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Time-variable components of the gravity potential field

1 Introduction

Within the collaborative European project “International timescales with optical clocks (ITOC)”, a coordinated programme of clock comparisons is carried out to validate the optical clocks at five different laboratories. LUH provides the static gravity potential values for the clock sites in order to correct for a general relativistic redshift correction (see Poster G02 “Gravity field modelling for optical clock comparisons” by H. Denker). The optical clocks are now targeting a relative accuracy of 10^{-18}, corresponding to a sensitivity of 0.1 m^2/s^2 in terms of the geopotential or 0.01 m in height. At this accuracy level, also temporal variations of the gravity field and vertical deformations of the Earth’s crust become significant. This is especially important for remote clock comparisons over larger distances, when relatively short averaging times are used, since in such situations the time-variable gravity potential effects may not average out sufficiently.

The aim of this study is to investigate relevant time-variable gravity potential signals and to estimate their magnitudes. Solid Earth tides (section 2.1) and ocean tides (2.2) are the dominant components with peak-to-peak ranges of roughly 5 m²/s² and up to 0.6 m²/s², respectively, while the amplitudes of the pole tides (2.3) remain well within 0.1 m²/s². Further time-varying effects arise from non-tidal mass redistributions in the atmosphere (3.1) and in the oceans (3.2) as well as due to continental water storage (3.3) with amplitudes of up to 0.2 m²/s². Table 1 summarizes all effects under investigation along with their maximum amplitude ranges and dominant time scales.

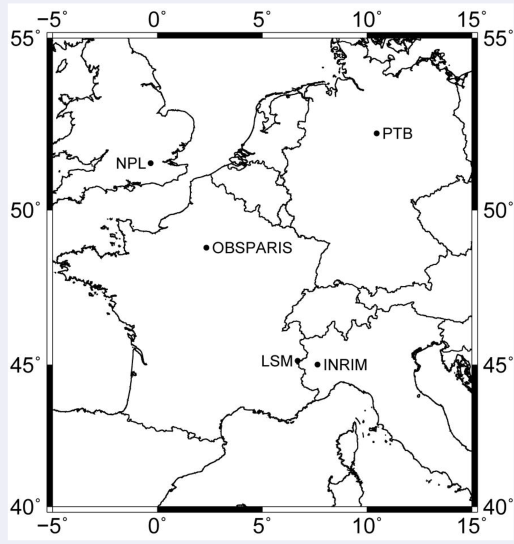

Fig 1. Optical clock sites at the national metrology institutes (NMI) involved in the ITOC project.

