Chapter

Storm Surge Risk Assessment for Non-Life Insurance

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Abstract

This chapter introduces the efforts of the storm surge risk assessment for non-life insurance especially focusing on Japan. First, the importance of storm surge risk assessment in non-life insurance, the requirements for storm surge risk assessment in insurance, and an overview of the natural disaster model that evaluates them are described. Second, study on stochastic storm surge risk assessment, study on storm surge hazard modeling, study on vulnerability modeling which convert hazard intensity into damage are presented. Third, as an actual calculation example, the results of applying the procedure with low calculation load presented by past study to Tokyo Bay are shown. As a result, it is confirmed that the procedure can reduce the calculation load and maintain the calculation accuracy. Finally, how to select the existing storm surge risk assessment procedures when risk assessment is actually performed for the insurance purposes is considered.

Keywords: storm surge, risk assessment procedure, non-life insurance, stochastic typhoon model, Tokyo Bay

1. Introduction

This section introduces the natural disaster model and background of development in the insurance industry focusing on Japanese topics.

In 2016, the Japanese government revised the basic disaster management plan of Japan. According to the updated plan, Japanese government encourages the transfer of flood risk to non-life insurance because future flood risk will increase due to climate change [1]. Globally, economic losses and insurance losses due to natural disasters are on the rise, and the number of wind and flood damage that directly causes insurance losses is increasing significantly [2]. In Japan, on average, over 140 billion yen has been paid annually for insurance due to wind and flood damage since 1991 [3]. With the background of such government trends and increase of wind and flood risk, the risk transfer to non-life insurance has become more critical.

Non-life insurance companies measure the amount of natural disaster risk for their own risk management [4]. Therefore, it is important to properly evaluate the amount of risk. Storm surge damage with strong wind damage accompanying typhoons can be serious when the typhoon is highly intensified, and if damages of wind and storm surge occur at the same time, it may be a peak risk for non-life insurance companies [5]. The Ministry of Land, Infrastructure, Transport and Tourism's Port Bureau published "Guidelines for Storm surge Risk Reduction Policies on Offshore Areas of Ports" in 2018 [6]. Over 80% of the harbor areas in the three major bays of Japan (Tokyo Bay, Ise Bay, and Osaka Bay) are offshore areas of levee, and this guideline has promoted taking measures against storm surges on the areas. Even on the coasts of the three major bays, where the population and assets are particularly concentrated, small storm surges may cause floodwaters and damage many assets.

A major Japanese non-life insurance company has adopted 99.5% Value at Risk as the maximum risk amount that can be directly used for management decision-making [4]. In the natural disaster model that measures the risk amount with a low exceedance probability, hazards and economic loss are evaluated based on a probabilistic approach [7].

The history of the introduction of the natural disaster model in the insurance industry is following [8]. Around the 1960s, manual mapping was used for risk management until then, but information technology and Geographic Information System (GIS) have gradually advanced, and the technical base has been established. With regard to data and theory, scientific measurements of natural disasters have made rapid progress since the first half of the 20th century, and studies have been published that theorize the source and frequency of events by the 1970s. A computer-based model (a natural disaster model) for measuring a potential catastrophe was developed by fusing these technological bases, data and theory. Because of Hurricane Andrew in 1992, nine insurance companies could not pay perfectly for insurance claims, and necessity of the natural disaster model had been increased as a basis for decision making in many insurance companies and reinsurance companies. Along with the growing needs of the insurance industry, vendors of natural disaster models has grown and developed.

The natural disaster model used in the insurance industry consists of three modules: hazard module, vulnerability module, and financial module (**Figure 1**) [9]. In the natural disaster model, the hazard module first calculates wind speed, inundation depth, etc., then the vulnerability module converts the information into the damage ratio of the target object such as a house, and finally the financial module calculates the insurance loss considering insurance contract conditions. Natural disaster models continue to be important in insurance industry decision-making [10].

In underwriting, which examines insurance risks, the spatial distribution of inundation depth for each return period may be used [11]. However, the hazard map released by the Japanese government is a result based on the assumed scenario and is not sufficient to utilize it for the purpose of underwriting. Also, the expected annual loss calculated by the natural disaster model is used as a reference when insurance is priced [12].

From the above, the basic requirements to be satisfied by the natural disaster model from the perspective of non-life insurance are as follows.

