ГЕОГРАФИЯ

APPLICATION OF SATELLITE RADAR ALTIMETRY FOR STUDIES OF VARIATIONS OF THE CASPIAN SEA LEVEL

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The Caspian Sea is well covered by TOPEX/Poseidon, Jason-1, GFO and ENVISAT satellite altimeters. Having a prolongation opportunity for the TOPEX/Poseidon data on the Caspian Sea level with data from Jason-1 along the same tracks, we constructed new time series of TOPEX/Poseidon extended by Jason-1. Average bias of common period for each TOPEX/Poseidon track extended by Jason-1 has been calculated. Time series of Jason-1 and ENVISAT have been also constructed and the average bias for their common period has been calculated. The average bias of common period for TOPEX/Poseidon and GFO has been also calculated. The average bias values have been applied to compute the variation of the Caspian Sea level in the multisatellite mode (from 1993 to present). Amplitude of the Caspian Sea level variations calculated along the TOPEX/Poseidon and Jason-1 tracks has been also studied. Maps with the amplitude of annual signal along tracks, and a map with an interpolation of the amplitude all over the Caspian Sea were constructed.

1. Introduction

Satellite radar altimetry is a successful technique for monitoring the variation in elevation of continental surface water, such as inland seas, lakes, rivers, and wetland zones. The surface water level is measured within a terrestrial reference frame with a repeatability varying from 10 to 35 days depending on the orbit cycle of the satellite.

Several satellite altimetry missions have been launched since the early 1990s: ERS-1, TOPEX/Poseidon, ERS-2, Jason-1 and ENVISAT. The TOPEX/Poseidon was launched in 1992 as a follow-up to SEASAT (1978) and GEOSAT (1985). The TOPEX/Poseidon together with ERS-1 (1991), ERS-2 (1995) and GFO (1998) showed the wide range of oceanographic applications that can be obtained from space. Using very powerful radar altimetry technology, this satellite detects the slightest variation in sea level and provides quick, synoptic, global, and regular measurements of ocean surface topography (Chelton *et al.*, 2001). The Jason-1 satellite was launched in 2001. Placed in the same orbit as TOPEX/Poseidon, Jason-1 delivers geophysical data to users within three hours of observation at a level of performance identical to TOPEX/Poseidon. The ENVISAT satellite was launched in 2002. Onboard this multi-mission satellite, a radar altimeter is running to take over the ERS-2 altimetric mission. The orbit repeating at 35 days (instead of 10 days for Jason and TOPEX/Poseidon) is sampling the ocean at a shorter spatial scale, complementing the large scale vision of TOPEX/Poseidon.

Although the primary mission of satellite altimetry was the study of water level of the open ocean, this technique have been successfully applied to monitor water level of inland seas such as the Caspian and Aral seas (Cazenave et al., 1997; Aladin et al., 2005; Cretaux et al., 2005; Lebedev and Kostianoy, 2005), large lakes (Ponchaut and Cazenave, 1998; Mercier et al., 2002), as well as large rivers, wetlands and floodplains

(Birkett, 1998; Maheu et al., 2003, Kouraev et al., 2004, Leon et al., 2006).

2. Satellite Altimetry of the Caspian Sea

Due to its large area (375000 km^2), the Caspian Sea is well covered by all satellite altimeters. Cazenave et al. have shown that satellite altimetry data can be successfully used for the investigation of the Caspian Sea level variability. They have analyzed three and a half years (from January 1993 through August 1996) of altimeter range data from the TOPEX/Poseidon mission over the Caspian Sea to estimate temporal variations in the sea level. They have shown that the Caspian Sea level was rising at a rate of 18.9±0.5 cm/yr between January 1993 and July 1995 and that the northwestern Caspian in the area of the Volga delta was rising faster (by ~3cm/yr) than the middle and south Caspian. However, by mid-1995, the sea level started to drop abruptly. The average sea level decrease recorded from mid-1995 amounts to -24.8±1.4 cm/yr (Cazenave et al., 1997).

Lebedev and Kostianoy have applied the satellite altimetry to monitoring of water level, wind speed and the wave height variations in the Caspian Sea, as well as in the Volga River. Lebedev and Kostianoy have analyzed 13 years of TOPEX/Poseidon and 3.5 years of Jason-1 data since September 1992 till December 2005. According to Lebedev and Kostianoy, between October 1992 and March 1995 the Caspian Sea level was rising at the rate of +20.4 cm/yr. In August 1995 the sea level started to drop abruptly and a negative trend was being observed until winter 2001/2002, when a local minimum (–27.3 m) was achieved. Since November 1995 to September 1996 the rate of the Caspian Sea level drop was 23.1 cm/yr, later it decreased to –5.3 cm/yr in October 1996 – June 1998 and to –9.1 cm/yr in December 1998 – April 2001. Since January 2002 till December 2005 the Caspian Sea level was rising with a mean rate of +7.5 cm/yr (Lebedev and Kostianoy, 2005).

