

# Kinematic

K I N E M A T I C   N A V I G A T I O N

## **PPro2 Static v2.21**

### ***User Guide***

Revision B

PPro2 Static is designed to process GPS code and phase observations given in RINEX-format. It is useful for obtaining meter, decimeter, centimeter, or even millimeter level accuracies. PPro2 is powered by the Wa1 baseline processing engine.

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## 1. Introduction

The baseline processing engine Wa1 processes the simultaneous code and carrier phase observations of pairs of GPS receivers in order to increase the relative positional accuracy. The observations must be given in RINEX-format with each file containing data of a single receiver deployed in static mode. The observation file names must conform to the RINEX conventions (STATDDD[S].YYo). The files may contain single frequency or dual-frequency observations.

In order to quickly process you may specify the RINEX observations files only:

Figure 1: Select Observation Files

In such a case it is assumed that all RINEX header information is correct, esp. the coordinates of the first station, which are used as reference coordinates, the antenna heights of both stations, and the antenna types and numbers if antenna phase center corrections are to be applied. The satellite ephemerides are expected to be stored in the current working directory or in the default Ephemeris directory in RINEX-format.

After processing has completed the results may be viewed and printed from the output tab:

Figure 2: View Processing Results

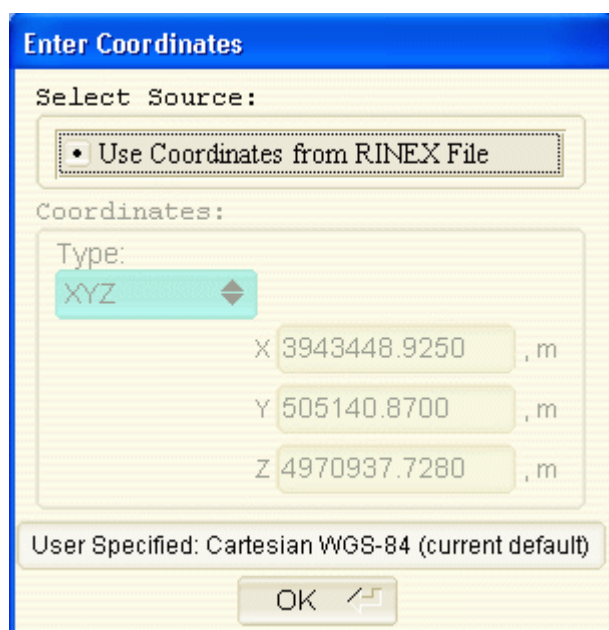
## 2. Basic Settings

To make effective use of the software one needs to be familiar with a few basic parameters.

### 2.1 Setting the Control Point Coordinates

Because we are processing the observations differentially, the resulting rover station coordinates can only ever be as good as the reference station coordinates. Thus, when absolute positional accuracy is required for the rover station one must make sure that the base station or control point coordinates are correct. When no control point is specified, the software automatically uses the approximate position information from the base RINEX observation file.

To specify the coordinates manually use the control point dialog:



The screenshot shows a dialog box titled "Enter Coordinates". It has a "Select Source:" section with a radio button selected for "Use Coordinates from RINEX File". Below this is a "Coordinates:" section with a "Type:" dropdown menu set to "XYZ". Three input fields are shown for X, Y, and Z coordinates, each followed by a unit indicator ", m". The X coordinate is 3943448.9250, Y is 505140.8700, and Z is 4970937.7280. At the bottom, there is a text box that says "User Specified: Cartesian WGS-84 (current default)" and two buttons: "OK" and a back arrow.

Figure 3: Enter Coordinates

When the source button is unselected one may manually specify the control point coordinates either as Cartesian coordinates, ellipsoidal coordinates or as UTM coordinates. When it is selected the coordinates from the base RINEX file will be used in processing.

## 2.2 Specifying the Processing Method

During processing the software will automatically detect and use the best processing method by looking at the quality of the data when the processing method is set to Best. One may however specify a specific solution type manually:

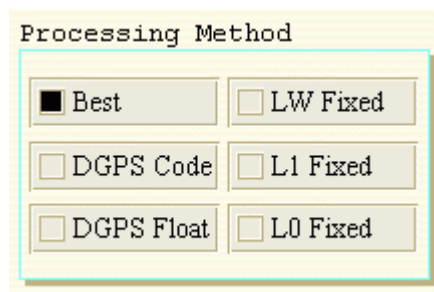


Figure 4: Specify Method

For a guideline of the appropriate method to use please consult the following table. Note that these figures assume the use of good equipment with geodetic antennas in low multipath conditions and at least seven visible satellites. This table is only a guide for selection of the appropriate processing method and not a reference to judge processing results.

