Statistical Analysis of Climate Evolution in Dobrudja Region

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***Abstract* — The temporal characteristics of temperature evolution are investigated to provide a framework for sustainable resources management in the region of Dobrudja, Romania. Using the statistical analysis, the evolution of temperature is examined. The temperature data for the period 1965-2005, from 10 meteorological stations were used. First, the temporal characteristics of temperature evolution were analysed and then, some break tests are performed in order to identify discontinuities in temperature time series. Finally, the model for trend is performed. The analysis indicates an increasing trend of the mean annual temperature evolution. After 1997 the mean annual temperature increases with 0.8^{o}C, fact that is in concordance with the estimation made for Europe.**

***Index Terms*—Break, statistical analyses, trend.**

I. Introduction

Many recent studies have been devoted to global, hemispherical, or regional long-term temperature variations. On a global scale, climatologically studies indicate an increase of 0.3–0.6^{0}C of the surface air temperature (0.5–0.7^{0}C for the Northern Hemisphere) since 1865 [1] – [3].

Climate scientists have concluded that: (1) the earth's surface air temperature increased by about 0.6^{0}C during the 20th century, and (2) the temperature augmentation was highest during the 1990s [4].

Based on surface temperature data from 100 European stations, ECSN [5] reports an increment in air temperature during the 20th century. The climate change scenarios for Europe indicate a warming rate between 0.1^{0}C and 0.4^{0}C per decade (ECSN, 1995). This warming is greatest over Southern and Northeast Europe.

The rapports of PRUDENCE and PESETA projects [6] – [7] provide a future warming in Europe. The most vulnerable areas are shown in the map from Fig. 1, where the temperature evolution until the century's end is represented. From this map we can see that one of the most affected Romanian areas is Dobrudja, where an increase of 4 to 4.5 ^{0}C is expected until the end of the century.

Such a situation can not be ignored because the effects could be tragic.

This work was supported by the Romanian UEFISCSU under Grant ID_262 and TAMMER 794 (sponsor and financial support acknowledgment goes here).

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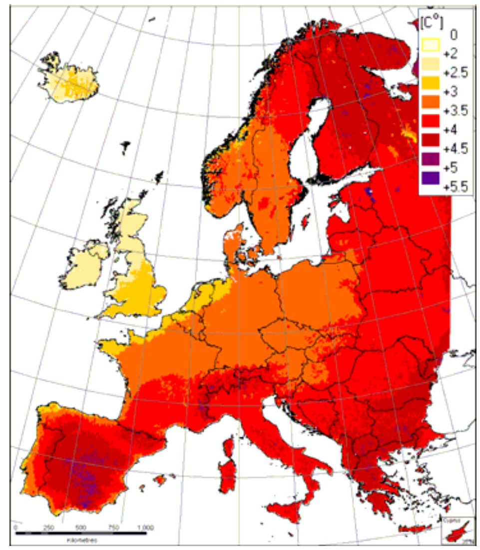


Fig. 1. The evolution of annual mean temperature to the end of century [7]

There is the risk to penalize the projects of agricultural development program and to perturb the efficiency of the establishments built in the previous years (see the irrigation improvement that sometimes couldn't work in summer as a result of the dramatic decreasing of the Danube water level). In this context, this paper attempts to identify discontinuities in temperature time series utilizing the statistical analysis.

II. The Dobrudja Region and Database

Dobruja or Dobrudja (Dobrogea in Romanian) is a region situated in the South – East of Romania, between the Black Sea and the lower Danube River (Fig.2).

Dobrudja's (without Danube Delta) structure is that of a plateau with hilly aspect. In the north, remnants of Hercinic and Caledonian mountains are present, with an altitude up to some 400m (Greci Peak 467m). The altitude decreases to the south, the average being between 100 and 180m [8].

Generally, Dobrudja's climate is temperate - continental and is divided in 2 units (Fig.2): a unit (I) which contains the Danube Delta, its south, the too lagoons (Razim lake and Sinoe lake) and the eastern region and another unit (II) which contain the rest of territory, where the climate is influenced by the moderate continental belt.

