Data pre-processing for ionosphere TEC retrieval based on DORIS observations

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Introduction

Since the third generation DORIS DGXX receiver start provide the dual-frequency raw data from the LEO satellites, it's possible to retrieve the ionospheric TEC (Total Electronic Contents) along signal path between globally distributed DORIS ground beacon to several LEO satellite based receivers (Dettmering D *et al.*, 2014).

DORIS TEC were calculated based on phase measurement which may not be able to provide absolute information, and any cycle slips on phase will result ionospheric disturbance. Mercier F *et al.* (2010) analyzed the DORIS phase data preprocessing on POD application.

In this research, the data pre-processing work for DORIS ionospheric TEC retrieval were discussed, including phase center correction on different frequency signals, impact of high order ionospheric delays and small cycle slip detection on phase measurements.

DORIS ionospheric TEC retrieval

DORIS ground beacons broadcast signals on 2036. 25MHz and 401.25MHz, and the first order ionosphere delays and the corresponding TEC could be calculated as following:

$$\delta_1^{1st} = \frac{f_2^2}{f_2^2 - f_1^2}(\lambda_1\varphi_1 - \lambda_2\varphi_2 + \lambda_1 N_1 - \lambda_2 N_2 + \Delta\rho) + \delta_{1,2}^{high} + \varepsilon$$

$$STEC = \frac{f_1^2 \cdot 10^{-16}}{40.309}\delta_1^{1st}$$

Here, δ_1^{1st} is the first order ionospheric delays on L1 frequency. $f_i, \lambda_i, \varphi_i$ are the frequency, wavelength and phase measurement on L_i signal.

Ignore the un-fixed phase ambiguities N on DORIS phase measurements, the data pre-processing work were list as following:

- The geometry difference correction between two frequencies $\Delta\rho$
- High order ionospheric delays $\delta_{1,2}^{high}$
- Possible cycle slips on the phase measurements N_i

Geometry difference corrections

The geometry difference between two frequencies observation are mainly related with the antenna phase center difference on both transmitters and receivers.

$$\Delta\rho \approx d_b \cdot \sin(elv) + d^s \cdot cos(90 - elv - \alpha)$$

Here：

d_b is the vertical difference on L_1 and L_2 phase center on ground beacon transmitter.

d^s is the vertical difference on L_1 and L_2 phase center on satellite receiver.

elv is the elevation angle of LEO satellite.

α is the vector angle between LEO satellite and ground beacon

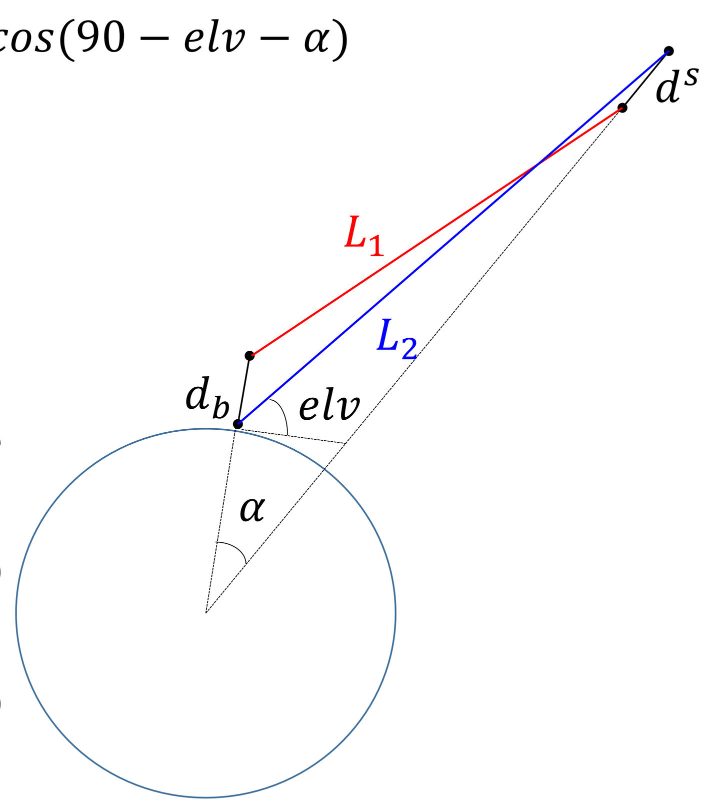

Figure 1. Schematic of the geometric difference corrections

Impact of high order ionospheric delays

Here the impacts of the second-order ionospheric delays on DORIS L_1 signal were calculated to evaluated the high order ionospheric delays

