The *Bernese GPS Software*

for the analysis of
GNSS, SLR and VLBI data

and for the
SINEX/NEQ combination

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Overview

1. Analysis of **observation data**
   a) GNSS
   b) SLR
   c) VLBI

2. Combined **GNSS+SLR** analysis using **satellite co-locations**

3. **Combination** using normal equations (intra- and inter-technique)

Analysis of GNSS data

Combined **GPS+GLONASS** analysis is possible with the *Bernese GPS Software (BSW)*

Global analysis:

$\rightarrow$ CODE: IGS analysis center

$\rightarrow$ Final, rapid and ultra-rapid products

$\rightarrow$ Operational GPS+GLONASS contribution since May 2003

Regional analysis:

$\rightarrow$ EUREF / SIRGAS contributions by most analysis centers

Extension to **multi-system** GNSS analysis:

$\rightarrow$ Different systems (GPS, GLONASS, Galileo, ...)

$\rightarrow$ Different/individual observation types per GNSS

Analysis of SLR data

SLR residual analysis w.r.t. given orbits / EOPs / station coordinates
→ Contribution of AIUB to ILRS as associated analysis center:
    SLR residuals w.r.t. GNSS orbits

Extension of the BSW to a **full SLR analysis** software package:
→ SLR observations to geodetic satellites (mainly Lageos, Etalon)
→ Estimation of SLR-specific parameters (orbits, range biases)
→ ILRS modeling and data handling issues are implemented

Intention: ILRS contribution of BKG generated with BSW
Status: ILRS Benchmark solutions submitted
        → validation process ongoing

Analysis of VLBI data

Extension of the BSW to a **VLBI analysis** software package

**Simplified VLBI analysis** for limited set of VLBI sessions possible:
$\rightarrow$ Low degree of automation
$\rightarrow$ Simple clock model
$\rightarrow$ VLBI-specific effects like telescope deformations not yet implemented
$\rightarrow$ Starting from NGS Card Format

Extensions needed to become a **full VLBI analysis** software package:
$\rightarrow$ Estimation of VLBI-specific parameters (e.g., quasar coordinates)
$\rightarrow$ Improvement of a priori models and parameterization (e.g., clocks, telescope deformation)
$\rightarrow$ Automation for analysing the entire history of VLBI sessions

Comparison of VLBI-derived troposphere zenith delays with GPS-derived estimates:
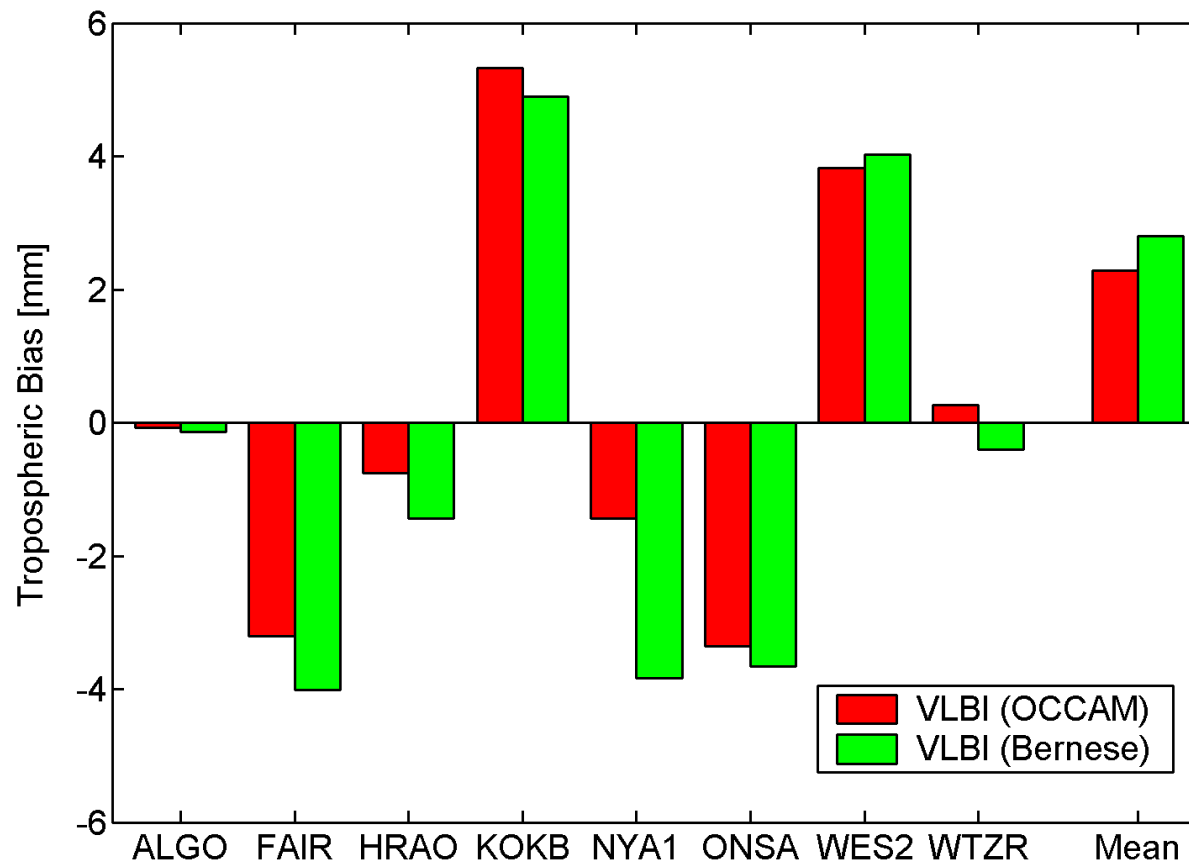
⇒ Remaining differences are not due to deficiencies in the software but due to unmodeled effects (e.g. uncalibrated radomes)

