Nearly a decade of Swarm monthly gravity field models

J. Encarnação[1,2] D. Arnold[3] A. Bezděk[4] C. Dahle[5] J. Guo[7] J. van den IJssel[1] A. Jäggi[3] J. Klokočník[4] S. Krauss[8] T. Mayer-Gürr[8] U. Meyer[3] J. Sebera[4] CK Shum[7] P. Visser[1] Y. Zhang[7]

[1]Delft University of Technology [2]Center for Space Research, The University of Texas at Austin [3]Astronomical Institute of the University of Bern [4]Astronomical Institute of the Czech Academy of Sciences [5]GFZ German Research Centre for Geosciences [6]Royal Netherlands Meteorological Institute [7]School of Earth Sciences of The Ohio State University [8]Institute of Geodesy of the Graz University of Technology

11 October 2023

Context and objectives

- ESA/DISC funded project (since 9/2017)
- Provide highest-quality monthly-independent GNSS-based gravity field models from Swarm
- Combine individual gravity solutions, computed with:
  - different kinematic orbit solutions
  - different inversion approaches
- Monthly combined Swarm gravity field models:
  - period length set by the calendar month (first to last day)
  - from 2013-12-01 to 2023-06-30
  - available from:
    - ICGEM `icgem.gfz-potsdam.de/series/02_COST-G/Swarm`
    - ESA `swarm-diss.eo.esa.int` > *Level2longterm* > *EGF*

Kinematic Orbits

Institute	Software	Reference
AIUB	Bernese v5.3	Jäggi et al. (2016)[1]
IfG	**GROOPS!** (**GROOPS!**)	Suesser-Rechberger et al. (2022)[2]
TUD	**GHOST!** (**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`

Individual Gravity field models

Inst.	Approach	Reference
AIUB!	**CMA!**	Jäggi et al. (2016)
ASU!	**DAA!**	Bezděk et al. (2016)
IfG!	**SAA!**	Suesser-Rechberger et al. (2022)
OSU!	**IEBA!**	Guo et al. (2015)

Combined Gravity field models

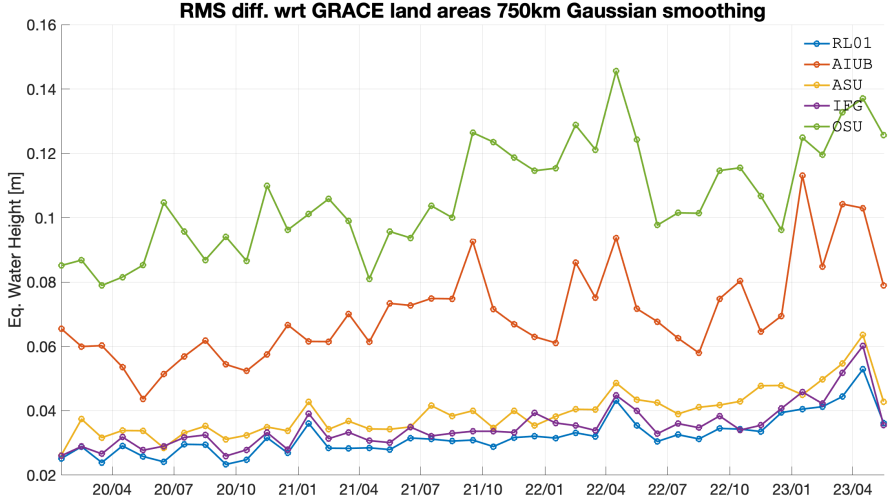
- Combination at the level of solutions, up to degree 40
- Weights applied to individual solutions derived from **VCE!** (**VCE!**)
- Degrees 2-20 considered in **VCE!**
- João Teixeira da Encarnação and Pieter Visser (2019). *TN-03: Swarm models validation*. Tech. rep. TU Delft. DOI: 10.13140/RG.2.2.33313.76640

