



Validation of GRACE Observations

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How to validate GRACE observed mass or gravity change?

Major Challenges

- ❑ Lack of adequate *in situ* observations
- ❑ Mismatch of spatial resolutions between GRACE and limited *in situ* data
- ❑ Leakage biases in GRACE estimates due to truncation and spatial filtering
- ❑ ...

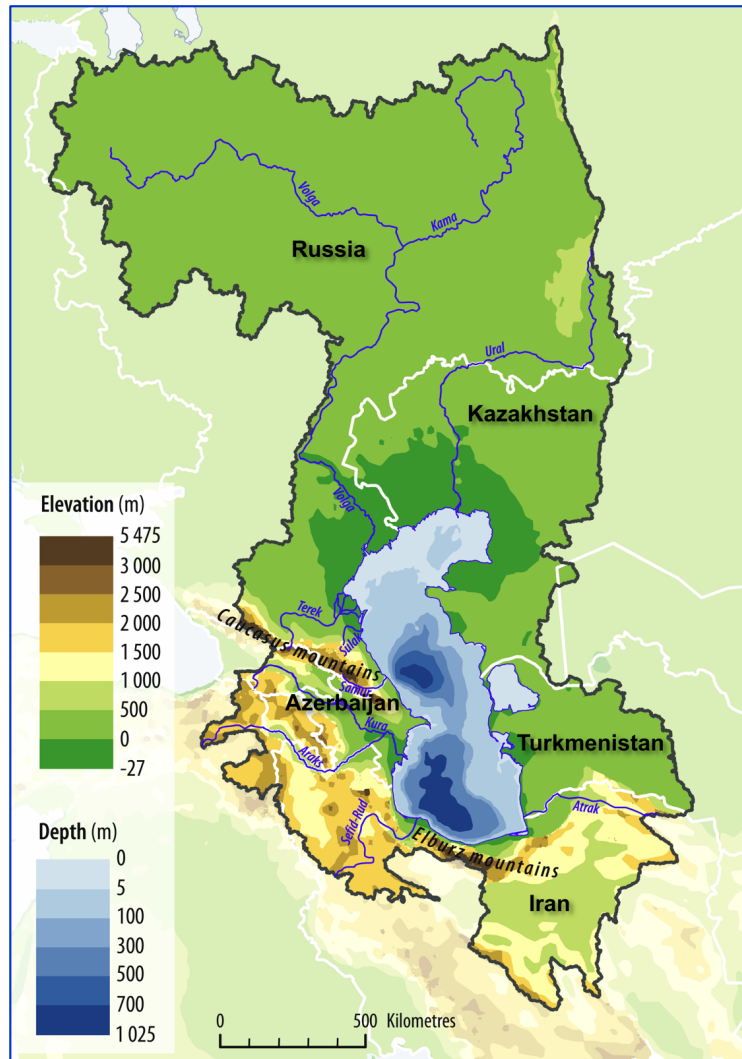


Limited Resources for Validating GRACE Observations

- ❑ Satellite laser altimeter (ICESat) and other remote sensing data over polar ice sheets
- ❑ Satellite radar altimeter global mean sea level change + Argo steric
- ❑ Groundwater level observations from dense well network in limited regions
- ❑ Low-degree gravitational changes from satellite laser ranging (SLR) and Earth rotation observations
- ❑ Invariable terrestrial water storage in the Sahara Desert (what a smart idea!)
- ❑ Water storage change of large lakes
- ❑ ...

