Spotlight on Bernese GNSS Software

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Reference Frames in Practice
Technical Seminar in the frame of XXVII FIG Congress
10.–11. September 2022, Warsaw, Poland

The Bernese GNSS Software

The *Bernese GNSS Software* is

- a scientific software package
- for multi-GNSS data analysis
- with highest accuracy requirements
- in regional to global scale networks.

It is developed, maintained and used at the
Astronomical Institute of the University of Bern
since many years.

The *Bernese GNSS Software* is online at
http://www.bernese.unibe.ch .

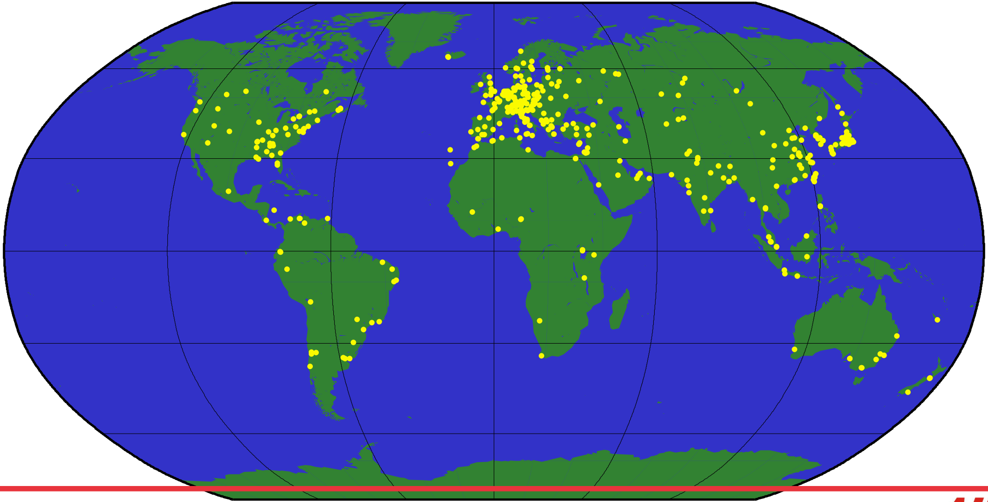
The Bernese GNSS Software

The Bernese GNSS Software is particularly well suited for:

- rapid processing of small-size surveys (static as well as kinematic stations — even LEOs)
- automatic processing of permanent networks (BPE: Bernese Processing Engine),
- combination of different receiver and antenna types,
  taking receiver biases and satellite antenna phase center variations into account,
- rigorosly combined processing of GPS, GLONASS, Galileo, BDS, and QZSS observations,
- ambiguity resolution on long baselines (2000 km and longer),
- precise point positioning (including ambigity resolution),
- generation of minimum constraint network solutions,
- ionosphere and troposphere monitoring,
- clock offset estimation and time transfer,
- orbit determination and estimation of Earth orientation parameters.
- . . .

Bernese GNSS Software: users

Distribution of institutions using the Bernese GNSS Software



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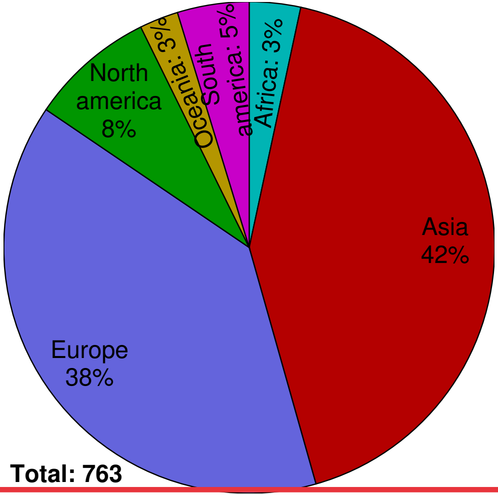
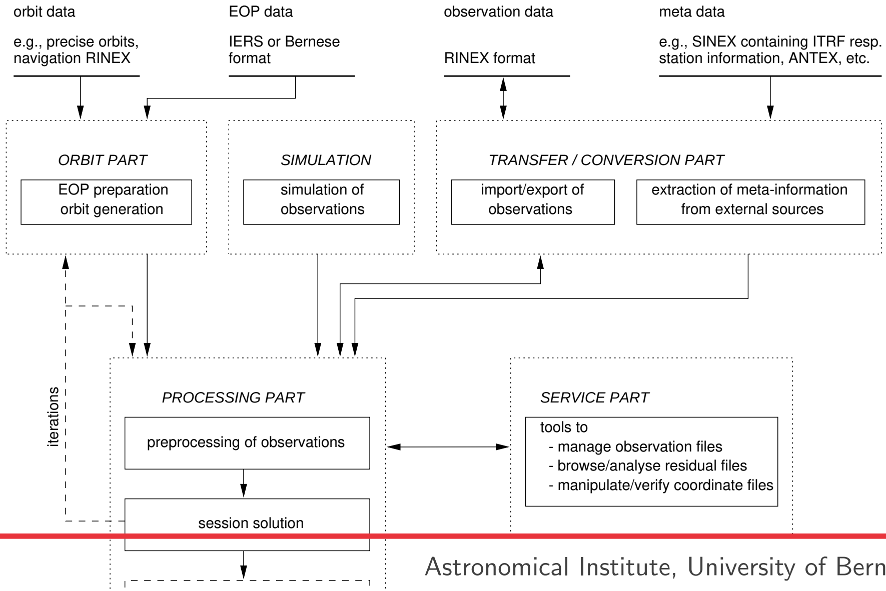


Bernese GNSS Software: Program Overview



Bernese GNSS Software: Program Overview

- Transfer Part:
  Programs for generating files in the Bernese format from RINEX. Furthermore, this part also contains a set of tools to cut/concatenate and to manipulate RINEX files.

- Conversion Part:
  Programs to extract external information necessary for the processing from international to Bernese specific formats
  (e.g., coordinates and velocities from ITRF in SINEX format, ANTEX, Bias SINEX).

