FRACTAL ANALYSIS ON CARTOGRAPHIC DOCUMENTS OF BLACK SEA

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***Abstract**: For a coherent understanding and interpretation due to evolving spatial-temporal dynamic complex interactions between human population and the Black Sea coast, it is needed to tackle by a transdisciplinary approach, theoretically by integrating a model framework of analysis for changes, transformations, trends and adjustments/identification of system understanding. Observed variations in coastal morphology on monthly to decadal timescales are often difficult to explain in terms of physical processes operating on shorter timescales. One reason could be that the morphology evolves to high-dimensional, self-organized states. Circumstantial evidence for this would be indicated by fractal distributions of the dynamical variables. Black Sea Coastal fractal analysis as nonlinear dynamical systems, consists of lengthy processes whose variability and diversity are essential for the stability and capacity support unit. This analysis does not overlook the implications map, taking into account the relationship between technology and capabilities, following the same principles. Coastal fractal analysis as nonlinear dynamical systems, consists of lengthy processes whose variability and diversity are essential for the stability and capacity support unit. This analysis does not overlook the implications map, taking into account the relationship between technology and capabilities, following the same principles.*

The problem of finding a set of indicators to illustrate the state of the Black Sea coast, is extremely important in this context and more complex if is desired in GIS. The concept of geographic information system of the Romanian coastline based on the idea of presenting to managers and the general public in the form of maps, sets of indicators status. Status indicators Map is an integration of sectoral indicators considered to illustrate the state of the area studied. In most cases sector indicators have equal weight in the production status indicator and in this case by fractal analysis can highlight the state of the coastal system. Through this paper we discuss the results of such analysis fractal.

***Keywords:** morphometric elements, water level, morphobathymetric configuration, fractal geometry , fractal dimension, cartographic documents*

1. Introduction

1.1 Motivation

The coastline length and area of the Black Sea have been measured and studied by many regional and outside authors (Ross et al., 1974; Nankinov, 1996; Panin, 1999, Loghin, 2000; Panin, 2007, Panin, 2009). By far, different values of the Black Sea coastline length and area have been determined.

Those for the coastline length range between 4020 km and over 4400 km. Values obtained of the Black Sea area also vary in large diapason: between 413 500 km^2 and 436 000

km^2. In 2006, Gâștescu write that the **area** of the sea waters is 413,490km^2. If we include the area of 38,000km^2 of the Azov Sea as we can find in a lot of papers, the area obviously increases correspondingly.

Furthermore, in most cases, there is no information pointing the type of spatial data, map scales or methods have been used for measuring the coastline length and area. Hence, potential reasons for such different values of the Black Sea area and coastline length could be mostly associated with different types of data sources, maps scale or images resolution, as well as due to different methodologies applied.(Stanchev, H. 2011)

1.2 The Black Sea

The geographical position

It is situated in the north emisphere , temperate zone, by its geographical coordinates (40˚55' and 46 ˚32' north latitude, 27˚42' and 41˚42' east longitude), and by its limited connection with the Planetary Ocean, and lying within the European continent we can consider it a **continental sea**.

The Bosphorus Strait makes the connection with the Meditarranean Sea, the Marmara Sea, Dardanelles Strait and farther the Aegean Sea spotted with many isles.

Main morphometric elements

The **maximum depth** is 2.245m, but other sources indicate 2,212m and it can be found in the central-southern part on a profile that would link approximately the cities of Ialta in the Crimean Peninsula (Ukraine) and Sinop in the peninsula of Minor Asia (Turkey). The average depth is 1.288m (other sources 1.278m)

The **water volume** at normal level 529,955km^2 , but other sources show 538,124km^2 .

The **maximum length** from west to east is 1,150km, between the ports of Burgas (Bulgaria) and Batumi (Georgia); the **maximum width** between Odessa Gulf (Ukraine) and rivermouth Sakarya (Turkey) is 600km, and the **minimum width** between the peninsula of Ialta and Burun Cape is300km. The Crimean Peninsula in the north and the Burun Cape in the south divide the basin of the Black Sea into two compartments – **western** and **eastern**, that influence and individualize the circulation of the sea currents.

