COST-G

Combination Service for Time-variable Gravity Models

# COST-G gravity field models: application in SLR orbit determination

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**22nd International Workshop on Laser Ranging**
**November 7-11, 2022, Yebes, Spain**

UNIVERSITÄT BERN

PosiTIM

Bundesamt für Kartographie und Geodäsie

# Combination Service for Time-variable Gravity Fields (COST-G)

# International Association of Geodesy (IAG)

Int. Gravity Field Service

International Association of Geodesy
I G F S

Int. Gravimetric Bureau

Int. Geoid Service

Int. Geodynamics and Earth Tide Service

Int. Center for Global Earth Models

Int. DEM Service

Permanent Service for Mean Sea Level

Int. Earth Rotation Service

Int. Laser Ranging Service

Int. VLBI Service

COST-G
Combination Service for Time-variable Gravity Fields
Product Center of the IGFS

# International Gravity Field Service (IGFS)

## Gravity and geoid metadata

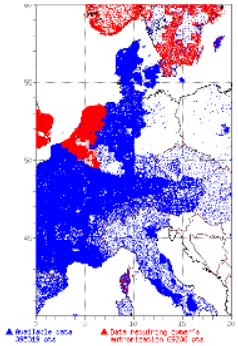
Online applications for the creation of metadata for gravity and geoid data. Service for searching the metadata database.

**g–μeta**
*the gravity metadata editor*
*(v0.2.6 – beta edition)*

**N–μeta**
*the geoid metadata editor*
*(v0.1.3 – alpha edition)*

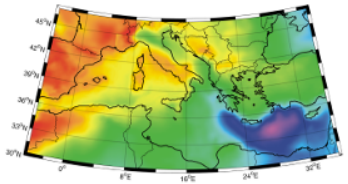
## Gravity data

Land, marine, airborne gravity data as point and gridded values. Absolute and relative gracity data, WGM



## Geoid

Geoid models and geoid determination software, geoid modeling processing methodologies

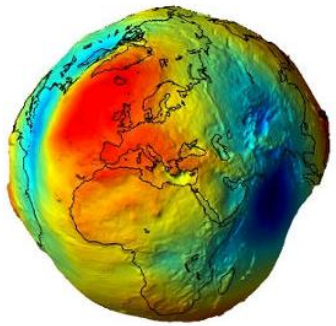


## SG and Earth tide data

Temporal variations of the Earth gravity field through long-term records from ground gravimeters, SG data, Earth tide data.

## Global Earth Models

Collection and archive of all existing global gravity field models, web interface for access to GEMs, model visualization and service.



## Time-variable GEMs

Combined gravity field solutions in SH coefficients and spatial grids for hydrological, oceanic and polar ice sheets applications.

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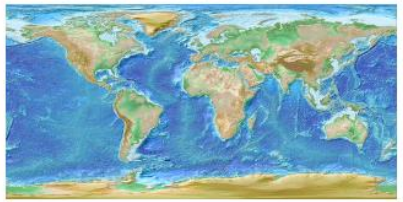
Combination Service for Time-variable Gravity Models

## DEM data

Digital Elevation Models, relevant software for DEM creation, assessment, manipulation and display, global relief and crustal models and spherical harmonic data sets.



**COST-G is a product center of the**

International Association of Geodesy
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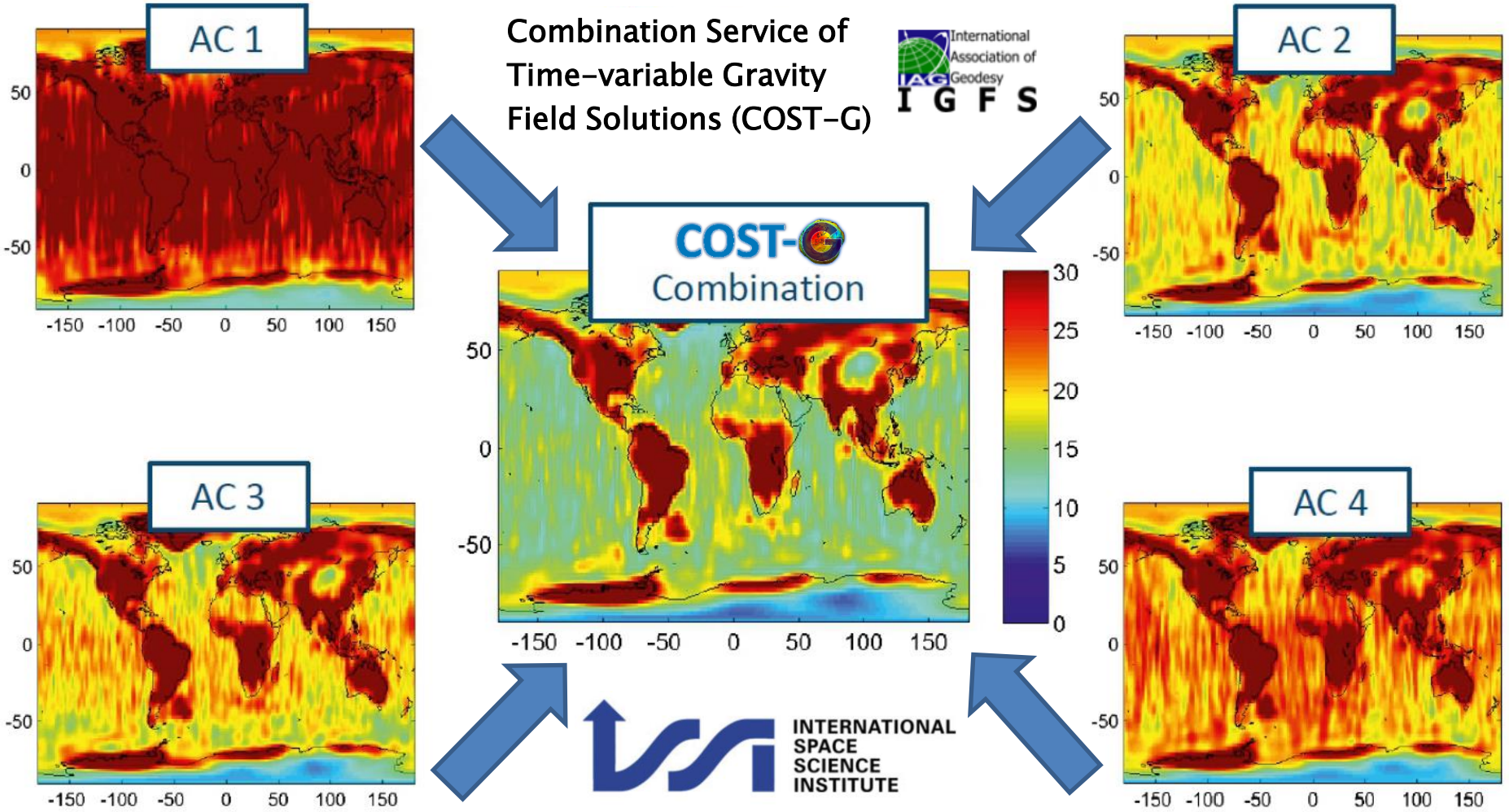
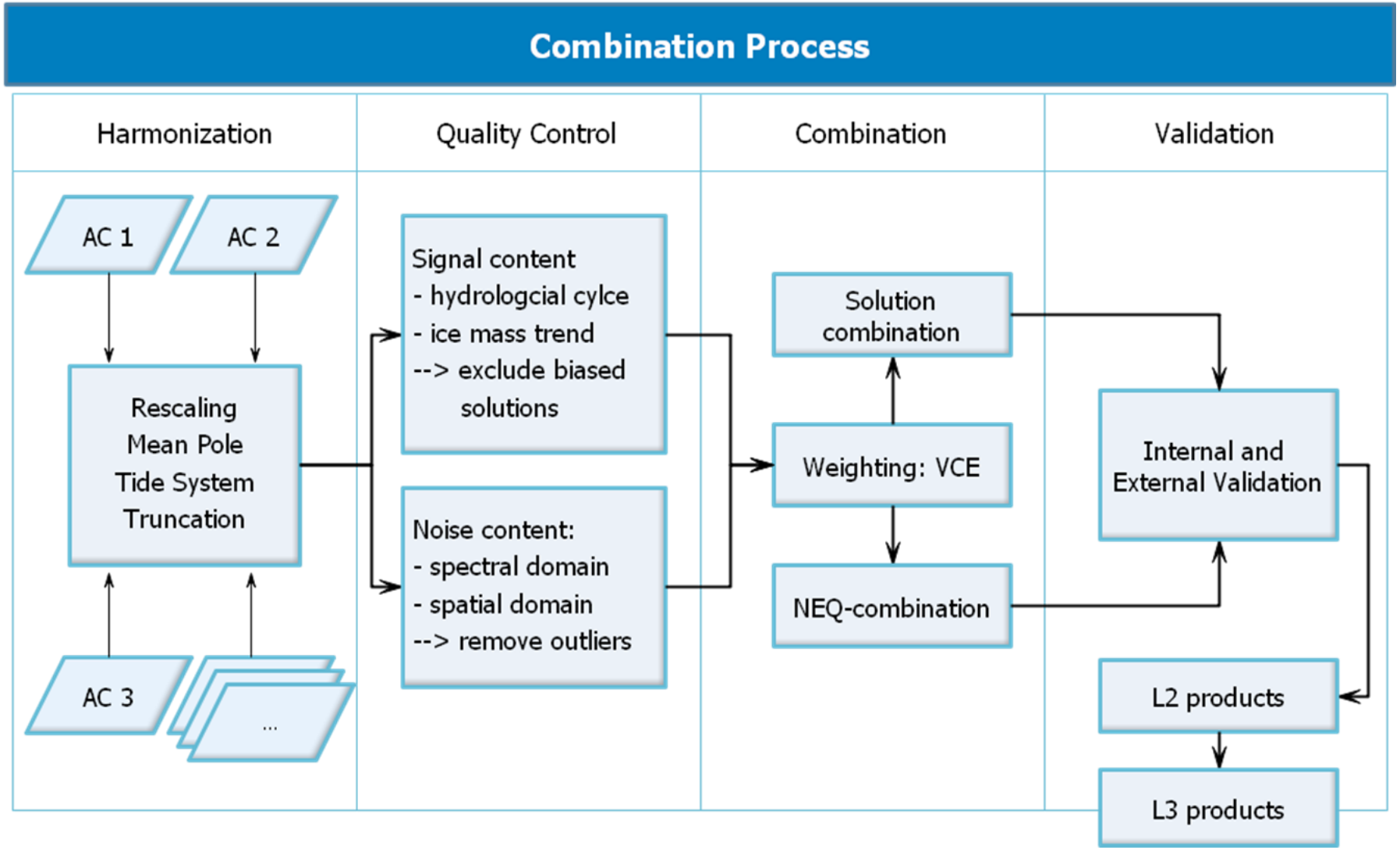
COST-G

