GRACE & GFO satellites data for Caspian Sea Region

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***Abstract* – The GRACE and GRACE-FO satellites provide data on the Earth's gravitational field changes and are among the most successful NASA/DLR geodetic missions in recent decades. We use multichannel singular spectral analysis (MSSA) to filter JPL Level 2 release 6.3 data on gravity field and apply river basins masks from Simulated Topological Network (STN-30p) database. We obtained principal components of mass changes since 2002 till now for the rivers flowing into the Caspian Sea. By comparison with altimetry data, we tried to estimate trends and role of these rivers. The trend for the Volga River of -2.7 km^3/year for GRACE and -4.8 km^3/year for GRACE-FO epochs is found to be important, but not the only reason of the Caspian Sea level (SL) drop. We estimated effect from the ICE-6G GIA model, showing small uplift of the sea bottom with positive contribution of +0.1 cm/year to the Caspian SL. The approximate influence on Earth rotation velocity (increase) is at the level of 1 microsecond per 10 cm of SL drop.**

Keywords* – *satellite gravimetry, GRACE, climate change, Caspian Sea level.

I. Introduction

Gravity Recovery and Climate Experiment (GRACE) satellites, launched on 17.03.2002 from Plesetsk, finished their work on October 2017. GRACE Follow-on (GRACE-FO or GFO) mission was launched on May 2018. It is providing a set of monthly Earth's gravity field observations. The Stokes coefficients of spherical decomposition up to degree and order 96 are provided as Level 2 data by several data processing centers, such as CSR, JPL, GFZ. They can be converted into global maps of monthly mass anomalies, expressed in the equivalent water heights (EWH) levels. Gravity data reflects total mass changes (hydrological, related to ocean and ice mass, and lithospheric densities) in different regions of the Earth.

The Caspian Sea is known as the largest closed sea (lake) on the planet. Its complex, though not completely explained, geodynamics is manifested in the Caspian Sea level (SL) changes, Fig. 1. SL rose from 1978 to 1995 followed by an unexpected fall, started in the 2000s [1,2]. Merged satellite altimetry data, shown in Fig. 2, gives by our estimates for all the sea on average/(for one-degree point near Baku city) the SL decrease of -4.1/(-5.6) cm/year since 1993; or -6.6/(-8.9) cm/year since 2005, varying from -5 to -20 cm/year. Assuming the sea area equal to 376 thousand km^2 (-28 m point in 2016-2017), every 10 cm of annual drop is equal to ~38 km^3/year of mass loss. It can be attributed to different factors. Among the major are: Volga River discharge, decrease of precipitation, increase of evaporation and temperatures in the region, and geological factors [2,3]. In particular, the Volga River is regulated and its water was increasingly diverted for irrigation in soviet times. Despite this, the Caspian SL was rising. After the USSR breakup in 1990, water intake was reduced, but SL started to drop. Therefore, not only one process is responsible for Caspian SL decrease.

Fig. 1. Caspian Sea level changes since 1900 in meters (from [1,2]).

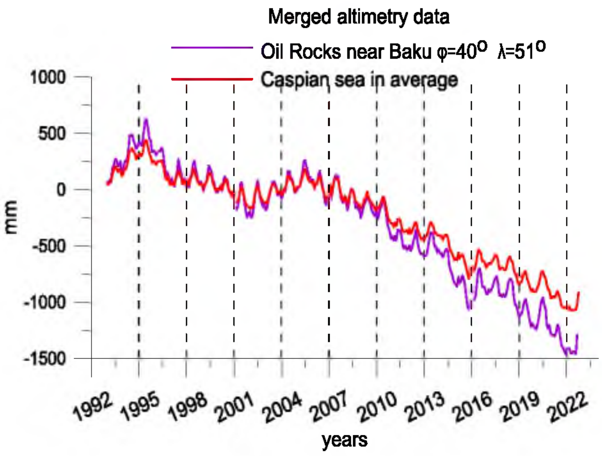

Fig. 2. Caspian Sea level changes since 1992 from satellite altimetry.

II. Data processing

We used JPL Level-2 RL06.3 monthly GRACE and GFO spherical harmonics data from 04.2002 to 06.2017 with coefficients complete to degree 60. 21 missing files were cubically-interpolated (overall N=183 files). Similarly, for GRACE-FO we used files from 06.2012 to 07.2025 with 2 files interpolated for 08.18. 09.18, overall, 86 files. C_{20} coefficients were replaced by SLR-derived. Glacial isostatic adjustment (GIA) effect was removed according to Peltier ICE-6G model. We applied the multichannel singular spectrum analysis (MSSA, or extended EOF) technique [4, 5] to filter GRACE and GRACE-FO Level 2 data. Then we constrain the rivers basins, flowing into Caspian Sea, using masks from Simulated Topological Networks STN 30-p hydrological database. MSSA lag parameters were chosen to be L=48 (4 years) for GRACE and L=36 (3 years) for GFO. The results were recalculated into EWH (cm) levels. By calculating the trends of masses in river basins, we estimate their possible contribution into Caspian SL decrease. Below, we briefly present the results of regional averaging of GRACE/GFO signals for 6 selected reiver basins.

