



**HAL**  
open science

# Caspian sea level from Topex-Poseidon altimetry: Level now falling

A. Cazenave, Pascal Bonnefond, K. Dominh, P. Schaeffer

► **To cite this version:**

A. Cazenave, Pascal Bonnefond, K. Dominh, P. Schaeffer. Caspian sea level from Topex-Poseidon altimetry: Level now falling. *Geophysical Research Letters*, 1997, 24 (8), pp.881-884. 10.1029/97GL00809 . hal-04919891

**HAL Id: hal-04919891**

**<https://hal.science/hal-04919891v1>**

Submitted on 30 Jan 2025

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Copyright

## Caspian sea level from Topex-Poseidon altimetry: Level now falling

A. Cazenave,<sup>1</sup> P. Bonnefond,<sup>2</sup> K. Dominh,<sup>1</sup> and P. Schaeffer<sup>1</sup>

**Abstract.** Tide gauge measurements recorded between 1978 and 1993 indicate that the Caspian sea level (CSL) has been rising at an average rate of  $\sim 12$  cm/yr during this 15-yr time span. Decadal CSL changes are currently attributed to changes in river runoff and effective evaporation. We have analysed 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. We show that the Caspian sea level was still rising at a rate of  $18.9 \pm 0.5$  cm/yr between January 1993 and July 1995 and that the northwestern Caspian in the area of the Volga delta was rising faster (by  $\sim 3$  cm/yr) than the middle and south Caspian. However, by mid-1995, the CSL started to drop abruptly, a trend still observed in 1996. The average sea level decrease recorded from mid-1995 amounts to  $-24.8 \pm 1.4$  cm/yr.

### Introduction

The Caspian sea is the largest inland sea of the world. It extends over 1200 km from north to south, between 47°N and 37°N. The sea is 27 m below the global mean sea level and is conventionally divided into three parts: southern, middle and northern Caspian. The southern basin is the deepest, reaching more than 1000 m, while the northern basin is very shallow, depth ranging between 1 m and 10-15 m.

The Caspian sea, as many other closed water bodies in the world, is characterized by large fluctuations in water level (Rodionov, 1994, Kosarev and Yablonskaya, 1994). Over the last century, tide gauges have recorded abrupt variations over decadal time scales (Fig. 1): After a 50-yr period of relative stability (1880-1930), the Caspian sea level (CSL) dropped abruptly from 1933 to 1940 by nearly 2 m. Until 1977, it continued to decrease at a smaller rate (3 cm/yr). In 1978, a sudden and unexpected rise has affected the Caspian sea. Tide gauge measurements indicate an average rate of rise of  $\sim 12$  cm/yr between 1978 and 1993 (Shiklomanov et al., 1995). Many coastal regions have been flooded, causing substantial environmental and economic damage (Dumont, 1995). The CSL decadal changes are generally assumed to result from modifications in the water balance of the sea (river runoff, precipitations and evaporation) in response to climatic variations (Vali-Khodjani, 1991, Rodionov, 1994, Kosarev and Yablonskaya, 1994, Shiklomanov et al., 1995, Ferronsky et al., 1995). However, the causes of these climatic changes are not yet understood. It is not clear if these result from large-scale rather than regional modifications in the atmospheric circulation patterns, nor if there is an impact from environmental

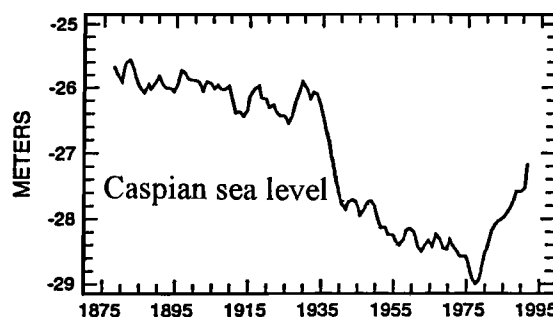
(anthropogenic) transformations that have affected the Caspian sea region.