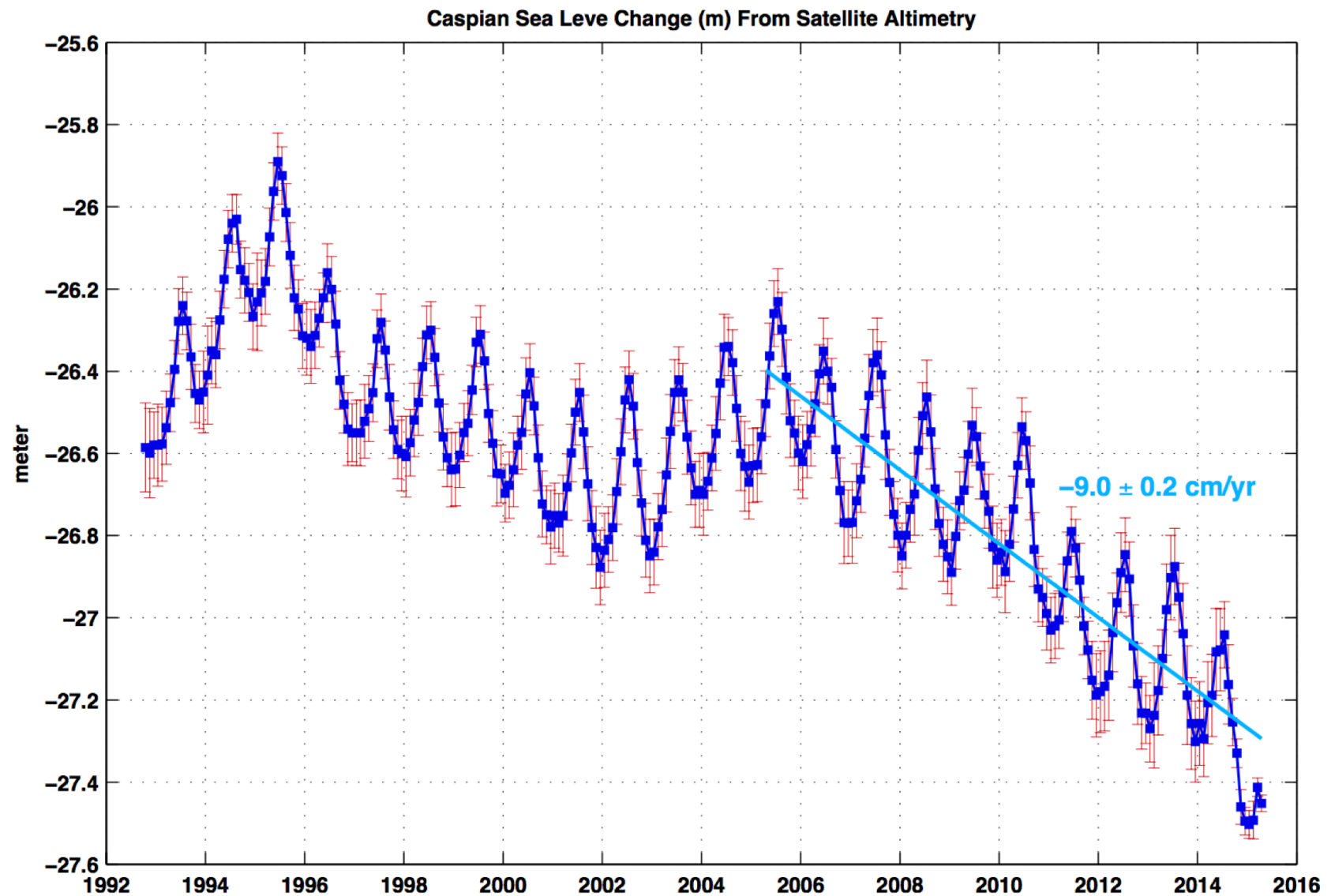


Caspian Sea Level Change and GRACE Validation

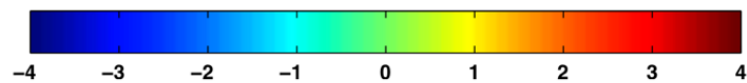
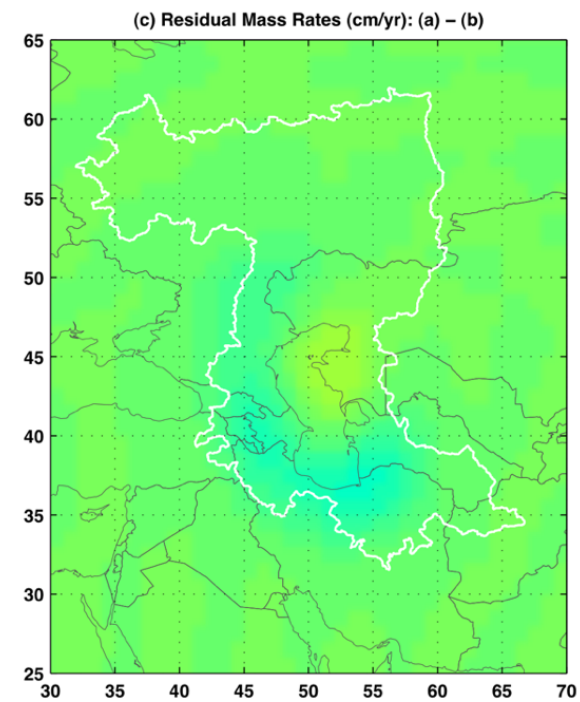
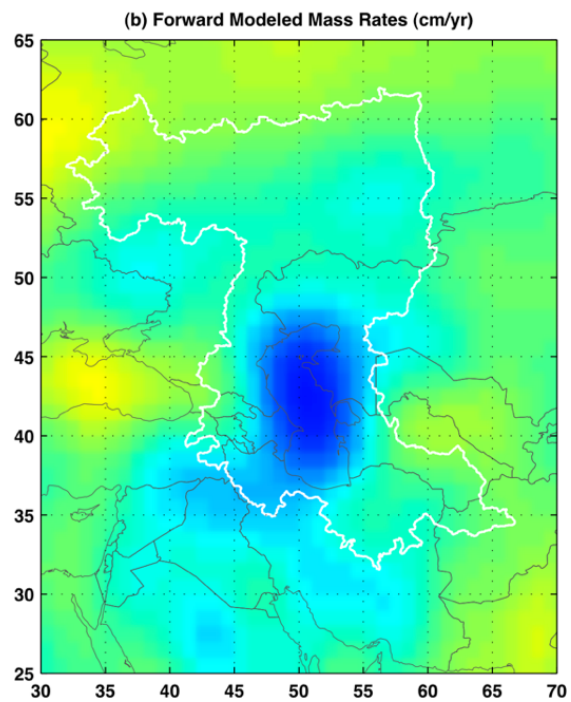
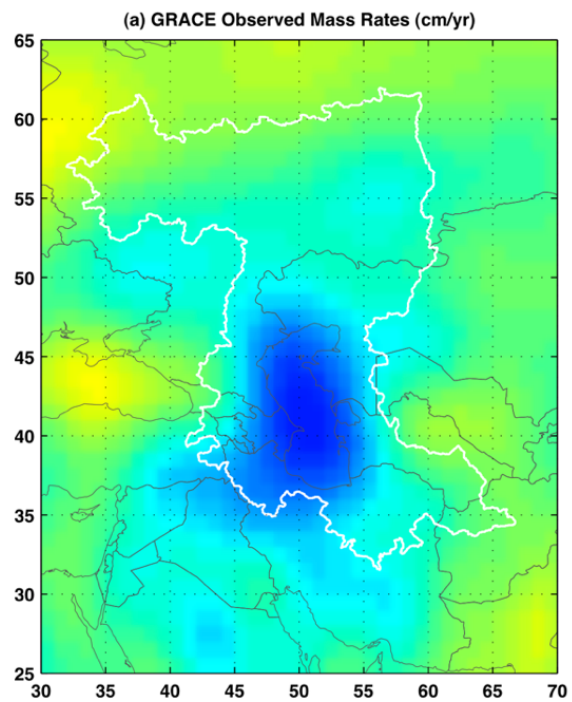


- ❑ The Caspian Sea is the largest enclosed inland body of water on Earth, with a surface area of $\sim 371,000 \text{ km}^2$.
- ❑ Average Caspian Sea level is currently about 27.5 m below mean sea level.
- ❑ Very large seasonal Caspian Sea level change ($\sim 40 \text{ cm}$ from peak-to-peak).
- ❑ Very large long-term Caspian Sea level change over the GRACE period ($\sim 9 \text{ cm/yr}$), almost 30 times larger than the global mean sea level rate.
- ❑ Caspian Sea level change is dominated by imbalanced water flux (precipitation, evaporation, and runoff).
- ❑ Surrounded by mostly arid regions (except for the very northern part).

