E01

Influence of Big Sediment Particles on Sediment Dispersion in Abukuma River Mouth Zone During Extreme Discharges

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1. Introduction

The contamination of the land surface by radioactive fallout in the vicinity around the Fukushima Daiichi Nuclear Power Plant is of much concern. While direct inputs of radionuclides from FDNPP to coastal waters have been estimated and modeled, less is known about the flux of radionuclides to the coastal zone derived from radioactive runoff into the river basin networks (Yamashiki et al., 2014) and about fate of the sediments during and after their transportation into the ocean.

2. Objectives and motivation

The goal of this study is to promote relevant numerical simulation on Land-Ocean coupling modeling approach applicable for the bay and estuary zone affected by river inflow and associated sediment transportation from the Abukuma river basin in Japan.

We tried to give detailed insight into fate of bigger sediment particles in river mouth zone during extreme discharges, in order to better understand mechanisms of transportation of pollutants in estuaries.

3. Methods

There is no single formula or procedure which is universally accepted for sediment transport rate. Navier-Stokes equation for turbulent-sediment transporting flow is commonly used.

In this study, the Atmosphere-Ocean-Land Multi-Scale Simulator for the Geoenvironment (MSSG) model developed by Japan Agency for Marine-Earth Science and Technology (JAMSTEC) was used for numerical calculation. Governing equations of the model are incompressible Navier-Stokes equations. Yin-Yang grid were used in the calculation of the flow field.

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v}\cdot\nabla\mathbf{v}\right) = -\nabla p + \mu\nabla^2\mathbf{v} + \mathbf{f} \qquad (1)$$

The equation (1), applied with finite elements method for the starting two time intervals:

$$\partial v/\partial t \quad \rightarrow \quad (v(t_2) - v(t_1)) / (t_2 - t_1) \qquad (2)$$

The equation (2) leads to the equation for velocity data in every cell in each subsequent time interval $v(t_n)$ throughout time steps for non-equilibrium state of water dynamics. If it is excluded external factor f from the equation (1), we can write:

$$v(t_2) = v(t_1) - v\ \nabla v - (\nabla p - \mu\nabla^2 v)/\rho \qquad (3)$$

ETOPO1, the 1 Arc Minute Global Relief Model was chosen as initial database for bathymetry data, while World Ocean Atlas 2005 dataset was chosen as initial 3D database for temperature, salinity, pressure, and velocity field data. Incompressive Navier-Stokes equation and Yin-Yang grid were used in the calculation of the flow field. The model was set up with rectangular 100*100 cells, 200 meters resolution. Depth layers had increment of 1 meter and reached up to maximal depth of 34 meters within the domain of the model. Computational time increment was set to 10 seconds while output time increment was set to 1 hour. River outlet was positioned in the central west point of the model, while the other 3 boundaries were closed. We used hydrostatic equilibrium equations, Smagorinsky turbulence model.

As our major intention was to consider influence of inflow from river side towards the ocean side, we manipulated with various boundary conditions solely from the river side, in order to simulate proper response from the ocean side. Major considerations were given to diverse hydrodynamic processes during various stages of extreme water waves.

Sediment transport processes were nested together with MSSG model outputs offline, with finding relations by using dimensional analysis similarity approach. Shields parameter is used as the most dominant parameter to solve bed-material sediment flux.

4. Results

In particular, we have assumed that majority of sediment particles were deposited within the structure of local dune placed on the right bank within the estuary, whose structure usually extends all the way from bottom to the top of the river, and sometimes even until half of width of the river on the surface level. Spatial change of topography structure of the local dune before and during extreme water waves was assumed as being major source of bigger sediment particles, so threshold conditions for breaking the structure of the dune were also considered as threshold conditions for putting bigger sediment particles into incipient movement.

In order to estimate bed-material sediment flux after the dune material is put into suspension, we used plot of dimensionless bed shear stress versus dimensionless unit sediment discharge, which will be extremely high after dune structure is broken, by several orders of magnitude in comparing to the hypothetical situation if the dune is just a shallow bed form.

5. Expected conclusions

Although more detailed study need to be done to further confirm conclusions, at this stage we may conclude that there are likely three important factors which contribute that big sediment particles within the Abukuma estuary are being trapped during and after extreme discharge event. Namely, breaking the stable structure of the local dune within the estuary where majority of bigger particles are deposited, which causes incipient movement of sediment particles, equal mobility criteria which causes mixed-sediment flux fractional separation, and salt wedge type of estuarine circulation, which causes strong vertical stratification of river and ocean fluid densities in the lower part of the water column within the river mouth for the given extreme discharges.

The presence of higher dense ocean water causes laminar boundary flow separation which is occurring on degrees lower than 90˚ from the front interface layer between 2 fluids in lower layers of the water column. However, in upper layers of the water column, flow separation is occurring within the turbulent boundary interface layer between two fluids, on degrees around 120˚, causing drag crisis to happen. Lighter sediment particles are then transported offshore in upper water columns, while heavier sediment particles are redeposited on the ocean bed or trapped within eddies within the estuary. We assume that this phenomena can be qualitatively well described with using Reynolds interface boundary layer number between two fluids with reference length described as vertical distance between the river bed and sharp boundary between two fluids on the river mouth outer point. Further experiment need to be done for quantitative analysis of the phenomena.

During cessation phase of the extreme event, denser ocean water progresses further into the river estuary. Many of turbulent eddies in lowermost zone of the water column disappear and release the trapped bigger fractions of bed-material sediments into loose suspended state. Part of the bigger fractions of sediment particles are then deposited by mass deposition mode on the river bed and then forms the basement for new local dune typical for Abukuma estuary, while the other part is expected to be re-deposited onto ocean floor close to the river mouth by ocean currents, as it is shown in Fig. 1.

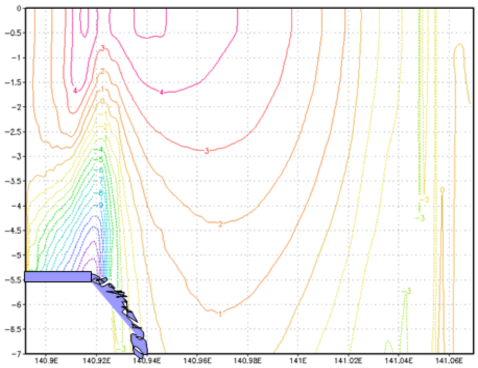

Fig. 1 Freshwater unidirectional flux, river mouth longitudinal section [psu*m/s]; U = 0.1 m/s; with expected sediment deposition during cessation phase

References

Yamashiki, Y., Onda, Y., Smith, H., G., Blake, W., H, Wakahara, T., Igarashi, Y., Matsuura, Y., Yoshimura, K. Initial flux of sediment-associated radiocesium to the ocean from the largest river impacted by Fukushima Daiichi Nuclear Power Plant, Scientific Reports, 2014