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CLIMATE CHANGE AND COASTAL DISASTERS (A REVIEW)

BY NOBUHITO MORI & TOMOYA SHIMURA

The Intergovernmental Panel on Climate Change (IPCC) Special Report on Ocean, Cryosphere in a Changing Climate (SROCC) [1] states that climate change may exacerbate sea level rise (SLR) up to 1.1 m for worst case scenario RCP8.5 at the end of century. The SROCC [1] also warns that extreme sea level changes, sea level plus waves and storm surges, and hazards in coastal regions would increase to various degrees under different Representative Concentration Pathway (RCP) climate scenarios. Impact assessment and adaptation of coastal regions to climate change considering regional effects are important for future coastal protection.

Introduction + Sea level rise

The impacts of climate change in the coastal regions depend on both the magnitude of changes and spatial distributions of hazards (i.e., sea-level-rise (SLR), waves and storm surges). On the other hand, adaptation to changing climate in coastal regions also differ depending on changing hazards. It is therefore important to consider the regional characteristics of changing hazards over time and the preferred protection strategy.

SROCC [1] states that climate change exacerbates global mean sea level up to 0.59 m and 1.10 m for the RCP2.6 and RCP8.5 scenarios at the end of this century, respectively. The regional differences of SLR are up to about 30 %, i.e. up to 33 cm relative to the global average. Climate change due to global warming is expected to have major impacts on tropical cyclones (TCs), monsoons and seasonal storms. Understanding future changes of ocean waves and storm surges is also important for assessing and adapting to the impact of climate on coastal, marine and ocean environments, and on engineering problems [2].

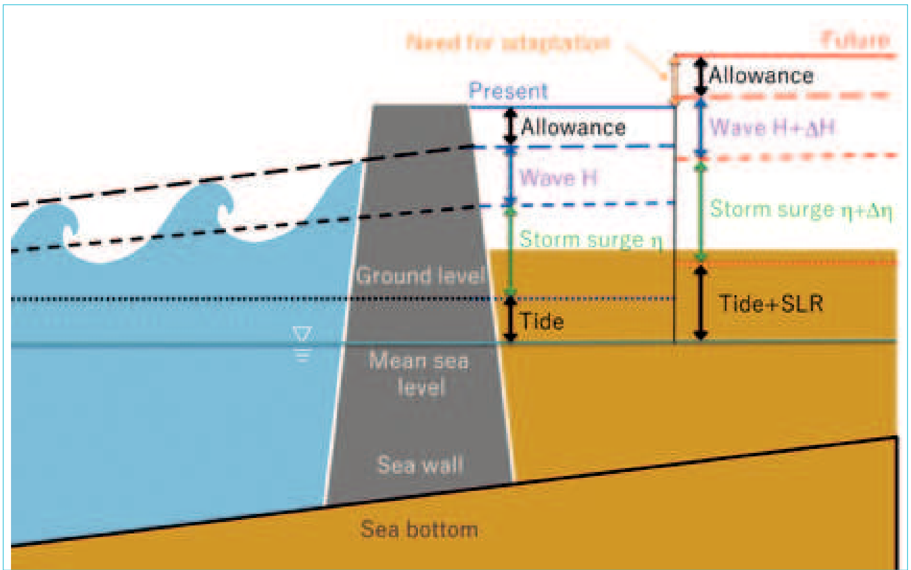

Figure 1. Illustration of climate change impact on coastal protection system.

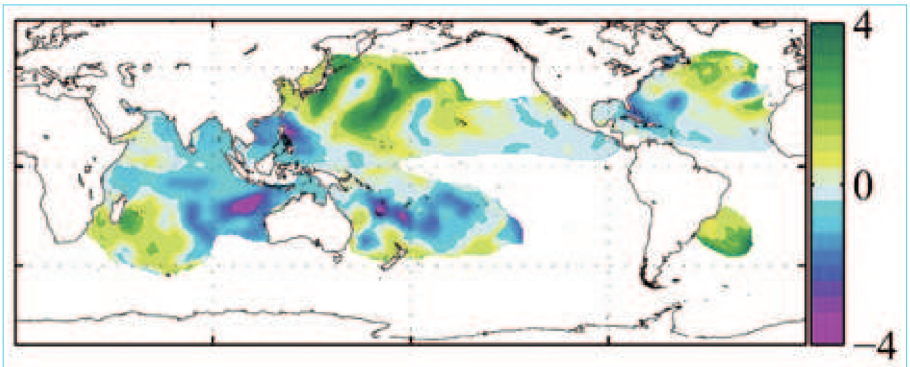

Figure 2. Future changes in 10-year return wave heights of TC-induced waves (unit: m). [8]