1. To be able to predict low-frequency loss.

2. To be able to calculate the expected annual loss.

3. To be able to create a low-frequency inundation depth map that is used for underwriting.

This Chapter aims to discuss how to select the existing storm surge risk assessment procedures for non-life insurance. In order to discuss this point, review of the procedures including the latest methods with low calculation load and high calculation accuracy are introduced.

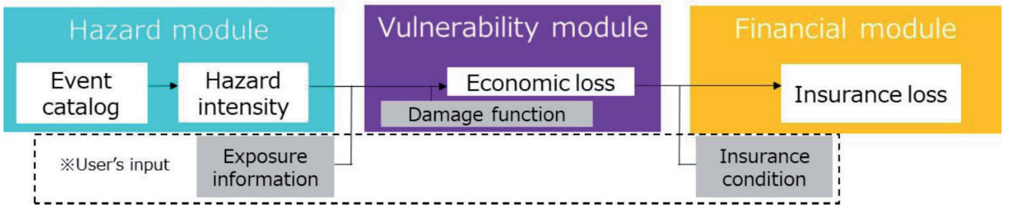

Figure 1.
Components of natural disaster model (based on InterRisk Research Institute & Consulting, Inc. [9] 2013).

2. Review of storm surge risk assessment methods

In this section, previous research and efforts related to storm surge risk assessment are described.

2.1 Study on stochastic storm surge evaluation

As a storm surge hazard study, Suzuki [13] conducted flood simulation over the whole of Japan, estimated the loss along the coast from the results, and developed loss function which is the relationship between water level at the representative point and the economic loss in the coastal area. The characteristics of this study are that the target area is wide and that large-scale storm surges due to climate change are also incorporated. However, since flood calculation is performed by a simple flood model, there is a issue in the accuracy of flood analysis, and no probabilistic discussion has been made in this study. Examples of publication on probabilistic storm surge damage estimation are following. Tsujita et al. [14] probabilistically calculated storm surge loss in the three major bays in Japan by using stochastic typhoon model. The stochastic typhoon model used in this study statistically processes past typhoon information and calculates the assumed typhoon that will occur in one year for 1000 patterns, so it does not consider future climate. The random variables are typhoon parameters (central pressure, location of typhoon, moving speed). This approach is common to the calculation of insurance purposes, which analyzes natural disaster risk in the coming year in many patterns and uses it for risk management and insurance premium setting. Exceedance probability used for risk management in non-life insurance companies is low. If the calculation period set long, the number of evaluation typhoons will increase and the calculation results will be stable and the uncertainty will decrease. The issue is that there is no discussion about the calculation period that was carried out. In addition, this study did not incorporate levees explicitly in the storm surge simulation, and no discussion on astronomical tide level setting. Similarly, Jiang et al. [15] probabilistically evaluated the current and future climate storm surge losses in the inner part of Ise Bay and showed the relationship between the annual exceedance probability and the storm surge loss. As for the present and future climates, a virtual typhoon for 25 ensembles of 200 years is used to evaluate the loss.

In the previous research mentioned above, it is common that firstly storm surge flood is calculated and secondly the loss is calculated from the inundation depth and the damage function which convert inundation depth into damage rate of the targeted assets. On the other hand, there is not enough discussion about uncertainty. In the process of calculating the storm surge loss, there are many parameters such as astronomical tide level, wind velocity/pressure distribution formula, maximum wind velocity radius, damage function, etc., and it is important to evaluate their effect on the estimated loss. Another issue is that there is no discussion about whether the calculation period is sufficient for the important return period.

A representative example of storm surge risk assessment efforts is the HUZUS-MH (Hazards U.S. Multi-Hazard) [16] developed by the Federal Emergency Management Agency (FEMA). This is software that estimates the damage caused by earthquakes, hurricanes, and floods in the United States, and displays damage of buildings and infrastructure due to past hazards. In addition, for the flood insurance program in the United States, FEMA has created a storm surge risk map with annual exceedance probability of 10, 2, 1, 0.2% in the United States, and has evaluated storm surge risk by various methods [17]. As a method, extreme value analysis, EST (Empirical Simulation Technique), and JPM (Joint Probability Method) have been studied. EST is a method of estimating the occurrence probability of the water level based on the observed tide level at a certain point by Probability distribution and constructing an artificial event set by the bootstrap method. JPM captures characteristics of hurricanes from observation information, constructs possible hurricanes from probability distributions of central pressure, moving speed and so on, and performs storm surge numerical calculation for all of them. While EST depends on limited observation data, JPM can comprehensively consider hurricanes etc. that may occur, and in recent years, JPM approach has been recognized as suitable for stochastic evaluation [17].

