Services for GNSS users provided by the Expert Service Center Ionospheric Weather within ESA Space Situational Awareness Programme

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Keywords: Ionosphere, space weather, service, GNSS
Topics: Atmosphere and Space Weather

Abstract

The ionosphere impacts transionospheric radio signals by delay, refraction and diffraction. This includes navigation signals transmitted by Global Navigation Satellite Systems (GNSS). The highly variable ionosphere affects the accuracy, availability, continuity and integrity of GNSS signals. Since GNSS services are relevant in diverse safety of life and precise positioning applications, detection, monitoring and prediction of ionospheric effects are important for mitigating related threats to human life and economy.

Within the Space Situational Awareness (SSA) Programme the European Space Agency (ESA) aims to help end-users in a wide range of affected sectors to mitigate the effects of space weather on their

systems, reducing costs and improving reliability. Currently, a comprehensive system to monitor, predict and disseminate space weather information and alerts is being developed. Within this activity, a dedicated space weather network is organized around internationally distributed Expert Service Centres (ESCs). Being part of this network, the ESC Ionospheric Weather comprises the expertise concerning space weather effects in the upper atmosphere, including the ionosphere. This expertise is specifically applicable in the domains of transionospheric radio links and space surveillance and tracking.

The requirements and design of the services to be provided in the SSA space weather network have been compiled based on intensive communication with end-users during the SSA Preparatory Phase. Now, initial services are available and we will show an overview on the currently operating ESC Ionospheric Weather. This includes the provided services and products, the targeted end-user groups and the contributing expert groups. We will start to show the current product delivery and describe the further developments as part of the currently active SSA Period 2. In order to improve the network support capabilities and the tailoring of its services we are keen to gather feedback and requirements from end-users within the navigation and positioning sector.

All the products and tools within the SSA space weather network are accessible through the SSA Space Weather Portal at http://swe.ssa.esa.int/ .

Introduction

The ionosphere impacts transionospheric radio signals by delay, refraction and diffraction. This includes navigation signals transmitted by Global Navigation Satellite Systems (GNSS). The ionosphere is the strongest error source in standard positioning and one of the strongest in differential positioning as well as precise point positioning and real-time kinematics (RTK). But, the highly variable ionosphere does not only affect the accuracy but also the availability, continuity and integrity of GNSS signals. Since GNSS services are relevant in diverse safety of life and precise positioning applications, detection, monitoring and prediction of ionospheric effects are important for mitigating related threats to human life and economy.

Space Weather affects end-users in a wide range of sectors, which have been grouped into 8 domains. Within the Space Situational Awareness (SSA) Programme the European Space Agency (ESA) aims to help these end-users to mitigate the effects of space weather on their systems, reducing costs and improving reliability. Currently, a comprehensive system to monitor, predict and disseminate space weather information and alerts is being developed. A diagramme illustrating ESA's SSA Space Weather network is shown in Fig.1. It demonstrates the organisation of the network's principal ground facilities and infrastructure. The first set of 'initial' Expert Service Centres (ESCs) will be expanded during the Programme's Period 2 (2012-16) and will be complemented by a new Heliospheric Weather ESC [5].

