Deliverable 2.6

Online provision of GNSS based ionospheric data base

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NOTICE

This report has been prepared under the scope of the AFFECTS project in collaboration of the following participants of Work Package 2 "Data, Calibration, Maintenance and Instrumentation" with Lead of UoT (C. Hall):

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Content

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1 Introduction and scope of the document

This document focuses on the description of online provision of GNSS based ionosphere data which are needed to operate the "Forecast System Ionosphere" to be developed in AFFECTS WP5. This includes the data provision for e.g. the TEC forecast tool, the slab thickness calculations using vertical sounding data provided by the University of Tromsø and the quality check of physics based model calculations performed by NOAA-SWPC. The computations of NOAA-SWPC are based on the "Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics Model" (CTIPe).

The ionospheric data base is one of a list of data bases (described in tasks 2.5-2.8 in [REF1]) to be established within the AFFECTS project. These data bases are collected at the SWACI server at DLR for subsequent processing and delivery of space weather products within the AFFECTS project (cf. [REF2]). To enable easy access to users and an effective data exchange between consortium partners, DLR Neustrelitz has established a specific SWACI AFFECTS Web portal (http://swaciweb.dlr.de/affects/).

The GNSS based ionospheric data are needed for the different processing modules of the Forecast System Ionosphere (FSI), described in the system architecture document [REF4] (see

Figure 1), and for the validation of CTIPe results. The data will be made available to the AFFECTS consortium via above mentioned SWACI AFFECTS website for the specific tasks described in the following.

This document summarizes all information on the layout and implementation of the online GNSS derived data base and describes its potential usage.

2 Review of GNSS based ionospheric data use

The GNSS derived data base contains the data needed for the FSI processing modules and related quality checks. The requirements and input and output data of these modules are described in the system architecture document [REF4]. An overview is shown in

Figure 1.

Provided GNSS based ionospheric data are used in the following FSI processing modules:

1) Module 2: TEC forecast
2) Module 3: Early warning for GNSS users
3) Module 4: ACE data analysis
4) Module 6: Vertical sounding
5) Evaluation of physics based modelling results using current TEC data - this CTIPe quality check routine is operated at NOAA-SWPC

2.1 Module 2: TEC forecast

INPUT data (GNSS based)

(1) Current TEC data over European Area (-20 - 40°E; 30 – 70°N), 2° x 2° gridded values at an update rate of 15 min

(2) Related medians of TEC computed from previous 27 days,

2° x 2° gridded values at an update rate of 15 min

OUTPUT data

(1) TEC forecast including perturbed conditions,
2° x 2° gridded values at an update rate of 15 min, forecast time period tbd

(2) Instantaneous quality control of TEC forecast,
2° x 2° gridded values at an update rate of 15 min, forecast time period tbd

(3) Statistical quality check of TEC perturbation forecast

2.2 Module 3: Early warning for GNSS users

The definition of the early warning message for GNSS users is described in [REF3]. TEC data can help to define warning levels and control the quality of the prediction. The data for the application of TEC in the FSI module 3 is provided in the ionospheric data base but its usage is not mandatory.

INPUT data (GNSS based)

(1) Current TEC data over European Area (-20 - 40°E; 30 – 70°N),
2° x 2° gridded values at an update rate of 15 min

(2) Related medians of TEC computed from previous 27 days,
2° x 2° gridded values at an update rate of 15 min

OUTPUT data

(1) Instantaneous quality control of Early warning message,
mid-latitudes MLAT and High Latitudes HLAT,
update rate of 15 min, warning time period tbd

(2) Statistical quality check of TEC perturbation forecast

2.3 Module 4: ACE data analysis

INPUT data (GNSS based)

(1) Current TEC data over European Area (-20 - 40°E; 30 – 70°N),
2° x 2° gridded values at an update rate of 15 min

OUTPUT data

(1) Correlation statistics between ACE parameter and TEC,
output regionalized at MLAT and HLAT, update rate: 15 min

(2) Preliminary ACE data based warning,
output regionalized at MLAT and HLAT, update rate: 15 min

