# Operational service for monitoring and evaluating the space weather impact on precise positioning

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## ABSTRACT

SWIPPA (Space Weather Impact on Precise Positioning Applications of GNSS) is a project, initiated by the German Aerospace Centre (DLR), aiming at establishing a specific space weather service for improving current Global Navigation Satellite System (GNSS) applications. This project is considered a substantial part of the preparations for future European Space Weather Programme and GALILEO services.

## 1. INTRODUCTION

Space weather is defined as 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 space-borne and ground-based technological systems and can endanger human life (OFCMS, 1995). Several studies have been already performed showing clear evidences of space weather - induced adverse effects on the Earth's ionosphere-plasmasphere system (Jakowski, 1996; Jakowski et al., 1996, 1998, 1999, 2002a, 2002b; Stankov, 2002). Such effects can ultimately cause various types of problems including: range errors, rapid phase and amplitude fluctuations (radio scintillations) of satellite signals, etc., leading to pronounced signal degradation, degradation in the system performance, its accuracy and reliability. Reported also are strong voltage fluctuations and harmonic frequencies in the electricity, electrical power line shutdowns and blackdowns. Being electrical conductors, oil and gas pipelines are also vulnerable to strong geomagnetic disturbances; geomagnetically induced currents (GICs) produce additional voltages between the pipeline and the ground which can easily exceed the protective voltage therefore damaging the corrosion protection. GICs hamper also rail traffic by disturbing some types of signalling systems. Aviation and space flights are particularly at risk due to increased radiation and possible navigation/telecommunication problems, etc. Apart from the increased risk of using the affected systems, the negative impact of adverse space weather can also have a purely economic dimension. With the future advancement of technology, the above-mentioned risks and possible financial losses will certainly increase unless suitable protective measures are taken in advance.

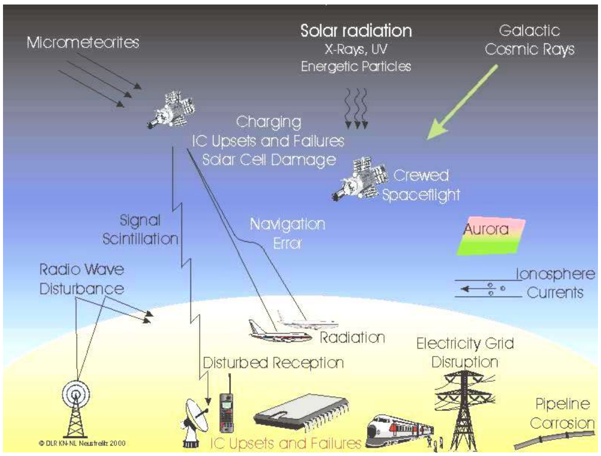


**Fig.1.** Space weather effects on technological systems.

## 2. MOTIVATION

There are several problems currently experienced by GNSS users which can be related to space weather effects.

### 2.1 Increased time required to fix GNSS signal phase ambiguities

Since the trans-ionospheric propagation errors are a major source of positioning errors in satellite-based navigation, the users of satellite navigation systems have to apply appropriate mitigation techniques such as: corrections based on dual frequency techniques, model-assisted corrections, local and/or global augmentation systems. With the help of transmitted GNSS corrections, a positioning with accuracy of a few centimetres is already achievable. One very important factor determining the performance of any GNSS reference network service is the time required to solve the phase ambiguities.

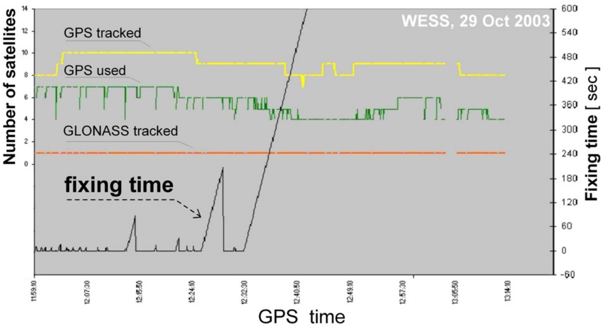


**Fig.2.** Time required to fix ambiguities: a case during the ionospheric storm on 29 Oct 2003. Notice the long fixing time (more than 3 minutes) at 12:24UT and the breakdown at 12:32UT.

The strong variability of the ionosphere obviously affects the determination of phase ambiguities. Presented here (Fig.2) is a case when difficulties arise and at a certain stage it becomes even impossible to fix ambiguities. At 12:32UT the real problem occur: the time to fix the ambiguities extends too much and it becomes impossible to get a fixed solution. During such periods it is very difficult to model the error influences and simultaneously the user cannot receive a precise positioning. Nowcast, and if possible, forecast of the ionosphere disturbances can certainly benefit the GNSS users.

## 2.2 Discrepancies between the number of tracked, processed and solved GNSS satellites

Another exemplary situation is presented here. Special computer programs are used for 'solving' phase ambiguities. To maintain a regular and reliable service, it is necessary to ensure that, at any given moment in time, the signal phase ambiguities are 'solved' for at least five GNSS satellites. For this purpose (to ensure this minimum number of 'solved' satellites), for each particular ground receiving station, as many GPS and GLONASS satellites as possible are tracked. Some of these 'tracked' satellites cannot be used due to restrictions imposed on the satellite elevation angle (elevation cutoff criterium), the signal-to-noise ratio (SNR criterium), etc. The remaining satellites are being 'processed', i.e. their signals are used in the processing software for fixing the ambiguities. Criteria also exist when trying to solve the ambiguities, for example the errors should be small and the solution stable. Therefore, due to the 'solving criteria' some of the 'processed' satellites cannot be used. Thus, the number of satellites, for which the ambiguities have been fixed (solved), are called 'solved' satellites and their number is equal to or less than the number of processed satellites. To maintain a regular and reliable service, five 'solved' satellites are needed at any moment in time. Under normal conditions, the number of 'processed' satellites should equal the number of 'solved' satellites. This is exactly the situation between 00:00UT and 06:00UT on 29 October 2003 when the numbers are equal and varying between 11 and 6 satellites (Fig.3). Obvious discrepancies between processed and solved satellites started at around 06:00UT – precisely at the time when the first severe geomagnetic storms started. The situation has worsened (discrepancies increased) as the storm has further developed with the solved/processed percentage ratio becoming 20-30% only. Moreover, the number of solved satellites has fallen even below the critical level of 5 satellites, meaning that the positioning is no longer reliable. The worst situation happened at around 14:00UT when the number of solved satellites dropped to the zero level when the service effectively stopped. Such extreme situations are rare but should they occur they can seriously disturb the work. As the storm enters the recovery phase (at around 15:00UT) the situation slightly improves - the number of solved satellites emerges above the critical level. However, the discrepancies are still large and the danger of falling again to unreliability is still present (e.g. at around 18:00UT). Significant discrepancies are maintained until around 22:00UT on 29 Oct 2003.

