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WROCŁAW UNIVERSITY
OF ENVIRONMENTAL
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Methodological Aspects of **Combining** **GNSS-derived Geocenter Motion:** Preprocessing and Parametrization Strategies

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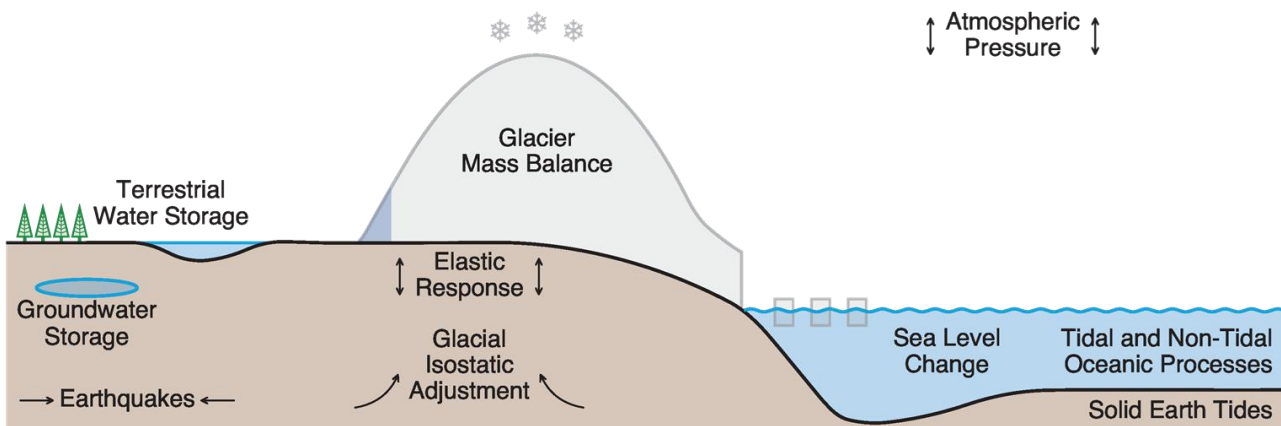
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Why does geocenter motion matter?

1 Earth system perspective

Geocenter motion reflects large-scale mass redistribution in the Earth system.



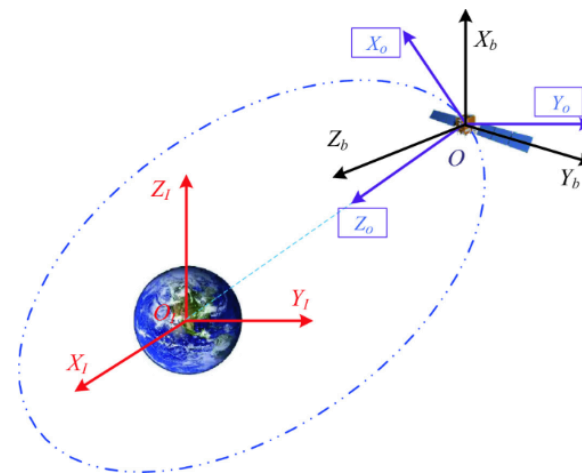
Sutterley, T. C., & Velicogna, I. (2019)



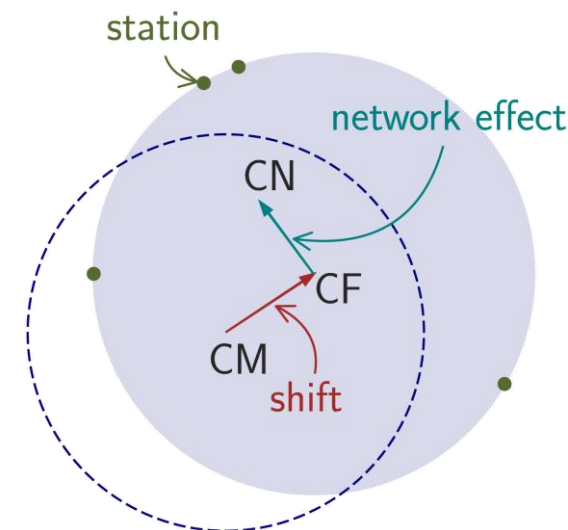
If the relations between **CM**, **CF**, and **CN** are not treated consistently, **network effects** can **leak** into the estimated geocenter motion and **bias derived geodetic products**.

2 Satellite geodesy perspective

The geocenter defines the origin relevant for satellite motion.



- **CM (Center of Mass)**
(mass/orbital origin)
- **CF (Center of Figure)**
(solid Earth geometry)
- **CN (Center of Network)**
(network realization)



Problem and goal

Main sources of inconsistency:

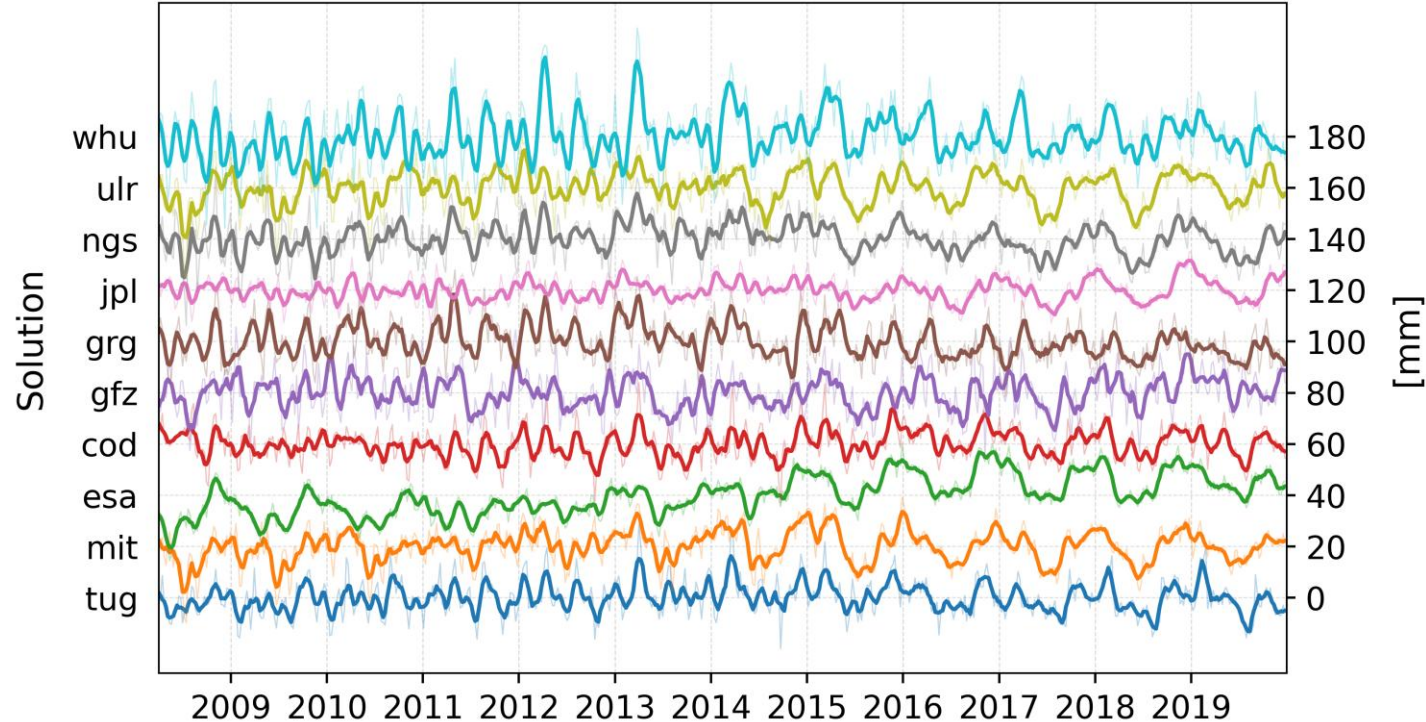
- ❖ different **processing strategies** and **background models**
- ❖ **network geometry** and reference frame realization
- ❖ orbit-related artifacts, including **draconitic signals**
- ❖ variable noise level and outliers

