Towards a **meteotsunami** warning system along the U.S. coastline. (TMEWS)

Numerical modeling of the generation of the bay oscillation by moving atmospheric disturbances at Boothbay area of Gulf of Maine.

Isaak Fain,

Sidney, BC, Canada, 2012

1. Introduction.

The goals of the current research are

1) to prove that the pressure disturbances of the such amplitudes can cause so big amplification on the coast (suppose to be a positive the answer)
2) To check is this event was really amplified by some specific factors like specific speed or direction of the disturbances or this is just nothing specific (suppose to say that the first is true because the event looks like really unique (nobody mentioned this before 2008).

2. Bathymetry.

The quality of the bathymetry is crucial for the modeling. Currently, the major source for the local bathymetry is NGDC's 3 arc-second U.S. Coastal Relief Model (CRM) provides the first comprehensive view of the U.S. coastal zone, integrating offshore bathymetry with land topography into a seamless representation of the coast [1]. For the illustrative purposes we used also GEBCO 30-arc second global relief [2].

Generally, the area is of very complicated land intersected by numerous passes and channels. In addition, the Gulf of Maine is characterized by extremely high semi-diurnal tide which can provide wetting and drying of some passes depending on the tidal phase.

The Figure 2 shows computational domain, which contains 909121 nodes, The spatial step is 3 arc second in both meridianal and zonal directions, or 66 m to 90 m.

The Figure 3 shows a central part of the domain, the major area of interest. Overlapping bathymetry with Google map demonstrates generally good agreement, though there are some inconsistencies. For example, the bathymetric map shows that the Boothbay Harbor doesn’t connect to Townsend Gut located to the west, while Google map shows they are connected by a wide pass. Probably, it is not the only problematic place.

3.The model.

We consider linear shallow water equations which, despite simplicity, provides most of the meteotsunami features. The system of the 2D equations can be written as:

$$\begin{aligned}\frac{\partial U}{\partial t} &= -\frac{b}{h}U - gh\frac{\partial \eta}{\partial x},\\ \frac{\partial V}{\partial t} &= -\frac{b}{h}V - gh\frac{\partial \eta}{\partial y},\\ \frac{\partial \eta}{\partial t} &= -\frac{\partial hU}{\partial x} - \frac{\partial hV}{\partial y} + \frac{\partial \zeta_A}{\partial t}.\end{aligned} \qquad \textbf{(1)}$$

where *U, V* are depth-integrated momentum in *x* and *y* directions, *h(x,y)* is the depth, *g* is gravity acceleration, η is sea level reduced by inverse barometer, ζ_A is pressure disturbance (in water column height unit), and *b* is a linear friction coefficient.

(1) can be solved numerically by using finite-difference method on Arakawa C-grid.

4. Results

Because the high-frequency pressure observations are not available, our goal here is to estimate the possible theoretical impact of the moving pressure disturbances on the sea-level oscillation at Boothbay Harbor, and check how the ocean response depends on the parameters of the disturbances (shape, duration, direction, speed etc).

Case 1. Pressure disturbance shape is step-like function

$$\zeta_A = \frac{a}{\pi}\left[\arctan\left(\frac{t - x/c - t_0}{\tau}\right) + \pi/2\right] \quad (2)$$

We will consider the duration parameter τ is equal to 180 s (case 1a) or equal to the 90s (case 1b). The equation (2) is written for the 1D propagation, the same was used for the 2D propagation, in that case x is the coordinate in propagating direction and the along-front distribution of the pressure assumed uniform,

The simulated meteotsunami records for the case 1a (τ=180s) , northern direction and c=27 m/s shows on the Figure 4.
The highest wave was in Boothbay Harbor (point 4) and neighbour Linekin Bay, located to the east (point 5). In both locations the wave amplitude was more than 35 cm, i.e. in 12 times more that the pressure jump value (3 cm). At other locations the wave was lower, even between two harbors (point 6, about 11 cm).

The simulated meteotsunami records for the case 1b (τ=90s) , northern direction and c=27 m/s shows on the Figure 5. The amplitude of the wave in this case was ~ 10-20% higher than that for the case 1a, but, generally, the results are very close: and character of the oscillations is the same.

Figures 6 and 7 shows results of the many calculations for the different propagation speed and direction for the cases 1a and 1b. For each case components of the phase velocity vectors were changed from 3 to 33 m/s (northern direction, step of 3 m/s) and from -30 m/s to 30 m/s in western-eastern direction, with step of 3 m/s), totally 231 runs.

Figure 6,a shows map of the maximum of the sea elevation in phase speed plane for the case 1a at the point 3, located at the entrance of the Bays at deep water. The general amplification is not high, about 2-3times, and maximum occurred when the disturbance propagate from the east-south to the west-north with speed about 30 m/s. Figure 6,b, shows the amplification at the Boothbay Harbor (point 4) shows much higher amplification, up to 13 (wave amplitude up to 40 cm). Almost the same we see at the point 5, located in the Linekin Bay. In all cases the maximum of the amplification corresponded to the propagating speed about 27-30 m/s and north-western direction.

