EGSIEM

European Gravity Service for Improved Emergency Management

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Table of Contents

2.Introduction

Background

One of the key scientific services of the EGSIEM project is to generate the optimally combined gravity products using various monthly GRACE solutions from different institutions. The official combined gravity products from EGSIEM were generated (see Deliverable 4.2) and validated (see Deliverable 4.3). While during the combination experiments implemented by UBERN, the long-term combined gravity solutions using all the existing monthly gravity solutions were also produced as a scientific product output. The detailed description of how this scientific product was generated can be found in Deliverable 4.1.

In addition to the gravity field products, the reference frame data (see Deliverable 3.1) were also generated as a scientific product within the EGSIEM project. These GNSS time series can be used for validating the long-term combined EGSIEM gravity solutions.

The aim of this document is to validate the long-term EGSIEM combined solutions along with other monthly GRACE gravity products using two different techniques, including:

1) The reference frame data as well as two other external GNSS time series;
2) Ocean bottom pressure (OBP) records.

Outline

In this report, the concepts behind validation using two different techniques are concisely presented in Section 3 including the evaluation metrics. A short description of the reference frame data post-processing is given in Section 4. Section 5 and Section 6 demonstrate the validation of the EGSIEM combined solutions using the three GNSS datasets as well as the OBP records in detail.

3. Concept of validation

Validation of products generated by EGSIEM is essential as validation allows us to assess the quality of our products and more importantly validation increases user's confidence in the datasets produced by EGSIEM. To evaluate the quality of different gravity field solutions, it is necessary to compare them to independent observations. In this section, we introduce two independent validation techniques. One is validation using the GNSS time series and the other validation is by the OBP records.

3.1 Concept of validation using GNSS time series

A consistent reference frame yields consistent GNSS station time series. The basic concept of GNSS validation is illustrated in the figure below. Surface displacements caused by mass variations, i.e. loading or unloading causing the Earth's surface to subside or rebound, are recorded by surrounding GNSS stations. Through the elastic loading theory (Farrell, 1972), we can easily use the surface mass variations, which are observed independently by the GRACE satellites in terms of the gravity products represented by spherical harmonic coefficients, to predict surface displacements at the GNSS stations. Consequently, GRACE-derived displacements can be compared with GNSS-observed deformation. A global network of GNSS stations are used in our validation.

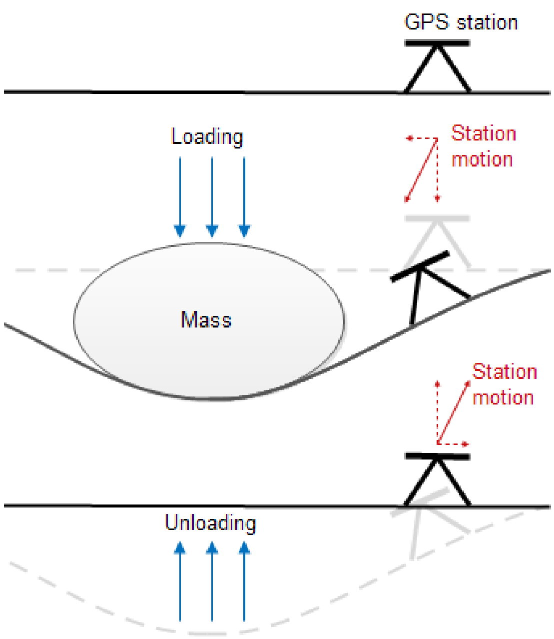

Figure 3.1: Concept of validation using GNSS time series

3.2 Concept of validation using OBP

Ocean bottom pressure recorders measure the combined oceanic and atmospheric mass above the sensor, and they are therefore directly comparable with the gravity fields and thus suitable for their validation. We use in situ data from a globally distributed set of OBP recorders as compiled by Macrander et al. (2010).

Before using the in-situ OBP data for validation, it must be pre-processed. Drifts were removed from the time series, as well as jumps that are present in some time series due to recovery and re-deployment of sensors. Trends were removed with a quadratic fit and the data was checked for outliers. Since most time series have temporal sampling of 1 hour or higher, it was changed to 1 hour in all time series to ensure uniformity. The tidal signal was removed with the T_TIDE Matlab package for classical harmonic analysis (Pawlowicz et al., 2002). Finally, the time series from identical geographic positions were stacked. For each in situ OBP measuring station, data from the four closest grid points in the GRACE gravity field solution are extracted and bilinearly interpolated to the station's location. Monthly means are then calculated from the in situ time series and compared to the monthly means as provided by GRACE.

3.3 Metrics for performance evaluation

To evaluate the performances of the combined EGSIEM gravity fields along with other gravity solutions, WRMS reduction and correlations are used when compared with the GNSS time series. For validation using OBP records, the relative explained variance is employed.

3.3.1 Correlation

Correlation coefficient measures the similarity of two separate time series. As it is well-known, the correlation coefficient is only sensitive to phases of two time series but insensitive to their amplitude differences. This characteristic normally leads us to apply other evaluation criteria along with the correlation coefficient.

3.3.2 WRMS reduction and its variants

WRMS reduction is used commonly to evaluate the agreements between GNSS-observed and GRACE-derived displacements, see van Dam et al. (2007), which is defined as

$$\text{WRMS redcution} = 1 - \frac{\text{WRMS[GPS} - \text{GRACE]}}{\text{WRMS [GPS]}}$$

It represents the percentage of signals in the GNSS time series that can be explained by GRACE and it ranges from minus infinity to 1, i.e. 100%. Its variant degree WRMS reduction is accordingly defined as

$$\text{Degree WRMS redcution} = 1 - \frac{\text{WRMS[GPS} - \text{GRACE}^{n}]}{\text{WRMS [GPS]}}$$

Superscript n indicates that the SHCs at degree n only from GRACE are used to compute the displacements. Certainly, we can use the SHCs up to degree n to indicate the accumulative degree WRMS reduction.

3.3.3 Relative explained variance

The agreement of the GRACE solution with the in situ ocean bottom pressure measurements is expressed in terms of relative explained variance:

$$REV = \frac{Var(insitu) - Var(insitu - GRACE)}{Var(insitu)}$$

Relative explained variance is the variance of the in situ measurements explained by the GRACE gravity field solution. It has negative values in case GRACE increases its variance, is zero in case GRACE does not alter the variance of the in situ data, and is 100% in the scenario that GRACE perfectly coincides with the signals observed in situ. In view of the area-averaging properties of GRACE, an achievement of 100% is highly unlikely.

4.Post-processing reference frame data

During the EGSIEM project, the reference frame products (see Deliverable 3.1) were generated this included a total of 393 raw GNSS station coordinate time series in the SINEX format spanning from 2003 to 2014. Out of 393 raw time series, 81 GNSS stations were removed due to either short time span, or very gappy data. The remaining 312 GNSS stations, see **Figure 4-1**, are post-processed for further validation for comparison with the GRACE products generated in the project.

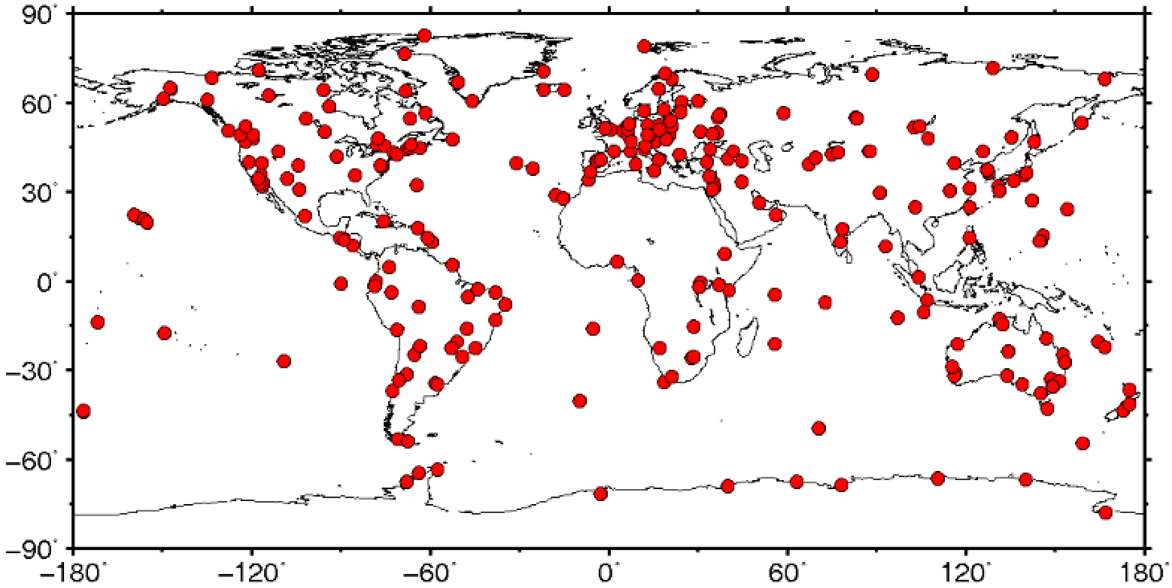

Figure 4-1: Global distribution of the 312 GNSS stations from the reference frame data

The post-processing includes the following steps: 1) coordinate transformation from Cartesian coordinate system to local NEU coordinate system; 2) offset detection and removal; 3) removing outliers and detrending; 4) averaging daily GNSS time series into monthly GNSS time series. Note that the last step is made for comparison with the monthly GRACE products.