How should individual GNSS geocenter series be preprocessed and weighted before combination?

Goal:

To develop and validate a **reproducible preprocessing** and **Variance Component Estimation (VCE)-based combination strategy** and assess its sensitivity to **methodological choices**.

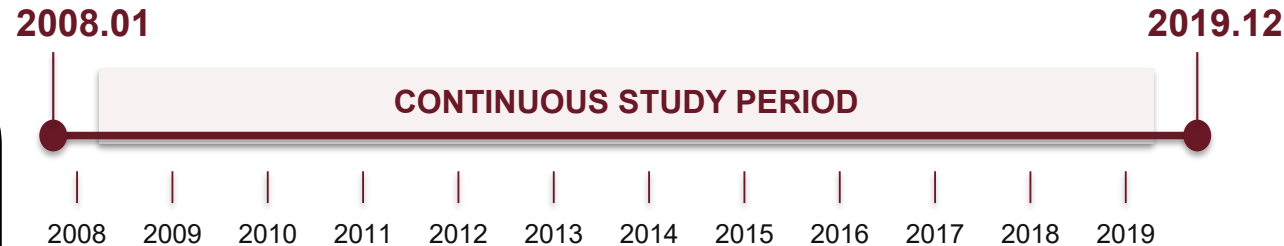
Example: Z-component of individual GNSS geocenter series



IGS Repro3

DAILY
REPROCESSED
GLOBAL GNSS
SOLUTIONS

3rd IGS Data Reprocessing
Campaign in the framework
of the ITRF2020 preparation



DAILY
X/Y/Z
GEOCENTER
SERIES



3rd
IGS Repro3
CAMPAIGN



12-YEAR
INTERVAL



COMPARISON
AGAINST
IGS
COMBINATION

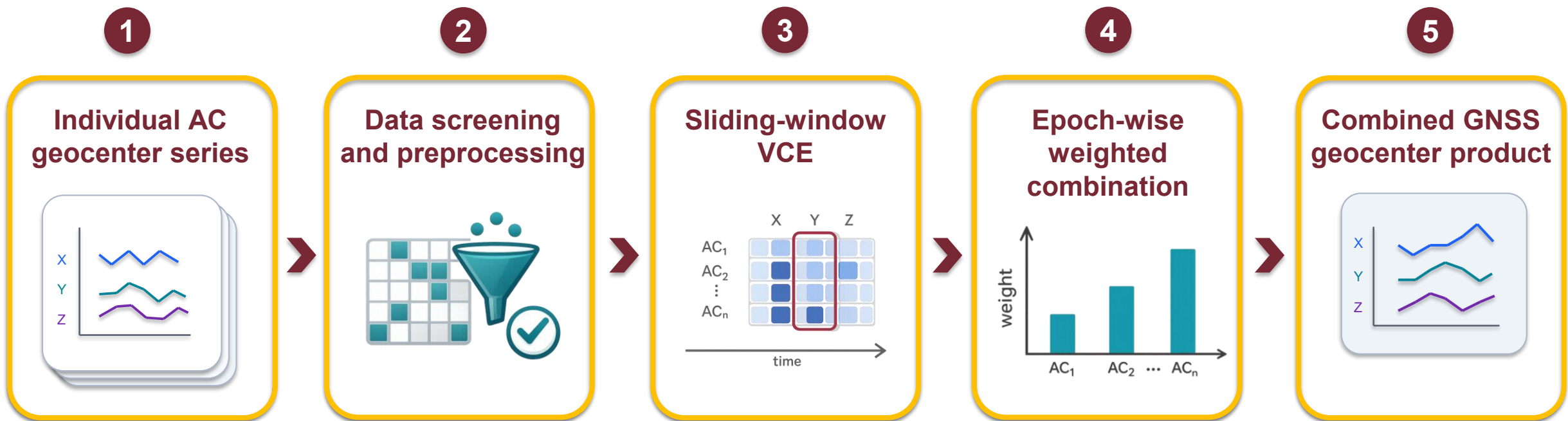
Rebischung, P., Altamimi, Z., Collilieux, X. et al.
ITRF2020 seasonal geocenter motion model.
J Geod 98, 78 (2024).
<https://doi.org/10.1007/s00190-024-01889-4>

10 Analysis Centers (ACs)

TUG	Graz University of Technology
MIT	Massachusetts Institute of Technology
ESA	European Space Agency
COD	Center for Orbit Determination in Europe
GFZ	GFZ German Research Centre for Geosciences
GRG	Groupe de Recherche en Géodésie Spatiale
JPL	Jet Propulsion Laboratory
NGS	National Geodetic Survey
ULR	Université de la Rochelle
WHU	Wuhan University

The combination is performed directly **at the parameter level**, using already estimated geocenter series, rather than through a **full normal-equation** or **SINEX-level combination**.

