

Total electron content monitoring using triple frequency GNSS data: A three-step approach

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Introduction

Global Navigation Satellite Systems, i.e. GPS and Galileo, emit radio frequencies which can be combined to compute the variability of the ionospheric plasma, and in particular the Total Electron Content (TEC) of the ionosphere

Development of a new TEC monitoring technique:

- using **triple frequency** measurements
- developed on **simulated** data and tested on **real** data
- **improved** in regards with the usual dual frequency technique

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GNSS system	Carrier signal	Frequency (MHz)
GPS	L1	1575.42
	L2	1227.60
	L5	1176.45
Galileo	L1	1575.42
	E5b	1207.14
	E5a	1176.45

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- realistic GNSS measurements
 - ◆ GPS and Galileo
 - ◆ triple frequency
 - ◆ code $P_{p,k}^i$ and phase $\Phi_{p,k}^i$ (with $k = L1, L2$ or $L5$)
- including all error sources (ionosphere,troposphere...)
- validated with real double frequency GPS data
- used to **develop** the monitoring technique
(before the availability of real triple frequency data)

- triple frequency (L1-E5a-E5b) code and phase measurements
- from **Giove-A** satellite
- for 3 stations (GNOR,GIEN,GKOU) and 7 days (DOY 013-020/2008)
- used to test and **validate** the monitoring technique

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- triple frequency technique
- divided in **three steps**:
 1. extra-widelane (EWL) ambiguities
 2. widelane (WL) ambiguities
 3. geometric-free system (GF)

- **advantage:** the availability of triple frequency measurements allow to form two dual frequency GF phase combinations

⇒ code measurements are only used in step 1

⇒ precision of TEC is not affected by code (hardware and multipath) delays and is therefore improved

N.B.: in the dual frequency technique, the use of the GF code combination is required for the ambiguity resolution process ⇒ precision = 2-3 TEC_u

Step 1

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- **Objective:** resolve the EWL ambiguities N_{25} which are integer numbers
- **Method:** compute the extra widelane narrowlane (EWLNL) combination C_{25}

$$C_{25} = \Phi_{p,L2}^i - \Phi_{p,L5}^i - \frac{f_{L2} - f_{L5}}{f_{L2} + f_{L5}} \left(\frac{f_{L2}}{c} P_{p,L2}^i + \frac{f_{L5}}{c} P_{p,L5}^i \right) = N_{25} + \Delta R_{25}$$

⇒ uses L2 and L5 code and phase measurements

- **Issue:** residual terms ΔR_{25} including code and phase hardware delays, multipath and noise
 ⇒ $\Delta R_{25} < 0.5$ cycle ?

- **Objective:** resolve the WL ambiguities N_{12} which are integer numbers

- **Method:** compute the differenced widelane (DWL) combination C_{125}

$$C_{125} = \left(\Phi_{p,L1}^i - \Phi_{p,L2}^i \right) - \left(\Phi_{p,L2}^i - \Phi_{p,L5}^i + N_{25} \right) \frac{\lambda_{25}}{\lambda_{12}} = N_{12} + \Delta R_{125}$$

⇒ uses L1, L2 and L5 phase measurements + EWL ambiguities

N.B.: not possible with the WLNL combination (see results)

- **Issue:** residual terms ΔR_{125} causing an error of several cycles on $N_{12} \Rightarrow N_{12} =$ approximated integer values

- **Objective:** use the results of the first two steps in order to achieve the monitoring of the TEC
- **Method:** resolve the system of two dual frequency Geometric Free phase combinations $\Phi_{p,GF}^i$ and $\Phi_{p,GF'}^i$ (GF system):

$$\begin{cases} \Phi_{p,GF}^i & = & a_{12} \text{TEC} - N_{p,L1}^i + c_{12} N_{p,L2}^i \\ \Phi_{p,GF'}^i & = & a_{25} \text{TEC} - N_{p,L2}^i + c_{25} N_{p,L5}^i \end{cases}$$

■ GF system

- ◆ 4 unknowns : TEC and ambiguities N_1, N_2, N_5
- ◆ we introduce N_{25} and N_{12} so that there remain 2 unknowns: TEC and N_2

- Issue: approximated N_{12} so approximated TEC
⇒ how is it possible to resolve N_{12} ?

