GPS - System 200

Guidelines on Processing RINEX Data with SKI

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1. Introduction

As surveying with GPS is becoming more and more popular, the demand for combining different types of receivers in the same project, and processing all data with one software package has increased.

A state-of-the-art GPS processing software like SKI is of course able to support data from third-party receivers. Nevertheless there are some restrictions and limitations. Most GPS software packages are designed and optimized for data from specific equipment. No receiver and software manufacturer can guarantee the quality of data from third-party receivers.

Therefore a surveyor who wants to combine data from different types of receivers has to be familiar with certain data characteristics, he has to know the strengths and the restrictions of the post-processing software to be used, and finally he has to have enough experience with GPS computations to assess the final results.

This guide outlines how the WILD GPS software SKI supports data from third-party receivers. It provides the user with hints on assessment of the data quality, and it shows how successful processing may be achieved even if the exact requirements of data quality are not met.

Although in the course of this guide it will be necessary to set up some quality characteristics for GPS receivers and to compare non-WILD data with data taken by Leica's System 200, it is not our intention to classify any of the mentioned third-party receivers. This booklet provides an advanced user with the information necessary to obtain the most benefit from SKI when processing all kinds of GPS data.

2. Import of Data using RINEX Input Option

2.1 RINEX Format

Each GPS receiver type has its own raw data format and data structure. E.g. System 200 data is organized in data set records consisting of different binary files. To facilitate GPS data exchange, a common format for GPS data has been defined and accepted as a standard by the GPS community: the RINEX format. RINEX stands for Receiver INdependent EXchange format. A detailed description of the format is published in the CSTG GPS-Bulletin Vol.2 No.3, May-June 1989, and Vol.3 No.3, September-October 1990. A copy of the latter is attached as an appendix.

The RINEX format describes the file structure and data format, as well as the naming convention of the files themselves. The following file names are recommended:

SSSSDDDF.YYT	where: SSSS	...	first 4 characters of station name	
	DDD	...	day of the year	
	F	...	file sequence number within a day	
	YY	...	last 2 digits of the year	
	T	...	file type:	O: Observation file
				N: Navigation file
				M: Meteorological data file

The following is an example of a RINEX observation file of Leica System 200 data. Note, that the added line numbers on the left are not part of the original RINEX file.

```
1     2              OBSERVATION DATA                           RINEX VERSION / TYPE
2   OBSTORNX                              11-NOV-92 19:49     PGM / RUN BY / DATE
3                                                             OBSERVER / AGENCY
4   01_L                                                      MARKER NAME
5   01_L                                                      MARKER NUMBER
6   100531              SR299                                 REC # / TYPE / VERS
7        0              SR299                                 ANT # / TYPE
8     4849322.2111  -360293.6708  4114733.5676                APPROX. POSITION XYZ
9           1.5100        0.0000        0.0000                ANTENNA: DELTA H/E/N
10       1     1                                              WAVELENGTH FACT L1/2
11       4    C1    L1    P2    L2                            # / TYPES OF OBSERV
12    1992     9    16    13     0   30.000000                TIME OF FIRST OBS
13                                                            END OF HEADER
14   92  9 16 13  0 30.0000000  0  6G11G15G28G21G 2G14                -0.000000091
15    20798235.239   109295441.866 7  20798240.377    85165398.558 7
16    20714528.154   108855554.164 8  20714530.584    84822631.949 7
17    22747578.156   119539334.035 6  22747586.428    93147647.769 6
18    23545213.186   123730906.407 6  23545217.080    96413808.950 5
19    23545131.262   123730507.894 6  23545132.888    96413504.199 6
20    23118431.802   121488177.096 6  23118437.825    94666245.247 6
21   92  9 16 13  0 45.0000000  0  6G11G15G28G21G 2G14                -0.000000016
22    20799123.684   109300112.672 7  20799128.962    85169038.166 7
23    20711081.870   108837447.819 8  20711085.557    84808523.139 7
24    22756614.000   119586797.715 6  22756619.193    93184632.430 6
25    23554456.318   123779467.394 6  23554459.139    96451648.639 5
26    23539796.703   123702498.596 6  23539803.635    96391678.800 6
27    23108898.239   121438075.883 6  23108904.150    94627205.442 6
```

Each RINEX observation file contains a header and various data records. Lines 1 to 13 define the observation file header. It provides the user with information on the site name, marker eccentricities, a priori marker position, and the types of observations that follow. The header ends with an "end of header" comment (version 2) or a blank line (version 1). A short explanation of the most important records follows, more detailed information can be found in above mentioned appendix:-

Line 1 : RINEX format version, observation file type
Line 4 : Name of the antenna marker
Line 8 : Approximate position of the marker (related to WGS84)
Line 9 : Antenna height and antenna eccentricities
Line 10 : Wavelength factor indicating full or half-cycle ambiguities
Line 11 : Number of observation types, and types and sequence of observations

Each data record (e.g. lines 14 to 20) comprises an epoch record , and a number of observation records. The epoch record (line 14) shows the epoch (16.09.1992, 13:00:30), the number of tracked satellites (6), the PRN numbers of the satellites (11, 15, 28, 21, 2, 14; G stands for GPS satellite), and the receiver clock offset (-91 nanoseconds). The observation records are repeated for each satellite given in the epoch record. The sequence of the observation types in every observation record follows the sequence defined in the RINEX file header (line 11).

2.2 Data Import into SKI

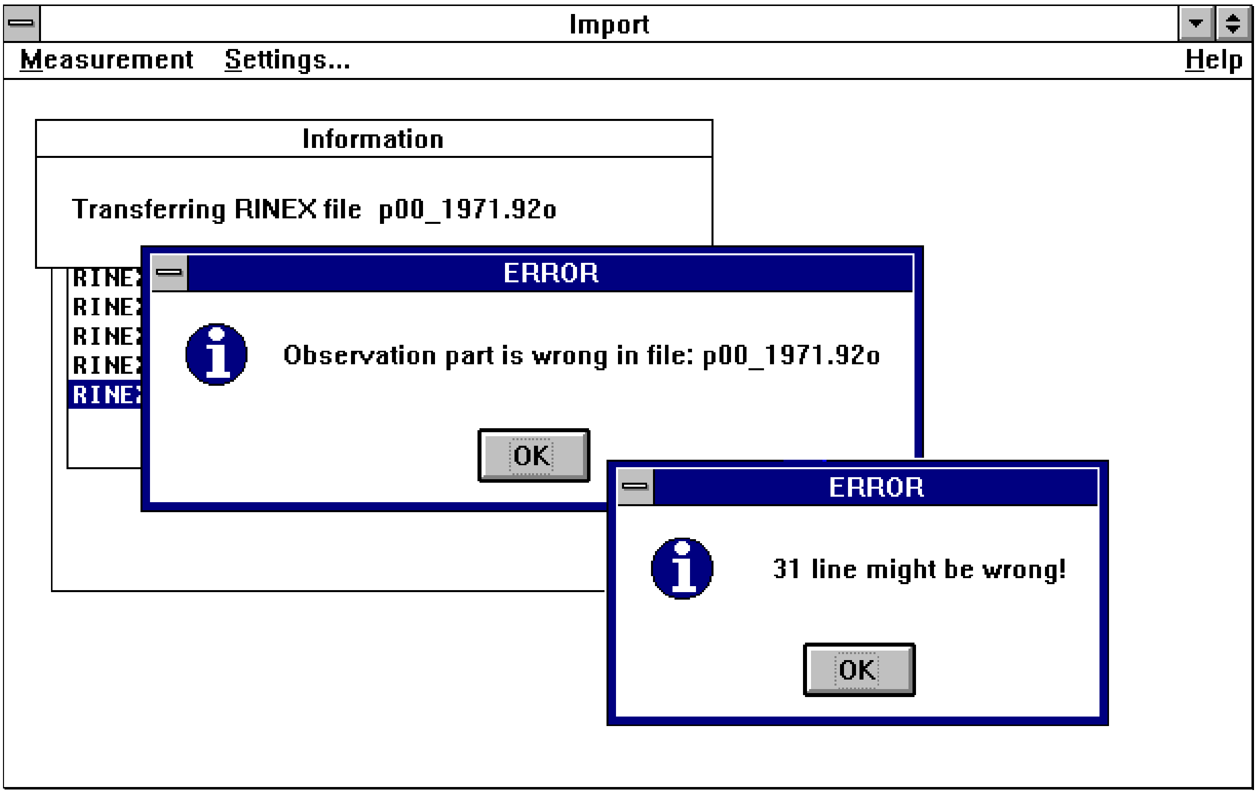
The SKI software supports both input and output of RINEX data. RINEX output may be used to backup System 200 data for further processing with a different software. Input of data from non-WILD receivers requires the RINEX import option for SKI. Both RINEX version 1 and version 2 are supported.

