CAN I EXPERIENCE FAILURE OF MY NAVIGATION SYSTEM DUE TO SPACE WEATHER?

e-swan
EUROPEAN SPACE WEATHER AND SPACE CLIMATE ASSOCIATION

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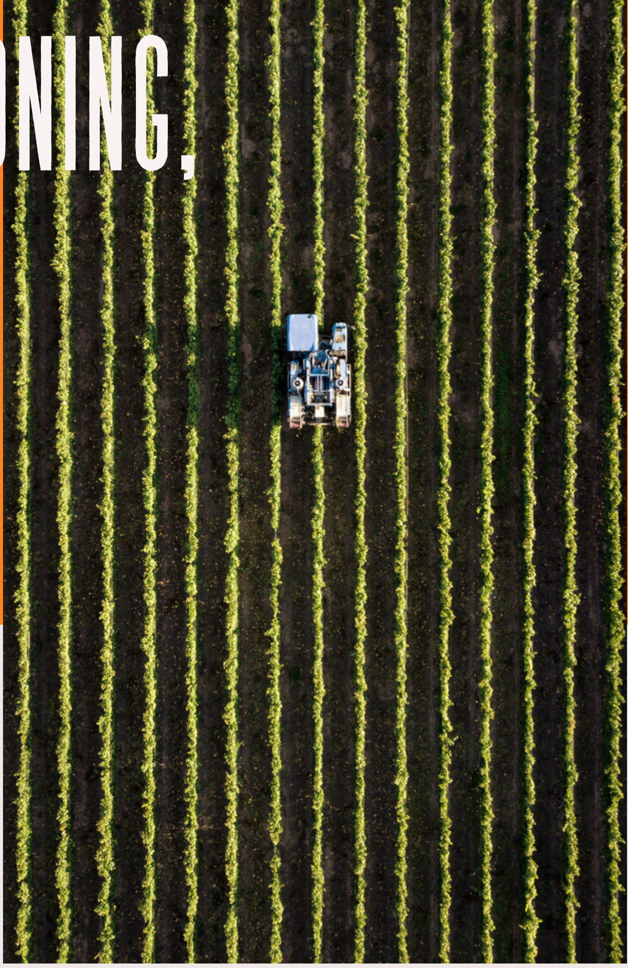
NAVIGATION, POSITIONING, AND TIMING IN TODAY'S WORLD



Long ago, people navigated by the Sun, Moon and stars. Today, we rely on a different kind of constellation — networks of satellites called GNSS, short for Global Navigation Satellite Systems — to guide us on land, at sea and in the sky. GPS (Global Positioning System) is the oldest and probably the best known among them.

These systems provide positioning, navigation, and timing information, supporting nearly every part of modern life. But this amazing service is not invulnerable — sudden disruptions can happen, and one surprising threat is space weather.

Where is GNSS used in modern life?

GNSS is woven into the fabric of our daily routines. From getting directions on your phone, driving to work, flying overseas, sailing across oceans, or simply withdrawing cash at an ATM — GNSS is working behind the scenes to support it. Here is where it shows up in our lives:

Everyday life: Real-time tracking helps you to know when your bus or train will arrive. GNSS also guides emergency services to incidents faster, and helps you find hotels, shops, or cafés straight from your phone.

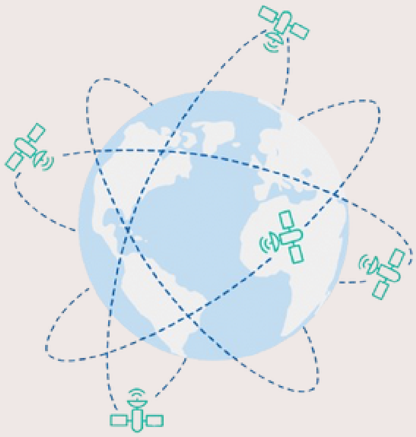
Business & industry: Farmers use it to guide tractors with centimetre or decimetre accuracy. Surveyors map the land for roads and buildings. Logistics companies keep deliveries on track while you follow your parcel's journey in real time. Banks rely on GNSS for precise time-stamping of transactions.

Space use: GNSS helps determine the position of Earth orbiting spacecraft and adjust the trajectory as needed. Ground stations use it to reliably track satellites and space missions in the Earth's environment.

Autonomous vehicles: From self-driving cars to automated assets in remote mining areas worldwide, GNSS enables novel ways of transport — no human driver is required.

Defence: Military and security agencies are major users of GNSS. It supports intelligence gathering, search and rescue, electronic warfare, and precision-guided systems.

