Long distance GPS baseline solutions using various software and EPN data

by

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1. Main Scope of this Study

? Experimentally test
the quality of GPS software packages
by processing long baselines
for professional engineering applications.

Software used

SKI-Pro v.3.0

Trimble Geomatics Office v.1.5

Javad Pinnacle v.1.0

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2. GPS Data – Baseline Information

? **15** GPS stations (**E**uropean **P**ermanent **N**etwork)
? **13** baselines from about 60 to 500 Km.

Baseline	Baseline Length (Km)	GPS Receivers
1 WARE – BRUS	63.6	Ashtech UZ12 – Z-XII3
2 DENT–BRUS	69.2	Ashtech UZ12 – Z-XII3
3 DOUR – BRUS	79.9	Ashtech UZ12 – Z-XII3
4 VENE – MEDI	113.3	Ashtech Z18 – Trimble 4000SSI
5 TERS – DELF	163.1	Trimble 4000SSI – 4700
6 EIJS – DELF	163.7	Trimble 4700 – 4700
7 GENO – MEDI	217.1	Trimble 4000SSI – 4000SSI
8 BZRG – MEDI	221.2	Leica GRX1200 – Trimble 4000SSI
9 TORI – MEDI	321.0	Trimble 4000SSI – 4000SSI
10 REYK – HOFN	328.3	AOA SNR8000 ACT – Trimble 4000SSI
11 MEDI – ZIMM	417.8	Trimble 4000SSI – NETRS
12 EIJS – ZIMM	450.9	Trimble 4700 – NETRS
13 BRUS – ZIMM	491.8	Ashtech Z-XII3 – Trimble NETRS

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? **GPS** stations are located in Belgium, Iceland, Italy, Netherlands and Switzerland.

? The large spatial site distribution over the EUREF network results in quantitatively different atmospheric errors affecting the data.

? The time duration of the test data covers 21 days, from 11th to 31st of December 2005.

? 21 days of GPS data processed for each baseline.

? Using IERS - transformation parameters and site velocities coordinates of the reference points are estimated in ITRF2000 for the current epoch.

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3. Baseline Processing Parameters

For simplicity and compatibility reasons identical processing strategies were applied.

Processing parameters

? Cut-off angle: 15°
? Observation rate: 30 sec (nominally rate for EPN)
? Orbit type: IGS final precise ephemeris
? Frequencies: L1 and L2
? Tropospheric model: Hopfield
? Solution type: Iono free fixed
? Observing session: One day

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3.1 Remarks on Baseline Solutions

- For three baselines (11, 12, 13) longer than 400Km, no Pinnacle solution with fixed ambiguities can be computed due to software restrictions in length.
- For b aseline No.10 (Reykjavik –Hoefn), TGO gives a fixed solution only for 14 out of 21 days, something to be discussed later.
- Software packages give too optimistic values for the a-posteriori reference variance.

- The separation of long and short term errors is possible for a long observation period (21 days ? 21 sessions).
- Orbital errors, atmospheric errors and multipath may be highly correlated over a time span of up to few weeks. These are long term errors and do not change significantly from day - to -day . In our study this assumption is valid.
- Professional engineers often use data of short time periods (few hours to a couple of days) and the precision is principally affected by short term errors.

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4. Precision measures
For the baseline lengths given by each software:

1st step: The repeatability (R) as a weighted rms – weights comes from the Software for each baseline in each day

-Best fitting lines of 21 R - values for each software

-Testing the compatibility between R-values

2nd step: Estimation of the repeatability (r) ignoring Software computed weights

-Best fitting lines of 21 r-values for each software

3rd step: Comparison between R and r

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4. Precision measures

1st step: **R**epeatability R as a **weighted rms**

- Short term precision ***R***, also called **R**epeatability, is expressed by the **weighted rms** about the mean of each daily estimate.

For *n* independent baseline lengths y_i with their standard deviations $\sigma_1, \sigma_2, \ldots, \sigma_n$ given by each software, in our case $n = 21$, **R** is computed by:

$$R = \sqrt{\frac{\frac{n}{n-1}\sum_{i=1}^{n}\frac{(y_i-\bar{y})^2}{\sigma_i^2}}{\sum_{i=1}^{n}\frac{1}{\sigma_i^2}}}, \text{ where } \bar{y} = \frac{\sum_{i=1}^{n}\frac{1}{\sigma_i^2}y_i}{\sum_{i=1}^{n}\frac{1}{\sigma_i^2}} \text{ the weighted mean of } y_i .$$

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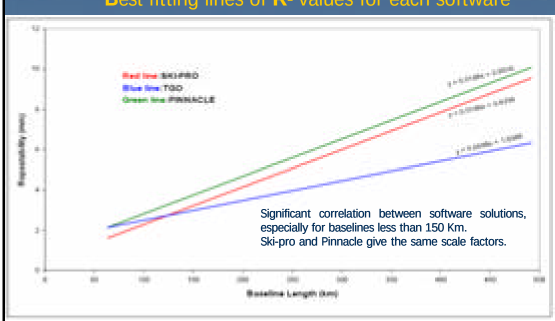
Best fitting lines of R- values for each software



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- Testing the compatibility between **R-values**

The ratio $\frac{R_i^2}{R_j^2}$ follows F - distribution.