The **shore length** (interface land-water) is 4,790km (without the shore of the Azov Sea) and is divided among the riverside countries as follows: Ukraine 2,007km; Russian Federation 500km; Georgia 310km (including the shore of the Autonomous Abhazian Republic); Turkey 1,350km; Bulgaria 378 km; Romania 245km.

The **hydrographic basin** of the Black Sea (including the Azov Sea basin) is 2,863,119km^2, containing the waters of both the Black Sea and Azov Sea. If the area of the two seas is excluded, the actual area drained by the Black and Azov seas is 2,402,119km^2. Out of this actual drainage area (2,402,119km^2) the Danube covers 34% with 817,000km^2 (actual drainage area), then comes the Nipru (Dnieper) with 504,000Km^2 (21%), the Don with 422,000km^2 (17,6%), the Kîzîl Irmak with 77,100km^2 (3.2%), the Nistru (Dniester) with 72,100km^2 (3.0%), the South Bug with 63,700km^2 (2.6%), the most important affluents that make together 80.9%.

Out of the 21 states the Russian Federation and Ukraine have almost 49% in the hydrographic basin of the Black Sea, then comes Turkey with 10.7% and Romania with 9.98%. As for the territory of the respective countries related with the same hydrographic basin we consider that Romania, the Republic of Moldavia and Hungary are entirely within its limits, being followed by Ukraine (98%), Austria (7.4%), Slovakia (96,3%), Bosnia-Herzegovina (91%), Yugoslavia (87.1%), etc.

The genesis and evolution of the sea depression

There have been issued more hypotheses about the age of the Black Sea depression, among which more interesting are those of Melanovski (1967) who assumes that it was formed in the Precambrian era, of Neprochnov and his collaborators (1967) who take it back to the Paleozoic era, of Brinkmann (1974) who affirms that it was formed in the medium-upper Mesozoic era, of Biju-Duval and his collaborators (1977) who place it in the Berriasan (upper Mesozoic), of Muratov and Neprochnov (1967) who reconsider it taking it back to the Paleocene - Neocene (inferior and medium Neozoic) and finally, that of Nelivkin (1960) who assumes that it was formed in the Quaternary era.

The evolution of the sea basin in the Quaternary era – for 600,000 years was characterized by periods when it could communicate with the Mediterranean Sea and periods when the connection was interrupted. In those circumstances the sea waters were either salted, saltish or sweet, thus influencing the fauna.

The **morphobathymetric configuration** allows the identification of the main morphostructural units that characterize most of the tectonic type sea basins. Thus, from the shore to the centre of the Black Sea stand out:

- the **shelf** (continental platform), delimited by the –100m isobath as far as the –200m isobath, depending on its interference with the continental slope; the shelf develops most in the north-west reaching a width of 200km in the Odessa Gulf and it is very limited on the south shore; the entire area of the shelf covers about 30%;
- the **continental slope** covers almost evenly the central zone, but the slope values vary between 8-10º and sometimes between 20-22º in the south-east.
- the **marginal depression** (the continental base) represents the passage to the abysmal zone;
- the **abysmal zone** (the abysmal field) situated in the centre of the Black Sea and being extended most in the eastern part, can be 2,000m deep, having a surface of about 12%.

The hydric balance and impact on morphobathymetric configuration

The greatest share at entrances is determined by rivers (42.2%) and at going outs the water is lost by evaporation (49.4%). Among the river sources, the Danube covers 60.3% through its 204km^3 , the Dnieper covers 15.6% (52.7km^3), the Dniester covers 2.9% (9.8km^3), Kîzîl Irmak covers 1.9% (6.3km^3).

The balance structure does not affect the whole water volume of the Black Sea but only the superficial layer between 0 and 150 – 200 m depth (580,000 km^2).

Long time variation of the water level

The secular and millenary variation has affected the climatic variations from Quaternary to the present, being a specific feature of the continental seas.