Table I. TRENDS OVER BASINS OF 6 RIVERS FLOWING INTO THE CASPIAN SEA FROM GRACE AND GFO

Basin number STN	River name	Area of basin, m^2	EWH trend from GRACE (cm/year)	EWH trend from GRACE–FO (cm/year)	Volume trend from GRACE (km^3/year)	Volume trend from GRACE–FO (km^3/year)
16	Volga	1476411,4	-0,18	-0.32	-2.65 ± 1.56	-4.78 ± 1.32
57	Garagum	373943,0	-0,08	-1.86	-0.32 ± 0.19	-6.96 ± 0.73
70	Ural	296282,8	-0,57	-0,57	-1.69 ± 0.32	-3.59 ± 1.13
91	Kura	218906,0	-2,52	-5.89	-5.51 ± 0.29	-12.89 ±0.88
218	Emba	72975,8	-0,84	-0.01	-0.61 ± 0.05	0.00 ± 0.19
249	Sefid-Rud	64653,2	-1.45	-6.87	-1.58 ± 0.08	-4.44 ± 0.33

III. METHODS AND RESULTS

For general understanding, the map in Fig. 3 demonstrates strong negative EWH trends over Caspian region from GRACE-FO data. EWH can be interpreted as the thickness of water layer required to compensate the gravity anomaly in the region. Fig. 4 shows one degree point data from GRACE and GRACE-FO for Baku. To emphasize its negative trend, we also show data for the point at Samarkand situated at the East edge of the map in Fig. 3.

Six largest rivers flowing into Caspian Sea were selected and their EWH trends estimated for GRACE and GFO time-spans. Results are given in Table 1. The trends in cm/year were recalculated into volume loss by multiplying by the basin's area. The difference of trends for GRACE and GFO could be related to the real climatological variations or, partly, to the instability of GFO accelerometer on decadal time intervals. A large negative trend for the Kura River could be caused by the signal leakage from Caspian Sea to the surroundings. The total decrease (sum of trends) of equivalent water mass over 6 basins are -12.4 km^3/year for GRACE and -32.7 km^3/year for GRACE-FO time spans, which explains sufficient, but not all the drop of Caspian SL.

Paying attention to the lithospheric hypothesis of Caspian Sea bottom deformation caused by oil extraction and other natural factors, we also estimated GIA ICE 6G model trends in the region. This model, relying on the mantle viscosity, gives the positive EWH trend of +0.1 cm/year, probably related to the sea bottom uplift.

We approximately estimated the SL drop influence on Earth rotation velocity. If we remove the point-mass of 38 Gt (38 km^3) at 40° latitude (10 cm of SL), the Earth's axial moment of inertia would reduce by 10^{27} kg*m^2, which, being 11 degrees less than its total moment of inertia, would cause the decrease of the length of day (LOD) by 1 microsecond. Assuming that mass being redistributed over a narrow spherical layer with the radius of the Earth, - by 0.3 μs.

GRACE and GFO data provide an independent access to global and regional mass distribution with ~300 km resolution and allow analysis of changes in the sea and river basins. Such drawbacks as signal leakage, presence of noises, etc. can be overcome by advanced filtering and do not eliminate the usefulness of GRACE/GFO data. Application of satellite gravimetry to rapid Caspian SL decrease problem can be an independent source of information and help to predict SL for the future.

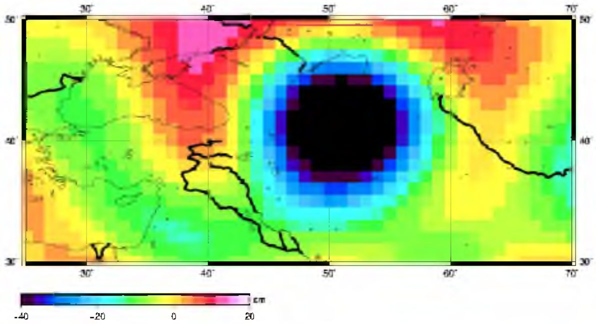

Fig. 3. Mass changes (trends, PC 1) from GRACE-FO since 6.2018 till 07.2025 for Black sea (left), Caspian sea (center) and Aral lake area.

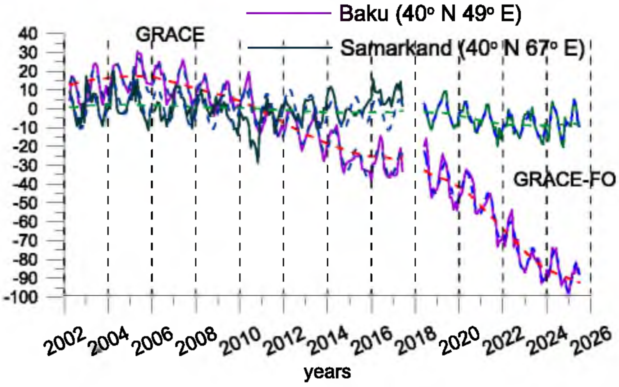

Fig. 4. GRACE/GFO data for the coordinates of Baku and Samarkand.

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