All files to be imported have to follow the RINEX naming convention, otherwise they will not show up in the file selection box. Files with the same "day of the year" and "file sequence" numbers will be grouped together to one record. During data transfer, each file will be checked for the consistency of its format with the RINEX definitions. Any inconsistencies will be reported and result in a termination of data import. An example of such a failed data import is shown below.

The reason for a failed data import may be either a general problem with the RINEX format (e.g. a line is longer than 80 characters), or SKI detecting inconsistencies within the data itself (e.g. an observation record header indicated 5 satellites tracked for that epoch, but measurements for only 4 satellites are recorded). In any case, SKI tries to give as much help as possible to detect the problem, but it will not try to fix it.

A much more critical case is if the RINEX file is formally correct, but the information given in it is wrong. SKI will not detect such errors during data import. The consequences may be unpredictable results or error messages during data processing. We ourselves have experienced the following problems when importing RINEX data from non-WILD receivers into SKI (an example will be give in a subsequent chapter):-
(1) The wavelength factor indicates full cycle ambiguities although the measurements were taken using a squaring technique, which results in half-cycle ambiguities. This affects the processing mode used for data processing, and may influence the cycle slip detection.

(2) The wavelength factor and the observation type information indicate dual frequency data although a single frequency unit was used. The observation columns for the second frequency were filled with zeros or blanks.



During data import SKI converts RINEX format into System 200 binary data format, and stores all necessary and available information (marker name, antenna height and eccentricities, a priori position, observations, wavelength factor, clock offset) into a project database. Before inserting the data into the SKI database, the user has to ensure that the information is correct.

Summary:

It is the users responsibility to ensure that:-

- **the file names follow the recommendations given in the RINEX format description,**
- **the data format follows the RINEX definitions (correctness of the format),**
- **the header information and the data is correct (correctness of the content).**

3. Processing non-WILD Data with SKI

One of the basic features of SKI is its user friendliness. Compared to many other commercial or scientific GPS processing packages, hardly any user intervention is necessary during data evaluation. Years of experience in the development of GPS software and the processing of GPS data has been integrated in the algorithms. All of the complex and highly sophisticated computation steps, like data screening, cycle slip detection and repair, satellite arc computation, and ambiguity resolution are hidden from the user and run in the background.

Such highly automated processing is possible because SKI software was designed and optimized for use with data from the GPS Sensor WILD SR299.

Processing RINEX data from non-WILD equipment with SKI is possible with the same degree of automation *if the data exactly matches the quality characteristics of SR299 data*.

If the data quality does not meet the required quality characteristics, processing may still be possible after manually modifying certain processing parameters and/or disabling observations. As Leica cannot guarantee the quality and correctness of non-WILD data, *Leica cannot guarantee that processing of such data will always be possible and successful.*

Summary:

- **Fully automatic processing of non-WILD data with SKI is possible if the data matches the quality characteristics of SR299 data.**
- **Successful processing of data which does not match the required quality characteristics may be possible after modifying certain processing parameters. However, no guarantee can be given.**

3.1 Data quality characteristics required for automated processing

The data quality characteristics required for automated processing with SKI are based on those of WILD SR299. They can be summarized as follows:-

- *The receiver clock offset from GPS time has to be smaller than 1 microsecond.* The SR299 uses the computed clock offset to synchronize the internal oscillator to true GPS time within a few hundred nanoseconds (so-called "time recovery").

- *The clock synchronization between the two receivers used for baseline computation has to be less than 1 microsecond.* With the SR299 observations are taken at the exact second. This, together with the time recovery feature mentioned above guarantees that the errors introduced by short-term satellite clock variations (up to 2mm within 1 microsecond) are well within the measurement noise.

- *There must be no half-cycle slips in the data.* Half-cycle slips, i.e. jumps in the raw observations amounting to an integer number of half carrier wavelengths, are automatically detected and repaired by the firmware in the WILD SR299. Thus half-cycle screening during post processing is not necessary and is not carried out.

- *There must be no inconsistencies between code measurements on both frequencies at any single epoch.* Code measurements on the L1 and L2 frequencies taken at a single epoch have to form a consistent set of observations.

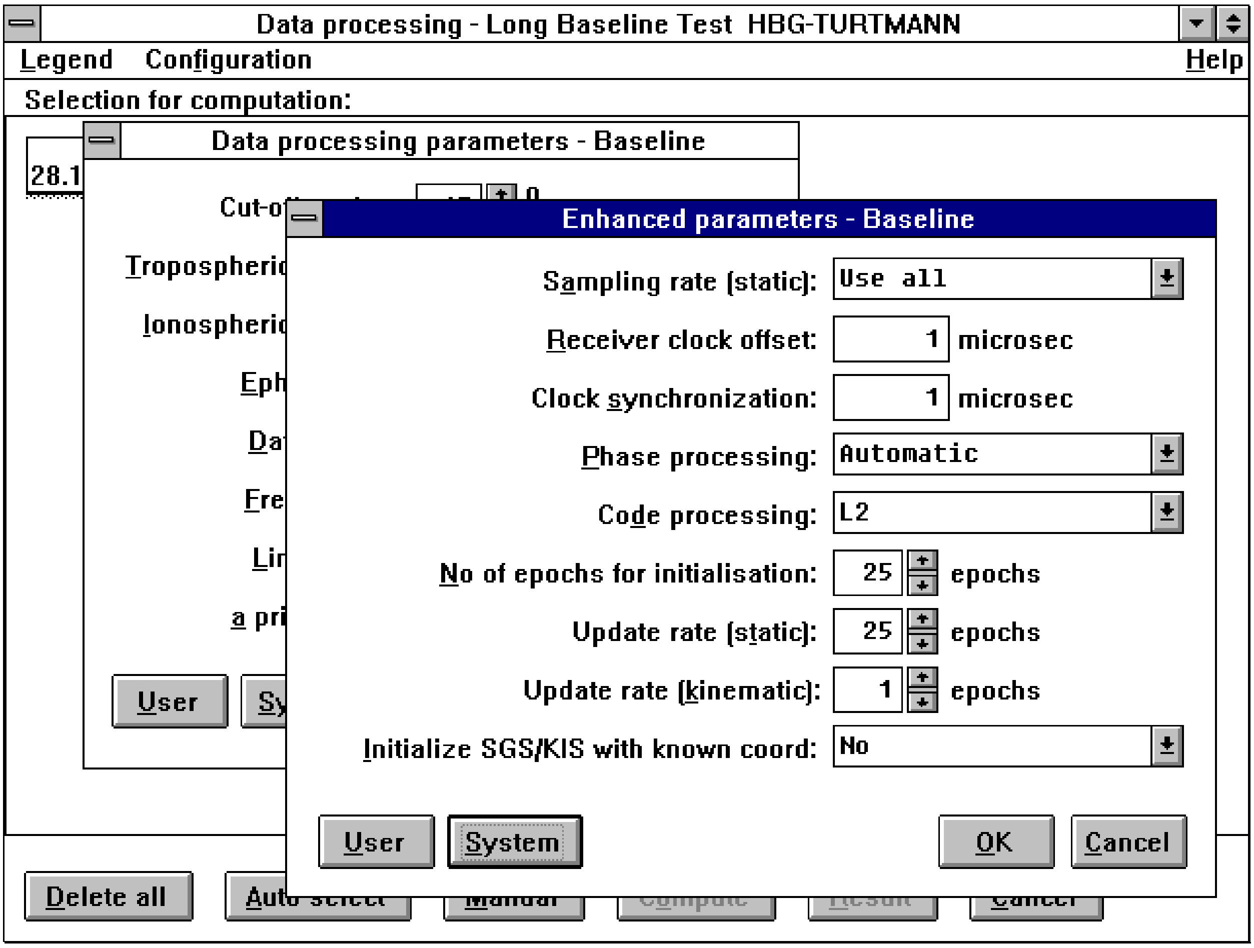
- *There must be no inconsistencies between code measurements from one epoch to the next.* All pseudorange measurements are a smooth function of time, thus there have to be no code biases in the data. Examples of the two "consistency characteristics" and their impact on computations will be given in a subsequent chapter.

