# Status and outlook of time-variable gravity field determination from  GRACE Follow-On  data at the AIUB

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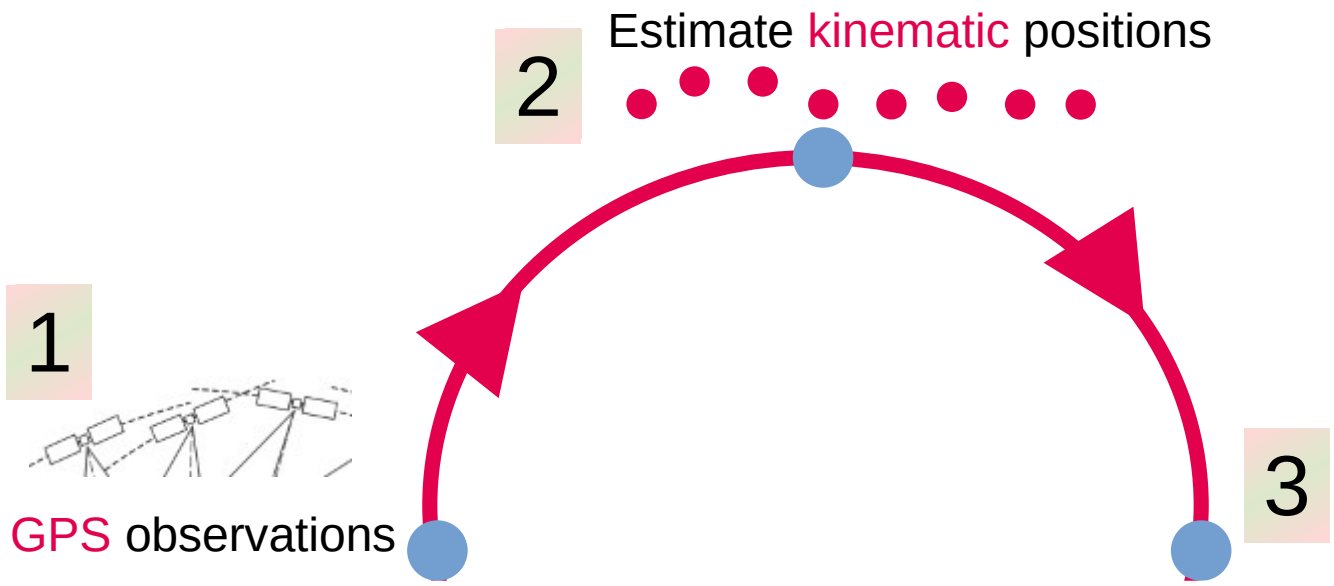
GRACE Follow-On Science Team Meeting 2025, 7 – 9 October 2025, Online

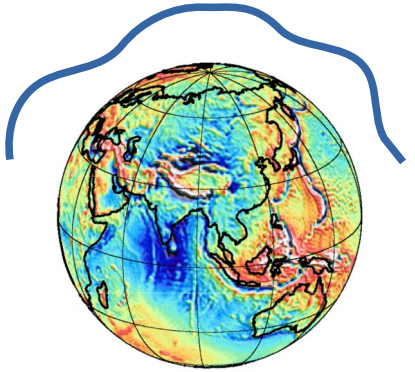
AIUB Astronomical Institute University of Bern

# Gravity Field Recovery

## A little detour



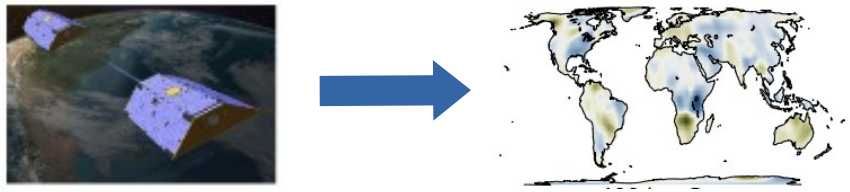

Take kinematic positions and KBR/LRI observations and estimate (reduced) dynamic orbit + gravity field



Background information
- Celestial Mechanics Approach (CMA, Beutler et al., 2010) applied
- CODE GNSS products
- PCV maps used
- Ambiguities integer-fixed

# Parametrisation

## For estimating gravity fields



### Basic parametrisation (per arc)

Daily arcs

- Initial conditions
- Bias in radial, along-track, cross-track
- ACC scaling factors
- Off-diagonal elements for ACC scaling

