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Computational Experiment in the Problem of the Recent Traces of Oceanic Cosmic Impacts

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The paper aims to fill the gap between geological practice on the problem of the recent traces of oceanic cosmic impacts and computational experiment on tsunami geology problem. Computational experiment and numerical analysis data of the oceanic comet impacts could be more effective for mega tsunami understanding and prediction than the traditional geological methods. We explored the depositional traces of large-scale water impact on the coast and modeling of mega tsunami given the steep waves and Mach reflection on the rocky shore and described chevron dunes form on the base of neural network technology to solve the inverse tsunami problem. The ocean impact craters were explored using the wavelet analysis digital data of the ocean bottom.

Keywords: ocean impact crater, tsunami geology problem, mega tsunami, chevron dunes, depositional traces, computational experiment, neural network technology, wavelet analysis.

Introduction

One of the most significant current discussions on the problem of the recent traces of oceanic cosmic impacts is tsunami geology [2, 3, 5, 6, 11]. Computational experiment is becoming increasingly fruitful in the complex investigation of the problem of tsunami formation deposits on the coastline. We believe that computational experiment is the leading way in this problem solution, because it is a universal approach [21].

Now computational experiment is a common methodology characterized by a complex approach for solution of direct and inverse tasks in this problem. Computational experiment is an important component in the investigation and plays the key role in study of the recent traces of oceanic cosmic impacts. In the investigation computational experiment has become a central issue for dune-chevrons study. The issue of dune-chevrons has received considerable critical attention, because they have the amazing geomorphologic forms.

Recent developments in the mega tsunami problem have raised the need to use computational experiment for the digital data numerical analyses of the ocean bottom relief on the base of wavelet transformation for the search and selection impact craters.

In recent years there has been an increasing interest in use of neural network processing for the solution of nonformalized tasks. Recent developments in the field of computational experiment have

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led to a renewed interest in use of this modern technology in the research of ocean cosmic impacts and tsunami geology. Recently, on the Tunguska phenomena conference in Krasnoyarsk, researchers have also shown an increased interest in computational experiment use to solve the problem of Holocene impacts and mega tsunami modeling for formation and describing chevrons form.

Abbott D., Breger D., Bryant E., Gusiakov V., Kelletat D., Masse W., Scheffers A., Scheffers S. and et. all. (2001–2008) show how the past research into dune-chevrons was mainly concerned with geology and geomorphology aspects [2, 3, 5, 6, 11, 20]. Recently, investigators have examined the effects of mega tsunami on coast and dune-chevrons formation. Previous studies have reported especially the geometry and relative position deposits and candidate crater. A considerable amount of literature has been published on tsunami deposit and dune-chevrons. These studies showed geomorphologic, geological and physical aspects of formation tsunami deposit and dune-chevrons.

Surveys, such as that conducted, showed that chevrons can describe the origin of tsunami caused by the collapse of cosmic bodies into the ocean. Previous studies have based their criteria for selection the form of geometric images obtained by a satellite against quality characteristics. Recent evidence suggests that without a quantitative description of the studied processes there will be no progress in understanding the geological aspects of the problem tsunami deposits.

More recently, literature has emerged that offers contradictory findings about the causes of the chevron formation and their connection with tsunami, caused by the impact forces in the ocean. In many conferences a debate take place between supporters and opponents of impact formation of chevron. The controversy about scientific evidence for relation chevron with mega tsunami has raged unabated for over a last decade. Traditional natural experiment suffers from several major drawbacks: it is labor demanding and expensive.

So far, however, there has been little discussion about the possibility of the chevron formation with tsunami waves at rocky shores, which can be described by a wave effect, which is called Mach reflection, when the height of waves in the coastal zone increases by several times. However, far too little attention has been paid to quantitative analysis of the qualitative data on the occurrence of floods in different regions due to cosmic impact on ocean. Most studies on chevron have only been carried out in a small number of areas: geomorphology and physical aspects. The research to date has tended to focus on qualitative description of the data rather than on numerical simulation and modeling.

So far, methodology of computational experiment has only been applied to normal wave tsunami, but not to cosmic tsunami impact. However, there have been no controlled studies which compare differences in approaches for chevrons description. However, few scientists have been able to draw on any structured research into the opinions and attitudes of this subject. This indicates a need to understand the various perceptions of phenomenon that exist among different researches, because the evidence for this relationship is inconclusive. What is not yet clear, is detailed impact of mega tsunami on coast. The physical basis of these phenomena is also poorly understood. No previous study has investigated these phenomena by computational technology, because the experimental data are rather controversial.

The purpose of this study is to develop an understanding of the potential of computational experiment to address the major challenges in the problem of the traces recently ocean cosmic impacts.

This article seeks to explain the development of coastal sediments, and other qualitative information based on the arsenal of modern computing. This case study seeks to examine the changing form of dune-chevrons by means of numerical experiments. The central question in this report is how the following impacts (craters) and coastal sediments (chevron) can promote the solution of the inverse problem of tsunami impact from space sources. In particular, this article will examine 3 main research questions also related to the construction of efficient technologies of computing experiment, in relation to this issue. The hypothesis that will be tested is that existing hydrodynamic models can describe the devastating waves and their run-up in relation to chevron formation.

Due to the practical constraints (insufficient empirical data), this paper cannot provide a comprehensive review of available capacity for numerical analysis. Part of the tsunami modeling, wavelet analysis and the use of neural networks were considered briefly, since is beyond the scope of this study to examine the practical aspects of the tsunami geology. The reader should bear in mind that the study is based on a small sample of digital data provided by: V. Gusiakov and D. Abbot, and also contained in the relevant articles. Our main reason for choosing this topic is personal interest to this problem, because for us it was an incomparable pleasure of communicating with the participants of the HIWG conference on Tunguska problem, which was held in Krasnoyarsk in summer 2008, where we got acquainted with famous scientists – Abbott D., Bryant E, Breger D., Gusiakov V., Hagstrum J., Masse W.

The overall structure of the study takes the form of 3 chapters and an introduction, an overall description of computational experiment, as the approach to the tasks solution. Finally, the conclusion gives a brief summary and critique of the finis area. While a variety of definitions of the term *computational experiment* have been suggested, this article uses the definition first suggested by A. Samarsky who understood it as a modern methodology and technology scientific research [17-18].

1. Numerical experiments of the submarine impact selection

A fast algorithm for two-dimensional wavelet transformation in the numerical experiment studied the data, as well as special procedures for the visualization of the earth's surface topography and the ocean floor. The potential of the computational method for the allocation of submarine impact craters shows that it can also be applied to the study of ring morphostructure an origin at the Earth's surface and ocean bottom [9-10].

Organization of the numeral process in solving these problems takes the form of computational experiment and includes the detection and identification of the required forms on the surface, followed by its contrast. Numerals experiments using the developed technology were carried out on the data describing the shape of the land surface in Central Siberia and Kazakhstan. The results obtained are very promising. Well-known ring structure (impact craters Papigay, Lagoncha, Zhimanshin and Chicxulub crater) effectively detected and clearly identified on the surface under study, the quantitative information being presented in the form suitable for subsequent processing and analysis.

The aim of this section is to describe a computational method for the allocation of submarine impact craters, presumably associated with the formation of chevron studied on the basis of digital bathymetry with the developed algorithm and software of the wavelet analysis of the data. We selected Burckle crater, presumably responsible for the initiation mega tsunami and of the chevron formation on shores Madagascar. The technique is suitable for large-scale numerical experiments for different areas of the ocean.

