CONT14 as a testbed for the combination of VLBI and GPS data on the observation level

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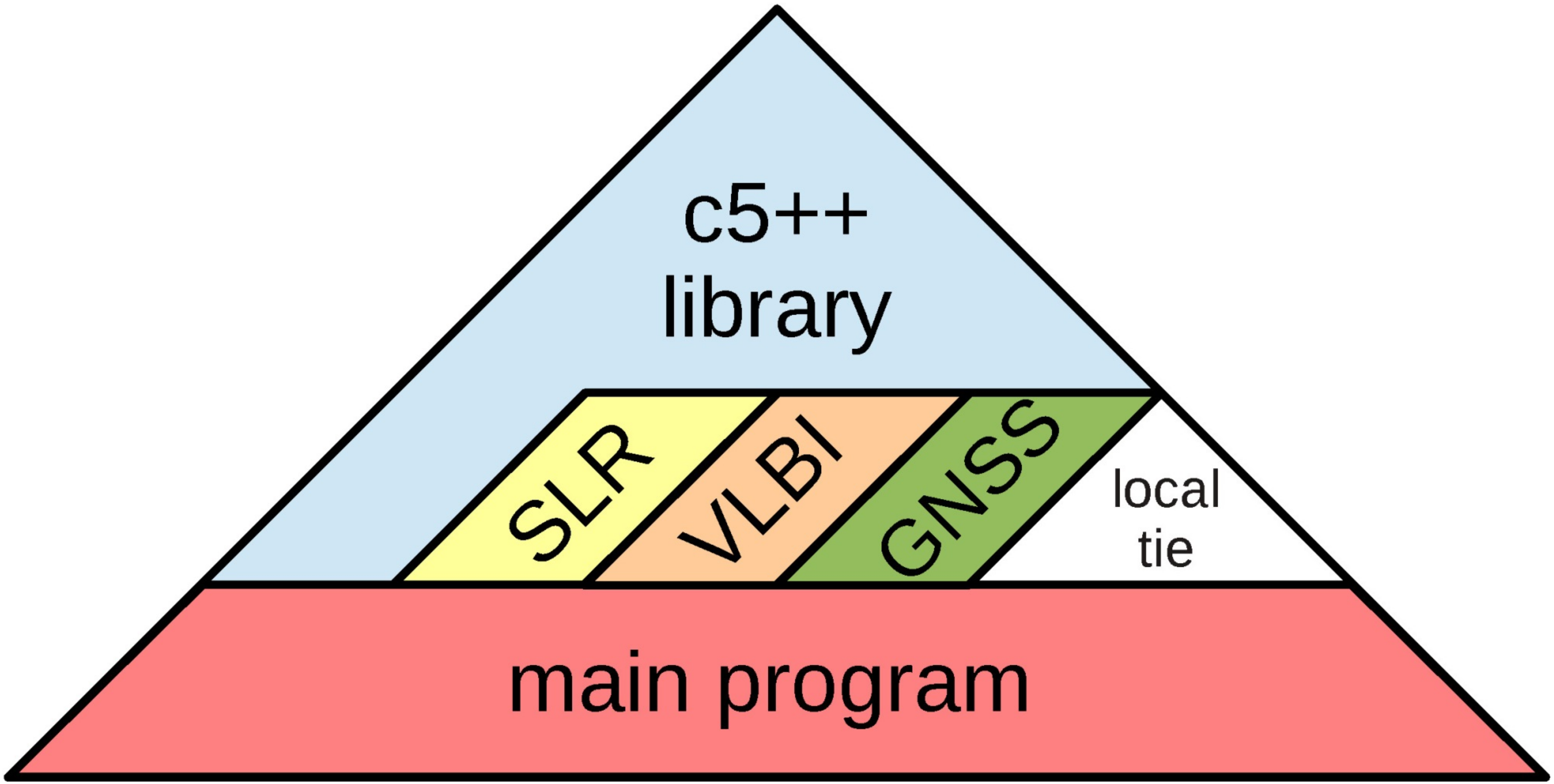
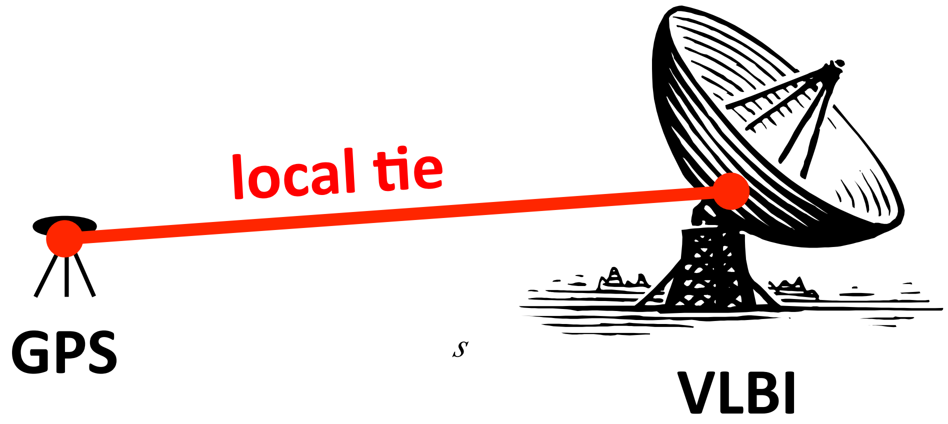
CHALMERS

c5++ concept



Local ties



$$\sqrt{(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2} - \sqrt{(x_V - x_G)^2 + (y_V - y_G)^2 + (z_V - z_G)^2} = 0 \pm \sigma$$