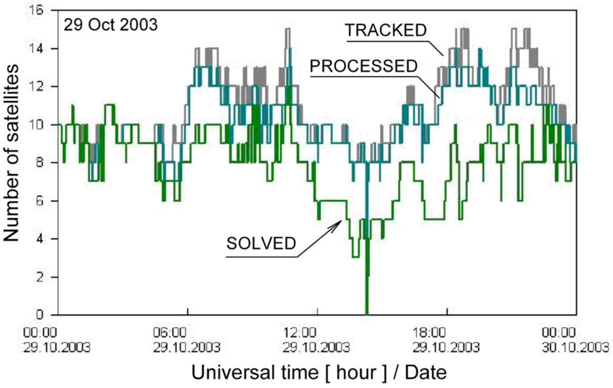


**Fig.3.** Storm effects demonstrated on the number of tracked, processed and solved satellites. Normally, the number of processed satellites should be equal to the number of solved satellites. Observed on 29 October 2003.

## 2.3 Phase and amplitude fluctuations

The phase and amplitude fluctuations are caused by the refractive and diffractive scatter due to ionospheric plasma-density irregularities, especially at equatorial and polar latitudes. The problem with such small-scale irregularities is that they can lead to cycle slips and tracking losses (scintillations). Medium-scale irregularities (TIDs) and strong ionospheric gradients may cause different signals at the reference station and at the user site, i.e. the correction message transmitted from the GNSS reference network centre to the user in the field will be definitely wrong. The strong phase fluctuations, observed during the storm on 6 April 2000, were in the order of $40\times10^{16}m^{-2}$ (approximately 6.50 m on the GPS L1 frequency) which caused serious difficulties for both the precise positioning and thenavigation (Jakowski et al., 2002b). During this event, strong phase fluctuations have been detected in Europe by both the GPS and GLONASS receivers (Fig.4).

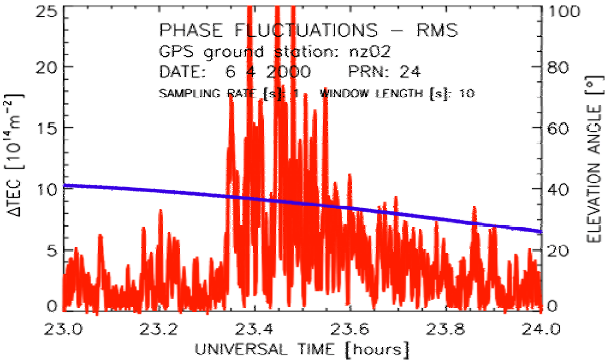


**Fig.4.** Phase fluctuations observed during 6/7 April 2000 storm.

## 3. THE IONOSPHERE DOSSIER

The ionosphere plasma, whose density peaks around the altitude of 300 km, is a dispersive and also - due to the presence of the geomagnetic field - anisotropic propagation medium for the radio waves. The ionospheric plasma interacts with the radio waves traversing the ionosphere and modifies wave parameters such as amplitude, phase and polarisation from the VHF up to the C-band frequency range. The travel time delay of transionospheric navigation signals is in the first-order approximation directly proportional to the total electron content of the ionosphere and amounts up to 60 m for GPS signals (Jakowski, 1996). 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. In reference networks, the ionospheric corrections degrade with increasing spatial de-correlation of propagation terms, particularly during major ionospheric storms.

Whereas medium-scale spatial and temporal variations, such as the traveling ionospheric disturbances (TIDs), impact mainly the reference networks, local small-scale irregularities can cause radio scintillations, thus inducing severe signal degradation and even loss of lock in the receiver. Out of the very broad spectrum of ionospheric propagation effects, the following principal conditions stand out and should be considered in a service:

- Regular ionospheric behaviour: accounts for the biggest component of the ionospheric delay and represents the main dependencies of the ionospheric delay, such as the local time, season, geomagnetic coordinates, solar and geomagnetic activities.
- Large-scale ionosphere perturbations: regional impact due to ionosphere storms, night-time enhancements, mid-latitude trough, low-latitude crest etc.
- TIDs and ionospheric scintillations: local impact of small scale ionospheric irregularities, their temporal and spatial behaviour.

How strongly the ionosphere reacts to space-weather events is clearly demonstrated below (Fig.5). Observed is a strong correlation between some space-weather environment parameters, such as the geomagnetic index Kp, the electron and proton fluxes measured onboard geostationary satellites (GOES) and the total electron content permanently monitored by DLR for the polar and European regions. The observed correlation can be successfully used in the frame of the proposed mitigation procedures discussed next.

