

# IMPACT OF THE CLIMATE CHANGE ON ADRIATIC SEA HYDROLOGY

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## Abstract

In the paper there are presented the impact of the climate change on Adriatic Sea hydrology. The study is based on the results of inversion of 6 thermologs data for the ground surface temperature history in Albania, and climate change according to the meteorological data from different regions of Albania. The wells and the meteorological stations are located in Sedimentary Basin of Albania, at the field region in the west of Central Albania and in the ophiolitic belt in the mountainous region of the northeast Albania. Based on inversion data at coastal plane western region of Albania, GST history presents a gradual cooling before a middle of the 19th century, followed by 0.6 K warming. Climate warming of 0.6 K in the 20<sup>th</sup> century is observed also in mountainous northwestern Albania. This warming mainly after the second half of the 20<sup>th</sup> century is presented also by meteorological data. The warming has caused its impact on country climate, inland and coastal water systems and ecosystems of the Albania

**Keywords:** Ground Surface Temperature, Climate Changes, Hydrology, Hydrographic System, Adriatic Sea, Environmental Impact.

## 1. Introduction

Processes of the forming and circulation of the Adriatic Sea water mass, as is well known, presents a discussible phenomenon of the Mediterranean oceanographic dynamics. One of the main factors, which have determined these processes, is water discharge from the Albanian Hydrographic System into Adriatic Sea (Pano N. 1964, 1965, 1978, 1995 e 1998). Analyze of the factors that conditioned water discharge and their impact on Adriatic Sea Hydrology are presented in the paper.

Climate, geomorphology, lithology and geographical situation of the Albanian Hydrographic Network Catchment, are caused their impact on the water discharge from Albania into Adriatic Sea. Its impact has been observed on some directions:

- Country climate change,
- Water systems and water resources changes. Impact of inland water resources changes on the hydrographic regime of the Adriatic Sea.
- Mechanism of the forming and circulation of the South Adriatic Sea water.

In the first part of the paper is presented detailed analyzes of the climate change in Albania (Frasheri 1995, Frasheri et al. 1999, 2002. Albania lies in a subtropical zone. It is a Mediterranean country. Winter is relatively short and mild, humid near the seaside areas. Summer lasts very long and it is hot and dry. To the east, in the mountain areas, the climate is Mediterranean mountainous. There, the temperature is lower than in seaside zones and the raining decrease. Sunshine varies from 2560 hours per year in Tirana, down to 2046 hours in Kukesi City. Average yearly temperature varies from 16.5°C in Vlora City, 11.8°C in Kukesi and 7.0°C in the northern area of the Albanian Alps. In Albania the rainfall is in average about 1430

mm/year. Albanian Alps is one of the most humid territories in Europe, up to 4444 mm/year rainfalls (Albanian Climate, 1978, Boriçi, M. and Demiraj, E. 1990, Mici, A. et al 1975). The climate in Albania varies from a region to the other, according to the location compared with the seaside, to the seasons, years, and centuries. The ground temperatures are conditioned by geographical position of the area, area's geology, and ground lithology, dynamics of the underground waters, meteorological conditions, and season. The climate change studies, are based on geothermal inversion results and meteorological observation data. (Frasheri A. 1995, Frasheri A. et al. 1999, 2002). There is analyzed the ground surface history (GSH) and paleoclimate change according to the temperature measurements in the different wells in Albania. Climate changes during the last half of the XX century has been analyzed also based on the meteorological data.

There are estimated continental water flow, created by atmospheric rainfalls and its impact on processes of the forming and circulation of the Adriatic Sea water mass has been analyzed.

According to the complicated nature of the Albanian Hydrographic System, in the second part of the paper, is presented the analytical methodic for estimation of the total continental water flow in this system. From multi annual analysis of the water flow, in the paper are selected and analyzed characteristics of two characteristic years, with great ( $p=1\%$ ) and small ( $p=99\%$ ) water flow.

In the last part of the paper the processes of the forming and circulation of the Adriatic Sea water mass impact for wet and dry years are analyzed. Results of the Albanian Expeditions "Saranda-1963" and "Patosi 1964", have used for the analysis of year with great water flow. For the dry year have analyzed Italian-Albanian Expedition "Italia 2001-2002" data.

## 2. Material and methods

Climate change are analyzed in two directions: firstly by temperature record in the deep wells and shallow boreholes, and secondly by the meteorological observations data. The ground surface temperature reconstruction for long period, about 5 centuries, has been performed by estimation of the ground surface temperature changes at the past, according to the present-day distribution of the temperature at the depth, recorded in the borehole. The study of geothermal field of Albania has been carried out based on the temperature logging in the wells and boreholes (Çermak, V. et al 1996, Frasheri, A. and Çermak, V. et al. 1995, 2004). Six thermoplots were used for inversion of the ground surface temperature history. Well Ko-10, Arza-31, are located at the plane region in the west of Central Albania (Fig. 1). Boreholes VI-1127, Gurth-595, Krasta-1 and Ragam-168 are located in the mountainous region of the northeast of the Albania (Fig. 1).

Air and ground temperatures, total annual rainfall quantity, wind speed and wetness, which are analyzed by records in Meteorological Stations (Fig. 1). These stations are located in different plane regions (Shkodra, Tirana, Kuçova and Fier) and in mountainous region of Albania (Kukes), where the investigated wells are situated (Albanian Climate, 1978, Boriçi, M. and Demiraj E. 1990, Gjoka, L. 1990, Mici, A. et al 1975, the data for 1985-2000 after Mustaqi V.).

Water potential of the Albanian Rivers System have been evaluated by a specific way, because this System is very complicated (Pano N. 1964, 1965, 1978, 1995 e 1998). This network has a surface of 43 305 km<sup>2</sup>, where 28 500 km<sup>2</sup> is inside the Albanian state territory, and water of the Albanian river system discharge into Adriatic and Ionian Sea. Albanian River System represents in general a mountainous hydrographic network, with an average altitude 785 m above the sea level. Part of Albanian Hydrographic Network are lake system, Prespa-Ohri, and Scutary

with a surface from 270-365 km<sup>2</sup>. A karstic phenomenon is very intensive in the limestone formation, which is extended in great surface of the country.

