MATLAB software for GPS cycle-slip processing

User manual

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1 Installation

Make sure you have MATLAB environment running.
The installation of the programs can be simply done by unzipping all files into a folder.

2 Run the programs

First of all, please load the m-file "GUIMain.m" into MATLAB and run it.

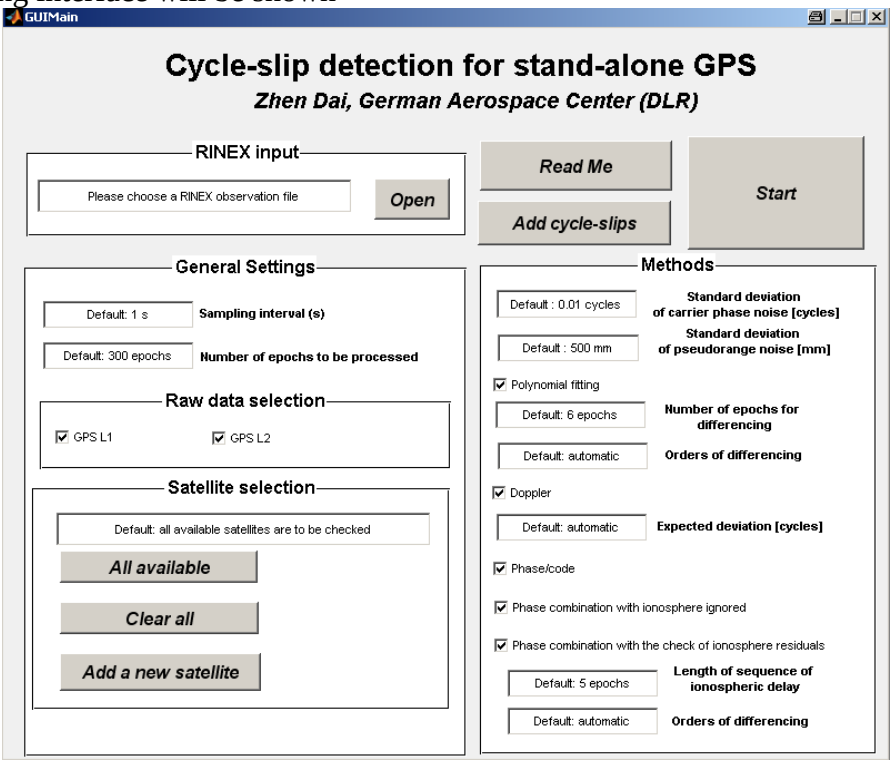
There are three steps for cycle-slip processing:

Step 1:
"GUIMain.m"→ Choose the input RINEX file and set related parameters
Step 2:
"mainpro.m"→According to the specified parameters, selected cycle-slip detection approaches will be performed
Step 3:
"DispResult.m"→The results generated by "mainpro.m" will be depicted in a GUI.

These three m-files can be loaded and run in MATLAB individually. However, the foregoing functions must have been invoked.

3 Step 1

An announcement will show up at first. You have to agree with it in order to go further. The following interface will be shown



Some general information:

- It can be seen that some default values are already presented. If you would like to use them, please keep them as they are. To user other values you could **clear the corresponding text box first and type in the expected number**. Please note the unit.
- **You may ignore all setting and simply click the "start" button at the right-upper corner**. In this case, the program will process the embedded RINEX file with the default settings.

The interface is divided into several areas with each performing a specific task

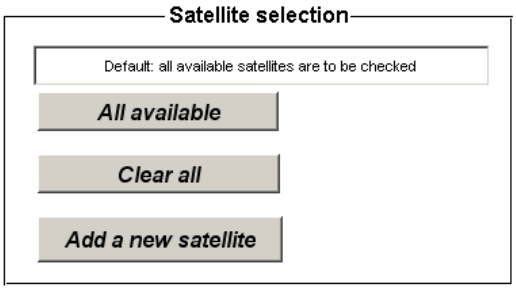
Area	***Options***	***Functions***
RINEX input	Open	Choose a RINEX observation file.
Buttons (upper right corner)	Read Me	Show readme file
	Add cycle-slips	User could manually add cycle-slips to raw data in order to test the algorithms. See section 3.2 for details.
	Start	Start cycle-slip processing with parameters set in the GUI. Please make sure all parameters are set as expected before clicking it.

