# Temporal gravity changes over nine years as observed by the Swarm satellites

EGU23-5798

João Encarnação[1,7], Daniel Arnold[2], Aleš Bezděk[3], Christoph Dahle[4,2], Junyi Guo[5], Jose van den IJssel[1], Adrian Jäggi[2], Jaroslav Klokočník[3], Sandro Krauss[6], Torsten Mayer-Gürr[6], Ulrich Meyer[2] Josef Sebera[3], CK Shum[5], Pieter Visser[1], Yu Zhang[6]

[1] Delft University of Technology, the Netherlands; [2] Astronomical Institute of the University of Bern, Switzerland; [3] Astronomical Institute of the Czech Academy of Sciences, Czech Republic; [4] GFZ German Research Centre for Geosciences, Germany [5] Ohio State University, USA; [6] Graz University of Technology, Austria; [7] University of Texas at Austin, USA

EGU General Assembly

## 1 Introduction

**Objective** : Provide highest-quality monthly-independent Swarm gravity field models

**Support** : ESA/DISC funded project (since Sep 2017)

**Rationale** : Combine individual gravity solutions, computed with:

- different kinematic orbit solutions
- different inversion approaches

**Product** : Monthly combined Swarm gravity field models:

- period length set by the calendar month (first to last day)
- from 2013-12-01 to 2022-12-31
- available from:
  - ICGEM: `icgem.gfz-potsdam.de/series/02\_COST-G/Swarm`
  - ESA: `swarm-diss.eo.esa.int` > *Level2longterm* > *EGF*

**Citation** : Teixeira da Encarnação et al. (2020)

## 2 Kinematic Orbits

| Institute | Software | Reference |
|---|---|---|
| AIUB | Bernese v5.3 | Jäggi et al. (2016)[1] |
| IfG | Gravity Recovery Object Oriented Programming System (GROOPS) | Zehentner and Mayer-Gürr (2016)[2] |
| TUD | GPS High precision Orbit determination Software Tool (GHOST) | IJssel et al. (2015)[3] |

[1] `ftp://ftp.aiub.unibe.ch/leo_orbits/swarm`
[2] `ftp://ftp.tugraz.at/outgoing/ITSG/tvgogo/orbits/Swarm`
[3] `http://earth.esa.int/web/guest/swarm/data-access`

## 3 Individual Gravity field models

| Inst. | Approach | Reference |
|---|---|---|
| AIUB | Celestial Mechanics Approach | Jäggi et al. (2016) |
| ASU | Decorrelated Acceleration Approach | Bezděk et al. (2016) |
| IfG | Short-Arcs Approach | Zehentner and Mayer-Gürr (2016) |
| OSU | Improved Energy Balance Approach | Guo et al. (2015) |

## 4 Combined Gravity field models

- Combination at the level of solutions, up do degree 40
- Weights applied to individual solutions derived from Variance Component Estimation (VCE)
- Degrees 2-20 considered in VCE item More details: Teixeira da Encarnação and Visser (2019)