### Additional parameters (per arc)

- 15 min PCA per satellite in
  - radial
  - along-track
  - cross-track

+ gravity field

| Force models | |
|---|---|
| Gravity field | AIUB_APR |
| Astronomic bodies | JPL DE421 (all planets) |
| Mean pole | Linear |
| Solid Earth tides | IERS2010 |
| Solid Earth pole tides | IERS2010 |
| Ocean tides | **MIXED2025 (TUG)** (+ admittances from TUG) |
| Ocean pole tides | Desai |
| Atmospheric tides | **TiME22** |
| Atmospheric & oeanic dealiasing | **AOD RL07 + AOe07** |
| Relativistic effects | IERS2010 |
| Accelerometer data | **JPL: ACH (ACX, ACX2)** |

# Piece-wise constant accelerations

## Constraining

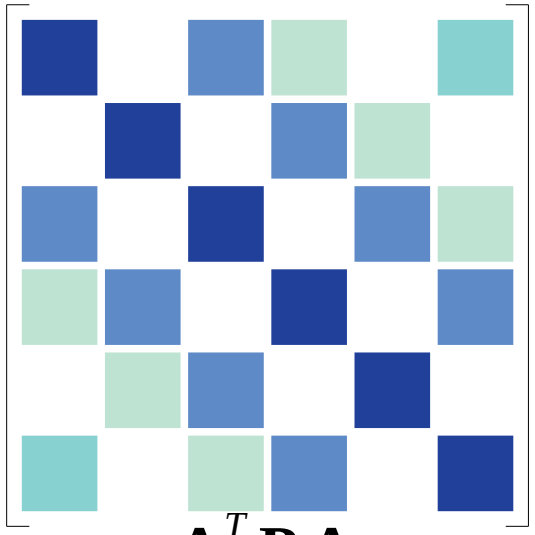
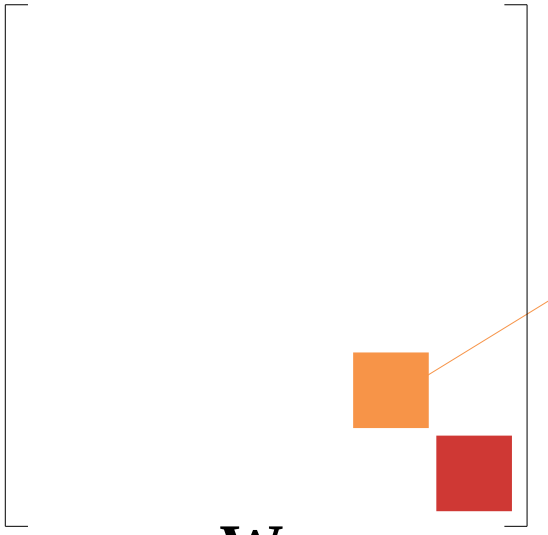
$\mathbf{N} = \left( \mathbf{A}^T \mathbf{P} \mathbf{A} \right)$ and $\boldsymbol{b} = \mathbf{A}^T \mathbf{P} \boldsymbol{l}$ → $\hat{\boldsymbol{x}} = \mathbf{N}^{-1} \boldsymbol{b}$

