EGSIEM

European Gravity Service for Improved Emergency Management

Validation of the EGSIEM GRACE gravity fields using GNSS and OBP records

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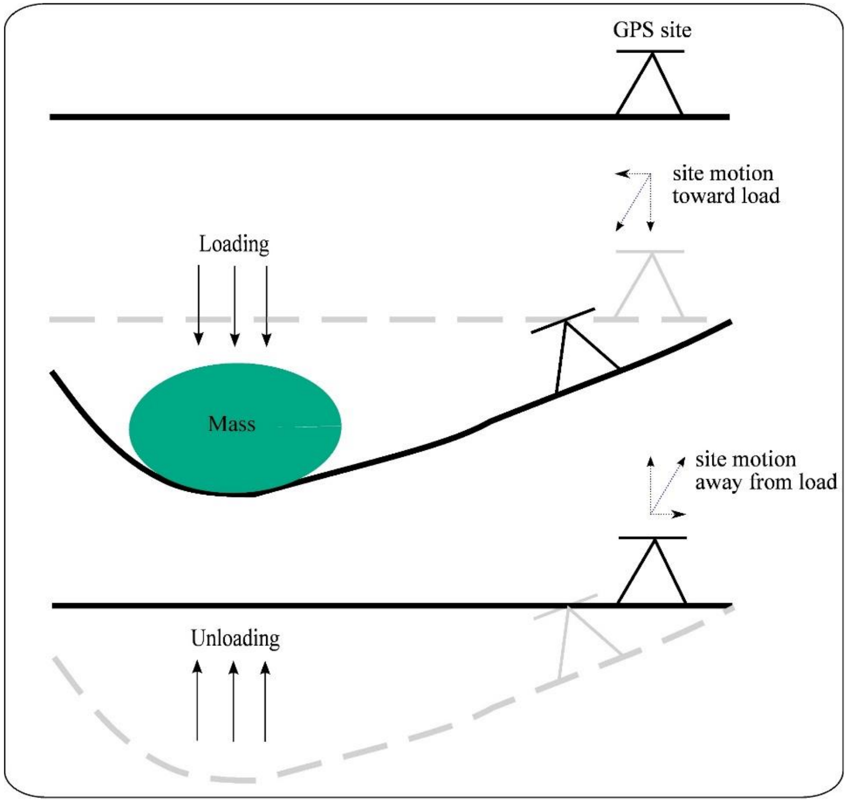
Horizon2020

Motivation

- Validation to increase our confidence in the delivered gravity products!
- Validation of
  - the official EGSIEM two-year combined monthly gravity solution as well as solutions from individual analysis centers (ACs)
  - the long-term EGSIEM combined monthly solution
  - the EGSIEM Level 3 monthly products
  - the EGSIEM daily gravity products as well as NRT fields
- External datasets: GNSS time series and in-situ ocean bottom pressure (OBP) records

Concept of Validation using GNSS



- GNSS observed vertical displacements
  - Monthly averaged reference frame data (EGSIEM)
  - Monthly averaged ITRF2014 time series (IGN, France)
  - Monthly averaged JPL GNSS time series (Public available)
- GRACE-derived vertical displacements

$$u_r(\theta_P, \lambda_P) = R \sum_{n=0}^{\infty} \frac{h'_n}{1+k'_n} \sum_{m=0}^{n} \tilde{P}_{nm}(\cos\theta_P) \cdot (\Delta C_{nm} \cos(m\lambda_P) + \Delta S_{nm} \sin(m\lambda_P))$$

  - R: Earth's radius
  - h'_n, k'_n: loading Love numbers
  - $\tilde{P}_{nm}$: normalized Legendre functions
  - $\Delta C_{nm}, \Delta S_{nm}$: gravity spherical harmonic coefficients from GRACE

Metrics

- WRMS reduction and its variants
  - Degree WRMS reduction
  - Accumulative degree WRMS reduction

$$\textit{Degree}\ \text{WRMS}\ \textit{reduction} = \frac{\text{WRMS}\left[h_i^{\text{GPS}}\right] - \text{WRMS}\left[h_i^{\text{GPS}} - h_i^{\text{GRACE}^n}\right]}{\text{WRMS}\left[h_i^{\text{GPS}}\right]}$$

Degree WRMS reduction at the i^{th} GPS station

Compute GRACE-derived displacements using SH *at only degree n* **OR** *up to degree n*

