GPS System 500

General Guide to Static and Rapid-Static

Version 3.0
English

Leica Geosystems

Congratulations on your purchase of a new Leica System GPS500.

Contents

Introduction

Surveying with GPS has become popular due to the advantages of accuracy, speed, versatility and economy. The techniques employed are completely different however, from those of classical surveying.

Provided that certain basic rules are followed GPS surveying is relatively straightforward and will produce good results. From a practical point of view it is probably more important to understand the basic rules for planning, observing and computing GPS surveys rather than to have a detailed theoretical knowledge of the Global Positioning System.

This guide outlines how to carry out Static and Rapid Static GPS surveys and emphasizes those points to which particular care has to be paid.

Although this guide has been written specifically for Leica GPS - System 500 and System 300, much of the information is of a general nature and applicable to all GPS surveying. Further information may be found in the various guidelines contained in the System 500 or System 300 documentation material.

Baseline length

A GPS receiver measures the incoming phase of the satellite signals to millimeter precision. However, as the satellite signals propagate through space to earth they pass through and are affected by the atmosphere. The atmosphere consists of the ionosphere and the troposphere. Disturbances in the atmosphere cause a degradation in the accuracy of observations.

GPS surveying is a differential method. A baseline is observed and computed between two receivers. When the two receivers observe the same set of satellites simultaneously, most of the atmospheric effects cancel out. The shorter the baseline is the more these effects will be reduced, as the more likely it is that the atmosphere through which the signals pass to the two receivers will be identical.

Rapid Static surveys feature short observation times. It is particularly important for Rapid Static that ionospheric disturbances are more or less identical for both sites.

Thus, for all GPS surveying, and for Rapid Static in particular, it is sound practice to minimize baseline lengths.

Temporary reference stations for Rapid Static surveys

As observation time and accuracy are mainly a function of baseline length, it is highly recommended that baseline lengths should be kept to a minimum.

Depending on the area and number of points to be surveyed by GPS, you should consider establishing one or more temporary reference stations.

Baselines radiating from a temporary reference station can be several kilometers in length. Remember, however, that it is advantageous to minimize baseline lengths. The table on page 16 provides a guide to baseline lengths and observation times.

In terms of productivity and accuracy, it is much more advantageous to measure short baselines (e.g. 5km) from several temporary reference stations rather than trying to measure long baselines (e.g. 15 km) from one central point.

Check the newly surveyed points

In all types of survey work it is sound practice to cross check using independent measurements. In classical survey you check for inaccurate or wrong control points, wrong instrument orientation, incorrect instrument and target heights, etc. You close traverses and level loops, you fix points twice, you measure check distances! Depending on the job and accuracy needed it is well worthwhile applying the same principles to GPS surveying.

One should be particularly careful with Rapid Static with short observation times. If the observation time is too short, or the satellite geometry (GDOP) is poor, or the ionospheric disturbances are very severe, it can happen that the post-processing software will resolve ambiguities but the results may exceed the quoted specifications.

Depending on the accuracy required, the user should be prepared to check newly surveyed points. This is particularly important if observation times have been cut to a minimum and recommendations regarding GDOP ignored.

For a completely independent check:

- Occupy a point a second time in a different window. This ensures that the set-up, the satellite constellation, and the atmospheric conditions are different.
- Close a traverse loop with a baseline from the last point to the starting point.
- Measure independent baselines between points in networks.

A partial check can be obtained by using two reference stations instead of one. You will then have two fixes for each point but each will be based on the same roving-receiver observations and set-up.

Generally speaking, the longer the baseline the longer one has to observe.

The ionosphere is activated by solar radiation. Thus ionospheric disturbance is much more severe by day than by night. As a result, the baseline range for night observations with Rapid Static can be roughly double that of day observations. Or, put another way, observation times for a baseline can often be halved at night.

At the present time ionospheric activity is increasing in an 11-year cycle.

The table on page 16 provides a guide to baseline lengths and observation times under the current ionospheric conditions.

For baselines up to about 20 km, you will usually attempt to resolve the ambiguities using the Rapid Static algorithm in the SKI-Pro post-processing software.

Under favourable conditions it is possible to resolve ambiguities also on baselines longer than 20 km.

For baselines longer than 80 km, it is usually not advisable to resolve ambiguities. In this case a different post-processing algorithm is used in SKI-Pro. This algorithm eliminates ionospheric influences to a large degree but destroys the integer nature of the ambiguities. Sufficient observation time is needed to meet the accuracy specifications.

Observation schedule - best times to observe

When you inspect the satellite summary and GDOP plots, you will usually see several good windows (see page 14) distributed through a 24 hour period. You should try to work with Rapid Static during good windows, and plan your schedule carefully.

It is impossible to plan GPS observations to the minute. Rather than trying to squeeze the maximum number of points into a window by cutting observation times to the bare minimum, it is usually better to measure one point less and to observe for a few minutes longer. Particularly for high-accuracy work, it pays to be conservative and not to risk poor results.