Summary:

Data quality characteristics required for automated processing:-
- **Clock offset < 1 microsecond.**
- **Clock synchronization < 1 microsecond.**
- **No half-cycle slips.**
- **Code measurements on both frequencies at a single epoch have to be consistent.**
- **Code measurements at consecutive epochs have to be consistent.**

3.2 Enhanced processing parameters

Automated processing, i.e. processing using the recommended default processing parameters, is only possible if all required data quality characteristics are met. As many non-WILD receivers may not meet these specifications, users have to be able to modify one or more parameters in order to be able to process data from such receivers. This can be done using the "enhanced parameter" panel. This panel provides an advanced user with the possibility to intervene in data processing. Note, however, that it is the user's responsibility to check the results if any of the enhanced parameters have been changed.



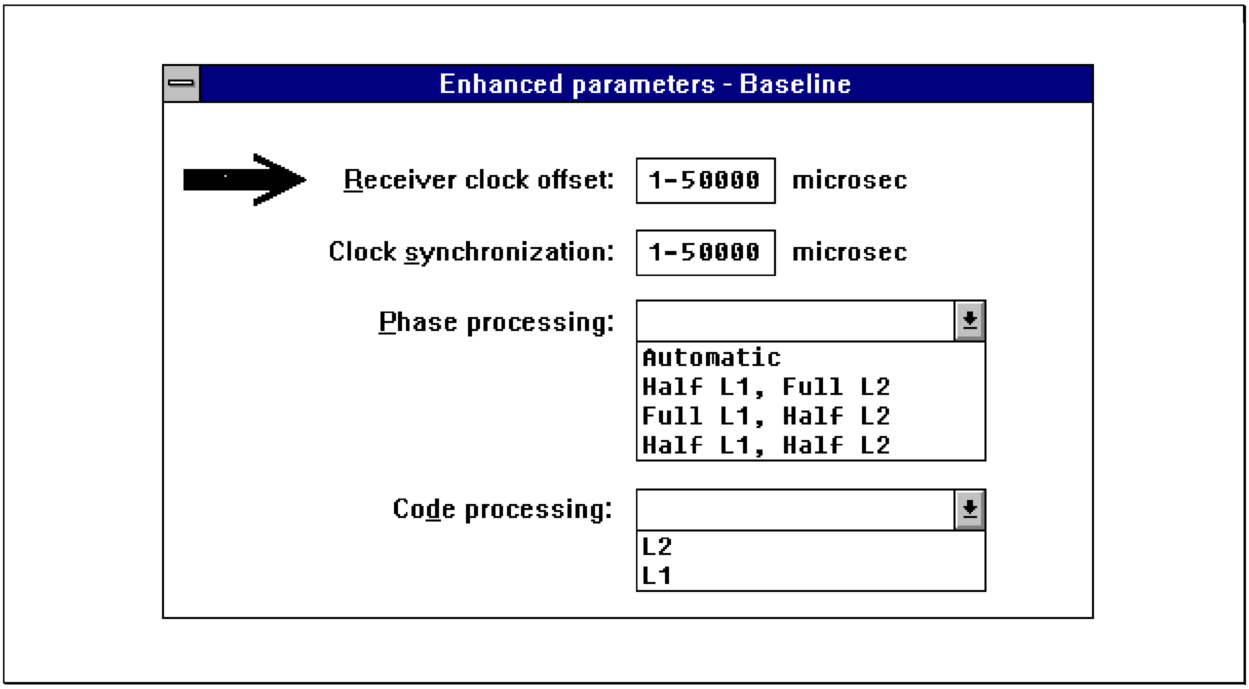
All parameters of interest will be explained in more detail in the following chapters.

3.3 Modifying the receiver clock offset parameter

The receiver clock offset is the difference between receiver time and GPS time. Although the quality of state-of-the-art receiver oscillators is extremely high, their stability is lower than those of the atomic clocks defining GPS time. Therefore there is always a difference between receiver time, to which the measurements are related, and GPS time, on which the satellite ephemeris information is based.

The WILD SR299 GPS Sensor computes a local clock offset, uses this offset to steer the receiver oscillator, and thus keeps the internal clock very close to GPS time (so-called time recovery). This guarantees that measurements with different SR299 receivers are taken simultaneously. This is especially important under Selective Availability ("SA"). Evaluations have shown, that a clock synchronization error of 1 microsecond may result in an error of up to 2 mm!

As the time recovery feature of the SR299 guarantees that all data taken with SR299 receivers will show a clock offset of only a few hundred nanoseconds, the receiver clock offset parameter in SKI is set by default to 1 microsecond. If a user wants to process data with a larger clock offset, the parameter has to be increased.



The clock offset parameter is a filter. It allows data with a clock offset value lower than the input parameter to be processed. Data with a higher value will be ignored. The clock offset information is taken from the RINEX file. If no information is available (e.g. RINEX 1 files), no check will be conducted.

It is important to note that the value of the clock offset parameter has no influence on the computation itself. SKI computes the clock offset for all epochs and corrects the measurements for the offset using a linear interpolation. But the higher the clock offset, the more errors are introduced because of short-term non-linear variations due to SA. In such a case, the user has to interpret the computation results carefully.

The following example shows the first few epochs of a RINEX file from a non-WILD receiver. The clock offset for every epoch is at the end of the epoch header (printed in bold letters for the readers convenience).

```
 92  9 16  9 30 60.0000000  0  5 17 28  3 21 23              .000797955
        -.48210  21405013.35500         -.32500  21405027.03600
        -.14610  21599734.54200         -.04900  21599744.59300
        -.61510  23592939.28000         -.02400  23592955.50900
        -.02310  23450499.36500         -.58800  23450508.96300
        -.70910  22043020.22400         -.15800  22043027.92000
 92  9 16  9 31 60.0000000  0  5 17 28  3 21 23              .000826994
   183377.87100  21439913.86100    142891.85100  21439922.60300
   -88326.88100  21582930.10400    -68826.03500  21582936.64800
   217843.86400  23634392.98800    169748.71500  23634409.58300
  -162308.86300  23419608.08200   -126474.85900  23419622.13000
   -48062.09000  22033871.84300    -37450.50900  22033882.36500
 92  9 16  9 32 60.0000000  0  5 17 28  3 21 23              .000858133
   371488.92900  21475704.88600    289471.86000  21475718.86300
  -172400.99500  21566926.91100   -134338.28800  21566937.73000
   439481.73200  23676574.47500    342453.35500  23676586.35800
  -320531.78600  23389499.00600   -249765.30300  23389513.22700
   -90761.00800  22025745.11900    -70722.32000  22025756.95100
 92  9 16  9 34   .0000000  0  5 17 28  3 21 23              .000891012
   563743.94100  21512290.40100    439280.90500  21512303.89000
  -252783.26000  21551634.48200   -196973.77900  21551641.49700
   664337.11800  23719360.00000    517665.13600  23719375.28700
  -475218.69700  23360061.74500   -370300.43700  23360077.25800
  -128656.74700  22018534.18300   -100251.39700  22018545.29900
 92  9 16  9 35   .0000000  0  5 17 28  3 21 23              .000925318
   759622.98100  21549565.84600    591913.87100  21549578.42800
  -329964.78500  21536943.63300   -257115.20300  21536954.05000
   891904.40300  23762666.25800         -.90100  23762680.32300
  -626847.99400  23331209.92100   -488453.00800  23331223.25300
  -162236.64000  22012141.78500   -126417.48200  22012155.08200
 92  9 16  9 36   .0000000  0  5 17 28  3 21 23              .000960815
   958728.87200  21587455.17300    747061.26800  21587467.38800
  -404315.25900  21522795.41500   -315050.60200  21522805.78000
        -.55410  23806408.82400          .00000          .00000
  -775777.88700  23302869.33700   -604502.17800  23302882.84300
  -191868.41900  22006506.13200   -149507.10800  22006516.32300
```

The clock offset in this example amounts to almost 0.001 seconds, that is 1000 microseconds.

