European troposphere and coordinate estimates from real-time PPP solution

Jan Douša and **Pavel Václavovic**

Research Institute of Geodesy, Topography and Cartography

G-Nut Software, s.r.o.

Research Institute of Geodesy, Topography and Cartography

EUREF Symposium 2021

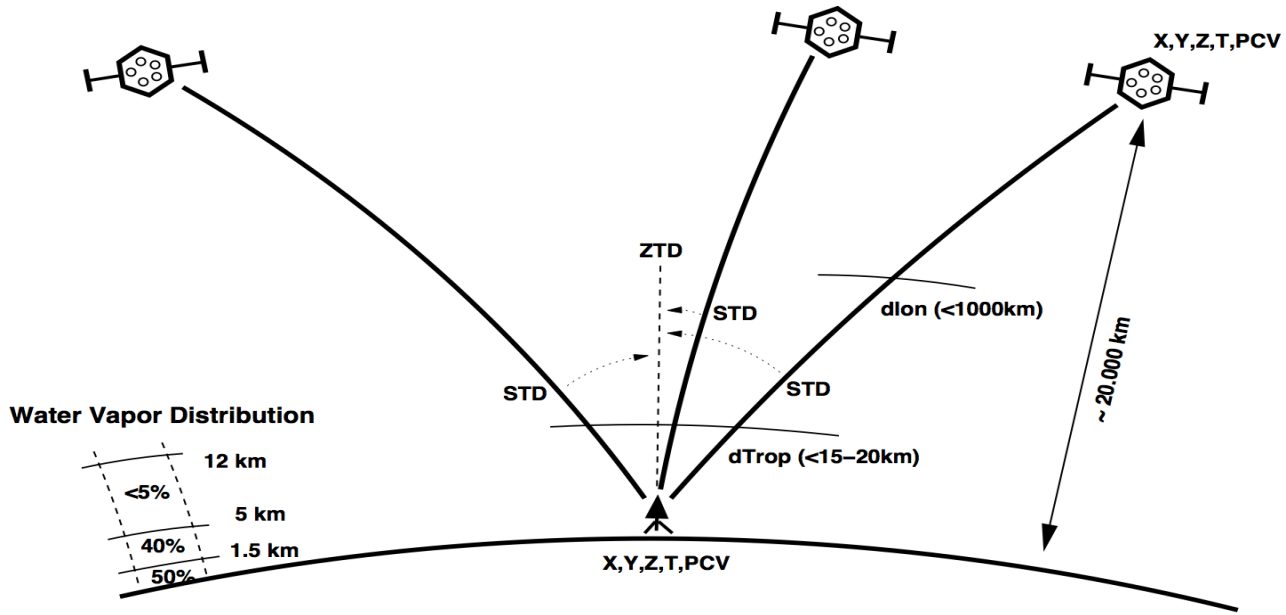
May 26-28 2021, Ljubljana

Content

- Introduction
- Real-time troposphere production in Europe
- Station coordinates monitoring within real-time solution
- Helmert parameters estimated within real-time solution
- Conclusion

Research Institute of Geodesy, Topography and Cartography
Geodetic Observatory Pecný

Concept of GNSS–Meteorology: ‘noise’ → ’signal’



→ *Monitoring signal path delays in the troposphere with GNSS analysis*

Tropospheric model:

- ZTD = ZHD *(dry)* + ZWD *(wet)*
- GRD = Linear horizontal gradients
- STD = Slant tropospheric delay (wet)

Fixed or modelled

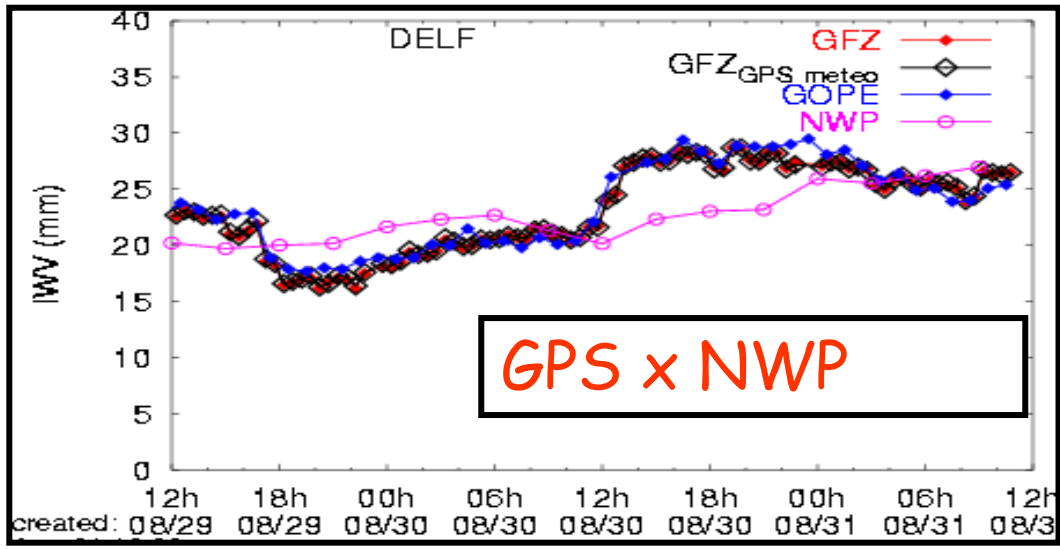
- **satellite positions** (satellite clocks, biases)
- **precise models** (PCVs, tidal models, mapping functions ...)

Eliminated

- **ionosphere effect** (receiver/satellite clock errors, biases)

Estimated:

- **troposphere delay** (gradients), ambiguities (receiver clocks)
- **station positions** (may be also predicted if region is stable)



Research Institute of Geodesy, Topography and Cartography
Geodetic Observatory Pecný

GOP – PPP real-time ZTD production (since 2013)

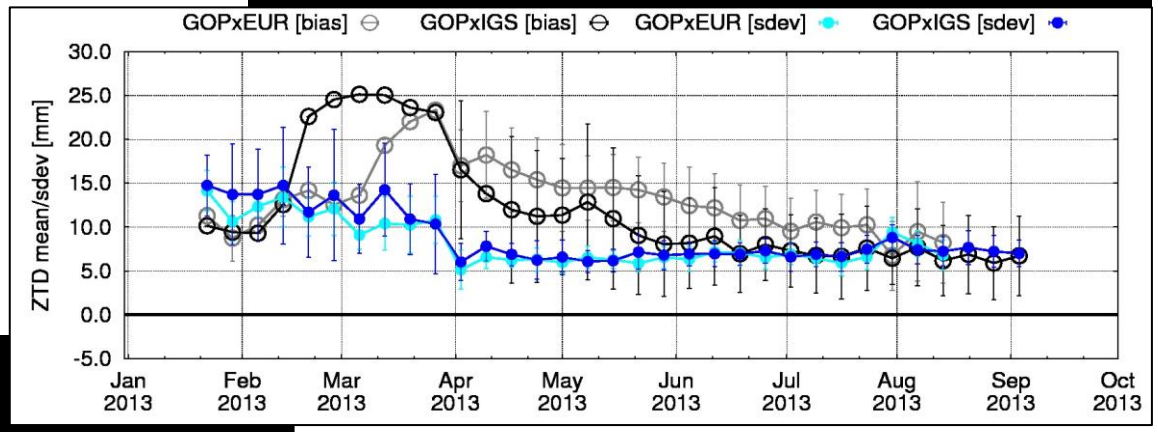
2013: GOP initial real-time PPP solution

2015-2019: organizing Real-Time Demonstration (GNSS4SWEC project)

2019-today: enhancing strategy & extending solution

- all-in-one strategy for Real-Time (RT) & Near Real-Time (NRT)
- Focus on gradients and slant tropospheric delays
- PPP using undifference & uncombined observation model

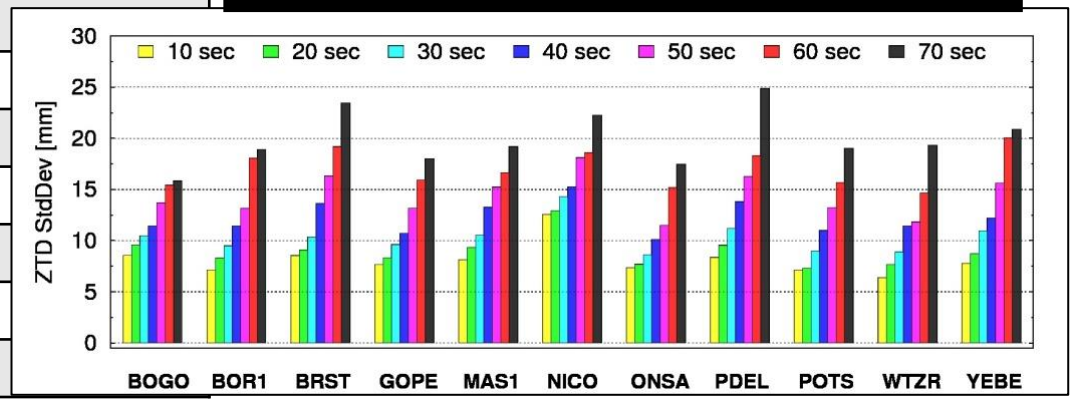
2013: GOP initial half-a-year real-time demo



2015-2019: GNSS4SWEC Real-time GNSS demonstration campaign

AC	Software	Start	Update	Solutions
GOP	G-Nut/Tefnut	9.4. 2015	real-time	GPS, GLO, gradients
TUW	TUW software	15.4. 2015	real-time	GPS
ROB	G-Nut/Tefnut	23.4. 2015	real-time	GPS, GLO, gradients
ASI	Gipsy-Oasis	5.5. 2015	hourly	GPS, gradients
UL	*(PPP-wizard)*	*15.6. 2015*	*real-time*	*GPS*
ICS	G-Nut/Shu (GOP)	12.7.2015	forecast	WRF model (EU, CZ)
TUO	RTKLib	5.11.2015	real-time	GPS
BKG	BNC	1.3.2016	real-time	GPS, GLO
GFZ	EPOS-RT	18.2.2017	Real-time	GPS, GLO

Impact of correction delay/prediction on ZTD



Douša, Václavovic, **Real-time zenith tropospheric delays in support of numerical weather prediction applications**, Adv Space Res, 2014

Ahmed, Václavovic, Teferle, Douša, Bingley, Laurichesse, **Comparative analysis of real-time precise point poisitioning zenith total delay estimates**, GPS Solutions, 2016

Douša et. al, **New Adaptable All-in-One Strategy for Estimating Advanced Tropospheric Parameters and Using Real-Time Orbits and Clocks**, Remote Sens, 2018.

