

Supplementary Material

Data-adaptive spatio-temporal filtering of GRACE data

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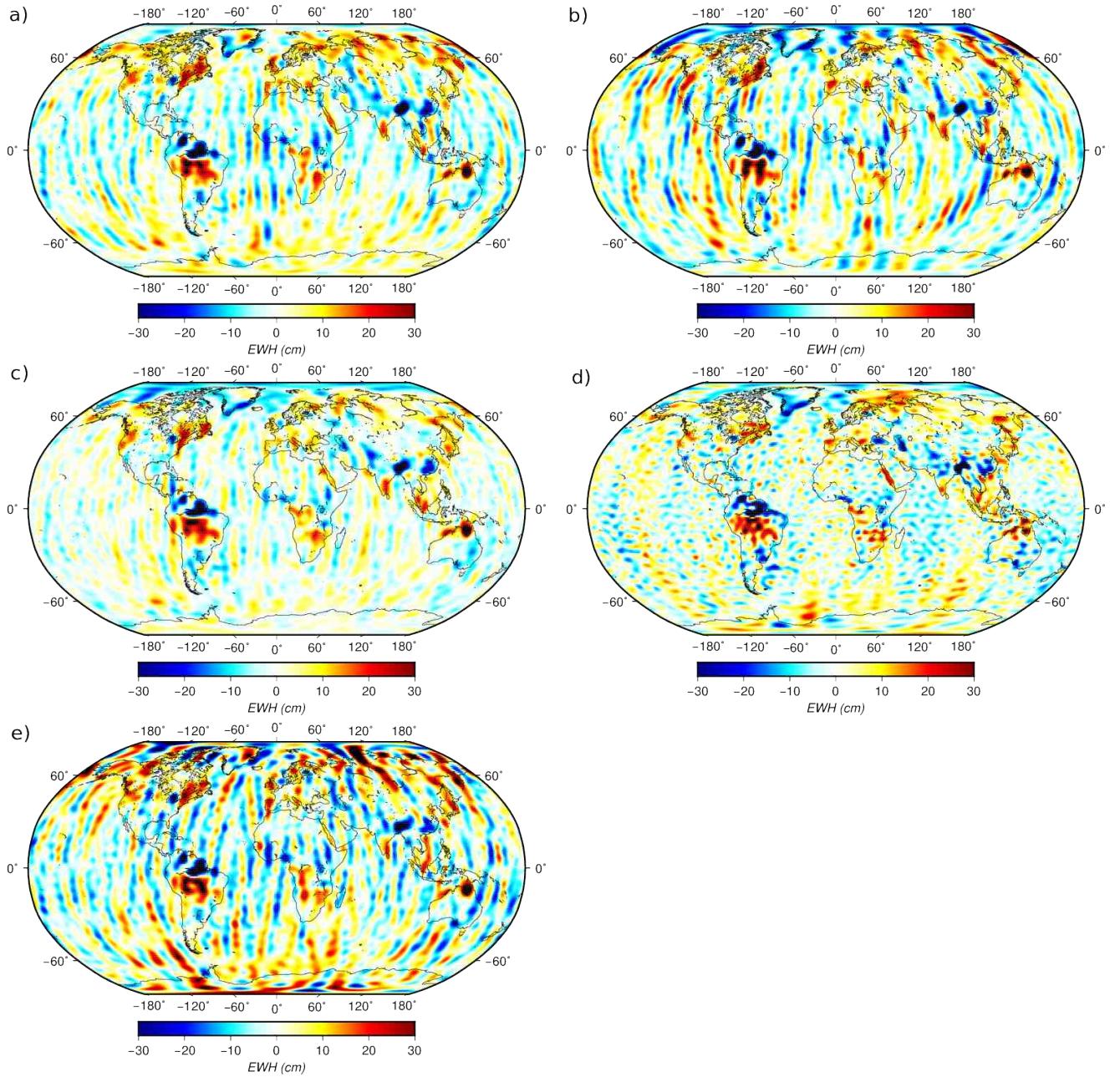


Figure S1: Surface mass density anomalies solutions for January 2006 relative to July 2005, expressed in equivalent water height (EWH in cm), derived from GRACE. (a) By CSR calculation centre and filtered with the decorrelation filter DDK5. (b) By GFZ calculation centre and filtered with DDK5. (c) By GRAZ calculation centre and filtered with DDK5. (d) By CNES/GRGS calculation centre. (e) By JPL calculation centre and filtered with DDK5.

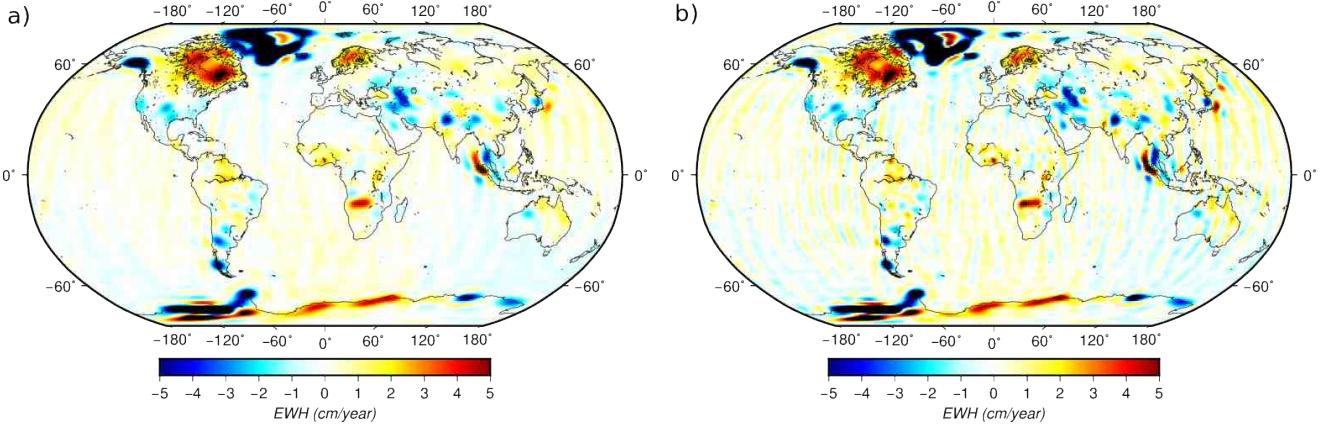


Figure S2: Mean of JPL, GFZ and CSR surface mass density rates from 2003 to 2015 expressed in equivalent water height (EWH) per year (in cm yr^{-1}), derived from GRACE. (a) with the decorrelation filter DDK5. (b) with the decorrelation filter DDK7.

