Processing VLBI observations with the Bernese GNSS Software – The First Solution –

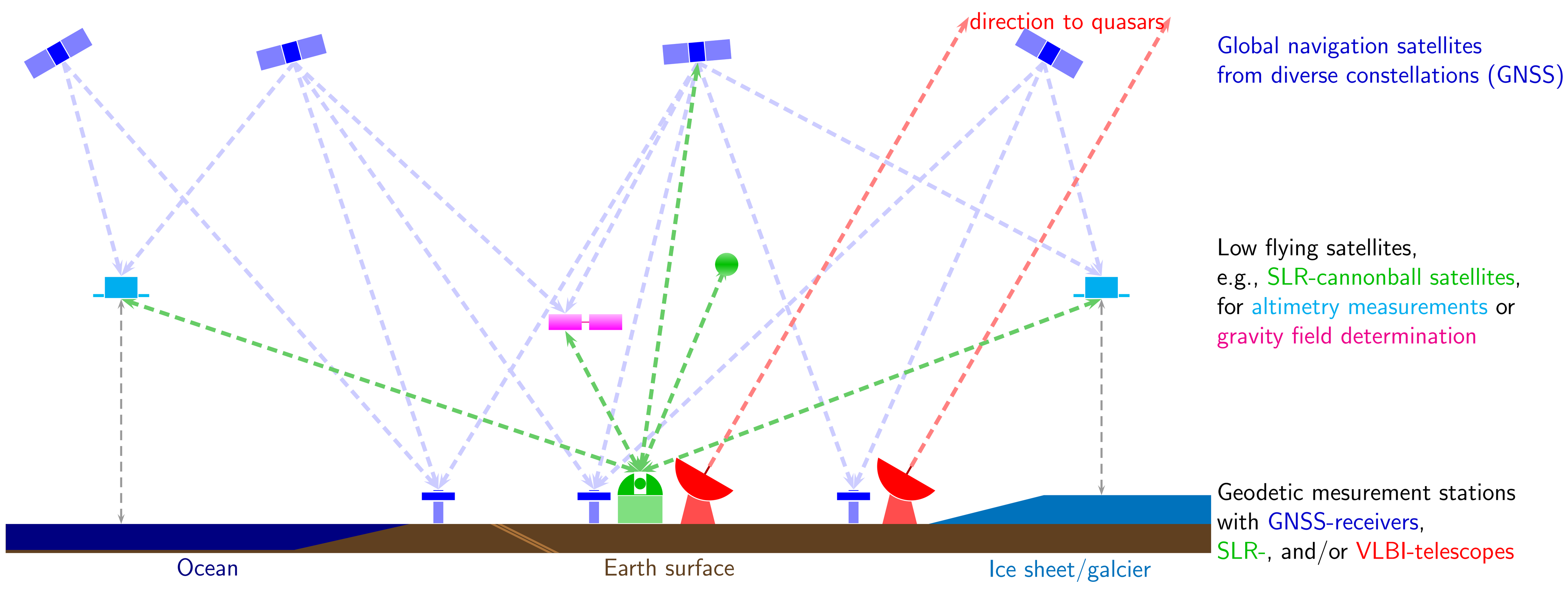
IVS-GM 2024: S4-02P

International VLBI Service for Geodesy and Astrometry
13th IVS General Meeting
04–09 March 2024, Tsukuba, Japan

C. Gattano[1], C. Flohrer[2], A. Walenta[2], D. Thaller[2], P. Stebler[1], R. Dach[1], U. Hugentobler[3]

(1) University of Bern, Astronomical Institute (AIUB), Bern, Switzerland
(2) Federal Agency for Cartography and Geodesy (BKG), Frankfurt am Main, Germany
(3) Institute for Astronomical and Physical Geodesy, Technical University of Munich, Munich, Germany

Motivation



The Bernese GNSS Software package was started in the 1980ies as a tool to analyse dual-frequency data from the Global Positioning System (GPS). Meanwhile it is supporting also the Russian GLONASS, the European Galileo, the Chinese BeiDou and the Japanese QZSS systems. As a multi-GNSS (Global Navigation Satellite Systems) analysis tool it is used at AIUB to compute the contribution to the IGS (International GNSS Service, Johnston et al., 2017).
During the 2000ies the orbit determination for Low Earth Orbiting Satellites (LEOs) was implemented based on the measurements of onboard GNSS receivers. In this context also the estimation the parameters describing the Earth gravity field was enabled.
Processing of Satellite Laser Ranging (SLR) measurements was first implemented for satellite orbits validation. In a collaboration between AIUB and BKG the capability was extended to process observations to the geodetic Cannonball satellites allowing BKG to switch its Analysis Center for the ILRS (International Laser Ranging Service, Pearlman et al., 2019) to the Bernese GNSS Software.
Four years ago a further extension towards processing of VLBI (Very Long Baseline Interferometry) was started. Enabeling VLBI would allow BKG to use the same Bernese GNSS Software also for its analysis center for the IVS (International VLBI Service for Geodesy and Astrometry, Nothnagel et al., 2017) .

