Ionospheric services for GNSS applications and related research at DLR

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Institute of Communication and Navigation
Working group „Ionospheric Effects and Mitigation Techniques“
Since 100 years research on the interaction of electromagnetic waves with the atmosphere/ionosphere at the site Neustrelitz.
Impact of ionospheric effects are a challenge for navigation, communication and earth observation.

The plasma of the ionosphere causes a delay of the radio signals.

→ *Pretending an excess in distance between the satellite and the measurement site*

- Plasma instability causes:
  - Signal strength fluctuations
  - Defocussing of the signal

→ *Possible loss of the signal*
The Ionosphere Monitoring and Prediction Center (IMPC) of DLR provides a near real-time information and data service on the current state of the ionosphere, related forecasts and warnings.

IMPC provides a service for:
- Science
- Governmental decisions
- Commercial application
- Public interest

IMPC Facilities I: GIFDS: Global Ionospheric Flare Detection System

Network of Very Low Frequency receiver stations for Flare Detection

- DLR Neustrelitz
- Krakow, Poland
- Boston College, MA
- Stanford University, CA
- National Central University, Taiwan

1 Hz data of VLF signals (Navy stations):

- Amplitude
- Phase

Solar radiation bursts at EUV and X-ray wave lengths can lead to a considerably increased plasma density in the ionosphere.

Need to distinguish between X-ray and EUV flare component:
- X-ray (red) primarily affects HF
- EUV (yellow) mainly influences GNSS

X-ray scales have only limited information for GNSS users
- Even strong X-ray flare may have weak EUV component (see X 1.3 on the right)
- False alarms are possible

Combination of GIFDS and TEC rate information shall help to derive user-specific warnings of flares.
IMPC Facilities II: Reception of solar wind data

DLR is a privileged partner of NOAA-SWPC, the US space weather prediction center and is as member of the Real Time Solar Wind (RTSW) observation network, engaged in the data transfer and analysis of NASA’s Advanced Composition Explorer (ACE) and the Deep Space Climate Observatory (DSCOVR).
IMPC Facilities III: Experimentation and Verification Network (EV-NET)

DLR operates its own high rate GNSS receiver network (50 - 100 Hz) for scintillation measurement from high latitudes (Kiruna/Sweden) down to equatorial regions (Bahir Dar/Ethiopia)
Technological ability for reception and distribution of GNSS ionosphere data streams

- Flexible software components have been developed in order to allow characterization of the actual state of the ionosphere.
- The system automatically processes and distributes high rate GNSS data (1Hz) of several hundred GNSS receivers from GNSS-reference networks worldwide (IGS, EUREF, UNAVCO, ASI, TrigNet).
Ionospheric Disturbance Index (DIX)

1/2 h integrated DIX 20161120DOY325T091500 UT

DIX 2.6 Level
17/03/2015, 05:00:00UT to 17/03/2015, 10:00:00UT
Sum of Elements with Measurements: 1503
i.e. Covered Area: (~32.4%)
Number of Level 1: 124 (~08.3%)
Number of Level 2: 033 (~02.2%)
Number of Level 3: 008 (~00.5%)
Number of Level 4: 005 (~00.3%)
Number of Level 5: 004 (~00.3%)

DIX 2.6 Level
17/03/2015, 16:00:00UT to 17/03/2015, 17:00:00UT
Sum of Elements with Measurements: 1857
i.e. Covered Area: (~40.0%)
Number of Level 1: 355 (~19.1%)
Number of Level 2: 178 (~09.6%)
Number of Level 3: 118 (~06.4%)
Number of Level 4: 084 (~04.5%)
Number of Level 5: 249 (~13.4%)

DLR
Global distribution of ionospheric irregularities

Rate of change of TEC index - 24h max

2014-09-22 00:00:00

ROTI [TECU/min]

0.0 0.6 1.2 1.8 2.4 3.0 3.6 4.2 4.8 5.4 6.0

Frequent

Infrequent
Expert Service Center „Ionospheric Weather“ (I-ESC)

The I-ESC provides, implements and supports the Ionospheric and upper Atmosphere Weather products and capabilities of the ESA SSA SWE network, including the observation, monitoring, interpretation, modelling and forecasting of Ionospheric and upper Atmosphere Weather conditions.

