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A Study on the Macrospatial Correlation Characteristics of Tsunami Wave Height and Tsunami Inundation Depth

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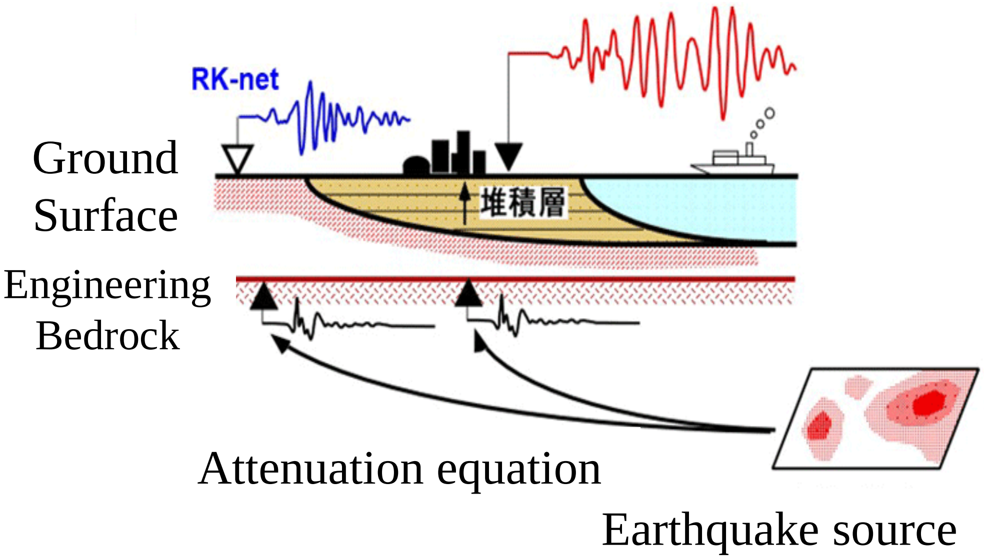
Research background

- In a probabilistic disaster risk assessment for multiple buildings, we need to consider **hazard correlation** among site locations and **damage correlation** among multiple buildings.
- In the case of probabilistic seismic hazard assessment and probabilistic seismic risk assessment (PSHA and PSRA), we generally assign various types of uncertainties to earthquake ground motions, ground characteristics, building response characteristics, and material strengths.
- Regarding earthquake ground motion that is evaluated by an attenuation formula, we need to consider it as having a spatial correlation according to the relative distance.



Ground motion prediction
(Central Research Institute of Electric Power Industry https://criepi.denken.or.jp/jp/civil/intro/earthquake.html)

Objective

- In the cases of probabilistic tsunami hazard assessment and probabilistic tsunami risk assessment (PTHA and PTRA), **we also need to consider the spatial correlation characteristics of tsunami hazard and damage**, but there have been no studies that evaluate this correlation.

The aim of this study is to evaluate the spatial correlation coefficients (ρ_R) of tsunami wave height and tsunami inundation depth according to the relative distance by using the results of tsunami numerical simulations with linear and nonlinear long-wave equations.

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We are assumed to be applied to tsunami damage assessment of building portfolio considering tsunami hazard correlation.

An evaluation method for the macrospatial correlation coefficient of tsunami hazards

Here, we use two buildings as a risk assessment target. Let C_1 and C_2 be random variables for the strength of the two buildings, and let R_1 and R_2 be random variables for the hazard value (e.g., peak ground acceleration and tsunami inundation depth) at the two building sites. Assuming that C_1 and C_2 are independent but that R_1 and R_2 have a certain correlation, we obtain performance functions F_1 and F_2 as follows:

$$F_i = \frac{C_i}{R_i} \leftrightarrow \ln(F_i) = \ln(C_i) - \ln(R_i), i = 1, 2$$