The drought and desertification are two processes that characterize this territory; the first region where this process was signalized [9] being Cernavoda-Macin. The researches proved that the frequency of the droughty years is 89 %; the longest rainless period was registered on the South Dobrogea and The Black Sea coast [10].

ISBN:978-988-17012-3-7

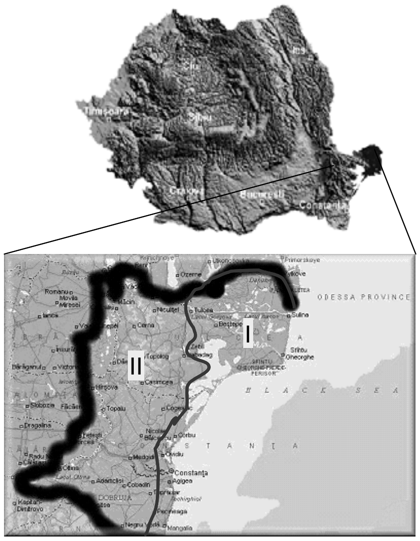
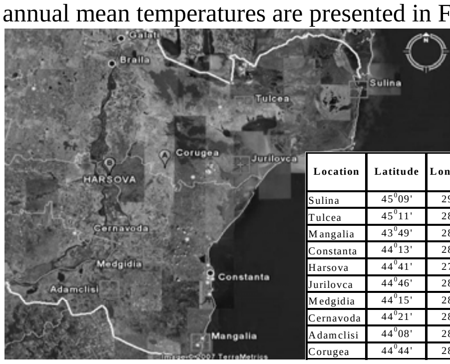


Fig. 2. Dobrudja region

In this study long time series of monthly averaged surface air temperature spanning the period 1965-2005 situated in Dobrudja region were used. The data were obtained from the archives of the Romanian National Institute of Meteorology. The stations name, the locations, the elevation and the multi annual mean temperatures are presented in Fig. 3.



Location	Latitude	Longitude	Elevation (m)	1965 - 2005 Avg temp (^{0}C)
Sulina	45^{0}09'	29^{0}39'	2.08	11.49
Tulcea	45^{0}11'	28^{0}49'	4.36	11.14
Mangalia	43^{0}49'	28^{0}35'	6.00	11.57
Constanta	44^{0}13'	28^{0}38'	12.80	11.74
Harsova	44^{0}41'	27^{0}57'	37.51	11.00
Jurilovca	44^{0}46'	28^{0}53'	37.65	11.01
Medgidia	44^{0}15'	28^{0}16'	69.54	11.04
Cernavoda	44^{0}21'	28^{0}03'	87.17	11.15
Adamclisi	44^{0}08'	28^{0}00'	158.00	10.86
Corugea	44^{0}44'	28^{0}20'	219.20	9.94

Fig. 3. Site description and locations of climate stations

III. Methodology

The methodology applied in this study consists of the analysis of temporal characteristics, followed by the analysis of spatial variability and the identification of the discontinuities in the temperature's time series.

The steps followed are:

- Estimated of annual mean temperature for each station;
- Estimated of multi - annual mean temperature for each station;
- Estimated of anomaly chart;
- Estimated the mean regional temperature of Dobrudja region, as a simple arithmetical mean and an weighted mean (a similar procedure with Thiessen procedure utilised in the regional precipitations' calculus);
- Estimated of standard deviation between the annual mean temperature of each station and the mean regional temperature;
- Estimated of the correlation coefficient between the series of the annual means temperatures of each station and the series of the mean regional temperature;
- Detecting discontinuities in data series.

In order to determine the discontinuities in temperature's regimen in the period 1965 – 2005, some homogeneity and break tests are performed.

We define a break as a change of the probability low at a certain moment [11].

