平成 29 年 1 月修士論文要旨
（東京大学大学院　新領域創成科学研究科　海洋技術環境学専攻）

久米島における海洋温度差発電所による放流水の環境影響予測

Environmental influence prediction of discharged water from ocean thermal energy conversion plant in Kume-Island by numerical simulations

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１． Introduction and objectives

Ocean thermal energy conversion (OTEC) is a promising renewable energy technology that exploits the thermal difference between the surface seawater and the deep seawater to drive the turbogenerator and generate electric power [1]. In the closed-cycle system, surface water and deep ocean water is mixed and discharged in the upper layer after the usage. The discharged water also has lower water temperature and higher nutrient concentration than the surface sea water. One of the prominent environmental concerns for OTEC plant is the potential for the upwelled nutrients to fertilize the surface waters. The distinct properties of the deep ocean water in the mixed water may alter the local marine environment. Furthermore, it may cause a phytoplankton bloom and perturb the natural population of marine organisms. Closed-cycle systemized 100MW offshore OTEC plant and 1MW onshore OTEC plant are being planned around Kume-Island. The discharged amount of 100MW and 1MW OTEC plant are 2,880,000 t/h and 22,100 t/h, respectively. The discharge depth for 100MW OTEC plant is 15m, and for 1MW OTEC plant, there are two options, 50m and 100m.

In this research, we focus on environmental influence prediction of the discharged water from 100MW offshore OTEC plant and 1MW onshore OTEC plant in Kume-Island. This study aims at clarifying the behavior of discharged water, predicting the distribution of water qualities and planktons, estimating the response of the ecosystem, investigating possible ways to control the environmental influence.

２． Computational model

The MEC-NEST [2] model, which is a three –dimensional hydrodynamic model for the calculation of seawater flow is adopted in the calculation. The governing equations are as bellows;

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho_0}\frac{\partial p}{\partial y}+fv+A_M\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\frac{\partial}{\partial z}\left(K_M\frac{\partial u}{\partial z}\right) \quad (2\text{-}1)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho_0}\frac{\partial p}{\partial y}-fu+A_M\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\frac{\partial}{\partial z}\left(K_M\frac{\partial v}{\partial z}\right) \quad (2\text{-}2)$$

$$0=-\frac{1}{\rho}\frac{\partial p}{\partial z}-g \qquad (2\text{-}3)$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \qquad (2\text{-}4)$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=A_c\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)+\frac{\partial}{\partial z}\left(K_c\frac{\partial T}{\partial z}\right) \qquad (2\text{-}5)$$

$$\frac{\partial S}{\partial t}+u\frac{\partial S}{\partial x}+v\frac{\partial S}{\partial y}+w\frac{\partial S}{\partial z}=A_c\left(\frac{\partial^2 S}{\partial x^2}+\frac{\partial^2 S}{\partial y^2}\right)+\frac{\partial}{\partial z}\left(K_c\frac{\partial S}{\partial z}\right) \qquad (2\text{-}6)$$

$$\rho=\rho^*(p,T,S) \qquad (2\text{-}7)$$

t is time, g is gravitational acceleration; ρ_0 is the standard value of seawater density; f is Coriolis parameter; A_M, K_M is the horizontal and vertical eddy viscosity coefficients, respectively. A_C, K_C is the horizontal and vertical eddy diffusivity coefficient, respectively.

We combine the hydrodynamic model with a low-trophic ecosystem model, which is based on NEMURO [3]. The behavior of nutrients (NO_3, NH_4, $SiOH_4$), organic matters (PON, DON, Opal), phytoplanktons (PS, PL), zooplanktons (ZS, ZL, ZP) are taken into account in this model.

Suppose that B is the variable of each comparment in the ecosystem model, the time variation of B will be calculated as follows;

$$\frac{\partial B_i}{\partial t}+u\frac{\partial B_i}{\partial x}+v\frac{\partial B_i}{\partial y}+w\frac{\partial B_i}{\partial z}=A_c\left(\frac{\partial^2 B_i}{\partial x^2}+\frac{\partial^2 B_i}{\partial y^2}\right)+\frac{\partial}{\partial z}\left(K_c\frac{\partial B_i}{\partial z}\right)+Q_{Bi}$$

Q_{Bi} represents the biological & chemical process concerning each compartment.