Similarly, in the natural disaster model of the insurance industry and probabilistic storm surge risk assessment in academic research, the method of calculating storm surges using assumed typhoons that capture past typhoon characteristics like JPM for a long term such as 1 year × 10,000 patterns has become common (eg AIRWORLDWIDE [18], Risk Management Solutions [19], Tsujita et al. [14]). That is, for example, when analyzing typhoons stochastically in Japan, it is assumed that a total of about 30,000 typhoons will land for 10,000 years because about 3 typhoons land in one year in average. However, it has been pointed out that the issue is that the computational cost is high because JPM calculates storm surges for all possible typhoons [17].

In order to reduce the calculation load of storm surge simulation, Jiang et al. [15] limited the typhoons that numerically calculate storm surge under the following three conditions.

- Typhoons that pass within 100 km of the bay
- Typhoons with a minimum central pressure of 950 hPa or less
- Typhoons with a typhoon speed of 20 km/h or more when landing

Through this process, typhoons that can flood are extracted. However, when considering variations in astronomical tide levels, it is not sufficient to evaluate storm surge risk because storm surge risk also depends on astronomical tide level, and it is necessary to use the total water level considering tides. In addition, the discussion on how much small and medium-scale storm surge damage can be extracted and uncertainty of annual expected loss of storm surge are insufficient in this paper.

In the US, FEMA has developed and is currently using JPM-OS (Joint Probability Method – Optimal Sampling), which is a method that reduces the calculation load of JPM (Johnson et al. [20]). Here, JPM-OS is briefly described. First, JPM-OS performs storm surge inundation analysis only on representative events selected from the numerous typhoon events. Then, the results are interpolated to estimate the inundation depth of the event for which no flood analysis has been performed. Although it is possible to reduce the calculation load by one digit compared to JPM [17], the problem is that uncertainty arises during interpolation. In order to reduce the uncertainty, research is underway on JPM-OS interpolation methods (eg Yang et al. [21]). Yang et al. compared the calculation results of the inundation depth for different JPM-OS interpolation method for each return period in Florida, USA. The RMSE of each method was 0.16 to 0.82 m when the inundation depth at each point was compared with the calculation result by JPM for each interpolation method for the return period of 50, 100, and 500 years. It was shown that an error occurs between the interpolated result and the numerical calculation result regardless of whether the return period is long or short.

As another approach, Hisamatsu et al. [5] selected a typhoon that can be inundated by a simple formula for typhoons of the stochastic typhoon model, and calculated the storm surge inundation only for the selected typhoon using a numerical model. Procedure by Hisamatsu et al. is described in **Figure 2**. This method aims at both reduction of calculation load and preservation of calculation accuracy by extracting floodable typhoons. Additionally, fluctuation of astronomical tide can be considered. The brief results of applying this procedure to the Tokyo Bay, Japan are shown in Section 3.

2.2 Study on hazard modeling

There are various storm surge models all over the world, but here some of them are introduced.

As a method for numerical analysis of storm surge hazards, a lot of studies have shown that considering wave set-up improves reproducibility. Kim et al. [22] developed a SuWAT (Surge-Wave-Tide coupled model), which is a model that considers wave set-up. SuWAT is a two-way coupled model that considers the interaction between tidal, storm surge and wave. The SuWAT model, composed of depth-integrated nonlinear shallow water equations and a simulated-waves near-shore (SWAN) model, can simultaneously run an arbitrary number of nested domains by using the message passing interface (MPI). Mase et al. [23] simulated typhoon Vera 1959 using SuWAT, and showed that the reproducibility of the storm surge is greatly improved if wave set-up is incorporated explicitly. Since SuWAT has been used by a lot of research especially in Japan and other Asian regions (eg Hisamatsu et al. [5]), this model has been adopted to natural disaster model of the insurance industry as numerical simulation model for storm surge [24].