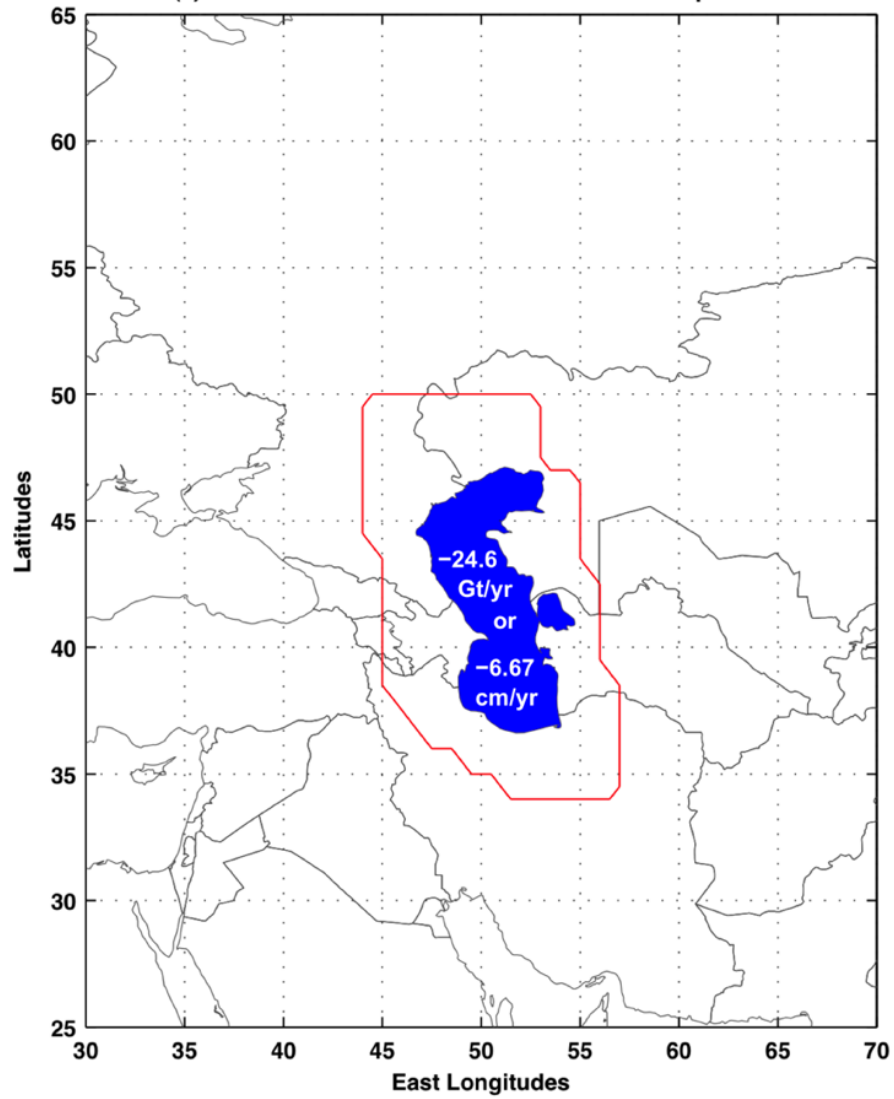
Caspian Sea Level Change From Satellite Altimetry (1992.10-2015.04)



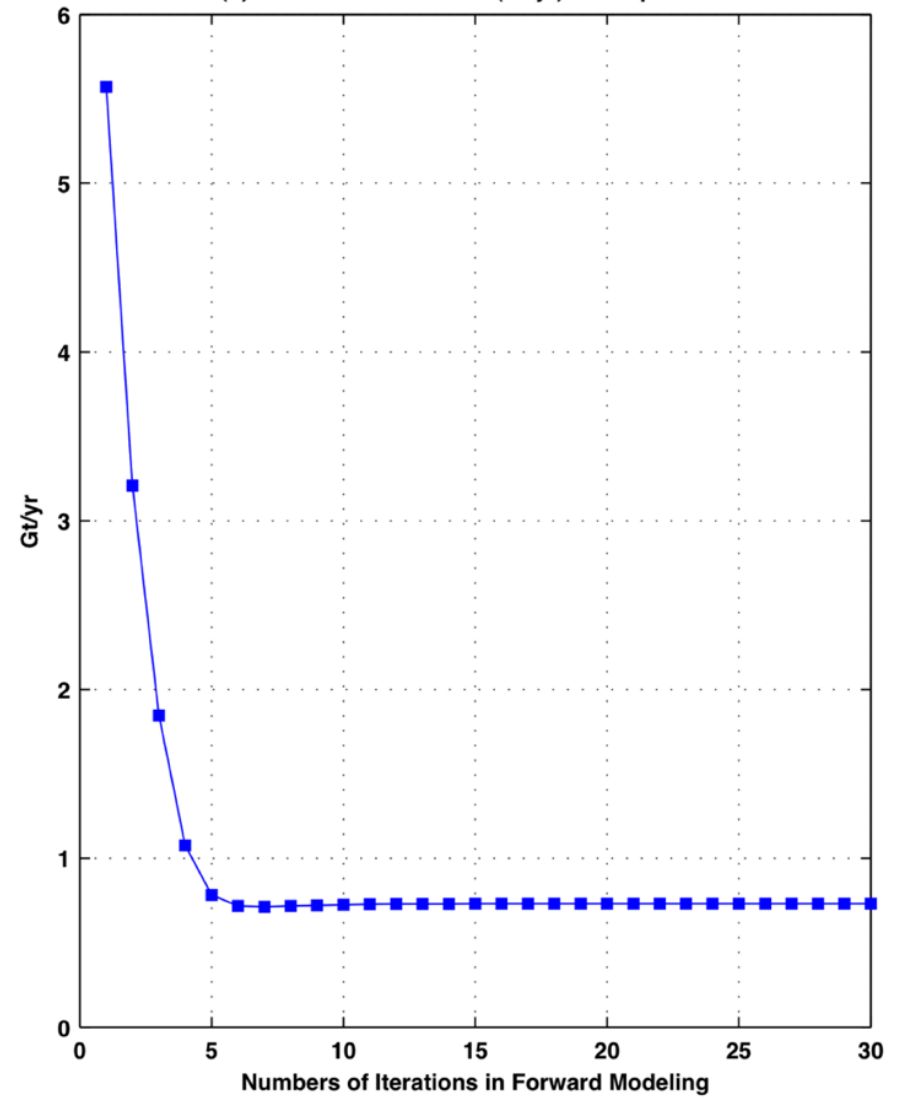
A Caspian Sea level rate of -9.0 cm/yr is equivalent to -33.4 km³/yr !



