Hydrological Research Letters **10**(3), 101–105 (2016)
Published online in J-STAGE (www.jstage.jst.go.jp/browse/hrl). DOI: 10.3178/hrl.10.101

Impact assessment of climate change on coastal hazards in Japan

Nobuhito Mori[1], Mark Kjerland[1], Sota Nakajo[2], Yoko Shibutani[3] and Tomoya Shimura[1]
[1]*Disaster Prevention Research Institute, Kyoto University, Japan*
[2]*Urban Design and Engineering, Osaka City University, Japan*
[3]*Tottori University, Japan*

Abstract:

Understanding future changes of ocean waves and storm surges is important for assessing and mitigating the impact of climate on coastal, marine and ocean environments and on engineering problems. This paper reviews the latest research results of climate change impacts on coastal hazards in Japan. First, future changes of wave climate and storm surges based on MRI-AGCM ensemble experiments are summarized. Second, the applications of coastal hazard projections to coastal structures and beach profiles are summarized as a series of climate impact assessment projects. There are clear increases in extreme values of wave heights and storm surges in the tropical cyclone dominant regions around the middle latitudes of the Western North Pacific including Japan. The influence of future climate change on caisson breakwaters is discussed considering sea level rise, extreme wave conditions and storm surges targeting the Pacific side of Japan.

KEYWORDS climate change; sea level rise; wave height; storm surge; coastal structures; beach profile

INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) WGI Fifth Assessment Report (AR5) (2013) states that climate change exacerbates the vulnerability on regional scales to extreme and impulsive physical processes, such as heavy precipitation (e.g., Takemi *et al.*, 2016), river flooding and storm surges (e.g., Yasuda *et al.*, 2010). For example, the local extreme precipitation intensity will be changed following saturated water vapor (e.g., Yamada *et al.*, 2014) and related hydrological cyclone activity is also expected to change under the warmer climate conditions (e.g., Nakaegawa and Mori, 2012). However, the impact assessment of natural hazards due to climate change is still difficult on regional scales due to scale differences between global/general circulation models (GCMs) and hazard scales (less than O (10–500 km)). The impact assessment of climate change on natural hazards was discussed in the IPCC-AR5 WGII (2014) but the number of available quantitative results is still limited on individual regional scales. The quantitative climate change impact on regional scales is expected for the next assessment report.

Climate change due to global warming is expected to have major impacts on phenomena such as typhoons, monsoons, precipitation, and seasonal storms. Understanding future changes of ocean waves and storm surges is important for assessing and adapting to the impact of climate on coastal, marine and ocean environments and on engineering problems. Study of ocean wind waves and storm surges in stormy conditions is important for coastal, ocean, and environmental engineering. Changes in the severity and occurrence of ocean wave and storm surges are some examples of how climate change affects coastal regions (e.g., Mori and Takemi, 2016). If extreme coastal hazards become more frequent and severe in the future, it is necessary to consider their effects to prevent or at least mitigate their impact on coastal areas. Although extreme events in coastal physics are important, average values are also important for understanding long-term changes in coastal environments such as beach profile. Furthermore, one major factor of climate change impact to the East Asia region is tropical cyclone activity and it is valuable to extend the latest results of climate change impact on natural hazards from atmospheric conditions and precipitation to coastal hazards.

This paper summarizes recent results on impact assessment of future change of waves and storm surges and their consequence in applications to coastal engineering studies targeting Japan and East Asia since 2012. An example framework assessing climate change impact on coastal hazards is shown in Figure 1.

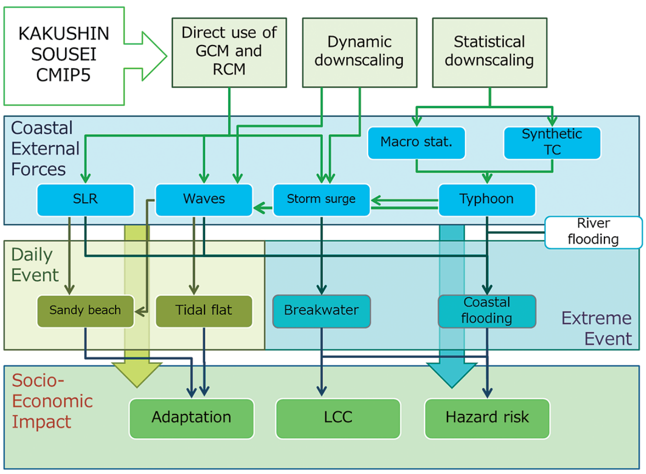

Figure 1. Overview of impact assessment of climate change on coastal hazards by SOUSEI program (TC: tropical cyclone, SLR: sea level rise, LCC: life cycle cost)