Sandy beaches and coastal dunes are major nature-based coastal protection features and need to be maintained as defenses against SLR and wave run-up. On the other hand, coastal urban areas are protected by hard engineered systems such as breakwaters, sea walls or storm surge barriers. Figure 1 illustrates the impact of climate change on key levels considered in the design of a typical coastal protection system. A coastal breakwater is designed accounting for the combination of maximum astronomical tidal level, maximum storm surge level and the pressure from the maximum wave condition, the so-called design wave, during the predetermined design lifetime. Coastal urban areas expected to be heavily affected by increases in storm surge include the heavily populated mega-delta regions of East Asia, South-East Asia, South Asia, Northern Europe and the Gulf of Mexico. Extreme waves are the main threat for locations which are open to ocean. Going beyond the current coastal protection level, it is important to project future SLR, extreme storm surge and wave heights (or wave run-up) considering regional characteristics. Future changes in SLR, ΔH and $\Delta\eta$ in Figure 1 are different by country and by region. Although areas of natural beaches may be affected by climate change gradually, sea wall protected areas are likely to be suddenly in danger when the total sea level becomes higher than the protection level in Figure 1. Combined projections of SLR,

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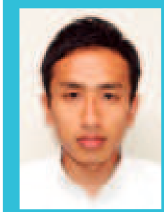

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wave heights and storm surge heights are important for understanding and preparing coastal protection.

Waves

Long term characteristics of ocean waves, called the wave climate, can be modulated by the changes in tropical cyclones (TC) and extra-tropical cyclone characteristics (frequency, duration, intensity and storm track). The wave climate can be represented by the long-term mean and extreme values of wave height, and the wave period and direction. Extreme wave conditions are important for coastal protection as indicated in Figure 1. The importance of the wave contributions, in addition to storm surge and tide, to extreme sea level change has been emphasized in recent studies. For example, Melet et al. [3] concluded that wave contributions can strongly affect long-term water-level change and variability. The mean wave climate is one of the main drivers of beach morphology and coastal ecosystem. Historical wave climate changes have been observed globally by satellites over the past three decades, showing that extreme wave heights have increased in the Southern and North Atlantic Oceans by around 1.0 cm yr^{-1} and 0.8 cm yr^{-1} over the period 1985– 2018 (IPCC, 2019)[1].