■ Resolution

- ◆ $N_{12} = \text{integer values}$
- ◆ 1 cycle $N_{12} \Leftrightarrow 12 \text{ TECu (in GF system)}$

1. $\text{TEC}_e = \text{rough estimation by dual frequency method}$
2. $\Delta \text{TEC}_e \Rightarrow \Delta N_{12}$
3. ΔN_{12} is precise enough to correct N_{12}
4. N_{12} again in GF system \Rightarrow TEC and ambiguities N_1, N_2, N_5

■ Precision of TEC

- ◆ use of GF **phase** combinations
- ◆ not affected by code (hardware and multipath) delays
- ◆ but by the corresponding **phase delays**

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STEP 1 - Influence of code multipath and noise on N_{25} for GPS and Galileo

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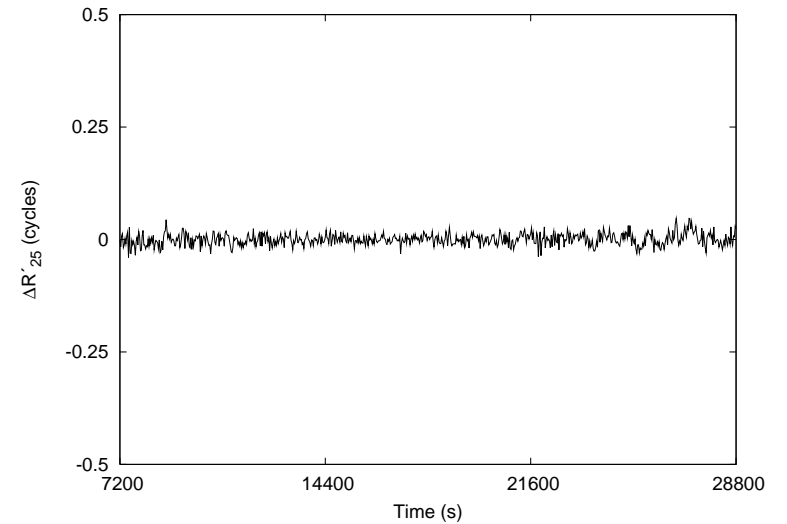