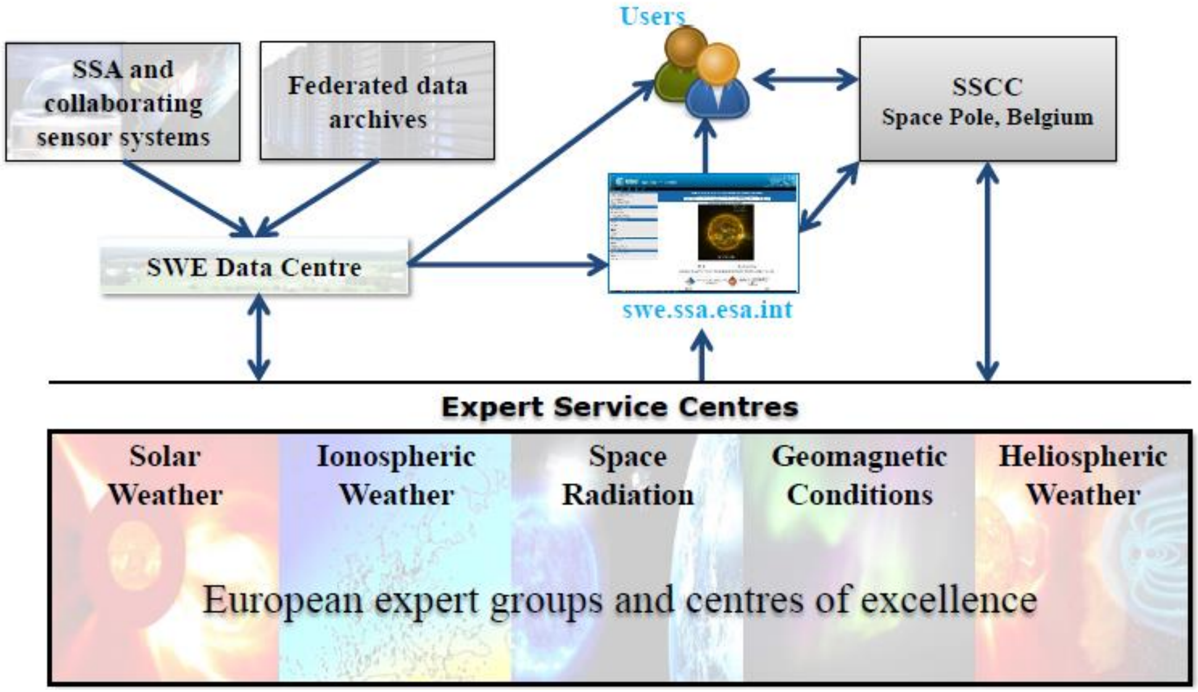


Figure 1 **SSA Space Weather Network.**

The mission of the Space Weather network of ESA is to fully exploit, develop, integrate and provide operational products and services based on the best available European expertise to the community of end-users. The purpose is to provide the public high quality and reliable forecasts, nowcasts, archives, warnings and alerts and expert advice as well as to demonstrate and assess the influences of Space Weather and to support end-users for any required mitigation.

This report is an update of the recent description in [6].

Expert Service Centre Ionospheric Weather

The ESC Ionospheric Weather (I-ESC) is part of the SSA space weather network. Its mission is to provide the functionalities, capabilities and expertise in the Transionospheric Radiolink (TIO) and Space Surveillance and Tracking (SST) domains that are needed within the ESA space weather network to achieve its mission of issuing public high quality and reliable forecasts, nowcasts, archives, warnings and alerts and providing expert advice as well as demonstrating and assessing the influences of Space Weather and supporting end-users in their required mitigation strategies. The I-ESC thus provides, implements and supports the Ionospheric and Thermospheric Weather products and capabilities of the ESA SWE network, including the observation, monitoring, interpretation, modelling and forecasting of Ionospheric and Thermospheric Weather conditions.

In the SSA programme, the I-ESC aims in a long term goal to develop a fully operational service for the TIO and SST service domains as far as possible under the governance and financial conditions. The vision for the fully fledged I-ESC is to respond to the needs of the end users within the TIO and SST domains. According to the results of an assessment in the Preparatory Phase of the SSA Programme, the I-ESC assumes the following user types in the TIO domain:

- Users of GNSS single frequency services with average accuracy, no integrity (e.g. typical GNSS mass market user)
- Users of GNSS single frequency services with average accuracy, using integrity (e.g. EGNOS user)
- Users of multi-frequency GNSS systems with average multi-frequency accuracy, no integrity (commercial services, public regulated services)
- Users of multi-frequency GNSS systems with average accuracy, integrity (aeronautical multi-frequency)
- Users or multi-frequency GNSS systems with very high accuracy (e.g. GNSS geodetic users, Real-Time Kinematics)
- Users of satellite data communications with high availability / continuity (e.g. Search-and-Rescue, Air Traffic Control/Management via Satellite, high availability/continuity data networks such as Galileo Ground Segment Data Network).
- Other space-based services/products users affected by the ionosphere (UHF - C-band radars, GNSS-R altimetry, UHF/low microwave radio astronomy and deep space communications)

And the following user types are assumed in the SST domain:

- Surveillance and tracking center(s), stations and services
- Spacecraft operators
- Collision warning services
- Re-entry risk assessment services

An example for space weather affecting the TIO domain is shown in Fig. 2 and Fig.3.

