Supplementary files for

GRACE Water Storage Estimates for the Middle East and Other Regions with Significant Reservoir and Lake Storage

Submitted to HESS

In discussion in HESSD

Longuevergne L. [1]; Wilson, C.R. [2]; Scanlon, B.R. [3]; Cretaux, J.F.[4]

(1) CNRS - Géosciences Rennes UMR 6118, Université de Rennes 1, Rennes, France
(2) Department of Geological Sciences, Jackson School of Geosciences, The University of Texas at Austin, Austin, TX, USA
(3) Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin, Austin, TX, USA
(4) CNES/LEGOS, 14, av. Édouard-Belin, 31400 Toulouse, France

1. *Numerical Experiment 1*

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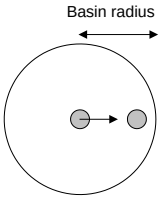
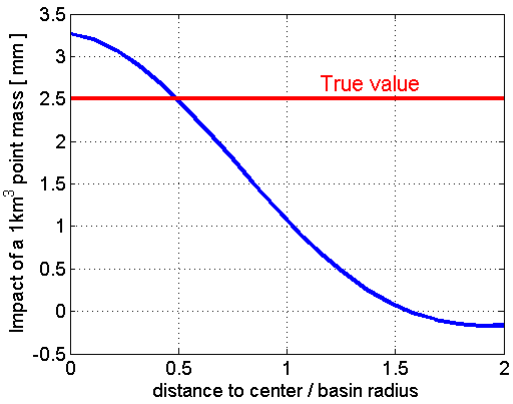
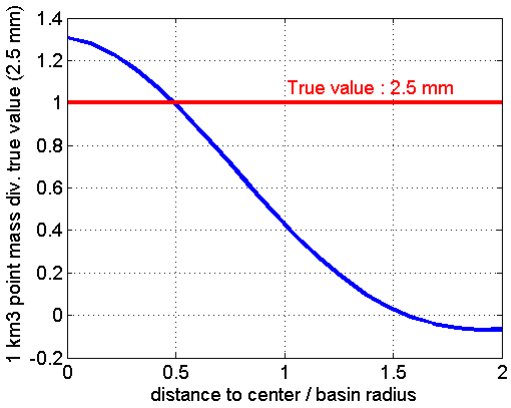
<tr><td> 
</td><td colspan="2">Figure S1 : Experiment 1: Experiment 1: Contours of ABS (apparent basin storage) in mm of water due to a 1 km3 point mass within a circular basin as a function of location relative to basin center (Ratio distance to center versus basin radius) and basin area (M km2, horizontal axis). TBS (true basin storage) is provided on top of the graphs. ABS is given as [mm] on the left to estimate observability of point masses on GRACE, and as reduced to the real value on the right, distributing the same mass uniformly on the basin, to investigate the apparent amplification or damping on GRACE compared to TBS</td></tr>
<tr><td>Degree 50, no smoothing , basin size 0.4 M km²</td><td> 
</td><td> 
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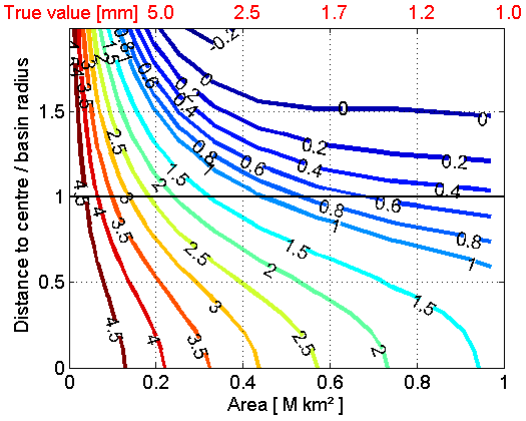
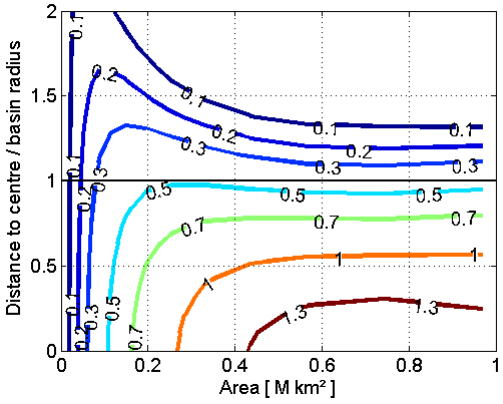
<tr><td>Degree 50, no smoothing</td><td> 
</td><td> 
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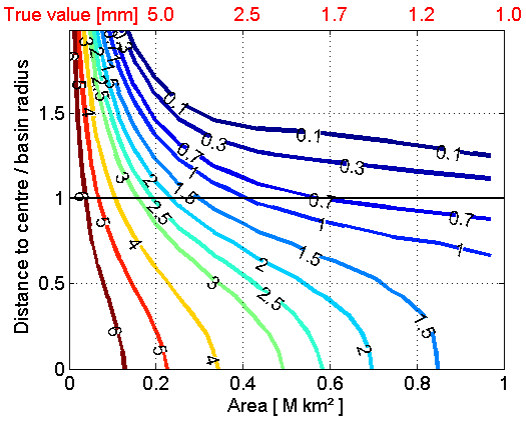
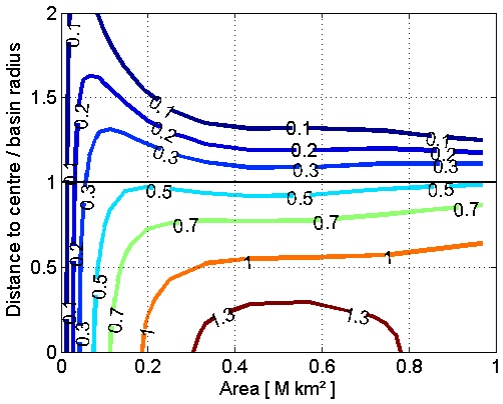
<tr><td>Degree 60, no smoothing</td><td> 
</td><td> 
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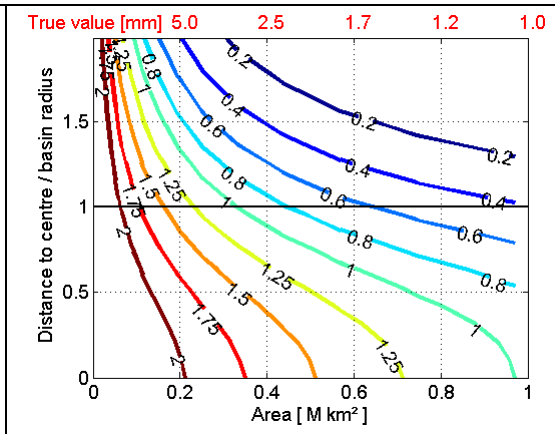
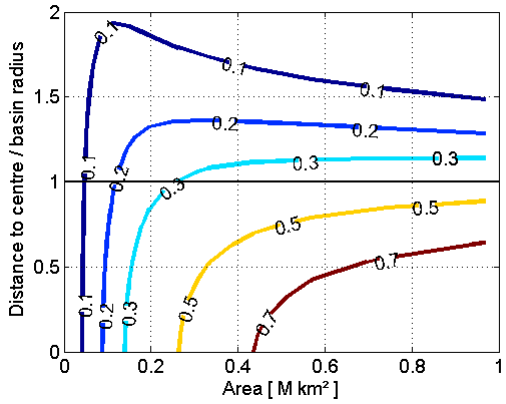
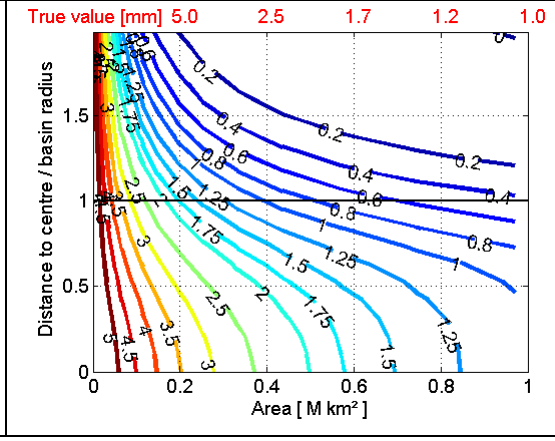
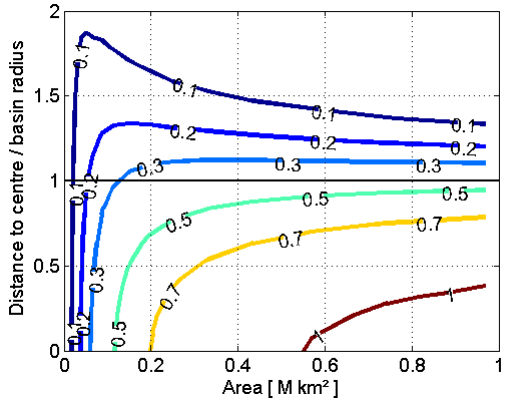
Degree 60, 300-km Gaussian smoother		
Degree 120, 200-km Gaussian smoother		