- Orbit Part:
  Programs for generation of a source-independent orbit representation (standard orbits), to update orbits, generate orbits in precise orbit format, compare orbits, etc. The Earth orientation related tools are included in this part too.

Bernese GNSS Software: Program Overview

- Processing Part:
  Programs for receiver clock synchronization, code and phase pre-processing, ambiguity resolution, parameter estimation based on GNSS observations (pgm. GPSEST) and on the superposition of normal equations (pgm. ADDNEQ2).

- Simulation Part:
  Program to generate simulated GNSS observations (code and/or phase, one or two frequencies) based on statistical information (RMS for observations, biases, cycle slips).

- Service Part:
  A collection of useful tools to edit/browse/manipulate binary data files, compare coordinate sets, display residuals, etc. A set of programs to convert binary files to ASCII and vice versa belong to the service part, too.

Bernese GNSS Software: Processing steps

1. Data transfer: copy data into the campaign area
2. Import observation data into Bernese format
3. Prepare EOP and orbit information
4. Data preprocessing: cycle slip detection and correction; outlier rejection
5. Make a first network solution (real-valued ambiguities)
6. Resolve ambiguities
7. Create normal equations containing all relevant parameters
8. NEQ-based single- or multi-session solution

Bernese Processing Engine

- The implementation of these steps for an automated processing is done in the frame of a BPE - Bernese Processing Engine.
- The BPE needs to know
  - what is to do: user scripts
  - the order of running the scripts (dependencies)
  - where a script can be started (CPU)
- Process Control File (PCF) is the way how this information is implemented.
- An example of such a PCF looks like:

Bernese Processing Engine

```
PID  SCRIPT     OPT_DIR    PARAMETERS
#
# Copy required files
# -------------------
001  R2S_COP    R2S_GEN    CPU=ANY
011  RNX_COP    R2S_GEN    CPU=ANY; WAIT=001;  NEXTJOB= 101 999
#
# Prepare the pole and orbit information
# --------------------------------------
101  POLUPD     R2S_GEN    CPU=ANY; WAIT=001
112  ORBGEN     R2S_GEN    CPU=ANY; WAIT=101 111
#
# Preprocess, convert, and synchronize observation data
# -----------------------------------------------------
221  RXOBV3     R2S_GEN    CPU=ANY; WAIT=011
231  CODSPP     R2S_GEN    CPU=ANY; WAIT=112 221
#
# Form baselines and pre-process phase data (incl. residual screening)
# --------------------------------------------------------------------
302  SNGDIF     R2S_GEN    CPU=ANY; WAIT=231
311  MAUPRP     R2S_GEN    CPU=ANY; WAIT=302
321  GPSEDT     R2S_EDT    CPU=ANY; WAIT=311
341  ADDNEQ2    R2S_GEN    CPU=ANY; WAIT=331
...
```

1 3 2 4 5

Bernese Processing Engine

```
PID  SCRIPT    OPT_DIR   PARAMETERS
...
#
# Resolve phase ambiguities
# -------------------------
411  GNSAMBAP  R2S_AMB   CPU=ANY; WAIT=401
412  GNSAMB_P  R2S_AMB   CPU=ANY; WAIT=411;  PARALLEL=411
#
# Compute ambiguity-fixed network solution, create final NEQ/SNX/TRO files
# ------------------------------------------------------------------------
501  GPSEST    R2S_FIN   CPU=ANY; WAIT=412;  PARAM2=V_FIN
511  ADDNEQ2   R2S_FIN   CPU=ANY; WAIT=501
513  HELMCHK   R2S_FIN   CPU=ANY; WAIT=511;  NEXTJOB= 511
514  COMPAR    R2S_FIN   CPU=ANY; WAIT=513
#
# Create summary file and delete files
# ------------------------------------
901  R2S_SUM   R2S_GEN   CPU=ANY; WAIT=513
902  R2S_SAV   R2S_GEN   CPU=ANY; WAIT=901
904  R2S_DEL   R2S_GEN   CPU=ANY; WAIT=902 903;  PARAM1=(10)
#
# End of BPE
# ----------
999  DUMMY     NO_OPT    CPU=ANY; WAIT=904
```

6

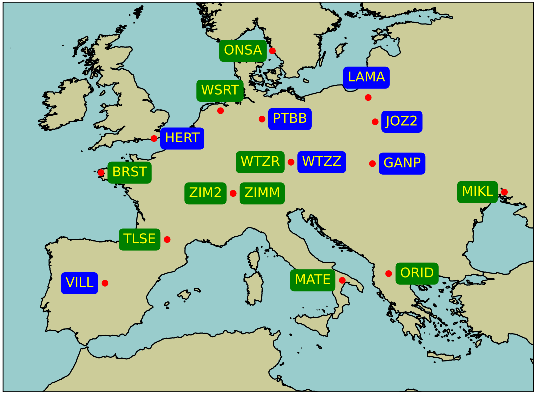
7

8

Example Data for Demonstration

Seventeen European stations of the IGS network and from the EPN:

BRST	Brest, FRA
GANP	Ganovce, SVK
HERT	Hailsham, GBR
JOZ2	Jozefoslaw, POL
LAMA	Olsztyn, POL
MATE	Matera, ITA
MIKL	Mykolaiv, UKR
ONSA	Onsala, SWE
ORID	Ohrid, MKD
PTBB	Braunschweig,DEU
TLSE	Toulouse, FRA
VILL	Villafranca, ESP
WSRT	Westerbork, NLD
WTZR, WTZZ	Kötzting, DEU
ZIM2, ZIMM	Zimmerwald, CHE



Stations used in example campaign (green stations with coordinates given in the IGS 20 reference frame)

Demonstration

Bernese GNSS Software: some facts

The software package consists of:

