Graduate School of Creative Science and Engineering
Waseda University

博 士 論 文 概 要
Doctoral Thesis Synopsis

論 文 題 目
Thesis Theme

Extreme Extratropical Cyclones in The North Atlantic and Arctic Oceans - Numerical Analysis of Coastal Impacts and Future Threats -

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Much of the high-impact weather events in Northern Europe and Arctic are associated with extratropical cyclones (ETCs). In addition to impacts as windstorms, ETC-s have caused heavy precipitation and storm surges in many coastal areas, including the Baltic Sea. Coastal zones are highly vulnerable to changes in Earth climate system, firstly, due to anticipated mean sea level rise, and secondly, regarding changes in storm activity. Concurrent impacts are inundation of low-lying urban areas, coastal erosion, damage to infrastructure or even loss of life. The activity of ETCs is a dominant feature anywhere in the mid- and high latitudes during the period from autumn to spring. Any change in this activity due to global warming would have a marked influence on socio-economic and ecological systems, as well as the daily lives of many people. Most of the future climate change studies for ETC impact tend to look at General Circulation Model (GCM) long-term outputs (usually by the end of the 21st century) in order to find any changes in storm signals (frequency, intensity and tracks). However, the scientific community is not certain what changes can be really expected in ETCs, the most agreed on result is that the storm tracks will likely shift pole-wards. The current study on the other hand aims to find out whether the extreme ETCs in the Arctic and Northern Europe will get stronger under warmer climate conditions. Any such changes would have a marked socio- and economical influence. The main contribution of the study lies in providing an appropriate method for mid- and high latitude storm studies in the Northern Europe and Arctic, respectively. The secondary contribution lies in the added value for scientific communities through future study results. More precisely, the results of this research should provide some additional perspective in regards to climate change effects on extratropical cyclones, and thereby decrease a level of uncertainty which revolves around these storm systems in the future. The study investigates four different extreme Northern European ETC events under late 21st century (2090) climate change scenarios RCP4.5 and RCP8.5 and a single Arctic storm event under mid-century (2050) scenarios RCP4.5 and RCP8.5. In accordance to study scope and aims, the dissertation work was conducted under 7 chapters as follows:

Chapter 1 one is the introduction section where necessary background information is compiled and presented to provide under the context of the study theme. Secondly, research aims and motivations are presented based on the background information. The background information shows the effects of contemporary climate change to coastal areas via ETCs. Additionally, it shows the need for more research studies since historical and future studies have not yielded in any consensus whether storms have become or will become more destructive for coastal communities in the future. Thereafter ETCs effects to Northern Europe and Arctic coastal areas are presented to provide the understanding as to what degree these storms affect the coastal areas. Finally, the potential climate change effects to these storms are presented to further the understanding whether the storms will get stronger or not. The study gap is identified through currently few existing studies that show the need for reducing uncertainty when it comes to understanding future ETC changes and their impact to potentially affected coastal communities. The introduction chapter concludes with rational and objectives, where the authors main intent is to provide an adequate methodology for modelling ETCs in the North Atlantic and Arctic Oceans, and to reduce a degree of uncertainty that revolves around the future of ETCs.

Chapter 2 presents a thorough literature review of ETCs and their historical and future projection studies. While there are many various storm systems in the world that can be classified under different names, then it is necessary to define what are ETCs. The review further gives explanation to how impactful and at what time of the year ETCs occur. While ETCs are a dominant weather pattern all year long, they are however most prominent and strongest during the winter months. Observations and trends of ETCs shows that it is difficult ascertain whether these storms have gotten stronger or not, since the storm impact and severity is highly dependant on coastline configuration and other geographical and geological factors. Furthermore, in the Arctic the historical data is highly lacking and therefore most of the analysis studies have been conducted through satellite data. The future climate studies for ETCs have been generally well studies since the socio-economic potential impact is highly desirable knowledge for any and all societal parties. However, results in general do not show an overall agreement and do not address extreme storm impacts in a local area. Although the mostly it is expected that storms will have a more marked impact at very least due to rising sea levels. In Arctic the largest change is expected from the decreasing sea ice extent that leaves the low-lying coastal areas open to storm surges and waves over a longer period of type, which is further magnified by the thawing permafrost.