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2. *Numerical Experiment 2*

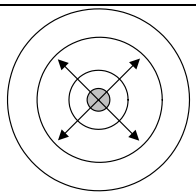
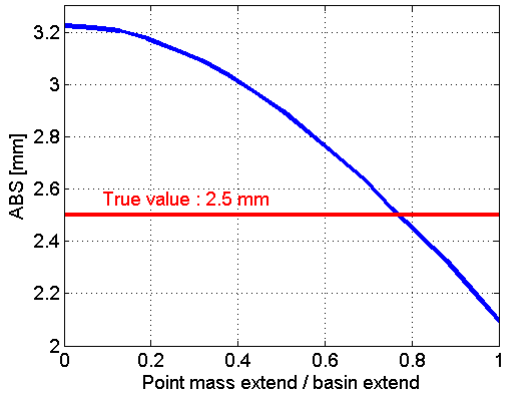
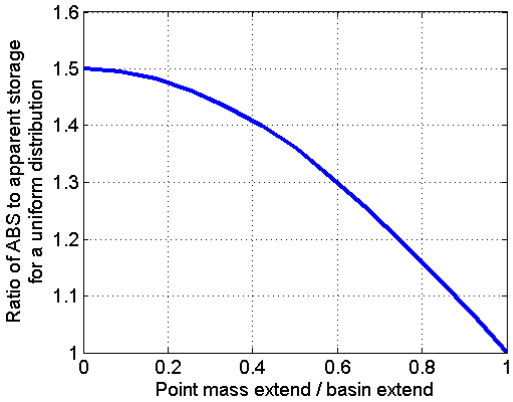


Figure S2: Experiment 2: Mass is centered at the basin center, but its size is varied symmetrically. Contours give ABS of the impact of a 1 km3 mass uniformly distributed, in [mm] on the left, reduced to the impact on GRACE of the same mass distributed over the basin on the right.