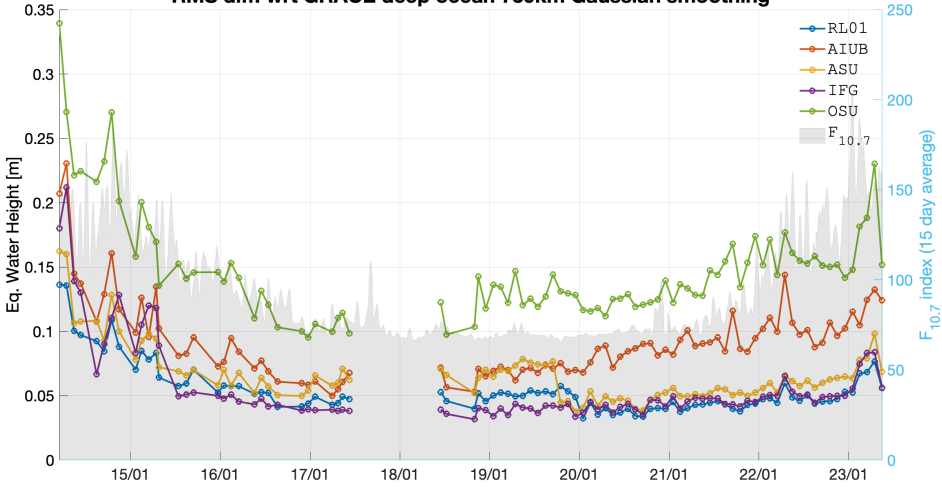
Gravity field model pre-processing

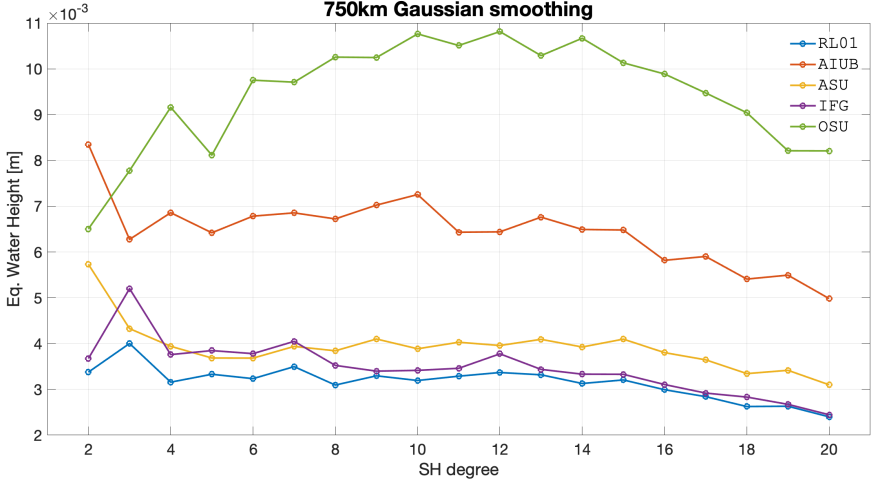
- Analysis spans 2016-01-01 until 2023-06-30
- Temporal variations relative to static GGM05G (Ries et al., 2016)
- Gaussian smoothing with 750-km radius
- C_{20} replaced with values from weekly **GRACE!** (**GRACE!**)/**GRACE-FO!** (**GRACE-FO!**) TN-14 time series
- Swarm ACC data not used