The break tests permit to detect a change in a time series mean. The methods used to detect a break are: Pettitt test [12], the test „U"- Buishand [13], [14], Lee and Heghinian test [15] and the segmentation procedure of Hubert [16],[17]. *Pettitt test* is a non-parametric one. The null hypothesis that must be tested is:

H_0: There is no break in the series $(X_i)_{i\in\overline{1,N}}$.

The tests "U" Buishand and Lee & Heghinian test are Bayesians procedures applied in the hypothesis that the studied series is normal. The break absence represents the null hypothesis, H_0.

The tests are based on the following model that supposes a change in the series mean:

$$X_i = \begin{cases} \mu + \varepsilon_i \quad , & i = 1,\ldots\ldots,m \\ \mu + \varepsilon_i + \delta\,, & i = m+1,\ldots\ldots N \end{cases},$$

where ε_i are independent and normal distributed random variables, with null expectance and a constant unknown variance, σ^2. The break point, *m*, and the parameters μ and δ are not known.

Lee & Heghinian method works in the hypothesis that $(X_i)_{i=\overline{1,N}}$ is a series of normal, independent variables, with a constant variance. The method determines a posteriori low of the parameters μ and δ, considering their a priori distributions and supposing that the break data follows a uniform distribution.

The moment of the break and its range are equal to the values of the modes of the a posteriori distributions of *m* and δ respectively.

Hubert's segmentation procedure detects the multiple breaks in time series. The principle is to cut the series in *m* segments (*m*>1) such that the calculated means of the neighbors sub-series significantly differ. To limit the segmentation, the means of two contiguous segments must be different. This constraint is satisfied by the Scheffe's test application. This method gives the moment of the breaks.

CUSUM procedure. CUSUM charts are constructed by calculating and plotting a cumulative sum based on the data. CUSUM charts show the cumulative sum of differences between the values and the average. Because the average is subtracted from each value, the cumulative sum also ends at zero.

Let x_i, $i = \overline{1,n}$, the data. From it, the cumulative sums S_0, S_1, …, S_i are calculated, following the steps:

1. Calculation of the average $\overline{x} = \sum_{i=1}^{n} x_i$;
2. Start the cumulative sum at zero, by setting $S_0 = 0$;
3. Calculation of other cumulative sums by adding the difference between current value and the average to the previous sum:

$$S_i = S_{i-1} + \left(x_i - \overline{x}\right), \quad i = \overline{1,n}. \tag{1}$$

The cumulative sums are not the cumulative sums of the values. Instead they are the cumulative sums of differences between the values and the average [18].

ISBN:978-988-17012-3-7

IV. RESULTS AND DISCUTIONS

A. The analysis of temperature variation

Fig. 4 represents the spatial evolution of the multi-annual mean temperatures in Dobrogea. The isotherms are automatic created in GIS ArcView®, by spline interpolation on the base of annual mean temperatures calculated at each station.

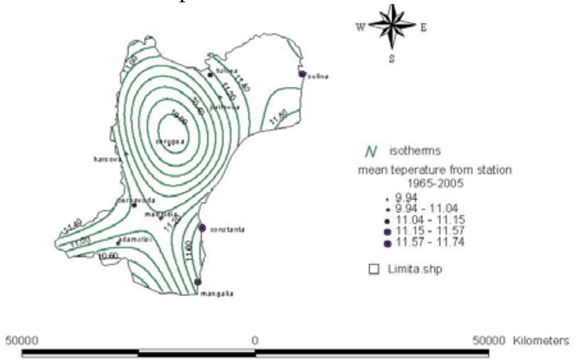


Fig. 4. Multi-annual mean temperatures

The multi-annual mean temperatures vary in small limits (10-12^{0}C approximately), the highest values being registered on the litoral. The temperature values decrease with the altitude. The smallest temperature was registered at Corugea – on the centre (9.94^{0}C at 219.2m), and the biggest at Constantza (11.74^{0}C at 12.8m) and Mangalia (11.57^{0}C at 6.0m) – on the coast, Tulcea and Sulina on the Danube Delta, respectively at Cernavoda (11.15^{0}C at 87.17m), on the Danube part (Fig. 4).