Wavelet transformation of one signal is the basis for its expansion, designed with certain properties of the solution function (wavelet) by means of large-scale changes and transfers [1]. An element of the basis of wavelet transformation is a well localized function, rapidly tending to zero outside a small interval, so that each function describes the basis of a spatial (temporal) frequency and its localization in physical space (time). In the case of two-dimensional data wavelet is a surface with a central symmetry that meets the same set of requirements, which in one case.

Consider the algorithm for constructing two-dimensional wavelet diagram, which was developed under a specific task – to search for the ring structures on the surface of the Earth. The initial data represent the *D* matrix *NxM* elements that contain values of some characteristics of the nodes of a rectangular grid. It is necessary to identify the structure of a given shape, weakly expressed on the background of the heterogeneity of the environment. For practical application, it is important to know the characteristics of a wavelet:

– Localization in space (time) and in frequency;

Zero mean: $$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\varphi(x,y)\,dxdy = 0; \tag{1.1}$$

Limited: $$\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\left|\varphi(x,y)\right|^2 dxdy < \infty; \tag{1.2}$$

Self-basis.

Next, we introduce the following symbols and functions:

$$\begin{aligned} & x, y \in (-M, M), \\ & \varphi(t) = -(1-t)\cdot e^{-t}, \\ & \Phi_{x+M,\,y+M} = \varphi\left(\frac{10((x-M)^2+(y-M)^2)}{M}\right); \end{aligned} \tag{1.3}$$

where M – scale wavelet transform, $\Phi_{x+M,y+M}$ – matrix of the base wavelet.

Fig. 1 shows the type of wavelet. Now the wavelet transform can be rewritten as an integral sum of:

$$\begin{aligned} W_{x,y} = \frac{\Delta x \Delta y}{\sqrt{M_i}}\cdot\Bigg(&\sum_{k=1}^{M}\sum_{l=1}^{M}\Phi_{M-k,M-l}\cdot(D_{x-k,y-l}+D_{x-k,y+l}+D_{i+k,j-1}+D_{i+k,j+1})+ \\ &\sum_{k=1}^{M}\Phi_{M-k,M}\cdot(D_{x-k,y}+D_{x,y-l}+D_{i+k,j}+D_{i,j+1})+\Phi_{M,M}D_{x,y}\Bigg). \end{aligned} \tag{1.4}$$

Because both components of the matrix are constant, the procedure of wavelet-transformation is reduced to multiplying the folding of a set of constants. These matrixes are organized in such a way that the numbers of operations in the computation of the elements of their coefficients were minimal. This greatly reduces the amount of computer time required for the calculations. The developed algorithmic and software demonstrated high efficiency in the real data processing.

Numerical data simulation using the wavelet transformation was carried out by the example of the allocation of the Burckle crater in the Indian Ocean at the depth of 3800 m, with 29 km in diameter. A summary of the Burckle crater is presented in Fig. 2.

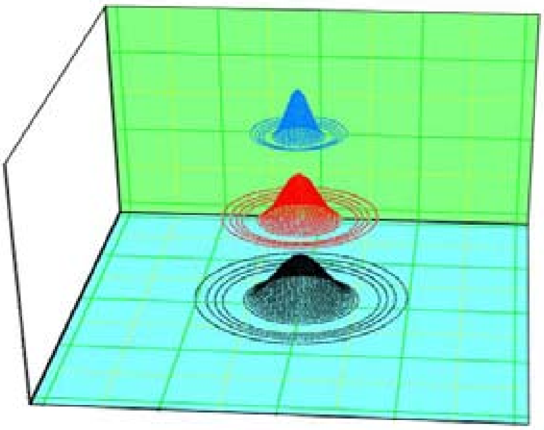

Fig. 1. Wavelet forms

Name: Burckle

Query: selected by name sorted by country, name

Page 1 of 1 Number of events: 1

Country	Name	Lat	Lon	Age	Diam	N	D	H	Appearance	Form	Type	Erosion	Rocks	V	Space view	Comment	Phot
Indian Ocean	Burckle	-30,865	61,365	0,0048	29	1		3000						3		comet most likely occured in May of 2807 BC	

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Fig. 2. Data on the location of the Burckle crater [http://tsun.sscc.ru/hiwg/hiwg.htm]

Calculations were carried out with the computing environment *MathSad14*, which has a built in function to calculate the wavelet transform based Dobeль. The result of wave function is a vector linked to a few coefficients with a wavelet spectrum.

Figs. 3–5 present the results of the filtering data. Fig. 5 clearly allocated to the location of the Burckle crater.

Further simulations were performed in the Burkle crater through Haar functions. The size of the area to the Burkle crater was 400*300 km with a step of 1 km, the effective diameter of a «cap» wavelet being 20 km, the results of calculations are shown in Figs. 6–8.

So, sections 1–3 present the findings of the research, focusing on the three key themes that have been identified in the data analysis: the search of impact craters on the basis of wavelet transformation of the digital ocean bottom, an effective visualization of the seabed topography and the land required in the solution of hydrodynamic problems, the use of the above models of neural networks for solving

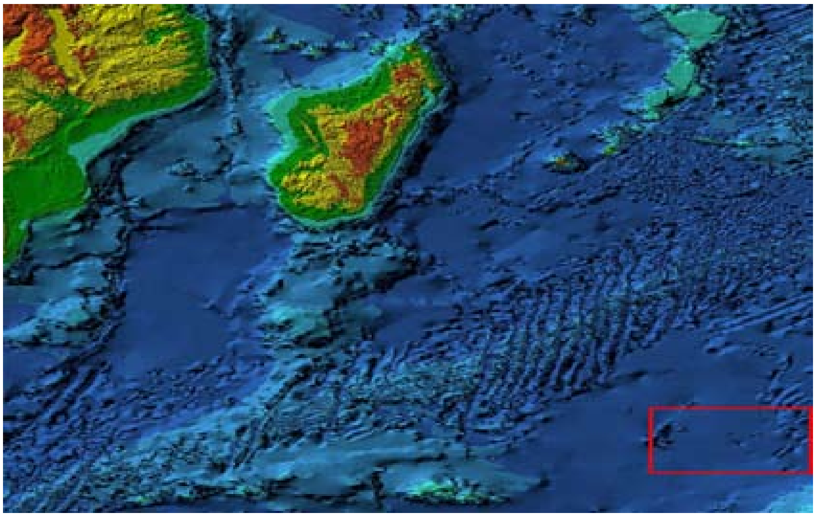


Fig. 3. Baseline data shows an array of the data for analysis [5-6]

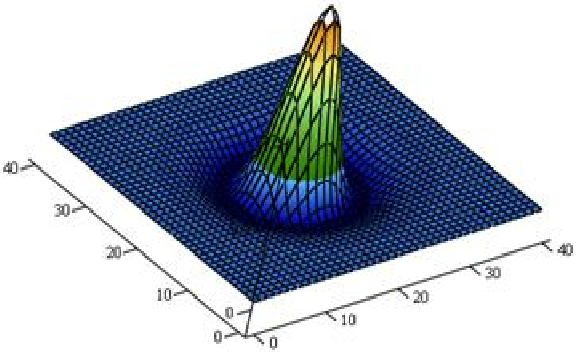
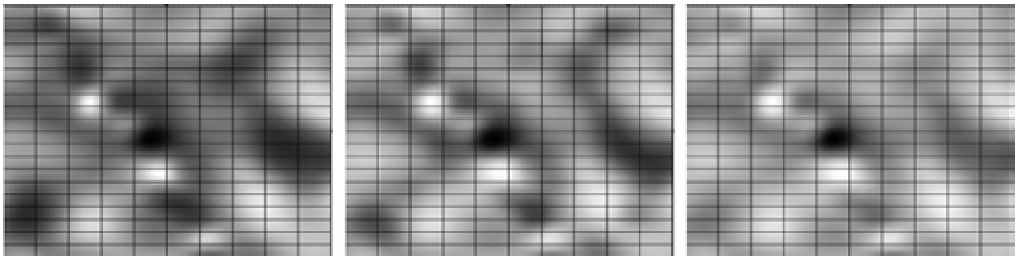


