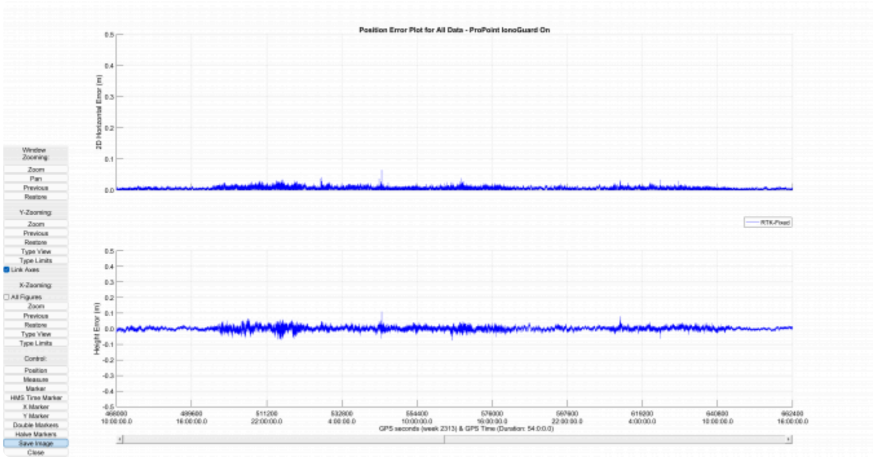


Figure 1: Effects of G5 geomagnetic storm on the Northern Alberta GNSS receiver in May 2024 (with purpose-built firmware deployed during Solar Cycle 25).

Inherently unpredictable

The Space Weather Prediction Center of the National Oceanic and Atmospheric Administration (NOAA) predicts that sunspot activity in the current cycle will be slightly below the recorded solar cycle average. Therefore, subsequent disruptions to GNSS signals on Earth should be relatively small. However, unpredictability is inherent to solar disturbances. Ionospheric scintillation, which is the rapid modification of radio waves in the ionosphere, extends from about 80 to 965km above Earth's surface. As NOAA describes, it is caused by small-scale (tens of metres to tens of kilometres) structures in the ionospheric electron density along the signal path and is the result of interference of refracted and/or diffracted (scattered) waves. While scintillation is more prevalent at low and high latitudes, mid-latitudes can experience scintillation during peak solar cycles. Severe scintillation conditions can prevent a GNSS receiver from locking on to the signal, making it very difficult to calculate a position.

For geospatial professionals who require centimetre accuracy and/or continuous high-accuracy positioning, preparedness is essential to minimize productivity disruptions. This gives reason to take proactive steps and plan accordingly to ensure operations remain resilient in the face of the potential challenges posed by the solar cycle peak. Three critical steps can help them to manage solar effects: leverage the latest technological improvements, put backup strategies in place, and keep an eye on solar activity and near real-time predictions.

GNSS frequency independence

Since the exact timing of a solar disturbance is unpredictable, it can be very helpful to understand in advance the true capabilities of GNSS-enabled equipment to withstand the challenges of solar storms and ionospheric disturbances. Ionospheric mitigation features have been added and improved upon in GNSS receivers over the past three solar cycles. One such adjustment is frequency independence. A receiver that can draw on multiple independent satellite systems (e.g. GPS, GLONASS, Galileo, BeiDou) reduces the chance of errors from solar disturbances. Multi-signal processing allows the receiver to deweight or eliminate satellites that are affected by ionospheric disturbances or other error sources, and still have sufficient satellites for effective positioning accuracy.

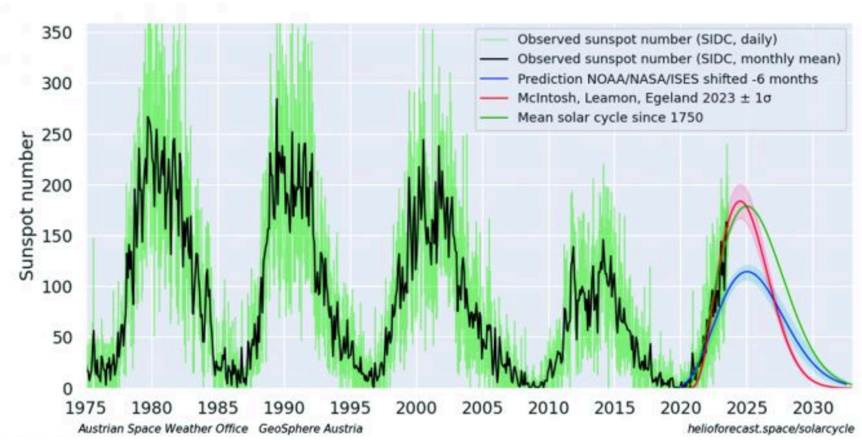


Figure 2: A chart showing sunspot numbers including predictions. (Image courtesy: Austrian Space Weather Office)