The situation presented on this map enters into the studies accomplished in this region, which show that the temperatures decrease from the coast to interior and from the Danube (seat on the West side of the region) to interior.

Table 1 present the descriptive statistics of the multi - annual mean temperatures at the measurement stations.

Table 1 Descriptive Statistics of the multi annual temperature distribution at 10 climate stations (units ^{0}C)

Station	Mean	Maximum (year of occurrence)	Minimum (year of occurrence)	SD	C_v
Adamclisi	10.86	12.2 (1994)	9.6 (1987)	0.68	0.06
Cernavoda	11.15	12.4(1994)	9.60 (1985)	0.72	0.07
Medgida	11.04	12.4 (1994)	9.8 (1987)	0.69	0.06
Harsova	11.00	12.4 (1994)	9.5 (1985)	0.68	0.06
Corugea	9.94	11.3 (2002)	8.62 (1985)	0.73	0.07
Tulcea	11.14	12.4 (1994)	9.6 (1985)	0.72	0.07
Sulina	11.49	12.7 (1999)	9.8 (1985)	0.71	0.06
Jurilovca	11.01	12.5 (1966)	9.5 (1985)	0.67	0.06
Constanta	11.74	13.1 (1999)	10.3 (1987)	0.69	0.06
Mangalia	11.57	12.9 (1999)	10.0 (1987)	0.68	0.06

According to Table 1, the lowest mean multi annual temperature occurred in 1985 (8.62^{0}C at Corugea station) and the warmest year ever recorded is 1999 (13.1^{0}C at Constatza station). Since the standard deviations are very small, it results that there is a very small dispersion of the multi – annual mean temperatures.

The variation of the annual mean temperature for each station (Fig. 5) reveals the succession of the cold and warm year over the study period.

It can be remarked that at all the stations the same evolution is preserved, i.e. starting to 1997, the mean annual temperature is higher than the multi - annual mean temperature at each station.

This remark suggests that the mean temperature of the sample 1965-1997 and that of the sample 1998-2005 are different.

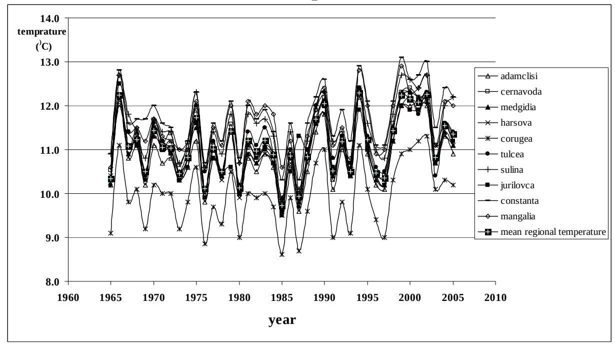


Fig. 5. The mean multi annual temperature at study stations in the period 1965-2005

In order to exemplify the previous remark, the values of the annual mean temperatures and the multi - annual mean temperature are represented for two stations (Figs. 6 and 7).

The multi – annual mean temperature at Mangalia station (Fig. 6) is 11.57^{0}C and starting to 1986, the annual mean temperatures are bigger than this value, the amplitude being of 2.9^{0}C.