2 Tides

2.1 Solid Earth tides

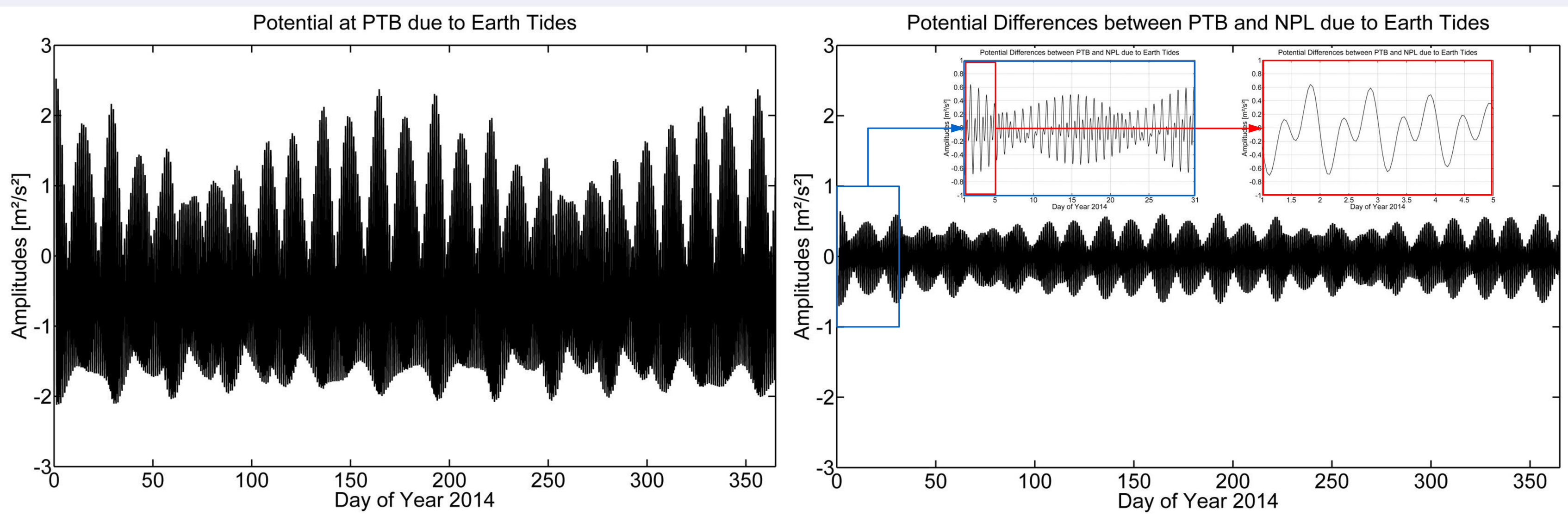

Fig. 2. The gravitational potential due to solid Earth tides [m²/s²] at PTB (left) and potential differences between PTB and NPL (right) in the year 2014 according to Love number combination $(1 + k_{lm} - h_{lm})$; computation by PREDICT (Wenzel, 1996) based on tidal potential catalogue HW95 (Hartmann and Wenzel, 1995); uniform global distribution of amplitudes; maximum potential differences within 7 hours

