A Comparison of Static GPS Baseline Solutions Using Trimble’s Geomatics Office (TGO) by Ian Grender, MS student, CEEGS January 2002
TGO BASELINE PROCESSING
TGO BASELINE PROCESSING REPORT

• A *Baseline Processing Report* was produced within TGO for each solution.

• The statistics, measurements, and estimated parameters contained in the reports are used as the basis for comparison.
ELEMENTS OF THE BASELINE PROCESSING REPORT
Baseline (~ 200m)
Example Baseline Processing Report

<table>
<thead>
<tr>
<th>Project Name:</th>
<th>L1_phase_fixed_dur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processed:</td>
<td>Wednesday, November 28, 20CL 5:57:59 PM</td>
</tr>
<tr>
<td></td>
<td>WAVE 3.00</td>
</tr>
<tr>
<td>From Station:</td>
<td>6596</td>
</tr>
<tr>
<td>Data file:</td>
<td>65962400.dat</td>
</tr>
<tr>
<td>Antenna Height:</td>
<td>0.069m True Vertical 0.000m Uncorrected</td>
</tr>
<tr>
<td>Position Quality:</td>
<td>Coordinates Unknown/Undefined</td>
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<tr>
<td>WGS 84 Position:</td>
<td>40°00'03.37006&quot;N 83°02'22.35989&quot;W 213.737m</td>
</tr>
<tr>
<td>To Station:</td>
<td>5547</td>
</tr>
<tr>
<td>Data file:</td>
<td>55470277.dat</td>
</tr>
<tr>
<td>Antenna Height:</td>
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<tr>
<td>WGS 84 Position:</td>
<td>39°59'58.21592&quot;N 83°02'27.23573&quot;W 216.202m</td>
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<tr>
<td>Start Time:</td>
<td>8/27/00 14:21:45.00 GPS</td>
</tr>
<tr>
<td>Stop Time:</td>
<td>8/27/00 17:49:12.00 GPS</td>
</tr>
<tr>
<td>Meas. Interval (seconds):</td>
<td>03:27:26.00</td>
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<tr>
<td>Solution Type:</td>
<td>L1 fixed double difference</td>
</tr>
<tr>
<td>Solution Acceptability:</td>
<td>Passed ratio test</td>
</tr>
<tr>
<td>Ephemeris:</td>
<td>Broadcast</td>
</tr>
<tr>
<td>Met Data:</td>
<td>Standard</td>
</tr>
<tr>
<td>Baseline Slope Distance</td>
<td>196.812m 0.00020693m</td>
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<tr>
<td>Normal Section Azimuth:</td>
<td>216°02'17.020633&quot;</td>
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<td>Vertical Angle:</td>
<td>0°43'03.516001&quot;</td>
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<tr>
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<td>dx = -102.199m 0.00018857m</td>
</tr>
<tr>
<td>Standard Deviations:</td>
<td>dy = -117.324m 0.00092071m</td>
</tr>
<tr>
<td></td>
<td>dz = -120.196m 0.00075992m</td>
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<td></td>
<td>dn = -158.987m 0.00021438m</td>
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<tr>
<td></td>
<td>de = -115.662m 0.00016291m</td>
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<tr>
<td></td>
<td>du = 2.453m 0.000117824m</td>
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<tr>
<td></td>
<td>dh = 2.453m 0.000117824m</td>
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<tr>
<td>Aposteriori Covariance Matrix:</td>
<td>3.555904E-008m</td>
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<tr>
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<td>-8.706673E-008m</td>
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<td>Variance Ratio Cutoff:</td>
<td>18.5 1.5</td>
</tr>
<tr>
<td>Reference Variance:</td>
<td>1.341</td>
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</tbody>
</table>
Variance Ratio: 18.5
Cutoff: 1.5
Reference Variance: 1.341

Observable Count/Rejected RMS: L1 phase 66835/272 0.004

Processor Controls:

[General]
Process start time: 8/27/00 14:21:46 GPS (1077 51706)
Process stop time: 8/27/00 17:49:12 GPS (1077 64152)
Elevation mask: 13 degrees
Maximum iterations: 10
Maximum fixable cycle slip: 600 seconds
Ephemeris: Broadcast
Residuals: Disabled
Antenna phase correction: Enabled

[Observables]
Baseline generation: User defined
Min baseline observation time 120 seconds

[Kinematic Network]
Processing: None
Min reference observation time: 120 seconds
Min static initialization time: 120 seconds
PDOP cutoff: 10
Fixed baseline rejection ratio: 3.0
Min OTF processing time: 200 seconds
Kinematic position output: None