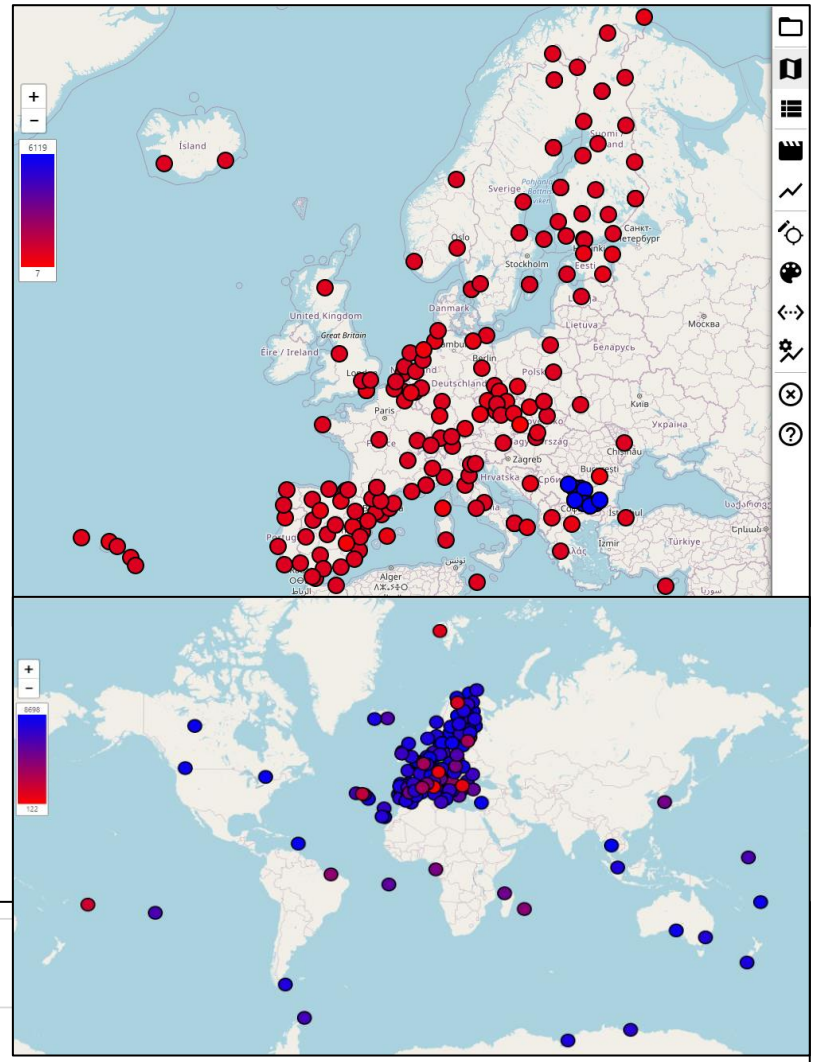
Research Institute of Geodesy, Topography and Cartography
Geodetic Observatory Pecný
VUGTK

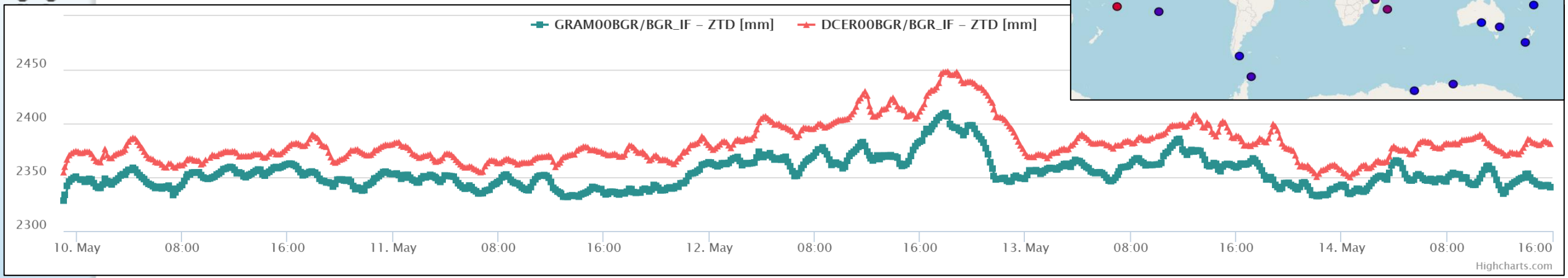
GNSS real-time troposphere solution

https://www.pecny.cz/RT-TROPO

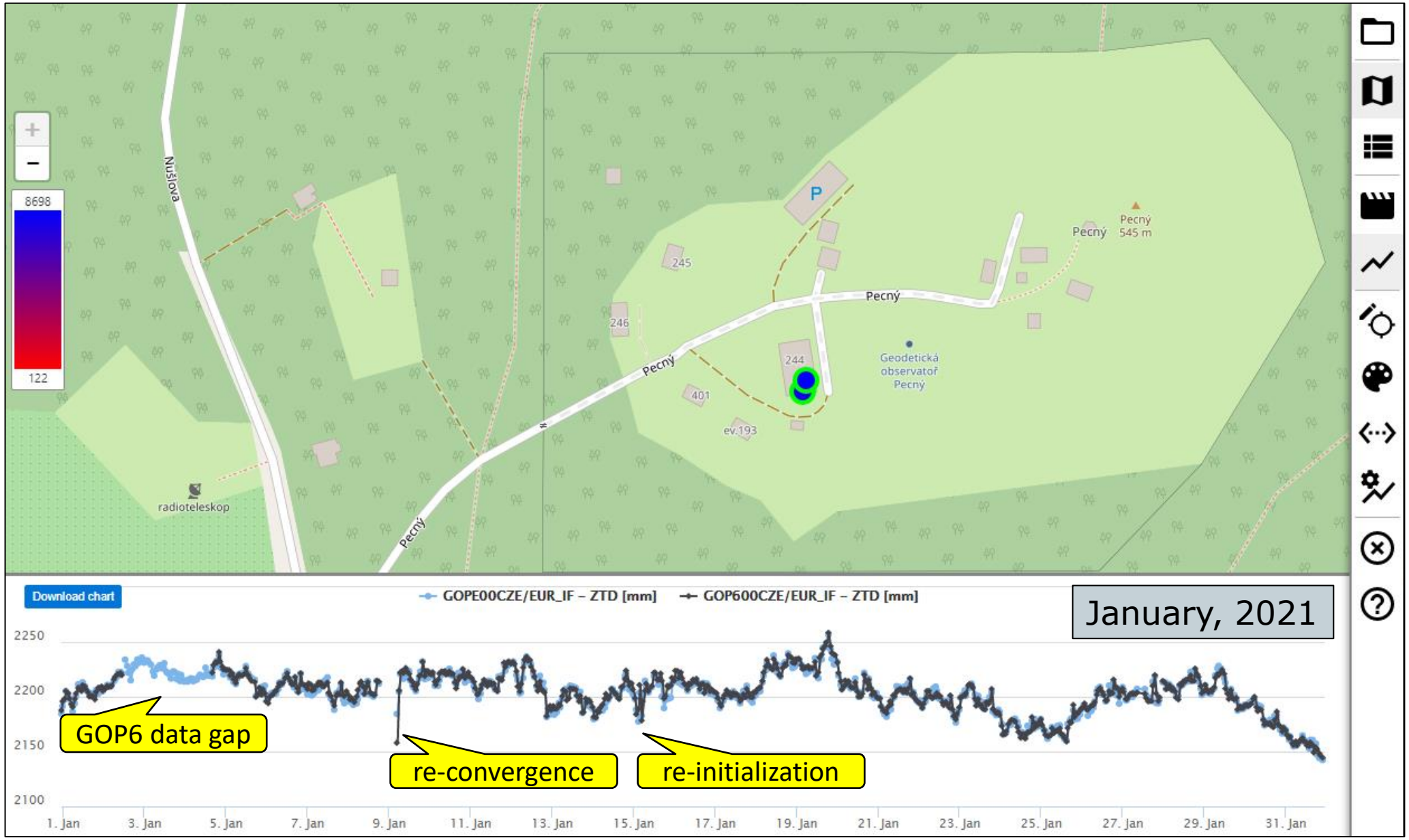
Software: G-Nut/Tefnut-RT (real-time)
Method: Precise Point Positioning (PPP)
Observations: ionosphere-free linear combination (IF)
Input products: RT precise orbits/clocks (IGS or CNES)
Supported systems: GPS (+GLONASS +Galileo +BeiDou)
Stations: 200+ European/global stations (no upper limit)
Site coordinates: estimated simultaneously (as static)

Troposphere parameters: ZTD & linear gradients (5 min)
Output products: 15-min files (TRO-SINEX v2 files or COST_716)





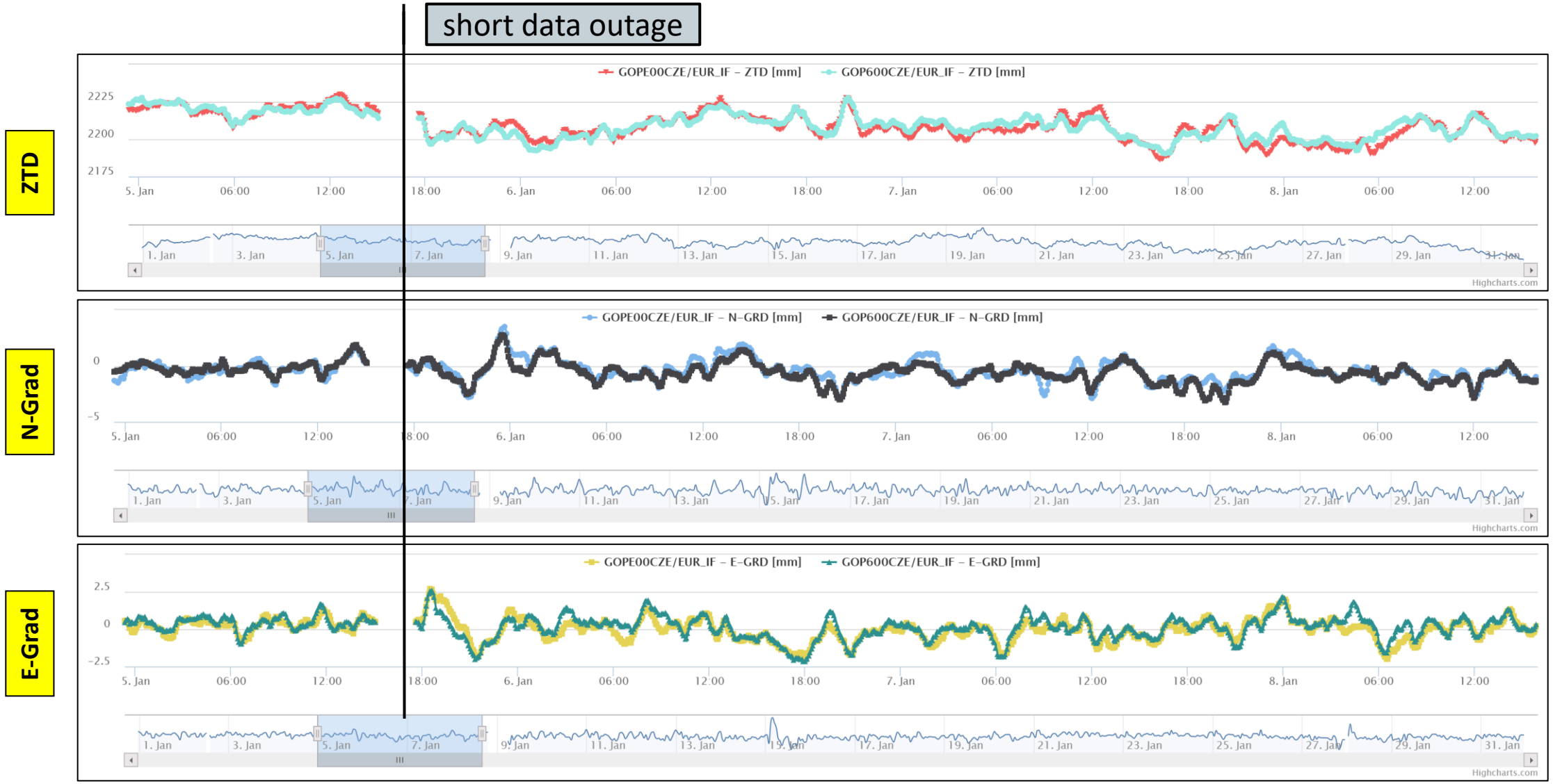
Troposphere monitoring at dual stations (GOPE:GOP6)



