On the Impact of Local- and Tropospheric Ties for the Rigorous Combination of GNSS & VLBI

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Motivation: Rigorous Combination of Space Geodetic Techniques

A **consistent** estimation of the TRF is required to achieve higher precision levels.

Typically, **local ties** are used to realise this combination.

Highly accurate **tropospheric-** and clock- **ties** as alternative ways to link techniques.

Goal: GNSS and VLBI joint processing (**observation level**), and investigations on the impact that **terrestrial and tropospheric ties** have on the precision.

	GNSS	VLBI	SLR	
Space				
Satellite Orbits	🟩	🟨	🟩	Space Tie
Quasar Positions	⬜	🟩	⬜	
EOP				
Polar Motion	🟩	🟩	🟩	
dUT1	⬜	🟩	⬜	Consistent EOP
LoD	🟩	🟩	🟩	
Nutation	⬜	🟩	⬜	
Atmosphere				
Troposphere	🟩	🟩	⬜	Tropo. Tie
Ionosphere	🟩	🟩	⬜	
Station				
Coordinates	🟩	🟩	🟩	Local Tie
Geocentre	🟩	⬜	🟩	
Clocks	🟩	🟩	🟩	Clock Tie
Datum	🟨	🟨	🟨	
Gravity Field				
Coefficients	🟩	⬜	🟩	

Characteristics & Limitations of the GNSS-VLBI Joint Processing

Modelling and a-priori information

Troposphere	6-hourly ECMWF-based hydrostatic troposphere delays mapped with VMF
Solid Earth tides	IERS 2010 conventions
Permanent tide	Conventional tide free
Ocean tide model	FES2004
Ocean loading	Tidal: FES2004, computed with the free ocean tide loading provider
	Non-tidal: 6-hourly GRACE AOD1B atmospheric and oceanic de-aliasing product
Source catalogue	ICRF3
Observations	RINEX – NGS Cards
Processing approach	LSE. SD. DD. PP + AR
Datum definition	NNT/NNR – Constrained – Free Network – Fixed
Earth rotation	Offset and Drift – Piecewise linear functions
Troposphere	Piecewise linear functions, with several mapping functions
Receiver clock	Offset and Drift – Piecewise linear functions
Satellite orbits	Dynamic modelling
Antenna	Axes offset. No thermal deformation
Inter-technique Weight	Based on Repeatabilities, and for NEQ

Available Dataset and Data Processing

CONT17 campaign:

- 28.11.2017 – 12.12.2017
- 28 Legacy S/X Stations
- + 180 GNSS stations (IGS Network)

Estimated parameters (daily solutions):

- Daily station coordinates (NNR–NNT)
- Daily Earth orientation parameters (EOP)
- Zenith tropospheric delays (1 h) + Gradients (24 h)
- VLBI clock offsets (3 h)
- Geocentre coordinates (GCC)
- GNSS orbits
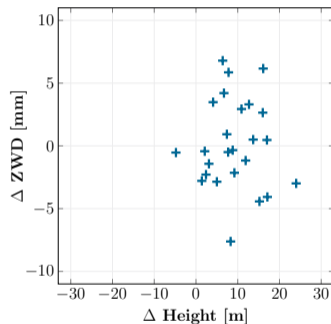
Combined solutions (15-day rigorous combination):

- GNSS + VLBI + Terrestrial ties + Tropospheric ties
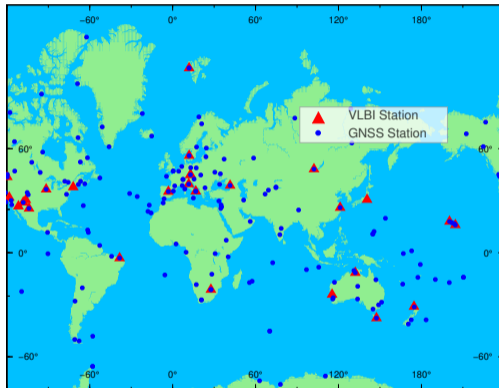
Behaviour of Troposphere Estimates

- In general: ZTD mean values within ± 10 mm (excluding Fort Davis)
- ZWD not correlated with height difference (FD-VLBI – MOD1: ≈ 7 mm)