Received 26 August, 2016
Accepted 24 October, 2016
Published online 30 November, 2016

Correspondence to: Nobuhito Mori, Disaster Prevention Research Institute, Kyoto University, Gokasho, Kyoto 611-0011, Japan. E-mail: mori@oceanwave.jp

PROJECTION OF OCEAN WAVES

The impact of climate change on wave climate was first examined in Mori *et al.* (2010), by dynamical projection, and subsequent studies examined similar wave climate projections (Hemer *et al.*, 2013). Although the dynamic projection of wave climate change was first discussed in Chapter 13 of IPCC AR5 WGI, the number of projections is quite limited and the uncertainty of projection is currently large (e.g., Hemer *et al.*, 2013).

The discussion of wave climate change in AR5 is mainly based on the multi-GCM and multi-wave model results in coarse resolution larger than 100 km scale. Therefore, it is difficult to discuss the regional impact of climate change on wave climate. A series of single GCM and single wave model ensemble projections has been conducted targeting the Western North Pacific (Shimura *et al.*, 2015a, 2015b). The wave climate project considered forcing by different future projections by MRI-AGCM with changes in sea surface temperature (SST) (Mizuta *et al.*, 2012). The dynamic wave projection was conducted by the spectral wave model WaveWatch III (Tolman, 2009). This is a time-slice experiment forced by the SRES A1B scenario (corresponding to RCP6.5 in AR5) changing spatial patterns of future SSTs and cloud physics targeting the period 1979 to 2009 for the present climate and 2075 to 2099 for the future climate (see detail in Mizuta *et al.*, 2012). A 12-simulation ensemble of future wave climate projections was conducted by the same AGCM and scenario. Similar impact assessments have been discussed in different sectors based on the MRI-AGCM projections in Japan as part of the SOUSEI program.

Figure 2 shows the future change of the 10 years return wave height H_{10} (hereafter referred to as extreme wave height) in the Western North Pacific Ocean (WNP) (Shimura *et al.*, 2015b). The extreme wave height will significantly increase in the southern part of the Japanese Pacific coast in the range of 3–4 m in a 10 years return period which corresponds to 15–20% changes in comparison with the 10 years return wave height H_{10} at the present climate condition. The major contribution to extreme wave climate change is changes of intensity, frequency and tracks of tropical cyclones (denoted hereafter by TC). Although the frequency of TC will be reduced due to a more stable atmospheric condition in the future climate, the warmer climate can generate stronger TCs and will shift their tracks eastward in the WNP (e.g., Mori, 2012). This will cause changes in the summer extreme wave climate with longer return periods in the WNP as well as changes in heavy precipitation. As coastal sea walls and other protections are designed based on 20–50 year return period wave conditions, such changes in extreme wave climate will have a significant impact on designing and maintaining coastal and ocean structures.

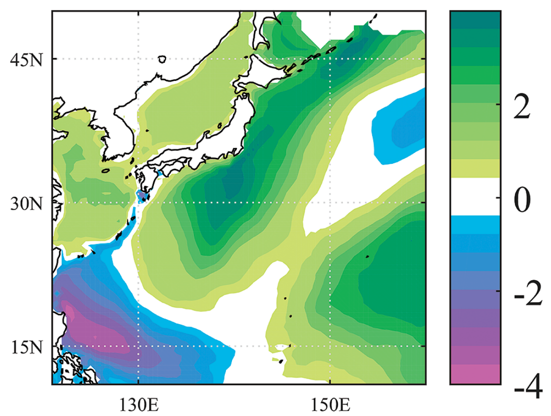

Figure 2. Ensemble results of future change of 10 year return wave height H_{10} of TC waves (unit: m). Figure 9(c) of Shimura *et al.* (2015b) with the permission of American Meteorological Society which holds the copyright of the original figure

