General Guide to Static and Rapid-Static

Version 2.0
English
Congratulations on your purchase of a new System GPS500 from Leica Geosystems.
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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 Geosystems 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.
Overall planning for a GPS survey

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 the truer this will be, 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.
**Night versus day observations. Measuring long lines**

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.

**Observation schedule - best times to observe**

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

For baselines over 20 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.

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 Guidelines to Datum/Map in the SKI-Pro Documentation for details on transformation using Datum/Map.
Consider the transformation to local coordinates, continued

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.

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.
Mission planning

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 ≤ 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 Survey Design 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 ≤ 8.

Whenever possible:
- ✓ 5 or more satellites.
- ✓ GDOP ≤ 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:

Good window - GDOP low and stable
Poor window - GDOP high
Avoid observing during this "spike"
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 20km 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°).
Observation times and baseline lengths, continued

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.

<table>
<thead>
<tr>
<th>Obs. Method</th>
<th>No. sats. GDOP ≤ 8</th>
<th>Baseline Length</th>
<th>Approximate observation time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>By day</td>
<td>By night</td>
<td></td>
</tr>
<tr>
<td>Rapid Static</td>
<td>4 or more</td>
<td>Up to 5 km</td>
<td>5 to 10 mins</td>
</tr>
<tr>
<td></td>
<td>4 or more</td>
<td>5 to 10 km</td>
<td>10 to 20 mins</td>
</tr>
<tr>
<td></td>
<td>5 or more</td>
<td>10 to 15 km</td>
<td>Over 20 mins</td>
</tr>
<tr>
<td>Static</td>
<td>4 or more</td>
<td>15 to 30 km</td>
<td>1 to 2 hours</td>
</tr>
<tr>
<td></td>
<td>4 or more</td>
<td>Over 30 km</td>
<td>2 to 3 hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Field observations

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 mission 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.
**Need for one known point in WGS 84**

The computation of a baseline in data 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 Position 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 to 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.
**Observing new points**

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 ≤ 8.

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**Use the Stop and Go Indicator as a guide**

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 two baseline ranges, 0 to 5 km and 5 to 10 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.
*Fill out a field sheet, continued*

**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:
Importing the data to SKI-Pro

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.
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.
Data-processing parameters

Cut-off angle

In the vast majority of cases, the default settings for data-processing may be accepted and may never be altered 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 15° cut-off angle in the receiver. 15° is also the system default value in data processing. Avoid cut-off angles less than 15° 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 a precise ephemeris.

**Data used for processing**

For precise GPS surveying, one will normally accept the system default setting "Automatic", which will usually use Code and Phase observations.

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

For the precise measurement of baselines it should make little difference whether one processes code and phase measurements together or "Phase only". The results should be more or less identical.

For long lines above about 100 km, code observations can assist a high-accuracy solution provided that the ephemerides are sufficiently good.

If code measurements are corrupted for some reason, one can process baselines using "Phase only".

For processing kinematic data, "Automatic" has to be used for precise results. "Code only" can be used if high accuracy is not required.
Fix ambiguities up to:

With this parameter you can determine how SKI-Pro should compute baselines. The system default value is 20 km.

For baselines up to this limitation value, L1 and L2 measurements are introduced as individual observations into the least-squares adjustment. 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. The statistical decision criteria used has been published previously together with a different search algorithm, the Fast Ambiguity Resolution Approach (FARA) by Dr. E. Frei and is now called FARA statistics.

For baselines above this limitation value, a so-called L3 solution is performed. The L3 observable is a linear combination of the L1 and L2 measurements. The advantage of the L3 solution is that it eliminates the influence of the ionosphere.

However, it also destroys the integer nature of the ambiguities, therefore no ambiguity resolution can be carried out. This is not important, however, as successful ambiguity resolution over long distances is in any case hardly feasible.

Rms threshold

The Rms threshold is used to minimize the possibility of unreliable baseline results.

During the computation of a baseline, the least-squares adjustment computes the root mean square (rms) of a single-difference phase observation (i.e. the rms of unit weight). This value is compared with the Rms threshold.

For most GPS surveying applications one will usually accept the system default "Automatic". This will automatically select an appropriate rms parameter depending on the duration of your occupation.

The rms of a single-difference phase observation is largely dependent on the baseline length, observation time, and ionospheric disturbance. Ionospheric disturbance is less at night.
**Rms threshold, continued**

The following table provides a very approximate guide to the rms of a single difference that a user could expect:

<table>
<thead>
<tr>
<th>Distance</th>
<th>Day Observation</th>
<th>Night Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>≤ 10 min</td>
<td>&gt; 10 min</td>
</tr>
<tr>
<td>Up to 5 km</td>
<td>&lt; 10 mm</td>
<td>&lt; 10 mm</td>
</tr>
<tr>
<td>5 to 10 km</td>
<td>&lt; 15 mm</td>
<td>&lt; 25 mm</td>
</tr>
<tr>
<td>10 to 20 km</td>
<td>&lt; 15 mm</td>
<td>&lt; 40 mm</td>
</tr>
</tbody>
</table>

If the rms of a single-difference observation exceeds the rms threshold, the baseline solution with fixed ambiguities will be rejected and only the float solution will be presented (ambiguities not resolved).

