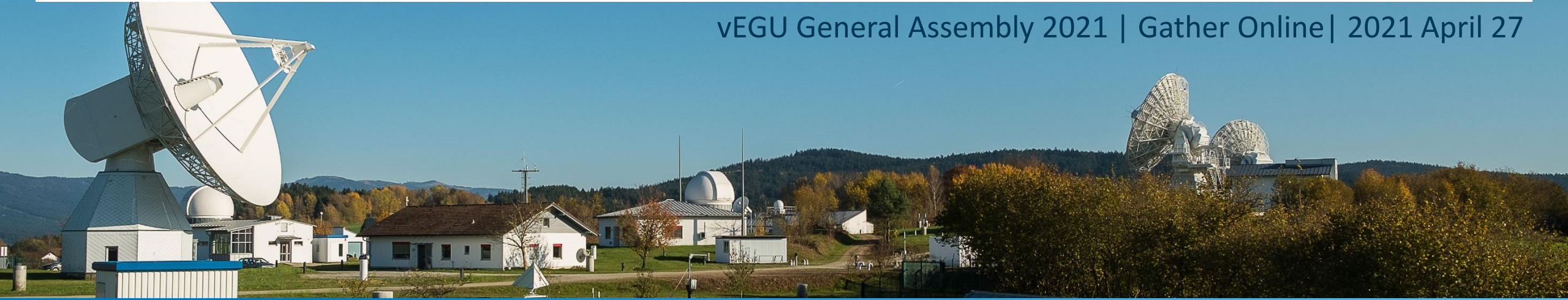




Federal Agency for
Cartography and Geodesy



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Combination of GNSS and VLBI data for consistent estimation of Earth Rotation Parameters

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Agenda

Motivation

Input for Combination

Combination Scheme - Overview

Constraining

Weighting

Daily Single-technique Solutions

Multi-day Intra-technique Combination - Procedure

Multi-day GNSS and VLBI Intensives Combination

Session-wise GNSS and VLBI R1/R4 Combination

Conclusion and Outlook

Motivation - Combination of GNSS and VLBI at NEQ level



ERP	R1/R4	INT		
dUT1	✓	✓	x	✓
LOD	✓	x	✓	✓
Polar motion	✓	x	✓	✓

Techniques' contributions to Earth Rotation Parameters (ERP)

benefits of combination of VLBI and GNSS

- + **GNSS** + **VLBI INT** daily resolution and shorter latency of a consistent set of all ERPs
- + stabilization of the ERPs by multi-day combination
- + stabilization of all ERPs through 24h **VLBI R1/R4** two times a week

current EOP daily combination @ IERS RS/PC, @ IERS EOP PC

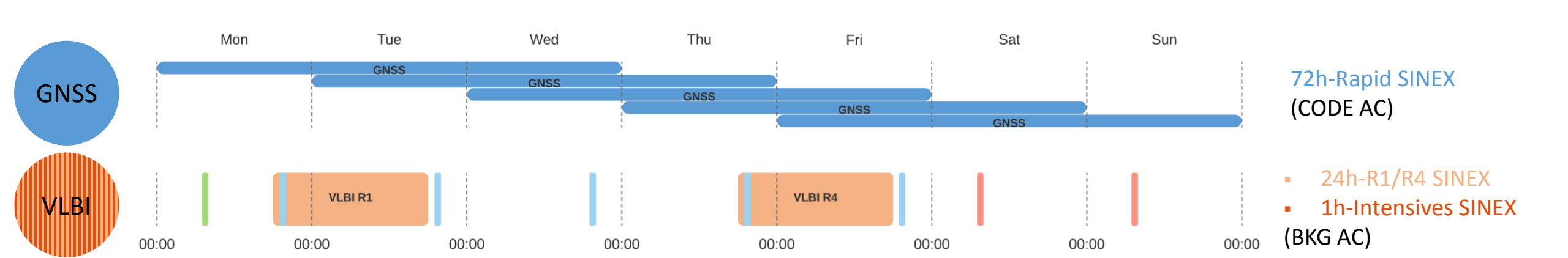
- combination at **parameter level**

IERS-14-C04

IERS-Bulletin-A

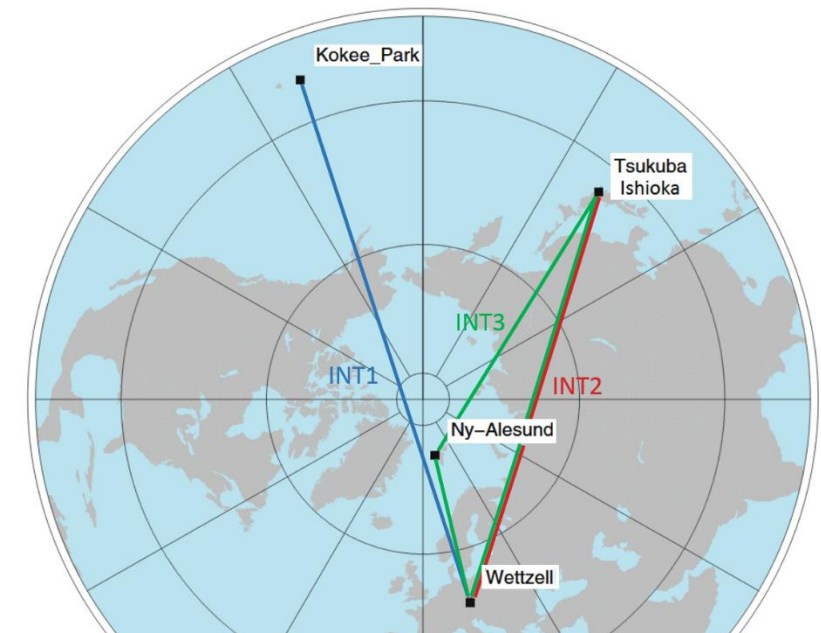
benefits of combination at **NEQ level** (SINEX)

- + considers correlations
- + consistent set of parameters
- + assures same underlying reference frame
- + flexibility to change reference frame / a priori
- + (positive) impact on other technique-specific parameters

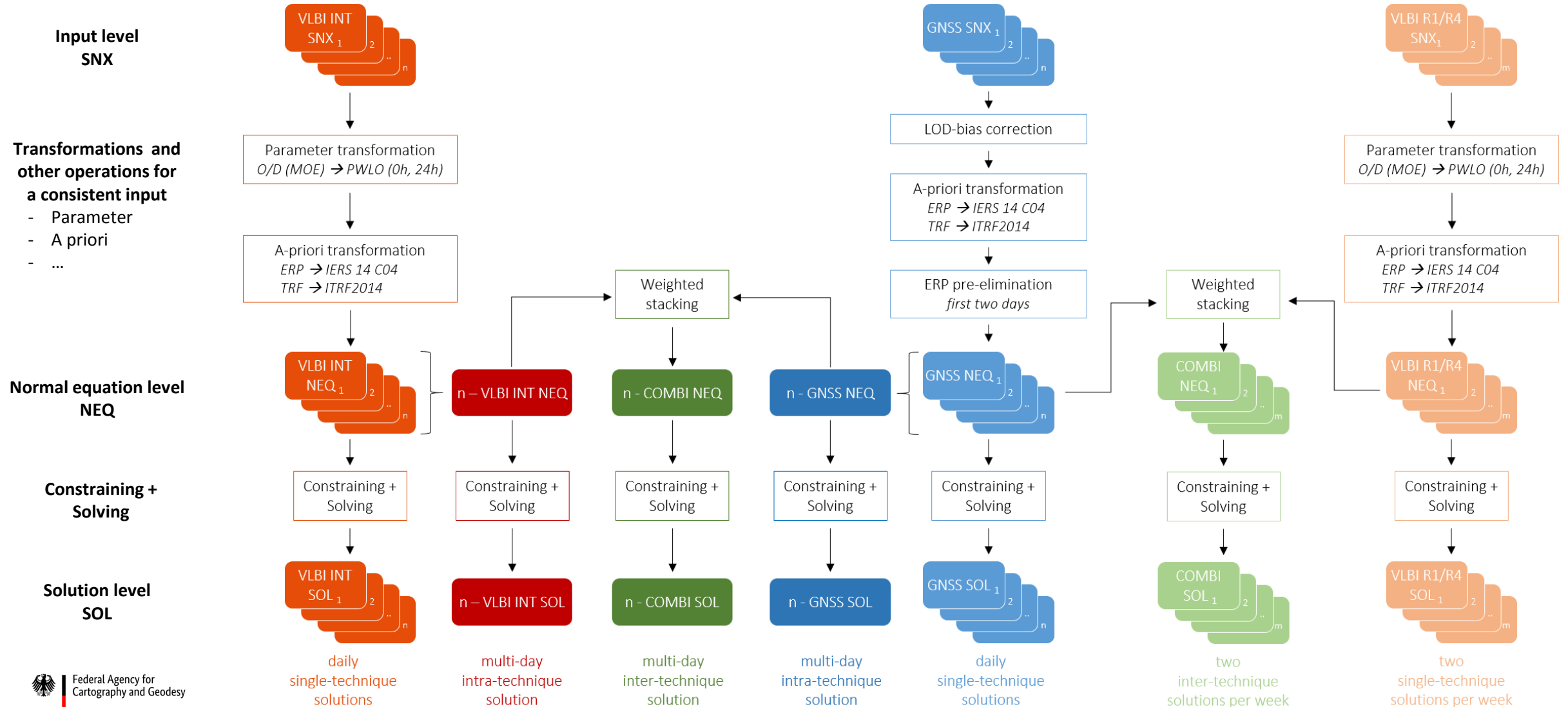


VLBI Intensive Sessions (INT)