Combination workflow



- 10 AC solutions
- daily X/Y/Z series

- availability screening
- mean removal
- outlier filtering

- **Förstner's VCE** approach
- VCE separately for X, Y, and Z

- weights renormalized at each epoch using available ACs

- daily combined X/Y/Z series



**Tested
setting**

- **VCE weighting
window length**

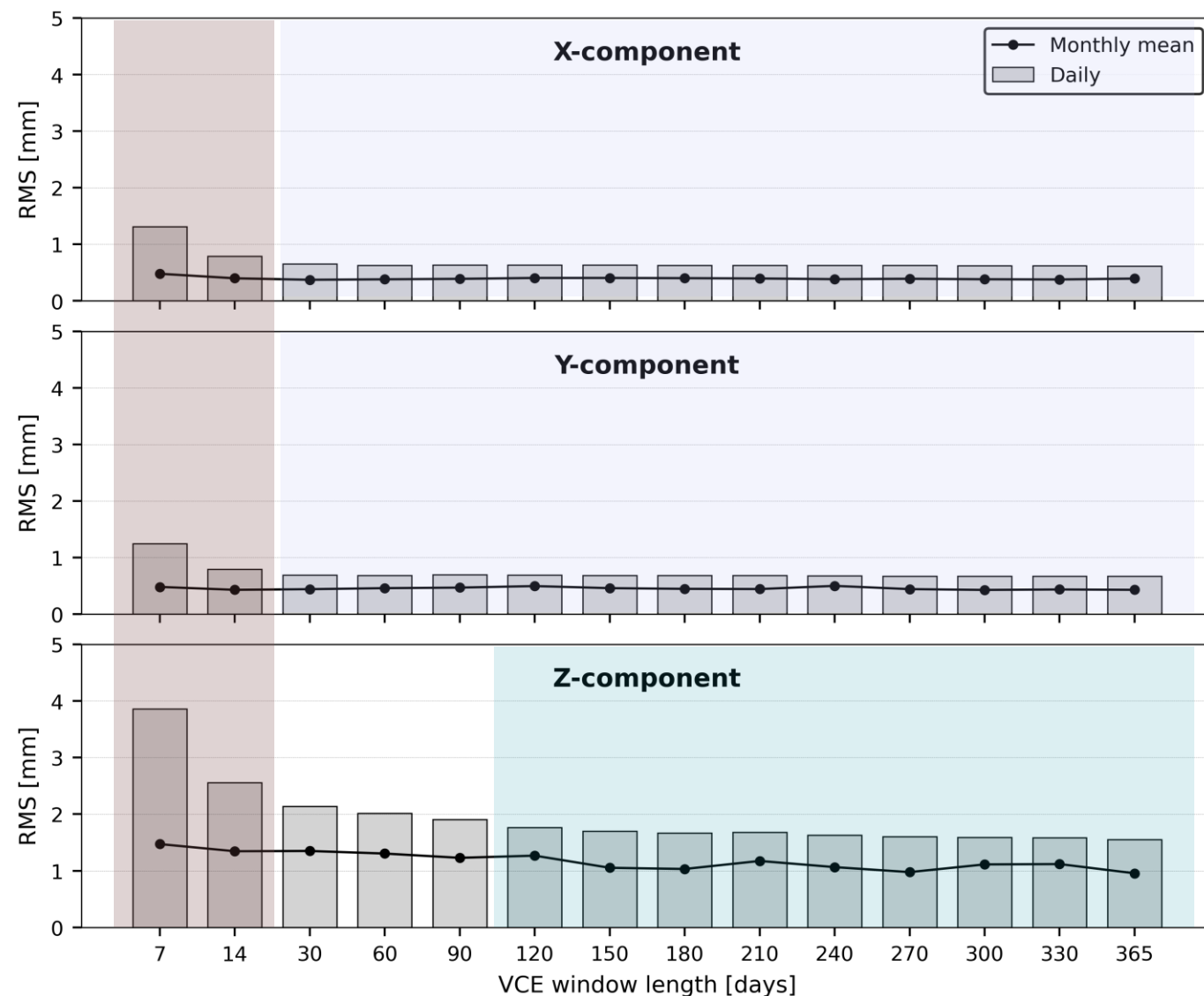
Methodology from:

*Zajdel R., Balidakis K., Nowak A., et al. (2026)
Three decades of GNSS-derived geocenter motion:
disentangling geophysical signal from systematic errors
Adv. Space Res., doi: 10.1016/j.asr.2025.11.053*

VCE window-length sensitivity

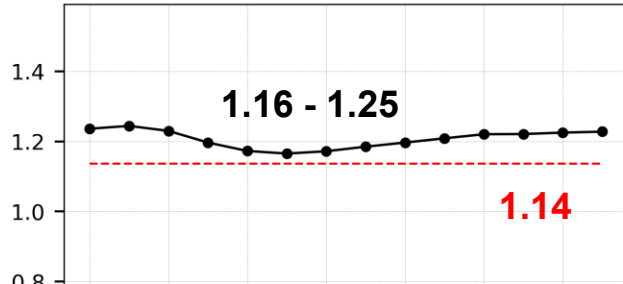
RMS of differences
relative to the **IGS combination**

- ❑ For **X** and **Y**, no substantial changes are observed beyond a **30-day window**.
- ❑ Further extension of the window produces only minor changes in the horizontal components.
- ❑ Intermediate windows, **around 90-120 days**, provide the best trade-off between stability and temporal responsiveness for the **Z component**.

