CASPIAN SEA WATER MASS VARIATIONS AND WATER CIRCULATION CYCLE FROM SATELLITE DATA

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ABSTRACT: In this study, by processing the 78 months of GRACE Satellite data, validates the performance of GRACE solutions in the detection of water mass variations and compared with Satellite altimeter derived water circulation cycle of the Caspian Sea. The results show that the GRACE monthly gravity field model can reflect the changes in the Caspian Sea area, including the annual and seasonal changes. Combination of satellite altimetry data to further understand the water cycle of Caspian Sea, that is between groundwater and lake water infiltration cycle.

1. INTRODUCTION

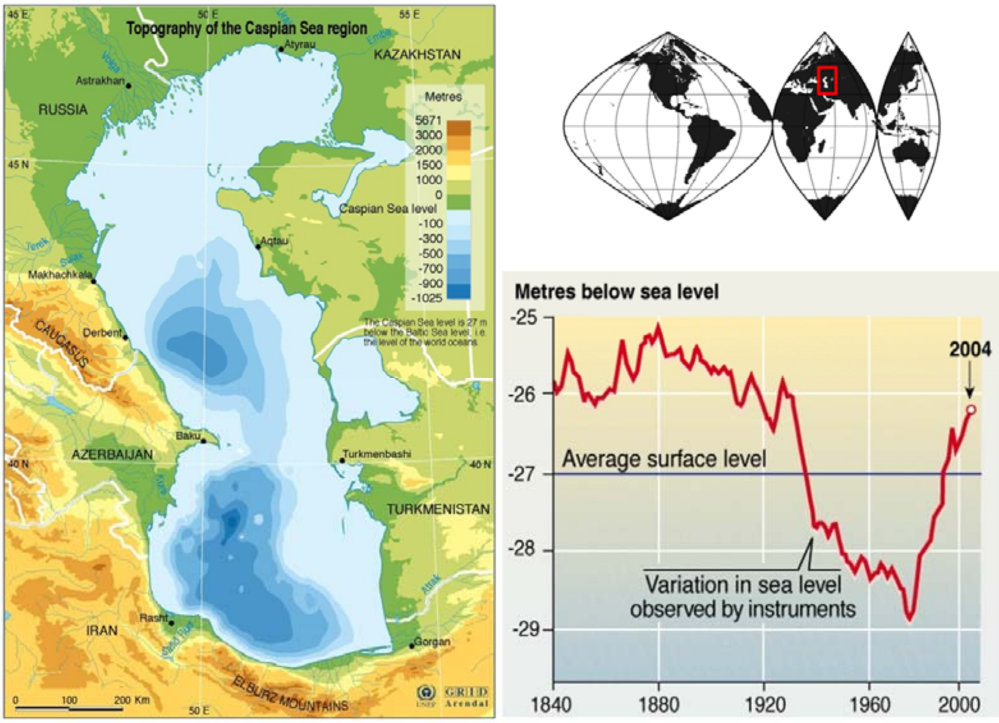
Since the GRACE(Gravity Recovery and Climate Experiment) satellites launched in March of 2002, it provides monthly gravity field model is considered today as valuable information to quantify mass variations of the Earth system, Especially in the hydrology study has been widely used (Tapley, 2004). Nearly 9 years of GRACE data have shown that total water storage (TWS) changes in continental hydrology are among the dominant mass variations that can be detected in the GRACE signal (Tapley, 2004; Schmidt et al., 2006; Huang et al., 2011).

There are difficulties in detecting TWS using GRACE satellite gravity data. The TWS is an organic aggregate of all forms of water in diverse layers above and below the ground. Its components are not easy to separate from each other. Therefore, the changes in the time series TWS detected by GRACE also represent water in diverse forms. In addition, most hydrological models, which are used as the subjects of comparative analysis, have uncertainties. Accordingly, instead of conducting studies on large-scale river basins, it is desirable to focus on lakes that have relatively simple composition.

In this study, by processing the 78 months of GRACE data, validates the performance of GRACE solutions in the detection of water mass variations and compared with Satellite altimeter derived water circulation cycle of the Caspian Sea.

2. STUDY AREA AND DATA PROCESSING

The world's largest lake, the Caspian Sea is located between Asia and Europe, with an area of 392,600km^2, and a mean water depth of 208m (Kostianoy and Lebedev, 2006). The main riverheads are the Ural River, Kura River, Terek River, and Volga River, which is the source for 80% of the lake's water. The Caspian Sea has three parts. The northern part is shallow with a depth of several meters leading to the plain, the middle part has a maximum depth of 788 m, and the southern part, which is distinguished from the middle part by the Apsheron rock layer, has a maximum depth of 1,025 m (Kroonenberg et al., 2000). The mean depth of the Caspian Sea is about 27 m below sea level. It has fluctuated over time. Continuously decreasing from the early 20th century, it hit a record low of 29 m below the world's mean sea level in 1977, and increased abruptly up to -26.5 m in 1995, which was about 2.5 m over 17 years (Kostianoy and Lebedev, 2006). Figure 1 displays the topography of the Caspian Sea.



