GOCE High-level Processing Facility

GOCE Level 1 and Level 2 Reprocessing Campaign

Technical Note

Computation of TEC and Rate of TEC Index (ROTI) from GOCE GPS

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Computation of TEC and Rate of TEC Index (ROTI) from GOCE GPS

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1. REFERENCE DOCUMENTS

[RD 1] Noja, M., Stolle, C., Park, J., and Lühr, H. (2013), Long-term analysis of ionospheric polar patches based on CHAMP TEC data, Radio Sci., 48, 289-301, doi: 10.1002/rds.20033.

[RD 2] Foelsche, U. and Kirchengast, G. (2002), A simple "geometric" mapping function for the hydrostatic delay at radio frequencies and assessment of its performance, Geophys. Res. Lett., 29(10), doi: 10.1029/2001GL013744.

2. SCOPE

This technical note summarizes the results obtained from validation of the GOCE Level 2 (L2) total electron content (TEC) and rate of TEC index (ROTI) products with the following file name (see Sect. 3.2):

GO_CONS_TEC_TMS_2__YYYYMMDDThhmmss_YYYYMMDDThhmmss_nnnn.cdf

3.INTRODUCTION

3.1 ALGORITHM

Ionospheric/plasmaspheric electrons delay the signals transmitted by the Global Navigation Satellite System (GNSS) before reaching the GOCE GNSS antenna. From the GNSS signal delay, we can estimate the slant total electron content (STEC), which is defined as "integrated" electron density along the line of sight from GNSS satellites to GOCE GPS receiver. Relative STEC is given by the following equation:

$$STEC = \frac{f_1^2 f_2^2}{f_1^2 - f_2^2} \frac{L_1 - L_2}{K},$$

where f_1 and f_2 are carrier frequencies of GNSS signals, L_1 and L_2 are ambiguity-corrected carrier phase observations, and $K \approx 40.3\, m^3 s^{-2}$. After corrections for differential code bias (DCB) of GNSS satellite transmitters and GOCE receivers, the relative STEC becomes absolute STEC. For a complete description on the algorithm, readers are referred to [RD 1].

The rate of TEC index (ROTI) values are also included in the GOCE TEC cdf files. ROTI is defined as standard deviation of the rate of change of TEC (ROT) over a defined time interval (here 1 minute) and has the same units as ROT, namely TECU/s:

$$ROTI_n = \sqrt{\frac{1}{N} \sum_{m=n-N/2}^{n+N/2-1} (ROT_m - \overline{ROT})^2},$$

where

$$ROT_m = \frac{TEC_m - TEC_{m-1}}{t_m - t_{m-1}}.$$

Here t is time measured in seconds. No ROTI values are defined if the number of points within a 1 minute time window is less than 50 for the 1 Hz data.

The absolute vertical TEC (VTEC) values that are also included in GOCE TEC cdf files can be derived from absolute STEC according to the following equations [RD 2]:

$$VTEC = STEC \cdot M(\theta),$$

$$M(\varepsilon) = \frac{H_{mapping}}{R_{Sw}+H_{mapping}}[\cos(\sin^{-1}(r \times \cos\varepsilon)) - r \times \sin\varepsilon]^{-1},$$

$$r = \frac{R_{Sw}}{R_{Sw} + H_{mapping}}.$$

Here M is the mapping function, R_{Sw} is the radius of the GOCE satellite (GOCE altitude + Earth's radius), ε is the elevation angle of the GNSS satellite as seen from GOCE, and $H_{mapping}$ is assumed to be 400 km. This means that the ionosphere is assumed to be a "thick shell" (height-independent plasma density with 400 km thickness) above the GOCE satellite.

No TEC and ROTI values are defined if the elevation angle value is less than 20°.