(3) Statistical quality check of ACE data based warning

2.4 Module 6: Slab Thickness

INPUT data (GNSS based)

(1) Current TEC data over European Area (-20 - 40°E; 30 – 70°N),
2° x 2° gridded values at an update rate of 15 min

OUTPUT data

(1) Measured critical frequency or peak electron density and estimated TEC

(2) Slab thickness over locations of the ionosondes at an update rate of 15 minutes

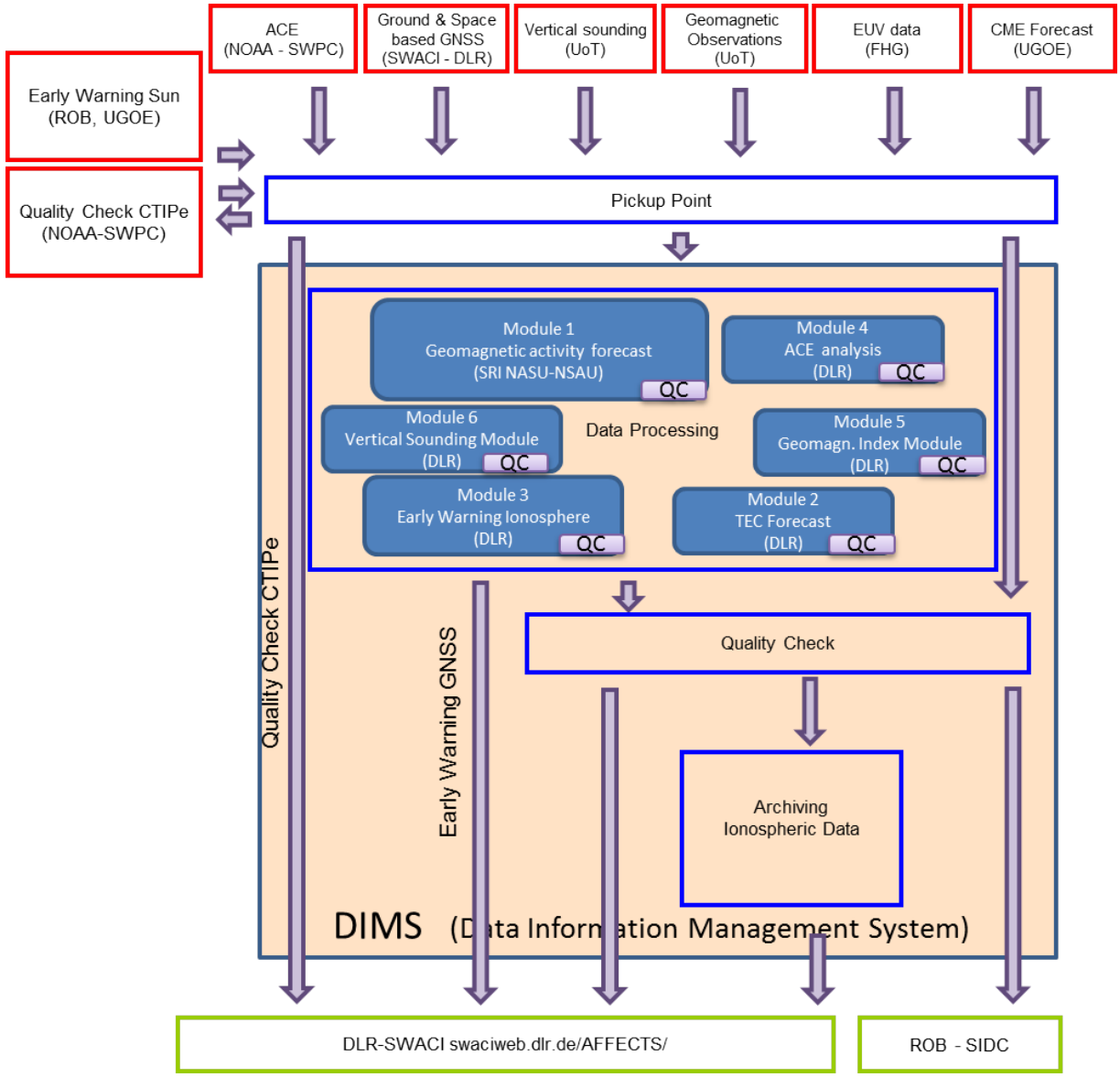

Figure 1 Overview on the ionospheric forecast system designed in WP5 [REF4].