[Quality]
Observation editing: Edit multiplier 3.5
Ratio test: Cutoff 1.5
Reference variance test: Disabled

[Tropo Correction]
Model: Hopfield
Estimated zenith delay interval: 2 hours
Use observed mets: Enabled

[Iono correction]
Correction: Ambiguity Pass
Applied to: Final Pass
Ionos Free
Static, Kinematic
Application threshold: 10 kilometers 5 kilometers

[Final solution]
Final solution type: L1 Fixed

[Satellites]
# Satellite Phase Tracking Summaries

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<thead>
<tr>
<th>SV</th>
<th>Satellite Phase Tracking Summary - 6594</th>
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</thead>
<tbody>
<tr>
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<table>
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<th>SV</th>
<th>Satellite Phase Tracking Summary - 5547</th>
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<td>26</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td></td>
</tr>
</tbody>
</table>

14:20:00 (51600)  20 min / div.

Full phase  Half phase
Residuals

Residuals - SV 2

Residuals - SV 6

Mean = -0.000855  Std. Dev. = 0.000619  Min. = -0.014870  Max. = 0.014869

Mean = 0.001577  Std. Dev. = 0.004221  Min. = -0.012115  Max. = 0.014828
PDOP & # of Satellites

![Graph showing PDOP and number of satellites over time.](image)
TGO Solutions
(10 Total)

• L1 Code
• L2 Code
• L1 Phase Fixed & Float
• L2 Phase Fixed & Float
• Wide Lane Fixed & Float
• Narrow Lane Fixed & Float
Time Duration Windows

• Each solution type was employed in three separate time windows.

  * 10 Minutes
  * 1 Hour
  * 3 ½ Hours
SOLUTIONS

<table>
<thead>
<tr>
<th>10 Minutes</th>
<th>1 Hour</th>
<th>3 - 1/2 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1 Code</td>
<td>L1 Code</td>
<td>L1 Code</td>
</tr>
<tr>
<td>L2 Code</td>
<td>L2 Code</td>
<td>L2 Code</td>
</tr>
<tr>
<td>L1 Phase Fixed</td>
<td>L1 Phase Fixed</td>
<td>L1 Phase Fixed</td>
</tr>
<tr>
<td>L2 Phase Fixed</td>
<td>L2 Phase Fixed</td>
<td>L2 Phase Fixed</td>
</tr>
<tr>
<td>L1 Phase Float</td>
<td>L1 Phase Float</td>
<td>L1 Phase Float</td>
</tr>
<tr>
<td>L2 Phase Float</td>
<td>L2 Phase Float</td>
<td>L2 Phase Float</td>
</tr>
<tr>
<td>Narrow Lane Fixed</td>
<td>Narrow Lane Fixed</td>
<td>Narrow Lane Fixed</td>
</tr>
<tr>
<td>Narrow Lane Float</td>
<td>Narrow Lane Float</td>
<td>Narrow Lane Float</td>
</tr>
<tr>
<td>Wide Lane Fixed</td>
<td>Wide Lane Fixed</td>
<td>Wide Lane Fixed</td>
</tr>
<tr>
<td>Wide Lane Float</td>
<td>Wide Lane Float</td>
<td>Wide Lane Float</td>
</tr>
</tbody>
</table>
Comparison Methodology

• Comparison of each particular solution across three time windows.

• Comparison of ten different solutions within each of the three time windows.
SOLUTIONS

10 Minutes
- L1 Code
- L2 Code
- L1 Phase Fixed
- L2 Phase Fixed
- L1 Phase Float
- L2 Phase Float
- Narrow Lane Fixed
- Narrow Lane Float
- Wide Lane Fixed
- Wide Lane Float

1 Hour
- L1 Code
- L2 Code
- L1 Phase Fixed
- L2 Phase Fixed
- L1 Phase Float
- L2 Phase Float
- Narrow Lane Fixed
- Narrow Lane Float
- Wide Lane Fixed
- Wide Lane Float

3 - 1/2 hours
- L1 Code
- L2 Code
- L1 Phase Fixed
- L2 Phase Fixed
- L1 Phase Float
- L2 Phase Float
- Narrow Lane Fixed
- Narrow Lane Float
- Wide Lane Fixed
- Wide Lane Float
Analysis of Results

Analysis is based upon a number of elements.

* Baseline Length
* Standard Deviation of Baseline Length
* RMS
* Reference Variance
* Variance Ratio
Baseline Length
• The Baseline Length is simply the magnitude of the solution vector.