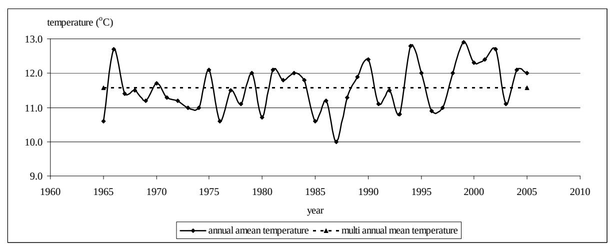


Fig. 6. The evolution of the mean temperatures at Mangalia station

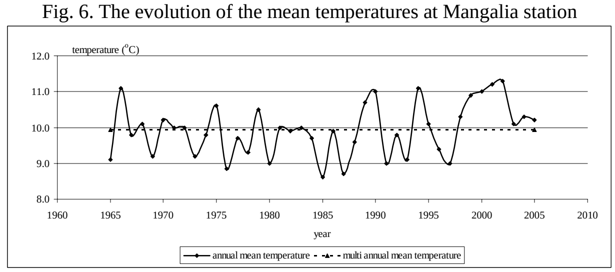


Fig. 7. The evolution of the mean temperatures at Corugea station

The multi – annual mean temperature at Corugea station (Fig. 7) is 9.9^{0}C and starting to 1998, the annual mean temperatures are bigger than this value, the amplitude being of 1.4^{0}C. It is important to remark the increasing of the minimum mean annual temperatures, approaching to the multi-annual mean temperature of each station.

Temperature anomaly chart shows the difference between the temperature of each year and the average temperature during a baseline period. The positive anomaly shows those years when the annual mean temperature exceeded the 1965-2005 baseline average, the negative anomaly shows those years when the mean temperature was less than the baseline average. Anomaly chart analyses reveal the succession of the negative and positive anomaly. We observed that since 1997 only positive anomaly has been registered. The period 1965-1997 contents more years with negative anomaly (generally 2 at 1). To demonstrate the previous remark, the anomaly chart for two stations (Figs. 8 and 9) are represented.

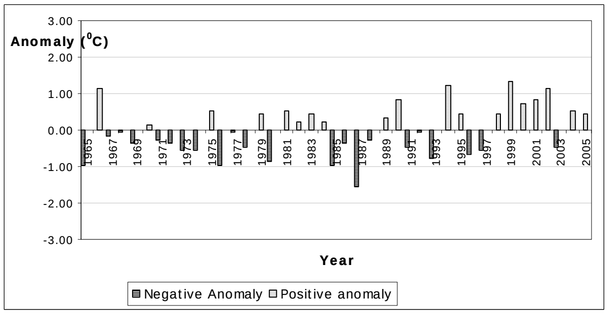


Fig. 8. Annual Temperature Anomaly (Base 1965 to 2005)- Mangalia station

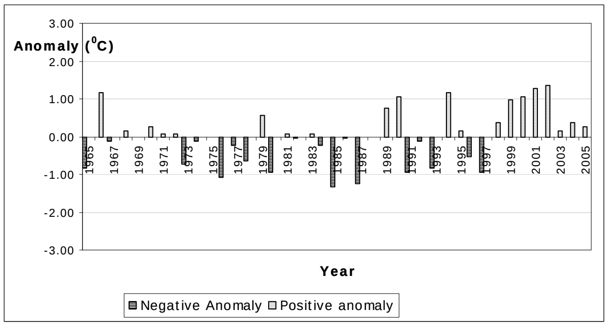


Fig. 9. Annual Temperature Anomaly (Base 1965 to 2005)- Corugea station

To study the spatial variability, the deviations $x_{ik} - \overline{x_k}$ were calculated, where x_{ik} represents the value of the annual mean temperature at the station i in the year k and $\overline{x_k}$ - the regional mean, in the year k, i.e. $\overline{x_k} = (1/10)\sum_{i=1}^{10} x_{ik}$, $k = \overline{1,41}$.

To compare the mean annual temperatures at the different climate stations, we use an *average station*, which is not a real one. It represents a station whose temperatures are the annual mean temperatures of the ten studied stations, i.e. $(\overline{x_k})_{k=\overline{1,41}}$.

The correlation coefficients between the annual mean temperatures of each station and those of the average station are in the interval [0.948, 0.986], denoting a strong correlation between the stations and the coherence of the data measured in the station network.

Trying to improve the significance of the average station data, a weighted average station was introduced. The temperatures assigned to it were calculated using *Thiessen's polygons method*, by analogy with the regional precipitations evaluation. This method is based on the hypothesis that the mean temperature at the station i, $i = \overline{1,10}$ is representative for the zone assigned to this station, with the area A_i. The value A_i will represent the weight factor attached to the annual mean temperature x_{ik}, registered at the station i, in the year k, in the calculus of the mean annual temperature at the weighted average station.