# Introduction to COST-G

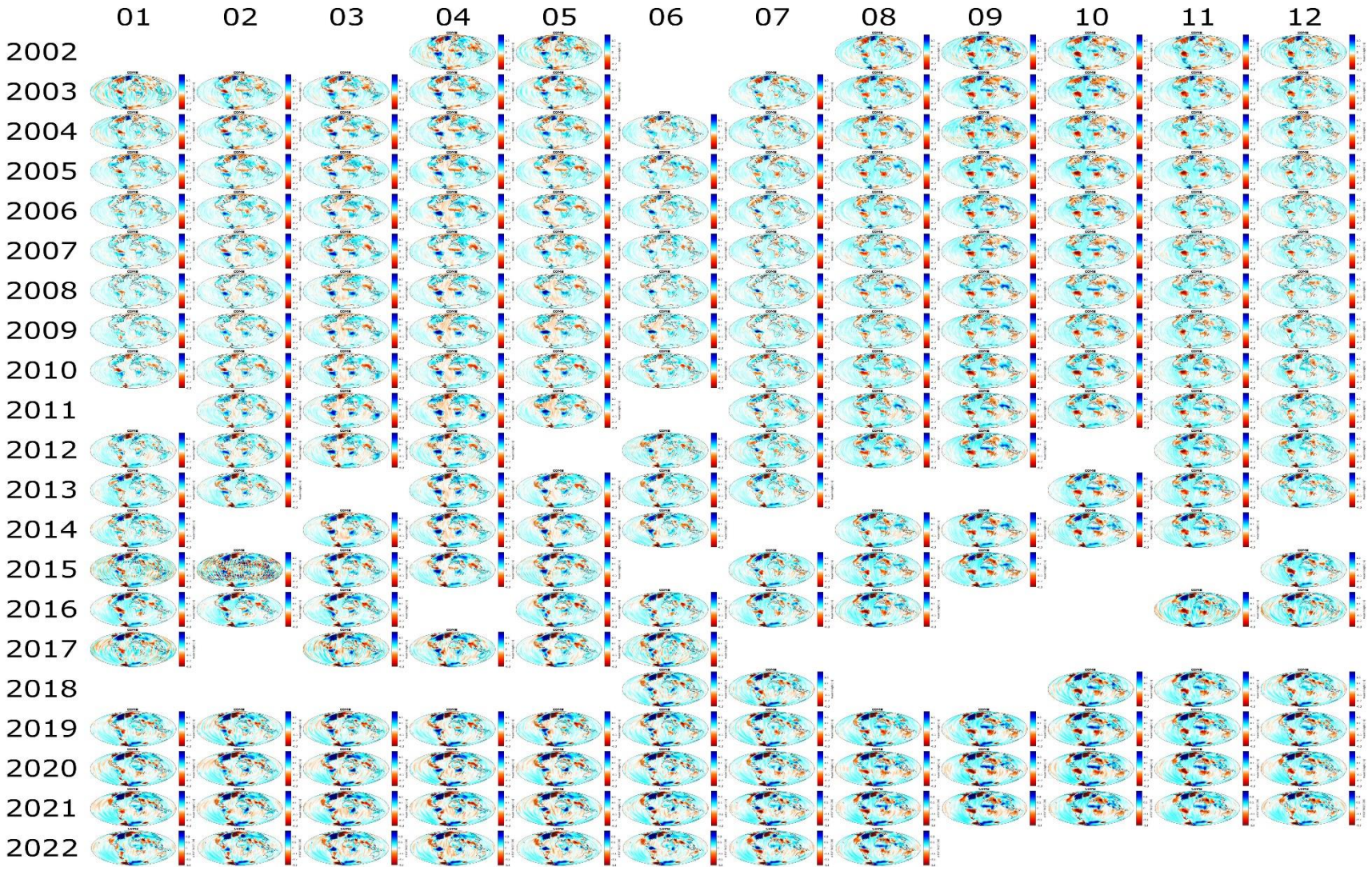



**Improved and consolidated product integrating the strengths of all ACs**

# Workflow of COST-G

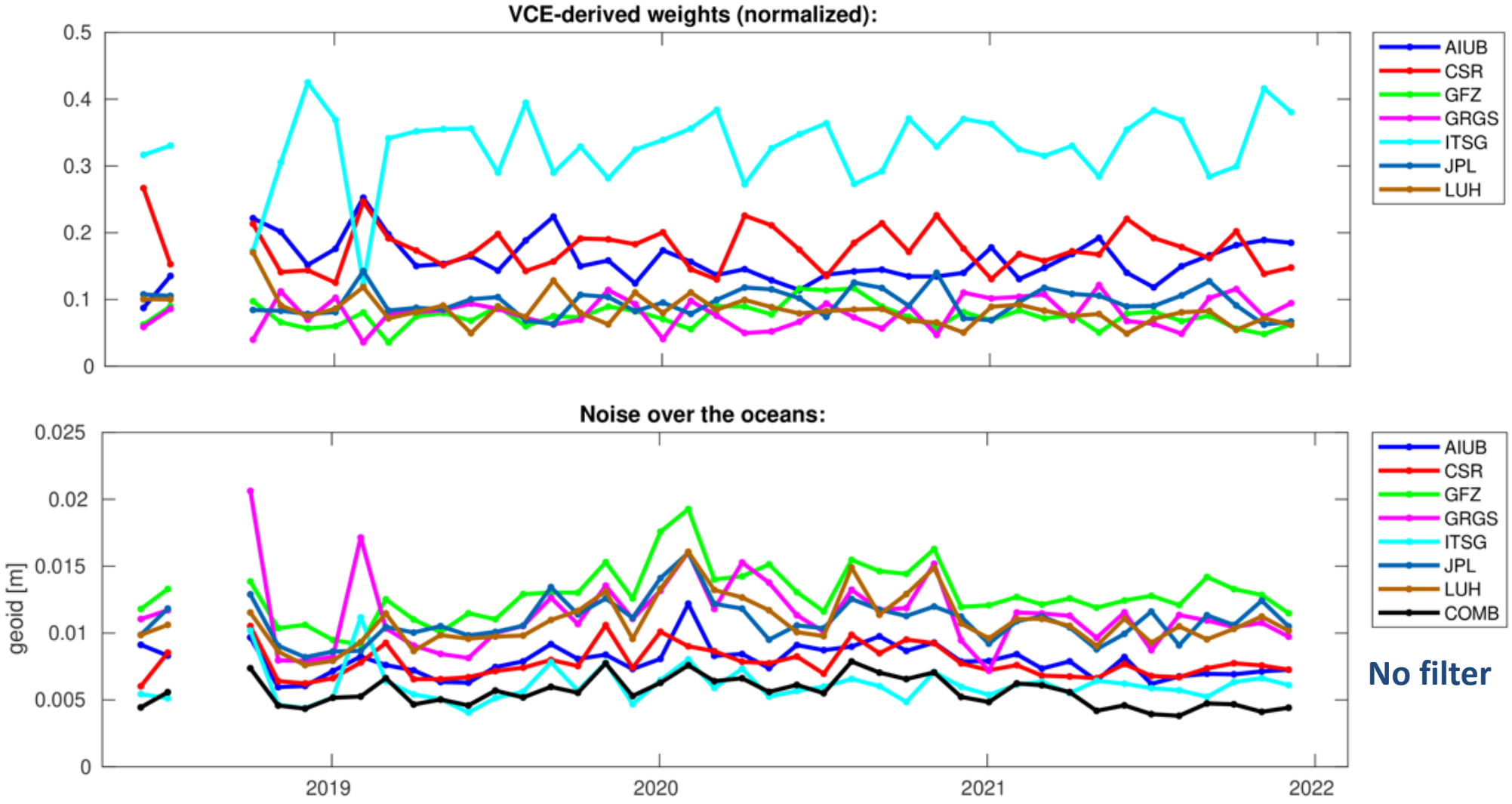


# GRACE-FO operational combined monthly gravity fields




**Flawless and uninterrupted operational combination with a latency < 2-3 months.**

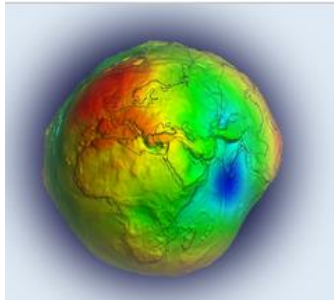
# Weighted combination and validation of the combined product




No filter

**Combination outperforms all individual solutions in 2021**

# Where to get the products: http://icgem.gfz-potsdam.de/series



ICGEM Home

Gravity Field Models

Static Models

Temporal Models

Topographic Gravity Field Models

Calculation Service

Regular grids

User-defined points

3D Visualisation

Static Models

Temporal Models

Trend & Amplitude

Spherical Harmonics

Evaluation

Spectral domain

GNSS Leveling

ICGEM

## Gravity Field Solutions for dedicated Time Periods

**The following gravity field time series are presently available:**

| GRACE and Grace-FO solutions from the Science Data System centers CSR, GFZ and JPL | | | | collapse all |
|---|---|---|---|---|
| - CSR | | | | Center for Space Research at University of Texas, Austin |
| CSR Release 05 | | monthly | | UTCSR Level-2 Processing Standards Document, Rev 4.0 May 29, 2012 |
| CSR Release 06 | DOI | monthly | | UTCSR Level-2 Processing Standards Document, Rev 5.0 April 18, 2018 |
| CSR Release 06 (GFO) | DOI | monthly | | UTCSR Level-2 Processing Standards Document, V 1.1 June 6, 2019 |