3.2 FILE NAMES

The GOCE Level 2 cdf file naming convention is defined as following (GO_CONS_TEC_TMS_2__YYYYMMDDThhmmss_YYYYMMDDThhmmss_nnnn):

- GO – GOCE
- CONS – consolidated
- TEC – total electron content
- TMS – time series
- 2 – Level 2
- *YYYYMMDD*T*hhmmss* – valid from
- *YYYYMMDD*T*hhmmss* – valid to
- nnnn – file version number

3.3 SCIENTIFIC RELEVANCE

GOCE L2-TEC data give integrated electron density along the line of sight from GNSS satellites to GOCE GPS receiver. There can be multiple STEC data points for a certain universal time (UT) as GOCE satellite can communicate simultaneously with as many as 12 GNSS satellites. Thanks to the wide spatial coverage at a given UT, the L2-TEC data can be a useful input to global ionospheric assimilations, which aim to specify 3-dimensional electron density structures.

4. DESCRIPTION OF THE DATA FORMAT

One data file of L2-TEC is produced per day and only when all the following input files are available: (1) GNSS RINEX observation files; (2) GOCE ephemerides; (3) GNSS satellite ephemerides; (4) DCB of GNSS satellite transmitters. The cadence of the L2-TEC data is 1 Hz (1 second). Table 1 presents the list of variables in the L2-TEC data product.

Table 1: The list of variables in the GOCE L2-TEC data product.

Variable name	Description	Unit
Timestamp	Time stamps in universal time (UT)	cdf epoch
Latitude	Geographic latitude of the GOCE satellite	degree
Longitude	Geographic longitude of the GOCE satellite	degree
Radius	Distance of the GOCE satellite from the Earth's center	m
GPS-Position	X-, Y-, Z-coordinates of the GNSS satellite used for STEC calculation	m
LEO-Position	X-, Y-, Z-coordinates of the Swarm satellite used for STEC calculation	m
PRN	Pseudo-Random Noise (PRN of GPS satellite) identifier of the GNSS satellite used for STEC calculation	no unit
L1	GNSS L1 carrier phase observation	m
L2	GNSS L2 carrier phase observation	m
P1	GNSS P1 carrier phase observation	m
P2	GNSS P2 carrier phase observation	m
S1	GNSS signal-to-noise ratio or raw signal strength on L1	no unit
S2	GNSS signal-to-noise ratio or raw signal strength on L2	no unit
Absolute-STEC	Absolute slant total electron content (TEC)	TECU
Absolute-VTEC	Absolute vertical TEC	TECU
Elevation-Angle	Elevation angle	degree
Relative-STEC	Relative slant TEC	TECU
Relative-STEC-RMS	Root mean square (RMS) error of relative slant TEC	TECU
DCB	GNSS receiver differential code bias (DCB)	TECU
DCB-Error	Error in the GNSS receiver DCB	TECU
ROTI	Rate of TEC index	TECU/s

<table>
<tr><th>Variable name</th><th>Description</th><th>Unit</th></tr>
<tr><td>Flag</td><td><table><tr><th>Value</th><th>Description</th></tr><tr><td>0</td><td>Default</td></tr><tr><td>1</td><td>Outlier is detected</td></tr><tr><td>2</td><td>Cycle slip is detected</td></tr></table></td><td>no unit</td></tr>
</table>

5. VALIDATION AND RECOMENDATIONS

5.1 VALIDATION EXAMPLES

Using independent software from FAE/A&S the validation of GOCE L2-TEC and ROTI data was performed during the chosen quiet (1 Aug 2009) and disturbed (1 Nov 2012) test days (Figure 1):

- Comparing ROT derived from TEC (GFZ) with ROT computed directly from GPS data (FAE/A&S);
- Comparing ROTI derived from both ROT data sets.

Here quiet and disturbed time defined as the amount of the loss of log (Figure 1).