It is estimated that the level was about 80 – 100 m lower than the present one, about 18,000 years ago during glaciations. While the ice was melting after the last glaciation the level began to rise with 2 –3 m/100 years, alterning with short periods of stagnation or an easy decline, so that 8,000- 9,000 years ago the level was still 20 m lower than the present one.

The establishing of the connection with the Mediteranean Sea 9,000 years ago led to the beginning of the marine level equalization process, reaching the “0” quota.

Refering to the present period, as a general tendence of rising of the Planetary Ocean level because of the greenhouse effect, it comes out that even the Black Sea level increases by 18 – 20 cm/100 years (1.8 – 2.0 mm/year).

2. Fractals and Fractal Geometry

Fractal geometry is a mathematical science where the straight lines that simply does not exist. And nature is a place where the straight line is an exception. If we want to know, for example, which is the length of line the coast of Britain, I say perhaps thousands or millions of kilometers. In fact, this coastline is infinitely long. Fractals are defined as geometric objects that are self-similar under a change of scale, i.e. their shape remains the same under any magnification or reduction. The object consists of elements of a certain dimension embedded in a higher dimensional space, e.g. a distribution of points (dimension zero) on a line (one-dimensional), or a collection of planes (two dimensional) embedded in a three-dimensional Euclidean space. A fundamental property of fractals is their 'fractal (also fractional) dimension', a noninteger value between the dimension of the constituting elements and the embedding dimension. Because of the self-similar pattern extending over an infinite range of scales, a fractal curve (composed of one dimensional line elements) embedded in a two-dimensional plane, for example, has an infinite length within a finite area of the plane. The fractal dimension characterizes the extent to which the fractal 'fills up' the embedding space and, in this example, will attain a value between 1 and 2.

If we go along the coastal beach for a few minutes, I noticed with surprise that the precise boundary between water and land can be very difficult area. Any distance we consider, by studying only a fraction of this, we see that new forms obtained determine the fraction that become ever longer, a phenomenon that is endless, finding every time new forms that extend the length of the boundary between land and water. In reality, the boundary between land and water can easily curve and if we look carefully at the stones and sand, it is clear that hundreds of small bumps give the impression of a surface that seems to weave this limit after a seemingly random pattern. And in fact, there is even more if we look under a microscope. This is the essence of fractal geometry. The more details we see in a fractal object, it becomes more obvious that its component parts have the same properties as the whole object. There is no straight line in nature, so a distance is really unlimited.

Fractal geometry explains how a structure can become infinitely complex and varied, giving the false impression of asymmetry, chaos and disconnection when in reality everything is interrelated. These concepts explain the development of life.

The evolution of a dynamic system through time can be observed by tracing the instantaneous values of n state variables in n-dimensional space, the phase space.

A system in a steady state will appear as a point in phase-space, while a stable oscillator traces a closed loop through phase-space. The point and the closed loop are both attractors for their respective systems, i.e. the systems develop toward those states regardless of a range of boundary conditions and perturbations. A forced and damped oscillator (such as a magnetically driven pendulum with friction, for example) may be represented in a 2D phase-space by its instantaneous angular deflection and speed (the two state variables).

An over-damped oscillator will spiral towards a point attractor as it grinds to a halt, while under a range of forcing–damping ratios, the oscillating system will trace out a closed loop in phase-space. However, this nonlinear system also exhibits chaotic behavior under the right conditions, and it traces as a fractal in phase space.

This fractal is the attractor for the system in phase-space, termed a 'strange attractor'.

Fractals can thus be temporal, spatial or phase space manifestations of chaos in nonlinear dynamic systems. Fractals are recognized in the time series of cotton prices and stocks and options (Mandelbrot, 1963), and in the occurrence of noise in communication lines (Berger and Mandelbrot, 1963). Spatial fractal patterns are recognized in a multitude of natural elements—at least over a certain range of scales—such as coastlines, snow flakes, fern leaves and the human lung. Fractals in phase-space can either be attractors themselves, i.e. strange attractors, such as the bifurcation diagram of the logistic equation, or they can constitute the dividing line between separate attractor basins in phase-space (Fig. 2).

