# An efficient dual and triple frequency preprocessing method for Galileo E1/E5a/E5b and GPS L1/L2/L5 signals

**Lonchay M.**[12] **- Bidaine B.**[12] **- Warnant R.**[1]

*M.Lonchay@ulg.ac.be*

[1] University of Liège (Belgium) - Geomatics Unit - www.geo.ulg.ac.be
[2] Fund for Scientific Research (Belgium) - FNRS

## Introduction

**GNSS** applications require advanced solutions for data **preprocessing**

The **Geomatics Unit** of the **University of Liège** acquired two **Septentrio PolaRx3eG** receivers

Space Weather applications
**Precise Point Positioning (PPP)**

New dual frequency data : **GPS L1/L5** and **Galileo E1/E5a**
Receivers in **Dourbes** (50°5'29.256" N - 4°35'28.140" E )
A preprocessing method is required for these new data

## Objectives

A **modern and efficient** preprocessing method

**Geometry-free** and **ionosphere-free** - *Space Weather*
**Standalone** and **Real-Time** properties - *PPP*
GPS/Galileo **dual** and **triple** frequency (DF/TF)

The method was designed to preprocess **Septentrio PolaRx3eG DF** data but has been enhanced for future **TF** data from first **IOV Galileo satellites**

Clock slips compensation
Cycle slips detection
Data quality assessment

## Conclusions

**Clock slips compensation** method allows to cope with clock slips and removes discontinuities in observables

Statistical approach of the **cycle slips detection** method makes it very efficient, in particular for **TF testing quantity (TF LPC)**

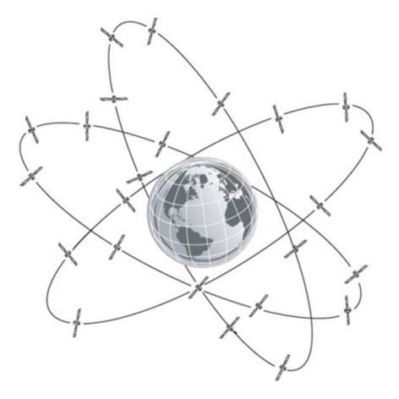
The **preprocessing method** provides a report with information about **code pseudorange noise**

*This point could be improved with a study of carrier-phase measurement noise and multipath, and a comparison with theoretical values (de Bakker, 2009).*

## Clock slips compensation

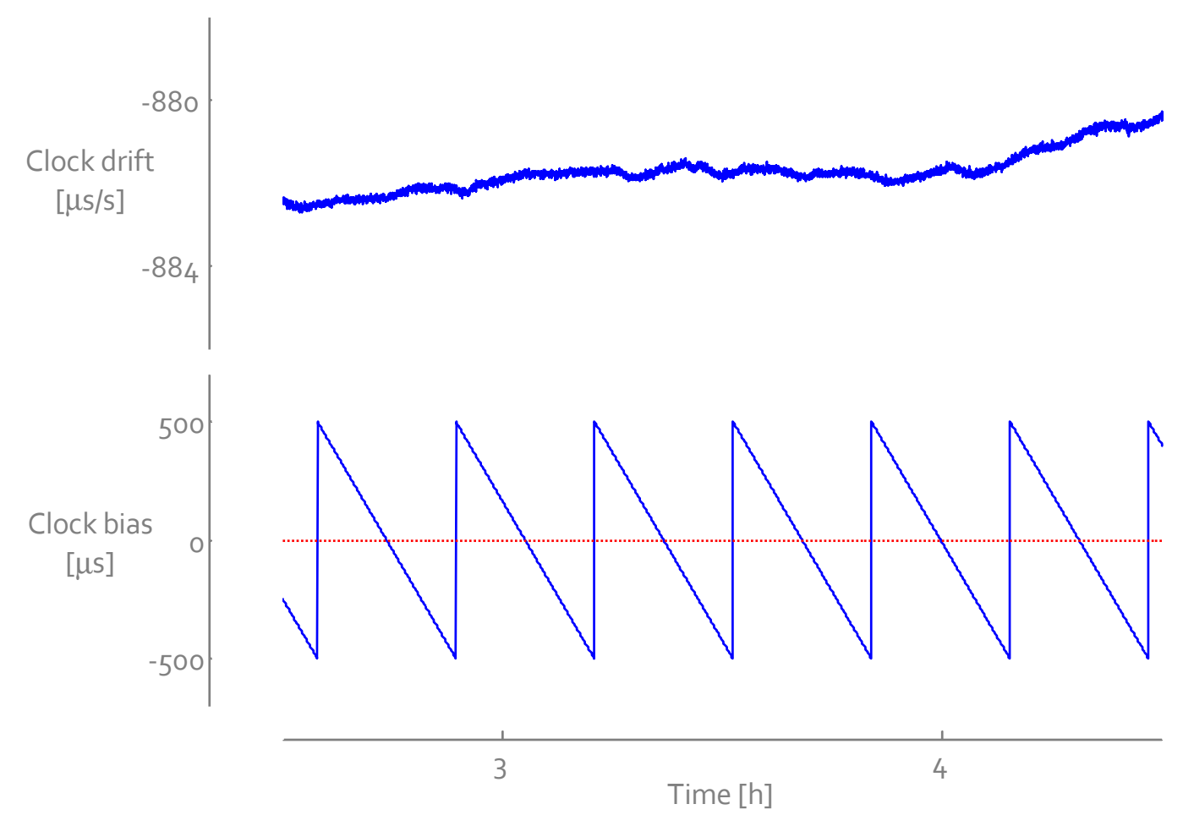
Satellite positioning involves **time measurements** in several **time scales** (Hofmann-Wellenhoff, 2008)

