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GFZ Helmholtz Centre Potsdam

Developments towards GNSS real-time service in GFZ

Dousa, J., Ge, M., Chen J., Gendt, G.

Helmholtz-Zentrum Potsdam,
Deutsches GeoForschungsZentrum

Geng, J.

University Institute of Engineering Surveying and Space Geodesy,
University of Nottingham

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  - impact study of zero-difference ambiguity resolution

Introduction

Precise Point Positioning (PPP)

☺ state-space representation suitable for global positioning service

☺ doesn't require bi-directional user/service communication

☺ highly efficient technique to support infinite number of autonomous users

☹ difficulties with (fast) ambiguity resolution

☹ long-convergence time (>20-30min)

☹ impossible to reduce regionally dependent systematic errors

☹ lower accuracy compared to regional services/RTK

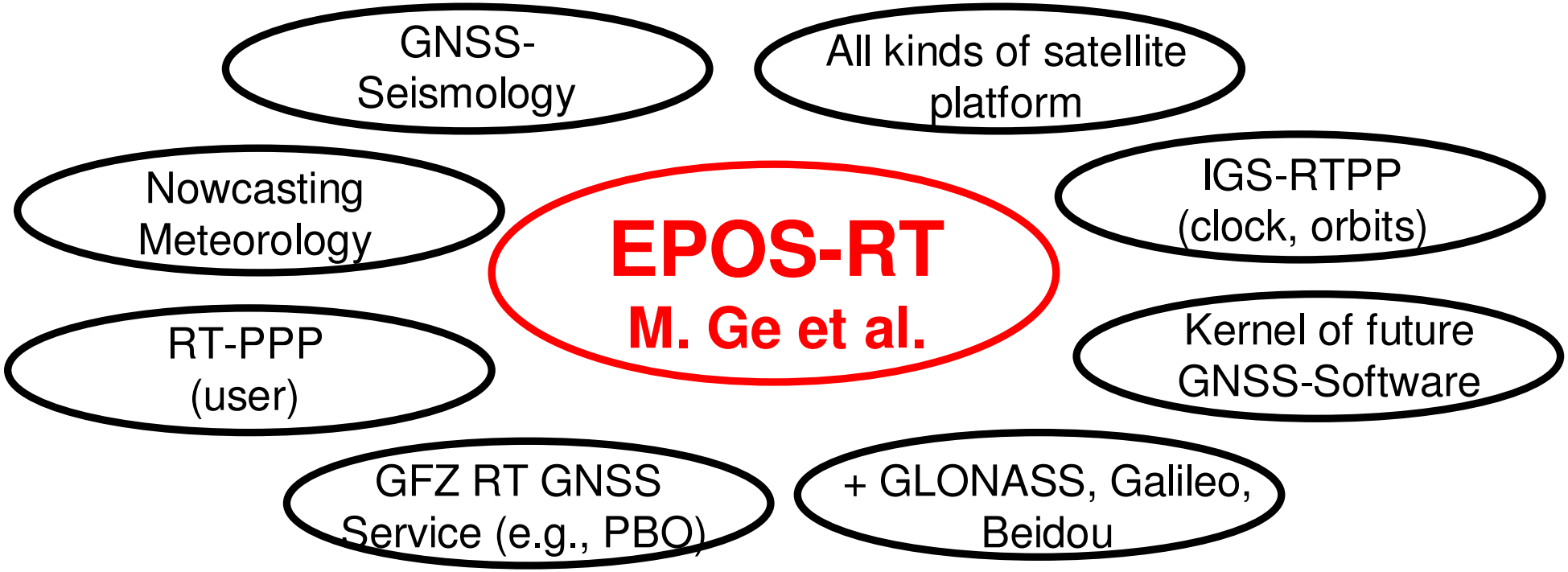
Existing projects/services

- IGS Real-time Pilot Project (IGS-RTPP)
- EUREF-IP project
- commercial services: OmniSTAR XP/G2, GDGPS, StarFire™ (two supports GPS+GLONASS)

EPOS-RT GNSS-Software

EPOS-RT (Earth satellite Positioning and Orbit determination System in Real-Time)

- designed and developed by ***Maorong Ge***
- contributions from ***Junping Chen, Jan Dousa, Gerd Gendt***
- **LAMBDA** ambiguity resolution technique from ***Delft University***
- **BNC/BNS** tools from ***BKG*** (receiving or casting data streaming via internet)
- **PANDA** subroutines and the **PIO-concept**, cooperated with ***Dr. Chuang Shi*** and his colleagues at the GNSS research Center of Wuhan.



EPOS-RT software

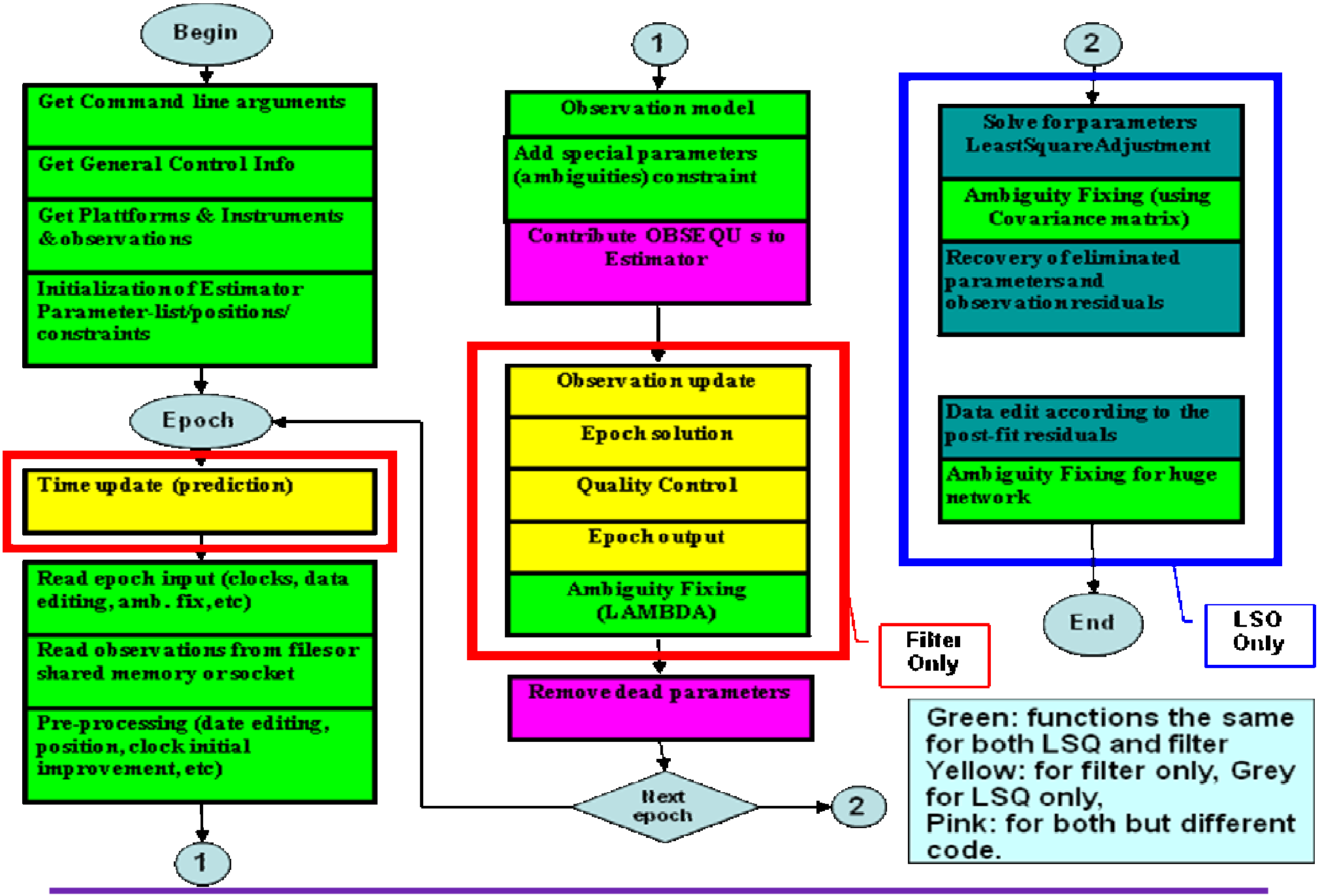
Core EPOS-RT software characteristics

- developed as a basis for future GFZ software
- high level of generality
  - PPP mode, network mode
  - Real-time, post-mission
  - Static, kinematic, dynamic positioning
  - Support for GNSS, VLBI, SLR, …
  - PIO concept (Platform, Instrument, Observation)
- all models for un-difference level processing