| - GFZ | | | | Helmholtz Centre Potsdam German Research Centre for Geosciences |
| GFZ Release 05 | | monthly | weekly | GFZ GRACE Level-2 Processing, Revised Edition, January 2013 |
| GFZ Release 06 | DOI | monthly | | GFZ GRACE Level-2 Processing Standards Document for Level-2 Products, Rev. 1.0, October 26, 2018 |
| GFZ Release 06 (GFO) | DOI | monthly | | GFZ GRACE Level-2 Processing Standards Document for Level-2 Products, Rev. 1.0, June 3, 2019 |
| - JPL | | | | Jet Propulsion Laboratory |
| JPL Release 05 | | monthly | | JPL Level-2 Processing Standards Document, Release 05.1 November 3, 2014 |
| JPL Release 06 | DOI | monthly | | JPL Level-2 Processing Standards Document, Release 06.0 June 1, 2018 |
| JPL Release 06 (GFO) | DOI | monthly | | JPL Level-2 Processing Standards Document, v 1.0 May 28, 2019 |

The processing standards to generate the GRACE Level-2 products of CSR, GFZ and JPL are also available in the Document Section of the GRACE archives at GFZ ISDC or JPL PO.DAAC

| COST-G (International Combination Service for Time-variable Gravity Field) | | | | collapse all |
|---|---|---|---|---|
| DSM | | quarterly | | Deterministic Signal Model |
| Grace | DOI | monthly | | |
| Grace-FO | DOI | monthly | | |
| Swarm | DOI | monthly | | |

*icgem (at) gfz-potsdam.de*

For operational LEO-POD a fitted signal model is generated additionally to the monthly products.

The COST-G fitted signal model is available in the ICGEM.2-format from the International Center for Global Earth Models.