Research Institute of Geodesy, Topography and Cartography
Geodetic Observatory Pecný

ZTD & horizontal gradients at dual-stations (GOPE)

- time-series of ZTD + horizontal gradients – a zoom window (January 5-9, 2021)



Collocated stations

Validation:

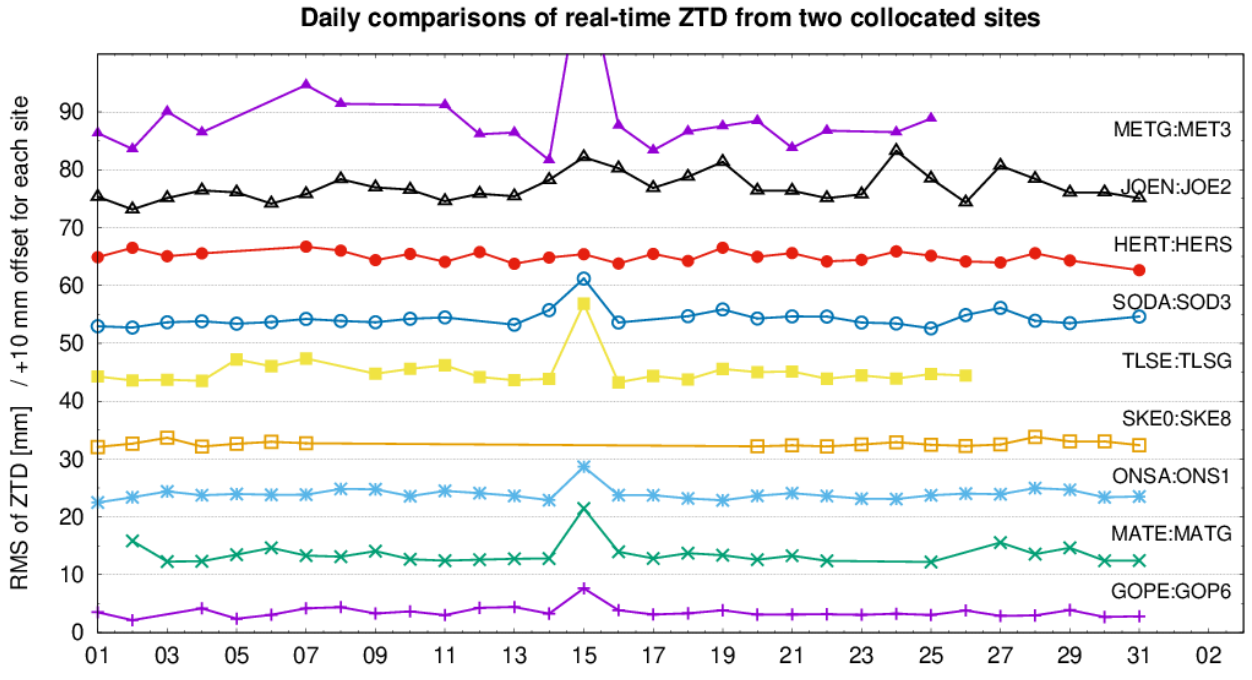
- 9 selected dual stations
- common epochs (5 min)
- GOP real-time (PPP)
- GPS only, iono-free LC

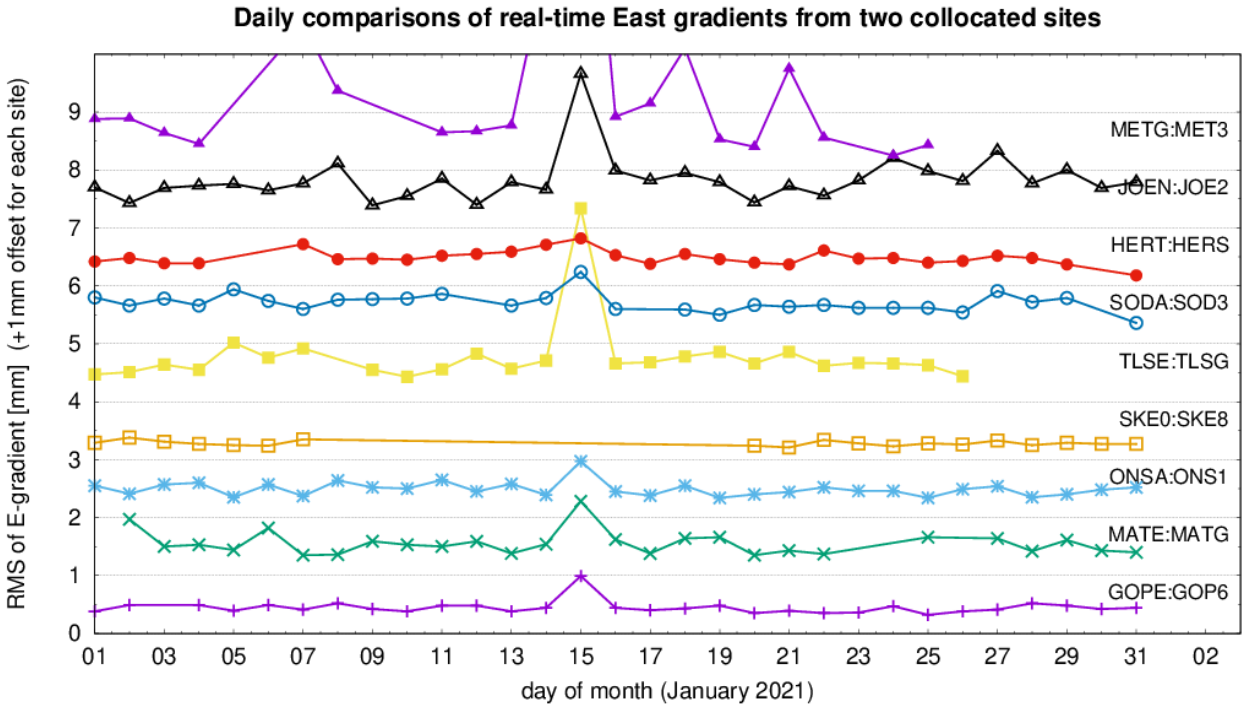
Statistics:

- January 2021
- daily RMS:
  - ➔ ZTD: 3-6 mm (top plot)
  - ➔ GRD: 0.5-0.8 mm (bottom plot)

Remarks:

- METG:METS (vert.diff. >20m!)
- re-initialization (January 15)





Research Institute of Geodesy, Topography and Cartography
Geodetic Observatory Pecný

Real-time ZTD vs Final ZTD

Validation:

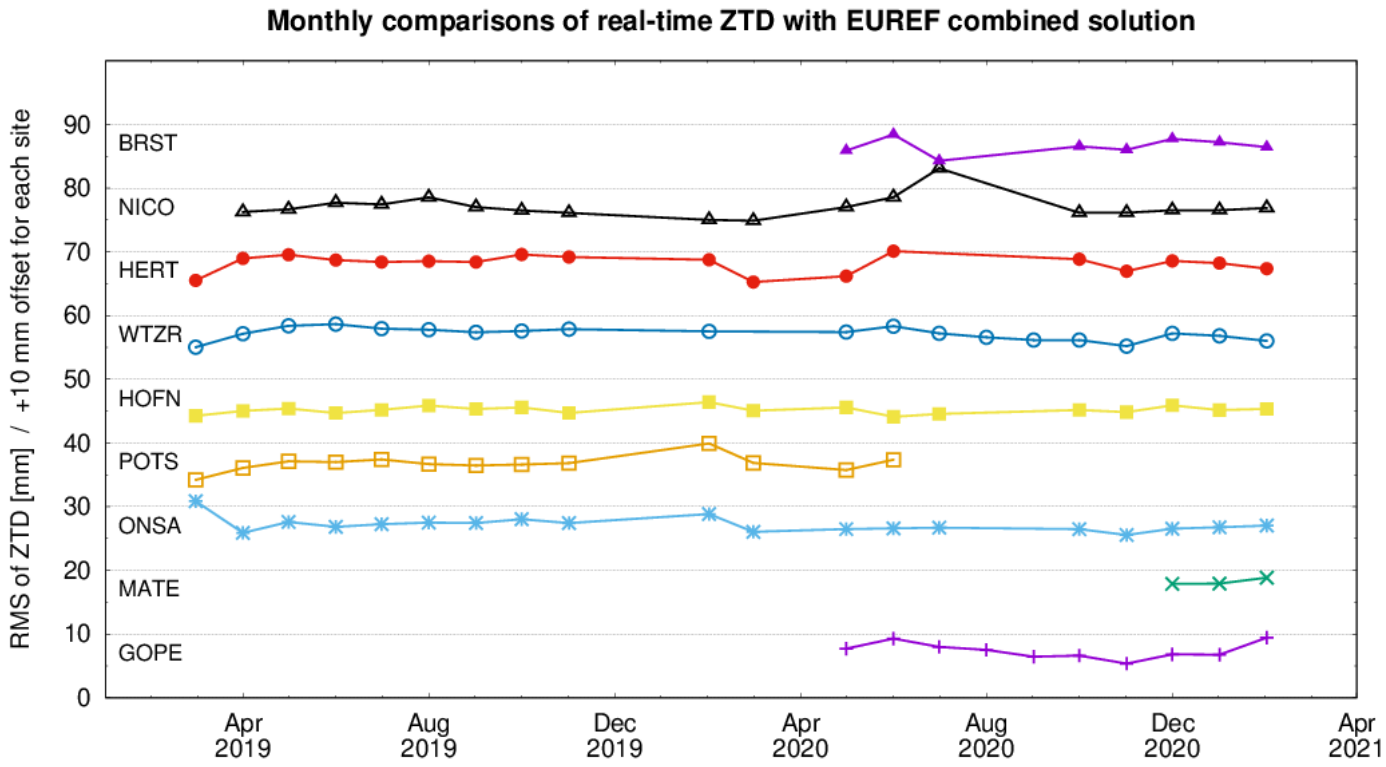
- 9 selected EUREF stations
- ZTD only (!GRD @ EUREF)
- common epochs (1 hour)
- period: 2019-2021

Solutions:

- GOP real-time (PPP)
- EUREF (final, combined)

Results:

- Figure: monthly RMS
  - ➔ ZTD: 6-10 mm
- Table: mean statistics
  - ➔ ZTD RMS: 5-8 mm



Station	Mean [mm]	Std Dev [mm]	RMS [mm]
BRST	2.58	5.95	**6.43**
NICO	3.15	6.04	**6.53**
HERT	5.42	6.02	**8.53**
WTZR	4.82	5.12	**7.20**
HOFN	2.34	4.64	**5.16**
POTS	4.28	5.08	**6.82**
ONSA	4.91	4.66	**6.76**
MATE	2.58	7.55	**7.91**
GOPE	4.14	5.43	**6.81**

Research Institute of Geodesy, Topography and Cartography
Geodetic Observatory Pecný
VUGTK