Method	Description	Carrier Phase Ambiguities	Single / Dual Frequency	Observation Time	Baseline Length	Expected Accuracy
<b>DGPS Code</b>	Pseudorange	Not Used	Single / Dual	1 Second	100km	1 – 3 meter
<b>DGPS Float</b>	Carrier Phase	Float	Single / Dual	3 minutes	10 – 50km	20 – 50cm
<b>L1 Fixed</b>	Carrier Phase	Fixed	Single	15 minutes	10km	1cm
<b>L1 Fixed</b>	Carrier Phase	Fixed	Dual	5 minutes	10km	1cm
<b>LW Fixed</b>	Widelane Combination	Fixed	Dual	3 minutes	50km	5cm
<b>L0 Fixed</b>	Ionosphere-free Combination	Fixed	Dual	5 minutes	50km	3cm
<b>Best</b>	Best Solution	Fixed	Dual	5 minutes	50km	3cm

Table 1: Processing Methods

### 3. Improving Precision

In demanding applications one may take additional steps to ensure the highest possible precision is reached.

#### 3.1 Use of Precise Ephemerides

Under normal conditions the decorrelation of the broadcast orbits between receivers results in a positioning error of about 7mm per 10km of baseline length. This is due to the low 20m accuracy of broadcast orbital information. On baselines longer than about 40km it becomes necessary to make use of precise satellite orbit information if precision of better than about 2cm is desired. If precise ephemerides are to be used, the software searches for files with names in the form \*.sp3 in the directories containing the observation files, and eventually in an additional directory containing broadcast ephemeris. But even then *broadcast* ephemerides in RINEX-format must be made available in order to provide satellite clock parameters. The software's internal algorithms are not affected by the selected kind of ephemerides.

Wa1 supports SP3-format version A, in which most kinds of precise ephemerides are made available. Files in SP3-format version B can be processed without any difficulties as well. Version C is also supported, but it is still considered unstable when all the features of version C are used. For normal use it should work fine however. The latest description of the SP3-format is found on the internet:

<ftp://igscb.jpl.nasa.gov/igscb/data/format>.

There are several sources of precise ephemerides, but the most commonly used are the ones of the International GPS Service (IGS). Three kinds of precise ephemerides are produced by the IGS:

- **IGU** - ultra-rapid ephemerides, updated every 12 hours, on each day at 3 and at 15 UT, each file contains orbits of 48 hours, which cover the time from 27 hours before publication to 21 hours after publication, accuracy in the order of few 10s of centimetres.
- **IGR** - rapid ephemerides, publication 17 hours after the last measurement, 24 h data sets, accuracy in the order of several centimeters.
- **IGS** - final ephemerides, publication 12 days after the last measurements, 24 h data sets, accuracy in the order of a few centimeters.

A 24 h data set of the IGR or IGS-orbits contains satellite coordinates every 15 minutes. The first data sets refers to midnight 00:00 UT, whereas the last data sets refers to 23:45 UT. Satellite positions are determined by interpolation for the broadcast times of the satellite signals. Hence, for all observations after 23:45 UT precise ephemerides of two consecutive days must be present. If this is not the case, all observations after 23:45 UT are flagged unusable and thus they are lost for the data processing.

Precise ephemerides are available from:

<ftp://cddisa.gsfc.nasa.gov/pub/gps/products/> .

### 3.2 Application of Antenna Phase Center Corrections

When using different antenna types together during processing one may experience erroneous results due to the fact that the antennas will have different phase characteristics. Variations between different antennas may reach up to a few centimeters. The antenna phase center also changes with the received satellite's azimuth and elevation. When precision on the millimeter level is required the application of antenna phase center corrections also becomes important.

No antenna phase center (APC) corrections are applied by default. The correction is activated by providing a correction file name in antenna tab. Two different correction files can be used or the observations of either one of the antennas can be corrected. The correction files may contain corrections in ANTEX-format or NGS-format. The software searches for corrections of the specific antenna type and eventually of the individual antenna as identified by its serial number. Antenna type and antenna number are read from the RINEX-file headers. They can be altered in stations tab.

Different kinds of APC corrections are distinguished: phase center offsets (PCO, six values all together - north, east, and height, and for both frequencies), elevation dependent phase center variations (PCV) and elevation and azimuth dependent PCV. The format of the National Geodetic Service (NGS, Maryland, USA, <http://www.ngs.noaa.gov/ANTCAL/>), which is almost identical with the old IGS-format, supports PCO and elevation dependent PCV only. The ANTEX-format of the International GPS Service (IGS) supports all kinds of corrections, even antenna type specific corrections and also antenna individual corrections.

Link to the detailed description of the ANTEX-format (new IGS-format):

[ftp://igscb.jpl.nasa.gov/pub/station/general/pcv\\_proposed](ftp://igscb.jpl.nasa.gov/pub/station/general/pcv_proposed).

