



Federal Agency for
Cartography and Geodesy



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Earth rotation parameters estimated from combined GNSS and VLBI data and its impact on satellite orbits

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(2) Federal Office of Topography (swisstopo, Wabern, Switzerland)

(3) Astronomical Institute of the University of Bern (AIUB, Bern, Switzerland)

Motivation for a combined ERP product

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ERP	GNSS	VLBI INT	VLBI R1/R4	SLR
dUT1	-	✓	✓	-
LOD	✓	-	✓	✓
Polar motion	✓	-	✓	✓

Techniques' contributions to Earth Rotation Parameters (ERP)


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Techniques' contributions to Earth Rotation Parameters (ERP)

Benefits of multi-technique combination

- **GNSS + VLBI INT** → daily resolution and shorter latency of a consistent set of all ERPs
- multi-day combination → stabilization of ERP

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- 24h **VLBI R1/R4** twice/week → stabilization of ERP
- stable contribution of LOD from **SLR** → improvement of ERP

Motivation for a combined ERP product



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Techniques' contributions to Earth Rotation Parameters (ERP)


Current ERP daily combination

- combination at **parameter level**

@ IERS RS/PC → IERS-14-C04

@ IERS EOP PC → IERS-Bulletin-A

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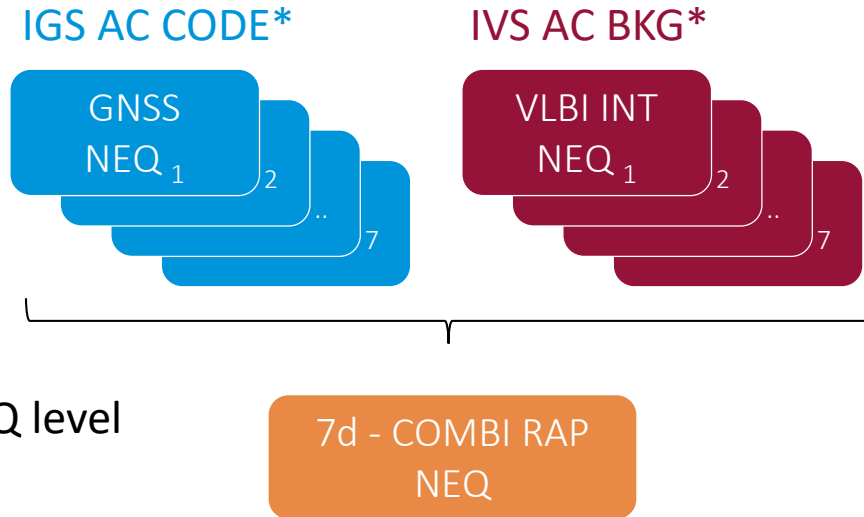
@ IERS EOP PC → IERS-Bulletin-A

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

- considers correlations
- consistent set of parameters
- assures same underlying reference frame
- (positive) impact on other technique-specific parameters

New BKG ERP product under development

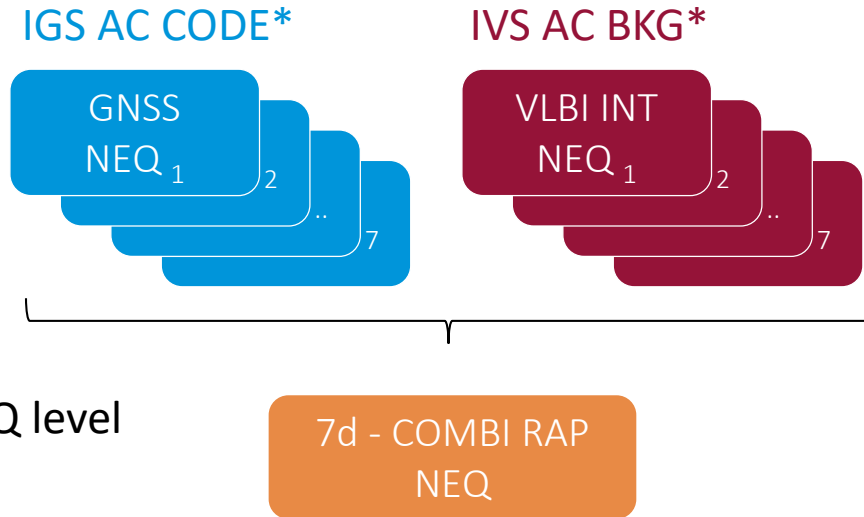
New BKG ERP product under development



- Derived from combination at NEQ level
- Using NEQ from SINEX files

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- * official VLBI Intensives solution from IVS Analysis Center "BKG"

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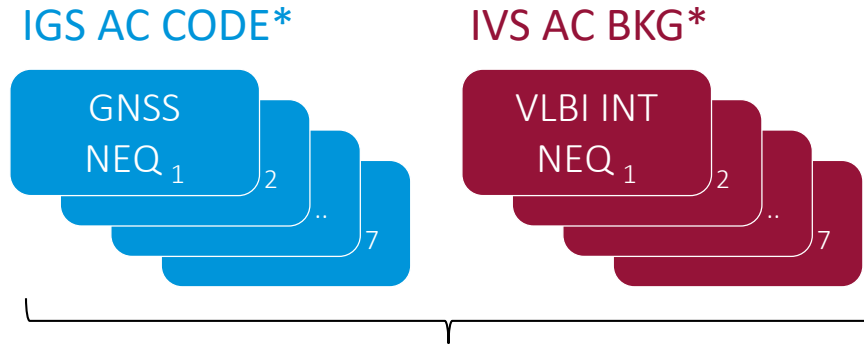
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CODE = Center for Orbit Determination in Europe, a consortium of

- Astronomical Institute of the University of Bern (AIUB, Bern, Switzerland)
- Swiss Federal Office of Topography (swisstopo, Wabern, Switzerland)
- Federal Agency for Cartography and Geodesy (BKG, Frankfurt a. M., Germany)
- Institut für Astronomische und Physikalische Geodäsie, Technische Universität München (IAPG/TUM, Munich, Germany)

IGS AC CODE is operated by AIUB, using the Bernese GNSS Software

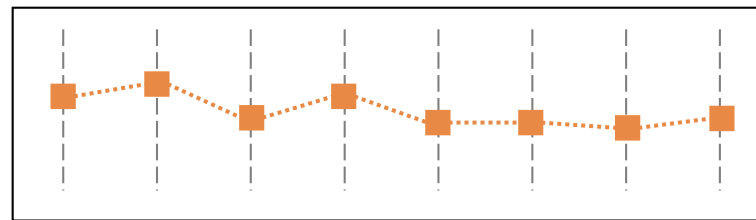
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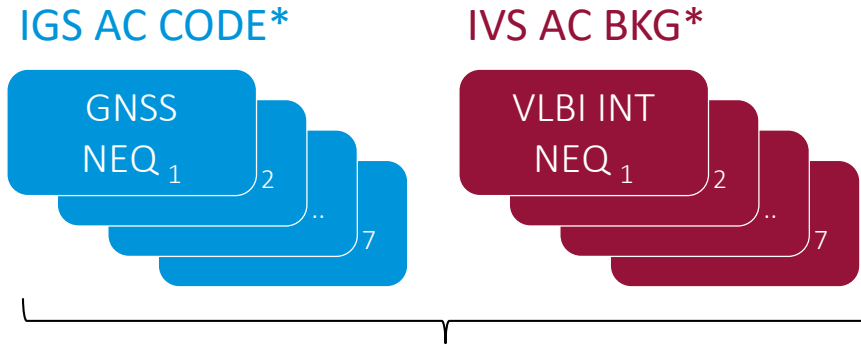
- Derived from combination at NEQ level
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- Best ERP result:
7-day piecewise linear polygon

7d - COMBI RAP
NEQ



BKG ERP Product

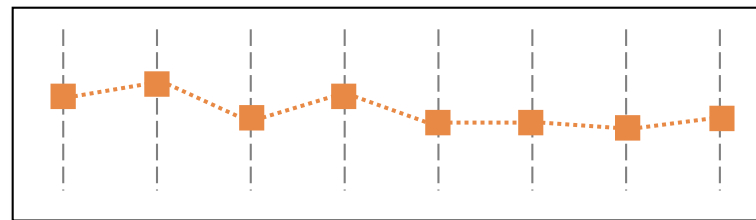
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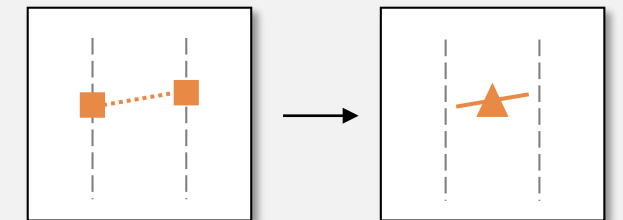
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BKG ERP Product

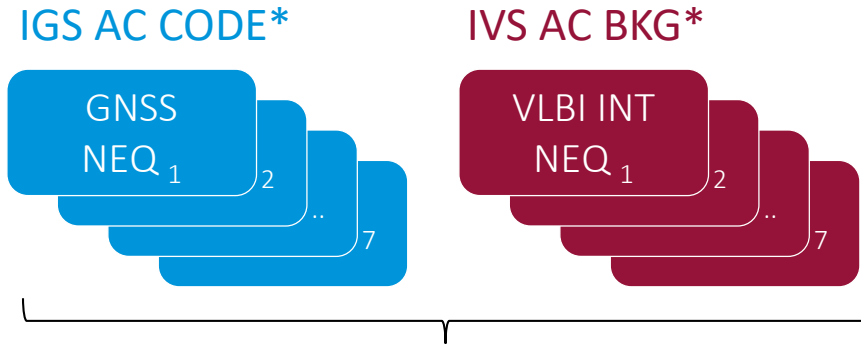
dUT1 parameter representation contains LOD implicitly



2 piecewise
linear offsets

offset + drift

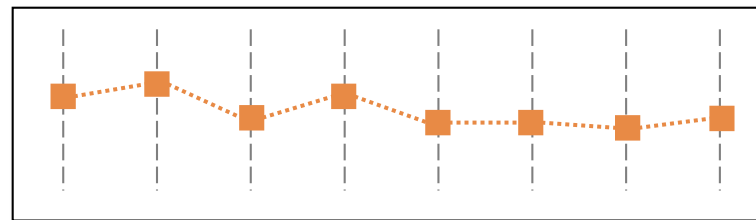
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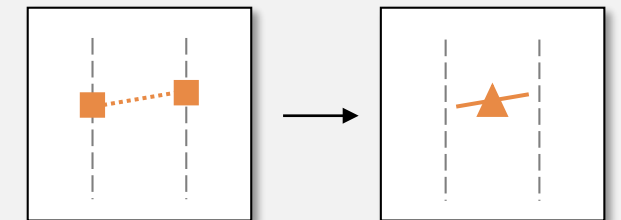
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BKG ERP Product

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Lengert L, Thaller D, Flohrer C, Hellmers H, Girdiuk A (2021):
Combination of GNSS and VLBI data for consistent estimation of Earth Rotation Parameters.
Proceedings of the 25th European VLBI Group for Geodesy and Astrometry Working Meeting (EVGA 2021). (eds. R. Haas). ISBN: 978-91-88041-41-8.
https://www.oso.chalmers.se/evga/25_EVGA_2021_Cyberspace.pdf

ERP product validation – OPTION 1

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Compare ERP product w.r.t. external reference

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Reference series: IERS-Bulletin-A, IERS-14-C04, ..

Validation epoch: 12:00 UTC, middle of VLBI observation epoch, ..

ERP product: different solutions A, B, C (technique, arc-length, ..)

