The Near Real Time Ionospheric Model of Latvia

M Kalinka\textsuperscript{1,2,3}, J Zvirgzs\textsuperscript{1,2}, D Dobelis\textsuperscript{2}, E Lazdāns\textsuperscript{2} and M Reiniks\textsuperscript{2}

\textsuperscript{1}University of Latvia, Institute of Geodesy and Geoinformatics, Riga, Latvia
\textsuperscript{2}Riga Technical University, Faculty of Civil Engineering, Department of Geomatics, Kalku Str. 1, Riga, LV-1658, Latvia

E-mail: maris.kalinka@rtu.lv

Abstract. A highly accurate ionosphere model is necessary to enable a fast and reliable coordinate determination with GNSS in real time. It is a partially ionized atmospheric region ranging up to 1,000 km height, affected by spatial variations, space weather, seasonal and solar cycle dependence. New approaches and algorithms of modelling techniques are sought to provide better solutions in the territory of Latvia. Ionospheric TEC value has large differences in Western Latvia and Eastern Latvia. Actual ionospheric map should be calculated and delivered to the surveyors near real time and published on the WEB. Delivering actual map to rover GNSS devices in a field will provide the surveyors with ionospheric conditions and allow choosing best time for surveying and making geodetic measurements with higher accuracy and reliability.

1. Introduction
The Global Navigation Satellite System (GNSS) has become an important tool for monitoring and predicting the variations in the earth’s ionosphere based on the total electron content (TEC). There are international services providing global and regional ionospheric products derived from GNSS data processing. To achieve more detailed results for small areas, the activity of ionosphere can be processed and modelled using Continuously Operating Reference Networks (CORS) data. CORS network in Latvia (LatPos) has been fully operational since year 2005. The post-processing data for research of ionospheric activity during last solar cycle is fully available from up to 25 permanent GNSS base stations. The data in RINEX format from LatPos base stations are used to develop techniques and algorithms to improve local ionosphere modelling.

In this study, the local ionosphere modelling from LatPos data is presented. The achieved results are compared to the global ionospheric products derived from IGS.

\textsuperscript{3} To whom any correspondence should be addressed.
To provide ionosphere activity related information to LatPos users, the data flow chart of calculations and ionosphere modelling in near real time are introduced.

2. Sets of the data
Continuously operating reference network system LatPos data have been used in calculations for the territory of Latvia. In the time span from 2005 to 2013, the positions of the antennas have been changed and new hardware installed. The network also has new stations installed. Base station “Ojars” was installed in 2001. The LatPos network schema is shown in figure 1.

![Figure 1. Continuously Operating Reference Network System LatPos – positions and names of base stations.](image)

At the maximum of the solar activity, the LatPos network showed a lot of problems for precise measurements. The high ionosphere activity was reached from 10 o’clock GPS time. LatPos network has a set of data to analyze the ionosphere changes at the regional and local level. Table 1 shows the GNSS base stations used for modelling the ionosphere models.

To show the influence of solar activity on GNSS data processing, periods of minimum and maximum values of solar activity have been used. As solar activity cycle is 11 Years, 24 hour data sets were selected on 1 August 2006 and 1 August 2012. Base station coordinates are shown in table 2.

### Table 1. LatPos station names and codes.

| Station Name   | Station code | 2006.08.01. GPS Day 213 | Station Name   | Station code | 2012.08.01. GPS Day 214 |
|----------------|--------------|-------------------------|----------------|--------------|-------------------------|
| VENTSPILS      | VENT         | IRBENE                  | IRBE           |
| LIEPAJA        | LIEP         | LIEPAJAI                | LIE1           |
| DOBELE         | DOBE         | DOBELEI                 | DOB1           |
| OJARS          | OJAR         | OJARS                   | OJAR           |
| VALMIERA       | VALM         | MAZSALACA               | MSLC           |
| BALVI          | BALV         | BALVI                   | BALV           |
| MADONA         | MADO         | MADONA                  | MADO           |
| DAUGAVPILS     | DAUG         | DAUGAVPILS1             | DAU1           |
Data model calculated using 8 base stations is shown in table 1. The network of the LatPos has been upgraded in the period from 2006-2012 and positions of the base stations have been changed. This does not affects data processing as the base stations provide information about the entire country and global ionosphere parameters of the ionosphere change in minimal amplitude. Base stations and calculated vectors are shown in figure 2.

