Effect of dynamical downscaling to cyclone simulation: a study case for Haiyan typhoon

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Abstract. The capacity of a global gridded climate data in describing tropical cyclone (TC) activity might be still less adequate due to its coarse resolution or the TC intensity itself. Grid refinement method such as a dynamical downscaling is one way to add values of the climate attributes in the data. However, the performance of the dynamical downscaling itself still contains many uncertainties. This paper aims to evaluate the effect of the dynamical downscaling model on the climate simulation during a strong tropical cyclone Haiyan. The snapshots and the best track data from the historical satellite imagery will be used for validation. In general the downscaled cyclone simulation does not give a significant change to the driven data, but it results in more finer resolution of wind field and improves the time and the position of the eye of the cyclone.

Keywords: Haiyan, typhoon, regcm, tropical, cyclone

1. Introduction
Design and maintenance of offshore structures require knowledge about historical and prediction in the future of wind as well as wave, especially during extreme conditions such as hurricanes or tropical cyclones (TCs). Not only for offshore structures, strong TCs may increase the surface elevation in the eye of the cyclone that can propagate to shallower or coastal area as the so called coastal storm surge. The coastal storm surge is one of many coastal extreme that may lead to the loss of life and property especially in low laying coastal areas [1]. As the main driving force of the storm surge, accurate reconstruction of TCs is highly necessary to obtain hindcasting data for design engineering purposes.

Available global re-analyses data that provide atmospheric information, including wind fields data, are usually too coarse, i.e. 50km to 210km, for describing tropical cyclones [2, 3, 4, 2, 3, 4, 5, 6]. The coarse global wind data cannot describe precisely the eye of the cyclone which leads to inaccurate simulation of storm surge. In general, there are three ways to reconstruct the wind during TCs. The first one is by parameterization method, where the shape of the wind fields, as well as pressure distribution during TC is modelled by characteristic functions, especially its vertical shape, horizontal spatial radius to represent the realistic TCs [7, 8]. The second method is by using observational wind, such as wind data set from the National Oceanic and Atmospheric Administration (NOAA) – Hurricane Research Division [9]. The third category is by simulating/reconstructing the TCs by using the so-called dynamic downscaling
simulation by using regional climate models. In the dynamic downscaling simulation, global atmospheric information, usually from global re-analysis model, is used as lateral boundary condition for simulating a regional model with finer grid.

In this paper, the third method approach; the dynamic downscaling simulation, is used for reconstructing TCs. In the dynamic downscaling simulation by using Regional Climate Model (RCM), atmospheric parameters from Global Climate Model (GCM) are used as boundary condition for simulating the climate in a regional area, with finer grid resolution. The aim is to obtain Earth system process in more detail than in the GCM [10]. One example is for reconstructing TCs. TCs reconstruction by using dynamic downscaling simulation has been perfomed by using regional model Weather Research and Forecasting (WRF) model [11, 12] especially for generating wind fields for storm surge simulation. The WRF model is a non-hydrostatic type of climate model, which computationally more expensive than hydrostatic type of model. In this paper, we use the hydrostatic type of climate model so-called RegCM or Regional Climate Model [13, 14] to achieve more efficient computational time than the WRF.

The aim of this paper is to perform the dynamic downsallcing method by using RegCM for reconstructing the super typhoon Haiyan which occurred in the Philippines in 1-8 November 2013. Here, the GCM that is used is the 6-hourly re-analyses data from ECMWF-ERA Interim as initial and boundary conditions. We validate results of the simulation with RegCM with the best track data from Japan Meteorological Agency (JMA) and snapshots of NOAA historical Satellite Imagery.

The structure of this paper is as follows. In Section 2, we describe briefly the RegCM model that is used for reconstructing the super typhoon Haiyan in which we aim to evaluate the effect of the dynamical downscaling model in that condition. The data and method that is used for the TC reconstruction is described in Section 3. In Section 4, validation between results of simulation with best track data as well as satellite imagery of NOAA is shown. Finally, we conclude the paper in the last section.

2. Model description
The Regional Climate Model, RegCM version 4.6 [13, 14] is a hydrostatic climate model in a regional scale. Unlike the Weather Research and Forecasting model [11, 12] where the non-hydrostatic pressure is included in the model, in the RegCM, this pressure is neglected such that the computation time is more efficient. Not only to achieve an efficiency in computing, the RegCM is the most commonly used by scientist and engineers in this area to perform dynamic downsallcing climate from global climate data, and results in good performance for various domain [15].

In this paper, we use the RegCM version 4.6 to dynamically downscale the super typhoon Haiyan. To that end, the model was set up with a domain covering Phillipines and the neighborhood ocean. The downscaling simulation aims to refine the global climate data about 0.7° into 0.25° horizontal resolution and 18 vertical levels. The period of the simulation is 1-15 November 2013 in which the strongest intensity of the cyclone occurred on 7-8 November 2013.