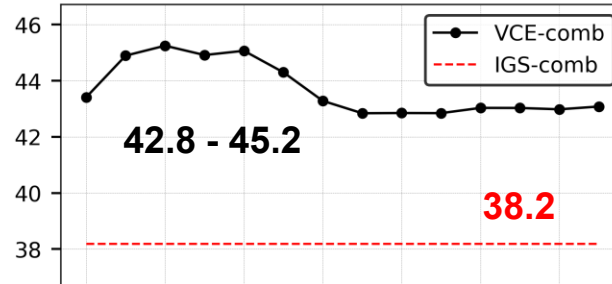


Annual signal recovery

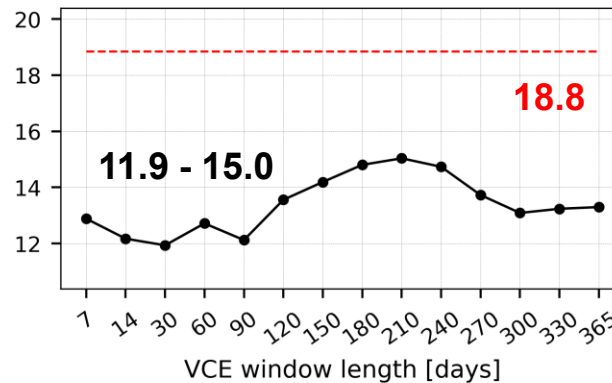
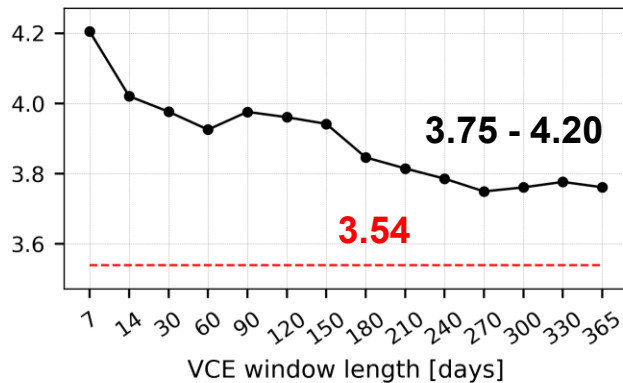
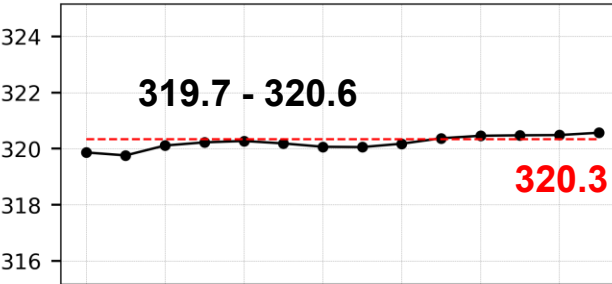
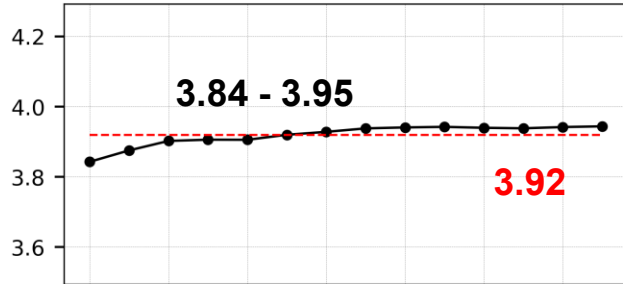
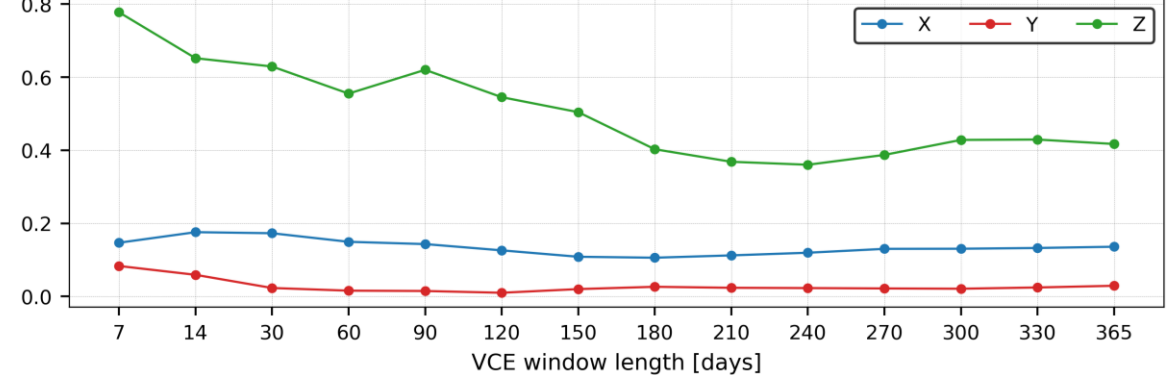
Annual amplitude [mm]



Annual phase [deg]



Annual phasor distance to IGS-comb [mm]



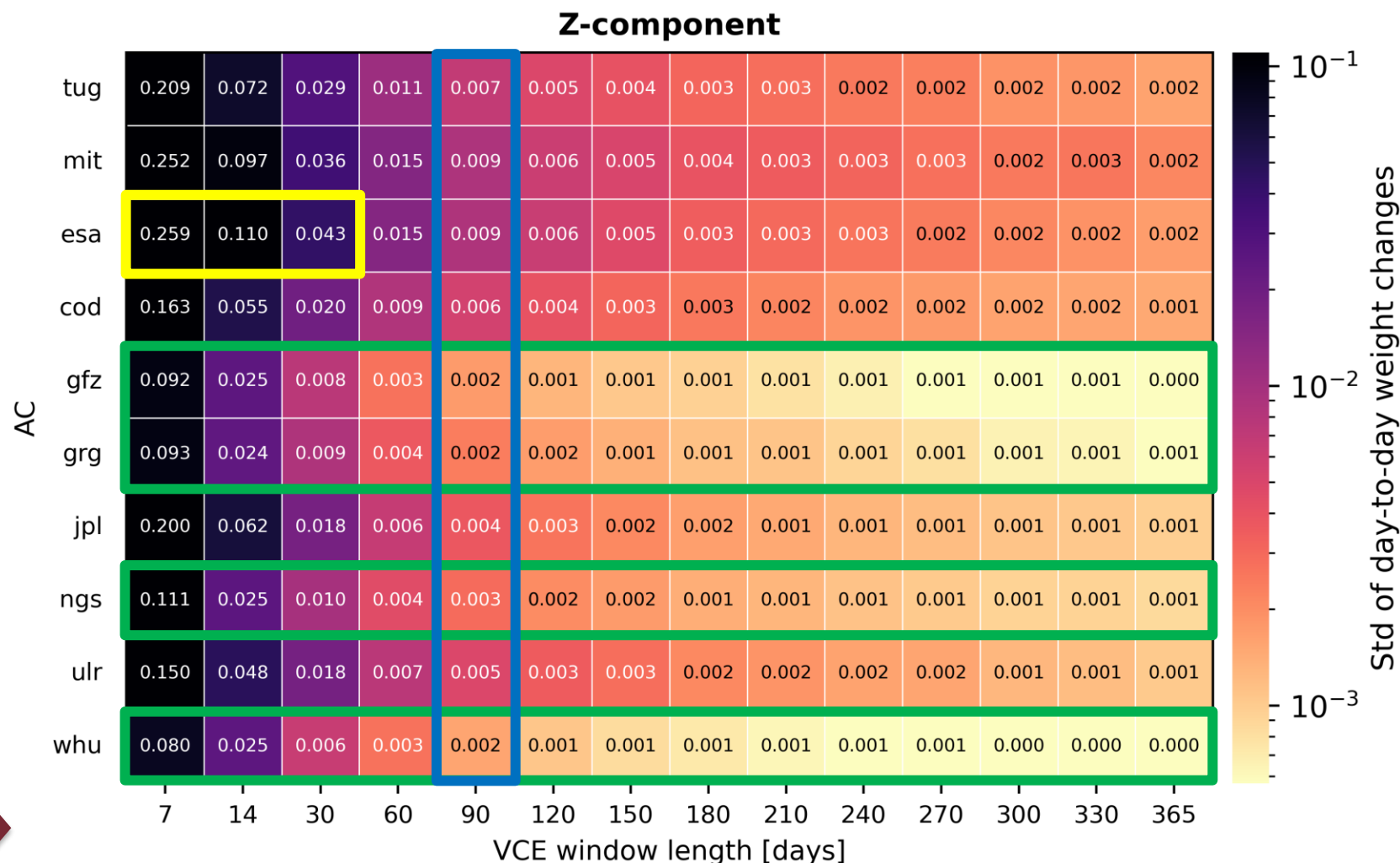
- ❖ The annual signal is well preserved in X/Y: phasor distance remains **below ~0.2 mm**
- ❖ The **Z component** is more sensitive: phasor distance **decreases from ~0.8 to ~0.4 mm** with longer windows