The covariance of $\ln(F_i)$ is now the same as the covariance of $\ln(R_i)$; therefore, we obtain the following relation:

$$\mathrm{cov}(lnF_1, lnF_2) = \mathrm{cov}(lnR_1, lnR_2)$$

From this relation, the damage correlation coefficient $\rho_{F_{12}}$ is as follows:

$$\rho_{F_{12}} = \frac{\mathrm{cov}(lnF_1, lnF_2)}{\sqrt{\mathrm{var}(\ln F_1)} \cdot \sqrt{\mathrm{var}(\ln F_2)}} = \frac{\mathrm{cov}(lnR_1, lnR_2)}{\sqrt{\mathrm{var}(\ln F_1)} \cdot \sqrt{\mathrm{var}(\ln F_2)}}$$

Then, we obtain the following equation:

$$\rho_{F_{12}} = \frac{\rho_{R_{12}} \zeta_{R_1} \zeta_{R_2}}{\sqrt{\zeta_{C_1}^2 + \zeta_{R_1}^2} \cdot \sqrt{\zeta_{C_2}^2 + \zeta_{R_2}^2}}$$

An evaluation method for the macrospatial correlation coefficient of tsunami hazards

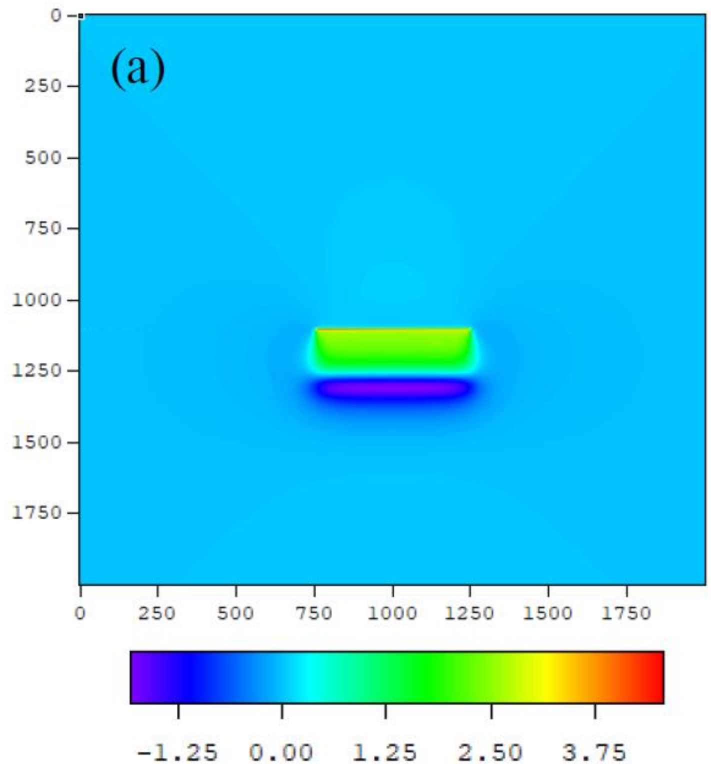
Here, let $\rho_{R_{12}}(=\rho(x))$ be the hazard correlation coefficient with respect to the distance x between two points, let ζ_n be the log normal standard deviation of *n* and let $\zeta = \sqrt{\zeta_{Ci}^2 + \zeta_{Ri}^2}\ (i = 1, 2)$ be the compound deviation. Finally, we obtain the following equation:

$$\rho_{F_{12}} = \frac{\boldsymbol{\rho_{R_{12}}} \zeta_{R_1} \zeta_{R_2}}{\zeta^2}$$

