Numerical wind analysis on complex topography using multiscale simulation model

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Abstract

We calculate the wind flow around the complex terrain to examine the environmental flow by the topography effect around the urban area. In Japan, comparatively many cities face the mountain and/or the ocean. In such cities, cold air may blow from the mountain and/or the ocean, and the wind from the mountainous topography affects the cities environment. To examine the wind environment of the urban, we investigate effect of the complex terrain for the wind flow. In this study, we calculate the wind flow using three-dimensional meso-scale meteorological model.

Key words: wind flow, complex topography, meso-scale meteorological model

1. INTRODUCTION

Wind field around the urban area is influenced by surrounding environment: atmospheric condition, complex terrain and surrounding ocean. In Japan, because many cities often face the mountainous topography and coastal line, the meso-scale winds, such as fall wind from mountain and sea breeze, flow into urban area. Therefore, it is not sufficient to calculate around only urban area. The calculation which includes the surrounding topographic effect and meteorological condition is very important to investigate the urban scale wind flow.
From the energy point of view, to evaluate the wind speed and direction at the point of wind turbine is very important for the energy power prediction. As local variations in the wind speed is very significant the accurate prediction. Since the wind turbine is often installed around the non-flat topography in Japan, the direction and power of the wind would not be stable. Therefore, it is very important to estimate the wind speed and direction at the point of wind turbine. The calculation which can simulate the wind condition around the wind turbine with high accuracy are widely desired.
In this work, we calculate the wind field by using the three-dimensional meso-scale meteorological model. This model calculates the atmospheric flow by solving the full compressible Navier-Stokes equation, and particularly includes Large-Eddy simulation (LES) model based on the Smagorinsky-Lilly type parameterizations by Lilly (1962) and Smagorinsky (1965). Therefore it is possible to calculate the turbulent motion around the steep mountain.

2. Method and Target site

2.1. Numerical Model

Numerical simulations of wind flow fields are done in order to calculate the flow over a complex terrain by using atmospheric model: MSSG-A (Atmospheric-part of Multi-Scale Simulator for the Geoenvironment) (Takahashi 2005), developed at Earth Simulator Center. MSSG-A is a three-dimensional nonhydrostatic meteorological model based on the finite difference discretization of unsteady advection-diffusion equation with LES (Large Eddy Simulation) method. In the LES framework, the behavior of vortices, whose spatial dimension are larger than grid scale, are calculated by solving Navier-Stokes equation, and the behavior of vortices of smaller scale are modeled by using the Smagorinsky-Lilly type parameterizations.

2.2. Target site

The site of Tappi Cape in Aomori prefecture was chosen for the calculation, as shown in Fig. 1. The annual mean wind speed of the Tappi site is around 10 m/s at 20 m height above ground level and the prevailing wind direction is east and west. The Tappi Wind-Park on the Tappi Cape has been operated by Tohoku Electric Power Company since 1991. For the wind turbine performance measurement, wind turbine and calibration mast were operated as the part of national research project from 1996 to 1998. Since the wind speed and angle of wind flow were measured at these points, we would compare with the simulation results at the point of wind turbine and calibration mast.

2.3. Grid system

In order to study the effect of complex terrain, we calculate atmospheric flows over terrain of Tappi site. The computational domain has a height of 10km in the z-direction and horizontal length of 5km in the x- and y-

directions. Fig.2 shows a perspective view of the computational domain which covers the northern part of Aomori prefecture in Japan.
The most important factor to the success of the numerical simulation of the atmospheric flow over three-dimensional topography is how to specify the topography model as the boundary condition in the computation. For this purpose, we use terrain following coordinate system, as shown in Figs. 3.
In order to consider the significant details of complex terrain, we overlaid horizontal grids with an equal size of and =10m in the x- and y-directions and vertical non-uniform grids in the z-direction, concentrated toward the ground, over the computational domain, as shown in Fig. 3. Minimum size of is 5m. The number of grid points in the x-, y- and z-directions 496 496 64.

2.4. Boundary condition

The boundary conditions are as follows: for velocity, directional inflow with logarithm distribution (v_{10}=5.0[m/s]) (horizontal boundary), free-slip condition (top boundaries): for pressure, Neumann condition (all boundaries).

3. Simulation result

Fig. 4 shows instantaneous streamlines at 40m height above ground level. The figure shows the calculation results under the condition of four types of inflow: north, east, south and west wind. From Fig. 4, we can see that qualitative features are successfully simulated in the numerical results. In addition, we can see that the wind speed is strongly difference among the conditions. For the cases of east and south wind, the global wind speed is large. On the other hand, for the north wind case, the wind speed is relatively small.
Fig. 5 shows the ratios of wind speed variation at the point of calibration mast and wind turbine for each cases of the wind directions, and experimental data. In the study of Imamura (2001), the measurement campaign has been performed in Tappi wind park. Comparing the wind speed variation between the experiment and simulation results, the ratios of the directions SSE, S and WNW are quite different and others are nearly equal.
Kamio(2007) shows the numerical site calibration for the Tappi wind park by using the non-linear wind prediction model MASCOT, and compare with the experimental data. The calculation shows that the ratios of the direction N, SSW and WNW are quite different from experiment data. The reason why the calcution for the wind direction S and WNW becomes large difference would cause by the terrain steepness. The slope of the terrain in a direction of S and WNW around the calibration point is over 40 degrees.