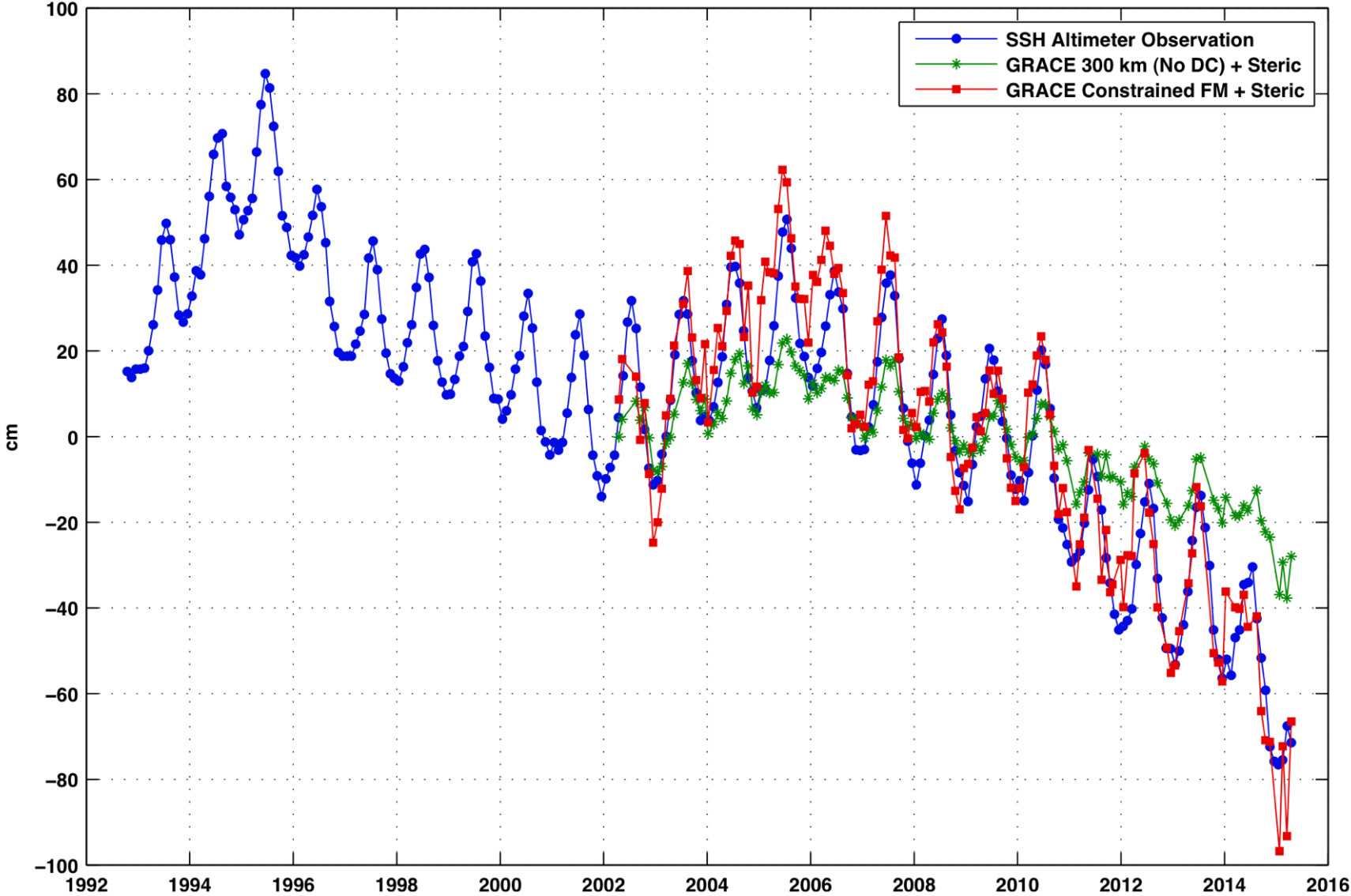
(a) Forward Modeled GRACE Mass Rates in Caspian Sea



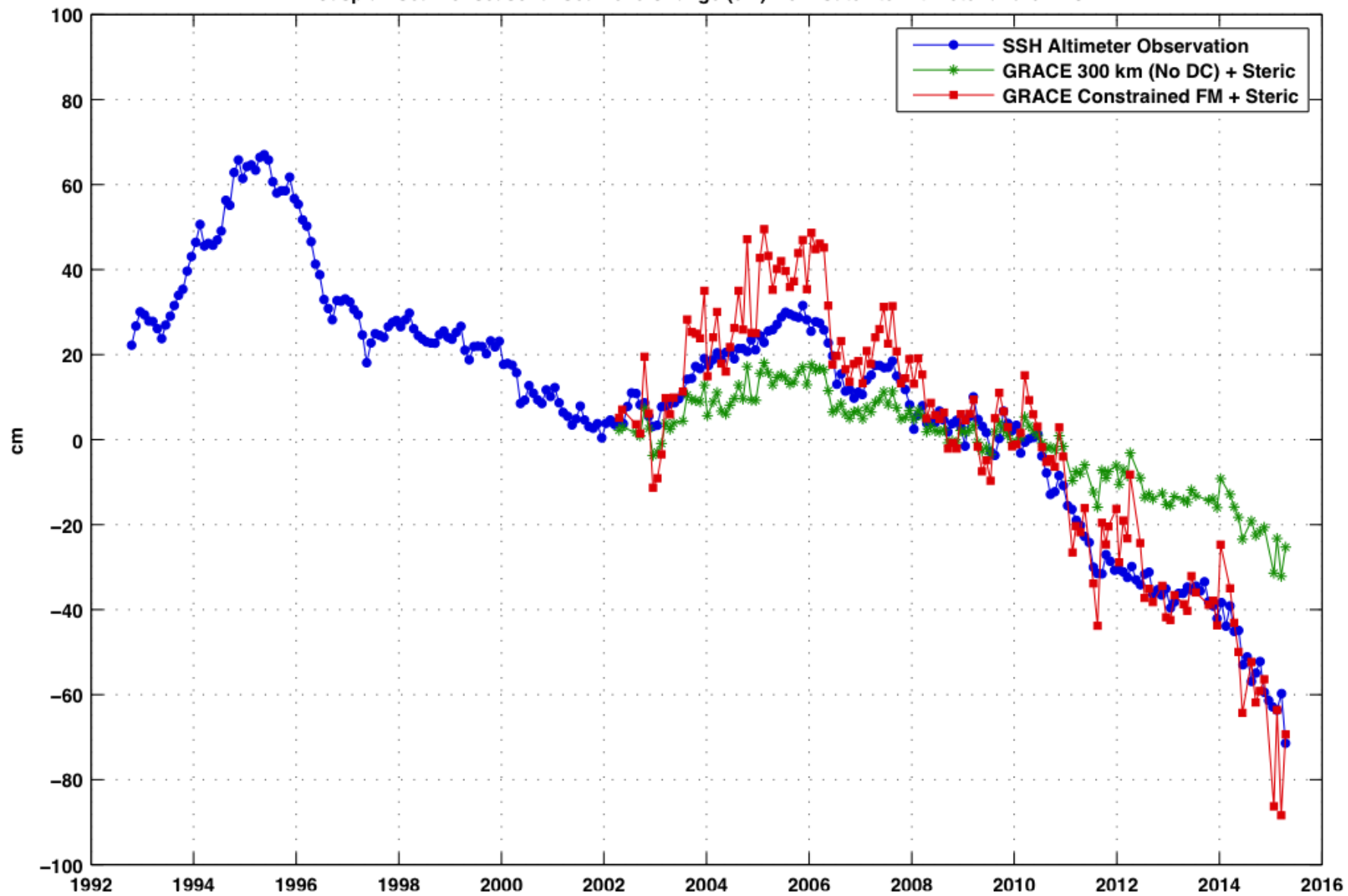
(b) RMS Residuals Total (Gt/yr) in Caspian Sea

