

In this poster we show that relatively narrow and shallow elongated areas in the propagation direction of a tsunami wave can produce largely amplified waves by the phenomenon that was called near-coast tsunami waveguiding (see [1]). This phenomenon may contribute to an explanation that tsunami wave heights and coastal effects show high variability along the coastline. To show this phenomenon, we use the recently derived Variational Boussinesq Model (VBM) as a dispersive wave model. This model is implemented numerically by using Finite Element Method (FEM) and used to simulate a tsunami that will show to possess the tsunami waveguiding property. We show simulations for synthetic data and for a real case in the Indonesian coastal area.

## Introduction

In many cases, tsunami wave heights and effects show a high variability along the coast. The possible causes are uncertainties about the tectonic plate motion, variability of bathymetry and interference between incoming and reflected waves. The understanding of the basic causes and effects is vital for reliable predictions that can support risk analysis and hazard mitigation.

In this poster we emphasize one aspect that may contribute to high variability along coast. A relatively narrow and shallow elongated area in propagation direction of a tsunami wave can produce largely amplified waves by *near coast tsunami waveguiding*, see [1]. The waveguiding is caused by the fact that different propagation speeds of waves between deeper and shallower part in the bathymetry give rise to characteristic distortions of the surface elevation near the waveguide. Inside the waveguide region the wave will have a largely amplified waveheight. But outside the waveguide the distorted wave has to adjust to the finite amplitude undisturbed external wave, which will influence both the profile and the velocity of guided tsunami waves, and which causes substantial transversal variability.

## Wave Model & Implementations

We consider the wave model described with the basic quantities : surface elevation  $\eta(x,y,t)$  and surface fluid potential  $\varphi(x,y,t)$ , which can be written in Hamiltonian form :

$$\partial_t \eta = \delta_\varphi H(\varphi, \eta)$$

$$\partial_t \varphi = -\delta_\eta H(\varphi, \eta)$$

where  $H$  is total energy. To show the waveguiding phenomenon, we use the recently derived Variational Boussinesq Model (VBM) as a dispersive wave model (see [2]). In the VBM approximation, we approximate the fluid potential by its value at the free surface plus a vertical potential profile that is multiplied by the spatially dependent variable :

$$\Phi(x,y,z) = \varphi(x,y) + F(z)\psi(x,y)$$

The additional variable  $\psi(x,y)$  is chosen in an optimal way by taking the minimization of the energy. So, instead of two dynamic equations, for VBM, we have an additional elliptic equation.

$$\partial_t \eta = \delta_\varphi H(\varphi, \eta; \psi)$$

$$\partial_t \varphi = -\delta_\eta H(\varphi, \eta; \psi)$$

$$0 = \delta_\psi H(\varphi, \eta; \psi).$$

This additional equation requires additional effort, but, several advantages can be achieved, i.e. :

- Exact energy conservation
- Dispersive property
- Deal with steep bottom bathymetry and moving bottom
- Easy implementation in Finite Element Method (standard linear spline basis functions).

The results of simulations to be presented were obtained using a pseudo-spectral implementation for the synthetic case, see [1,3], and by using finite element implementation for the case of realistic bathymetry, see [4].

