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Integrated Tsunami Database: simulation and identification of seismic tsunami sources, 3D visualization and post-disaster assessment on the shore

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One of the most important problems of tsunami investigation is the problem of seismic tsunami source reconstruction. Non-profit organization WAPMERR (http://wapmerr.org) has provided a historical database of alleged tsunami sources around the world that obtained with the help of information about seaquakes. WAPMERR also has a database of observations of the tsunami waves in coastal areas. The main idea of presentation consists of determining of the tsunami source parameters using seismic data and observations of the tsunami waves on the shore, and the expansion and refinement of the database of presupposed tsunami sources for operative and accurate prediction of hazards and assessment of risks and consequences. Also we present 3D visualization of real-time tsunami wave propagation and loss assessment, characterizing the nature of the building stock in cities at risk, and monitoring by satellite images using modern GIS technology ITRIS (Integrated Tsunami Research and Information System) developed by WAPMERR and Informap Ltd. The special scientific plug-in components are embedded in a specially developed GIS-type graphic shell for easy data retrieval, visualization and processing.

The most suitable physical models related to simulation of tsunamis are based on shallow water equations. We consider the initial-boundary value problem in $\Omega := \left\{(x,y) \in \mathrm{R}^2 :\ x \in (0,L_x),\, y \in (0,L_y),\ L_x, L_y > 0\right\}$ for the well-known linear shallow water equations in the Cartesian coordinate system in terms of the liquid flow components in dimensional form

$$\left\{\begin{array}{l} L\eta := \eta_{tt} - div(c^2(x,y)\, grad\, \eta) = 0, \qquad (x,y,t) \in \Omega_T; \\ \eta(x,y,t)|_{t=0} = q(x,y), \quad \eta_t(x,y,t)|_{t=0} = 0, \quad (x,y) \in \Omega; \\ \eta_t - c(x,y)\eta_x = 0, \quad (x,y,t) \in \Gamma_1 := \left\{(x,y,t) \in \Gamma_T :\, x = 0\right\}; \\ \eta_t + c(x,y)\eta_x = 0, \quad (x,y,t) \in \Gamma_2 := \left\{(x,y,t) \in \Gamma_T :\, x = L_x\right\}; \\ \eta_t - c(x,y)\eta_y = 0, \quad (x,y,t) \in \Gamma_3 := \left\{(x,y,t) \in \Gamma_T :\, y = 0\right\}; \\ \eta_t + c(x,y)\eta_y = 0, \quad (x,y,t) \in \Gamma_4 := \left\{(x,y,t) \in \Gamma_T :\, y = L_y\right\}. \end{array}\right. \tag{1}$$

Here $\eta(x,y,t)$ defines the free water surface vertical displacement, i.e. amplitude of a tsunami wave, $q(x,y)$ is the initial amplitude of a tsunami wave. The lateral boundary is assumed to be a non-reflecting boundary of the domain, that is, it allows the free passage of the propagating waves.

Assume that the free surface oscillation data at points (x_m, y_m) are given as a measured output data from tsunami records:

$$f_m(t) := \eta\left(x_m, y_m, t\right), \quad (x_m, y_m) \in \Omega,\ t \in (T_{m_1}, T_{m_2}),\ m = 1,2,...,M,\ M \in \mathrm{N} \tag{2}$$

The problem of tsunami source reconstruction *(inverse tsunami problem)* consists of determining the unknown initial perturbation $q(x,y)$ of the free surface defied in (1) from knowledge of the free surface oscillation data $f_m(t)$ given by (2).

We present a numerical method to determine the tsunami source using measurements of the height of a passing tsunami wave. Proposed approach based on the weak solution theory for hyperbolic PDEs and adjoint problem method for minimization of the corresponding cost functional

$$J(q) = \|Aq - F\|^2, \ \ F = (f_1, ..., f_M)\,. \tag{3}$$

The adjoint problem is defined to obtain an explicit gradient formula for the cost functional (3). Different numerical algorithms (finite-difference approach and finite volume method) are proposed for the direct as well as adjoint problem. Conjugate gradient algorithm based on explicit gradient formula is used for numerical solution of the inverse problem (1)-(2).

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