# Time-variable gravity field recovery from kinematic positions of Low Earth Orbiting satellites

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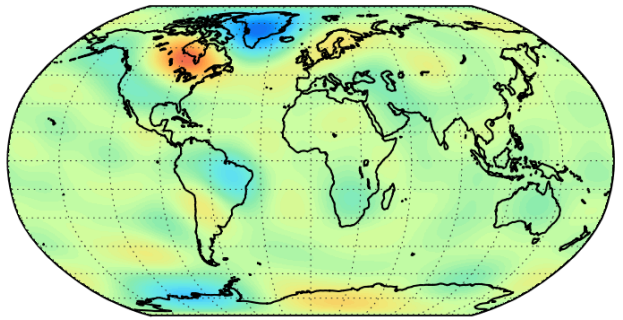
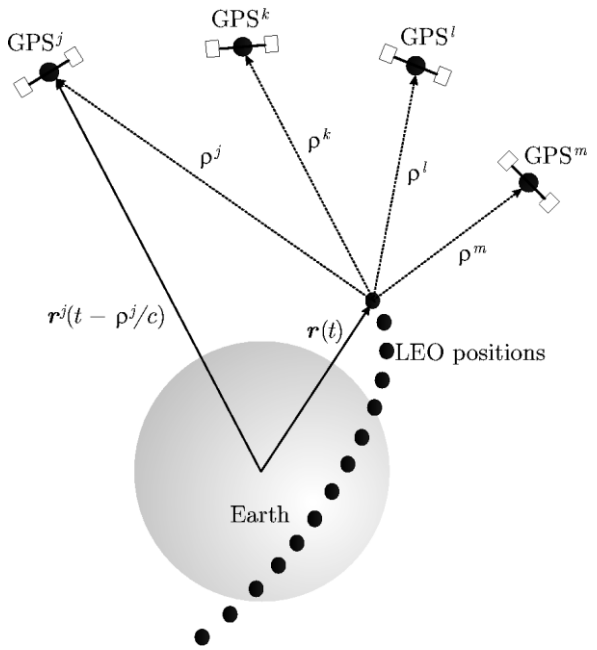
# Introduction

- The Earth's time-variable gravity field
  - Provides important information for monitoring changes in the Earth's system
  - Dedicated satellite missions like GRACE/-FO use ultra-precise K-Band data (inter-satellite ranging) to derive time series of monthly gravity field solutions
  - In addition: any Low Earth Orbiting (LEO) satellite equipped with an on-board GPS receiver may also serve as a gravity field sensor



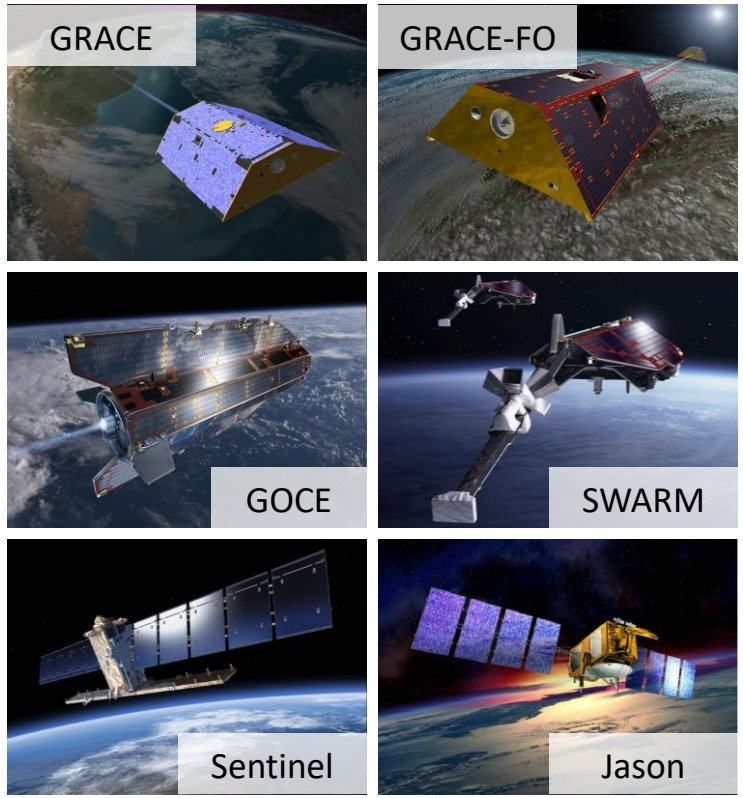
- Gravity field recovery from kinematic LEO positions
  - GPS-based kinematic LEO positions are purely geometrically determined and therefore suitable for gravity field recovery
  - Although less sensitive, this technique provides mostly uninterrupted series
  - Combined Multi-LEO gravity field solutions can take advantage of many observations and the variety of complementary orbital configurations



# GPS-based orbit and gravity field determination

- Precise orbit determination
  - GPS-based kinematic orbits are routinely processed at AIUB for various LEO satellites like GRACE/-FO, GOCE, SWARM, Sentinel, …
  - Bernese GNSS Software with GNSS products of CODE
  - In-flight calibrated phase center variation (PCV) maps
  - Ambiguity-float and nowadays also ambiguity-fixed orbit solutions

- Gravity field processing (Celestial Mechanics Approach)
  - Kinematic LEO positions are used as pseudo-observations in a generalized orbit determination problem
  - Orbit and gravity field parameters are estimated simultaneously
  - Unmodeled forces are absorbed by empirical/stochastic parameters




Source: ESA, NASA

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# Gravity field processing

- Focus of this talk: GRACE/-FO GPS-only solutions

| | GRACE | GRACE-FO |
|---|---|---|
| Processing period | 2009/01 – 2017/10 | 2018/06 – 2021/02 |
| Kinematic orbit | ambiguity-float | ambiguity-fixed |
| Data sampling | 10 s | |
| Initial conditions | 6 orbital elements (daily) | |
| Empirical parameters | - | |
| Stochastic parameters | Piecewise constant accelerations (15 min) | |
| Accelerometer data | Yes / Bias and Scaling factors (daily) | |
| Gravity field coefficients | d/o 90 (monthly) | |

- Further used GPS-only solutions

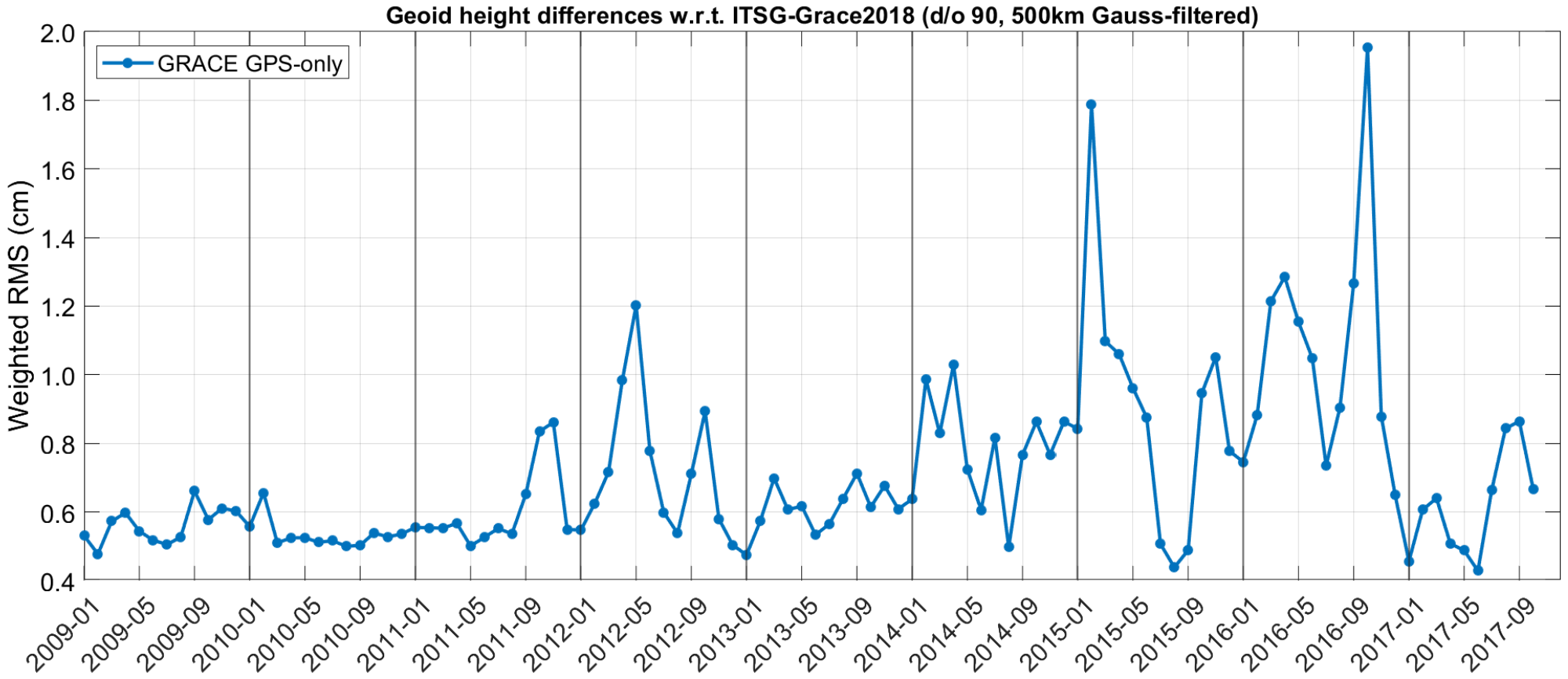
| GOCE (Arnold et al. 2021) | SWARM (Dahle et al. 2017) |
|---|---|
| 2009/11 – 2013/10 | 2013/12 – 2020/12 |
| ambiguity-float | ambiguity-float |
| 1 s | 10 / 5 s |
| 6 orbital elements (daily) | 6 orbital elements (daily) |
| Constant and 1/per rev accelerations (daily) | Constant accelerations (daily) |
| Pseudo-stochastic pulses (6 min) | Piecewise constant accelerations (15 min) |
| Yes / – | – / – |
| d/o 120 (monthly) | d/o 40, 70 (monthly) |

- Monthly ITSG-Grace2018 / ITSG-Grace_op solutions are used as reference (Mayer-Gürr et al. 2018)

# GRACE GPS-only gravity field solutions

# GRACE GPS-only gravity field solutions

- Quality of monthly GRACE GPS-only gravity field solutions

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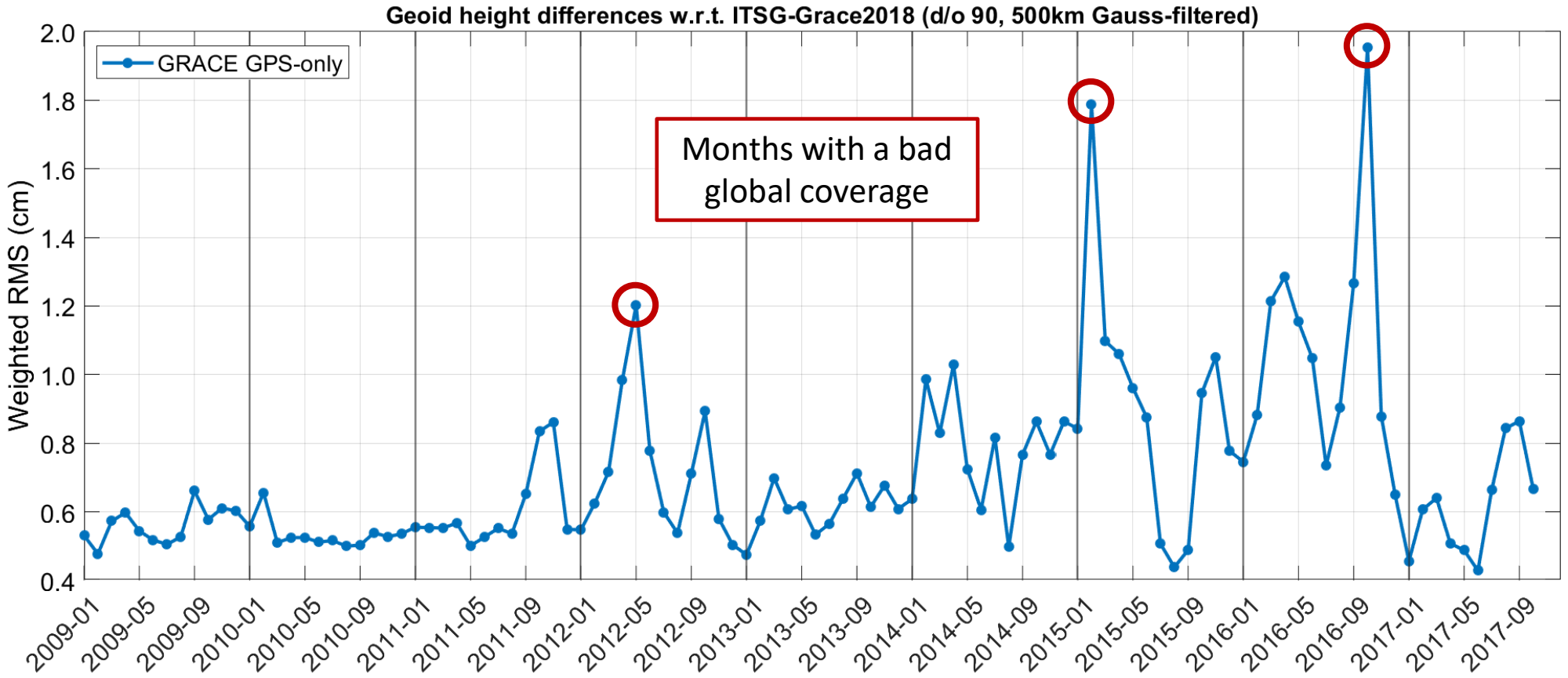