Storm Demonstrator

➔ **EUREF presentation by G. Guerova et al.**

Friday - May 28, 2021

- collaboration on developing
  a new Storm Demonstrator in Bulgaria

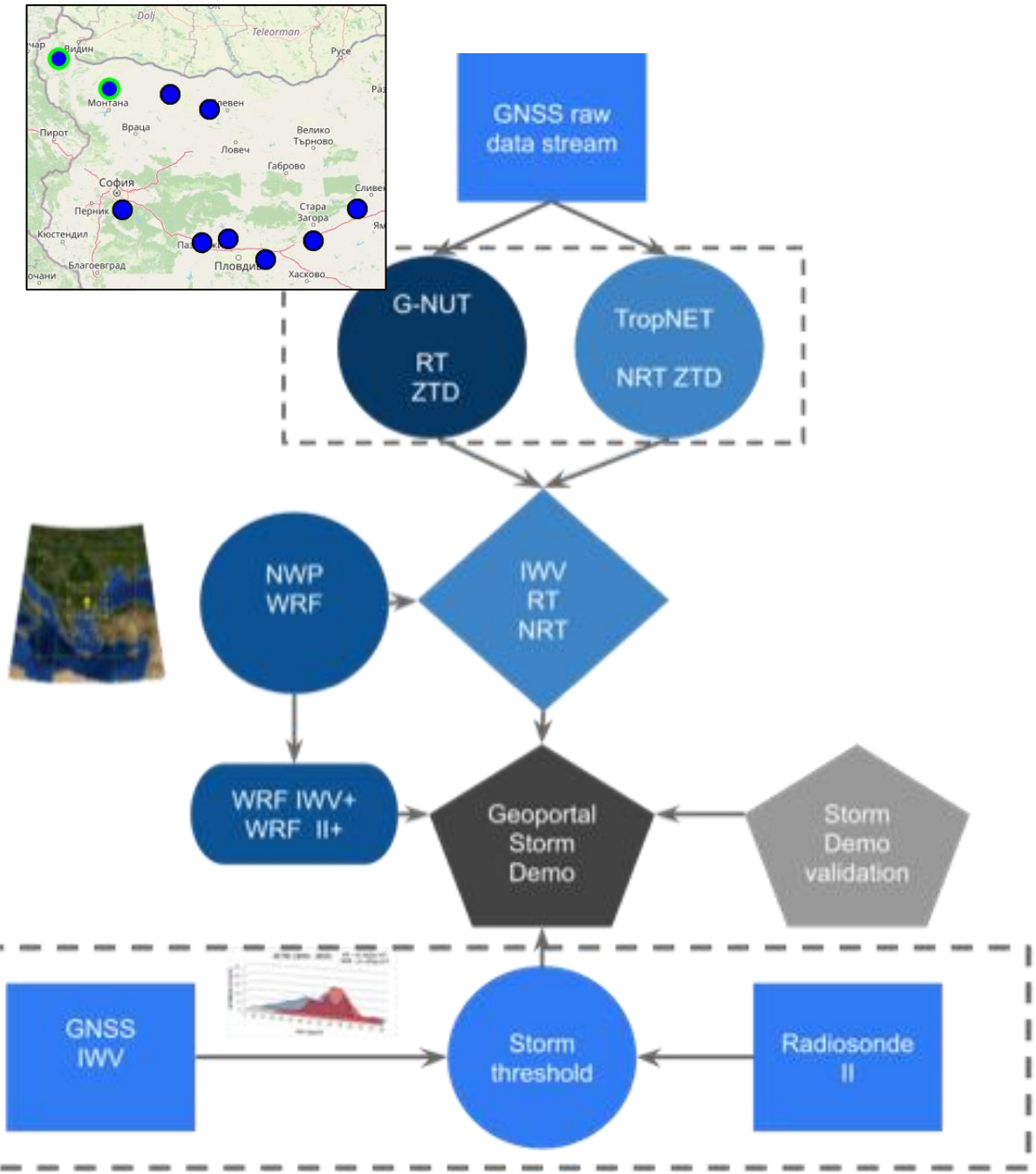
- support with two GNSS troposphere monitoring solutions:

➔ **GOP near real-time – TropNET solution:**

- 60 min ZTD production

➔ **G-Nut real-time - G-Nut/Tefnut RT:**

- 5 min (15 min) ZTD + GRD production

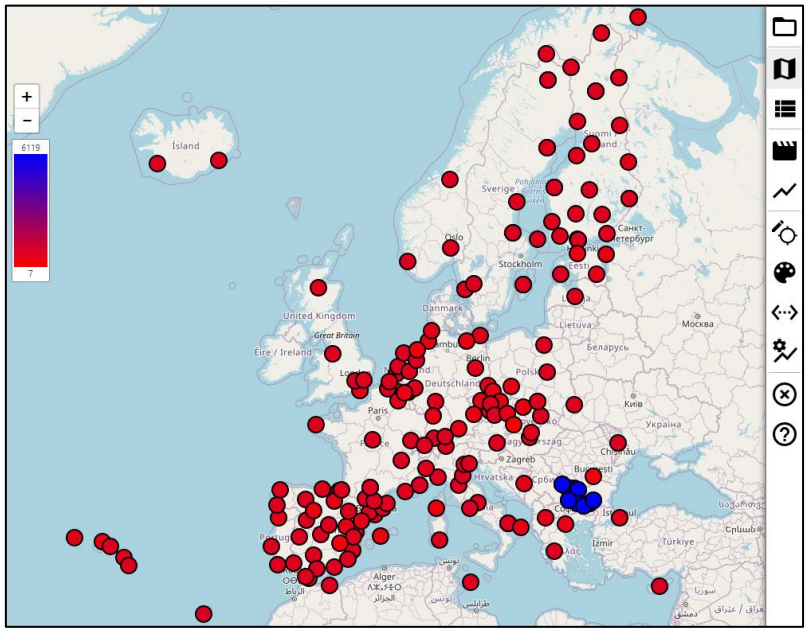


Research Institute of Geodesy, Topography and Cartography
Geodetic Observatory Pecný

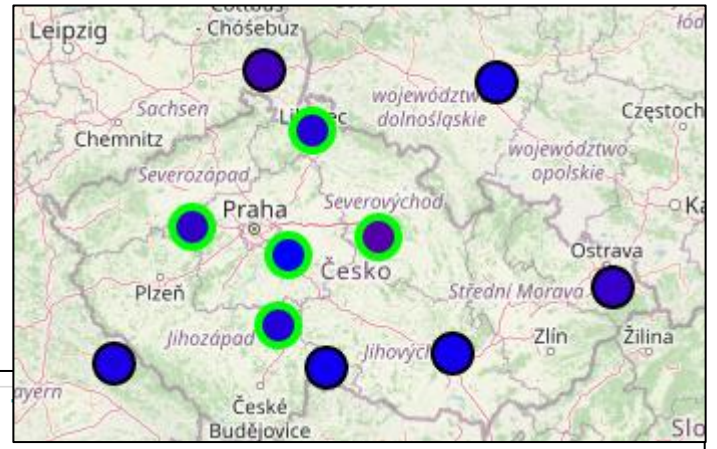
Real-time coordinate monitoring

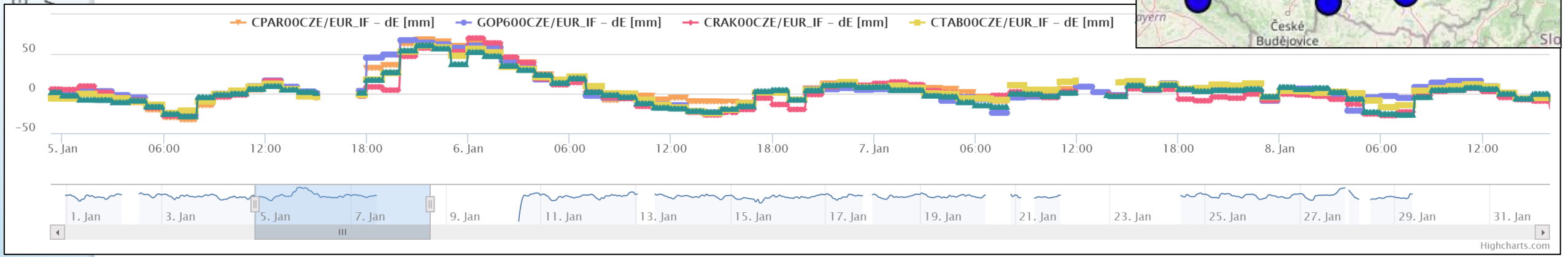
- **Site coordinates** estimated (as static) simultaneously with the tropospheric parameters

➔ stored in hourly TRO-SINEX (v2.0) output files



- Stations selected in the Czech Republic (radius <250km)
- Systematic behavior observed
  - East component dominating

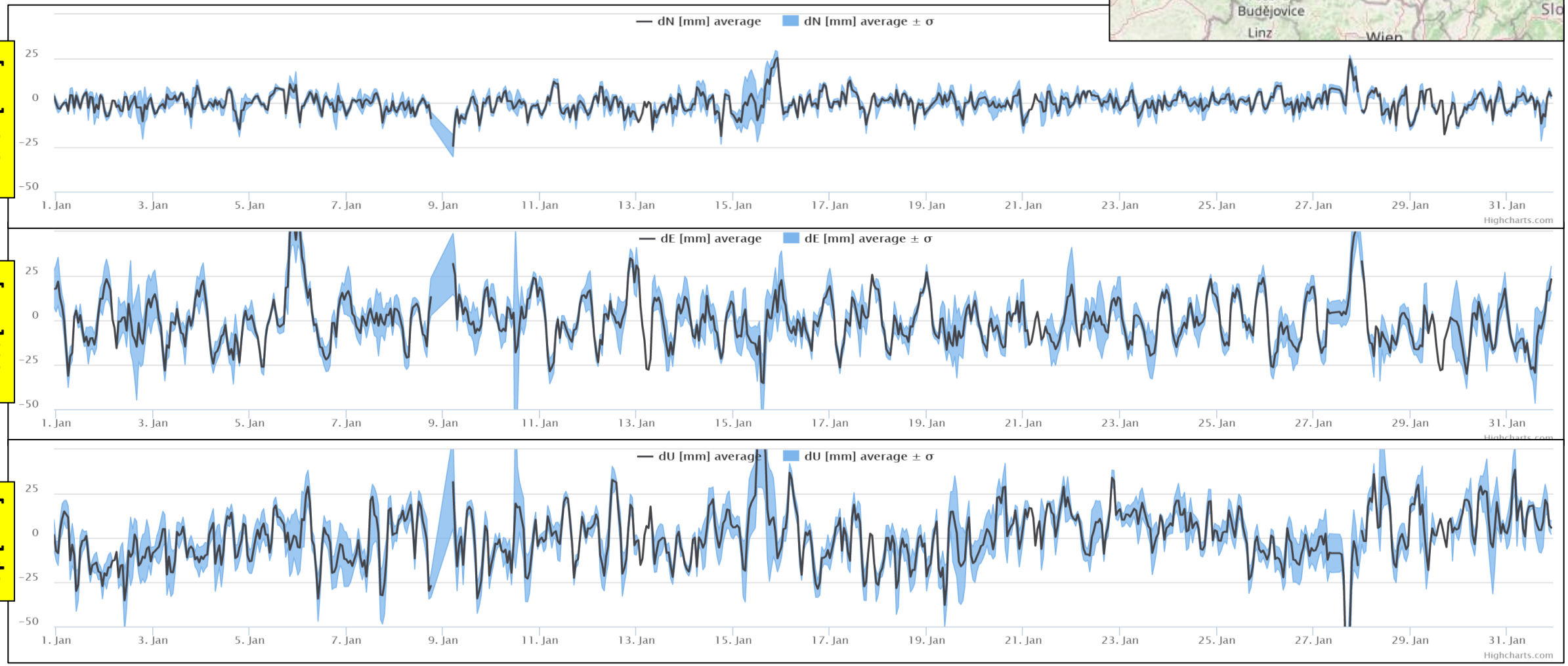




Coordinate residuals in RT PPP

- 5 stations selected in the Czech Republic (radius <250km)
- Figures below show 1-sigma envelope of NEU residuals

