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Impact assessment of climate change on water-related disasters for building up an adaptation strategy

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Abstract To estimate probabilistic characteristics of extreme floods and to predict the magnitude of a largest-class flood under a changing climate are a key issue for building up an adaptation strategy. In this research, a physically-based method to estimate a probable largest-class flood and a flood damage assessment method considering probabilistic flood characteristics are introduced. Based on the future flood prediction techniques, an adaptation strategy to cope with flood disasters is discussed.

Keywords *river discharge prediction*, *climate change*, *a largest-class flood*, *flood risk curve*

Introduction

Flood predictions are classified into three categories: the flood magnitude prediction in terms of the flood frequency such as the annual maximum 100-year flood, the largest-class flood prediction such as a probable maximum flood (PMF), and the real-time flood prediction. To improve these flood prediction techniques is a key engineering issue to cope with flood disasters. In this study, a largest class flood prediction and a probabilistic assessment of flood damage occurrence are focused.

To estimate a largest-class flood, a physically-based flood prediction method using a multi-track ensemble numerical typhoon simulation (Ishikawa *et al*., 2012; Oku *et al*., 2014) is proposed. The method was applied to the historical large typhoon, the Ise-Bay Typhoon in 1959 under a present climate condition and a pseudo global warming condition (Takemi *et al*., 2013). The estimated precipitation data was given to a distributed rainfall-runoff simulation model (1K-DHM, Tachikawa and Tanaka) to predict river discharge. The estimated flood magnitude under a pseudo global warming condition is a central issue with respect to an adaptation measure to avoid catastrophic damage.

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Secondly, a method to develop a flood risk curve is presented to assess flood damage probabilistically. A flood risk curve is a relation between flood inundation damage and its exceedance probability. A procedure to develop a flood risk curve is below: 1) a probability distribution of annual maximum rainfall is obtained from historical record; 2) the relations between the *T*-year annual maximum rainfall and the maximum inundation water depth are obtained through rainfall-runoff and inundation simulations for different spatio-temporal rainfall patterns; 3) economic damage is estimated for each rainfall-runoff and inundation simulation; and finally 4) the relation between economic damage and its exceedance probability is obtained by integrating the exceedance probability of the annual maximum rainfall that causes the inundation damage for all spatio-temporal rainfall patterns. To cope with huge rainfall-runoff and inundation simulations, a nesting rainfall-runoff-inundation method is newly developed to reduce computational burden.

Largest-class flood prediction

Takemi *et al*. (2013) developed a heavy rainfall dataset based on an ensemble simulation of the historical extreme typhoon, the Ise-Bay Typhoon (1959) using a mesoscale meteorological model, the Weather Research Forecasting (WRF) model version 3.1.1. The ensemble simulation method realizes to generate different typhoon tracks perturbed from the original track of the typhoon by applying a potential vorticity inversion (PVI) method (Ishikawa *et al*., 2012; Oku *et al*., 2014). Fig. 1 shows the typhoon tracks simulated by the PVI method for the Ise-Bay Typhoon in 1959. The ensemble simulation approach was also applied to the typhoon under a pseudo global warming condition by setting a different sea surface temperature. The difference of the sea surface temperature was given based on the difference of the monthly mean SST in September between the end 21st century climate experiment (2075-2099) and the present climate experiment (1979-2003) simulated by MRI-AGCM3.2 (Mizuta *et al*., 2012).