2.2 Ocean tides

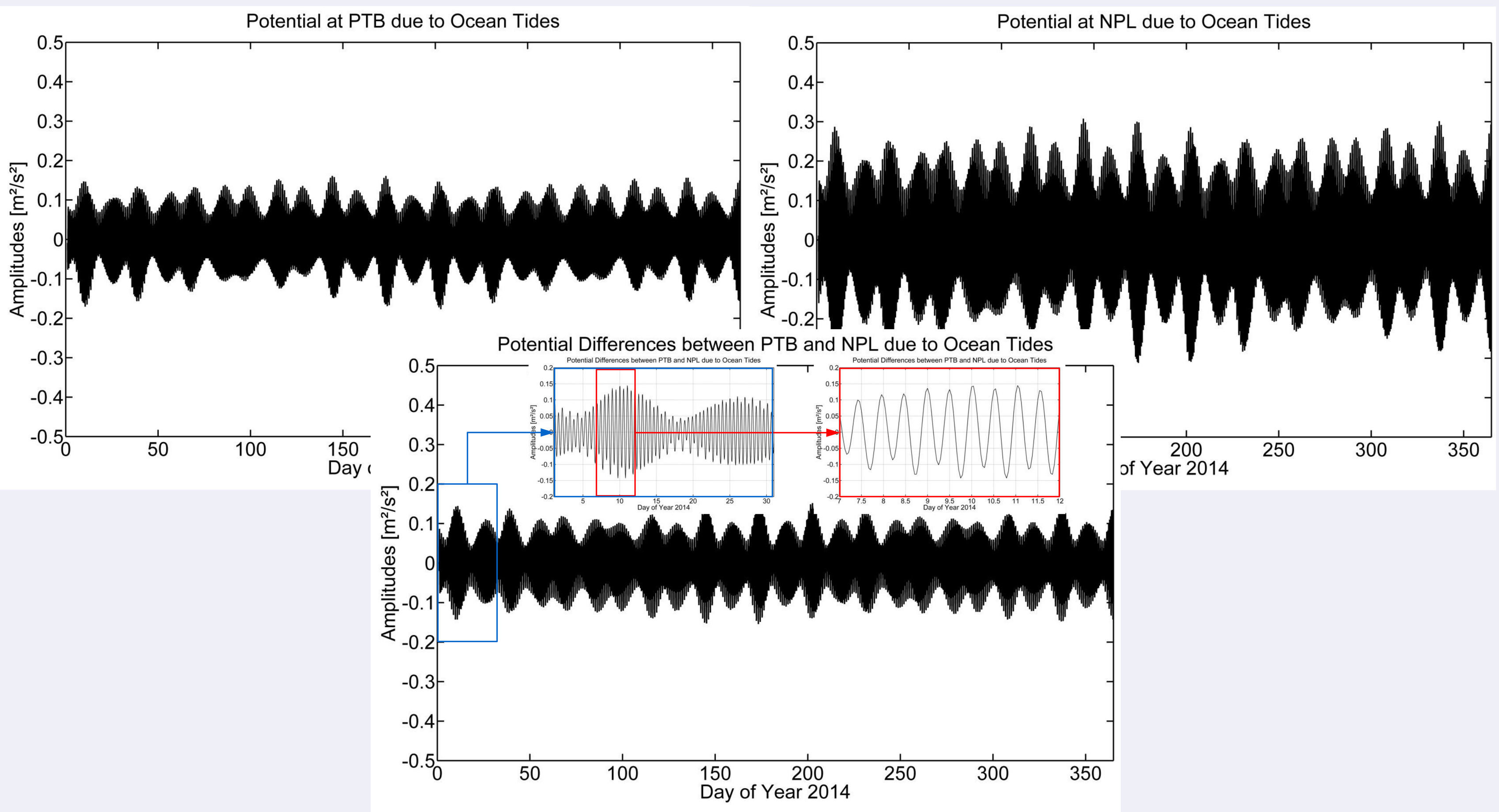

Fig. 3. The gravitational potential due to ocean tides [m²/s²] at PTB (top left) and NPL (top right) as well as potential differences between PTB and NPL (bottom) in the year 2014 according to Love number combination $(1 + k_l' - h_l')$; computation by SPOTL (Agnew, 2013; Agnew, 1997) based on EOT11A (Savcenko and Bosch, 2012); strong local variation of amplitudes depending on the distance to tidally induced coast; maximum potential differences within 6 hours