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# GRACE GPS-only gravity field solutions

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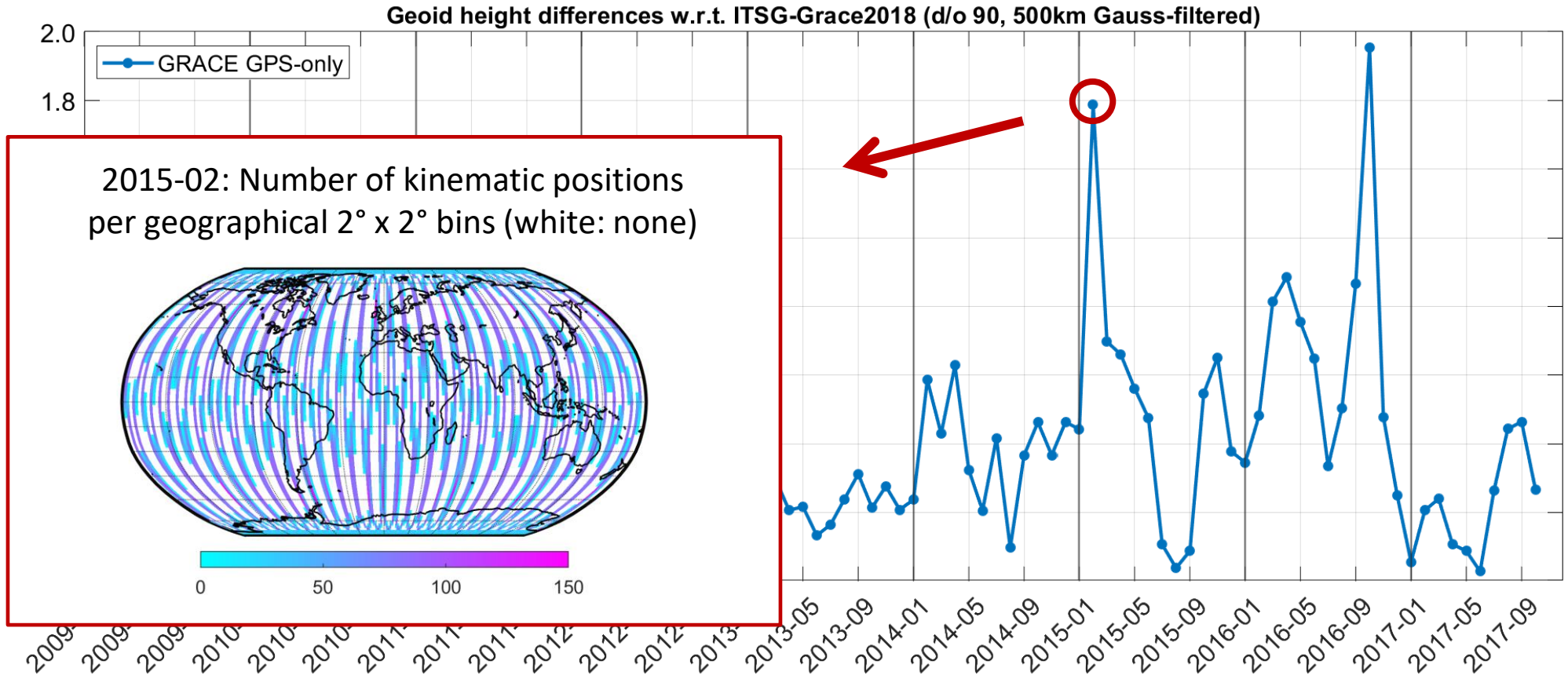
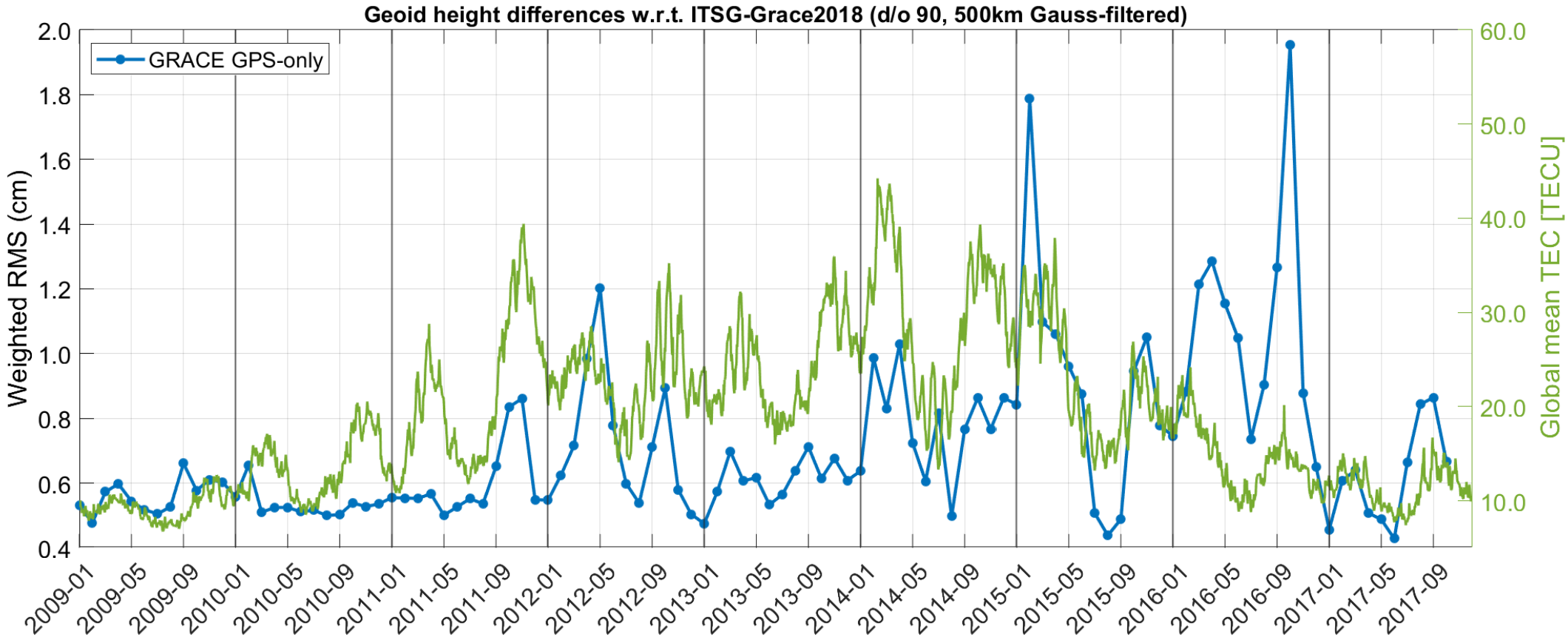


# GRACE GPS-only gravity field solutions

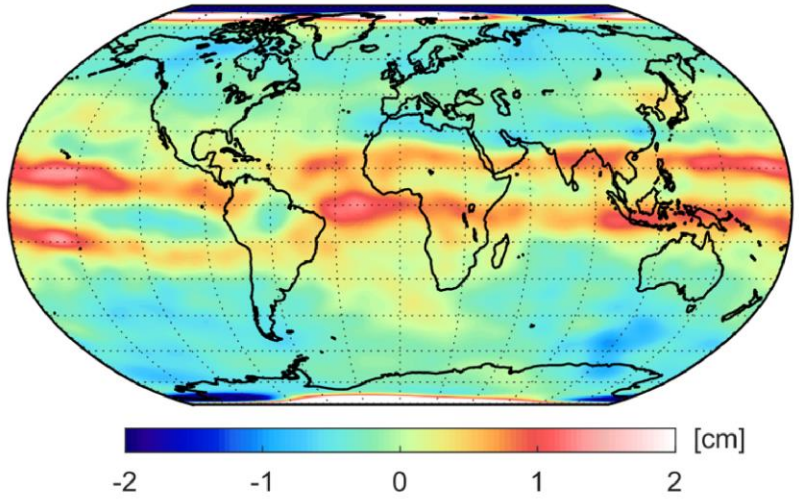
- Correlation with the ionospheric activity represented by the global mean total electron content (TEC)



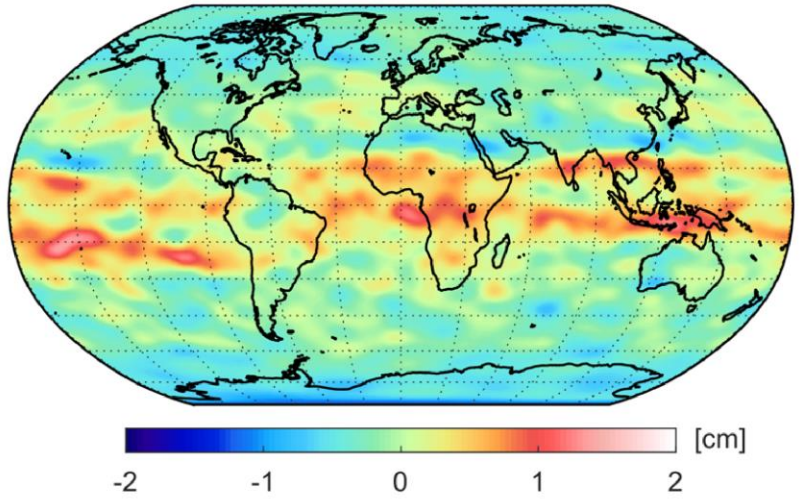
# Effects of ionospheric disturbances

- Degradation of kinematic positions directly propagates into GPS-only gravity field solutions
- Artifacts along the geomagnetic equator, known from GOCE / SWARM, are also visible for GRACE

GOCE (2013 Jan–Oct)




GRACE (2013 Jan–Oct)




Geoid height differences w.r.t. ITSG-Grace2018

(500 km Gauss-filtered)