ERP product validation – OPTION 1

Compare ERP product w.r.t. external reference

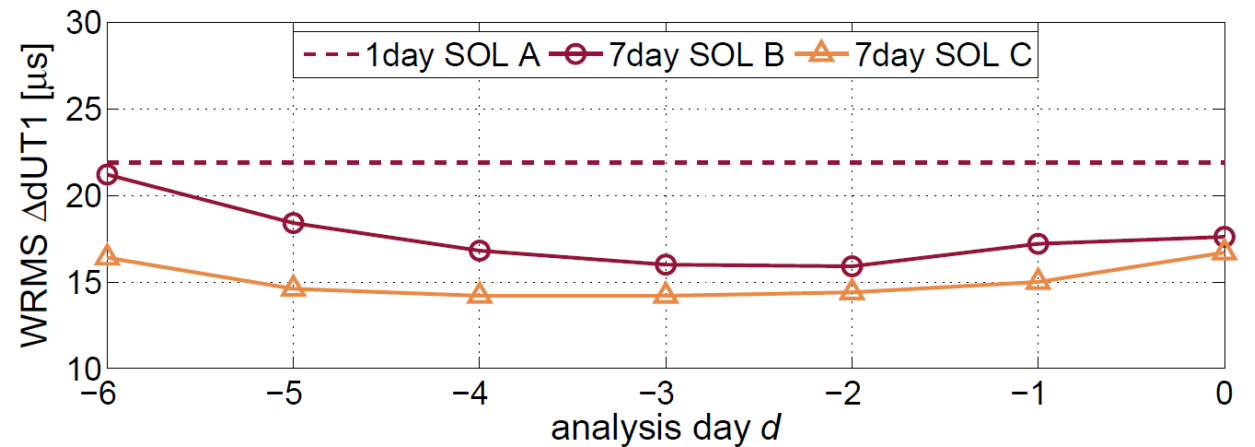
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ERP product: different solutions A, B, C (technique, arc-length, ..)

Analyse WRMS of ERP differences

- absolute value → depends on the reference
- relative value → shows improvement, but also w.r.t. reference
- reference ≠ “truth”



ERP product validation – OPTION 2

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Check impact on other parameter from same solution

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Which impact has the **combined solution**
(ERP from combining GNSS+VLBI)
on GNSS orbit parameters?

ERP product validation – OPTION 2

Check impact on other parameter from same solution



Which impact has the **combined solution** (ERP from combining GNSS+VLBI) on GNSS orbit parameters?

Why to look at orbits?

GNSS orbits still have some deficiencies

- .. Solar radiation pressure modelling
- .. CODE estimates 3-day arcs
- .. LOD bias exists, but not understood

ERP product validation – OPTION 2

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Potential answers:

- Improved orbits
- No impact
- Worse orbits

ERP product validation – impact on orbits

Overview of estimated parameters in combined solution

ERP product validation – impact on orbits

Overview of estimated parameters in combined solution

Combined NEQ (7 days)

GNSS Rapid - CODE

VLBI INT - BKG

IGS station coordinates

IVS station coordinates

ERP

- Pole coordinates
- dUT1 (piecewise linear offsets)

Orbits

- Keplerian elements
- Dynamical parameter
- Stochastic pulses

Troposphere

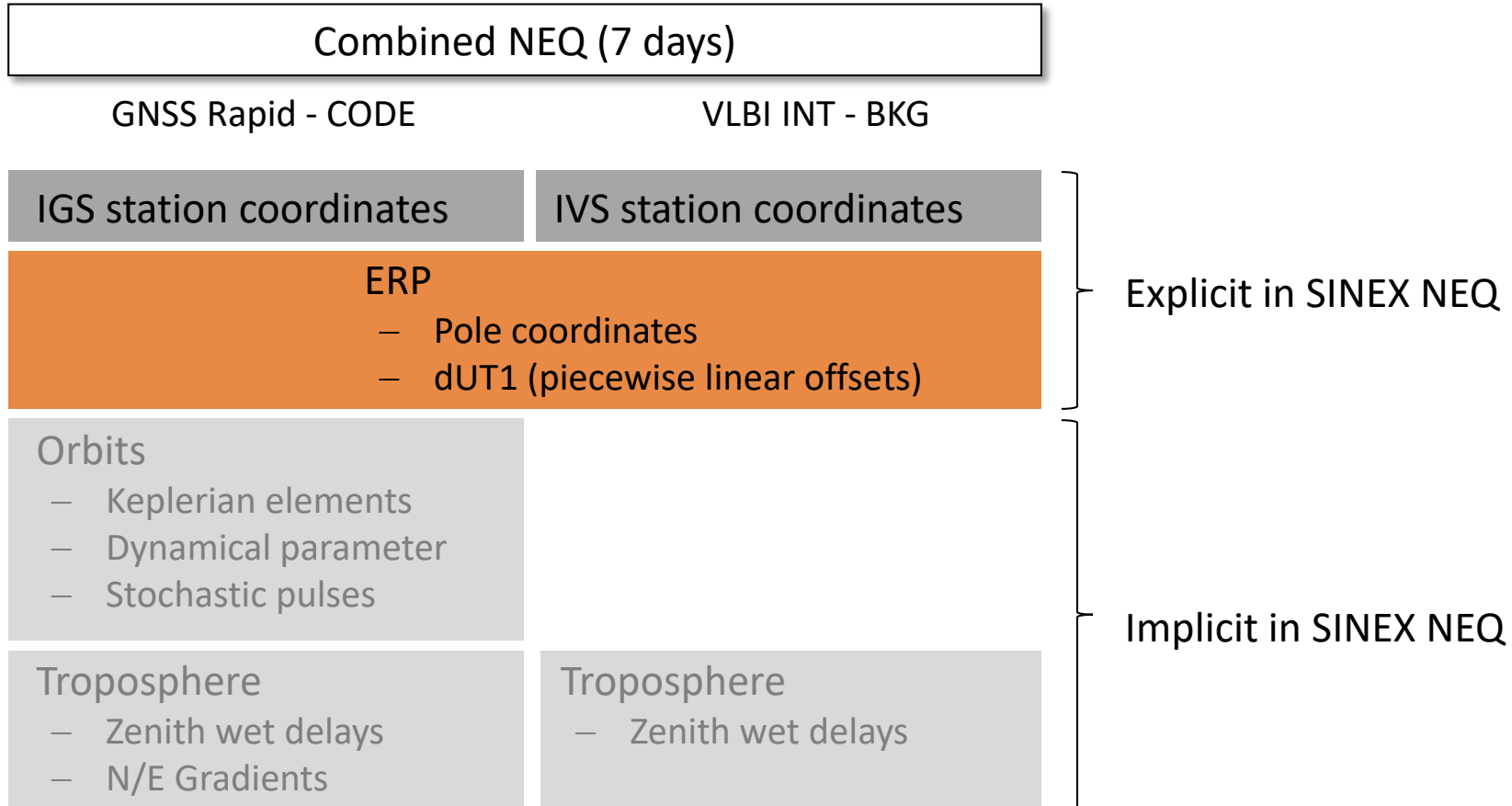
- Zenith wet delays
- N/E Gradients

Troposphere

- Zenith wet delays

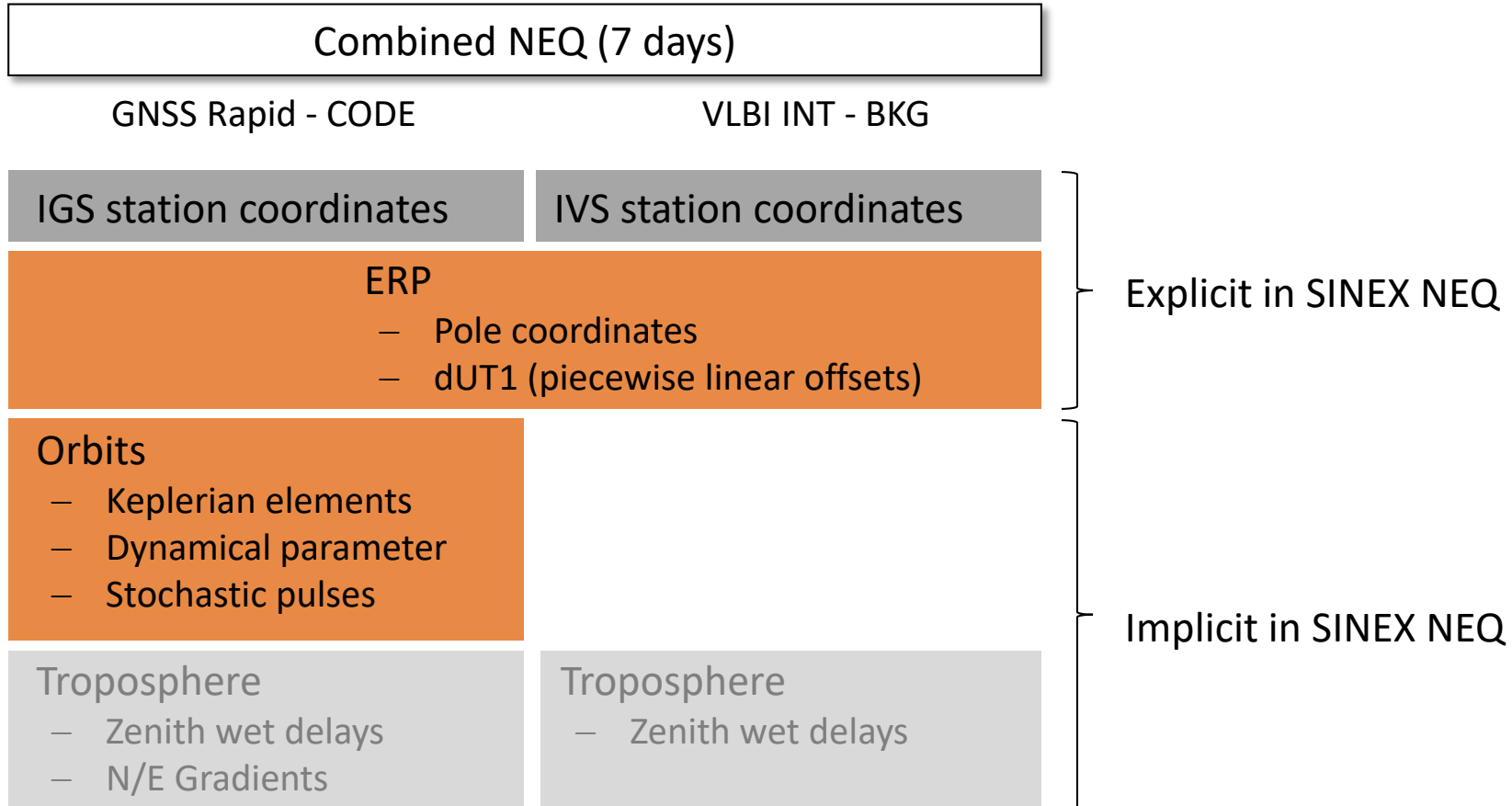
ERP product validation – impact on orbits