Degree 50, no smoothing, basin size 0.4 M km²





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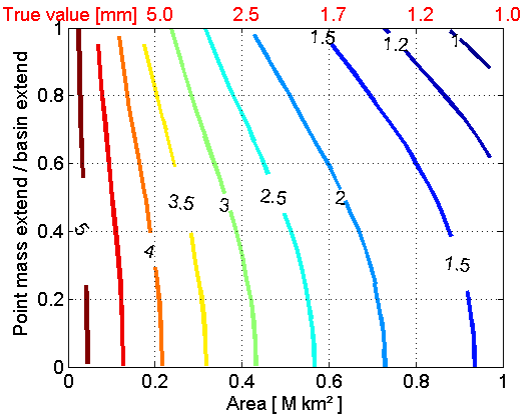

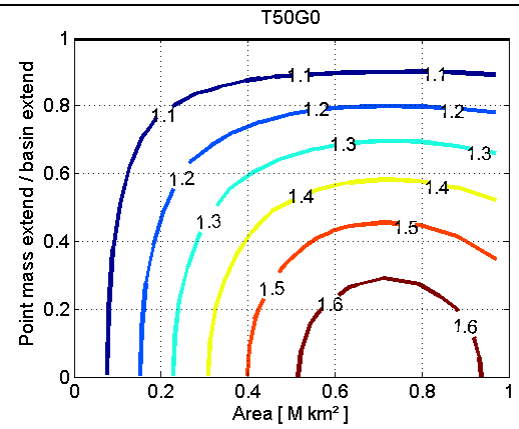

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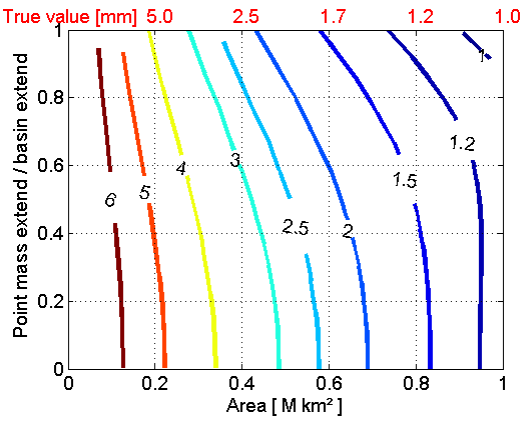
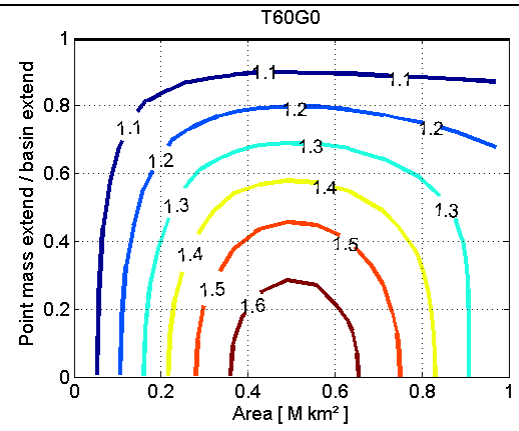
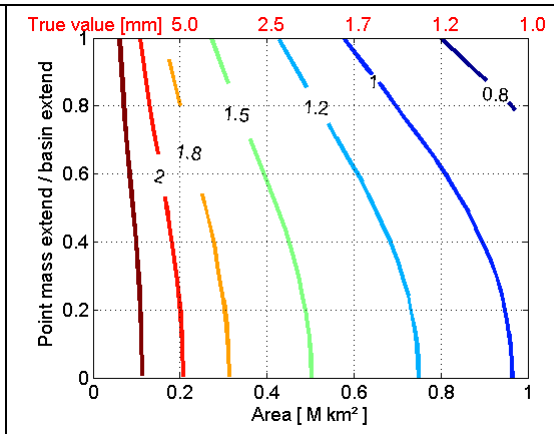
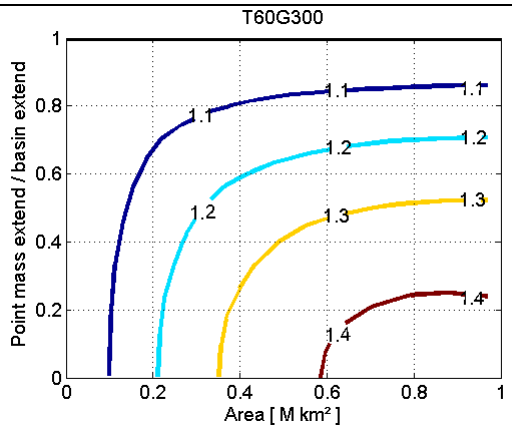
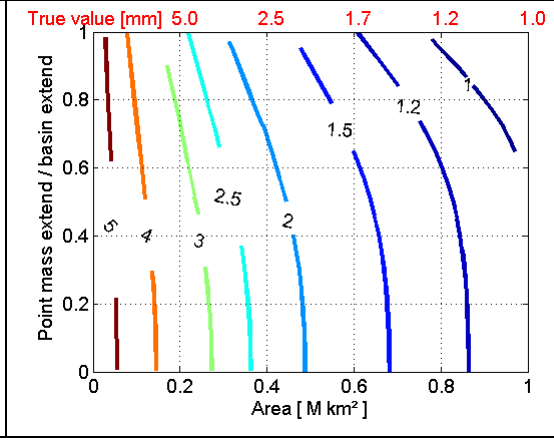
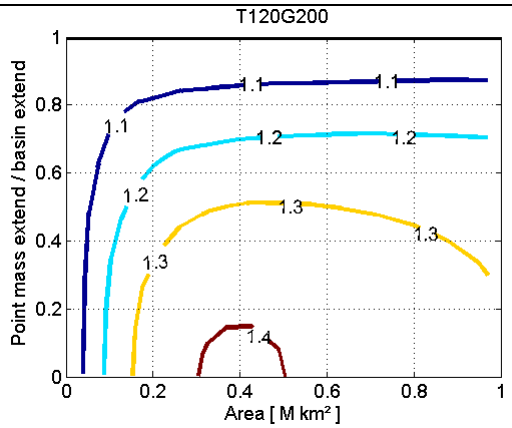




