Validation of the EGSIEM combined monthly GRACE gravity fields

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1. Introduction

Observations indicate that global warming is affecting the water cycle. The consequences include the decreasing availability of fresh water resources in some regions as well as flooding and erosion of coastal and low-lying areas in other regions. These weather related effects impose heavy costs on society and the economy. We cannot stop the immediate global warming effects on the water cycle. But there may be measures that we can take to mitigate the costs to society.
The Horizon2020 supported project, European Gravity Service for Improved Emergency Management (EGSIEM), will add value to Earth observations (EO) of variations in the Earth's gravity field. In particular, the EGSIEM project will interpret the observations of gravity field changes in terms of changes in continental water storage. The project team will develop tools to alert the public whenever water storage conditions could indicate the onset of regional flooding or drought.
As part of the EGSIEM project, a combined GRACE gravity product is generated using various monthly GRACE solutions from associated processing centers (ACs). Since each AC follows a set of common processing standards but applies its own independent analysis method, the quality, robustness, and reliability of the monthly combined gravity fields should be significantly improved as compared to any individual solution. To ensure the quality of the EGSIEM products, external validation using hydrological models and other satellite derived observations is essential as they can help us to identify outliers, and more importantly increase user's confidence in our data products. To this end, in this study, we present detailed and updated mutual comparisons among the combined EGSIEM GRACE gravity products, GNSS station position time series and hydrological models.

2. Methodology and datasets

Converting surface loading into displacements

To be compared with GNSS vertical displacements, surface loading from the hydrological models as well as the combined EGSIEM gravity solutions are converted into displacements via the following approaches. All the displacements are computed at the Center of Figure (CF) frame.

- Green's functions approach for the hydrological models
  In terms of Farrell (1972), convolving the load mass change $\Delta\sigma(\theta_Q, \lambda_Q)$ and the vertical Green functions $G_u(\phi_{PQ})$ in the spatial domain leads to vertical displacement $u_r(\theta_P, \lambda_P)$

$$u_r(\theta_P, \lambda_P) = R^2 \iint \Delta\sigma(\theta_Q, \lambda_Q) G_u(\phi_{PQ}) d\Omega \,, \tag{1}$$

  where $d\Omega = \sin\theta_Q d\theta_Q d\lambda_Q$ and R is the radius of the Earth.
- Spherical harmonics approach for the EGSIEM combined gravity models
  The corresponding convolution of Eq. (1) in the spectral domain is given as follows

$$u_r(\theta_P, \lambda_P) = R \sum_{l=0}^{\infty} \frac{h'_l}{1+k'_l} \sum_{m=0}^{l} \bar{P}_{lm}(\cos\theta_P) \cdot (\Delta C^g_{lm} \cos(m\lambda_P) + \Delta S^g_{lm} \sin(m\lambda_P)) \,, \tag{2}$$

  where ΔC^g_{lm} and ΔS^g_{lm} represent the GRACE spherical harmonic coefficients; $\bar{P}_{lm}$ is the normalised associated Legendre functions; h'_l and k'_l are the load Love numbers of degree l.

Datasets

- GNSS datasets
  - Latest global daily GNSS time series from JPL and SOPAC with cleaned detrended datasets;
  - Residuals from the ITRF2014 stacking of the IGS repro2 daily solutions (Rebischung et al., 2016): station velocities and discontinuities removed; annual and semi-annual signals restored;
  - Daily GNSS observations are averaged into monthly solutions;
  - 528 common stations among JPL, SOPAC and ITRF2014 solutions are selected.
- Continental water storage models
  - GLDAS Noah model, monthly, $1^\circ \times 1^\circ$, 1979-present, soil moisture and snow water;
  - WGHM_2.1f6, monthly, $0.5^\circ \times 0.5^\circ$, 2002.01-2013.12;
  - WGHM_2.2_STANDARD, latest official version, monthly, $0.5^\circ \times 0.5^\circ$, 2002.01-2010.10;
  - WGHM_2.2_STANDARD_CRU, a modification of 2.2 standard but not calibrated for the climate input, monthly, $0.5^\circ \times 0.5^\circ$, 2002.01-2012.12;
  - Except soil moisture and snow water, WGHM models consist of surface water (water in rivers, lakes, reservoirs and wetlands) and groundwater as well.
- Combined monthly EGSIEM gravity solutions, see Jean et al. (2015)
  - C_{20} is replaced from SLR observations and degree-1 coefficients are added back;
  - The Gaussian filtering with a smoothing radius of 500 km is applied;
  - In particular, when comparing with GNSS, the AOD1B atmospheric and oceanic de-aliasing products are added back as well.