Combined GNSS+SLR analysis

Idea: Use satellite co-locations for connecting GNSS and SLR

$\rightarrow$ GNSS observations: GPS, GLONASS, (Galileo)

$\rightarrow$ SLR observations to GNSS satellites: 2/1 GPS, 3 GLONASS, ???

1. **Common parameters:**
   - *EOP*
   - *Geocenter*
   - *Station coordinates*

   Already done for combination at NEQ level

   - *Satellite orbit parameters (dynamical)*

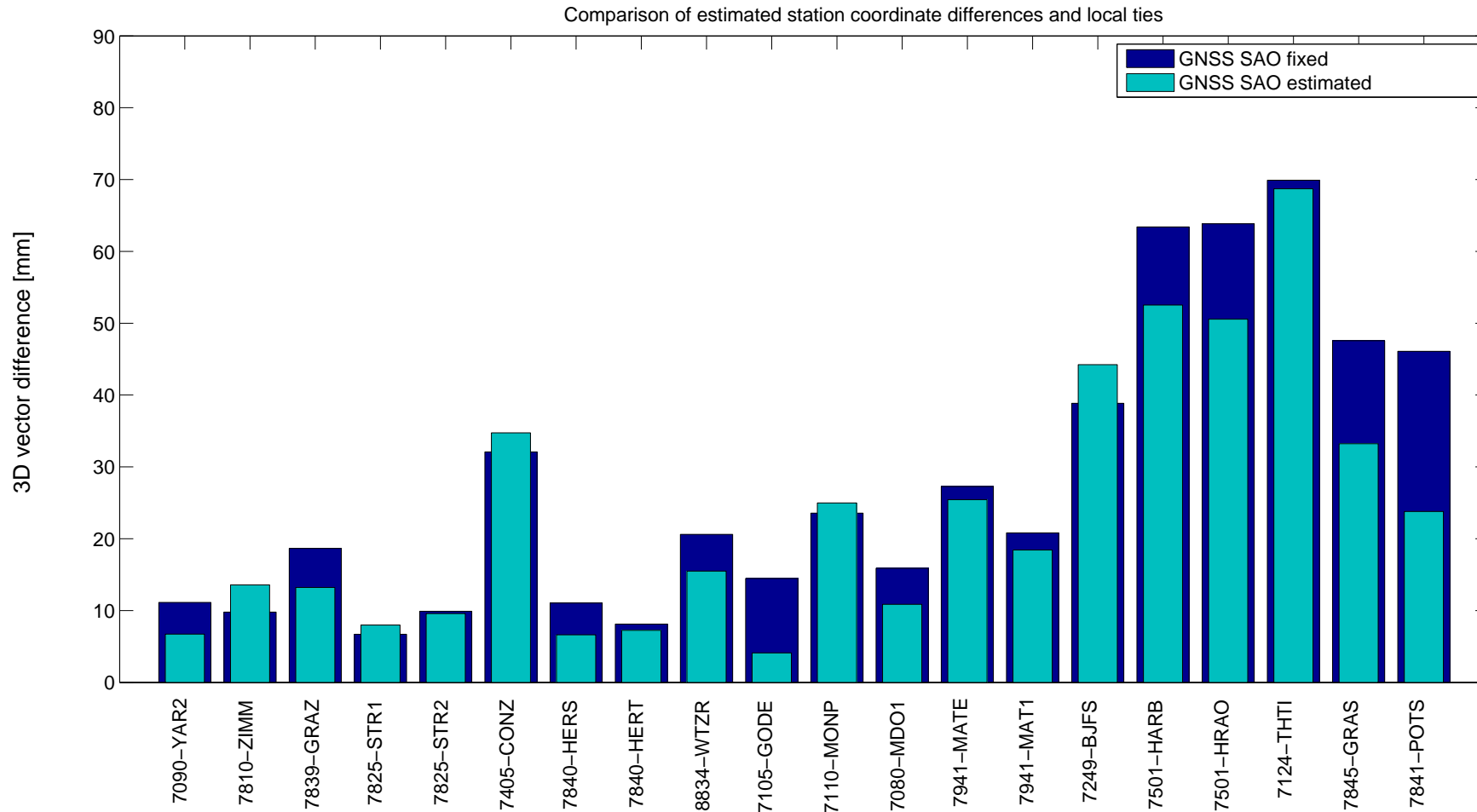2. **Needed for connection:**
   - Stations: **Local ties**
   - Satellite CoM: **Vectors to** microwave antenna and to laser retro-reflectors