Overview of estimated parameters in combined solution



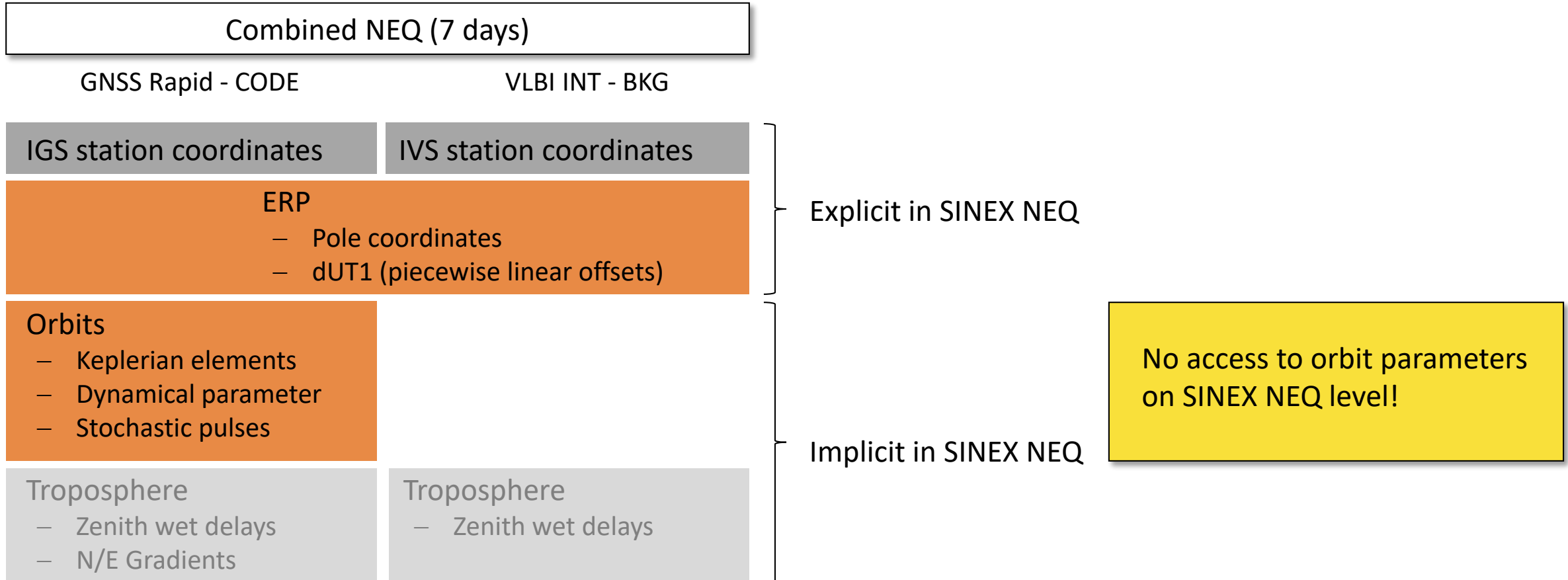
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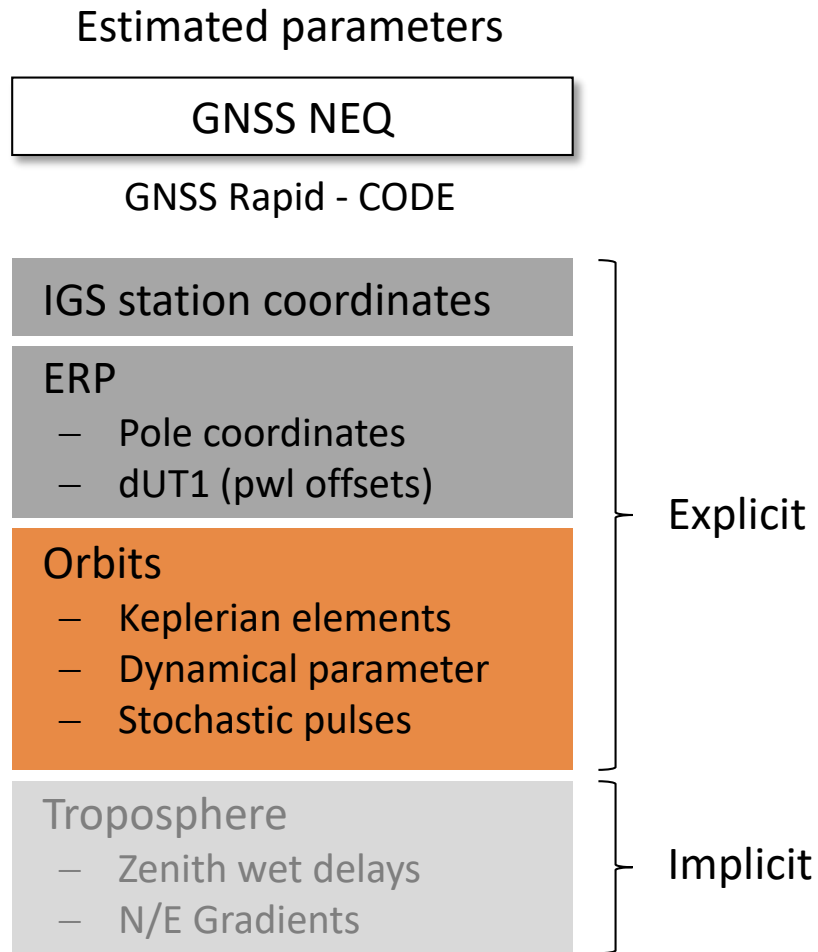


ERP product validation – impact on orbits

Overview of estimated parameters in combined solution



ERP product validation – impact on orbits



Get access to orbit parameters from combined analysis by

- Re-running GNSS Rapid solution from CODE
- Using NEQs provided by CODE (containing orbits as explicit parameters)

ERP product validation – impact on orbits

Estimated parameters

GNSS NEQ

GNSS Rapid - CODE

IGS station coordinates

ERP

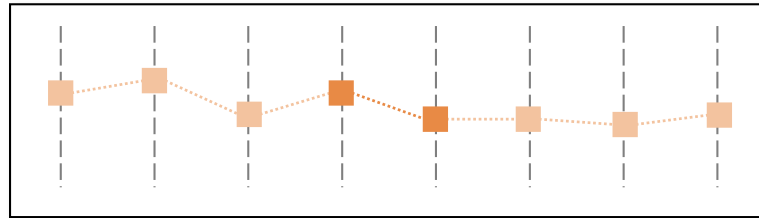
- Pole coordinates
- dUT1 (fix all)

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Get access to orbit parameters from combined analysis by

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- Introducing combined ERP product and fixing all dUT1 values

ERP product validation – impact on orbits

Estimated parameters

GNSS NEQ

GNSS Rapid - CODE

IGS station coordinates

ERP

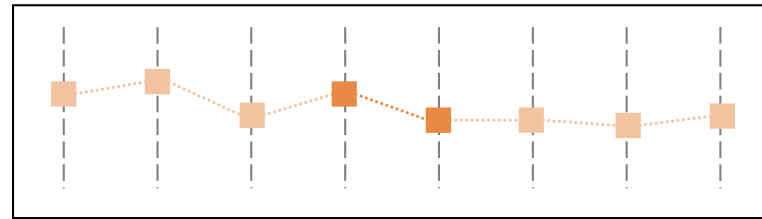
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BKG
solution

BKG

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GNSS Rapid - CODE

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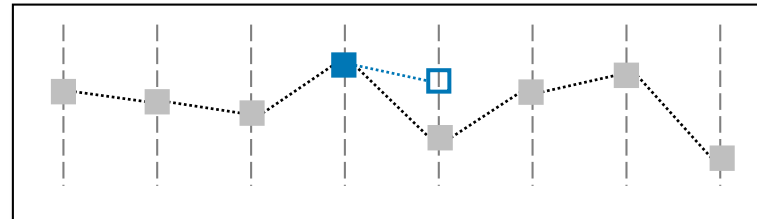
- Pole coordinates
- dUT1 (fix first)

Orbits

- Keplerian elements
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Troposphere

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Reference
solution

REF

Use GNSS Rapid solution from CODE as reference

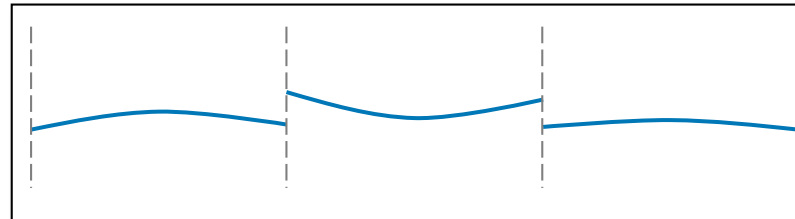
- Using IERS-Bulletin-A as a priori ERP
- Fix first dUT1 value

Orbit validation

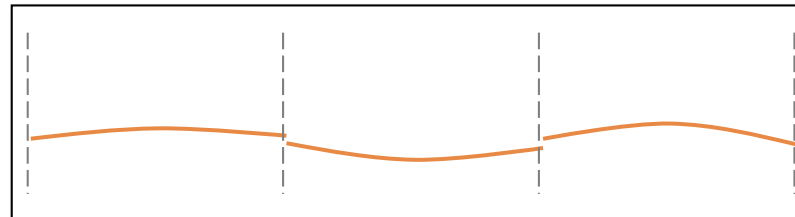
Orbit validation

- 3 GNSS: GPS | GLONASS | Galileo
- 1-day arcs
- 113 days
- DoY 045-157 2022

REF



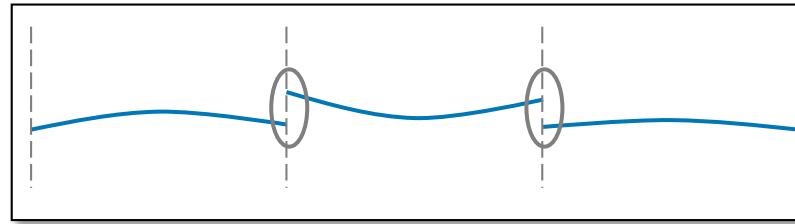
BKG



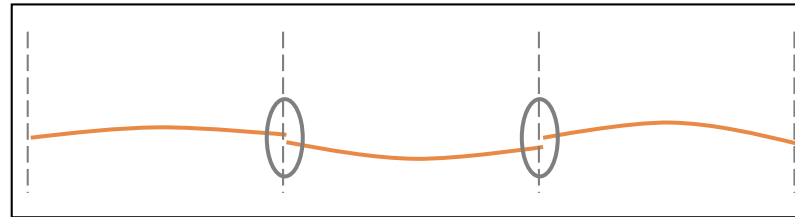
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Analyse orbit differences at day boundaries

REF



BKG

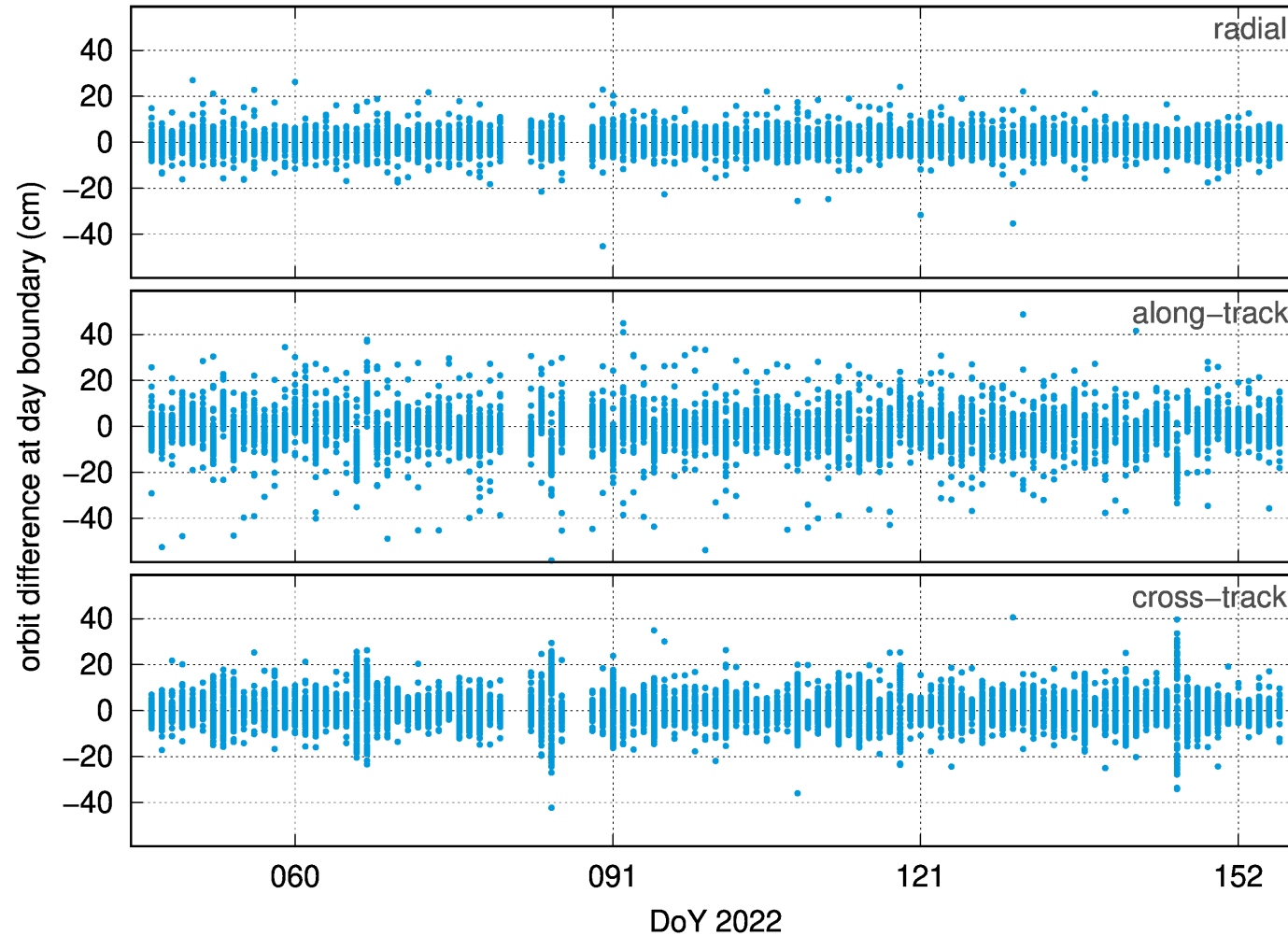


Satellite-specific orbit differences at day boundaries (1-day arcs)