Validation of the official EGSIEM two-year combined monthly solution using GNSS

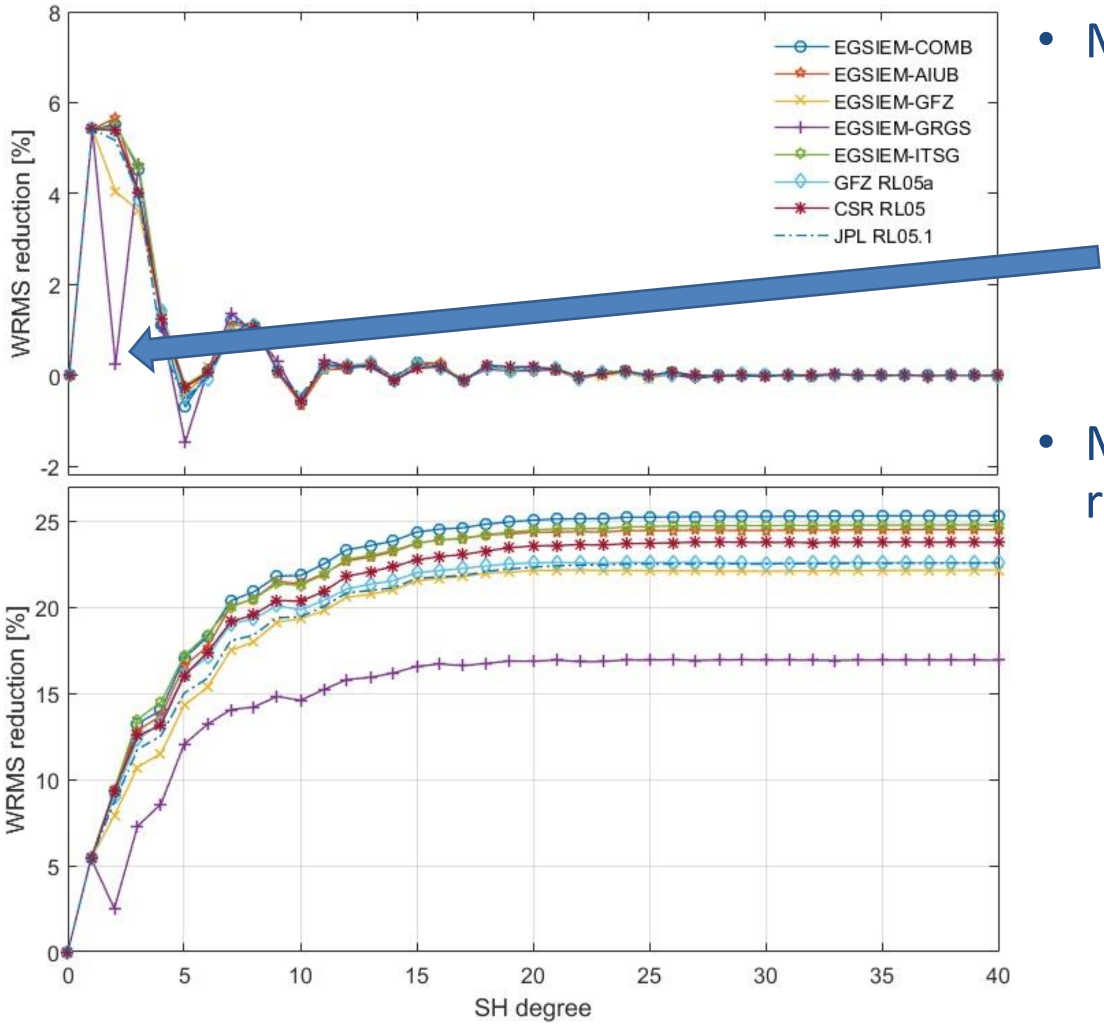
Post-processing monthly gravity fields

- Monthly gravity fields of 2006&2007
  - Official EGSIEM combined solution at the **normal equation level**
  - Products from four individual ACs (AIUB, GFZ, GRGS, ITSG)
  - Products from three official GRACE ACs (GFZ RL05a, CSR RL05, JPL RL05.1)

- Standard processing steps
  - Replacing C_{20} from SLR (Cheng et al., 2011)
  - Restoring degree-1 from SLR (Sośnica et al., 2015)
  - Adding back AOD1B GAC RL05
  - Filtering with a Gaussian filter 500 km
  - Deriving displacements at GNSS stations
  - Removing the mean and trend

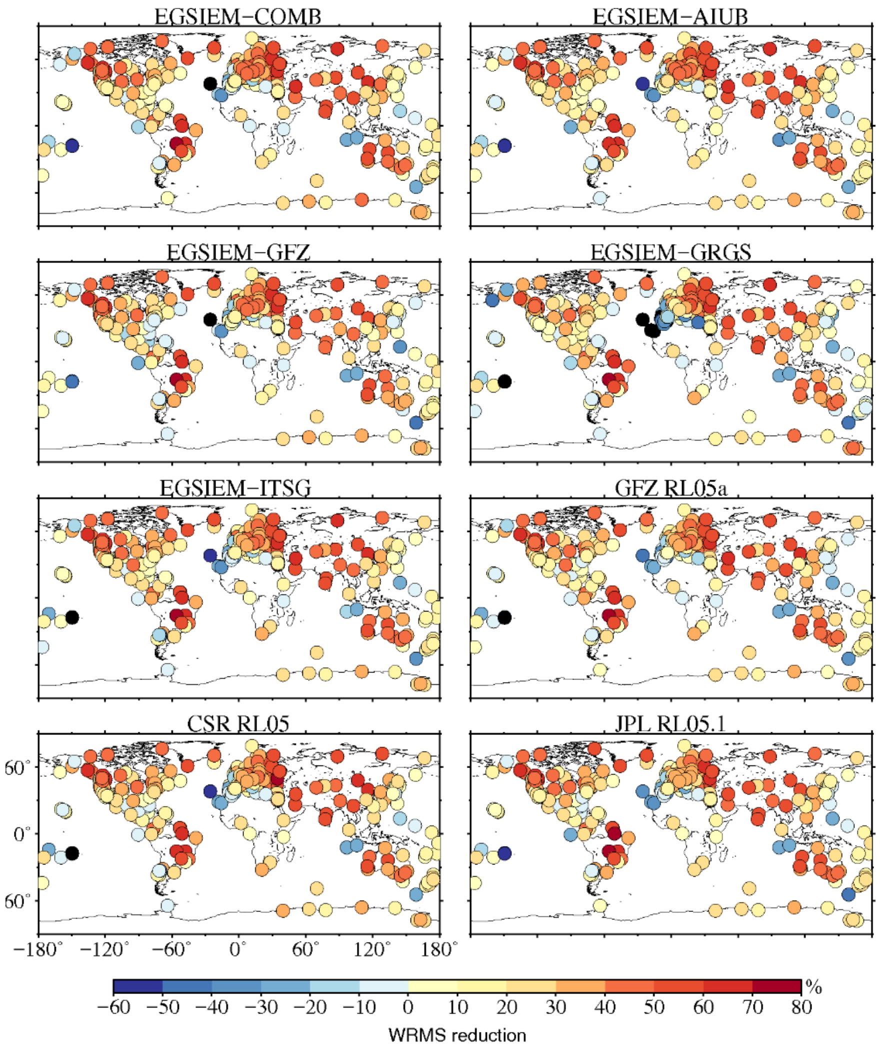
Meyer U., Jean Y., Jäggi A. Combination of GRACE monthly gravity fields on normal equation level. In preparation