General Settings	Sampling interval in [seconds] Default: 1 s	Sampling interval of the RINEX observation file. This allows you to process the data sampled at a lower rate. For example, you have a 20-Hertz GPS raw data (namely 0.05 s sampling interval)and want to reduce the sampling interval to 0.1 s, then you could simple type in 0.1 in this text box.
	Number of epochs to be processed Default: 300 epochs	You may not want to process all the data contained in the file. This option allows you to process a specific number of epochs from the beginning of a RINEX file according to the specified sampling intervals. If you specify a sampling interval of 1 s and you want to process 100 epochs, then the program will try to collect the first 100 data sampled on "integer" seconds.
Raw data selection	☑ GPS L1 ☑ GPS L2	The program allows the processing of GPS L1 and L2 signals. Checking a box means that the associated signal is to be processed.
Satellite selection	See section 3.1	
Method	☑ Polynomial fitting ☑ Doppler ☑ Phase/code … …	Methods used to process cycle-slips. Each method needs related measurements. A method will be invoked only if the corresponding measurements are found in the raw data. Otherwise, this method is not taken into account even if you do select it.
	Standard deviation of carrier phase noise in [cycles] Default : 0.01 cycles	The standard deviation of carrier phase noise. This value affects the sensitivity of detection approaches using phase differencing and phase combination. It is assumed that the carrier phase on both carrier signals contain the same level of noise.
	Standard deviation of pseudorange in [mm] Default : 500 mm	The standard deviation of pseudorange noise. This value affects the sensitivity of detection approaches using phase/code combination. It is assumed that the pseudoranges on both carrier signals contain the same level of noise.
	(method-oriented) Number of epochs for differencing Default: 6 epochs	This is related to the cycle-slip detection by high-order differencing of carrier phase data. In this approach, previous epochs need to be collected into a queue in order to obtain the statistics of the differenced phase measurements. This option specifies the length of the queue. A larger number yields a better estimation of the mean value. However, only when the queue is full, can the cycle-slip detection be carried out.

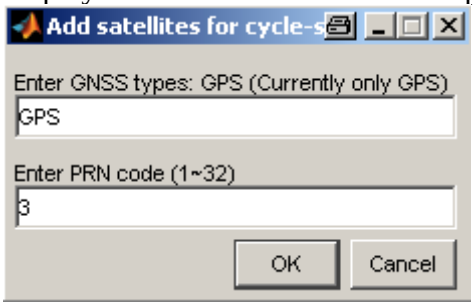
	(method-oriented) Order of differencing Default: automatic	This is related to the cycle-slip detection by high-order differencing of carrier phase data. You may specify the order of differencing. This value is usually 3 or 4 and depends on the sampling interval. The algorithm could determine this value automatically. A general principle to determine the order is that a proper order should yield the differenced residuals significantly lower than that obtained from an order higher and an order lower.
	(method-oriented) Expected deviation Default: automatic	This is related to the cycle-slip detection by using Doppler data. This method checks the deviation between the Doppler data and the between-epoch carrier phase variation. The deviation to be identified here serves as the threshold to judge a cycle-slip. This value depends on the application scenario, the sampling interval, and the quality of data. The algorithm allows an automatic determination of the threshold by calculating the averaged deviations of all data available for each individual satellite. This might be a little time-consuming. If you give another number here, this number will be used for all satellites for the sake of simplicity.
	(method-oriented) Length of sequence of ionosphere delay Default: 5 epochs	This is related to the cycle-slip detection by constructing geometry-free phase combination and checking the ionospheric residuals. This method checks the abnormal jumps inside the estimated between-epoch ionosphere variation obtained by geometry-free carrier phase combination. The length of the sequence affects the derived mean value of ionosphere variation.
	(method-oriented) Order of differencing Default: automatic	This is related to the cycle-slip detection by constructing geometry-free phase combination and checking the ionospheric residuals. If the sampling interval is large, the estimated ionosphere variation can be further differenced to improve the detection sensitivity. The program allows an automatic determination.

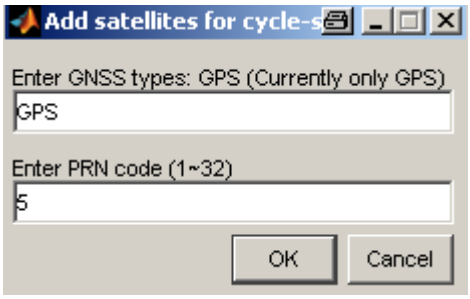
3.1 *Selection of satellites*

You may specify a set of satellites in which you are interested.
Note that you have to first check the RINEX file and make sure that the selected satellites really exist.

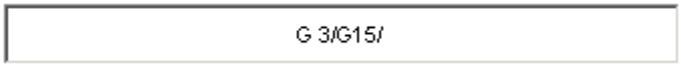


- By default, all satellites will be processed. You can restore the default settings by clicking "All available",
- By clicking "add a new satellite" you can specify a PRN number. The selected satellites will be displayed on the text box. For example, you can choose PRN 3 and PRN 15 by doing:





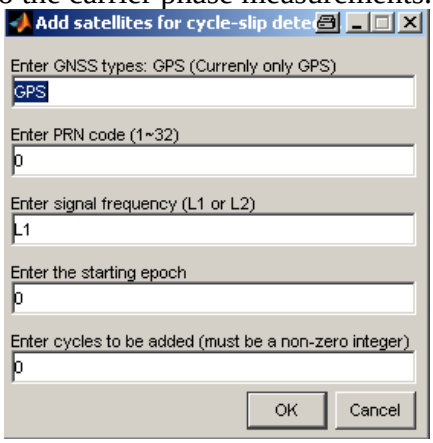
And you will see the output like:



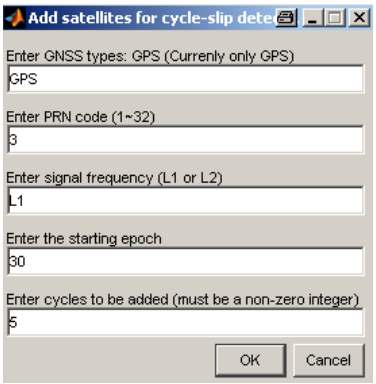
- By clicking "Clear all" you can clear all satellites selected. In this case, there is no satellite to be processed.
- If you select a satellite which is not contained in the RINEX file, this satellite will not be considered. However, there is no error massage to alert you to this fact.
- Readers may modify the source code to handle GLONASS or GALILEO, whereas the program currently can only support GPS data.

3.2 *Add synthetic cycle-slips*

You may want to test, improve or debug the algorithms. For these purposes, the program allows you to add cycle-slips onto the carrier phase measurements.



- You can input satellite PRN number, frequency (L1 or L2), starting epoch and size of cycle-slip. For example, you can add a 5-cycle slip onto L1 signal of GPS PRN 3 starting from 30th epoch by doing so:



- The added cycle-slip will remain in the following epochs after the specified "starting epoch"
- The added cycle-slips will just be stored in the internal data base (the original RINEX file will not be modified).

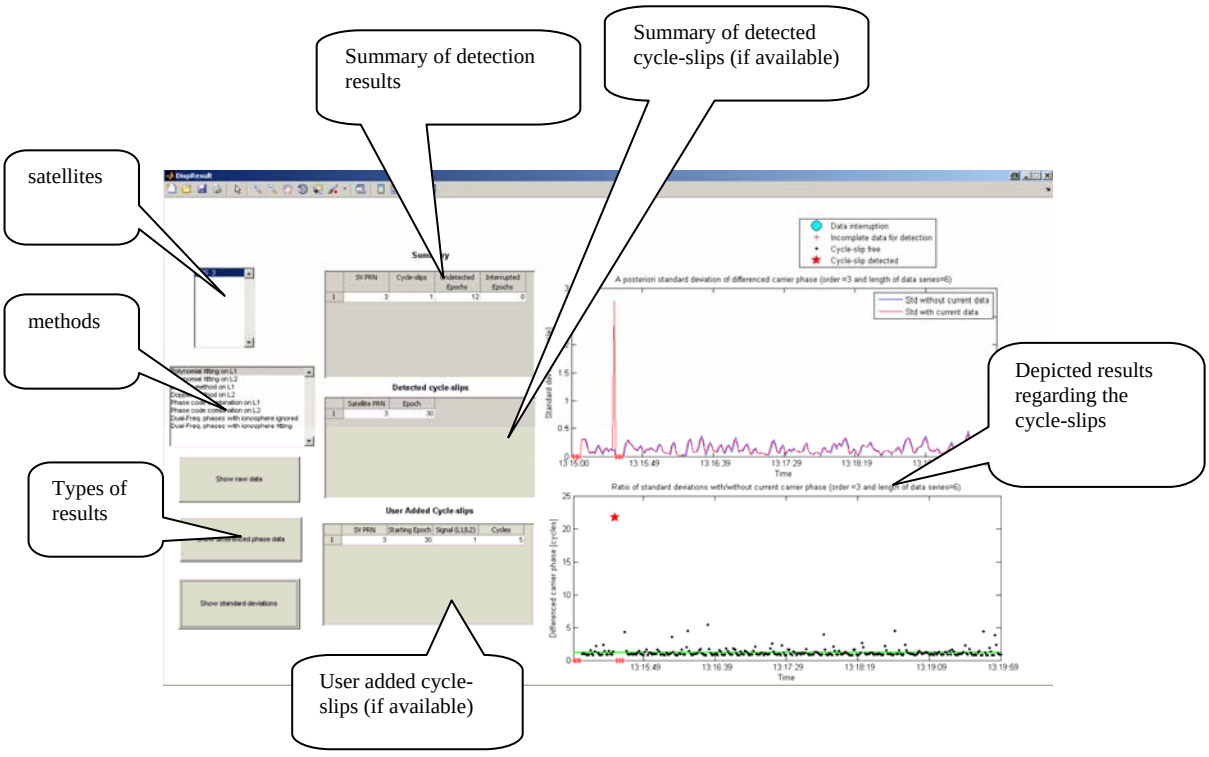
4 Step 2

After clicking the "Start" button, the main program will be called.
Following steps will go through:

(1) RINEX observation file will be read in and saved in an internal format.
(2) Synthetic cycle-slips will be added.
(3) The selected methods will be invoked to detect the cycle-slips. The results will be saved in an internal format and will be depicted afterwards.