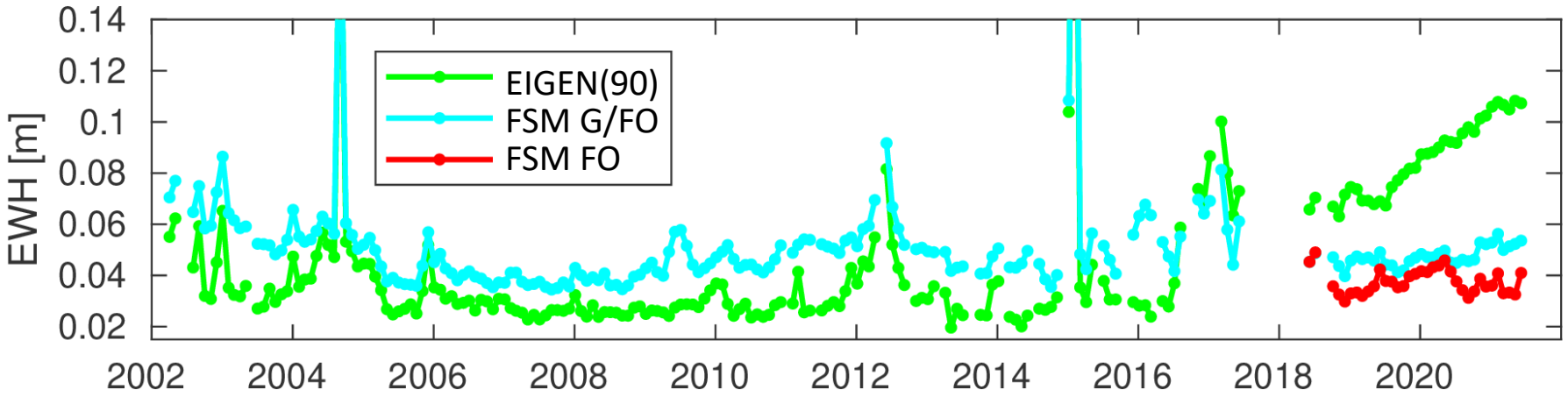
It is updated quarterly with the newest combined monthly GRACE-FO gravity fields.

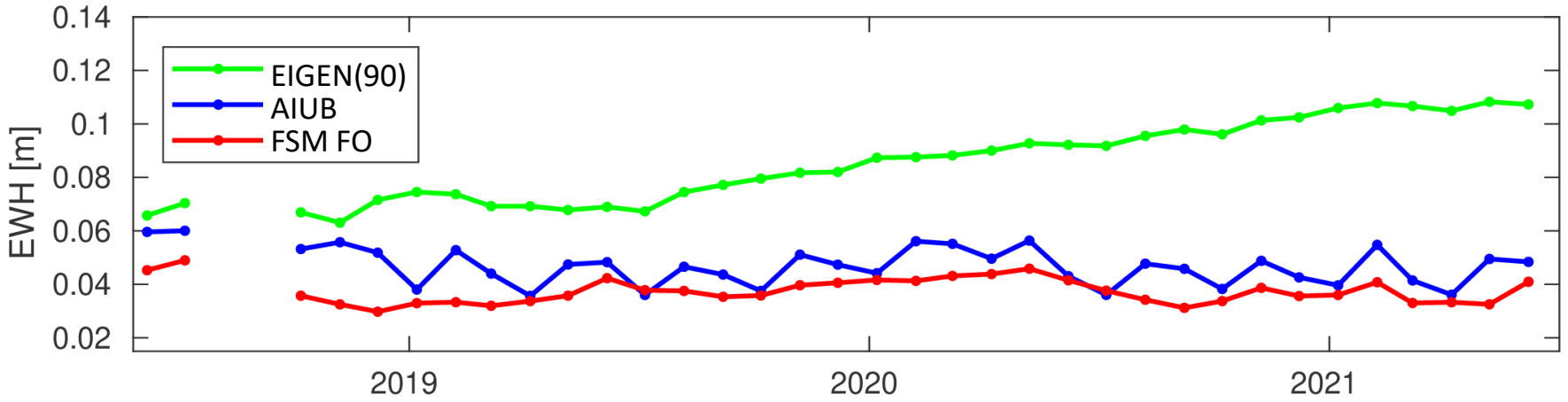
# COST-G FSM in ICGEM2.0-Format

```
CMMNT COST-G GRACE-FO deterministic gravity field model.
begin_of_head
format                  icgem2.0
product_type            gravity_field
modelname               GSM-2_MODEL_GRFO_COSTG_test_2015
earth_gravity_constant  0.3986004415E+15
radius                  0.6378136300E+07
max_degree               90
errors                  formal
norm                    fully_normalized
tide_system             tide_free

key    L    M  C                  S                  sigma C    sigma S    yyyymmdd.xxxx yyyymmdd.xxxx y

end_of_head
=============================================================================================================
gfc    0    0  1.00000000000E+00  0.00000000000E+00 0.0000E+00 0.0000E+00
gfc    1    0  0.00000000000E+00  0.00000000000E+00 0.0000E+00 0.0000E+00
gfc    1    1  0.00000000000E+00  0.00000000000E+00 0.0000E+00 0.0000E+00
gfct   2    0 -4.84165346490E-04 +0.00000000000E+00 6.0725E-11 0.0000E+00 20150101.0000 20180101.0000
trnd   2    0 -7.39420829887E-11 +0.00000000000E+00 6.0842E-11 0.0000E+00 20150101.0000 20180101.0000
acos   2    0 +4.13443094398E-11 +0.00000000000E+00 5.9933E-11 0.0000E+00 20150101.0000 20180101.0000 1.0
asin   2    0 +2.53863222596E-11 +0.00000000000E+00 6.6495E-11 0.0000E+00 20150101.0000 20180101.0000 1.0
acos   2    0 +2.65048085336E-11 +0.00000000000E+00 6.0809E-11 0.0000E+00 20150101.0000 20180101.0000 0.5
asin   2    0 -2.15182898423E-12 +0.00000000000E+00 6.4827E-11 0.0000E+00 20150101.0000 20180101.0000 0.5
…
```