$\mathbf{N} = \left( \mathbf{A}^T \mathbf{P} \mathbf{A} + \mathbf{W} \right)$

$\mathbf{A}$ design matrix

$\mathbf{P}$ weight matrix

$\boldsymbol{l}$ obser-vations

$N =$  $+$ 

$\mathbf{A}^T \mathbf{P} \mathbf{A}$ $\mathbf{W}$

$\frac{\sigma_0^2}{\sigma_{PCA}^2}$,

$\sigma_{PCA}^2 =$ e.g., $3 \times 10^{-10}$ ms$^{-2}$

# Piece-wise constant accelerations

## Constraining

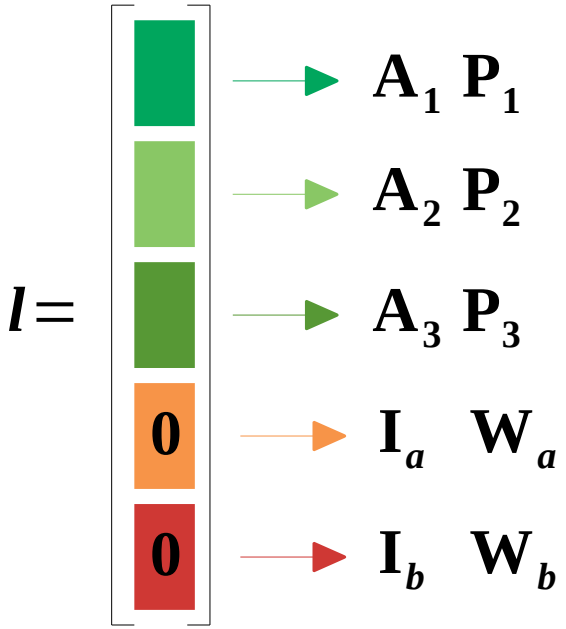
$$\mathbf{N} = \left( \mathbf{A}^T \mathbf{P} \mathbf{A} \right) \quad \text{and} \quad \boldsymbol{b} = \mathbf{A}^T \mathbf{P} \boldsymbol{l} \longrightarrow \hat{\boldsymbol{x}} = \mathbf{N}^{-1} \boldsymbol{b}$$

$$\mathbf{N} = \left( \mathbf{A}^T \mathbf{P} \mathbf{A} + \mathbf{W} \right)$$

$\mathbf{A}$ design matrix

$\mathbf{P}$ weight matrix

$\boldsymbol{l}$ observations



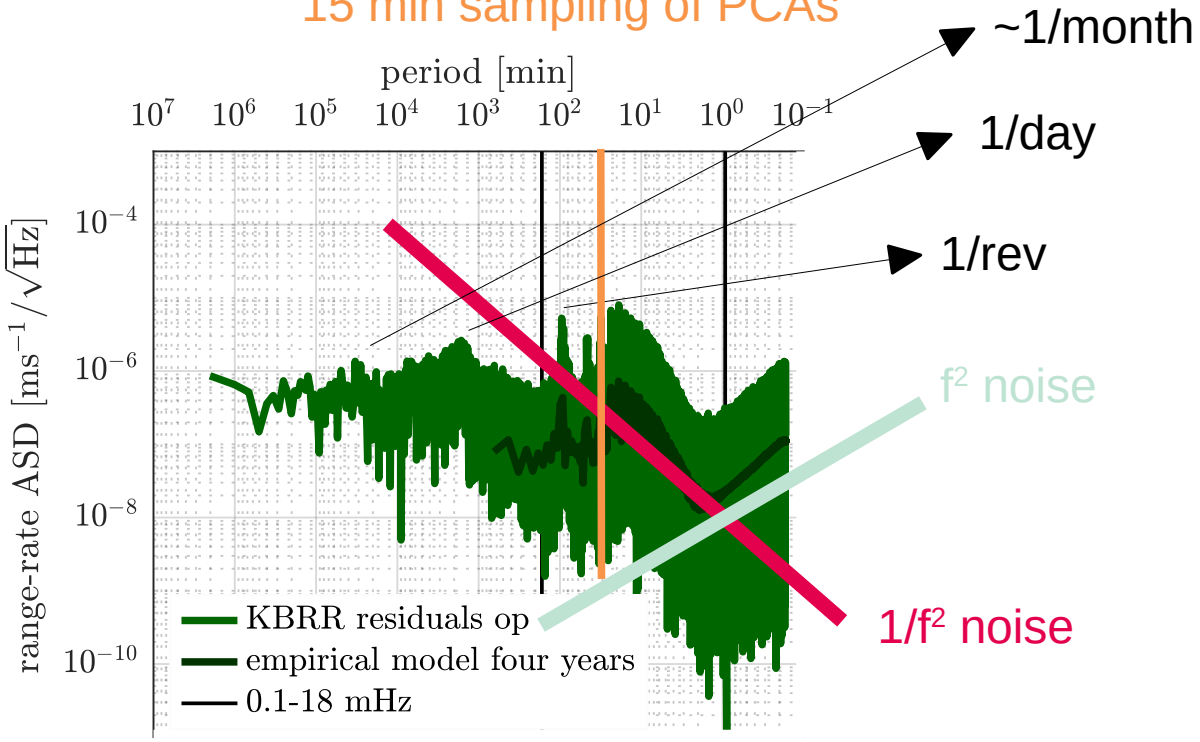

- The observations of each arc are used to set up the normal equations (NEQs).
- Each arc is treated as being independent.
- Fictional zero-observations for constraints are treated as independent observation group.