(Source by The Caspian Environment Programme & The Academy of Geography in Azerbaijan)

Figure 1. Topography and Water level changes of Caspian Sea

2.1 GRACE Level-2 products

The changes in the TWS in the lakes were additionally extracted and were compared with the actual water level observation data, which satellite altimeter data. The monthly gravitational field model (Level 2, Version RL04) provided by UTCSR were used as GRACE satellite gravity data. Using the mean gravitational field model, changes in TWS were obtained by calculating the changes in the time series gravitational field over 78 months from August 2002 to March 2009 (excluding June 2003 and January 2004), based on the gravity data from 2003 to 2007. The spherical harmonics were developed at 1° lattice intervals up to the 60th order, and a 500 km-radius Gaussian filter was used (Jekeli, 1981). To identify the annual and seasonal changes around the Caspian Sea, the changes in the TWS for the year 2005 were extracted and analyzed. Finally, get the results 1 degree interval water mass distribution in Caspian Sea area (46°E-56°E, 34°N-48°N). If the change in the gravity of the lake basin is wholly due to the change in the water on land, the gravity change is converted into equivalent water thickness (EWT), as follows (Wahr et al., 1998):

$$\Delta\overline{\sigma} = 2\pi \frac{a\rho_{a\upsilon}}{3} \sum_{n=2}^{n_{\max}} \frac{2n+1}{1+k_n} W_n \sum_{m=0}^{n} (\overline{C}_{nm} \cos m\phi + \overline{S}_{nm} \sin m\phi) \overline{P}_{nm}(\cos\theta) \quad (1)$$

2.2 Satellite Altimetry data

In order to compare the relationship between water mass variation from GRACE and changes in the actual surface, provided by the AVISO sea surface height anomaly data (Delayed Time-Maps of Sea Level Anomaly, DT-MSLA), which are produced by composing data of multiple satellite altimeter such as TOPEX/Poseidon, Jason-1/2, ERS and ENVISAT. Data are provided optimal results with a time resolution of seven days and spatial resolution of 1/3°. Analysis for phase correlation between two datasets was applied wavelet transform method (Torrence et al., 1999; Cooper and Cowan, 2008).

DT-MSLA (Delayed Time-Maps of Sea Level Anomaly), which is the NetCDF-format satellite altimeter sea level change data provided by AVISO (Archiving, Validation and Interpretation of Satellite Oceanographic data), France, was used for the comparative analysis of the changes in time-series storage of the Caspian Sea. DT-MSLA combines satellite altimeter data from NASA's TOPEX/Poseidon and JASON-1/2, and Europe's ERS and Envisat to provide optimal results with a time resolution of seven days and spatial resolution of 1/3°.

This study extracted the changes in the Caspian Sea level from July 31, 2002 to December 3, 2008 by dividing the region into the northern area (43.5-45°N, 48-50°E), middle area (41-43°N, 49.5-51.5°E), and southern area (38-40°N, 50-52.5°E) to determine changes in the entire lake's water level. In addition, to compare the results with the changes in the GRACE TWS data, relative time-series changes were calculated based on the mean water level (2003-2007).

3. SEASONAL VARIATION

Figure 2 displays TWS variation of Caspian Sea region for 2005. The TWS in the Caspian Sea region was above average from February to August, and below average from September to December. The changes in TWS appeared at the center of the lake as reference location. In January, it was below average at the center but above average downstream the Ural River, which is the upper Caspian Sea. Changes in the TWS increased from the north, west and south regions, where most rivers flowing into the Caspian Sea are located, to the east (March-May). From June to August, the storage was large at the center of the lake but decreased in the areas around the lake. The water storage of the Caspian Sea was contrary to that of the drainage basin of the surrounding river because of its characteristic as an inland lake, where the inflowing water from rivers decreases due to evaporation.