- a QT-based graphical user interface
- a set of processing programs (Fortran 2003)
- distribution contains the full source code
- it runs on PC/Windows, UNIX/LINUX, MAC

```
! Update the statistics over all files per system
DO iSys = 1,maxSys
  CALL statisSysAll%stat(iSys)%stack(statisSys%stat(iSys))
ENDDO

! Update the statistics over all files and satellites
CALL statisTotAll%stat(1)%stack(statisTot%stat(1))

! Print the statistics for this observation file
CALL obxprt(opt, iFil, obsHeadObx, statisSat, statisSys, stat

! Consider the condition regarding file selection
IF ( opt%what%isOptionWhatObservation() ) THEN
  IF ( opt%checkObs(statisTot%stat(1)) ) THEN
    CALL opt%lstFile%append(opt%fillst(1,iFil))
  ELSE
    CALL opt%delFile%append(opt%fillst(1,iFil))
    CALL opt%delFile%append(opt%fillst(2,iFil))
  ENDIF
ENDIF
```

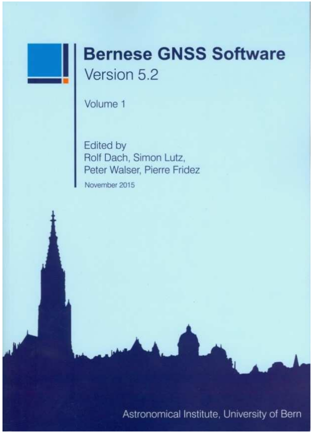
The software package counts today:

- nearly 90 processing programs and 1400 subroutines, functions, and modules about 600,000 lines of source code (including comment lines),
- the GUI/BPE-program with 18,000 lines of source code

Bernese GNSS Software: some facts

Intensive user support includes

- online-help system provides explanations on the options,
- a 850 pages user manual (downloadable as PDF for free),
- a series of README-files on various topics
- FAQ-section on the webpage,
- e-mail support to help with potential problems,
- regular updates for bugfixes and improvements,
- a one week introductory course in Bern.



Processing examples:

The distribution of the software package contains ready-to-use examples:

- PPP – PRECISE POINT POSITIONING
  - standard PPP for coordinate, troposphere, and receiver clock determination
  - as single- or multi-GNSS solutions (GPS, GLONASS, Galileo, BeiDou, QZSS)
  - ambiguity resolution, if the consistent bias products are available
  - several extended processing examples can be enabled: geocenter estimation, pseudo-kinematic, high-rate troposphere

Processing examples:

The distribution of the software package contains ready-to-use examples:

- RNX2SNX: RINEX-to-SINEX
  - standard double difference network solution
  - primary products are coordinates and troposphere corrections
  - as single- or multi-GNSS solutions (GPS, GLONASS, Galileo, BeiDou, QZSS)
  - extended ambiguity resolution scheme
  - datum definition with verification based on minimum constraint solution
- CLKDET: CLOCK DETERMINATION
  - standard zero difference network solution
  - primary products are receiver and satellite clock corrections (also, w.r.t. an existing coordinate and troposphere solution)
  - as single- or multi-GNSS solutions (GPS, GLONASS, Galileo, BeiDou, QZSS)

Processing examples:

The distribution of the software package contains ready-to-use examples:

- IONDET: IONOSPHERE MODEL DETERMINATION for LEOs
  - ionosphere model determination from regional or global networks for dual-frequency
- LEOPOD: PRECISE ORBIT DETERMINATION for LEOs
  - Precise Orbit Determination for a Low Earth Orbiting Satellites based on on-board GPS-measurements (e.g., for GRACE)
- SLRVAL: SLR ORBIT VALIDATION
  - Validation of an existing GNSS or LEO orbit using SLR measurements

Processing examples:

Each example BPEs is accompanied by an extensive README file:

- explaining the main purpose,
- providing a detailed description on the realization of the purpose,
- showing where to find the key quality indicators for the results and giving some ideas about potential sources of problems,
- listing of the BPE example configuration,
- listing the necessary input and result files.

Processing examples: coordinate computation

The processing examples distributed with the *Bernese GNSS Software* offer three ways to compute coordinates:

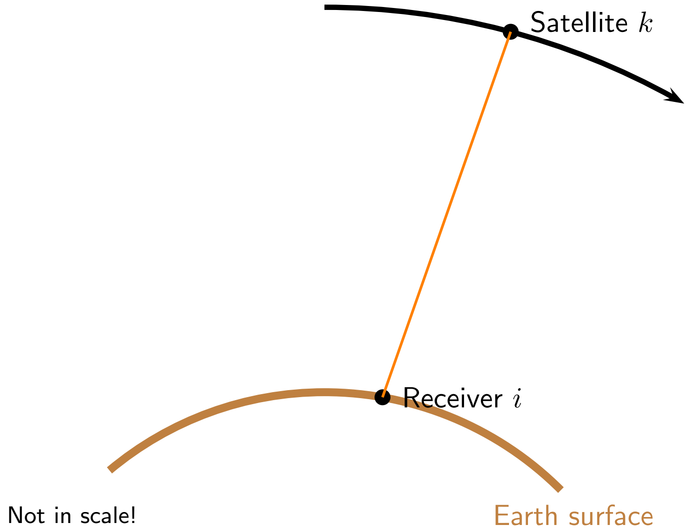
1. PPP: Precise Point Positioning
   processing of single stations, very efficient in case of parallelization

2. RNX2SNX: double-difference network solution
   efficient because clock parameters are not explicitly setup, but
   needs bookkeeping to consider correlations due to differencing

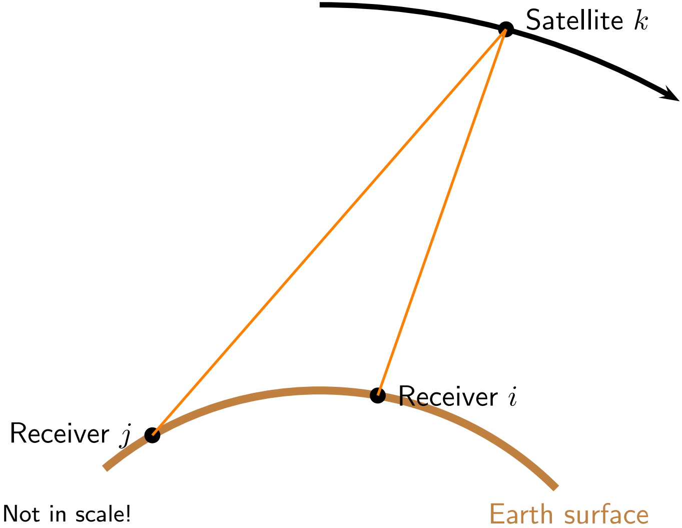
3. CLKDET: zero-difference network solution
   network solution means, to solved for satellite and receiver clock corrections
   at least a normal equation with all satellite clock parameters need to be inverted.