"O – C"

Local ties

NOTE 1: We don't introduce ties as 3D vectors, but only use the (invariant!) distance between the instruments as constraint

$$\sqrt{(\Delta x)^2+(\Delta y)^2+(\Delta z)^2}-\sqrt{(x_V-x_G)^2+(y_V-y_G)^2+(z_V-z_G)^2}=0\pm\sigma$$

"O – C"

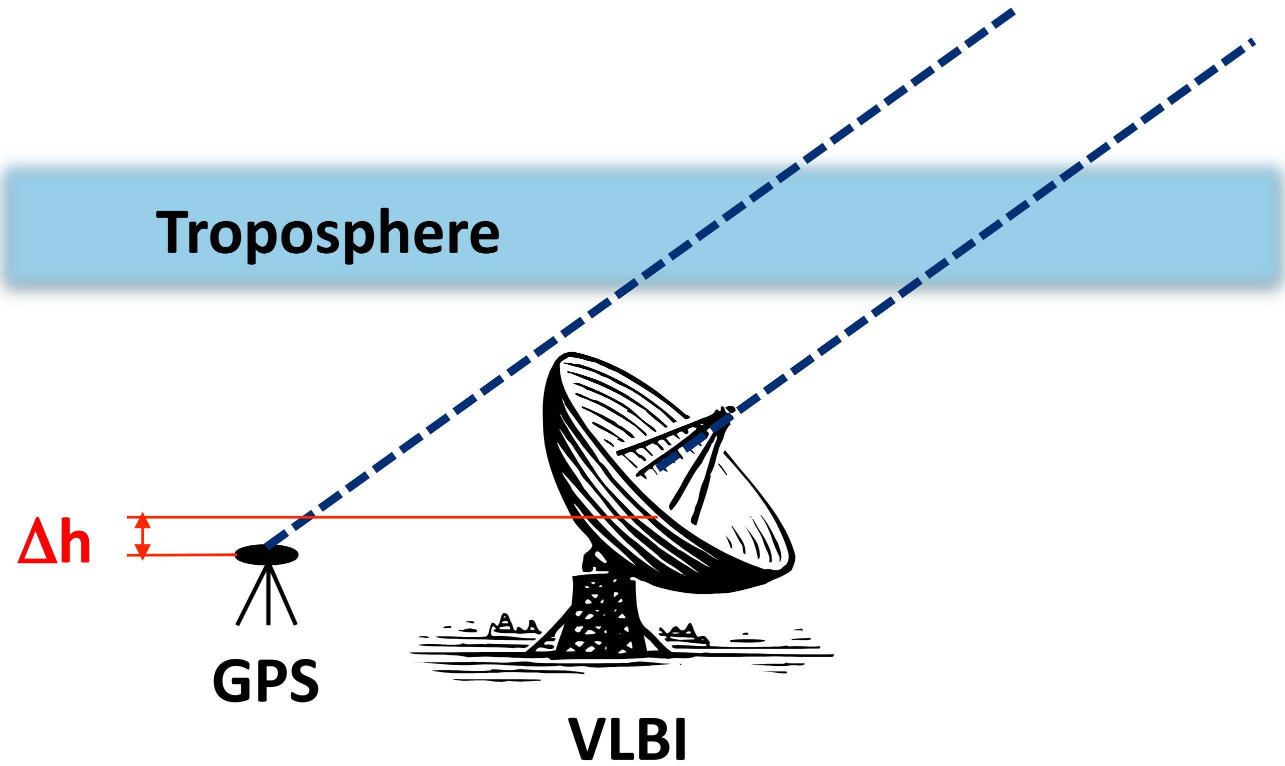
Local ties

NOTE 2: We don't use the formal errors from the site survey, but weight the constraints based on VCE results

$$\sqrt{(\Delta x)^2+(\Delta y)^2+(\Delta z)^2}-\sqrt{(x_V-x_G)^2+(y_V-y_G)^2+(z_V-z_G)^2}=0\pm\sigma$$

"O – C"

"Troposphere ties"