The null hypothesis between each pair of software $H_0 : R_i^2 = R_j^2$

is tested against the alternative $H_\alpha : R_i^2 \neq R_j^2$

For a significance level a=0.05, H_0 is accepted if

$$\frac{R_i^2}{R_j^2} \leq F^{\alpha/2}_{n_i-1, n_j-1}$$

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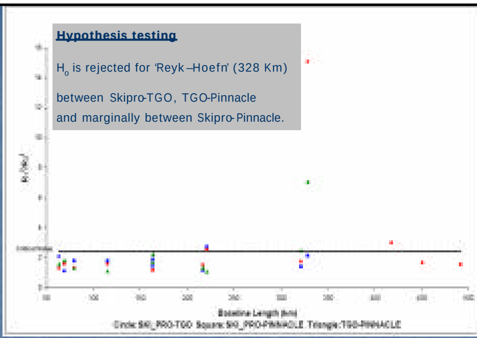

2nd step: repeatability ignoring weights

? Instead of the precision s_i^2 given by each software and used in *R-formula*, in this approach the precision is computed by *r-formula* ignoring s_i^2 *(equal weights = 1)*

$$r = \sqrt{\frac{1}{n-1}\sum_{1}^{n}(x_i - \bar{x}_i)^2} \quad , \quad \bar{x} = \frac{1}{n}\sum_{1}^{n} x_i$$

where x_i the daily equal-weight estimates of the baseline lengths.

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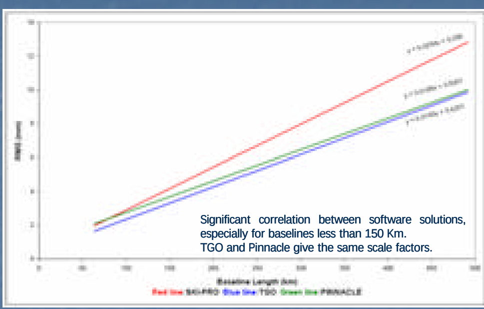
? Best fitting lines of **r-values** for each software



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3rd **Precision Comparison** between R and r

Lines from **R -values**	Lines from **r - values**	
1.51 *mm* + ***0.98*** *parts in* 10^8	***0.42*** *mm* + ***1.93*** *parts in* 10^8	TGO
0.42 *mm* + ***1.86*** *parts in* 10^8	***0.35*** *mm* + ***2.54*** *parts in* 10^8	Ski-pro
0.95 *mm* + ***1.86*** *parts in* 10^8	***0.92*** *mm* + ***1.85*** *parts in* 10^8	Pinnacle

A reduction of the constant term is noted from R to r fitting lines whereas the scale factor increases for TGO, Ski-pro and remains almost the same for Pinnacle.

The two approaches *do not differ significantly*.
The same conclusion is derived from the statistical test.

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5. Accuracy measures

By Comparing software estimated baseline lengths to the "True" lengths

? "true" lengths computed by EPN – ITRF2000 coordinates.

? This is a check of the external accuracy or reliability as EPN- ITRF coordinates derive by means of network adjustment using more sophisticated software like Bernese an other high accuracy data sources.

5.1 Baseline Length Differences and precision R

5.2 Baseline Length Differences and precision r

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5.1 Baseline length differences and precision R

BASELINE	SKI-PRO v.3.0		Trimble Geomatics Office v.1.5		Javad Pinnacle v.1.0	
	Difference (mm)	R-values WRMS (mm)	Difference (mm)	R-values WRMS (mm)	Difference (mm)	R-values WRMS (mm)
WARE-BRUS	4.32	0.56	2.82	0.64	1.97	0.81
DENT-BRUS	2.66	1.97	2.10	1.55	2.65	2.09
DOUR-BRUS	5.16	1.85	6.67	2.15	6.28	2.46
VENE-MEDI	8.13	2.90	9.05	3.68	9.73	3.87
TERS-DELF	8.89	4.41	9.67	4.10	10.75	5.32
EIJS-DELF	3.52	3.09	4.95	2.82	5.55	4.20
GENO-MEDI	5.60	4.73	5.95	5.85	11.77	5.04
BZRG-MEDI	3.62	2.85	0.79	4.55	5.05	4.73
TORI-MEDI	5.90	5.15	8.41	3.91	6.50	6.14
REYK-HOEN	13.20	10.56	28.74	2.72	21.40	7.24
MEDI-ZIMM	9.15	8.22	7.52	4.74	-	-
EIJS-ZIMM	10.87	8.16	13.29	6.30	-	-
BRUS-ZIMM	9.25	8.71	11.13	6.99	-	-