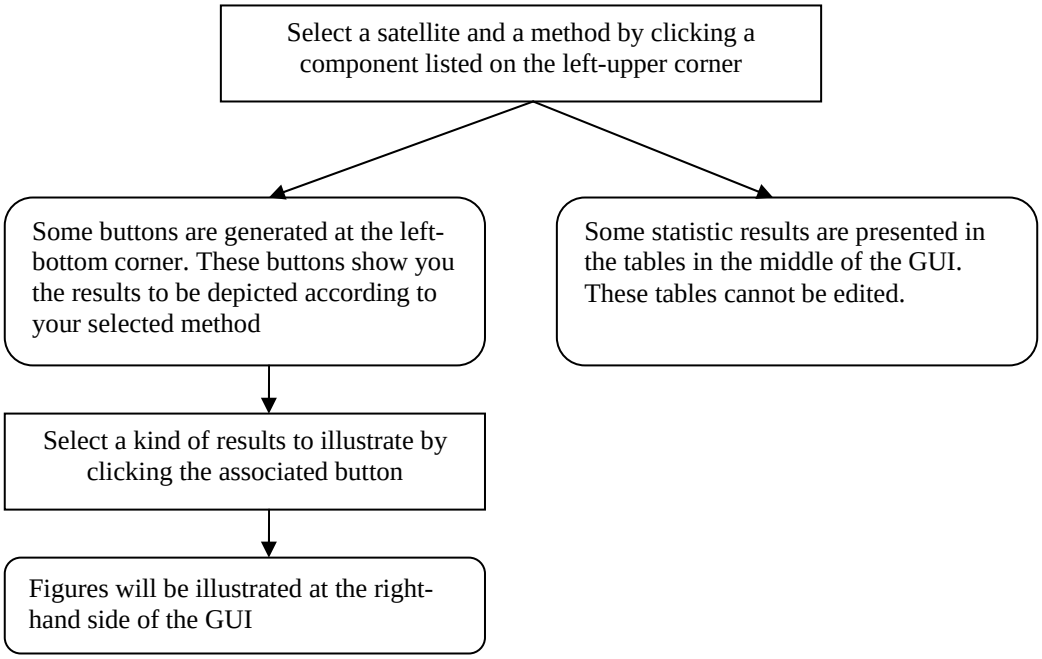
5 Step 3

Another GUI depicts the detection results. The interface is composed of several areas as marked below:



5.1 *Procedure for viewing the results*

Following operations guide you to view the results.

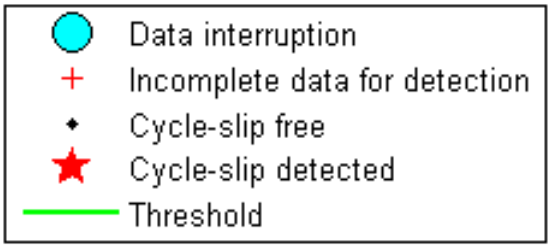


- You should first identify a specific satellite and a specific method by clicking the component listed on the left-upper corner. The satellites and methods listed there are either from your selection or from the GPS raw data.
- Then you could see some buttons showing up at the left-bottom corner. These buttons show you the results to be depicted according to your selected method. By clicking a button, you will see figures come out at the right-hand side.
- In the middle you will see three tables arranged vertically.

Table	***Content***
Summary SV PRN / Cycle-slips / Undetected Epochs / Interrupted Epochs 1: 3 / 1 / 12 / 0 2: 15 / 2 / 18 / 0 3: 16 / 0 / 6 / 0 4: 18 / 0 / 6 / 0 5: 19 / 0 / 6 / 0 6: 21 / 0 / 6 / 0 7: 22 / 0 / 6 / 0 8: 27 / 0 / 6 / 0	The statistics of the detection results regarding to the selected satellite and method. Information to be presented includes (1) the satellite PRN; (2) total number of detected cycle-slips; (3) number of epochs at which the cycle-slip detection is suspended; (4) number of epochs at which the expected observations are not found, namely observation interrupted.
Detected cycle-slips Satellite PRN / Epoch 1: 3 / 44 2: 15 / 66 3: 15 / 77 (following only in case of dual-frequency	Detected cycle-slips. Information to be presented includes (1) the satellite PRN. (2) the starting epoch of cycle-slips. (3) the estimated size of cycle-slips (only for dual-frequency phase combination)

phase measurements used) **Detected cycle-slips** Satellite PRN / Epoch / Est. Slip L1 / Est. Slip L2 1: 1, 44, 2, 0 2: 2, 66, 2, 0 3: 2, 77, 1, 0	
User Added Cycle-slips SV PRN / Starting Epoch / Signal (L1/L2) / Cycles 1: 3, 44, 1, 2 2: 15, 77, 1, 1 3: 15, 66, 1, 2	The synthetic cycle-slip you added. You may compare it with the detected cycle-slips see whether these "synthetic" cycle-slips are really detected. Information to be presented includes (1) the satellite PRN; (2) the starting epoch of cycle-slips. (3) carrier signal, where 1 stands for L1 signal and 2 stands for L2 signal. (4) the size of cycle-slips in units of cycles. The maximum value for a cycle-slip is limited by the MATLAB function "str2num".