３． Validation

The validation is accomplished by adopting the data of research on effect of ocean nutrient enhancer “Takumi”. In the experiment, the tracer was used to identify behavior of the water. The tracer was put in the calculation of validation, and compared with the observational data.

４． Simulation

4.1 Computational Condition

As for the meteorological conditions, the data of August from Kume-Island observational sites and Naha observational sites are used. In this research, two sets of August’s data was put in. As for the boundary conditions, the M2 tide sea surface displacement from Tide Model NA099b was given along the computational domain. Based on the statistics that were taken from JODC and WOA13, the data for water quality were given. As for the initial conditions, the same values as the boundary conditions were given. A finer grid system was verified and used in the calculation.

4.2 Computational Results and Discussion

For the case of 100MW offshore OTEC plant, the most affected area in terms of water temperature and the nitrate concentration are both in the depth of 55 meters, and the amount of water mass where temperature and nitrate concentration changes is not much. We notice that large phytoplankton does not grow very well in the vicinity of the OTEC plant, but at the northward and eastward of the plant, the phytoplankton grows.

For the case of 50m depth discharge, The water temperature decreases about 0.5℃ at the discharge outlet, but the impacted area is rather limited in the vicinity of discharged point because of the smaller discharge rate from the plant. The nitrate concentration at the depth of 55m increases, but it exceeds 1μmolN/L in very little sea area. The phytoplankton concentration increases in the layer below the depth of discharge outlet and it increases only around 1×10^{-7}μmolN/L.

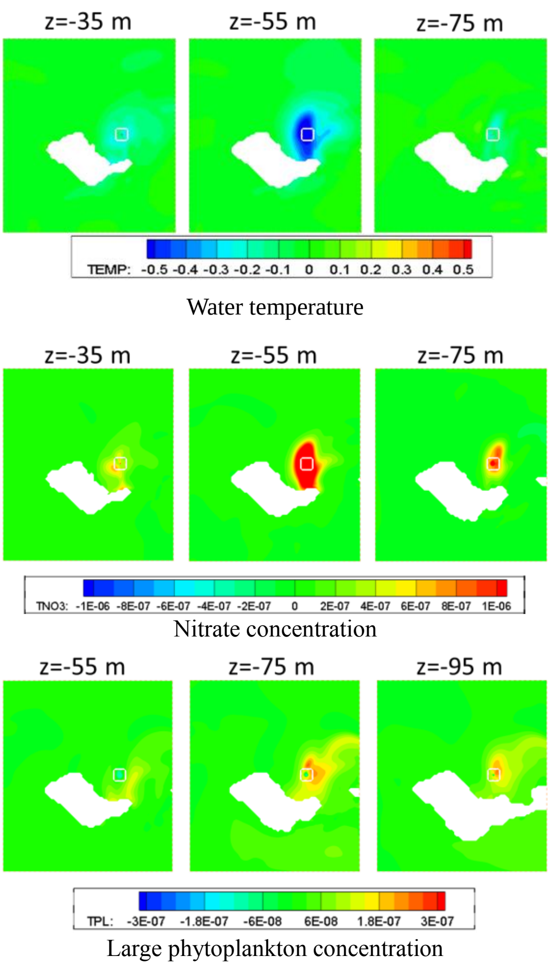

Fig. 1 Distribution of the changes of each variables in horizontal plain due to discharged water from 100MW OTEC plant