With respect to ITRF2014 time series – full signal level



- Mean degree WRMS reduction (top)
  - higher WRMS reductions at low SH degrees
  - abnormal C_{21} and S_{21} terms of EGSIEM-GRGS solution
- Mean accumulative degree WRMS reduction (bottom)
  - no significant contributions beyond degree 30
  - The EGSIEM combined solution with the best accumulative degree WRMS reduction
  - EGSIEM combination at NEQ level overcoming the outliers

With respect to ITRF2014 time series – full signal level

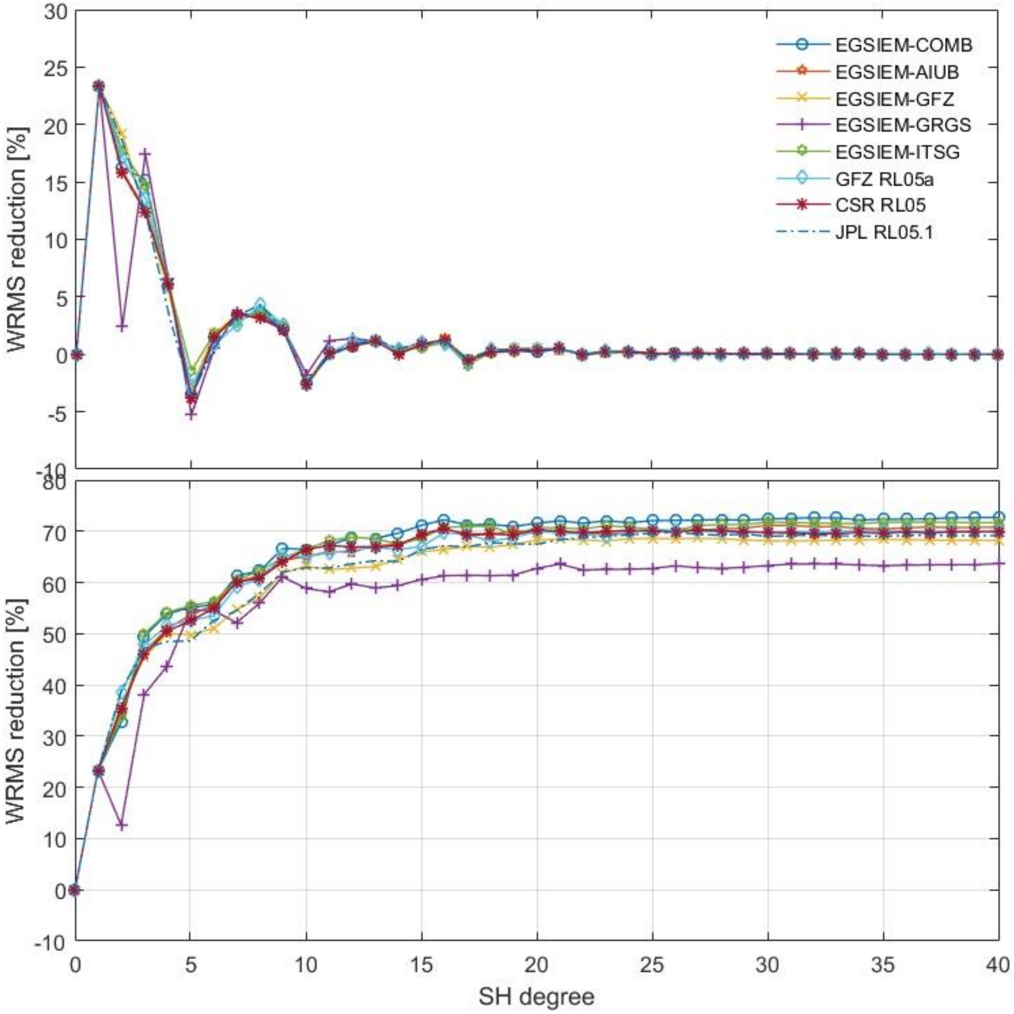


	Mean WRMS reduction [%]	Positive WRMS reduction [%]
EGSIEM-COMB	**25.31**	**89.95**
EGSIEM-AIUB	24.50	89.69
EGSIEM-GFZ	22.17	83.51
EGSIEM-GRGS	16.95	81.70
EGSIEM-ITSG	24.78	88.66
GFZ RL05a	22.61	84.79
CSR RL05	23.78	88.14
JPL RL05.1	22.56	86.08

- EGSIEM-COMB with the best performance
- The mean WRMS reductions shown much better than those from Gu et al. (2017, GRL, Table S3) who achieved maximum values of 15%.