Dealing with offsets

The accuracy of the GNSS time series is significantly affected by the offsets embedded in the GNSS time series, which result from both known phenomena, e.g. equipment changes and seismic events, and other unknown reasons (Gazeaux et al., 2013). Detection and removal of offsets has been a complicated and non-trivial task in the post-processing of the GNSS time series. As stated by Gazeaux et al (2013), no effective automated approaches have been found so far to detect the offsets. Alternatively, manual detection by combining visual inspection and reported offsets from NGL[1], JPL and SOPAC is done for the 312 GNSS stations. 264 stations out of 312 are affected by offsets including 33 stations with postseismic relaxation effects. A bundle of offset datasets has been detected and collected for the reference frame data.

We use the extended linear trajectory model (ELTM) suggested by Bevis and Brown (2014) to model and remove the detected offsets including the postseismic relaxation. As demonstrated by Bevis and Brown (2014) ELTM is not sensitive to the transient timescale parameter T_i and T_k, we

[1] http://geodesy.unr.edu/NGLStationPages/steps.txt

take the parameters from the published parameters from the JPL[1] GNSS time series instead of estimating them. **Figure 4-2** shows one example of post-processing with offsets, outliers and trend removed. A comparison of post-processed reference frame data with respect to the ITRF2014 residuals at POVE is shown in **Figure 4-3**. The overall quality of the post-processed reference frame data is validated by comparing to the common stations in Section 5.3.

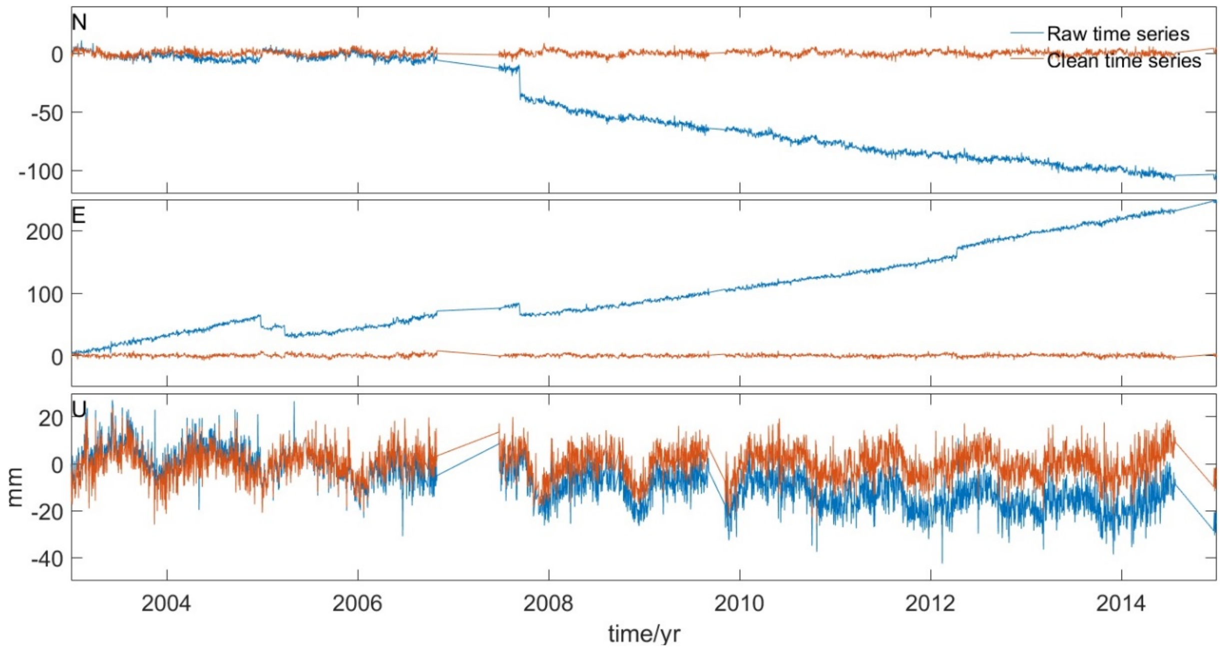

Figure 4-2: Comparison of raw reference frame data with the post-processed reference frame data at NTUS. The post-seismic relaxation effect is modeled and removed using the ELTM model.

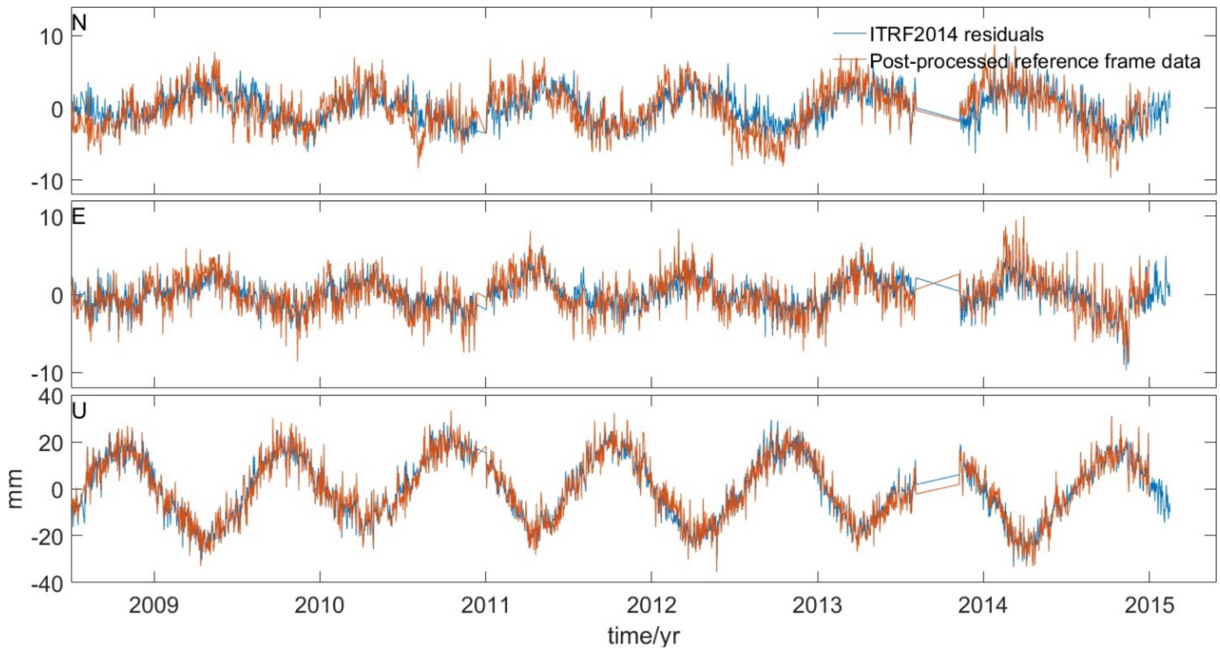

Figure 4-3: Comparison of post-processed reference frame data at POVE with respect to that from the ITRF2014 residuals provided by IGN (Rebischung et al., 2016).