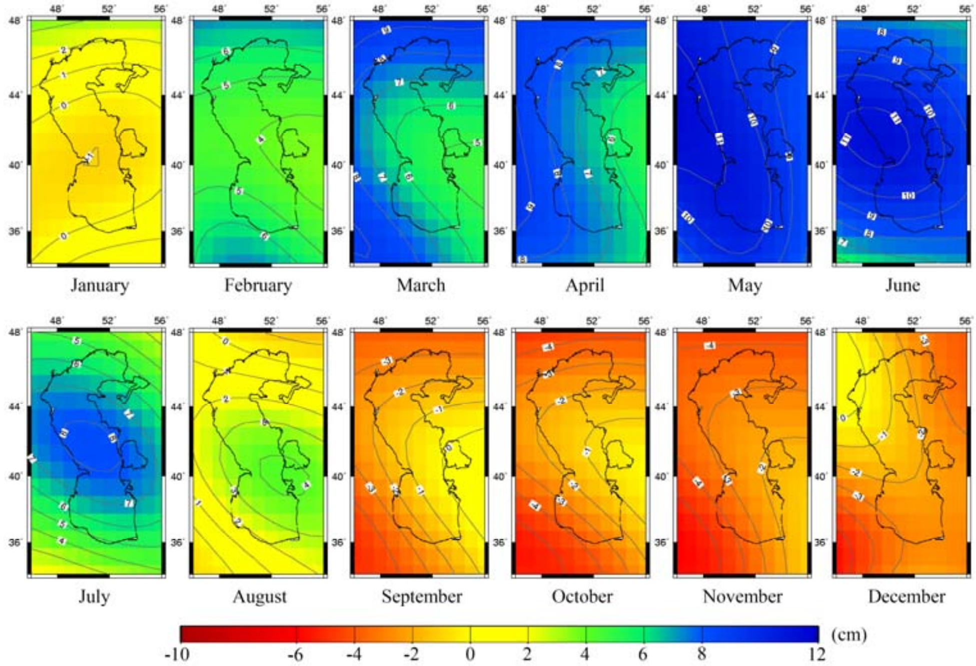


Figure 2. TWS variation of Caspian Sea region for 2005

4. WATER CYCLE OF CASPIAN SEA REGION

Figure 3 (A) shows the changes in the GRACE monthly TWS (presented in dots) and satellite altimeter sea level (presented in solid lines) at seven-day intervals. The water level of the Caspian Sea has fluctuated over time. Continuously decreasing from the early 20th century, it hit a record low of 29m below the world's average sea level in 1978, and abruptly increased up to -26.5m in 1995, which was about 2.5m over 17 years. During the subject period of this study, the water level gradually increased until 2005 and started decreasing again.

The wavelet coherence (WTC) analysis was conducted to analyze the correlation between two time-series data, Figure 3 (B) shows the results. The cone-shaped boundary represents the cone of influence, and the thick black line represents the 5 % significance level (confidence interval: 95 %). The arrow vector represents the relative phase angle. The right direction of the arrow means that the two time-series data have the same phase, the left direction means that they have opposite phases, and the upper direction, that the phase of Y lags behind that of X by 90°. In the Caspian Sea, the correlation between GRACE TWS and satellite altimeter SLA was very high (correlation coefficient: 0.65); the time-series data of GRACE TWS and satellite altimeter had a phase difference of about 45° (1.5 months).

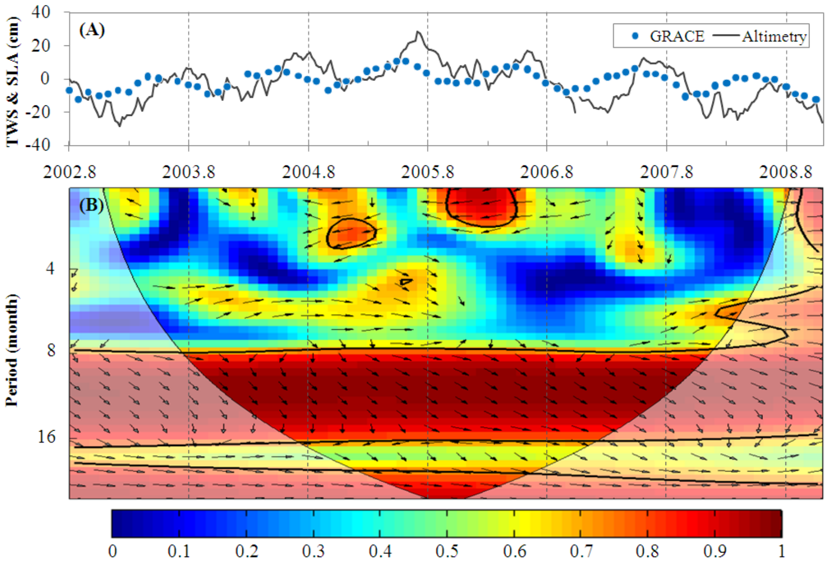


Figure 3. (A) Variations of the Mean Sea level and TWS's variation of Caspian sea during Feb. 2002 to Mar. 2009; (B) Wavelet Analysis for two time series data

5. CONCLUSION

This study calculated the changes in TWS via the spherical harmonics analysis of up to the 60th order and 500 km-radius smoothing process to analyze the changes in the TWS for the Caspian sea. The results show that the GRACE monthly gravity field model can reflect the changes in the Caspian Sea area, including the annual and seasonal changes. Combination of satellite altimetry data to further understand the water cycle of Caspian Sea, that is between groundwater and lake water infiltration cycle.

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