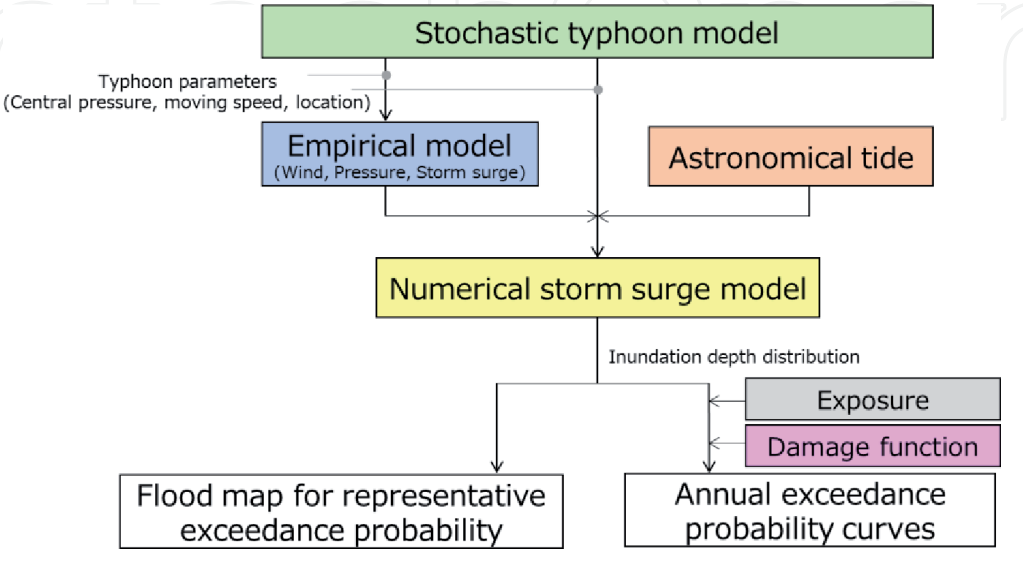

Figure 2.
Procedure of stochastic storm surge proposed by Hisamatsu et al. (based on Hisamatsu et al. [5] 2020).

In flood calculation, models that improve the calculation speed have been used. For example, Ramirez et al. [25] used LISFLOOD-FP [26] for flood calculation, which is dynamic and has a small calculation load. Inundation calculation load of storm surge was further reduced by using the flood model with the results of the storm surge model as boundary conditions (eg. Tsujita et al. [14]).

2.3 Study on vulnerability modeling

Some existing research on the damage function, which estimates the damage of assets from the inundation depth, are presented.

Regarding the relationship between tsunami inundation depth and its damage, as a representative of the tsunami damage caused by the 2011 Great East Japan Earthquake, the fragility curves expressing the probability of occurrence for each degree of damage have been published (eg Suppasri et al. [27], Aránguiz et al. [28]). These fragility curves are functions that calculate the occurrence probability P_i of each damage level i (minor, moderate, major, complete) using the inundation depth η as an explanatory variable as shown in the following equation (Eq. (1)).

$$P_i = f_i(\eta) \tag{1}$$

However, since this fragility curve does not show the damage ratio of assets, it is not possible to directly calculate the loss from the hazard intensity of the tsunami. Dias et al. [29] presented a method of converting the fragility curves into damage function. In other words, the tsunami fragility curves that have been accumulated so far can be converted into a tsunami damage function that can directly calculate the asset damage ratio R using the inundation depth as an explanatory variable, as shown in the following equation (Eq. (2)).

$$R = f(\eta) \tag{2}$$

The storm surge damage function of HAZUS in the United States is frequently used to estimate the storm surge damage amount, which converts the storm surge inundation depth into asset damage rate (eg, Johnson et al. [20], Lin et al. [30]). The damage function installed in HAZUS was developed by US Army Corps of Engineers through post-flood research and interviews with experts [31, 32]. In addition, Kar and Hodgson [33] theoretically constructed a storm surge damage function.

In Japan, damage functions in Manual of Economic Survey for Water Management published by Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan is widely used (eg Hisamatsu et al. [5], Tsujita et al. [14], Jiang et al. [15]). The reason is that there is no other storm surge damage function for Japanese assets. This was constructed based on the survey conducted in 1993 to 1996, and the issue is that the information of the material and equipment of the house, etc. surveyed deviates from present. Therefore, some study described relationships between inundation depth and damage ratio based on survey and simulation as following. Suzuki et al. developed flood damage function by hearing-based survey [34]. And Hisamatsu et al. developed flood damage function using the result of flood simulation and insurance data [35]. Unfortunately, small number of studies on damage functions is conducted. However, it is possible to accumulate storm surge damage functions based on the approach described above for actual events.