A representative list of GNSS based ionospheric data is provided in Table 1:

Table 1 List of GNSS based ionospheric data provided via AFFECTS

Index of product	Ionospheric GNSS based data product	Temporal resolution (min)	Spatial resolution
(1)	TEC nowcast over Europe (-20 – 40 °E; 30 – 70 °N), latency < 5 min	15	2 deg x 2 deg
(2)	TEC medians over Europe from previous 27 days	15	2 deg x 2 deg
(3)	Global TEC nowcast, latency < 5 min	60	5 deg x 5 deg
(4)	Slab Thickness	15	Local measurement

3 Product description

The online GNSS based ionospheric data base incorporates a product description assigned to each product of the data base. The product descriptions are given below.

3.1 European near real time TEC maps

The Total Electron Content (TEC) is defined as the integral of the electron density along the ray path between satellite and receiver. Thus, TEC provides the number of electrons per square meter. The most frequently used unit is 1TECU = $1x10^{16}$ electrons / m^2.

TEC is derived from dual frequency code and carrier phase measurements provided by Global Navigation Satellite Systems (GNSS) via the SWACI processor. GPS measurements from various European GNSS networks such as IGS and EUREF distributed by BKG Frankfurt and from SAPOS are used.

The GNSS dual frequency measurements must be calibrated in a first step to compensate instrumental biases from satellites and receivers. In a second step the usually along a slant ray path measured data are mapped to the vertical at so-called piercing points for normalization. To generate a TEC map, the derived TEC values at piercing points are assimilated into a background TEC model (e.g. [REF5], [REF7]).

In a first approximation the ionospheric range error in GNSS is proportional to TEC. This is the reason why TEC is the key parameter for characterising the impact on GNSS.

3.2 European median TEC maps

To estimate large scale ionospheric perturbations, at each grid point the medians of TEC for the previous 27 days are computed as reference values. The medians are computed from 27 previous days. Median data have to be computed for each grid point in a sliding window.

3.3 Global TEC maps

Global TEC maps are generated in the same way as regional European TEC maps. For map generation via data assimilation we use the recently developed NTCM-GL [REF6] model. Global TEC map generation is mainly based on current GNSS data provided by the International GNSS Service Real-Time Pilot Project (IGS-RTPP).

3.4 Equivalent slab thickness

The equivalent slab thickness is a measure of the width of the shape of the vertical electron density profile of the ionosphere. It is defined by the ratio of the total electron content (TEC) and the peak electron density of the local ionosphere. To compute the peak electron density, vertical sounding data from the ionosonde stations are used which are provided every 15 minutes. The corresponding TEC data over the ionosonde stations are extracted from the SWACI TEC maps.

4 Layout

A huge data base of GNSS based ionospheric data is available at the SWACI Service provided by DLR. An SWACI AFFECTS website has been established (http://swaciweb.dlr.de/affects/). The scope of this website is the provision of data to the AFFECTS consortium. The SWACI AFFECTS website already provides a solar wind and a geomagnetic index data base (D2.4 and D2.5), partly realised by direct data provision and partly by hyper linking. The GNSS based ionospheric data base is now incorporated as well in this website.

The layout of the SWACI AFFECTS website is described in [REF2]. The website contains the menu item "GNSS based TEC" which is linked to the GNSS based ionospheric data base. The arrangement of the data products available through the website will take care of the products under development (e.g. TEC forecast). These will be integrated into the data base after their release.