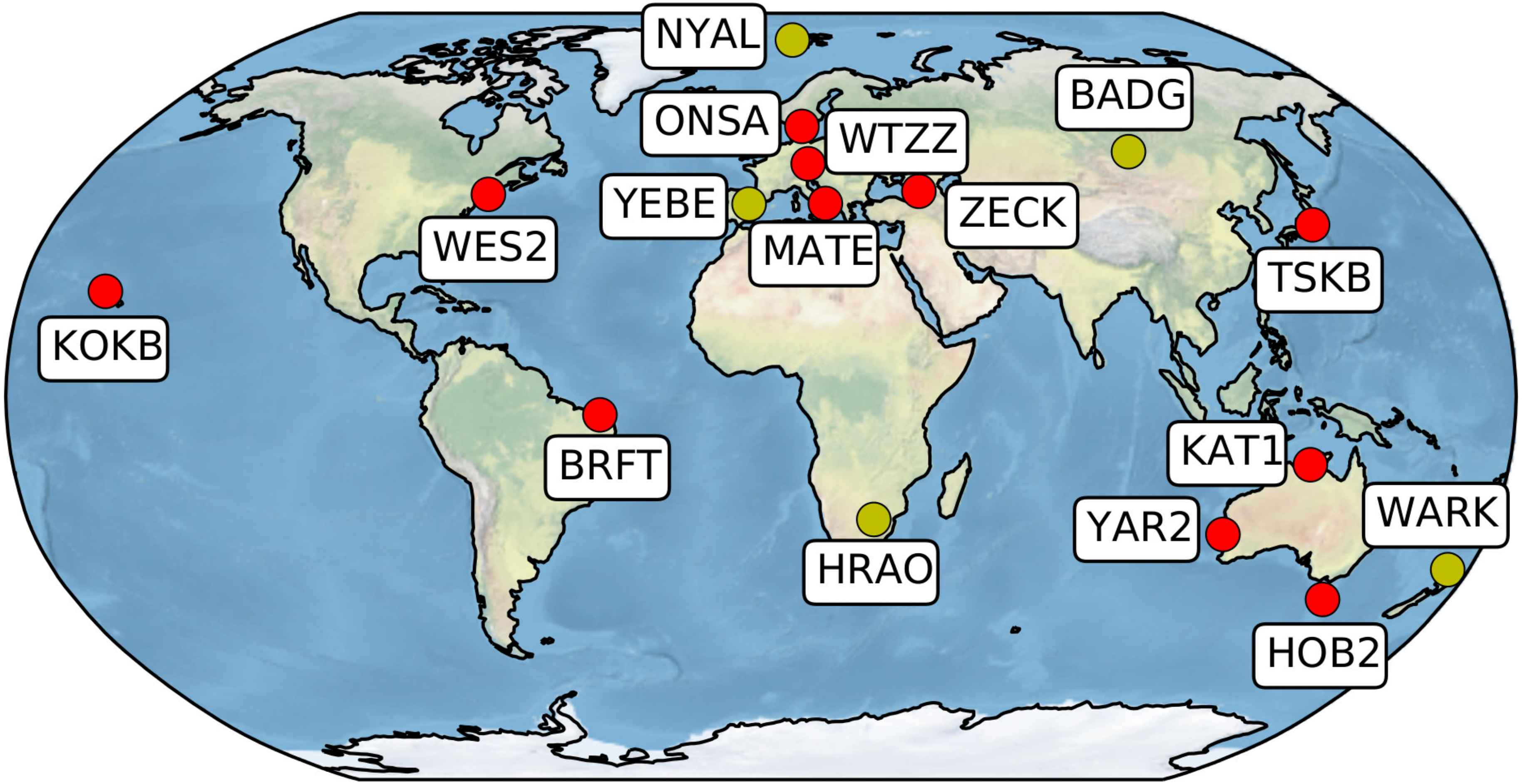
$$\tau_{GPS} = ZHD \cdot mf_h(\varepsilon) + ZWD \cdot mf_w(\varepsilon) + mf_g(\varepsilon) \cdot (G_N \cos\alpha + G_E \sin\alpha)$$

$$\tau_{VLBI} = \tau_{GPS} + \Delta D \cdot mf_h(\varepsilon)$$

Variance component estimation (VCE)

- Implemented via simplified Helmert method
- Allows to estimate one VC for
  - VLBI
  - SLR (not used in this presentation)
  - (all) local ties [note: highly unbalanced VCE]
  - GPS code phase measurements / site
  - GPS carrier phase measurements / site