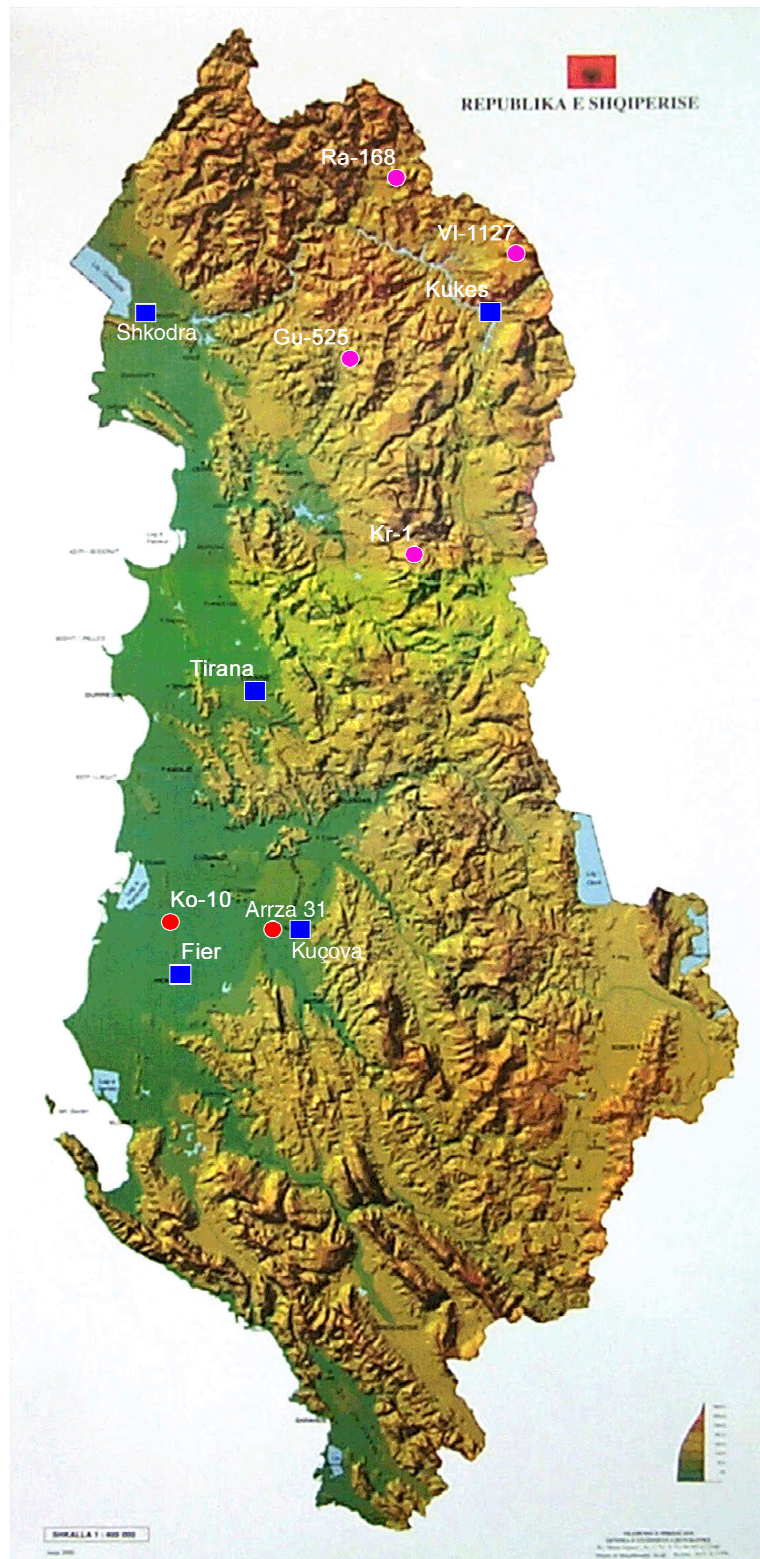


Fig. 1. Map of Albania and location of the Kol-10, Arza-31, VI-1127, Gurth-595, Krasta-1 and Ragam-168 wells and Meteorological Stations.

Water potential evaluation of the Albanian River Basin based on the multi annual archival data of the Albanian Hydrometeorological Institute of the Academy of Sciences. The monitoring network has more than 22 meteorological and hydrometric stations, during the observed period 20-100 years.

The methodology of the estimation of the water potential, have calculated the annual run-off discharge of the Albanian River System according to the corresponded types of the water supply, structure of the annual discharge distribution, and hydrogeographical types of the river catchment. Estimation of run-off discharge ( $Q_i$ ) are performed for two categories of river basins, with different hydrographical and hydraulical natural conditions:

- 1) Water system: Scutary Lake-Drini River-Buna River), where the run-off discharge  $Q_i$  is computed by  $Q_i = F(H_i, Q_i)$ , where  $Q_i$  represent the discharge of the lateral source..
- 2) Drini, Mati, Ishmi, Semani , Vjosa River systems, etc), where the run-off discharge  $Q_i$  is computed by  $Q_i = f(H_i)$ , where  $H_i$ - level in the river  $Q_i = f(H_i)$ , where  $H_i$  is altitude of the water level river (i) section.

The hydrographical complex Scutary Lake-Drini River-Buna River, with a great catchment surface of about 20 000 km<sup>2</sup>, as well is known, is very complicated and unique for its hydraulic regime, in the Mediterranean hydrography. This particularity has made necessary the particular modeling for estimation of the water flow of Buna River.

This particularity has made it difficult to valuate the water flow of Buna through the well known classic methods of the engineering hydrology. A particular way to calculate the water flow of the Buna River is found. This way consist the particular hydraulic conditions:

The discharge of the Buna River, when it flows away from the Scutary Lake  $Q_2$  depends not only from the level of the water  $H_2$ , but also on the level  $H_2$  and the Drini River discharge in to the Buna River  $Q_4$ . So, the only possibility to calculate the discharge of the Buna River  $Q_2$  is to find the connection  $Q_2 = f(H_2, Q_4)$ . This connection is deducted by the following equations:

$$Q_2 = A_1 \cdot H_2^B \cdot \sqrt{\Delta H_{2-3}} \quad (1)$$

$$Q_3 = (Q_2 + Q_4) = A_1 \cdot H_3^{B_1} \quad (2)$$

The dislevel  $\Delta H_{2-3}$  can be determined through:

$$\Delta H_{2-3} = (H_2 - H_3) \quad (3)$$

if we put the equation (3) to the putting equation (1) , we will have:

$$Q_2 = A \cdot H_2^B \cdot \sqrt{H_2 - H_3} \quad (4)$$

we find  $H_2$  from equation (4):

$$\frac{Q_2 + Q_4}{A_1} = \left[ H_2 - \frac{Q_2^2}{(A \cdot H_2^B)^2} \right]^{B_1} \quad (10)$$

From equation (10) it results:

$$Q_2 = \left\{ A_1 \cdot \left[ H_2 - \frac{Q_2^2}{(A \cdot H_2^B)^2} \right]^2 - Q_4 \right\} \quad (11)$$

Where: A, A<sub>1</sub>, and B, B<sub>1</sub> = parameters (A=0.073; A<sub>1</sub>=0.025; B=1.61413; B<sub>1</sub>=1.85  
 $\Delta H_{2-3}$  - dislevel (H<sub>2</sub>-H<sub>3</sub>)

Putting the above parameter, equation (11) has the final form:

$$Q_2 = \left\{ 0.025 \cdot \left[ H_2 - \frac{Q_2^2}{(0.0073 \cdot H_2^{1.61413})^2} \right]^{1.85} - Q_4 \right\} \quad (12)$$



The  $Q_2=f(H_2, Q_4)$  correspond to the results obtained through the hydraulic calculations the dependence  $Q_3=f(H_3)$ , topomorphometric data, and the hydraulic parameters of the rivers discharge are the basic dependence of this calculation. The methods of Pavlovskiy and Van Te Chen-1963 were used in this calculation. The differences of the discharge  $Q_2$  for all the game of the discharge between both methods are small, about  $\delta Q = \pm 3\%$ .

Giving standard values to the discharge  $Q_4$  equal to 50, 100, 300 1 500 m<sup>3</sup>/s and salving the dependence of  $Q_2$  as an explicit function from the Scutary Lake level  $H_2$  and the Drini discharge  $Q_4$ , it was made possible to from a single family of the countable curves of the Buna discharge in the Scutary Lake.

The phenomenon of dry and wet years has always had a significant role and great interest. In this paper, the importance of preliminary hydrologic analyses of the raw data, which, apart from an estimation of the basic statistic parameters, verification of consistence, representatively, homogeneity and independence, includes an investigation of the periodicity of time series, is discussed.