The build of Thiessen's polygons is indicated in Fig. 10. To determine the influence zones, each two neighbour stations are connected by a straight line segment, on which the median perpendicular is drawn. The intersections of the median perpendiculars determine polygons, assigned to the stations situated in those zones.

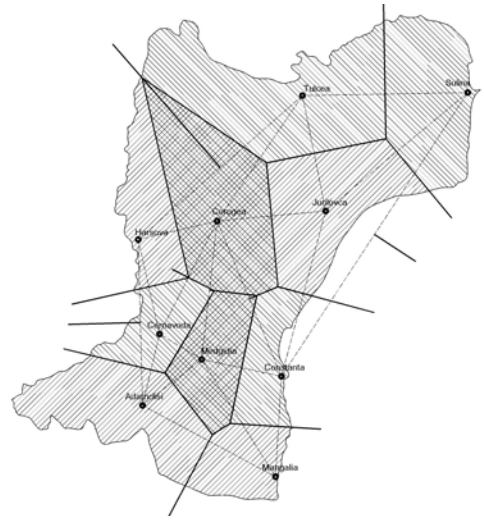


Fig. 10. Thiessen's polygon method

The weighted temperature is calculated by the formula: $\overline{x_k} = \sum_{i=1}^{10} (A_i / A) x_{ik}$, where A is the surface of the region Dobrudja.

Applying this formula, the correlation coefficients between the series of the mean annual temperatures at each station and that of the weighted average station are in the interval [0.944, 0.983]. We note a very small decrease of the correlation coefficients (between 1 and 5‰) with respect to those calculated using the temperatures of the average station. So, in what follows we shall use the weighted average station, since this representation is more realistic.

In the years with the smallest mean temperatures, the variation coefficient, C_v (%), is less than 3.7% and in the most arid years, C_v (%) is higher than 6,5%. After 1998 only a value of C_v (%) is less than 5.5%, these years having the mean multi-annual temperatures over the multi-annual mean.

The absolute deviation of the mean temperatures of all the stations from the temperatures of the weighted average station are in the interval [0.074, 2.874], proving that the temperatures of this mean station are good approximations of the values registered at the base stations. Practically, at spatial scale, there is not a significant variability.

B. Break analysis

Since a part of the break tests assumes that the data are normally distributed, our data were first tested for normality, using Kolmogorov-Smirnov test and Q-Q plots. As the results, the normality hypothesis was accepted.

The results of the break tests, for the climate stations are given in Table 2. "Yes" signifies that the hypothesis H_0 (there is no break in the data series) is accepted.

First, the hypotheses of the tests application were verified, using respectively Kolmogorov – Smirnov test, for normality, the autocorrelation function, for independence and Bartlett test for homoscedasticity [19].

Three tests (Lee & Heghinian, Hubert and Buishand - at the confidence level of 90%) give the same result, i.e. there is a break in the mean annual temperatures series. The tests Lee & Heghinian and Hubert mention also the breaks moments, that appear in 1997 (six cases), 1998 (three cases) and in

1988 (one case).

Table 2. The break analysis

station	Buishand 99%	Buishand 95%	Buishand 90%	Pettitt 99%	Pettitt 95%	Pettitt 90%	Pettitt year	Lee & Heghinian	Hubert
Adamclisi	yes	yes	no	yes	yes	yes	-	1997	1997
Cernavoda	yes	yes	no	yes	yes	yes	-	1997	1997
Medgidia	yes	yes	no	yes	yes	yes	-	1997	1997
Harsova	yes	yes	no	yes	yes	no	1998	1998	1998
Corugea	yes	no	no	yes	yes	no	1997	1997	1997
Tulcea	yes	yes	no	yes	yes	no	1988	1988	1988
Sulina	yes	yes	no	yes	yes	yes	-	1997	1997
Jurilovca	yes	yes	no	yes	yes	yes	-	1998	1998
Constanta	yes	no	no	yes	yes	no	1988	1997	1997
Mangalia	yes	yes	no	yes	yes	yes	-	1998	1998

