Space Weather Applications Center Ionosphere

SWACI space weather service for high precision GNSS positioning

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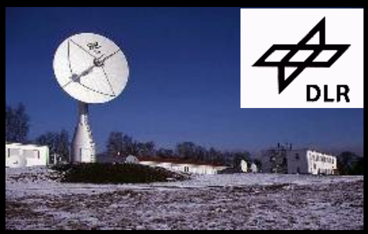
Space Weather - all conditions, on the Sun and in the solar wind, magnetosphere, ionosphere and thermosphere systems, that can influence the performance and reliability of ground-based and space-borne technological systems and can endanger human health and life.

Objectives

The German Aerospace Center (DLR) established a novel operational space-weather monitoring service as a part of the project SWACI - Space Weather Application Centre Ionosphere. The main objective is to provide a permanent service, based on GNSS and space weather observations, that generates and distributes specific products to operators of GNSS-based reference networks in order to help them deliver more reliable, precise and secure positioning services and to reduce the operation, production, and other business costs. This objective is achieved by permanently monitoring the ionosphere/space weather, operationally providing ionospheric/space weather observations, pre-processing and calibrating GNSS data, generating value-added products covering the European and Polar regions, post-processing and analysis of ionospheric/space weather information, analysis of ionospheric/space weather effects, user benefit analysis, etc. Development of various forecast products, including those addressing the ionospheric space weather effects on GNSS applications, are other key objectives of the project.

SWACI is a joint project of the DLR Institute of Communications and Navigation (IKN) and the DLR Remote Data Center (DFD). The project is supported by the German State Government of Mecklenburg and Western Pomerania.

Partners and Data Providers

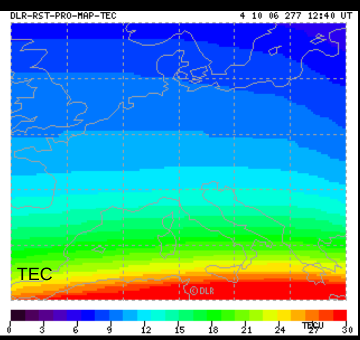


Several national and international partners (NOAA Space Environment Center, European Space Agency SWENET, GFZ Potsdam, IAP Kuhlungsborn, Allsat network+services GmbH, BKG, and others) contribute to the successful realisation of the SWACI project and its main objective to continuously monitor the Earth's ionosphere-plasmasphere system by means of comprehensive ground- and space-based observations. By having both nowcast and forecast capabilities, SWACI is able to generate and distribute several value-added products such as: regional maps of the total electron content (TEC) value, TEC spatial and temporal gradients, reconstruction of the global ionisation, etc. All products are delivered to the users in a high temporal and spatial resolution mode. SWACI services are deemed suitable for various types of users - from both the industry and academia.

Products – Based on Comprehensive Observations from Ground and Space

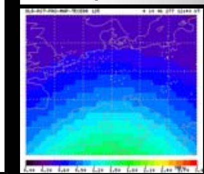
TEC

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 other geodetic networks used via the Federal Agency for Cartography and Geodesy (BKG) and the NTRIP technology, [1]. 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 the TEC maps over Europe, the measured and calibrated TEC data are assimilated into the regional TEC model Neustrelitz TEC Model (NTCM2).

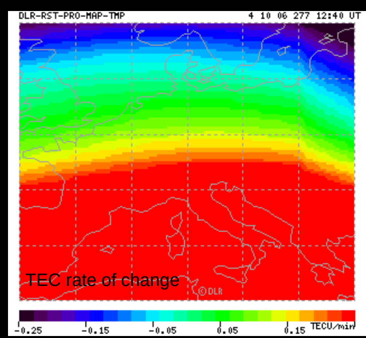


TEC Rate of Change

Existence of strong temporal gradients (high rate of change) indicates the development of highly dynamic processes in the ionosphere-plasmasphere system with a potential of degrading GNSS positioning and navigation. TEC rate-of-change maps can clearly indicate regions with enhanced dynamics.



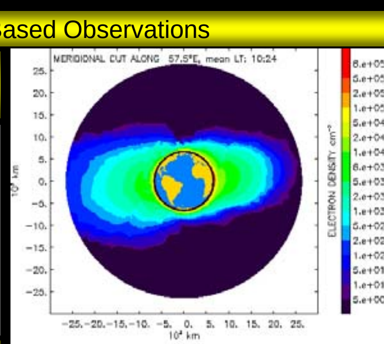
Note: A novel in-house procedure, [7], has been developed for monitoring the TEC mapping quality by estimating the so called Grid Ionospheric Vertical Delay (GIVD) and the Grid Ionospheric Vertical Error (GIVE).