$$\delta_i^{2rd} = \frac{-1.1284 \times 10^{-4} B cos\theta}{f_i^3} STEC_{GIM}$$

$$\Delta STEC^{2rd} = \frac{f_2^2}{f_2^2 - f_1^2}(\delta_1^{2rd} - \delta_2^{2rd})$$

The $STEC_{GIM}$ were calculated from IGS global ionospheric TEC map (GIM), and the values of B and θ can be obtained from the IGRF-12 model. The Figure 2 shown the magnitude of the impact 2rd ionospheric delays in TEC retrieval.

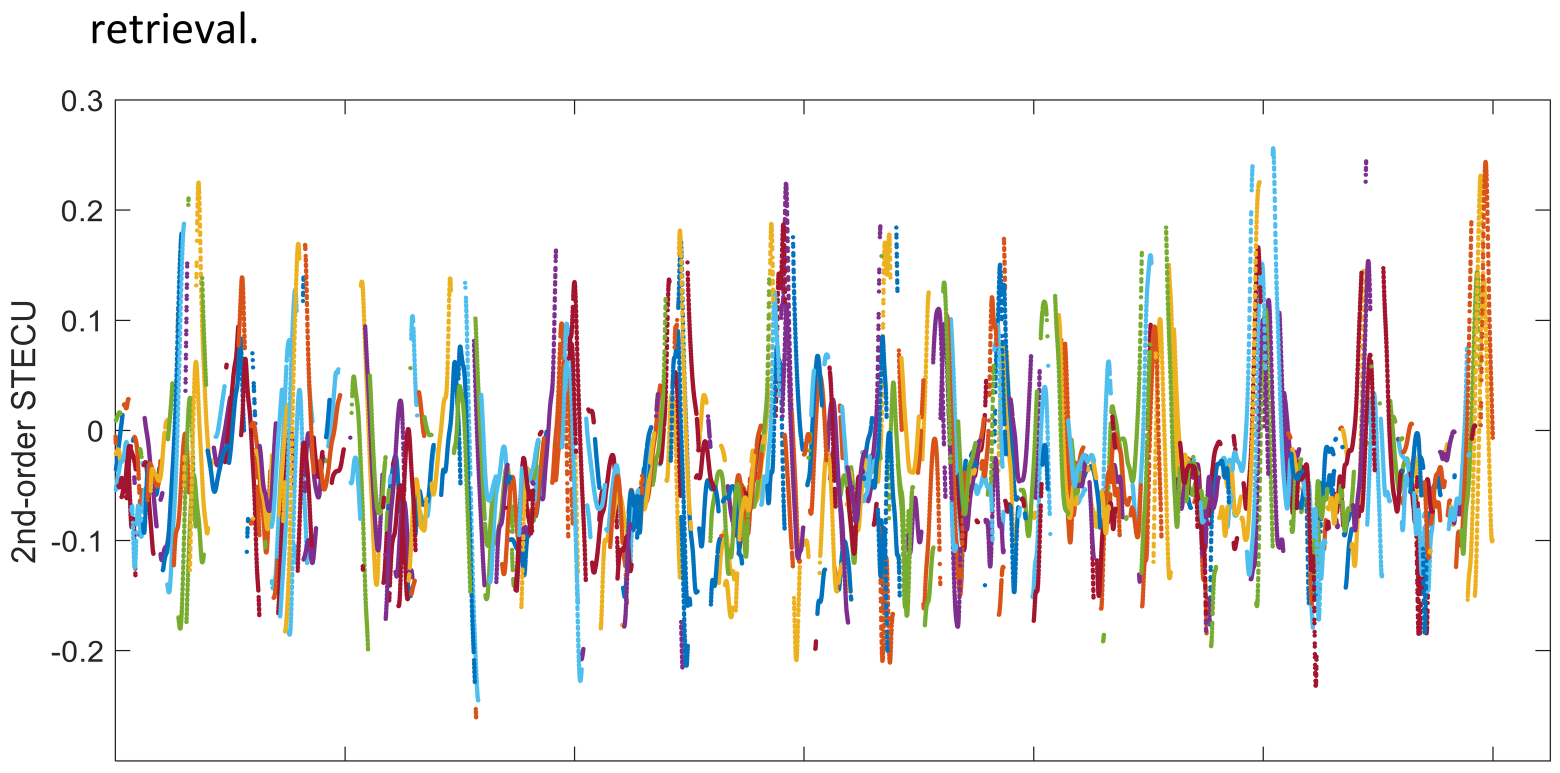

Figure 2. Impact of second order ionospheric delays on Jason-2 STEC unit retrieval on Jan. 1st, 2014 (Solar active year)

Cycle slips detection

As both the ground beacons and LEO receivers were equipped with Ultra Stable Oscillator (USO), the clocks stabilities are less than 2×10^{-12}. The phase measurements were model with a polynomial function as following:

$$\varphi_i = \sum_{j=0}^{n} a_j (t_i - t_1)^j + \varepsilon, (i = 1,2,\cdots,m)$$

We set m=12, n=6, the internal reliability named as minimal detectable biases(MDB) were introduced(Teunissen PJ, 1998), the hypothesis without and with cycle slips as H_0 and H_1:

$$H_0: \boldsymbol{E}\{\boldsymbol{y}\} = \boldsymbol{Ax}, \qquad \boldsymbol{D}\{\boldsymbol{y}\} = \boldsymbol{Q_y}$$

