EGSIEM

European Gravity Service for Improved Emergency Management

Validation of the EGSIEM combined monthly gravity fields with GNSS

Overview of validation work within WP3 and WP4

Qiang CHEN

University of Luxembourg

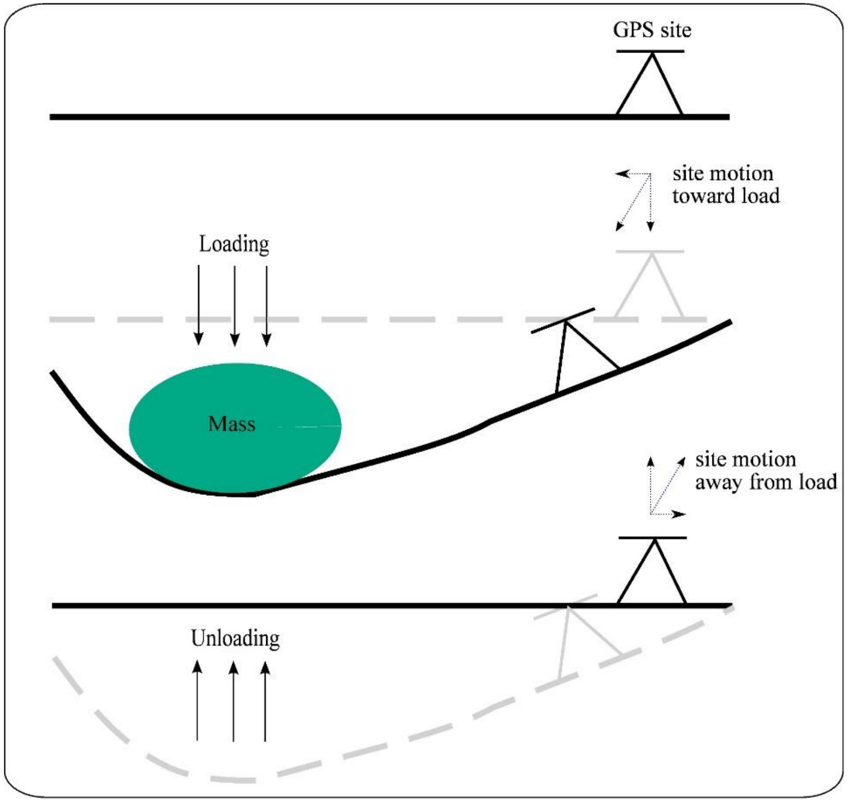
EGSIEM Final Project Meeting

8-9 February 2018

Objectives

- Validation of the EGSIEM official two-year combined gravity solutions
  - 2006&2007
  - WP4
- Validation of the EGSIEM Level-3 gravity products for hydrology
  - 2006&2007
  - WP4
- Validation of the EGSIEM long-term combined solutions
  - 2002-2014
  - WP3
- Validation of the reference frame data
  - 2003-2014
  - WP3

Concept of Validation



- 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

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

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

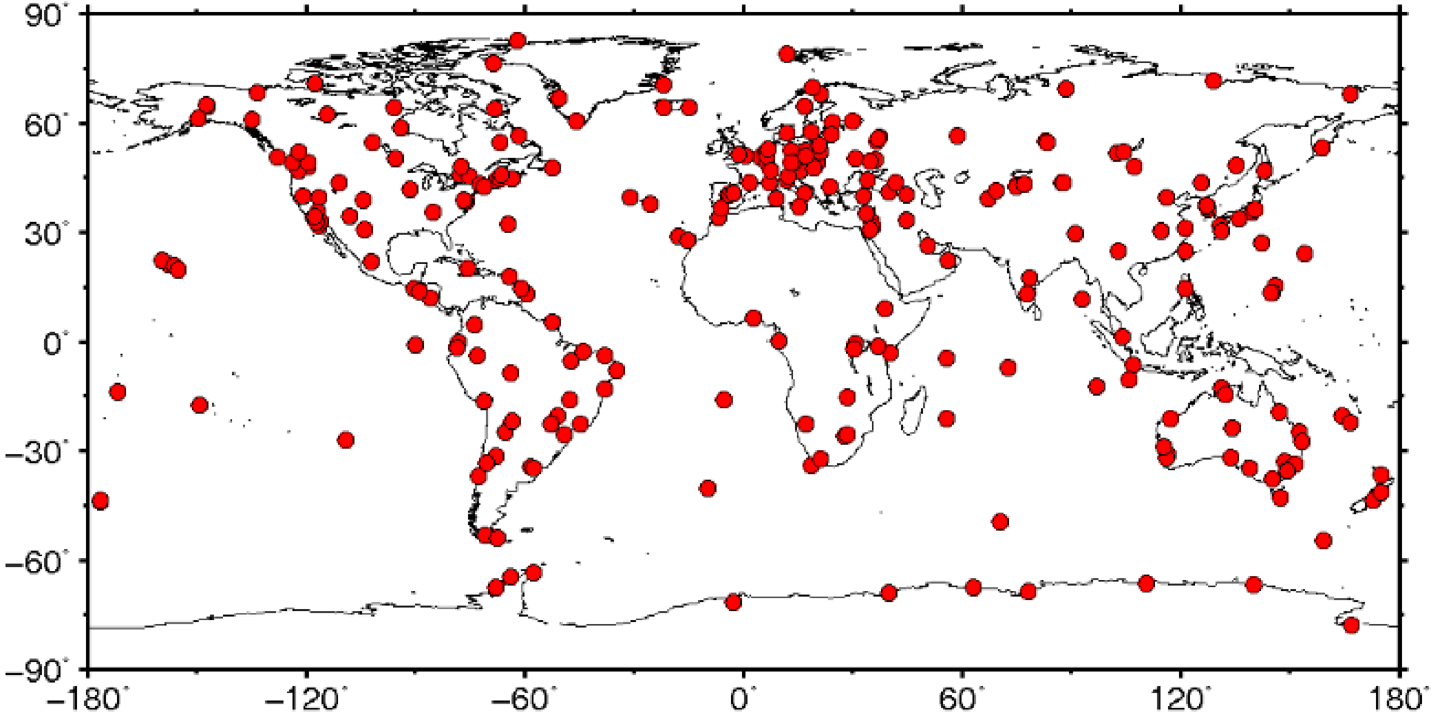
Degree WRMS reduction at the *i*th GPS station

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

WRMS reduction is similar (or equivalent) to Relative Explained Variance used by Lea in validation using the OBP data!

