LGO GPS Post-Processing Report

Content:
- Report Templates
- Point Information
- Processing Parameters
- Satellite Selection
- Antenna Information
- Observation, Ambiguity and Cycle Slip Statistics
- Final Coordinates

Exercise:
- Examine Baseline Data Processing Report for:
  - Processing Parameters used in calculations, Observation, Ambiguity and Cycle Slip Statistics
  - and Final Solution Information.

Notes:
LGO has a Report Templates Management Icon which provides access to different Report Types: GPS Summary, Level Summary, GPS Post-Processed Baselines, GPS Post-Processed Kinematic Tracks, GPS Single Point Positioning (SPP), QC Mean Coordinates with Differences, Import Fieldbook Reports from GPS RTK or TPS Jobs and Datum/Map Transformation Calculation Details.

General Information, Contents, Coordinate Types, Format and Header Information can be specified to display Data Processing Report contents in proper or used-defined format by right clicking over a default type and by selecting Properties.

Data Processing Reports are embedded in the Results Tab manager view so they can be opened in a stand-alone window to quickly switch between different reports.
Notes:

Data Processing Reports are accessed in the Results Tab from the management view of Results folders following the calculations of one or more GPS baselines.

For each processing run, a Report Summary containing general information about the computed results can be accessed by right clicking over Report.

Individual Reports for each computed baselines or points are also available. More information about data processing can be found in each individual report by right clicking over it and opening the report. The Data Processing Report will contain the information type selected in the Report Template Properties.

The Point Information section contains Reference and Rover Site related information such as: Point Identification, Receiver and Antenna Types, Antenna Heights and Initial Coordinates.

Antenna heights are the manually entered height readings between the survey marker and the Antenna setup type (tripod, pole or pillar) measured for each site occupation. Additional antenna height vertical offsets for the different antenna setup types are reported in the Antenna Information section.

Duration and common time span for data processing are presented.

Site Windowing periods excluded from data processing are also listed from either reference or rover occupation interval.
LGO Processing Report: Parameters

<table>
<thead>
<tr>
<th>Processing Parameters</th>
<th>Selected</th>
<th>Used</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut-off angle</td>
<td>15°</td>
<td>15°</td>
<td>No precise ephemeris available, switched to broadcast ephemeris</td>
</tr>
<tr>
<td>Ephemeris type</td>
<td>Precise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solution type</td>
<td>Automatic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>Automatic</td>
<td>60 km</td>
<td></td>
</tr>
<tr>
<td>Fix ambiguities up to</td>
<td>Automatic</td>
<td>60 km</td>
<td></td>
</tr>
<tr>
<td>Min. duration for float solution (static)</td>
<td>5' 00&quot;</td>
<td>5' 00&quot;</td>
<td></td>
</tr>
<tr>
<td>Sampling rate</td>
<td>Use all</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Tropospheric model</td>
<td>Hopkins</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ionospheric model</td>
<td>Automatic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use stochastic modelling</td>
<td>Yes</td>
<td>Yes</td>
<td>Internal weighting based on distance separation</td>
</tr>
<tr>
<td>Min. distance</td>
<td>8 km</td>
<td>8 km</td>
<td></td>
</tr>
<tr>
<td>Ionospheric activity</td>
<td>Automatic</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:

Processing parameters initially selected and the ones effectively used by LGO are reported with comments about the changes (if any) in the parameter selection.

If some of the parameters used in the calculations are found to be inadequate, manual entries can be used to specify the parameters.

Additional information about the frequency or frequency combination used in the calculations are found in the Final Coordinates section.

The Automatic selection for the Ionospheric Activity is based on the distance separation between the reference and rover sites.

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LGO Processing Report: Satellite Selection

<table>
<thead>
<tr>
<th>Satellite Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite Windows (Exclude):</td>
</tr>
<tr>
<td>Satellite</td>
</tr>
<tr>
<td>SV17</td>
</tr>
<tr>
<td>SV23</td>
</tr>
<tr>
<td>SV29</td>
</tr>
</tbody>
</table>

Notes:

Satellite(s) completely excluded from data processing (s) are reported for all selected baselines or site occupations.

Partially excluded satellite(s) from different Satellite Windowing intervals are reported from either Reference or Rover occupation intervals.

Completely or partially excluded satellite(s) will be reported as Not Tracked in the Observation Statistics.

Satellite excluded windows will remain enabled until satellite windows are removed or included back in data processing.
## LGO Processing Report: Ionospheric Model

**Computed Iono Model:**

- **Number of computed models:** 1
- **Sampling rate of iono model:** 30 sec
- **Height of single layer:** 350 km

### Model 1:

**Origin of development:**

- **Latitude:** 43°44'40.971471'N
- **Longitude:** 85°51'27.394517'W
- **Time (UT):** 10/08/1989 15:23:10

**Validity:**

- **From epoch:** 10/08/1989 19:23:10
- **To epoch:** 10/08/1989 21:15:30

### Coefficients:

<table>
<thead>
<tr>
<th>Deg. Lat</th>
<th>Value</th>
<th>msn</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.151905651</td>
<td>0.00030691</td>
</tr>
<tr>
<td>0</td>
<td>0.79283682</td>
<td>0.01730719</td>
</tr>
<tr>
<td>0</td>
<td>-0.3161624</td>
<td>0.01693422</td>
</tr>
<tr>
<td>1</td>
<td>-0.63708541</td>
<td>0.01491484</td>
</tr>
<tr>
<td>1</td>
<td>0.27610449</td>
<td>0.01590749</td>
</tr>
</tbody>
</table>

Notes:

Results from Computed Ionospheric Model(s) using dual frequency data at selected reference Station(s) during 45 minutes or more time interval(s) are reported.

These coefficients are applied to partially remove ionospheric biases in common data related to each baseline involving the reference (static) Station(s) and rover Station(s) (static or kinematic) within the common time intervals.

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## LGO Processing Report: Antenna Information

### Antenna Information:

- **Reference: E95**
- **Rover: BULLDOG**

**Antenna type:**

- Reference: A890 Tripod
- Rover: A890 Tripod

**Vertical offset:**

- Reference: 0.0000 m
- Rover: 0.3300 m

**Additional corrections:**

- Elevation and azimuth

**Phase center offsets:**

- L1 (Reference): 0.0788 m
- L1 (Rover): 0.0943 m
- L2 (Reference): 0.0983 m
- L2 (Rover): 0.0712 m

**East:**

- Reference: 0.0000 m
- Rover: 0.0000 m

**North:**

- Reference: 0.0000 m
- Rover: 0.0000 m

### Additional corrections (Reference):

<table>
<thead>
<tr>
<th></th>
<th>0°</th>
<th>10°</th>
<th>20°</th>
<th>30°</th>
<th>40°</th>
<th>50°</th>
<th>60°</th>
<th>70°</th>
<th>80°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Additional corrections (Rover):

<table>
<thead>
<tr>
<th></th>
<th>0°</th>
<th>10°</th>
<th>20°</th>
<th>30°</th>
<th>40°</th>
<th>50°</th>
<th>60°</th>
<th>70°</th>
<th>80°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:

The Antenna Information lists the Antenna Type, Horizontal and Vertical offsets from the antenna height readings to the Antenna Reference Plane (ARP) for the different Reference and Rover antenna setup types (tripod or pillar).

Phase center eccentricities of the antenna type used at the reference and rover stations are presented by displaying the mean L1 & L2 Horizontal and Vertical antenna phase center offsets with respect to the plumb line and Antenna Reference Plane. Calibration values of Phase Center Variations (PCV) for L1 & L2 frequencies with respect to Satellite Zenithal angles are also presented.

All the Antenna Phase Center information are based from Tables contained in the Antenna Management Group.

If incorrect Antenna Phase Center Offset and calibration values are used for one antenna with respect to the other, vertical information derived from baseline solutions could be significantly affected.
### Observation Statistics

<table>
<thead>
<tr>
<th>Number of common epochs</th>
<th>1300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of used observations (L1)</td>
<td>7230</td>
</tr>
<tr>
<td>Number of rejected observations (L1)</td>
<td>767</td>
</tr>
<tr>
<td>Number of used observations (L2)</td>
<td>7230</td>
</tr>
<tr>
<td>Number of rejected observations (L2)</td>
<td>732</td>
</tr>
</tbody>
</table>

### Tracking Status L1:

<table>
<thead>
<tr>
<th>Satellite</th>
<th>From</th>
<th>To</th>
<th>Status</th>
</tr>
</thead>
</table>

### Tracking Summary:

<table>
<thead>
<tr>
<th>Satellite</th>
<th>From</th>
<th>To</th>
<th>Status</th>
</tr>
</thead>
</table>

### Notes:

The Observation Statistics provide information about the total number of common measurement epochs, the total number of used and rejected observations for either L1 or both L1 and L2 frequencies with the associated L1 and L2 Tracking Status for all common satellites.

The Tracking Status gives a detailed report about how long each satellite was used and how often it was excluded in the calculations.

Satellite showing several occurrences of "Tracked / Rejected" indicate that measurements could not be used in the fixed ambiguity determinations and should be further investigated for possible cycle slips, measurement biases or high measurement noise.

A Tracking Summary of common data Tracked, Used and Rejected between Reference and Rover Site Occupations is presented.

Common data used in data processing are shown in green for either L1 or L2 frequencies for each common satellite.

Common data rejected in data processing are shown in Yellow which indicates the time intervals when common measurements were not used in the baseline calculations.

Satellites showing several and long intervals of "Tracked / Rejected" indicate that measurements could not be used in the fixed ambiguity determinations and should be further investigated for possible cycle slips, measurement biases or high measurement noise.
LGO Processing Report: Ambiguity Statistics

Ambiguity Statistics

| Total number of ambiguities: | 127 |
| Number of fixed ambiguities: | 29 |
| Number of independent fixes: | 19 |
| Avg. time between independent fixes: | 20" |
| Percentage of fixed epochs (L1): | 72% |
| Percentage of fixed epochs (L2): | 57% |
| Percentage of fixed epochs (overall): | 50% |

Overall Statistic:

<table>
<thead>
<tr>
<th>Status</th>
<th>From</th>
<th>To</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not fixed</td>
<td>10/08/1999 19:51:45</td>
<td>10/08/1999 20:04:05</td>
<td>12° 20&quot;</td>
</tr>
<tr>
<td>Fixed</td>
<td>10/08/1999 20:04:05</td>
<td>10/08/1999 20:12:40</td>
<td>8° 35&quot;</td>
</tr>
<tr>
<td>Fixed</td>
<td>10/08/1999 20:27:10</td>
<td>10/08/1999 21:10:05</td>
<td>42° 55&quot;</td>
</tr>
<tr>
<td>Not fixed</td>
<td>10/08/1999 21:10:05</td>
<td>10/08/1999 21:51:35</td>
<td>5° 30&quot;</td>
</tr>
</tbody>
</table>

Notes:
The Ambiguity Statistics provide information about the total number of satellite ambiguities (initial and re-initialized) for all common satellites on L1 only or both L1 & L2 frequencies, the number of fixed satellite ambiguities and the number of independently fixed ambiguity solutions with the average time interval between 2 or more consecutive fixed solutions.

The Overall Statistic lists the time period(s) for which at least one successful ambiguity resolution has been achieved and confirmed to be correct together with the period(s) when no fixed ambiguity solutions were available.

The total number of Satellite Ambiguities should remain reasonably small. Ideally, there should be a minimum of 1 ambiguity per satellite per frequency. Large number of Satellite Ambiguities may indicate several losses of lock in the data provoking several re-initialized ambiguities. Periods having no Fixed Ambiguity solutions should be examined for satellite outages, poor DOP values and high measurement noise.

LGO Processing Report: Cycle Slip Statistics

Cycle Slip Statistics

<table>
<thead>
<tr>
<th>Time</th>
<th>Satellite</th>
<th>Frequency</th>
<th>Slip value</th>
<th>Flags</th>
</tr>
</thead>
<tbody>
<tr>
<td>08/29/2000 22:44:50</td>
<td>SV 23</td>
<td>L1</td>
<td>153.00</td>
<td>ucs + ria</td>
</tr>
<tr>
<td>08/29/2000 22:47:30</td>
<td>SV 11</td>
<td>L1</td>
<td>174.00</td>
<td>flagged</td>
</tr>
<tr>
<td>08/29/2000 22:50:30</td>
<td>SV 11</td>
<td>L1</td>
<td>174.00</td>
<td>flagged</td>
</tr>
</tbody>
</table>

Notes:
The Cycle Slip Statistics indicate the total number of cycle slips and their Slip values detected and repaired in phase data processing on specific satellites at given time epochs on each frequency.

Cycle Slips of less than 1 cycle are reported but their values are not listed. These Cycle Slips may indicate severe ionospheric disturbances in phase measurements causing the algorithm to re-initialize the Satellite Ambiguities.

Flags showing " ria " indicate that ambiguities had to be re-initialized causing the overall number of ambiguity unknowns to grow during calculations. Flags showing " ucs " indicate that cycle slips were not detected by GPS receivers during data collection. Flags showing " flagged " indicate that cycle slips were detected by GPS receivers.

Additional information on Cycle Slips can be further investigated in the Data Analysis Tools by examining Triple Difference Phase Residuals for possible remaining cycle slips in the solution.
## LGO Processing Report: Final Coordinates

### Final Coordinates

<table>
<thead>
<tr>
<th>Reference: 95WR</th>
<th>Rover: E95</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coordinates:</strong></td>
<td></td>
</tr>
<tr>
<td>Latitude:</td>
<td>43° 29' 24.92381&quot; N</td>
</tr>
<tr>
<td>Longitude:</td>
<td>85° 20' 33.00052&quot; W</td>
</tr>
<tr>
<td>Ellip. Hgt.:</td>
<td>285.2887 m</td>
</tr>
<tr>
<td><strong>Solution type:</strong></td>
<td>Phase</td>
</tr>
<tr>
<td><strong>Frequency:</strong></td>
<td>IonoFree (L3)</td>
</tr>
<tr>
<td><strong>Ambiguity:</strong></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Quality:</strong></td>
<td>Sd. Lat: 0.0015 m</td>
</tr>
<tr>
<td></td>
<td>Sd. Posn. 0.0018 m</td>
</tr>
<tr>
<td><strong>M0:</strong></td>
<td>0.7604 m</td>
</tr>
<tr>
<td><strong>Cofactor matrix Qxx:</strong></td>
<td>0.000000378</td>
</tr>
<tr>
<td></td>
<td>0.000000154</td>
</tr>
<tr>
<td></td>
<td>0.00002562</td>
</tr>
<tr>
<td><strong>Baseline vector:</strong></td>
<td>dLat: 0° 15' 25.15220&quot;</td>
</tr>
<tr>
<td></td>
<td>dHgt: -42.1544 m</td>
</tr>
<tr>
<td></td>
<td>Slope: 60440.1495 m</td>
</tr>
<tr>
<td><strong>DOPs (min-max):</strong></td>
<td>GDOP: 2.3 - 86.8</td>
</tr>
<tr>
<td></td>
<td>PDOP: 2.0 - 67.3</td>
</tr>
<tr>
<td></td>
<td>VDOP: 1.7 - 62.3</td>
</tr>
</tbody>
</table>

- when it has to be right

### Notes:

The Final Coordinates indicate the selected Reference and computed Rover coordinates, the Solution/Data type, the final Frequency (or Frequency combination) used and the Ambiguity Status of the final solution.

Position Quality information in terms of Coordinate Standard Deviations, 2-D Horizontal and 1-D Vertical Position Quality together with the square-root of the Variance Factor (M0) and the baseline cofactor matrix (Qxx) are also reported.

The estimated RMS errors can be computed by multiplying the M0 value by the a priori measurement error (0.01m for phase data).