Figure 7 (1bcase) shows very close to the previous case 1b results at all locations. The only difference is slightly (10-25%) increase in the response.

Case 2.

In this case we used bell-like shape of the pressure disturbance or the next function:

$$\zeta_A = \begin{cases} \dfrac{a}{2}\left[\cos\left(2\pi\dfrac{t - x/c - t_0}{\tau}\right) + 1\right], & |t/\tau| < 0.5 \\ 0, & |t/\tau| >= 0.5 \end{cases} \quad (3)$$

Figure 8 shows the simulated records at the stations 1-7 for the case2 for the same condition as for the case 1. The parameter τ was 360 s. Records show higher amplitudes and more high frequency energy in comparison to that for the case 1a and case 1b. Typical wave periods goes down to 10-12 min (which is understandable because the time-derivative of the forced function (3) has maximum spectra at 12 min period). Again, at the stations 4 and 5, located at the Boothbay Harbor and Linekin Bay, the waves are biggest, the maximum of the wave highest reached 1m. at both locations.

Figure 9 shows map in the phase speed coordinates, which demonstrate basically the same effect was already seen at the Figures 6-7 maximum of the amplification occurred at phase speed 27-30 m/s and north-western direction. The amplification for the case 2 higher than at the case 1, especially at the bay heads (figure 9,b,c) where the wave amplitude reached 90 cm.

5. Conclusion.

The results, in my opinion, can shed some light on the Boothbay event.
Firstly, though the modelled amplitudes are still less than observed, there many other factors which we didn't take into accounts so, it is possible that the such big waves was cheated just by moving atmospheric disturbances as it happened in the Mediterranean areas. Examples of such effects may include train of waves (instead of the single wave) or additional amplification in near-shore area (which was missed because of the numerical modeling requirements).
Secondary, it is clear that the maximum of the amplification was for the parameters of the pressure movement actually occurred. And if 27-30 m/s of the pressure phase speed, probably, more or less typical for many area, it can be concluded that the north-western direction of the disturbances, which is the most dangerous and which was actually also occurred, is quite seldom for such place. That is why such events are so seldom and unusual for this specific location.

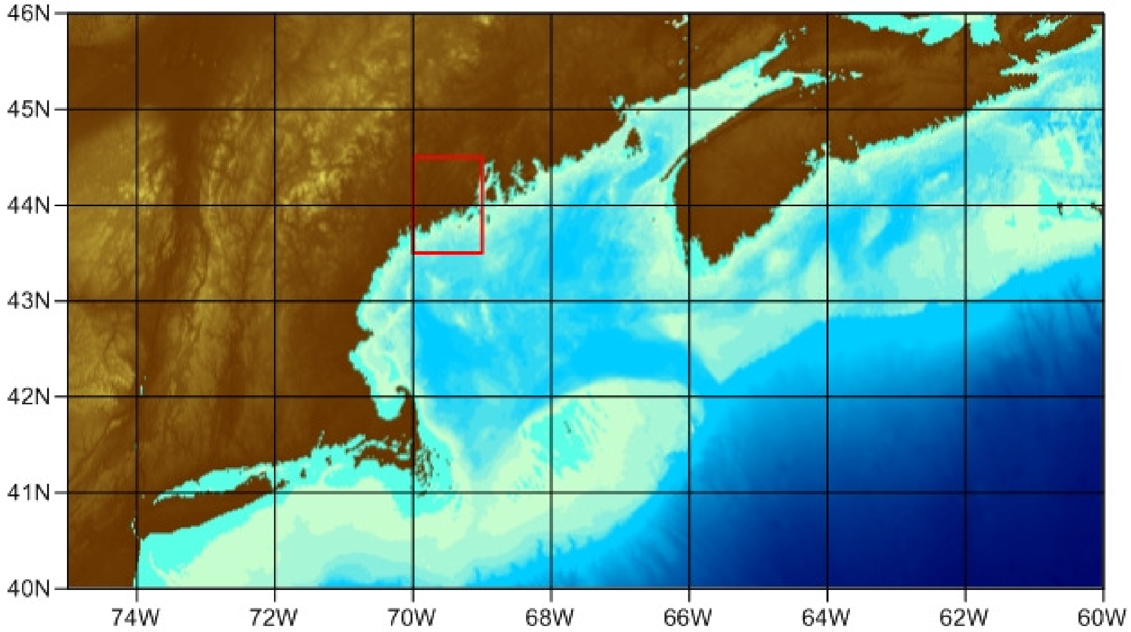

Figure 1 Bathymetry at North-East of the US and Canada based on GEBCO [2] dataset. Shown the modeled domain area at the Gulf of Maine coast .