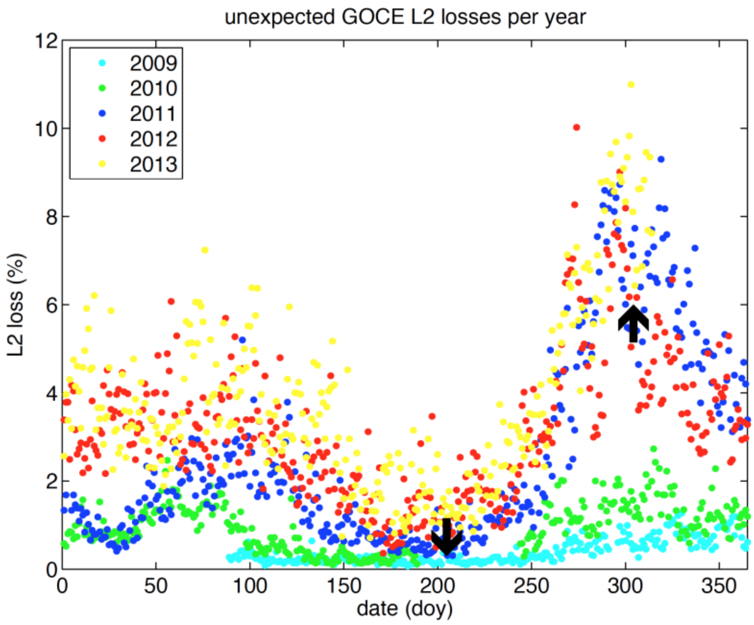

Figure 1: Black arrows show the quiet and disturbed day.

Figure 2 shows an example Flag, ROT, ROTI and elevation angle values for the test quiet day, 1 August 2009, and for the PRN 4. As one can observe there is very good agreement between two independent software products but for the elevation angle less than 20°. The

GFZ software does not calculate TEC and ROTI values below this limit. Figure 3 shows the single pass comparison for the same day as before but without detected cycle slips. Again very good agreement can be seen.

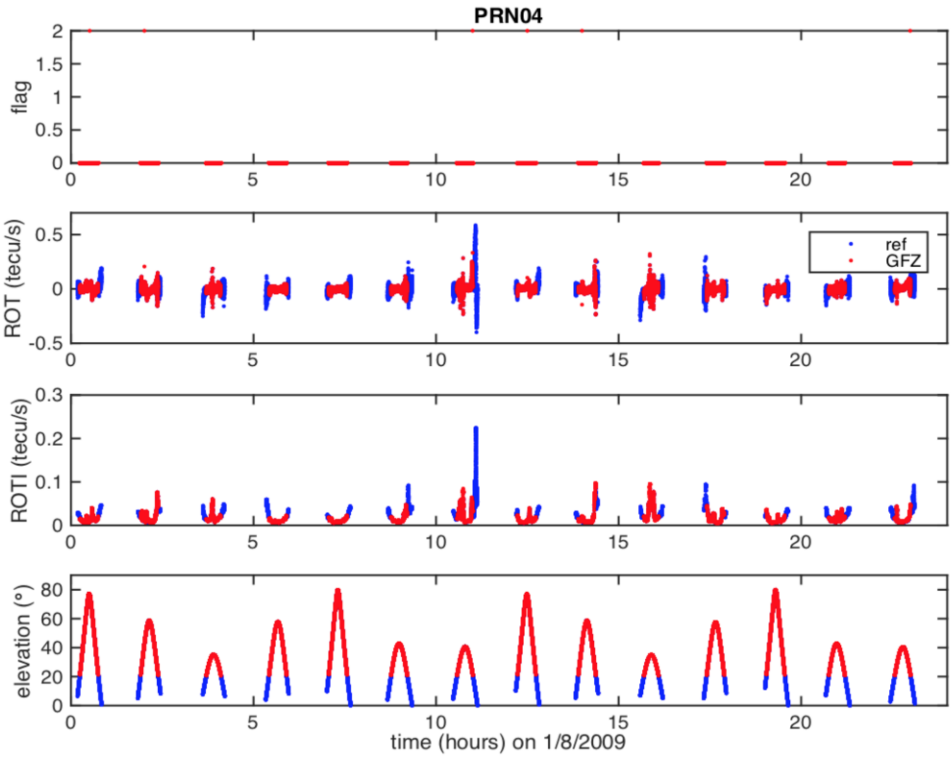

Figure 2: Flag, ROT, ROTI and elevation angle values from top to bottom for the quiet day (1 Aug 2009) and for one PRN.