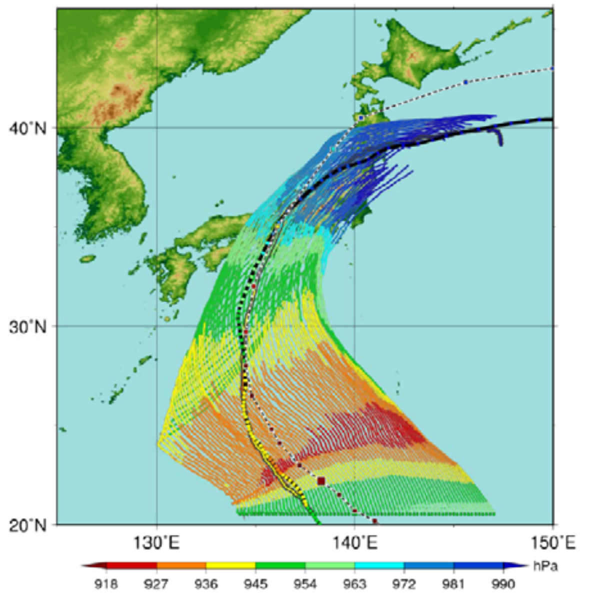


Fig. 1 Virtual shifting of typhoon's initial position for the Ise-Bay Typhoon in 1959 (Takemi *et al.*, 2013).

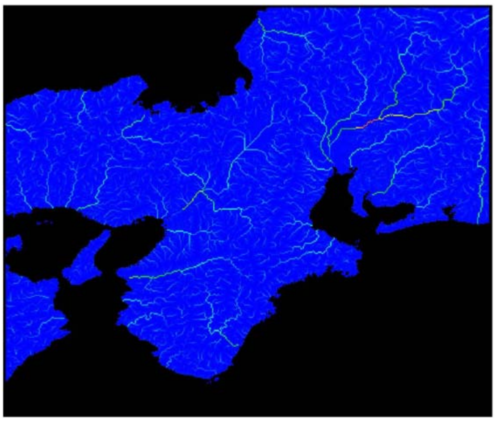
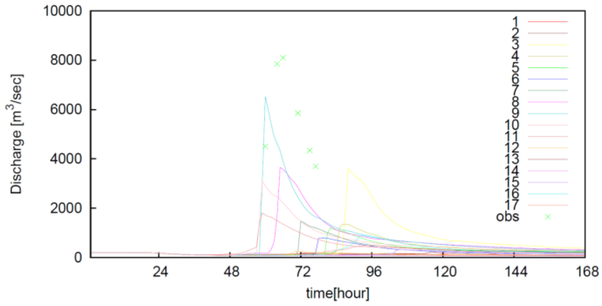
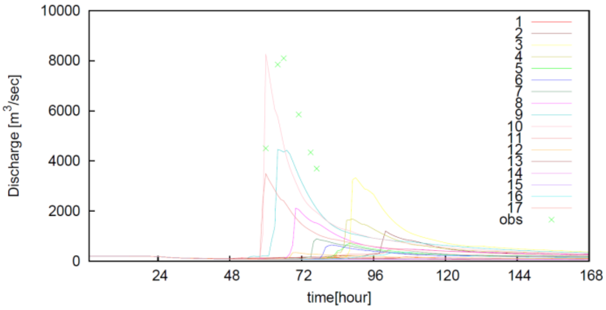


Fig. 2 Spatially distributed river flow for the Central and Kansai regions in Japan simulated by a distributed hydrologic model, 1K-DHM.

The simulated rainfall data was given to a distributed rainfall-runoff model (1K-DHM) developed for the Central and Kansai regions in Japan (Fig. 2). The simulated discharge for each typhoon track was stored with about 1km grid resolution. Fig. 3 shows the simulated hydrographs at the Hirakata station (7,281km^2) in the Yodo River basin for various typhoon tracks. For each grid cell in the study region, the typhoon track which causes the maximum discharge was analyzed. Fig. 4 shows a spatial distribution of the typhoon track number that caused the maximum discharge for each grid cell. The flood runoff simulation results for the present climate condition shown in Fig. 3 underestimate the observed data, however, the ones for the pseudo global warming condition clearly shows the increase of flood flow.



(a) Simulated flood hydrographs for the present climate condition.



(b) Simulated flood hydrographs for the pseudo global warming condition.

Fig. 3 Simulated flood hydrographs at the Hirakata station (7,281km^2) for different conditions.