Fig.2, top-left panel shows a map of the Rate-Of-TEC Index (ROTI), which is a measure of ionospheric turbulence. Higher ROTI corresponds to more noise in the phase observables of the GNSS signals, and ultimately more noise in the position solution. At the time shown, there is significant ionospheric turbulence over large parts of Scandinavia.

Fig. 2, top-right panel shows a map of the Vertical Total Electron Content (vTEC). TEC cause delays in GNSS signals, which can lead to large errors if they are not handled. Dual-frequency receivers can eliminate most of this effect, while single-frequency receivers need to mitigate it by obtaining information from external sources (e.g. EGNOS).

Fig. 2, bottom panels show maps of the scintillation indices S4 and sigma_phi, which are measured by specialized receivers and correspond to the most severe error sources for GNSS signals. Large scintillation values will cause cycle slips and loss of lock.

Fig. 3 show maps of the availability of APV-I navigation, as a percentage of time for a whole day. The system is defined to be working well if the availability is 99% or more (the dark orange and red areas of the plot). During the days of the storm, the coverage dropped below its criterium in Iceland, Norway, Sweden, Finland and Spain.

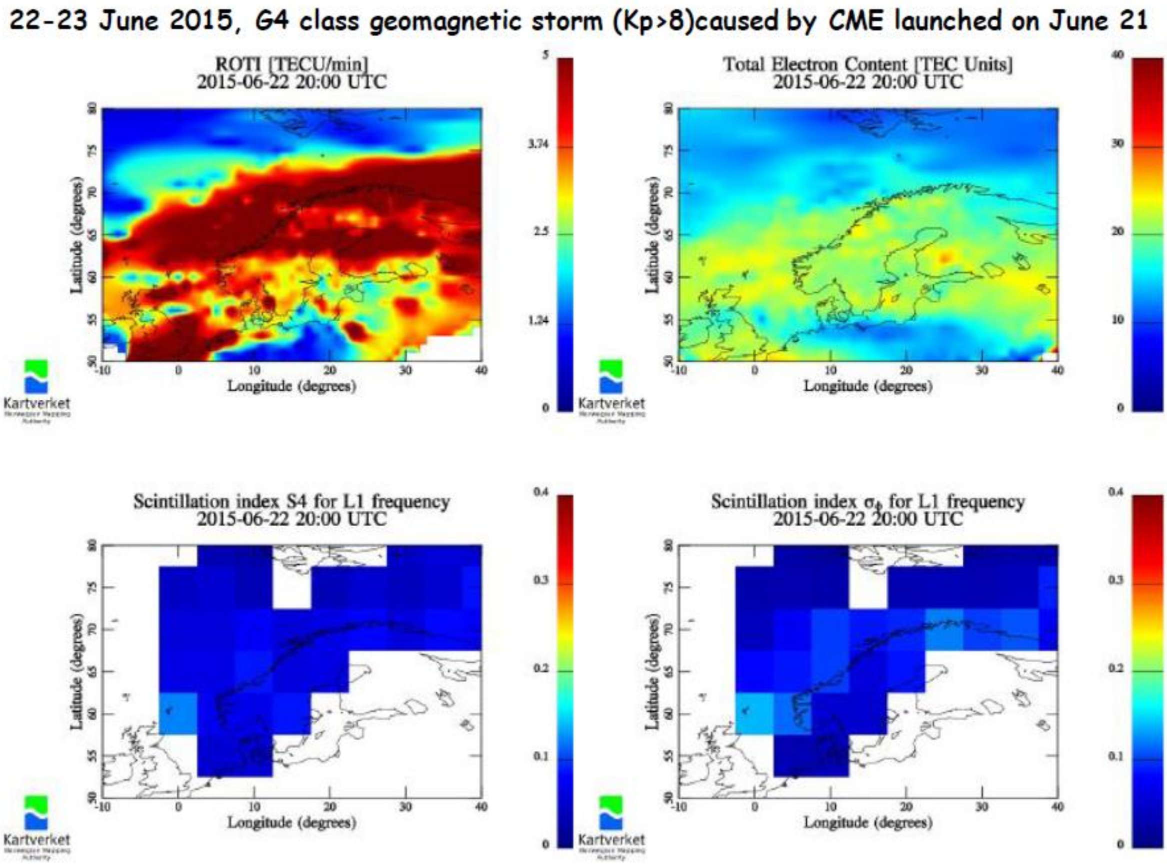


Figure 2 Example for ionospheric perturbations during 22-23 June 2015 geomagnetic storm.

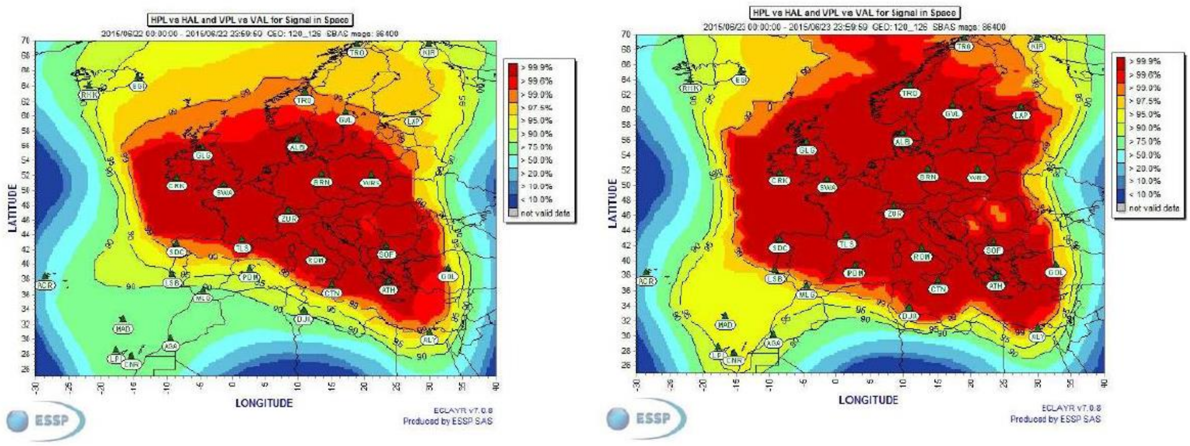


Figure 3 EGNOS performance during 22-23 June 2015 geomagnetic storm.

The services in the I-ESC which are relevant for GNSS users are:

- Near real-time Total Electron Content (TEC) maps (TIO/tcr)
- Forecast TEC maps (TIO/tcf)
- Quality assessment of ionospheric correction (TIO/qua)

- Near real-time ionospheric scintillation maps (TIO/sci)
- Monitoring and forecast of ionospheric disturbances (TIO/for)

The I-ESC will address significant service enhancements during the SSA Period 2. Regular updates of the space weather customer requirements document [2] and the space weather asset database [4], based on revisions and user feedback, will ensure a permanent development of the I-ESC.

Figure 4 Overview on currently contributing expert groups in the I-ESC.