• The Standard Deviation of the baseline length is defined as usual. The units are meters.
Baseline Distances

![Baseline Distances Graph]

- L1 CODE
- L2 CODE
- L1 PHASE FIXED
- L1 PHASE FLOAT
- L2 PHASE FIXED
- L2 PHASE FLOAT
- NARROW LANE FIXED
- NARROW LANE FLOAT
- WIDE LANE FIXED
- WIDE LANE FLOAT
Baseline Distances

• Range:
  High: 196.692m
  Low: 196.276m
  Spread: 0.416m

• Median 196.612m

• Mode: 196.612m

• Solution with smallest Standard Deviation:
  196.612m

• The fixed solutions show the greatest consistency.
Standard Deviations
Standard Deviations: By Solution Type In Each Time Window
Standard Deviations In Baseline Distance By Solution Type Across Three Time Windows
Standard Deviations
By Solution Type

Fixed Solutions Only
Standard Deviations: By Time Window in Each of 10 Solution Types
Standard Deviations

10 Min. Solutions
1 Hour Solutions
3.5 Hour Solutions
Selected Standard Deviations

- Narrow Lane Fixed
- L1 Phase Fixed
- L2 Phase Fixed

Y-axis: Standard Deviations
X-axis: Solution Times
- 10 MINUTE SOLUTIONS
- 1 HOUR SOLUTIONS
- 3.5 HOUR SOLUTIONS
Root Mean Square
• The RMS as defined by TGO personnel: “The square root of the meaned squared residuals from the a posteriori least squares residual vector (not normalized).”

• Note that this value carries no units in TGO.

• The RMS values are of somewhat limited use as an element of comparison because many of the values are not sufficiently distinct. That is, the values are the same or very similar among many solutions.
RMS: By Solution Type Across Three Time Windows
RMS Code Solutions

Solution Type

L1 CODE

L2 CODE
RMS: By Time Window Across in Each of Ten Solution Types
Reference Variance
• The Reference Variance provides a measure of how well a solution met with expected errors.

• By itself it does not provide a very useful means of comparison between solutions.

• However, if a large value is encountered it may be cause to eliminate that solution from any comparison.
Reference Variances

L1 CODE
L2 CODE 10 MIN.
L1 PHASE FIXED
L1 PHASE FLOAT
L2 PHASE FIXED
L2 PHASE FLOAT
NARROW LANE FIXED
NARROW LANE FLOAT
WIDE LANE FIXED
WIDE LANE FLOAT
Variance Ratio
The Variance Ratio provides a measure of confidence in the resolution of the integer ambiguity. It is the ratio of the quality of the provided solution to the next best solution (not provided). A higher ratio indicates a clearly superior solution. It is provided only for phase fixed solutions.

Variance Ratio values are always in the same proportion where they exist, and therefore are of limited use a standard of comparison among the solutions. Like the reference variance, it serves to provide a means of evaluating which solutions to include in the comparison.
CONCLUSIONS
Solutions in Order Of Increasing Standard Deviation in Distance
<table>
<thead>
<tr>
<th>10 Minutes</th>
<th>1 Hour</th>
<th>3.5 Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrow Lane Fixed</td>
<td>Narrow Lane Fixed</td>
<td>Narrow Lane Fixed</td>
</tr>
<tr>
<td>L1 Phase Fixed</td>
<td>L1 Phase Fixed</td>
<td>L1 Phase Fixed</td>
</tr>
<tr>
<td>L2 Phase Fixed</td>
<td>L2 Phase Fixed</td>
<td>L2 Phase Fixed</td>
</tr>
<tr>
<td>Wide Lane Fixed</td>
<td>Wide Lane Fixed</td>
<td>L1 Phase Float</td>
</tr>
<tr>
<td>L1 Phase Float</td>
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<td>L2 Phase Float</td>
<td>L2 Phase Float</td>
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</tr>
<tr>
<td>L1 Code</td>
<td>Wide Lane Float</td>
<td>Wide Lane Float</td>
</tr>
<tr>
<td>L2 Code</td>
<td>L1 Code</td>
<td>L1 Code</td>
</tr>
<tr>
<td>Wide Lane Float</td>
<td>L2 Code</td>
<td>L2 Code</td>
</tr>
</tbody>
</table>
Comparison of the Three “Best” Solutions (Based Upon Standard Deviations in Baseline Distance)

- Difference the Narrow Lane, L1 Phase, and L2 Phase solutions with respect to each of the three time windows. That is, the reduction of the standard deviation due to the solution type chosen.
Differences Between 10 Minute Solutions

Narrow Lane VS. L2 Phase

L1 Phase VS. L2 Phase

Narrow Lane VS. L1 Phase
Differences Between 1 Hour Solutions

- Narrow Lane VS. L2 Phase
- L1 Phase VS. L2 Phase
- Narrow Lane VS. L1 Phase
3.5 Hour Solutions