Example of APC corrections in NGS-format:

ANTENNA ID	DESCRIPTION										
	[north]	[ east]	[ up ]								L1 Offset (mm)
	[90]	[85]	[80]	[75]	[70]	[65]	[60]	[55]	[50]	[45]	L1 Phase at
	[40]	[35]	[30]	[25]	[20]	[15]	[10]	[ 5]	[ 0]		Elevation (mm)
	[north]	[ east]	[ up ]								L2 Offset (mm)
	[90]	[85]	[80]	[75]	[70]	[65]	[60]	[55]	[50]	[45]	L2 Phase at
	[40]	[35]	[30]	[25]	[20]	[15]	[10]	[ 5]	[ 0]		Elevation (mm)
TRM23903.00	1.2	.4	77.0								
	.0	4.8	9.3	13.1	16.4	18.8	20.5	21.5	21.7	21.3	
20.3	18.9	17.2	15.6	14.2	13.4	13.4	.0	.0			
	.5	4.0	75.6								
	.0	.1	.5	1.1	1.7	2.2	2.7	3.0	3.1	3.0	
	2.8	2.4	1.9	1.3	.8	.5	.4	.0	.0		
TRM22020.00+GP	-.1	-.6	74.2								
	.0	4.6	8.9	12.6	15.8	18.3	20.0	20.9	21.1	20.6	
19.5	18.1	16.3	14.5	13.0	12.0	11.8	.0	.0			
	-.5	2.8	70.5								
	.0	.3	1.0	1.9	2.8	3.6	4.3	4.8	5.1	5.0	
	4.7	4.1	3.3	2.4	1.4	.5	-.1	.0	.0		

The header lines can also be left out. They describe the file format and contents.

Each correction data set consists of 7 lines:

1st line: antenna type, 20 characters starting in column 1,  
2nd line: PCO (north, east, height) for L1 in mm,  
3rd line: elevation dependent PCV corrections for 90 to 45 degree in steps of 5 degree for L1 in mm  
4th line: elevation dependent PCV corrections for 40 to 0 degree in steps of 5 degree for L1 in mm  
5th line: PCO (north, east, height) for L2 in mm,  
6th line: elevation dependent PCV corrections for 90 to 45 degree in steps of 5 degree for L2 in mm  
7th line: elevation dependent PCV corrections for 40 to 0 degree in steps of 5 degree for L2 in mm.

Differences to the old IGS-format are limited to the antenna type information in the first line of each correction data set.

The selection of APC corrections must be performed with utmost care. Corrections of different antennas must fit together. Relative corrections must refer to the same reference antenna. If absolute corrections are used, all corrections must be absolute or they need to be transformed to absolute corrections first. The corrections must refer to the same antenna reference point as the antenna heights.

Sources of antenna type specific corrections:

in ANTEX-format: [ftp://igs.cb.jpl.nasa.gov/pub/station/general/pcv\\_proposed](ftp://igs.cb.jpl.nasa.gov/pub/station/general/pcv_proposed)

in NGS-format: <http://www.ngs.noaa.gov/ANTCAL/>.

## 4. Intermediate Options

### 4.1 Overriding Parameters in the Observation Files

Before processing one may specify alternative values for some parameters that are normally taken from the RINEX observation files. Specifying values in this way will not alter the original RINEX file in any way, but will affect the processing thereof. This function is mainly used to alter the antenna height used during processing as the correct value may not always be entered into the RINEX file during data collection. It also allows one to specify different antenna information to be used when applying antenna phase center corrections.

Parameter	Description
Short Name	First 4 Characters of Filename
Long Name	Unique Antenna Marker Number
Antenna Type	Antenna Type (Manufacturer / Model)
Antenna Number	Antenna Number
Antenna Height	Height of Bottom Surface of Bottom Surface of Antenna Above Marker in Meters

Table 2: Observation File Parameters

The data in each observation file may easily be retrieved by clicking on the “Read from RINEX” button. Unselecting a parameter will command the software to disregard the specified value and use the corresponding value from the RINEX file instead.

Base Station:		Rover Station:	
<input checked="" type="checkbox"/> Short Name	virt	<input checked="" type="checkbox"/> Short Name	harb
<input type="checkbox"/> Long Name		<input checked="" type="checkbox"/> Long Name	30302M009
<input checked="" type="checkbox"/> Antenna Type	0	<input checked="" type="checkbox"/> Antenna Type	0220136820
<input checked="" type="checkbox"/> Antenna Number	TRM29659.00	<input checked="" type="checkbox"/> Antenna Number	TRM29659.00
<input checked="" type="checkbox"/> Antenna Height	0.000000	<input checked="" type="checkbox"/> Antenna Height	3.052000
<input type="button" value="Read from RINEX File"/>		<input type="button" value="Read from RINEX File"/>	