Consider the transformation to local coordinates

System 500 and System 300 provide accurate relative positions of points that are observed in a GPS network and linked in post-processing. The coordinates are based on the WGS 84 datum.

For most projects it will be necessary to transform the WGS 84 coordinates obtained from GPS survey into local grid coordinates, i.e. into grid coordinates on the local projection based on the local ellipsoid.

In order to be able to compute this transformation, known points with local coordinates have to be included in the GPS network. These common points, with WGS 84 and local coordinates, are used to determine the transformation parameters and to check the consistency of the local system.

The common points should be spread evenly throughout the project area. For a correct computation of all transformation parameters (shifts, rotations, scale), at least three - but preferably four or more - points have to be used.

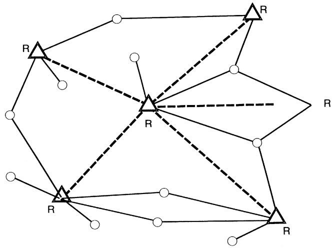
Read the Online Help on Datum/Map for details on calculating transformations in SKI-Pro.

Overall Planning

- ✓ Plan the campaign carefully
- ✓ Consider the job, number of points, accuracy needed
- ✓ Consider connection to existing control
- ✓ Consider the transformation to local coordinates
- ✓ Consider the best ways to observe and compute
- ✓ For high accuracy, keep baselines as short as possible
- ✓ Use temporary reference stations
  - Consider the need for independent checks:
  - Occupying points twice in different windows
  - Closing traverse loops
- ✓ Measuring independent baselines between points
- ✓ Consider using two reference stations
- ✓ Use good windows
- ✓ Consider observing long lines at night
- ✓ For high-accuracy work, try not to squeeze the maximum number of points into a window

Temporary Reference Stations

In terms of productivity and accuracy, it is usually preferable to measure short baselines from several temporary reference stations rather than trying to measure long baselines from just one central point.



R-Temporary Reference Site

Example:

Establish 6 temporary reference stations using Static or Rapid Static.

- Check network of temporary reference stations using double fixes or independent baselines.
- Fix new points from temporary reference stations using Rapid-Static radial baselines.
- Consider the need to check critical points.

GDOP - Geometric Dilution of Precision

The GDOP value helps you to judge the geometry of the satellite constellation. A low GDOP indicates good geometry. A high GDOP tells you that the satellite constellation is poor. The better (lower) the GDOP the more likely it is that you will achieve good results.

Poor satellite geometry can be compared with the "danger circle" in a classical resection. If the geometry is poor, the solution in post-processing will be weak.

For Rapid Static you should observe when the GDOP is less than or equal to 8. A GDOP of 5 or lower is ideal.

Selecting good windows for successful GPS surveying

For successful, high-accuracy GPS surveying it is advisable to take the observations in good windows. Provided that you know the latitude and longitude to about 1°, the satellite summary, GDOP, elevation, and sky-plot panels in the Survey Design component of SKI-Pro will help you to select good windows in which to observe.

You should take particular care when selecting windows for Rapid Static observations.

A suitable observation window for Rapid Static must have four or more satellites, with GDOP < or = 8, above a cut-off angle of 15° at both the reference and roving receiver.

Poor windows should only be used to bridge between two or more good windows when observing for long periods of time, e.g. at reference stations and for long lines.

If there are obstructions near a point, use the sky plot to find out if the signals from a satellite could be blocked. This could cause the GDOP to deteriorate. Check the GDOP by clicking the satellite "off" in the Satellite Availability component. A careful reconnaissance of such sites is well worthwhile.

Selecting Good Windows

Window for Rapid Static:

- ✓ 4 or more satellites above 15° cut-off angle.
- ✓ GDOP < or = 8.

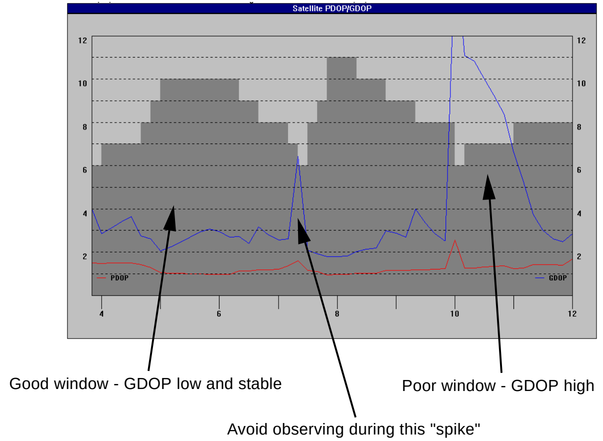
Whenever possible:

- ✓ 5 or more satellites.
- ✓ GDOP < or = 5.
- ✓ Satellites above 20°.

Always:

- ✓ Use sky plot to check for obstructions.
- ✓ Recompute GDOP if a satellite is obstructed.
- ✓ Be wary if 2 out of 4 or 5 satellites are low (<20°).