Note, that the advanced parameter "Use stochastic modelling" (see page 29) will additionally reduce the rms values of a single difference.

For Rapid Static observations with up to 10 minutes of measurement time, one should be cautious about increasing the rms threshold because an unreasonably high rms value could lead to a weak solution being accepted.

For longer observation times - let us say about 30 minutes or more - the rms threshold can be set higher without undue risk.

Note that the rms threshold applies only to baselines up to the limitation value (see page 26). For baselines above the limitation value ambiguity resolution is not attempted.
**Solution type**

The solution type parameter applies to all baseline up to which ambiguities are attempted to be fixed (see page 26). If solution type "Standard" is chosen, SKI-Pro will attempt to fix ambiguities and apply ionospheric corrections as defined in the parameter "Ionospheric model".

If solution type "Iono free fixed" is chosen then the baseline computation is done in two steps. First ambiguities are attempted to be fixed, then in the second step an ionospheric free solution is calculated using fixed L1 and L2 ambiguities.

The advantage of this approach is that any ionospheric disturbance is eliminated while fixed ambiguities are used; it is recommended to choose this solution type for all baselines between 5 km and 20 km, in particular if daylight observations have been taken.

**Ionospheric model**

This parameter is only used for baselines up to the limitation value (see page 26, "Fix ambiguity up to"), that is for baselines for which SKI-Pro will try to resolve ambiguities.

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

A "Computed model" may be used instead of the standard model. This 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 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.

For long lines above the limitation value (see page 26), the ionospheric effects are eliminated by evaluating a linear combination of L1 and L2 measurements, the so-called L3 observable. Ambiguity resolution is not attempted.
Use stochastic modelling

Using this option may support ambiguity resolution on medium and longer lines when you suspect the ionosphere to be quite active.

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

This is why by default this setting is only used for baselines longer than 10 km.

Note that in order to ensure reliable results this option will not be used for the processing of kinematic data.

Frequency

SKI-Pro will automatically select to process whatever data is available. Thus there is little point in processing with anything but "Automatic".

Short observation times with Rapid Static are only possible with dual-frequency observations. Long lines can only be processed successfully using L1 and L2 data.

Selecting "Iono free float" makes SKI-Pro compute an L3 solution even if the baseline length remains under the limit to fix ambiguities (see p.26). Remember, that for an L3 solution the observation time has to be long enough.

Tropospheric model

It will not make much difference to the end result as to whether you select the Hopfield or Saastamoinen model, but you should never work with "No troposphere". You cannot expect to achieve good results if no tropospheric model is used.
Baseline selection - Strategy for computation

Before starting data processing one should consider carefully how best to compute the network. Points to be considered include:

• 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.
Baseline selection - Strategy for computation, continued

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
• Data-processing parameters
Interpreting the baseline results

When interpreting the results, one has to distinguish between baselines up to the limitation value (“Fix ambiguities up to”) and baselines above this value (see page 26).

For baselines up to the limitation value, ambiguity resolution using the Lambda search and the FARA statistics is always attempted.

For baselines above the limitation value, a so-called L3 solution (linear combination of L1 and L2 measurements) is performed. This eliminates the ionospheric effects but destroys the integer nature of the ambiguities. Thus ambiguity resolution is not carried out.
Baselines up to the limitation value

Ambiguities resolved

For baselines up to 20 km (system default for "Fix ambiguities up to"), ambiguity resolution should always be successful if good results are to be achieved.

For baselines up to the limitation value, SKI-Pro searches for all possible combinations of ambiguities and evaluates the rms of a single-difference observation for each set of ambiguities. It then compares the two solutions with the lowest rms values. If there is a significant difference between the two rms values, the ambiguity set yielding the lowest rms value is considered as the correct one. This decision is based on statistical methods.

The reader will realize, of course, that a least-squares adjustment can only provide the "most probable" values.

These will usually be the "true values".

However, one should also be aware that very severe ionospheric disturbances can cause systematic biases in the phase observations. In this case, although the results of the least-squares adjustment will be statistically correct, they could be biased away from the true values.

The statistical methods implemented in FARA are based on very restrictive criteria in order to try to ensure the highest probability of a reliable result. When the ambiguities are resolved, you know that SKI-Pro has found a "most probable" solution with an rms value that is significantly lower than for any other possible ambiguity set.

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.