Combined GNSS+SLR analysis: Advantages

Comparison of estimated station coordinate differences and local ties
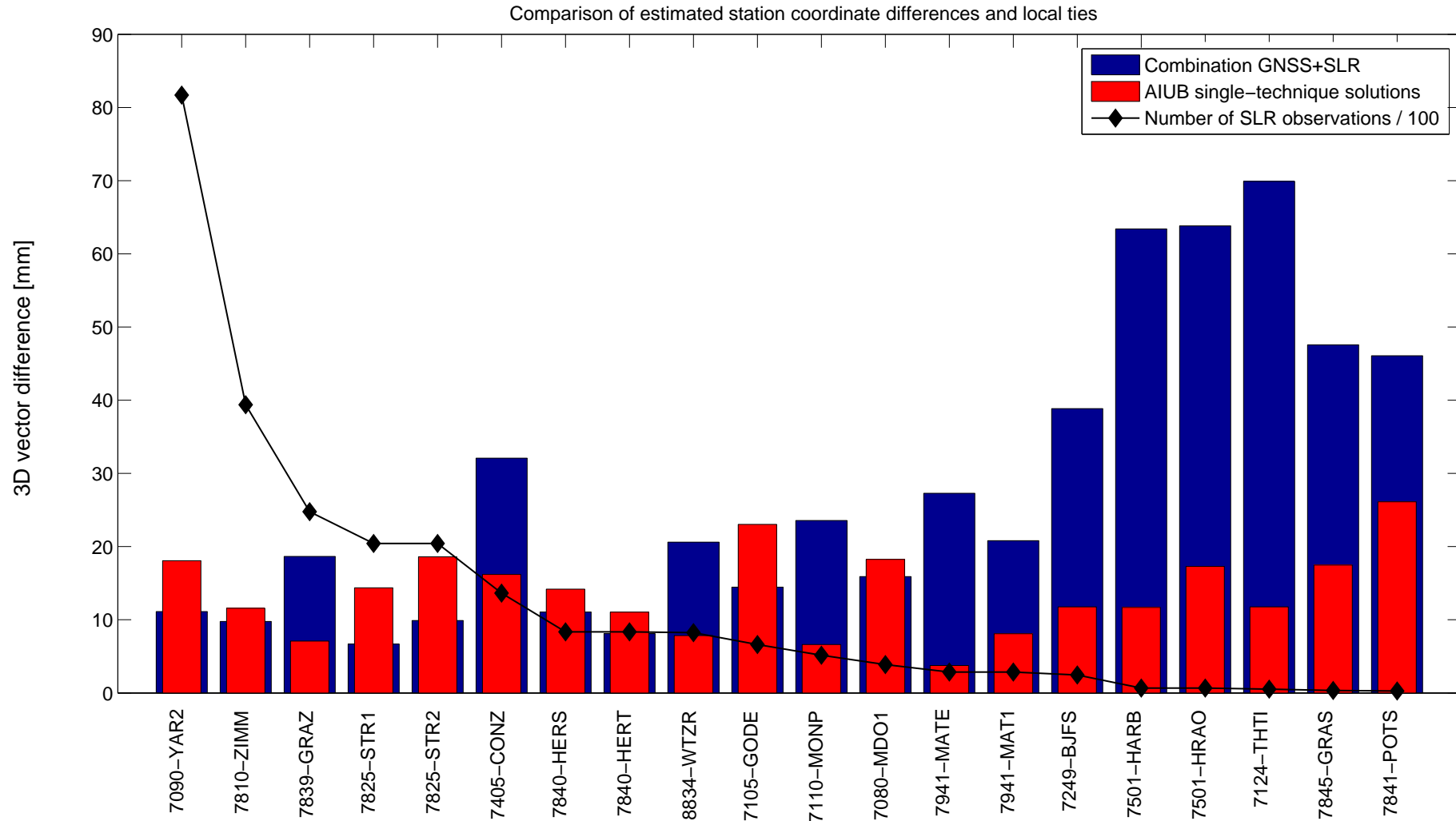
→ Connection of techniques either *on ground (LT)* or *in space (orbits)*