Are there differences between the three strategies or are they equivalent?

Principle of GNSS Network Solution



Principle of GNSS Network Solution



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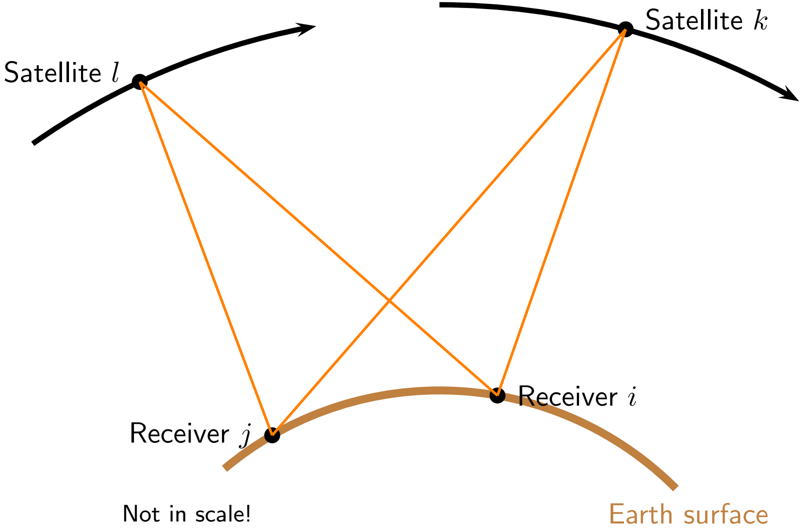

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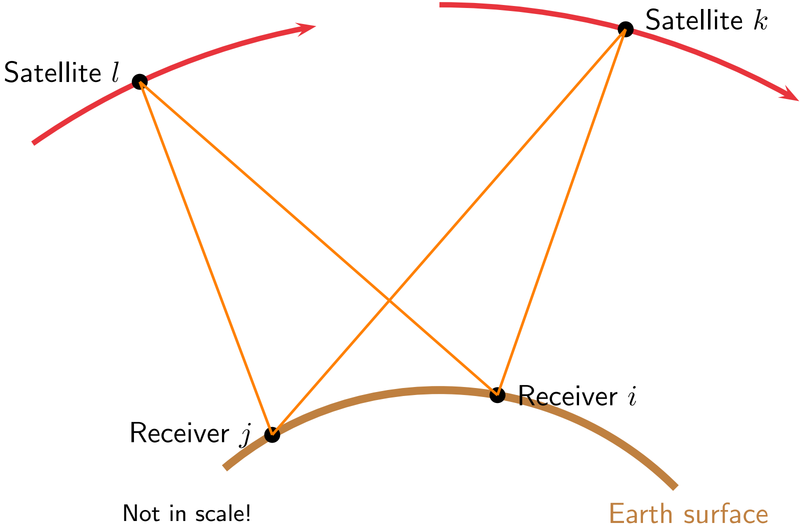

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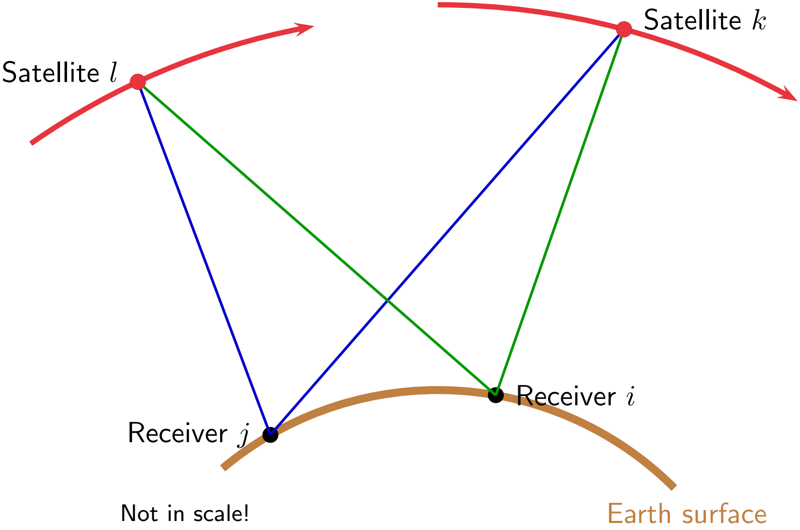

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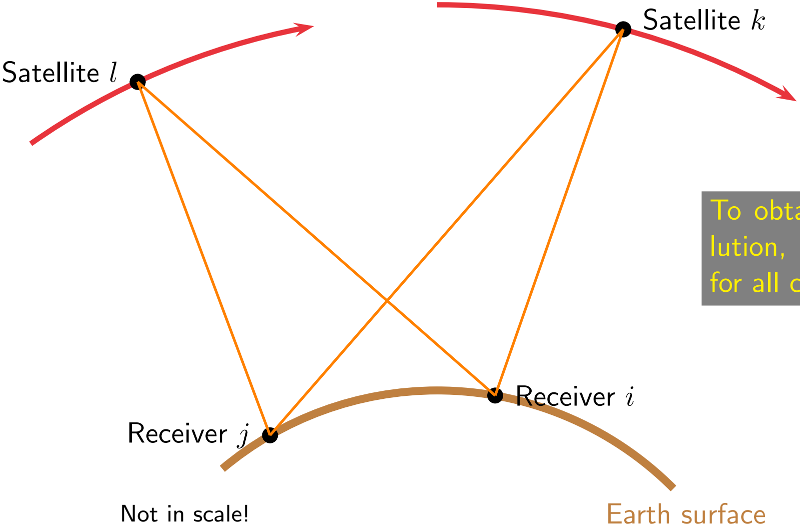

To obtain a network solution, we have to solve for all clock parameters.