Example:



Observation times and baseline lengths

The observation time required for an accurate result in post-processing depends on several factors: baseline length, number of satellites, satellite geometry (GDOP), ionosphere.

As you will only take Rapid Static observations when there are four or more satellites with GDOP < 8, the required observation time is mainly a function of the baseline length and ionospheric disturbance.

Ionospheric disturbance varies with time and position on the earth's surface. As ionospheric disturbance is much lower at night, night-observation times for Rapid Static can often be halved, or the baseline range doubled. Thus it can be advantageous to measure baselines from about 20 km to 30 km at night.

Unless one is extremely restrictive, it is impossible to quote observation times that can be fully guaranteed. The following table provides a guide. It is based on tests in mid-latitudes under the current levels of ionospheric disturbance with a dual frequency Sensor.

Ionospheric activity is currently increasing to a high level in an 11-year cycle. As the activity increases it can be expected that observation times have to be increased or baseline lengths reduced. Ionospheric activity is also a function of position on the earth's surface. The influence is usually less in mid latitudes than in polar and equatorial regions.

Note that signals from low-elevation satellites are more affected by atmospheric disturbance than those from high satellites. For Rapid Static observations, it can be worth increasing the observation times if two out of four or five satellites are low (say < 20°).

Times and Baseline Lengths

Observation time depends upon:

- Baseline length
- Number of satellites
- Satellite geometry (GDOP)
- Ionosphere
  Ionospheric disturbance varies with time, day/night, month, year, position on earth's surface.

The table provides an approximate guide to baseline lengths and observation times for mid latitudes under the current levels of ionospheric activity when using a dual frequency Sensor.

Obs. Method	**No. sats. GDOP <= 8**	**Baseline Length**	**Approximate observation time**	
			By day	*By night*
Rapid Static	4 or more 4 or more 5 or more	Up to 5 km 5 to 10 km 10 to 15 km	5 to 10 mins 10 to 20 mins Over 20 mins	5 min 5 to 10 mins 5 to 20 mins
Static	4 or more 4 or more	15 to 30 km Over 30 km	1 to 2 hours 2 to 3 hours	1 hour 2 hours

Reference site

GPS surveying is a differential technique with baselines being "observed" and computed from the reference to the rover. As many baselines will often be measured from the same reference station, the choice and reliability of reference stations are of particular importance.

Sites for reference stations should be chosen for their suitability for GPS observations. A good site should have the following characteristics:

- No obstructions above the 15° cut-off angle.
- No reflecting surfaces that could cause multipath.
- Safe, away from traffic and passers-by. Possible to leave the receiver unattended.
- No powerful transmitters (radio, TV antennas, etc.) in the vicinity.

The results for all roving points will depend on the performance of the reference receiver! Thus the reference receiver must operate reliably:

- Power supply must be ensured. Use a fully-charged battery. Consider connecting two batteries. When possible, consider a transformer connected to the mains.
- Check that there is ample capacity left in the memory device for storing all observations.
- Double-check the antenna height and offset.
- Make sure that the configuration parameters (observation type, recording rate etc.) are correctly set and match those of the roving receiver.

☞ Note that the reference receiver does not have to be set up on a known point. It is far better to establish temporary reference stations at sites that fulfill the requirements listed above than to set up the reference receiver on known points that are not suitable for GPS observations.

For computing the transformation from WGS 84 to the local system, known points with local coordinates have to be included in the GPS network. These points do not have to be used as reference stations. They can be measured with the roving receiver.

The computation of a baseline in GPS-processing requires that the coordinates of one point (reference) are held fixed. The coordinates of the other point (rover) are computed relative to the "fixed" point.

In order to avoid that the results are influenced by systematic errors, the coordinates for the "fixed" point have to be known to within about 20 meters in the WGS 84 coordinate system. Whenever possible, the WGS 84 coordinates for the "fixed" point should be known to within about 10 meters otherwise scale errors of about 1 to 2 ppm will be introduced.

This means that for any precise GPS survey the absolute coordinates of one site in the network have to be known in WGS 84 to about 10 meters. WGS 84 coordinates for one site will often be available or can be easily derived as explained on page 23.

If WGS 84 coordinates for one site are not known or cannot be derived, the Single Point Position computation in SKI-Pro can be used. Remember, however, that Selective Availability (SA) may be switched on. The only way to overcome SA is to observe for sufficient time for the effects of SA to be averaged out in the Single Point Position computation.

The reference receiver will usually observe for several hours as the rover moves from point to point. In such a case, the Single Point Positi-on for the reference receiver computed in SKI-Pro should be relatively free from the effects of SA. If a Single Point Position is computed from only a few minutes of observations, the effects of Selective Availability will not be averaged out. The result could be wrong by 100m or more due to SA.

When computing the Single Point Position for the starting point of a network, always compute for a site for which you have several hours of observations. The resulting WGS 84 coordinates should then be correct within about 10 meters.

The minimum observation for the computation of a reliable Single Point Position is probably about 2 to 3 hours with four or more satellites and good GDOP. The longer the observation time, the better the Single Point Position will be.