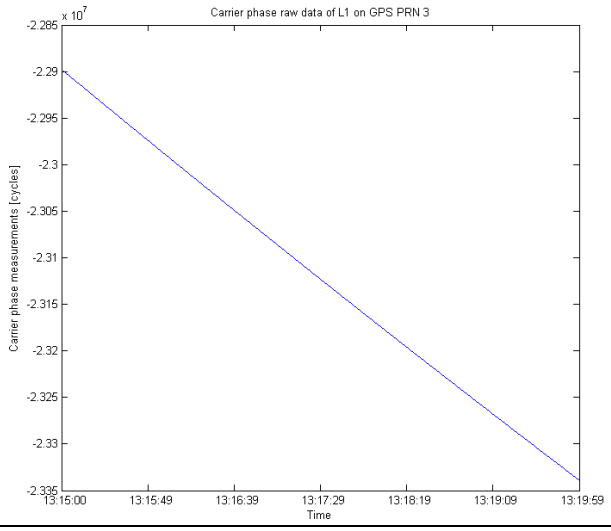
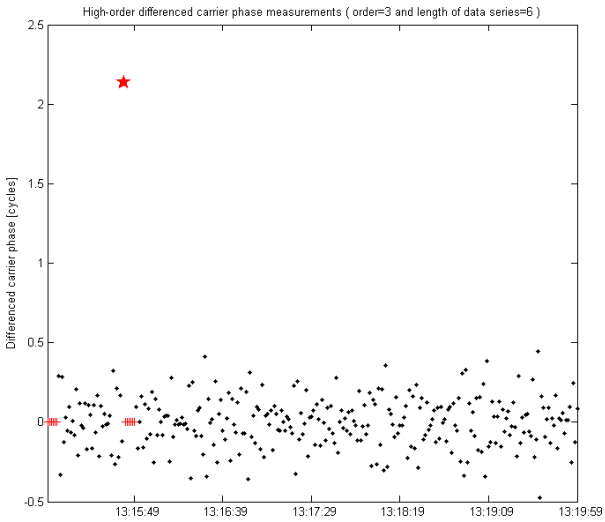
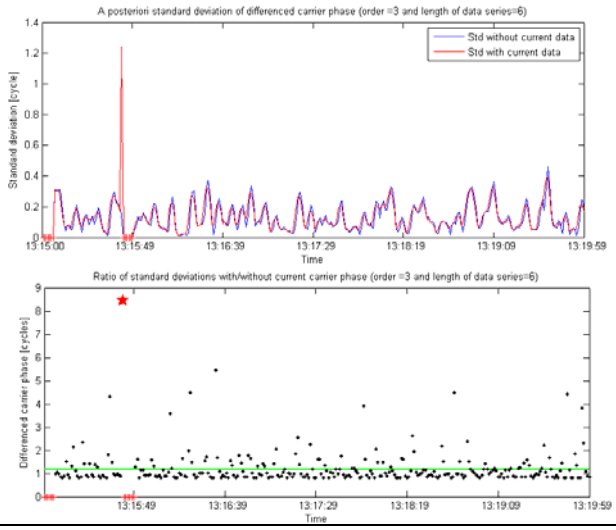
- Following legends will be used for each figure in order to identify different status at each epoch.