Satellite altimetry has proved to be quite a powerful technique for precisely measuring absolute sea level variations with homogeneous spatio-temporal coverage (e.g., Minster et al., 1995; Nerem, 1995). Such a method also applies well to monitor lake level changes as shown by Birkett (1994, 1995). In this study, we have estimated the CSL changes between January 1993 and August 1996, using altimeter range data of the TOPEX-POSEIDON mission. We have focused our analysis on the interannual CSL variations and have studied their geographical variations. Changes in some hydrometeorological factors have also been examined.

### TOPEX-POSEIDON data

TOPEX-POSEIDON (T/P) is a joint NASA/CNES (Centre National d'Etudes Spatiales, France) altimeter mission devoted by study ocean dynamics (Fu et al., 1994). T/P was launched in August 1992 on a 66° inclined orbit at 1336 km altitude. The satellite carries two altimeters: Topex and Poseidon. The orbit repeat period (or orbital cycle) is 9.916 days which corresponds to an intertrack spacing of 250 km at equator. Altimeter range measurements (or Geophysical Data Records, GDRs) are provided at 1-s interval (6 km along-track) by the AVISO (Archiving Validation and Interpretation of Satellite Oceanography) data center at CNES. The T/P track coverage over the Caspian sea is shown in Fig. 2. Instantaneous sea surface height (SSH) is simply obtained from the difference between the radial component of the orbit and the altimeter measurement. For previous altimeter missions, uncertainty in the radial orbit component was the largest source of error affecting SSH (amounting to 10-20 cm or even more). For T/P, the orbit precision has been improved by nearly an order of magnitude and is currently 2-3 cm rms (Tapley et al., 1994a, Nouel et al., 1994).

We have analysed 3.7 years of T/P data from Dec. 31, 1992 through August 20, 1996 (cycles 11 through 144). The first cycles of the mission have not been used because of spacecraft



**Figure 1.** Long term Caspian sea level fluctuations (annual means) measured by tide gauges (redrawn from Rodionov, 1994).

<sup>1</sup>A. Cazenave, K. Dominh and P. Schaeffer, CNES-CNRS-UPS, UMR5566 18, Avenue Edouard Belin, 31401 Toulouse Cedex 4, France.

<sup>2</sup>P. Bonnefond, GRGS-OCA, Avenue Copernic, 06130 Grasse, France.

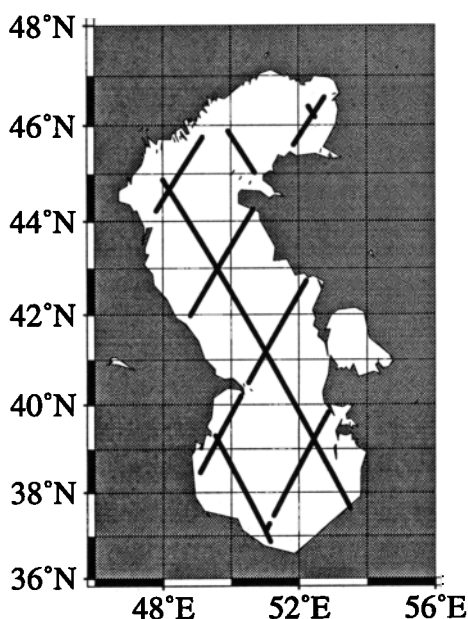


Figure 2. TOPEX-POSEIDON track coverage over the Caspian sea.