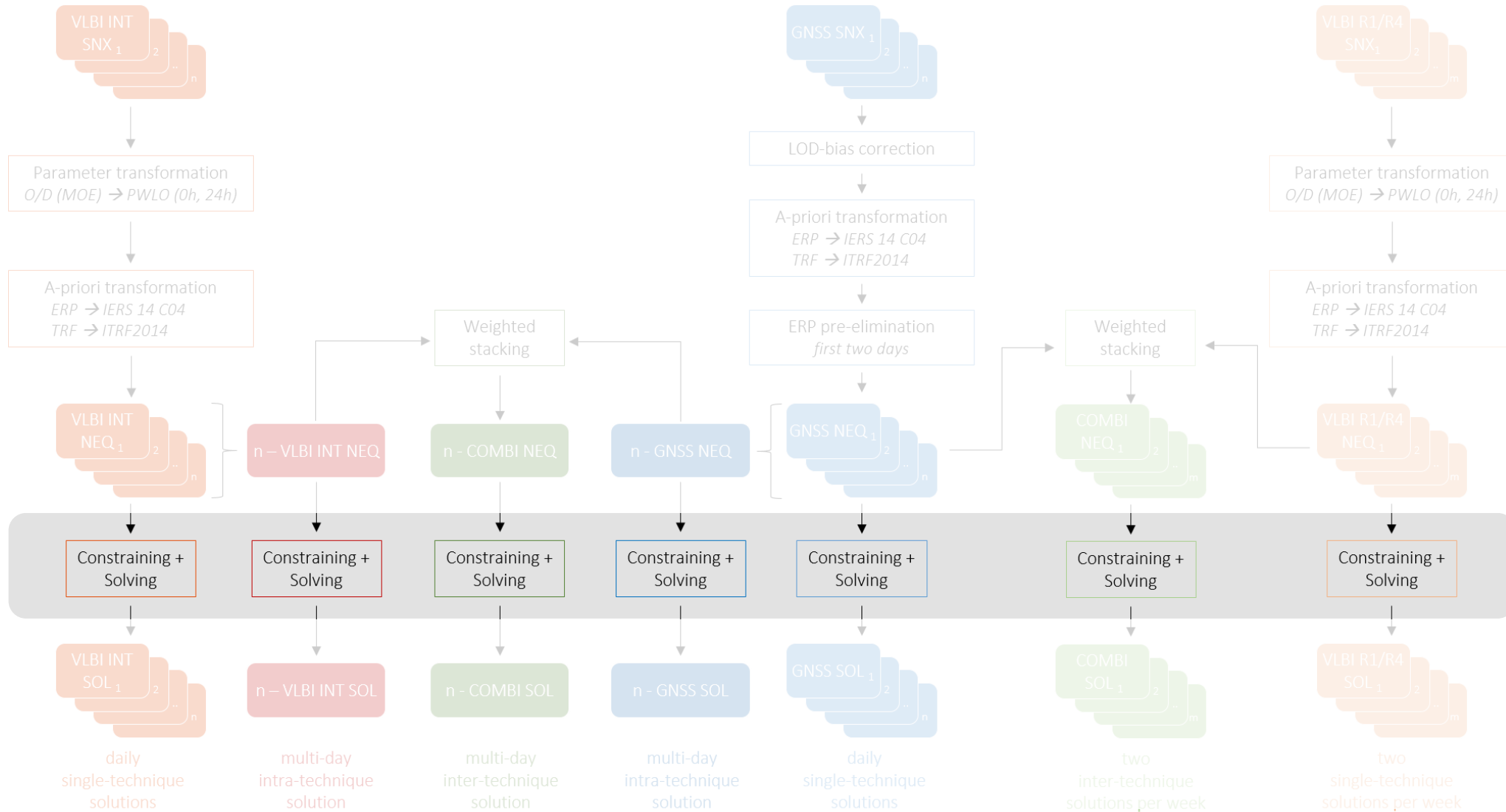
- Baselines optimized in East-West direction for the estimation of dUT1
- One hour observation per day, not equidistant in time
- 1-2 days latency (R1/R4 Sessions 14 days)



