THE CASPIAN SEA LEVEL, DYNAMICS, WIND, WAVES AND UPLIFT OF THE EARTH'S CRUST DERIVED FROM SATELLITE ALTIMETRY

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ABSTRACT. The oscillations of the Caspian Sea level represent a result of mutually related hydrometeorological processes. The change in the tendency of the mean sea level variations that occurred in the middle 1970s, when the long-term level fall was replaced by its rapid and significant rise, represents an important indicator of the changes in the natural regime of the Caspian Sea. Therefore, sea level monitoring and long-term forecast of the sea level changes represent an extremely important task. The aim of this presentation is to show the experience of application of satellite altimetry methods to the investigation of seasonal and interannual variability of the sea level, wind speed and wave height, water dynamics, as well as of uplift of the Earth's crust in different parts of the Caspian Sea and Kara-Bogaz-Gol Bay. Special attention is given to estimates of the Volga River runoff derived from satellite altimetry data. The work is based on the 1992-2005 TOPEX/Poseidon (T/P) and Jason-1 (J-1) data sets.

KEY WORDS: Sea level, Caspian Sea, Kara-Bogaz-Gol Bay, satellite altimetry.

1. INTRODUCTION

The Caspian Sea presents the world's largest isolated water reservoir, with only isolation being its significant dissimilarity from the open seas. The other features of the Caspian Sea including its size, depth, chemical properties, peculiarities of the thermohaline structure and water circulation enable to classify it as a deep inland sea. Currently its level is at –27 m measured against the World Sea Level. The sea occupies an area of 392,600 km^2, with mean and maximum depths being 208 m and 1025 m, respectively (Fig.1). The Caspian's longitudinal extent is three times larger than its latitudinal one (1000 km vs. 200-400 km), resulting in great variability of climatic conditions over the sea. The isolation of the Caspian Sea from the ocean and its inland position are responsible for a great importance of the outer thermohydrodynamic factors, specifically, the heat and water fluxes through the sea surface, and river runoff for the sea level variability, formation of its 3D thermohaline structure and water circulation (Kostianoy and Kosarev, 2005).

Over the past half-century, there was a regression of the Caspian Sea until 1977 when the sea level lowered to –29 m (Fig.2). This drop is considered to be the deepest for the last 400 years. In 1978 the water level started to rise rapidly, and now it has stabilized near the –27 m level. There has been increasing concern over the Caspian Sea level fluctuations. Since the early 1990s regular measurements of the Caspian Sea level and main thermohydrodynamic parameters are practically absent. Today, the monitoring of the Caspian sea surface temperature, sea level, chlorophyll concentration, mesoscale dynamics, wind and waves, and some of the meteo parameters is organized based on the satellite IR and VIS data (AVHRR NOAA, MODIS), altimetry data (TOPEX/Poseidon, Jason-1) and re-analysis data.

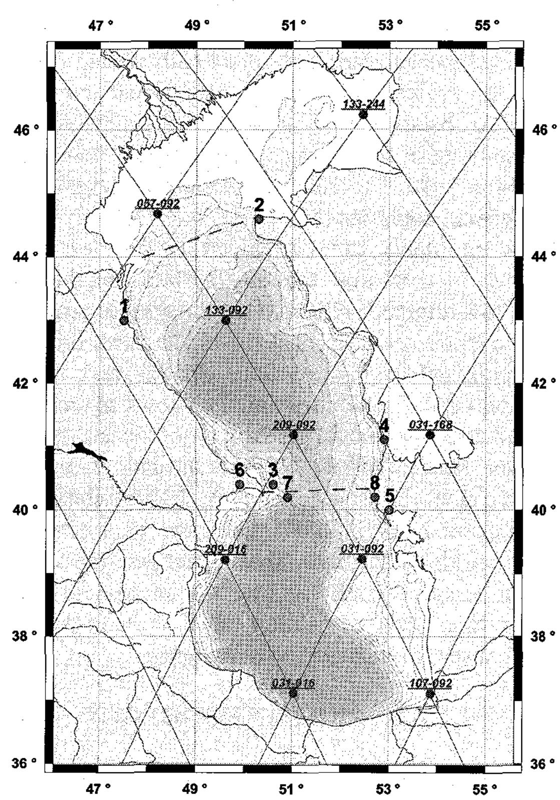

Figure 1. Map of the Caspian Sea and ground tracks of the T/P and J1. Sea level gauges are shown as follows: 1 – Makhachkala, 2 – Fort Shevchenko, 3 – Zhiloy Island, 4 – Kara-Bogaz-Gol, 5 – Turkmenbashi, 6 – Baku, 7 – Neftyanye Kamni, 8 – Kuuli Mayak