Post-processing reference frame data

- Reference frame data (Repro3, GNSS position time series) provided by UBERN in SINEX format from 2003 to 2014
  - 312 stations for further processing (393 stations in total with 81 stations removed due to short time span, very big gaps or very bad data)

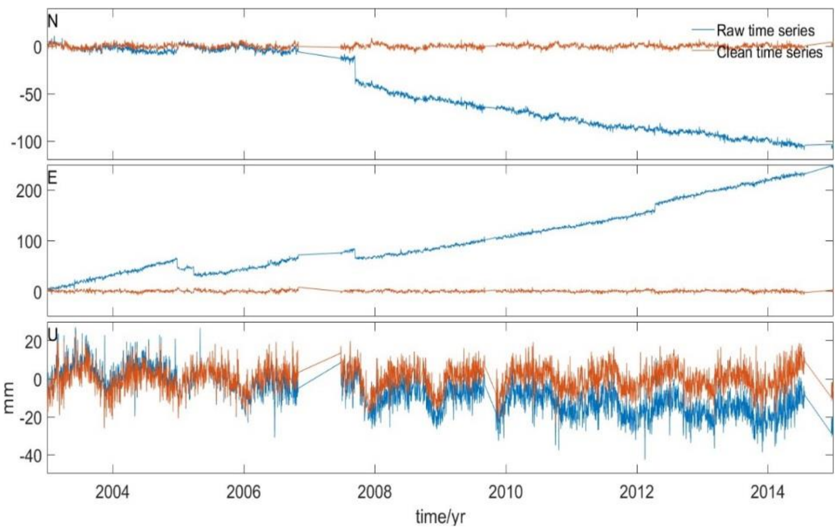


Post-processing reference frame data

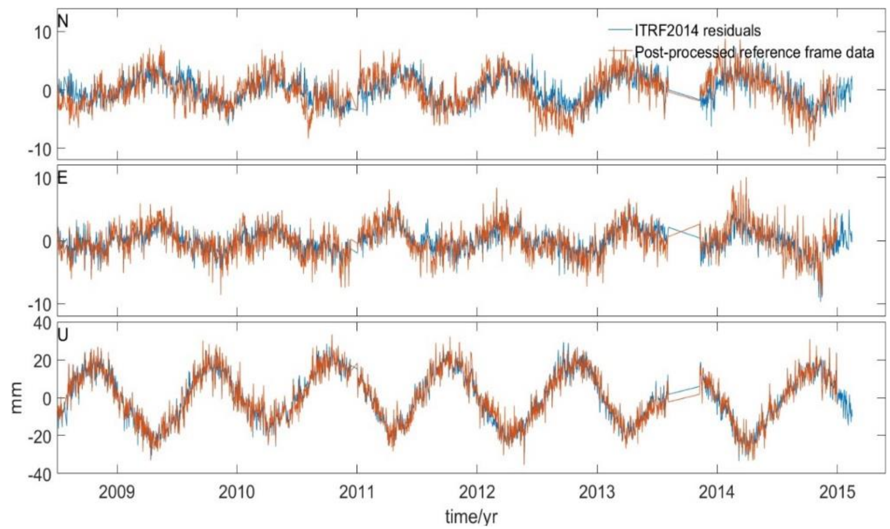
- Processing procedure
  - Coordinate transformation from XYZ to NEU
  - Offsets detection and removal
  - Removing outliers
  - Average daily data into monthly data
- Offsets detection and removal
  - Including jumps, coseismic offsets and postseismic relaxation
    - 264 out of 312 stations with offsets (84.62%)
    - 33 out of 264 stations with postseismic relaxation
  - Visual inspection and detection with offset datasets from NGL, JPL and SOPAC
  - Extended Trajectory Model (ETM) to remove postseismic relaxation (Bevis and Brown, 2014)

Post-processing reference frame data

- Example of offsets detection and removal: NTUS



- Comparison with respect to the ITRF2014 time series: POVE



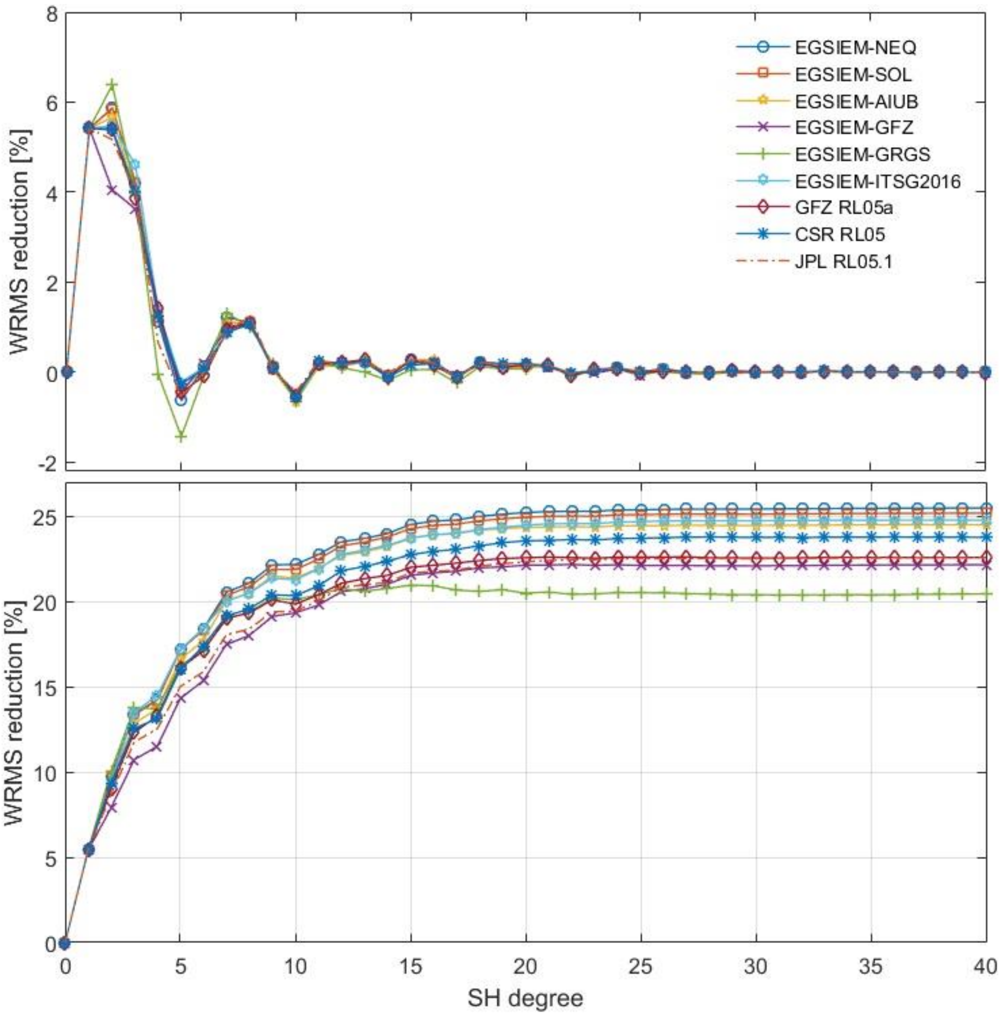
Validation of the official combined solutions

