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Optimal Coastal Flood Structural Adaptation Decision Making under Climate Change in Osaka Bay, Japan

〇Si HA, Hirokazu TATANO, Toshio FUJIMI

Introduction

Coastal flooding is a frequent and devastating natural hazard caused by a coastal process such as tides, waves, and storm surges, where storm activity can temporarily raise sea levels well beyond the normal tide range. This rise in water level can cause extreme flooding in coastal areas Especially when storm surge coincides with normal high tide. As the agglomeration of population and assets, Coastal cities are particularly vulnerable to this hazard. Moreover, it is widely recognized that climate change could pose significant challenges and impacts on many coastal communities. Therefore, it is imperative to assess storm surge inundation risks under climate change scenarios to support decision-making regarding coastal flood risk management and adaptation strategies.

There has been little research on Dynamic Decision Making for structural adaptation strategies, even though this is necessary the case in real-world applications. Decision making on adaptation strategies is challenging due to the high costs of investments and the high degrees of uncertainty surrounding benefits, especially when risks are low probability, high-consequence events. Our study addresses this gap in the literature by proposing a novel dynamic decision-making model approach for structural adaptation strategies planning and enhancement. To examine the optimal plan for the scale and timing of the dike raising under the uncertainty of climate change prediction and the change of the inundation expected annual damage cost with time. This research presents a framework for developing dynamic cost-efficient structural adaptation strategies to tackling global warming impact that can be useful for a coordinated research effort focusing on enhancing climate change adaptation.

Methodology

By developing a framework that couples stochastic tropical cyclones model, storm surge model, inundation model, climate change projections, coastal protection, adaptation measures. We could identify storm surge inundation risk under climate change and provide evidence for improving the climate change adaptation that can reduce inundation damage caused by storm surges.

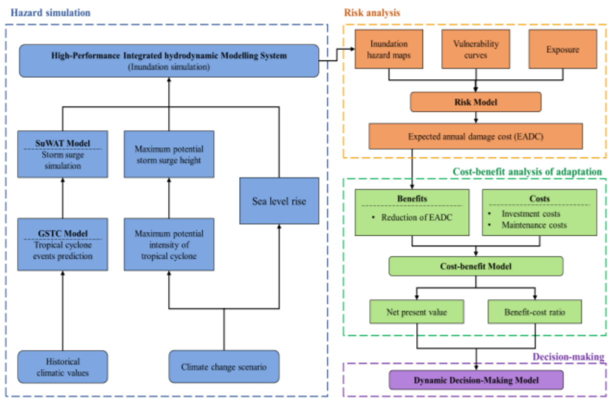

Fig.1 Research Framework

In value iteration function, the value at every state will evaluate the current reward and the possible accumulated rewards it may get in the future. From the last period to beginning, the action with the minimum results will be chosen, and at the end, a list of optimal strategies will be derived.

The decision to raise the dikes is made by considering the expected damage from storm surge inundation, the damage reduction effect of raising the dikes, and the cost of raising the dikes. The dynamic decision-making model to obtain the optimal dike raising plan is expressed by the following equation.

$$V_t(s,x) = \max_{a \geq 0} W_t(s,x+a)$$

$$W_t(s,x+a) =$$

$$\begin{cases} -C(a,x) + \sum_{k=0}^{f-1} \beta^{f-1-k} \sum_{i=0}^{f-1-k} C_i^{f-1-k} p_u^i p_m^{f-1-k-i} EL(s+i,x) + \beta^f \sum_{i=0}^{f} C_i^f p_u^i p_m^{f-i} V_{t+f}(s+i,x+a) & if\ a > 0 \\ -EL(s,x) + \beta\{p_u V_{t+1}(s+1,x) + p_m V_{t+1}(s,x)\} & if\ a = 0 \end{cases}$$

In reality, there is a time lag between the decision to raise the dike and its implementation, because it takes time to acquire land and construct the dike. There are also some cases that the Decision maker will not always face two options in every period. Sometimes they tend to keep at the state for several periods right after a construction. Here the delay of facing two options are called lead time.