Space-Based Observations

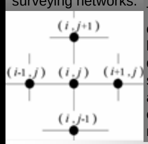
Reconstruction - Topside Ionosphere

The 0.1 Hz sampled dual frequency navigation measurements onboard LEO satellite CHAMP are used to derive the TEC along the ray paths between the CHAMP and GPS satellites. After assimilating these integral measurements into a Parameterized Ionospheric Model of local electron density, the electron density distribution in the CHAMP orbit plane is reconstructed. In combination with ground based measurements the technique provide the entire ionosphere.



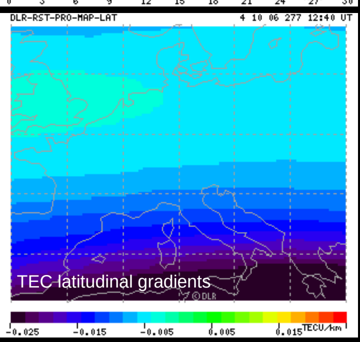
TEC Gradients - Latitude

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.



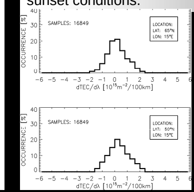
The horizontal gradients are calculated at each grid point (I,j) by using a 2nd-order finite-difference representation of spatial derivatives of functions and using an (I,j)-centred 5-point computational molecule. The grid resolution is 1 degree.

Latitudinal (North-South) gradients and the mapping reveals how the disturbances develop and how far they propagate toward lower latitudes.



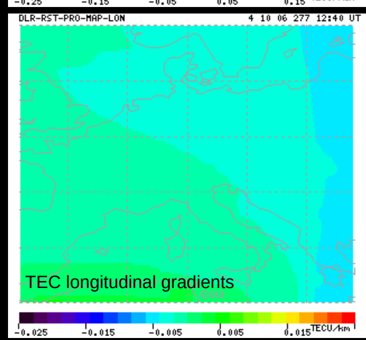
TEC Gradients - Longitude

The longitudinal (East-West) gradients 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.



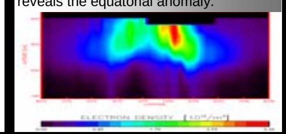
Severe ionospheric storms cause significant redistribution of plasma resulting in large longitudinal gradients which may also have a negative impact on positioning.

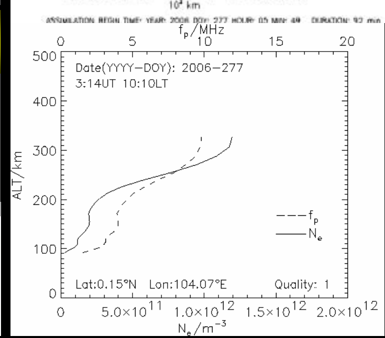
The figure shows gradient statistics for year 1995 (low solar activity).



IRO Reconstruction - Bottomside Ionosphere

More than 200,000 vertical electron density profiles were retrieved from ionospheric radio occultation (IRO) measurements onboard CHAMP. IRO profiles are globally distributed and used in many applications. For example, a detailed statistical analysis clearly reveals the equatorial anomaly.





Operational Infrastructure

Multi - Mission Data Management

For the management of SWACI data the Data and Information Management System (DIMS) of German Remote Sensing Data Center (DFD) is used. DIMS provides an integrated solution that is flexible, to be adapted to nearly any conceivable data management scenario. It is designed as a facility that provides the core components to support the tasks required to handle earth observation data in a multi mission scenario.