-

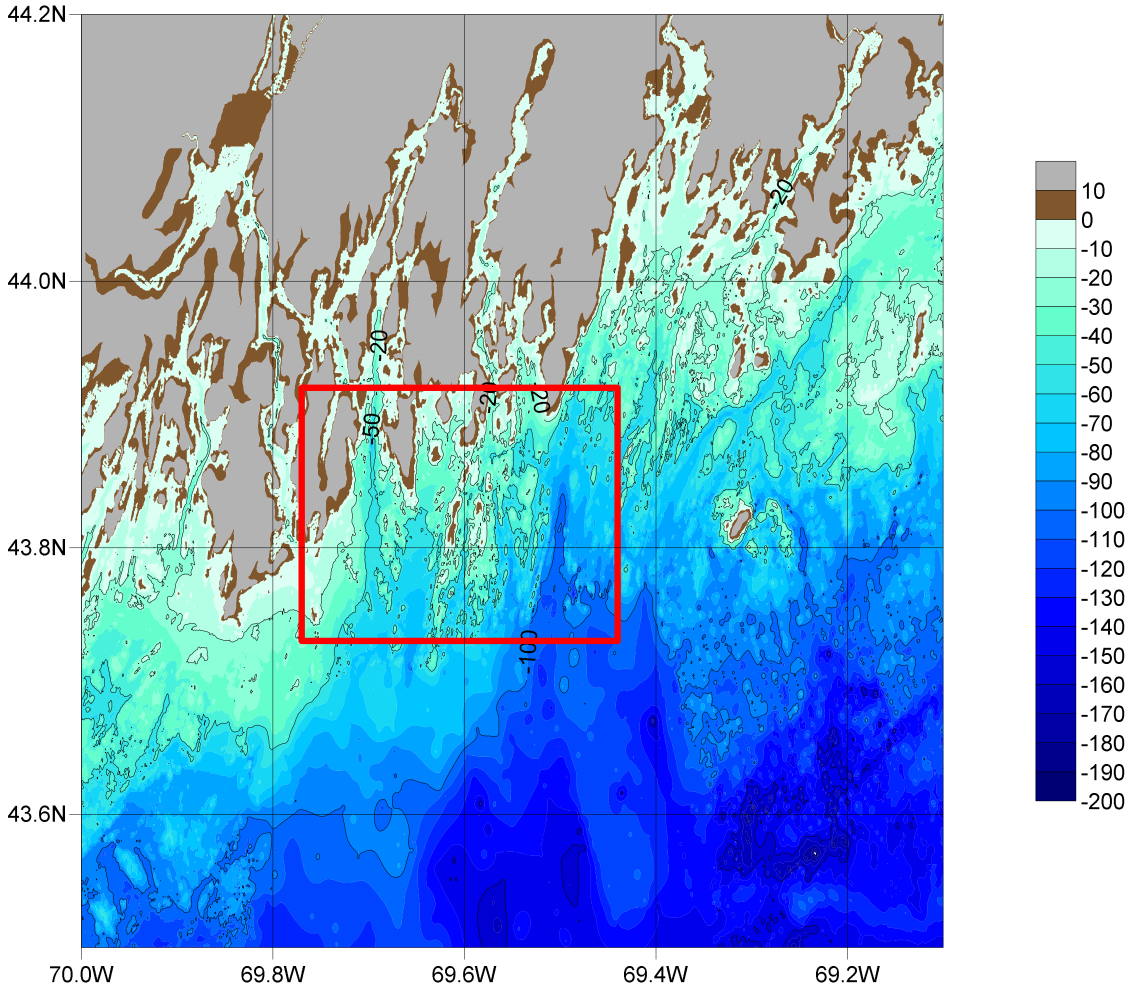

Figure 2. Bathymetry in the vicinity of the Boothbay (part of the coast of Gulf of Maine) based on the CRM relief [1] which was used in the modeling (see Figure 1 for location of the grid). The grid size of the domain is 1081 x 841 =909 121 points. Red rectangle shows a central part of the domain.

