Localisation précise par moyens spatiaux

Bernese GNSS Software

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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](http://www.bernese.unibe.ch).
Milestones in the development

Summer 1983 to Autumn 1984: visit of Gerhard Beutler in Canada start of the first routines for the Bernese GPS Software

21. June 1992: the AIUB/CODE starts the activities as an analysis center of the IGS

1988 to 1995: release of version 3.0 to 3.5 in short intervals

September 1996: version 4.0 with ADDNEQ and BPE is published

November 1999: version 4.2 contains capabilities for GLONASS processing and comparison of SLR measurements with GNSS orbits

May 2003: start of GPS/GLONASS combined solutions for the IGS

April 2004: version 5.0 with new BPE and GUI based on QT is released

Summer 2012: version 5.2 is prepared for the release
Users of the Bernese GNSS Software
Users of the Bernese GNSS Software

- Europe: 238
- Asia: 205
- N.America: 44
- S.America: 23
- Africa: 15
- Oceania: 17

Total: 542
The Bernese GNSS Software is particularly well suited for:

- rapid processing of small-size single and dual frequency surveys (static as well as kinematic stations — even LEOs),
- automatic processing of permanent networks (BPE),
- processing of data from a large number of receivers,
- combination of different receiver types, taking receiver and satellite antenna phase center variations into account,
- combined processing of GPS and GLONASS observations,
- ambiguity resolution on long baselines (2000 km and longer),
- generation of minimum constraint network solutions,
- ionosphere and troposphere monitoring,
- precise point positioning,
- clock offset estimation and time transfer,
- orbit determination and estimation of Earth orientation parameters.
Highlights of the Bernese GNSS Software:

- compliant to the IERS2010 and IGS standards

- ambiguity resolution not only for GPS but also for GLONASS
- estimation of clock corrections from GLONASS data (IFB)

- extensive use of normal equation operations
  (much more efficient for starting each operation on observation level)

- automated analysis of time series (FODITS)

- intensive check of meta-data when importing observation files
**Bernese GNSS Software, Version 5.2**

**Highlights of the Bernese GNSS Software:**

- receiver/satellite antenna model estimation
- GLONASS-GPS translation bias to compensate for antenna model deficiency
- State-of-the-art modelling for
  - troposphere modeling: GMF/GPT, VMF1
  - ionosphere modeling: higher order ionosphere correction
- introducing corrections for up to three loading effects from grid files (on observation level with scaling factor)
- handling (estimation) of repositioning events of GPS satellites
The Bernese GNSS Software supports all important international formats:

- **RINEX** for observations, navigation messages, meteo data (input)
- **SP3c** for precise orbits (input/output)
- **IGS/IERS** for pole information (input/output)
- **Clock RINEX** for satellite and station clocks (input/output)
- **IONEX** for regional and global ionosphere models (output)
- **SINEX** for solutions and meta–information (input/output)
- **Troposphere SINEX** for troposphere parameter estimates (output)
- **ANTEX** for antenna phase center offsets and variations (input)
- **Vienna Grid Files** coefficients for VMF1 corrections (input)
The Bernese GNSS Software is not only designed for “classical”, geodetic, ground-based applications.

- GPS-data from Low Earth Orbiters (LEOs) may be processed.

- Orbits can be computed on a few cm level.

- Kinematic as well as a reduced–dynamic orbit determination

- CHAMP, GRACE, GOCE, but also MetOp, JASON, SAC–C, . . .

- For the GOCE mission the AIUB is responsible for the Precise Science Orbit.

- Full consistency of the models for the IGS-product generation and their use for LEO orbit determination.
Based on the Bernese GNSS Software a special environment for gravity field determination has been developed.

- full consistency with IGS- and LEO-orbits
- gravity field determination based on kinematic LEO trajectories, K-band (GRACE), and gradiometer (GOCE) measurements.

**CHAMP, GRACE, GOCE**
Bernese GNSS Software, developments

Monthly mean geoid heights from CHAMP from years 2002-2009,
Prange : Geodätisch-geophysikalische Arbeiten in der Schweiz, vol. 81
Bernese GNSS Software, developments

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The Bernese GNSS Software can also process SLR measurements.

- independent validation of estimated orbits for GNSS and LEO satellites

Project with BKG, Frankfurt a. M.:
- extended to process LAGEOS/ETALON satellites
- ILRS analysis center at BKG is using the software for their activities (ILRS-Benchmark test passed in 2010)

- meanwhile further extended to other (lower) geodetic laser satellites
Bernese GNSS Software, Version 5.2

- Microwave solution for GNSS satellites
  - GNSS stations
  - GNSS satellite orbit
  - ERP/geocenter
  - Solution specific parameters