Figure 5: Change Parameters

## 4.2 Satellite Options

### 4.2.1 Removing a Satellite from Processing

When experiencing problems with one or more particular satellite, that satellite may be eliminated from processing by selecting its PRN in the Remove Satellites box. For instance, one may remove satellite PRN number 5 as follows:

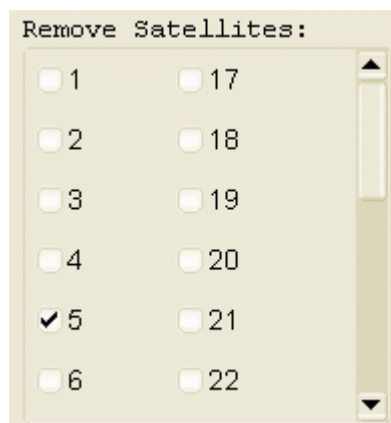


Figure 6: Remove Satellites

### 4.2.2 Adjusting the Elevation Mask

In conditions where less than four satellites are visible above the default elevation mask of 10 degrees, naturally one may lower the elevation mask to have more satellites available. This is not recommended as this will severely reduce the precision due to the significant atmospheric influence and multipath on GPS signals below about ten or eleven degrees elevation. When many satellites are visible one may even lift the elevation mask to about 14 degrees in order to minimize atmospheric and multipath effects.

### 4.2.3 Epoch Interval Decimation

When the observation files are huge due to closely spaced observations one may decimate the observations to a larger interval. If problems occur during processing of data with an interval of less than one second, try setting the decimation to 1 second. Also, when processing baseline longer than about 1000km with observations spanning many hours one may use a decimation setting of 30 seconds to counter processing problems. The default setting "0" specifies no decimation.

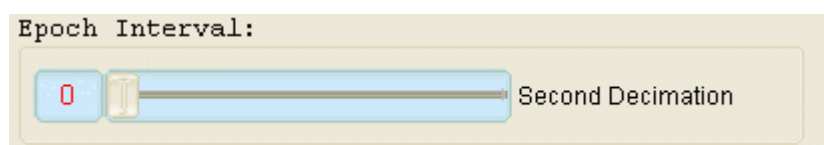


Figure 7: Epoch Decimation

## **4.3 Limiting Data**

### **4.3.1 Trimming Observation Data**

The start and end of observation data may be disregarded for processing. This is useful when one suspects that there may have been some antenna movement just after data collection started or just before it ended.

### **4.3.2 Restricting Processing**

When processing large observation files spanning perhaps several hours one may restrict the processing to a few minutes to verify that all settings are correct before processing the full dataset. This will save some time during adjustment of settings.

### **4.3.3 Specific Times**

Processing data can also be limited to start and stop at specific times. Please keep in mind that the time specified is GPS time. The offset between GPS time and UTC varies due to the insertion of leap seconds, and is always an integer value. As of August 2005 GPS time is ahead of UTC by thirteen (13) seconds. There may also be an offset of several hours between your time zone and UTC.

## **5. Advanced Options**

### **5.1 Short Baseline Limit**

This is the limit in kilometers between short and long baselines. At certain instances it may be useful to lower this value slightly. An example would be during traveling wave ionosphere disturbances, when the ionospheric decorrelation between receivers has a very steep gradient. Lowering this value would help the software in such a situation. Do note however, that this value is only applicable when processing dual frequency data.