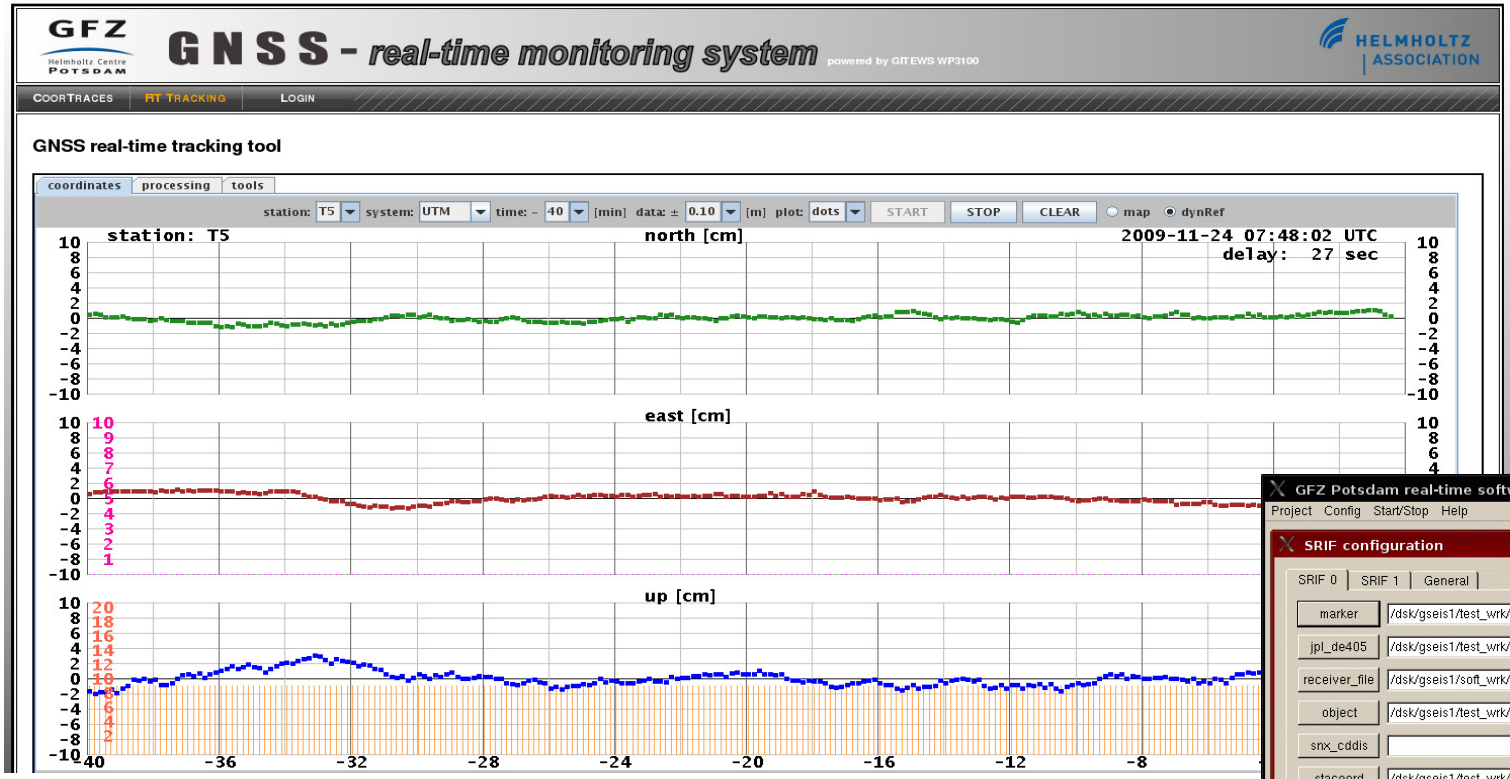
Components:

- SRIF estimator (+ LSQ in preparation) – fotran
- central control unit (CCU) – c++
- open source software (BNC, BNS, StreamOrbits, ...)
- web-monitoring tool (MySQL, php/java)

EPOS-RT


Begin
Get Command line arguments
Get General Control Info
Get Plattforms & Instruments &observations
Initialization of Estimator Parameter-list/positions/ constraints
Epoch
Time update (prediction)
Read epoch input (clocks, data editing, amb. fix, etc)
Read observations from files or shared memory or socket
Pre-processing (date editing, position, clock initial improvement, etc)
1
1
Observation model
Add special parameters (ambiguities) constraint
Contribute OBSEQU s to Estimator
Observation update
Epoch solution
Quality Control
Epoch output
Ambiguity Fixing (LAMBDA)
Remove dead parameters
Next epoch
2
2
Solve for parameters LeastSquareAdjustment
Ambiguity Fixing (using Covariance matrix)
Recovery of eliminated parameters and observation residuals
Data edit according to the post-fit residuals
Ambiguity Fixing for huge network
End
Filter Only
LSQ Only
Green: functions the same for both LSQ and filter
Yellow: for filter only, Grey for LSQ only,
Pink: for both but different code.

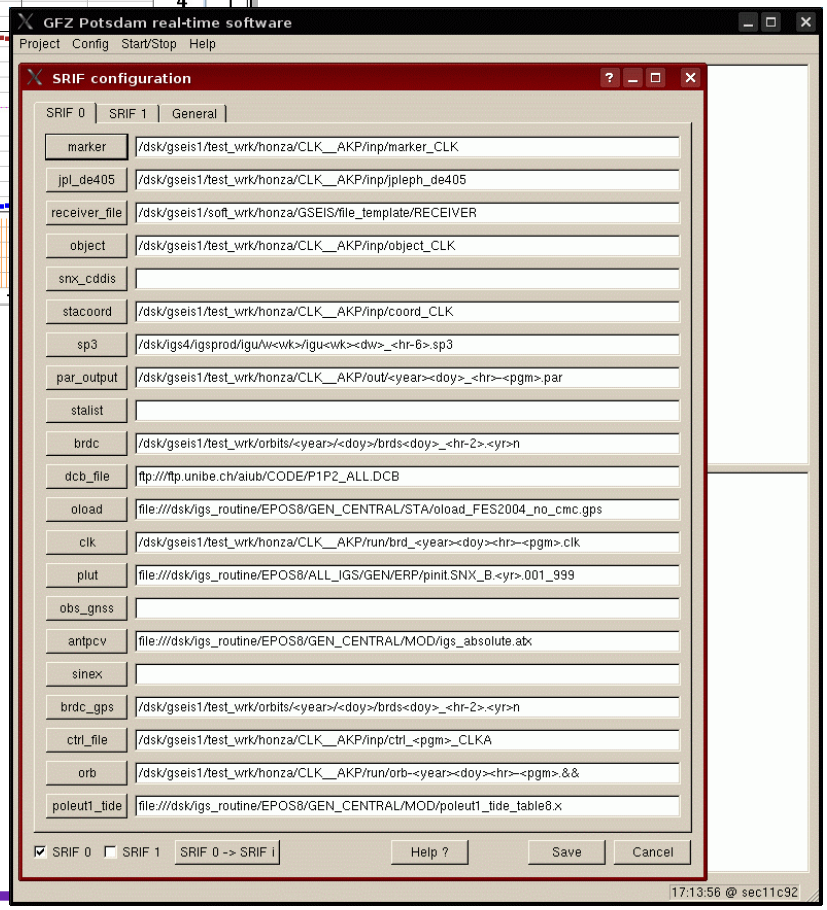
EPOS-RT Interface



Web monitoring:

developed at GPS group within the GITEWS project (GFZ)

C. Falck et al. 2009



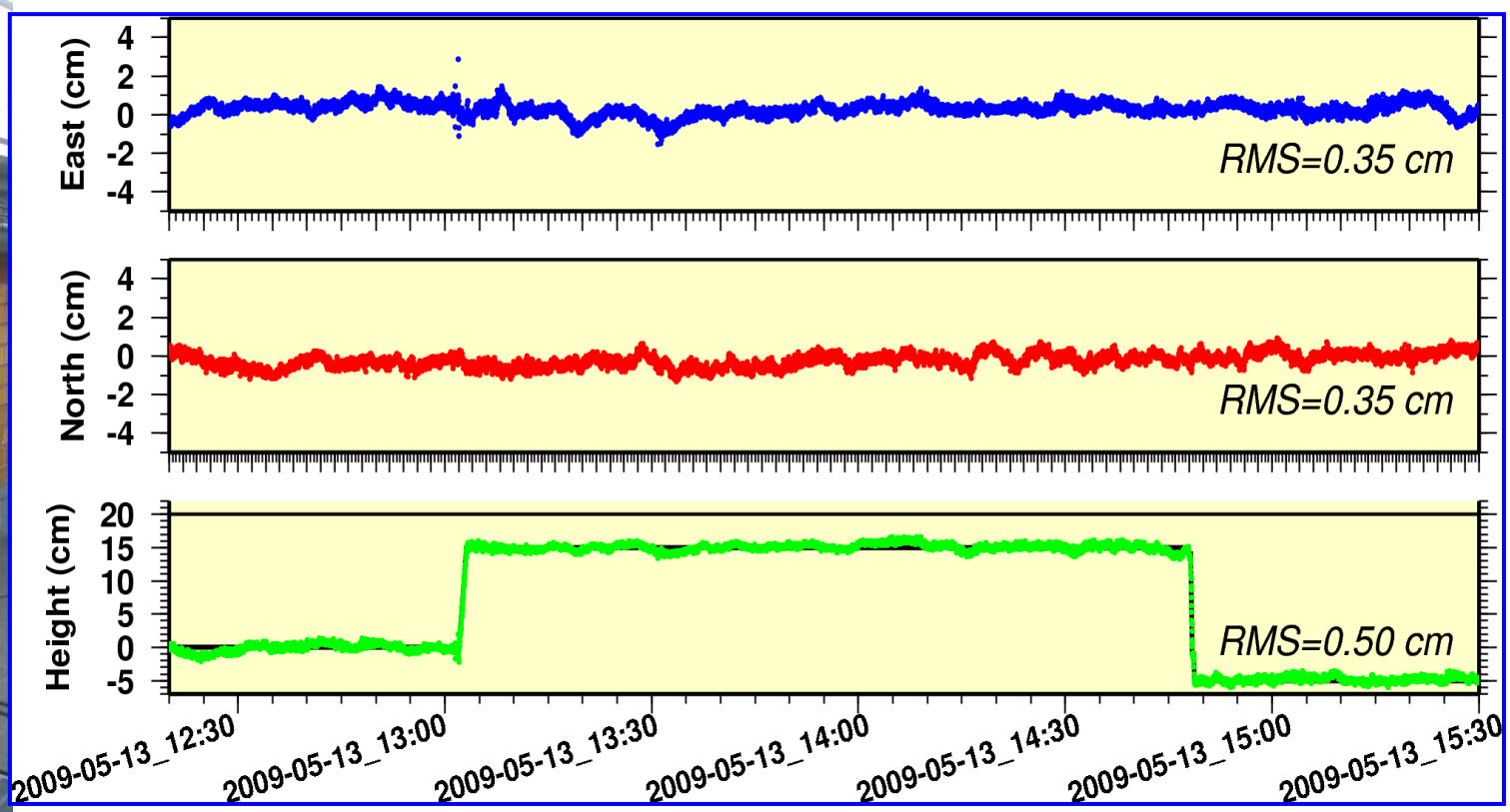
Central Control Unit:

- Configuration, control of the system
- UDP, TCP, NTRIP server, shared memory
- Monitoring and e-mail warnings
- Job scheduler
- Download external files via FTP
- Graphic user interface

Real-time motion monitoring (1)

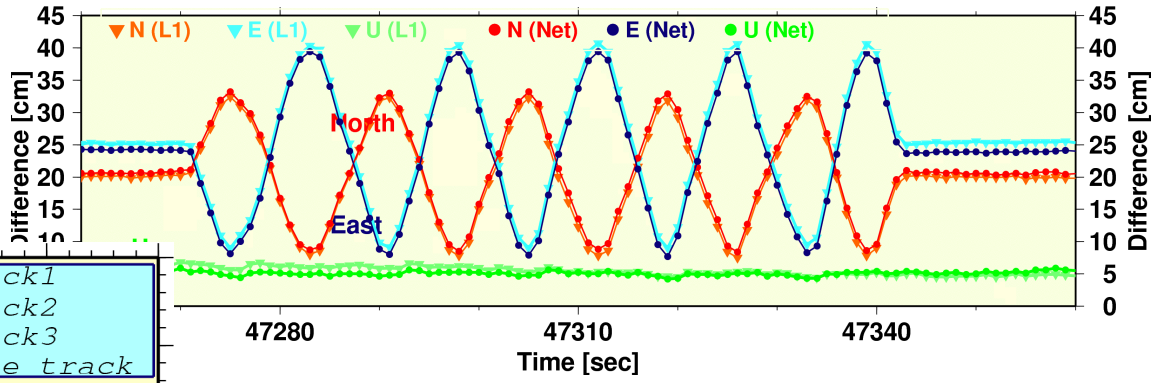
Software: EPOS-RT

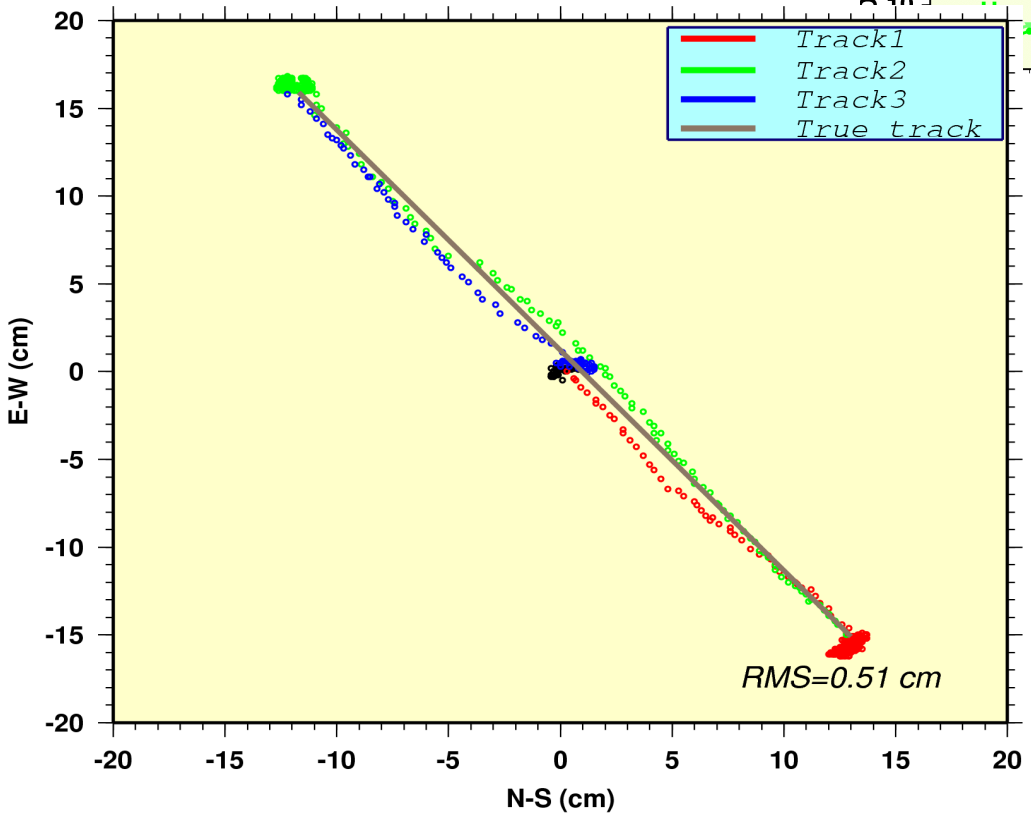
- Station on the roof of building A17 at GFZ, instrument to change station height
- BNC used to receive real-time streams
- Reference station POTS meters away, L1 real-time solution with ambiguity fixing
- antenna height change up (+15 cm) and after 105 min down (-20 cm)

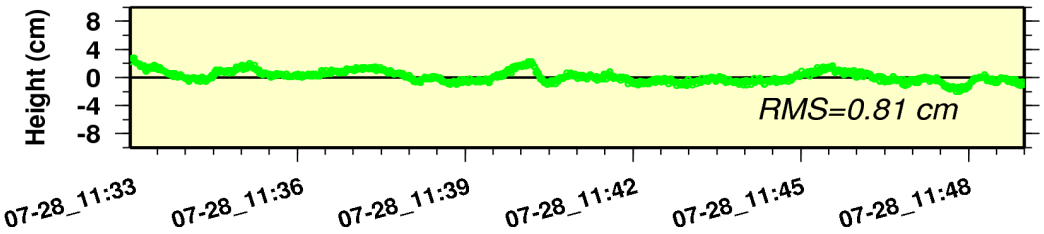


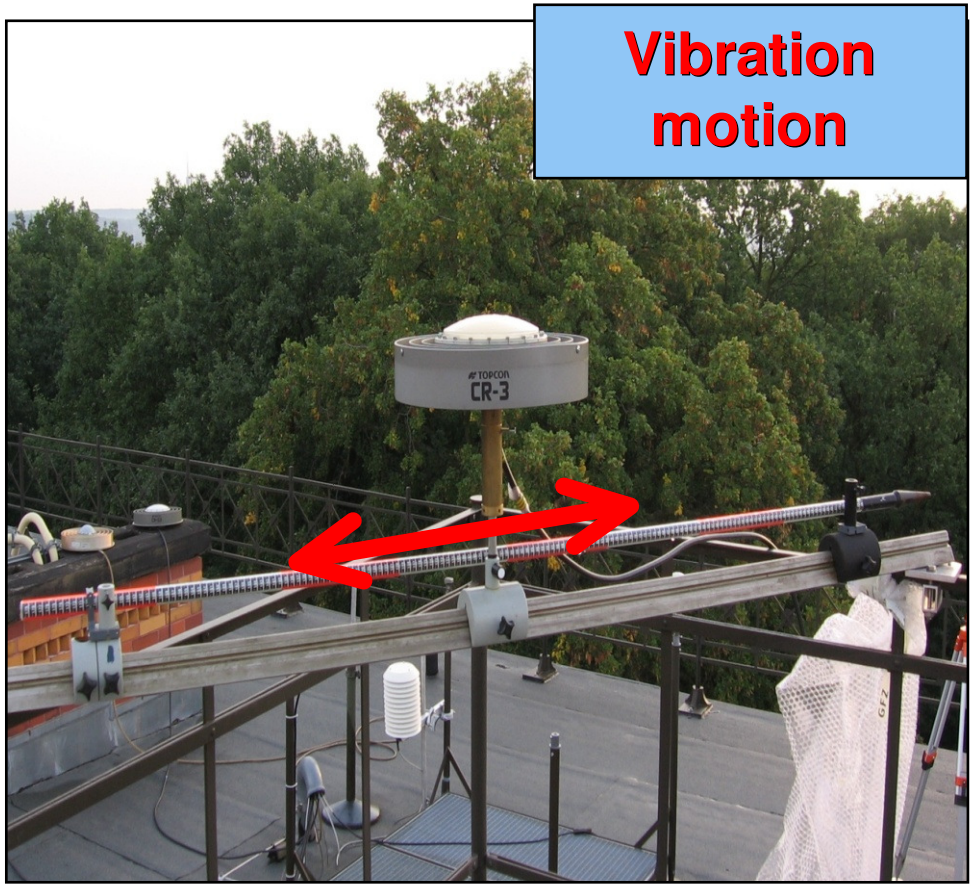
Real-time motion monitoring (2)

- Controlled linear movements
- Simulated 'Earthquake'