The mean wave height will also change due to global warming effects. The average changes and their deviation vary significantly by season and sea area. Shimura *et al.* (2015a) discussed the future changes of mean wave climate based on the same ensemble run of extreme wave climate in the WNP. The mean wave height significantly increases (up to approximately 0.4 m) in the center of the Northern Pacific in December-February. On the other hand, there is a significant decrease in the mean wave height in the WNP. The range of change is approximately 7.5% of the mean wave height in the present condition. The ranges of change in the wave height off southern Japan and East Asia are significant in June-August and September-November, but the projections in the sea area have a large uncertainty due to SST. In addition, the projected changes of mean wave height in the WNP is similar in scale to projections of sea level rise (SLR) but they have different spatial distributions. Thus it is important to discuss the combination of mean wave height change and SLR in the regional impact assessment.

PROJECTION OF STORM SURGES

It is important to consider the influence of climate change on storm surges as well as SLR and wave climate change. As storm surge height is highly sensitive to local bathymetry and TC characteristics (e.g., intensity and track), a long-term impact assessment is not easy due to infrequent occurrence O (100 years) at any particular bay (e.g., Kumagai *et al.*, 2016). To evaluate the climate change impact on storm surges, there are several methodologies of storm surge assessment. First is direct storm surge simulation based on wind fields and sea level pressure of GCM output (referred to as direct GCM simulation; e.g., Yasuda *et al.*, 2010, 2014). Second is based on a regional climate model with a pseudo global warming technique (denoted by PGW; e.g., Takayabu *et al.*, 2015; Ninomiya *et al.*, 2016). Third is statistical modeling based on a synthetic tropical cyclone model (denoted by STM; e.g., Nakajo *et al.*, 2014).

The direct GCM simulation for storm surge is quite straightforward and useful. Figure 3 shows a 25 year return value of storm surge height and its variance around the western part of Japan (Yasuda *et al.*, 2016). A storm surge simulation was conducted using a nonlinear shallow water model to evaluate the intensity of the change in the recurrence probability values forced by wind speed and sea level pressure from 20 km and 60 km MRI-AGCM under the SRES A1B scenario, similar to the wave climate projection in the previous section. The 25 year return value of storm surge

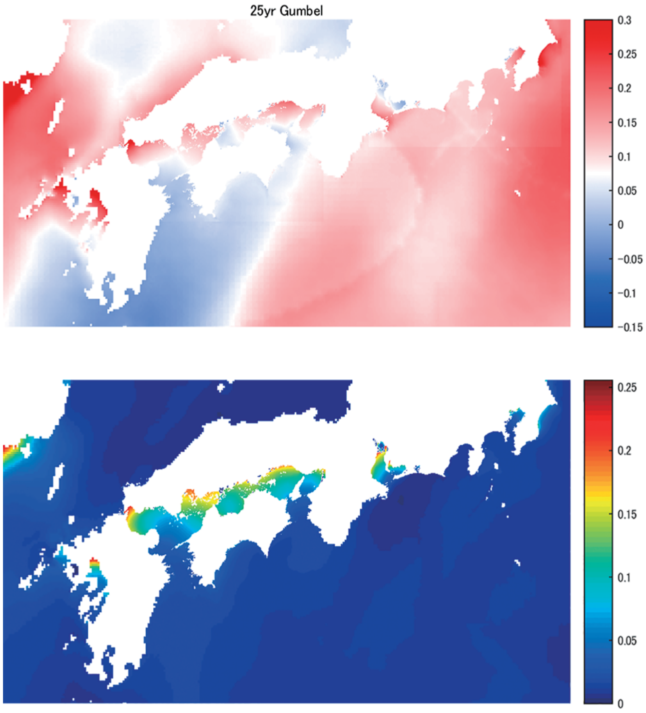

Figure 3. Ensemble mean and variance of 25 year return value of storm surge height based on 16 ensemble runs (unit: m; top: mean, bottom: variance). Figure 6 of Yasuda *et al.* (2016) with the permission of Japan Society of Civil Engineers which holds the copyright of the original figure

height will increase in most of the Seto Inland Sea region from Shimonoseki to Osaka, in Ise Bay including Nagoya, and in other areas. The differences of future change of local storm surge may be due to the deviation in the frequency and track of typhoons in the present and future climates, but could be due to the differences in typhoon intensity and track shift (Mori and Takemi, 2016). Although many typhoons pass through areas near the Kyushu Island under the present climate, the AGCM projected that the number of passing typhoons around this area will decrease in the future. However, due to the limited number of ensembles and the experimental period (total 400 years in this case), the sample size may be insufficient for long-term impact assessment over 50 years. Thus, evaluating the reliability and uncertainty of the absolute values is a future challenge.