Degree 60, 300-km Gaussian smoother		
Degree 120, 200-km Gaussian smoother		

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3. SH spectra for example regions

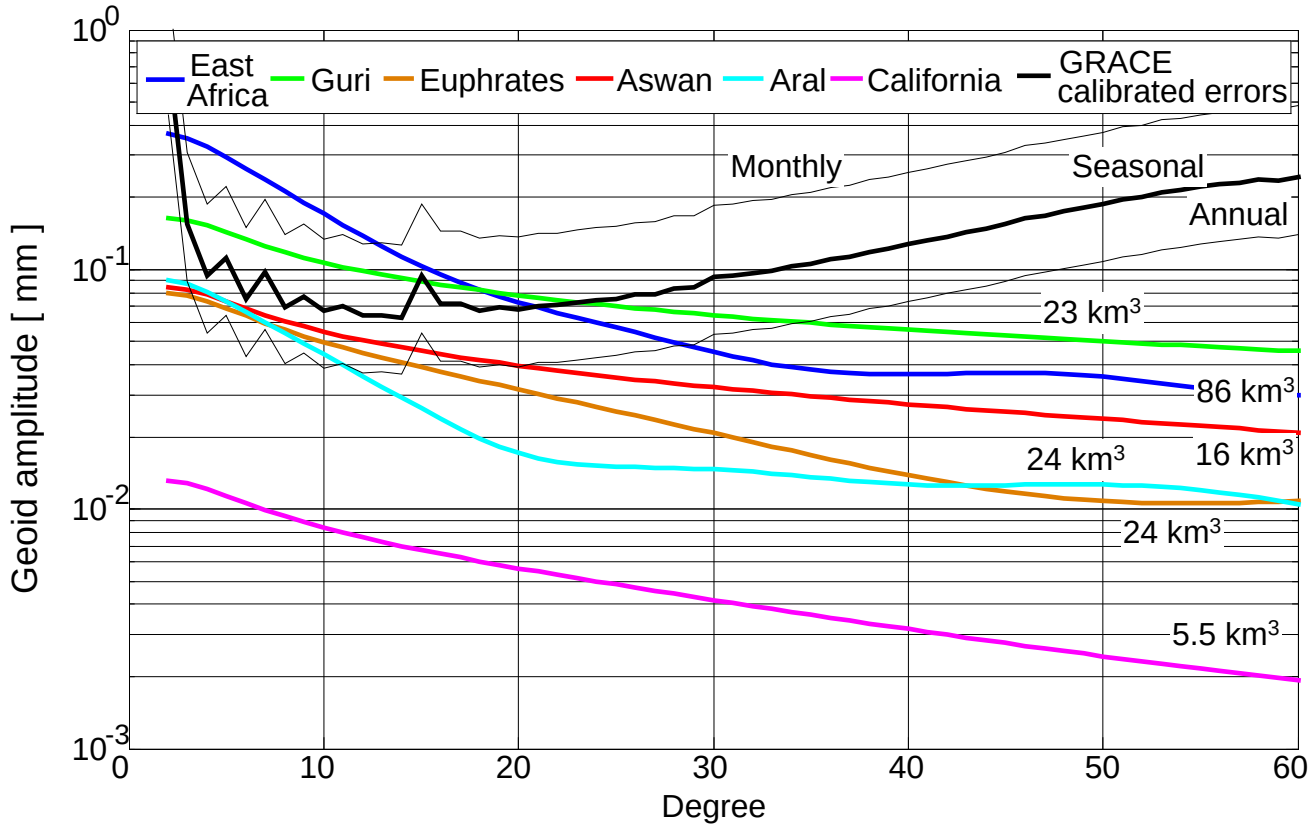


Figure S3: Spherical harmonic (SH) degree-amplitude spectra for GRACE calibrated errors and reservoir storage for the example basins. “Seasonal” and “Annual” calibrated errors are estimated from the decimation process. Lake volume variability is also indicated for each basin. For the California case refer to (Scanlon et al., 2012a). The signature of concentrated masses is evident in the SH domain where a point mass (impulse) contains all harmonics with equivalent amplitude. Because of the small spatial extend of the reservoir, the amplitude spectrum is decreasing slowly with the harmonic degree

Table S1: Lake and Reservoir Data Summary.