## 6. Output Files

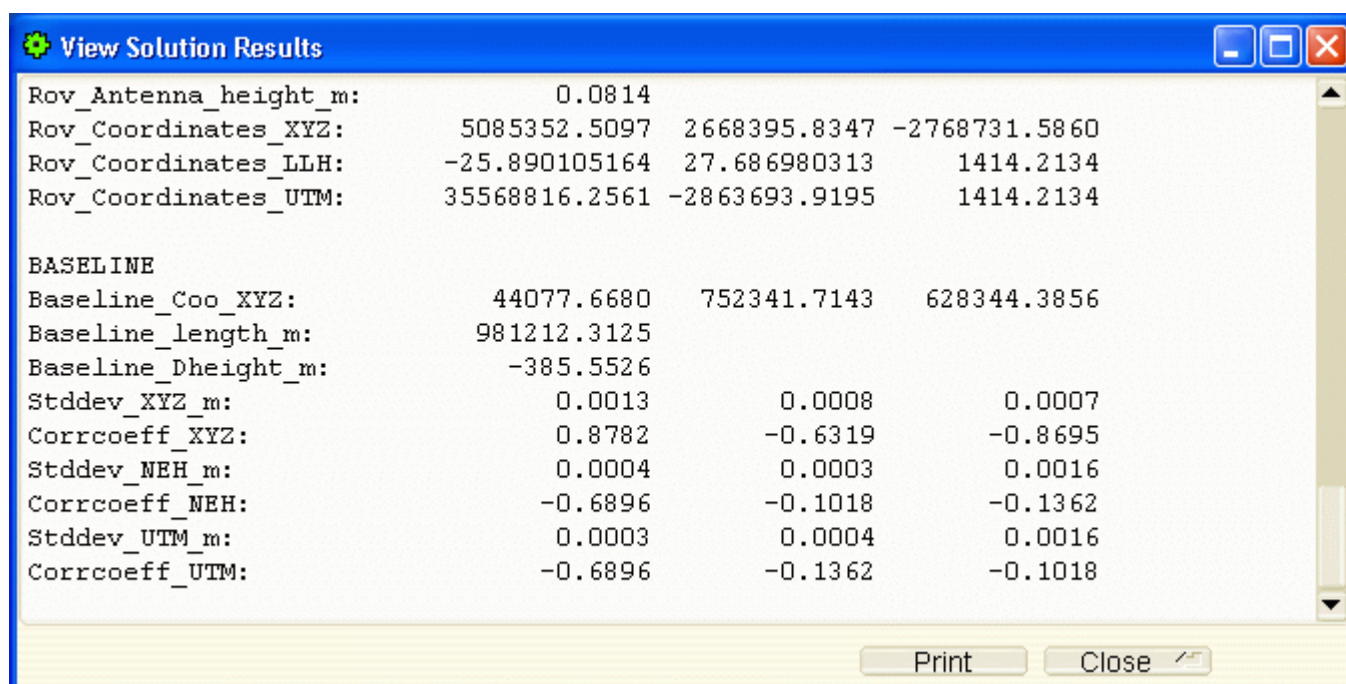
### 6.1 Solution File

At the end of each baseline processing a solution file is written. This file may be viewed through the viewer in the output tab. One may also print the solution file from the viewer. If the processing was terminated early because of an error the solution file contains an error message.

Each coordinate solution is accompanied by its solution type (*DGPS*, *DGPS Float*, *Fixed LW*, *Fixed L1*, *Fixed L0*) and by a solution quality indicator (low, medium, high). A solution quality of "high" is given only to those *Fixed L1* or ionosphere-free *Fixed L0* solutions, which fulfil certain requirements with respect to percentage of fixed ambiguity, standard deviation of unit weight, number of satellites, and PDOP. Solutions of type *Fixed LW* are always of "medium" quality. *Float DGPS* solutions may be either of "medium" or of "low" quality, mainly depending on the amount of observation data. The quality indicator of a *DGPS* solution is always set to "low".

The output coordinates of the reference station (first station) are taken from the header of its RINEX observation file or from the user's input. They are provided as Cartesian coordinates, ellipsoidal coordinates or as UTM coordinates. The reference station coordinates were kept fixed. Hence, no accuracy estimates exist.

The output coordinates of the rover station (second station) are the computed ones. They are provided as Cartesian coordinates, ellipsoidal coordinates or as UTM coordinates. Additionally, baseline coordinates in the form of Cartesian coordinate differences are written to the solution file. The standard deviations and correlation coefficients of the absolute rover coordinates are also valid for the coordinate differences of the baseline. Ellipsoidal coordinates in latitude, longitude and height [ $^{\circ}$ , $^{\circ}$ ,m] are accompanied by standard deviations and correlation coefficients: NEH [m]. These accuracy estimates are the same as the ones for the UTM coordinates, except that their order as been changed form north-east-height to east-north-height.