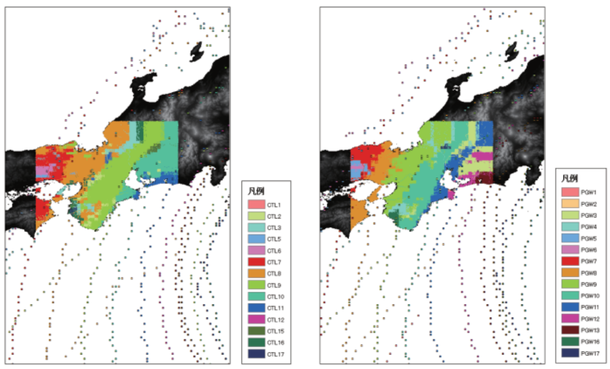


Fig. 4 Spatial distribution of the maximum discharge caused by different typhoon tracks.

New typhoon ensemble simulations using other boundary conditions and for other historical typhoons are ongoing. Improvement of the distributed hydrologic model including introduction of the dam reservoir operations and readjustment of model parameters are also underway. An inundation hydraulic simulation model will be combined with the hydrologic simulation. The method proposed here provides information on physically-based largest-class floods under a changing climate, which is basic information for building up an adaptation strategy.

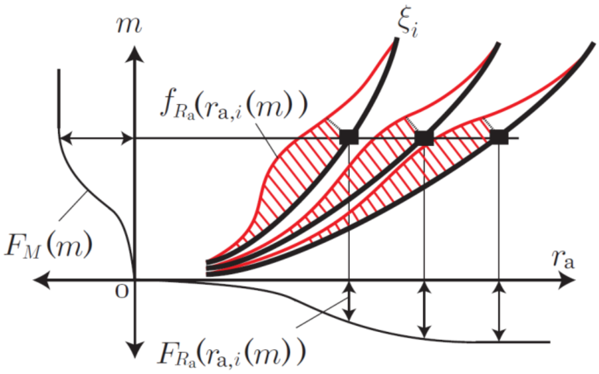


Fig. 5 Schematic explanation of the translation of a distribution function of the *D*-day annual maximum rainfall r_a to a distribution function of inundation damage *m* through various rainfall patterns (Tanaka *et al*., 2015).

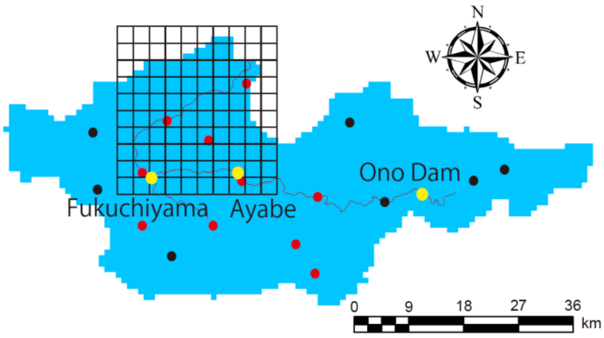


Fig. 6 Yura River basin (1,882 km^2) in Japan. A distributed hydrologic model 1K-DHM was applied to the entire basin and inundation simulations were applied to the gridded area. The black and red marks represent rainfall observation stations and the yellow marks represents river stage gauging stations.

Probabilistic assessment of flood damage using flood risk curve

To manage flood disasters flood risk control based on appropriate risk assessment is essential. To realize an integrated economic risk assessment by flood disasters, a flood risk curve plays an important role. A flood risk curve provides a relation between flood inundation damage and its exceedance probability. A method to obtain the flood risk curve considering the uncertainty of spatio-temporal rainfall distribution is newly proposed (Tanaka *et al*., 2015).

A flood risk curve is generated from a probability distribution function of the annual maximum rainfall distribution through the following processes (Fig. 5): 1) to prepare typical extreme rainfall patterns ξ_i; 2) to obtain a probability distribution of the annual maximum rainfall $F_R(r_a)$ from the historical data; 3) to obtain relations between *T*-year annual maximum rainfall and the maximum inundation water depth through a rainfall-runoff and inundation simulation; and 4) the economic damage *m* is estimated for each maximum inundation depth caused by the *T*-year annual maximum rainfall r_a. These procedures are conducted for each typical extreme rainfall pattern. Finally, the relation between economic damage *m* and its exceedance probability $F_M(m)$ is obtained by integrating the exceedance probability of each inundation damage. The schematic instruction of the development of the flood risk curve is shown in Fig. 5. This method requires many rainfall-runoff and inundation simulations, thus a nesting runoff-inundation simulation method to reduce computational costs was also developed.