The pseudo global warming technique (PGW) is an alternative choice to evaluate extreme storm surge height at a particular location. The PGW makes an impact assessment of storm surge considering the worst-case scenario which analyzes perturbations of typhoon characteristics (e.g., track, intensity) for a specific typhoon event at a specific location. The PGW experiments adds future climate condition over particular historical events and gives consistent results to historical extremes. One example of the worst case scenario was estimated for a historical extreme storm surge caused by Typhoon Vera (1959) using a regional weather model, the Weather Research and Forecasting Model (WRF), based on a pseudo global warming approach to investigate the changes in storm surge height for the district of Nagoya in Japan. The effects of global warming were applied towards typhoon intensity based on the Coupled Model Intercomparison Project Phase 3 and 5 (CMIP3 and CMIP5) analysis (Mori and Takemi, 2016). Based on the pseudo global warming approach with worst case track, the maximum storm surge height for this event in a future climate is 4.67 m, which is an increase of 1.14 m and 0.48 m in the storm surge deviation compared with the historical record and the worst case track, respectively. As the maximum storm surge height with climate change and worst case track becomes more severe in comparison with worst case track without climate change, both the global warming and the worst case scenario have significant impact on maximum storm surge height. The ratio of global warming and worst case track can be changed depending on the target region and event. It is important to know the worst case scenario and related risk of storm surge using this type of perturbation approach due to the sensitivity of storm surge to the typhoon track (e.g., Jiang *et al.*, 2015).

The third methodology uses a synthetic tropical cyclone model (STM) which can generate an unlimited number of tropical cyclones based on the historical statistical characteristics (e.g., Mori, 2012). The STM can significantly increase the number of TCs over the globe and is useful for storm surge modeling if we apply a parametric TC model for the wind fields.

COASTAL STRUCTURES AND BEACH PROFILE

The future changes in extreme waves has a significant impact on coastal and ocean structures and protections. There are several applications of impact assessment for breakwaters (e.g., Suh *et al.,* 2012), wave dissipation blocks (e.g., Mase *et al.*, 2013) and wave overtopping (e.g., Mase *et al.*, 2015). These applications require knowledge of the above-mentioned extreme coastal environmental forces such as ocean waves, storm surges and sea level rise.

Figure 4 shows an example application of wave climate change to reliability design of a breakwater at the port of Hitachinaka in Japan (Suh *et al.*, 2012). Both wave climate change and sea level rise have been considered for the reliability design of the breakwater. This is one case study and the results strongly depend on the locality of future change and the specification of the coastal structure. The Port of Hitachinaka is an important major port in Japan whose construction began in 1983. Construction of the east breakwater began in 1989 with plans to build a long offshore breakwater; it is still under construction with 5,280 m completed as of April 2010. The bottom slope near the Port of Hitachinaka varies from 1 : 80 to 1 : 100, with a depth of 10 m at 0.8 km offshore and a depth of 20 m at a distance of 2.0 km offshore. The water depth at the breakwater site is 24.2 m (below low water level: LWL), and the breakwater is located about 2.6 km from the shoreline. The breakwater is 6 km long, is oriented in the north-south direction, and is parallel to the shoreline. In performance-based design, the caisson is designed so that the expected sliding distance (SD) is below a tolerable limit. The sliding distance is calculated with the model of Shimosako and Takahashi (2000). The computational procedure to calculate the expected sliding distance and the mathematical model to calculate the sliding distance can be found in many papers (e.g., Shimosako and Takahashi