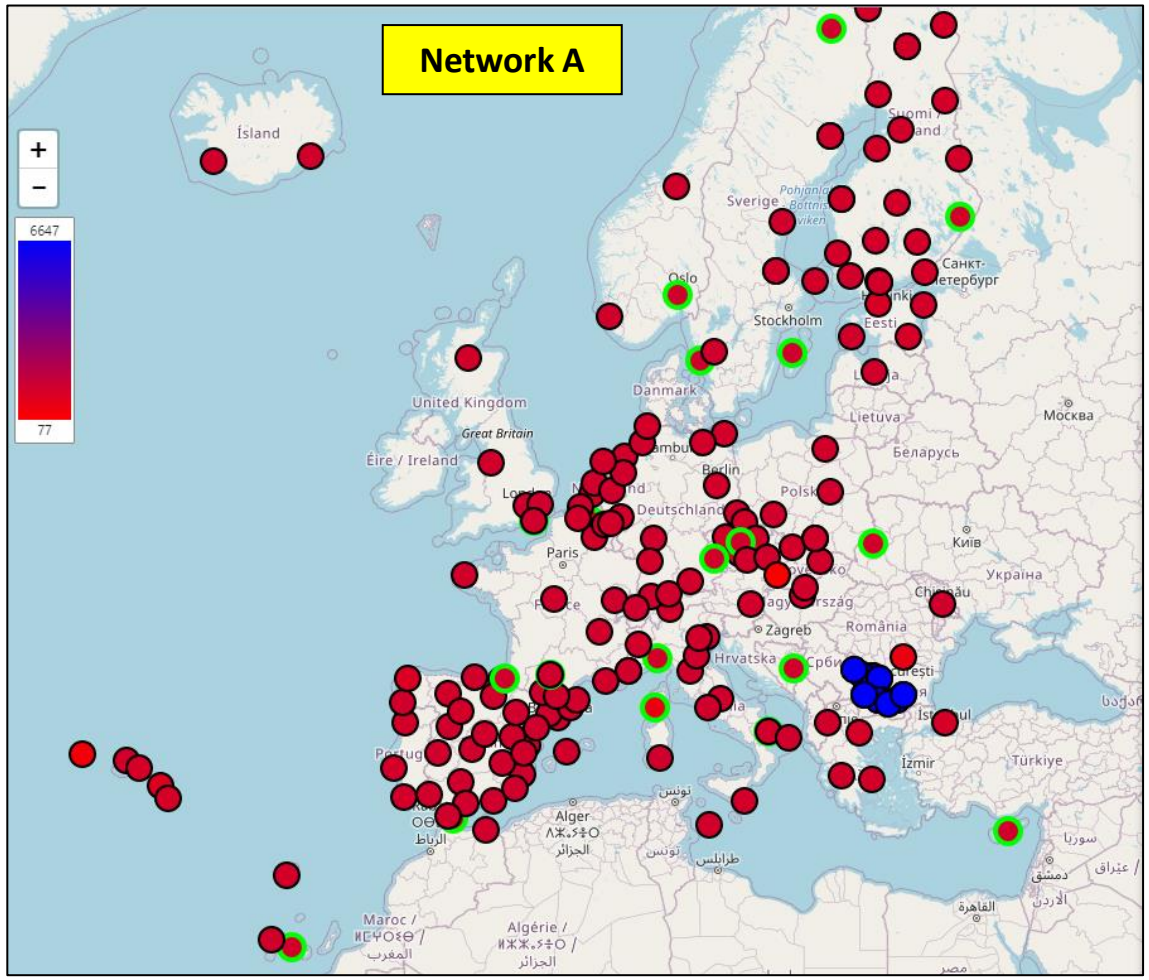
  X-range: January 2021 ; Y-range ± 25 mm

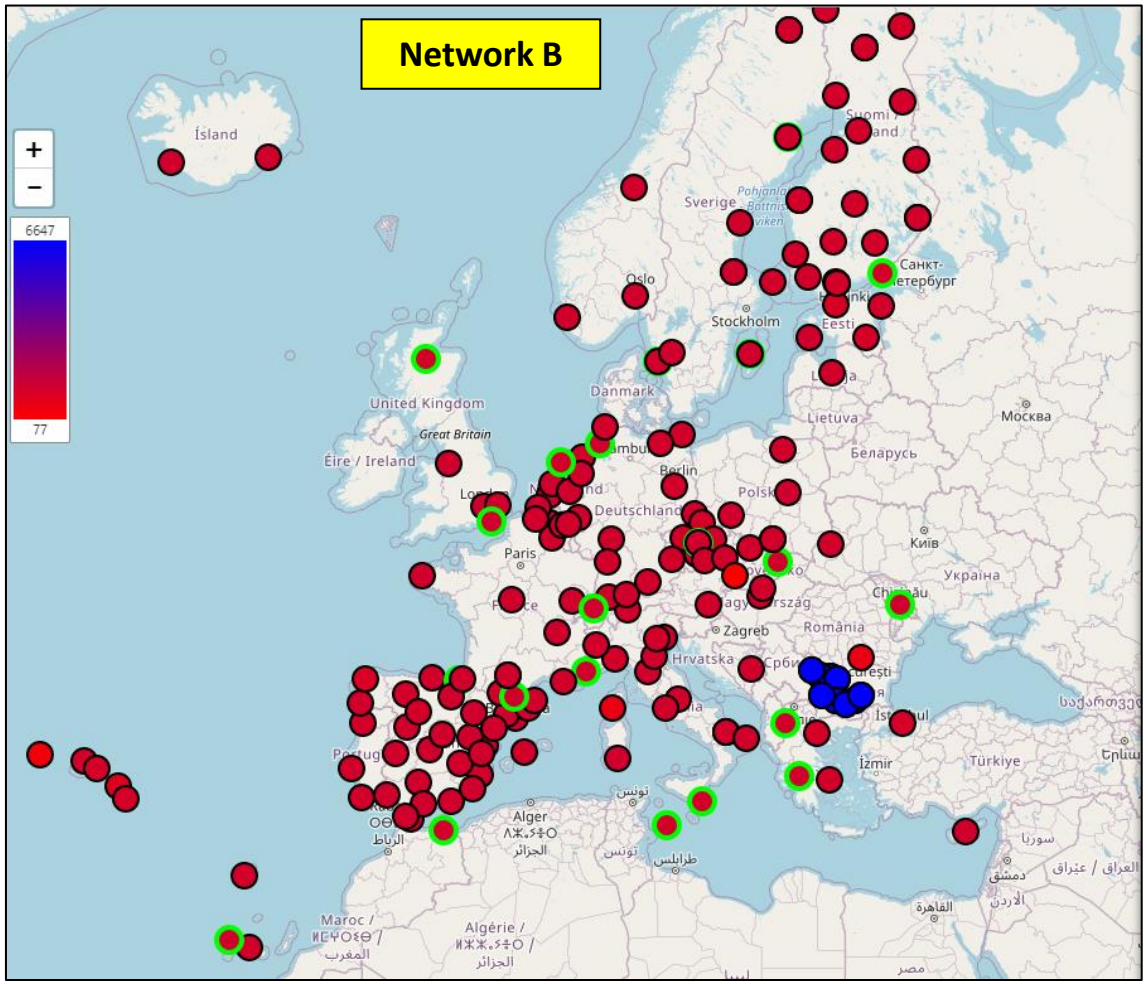


Research Institute of Geodesy, Topography and Cartography
Geodetic Observatory Pecný

Estimating transformation parameters

- EUREF stations (Class A) → Network A + Network B (two independent regional)
- IGS stations → Network Z (global)
- Helmert transformation → local & global → TRA, ROT, SCL parameters (and their combinations)



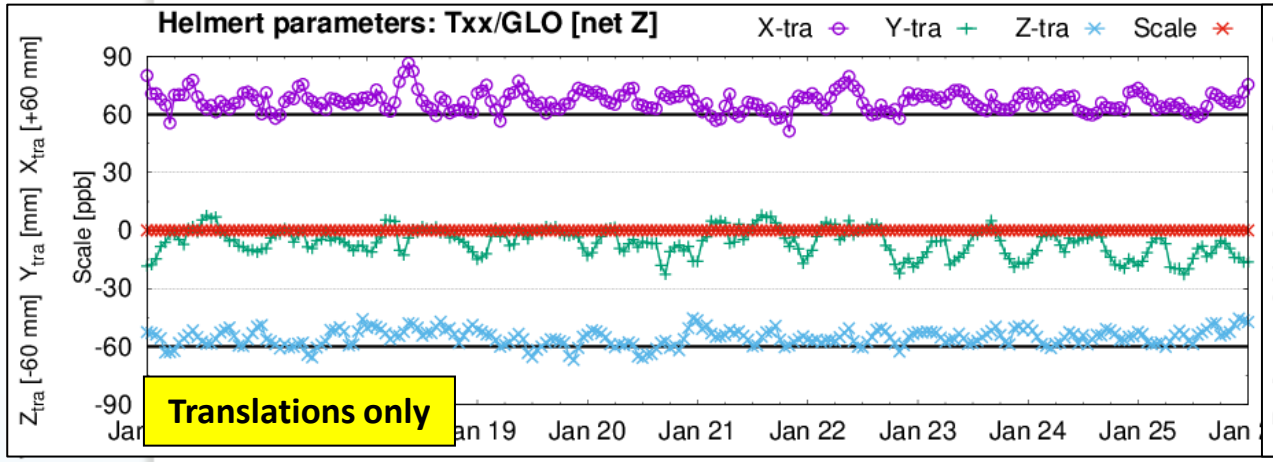


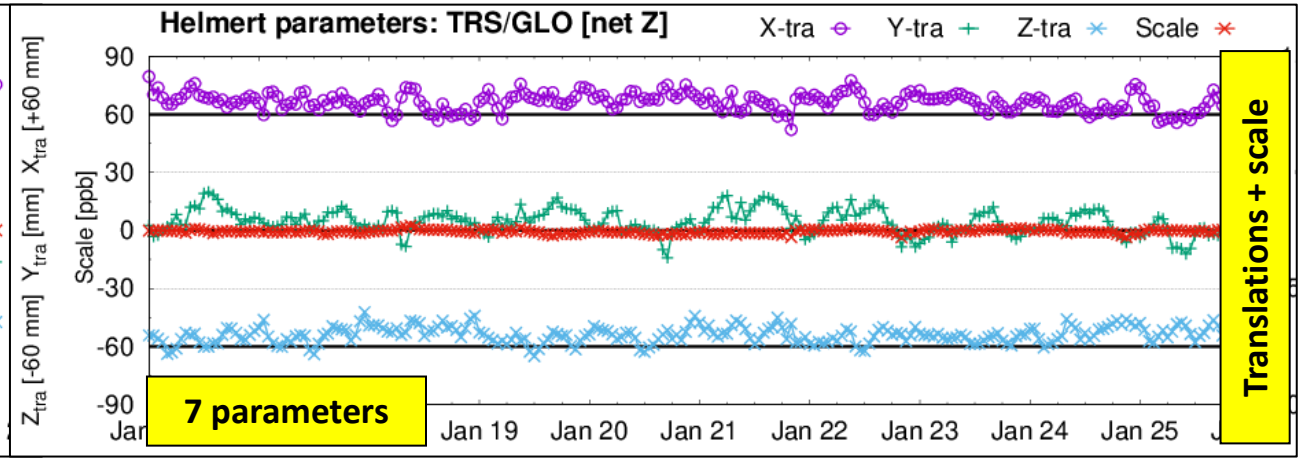
Research Institute of Geodesy, Topography and Cartography
Geodetic Observatory Pecný
VUGTK