After evaluation of the water flow  $Q_i$ , have been calculated multi annual average discharge  $\bar{Q} = \frac{\sum Q_i}{r}$ , standard deviation  $S = \frac{1}{n-1} \left( Q_i - \bar{Q} \right)^2$ , variation coefficient  $C_v = \frac{S}{\bar{Q}}$ , and

asymmetry coefficient  $C_s = \frac{n}{(n-1) \cdot (n-2)} \cdot \frac{1}{S^3} \cdot \sum_1^n \left( Q_i - \bar{Q} \right)^3$ .

All modeling and calculations have been performed for the model of dry and wet characteristic years, to analyze the climate impact on Albanian Hydrographic System.

Processes of the forming and circulation of the Adriatic Sea water mass have analyzed based on hydrographic data and Results of Albanian Marine Expeditions “Saranda 1963”, “Patosi 1964” for the wet years (Pano N. 1974), and Italian-Albanian Expeditions “Italica I and II, 2000 and 2001” for dry years.

### 3. Results and discussion

The ground surface temperature reconstruction of the thermoplots of Kolonja-10 and Arza-31 deep wells, which are located at coastal plane region of western Albania, are shown in fig. 2. As it is seen in this figure, the GST history yielded by tighter inversion of Ko-10, presents a gradual cooling of 0.6 K, before a middle of the 19<sup>th</sup> century. Later followed by 0.6 K warming, with a gradient 5.4 mK/years, that seems quite reasonable and is consistent with generally accepted ideas about the climate of the last 2-3 centuries. On the contrary, the paleothermal history, obtained from Arza-31 well, presents a monotone warming of 1,7 K, by a gradient 5.7 mK/year, during the 17th and 19th centuries. This trend of the warming has only explanation caused by a deforestation of the area and presence of the paleo-swamp.

Fig. 3 shows a GST history of VI-1127, Gurth-595, Krasta-1 and Ragam-168 boreholes, which are located in the mountainous regions of Northeast Albania. Some changes are observed in these regions as to the cooling of 0.2 K during the 19<sup>th</sup> century. Later, the warming trend of 0.6 K during the 20<sup>th</sup> century, by a gradient 6.7 mK/year. Warming gradient increasing at mountainous regions, in comparison with coastal areas, is caused by intensive deforestation during the last half of 20<sup>th</sup> century.

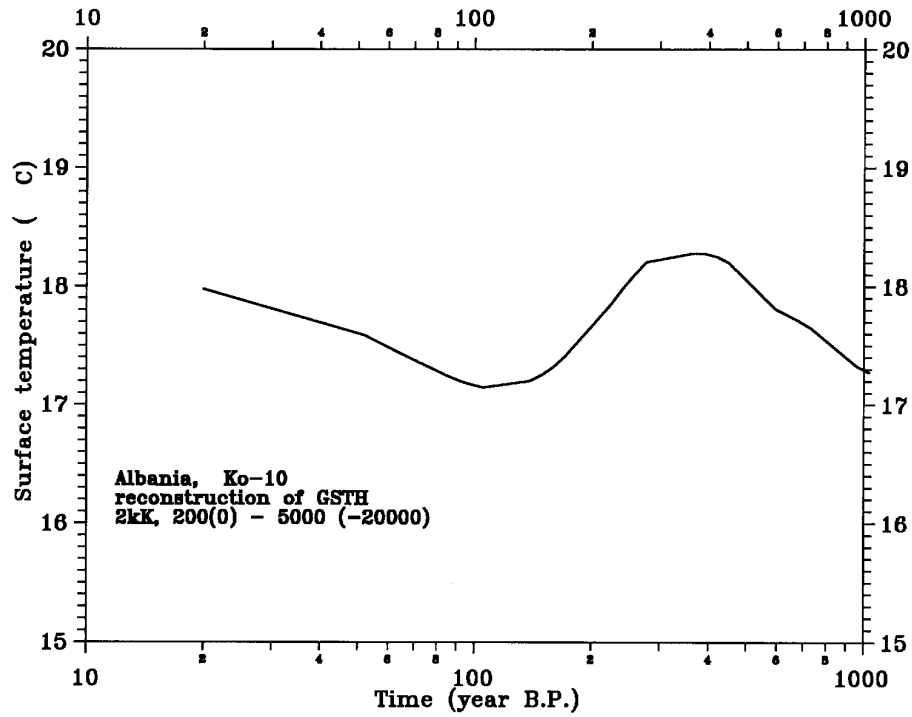


Fig. 2. Ground surface temperature history according to thermoplot of Ko-10 and Arza-31 wells (According to the Šafanda, J. calculations).

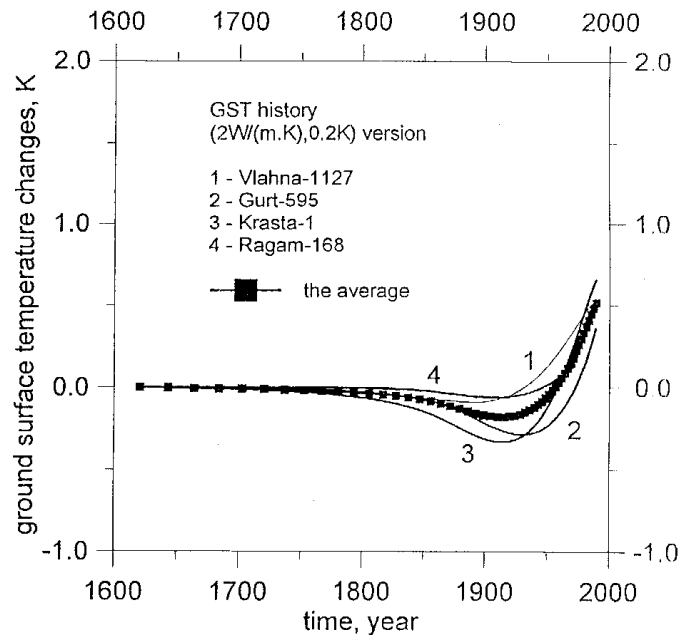


Fig. 3. Ground surface temperature history according to thermoplot of Vl.-1127, Gurth-595, Krasta-1 and Ragam-168 boreholes (According to the Čermak, V. and Safanda, J. calculations).

Climate changes in Albania are observed also by the hydrometeorological studies. Fig. 4 presents graphics of yearly average temperature of the air in Tirana and Shkodra Meteorological Stations, for the period from 1931 to 2000. As well known, Tirana is located in Central Albania. In general, the end of first observes half 20th century, a warming of climate, about 1°C. Thirty quarter of 20<sup>th</sup> century is characterized by a cooling of 0.6°C, and later, up to present a warming of 1.2°C. The same climate changes are observed also at Shkodra City, in northwestern plane area of Albania. The cross correlation coefficient is  $C_c = 0.78$  between variation curves of the average annual temperatures of both of these stations. Warming trend of maximum 1.2°C, in particular after seventy years, is observed in all Albanian territory (Fig. 5). There are good cross correlation between variation curves of the average annual temperatures of Shkodra, Tirana and Kukesi, respectively  $C_c = 0.78$  and 0.79. Weak cross correlation  $C_c = 0.58-0.68$  is observed between temperature variation of the Kuçova area and other northern regions. This phenomenon presents the influence of the local character of the climate changes of Kuçova area. Warming of the soil is more intensive than air warming (Fig. 6).