Post-processing monthly gravity fields

- Monthly gravity fields of 2006&2007
  - EGSIEM combined solutions at NEQ level and Solution level
  - Products from four ACs (AIUB, GFZ, GRGS, ITSG)
  - Products from three official GRACE ACs (GFZ RL05a, CSR RL05, JPL RL05.1)

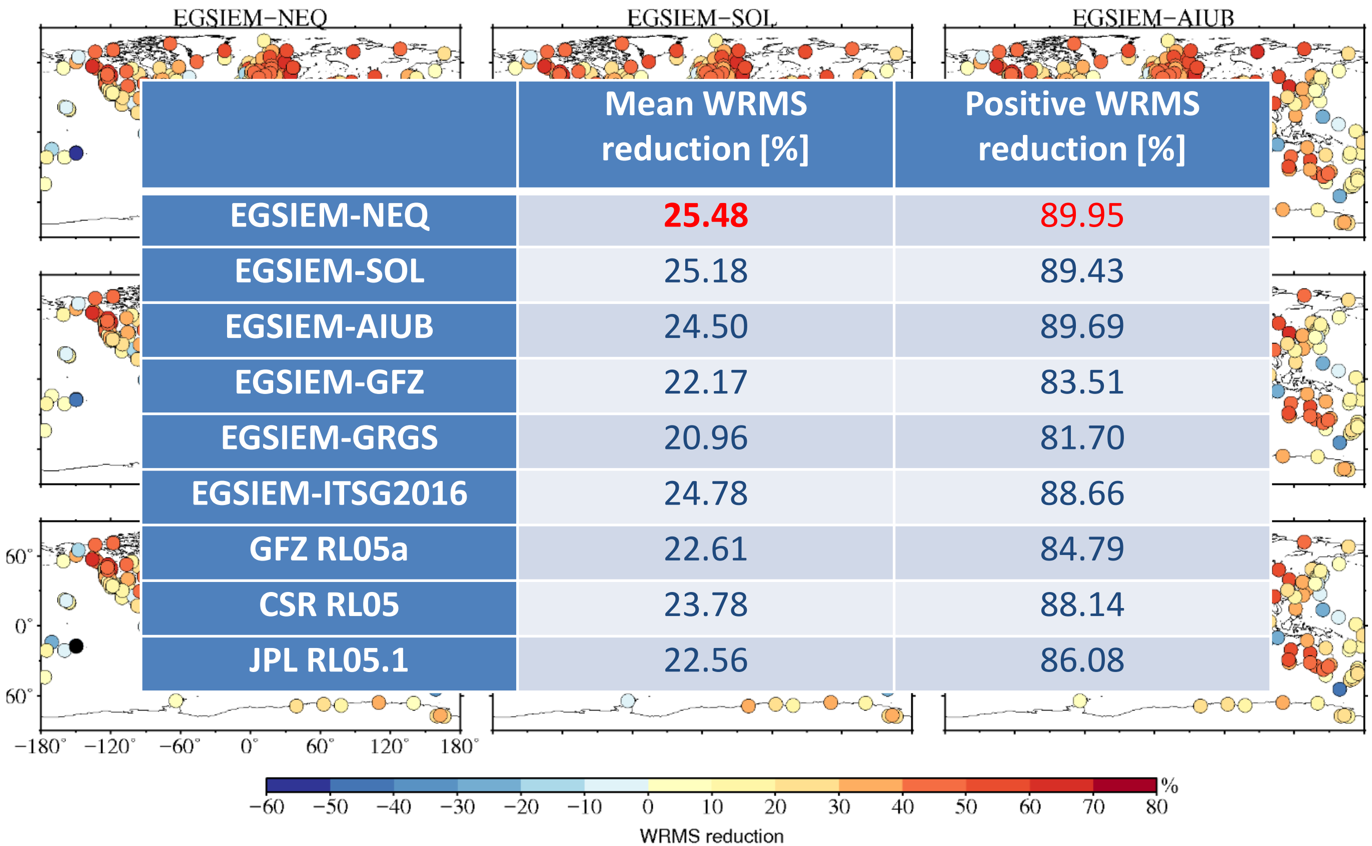
- Standard processing steps
  - Replacing C_{20} from SLR (Cheng et al., 2011)
  - Restoring degree-1 from SLR (Sośnica et al., 2015)
  - Adding back AOD1B GAC RL05
  - Filtering with a Gaussian filter 500 km
  - Deriving displacements at GNSS stations
  - Removing the mean and trend

With respect to ITRF2014 time series – full signal level



- Degree WRMS reduction (top)
  - higher WRMS reductions at low SH degrees
  - best performance at degree 2 from EGSIEM-GRGS (6.38%)
- Accumulative Degree WRMS reduction (bottom)
  - no significant contributions beyond degree 30
  - two EGSIEM combined solutions with the best accumulative degree WRMS reductions