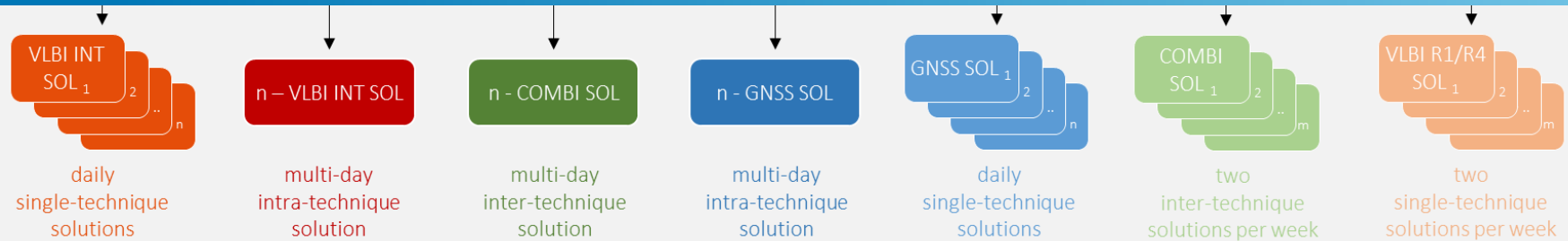
Combination Scheme - Overview



Combination Scheme – Constraining

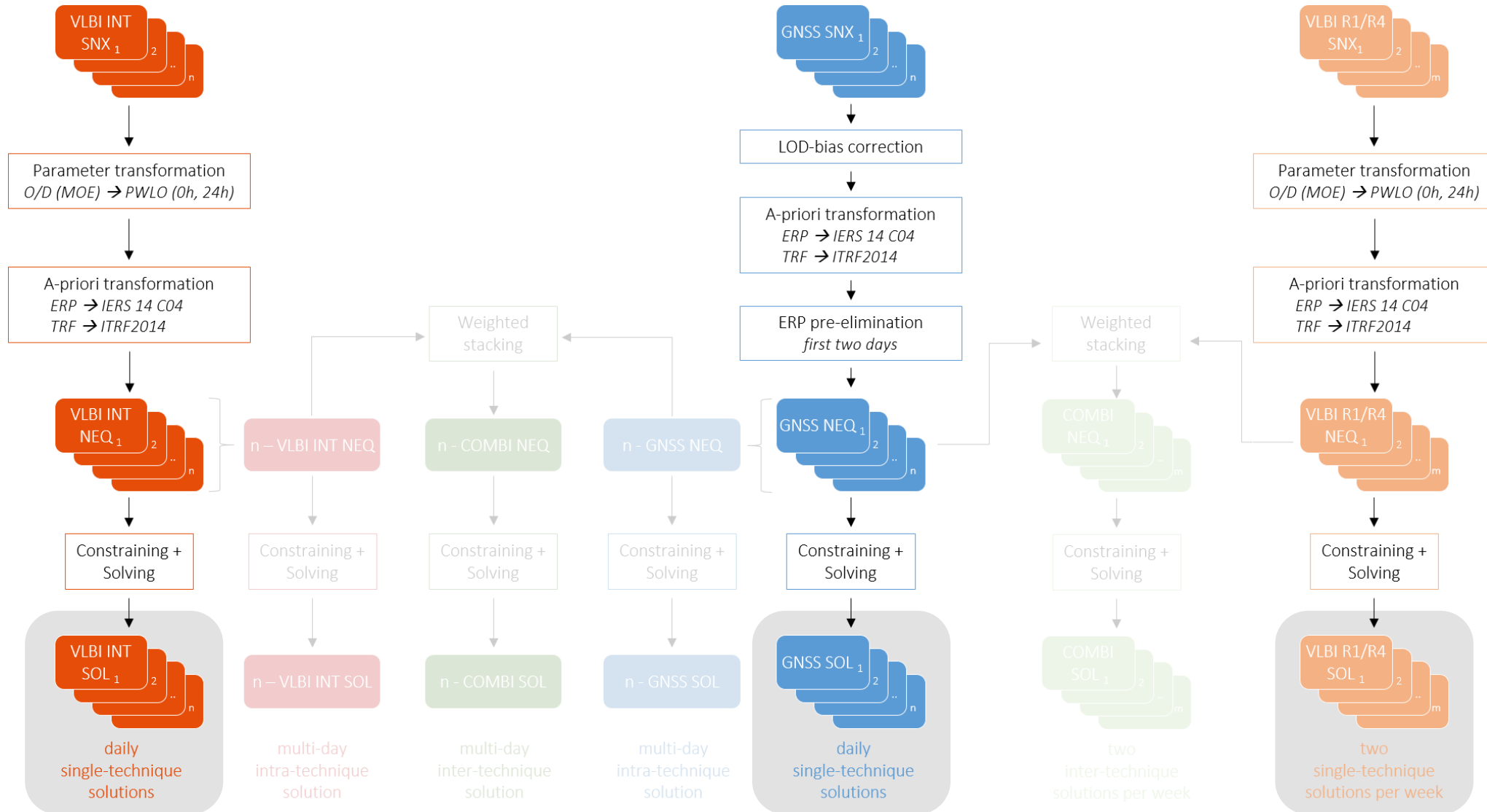


Constraining – Overview

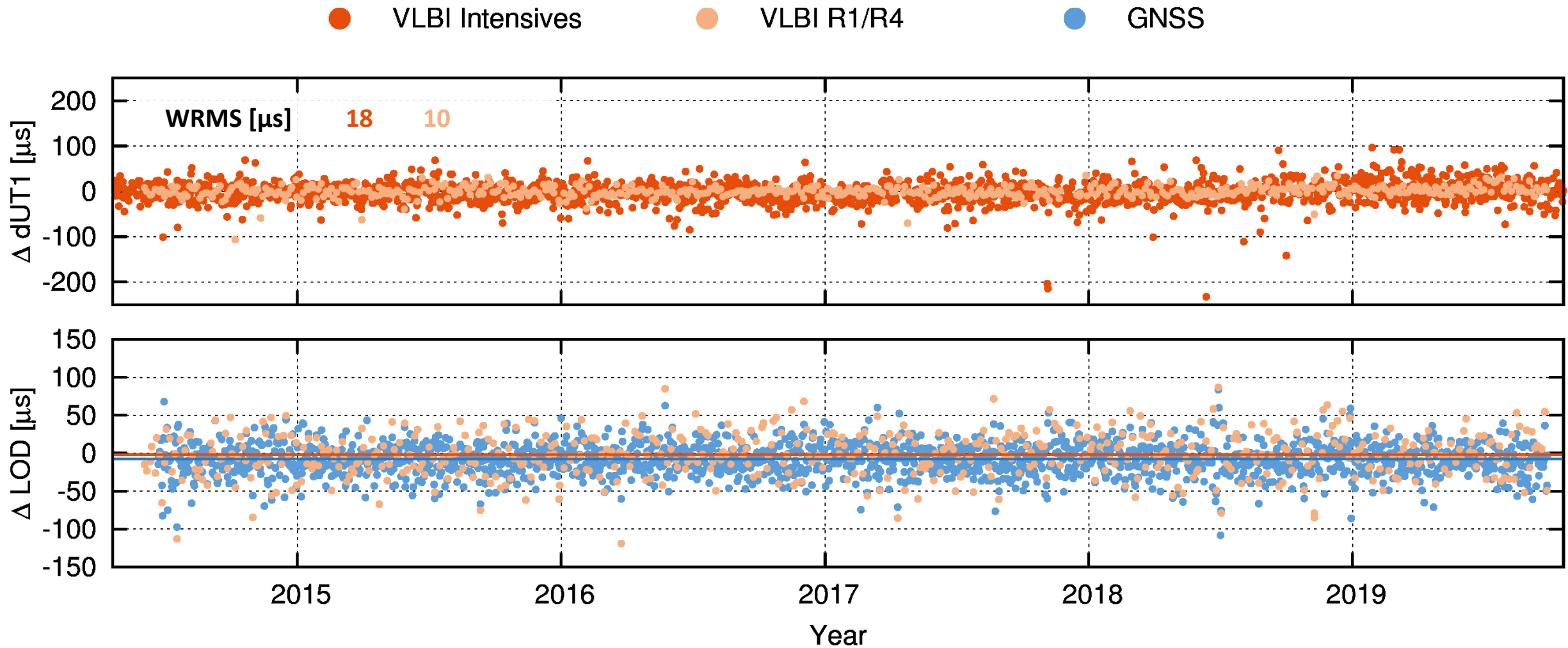


Parameter (explicit)		VLBI INT	n-VLBI INT	n-COMBI	n-GNSS	GNSS	COMBI	VLBI R1/R4
EOP	UT1-UTC (dUT1)	LOD fixed to IERS-14-C04	-	-	first dUT1 fixed to IERS-14-C04	first dUT1 fixed to IERS-14-C04	-	-
	X-/Y-pole	fixed to IERS-14-C04	fixed to IERS-14-C04	-	-	-	-	-
	nutation	-	-	-	-	-	-	-
TRF		fixed to ITRF2014	fixed to ITRF2014	GNSS: NNR/NNT for IGS core sites, VLBI: fixed to ITRF2014	minimum constraints (NNR/NNT for IGS core sites)	minimum constraints (NNR/NNT for IGS core sites)	GNSS: NNR/NNT for IGS core sites, VLBI: NNR/NNT for IVS core sites	minimum constraints (NNR/NNT for IVS core sites)
CRF		-	-	-	-	-	-	fixed to ICRF-3 defining sources
technique-specific (GNSS)	Geocenter	-	-	fixed to zero	fixed to zero	fixed to zero	fixed to zero	-
	Satellite PCO in Z-direction	-	-	fixed to a priori (SINEX)	fixed to a priori (SINEX)	fixed to a priori (SINEX)	fixed to a priori (SINEX)	-

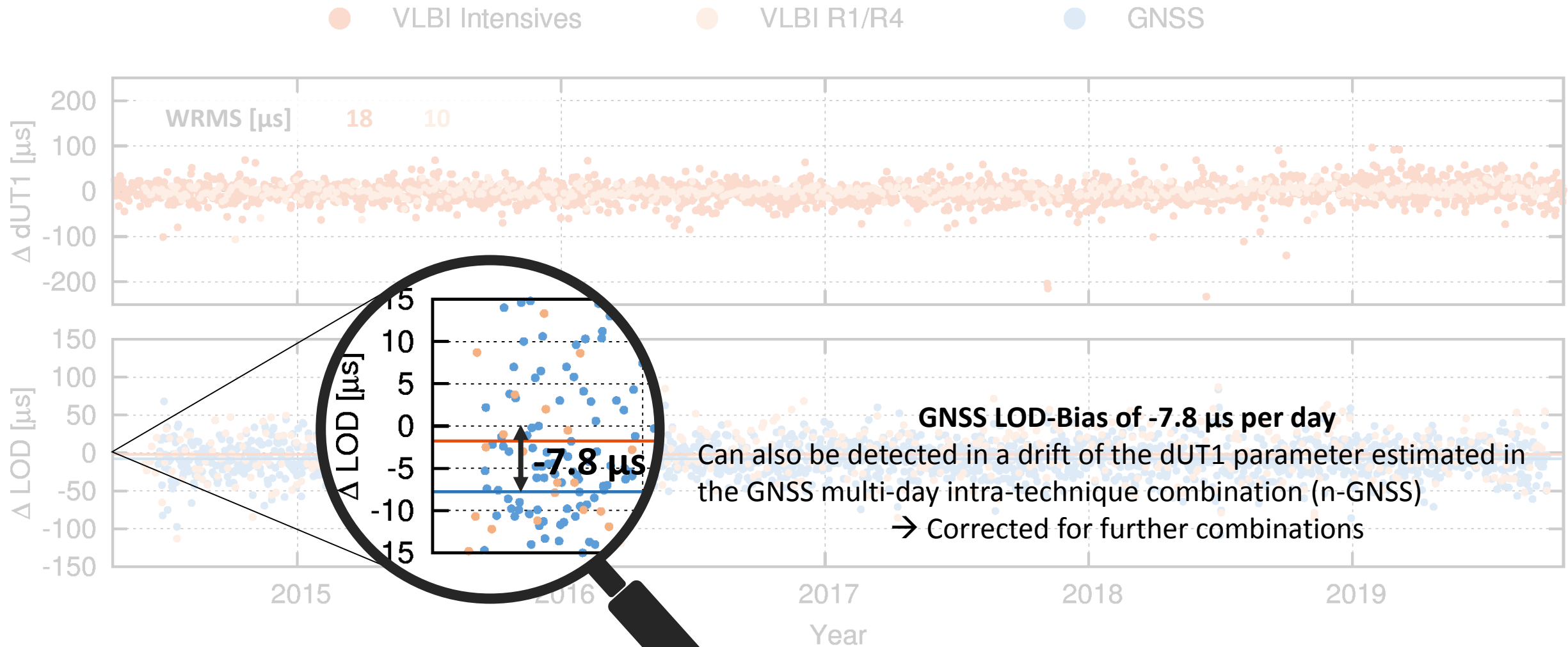
Combination Scheme – Single-technique Solutions



