Assessing the Impacts of Typhoon Hazards at Local-Scales by Dynamical Downscaling Experiments

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Abstract: We describe some case studies on typhoon hazards downscaled at local-scales by using a regional meteorological model. A pseudo-global warming experiment is used to assess the impacts of future global warming on the severity of typhoon hazards. Analysis of typhoon wind hazard within urban districts is also investigated by merging a meteorological model and large-eddy-simulation model simulations.

Keywords: typhoon, meteorological hazard, impact assessment, dynamical downscaling, large-eddy simulation

1. Introduction

A typhoon is one of the major meteorological hazards in the western North Pacific region. Typhoons cause various types of disaster-spawning phenomena such as heavy rainfalls, flooding, landslides, strong winds, storm surge, and high waves. Quantitative representations of typhoon hazards is critically important in order to assess the impacts of typhoon hazards not only for past disastrous events but also as for anticipated extreme events under future global warming. Furthermore, hazard information at local-scales is required because the resulting phenomena occur depending on their local geographic and topographic features.

Since the Innovative Program of Climate Change Projection for the 21st Century (KAKUSHIN Program, FY2007-2012) funded by the Japanese Government, we have been studying the impacts of extreme weather under future global warming (Ishikawa et al., 2013; Oku et al., 2014; Takayabu et al., 2015; Mori and Takemi, 2016; Takemi et al., 2016a, 2016b, 2016c; Takano et al., 2016; Kanada et al., 2017; Nayak and Takemi, 2019) under the subsequent Program for Risk Information on Climate Change (SOUSEI Program, FY2012-2017, Takemi et al., 2016c) and the latest Integrated Research Program for Advancing Climate Models (TOUGOU Program FY2017-). Heavy rainfalls and strong winds induced by typhoons were quantitatively examined as case studies for specific disaster-spawning typhoons.

In this paper, we describe some of the case studies on typhoons that made landfall over the Japanese islands by employing a dynamical downscaling approach with a regional-scale meteorological model. The impacts of future global warming were investigated through a pseudo-global warming (PGW) experiment. In addition to the dynamical downscaling with a meteorological model, further downscaling at building-scales in urban districts was conducted to investigate local-scale hazards in urban areas.

2. Heavy Rainfall by a Slow-Moving Typhoon

Typhoon Talas (2011) generated torrential rainfall exceeding 2000 mm and caused widespread landslides over the Kii Peninsula, Japan in September 2011. This typhoon was a slow-moving storm and produced long-lasting rains for 5 days. Here we investigated the impacts of global warming on the extreme rainfall of Typhoon Talas (2011) by dynamical downscaling at the 1-km grid spacing.

2.1 Method

This study used the Weather Research and Forecasting (WRF) model Version 3.3.1 (Skamarock et al., 2008). Two computational domains were set: the outer domain (Domain 1) covered a wide region of 4875 km by 4150 km in the western North Pacific at the 5-km grid spacing; and the nested domain (Domain 2), two-way interacting with Domain 1, covered the central part of Japan at the 1-km grid. Both domains had 56 vertical levels, with the interval stretched with height and the top at the 20-hPa level. Physics parameterizations chosen were the same with those used in Takemi et al. (2016b). The 6-hourly, 1.25o-resolution Japanese 55-year Reanalysis (JRA-55) dataset was used as the initial and boundary conditions. In PGW experiments, the warming increments are derived by the differences of the future climate states from the present climate states, obtained by global climate model simulations. In the present study, the warming increments are defined as the differences, computed as a grid-point basis, averaged in September both in the present-climate simulation and in the future-climate projection. The global-warming increments were created from the outputs of the 20-km-mesh MRI-AGCM Version 3.2 (Mizuta et al., 2012) for the present climate and the future climates under the Representative Concentration Pathway (RCP)-8.5 scenario. The warming increments were defined as the difference in the monthly means of September between the present and the future climates, and the increments of SST, air temperature, and geopotential height were added to the JRA-55 field.

2.2 Results

The track and translation speed of the typhoon were successfully simulated in the present-climate experiments and were reproduced also in the PGW experiments. The PGW experiments produced stronger typhoons with their lifetime minimum central pressure being in the range of 905.0-937.9 hPa.