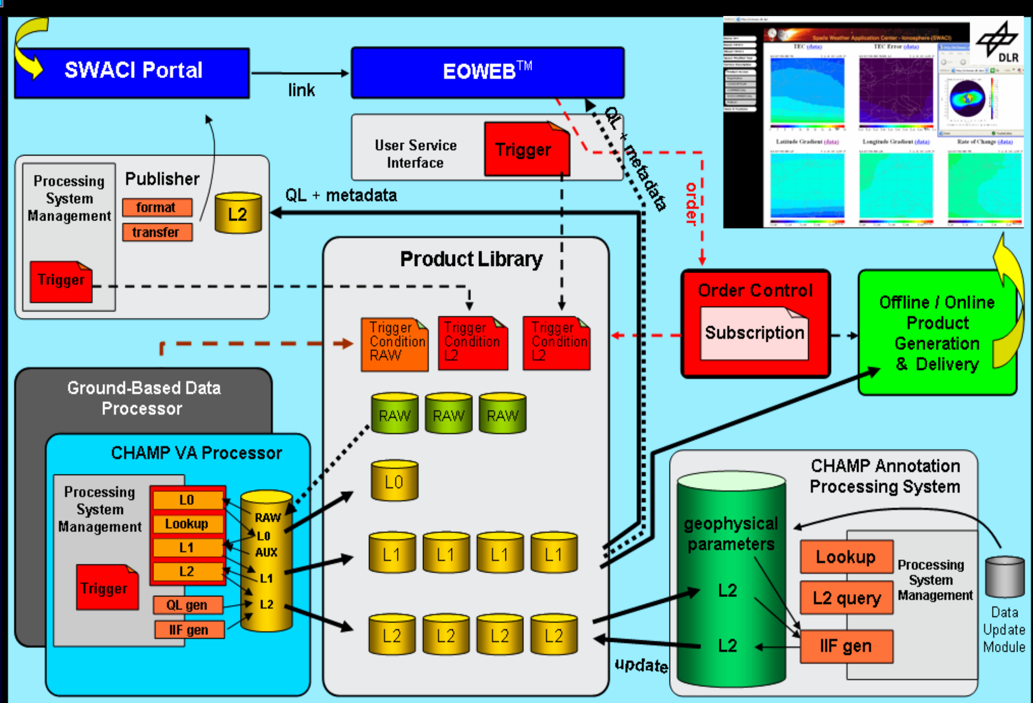
To achieve the multi-mission capability of DIMS, it has been designed to be decoupled from the internal structure and processing requirements of the data that is handled. DIMS provides a sustainable solution that supports all the basic workflows of digital data management like production management, cataloguing, long-term archiving, WWW user access, ordering and on-line/off-line delivery by means of a set of comprehensive services. This includes WWW user information services (with on-line delivery), off-line delivery, post-processing, data product inventory and archiving, ordering control and production control.

Data will be ingested into the system via adapter modules. A cornerstone of the system is a highly scalable product library which is the source of processing input and the destination of the processing output. It provides a complete and consistent reference to all data products. Since data from different sources (ionospheric observations as well as other solar-terrestrial data such as geomagnetic observations) are involved, a solution with a flexible product model is required. To incorporate a new product type it suffices to provide a small program that extracts the desired inventory information and optionally generates a quick look image for the product. Data processing is carried out via configurable workflows that can be as simple as a single step processor call or as complex as a month long procedure on a multi machine cluster to compute the mean value of a measured quantity derived from several product types.

Facility

The figure describes SWACI facility with the scenario from the beginning of the data chain with the CHAMP-VA Processing System up to the accessibility of meta data and browse data via the SWACI Portal. All Processing Systems (CHAMP VA Processing System, CHAMP Annotation and Ground Based Data Processing System) are integrated into DIMS via unified interfaces. First full automatic system produces L0, L1 and L2 products based on the CHAMP raw data, which were acquired in the receiving ground station Neustrelitz. The products are stored in the Product Library. Each product consists of meta-data and different product components. The product components will be archived in one ore more file system archives while the metadata are stored in an object relational inventory that ensures fast access. After successful generation of data products the CHAMP Annotation Processing System upgrades the L2-products based on actual geophysical parameters. To ensure the fast access to the Quick-Look (QL) data and metadata for the users, the data will be transferred immediately after a L2-trigger was fired from the Product Library through the publisher to the SWACI-Portal. The SWACI-Portal represents a specific User interface, which based on the EOWEB™ configuration but with specific features to publish the parameters ionospheric and solar-terrestrial data products. The final aim is, to integrate the SWACI Portal fully into the EOWEB™ configuration. Currently, the connection is realized via a link. An integrated browsing image system adds to the ease of data retrieval. The service-based architecture is very flexible and can be customized and scaled to a large degree by means of configuration. Key features of the SWACI solution are:

- CHAMP Processing Systems with specific processors and integrated processing control, which is a part of the Processing System management software.
- Archive facility with an automatic robot archive and inventory with optimized access methods, support for products from many sources
- SWACI Portal with online information services



Product Dissemination

Ionospheric and space weather data are collected, checked for quality, calibrated, adjusted, analyzed, fed into models for generating value-added products and distributed in near real time and/or archived.