The menu item "GNSS based TEC" is divided into two submenu items, one for European TEC maps and one for global TEC maps. The submenu item "Europe" incorporates the EU TEC nowcast maps and the corresponding medians whereas the submenu item "Global" incorporates the global TEC nowcast maps. After the completion of the EU TEC Forecast (AFFECTS deliverable 4.4) the TEC forecast maps and the quality check will be included in the "Europe" submenu item. Global CTIPe TEC maps and quality checks will be incorporated in the course of the development of the "Forecast System Ionosphere". They will appear in the submenu item "Global". Figure 2 provides an overview on the layout of the menu item "GNSS based TEC". Black fonts indicate the data which are already disseminated and gray fonts indicate the data which will be incorporated in the course of AFFECTS.

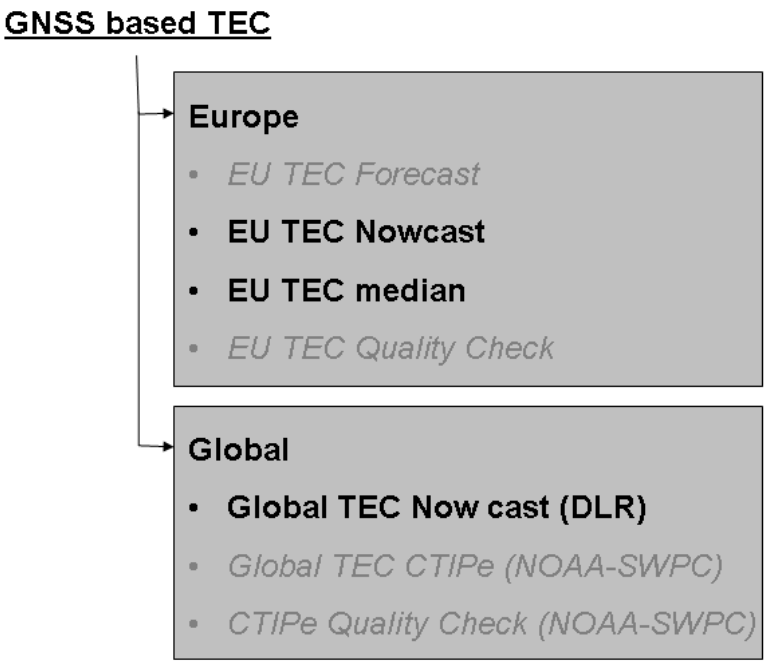

Figure 2 Incorporation of the GNSS based ionospheric data base into the SWACI AFFECTS website. Black fonts indicate the fundamental data which have already been incorporated. Gray fonts indicate data that will be incorporated in the course of the AFFECTS project.

The menu item "vertical sounding" comprises the online products retrieved from vertical sounding data delivered by the University of Tromsø, including EISCAT. Up to now this is the slab thickness which is calculated in combination with ground based TEC measurements. The website provides for each vertical sounding station the critical frequency *foF2*, the height of the F2 layer *hmF2*, TEC and the slab thickness τ.

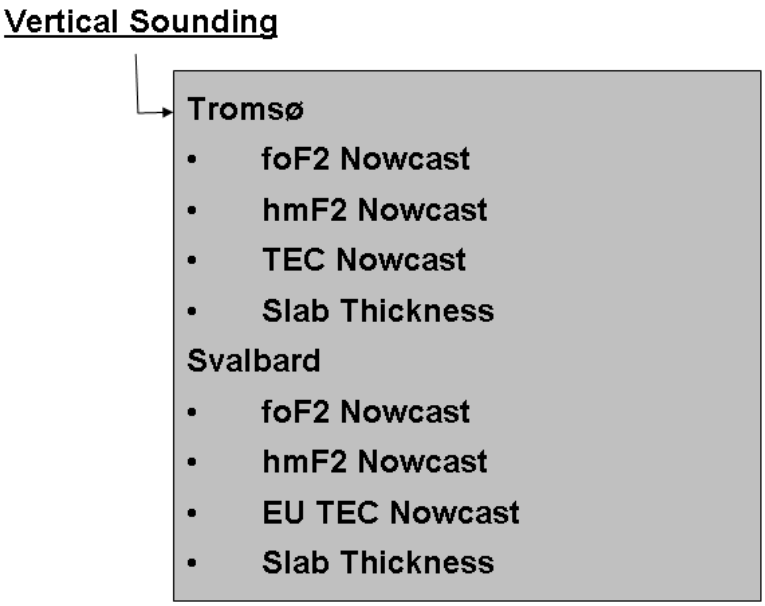

Figure 3 Incorporation of the slab thickness products using vertical sounding data within the AFFECTS-SWACI website.

