Space Weather Applications Center Ionosphere

On the relation between Network RTK performance and ionospheric conditions

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GNSS RTK (Real-Time Kinematic) positioning techniques are based on precise but ambiguous carrier phase observations. The ambiguities can be resolved by properly modelling the ionospheric influence. However, under perturbed ionospheric conditions, the ionospheric modelling may become inaccurate and thus to lead to degraded network performance. Addressed here are the adverse space weather effects on GNSS-based positioning and discusses possible problems of reference network concepts that can be attributed to ionospheric interference in particular. For the purpose, analysed is the relation between the residual ionospheric error and the ionospheric activity. Generally, the ionospheric impact is noticeably stronger during ionospheric perturbations/storms, which raises the question of how the reference networks perform during such unfavourable conditions. Analysed also is the feasibility and effectivity of an operational space weather monitoring service for improving the performance and maintaining the integrity of network RTK.

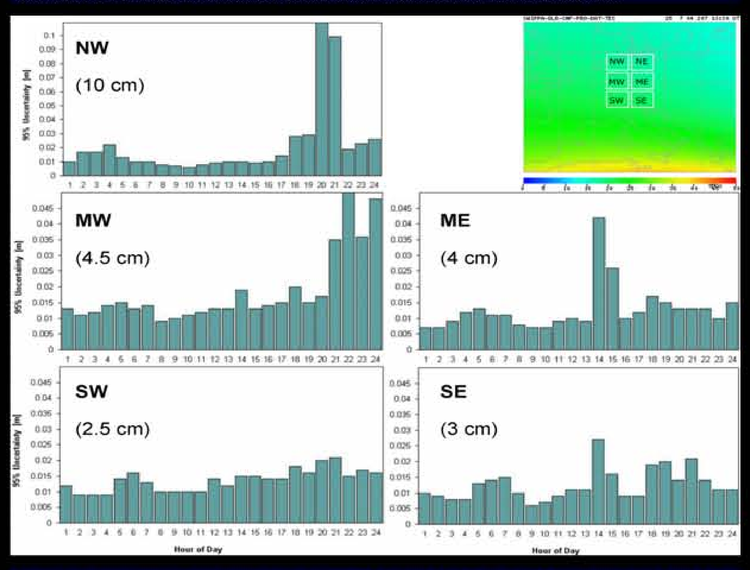
Service

Space Weather is the set of all conditions -- on the Sun, and in the solar wind, magnetosphere, ionosphere and thermosphere -- that can influence the performance and reliability of ground-based and space-borne technological systems and can endanger human health and life. The project provides specific space weather information to GNSS reference network operators to help them deliver more reliable, precise and secure positioning services and to reduce operation, production, and other business costs. Another major task is to regularly provide relevant information and support to the Space Weather European Network (SWENET).

Data / Information Exchange System

Network Model Integrity

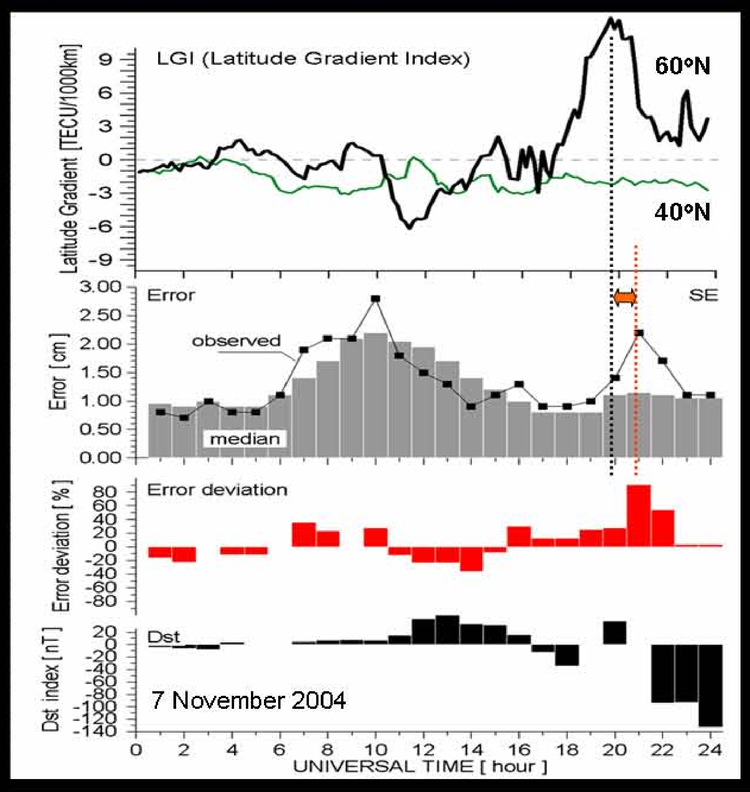
The Network Model Integrity module is used within the software of the *ascos satellite positioning services* reference network to describe the non-linear error in the generated data. The software determines the ionospheric influence on GNSS signals and then removes the linear parts of these effects by applying ionospheric and geometric corrections to the raw data. An associated problem is that, during periods of disturbed ionosphere, the ionospheric residuals cannot be considered as linear. The integrity module estimates the non-linear error in the generated data. The error itself is determined by omitting one station from the calculation of the ionospheric influence, and then the surrounding stations are employed to predict the ionospheric influence for the site of the omitted station. Finally, the predicted error is compared with the measured values and the ionospheric and geometric errors are shown separately. Recent experiences teach that it is hardly possible to obtain precise and accurate results while the error is larger than 8 cm. If the error is between 4 and 8 cm, the reference network user has to accept longer times to fix ambiguities. Smaller values represent a quiet ionosphere.