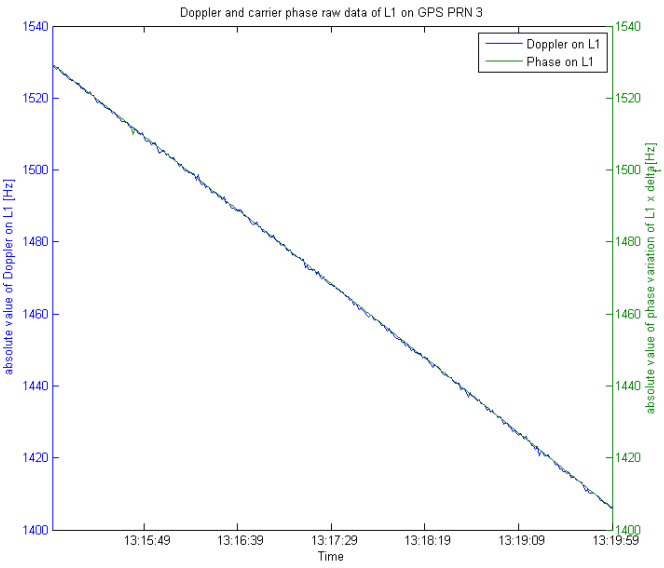
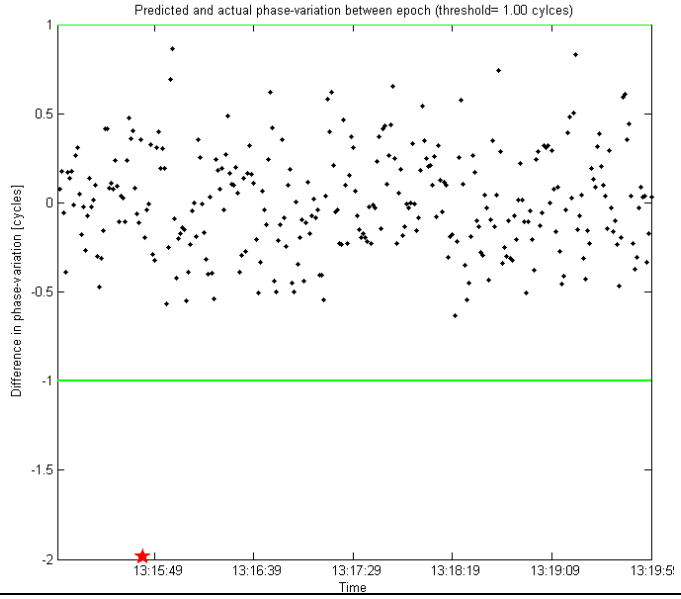
Status	***Remarks***
Data interruption	The necessary measurements are missing on the expected epoch. The reason might lie in the loss of signal, tracking problems in the receiver, problems in the conversion from raw signal to RINEX data, or an improper sampling interval identified. Loss of data does not mean a cycle-slip, however, it might also cause fatal errors to the processing algorithms.
Data incomplete	Each method requires a minimal set of data. If the data set is not yet complete, the related method cannot run and has to wait for the data of the next epoch(s). It means that the cycle-slip detection is suspended for the current epoch. Such a situation usually takes place either at the beginning of the processing of a RINEX file or after a detected cycle-slip.
Cycle-slip free	The cycle-slip detection is executed and no cycle-slip is found on the associated signal(s) at current epoch
Cycle-slip detected	The cycle-slip detection is executed and a cycle-slip is found on the

	associated signal(s) at current epoch. After a cycle-slip is found, all the cycle-slip detection approaches will be reset after this epoch.

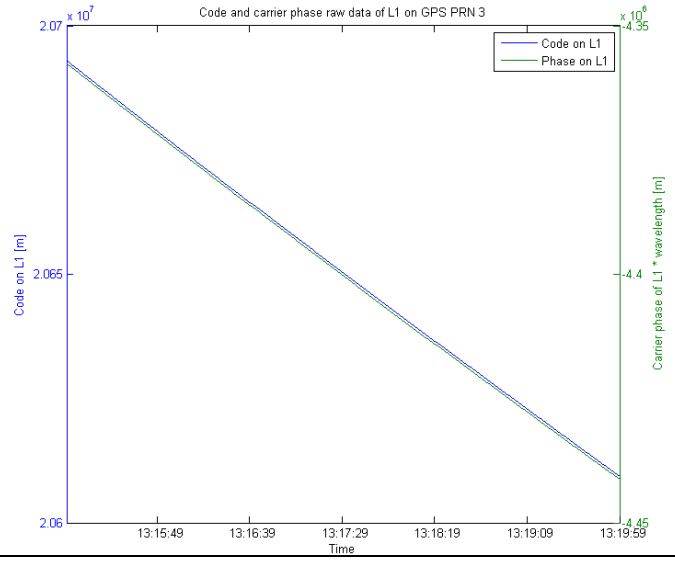
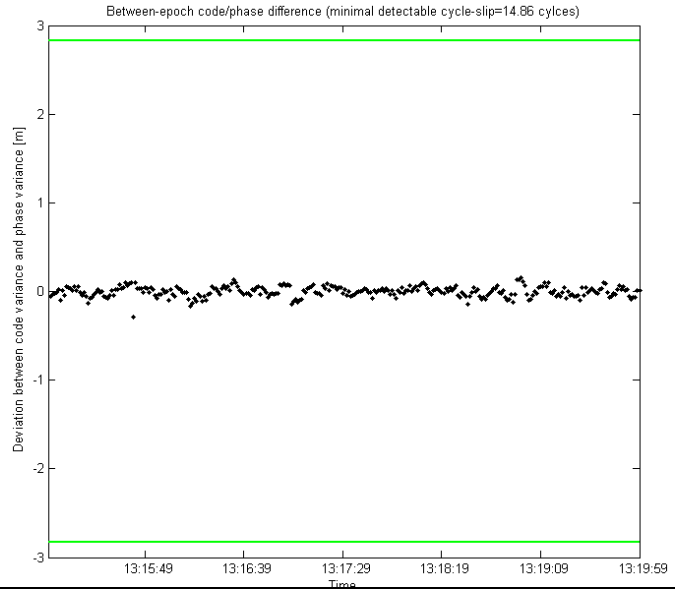
5.2 *Results from phase differencing*

Button	***Figure***	***Explanation***
 Show raw data		The carrier phase raw data will be plotted versus time
 Show differenced phase data		The residuals of carrier phase after high-order differencing. These points should be limited with a certain range. A excessive jump means a cycle-slip, as the red star shown in the figure. A cycle-slip manifests itself as a large jump. By default, if the deviation is larger than 1 cycle or "significantly" larger than the mean value of previous data, a cycle-slip is identified.
 Show standard deviations		The standard deviation of the differenced carrier phase. The upper figure shows the standard deviations with/without current carrier phase measurement. The lower figure shows the ratio of both standard deviations. The threshold is set as 3 by default. In the source code you can change it.