Chapter 3 presents all the study areas from a meso to local scale and their respective individual extreme storm cases that were considered as case studies in this research. For Atlantic this includes Northern Atlantic Ocean, Baltic Sea and Pärnu (Pärnu Bay). The ETC that were considered here are most recent extreme events, that caused various damages (surge, wave, wind and precipitation) in European countries, the details of each storm are presented and discussed in more detail from Estonia perspective. For Arctic, this includes the Arctic Ocean, Beaufort Sea and Tuktoyaktuk (Kugmallit Bay) and a single storm case was identified that caused potentially high coastal impact in the Canadian Beaufort port hamlet Tuktoyaktuk. While in Europe high impact weather events are more noticeable due to their apparent socio-economic effects, then in Arctic individual events are harder to deduce since the interest and impact from the afore mentioned standpoint is not usually considered impactful. Therefore in the Arctic an available data compilation and analysis is important to understand the potential of any historical storm impacts.

Chapter 4 presents the methodology and all the data used in the study in detail. This study is based on numerical modelling techniques and employs various models and datasets for the necessary tasks. The initial methodology phase consists model hindcasting, where the selected total of 5 ETC were simulated with atmospheric model Weather Research and Forecasting model (WRF) to achieve best suitable accuracy by using as homogeneous initial and boundary conditions. The main aim for that was to reduce any potential biases that might otherwise arise from future climate simulation where the meteorological data would be altered in accordance to GCM scenario projections. After weather hindcasting, ocean models Finite Volume Community Ocean Model with unstructured Simulating WAves Nearshore (FVCOM-SWAVE) model and SWAN model to determine significant wave height and coastal surge accuracy in the local study sites (e.g. Pärnu and Tuktoyaktuk). For future simulations the 14 GCM ensemble was used to create new atmospheric conditions. For this the study considered 3 main climate parameters: atmospheric air temperature, sea surface temperature and relative humidity. These 3 parameters were interpolated to hindcast meteorological grids. The interpolated values were achieved by deducting future period values from control period values that were gained from the GCM outputs.

Chapter 5 presents all the study results. The GCM output for each of the models and for ensemble are shown first to see what degree of changes could be expected from all of the 3 considered parameters. Since Arctic and North Atlantic domains are different and study timeframe also differs (mid century vs. end of the century, respectively) then having comparable results for both was necessary. Thereafter all the meteorological and ocean modelling results are presented in the context of all 5 ETC events. The storm surge and wave fields are shown for the storm Gudrun and St. Jude in the Northern European domains, and for the Arctic storm. For all the storms, wind fields are shown and also precipitation for North Atlantic storms. For the most part, results are compared against measurement stations. For each storm case, both hindcast and future scenario. Future scenarios for the North Atlantic included: 2090 RCP4.5, 2090 RCP8.5. For Arctic they were: 2050 RCP4.5 and RCP8.5. Also, for Arctic future simulation the sea ice extent from simulation domain was neglected.

Chapter 6 discusses the study results in detail. The main discussion points included modelling accuracy, limitations and potential implications with future outlook. Based in the results in chapter 5, the modelling results for hindcasting (i.e. historical simulations) showed good accuracy, indicating that the applied modelling system could be used to capture coastal processes with sufficient level of confidence. The strong storm events were captured better in contrast to weaker ones, reason being that the models have difficulty in reproducing weak synoptic events (wind accuracy directly effects ocean modelling accuracy). The main limitations were set in regard to data availability in the Arctic, especially in regard to lack of surge and wave observations which made verification of the results are difficult. However for the Arctic the main purpose was the develop a method that could and will be used in future studies. Future simulations showed some increase under strongest ETC events (i.e. storms Gudrun and St. Jude), while for the rest the results were more mixed leaving some uncertainty there. Under future scenario 2090 RCP8.5 the changes were most prominent, however some change was also observed for RCP4.5 In terms of future implications the research shows that some changes under RCP8.5 scenario could be expected for the strongest ETCs and to some degree also for RCP4.5 by the end of the century. The impact to coastal communities could become more severe, especially considering the relative sea level rise and changes in the morphodynamics of coastal evolution as a result. While the in Europe the communities in general are better prepared for such hazards, then in the Arctic the changes are already happening and likely will get worse.

Chapter 7 concludes the study by recapping the main take-aways from the previous chapters. The ETCs can cause significant coastal hazards anywhere in mid and high latitudes. The study focused in Northern European and Canadian Arctic individual extreme ETCs under future climate scenarios (RCP4.5 and RCP8.5) by 2090 and 2050 respectively through numerical modelling techniques. The results indicate that under the most extreme scenario RCP8.5, some changes in most extreme ETC storm events could worsen which would could leave coastal communities open higher storm surges and wave damage. Effect would be further amplified by the expected rising sea levels.