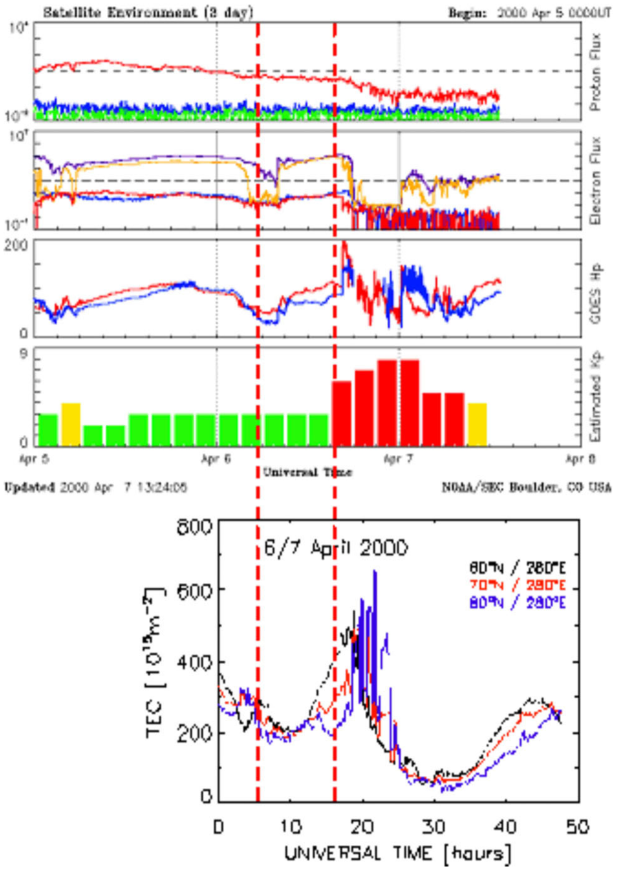


**Fig.5.** A demonstration of the relationship between space-weather parameters (top panel) and polar TEC (bottom panel) observed during the 6/7 April 2000 geomagnetic storm events.

## 4. HOW WE CAN HELP

The DLR Institute of Communications and Navigation (DLR/IKN) has a long-term experience in the detailed monitoring, analysing and studying ionospheric perturbations and ionospheric propagation errors based on both ground- and space-borne GPS measurements. Over the years, several advanced techniques and algorithms have been successfully developed and utilised to extract crucial information about the Earth's ionosphere and plasmasphere and to produce reliable simulation tools (Jakowski et al., 1996, 1999, 2002a, 2002c; Heise et al., 2002; Klaehn e al., 2003; Stankov et al., 2001, 2003a, 2003b).

Since 1995, the DLR Institute of Communications and Navigation (DLR/IKN) at Neustrelitz has been operating a new system for regularly processing data and producing maps of the integrated ionospheric electron content (TEC) over the European region based on GPS measurements from the International GPS Service (IGS). The 30s data from GPS stations of the European IGS network allow the determination of slant TEC values along numerous satellite-receiver links over the European area with high time resolution. The instrumental biases are separated from the observations by assuming a second-order polynomial approximation for TEC variations over the observing GPS ground station. Both TEC and the instrumental satellite-receiver biases are estimated simultaneously by a Kalman filter run over 24 hours. The slant TEC data are then mapped onto the vertical by applying a mapping function which is based on a single layer approximation at $h_{sp}$=400km. Finally, the observed TEC data are combined with a regional TEC model, NTCM (Neustrelitz TEC Model), in a way that the map provides measured values near measuring points and model values at regions without measurements. The advantage of the above procedure is in that, in case of a low number of measurements, it would still deliver reasonable ionospheric corrections which can be used for enhancing the accuracy and integrity of positioning.

The existing large database, containing data from the whole range of solar and geomagnetic conditions, is an optimal background for the validation of the ionospheric corrections especially at highly disturbed ionospheric conditions when other measurement techniques, e.g. ground-based vertical incidence sounding, are of limited use. Since the travel time delay of trans-ionospheric navigation signals is, in first order approximation, directly proportional to the total electron content of the ionosphere, the TEC maps directly provide the ionosphere-induced propagation error in the navigation signals. The computed European TEC maps (comparable to WAAS and ESTB ionospheric correction maps) cover a region of 32.5°N to 70°N in latitude and from –20°E to 60°E in longitude; the measurements have a routine time resolution of 10 minutes. Former verification studies by independent data sources (EISCAT, ionosondes) have shown that the absolute errors of the estimated TEC values are less than about 2-3 TECU (1TECU=$10^{16}$el/$m^2$).

Provided here is an example of European TEC maps produced for the morning hours of January 2, 2002 (Fig.6), showing the ionosphere-induced vertical delay on the L1 frequency of GPS. According to these maps, a single frequency user located in the southern part of Europe has to consider an ionosphere induced range error of more than 25m at an elevation angle of 10°, whereas a user in higher latitudes has to take into account a propagation error of less than 15m under equivalent geometrical conditions.

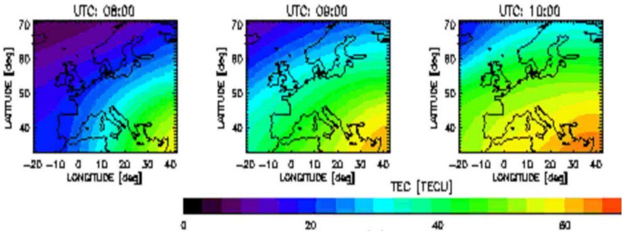


**Fig.6.** European TEC maps for 2.01.2002 at 0800, 0900, 1000UT.

Recently, the TEC monitoring system has been upgraded and currently TEC maps of both the northern and southern polar ionosphere are also being produced. Such polar maps show coupling processes with the magnetosphere and the solar wind through the cusp region. Since the ionosphere-thermosphere perturbation processes propagate towards lower latitudes, this type of information is crucial for the early detection of the ionospheric perturbations at middle latitudes. Similarly to the European TEC maps, the polar TEC maps are generated by combining actual measurements with NTCM-P model values; NTCM-P is actually the NTCM model but modified for the high-latitude regions. As an example, provided below are polar TEC maps showing the first impact of a space weather storm (30 October 2003) on the Earth's polar ionosphere (Fig.7).

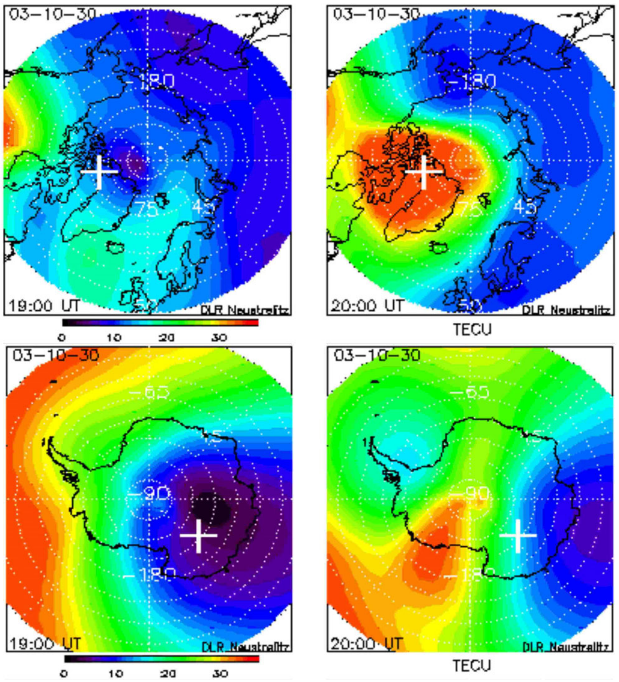


**Fig.7.** TEC maps of the North (top panels) and South (bottom panels) polar regions for 30 Oct 2003 at 1900UT (left panels) and 2000UT (right panels). The sharp increase in TEC at 200OUT is clearly observed showing the severe impact of the storm.