Use the Stop and Go Indicator as a guide

The operator of the roving receiver should also pay attention to certain points. This is particularly important for Rapid Static surveys with short measuring times.

- Make sure that the configuration parameters (e.g. recording rate etc.) are correctly set and match those of the reference receiver.
- Check the antenna height and offset.
- Watch the GDOP when observing for only a short time at a point.
- For 5 to 10mm + 1 ppm accuracy with Rapid Static, only take measurements with GDOP < or = 8.

The Stop and Go Indicator on the sensor provides the roving-receiver operator with an approximate guide to measuring times for Rapid Static observations with four or more satellites and GDOP less than or equal to 8. It estimates when sufficient observations should have been taken for successful post-processing (ambiguity resolution) to be possible.

At the present time estimates are calculated for three baseline ranges, 0 to 5 km and 5 to 15 km and above 15 km. The estimates are based approximately on the current situation for GPS observations in mid latitudes and assume that the reference and roving receiver are tracking the same satellites.

As the Stop and Go Indicator can only monitor the roving receiver it can only provide an estimate for the required measuring time. It should be used only as a guide.

Fill out a field sheet

As with all survey work, it is well worthwhile filling out a field sheet for each site when taking GPS observations. Field sheets facilitate checking and editing at the data-processing stage.

Reference Stations

- ✓ No obstructions above 15° cut-off angle.
- ✓ No reflecting surfaces (multipath).
- ✓ Safe, can leave equipment unattended.
- ✓ No transmitters in vicinity.
- ✓ Reliable power supply.
- ✓ Ample memory capacity.
- ✓ Correct configuration parameters (e.g. recording rate).
- ✓ Check antenna height and offset.
- ✓ Does not have to be a known point.
- ✓ It is better to establish temporary reference stations at good sites rather than at unsuitable known points.

For precise GPS surveying, WGS 84 coordinates for one point have to be known to about 10 meters.

Roving Receiver

- ✓ 15° cut-off angle.
- ✓ Obstructions should not block signals.
- ✓ No reflecting surfaces (multipath).
- ✓ No transmitters in vicinity.
- ✓ Fully-charged battery.
- ✓ Sufficient memory capacity.
- ✓ Correct configuration parameters (e.g. data-recording rate).
- ✓ Check antenna height and offset.
- ✓ Observe in good windows.
- ✓ Watch the GDOP <= 8.
- ✓ Use Stop and Go Indicator as a guide.
- ✓ Fill out a field sheet.

Practical Hints

- ✓ Tribrachs: check the bubble and optical plummet.
- ✓ Level and center the tribrach and tripod correctly.
- ✓ Check the height reading and antenna offset.
- ✓ An error in height affects the entire solution!
- ✓ Use a radio to maintain contact between reference and rover.
- ✓ Consider orienting the antennas for the most precise work.

Field Sheet

Point Id.:	Date:	
Receiver Serial No.:	Operator:	
Memory card No.:		
Type of set up:		
Height reading:		
Time started tracking:		
Time stopped tracking:		
Number of epochs:		
Number of satellites:		
GDOP:		
Navigation position: Lat.	Long.	Height
Notes:		

Checking and editing during data transfer

Data can be transferred to SKI-Pro directly via a PC-card slot, or via a card reader, from the controller (System 300) or receiver (System 500), or from a disk with backed-up raw data. During data transfer, the operator has the opportunity to check and edit certain data. It is particularly advisable to check the following:

- Point identification: Check spelling, upper and lower case letters, spaces etc.
- Make sure that points that have been observed twice have the same point identification. Make sure that different points in the same project have different point identifications.
- Height reading: Compare with field sheets.

Note that some of the above site-related parameters can be changed in some components of SKI-Pro. However, the affected baselines have then to be recomputed.

Backing up raw data and projects

After reading in a data set **always** make a back-up on either a diskette or on the hard disk. You can then erase and reuse the memory card but you still have the raw data. When backing up data from several memory cards, it is advisable to create a directory for each card.

After importing all the data related to the project it is often worthwhile making a backup of the whole directory where the project is located before starting to process the data.

Deriving initial WGS 84 coordinates for one point

As explained on page 18, the computation of a baseline requires that the coordinates of one point are held fixed. The coordinates of the other point are computed relative to the "fixed" point.

For any precise GPS survey the absolute coordinates of **ONE** site in the network have to be known in WGS 84 to about 10 meters. WGS 84 coordinates for one site will often be available or can be easily derived.

Using SKI-Pro it is easy to convert the grid coordinates of a known point to geodetic or Cartesian coordinates on the local ellipsoid. If the approximate shifts between the local datum and WGS 84 are known, WGS 84 coordinates to well within the required accuracy can be derived. The local Survey Department or University will usually be able to provide approximate transformation parameters.

As explained on page 17, the reference receiver does not have to be on a known point. If the reference receiver was on a new (unknown) point and a known point was observed with the roving receiver, simply compute the first baseline from the known point (rover) to the unknown point (reference) in order to obtain and store the required initial WGS 84 coordinates for the reference receiver.