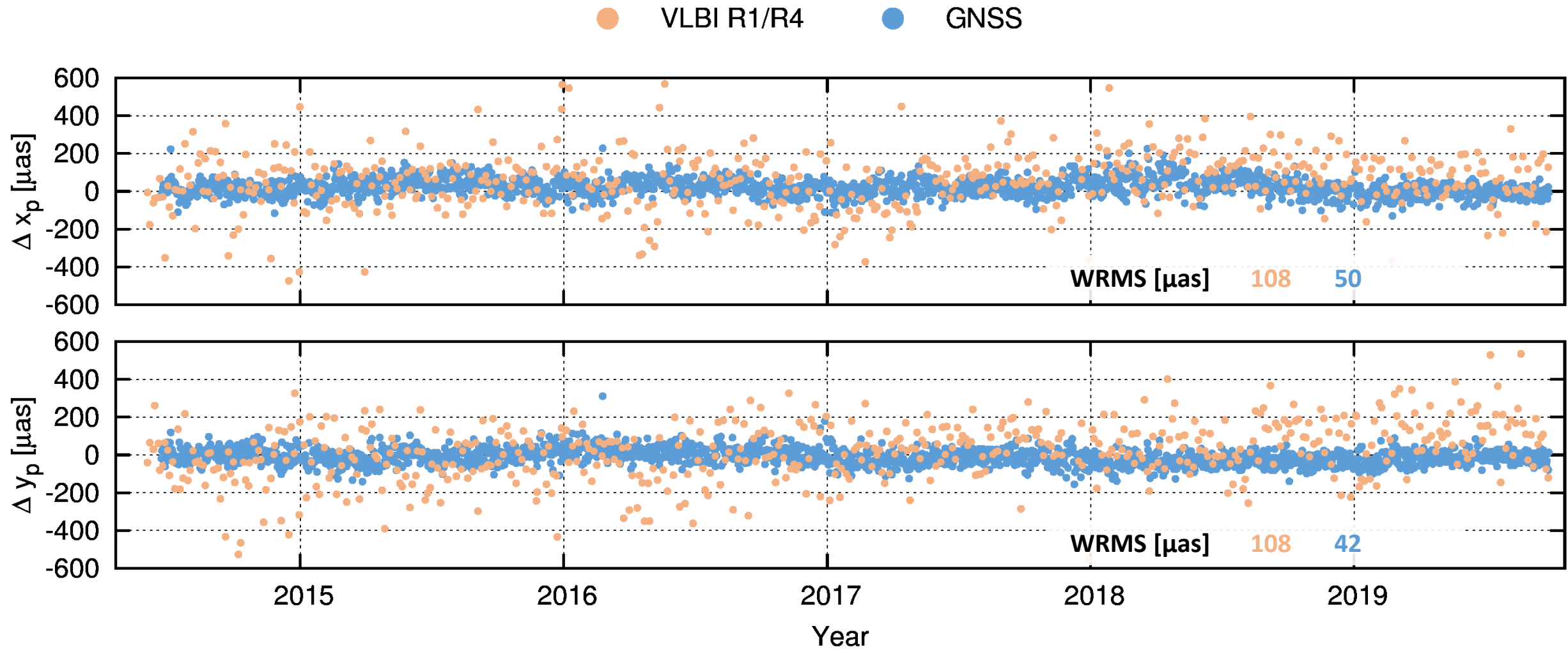
Single-technique solutions – dUT1 and LOD w.r.t. Bulletin A



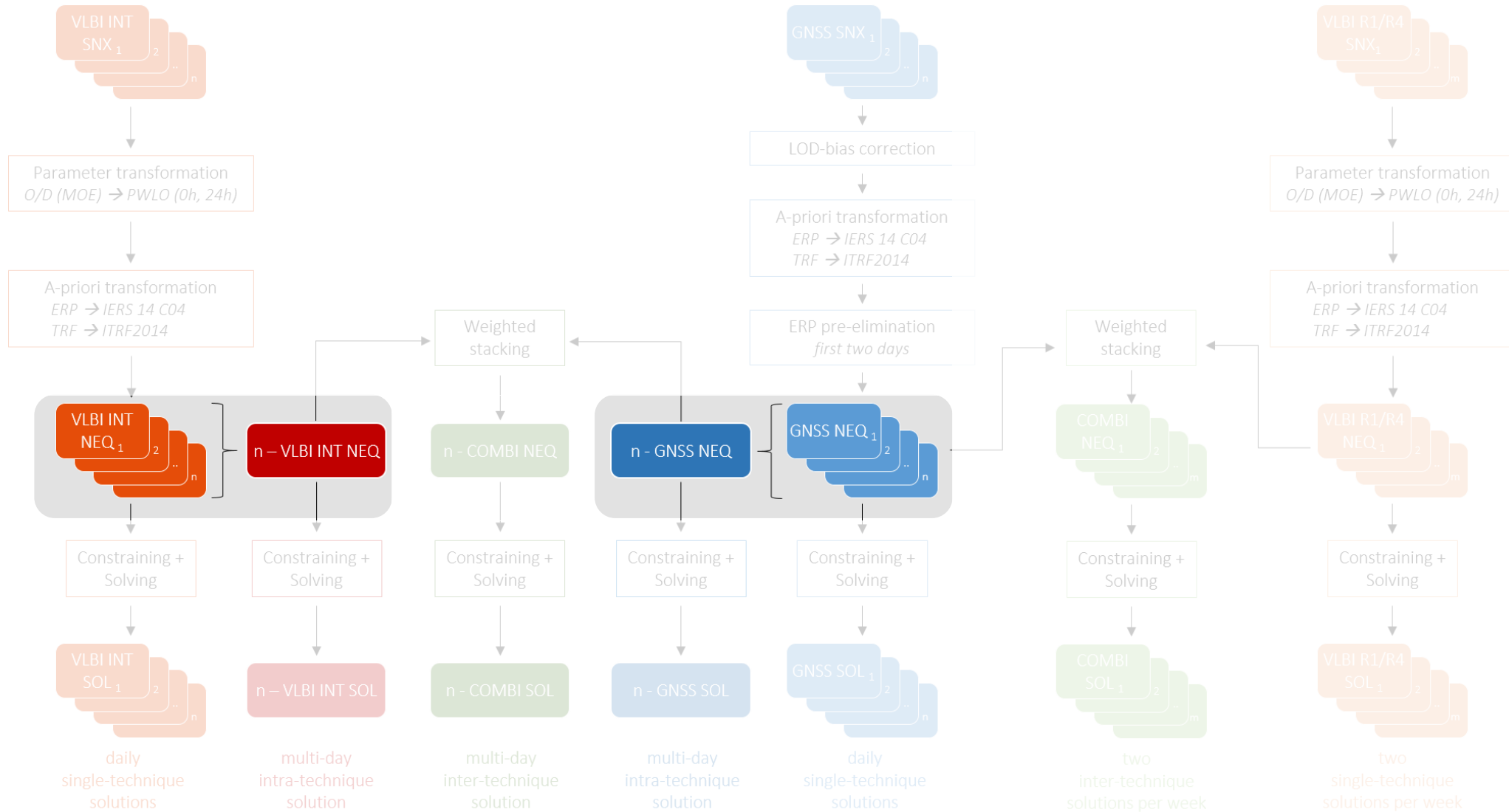
Single-technique solutions – dUT1 and LOD w.r.t. Bulletin A