## Simulation above Synthetic Bathymetry

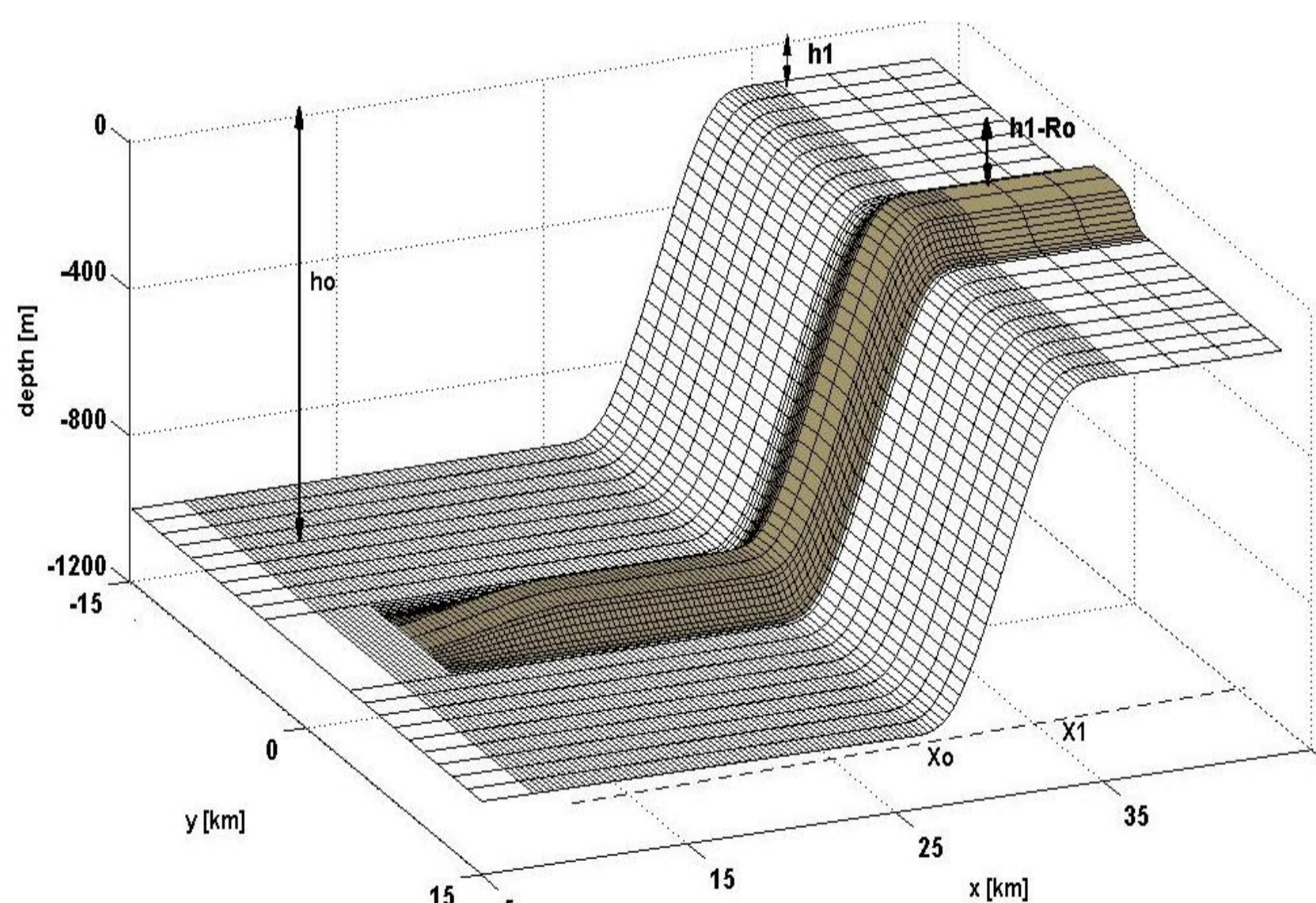


Fig.1 Synthetic bathymetry for tsunami waveguiding.

### Numerical Bathymetry :

- 2km wide waveguide of 40m ridge height ( $R_0$ )
- Incoming long plane wave, generated at 4000m with 40 km wavelength
- Simulation starts at 1000m depth, amplitude 1m