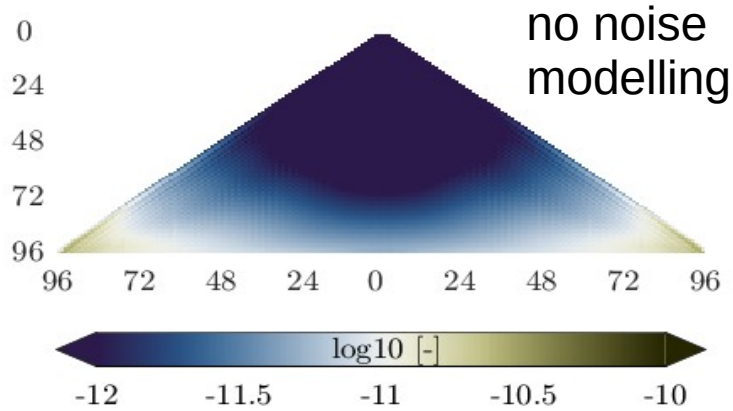
VCE: Each group of observations gets a weight based on its contribution to the final solution.

# Noise modelling

## Based on post-fit residuals

15 min sampling of PCAs



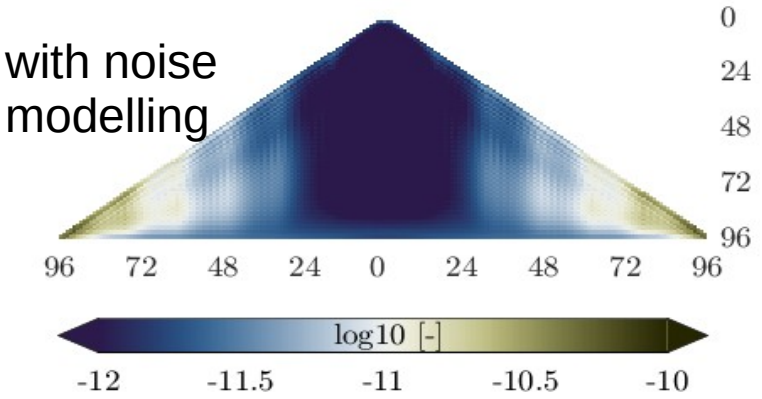




initial solution → residuals

auto covariance function →

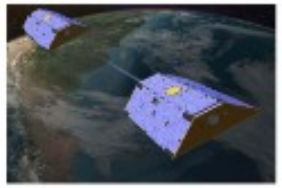
covariance matrix →

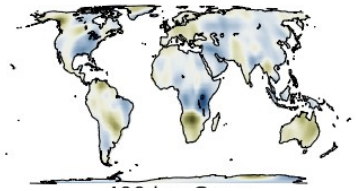
weight matrix → new estimation



# Parametrisation: Extended for AO errors

## AOe07 variance information





Basic parametrisation (per arc)

Additional parameters:
Piecewise-constant accelerations
(per arc; constraints estimated with VCE)

+

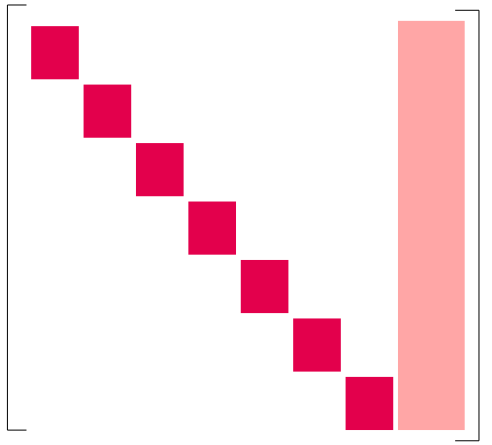
Additional parameters:
Spherical harmonic coefficients
(per arc; constrained by AOe07)

- According to Shihora et al. [2023]
- Arc-wise spherical harmonic coefficients up to d/o=96

\+ gravity field

monthly gravity field parameters (d/o=2..96)