The shape of the damage function is roughly divided into two types, a step function and a continuous function. Kar and Hodgson [33] and the MLIT are the former, while US Army Corps of Engineers [32], Suzuki et al. [34] and Hisamatsu et al. [35] are the latter. In other cases, such as Tsujita et al. [14], the step function of the MLIT is regressed and converted into a continuous function and is used for damage estimation. In the case of the step function, since the damage function is constructed by setting the damage of modeled building according to the inundation depth, the function that the damage increases when the water level reaches the floor or ceiling of the modeled building. However, the structures of buildings that are actually damaged vary, damage ratio at the same inundation depth differs depending on the building. Therefore, the damage functions of US Army Corps of Engineers [32] and Suzuki et al. [34], which were constructed based on the disaster survey, is a continuous damage function because it covers buildings with various structures.

3. Case study in the Tokyo Bay, Japan

The storm surge risk assessment procedure described in **Figure 2** was applied to the Tokyo Bay where assets are concentrated in Japan in order to whether the calculation accuracy can be maintained by reducing the calculation load is considered.

As a stochastic typhoon model, global stochastic typhoon model (GSTM) developed by Nakajo et al. [36] is used for evaluation. Typhoons created by the GSTM is extracted around Tokyo Bay (**Figure 3**), and top 1000 typhoons are used as input data of numerical model SuWAT following proposed procedure. Prior to apply SuWAT, reproductivity of the model is validated by calculating time series storm surge levels of Typhoon Irma along the Tokyo Bay coast. The astronomical tide level