If good initial WGS 84 coordinates for the reference site are not known or cannot be derived as explained in the last two paragraphs, the Single Point Position computation in SKI-Pro can be used. When using the Single Point Position computation always compute for a site for which there are several hours of observations. The effects of Selective Availability should then average out and the resulting WGS 84 coordinates should be correct to within the required 10 meters.

See section *"Need for one known point in WGS 84"* on page 18 for further details.

Always keep in mind that poor initial coordinates for the reference receiver will affect the baseline computation and can lead to results outside the quoted specifications.

Cut-off angle

In the vast majority of cases, the default settings for GPS-processing can be accepted and never need to be changed by the operator. On some rare occasions the operator may need to modify one or more of the data processing parameters. The most common ones are described below.

It is common practice in GPS surveying to set a 10° cut-off angle in the receiver. 15° is the system default value in data processing. Avoid cut-off angles below 10° if precise results are to be obtained.

Although you can increase the cut-off angle you should be cautious when doing so. If the cut-off angle for data processing is set higher than in the receiver some observations will not be used for the baseline computation and you may "lose" a satellite. It could happen that only three satellites would be used in the computation instead of four. You cannot expect a reliable answer with only three satellites.

It can sometimes be advantageous, however, to increase the cut-off angle to about 20° in case of a disturbed ionosphere and provided that sufficient satellites above 20° with good GDOP have been observed (use the *Satellite Availability* component in SKI-Pro to check the GDOP).

You may sometimes find that a baseline result is outside specifications even though five satellites have been observed. If one of the satellites never rises above about 20° the observations to this satellite may be badly affected by the ionosphere. Raising the cut-off angle and computing with only four high-elevation satellites can sometimes produce a better result.

Ephemeris

SKI-Pro uses the broadcast ephemeris recorded in the receiver. This is standard practice throughout the world for all routine GPS surveying. For standard GPS survey work there is little to be gained by using precise ephemeris.

Solution type

For precise GPS surveying you normally accept the system default setting *"Automatic"*. If available *Code* and *Phase* observations will then be used for computation.

It should make little difference whether you select *"Automatic"* or *"Phase"* only. The results should be more or less identical.

Use*"Code"* for the rapid calculation of baselines when high accuracy is not required, for instance in exploration or offshore work. If only code observations are processed the accuracy cannot be better than about 0.3m in position.

Selecting *"Float"* enforces that ambiguities are not resolved. Depending on the frequency you can process an L1 float, an L2 float, an L1+L2 float or an L3 float solution.

Selecting an L3 float solution is useful when you process long baselines and have long observation times.
Note that if a baseline is longer than the value set under *"Fix ambiguities up to"* a float solution will be computed automatically.

SKI-Pro automatically selects the best frequency or combination of frequencies for the final solution. Thus, there is little point in processing with anything but *"Automatic"*. If dual-frequency data is available both frequencies will typically be used.

Because signal delay through the ionosphere is different for the L1 and L2 frequency a linear combination of the two frequencies, which eliminates the influence of the ionosphere can be calculated. However, this so-called L3 solution also destroys the integer nature of the ambiguities. A float solution is computed instead while the ambiguities remain unfixed. For very long baselines (e.g. longer than 80 km) it is not critical to have a float solution (instead of ambiguities fixed). The L3 float solution is accurate enough according to the system specifications provided that the observation time is long enough.

If L1 and L2 ambiguities can be resolved previously a second processing run can be started introducing the fixed L1 and L2 integer ambiguities into the ionospheric-free linear combination. Ionospheric disturbances are eliminated while fixed ambiguities are used. This strategy is preferably used if ambiguities can be resolved but the ionospheric influence is significant (e.g. with baselines longer than 15 km).

With short baselines, though, using the ionospheric-free linear combination would increase the noise with little benefit. A standard L1+L2 solution is best used then.

Selecting *"Automatic"* makes SKI-Pro use an L3 solution if dual-frequency data is available and the baseline is longer than 15 km. If ambiguities can be resolved these are introduced into the ionospheric-free solution.

If ambiguities cannot be resolved, the result will be an L3 float solution. If the baseline is shorter than 15 km L1+L2 will be processed.

Selecting *"L1+L2"* will force the computation to use both frequencies L1 and L2 without a second iono-free processing run independent of the baseline length.

Selecting *"Iono free (L3)"* makes the system compute an L3 solution independent of the baseline length.

Fix ambiguities up to

This value defines the maximum distance of a baseline for which the system should try to resolve ambiguities. The system default value is 80 km. Although you can set the limitation to a higher value, you should take care when doing so. Certainly there is no point in setting the value unrealistically high. For baselines above the limit a float solution will be computed.

The frequency used for computation depends on the selected *"Frequency"* parameter. If *"Automatic"* has been selected an L3 solution will be computed for baselines longer than 15 km. For long baselines (with typically long observation times!) it is not critical to have an L3 float solution (instead of ambiguities fixed). The L3 float solution will be accurate enough according to the system specifications.