# GRACE-FO GPS-only gravity field solutions

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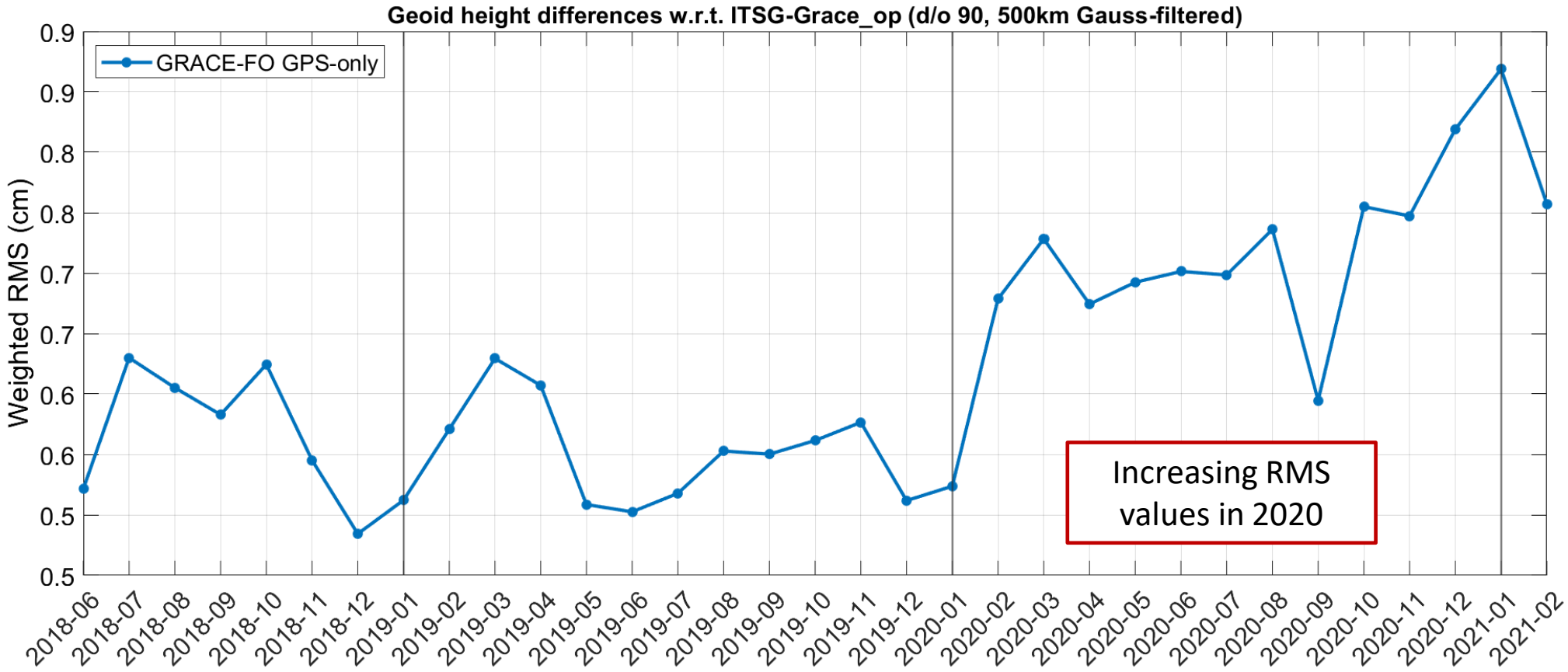
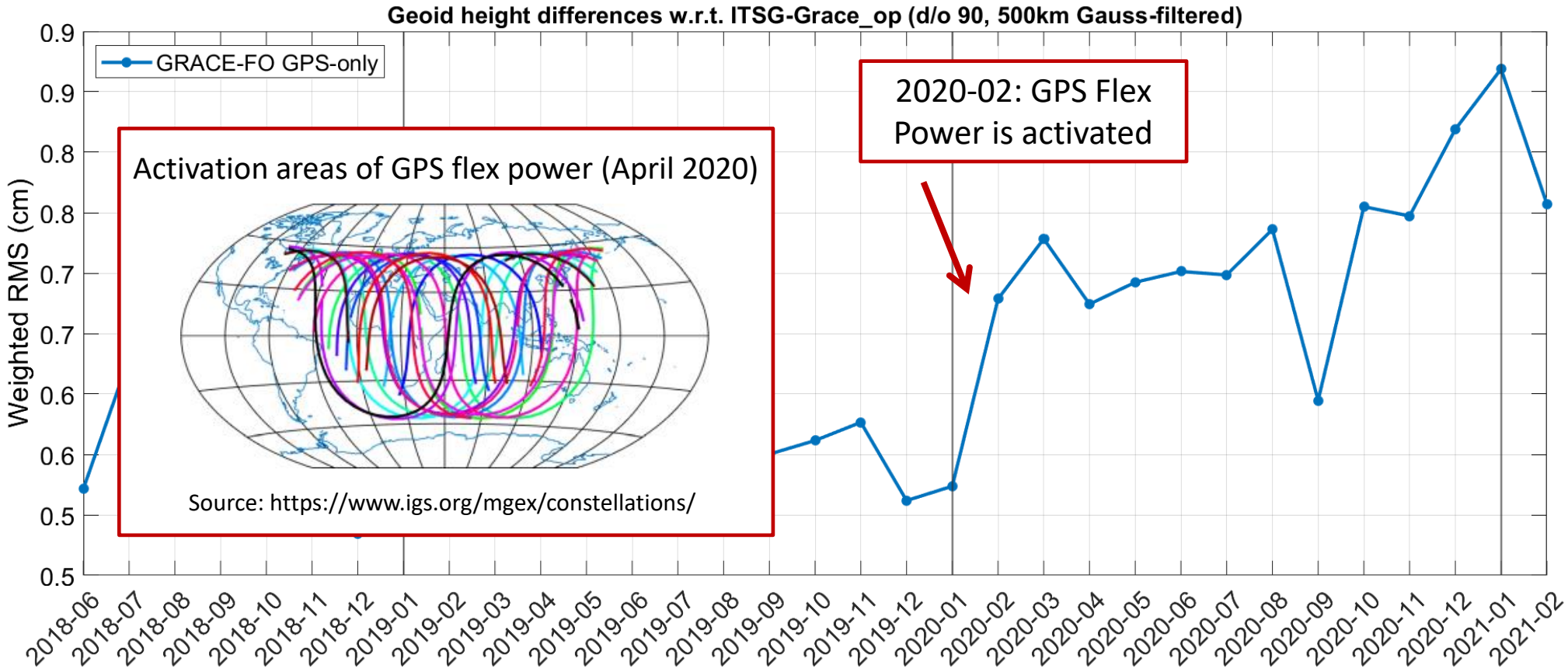
- Quality of monthly GRACE-FO GPS-only gravity field solutions



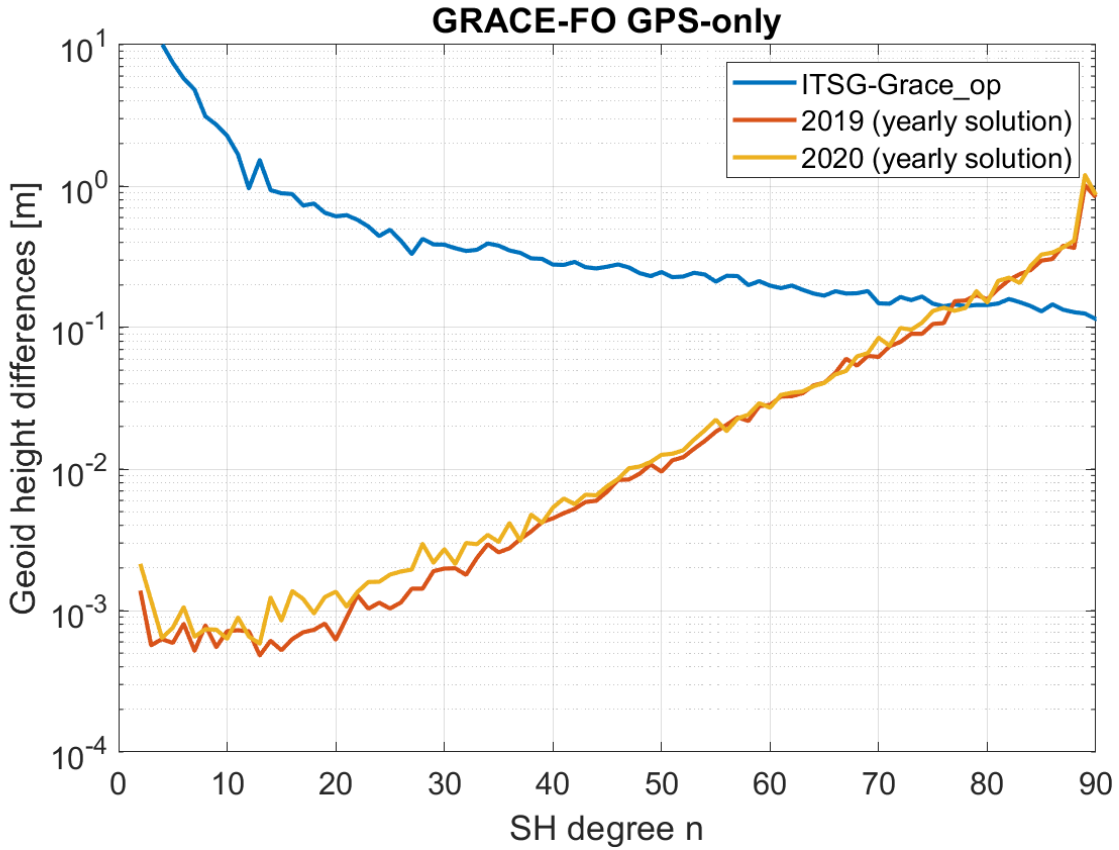
# GRACE-FO GPS-only gravity field solutions

- Activated GPS Flex Power affects the orbit and gravity field quality (under investigation)



# GRACE-FO GPS-only gravity field solutions

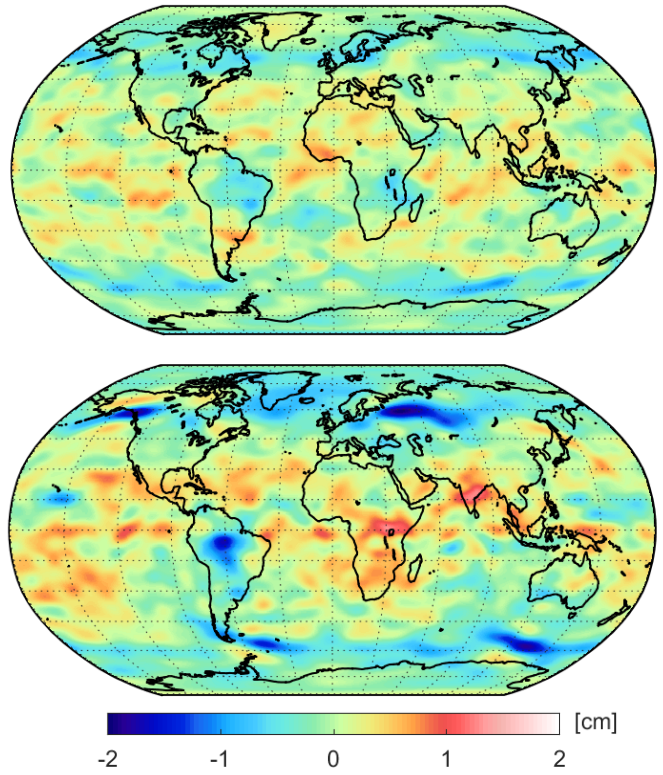
- Comparison of accumulated yearly solutions for 2019 and 2020




Geoid height differences

2019

2020

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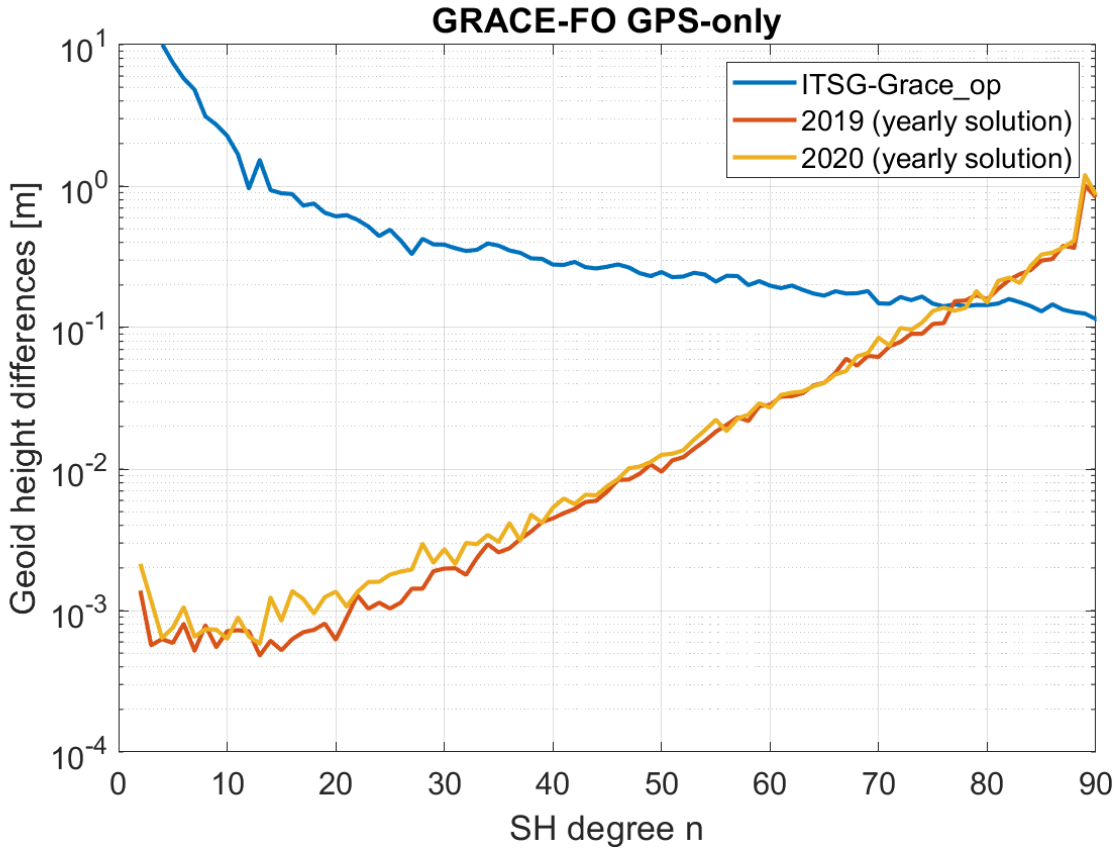