5 Implementation

The implementation of the data provision through the SWACI AFFECTS website is realized by establishing a stable data link between the SWACI processing machine and the SWACI AFFECTS website at DLR. This implementation procedure requires the consideration of technical and safety related requirements.

Basically, the implementation of the "Online GNSS based ionospheric data base" is made up in the following three steps:

1. Configuration: AFFECTS is registered as a new user within SWACI.
2. File transfer: Data are uploaded to the SWACI AFFECTS website.
3. Adjustment of the website: Subsequent website development following the descriptions of section 4.

6 Demonstration of operability

The testing procedures include quality checks on the data transfer stability from the SWACI processor to the SWACI AFFECTS website as an automatic control procedure within the service.

In order to demonstrate its operability, screenshots and download tests are performed as follows:

6.1 Screenshots

Screenshots of the SWACI AFFECTS web portal are shown in Figure 4 and Figure 5. Figure 4 demonstrates the data provision of the GNSS based TEC maps and Figure 5 illustrates the menu item "vertical sounding" in form of plots of the slab thickness data. In Figure 4 the image of the Europe TEC map is a hyperlink to the TEC Europe menu item, where the TEC rate data is provided. Analogous the image of the global TEC map is the hyperlink to the "TEC Global" menu item.

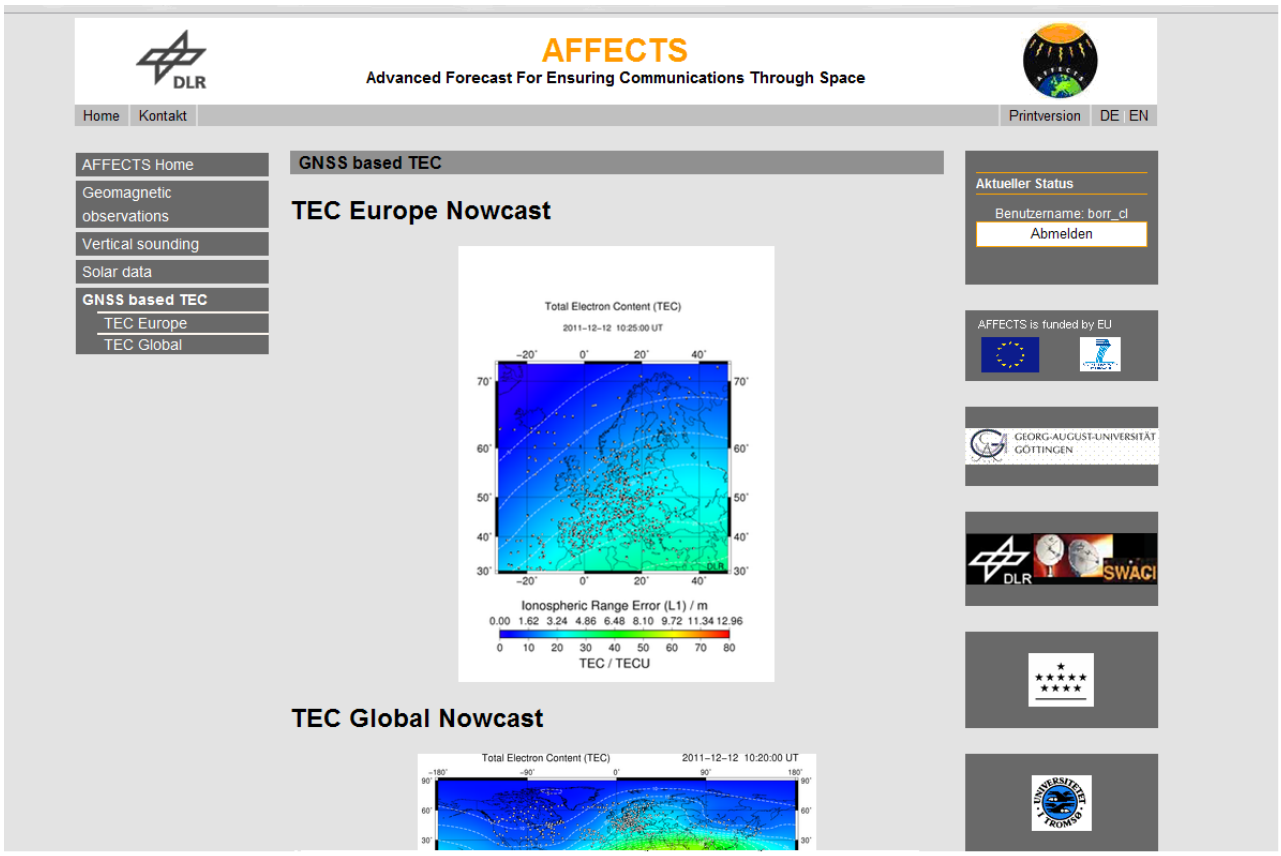

Figure 4 Screenshot of the SWACI AFFECTS website showing the "GNSS based TEC" menu item.