Furthermore, in the frame of the EGNOS Test Bed (ESTB), DLR/IKN developed the software modules for real-time estimations of the grid ionospheric vertical delay (GIVD) and the grid ionospheric vertical errors (GIVE) for the ECAC area (Klaehn et al., 2003). The lower the value of GIVE, the higher is reliability of the GIVD estimation. It is obvious from the given example (Fig.8) that the most reliable estimate is provided for the European area where sufficient monitoring data are available.

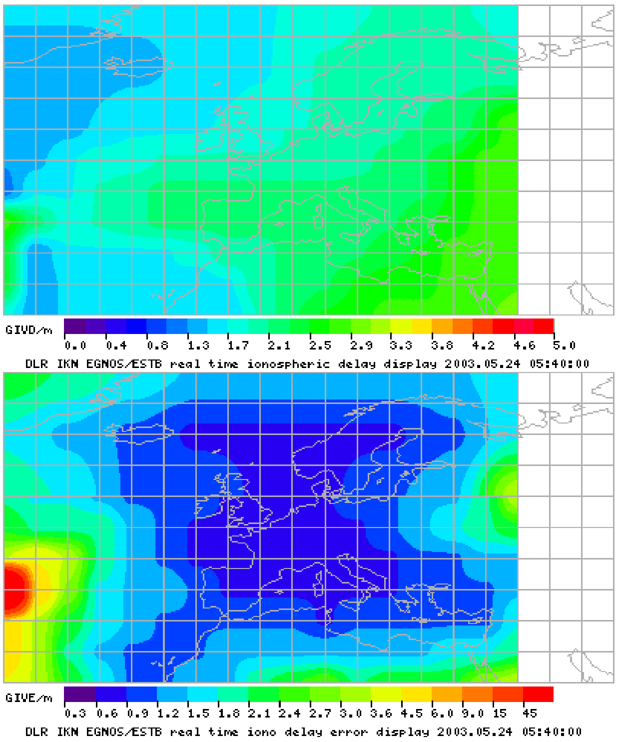


**Fig.8.** Maps of the Grid Ionospheric Vertical Delay (top panel) and the Grid Ionospheric Vertical Error (bottom panel) for 24.05.2003 at 0540UT.

Short-term predictions of the most important ionospheric characteristics, such as the critical frequency and the total electron content, can be very helpful in our efforts to mitigate the impact of space weather. Various approaches have been used to predict the behaviour of these characteristics: empirical, theoretical, neural networks, etc. New, auto- and cross-correlation procedures have been recently developed at DLR/IKN for predicting both the critical frequency and the TEC, strongly relating the short-term forecast to present and future geomagnetic activity (Stankov et al., 2001). Preliminary results of these methods/procedures have been already tested and reported for the one-dimensional case when forecasting is performed at a given location based on GPS measurements of the total electron content and on solar and geomagnetic activity indices. If such a prediction is made at several locations in a given region, then instantaneous maps of the forecast can be constructed covering the region of interest. The short-term forecast method is capable of delivering a forecast up to 24 hours ahead based on a prediction of the 'quite-time behaviour' of TEC and a subsequent correction on the relative deviations of the measured TEC from its median (quiet-time) values. These deviations, if large enough, are related to the perturbations induced by the eventual geomagnetic storm developing at the same time. The research and development activities continue. Considering the regularity and reliability of the present day GNSS measurements and the availability in real time of the basic space weather parameters, it becomes clear that the TEC short-term prediction can be utilized successfully to improve the precise positioning.

As mentioned before, the phase and amplitude scintillations are of major concern for the precise positioning/navigation practice. The phase fluctuations (scintillations) are traditionally monitored by estimating the standard deviation of the power spectrum of detrended carrier phase of GNSS satellite signals. The 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. In order to better monitor the polar scintillation activities, DLR/IKN installed a GPS receiver in Tromsoe (data analysed and processed at 50Hz sampling frequency) and started to produce estimates of S4 and Sigma-phi (Fig.9).

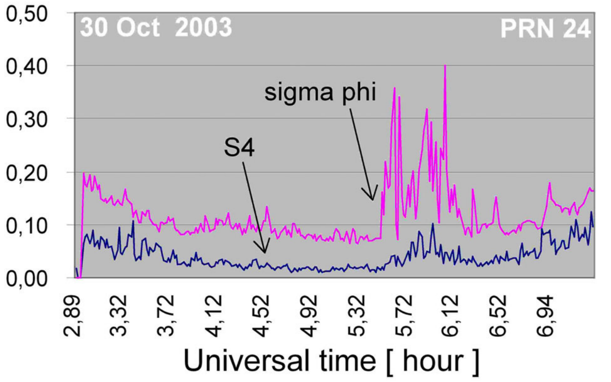


**Fig.9.** Estimates of S4 and Sigma-phi obtained on 30.10.2004 at Tromsoe (69.35ºN,19.13ºE).

S4 values that are lower than 0.3 indicate small/weak fluctuations regime, whereas values between 0.3 and 0.6 correspond to medium-scale and values greater than 0.6 correspond to strong (large) fluctuations. Any GPS receiver locking up on a GPS satellite has to do a two-dimensional search for the signal. The first dimension is time. The GPS signal structure for each satellite consists of a 1023 bit long pseudo-random number (PRN) sequence sent at a rate of 1.023 megabits/sec, i.e. the code repeats every millisecond. The receiver needs to correctly adjust the internal clock by trying all possible values in the 1023 possible time slots. Once the correct delay is found, it is tracked with a Delay Lock Loop (DLL). The second dimension is frequency. The receiver must correct for inaccuracies in the apparent Doppler frequency. Once the carrier frequency is evaluated, it is tracked with a Phase Lock Loop (PLL). When the receiver is unable to track the carrier phase, the signal is lost. Loss of lock is directly related to the PLL cycle slips. One of the very useful outcomes of our observations in Tromsoe and the successive computation of S4 and Sigma-phi is that the S4 value provides an opportunity to directly estimate the loss-of-lock probability. In the polar regions, the sigma-phi values are much larger than the S4 values; the opposite is observed in the equatorial region.