Self-similarity extends one of the most successful concepts of elementary geometry: the similarity. Two objects are similar if they have the same shape, regardless of their size. Corresponding angles, however, must remain equal and corresponding line segments must have the same factor of proportionality. For example, when a picture is enlarged, it is enlarged by the same factor in both the horizontal and vertical directions. Even an oblique line segment, non-horizontal, non-vertically between two points of origin will be extended by the same factor. We call this extension scaling factor. Transforming objects by scaling factor is called similar transformation.

The scale-invariance of fractals is frequently coupled with self-organization in nonlinear dynamic systems consisting of large aggregations of interacting elements. As such a system moves on a strange attractor in phase-space, any particular length scale from external forcing is lost ('forgotten') and instead, the smallest length scale of the individual elements propagates its effect across all scales. This generates pattern formation that may or may not exhibit fractal properties. An example is Rayleigh–Benard convection, where individual fluid motions are chaotic while a pattern of convection cells is formed that scales with the viscosity of the fluid (instead of with the amount of heat dissipation or the dimensions of the container). The emergence of structure, or order, in a system through its internal dynamics and feedback mechanisms is the essence of self-organization, as opposed to the generation of regularity as a result of external forcing. In a thermodynamic perspective, self-organization arises in nonlinear systems that are far from equilibrium and dissipative (irreversible). Coherent motions and patterns created in such systems are therefore called dissipative structures (Kauffman, 1995). Further thermodynamic interpretations of complex systems lead to principles of minimum entropy production in open systems and maximum entropy states in closed systems (Prigogine and Stengers, 1984). The stochastic interpretation of these entropy principles in complex systems can in turn be related to information theory (Shannon and Weaver, 1949; Jaynes, 1957; Brillouin, 1962; Kapur and Kesavan, 1992).

On a final note, it must be remarked that some of these ideas are controversial, especially with regards to their application to real physical systems. Furthermore, it is generally acknowledged that the peak of popular research interest into chaos, fractals and selforganization has passed. At the same time, it is also recognized, however, that these concepts still provide valuable new insights and approaches and offer certain distinct advantages when dealing with systems containing large collections of elements involving multiple or complex interactions. As such, they have been adopted as models and analysis tools in a broad range of scientific disciplines.

3. Methods and Analyse

Fractal Analyze on Coastal geomorphology

Geomorphology is an area with real possibilities for application of chaos theory, fractals and concepts of self-organization. All landscapes presents a series of nonlinear dynamical interactions between the components. In addition, many features of the natural landscape they look fractal. Indeed, one of the concepts of fractals performed by analyzing the set of measurements Richardson (1961) on the coast of Great Britain - Mandelbrot (1967), who later described a number of features, in terms of fractals (Mandelbrot, 1982). Geomorphology fractal dimensions are used primarily as a means of models and parameter descriptive of the topography of the landscape, such as a measure of the roughness of a surface. Fractal dimensions can be determined from the two-dimensional contour lines of the cross sections, or in three dimensions using DEM (BURROUGH, 1981; Turcotte, 1992; Tate, 1998). An extensive review of methods of measurement of fractal landscapes found in Xu et al. (1993).

For the Black Sea fractal analysis I used the following cartographic documents:

- Francesco Ghisolfi (1533-1560), Italy (Fig.1)