Mean ZWD Differences: VLBI-GNSS

Determination of the Optimal Weighting of the Combination

Quadratic mean repeatability: $r^2 = \dfrac{r_e^2 + r_n^2 + r_u^2}{3}$

Relative weighting: $w_{r_{ij}} = \dfrac{r_i^2}{r_j^2}$

Main diagonal elements of the NEQ : $\overline{N} = \frac{1}{n_{crd}} \sum_{i=1}^{n_{crd}} N_{ii}$

Weighting a technique j w.r.t. the technique i: $w_{ij} = \dfrac{\overline{N}_i}{\overline{N}_j} \cdot w_{r_{ij}}$

Optimal Weight: 0.276 to VLBI NEQs

σ-aposteriori [mm]
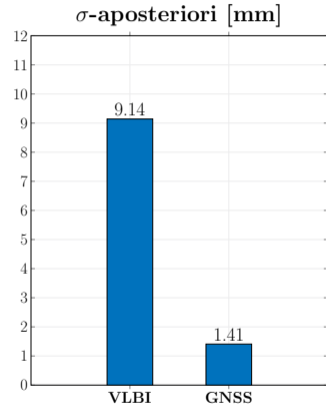
Optimal Weighting of the Combination

4 inter-technique weights: 100^{-2}, **0.276**, 1, 100^2 to **VLBI NEQs**.
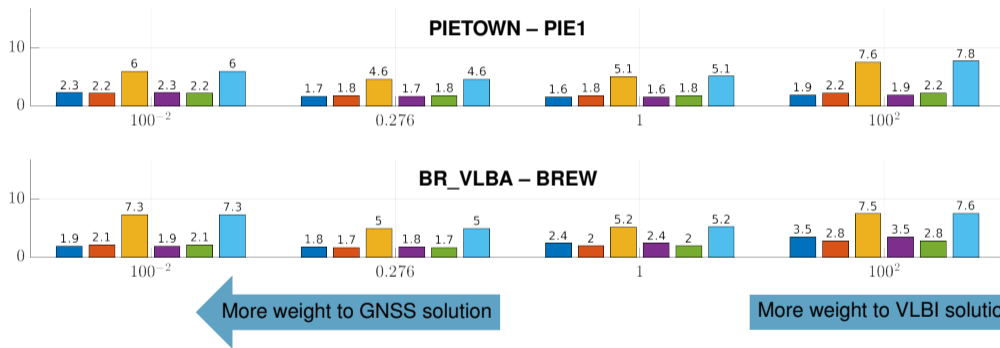
0.276 is the optimal w.r.t repeatabilities performance

Optimal Weighting of the Combination: All Repeatabilites
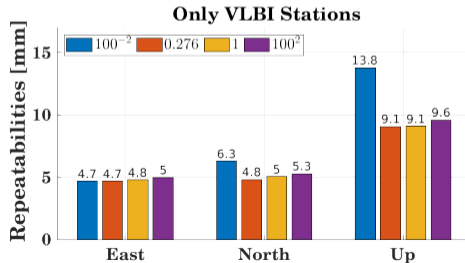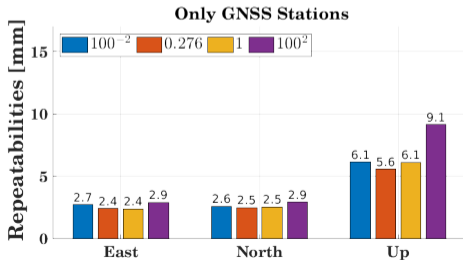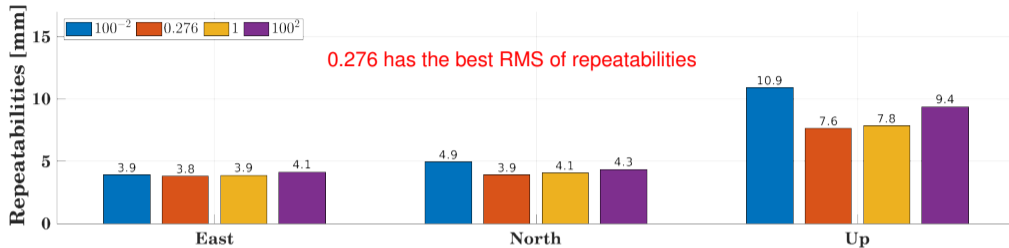
Optimal Weighting of the Combination: EOPs