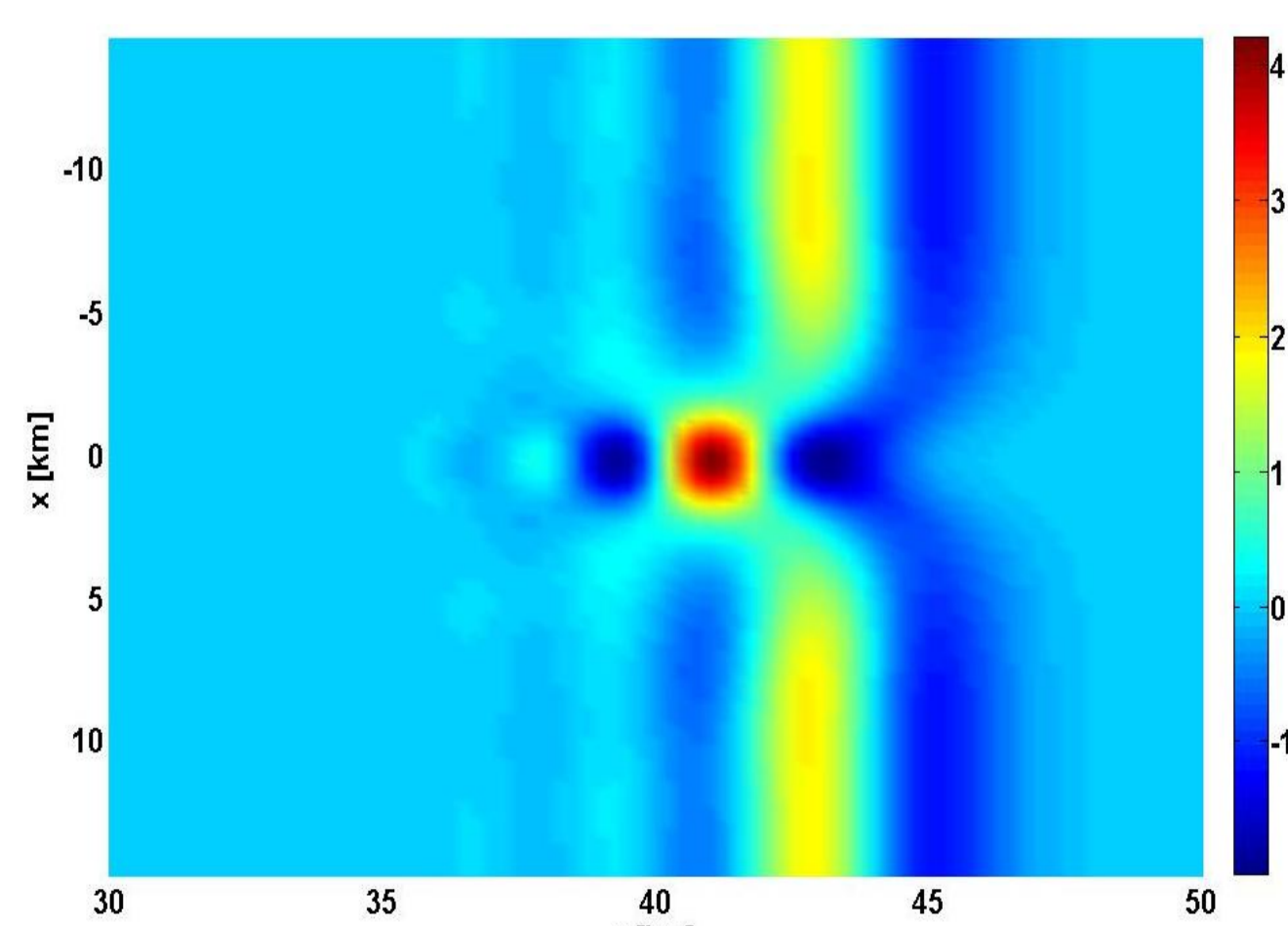


Fig.2 Snapshot of density plot at  $t=720s$ . Notice the delay of the wave above the waveguide.