Before importing data into SKI, the user should check the RINEX file carefully to determine the necessary value for the clock offset parameter. If the clock offset parameter has not been set properly, computation will be terminated, the ambiguity resolution indicator in the result panel will show a question mark ("?"), and the processing logfile will contain the following error message:-

```
BL_ER.1    ERROR MESSAGE
------------------------
No Common epochs!  Check clock offset and satellite selection.

BL_FC.1    FINAL  COORDINATES
-----------------------------
Rov:0009  Ref:0006   Amb: ?
```

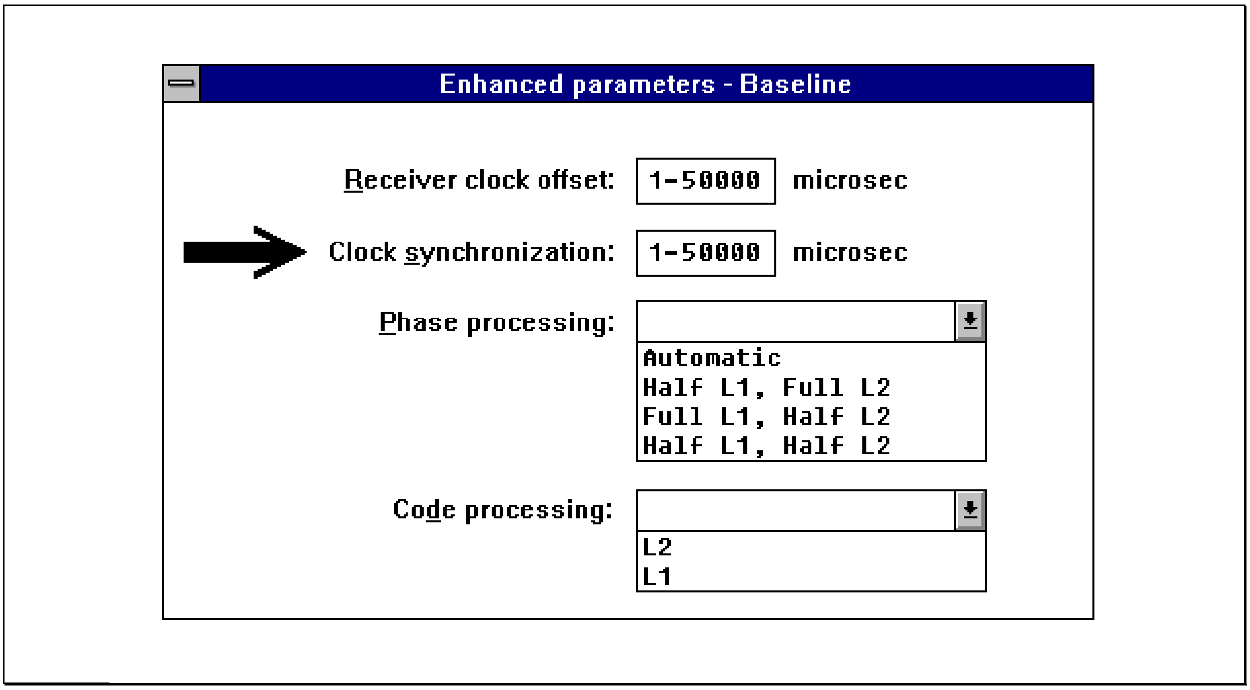
Summary:

The clock offset parameter is a filter. Data for which the receiver clock offset is higher than the value set in SKI will be ignored. The user has to be aware that a high receiver clock offset influences the observations used for baseline computation and therefore may affect the results.

3.4 Modifying the clock synchronization parameter

To compute a baseline, one needs common measurements taken at both ends of the baseline. If one receiver is operating with a recording rate of 30 seconds and the other one takes data at a 10 second rate, common epochs occur only every 30 seconds, and two third of all measurements taken at the one station cannot be used. The same applies to the synchronization of the receivers to each other. If one receiver takes measurements at exactly the full second, and the other receiver half a second later, the post processing software used for data evaluation will hardly find any common epochs.

The WILD SR299 GPS Sensor takes measurements at exactly the full second. Therefore measurements taken with several SR299 at the same time are always perfectly synchronized. Some other types of receivers shift their time tag - i.e. the epoch at which measurements are taken - slightly. If all receivers used in a campaign shift their measurement epochs in a similar way, the receivers will still be synchronized. Problems can occur if different receiver types have to be combined. The effect is exactly the same as with a high clock offset (see previous chapter). Due to short-term variations caused by Selective Availability the accuracy of the results may be degraded.



Clock offset and clock synchronization are in fact closely related. Measurements used for differential processing have to be synchronized. The easiest and most straight forward way to synchronize measurements is to keep the internal receiver clock close to GPS time, as is done in the WILD SR299.

A user should carefully inspect the RINEX files for both the reference and roving receiver to determine the clock synchronization offset. When evaluating data from certain non-WILD receivers, we have found that many receiver clocks drift slightly with time, i.e. the longer they are operating, the higher may become the synchronization offset between the receivers. An example of data from such a receiver can be found in the following RINEX file. The first and the last epochs of the site occupation are shown. The epochs (hours, minutes, seconds) are printed in bold letters.

```
92  9 16  9 36   .0000000  0  5 17 28  3 21 23           .000960815
    958728.87200  21587455.17300    747061.26800  21587467.38800
   -404315.25900  21522795.41500   -315050.60200  21522805.78000
         -.55410  23806408.82400          .00000          .00000
   -775777.88700  23302869.33700   -604502.17800  23302882.84300
   -191868.41900  22006506.13200   -149507.10800  22006516.32300
92  9 16  9 37   .0000000  0  6 17 28  3 21 23 11        .000997288
   1160754.20500  21625901.24800    904483.56000  21625911.21200
   -476113.30900  21509133.90100   -370997.11800  21509143.13200
    231927.59400  23850534.02000         -.04100  23850562.46400
   -922275.92500  23274990.97300   -718656.38500  23275004.95100
   -217829.71400  22001565.03300   -169736.62100  22001576.14900
         -.49710  24732049.46400          .00000          .00000
92  9 16  9 38   .0010000  0  6 17 28  3 21 23 11        .000034658
   1365484.43700  21664857.65500   1064013.55200  21664870.08000
   -545550.34100  21495920.91000   -425103.87700  21495929.63600
    465688.00500  23895022.44300          .00000          .00000
  -1066522.47100  23247544.80000   -831056.18200  23247555.75900
   -240308.63300  21997290.13100   -187252.60500  21997298.54200
    -98485.18600  24713322.67500         -.83900  24713333.09300
92  9 16  9 39   .0010000  0  6 17 28  3 21 23 11        .000072788
   1572743.17900  21704298.46300   1225513.81400  21704310.22400
   -612764.15000  21483130.32000   -477478.25200  21483139.41100
    701117.82600  23939825.19600          .00000          .00000
  -1208641.83700  23220500.85400   -941798.45000  23220510.74800
   -259443.79300  21993646.85700   -202163.06900  21993657.27500
   -195605.76200  24694840.27700    -75679.09000  24694851.37500

...
...
...

92  9 16 11 29   .0070000  0  5 15 28 21 23 11          .000913189
   -193525.05900  26493111.23300   -150799.09900  26493130.98700
   4871371.68800  22526728.18400   3795874.03100  22526735.82800
  -2749869.53400  22927211.24000  -2142748.92100  22927219.26700
  15284044.05900  24951474.27800  11909644.01000  24951486.47500
  -5136545.85700  23754606.28200  -3925756.41100  23754615.61800
92  9 16 11 30   .0070000  0  5 15 28 21 23 11          .000994978
   -256518.64000  26481133.09000   -199884.84300  26481143.28100
   5051659.12700  22561034.70200   3936357.72100  22561043.34000
  -2615006.44700  22952877.50900  -2037660.80400  22952882.88400
  15564281.31700  25004805.79000  12128010.62100  25004813.45100
  -5123813.79400  23757028.89500  -3915835.30600  23757038.40600
```

Within two hours of operation, the time tag was shifted by 0.007 seconds, i.e. 7 milliseconds. The reason is that the clock offset (i.e. the difference between oscillator and GPS time) increased continuously. As soon as the clock offset became higher than 1 millisecond, the time tag was shifted by the same amount. A user wanting to process this data with SKI, would have to set the clock offset parameter to 1'000 microseconds, and the clock synchronization parameter to 10'000 microseconds (assuming that the second receiver took measurements at exactly the full second).