Advanced algorithms

Additionally, sophisticated algorithms can play a crucial role in ensuring the integrity and reliability of survey data, even in the face of solar activity. Algorithms built into today's modern receivers can be designed to detect and filter out erroneous or unreliable GNSS data that may be affected by the disruptions caused by solar storms. These advanced solutions evaluate all the parameters associated with an ionospheric impact for each satellite signal. Then, they adjust the positioning calculation proce and compensate for the estimated noise/errors int disturbances. This allows the receiver to still make partial use of satellites experiencing some ionospheric noise rather than discarding them, improving overall positioning accuracy during disturbed conditions.

Moreover, these algorithms can go beyond just filtering out problematic data. They can also combine information from multiple GNSS constellations, as well as other sensors like inertial measurement units (IMUs), to provide more robust and resilient positioning solutions. A sensor fusion approach can help geospatial professionals maintain productivity and accuracy, even when individual GNSS signals are disrupted by the effects of solar storms.

Purpose-built firmware

The emergence of purpose-built firmware to counteract the effects of Solar Cycle 25 is also making a difference. Solutions such as Trimble's IonoGuard are designed to mitigate ionospheric disruptions in positioning and navigation. When evaluating signals from multiple satellites, it rejects the measurements severely impacted by the ionosphere. It adjusts the processing of all remaining measurements by assessing several per-satellite metrics in a sophisticated GNSS positioning engine. The result is the position derived from measurements that extract as much information as possible under the current ionospheric conditions. IonoGuard has been tested in some of the most challenging atmospheric conditions. For instance, the G5-level geomagnetic storm in May 2024 – the most significant geomagnetic storm since 2003 – lasted for two days. NOAA's Space Weather Prediction Center measured its Estimated Planetary K-index (Kp) on a nine-point scale, on which it hit maximum values at various monitoring stations.

For example, the Northern Alberta GNSS receiver was on a 1.8km real-time kinematic (RTK) baseline. As shown in Figure 1, the ionospheric disturbance began at around 18:00 hours UTC on 10 May 2024, with significant 'noise' seen in the position solution. The receiver was clearly struggling to maintain an RTK-fixed solution mode, as RTK-fixed operation dropped below 91%. Conversely, a GNSS receiver on the same antenna running IonoGuard reflected a dramatic improvement in positioning performance. The system maintained an RTK-fixed solution mode throughout the entire geomagnetic storm as shown in Figure 2. Since not all satellites were affected equally at the same time, the firmware was able to form the best solution from available satellites.

Notably, users in areas affected by scintillation and disturbances reported being able to work through IonoGuard, while other machines were forced to stop due to positioning inaccuracies – and those errors are clearly visible in Figure 1. As the performance of the position degrades, the solution inflates the estimated error. Once the error estimate is above the customer's requirement, they will stop executing. However, while advanced firmware can greatly improve positioning accuracy even during extreme events, ionospheric activity can require a wait-and-see approach. Continuous monitoring is necessary when high precision is required.

Figure 3: Aurora Borealis (Northern Lights) over Scandinavia from the International Space Station. Elements of this image supplied by NASA.

Sources of informed insights

As Sir Francis Bacon was once quoted as saying, "knowledge is power," – and those words are especially true when dealing with the disruptive effects of solar activity. Various resources are available to help professionals stay informed about changing conditions and the potential for disturbances, such as the NOAA website and Spaceweather.com. NOAA's Space Weather Prediction Center tracks geomagnetic storm activity and provides colour-coded charts to indicate the magnetic storm level. This website issues geomagnetic storm alerts and timely notifications of impending space weather events. Notably, the significant solar storm that occurred in May 2024 was well documented and forecasted by NOAA days in advance.