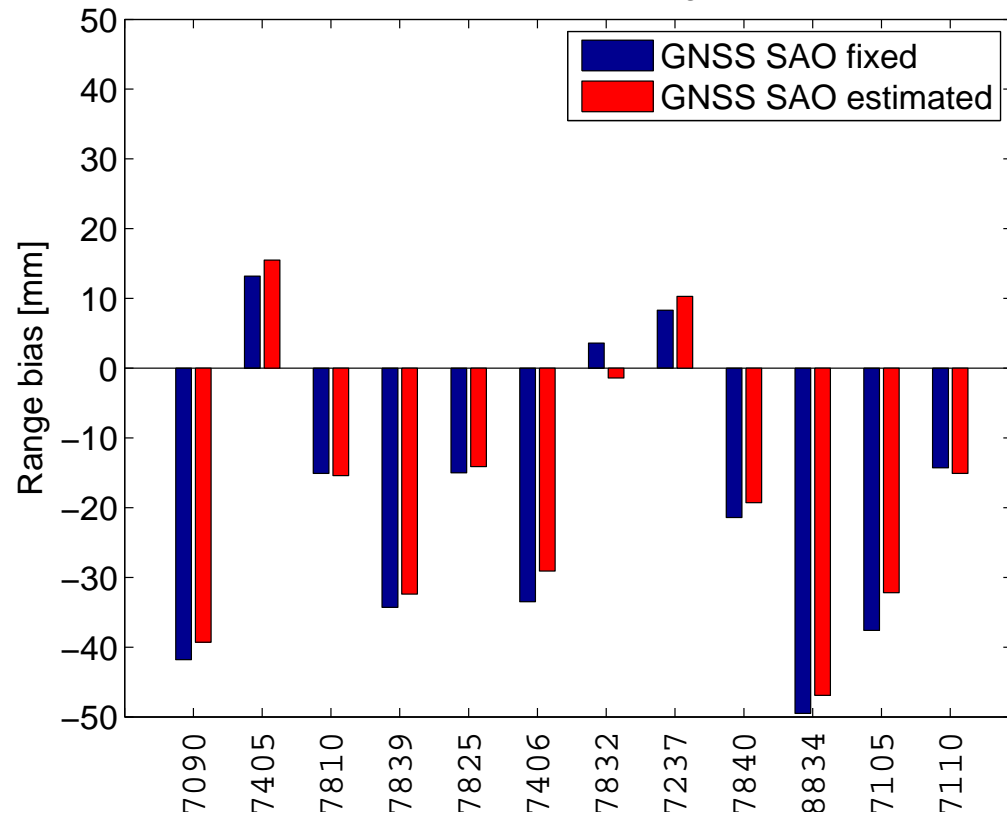# Combined GNSS+SLR analysis: Advantages

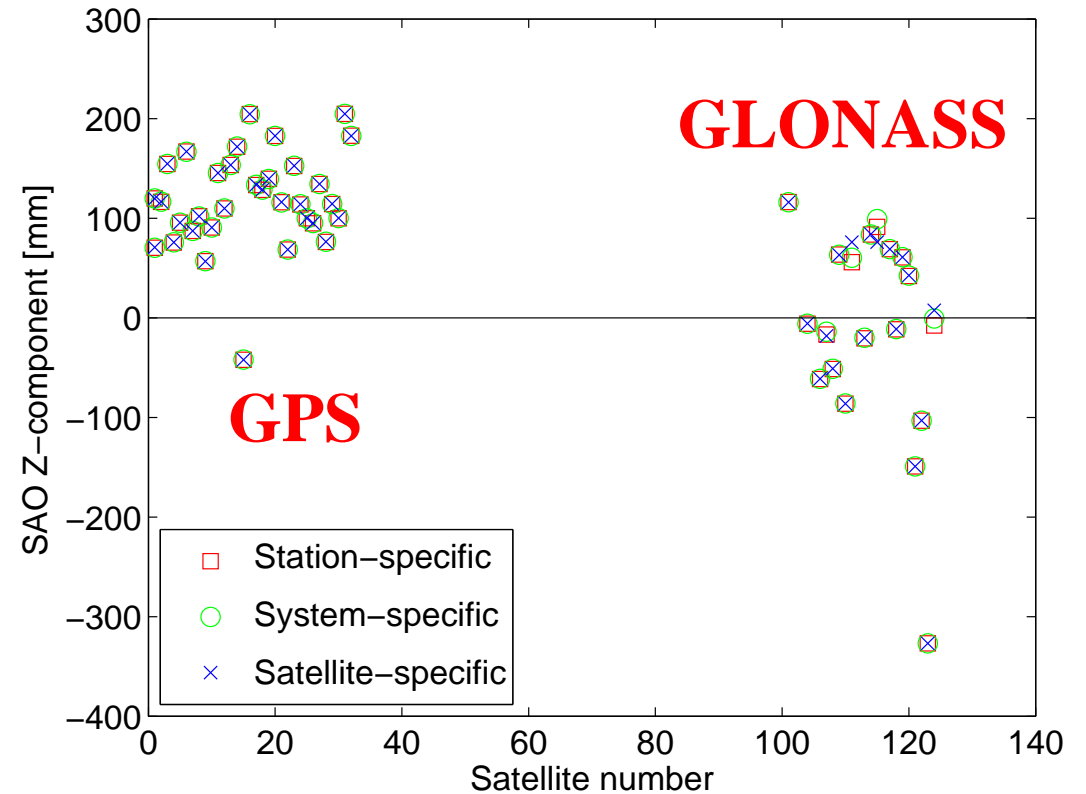Comparison of estimated station coordinate differences and local ties

→ Allows transfer of **scale** information from SLR into GNSS network
→ Estimation of **SLR range biases (RGB)** together with **GNSS satellite antenna offsets (SAO)** is possible

Combined GNSS+SLR analysis: Advantages

Station−specific SLR range biases

SAO corrections for different RGB estimation

→ Allows transfer of **scale** information from SLR into GNSS network

→ Estimation of **SLR range biases (RGB)** together with **GNSS satellite antenna offsets (SAO)** is possible

→ Estimation of **SAO** consistently for GPS and GLONASS, and consistently with SLR scale

Combined GNSS+VLBI analysis

Common parameters:
- EOP
- Troposphere
- Station coordinates

Advantages:
- **Full EOP information** from VLBI transferred to GNSS (polar motion, UT/LOD, nutation)
- Stabilization of coordinates by **common troposphere estimates**