The maximum and minimum GDOP, PDOP, HDOP and VDOP values encountered during the data processing interval are also provided.
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GPS Data Analysis Tools
LGO GPS Data Analysis Tools

Content:
- Access to Analysis Tools
- Satellite Azimuth, Elevation Angle and DOPs Graphs
- Single Difference Code Measurement Residuals
- Double Difference Phase Measurement Residuals
- Triple Difference Phase Measurement Residuals
- Geometric-Free Phase Measurement Residuals
- Baseline Multi-Loop Closures

Exercise:
- Examine the different Data Analysis Tools for:
  - Satellite Azimuth, Elevation Angle and DOPs
  - Measurement Residuals from final baseline solution
  - Baseline Multi-Loop Closures from the Adjustment module

Notes:

The Analysis Tools consist of a series of Graphs and Tables showing Measurement Residuals, DOPs, Azimuths and Elevation Angles for each computed baseline or rover point.

Plots and Graphs from the Analysis Tools are accessed by selecting Analyse when right clicking over a given baseline or computed point in the Results Tab following data processing calculations.

Satellite elevation angles and DOPs graphs should be first examined prior to analyzing the different measurement residual graphs.
**Notes:**

Graphs showing Satellite Elevation Angles illustrate (by color) which satellites were mostly used during data processing and the ones used less often.

Data from low satellite elevation angles (15 degrees or less) have low signal strengths and are more subject to local interference whereas data from high satellite elevation angles (70 degrees or more) have high signal strengths and are less subject to local interference.

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**Notes:**

Graphs showing GDOP, PDOP, HDOP and VDOP values illustrate (by color) the dilutions of precision for the different rover position coordinate components computed from the continuous processing of satellite data at each epoch.

The Table lists the Mean, Minimum and Maximum values for the different DOPs encountered during data processing. Too many sudden and big changes can affect the stability of the computed solution and the ability to fix satellite ambiguities during these intervals.

These graphs should be examined in conjunction with the Overall Statistic portion of the Ambiguity Statistics from GPS Data Processing Report to relate the dilution of precision existing during the periods where ambiguities were resolved.
Notes:

LGO baseline calculations are mainly based on Single Difference data processing. Single Difference observations are processed to obtain either Code Only Differential solutions or Code and Phase Floating Point Ambiguity solutions.

If phase ambiguities can be resolved to their nearest integer values, Fixed Integer Ambiguity solutions are obtained from Double Difference Phase measurements.

Triple Difference data processing is not used to obtain final solutions. Instead, residuals from Triple Difference Phase measurements are used to confirm that cycle slips have been correctly repaired.

Notes:

The LGO Measurement Analysis Tools consist of Graphs and Tables corresponding to the different selection of Residual types (Single, Double and Triple Differences) associated with Code or Phase data types based on the different frequencies available (CA/P1, P2, Iono free, Geometry free for Code data and L1, L2, L3 and L4 for Phase data).

Residuals associated with the data and frequency(ies) used to obtain the final coordinates should be first examined. Satellite(s) showing high residuals and/or large biases can be easily identified by examining the Mean and Standard deviation values from the Tables and by disabling the satellite(s) from the corresponding Graphs. Time periods showing high noise and/or large biases can be precisely identified by zooming the associated portion(s) of the graphs.
Notes:

Solutions obtained from code only data processing are derived from Single Difference Code measurements on the selected frequency (L1, L2 or L3) with no phase ambiguities as reported in the Final Coordinates section of the GPS Data Processing Report.

Single Difference Code residuals should normally be unbiased (zero mean) with an average code noise of +/-0.1 to +/-0.2 m (standard deviation).

Single Difference Code solutions are very sensitive to GDOP values prevailing during the processing (occupation) interval.

L3 (Ionospheric-Free) code solutions are corrected for ionospheric disturbances but exhibit more noise (instability) by a factor of 3 than solutions obtained from single frequency code data.

Notes:

Although LGO baseline solutions are based on Single Difference data processing, Double Difference Phase residuals should be first examined for Fixed Phase Ambiguity solutions based on the frequency (or frequency combination) reported with the Final Coordinates.

Double Difference Phase residuals are free from clock errors and provide the possibility to select a different reference satellite than the one (highest elevation angle and smaller Single Difference Phase noise) initially selected by LGO.

Double Difference Phase residuals should normally be unbiased (zero mean) with an average phase noise of +/-0.01 to +/-0.02 m (standard deviation).

L3 Ionospheric-Free Phase residuals are systematically corrected for ionospheric disturbances but exhibit more noise (instability) by a factor of 3 than single frequency phase residuals.
LGO Triple Difference Phase Residuals

Notes:

Triple Difference Phase residuals can be used to assess the short term stability of satellite phase measurements on the selected frequency by examining their standard deviations which should be typically around 0.005 m.

Sudden jumps in L1 or L2 triple difference phase residuals of about 20 cm or more may indicate cycle slips remaining in the solution.

Triple Difference Phase residual graphs should be examined in conjunction with the Cycle Slips Statistics from the Data Processing Report to confirm that detected cycle slips have been correctly repaired.

LGO Geometric-Free (L4) Residuals

Notes:

L4 Geometric-Free Single or Double Difference Phase residuals can be used to assess the effect of ionospheric disturbances on the Satellite Phase measurements during the data processing interval.

Ionospheric Disturbances are very high and unstable during the day compared to very low and more stable during the night.

Long observation sessions of a few hours or more are required to provide a good indication of the effect of Ionospheric Disturbances on the Satellite Phase measurements.
Notes:

All independent 3-D loop combinations of baselines stored in a project can be computed in the Adjustment Tab.

A Loop Misclosure Result file can be examined by selecting Results Loops from the Adjustment tasks list.

The multi-loop closure program uses the default or current Adjustment Standard Deviation settings and the Statistical Test Criteria parameters to perform an outlier detection test on all individual baseline loop misclosure components in both Cartesian or Geodetic units.

GPS Standard Deviation Settings and Statistical Test Criteria parameters are accessible in the General Parameters of Adjustment Configuration.

Notes:

A 3-D loop misclosure report from the MOVE3 adjustment module is presented for all independent loop closure combinations following the calculations of the Multi-Loop closure program.

Raw Baseline vector components, 3-D Total misclosure, PPM ratio and loop perimeter are reported for each loop. Standardized Misclosures used in the Outlier Detection (W-) Test are then presented for each misclosure components in both Cartesian and Geodetic units. If the Standardized Misclosures exceed the W-Test critical value, they are then flagged and may contain possible outliers in one or more baseline vector components.
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GPS Baseline Troubleshooting
LGO GPS Baseline Troubleshooting

Content:
- Site Occupation Windowing
- Satellite Windowing under a given Occupation
- GPS Processing Parameters Modification
- Baseline Loop Closure and Point Coordinate Averaging

Exercise:
- Edit Processing Parameters, Site Occupation & Satellite Windows to obtain the best solutions based on GPS Data Processing Report File Examination.
- Compute Baseline Closures and Examine Point Averaging.

LGO General GPS Processing Parameters

Notes:
The General Processing parameters consist of: Satellite Elevation Cut-Off angle, Ephemeris Type (Broadcast or Precise) and Solution Type which affect all positioning calculations. The General Processing Parameters also contains a list of satellites that can be completely disabled for all positioning calculations within the entire project.

Additional parameter groups such as Strategy and Extended Outputs can be accessed by selecting Show advanced parameters to obtain optimal Fixed or Float Ambiguity solutions and to display measurement residuals.
Notes:

Data processing parameters related to the Frequency, Fix Ambiguity range (maximum distance), Minimum Duration for float ambiguity solutions, Tropospheric and Ionospheric models with Stochastic Modelling of the Ionosphere can be set to Automatic or be manually specified.

If baseline lengths are greater than the Fix Ambiguity range, an L3 (Ionospheric-Free) Float solution will be obtained from dual frequency data.

The internal limits associated with the Automatic settings of Strategy Parameters are based on the common data frequency(ies) available between Reference and Rover, baseline lengths and occupation time intervals.

Notes:

Site Occupation windowing is accessed by right clicking in the GPS Processing Tab working space and by selecting the proper Window Type (Exclude).
Notes:

Data windowing for a given Site Occupation is done graphically by holding and moving the mouse cursor over the occupation bar corresponding to the desired window interval.

All satellite data contained in the selected site window interval will be omitted during data processing. Two or more window intervals can be selected for a given Site Occupation.

More precise window intervals can be defined by either zooming portion of the selected Site Occupation or by entering the exact values. Manual entries of Start and End time epochs for windowing must be enabled in the Data Processing option from the Tools pull-down menu before defining the project.

Notes:

Satellite Data windowing is accessed by right clicking over the specific site occupation bar in the GPS Processing Tab and by selecting Satellite Windows.
LGO Satellite Observation Intervals

Notes:
The Satellite Windows show the Observation Intervals for all satellites tracked by the receiver at a given site occupation.
The proper Satellite Windowing option should be first selected by right clicking in the working space and by selecting satellite windowing (Exclude).

LGO Satellite Windowing

Notes:
Satellite windowing for a specific satellite is done graphically by holding and moving the mouse cursor over the satellite occupation bar corresponding to the desired window interval.
Two or more window intervals can be selected for one or more satellite observation intervals.
More precise time intervals can be specified by entering the exact values. Manual entries of Start and End time epochs for windowing must be enabled in the Data Processing option from the Tools pull-down menu.
LGO Site and Satellite Windowing Intervals

Notes:
Confirmation of the different Windowing intervals on Site and Satellite Data are illustrated in the GPS Processing Tab working space.
Proper amount of common data between site occupations should be provided for adequate baseline vector solutions.

LGO Site Windowing Reset Options

Notes:
All selected Site windowing intervals can be reset by right clicking in the GPS Processing Tab working space and by selecting Windowing options for including, deactivating or removing all windows.
All GPS Processing parameters previously modified in the General and Strategy Parameters Panels should also be reset to User or Default values for subsequent baseline processing in the project.
LGO Satellite Windowing Reset Options

Notes:
All selected Satellite specific windowing intervals at a given Site can be reset by accessing the Satellite Windows, right clicking in the Satellite Observation diagram and by selecting Satellite windowing options for including or removing all satellite windows.
All GPS Processing parameters previously modified in the General and Strategy Parameters Panels should also be reset to User or Default values for subsequent baseline processing in the project.

LGO Point Averaging Warning & Examination

Notes:
Following the storage of baselines in the Results Tab, Warning Messages related to averaging limits exceeded at one or more Stations are illustrated by dashed squares in the View/Edit and Adjustment Tabs.
Point Averaging information is accessed by right clicking over the point, selecting Properties and the Mean option tab.
Coordinate differences between the mean solution and the different determinations are presented with the one(s) exceeding the Project Averaging limits initially set in the Project General Properties.
Mean Coordinate values are the weighted mean values derived from the different determinations within the averaging limits. They are not adjusted coordinates in a Least-Squares Network Adjustment sense.
Different determinations can be selected or de-selected to modify the Mean Coordinates. GPS baselines vectors are not affected by Mean Coordinates editing.
Notes:

Editing a Point Interval for Antenna Height or Annotation corrections is accessed by right clicking over the Point and by selecting Edit Interval option in the View/Edit Tab working space.

Interval information consists of Antenna Height and Annotations for all occupation intervals over that point.

Changes in antenna heights will delete baseline solutions originating or going to that point for the selected time intervals.

Annotations from field notes can be changed for each occupation interval for that point.

Notes:

Manual GPS Baseline Loop Misclosure calculations are accessed by right clicking in the View/Edit Tab working space and by selecting Show Loop Misclosure.

Three or more GPS baseline vectors linked together can be selected to compute a loop misclosure in 3 dimensions.

Manual GPS Baseline misclosures calculations are performed by either clicking over the appropriate baselines or by selecting a starting point and by adding next points until a closed figure loop is achieved.

Different solutions of a given baseline will be presented to select a specific solution from the different occupations.

The differences in Latitude (North-South), Longitude (East-West) and Height (Up-Down) components are reported as misclosures from the summation of selected baseline vector components. Baseline vector components and coordinates are not adjusted from a Loop Misclosure.
Notes:

GPS and/or TPS Raw Observations can be examined in View Observations in either View/Edit or Adjustment Tab.

The View Observation Table displays for each raw observation triplet, Reference (Station) and Rover (Target) Site Names, Occupation Date and Time, Antenna (Instrument and Target) Heights, Site and Target Offsets, Raw Measurements with their associated Quality Indicators.

Specific GPS and/or TPS Raw Measurements can also be accessed graphically by right clicking over the raw measurements and select Find or Zoom to Observations.

The View Observation feature should complement GPS Baseline or TPS Measurement Troubleshooting.
Leica SYSTEM 1200

Leica Geo Office
Adjustment Parameters
LGO Adjustment Parameters

Content:
- General Adjustment Settings & Parameters
- Adjustment Control
- GPS & TPS Observation Errors
- Station(Ref)/ Target(Rover) Setup Errors
- Statistical Constraining Schemes
- Statistical Test Parameters
- Datum Parameters
- Terrestrial Parameters for TPS Measurements

Exercise:
- Setup parameters for TPS and GPS Network Adjustment.

Notes:
The Adjustment Network Design, 3-D Multi-Loop Closure and Adjustment Calculation tasks for either GPS and/or TPS Data are accessed by selecting the Adjustment Tab in a Project.

Following the Adjustment Tab selection, the different Design and Adjustment options are listed by clicking the Adjustment pull-down menu in the Task bar or by right clicking in the Adjustment working area.

General Parameters should be first selected prior to conduct Network Design Error Analysis, 3-D Multi-Loop Closure or Data Adjustment calculations.

Additional parameters for Terrestrial (TPS) Data can also be selected prior to conduct Network Design Error Analysis or TPS Data Adjustment calculations.
The Control Parameter sets up the mode in which the Adjustment options will be used as either to conduct Network Design Error Analysis or Data Adjustment calculations.

The number of iterations and the step Iteration Criteria limit can be set to guarantee proper solution convergence and numerical stability in the adjustment.

Usually, 1 or 2 iteration(s) at 0.0001 m step limit are sufficient for GPS vector adjustment whereas 2 to 3 iterations are sufficient for TPS Observation adjustment.

The default dimension of the Adjustment module is set for 3-D. However, 2-D Horizontal or 1-D Vertical Data adjustments can be performed with appropriate entries and constraints.

The Standard Deviation Parameters provide initial error estimates to all Terrestrial or GPS Observations for Network Designs, 3-D Multi-Loop Closures and Data Adjustment calculations.

These observation error estimates can be used to overwrite individual observation errors if they are set as the default settings for all GPS or Terrestrial observations.

In the case of GPS vector adjustment, the individual settings for GPS observations should be selected to use the GPS vector covariance as the initial error estimates multiplied by the Sigma a priori (Test Criteria) GPS factor for Network Designs, 3-D Multi-Loop Closures or Data Adjustment calculations.
LGO Adjustment Centering/Height Errors

**Notes:**

The Centering/Height Parameters provide additional errors to initial observation error estimates based on Station (Reference for GPS/Target (Rover for GPS) Horizontal and Vertical setup errors to all Terrestrial or GPS Observations for Network Design or Data Adjustment calculations.

These Station Setup errors can be used if the default settings for all observations option is selected. Otherwise, the individual settings for all observations can be selected or be ignored in order to prevent using these setup errors in the Design or Adjustment calculations.

LGO Adjustment Constraining Options

**Notes:**

The Known Station Parameter sets the type of coordinate constraining to be applied in Network Design or Data Adjustment calculations.

The default Known Station parameter is Fully Constrained Adjustment where control coordinates are absolutely held fixed in the adjustment.