[1] ftp://garner.ucsd.edu/pub/timeseries/measures/ats/Global/

5.Validation using GNSS-observed vertical displacements

Apart from the post-processed reference frame data, we also use the ITRF2014 daily residuals provided by IGN (Rebischung et al., 2016) and the publicly available daily GNSS time series from JPL[1] to validate the EGSIEM combined solutions. These daily residuals from IGN and JPL are free of outliers, offsets and linear trends. To compare with monthly GRACE solutions, these daily solutions are averaged into monthly solutions. We select GNSS stations with at least 24 monthly observations and end up with 928 GNSS stations from the ITRF2014 residuals and 788 GNSS stations from JPL.

Meanwhile, we also employ the GRACE solutions to validate our post-processed reference frame data. To this end, a GNSS dataset of 236 common stations from all the three GNSS datasets are selected.

5.1 Post-processing of the monthly GRACE products

In addition to the EGSIEM combined solutions, monthly gravity solutions from the three official GRACE data processing centers, i.e. CSR RL05, GFZ RL05a and JPL 05.1, as well as other institutions, e.g. AIUB RL02 from UBERN and ITSG2016 from TU Graz, have been included as well, see details in **Table 5-1**.

Table 5-1 GRACE products used in the validation.

	Institution	Time span	Maximum degree	Reference
EGSIEM combined	UBERN	2002.08~2014.10	90	D4.1
AIUB RL02	UBERN	2003.03~2014.03	90	Meyer et al. (2016)
GFZ RL05a	GFZ	2002.08~2014.10	90	Dahle et al. (2012)
CSR RL05	CSR	2002.08~2014.10	60	Bettadpur (2012)
JPL RL05.1	JPL	2002.08~2014.10	90	Watkins and Yuan (2012)
ITSG2016	TU Graz	2002.08~2014.10	90	Mayer-Gürr et al. (2016)

When comparing with the GNSS time series, all the GRACE L2 GSM SHCs from both EGSIEM combined and other institutions have been post-processed in the same way. Firstly, C_{20} terms are replaced with that from SLR (Cheng et al. 2011). Degree-1 coefficients are restored by using the datasets provided by Swenson et al (2008) to be consistent with GNSS in the same reference frame. The dealiasing products, i.e. GAC products, have also been restored to GSM SHCs. Finally, all GSM SHCs are filtered with the Gaussian filter with the smoothing radius of 500 km and converted into the vertical displacements at the selected GNSS stations. The mean and linear trend are removed from each vertical displacement time series in order to get rid of the mean field as well as the GIA effects.

[1] ftp://garner.ucsd.edu/pub/timeseries/measures/ats/Global/

5.2 Validation at the global scale

5.2.1 Full signal level

We commence the validation with showing the mean degree WRMS reductions and accumulative degree WRMS reductions of the six considered gravity solutions using the post-processed reference frame data over 312 GNSS stations globally in **Figure 5-1**. Inspection of the mean degree WRMS reductions in the top panel of **Figure 5-1**, clearly show that the lower spherical harmonic degrees of the gravity fields contribute largely to the total WRMS reductions. Degree-2 and degree-3 share the most significant contributions. It is interesting to observe that different gravity solutions show slightly different performances at each SH degree. For example, CSR RL05 seems to be visibly better at degree-2 using both the post-processed reference frame data as well as the ITRF2014 residuals (see **Figure 9-1** in Annexes).

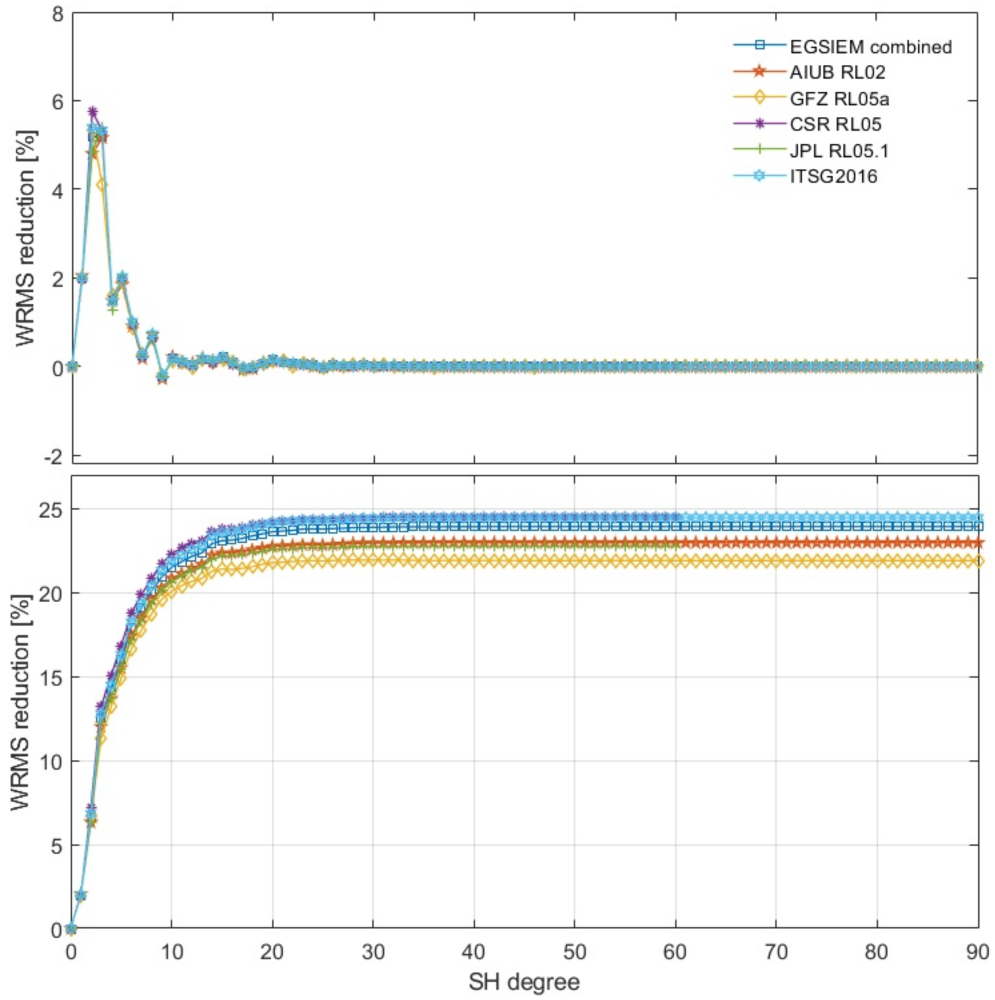

Figure 5-1: Mean degree WRMS reductions (top) and accumulative degree WRMS reductions (bottom) of different gravity solutions using the post-processed reference frame data at the full signal level from UBERN over 312 GNSS stations globally.

The bottom panel of **Figure 5-1** presents the mean accumulative degree WRMS reductions for all the GRACE solutions. The EGSIEM combined solutions, ITSG2016 and CSR RL05 show very close performances and slightly better than other solutions. GFZ RL05a provides marginally worse accumulative WRMS reductions which might be due to its inferior performance at degree-3 (see also **Figure 9-1** for the ITRF2014s residuals and **Figure 9-2** for the GNSS time series from JPL). Nevertheless, the mean accumulative WRMS reductions shown here from all six gravity solutions are better than that from the latest results (maximum mean WRMS reduction up to 15%, see **Table S3**) published by Gu et al (2017). One more feature to be gleaned from **Figure 5-1** is that no significant contributions come from degree beyond 30, which has been demonstrated in Deliverable 4.3.