RMS of Polar Motion differences to IERS C04 Series [μas]
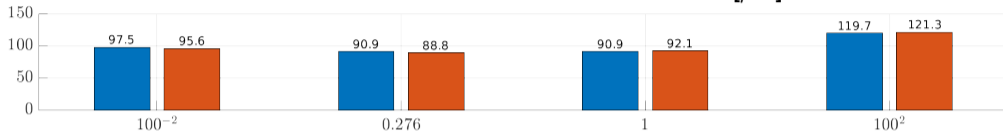
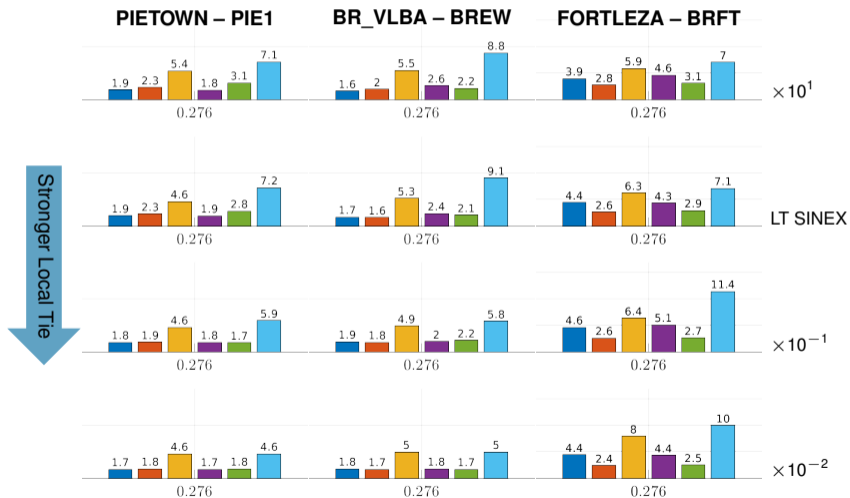**RMS of UT1-UTC and LoD differences to IERS C04 Series [μs, $\mu s/day$]**
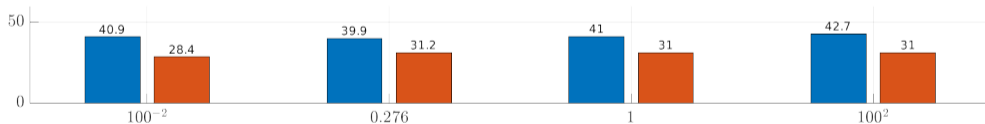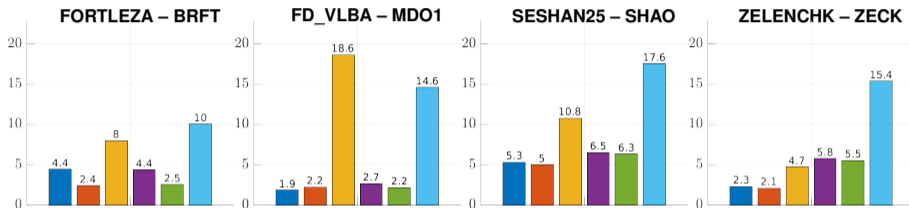
More weight to GNSS solution