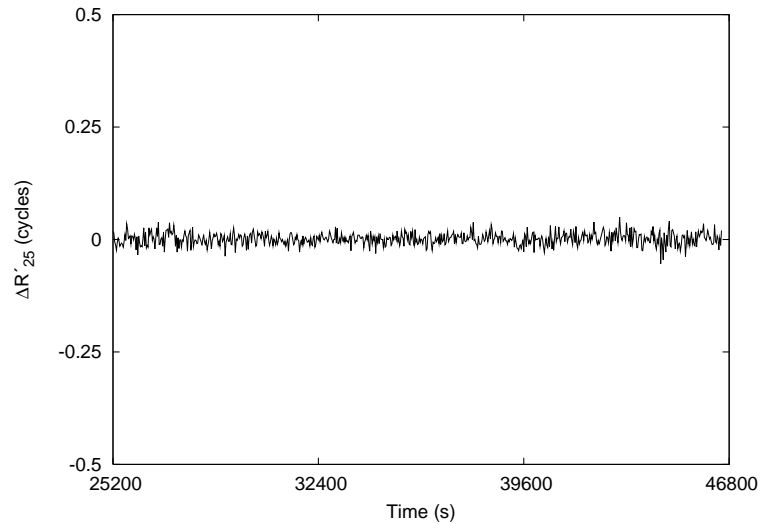
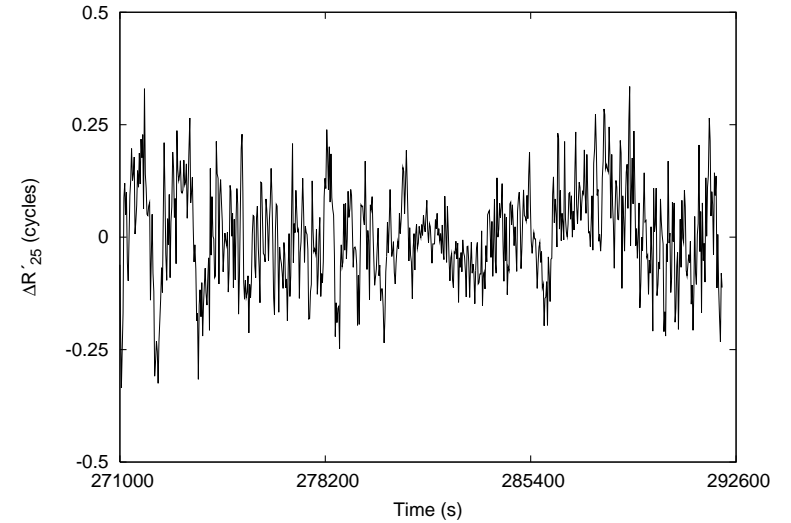
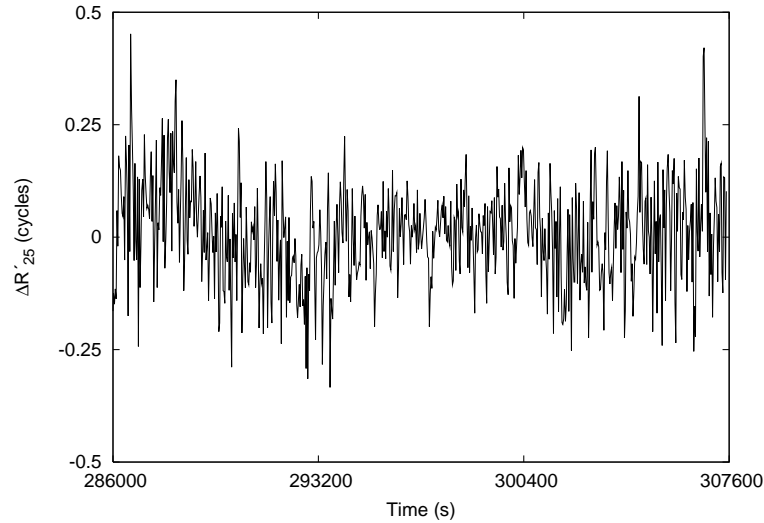
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Influence $\approx 0.25/0.1$ cycle resp. for GPS and Galileo

Why such a difference ?

- amplitude of code **multipath** and **noise** lower for Galileo
- wavelength of EWLNL combination :
5.861/9.768 m resp. for GPS and Galileo

Resolution possible?

- estimation of the influence of code and phase **hardware** delays (constant): should not exceed the remaining margin (0.25/0.4 cycle) \Rightarrow yes, and easier for Galileo
- results : we obtain the initial simulated N_{25} values