3. Data and method
3.1. Data
The regional climate simulation are driven by the global multi-resolution terrain elevation data (GMTED) as the topography profile, the optimum interpolation of NOAA sea surface temperature data, and the 6-hourly reanalysis data from ECMWF ERA Interim (ERAIN) 0.7° spatial resolution as the initial and lateral boundary condition.

The validation of the model simulation result will be based on the best track data from Japan Meteorological Agency (JMA) and the snapshots of NOAA historical Satellite Imagery.
3.2. Cyclone tracking method
The tropical cyclone intensity is measured from the maximum wind speed over an open flat land or water. To determine the Haiyan cyclone track we estimate the eye cyclone by Kyklop without the precipitation criteria as implemented in [16]. Kyklop is a cyclone tracker scheme for high resolution climate models developed by Fuentes-Franco et. al [17]. We modify some parameters threshold, i.e. the eccentricity 0.95, the minimum pressure 1002, and the maximum wind speed 17.5. These choices are based on our preliminary experiments which result that these threshold combination performed best in capturing the Haiyan cyclone, while the default threshold could not capture the track. We chose the eccentricity 0.95 instead of 0.75 since the simulation domain is quite narrow while the cyclone are relatively wide. Then the larger eccentricity is chosen to consider the eye-cyclone close to the boundary. Meanwhile, the criteria of the wind speed associated with a local minimum sea level pressure is according to the track TCs method by Chauvin et. al [18] which was also mentioned in [19].

4. Result and discussion
4.1. The track of Haiyan
The results of the Haiyan cyclone track is shown in Fig. 1. Both ERAIN and the downscaled data can detect the track of the cyclone quite well, even though the distance of the eye cyclone between the simulation and the JMA data can be up to 10, see Table 1. The downscaled climate data does not so much changes from the ERAIN. This shows that the dynamical downscaling model has high dependency to the initial and boundary condition, so that the performance of the model will rely on the forcing data itself.

Figure 1. Haiyan cyclone track based on JMA best track data, ERAIN, and the downscaled climate data.
4.2. Effect of downscaling to wind pattern

The downscaled climate data gives the pattern of the wind field more detail, so that the tracking method performed more precisely in detecting the eye cyclone, see Fig. 2 top. At the first row of Fig. 2, the snapshot of the satellite imagery was taken on 18:57 (approximately an hour later than the wind field in second and third column).

In addition, the dynamical downscaling method relatively increase the wind speed. This is shown in Figure 3 left that presents the maximum and the mean of the windspeed from ERAIN and RegCM simulation during the strong cyclone.

4.3. Effect of downscaling to surface pressure

In general, the surface pressure of the downscaled data are smoother than ERA Interim especially along the coastlines, see Fig. 4. Meanwhile, the minimum pressure of the downscaled data decreases about 30 hPa from the forcing data, see Fig. 3 right.

5. Summary

In this paper, we have performed dynamical downscalling simulation, especially for reconstructing Tropical Cyclone (TCs), i.e. the super typhoon Haiyan, that occured in 1-8 November 2013 in the Phillipines. The reconstruction has been done successfully by using the RegCM as the regional climate model in combination with initial and boundary conditions from ECMWFERA Interim. The eye of the cyclone as well as the track of the cyclone can be represented well by the results of the RegCM simulation. In this case, the dynamic downscaling simulation is using grid refinement from approximately 78 km to 25 km horizontal resolution. The result shows significant improvement in term of wind pattern as well as cyclone track (see Table 1). The proposed reconstruction method for TCs in this paper can be used for generating wind fields especially for simulating storm surge.

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Figure 2. The first column shows the snapshots of Haiyan on November 7th, 2013 at 18:57, November 8th, 2013 at 00:30 and 06:30 respectively. The second column shows the wind field from ERA Interim data on November 7th, 2013 at 18:00, November 8th, 2013 at 00:00 and 06:00 respectively. The third column shows the wind field from RegCM simulation on November 7th, 2013 at 18:00, November 8th, 2013 at 00:00 and 06:00 respectively. The blue dot in the wind field data shows the detected eye cyclone.

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Figure 3. The left graphic shows the maximum (blue) and the mean (red) of the wind speed from the ERAIN (solid line) and RegCM simulation (dashed-line). The right graphic shows the minimum surface pressure during the strong cyclone.

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Figure 4. The left column shows the surface pressure from ERA Interim data on November 7th, 2013 at 18:00, November 8th, 2013 at 00:00 and 06:00 respectively. The right column shows the surface pressure from RegCM simulation on November 7th, 2013 at 18:00, November 8th, 2013 at 00:00 and 06:00 respectively. The red dot shows the detected eye cyclone.