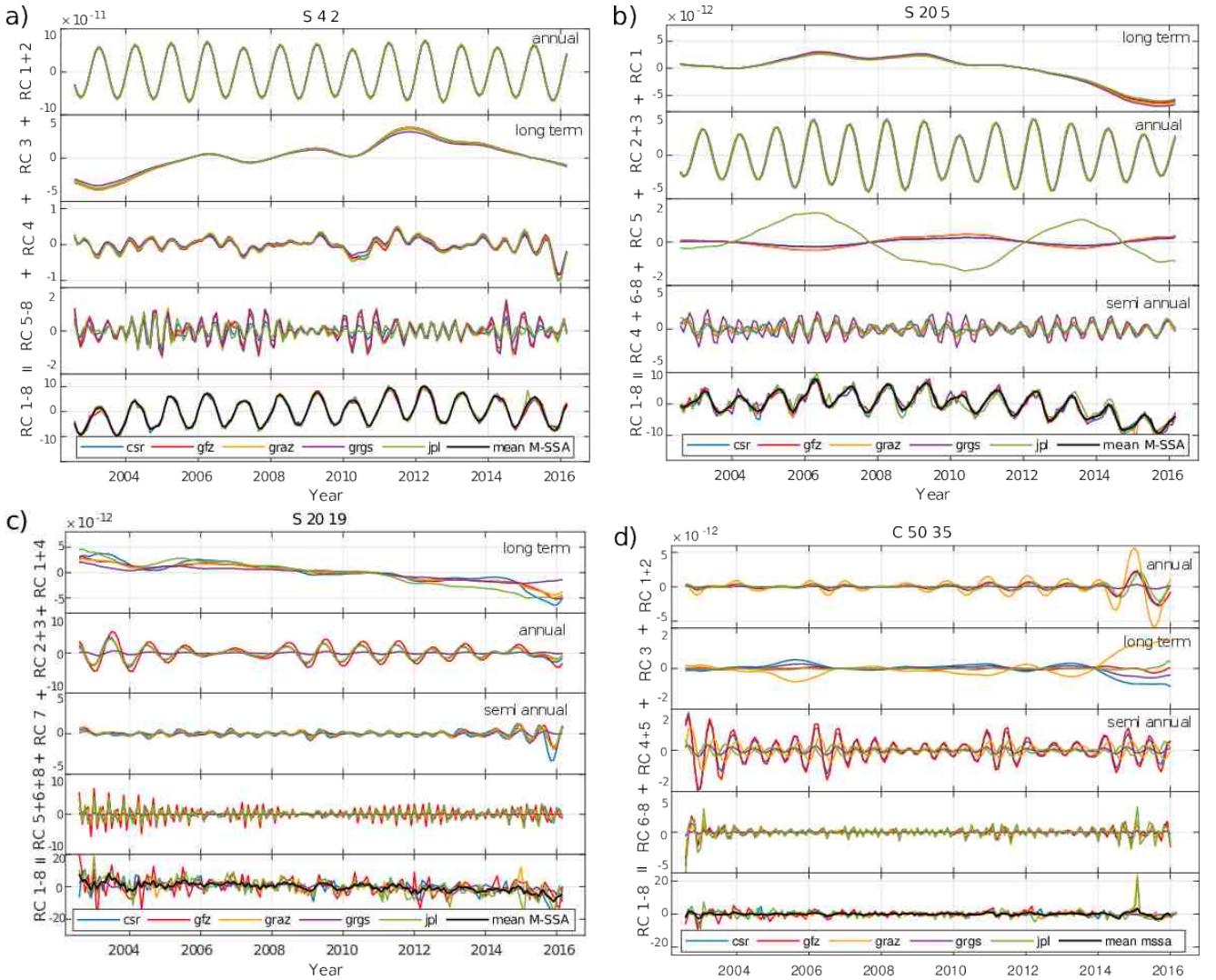


Figure S3: Multichannel Singular Spectrum Analysis (M-SSA) step 1 decomposition of GRACE spherical harmonics. The first 4 panels show one or a visually made combination of partial reconstructions (RCs) of similar nature for each processing center: CSR (blue), GFZ (red), yellow (GRAZ), CNES/GRGS (purple) and JPL (green). The bottom panel shows the signal reconstructions using the first 8 RCs for each of the 5 GRACE solutions and the mean of the reconstructions (black). (a) $S_{4.2}$. (b) $S_{20.5}$. (c) $S_{20.19}$. (d) $C_{50.35}$.

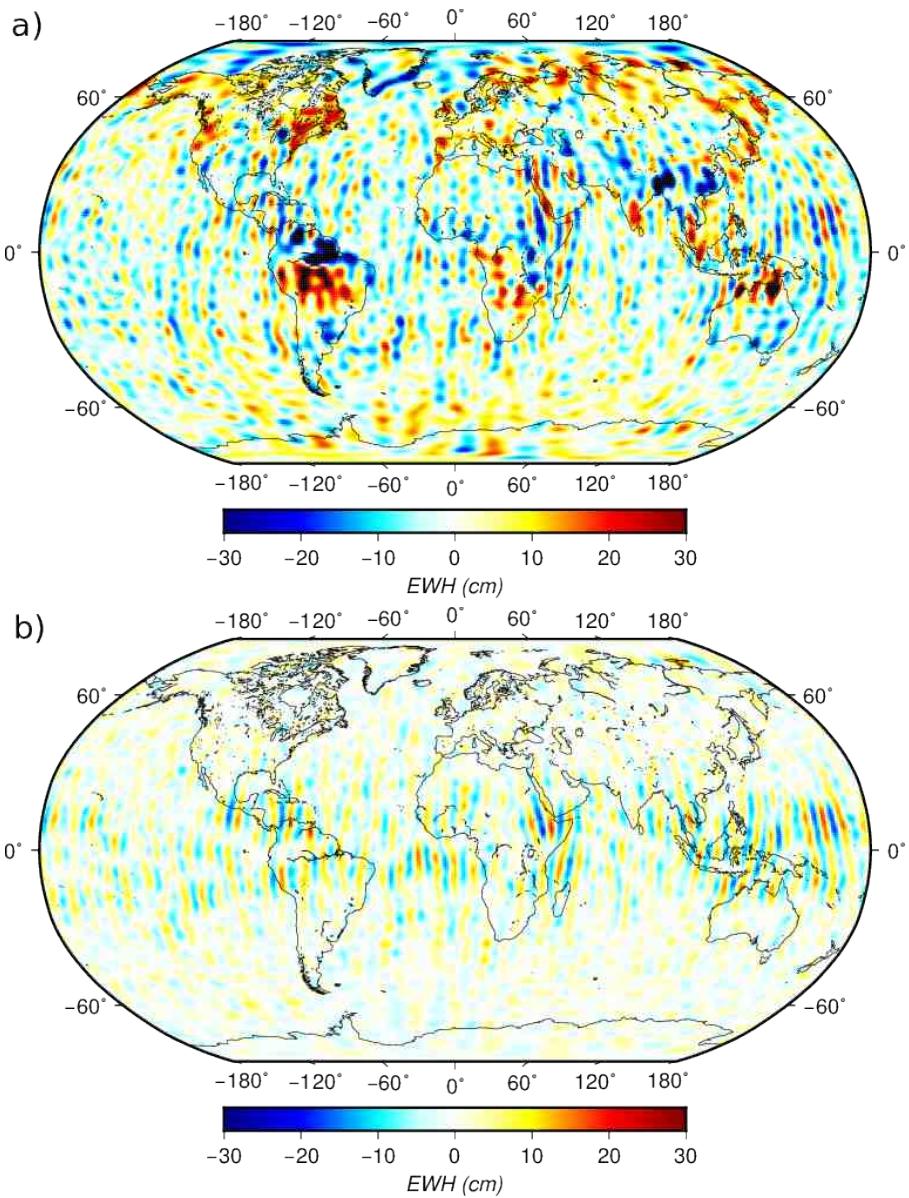


Figure S4: Surface mass density anomalies solutions for January 2006 relative to July 2005, expressed in equivalent water height (EWH, in cm). (a) the M-SSA GRACE step 1 solution obtained from the mean of all 5 processing centers' signals filtered with DDK7 and reconstructed from the leading 12 RCs of the M-SSA step 1; (b) the difference between the reconstructed signal with 12RCs and the one with 8RCs.

