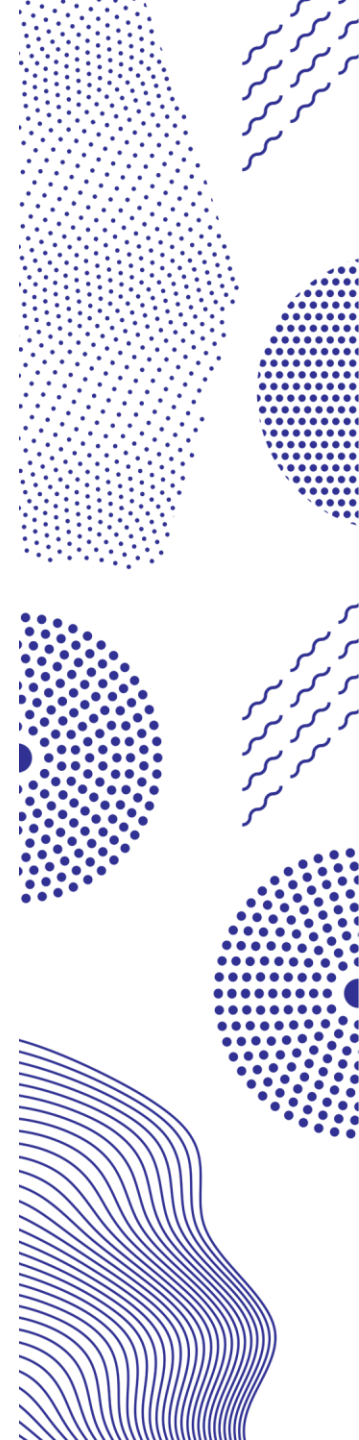


Use case demonstration on the SWIGPAD API service for creating GNSS performance indicator maps

United Nations/Finland Workshop on the Applications of Global Navigation Satellite Systems

26.10.2023

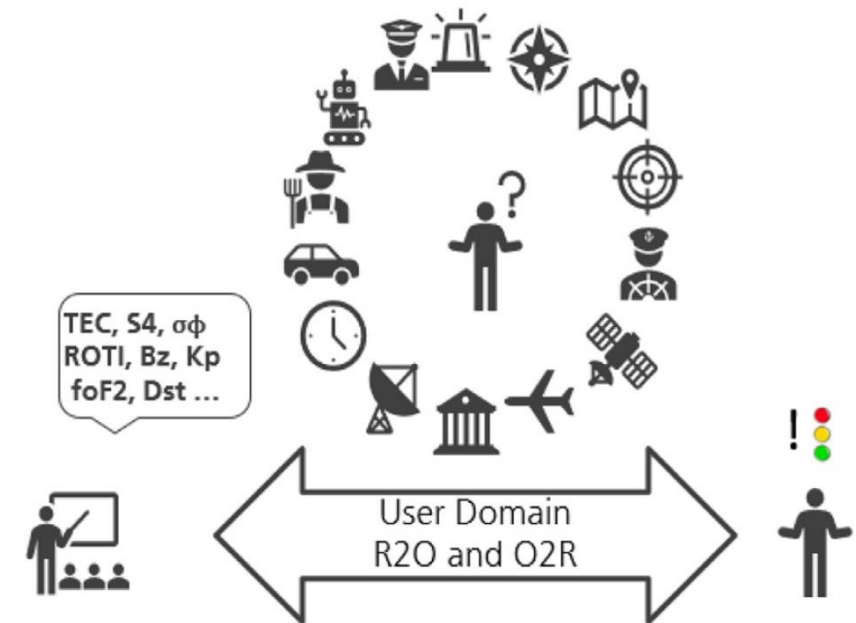
Elias Hirvonen, Kirsti Kauristie, Jens Berdermann,
Paul David, Martin Kriegel, Vincent Fabbro,
Knut Stanley Jacobsen



SWIGPAD and GPI



- Space Weather Impact on GNSS Performance: Application Development (SWIGPAD) - project created GNSS performance indicators (GPI)
- GPI combines multiple space weather data into a simple indicator value
- Data is available in ESA Space Weather Service Portal (ESA SWE)
<https://swe.ssa.esa.int/>
- Object of GPI is to simplify space weather products for user friendly format



GPI source data

- The source data used for GPI is available from the ESA SWE portal
- Scintillation indices: $S4$, σ_{ϕ}
- Total Electron Content (TEC)
- Rate of change of TEC (ROT)
- Rate of change of TEC index (ROTI)
- Geomagnetic activity (K_p)

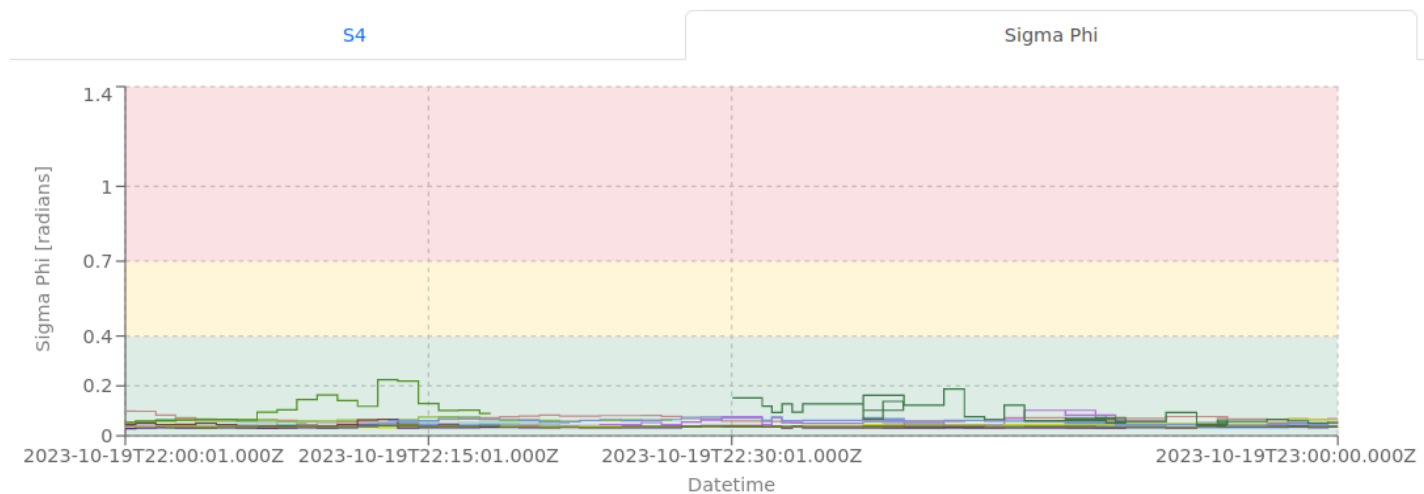
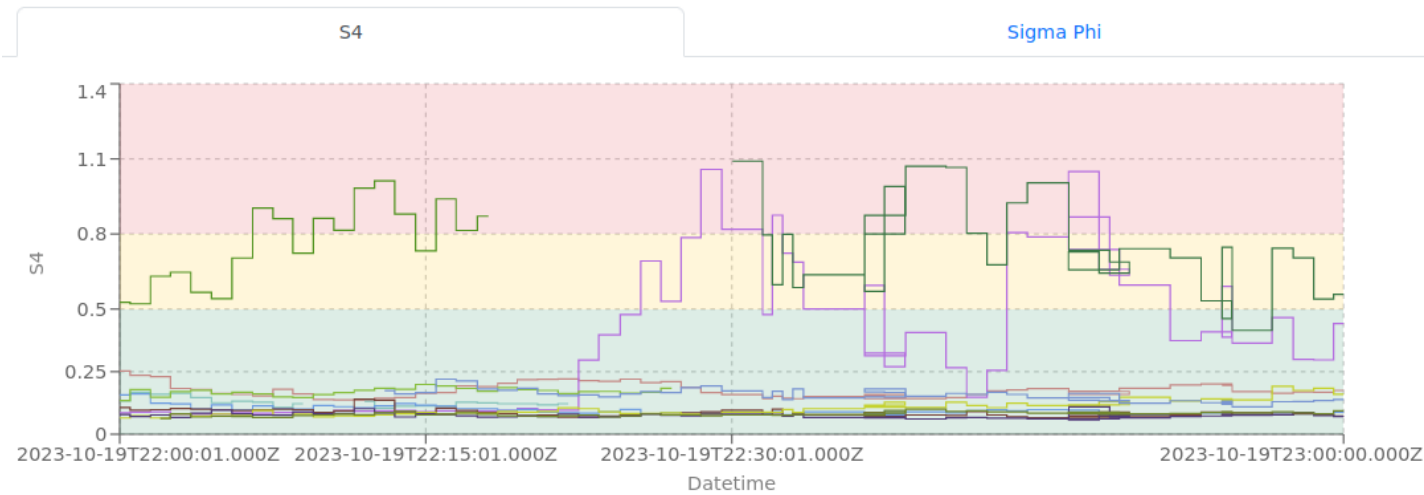
Data providers