Partial constraining on coordinates can be selected using position standard deviations obtained from previous calculations or manually entered under control coordinate class and sub-classes for a Weighted Constrained adjustment.
LGO Adjustment Control Coordinate Options

Notes:

Known coordinate values can be manually entered by right clicking over a Point in the Adjustment Tab working space and by selecting the Point properties and then accessing the Control Coordinate Class.

One of the 3 Control sub-classes for coordinate constraining in 3 dimensions, 2 dimensions for horizontal and 1 dimension for vertical (height) constraining can be further specified.

Constraints in Heights are related to Ellipsoid Heights and not to Orthometric (Mean Sea Level) Heights unless a Coordinate System containing a Geoid Model with already computed Geoid Separations to the Local Geodetic or WGS84 ellipsoid are available in the Project.

Coordinate Standard deviations can also be entered and used for partial constraining when selecting the Weighted Fixed Station parameter option.

LGO Adjustment Statistical Test Parameters

Notes:

The Test Criteria Parameters set the Error Probability (Alpha) and Power (1-Beta) levels for the different statistical tests: Variance Ratio (F-Distribution), Outlier Detection (W-Distribution) and 3D GPS vector magnitude Outlier Detection (T-Distribution) conducted in Network Design, 3-D Multi-Loop Closure and Data Adjustment calculations.

A sigma a priori value for GPS data can be used to scale the GPS initial observation error estimates (vector covariance) for the Variance Ratio F-Test and the 3-D Loop Misclosure Outlier Detection Test.

The sigma a posteriori value is normally used to scale the adjusted coordinate, observation and residual covariance matrices.
LGO Adjustment Coordinate System Options

Refraction Coefficient for TPS Adjustment

Notes:
The Coordinate System Parameters provide the capability of computing the adjustment directly on a Local Geodetic (Ellipsoid with or without Map Projection) Coordinate System or directly on a Local (Arbitrary) Grid System for TPS measurements only.

Additional unknowns such as 3 Rotations along each cartesian axis and 1 Scale Factor can be determined together with the coordinate unknowns in order to adjust GPS data to existing known controls on a Local Geodetic System.

If the values of the local datum parameters are known with respect to the WGS84 system, they can be manually entered in order to be held fixed in the adjustment.

Adjustment of orthometric heights can be directly conducted when selecting a Local Geodetic or Grid System from 1 or more known orthometric heights used as vertical constraints in absence of a Geoid Model.

Notes:
The default value of 0.13 for the Vertical Angle Refraction Coefficient is normally not enabled. However, if the Refraction Coefficient affecting all Zenith Angle measurements is known, it can be manually specified.

The Refraction Coefficient affecting all Zenith Angle measurements can also be estimated and applied in the adjustment. Three or more stations known in vertical must be held fixed to correctly determine this additional parameter in the adjustment of TPS data.
Azimuth Offset for TPS Adjustment

Notes:
The default value of 0 degree (Geodetic North) for the Azimuth Offset is normally not enabled. However, if the Azimuth Offset value affecting all Azimuth measurements is known, it can be manually specified. The Azimuth Offset affecting all Azimuth measurements can also be estimated and applied in the adjustment. Two or more stations known in horizontal must be held fixed to correctly determine this additional parameter in the adjustment of TPS data.

Distance Scale Factor for TPS Adjustment

Notes:
The default value of 0.0 ppm for the Distance Scale Factor is normally not enabled. However, if the Distance Scale Factor value affecting all Distance measurements is known, it can be manually specified. The Distance Scale Factor affecting all distance measurements can also be estimated and applied in the adjustment. Two or more stations known in horizontal must be held fixed to correctly determine this additional parameter in the adjustment of TPS data.
Coordinate classes in the Adjustment consist of two main classes: Adjusted and Control.

The Control Coordinate class has 3 sub-classes for coordinate constraining in 3 dimensions, 2 dimensions for horizontal and 1 dimension for vertical (height) constraining.

The adjustment of GPS and/or TPS data is computed in a 3-dimensional Geodetic System based on either the WGS84 or a Local Geodetic ellipsoid surface. Coordinate constraining must then be based directly on WGS84 Latitude, Longitude & Ellipsoid Height values or indirectly on Local Geodetic (Ellipsoid with or without Mapping Grid) coordinates with Ellipsoid Heights (Orthometric with Geoid Separation) via an adequate Local Geodetic Coordinate System attached to the Project.
LGO Adjustment Report

Content:
- LGO Adjustment Statistical Tests
- Adjustment Result Examination
- General Adjustment Statistics
- Estimated Variance Factor (F-Test)
- Input Observations and Initial Errors
- Adjusted Coordinates and Confidence Regions
- Outlier Detection (W- and T-Tests)
- Estimated Errors on Observations and Known Coordinates

Exercise:
- Examine Adjustment Report to Identify Poor Measurements.

LGO Statistical Hypothesis Testing

Statistical testing involves accepting or rejecting a statement using a Prime and an Alternate Hypothesis:
- The acceptance of the Prime hypothesis while in fact the statement is false leads to a Type II decision error having a probability given by \( \beta \), where \( (1-\beta) \) is the power level of the test.
- The rejection of the Prime hypothesis while in fact the statement is true leads to a Type I decision error having a probability given by \( \alpha \), where \( \alpha \) is the error probability level of the test.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Decision: accept Prime (reject Alternate)</th>
<th>Decision: reject Prime (accept Alternate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>True</td>
<td>correct decision: probability = ( (1 - \alpha) )</td>
<td>Type I Decision Error: probability = ( \alpha )</td>
</tr>
<tr>
<td>False</td>
<td>Type II Decision Error: probability = ( \beta )</td>
<td>correct decision: probability = ( (1 - \beta) )</td>
</tr>
</tbody>
</table>

Notes:
There are 3 Statistical Tests conducted in LGO Adjustment. A Variance Ratio test (F-Test) is performed by comparing the ratio between the computed a-posteriori variance factor and the a-priori variance factor with a statistical value derived from a F Probability Distribution. Two Measurement Blunder Detection tests are conducted by comparing the individual Standardized Residuals (W-Test) and GPS vector group Standardized Residuals (T-Test) with statistical values derived from a Tau Probability Distribution. All Statistical Tests are based on standard hypothesis testing (Prime and Alternate Hypotheses) with Error Probability (Alpha) and Power of Test (1-Beta) Levels.
The Alpha value sets the Error Probability Level for the F, W and T Tests. An Alpha value of 5% corresponds to a 95% confidence level (2-sigma value) for tight (small critical values) Variance Ratio and Blunder Detection Tests. An Alpha value of 1% corresponds to a 99.0% confidence level (2.5-sigma value) for fair Variance Ratio and Blunder Detection Tests. An Alpha value of 0.1% corresponds to a 99.9% confidence level (3-sigma value) for loose (large critical values) Variance Ratio and Blunder Detection Tests.

Notes:

The (1 - Beta) value sets the Power of the F, W and T Tests together with calculation of Internal and External Reliability values related to the Observations and Coordinates respectively.

A (1-Beta) value of 70% slightly increases critical values to further relax the Variance Ratio and Blunder Detection Tests.

A (1-Beta) value of 80% provides fair critical values for the Variance Ratio and Blunder Detection Tests.

A (1-Beta) value of 90% slightly reduces critical values to further tighten the Variance Ratio and Blunder Detection Tests.

The a priori sigma for GPS is a factor which scales the initial GPS vector covariance for the Variance Ratio F-test.
Notes:
The Variance Ratio test is a 1-tail test comparing the Variance Ratio against a F-Critical Value.

If Variance Ratio < F-Critical value => the F-Test passes
The Variance Ratio is given by the following expression: $\sigma^2 / \sigma_0^2$
where: $\sigma^2$ = a-posteriori (computed) variance factor which is the Weighted Sum of the Squares of Residuals divided by the Degree of Freedom.
$\sigma_0^2$ = a-priori (initial) variance factor used for observation weighting (normally 1.0)
F-Critical Value = Statistical value based on Degrees Of Freedom and Error Probability from a F-Distribution.

Notes:
The W-Blunder Detection test is a 2-tail test comparing the individual Standardized Residuals (Std. Res.) with a W-Critical Value derived from a Tau-Distribution.

If -W Critical Value < Std. Res. < W Critical Value => W-Test passes
where: Std. Res. = $r / (\sigma^2)^{1/2}$ (Residual over its Standard Deviation)
W-Critical Value = Statistical value based on Error Probability and degrees of freedom from a Tau-Distribution.
LGO Group Blunder Detection T - Test

Prime Hypothesis  |  Alternate Hypothesis

T - Distribution
T - Test
Confidence Level (%)

Power of test
T - Test
Error Probability Level (%)

Notes:
The T - Blunder Detection test is a 1-tail test comparing Group Standardized Residuals (Grp. Std. Res.) with a T - Critical Value derived from a Tau-Distribution.

If Grp.Std. Res. < T-Critical Value => T-Test passes

where: Grp.Std.Res. = Group Residual Value / Group Residual Standard Deviation
T - Critical Value = Statistical value based on Degrees Of Freedom and Error Probability from a Tau-Distribution

LGO Adjustment Report Project Information

Network Adjustment

Project Information

| Project name:          | FERRIS_NETWORK          |
| Date created:         | 04/25/2005 10:29:47    |
| Time zone:             | -6:00                  |
| Coordinate system name: | Michigan South NAD83   |
| Application software:  | MOVE3 3.3.1            |
| Processing kernel:    | MOVE3 3.3.1            |

Notes:
The LGO Adjustment Report Project contains general information about the version of the MOVE3 adjustment kernel and the Coordinate System (Local Geodetic or WGS84) currently attached to the Project.
The contents of the Adjustment Report can be selected in the Report Template Management Group for the Network Adjustment Default Settings.
### LGO Adjustment Report General Information

**General Information**

<table>
<thead>
<tr>
<th>Adjustment</th>
<th>Constrained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension:</td>
<td>3D</td>
</tr>
<tr>
<td>Coordinate system:</td>
<td>Local geodetic</td>
</tr>
<tr>
<td>Height mode:</td>
<td>Ellipsoidal</td>
</tr>
<tr>
<td>Number of iterations:</td>
<td>2</td>
</tr>
<tr>
<td>Maximum coord correction in last iteration:</td>
<td>0.000 m (tolerance is met)</td>
</tr>
<tr>
<td>Stations:</td>
<td>6</td>
</tr>
<tr>
<td>Number of (parly) known stations:</td>
<td>17</td>
</tr>
<tr>
<td>Total:</td>
<td>23</td>
</tr>
<tr>
<td>Observations:</td>
<td>111 (57 baselines)</td>
</tr>
<tr>
<td>Known coordinates:</td>
<td>9</td>
</tr>
<tr>
<td>Total:</td>
<td>120</td>
</tr>
<tr>
<td>Unknowns:</td>
<td>69</td>
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<tr>
<td>GPS transformation parameters:</td>
<td>4</td>
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<tr>
<td>Total:</td>
<td>73</td>
</tr>
<tr>
<td>Degrees of freedom:</td>
<td>47</td>
</tr>
</tbody>
</table>

### LGO Adjustment Report Testing Information

**Testing**

<table>
<thead>
<tr>
<th>Null hypothesis</th>
<th>$\mathcal{H}_0$ (multi dimensional):</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alls (one dimensional):</td>
<td>Name</td>
</tr>
<tr>
<td>Beta:</td>
<td>Sigma a-priori (GPS):</td>
</tr>
<tr>
<td>Critical value W-test:</td>
<td>1.96</td>
</tr>
<tr>
<td>Critical value T-test (2-dimensional):</td>
<td>2.42</td>
</tr>
<tr>
<td>Critical value T-test (3-dimensional):</td>
<td>1.80</td>
</tr>
<tr>
<td>Critical value F-test (rejected):</td>
<td>0.96</td>
</tr>
</tbody>
</table>

**Notes:**

The Adjustment Report General Information presents the adjustment type (Inner (fully free), Minimally or Fully Constrained), Coordinate System (Local Geodetic or WGS84) used to adjust the observations and the Height Mode (Ellipsoidal or Orthometric) used in the adjustment.

The Number of Iterations and its the brake point are presented together with the Number of Stations, Coordinate Unknowns, Observations and the Degrees of Freedom in the adjustment.

The Degrees of Freedom is the difference between the total number of Observations and the number of Unknowns to be determined. It is used in the calculation of the a-posteriori variance factor and in the determination of the critical values associated to the different statistical tests.

The larger the Degrees of Freedom is the more meaningful statistical tests become.

**Notes:**

Critical values for the $F$, $W$ & $T$ tests are presented for the selected Error Probability and Power Levels based on the Degrees of Freedom and the Associated Probability Distributions.

The acceptance or rejection of the $F$-Test is presented by indicating the computed Variance Ratio value.

A Variance Ratio significantly greater than the $F$-Critical value indicates that residuals are too big compared to the initial observation errors or that initial observation errors are small compared to the residuals so that the $F$-Test is rejected.

A Variance Ratio close to 1.00 indicates that the initial observation errors are in agreement with the residuals so that the $F$-Test is accepted.

A Variance Ratio significantly smaller than 1.00 indicates that the initial observation errors are too large compared with residuals even if the $F$-Test passes.
# LGO Adjustment Report Initial Coords. &Parms.

## Input data

### Approximate Coordinates

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Height [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>S4102</td>
<td>43° 41' 02.1994&quot; N</td>
<td>66° 29' 00.9664&quot; W</td>
<td>367.1608</td>
</tr>
<tr>
<td>54192</td>
<td>43° 26' 24.6756&quot; N</td>
<td>66° 29' 32.8205&quot; W</td>
<td>370.7403</td>
</tr>
<tr>
<td>ADVANTAGE</td>
<td>43° 41' 12.2036&quot; N</td>
<td>66° 29' 32.8205&quot; W</td>
<td>362.3479</td>
</tr>
<tr>
<td>8341</td>
<td>43° 56' 38.8936&quot; N</td>
<td>65° 56' 00.0097&quot; W</td>
<td>366.8506</td>
</tr>
<tr>
<td>BARTLETT</td>
<td>43° 41' 17.3895&quot; N</td>
<td>65° 39' 33.7460&quot; W</td>
<td>252.2444</td>
</tr>
<tr>
<td>BENDON</td>
<td>43° 41' 16.5831&quot; N</td>
<td>65° 39' 33.7460&quot; W</td>
<td>265.7702</td>
</tr>
</tbody>
</table>

### Initial Geodetic Coordinate Values

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Height [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>S4102</td>
<td>43° 41' 02.1994&quot; N</td>
<td>66° 29' 00.9664&quot; W</td>
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<tr>
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<td>252.2444</td>
</tr>
<tr>
<td>BENDON</td>
<td>43° 41' 16.5831&quot; N</td>
<td>65° 39' 33.7460&quot; W</td>
<td>265.7702</td>
</tr>
</tbody>
</table>

## Additional Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Std</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS rotation x-axis</td>
<td>0.00000 &quot;</td>
<td>free</td>
</tr>
<tr>
<td>GPS rotation y-axis</td>
<td>0.00000 &quot;</td>
<td>free</td>
</tr>
<tr>
<td>GPS rotation z-axis</td>
<td>0.00000 &quot;</td>
<td>free</td>
</tr>
<tr>
<td>GPS scale factor</td>
<td>1.000000000000</td>
<td>free</td>
</tr>
</tbody>
</table>

### GPS to Local Datum Parameters

<table>
<thead>
<tr>
<th>GPS station</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DK</td>
<td>0.00000 &quot;</td>
</tr>
<tr>
<td>DZ</td>
<td>0.00000 &quot;</td>
</tr>
</tbody>
</table>

## Notes:

Initial coordinates are presented in Geodetic units with indicators that some of their component(s) will be completely or partially held fixed in the adjustment.

Additional input parameters related to the overall TPS and GPS measurements are also presented with their initial value and their constraining (Std) status before adjustment.