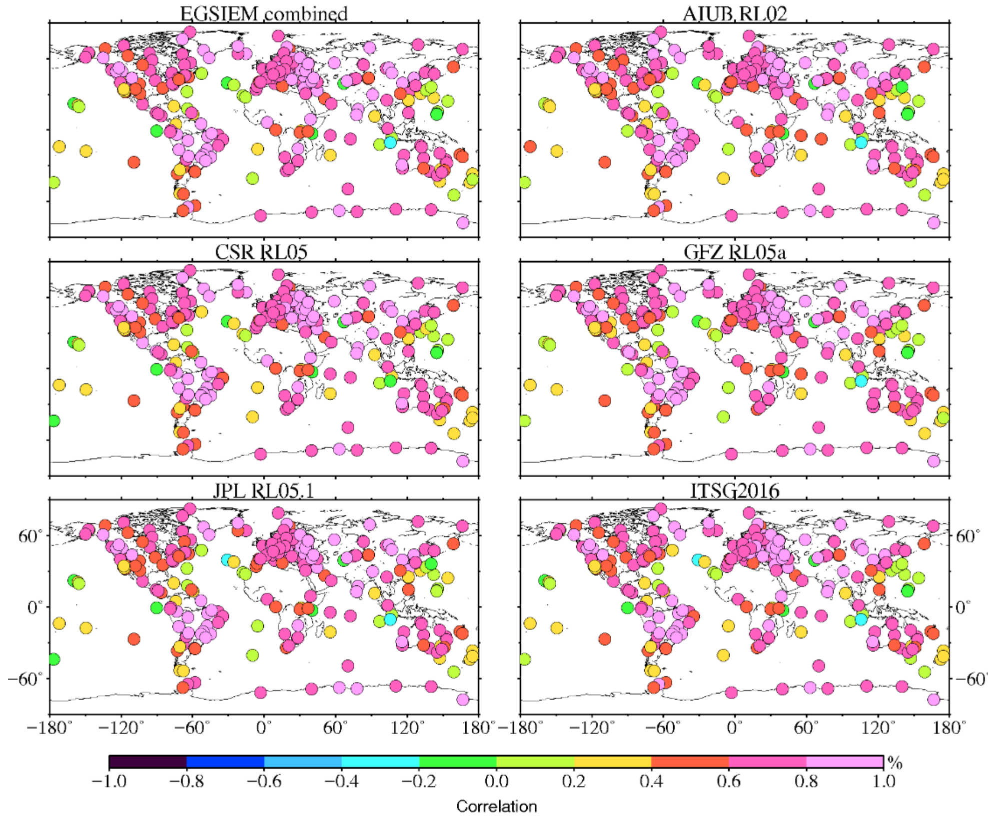

Figure 5-2: Correlations between GNSS-observed and GRACE-derived displacements over 312 GNSS stations using the post-processed reference frame data.

The spatial plots showing correlations between GNSS-observed and GRACE-derived displacements are presented in **Figure 5-2**. In terms of spatial correlation plots, all gravity solutions depict similar patterns with colors in red to pink clearly dominating, this implies excellent consistency between GNSS and GRACE. To be more specific, GNSS stations located in the continent exhibit strong correlations, especially in regions such as the Amazon where the most significant water mass variations happen. While the stations located in the islands or close to the coast display lower or even negative correlations, i.e. light yellow to cyan colors.

Besides the correlation maps, the WRMS reduction maps of the gravity solutions up to their full spectrum are shown in **Figure 5-3**. As seen clearly from **Figure 5-3**, yellow to red colors overwhelmingly distribute over the globe confirming the strong agreement between GNSS and GRACE. The highest WRMS reduction is observed at the POVE station located in Porto Velho, Brazil with a number up to 78.1% from the EGSIEM combined solutions. Note that this number varies with different GNSS datasets. For example, the highest WRMS reduction using the ITRF2014 residuals is 76.3% at the same station from the EGSIEM combined solutions.

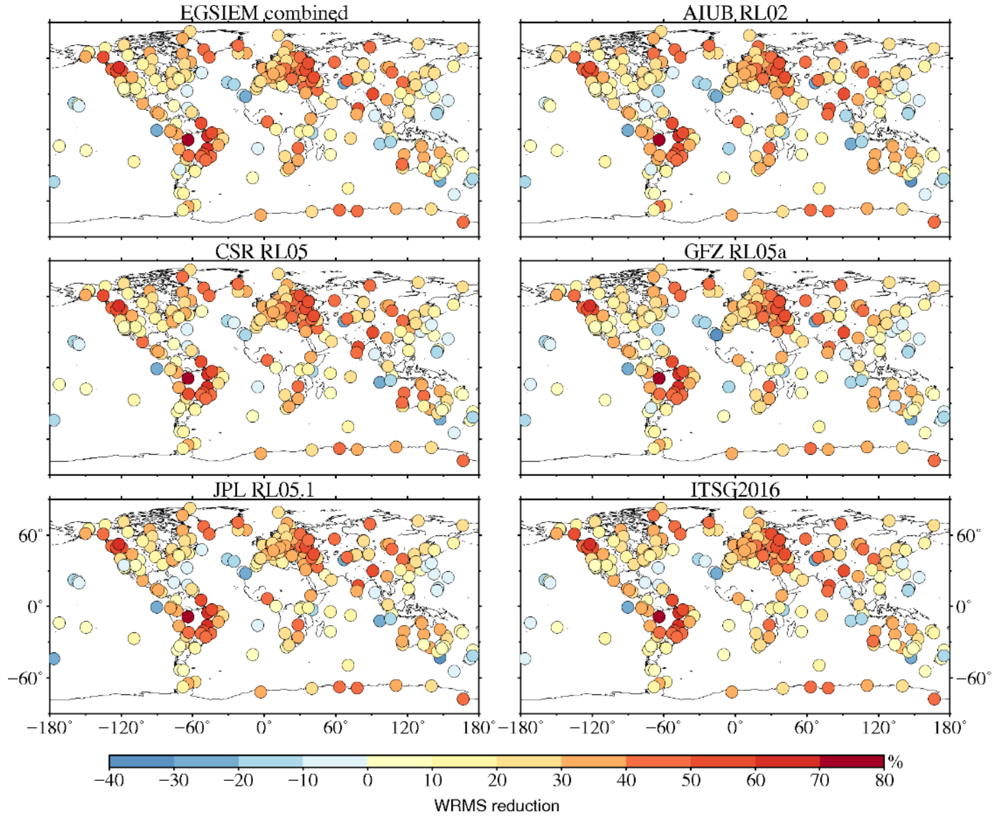

Figure 5-3: WRMS reduction at the full signal over 312 GNSS stations using the post-processed reference frame data. GRACE gravity solutions up to their full spectrum are used to compute the displacements.

The statistics from **Figure 5-3** as well as **Figure 9-5** and **Figure 9-6** in Annexes are summarized in **Table 5-2**. Note that the different number of stations from the three GNSS datasets are used for the table. The aim of **Table 5-2** is to evaluate the performances of different gravity solutions under different GNSS datasets. Statistically, the EGSIEM combined solutions perform overwhelmingly good using the three different GNSS datasets. The EGSIEM combined solutions together with CSR RL05 and ITSG2016 show consistently close performances and slightly outperform other three gravity solutions.

Table 5-2 Mean and positive WRMS reductions between six GRACE products and three GNSS datasets at the full signal level. Note that the table cannot serve as comparison among the three GNSS datasets as different numbers of stations are used.

	Reference frame data		ITRF2014 residuals		JPL GNSS time series	
	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

Table 5-2 also demonstrates that the differences of the statistics using the same GNSS dataset are less than that of using different GNSS datasets. This phenomenon is also supported by the below-mentioned **Table 5-3** and **Table 5-4**. These tables indicate that the differences among different GNSS products are larger than the differences among different gravity field solutions, which is also strongly suggested by Gu et al (2017) who used multi-institutional GNSS and GRACE products. In other words, the consistency of the various GRACE products is better than that of various GNSS products.

5.2.2 Annual signal level

Apart from the validation of the gravity fields at the full signal level, the performances of the six considered gravity solutions are evaluated annually. **Figure 5-4** presents the median degree and accumulative degree WRMS reductions at the annual signal level. Similarly, low SH degrees representing the long-wavelength mass variations display significant WRMS reductions indicating high agreements between GNSS-observed and GRACE-derived vertical displacements at the annual period. The bottom panel of **Figure 5-4** exhibits more than median values of 70% WRMS reductions over 312 global GNSS stations for all six gravity solutions. In addition, all the six gravity solutions except JPL RL05.1 show very close results at the annual signal level.