Aspects on the implementation

The implementation of VLBI processing was an opportunity to redesign the Bernese GNSS Software towards a multi-technique software. With the features offered by modern, object-oriented coding (as for instance available by Fortran 2003) some fundamental technical advances – not only directly related to VLBI – have been implemented: A space geodetic object class hierarchy was implemented and the observation file format was newly designed (see below).

The implementation of the VLBI processing capability was started in two directions. First, the reading of SINEX files containing VLBI solution was introduced and the normal equation manipulation tool (the program ADDNEQ2) was extended in order to combine several solutions and to write a new SINEX file containing the combination. In parallel, the program to process the observation files GPSEST was also transformed to welcome VLBI as an additional technique to be selected using both new structures (space geodetic objects and observation handling).

The VLBI observations are imported directly from the vgosDB using a new program VLBI2OBS. Some parts of Bernese already existing for GNSS and SLR were also updated, like the nutation modeling, including now the new CIO-based representation of the nutation offsets.

Satellite geodetic objects

- **Space geodetic object**
  - Identifier: Name (Bernese convention)
  - Select corrections to be applied
  - **Object in space**
    - **Quasar**
      - Multi-frequency positions and meta-data from Quasar Coordinate File in celestial frame
    - **Satellite**
      - External identifiers: SVN, COSPAR, ...
      - Positions from Orbit File in quasi-inertial frame
      - **GNSS satellite**
        - Apply corrections: phase center, satellite clock
        - system and PRN identifier
      - **LEO satellite**
        - Apply corrections: antenna phase center, satellite clock
      - **Cannonball satellite**
  - **Ground object**
    - Apply corrections: crustal deformations, atmospheric delays
    - Positions from Station Coordinate File in terrestrial frame
    - **VLBI antenna**
      - Apply corrections: Axis offset, thermal and gravitational deformation
    - **GNSS receiver**
      - Apply corrections: antenna phase center
    - **SLR station**

Observation handling

The generic definition of the "space geodetic objects" allows a flexible handling of observations. The base object is typically collecting the data from one or several partner objects.

Technique	VLBI		GNSS		SLR	
Base object	(2)	VLBI antenna	(1–2)	Receiver on ground or on LEO satellite	(1) (1)	Laser station (possibly a 2nd station)
Partner object	(n)	Quasars or satellites	(n)	GNSS satellites	(n)	Cannonball/satellites with retroreflector

Bernese observation data file
- Space geodetic technique
- Time frame
- header

Epoch entry 1 (2 ...)
- Nominal epoch
- Time offset

System entry 1 (2 ...)
- System
- Time offset

Obs. type entry 1 (2 ...)
- Obs. type

Partner entry 1 (2 ...)
- Partner
- Record
- Error
- Main flag
- Quality code
- Other flags
- Other info

Bernese observation header file
- File version, history, comments
- Project/campaign name
- Nominal observation time window
- Real observation time window
- List of base objects + metadata
- List of partner objects
- List of observation types
- Observation type statistics (nObs)
- Partner object statistics (nObs, nGood, nMarked, nRejected per obs. types)

if GNSS...
- GNSS-specific flags
- Source of data (simulated or RINEX) + RINEX version
- Nominal time interval
- Ambiguity information
- Clock information

if VLBI...
- VLBI-specific flags
- List of scan time tags
- Clock information
- Reference frequency for each band

if SLR...
- SLR-specific flags
- List of wavelengths

Status of implementation

Processing VLBI observations with Bernese GNSS Software is now possible following a minimal a priori modeling. The currently implemented model includes the geometric term formed from the orientation of the baseline with respect to the quasar direction, following the consensus model for the relativistic correction restricted to a Sun-Earth version. The clocks are modeled as piece-wise linear function. The troposphere can be represented from various models including the latest VMF3 representation as it is also used when processing GNSS data. The different time-dependent crustal deformations of the Earth are taken into account and the EOP can be represented with an equinox-based or CIO-based origin on the equator.