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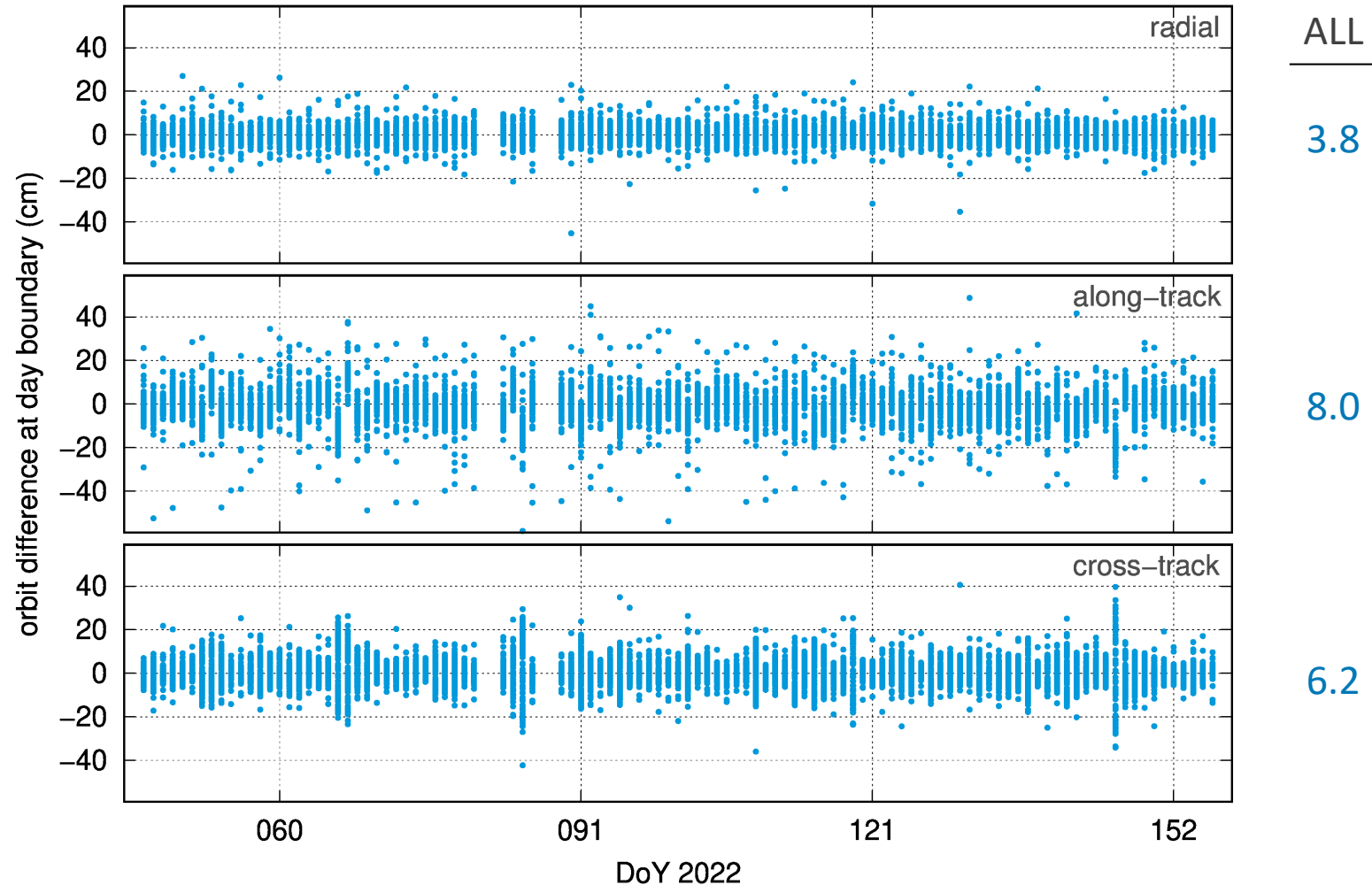
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Satellite-specific orbit differences at day boundaries (1-day arcs)

RMS (cm)

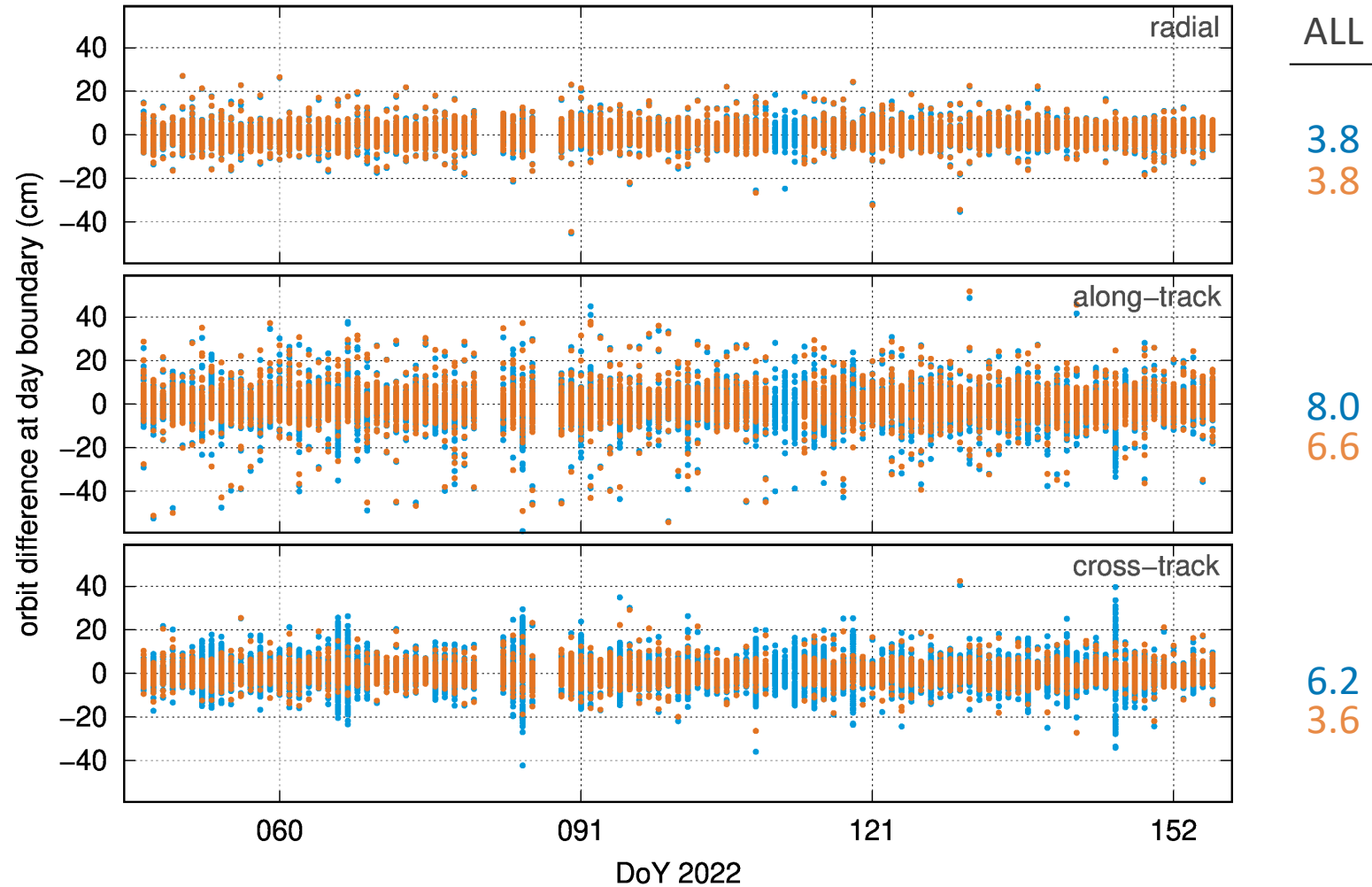
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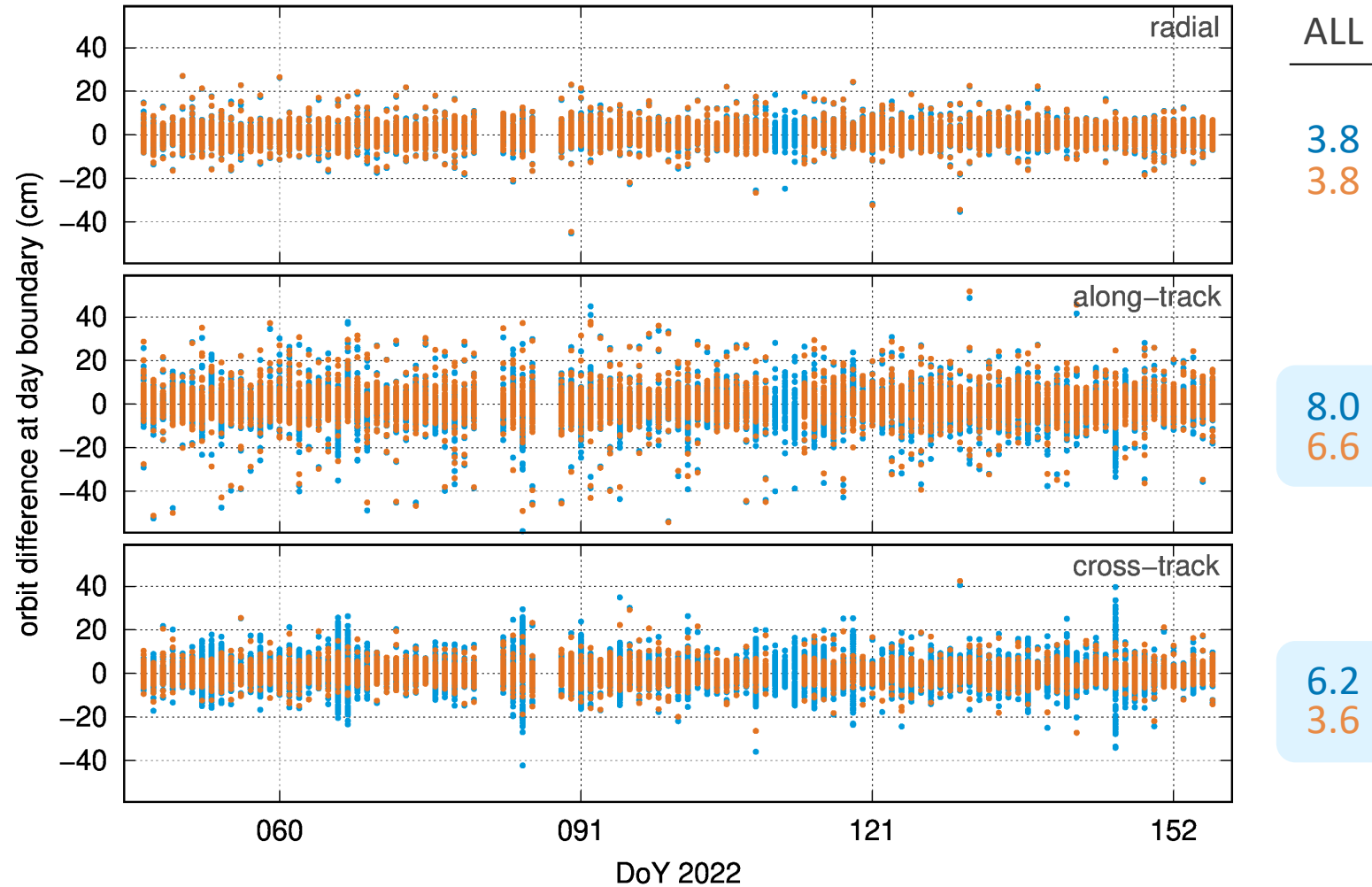
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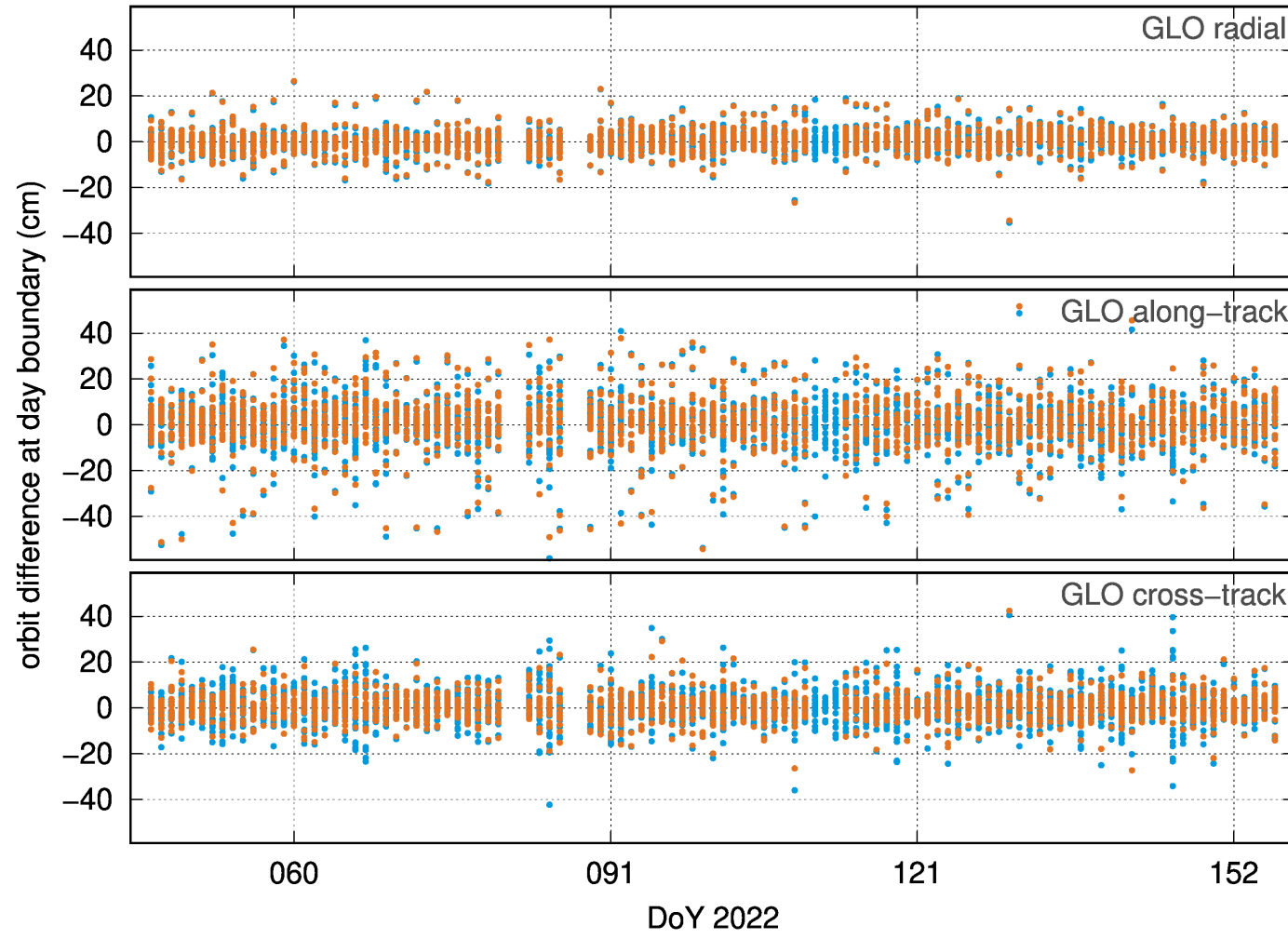