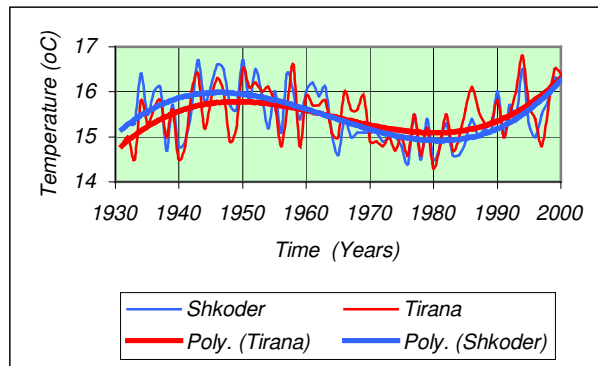


Fig. 4. Air Average Annual Temperature Variation at Tirana and Shkodra Meteorological Stations (Period 1931-2000).

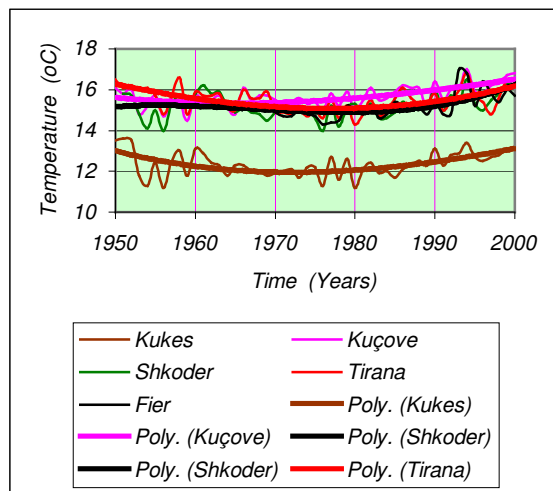


Fig. 5. Cross-correlation of the Air Average Annual Temperature variations at Shkodra, Kukes, Tirana, Kuçova and Fier Meteorological Stations (Period 1950-2000).

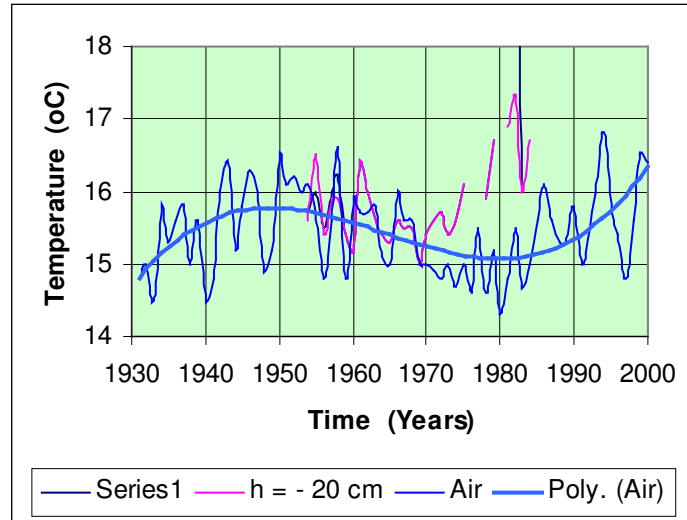


Fig. 6. Air and Ground Average Annual Temperature Variation at Tirana Meteorological Station.

The meteorological data shows that the warming trend is not a monotone one. In short intervals are observed cooling and warming (Fig. 4, 5, 6). The meteorological studies have verified warming of the climate during the last quarter of the XX<sup>th</sup> century, too. It has been consisted that: “Around the 1980’s a warming trend is observed” (Boriçi M., Demiraj E. 1990, Demiraj E. et al 1996).

The warming period in Albania is accompanied with changes of the rainfall regime., wind speed and wetness. There are observed a decreasing of the total year rainfall quantity, for about 200-400 mm. (Fig. 7,8,9).

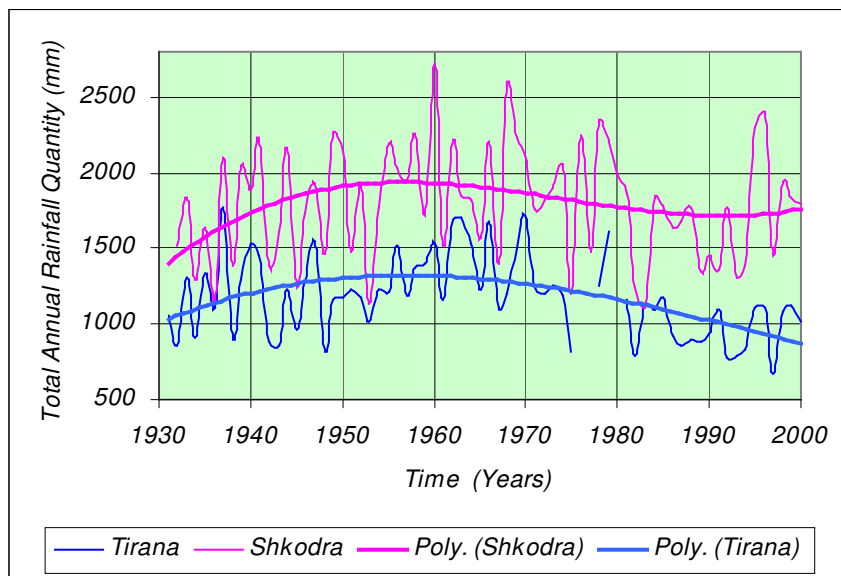


Fig. 7. Total year rainfall quantity of the Tirana and Shkodra Meteorological Station (Period 1930-2000).

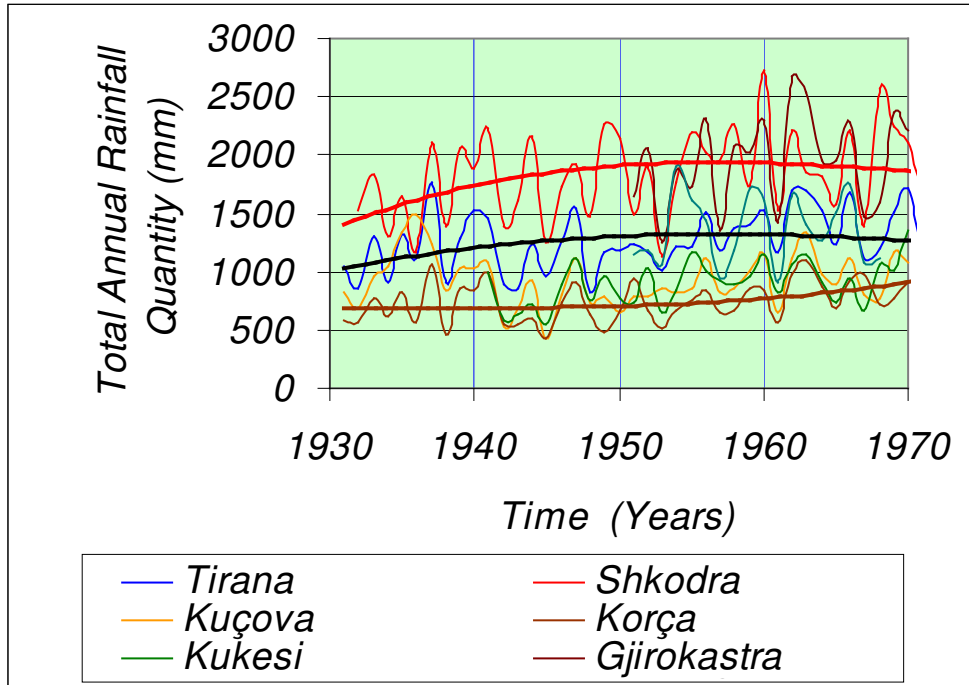


Fig. 8. Cross correlation of the Total Year Rainfall Quantity of the Tirana, Shkodra, Kuçova, Korça, Kukesi, Gjirokaster, Vlora Meteorological Station (Period 1930-1970).