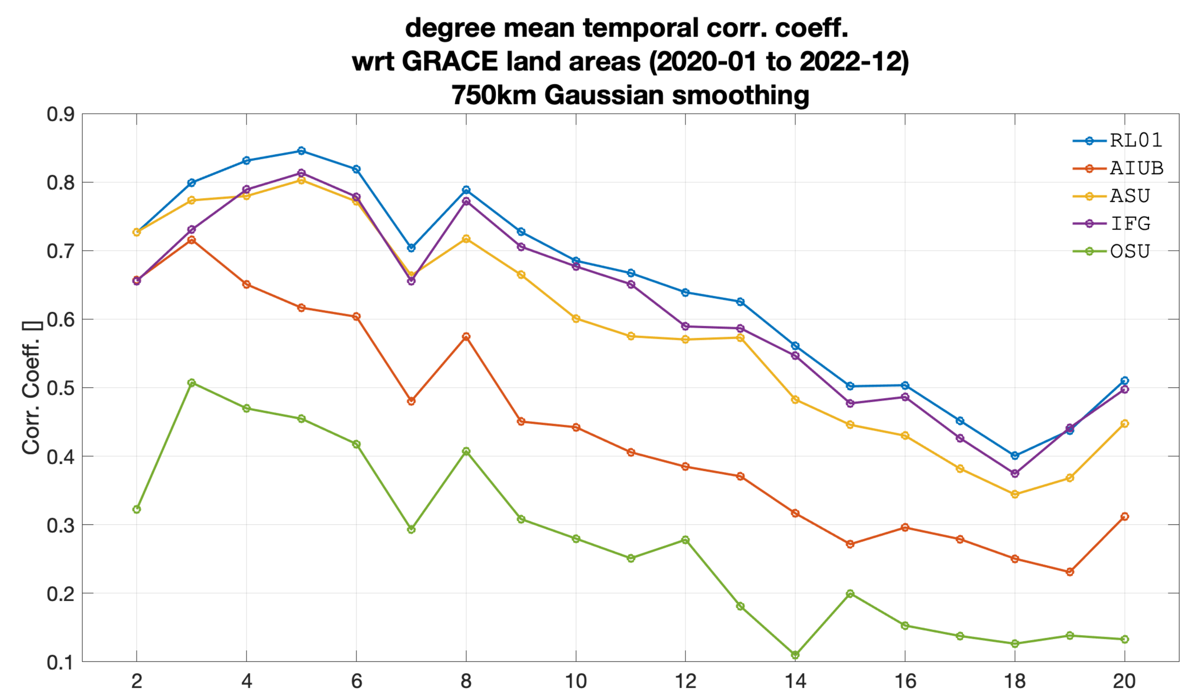
## 5 Gravity field model pre-processing

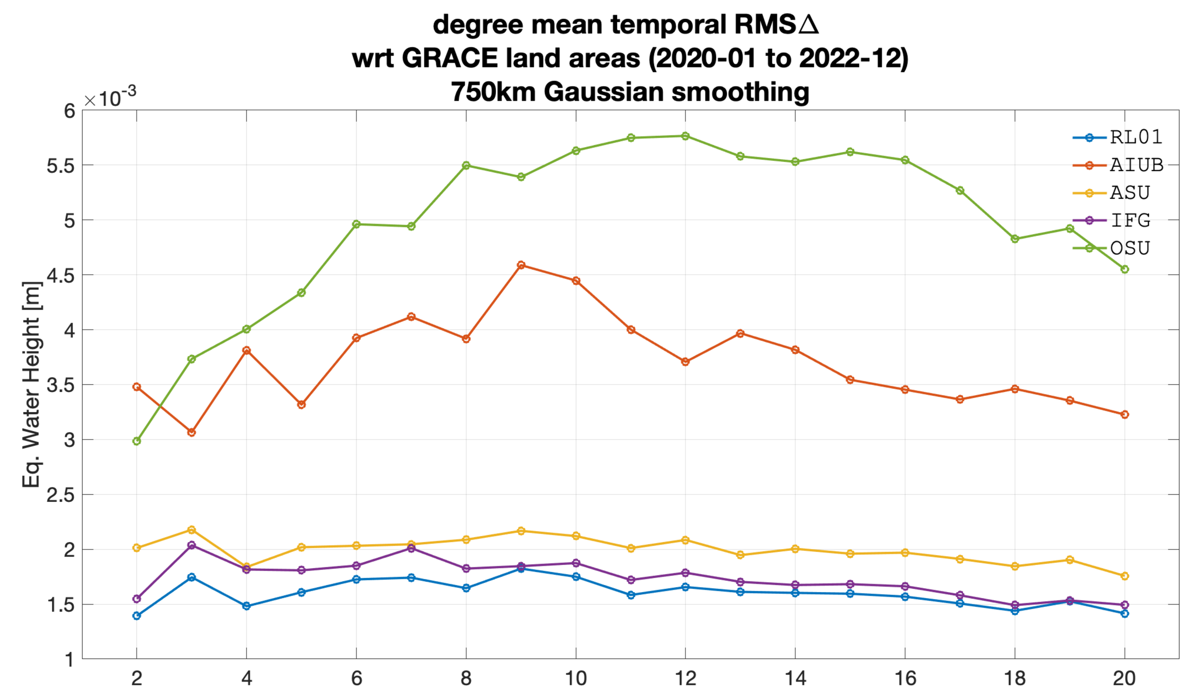
- Analysis spans 2016-01-01 until 2022-12-31
- 2013-12 to 2015-12:
  - high solar activity and data problems
  - low quality → not representative
- Temporal variations relative to static GGM05G
- Gaussian smoothing with 750 km radius
- $C_{20}$ replaced with values from weekly GRACE TN-14 time series
- ACC data not used