---

# LGO Adjustment Observations & Initial Errors

## Observations

<table>
<thead>
<tr>
<th>Station</th>
<th>Target</th>
<th>Sth, Tph</th>
</tr>
</thead>
<tbody>
<tr>
<td>DK</td>
<td>NORM</td>
<td>123,223 m</td>
</tr>
<tr>
<td>DZ</td>
<td>NORM</td>
<td>123,223 m</td>
</tr>
<tr>
<td>DV</td>
<td>NORM</td>
<td>123,223 m</td>
</tr>
</tbody>
</table>

## Standard deviations

### Lower Triangular Part of GPS Vector Covariance Matrix: Standard Deviations in diagonal elements and Correlation Factor in off-diagonal elements.

<table>
<thead>
<tr>
<th>Station</th>
<th>Target</th>
<th>Sd ele / Cor</th>
<th>Sd rel / Cor</th>
<th>Sd rel / Cor</th>
</tr>
</thead>
<tbody>
<tr>
<td>DK</td>
<td>NORM</td>
<td>0.0010 m</td>
<td>0.0000 m</td>
<td></td>
</tr>
<tr>
<td>DZ</td>
<td>NORM</td>
<td>0.0010 m</td>
<td>0.0000 m</td>
<td></td>
</tr>
<tr>
<td>DV</td>
<td>NORM</td>
<td>0.0010 m</td>
<td>0.0000 m</td>
<td></td>
</tr>
</tbody>
</table>

---

## Notes:

GPS Input Observations are related to Reference and Rover names respectively. GPS Vector components are the Cartesian coordinate differences between the reference and the rover units.

Initial Errors for GPS vectors are presented by the Lower Triangular Part of the vector covariance matrix in Cartesian units with standard deviation values (m) along the diagonal and correlation factors (dimensionless) in the off-diagonal positions. The initial GPS Vector errors include the Reference and Rover Centering and Height Set Up errors.

The Initial Observation Errors can be changed by selecting the proper values in the Standard Deviations Panel for TPS measurements, Centering and Height Error Panel for TPS and GPS and the proper GPS a priori factor in the Test Criteria Adjustment Parameter Tabs.
LGO Adjusted Coordinates and Precisions

Corrections from initial to adjusted coordinate values

<table>
<thead>
<tr>
<th>Station</th>
<th>Coordinates</th>
<th>Coord</th>
<th>Prec (95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>54102</td>
<td>Latitude</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Longitdue</td>
<td>43° 41' 02.1202&quot; N</td>
<td>0.0031 m</td>
</tr>
<tr>
<td></td>
<td>Height</td>
<td>267.1869 m</td>
<td>0.0020 m</td>
</tr>
<tr>
<td>95985R</td>
<td>Latitude</td>
<td>43° 39' 04.3362&quot; N</td>
<td>0.0020 m</td>
</tr>
<tr>
<td></td>
<td>Longitude</td>
<td>98° 20' 09.3977&quot; W</td>
<td>0.0020 m</td>
</tr>
</tbody>
</table>

Coordinate Precision at Confidence Level

Additional Parameters

<table>
<thead>
<tr>
<th>Adj. vars</th>
<th>Coord</th>
<th>Sd</th>
</tr>
</thead>
<tbody>
<tr>
<td>x-axis</td>
<td>-1.2982 *</td>
<td>2.0903 *</td>
</tr>
<tr>
<td>y-axis</td>
<td>-0.9521 *</td>
<td>2.3602 *</td>
</tr>
<tr>
<td>z-axis</td>
<td>-0.6193 *</td>
<td>2.3602 *</td>
</tr>
</tbody>
</table>

Notes:

Final adjusted Station coordinates are presented with their corrections applied from their initial or previously adjusted values together with their standard deviations (precision estimates) at the selected Confidence Level.

Precision estimates are based on the final adjustment covariance scaled by either the computed or the initial variance factor times the factor corresponding to the selected confidence level: 68% (1-sigma), 95% (2-sigma) or 99.9% (3-sigma).

However, these precision estimates are stored in the LGO Data Base Point Stochastic Properties as 1-Sigma (68%) error estimates.

Terrestrial and GPS to Local Datum parameters can be estimated to relax the adjustment from external constraints. These external parameters are reported with their associated standard deviations.

LGO GPS Adjusted Observations & Residuals

Observations and Residuals

<table>
<thead>
<tr>
<th>Station</th>
<th>Residuals in Cartesian Units</th>
<th>Residuals in Geographic Units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Target</td>
<td>Adj. elo</td>
</tr>
<tr>
<td>D0</td>
<td>NORM</td>
<td>LEICA</td>
</tr>
<tr>
<td>D0</td>
<td>NORM</td>
<td>HOLLAND</td>
</tr>
<tr>
<td>D0</td>
<td>NORM</td>
<td>GIFFLES</td>
</tr>
<tr>
<td>D0</td>
<td>NORM</td>
<td>HOLLAND</td>
</tr>
<tr>
<td>D0</td>
<td>NORM</td>
<td>GIFFLES</td>
</tr>
<tr>
<td>D0</td>
<td>NORM</td>
<td>GIFFLES</td>
</tr>
<tr>
<td>D0</td>
<td>NORM</td>
<td>GIFFLES</td>
</tr>
</tbody>
</table>

Notes:

Residuals are the minimum corrections applied to observations in order to determine the best-fit set of adjusted coordinates. They are presented in their original measurement units.

GPS vector residuals are also presented in their East, North and Height components to easily detect possible blunders in both horizontal and/or vertical observation components such as centering and antenna height errors respectively.

Small and unbiased (zero mean) residuals indicate good agreement between measurements whereas large and biased residuals indicate noisy measurements with systematic errors possibly remaining in the observations.

GPS Baseline Vector Residuals

<table>
<thead>
<tr>
<th>Station</th>
<th>Target</th>
<th>Adj. Vector [m]</th>
<th>Resid [m]</th>
<th>Resid [ppm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>D0</td>
<td>NORM</td>
<td>LEICA</td>
<td>283.4626 m</td>
<td>0.0003</td>
</tr>
<tr>
<td>D0</td>
<td>NORM</td>
<td>HOLLAND</td>
<td>69.4063 m</td>
<td>0.0004</td>
</tr>
<tr>
<td>D0</td>
<td>NORM</td>
<td>GIFFLES</td>
<td>63.9437 m</td>
<td>0.0014</td>
</tr>
<tr>
<td>D0</td>
<td>NORM</td>
<td>54102</td>
<td>30966.502 m</td>
<td>0.0009</td>
</tr>
<tr>
<td>D0</td>
<td>NORM</td>
<td>LEICA</td>
<td>209.3660 m</td>
<td>0.0023</td>
</tr>
</tbody>
</table>

Notes:

Residuals are the minimum corrections applied to observations in order to determine the best-fit set of adjusted coordinates. They are presented in their original measurement units.

GPS vector residuals are also presented in their East, North and Height components to easily detect possible blunders in both horizontal and/or vertical observation components such as centering and antenna height errors respectively.

Small and unbiased (zero mean) residuals indicate good agreement between measurements whereas large and biased residuals indicate noisy measurements with systematic errors possibly remaining in the observations.

GPS Baseline Vector Residuals are reported as 3-dimensional baseline vector error estimates after adjustment. A 3-D Part Per Million is also presented for each adjusted vector by computing the 3-D baseline vector error estimate over the baseline distance.
### LGO External Reliability on Coordinates

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>E96</td>
<td>0.0119</td>
<td>0.0010</td>
<td>0.0000</td>
</tr>
<tr>
<td>BULLDOG</td>
<td>0.0050</td>
<td>0.0002</td>
<td>0.0001</td>
</tr>
<tr>
<td>E81</td>
<td>0.0040</td>
<td>0.0003</td>
<td>0.0005</td>
</tr>
<tr>
<td>ADVANTAGE</td>
<td>0.0030</td>
<td>0.0001</td>
<td>0.0005</td>
</tr>
<tr>
<td>E81</td>
<td>0.0010</td>
<td>0.0010</td>
<td>0.0000</td>
</tr>
<tr>
<td>BULLDOG</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

### Notes:
The External Reliability values are stochastic estimates approximating the maximum influence of one undetected observation blunder on the adjusted coordinates.

Small External Reliability values indicate that adjusted coordinates are stable even if a measurement blunder remains in the observations.

---

### LGO Absolute & Relative Confidence Regions

#### Semi Major Axis

<table>
<thead>
<tr>
<th>Station</th>
<th>A [m]</th>
<th>B [m]</th>
<th>A/B</th>
<th>Orientation from North</th>
</tr>
</thead>
<tbody>
<tr>
<td>E96</td>
<td>0.0118</td>
<td>0.0089</td>
<td>1.4</td>
<td>4.9°</td>
</tr>
<tr>
<td>BULLDOG</td>
<td>0.0230</td>
<td>0.0184</td>
<td>1.2</td>
<td>-11°</td>
</tr>
<tr>
<td>ADVANTAGE</td>
<td>0.0030</td>
<td>0.0030</td>
<td>1.0</td>
<td>6°</td>
</tr>
<tr>
<td>E81</td>
<td>0.0010</td>
<td>0.0010</td>
<td>1.0</td>
<td>6°</td>
</tr>
</tbody>
</table>

#### Semi Minor Axis

<table>
<thead>
<tr>
<th>Station</th>
<th>A [m]</th>
<th>B [m]</th>
<th>A/B</th>
<th>Orientation from North</th>
</tr>
</thead>
<tbody>
<tr>
<td>E96</td>
<td>0.0089</td>
<td>0.0118</td>
<td>0.76</td>
<td>4.9°</td>
</tr>
<tr>
<td>BULLDOG</td>
<td>0.0184</td>
<td>0.0030</td>
<td>6.1</td>
<td>-11°</td>
</tr>
<tr>
<td>ADVANTAGE</td>
<td>0.0030</td>
<td>0.0030</td>
<td>1.0</td>
<td>6°</td>
</tr>
<tr>
<td>E81</td>
<td>0.0010</td>
<td>0.0010</td>
<td>1.0</td>
<td>6°</td>
</tr>
</tbody>
</table>

#### Axis Ratio

<table>
<thead>
<tr>
<th>Station</th>
<th>A/B</th>
<th>Orientation from North</th>
</tr>
</thead>
<tbody>
<tr>
<td>E96</td>
<td>1.4</td>
<td>4.9°</td>
</tr>
<tr>
<td>BULLDOG</td>
<td>1.2</td>
<td>-11°</td>
</tr>
<tr>
<td>ADVANTAGE</td>
<td>1.0</td>
<td>6°</td>
</tr>
<tr>
<td>E81</td>
<td>1.0</td>
<td>6°</td>
</tr>
</tbody>
</table>

#### Standard Deviation in Height

<table>
<thead>
<tr>
<th>Station</th>
<th>SD Hgt [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>E96</td>
<td>0.0001</td>
</tr>
<tr>
<td>BULLDOG</td>
<td>0.0002</td>
</tr>
<tr>
<td>ADVANTAGE</td>
<td>0.0003</td>
</tr>
<tr>
<td>E81</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

#### Relative Error Ellipses (90%)

<table>
<thead>
<tr>
<th>Station</th>
<th>A [m]</th>
<th>B [m]</th>
<th>A/B</th>
<th>Orientation from North</th>
</tr>
</thead>
<tbody>
<tr>
<td>E96</td>
<td>0.0118</td>
<td>0.0089</td>
<td>1.4</td>
<td>4.9°</td>
</tr>
<tr>
<td>BULLDOG</td>
<td>0.0230</td>
<td>0.0184</td>
<td>1.2</td>
<td>-11°</td>
</tr>
<tr>
<td>ADVANTAGE</td>
<td>0.0030</td>
<td>0.0030</td>
<td>1.0</td>
<td>6°</td>
</tr>
</tbody>
</table>

#### Orientation from Azimuth

<table>
<thead>
<tr>
<th>Station</th>
<th>Orientation from Azimuth</th>
</tr>
</thead>
<tbody>
<tr>
<td>E96</td>
<td>4.9°</td>
</tr>
<tr>
<td>BULLDOG</td>
<td>-11°</td>
</tr>
<tr>
<td>ADVANTAGE</td>
<td>6°</td>
</tr>
<tr>
<td>E81</td>
<td>6°</td>
</tr>
</tbody>
</table>

#### Standard Deviation in Height Difference

<table>
<thead>
<tr>
<th>Station</th>
<th>SD Hgt [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>E96</td>
<td>0.0001</td>
</tr>
<tr>
<td>BULLDOG</td>
<td>0.0002</td>
</tr>
<tr>
<td>ADVANTAGE</td>
<td>0.0003</td>
</tr>
<tr>
<td>E81</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

### Notes:
Absolute Confidence Regions provide Error Ellipses at each point whereas Relative Confidence Regions provide relative Error Ellipses between points at the selected confidence level(%) of each coordinate component.

Confidence regions are derived from the adjusted coordinate covariance matrix times the factor associated with the selected confidence level (68%, 95% or 99.9%) for each coordinate component.

However, these confidence regions are stored in LGO Data Base as 1-sigma (68%) error ellipses and height error intervals.
LGO Test on Known Coordinates

**Testing and Estimated Errors**

<table>
<thead>
<tr>
<th>Coordinate Tests</th>
<th>MDB</th>
<th>BNR</th>
<th>W Test</th>
<th>T-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>54102</td>
<td>0.0391 m</td>
<td>996.9</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>95407</td>
<td>0.0317 m</td>
<td>996.9</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>B341</td>
<td>0.0107 m</td>
<td>999.9</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>BULLDOG</td>
<td>0.0184 m</td>
<td>999.9</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>DRS</td>
<td>0.0146 m</td>
<td>999.9</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>NORM</td>
<td>0.0175 m</td>
<td>999.9</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Notes:

Tests on Known Coordinates are conducted from a Fully-Constrained Network Adjustment when 2 or more stations are held fixed to given values.

Estimated Errors on constrained coordinates are reported as Minimum Detectable Biases (MDB) computed from the estimated errors after adjustment times the threshold generated from the W- & T- Tests critical values to indicate the magnitude and sign of the potential station coordinate errors.

The Bias to Noise Ratio (BNR) is a dimensionless parameter showing the possible influence of a coordinate bias on the adjustment.

Terrestrial and GPS to Local Datum parameters can be estimated to relax the adjustment from external constraints. These external parameters are reported with their associated standard deviations.

---

LGO Observation Blunder Detection (W & T Tests)

**Testing and Estimated Errors**

<table>
<thead>
<tr>
<th>Observation Tests</th>
<th>Station</th>
<th>Target</th>
<th>MDB</th>
<th>Red</th>
<th>BNR</th>
<th>W-Test</th>
<th>T-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DK</td>
<td>BULLDOG</td>
<td>0.0254 m</td>
<td>39</td>
<td>3.4</td>
<td>-0.13</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>CY</td>
<td>BURGH</td>
<td>0.0040 m</td>
<td>51</td>
<td>3.0</td>
<td>-0.10</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>CZ</td>
<td>0.0303 m</td>
<td>68</td>
<td>2.7</td>
<td>-0.20</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DK</td>
<td>BULLDOG</td>
<td>0.0251 m</td>
<td>52</td>
<td>2.6</td>
<td>-0.11</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>CY</td>
<td>0.0240 m</td>
<td>81</td>
<td>1.6</td>
<td>0.13</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CZ</td>
<td>0.0339 m</td>
<td>127</td>
<td>1.0</td>
<td>0.90</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DK</td>
<td>B341</td>
<td>0.0239 m</td>
<td>52</td>
<td>2.5</td>
<td>0.67</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>CY</td>
<td>0.0301 m</td>
<td>77</td>
<td>1.8</td>
<td>0.26</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CZ</td>
<td>0.0135 m</td>
<td>49</td>
<td>2.7</td>
<td>0.20</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DK</td>
<td>B341</td>
<td>0.0190 m</td>
<td>80</td>
<td>1.5</td>
<td>0.73</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>CY</td>
<td>0.0312 m</td>
<td>76</td>
<td>1.1</td>
<td>0.63</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CZ</td>
<td>0.0279 m</td>
<td>63</td>
<td>1.2</td>
<td>0.63</td>
<td>0.39</td>
<td></td>
</tr>
</tbody>
</table>

Notes:

The Internal Reliability is expressed by the Minimum Detectable Bias (MDB) which represents the size of the smallest possible observation error detectable by the W-Blunder Detection test with a probability equal to the power (1-Beta) of the test.