Global **GNSS** time scale
**Satellite** time scale
**Receiver** time scale

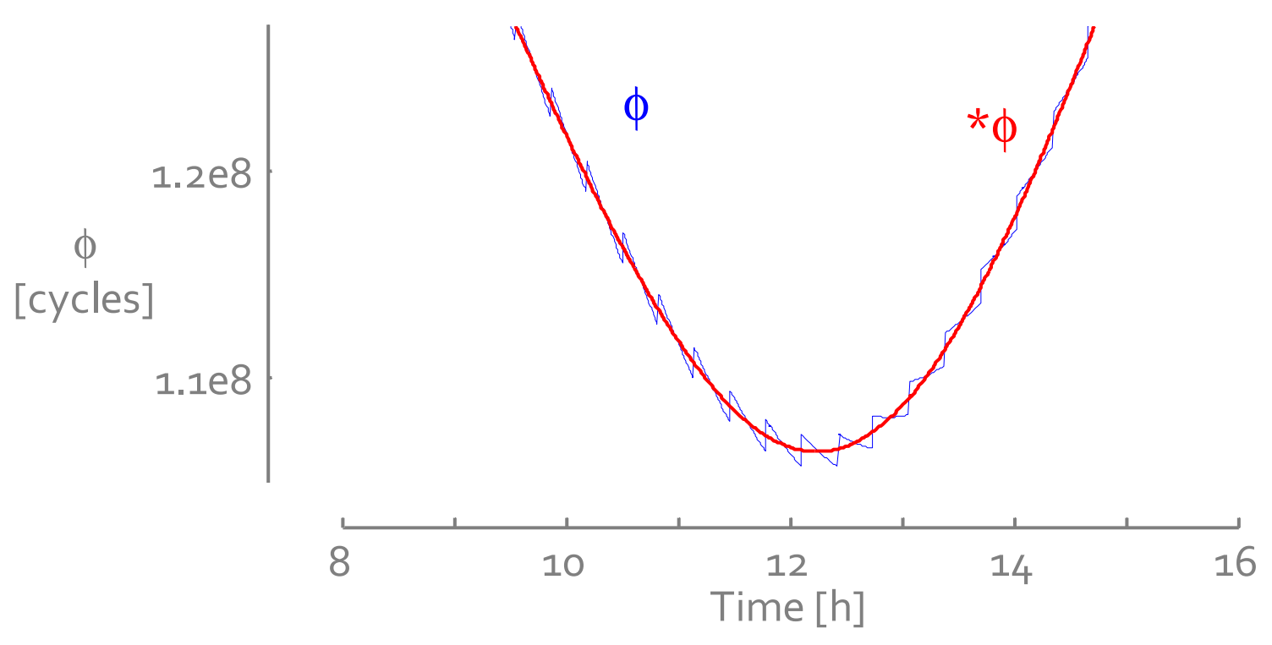


**Receivers** and **satellites** clocks are unavoidably **drifting** relative to reference GNSS time scale

**Septentrio PolaRx3eG** receivers handle their internal clock drift by imposing **clock jumps** (Septentrio, 2009)



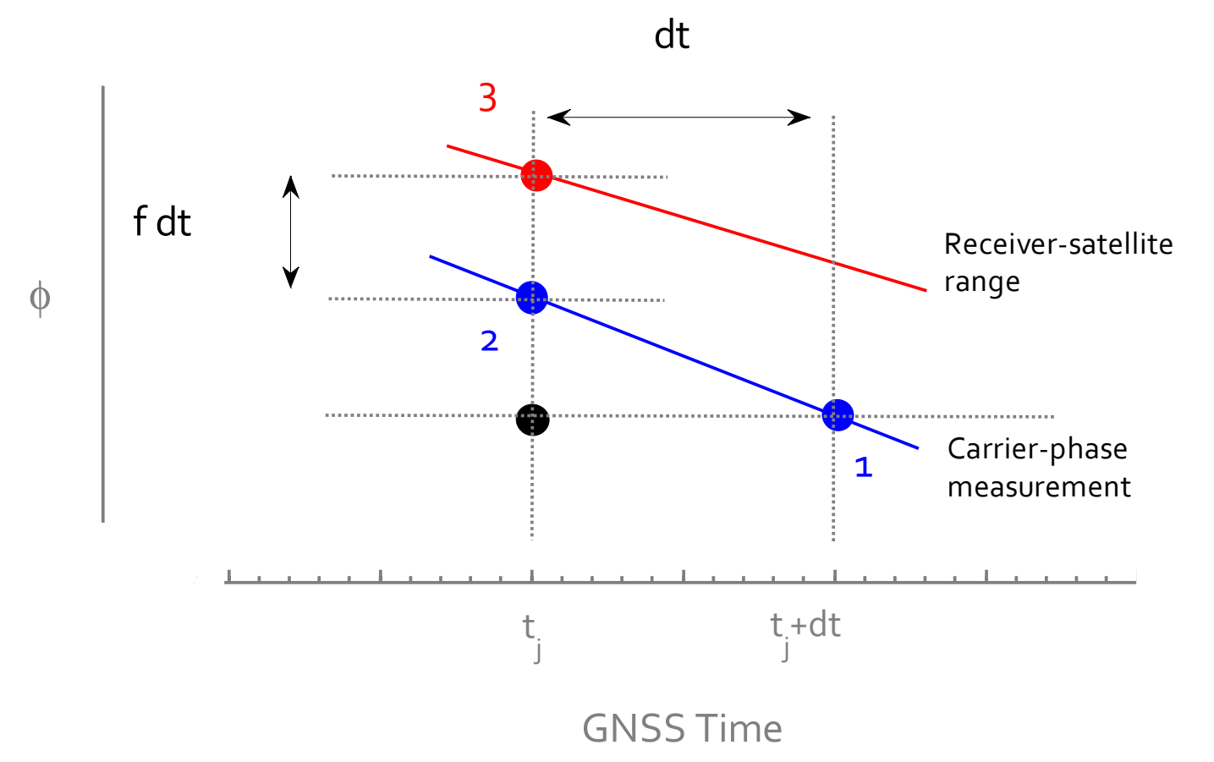
Clock jumps generate **discontinuities** in **raw observables measurements** (Misra, 2006)



We developed a standalone **clock slips compensation only** based on **observation RINEX files** information

$$\bar{\phi}(t_j) \approx \phi(t_j + dt) + D\,dt + f\,dt$$

$\bar{\phi}$ *Carrier-phase clock compensated [cycles]*
$\phi$ *Carrier-phase measurement [cycles]*
$D$ *Doppler measurement [cycle/s]*
$dt$ *Receiver clock bias [s]*
$f$ *Signal frequency [Hz]*

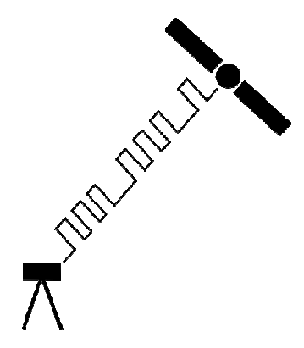


## Cycle slips detection

A **cycle slip** indicates a change in the value of the **initial integer phase ambiguity** of carrier-phase measurements (Leick, 2004)