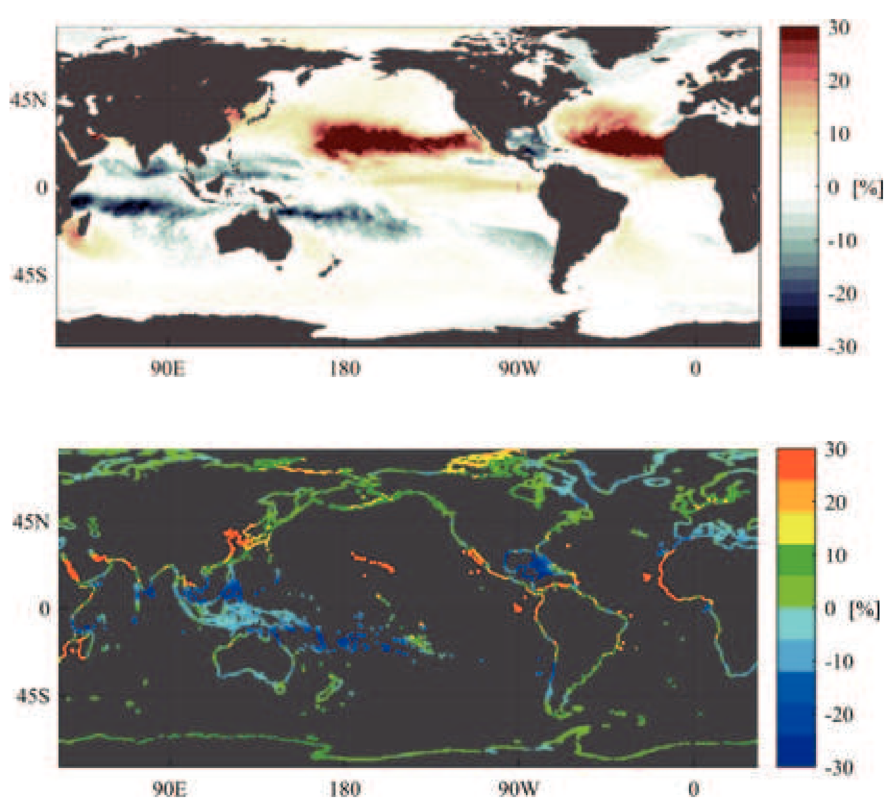

Figure 3. Example of future percent change in sea surface wind speeds (upper panel) and storm surges (lower panel) in 100-year return periods. (unit: percentage) [9]

Future projections of the global wave climate have been conducted by several research groups since IPCC-AR4[4]. Based on the average of projections by different research groups, first community-derived ensemble global wave climate projection has been summarized in the Coordinated Ocean Wave Climate Project (COWCLIP) [5] and reported in IPCC-AR5 [6]. At that time, future expected increases in wave height in the Southern Ocean were described as "*likely*". A second community-derived ensemble global wave climate projection has been conducted more recently [7]. The number of ensemble members was 148, which represents a great increase compared with the first ensemble that had only 20 members. It is *highly likely* that significant wave heights are projected to increase across the Southern Ocean and the tropical Eastern Pacific and decrease over the North Atlantic and the Mediterranean Sea under RCP8.5 by 10 % of the present climate value [1]. The knowledge of expected changes in wave period and direction is currently more limited compared with that of changes in wave height,

In terms of extreme wave climate, TC intensity is projected to increase in the future climate and thus TC-induced extreme wave conditions are expected to be more severe. There is no quantitative assessment of projected changes in TC-induced extreme waves yet (see SROCC, Chapter 4) [1]. The reason is that realistic TC intensity and the related extreme winds cannot be represented well in the Atmosphere-Ocean coupled Global Climate/Circulation Models (AOGCMs) which have been used generally for wave climate projection studies. However, based on high-resolution Atmospheric GCM climate simulations [8] predicted changes in the 10-year return period wave heights of TC-induced waves (Figure 2). The simulations showed that global TC waves would tend to decrease over the lower latitudes and increase over the higher-latitude regions. The 10-year return wave heights of TC-induced waves over the western North Pacific would either increase or decrease by 30 % maximally depending on the region. The spatial distribution of future changes in TC waves can be explained by an eastward shift of TC tracks. However, the number of extreme wave climate projection is limited. Therefore, even though a prediction of global mean wave heights is available, a quantitative assessment of expected changes in mean period, direction and extreme wave conditions, which are important for developing coastal protection measures, remains a future challenging task.

Storm surges

The impact assessment of the impact of climate change on storm surge at regional scale is difficult due to the scale differences between global/general circulation models (GCMs) and storm surge scales (less than O (1–100 km)). The impact of climate change on storm surge was discussed in the SROCC (2019) [1], which only used empirical projections based on observed data. A quantitative summary of the climate change impact at regional scale storm surge is expected to be included in the next assessment report. Assessing the impact of climate change on storm surge risk requires accounting for a number of factors besides the nature of the storm event itself (e.g. TC or extra-TC); storm surge at a particular location is affected by several storm characteristics such as the moving speed and incident angles not only frequency and intensity of storm. Therefore, assessing the storm surge risk in a particular region is difficult even when considering the historical climate alone because landfalls are not very frequent (happening in many areas only once every few decades).

