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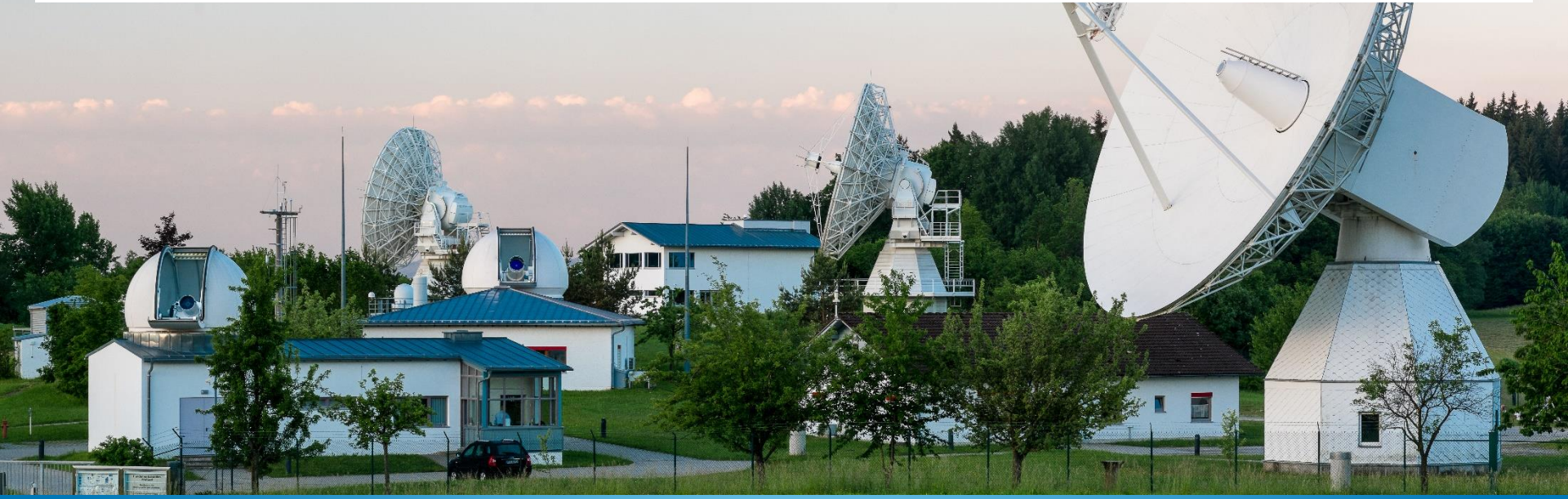

# Combination of GNSS and VLBI data for consistent estimation of Earth Orientation Parameters

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# Agenda

**Motivation**

**Data Input – VLBI Intensive Sessions**

**1-day Inter-technique Combination**

**Multi-day Inter-technique Combination**

**Conclusion and Outlook**

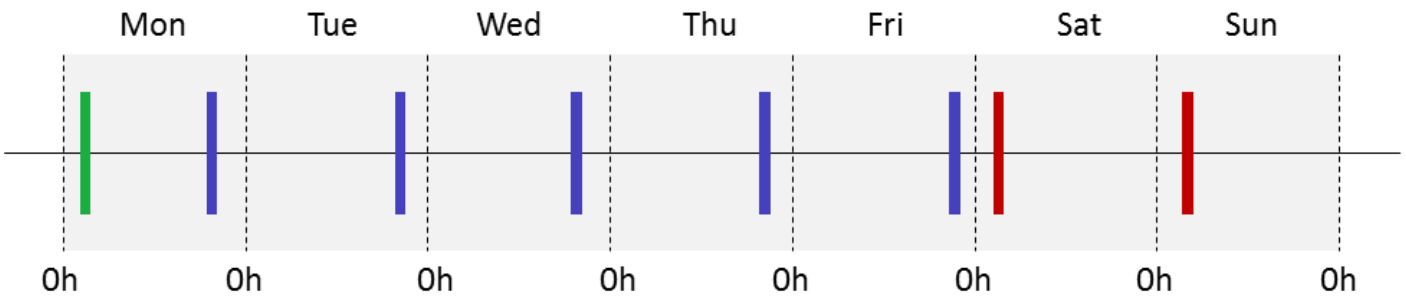
# Motivation - Combination of GNSS and VLBI

## Earth Rotation Parameters (ERPs)

| | GNSS | VLBI Intensive | VLBI R1/R4 | Combination |
|---|---|---|---|---|
| Polar motion | ✓ | X | ✓ | ✓ |
| UT1−UTC (dUT1) | X | ✓ | ✓ | ✓ |
| LOD | ✓ | X | ✓ | ✓ |

- Combination of GNSS and VLBI Intensives on normal equation level
  - Estimation of a full and consistent set of ERPs
  - Taking into account all correlations
  - Independent from a priori values of the ERPs
- Temporal resolution: 1 day
- Shorter latency → faster availability of a consistent set of all ERPs
- Stabilization of the ERP estimation by multi-day solution

# Data Input - VLBI Intensive Sessions




- Baselines optimized in East-West direction for the estimation of dUT1
- One hour observation per day, not equidistant in time
- 1-2 days latency