Table 2. LatPos base station coordinates.

| NUM | STATION NAME | X (M)       | Y (M)       | Z (M)       |
|-----|--------------|-------------|-------------|-------------|
| 1   | IRBENE       | 3183614.9330| 1276707.5630| 5359315.0420|
| 2   | BALVI        | 3084535.0560| 1589675.9260| 5333791.7030|
| 3   | DAUGAVPILSI  | 3209600.8390| 1601536.4170| 5256389.4850|
| 4   | DOBELE1      | 3229567.8250| 1389764.1370| 5303835.6430|
| 5   | LIEPAJA1     | 3293067.5830| 1265205.9660| 5295955.7890|
| 6   | MADONA       | 3136049.8430| 1544577.1080| 5317122.7360|
| 7   | MAZSALACA    | 3081539.1520| 1440527.8530| 5377339.2580|
| 8   | OJARS        | 3185444.6290| 1423322.9900| 5321411.2010|
| 9   | DAUGAVPILS   | 3209659.7949| 1265426.8193| 5349535.1459|
| 10  | DOBELE       | 3230387.1544| 138950.5810  | 5303282.7935|
| 11  | LIEPAJA      | 3293151.6277| 1264543.6873| 5296068.1552|
| 12  | VALMiera     | 3099939.8934| 1472346.3504| 5358234.0646|
| 13  | VENTSPILS    | 3204596.0472| 1265426.8193| 5349535.1459|

3. Methods of calculation
Bernese GPS V5.0 software with two modeling principles – the local and regional model – was used for calculating the ionosphere models.
Local TEC model can be calculated if one or more double frequency stations have been used. The model can be described with the following algorithm:

\[
E(\beta, s) = \sum_{n=0}^{n_{\text{max}}} \sum_{m=0}^{m_{\text{max}}} E_{nm} (\beta - \beta_0)^n (s - s_0)^m,
\]

where

- \( n_{\text{max}}, m_{\text{max}} \) are the maximum degrees of two-dimensional Taylor series expansion in latitude \( \beta \) and longitude \( s \),
- \( E_{nm} \) are the (unknown) TEC coefficients of the Taylor series, i.e., the local ionosphere model parameters to be estimated, and
- \( \beta_0, s_0 \) are the coordinates of the origin of the development.

\( \beta \) is the geographic latitude of the intersection point of the line receiver-satellite with the ionospheric layer and \( s \) is the sun-fixed longitude of the ionospheric pierce point (or sub-ionospheric point). \( s \) is related to the local solar time (LT) according to

\[
s = LT - \pi \approx UT + \lambda - \pi
\]

UT is Universal Time and \( \lambda \) denotes the geographical longitude of the sub-ionospheric point. For satellites at elevation angles 15/20 with widely different azimuth, these sub-ionospheric points can be separated by up to 3000/2000 kilometers. Nevertheless, the representation of algorithm for local ionosphere models not well suited for regional or even global applications because of limitations in the \((\beta, s)\)-space.

Regional ionosphere model was used as a global model, including the geometrical parameters of the region. The mathematical algorithm for calculating the global ionosphere model is:

\[
E(\beta, s) = \sum_{n=0}^{n_{\text{max}}} \sum_{m=0}^{n} \tilde{P}_{nm} (sin\beta)(a_{nm}\cos ms + b_{nm}\sin ms),
\]

where

- \( n_{\text{max}} \) is the maximum degree of the spherical harmonic expansion,
- \( \tilde{P}_{nm} = A(n, m)P_{nm} \) are the normalized associated Legendre functions of degree \( n \) and order \( m \), based on normalization function \( A(n, m) \) and Legendre functions \( P_{nm} \), and
- \( a_{nm}, b_{nm} \) are the (unknown) TEC coefficients of the spherical harmonics, i.e., the global ionosphere model parameters to be estimated.

4. Results
The ionosphere models from stations mentioned in the previous sections are plotted in the following figures. For each base station, local ionosphere model was calculated each hour to get daily changes of VTEC. Changes of VTEC on 1 August 2006 and 1 August 2012 from several base stations can be seen in figure 3. The values of CODE processed global ionosphere model for Europe are also added to see the correlation between them.
In figure 4 and figure 5, the visualization of the regional ionosphere model over the territory of Latvia can be seen. The activity of ionosphere was visualized in two different epochs – at low activity (top of each figure) and high activity (bottom of each figure). The values in these figures are taken form IONEX ionosphere exchange format files calculated with Bernese GPS software v.5.0.

**Figure 3.** Changes of VTEC values at several LatPos base stations on 1 Aug 2006 (left) and on 1 Aug 2012 (right).

**Figure 4.** Regional ionosphere model visualization over the territory of Latvia on 1 Aug 2006.
5. Ionosphere modelling in near real time

Information about ionosphere activity today and in the next years will be very important for CORS users. If the CORS users can get information about daily ionosphere changes, they can better plan the schedule for RTK measurements. Furthermore, possibility to check the actual status of ionosphere in near real time is very helpful to detect problems and validate the measurements in problem cases. Due to the facts mentioned above, the research on ionosphere modelling in near real time mode is still going on. The principal data flow and processing chart are introduced in figure 6. The introduced data flow chart includes many processing modules starting from GNSS data conversation to standard RINEX format, followed with pre-processing part of GNSS data (done with open source software BNC.EXE, teqc.exe), in the next step the ionosphere is calculated with Bernese GPS software, and later the data are stored in the database to accumulate ASCII data for ionosphere visualizations in WEB or mobile applications.
6. Conclusion
Differences in ionosphere activity on relatively small areas can be determined if ionosphere is modelled from GNSS data of the local area CORS networks. It can be noticed that TEC values change during the day period and depending on geographical location.
Ionosphere modelling in near real time and data delivery to the users for information purposes and/or calculations is important due to high solar activity.

7. References
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