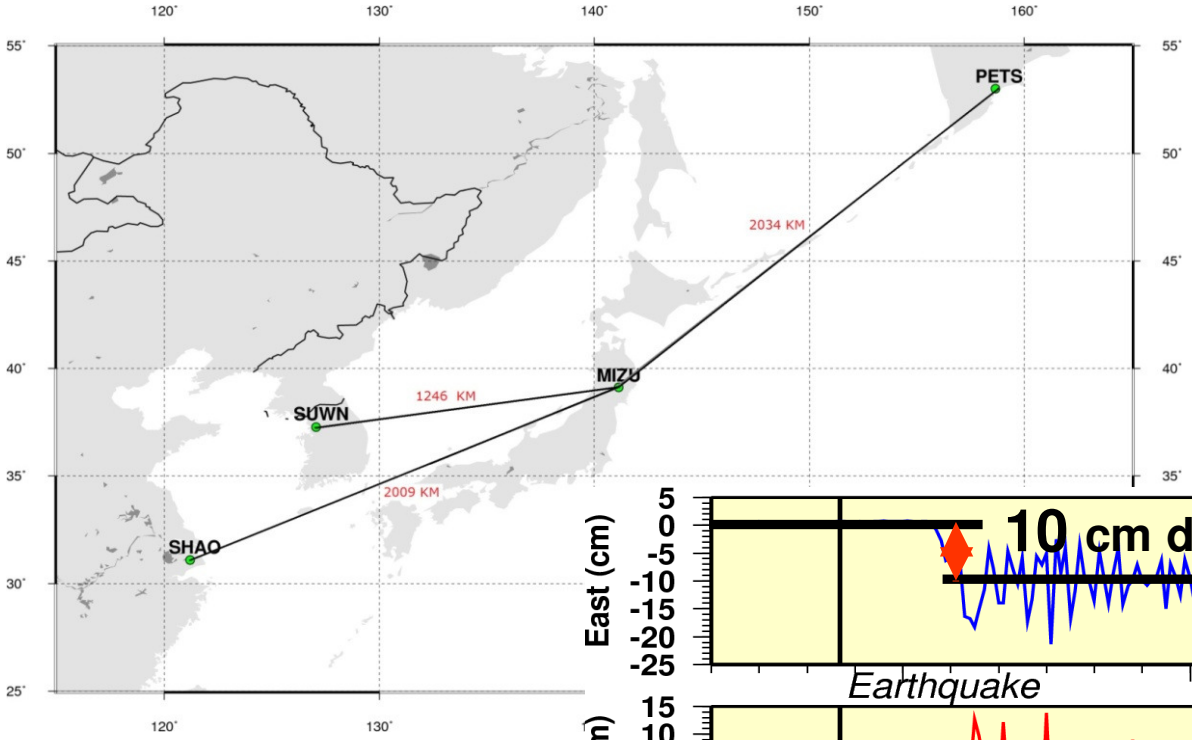






Coseismic deformation monitoring

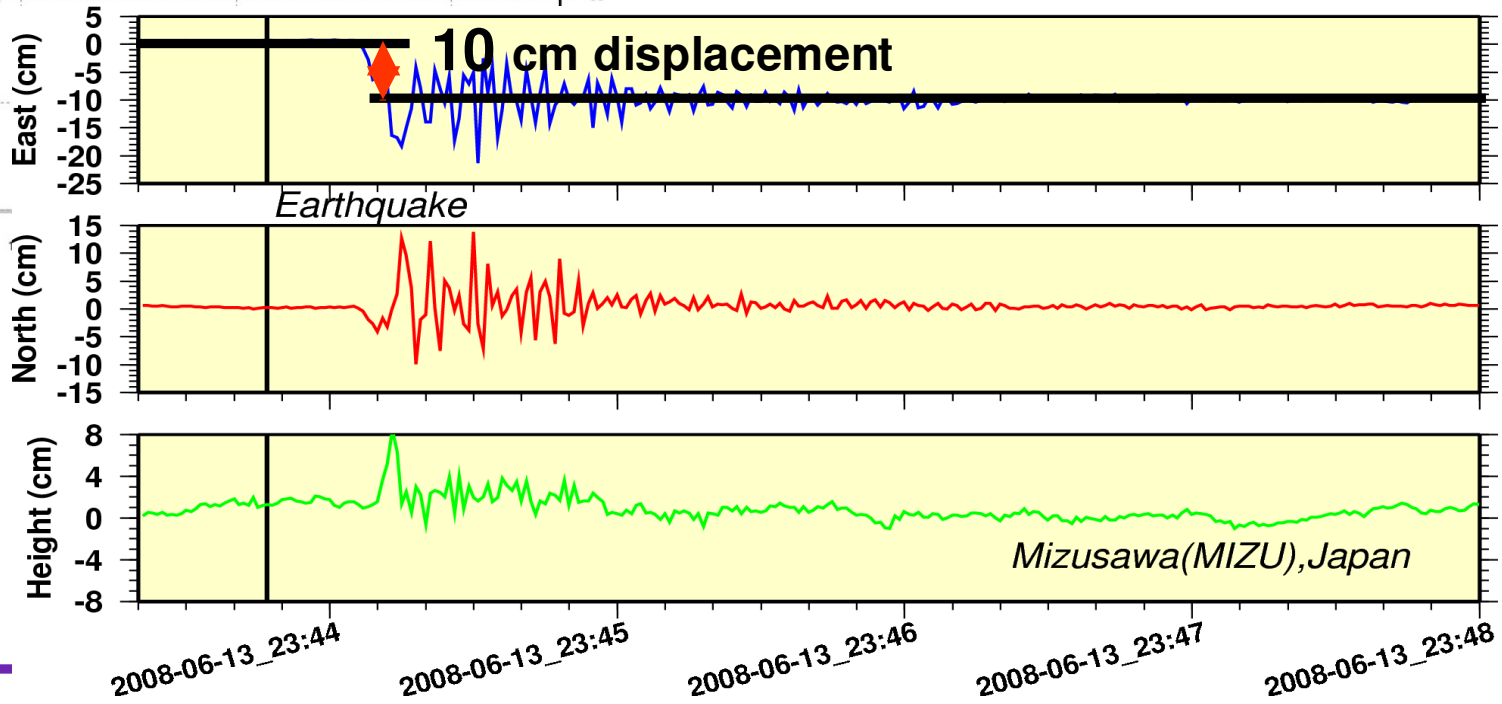
- 13, June, 2008, Mw 6.9 earthquake, EASTERN HONSHU, JAPAN
- Reference stations: PETS(Russia), SUWN(South Korea) and SHAO(China)
- MIZU:(~50 km away from epicenter)



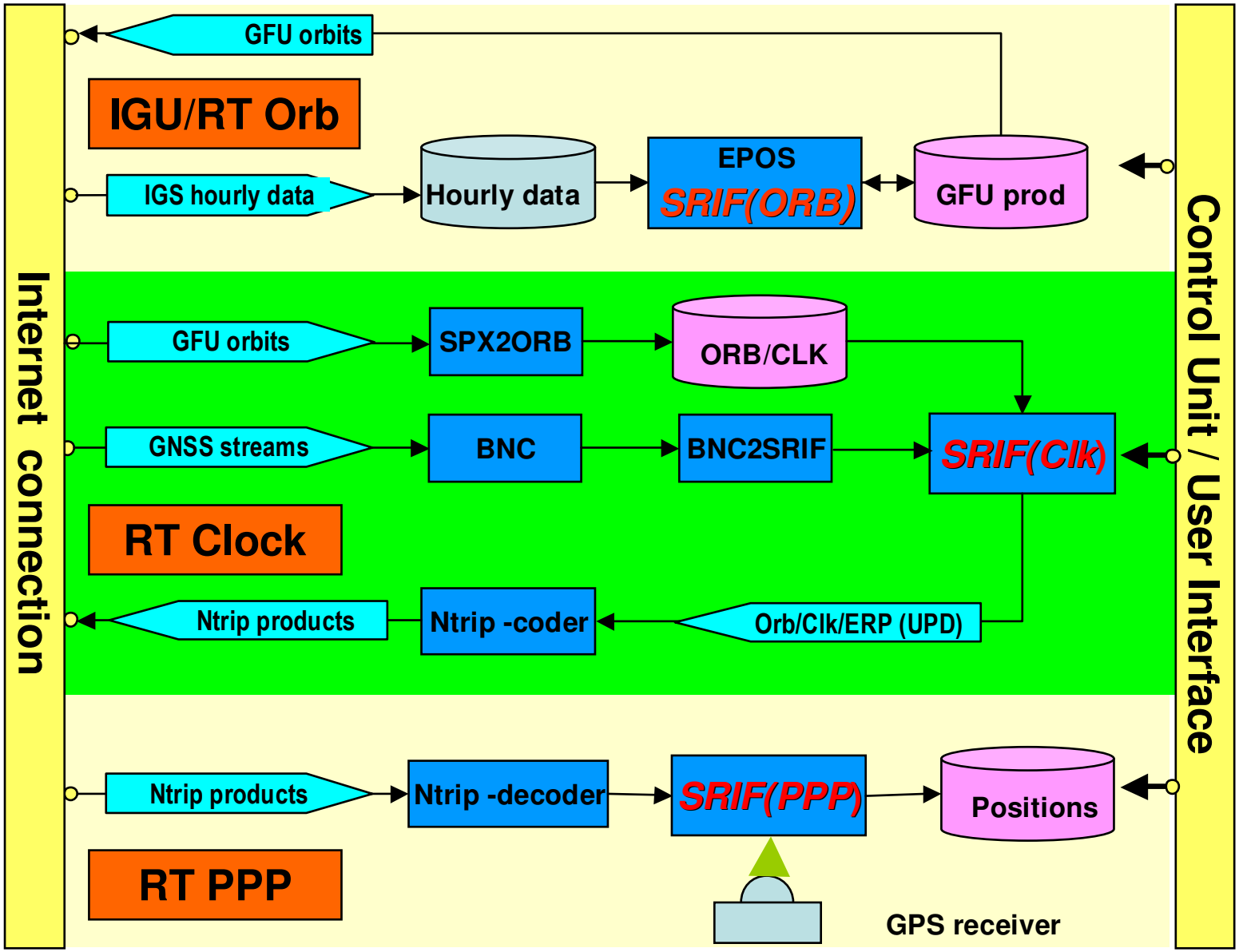
1Hz kinematic coordinates

Comparison to coordinates from day before

GFZ ultra-rapids orbits
kinematic coordinates
ambiguities
satellite clocks
receiver clocks
ZTDs