We extended **existing techniques** in order to develop a cycle slips detection method with **specific properties** (Bisnath, 2000)

**Standalone and Real-Time**
**Geometry-Free (GF) and Ionosphere-Free (IF)**
**Dual and triple frequency GPS/Galileo data**



### Raw Observables

$$\varphi_i = \frac{\Phi_i}{\lambda_i} = \frac{1}{\lambda_i}[G - I_i + E_{\Phi_i} + M_{\Phi_i} + \xi_{\Phi_i} + \varepsilon_{\Phi_i}] + N_i$$

$$P_i = G + I_i + M_{P_i} + \xi_{P_i} + \varepsilon_{P_i}$$

$$G = \rho + c\,\Delta t + T$$

$P$ *Code pseudorange measurement [m]*
$\Phi$ *Carrier-phase measurement [m]*
$\varphi$ *Carrier-phase measurement [cycles]*
$G$ *Geometric term [m]*
$\rho$ *Satellite-receiver geometric range [m]*
$T - I$ *Tropospheric delay [m] - Ionospheric delay [m]*
$\Delta t - \xi$ *Clock biases [m] - Instrumental delay [m]*
$M - \varepsilon$ *Multipath delay [m] - Random noise [m]*
$N$ *Initial integer phase ambiguity [cycles]*
$\lambda$ *Signal wavelength [m]*
$i$ *Signal indice [1,2,5,6,7,8]*

### DF Testing Quantity

**DF Widelane-Narrowlane [cycles]** (Bisnath, 2000)

$$w_{15} = WL_{\varphi_{15}} - NL_{P_{15}}$$

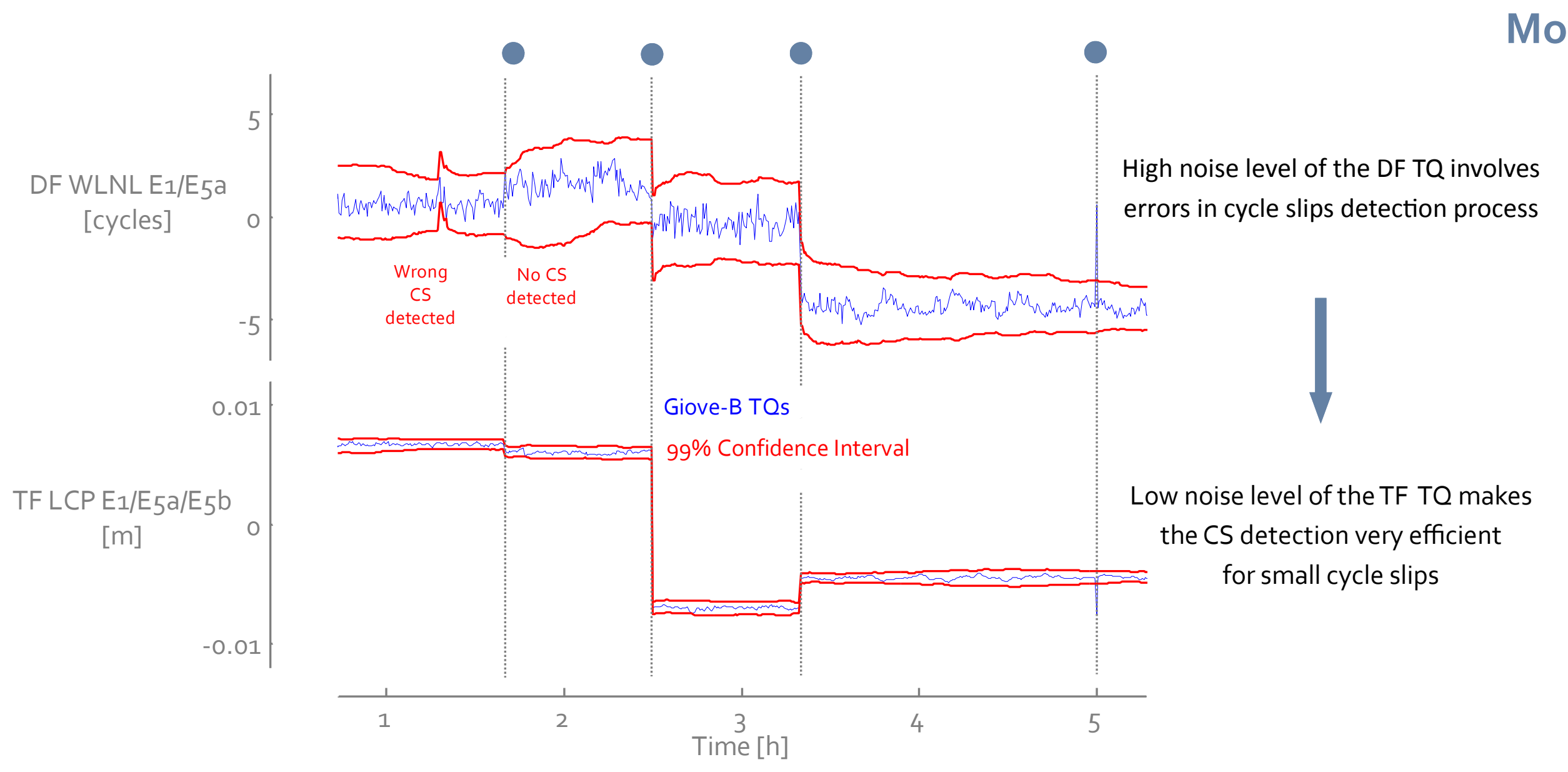
$$w_{15} = \varphi_1 - \varphi_5 - \frac{f_1 - f_5}{f_1 + f_5}\left[\frac{P_1}{\lambda_1} + \frac{P_5}{\lambda_5}\right] = N_1 - N_5 - K_{15}\left[\frac{M_{P_1} + \varepsilon_{P_1}}{\lambda_1} + \frac{M_{P_5} + \varepsilon_{P_5}}{\lambda_5}\right]$$