It is our experience that processing of data showing a clock synchronization error of a few microseconds should not be a problem. The situation is completely different, however, if the clock does not drift continuously with time, but shows "irregular" jumps of tens and hundreds of microseconds. An example of such data is shown in the following RINEX file.

```
92  6 10  7 37 30.2400000  0  5 11 12 17 21 23           .000854700
125175408.99400  24057673.84600          .00000          .00000
109881746.83300  21217226.76400          .00000          .00000
120569301.76800  23200979.67900          .00000          .00000
108382650.64400  20883965.75100          .00000          .00000
107521815.48500  20716784.81200          .00000          .00000
92  6 10  7 38 15.0400000  0  5 11 12 17 21 23           .000854790
125183142.43000  24059147.36000          .00000          .00000
109918217.44400  21224168.39000          .00000          .00000
120730502.58900  23231653.56700          .00000          .00000
108302252.46800  20868665.05100          .00000          .00000
107545291.64000  20721248.17700          .00000          .00000
92  6 10  7 38 30.1440000  0  5 11 12 17 21 23           .000854836
125186062.47200  24059706.55200          .00000          .00000
109930866.73800  21226576.59000          .00000          .00000
120784946.50700  23242013.51700          .00000          .00000
108275321.18100  20863535.73400          .00000          .00000
107553404.45200  20722792.87000          .00000          .00000
92  6 10  7 38 45.2480000  0  5 11 12 17 21 23           .000854812
125189140.13700  24060291.11700          .00000          .00000
109943694.01900  21229015.99100          .00000          .00000
120839439.02300  23252385.40300          .00000          .00000
108248477.11600  20858431.56300          .00000          .00000
107561617.58100  20724354.78700          .00000          .00000
92  6 10  7 39   .0960000  0  5 11 12 17 21 23           .000854776
125192319.24800  24060889.18800          .00000          .00000
109956477.31200  21231445.27100          .00000          .00000
120893057.72600  23262588.44100          .00000          .00000
108222172.87000  20853423.78700          .00000          .00000
107569789.03200  20725911.25900          .00000          .00000
92  6 10  7 39 15.2000000  0  5 11 12 17 21 23           .000854799
125195709.24700  24061538.68500          .00000          .00000
109969657.24700  21233955.45000          .00000          .00000
120947653.58900  23272976.50300          .00000          .00000
108195500.45000  20848347.79700          .00000          .00000
107578197.72300  20727510.83300          .00000          .00000
```

Processing such data with SKI will only be possible if the second receiver shows the same clock behavior. Combining such a receiver with other receiver types is definitely not advisable and may lead to unpredictable results even if the clock synchronization parameter is set to its maximum value of 50 milliseconds.

Summary:

The clock synchronization parameter is a filter. If the clock synchronization error between two receivers (one at each end of the baseline) is higher than the value set in SKI, the data will be ignored. The user has to be aware that a high clock synchronization error may degrade the baseline accuracy. The user should be especially careful when combining different receiver types with different clock behavior in one baseline computation.

3.5 Modifying the phase processing parameter

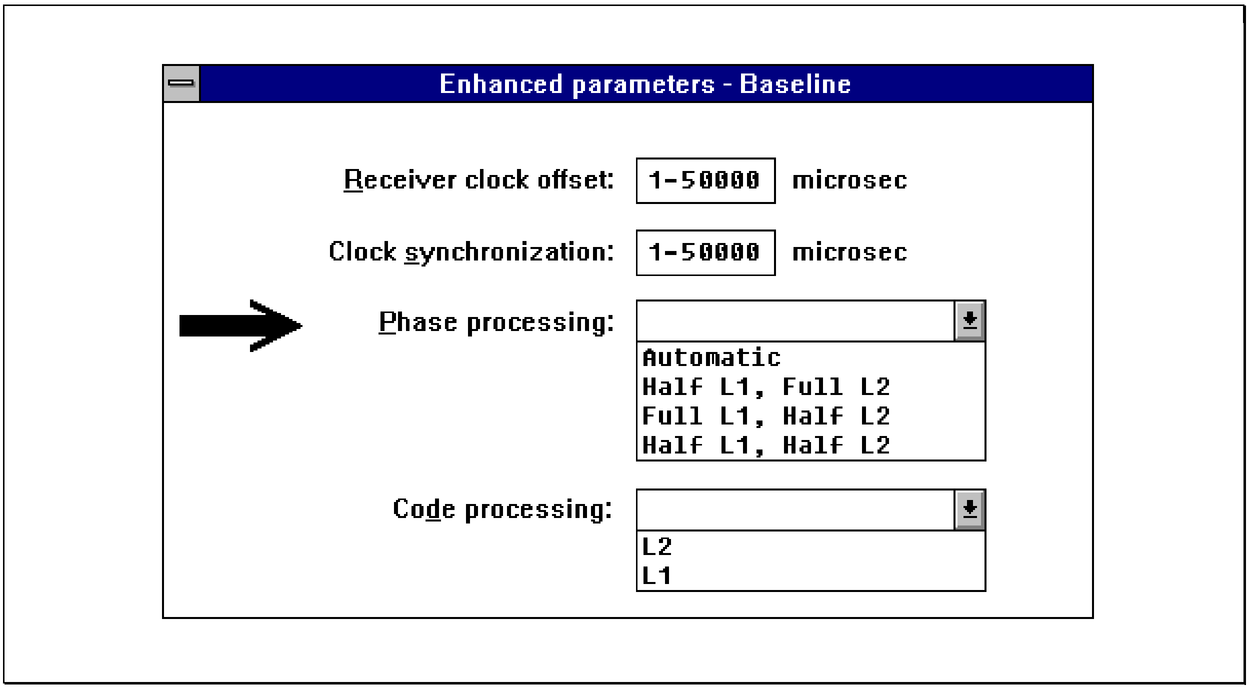
Cycle slips are jumps in the observations of an integer number of full carrier wavelengths. They may be caused either by the electronic components of a receiver or by signal obstructions. These integer jumps will be automatically detected and repaired by SKI during baseline processing. A report of all corrected cycle slips may be generated as part of the computation logfile.

Half-cycle slips, caused by electronic components in the tracking loops of the receiver, are automatically repaired by the WILD SR299 GPS Sensor. Thus half-cycle slips never occur in System 200 data. It is for this reason that SKI does not search for jumps of an integer number of half carrier wavelengths when processing data using the default processing parameters. However, there can be two cases when screening for half-cycle slips will be necessary:-

(1) The used receiver type does not detect or cannot repair all half-cycle slips. We have experienced problems of this nature especially with some handheld navigation receivers and OEM cards.

(2) The receiver tracked data using a squaring technique, but the wavelength factor in the header of the RINEX file indicated full wavelength data.

In both cases the user has to screen for half-cycle slips on L1 and/or L2. All possible combinations can be selected using the phase processing parameter in the enhanced parameter panel. If the default parameter "automatic" is selected, the software relies totally on the information given in the RINEX file. E.g. if the wavelength factor for L1 is give as full wavelength, and the factor for L2 as half wavelength, the processing mode "Full L1, Half L2" will be selected automatically.