attitude control problems (e.g., Nerem, 1995). The data are given with a number of geophysical corrections to apply to the SSH: ionospheric correction, dry and wet tropospheric corrections, solid Earth and ocean tides, ocean tide loading, pole tide, inverted barometer correction, electromagnetic (sea-state) bias, and instrumental corrections. For the Caspian sea, we did not apply the ocean tide nor the inverted barometer corrections. The best available ocean tide model for T/P is the CSR3 model developed at the University of Texas at Austin. However the model may not apply to closed water bodies such as the Caspian sea. Neither did we apply the inverted barometer correction which assumes that the sea surface responds statically to surface pressure variations. The correction has shown to be valid in open seas, but in closed basins, it is not known a priori if the water level responds as an inverted barometer. We replaced the orbit given by AVISO by the most precise orbit available to date computed by NASA with the JGM-3 geopotential model (Tapley et al., 1994b). The wet tropospheric correction is based on water vapor measurements collected by the onboard microwave radiometer. The ionospheric correction is derived from the dual-

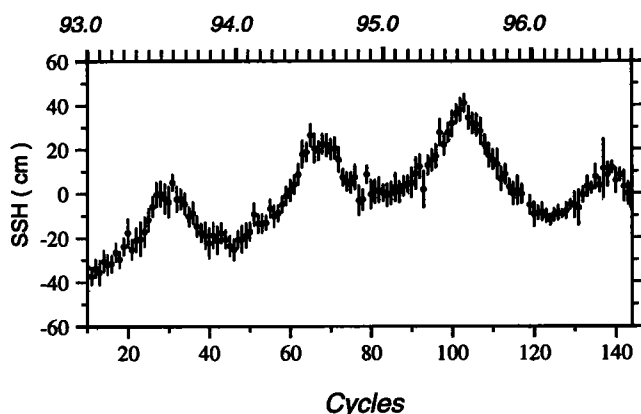


Figure 3. Mean Caspian sea level variations measured by TOPEX-POSEIDON between January 1993 (orbit cycle 11) and August 1996 (orbit cycle 144). In cm.

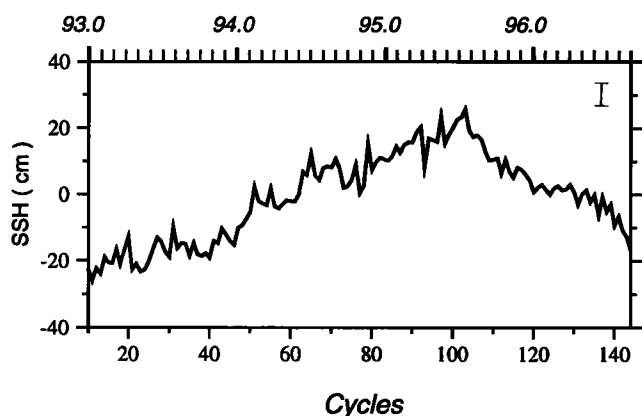
frequency range measurements for the Topex altimeter and for Poseidon, from Doppler data of the DORIS tracking system onboard the T/P satellite. The electromagnetic bias is based on the four parameter model of Gaspar et al. (1994). Drifts of the Topex instrument (altimeter and oscillator) have been corrected for. Data editing criteria are based on the index quality given with the GDRs by AVISO. Additional selection criteria have been applied. These are described in Minster et al. (1995) and Cazenave et al. (1996). In addition, we removed data within 80 km from the coasts because of erroneous radiometer measurements at sea-land transitions. Some SSH data over the northeastern part of the Caspian sea appear sometimes noisy, possibly a result of large water level fluctuations in response to wind stress variations on a few days time scale or of the presence of ice (e.g., Birkett, 1995). These data have been excluded.

### Analysis and results

The instantaneous SSH is the sum of two components: (1) the height of the geoid (the equipotential surface of the gravity field) above the reference ellipsoid and (2) the sea surface height above the geoid. For this investigation, we averaged collinear altimeter passes of each 10-day repeat cycle, over three complete years (1993, 1994, 1995). These averaged SSH data represent the Caspian mean sea level for the 3 years considered, which may approximate the Caspian sea geoid. At each latitude-longitude location along the ground tracks, CSL variations with time are obtained by computing the differences between SSH of each 10-day cycle and 3-yr averaged SSH. In the following we keep the notation SSH for these differences. Two sets of data have been computed: (1) times series of SSH at each latitude-longitude location of a given ground track, (2) times series of mean SSH over the Caspian sea. The purpose of computing (1) is to estimate at each latitude-longitude location, a particular component of the CSL variation (e.g., interannual) and derive its geographical distribution.