HOW DOES GNSS WORK?



GNSS is a global system that tells your device where it is — whether you are walking down the street or flying through the clouds.

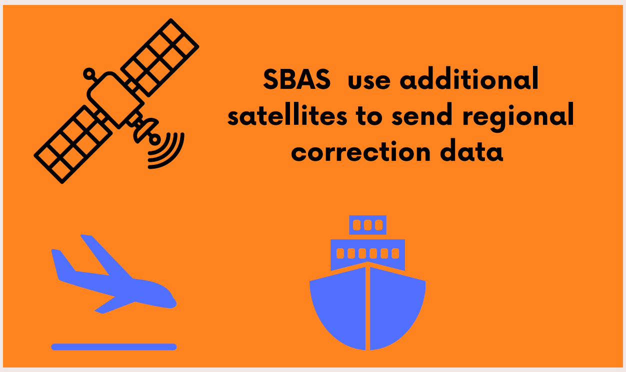
It works thanks to a group of satellites that orbit high above the planet (about 20,000 km up) and constantly send out signals.

These signals tell your device two things: where the satellite is located and the exact time the signal was sent.

Your phone, car, or other device with a GNSS receiver use signals from several satellites to figure out your exact location, how fast you are moving, and what time it is — all in real time!

GNSS is used in many applications, and each one provides a different level of accuracy, depending on use.

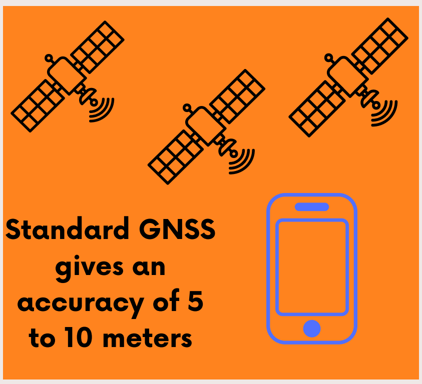
Standard GNSS, like the one in your smartphone or car, provides basic location tracking and works pretty much anywhere on Earth. It does not need supplementary equipment and typically gives accuracy within 5 to 10 meters— plenty for navigation and everyday use.

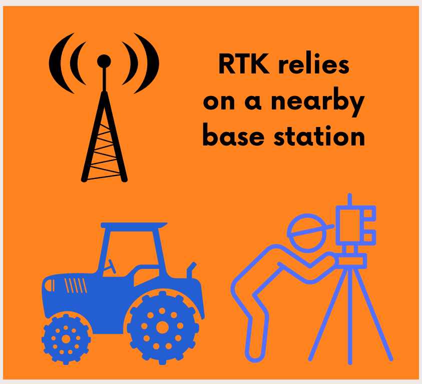


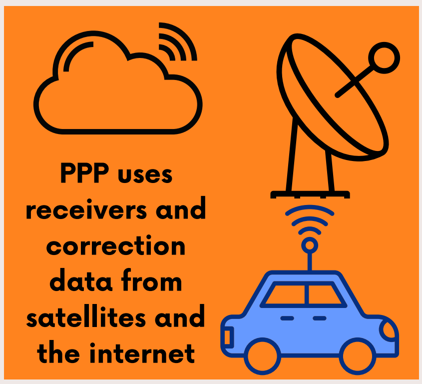
Real-Time Kinematic, or RTK, is much more precise. It relies on a nearby base station with known geodetic coordinates that shares positioning corrections in real time. This setup allows RTK to deliver centimeter-level accuracy, which is essential for applications like land surveying, high precision short range drone operation, and precision agriculture. However, it only works within a limited range — usually around 20 kilometers from the base — and requires more specialized gear.

Then there is Precise Point Positioning, or PPP. It also aims for high accuracy but does not rely on a local base station. Instead, it uses sophisticated receivers and correction data delivered via satellite or internet, often taking a few minutes to reach sufficiently high accuracy. PPP is useful for scientific monitoring, offshore work, or autonomous vehicles where wide-area coverage is needed but local infrastructure is not available.

Finally, Satellite-Based Augmentation Systems (SBAS) offer improved accuracy for standard GNSS by using satellites to send regional correction data. With an SBAS-capable receiver, you can get positioning precision down to 1–3 meters. SBAS is especially helpful in aviation — for safe landings — and maritime navigation, and it is available regionally across areas like Europe and North America.