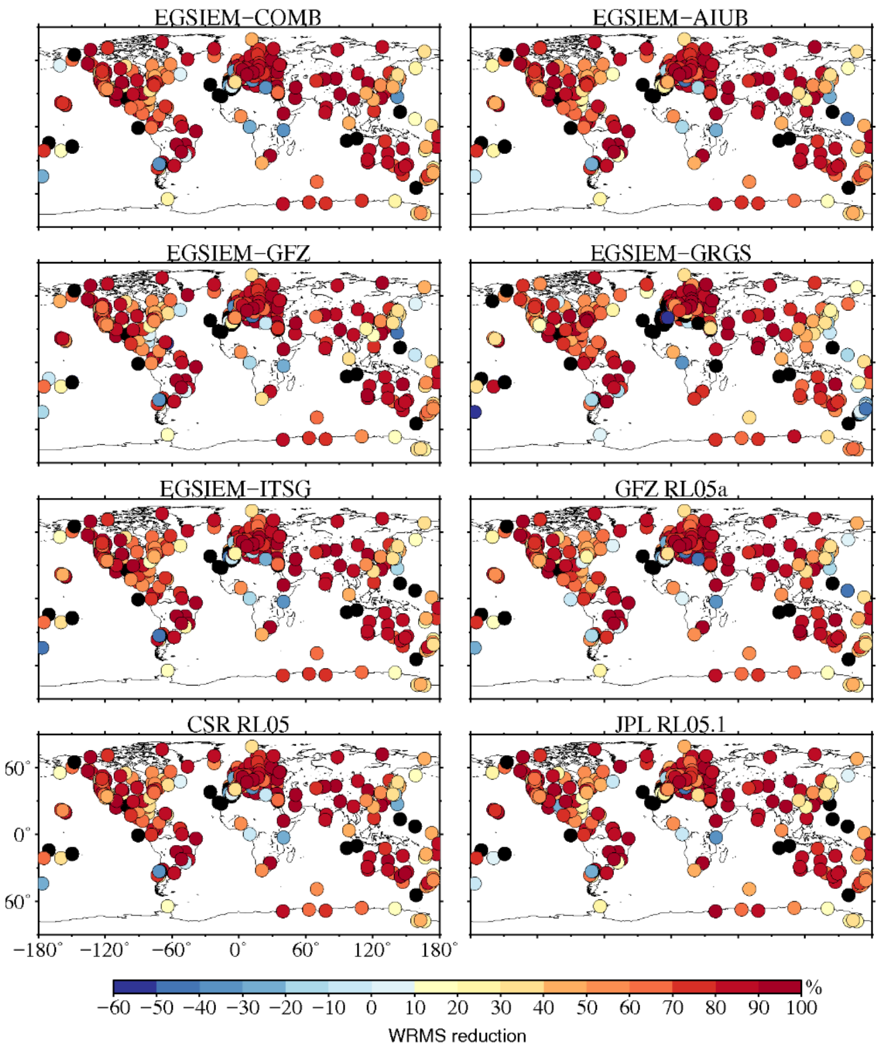
Gu et al. (2017). Comparison of observed and modeled seasonal crustal vertical displacements derived from multi-institution GPS and GRACE solutions. GRL, doi: 10.1002/2017GL074264

With respect to ITRF2014 time series – annual signal level



- Median degree WRMS reduction (top)
  - higher degree WRMS reductions at annual period than those at full signal
- Median accumulative Degree WRMS reduction (bottom)
  - up to median values around 70% for all gravity models
  - similar performances among different gravity models at annual period

With respect to ITRF2014 time series – annual signal level



	Median WRMS reduction [%]	Positive WRMS reduction [%]
EGSIEM-COMB	**72.72**	**88.66**
EGSIEM-AIUB	70.64	88.40
EGSIEM-GFZ	68.28	87.11
EGSIEM-GRGS	63.64	81.19
EGSIEM-ITSG	71.63	88.40
GFZ RL05a	70.20	88.40
CSR RL05	70.20	87.89
JPL RL05.1	69.17	87.63