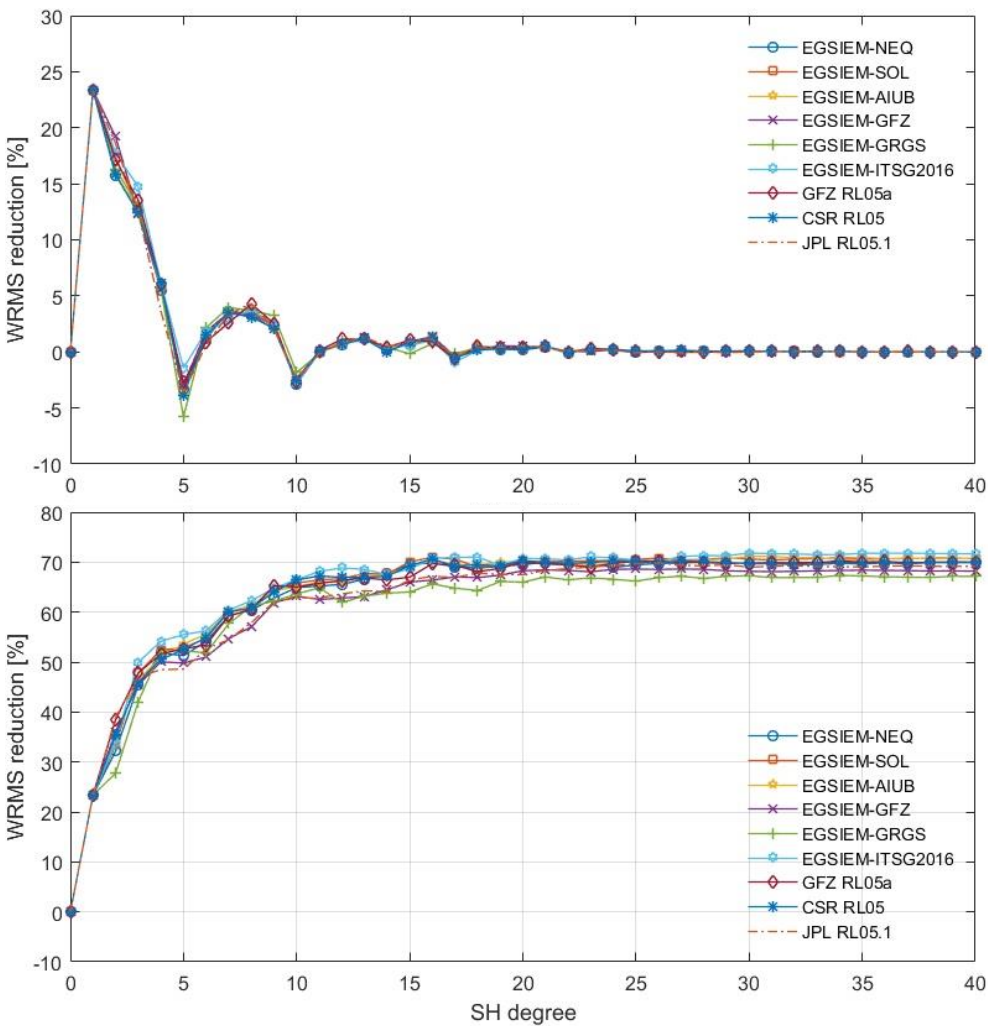
With respect to ITRF2014 time series – full signal level



	Mean WRMS reduction [%]	Positive WRMS reduction [%]
EGSIEM-NEQ	**25.48**	89.95
EGSIEM-SOL	25.18	89.43
EGSIEM-AIUB	24.50	89.69
EGSIEM-GFZ	22.17	83.51
EGSIEM-GRGS	20.96	81.70
EGSIEM-ITSG2016	24.78	88.66
GFZ RL05a	22.61	84.79
CSR RL05	23.78	88.14
JPL RL05.1	22.56	86.08

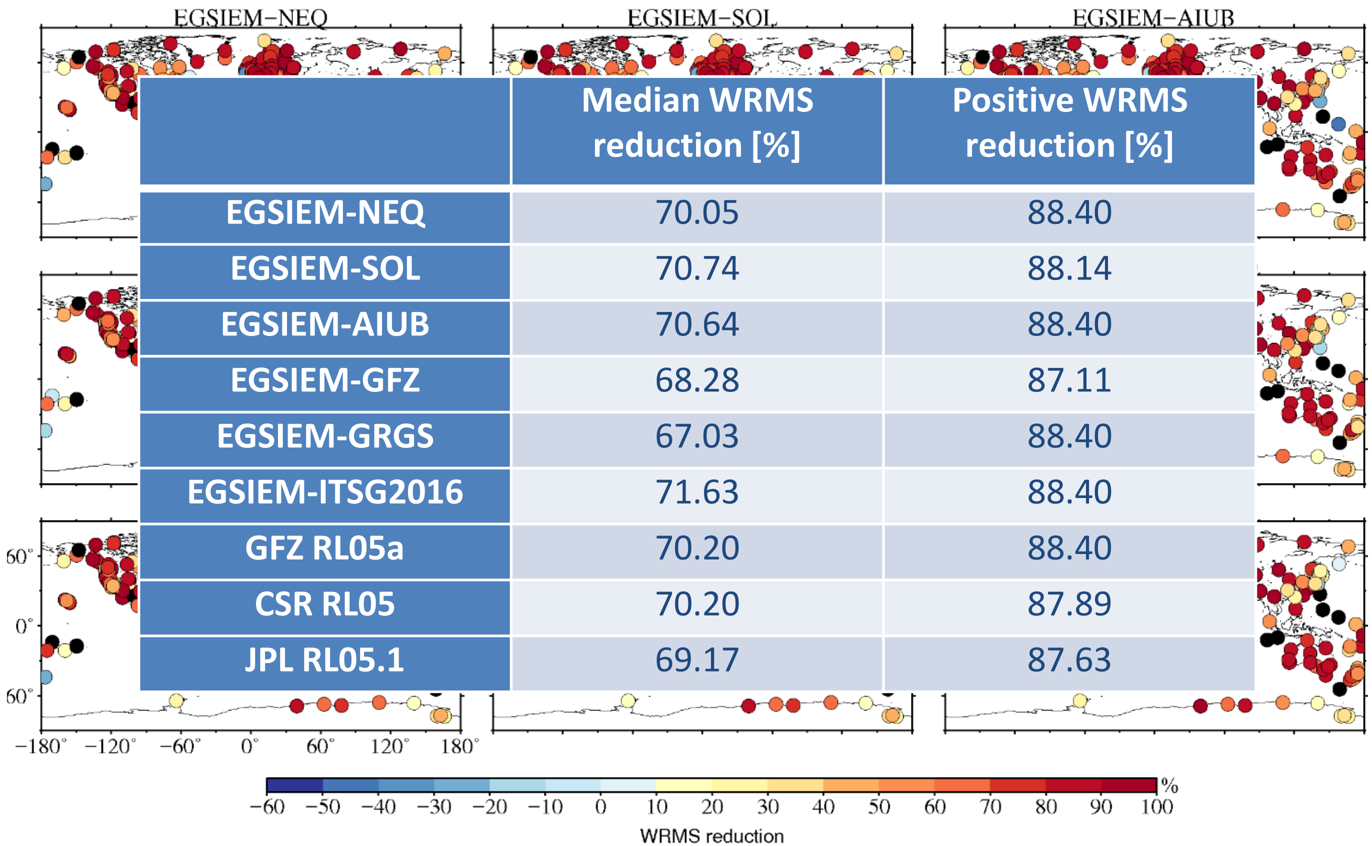
The mean WRMS reductions shown here are much better than these from Gu et al. (2017, GRL, Table S3) who have achieved maximum values of 15%.