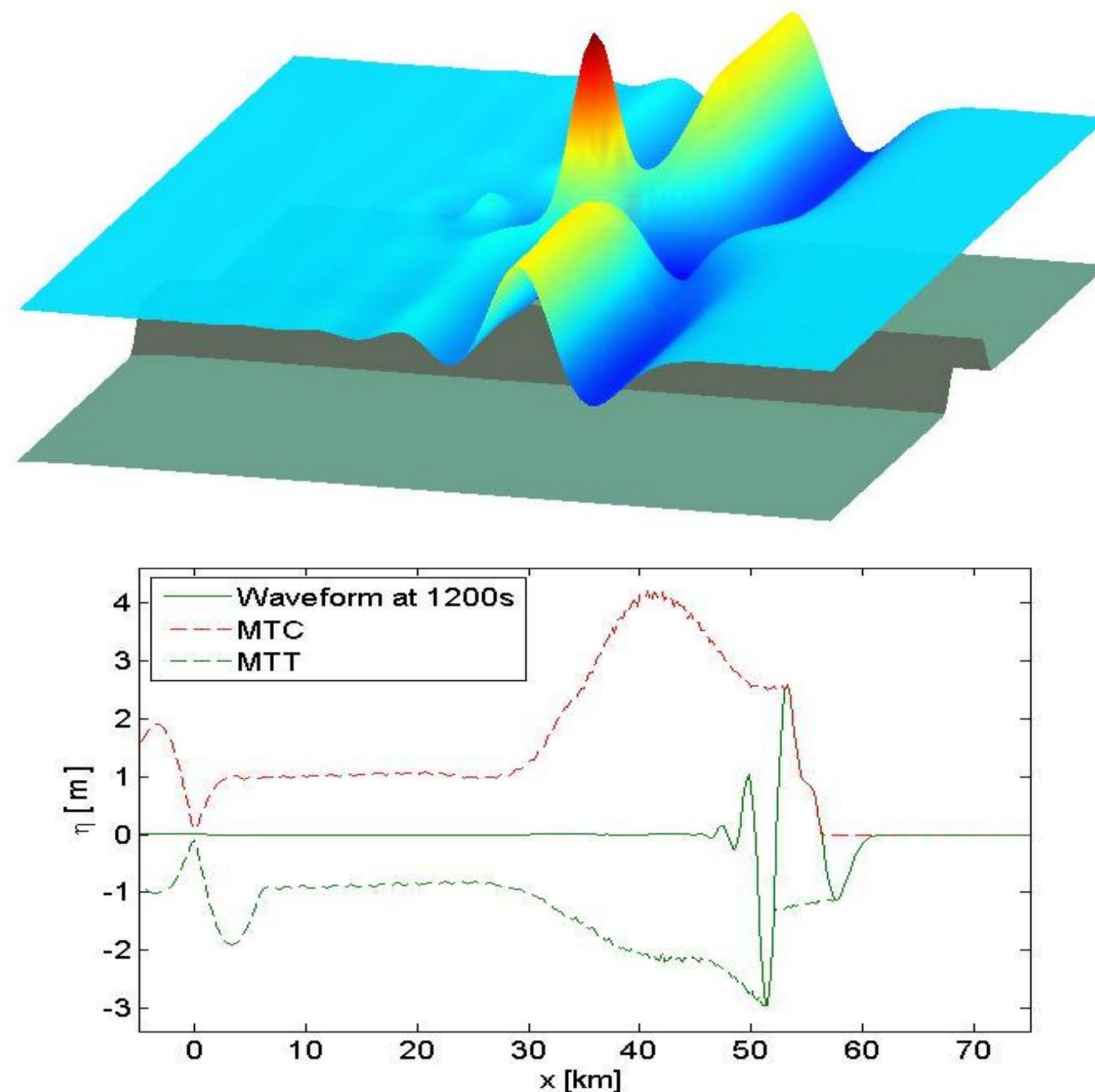


Fig.3 The upper plot shows the 3-D impression of snapshot at  $t=720s$  and the lower plot shows a vertical cross section at  $y=0$  after 20 minutes, the wave encountered a sloping bottom between 25 and 35km that increases from 1000m to 100m, with 40m shallower waveguiding areas. The amplitude amplification for this case is 4.2 (by comparing the maximum crest-height to initial crest-height).

## Simulation above Realistic Bathymetry

We have investigated the Indonesian coast for possible tsunami waveguiding areas. As one of the potential areas we identified the coastal area in Lampung, south of Sumatra. There is a very shallow, rather large, wedge-shaped area that is surrounded by deep water, see Fig. 4