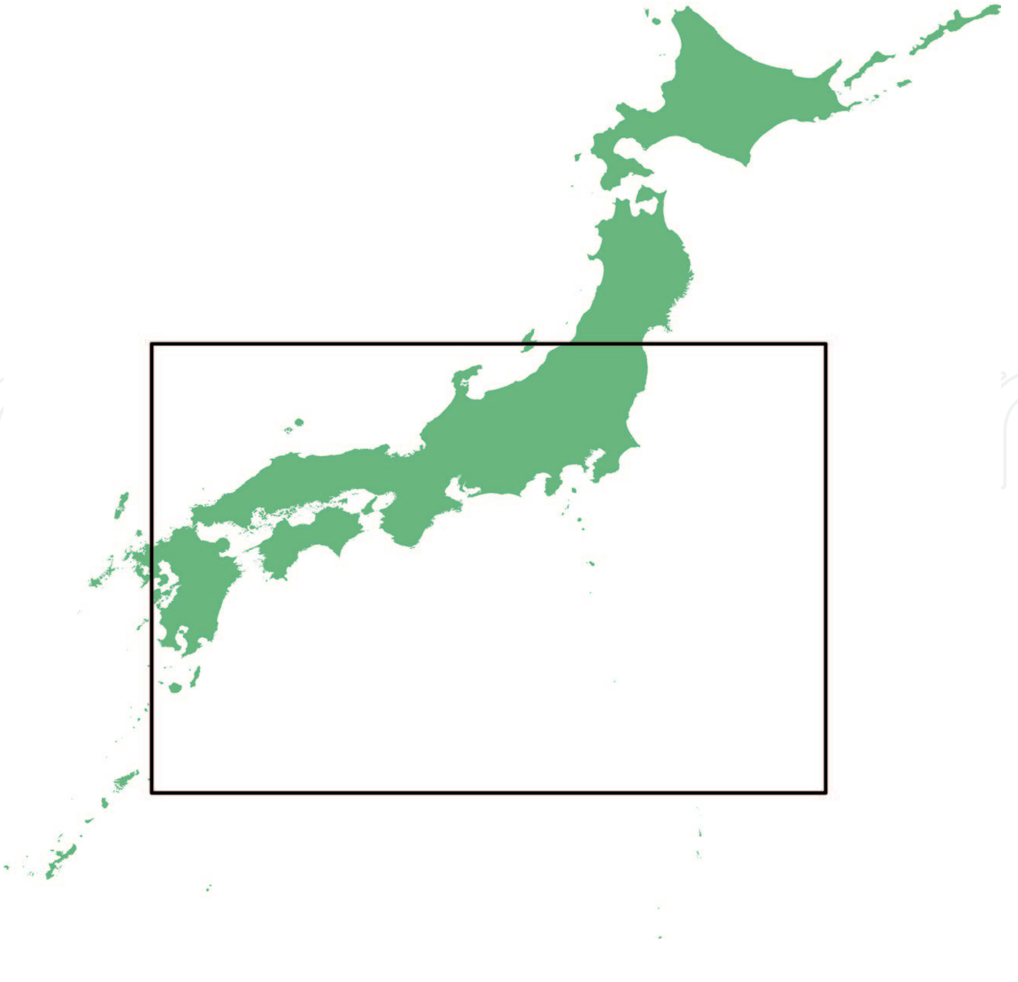

Figure 3.
Area where typhoon is extracted (Hisamatsu et al. [37] 2020).

was calculated by using the harmonic constants to estimate the time series tide level at the Tokyo tidal station for 100 years from January 2000 to December 2099. The astronomical tide level for each typhoon was set by randomly extracting from this histogram of calculated astronomical tide levels. From above calculation, storm surge inundation depth distributions due to 1000 typhoons are obtained. Example of the results is shown in **Figure 4**.