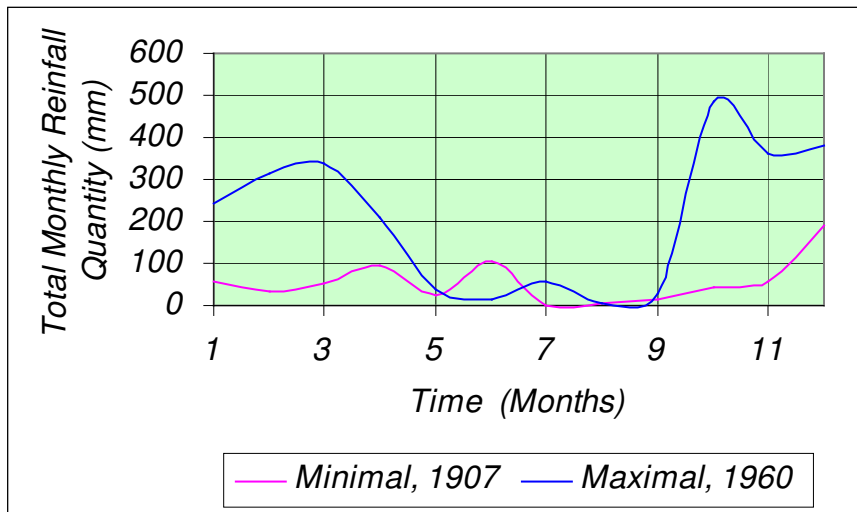


Fig. 9. Total Year Rainfall Quantity in the most dry and wet year, respectively, of the Shkodra Meteorological Station (respectively 1907 and 1960 years).

In the dependence of the geographical location of the areas changes the cross correlation of the rainfall quantity: Tirana area with Shkodra area  $C_c=0.62$ , with Korça  $C_c=0.81$ , Kuçova  $C_c=0.66$ , Kukesi  $C_c=0.88$ , Gjirokaster  $C_c=0.88$ , Vlora  $C_c=0.53$ , during the period of 1930-1970. Fig. 8 is presented the difference of the total year rainfall quantity in the most dry and wet years,



respectively 1907 and 1960. The warming have accompanied with decreasing of the wind speed about 1.5 m/sec and 5% increasing of the wetness, during the period of 1950-1994 (Fig. 10).

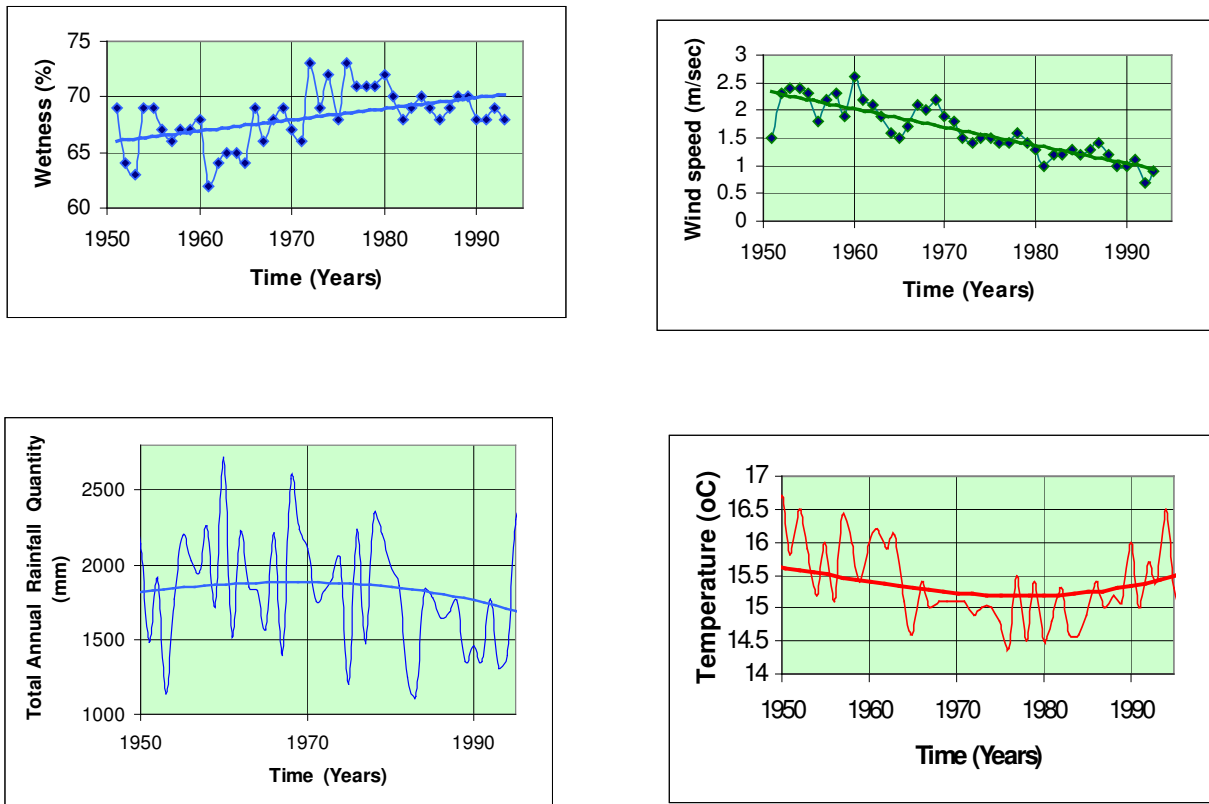


Fig. 10. Air Average Annual Temperature, Total Year Rainfall Quantity, Wind Speed and Wetness Variations, at Shkodra Meteorological Stations (Period 1950-1994).

This warming is part of the global Earth warming during the second half of XX century.

Its impact has been observed also on water systems and water resources. Inland water resources change has its impact on the hydrographic regime of the Adriatic Sea. Processes of the forming and circulation of the Adriatic Sea water mass, as is well known, presents a discussible phenomenon of the oceanographic dynamics. These processes, in the particularly intensity of the penetration of the Levantine hot and saline waters in the Adriatic Sea through Otranto Strait, for long time period have been explained by the external phenomena from this sea (Buljan M, 1948, 1955, Armanda Zore 1960). Has been supposed that Adriatic Sea doesn't participate in this penetration.

Based on two Albanian Oceanographic Expedition "Saranda-1963" (Fig. 11) and "Patosi-1964" collected data has been proposed other mechanism of the forming and circulation of the Adriatic Sea water (Pano 1974, 1984, 1994, Pano et al. 1997). There are great impact of the specific natural conditions of the Albanian Hydrographic System catchment, with a surface of 43 304 km<sup>2</sup>, in the particularly extraordinary atmospheric winters, in these processes.

The water potentials of Albanian rivers system is  $W_o = 41,249.10^9 \text{ m}^3$  that correspond to a mean annual discharge of  $Q_o = 1306 \text{ m}^3/\text{s}$ . So, Albania is one of high specific water potential in Mediterranean.