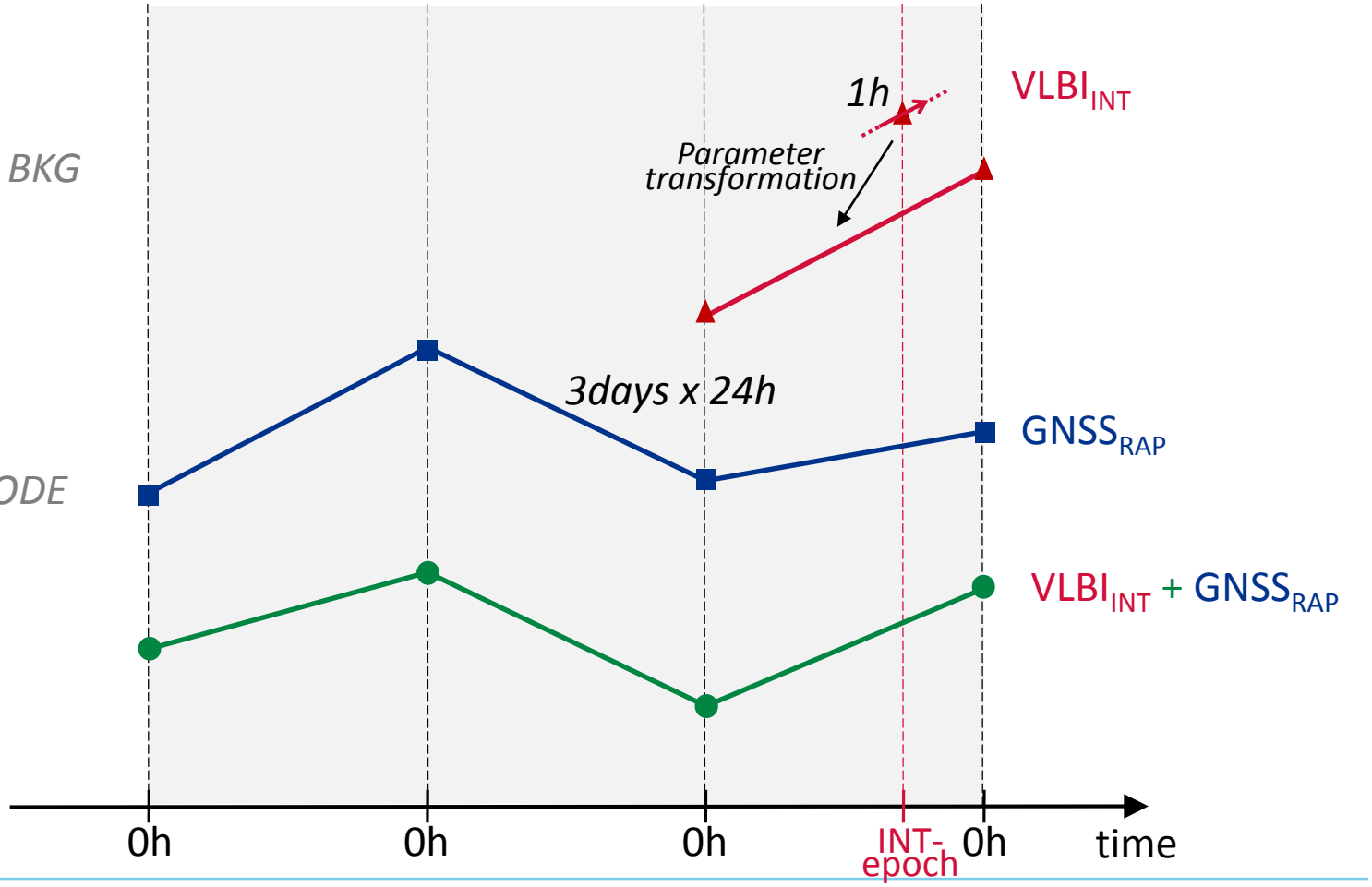

http://www.freeworldmaps.net/de/weltkarten/weltkartezweifarbig.jpg, access date: May 27th, 2019