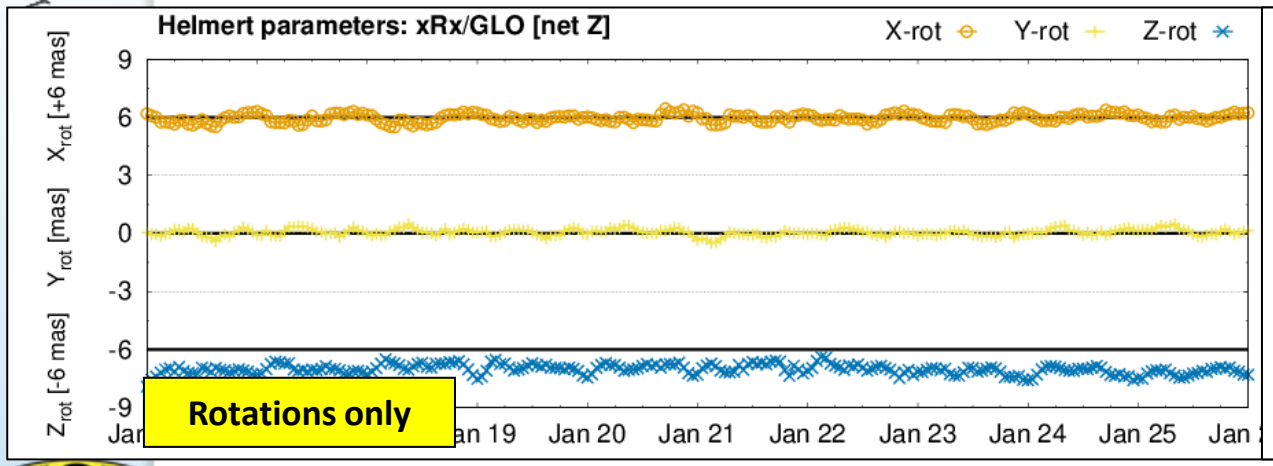
GLOBAL Helmert parameters / global (IGS)

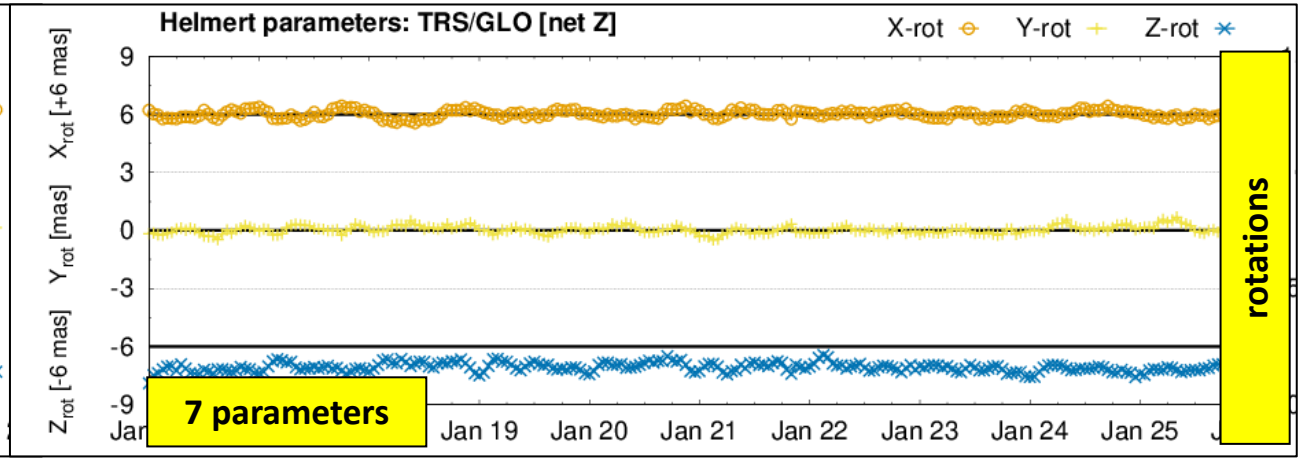
GLOBAL Helmert parameters estimated:

- translations (Txx), rotations (xRx) and scale (xxS) / **left**, or their combinations, e.g. all (TRS) / **right**
- hourly GOP real-time solutions vs **IGS cumulative combined solution**





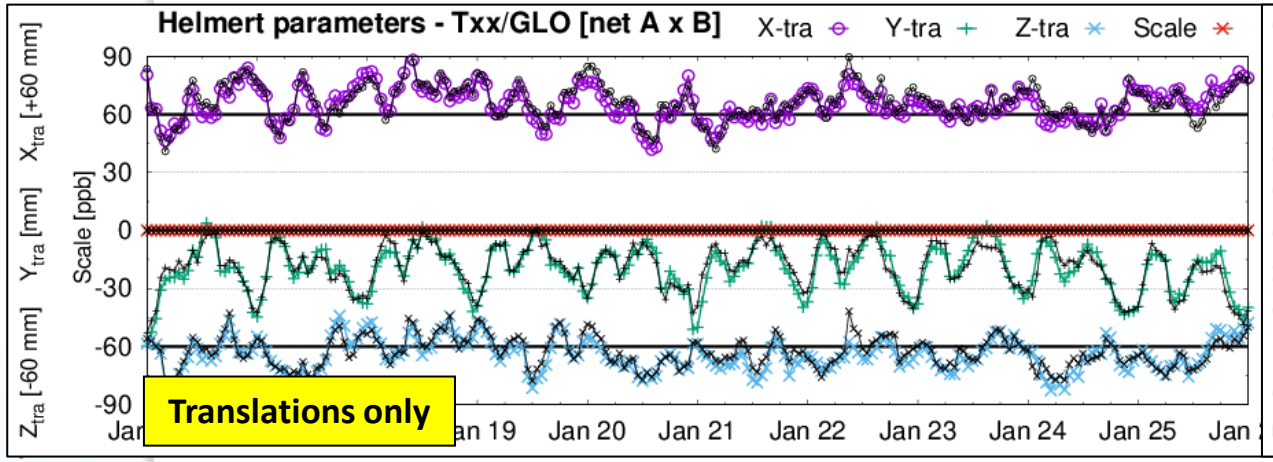


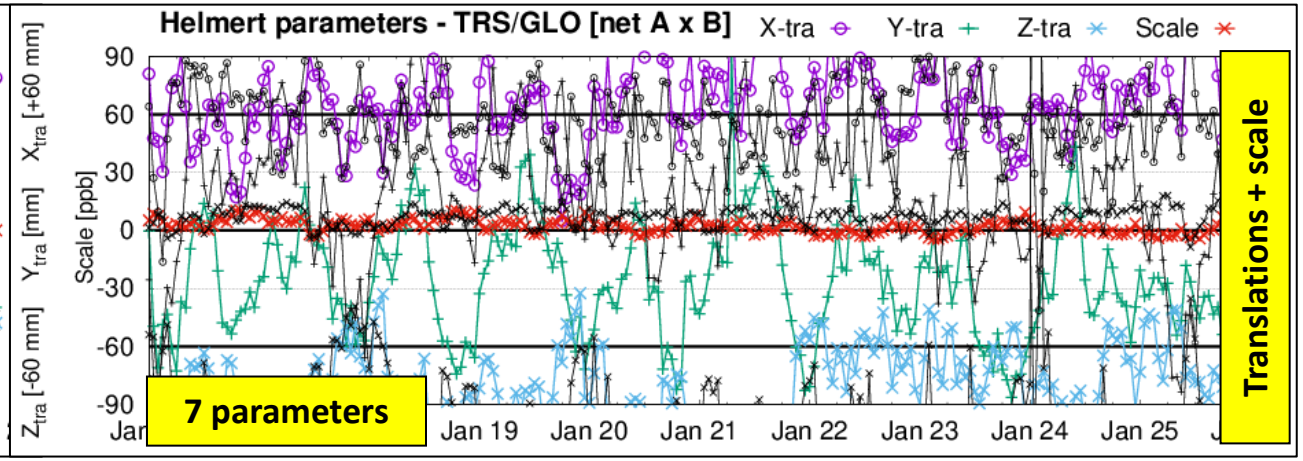


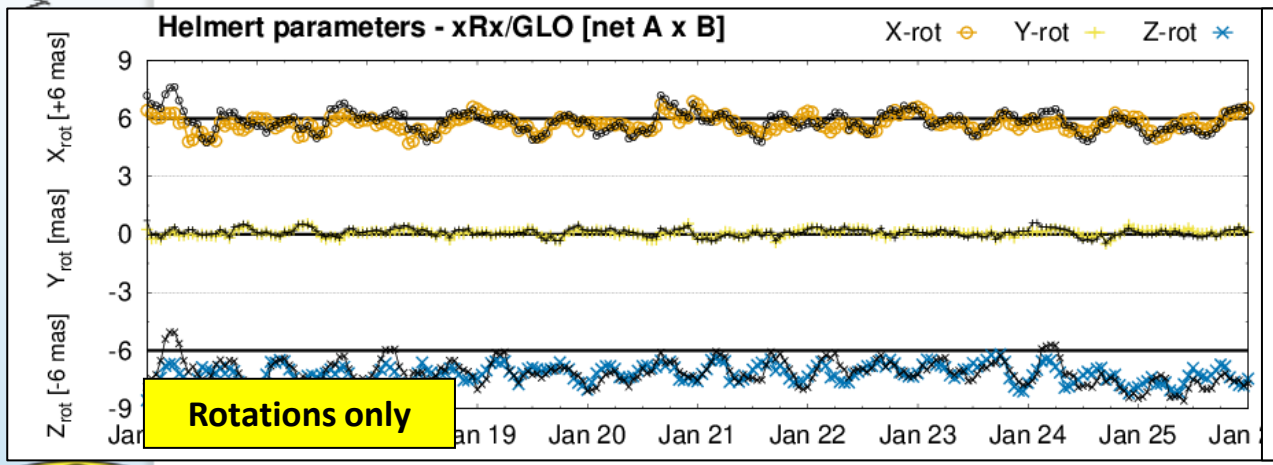
GLOBAL Helmert parameters / regional (EUREF)