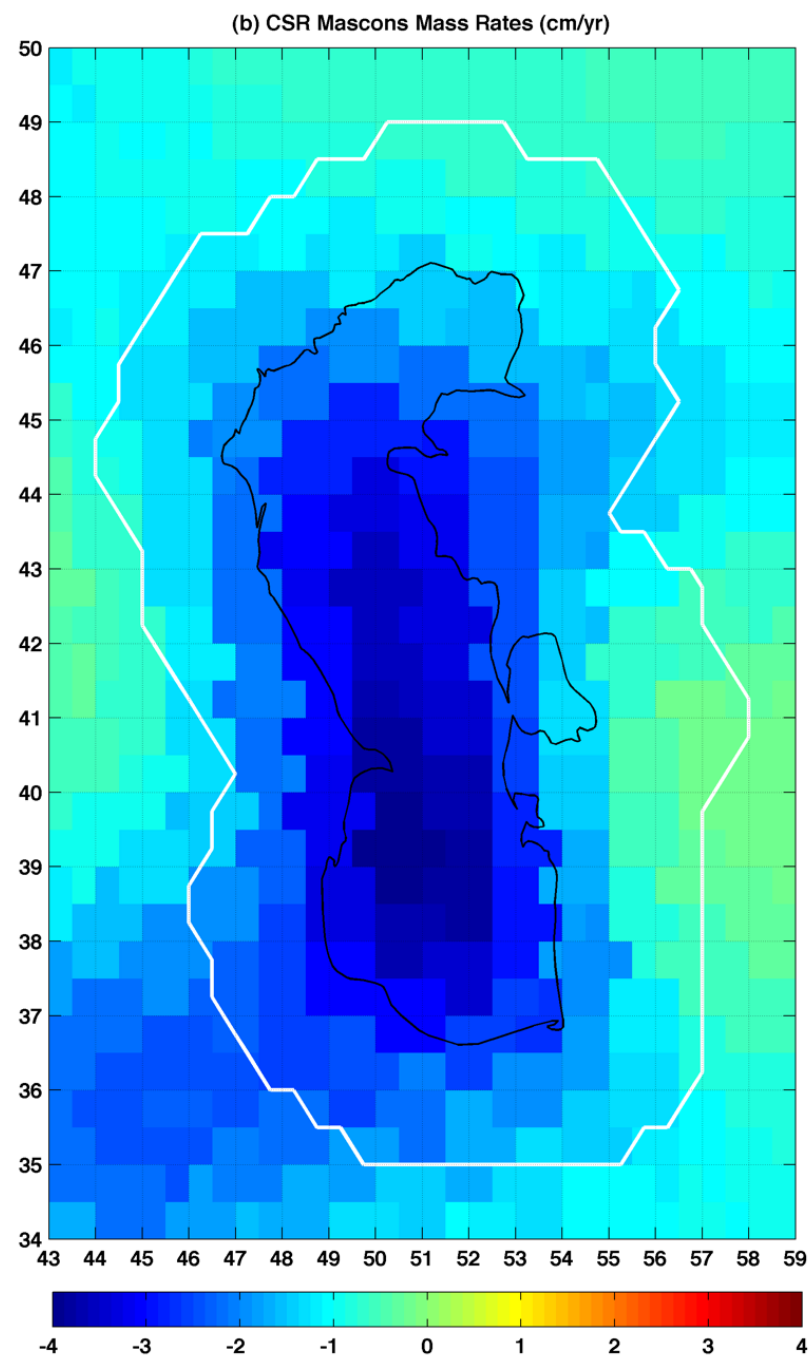
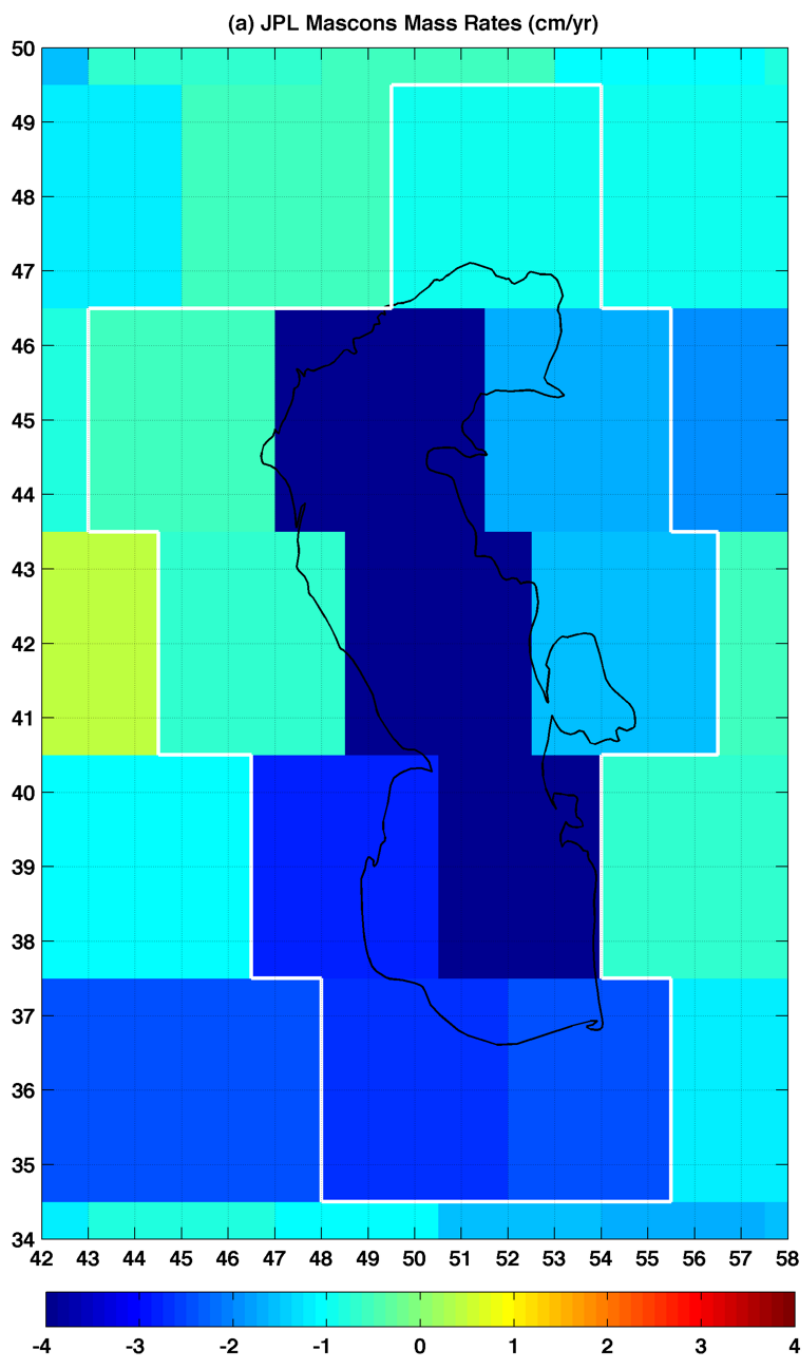