Weight stability

Why are short windows problematic?



Focus on **Z-component**: the most sensitive component in the previous test.

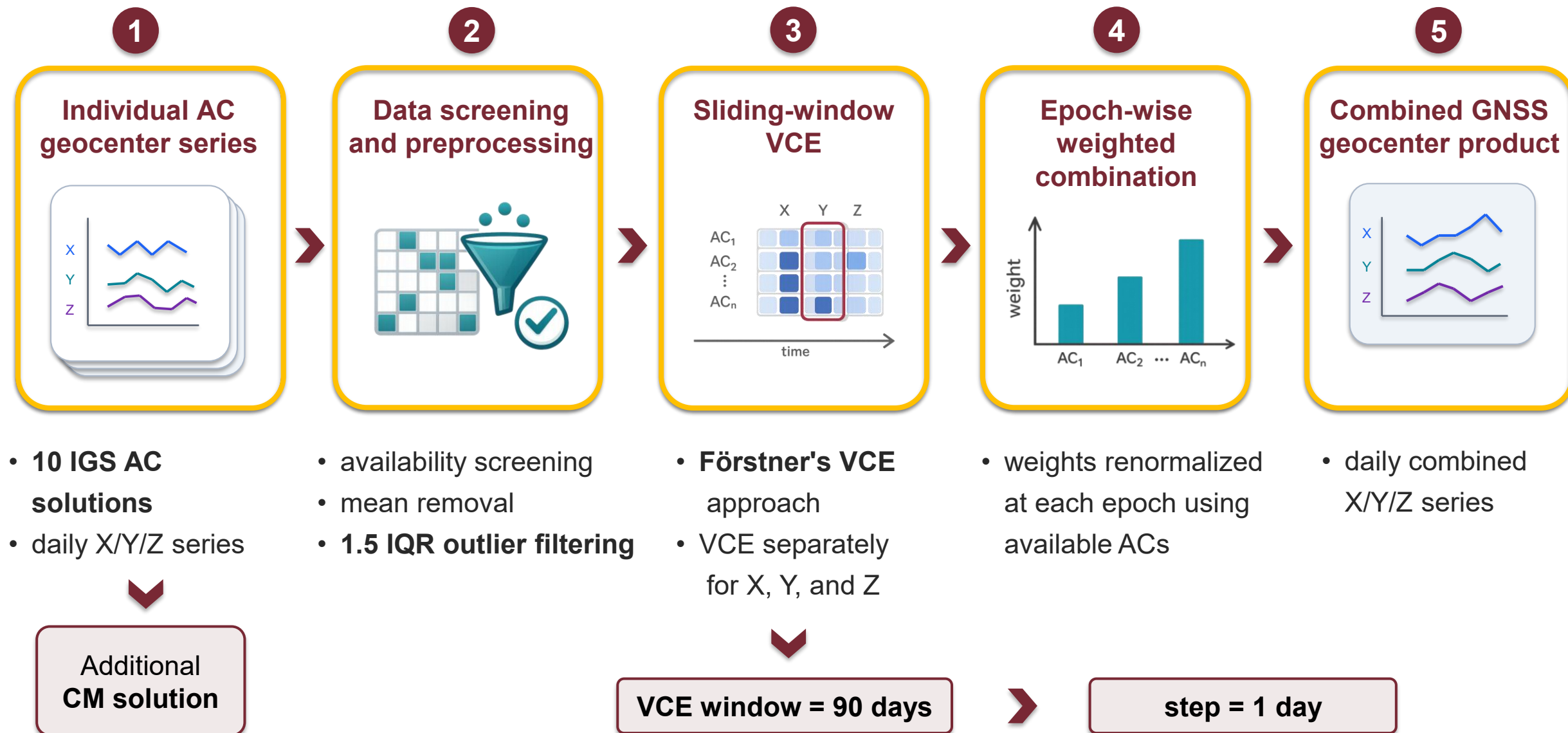


Each cell shows the standard deviation of day-to-day weight changes for a given AC and VCE window length.

Lower values indicate more stable weights.



Combination workflow of the final combination



CM approach

Two main approaches for estimating the geocenter motion from GNSS:

1 Translational (direct)

Network Shift (NSH) approach

- **Geometric** approach
- Estimates the **CM-CF translation** directly from the GNSS network solution
- Limitations: sensitive to **network geometry** and **correlations** between translation parameters and dynamic **orbit parameters**

10 IGS AC series used in this study

2 Deformation-based (inverse)

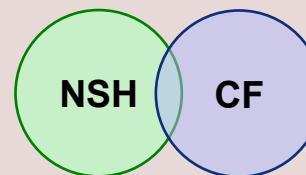
Degree-1 deformation (CF approach)

- **Estimates degree-1 load coefficients** from GNSS station displacements
- Based on **elastic loading theory** and **load Love numbers**
- Limitations: sensitive to **spatial aliasing** of higher-degree signals and **uneven station coverage**

Unified CM approach (Lavallée et al., 2006)



Both approaches provide complementary information and contribute to a common geocenter estimate in the **CM frame**, since **degree-1 deformations include a translational component**.



CM series used in this study:

Nowak et al. (2026)



?