- Up to 99% agreement at annual period for a large group of GNSS stations

Validation of the long-term EGSIEM combined monthly solution using GNSS

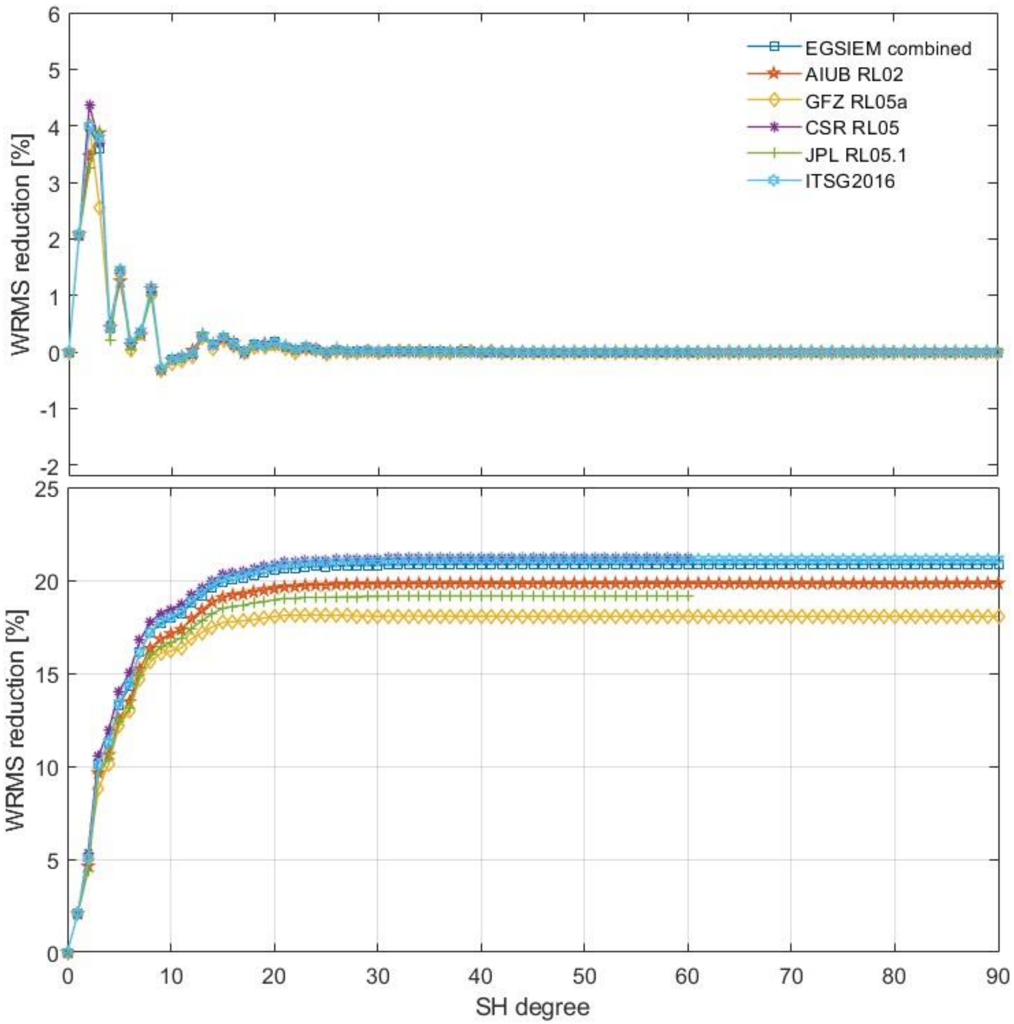
Post-processing monthly gravity fields

- Long-term monthly gravity fields (2002.8 – 2014.10)
  - EGSIEM combined solution at the solution level (2002.8-2014.10, see Jean et al. (2018))
  - Products from three official GRACE ACs (GFZ RL05a, CSR RL05, JPL RL05.1)
  - Additional products from AIUB RL02 and ITSG2016

- Standard processing steps
  - Replacing C_{20} from SLR (Cheng et al., 2011)
  - Restoring degree-1 from Swenson et al (2008)
  - Adding back AOD1B GAC RL05
  - Filtering with a Gaussian filter 500 km
  - Deriving displacements at GNSS stations
  - Removing the mean and trend

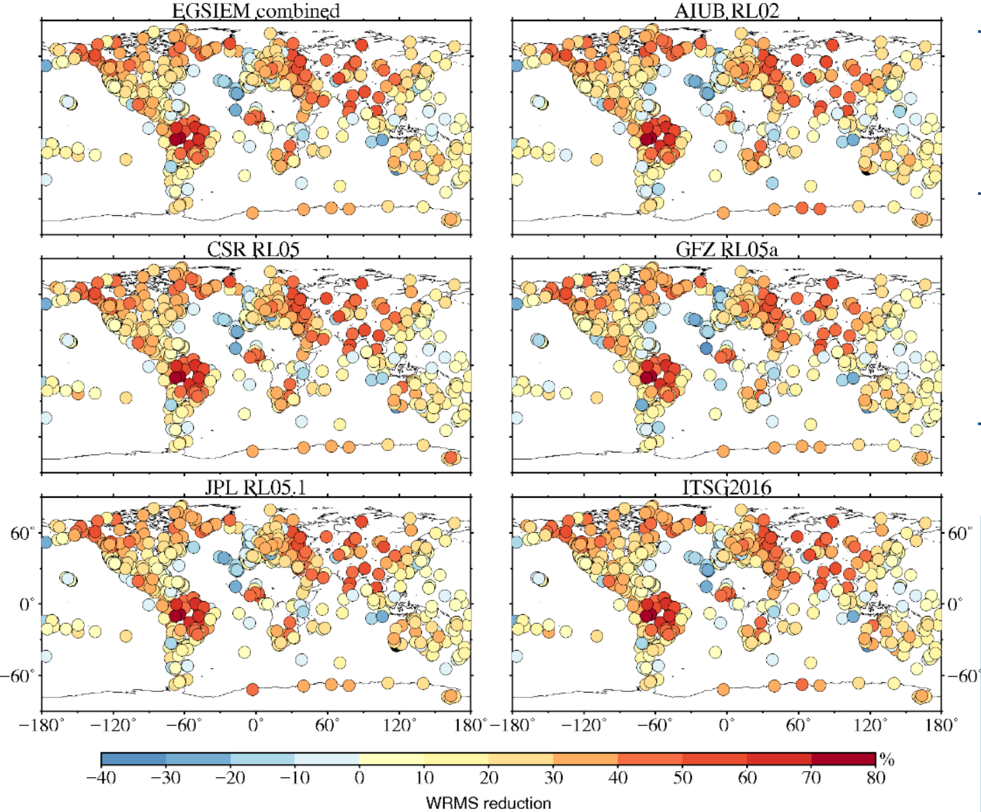
Jean et al. (2018). Combination of GRACE monthly gravity field solutions from different processing strategies. Journal of Geodesy, doi: 10.1007/s00190-018-1123-5