# 1-day Inter-technique Combination
# GNSS Rapids CODE + VLBI Intensives BKG

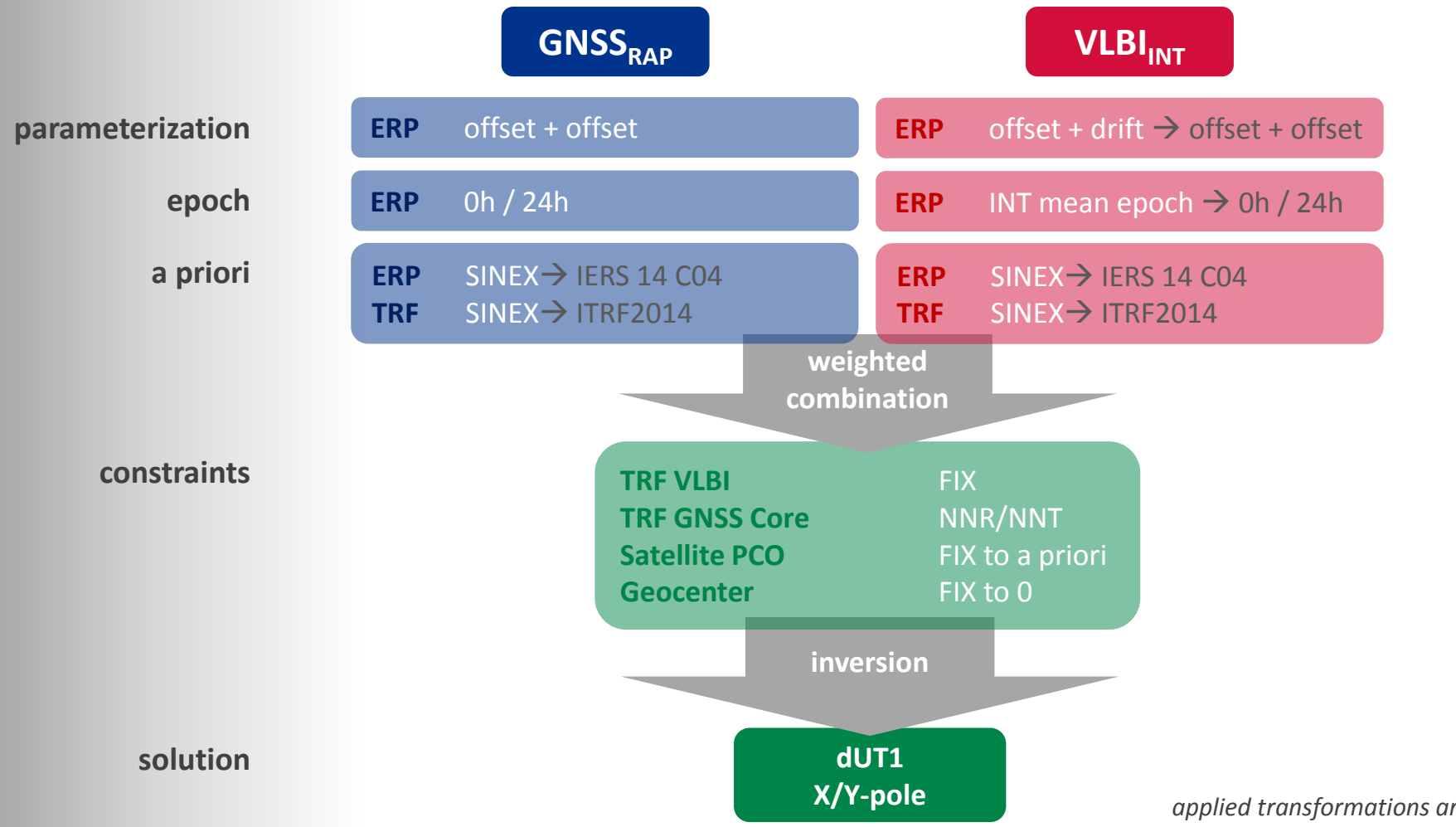
***Input used***

*VLBI Intensives BKG*

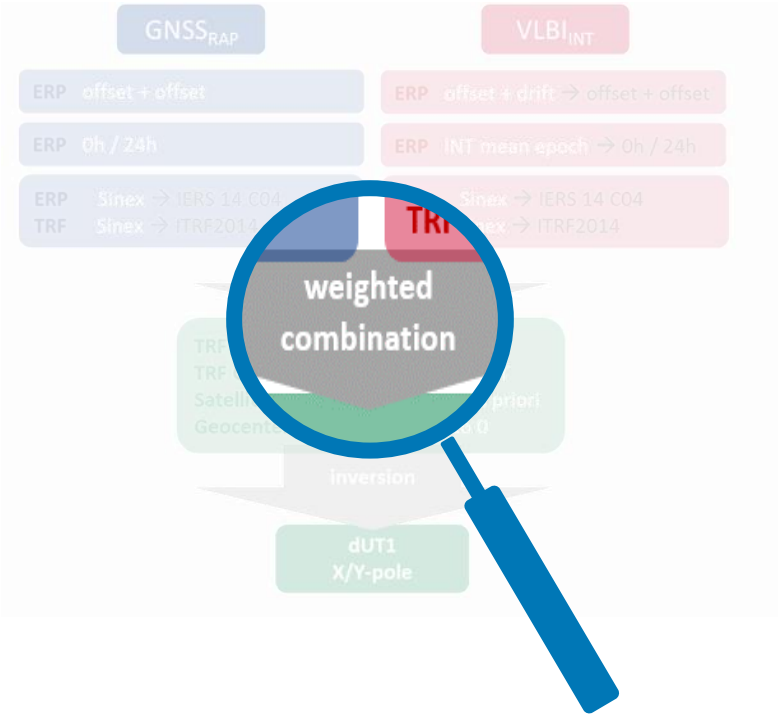
*GNSS Rapids CODE*



# 1-day Inter-technique Combination – Scheme



# Scaling studies



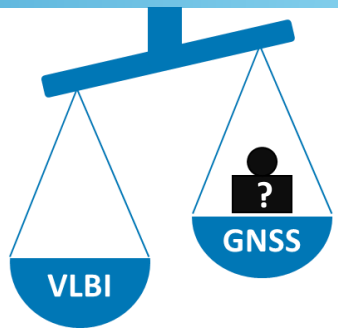

Imbalance in the size of the NEQ elements of both techniques

GNSS too weak compared to VLBI

→ **Re-scaling of the NEQ needed**

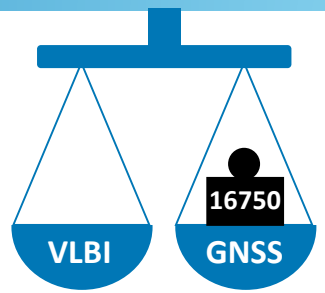
WRMS w.r.t. IERS 14 C04 of estimated ERPs with different weights for GNSS NEQ

| GNSS NEQ weight | dUT1 [ms] | x-pole [mas] | y-pole [mas] |
|---|---|---|---|
| **Single-technique** | **0.0265** | **0.0496** | **0.0423** |
| 100 | 0.0250 | 0.1545 | 0.0879 |
| 1 000 | 0.0251 | 0.0535 | 0.0428 |
| 5 000 | 0.0251 | 0.0491 | 0.0419 |
| 10 000 | 0.0254 | 0.0489 | 0.0420 |
| 15 000 | 0.0257 | 0.0489 | 0.0420 |
| 16 750 | 0.0259 | 0.0488 | 0.0420 |
| 20 000 | 0.0262 | 0.0488 | 0.0420 |
| 30 000 | 0.0271 | 0.0488 | 0.0420 |
| 50 000 | 0.0288 | 0.0488 | 0.0420 |
| 100 000 | 0.0323 | 0.0488 | 0.0421 |
| 300 000 | 0.0398 | 0.0488 | 0.0421 |
| 500 000 | 0.0442 | 0.0488 | 0.0421 |



# Scaling studies

| Scale GNSS NEQ | NEQ ratio GNSS : VLBI TRF | Pole | dUT1 |
|---|---|---|---|
| 16750 | **72 : 1** | 701 : 1 | 36 : 1 |
| 450 | 2 : 1 | 19 : 1 | 1 : 1 |



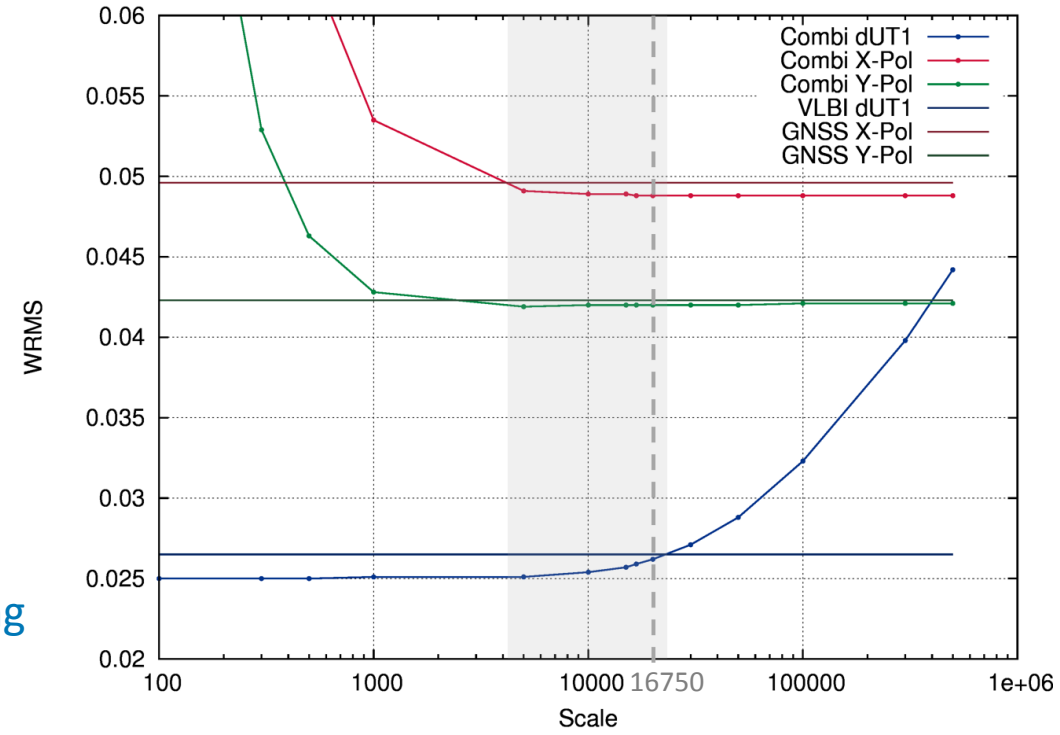

Ratios of the average NEQ diagonal element per parameter group (TRF, pole, dUT1) between GNSS and VLBI