# Fitted Signal Model (FSM) for operational LEO-POD

# RMS of differences (over land, 300 km Gauss): FSM - monthly gravity fields



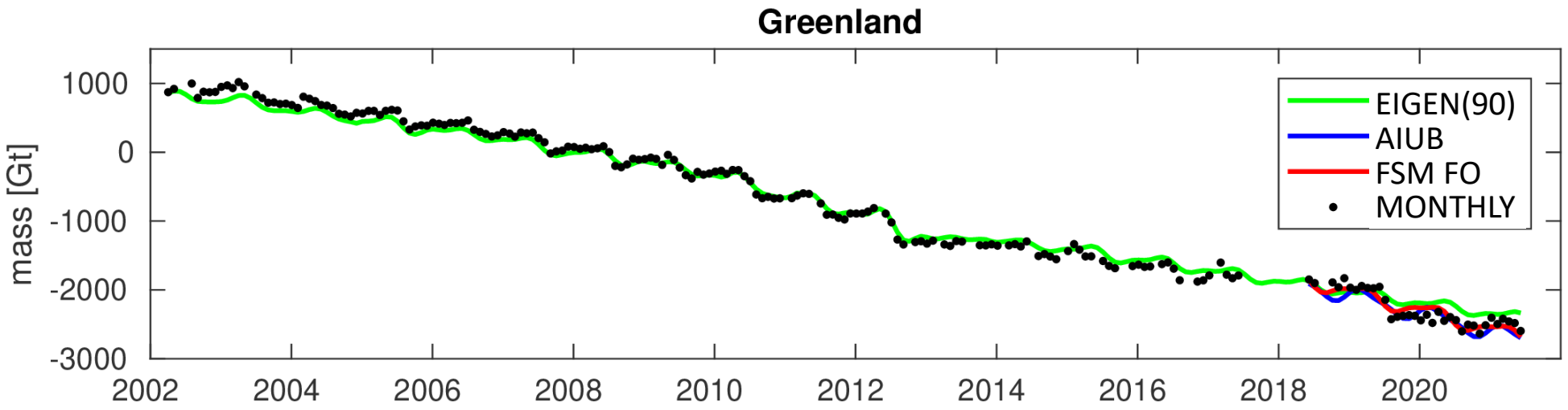



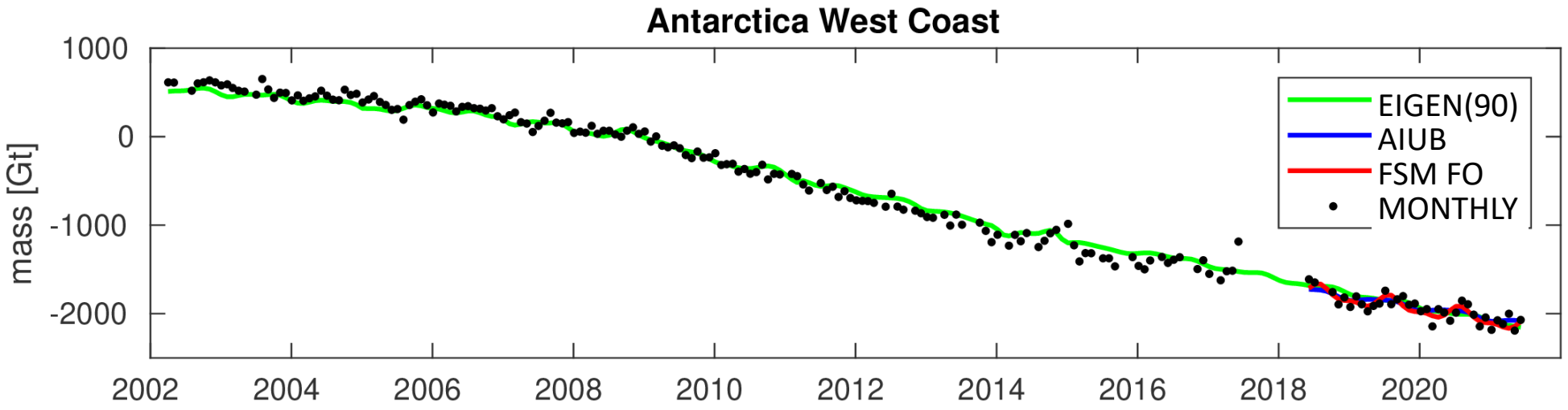

Operational precise orbit determination (POD) of low Earth orbiters (LEO) relies on a Earth gravity model including time-variable gravity (TVG).

The EIGEN-GRGS-RL04 model (green) has been the standard for LEO-POD of altimeter satellites, but the extrapolation to the GRACE-FO period reveals large prediction errors.

For comparison, a model fitted to COST-G GRACE-FO gravity fields is shown (red).

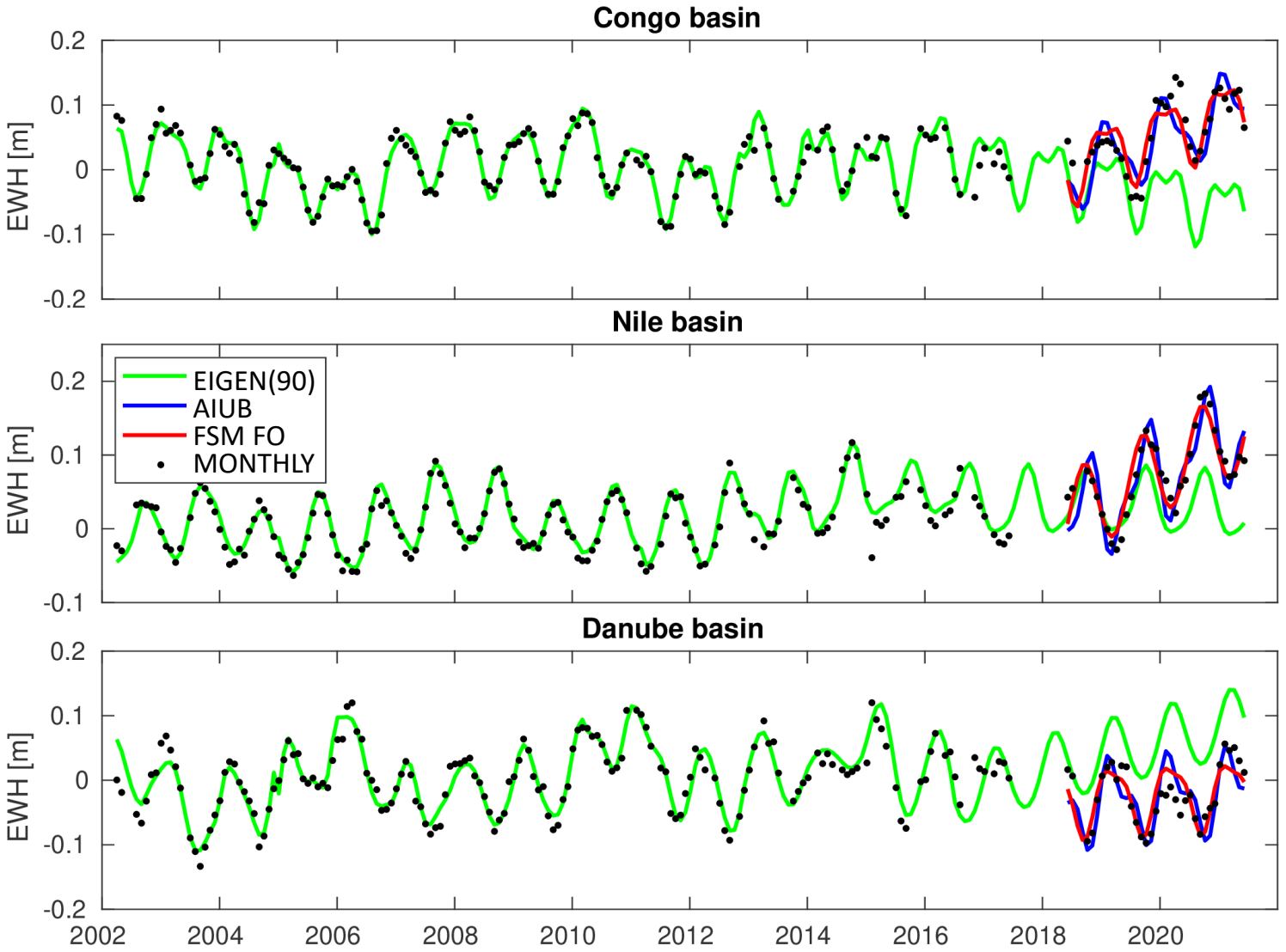
# Polar mass trend (no filter)




Surprisingly, the reason for the prediction error in the EIGEN-GRGS-RL04 model (green) seems not to be in regions with strong mass trends.