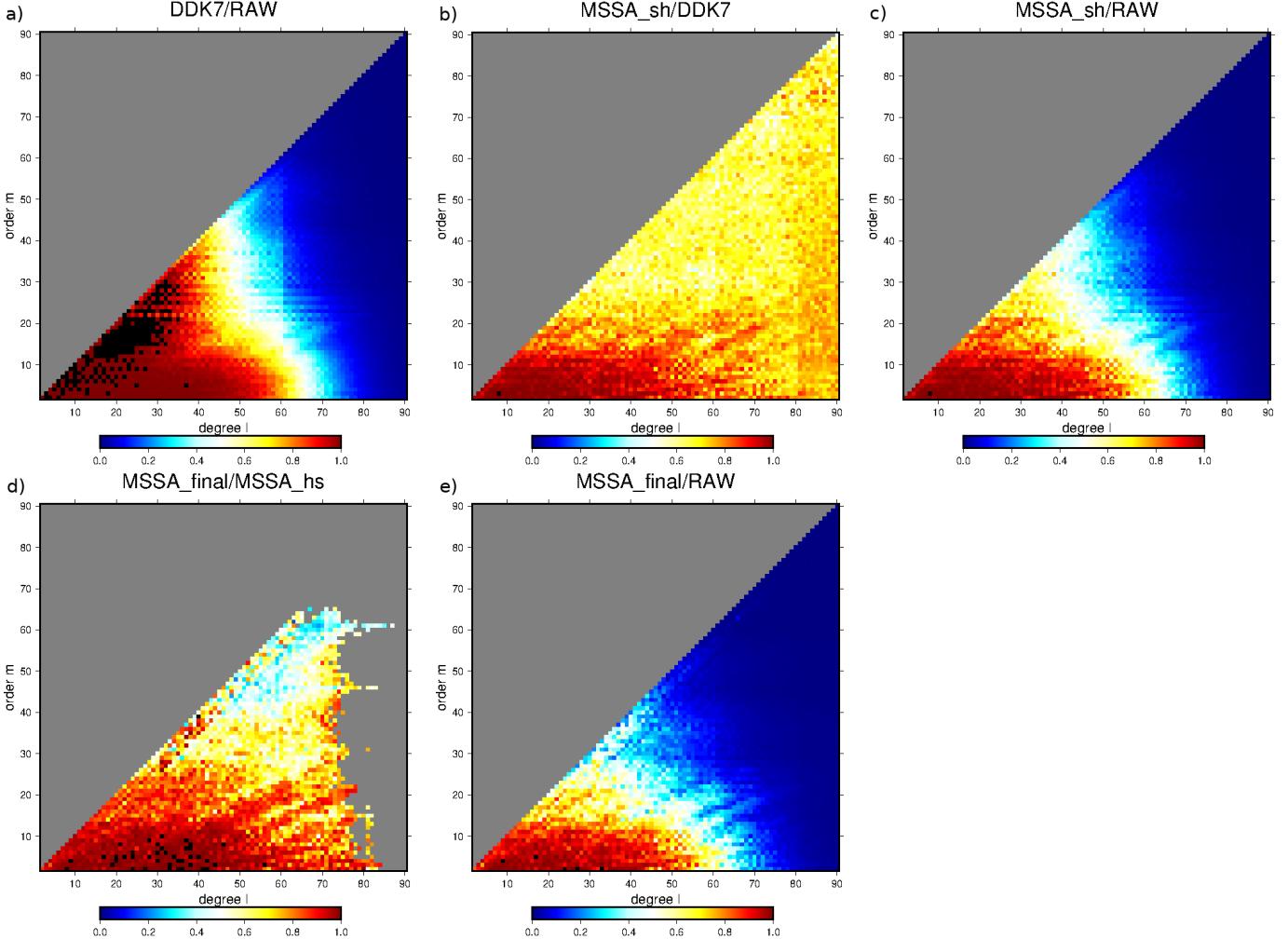


Figure S5: Standard deviation ratio of time dependent spherical harmonics $Y_{lm}(t)$ between (a) the mean of the five centers filtered with DDK7 and the mean of the raw ones; (b) MSSA filtered (step 1) and the mean of the DDK7 filtered ones; (c) MSSA (step 1) filtered and the mean of the raw ones; (d) MSSA (step 2) filtered and MSSA (step 1) filtered ones (in grey when $\text{var}(Y_{lm}(t)) < 3 * 10^{-3}$); and (e) MSSA (step 2) filtered and the mean of the raw ones.

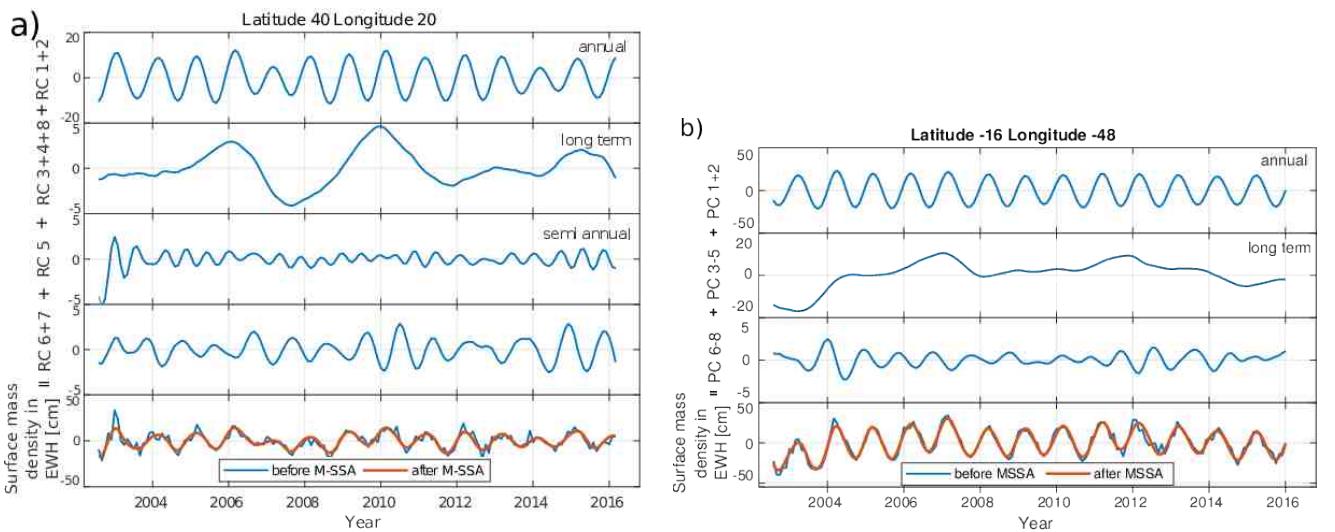


Figure S6: Multichannel Singular Spectrum Analysis (M-SSA) step 2 decomposition of surface mass density anomalies time-series derived from GRACE. The first 3 or 4 panels show one or a visually made combinations of partial reconstructions (RCs) of similar nature. The bottom panel shows the time-series prior to the final M-SSA (blue) and the signal reconstructed using the first 8 RCs (red). (a) at latitude 40° N and longitude 20° E. (b) at latitude 16° S and longitude 48° W.

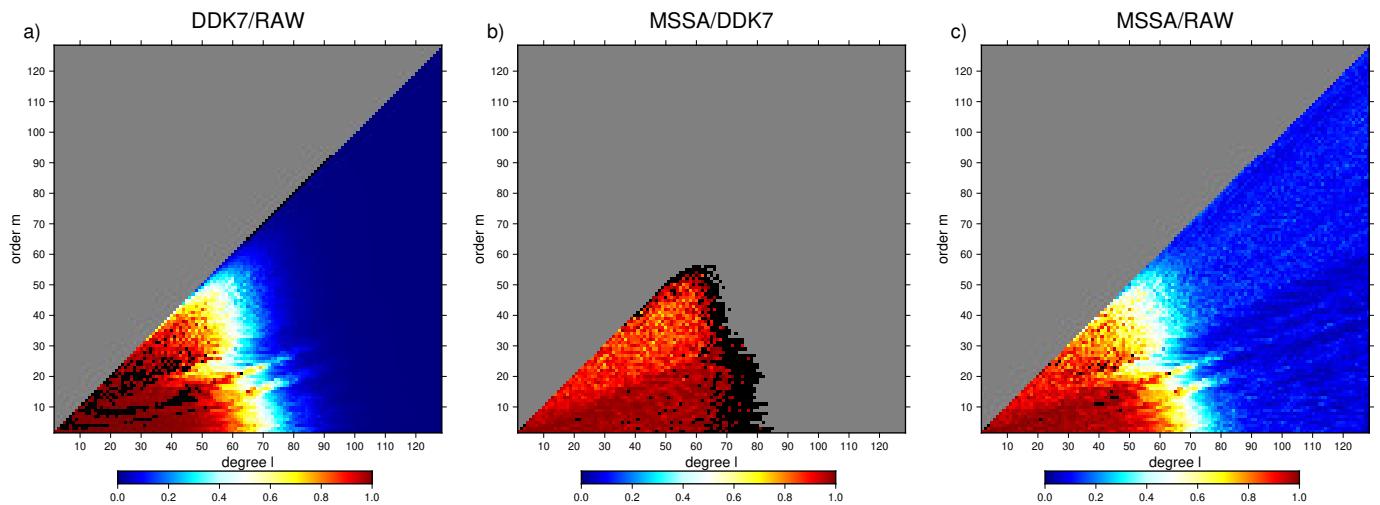


Figure S7: Standard deviation ratio of time dependent spherical harmonics coefficients $Y_{lm}(t)$ from GLDAS data between (a) the one filtered with DDK7 and the raw ones; (b) the M-SSA filtered and the DDK7 filtered ones (in grey when $\text{var}(Y_{lm}(t)) < 3 * 10^{-3}$); (c) the M-SSA filtered and the raw ones.