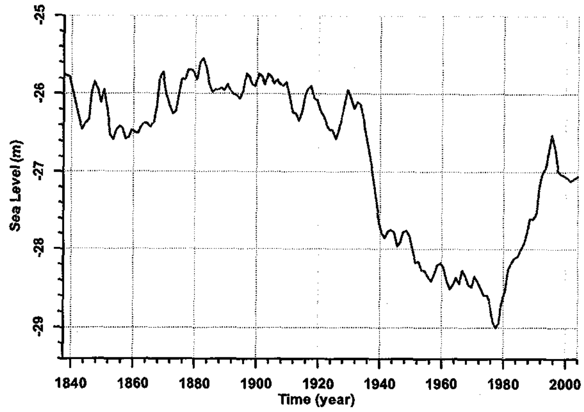

Figure 2. Interannual variations of the Caspian Sea level measured by sea level gauges (1837–2004)

Traditionally, the sea level variations, which are conditioned by different factors, were investigated basing on the sea level gauge data. But these data usually give information on sea level change only nearby the coastline, which has a significant impact on the measured data. Also, according to the last GPS measurements, some of the sea level gauges, for example, in the Barents, Baltic and Caspian seas (Scherneck et al., 2001), have a positive vertical lift, which is conditioned by the motion of earth crust. It also introduces considerable error in the interannual variability of sea level. Moreover, regular sea (lake) level measurements are practically absent for some regions in Africa and Central Asia (Kostianoy et al., 2004). For instance, in Former Soviet Union it was 79 gauge stations in the Caspian Sea in 1960, then - 51 in 1972, 36 in 1992, 3 in 2004 in Russia plus 4-5 stations in other Caspian countries (Fig.1).

These problems can be solved by use of satellite altimetry. It measures the sea surface height (SSH) relative to a reference ellipsoid (or the gravity center) that allows to eliminate a vertical lift of the earth crust from the interannual level variation. Spatial and temporal resolution of the satellite altimetry allows to investigate seasonal and interannual variability of ocean, sea, lake and river levels (Birkett, 1995; Larnicol et al., 1995; Cazenave et al., 1997; Mercier et al., 2002; Lebedev et al., 2003; Kostianoy et al., 2004). Cazenave et al. (1997) and Vasiliev et al. (2002) have shown that satellite altimetry data can be successfully used for the investigation of the Caspian Sea level variability in a deficiency of the traditional sea level gauge measurements.

2. DATA AND METHODOLOGY

For the analysis of the Caspian Sea level variations the measurements of T/P and J1 satellites were used for the following reasons. The precision of the measurements of SSH by T/P and J1 to the relative reference ellipsoid is 1.7 cm that is higher than in other altimetry missions. At the same time, accuracy of sea level measurements is of ~4 cm (Birkett, 1995) that allows to conduct the studies with an adequate accuracy. The position of the T/P and J1 ground tracks (Fig. 1) is optimal for the analysis of sea level variations in the Caspian Sea. The orbital repeat period (~10 days) enables the analysis of interannual and seasonal variability of the sea level. The T/P data represent the longest time-series of satellite altimetric measurements (since September 1992 to August 2002 or from 1 to 365 cycle) with a possibility of its extension by the J1 data along the same tracks (since August 2002 to present time).

We have analyzed 13 years of T/P and 3.5 years of J1 data since September 1992 till December 2005. Satellite altimetry data from T/P and J1 were obtained from the NASA Goddard Space Flight Center (GSFC) Ocean Altimeter Pathfinder Project. Besides, the T/P merged geophysical data records (MGDR) were obtained from the NASA Physical Oceanography Distributed Active Archive Center (PODAAC) at the Jet Propulsion Laboratory (JPL) of California Institute of Technology. The J1 Interim Geophysical Data Record (IGDR) and Geophysical Data Record (GDR) were obtained from AVISO (Archivage, Validation et Interprétation des données des Satellites Océanographiques) and PODAAC (AVISO and PODAAC, 2003). Information and software of Integrated Satellite Altimetry Data Base (ISADB) developed in the Geophysical Center of Russian Academy of Sciences (Medvedev et al., 1998) have been used for data processing and analysis. Methodology of data processing and analysis as well as the obtained results on the Caspian Sea level, wind speed and wave height variations were described in detail in (Lebedev and Kostianoy, 2005).

3. THE CASPIAN SEA

Temporal variation of the Caspian Sea level was calculated on the base of the SSH variation in different crossover points of ascending and descending passes (Fig.1). We took two points in the Northern Caspian (057-092 and 133-244), two points in the Middle Caspian (133-092 and 209-092) and three points in the Southern Caspian (209-016, 031-092, 031-016). Integrated sea level variability for the whole Caspian Sea is shown in Fig.3.