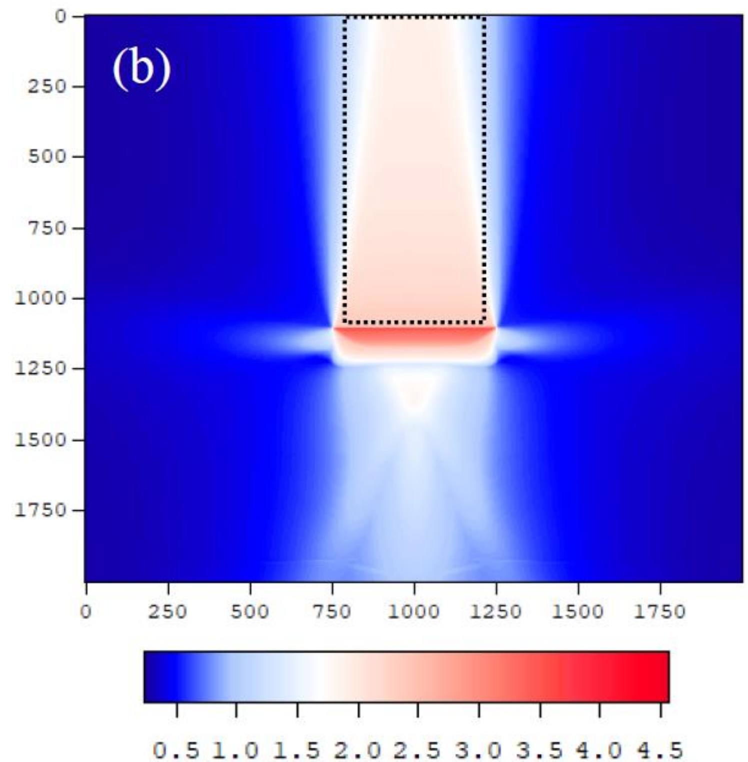
- For cases of earthquake hazard and damage assessment, we already know the values of ζ^2, ζ_{R_1} and ζ_{R_2} from past earthquake records and damage records; therefore, we can determine $\rho_{F_{12}}$ when we evaluate $\rho_{R_{12}}$.
- However, in the case of tsunami hazards, there are no studies on the correlation coefficient of tsunami hazards.
- Based on this background, we evaluate **the macrospatial correlation coefficient of a tsunami wave height and tsunami inundation depth in this study.**

Numerical study on the macrospatial correlation of tsunami wave height

- First, we establish a large virtual fault with a length of 250 km and a width of 100 km in the center of a virtual sea area with a water depth of 1000 m. The fault parameters of the large fault are a slip amount of 10 m, strike of 90°, dip of 15°, rake of 90° and fault depth of 1 km.
- We solved the continuous equation and linear long-wave equation by using the staggered leapfrog method and plane rectangular coordinates with a 500 m grid.



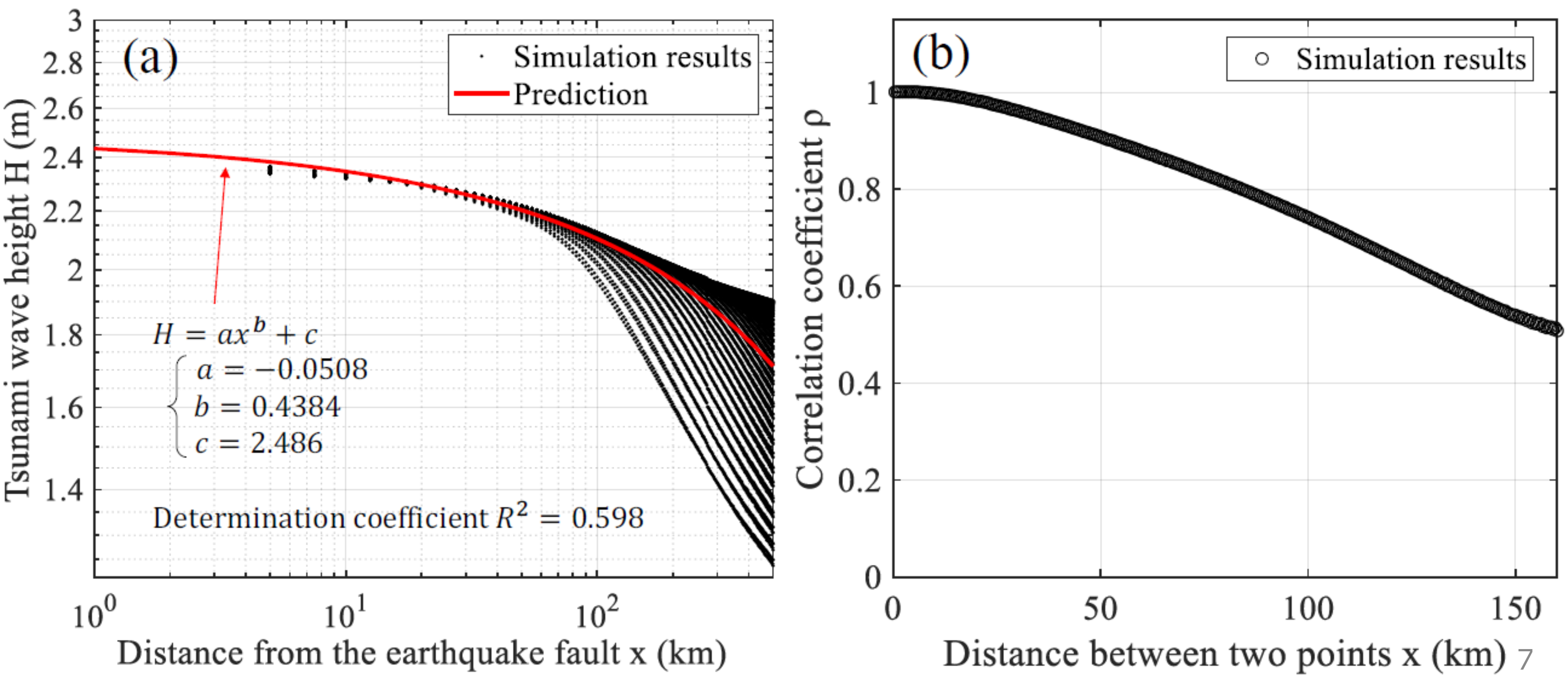
(a) Initial water displacement (m) due to fault movement