# Hydrological cycle in large river basins (300 km Gauss)

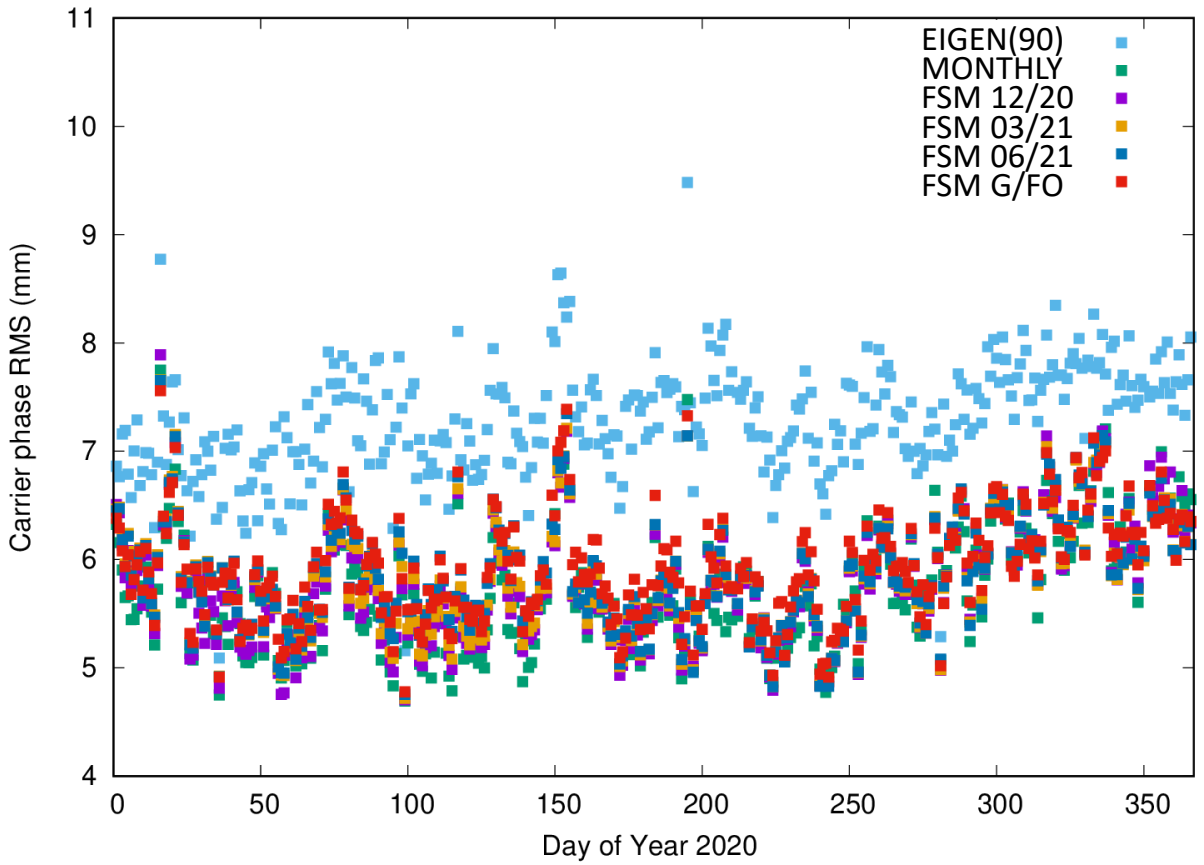


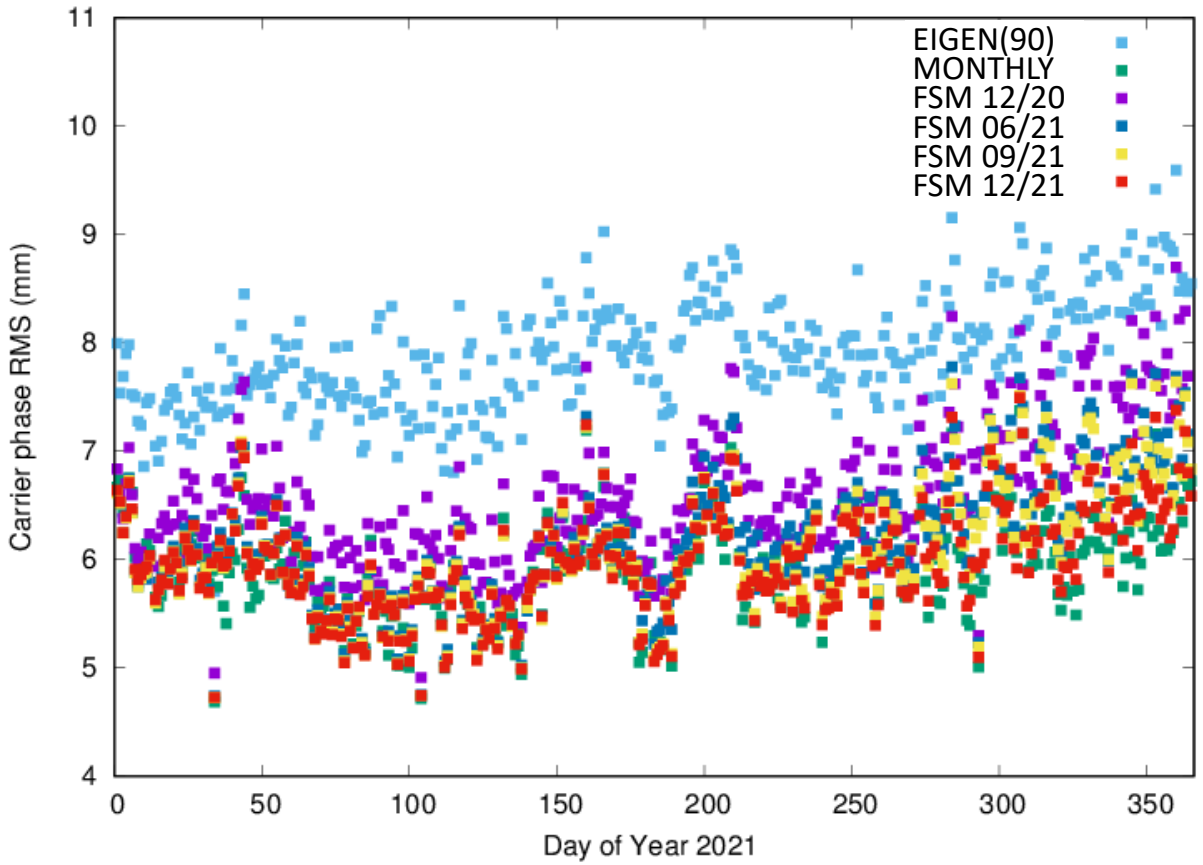

The time-series of monthly GRACE gravity field solutions was fitted in yearly batches for the EIGEN-GRGS-RL04 model.

While the fit in the GRACE period is very good, the extrapolation of the last of these batches leads to large errors in river basins with strong non-seasonal variations.

# Application to Sentinel orbit POD

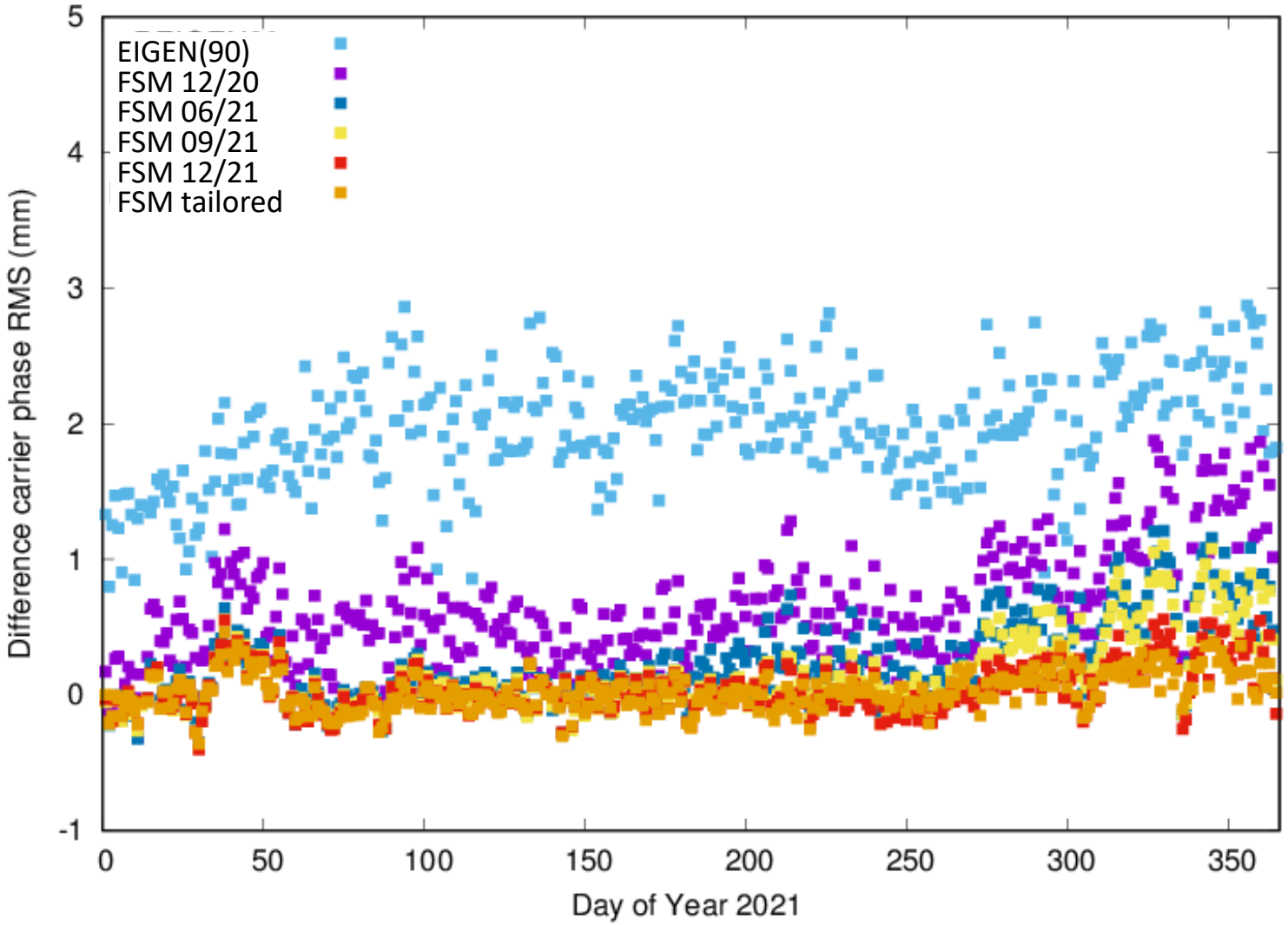
# Sentinel - 3B (altitude 811 km) orbit determination