In addition to storm alerts, the NOAA Geomagnetic Dashboard offers real-time visualizations of auroral activity on maps and plots of solar wind properties. Spaceweather.com complements the NOAA resources, providing daily updates and metrics on solar storms and their resulting geomagnetic and ionospheric effects. Another easy-to-use resource is Trimble's free online GNSS planning tool, which provides an overview of curre forecasted conditions. Trimble has established a g measurement network that allows users to plan ahead and avoid working during times when there is a higher probability of disturbance. The website includes options for satellite availability planning, with users able to choose their location and date/time in the future (based on published almanacs) to plan the best satellite availability. The website also presents total electron content (TEC) and scintillation models that are created by Trimble RTX server software.

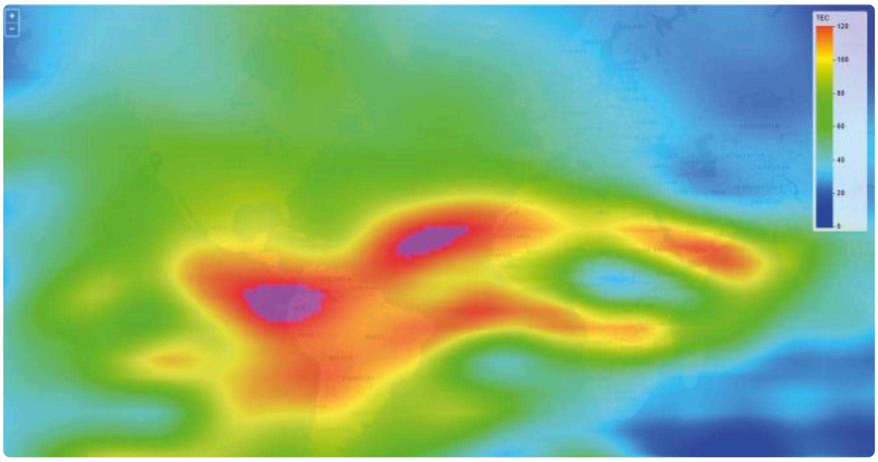


Figure 4: An example map of total electron content, TEC. (Image courtesy: Trimble)

Proactive preparation

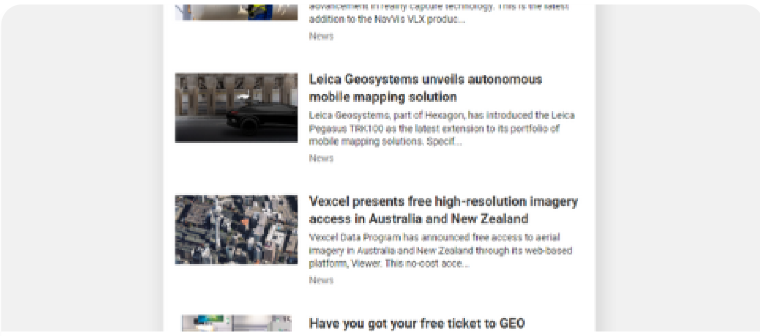
For applications that require precision or semi- and fully autonomous operations, the loss of GNSS signal due to solar events can be highly troublesome. To minimize the operational impact of such disruptions, geospatial professionals should ask their GNSS providers pointed questions about the performance of their equipment during periods of scintillation and high ionospheric activity. This includes gaining an understanding of how the technology fared during previous solar storms, as this can provide valuable insights into its ability to withstand the challenges posed by the current solar cycle peak. By engaging with GNSS providers, understanding the technological capabilities of their equipment and leveraging the power of advanced algorithms, every professional can better prepare themselves to weather the solar storm and maintain the accuracy and reliability of their work, even during periods of heightened ionospheric activity.

Further reading

https://www.swpc.noaa.gov/

https://www.spaceweather.com

http://www.gnssplanning.com/#/charts



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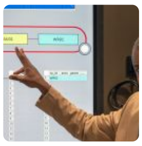

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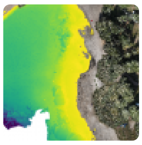

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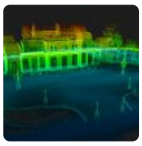

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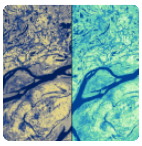

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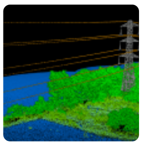

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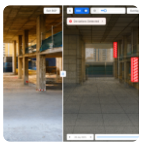

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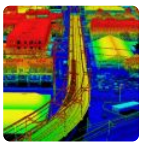

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