The Redundancy Number (Red) indicates how much in percentage an observation contributes to the overall Degrees of Freedom.

The Bias to Noise Ratio (BNR) is a dimensionless parameter showing the possible influence of a single observation on adjusted coordinates.

The W and T-Test values represent the computed Standardized Residuals for the individual and group (GPS) of observations respectively. These values are tested against the W and T Critical values for possible measurement blunders.
LGO Adjustment Redundancy Number Graph

% 100 90 80 70 60 50 40 30 20 10 0
0 10 20 30 40 50 60 70 80 90 100 Redundancy

Notes:
A Redundancy Number Histogram is presented to summarize how many of these numbers are within specific intervals.
Most of the observations should have redundancy numbers of 50 or greater to illustrate their contribution to the overall network Adjustment.

LGO W-Test Individual Outlier Detection Graph

W-Test Critical Value

Notes:
A W-Test Individual Outlier Detection Histogram is presented as a summary showing the percentage of individual observations that were flagged as possible outliers exceeding the critical value of the W-Test. Observations exceeding the critical value are indicated in red and and their number should be small (low percentage) whereas observations not exceeding the critical value are presented in blue and should contain the majority of measurements (high percentage).
A T-Test Individual Outlier Detection Histogram is presented as a summary showing the percentage of Observation Groups (GPS baseline vectors) that were flagged as possible outliers exceeding the critical value of the T-Test. Observation Groups exceeding the critical value are indicated in red and their number should be small (low percentage) whereas observation groups not exceeding the critical value are presented in blue and should contain the majority of measurement groups (high percentage).

Notes:

Estimated Errors (up to 10) on flagged individual and group standardized residuals from the W and T-Tests are computed from the measurement residuals with respect to its expected error and redundancy number. Estimated errors are based on the alternate hypothesis that only one individual or group observation contains a significant measurement blunder.

The adjustment also estimates errors in GPS baseline vertical components for potentially wrong antenna heights.

Flagged measurements exceeding 2 or more times their expected errors and significantly bigger than their MDB values should be critically examined for potential blunders (systematic errors) remaining in the observations.
Leica SYSTEM 1200

Leica Geo Office
Coordinate Systems
LGO Coordinate Systems

Content:
- Definition
- Coordinate System elements:
  - Transformation
  - Ellipsoid
  - Projection
  - Geoid Model
  - Country Specific Coordinate System (CSCS) Model

Exercise:
- Create Coordinate System and its elements
- Upload Coordinate System to GPS500 & System 1200

Notes:
The main purpose of a Coordinate System is to convert coordinates between WGS84 and Local (Geodetic, State Plane Grid or Arbitrary Grid) systems in LGO projects, GPS500 and SYSTEM1200 units.

A Coordinate System may contain one or more of the following components: a Transformation, an Ellipsoid, a Projection or State Plane Zone, a Geoid Model and a Country Specific Coordinate System (CSCS) Model.

Coordinate Systems containing a One-Step Transformation do not have Ellipsoid, Projection, Geoid and CSCS Models whereas Coordinate Systems having no Transformation (None), a Two-Step or a 3D Classical Transformation type will be related to a local Ellipsoid, Map Projection with a Geoid and a CSCS Model.

Coordinate Systems defined in LGO can be transferred to GPS500 and SYSTEM1200 hardware and be attached to any Jobs.
Notes:

A 3D or a 2D Classical Transformation type can be manually defined in LGO by right clicking over 'Transformations' and select 'New'.

The Transformation parameters From WGS84 → To Local Geodetic System can be manually specified by entering the appropriate information.

All other transformation types such as: One-Step, Two-Step, Stepwise, 3D Interpolation and the determination of 3D & 2D Classical transformation parameters have to be computed either in the LGO 'Datum and Map' option or in GPS500 or System1200 Hardware (One-Step, Two-Step or 3D Classical Transformation type for field units).

Notes:

A new Ellipsoid can be created by right clicking over 'Ellipsoids' and by selecting 'New'.

A new Ellipsoid is defined by a Name, its Semi-Major Axis in metres or feet and its Reciprocal Flattening (1/f).

In North America, it is not necessary to define ellipsoids. The GRS1980 ellipsoid can be selected for NAD83 State Plane Coordinate Systems and the Clarke 1866 ellipsoid can be selected for NAD27 Coordinates.
Creation of a Projection in LGO

Notes:

All projections in North America are available either in 'Projections' or in 'State Plane Zones' folder type as long as the North America option was selected during LGO installation.

A new Projection can be created by right clicking over 'Projection' and select 'New'.

The Projection type must be first selected prior to entering a new Name and the associated projection parameters.

Creation of a Geoid Model in LGO

Notes:

A new Geoid Model is defined by specifying a new Name, a reference Ellipsoid, a Coordinate Type (Geodetic or Grid) and the Path where the Geoid Model EXE file resides.

Geoid Models for North America are related to NAD83 which is a Geodetic System based on the GRS 1980 ellipsoid. Geoid separations are normally computed from the Local Geodetic coordinates.

If a Geoid Model is created with respect to the WGS84 ellipsoid, it can be used with Geodetic coordinates from WGS84 (Global) or Local system. If the WGS84 Geoid model is not applied on the Local side, geoid separations will be used to convert directly WGS84 ellipsoid heights to Local Orthometric heights without using the vertical part of any transformation set attached to the Coordinate Systems. On the other hand, if the WGS84 Geoid model is applied on the Local side, orthometric heights will be derived from the Local ellipsoid heights derived after the vertical part of the Local transformation.
Creation of a CSCS Model in LGO

Notes:
A Country Specific Coordinate System (CSCS) Model can be used to convert cartesian, geodetic or grid coordinates between a Country Coordinate System and WGS84. The conversions are based on coefficients provided by each local country coefficient file.

A new CSCS Model can be created by right clicking over 'CSCS Models' and by selecting 'New'. A new CSCS Model Name with the location of the CSCS Model *.csc file must be specified.

Additional CSCS Models for local coordinate conversions can be added to the existing CSCS Models list by converting the Country Specific coefficient file to LGO *.csc file. The csc file conversion routine resides in the Bin subdirectory of LGO under C:\Program Files\Leica Geosystems\Combined or Terrestrial\Bin. The CSCSModelConvert.exe file must be executed to create a csc file from the original Country-Specific Coordinate System file.

Creation of a Geoid Field File for GPS Units

Notes:
A Geoid Model Field File can be created by selecting the 'Tools' pull-down menu and 'Create Geoid Model Field File' option.

A Geoid Model residing in LGO or SKI-Pro must be selected with 'Centre and radius' or 'South-West and North-East Corner Extents for the area covering the project with a grid spacing.

LGO will display the actual file size for the extracted geoid undulations. Pressing 'Save' will prompt the user to enter the geoid field filename in a given subfolder. LGO will automatically provide the file extension *.gem to the geoid field filename.

Geoid Field files can reside on PC/CF-card to prevent exceeding the maximum storage in GPS500 and System1200 internal RAM.
Creation of a CSCS Field File for GPS Units

A CSCS Model Field File can be created by selecting the 'Tools' pull-down menu and the 'Create CSCS Model Field File' option.

A 'CSCS Model' residing in LGO must be selected with 'Centre and radius' or 'South-West and North-East corners Extents' for the selected area.

LGO or SKI-Pro will automatically display the actual file size for the extracted CSCS corrections. Pressing 'Save' will prompt the user to specify the CSCS field filename. LGO will also provide the file extension *.csc.

CSCS Field Model files can reside on PC/CF-card to prevent exceeding the maximum storage in GPS300 and System1200 internal RAM.

Upload Coordinate System to Field Units

Notes:
Coordinate Systems can be transferred to either a hard disk directory, PC/CF-Card or directly to sensor System RAM using the Data Exchange Manager. Click and drag the Coordinate System Object on the right hand side to the PC/CF-Card File on the left hand side. LGO will put the Coordinate System in the appropriate subdirectory under the proper file structure.

Geoid and/or CSCS Model Field Files can also be transferred to PC/CF-Card by clicking and dragging the *.gem or *.csc file to the PC/CF-Card File on the left hand side.
Data Exchange Manager

Notes:
The Data Exchange Manager allows data to be transferred graphically between PC, LGO Database Objects, PC/CF-Card and Sensor.
The Data Exchange Manager consists of two-panel window. The left panel displays the folders or device types available on the PC whereas the right panel lists the PC folders and the LGO Database Object folders.
Prior to transferring LGO Object folders to PC/CF-Card, the System type should be selected by right clicking in the open space and by selecting Settings. General and COM Settings options can then be specified.
Transfer of data between the left and the right panel folders are initiated by clicking, dragging the appropriate information and dropping it over the correct folder or device type.

LGO Database Transfer to PC-Card or Sensor

Notes:
Different LGO Database items namely: Projects, Coordinate Systems, Antennas, Codelists, Format Files, Geod Model Field Files and CS CDS Model Field Files can be transferred to the PC-Card residing either on the PC or in the Sensor by first accessing the Objects folder type on the right panel and selecting the proper folder to be transferred.
Once the LGO folder has been selected, the transfer is executed by dragging the mouse over the PC-Card folder type or the COM Serial Port folder if the PC-Card resides in the Sensor.
LGO will manage the correct folder handling and will know where the selected information has to go.
Final Destination of Transferred LGO Folders

<table>
<thead>
<tr>
<th>LGO Objects</th>
<th>PC/CF Card directory</th>
<th>Final Destination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projects</td>
<td><code>geoblib\job</code> for GPS500</td>
<td>PC/CF Card</td>
</tr>
<tr>
<td></td>
<td><code>DBX\job</code> for GPS1200</td>
<td></td>
</tr>
<tr>
<td>Antennas</td>
<td><code>gpslist.ant</code></td>
<td>System RAM **</td>
</tr>
<tr>
<td>Coordinate Systems</td>
<td><code>geodb\gps\sat\dat for 500</code></td>
<td>System RAM **</td>
</tr>
<tr>
<td></td>
<td><code>DBX\trf\set\dat for 1200</code></td>
<td></td>
</tr>
<tr>
<td>Format Files</td>
<td><code>\convert\fl</code></td>
<td>System RAM **</td>
</tr>
<tr>
<td>Codelists</td>
<td><code>\codel\conf for GPS500</code></td>
<td>System RAM **</td>
</tr>
<tr>
<td></td>
<td><code>\codel\conf for GPS1200</code></td>
<td></td>
</tr>
</tbody>
</table>

(**) Notes:

After having transferred folders from 'Antennas', 'Coordinate Systems' or 'Codelists' to the PC/CF-Card, the 'Transfer' (Transfer Objects) function on the Terminal must be used to copy the content of these folders from 'PC/CF-Card' to 'Sensor' System RAM.

Final Destination of Transferred PC Files

<table>
<thead>
<tr>
<th>PC Files</th>
<th>PC-Card directory</th>
<th>Final Destination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Firmware</td>
<td><code>gps\progl\fw for GPS500</code></td>
<td>System RAM **</td>
</tr>
<tr>
<td></td>
<td><code>\system\fw for System1200</code></td>
<td></td>
</tr>
<tr>
<td>Terminal Firmware</td>
<td><code>gps\progl\fw for GPS500</code></td>
<td>TR500 **</td>
</tr>
<tr>
<td></td>
<td><code>\system\fw for GPS1200</code></td>
<td>RX1200</td>
</tr>
<tr>
<td>Geoid Field File</td>
<td><code>data\gps\geoid\geod\gms</code></td>
<td>RAM or PC-Card</td>
</tr>
<tr>
<td>CSFCS Field File</td>
<td><code>data\gps\scs\scs\csc</code></td>
<td>RAM or PC-Card</td>
</tr>
<tr>
<td>Configuration Set</td>
<td><code>gps\confr\conf for GPS500</code></td>
<td>System RAM **</td>
</tr>
<tr>
<td></td>
<td><code>\confi\xf for GPS1200</code></td>
<td></td>
</tr>
</tbody>
</table>

(**) Notes:

After having transferred folders from Sensor Firmware Upload, Terminal Firmware Upload, Geoid Model Field File, CSFCS Model Field File and Configuration Set to PC-Card, the 'Transfer (transfer Objects)' function on Terminal must be used to copy these folders from 'PC/CF-Card' to 'Sensor' System RAM.

Geoid and CSFCS Model Field Files can be residing on PC-Card to handle large sets of data without filling up the Sensor System RAM.
Leica SYSTEM 1200

Leica Geo Office

Data Export
LGO Data Export

Content:
- Export RINEX Data from LGO Projects
- ASCII Data Output from LGO Projects
- GIS/CAD Output Option
- Data Exchange Manager
- LGO Data Base Objects (Folders)
- Sensor Serial Transfer
- PC-card and PC file Folders

Exercise:
- Export Data from a LGO Project in ASCII file format

RINEX Data Export from an entire Project

Notes:
GPS observations stored in LGO projects can be exported in RINEX 2 format. RINEX 2 data can be exported to ASCII file(s) from a LGO Project by either selecting the whole LGO project, or individual site occupations (tracks).

To export all GPS observations from a LGO Project, select 'RINEX' from 'Export' menu or 'Export RINEX Data' in 'Tool' List Bar, select a Project and then specify or create a new location in the PC with the RINEX export options.

If a LGO project is not yet opened, it will allow user to select a LGO project to export RINEX data from all site occupations (tracks).
RINEX Data Export from Site Occupations

Notes:

RINEX data can be exported from individual Site Occupations (tracks) by opening a LGO project and by accessing the 'GPS-Proc' Tab and going over the following steps:

Right click over a given Site Occupation interval. Select 'Export to RINEX' and then specify or create a new location in the PC with the RINEX export options.

Export Project Information to ASCII file

Notes:

Point and/or Baseline information contained in LGO projects can be exported to a variety of pre-defined formats.

To export the information from a whole LGO Project in ASCII files, select 'ASCII' from 'Export' menu or 'Export ASCII Data' in 'Tools' List Bar.
Notes:

Project information can be output in one of the following formats: SKI ASCII file Text Format, Tab delimited (*.txt), Formatted Text Space delimited (*.prn), CSV Comma delimited (*.csv), Semi-colon delimited (*.svv), NGS G-File (*.ngs), IDEx file (*.idx) or Custom ASCII file (*.txt) generated from Format Manager.

Record types and format information can then specified by accessing Settings. The Settings can be saved as a new template for future use.

If 'Custom ASCII file' is selected, templates created by Format Manager can be used. Otherwise, Format Manager can be launched by Right-Mouse click over 'Format Template'.

---

Notes:

In the General Tab, the Coordinate Type can be selected as Cartesian, Geodetic or Grid for Local Systems or as Cartesian and Geodetic for WGS84.

The Height Mode can be selected as Ellipsoid (WGS84 or Geodetic Local System) or Orthometric (Local System).

The Coordinate Class can be selected as: Current, Main, Control, Adjusted, Reference, Average, Measured, SPP, Navigated, Estimated or All. Current refers to the current best coordinate class for each point, whereas Main refers to overall best coordinate class for each point. All will output all coordinate classes for each point.