Caspian Sea Leve Change (cm) from Satellite Altimeter and GRACE

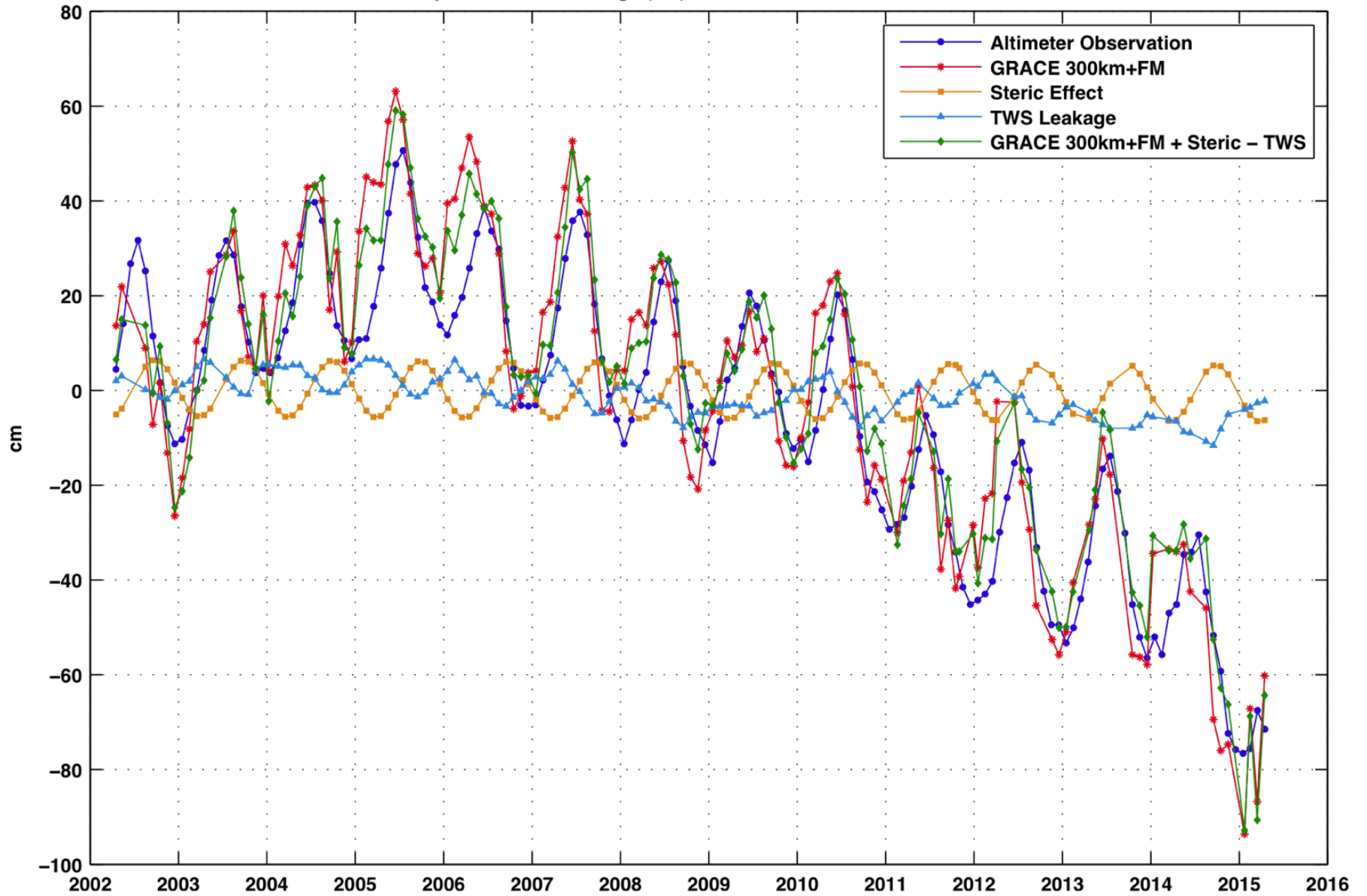


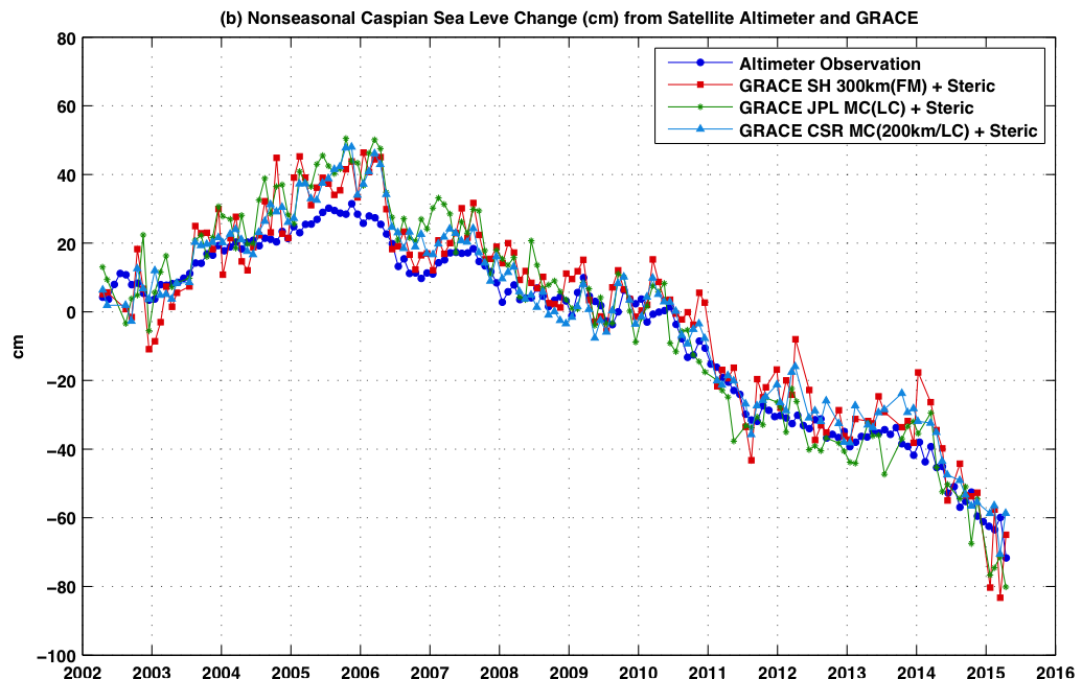