With respect to ITRF2014 time series – full signal level



- Degree WRMS reduction (top)
- Accumulative Degree WRMS reduction (bottom)
- Similar characteristics as the the two-year monthly gravity models

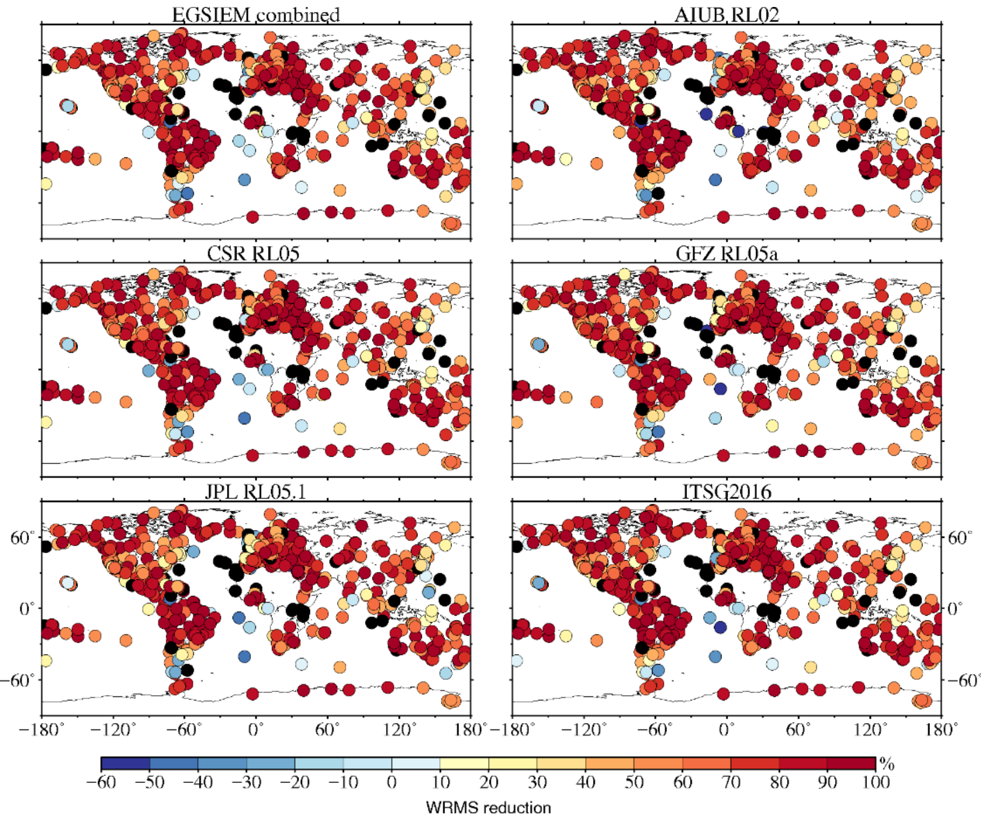
With respect to ITRF2014 time series – full signal level



	Reference frame data (312 stations)	ITRF2014 residuals (928 stations)	JPL GNSS time series (788 stations)
	Mean [%]	Mean [%]	Mean [%]
EGSIEM	**23.9**	**20.9**	**16.0**
AIUB RL02	23.0	19.8	**16.0**
CSR RL05	**24.5**	**21.2**	15.7
GFZ RL05a	21.9	18.1	13.8
JPL RL05.1	22.8	19.2	15.2
ITSG2016	**24.5**	**21.1**	**16.1**

- EGSIEM, CSR RL05a and ITSG2016 demonstrating similar performance and slightly better than others
- The mean WRMS reductions shown here much better than those from Gu et al. (2017, GRL, Table S3) who achieved maximum values of 15%.