(b) Maximum tsunami wave height (m)

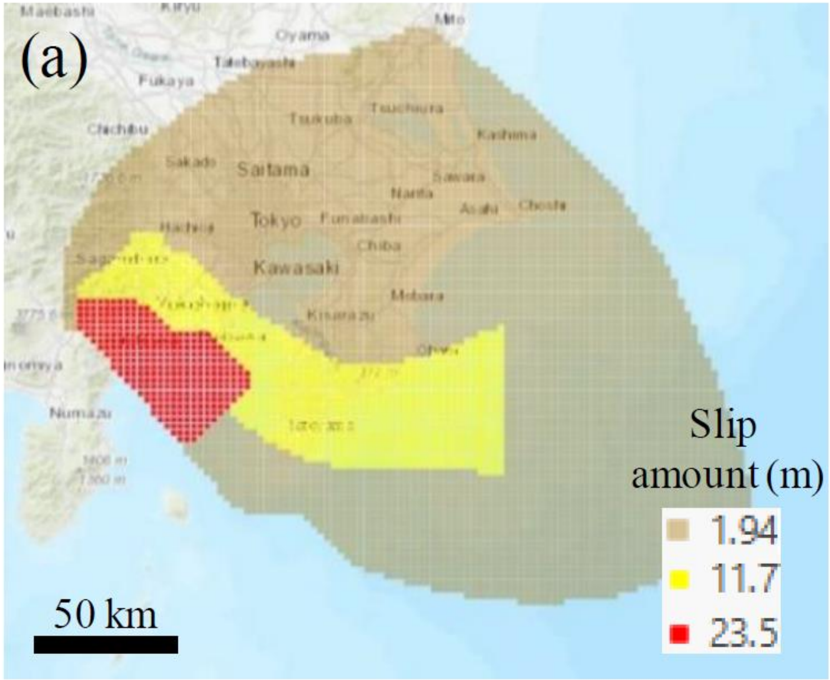
Numerical study on the macrospatial correlation of tsunami wave height

- We regressed the power function $H = ax^{b} + c$ using the least squares method to determine the median values.
- The regression coefficients were a = -0.0508, b = 0.4384, and c = 2.486, and the determination coefficient was 0.598.
- The standard deviation of the residual between the numerical simulation results and the predicted values from the power function was σ^2 = 0.022.