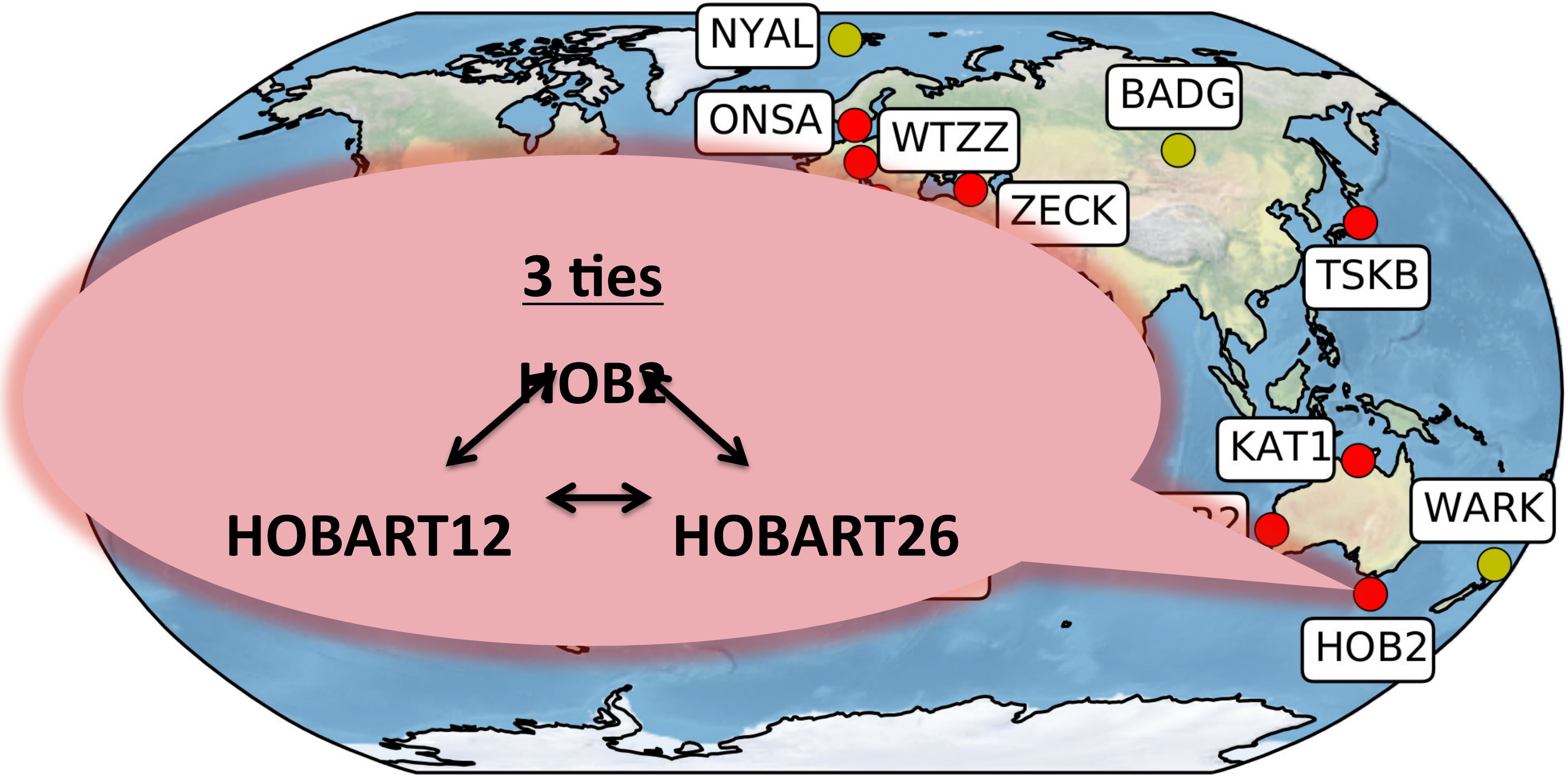
Connecting GPS and VLBI during CONT14



Local tie available in SINEX

No local tie info

Connecting GPS and VLBI during CONT14