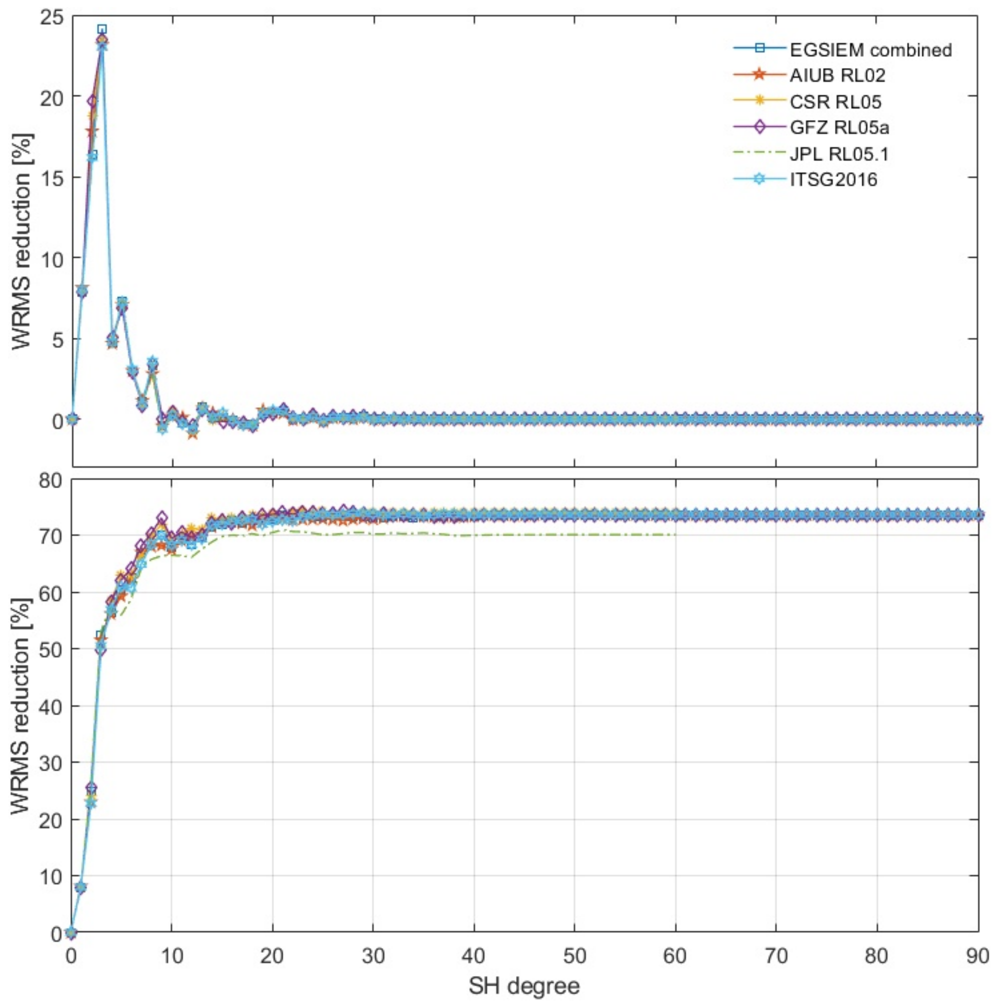

Figure 5-4: Median degree WRMS reductions (top) and accumulative degree WRMS reductions (bottom) of different gravity solutions using the post-processed reference frame data at the annual signal level from UBERN over 312 GNSS stations globally.

These phenomena are observed as well in the spatial plots shown in Figure 5-5. Most of stations show very high up to 100% WRMS reductions at the annual signal level indicating remarkable good agreement between GNSS and GRACE. The statistics at the annual period from the three GNSS products are shown in Table 5-3. Examination of Table 5-3 confirms the above-mentioned finding that the discrepancies among the different GNSS datasets are more significant than those of the different gravity solutions. At the annual period, the maximum difference of the median WRMS reductions among three GNSS datasets using the same GRACE product (GFZ RL05a) is 15.7% which is much larger than 6.3% the maximum difference of the median WRMS reductions among different gravity solutions using the same GNSS dataset (JPL GNSS time series).

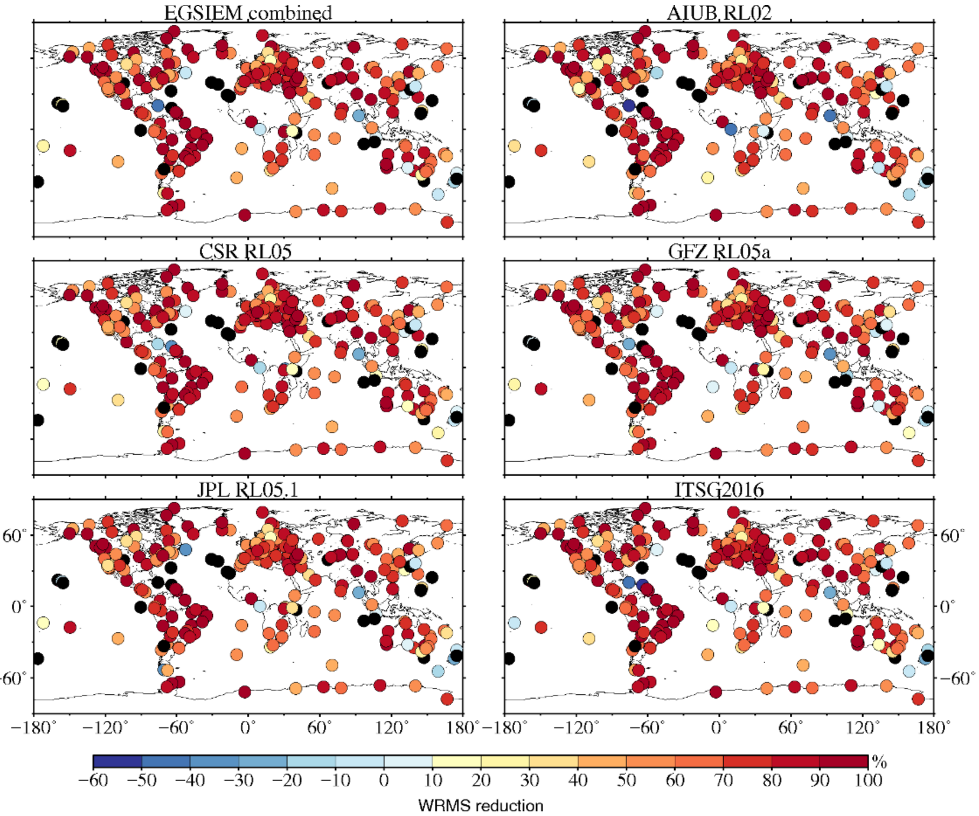

Figure 5-5: WRMS reduction at the annual signal over 312 GNSS stations using the post-processed reference frame data. GRACE gravity solutions up to their full spectrum are used to compute the displacements.

Table 5-3 Median and positive WRMS reductions between six GRACE products and three GNSS datasets at the annual signal level. Note that the table cannot serve as comparison among the three GNSS datasets as different numbers of stations are used.

	Reference frame data		ITRF2014 residuals		JPL GNSS time series	
	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

5.3 Validation over common GNSS stations

Contrary to the previous analysis, this subsection reports on validation of our post-processed reference frame data using the GRACE products. We simply extract the common GNSS stations from the three GNSS products and summarize their statistics in **Table 5-4**. A number of 236 common stations is obtained.

Statistics in **Table 5-4** indicate clearly that the quality of our post-processed reference data is very close to the latest ITRF2014 residuals, which can be regarded as the best GNSS time residuals up to date.

Table 5-4 Mean and positive WRMS reductions between six GRACE products and three GNSS datasets at the full signal level over 236 common 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

5.4 Summary

In summary, by comparing the six monthly gravity field products with respect to the three independent GNSS datasets, we can conclude that the strong agreements between GNSS and GRACE have been clearly observed at both the full signal level as well as the annual signal level. In addition, the EGSIEM-combined solutions show the same level of performance as the ITSG2016 and CSR RL05 monthly solutions, and slightly better than other three monthly solutions. A comparison of GNSS and GRACE over the 236 common GNSS stations indicates the good performance of the EGSIEM reference frame data as well.