Principle of GNSS Network Solution

We have the GNSS observations of several stations to some satellites:

$$L_i^k = \left|\vec{x^k} - \vec{x_i}\right| + T_i^k + c\delta_i - c\delta^k + \lambda N_i^k \qquad L_i^l = \left|\vec{x^l} - \vec{x_i}\right| + T_i^l + c\delta_i - c\delta^l + \lambda N_i^l \qquad \ldots$$

$$L_j^k = \left|\vec{x^k} - \vec{x_j}\right| + T_j^k + c\delta_j - c\delta^k + \lambda N_j^k \qquad L_j^l = \left|\vec{x^l} - \vec{x_j}\right| + T_j^l + c\delta_j - c\delta^l + \lambda N_j^l \qquad \ldots$$

Principle of GNSS Network Solution

If you are not interested in the clock parameters ...

$$L_i^k = \left| \vec{x^k} - \vec{x_i} \right| + T_i^k + c\delta_i - c\delta^k + \lambda N_i^k \qquad L_i^l = \left| \vec{x^l} - \vec{x_i} \right| + T_i^l + c\delta_i - c\delta^l + \lambda N_i^l \qquad \ldots$$

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... we may form differences between observations to cancel out the clock parameters:

$$L_i^k - L_j^k = \left|\vec{x^k} - \vec{x_i}\right| - \left|\vec{x^k} - \vec{x_j}\right| + T_i^k - T_j^k + c\left(\delta_i - \delta^k - \delta_j + \delta^k\right) + \lambda\left(N_i^k - N_j^k\right)$$

$$L_i^l - L_j^l = \left|\vec{x^l} - \vec{x_i}\right| - \left|\vec{x^l} - \vec{x_j}\right| + T_i^l - T_j^l + c\left(\delta_i - \delta^k - \delta_j + \delta^k\right) + \lambda\left(N_i^l - N_j^l\right)$$

Principle of GNSS Network Solution

If you are not interested in the clock parameters . . .

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Principle of GNSS Network Solution

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R. Dach and the BSW-development team: Spotlight on Bernese GNSS Software
FIG, Technical Seminar, 10.–11. Sept. 2022, Warsaw, Poland

Principle of GNSS Network Solution

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Principle of GNSS Network Solution

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Principle of GNSS Network Solution

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Principle of GNSS Network Solution

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Principle of GNSS Network Solution

If you are not interested in the clock parameters ...

$$L_i^k = \left|\vec{x^k} - \vec{x_i}\right| + T_i^k + c\delta_i - c\delta^k + \lambda N_i^k \qquad L_i^l = \left|\vec{x^l} - \vec{x_i}\right| + T_i^l + c\delta_i - c\delta^l + \lambda N_i^l \qquad \ldots$$

$$L_j^k = \left|\vec{x^k} - \vec{x_j}\right| + T_j^k + c\delta_j - c\delta^k + \lambda N_j^k \qquad L_j^l = \left|\vec{x^l} - \vec{x_j}\right| + T_j^l + c\delta_j - c\delta^l + \lambda N_j^l \qquad \ldots$$

... we may form differences between observations to cancel out the clock parameters:

$$L_{ij}^k = \left|\vec{x^k} - \vec{x_i}\right| - \left|\vec{x^k} - \vec{x_j}\right| + T_{ij}^k + c\,(\delta_i - \delta_j) + \lambda N_{ij}^k$$

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$$L_{ij}^{kl} = \left|\vec{x^k} - \vec{x_i}\right| - \left|\vec{x^k} - \vec{x_j}\right| - \left|\vec{x^l} - \vec{x_i}\right| + \left|\vec{x^l} - \vec{x_j}\right| + T_{ij}^{kl} + \lambda N_{ij}^{kl}$$

Principle of GNSS Network Solution

Conclusions:

- A consequent creation of (artificial) double-difference observations is equivalent to pre-eliminating the clock parameters on normal equation level.

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- The ambiguity resolution is directly possible only on double-difference level (otherwise some bias parameters are needed).

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Conclusions:

- A consequent creation of (artificial) double-difference observations is equivalent to pre-eliminating the clock parameters on normal equation level.
- When using the same original observations, we obtain the same estimates for the geometry-related parameters on zero, single or double difference level (given that all existing correlations are considered).
- The ambiguity resolution is directly possible only on double-difference level (otherwise some bias parameters are needed).
- Effects that cancel out when differencing the observations are absorbed by the satellite clock parameters in the zero-difference approach.

Processing examples: coordinate computation

The processing examples distributed with the *Bernese GNSS Software* offer three ways to compute coordinates:

1. PPP: Precise Point Positioning
   processing of single stations, very efficient in case of parallelization

2. RNX2SNX: double-difference network solution
   efficient because clock parameters are not explicitly setup, but
   needs bookkeeping to consider correlations due to differencing

3. CLKDET: zero-difference network solution
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Are there differences between the three strategies or are they equivalent?

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Zero- and double-difference solutions are equivalent.

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What is the consequence of introducing the GNSS orbits?

Datum Definition in a Network Solution

The *Bernese GNSS Software* supports:

- Free network solution
  no constraints on station coordinates
  Datum information is only introduced by fixed satellite orbits.