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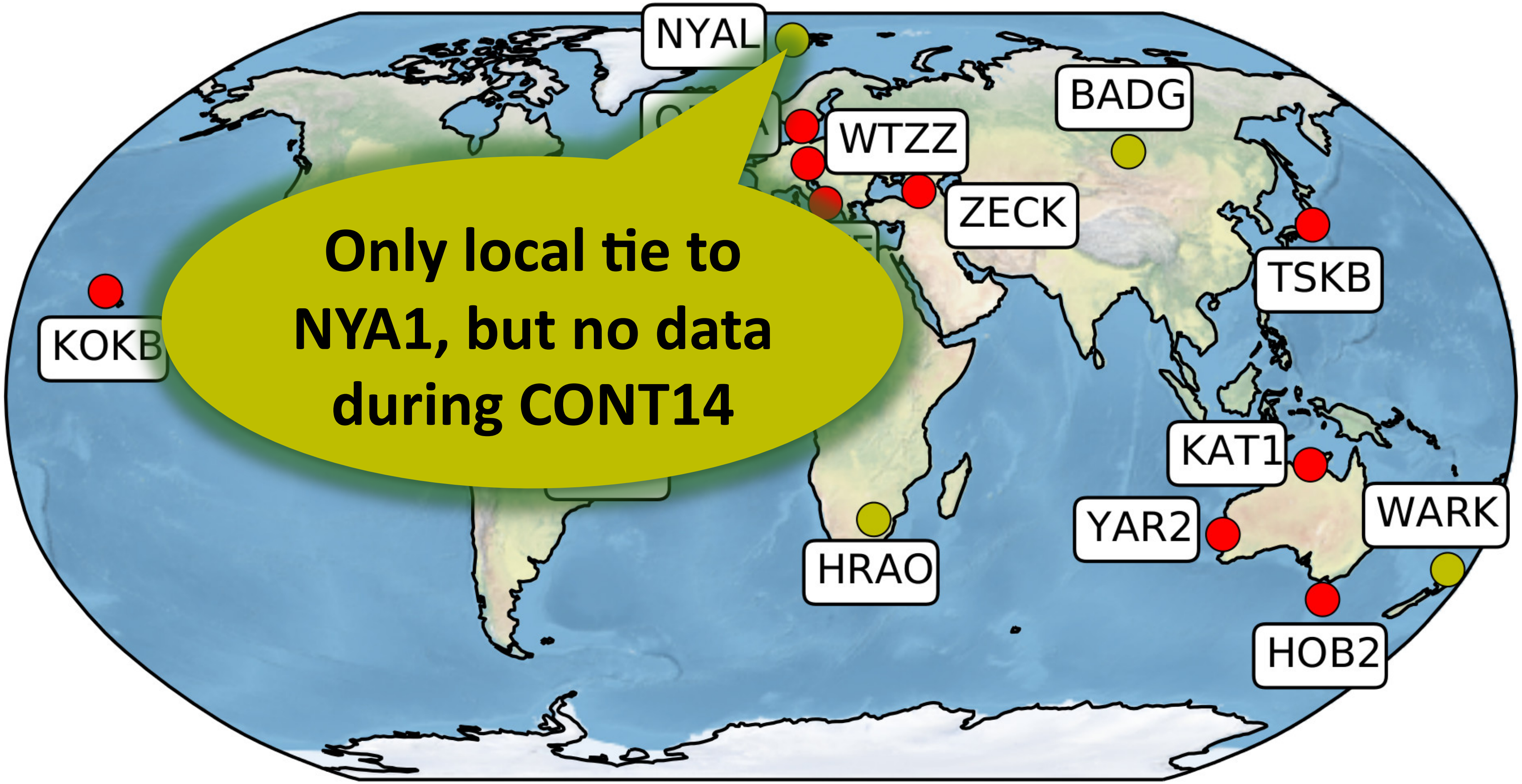

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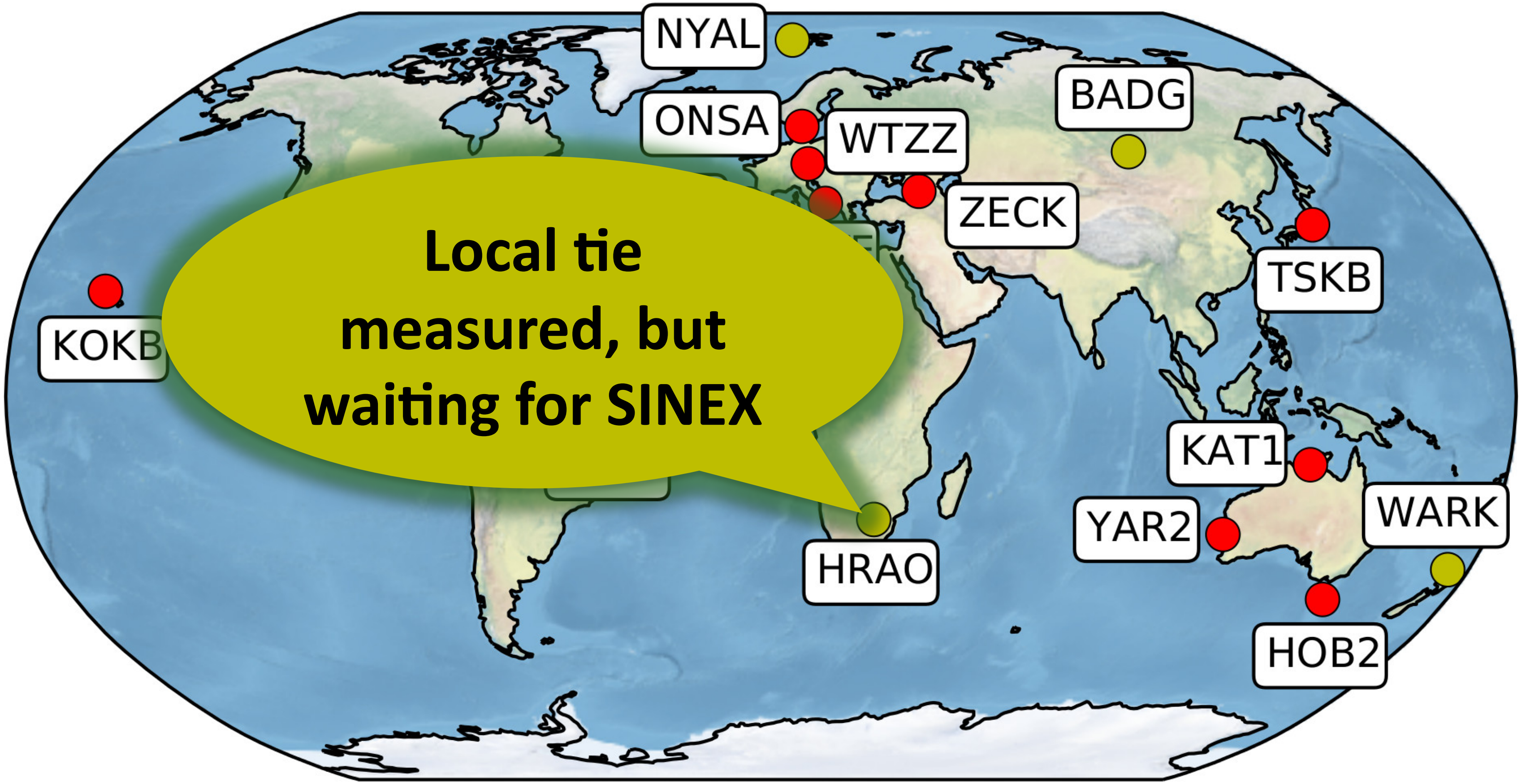
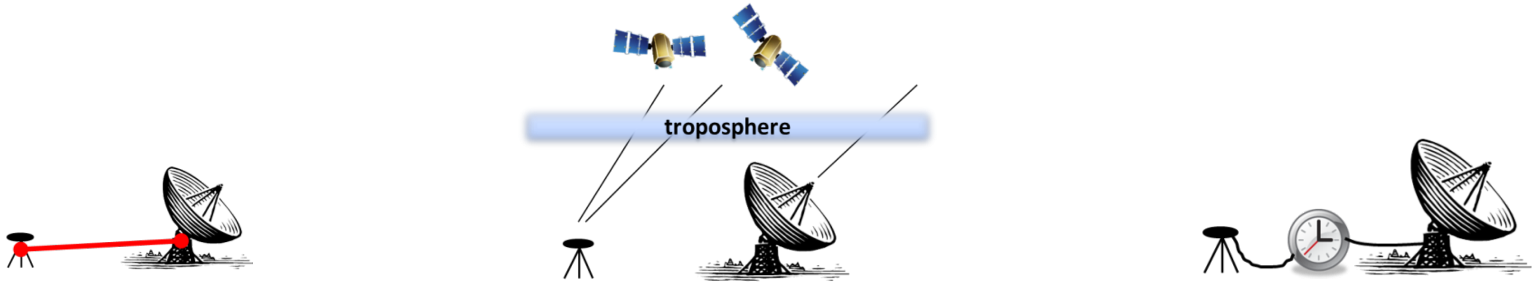