- German Research Centre for Geosciences (GFZ)
- German Aerospace Center (DLR)
- Institute of Space Science Romania (ISS Romania)
- Swedish Institute of Space Physics (IRF)
- Norwegian Mapping Authority (NMA)

GNSS Scintillation

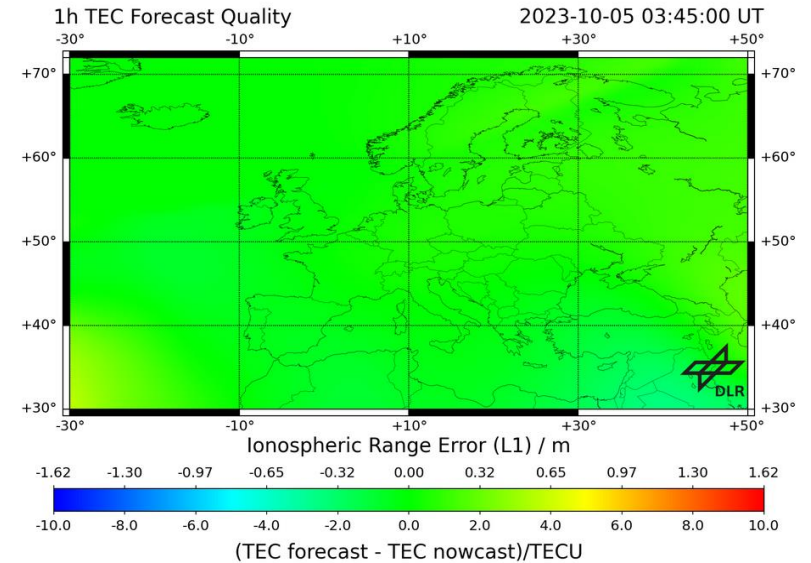
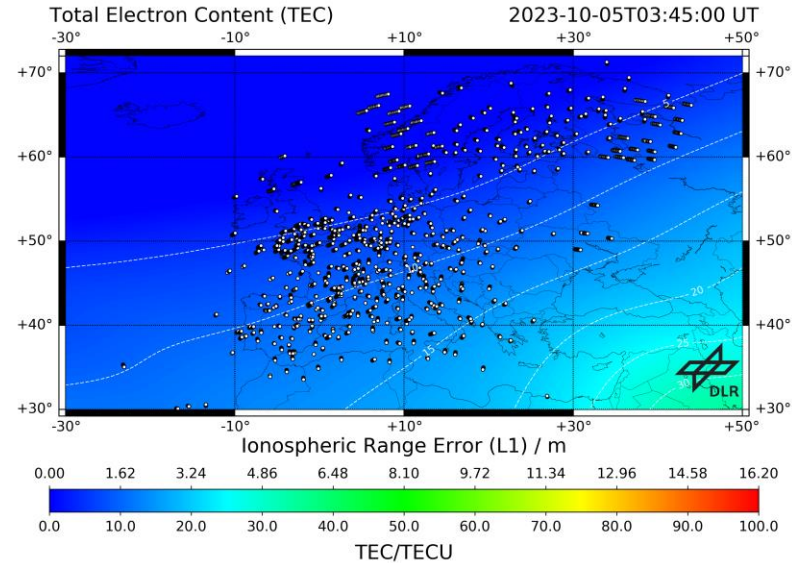
- Amplitude scintillation S4
- Phase scintillation $\sigma\phi$

Time series of scintillation indices for GNSS station MSTE01:

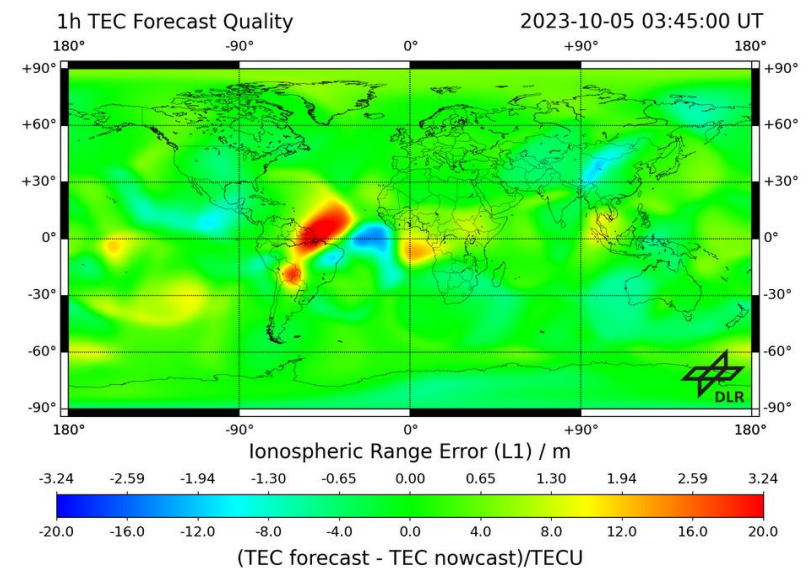
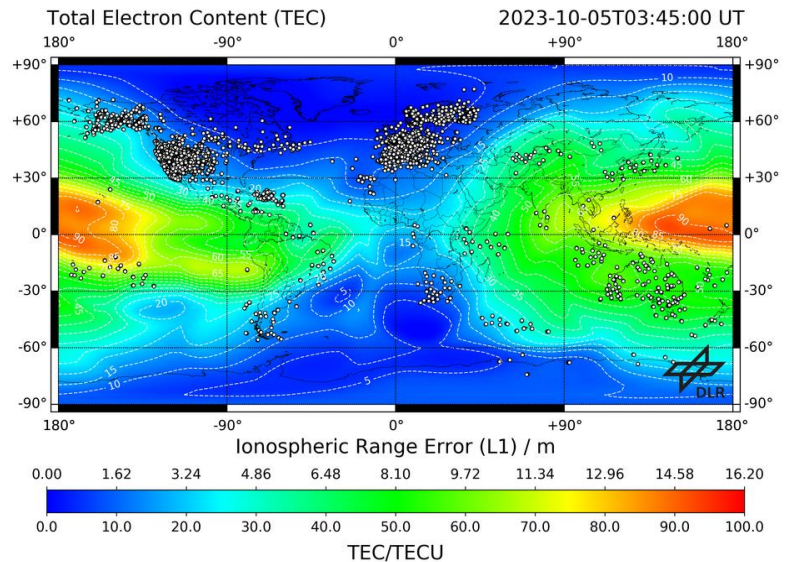