2.3 Solid Earth pole tides

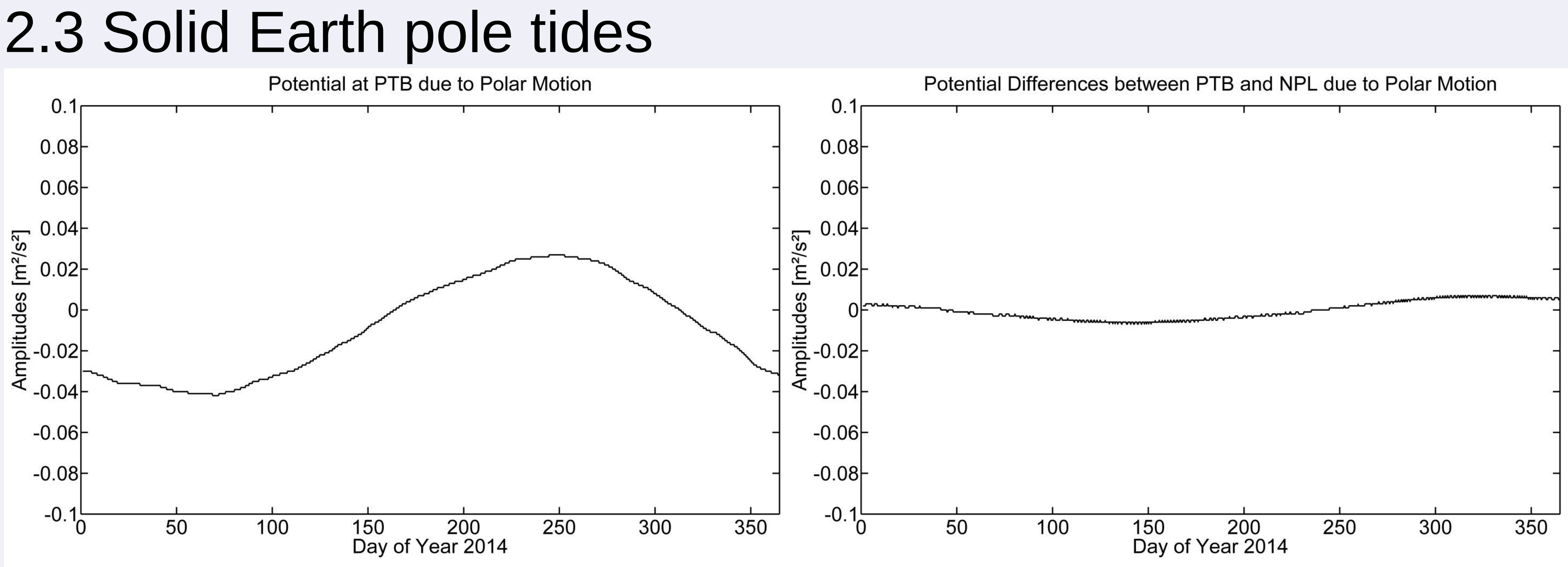

Fig. 4. The centrifugal potential due to polar motion [m²/s²] at PTB (left) and the potential differences between PTB and NPL (right) in the year 2014; computation based on polar motion (IERS, 2010); amplitudes largely cancel out for the potential differences

3 Non-tidal mass redistributions

3.1 Atmosphere

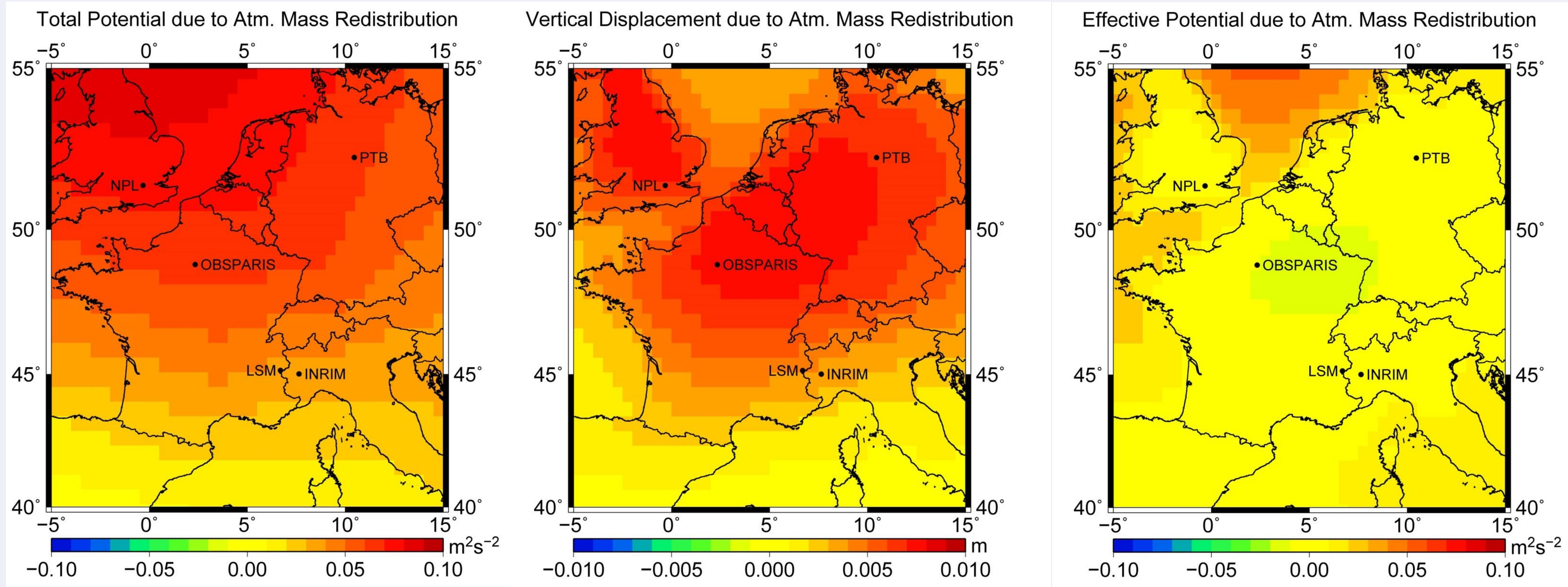

Fig. 5. The total gravitational potential [m²/s²] due to non-tidal mass redistributions in the atmosphere based on ECMWF caused by a hurricane from the North-West Atlantic at 12 UTC on 13 February 2014 according to load Love number term $(1 + k_l')$ from AOD1B ATM (Flechtner et al., 2014) (left), the corresponding vertical displacement [m] of the Earth’s surface according to load Love number h_l' from Loading Service of University of Strasbourg (middle) and the effective gravitational potential [m²/s²] according to load Love number combination $(1 + k_l' - h_l')$ (right); the first two effects have similar amplitudes and act strongly reverse on the effective potential