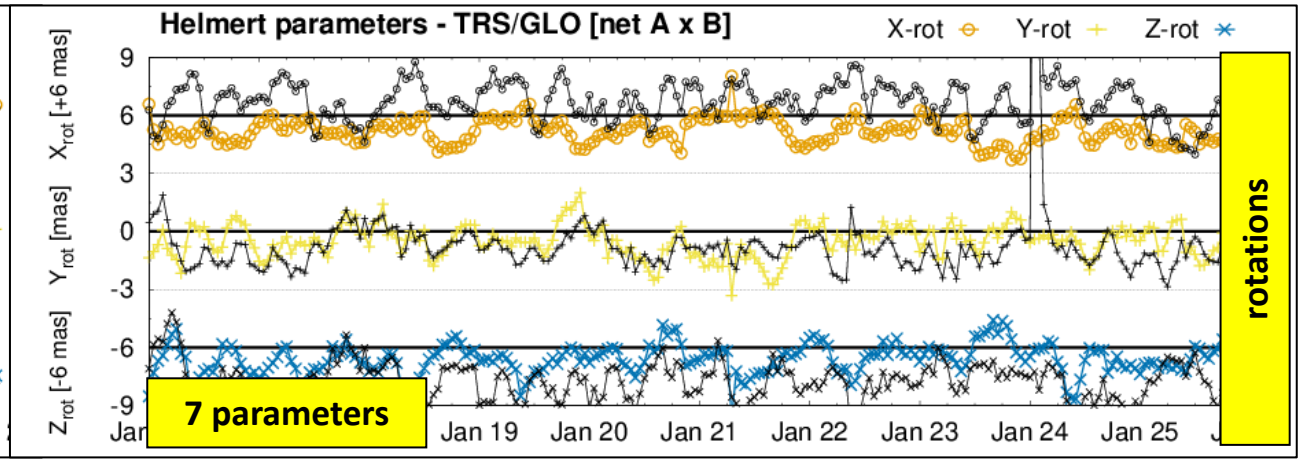
GLOBAL Helmert parameters estimated:

- translations (Txx), rotations (xRx) and scale (xxS) / **left**, or their combinations, e.g. all (TRS) / **right**
- hourly GOP real-time solutions vs **EUREF cumulative combined solution**





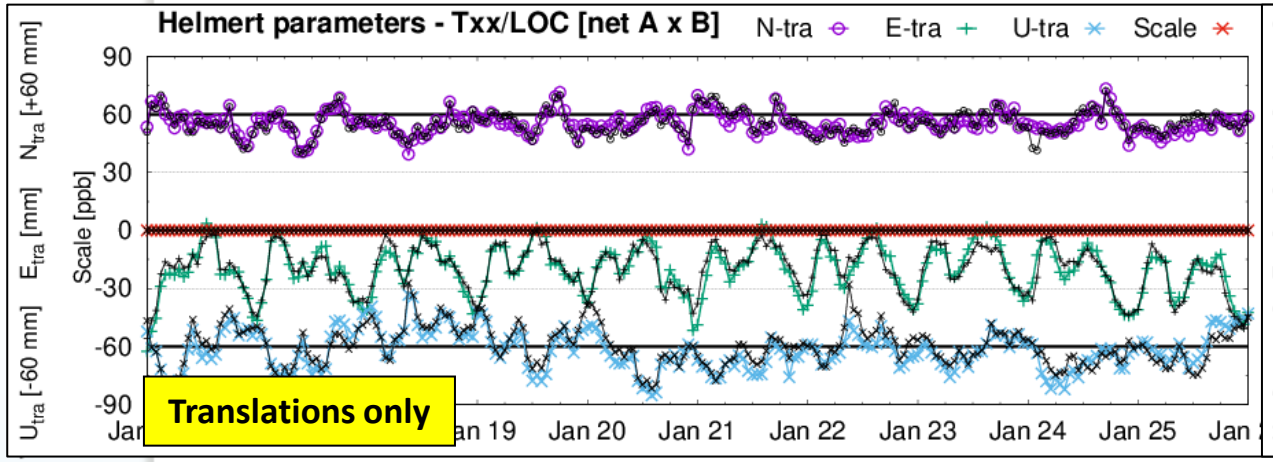


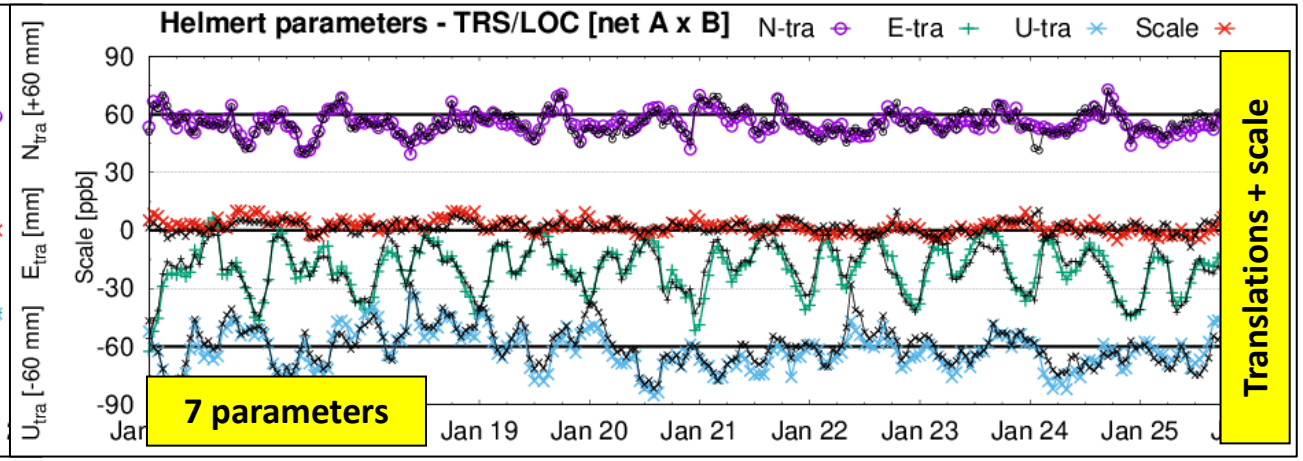


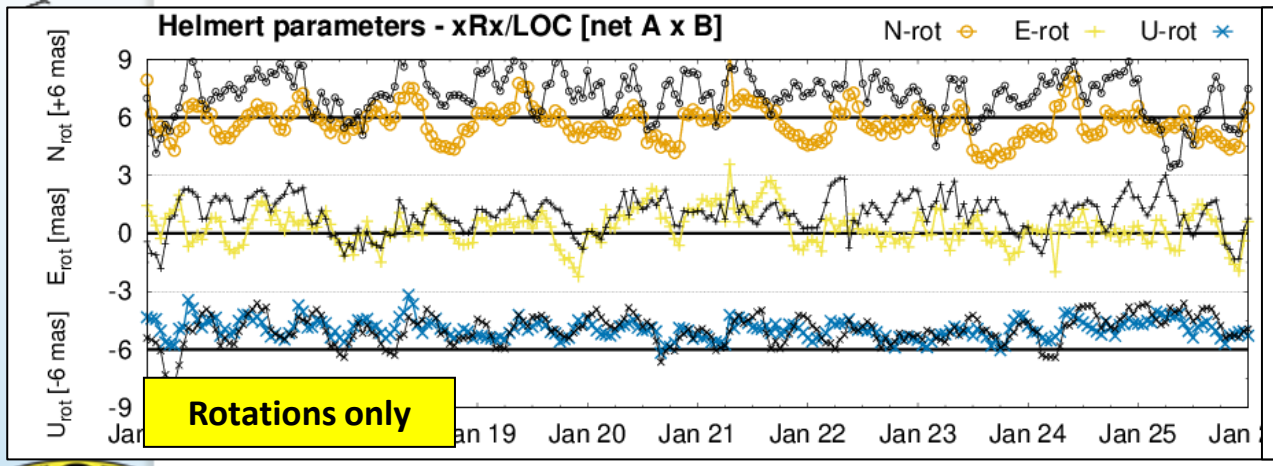
LOCAL Helmert parameters / regional (EUREF)

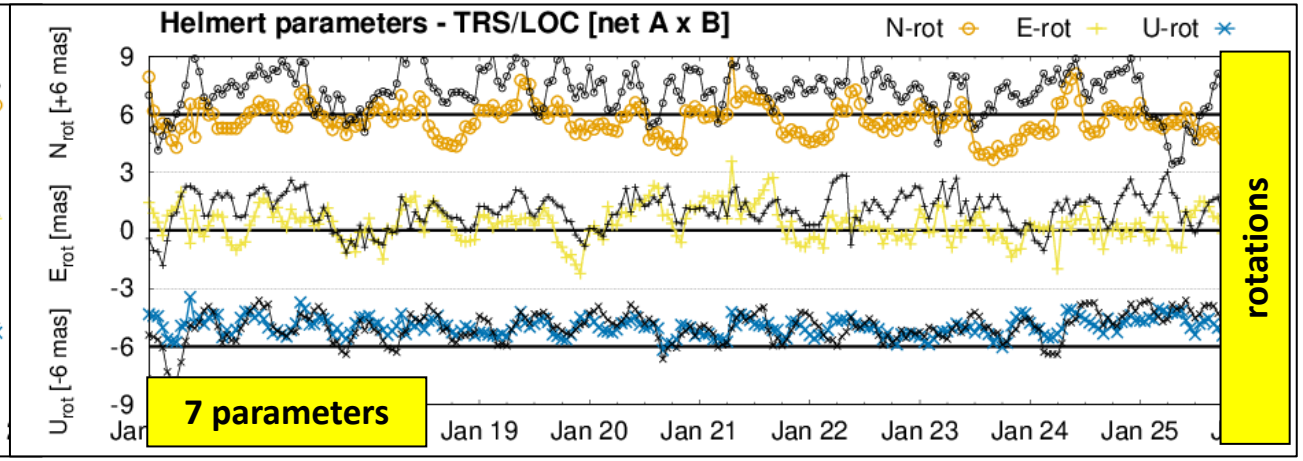
LOCAL Helmert parameters estimated:

- translations (Txx), rotations (xRx) and scale (xxS) / **left**, or their combinations, e.g. all (TRS) / **right**
- hourly GOP real-time solutions vs **EUREF cumulative combined solution**