3. Comparison between GNSS observed and EGSIEM derived vertical displacements

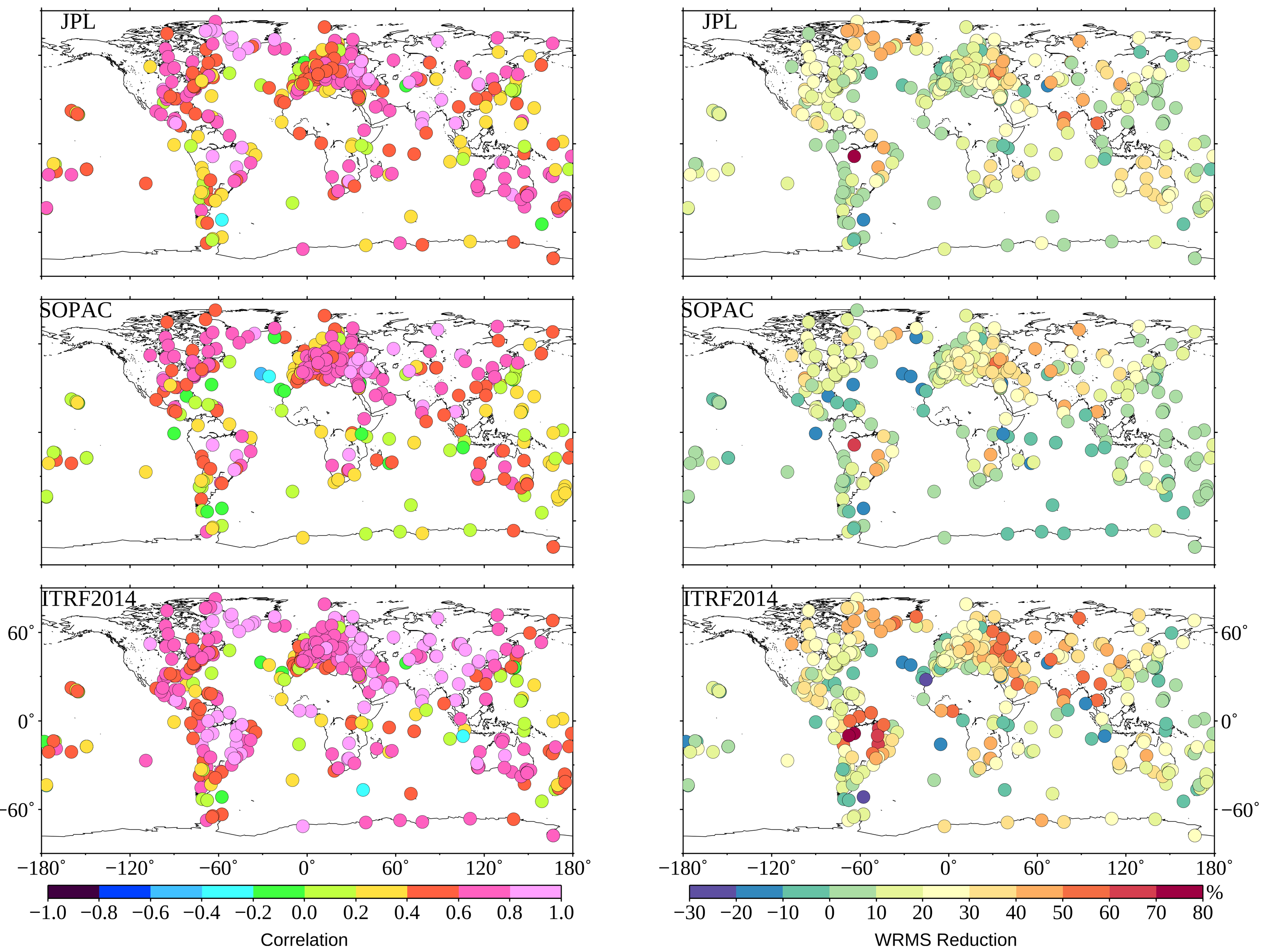

Figure 1: *Correlations and WRMS reductions between three GNSS solutions and the EGSIEM derived vertical displacements. Up to 75% WRMS reduction is observed at POVE (Porto Velho, Brazil) for JPL and ITRF2014 solutions.*

Table 1: *Statistics between GNSS and EGSIEM. High percentages of stations with positive WRMS reductions are observed using the three GNSS solutions.*

	Correlation			Stations with correlation> 0.6 [%]	WRMS reduction [%]			Stations with positive WRMS reduction [%]
	min	max	mean		min	max	mean	
JPL	-0.37	0.98	0.53	43.98 [190/432]	-26.00	75.69	17.12	92.82 [401/432]
SOPAC	-0.46	0.97	0.48	43.70 [170/389]	-30.41	68.79	14.58	85.35 [332/389]
ITRF2014	-0.38	0.97	0.59	59.83 [280/468]	-27.73	74.56	22.43	88.03 [412/468]