Region	Lake name	Area [km²]	Variability [km^3]	Volume / Level data
Lower Nile (410 000 km²)	**Aswan**	**6216 km²**	**16 km^3**	**Level**
Lower Orinoco (350 000 km²)	**Guri**	**3919 km²**	**23 km^3**	
Tigris-Euphrates (790 000 km²)	**TOTAL**	**15268 km²**	**24 km^3**	
	Asad	447	0.30	Level
	Ataturk	707	1.6	Level
	Daryace	5200	3.1	Level
	Mossoul	285	1.7	Level
	Qadisiyah	415	2.8	Volume
	Razazah	1501	1.3	Level
	Saksak	458	1.6	Volume
	Tharthar	2500	8.5	Level
	Van	3755	1.0	Level
East Africa (1 125 000 km²)	**TOTAL**	**175144 km²**	**86 km^3**	
	Albert	5270	2.9	Level
	Bangwelu	9840	3.9	Level
	Cahora Bassa	2739	5.6	Level
	Edouard	2150	0.48	Volume
	Kariba	5400	10.6	Level
	Kivu	2700	0.63	Level
	Kyoga	1720	1.2	Level
	Malawi	29500	14	Level
	Mweru	5120	3.0	Level
	Rukwa	2600	2.3	Level
	Tanganyka	32900	12	Level
	Turkana	6405	4.6	Level
	Victoria	68800	25	
Amu - Syr Darya (1 180 000 km²)	**TOTAL**	**39316 km²**	**24 km3**	
	Aral sea – North	3300	2.5	Volume
	Aral sea – South	3000	2.6	Volume
	Aydarkul	3000	2.4	Level
	Balkhash	16996	3.9	Level
	Chardarya	250	0.55	Volume
	Issykkul	6286	0.80	Level
	Kapchagayskope	1200	0.56	Level
	Sarykamish	5000	5.3	Level
	Toktogul	284	5.5	Volume

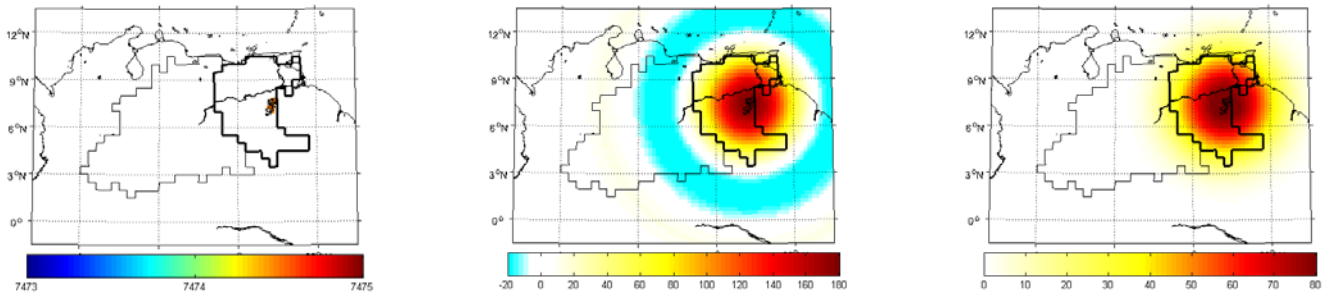
4. Tigris-Euphrates Basin – LSM Estimates

Table S2: Comparison between GRACE, ∆SMS and ∆RES for Tigris-Euphrates basin. In all cases, adding predicted ∆RES contribution to LSM output drive to a better agreement with GRACE data