Narrow Lane VS. L2 Phase

L1 Phase VS. L2 Phase

Narrow Lane VS. L1 Phase
Difference the three time windows with respect to the Narrow Lane, L1 Phase, and L2 Phase solutions. That is, the reduction in the standard deviation due to the time length of observation.
Narrow Lane Differences

10 Min VS. 1 Hour 10 Min VS. 3.5 Hours 1 Hour VS. 3.5 Hours
L1 Phase Fixed Differences

- 0.0000
- 0.0001
- 0.0002
- 0.0003
- 0.0004
- 0.0005
- 0.0006
- 0.0007
- 0.0008
- 0.0009
- 0.0010

10 Min VS. 1 Hour
10 Min VS. 3.5 Hours
1 Hour VS. 3.5 Hours
L2 Phase Fixed Differences

10 Min VS. 1 Hour
10 Min VS. 3.5 Hours
1 Hour VS. 3.5 Hours

Values:
- 0.0000
- 0.0001
- 0.0002
- 0.0003
- 0.0004
- 0.0005
- 0.0006
- 0.0007
- 0.0008
- 0.0009
- 0.0010
Precision Ratios

- Division of baseline distance by its associated standard deviation.

<table>
<thead>
<tr>
<th></th>
<th>10 Minutes</th>
<th>1 Hour</th>
<th>3.5 Hours</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1 : 628,400</td>
<td>1 : 1,054,300</td>
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<tr>
<td>L1 Phase</td>
<td>1 : 215,500</td>
<td>1 : 532,700</td>
<td>1 : 950,100</td>
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<tr>
<td>L2 Phase</td>
<td>1 : 162,300</td>
<td>1 : 461,100</td>
<td>1 : 689,800</td>
</tr>
</tbody>
</table>
Astounding Precision from a Land Surveying Perspective
Precision Ratios If the Standard Deviations are Overly Optimistic by an Order of Magnitude

<table>
<thead>
<tr>
<th></th>
<th>10 Minutes</th>
<th>1 Hour</th>
<th>3.5 Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrow Lane</td>
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<td>1 : 62,400</td>
<td>1 : 105,430</td>
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<tr>
<td>L1 Phase</td>
<td>1 : 21,500</td>
<td>1 : 53,700</td>
<td>1 : 95,100</td>
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<tr>
<td>L2 Phase</td>
<td>1 : 16,300</td>
<td>1 : 46,100</td>
<td>1 : 68,800</td>
</tr>
</tbody>
</table>
A More Reasonable Precision from a Land Surveying Perspective.
Note on TGO Solutions

- The final solution provided by TGO is somewhat beyond the user’s control. The software does not allow any control over certain solution parameters. For example, the software chooses what type of differencing to employ and which receiver acts as the base in differencing the final solution.
BEWARE!

✓ The algorithms employed to derive precision estimates are hidden. More to the point, Trimble is hesitant to “divulge” even simple definitions.

✓ The variances, standard deviations, and RMS values are suspiciously low (much better than may be had by resolving the carrier frequency to within 1/100 of a wavelength).

✓ The variance components are almost uniformly > 1

✓ The variance ratios are consistent among solutions.

✓ Certain solution elements are beyond the user’s control.
Some Comments on Selective Availability
This is a plot of GPS navigational errors through the SA transition prepared by Rob Conley of Overlook Systems for U.S. Space Command in Colorado Springs, Colorado. The GPS errors can be seen diminishing significantly around 0405 UTC (shortly after midnight EDT). The data indicates a circular error of only 2.8 meters and a spherical error of 4.6 meters during the first few hours of SA-free operation. The data was measured using a Trimble SV6 receiver.
SA Transition -- 2 May 2000

Colorado Springs, Colorado

Time of Day (Hours UTC)

Instantaneous Error (meters)

Horizontal Error (meters)

Vertical Error (meters)

2 May 2000

SPS CEP AFTER TRANSITION: 2.8 meters
SPS SEP AFTER TRANSITION: 4.6 meters
The images compare the accuracy of GPS with and without selective availability (SA). Each plot shows the positional scatter of 24 hours of data (0000 to 2359 UTC) taken at one of the Continuously Operating Reference Stations (CORS) operated by the NCAD Corp. at Erlanger, Kentucky. On May 2, 2000, SA was set to zero. The plots show that SA causes 95% of the points to fall within a radius of 45.0 meters. Without SA, 95% of the points fall within a radius of 6.3 meters.

As illustration, consider a football stadium. With SA activated, you really only know if you are on the field or in the stands at that football stadium; with SA switched off, you know which yard marker you are standing on.