Geoid height differences

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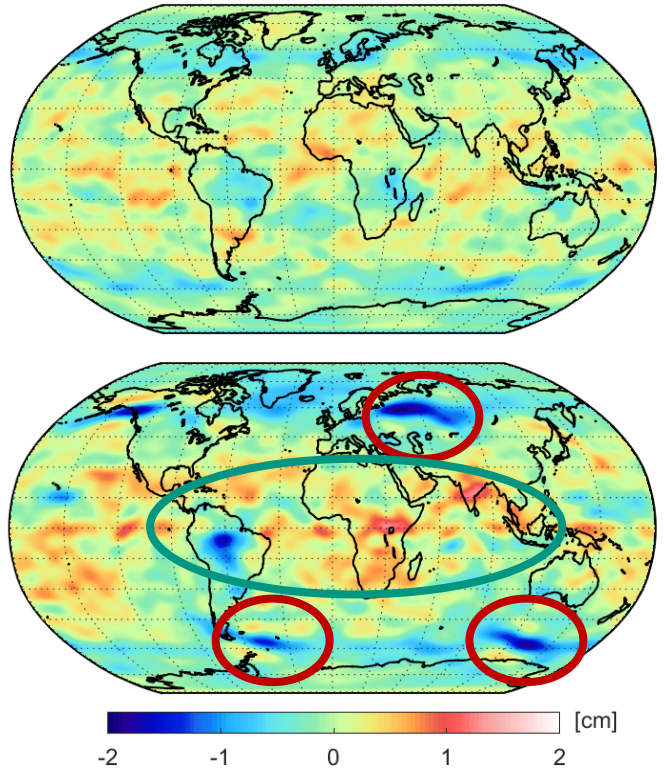
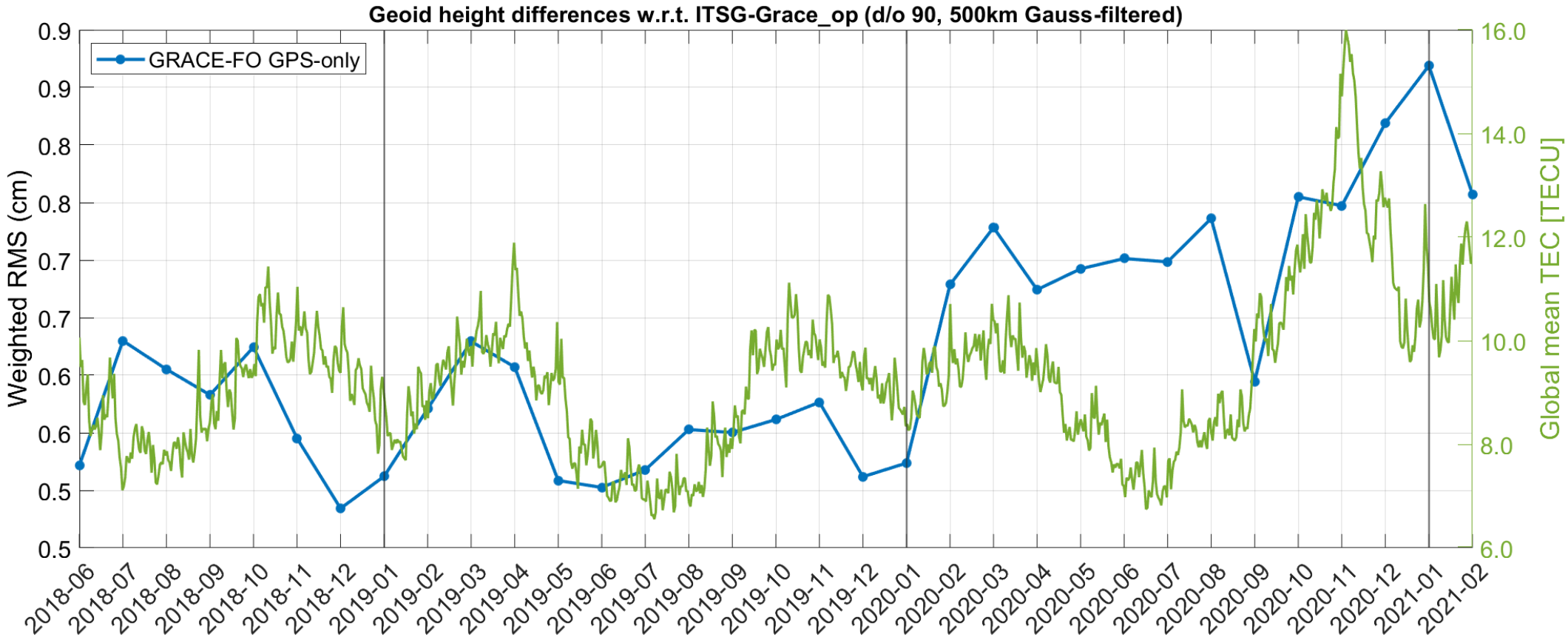



amplified noise

systematic signatures

# GRACE-FO GPS-only gravity field solutions

- Correlation with TEC values might also be seen for GRACE-FO (but much lower ionospheric activity)



# Evaluation of mass trends and changes

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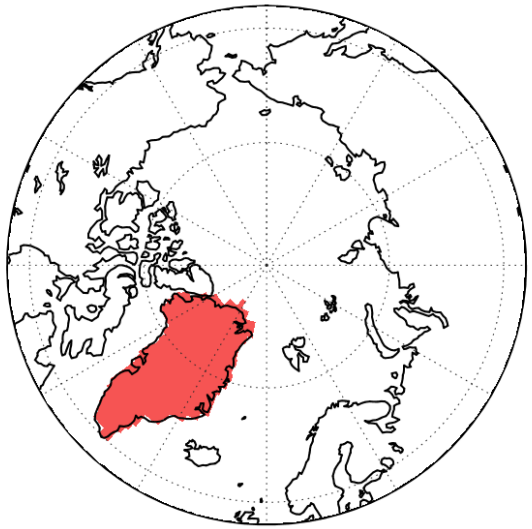
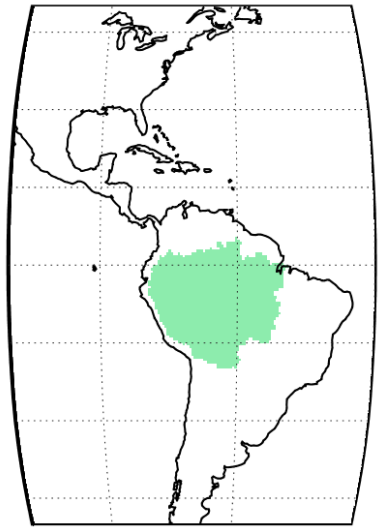
- Time series of monthly GPS-only solutions are used for the evaluation of mass trends and changes
- Analysis of mean equivalent water height (EWH) values averaged over selected regions

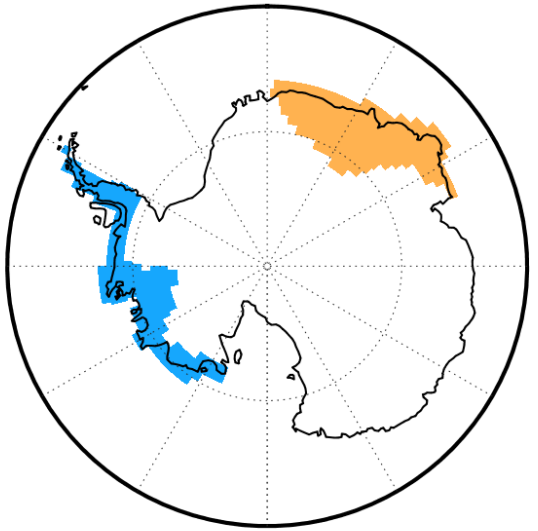
Greenland



Amazon river basin



West/East-Antarctica



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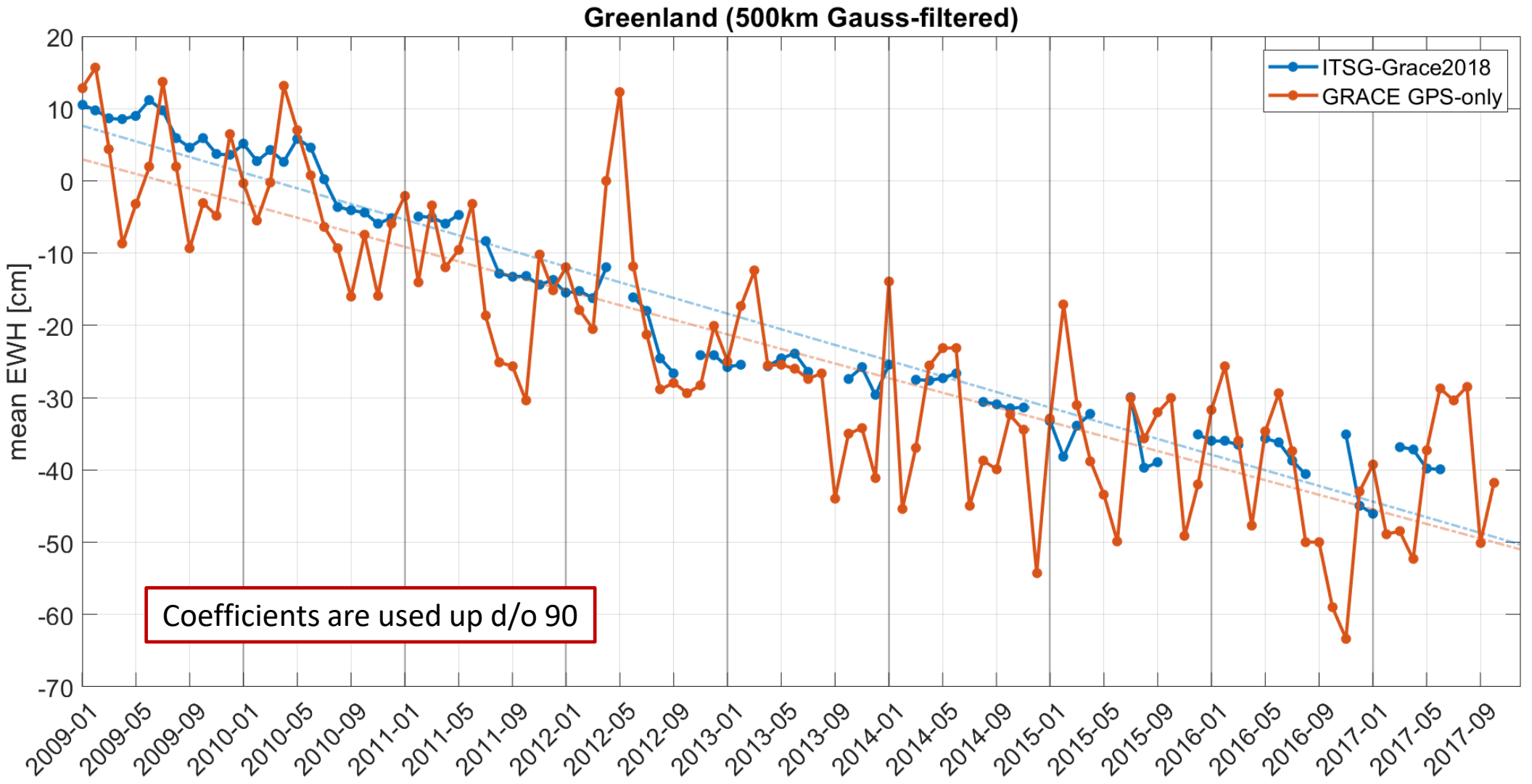