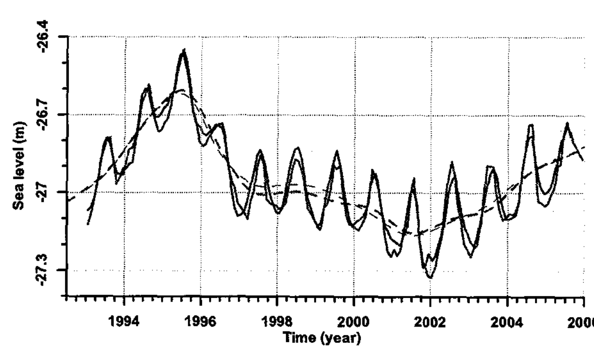

Figure 3. The Caspian Sea level variability (m) since January 1993 till January 2006 on the base of satellite altimetry data of T/P and J-1 (blue) and sea level gauges

(red). Dashed lines – interannual variability, solid lines – seasonal variability

Between October 1992 and March 1995 the Caspian Sea level was still 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 (Fig.3). 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. We have to note that the Northern, Middle and Southern Caspian have a little bit different temporal behavior of their sea levels as well as their rate of change (Lebedev and Kostianoy, 2005).

Comparison of SSH variations in 7 crossover points with data of 8 sea level gauges has shown that the maximal value of correlation coefficient 0.96 was observed between a station in Baku and 209-092 crossover point (Fig.1).

Interannual and seasonal variability of wind speed (Fig.4) and wave height (Fig.5) have been investigated on the base of the same data sets (Lebedev and Kostianoy, 2005).

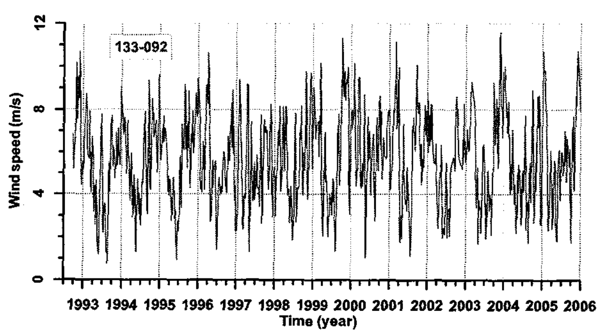

Figure 4. Wind speed (m/s) at crossover point 133-092 in the Middle Caspian in Sept. 1992 – Dec. 2005

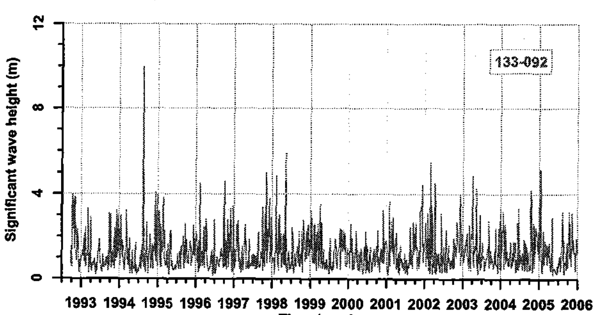

Figure 5. Wave height (m) at crossover point 133-092 in the Middle Caspian in Sept. 1992 – Dec. 2005

4. THE KARA-BOGAZ-GOL BAY

In March 1980, in order to restrict the losses of the Caspian waters and to decelerate the fall of the level of the Caspian Sea, which, in 1977, had been the lowest over the past 400 years (-29 m), the Kara-Bogaz-Gol strait was closed by a nonoverflow sand dam; this way, the delivery of the seawater to the bay was stopped. After the separation of the bay, it was rapidly dried off. By the middle of 1984, the bay had been almost completely dried off and transformed into a "dry" salt lake. In order to protect and develop the unique salt field on the Caspian Sea under the conditions of the rapid sea level rise (Fig.2), it was decided to rehabilitate the water supply to the Kara-Bogaz-Gol. In June 1992, the dam was destroyed and the natural seawater runoff to the bay resumed.

The process of the filling of the bay and its acquisition of the climatic regime is well traced in the satellite altimetry data of T/P and J1 because the area of the bay is crossed by two tracks of the above-mentioned satellites. Up to the middle of 1996, the bay was rapidly filled with the Caspian water (Fig.6) causing a rate of the level rise of about 168 cm/yr (Lebedev and Kostianoy, 2005). Then, the level rise stopped and its variations started to reflect seasonal changes (Fig.6) well correlated with the seasonal level changes in the Caspian Sea. Thus, the rate of the level fall (until winter 2001/2002) in both of the basins comprised approximately 6 cm/yr. At present, the level of the bay oscillates near an absolute mark of -27.5 m.