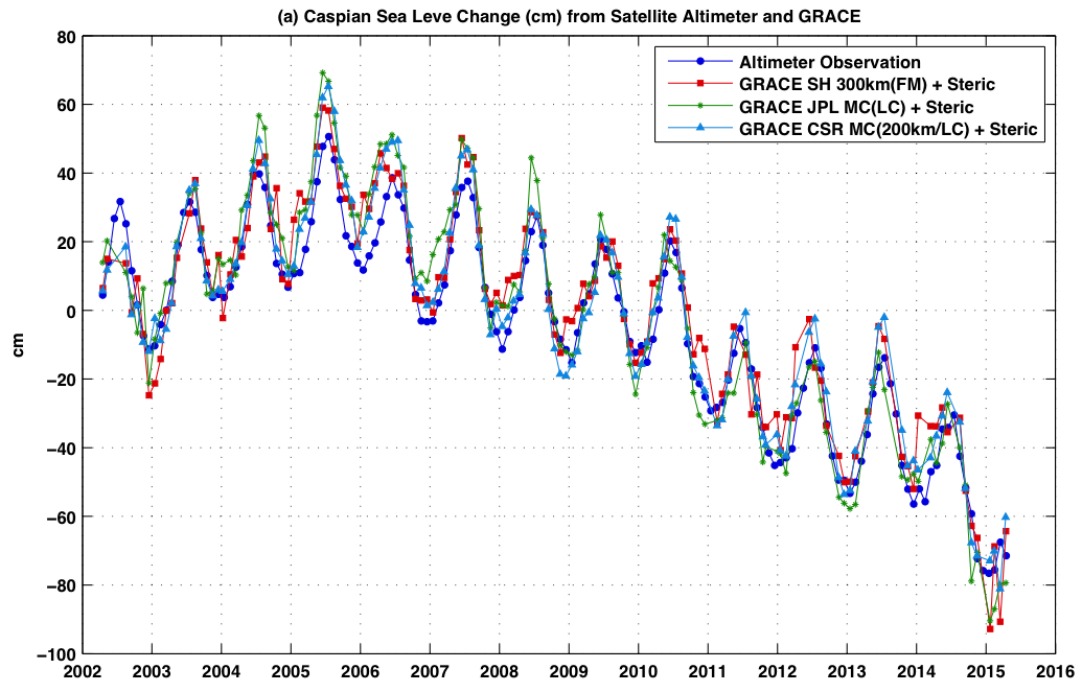
Caspian Sea Nonseasonal Sea Level Change (cm) from Satellite Altimeter and GRACE