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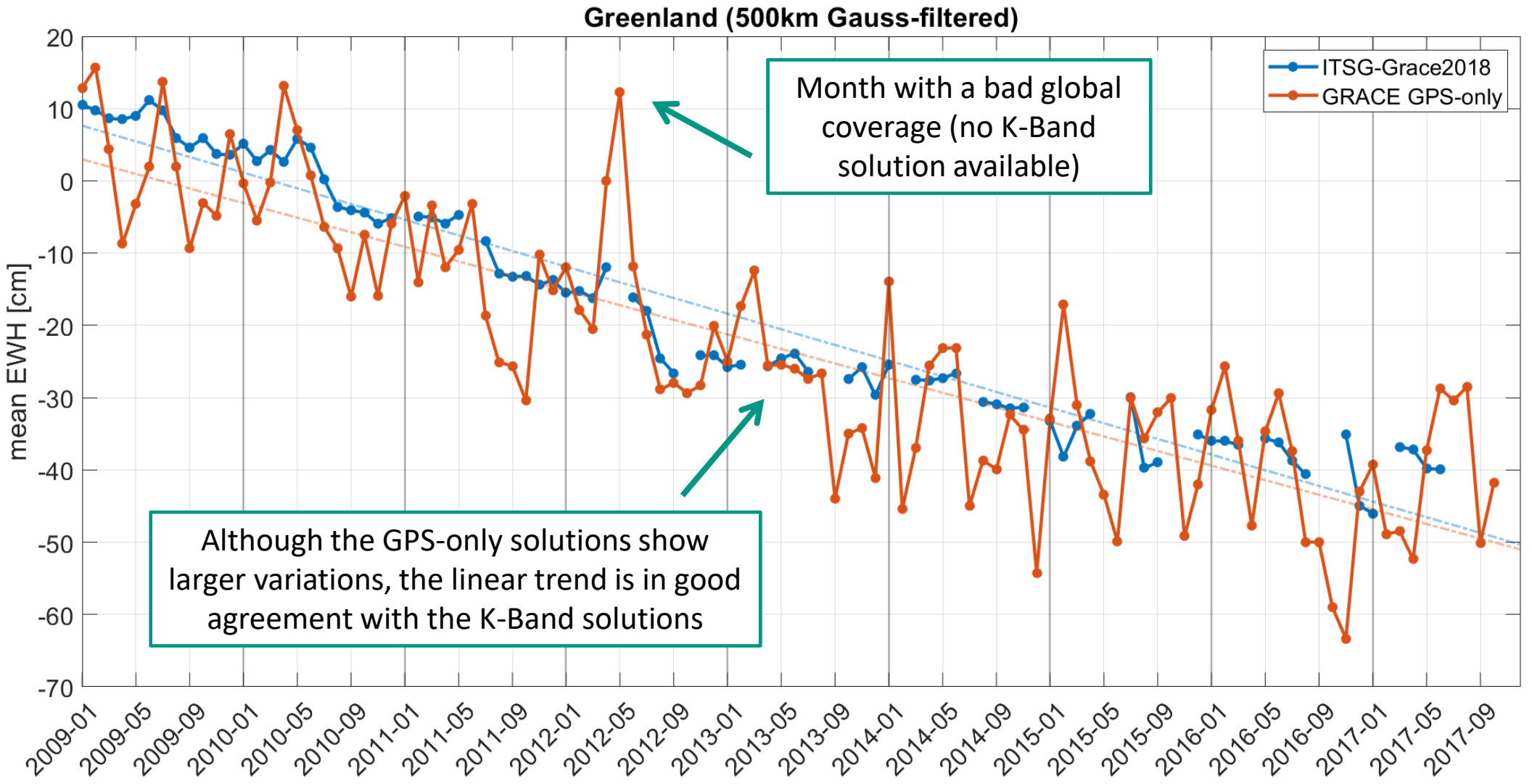


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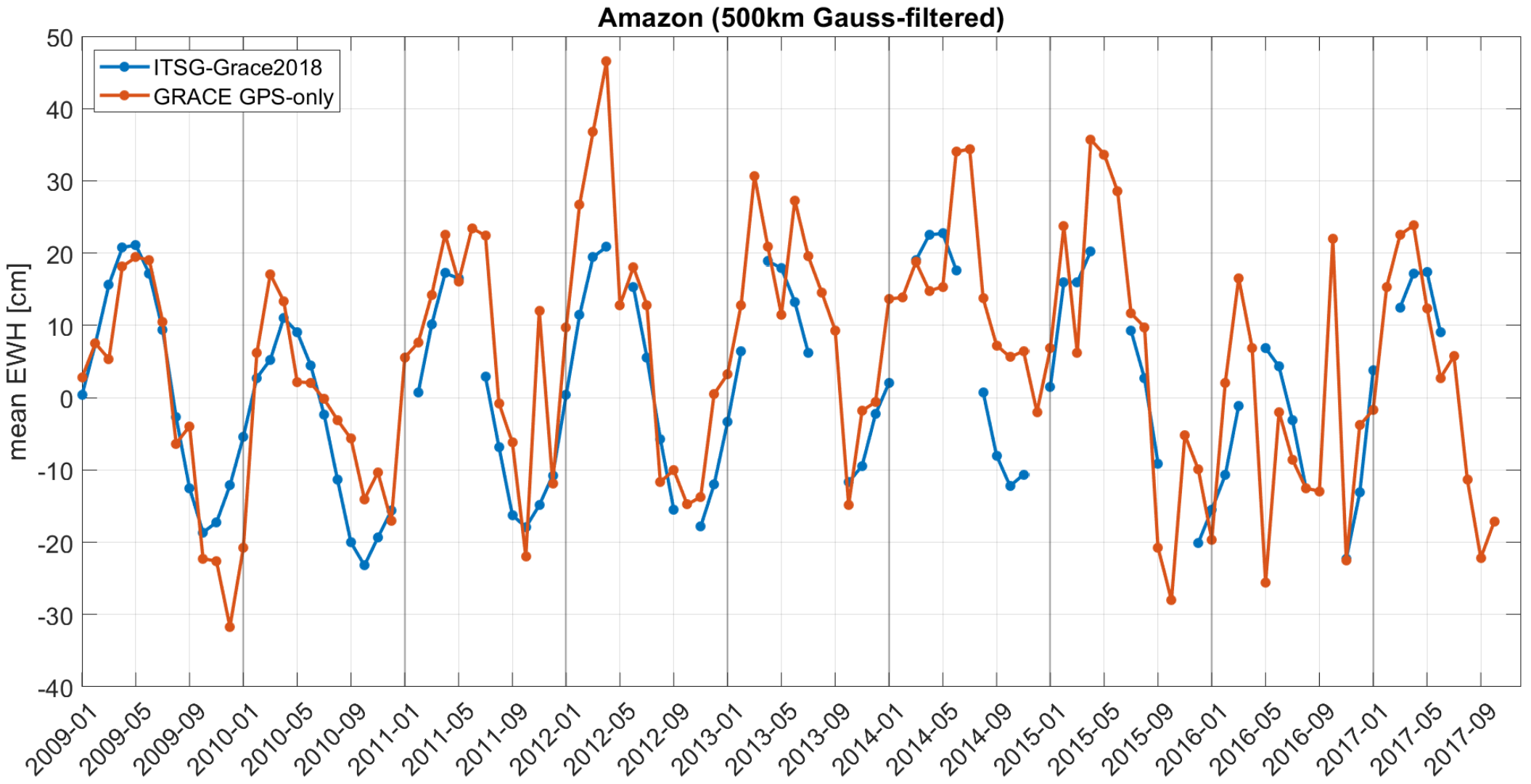


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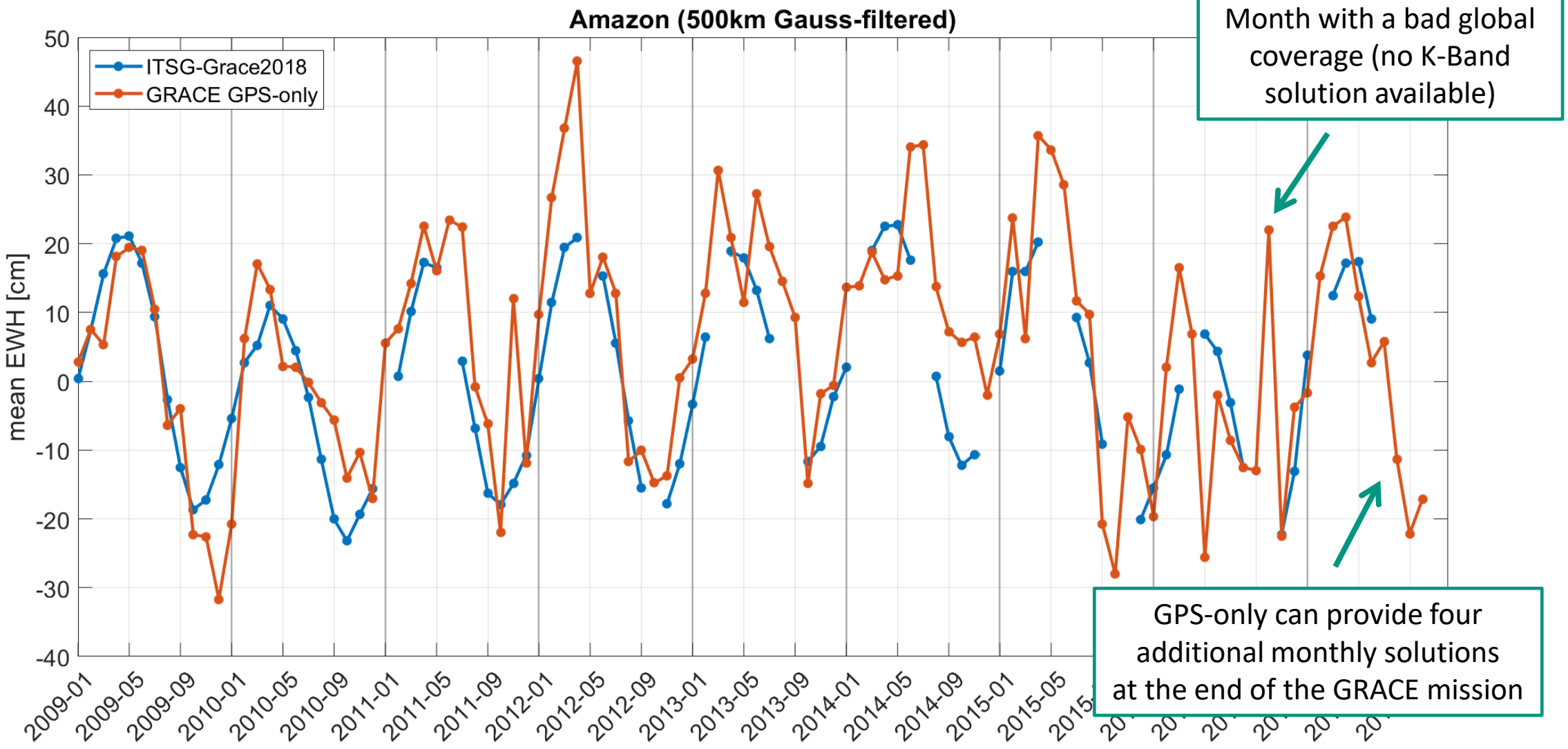


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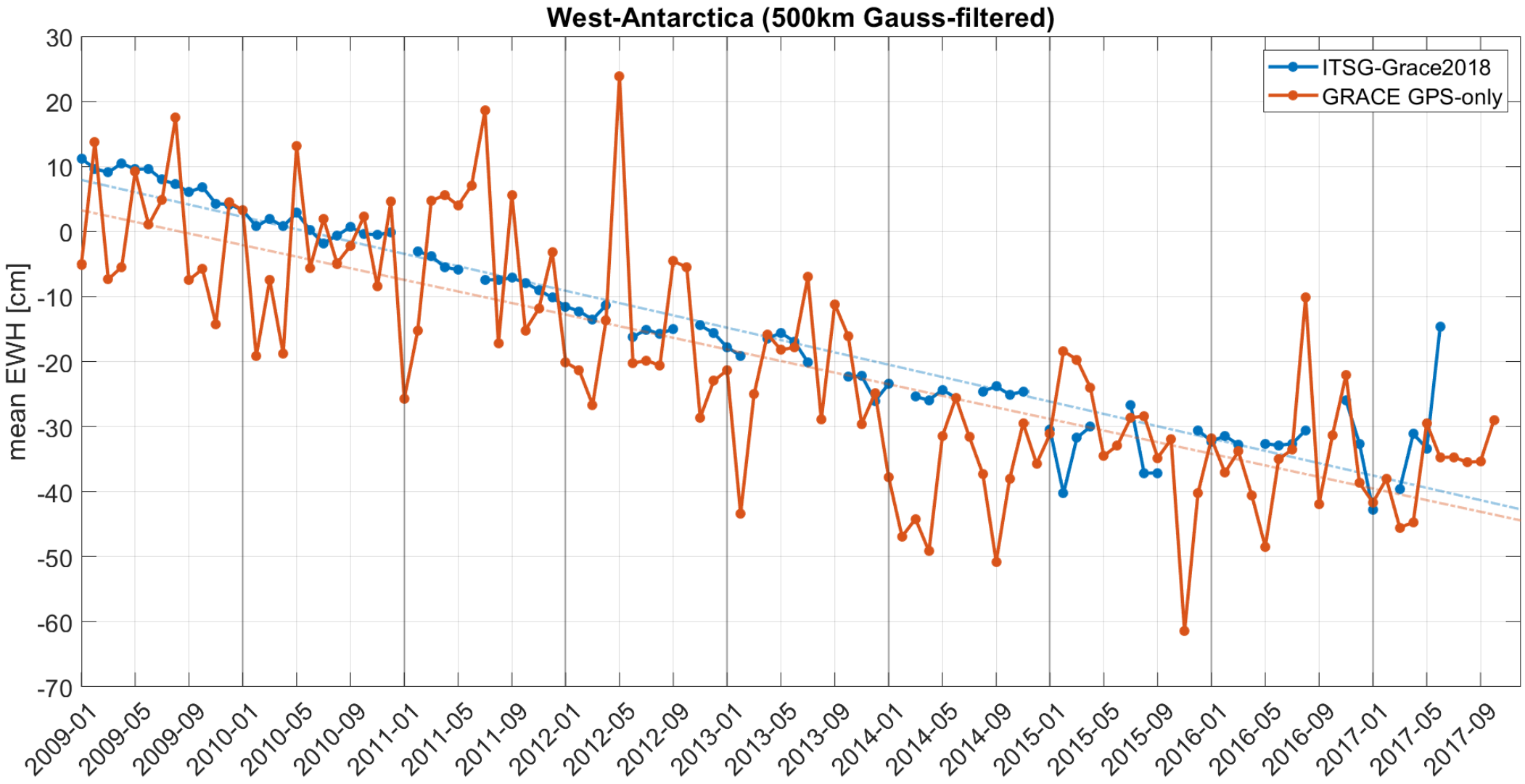