Table 3. The result for CUSUM chart for climate stations

	Adamclisi	Cernavoda	Medgidia	Corugea	Harsova	Tulcea	Sulina	Jurilovca	Constanta	Mangalia
Overall mean	10.86	11.15	11.04	9.94	11.00	11.14	11.49	11.01	11.74	11.57
Change point year	1997	1997	1997	1997	1997	1997	1997	1997	1997	1997
Average 1	10.71	11.01	10.90	9.78	10.87	11.03	11.35	10.90	11.59	11.43
Average 2	11.37	11.67	11.53	10.48	11.46	11.56	12.00	11.42	12.30	12.06

Pettitt test gives the same result as Lee & Heghinian and Hubert tests for Harsova (1998), Corugea (1997), Tulcea (1988), but a different break moment for Constantza (1988).

Using the same test, we accept the hypothesis H_0, at the confidence level of 90%, for the rest of stations. Excepting one case, the results of Buisard and Pettitt tests determine us to accept the hypothesis H_0, at the confidence levels of 95% and 99%.

Interpreting a CUSUM chart requires some practice. The CUSUM chart trend shows the way in which the individual values compare to the overall average. Each time when the measurements are below the overall average, the CUSUM decreases. Each time when the values are above the overall average, the CUSUM increases. A slope change in the CUSUM graph indicates a sudden change in the average. Periods where the CUSUM chart follows a relatively straight path indicate a period where the average did not change [18].

The cumulated sums calculated according to (1) are plotted in Figs. 11 and 12 (for Corugea and Mangalia station). Looking at Figs.11 and 12 the CUSUM chart takes a sudden change in direction around 1997.

The result of CUSUM charts for the ten climate stations are presented in Table 3. Generally, around 1997 the average shifted. The change in the CUSUM slope direction downwards indicates that the annual mean temperature is below the 41 years' average. The change in the CUSUM slope direction upward indicates that the annual mean temperature is above the 41 years' average.

The results obtained from the analysis of annual mean temperature and break tests and CUSUM procedure lead to the conclusion that the thermic regime is modifying in Dobrudja.

This dramatic enhancement, felt at the beginning of the years 1997, is reflected in net modification in the temperatures time series.

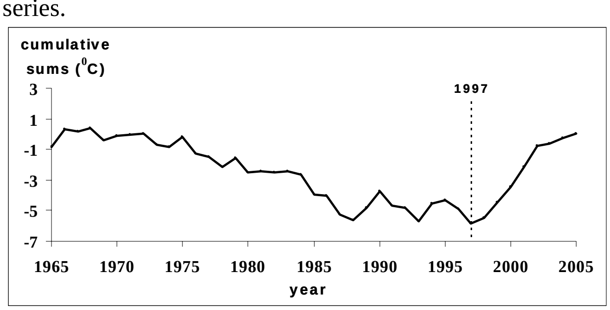


Fig. 11. Cumulative chart for Corugea station

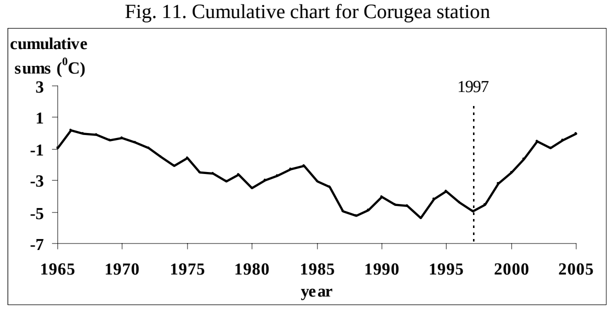


Fig. 12. Cumulative chart for Mngalia station

In Figs.11 and 12 we present the temperatures at Mangalia and Corugea stations, with the sub-samples resulted after the application of the break tests and CUSUM procedure.