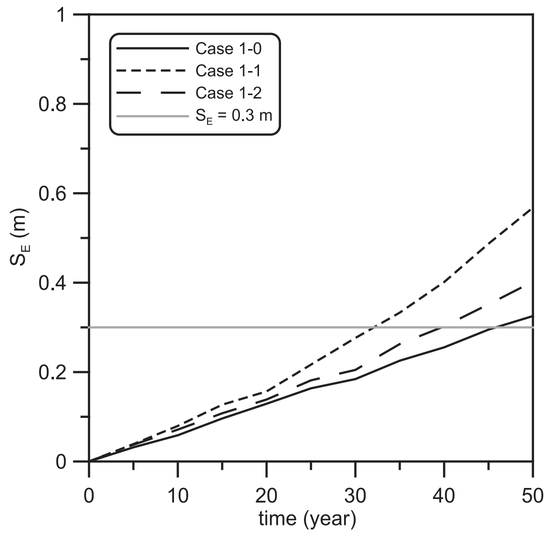

Figure 4. Temporal variation of expected sliding distance (S_E) considering climate change (Case 1-0: no climate change, Case 1-1: sea level rise and linear wave height increase trend in the future, Case 1-2: sea level rise and quadratic wave height increase trend in the future). Figure 4 of Suh *et al.* (2012) which is permitted for author to reuse by copyright holder, American Society of Civil Engineers

2000). The breakwater was assumed to be completed in 2000, and the computations were made for 50 years, from 2000 to 2050. The future change of wave climate was computed comparing two different periods (1979–2004 and 2075–2099) so the temporal change of extreme wave climate cannot be projected directly. Therefore, a linear and quadratic increase in extreme wave height were assumed from the results of the previous section. The sea level rise based on the CMIP3 multi-model ensemble for the A1B scenario was used near the target region (Mori *et al.*, 2013). The projected mean sea level rise on the Pacific Ocean side of Japan (130–145°E, 25–40°N) is about 20 cm at the end of 21st century. It was assumed that the threshold value of the breakwater's functional value is constant, so the allowable expected sliding distance is 0.3 m.

Figure 4 compares the temporal variations of expected sliding distance across the three cases. Case 1-0 is the case where no climate change impacts were considered (present day case), and Cases 1-1 and 1-2 are the cases where both sea level rise and wave height increase were considered, assuming linear or quadratic increase of wave height, respectively. A linear increase in wave height yields larger expected sliding distance values than a quadratic increase. The 50 year return period deep-water wave height changes from 8.28 m to 9.15 m during the period of 2000–2050 if a linear increase is assumed, while it changes from 8.28 m to 8.71 m for a quadratic increase. The detail of analysis was described in Suh *et al.* (2012). With expected sliding distance, the critical years when the allowable sliding distance is exceeded are 46 years (no climate change impact), 40 years (quadratic increase), and 32 years (linear increase). Assumed future change of extreme wave climate and sea level rise had been discussed by the previous climate change impact assessment study. Using the projected future change of extreme wave climate based on the GCM results, the future change of extreme wave climate has a much more significant impact on coastal structure design than sea level rise due to tropical cyclone activity change at the middle latitudes. The extreme wave climate change can be a major factor if the design water depth becomes deeper. A similar case study for composite breakwater has been discussed by Mase *et al.* (2013). They concluded that the effects of climate change on the sliding distance of composite caisson and necessary caisson width are larger than those calculated by the present climate's conditions.

The mean wave climate change relates to coastal morphology. Regarding nearshore processes, coastal erosions are another critical issue associated with the climate change, since more than 70% of sandy beaches around the world are presently erosional (Leatherman *et al.*, 2000). The equilibrium conditions of coastal beach profiles depend on seasonal or annual changes in the wave height, period, and direction, and historical records indicate a relationship between long-term variations of shoreline change and wave climate (e.g., Kuriyama *et al.*, 2012; Barnard *et al.*, 2015). The wave climate change is not only changing heights but also changing directions depending on the region. As beach profiles are sensitive to wave direction, regional scale projections of beach profiles should include changes in wave heights, periods and directions. This is a future challenge of coastal impact assessment and adaptation.

DISCUSSION AND CONCLUSION

This paper reviewed the latest projections of ocean waves, storm surges, and their applications for coastal structures and beach profiles. Based on MRI-AGCM projections and their single model ensemble experiments, a series of impact assessments has been conducted targeting coastal hazards and related applications.