$$H_1: \boldsymbol{E}\{\boldsymbol{y}\} = \boldsymbol{Ax} + \boldsymbol{c}\nabla, \quad \boldsymbol{D}\{\boldsymbol{y}\} = \boldsymbol{Q_y}, \quad c = [\underbrace{0,0,\cdots 0}_{k\geq 1}; \underbrace{1,1,\cdots,1}_{m-k}]$$

Here, the ∇ is the possible cycle slips, and test statistic T is established as:

$$T = \frac{\boldsymbol{c}^{\mathrm{T}}\boldsymbol{Q}_y^{-1}\boldsymbol{P}_{\underset{A}{1}}\boldsymbol{y}}{\boldsymbol{c}^{\mathrm{T}}\boldsymbol{Q}_y^{-1}\boldsymbol{P}_{\underset{A}{1}}\boldsymbol{c}}, \qquad \boldsymbol{P}_{\underset{A}{1}} = \boldsymbol{I} - \boldsymbol{A}\left(\boldsymbol{A}^{\mathrm{T}}\boldsymbol{Q}_y^{-1}\boldsymbol{A}\right)^{-1}\boldsymbol{A}^{\mathrm{T}}\boldsymbol{Q}_y^{-1}$$

T has the Chi-squared distribution under H_0 and H_1

$$H_0: T \sim \chi^2(1,0); \qquad H_1: T \sim \chi^2(1,\lambda_0)$$

The non-centrally parameter is defined as:

$$\lambda_0 = \nabla^2 \boldsymbol{c}^{\mathrm{T}}\boldsymbol{Q}_y^{-1}\boldsymbol{P}_{\underset{A}{1}}\boldsymbol{c}$$

The test power with confidence value $\boldsymbol{\alpha} \rightarrow \boldsymbol{K_\alpha}$

$$\beta_0 = 1 - \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{K_\alpha - \lambda_0} e^{\frac{u^2}{2}} du + \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{-(K_\alpha + \lambda_0)} e^{-\frac{u^2}{2}} du$$