Points can be sorted by Id or by Time. Sort by 'Time' is used for 'Free Codes' with the appropriate output information in the subsequent Free Codes Tab.

Header/Footer and Column headings can be specified with or without deactivated point information.
Notes:

In the Point Tab, we can select the order of information that will be output in each line record of the ASCII file by selecting the output elements from the left box and by moving them to the right. The default code type is thematical unless free code type has been previously selected in the General settings panel.

Depending on the previously selected Coordinate Type and Height Mode, the appropriate elements will be selectable. For multiple Attributes and Annotations, we can select the different combinations fitting the output requirements.

In the Coordinate System Tab, the current Coordinate System attached to the project is presented. However, any other existing Coordinate Systems can be used to output coordinates in different systems without modifying the Project Properties.

Notes:

Coordinates with Free Code Information can be exported in ASCII file by sorting Points by Time in the General Settings Tab. Free Codes check box can be selected to produce a Free Codes Tab.

Point information elements can be normally selected in the Point Setting Tab followed by Free Code elements from the Free Codes Tab for different Free Code output options.
Export ASCII Data as per Format Manager

Notes:

ASCII Data can be exported as per specific format files created in the Format Manager Tool.
The file type must be a Customer (*.cst) ASCII file type. Once the cst file type is selected, the General Settings can be selected. The location of the Format file (*.frt) must be specified in the Format template *.frt file location.
Access to the Format Manager Tool can be initiated by right clicking over the Format Template location box.

GIS/CAD Information Output and Settings

Notes:

LGO Project information can be exported in GIS/CAD format by selecting 'GIS/CAD' from 'Export' menu or 'Export GIS/CAD Data', in 'Tools' List Bar. This option will be displayed as long as the GIS/CAD option is set in the software protection key when plugged in PC.
If LGO project is not yet opened, it will allow to select a LGO project to export in GIS/CAD.
GIS/CAD output can be in one of the following formats: AutoCAD Files (*.dxf, *.dwg), MicroStation Files (*.dgn) and MapInfo Files (*.mil).
Prior to selecting the different Settings, a Lookup Table must be specified for the specific CAD File type to relate and match the proper LGO Coding elements with the CAD Code Table template.
The Settings will allow the selection of proper CAD output type version and format.
Export and Save ASCII Data File

Notes:

Once all output settings and elements have been selected, an Output Template can be defined by right clicking over the Settings Name box. A new Output Template name will save the last settings for future use.

A filename can be entered and be specified in a PC subfolder location. All output information will be saved under that filename.

LGO will automatically include the proper file extension to the filename.
LGO Data Processing Appendices

- Contents:
  - LGO Automatic GPS Processing Parameters
  - LGO GPS Baseline Result Analysis
  - LGO Adjustment Result Analysis
  - Guidelines to GPS Data Processing in LGO.
  - GPS Antenna Heights and Phase Centers Handling
  - GPS Baseline Positioning from Phase Measurements
  - GPS L1 & L2 Phase Frequency Combinations
  - TPS Requirements for GSI Observations in LGO
**LGO Automatic GPS Processing Parameters**

*Which GPS processing parameters are used when the automatic options are selected in LGO*

1. **Automatic Solution Type:**

   *All common measurement types (Code & Phase) available from both Reference and Rover site occupations are initially used to obtain Double Difference Fixed Ambiguity solutions. If less than 60% of common phase data are available, Code data will be used to obtain Single Difference Float Ambiguity solutions.*

2. **Automatic Frequency:**

   *The best frequency or frequency combination is automatically selected. If dual frequency data is available and the baseline lengths are greater than 15 km, Ionospheric-Free L3 frequency combination will be selected following successful Fixed ambiguity solutions. If dual frequency data is available and the baseline lengths are smaller than 15 km, L1+L2 (Wide Lane) Fixed ambiguity solutions will be selected.*

3. **Automatic Ionospheric Model:**

   *The Computed Model is selected if dual frequency data is available at the Reference Site for a minimum of 45 minutes. Otherwise, the Klobuchar Model is used if Almanac data have been imported with raw data. If there are less than 45 minutes of dual frequency data at the reference site and no Almanac with raw data, No Ionospheric Model is used.*

4. **Automatic Ionospheric Activity:**

   *Based on the baseline length and occupation time interval, the best level of Weight (Small, Medium or High) to be applied to the Stochastic Bias estimates is selected.*
LGO Baseline Result Analysis

What to look for in GPS Processing Report and Analysis Tools:

1. Site Occupation Information:
   - Antenna Heights and Offsets for both Reference and Rover sites
   - Excluded Site Processing Interval(s) (Site Window(s))

2. Selected and Used Processing Parameters:
   - Selected & Used parameters for solution type, frequency and models

3. Common Satellites Used:
   - Completely disabled satellite(s) and/or excluded satellite window(s)

4. Observation Statistics:
   - Tracked/Not Used Status messages for each satellite and frequency

5. Ambiguity Statistics
   - Small number of Total and Fixed Satellite Ambiguities with large number of independent fixed ambiguity solutions

6. Cycle Slips Statistics:
   - Total number of Cycle Slips with "ucs" or "ria" flags

7. Final Coordinates:
   - Solution Type, Frequency Used and Ambiguity Status
   - M0 value < 1.0 for an initial 10-mm phase measurement noise

8. Satellite Elevation and DOP Graphs:
   - Satellite having low elevation angles and periods of high GDOP values

9. Measurement Residuals Tables and Graphs:
   - Small and unbiased residuals for Data Type and Frequency used

LGO Adjustment Result Analysis

What to look for in LGO Adjustment Report File:

1. Adjustment Parameters:
   - Type of Adjustment: Inner, Minimally or Fully Constrained
   - Number of GPS/TPS Observations & Unknowns, Degrees Of Freedom
   - Error Probability and Power Level of Statistical Tests in %
   - Critical values used for the F, W & T-Tests

2. Variance Ratio (F-)Test:
   - If rejected (>1): check for high residuals and/or for small a priori error
   - If accepted (<1): check for too high a priori measurement error

3. Initial Coordinates and Input Measurement Errors:
   - coordinates being held fixed in the adjustment
   - magnitude of initial measurement errors

4. Adjusted Coordinates, Precision and Confidence Regions:
   - a posteriori variance factor being used to scale error estimates
   - coordinate precision estimates and confidence level in %

5. Adjusted Observations, Residuals and Standard Deviations:
   - Magnitude of residuals for each observation component
   - Residuals in Vertical (Up) components for GPS Antenna Heights
   - Magnitude of Measurement Standard Deviations for W & T-Tests

   - Flagged standardized residuals being 2 or more times greater than their W & T-Test critical values

7. Estimated Measurement Errors from W & T-Test Failures:
   - Estimated Errors having an expansion factor of greater than 2
   - Estimated Antenna Height Errors greater than the MDB values
GPS Surveying

Guidelines to GPS Data Processing
In Leica Geo Office

June 2005
1.0 Introduction

A new data processing kernel, PSI-Pro, is implemented in LGO. The PSI-Pro kernel is based on the RTK algorithm computing positions in all SYSTEM-500 and GPS1200 receivers. Continuous ambiguity determinations are performed at regular time intervals (typically 30 to 180 seconds) as opposed to only one major ambiguity set determination per baseline in previous versions. The same kernel is used to process Rapid Static and Long Static observation sessions together with On-The-Fly, Static Initialization and StopGo kinematic trajectories as opposed to 5 different kernels in previous LGO releases. The new kernel should provide similar processing performance and positioning results obtained from RTK survey solutions.

Based on these new changes, the data processing Report is different from the previous baseline solution report (lofqfile). FARA Statistics are replaced by the Ambiguity Statistics. New Result Analysis Tools display Satellite Azimuth, Elevation Angles and DOPs graphs combined with measurement residual Plots and Tables for the different data types and frequency combinations used in data processing.

The following sections describe the most important aspects of the new kernel by examining the data processing parameters, new sections of the baseline solution report and the critical plots from the Analysis Tools. Relationships between sections from the Data Processing Report and Graphs from the Analysis Tools are provided as initial guidance to data processing assessment.
2.0 GPS Data Processing Parameters

Overview

The GPS data processing parameters have been reduced and optimised to provide the best solutions under different observation scenarios. One of the main questions to be addressed concerning data processing parameters is:

Which parameters or combination of parameters to select for different observation scenarios?

System Default and Automatic parameters should initially be used to process data. The PSI-Pro is designed to internally select the best set of parameters to provide optimal results. The following subsections describe the Automatic parameter and System Default selection.

2.1 General GPS Processing Parameters

Solution Type: Automatic

Automatic selects code and phase data to obtain the best baseline solution type. However, if less than 60% of phase data is available for the processing interval, code data will be used to obtain single difference solutions. It is possible to specify any of these data types individually or to force PSI-Pro to compute float ambiguity single difference solutions.

Figure 1 illustrates the different options for the General GPS Parameters of LGO.
2.2 Strategy Parameters

Frequency:
Automatic

- L3 Ionospheric-Free solutions if L1 and L2 data are available and baseline lengths are greater than 15 km.
- L1+L2 (Wide lane) solutions if L1 and L2 data are available and baseline lengths are smaller than or equal to 15 km.

It is possible to specify L1, L2, L1+L2 or L3 for data processing as long as such data is available on the selected frequency.

Minimum Duration (For Float Ambiguity Static Baselines):
Automatic

The System Default is set to 5 minutes minimum to provide optimal float ambiguity single differencing. Otherwise, code single difference solutions are computed. It is possible to reduce the minimum interval at the expense of not being optimal.

Ionospheric Model:
Automatic

The default Ionospheric Model is based on the Hopfield Model. Other models such as: Simplified Hopfield, Saastamoinen, Essen and Froome can be selected. The No Model option can also be selected to avoid any attempt to model the effect of ionospheric on the data. A Computed Model can be estimated as a stochastic bias parameter for the Tropospheric Zenith Delay over time. This Computed Model should allow the algorithm to compensate for the change of tropospheric effects over time.

Figure 2 illustrates the different options for the Strategy Parameters of LGO.

Figure 2: LGO Strategy Parameter Options

Continued on next page
2.3 Extended Output

The Extended Output options allow LGO to report additional information to be accessed from the Analysis Tools. Internal storage of DOPs, Azimuths and Elevation Angles can be set at different output rates for plotting purposes. Residuals for the different observation types, frequencies and measurement types can be selected for additional data analysis.

Figure 3 illustrates the different options for Extended Output of LGO.

![Figure 3: Extended Output Options from LGO](image)

---

3.0 GPS Data Processing Report

**Reporting**

The GPS Data Processing Report has been completely changed to reflect the characteristics of the new PSI-Pro processing algorithm. Some sections are confirmation of entries such as: cut-off angle, ephemeris type, fix ambiguity range, site and satellite excluded window intervals. Other sections are related to the parameters effectively used in data processing, data used and rejected during calculations. One of the main questions to be addressed concerning the new Data Processing Report is:

*What to look for in the GPS Data Processing Report to confirm the appropriateness of the solution and/or identify problems encountered during data processing?*

Most of the contents related to the different GPS Data Processing Report types should be selected in the Report Templates Management Group as per Figure 4.

![Figure 4: Selection of Contents for GPS Baseline Data Processing Report in LGO](image)

---

Guidelines to GPS Data Processing in LGO

June 2005

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3.0 GPS Data Processing Report...Continued

A GPS Data Processing Report is available for each individual baseline solution or kinematic trajectory from the Results Tab within a project as shown in Figure 5.

Figure 5: Access to a GPS Baseline Data Processing Report in LGO.

3.1 Selected and Used Processing Parameters

Processing parameters initially selected and the ones effectively used by the kernel are reported with comments about the changes (if any) in the parameter selection. If some of the parameters used in the calculations are found to be inadequate, manual entries can be used to specify the parameters to be used.

Figure 6 shows the section on Processing Parameters from the LGO GPS Data Processing Report.

Processing Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Selected</th>
<th>Used</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut-off angle</td>
<td>10°</td>
<td>10°</td>
<td>Broadcast</td>
</tr>
<tr>
<td>Ephemeris type</td>
<td>Precise</td>
<td></td>
<td>No precise ephemeris available, switched to broadcast ephemeris</td>
</tr>
<tr>
<td>Solution type</td>
<td>Automatic</td>
<td></td>
<td>Phase</td>
</tr>
<tr>
<td>Frequency</td>
<td>Automatic</td>
<td></td>
<td>80 km</td>
</tr>
<tr>
<td>Fix ambiguities up to</td>
<td>80 km</td>
<td></td>
<td>80 km</td>
</tr>
<tr>
<td>Min. duration for float solution (static)</td>
<td>5'00&quot;</td>
<td></td>
<td>5'00&quot;</td>
</tr>
<tr>
<td>Sampling rate</td>
<td>Use all</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Topographic model</td>
<td>Hayfield</td>
<td></td>
<td>Hayfield</td>
</tr>
<tr>
<td>Ionospheric model</td>
<td>Automatic</td>
<td></td>
<td>Computed</td>
</tr>
<tr>
<td>Use stochastic modelling</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Min. distance</td>
<td>8 km</td>
<td></td>
<td>8 km</td>
</tr>
<tr>
<td>Ionospheric activity</td>
<td>Automatic</td>
<td></td>
<td>Automatic</td>
</tr>
</tbody>
</table>

See the Final Coordinates section for Frequency used

Refer to internal weighting Based on distance separation

- Figure 6: Selected and Used Processing Parameters from LGO Report

Continued on next page
3.2 Observation Statistics

The Observation Statistics provide information about the total number of measurement epochs, the total number of used and rejected observations for either L1 or both L1 and L2 frequencies with the associated L1 and L2 Tracking Status for all common satellites. The Tracking Status gives a detailed report about how long each satellite was used and how often it was excluded in the solution. Satellites showing several occurrences of “Tracked / Not used” indicate that measurements could not be used in the fixed ambiguity determinations. These intervals are automatically eliminated for the final processing run. Additional information about Satellite Tracking Status can be accessed by examining the graphs related to Elevation Angles and measurement residuals.

Figure 7 shows excerpts from the Observation Statistics of LGO Data Processing Report.

A graph summarizing Common Satellite Tracking based on the Observation Statistics can also be examined from Figure 8.

### Observation Statistics

<table>
<thead>
<tr>
<th>Observation Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of common epochs: 1360</td>
</tr>
<tr>
<td>Number of used observations (L1): 8620</td>
</tr>
<tr>
<td>Number of rejected observations (L1): 469</td>
</tr>
<tr>
<td>Number of used observations (L2): 8622</td>
</tr>
<tr>
<td>Number of rejected observations (L2): 429</td>
</tr>
</tbody>
</table>

### Tracking Status L1:

<table>
<thead>
<tr>
<th>Satellite</th>
<th>From</th>
<th>To</th>
</tr>
</thead>
<tbody>
<tr>
<td>SV 03</td>
<td>10/06/1999 20:23:10</td>
<td>10/07/1999 20:34:59</td>
</tr>
<tr>
<td>SV 05</td>
<td>10/06/1999 20:48:40</td>
<td>10/07/1999 21:01:25</td>
</tr>
<tr>
<td>SV 09</td>
<td>10/06/1999 21:01:25</td>
<td>10/07/1999 21:01:25</td>
</tr>
<tr>
<td>SV 15</td>
<td>10/06/1999 21:01:25</td>
<td>10/07/1999 21:01:25</td>
</tr>
</tbody>
</table>

### Tracking Status L2:

<table>
<thead>
<tr>
<th>Satellite</th>
<th>From</th>
<th>To</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 L2</td>
<td>10/06/1999 20:23:10</td>
<td>10/07/1999 20:34:59</td>
</tr>
<tr>
<td>L1 L2</td>
<td>10/06/1999 20:48:40</td>
<td>10/07/1999 21:01:25</td>
</tr>
<tr>
<td>L1 L2</td>
<td>10/06/1999 19:23:10</td>
<td>10/07/1999 20:34:59</td>
</tr>
<tr>
<td>L1 L2</td>
<td>10/06/1999 21:01:25</td>
<td>10/07/1999 21:01:25</td>
</tr>
</tbody>
</table>

Figure 7: Observation Statistics from LGO Data Processing Report

Continued on next page
3.3 Ambiguity Statistics

The Ambiguity Statistics provide information about the possible number of satellite ambiguities (initial and re-initialized) for all common satellites on L1 only or both L1 independently fixed ambiguity determinations with the number of between consecutive fixed solutions. The Overall Statistic lists the time period(s) for confirmed to be correct together with the period(s) when no ambiguity resolution was available.