**DLR has been contracted by ESA to:**

- Coordinate the ESC Ionospheric Weather
- Planning and Development of the ESC
- Data provision and service
ESA-SSA-SWE ESC Ionospheric Weather Team

- German Aerospace Center
- Norwegian Mapping Authority
- Polish Space Research Center PAS
- Danish Technical University
- Finnish Meteorological Institute
- Italian National Institute for Geophysics and Vulcanology
- Collecte Localisation Satellites
- Institute of Atmospheric Physics
- National Observatory of Athens
Ionospheric Weather Expert Service Centre

This page provides access to the latest data, products and analysis tools from the SSA SWE Ionospheric Weather Expert Service Centre.

Latest data

One Hour TEC Forecast

2017-05-03 11:15:00 UT

Ionospheric Range Error (L1) / m

0.00 1.62 3.24 4.86 6.48 8.10 9.72 11.34 12.96 14.58 16.20

0 10 20 30 40 50 60 70 80 90 100

TEC / TECU

ESC tools and products

IMPC
- TEC Europe and TEC Europe forecast
- TEC Global forecast
- Slab Thickness
- Scintillation Index
- ROTI maps for Europe

RTIM
- Plasma content above Nordic region
- Turbulence index over Nordic region
- Ground disturbances over Norway
- Scintillation map over Nordic region
- ROTI at ground time series (Selected locations in northern Europe)

EIS
- Integrated Electron Density Maps
- Current Ionospheric Conditions
- foF2 nowcast maps
- Long Term Prediction maps of foF2

RESOSS
- VTEC maps (Northern Europe)
- ROTI maps (Northern Europe)
- S4 and sigma-phi maps (Northern Europe)
- ROTI at ground time series (Selected locations in northern Europe)

SISTED
- Sunlit Ionosphere Sudden TEC Enhancement Detector

GSFLAI
- GNSS Solar Flare Activity Indicator

SGIrv
- Archive of solar and geomagnetic indices for thermospheric drag calculation
Development of 3D kriging to estimate STEC and Ne

Kriging of VTEC already applied, cf. e.g. IGS TEC maps & WAAS

NTCM Ionospheric Correction Model driven by Klobuchar coefficients

- Single frequency operations require ionospheric information to correct the range error
- We have developed an ionospheric correction algorithm called Neustrelitz TEC model

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<td>NeQuick</td>
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- In recent investigations using our NTCM driven by Klobuchar parameters we could show a significant better performance than obtained by the ICA algorithm.

- Our approach doesn’t require technology changes for GPS users, but just to use the NTCM approach in order to complement the existing ICA algorithm.
New ionosphere mapping function

- The vertical structure of the ionosphere is reduced to a single thin-shell.

- The mapping function error was found as large as 10 m for vertical range error estimates during the October 2003 storm which will be a factor of 2-3 times higher for slant estimates.
New ionosphere mapping function

Proposed multi-shell ionosphere approach
[Hoque & Jakowski, ION GNSS 2013; Hoque et al., ION GNSS 2014]

- The idea behind our new approach is to utilize as much information as available from broadcast delays at IGPs.
- Considering broadcast delays at different geographic locations along the ray path projected on the thin-shell at 350 km height, our algorithm incorporates horizontal gradients in the slant delay computation.
- The vertical structure of the ionosphere is taken into account considering Chapman layer assumption.

-23/10/2011, F10.7 = 154 f.u.
Empirical 3D plasmasphere model

- An improved 3D plasmasphere model has been developed with several advantages compared to frequently used PIM model.

- Climatological model approach describing dependencies on local time, geographic/geomagnetic location and solar irradiance and activity.

- The Model is developed based on recent topside GPS data and describes main plasmaspheric features in good quality with a minimal number of model coefficients and parameters.

Thank you!

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