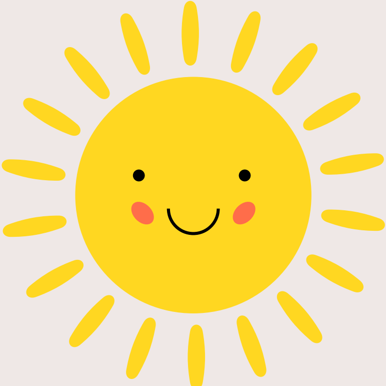






WHAT IS SPACE WEATHER?

Auroras are vivid signatures of space weather—caused by solar particles colliding with Earth's atmosphere near the poles. Their colours reveal the altitude and type of gas involved: green from oxygen at mid-altitudes, red from high-altitude oxygen, and purples or blues from nitrogen lower down. Image credit : Alex Dostie/UGC



Space weather refers to changing conditions in space, mostly caused by solar activity. Just like Earth has its own weather — think rain, wind, and storms — space has "weather" too, and it can impact the area surrounding our planet.

The Sun is the main source influencing space weather. It constantly releases energy and particles into space. When the Sun gets more active — especially during events like solar flares or coronal mass ejections (CMEs) — it can send large amounts of radiation and charged particles towards the Earth. These can disturb the Earth's magnetic field and the outer regions of our atmosphere, such as the ionosphere.

The ionosphere is a region of Earth's upper atmosphere, starting around 80 km altitude and stretching to about 600 km. It is filled with primarily neutral atoms (mostly oxygen) and a small proportion of charged particles (ions and electrons) created mostly by the interaction between solar radiation and particles in the upper atmosphere. This region is very important because it enables radio signals to travel and reach ground locations at long distances from the transmitter.

A filament eruption on the Sun, captured on August 31, 2012. A filament is a large mass of dense plasma suspended above the Sun's surface by magnetic fields. Filament can erupt into space affecting satellites and power grids. Image credit : NASA

The main space weather drivers are:

- **Solar wind:** A steady stream of charged particles flowing from the Sun. A solar storm can drive the solar wind to a higher than usual speed.
- **Solar flares:** Powerful explosions on the Sun's surface that release bursts of energy and radiation. These can disrupt radio and satellite signals here on Earth.
- **Coronal mass ejections (CMEs):** Huge clouds of plasma and magnetic fields thrown out from the Sun. If they hit the Earth's magnetic field, they can cause geomagnetic storms. Geomagnetic storms are disturbances in the Earth's magnetic field which can have an impact on satellite orbits, GNSS signal propagation, power grids, and radio communication.
- **Solar proton events:** Surges of high-energy protons from the Sun. These are especially dangerous to astronauts and can damage satellite electronics.

HOW DOES SPACE WEATHER SHAKE THINGS UP?