4. Conclusion

The nonhydrostatic atmospheric model MSSG-A is used to analyze the wind field of the Tappi wind park. The simulations are calculated with a spatial 5m grid using non-linear and three-dimensional compressible Navier-Stokes equation. The flow field owing to complex terrain is calculated with LES. As a result, most conditions of the wind flow variation are nearly equal to experiment data, however, the S and SSE directional wind conditions are quite different.

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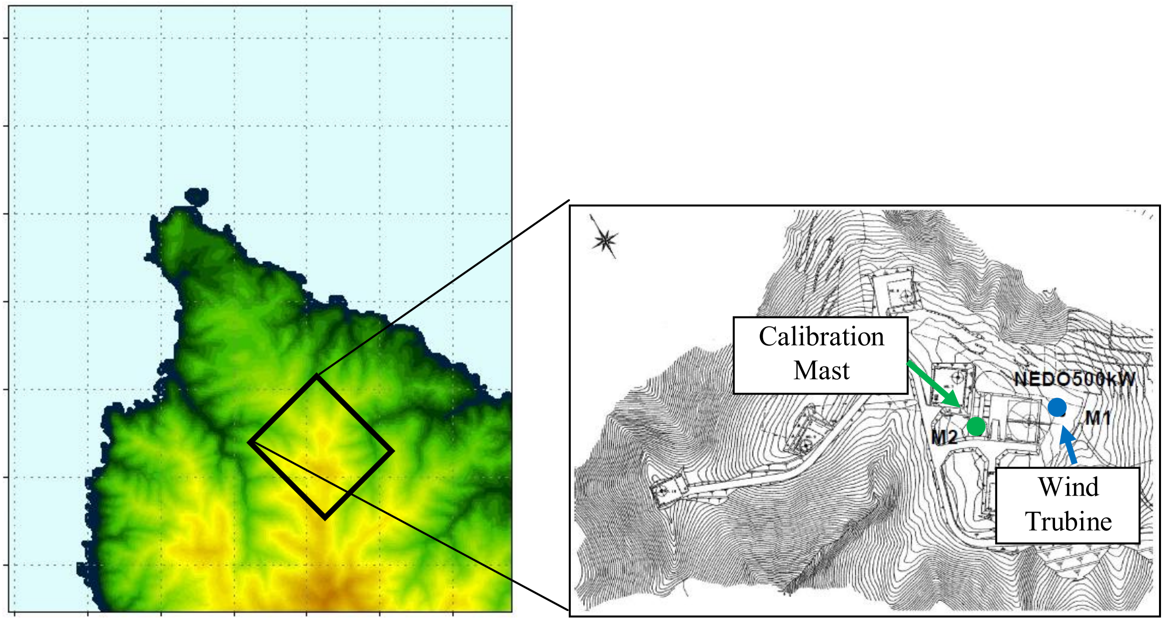
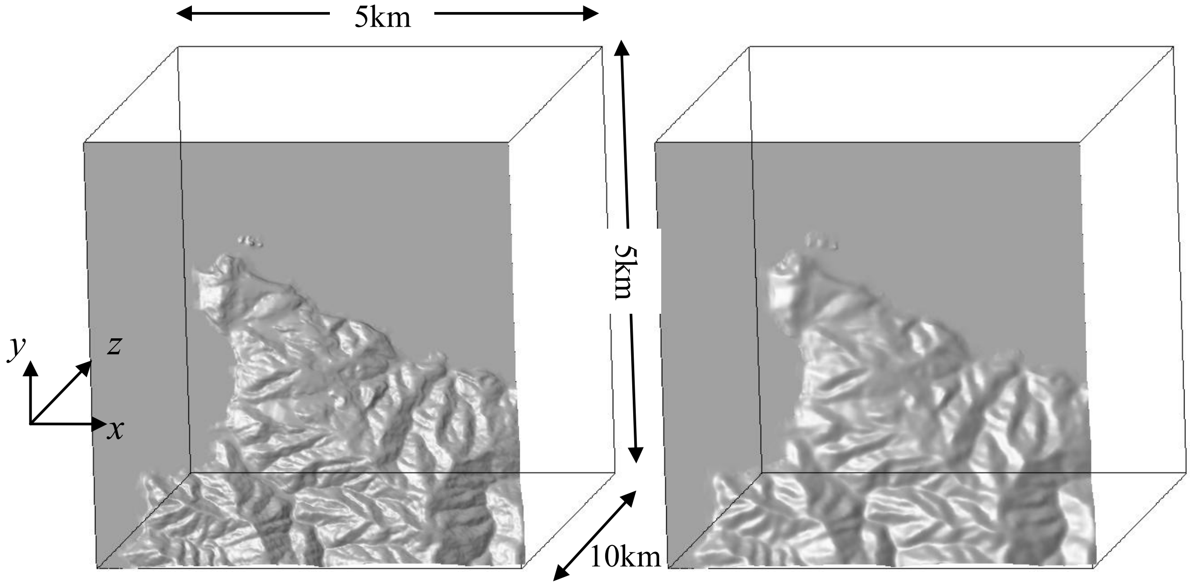