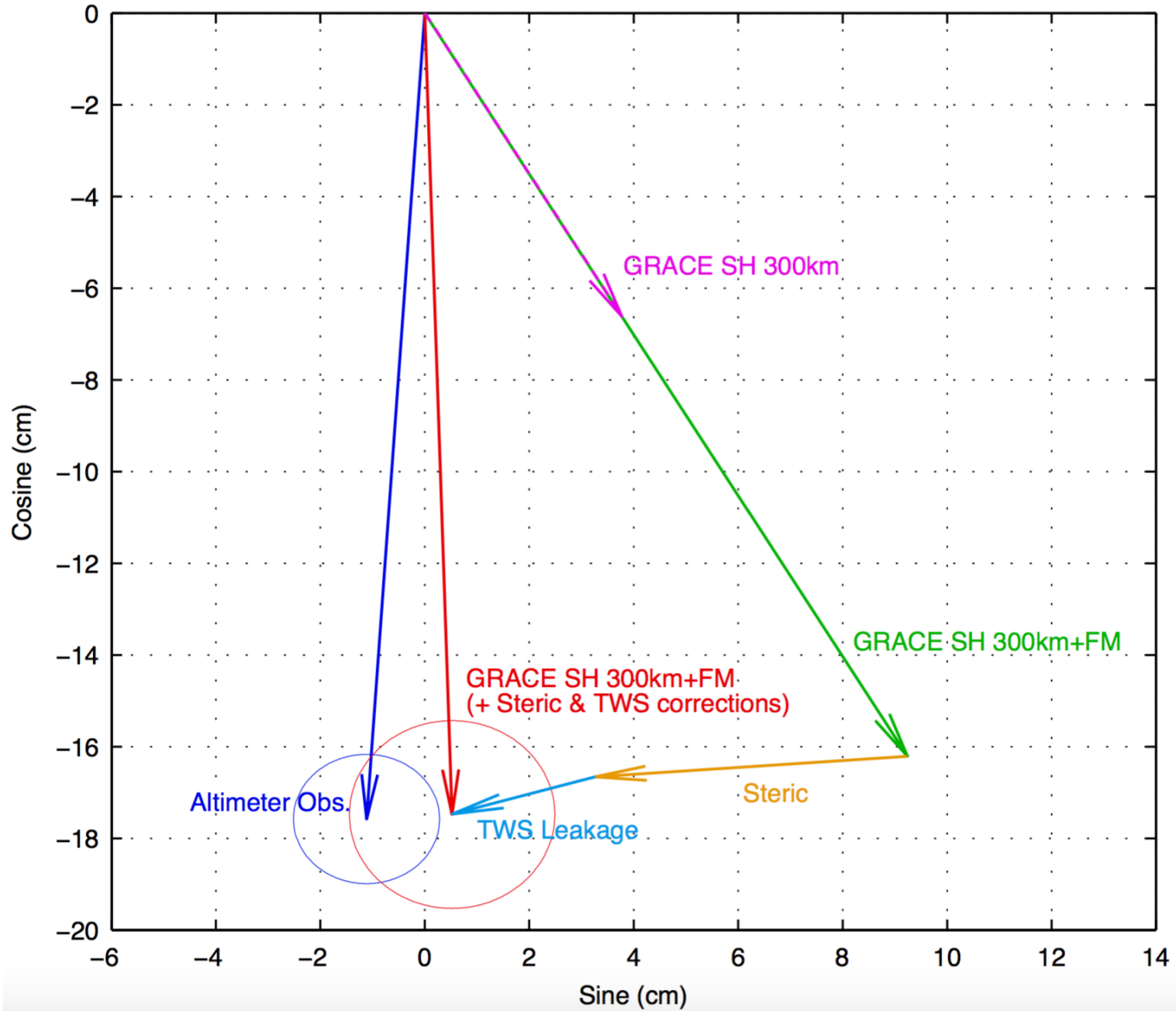


Caspian Sea Leve Change (cm) from Satellite Altimeter and GRACE





Phasor Diagram of Annual Mean Sea Level Change: Altimeter vs. GRACE



Caspian Sea Level	Annual Amplitude (cm)	Phase (deg)	Semiannual Amplitude (cm)	Phase (deg)	Linear Trend (cm/yr)
Altimeter Observation	17.6 ± 1.4	266 ± 5	3.3 ± 1.4	69 ± 25	-6.07 ± 0.26
GRACE SH 300km+FM + Steric – TWS	17.5 ± 2.0	272 ± 6	4.2 ± 2.0	78 ± 27	-6.00 ± 0.39
GRACE JPL MC (+LC) + Steric – TWS	20.1 ± 2.0	274 ± 6	5.4 ± 2.0	81 ± 21	-7.19 ± 0.39
GRACE CSR MC (+SF/LC) + Steric	16.2 ± 1.9	270 ± 5	6.2 ± 1.8	80 ± 17	-6.29 ± 0.35
GRACE CSR MC (+200km/LC) + Steric–TWS	21.0 ± 1.9	270 ± 5	6.3 ± 1.8	79 ± 16	-6.08 ± 0.34
GRACE CSR MC (+100km/LC) + Steric – TWS	16.5 ± 1.5	264 ± 5	5.2 ± 1.5	79 ± 16	-5.06 ± 0.28
GRACE SH 300km+FM	18.7 ± 2.1	300 ± 6	4.5 ± 2.1	80 ± 26	-6.70 ± 0.40
GRACE SH 300km	6.7 ± 0.8	300 ± 6	1.6 ± 0.7	80 ± 26	-2.41 ± 0.14
GRACE SH 300km+DC+FM	14.7 ± 1.3	313 ± 5	3.4 ± 1.3	82 ± 22	-4.49 ± 0.25
GRACE SH 300km+DC	5.6 ± 0.5	313 ± 5	1.3 ± 0.5	82 ± 22	-1.69 ± 0.09
GRACE JPL MC+LC	21.2 ± 2.0	310 ± 6	5.2 ± 2.0	81 ± 23	-8.15 ± 0.40
GRACE JPL MC	9.6 ± 1.1	297 ± 6	3.0 ± 1.1	78 ± 20	-3.89 ± 0.21
GRACE CSR MC+200km/LC	20.9 ± 1.9	305 ± 5	6.1 ± 1.9	77 ± 17	-7.16 ± 0.36
GRACE CSR MC+SF/LC	16.9 ± 1.9	290 ± 6	6.2 ± 1.9	77 ± 17	-6.20 ± 0.35
GRACE CSR MC	8.2 ± 0.9	291 ± 6	3.0 ± 0.9	79 ± 17	-3.01 ± 0.17
Steric Effect	6.0 ± 0.0	184 ± 0	0.04 ± 0.0	155 ± 0	-0.09 ± 0.0
TWS Leakage (w/ FM)	2.9 ± 0.3	17 ± 6	0.3 ± 0.3	103 ± 47	-0.78 ± 0.05
TWS Leakage (w/o FM)	0.8 ± 0.1	17 ± 6	0.1 ± 0.1	103 ± 47	-0.21 ± 0.01
TWS Leakage (JPL MC+LC)	7.1 ± 0.3	28 ± 3	0.2 ± 0.3	237 ± 93	-1.05 ± 0.06
TWS Leakage (CSR MC+200km)	6.9 ± 0.3	30 ± 3	0.2 ± 0.3	299 ± 106	-1.17 ± 0.06
TWS Leakage (CSR MC+100km)	3.5 ± 0.2	34 ± 3	0.1 ± 0.2	311 ± 111	-0.54 ± 0.03