Fig. 4. Dobeš wavelet



a

b

c

Fig. 5. Phased wavelet filter surface of the ocean floor topography: a – filter M30; b – filter |M30|-M15; c – the result of filtering

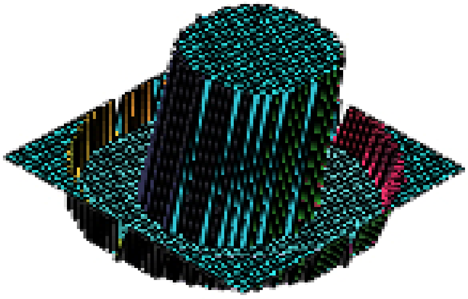


Fig. 6. Haar wavelet

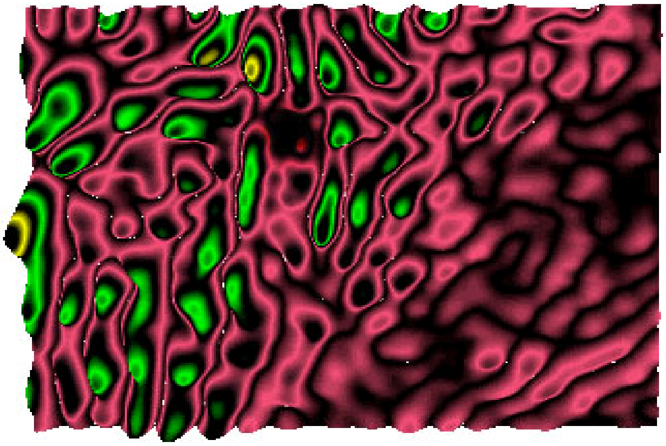


Fig. 7. Output filtering of the Haar wavelet, Burkle crater

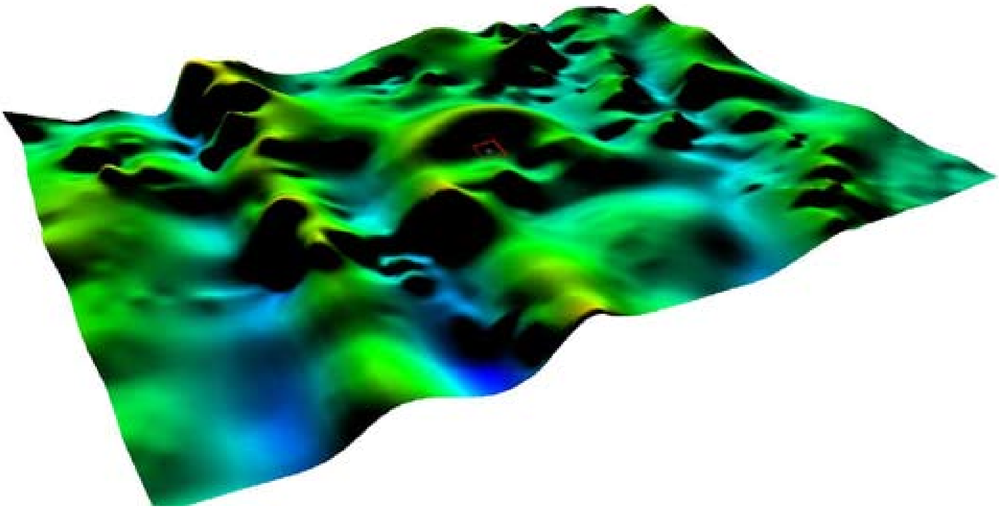


Fig. 8. View of the Burckle crater, obtained using Global_mapper

the problem of reconstruction of the characteristics of waves in the run-up on the coast and chevron formation.

2. Neural network analysis of the observational data of coastal structures

In addition to scientific and technical tasks, allowing a rigorous formal description, there are challenges when a formal description of the phenomenon does not exist, or it is difficult to analyze it. Numerical (information) simulation of mega tsunami traces – in chevron form represents an ideal type of task. Neural algorithms allow the search of regularities in large data arrays with an arbitrary statistical distribution of random variables. When the patterns are identified, then the developed numerical network model can be put into performance [24].

Proposed numeric experiments are based on observations of chevron and the relief of the coastal areas, construction of their models being approximating the spatial functions. Proposed use of the numerical network analysis technology is a rapid multi-parameter regression model of observational data, including procedures for constructing the model (learning) and its testing. As a result, appropriate algorithmic and software numerical network modeling of coastal structures is adapted.

In most cases, the regression (neural networks) optimization principles are used. A functional, assessing the quality of the regression model, is optimized by gradient or other methods. The classical approach is the method of least squares. It minimized functional, estimating the model with the experiment:

$$H = \sum_i (y(\vec{x}_i, \vec{p}) - \tilde{y}_i)^2, \tag{2.1}$$

i – number of experimental; $y(\vec{x}, \vec{p})$ – approximating function; $\vec{x}$ – the vector of variables, which is addiction; $\vec{p}$ – adjusts the parameters of vector function; $\tilde{y}_i$ – the experimental value. As a result, the parameters are standard functions (usually linear), which approximate the experimental dependence. But in the experiment not all data may have the same credibility; therefore, weighted least squares method introduces weights reflecting the impact of each experiment:

$$H = \sum_i \left(\frac{y(\vec{x}_i, \vec{p}) - \tilde{y}_i}{\delta \tilde{y}_i} \right)^2, \tag{2.2}$$

$\delta \tilde{y}_i$ is confidence interval, the precision with which the determined $\tilde{y}_i$.

To build a regression (neural networks) models are used in the developed software *«Models»*. The used the approximation depending exits from the entrances to the following:

$$\alpha^t{}_a = b_a + c_a \sum_j \sin(\varphi_{aj} + \sum_i w_{ji} X^t{}_i), \tag{2.3}$$

where X – input data; i – number of inputs; j – number of harmonics; t – number of tasks in the sample; a – adjusts the parameters, b, c, w, φ – number of exit.

Nonsmoothness function was assessed as the mean first-order sensitivity of the output:

$$U = \frac{\sum_a \left\langle \left(\frac{\partial \alpha_a}{\partial x_j} \right)^2 \right\rangle}{\sum_a \left\langle a_a{}^2 \right\rangle} = \sum_j \sum_i w_{ji}^2 . \tag{2.4}$$