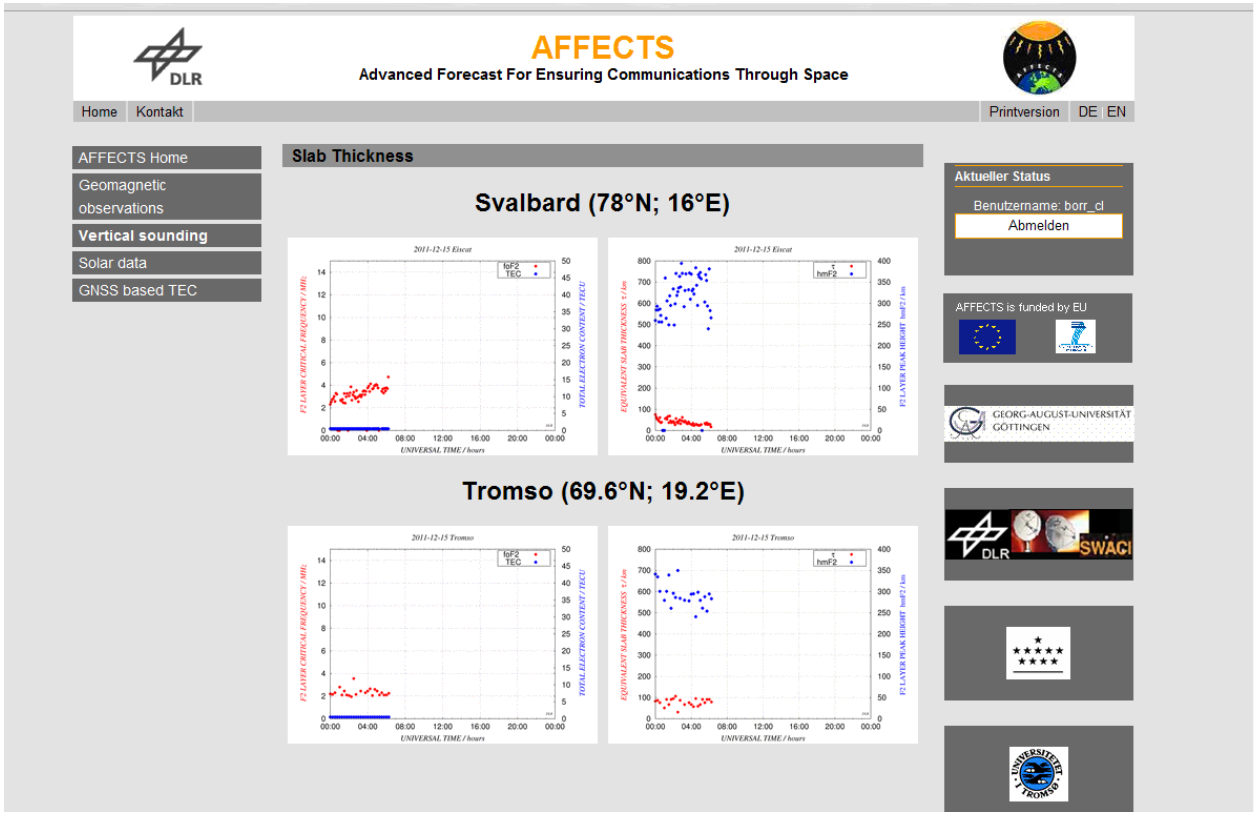

Figure 5 Screenshot of the SWACI-AFFECTS portal showing the "vertical sounding" menu item.

6.2 Download demonstration

Figure 6 shows a screenshot of the menu item „TEC Europe" of the SWACI AFFECTS web portal at DLR. An image demonstrating the TEC nowcast and the TEC rate is situated in the upper part of the website. Below the image there is a hyperlink for the data