The future wave climate changes strongly depend on region and conditions. Future increases in extreme waves and winds were detected in the Western North Pacific including Japan due to changes of tropical cyclone activities. Changes in the 10-year return values of significant wave height, Hs, in the Western North Pacific Ocean are more than 2–3 m over present climate values at the maximum. Storm surge will be stronger in the future climate and is expected to increase 0.5–1.0 m at particular locations. Changes in both TC intensities and tracks are related to future changes in extreme wave climates and storm surges in the WNP. The climate change impact on coastal structures suggests a significant change in breakwater design due to a combination of extreme wave climate change and sea level rise. The extreme wave climate change can become a major factor if the design water depth becomes deeper. The wave climate, storm surge and sea level rise projections on regional scales are among the key issues for future study of climate change impact and adaptation in coastal studies.

ACKNOWLEDGMENTS

This research was supported by the SOUSEI Program and by a Kakenhi Grant-in-Aid of the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), Japan.

REFERENCES

Barnard PL, Short AD, Harley MD, Splinter KD, Vitousek S, Turner IL, Allan J, Banno M, Bryan KR, Doria A, Hansen JE, Kato S, Kuriyama Y, Randall-Goodwin E, Ruggiero P, Walker IJ, Heathfield DK. 2015. Coastal vulnerability across the Pacific dominated by El Niño/Southern Oscillation. *Nature Geoscience* **8**: 801–807. DOI: 10.1038/ngeo2539.

Intergovernmental Panel on Climate Change (IPCC). 2013. Climate change 2013: The physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK and New York, USA; 1533. DOI: 10.1017/CBO9781107415324.

Intergovernmental Panel on Climate Change (IPCC). 2014. Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK and New York, USA; 1132.

Hemer M, Fan Y, Mori N, Semedo A, Wang X. 2013. Projected changes in wave climate from a multi-model ensemble. *Nature Climate Change* **3**: 471–476. DOI: 10.1038/nclimate 1791.

Jiang X, Mori N, Tatano H, Yang L, Shibutani Y. 2015. Estimation of property loss and business interruption loss caused by storm surge inundation due to climate change: A case of Typhoon Vera revisit. *Natural Hazards* **84**: 35–49. DOI: 10.1007/s11069-015-2085-z.

Kumagai K, Mori N, Nakajo S. 2016. Storm surge hindcast and return period of a Haiyan-like super typhoon. *Coastal Engineering Journal* **58**: 1640001. DOI: 10.1142/S0578563 416400015.

Kuriyama Y, Banno M, Suzuki T. 2012. Linkages among interannual variations of shoreline, wave and climate at Hasaki, Japan. *Geophysical Research Letters* **39**: L06604. DOI: 10.1029/ 2011GL050704.

Leatherman SP, Zhang K, Douglas BC. 2000. Sea level rise shown to drive coastal erosion. *Eos, Transactions American Geophysical Union* **81**: 55–57. DOI: 10.1029/00EO00034.

Mase H, Tsujio D, Yasuda T, Mori N. 2013. Stability analysis of composite breakwater with wave-dissipating blocks considering increase in sea levels, surges and waves due to climate change. *Ocean Engineering* **71**: 58–65. DOI: 10.1016/j. oceaneng.2012.12.037.

Mase H, Tamada T, Yasuda T, Karunarathna H, Reeve, DE. 2015. Analysis of climate change effects on seawall reliability. *Coastal Engineering Journal* **57**: 1550010. DOI: 10.1142/ S0578563415500102.

Mizuta R, Yoshimura H, Murakami H, Matsueda M, Endo H, Ose T, Kamiguchi K, Hosaka M, Sugi M, Yukimoto S, Kusunoki S, Kitoh A. 2012. Climate simulations using MRI-AGCM3.2 with 20-km grid. *Journal of the Meteorological Society of Japan* **90A**: 233–258. DOI: 10.2151/jmsj.2012-A12.

Mori N. 2012. Projection of future tropical cyclone characteristics based on statistical model. In Cyclones formation, triggers and control, Oouchi K, Fudeyasu H (eds). Nova Science Publishers, NewYork, USA; 249–270.

Mori N, Takemi T. 2016. Impact assessment of coastal hazards due to future changes of tropical cyclones in the North Pacific Ocean. *Weather and Climate Extremes* **11**: 53–69. DOI: 10. 1016/j.wace.2015.09.002.