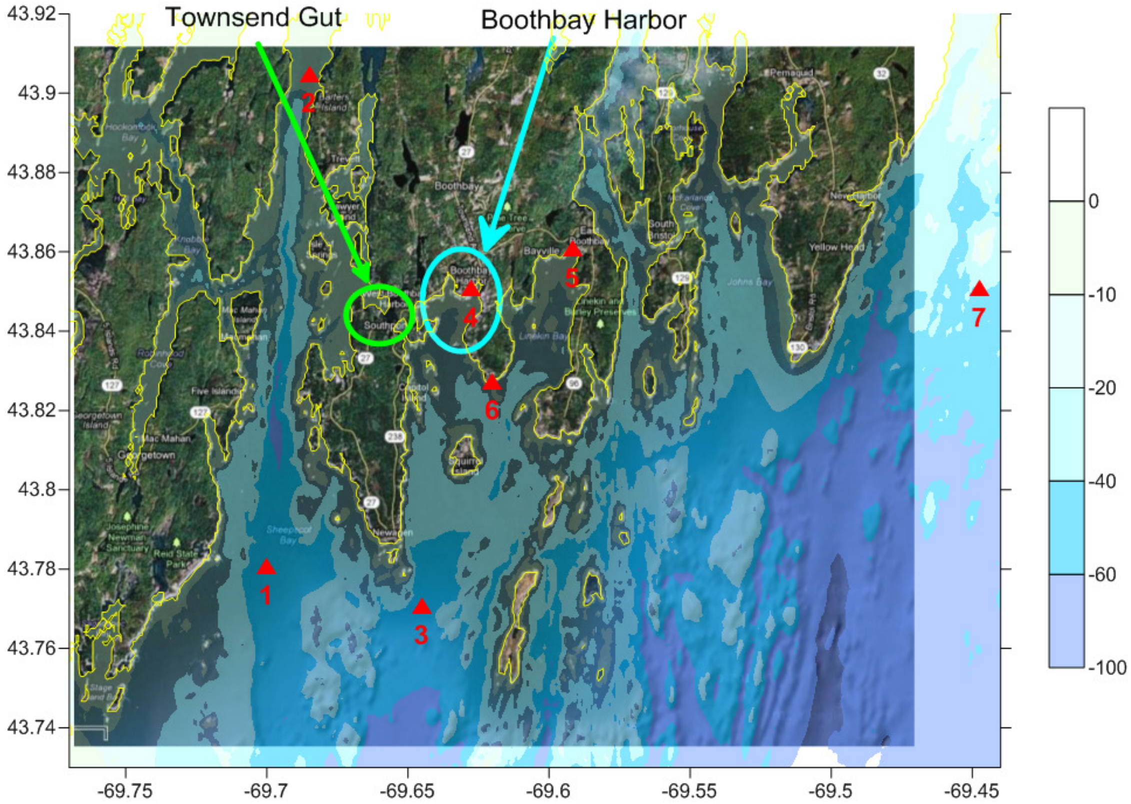

Figure 3. Central part of the domain overlapped by Google map.