## 6 Analyses setup

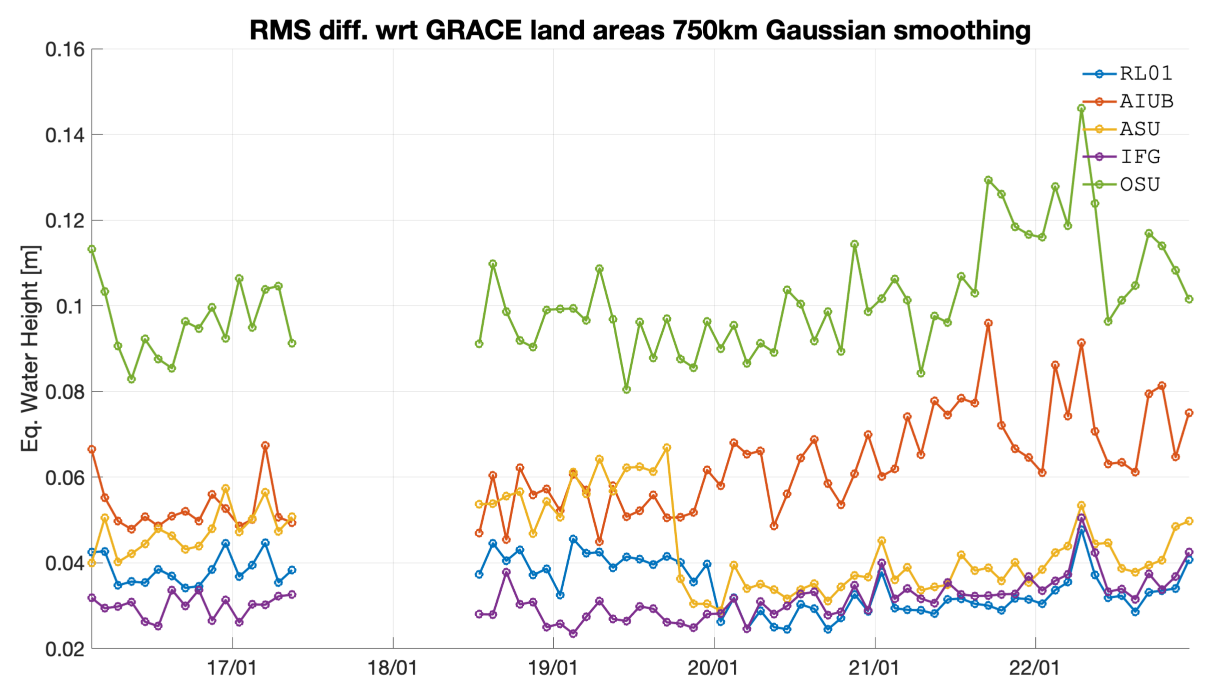
- Swarm is compared to GRACE/GRACE-FO CSR RL06 (with same pre-processing)
- GRACE/GRACE solutions interpolated/evaluated at Swarm model epochs (except over gaps longer than 120 days)
- Ocean signal, with no buffer zone, removed for land analyses
- IfG KO orbits:
  - Considered for ASU solutions for Oct - Dec 2019 (and later)
  - Not considered for RL01 solutions prior to Jan 2020