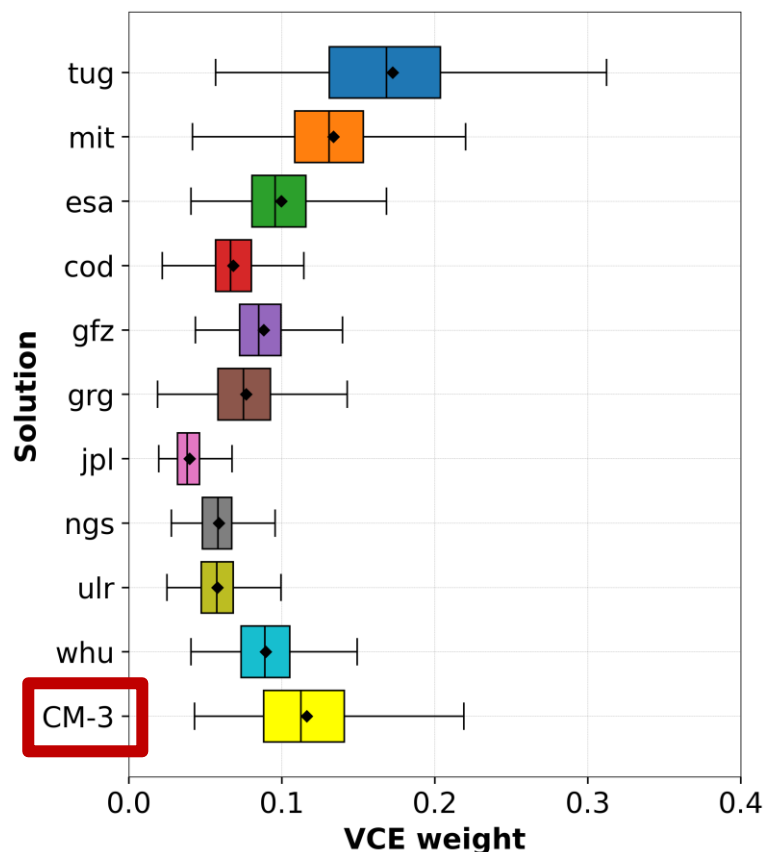
Can adding the **CM solution** strengthen the GNSS combination, especially in the **z** component?