3.2 Oceans

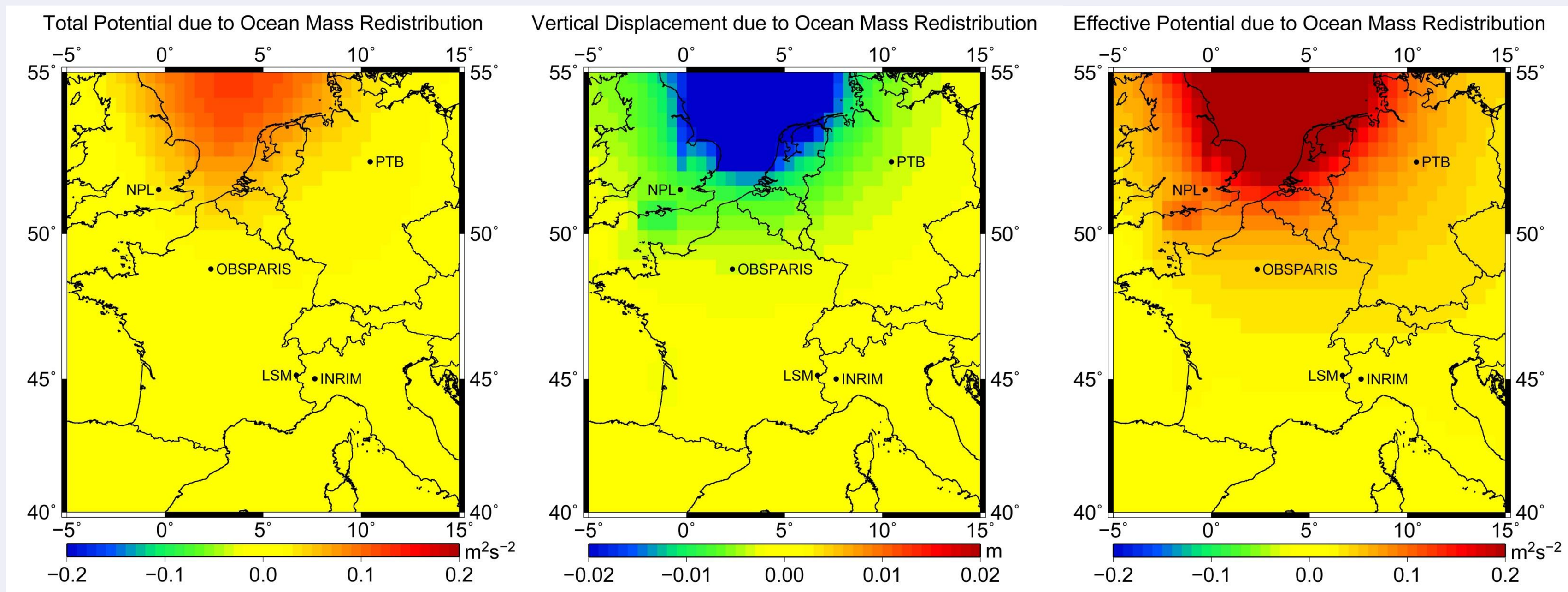

Fig. 6. The total gravitational potential [m²/s²] due to non-tidal mass redistributions in the oceans based on OMCT at 3 UTC on 30 January 2000 according to load Love number term $(1 + k_l')$ from AOD1B OCN (Flechtner et al., 2014) (left), the corresponding vertical displacement [m] of the Earth’s surface based on ECCO according to load Love number h_l' from Loading Service of University of Strasbourg (middle) and the effective gravitational potential [m²/s²] according to load Love number combination $(1 + k_l' - h_l')$ (right); the first two effects add up for the effective potential