More weight to VLBI solution

Constraints for the Local Ties

Repeatabilities [mm] for 4 different levels of Local Ties Constraints (based on formal errors)
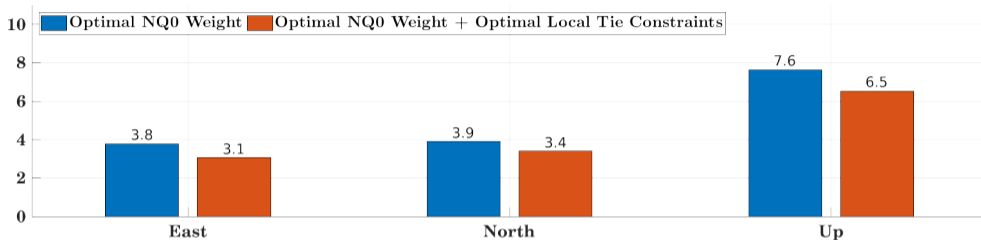
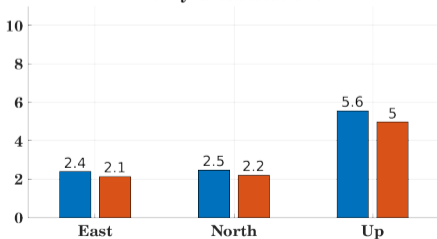# Coordinate Repeatabilities [mm]: Improvement per Station

Optimal NEQ Weight
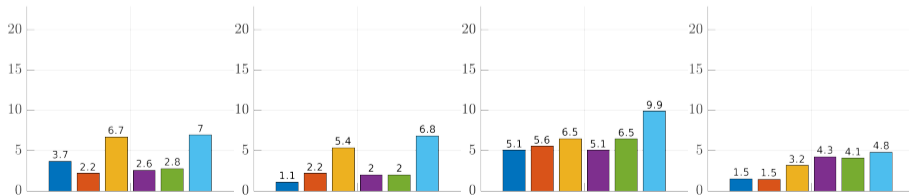
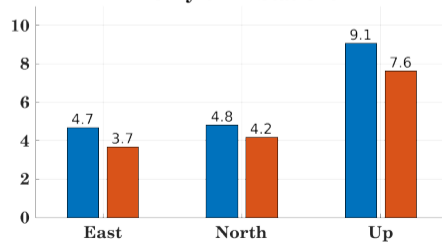Optimal NEQ Weight + Optimal Local Tie Constraints