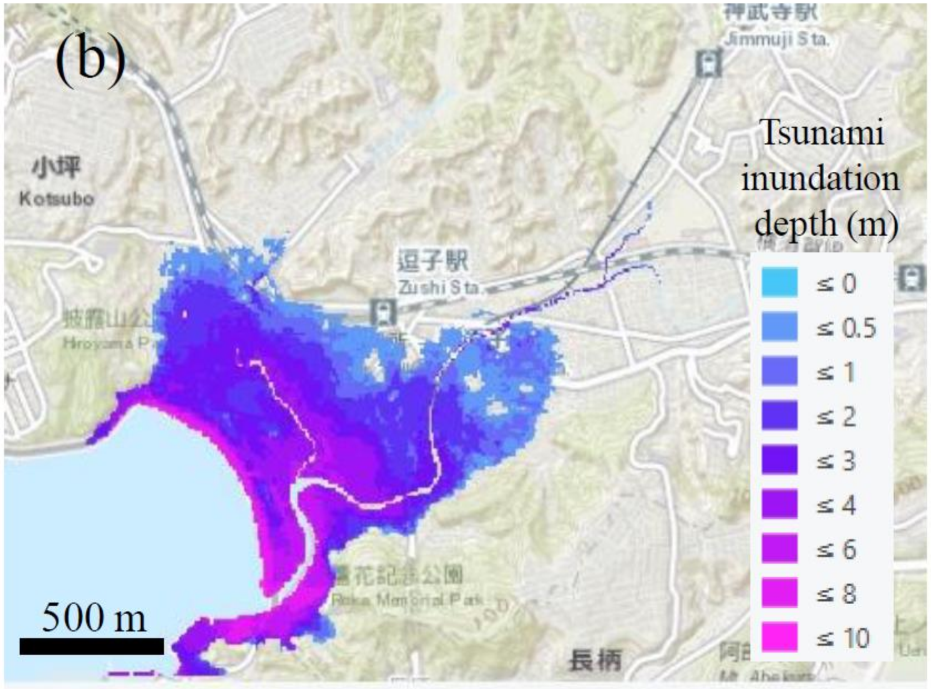


Numerical study on the macrospatial correlation of tsunami inundation depth

- We first constructed the fault parameters of the earthquake of the Sagami trough, which has a large slip off the Kanto area in Japan.
- Using the initial water displacement calculated from the earthquake parameters as input data, we solved the continuous equation and nonlinear long-wave equations by using the staggered leapfrog method and plane rectangular coordinates. We nested the four grid data with mesh lengths of 270 m, 90 m, 30 m and 10 m.