### TF Testing Quantity

**TF Phase Linear Combination [m]** (Simsky, 2006)

$$s_{ijk} = a_i\,\lambda_i\,\varphi_i + a_j\,\lambda_j\,\varphi_j + a_k\,\lambda_k\,\varphi_k = \sum_{l=i,j,k} a_l \lambda_l N_l + a_l (M_{\Phi_l} + \varepsilon_{\Phi_l})$$

$a_j = \lambda_i^2 - \lambda_k^2$
$a_i = \lambda_k^2 - \lambda_j^2$
$a_k = \lambda_j^2 - \lambda_i^2$



High noise level of the DF TQ involves errors in cycle slips detection process

Low noise level of the TF TQ makes the CS detection very efficient for small cycle slips

**Validation** was made by **inserting cycle slips** (**CS**) and **outliers** (**O**) into raw **carrier-phase measurements** ●

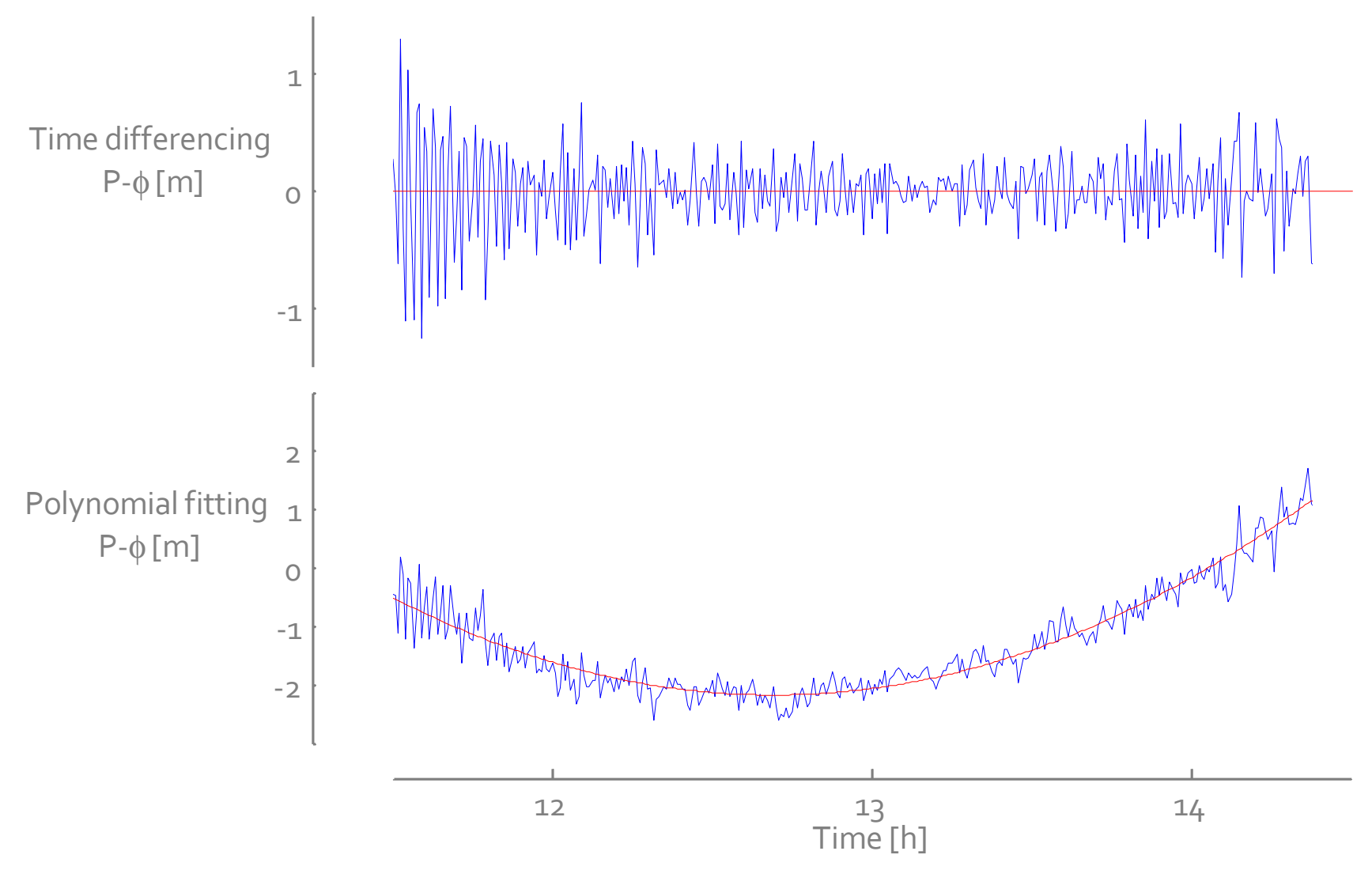
**Noise level** of the DF WLNL E1/E5a degrades the efficiency of the cycle slips detection

**Low noise TF TQ** makes **TF CS detection powerful**

## Data quality assessment

**Data quality assessment** stage of the preprocessing method provides a **report** with **stochastic** information about **data quality** (de Bakker, 2009) (de Bakker, 2011)

**Mathematical model**: **code-minus-phase combination**
**Time differencing / Low-order polynomial fitting**
**Residuals mean standard deviation** **($C/N_0$ = 45 dB-Hz)**

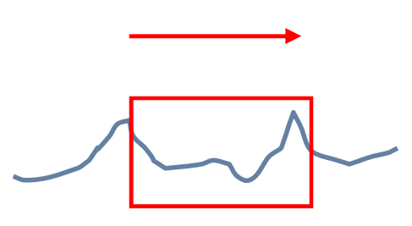


**Objective**: **statistical parameters** to compare **noise level** of **code pseudorange measurements** with theoretical values and to build a **stochastic model**

### Detection Process

The detection process is based on an **average filtering technique (DF + TF)** (Blewitt, 1990)

**Moving Average Filter (MAF)**



- Based on solid **statistical principles**
- Fixed-size convolution **window** to make moving **statistical parameters** **highly adaptable to data**
- **MAF exploits data statistical information**
- **Events**

  **Outliers** are not included in statistical parameters computation

  **Cycle slips** detected involve a **moving mean shift** but **no reinitialization of the moving standard deviation**

*Testing quantity value [m]* $v$
*Moving mean [m]* $\alpha$
*Moving standard deviation [m]* $\beta$
*Convolution window size* $\gamma$
*Current epoch identifier* $t$

$$\alpha_t = \frac{\sum_{i=1}^{\gamma} v_{t-i}}{\gamma} \qquad \beta_t = \sqrt{\frac{\sum_{i=1}^{\gamma} (v_{t-i} - \alpha_t)^2}{\gamma - 1}}$$