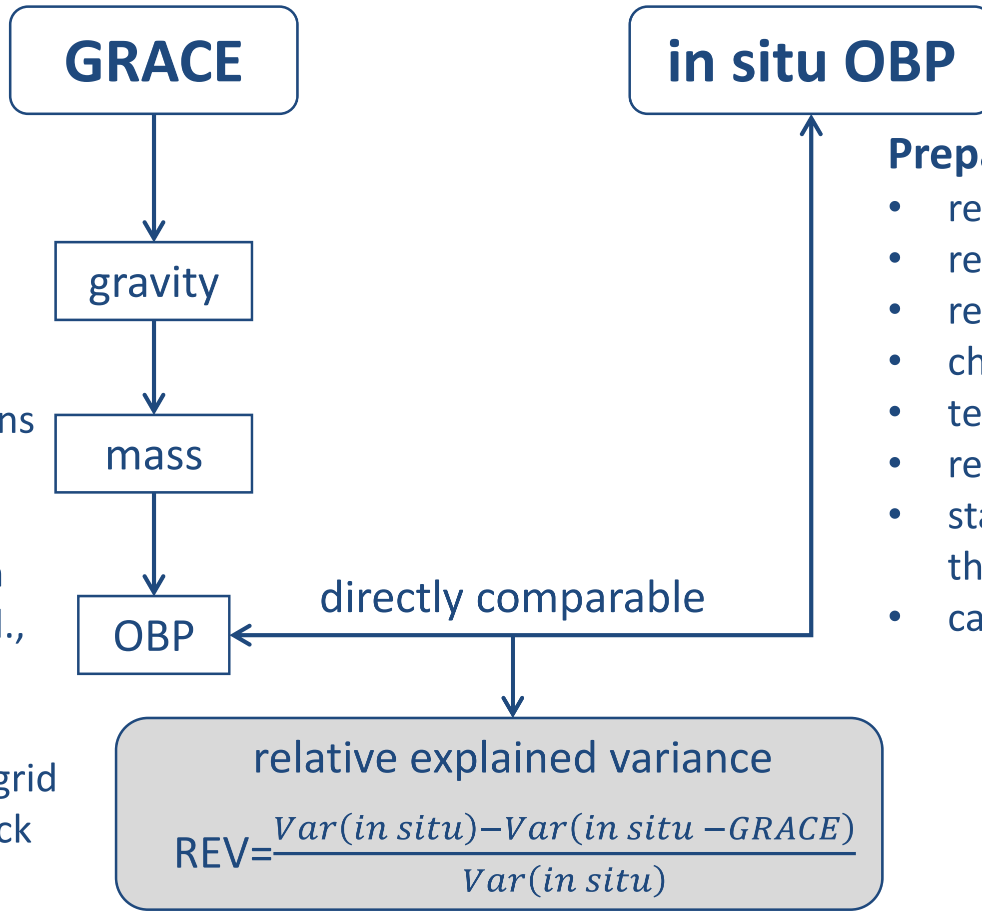
With respect to ITRF2014 time series – annual signal level



	Reference frame data (312 stations)	ITRF2014 residuals (928 stations)	JPL GNSS time series (788 stations)
	Median [%]	Median [%]	Median [%]
EGSIEM	73.5	67.7	61.4
AIUB RL02	73.6	68.8	64.1
CSR RL05	74.0	69.7	59.8
GFZ RL05a	73.5	68.4	57.8
JPL RL05.1	70.1	66.8	61.6
ITSG2016	73.6	69.0	60.7

Validation of the long-term EGSIEM combined monthly solution using OBP records

Concept of Validation using OBP records



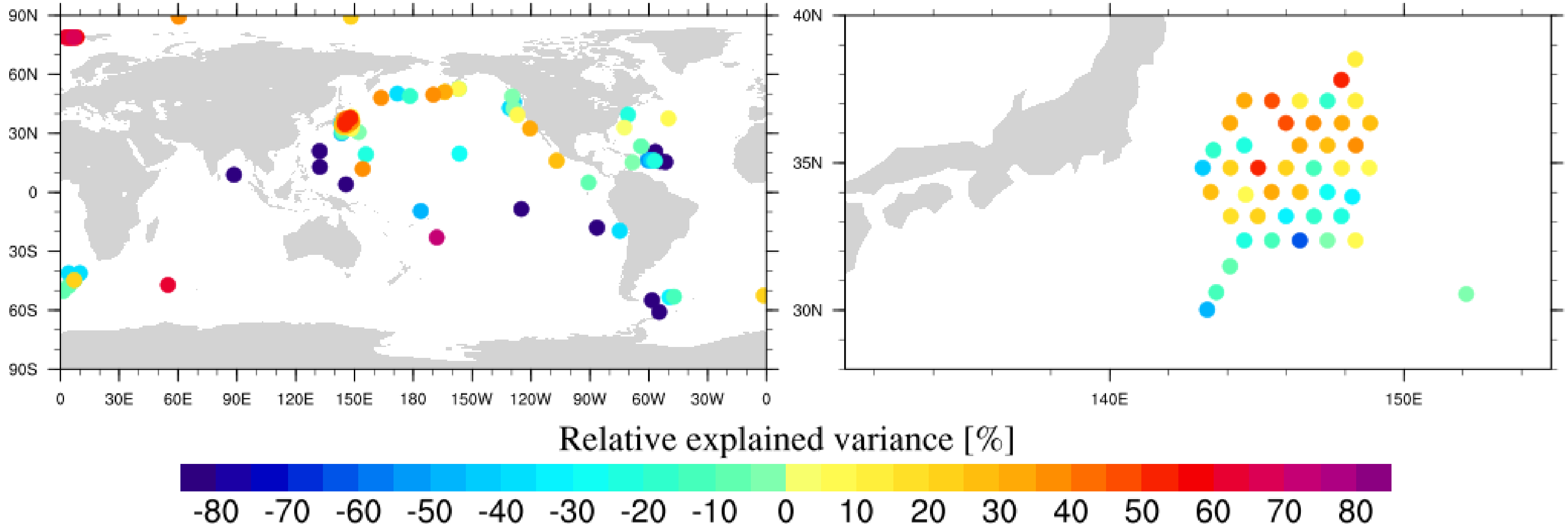
Post-processing of GRACE data:

- adding degree-1 coefficients
- replacing the C20 coefficient with solutions from SLR
- removing mean
- applying GIA correction (model by Paulson et al., 2007)
- DDK1 filter
- re-synthesizing to a 1° grid
- GAD product added back

Preparation of in-situ data:

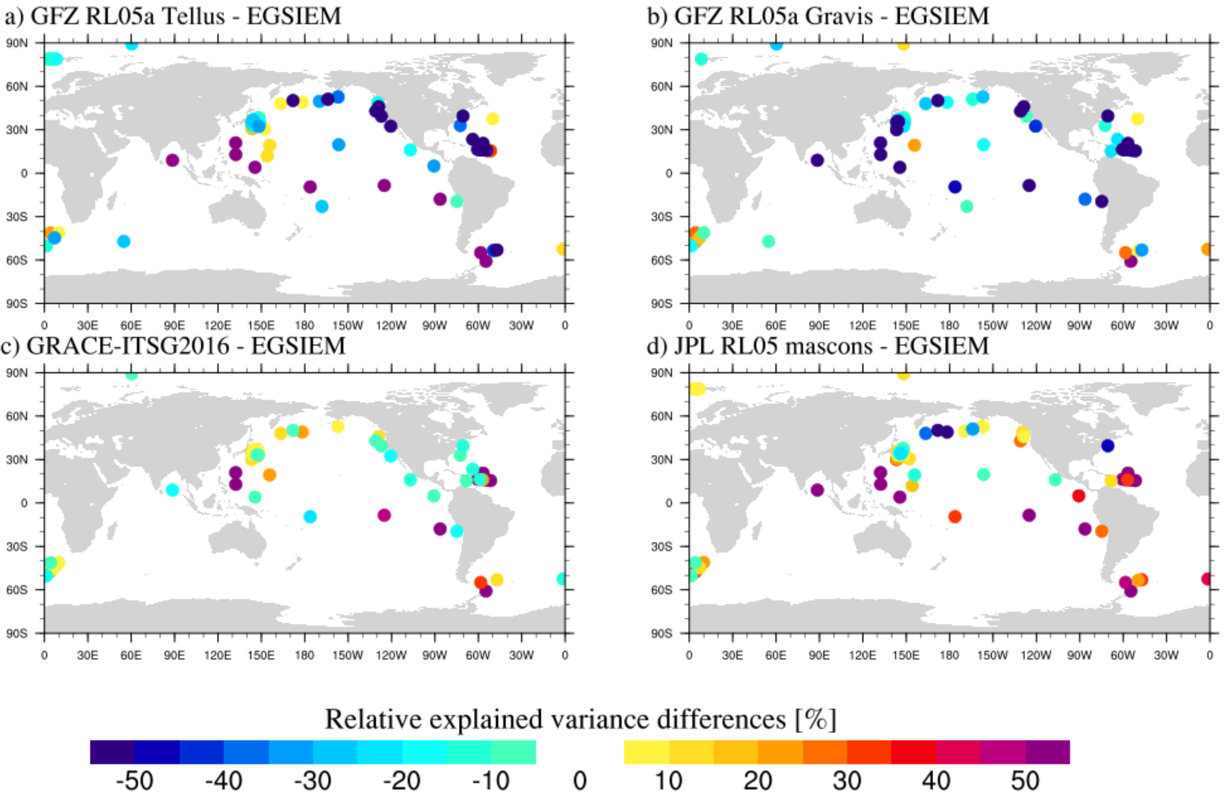
- removing drifts
- removing jumps
- removing trends
- checking for outliers
- temporal sampling to 1 h
- removing tidal signal
- stacking time-series from the same station
- calculating monthly mean

Validation of the long-term EGSIEM combined solution



- Left: global; right: Kuroshio Extension System Study (KESS)
- Globally, close to zero change in variance when subtracting GRACE at many in-situ stations, in particular the tropics and sub-tropics regions.
- Large explained variances in the stations in the Arctic ocean
- Good correspondence also in the surroundings of the Antarctic Circumpolar Current

Validation of the long-term EGSIEM combined solution



- Differences of explained variances between other gravity solutions and EGSIEM combined solution
- JPL RL05 mascons revealing slightly better fit with in-situ OBP records than EGSIEM
- Similar performance between ITSG2016 and EGSIEM, and both solutions better than GFZ RL05a, which is also observed by the validation using GNSS
- GFZ RL05a Tellus generally performing worse than all other solutions which is due to the different post-processing strategy

Summary

- Validation using GNSS time series
  - Generally, good agreement between the GRACE-derived vertical displacements and the GNSS-observed counterparts, especially at the annual period
  - The best performance from the official EGSIEM combined solution with respect to other gravity products for 2006&2007
  - Similar performances of the long-term EGSIEM combined solution with CSR RL05 and ITSG2016, and slightly better than others
  - Degree and accumulative degree WRMS reduction analysis being useful for validation
- Validation using OBP records
  - Good agreement between in-situ OBP records with GRACE over the Arctic ocean and the Antarctic Circumpolar Current
  - JPL mascons with the slightly better performance than others
  - Similar performance between EGSIEM and ITSG2016, better than GFZ RL05a (confirmed by GNSS as well)
  - Different GRACE data post-processing strategies affecting the validation results, e.g. GFZ RL05a Tellus

Thank you very much!