Total Electron Content (TEC)

- Europe TEC
- Europe TEC forecast

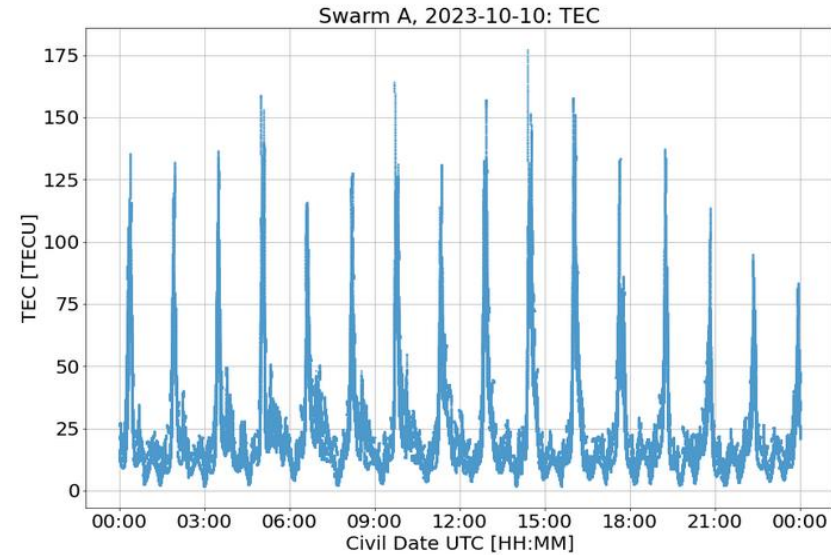


- Global TEC
- Global TEC forecast

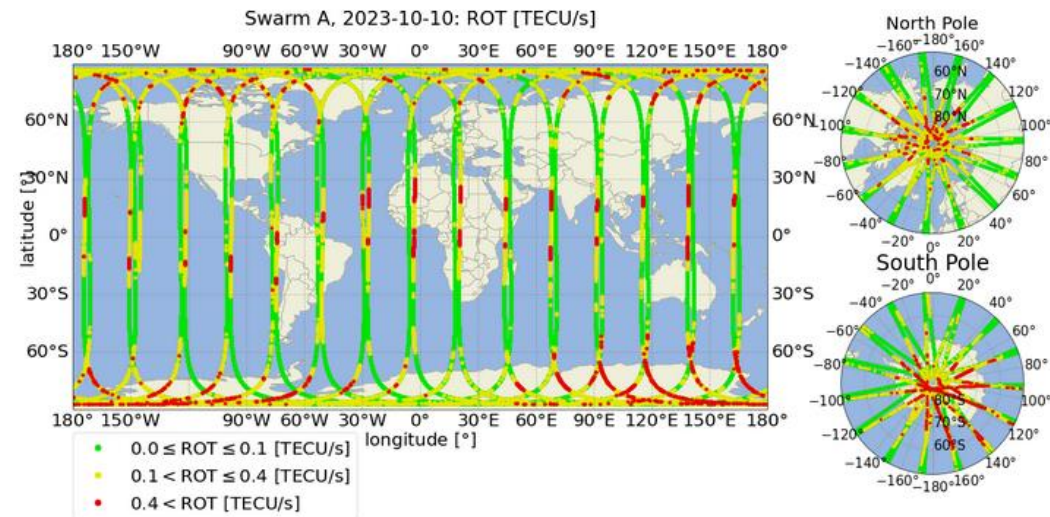


Total Electron Content (TEC)

- Swarm TEC

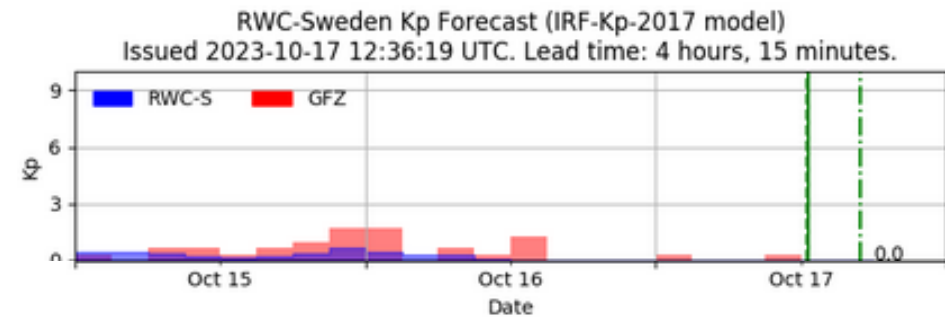
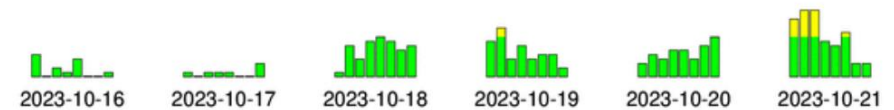
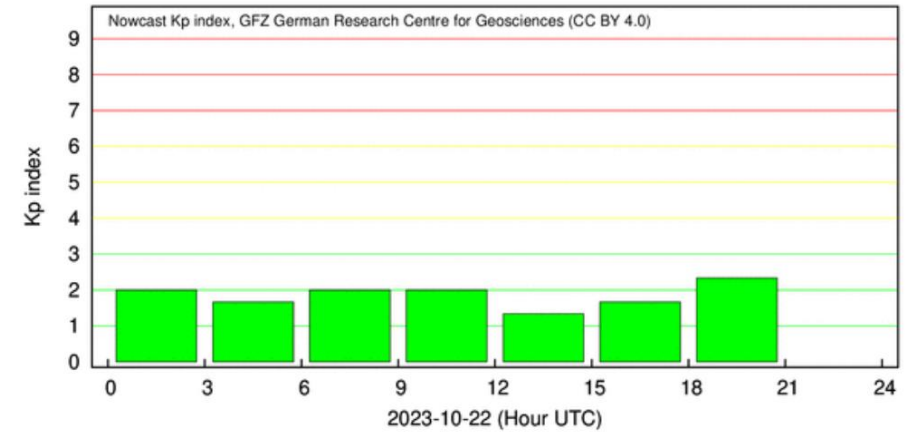


- Swarm ROT



Global geomagnetic activity (Kp)

- 3h Kp index
- Kp forecast



User groups

- ESA has identified 6 groups of GNSS users
- GPI is calculated for the user groups differently depending on the group interest and which parameter is more valid for it
- In future the scaling could be modifiable by user

Table 1

User groups of the ESA space weather service networks transionospheric radio link service domain defined in the SSA customer requirements document.