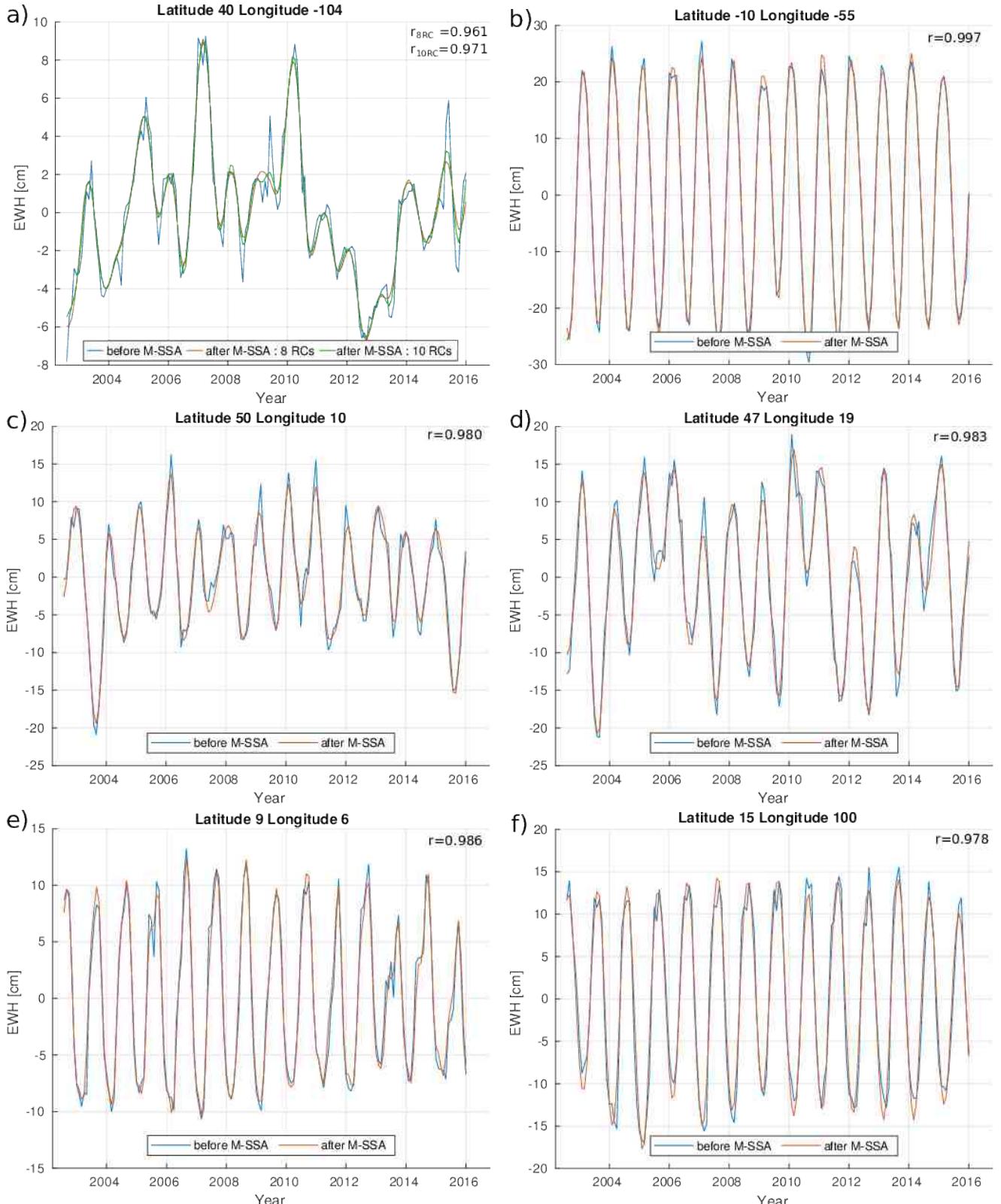


Figure S8: Time-series of total water storage from GLDAS data before (blue) and after (red) the M-SSA with 8 RCs, and r the correlation coefficient between these time-series. (a) In Colorado at latitude 40° N and longitude 104° W; (b) in Brazil at latitude 10° S and longitude 55° W; (c) in Germany at latitude 50° N and longitude 10° E; (d) in Hungary at latitude 47° N and longitude 19° E; (e) in Nigeria at latitude 9° N and longitude 6° E; (f) in Thailand at latitude 15° N and longitude 100° E. In panel (a), the time-serie after M-SSA but with 10RCs has been added (green curve).

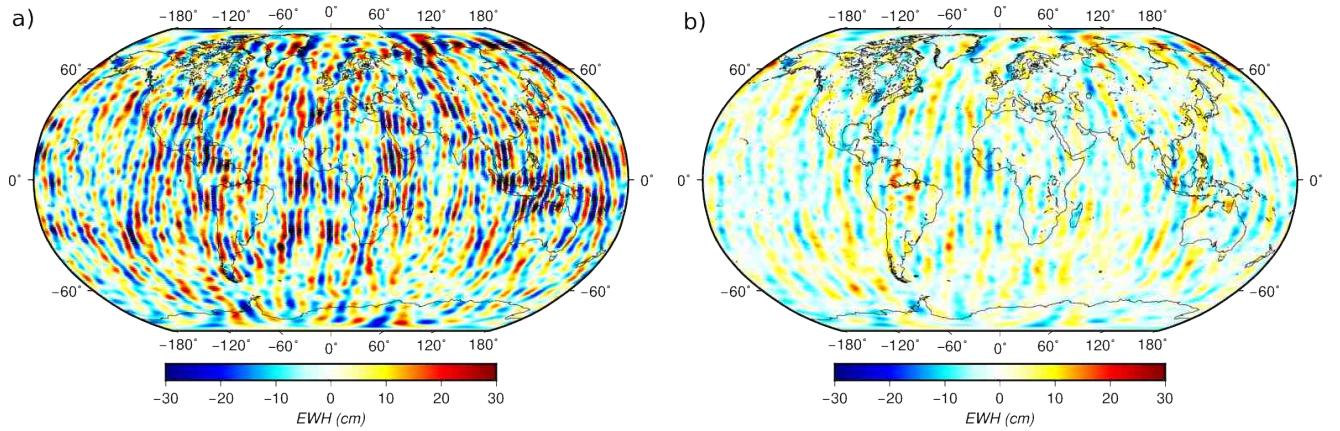


Figure S9: (a) Surface mass density anomalies difference for January 2006 relative to July 2005, expressed in equivalent water height (EWH in cm), between the mean of the JPL, GFZ and CSR solutions, each filtered with DDK7, and the M-SSA solution obtained herein after M-SSA step 2. (b) Same difference map as in panel (a) but the mean of the JPL, GFZ and CSR solutions is filtered with the stronger DDK5 filter.

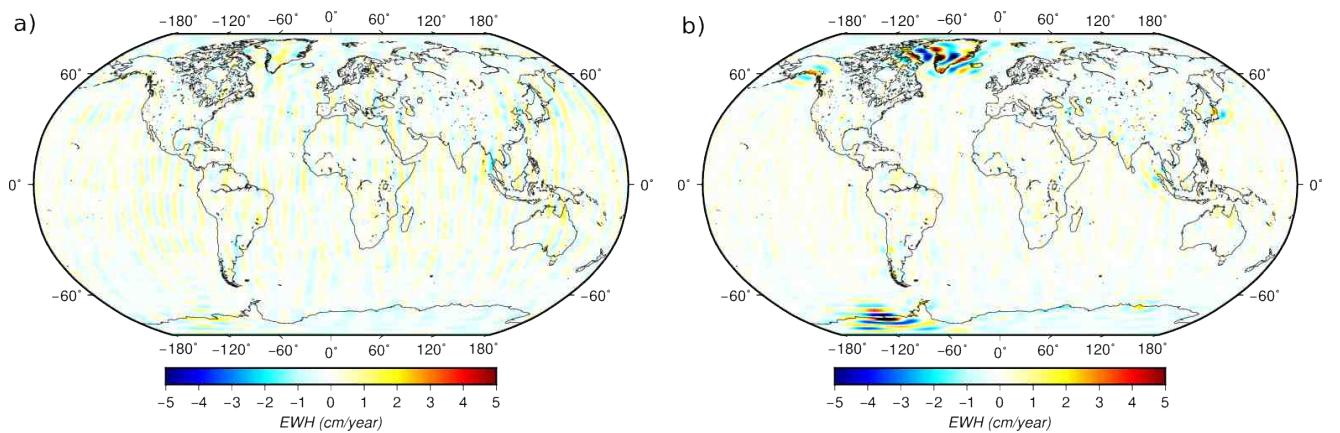


Figure S10: (a) Surface mass density rates from 2003 to 2015 difference expressed in equivalent water height (EWH) per year (in cm yr^{-1}), between the mean of JPL, GFZ and CSR solutions filtered with the decorrelation filter DDK7 and the final M-SSA solution. (b) Same mass rates difference but the mean of JPL, GFZ and CSR solutions is filtered with the decorrelation filter DDK5.