Four types of space weather products are available: warning, nowcast, forecast, and post-analysis products.

Warnings are issued for events that may harm the propagation of radio signals used in telecommunication and navigation applications.

The nowcast, based on real time GNSS measurements, specifies the current ionospheric conditions in the European region.

The forecast is based on modeling techniques using information on the ionospheric behaviour under specific solar-terrestrial conditions, [6]. The focus is on the short - term forecasts of up to 24 hours ahead.

Post analysis is possible due to the DIMS archiving capabilities of original observation data and selected products. The analysis is assisted by an effective data bank management system and corresponding search and visualization tools.

The access to the SWACI products is arranged via the user service interface. 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, the user obtains a password to access the products/services according to the established rules and membership status.

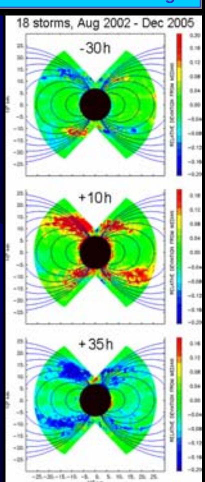
SWACI services have been integrated into the Space Weather European Network (SWENET) for the purposes of data exchange and cooperation.

Applications

Global Ionospheric Storm Monitoring

The Earth's ionosphere - plasmasphere system reacts to perturbations in the entire solar-terrestrial environment. Enhanced space weather impact is expected first on the high-latitude ionosphere because the latter is much stronger coupled with the magnetosphere and the solar wind.

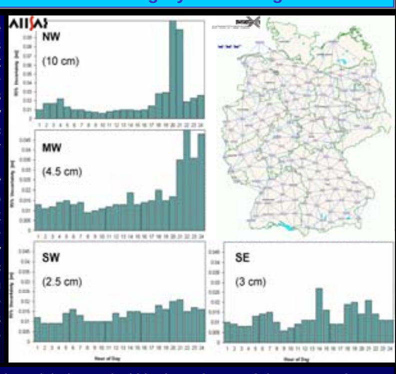
The plots show the relative deviations from corresponding median electron density values in the LEO CHAMP satellite orbit's plane several hours before and after the nominal start of the perturbations. Notice the strong increase in the ionisation shown on the +10h plot. Results are based on 18 major storms occurring from Aug. 2002 to Dec. 2005.



Since the ionosphere perturbations propagate from the polar to the middle and lower latitudes, GNSS-based applications may also be affected, [5]. As an example, here we present some recent observations on the ionospheric residual error measured in GNSS reference networks as part of the network integrity monitoring.

GNSS Reference Network Integrity Monitoring

GNSS-based 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. Generally, the ionospheric impact is noticeably stronger during ionospheric perturbations and storms, which raises the question of how the GNSS reference networks perform during such unfavourable conditions.

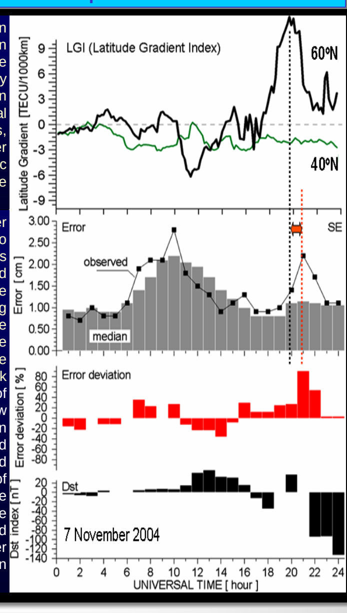


The Network Model Integrity (NMI) module is used within the software of the *ascos* reference network to describe the non-linear error in the generated data due to the ionospheric conditions. The software determines the ionospheric influence on GNSS signals and then removes the linear parts of these effects by applying ionospheric and geometric corrections to 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 value 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.

Early Prediction of Space Weather Effects

The SWACI services can help GNSS users in predicting some space weather effects. By generating high-resolution maps of the TEC spatial and temporal gradients, especially for the higher latitudes, the ionospheric disturbances can become easily detectable.

Since the space weather disturbances can lead to increased residual errors (leading to decreased integrity, respectively), the TEC real-time mapping service can effectively be used for alerting the GNSS users for possible degradation in network integrity. The feasibility of implementing a new ionospheric perturbation index has been assessed [2,3,4]. It is concluded that the development of an index, that is more closely related to the ionospheric effects and oriented towards the user needs for higher precision positioning, is necessary.



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Access

http://w3swaci.dlr.de/

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