6.Validation using OBP records

Four different GRACE monthly gravity field solutions extending over the time-period 2003-2012 were validated against OBP in situ measurements. The EGSIEM combination study by Jean et al. (Aug 30, 2017) is compared to the ITSG-Grace2016 (Mayer-Gürr et al., 2016) and GFZ RL05a (Dahle et al., 2012) solutions, as well as to the GFZ Tellus solution (Chambers, 2012). GFZ RL05a, ITSG 2016 and the EGSIEM solution were all post-processed in the same manner: degree-1 coefficients are added, C20 coefficient is replaced with solutions from Satellite Laser Ranging, mean is removed, glacial isostatic adjustment correction is applied based on the model by Paulson et al. (2007), DDK1 filter is applied to the data and GAD (Dobslaw et al., 2013) was added back to include all the atmospheric and oceanic contributions to the ocean bottom pressure anomalies. Trend has been removed from all GRACE solutions to match the in situ data.

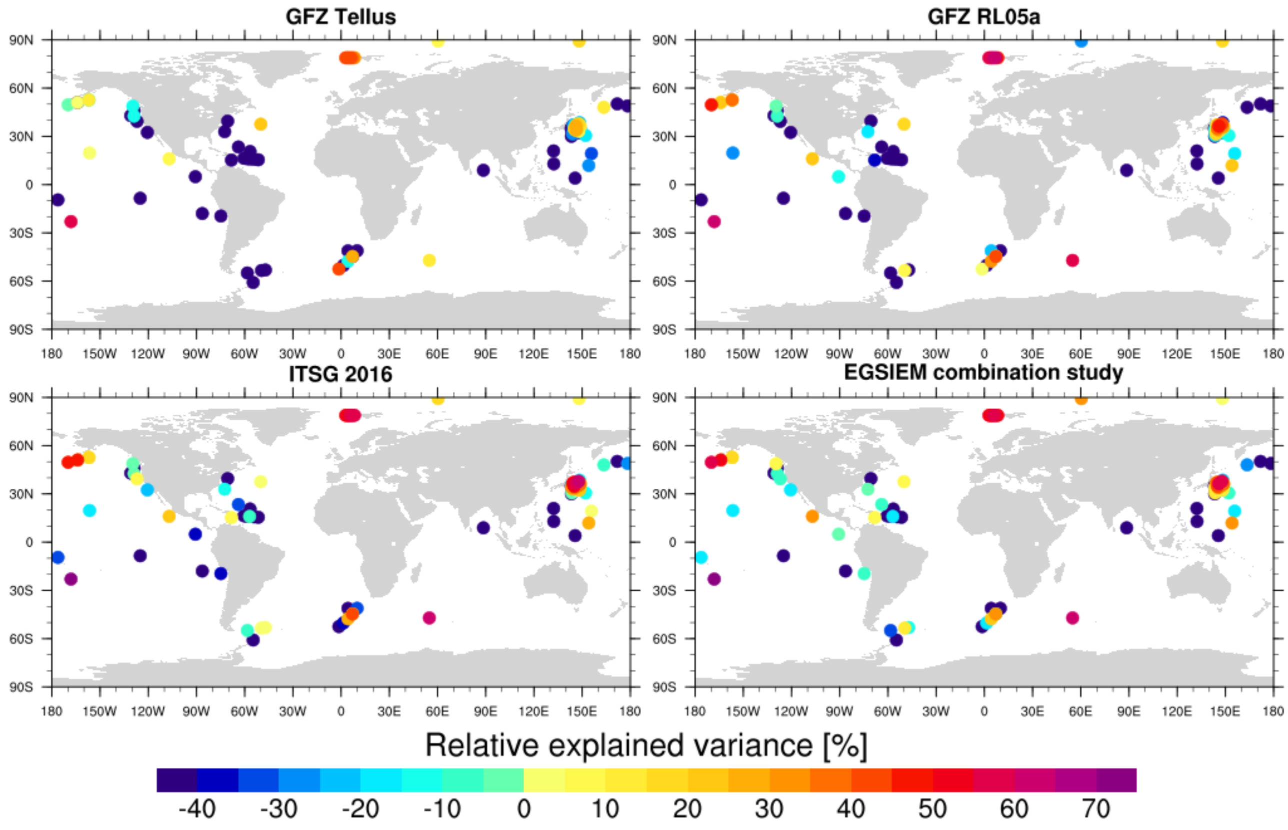

Figure 6.1: Relative explained variance for GFZ Tellus, GFZ RL05a, ITSG 2016 and EGSIEM combined solution against in situ ocean bottom pressure.

For the timespan considered, there are 103 stations with time series that are sufficiently long to allow us to validate the monthly solutions. While for approximately 50% of all stations the relative explained variance is negative for all considered gravity field solutions, i.e. the GRACE measurements do not correspond to the in-situ measurements. For the remaining stations, it is possible to see a clear distinction among the four solutions (**Figure 6.1**). Most stations with negative explained variance are located near the coast and therefore affected by continental leakage. Since 43 out of 103 in situ stations are from the Kuroshio Extension System Study (Kennelly et al., 2008) near Japan and therefore cover a very small area (they are shown separately on **Figure 6.2**). The differences due to post-processing between the GFZ Tellus and GFZ RL05a solutions are larger than the differences between solutions from different processing centers, which demonstrates the importance of careful post-processing. On the global average ITSG 2016 and EGSIEM solution demonstrate a similar quality level and slightly better precision than the GFZ solution. The differences are most obvious in the KESS array, where for the GFZ Tellus solution none of the stations have relative explained variance above 30% and roughly half of them are negative, while for the ITSG 2016 and the combined EGSIEM solution most stations are positive and several exceed 50%.

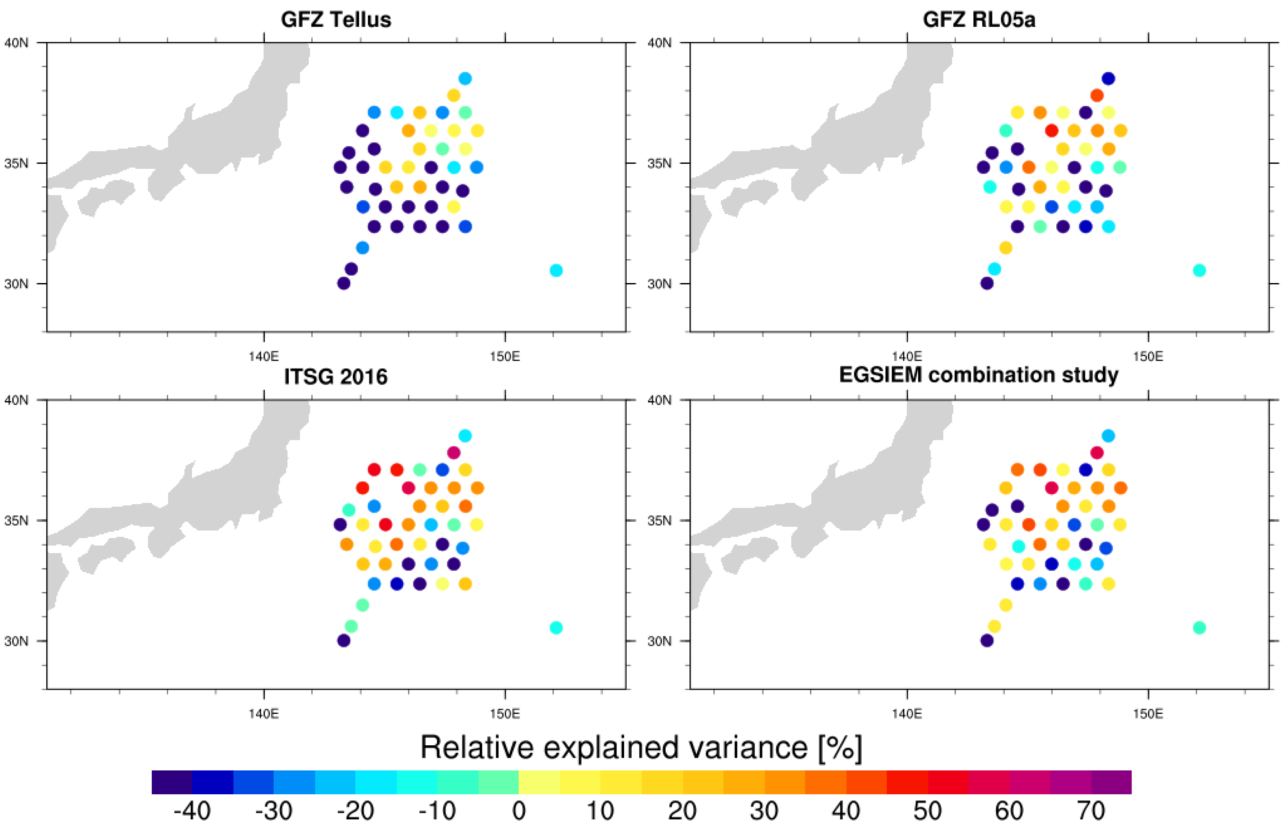

Figure 6.2: Relative explained variance for GFZ Tellus, GFZ RL05a, ITSG 2016 and EGSIEM combined solution against in situ ocean bottom pressure for the Kuroshio Extension System Study near Japan.