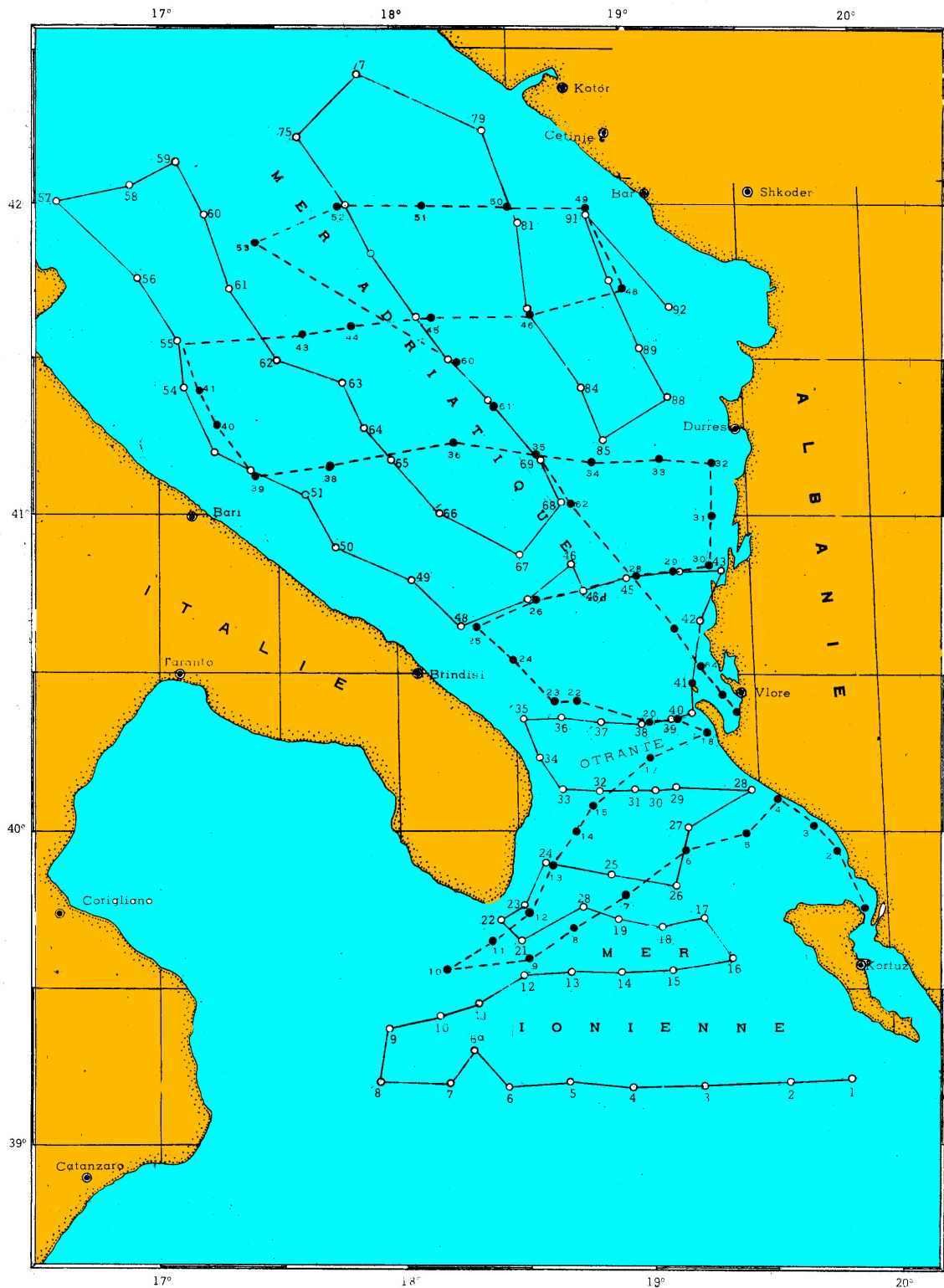


Fig. 11. Albanian Oceanographic Expedition "Saranda-1963" surveys lines

The multi annual data have arguments that the total discharge of the Albanian rivers system in the Adriatic and Ionian Seas varies in very wide limits. Minimal discharge is 700-800 m<sup>3</sup>/s for the hydrological dry years of low precipitation, up to maximal values 1900-2200 m<sup>3</sup>/s for the hydrological wet years of high precipitation. Buna River is one of the most important rivers of the Mediterranean Basin. This river, together with Po River in Italy, are determinant in the water balance of the Adriatic Sea.



View of Buna River discharge in Adriatic Sea.

The oceanographically situation of the wet years 1963-1964 has been characterized by formation of "The Bridge" with continental water in the Adriatic sea (Fig. 12). "The Bridge" is closely linked with the intensity of the river flow (Pano N. 1974). The eastern water mass are formed in SE Adriatic Sea area by the discharge of the Albanian rivers, and the Adriatic North water masses are formed by the discharge of Po River, Italy. This "Bridge", includes not only the surface layer, but also the Levant Intermediate Water (LIW) up to 600 m. depth. Low salt content and density of the seawaters are observed over "the bridge" (Fig. 13. 14). This phenomenon has a complex and an important influence on many dynamics aspects of the formation Adriatic Deep Water (ADW), the deportation Levant Intermediate Water (LIW), and the monitoring mechanism of water into Otranto Street. All these peculiarities have impact also on the seawater temperature distribution in this area (Fig. 15). Consequently, "The Bridge" with the continental water in South Adriatic is an important component of the hydrological regime of the Sea. It is important to observed that under "the bridge" is located also an heat flow density at the sea bottom (Geothermal Atlas of Europe, 1992) (Fig. 16). This figure shows that "the Bridge" direction is corresponds with the prolongation of well-known Scutary-Pec regional tectonic transversal over the Albanides onshore.