USER GROUP	DESCRIPTION
SWE-CRD-TIO-USR-01	Users of GNSS Single frequency services with average accuracy, no integrity (e.g. typical GNSS mass market user)
SWE-CRD-TIO-USR-02	Users of GNSS Single frequency services with average accuracy, using integrity (e.g. European Geostationary Navigation Overlay Service (EGNOS) user)
SWE-CRD-TIO-USR-03	Users of multi-frequency GNSS systems with average multifrequency accuracy, no integrity (commercial services, Public Regulated Services (PRS))
SWE-CRD-TIO-USR-04	Users of multi-frequency GNSS systems with average accuracy, integrity (aeronautical multifrequency)
SWE-CRD-TIO-USR-05	Users of multi-frequency GNSS systems with very high accuracy (e.g. GNSS geodetic users, Real-time kinematic positioning (RTK))
SWE-CRD-TIO-USR-06	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) and other space-based services/products users affected by the ionosphere (Ultra-high frequency (UHF) - C-band radars, GNSS reflectometry (GNSS-R) altimetry, UHF/low microwave radio astronomy and deep space communications)

GPI parameters

- User group (1-6)
- Location (latitude and longitude)
- Datetime or timeseries (max 6 points)
- Advanced:
 - Satellite constellations (GPS, GLONASS, Galileo, BEIDOU, QZSS)
 - Coordinate error accuracy (North, East, Vertical)
 - Positioning error probability confidence level (sigma)

GPI GUI at ESA SWE



- Available at ESA SWE (Login required)
<https://swe.ssa.esa.int/>
- Expert Service Center -> Ionospheric Weather -> Contributions -> DLR

The screenshot displays the ESA Space Weather Service Network interface. The top navigation bar includes the user name 'Elias Hirvonen', the ESA logo, and a welcome message. The left sidebar contains a menu with categories like 'CURRENT SPACE WEATHER', 'SPACE WEATHER SERVICES', and 'EXPERT SERVICE CENTRES'. The main content area is titled 'Ionospheric Weather Expert Service Centre (I-ESC)' and features a 'Contributions' tab. Under this tab, it lists current products provided by the I-ESC, including a section for the German Aerospace Center (DLR) with sub-sections for 'GPI' (GNSS Performance Indicator) and 'IMPC' (Ionospheric Monitoring Products Catalogue). The IMPC section lists various TEC maps and indices, such as I.101b, I.102b, I.103b, I.104b, I.105a, I.105b, I.106, and I.124. Other contributing centers like GFZ and SRC PAS are also listed at the bottom.

GPI GUI at ESA SWE



Federated products from the German Aerospace Center (DLR)



GNSS Performance Indicators About Help

Input

Latitude: Longitude:

User Type:

Date & Time (UTC):

Advanced Options:

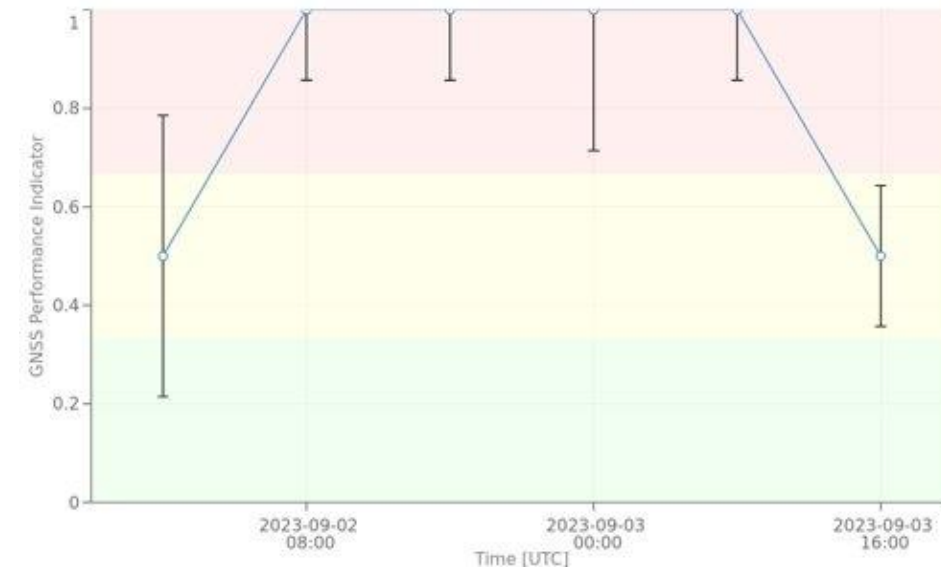
Output

Details
Download

Performance Indicator
0.5000

Position	60.2°N, 24.9°E
User Type	USR01

Output



Performance Indicator 0.5000	
Position	60.2°N, 24.9°E
User Type	USR01
Date & Time - Start (UTC)	2023-09-02T00:00
Warning / Error Message	

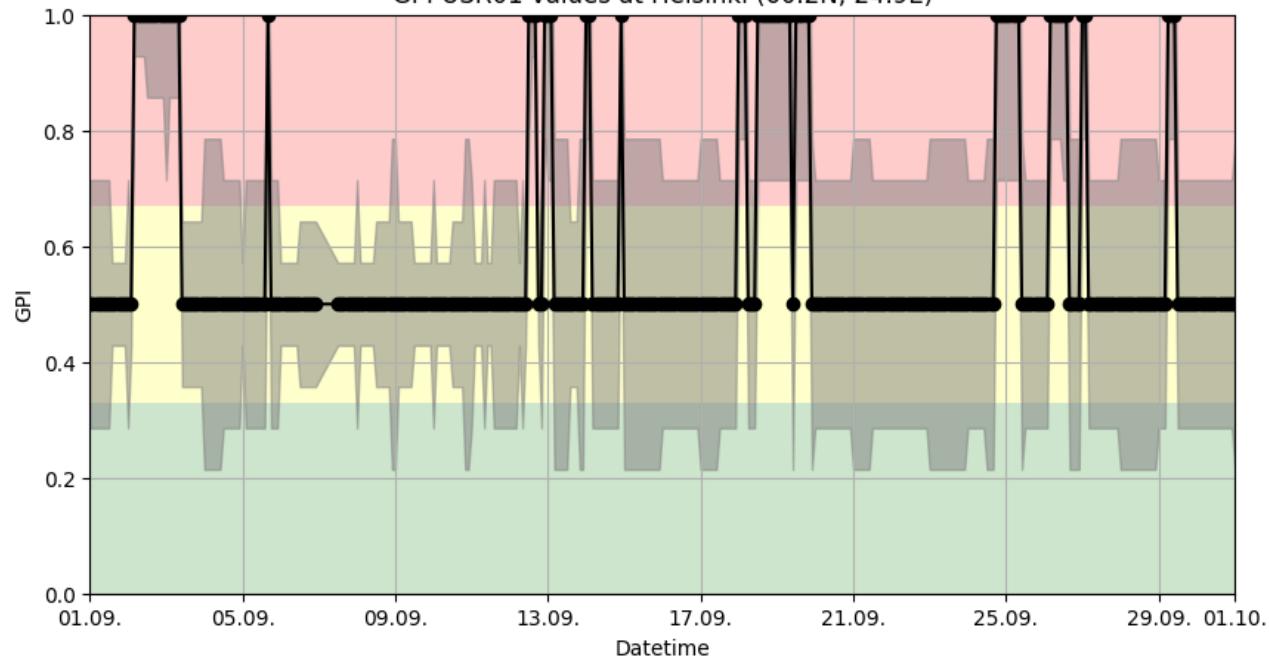
GPI with SWIGPAD API

- GPI is also available from an API (Requires login token)
<https://swigpad.impc.dlr.de/api/v1/>
- Add token in POST cookies and request parameters in POST data
- Returns data in json format