Improvement in along-track and cross-track

Satellite-specific orbit differences at day boundaries (1-day arcs)

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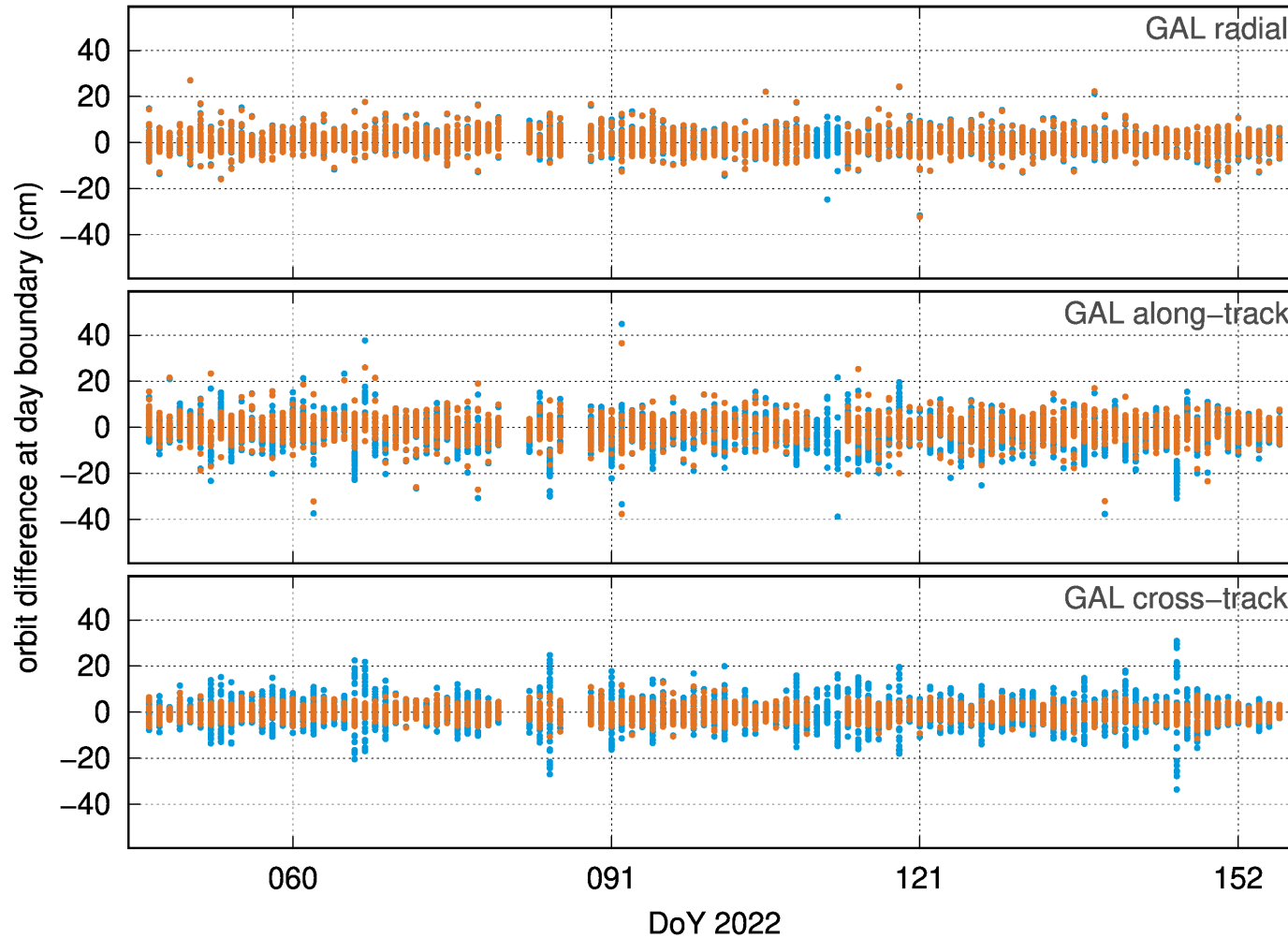


	ALL	GLO
GLO radial	3.8 3.8	4.7 4.7
GLO along-track	8.0 6.6	11.4 10.9
GLO cross-track	6.2 3.6	7.6 5.6

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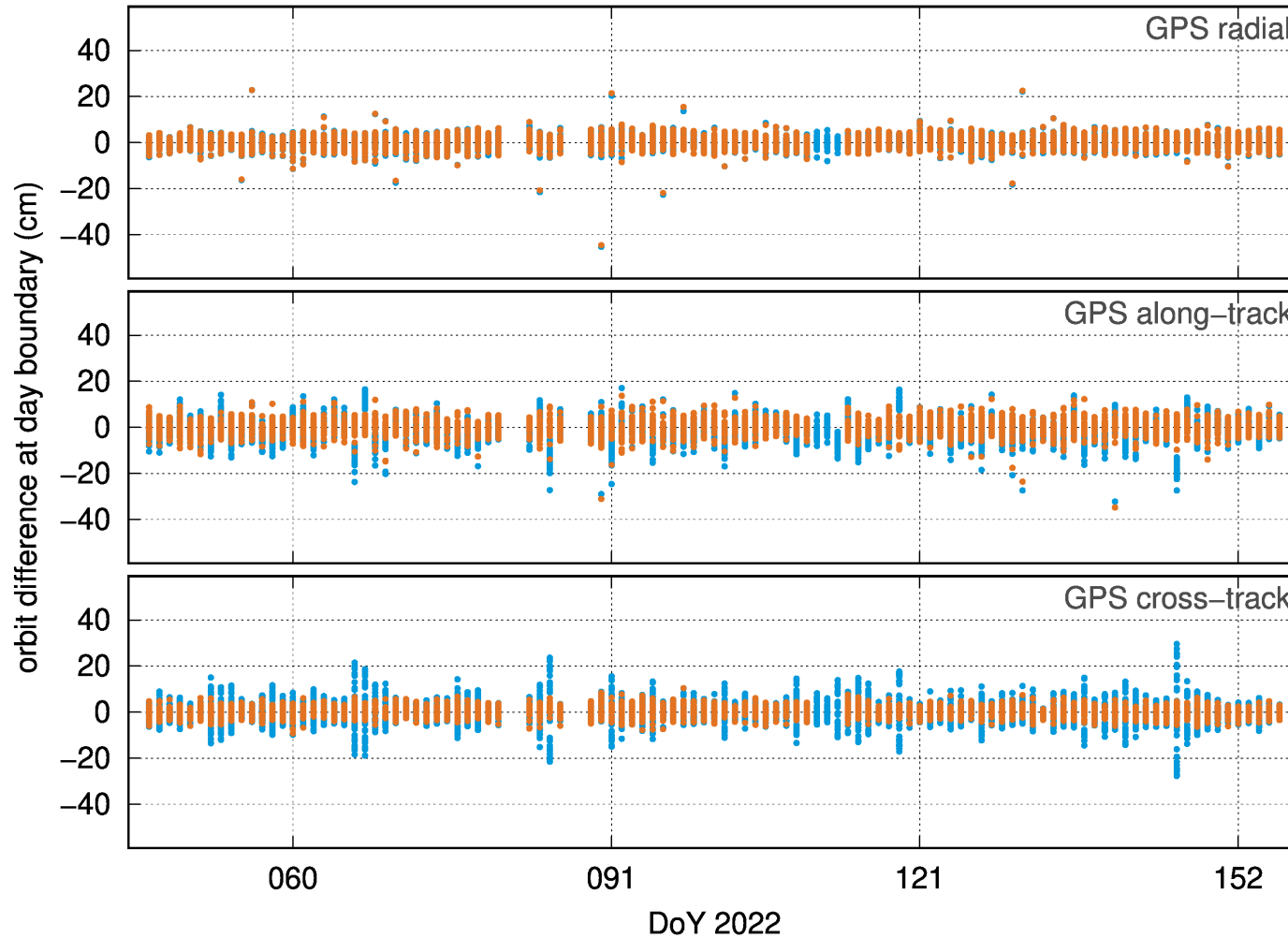


	ALL	GLO	GAL
GAL radial	3.8 3.8	4.7 4.7	4.1 4.1
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Satellite-specific orbit differences at day boundaries (1-day arcs)

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	ALL	GLO	GAL	GPS
GPS radial	3.8 3.8	4.7 4.7	4.1 4.1	2.8 2.9
GPS along-track	8.0 6.6	11.4 10.9	7.4 4.9	5.8 3.5
GPS cross-track	6.2 3.6	7.6 5.6	6.0 2.7	5.4 2.3

Conclusions



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Answer: **Improved orbits**

- in along-track and cross-track orbit differences at day boundaries
- for GPS, GLONASS, Galileo
- for 1-day (and 3-day) arcs

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Solar radiation pressure modelling?
Plane-specific dependencies?
Eclipse behavior?
LOD bias?

..



Federal Agency for
Cartography and Geodesy



Thank you for your kind attention!