→ Benefit already shown for combination at *NEQ level*
→ Not yet done for combination at the *observation level*

Combination using NEQs
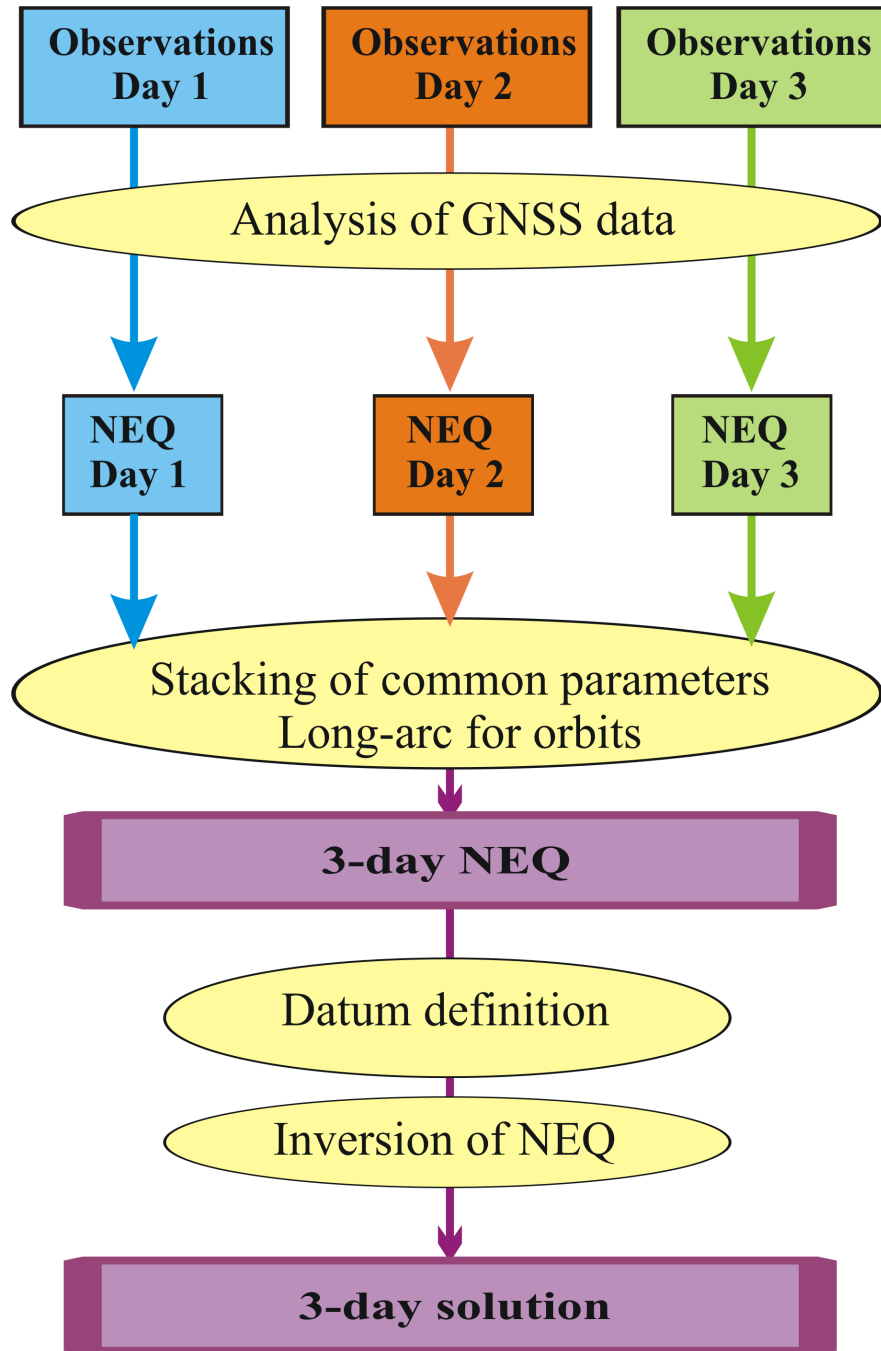
General strategy in BSW concerning **constraints**:
- **NO** constraints when storing individual NEQs
- Application of constraints only if
  a) pre-eliminating parameters
  b) generating a solution (before inversion of NEQ)