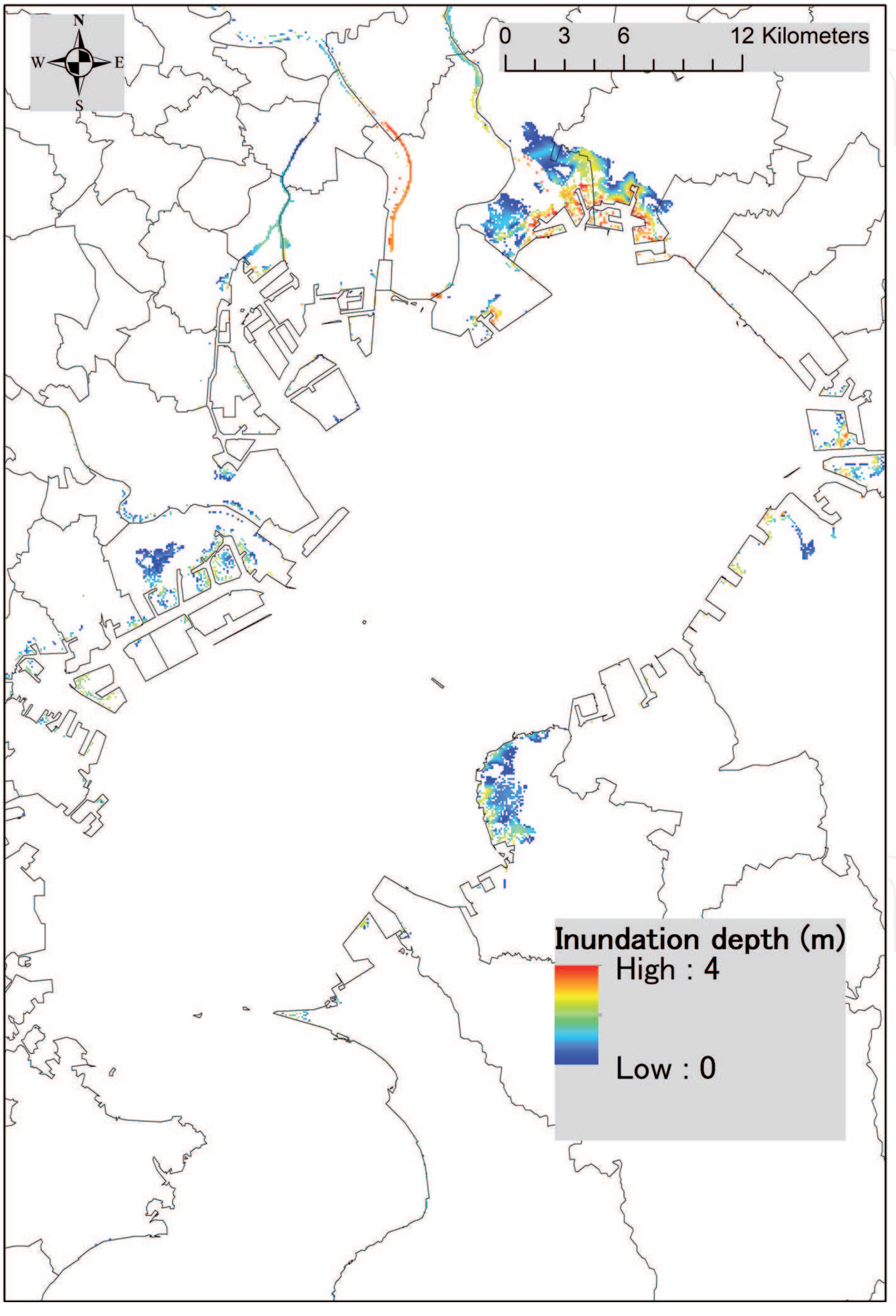

Figure 4.
Example of simulation result.

In addition, economic loss is estimated by using the inundation depth calculated and damage functions by MLIT. Targeted assets are houses and business establishments and loss calculation consider number of floors. By using calculated loss amount, exceedance probability curve is created as described in **Figure 5**.

From the above calculations, it was confirmed that the insurance requirements shown in Section 1 are satisfied by applying suggested procedure. However, it is necessary to consider whether or not calculation accuracy can be maintained by reducing the calculation load following the procedure. Here, consideration conducted by Hisamatsu et al. [37] is introduced.

The storm surge loss introduced in this section was estimated by extracting typhoons from the stochastic typhoon model based on the top 1000 water levels by the storm surge empirical formula. The maximum water level by the storm surge empirical formula used in the extraction process is different from the numerical model result. Therefore, the ranking of the maximum water level in the Tokyo Bay differs between the numerical model and the empirical formula. It is important to check whether the number of events extracted by empirical formula was sufficient for insurance purposes, in order to confirm the usefulness of the proposed procedure. **Figure 6** shows the estimated loss by rank for each number of extracted typhoons. The horizontal axis shows the number of typhoons extracted from the top of the total water level based on the empirical formula, in other words, number of typhoons used for the analysis, and confirms how many typhoons the loss amount of the target order will converge. In the analysis based on 1000 typhoons, the losses in the top 50 and above were almost converged. It was suggested that 1000 typhoons based on the proposed procedure are generally sufficient to obtain low-frequency damage amounts for the purpose of insurance. In addition, it was confirmed that the infrequent water levels in Chiba, Yokohama, and Yokosuka would converge with 1000 typhoons extracted in the same way.

According to discuss the annual expected loss amount, it was confirmed that the annual expected loss amount not being fully converged. It was found that the reason was the creation of the asset amount distribution. Since the amount of assets is created from statistical information, the resolution is coarser than that of storm surge numerical analysis. Because the statistical information is distributed according to the resolution of the numerical analysis, it is distributed to the place where the asset originally does not exist and the loss amount is calculated.

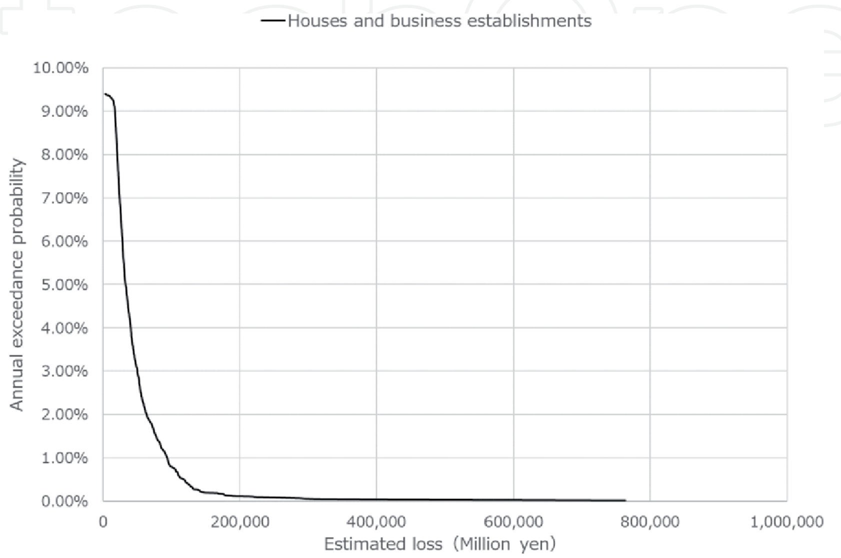

Figure 5.
Annual exceedance probability curve.