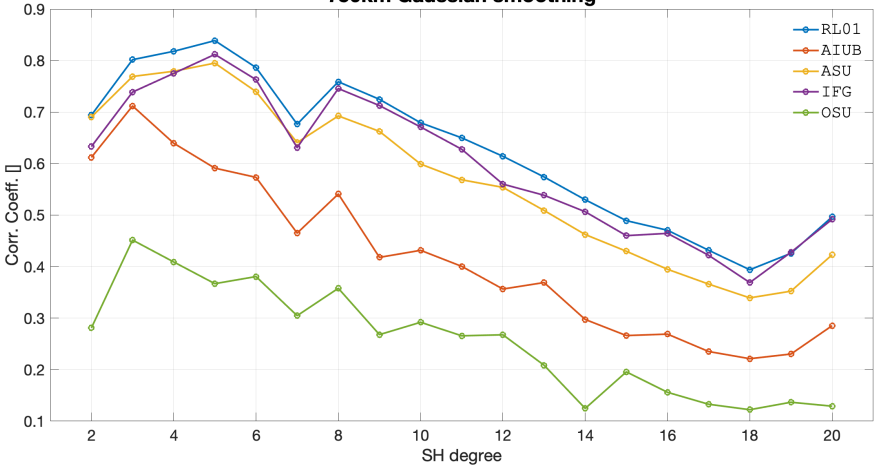
Analyses setup

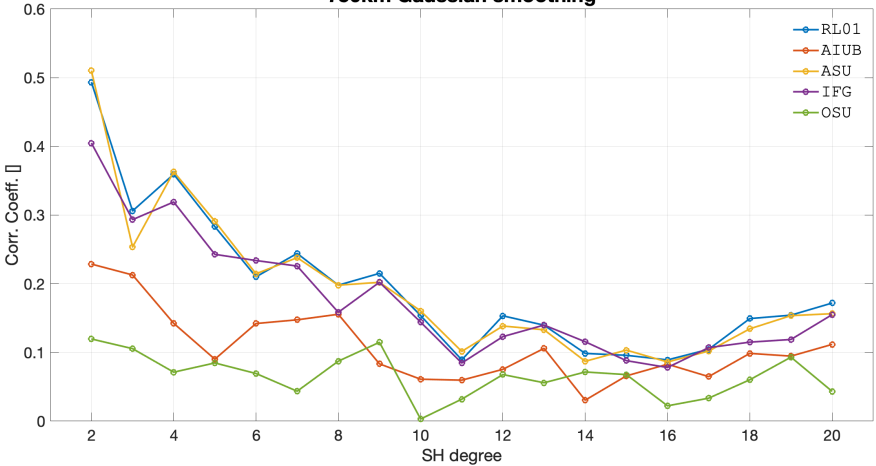
- **GRACE!**/**GRACE-FO!** CSR RL06 considered (with same pre-processing)
- **GRACE!**/**GRACE-FO!** solutions interpolated at Swarm model epochs (except over gaps longer than 120 days)
- Ocean signal, with no buffer zone, removed for land analyses
- Ocean analyses exclude coastal areas $\approx$ 1000km or less from coast lines
- **IfG! KO!** orbits:
  - Considered for **ASU!** solutions for Oct - Dec 2019 (and later)
  - Not considered for RL01 solutions prior to Jan 2020


RMS diff. wrt GRACE land areas 750km Gaussian smoothing
Eq. Water Height [m]
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
20/04
20/07
20/10
21/01
21/04
21/07
21/10
22/01
22/04
22/07
22/10
23/01
23/04
RL01
AIUB
ASU
IFG
OSU

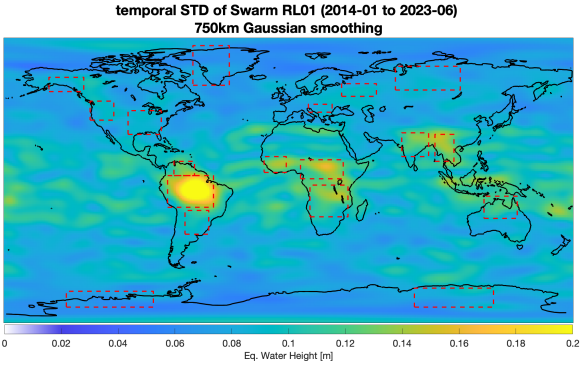

RMS diff. wrt GRACE deep ocean 750km Gaussian smoothing
Eq. Water Height [m]
F10.7 index (15 day average)
RL01
AIUB
ASU
IFG
OSU
F10.7
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
250
200
150
100
50
0
15/01
16/01
17/01
18/01
19/01
20/01
21/01
22/01
23/01

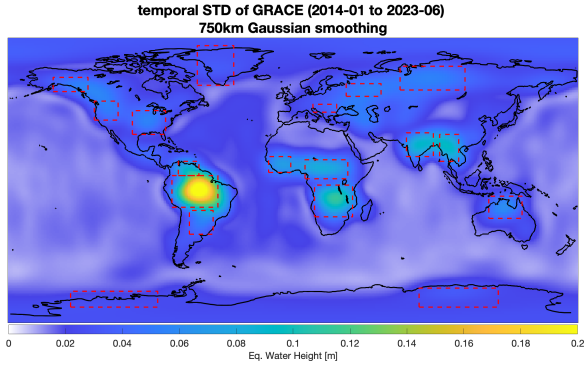

degree mean temporal RMS△
wrt GRACE (2020-01 to 2023-06)
750km Gaussian smoothing
×10-3
Eq. Water Height [m]
SH degree
RL01
AIUB
ASU
IFG
OSU