Federal Agency for Cartography and Geodesy (BKG)
Section G1

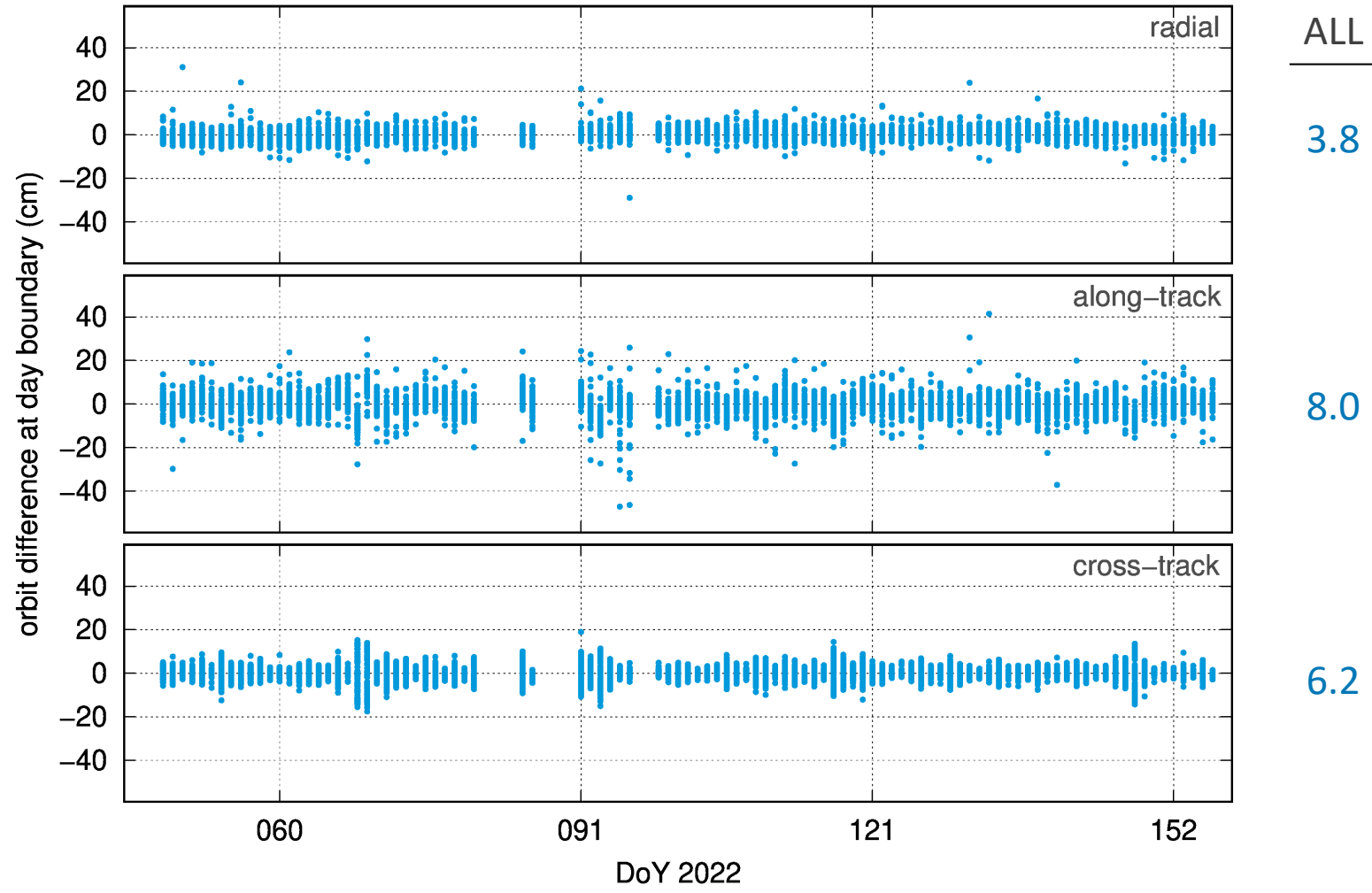
Richard-Strauss-Allee 11
D-60598 Frankfurt am Main, Germany

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claudia.flohrer@bkg.bund.de
www.bkg.bund.de
Phone +49 69 6333 – 456

Satellite-specific orbit differences at day boundaries (3-day arcs)

RMS (cm)

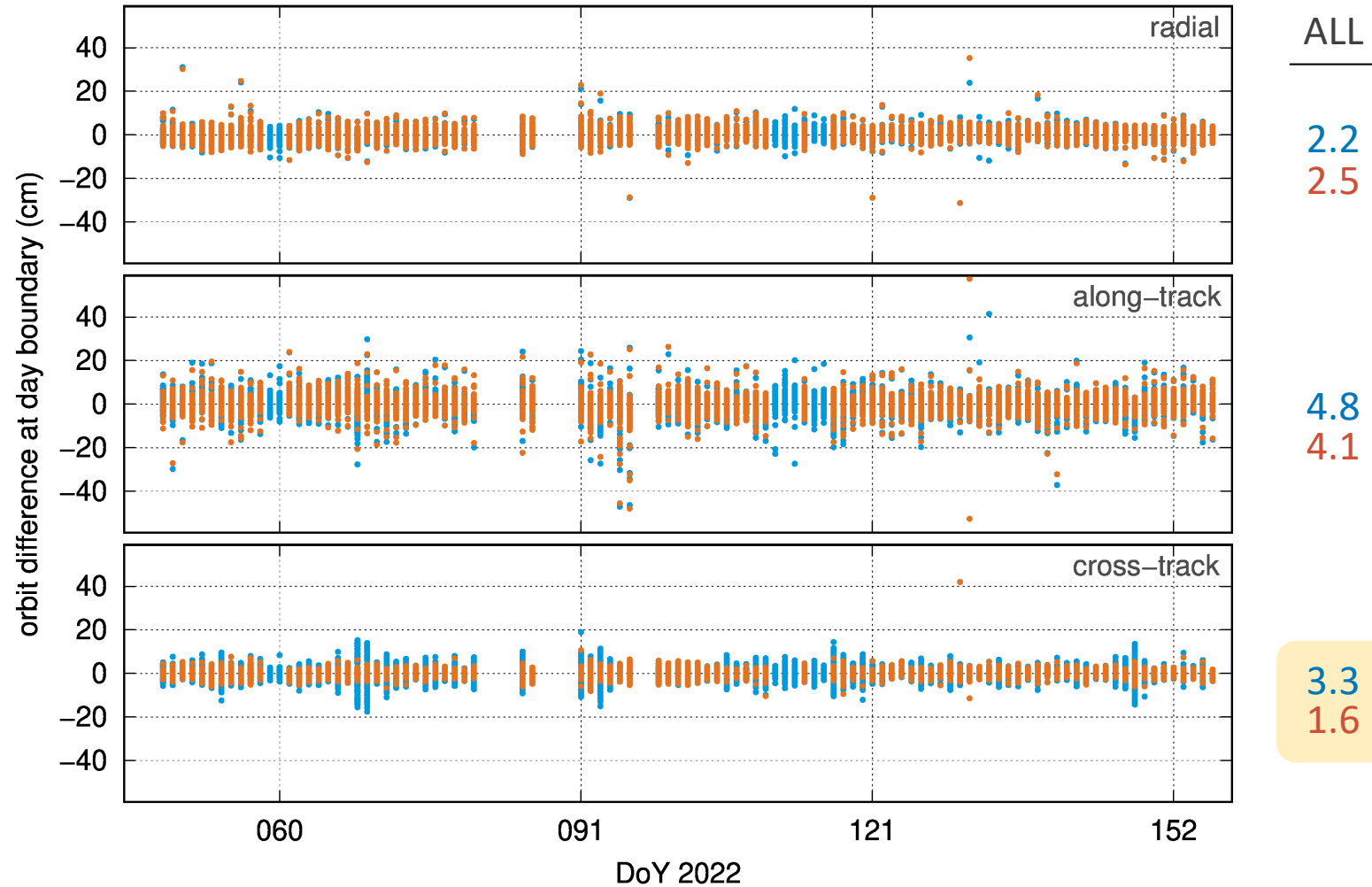
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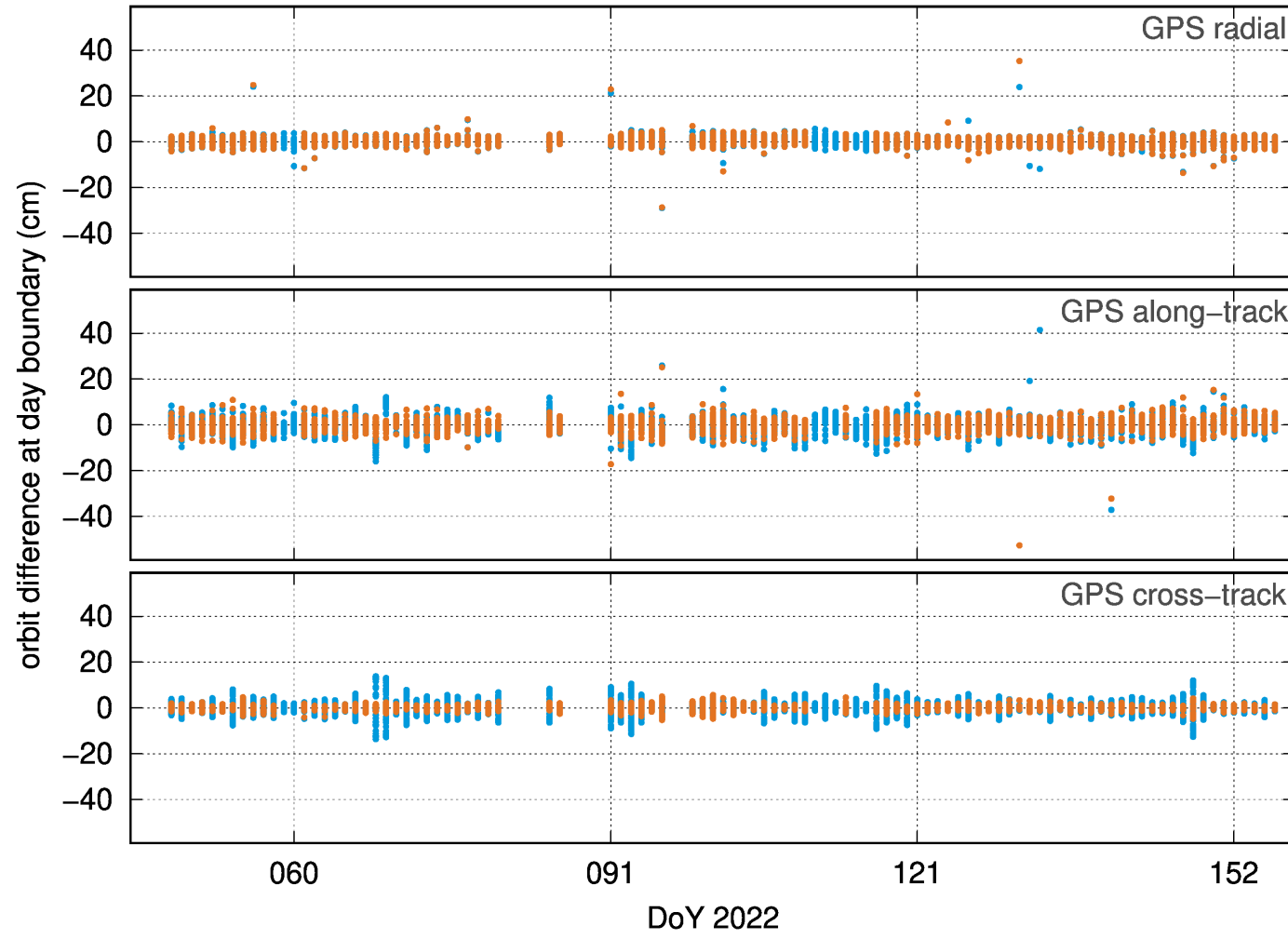
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Satellite-specific orbit differences at day boundaries (3-day arcs)