3.3 Continental water storage

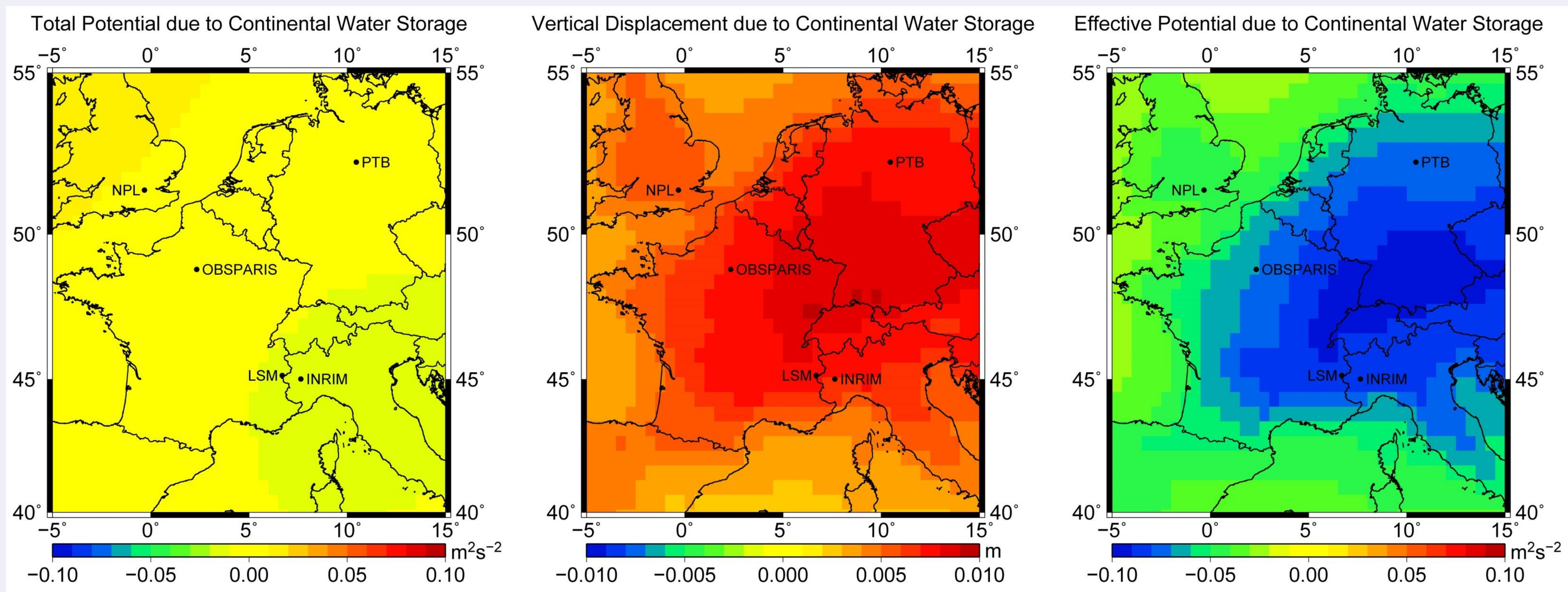

Fig. 7. The total gravitational potential [m²/s²] from filtered GFZ Release 05 GRACE monthly solutions (left) in September 2003 according to load Love number term $(1 + k_l')$, the corresponding vertical displacement [m] of the Earth’s surface based on GLDAS according to load Love number h_l' from Loading Service of University of Strasbourg (middle) and the effective gravitational potential [m²/s²] according to load Love number combination $(1 + k_l' - h_l')$ (right); the amplitudes related to the first two effects induced by continental water storage add up for the effective potential with the major contribution from vertical displacement

4 Summary

Table 1. Differences of time variable gravity potential components with maximum amplitude ranges (peak-to-peak) and dominant time scales between laboratory sites over continental and intercontinental scales

Phenomenon	Contributor	Max amplitude range [m²/s²]		Dominant time scales
		Conti-nental	Interconti-nental	
Tides	Solid Earth tides	1.3	10.0	from permanent to semidiurnal
	Ocean tides	0.3	1.1	diurnal and semidiurnal
	Solid Earth pole tides	0.01	0.12	annual and 433 days
	LOD tides	0.001	0.001	secular
	Ocean pole tides	0.001	0.03	annual and 433 days
	Atmospheric tides	0.005	0.005	diurnal and semidiurnal
Non-tidal mass redistributions	Atmosphere	0.05	0.1	hours and days
	Oceans	0.1	0.2	hours and days
	Continental water storage	0.1	0.2	seasonal
	Local hydrology	-	-	seasonal
	Sea level changes	0.01/yr		secular
	Solid Earth processes (GIA)	0.05/yr		secular