Scale 16750 ≙ 72:1 (TRF GNSS:VLBI)

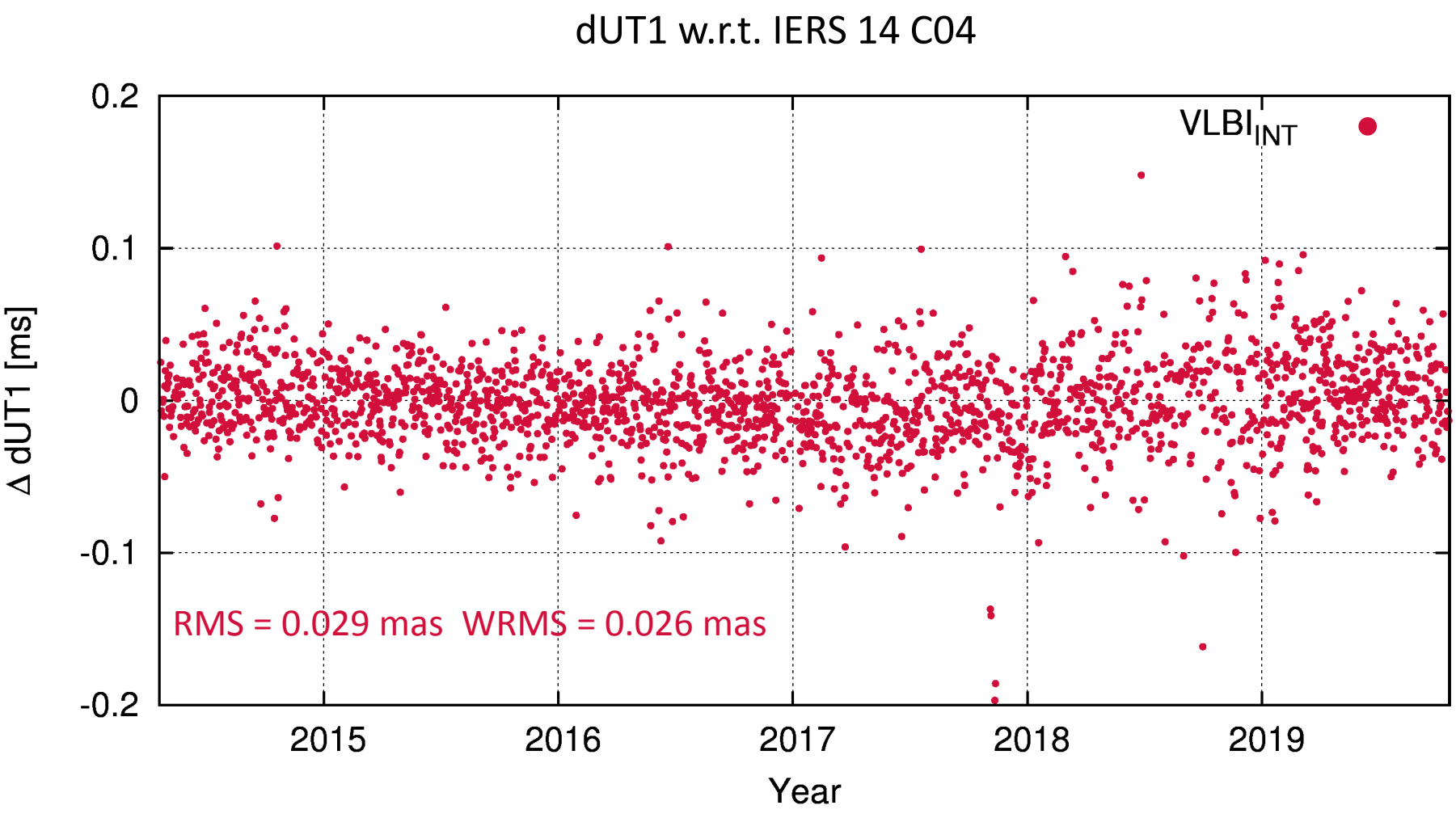
→ Ratio of the observation periods (72h $GNSS_{RAP}$ : 1h $VLBI_{INT}$)