For baselines up to the given limitation value, L1 and L2 measurements are introduced as individual observations into the computation. The Lambda search developed by Prof. Teunissen and his co-workers at the TU Delft is used as an efficient approach to find possible candidate sets of integer ambiguities. Various statistical decision criteria are used to verify the correctness of the ambiguity resolution.

Min. duration for float solution

This parameter defines the minimum time for which SKI-Pro allows the computation of a float solution for static intervals. For short observation times float solutions may not be accurate enough and a simple code solution may be preferable. The default setting of 300 sec. makes SKI-Pro switch to a code-only solution in case the ambiguities cannot be resolved for observation periods which are shorter than 300 sec.

Tropospheric model

It does not make much difference whether you select the *Hopfield* or the *Saastamoinen* or the *Essen and Froome* model, but you should never work with "*No troposphere*". You cannot expect to achieve good results if no tropospheric model is used.

Ionospheric model

This parameter defines which model is used to reduce the impact of the ionosphere. This is of special importance if you try to resolve ambiguities.

The default parameter is *"Automatic"*, which automatically selects the best possible choice. If sufficient observation time is available on the reference, this will be the *"Computed model"*. Otherwise the *"Klobuchar model"* will be taken provided that almanac data is available. Typically there is no need to change the default.

The *Computed model* can also be selected manually. It is computed using differences in the L1 and L2 signal as received on the ground at the sensor. The advantage of using this model is that it is calculated according to conditions prevalent at the time and position of measurement.

At least 45 minutes of data is required for a *Computed model* to be used.

The *Klobuchar model* reflects the 11-year cycle of solar activity particularly well. To use this model can be advantageous during the time of high solar activity. The *Klobuchar model* should only be selected if observation data from Leica receivers is being processed, since this kind of data contains the necessary almanac files.

The *"Standard"* model is based on an empirical ionospheric behaviour and is a function of the hour angle of the sun. When the *Standard* model is chosen corrections are applied to all phase observations. The corrections depend on the hour angle of the sun at the time of measurement and the elevation of the satellites.

Use stochastic modelling

Select this option if you want to model the ionosphere additionally by calculating the ionospheric impact for each epoch. Stochastic modelling supports ambiguity resolution on medium and longer baselines when you suspect the ionosphere to be quite active.

You should, however, be careful with short baselines since bad data –e.g. data influenced by multipath or obstructions- may be misinterpreted as being influenced by ionospheric noise.

It is recommended to leave the default value for the "*Min. distance*" set to 8 km. With shorter baselines the ionospheric influence is smaller and stochastic modelling is not necessary.

It is advisable to leave the Ionospheric activity option set to "*Automatic*".

SKI-Pro will then, depending on the baseline length, automatically set the level by which the changing of the ionospheric activity from epoch to epoch is modelled.

You may set the Ionospheric activity parameter manually to *Low*, *Medium* or *High*, if you have reliable indications on the current ionospheric activity.

Baseline selection - Strategy for computation

Before starting the GPS-processing you should consider carefully how the network can best be computed. Points to be considered are:

- Obtaining good initial WGS 84 coordinates for one point.
- Connections to existing control.
- Computing the coordinates of temporary reference stations.
- Rapid static measurements from temporary reference stations.
- Long lines.
- Short lines.

If more than one temporary-reference station has been used, this "network" of temporary-reference stations should be computed first. This may also involve the connection to existing control points. Select and compute line by line, inspect the results, and store the coordinates of temporary reference stations if the baseline computations are in order.

It is highly advisable to check the coordinates for each temporary-reference station using double fixes or other means, as all radial roving points depend on temporary-reference stations.

Once the "network" of temporary-reference stations has been computed, all remaining baselines - i.e. the radial baselines from the temporary-reference stations to roving-receiver points - can be computed.

If baselines of greatly differing lengths have to be computed, it can be worthwhile making two or more baseline selections and computation runs. In this way you can select and compute batches of baselines which fall into the same category of parameter sets.

Try to avoid mixing baselines of totally different lengths in the same computation run. And avoid mixing short-observation *"Rapid-Static"* baselines with long-observation *"Static"* baselines.

Data Import and Computation

Check and edit during data transfer:

- ✓ Point identification
- ✓ Height reading and antenna offset
- ✓ WGS 84 coordinates of initial point
- ✓ Back up raw data and project

Consider the following carefully:

- How best to compute the network
- The need for good WGS 84 coordinates for one point
- Connection to existing control
- The need to transform to local coordinates
- Computation of network of temporary reference stations
- Computation of new points from temporary reference stations
- Long lines
- Short lines
- GPS-processing parameters

Resolving ambiguities

Before starting a processing run you When interpreting the results, you have to distinguish between baselines for which ambiguity resolution has been attempted and baselines for which a float solution has been requested.