Mori N, Shimura T, Yasuda T, Mase H. 2013. Multi-model climate projections of ocean surface variables under different climate scenarios – Future change of waves, sea level and wind. *Ocean Engineering* **71**: 122–129. DOI: 10.1016/j.oceaneng. 2013.02.016.

Mori N, Yasuda T, Mase H, Tom T, Oku Y. 2010. Projection of extreme wave climate change under the global warming. Special Collections of Weather extreme event projections and their impact assessments. *Hydrological Research Letters* **4**: 15–19. DOI: 10.3178/hrl.4.15.

Nakajo S, Mori N, Yasuda T, Mase H. 2014. Global stochastic tropical cyclone model based on principal component analysis and cluster analysis. *Journal of Applied Meteorology and Climatology* **53**: 1547–1577. DOI: 10.1175/JAMC-D-13-08.1.

Nakaegawa T, Mori N. 2012. Special Collection: Weather extreme event projections and their impact assessments. *Hydrological Research Letters* http://www.hrljournal.org/special-collections/ special-collection-1, Last access August 31, 2016.

Ninomiya J, Mori N, Takemi T, Arakawa O. 2016. Impact assessment of future storm surge due to typhoon Vera as revealed by pseudo-global warming experiments. *Journal of Japan Society of Civil Engineers, Ser. B2 (Coastal Engineering)* **72**: I_1501–I_1506.

Shimosako K, Takahashi S. 2000. Application of deformation-based reliability design for coastal structures. *Proceedings of International Conference on Coastal Structures '99*, A. A. Balkema, Spain; 363–371.

Shimura T, Mori N, Mase H. 2015a. Future projection of ocean wave climate: analysis of SST impacts on wave climate changes in the Western North Pacific. *Journal of Climate* **28**: 3171–3190. DOI: 10.1175/JCLI-D-14-00187.1.

Shimura T, Mori N, Mase H. 2015b. Future projections of extreme ocean wave climates and the relation to tropical cyclones: Ensemble experiments of MRI-AGCM3.2H. *Journal of Climate* **28**: 9838–9856. DOI: 10.1175/JCLI-D-14-00711.1.

Suh KD, Kim SW, Mori N, Mase H. 2012. Effect of climate change on performance-based design of caisson Breakwaters. *Journal of Waterway, Port, Coastal and Ocean Engineering* **138**: 215–225. DOI: 10.1061/(ASCE)WW.1943-5460.0000 126.

Takayabu I, Hibino K, Sasaki H, Shiogama H, Mori N, Shibutani Y, Takemi T. 2015. Climate change effects on the worst-case storm surge: a case study of Typhoon Haiyan. *Environmental Research Letters* **10**: 064011. DOI: 10.1088/1748-9326/10/ 6/064011.

Takemi T, Okada Y, Ito R, Ishikawa H, Nakakita E. 2016. Assessing the impacts of global warming on meteorological hazards and risks in Japan. *Hydrological Research Letters* (in press).

Tolman HL. 2009. User manual and system documentation of WAVEWATCH III TM version 3.14. Technical note, MMAB Contribution, 276: 220.

Yamada T, Farukh MA, Fukushima T, Inatsu M, Sato T, Pokhrel YN, Oki T. 2014. Extreme precipitation intensity in future climates associated with the Clausius-Clapeyron-like relationship. *Hydrological Research Letters* **8**: 108–113. DOI: 10.3178/hrl.8.108.

Yasuda T, Mase H, Mori N. 2010. Projection of future typhoons landing on Japan based on a stochastic typhoon model utilizing AGCM projections. *Hydrological Research Letters* **4**: 65–69. DOI: 10.3178/hrl.4.65.

Yasuda T, Yamamoto Y, Mori N, Mase H. 2016. Future change projections of storm surge using MRI-AGCM3.2H ensembles. *Journal of Japan Society of Civil Engineers, Ser. B2 (Coastal Engineering)* **72**: I_1477–I_1482.

Yasuda T, Nakajo S, Kim S, Mase H, Mori N, Horsburgh K. 2014. Evaluation of future storm surge risk in East Asia based on state-of-the-art climate change projection. *Coastal Engineering* **83**: 65–71. DOI: 10.1016/j.coastaleng.2013.10. 003.