How does a user know which processing mode has to be selected? The difficulty is that there is no indication in the RINEX file whether the data contains any half-cycle slips. The user should first process the data using the default parameter "automatic". The he should inspect the computation logfile to find the best possible phase processing mode for the data. The following example shows parts of a SKI data processing logfile. The data is from a navigation receiver combined with System 200 data.

```
BL_FS.1    FARA  STATISTICS
---------------------------

Ambiguities to be resolved :
-----SVid-----Ref SVid-----Carrier-----Wavelength factor---
      28         17         1               1
      21         17         1               1
      26         17         1               1


BL_CS.1    CYCLE  SLIP  INFORMATION
-----------------------------------

Total no of cycle slips : 11

      Time             time from    SV   freq        slip value  fraction
                      start (sec)   id                 (cycle)    (cycle)

  23.09.92 22:25:26          20     26     1            -1.0       0.476
  23.09.92 22:29:26         260     28     1            -1.0       0.471
  23.09.92 22:30:26         320     28     1             1.0      -0.468
  23.09.92 22:30:26         320     21     1             1.0      -0.452
  23.09.92 22:30:26         320     26     1             1.0      -0.465
  23.09.92 22:33:03         477     26     1            -1.0       0.471
  23.09.92 22:33:58         532     21     1            -1.0       0.463
  23.09.92 22:34:01         535     28     1            -1.0       0.497
  23.09.92 22:38:44         818     28     1             1.0      -0.470
  23.09.92 22:38:44         818     26     1             1.0      -0.487
  23.09.92 22:38:48         822     28     1            -1.0       0.387
```

The wavelength factor "1" under "FARA statistics" indicates that full wavelength processing mode was used. All detected cycle slips are listed under "cycle slip information". The column "fraction" lists the remaining fractional parts in cycles after detected cycle slips have been repaired. In theory a cycle slip is an integer number, hence the remaining part should be close to zero. In the example all values are close to 0.5, i.e. half of a cycle, which is a good indication that the data still contains non-detected half-cycle slips. A new computation run was started using the phase processing mode "Half L1, ..." (the L2 mode was of no interest as the navigation receiver was a single frequency unit). Compare the following logfile for this new computation with the previous one.

```
BL_FS.1    FARA  STATISTICS
---------------------------

Ambiguities to be resolved :
-----SVid-----Ref SVid-----Carrier-----Wavelength factor-----
      28          17          1                2
      21          17          1                2
      26          17          1                2


BL_CS.1    CYCLE  SLIP  INFORMATION
-----------------------------------

Total no of cycle slips : 11

      Time            time from    SV    freq        slip value  fraction
                     start (sec)   id                  (cycle)    (cycle)

  23.09.92 22:25:26          20    26      1            -1.0      -0.048
  23.09.92 22:29:26         260    28      1            -1.0      -0.059
  23.09.92 22:30:26         320    28      1             1.0       0.064
  23.09.92 22:30:26         320    21      1             1.0       0.096
  23.09.92 22:30:26         320    26      1             1.0       0.071
  23.09.92 22:33:03         477    26      1            -1.0      -0.060
  23.09.92 22:33:58         532    21      1            -1.0      -0.073
  23.09.92 22:34:01         535    28      1            -1.0      -0.006
  23.09.92 22:38:44         818    28      1             1.0       0.061
  23.09.92 22:38:44         818    26      1             1.0       0.026
  23.09.92 22:38:48         822    28      1            -1.0      -0.226
```

The wavelength factor "2" stands for half-cycle processing mode. The fractional parts after cycle slip repair are now close to zero. Due to this, the final root mean square of weight unit of the float solution decreased by about 20 %.

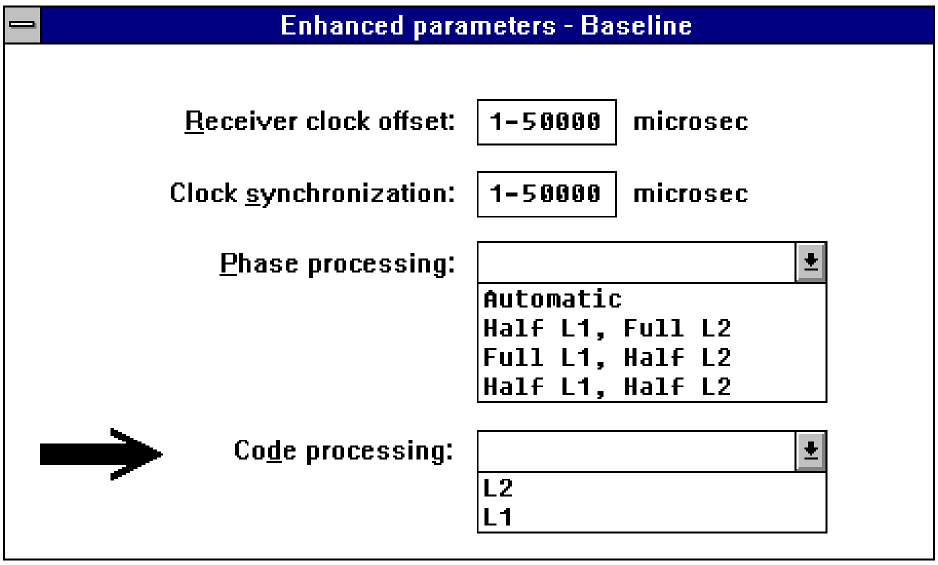
Summary:

The phase processing parameter allows the user to change the automatically selected phase processing mode, which depends on the wavelength information given in the RINEX file header. By changing this parameter it is possible to screen the data for half-cycle slips.

3.6 Modifying the code processing parameter

A unique feature of SKI is that its ambiguity resolution algorithm (Fast Ambiguity Resolution Approach - "FARA") are totally independent of any code measurements. Phase measurements on L1 and/or L2 are used in combination with sophisticated search algorithms to determine the best possible set of ambiguities. Single frequency code measurements are only used in a previous computation step to compute a better a priori position for the rover station and to calculate certain clock parameters.

As the P-code on the L2 frequency is more accurate than the C/A-code on L1, and as the WILD SR299 GPS Sensor provides code measurements on the L2 frequency even under Anti-Spoofing ("AS"), the default code processing mode in SKI is set to L2 code measurements. If no code measurements on the second frequency are available, SKI will automatically use the code data on L1. If necessary, a user can change the code processing mode. For example, he may wish to do this either because he knows that the code data on one frequency are of bad quality, or simply because he wants to check the influence of the code measurements on the result.



Summary:

The code processing parameter allows the user to change the automatically selected code processing mode, which depends on the available code measurements. Code measurements are not necessary for ambiguity resolution, but are used to determine an improved absolute a priori position for the roving site.

3.7 Processing single frequency data

The Fast Ambiguity Resolution Approach ("FARA") implemented in SKI shows full performance when processing dual frequency data. The Rapid Static technique is specially tailored for use with an L1+L2-receiver ,e.g. the WILD SR299 GPS Sensor. Nevertheless, SKI can process single frequency data. The appropriate processing parameters will be modified automatically for the computation.

The requirement for successful automatic processing is that the information given in the RINEX file header is correct and consistent with the subsequent data information. We have seen RINEX files where the header information indicated dual frequency data although the receiver was a single frequency unit. An example of such a RINEX file follows.

```
     2              OBSERVATION DATA                    RINEX VERSION / TYPE
N.N.                N.N.                10 07 1992      PGM / RUN BY / DATE
                                                        COMMENT
SITE A                                                  MARKER NAME
N.N.                N.N.                                OBSERVER / AGENCY
     1              N.N.                1               REC # / TYPE / VERS
     1              N.N.                                ANT # / TYPE
  4281519.6371   905621.0182  4625730.7536              APPROX POSITION XYZ
        2.8500         .0000         .0000              ANTENNA: DELTA H/E/N
     1     2     0                                      WAVELENGTH FACT L1/2
     4    L1    C1    L2    P2                          # / TYPES OF OBSERV
    60                                                  INTERVAL
  1992     9    16     7     1     .000000              TIME OF FIRST OBS
                                                        END OF HEADER
 92  9 16  7  1   .0000000  0  5  3 20 25 17 16             .000336685
         -.51110  20335509.33400         .00000          .00000
         -.80710  21693592.30000         .00000          .00000
         -.00610  21381472.75000         .00000          .00000
         -.66810  21695585.23700         .00000          .00000
         -.08210  24253170.62400         .00000          .00000
 92  9 16  7  2   .0000000  0  5  3 20 25 17 16             .000335403
     10390.88300  20337487.35100         .00000          .00000
    148200.72500  21721791.18900         .00000          .00000
     91063.77600  21398800.13600         .00000          .00000
   -175481.28800  21662194.69900         .00000          .00000
    -53834.26400  24242927.06700         .00000          .00000
```

There are two lines with wrong information in this RINEX header:-

(1) The value "2" in the second column of the line "wavelength factor" indicates half-cycle ambiguities on the L2 frequency. A "0" in this column indicating single frequency data would be correct.

(2) The line "# / types of observations" denotes four (4) different observation types: phase measurements on L1, C/A-code measurements on L1, phase measurements on L2, and P-code measurements on L2.

Both lines indicate dual frequency data, although the instrument was an L1-receiver. The missing data within the L2 data records are filled with zeros. This is in accordance with the RINEX format definition.