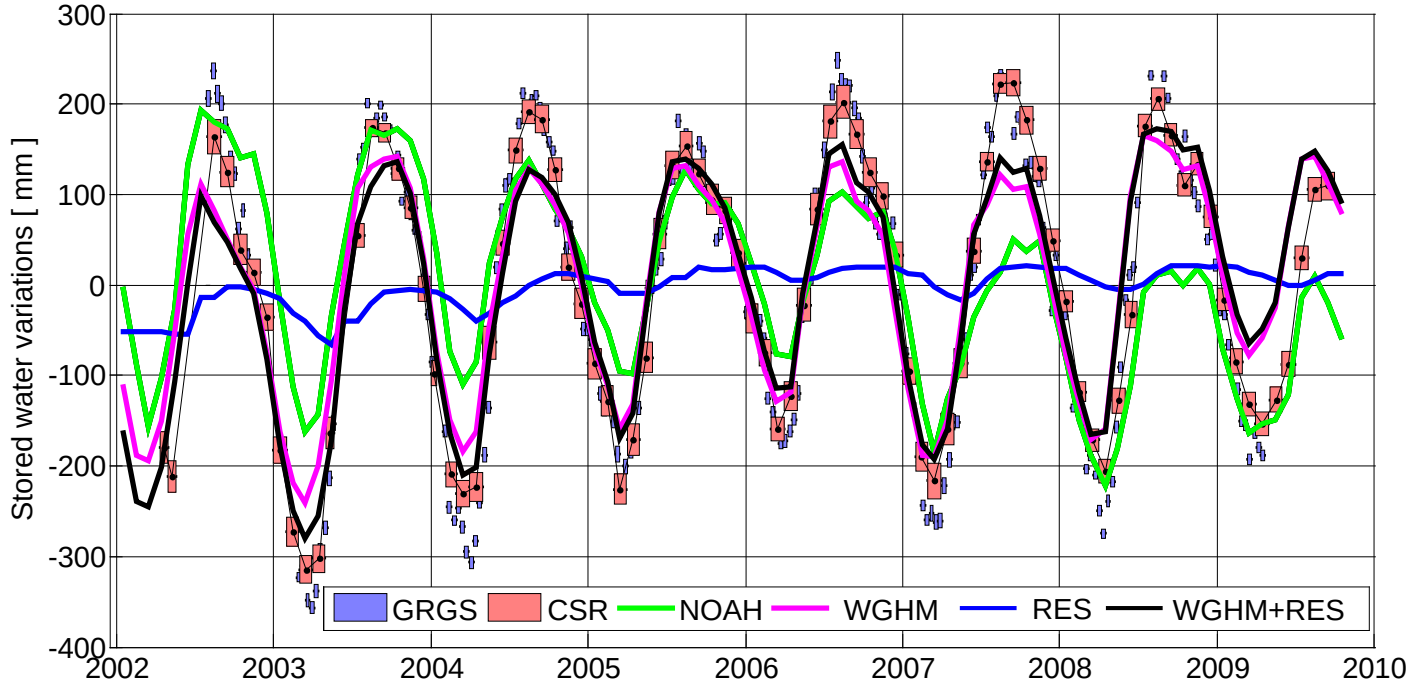
	GRACE CSR	CLM	CLM + ∆RES	MOSAIC	MOSAIC + ∆RES	NOAH	NOAH + ∆RES	VIC	VIC + ∆RES	WGHM	WGHM + ∆RES
Amplitude of seasonal variations [mm]	63.1	22.7	**23.4**	56.6	**62.9**	44.2	**45.2**	47.7	**49.1**	39.7	**40.8**
Phase (seasonal) [days]	Ref.	-36	**-15**	-16	**-1.2**	-29	**-17**	-26	**-16**	-29	**-16**
Correlation	Ref.	0.80	**0.89**	0.93	**0.95**	0.88	**0.93**	0.82	**0.93**	0.86	**0.92**
RMS with GRACE [mm]	Ref.	47	**38**	25	**20**	34	**25**	37	**27**	36	**28**
Trend (2002/10 - 2009/09) [mm/year]	-11	- 3.2	**-7.3**	- 8.4	**-12**	-6.0	**-11**	-3.2	**-7.3**	-5.2	**-9.2**
Trend (2006/10 – 2009/09) [mm/year]	-39	-7	**-26**	-21	**-39**	-18	**-37**	-7.9	**-27**	-14	**-33**

5. Lower Orinoco - Guri Dam

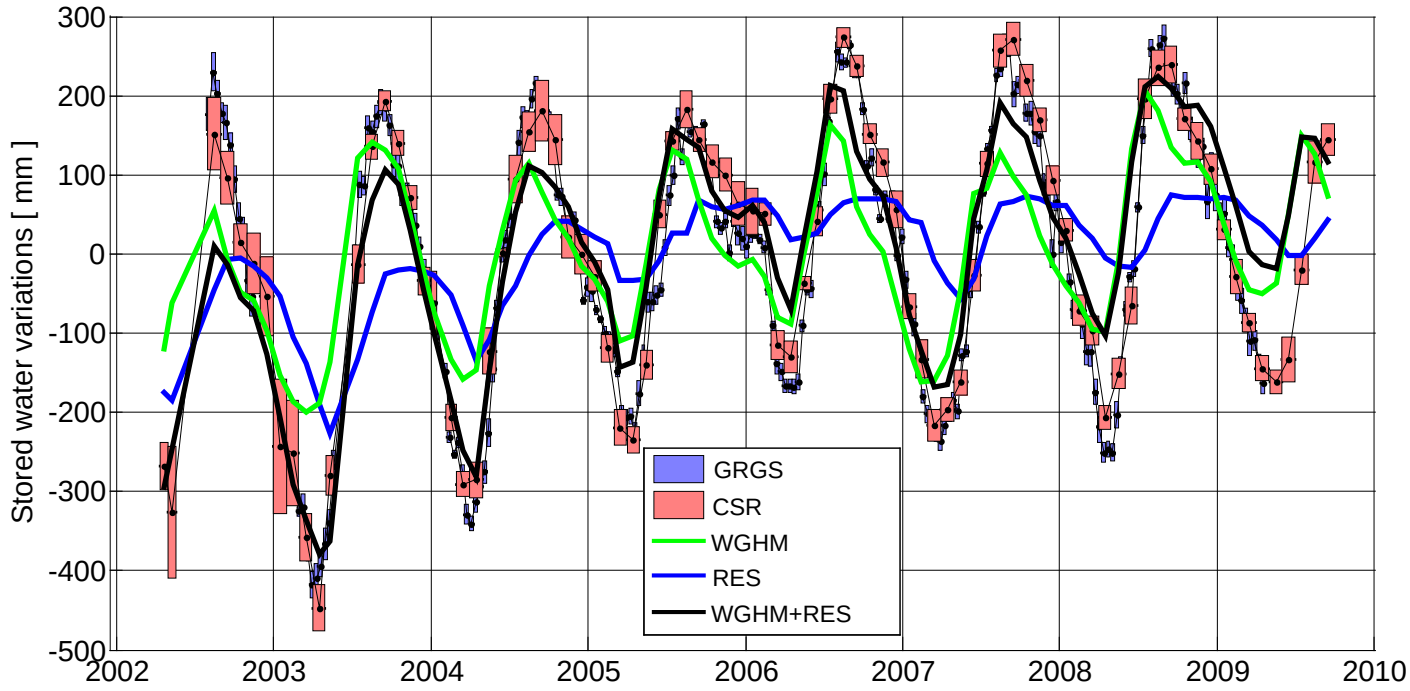
a) b) c)