The NMI graphs show the remaining errors at different locations as estimated by the network model integrity on 25 July 2004. The remaining error of a single subnet is plotted with an average value. The plots of the different subnets are shown according to the area they cover in Germany (NW – North West, NE - North East, MW – Mid West, ME – Mid East, SW - South West, SE – South East). Around noon, higher-than-usual values are observed in the eastern areas ME and SE. Later, the influence is detected in the western areas NW, MW, and SW as well. As the ionosphere perturbations propagate from polar to lower latitudes, GNSS applications are also affected. However, the influence decreases at lower latitudes.

Early detection of disturbances

Demonstrated next is how SWACI products and services can help. By generating high-resolution maps of TEC spatial and temporal gradients, particularly at higher higher latitudes, ionospheric disturbances become. As the space weather / ionospheric disturbances lead to increase in the residual error (decreased NMI respectively), the TEC maps can be effectively used for alerting the GNSS user for possible NMI degradation.



Products

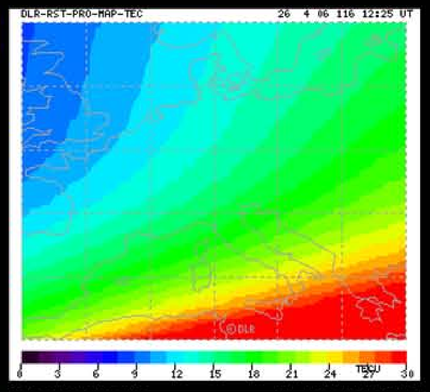
Within the SWIPPA project, several near real time data products and services – such as TEC maps, TEC spatial and temporal gradient maps, cycle slip monitoring, space weather warnings, etc. -- are offered to the consortium members, designated users, and general public. These products and services are based on information of the actual and predicted state of the ionosphere-plasmasphere system and deliver only such type of space weather information which GNSS users need for the execution of their routine tasks [1,3].

TEC

DLR operates a system for regularly processing ground based GPS data and producing maps of the integrated ionospheric electron content over the European region.

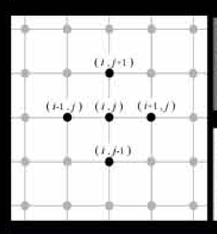
Measurements from the *ascos* ground reference network and from other geodetic networks via BKG (Bundesamt für Kartografie und Geodesie) are used.

The 1sec GPS data allow the determination of slant TEC values along numerous satellite-receiver links over the European area with a high time resolution. The slant TEC data are then mapped onto the vertical axis by applying a mapping function which is based on the single layer approximation at hsp=400km. Finally, to produce regional TEC maps over Europe, the measured and calibrated TEC data are assimilated into the regional TEC model Neustrelitz TEC Model (NTCM2).



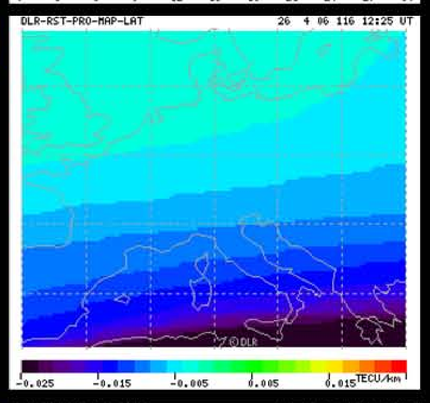
TEC gradients - latitude

Strong gradients in the horizontal TEC structure as well as small scale structures of the ionospheric plasma may seriously complicate or even prevent the resolution of phase ambiguities in precise geodetic or surveying networks.