SKI attempts to process the data assuming the dual frequency processing parameters are correct. Processing is not possible of course. SKI uses the default code processing mode (L2), the computation will be terminated without a result. A question mark in the results panel refers to the following error message in the logfile.

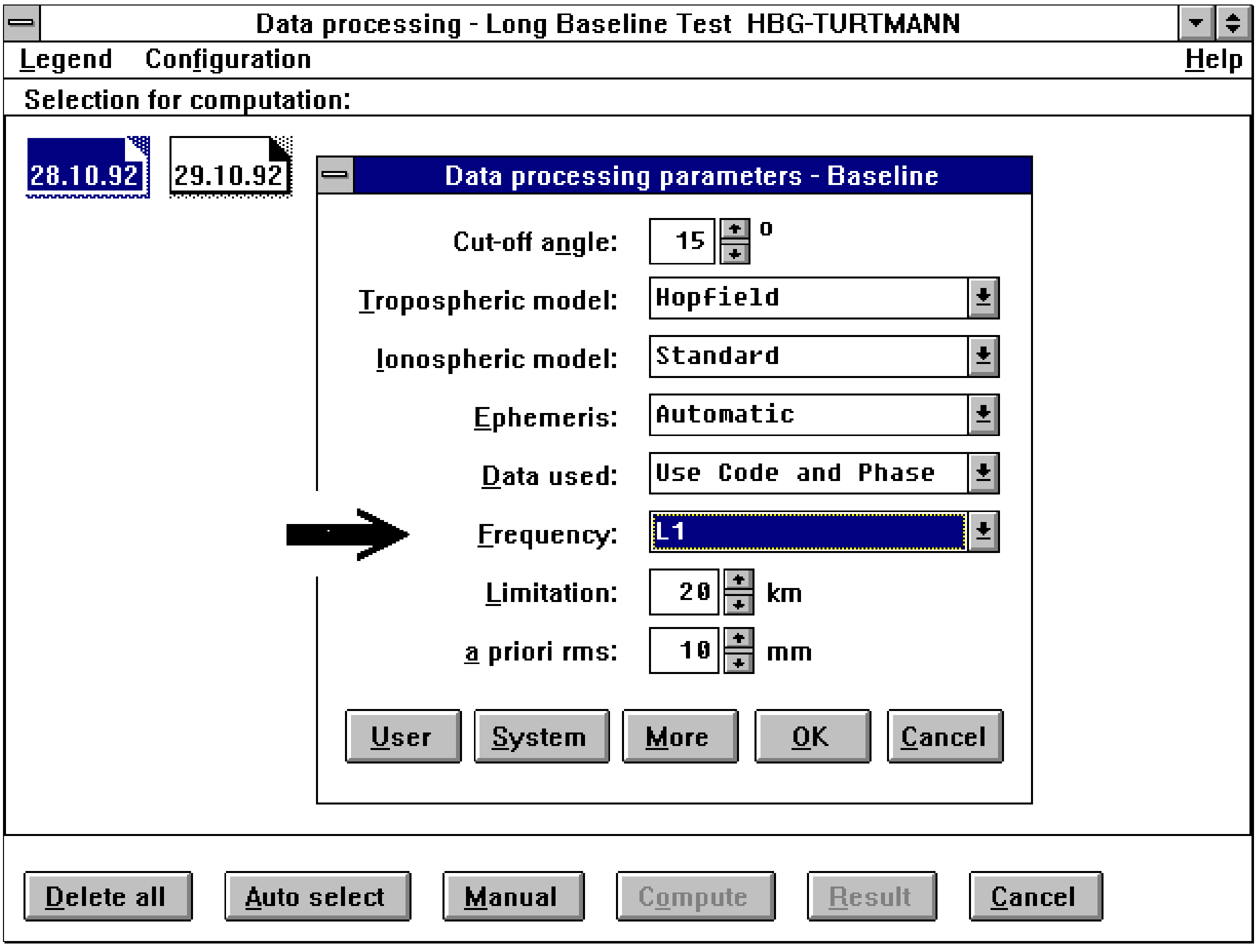
```
BL_ER.1    ERROR MESSAGE
------------------------

 ERROR OCCURRED IN MODULE XSSTCL
 ERROR NUMBER              6005
 ERROR MESSAGE  NOT ENOUGH OBSERVATIONS FOR CLOCK ESTIMATION RECEIVER 1
```

This error message indicates that not enough code observations are available to estimate the clock parameters for one receiver. The reason of course is that SKI was set for code on L2 while the receiver supplied code on L1 only. After changing the code processing parameter to L1 , computation was possible but the ambiguities still could not be resolved. The following information showed up in the logfile.

```
BL_FS.1    FARA  STATISTICS
---------------------------

Ambiguities to be resolved :
-----SVid-----Ref SVid-----Carrier-----Wavelength factor-----
      25          3          1                1
      20          3          1                1
      17          3          1                1
      16          3          1                1


-------  FARA  ------------------------------  Iteration :  1  --------

* Less than 4 common satellites on both frequencies ! *
* No attempt to resolve ambiguities undertaken *

* Ambiguity Search not successful *

-----------------------------------------------------------------------
* Ambiguity Resolution not successful *
-----------------------------------------------------------------------
```

Remember that the RINEX header indicated dual frequency data. Thus to start the ambiguity search process, at least four (4) common satellites have to be tracked on both frequencies, as dual frequency processing mode has been selected. However the L2 observation columns are filled with zeros, thus SKI cannot find any common measurements on the second frequency.

To overcome this problem, change the frequency processing parameter in the first parameter panel to L1-processing.



With this last change of parameters processing will be successful. To avoid problems of this nature the user should carefully inspect the RINEX files, especially the correctness of the wavelength factors and the observation types, before importing the data into SKI.

Summary:

SKI can process single frequency data. The processing parameters will be modified automatically provided the information in the header of the RINEX file is correct.

3.8 Modifying the observation interval

In this section we will consider two of the data quality characteristics required for automated processing of non-WILD data with SKI (see section 3.1):-

* Code measurements at consecutive epochs have to be consistent.
* Code measurements on both frequencies at a single epoch have to be consistent.

Both criteria are somewhat difficult to understand and may be best explained using examples of data which do not fulfill the consistency requirements. The first example shows data in which consecutive code measurements are inconsistent.

```
     2              OBSERVATION DATA                         RINEX VERSION / TYPE
ABCDEFGH                                  08-OCT-92 11:46  PGM / RUN BY / DATE
BASE                                                       MARKER NAME
N.N.                N.N.                                   OBSERVER / AGENCY
                    N.N.                                   REC # / TYPE / VERS
                                                           ANT # / TYPE
  1761065.3800 -4076611.4100  4562958.4300                 APPROX POSITION XYZ
        0.9893        0.0000        0.0000                 ANTENNA: DELTA H/E/N
     1     2                                               WAVELENGTH FACT L1/2
     3    L1    L2    C1                                   # / TYPES OF OBSERV
    15                                                     INTERVAL
  1992    10     8    13    33   15.000000                 TIME OF FIRST OBS
                                                           END OF HEADER
 92 10  8 13 33 15.0000000  0  4  2 12 13 14          0.000705630
     49090.723 8     38252.825 7  24335608.409
     -6336.596 6     -4937.662 5  26130975.202
    -18263.351 7    -14231.481 5  23857341.406
     11084.169 7      8637.285 6  24340408.086
 92 10  8 13 33 30.0000000  0  4  2 12 13 14          0.000709170
    100089.337 7     77991.965 7  24345306.695
    -12870.126 6    -10028.765 5  26129727.466
    -37297.656 7    -29063.391 5  23853724.110
     22639.553 7     17641.481 6  24342608.863
 92 10  8 13 33 45.0000000  0  4  2 12 13 14          0.000712640
     49343.863 7     38450.141 7  21956683.005
     -6239.648 6     -4862.322 5  23730156.255
    -18436.649 7    -14366.465 5  21451754.859
     11245.345 7      8762.703 7  21946475.971
 92 10  8 13 34  0.0000000  0  4  2 12 13 14          0.000716130
    100406.299 8     78239.010 7  21966401.077
    -12590.370 6     -9810.941 5  23728952.588
    -37506.489 7    -29226.075 5  21448126.471
     22965.765 7     17895.495 7  21948711.523
 92 10  8 13 34 15.0000000  0  5  2 12 13 14 24       0.000719490
    151534.534 8    118079.158 7  21976132.040
    -18818.994 6    -14664.371 5  23727757.016
    -56563.324 7    -44075.562 5  21444493.886
     34801.631 7     27118.242 6  21950962.965
    -39408.351 6    -30707.521 5  24439216.083
```