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Coordinate Repeatabilities [mm]: Overall Improvement
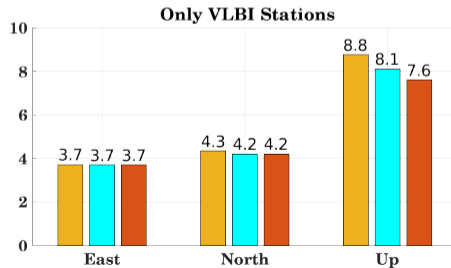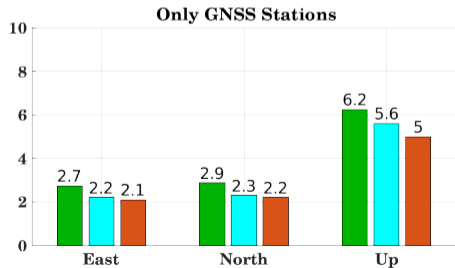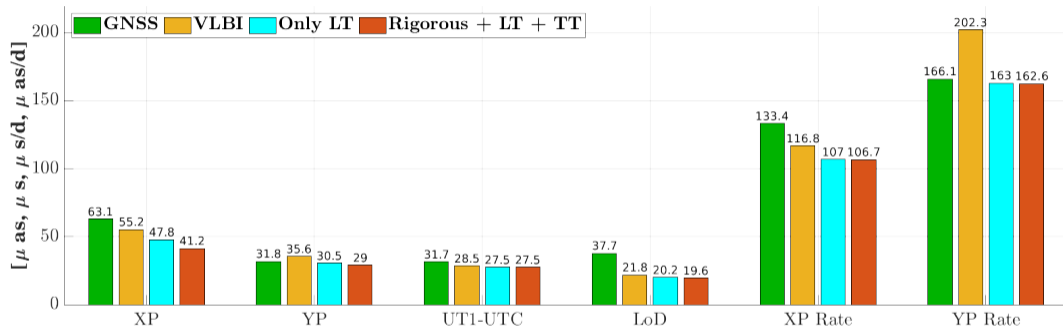
Comparison with Individual Solutions: Coordinate Repetabilities [mm]
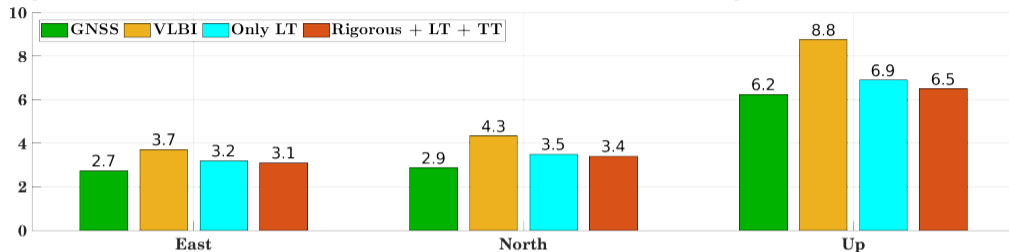
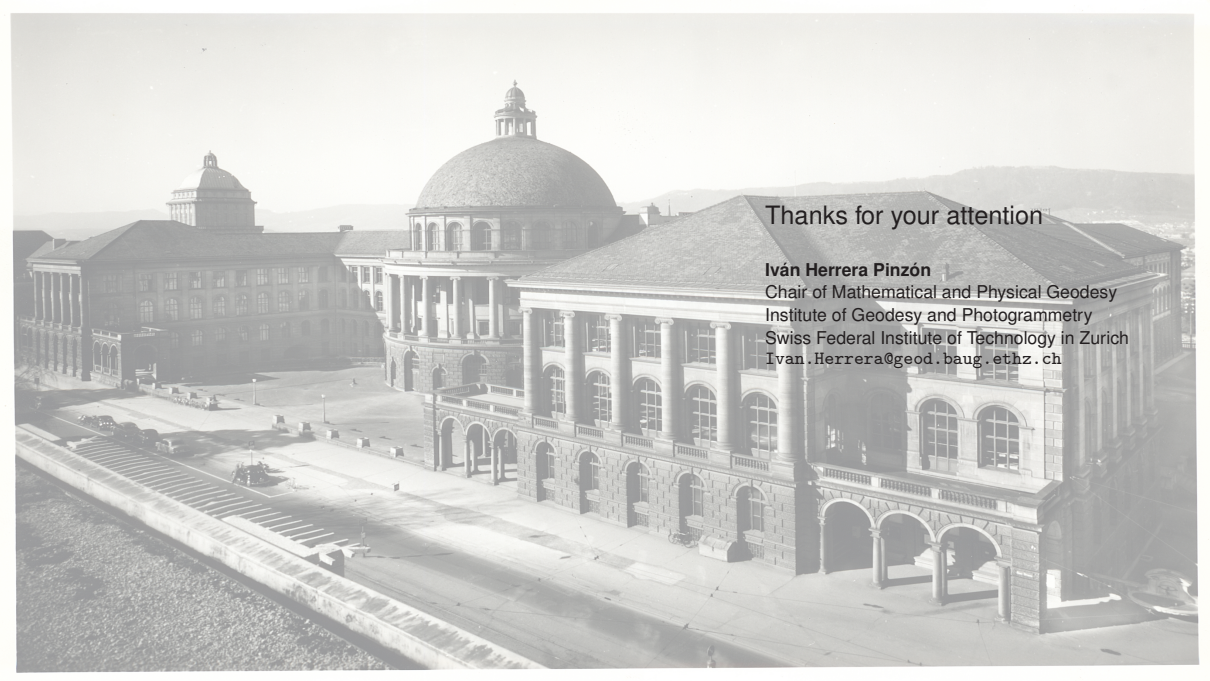Improvement in the vertical component from ZTD

Comparison with Individual Solutions: EOPs

- RMS of daily EOP differences to IGS for both individual solutions, and the combined solution
- Improvements on Polar Motion and LoD

Summary and Outlook

- A **rigorously** combined solution VLBI-GNSS for the estimation of a TRF has been achieved.

- This solution profits from **local and tropospheric ties** at (selected) co-location sites. Inter-technique weights and proper local tie constraints were used.

- The combined solution with local and troposphere ties generally **improves the precision** of all the estimated geodetic parameters.

- In particular: **coordinate repeatabilities**, **polar motion** and **LoD** estimates are improved.

Thanks for your attention

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