Nevertheless, as explained above, it is simply impossible to eliminate completely the possibility of the occasional biased result.
**Ambiguities not resolved**

As already explained, ambiguity resolution should always be successful for baselines up to 20 km if good results are to be obtained.

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, as a rough guide, one could multiply the sigma values for each estimated coordinate by 10 in order to obtain an approximate estimate of the accuracy of the baseline computation.

**Baselines above the limitation value**

Note that for baselines up to 20 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 rms values in the logfile (see next page).

For baselines above the limitation value (system default = 20 km), SKI-Pro eliminates the ionospheric effects but does not attempt to resolve ambiguities.

Thus the result will always show "Ambiguities not resolved" (Ambiguity status = no).

Note that there is usually no benefit in trying to resolve ambiguities for lines over 20 km.
Inspecting the logfile and comparing results

Baselines up to the limitation value

For baselines up to the limitation value, ambiguity resolution using the Lambda search and the FARA statistics is always attempted.

As explained in section "Rms threshold" (see page 26), if the rms float exceeds the rms threshold, the baseline solution with fixed ambiguities will be rejected and only the float solution will be presented (ambiguities not resolved). Thus if ambiguities are resolved the rms float and rms fix have to be lower than the rms threshold.

The table on page 27 provides an approximate guide to the rms values (float and fix) that can be expected.

The reason is that this could allow unreasonably high rms float and fix values and could therefore lead to a weak solution being accepted.

Manually widening the rms threshold value for successful baseline computation requires a certain amount of experience and judgement.

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.

When you look at the logfile, you will find a summary of the FARA statistics at the end of each baseline output. You should check the following:

- Number of satellites: there should always be at least four.
- The rms float: this is the rms value before fixing ambiguities.
- The rms fix: this is the rms value after fixing ambiguities. The rms fix will usually be slightly higher than the rms float.

If the rms threshold is lower than the rms float or rms fix one can consider manually increasing the rms threshold value. However, as explained on page 27, one should exercise a certain amount of caution when doing this for Rapid Static observations with up to 10 minutes of measurement time.
<table>
<thead>
<tr>
<th><strong>Baselines above the limitation value</strong></th>
<th><strong>Compare the logfile against the field sheets</strong></th>
<th><strong>Compare the results for double fixes</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>For baselines above the limitation value (system default = 20 km), SKI-Pro eliminates the ionospheric effects but does not attempt to resolve ambiguities.</td>
<td>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.</td>
<td>If a point was observed twice in different windows or two reference receivers were operating simultaneously, you should compare the resulting coordinates.</td>
</tr>
<tr>
<td>When inspecting the logfile check the following:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• The number of satellites observed.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• The rms of unit weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The rms of unit weight should be less than about 20 mm for lines of about 20 km to 50 km. For lines over 50 km the rms of unit weight will usually be higher due to the minor inaccuracies in the broadcast ephemeris.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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 lines up to 20 km, ambiguity resolution should be successful if high-accuracy results are to be obtained.

• For long lines over 20 km, the L3 solution without ambiguity resolution will normally be used.

• Baselines up to the limitation value (default = 20 km):
  
  Ambiguity resolution always attempted.

  Ambiguities resolved (Ambiguity status = yes):
  
  SKI-Pro has found most probable solution.
  
  Results should normally meet specifications.

  Ambiguities not resolved (Ambiguity status = no):
  
  Float solution presented.
  
  Result outside specifications, inspect logfile.
  
  Consider increasing the rms threshold and recomputing.

• Baselines above the limitation value (default = 20 km):
  
  L3 solution, ambiguity resolution not attempted.
  
  Results should meet 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 stored.
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. See SKI-Pro online help "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.
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:

<table>
<thead>
<tr>
<th>Baseline-length</th>
<th>Observation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 km</td>
<td>15 min.</td>
</tr>
<tr>
<td>2 km</td>
<td>15 min</td>
</tr>
<tr>
<td>3 km</td>
<td>15 min</td>
</tr>
<tr>
<td>4 km</td>
<td>20 min</td>
</tr>
<tr>
<td>5 km</td>
<td>25 min</td>
</tr>
<tr>
<td>6 km</td>
<td>30 min</td>
</tr>
<tr>
<td>7 km</td>
<td>35 min</td>
</tr>
<tr>
<td>8 km</td>
<td>40 min</td>
</tr>
<tr>
<td>9 km</td>
<td>45 min</td>
</tr>
<tr>
<td>10 km</td>
<td>50 min</td>
</tr>
<tr>
<td>&gt; 10 km</td>
<td>&gt; 60 min</td>
</tr>
</tbody>
</table>

A Rapid Static observation can usually be considered to be successful when 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 9 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. These default settings can be changed in the Data Processing component of SKI-Pro, but this is not recommended.
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 that 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.
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