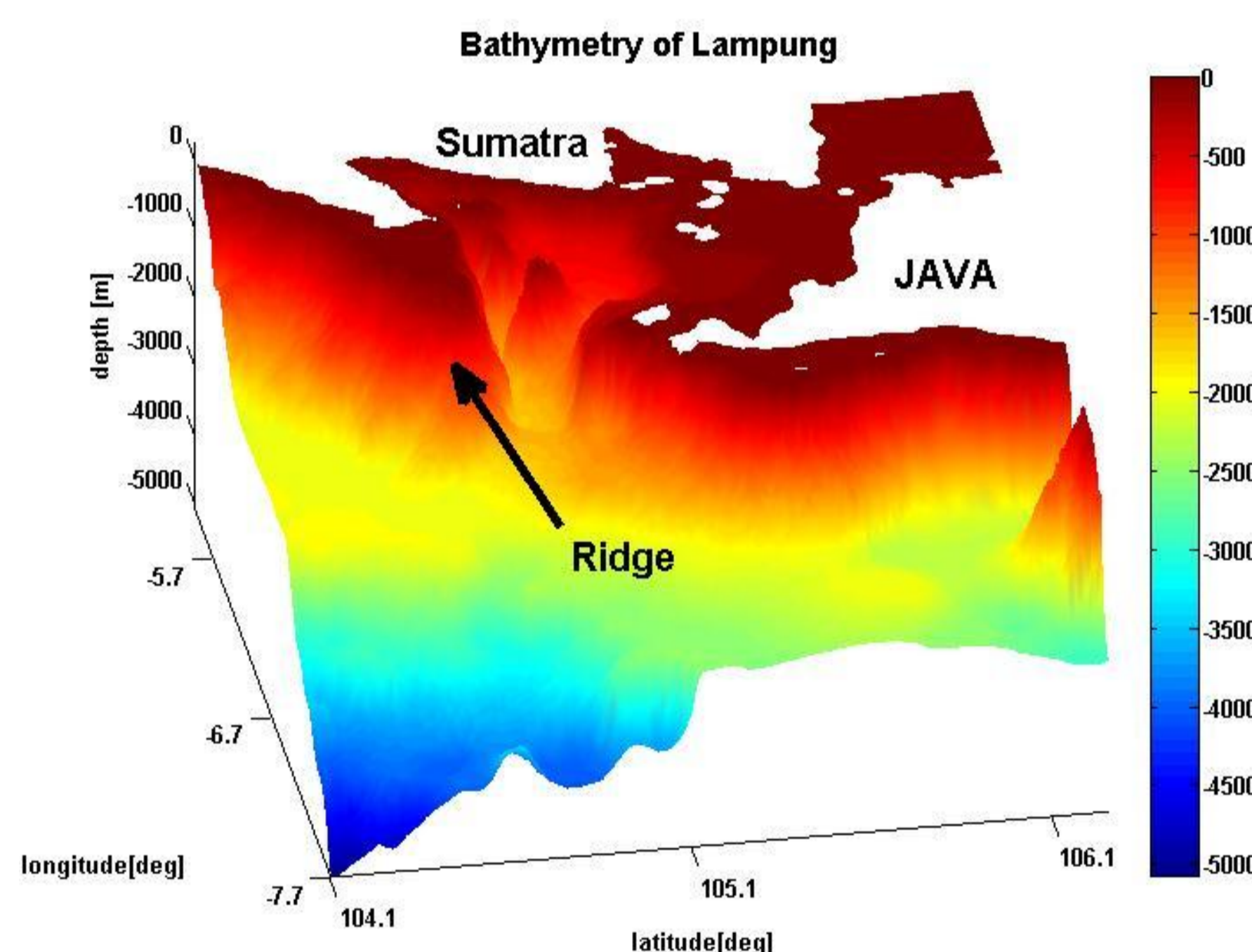


Fig.4 Plot of the bathymetry of Lampung, south of Sumatra, Indonesia.

To do the simulation above this realistic bathymetry, we consider an artificial initial wave (a bipolar hump with amplitude 2m) with a wavelength of 40km that is generated by a fast bottom excitation with this shape. This initial wave profile is released without initial velocity.