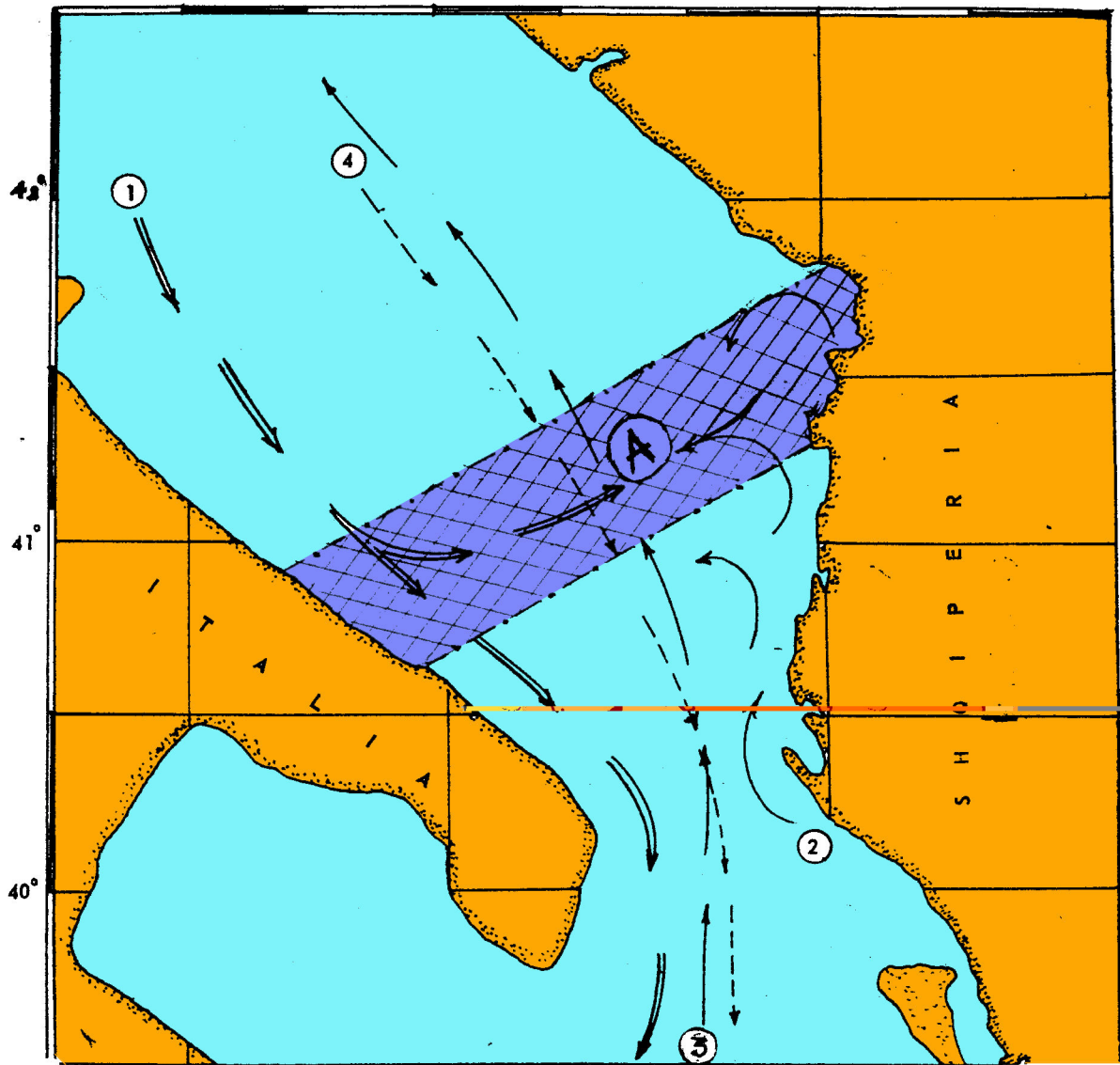


Fig. 12. "The Bridge" of continental water in the Adriatic Sea.

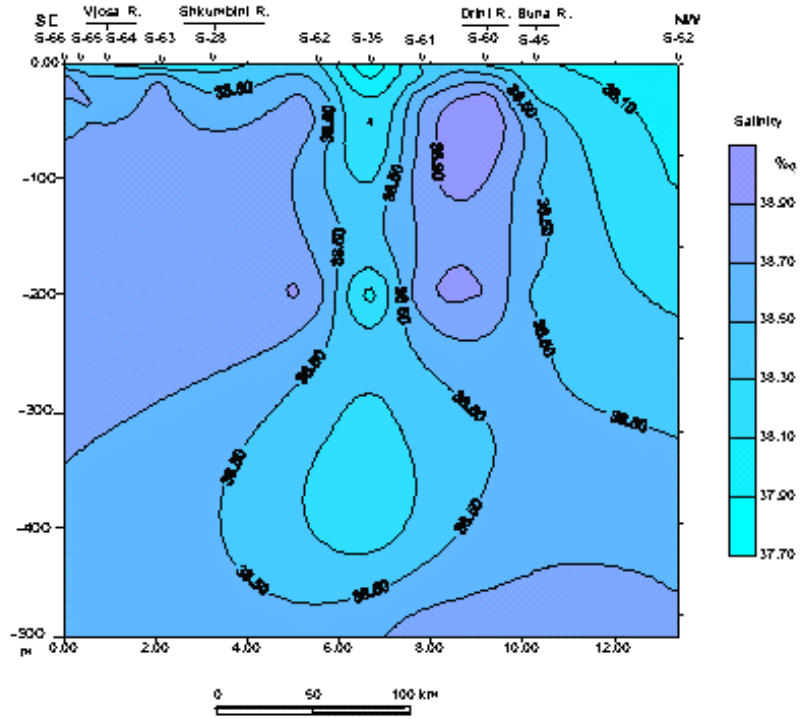


Fig. 13. Vertical salinity section 1-1, Adriatic Sea, wet hydrographical year 1963.

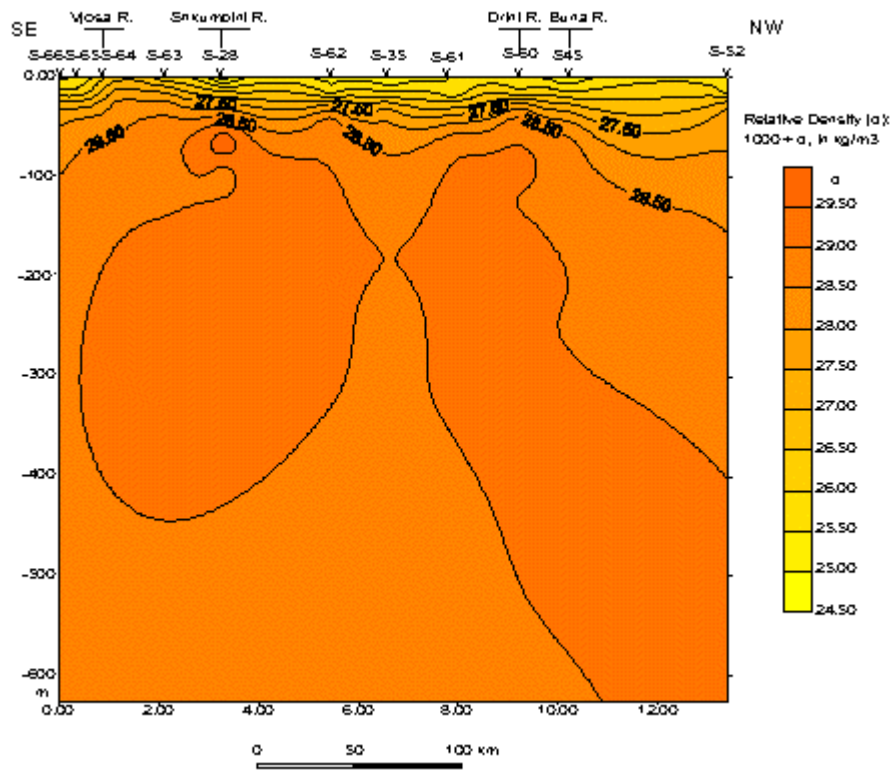


Fig. 14. Vertical density section 1-1, Adriatic Sea, wet hydrographical year 1963.