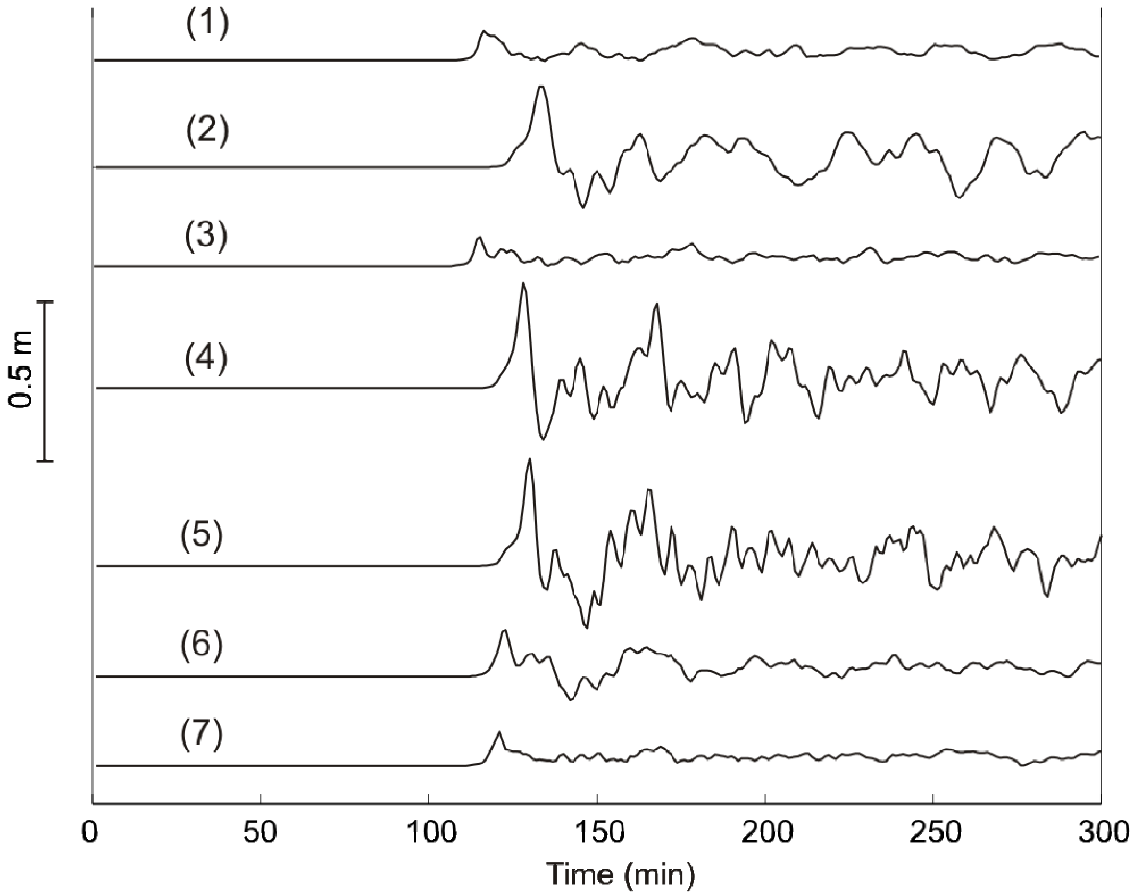

Figure 4. Simulated sea level records at the points 1-7 for the case cx=0 m/s, cy=27 m/s. Duration parameter is 180 sec, Δp=3mb

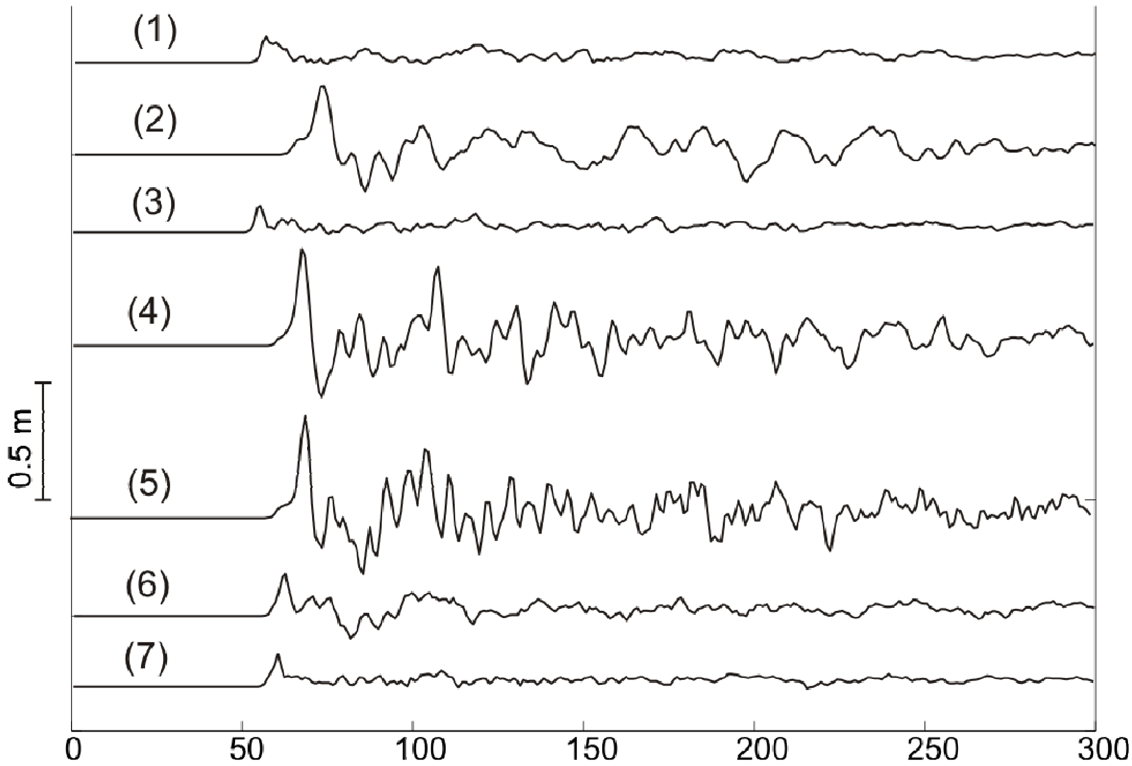

Figure 5. The same as at the Figure 4 for the duration parameter is 90 sec.