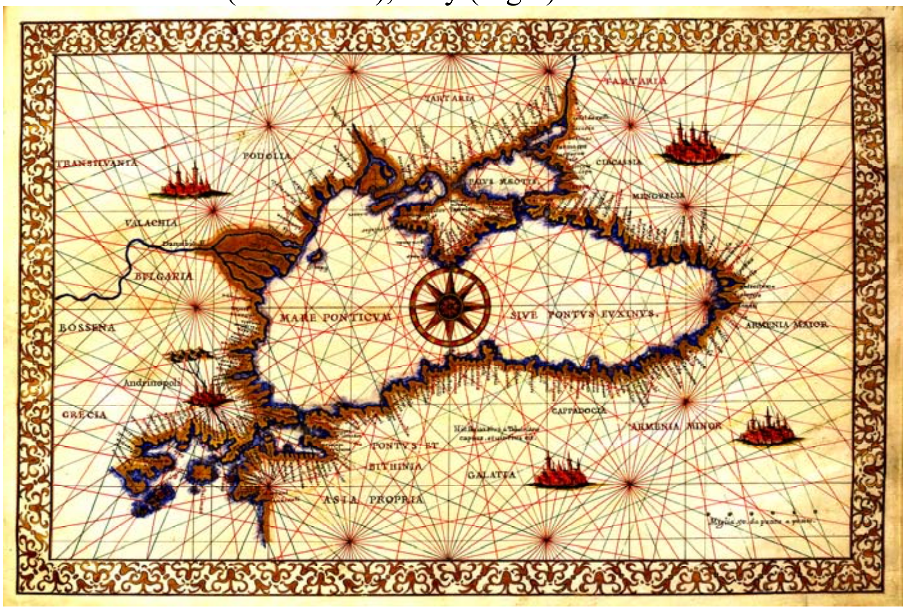

Fig. 1

- 1797 - Black Sea, Balkan & Ukraine Blondeau - Partie Orientale de L'Empire Romain ou du Monde connu des Anciens - Paris, Lapie 1797 Copper engraving, hand colored in outline when published. Eastern part of the Roman Empire showing showing prominently the Balkan, Asia Minor, the Black Sea and the Ukraine. 35,1 x 54,3 (Fig.2)

Fig. 2

- 1855 Spruneri Map of the Black Sea or Pontus Euxinus in Ancient Times - Geographicus - PontusEuxinus-spruneri-1855.jpg (Fig.3)

Fig. 3

- 1832 Black Sea & Caspian Sea Hamm, P.E. A comparative view of the Inland seas & principal lakes in the eastern Hemisphere. Philadelphia, Carey & Lea 1832 - Steel engraving, hand colored in outline and wash when published. Engraved by P.E. Hamm. 82 by 142mm (3¼ by 5½ inches) (Fig.4).

Fig. 4

- 1941 – Marea Neagră- Antipa, Gr. – Oceanografia, bionomia şi biologia general a Mării Negre - Monitorul Oficial şi Imprimeriile Statului, Imprimeria Naţională, Bucureşti, 1941.(Fig.5)

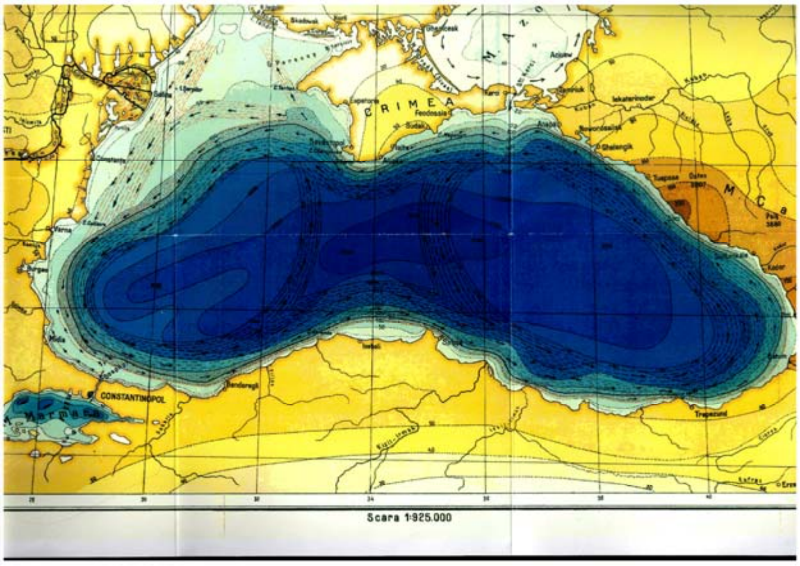

Fig. 5

Also we identify the coastline onto satellite images from Landsat 2015. These images was transposed into BMP format to be interpreted in two different analyse program software – Benoit – Truesoft and ImageJ of National Institutes of Health, USA using the folowing computing relations:

Table 1. Relations of computing for different fractal dimensions (Craciun,D& Isvoran, A. – 2011)

Fractal dimension	*Formula*	*Scale relationship*
Dimension "box counting"	$Df = \lim_{\varepsilon \to 0}\left(\frac{log(N(\varepsilon))}{log\left(\frac{1}{\varepsilon}\right)}\right)$ *with ε cell dimension and N(ε) – number of needed cells to cover the analyzed object*	$N(\varepsilon) \sim \varepsilon^{Df}$
Fractal Dimension of a curve	$Df = 1 - \lim_{\varepsilon \to 0}\left(\frac{log(N(\varepsilon))}{log\left(\frac{1}{\varepsilon}\right)}\right)$ *with ε etalon dimension and N(ε) etalons number needed to cover the analyzed curve.*	$L \sim \varepsilon^{1-Df}$

Fractal dimension associated to the mass of a fractal object	$Df = \lim_{r \to 0} \left(\frac{log(M)}{log(r)} \right)$ *with r circle radius in which is framed the mass M*	$M \sim r^{Df}$

4. Results and conclusions

The focus of this research was on texture analyse since these are the parameters most influenced by the antropogenetic factors and global changes conditions.

Even if cartographic documents shows an image with low precision depending on methods and instruments used in a particular historical periods and may not provide clear comparative data on the evolution of the coastline of the Black Sea, they are very useful in understanding and assessing changes in textural and structural thereof . This brings into question fractal analysis of fractal dimension of a complex structure - characteristics of the shoreline.

Fractal analysis results are indicated in Table 2 and illustrated by Figures 6-8

Table 2 Results of Fractal Analyse

Nr.	*Year of the Cartographic Document*	*D_fBC Box Counting*	*D_fPA Perimeter/Area Report*	*M_D Mass Dimension*	*D_fRD Ruler Dimension*
1	*1533*	*1.769*	*1.128*	*1.893*	*1.038*
2	*1797*	*1.822*	*1.100*	*1.906*	*1.029*
3	*1832*	*1.846*	*0.992*	*1.896*	*1.120*
4	*1850*	*1.806*	*1.099*	*1.909*	*1.023*
5	*1941*	*1.885*	*0.933*	*1.927*	*1.036*
6	*2015*	*1.883*	*1.215*	*1.936*	*1.024*

By quantifying fractal dimension of data with fractal analysis and developing trends over time, the deterioration/change rate of the geometry can be assessed and maintenance/remedial input planned accordingly. Fractal analysis provides four basic parameters: the slopes of the fractal plot, and the tender of the slopes. The variation in these parameters along the coast can also provide an indication of the tendency condition, providing up to six parameters for trend analysis. Each of these parameters could potentially highlight different safety or maintenance concerns.

If the employment of fractal dimension for the ratio between perimeter and area of the Black Sea, does not register a correlation, r^2 is 0.0005, which shows major changes over time, the fractal dimension of the center of mass is given by the equation $y = 1.8821 + 0.0083x$ the correlation $r^2 = 0.8292$ (Fig.9)