Scale 16750 was used for all following combination results

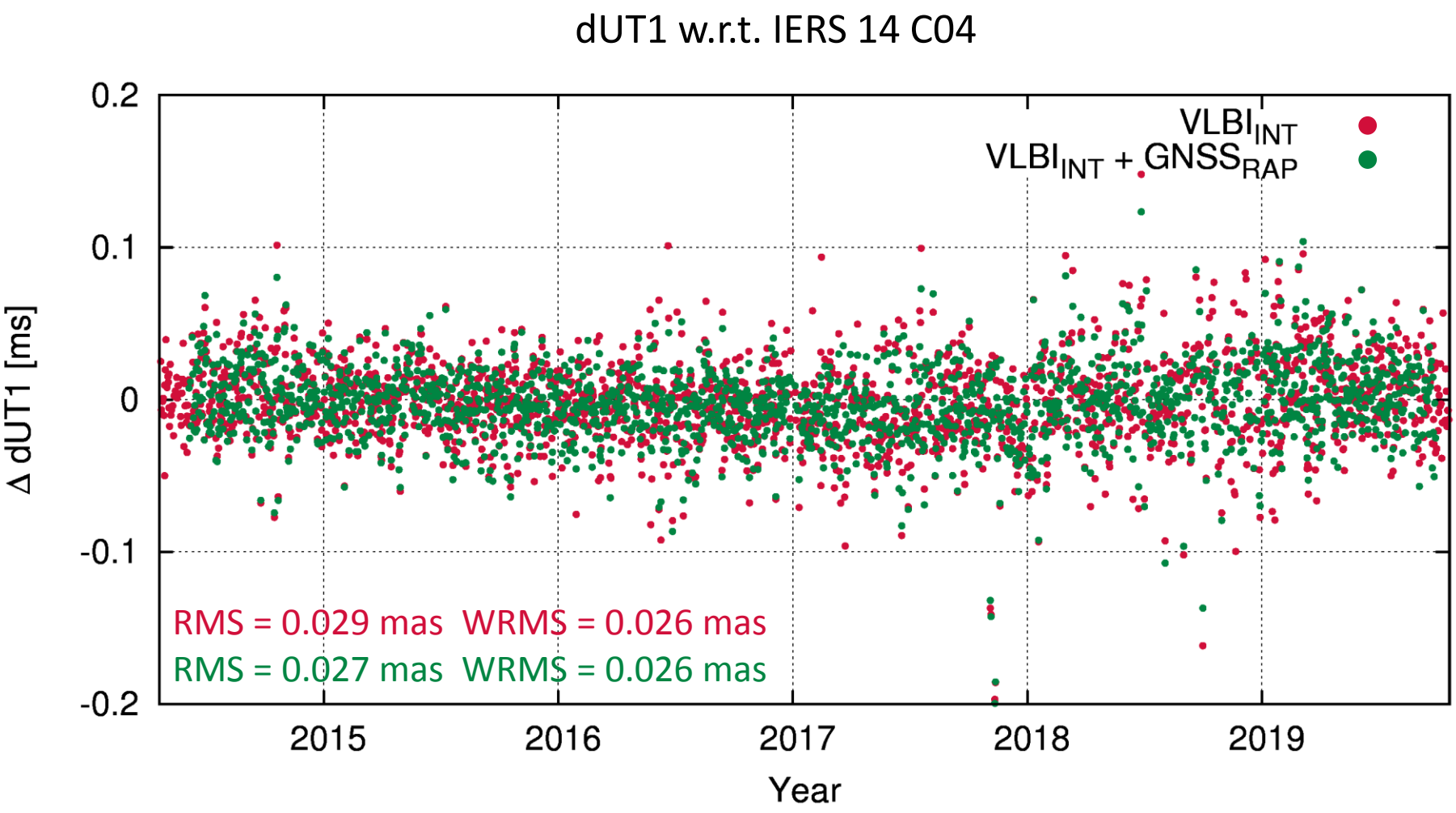
WRMS w.r.t. IERS 14 C04 of the estimated ERPs



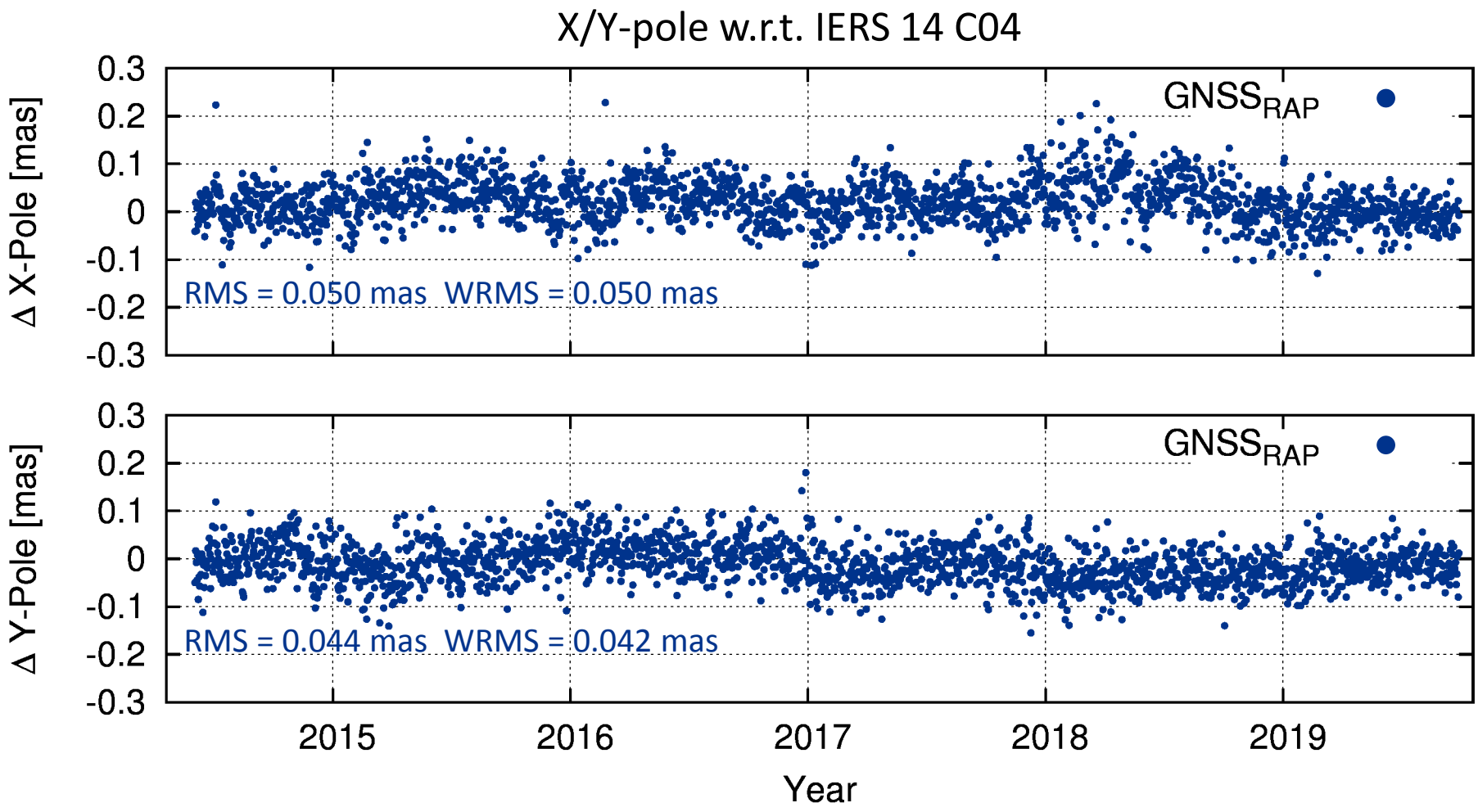
# $VLBI_{INT}$ Single-technique – Results at 12:00 epochs