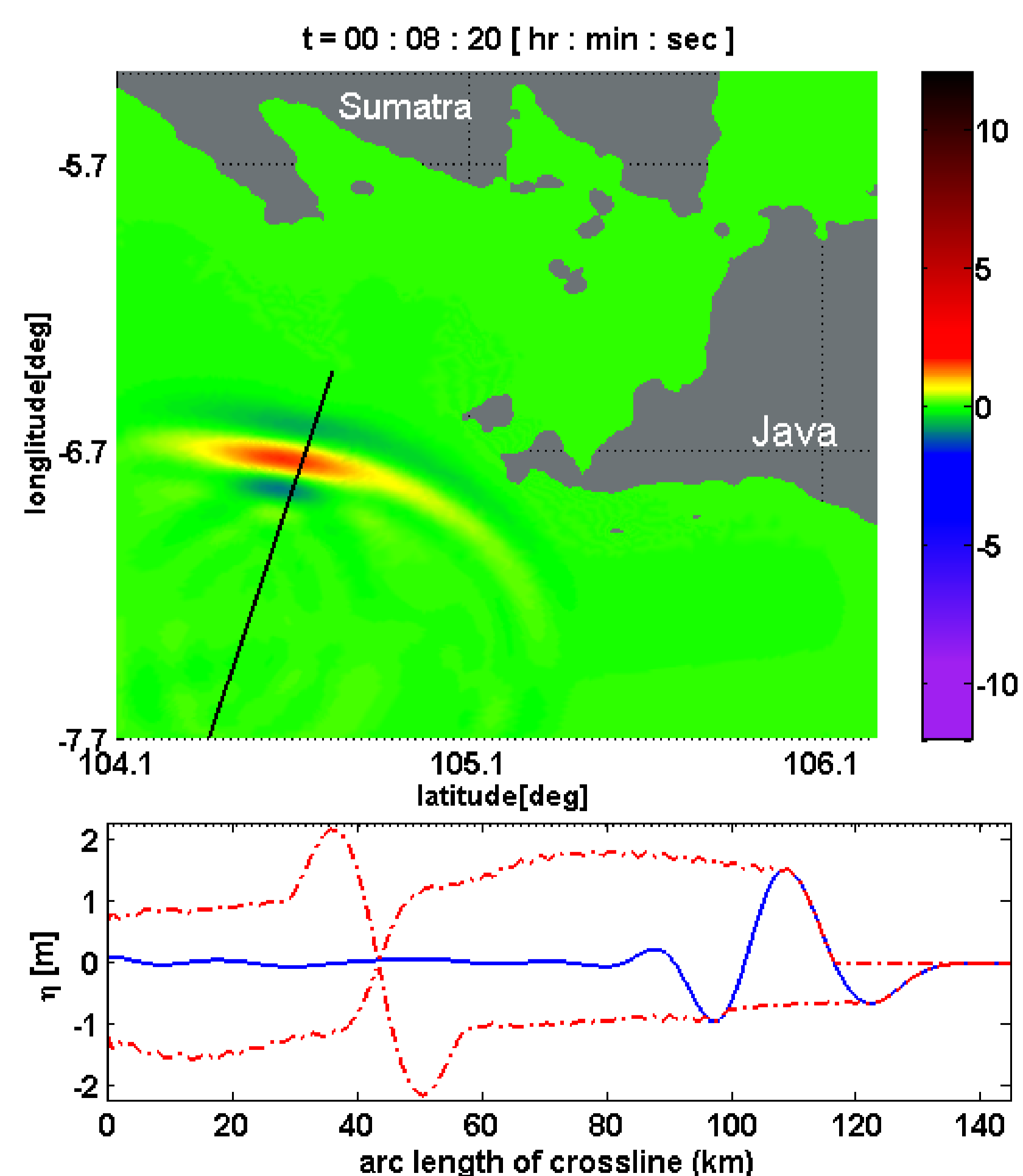


Fig.5 In the upper plot, the surface elevations is shown after 8 minutes. In the lower plot, the cross section along the black line in the upper plot is shown. The blue line shows the wave, the dashed lines show the maximal (upper) and minimal (lower) values of the surface elevation that the wave has passed.