$A =$

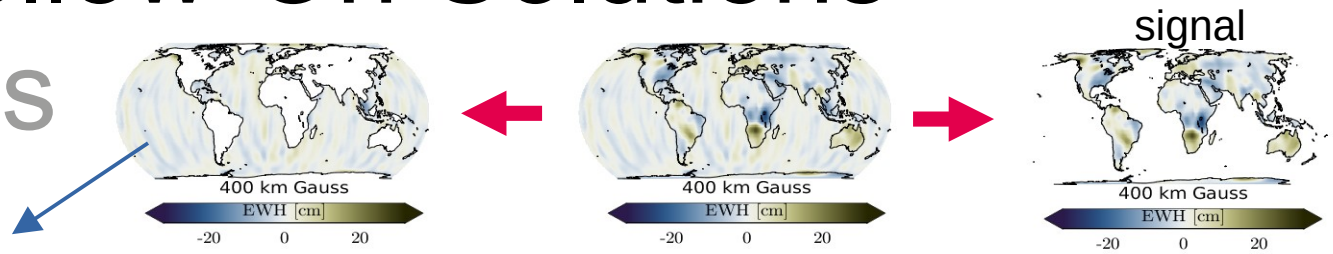


pre-eliminated on arc-wise level

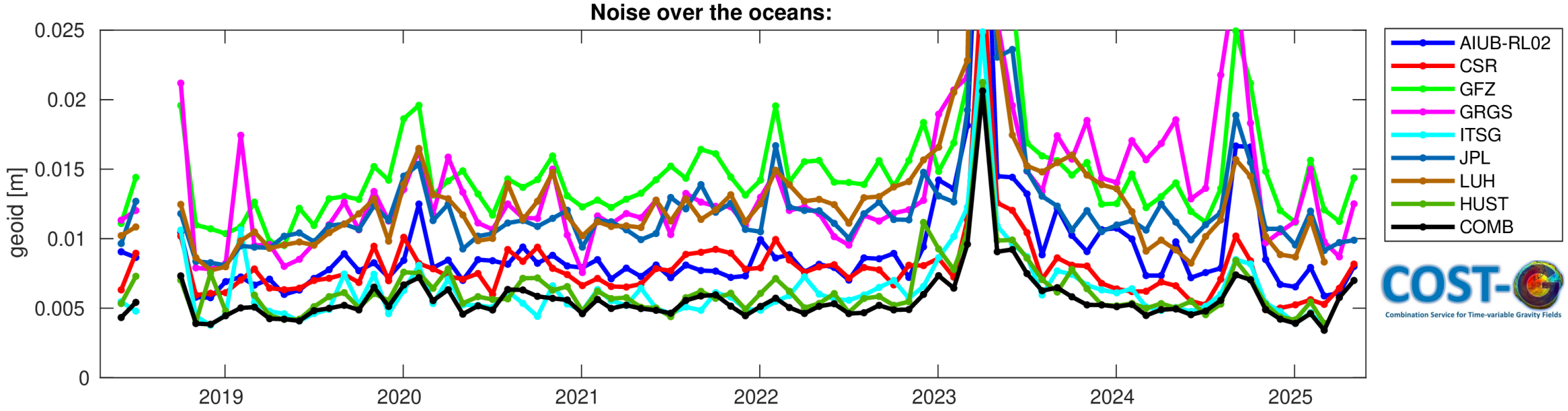
arc-wise parameters
→ orbit: ORB, ACC, PCA
→ **AOerr**: d/o=96

# AIUB GRACE Follow-On Solutions

## RMS over oceans




RMS over the oceans
(geoid heights w.r.t. COST-G mean)