Results

Based on the premise of RCP2.6 (equivalent to a 2°C rise), which is consistent with the target of the Paris Agreement, the impact forecast is reflected in coastal protection policies and plans, and maintenance are promoted. While assuming RCP2.6 as the target for coastal protection, the pessimistic forecast of RCP8.5 (equivalent to a rise of 4°C) is also considered. Under the RCP emission scenarios, the boundary above and below shows the high-end and low-end scenarios. The range between boundary is the states that the binomial process model can be used to make decisions on raising dike height. The period covered by the study will be from 2000 to 2100, with one period being five years. Model calculations were performed for 100, 150, 200, and 300 years in order to verify the impact of setting the damage amount for the final period. Storm surge inundation loss $EL(x,s)$ under each scenario was calculated from inundation simulations.

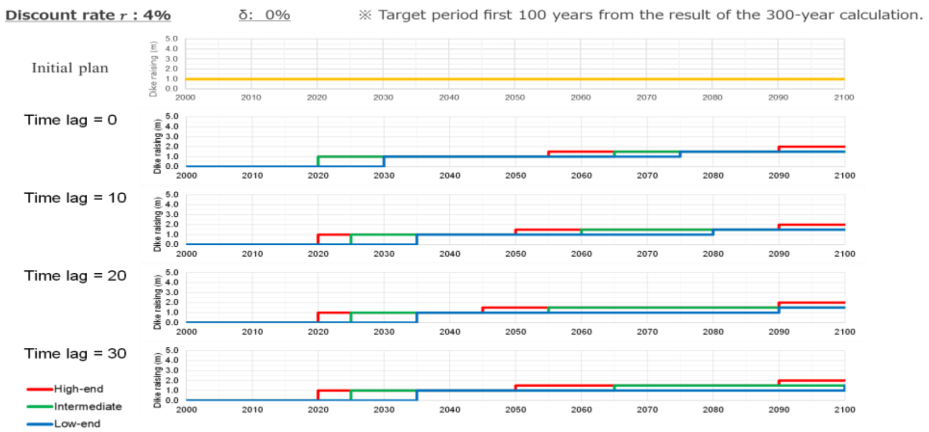

Fig.2 Optimal Adaptation Decision Making (RCP8.5)

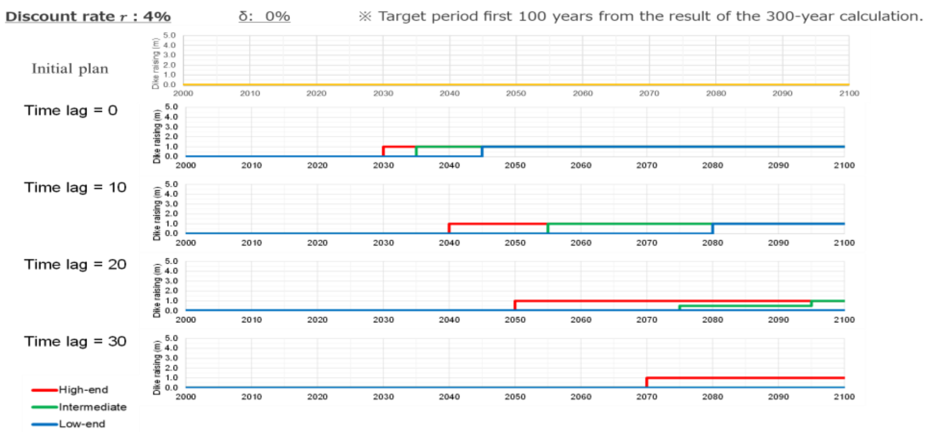

Fig.3 Optimal Adaptation Decision Making (RCP2.6)