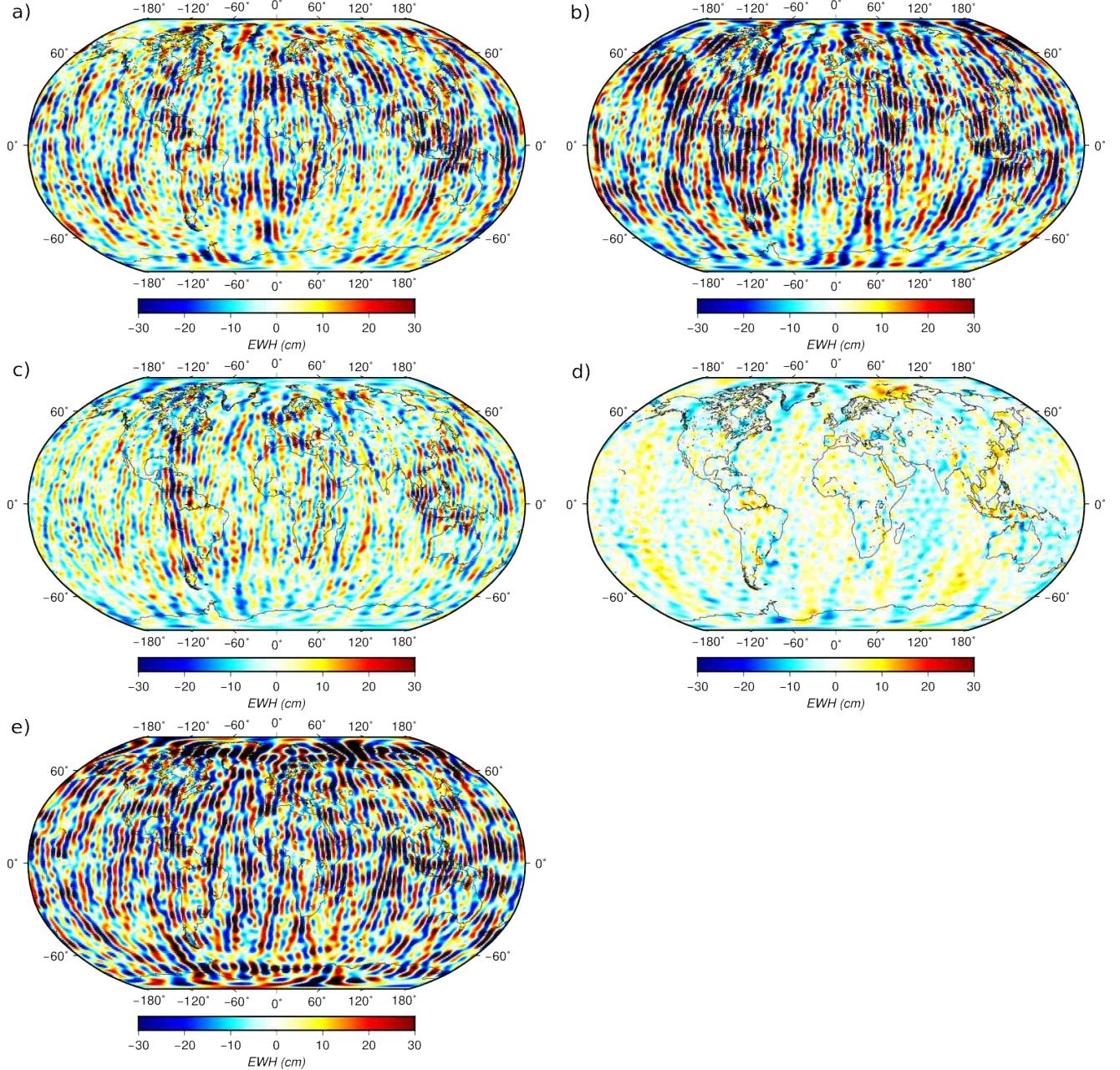


Figure S11: Surface mass density anomalies difference for January 2006 relative to July 2005 expressed in equivalent water height (EWH in cm), between one of the used common solutions filtered with the decorrelation filter DDK7 and the M-SSA solution: (a) solution from CSR. (b) solution from GFZ. (c) solution from GRAZ. (d) solution from GRGS. (e) solution from JPL.

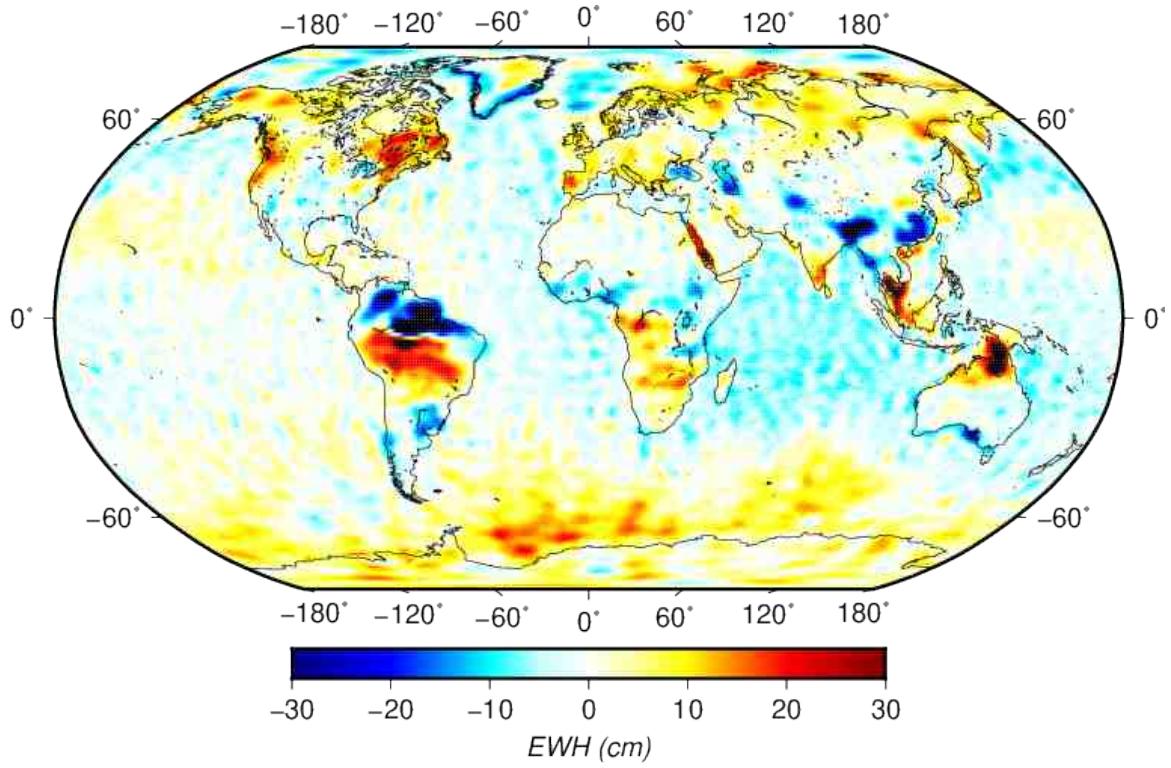


Figure S12: M-SSA surface mass density anomalies solutions for January 2006 relative to July 2005, expressed in equivalent water height (EWH in cm), after restoration of the ocean and atmospheric model over oceans (from AOD1B, ERA-Interim and TUGO) that is removed during the processing of GRACE spherical harmonics data. We need to add them back to compare the M-SSA solution to mascons solution that do not use this correction.