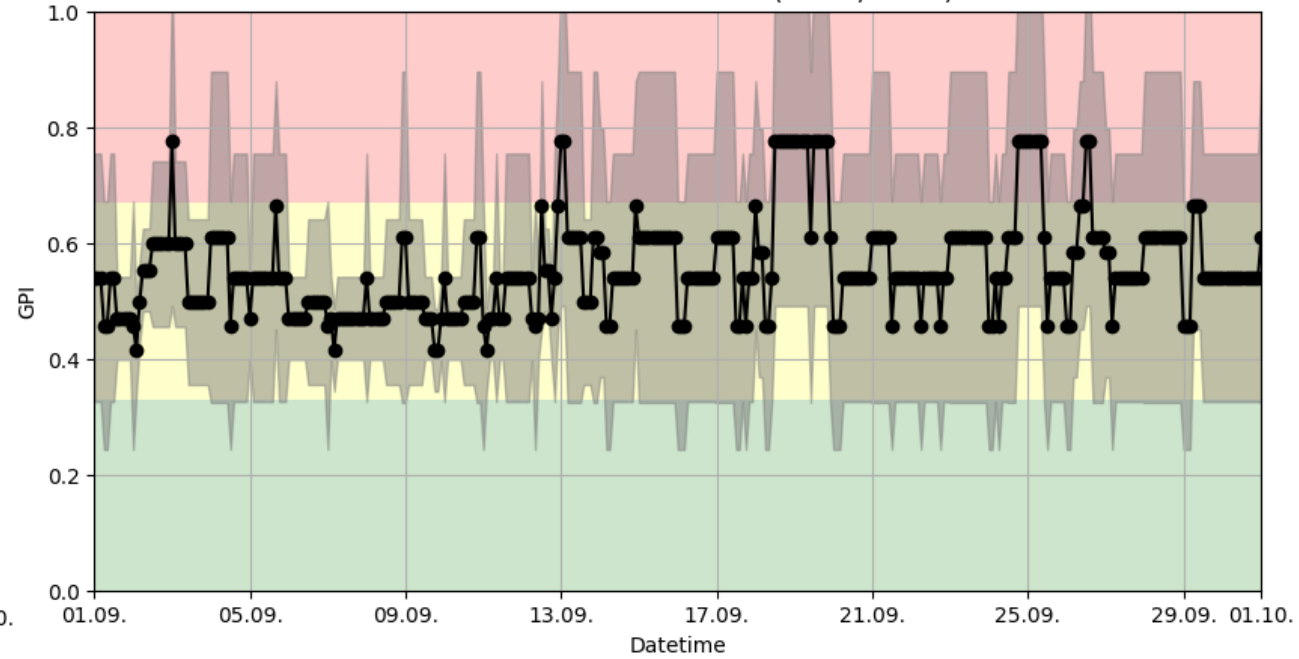
Use case: GPI timeseries

- Use case when user is only interested of a single point information
- Single API call can have max 6 timesteps
- Continuous monitoring requires multiple API calls with modifying the time start and stop parameters

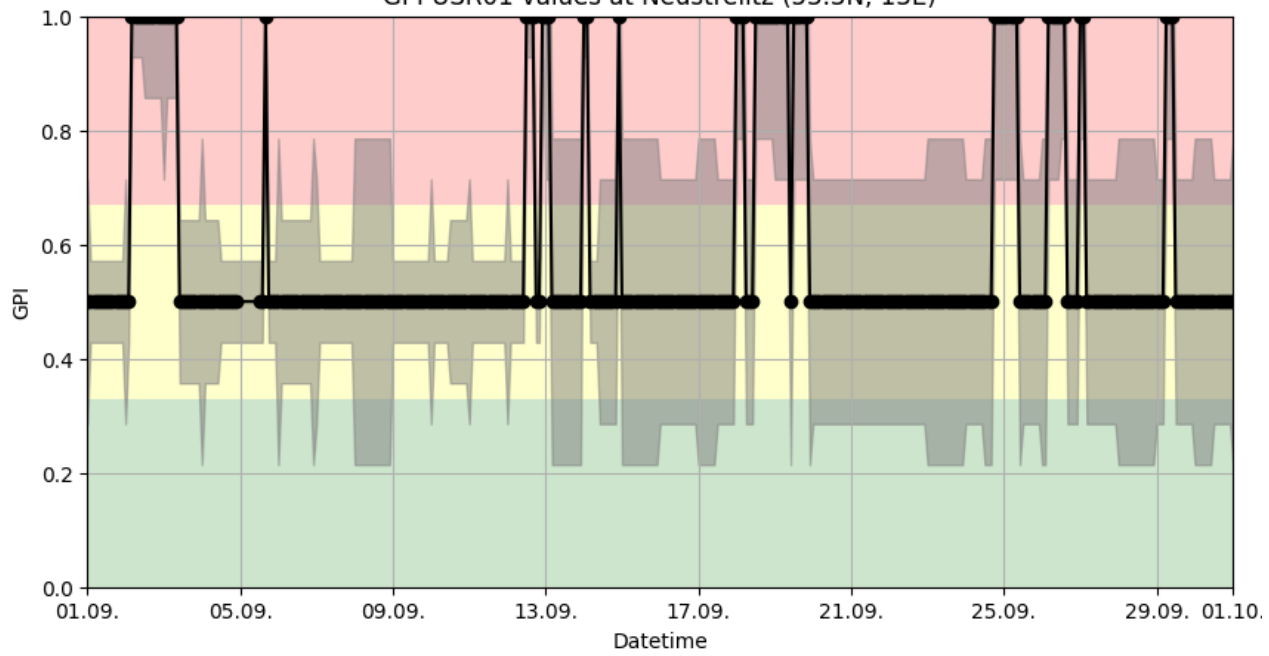
GPI USR01 values at Helsinki (60.2N, 24.9E)



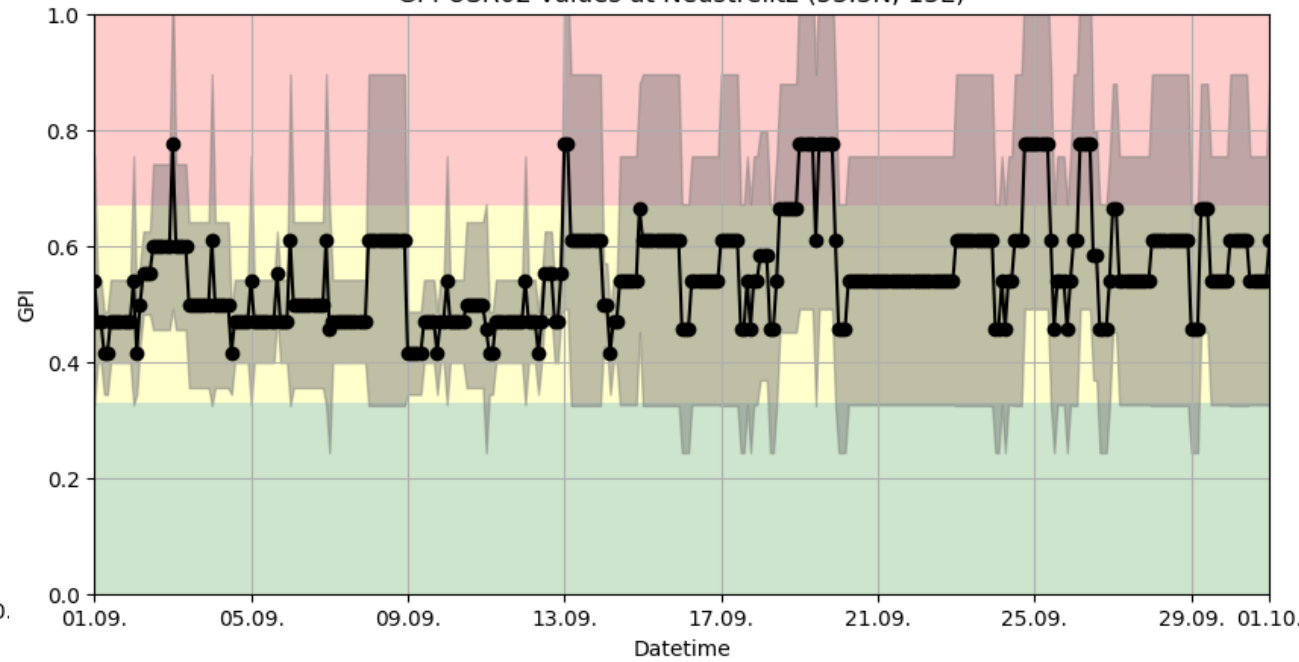
GPI USR02 values at Helsinki (60.2N, 24.9E)



