Benefits of double stations in permanent GNSS networks

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Swiss Permanent Network AGNES

- 30 stations
- since 1998 operational
- 50 km spacing

- GNSS since 2007.5
  (22 antenna changed + but 8 double stations for reference frame monitoring)

- Analysed by Bernese GNSS Software together with EUREF- and IGS stations (hourly + daily + weekly + multi-annually) and VRS3Net (real-time)
Double / Triple / Multi station concept
Example Zimmerwald

- GPS (since 1991)
- MULTI GNSS (since 2011)
- GPS + GLONASS (since 2007)
- MULTI GNSS (since 2013)

ZIMM, ZIM2, ZIM3
Benefits of Double Stations = Content of this presentation

1. Long-term stability and reference frame monitoring using stations with uninterrupted time series

2. Sophisticated analysis methods are available for short baselines ("twins check each other")
   - Coordinate monitoring: L1 data analysis (instead iono-free L3) applicable for static and kinematic solutions
   - Troposphere checks

3. Comparison with ground truth from local ties
Velocity precision and antenna change

Coordinate jumps + relative velocity constraints!

### Formal error of the velocities (weekly coordinate rms of 4 mm)

- **no antenna change**
- **antenna change + jump**
- **antenna change + jump known with 4 mm rms**
- **antenna change + jump known with 0.4 mm rms**
- **antenna change + jump known with 0.04 mm rms**

### Changing technology every 5-7 years?

- **3 years continuous = 10 years with 2 changes**

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Statistic of the length of an observation interval

- ~75 stations (CH + Double stations + RTK-stations A + D)

22 antenna changes in 2007 due to GLONASS

8 double stations – valuable for velocity estimation

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Time is working for you! $\sqrt{dt^3}$
Combined multi-annual solutions: vertical velocities

- Reference: min. constraints for some IGS sites w.r.t. ITRF2008 at mean epoch of obs.
Weekly L3 repeatability: HOHT-HOH2

Weekly L3 network solutions

Coordinate repeatability of HOHT

- North: std 1.40 mm
- East: std 0.79 mm
- Up: std 2.70 mm

Coordinates of HOHT:

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Short BSL repeatability: HOHT-HOH2

Daily L1 baseline solutions

Conclusion:
Comparison Weekly L3 network vs. Daily L1 baseline:
- Repeatability increase by factor of 3 (factor 6-8 considering daily – weekly)
- artificial effects L3 / Tropo – antenna model dependencies detectable

sub-millimeter!
Short BSL repeatability: ETHZ-ETH2

- Daily L1 baseline solutions
- 3-4 mm amplitude
- \( \rightarrow \) Instable buildings
- no east-west

North north-east

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Short BSL repeatability: ZIMJ-ZIMM

Daily L1 baseline solutions

- Loose adapter screw

Fixing screw on July 2008 (local tie including new site ZIM2)
Short BSL repeatability: WAB1-WAB2

Coordinate repeatability of WAB2

North [mm]
-20
-15
-10
-5
0
5
10
15
20
std 0.28 mm
North

East [mm]
-20
-15
-10
-5
0
5
10
15
20
std 0.45 mm
East

Up [mm]
-40
-30
-20
-10
0
10
20
30
40
std 0.19 mm
Up

YEAR
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0.2 mm height repeatability (daily L1 baseline solutions)

-> Incredible!

Twins check each other
Kinematic short baselines (for static station)

L3 kinematic solutions
Example ZIM2

L1 kinematic solutions
Example ZIM2-ZIMM

Coordinate repeatability of ZIM2

std ± 5.10 mm
North

std ± 3.92 mm
East

std ± 9.11 mm
Up

Coordinate repeatability of ZIM2

std ± 2.61 mm
North

std ± 1.07 mm
East

std ± 4.60 mm
Up

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- Repeatability improvement factor 2: sub-daily variation detection – seen already in ZIMM (9 mm horizontally at sunny day)

Conclusion:

- L3 and L1 kinematic solutions performed as quality indicator for all permanent analyses (swisstopo web) as well as for campaign processing (html protocol)

http://www.swisstopo.ch/pnac
Troposphere of double stations

- should be stable
- bias due to antenna changes
- TRP as sensitive QC parameter
- climate change monitoring needs uninterrupted time series
Comparison Local Tie vs. GNSS (GPS)

- **independent measurement techniques**

- **Validation**
  - GPS processing options using local tie as reference
  - “Antenna quality” GNSS (GPS antenna remained)
    - 2008: Trimble Zephyr 2
    - 2009: Coke Ring GNSS

Details presented to EUREF 2009
Summary: GPS versus local tie

L1 ok., L3+Tropo better agreement to local tie using Chokering antennas, but still biased.

Bias of L3 w.r.t local tie limits the “absolute” accuracy in GNSS reference frame realization!

PCV: absolute individual

Statistics for sites: ARDE, DAVO, BOUR, MART
Conclusion: Benefits of Double Stations

1. Long-term stability gave >10 sites with >10 years uninterrupted time series and reliable velocities.
2. Sub-millimeter results are available for short baselines (“twins check each other”): detection of station problems in several cases; artefacts of L3 solutions; sub-daily movement detection using kinematic L1 solutions; tropo qc.
3. Comparison with ground truth from local ties: detection of antenna phase center model problems and quantifying “absolute” reference frame accuracy.