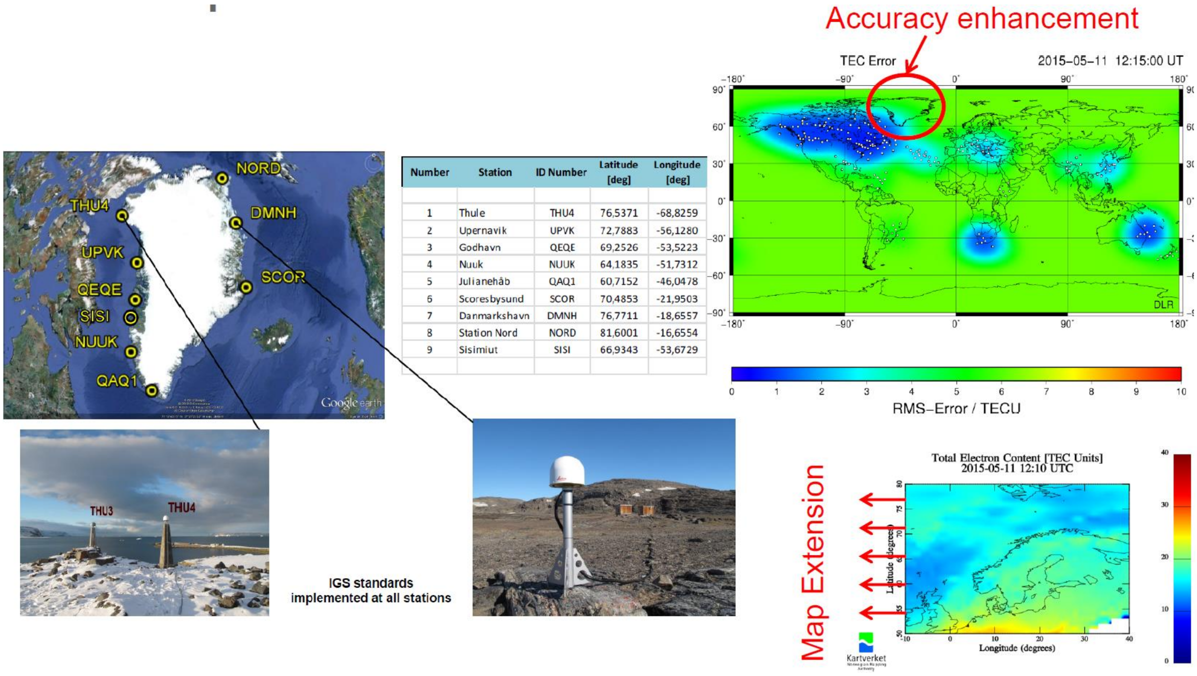
Currently, nine expert groups are contributing by product provision or development to the services for GNSS users in the I-ESC. An overview of these expert groups is shown in Fig. 4.

The coordination of the I-ESC will be performed by DLR. The currently nine expert groups will be complemented during Period 2 through new expert groups, data and products. An Ionospheric Weather ESC advisory board will constantly support the ESC coordinator in his duty to organize the development and operation of the I-ESC services. A continuous network extension and development are the vision of the ESC. Therefore, the initial assets and groups involved in the ESC will be complemented by others extending the network and integrating additional and new products into the I-ESC.

Evolution towards a Space Weather Service for GNSS Users

The vulnerability of the GNSS system to space weather is well known [1]. However, the risks to specific applications like transportation, avionics, automotive, survey, precise agriculture, surveillance, etc. are not well understood. Therefore, the user feedback and requirements is essential for further development and improvement of the I-ESC services for GNSS users. The first contact point for users to the the SSA Space Weather Portal at http://swe.ssa.esa.int/ and the SWE Service Coordination Centre (SSCC, helpdesk.swe@ssa.esa.int)

Based on the current knowledge, documented in [4] and [2], the I-ESC will receive substantial development in three ways within the next years. At first, the basis for the sustainability of the I-ESC will be set by compiling a dedicated definition and development plan based on the existing customer requirements document, system requirements document and roadmaps. Constant user feedback and test campaigns will be used to permanently keep these documents updated. Second, substantial development of existing and new products will enlarge the capabilities of the I-ESC.