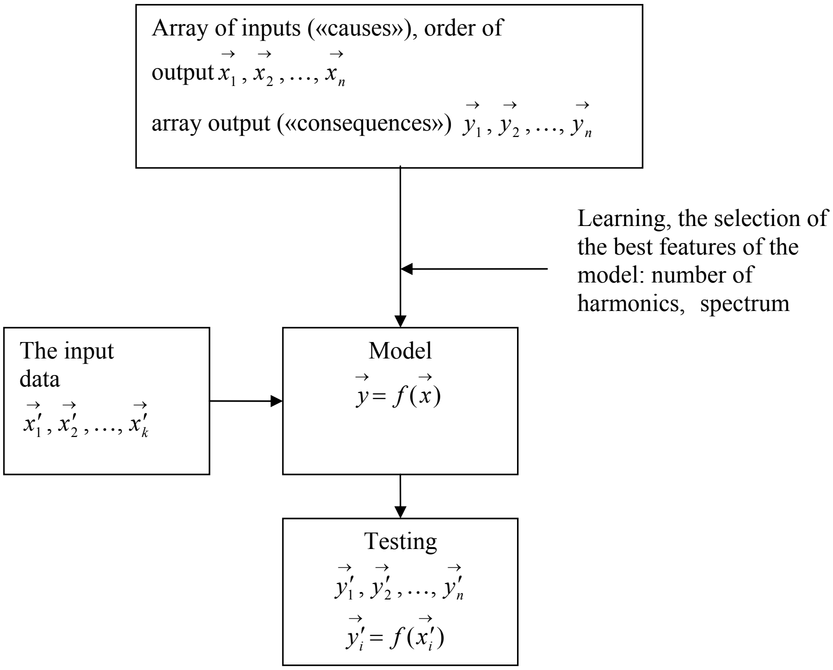
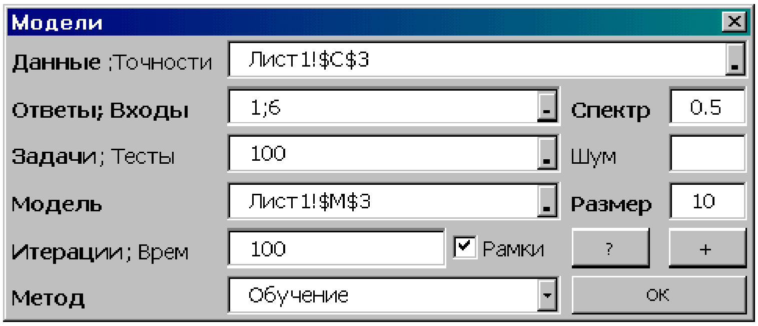


Fig. 9. Present the modeling of the observational data using the software *«Models»*



Данные ;Точности: Лист1!$C$3

Ответы; Входы: 1;6

Спектр: 0.5

Задачи; Тесты: 100

Шум:

Модель: Лист1!$M$3

Размер: 10

Итерации; Врем: 100

☑ Рамки

Метод: Обучение

Fig. 10. The dialog program *«Models»*

This value restricts the top, depending on the task. During the training, by adjusting the parameters *w* are changed in such a way that they do not exceed user-defined limits. For optimization the method of conjugate gradient is used.

The program *«Models»* is designed for the rapid synthesis of large amounts of empirical and analytical models to experimental data (Fig. 9). Synthesized approximate analytical models reproduce the original object of cause-effect relationships, to the extent that they regard themselves in the collection of empirical data. The analytical model can replace experiments with the original object to resort to numerical experiments with the model.

Fig. 10 presents a dialog window *«Models»* to work in the computing environment *«Excel»*. It is necessary to specify the location of a book *«Excel»* source of empirical data, as well as items that will be posted the results of the program. It is assumed that the empirical data are organized in *b-array* consisting of two related arrays – an array of inputs («causes») and the array outputs (responses, «consequences»).

Another two *b-array* need to display results: *b-array «Projections»,* which has the same structure and size as the *b-array* of empirical data and their accuracy, and *b-array «Model»* (address placement is given in paragraph *«Model»* dialog box) with the same horizontal size as the other *b-array*, but differs in the vertical size, user (Item *«Size»).*

In *b-array «Projections»* posted the results of model smoothing of empirical data, *b-array «Model»* stored information about the parameters of the analytical model. Two upper rows b-array *«Model»* are of informational status – in particular, in the first line of the first input column posted on the error model of the last instruction and the range of values in the second row indicate the significance of the relevant input parameter for the predictions – the smaller the figure, the less important is its corresponding to input information. The remaining positions adjust the model parameters.

Synthesis of the model performs the *«Learning»* procedure, by the iterative search of the model parameters, where the standard deviation of responses (opinions) models and related empirical data in an array of responses are minimized. The number of iterations is defined by *«Iteration»* paragraph. For the training the restriction on nonsmoothness function (item *«Spectrum»*) must be set strictly greater than zero level of the spectral density. If the observation occurs, plaque indicating the number of past iterations, estimate (error), the proportion of the fall assessment on the last iteration and the current spectral density are defined.

The calculation shows the actual observations of the spectral density, while the dialog is established recommended. If the actual spectral density is significantly (by several tens of percent) greater than recommended, it implicitly refers to the fact that raising the level recommended by the spectral density decreases error learning, but does not necessarily diminish the bug testing. If the actual spectral density is significantly lower than recommended, it is advisable to try to reduce the spectral density. Based on the results of the testing calculated the most suit-user spectral density may be, so that both the training and testing errors were smaller. At high spectral density it is easier to achieve error reduction training without the requirement of smoothness of interpolation, but the deteriorating performance of test predictions can occur. Also selecting the size of the model, take into substantially, that large sizes and, consequently, increase of the model machine time.

Thus, non-linear regression (neural networks) analysis allows information to build predictive models of studied phenomena (the process) and use them in the systems of control and monitoring.

We were having outlined the general scheme of computational experiment and a brief description of its main stages. Be aware, that computing experiment in a narrow sense, as the creation and study of mathematical models of the object with the help of computational tools, can be identified as the basis for the triad: a model – an algorithm – a program. Broadly (methodological) sense of computational experiments is understood as techniques of research [17]. For the investigated object (chevron) first, a mathematical (neural networks) model is developed. Computing experiment, in essence, provides a study group near regression (approximation) model. Initially, we construct a simple, but quite meaningful model for description of the object in terms of proximity to the experimental data neural networks (information) model.

In the computational experiment, the subsequent cycles of the model states new developments are taken into account, etc. Therefore, we can write about the orderly recruitment (hierarchy) of mathematical models, each with an accuracy of describing reality. Thus, in the most simple model, it is necessary to seek agreement with the experiment, it is the aim of the computational experiment.

Here are the basic elements of numerical experiments on simulation of chevron structures: a full-scale experiment, the construction of a mathematical model, the choice and application of numerical method for finding solutions, building a software implementation of mathematical models to find the numerical solution, processing the results of calculations, compared with full-scale experiment, the decision on continuation of full-scale experiments, the continuation of full-scale experiment to obtain the data necessary to refine the model, the accumulation of experimental data. Adapted, depending on the specifics of the problem, the chain of these phases of computational experiment, implemented in a single software system, and is «technology» computing experiment.

Thus, the proposed computational technique based on neural networks modeling of observational data for the numerical description of mega tsunami builds a model (approximation of spatial functions to study the structure-surface) in form chevron. It can also simulate bottom topography and land in their expressions for the detection of these interactions and processes, their formation at up rush mega tsunami on rocky shores. Later, on that basis the numerical analysis of the diversity of chevron geometries was performed for the assessment of the predominant angle of the axis of chevron to the coastline. Grade azimuth geometry chevron indicates a possible source area of the epicenter and the tsunami probable submarine impact craters. The contours of chevron in the depths of the land would allow detailed modeling of run-up of the mega tsunami.

Baseline data of coastline and chevron, digitized with a step of 2 mm (1 mm = 125 m), are expressed in *b-arrival* on the worksheet *«Excel»* (Fig. 11–12). Two arrays with the input *X* (common to the shoreline and chevron) and the output *Yb* (to shore) and *Ych* (for chevron) are located nearby – on the left array of consequences, on the right – an array of reasons. This calculation is one an *«input»* and one an *«output»*. After placing the initial data on the *«Excel»* sheet, turn to the procedure for the synthesis of the model, filling in a dialog window *«Models»*. Then, after filling the required fields in the dialog box appears *b-arrival «Model»*, which contains adjusted parameters of the base dependence. Two tops of the array contain the values of average error and the spectrum. Then it is necessary to compare the original data with the results of testing and by changing the settings range from 20 to 200 and size from 20 to 100, making the best result compared field and calculated data (smallest error).