d) Orinoco basin *(1 M km²)*



e) Lower Orinoco basin *(350 000 km²)*



f) Lower Orinoco Basin *(350 000 km²)*

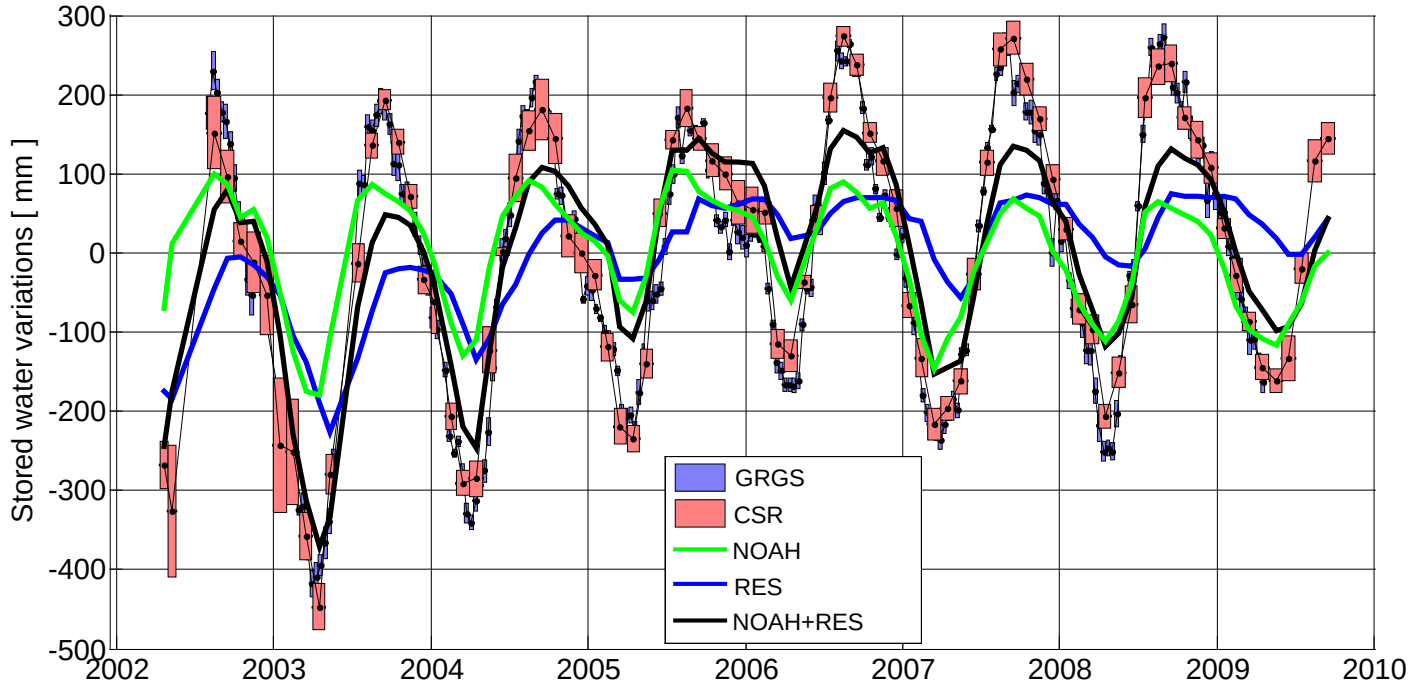


Figure S4: Lower Orinoco and Guri lake contribution. The Guri dam impounds the Caroni River (Venezuela) and creates a lake of 3919 km². The first stage of the facility was completed in 1969 and completed in 1986, as a 162-m high earth and rockfill dam with a crest length of 11 km. It is mainly used for hydropower purpose (capacity of 10 300 MW) and covers 50% of Venezuela's electricity. (a) Reservoir distribution and standard deviation of Guri lake level variation within the basin, (b) same map after truncation at degree 50, (c) same map after truncation at degree 60 and 300-km Gaussian smoother applied. Thick line is lower Orinoco basin (d) GRACE Water storage variations in the Orinoco basin (1 M km²) compared to GLDAS, WGHM and RES from Guri dam, (e) GRACE water storage variations in the Lower Orinoco basin (320 000 km²) compared to WGHM (f) same as e but comparison with NOAH model. Water mass variations from the Inundated area along the course of the river are not modeled in GLDAS and may explain remaining discrepancy with GRACE.