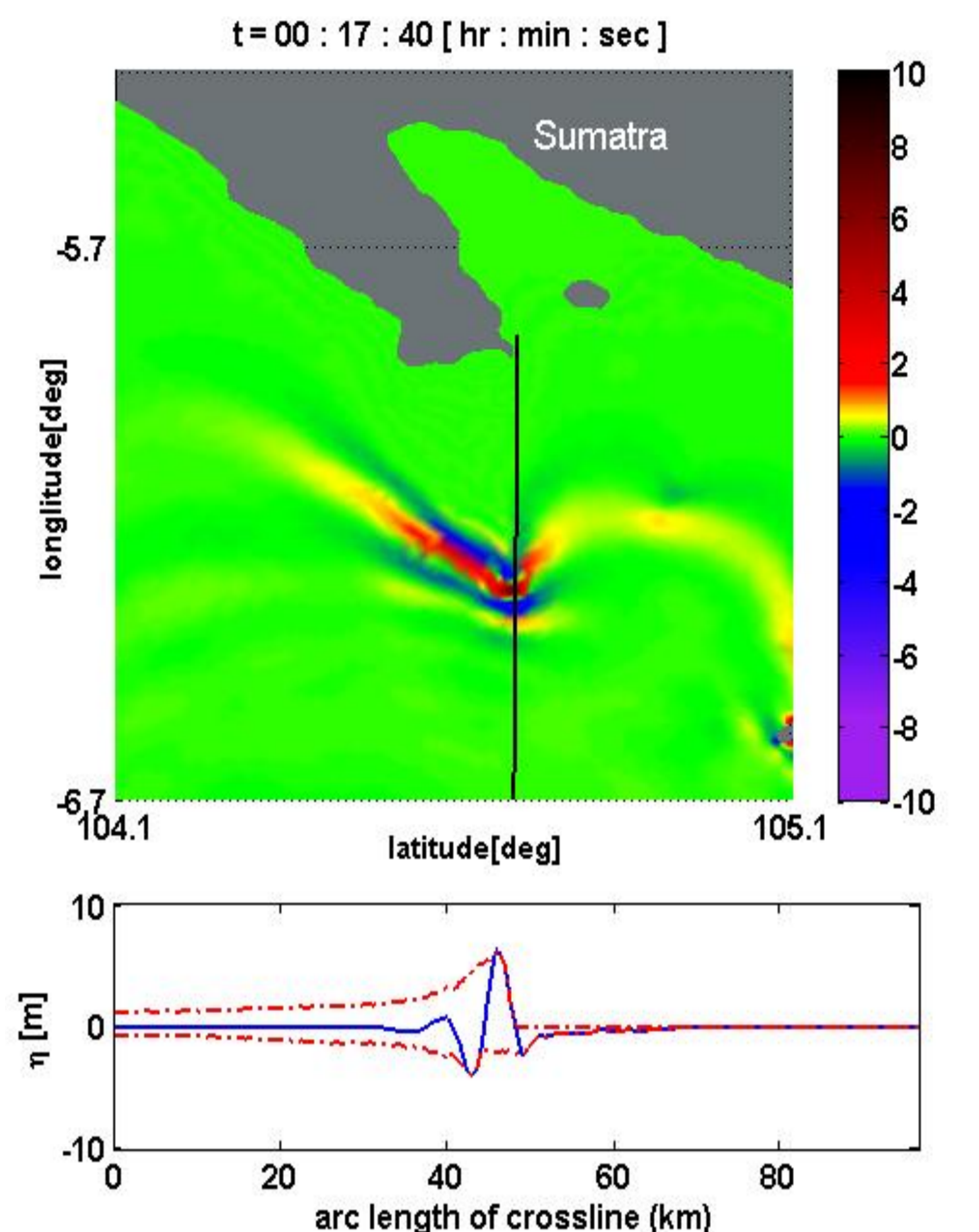


Fig.6 The surface elevations is shown after 18 minutes. The elevation along the cross section shows the large amplification when entering the shallow ridge area.

The appearance of extremely large surface elevation of almost 10m high is shown in fig. 6. This high wave can be followed in time and remains higher than the surrounding elevation, until at the coastline interaction with reflected waves leads to interference and very diverse wave heights. A plot of the maximum crest-height during 1 hour simulation in Fig. 7 shows the most vulnerable part of the shore line south of Lampung.