Data gathered by TOPEX/Poseidon represent uninterrupted and most continuous measurements that have a prolongation possibility with data from Jason-1 along the same tracks. Having this possibility, we constructed new time series of TOPEX/Poseidon extended by Jason-1 and calculated the average bias. Time series of Jason-1 and ENVISAT were also constructed and the average bias for their common period was calculated. The average bias of common period for TOPEX/Poseidon and GFO was also calculated. Making estimated the bias between satellites permits us to compute the variation of the Caspian Sea level in the multisatellite mode. We have also studied the amplitude of the Caspian Sea level variations calculated along the TOPEX/Poseidon and Jason-1 tracks. Amplitude of annual signal along tracks, and an interpolation of the amplitude were mapped. Obtained results are given in the present paper.

3. Data processing

In our study, the database created at LEGOS (Laboratoire d'Etudes en Géophysique et Océanographie Spatiales) was used. After creating necessary files with data, a processing started using CTOH (Centre de Topographie des Océans et de l'Hydrosphère) software. Several tracks were processed for the following satellites: TOPEX/Poseidon, Jason, GFO and ENVISAT. Due to its large area (375000 km^2), the Caspian Sea is well covered by all satellite altimeters. For mapping each or all tracks, a program was used which also permits us to select necessary traces and dismiss the rest. The procedure started with selecting the exact track from the list and giving the information as satellite's and lake's names. After the calculation process, as a result, we had some data about variation in the proper files. The same procedure was applied to all satellites. The results were used to construct time series.

Data gathered by TOPEX/Poseidon represent uninterrupted and most continuous measurements (from September, 1992 to August, 2002) that have a prolongation opportunity with data from Jason-1 along the same tracks (from January, 2002 up to now). Having this opportunity, new time series of TOPEX/Poseidon extended by Jason-1 were constructed. In Figure 1 we give, as an example, the water level fluctuation for track 92 of TOPEX/Poseidon extended by Jason-1. Average bias of common period for each TOPEX/Poseidon track extended by Jason-1 was also calculated (Table).

The average bias of common period for TOPEX/Poseidon and Jason-1

Track number	TOPEX/Poseidon average bias (m)
16	0,056
31	0,075
57	0,054
92	0,073
133	0,07
168	0,067
209	0,012
244	0,177
All tracks after reconstruction	-0,06

Time series for GFO and ENVISAT tracks were mostly with a lot of errors. On the other hand, the tracks of TOPEX/Poseidon and Jason-1 have a few time series with errors. Analysis shows that the data from TOPEX/Poseidon and Jason-1 are most optimal for satellite monitoring of the Caspian Sea level variation. So, next step was eliminating of the tracks with mistakes and reconstructing the time series only with good tracks numbers. Continuing with TOPEX/Poseidon and Jason-1, reconstructed time series were put together (Figure 2) and the average bias for their common period (i.e. from January, 2002 to August 19, 2002) was calculated (the calculated average bias was -0.06 m). Time series of Jason-1 and ENVISAT were also constructed and the average bias for their common period was calculated (the calculated average bias was -0.35 m). The average bias of common period for TOPEX/Poseidon and GFO was -0.15 m. First of all, it was necessary to estimate bias between each satellite before computing the Caspian Sea level variation in the multisatellite mode. Bias observed on the Caspian Sea was in the range of 10-20 cm.

Next step was to calculate the Caspian Sea level variations in the multisatellite mode. Data processing results are shown in Figure 3. First of all, Figure 3 indicates interannual variations correlated with hydrological conditions of the Caspian Sea basin.