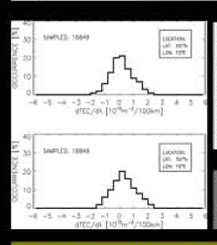
Gradients are calculated at each grid point (1 deg resolution) over Europe using the computational molecule (left side map).

Latitudinal (North-South) gradients (right side map) show how and how far the disturbances propagate toward lower latitudes.



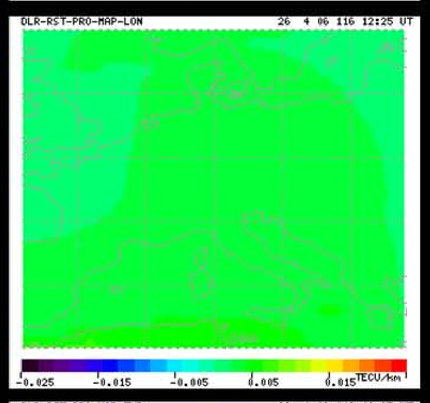
TEC gradients - longitude

Longitude (East-West) gradients (right side map) show how the disturbances move between different local-time sectors and can be helpful in the same way as the latitudinal gradients in particular under sunrise and sunset conditions.

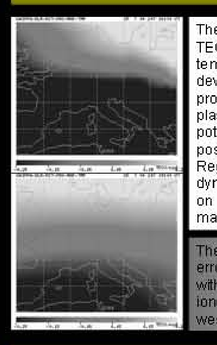


Severe ionospheric storms cause significant redistribution of plasma resulting in large longitudinal gradients which may also have a negative impact on positioning.

The left side figure shows gradient statistics for year 1995 (low solar activity).

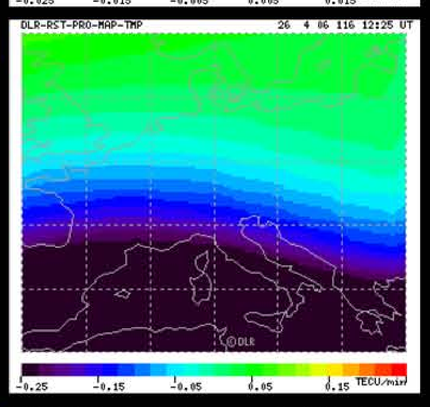


TEC rate of change



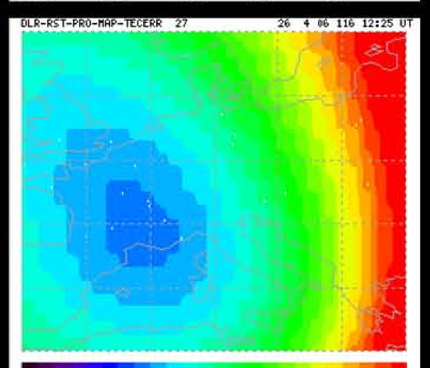
The existence of quick and strong TEC changes with time, i.e. temporal gradients, indicate the development of highly dynamic processes in the ionosphere-plasmasphere system with a potential of degrading GNSS positioning and/or navigation. Regions of enhanced ionospheric dynamics can easily be detected on the TEC temporal gradient maps (right).

The propagation of NMI non-linear errors is found to well correlate with the propagation of ionospheric disturbances in south-west direction (left).



TEC Error Monitoring

For monitoring the TEC mapping quality, a novel in-house procedure has been developed for practical estimation of the TEC calculation error (Klaehn et al., 2003). The method is based on estimations of the Grid Ionospheric Vertical Delay, GIVD, and the Grid Ionospheric Vertical Error, GIVE. The GIVD at an Ionospheric Grid Point (IGP) is calculated from the calibrated vertical Ionospheric Propagation Error (IPE) obtained by the Parameterized Ionospheric Background Model (PIBM) used at the IGP. For GIVE calculation, it is necessary to use an algorithm capable of estimating GIVE at locations near a measurement (i.e. dominated by local error of PIBM) and also at locations away from a measurement (worst case error of PIBM). IPE error includes individual errors from the estimation of instrumental biases and estimates of the errors due to the phase ambiguities resolution method. Users can also monitor the distribution of the ionospheric piercing points (the intersection of the raypaths with the idealized ionospheric layer at 400 km altitude) during the generation of a TEC map.



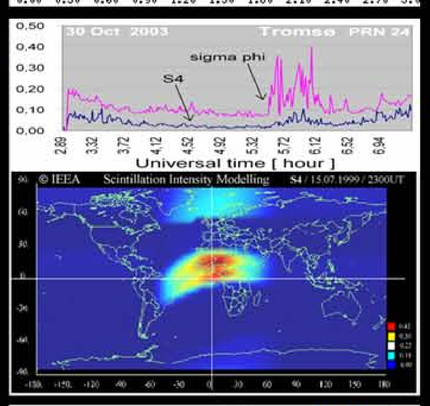
Scintillation Monitoring

Phase scintillations are traditionally monitored by estimating the standard deviation of the power spectrum of detrended carrier phase of GNSS satellite signals.