The method was applied to the Yura River basin (1,882 km^2, Fig. 6) in Japan. Rainfall-runoff simulation was applied to the entire basin using a distributed hydrologic model 1K-DHM with about 1km spatial resolution. Then, inundation simulations were applied to the gridded area located at the lower part of the basin. The estimated spatial distributions of indention depth were used to calculate the indention damage amount using a guideline to estimate the economic damage (MLIT, 2005).

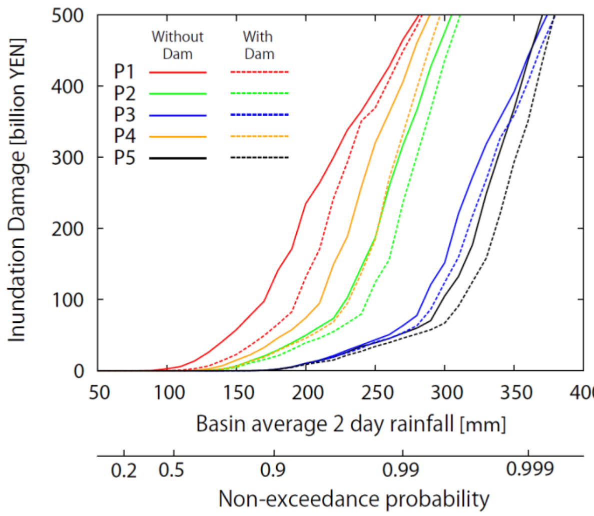


Fig. 7 Relation between the 2-day basin average rainfall and inundation damage estimated by rainfall-runoff and inundation simulations. The lines P1 to P5 show the relation for each rainfall pattern. Solid and dashed lines represent case studies with and without dam operation (Tanaka *et al*., 2015).

Fig. 7 shows the estimated relations between the 2-day basin average rainfall at the Yura River basin and inundation damage obtained by rainfall-runoff and inundation simulations. The lines indicated by P1 to P5 show the relation for each rainfall pattern. Solid and dashed lines represent case studies with the dam operation at the Ono dam and without the dam operation. Each risk curves reflect the magnitude of rainfall and a difference scenario of flood works.

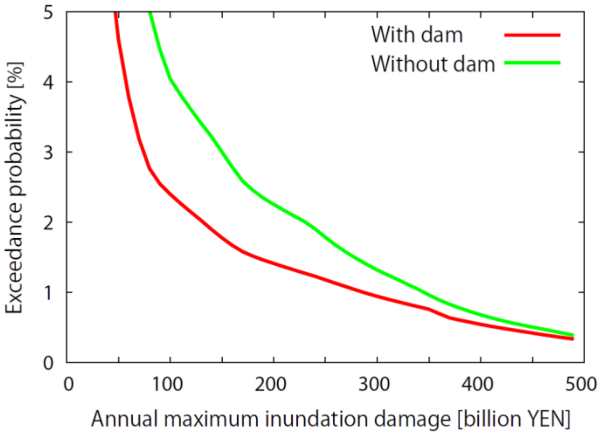


Fig. 8 Estimated flood risk curve at the Yura River basin (Tanaka *et al*., 2015).

Fig 8 show the integrated flood risk curve which was derived by integrating the relation shown in Fig. 7. The flood risk curve considers the spatio-temporal rainfall patterns and a distribution function of the magnitude of rainfall which cause inundation disasters at the Yura River basin. This information reflects the probabilistic occurrence of heavy rainfall and flood under various scenarios, which provides key information to cope with water-related disasters.

Summary and conclusions

In this study, predictions of a largest-class flood and a probabilistic assessment of flood damage occurrence are introduced. To provide a physically-based prediction of a largest-class flood, a rainfall-runoff simulation with the multi-track ensemble numerical typhoon simulation under a pseudo global warming condition was demonstrated. Then, a development of a flood risk curve was presented to assess flood damage probabilistically. The proposed methods provide essential information to develop an adaptation strategy to cope with water-related disasters

Acknowledgement

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