Fig. 3 shows the mean CSL as a function of time (e.g., time series of SSH measurements averaged over the Caspian sea). Each error bar is the standard deviation computed in averaging SSH over the sea area and over a repeat cycle. It represents the space and time (over 10 days) variability of the SSH. On Fig. 3, an annual cycle is clearly visible, with maxima occurring late June. We have computed the mean annual cycle after detrending the time series. Its amplitude is  $\sim 16$  cm. The CSL residuals (seasonal component removed, trend restored) (Fig. 4) are dominated by a large positive drift until mid-1995. Linear regression applied to the residuals between January 1993 and July 1995 gives an amplitude of  $+18.9 \pm 0.5$  cm/yr. This CSL rise corresponds to  $\sim 73$  km<sup>3</sup>/yr of annual water volume increase. The CSL rise measured by T/P between January 1993 and July 1995 is much larger than the mean value,  $\sim 12$  cm/yr, deduced from tide gauge measurements between 1978 and 1993 (Rodionov, 1994, Shiklomanov et al., 1995).

Fig. 4 shows that by mid-1995, the CSL started to decrease abruptly at an average rate of  $-24.8 \pm 1.4$  cm/yr. This CSL drop, initiated in July 1995, is still observed with the most recent T/P data available (cycle 144, August 1996). It is confirmed by tide gauge measurements (S. Tateviian, personal communication, Oct. 1996). Although, longer time series are needed to distinguish between a temporary change or a long term reversal, it is worth noting that the CSL has been decreasing regularly by more than one year after a period of accelerated rise (19 cm/yr between January 1993 and July 1995 versus 12 cm/yr on the average for



**Figure 4.** Mean Caspian sea level variations derived from T/P as a function of orbital cycle, after removing the seasonal component. In cm.

the preceding 15 years). This kind of behavior has been observed in the past when new decadal trends have established (Rodionov, 1994).

We have investigated the geographical distribution of the CSL rise observed between January 1993 and July 1995. For this purpose, at each latitude-longitude location of each ground track, we have constructed SSH time series and for each point, computed the drift. The observed drifts were then mapped as a function of geographical location. These are shown in Fig. 5. The drifts show smooth variations ranging from  $18 \pm 0.5$  cm/yr in the southern and middle Caspian to  $\sim 21 \pm 1$  cm/yr in the northern Caspian. The largest rise corresponds to the Volga delta. In spite of the sparse coverage of the T/P tracks, we believe that the pattern of northward drift increase is real, since it is also clearly seen along individual tracks, in particular along the longest T/P track that crosses the Caspian sea from north to south.

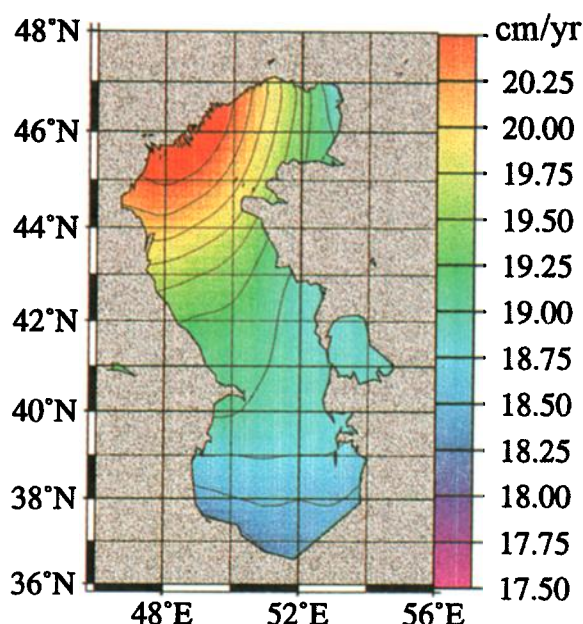
## Discussion

Water level variations of closed bodies, such as the Caspian sea, are known to be sensitive indicators of climate changes. Water level balance can be written as (e.g., Mason et al., 1994):