7.Summary

In summary, this report has successfully demonstrated the capabilities of the GNSS time series and OBP records for validating the EGSIEM combined monthly gravity fields. We have shown that both validation techniques are able to evaluate the qualities of different monthly gravity fields including assessment of the effects of different post-processing strategies.

By comparing the six monthly gravity field products with respect to the three independent GNSS datasets, we can conclude that the strong agreements between GNSS and GRACE have been clearly observed at both the full signal level as well as the annual signal level. In addition, the EGSIEM-combined solutions show the same level of performance as the ITSG2016 and CSR RL05 monthly solutions, and slightly better than other three monthly solutions. A comparison of GNSS and GRACE over the 236 common GNSS stations indicates the good performance of the EGSIEM reference frame data as well.

Validation using the OBP records confirms the conclusions drawn by validation using the GNSS time series although less gravity field models are used. In particular, it is demonstrated that in-situ OBP records are able to assess the effects due to different post-processing strategies applied to the same monthly gravity fields.

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9.Annexes

The following figures serve as supplementary materials for this deliverable. They are the same as **Figure 5-1**, **5-2** and **5-3** but for the ITRF2014 residuals and the JPL GNSS time series, respectively.

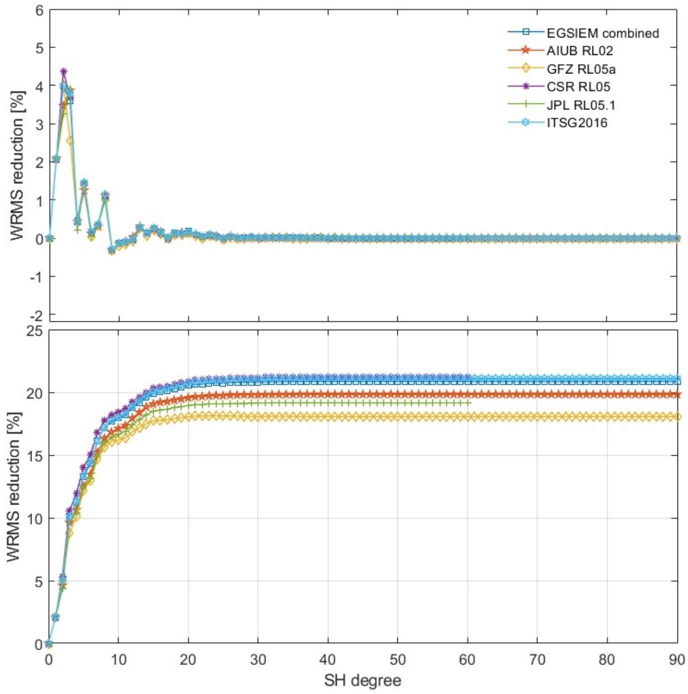

Figure 9-1: Mean degree WRMS reductions (top) and accumulative degree WRMS reductions (bottom) of different gravity solutions using the ITRF2014 residuals over 928 GNSS stations globally.

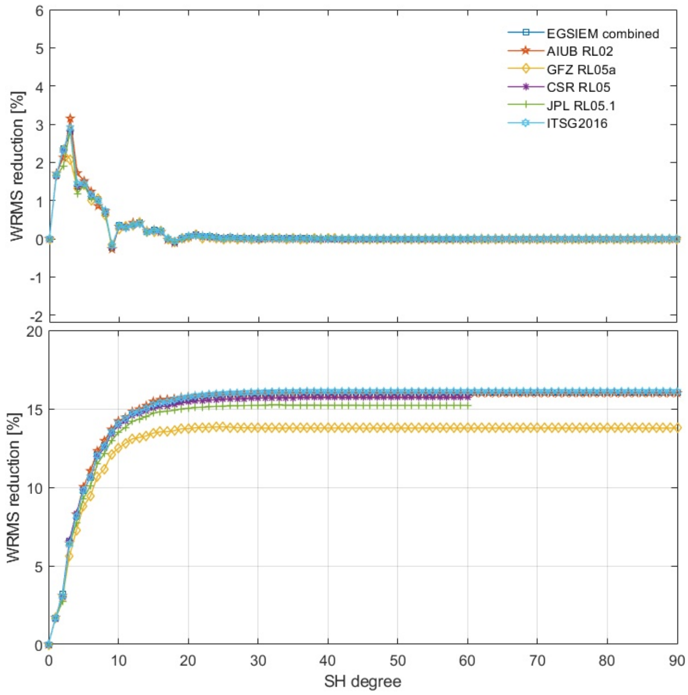

Figure 9-2: Mean degree WRMS reductions (top) and accumulative degree WRMS reductions (bottom) of different gravity solutions using the GNSS time series from JPL over 788 GNSS stations globally.

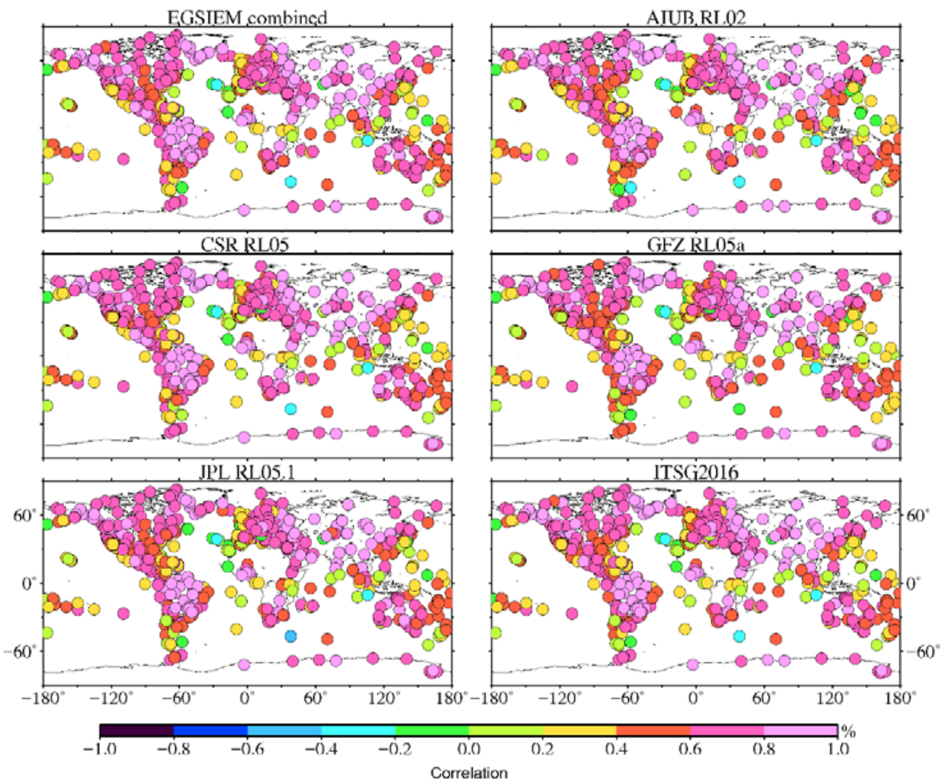

Figure 9-3: Correlations between GNSS-observed and GRACE-derived displacements over 928 GNSS stations using the ITRF2014 residuals.