The continuous ambiguity checking method provides the highest reliability possible in baseline processing, as ambiguities are continuously monitored over the entire observation interval. To further investigate the reliability, the number of fixed ambiguity determinations together with the average time number of independent fixes the more reliable the solution would be. Intervals insufficient number of satellites (3 or less) available or that measurement RMS error percentage of fixed solutions will still represent a highly reliable result if the duration by examining graphs related to DOPs and measurement residuals from the Analysis Tools.

Figure 9 shows excerpts from the Ambiguity Statistics of the LGO Data Processing Report.

### Ambiguity Statistics

<table>
<thead>
<tr>
<th>Total number of ambiguities:</th>
<th>127</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of fixed ambiguities:</td>
<td>59</td>
</tr>
<tr>
<td>Number of independent fixes:</td>
<td>19</td>
</tr>
<tr>
<td>Avg. time between independent fixes:</td>
<td>20'</td>
</tr>
<tr>
<td>Percentage of fixed epochs (L1)</td>
<td>72%</td>
</tr>
<tr>
<td>Percentage of fixed epochs (L2)</td>
<td>57%</td>
</tr>
<tr>
<td>Percentage of fixed epochs (overall)</td>
<td>50%</td>
</tr>
</tbody>
</table>

**Overall Statistic:**

<table>
<thead>
<tr>
<th>Status</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not fixed</td>
<td>00/3/1999 19:23:13 00/3/1999 19:51:45</td>
</tr>
<tr>
<td>Fixed</td>
<td>00/3/1999 19:51:45 00/3/1999 20:04:05</td>
</tr>
<tr>
<td>Not fixed</td>
<td>00/3/1999 20:04:05 00/3/1999 20:12:40</td>
</tr>
<tr>
<td>Fixed</td>
<td>00/3/1999 20:12:40 00/3/1999 20:13:15</td>
</tr>
<tr>
<td>Not fixed</td>
<td>00/3/1999 20:13:15 00/3/1999 20:27:10</td>
</tr>
<tr>
<td>Fixed</td>
<td>00/3/1999 20:27:10 00/3/1999 21:00:05</td>
</tr>
<tr>
<td>Not fixed</td>
<td>00/3/1999 21:00:05 00/3/1999 21:10:05</td>
</tr>
</tbody>
</table>

Figure 9: Ambiguity Statistics from LGO Data Processing Report

---

The following further describes the information in the Ambiguity Statistics section of the Report:

- Total number of ambiguities: For each satellite and each frequency an integer ambiguity needs to be resolved. Ambiguities which needed to be re-initialized due to a loss of lock will also be counted.
- Number of fixed ambiguities: Number of ambiguities which have finally been resolved.
- Number of independent fixes: Number of times an independent ambiguity search routine has successfully been completed leading to a confirmation of previously calculated ambiguity values.
- Avg. Time between independent fixes: Average time between independent (consecutive) fixed solutions.
- Percentage of fixed epochs (L1 and L2): Percentage of epochs (calculated for all satellites) for which L1, and respectively L2 ambiguities have been resolved. Note that in case an ambiguity could not be resolved for a specific satellite or a specific frequency this number can be below 100% even if the overall percentage of fixed epochs is 100%.
- Overall Statistic: Percentage of all epochs for which a successful ambiguity resolution has been available. This corresponds to the percentage of epochs for which a fixed solution would be available if the data was calculated in a kinematic mode. Note that for static intervals the overall ambiguity resolution can be successful (Amb > Yes) even if this percentage is below 100%.

Overall: This overview lists the time periods for which ambiguities have successfully been resolved and confirmed to be correct as well as the periods when no ambiguity resolution has been available.

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Guidelines to GPS Data Processing in LGO

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3.4 Cycle Slip Statistics

The Cycle Slip Statistics indicate the number and nature of discontinuities encountered in phase data processing on specific satellites at given time epochs on each frequency. Slip value showing "-" indicates that the slip value was less than 1 cycle. Flags showing "u.s. + r" indicate undetected cycle slips from the GPS sensors which generates new ambiguities to be determined (re-initialized) causing the overall number of ambiguity unknowns to grow during calculations. Additional information on Cycle Slips can be further investigated by examining Triple Difference Phase Residuals for remaining cycle slips in the solutions from the Analysis Tools.

Figure 10 shows the Cycle Slip Statistics from the LGO Data Processing Report.

<table>
<thead>
<tr>
<th>Time</th>
<th>Satellite</th>
<th>Frequency</th>
<th>Slip value</th>
<th>Flags</th>
</tr>
</thead>
<tbody>
<tr>
<td>09/09/2002 21:44:50</td>
<td>SV 23</td>
<td>L1</td>
<td>152.00</td>
<td>flagged</td>
</tr>
<tr>
<td>09/09/2002 22:46:30</td>
<td>SV 11</td>
<td>L1</td>
<td>153.00</td>
<td>flagged</td>
</tr>
<tr>
<td>09/09/2002 22:46:50</td>
<td>SV 11</td>
<td>L1</td>
<td>174.00</td>
<td>flagged</td>
</tr>
<tr>
<td>09/09/2002 22:50:20</td>
<td>SV 11</td>
<td>L1</td>
<td>186.00</td>
<td>flagged</td>
</tr>
</tbody>
</table>

Figure 10: Cycle Slip Statistics from LGO Data Processing Report

3.5 Final Coordinates

The Final Coordinates indicate the selected Reference and computed Rover coordinates, the Solution/Data type, the final Frequency used and the Ambiguity Status of the final solution. Position Quality information in terms of Coordinates Standard Deviations, 2-D Horizontal and 1-D Vertical Position Quality together with the square-root of the Variance Factor (M0) and the baseline cofactor matrix (Qxx) are also reported. The maximum and minimum GDOP, PDOP, HDOP and VDOP values encountered during the data processing interval are also provided.

The square-root of the variance factor indicates the stability of the final solution with respect to the a priori measurement error. The estimated RMS errors can be computed by multiplying the M0 value by the a priori measurement error (0.01 m for phase data). Additional information concerning the variations in GDOP, PDOP, HDOP and VDOP values versus time can be further investigated by examining the DOP's plots from the Analysis Tools.

Figure 11 shows the information contained in the Final Coordinates section of the LGO Data Processing Report.

<table>
<thead>
<tr>
<th>Reference: 85WR</th>
<th>Rover: BS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinates:</td>
<td></td>
</tr>
<tr>
<td>Latitude:</td>
<td>43°26'24.42361&quot;N</td>
</tr>
<tr>
<td>Longitude:</td>
<td>85°30'33.000052&quot;W</td>
</tr>
<tr>
<td>SLP. Hgt.:</td>
<td>206.2607 m</td>
</tr>
<tr>
<td>Solution type</td>
<td>Phase</td>
</tr>
<tr>
<td>Frequency:</td>
<td>Ionosphere (I3)</td>
</tr>
<tr>
<td>Ambiguity:</td>
<td>Yes</td>
</tr>
<tr>
<td>Quality:</td>
<td>Std. Lat.: 0.00015 m</td>
</tr>
<tr>
<td></td>
<td>Pos. Gryo.: 0.0018 m</td>
</tr>
<tr>
<td>MD:</td>
<td>0.7604 m</td>
</tr>
</tbody>
</table>
| Collector matrix Qxx:
| 0.00000000015  | 0.000000019  | 0.00000000015 |
| 0.000000154     | 0.00000000015 |
| 0.000000000062  |                                        |
| Baseline vector: d.u.: 0°15'25.152207" | d.u. v.: 0°18'30'54.38561" | hgt.: -42.1544 m |
| SLP.: 50440.1465 m |  |  |
| DOPs (min-max): GDOP: 2.3 - 28.6 | PDOP: 2.1 - 109 | HDOP: 1.0 - 25.9 |
| VDOP: 1.7 - 82.3 |          |                                        |

Figure 11: Final Coordinates Information from LGO Data Processing Report

Continued on next page
4.0 Analysis Tools

Overview

The Analysis Tools consist of a series of Graphs and Tables showing Residuals, DOP's, Azimuths and Elevation Angles for each computed baseline or Rover point. Plots and Graphs from the Analysis Tools are accessed by selecting Analyse when right clicking over a given baseline or computed point. Graphs and Tables related to Residuals are available for different measurement types (Single, Double and Triple Difference), different data types (Code and Phase) and also for different frequencies and frequency combinations (L1, L2, L3 Ionospheric-Free frequency combination and L4 Geometric-Free frequency combination). One of the main questions to be addressed concerning the new Analysis Tools is:

Which series of Graphs and Tables should be first examined to assess the computed solution and to further analyze the data?

The following sections describe the most critical Graphs and Tables to be first examined after data processing.

Continued on next page

4.1 Satellite Elevation Angle Graphs

Satellite Elevation Angle Graphs

Graphs showing Satellite Elevation Angles illustrate which satellites were mostly used during data processing and the ones used less often. Data from low satellite elevation angles have low signal strengths and are more subject to local interference whereas data from high satellite elevation angles have high signal strengths and are less subject to local interference.

Figure 12 shows Satellite Elevation Angle Graphs from LGO Analysis Tools.
4.2 GDOP, PDOP, HDOP, & VDOP Graphs & Table

DOP Graphs & Table

Graphs showing GDOP, PDOP, HDOP, and VDOP values illustrate the dilution of precision for the different coordinate components computed from the simultaneous processing of satellite data at each epoch. The Table lists the Mean, Minimum, and Maximum values for the different DOPs. Sudden jumps in DOP graphs indicate sudden changes in satellite data processing. These changes can affect the stability of the computed solution and the ability to fix satellite ambiguities. These graphs can be examined in conjunction with the Overall Statistic portion of the Ambiguity Statistics to relate the dilution of precision existing during the periods where ambiguities were resolved.

Figure 13 shows GDOP, PDOP, HDOP, and VDOP Graphs and Table from LGO Analysis Tools.

4.3 Residual Graphs and Tables for the Computed Solution

Residual Graphs and Tables from Computed Solution

Although LGO baseline solutions are based on single difference data processing, double difference residuals associated with the data and frequency used to obtain the final coordinates should be first examined. Double difference residuals are free of clock error and provide full flexibility to select different reference satellites. The reference satellite selected by LGO is based on the satellite having the highest elevation angle during the data processing interval. This satellite usually has the highest signal strength and the lowest Single Difference residual standard deviation. Information contained in the Final Coordinates section of the Data Processing Report should be first examined prior to selecting the proper sets of measurement residuals to be displayed. For SPP it is possible to plot “zero” difference residuals.

Tables of Residuals show the Mean, Standard Deviation, Minimum and Maximum values of each satellite measurement residuals for the selected data type and frequency. High residual standard deviation values could indicate unstable measurements from the corresponding satellite(s) during a given time interval and should be confirmed by examining the corresponding satellite(s) in the residual graph(s). These graphs should be examined in conjunction with the Tracking Statistics for each satellite on each frequency from the Observation Statistics to confirm the acceptance and rejection of the data.

Figure 14 shows L3 Double Difference Phase residuals Graphs and Table from LGO Analysis Tools.
4.4 Additional Residual Graphs and Tables for Further Analysis

Other Residual plots can sometimes provide additional information about the overall quality of the data and the processing performance. L4 Geometric-Free Single or Double Difference Phase residuals can assess the effect of ionospheric disturbances on the baseline during the data processing interval. Triple Difference Phase residuals can be used to assess short-term stability of phase measurements on the selected frequency. Sudden jumps in triple difference phase residuals of about 20 cm or more may indicate cycle slips remaining in the solution. Triple Difference Phase residual graphs should be examined in conjunction with the Cycle Slips Statistics to confirm that detected cycle slips have been correctly repaired.

Figure 15 illustrates L1 Triple Difference Phase Residuals Graphs and Table from LGO Analysis Tools.

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5.0 Summary and Conclusion

Summary

LGO contains a new data processing kernel based on the RTK positioning algorithm residing in SYSTEM-500 and GPS1200 receivers. Continuous ambiguity determinations provide the highest possible reliability in final fixed ambiguity solutions derived from phase double difference processing. The PSI-Pro kernel uses the best combinations of parameters, data type and frequency to obtain optimal results under typical observation scenarios. Data processing parameters can be manually specified to completely control the processing of data.

The new Data Processing Report and Analysis Tools provide comprehensive information about the performance of data processing related to the computed solutions. Sections of the Data Processing Report pertaining to the Observation, Ambiguity and Cycle Slip Statistics can be further analyzed by examining Satellite Elevation Angle, DOPs and Residual Graphs and Tables from the Analysis Tools. Additional Graphs and Tables can be generated to further investigate the overall quality of data using different observation types and frequency combinations.

The PSI-Pro kernel should provide the same processing performance and positioning results obtained from RTK survey solutions by solving ambiguities and modeling the effect of ionospheric disturbances over long distances in both Static and Kinematic positioning modes.
6.0 References

References


Antenna Heights and Phase Centers Handling

in

LGO, SYSTEM300, SYSTEM500 and GPS1200

by

Henri B. Ayers
LEICA Geosystems Limited
December, 2004

ABSTRACT

The handling of GPS antenna heights and phase centers in LGO data processing and SYSTEM-500/GPS1200/GPS1200 real-time positioning is presented. The location of SYSTEM-500/GPS1200/GPS1200 and SYSTEM-300 Antenna Mechanical Reference Planes are first described. The processing of antenna heights and phase center locations in LGO Antenna Management, Antennas Tab and Site Occupation Intervals is examined. The use of third party GPS antenna heights and phase center locations in LGO and RTCM real-time positioning is also discussed. A close examination of the report reveals that SYSTEM-500/GPS1200/GPS1200 and LGO contain the necessary provisions to properly control, modify and assess the handling of the various GPS antenna models with their calibrated phase center values in order to provide optimal results in both real-time positioning and data post-processing.
1.0 General Information:

Antenna height readings and additional offsets used in SYSTEM-500/GPS1200 real-time positioning and LGO data processing are referred to the Mechanical Reference Plane (MRP) of a given antenna type. The MRP is a physical plane or mark on the antenna where all heights and phase center offsets are related together. Figure 1 illustrates the MRP of different SYSTEM-500/GPS1200 antenna types.

![Figure 1: Mechanical Reference Plane of AT502, 503 and 504 Antenna Types](image1)

Additional vertical offsets to the initial antenna height values are also used to relate the L1 and L2 phase center locations with respect to the selected antenna MRP. The next two sections describe in detail the relationships between the user entered antenna height reading, the selected additional vertical offset based on the antenna setup and the Phase Center offsets from calibration values for a given antenna type.

2.0 SYSTEM-500/GPS1200 Antenna Heights and Phase Centers:

SYSTEM-500/GPS1200 antenna heights and phase center locations are handled as per the different antenna types, setups, MRP locations with their corresponding L1 and L2 vertical phase center calibration values. These values consist of the Vertical Reading (VR) entered by the user, Vertical Offset (VO) corresponding to a specific setup such as Tripod, Pillar or any other setup with L1 and L2 Vertical Eccentricities (VR1 and VR2 respectively). Figure 2 illustrates the Vertical Reading (VR) from the height hook, Vertical Offset (VO) for the Tripod setup and Vertical Phase Center Eccentricities (VE1 and VE2) with respect to the AT502 MRP.