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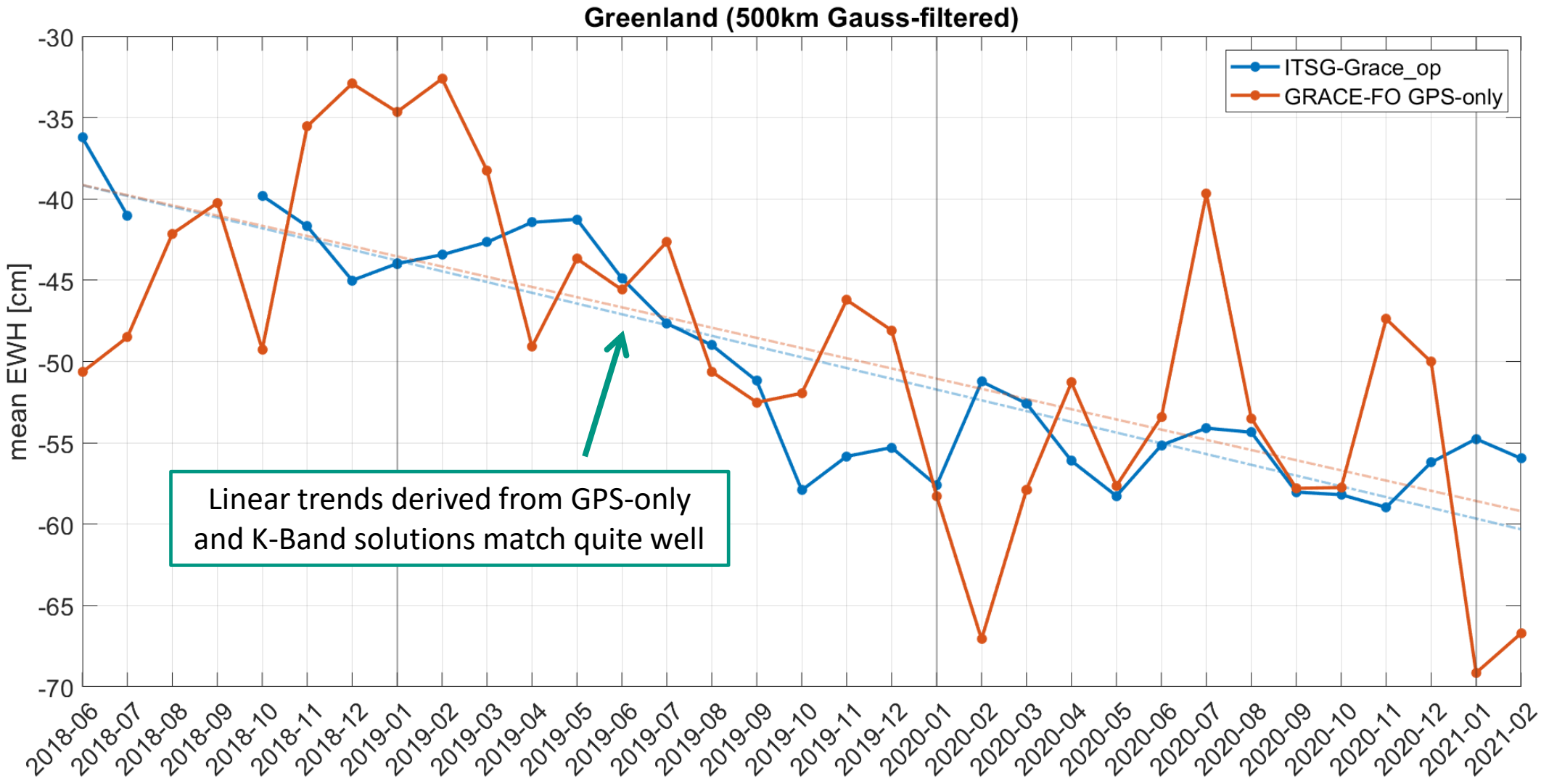


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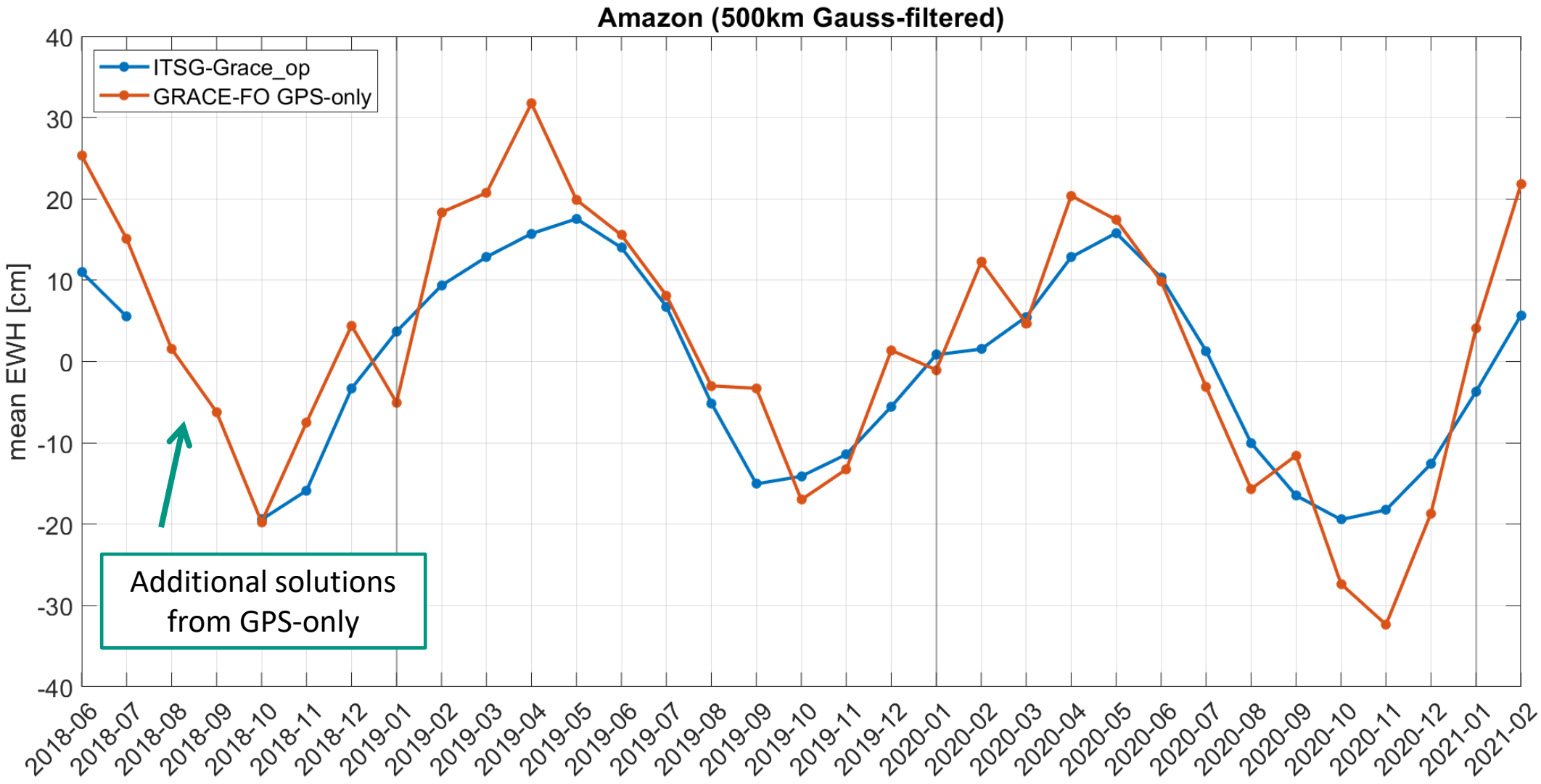


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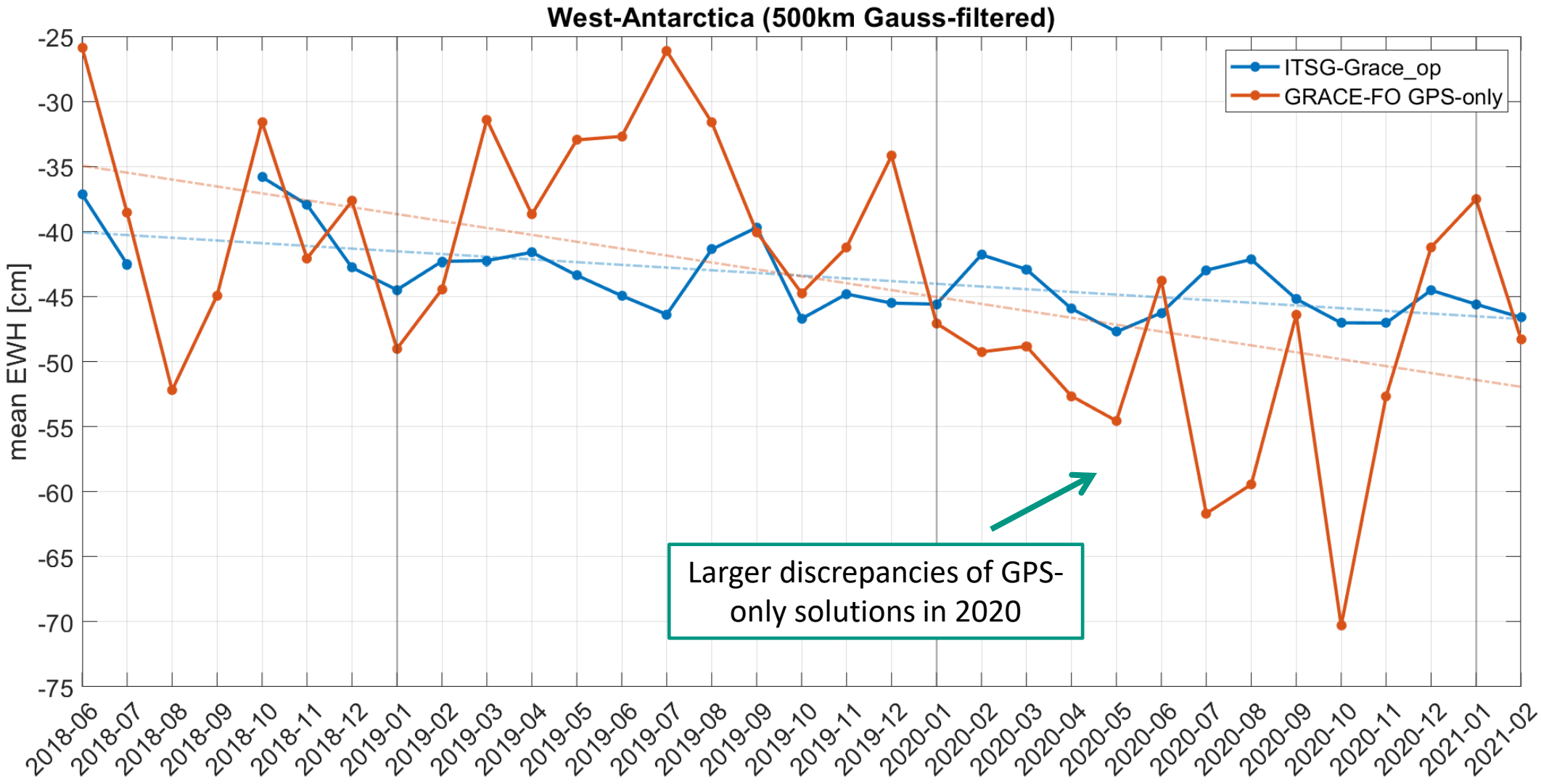