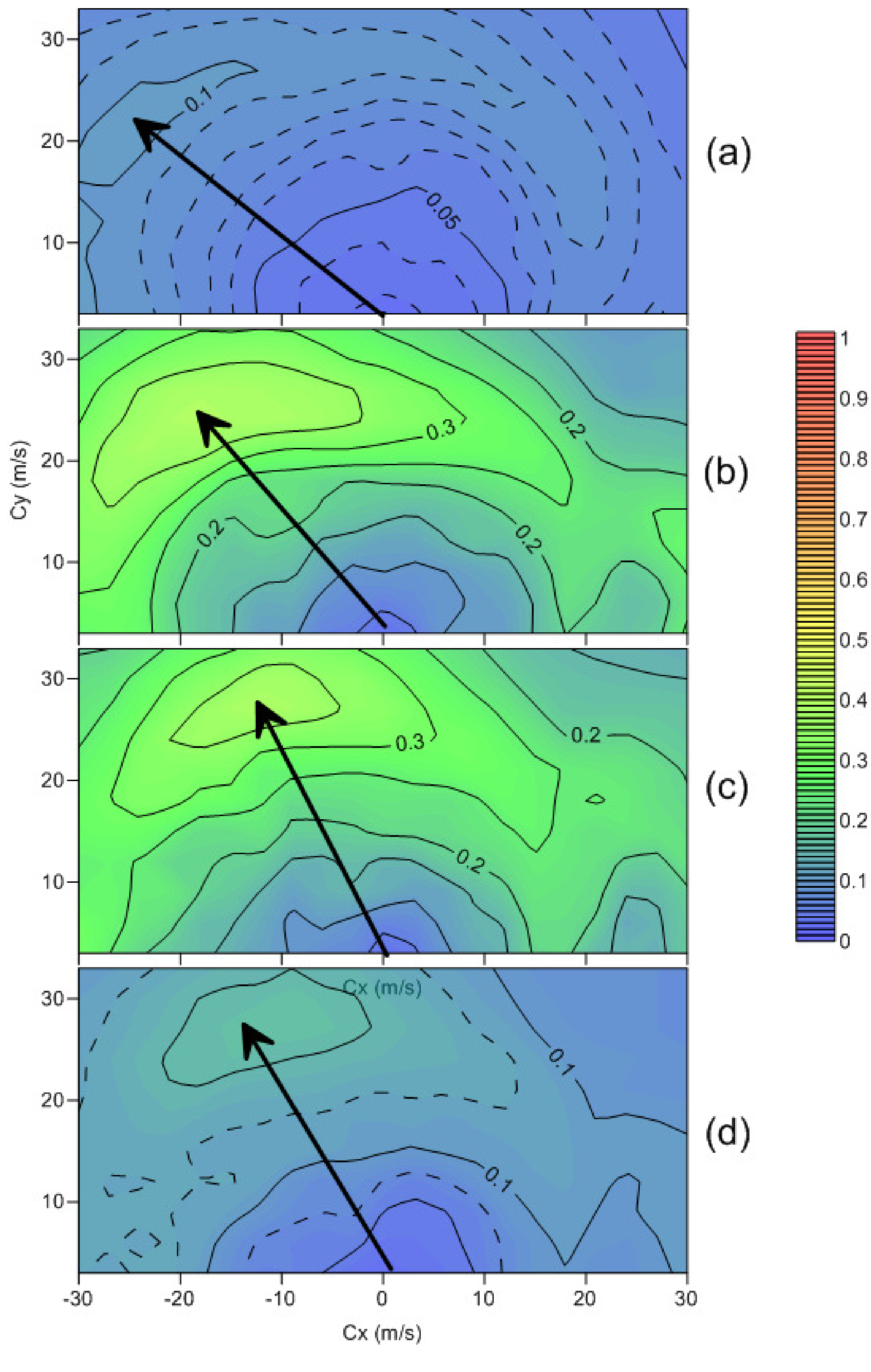

Figure 6. Map of maximum of the sea level elevation at the station 3(a), station 4 (b), station 5 (c) and station 6 (d) for the different speeds of the step-like pressure disturbance propagation. The duration of the step-like disturbance of 3 mb is 180 sec, See figure 3 for the station location.