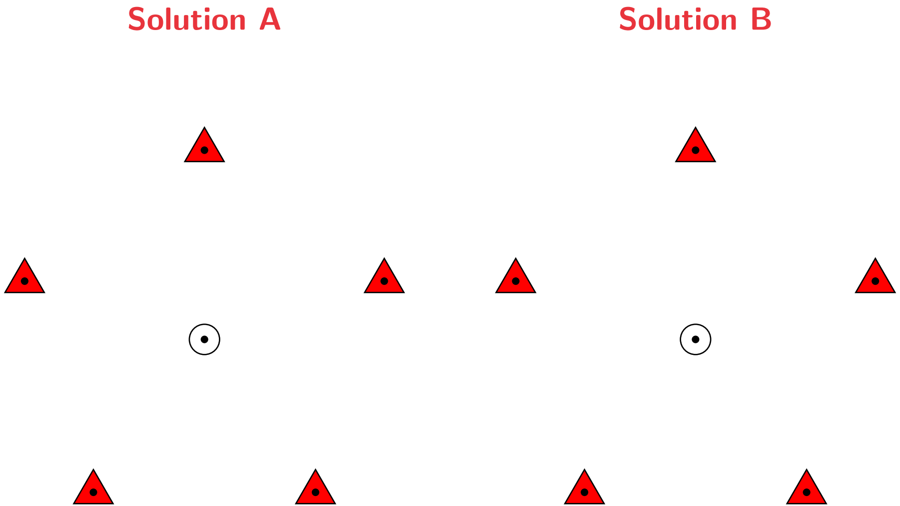
- Minimum constraint solution
  no-net translation, no-net rotation, no-net scale
  w.r.t. reference network

- Coordinates constrained:
  Constraining of station coordinate parameters

- Coordinates fixed:
  Deleting coordinate parameters from the NEQ
  Not recommended if NEQ-files are stored.

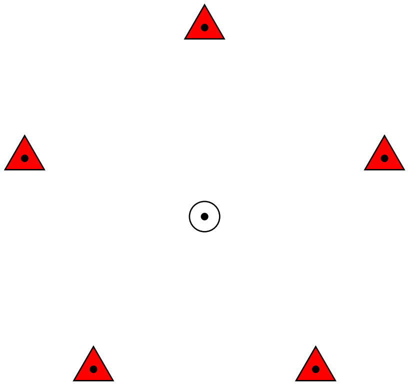
Demonstration

Principle of datum definition



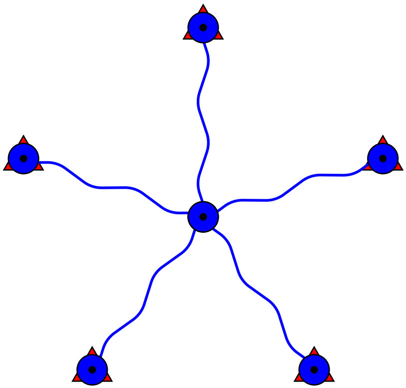
Principle of datum definition

Solution A



Solution B

Fixed reference coordinates



Principle of datum definition

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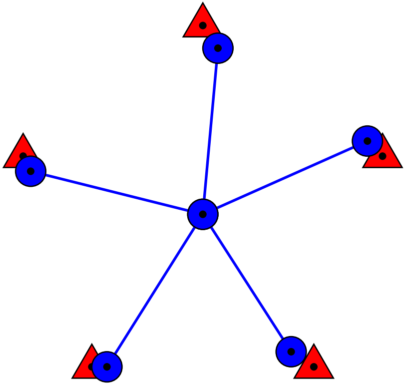
Minimum constraint solution



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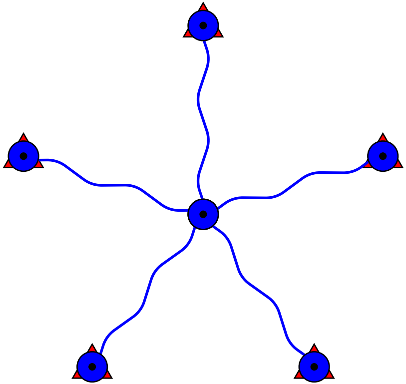

Datum definition in the Bernese GNSS Software

Minimum constraint solution:

- Constraint on translation/rotation/scale of the network w.r.t. reference sites
- No distortion of the network geometry
- All coordinates are improved
- Well suited to identify problems with reference sites
  List of reference sites may automatically be verified by HELMR1-program.

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Usually (regional solutions):

- Orientation of the network is given if the orbits were introduced as fixed ⇒ no-net-rotation conditions are not needed/reasonable
- Only "Center of network" condition (translations), i.e., the center of selectable reference sites remains unchanged

Datum definition in the Bernese GNSS Software

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  List of reference sites may automatically be verified by HELMR1-program.

Coordinates introduced:

- "Fixing" coordinates of reference stations is useful if they are expected to be more accurate than the current GNSS solution.
- In that scenario it is even more essential to Check the consistency first!

Processing examples: coordinate computation

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A consistent datum definition is indispersible.

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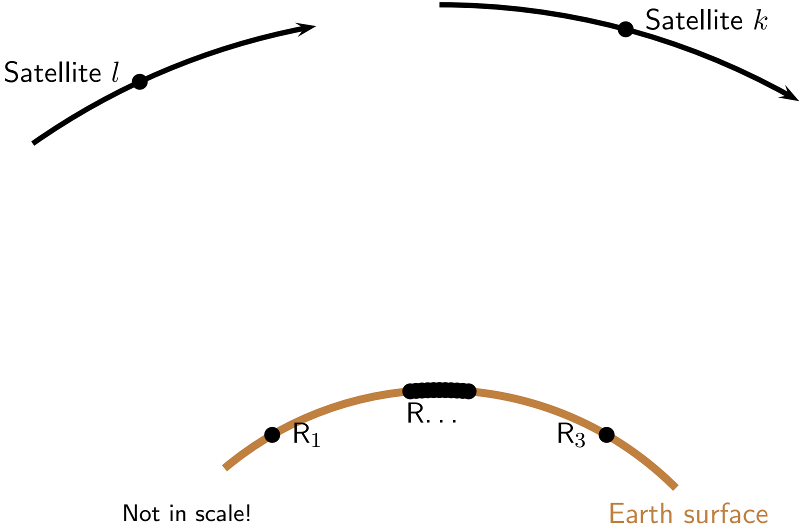
What about the datum definition in case of PPP?