Single-technique solutions – Pole Coordinates w.r.t. IERS-14-C04



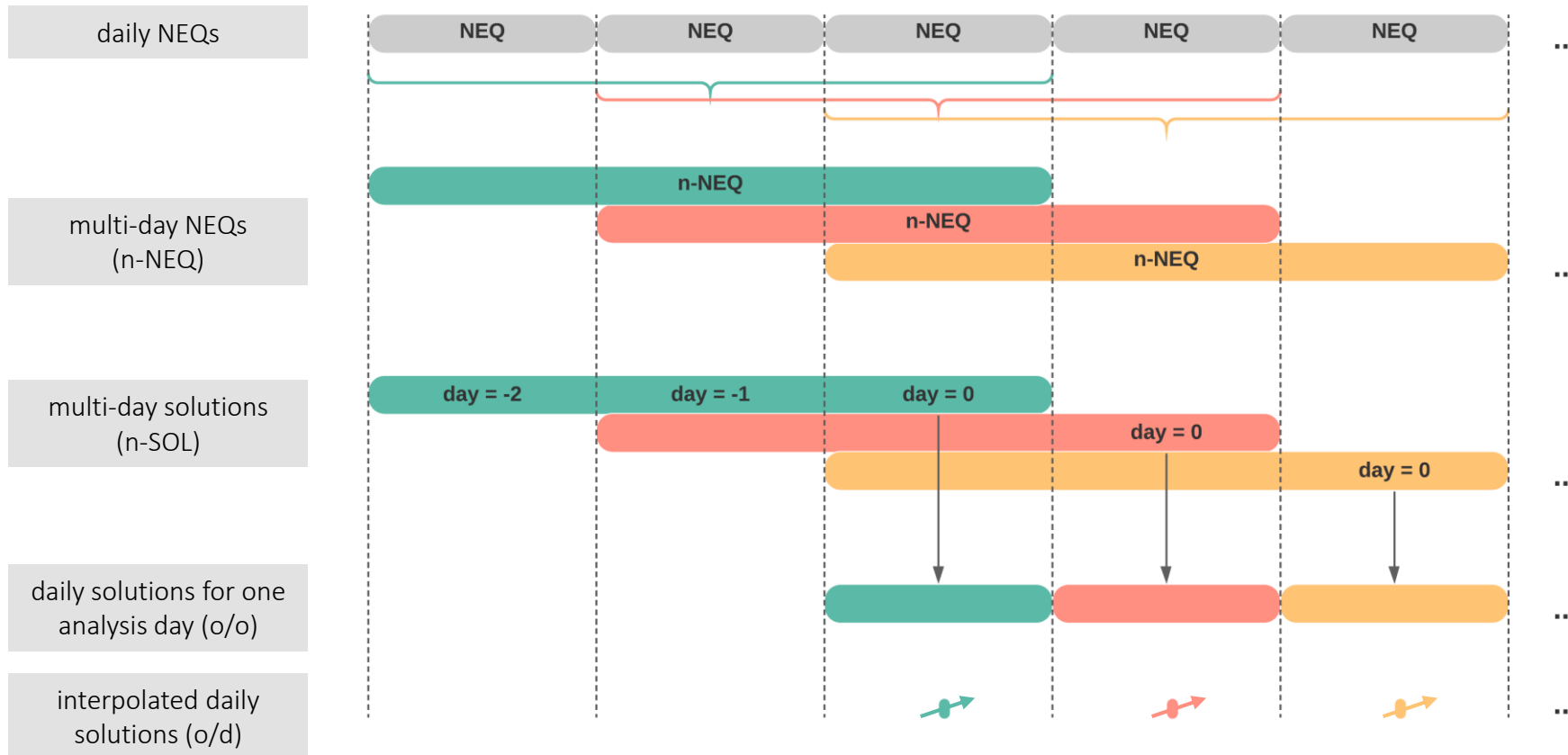
Combination Scheme – Multi-day Intra-technique Combination Procedure



Multi-day Intra-technique Combination - Procedure

Example for a 3-day intra-technique combination ($n=3$)

n ... Number of combined days



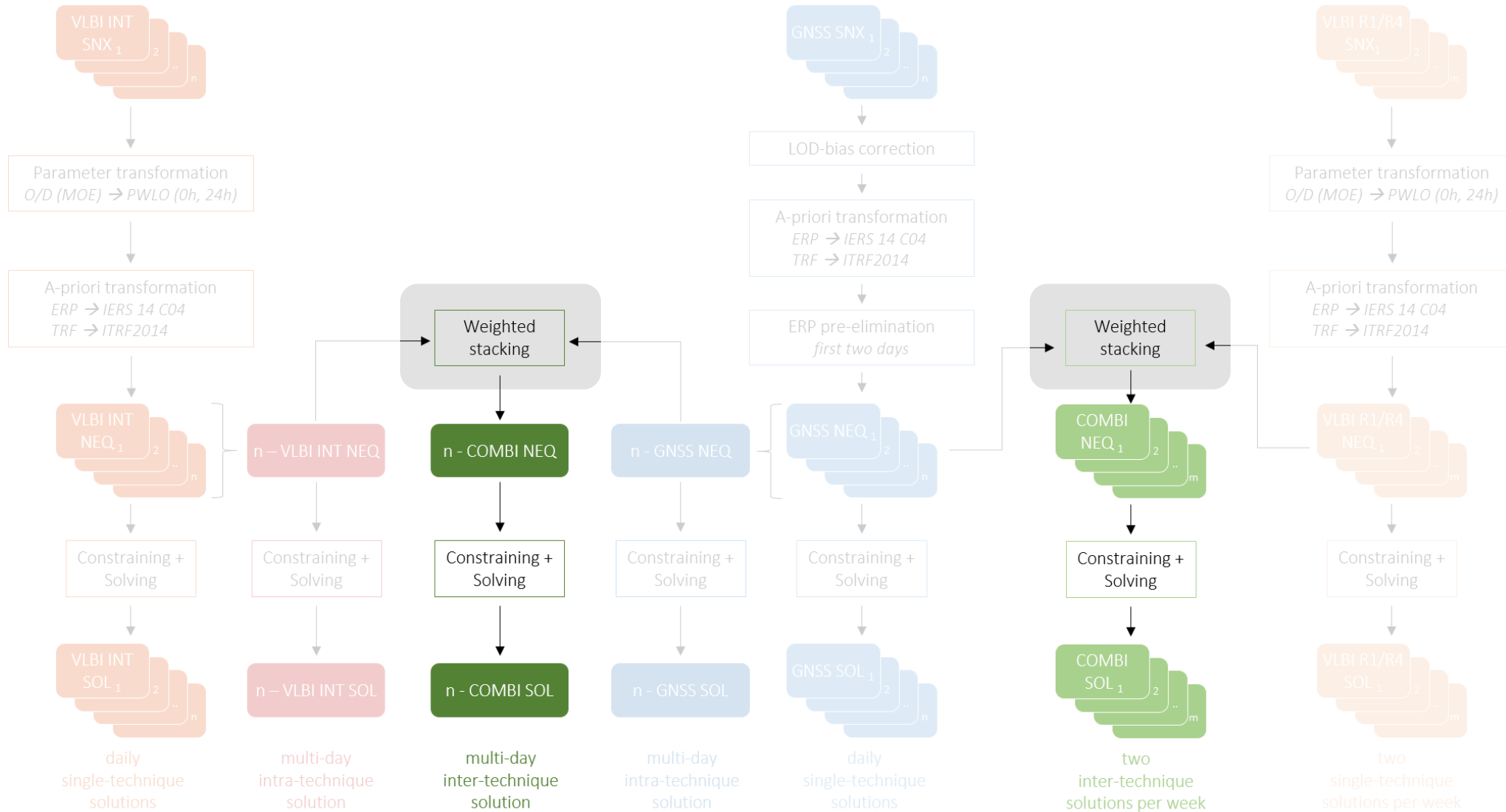
Generation of multi-day NEQs by shifting a "sliding window" by one day and stacking the daily NEQs

Constraining + Solving

ERP extraction of one selected day of the multi-day polygons (e.g. day=0)