download. An example for the data set is shown in the additional browser window. It opens after applying the hyperlink.

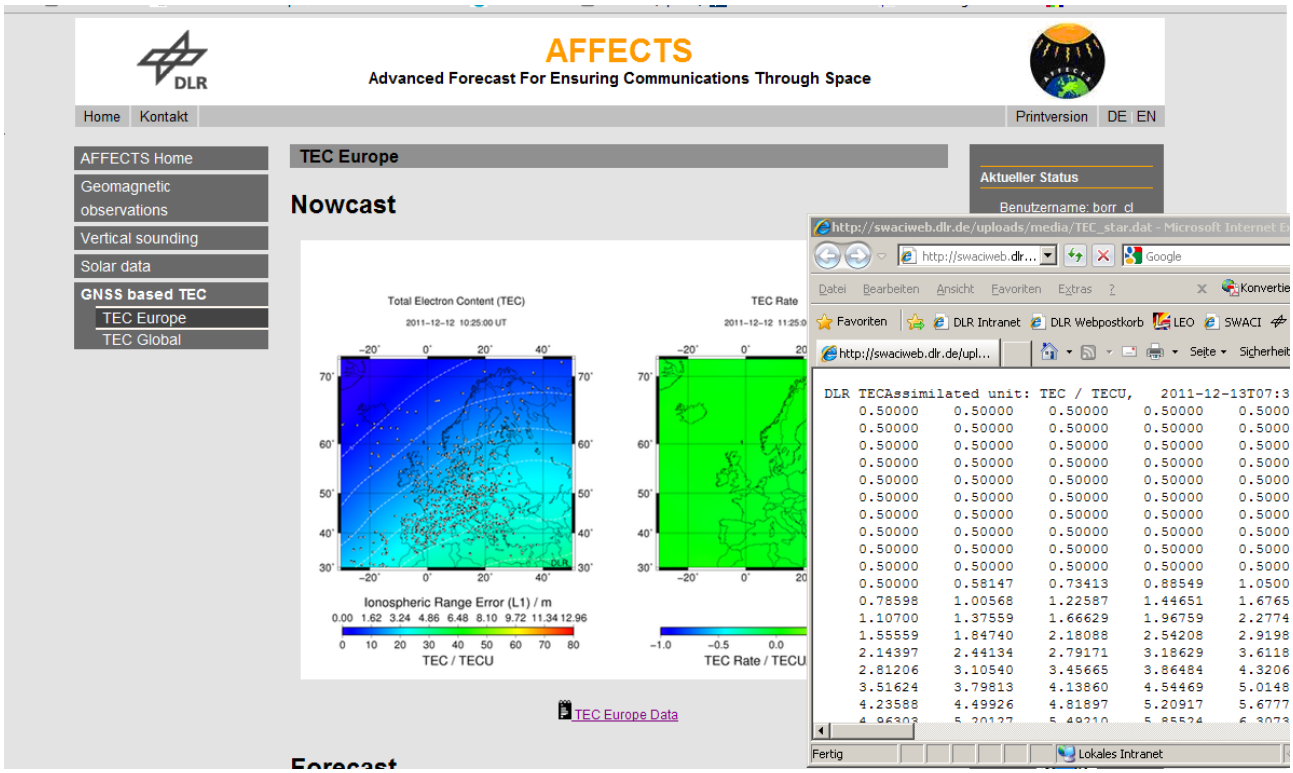

Figure 6 Screenshot showing the "TEC Europe" menu item of the SWACI AFFECTS web portal. The additional browser window pops up after clicking on the "TEC Europe Data" hyperlink situated below the images. The new window shows the TEC data to be downloaded.