$$\frac{dSSH}{dt} = \frac{1}{A} [(R + P + G_i)] - (D + E + G_o) \quad (1)$$

where  $dSSH/dt$  is rate of change in water level with time  $t$ ,  $A$  is sea area,  $R$  is river runoff,  $D$  is discharge rate into or out the sea,  $P$  and  $E$  are respectively total precipitation and evaporation rates,  $G_i$  and  $G_o$  are rates of underground inflow or outflow.

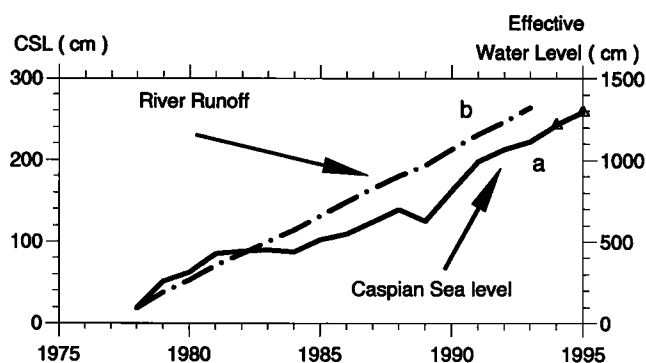
The water balance of the Caspian sea has been estimated over different time intervals since the end of the last century (Kosarev and Yablonskaya, 1994, Shiklomanov et al., 1995): River water inflow to the Caspian sea is mostly due to the Volga river, which contributes of 85% the total runoff. Outflow through the Kara-Bogaz-Gol (KBG) Bay located on the east side of the sea near  $41^\circ\text{N}$ , was completely negligible between 1980 and 1992 when the strait was blocked by a dam, preventing sea water from the Caspian to penetrate into the bay. Although the strait was reopened in 1992, outflow is small,  $<10\%$  of the river inflow. Underground inflow to the Caspian is difficult to measure, but from direct geohydrological investigations, is estimated as less than 1% of river inflow. Underground outflow is generally assumed to be even less (0.5% of the river inflow). Thus the



**Figure 5.** Geographical variation of the Caspian sea level rise measured by T/P between January 1993 and July 1995. In cm/yr.

Caspian sea water balance equation is dominated by changes in  $R$ ,  $P$  and  $E$  (Shiklomanov et al., 1995).

The favoured cause of the CSL rise observed between 1978 and 1995 is change in climatic factors which have affected the water balance towards an increase of the positive components (river inflow and precipitation over the sea and drainage basin) and a decrease of evaporation over the sea. Shiklomanov et al. (1995) provide annual means of observed CSL, total river runoff and outflow to the KBG Bay from 1978 to 1993: Fig. 6 shows, for that period, CSL changes recorded by tide gauges as a function of time (curve a), and effective water inflow (i.e., river runoff corrected for outflow to the KBG Bay and underground inflow) (curve b). For convenience, curve b is expressed in cm of water layer of the sea. On curve (a) we have included the mean CSL observed by T/P for the years 1994 and 1995 (until July), assuming that the mean level for 1993 derived from tide gauges coincides with the T/P estimate. During the years 1978-1993, the mean CSL annual increment was 13.9 cm. Results from T/P show that in 1994 and 1995 (until July), increments



**Figure 6.** Annual means of (a) CSL (in cm, left axis) and (b) effective river runoff expressed in equivalent water level (in cm, right axis) between 1978 and 1993 (In situ data are from Shiklomanov et al., 1995). Mean CSL measured by T/P in 1994 and 1995 is also reported (triangles).

were 20.1 cm and 16.1 cm respectively. Thus, by mid-1995, the CSL was 2.5 m higher than the record low value in 1977 (-29.00 m). Fig. 6 shows that for the period 1978-1993, effective runoff has varied linearly with time, as did CSL, suggesting a direct link between the two parameters.