Figure 4 shows an example for the disturbed day, 1 November 2012, and for PRN 4. As before (Figure 2) a good agreement is clearly visible for the presented variables. Figure 5 presents the single pass results with detected cycle slips. And again a very good agreement can be observed also for the disturbed day also with detected and corrected cycle slips.

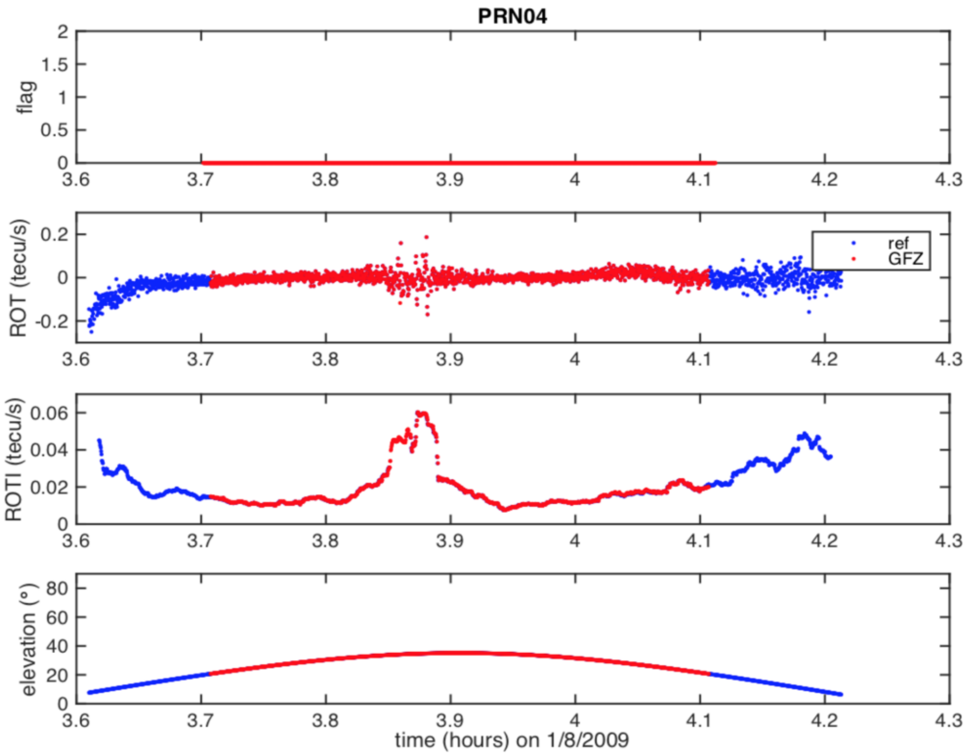

Figure 3: Flag, ROT, ROTI and elevation angle values as in **Figure 2** but only for one pass (zoom in).