Satelitte Image, 2015

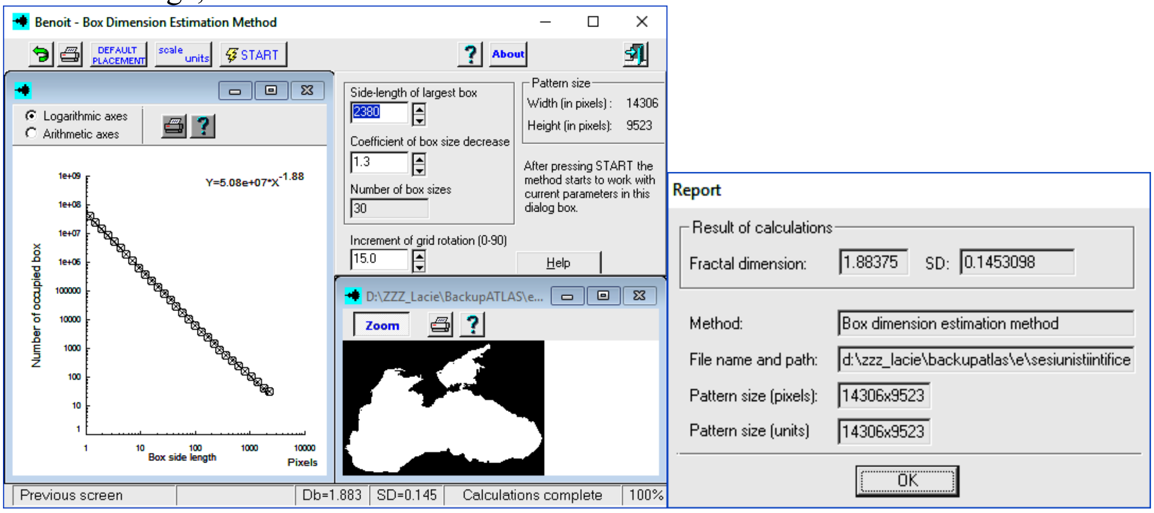

Fig 6. Black Sea - Box Dimension

Gr.Antipa Map 1941

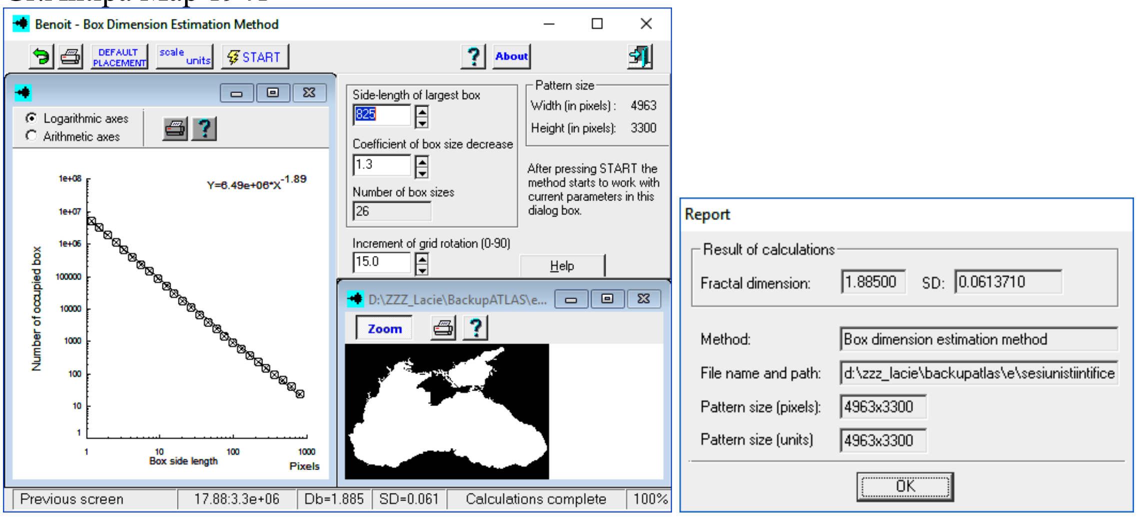

Fig 6. Black Sea - Box Dimension

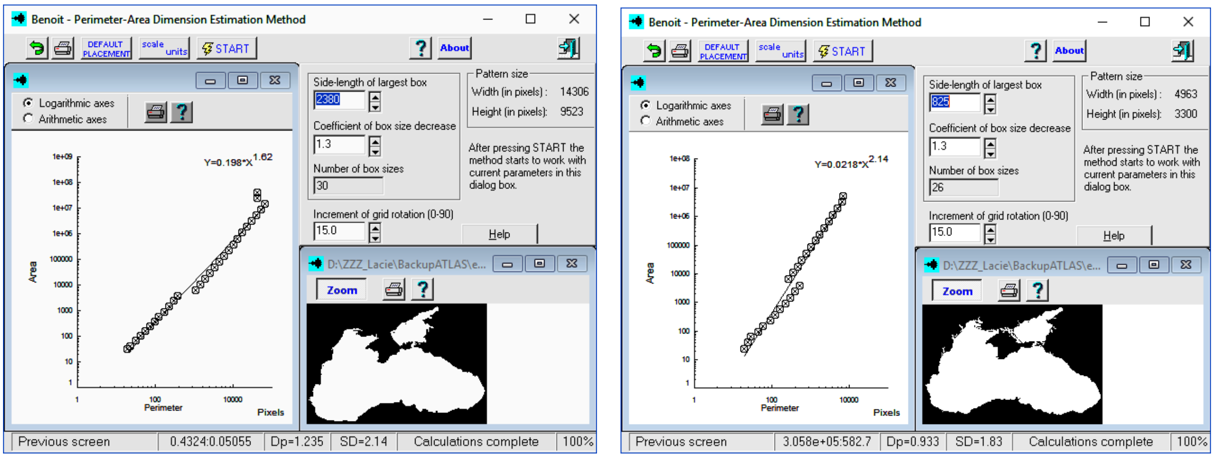