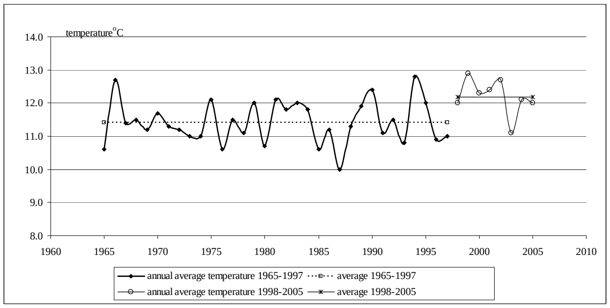


Fig. 13. The sub - samples temperatures for Mangalia station

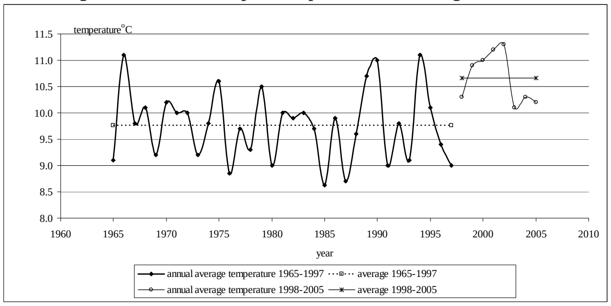


Fig. 14. The sub - samples temperatures for Corugea station

Analysing the results for all the stations we observe that after 1997 the mean annual temperature increases with 0.8^0C, fact which is in concordance with the estimation made for Europe.

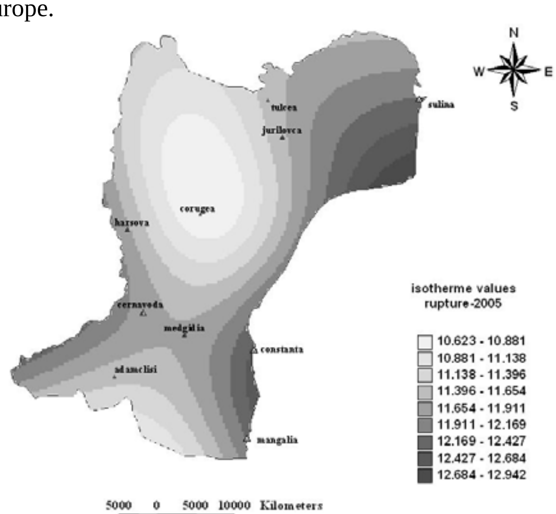


Fig. 15. The isotherms map from break to 2005

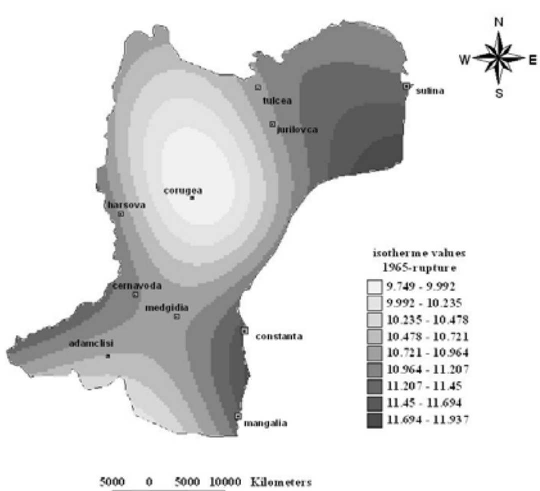


Fig. 16 The isotherms map from 1965 to the break

The isotherms maps (Fig. 15) relieve a general increase of the mean multi-annual temperatures after 1997, comparatively to the period 1965-1997 (Fig. 16). Looking the maps presented in Figs. 15 and 16 we can conclude that, generally, starting to 1997, we assist to an important movement of the isotherm to North-West and at the setting of some mean temperature extremely high.

ACKNOWLEDGMENT

The authors thanks to C.A.N.M. which provided us the data. Last but not least the authors thank two anonymous reviewers for their comments on an earlier version of the paper. ESRI software has been used to create maps. The break tests are realised with the free software "*Kronostat"* (J.F. Boyer).

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