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5.2 Baseline length differences and precision r

BASELINE	SKI-PRO v.3.0		Trimble Geomatics Office v.1.5		Javad Pinnacle v.1.0	
	Difference (mm)	r-values RMS (mm)	Difference (mm)	r-values RMS (mm)	Difference (mm)	r-values RMS (mm)
WARE-BRUS	4.32	0.56	2.82	0.64	1.98	0.80
DENT-BRUS	2.66	1.97	0.67	1.96	1.62	1.53
DOUR-BRUS	5.11	2.43	6.58	2.42	6.23	2.43
VENE-MEDI	7.34	3.14	7.89	3.80	12.96	3.84
TERS-DELF	8.10	5.18	8.86	4.11	9.56	5.28
EIJS-DELF	1.13	3.14	5.03	2.78	5.55	4.28
GENO-MEDI	1.36	6.08	4.39	5.86	11.64	5.03
BZRG-MEDI	3.01	3.12	0.49	3.97	1.96	4.46
TORI-MEDI	3.79	7.75	10.78	6.59	5.40	6.28
REYK-HOEN	11.42	21.17	28.37	3.30	21.67	7.06
MEDI-ZIMM	3.39	8.69	4.85	11.46	-	-
EIJS-ZIMM	9.35	9.77	12.34	8.85	-	-
BRUS-ZIMM	7.61	10.51	8.81	9.49	-	-

6. Quality Check on raw data for 'Reyk-Hoefn' baseline

Differences between EPN and software solutions for the 'Reyk-Hofn' baseline are about *three to four* times bigger than **all** other baseline length differences.

Probably Accuracy depends on the performance of the GPS receivers and the quality of the software.

For that reason:
A quality check on Rinex GPS data was applied using Leica *GNSSQC* program.

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6.1 Quality Check Results

1. Tracking Performance on L_1& L_2 – Data Completeness:
For both receivers in Reykjavik (AOA SNR8000ACT) and in Hoefn (Trimble 4000SSI) the quality indicators were almost **100%.**

2. Number of Cycle Slips: Many cycle slips, especially for the receiver in Hoefn and only for a few days.

3. The receiver clock offset:
Change in clock bias changes the observations (see plots).

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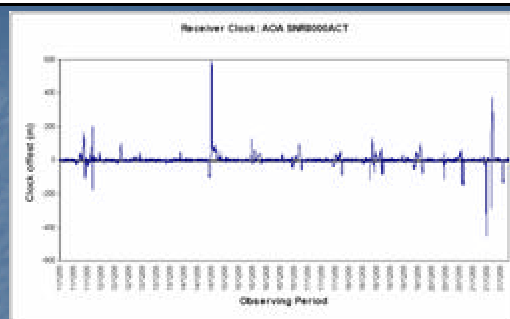

? Clock behavior: Unpredictable jumps influences the observations.

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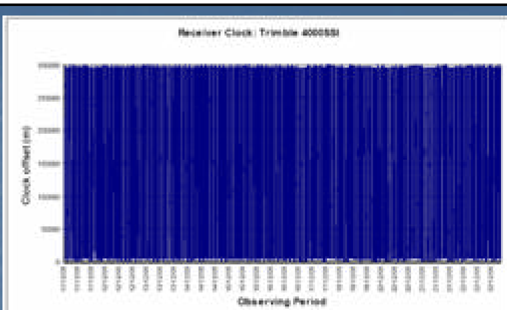

Predictable clock behavior (constant bias eliminable), swing widely constant

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? *Reprocessing* the 'Reyk-Hoefn' baseline excluding data with cycle slips and big clock variations:

? All software resolved the ambiguities (including TGO soft.)

? The baseline vectors changed insignificantly - only few millimeters

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7. Conclusions

? Ski-pro, TGO and Pinnacle software showed almost the same behavior.

? Obtained precision by software baseline adjustments is too optimistic.

? Precision gets more realistic when expressed by repeatability measures.

? A repeatability scatter can be modeled by a best fitting line.

? Differences in baselines lengths between the software estimated and the 'EPN –coordinates ' which derived are of the order of few millimeters.

? Commercial software packages can produce reliable results and be used in almost any type of professional engineering projects.

? More sophisticated analysis on data processing is needed when processing very long baselines (over 500 Km) or in producing high accuracy estimates, like site velocities.