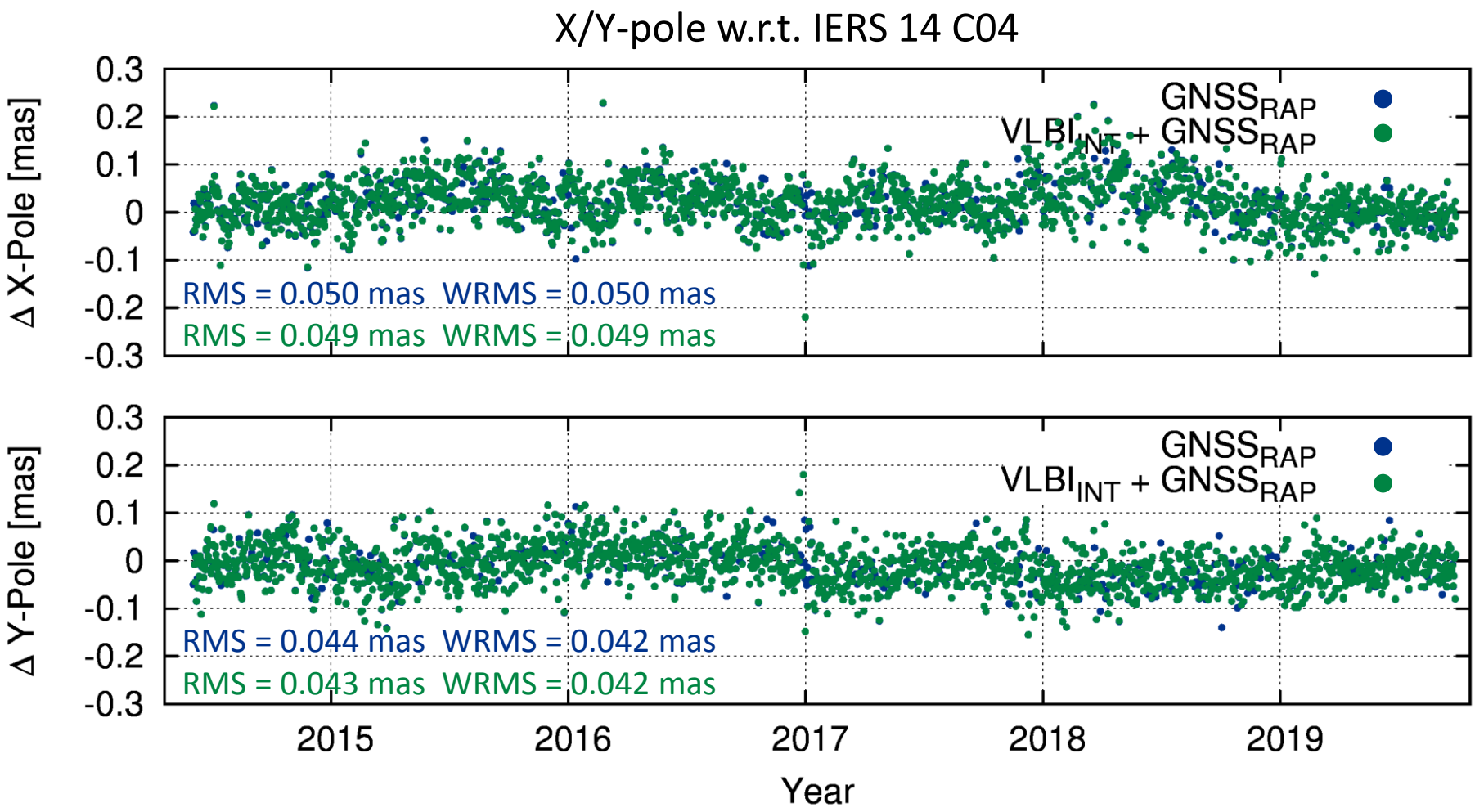
# 1-Day Inter-technique Combination – Results at 12:00 epochs



# $GNSS_{RAP}$ Single-technique – Results at 12:00 epochs



# 1-Day Inter-technique Combination – Results at 12:00 epochs



# Multi-day Combination – Intra- and Inter-technique

## Intra-technique

### VLBI Intensives

(1) Transformation of the ERPs from offset/drift parameterization at the observation mean epoch to offset/offset parameterization at day boundaries
(2) Stacking of the normal equations of several days → continuity

### GNSS Rapids

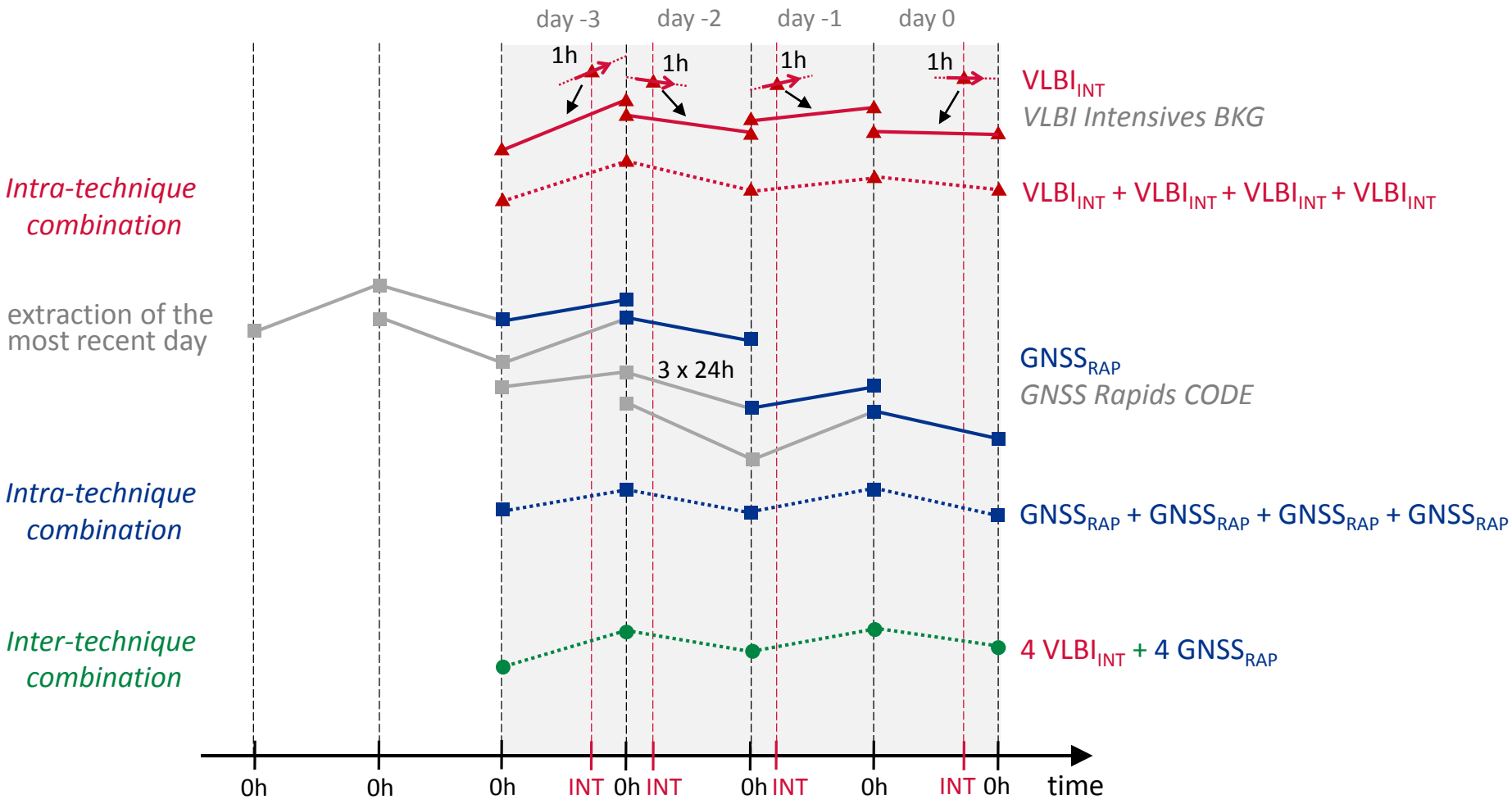
(1) Extraction of the most recent day ( pre-elimination of the first two days)
(2) Stacking of the normal equations of several days → continuity