Based on the results of numerical simulation data of the studied chevron forms and coastline we have come to the following conclusions: the best result in the simulation is obtained for the range = 200 for all the input data and the number of subscript parameters – 35 for the first chevron, and 40 – for the second chevron, revealed that chevron, along the coast, remain in a general form similar to the form of appropriate shoreline, which in turn can characterize the run-up catastrophic waves, as a result of which the respective chevron is formed.

3. Numerical simulation mega tsunami in the coastal zone

We were reviewed of the results of hydrodynamic modeling of the single wave's interaction with oblique wall to form a *Mach* leg. In Future, the numerical study of chevron distribution, its orientation to the coastlines, the relationship to a coastal forms (cliffs, coastal embankments), will disclose the mystery of the impact of mega tsunami cosmic origin in the coastal area.

Let us consider the hydrodynamic models that can estimate the nonlinear transformation of tsunami waves of types in the coastal zone within the above tasks. Palmer and others [15] performed laboratory experiments to model the anomalous strengthening of the tsunami in Hilo Bay, which had

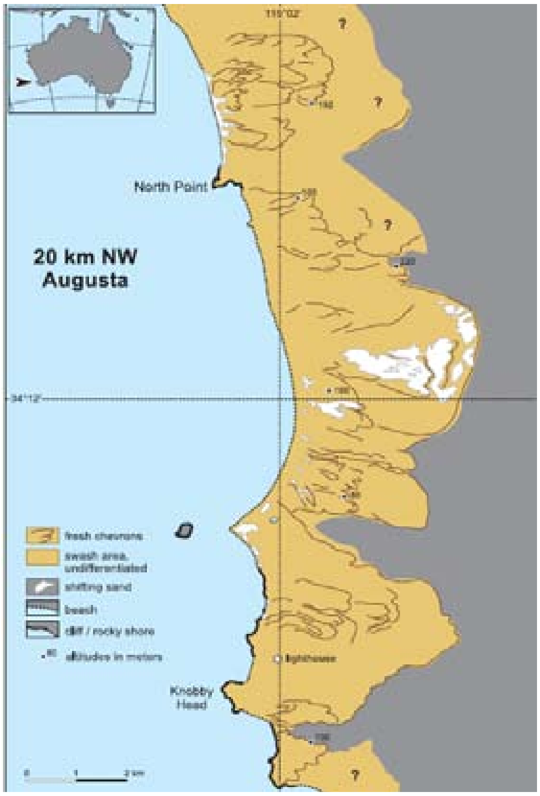
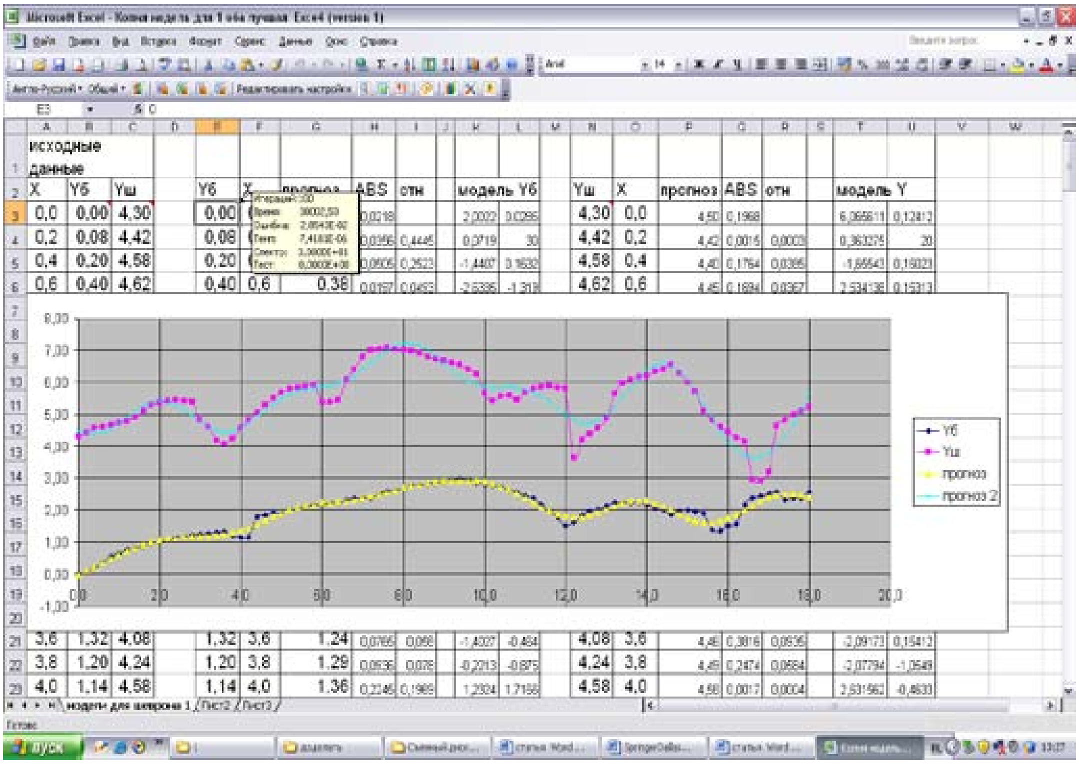


Fig. 11. Chevron form (Australia) [20]



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	исходные данные																				
2	X	Yб	Yш		Yб	X	прогноз	ABS	отн		модель Yб			Yш	X	прогноз	ABS	отн		модель Y	
3	0,0	0,00	4,30		0,00			0,0218			2,2022	0,0295		4,30	0,0	4,50	0,1968			6,065611	0,12412
4	0,2	0,08	4,42		0,08			0,0356	0,4445		0,0719	30		4,42	0,2	4,42	0,0015	0,0003		0,363275	20
5	0,4	0,20	4,58		0,20			0,0505	0,2523		-1,4407	0,1632		4,58	0,4	4,40	0,1764	0,0385		-1,65543	0,15023
6	0,6	0,40	4,62		0,40	0,6	0,38	0,0157	0,0493		-2,6395	-1,318		4,62	0,6	4,45	0,1694	0,0367		2,534136	0,15313
21	3,6	1,32	4,08		1,32	3,6	1,24	0,0765	0,068		-1,4027	-0,484		4,08	3,6	4,46	0,3816	0,0935		-2,09173	0,15412
22	3,8	1,20	4,24		1,20	3,8	1,29	0,0536	0,078		-0,2213	-0,875		4,24	3,8	4,49	0,2474	0,0584		-2,07794	-1,0549
23	4,0	1,14	4,58		1,14	4,0	1,36	0,2245	0,1989		1,2324	1,7156		4,58	4,0	4,58	0,0017	0,0004		2,531562	-0,4633