Processing steps

Data import from vgosDB

Input Files
- vgosDB
- wrapper file V004
- extraction file

→ **program VLBI2OBS** →

Output Files
- Set of Bernese observation files
- **Table of content** variables within the vgosDB
- **Table of extracted data** associated following cross-references

Data processing

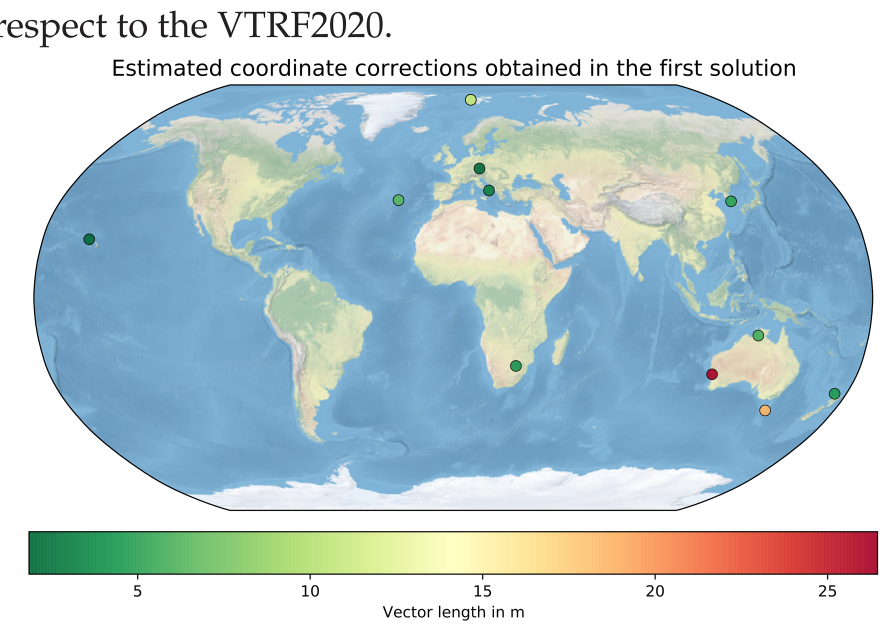
Input Files
- Set of Bernese observation files
- Station information file
- Quasar coordinate file
- +EOP, VMF, ... files

→ **program GPSEST** →

Output Files
- Station coordinates
- Clock offset
- Tropospheric ZPD
- EOP
- ...

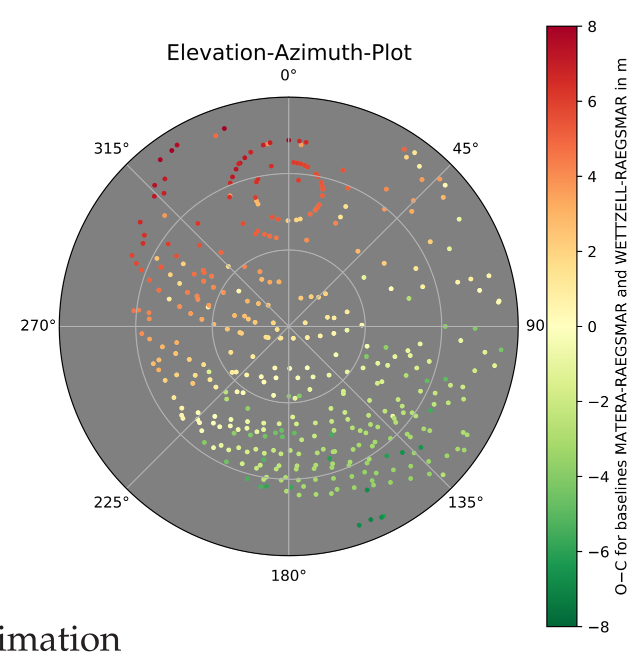
First solution

As with a telescope the "first light event" is celebrated, we have obtained a first solution after implementing the new structures into the data processing program GPSEST.
For this purpose the R1-session 2022-262 (September 19th, 2022) was selected where 12 VLBI stations participated. A total of 78 quasars were observed.
The quasar coordinates were introduced from the ICRF3 and the IERS I20 C04 Earth rotation series was applied together with the IAU2006 nutation model (CIO-based). The ionosphere corrections are applied from the vgosDB; the dry and wet part of the troposphere were corrected from VMF3. The station clock corrections were introduced from a reference solution (IVS-standard solution by the BKG analysis center). The only parameters that have been estimated are the site coordinates that have still meter differences with respect to the VTRF2020.



Next steps to go

The systematics in the observed minus computed values of two baselines pointing towards station RAEGSMAR indicate the importance of the antenna axis offset correction to be implemented as the next step together with the estimation of station clock corrections. In the next phase, a list of further corrections will be implemented, e.g,



- Quasar coordinate estimation
- Extract Bernese meteo file from a vgosDB dataset and potentially use them for troposphere corrections
- Antenna thermal and gravitational deformation correction
- Extract and apply cable calibration
- Extend the Sun-Earth relativistic model to a solar system multi-body relativistic model
- Implement and apply galactic aberration correction

Contact address

César Gattano
Astronomical Institute, University of Bern
Sidlerstrasse 5
3012 Bern (Switzerland)
Email cesar.gattano@unibe.ch

AIUB

Poster compiled by César Gattano, February 2024
Astronomical Institute, University of Bern, Bern
Email cesar.gattano@unibe.ch

UNIVERSITÄT BERN