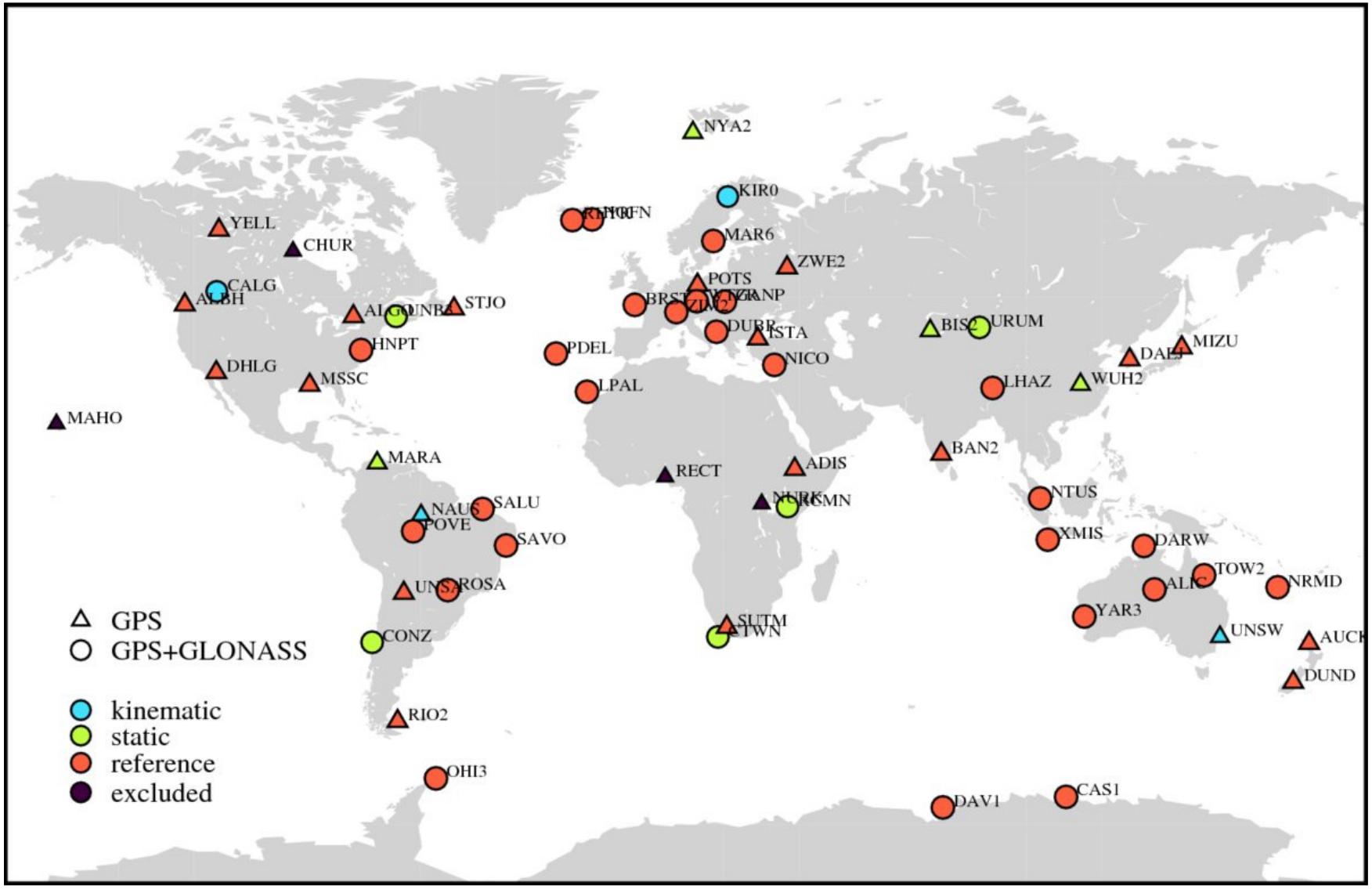


PPP based positioning system



Global real-time network

- 70 real-time streams configured: IGS RTPP / EUREF-IP / GFZ
- reality: approximately 45-50 available



Real-time clock estimation

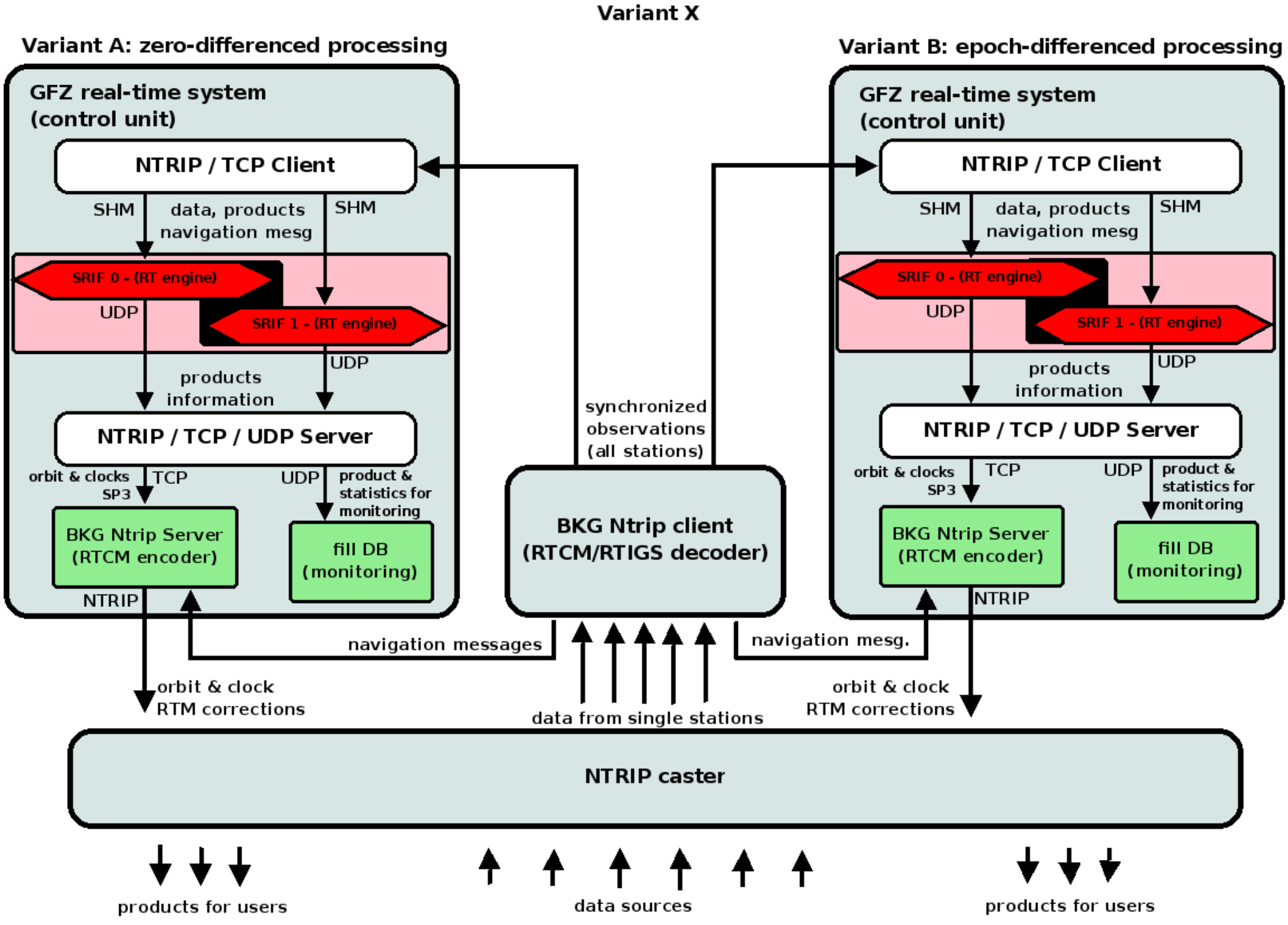
Processing strategy

- Orbits fixed to IGS/GFZ ultra-rapid products (6h/3h update)
- Estimated satellite & receiver clocks and ZTDs
- Station coordinates actually fixed to the long-term IGS coordinates
- Three stations estimated with kinematic coordinates for monitoring
- Bancroft/channel filter pre-processing, a posteriori quality check
- Two processing strategies applied:

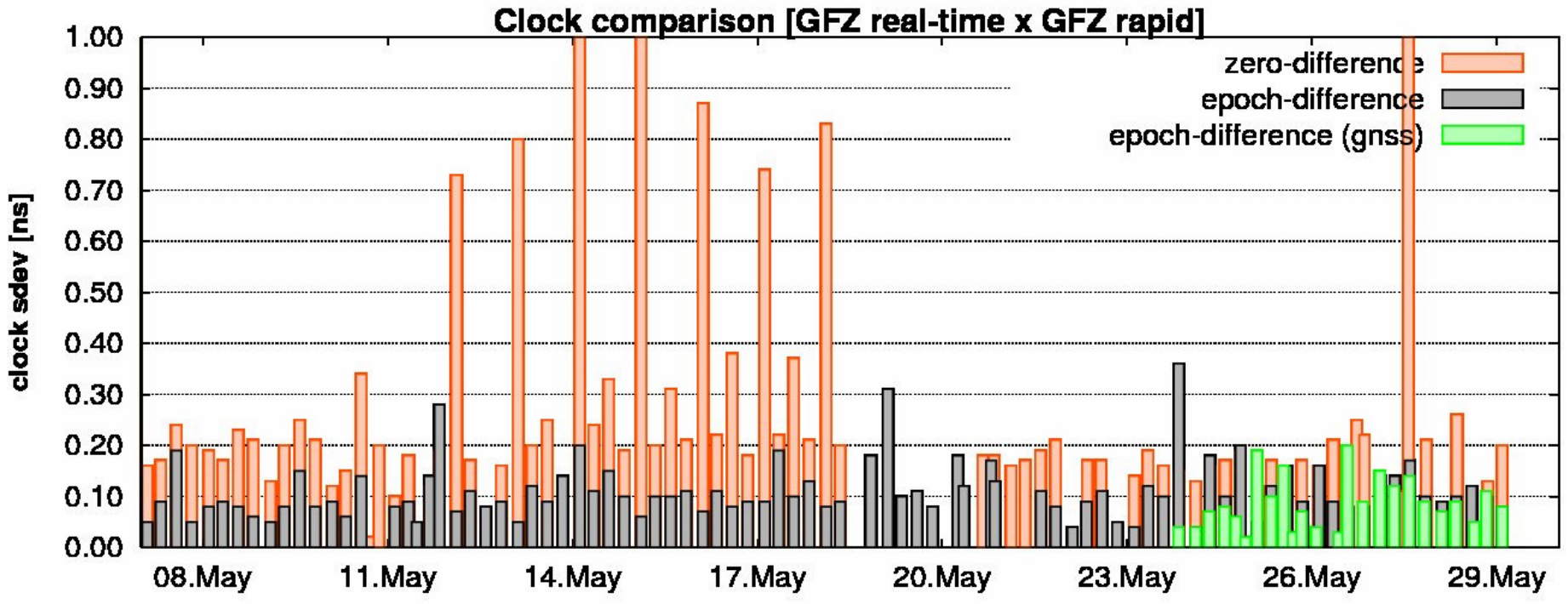
1) **zero-differenced observations**
   - epoch-by-epoch independent clock estimation
   - better alignment thanks to the 'absolute' estimation
   - need for convergence time (tens minutes)
   - many ambiguities (large normal equations)
   - requires more CPU (actually 5 sec update rate)