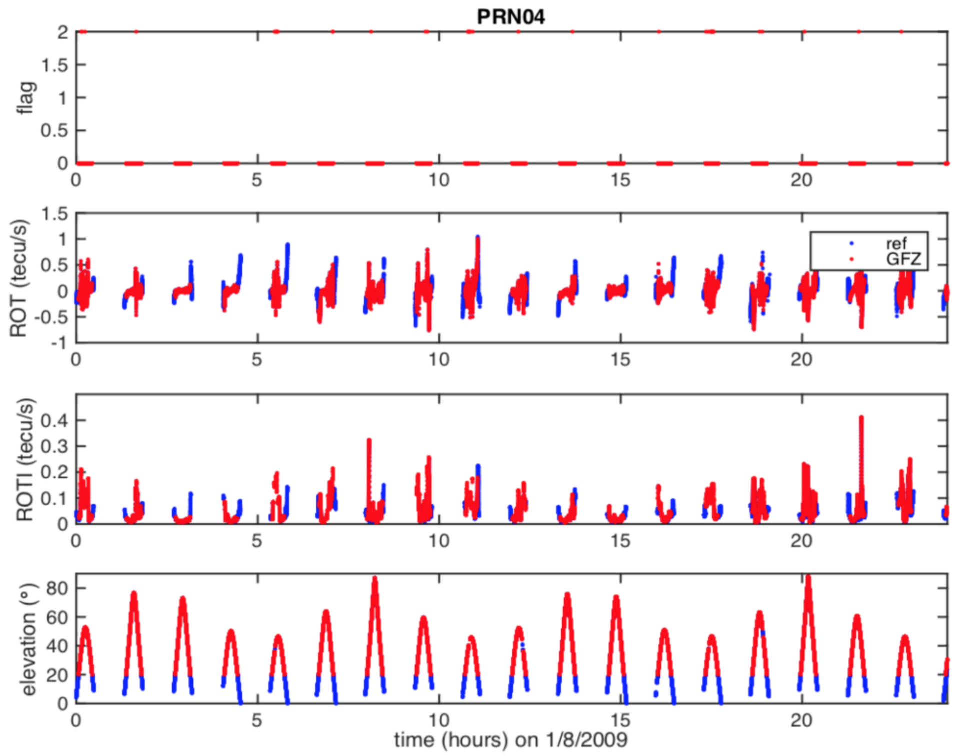

Figure 4: Flag, ROT, ROTI and elevation angle values as in **Figure 2** but for the disturbed day (1 Nov 2012).

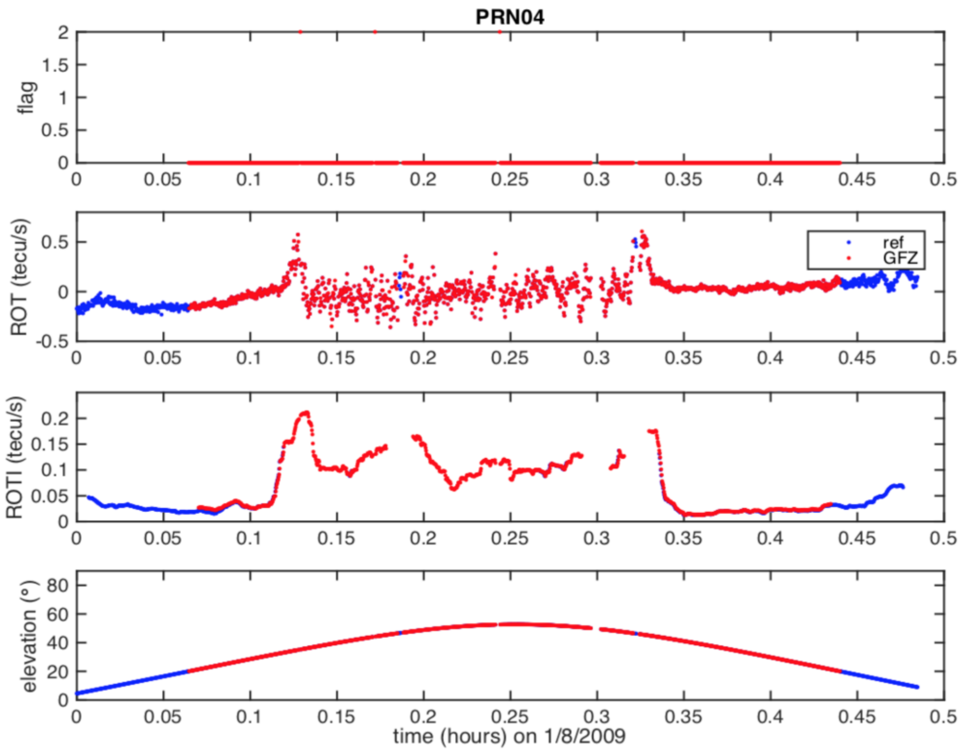

Figure 5: Flag, ROT, ROTI and elevation angle values as in **Figure 4** but only for one pass (zoom in).

5.2 RECOMMENDATION FOR USING VTEC DATA

It is recommended to use absolute VTEC data with corresponding elevation angles of the GPS rays of at least 50°. The elevation angle values are available in the standard GOCE L2-TEC cdf files (see Table 1). The recommendation is given since the uncertainty of the mapping function increases with decreasing elevation angle (see section 3.1).

Note that STEC data can be used for the all elevation angels without any limitations.

6.CONCLUSIONS

The obtained results confirm the scientific validity of GOCE L2-TEC data product.