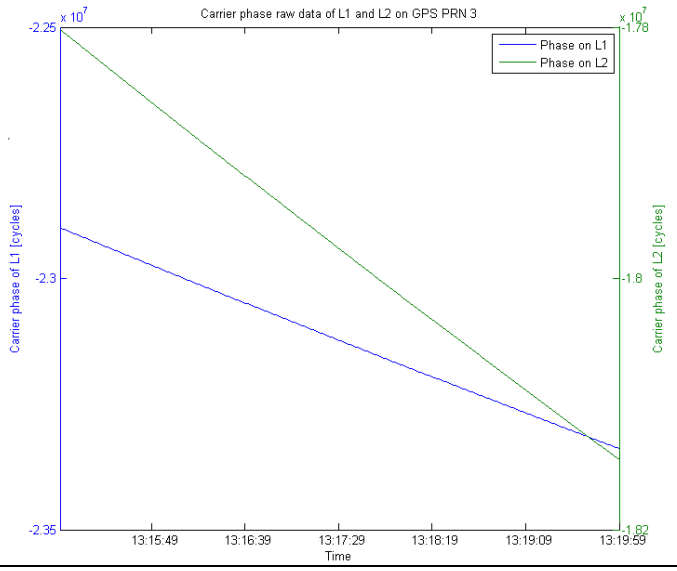
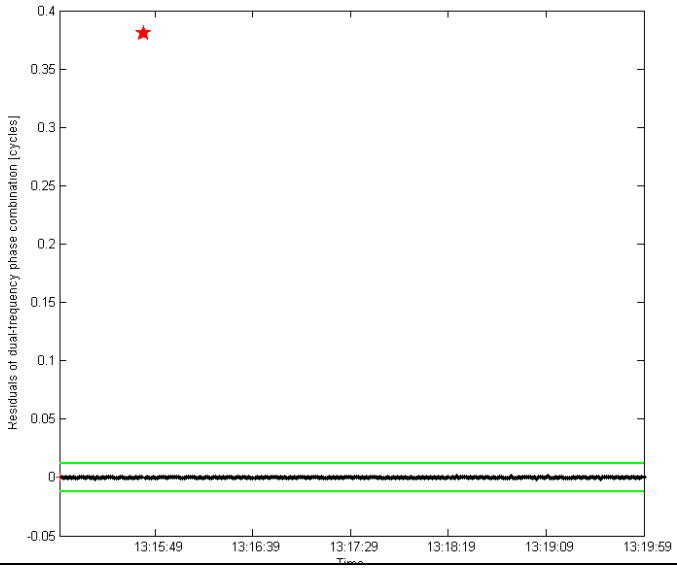
5.3 *Results using Doppler data*

Button	***Figure***	***Explanation***
 Show raw data		The Doppler data and the between-epoch carrier phase deviations are presented with time. Note that the carrier phase data is differenced in time to be presented in units of Hertz (like the Doppler data). The presented results are actually the absolute values.
 Show deviation		The between-epoch variation of carrier phase can be obtained from raw data or estimated from Doppler. The deviation between both is plotted here. The threshold can be either determined by the user or by the algorithm automatically. A large jump indicates a cycle-slip, as shown by the red star.