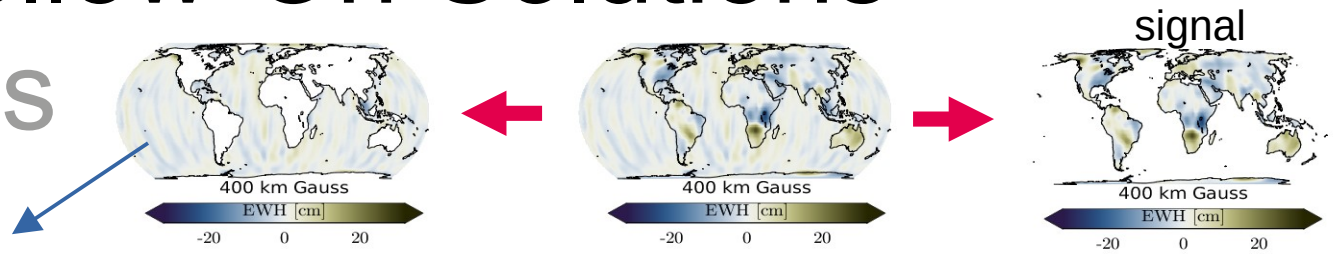



Comparison within COST-G

AIUB (RL02) solution based on FES2014b, AOD RL06 without uncertainty information

# AIUB GRACE Follow-On Solutions

## RMS over oceans




RMS over the oceans
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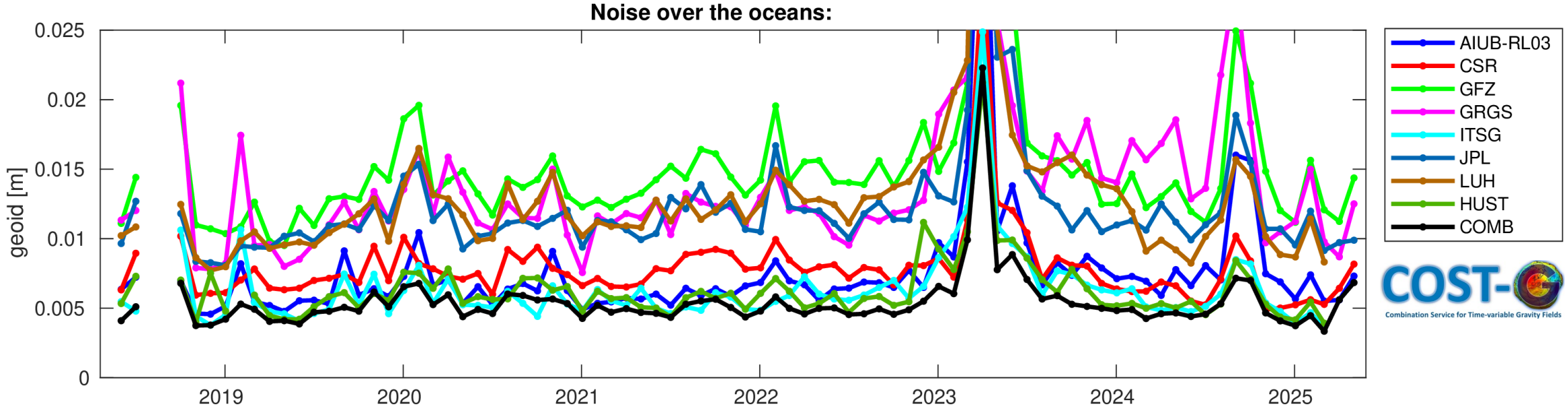
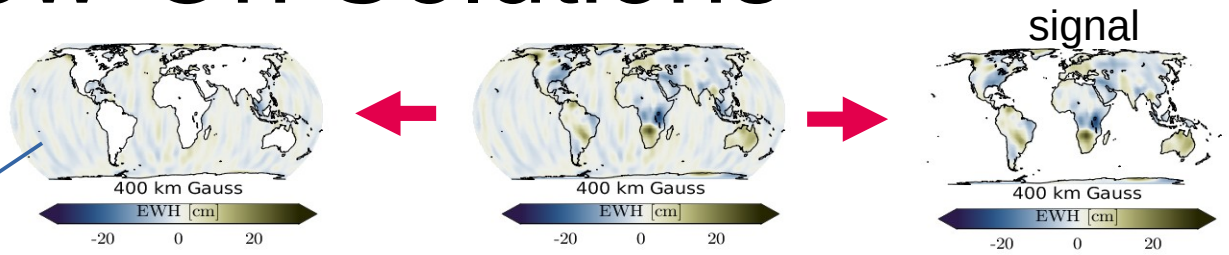