2) **epoch-differenced observations**
   - fast initialization
   - epoch-difference clocks estimation w.r.t to reference clocks
   - requires clock-differences accumulation in time
   - ambiguities eliminated (small normal equations)
   - small demands for CPU (actually 1 sec update rate)

Real-time System Scheme



Real-time clocks comparison

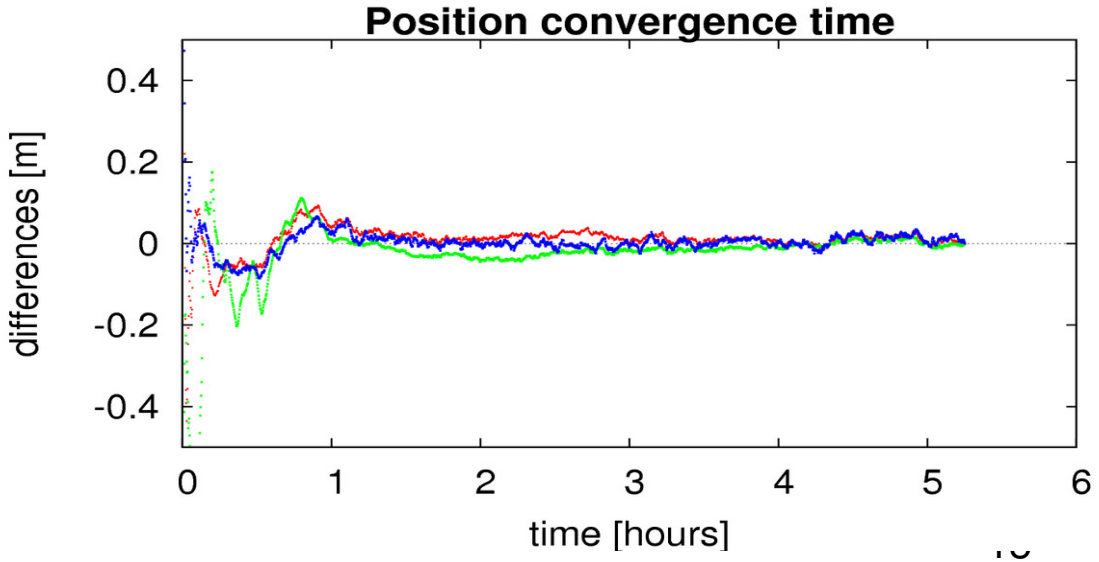


Epoch-difference

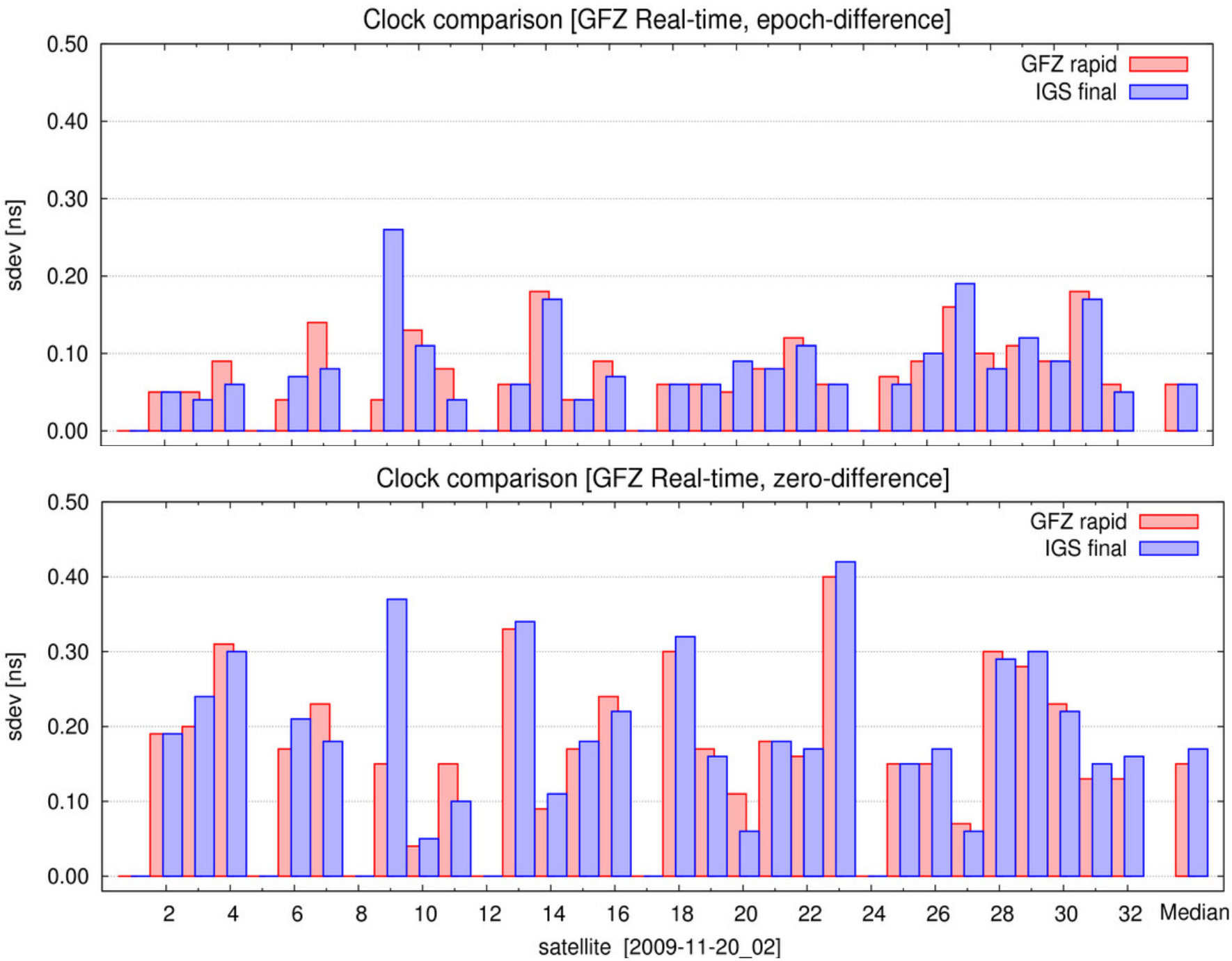
stddev ~ 0.1 ns (~10cm)

Zero-difference

stddev ~ 0.2 ns (~20cm)



Real-time clock estimation



Potential for PPP improvements

Impact study for PPP improvements

- epoch-by-epoch processing (post-mission)
- kinematic positioning mode (30 sec sampling)
- precise orbits and clocks fixed (based on batch processing)
  - **multi-GNSS solution**
  - **ambiguity resolution in PPP**

Multi-GNSS solution

- GPS, GLONASS and in future Galileo, COMPAS, ...
- better geometry, more observations
- inter-channel biases for multi-GNSS (and GLONASS)

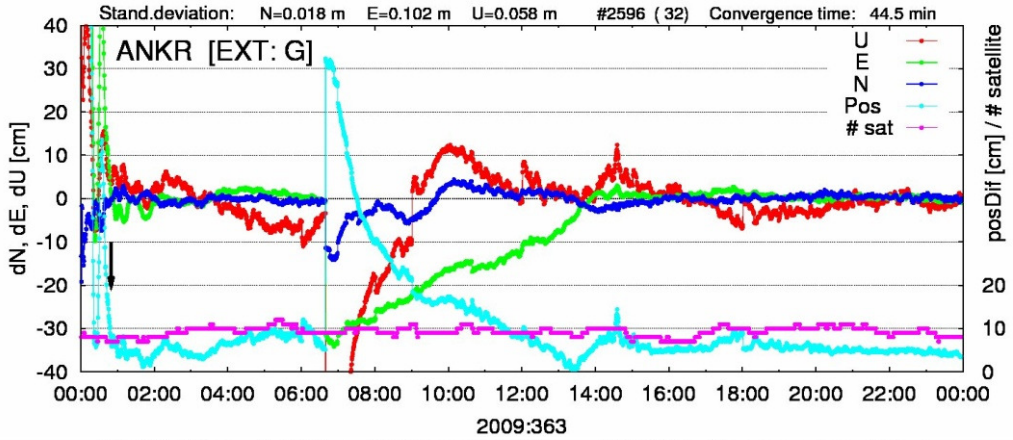
PPP (zero-difference) ambiguity fixing

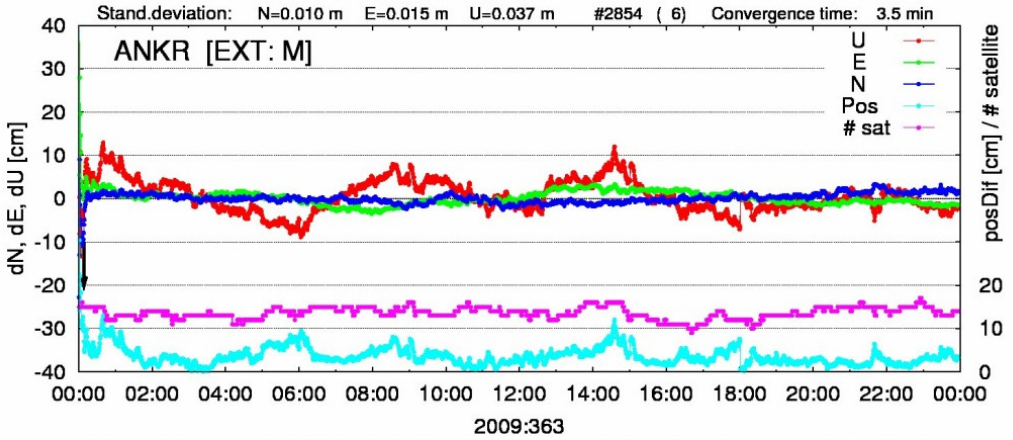
- based on the possibility to restore the integer nature of zero-difference ambiguities by estimating two-step procedure:

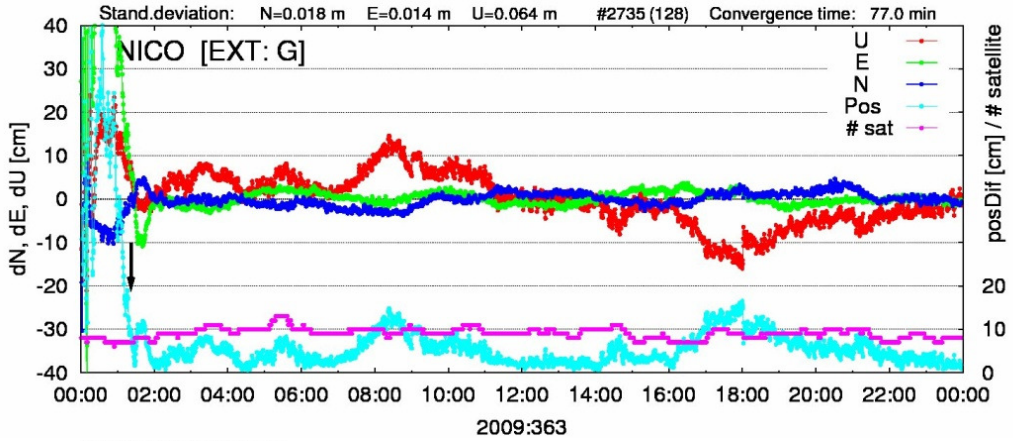
1. **Service side:** estimating fractional wide-lane (WL) and narrow-lane (NL) uncalibrated phase delays (UPDs) for satellite-based single-differences (SD)
2. **User side (PPP)**: applying SD WL & NL UPDs and resolve the ambiguities

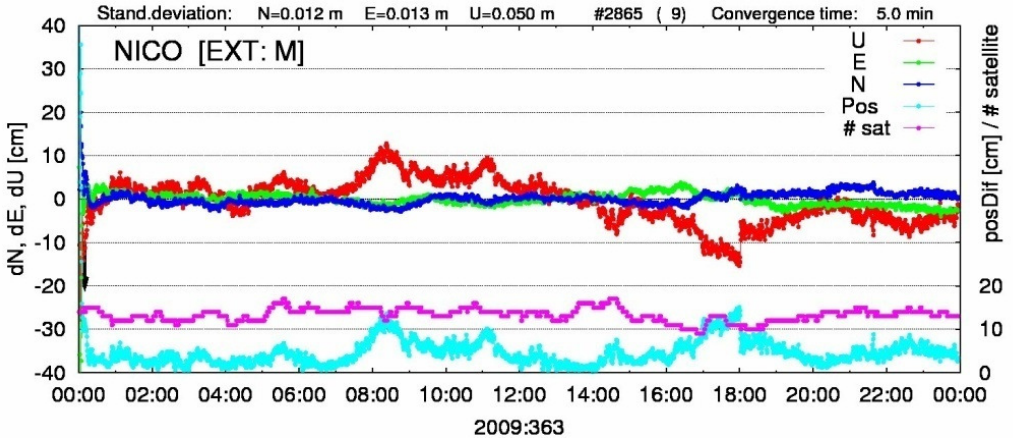
- *Ge, M., Gendt, G., Rothacher, M., Shi, C., Liu, J. (2007), Resolution of GPS carrier-phase ambiguities in precise point positioning (PPP) with daily observations, J Geod, Vol 82, No 7, pp 389-399*
- *Geng, J., Teferle, F.N., Shi, C., Meng, X., Dodson, A.H., Liu, J. (2009), Ambiguity resolution in precise point positioning with hourly data, GPS Solut*