Fig. 12. Placement of data numeric experiments on the sample *«Excel»* sheet

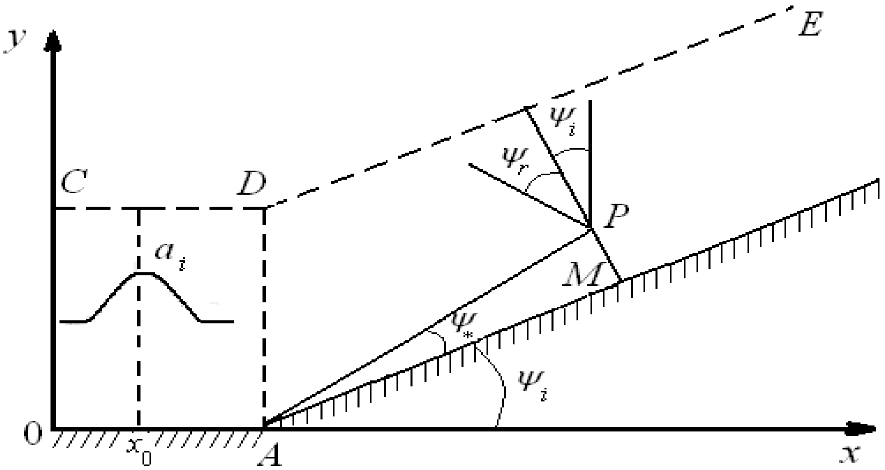


Fig. 13. Wave scheme of *Mach* reflection

occurred in 1946, 1952, 1957 and 1960. They believed that the anomalous strengthening of the tsunami caused by a combination of several characteristics of the geometrical of the bay: underwater ridge at the entrance to the bay led to refraction of tsunami waves, sending them into the bay, the bay having a triangular configuration due to wave of accumulating effect in the bay top where the port of Hilo. In this paper, [23] described the experiments of [16] to study the interaction solitary wave a_i amplitude with a flat vertical wall, to which the wave come at some angle ψ_i. The reflected waves from the wall to be were found regular or irregular (*Mach*) depending on the amount ψ_i. Regular reflection of ridges crossing the incident and reflected waves occurred at the wall, and at *Mach* formed a third wave, called the *Mach* leg, which is located between the wall and the point of the first two wave crests intersection.

Mach reflection scheme let us consider in detail, following [8], which is depicted in Fig. 13.

Theoretical studies of skew run-up on a wall in were made be Miles [13-14]. These analytical formulas for the maximum run-up R, the amplitude a_i of the reflected waves ψ_i, the angle and the angle of reflection, which is visible to the *Mach* leg from point A, were obtained through the study some nonlinear-dispersion model of shallow water of solutions. At the same time many possible schemes for the wave interaction with a wall to use the wave configurations that have been observed in experiments [16]: double and triple configurations. The distance from the zone of interaction of all waves are assumed to be in the form of solutions, as in the case of *Mach* reflection wave parameters are related to additional terms of the resonant interaction. When assumptions are specified the following formula for the maximum run-up is suggested:

$$\frac{R}{a_i} = \begin{cases} \dfrac{4}{1+\left(1-3a_i/\psi_i^2\right)^{1/2}}, \dfrac{\psi_i^2}{3a_i} \geq 1; \\ \left(1+\dfrac{\psi_i}{(3a_i)^{1/2}}\right)^2, \dfrac{\psi_i^2}{3a_i} \leq 1. \end{cases} \tag{3.1}$$

Thus, if the solitary wave at the free-wall falls at an angle, then the run-up value may reach the value $R_* = 4a_i$. In the Melville experiments [12] the depth of the pool reaches 30 cm, but for the magnitude of R is found, not to exceed $2a_i$.

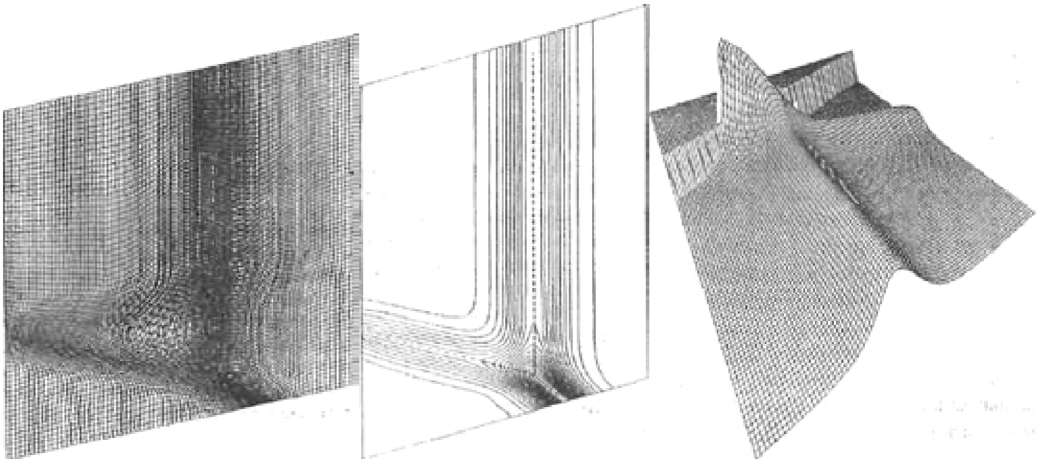


Fig. 14. Free surface wave, its contours and grid for free surface at the relevant time [8]

The authors of [19] proved that such a small *R* value was due to the fact that [12] actually examined only the initial phase of the wave interaction with a wall, and to achieve steady-state *R* values is required that the wave to pass a distance of at least ten times longer than in Melville experiments. Currently the creation of large experimental facilities for the study of skew run-up solitary waves is problematic computational experiments have become the best solution.

Numerical simulation of oblique run-up was described in [4] Miles received the theoretical dependence by calculations based on a mathematical model. At the same time, is for practical interest the process of roll waves of finite and not infinitely small amplitude. In the absence of reliable experimental data and the theory of skew roll waves of finite amplitude, numerical simulation is the only tool to study this phenomenon. Funakoshi [4] used the finite-difference method for calculating the wave with an amplitude of $a_i = 0.05$, Tanaka [22] $a_i = 0.3$ applied to the spectral method. A large series of calculations in the range of amplitudes $a_i = 0.05$–0.30 carried out complied by Serebrennikova and Frank [19] was based on the discrete model of an incompressible fluid. Given the existing differences of numerical results for some parameter values calculations based on other mathematical models and algorithms should be undertake.

Khakimzyanov G.S. [7, 8] presented the results of calculations in the nonlinear-dispersion model Zheleznyak-Pelinovsky (*NDM*) and three-dimensional models of potential flows from the finite-difference method using a dynamically adaptive grid, and provided a comparison of the results obtained in the calculations of other authors. In numerical solution of the problem curvilinear grid used adapted to the field form, and depending on the solution, so that the concentration of grid nodes increased in areas of the phenomena to be investigated: ridges in the vicinity of the incident and reflected waves, legs, and the *Mach* zone run-up. A fragment of such a grid, lying on the free surface, is shown in Fig. 14. One can see that from the grid tracks the main features of the modeled currents, in particular *Mach* leg.

Fig. 15 shows the dependence of the R/a_i value of values for different $\psi_i \big/ \sqrt{3a_i}$ values of free-wave amplitude (*MPF* – a model of potential flows [8]).

In this paper [13] was obtaining the dependence run up wave of small amplitude at regular reflection:

$$\frac{R}{a_i}=2+a_i\left(\frac{3}{2\sin^2\psi_i}-3+2\sin^2\psi_i\right). \tag{3.2}$$

Fig. 15 contains two curves (3.2): a_i=0.1 (I) *and* a_i=0.5 (II).

Points – calculation results, solid line – theoretical dependence (3.1); bar – the theoretical dependence (3.2) (I – a_i= 0.1; II – a_i = 0.5): a_i= 0.05*:* 1 – [4]; 2 – *MPF;* a_i= 0.1: 3 – *NDM,* 4 – *MPF;* a_i= *0.3:* 5 – [22]; 6 – [19]; 7 – *MPF;* a_i= *0.5:* 8 – *MPF.*

Thus, Fig. 15 shows graphs of theoretical dependence (3.1). We see that at finite values of amplitude a_i the results of the calculations are close the curve (3.1) *Mach* reflection. Fig. 16 shows the chevron form of southern coast of Madagascar.