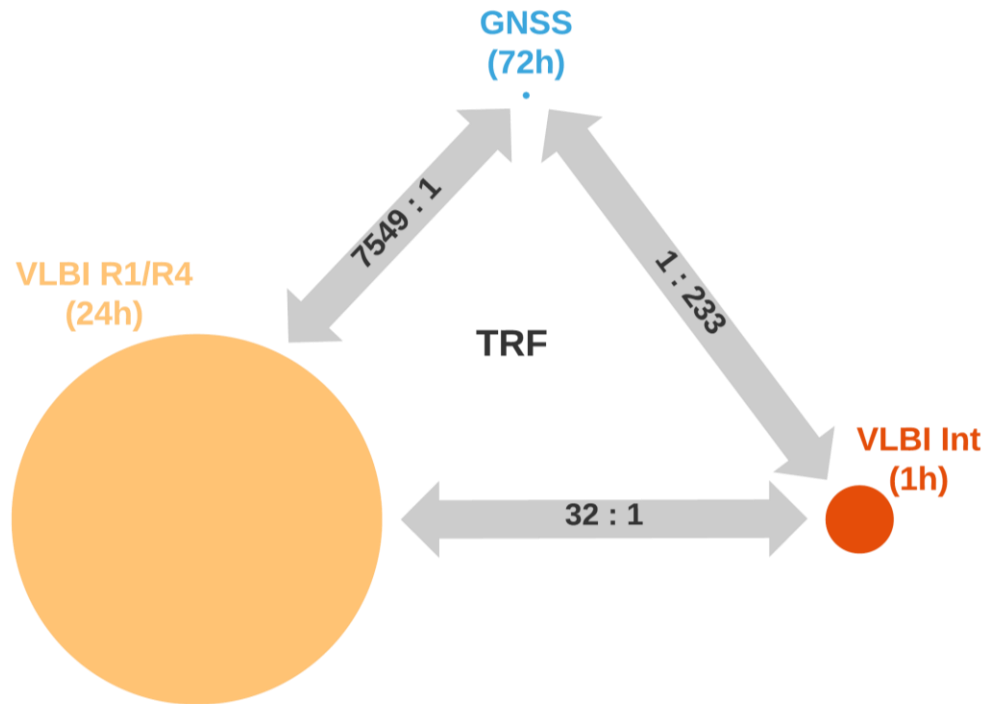
ERP interpolation to obtain one validation epoch per day (e.g. 12h)

Combination Scheme – Weighting of the technique-specific NEQs

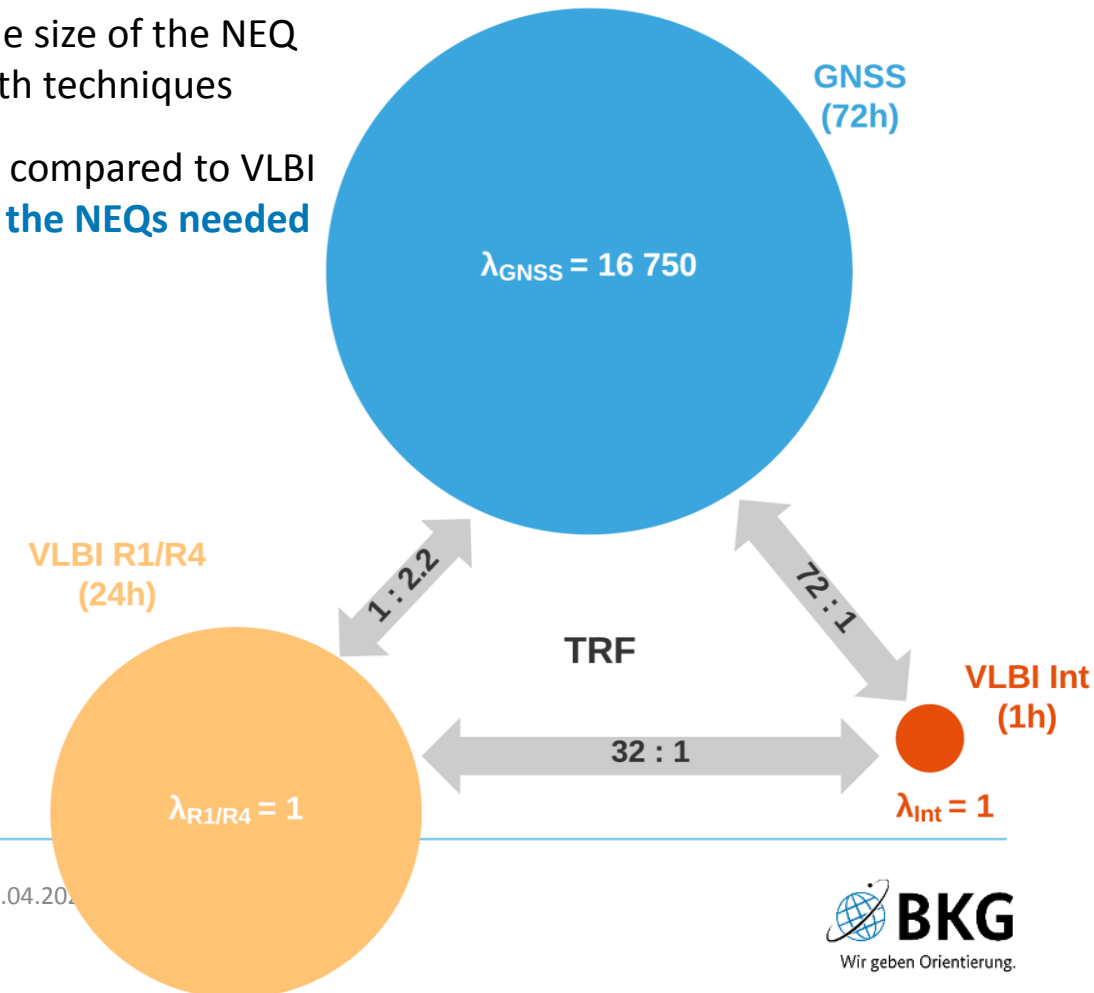


Weighting of the technique-specific NEQs

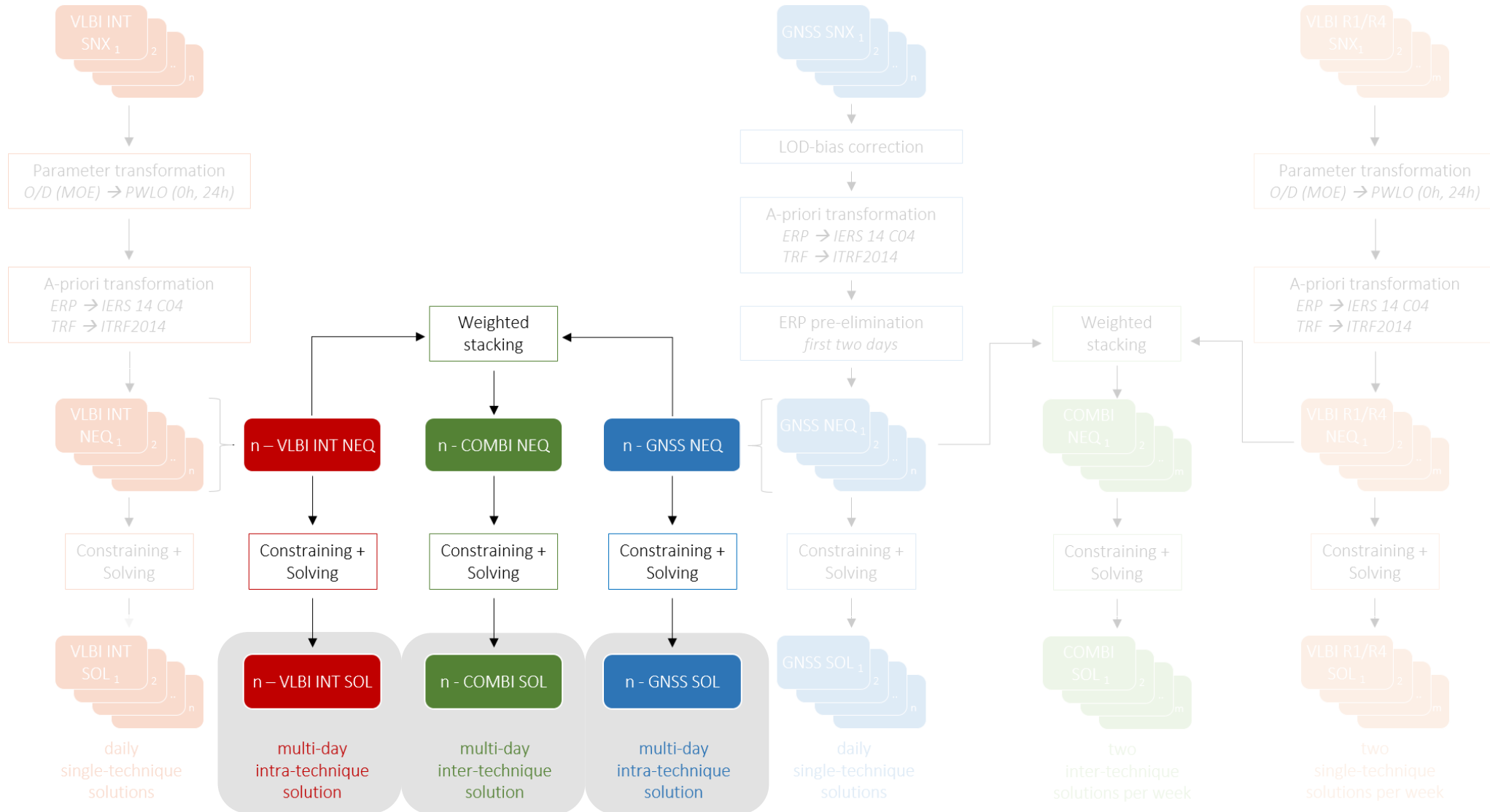
- Ratios of the **average NEQ diagonal element per parameter group** (TRF, pole, dUT1) between GNSS and VLBI
- **Imbalance** in the size of the NEQ elements of both techniques
- GNSS too weak compared to VLBI
→ **Rescaling of the NEQs needed**