STEP 2 - Influence of code multipath and noise on N_{12} for GPS and Galileo

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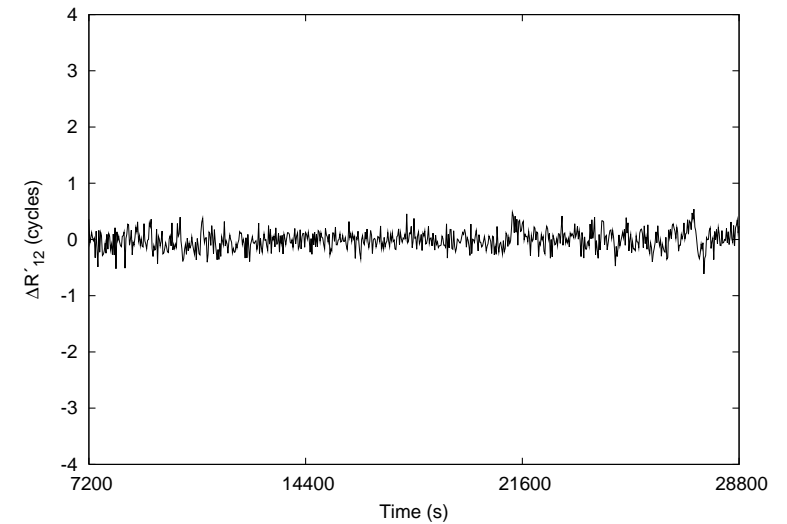
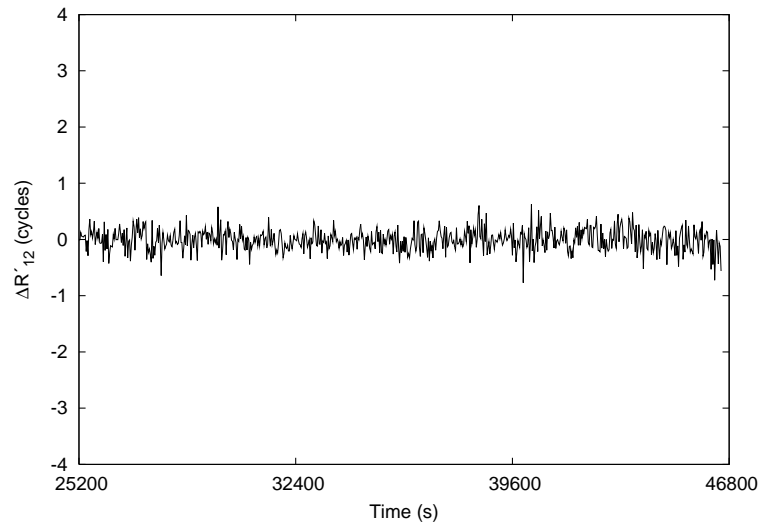
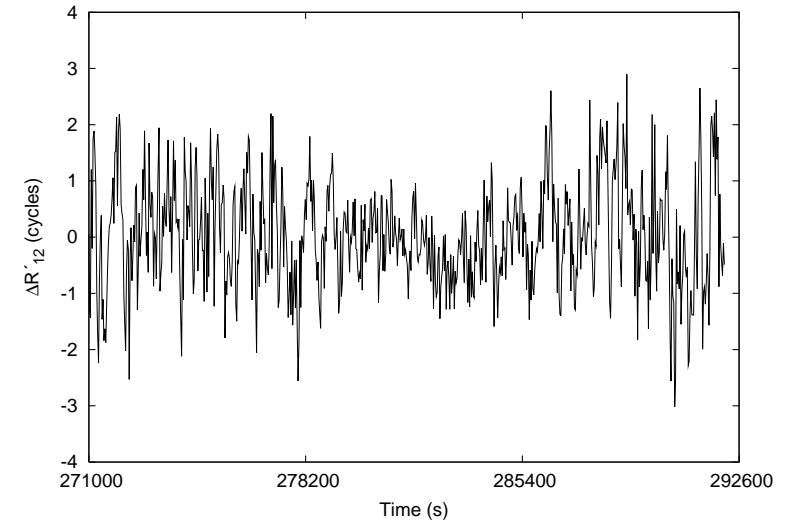
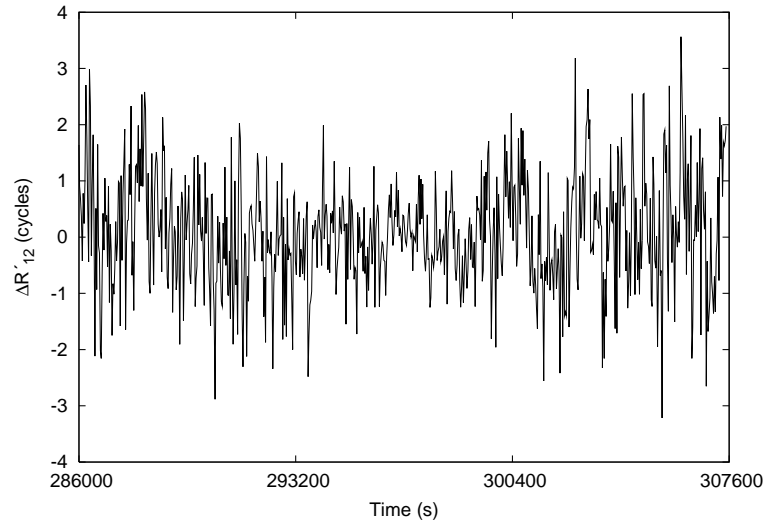
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Influence > 0.5 cycle for GPS and Galileo