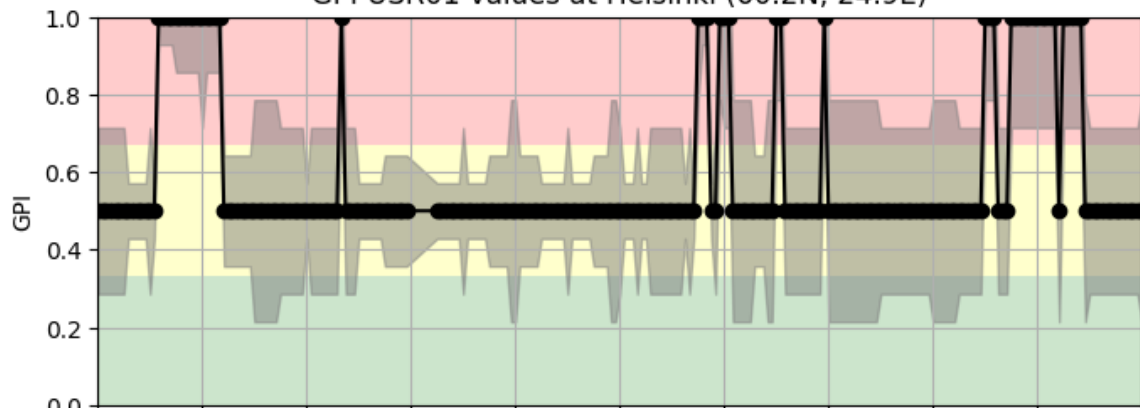
GPI USR01 values at Neustrelitz (53.3N, 13E)



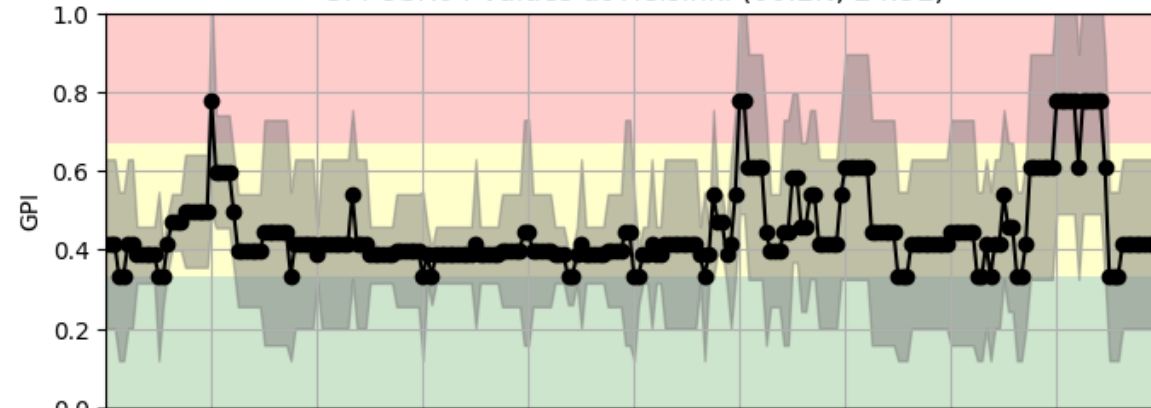
GPI USR02 values at Neustrelitz (53.3N, 13E)



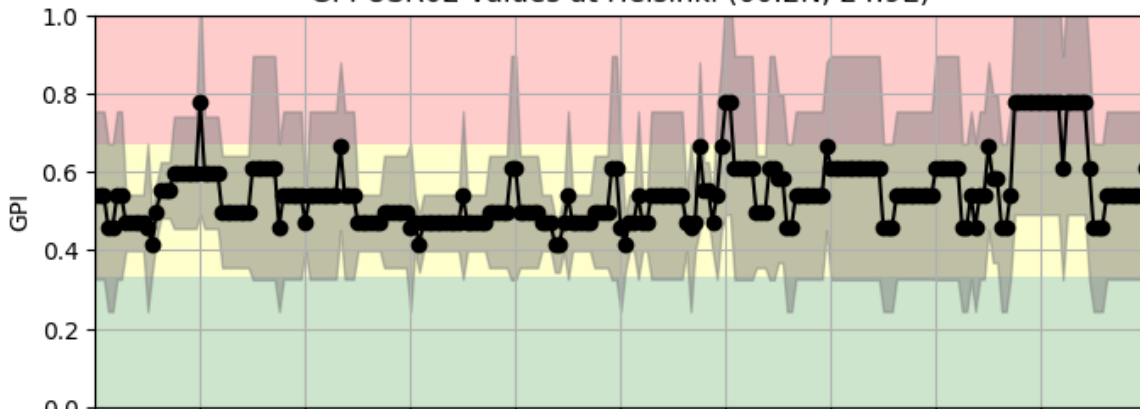
GPI USR01 values at Helsinki (60.2N, 24.9E)



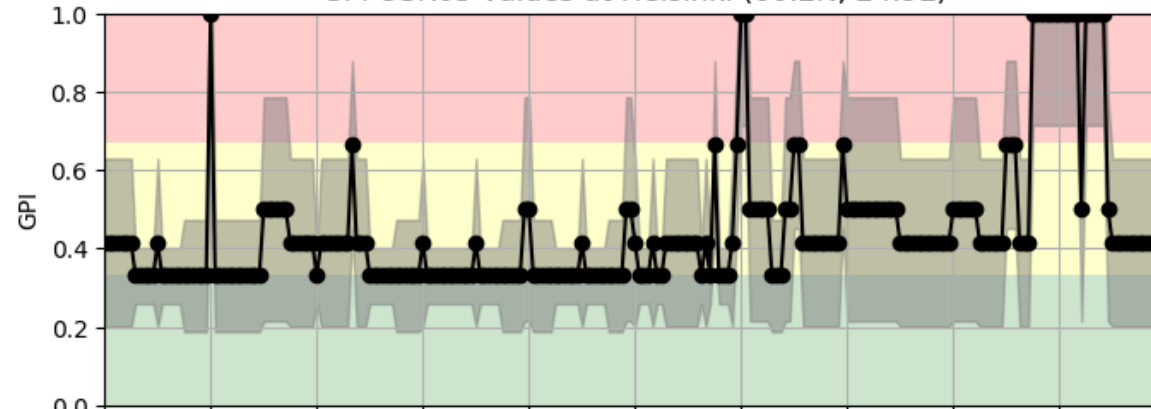
GPI USR04 values at Helsinki (60.2N, 24.9E)