With respect to ITRF2014 time series – annual signal level



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

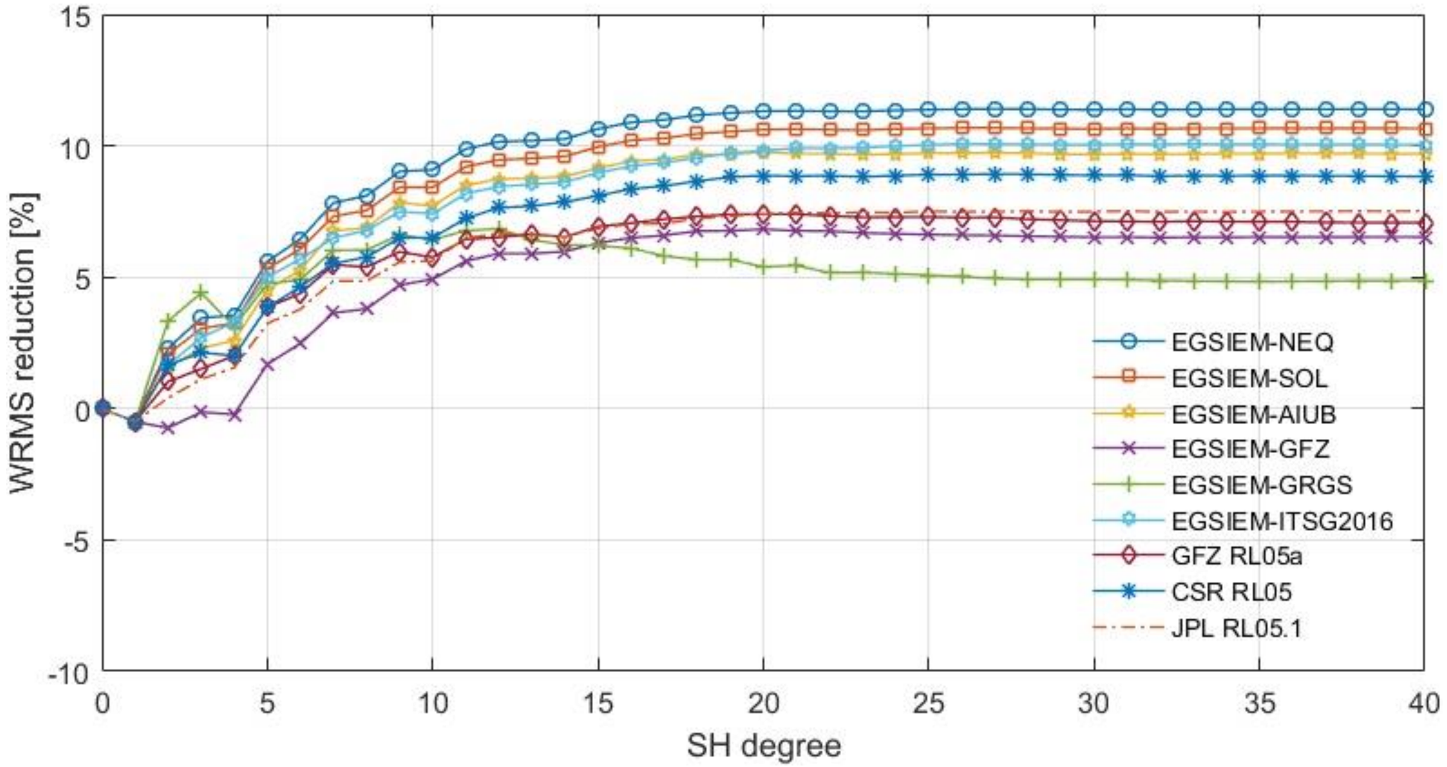
With respect to ITRF2014 time series – annual signal level



	Median WRMS reduction [%]	Positive WRMS reduction [%]
EGSIEM-NEQ	70.05	88.40
EGSIEM-SOL	70.74	88.14
EGSIEM-AIUB	70.64	88.40
EGSIEM-GFZ	68.28	87.11
EGSIEM-GRGS	67.03	88.40
EGSIEM-ITSG2016	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

With respect to ITRF2014 time series – residual level



See more detail in D4.3

Validation of the Level 3 products for hydrology

Datasets

- L3 products
  - EGSIEM L3 products for land (2006&2007)
  - GRACE Tellus L3 products for land from GFZ, CSR and JPL (2006&2007)

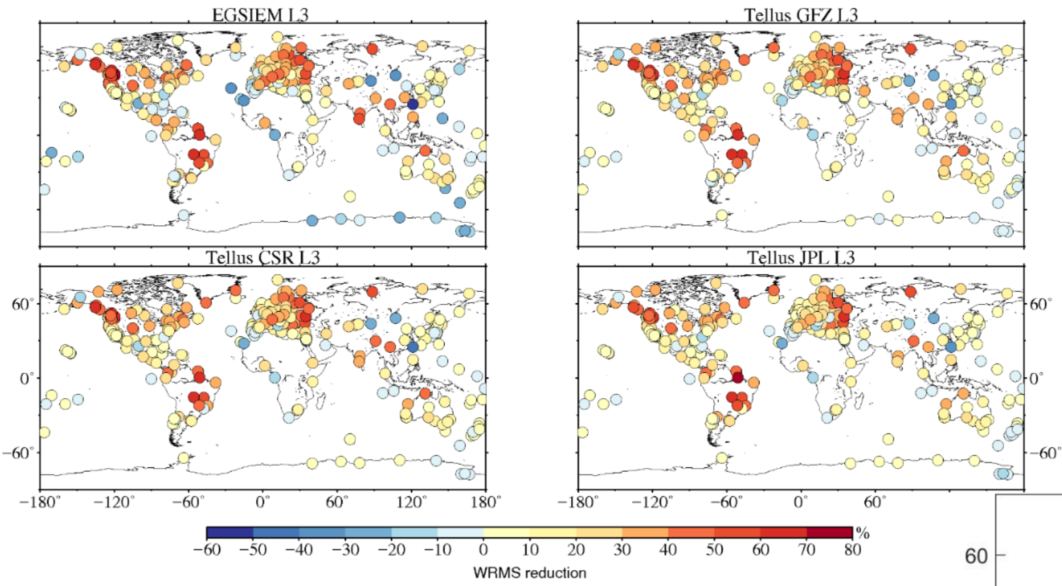
- GNSS data
  - Monthly averaged ITRF2014 time series at 388 GNSS stations