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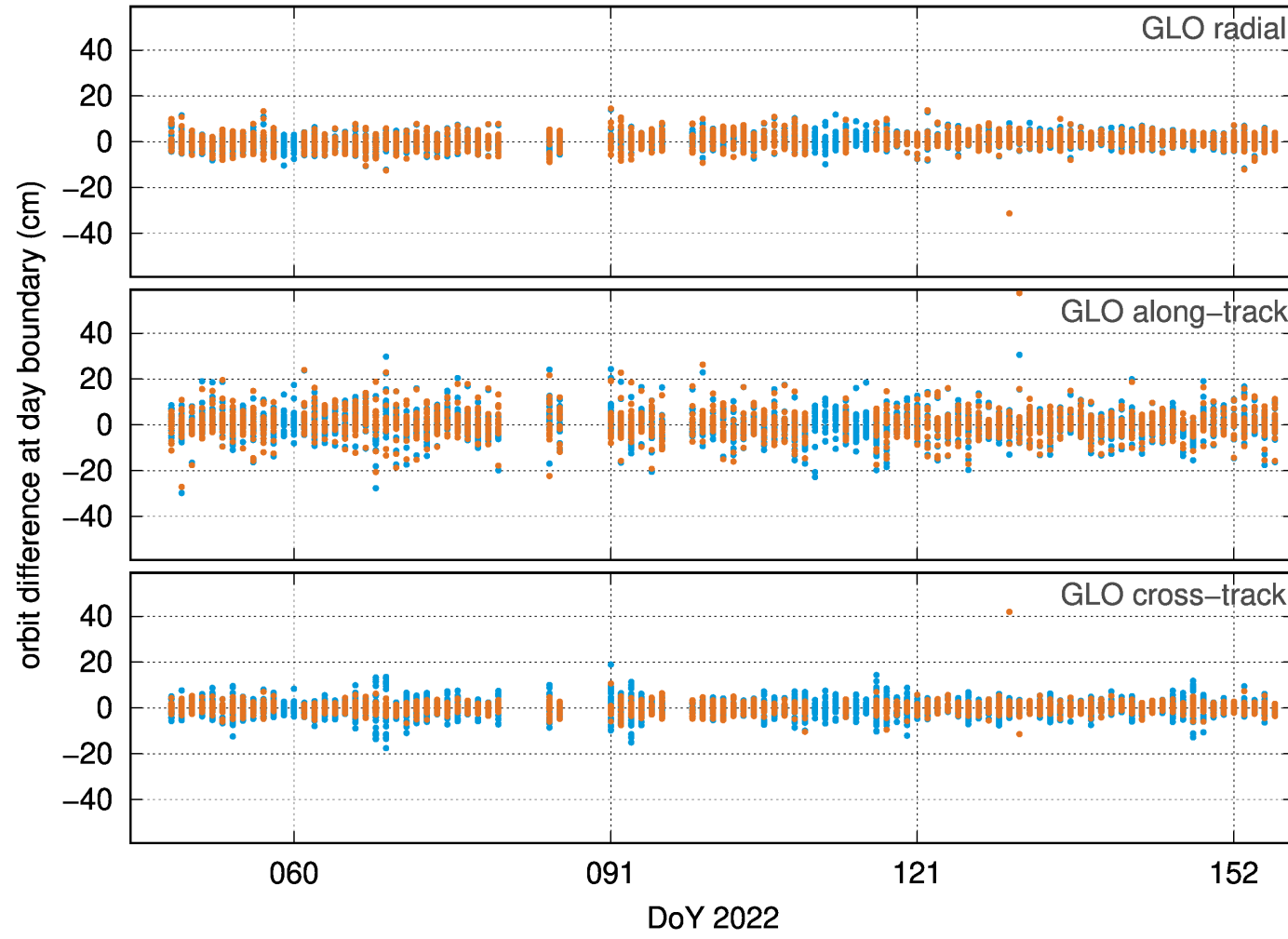


	ALL	GPS
GPS radial	2.2 2.5	1.7 1.8
GPS along-track	4.8 4.1	4.1 2.7
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Satellite-specific orbit differences at day boundaries (3-day arcs)

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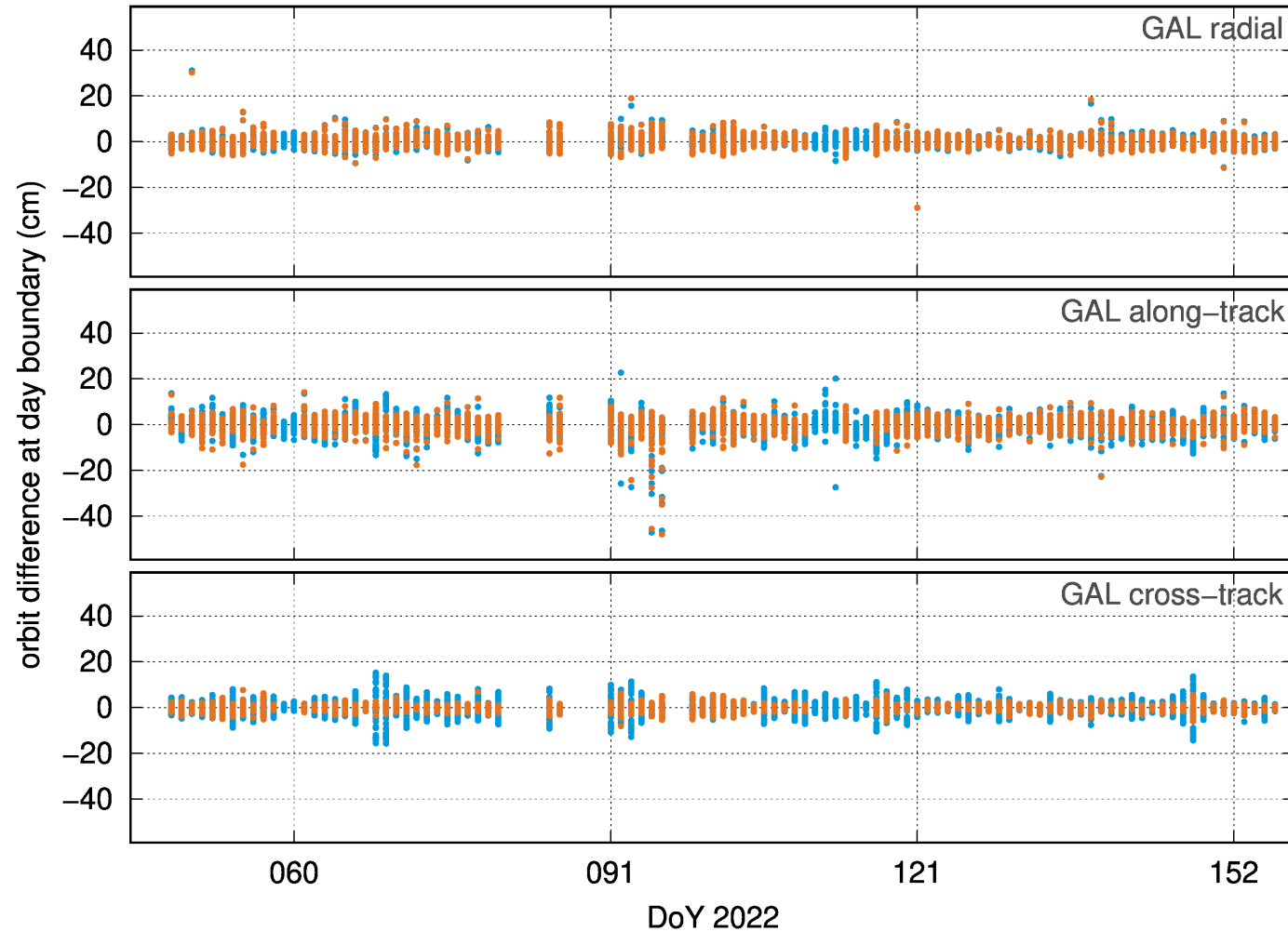
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	GPS	GLO
ALL	1.7	2.9
	1.8	3.2
	4.1	6.0
	2.7	5.9
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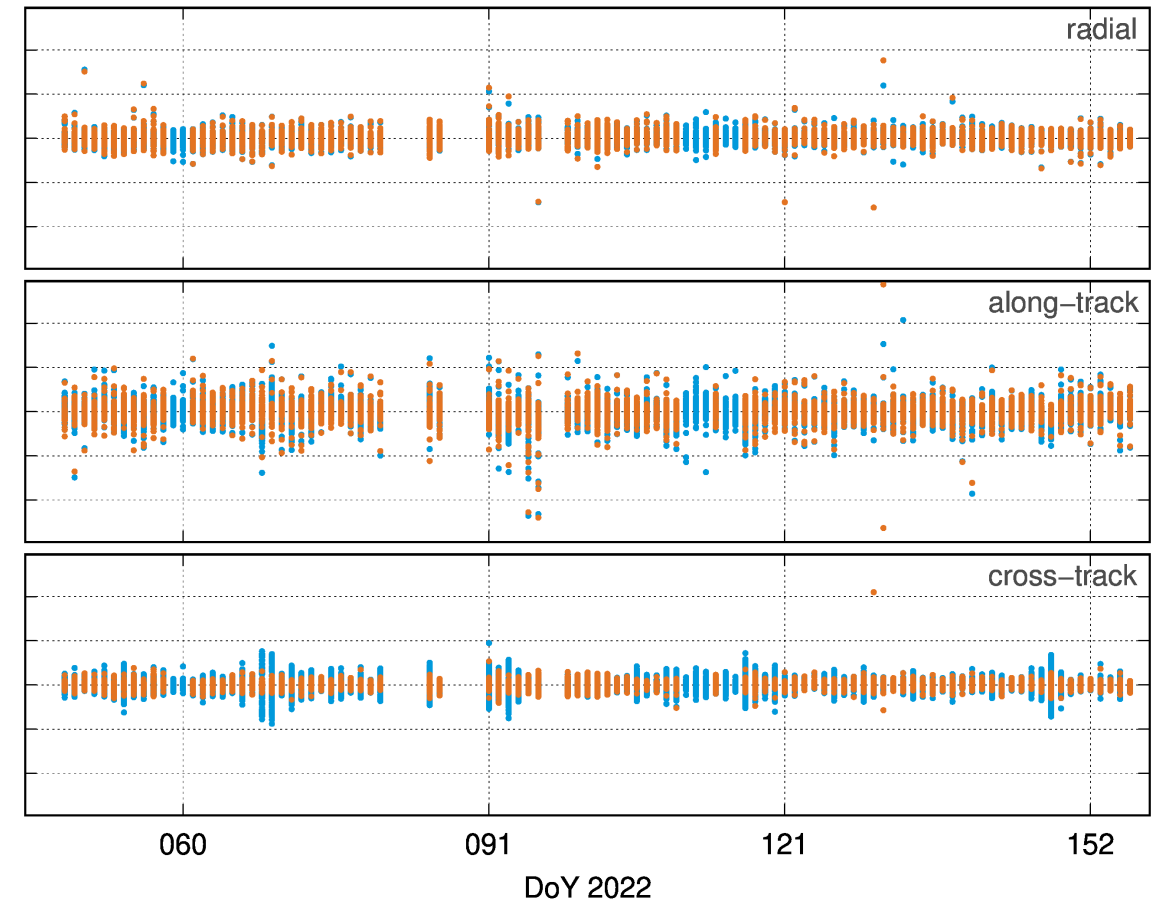
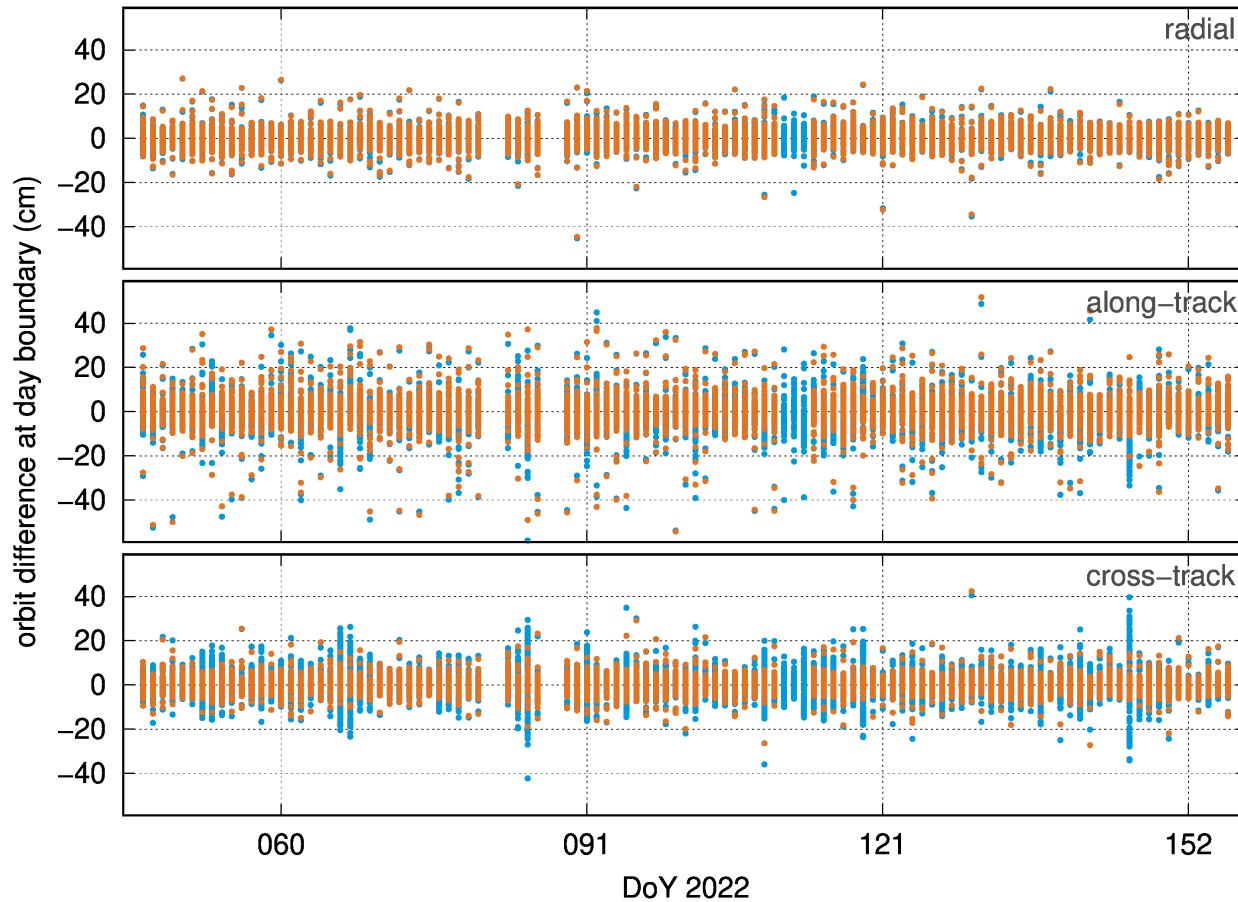
RMS (cm)