4. Comparison between vertical displacements derived from hydrological models and EGSIEM gravity solutions

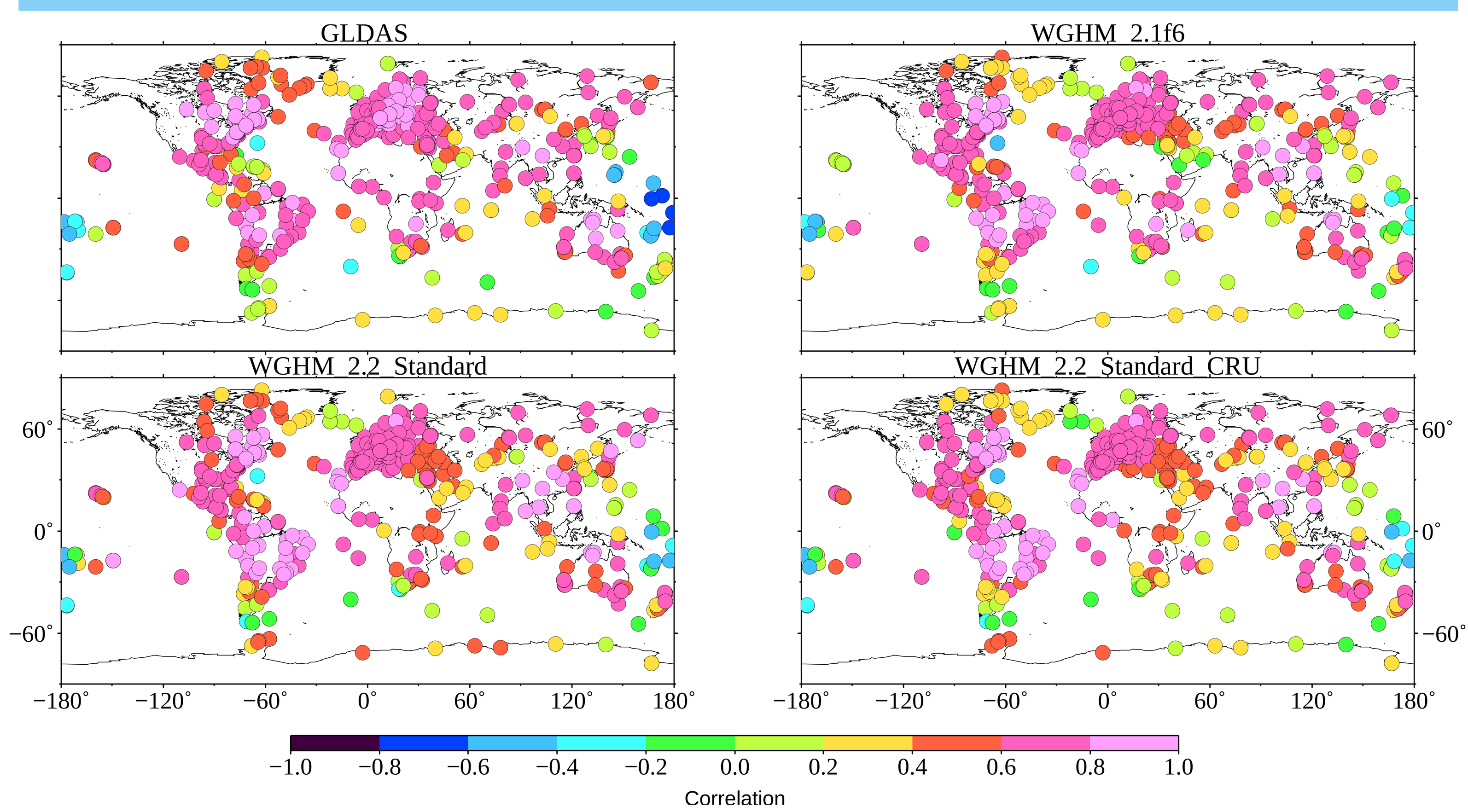

Figure 2: *Correlations between hydrological models and EGSIEM at selected common stations.*

Table 2: *Statistics between the four continental water storage models and EGSIEM*

	Correlation			Stations with correlation> 0.6 [%]
	min	max	mean	
GLDAS	-0.68	0.91	0.56	63.45 [335/528]
WGHM_2.1f6	-0.58	0.95	0.55	58.14 [307/528]
WGHM_2.2_Standard	-0.51	0.94	0.56	59.66 [315/528]
WGHM_2.2_Standard_CRU	-0.52	0.93	0.54	55.30 [292/528]