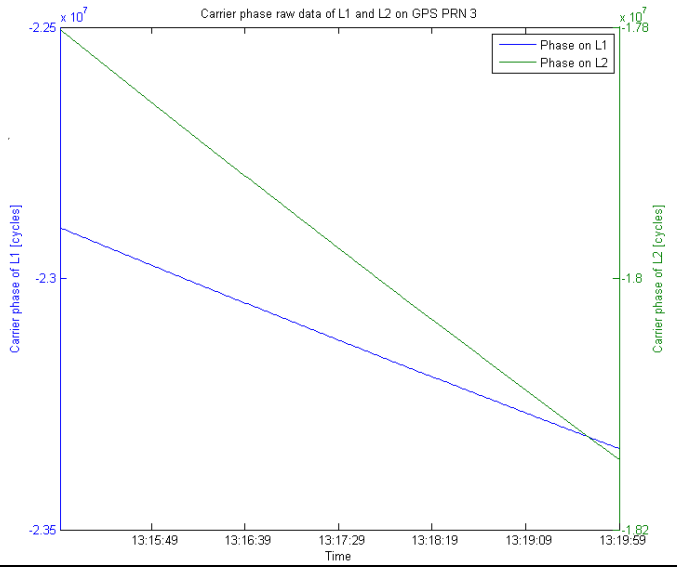
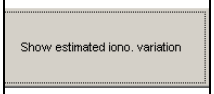
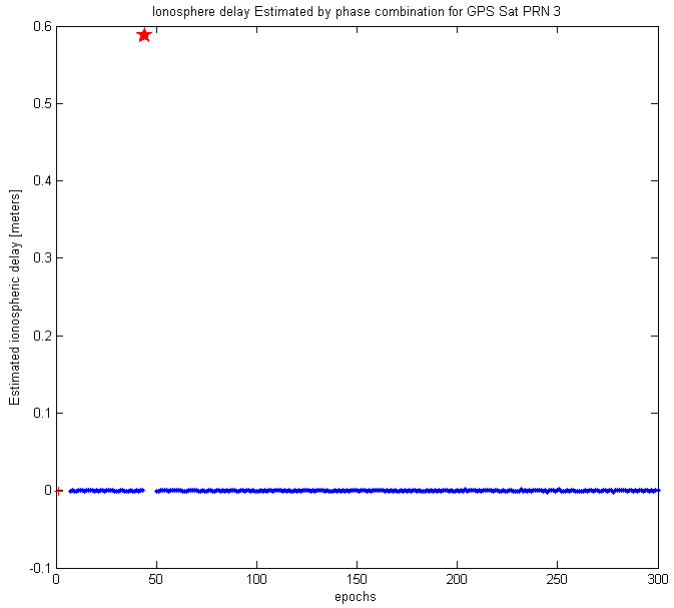
5.4 *Results using phase/code combination*

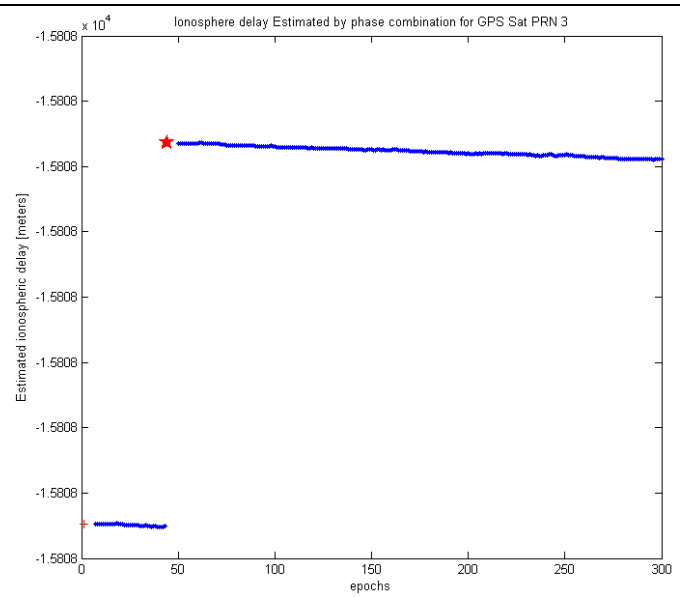
Button	***Figure***	***Explanation***
Show raw data Show raw data		Both of carrier phase and pseudorange measurements are plotted versus time. Carrier phase is multiplied with its wavelength to be presented in units of meters.
Show code/phase diff. Show code/phase difference		Difference between the between-epoch phase variation and code variation. A large difference means probably a cycle-slip. The threshold is mainly dependent on the code quality identified by the user. Spurious pseudoranges (outliers) may also cause large differences.

5.5 *Results using phase combination with ionosphere ignored*

Button	***Figure***	***Explanation***
 Show raw data		Carrier phase on both signals are plotted versus time.
 Show dual-frequency residual		The residuals resulted from the geometry-free phase combination. A cycle-slip, except for some special ones, will clearly override the threshold determined by the carrier phase noises.

5.6 *Results using phase combination with ionosphere check*

Button	*Figure*	*Explanation*
 Show raw data		Carrier phase on both signals are plotted versus time.
 Show dual-frequency residual		The estimated between-epoch ionosphere variation. Normally the ionosphere delay should change quite smoothly, so that the between-epoch variation should be restricted in a certain range. A cycle-slip can manifest itself as a jump.

Show ionosphere estimates Show ionosphere estimates		The estimated ionosphere delay on L1. A cycle-slip will clearly break the smooth variation of the ionosphere delay.

6 A short introduction to the embedded functions

The functions of the M-files can be roughly known by names

Name format	***Functions***
GUI_Main_*xxx*	Functions related to the GUI where user specifies the parameters
GUI_Results_*xxx*	Functions related to the GUI for displaying the results
Method_*xxx*	Main program for each method
Method_Core_*xxx*	Auxiliary operations and calculations for cycle-slip processing
mainpro.m	Main program for invoking all methods
DispResult	Show the GUI for displaying results

7 Contacts

The author would like to have any comments, suggestions and critiques sent to

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or

to the associated editors of the journal “GPS solutions” under

http://www.ngs.noaa.gov/gps-toolbox/.

The author will reply your email as soon as possible. However, as the development of this software package is currently not part of his official job, the author might not be able to reply in “real-time”.