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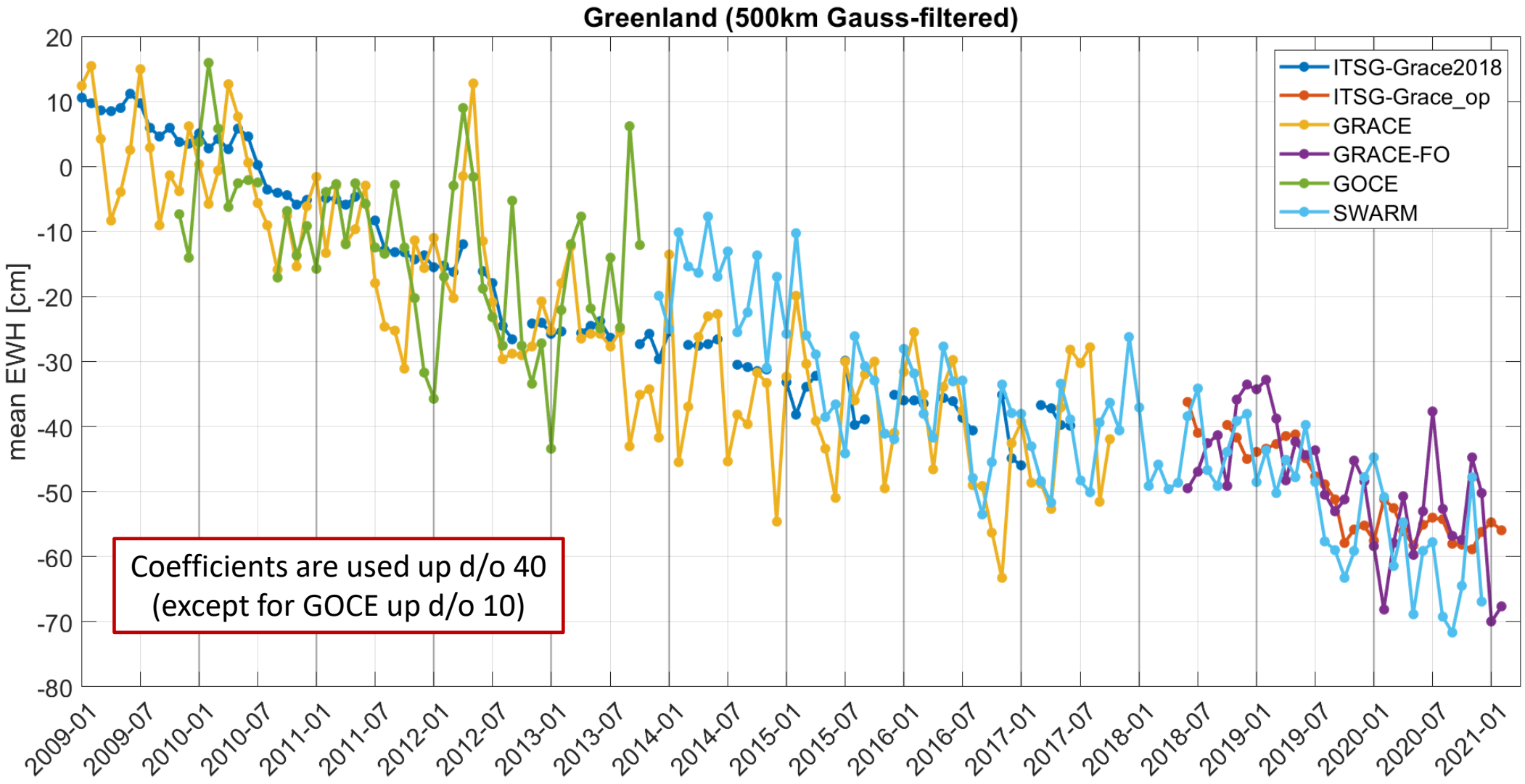
# Comparisons to time series of other LEOs

# Evaluation of mass trends and changes: Comparison to other LEOs

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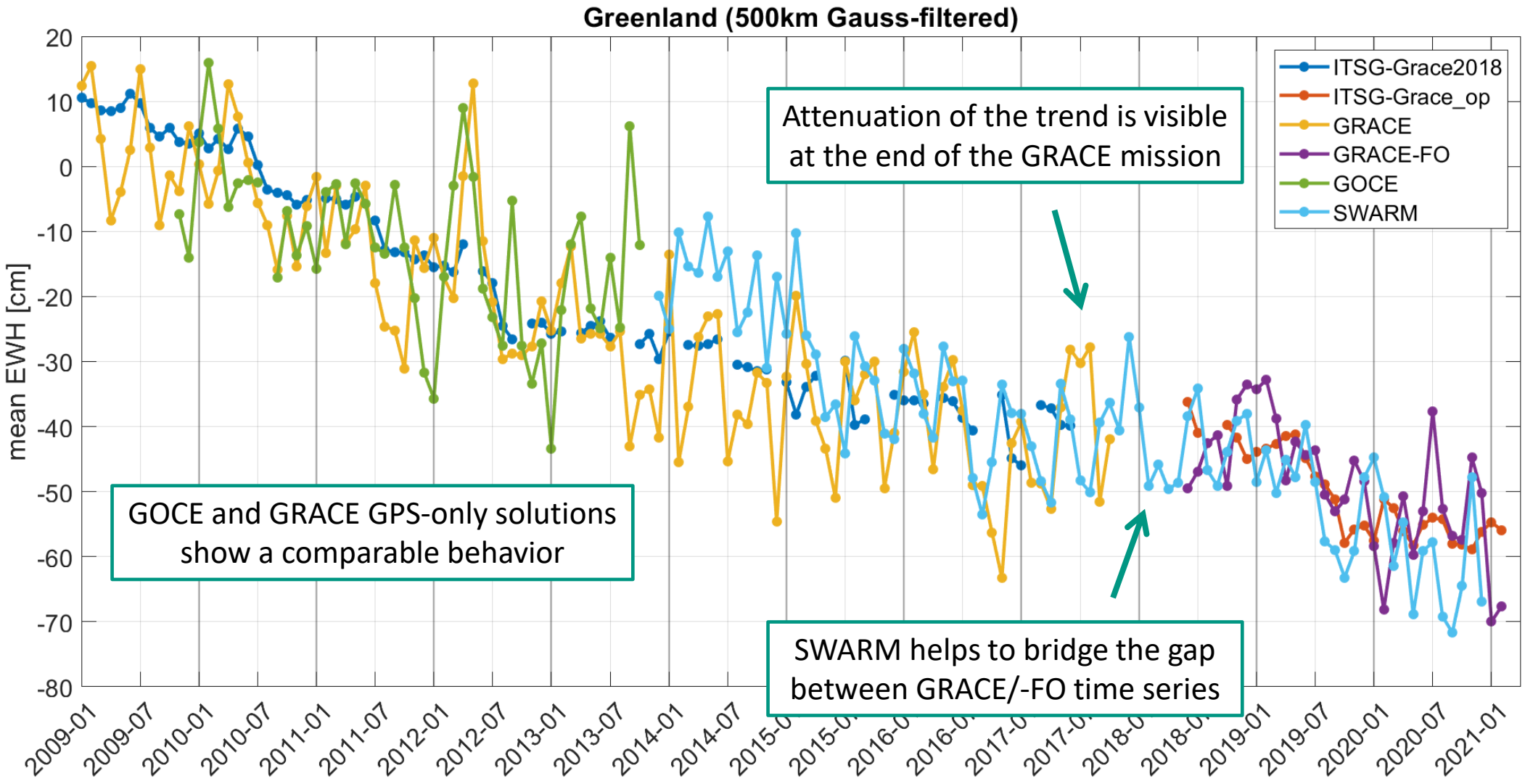


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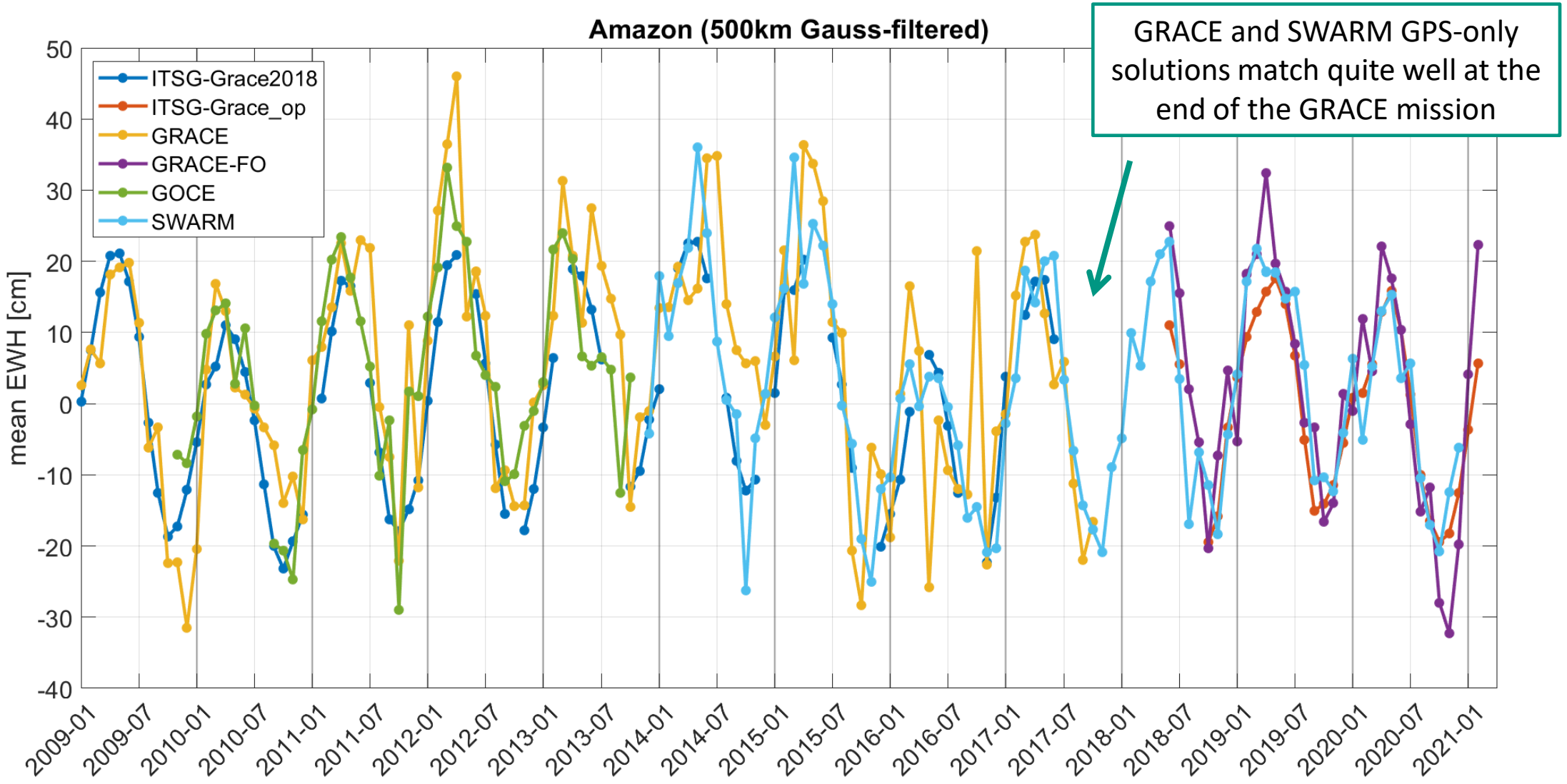


GRACE and SWARM GPS-only solutions match quite well at the end of the GRACE mission