A new model, Global Ionosphere Scintillations Model (GISM), is currently being developed by IEEA (Beniguel, 2002), which is estimating the scintillations for a particular link or in a specific region. It is composed of three sub-models: ionospheric electron density model, a model allowing to set irregularity characteristics, and a propagation model. Irregularities characteristics are taken from a data bank. Parameters of interest are the average size of irregularities, their location, amplitude and probability of occurrence depending on the local time and period of the year. The signal modifications due to the propagation through the medium are calculated by a propagation model based on the phase screen technique. The algorithm is based on a solution of the parabolic equation by means of FFT techniques. Model calculations show clearly the regions where most scintillations occur – the auroral and geomagnetic equator zones (Fig.10).

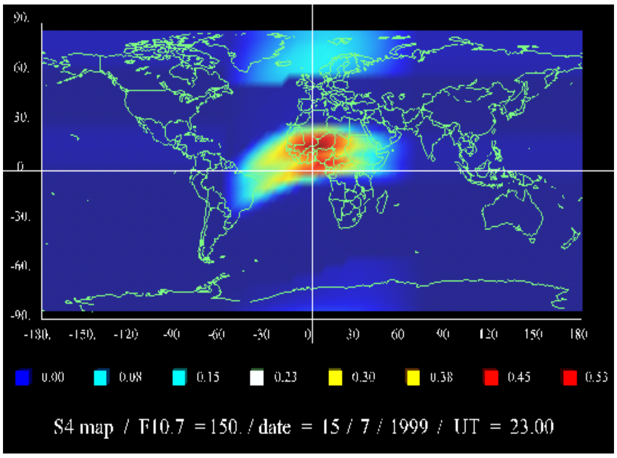


**Fig.10.** Intensity scintillation map obtained with GISM model.

## 5. THE SWIPPA PROJECT

Motivated by the several problems experienced by GNSS users, analysing these problems and finding a possible relation to adverse space weather effects, and considering the research and operational monitoring experience, the DLR/IKN team has initiated a project that offers an operational service for monitoring and evaluating the impact of space weather on precise positioning (SWIPPA).

### 5.1 Consortium

The idea of setting such an operational service for GNSS users has quickly developed and the DLR/IKN has been joined by other well respected research laboratories, universities, companies and governmental institutions to continue with this project which is expected to benefit all parties involved. Here is the list of the founding consortium members:

- **German Aerospace Centre** - Institute of Communications and Navigation, Neustrelitz (http://www.kn.nz.dlr.de),
- **Allsat GmbH network+services**, Hannover (http://www.allsat.de),
- **IEEA - Informatique Electromagnetisme Electronique Analyse numerique**, Courbevoie (http://www.ieea-fr.com),
- **SENSYS - Sensorik & Systemtechnologie GmbH**, Bad Saarow (http://www.sensys.de),
- **LVMV - Land Surveying Office of Mecklenburg-Vorpommern**, Scwerin (http://www.lverma-mv.de),
- **Swiss Reinsurance**, Zurich (http://www.swissre.com),
- **GeoForschungsZentrum** (GFZ), Potsdam (http://www.gfz-potsdam.de),
- **University of Applied Sciences** - Neubrandenburg (http://www.fh-nb.de).

The project has been further approved and additionally funded by the European Space Agency (ESA) as part of its Space Weather Pilot Project.

### 5.2 Objectives

The SWIPPA project focuses on the direct and combined use of relevant ionosphere-plasmasphere system observations and available space-weather information in the operational GPS reference networks for the purposes of precise and reliable positioning. The proposed solution is in the development of a real-time monitoring system including nowcast and forecast services available to the designated users (Fig.11).

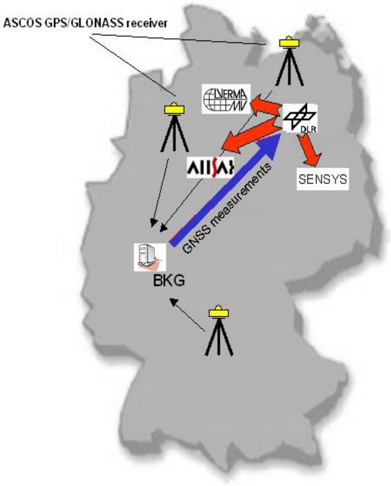


**Fig.11.** SWIPPA project service scheme.

### 5.3 Processing system

The SWIPPA service centre operates a powerful data processing system (Fig.12) working in both real-time and post-processing modes to provide the customers with actual information and to feed the forecasting module with the newest information available from our partners, from the Space Weather European Network (SWENET) community, and from external sources, like World Data Centres (WDC). The SWIPPA data processing system generates near real-time products based on data from the *ascos*® (http://ascos.ruhrgas.de/) and the *SAPOS*® (http://www.sapos.de/) reference networks. Typically, these networks are operated at monitoring stations with a sampling rate of 1 measurement per second (1Hz sampling rate). Depending on the data source, the data is formatted and transferred to the SWIPPA processing facility at DLR according to the Allsat and LVMV in-house formatting and data transfer protocol. According to the products that shall be delivered in the framework of the SWIPPA Processing System, several processing chains had to be designed and implemented. Because of the experimental nature of the project, aimed at demonstrating the potential of the space weather information as derived from ionospheric monitoring systems, advantage will be taken of pre-existing DLR software components and universal processing structures that have been applied by DLR in several projects before (e.g. ESTB, APAF, CHAMP). In the implementation of the service, the access to a common data pool and data management sub-system will be used.