Here we set $\alpha = 0.001 (K_\alpha = 3.20)$ and ∇ set as 1 cycle, figure 3 shows a sample dataset of β_0 from Jason-2 satellite were calculated, and simulated 1 cycle jump were set on epoch 20 and 51. (Jan 1st, 2014. 45908.9～46498.9s)

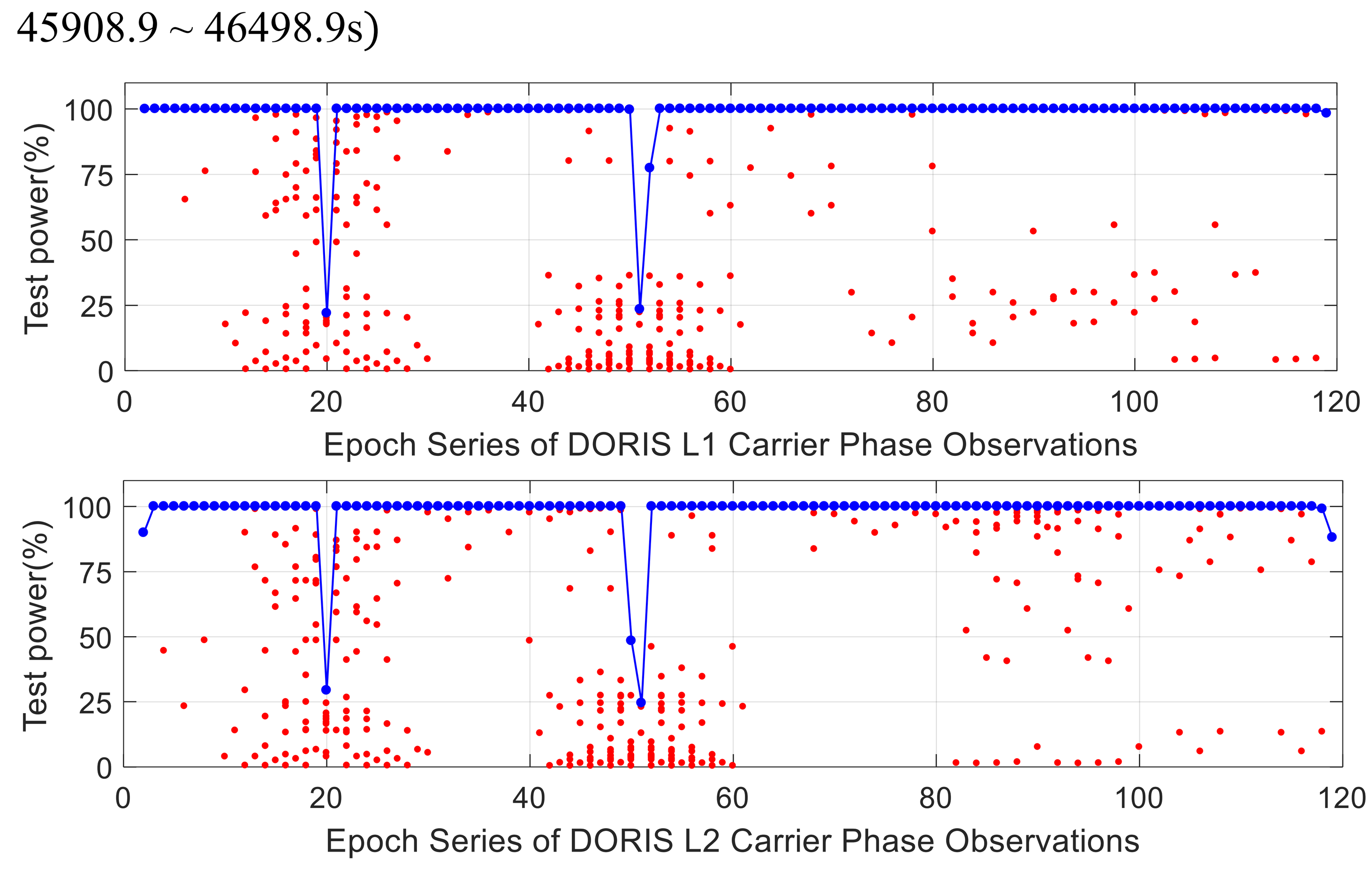

Figure 3. Test Power of Jason-2 on beacon D01 STKB on Jan. 1st, 2014.(red points were test powers with different k value in c vector, and blue point were max test power)