For baselines up to the limitation value (“*Fix ambiguities up to*”), ambiguity resolution is always attempted unless the Solution type has been set to *Float* or *Code*. When using the Rapid Static technique with short observation times, ambiguity resolution is always necessary if good results are to be achieved.

For long baselines with long observation times a so-called L3 float solution (a linear combination of L1 and L2 measurements) can be used. This eliminates the ionospheric effects, but destroys the integer nature of the ambiguities. Accuracy specifications can only be met with sufficient observation times.

For baselines up to about 20-30 km ambiguity resolution should always be attempted if good results are to be achieved. Under favorable conditions ambiguity resolution can also be successful on longer baselines.

For baselines up to the limitation value, SKI-Pro searches for all possible combinations of ambiguities. Rigorous statistical techniques are used to determine the “most probably correct” solution and the “second most probably correct” solution. These two “most probable” solutions are then compared and if the probability that the first solution is much more likely to be correct than the second solution then the first solution is taken as the correct answer.

Immediately after having completed the ambiguity search routine and having computed the most likely ambiguities with one set of GPS observations, SKI-Pro repeats the whole ambiguity search routine using a different set of GPS observations. This results in a second set of ambiguities.

The ambiguities computed from this second search routine are then compared with the ambiguities computed from the first ambiguity search. If the two sets of ambiguities are identical, then the ambiguities are considered to be correct. In order to ensure the highest possible reliability the ambiguity search routine is continually repeated for the entire observation interval.

Note, however, that very severe ionospheric conditions, multipath or other disturbances can cause systematic biases in the phase observations.

Resolving ambiguities, continued

This can result in discrepancies in the computed ambiguity sets and the ambiguities will then not be declared resolved. Under such conditions enough observation time with good satellite geometry is necessary to allow a successful ambiguity resolution.

If the guidelines for baseline lengths, observation windows, number of satellites, GDOP and observation times are followed (combined perhaps with your own experience), the results of baselines for which the ambiguities are resolved should be within the system specifications.

If insufficient observations were taken or the satellite constellation was poor, SKI-Pro will not be able to resolve the ambiguities. If the ambiguities are not resolved it is most unlikely that the system specifications will be achieved.

If the ambiguities are not resolved in Rapid Static (short observation times) it is difficult to give an indication of accuracy. However, to give you a rough guideline, you can multiply the sigma values for each estimated coordinate by 10 in order to obtain an approximate estimate of the accuracy of the baseline computation.

Note that for baselines up to 20-30 km it should normally be possible to resolve the ambiguities provided that sufficient observations have been taken (see page 15 for a guide to baseline lengths and observation times). If the ambiguities are not resolved check the logfile (see next page).

Float solutions

For baselines above the limitation value (system default = 80 km), SKI-Pro eliminates the ionospheric effects but does not attempt to resolve ambiguities. This can also be enforced by selecting Solution type *Float* and Frequency *Iono-free (L3)*.

The result will always show *"Ambiguities not resolved“* (Ambiguity status = no) in these cases. The accuracy specifications will however be met, if sufficient observation time was taken.

Note that there is usually no benefit in trying to resolve ambiguities for lines longer than 80km.

Inspecting the logfile and comparing results

For baselines up to the limitation value ambiguity resolution as described in the previous chapter is always attempted.

When you look at the logfile, you will find a summary of the computation results for each baseline. You should check the following:

- Observation Statistics: Check the number of satellites: there should always be at least four. The logfile lists the number of observations used and the number of observations rejected for each satellite. Check if there is an unusual high number of rejections for a specific satellite.

- Ambiguity Statistics: The total number of independent ambiguity fixes for the whole observation interval is shown.

  Check, if there are parts inside the static interval, for which no ambiguities could be fixed.

- Cycle Slip Statistics: Cycle slips are discontinuities in the integer ambiguities resulting from signal interruptions. Normally, they are repaired and reported in the logfile. Check if there is a high number of cycle slips for a specific satellite.

SKI-Pro also allows you to inspect the DOP values and the residuals of the computation. DOP values reflect the satellite geometry, whereas residuals give an indication of the measurement noise contained in the data. To inspect DOP values or residuals the corresponding checkboxes have to be ticked in the *GPS-Processing Parameters/ Extended Output* page before a computation run is started.

Please refer to the Online Help for detailed information.

The minimum and maximum DOP values are also listed in the Results Manager, which gives you a quick overview on whether a baseline has been computed with poor satellite geometry.

If ambiguity resolution has not been successful with short observation times, the results will not be within the specifications. Consider a second processing run with using satellite windows, deselecting a specific satellite or modifying the parameters. However you should take care to that you retain enough observation time. Only change your settings, if the logfile gives a reason to do so.

For baselines above the limitation value (system default = 80 km) or if an L3 Float solution has been selected manually, SKI-Pro eliminates the ionospheric effects but does not attempt to resolve ambiguities.

When inspecting the logfile check the number of satellites observed.

The results will show *"Ambiguities not resolved"* (Ambiguity status = no). However, these results meet the system specifications provided that sufficient observations have been taken.

