Journal of Computational and Applied Mathematics 259 (2014) 887–896

Contents lists available at ScienceDirect

Journal of Computational and Applied Mathematics

journal homepage: www.elsevier.com/locate/cam

# Numerical simulation of tsunami wave height distribution for Turkish Black Sea coast in nonlinear dynamic keyboard model of underwater seismic source

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ARTICLE INFO

*Article history:*
Received 15 February 2013
Received in revised form 4 August 2013

*Keywords:*
Tsunami
Earthquake
Keyboard model

ABSTRACT

In frames of nonlinear shallow water equations taking into account dissipative effects and bottom friction a numerical simulation of a possible catastrophic tsunami in the Black Sea basin is performed. The computation was performed for seismic sources with various locations in the south-eastern and north-western parts of the Black Sea basin. The location of model sources was selected taking into account more seismoactive zones and proposed recurrence periods of tsunamis for a given region. A seismic source was constructed in frames of a keyboard model of the earthquake source taking into account possible temporal and velocity characteristics of seismic processes in a concrete source. Using a keyboard model of the source, both kinematic and dynamic models of earthquake sources were considered. The keyboard model of an earthquake source with different-time motions of keyboard blocks permits considering various scenarios of processes possible at earthquakes in seismic sources and estimating the influence of these processes on the distribution of maximum wave heights along the coast. Two scenarios for each seismic source were considered: a dynamical model, when the source is divided into keyboard blocks which are shifted in the vertical direction for different times and a single block moving according to certain laws describing unloading in the seismic source on the realization of an earthquake. For each of the scenarios considered, wave characteristics were obtained and a spectral analysis was performed which permits clearing the most dangerous places of the coast for moderate or strong tsunamigenic earthquakes.



## 1. Introduction

The numerical simulation of a tsunami in the Black Sea basin, including an evaluation of tsunami and seismic danger of the coast (see, e.g. [1–11]), is an actual problem of the last decade. The high industrial potential of various parts of the region (large seaports, gas- and oil-pipeline terminals, dense population, the presence of large health-resort zones) determines the importance of this problem. The actuality of such computations is connected, in particular, with the problem of the exploitation of the sea part of the Russia–Turkey gas-pipeline (the "Blue Stream" project), connecting territories of these countries on the Black Sea bottom, which operates in conditions of high seismicity and landslide danger of the Russian and Turkish slopes of the Black Sea [12–18].

Since the real dynamics of underwater seismic sources is complicated enough, then for the numerical simulation of surface water waves the corresponding movements in the source are usually re-counted to a vertical shift of blocks (up and down). Such an approach gives the possibility of adequate simulation of a tsunami in frames of a keyboard model of an underwater seismic source, (see, e.g. [17,19,20]).

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http://dx.doi.org/10.1016/j.cam.2013.08.034

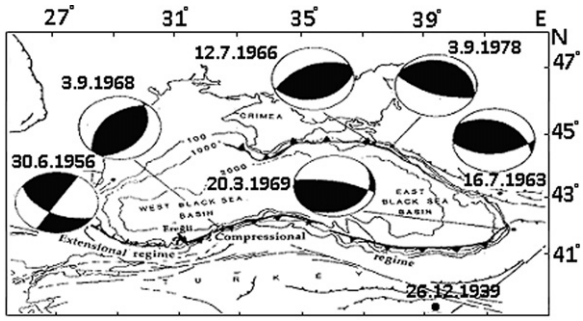


**Fig. 1.** Focal mechanisms of some last-century strong earthquakes in the Black Sea region, most of which generated tsunamis. Bottom displacement orientation: black or white colors correspond to downward or upward movements in the source, respectively (after [17]).

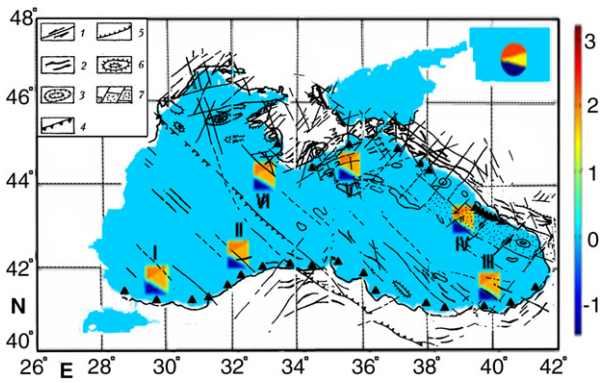


**Fig. 2.** The computation zone of the Black Sea basin; numbers I–VI correspond to locations of model seismic sources (right inset: elliptical form of source, see text); points 1–30 correspond to the location of virtual tide gauges (marked by triangles). The scheme of the location of main geostructures at sections of the Crimean and Caucasian coasts of the Black Sea (left inset: 1 - fault–shear; 2 - fault–uplift; 3 - regional axes of folders; 4 - folders–outcomes; 5 - folders–troughs; 6 - blocks of the Georgian middle massif; 7 - edge faults of Eastern-European and the Arabian–Nubian platform (Zagros fault)) (after [21,22]).

The principal feature of the study, performed in this work, is connected with the generation of tsunami waves by a kinematic seismic source, considered in frames of a keyboard model of an earthquake (see, e.g. [19]). The location of model sources was selected taking into account most seismoactive zones in the southern and north-eastern parts of the Black Sea Depression and proposed tsunami recurrence periods for the given region (see Figs. 1, 2). By using a keyboard model of source, both kinematic and dynamic models of earthquake sources were considered. The keyboard model of an earthquake source with different-time movements of keyboard blocks permits us to consider various scenarios of processes, possible in the seismic source during an earthquake and to evaluate the influence of these processes on the formation of a tsunami source, the generation of tsunami waves, their propagation in the basin and to then perform an evaluation of the maximum wave height distribution along concrete parts of the coast.

## 2. The statement of the problem

The principal distinction of research performed in the given work is connected with the generation of tsunami waves as a long-term process rather than an instant one. The generation of a tsunami wave by a kinematical source is considered, in frames of a keyboard model of the earthquake source [19]. As it is noted in the work [18], conventional numerical tsunami models take into account only geometric characteristics of the source, i.e. the spatial distribution of residual bottom displacements. Then, in the work [2] it was emphasized that "For tsunami wave prognosis it is important the circumstance that amplitude characteristics are essentially dependent on type of seismoactive movements, shape of tsunami source and residual bottom displacement distribution. These points for earthquakes of the Black Sea Trough are studied not enough". In contrast to "piston" models (instant movements), the keyboard model (kinematical and dynamic models) permits, for the same earthquake magnitude, obtaining a different character of directivity of tsunami waves, that principally gives different wave height distributions along the coast, depending on the scenario of the development of the seismic process in the earthquake source. The principal distinction of the given method of computations of tsunami wave generation by a seismic source using shallow water nonlinear equations taking into account dissipative effects is in the introduction of a dynamical bottom function $B(x, y, t)$ instead of a static one. This function permits us to take into account the duration of the seismic process in an earthquake source and temporal bottom displacements which in their turn are re-calculated to the water