Why ?

- wavelength of WLNL combination :
0.862/0.814 m resp. for GPS and Galileo

Solution ?

- use of a different combination (DWL)
- results : we obtain the correct N_{12} integer values + 2-3 cycles

STEP 3

- N_{25} and N_{12} values in GF system
- dual frequency estimation of TEC
- results : we obtain the initial simulated TEC values
 - ◆ whatever the ionospheric model used (constant or Klobuchar)
 - ◆ whatever the ionization level
- precision : tests with different mm-level amplitude and different sign values of phase delays
 - ⇒ influence = several tenth of TEC_u ⇒ improvement

STEP 1 - EWLNL combination

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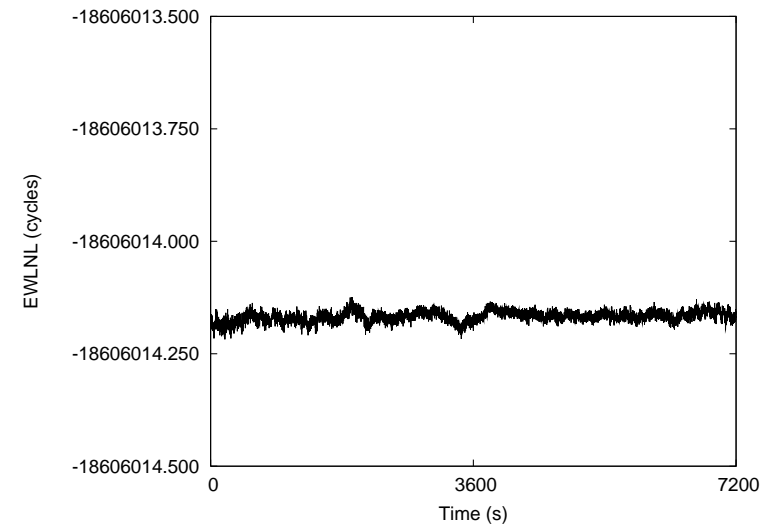
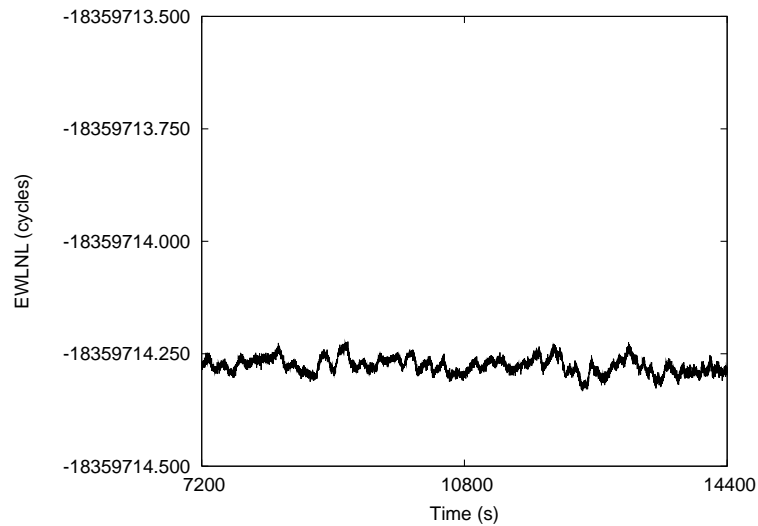
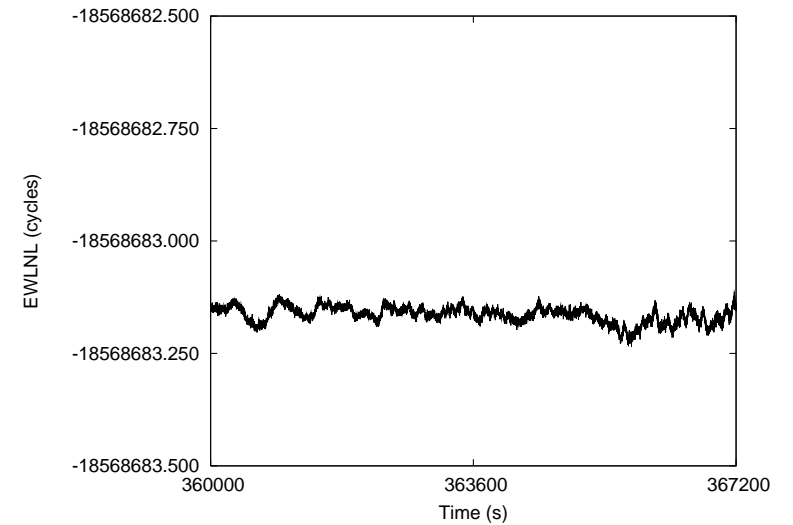
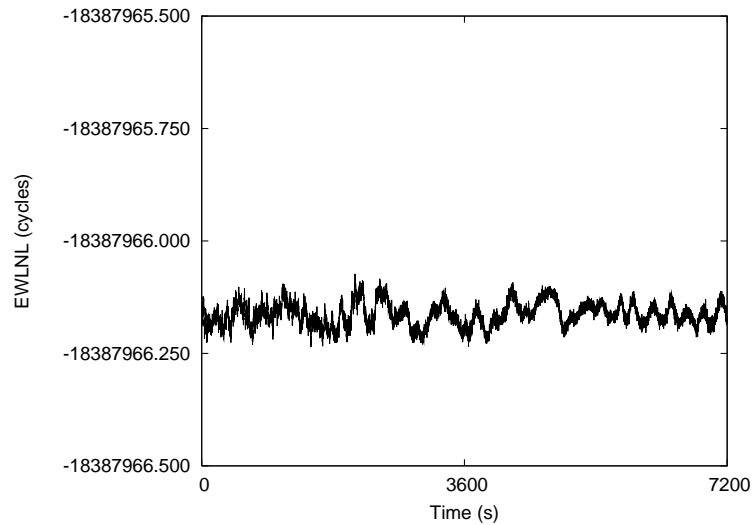
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Results

Variability ?

- low : < 0.1 cycle
- in total agreement with simulated results

Resolution possible ?

- despite the bias caused by hardware delays ?
- we need to process the further steps and validate the results...

Conclusions

Development of a new TEC monitoring technique:

- using **triple frequency** code and phase GNSS measurements
- based on the resolution of **integer** ambiguities (EWL-WL)
- using two GF **phase** combinations \Rightarrow precision of TEC improved
- allowing **new opportunities** for ionospheric studies

Perspectives

Further validation of the TEC monitoring technique with real data:

- compute a rough estimation of TEC by using the usual dual frequency technique (in progress)
- use it in the GF system
- validate the results with external data (ex. IONEX)

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