EGSIEM L3 vs GRACE Tellus L3 (Land)

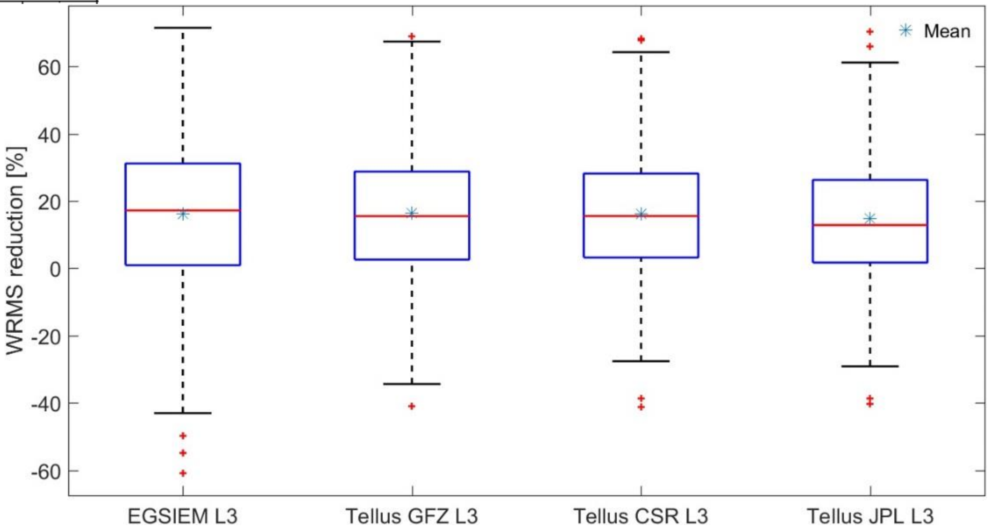
	EGSIEM L3 for Land	GRACE Tellus L3 for Land
C_{20} coefficient	no replacement	replaced from SLR (Cheng et al, 2011)
Degree-1 SHCs	restored from SLR by Sośnica et al (2015)	restored from Swenson et al (2008)
GIA correction	correction applied based on the GIA model from A and Wahr (2013)	correction applied based on the GIA model from A and Wahr (2013)
Filter scheme	time-varying filters (D4.2)	destriping filter plus Gaussian filter of 300 km
GAC	not added back	not added back
EWH grids	1° × 1° global grids	1° × 1° global grids

Green's functions approach for deriving displacements from L3 grids at GNSS stations

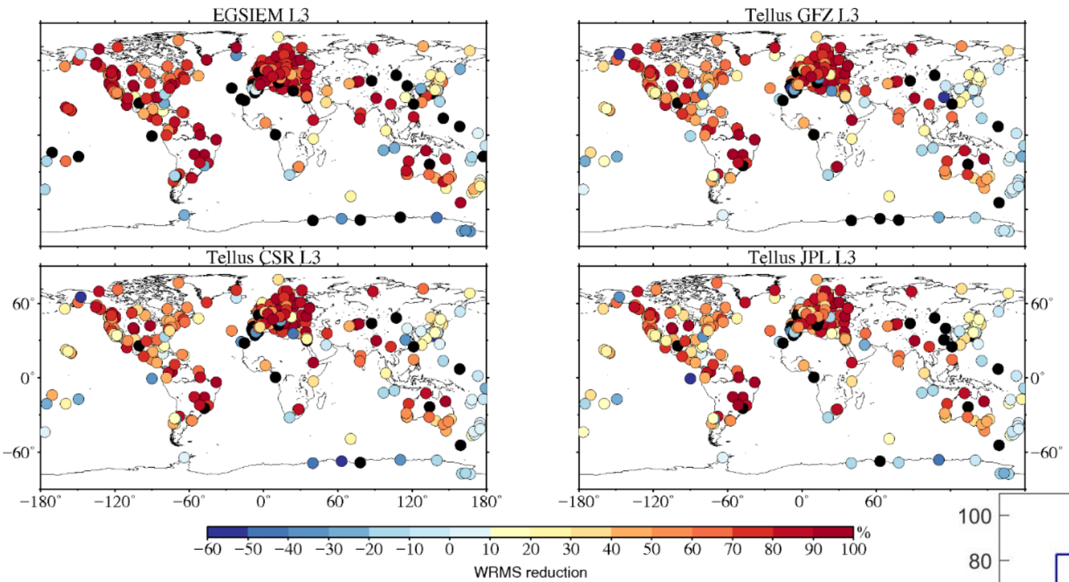
With respect to ITRF2014 time series – full signal level



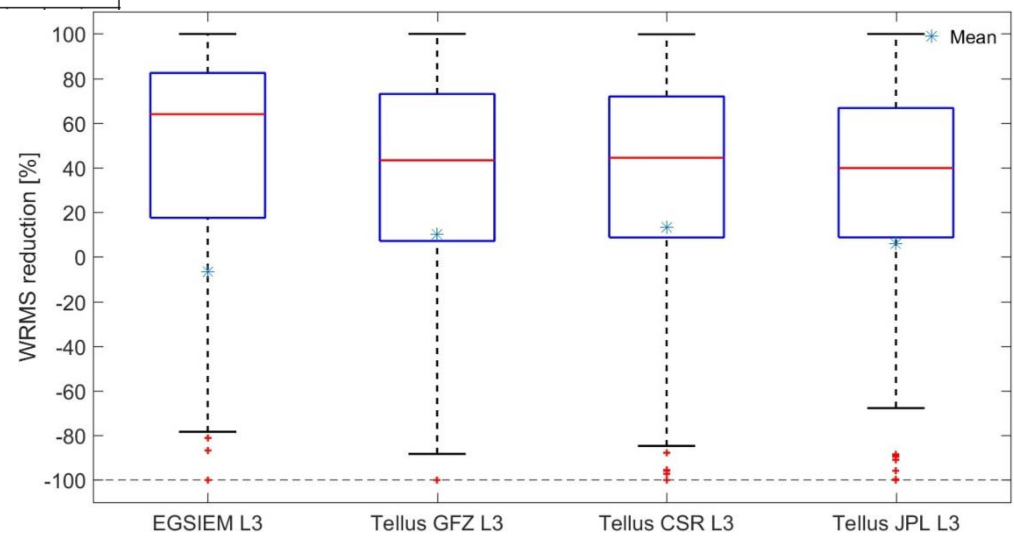
Similar performances among L3 products at full signal level.