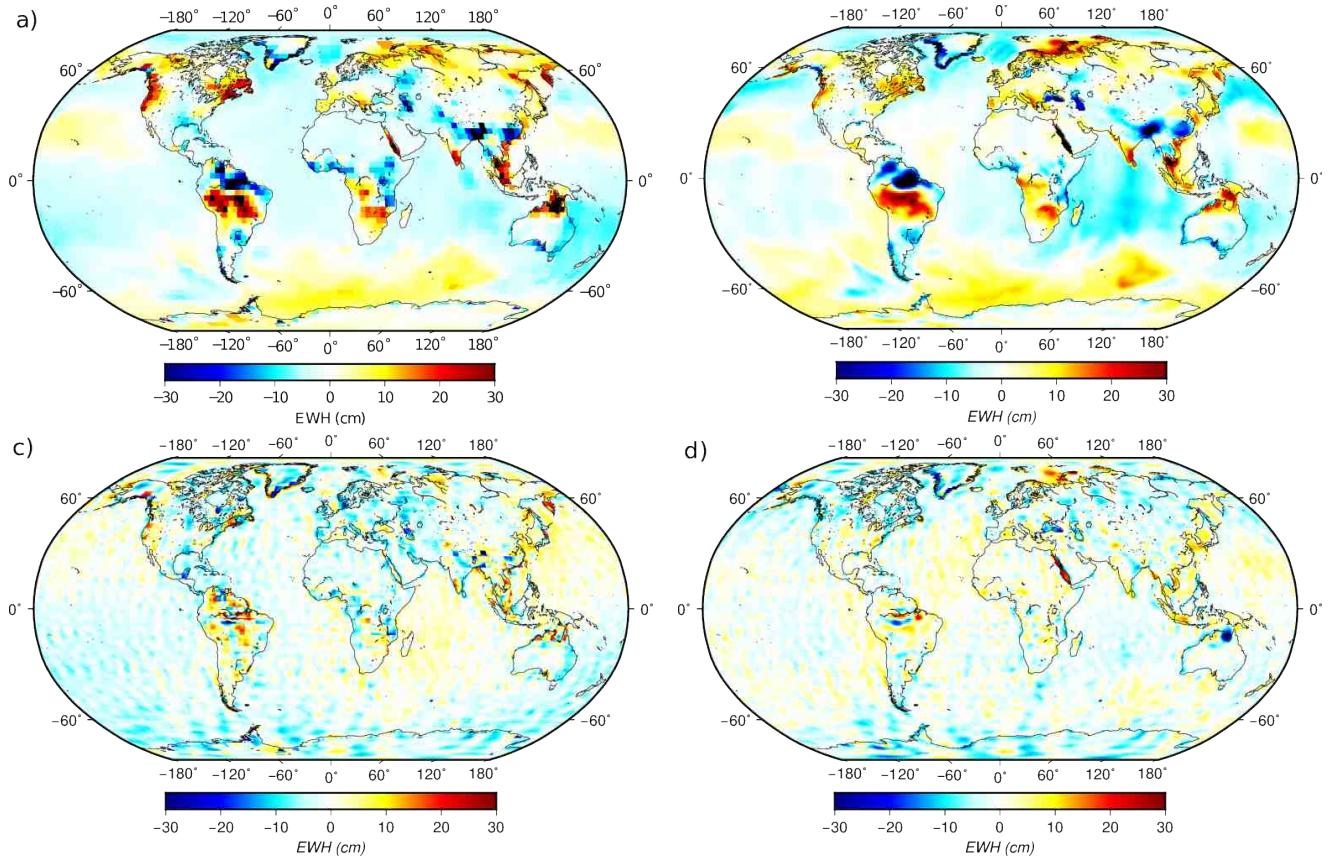


Figure S13: Mascons surface mass density anomalies solutions for January 2006 relative to July 2005, expressed in equivalent water height (EWH in cm). (a) JPL mascons solution. (b) Goddard mascons solution. And surface mass density anomalies differences for January 2006 relative to July 2005, expressed in equivalent water height (in cm), between a mascons solution and the M-SSA solution. (c) JPL mascons. (d) Goddard mascons

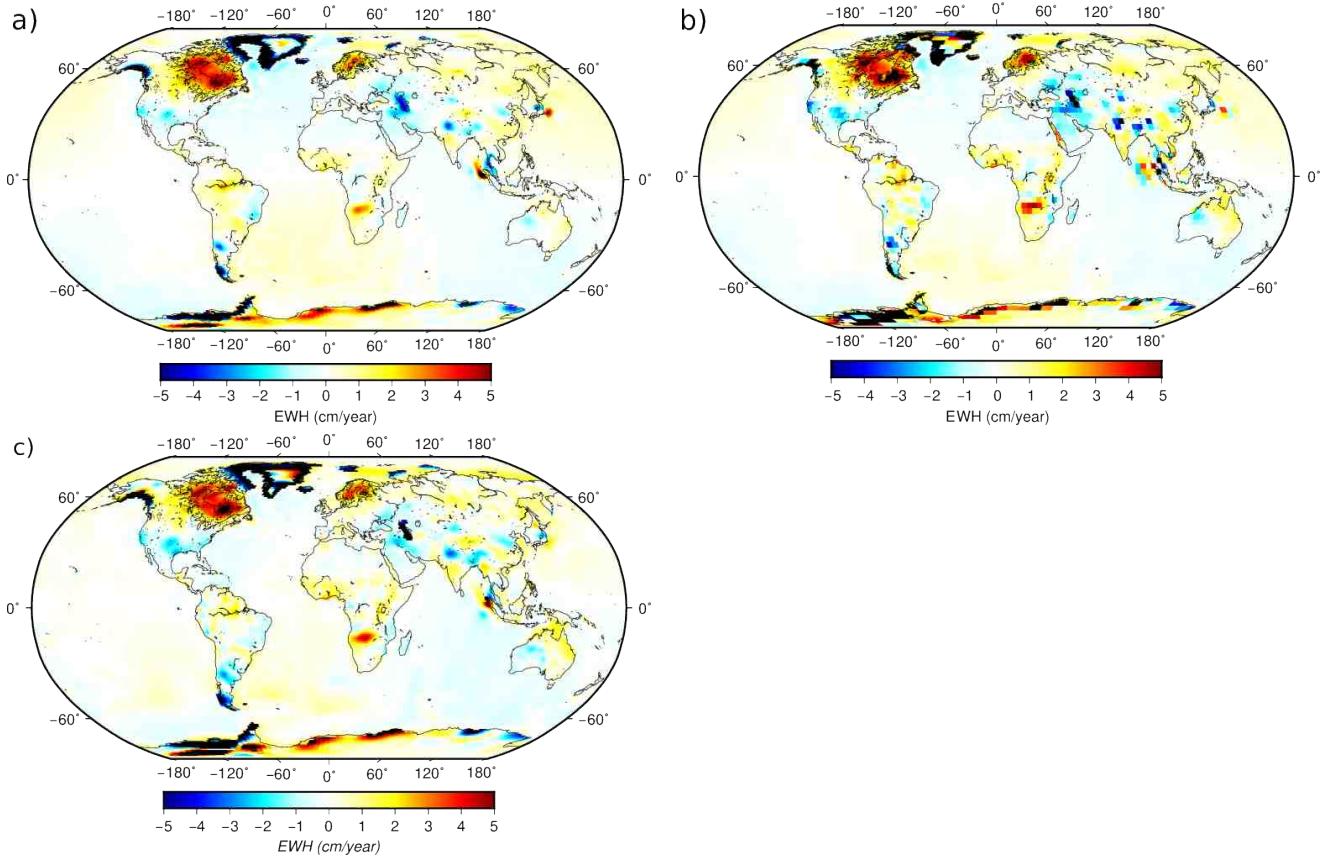


Figure S14: Mascon surface mass density rates from 2003 to 2015 expressed in equivalent water height (EWH) per year (in cm yr^{-1}). (a) CSR mascons. (b) JPL mascons. (c) Goddard mascons.