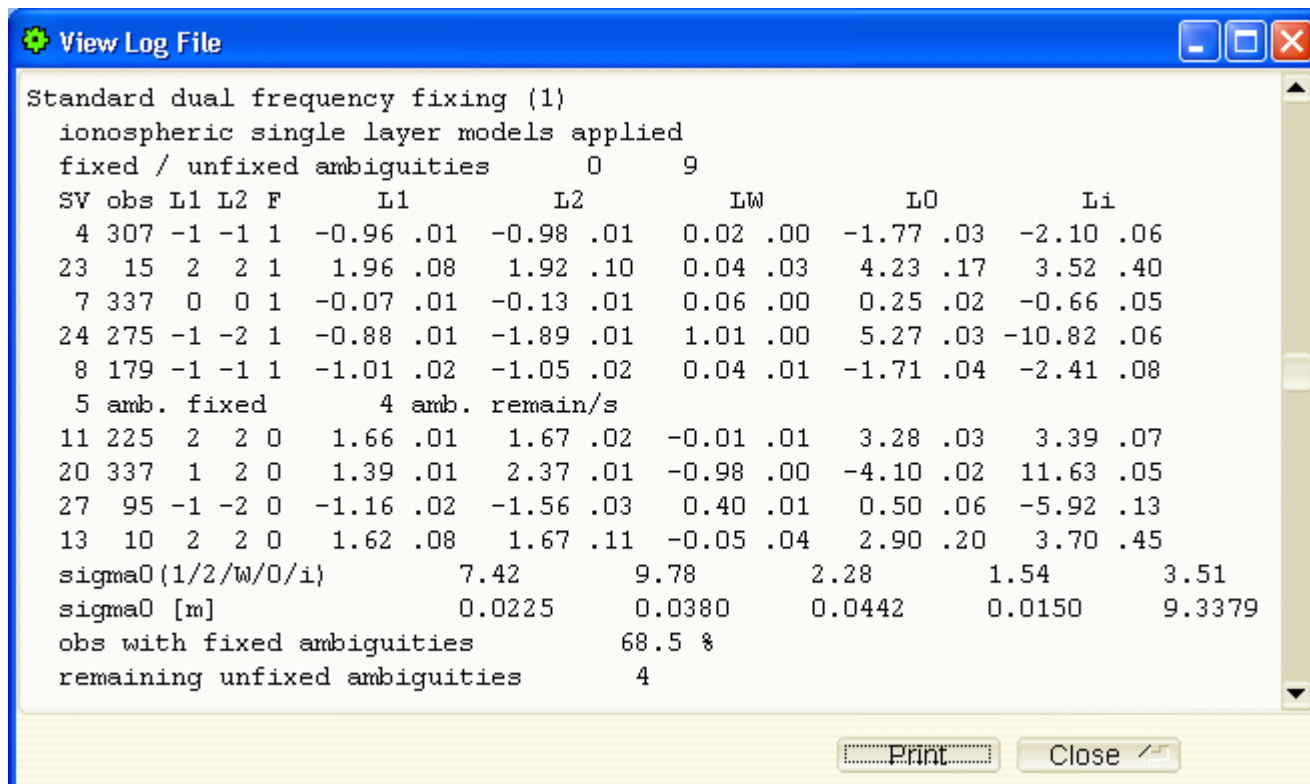


View Solution Results			
Rov_Antenna_height_m:	0.0814		
Rov_Coordinates_XYZ:	5085352.5097	2668395.8347	-2768731.5860
Rov_Coordinates_LLH:	-25.890105164	27.686980313	1414.2134
Rov_Coordinates_UTM:	35568816.2561	-2863693.9195	1414.2134
BASELINE			
Baseline_Coo_XYZ:	44077.6680	752341.7143	628344.3856
Baseline_length_m:	981212.3125		
Baseline_Dheight_m:	-385.5526		
Stddev_XYZ_m:	0.0013	0.0008	0.0007
Corrcoeff_XYZ:	0.8782	-0.6319	-0.8695
Stddev_NEH_m:	0.0004	0.0003	0.0016
Corrcoeff_NEH:	-0.6896	-0.1018	-0.1362
Stddev_UTM_m:	0.0003	0.0004	0.0016
Corrcoeff_UTM:	-0.6896	-0.1362	-0.1018

Figure 8: Solution Output

## 6.2 Log File

A log file is produced in addition to the solution file. Information about the settings used during processing and the presence of observations is available in the log file. An extensive log file is obtained by selecting detailed log level in the advanced tab. This enables output of information about the results from different processing methods, as well as ionosphere model information and cycle slip fixing. Information about the fixing of ambiguities is also recorded.



```

Standard dual frequency fixing (1)
ionospheric single layer models applied
fixed / unfixed ambiguities      0      9
SV obs L1 L2 F      L1      L2      LW      L0      Li
  4 307 -1 -1 1   -0.96 .01  -0.98 .01   0.02 .00  -1.77 .03  -2.10 .06
 23  15  2  2 1    1.96 .08   1.92 .10   0.04 .03   4.23 .17   3.52 .40
  7 337  0  0 1   -0.07 .01  -0.13 .01   0.06 .00   0.25 .02  -0.66 .05
 24 275 -1 -2 1   -0.88 .01  -1.89 .01   1.01 .00   5.27 .03 -10.82 .06
  8 179 -1 -1 1   -1.01 .02  -1.05 .02   0.04 .01  -1.71 .04  -2.41 .08
  5 amb. fixed      4 amb. remain/s
 11 225  2  2 0    1.66 .01   1.67 .02  -0.01 .01   3.28 .03   3.39 .07
 20 337  1  2 0    1.39 .01   2.37 .01  -0.98 .00  -4.10 .02  11.63 .05
 27  95 -1 -2 0   -1.16 .02  -1.56 .03   0.40 .01   0.50 .06  -5.92 .13
 13  10  2  2 0    1.62 .08   1.67 .11  -0.05 .04   2.90 .20   3.70 .45
sigma0(1/2/w/0/i)      7.42      9.78      2.28      1.54      3.51
sigma0 [m]              0.0225    0.0380    0.0442    0.0150    9.3379
obs with fixed ambiguities      68.5 %
remaining unfixed ambiguities      4
  
```

Figure 9: Log Output

## **7. Examples**

Please see the support section of our website for example files.