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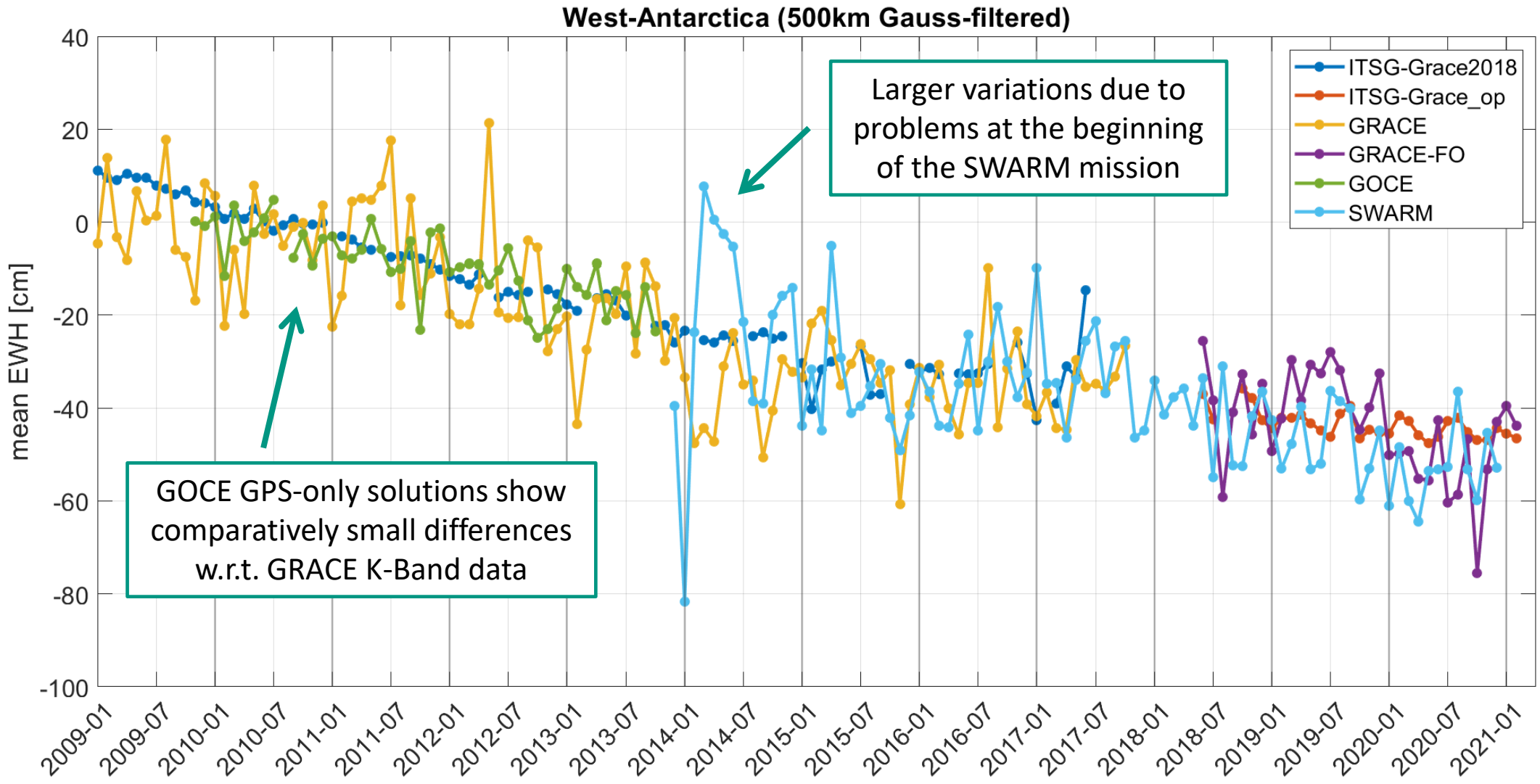

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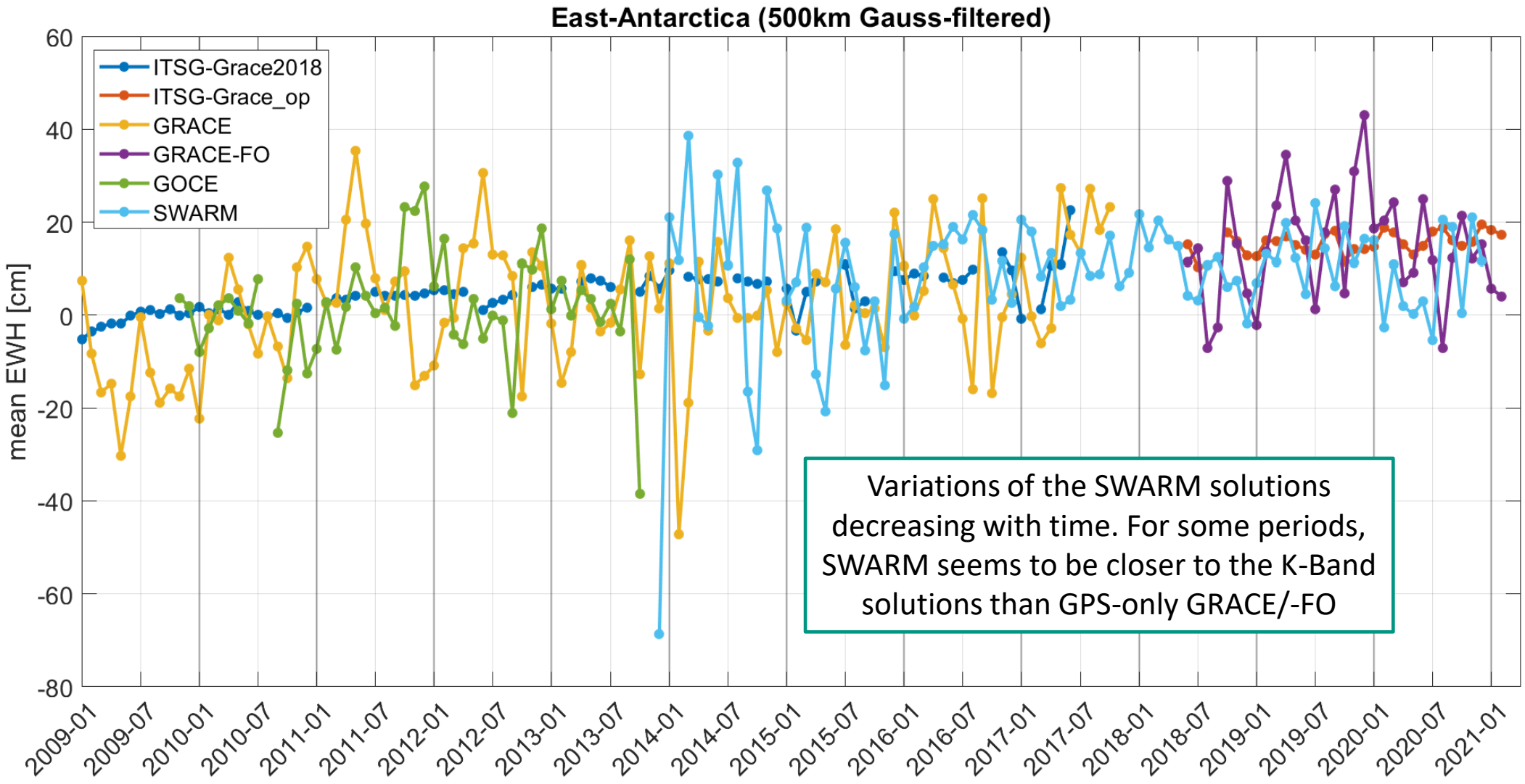


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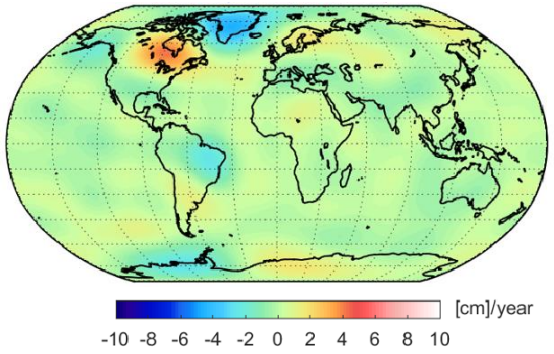
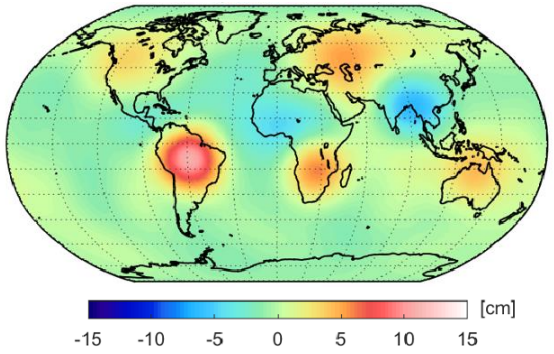
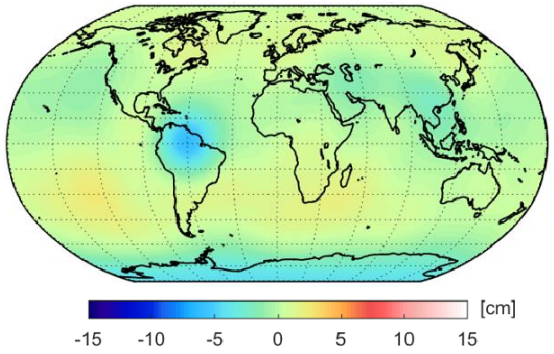
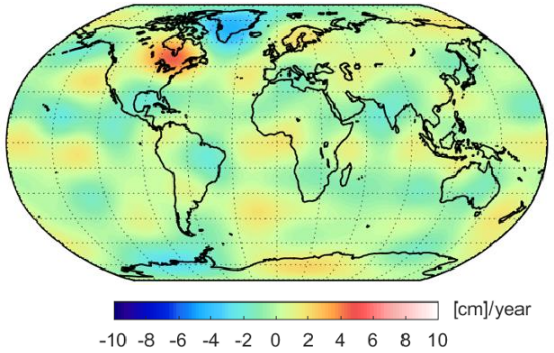
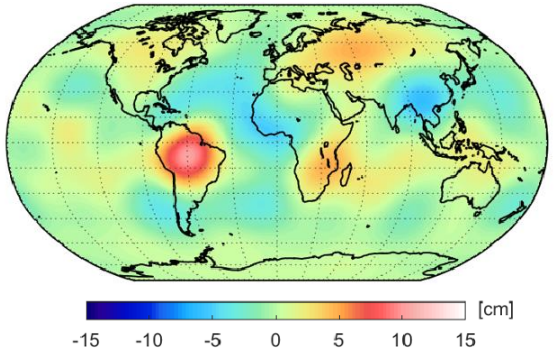
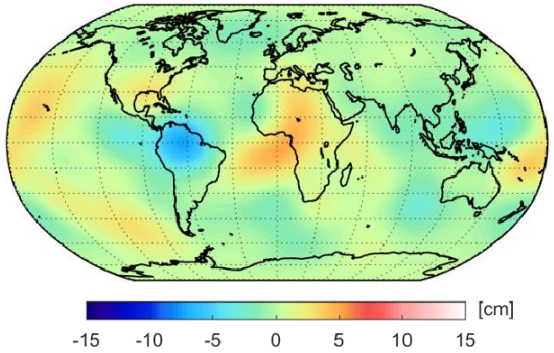
# Estimation of trends and annual variations (Jan 2009 − Oct 2017)

- A posteriori fit of monthly gravity field solutions (up to d/o 10)

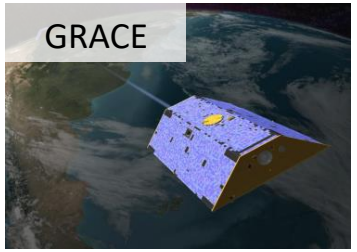
| | Trend | Sine | Cosine |
|---|---|---|---|
| ITSG Grace2018 |   |   |   |
| GRACE GPS-only |   |   |   |
| | 500 km Gauss-filtered | 1500 km Gauss-filtered | 1500 km Gauss-filtered |

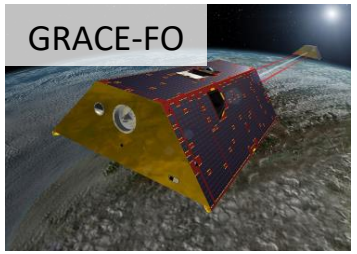
Equivalent water heights

# Summary and Outlook

- Time-variable gravity field recovery from kinematic LEO positions
- Processing of time series of monthly gravity field solution from
  - 8.8 years of GRACE GPS data (2009/01 − 2017/10)
  - 2.8 years of GRACE-FO GPS data (2018/06 − 2021/02)
- Major mass trends and changes in Greenland, Antarctica and the Amazon river basin are in good agreement with those derived from inter-satellite ranging

  (however: as expected GPS-only solutions exhibit larger variations)
- Comparisons to time series based on GOCE and SWARM GPS data are promising in the view of future combinations
- Next steps
  - Extension of the monthly GRACE and GRACE-FO time series
  - Combined time series based on kinematic orbits of multiple LEO satellites



Source: ESA, NASA

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