We have analysed sea surface temperature (SST) over the Caspian sea between January 1993 and July 1995 using the SST fields computed by Reynolds at monthly intervals (e.g., Reynolds and Smith, 1994). The Caspian SST is dominated by a large seasonal signal (annual and semi-annual components, of amplitude 8.6°C and 1.5°C respectively) on which is superimposed a positive drift, of  $1.0 \pm 0.25^\circ\text{C}/\text{yr}$ . We crudely estimated the steric contribution to the observed CSL rise, i.e., that part of the sea level rise due to thermal expansion. Considering a thermal coefficient dependence on SST for a mean salinity of 13‰ and a mean annual temperature of 15°C (characteristic values for the Caspian sea) and assuming an average mixing layer of 50 m, we find that  $1^\circ\text{C}/\text{yr}$  drift in SST contributes to less than 1 cm/yr in the CSL rise and conclude that the steric effect is negligible. We also analysed the spatial variability of the SST drift. The maximum ( $1.5^\circ\text{C}/\text{yr}$ ) is observed along the western coast between 42°N and 43°N and the minimum ( $0.5^\circ\text{C}/\text{yr}$ ) in the northern region between the Volga and Ural river deltas. The geographical distributions of the SSH and SST drifts appear uncorrelated. We also analysed surface wind speed (a by-product of the altimeter measurement which is given by AVISO with the GDRs). Spatially averaged wind speed shows no significant drift over the period January 1993-July 1995, suggesting that the reported SSH rise is unrelated to this meteorological parameter.

The conclusion of the above analyses supports the current understanding of the CSL rise, which invokes river runoff increase due to enhanced precipitations over the Caspian sea drainage area, in combination with effective evaporation decrease over the sea. The cause for the observed geographical variation of the CSL rise is unclear. We note that maximum rise occurs at the Volga delta, thus corresponds to freshened waters associated with the river inflow. It has been reported that on interannual time scales, changes in salinity are greater in the northern Caspian sea and that these are closely related to the Volga inflow variations (Kosarev and Yablonskaya, 1994). It is not clear however why the sea is rising faster in low salinity areas. This question which is beyond the scope of the present study will need further investigation.

The falling of the Caspian sea recorded since mid-1995 was totally unexpected. It appeared abruptly during summer 1995. The cause for this sudden change is probably related to the lesser Volga inflow recorded in 1995 (S. Tatevian, personal communication, Oct. 1996) and may also result from an increase of evaporation.

## Conclusion

Satellite altimetry based on TOPEX-POSEIDON indicates that the CSL has continued to rise between January 1993 and July 1995 at an average rate of  $18.9 \pm 0.5$  cm/yr. This analysis has shown however that the rise is not uniform and depends upon geographical location. The CSL rise increases from south to north by  $\sim 3$  cm/yr. The largest rise is observed in the northwestern Caspian, just south of the Volga river delta. By mid-1995, an abrupt reversal has been initiated. T/P data show that since July 1995, the CSL is falling at a rate of  $-24.8 \pm 1.4$  cm/yr, which is a considerable amount. Future measurements

of the CSL variations will allow to distinguish between a transitory regime or a new long-term (decadal) fluctuation. Continuing monitoring of the CSL by satellite altimetry in quasi real time, and high temporal, open sea coverage will be of high interest for surveying the newly established trend of the Caspian sea level. Ultimately, this may help in clarifying the relationship between the sea level variations and the climatic factors that affect amount and regime of river inflow to the sea, thermal regime, evaporation and precipitation over the sea area, and eventually in distinguishing between natural climate effects and anthropogenic factors.