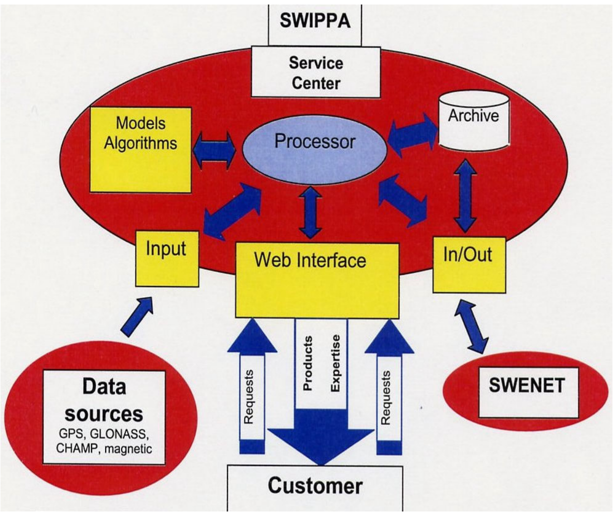


**Fig.12.** SWIPPA operational data processing system.

### 5.4 Products and services

During the preliminary discussions and several conferences and work meetings, the project consortium members substantiated their needs for SWIPPA services, selected the products which they need, defined hierarchy of priorities, and specified the user requirements related to the selected products.

- **Total Electron Content**

The hourly TEC maps present vertical TEC (in TECU) covering Europe. As explained earlier, the travel time delay of trans-ionospheric navigation signals is in first order approximation, directly proportional to the total electron content of the ionosphere. Thus, a TEC map can provide also the ionosphere propagation error. The scales represent the vertical TEC and the corresponding range error for the L1 frequency at 10 and 30 degrees elevation. It is possible also to provide polar TEC maps, GIVD and GIVE maps described in the previous section.

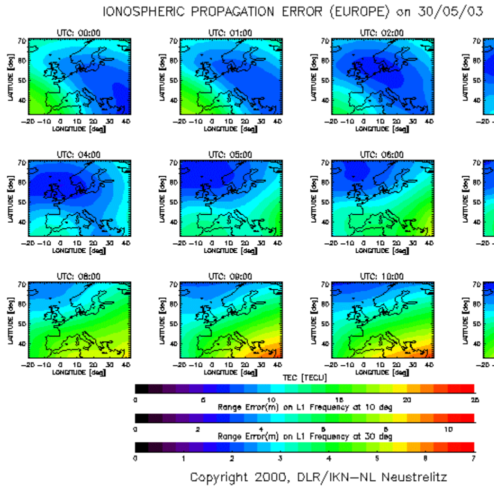


**Fig.13.** Ionospheric propagation error maps

- **Phase fluctuations**

As mentioned already, the observance of strong phase fluctuations indicates existence of small-scale irregularities in the ionosphere, which irregularities cause differences in the received signals meaning that the correction message transmitted from the GNSS reference network centre to the user will be wrong. Therefore, it is envisaged that the users receive maps (Fig.14) to help them overcome problems associated with those fluctuations.

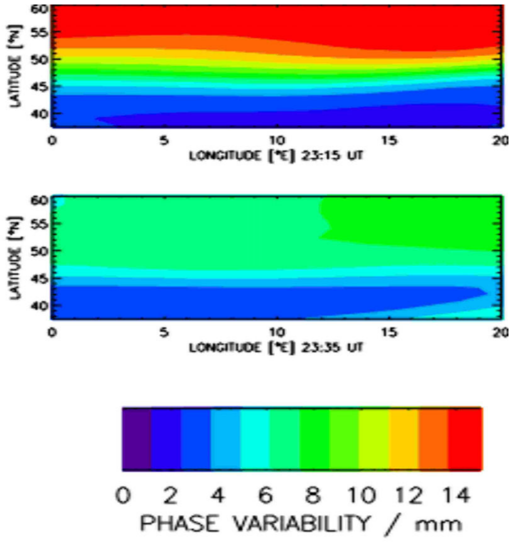


**Fig.14.** Exemplary maps of observed phase fluctuations.

- **Ionospheric Gradients**

The observance of strong ionospheric gradients indicates the development highly dynamic processes in the Earth's ionosphere-plasmasphere system with the potential of having degrading effect on positioning/navigation. For example, both WAAS and LAAS receivers utilize carrier-smoothing filters to reduce the effects of multipath and thermal noise at the aircraft. By applying such filters, users can ultimately improve accuracy. However, the presence of significant ionospheric gradients can introduce a bias into this filter's output; if unmitigated, this bias can grow to be much larger than the noise and multipath effects the filter is supposed to reduce. Ionospheric gradients are reportedly capable of inducing biases as large as 20-30m (Walter et al., 2004). The production of TEC gradients maps (Fig.15) is based on the calculation of temporal and spatial gradients at each grid point in the European region (optimally, 5 deg separation). Three types of gradient maps will be created – latitudinal gradients (GLAT), longitudinal gradients (GLON), and temporal (time) gradients (GTIM).

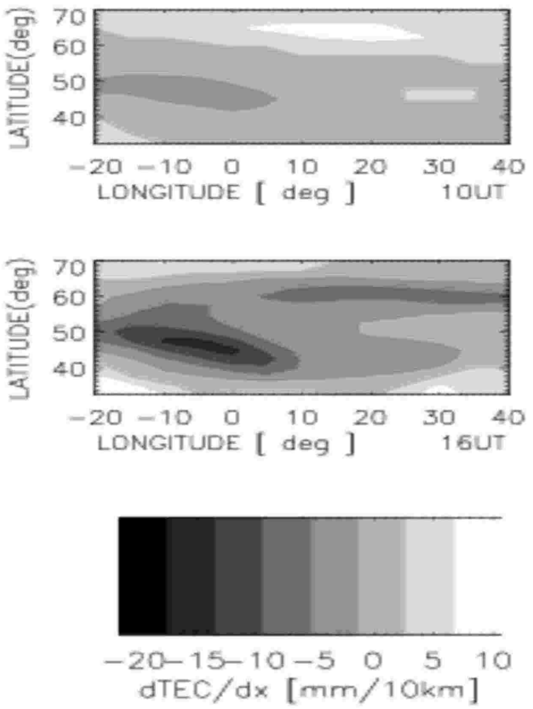


**Fig.15.** Exemplary maps of the TEC latitudinal gradients.

- **Warnings**

After analysing and synthesising the incoming geophysical information (Fig.16), short messages are forwarded to users, warning them about on-going ionosphere disturbances. The warning message is kept simple so it can be conveniently used by programmers via the ftp protocol. The warning is mostly based on the geomagnetic index Kp estimations/predictions using solar wind observations (wind density, speed) onboard satellite ACE (Advanced Composition Explorer). Additional data are also considered such as the geomagnetic field's horizontal component and the percentage deviation of the critical frequency from the monthly medians. For the time being, the ionosonde values are used only in the mornings on working days only. Inclusion of additional data are also planned (for example, the storm index Dst estimations).