Local tie available in SINEX

No local tie info

Parameterization for the 15 daily solutions



Solution	Local tie	ZWD GPS	ZWD VLBI	Gradient GPS	Gradient VLBI	clock GPS	clock VLBI
VLBI			2h		6h		1h
GPS		2h		6h		5′	
COMB	✓	2h(+tropo tie)		6h		5′	1h

(All parameters estimated as piece-wise linear offsets)

Parameterization for the 15 daily

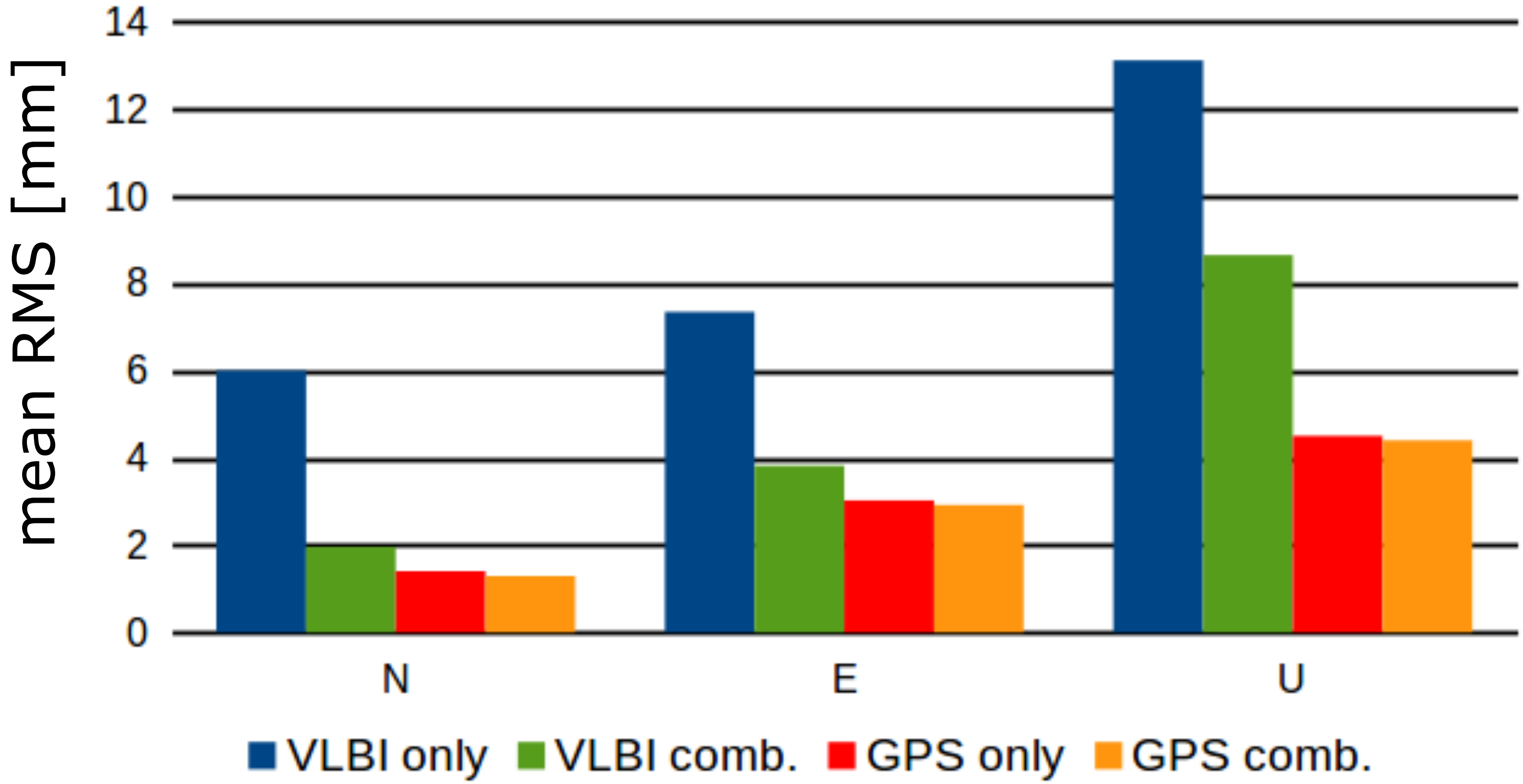
"clock ties" were not estimated for CONT14. BUT: See our poster how "clock ties" help to utilize VLBI for intercontinental frequency transfer!!