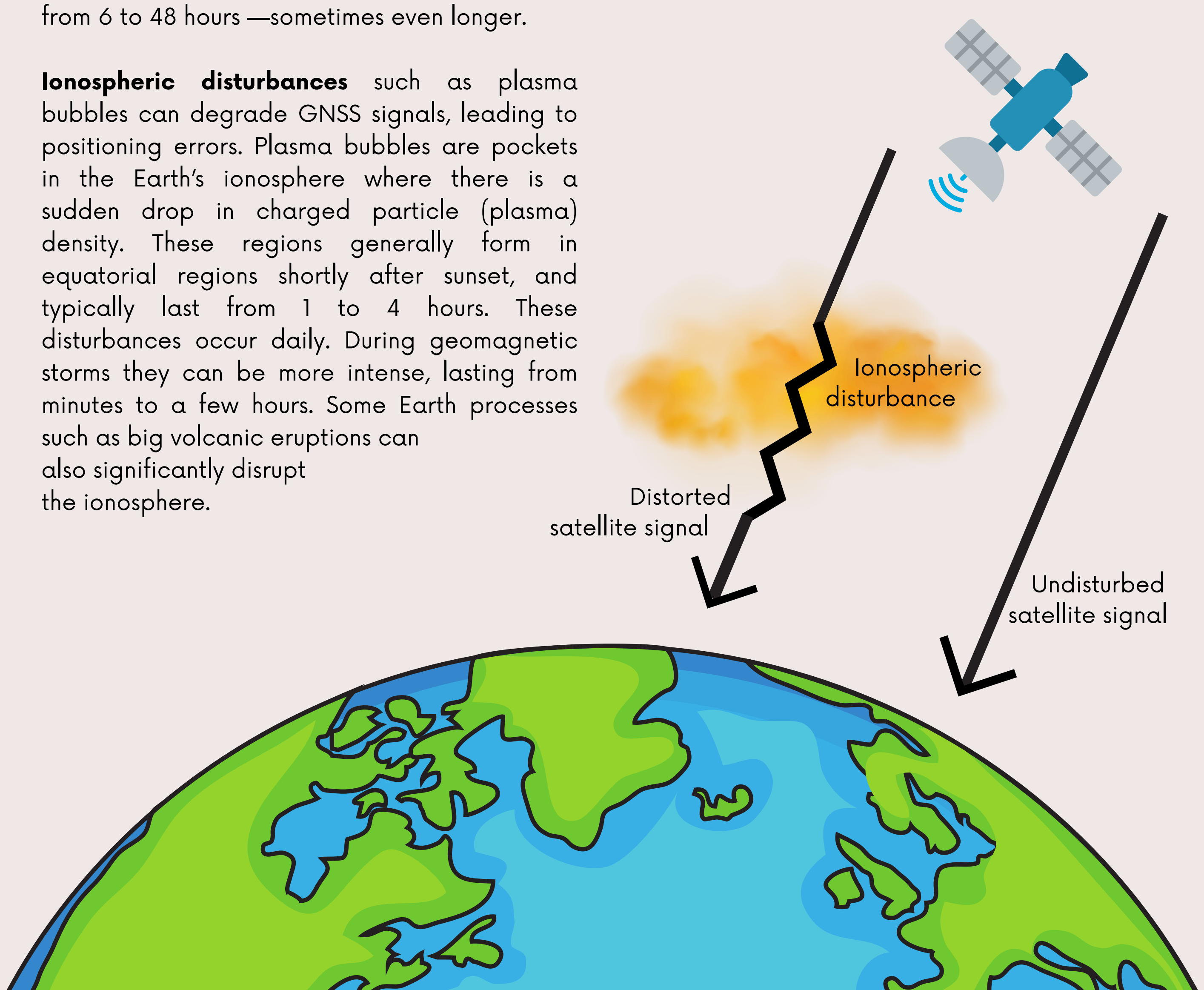
During **solar flares**, the Sun emits intense bursts of electromagnetic radiation such as X-rays and, occasionally, strong radio waves. The X-rays rapidly impact the lower ionosphere, increasing ionization which causes short-wave radio fadeouts that disrupt HF communications. Meanwhile, the flare's radio emissions—if they occur at GNSS frequencies—can overwhelm satellite signals, leading to degraded or lost GNSS performance. Strong solar flares can last from 15 minutes to several hours, and may occur a few times per year.

Geomagnetic storms disturb Earth's magnetic field and can interfere with GNSS signals, making them less reliable. These storms are relatively common, occurring between 20 and 150 times a year, and they usually last anywhere from 6 to 48 hours —sometimes even longer.

Ionospheric disturbances such as plasma bubbles can degrade GNSS signals, leading to positioning errors. Plasma bubbles are pockets in the Earth's ionosphere where there is a sudden drop in charged particle (plasma) density. These regions generally form in equatorial regions shortly after sunset, and typically last from 1 to 4 hours. These disturbances occur daily. During geomagnetic storms they can be more intense, lasting from minutes to a few hours. Some Earth processes such as big volcanic eruptions can also significantly disrupt the ionosphere.

Lastly, **ionospheric scintillation** is the resulting effect of these disturbances on satellite signals as they pass through the ionosphere and make signals flicker or fade in and out. This causes short-term glitches in GNSS performance and is especially common near the equator and in the auroral zones. Scintillation can last from seconds to several hours, depending on factors such as location, season, and solar activity.

Even though some of these effects are small, a severe space weather event can substantially amplify their impact on GNSS performance and degrade the operation of other satellite systems — making it harder to navigate, track, or get accurate timing.



HOW IS SPACE WEATHER IMPACT MITIGATED?