5. Comparison between GNSS observed and the hydrological models derived vertical displacements

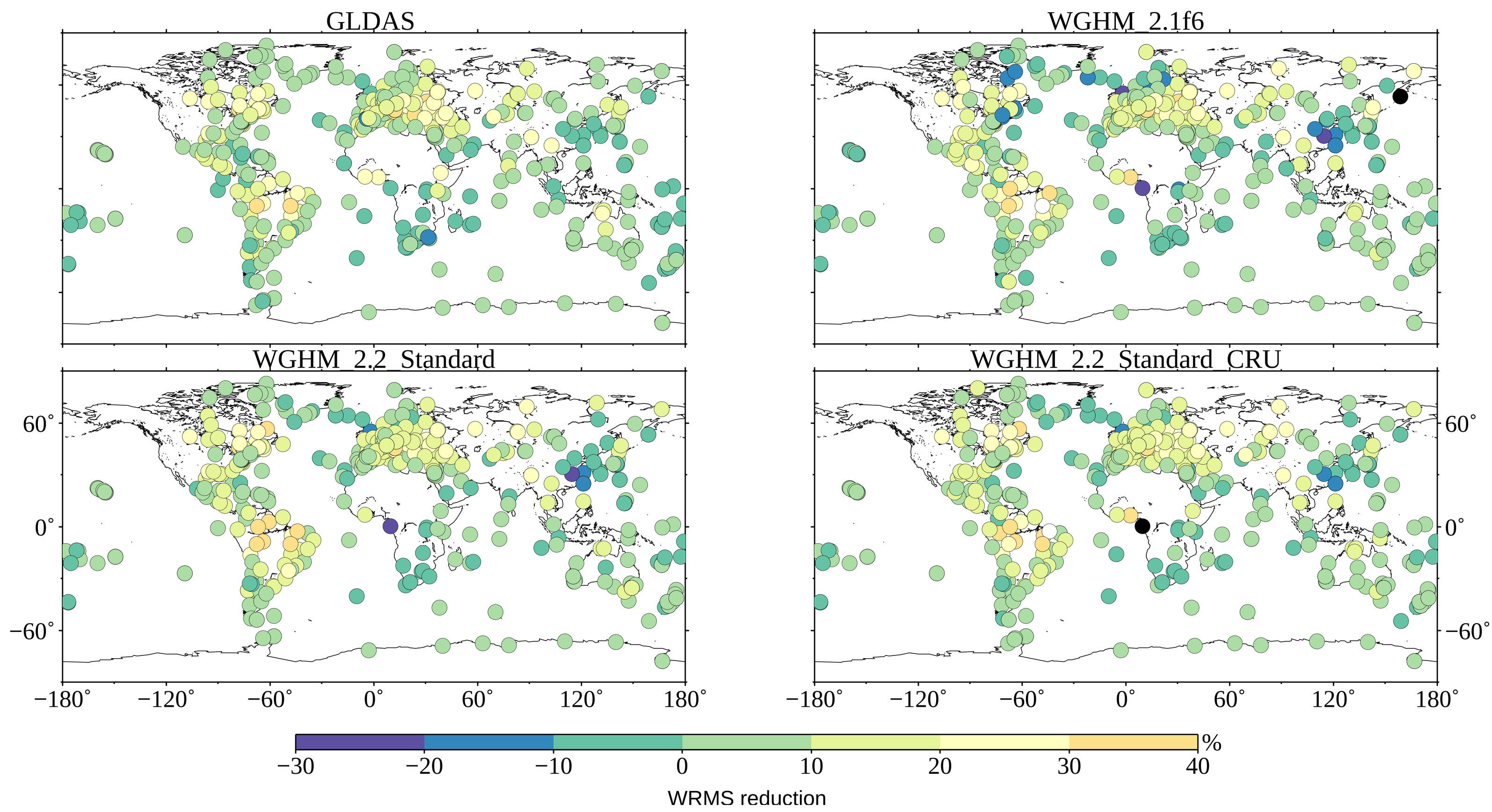

Figure 3: *WRMS reductions between the ITRF2014 solutions and the four hydrological models at selected common stations. The same color scheme as Figure 1 (right) is applied here but limited up to the maximum 40%. WRMS reductions between two other GNSS solutions with the four hydrological models are not shown here.*

Table 3: *Stations with positive WRMS reductions [%] between the three GNSS solutions and the four hydrological models*

	JPL	SOPAC	ITRF2014
GLDAS	58.73	77.94	79.55
WGHM_2.1f6	55.24	75.98	74.90
WGHM_2.2_Standard	67.29	80.95	81.40
WGHM_2.2_Standard_CRU	62.90	80.71	81.09

6. Conclusions

- The GNSS observed and the EGSIEM derived displacments are in strong agreement.
- The hydrological models are also consistent with the EGSIEM gravity solutions in terms of displacements. GLDAS seems to outperform the other three WGHM models. Further investigation is underway to understand this phenomenon.
- Agreement between the four hydrological models and the three GNSS solutions is good as well and better agreement is found with the ITRF2014 time series than the JPL and SOPAC time series.
- With respect to the three GNSS station position time series, EGSIEM shows better statistics than the hydrological models.

References

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