Contribution of the CM solution

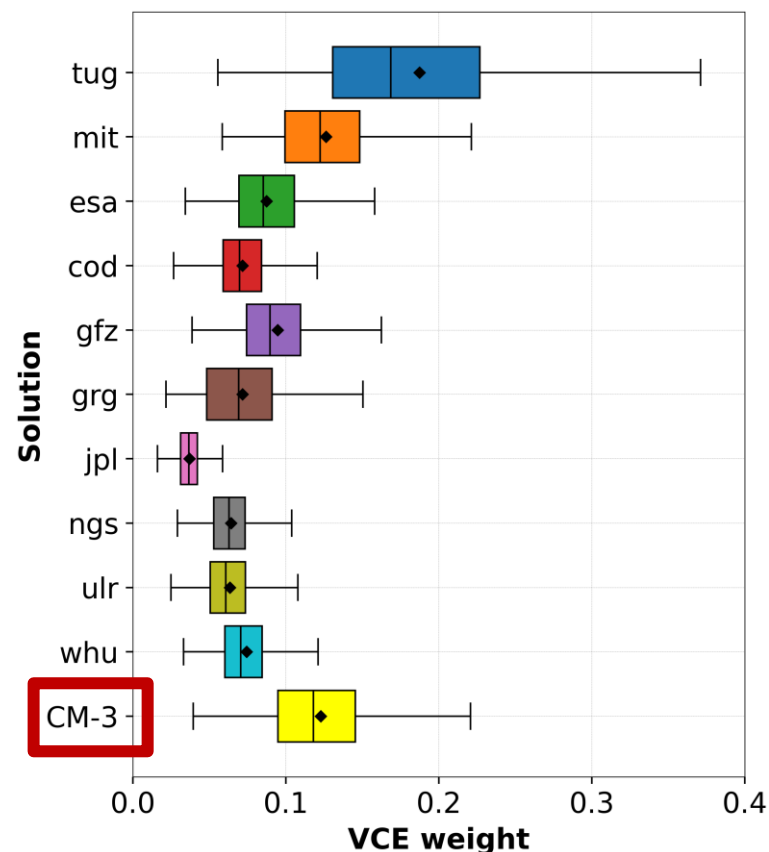


CM-3 used here:
CODE repro3 station displacements
→ degree-3 loading inversion

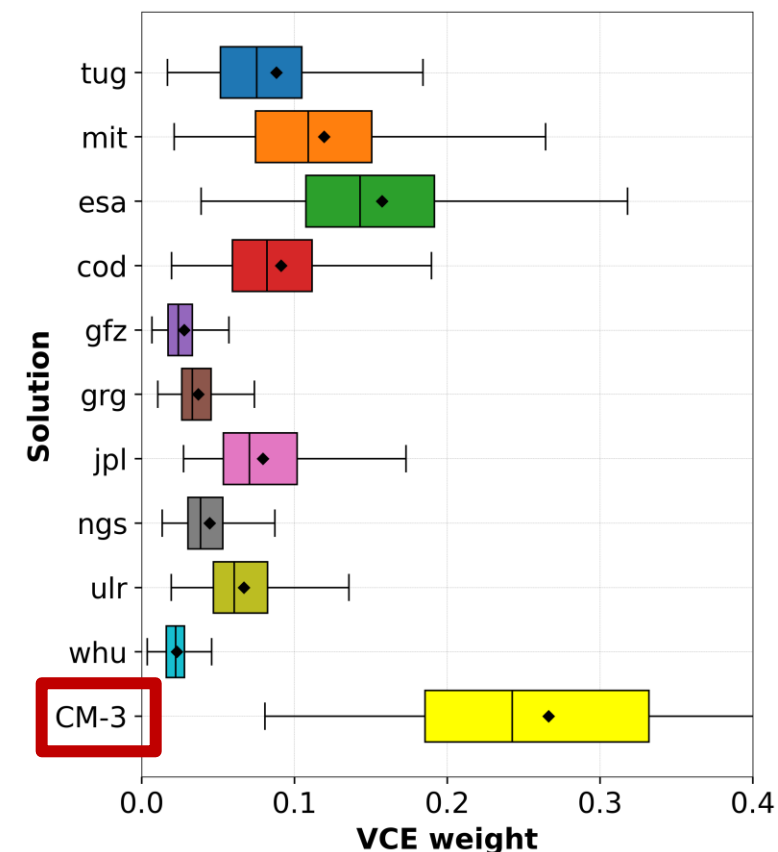
X-component



Y-component



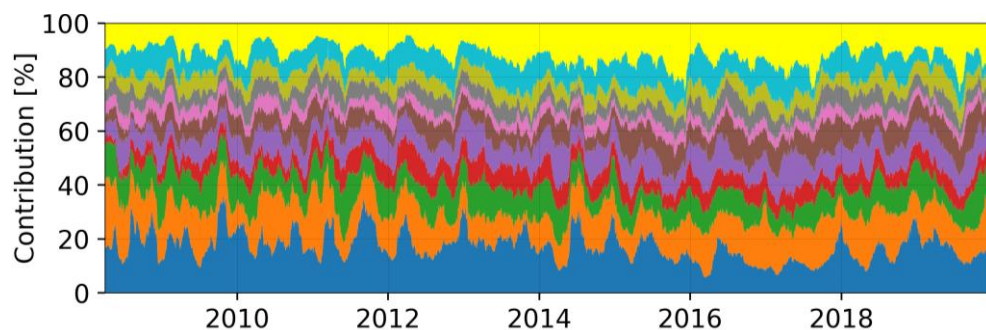
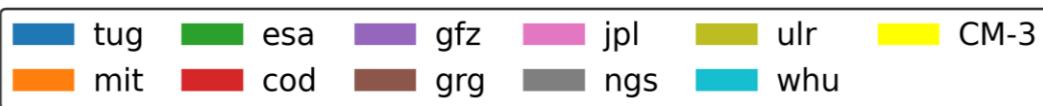
Z-component



X/Y: CM remains one of several major contributors, with the **third-highest median weight**.

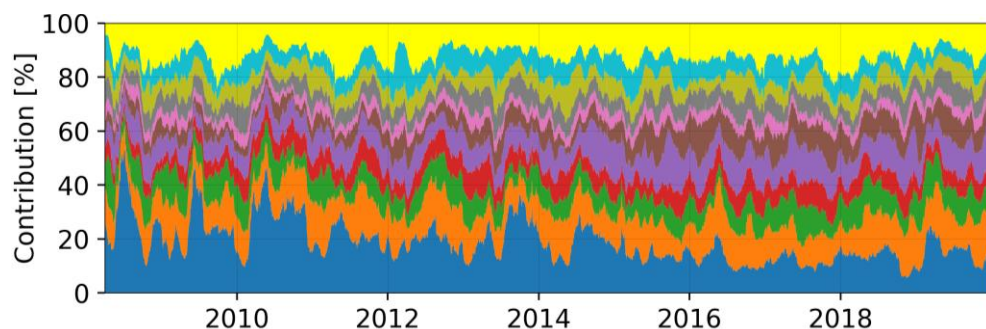
Z: CM receives the **largest median weight**.

Temporal evolution of weights



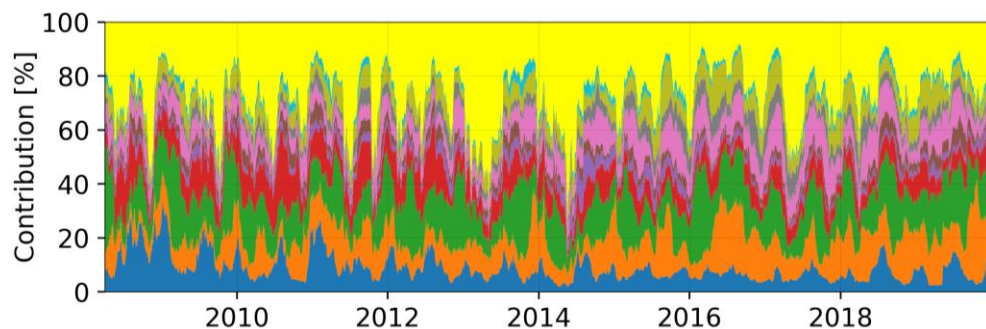
X-component

Broadly distributed contributions across several ACs, with only moderate temporal redistribution and **no persistent dominance of a single solution**.



Y-component

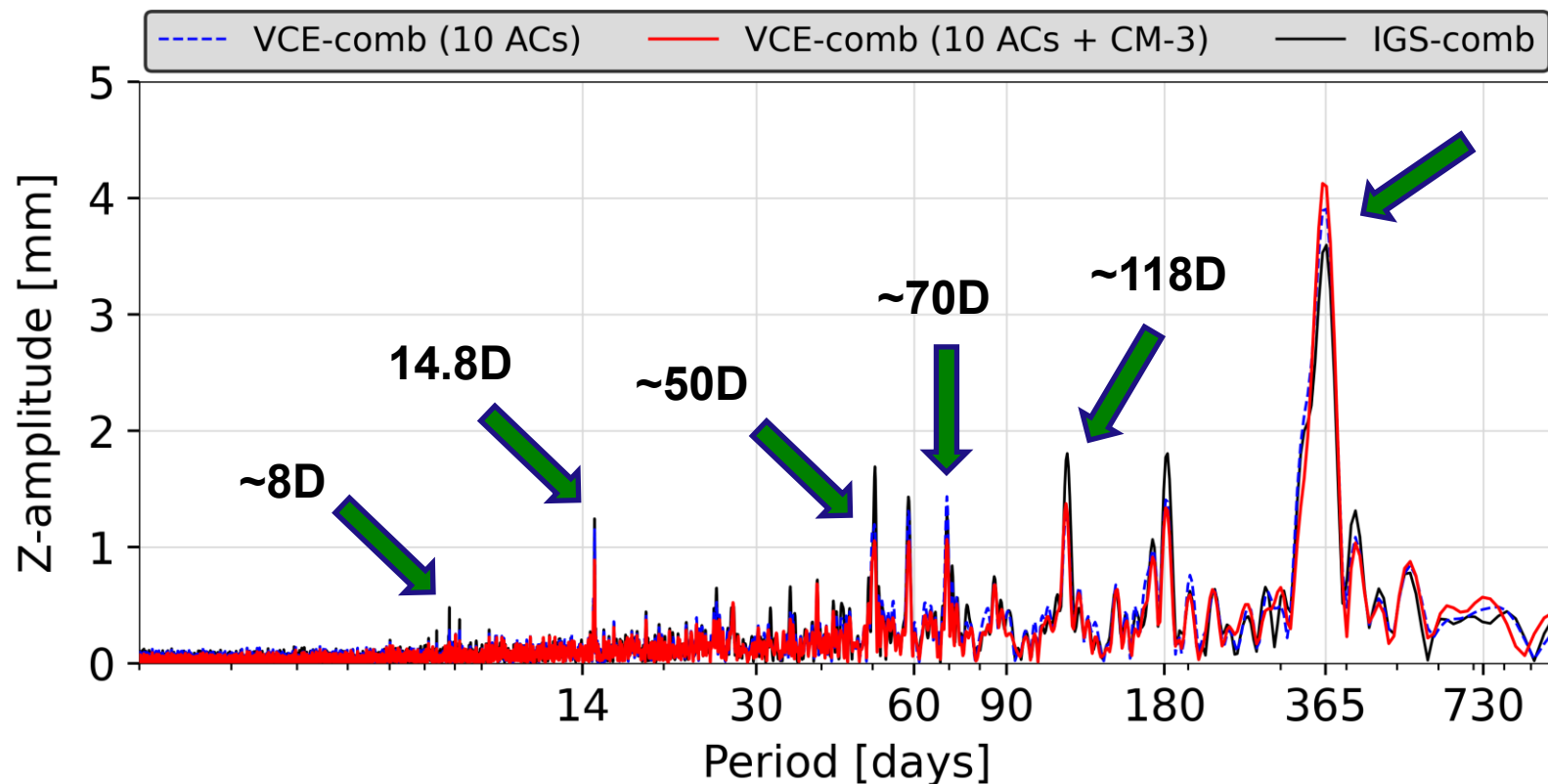
Similar to X: broadly distributed weights, moderate temporal variability, and no persistent dominance of CM solution.