Compare the code measurements (third column) for each satellite. The measurements for satellite PRN 2 are shown in bold print. There is a large jump between the second and third epochs. From the third epoch onwards the code measurements are a smooth function of time. Inconsistencies between the code measurements on both frequencies at the same epoch together with a "consistency-jump" between epochs will be shown in the next example.

```
     1              OBSERVATION DATA                         RINEX VERSION / TYPE
```

```
N.N.                N.N                 28-OCT-92 11:42  PGM / RUN BY / DATE
ZIMM                                                     MARKER NAME
N.N.                N.N.                                 OBSERVER / AGENCY
    76              N.N.                                 REC # / TYPE / VERS
   535              MICROSTRIP                           ANT # / TYPE
  2987386.3800   923224.4200  5540593.1800               APPROX POSITION XYZ
        1.5520          .0000         .0000              ANTENNA: DELTA H/E/N
     1     1                                             WAVELENGTH FACT L1/2
     4    C1    L1    L2    P2                           # / TYPES OF OBSERV
    15                                                   INTERVAL
  1992    10    23     2    31   30.000000               TIME OF FIRST OBS

 92 10 28 14  1   .0000000  0  3 20 12 24
  23069649.794      397618.800 7    263214.257 6  26067593.351
  23441447.154   -22623360.644 5 -10852645.040 5  21043135.401
  24282273.592    21819895.835 6  12649819.041 7  23382916.844
 92 10 28 14  1 30.0000000  0  3 20 12 24
  20385482.064     1198474.779 9    903032.340 9  20385502.510
  26090631.652       -3431.126 7     -2673.393 6  23992103.273
  24278317.051      526174.982 9    410008.001 9  22179789.961
 92 10 28 14  2   .0000000  0  3 20 12 24
  20385178.375       -1450.469 9     -1129.854 9  20385194.593
  24014904.288       -1222.248 7      -952.229 6  24014921.826
  22180686.101        -849.179 9      -662.184 9  22180704.358
 92 10 28 14  2 30.0000000  0  3 20 12 24
  20384702.124       -3933.214 9     -3064.461 9  20384722.091
  24037493.859      117484.716 7     91546.693 6  24037510.198
  22181459.805        3195.314 9      2489.365 9  22181473.805
 92 10 28 14  3   .0000000  0  3 20 12 24
  20384095.344       -7149.560 9     -5570.698 9  20384109.914
  24059881.730      235141.943 7    183227.632 6  24059900.917
  22182102.260        6595.871 9      5139.152 9  22182120.907
```

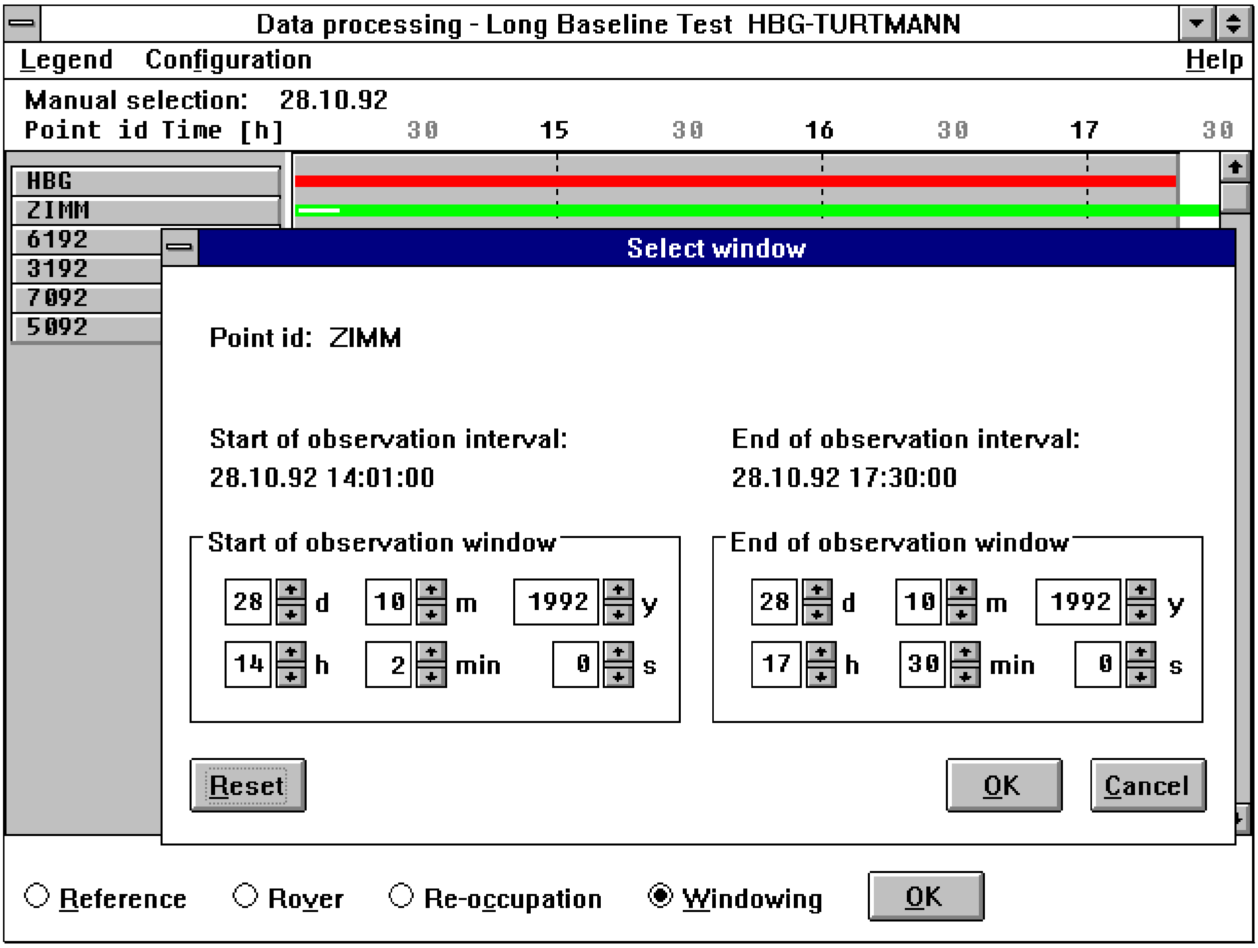
Compare the code measurements on the L1 frequency (first column) with the code measurements on L2 (fourth column). The measurements for satellite PRN 24 are in bold prints. For the first two epochs the pseudo range measurements on both frequencies are completely different. Only from the third epoch onwards that the code observations are consistent within the same epoch and also from epoch to epoch.

Such data inconsistencies are almost certainly due to the electronic components of the receiver. There can be various consequences if one attempts to process such data with SKI. In some cases we have found that computation is possible without any problems. In other cases SKI has terminated processing and has come up with one of the following error messages.

```
BL_ER.1    ERROR MESSAGE
------------------------

 ERROR OCCURRED IN MODULE XSMRKC
 ERROR NUMBER              5012
 ERROR MESSAGE     NUMBER OF MARKED OBSERVATIONS TOO BIG


 ERROR OCCURRED IN MODULE XSCLOB
 ERROR NUMBER              5013
 ERROR MESSAGE     NUMBER OF CYCLE SLIPS TOO BIG


 ERROR OCCURRED IN MODULE XSUPDT
```

```
ERROR NUMBER                6008
ERROR MESSAGE         QUALITY OF SOLUTION NOT ACCEPTED (TERMINATE PROCESSING)
```

The only way to avoid such error messages and to process this type of data successfully is to cut out the inconsistent observation epochs. This can be done either by editing the RINEX file manually before importing the data into a SKI project, or by using SKI's "Windowing" function.



In any case, a careful inspection of the RINEX file will help the user to detect any data inconsistencies and to eliminate data of insufficient quality.

Summary:

Inconsistent observation epochs should be eliminated before processing. This can be done by cutting the observation interval using the "Windowing" function of SKI. Inconsistent observation epochs are epochs with : (a) inconsistent code measurements between consecutive epochs, and/or (b) inconsistent code and phase measurements taken at the same epoch.

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