Take $\beta_0 > 80\%$ as a criteria for cycle slips detection, over 10 days data from Jason-2 on station STKB beacon were analyzed for cycle slips detection as shown in Figure 4

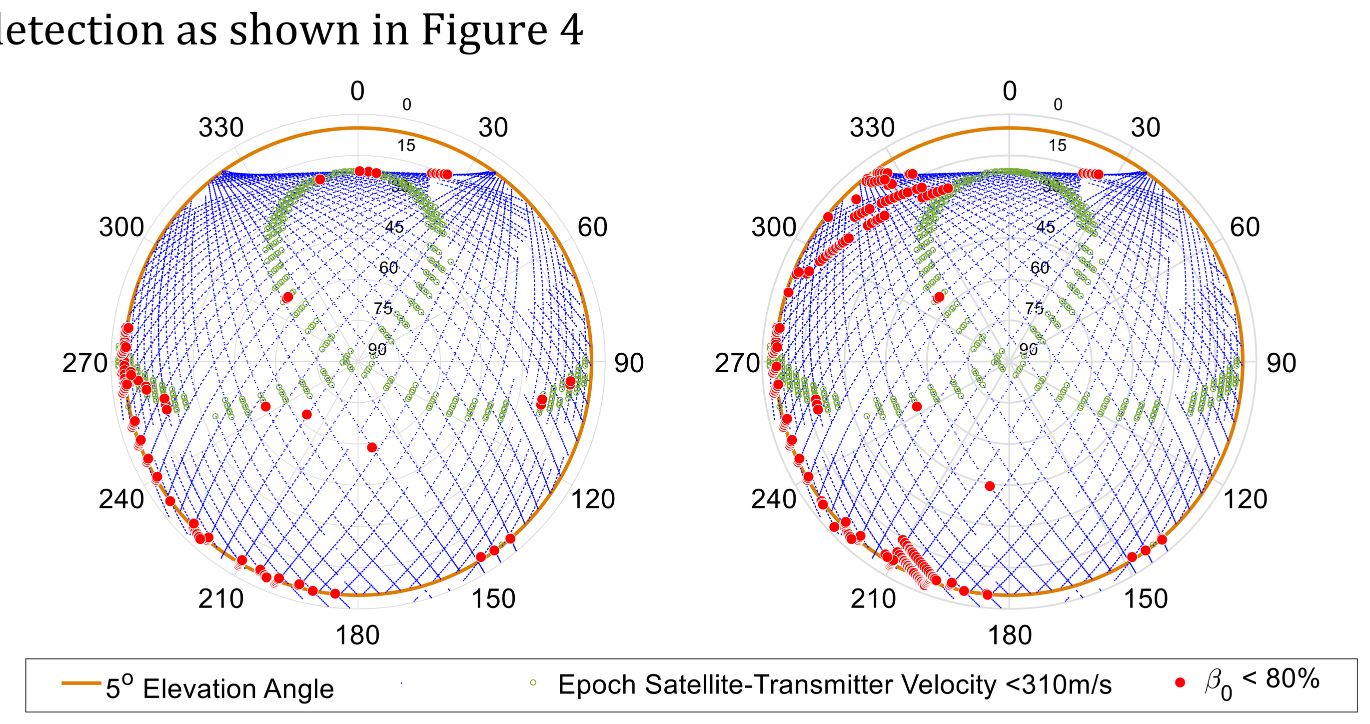

Figure 4. Ten days cycle slip detection for Jason-2 on station STKB(Jan. 1st, 2014~Jan. 10th, 2014)

Summary

The data pre-processing work for DORIS ionospheric TEC retrieval were discussed in this research. The signals geometric center corrections mathematic model were proposed; the impact of second-order delays is less than 0.2TECU, which can be ignored on most of applications; and the internal reliability test were proposed for DORIS cycle slip detections.

References

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