### Maximum Crest-height during 1 hour of Simulation

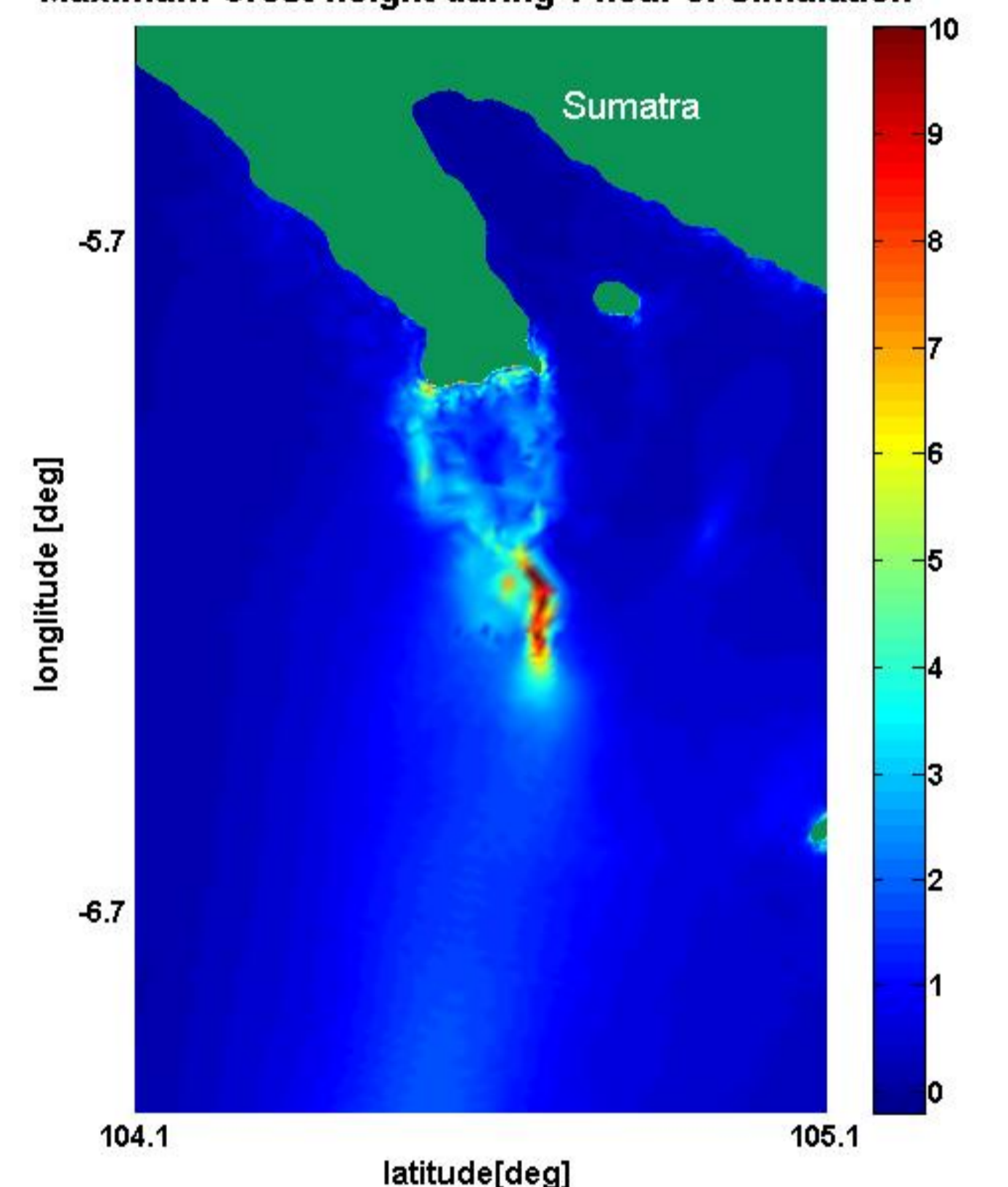


Fig. 7 Plot of the maximum crest-height during 1 hour of simulation. Notice the most vulnerable area south of Lampung that is affected by the presence of the shallow ridge.

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## References

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