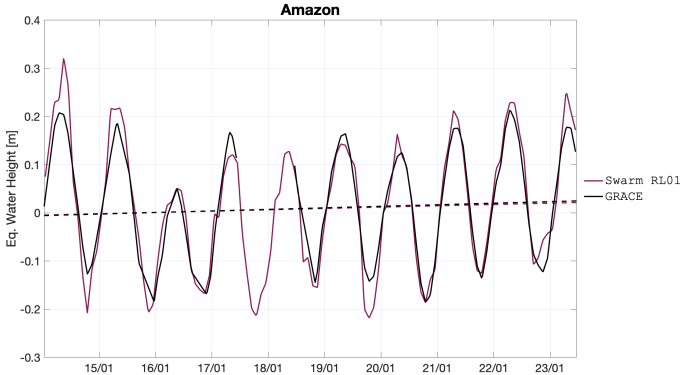

degree mean temporal corr. coeff.
wrt GRACE land areas (2020-01 to 2023-06)
750km Gaussian smoothing
Corr. Coeff. []
SH degree
RL01
AIUB
ASU
IFG
OSU
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
2
4
6
8
10
12
14
16
18
20


degree mean temporal corr. coeff.
wrt GRACE deep ocean (2014-01 to 2023-06)
750km Gaussian smoothing
Corr. Coeff. []
SH degree
RL01
AIUB
ASU
IFG
OSU
0
0.1
0.2
0.3
0.4
0.5
0.6
2
4
6
8
10
12
14
16
18
20

Signal variability

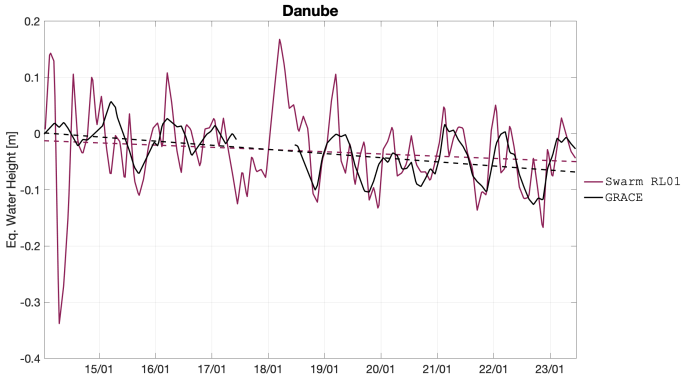






solution	constant term [cm]	constant term Δ [cm]	linear term [cm/year]	linear term Δ [cm/year]	corr. coeff. [ ]
Swarm RL01	1.41	-1.04	0.27	-0.05	0.96
GRACE	2.45	0.00	0.32	0.00	1.00

latitude -17 to 3 degrees, longitude -76 to -47 degrees



solution	constant term [cm]	constant term Δ [cm]	linear term [cm/year]	linear term Δ [cm/year]	corr. coeff. [ ]
Swarm RL01	-3.00	0.27	-0.39	0.34	0.36
GRACE	-3.26	0.00	-0.74	0.00	1.00

latitude 43 to 48 degrees, longitude 13 to 28 degrees

Statistics from all 18 analysed basins

solution	constant term Δ **RMS!** [cm]	linear term Δ **RMS!** [cm/year]	corr. coeff. mean [ ]
Swarm RL01	0.90	0.36	0.75
GRACE	0.00	0.00	1.00

Conclusions (I)

- Combined model better than individual models under any metric
- Swarm signal useful below degree 15 (750 km radius smoothing)
- Swarm gravity field model quality stable since 2016,
  - but increase in solar activity slowly degrading disagreement with **GRACE!**/**GRACE-FO!**
- **IfG! KO!** orbit processing changes result in a visible improvement since 2020
- Ocean areas are $\approx$ 30-50% noisier than land areas

Conclusions (II)

- Seasonal land signal clearly resolvable by Swarm (compared to **GRACE!**/**GRACE-FO!**):
  - Temporal correlations dip under 0.5 over degree 14
  - Global spatial agreement at $\approx$ 3-4 cm RMS EqWH
  - Over 18 analysed basins (of various sizes), considering **all Swarm data**:
    - trends agree under 0.36cm/year EqWH
    - correlation is at 0.75

Please cite

João Teixeira da Encarnação 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. URL: https://essd.copernicus.org/articles/12/1385/2020/