Fig 7. Perimeter-Area Dimension

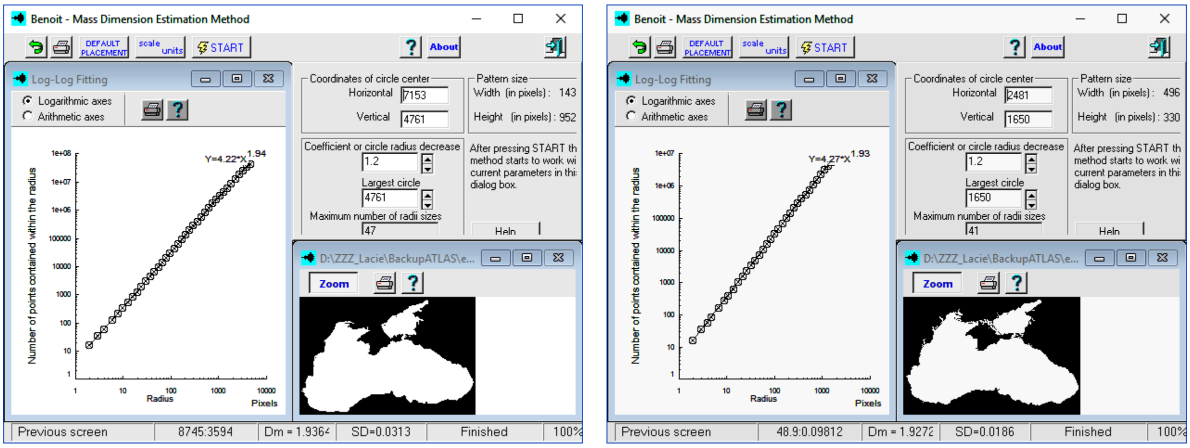

Fig.8 Mass Dimension

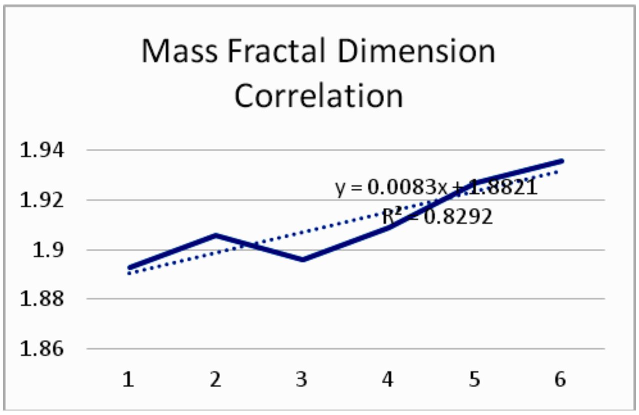

Fig.9 Mass Fractal Dimension Correlation

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