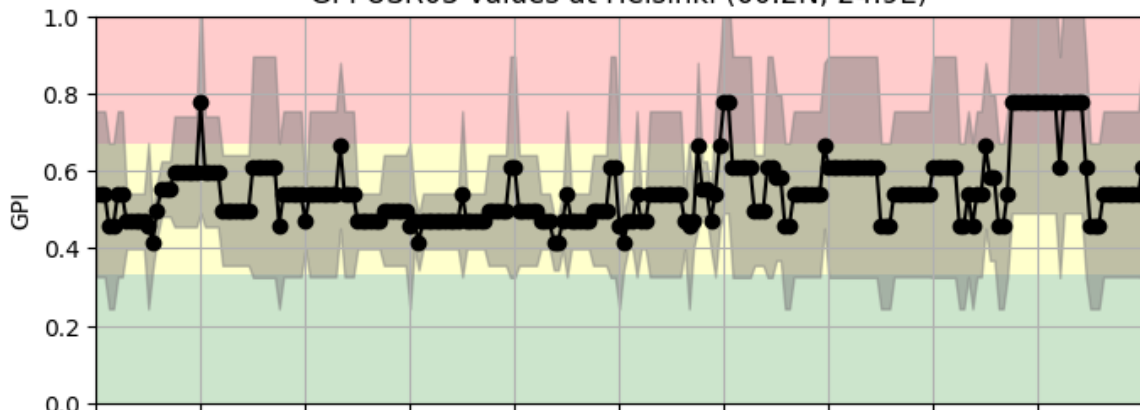
GPI USR02 values at Helsinki (60.2N, 24.9E)



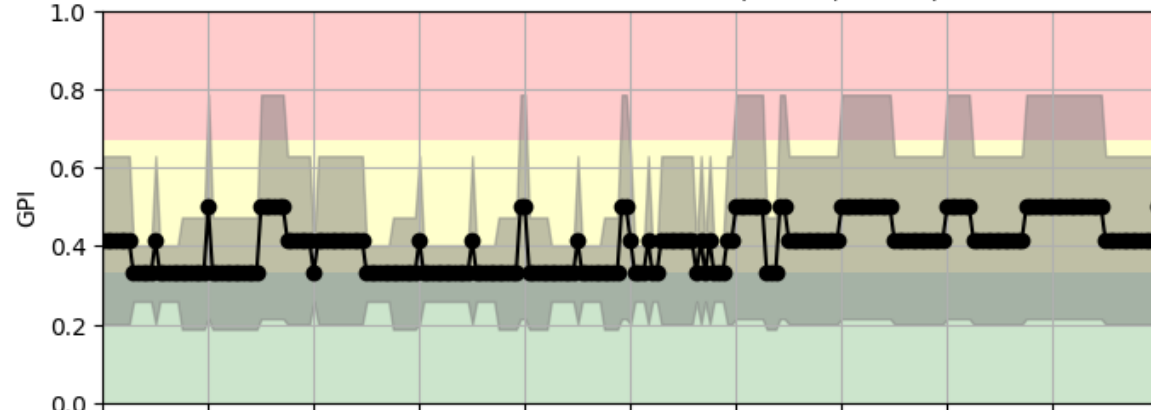
GPI USR05 values at Helsinki (60.2N, 24.9E)



GPI USR03 values at Helsinki (60.2N, 24.9E)



GPI USR06 values at Helsinki (60.2N, 24.9E)



01.09. 03.09. 05.09. 07.09. 09.09. 11.09. 13.09. 15.09. 17.09. 19.09. 21.09.
Datetime

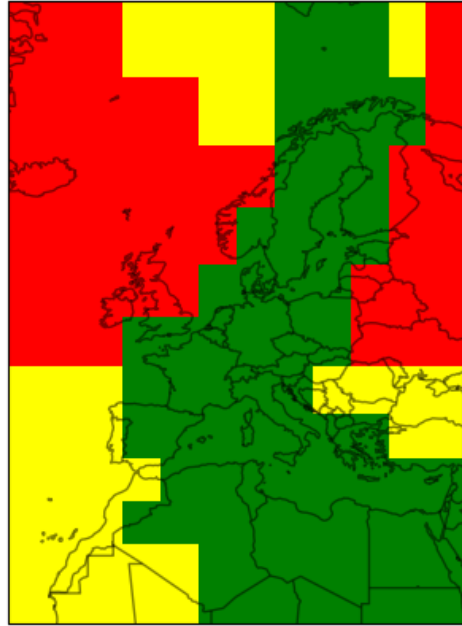
01.09. 03.09. 05.09. 07.09. 09.09. 11.09. 13.09. 15.09. 17.09. 19.09. 21.09.
Datetime

Use case: GPI map

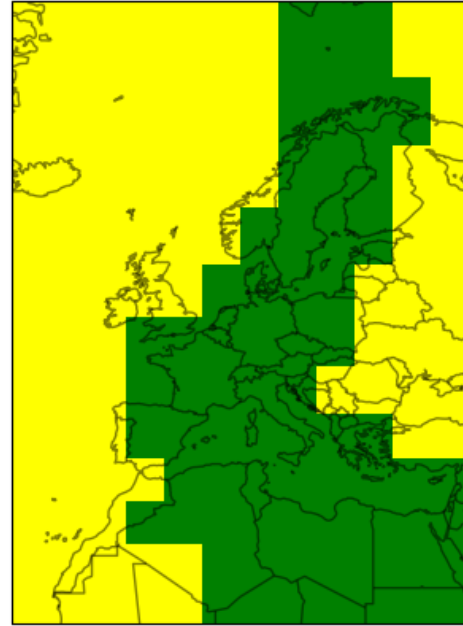
- Users that have interest for monitoring broad range of coordinates
- Each map point requires a call, thus parallel calls are recommended
- Map resolution for GPI is related on the source data resolution
- TEC resolution is higher compared to Kp or scintillation
- Using timeseries allows 6 maps to be created at the same time