- SLR solution for LAGEOS/ETALON
  - SLR stations
  - LAGEOS/ETALON orbit
  - ERP/geocenter
  - Solution specific parameters
Bernese GNSS Software, Version 5.2

microwave solution for GNSS satellites

GNSS stations

GNSS satellite orbit

solution specific parameters

local tie

ERP/geocenter

SLR solution for LAGEOS/ETALON

SLR stations

LAGEOS/ETALON orbit

solution specific parameters
Bernese GNSS Software, Version 5.2

microwave solution for GNSS satellites

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SLR solution for GNSS satellites

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microwave solution for GNSS satellites

SLR solution for GNSS satellites

SLR solution for LAGEOS/ETALON

GNSS stations

SLR stations

GNSS satellite orbit

LAGEOS/ETALON orbit

ERP/geocenter

solution specific parameters

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solution specific parameters
With the Bernese GNSS software we can provide the following three fully consistent solutions:

- microwave GNSS solution
- SLR solution for geodetic SLR satellites
- SLR solution for GNSS satellites

Alternative to local ties are space ties:

- uncertainty of the knowledge of the local tie is replaced by the problem of the location of the sensors at the satellite.
Bernese GNSS Software some facts

The software package consists of:
- a QT-based graphical user interface
- a set of fortran (F90) processing programs
- the Bernese Processing Engine (BPE) for automated processing

The software package counts today:
- 108 processing programs and
  1329 subroutines, functions, and modules
- nearly 425,000 lines of source code (including comment lines),
- the GUI/BPE-program with 17500 lines of source code
- 5875 input/output filenames and processing options
- supported my an online-help system, a 600 pages user manual, and
  a one week introductory course in Bern.
Processing examples

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

PPP_BAS.PCF
Standard PPP for coordinate, troposphere, and receiver clock determination based only on GPS data or a combined GPS/GLONASS solution

PPP_DEMO.PCF
PPP containing several extended processing examples, like pseudo-kinematic, high-rate troposphere, or ionosphere solutions
Processing examples

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

**RNX2SNX.PCF**
Standard double-difference network solution based only on GPS data or a combined GPS/GLONASS solution with an extended ambiguity resolution scheme

**CLKDET.PCF**
Zero-difference network solution based only on GPS data or a combined GPS/GLONASS solution providing clock corrections (e.g., w.r.t. an existing coordinate and troposphere solution)
Processing examples

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

LEOPOD.PCF
Precise Orbit Determination for a Low Earth Orbiting Satellites based on on-board GPS-measurements (e.g., for GRACE)

SLRVAL.PCF
Validation of an existing GNSS or LEO orbit using SLR measurements
Program flow chart

**ORBIT**
- EOP preparation
- orbit generation

**SIMULATION**
- simulation of observations

**TRANSFER/CONVERSION**
- import/export of observations
- extraction of meta-information from external sources

**SERVICE**
- tools to
  - manage observation files
  - browse/analyse residual files
  - manipulate/verify coordinate files

**PROCESSING**
- preprocessing of observations
- session solution
- multi-session solution

**result files**

**orbit data**
- e.g., precise orbits, navigation RINEX

**EOP data**
- IERS or Bernese format

**observation data**
- observation RINEX

**meta data**
- e.g., SINEX containing ITRF resp. Station information, ANTEX etc.
Program structure

- **Transfer Part:**
  Programs for generating files in the Bernese format from RINEX and vice versa. 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 (e.g., coordinates and velocities from ITRF in SINEX format, ANTEX).

- **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.
Program structure

- **Processing Part:**
  Programs for code processing (single station), single/dual frequency code and phase pre-processing, parameter estimation based on GPS and/or GLONASS observations (pgm. GPSEST) and on the superposition of normal equations (pgm. ADDNEQ2).

- **Simulation Part:**
  Program to generate simulated GPS and GLONASS observations (code and/or phase, L1 or L1/L2) 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.
Directory structure

Program area

Program files
Help files
General Files

User area

User 1
Campaign A
Campaign B

User 2
Campaign C
Campaign D

User 3
Campaign E

Data area
Directory structure

Program area
- contains the program source code, the executable and
- general files used by all programs independent from the processed data

User area
- contains user-specific program configuration files and
- the files needed to run a BPE

Data area
- contains relevant data and related files for processing
  in project- (campaign)-specific directory structures
## Processing steps

<table>
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<tr>
<th>Processing step</th>
<th>Involved programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Data transfer copy data into the campaign area</td>
<td>ftp, cp, perl</td>
</tr>
<tr>
<td>2 PPP procedure to complete the list of a priori coordinates/velocities (if necessary)</td>
<td>BPE example PPP_BAS</td>
</tr>
<tr>
<td>3 Import observation data into Bernese format</td>
<td>RXOBV3</td>
</tr>
<tr>
<td>4 Prepare EOP and orbit information</td>
<td>POLUPD, PRETAB, ORBGEN</td>
</tr>
<tr>
<td>5 Data preprocessing: cycle slip detection and correction; outlier rejection</td>
<td>CODSPP, SNGDIF, MAUPRP, GPSEST, RESRMS, SATMRK</td>
</tr>
<tr>
<td>6 Make a first network solution (real-valued ambiguities)</td>
<td>GPSEST</td>
</tr>
<tr>
<td>7 Resolve ambiguities</td>
<td>GPSEST</td>
</tr>
<tr>
<td>8 Create normal equations containing all relevant parameters</td>
<td>GPSEST</td>
</tr>
<tr>
<td>9 NEQ-based single- or multi-session solution</td>
<td>ADDNEQ2</td>
</tr>
</tbody>
</table>
Realization of the processing scheme

- This processing scheme is realized in the ready-to-use example: RNX2SNX.PCF (full description in RNX2SNX.README)

- *PCF stands for Process Control File*
  to be used by a BPE for automated processing.