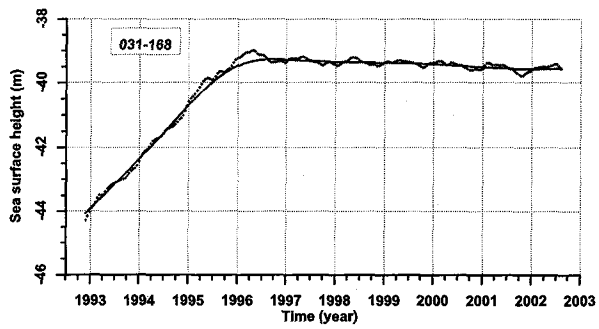

Figure 6. Interannual and seasonal variability of SSH (m) in the Kara-Bogaz-Gol Bay at crossover point 031-168 in September 1992 – August 2002

5. THE VOLGA RIVER

The Volga River, whose mean annual runoff makes about 240 km^3/yr, provides about 80% of the total riverine runoff to the Caspian Sea. The greatest runoff equal to 368 km^3/yr was recorded in 1926, while the minimum and extremely small values equal to 150 and 163 km^3/yr were noted in 1921 and 1973, respectively. Up to 25% of the Volga River runoff is supplied to the sea in May–June during the flood periods.

River water level variability was analyzed also basing on SSH in crossover points of 235 passes with riverbed. The obtained results were verified with water discharge rate at the Volgograd hydroelectric power station located far upstream (Fig.7). The correlation coefficient was about 0.83 for annual values and 0.71 for monthly mean values. Negative SSH trend 46.7 cm/yr in 1993–1996 corresponds to the decrease of average annual water discharge in the Volgograd power station from 10,654 to 5,609 m^3/s. Close to the track pass there are three hydrological stations at the river – Enotaevka, Seroglazovka and Verkhnee Lebyajye. Satellite SSH correlates with daily measurements at these stations much better – 0.8-0.9 (Lebedev and Kostianoy, 2005).

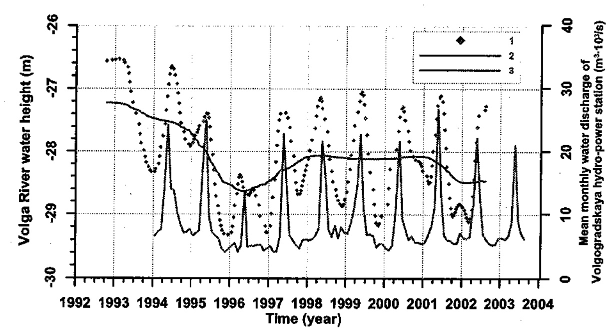

Figure 7. Variations of (1) the Volga River SSH (m) and (2) SSH interannual variability derived from T/P altimetry (January 1992 – December 2003), and (3) mean monthly water discharge at the Volgograd power station

6. ESTIMATED VALUE OF THE EARTH'S CRUST UPLIFT

Value of the Earth's crust uplift was estimated basing on the difference between monthly (and/or annual) sea level gauge measurements and sea level derived from satellite altimetry data since October 1992 till December 2005 (Fig.8):

	Level gauges	Whole sea (altimetry) monthly data / annual data (cm/year)
Middle Part	Makhachkala	-0.449/-0.455
	Fort Shevchenko	-0.459/-0.446
Southern Part	Turkmenbashi	-0.459/-0.446
	Baku	-0.614/-0.605

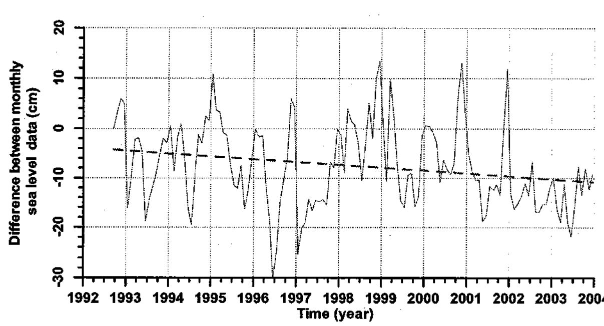

Figure 8. Difference between monthly Makhachkala sea level gauges and satellite altimetry data.

7. ACKNOWLEDGEMENTS

This study was supported by the project "Elaboration of technologies for multi-level regionally adapted ecological and geodynamical monitoring of the Russian seas" of the Russian Ministry of Education and Science, Russian Foundation for Basic Research grant N 06-05-64871, NATO SfP PROJECT №981063 "Multidisciplinary Analysis of the Caspian Sea Ecosystem" (MACE), and by the INTAS "ALTICORE" Project.

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