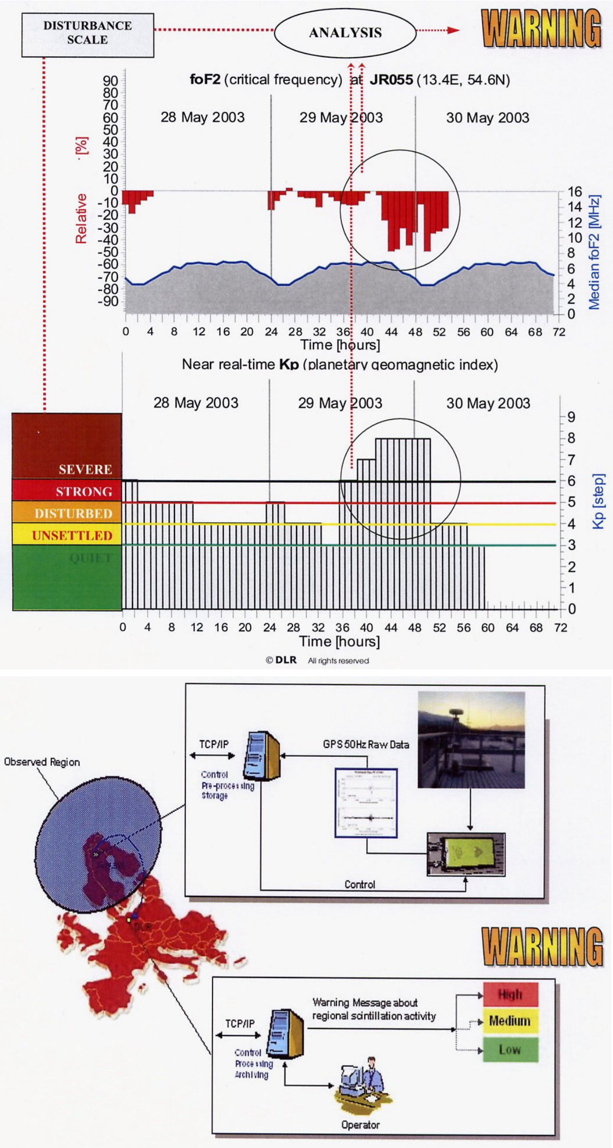


**Fig.16.** Synthesis of warning geophysical messages based on nowcast/forecast information from various ground- and space-based observations. The top panel presents an example based on the ionospheric storm events of 29-30 May 2003. The plot is based on real-time data which explains the existence of some gaps and possible innacuracies in the estimation of the relative deviation; nevertheless, the storm effects are visible. The disturbance scale reflects preliminary estimations of the space-weather impact on positioning and will be further adjusted to different users/practices. The bottom panel shows the organisation of warning service based on scintillation observations at Tromsoe.

- **Forecasts**

Two types of forecast are delivered – one based on a synthetic index of space-weather activity (Fig.16) and a forecast of the TEC value based on a prediction of the TEC ‘quite-time behaviour’ and a sub-sequent correction deduced from measured TEC relative deviations from its quiet-time values (Fig.17) (Stankov, 2002; Stankov et al., 2002).

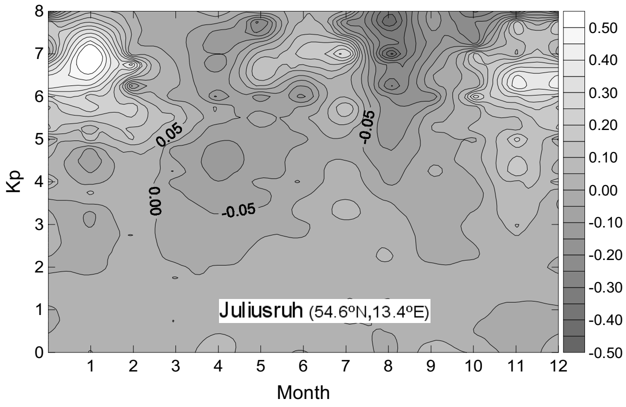


**Fig.17.** Average magnitude of the GPS TEC relative deviations from monthly medians, deduced with respect to the geomagnetic activity index $K_p$ and month of year. Results obtained for the site of station Juliusruh (54.6°N,13.4°E) based on 1995-2001 data.

- **Cycle slip number**

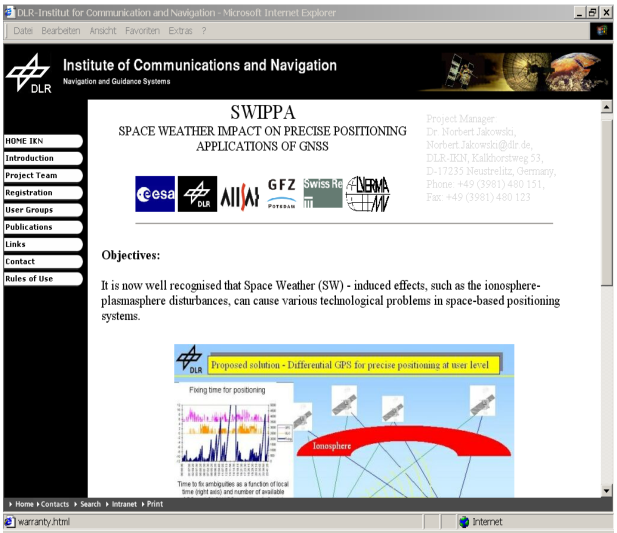
A cycle slip in a carrier phase $L_i$ , denoted $\Delta n_i$ , is defined as an integer discontinuing in the value of the corresponding bias $b_i$ . Similarly, a cycle slip in dual frequency data is expressed as $(\Delta n_1,\Delta n_2)=(b_1'-b_1,b_2'-b_2)$, where $b_1'$ and $b_2'$ are the new values of the phase biases after the cycle slip. Because cycle slips can occur concurrently and differently on the $L_1$ and $L_2$ channels, non-zero values of $\Delta n_1$ and $\Delta n_2$ must be independently detectable. For rapid cycle slip detection and correction, we follow the GPS data editing algorithm (Blewitt, 1990) which is insensitive to clock variations, receiver-satellite relative motion, and frequency variations of selective availability. The number of cycle slips is an important indicator of the GPS service quality.