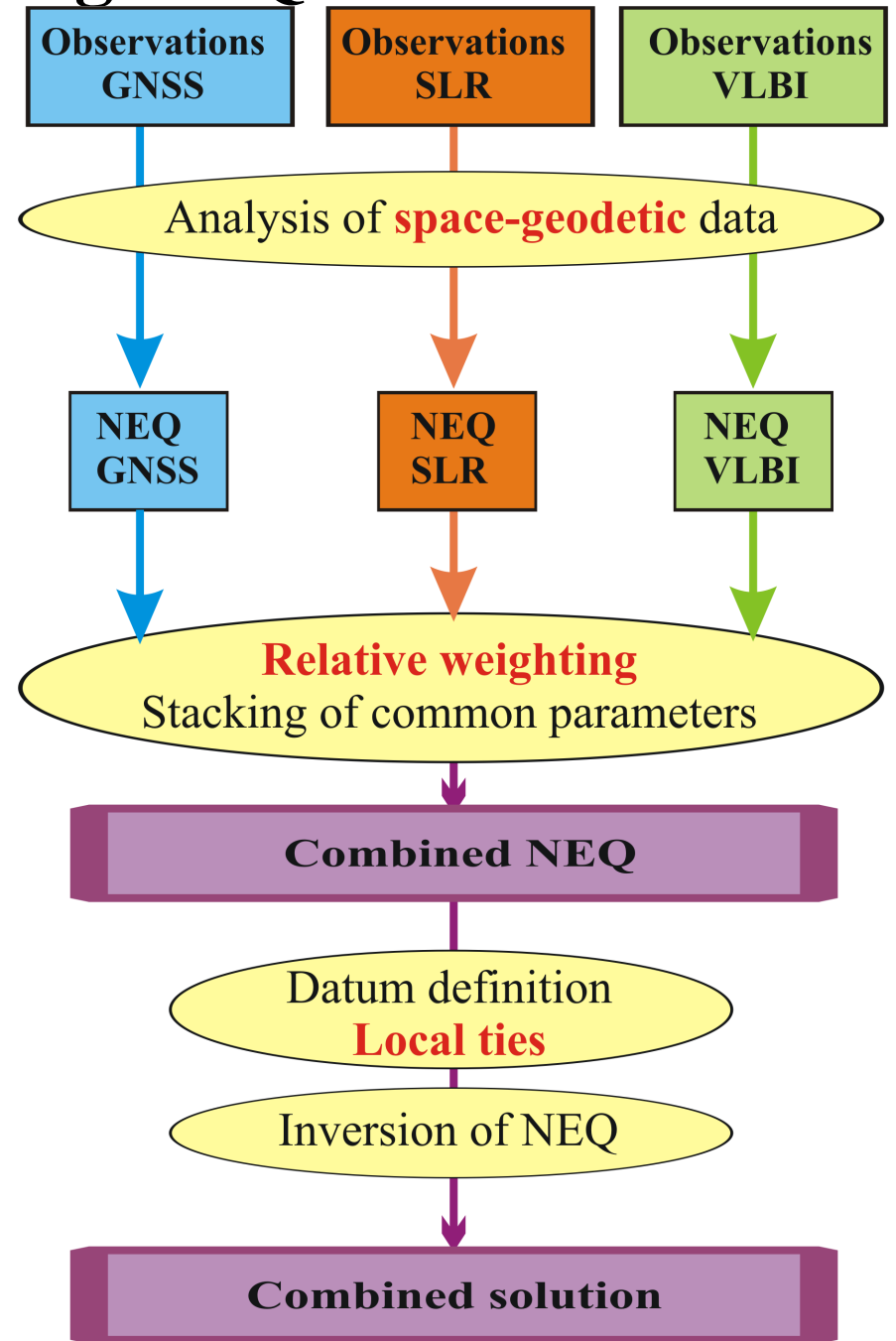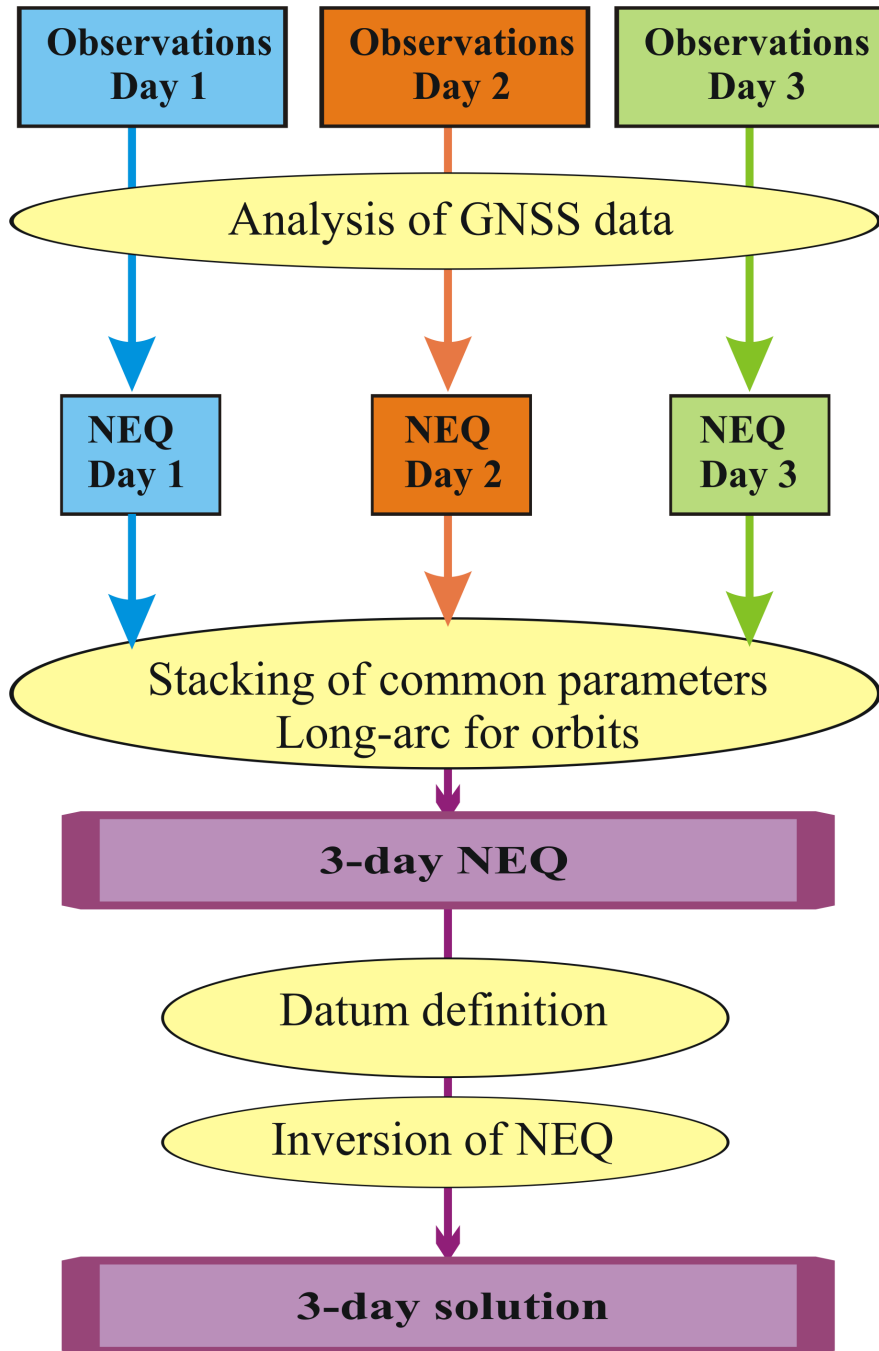$\Rightarrow$ **Full flexibility** for computation of combined solutions

3 equivalent applications within BSW:
- GNSS 1-day analysis $\Rightarrow$ GNSS n-day solution (e.g. 3-day)
- Separate GNSS/SLR/VLBI analysis $\Rightarrow$ Combined solution
- SINEX input $\Rightarrow$ Combined solution

Combination using NEQs

Working Group on Combination at the Observation Level, 21./22. October 2009, Warsaw

Combination using NEQs