Z-component

The **strongest temporal redistribution**, with the CM contribution becoming markedly larger around 2013–2015 and remaining more variable than in X/Y.

Impact of adding the CM solution



Amplitude of annual signal:

IGS-comb = **3.64 mm** → VCE-comb (10 ACs) = **3.95 mm** → VCE-comb (10 ACs + CM-3) = **4.17 mm**

Adding CM reduces selected draconitic and shorter-period GNSS artifacts while increasing the amplitude of the annual signal by about 0.2 mm.

Conclusions and outlook

1

X/Y show little sensitivity to VCE window length beyond ~30 days, while Z requires ≥ 90 -day windows for stable weights

2

CM-3 remains one of several contributors in X/Y, but receives the largest median weight in Z

3

Adding CM-3 reduces selected draconitic peaks and increases the amplitude of the annual signal by ~0.2 mm



Component-dependent VCE weighting, combined with a deformation-based CM solution, strengthens the GNSS geocenter combination, with the clearest effect in the Z component.

Outlook

- **Validation against independent SLR and geophysical loading series.**
- Extension toward a **multi-technique** geocenter combination.



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Thank you for your attention!

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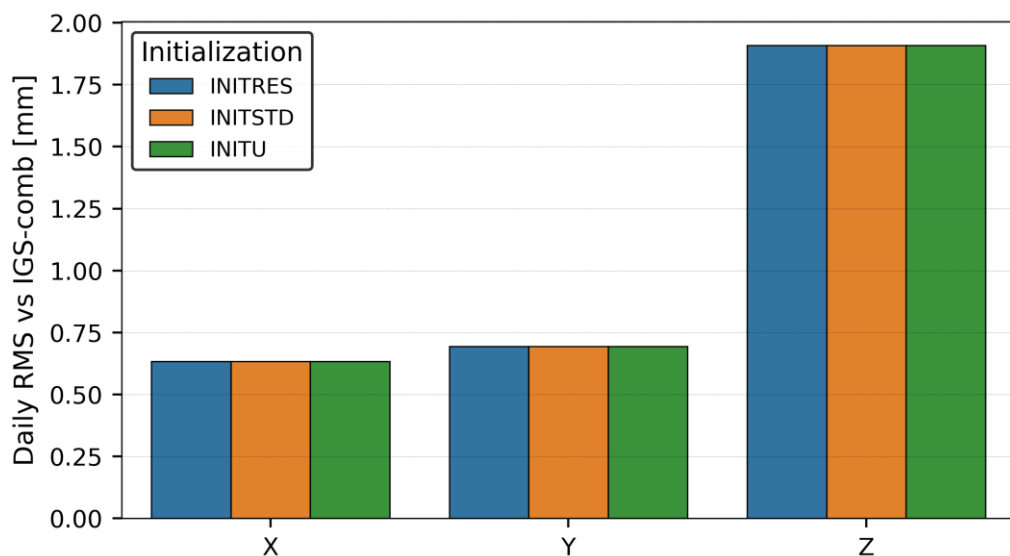
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Parametrization sensitivity

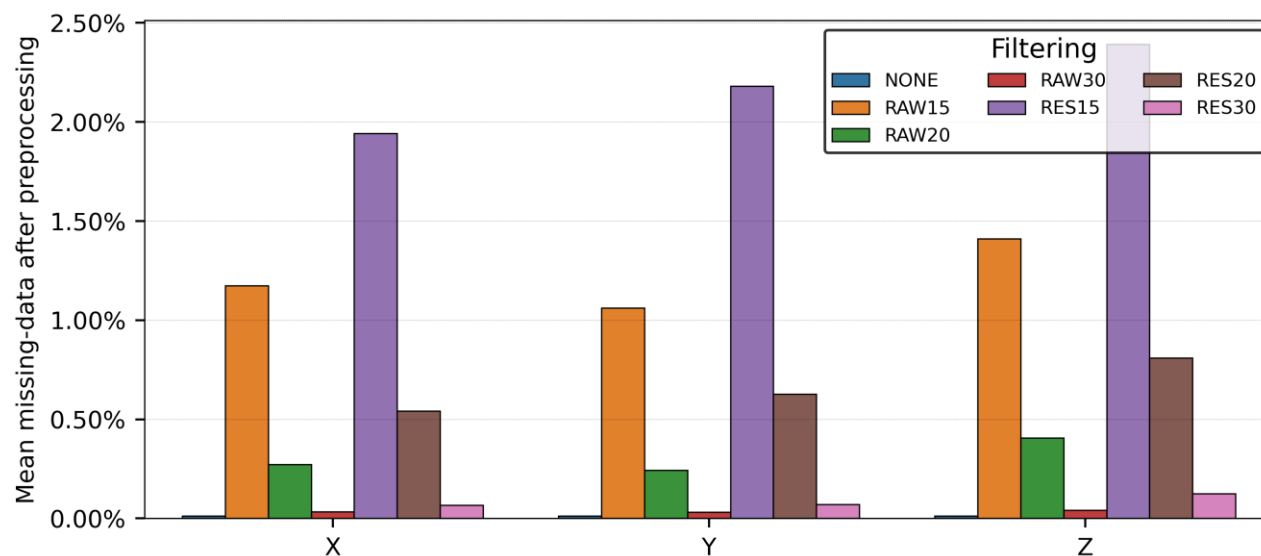
Variance initialization

- ❖ Initialization slightly affects convergence speed, but not the final combined series.



Outlier filtering

- ❖ Outlier filtering has a measurable impact, especially for the Z component.



RAW15 provides the best compromise between robustness and limited data removal.