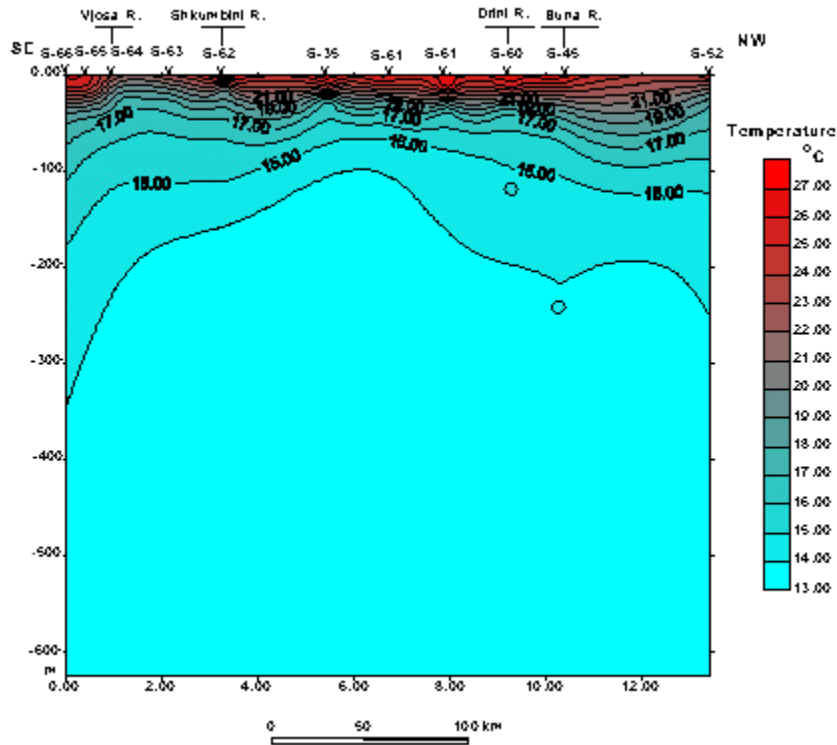


Fig. 15. Vertical temperature section 1-1, Adriatic Sea, wet hydrographical year 1963.

Consequently, climate change in Albania, in the complex, has impact on some directions:

- Country climate,
- Water systems and water resources. The rainfall regime changes have their consequences in the fresh water resources of the country, of surface's and underground waters.
- Inland water resources changes have their impact on the hydrographic regime of the Adriatic Sea.
- Ecosystems, and biodiversity, in the particularly in the water's flora and fauna. Temperature augmenting has caused increasing of the evaporation in the water systems. Consequently in the river system, reservoirs, wetlands, lakes and lagoon system has been observed thermal stress. In very beautiful ecosystems of Albanian lagoon as Narta, Karavasta, Kune-Vaini and Micro Prespa Lake etc. thermal stress has its impact, first of all on the biodiversity. This stress is extended also in the shallow coastal waters; consequently there are observed diminution of the fish quantity.
- Adriatic Sea hydrology.



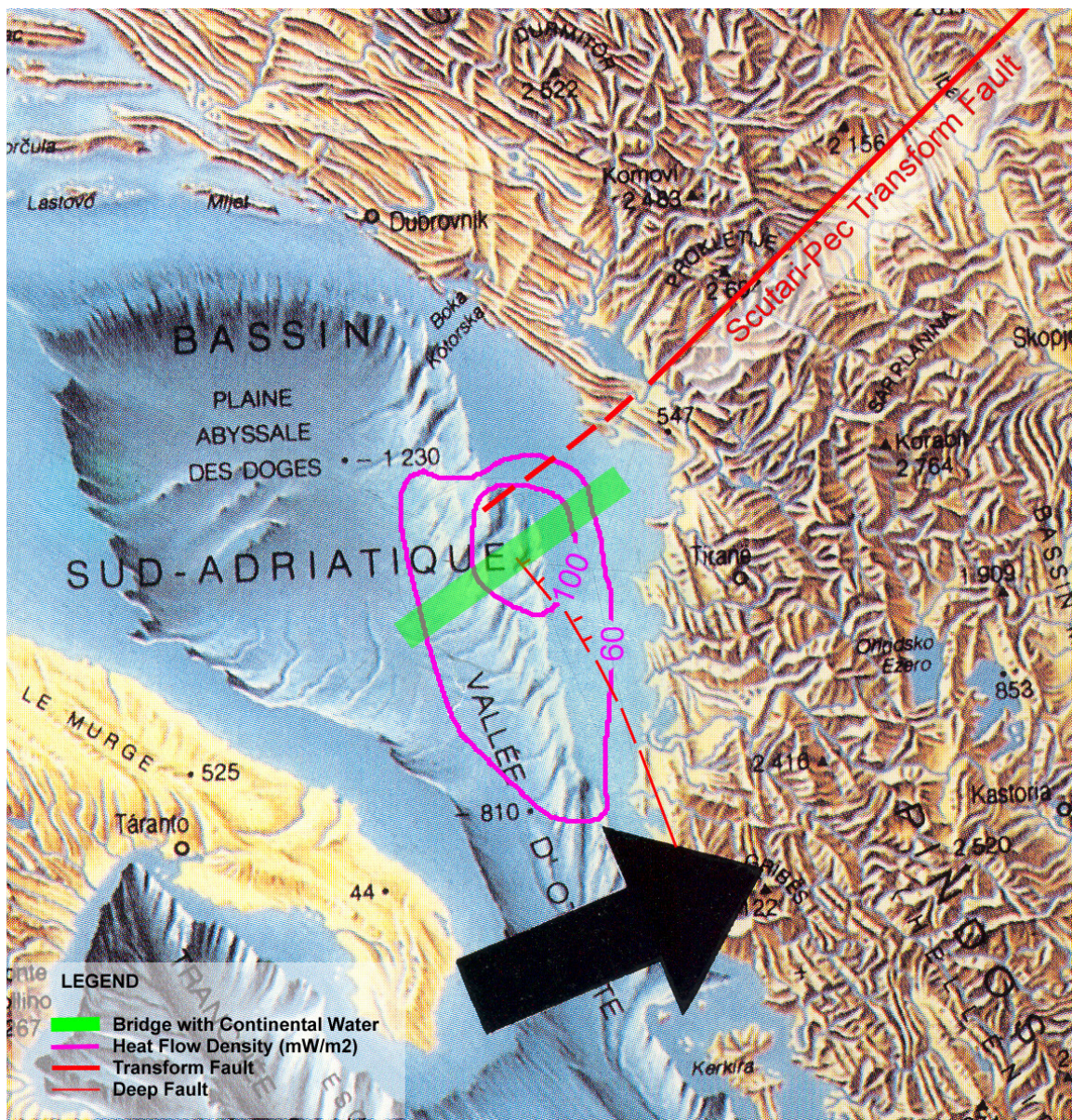


Fig. 16. Adriatic Heat Flow Density anomaly.

#### 4. Conclusions

Based on the results of inversion of the thermologs data, recorded in deep wells and boreholes, for the evaluation of the ground surface temperature GST history and hydrometeorological data, we have arrived in following conclusions:

1. The climate at coastal plane region of Western of Albania was cooled of .6 K before of middle of 19<sup>th</sup> century. Later a warming of 0.6 K occurred, from last quarter of 19<sup>th</sup> until present-day.
2. Temperature records in northwestern mountainous region of Albania confirmed also a climate warming of 0.6 K during 20<sup>th</sup> century. At mountains regions, the warming has started about quarter of century later than at coastal plane area of western Albania.
3. Warming, mainly during the last quarter of the 20<sup>th</sup> century, is demonstrated also by meteorological data.



4. The rainfall regime changes have their consequences in the fresh water resources of the country, of surface's and underground waters.
5. Warming has caused its impact on country climate and ecosystems. There is observed a decreasing of the water resources of the country, and thermal stress in the wetlands, lagoons and lakes of Albania. Impact it is observed first of all on the biodiversity.
5. The oceanographically situation in the Adriatic Sea is characterized from the formation of "The bridge" with continental water in the Adriatic Sea. "The bridge" is closely linked with the intensity of the river flow.
6. It is necessary to continued realizing, by a new project, of the analytical integrated studies of environmental impact of the global warming in Albanian territory and its consequences, carried out up to present, by the NGO Society "Protection and Conservation of the Albanian Inland and Coastal Waters".

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