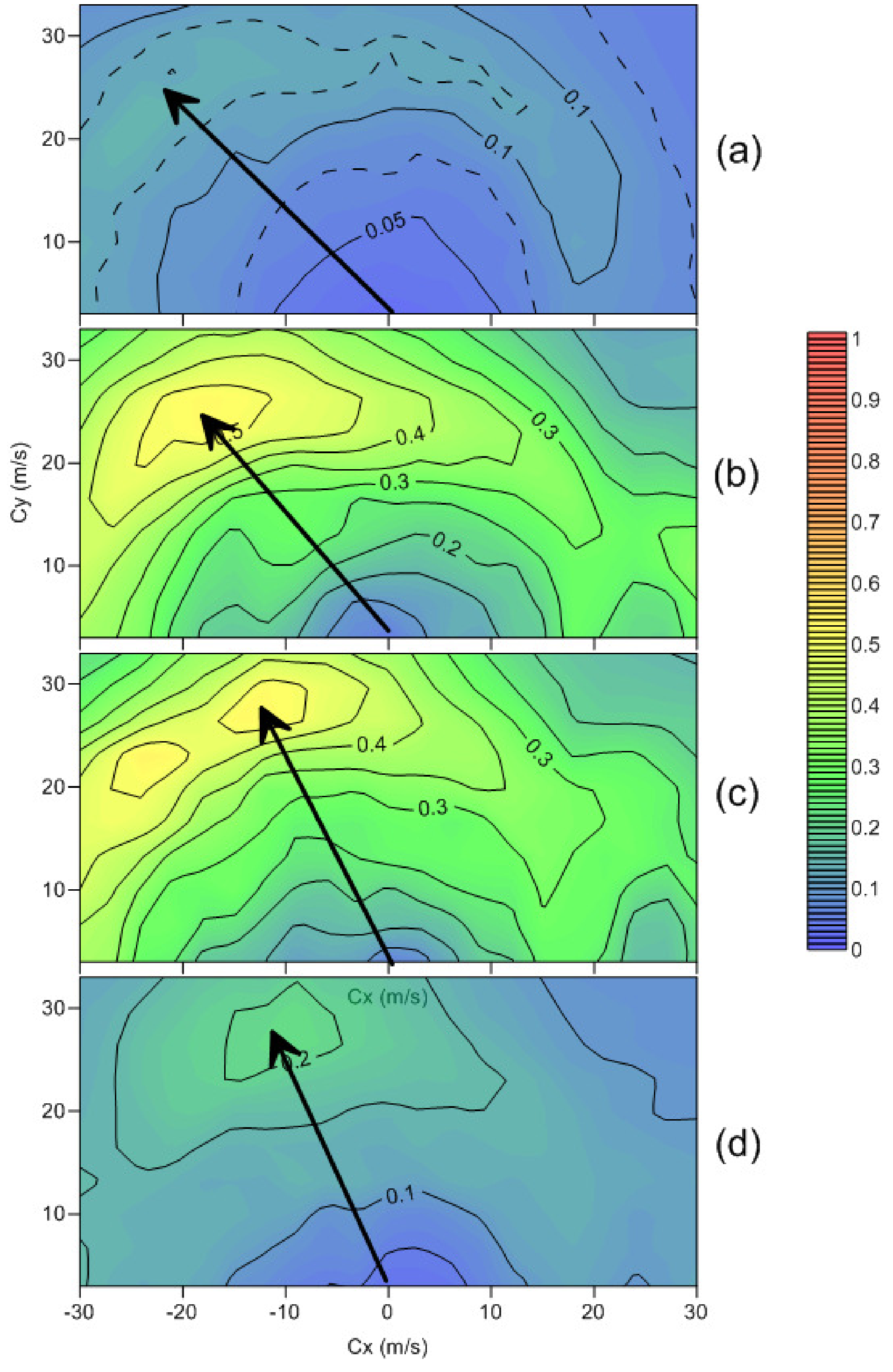

Figure 7. The same as on the figure 6 for the pressure jump duration of 90 sec.