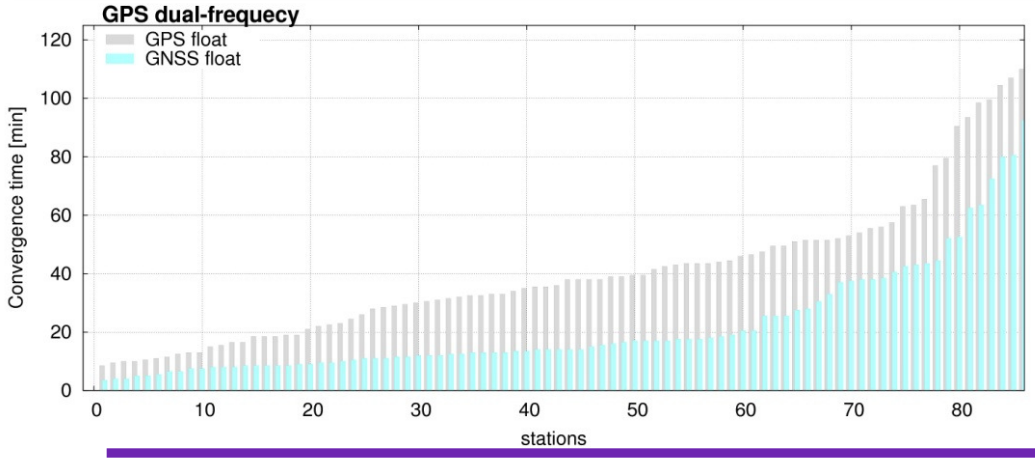
Impact of multi-GNSS

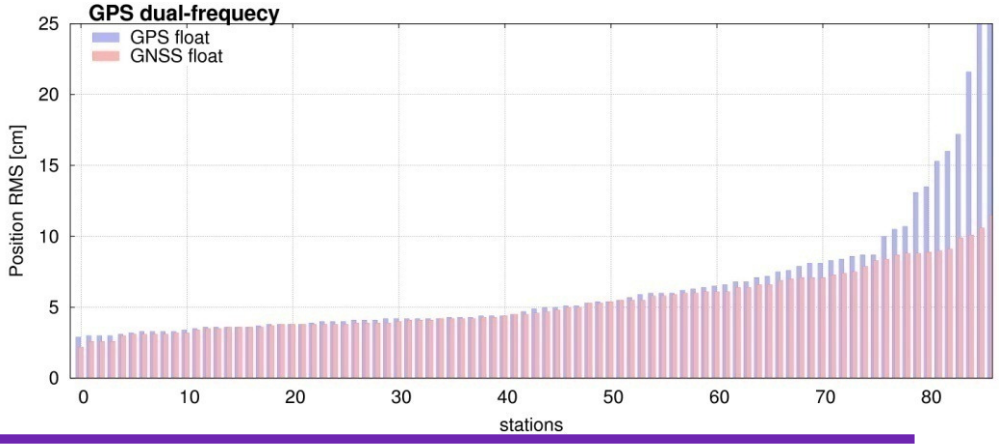




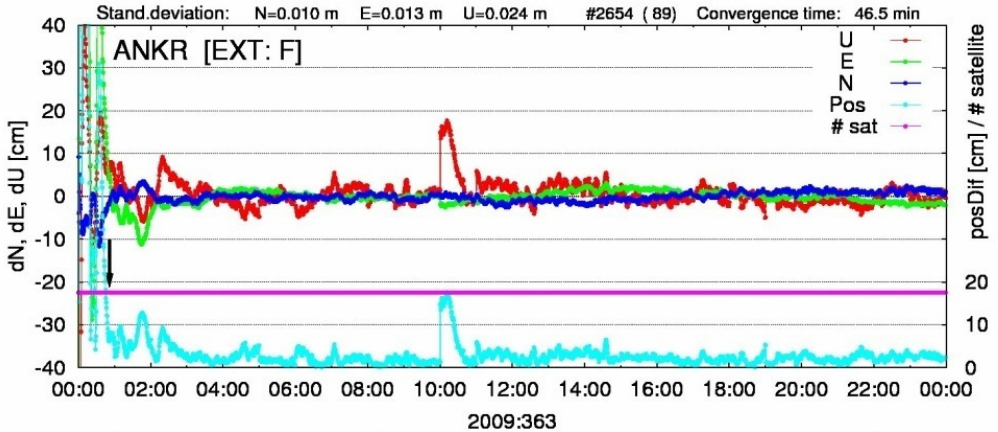


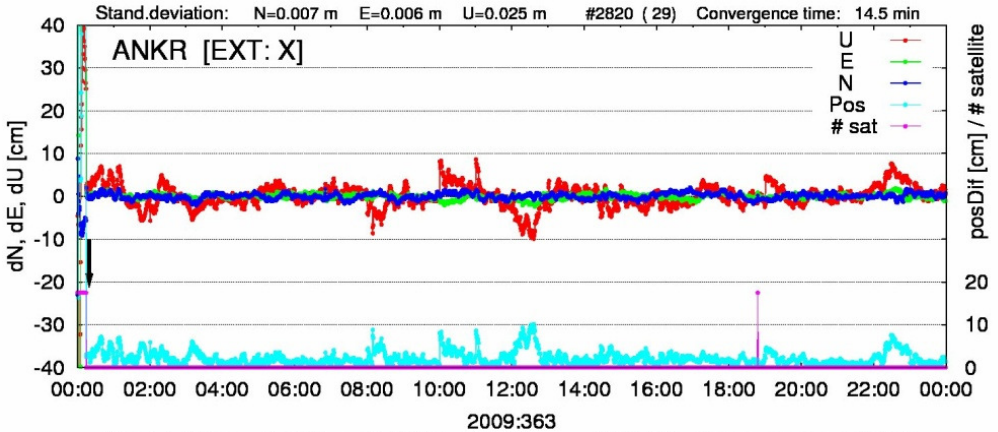


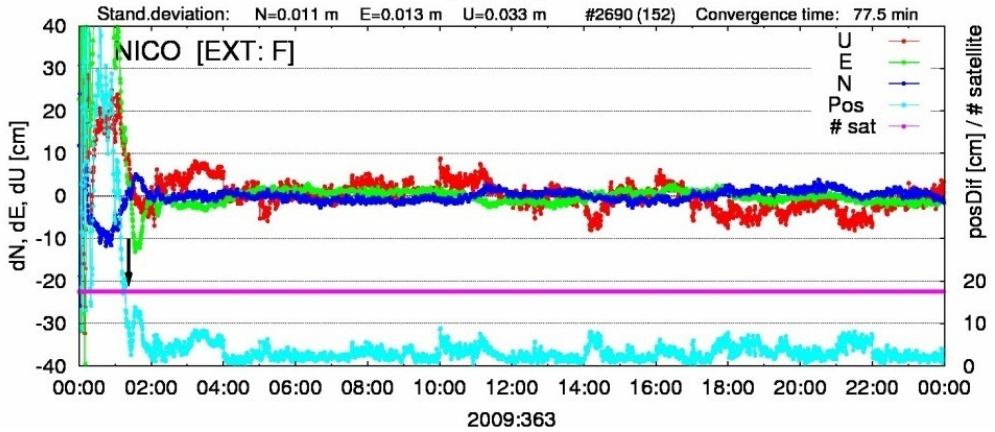


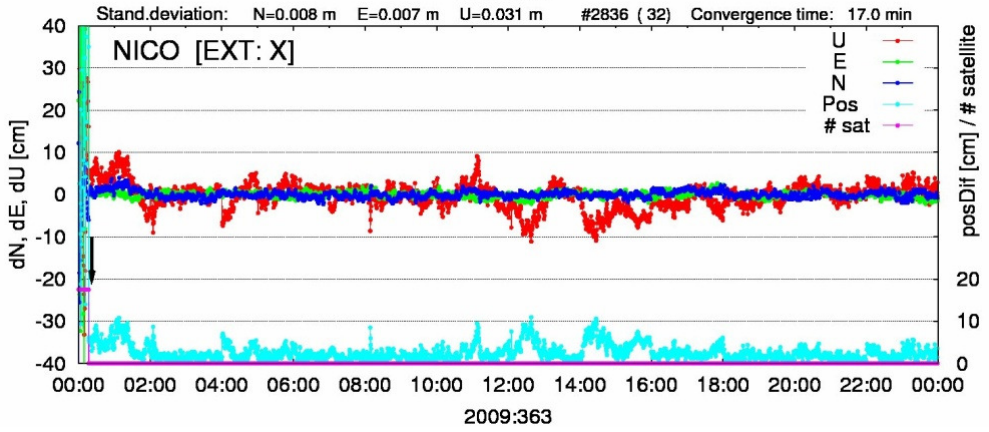


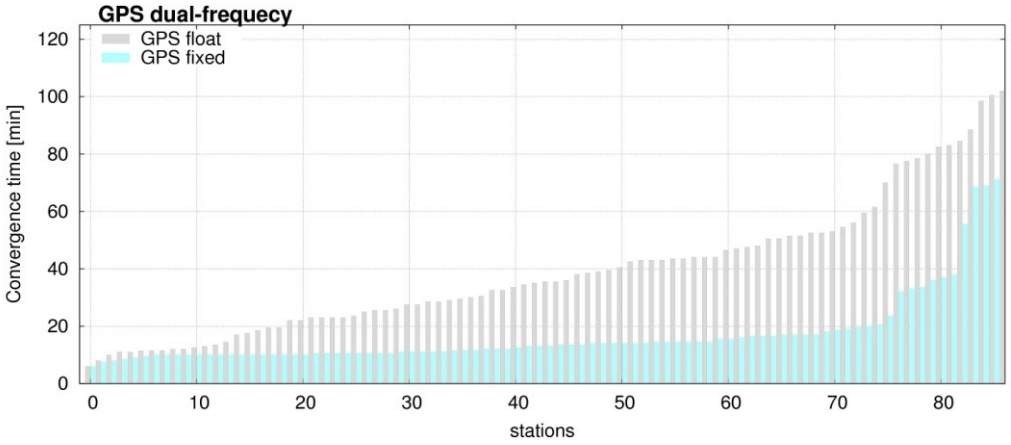
Impact of ambiguity fixing

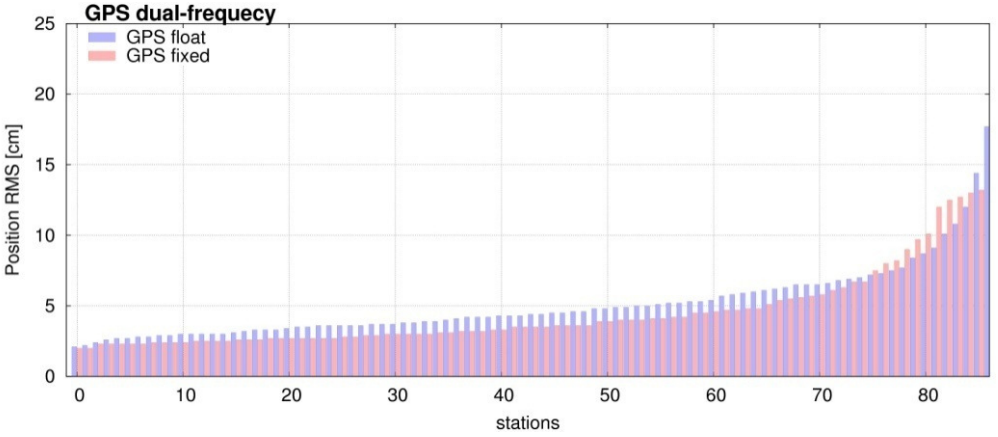












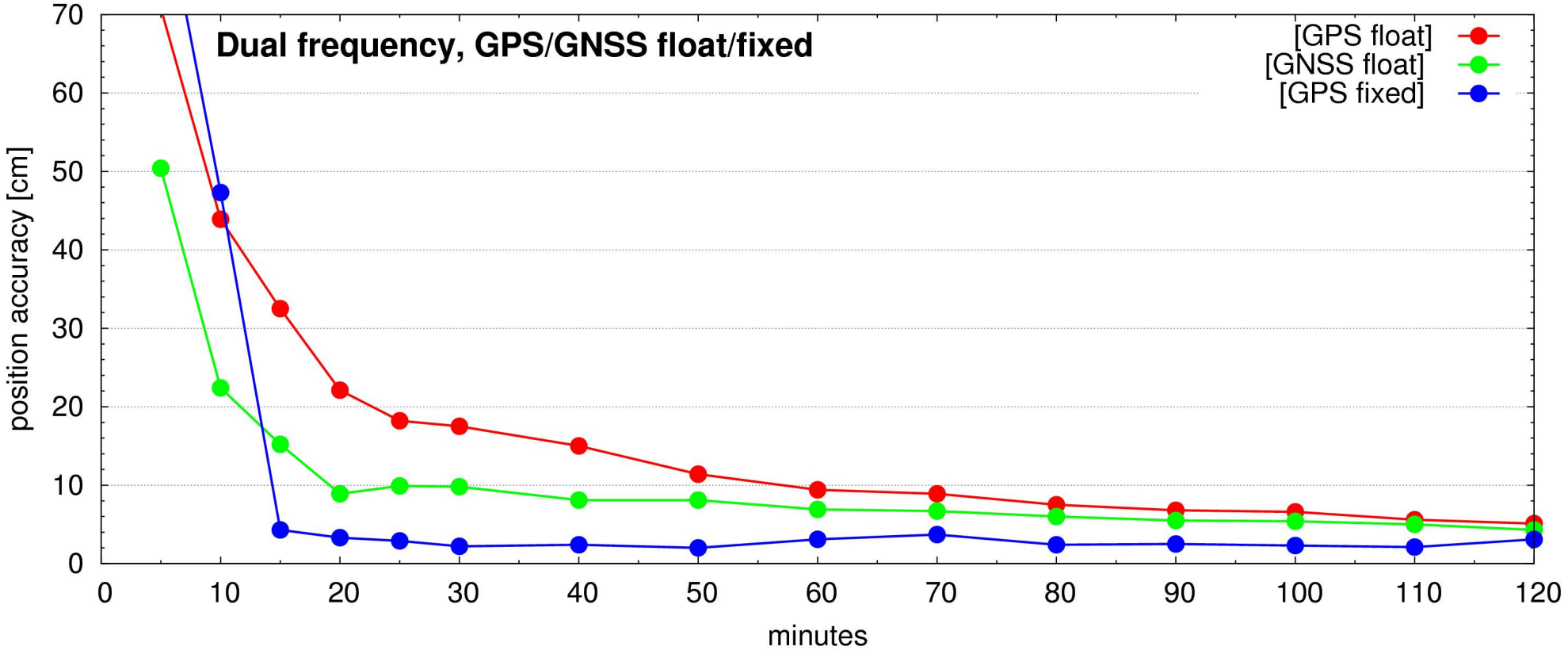
Results of impact study

Multi-GNSS PPP solution supports:

- shorter convergence time (reduced by a factor of ~ 2)
- slightly improved achievable accuracy
- more robust solution

Integer ambiguity resolution in PPP supports:

- convergence time is equivalent to the time-to-first-fix (TTFF)
- improved accuracy and high stability after TTFF



Summary

EPOS-RT software

- developed as a general software package (and future GFZ software)
- evaluated in different real-time/simulated processing modes
- RT-service & PPP mode, network mode…

Real-time service in GFZ

- RT satellite clock estimation (~50 stations):
  - 1.0 Hz epoch-difference mode StdDev ~0.1 ns
  - 0.2 Hz zero-difference mode StdDev ~0.2 ns
  - ….. new combined mode in preparation
- Achievable kinematic coordinate accuracy (RMS)
  - horizontal ~3 cm
  - vertical ~5 cm

On-going developments for improving PPP positioning

- multi-GNSS solution
- support for integer ambiguity resolution in real-time
- regional augmentations

Thank you!