## 8. Evaluation Mode

Without a license file the software runs in evaluation mode. Evaluation mode allows the user to evaluate the software without the need for a license file. One can tell when this is the case by looking at the solution and log files:

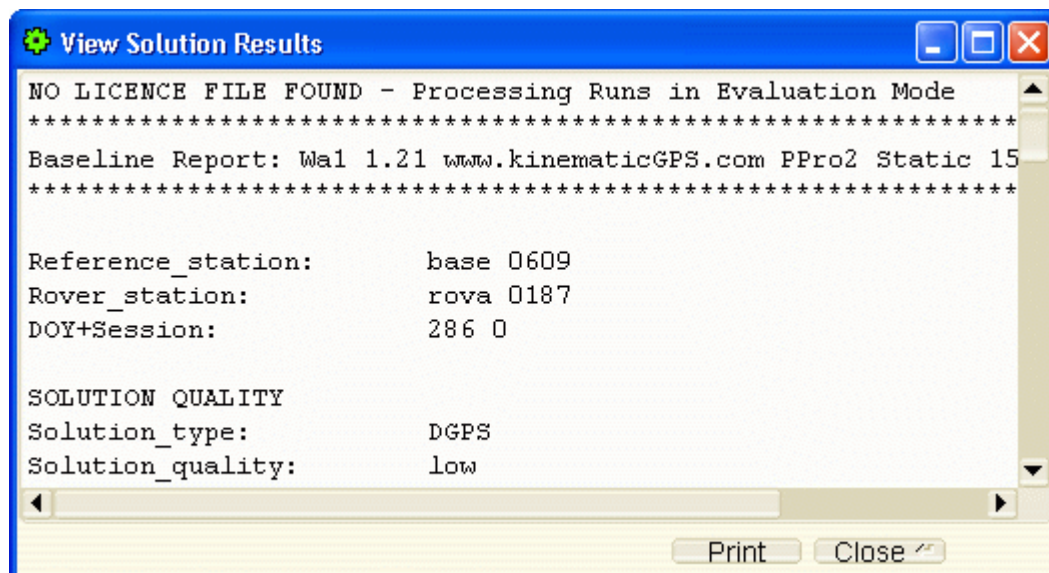


Figure 10: Evaluation Mode

In evaluation mode the software will allow processing in the following ways:

Date of observation files:	Processing methods available in evaluation mode:
Before 1 January 2005	Best, DGPS, DGPS Float, LW Fixed, L1 Fixed, L0 Fixed
After 1 January 2005	DGPS

Table 3: Valid Methods in Evaluation Mode

When processing observation data that were recorded after 1 January 2005, the software will automatically override any processing method selection that the user has made with the *DGPS* method. There are no limits to the amount of data that can be processed in evaluation mode and the software will never expire in evaluation mode.

## 9. Licences

In order to use the software fully with new observation data, a license file is required. A license file can be obtained by purchasing the software. For pricing information please see our website at [www.kinematicGPS.com](http://www.kinematicGPS.com). Each license number in the license file enables the software on a specific PC for a specific amount of time. The file name is `WASOFT.LIC` and it needs to be placed in the home directory of the software. One may view the file by using the license utility located in the help menu. In order to obtain a license file after you have purchased the software you are required to send a request with your PC's identification number to us. The identification number is available in the license utility by clicking on the *Request* button. Please email this number along with your contact details to [license@kinematicGPS.com](mailto:license@kinematicGPS.com). Within the next 24 hours you will receive a license file to enable your software for complete functionality.

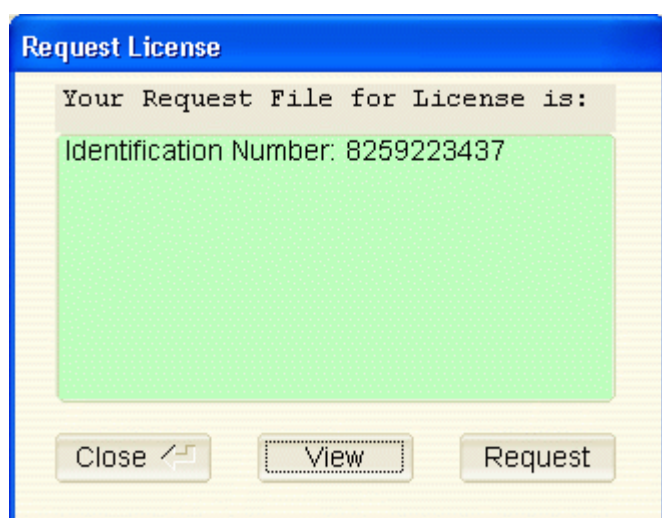


Figure 11: Identification Number

## 10. Error Messages

All error messages which indicate an early termination of the data processing consist of a 4-digit error code and a short error message. They are written to the solution file. Whenever the solution file contains an error message, the data processing has been terminated early and thus the processing is incomplete.