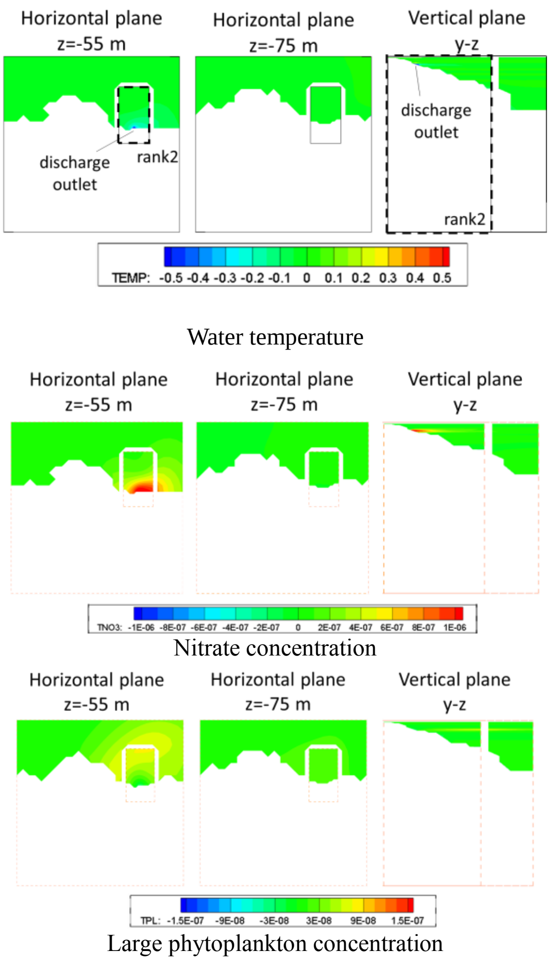

Fig. 2 Distribution of the changes of each variables due to discharged water from 1MW OTEC plant, 50m discharge depth.

For the case of 200m depth discharge, the water temperature and the nutrient concentration change a little bit at the depth of discharge outlet, but the change is even smaller than the previous case because the water temperature is lower and the nutrient concentration is higher at the depth of 200 meters. The phytoplankton concentration almost does not changes because of the weak solar radiation in deeper layer.

5． Effect of difference in discharge scheme

5.1 Different Depth

Four other discharge depths were attempted to investigate the environmental change due to the discharged depth. The depth of the selected layers are 7.5m, 25m, 55m, and 205m. From the results showed in Fig.3, the changes of the water temperature becomes smaller, when we discharge the water into deeper layer.

5.2 Different proportion of deep sea water and surface water

Two other proportions of deep sea water and surface water were attempted. In order to maintain the efficiency of the OTEC facility, only the surface water was increased. From Fig.4, no large difference occurred in terms of water temperature.

Changing the depth is an effective way of controlling the environmental influence caused by the discharged water.

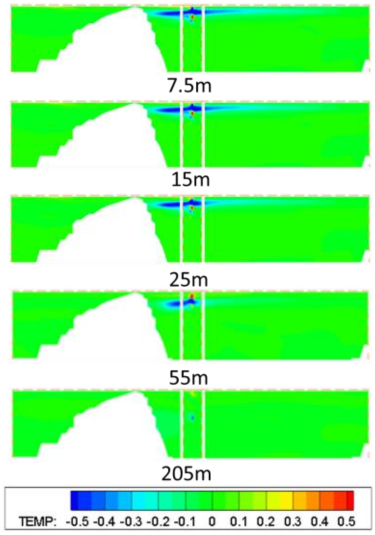

Fig. 3 Distribution of the changes of water temperature in horizontal plain due to discharged water from 100MW OTEC plant

6． Summary

6.1 Accomplishment achievement

The environmental influence prediction of discharged water from OTEC plant in Kume-Island was conducted. The behavioral characteristics of the discharged water was clarified and the variation of the oceanographic factors and phytoplanktons is simulated by using the MEC-NEST model which is combined with the low trophic ecosystem model. By changing the depth and proportion of surface water and deep water, the proper way of controlling the environmental influence is also clarified.

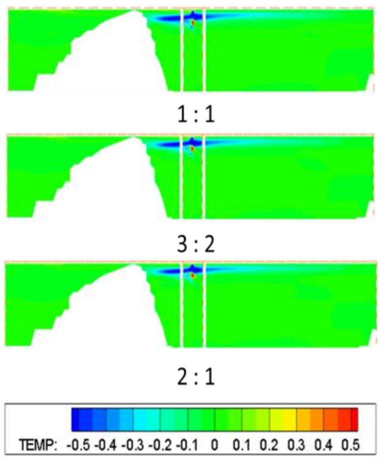

Fig. 4 Distribution of temperature change of different proportion of surface water and deep ocean water

6.2 Future tasks

In the present calculation, we did not take the ocean currents into account. In reality, there are still some other ocean currents around Kume-Island. Besides, the ecosystem model and parameters that we used in the current model are those of ecosystem in the middle latitude of North Pacific Ocean. Since Kume-Island is located in subtropical area, the model and parameters need to be adjusted according to the observational data.

Reference

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