Comparison within COST-G

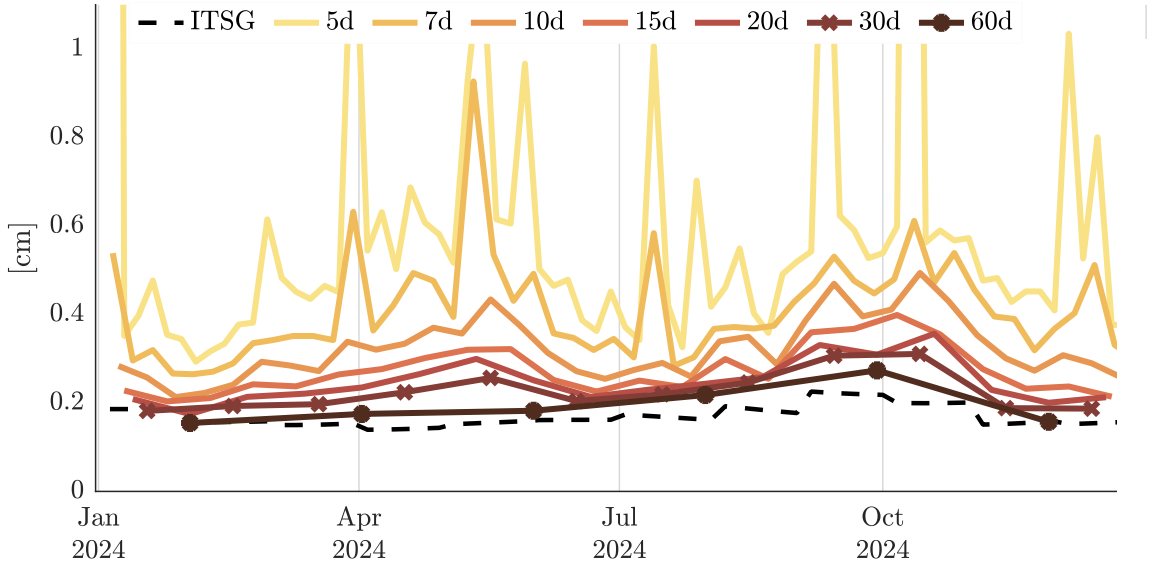
AIUB (RL03) solution based on MIXED2025, AOD RL07 including AOe07

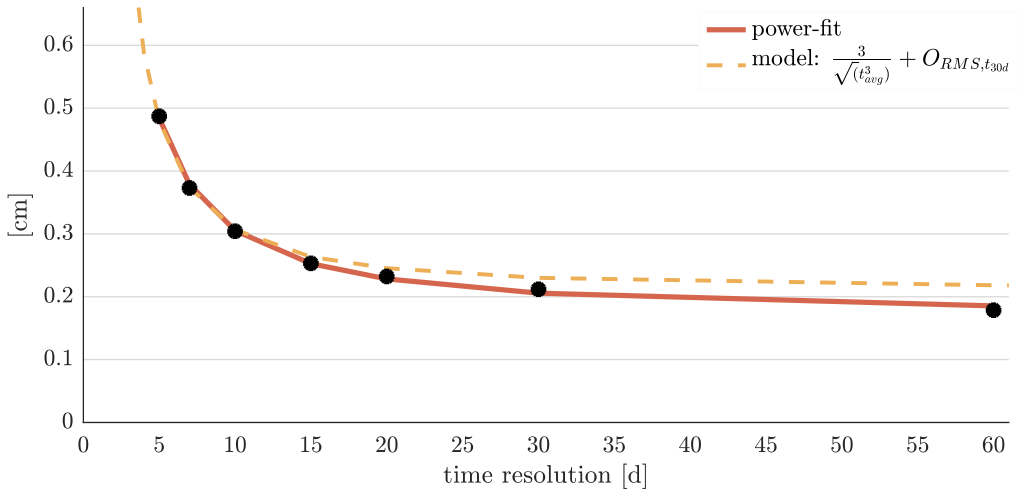
# AIUB GRACE Follow-On Solutions

## RMS over oceans – 5..60 days




RMS over the oceans
(geoid heights w.r.t. GOCO06s)




Quick check: What RMS over the oceans can be achieved from real data for different temporal resolutions (5, 7, 10, 15, 20, 30, 60 days)?

Based on data in 2024, parametrisation & modelling as shown on previous slides

# Summary
## & Conclusions

- Updated background models improve solution noticeably.
- AO error gives crucial and realistic noise information.

- Estimation of variance components for PCAs important (especially with more challenging data).

- Observation noise modelling important for realistic variance estimation.

- ACH2 (ACX2) improves results.

Further steps:

- Screening procedure needs an update.

# Thank you for your attention

**Contact**

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