Solut…				clock GPS	clock VLBI
VLBI					1h
GPS		2h	6h		
COMB	✓	2h(+tropo tie)	6h	5′	1h

(All parameters estimated as piece-wise linear offsets)

Results

Station position repeatability



Mean VC

GPS

Θ [mm]	Code phase	Carrier phase
BADG	526.4 ± 9.5	3.4 ± 0.1
FORT	294.1 ± 10.8	4.7 ± 1.1
HRAO	666.6 ± 12.0	2.5 ± 0.3
HOB2	317.8 ± 16.9	3.5 ± 0.5
KAT1	323.2 ± 8.1	3.0 ± 0.2
KOKB	709.8 ± 17.9	3.3 ±0.2
MATE	376.3 ± 20.2	2.8 ± 0.3
NYAL	414.3 ± 10.6	2.1 ± 0.2

Θ [mm]	Code phase	Carrier phase
ONSA	425.1 ± 7.3	2.6 ± 0.1
TSKB	557.6 ± 22.5	3.1 ± 0.4
WARK	839.2 ± 11.5	4.2 ± 0.4
WES2	405.1 ± 13.4	3.3 ± 0.3
WTZZ	628.1 ± 12.3	4.3 ± 0.3
YAR2	849.3 ± 14.3	2.5 ± 0.5
ZECK	509.5 ± 9.3	3.7 ± 0.3

Mean VC

Θ [mm]	Code phase	Carrier phase
BADG	526.4 ± 9.5	[illegible]
FORT	294.1 ± 10.	[illegible]
HRAO	666.6 ± 12.	[illegible]
HOB2	317.8 ± 16	[illegible]
KAT1	[illegible]	[illegible]
KOKB	709.8 ± 17.	[illegible]
MATE	376.3 ± 20.2	2.8 ± 0.3
NYAL	414.3 ± 10.6	2.1 ± 0.2

Θ [mm]	Code phase	Carrier phase
[illegible]	[illegible]	.1
[illegible]	[illegible]	.4
[illegible]	[illegible]	.4
[illegible]	[illegible]	.3
[illegible]	[illegible]	.3
[illegible]	[illegible]	.5
ZECK	509.5 ± 9.5	3.7 ± 0.3

GPS

- Code phase VC: 300 – 700 mm (relates to local multi-path environment)
- Carrier phase VC: 2-5 mm

Mean VC

GPS

Θ [mm]	Code phase	Carrier phase
BADG	526.4 ± 9.5	[illegible]
FORT	294.1 ± 10.	[illegible]
HRAO	666.6 ± 12.	[illegible]
HOB2	317.8 ± 16	[illegible]
KAT1	[illegible]	[illegible]
KOKB	709.8 ± 17.	[illegible]
MATE	376.3 ± 20.2	[illegible]
NYAL	414.3 ± 10.6	2.1 ± 0.2

Θ [mm]	Code phase	Carrier phase
[illegible]	[illegible]	.1
[illegible]	[illegible]	.4
[illegible]	[illegible]	.4
[illegible]	[illegible]	.3
[illegible]	[illegible]	.3
[illegible]	[illegible]	.5
[illegible]	[illegible]	.3