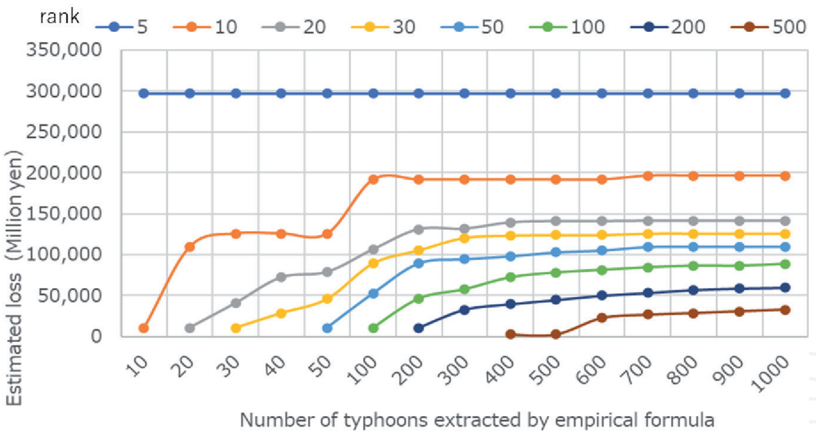

Figure 6.
Estimated loss by rank for each number of extracted typhoons (based on Hisamatsu et al. [37] 2020).

On the other hand, the places where the number of floods was extremely high in the numerical calculation of storm surges are waterside areas where no assets actually exist. As a result of estimating the loss amount ignoring the loss at these areas, it was confirmed that the expected annual loss amount has converged. Therefore, if the asset amount distribution can be corrected more realistic this problem will be solved. It also suggests that asset allocation is very important for risk assessment.

4. Conclusion

In this chapter, the efforts of storm surge risk assessment in the non-life insurance industry are introduced based on the author's experience. In the insurance industry, probabilistic storm surge risk assessment is required for risk management and underwriting, and a lot of analysis is required. Therefore, how to reduce the calculation load without degrading the calculation accuracy is being discussed. In this chapter, author introduced a previous study on reducing computational load. In particular, an example in which the procedure of numerically calculating only typhoons that can cause floods was applied to Tokyo Bay is introduced.

This procedure is useful in two ways. The first point is to significantly reduce the calculation load. The procedure aims at both the reduction of the calculation load and the reduction of the calculation error compared to other methods. By applying the procedure, it was found that for Tokyo Bay, the number of typhoons to be calculated can be reduced from about 90,000 to 1000 and the calculation accuracy can be maintained. By utilizing this procedure, the cost of storm surge risk assessment can be reduced, and the reduction of insurance rate may be possible, so that taking out insurance and transferring risks to ensure a safer life for more people are expected. In addition, even if the stochastic typhoon model is updated, the risk can be quickly evaluated based on the latest knowledge considering climate change and reflected in the risk management of the insurance company. The second point is that the loss amount can be evaluated more appropriately by considering the variation of the astronomical tide level. The uncertainty associated with risk assessment for insurance purposes can be recognized and reduced by varying the astronomical tide level.

In the insurance industry, the procedure applied to the Tokyo Bay in this chapter and the method like JPM-OS should be used separately. First, the characteristics of the evaluation target site should be considered. Since the procedure applied to the Tokyo Bay analyzes storm surges for all typhoons that may flood, it has a great effect on reducing computational load in areas where flooding is unlikely to occur, such as the Tokyo Bay. However, when targeting areas with high flooding frequency, such as Southeast Asia, the number of typhoons that can be flooded will be huge, and the effect of reducing computational load cannot be expected. Therefore, it is necessary to judge the risk assessment by JPM-OS allowing the calculation accuracy in such areas with high flood frequency. Next, requirements to be evaluated should be considered. It is necessary to analyze a lot of typhoons, especially when obtaining the expected annual loss. The distribution of inundation depths for each return period used for underwriting and the loss for the representative return period required for risk management target at low-frequency risks, so it is not necessary to analyze all typhoons of stochastic typhoon model. In this case, if the method applied to the Tokyo Bay in this chapter is used to calculate until the hazard and loss amount in the representative return period converge, it is possible to reduce the calculation load and evaluate with high accuracy.

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Conflict of interest

The authors declare no conflict of interest.

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