(a) A slip distribution of the Sagami trough earthquake around the Kanto region



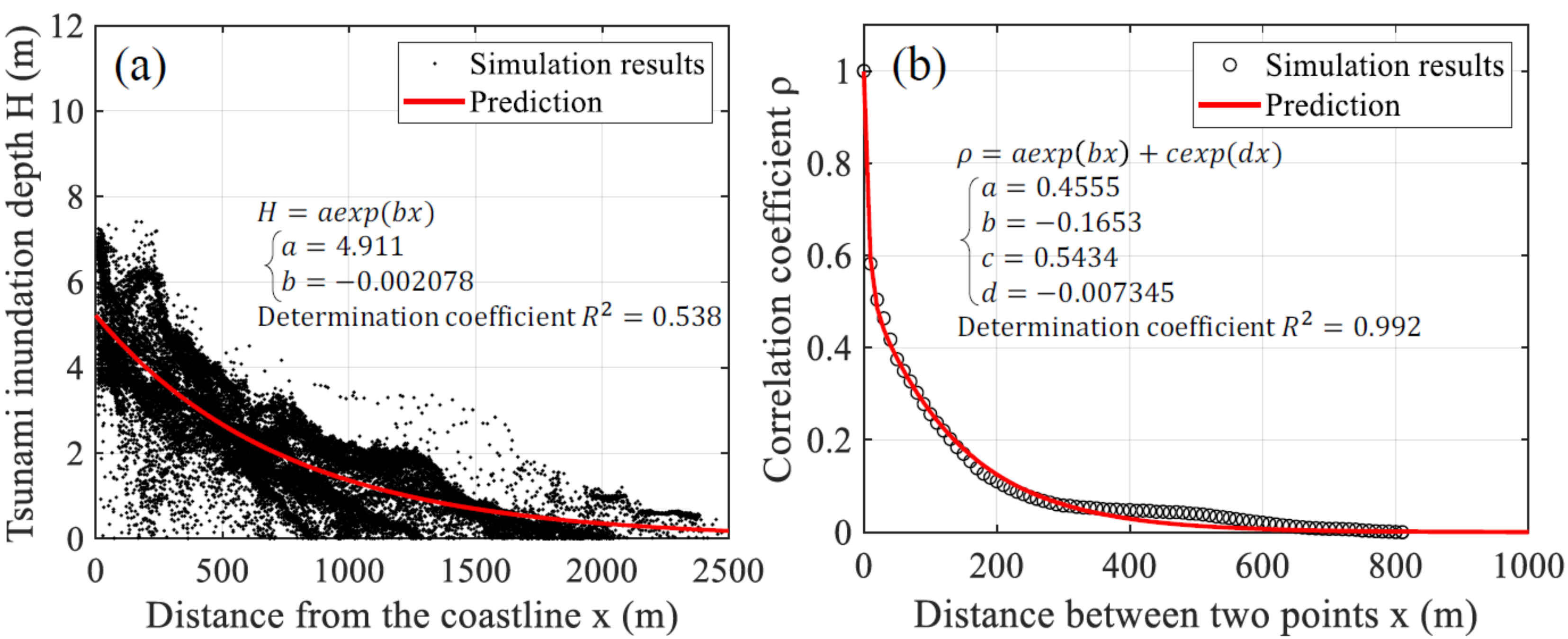
(b) Tsunami inundation depth distribution in Zushi city, Kanagawa Prefecture

Numerical study on the macrospatial correlation of tsunami inundation depth

- For the relationship between the shortest distance from the coastline and the tsunami inundation depth, we regressed the exponential function $H = \mathrm{a}\exp(\mathrm{b}x)$ using the least squares method to determine the median values. The regression coefficients were a = 4.911 and b = -0.002078
- For the the correlation coefficients between two points, We regressed the following exponential function using the least squares method:

$$\rho(x) = \mathrm{a}\exp(\mathrm{b}x) + c\exp(\mathrm{d}x) \begin{cases} \mathrm{a} = 0.4555 \\ \mathrm{b} = -0.1653 \\ \mathrm{c} = 0.5434 \\ \mathrm{d} = -0.007345 \end{cases}$$

The correlation length was 53.2 m, which the correlation coefficient was equal to 1/e.



Conclusions

We determined the following spatial correlation features of tsunami wave height and tsunami inundation depth as the results of the tsunami numerical experiments using linear and nonlinear long-wave equations:

- The macrospatial correlation coefficients of the tsunami wave height in the offshore region have a tendency to decrease as the distance increases, but the correlation coefficient is as high as approximately 0.74 even at a distance of approximately 100 km.
- The macrospatial correlation coefficients of the tsunami inundation depth in the tsunami run-up region have a tendency to decrease as the distance increases, but the rate of decrease is greater compared to the macrospatial correlation coefficient results of the tsunami wave height in the offshore region. The correlation coefficient decreases by approximately 0.78 at a distance of 10 m, indicating a low correlation of the tsunami inundation depth. This result occurs because the run-up tsunamis on the land are affected in various ways by the bottom friction and attenuate faster compared to those in the offshore region.
- The macrospatial correlation coefficient of the tsunami inundation depth can be evaluated by the exponential function (Eq.(20): $\rho(x)= exp(x)+ exp(x)$) regardless of the land gradient.

Thank you for your attention.