![Figure 2: Relationships between Vertical Reading, Offset and Phase Center Locations for an AT502 Antenna set up on a Tripod](image2)
Once GPS raw measurements from SYSTEM-500/GPS1200 units are being imported in LGO, the L1 and L2 Vertical Phase Center Eccentricities are immediately assigned the corresponding values listed in the Antenna Management Phase Center Table. Figure 3 illustrates the different SYSTEM-300 and SYSTEM-500/GPS1200 external antenna types, setups and Phase Center locations with respect to their MRP.

When the raw data is inserted in a LGO project, the total antenna height associated to a given occupation corresponds to the sum of the Vertical Reading (VR) and the Vertical Offset (VO) values. Only the Height Reading (no offset) can be changed in the Antenna Interval Properties panel in the View/Edit Tab. Figure 4 shows the antenna height properties for a given site occupation interval in the View/Edit Tab.

Figure 3: Vertical and Phase Center Offsets of SYSTEM-300 and SYSTEM-500/GPS1200 External Antenna Models

Figure 4: Properties of Antenna Height Site Occupation Interval in View/Edit Tab
Vertical Offset, L1 and L2 Phase Center Eccentricity values can be changed within a project by modifying the Properties of the antenna type in the Antennas Tab associated in the project. However, any modifications to the parameters of an antenna type and setup must be done with respect to the definition of the MRP related antenna characteristics. Figure 5 shows the Properties of an antenna type from the Antennas Tab associated to a LGO project.

A report on the handling of antenna phase center eccentricities in baseline vector calculations can be selected from the Log File configuration. The different L1 and L2 phase center eccentricities are used to shift phase measurements according to their profile values for different satellite elevation angles together with the relative shift values between the reference and rover antenna types. Figure 6 illustrates the report selection of Antenna Phase Center Eccentricities in LGO Baseline Log file.
3.0 SYSTEM-300 Antenna Mechanical Reference Planes:

3.1 SYSTEM-300 Antennas in LGO Data Processing:

SYSTEM-300 antenna heights and phase center locations are handled in LGO by subtracting the thickness of the SR299/399 Internal (0.091 m) or AT202/302 External (0.089 m) antenna from the total height reading. This subtraction is necessary to reduce the antenna height readings to their MRP so that the L1 and L2 antenna phase center offset values from the LGO table can be used. The MRP locations of SYSTEM-300 Internal and External antennas are located at the bottom of the antenna housing without the antenna adapter for pole or tripod. Figure 7 illustrates the locations of the MRP corresponding to the SR299/399 internal and AT202/302 external antennas.

![Figure 7: SR299/399 Internal and AT202/302 External Antenna Mechanical Reference Planes](image)

3.2 SYSTEM-300 Antennas in SYSTEM-500/GPS1200 Real-Time Positioning:

SYSTEM-300 Base Station antenna heights and phase center locations are processed in SYSTEM-500/GPS1200 by subtracting the thickness of SR299/399 Internal or AT202/302 External antenna from the Ellipsoid Height value of the Reference Station L1 Phase Center using RTCM messages type. The default names of both SYSTEM-300 reference sensor and the corresponding antenna types must be selected in the SR-530 Real-Time rover config set in order to correctly use the SYSTEM-300 as Base unit with SYSTEM-500/GPS1200 rover.

Figure 8 illustrates the selection of the reference sensor and reference antenna type for a SR399 Sensor with Internal Antenna Base unit in a SR-530 rover.

![Figure 8: Selection of SR399 Sensor with Internal Antenna in SR-530 Rover Unit](image)

4.0 Third-Party GPS Antenna Heights and Phase Centers:

4.1 Third Party GPS Antennas in LGO Data Processing:

Third party GPS antenna heights are usually imported in LGO via RINEX Data Import. A single antenna height reading referred to the Mechanical Reference Plane of the third party GPS antenna is normally provided in the RINEX observation file. The third party vertical phase center locations and their profile values can be used by matching the Antenna Name, Type or Model with the ones contained in the list of the LGO Antenna Management Group. If the third-party GPS Antenna names contained in the RINEX files are not matching the ones contained in the LGO Antenna Table, no L1 and L2 phase center offset values will be assigned to the antenna. New names should be defined for the third-party GPS antennas with proper phase center offsets.

The International Geodetic Service (IGS) or the National Geodetic Survey (NGS) antenna phase center calibration values can be imported in the LGO Management group. Third party vertical phase center offset values can also be manually entered. When using third party GPS antenna phase center values with SYSTEM-300 or SYSTEM-500/GPS1200 antenna types, it is advisable to use offsets derived from the same table (IGS or NGS table) since they may slightly differ between the tables and also from the ones internally defined in LGO. Figure 9 illustrates a list of third party GPS antenna models with their related L1 and L2 Phase Center locations in relation to their respective MRP.
4.2 Third-Party GPS Antennas in SYSTEM-500/GPS1200 Real-Time Positioning:

Third party GPS antenna types including the ones from SYSTEM-300 can be used in real-time positioning by setting receivers for RTCM messages. In RTCM, Base Station coordinates are referred to the WGS-84 coordinates of the L1 Antenna Phase Center location. Therefore, no antenna height and offset values are transmitted from the RTCM Base Station. Instead, the WGS-84 Reference Station Ellipsoid height contains the ellipsoid height of the survey marker with the total height reading including the L1 vertical offset value. Figure 10 illustrates the L1 Antenna Phase center location from a Base Station used in RTCM real-time positioning.

Baseline vectors determined by RTCM messages are reported as vectors between the L1 Phase center location at the Base and the Ground at the Rover. This configuration provides ground positions at the Rover but creates difficulty when adjusting baseline vectors from different antenna height setups at the same or different Base and also when fixing reference stations to known values defined on the ground.

In order to avoid difficulty in adjusting RTCM RTK vectors without affecting the integrity of RTCM real-time positioning, the Base Antenna Height should always be set at 0.0 m. and the Rover Antenna Height be subtracted by the Base Antenna Height value corresponding to its actual setup. The modified Rover Antenna Height will generate baseline vectors between the Survey Marker at the Base and the Ground at the Rover as per Figure 11.
5.0 Conclusion:

GPS antenna heights and phase center locations are critical for both real-time and data post-processing. Antenna heights are measured up to a Mechanical Reference Plane (MRP) on the antenna whereas phase center calibration values are located above the MRP. Proper antenna model selection, setup and vertical phase center offsets will provide adequate height solutions between the reference and rover receivers especially when mixing different antenna types in baseline processing. SYSTEM-500/GPS1200 and LGO contain provisions to properly handle the various GPS antenna models with their calibrated phase center values in order to provide optimal results in both real-time positioning and data post-processing.

6.0 References:

- SYSTEM-500/GPS1200 and SYSTEM-300 Technical Reference Manuals
- LGO On-Line Help
- RTCM SC-104 V2.1 Message Format
- GPS Newletters 00/27 and 00/28 on RTK with System 300 & System 500
Leica Geosystems GPS Training

GPS
Baseline Positioning
From Phase Measurements
Table of Contents

- Range Observations from Phase Measurements
- Single Difference Phase Baseline Positioning
- Double Difference Phase Baseline Positioning
- Triple Difference Phase Baseline Positioning

Range Observations from Phase Measurements

\[ D_x = \phi_x \cdot \lambda = (N_0 + \sum_{t=0}^{t=N} \phi_x) \cdot \lambda \]

Notes:

Phase Measurements can be used as Range Observations by multiplying phase data \( \phi \) by the signal wavelength \( \lambda \). Phase Measurements do not provide complete range distances between satellites and the receiver. An Initial Phase Ambiguity \( N_0 \) exists in phase measurements from a given satellite. Initial Phase Ambiguities are not measured by the receiver. Only fractional phase data \( \phi \) with the accumulated phase cycle changes \( \sum N \) over time are measured by the receiver.

Phase measurements are affected by satellite and receiver clock errors and also by atmospheric biases. Initial Phase Ambiguities need to be determined as integer numbers.
Single Difference Phase Baseline Positioning

Notes:

Single Difference Phase Relative Positioning consists of determining the coordinates of one receiver with respect to another by differencing phase measurements between two receivers observing the same satellites for each common time epochs.

Single Difference Phase data processing removes common satellite related errors such as satellite clock and ephemeris errors and reduces the effect of atmospheric biases. It contains however initial phase ambiguities and relative receiver clock errors associated with each single difference phase measurements.

Double Difference Phase Baseline Positioning

Notes:

Double Difference Phase Relative Positioning consists of determining the coordinates of one receiver with respect to another by differencing single difference phase measurements with respect to a reference satellite for each common time epochs.

Double Difference Phase data processing removes common satellite clock and ephemeris errors together with relative receiver clock errors. It also reduces the effect of atmospheric biases. It contains however initial phase ambiguities associated with each double difference phase measurements.
**Triple Difference Phase Baseline Positioning**

**Notes:**

Triple Difference Phase Relative Positioning consists of determining the coordinates of one receiver with respect to another by differencing double difference phase measurements between two consecutive time epochs (t1 and t2).

Triple Difference Phase data processing removes common satellite and common receiver related errors as well as reducing the effect of atmospheric biases. It also removes initial phase ambiguities as long as phase measurements from both receivers are continuous and unaffected by cycle slips or other local site related disturbances.

---

**Triple Difference Phase Measurement**

\[
TD_{\phi} = DD_{\phi}^{r-b} - DD_{\phi}^{r-b}
\]

\[
= (SD_{\phi}^{t2} - SD_{\phi}^{t1}) - (SD_{\phi}^{r-b}^{t2} - SD_{\phi}^{r-b}^{t1})
\]

\[
= (\phi^{t2} - \phi^{t1}) - (\phi^{r-b}^{t2} - \phi^{r-b}^{t1})
\]

\[
= (\phi^{t2} - \phi^{t1}) - (\phi^{r-b}^{t2} - \phi^{r-b}^{t1}) + (\phi^{r} - \phi^{b})
\]

where:
- **TD** = Triple Phase Difference (between time epochs)
- **DD** = Double Phase Difference (between satellites)
- **SD** = Single Phase Difference (between receivers)
- \( \phi \) = Raw Phase Measurement

**Notes:**

One Triple Difference Phase measurement consists of taking the difference between 2 Double Difference Phase measurements at times t1 and t2.

Each Double Difference Phase measurement consists of taking the difference of 2 Single Difference Phase measurements (one from a satellite SI and another from the reference satellite Sr having the highest elevation angle from the group).

Each Single Difference Phase measurement consists of taking the difference of raw phase measurements between the remote r and base b receivers from the same satellite at the same time epoch.

A minimum of 3 Triple Difference Phase measurements are required to determine the Remote receiver position with respect to the Base receiver.
L1 and L2
Frequency Combinations Of
Phase Measurements
(L1+L2) Wide-Lane Phase Combination

\[ \phi_{L1+L2} \cdot \lambda_{L1+L2} = (f_1 \cdot \lambda_1 \cdot \phi_{L1} - f_2 \cdot \lambda_2 \cdot \phi_{L2}) / (f_1 - f_2) \]

where: \( \phi_{L1+L2} = \) Wide-Lane L1+L2 Phase Measurement
\( \phi_{L1} = \) L1 Raw Phase Measurement
\( \phi_{L2} = \) L2 Raw Phase Measurement
\( f_1 = \) L1 Frequency (1575.42 MHz)
\( f_2 = \) L2 Frequency (1227.60 MHz)
\( \lambda_1 = c / f_1 = \) L1 Wavelength (0.19029... m)
\( \lambda_2 = c / f_2 = \) L2 Wavelength (0.24421... m)
\( \lambda_{L1+L2} = c / (f_1 - f_2) = \) L1+L2 Wavelength (0.86191... m)
\( c = \) Speed of Light (299792458 m/s)

Notes:
The Wide-Lane combination consists of combining L1 and L2 phase measurements to create a new wavelength of about 86-cm long to perform rapid ambiguity determination.
The Wide-Lane process assumes that both Tropospheric and Ionospheric biases are negligible or have been removed from pre-computed models before determining wide-lane ambiguities at the double difference processing stage.
Once the wide-lane ambiguities have been resolved, the double difference solution is referred to L1-fixed ambiguity values with no correction or elimination for Ionospheric biases.
(L3) Ionospheric-Free Phase Combination

\[ \phi_{L3} \cdot \lambda_{L3} = (f_1^2 \cdot \lambda_{L1} - f_2^2 \cdot \lambda_{L2}) / (f_1^2 - f_2^2) \]

where: 
\( \phi_{L3} \) = Ionospheric-Free L3 Phase Measurement 
\( \phi_{L1} \) = L1 Raw Phase Measurement 
\( \phi_{L2} \) = L2 Raw Phase Measurement 
\( f_1 \) = L1 Frequency (1575.42 MHz) 
\( f_2 \) = L2 Frequency (1227.60 MHz) 
\( \lambda_{L1} = c / f_1 \) = L1 Wavelength (0.19029... m) 
\( \lambda_{L2} = c / f_2 \) = L2 Wavelength (0.24421... m) 
\( \lambda_{L3} = c / (f_1 + f_2) \) = L3 Wavelength (0.10695... m) 
\( c \) = Speed of Light (299792458 m/s)

Notes:
The Ionospheric-Free combination consists of combining L1 and L2 phase data to practically eliminate ionospheric bias from measurements. Ionospheric-Free (L3) phase ambiguities are no longer integer values. However, if Wide-Lane (L1+L2) ambiguities are known, double difference fixed ambiguity solution can be systematically corrected for ionospheric bias affecting phase measurements otherwise L3-phase ambiguities must be solved with position unknowns.
The L3 Ionospheric-Free linear combination increases the initial phase measurement noise by about 3.

(L4) Geometric-Free Phase Combination

\[ \phi_{L4} \cdot \lambda_{L4} = \lambda_{L1} \cdot \phi_{L1} - \lambda_{L2} \cdot \phi_{L2} \]

where: 
\( \phi_{L4} \) = Geometric-Free L4 Phase Measurement (0.0) 
\( \phi_{L1} \) = L1 Raw Phase Measurement 
\( \phi_{L2} \) = L2 Raw Phase Measurement 
\( f_1 \) = L1 Frequency (1575.42 MHz) 
\( f_2 \) = L2 Frequency (1227.60 MHz) 
\( \lambda_{L1} = c / f_1 \) = L1 Wavelength (0.19029... m) 
\( \lambda_{L2} = c / f_2 \) = L2 Wavelength (0.24421... m) 
\( \lambda_4 = \infty \) 
\( c \) = Speed of Light (299792458 m/s)

Notes:
The Geometric-Free combination consists of combining L1 and L2 phase data to estimate the ionospheric bias from measurements. It is independent of receiver clock and satellite orbit to station coordinates geometry. It contains ionospheric delay and initial phase ambiguities.
TPS Requirements for GSI Observations

Which GSI Word Indexes to use for TPS Data Adjustment in LGO:

To successfully import TPS Observations for adjustment, all data must be recorded using Standard GSI Word Indexes with approximate 3-D coordinates for all Station and Target Points.

Definition of the Standard GSI consists of the Word Indexes: 11, 21, 22, 31, 51, 72 to 79 and 81 to 88, Station and Target setup (Pt Id, HI, East., North. and Elev.) and Observations (one or more Direction, Slope Distance and Vertical Angle). Information on these data elements can be found in the LGO On-line Help.

True slope distances are required with no geometrical reductions for full 3-D adjustment of TPS data.

Leica Geosystems Ltd
December, 2004