Conclusions

This paper has given an account of and the reasons for the widespread use of computational experiments in the recent issue of the cosmic impacts of ocean traces. This paper has argued that a computational experiment is the best instrument to research this complex interdisciplinary problem. The purpose of the current investigation was to determine the possibility of computational experiments to refine our understanding of the studied effects. This project was undertaken to design computing technology of numerical data analysis and evaluate the quality of these data to address relevant problems. Returning to the hypothesis posed at the beginning of this research, it is now possible to state that calculations make it possible to disclose material aspects of the physical phenomena.

This investigation has shown that pooling disparate data and computational algorithms helps to solve the tasks more efficiently. These findings suggest that in general the hypothesis adopted at the beginning of the study of recent cosmic impact effects in marine waters is justified. One of the most significant findings to emerge from this study is that it identified a set of computational techniques that allow most effectively. It also showed that the present computational technology it is important to integrate in a single computational experiment. This research has found that on the whole iterative procedures, computational experiment provided the necessary evidence and the validity of obtained solutions.

The most obvious finding to emerge from this study is that in this problem there is a set of interconnected data, which allows answering the fundamental question of the space object of the origin. Multiple regression analysis revealed that the form of dune-chevron reflect not only the relief of the coast line, but the bathymetry offshore.

The evidence from this study suggests that the results of numerical simulations do not contradict the empirical data. The results of this study indicate that the hydrodynamic models are consistent with the geomorphologic data. The results of this research support the idea that outer impact marine water was most probable cause of a research of natural phenomena. Taken together, these results suggest that hypothesis on the significant prevalence of recent cosmic impact of marine influences is much unsubstantiated.

The computational experiment that we have identified therefore assists in our understanding of the role of simulation in solving the problem. This research will serve as a base for future investigations and introduce a new productive hypothesis on this issue. The current findings add substantially to our understanding of the physical nature of the phenomenon. The research has gone

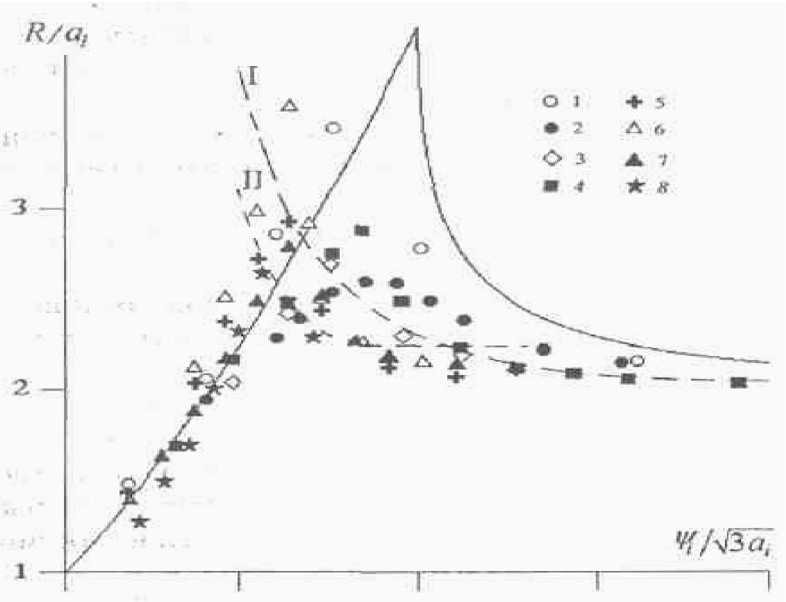


Fig. 15. The dependence runs up wave $R/a_i$from $y_i/\sqrt{3a_i}$ [8]

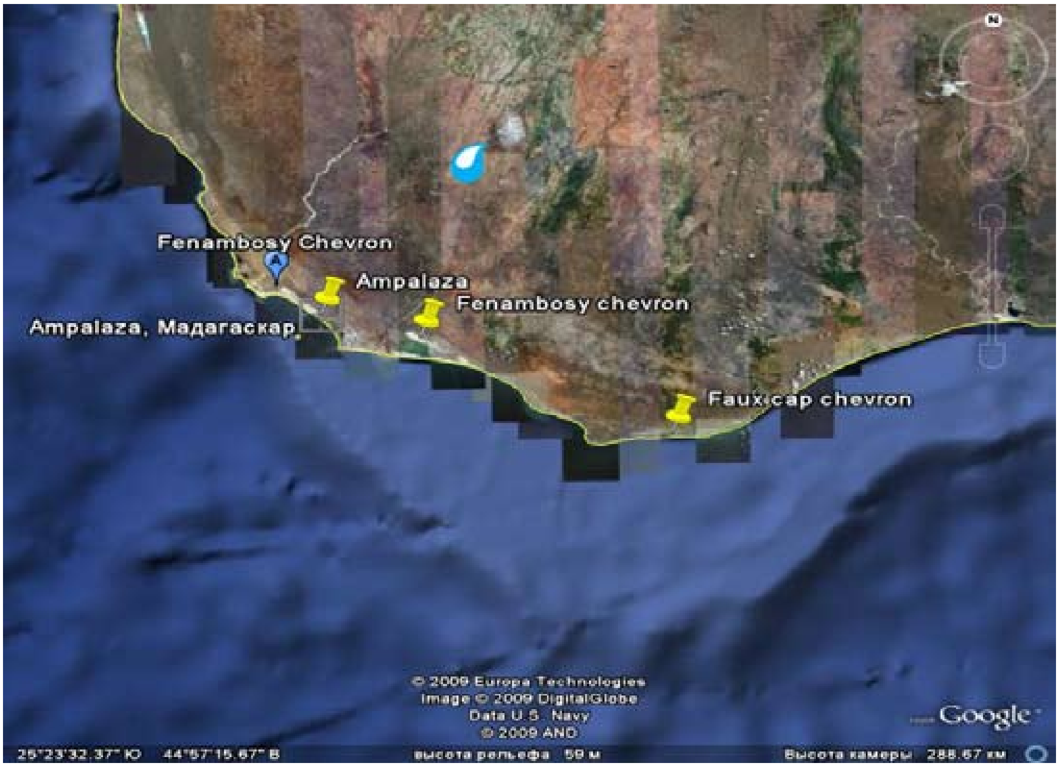


Fig. 16. Chevron forms of southern coast of Madagascar

some way towards enhancing our understanding of the overall relationship of the investigated sites. The methods used for this object may be applied to other similar elsewhere in the world. Taken together, these findings suggest a role for our methodology in promoting solution to this pressing problem.

Finally, a number of important limitations need to be considered. The most significant limitation lies in the fact, that important data are fragmented and characterized by a qualitative description. Therefore, the current study was limited to individual objects, the data on which enables the main stages of the computational experiment. Note that the current study was not specifically designed to evaluate factors related to geochronology and computer data processing, analysis, obtained with the help of a microscope. Therefore, with a small sample number, caution must be applied, as the findings might not be transferable to other unique objects.

Of course, this research has thrown up many questions in need of further investigation. Further work needs to be done to establish whether the model obtained is adequate for use in justifying the basic concepts in the problem of the recent cosmic impact space traces. The further research is recommended to be undertaken in the following areas: building models related to the recent variability of the climate, the creation of an expert database of forms and parameters of chevron in various maritime areas, the adaptation of the hydrodynamic models megatsunami of run-ups for specific coastal areas, collection and systematization of manifestations of the recent cosmic catastrophes.