## Inter-technique

### $VLBI_{INT}$ + $GNSS_{RAP}$

(1) Combination of multi-day VLBI and GNSS normal equations
(2) Systematic investigation for one up to seven combined solutions

# Multi-day Combination



# Multi-day Inter-technique Combination – Results at 12:00 epochs

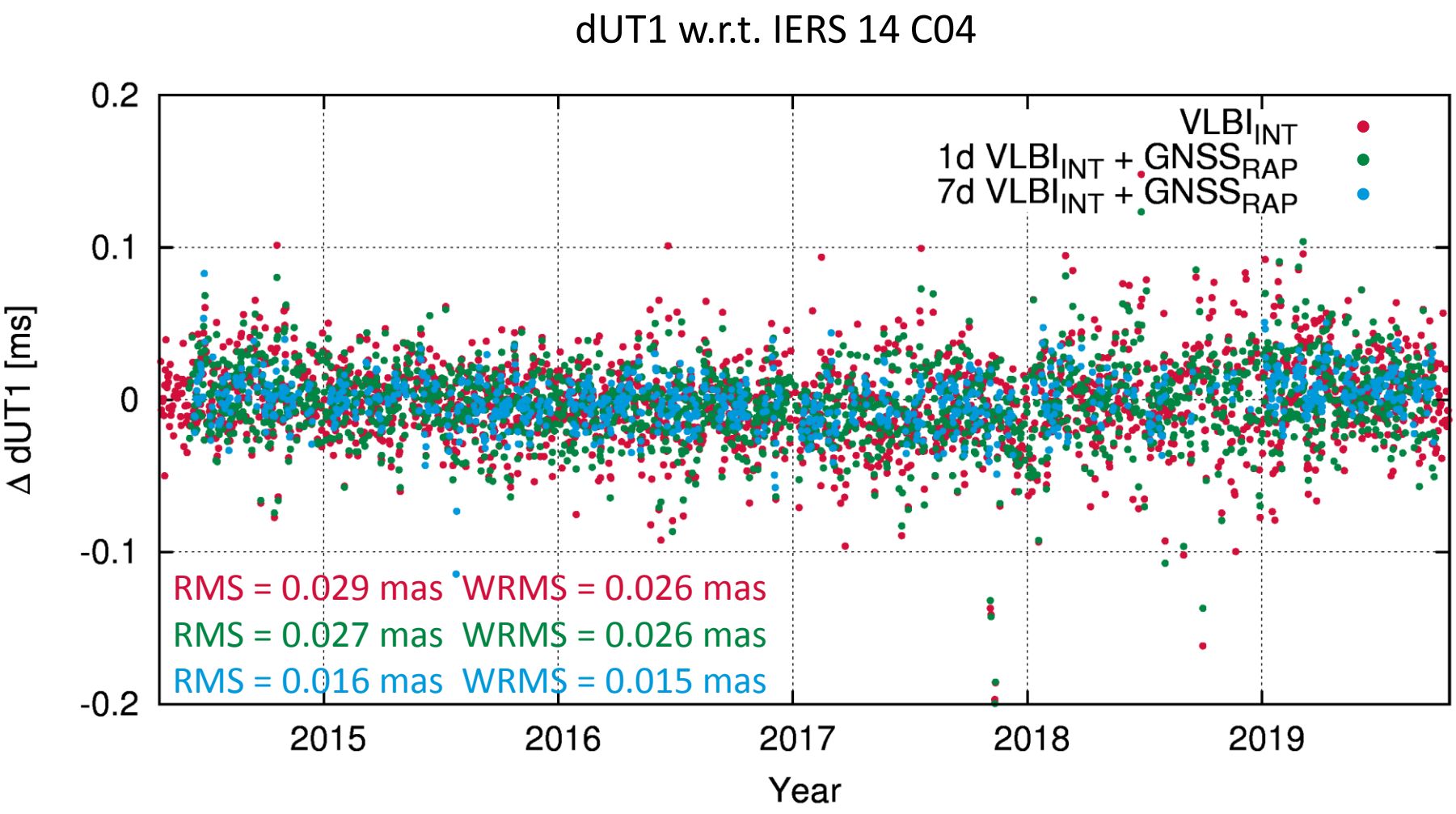
WRMS dUT1 [ms]

| #days \ day | -6 | -5 | -4 | -3 | -2 | -1 | 0 |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | 0.0259 |
| 2 | | | | | | 0.0213 | 0.0202 |
| 3 | | | | | 0.0188 | 0.0159 | 0.0195 |
| 4 | | | | 0.0220 | 0.0160 | 0.0166 | 0.0212 |
| 5 | | | 0.0245 | 0.0171 | 0.0154 | 0.0177 | 0.0228 |
| 6 | | 0.0256 | 0.0178 | 0.0149 | 0.0157 | 0.0187 | 0.0239 |
| 7 | 0.0263 | 0.0185 | 0.0150 | 0.0148 | 0.0163 | 0.0196 | 0.0250 |

The more days are stacked, the smaller the WRMS of the middle days w.r.t. IERS 14 C04 becomes
→ stabilization of the ERPs through continuity at the day boundaries

The more days (days > 2) are stacked, the larger the WRMS of the peripheral days w.r.t IERS 14 C04 becomes
→ due to the known effect of the GNSS LOD-Bias?