PPP – Precise Point Positioning



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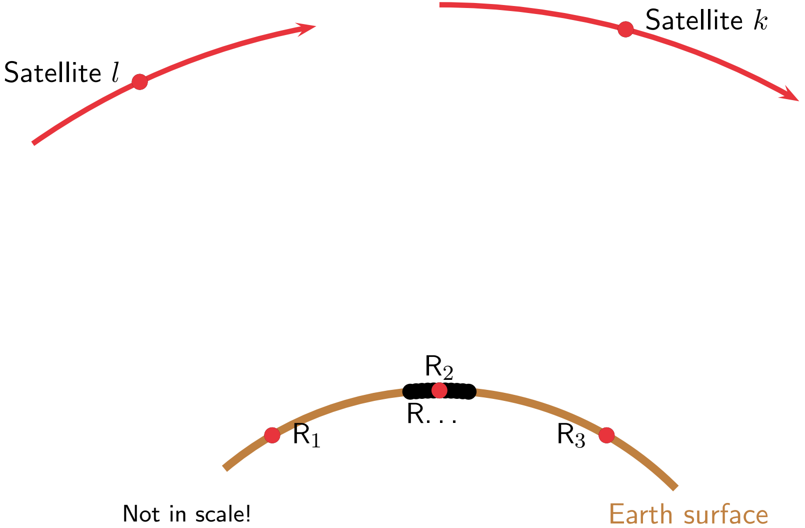

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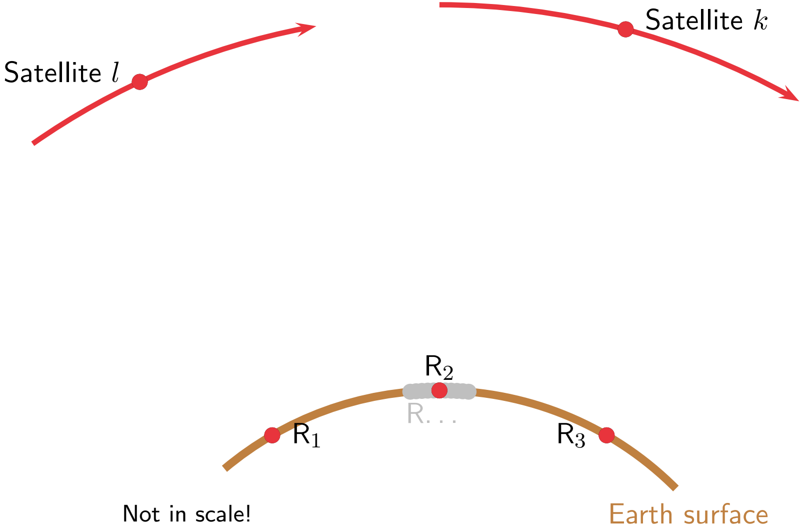

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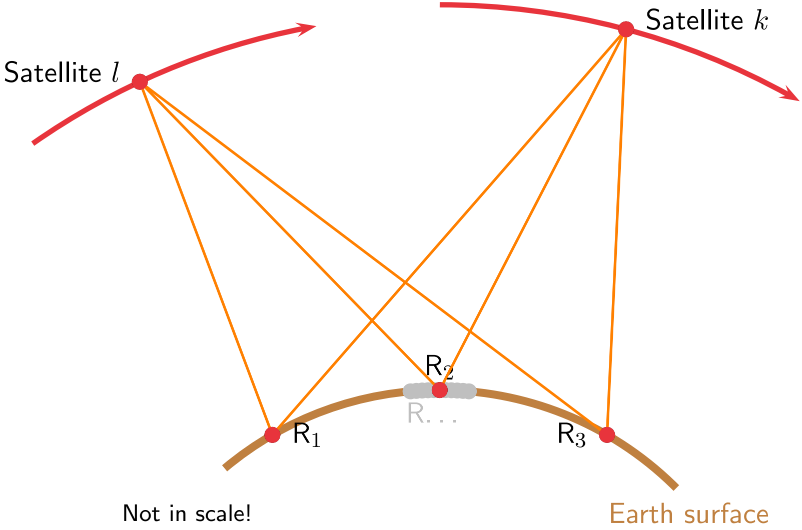

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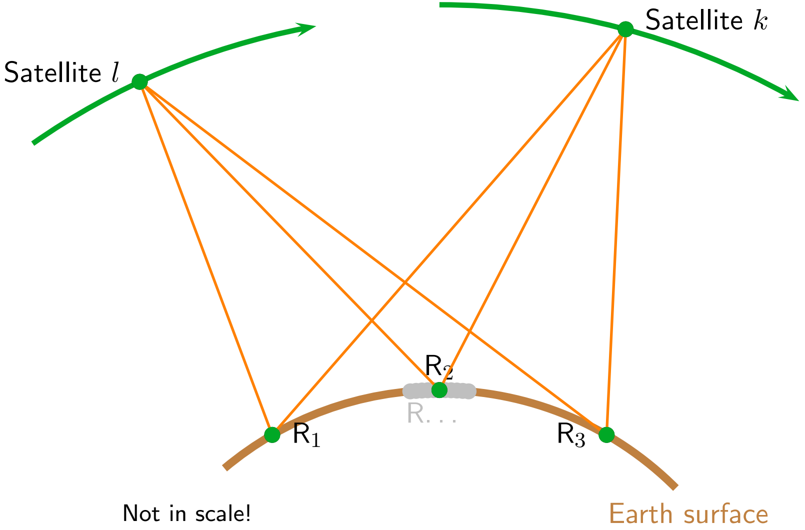