If baselines of greatly differing lengths have to be computed, it is advisable to make two or more computation runs. In this way you can select and compute batches of baselines which fall into the same category of processing parameter sets.

Compare the logfile against the field sheets

If the results are not as good as you would expect, it can be well worthwhile comparing the information in the logfile with that in the field sheets. Check if the number of satellites used in the baseline computation is the same as that noted in the field sheets. Remember to check the reference station as well as the rover. If the number of the satellites is not the same, the GDOP values could be higher than you expected. Check the actual GDOP for the satellites used in the computation using the Satellite Availability component of SKI-Pro.

Compare the results for double fixes

If a point was observed twice in different windows or two reference receivers were operating simultaneously, you should compare the resulting coordinates.

Storing the results

After inspecting the summary of results and the logfile, store the results that meet your accuracy requirements.

The coordinates are averaged (weighted mean) if more than one solution for a point is stored. For instance if you store the coordinates for point A from one baseline solution and then you compute and store the coordinates for point A again from another baseline solution, the stored coordinates will be updated to the weighted mean values from the two solutions. The weighted mean is taken provided the coordinates agree in both height and position to within the *"Limits for Automatic Coordinate Averaging"* set in SKI-Pro (default = 0.075m).

It follows that you should exercise a certain amount of care when storing points that have been fixed in more than one baseline computation. Compare the results before storing.

Interpreting and Storing the Results

- For Rapid Static baselines with short observation times ambiguity resolution must be successful if high-accuracy results are to be obtained.
- For longer lines with longer observation times the L3 solution without ambiguity resolution will normally be used.
- Baselines up to the limitation value (default = 80 km):

    Ambiguity resolution is always attempted.

  Ambiguities resolved (Ambiguity status = yes):

    SKI-Pro has found the most probable solution.

    Results should normally meet the specifications.

  Ambiguities not resolved (Ambiguity status = no):

    A Float solution is presented.

    The Result is outside the specifications unless you have long observation times.

    Inspect the logfile and consider recomputing with modified settings.

- Baselines above the limitation value (default = 80 km):

    L3 solution, ambiguity resolution is not attempted.

    Results should meet the specifications provided sufficient observations are taken.

    Long lines need long observation times.

- Inspect double fixes, independent baselines etc.
- Store results that meet accuracy requirements.
- Coordinates averaged if more than one result is stored.

Adjustment, Transformation and Output of Results

After the observations have been computed, you may wish to adjust the results if multiple observations to points exist. This provides the best estimates for the position of the points. Refer to the SKI-Pro Online Help on *"Adjustment"* for further details.

The results of the baseline computations are coordinates in the WGS 84 system. Using a *"Coordinate System"* in SKI-Pro, these coordinates can be transformed into coordinates in any local datum or grid system. Refer to the SKI-Pro Online Help for further details.

The final coordinates can then be exported in various formats using the ASCII Export functionality of SKI-Pro. Refer to the SKI-Pro Online Help for further details.

Notes on single-frequency Static and Rapid Static measurements

When measuring with the SR510 (System 500) or SR9400 / SR261 (System 300) there are several points that should be noted in order that the measurements are successful and good results can be obtained.

Only observation windows with a minimum of 5 satellites above 15° and a good GDOP (< 8) should be used.

The minimum observation time in Static or Rapid Static should never be less than 15 minutes.

As a rule of thumb the baseline observation time should be 5 minutes per kilometre of the baseline length with a minimum time of 15 minutes.

Recommended (minimum) observation times:

Baseline length	Observation time
1 km	15 min.
2 km	15 min.
3 km	15 min.
4 km	20 min.
5 km	25 min.
6 km	30 min.
7 km	35 min.
8 km	40 min.
9 km	45 min.
10 km	50 min.
> 10 km	> 60 min.

A Rapid Static observation can usually be considered to be successful if SKI-Pro can resolve the ambiguities. Providing an estimate of the required observation time is more difficult for single frequency receivers than for dual frequency equipment as considerably less information is available for the post processing software. Never the less, the above table should serve as a guide.

By default, SKI-Pro will not attempt to resolve ambiguities if less than 5 minutes of (rapid) static, single-frequency data is available. This is done in order to avoid unreliable results. Once the ambiguities are resolved correctly the length of the baseline will normally be accurate to about 5 - 10 mm plus 2 ppm.

If the highest possible accuracy should be achieved it is recommended to orient the antennas in a common direction.

On long baselines above 10 km the accuracy which can be achieved with single frequency Sensors is inferior to which can be achieved with dual frequency Sensors due to ionospheric effects which cannot be eliminated with single frequency data. Users who have previously worked with dual frequency equipment should be aware of this fact.

Leica Geosystems AG, Heerbrugg, Switzerland, has been certified as being equipped with a quality system which meets the International Standards of Quality Management and Quality Systems (ISO standard 9001) and Environmental Management Systems (ISO standard 14001).

TQM
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Total Quality Management- Our commitment to total customer satisfaction

Ask your local Leica Geosystems agent for more information about our TQM program

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