Amplitude scintillations are monitored via the S4 index. The S4 index value, normally calculated over a 60 second interval, is deduced from detrended signal intensity (actually, the received signal power) of GNSS satellite signals.

To better monitor the polar scintillation activities, DLR has installed a GPS receiver in Tromsoe (data analysed and processed at 50Hz sampling frequency) and started to produce estimates of S4 and Sigma-phi.

Additionally, the IEEA Global Ionospheric Scintillation Model (GISM) is used to provide estimates of the scintillation intensity [4].

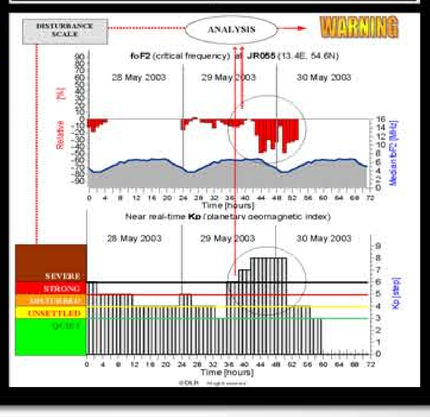


Space Weather Warning

After analysing and synthesizing the incoming geophysical information, short messages are forwarded to users. Each message consists of a single word (quiet, unsettled, disturbed) describing the level of expected ionospheric disturbances and indicating the probability of experiencing positioning problem(s). The warning message is kept as simple as possible in order to be conveniently used by programmers via the ftp protocol and for developing derivative services.

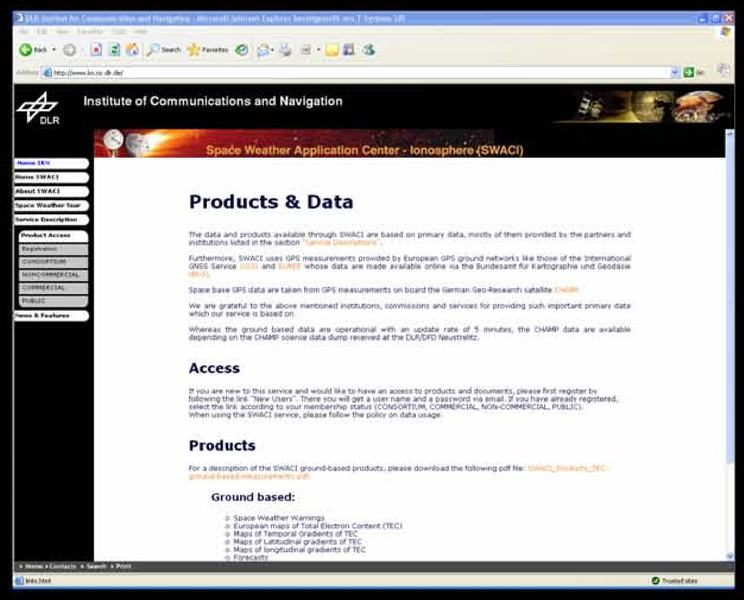
The operational analysis that is required prior to producing each warning message is mostly based on estimations and predictions of the geomagnetic index Kp by using real-time solar wind observations (wind density, speed) onboard the satellite ACE (Advanced Composition Explorer).

Additional measurements are also considered, such as the geomagnetic field's horizontal component and the percentage deviation of the critical frequency from the monthly medians.



Access

The transfer of generated data products, services and additional information to both the consortium and the external users is realized by an independent server unit. To safeguard the integrity of the service, preliminary registration of all users is required. Upon registering, each user obtains a password to access the products/services according to the already established rules and membership status: Consortium, Non-commercial, Commercial, and Public.



To facilitate the post analysis and further development of the service an independent archive unit will be maintained during the project.

Prospective for service improvements

The experience gained so far by service developers and users so far during the project guarantees the rich prospective for improvement and expansion:

- Develop new improved service to address a larger set of GNSS users
- Focus on forecast products;
- Spatial resolution less than 100 km
- Forecast up to 24h ahead
- Improve spatial and temporal resolution of nowcast
- Improve quality of short-term ionospheric forecast
- Utilize space-based measurements for plasmasphere reconstruction
- Deliver new, more specific, products to be directly used in GNSS algorithms
- Extend current regional mapping towards local and global coverage

Partners

German Aerospace Center
Institute of Communications and Navigation, Neustrelitz, Germany
German Remote Sensing Data Center, Neustrelitz, Germany
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Website

http://www.kn.nz.dlr.de/swaci

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