**Acknowledgements.** We thank S. Tatevian for exchange of information on the Caspian sea level changes. We also thank E.A. Okal for reviewing the various versions of the manuscript. C. Brossier, M.C. Gennero and the AVISO team of CNES are acknowledged for help and support in altimeter data processing. This work was supported by CNES and CNRS.

## References

- Birkett, C.M., Radar altimetry: A new concept in monitoring lake level changes, *EOS*, 75, 273-275, 1994.
- Birkett, C.M., The contribution of TOPEX/POSEIDON to the global monitoring of climatically sensitive lakes, *J. Geophys. Res.*, 100, 25179-25204, 1995.
- Cazenave, A., Schaeffer, P., Berge, M., Brossier, C., Dominh, K. and Gennero, M.C., High-resolution mean sea surface computed with altimeter data of ERS-1 (geodetic mission) and TOPEX-POSEIDON, *Geophys. J. Int.*, 125, 696-704, 1996.
- Dumont, H., Ecocide in the Caspian sea, *Nature*, 377, 673-674, 1995.
- Ferronsky V.I., Brezgunov V.S., Romanov V.V., Vlasova L.S., Polykov V.A. and Bobkov, A.F., Isotope studies of Caspian sea level rise implications, in Intergovernmental Oceanographic Commission Workshop reports, UNESCO, Paris, 1995.
- Fu, L.L., Christensen, E., Yamarone, C., Lefebvre, M., Menard, Y., Dorrer, M. and Escudier, P., TOPEX-POSEIDON mission overview, *J. Geophys. Res.*, 99, 24369-24381, 1994.
- Gaspar P., Ogor F., LeTraon P.Y. and Zanife O., Estimating the sea state bias of the Topex and Poseidon altimeters from crossover differences, *J. Geophys. Res.*, 99, 24981-24994, 1994.
- Kosarev A.N., and Yablonskaya E.A., *the Caspian sea*, SPB Academic Publishing, the Hague, the Netherlands, 1994.
- Mason I.M., Guzkowska M.A.J., Rapley C.G. and Street-Perrott, F.A., The response of lake levels and areas to climatic changes, *Climatic changes*, 27, 161-197, 1994.
- Minster, J.F., Brossier, C. and Rogel, P., Variation of the mean sea level from TOPEX-POSEIDON data, *J. Geophys. Res.*, 100, 25153-25161, 1995.
- Nerem, R.S., Measuring global mean sea level variations using TOPEX-POSEIDON altimeter data, *J. Geophys. Res.*, 100, 25135-25151, 1995.
- Noel, F. et al., Precise CNES orbits for TOPEX-POSEIDON: is 2 cm still a challenge?, *J. Geophys. Res.*, 99, 24405-24420, 1994.
- Reynolds, R.W. and Smith T.M., Improved global sea surface temperature analyses using optimum interpolation, *J. Climate*, 7, 929-948, 1994.
- Rodionov, S.N., *Global and regional climate interaction: the Caspian sea experience*, Water Science and Tech. Library, Kluwer Academic Pub., Dordrecht, 1994.
- Shiklomanov I.A., Georgievsky V.Y., and Kopalani Z.O., Water balance of the Caspian sea and reasons of water level rise in the Caspian sea, in Intergovernmental Oceanographic Commission Workshop reports, UNESCO, Paris, 1995.
- Tapley, B.D. et al., Precision orbit determination for TOPEX-POSEIDON, *J. Geophys. Res.*, 99, 24383-24404, 1994a.
- Tapley, B.D. et al., The JGM-3 gravity model, *Ann. Geophys.*, 12, Suppl. 1, C192, 1994b.
- Vali-Khodjeini A., Hydrology of the Caspian sea and its problems, in *Hydrology of natural and manmade lakes*, Schiller G., Lemnela R. and Spreafics M. Editors, IAHS publication n°206, Washington D.C., 1991.

(Received: May 9, 1996; Revised: Feb 25, 1997; Accepted: Feb 25, 1997)