### 5.5 Products dissemination

The transfer of generated data products, services and additional information to both the consortium and the external users of SWIPPA is realised by an independent server unit. However, in the first prototype of the SWIPPA operational system (SOS), used was the already existing DLR/IKN WEB / FTP - Server ( www.kn.nz.dlr.de / ftp.kn.nz.dlr.de ).

To prevent data leakage, but also for scientific purposes (e.g. long-term statistics, algorithm/code development, etc.) an independent archive unit will be maintained as part of the SOS.

The SWIPPA project has already obtained its own website (http://www.kn.nz.dlr.de/swippa/index.htm) where potential users can register, find relevant information, and access products and services (Fig.17). To safeguard the integrity of SWIPPA 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, ESA, SWENET, or Public.



SWIPPA

SPACE WEATHER IMPACT ON PRECISE POSITIONING APPLICATIONS OF GNSS

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**Objectives:**

It is now well recognised that Space Weather (SW) - induced effects, such as the ionosphere-plasmasphere disturbances, can cause various technological problems in space-based positioning systems.

**Fig.18.** The SWIPPA website provides easy access to services (http://www.kn.nz.dlr.de/swippa/index.htm).

From user point of view, the web server allows for quickly checking the current space weather situation (Fig.18), while the ftp server allows for much better handling of the operational data flow.

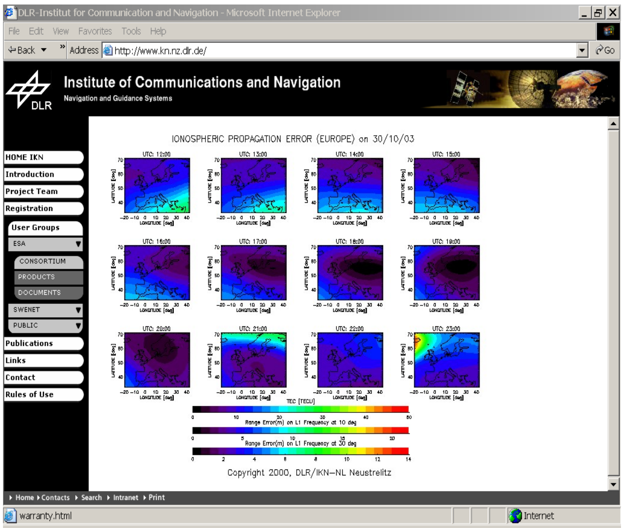

**Fig.18.** SWIPPA products accessibility via the web server.

### 5.6 Expected benefits

The major objective of SWIPPA is to demonstrate the social and economic benefit of the proposed space weather service for the concrete precise positioning work made by the users of the consortium. This is done in the project phase dedicated to the evaluation of service. This task also includes (to a certain extent) the technical service because the accuracy, temporal and spatial resolution of service parameters, their continuous and in-time provision constitute the basis for a proper and reliable application. However, the evaluation of service focuses mainly on space-weather issues and considers fundamental aspects of the service, such as the effectiveness (how the service affects the users professional activity) and the assessment of the financial benefit for the service users.

The evaluation phase is as important as the operational service, so both activities go parallel. Moreover, the service evaluation helps improving the service on an on-going basis. The estimation of the technological, social and economical benefit requires at first a comprehensive analysis of space weather effects in the navigation signals and positioning data. This will be done by correlation studies e.g. between provided space-weather service parameters and fixing time for positioning. Furthermore, it has to be find out whether the specific space-weather information is translated to the user in a proper way. This is a crucial point in many applications, because the service parameters should meet the practical needs in the most effective way. Since the technology is continuously developing, this control is a permanent task to optimise the space-weather information to the service clients. This includes also the discussion on how space weather information can be implemented into GNSS network algorithms.

## 8. SUMMARY AND OUTLOOK

The SWIPPA project focuses on the concrete use of space weather information in operational GNSS reference networks for the purpose of precise and reliable positioning. Several data products are offered to the designated users, and general public. These products, based on information of the actual and predicted state of the ionosphere, will provide the users with the type of space weather information they really need for their routine tasks.

Present GPS and future GALILEO system customers will be provided with warnings, now-casts and forecast of the ionospheric status in order to deliver a precise and secure positioning service and to reduce the operation, production, and other business costs.

Another major task of the project activities is to provide relevant information and support to the SWENET (the European Space Weather Network) community on a regular basis. SWENET aims at federating existing and newly created space weather services, assisting in the development of a common network, developing associated software infrastructure, providing support to service development activities, encouraging common development, undertaking public outreach activities, assessing user requirements, etc.

The benefits of the proposed space weather service will be independently evaluated and recommendations for service improving will be given. Expected is a growing market for precise positioning and navigation applications in the near future, particularly when GALILEO becomes fully operational.

## ACKNOWLEDGEMENTS

The SWIPPA project is jointly supported by the German Aerospace Centre and the European Space Agency (ESA) under contract ESTEC 16952/02/NL/LvH.

The authors thank the International GPS Service (IGS), NOAA Space Environment Center (SEC), Bundesamt fuer Kartographie und Geodaesie, GeoForschungsZentrum Potsdam (GFZ), Adolf-Schmidt-Observatorium fuer Geomagnetismus Niemegk, Institute of Atmospheric Physics Kuehlungsborn, and Tromsoe Geophysical Observatory for kindly providing data needed for the SWIPPA project.

Gratefully acknowledged is the past and ongoing contribution of E.Daly, A.Glover, A.Hilgers, T.Noack, A.Wehrenpfennig, J.Kunches, B.Huck, C.Daub, A.Rietdorf, H.Luehr, H.J.Linthe, R.Favre, J.Mielich, J.Rubach, K.Behnke, A.Fischer, C.Hall, and O.Husoy.

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