早稲田大学　博士（工学）　学位申請　研究業績書

(List of research achievements for application of doctorate (Dr. of Eng.), Waseda University)

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Journals	
○1)	**Mäll M.**, Suursaar Ü., Nakamura R., Shibayama T. Modelling a storm surge under future climate scenarios: case study of extratopical cyclone Gudrun (2005). Natural Hazards. Vol.89(3), pp.1119-1144, 2017.
2)	Nakamura, R., **Mäll, M.**, Shibayama, T. (2019). Street-scale storm surge load impact assessment using fine-resolution numerical modelling: a case study from Nemuro, Japan, Natural Hazards, Vol.99(1), pp.391-422, 2019.
3)	Takabatake, T., **Mäll M.**, Esteban M., Nakamura R., Kyaw T.O., Ishii, H., Valdez, J.J.P., Nishida Y., Noya F., Shibayama T. Field Survey of 2018 Typhoon Jebi in Japan: Lessons for Disaster Risk Management. Geosciences. Vol.8(11), pp.412-431, 2018.
○4)	Suursaar Ü., Sepp M., Post P., **Mäll M**. An Inventory of Historic Storms and Cyclone Tracks That Have Caused Met-Ocean and Coastal Risks in the Eastern Baltic Sea. Journal of Coastal Research. Vol.85(special issue), pp.531-535, 2018.
5)	Nakamura R., Iwamoto T., Shibayama T., Mikami T., Matsuba S., **Mäll M.**, Tatekouji A., Tanokura Y. Field survey and mechanism of storm surge generation invoked by the low pressure with rapid development in Nemuro Hokkaido in December 2014. Transactions of the Japan Society of Civil Engineers (Ocean Development). Vol.71(2), pp.31-36, 2015.
Conference articles	
○1)	**Mäll, M.**, Suursaar, Ü., Nakamura, R., Tasnim, K.M., Shibayama, T. (2019). Modeling parameters and impacts of future cyclones: South-East Asian and Northern European case studies. *2019 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), July 28–August 2, 2019, Yokohama, Japan.* IEEE, 9346−9349.
○2)	**Mäll, M.**, Suursaar, Ü., Shibayama, T., Nakamura, R. (2019). Modeling cyclone-related precipitation changes in future climates using WRF model and CMIP5 output data. *2019 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), July 28–August 2, 2019, Yokohama, Japan.* IEEE, 7590−7593.

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Conferences	
○1)	**Mäll M.**, Suursaar Ü., Shibayama T., Nakamura R. Modeling cyclone-related precipitation changes in future climates using WRF model and CMIP5 output data. IEEE International Geoscience and Remote Sensing Symposium (IGARSS). Yokohama, Japan, July-August, 2019. (peer reviewed, presentation type: oral)
○2)	**Mäll M.**, Suursaar Ü., Nakamura R., Tasnim K.M., Shibayama T. Modeling parameters and impacts of future cyclones: South-East Asian and Northern European case studies. IEEE International Geoscience and Remote Sensing Symposium (IGARSS). Yokohama, Japan, July-August, 2019. (peer reviewed, presentation type: oral)
○3)	**Mäll, M.**, Nakamura R., Shibayama T., Suursaar Ü. Modelling parameters and impacts of four extratropical cyclones under climate scenarios. The 36th International Conference on Coastal Engineering. Baltimore, US, July-August, 2018. (peer reviewed, presentation type: oral)
○4)	**Mäll, M.**, Kull A., Nakamura R., Shibayama T., Suursaar Ü. Modelling storm surge conditions under future climate scenarios: A case study of 2005 January storm Gudrun in Pärnu, Estonia. The 35th International Conference on Coastal Engineering. Antalya, Turkey, November, 2016. (peer reviewed, presentation type: oral)
5)	Nakamura R., **Mäll M.**, Shibayama T., Kato S. Inter-comparison of coastal models: case study of storm surge at Nemuro in Japan. The 36th International Conference on Coastal Engineering. Baltimore, US, July-August, 2018. (peer reviewed, presentation type: poster)
6)	Nakamura R., Shibayama T., Mikami T., Esteban M., Takagi H., **Mäll M.**, Iwamoto T. Comparison of two recent storm surge events based on results of field surveys. Proceedings of The International Conference of Global Network for Innovative Technology and AWAM International Conference in Civil Engineering. Penang, Malaysia, August, 2017. (peer reviewed, presentation type: oral)