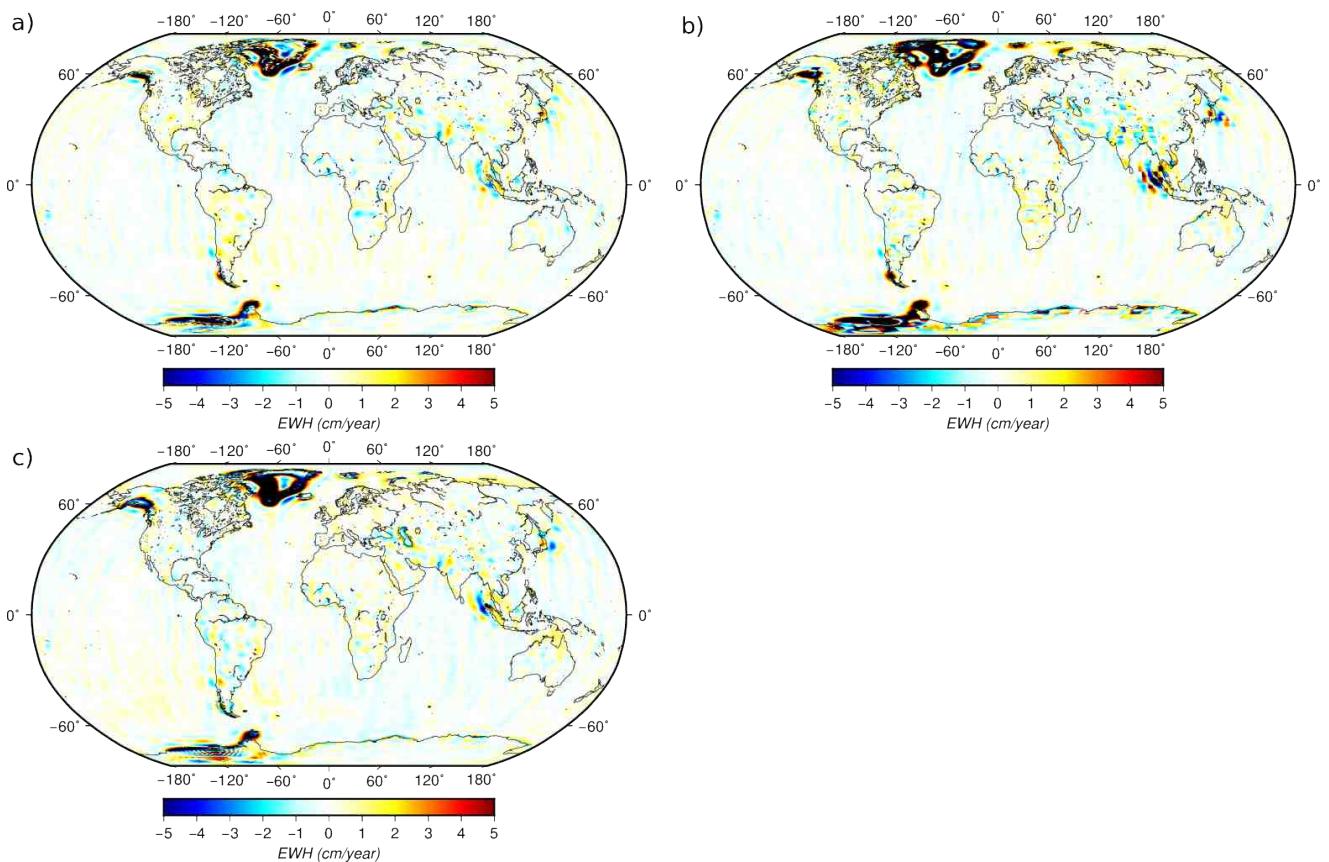


Figure S15: Surface mass density rates from 2003 to 2015 difference expressed in equivalent water height (EWH) per year (in cm yr^{-1}) between a mascons solution and the M-SSA solution. (a) CSR mascons. (b) JPL mascons. (c) Goddard mascons.

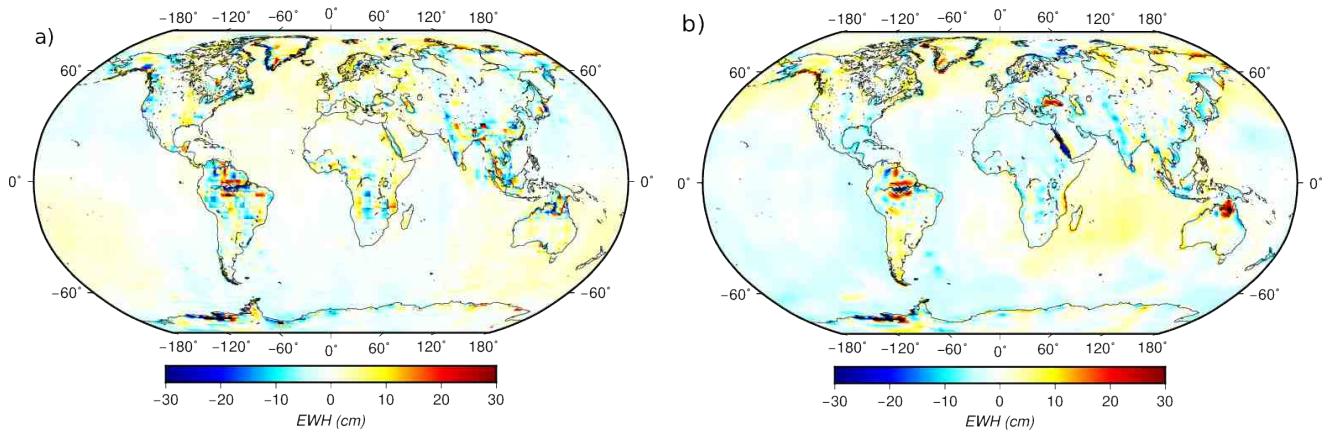


Figure S16: Mascons surface mass density anomalies differences for January 2006 relative to July 2005, expressed in equivalent water height (EWH in cm) between the mascons solution from CSR and :(a) the mascons solution from JPL (b) the mascons solution from GFSC.

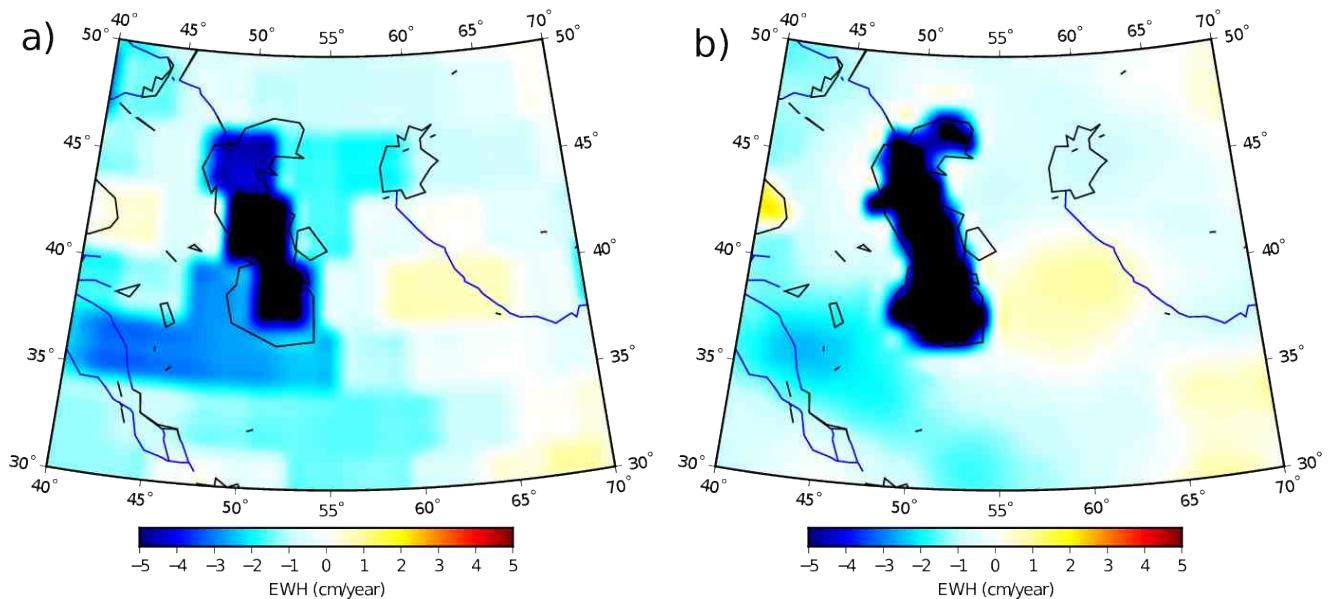


Figure S17: Surface mass density rates from 2003 to 2015 expressed in equivalent water height (EWH) per year (in cm/year) in the Caspian Sea and surrounding regions. (a) JPL mascons. (b) Goddard mascons.