With respect to ITRF2014 time series – annual signal level



Much better performance from EGSIEM L3 than GRACE Tellus L3 at the annual signal level.



See more detail in D4.3

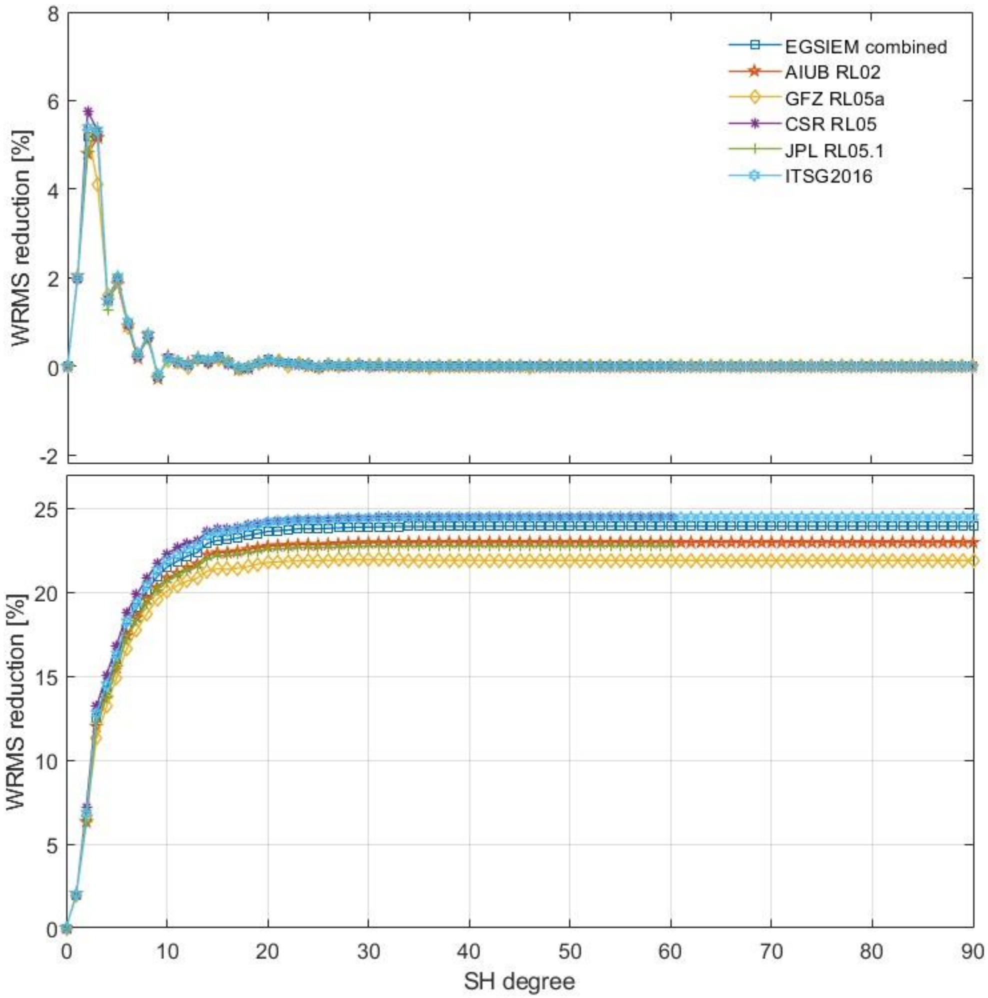
Validation of the EGSIEM long-term combined solutions

Post-processing monthly gravity fields

- Long-term monthly gravity fields (2002.8 – 2014.10)
  - EGSIEM combined solutions (TEST version, 2002.8-2014.10, see D4.1)
  - Products from three official GRACE ACs (GFZ RL05a, CSR RL05, JPL RL05.1)
  - Additional products from AIUB RL02 and ITSG2016

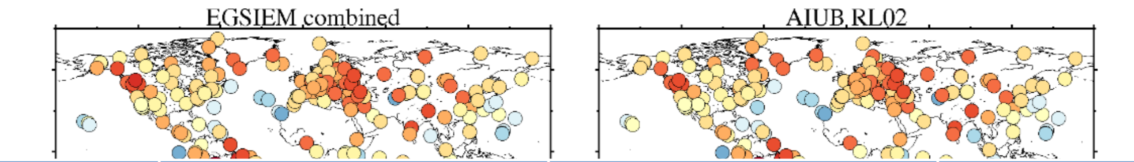
- Standard processing steps
  - Replacing C_{20} from SLR (Cheng et al., 2011)
  - Restoring degree-1 from Swenson et al (2008)
  - Adding back AOD1B GAC RL05
  - Filtering with a Gaussian filter 500 km
  - Deriving displacements at GNSS stations
  - Removing the mean and trend

With respect to reference frame data – full signal level

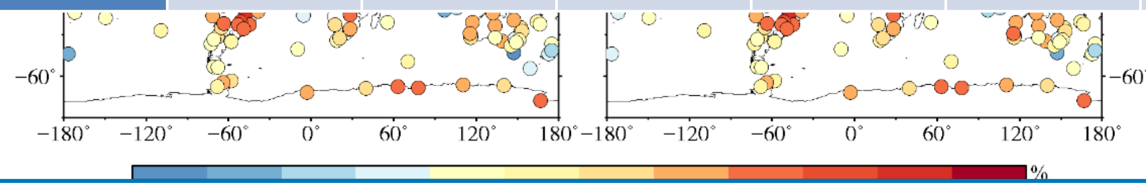


- Degree WRMS reduction (top)
- Accumulative Degree WRMS reduction (bottom)
- Similar characteristics as the the two-year monthly gravity models