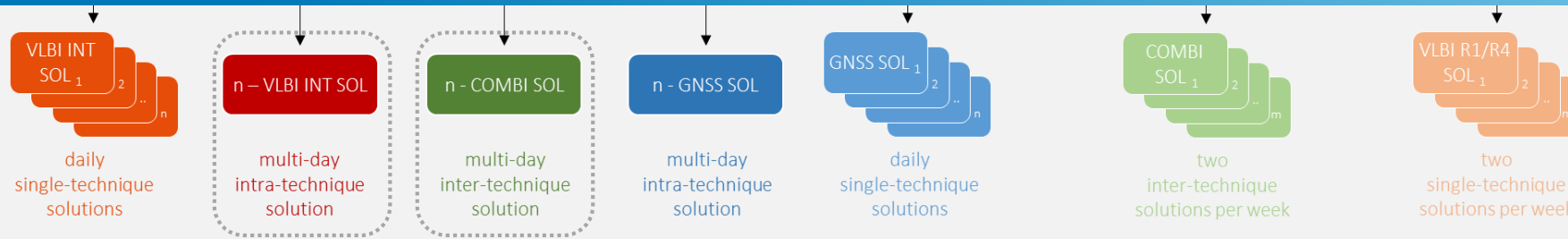
- Scale $16750 \triangleq (72\text{h GNSS} : 1\text{h VLBI}_{\text{INT}} : 24\text{h VLBI}_{\text{R1/R4}})$
→ **Ratio of the observation periods**
- Scale 16750 was used for **all following combination** results



Combination Scheme – Multi-day Combination of VLBI Intensives and GNSS



Multi-day Combination of VLBI Intensives and GNSS – Solutions

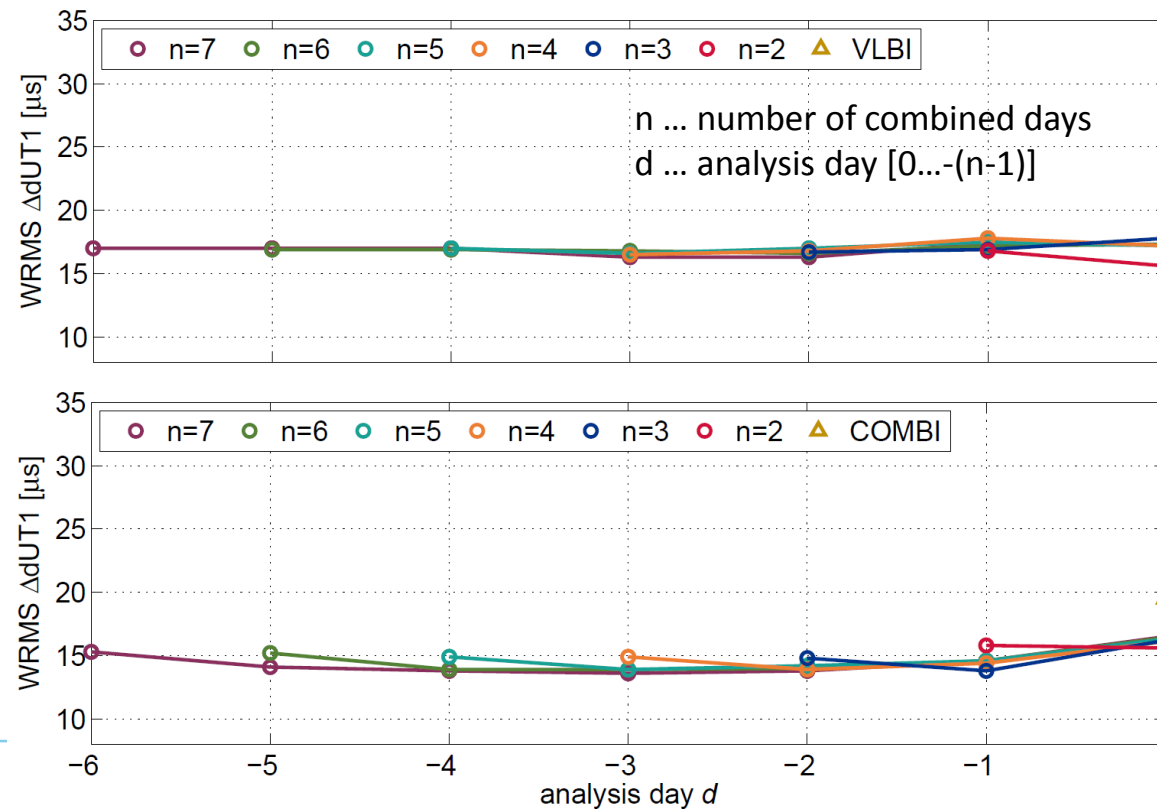


An example for dUT1 from ...

... **n-day intra-technique VLBI INT solution**

... **n-day inter-technique COMBI solution**

WRMS w.r.t. Bulletin A
analyzed at middle observation
epochs of the VLBI Intensives



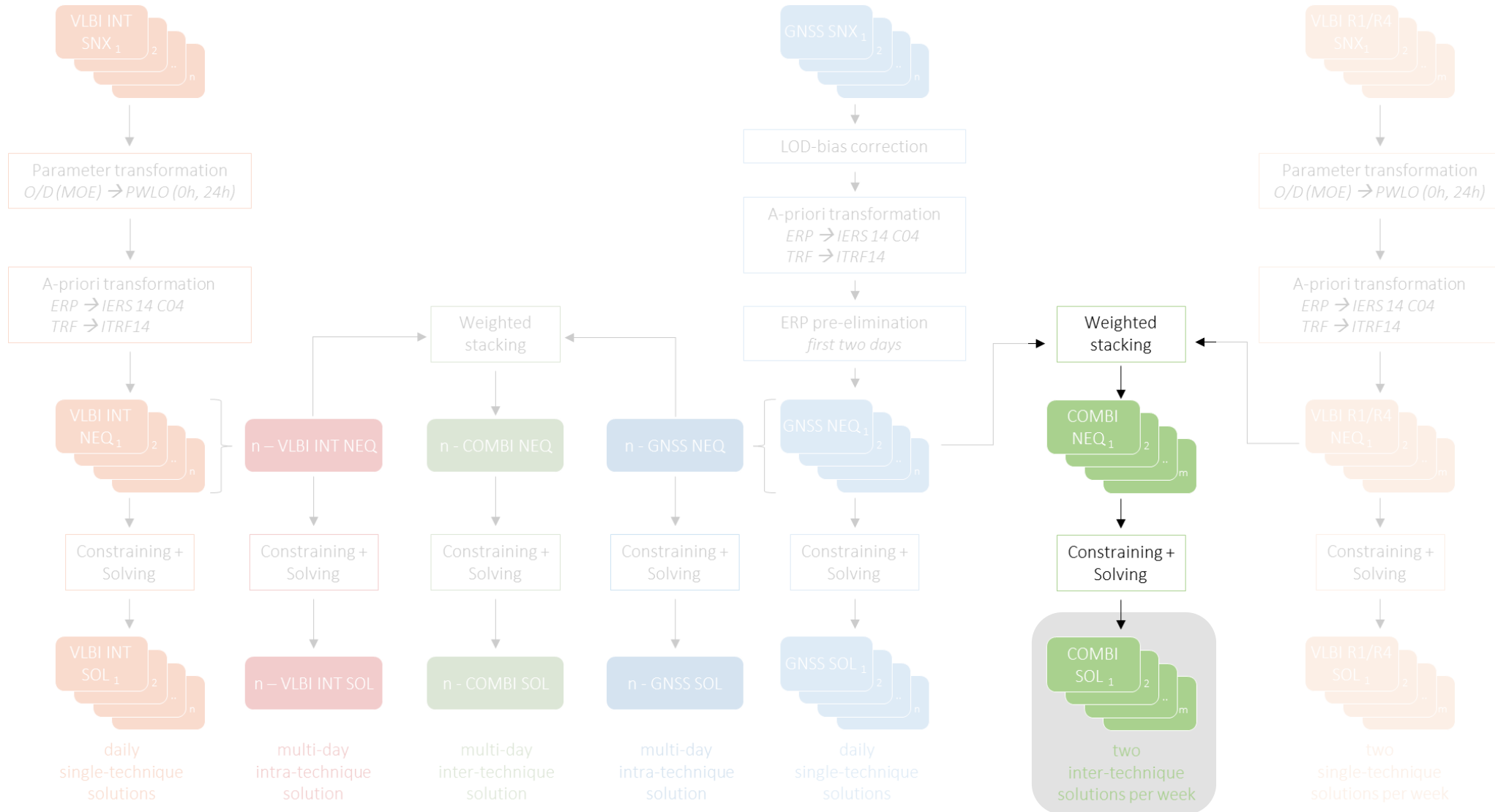
n – VLBI INT

- constant level of accuracy regardless the number of combined days n and the day of analysis d at INT epochs (15.6-17.8 μs)
- no constraining of the LOD** parameter by fixing the a priori value is required
- Higher accuracies outside the INT** observation period