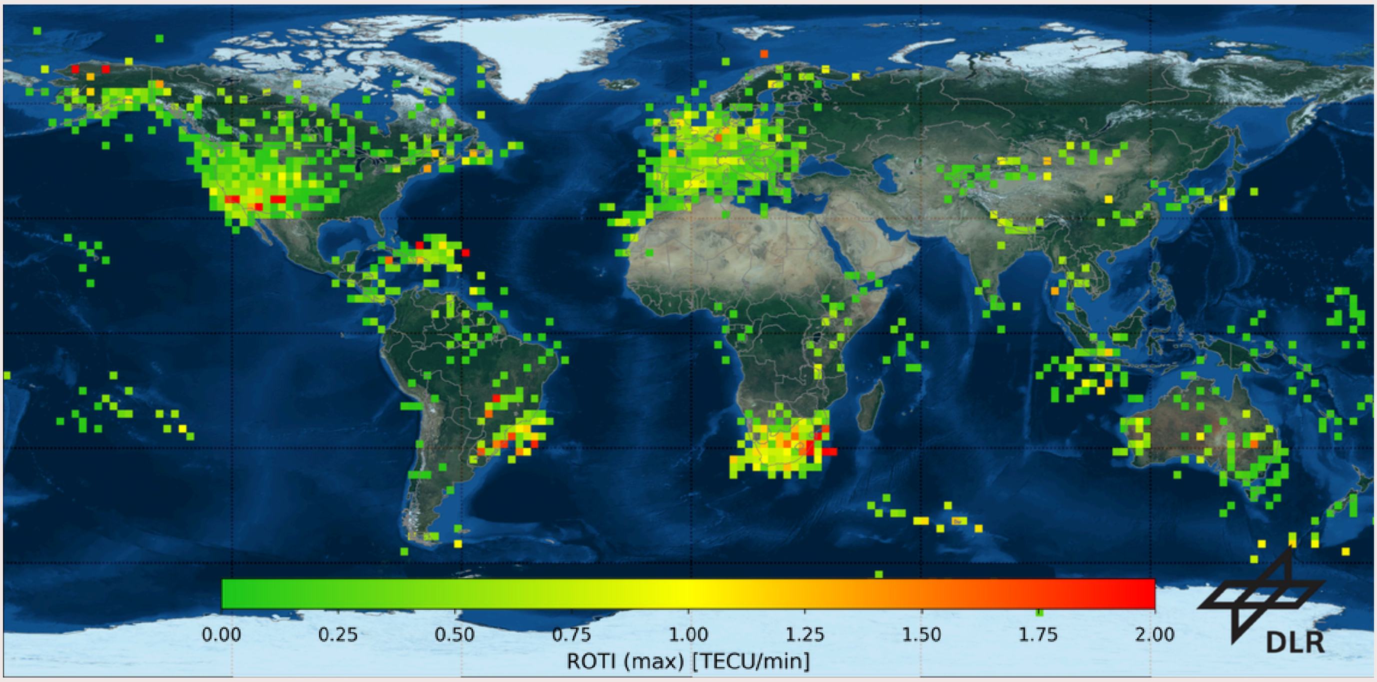
Image credit : NASA

No matter where we live, the services provided by GNSS constellations pervade every aspect of our daily life. And yet, a significant space weather event has the potential to disrupt many of the systems we rely on, from banking and finance to the way we plant our crops and navigate in our cities.

Space weather centres around the world monitor solar activity and produce daily summaries, alerts and warnings about events on the Sun that have the potential to disrupt GNSS services. Some centres provide email subscription products that are delivered directly to your inbox.

If an adverse space weather event is observed, space weather centres issue GNSS advisories for ICAO, the International Civil Aviation Organization. This enables air crews to take mitigation measures if necessary.

Learning about space weather can help individuals and industries anticipate and mitigate disruptions to GNSS services, protect critical infrastructure, and maintain access to the systems we depend on - whether for navigation, communication, positionning, or timing. It is an essential step in our technology-driven world!



On this map, green squares indicate undisturbed ionospheric conditions and orange and red squares indicate ionospheric irregularities. This map was compiled on October 8, 2025 by the Ionosphere Monitoring and Prediction Center (IMPC) using GPS data. It represents the Rate of Total Electron Content index (ROTI). This index indicates how quickly the electron density is fluctuating.

E-SWAN EDUCATION AND OUTREACH COMMITTEE

What is E-SWAN?

The European Space Weather and Space Climate Association (E-SWAN), founded in 2022, is a non-profit organization working to unite and develop European activities in space weather and space climate. E-SWAN aims to achieve this through various means, including organizing conferences, supporting early career scientists, promoting education, and fostering collaboration between scientists, engineers, and stakeholders. E-SWAN's focus is on Europe, but it also collaborates internationally to raise awareness of the impact of space weather.

What is EOCOM?

EOCOM, the Education and Outreach Committee of E-SWAN, works to bridge the gap between the Space Weather and Space Climate (SWSC) community and the general public. Activities include creating a social media presence, running SWSC courses and webinars, publishing a SWSC book, and enriching the E-SWAN website. These efforts aim to raise public awareness of SWSC's impact in Europe, distribute scientific knowledge, and promote educational opportunities within the field.

About this booklet

This informative booklet, "Can I experience failure of my navigation system due to space weather?", was written by Sophie Chabanski, Emmy Nagar, Lisa Nelson, Jan Janssens, Jean Lilensten, Corentin Liber, and Elke D'Huys.

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