Figure 3 shows an example of the future percent change in storm surge heights and sea surface winds for 100-year return period events [9]. Extreme storm surges were obtained from over 5000-year GCM simulations [10] and a simple storm surge model. Future 100-year return values of storm surge increase about 20% along the East Asian eastern coast and the US western coast, although future 100-year return values of wind speed increase by only 10% due to TCs in these areas. A moderate, future change in storm surge within 10% increase is found in the higher latitudes; which is due to a change in polar circulation in both hemispheres. Changes in wind speed by extra-tropical cyclones will be stronger in the higher Western North Pacific, but they will not be significant in the higher Northern Atlantic. As such, it is necessary to analyze how extra-tropical cyclones and related storm surges will change in the near future. These changes in extreme storm surges depend on the length of return periods. The results in Figure 3 show one such example.

Conclusion

SLR and changes in wave heights and storm surge heights in coastal areas can have a significant impact on the development of coastal protection measures.
Combined projections of SLR, wave heights and storm surge heights are important for understanding and preparing coastal protection from the present to middle or end of this century. ■

References

[1] IPCC (2019) Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, J. Petzold, B. Rama, N. Weyer (eds.)]. 1170 p.
[2] Mori, N. and T. Takemi (2016) Impact assessment of coastal hazards due to future changes of tropical cyclones in the North Pacific Ocean, Weather and Climate Extremes, Vol.11, pp.53-69.
[3] Melet, A. et al. (2018) Under-estimated wave contribution to coastal sea-level rise. Nature Climate Change, 8, pp.234-239.
[4] IPCC (2007) Climate Change 2007: The Physical Science Basis [S. Solomon, D. Quin, M. Manning, Z. Chen, M. Marquis, K. Averyt, M. Tignor, and H. L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 p.
[5] Hemer, M. A. et al. (2012). Advancing wind-waves climate science: The COWCLIP project. Bulletin of the American Meteorological Society, 93(6), pp. 791-796.
[6] IPCC (2013) Climate Change 2013: The Physical Science Basis [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)] Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.
[7] Morim J. et al. (2019) Robustness and uncertainties in global multivariate wind-wave climate projections, Nature Climate Change, 9, pp. 711–718.
[8] Shimura T., N. Mori and H. Mase (2015) 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.
[9] Mori N. et al (2019) Future changes in extreme storm surges based on mega-ensemble projection using 60-km resolution atmospheric global circulation model, Coastal Engineering Journal, 61, pp. 295-307.
[10] Mizuta R. et al. (2017) Over 5000 years of ensemble future climate simulations by 60km global and 20km regional atmospheric models, The Bulletin of the American Meteorological Society, 98, pp.1383-1398.

DURCWAVE “AMENDING THE DESIGN CRITERIA OF URBAN DEFENCES IN LECZS THROUGH COMPOSITE-MODELLING OF WAVE OVERTOPPING UNDER CLIMATE CHANGE SCENARIOS”

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assess stability for pedestrian and vehicles in the vicinity of the sea dike, demonstrating that design criteria based just on average overtopping discharges and maximum individual overtopping volume are necessary but not sufficient conditions to be met. It is therefore necessary to investigate further the overtopping and post-overtopping processes taking into account the particular dike layout and protection countermeasures (e.g. storm walls) and go beyond or amend the current design methodology for wave overtopping. This will be achieved by the end of DURCWAVE project, foreseen for April 2021. ■

References

[1] Weisse R., von Storch H., Niemeyer H.D., Knaack, H. (2012). Changing North Sea storm surge climate: An increasing hazard?. Ocean & Coastal Management, Volume 68, November 2012, Pages 58-68, ISSN 0964-5691, http://dx.doi.org/10.1016/j.ocecoaman.2011.09.005
[2] IPCC 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
[3] Hugo G. (2011). Future demographic change and its interactions with migration and climate change. Global Environmental Change, v 21, Suppl. 1: S21–S33.
[4] Neumann B, Vafeidis AT, Zimmermann J, Nicholls RJ (2015) Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding - A Global Assessment. PLoS ONE 10(3): e0118571. doi:10.1371/journal.pone.0118571.
[5] Crespo A.J.C., Domínguez J.M., Rogers B.D., Gómez-Gesteira M., Longshaw S., Canelas R., Vacondio R., Barreiro A., García-Feal O. 2015. DualSPHysics: open-source parallel CFD solver on Smoothed Particle Hydrodynamics (SPH). Computer Physics Communications 187, 204-216.

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