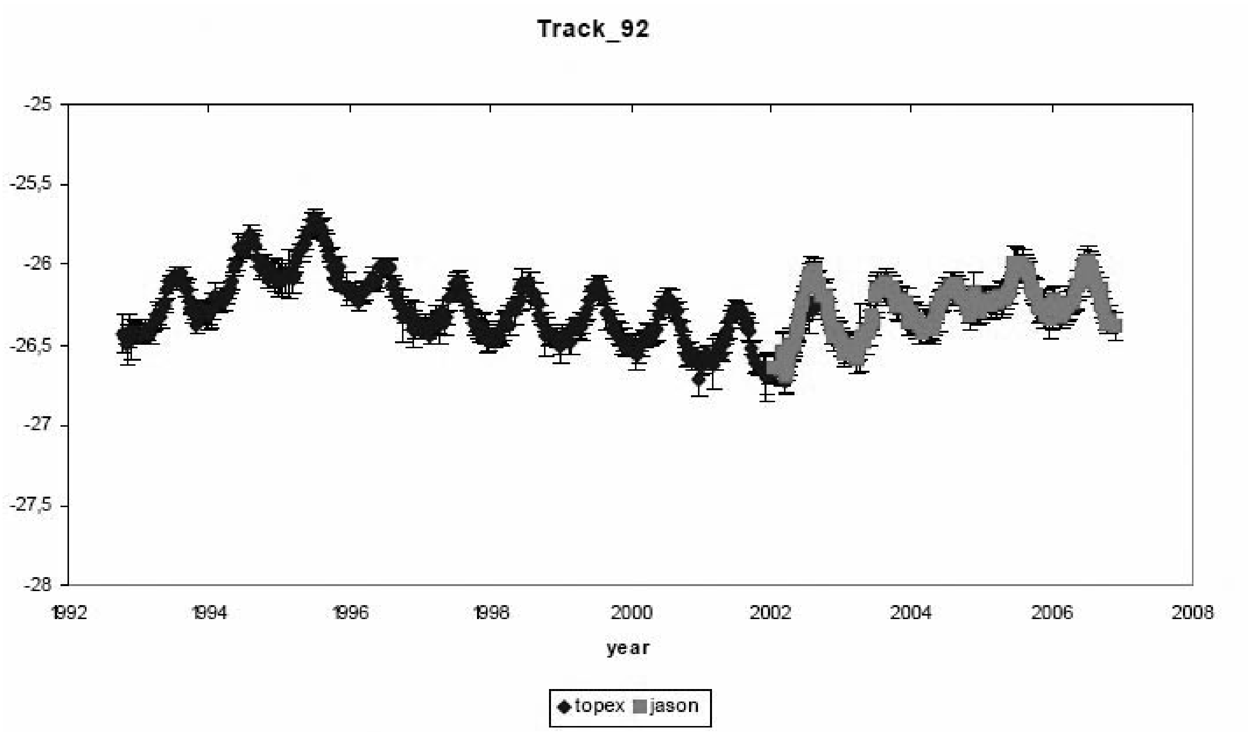

Figure 1. Water level fluctuation, TOPEX/Poseidon extended by Jason-1 track 92

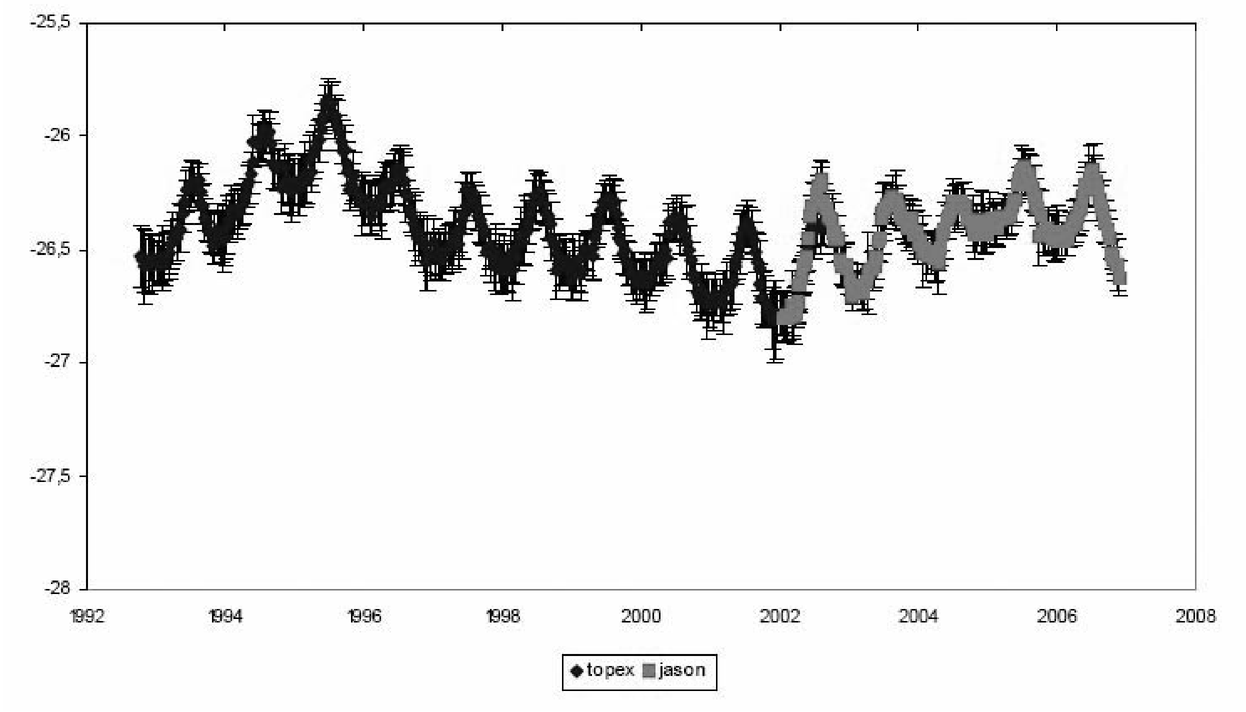

Figure 2. Reconstructed time series of TOPEX/Poseidon extended by Jason-1

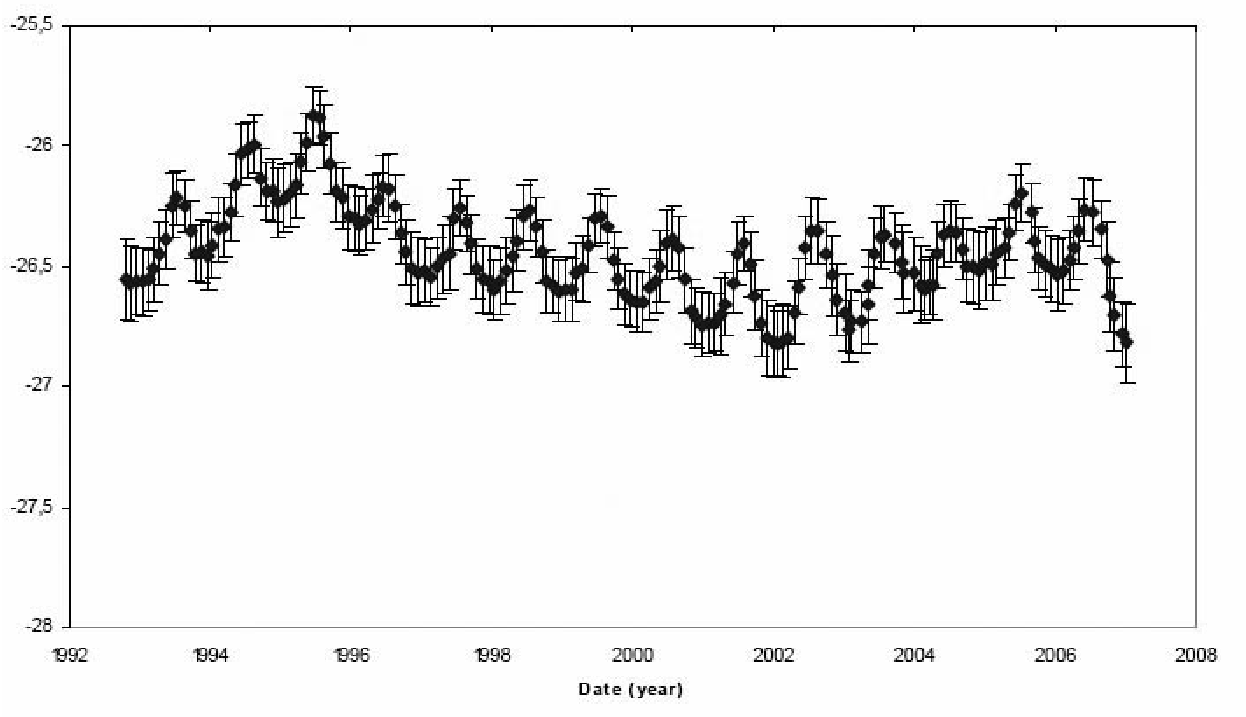

Figure 3. The Caspian Sea level variation in the multisatellite mode

Amplitude of the Caspian Sea level variations calculated along the TOPEX/Poseidon and Jason-1 tracks was also studied. Calculations were made cellularly for selected tracks. Then maps with the amplitude (in cm) of annual signal along tracks, and a map with an interpolation of the amplitude were constructed.

4. Conclusion

Obtained results indicate interannual level variations correlated with hydrological conditions of the Caspian Sea basin. Amplitude of the Caspian Sea level variation is not a constant in terms of spatial distribution. There is a strong geographical pattern with more than 18 cm of annual amplitude in central Caspian Sea. In the north part of the basin, the annual amplitude does not exceed 10 cm. In the south part of the basin, the annual amplitude is approximately 17 cm. Evaporation, precipitation, snowmelt process, and the Volga and Ural rivers discharge could be accepted as a reasonable explanation for the obtained results.

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