7 Data use

GNSS based ionospheric data are used in the AFFECTS subsystem of SWACI. As described earlier in section 2, these data are processed in the following modules: Module 2 (TEC forecast), Module 3 (Early warning for GNSS users) and Module 4 (ACE data analysis). In addition to these internal processing modules, global TEC data are used for evaluation of the physics based model CTIPe which is operated by NOAA-SWPC.

8 Summary and Conclusions

This paper describes the provision of a GNSS related data base for ionospheric now and forecast service provided through the SWACI AFFECTS web portal. Although the forecast system is in its development phase, ionospheric data (viz. deliverable 2.6) are already in use for developing and testing the forecast system. Various items will be updated in the course of the project work to enhance the performance of the system and its space weather products. The specific description of the individual product will be implemented soon. In summary, the GNSS based ionospheric data base is ready for use in terms of product generation modules.

9 References

[REF1] AFFECTS Grant Agreement, Annex I (Description of Work), Part A

[REF2] AFFECTS deliverable 2.4 report

[REF3] AFFECTS deliverable 3.2 report

[REF4] AFFECTS deliverable 5.1 report

[REF5] Jakowski, N., TEC Monitoring by Using Satellite Positioning Systems, Modern Ionospheric Science, (Eds. H.Kohl, R. Rüster, K. Schlegel), EGS, Katlenburg-Lindau, ProduServ GmbH Verlagsservice, Berlin, pp 371-390,1996

[REF6] Jakowski N, Hoque MM, Mayer C (2011) A new global TEC model for estimating transionospheric radio wave propagation errors, Journal of Geodesy, 10.1007/s00190-011-0455-1

[REF7] Jakowski, N., C. Mayer, M. M. Hoque, and V. Wilken (2011), TEC Models And Their Use In Ionosphere Monitoring, Radio Sci., doi:10.1029/2010RS004620, in press.

10 Appendix

10.1 List of Acronyms

ACE	**A**dvanced **C**omposition **E**xplorer
AFFECTS	**A**dvance **F**orecast **F**or **E**nsuring **C**ommunications **T**hrough **S**pace
CME	**C**oronal **M**ass **E**jection
CTIPe	**C**oupled **T**hermosphere **I**onosphere **P**lasmasphere **E**lectrodynamics Model
DLR	**D**eutsches Zentrum für **L**uft- und **R**aumfahrt
DoW	**D**escription **o**f **W**ork
EISCAT	**E**uropean **I**ncoherent **SCAT**ter facility
EU	**EU**rope
EUREF	**EU**ropean **REF**erence System
GNSS	**G**lobal **N**avigation **S**atellite **S**ystem
IGS	**I**nternational **G**NSS **S**ervice
IMF	**I**nterplanetary **M**agnetic **F**ield
NOAA	**N**ational **O**ceanic and **A**tmospheric **A**dministration
NRT	**N**ear **R**eal **T**ime
ROB	**R**oyal **O**bservatory of **B**elgium
RTSW	**R**eal **T**ime **S**olar **W**ind network
SAPOS	**SA**tellite **POS**itioning Service of Germany
SIDC	**S**olar **I**nfluence **D**ata analyis **C**enter
SWACI	**S**pace **W**eather **A**pplication **C**enter – **I**onosphere
SWPC	**S**pace **W**eather **P**rediction **C**enter Boulder
TEC	**T**otal **E**lectron **C**ontent
UGOE	Georg-August-**U**niversity **Gö**ttingen
UoT	**U**niversity **o**f **T**romsø
UT	**U**niversal **T**ime
WP	**W**ork **P**ackage