# 7-Day Inter-technique Combination – Day -3



# Multi-day Inter-technique Combination – Results at 12:00 epoch

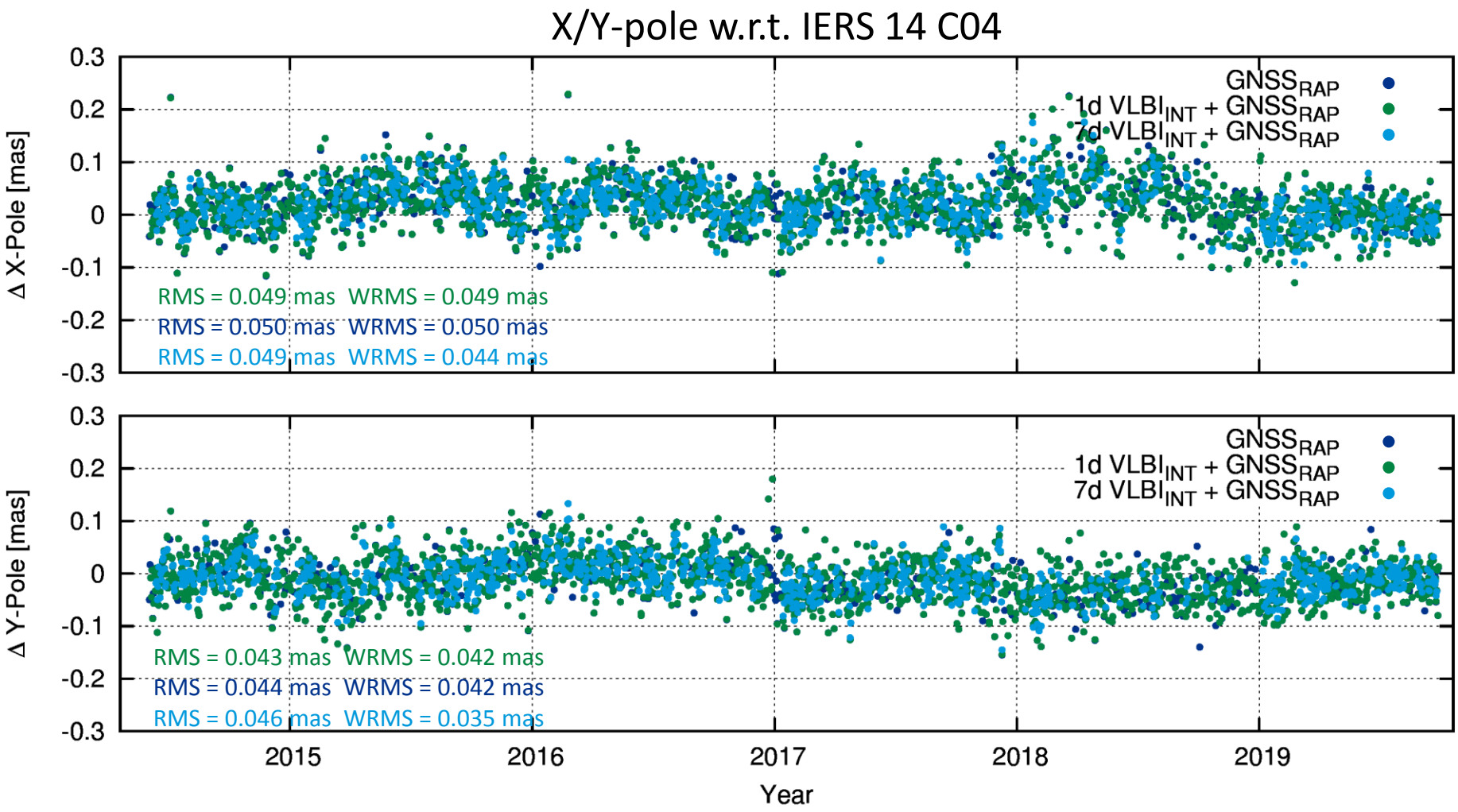
WRMS X-pole [mas]

| #days \ day | -6 | -5 | -4 | -3 | -2 | -1 | 0 |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | 0.0488 |
| 2 | | | | | | 0.0451 | 0.0491 |
| 3 | | | | | 0.0493 | 0.0452 | 0.0492 |
| 4 | | | | 0.0449 | 0.0435 | 0.0444 | 0.0478 |
| 5 | | | 0.0452 | 0.0440 | 0.0437 | 0.0441 | 0.0473 |
| 6 | | 0.0453 | 0.0441 | 0.0441 | 0.0433 | 0.0436 | 0.0469 |
| 7 | 0.0452 | 0.0443 | 0.0441 | 0.0437 | 0.0428 | 0.0432 | 0.0465 |

WRMS Y-pole [mas]

| #days \ day | -6 | -5 | -4 | -3 | -2 | -1 | 0 |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | 0.0420 |
| 2 | | | | | | 0.0361 | 0.0420 |
| 3 | | | | | 0.0421 | 0.0360 | 0.0423 |
| 4 | | | | 0.0349 | 0.0353 | 0.0360 | 0.0421 |
| 5 | | | 0.0345 | 0.0344 | 0.0358 | 0.0362 | 0.0422 |
| 6 | | 0.0347 | 0.0341 | 0.0349 | 0.0361 | 0.0363 | 0.0426 |
| 7 | 0.0343 | 0.0344 | 0.0346 | 0.0351 | 0.0364 | 0.0367 | 0.0428 |

# 7-Day Inter-technique Combination – Day -3



# Conclusion and Outlook

## Conclusion

- Combination of GNSS Rapids and VLBI Intensives provides a full and consistent set of ERPs
- Faster availability of ERPs due to shorter latencies (1-2 days)

**1-day Inter-technique Combination**

- Slight improvement of dUT1 and pole

**Multi-day Inter-technique Combination**

- Stabilization of the ERP estimation through continuity at the day boundaries
- **dUT1** significant improvement of dUT1
  larger WRMS of the peripheral days (GNSS LOD bias?)
- **X-pole** smaller WRMS of the middle and peripheral days
- **Y-pole** smaller WRMS of the oldest days (#days > 4 )

## Outlook

- Combination with bigger VLBI sessions (24h R1/R4) and other techniques (SLR)
- Study impact of GNSS LOD bias (first investigations showed a bias of only 8 micro-seconds)
- Improvement of datum definition by adding local ties

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# Thank you for your kind attention!

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