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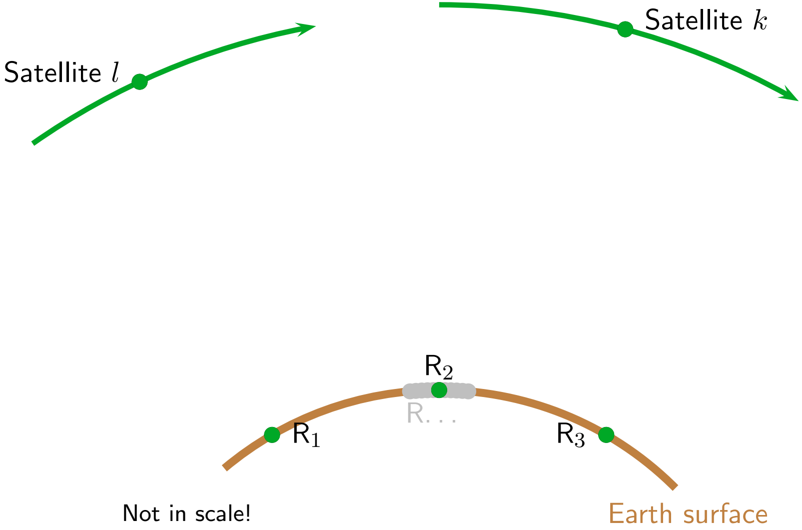

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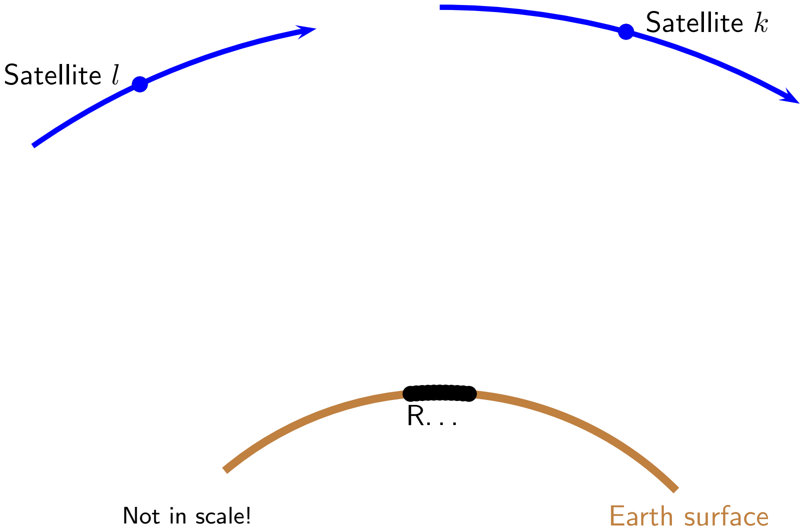

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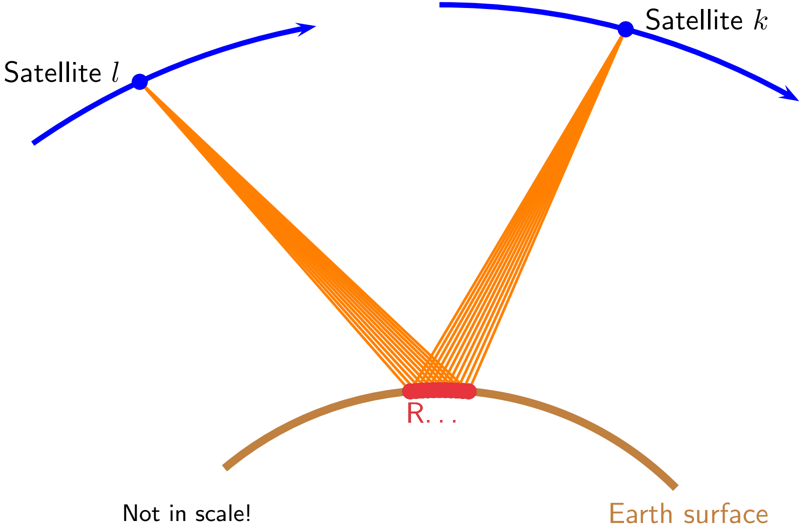

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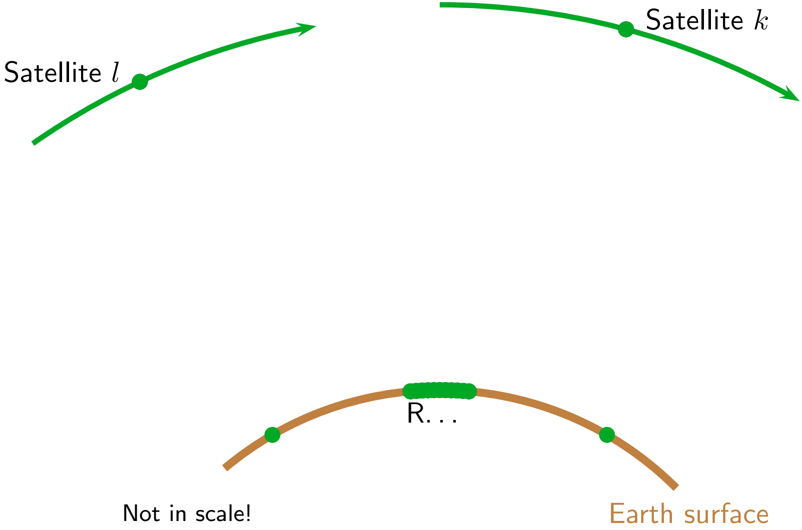

Not in scale!

PPP – Precise Point Positioning

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GNSS observation equations for a large number of stations

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R. Dach and the BSW-development team: Spotlight on Bernese GNSS Software
FIG, Technical Seminar, 10.–11. Sept. 2022, Warsaw, Poland

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- Even if PPP stands for "Precise *Point* Positioning", the observation equations of an individual point are in any case a part of a global network solution with a zero-weight for station-independent parameters.

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  Any inconsistency will degrade your PPP results.

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  Any inconsistency will degrade your PPP results.

- PPP-based station coordinates join the datum realization of the original network solution.

Demonstration

THANK YOU

for your attention

Publications of the satellite geodesy research group:

`http://www.bernese.unibe.ch/publist`