	GPS	GLO	GAL
ALL			
	1.7	2.9	2.2
	1.8	3.2	2.5
	4.1	6.0	4.8
	2.7	5.9	3.8
	3.1	3.6	3.4
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Satellite-specific orbit differences at day boundaries

(1-day arcs)

(3-day arcs)



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BKG

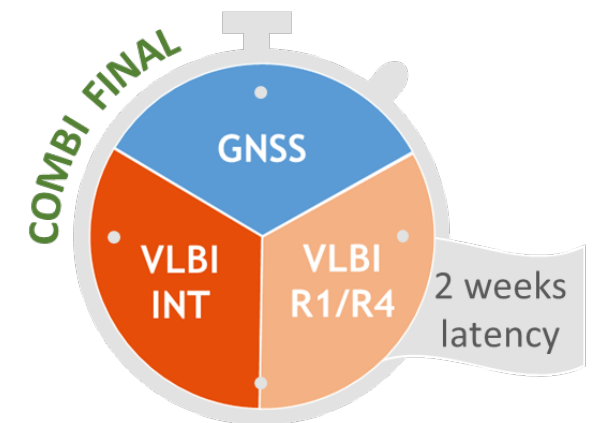
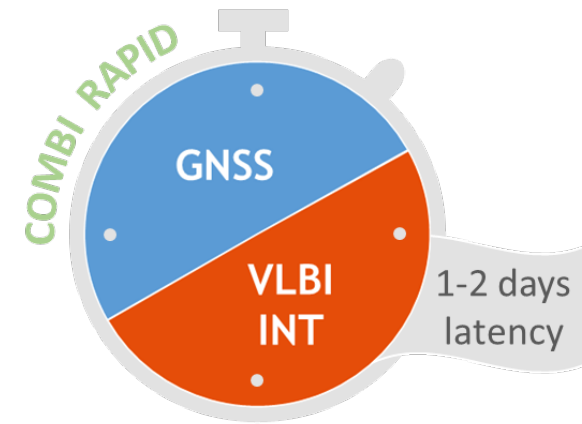
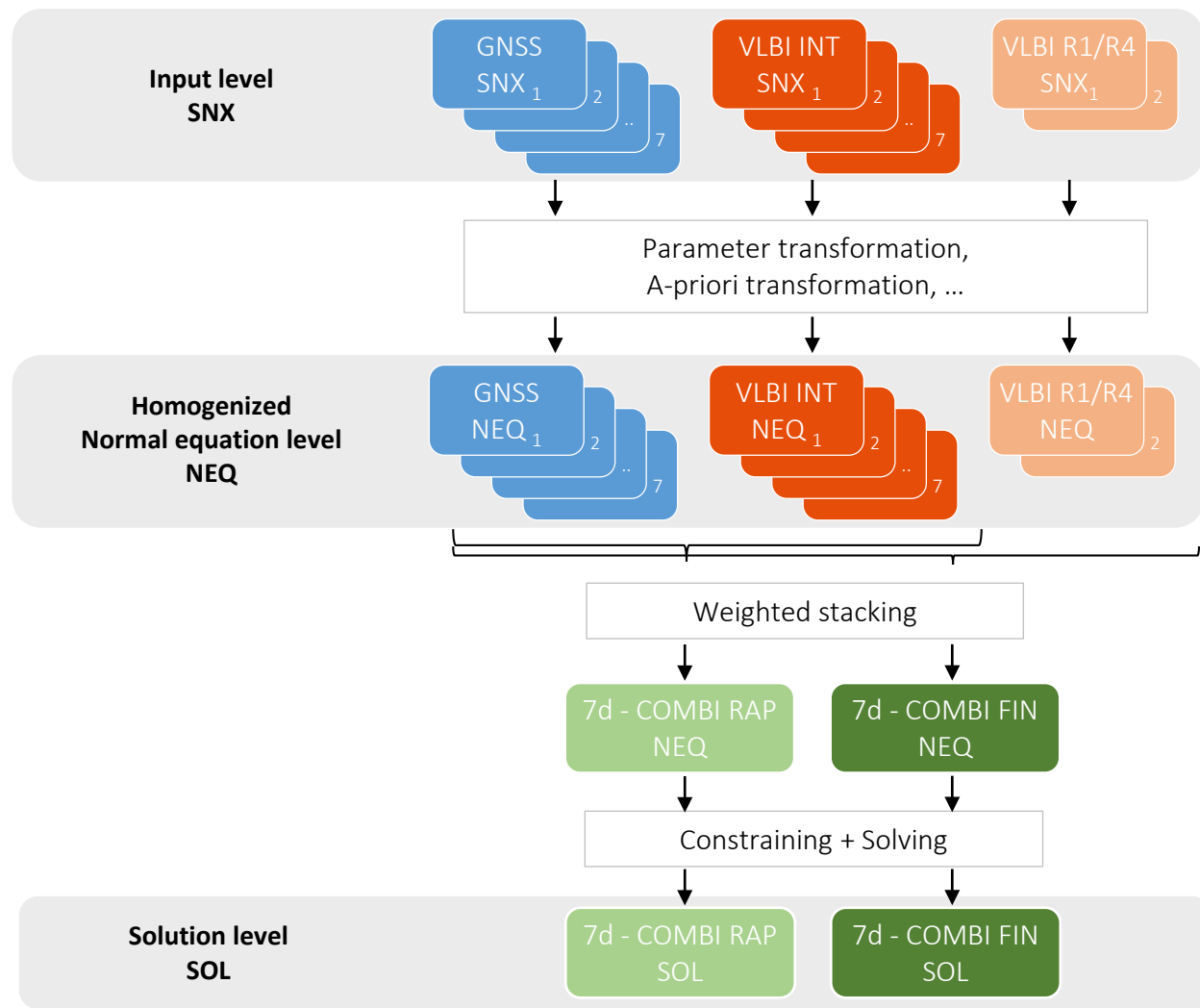
2019-2022 (GALILEO ab 2071_4)

GNSS LOD Bias – 7-day GNSS single-technique

	Day n	μ_{dUT1} [ms]	LoD [ms/d] ($\mu_{dUT1_n} - \mu_{dUT1_{n-1}}$)
7-day GNSS without LOD bias correction	-6	0.0032	
	-5	0.0093	0.0061
	-4	0.0154	0.0061
	-3	0.0213	0.0059
	-2	0.0275	0.0061
	-1	0.0336	0.0061
	0	0.0396	0.0060
	Day n	μ_{dUT1} [ms]	LoD [ms/d] ($\mu_{dUT1_n} - \mu_{dUT1_{n-1}}$)
7-day GNSS with LOD bias correction of 6.1μs	-6	0.0002	
	-5	0.0003	0.0001
	-4	0.0008	0.0005
	-3	0.0010	0.0002
	-2	0.0014	0.0004
	-1	0.0018	0.0004
	0	0.0025	0.0007

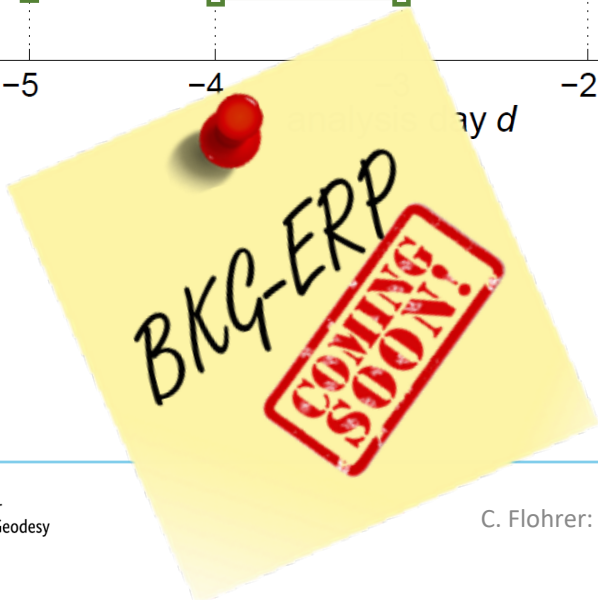
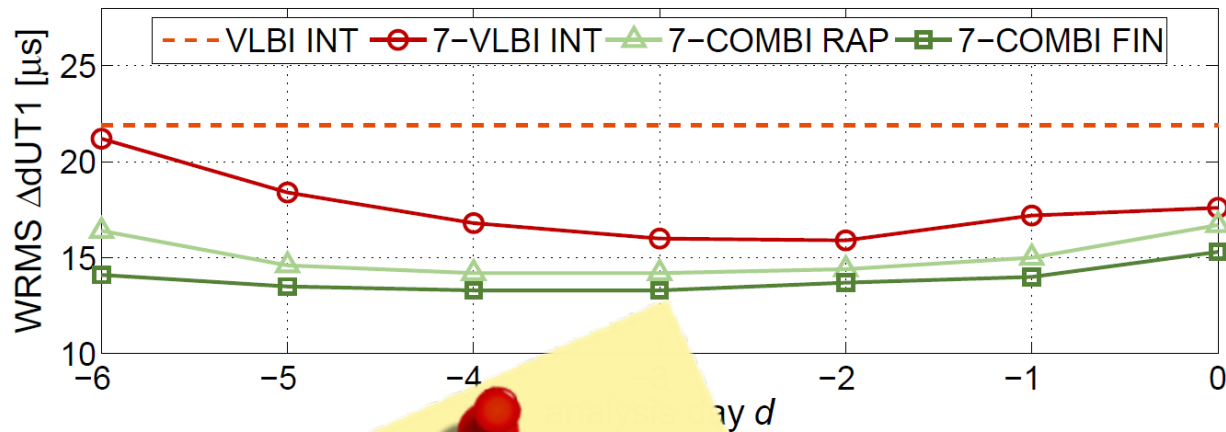
GNSS RAP CODE (72h session)			
explicit	Station coordinates		constant offset
	ERP	Pole coordinates	PWL offsets every 24h (4/72h)
		dUT1	PWL offsets every 24h (4/72h)
	Geocenter Satellite PCO	Z-direction	constant offset constant offset
implicit	Satellite orbit	Keplerian elements Dynamical parameter	constant offsets in D-, Y-, and B-direction periodic 1pr in B-direction periodic 2pr in D-direction
		Stochastic pulses	small velocity changes every 12h in radial along-track and out-of-plane direction
	Troposphere	ZWD Gradients	PWL offsets every 2h for each station constant offsets for 24h
VLBI INT BKG (1h session)			
explicit	Station coordinates		constant offset
	ERP	Pole coordinates	constant offset
		Pole rates	drift
		dUT1	constant offset
		LOD	drift
implicit	Source coordinates		constant offset
	Troposphere	ZWD	constant offset for each station
	Station clocks		quadratic polynomial for each station

Combination Scheme – 7-day Combination of VLBI and GNSS



Results – 7-day Combination of VLBI and GNSS

Validation epoch: **12:00 UTC**
Reference series: **IERS-Bulletin-A**



7-day VLBI INT

- significant reduction of the WRMS values
- no constraining of the LOD is required
- improves accuracies outside the INT observation period



7-day COMBI RAPID

- significant reduction of the WRMS values
- polar motion and LOD from GNSS complements dUT1 from VLBI INT
 - daily, consistent and regularly spaced high-precision ERP
 - short latency of 1-2 days



7-day COMBI FINAL

- significant reduction of the WRMS values, especially at the boundary days of the 7-day polygon (d = 0, -6)
- stabilization of all ERP through 24h VLBI R1/R4 twice a week
 - daily, consistent and regularly spaced high-precision ERP including the celestial pole offsets
 - latency of 14 days