## 7 Spectral analysis land areas

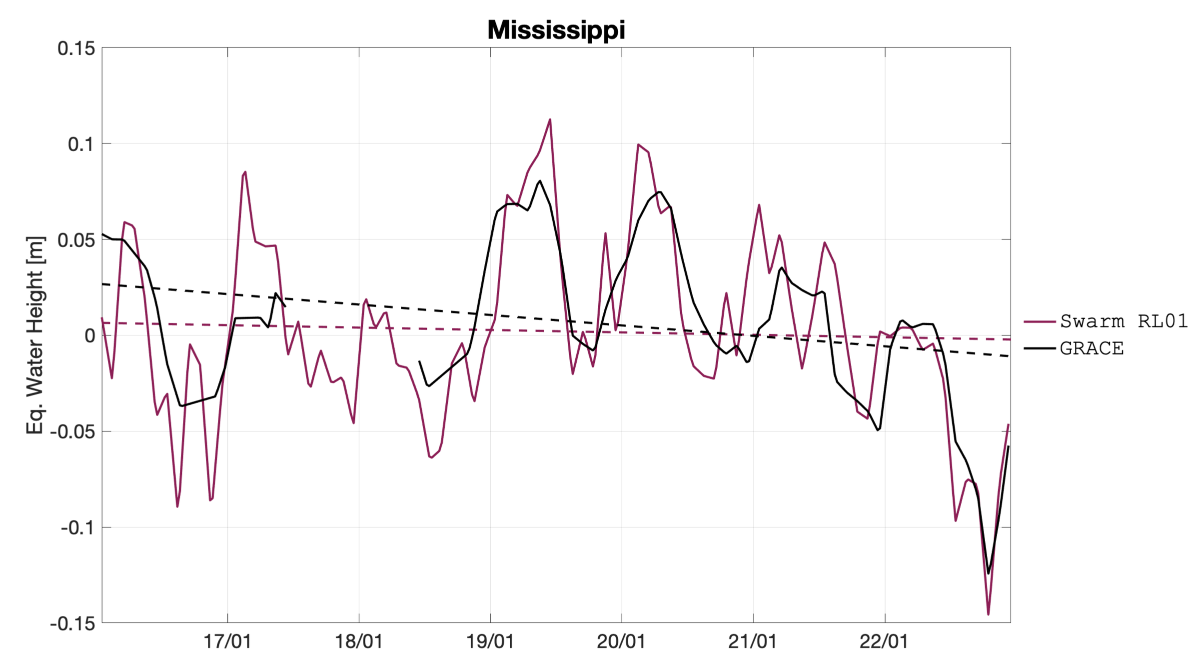


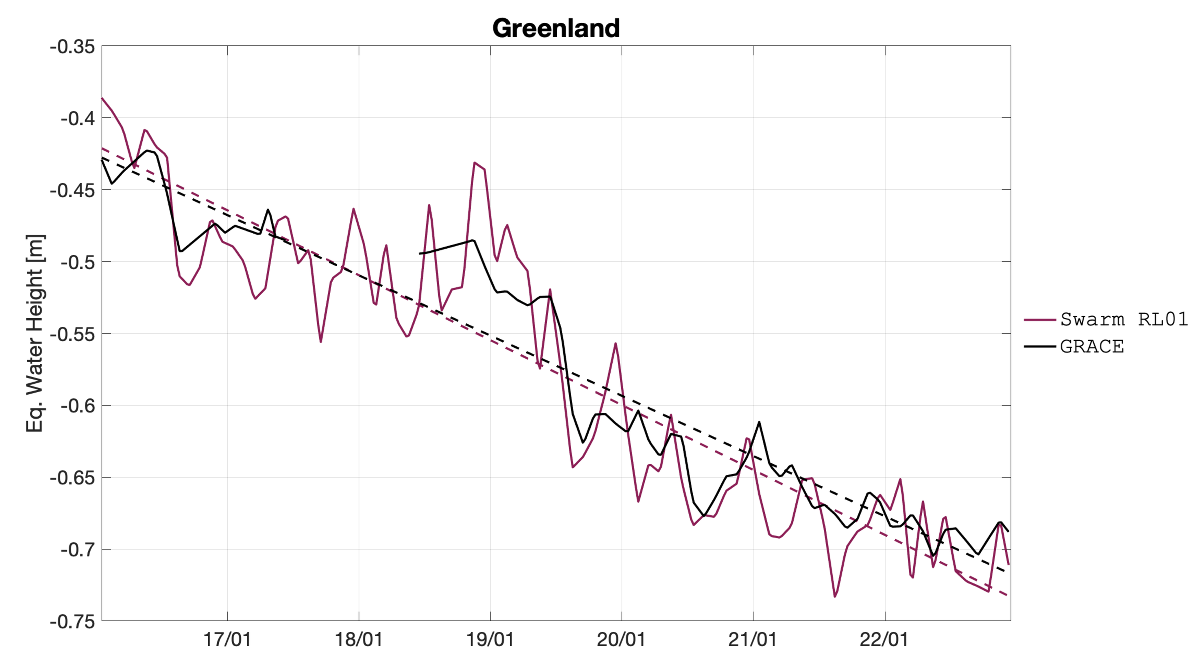




## 8 Agreement with GRACE




## 9 Basin time series




### 9.1 Statistics for 18 basins

| Bias (*) Δ RMS [cm] | Trend Δ RMS [cm/year] | corr. coeff. mean [ ] |
|---|---|---|
| 1.02 | 0.40 | 0.81 |

(*) Average basin storage from 2016-01-01 until 2022-12-31.

## 10 Conclusions

- Combined model better than individual models under any metric
- Since January 2020:
  - IfG KO orbit processing improvements visible
  - Increase in solar activity slowly degrading agreement with GRACE
- Seasonal land signal clearly resolvable by Swarm:
  - Temporal correlations dip under 0.5 only above degree 16
  - Global spatial agreement with GRACE model at 3-4 cm RMS EqWH
  - Trends over 18 analysed basins (of various sizes) agree with 4 mm/year EqWH, with temporal correlation averaging 0.81
  - Abnormal mass variations well represented: Mississippi in late 2022

## References

Bezděk, Aleš et al. (2016). **Time-variable gravity fields derived from GPS tracking of Swarm**. In: *Geophysical Journal International* 205.3, pp. 1665–1669. DOI: `10.1093/gji/ggw094` (cit. on p. 1).

Guo, J. Y. et al. (2015). **On the energy integral formulation of gravitational potential differences from satellite-to-satellite tracking**. In: *Celestial Mechanics and Dynamical Astronomy* 121.4, pp. 415–429. DOI: `10.1007/s10569-015-9610-y` (cit. on p. 1).

IJssel, Jose van den et al. (2015). **Precise science orbits for the Swarm satellite constellation**. In: *Advances in Space Research* 56.6, pp. 1042–1055. DOI: `10.1016/j.asr.2015.06.002` (cit. on p. 1).

