Assessing the Possibility of Summer Hypoxia Occurrence Due to Flooding Events in Coastal Waters Under Large Ensemble Climate Simulation

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1. Introduction

Global warming is a major driver of climate change, intensifying extreme weather events such as heavy rainfall, which has caused serious impacts on coastal economies and marine ecosystems[1]. The Ariake Sea, a shallow coastal region producing 40% of Japan's cultured laver, is classified as a Region of Freshwater Influence (ROFI). Since the 1990s, the region has faced growing environmental challenges, with hypoxia becoming a critical concern.

This study used dynamical downscaling with a Regional Climate Model (RCM) based on the Atmospheric General Circulation Model (AGCM) from the d4PDF dataset. The RCM captures regional climate features such as monsoons and tropical cyclones, enabling high-resolution assessment of flood-related impacts. This approach improves simulation accuracy and is well-suited for evaluating future flood and hypoxia scenarios in the Ariake Sea[2].

2. Method

2.1 Data sources

The climate data used for the numerical model came from d4PDF's RCM with a 20-kilometer grid spacing. This dataset included historical simulations (HPB) and future scenarios (+2°C and +4°C, HFB), with the study focusing on the HPB dataset (50 members from 1981 to 2009, totaling 1500 simulations). River discharge for class A rivers was calculated using rainfall data from the HPB, employing the 1K-DHM rainfall-runoff model. The model's accuracy was enhanced by considering parameter uncertainty, using d4PDF data as input[3]. Input data for the numerical model were randomly selected from the 1500-year simulations of the Chikugo River, based on 48-hour maximum discharge events.

2.2 Numerical models

This study employed the open-source numerical simulation software package Delft3D, which integrates the FLOW and WAQ modules. Horizontal grid is structured as rectangular in a Cartesian frame of reference, while the vertical grid is based on a σ-coordinate system. The vertical grid consists of 10 layers with varying thicknesses. Open boundaries are situated beyond the mouth of the Ariake Sea and along the line linking Kabashima and Akune. Harmonic constants for the major tidal components (M2, S2, K1, and O1) were applied at these open boundaries. The Murakami model was used to simulate surface heat flux. Freshwater inflows were considered from eight A-class rivers and nine B-class rivers, which was constructed after 1997 (**Fig. 1**).

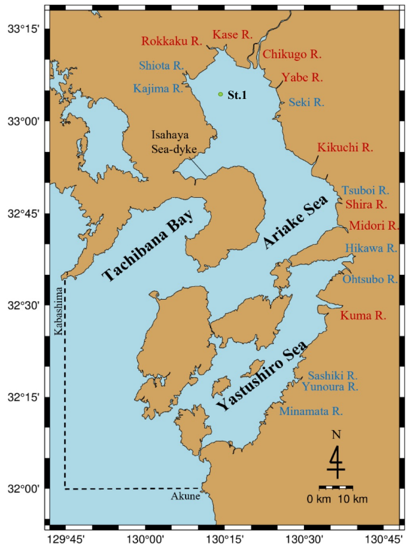

Figure 1. Calculation domain.

The physical conditions simulated by the FLOW module were coupled with the WAQ module to simulate the transport and transformation of water quality parameters, as depicted in **Fig. 2**. In this study, we simplified the general ecological model and considered only one phytoplankton species (green algae). The model variables include living organic matter (algae), dissolved organic matter (DOM), particulate organic matter (POM), dissolved inorganic nutrients (NH4-N, NO3-N, and PO4-P), and dissolved oxygen (DO) concentration.

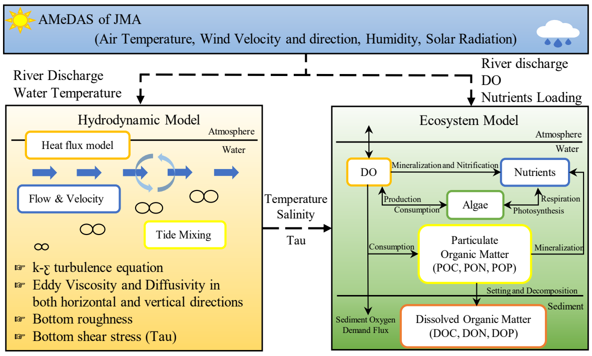

Figure 2. Conceptual diagram of the numerical model.

3. Results and Discussion

The Chikugo River, one of the largest primary rivers flowing into the Ariake Sea, serves as a major source of freshwater inflow, influencing the marine environment and ecosystem. **Fig.3** (left) presents the exceedance probability of 48-hour discharge volumes, where the highest annual maximum 48-hour discharge volume is approximately 0.88 km³, corresponding to an exceedance probability of 3/1501.

Fig.3 (middle and right) shows the relationships among the exceedance probability of the annual maximum 48-hour discharge volume, hypoxia duration, and hypoxia area. Using the hypoxia duration associated with the maximum discharge volume in the dataset and a 1/100 exceedance probability as thresholds, all data points are categorized into four quadrants, facilitating a deeper understanding of these relationships and enabling more precise risk assessments. Both hypoxia duration and hypoxia area exhibit a moderate positive correlation with discharge volume, with R-values of 0.52 and 0.42, respectively. The first quadrant (green dots) represents large-scale hypoxia events occurring under extreme rainfall conditions (exceedance probability < 0.01), while the fourth quadrant represents large-scale hypoxia events under moderate rainfall conditions. Further investigation is required to elucidate the mechanisms governing hypoxia occurrences in these scenarios.

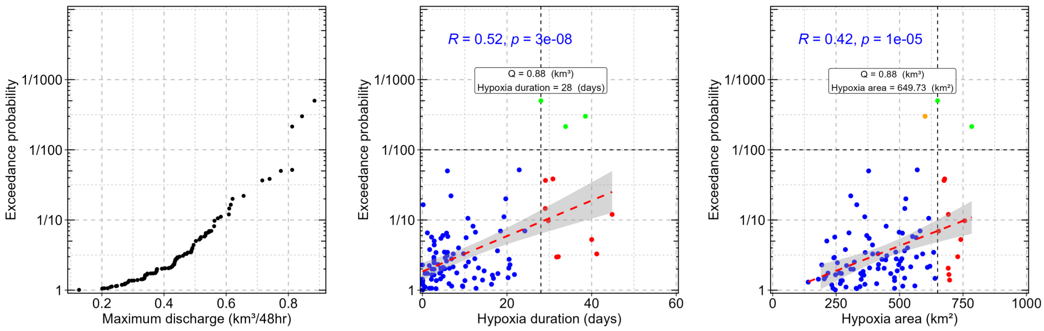

Figure 3. Exceedance probability of the 48-hour discharge volume of the Chikugo River (left) and its relationship with hypoxia duration (middle) and hypoxia area (right). The red dotted line represents the regression line, and the gray bar indicates the 95% confidence interval.

4. Conclusion

This study examines the link between flood exceedance probability and hypoxia in the Ariake Sea using a hydrodynamic-ecosystem model driven by d4PDF climate data. Floods with a 1/100 exceedance probability are especially likely to cause prolonged hypoxia, though even less extreme events can do so under warm conditions. Future research should explore these relationships under climate change scenarios to better understand hypoxia dynamics and inform marine resource management.

Reference

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