Two kinds of error messages exist. Error code numbers from 0001 to 4999 indicate errors which need to be solved by the software user. Error code numbers from 5000 to 9999 indicate problems in the software programming and usually they should not appear. The user will have difficulties to find out how to handle the second kind of errors. Please report them to Kinematic GPS.

Error messages with code numbers from 0001 to 4999:

```
0001 Could not open internal obs file
0002 Could not open extraction file
0003 At least one of the RINEX files does not exist or is invalid
0004 Identical observation file names
0005 Could not open observation file FILE
0006 No corresponding observations or no valid observations at all
0007 FILE: 1st station position seems not to be on the Earth's surface
0008 Error collecting broadcast ephemeris
0009 Error collecting precise ephemeris
0010 FILE: 2nd station position seems not to be on the Earth's surface
0011 Error allocating memory for iono model parameters
0101 Error reading WA.INI: unknown keywords or incorrect values, see Log-file
0201 Could not find "# / TYPES OF OBSERV" in FILE
0202 End of kinematic observations detected
0203 Epoch interval has a negative value: error in observation file FILE
0301 Absolute positioning of 2nd station failed
0401 No observation epochs at all
0501 Could not open APC-correction file FILE
0502 No APC-corrections for station X found: ANT-TYPE ANT-NUMBER
0701 No input file names in WA1.INI
0702 Error reading command line options, see Log-file
0801 Could not produce any valid baseline solution
0901 No valid SP3 file found
0902 SP3 files with different epoch intervals
3333 Wa1-licence expired
```

## Error messages with code numbers from 5000 to 9999:

9001 Could not open internal precise eph-file  
9002 Could not open internal iono model file  
9003 DGPS-computation failed  
9004 Cycle-slip detection failed  
9005 Cycle-slip fixing failed  
9006 Removal of singular ambiguities failed  
9007 Float/DGPS-computation failed  
9008 L1 search failed  
9009 L1 fixing failed  
9010 L1 solution failed  
9011 Widelane search failed  
9012 Widelane fixing failed  
9013 Widelane solution failed  
9014 Dual frequency search failed  
9015 L1 position update failed  
9016 Standard fixing failed  
9017 Position estimation failed  
9018 Long baseline fixing failed  
9019 Position estimation failed  
9020 Final solution failed  
9021 Final position update failed  
9022 Robust position update failed  
9101 Could not open internal eph-file  
9201 Could not find iono correction  
9301 B\_ESTI/MINV: matrix inversion failed at POS  
9401 B\_MODEPO: amb already fixed  
9402 B\_MODEPO: amb flag expected but not found  
9403 B\_MODEPO: amb already fixed  
9404 B\_MODEPO: unexpected amb flag found  
9405 B\_MODEPO: amb flag expected but not found  
9406 B\_MODEPO: amb already fixed  
9501 Could not open SP3 file FILE  
9502 Could not read SP3 file FILE  
9503 Could not open SP3 file FILE  
9504 Error reading internal precise ephemeris data  
9601 Error allocating memory for iono model processing  
9602 More unknowns than expected in iono modelling  
9701 Programming error calling PERMUT7  
9801 ROBUST: matrix inversion failed at POS

## **Appendix A: Overview of Algorithms and Models**

Wa1 processes static single-frequency or dual-frequency GPS-observations from short term or long term observation sessions. The applied corrections, algorithms and models are listed below. Wa1 automatically selects the appropriate algorithms and models based on baseline length, observation period, and intermediate results of the data processing.

### **Ephemerides**

Processing of *broadcast* ephemerides and precise ephemerides

### **Antenna Phase Centre Corrections**

Application of antenna phase centre corrections: NGS-format, ANTEX-format

### **Cycle-Slip Detection**

Code-carrier-comparison for non-differenced observations,

Single-frequency and multiple-frequency triple-difference method for baseline observations

### **Fixing of Cycle-Slips**

Triple-difference method for single-frequency and multiple-frequency observations

### **Ambiguity Resolution**

Fixing of single ambiguities of L1, widelane, and of multiple-frequency observations;

Search algorithms for L1, widelane, and for multiple-frequency observations;

Ionosphere-resistant ambiguity resolution for long baselines.

### **Ionospheric Model**

Estimation of a regional ionospheric model from non-differenced observations, two dimensional polynomials in latitude and local time, applicable to long baseline processing

### **Tropospheric Model**

Estimation of relative or absolute zenith delays, for baselines of medium length and long baselines, respectively

### **Coordinate Estimation**

Robust least-squares estimation