Jäggi, A. et al. (2016). **Swarm kinematic orbits and gravity fields from 18 months of GPS data**. In: *Advances in Space Research* 57.1, pp. 218–233. DOI: `10.1016/j.asr.2015.10.035` (cit. on p. 1).

Teixeira da Encarnação, João and Pieter Visser (2019). **TN-03: Swarm models validation**. Tech. rep. TU Delft. DOI: `10.13140/RG.2.2.33313.76640` (cit. on p. 1).

Teixeira da Encarnação, João et al. (2020). **Description of the multi-approach gravity field models from Swarm GPS data**. In: *Earth System Science Data* 12.2, pp. 1385–1417. DOI: `10.5194/essd-12-1385-2020` (cit. on p. 1).

Zehentner, Norbert and Torsten Mayer-Gürr (2016). **Precise orbit determination based on raw GPS measurements**. In: *Journal of Geodesy* 90.3, pp. 275–286. DOI: `10.1007/s00190-015-0872-7` (cit. on p. 1).

## Acknowledgements

This research was funded by the European Space Agency (contracts SW-CO-DTU-GS-111 and SW-CN-DTU-GS-027, part of contract 4000109587/13/I-NB), partially supported by the Strategic Priority Research Program of the Chinese Academy of Sciences (grant XDA19070302), by the National Key Research & Development Program of China (Grant 2017YFA0603103-3), by the National Natural Science Foundation of China (Grant 41584016) and by the Ministry of Education, Youth and Sports of the Czech Republic (Grant LTT18011).

## Contact

Astrodynamics and Satellite Missions, Delft University of Technology
Kluyverweg 1, 2629 HS Delft, the Netherlands
Email: `j.g.deTeixeiradaEncarnacao@tudelft.nl`