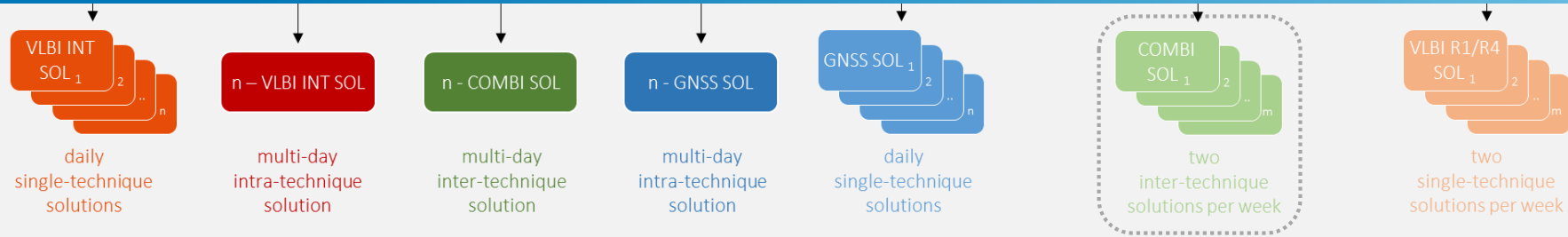
n – COMBI

- Significant reduction of WRMS** compared to VLBI, n-VLBI as well as COMBI
- Merging of the *continuous relative 24h-GNSS-LOD* and high quality, but limited to *one hour per day, absolute VLBI-INT-dUT1*
→ **high-quality 24h-dUT1 product**

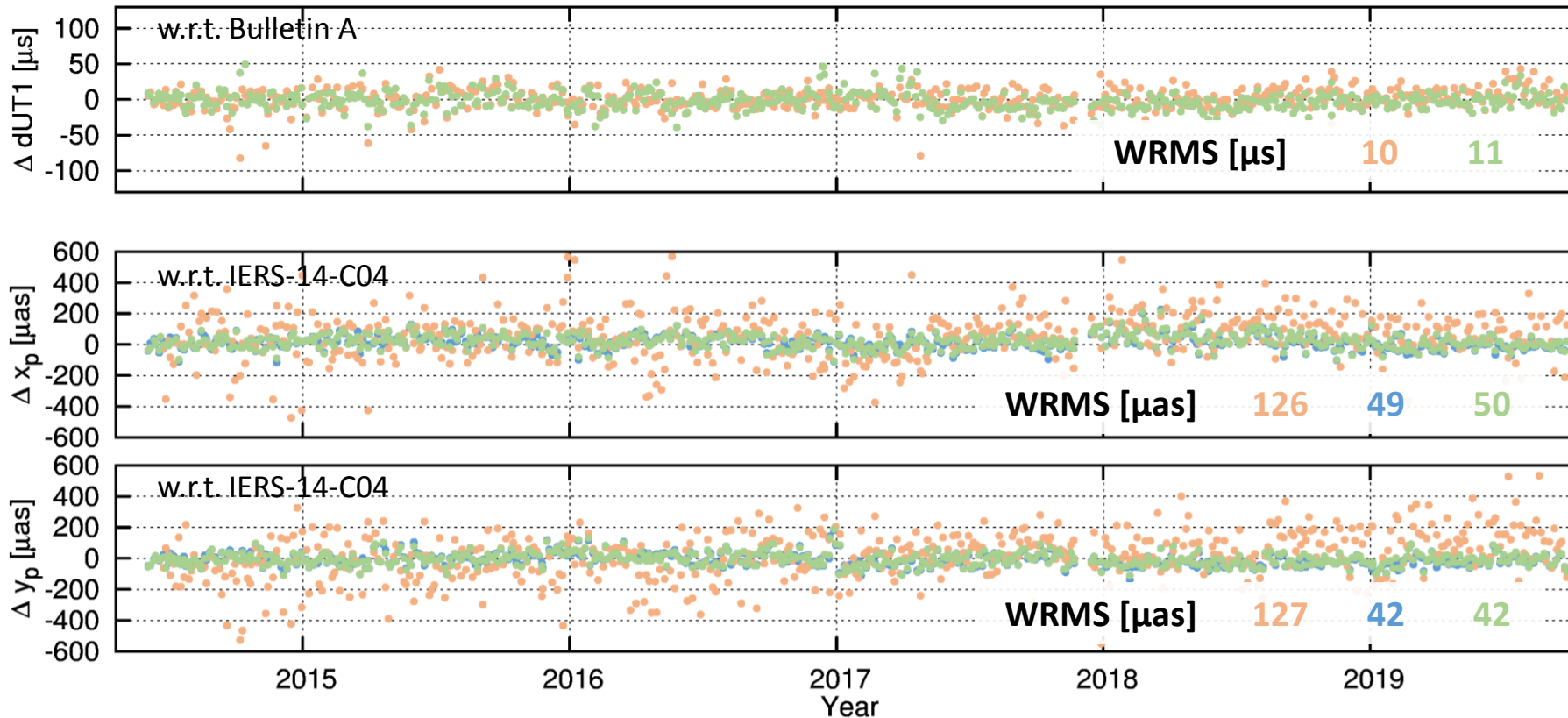
Combination Scheme – Combination of VLBI R1/R4 and GNSS Solutions



Combination of VLBI R1/R4 and GNSS Solutions – dUT1 and Polar motion



● VLBI R1/R4 ● GNSS ● COMBI VLBI R1/R4 + GNSS



→ **Combined dUT1** at the same precision level as the high-quality VLBI-dUT1

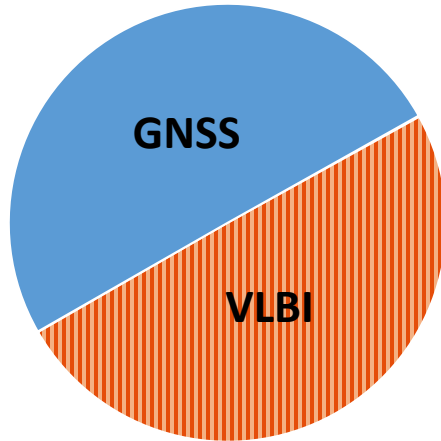


→ **Combined pole coordinates** at the same precision level as the high-quality GNSS-pole



Conclusion and Outlook

Conclusion



- ✓ Combination of GNSS and VLBI provides a **full and consistent** set of ERPs
- ✓ Combination based on homogenized, datum-free NEQs with same parameterization and a priori values of parameters

→ Allows a rigorous **combination on NEQ level**

GNSS + VLBI Intensives

- ✓ ability to determine **polar motion and LOD with GNSS** complements the estimation of **dUT1 with VLBI INT**
 - **Daily and consistent set of all ERPs with short latencies** (1-2 days)
- ✓ Multi-day combinations: Estimation of ERPs as continuous, piece-wise linear polygons
 - **Stabilizing effect** on the estimated parameters, especially for dUT1
 - **regularly spaced time series** (at e.g. 12:00 epochs) of dUT1 together with polar motion

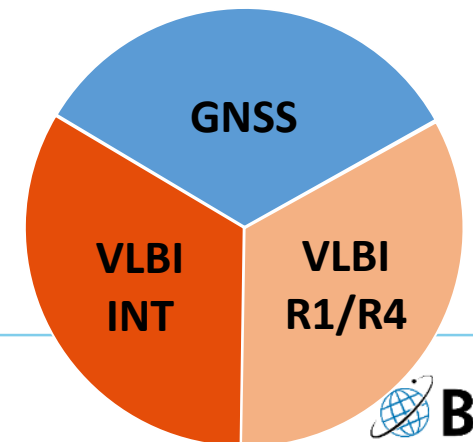
GNSS + VLBI R1/R4

- ✓ consistent set of high-quality ERPs **two times a week**

Outlook



- Multi-day combination of all three session types **VLBI INT + VLBI R1/R4 + GNSS**
- Improvement of **datum definition** by adding local ties at collocated sites
- **Development of an operational combined ERP product**





Federal Agency for
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Thank you for your kind attention!

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