GPI USR05 map created for looping 144 points with 6timestep

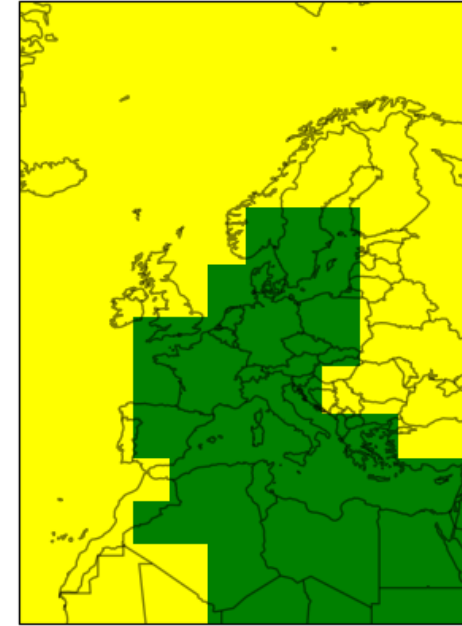
2023-09-12T16:00:00



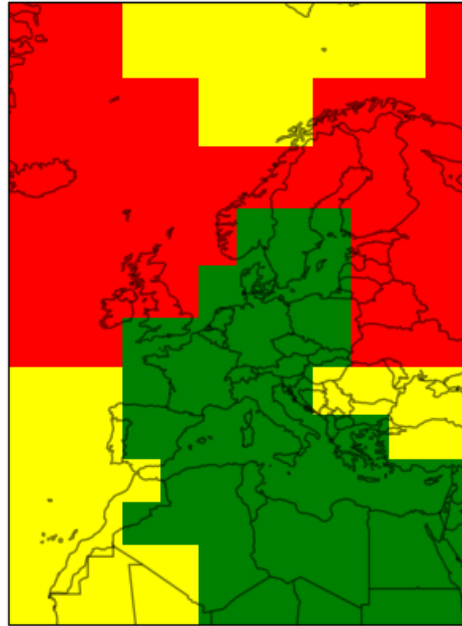
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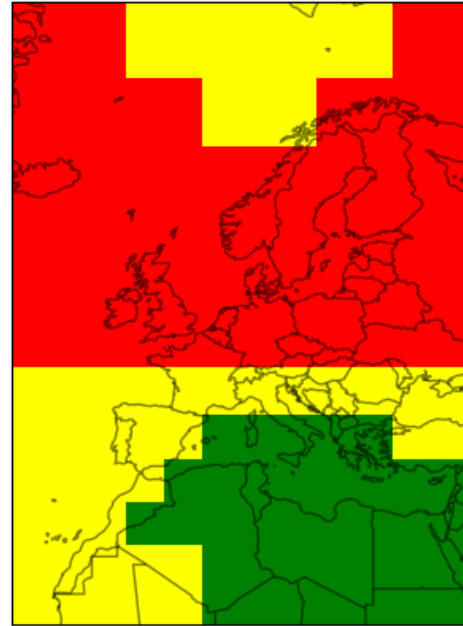
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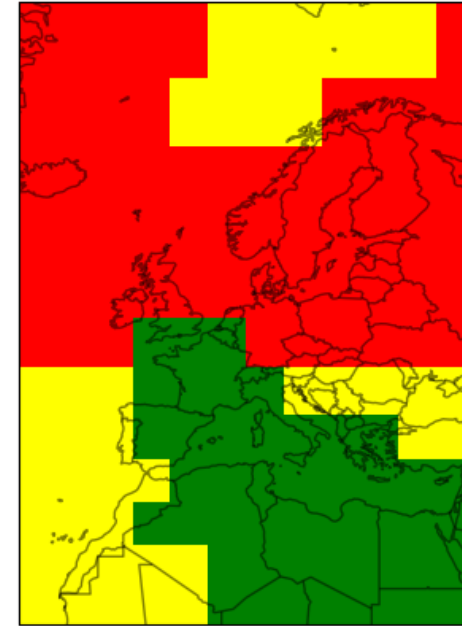
2023-09-12T22:00:00



2023-09-13T00:00:00



2023-09-13T02:00:00



Conclusions

- The GPI combines a variety of data affecting the GNSS and provides a simple traffic light approach for GNSS precision
- The GPI and its source data are available at ESA SWE portal
- 6 predefined user cases that weight the source data differently
- The SWIGPAD API can be used to customize the GPI presentation for example long time variability and maps

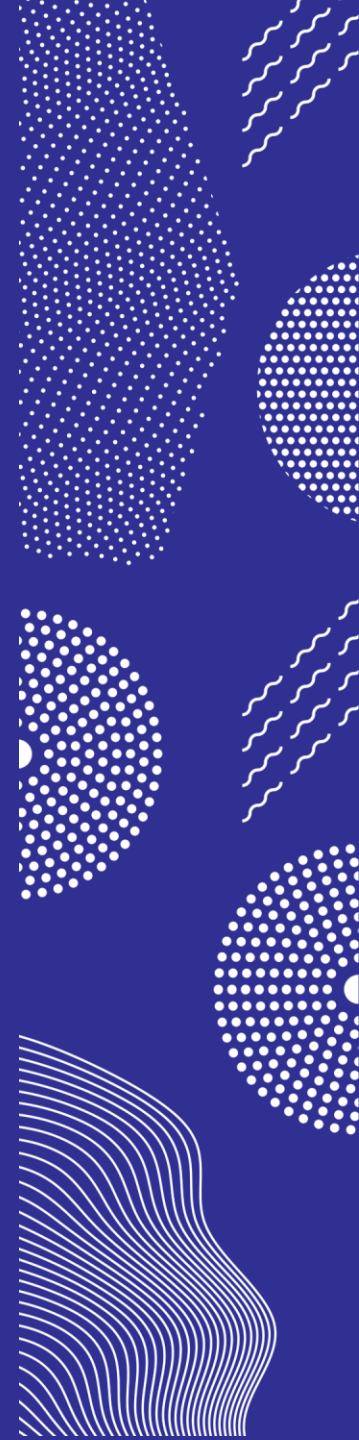
References

- [1] David, P., Kriegel, M., Berdermann, J., Kauristie, K., Jacobsen, K. S., Fabbro, V., Keil, R. (2023). Performance indicator development addressing mitigation of the space weather impacts on gnss. *Journal of Space Safety Engineering*, 10 (3), 324-330.
Doi:10.1016/57j.jsse.2023.07.004



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FINNISH METEOROLOGICAL INSTITUTE

Thank you!



Source data classifications

Table 2
Table of performance indicator value based on S4 scintillation index.

Performance indicator value S4 index (no unit)	Description	Color
0	"no data."	gray
$0 < S4 < 0.3$	"No amplitude scintillation to weak amplitude scintillation."	Green
$0.3 \leq S4 < 0.6$	"Mean/moderate amplitude scintillation intensity."	Yellow
$S4 \geq 0.6$	"Strong amplitude scintillation."	Red

Table 3
Table of performance indicator value based on $\sigma\phi$ scintillation index.

Performance indicator value $\sigma\phi$ (rad)	Description	Color
0	"no data."	Gray
$0 < \sigma\phi < 0.1$	"No phase scintillation."	Green
$0.1 \leq \sigma\phi < 0.25$	"Weak phase scintillation."	Green
$0.25 \leq \sigma\phi < 0.5$	"Moderate phase scintillation intensity."	Yellow
$\sigma\phi \geq 0.5$	"Strong phase scintillation."	Red

Table 4
Table of performance indicator value based on ROTI scintillation index.

Performance indicator value ROTI (TECU/60 s)	Description	Color
0	"no data."	Gray
$0 < ROTI < 1$	"Low activity. No adverse effects expected."	Green
$1 \leq ROTI < 3$	"Normal activity. For most users, this level of activity will not cause problems. A slight increase in position error may be detected in high-accuracy applications."	Green
$3 \leq ROTI < 5$	"Moderate activity. Users may have difficulty getting a good coordinate solution."	Yellow
$ROTI \geq 5$	"High activity. Users will have difficulty getting a good coordinate solution. Network base stations may lose lock on satellites."	Red

Table 5
Table of performance indicator value based on TEC variability.

Performance indicator value dTEC (TECU)	Description	Color
0	"no data."	Gray
$0 < dTEC < dTEC_{max}$	"Correct estimation of TEC."	Green
$dTEC \geq dTEC_{max}$	"Incorrect estimation of TEC."	Red

Table 6
Table of performance indicator value based on positioning error probability $1 \times \sigma$ and Gaussian distribution of error.

Performance indicator value probability in%	Description	Color
0	"no data."	Gray
$p < 68.3\%$	"Positioning error variability lower than criterion."	Green
$p \geq 68.3\%$	"Positioning error variability higher than criterion."	Red

Table 7
Table of performance indicator value based on Kp index.

Performance indicator value Kp	Description	Color
0	"no data."	Gray
$Kp < 4$	"Low magnetic activity or normal activity."	Green
$Kp \geq 4$	"High magnetic activity, indicating a geomagnetic storm."	Red