With respect to reference frame data – full signal level

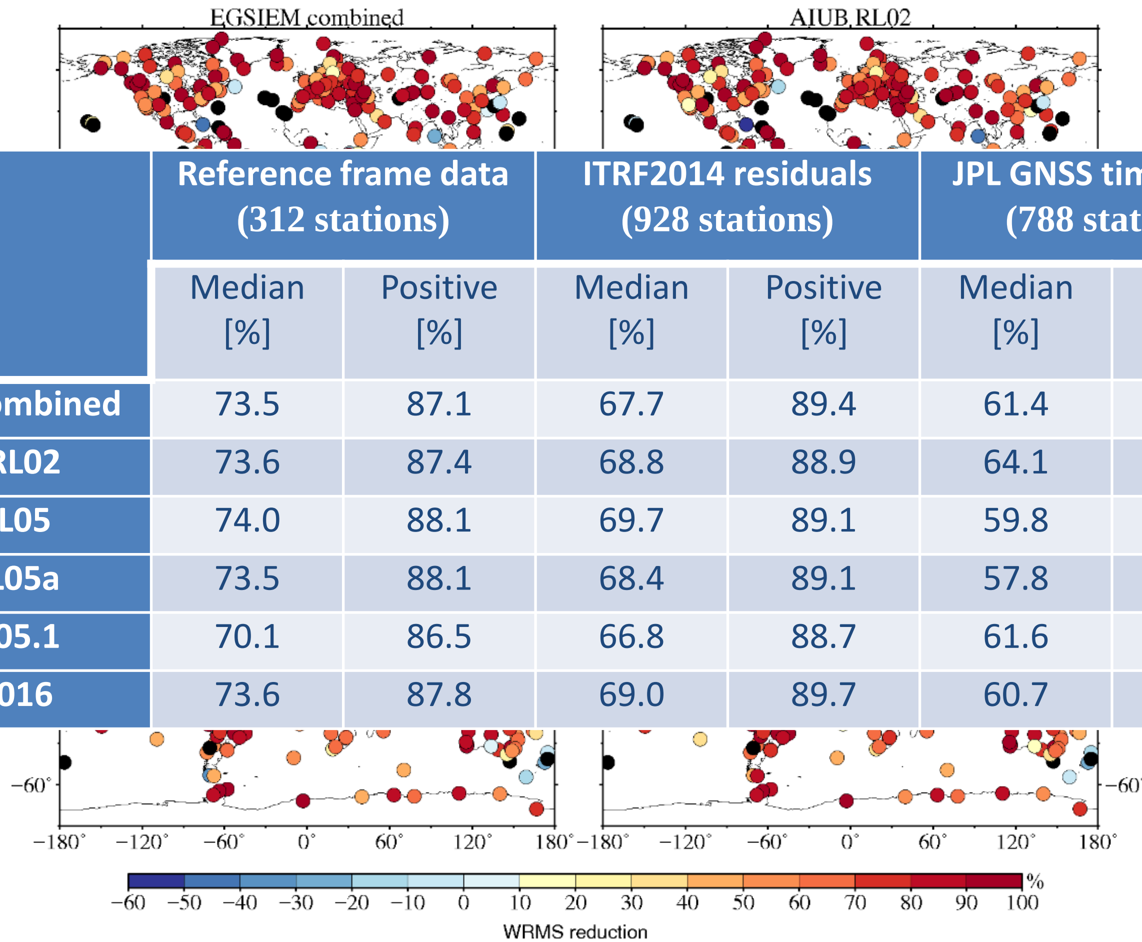


	Reference frame data (312 stations)		ITRF2014 residuals (928 stations)		JPL GNSS time series (788 stations)	
	Mean [%]	Positive [%]	Mean [%]	Positive [%]	Mean [%]	Positive [%]
EGSIEM combined	23.9	88.1	20.9	89.2	16.0	88.8
AIUB RL02	23.0	87.4	19.8	87.7	16.0	87.5
CSR RL05	24.5	89.7	21.2	90.6	15.7	87.1
GFZ RL05a	21.9	86.9	18.1	85.8	13.8	85.9
JPL RL05.1	22.8	86.9	19.2	88.4	15.2	87.7
ITSG2016	24.5	90.1	21.1	89.7	16.1	87.9



The mean WRMS reductions shown here are also much better than these from Gu et al. (2017, GRL, Table S3) who have achieved maximum values of 15%.

With respect to reference frame data – annual signal level



	Reference frame data (312 stations)		ITRF2014 residuals (928 stations)		JPL GNSS time series (788 stations)	
	Median [%]	Positive [%]	Median [%]	Positive [%]	Median [%]	Positive [%]
EGSIEM combined	73.5	87.1	67.7	89.4	61.4	78.8
AIUB RL02	73.6	87.4	68.8	88.9	64.1	79.6
CSR RL05	74.0	88.1	69.7	89.1	59.8	78.2
GFZ RL05a	73.5	88.1	68.4	89.1	57.8	77.6
JPL RL05.1	70.1	86.5	66.8	88.7	61.6	80.3
ITSG2016	73.6	87.8	69.0	89.7	60.7	79.0

See more detail in D3.2

Validation of the reference frame data

236 common GNSS stations

	Reference frame data		ITRF2014 residuals		JPL GNSS time series	
	Mean [%]	Positive [%]	Mean [%]	Positive [%]	Mean [%]	Positive [%]
EGSIEM combined	23.2	86.4	25.5	90.3	18.1	94.5
AIUB RL02	22.3	85.6	24.6	88.6	17.7	91.1
CSR RL05a	23.8	88.1	25.8	90.7	18.0	94.1
GFZ RL05	21.1	84.8	23.2	87.7	16.2	91.5
JPL RL05.1	21.9	85.2	23.9	90.3	17.4	93.6
ITSG2016	23.6	88.1	25.6	90.7	18.1	93.6

Performance of the EGSIEM-generated reference frame data close to ITRF2014 time series, and much better than JPL GNSS time series.

Summaries

- Generally, the GRACE-derived vertical displacements have good agreement with the GNSS-observed counterparts, especially at the annual period.
- The official EGSIEM combined solutions demonstrate the best performance with respect to other gravity products for 2006&2007.
- The EGSIEM L3 products for land outperforms the counterparts from GRACE Tellus for 2006&2007.
- The long-term EGSIEM combined solutions show similar performances with CSR RL05 and ITSG2016, and slightly better than others.