Table S2: Comparison between GRACE, ∆SMS and ∆RES for Lower Orinoco basin (350 000 km²)

	GRACE CSR	∆RES Contribution	NOAH	NOAH + ∆RES	WGHM	WGHM + ∆RES
Seasonal amplitude [mm]	199	51 (25%)	85	**129**	116	**143**
Phase (seasonal) [days]	Ref.	+39	-14	**0**	-28	**-8**
Correlation	Ref.		0.87	**0.93**	0.84	**0.91**
Trend [mm/year]	22	20	-4.6	**16**	16	**36**

Table S3: Comparison between GRACE, ∆SMS and ∆RES for Orinoco basin (1 M km²)

	GRACE CSR	∆RES Contribution	NOAH	NOAH + ∆RES	WGHM	WGHM + ∆RES
Seasonal amplitude [mm]	185	16.5 (9%)	113	**127**	146	**156**
Phase (seasonal) [days]	Ref.	+44	7	**11**	-10	**-5**
Correlation	Ref.		0.78	**0.83**	0.93	**0.95**
Trend [mm/year]	8.1	5.3	-23	**-18**	10	**16**

6. East African Lakes

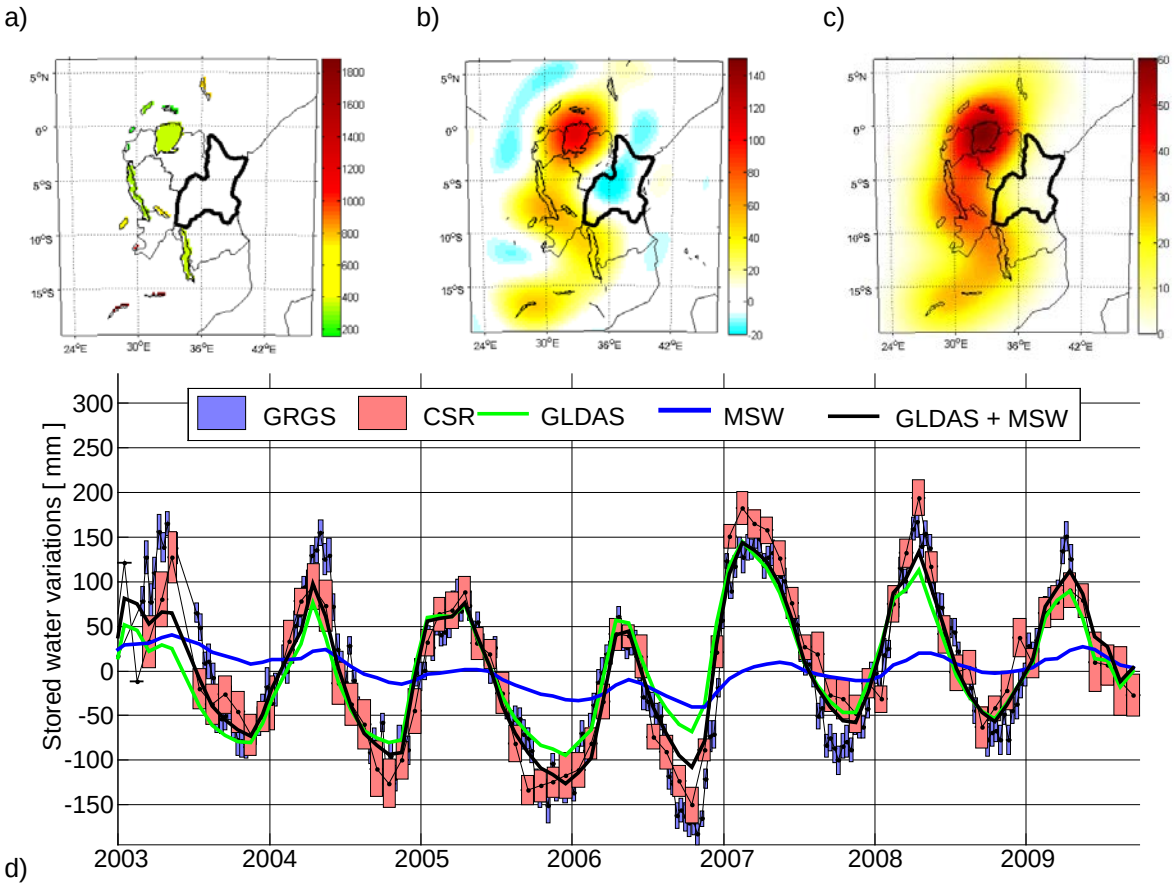


Figure S5: This example explains lake contributions from GRACE from Xie et al.,[2012]. (a) reservoir distribution and mass variations for each of the 34 lakes, (b) associated mass variations after truncation to degree 50, (c) mass variations after truncation at degree 60 with 300-km Gaussian smoothing. Thick outline is the North Tanzania coastal basin (355 000 km²). Note that the predicted lake effect on CSR and GRGS shows different leakage amplitudes and signs in this basin. (d) comparison between lake storage, GLDAS NOAH and GRACE on Tanzania (1 125 000 km²).