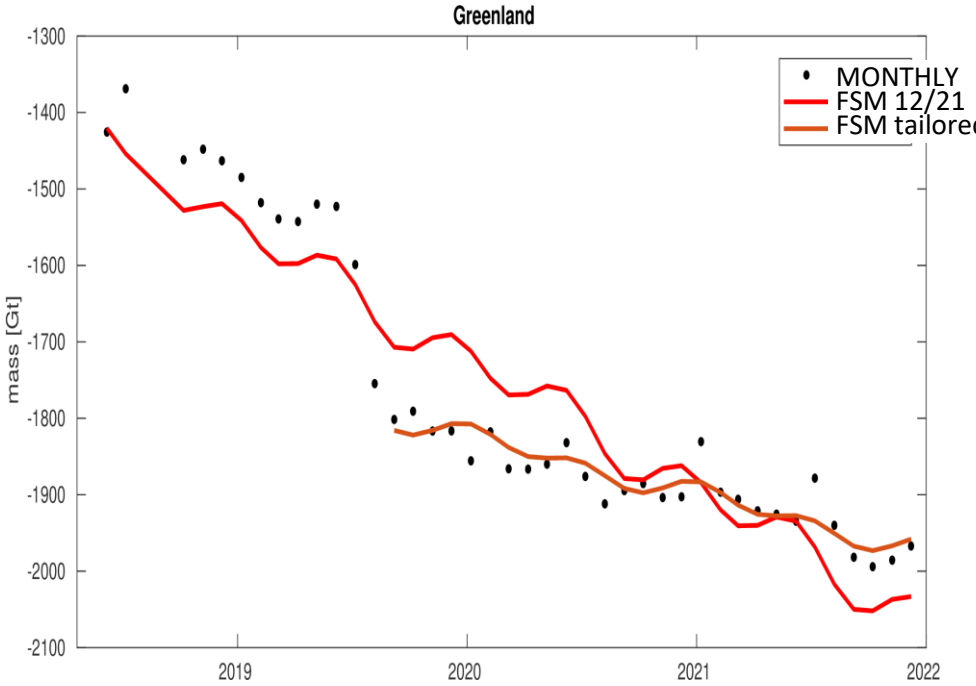



The carrier phase RMS of dynamic Sentinel-3B satellite orbits (orbit altitude 811 km) based on monthly GRACE-FO gravity fields (green) or different fitted signal models reveals the benefit of up-to-date models. All models were truncated at max. degree/order 90.

# Impact of fit period on LEO-POD (Sentinel-3B, altitude 811 km)




Carrier phase residuals of Sentinel-3B orbits (811 km orbit altitude) confirm the sensitivity on the data period that entered the model.

# Independent orbit validation

# SLR-validation Sentinel-3B

## Data: Year 2020, Sentinel-3B, SLR validation, 12 stations (cm)

| Gravity field model | Mean (cm) | RMS (cm) | Standard deviation (cm) |
|---|---|---|---|
| DEIGEN120 | 0.29 | 1.01 | 0.97 |
| DEIGEN90 | 0.29 | 1.01 | 0.97 |
| D90MONTHLY | 0.28 | 0.91 | 0.87 |
| D90MODEL2012 | 0.28 | 0.92 | 0.88 |
| RDEIGEN120 | 0.31 | 0.91 | 0.85 |
| RDEIGEN90 | 0.31 | 0.91 | 0.85 |
| RD90MONTHLY | 0.31 | 0.88 | 0.82 |

The limited max. degree does not negatively affect LEO POD (S3B)

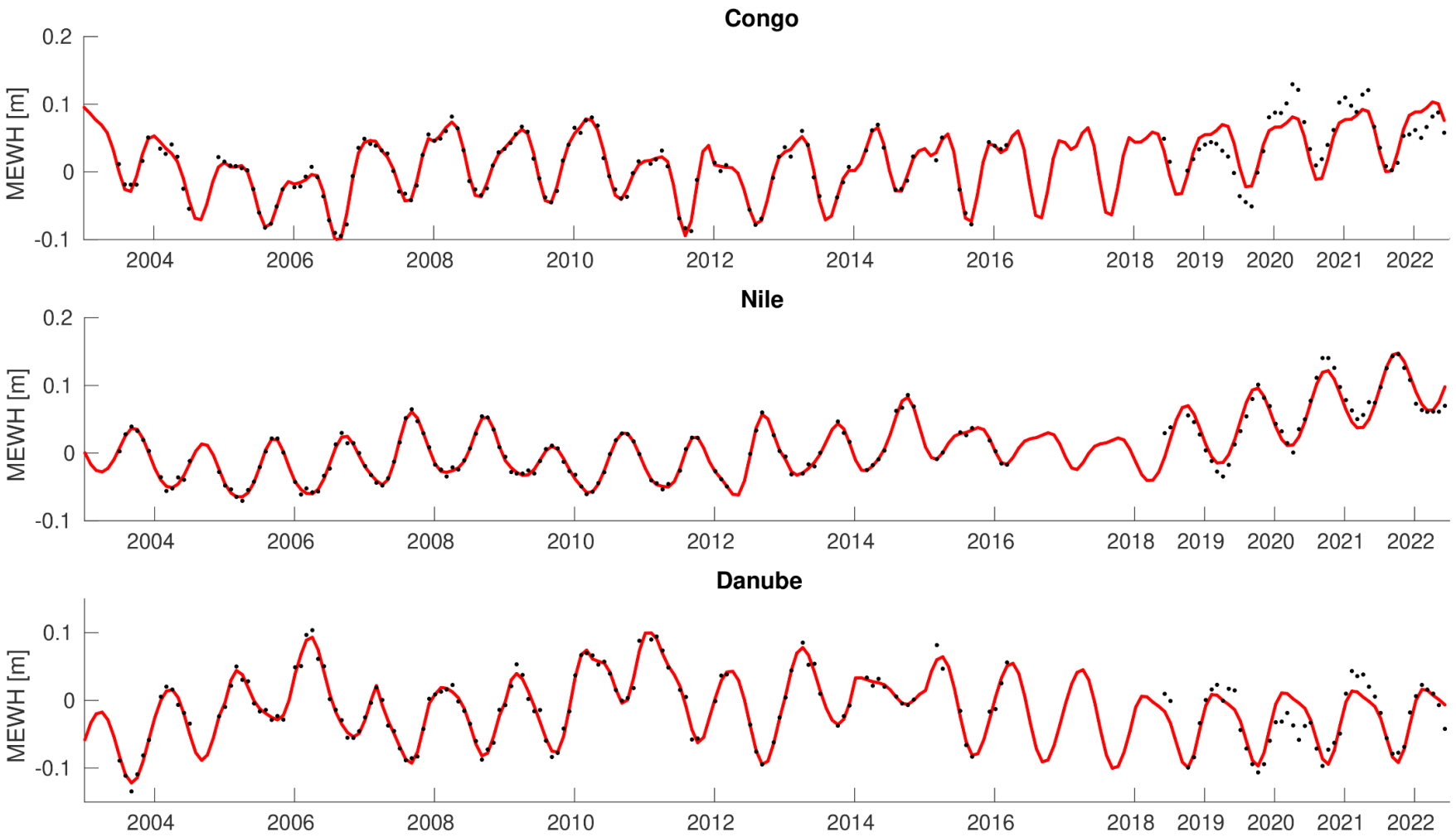
LEO POD profits from monthly gravity fields