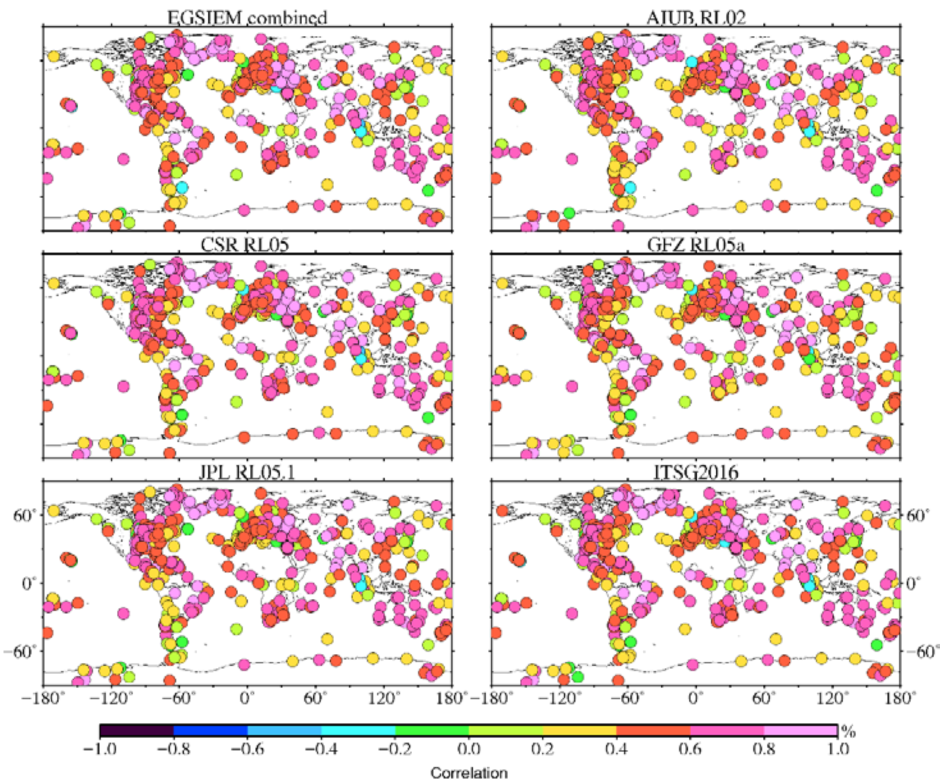

Figure 9-4: Correlations between GNSS-observed and GRACE-derived displacements over 788 GNSS stations using the JPL GNSS time series.

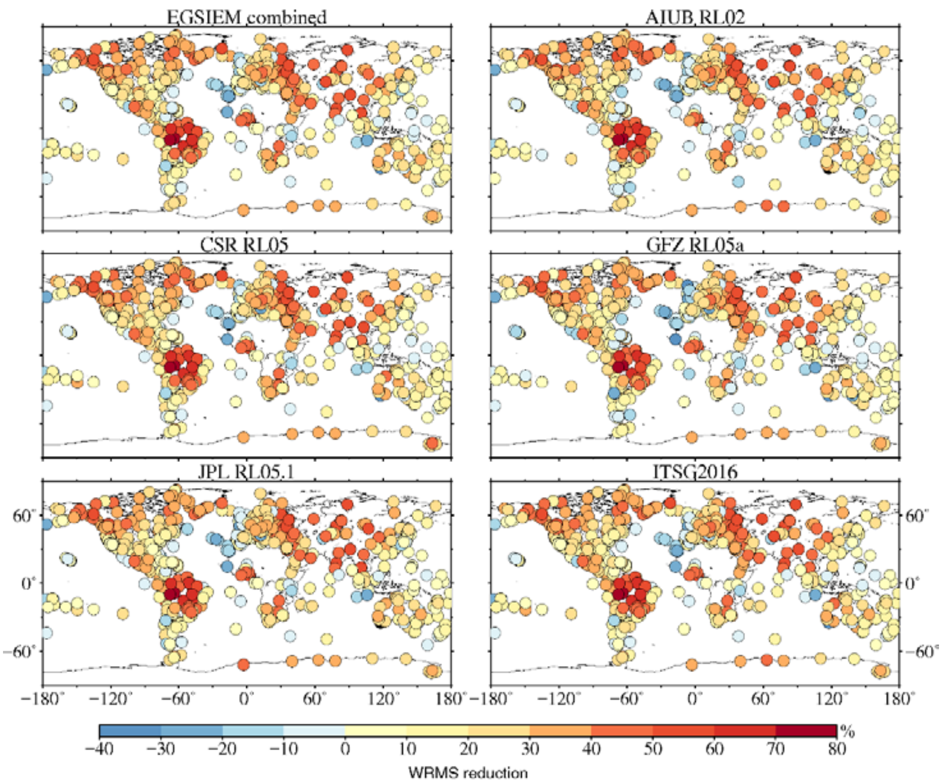

Figure 9-5: WRMS reduction at the full signal over 928 GNSS stations using the ITRF2014 residuals. GRACE gravity solutions up to their full spectrum are used to compute the displacements.

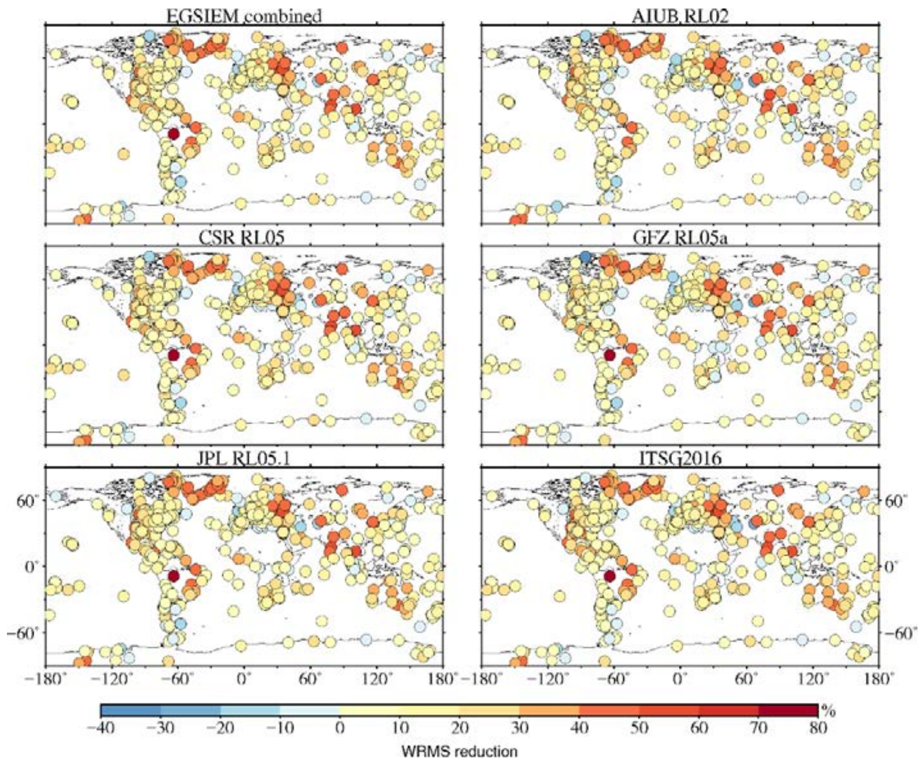

Figure 9-6: WRMS reduction at the full signal over 788 GNSS stations using the JPL GNSS time series. GRACE gravity solutions up to their full spectrum are used to compute the displacements.

10.Glossary

AC	Analysis Center
AIUB	Astronomical Institute, University of Bern
CSR	Center for Space Research, Austin, Texas
EGSIEM	European Gravity Service for Improved Emergency Management
ELTM	Extended Linear Trajectory Model
GAC	Geopotential coefficients of averaged combination of non-tidal atmosphere and ocean
GAD	Geopotential coefficients of averaged combination of bottom pressure over oceans
GFZ	Helmholtz Centre Potsdam, German Research Centre for Geosciences
GIA	Global Isostatic Adjustment
GNSS	Global Navigation Satellite System
GRACE	Gravity Recovery and Climate Experiment
GSM	Geophoten coefficients of GRACE-derived static gravity field
ITRF	International Terrestrial Reference Frame
JPL	Jet Propulsion Laboratory, Pasadena, California, USA
KESS	Kuroshio Extension System Study
OBP	Ocean Bottom Pressure
RMS	Root Mean Square
REV	Relative Explained Variance
SHC	Spherical Harmonic Coefficient
SLR	Satellite Laser Ranging
UBERN	University of Bern
WRMS	Weighted RMS