The extreme amount of the total rainfall within the region increases from the present-climate to the PGW conditions. If the higher extremes of the rainfalls are focused, the total rainfall in all the PGW cases indicates a higher frequency in the higher extremes than that in the present-climate cases. In some PGW cases, the areas of the rainfall exceeding 2000 mm become wider and the total rainfall generally is more enhanced. In these cases, the hourly rainfall also becomes stronger than in the present-climate cases. The environmental factors affecting these climate change influences indicate competing contributions from increased moisture content, which promotes convection, and decreased instability, which prohibits convection. In some PGW cases that exhibit clearer signature of the increased extreme rainfall, their environmental precipitable water is significantly larger among all the PGW cases. This indicates that in terms of the rainfall impact the positive contribution from increased moisture becomes stronger than the negative contribution from decreased instability. Therefore, with a sufficient amount of moisture, strong convection develops despite an increased stability, leading to extreme rainfall.

3. Hazard Analysis in Urban Districts

Typhoon Jebi (2018) made landfall on the islands of Shikoku and Honshu, crossing over the Osaka Bay, and spawned storm surges/high waves around the bay areas as well as strong winds over the inland areas. Kansai International Airport (KIX) established on a reclaimed island in the Osaka Bay in 1994 was seriously damaged by storm surge. Furthermore, a large number of points observed extreme winds, which caused severe damages to houses/buildings, trees/forests, power lines, etc. This typhoon is the most costly hazard in Japan in terms of the insurance payment. Typhoon Jebi obtained the lifetime minimum central pressure of 915 hPa and took a track very similar to Typhoon Nancy (1961) (i.e., Daini-Muroto Typhoon) and Muroto Typhoon in 1934. Considering the time period spanning from 1934 to 2018, the influences of urbanization and global warming should be taken into account. This analysis focuses on the influences of urbanization on strong winds by Typhoon Jebi (Takemi et al., 2019). The study used both a mesoscale meteorological model and a building-resolving large-eddy simulation (LES) model. The meteorological model was intended to simulate the typhoon and its meteorological background, while the LES model simulated turbulent airflows within a business district of Osaka City. We used the LES model developed by Yoshida et al. (2018).

Figure 1 demonstrates the spatial distributions of the pointwise maximum U_{10} (surface wind) during the simulated time period. Figure 1 indicates remarkable characteristics: stronger winds around the high-rise buildings and along the wide streets specifically oriented in the north-south direction, and over wide open spaces, while weaker winds within densely built areas and along some streets oriented in the east-west direction. The ratios of U_{10} to U_{∞} (wind speed at the 326-m height) exceed 0.8 and approach 1.0 in most locations of the strong-wind regions, suggesting that the maximum wind gust reaches as strong as 60-70 m s^{-1}.

4. Summary

The significance of the slow-moving TC is that the impacts of global warming will appear remarkably for the total accumulated rainfall despite minor changes in hourly rainfall, because of long-lasting rainfall. Therefore, we conclude that the time duration of rainfall caused by slow-moving typhoons is critical in assessing the impacts of such TCs on rainfall hazards.

We further provide preliminary estimates of wind gusts in an urban district of Osaka City during the passage of Typhoon Jebi (2018) by merging the simulated results of the WRF model and the LES model. WRF successfully reproduced the track and intensity of the typhoon, which was able to provide the quantitative winds as a reference for the LES model. By explicitly resolving the buildings in a business district of Osaka City, LES reproduced airflows within the urban canopy and stronger winds around high-rise buildings and along major streets. The maximum wind gust in the analysis area was estimated as 60-70 m s^{-1}, comparable to the wind speed at the height of about 300 m.

By employing a dynamical downscaling approach and the PGW experiments, we are able to quantitatively assess the impacts of typhoons on local-scale meteorological hazards. Building-resolving LESs prove to be promising to provide quantitative hazards within urban districts.

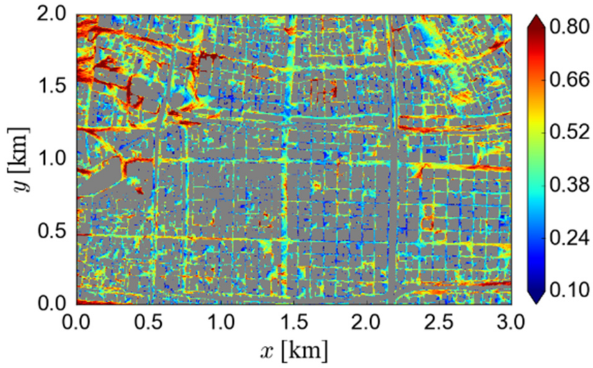

Figure 1. The spatial distribution of the maximum instantaneous wind speed at the 10-m height from the time series of the wind speed at each grid point in Osaka City.

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