  The BPE needs to know:
  - what is to do: user scripts
  - there are any dependencies in the order of running the scripts
  - where a script can be started (CPU)

- At the end of the BPE a protocol file summarizes the main results from the run (e.g., R2S102070.PRC)
# RNX2SNX.PCF

# Purpose: RINEX-TO-SINEX (RNX2SNX): standard double difference processing for regional networks for static, dual-frequency stations.

# Copy required files

001 R2S_COP R2S_GEN ANY 1
002 ATX2PCV R2S_GEN ANY 1 001
003 COOVEL R2S_GEN ANY 1 001
004 COOVEL R2S_GE2 ANY 1 001
005 CRDMERGE R2S_GEN ANY 1 003 004
011 RNX_COP R2S_GEN ANY 1 001
021 OBSMRGAP R2S_GEN ANY 1 011
022 OBSMRG_P R2S_GEN ANY 1 021
031 ION_MRG R2S_GEN ANY 1 011
099 DUMMY R2S_GEN ANY 1 002 005 022 031

# Prepare the orbits

101 POLUPDH R2S_GEN ANY 1 001
RNX2SNX BPE PROCESSING SUMMARY FOR YEAR-SESSION 10-2070

Summary file generated at 07-Aug-2012 13:59:51 by R2S_SUM

General files:
- Antenna phase center eccentricity file: PCV.I08
- Satellite information file: SATELLIT.I08
- Satellite problem file: SAT_2010.CRX
- Orbit, ERP and clock products used from: ${D}/COD

Observation file selection:
- RINEX files copied from: ${D}/RINEX/
- Station selection: all stations

Reference frame and station related files:
- Station related files used from: ${D}/REF52/
- External reference frame file series: IGS08_R.(CRD|VEL)
- Project specific station file series: EXAMPLE
  - Station information file: STA/EXAMPLE.STA
  - RINEX inconsistency file: STA/EXAMPLE.BLQ
  - Ocean tidal loading table: STA/EXAMPLE.BLQ
  - Atmosphere tidal loading table: STA/EXAMPLE.ATL

Other options from PCF:
- Antenna phase center model was not updated.
- Satellite system(s) included: GPS/GLO
IGS processing

Different BPEs are running daily at AIUB for the IGS activities:

- **ultra-rapid** (several times per day for orbits/EOP)
- **rapid** (orbits/EOP, clocks, ionosphere products)
- **final** (orbits/EOP, clocks, ionosphere, weekly coordinate products)
- **EUREF** (weekly coordinate solutions)
What do we expect in the future?

Today we have 32 GPS and 24 GLONASS satellites.

Modernization programs:

- GPS third frequency
  (first Block IIF since May 2010)
- GLONASS third frequency, FDMA to CDMA
  (first GLONASS-K since Feb. 2011)

New GNSS:

- Galileo a new GNSS with up to five frequencies
  (2011: launch of IOV satellites, 2013: FOC)
- Compass, and other GNSS
Flexible handling of observation types is necessary:

- All observation types from RINEX3 are kept together in one Bernese observation file per station and session.

- A complex set of modern F90 modules guarantees a flexible access to the measurements with individual linear combinations for each GNSS.

- The use of these modules simplifies the observation handling within the processing programs.

- New linear combinations may be easily implemented at one place for the entire software package.
New file formats are necessary:

- Bernese observations files
  (may contain all types of observations in one (common) file)

- Bernese residual files
  (considering the new linear combinations)

- Differential code biases
  (many new DCBs have to be expected with the new signal types)

- Receiver information file
  (receiver type: which signal and priority lists for observ. selection)

- Antenna phase center corrections
  (GNSS-dependent receiver antenna PCV information)
Bernese GNSS Software in future

Further developments to get a multi—GNSS software:

- more satellites have to be processed together
  (32 GPS + 30 GLONASS + 36 Galileo ≈100 satellites)

- input/output IDs for each GNSS for all external files
  (e.g., precise orbit file, clock RINEX file, ...)

- GNSS dependent parameter setup
  (e.g., receiver antenna phase center offsets/variations, Earth rotation parameters, ...)

- dynamic memory allocation in the processing programs
Thank you for your attention

Hurra – Bernese is cool!