The fitted signal models perform close to the monthly gravity fields

Reduced dynamic LEO POD is less sensitive to model deficiencies.

# Outlook

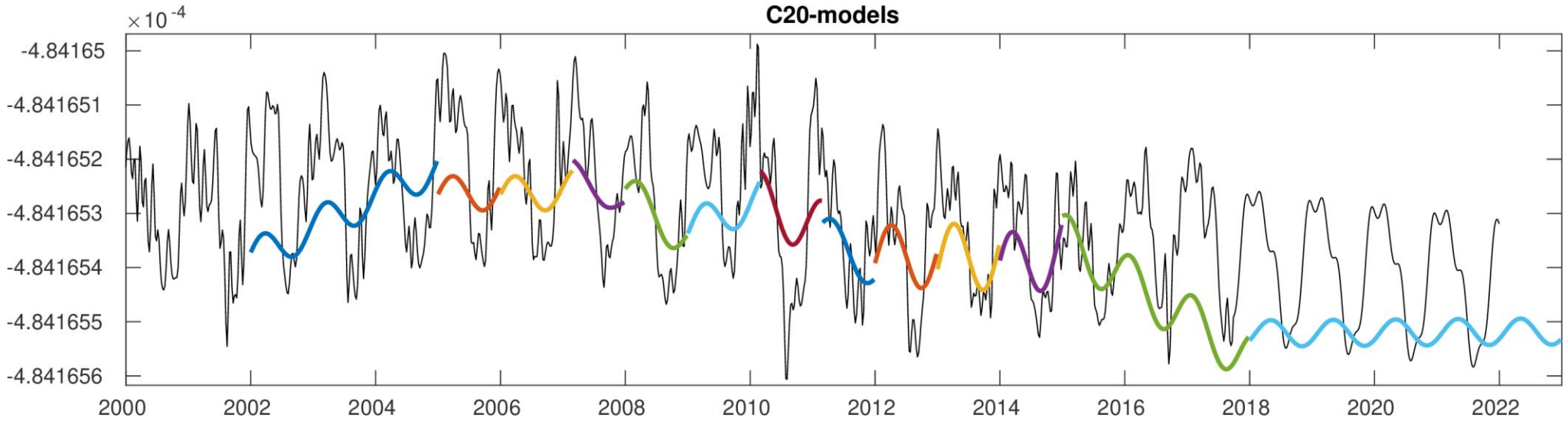
# Extension of COST-G FSM for REPRO purposes



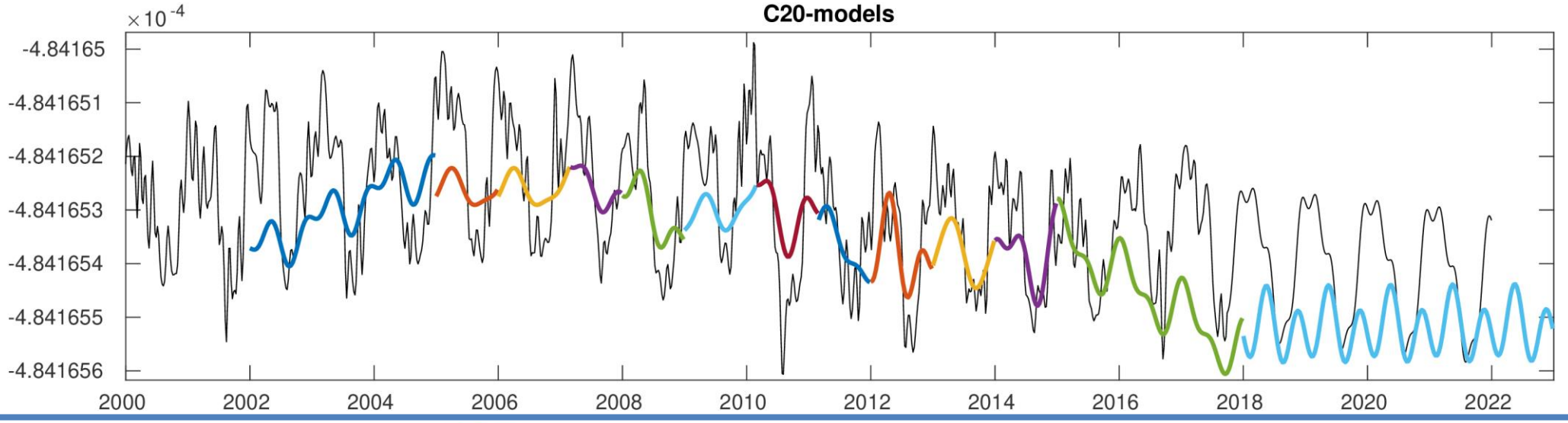

Extension of the COST-G FSM to cover the whole GRACE/FO period:

- Fit of GRACE monthly models in yearly batches
- Continuity conditions between individual batches
- Fit of GRACE-FO monthly models in one batch to allow for prediction.

# Comparsion of C20-Models




Only trends and annual variations




Including semi-annual variations

# LAGEOS 7d-solutions (obits/stations/ERPs/GCM)

| No 1/rev. cross-track par. | X-pole: bias [µas] | RMS [µas] | Y-pole: bias [µas] | RMS [µas] |
|---|---|---|---|---|
| GGM05S (static) | 66.3 | 261.1 | 86.5 | 245.8 |
| ILRS (time-var.) | 54.3 | 219.4 | 88.0 | 201.1 |
| COST-G FSM (time-var.) | 51.0 | 215.6 | 80.6 | 196.7 |

| + periodic cross-track | X-pole: bias [µas] | RMS [µas] | Y-pole: bias [µas] | RMS [µas] |
|---|---|---|---|---|
| GGM05S (static) | 91.4 | 148.1 | 68.4 | 119.8 |
| ILRS (time-var.) | 73.7 | 142.3 | 75.9 | 126.2 |
| COST-G FSM (time-var.) | 68.8 | 132.8 | 66.0 | 117.8 |

| + C20 | X-pole: bias [µas] | RMS [µas] | Y-pole: bias [µas] | RMS [µas] |
|---|---|---|---|---|
| GGM05S (static) | 68.8 | 175.9 | 72.2 | 156.1 |
| ILRS (time-var.) | | | | |
| COST-G FSM (time-var.) | 49.3 | 164.5 | 65.5 | 157.2 |

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| + C20 | X-pole: bias | RMS | Y-pole: bias | RMS |
|---|---|---|---|---|
| GGM05S (static) | 68.8 | 175.9 | 72.2 | 156.1 |
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| COST-G FSM (time-var.) | 49.3 | 164.5 | 65.5 | 157.2 |