Number	Station	ID Number	Latitude [deg]	Longitude [deg]
1	Thule	THU4	76,5371	-68,8259
2	Upernavik	UPVK	72,7883	-56,1280
3	Godhavn	QEQE	69,2526	-53,5223
4	Nuuk	NUUK	64,1835	-51,7312
5	Julianehâb	QAQ1	60,7152	-46,0478
6	Scoresbysund	SCOR	70,4853	-21,9503
7	Danmarkshavn	DMNH	76,7711	-18,6557
8	Station Nord	NORD	81,6001	-16,6554
9	Sisimiut	SISI	66,9343	-53,6729

Figure 5 TEC enhancement during P2-SWE-I activity

Within the next years, existing TEC maps will be improved not only by including additional receivers in the TEC map generation processors, but also in upgrading the technology readiness levels of each processor. Furthermore, the scintillation product will be enhanced by additional receivers especially at high latitudes. Finally, new products will be added to the I-ESC services, e.g. solar flare monitors, quality data for scintillation and ROTI (Rate of TEC index) maps for Europe. The third development activity concerns the I-ESC network extension. Further product development activities are executed within the SSA Programme and other ESA and EU programmes. As these developments mature, inclusion of relevant existing new or updated products into the I-ESC is foreseen.

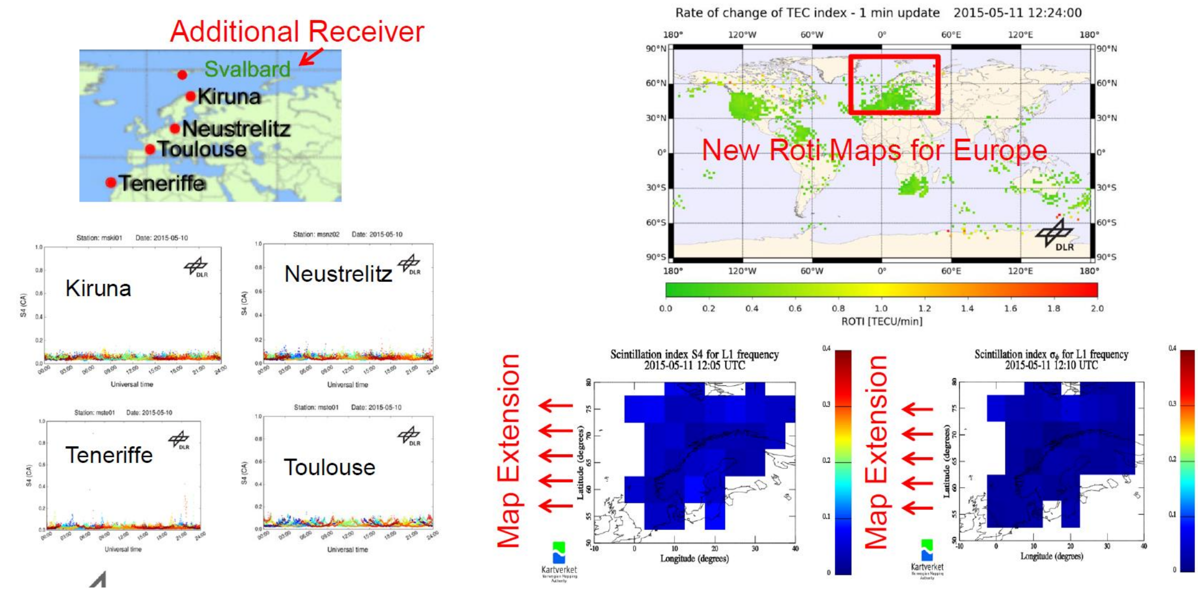


Figure 6 Examples for the upgrade of scintillation products provided in the I-ESC

Summary

The ESA SSA programme is driving the development of a system to monitor, predict and disseminate space weather information and alerts, including products and services available for use by the GNSS end user communities. This development process is guided by regular assessments of the requirements and of the product quality, with end users in the loop. The challenge of this process is to understand the user needs and to translate them into targeted services providing accurate and timely space weather information. The GNSS end user communities are therefore invited to contribute with feedbacks and recommendations.

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