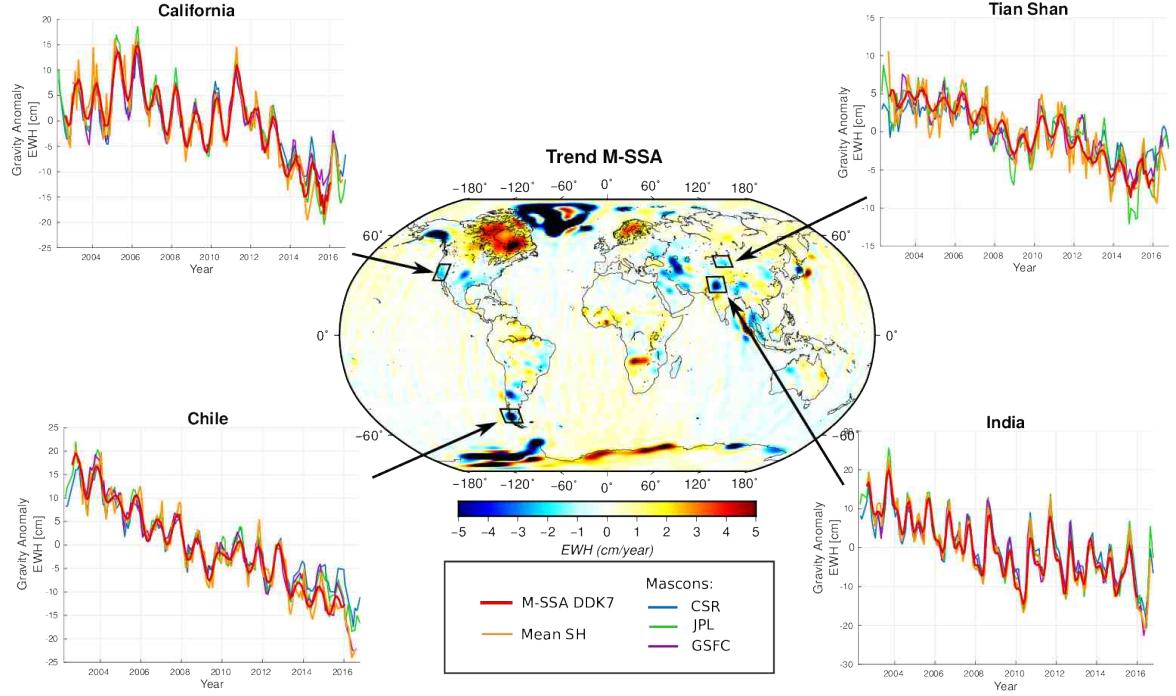


Figure S18: Surface mass density rates from 2003 to 2015 expressed in equivalent water height (EWH) per year (in cm/year) of the M-SSA solution and surface mass density anomalies in EWH time-series at four places on Earth represented by the boxes on the map.

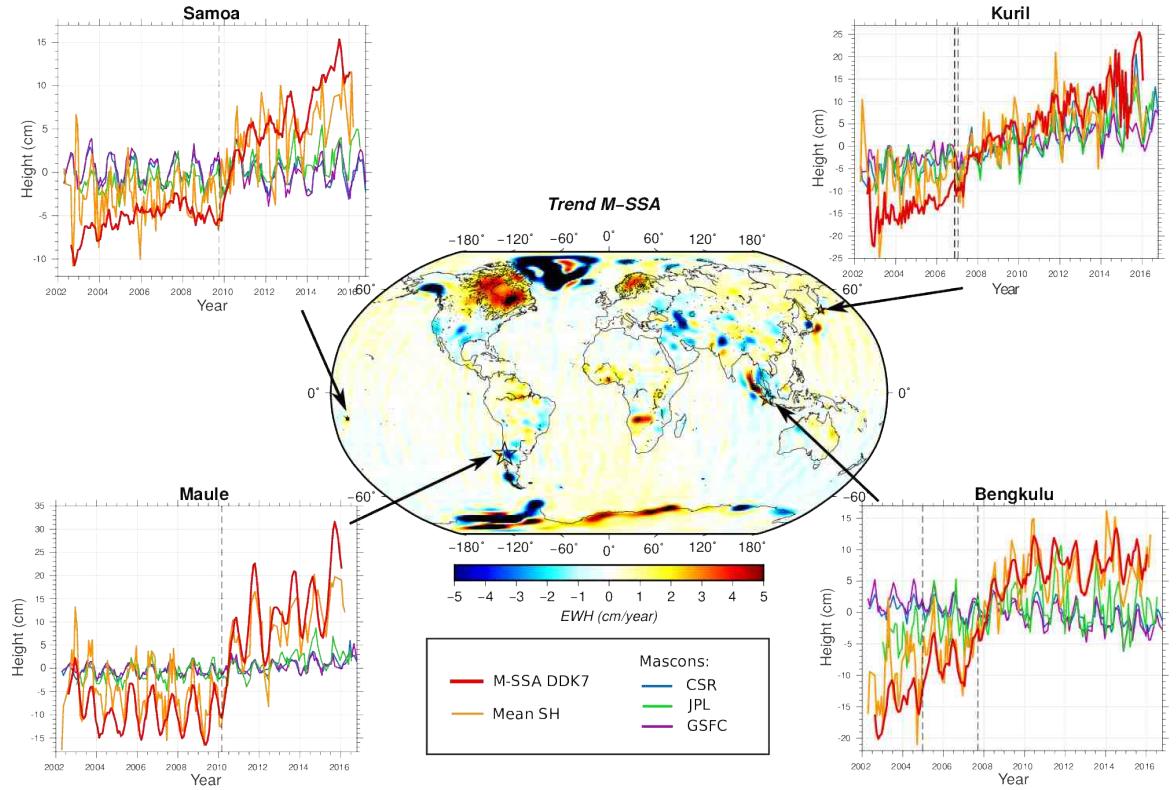


Figure S19: Surface mass density rates from 2003 to 2015 expressed in equivalent water height (EWH) per year (in cm/year) of the M-SSA solution and surface mass density anomalies in EWH time-series at four places on Earth represented by the stars on the map. Co- and post-seismic signals linked to six major earthquakes can be seen on these time-series from M-SSA and usual spherical harmonics solutions. In the contrary, times series from the three mascons solutions don't show any sign of seismic signal.

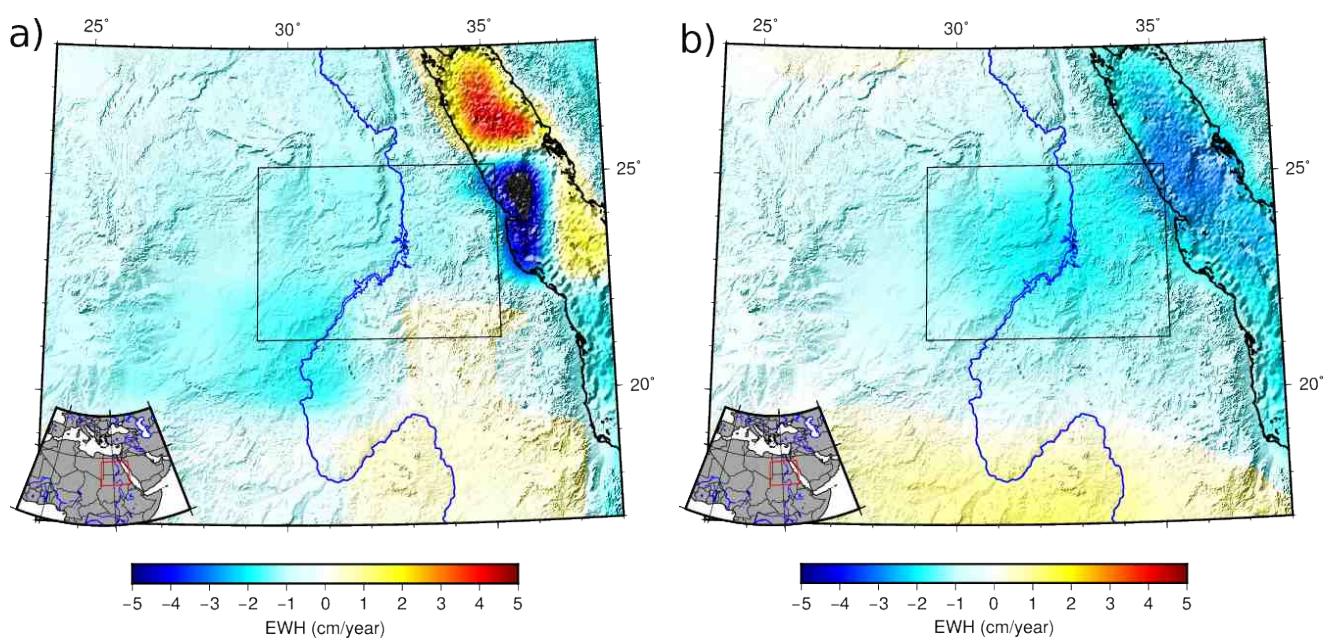


Figure S20: Surface mass density rates from January 2008 to December 2011 expressed in equivalent water height (EWH) per year (in cm yr^{-1}) for different solutions. (a) the GRACE JPL mascon solution. (b) the GRACE GSFC mascon solution.