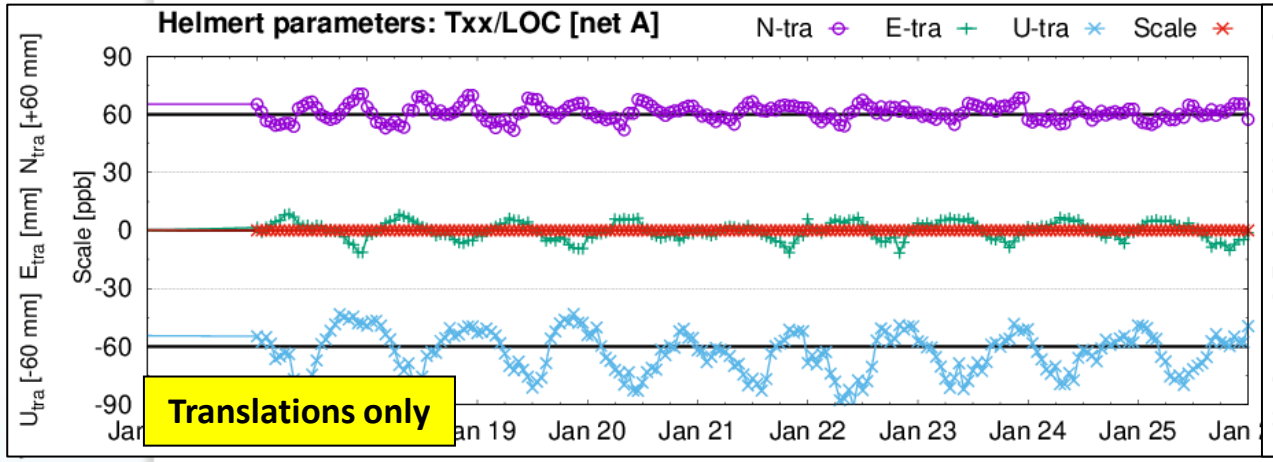


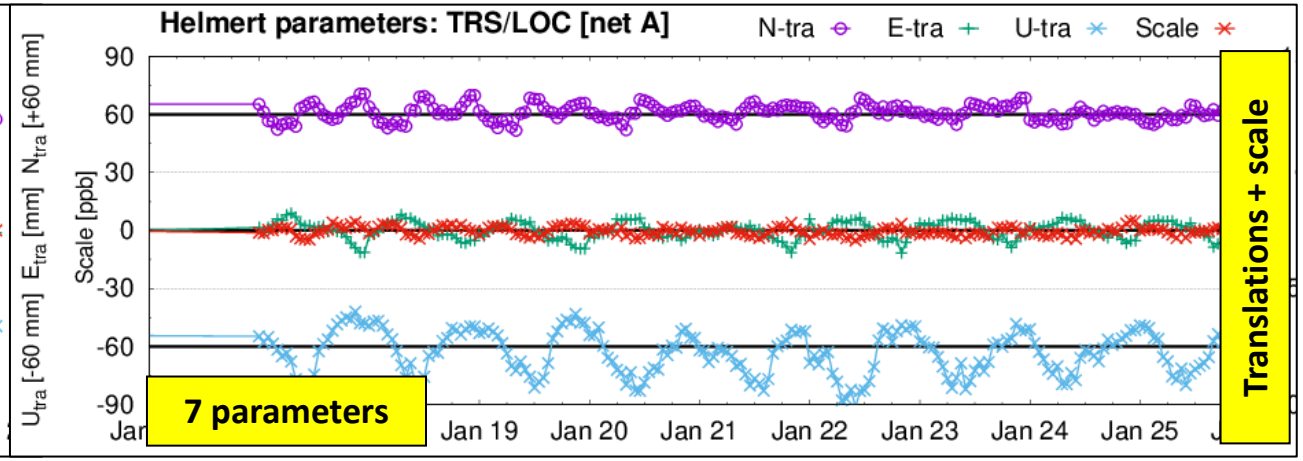


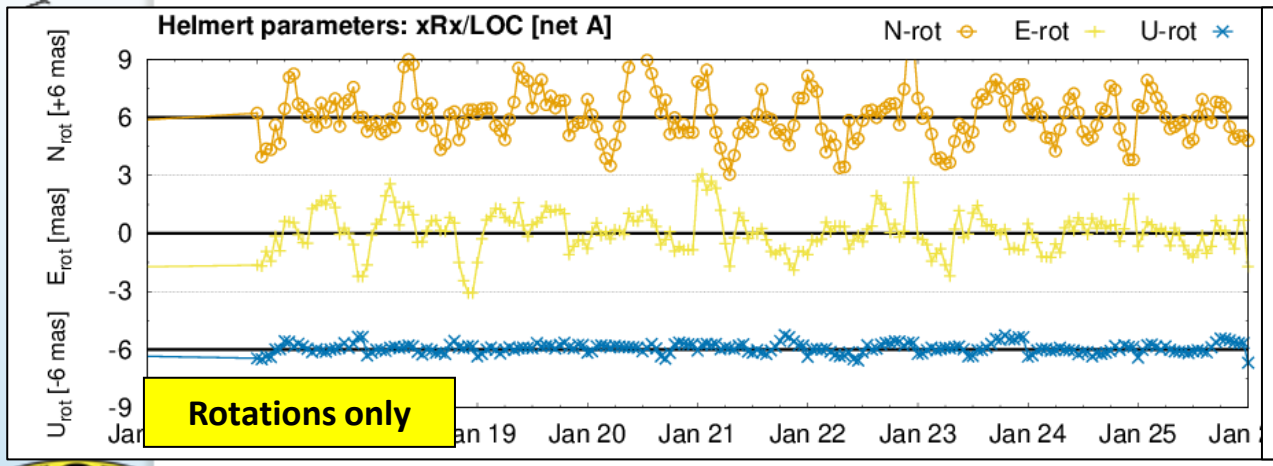
LOCAL Helmert parameters / regional (EUREF)

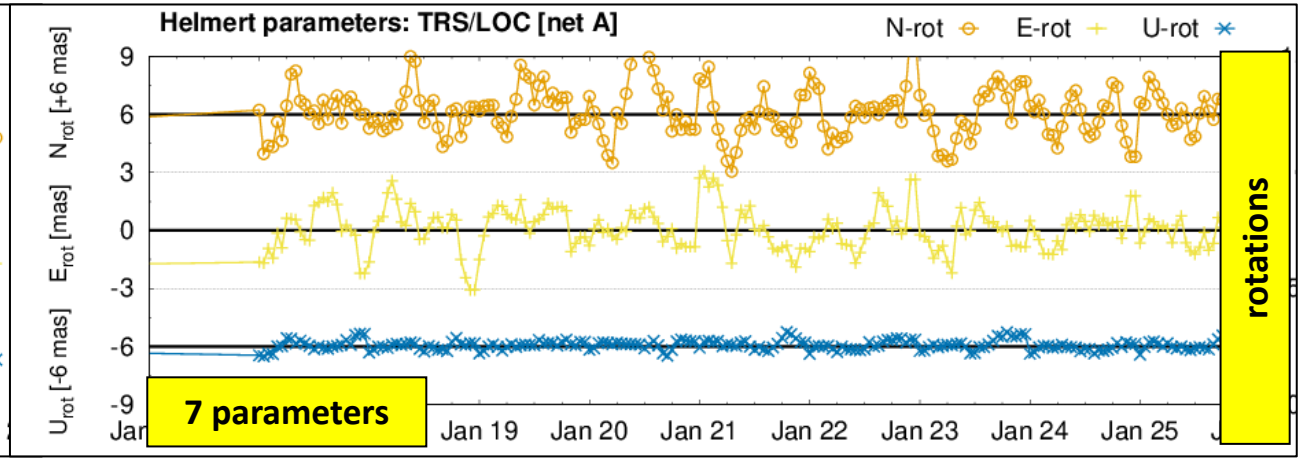
LOCAL Helmert parameters estimated:

- translations (Txx), rotations (xRx) and scale (xxS) / **left**, or their combinations, e.g. all (TRS) / **right**
- hourly GOP **post-processing** solutions vs **EUREF cumulative combined solution**





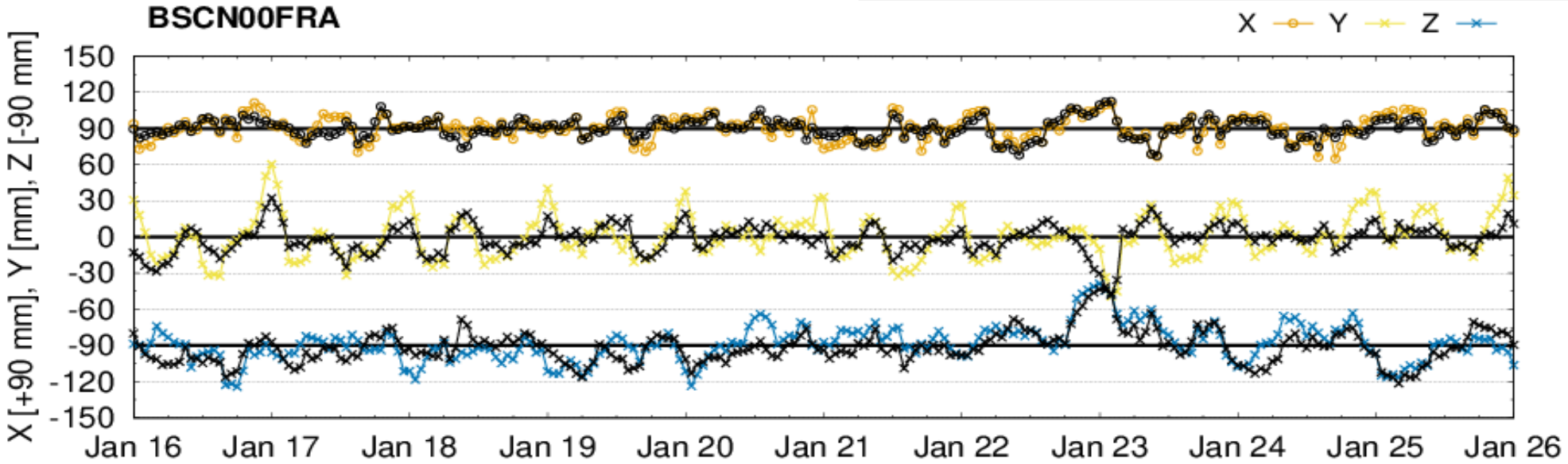




RT coordinates improved by Helmert parameters

- Helmert parameters (3, 4, 7) can be estimated from several stations in region
- estimated parameters can be disseminated and applied to other stations targeting precise coordinates (e.g. kinematic mode)
- A current improvement could reach up to 40%

station	Coordinate RMS without Helmert	Coordinate RMS with Helmert	Coordinate RMS Improvement
GOPE00CZE	29 mm	18 mm	38 %
MARS00FRA	29 mm	27 mm	7 %
KRAW00POL	26 mm	21 mm	19 %
GRAZ00AUT	25 mm	16 mm	36 %
BUTE00HUN	25 mm	19 mm	24 %
EISJ00NLD	28 mm	16 mm	43 %
BSCN00FRA	27 mm	19 mm	30 %
ACOR00ESP	28 mm	23 mm	18 %



Research Institute of Geodesy, Topography and Cartography
Geodetic Observatory Pecný

Conclusion

- Real-time PPP ZTDs + horizontal gradients estimated continuously since 2013/2015:
  - The quality of real-time (RT) product (ZTD+GRD) is now close to 'traditional' near real-time (NRT)

➔ Recently, the GOP solution has been extended to a global & pan-European scope

➔ Stable solution, ready to upload files routinely to the E-GVAP on hourly or 5-min basis

➔ Real-time troposphere to supports Bulgarian project for developing Storm Demonstrator

➔ Any further interest on collaborating on real-time troposphere products is welcome

- Station coordinates from the RT PPP monitored recently:
  - Helmert parameters (GLOBAL/LOCAL) can be estimated every hour (in NRT) from cumulative coordinates from reference stations of EUREF (class A) or IGS (global) networks
  - Helmert parameters may be disseminated to users to reduce systematic errors from in products (improvements can reach 20-40 % for stations in Europe):

➔ Global Helmert vs IGS – 3 rotations (+scale)

➔ Global Helmert vs EUREF – 3 translations (+scale)

➔ Local Helmert vs EUREF – 3 translations (+scale)

Research Institute of Geodesy, Topography and Cartography
Geodetic Observatory Pecný
VUGTK

Research Institute of Geodesy, Topography and Cartography
Geodetic Observatory Pecný

Thank you for attention

Acknowledgments:

- **IGS** for providing real-time orbit and clock products and precise models
- **CNES** for providing real-time orbit and clock products
- **EUREF, EPN, and agencies** providing GNSS data in real-time streams

Contact: *jan.dousa@pecny.cz*