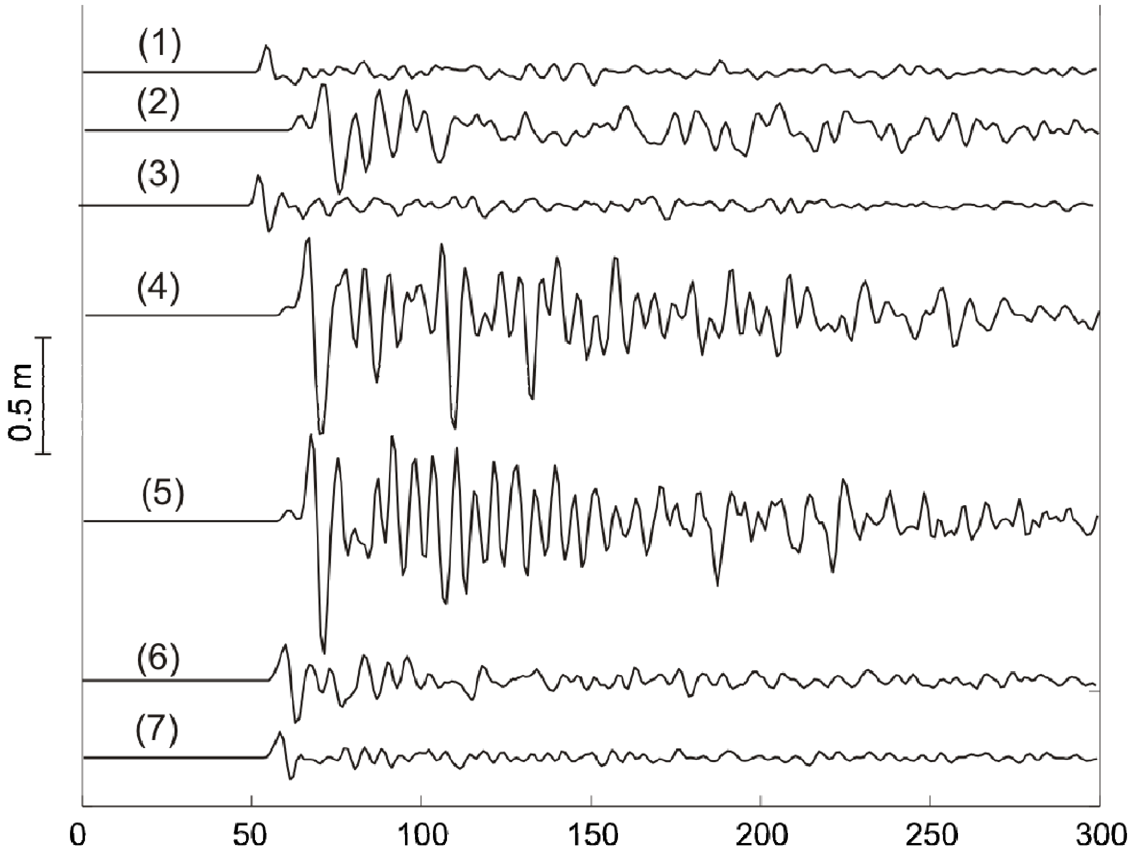

Figure 8. The same as at the Figure 4 for the bell-like disturbance. Duration parameter is 90 sec.

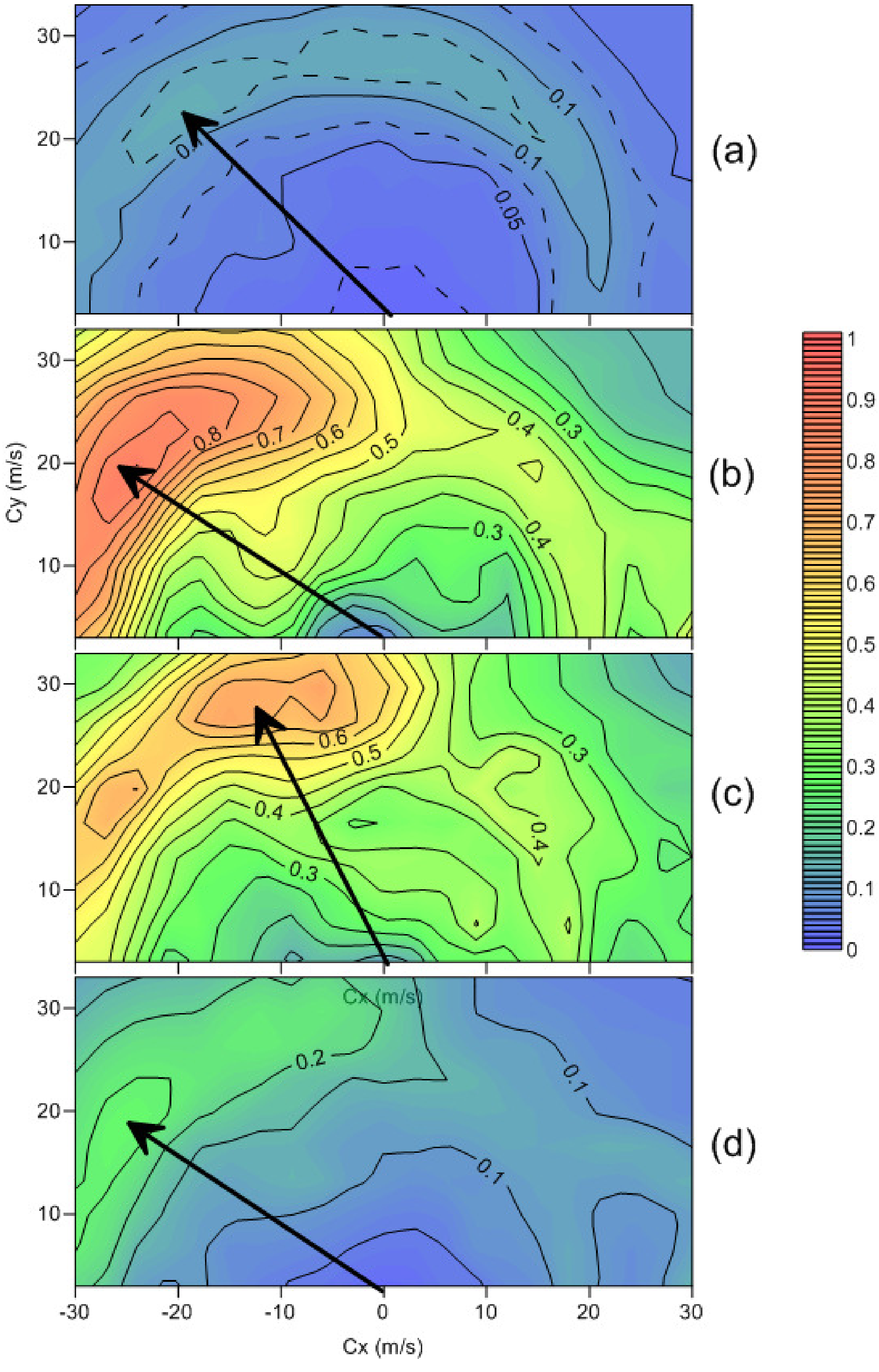

Figure 9. The same as on the figure 6 for bell-like pressure disturbance. Duration parameter is equal to 90 sec.