- Code phase VC: 300 – 700 mm (relates to local multi-path environment)
- Carrier phase VC: 2-5 mm

VLBI

$$\Theta = 2.33 \pm 0.24 \; []$$

Mean VC

GPS

Θ [mm]	Code phase	Carrier phase
BADG	526.4 ± 9.5	
FORT	294.1 ± 10.	
HRAO	666.6 ± 12.	
HOB2	317.8 ± 16	
KAT1		
KOKB	709.8 ± 17.	
MATE	376.3 ± 20.2	2.8 ± 0.3
NYAL	414.3 ± 10.6	2.1 ± 0.2

Θ [mm]	Code phase	Carrier phase
		.1
		.4
		.4
		.3
		.3
		.5
ZECK	309.3 ± 9.3	3.7 ± 0.3

- Code phase VC: 300 – 700 mm (relates to local multi-path environment)
- Carrier phase VC: 2-5 mm

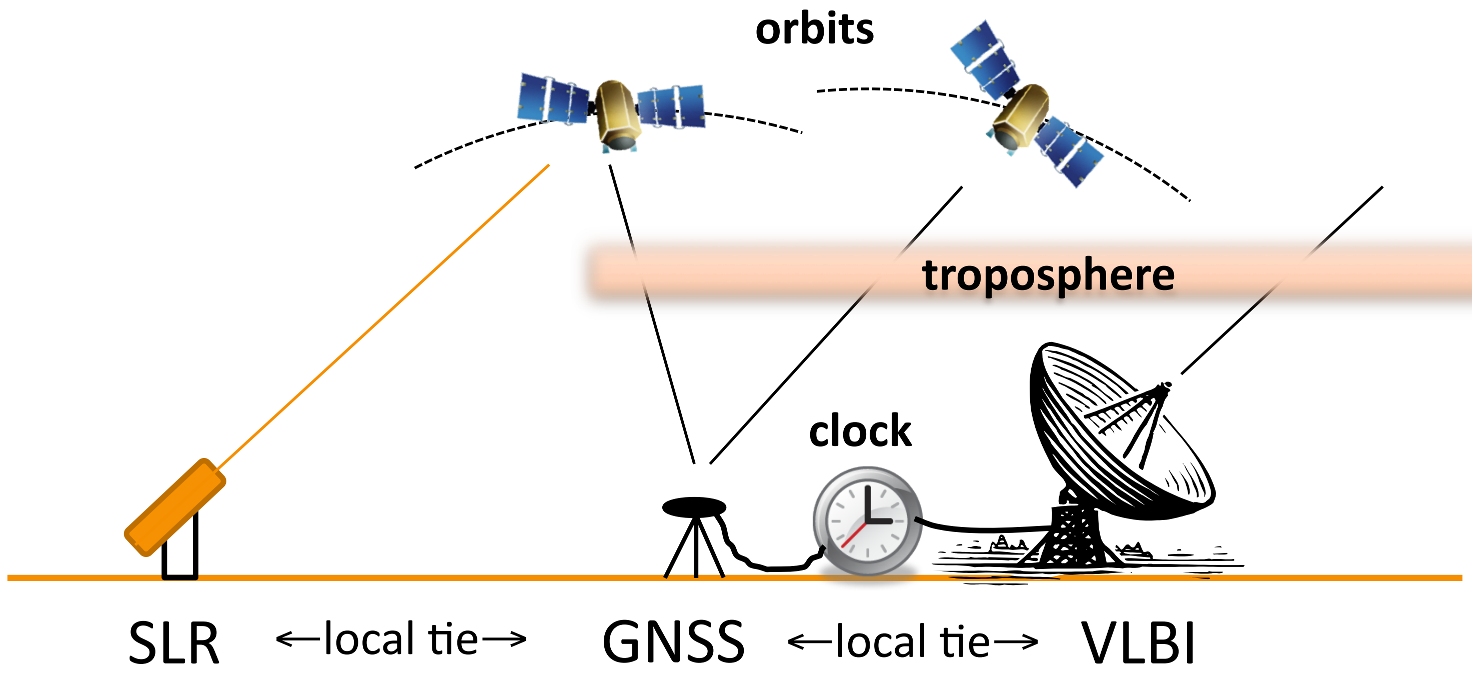
VLBI Θ = 2.33 ± 0.24 []

LOCAL TIES Θ = 12.1 ± 3.8 [mm]

Conclusions

- Combination on the observation level works
- Amount of observations highly unbalanced
  - $N_{GPS} > N_{VLBI} > N_{LOCAL\ TIE}$
- VCE helps to find "natural weights"
  - Shows that formal errors of local ties are too optimistic (note: this does not mean that local ties are not measured that accurate, but rather reflects the fact that other biases do not allow to access the reference points with that accuracy)

The next steps …



… but first we need to find a way to handle the large number of observations efficiently.

Thank you very much for your attention!

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