Further experimental investigations are needed to estimate constructed hydrodynamic and statistical models. More broadly, a new research is also necessary to determine the reliability of the assumptions made and the hypotheses, as well as their adequate justification. It is suggested that the association of these factors is investigated in future studies. Further research can explore more detailed and subtle effects of the studied phenomenon. Further research in this field regarding the role of the computational experiment would be of great help in numerical processing and the rationale for experimental studies. Note also that more information on marine space impact trace would help us to establish a greater degree of accuracy on matter of the nature of the studied processes. It would be interesting to assess the effects of (damage) of the new catastrophic event that would occur, for example, in the vicinity of the Burkle crater with characteristics close to the site.

These findings suggest several courses of action for the development of technologies of computational experiment to study the issue of the recent cosmic impact ocean traces. However, the findings of this study have a number of important implications for future practice of searching these traces, their systematization and the creation of an expert database dune-chevron is constriction. At the same time, there is a number of important changes to be made to enhance the opportunities of mathematical modeling of the phenomenon and the numerical analysis. Another important practical implication is that the results of numerical experiments can be used and compared with the new data to be received during the field work. This information can be used to develop targeted interventions aimed at building a new physical and mathematical model of the studied phenomenon. Our work here is just the first step in this endeavor.

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References

1. Astafieva N.M. Wavelet analysis: basic theory and examples of the application / N.M. Astafieva // Uspekhi Fizicheskikh Nauk, 1998. – V. 166. – № 11. – P. 1145-1170. (in Russian)

2. Bobrowsky P. Comet / P. Bobrowsky, H. Rickman // Asteroid Impacts and Human Society. Springer Press, Berlin, 2007.

3. Bryant E. Tsunami: The Underrated Hazard / E. Bryant // Cambridge University Press, Cambridge, 2001.

4. Funakoshi M. Reflexion of obliquely incident solitary waves / M. Funakoshi // J. of Phys. Soci. of Japan. – 1980. – V. 49, № 6. – P. 2371-2379.

5. Gusiakov V.K. Tsunami as a Destructive Aftermath of Oceanic Impacts / V.K. Gusiakov // In: P. Bobrowsky, H. Rickman (eds.) – Asteroid / Comet Impacts and Human Society. Springer Press. Berlin. – 2007. – P. 247-263.

6. Gusiakov V.K. Mega Tsunami of the World Ocean: Chevron Dune Formation, Micro-Ejecta and Rapid Climate Change as the Evidence of Recent Oceanic Bolides Impacts / V.K. Gusiakov, D.H. Abbott, E.A. Bryant, W.B. Masse // in Beer, T., ed., Geophysical Hazards: Minimizing risk, maximizing awareness: Berlin / New York, Springer, 2009 (in press).

7. Khakimzyanov G.S. Numerical simulation of oblique interaction of solitary waves with a vertical wall / G.S. Khakimzyanov // Simulation of the mechanics. – Novosibirsk, 1992. – T. 6 (23). – № 1. – P. 141-146. (in Russian)

8. Khakimzyanov G.S. Numerical simulation of fluid flows with surface waves / G.S. Khakimzyanov, Y.I. Shokin, V.B. Barakhnin, N. Shokina // Novosibirsk, 2001. (in Russian)

9. Marchuk An.G. The possible impact craters discovering on the Earth surface using the DEM data processing / An.G. Marchuk, K.V. Simonov // Bulletin of the Novosibirsk Computing Center. Series: Mathematical Problems in Geophysics. Issue 10. – 2005. – P. 59-69.

10. Marchuk An.G. Detection of possible impact craters using the digital elevation data processing / An.G. Marchuk, K.V. Simonov, S.A. Peretokin // Materials of the All-Russian conference «asteroid-comet danger-2005». – St-Petersburg: Institute of Applied Astronomy, Russian Academy of Sciences, 2005. – P. 241-244.

11. Masse W.B. The Archaeology and Anthropology of Quaternary Period Cosmic Impact / W.B. Masse // In: P. Bobrowsky, H. Rickman (eds.) – Asteroid / Comet Impacts and Human Society. Springer Press. Berlin. – 2007. – P. 25-70.

12. Melville W.K. On the Mach reflexion of a solitary wave / W.K. Melville // J. Fluid Mech. – 1980. – V. 98, part 2. – P.285-297.

13. Miles J.W. Resonantly interacting solitary waves / J.W. Miles // J. Fluid Mech. – 1977 a. – V. 79, part 1. – P. 171-179.

14. Miles J.W. Obliquely interacting solitary waves / J.W. Miles // J. Fluid Mech.–1977 b. – V. 79.–P. 157-169.

15. Palmer R.Q. Hilo harbor tsunami model-reflected waves superimposed / R.Q. Palmer, M.E. Mulvihill, G.T. Funasaki // Proc. 10th Conf. Coastal Eng. Am. Soc. Civ. Eng., 1965. – P. 21-31.

16. Perraud P.H. The solitary wave reflection along a straight vertical wall at oblique incidence / P.H. Perraud // – PhD thes. Univ. Calif., Berkeley, 1957.

17. Samarsky A.A., Vabishevich P.N. Mathematical modeling and numerical experiment / A.A. Samarsky, P.N. Vabishevich // – 2000 (http // www.imamod.ru / publication).

18. Samarsky A.A., Mikhailov A.P. Mathematical modeling. Ideas. Methods. Examples / A.A. Samarsky, A.P. Mikhailov // – M.: Fizmatlit, 2001. – 320 pp. (in Russian)

19. Serebrennikova O.A. Numerical simulation of Mach reflection of solitary waves / O.A. Serebrennikova, A.M. Frank // PMTF. – 1993. – № 5. – P. 15-24. (in Russia)

20. Scheffers A. Chevron-shaped accumulations along the coastlines of Australia as potential tsunami evidences? / A. Scheffers, D. Kelletat // Science of Tsunami Hazards. – 2003. – Vol. 21. – No. 3. – P. 174-188.

21. Shokin Y.I. Computational experiment in the problem of modeling and risk assessment of natural disasters / Y.I. Shokin, L.B. Chubarov, K.V. Simonov, Z.I. Fedotova // Computational Technologies. – 2004. – Vol. 9. – Part 4. – P. 335-345. (in Russian)

22. Tanaka M. Mach reflection of a large-amplitude solitary wave / M. Tanaka // J. Fluid Mech. – 1993. – V. 248. – P. 637-661.

23. Wiegel R.L. Oceanographical engineering / R.L. Wiegel // New Jersey: Englewood Cliffs, Prentice-Hall, 1964. – 532 p.

24. Zakharov A.V. Some approaches to solving the approximation tasks in geomonitoring data interpretation / A.V. Zakharov, K.V. Simonov, S.A. Peretokin // Proceedings of the International Conference of ICCM-2004 – Novosibirsk: SB RAS ICM&MG, 2004 – P. 110-115.

Вычислительный эксперимент в проблеме недавних следов космических океанских воздействий

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Статья призвана заполнить пробел между геологическими изысканиями по проблеме недавних следов космических океанских воздействий и возможностями вычислительного эксперимента по проблеме геологических следов цунами. Вычислительный эксперимент и численный анализ данных о последствиях воздействий комет на океан могут быть более эффективными для понимания и прогнозирования мегацунами, чем традиционные геологические методы. Мы анализировали следы отложений от крупномасштабных воздействий воды на побережье и моделирование мегацунами с учетом крутизны волны и отражения Маха на скалистом берегу, а также описание формы дюн-шевронов на основе нейросетевой технологии для решения обратной задачи цунами. Импактные кратеры в океане были изучены с использованием вейвлет-анализа цифровых данных океанского дна.

Ключевые слова: океанский импактный кратер, геологические проблемы цунами, мегацунами, дюны-шевроны, отложения следов, вычислительный эксперимент, технология нейронных сетей, вейвлет-анализ.