Fig. 1 The site of Tappi Cape



(a) high resolution topography (b) low resolution topography

Fig. 2 Computational domain

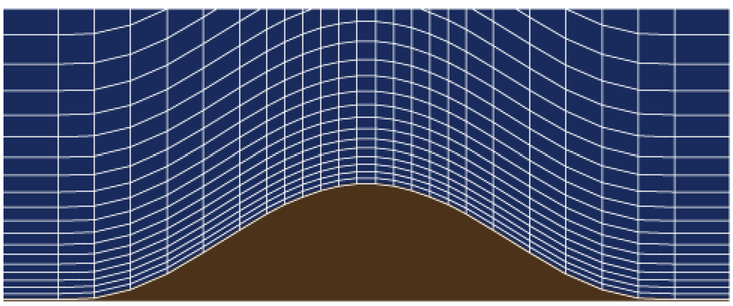
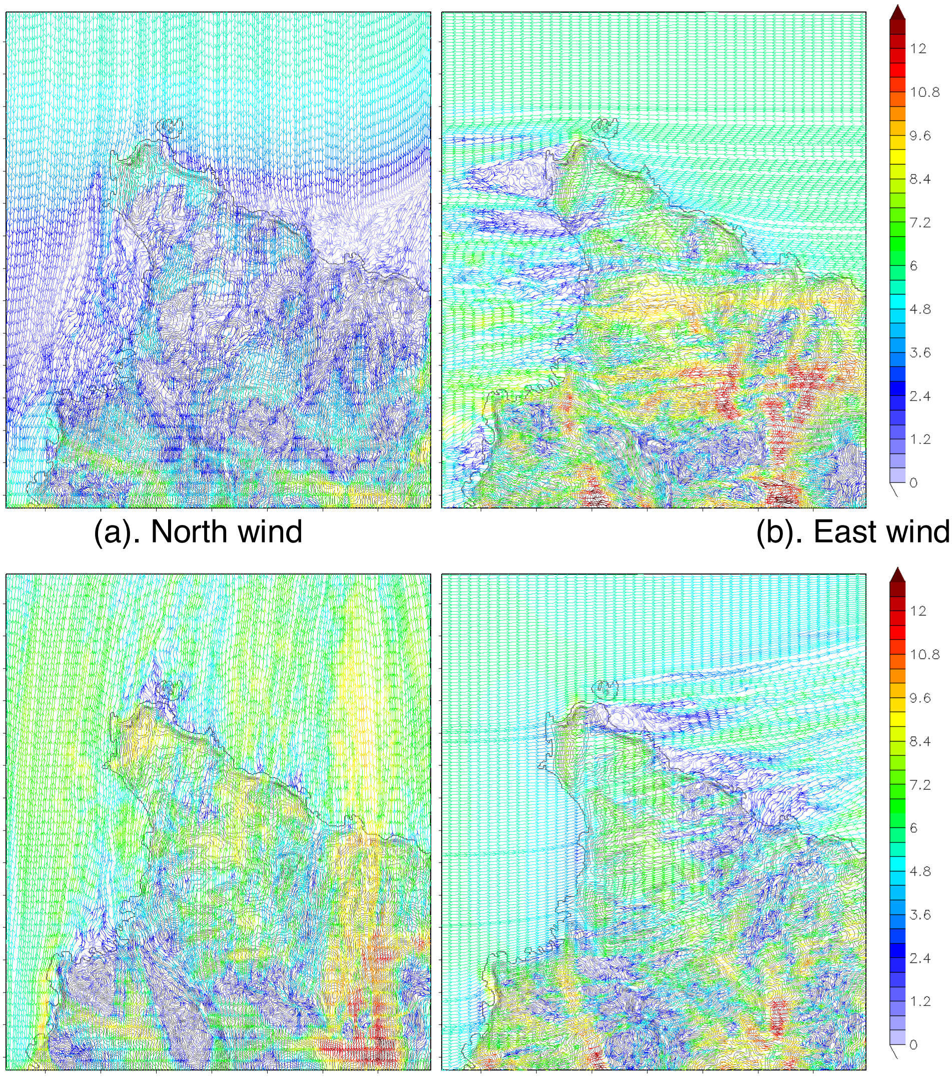


Fig. 3 Terrain following coordinate system



(a). North wind (b). East wind

(c). South wind (d). West wind

Fig. 4 Streamlines at 40m height

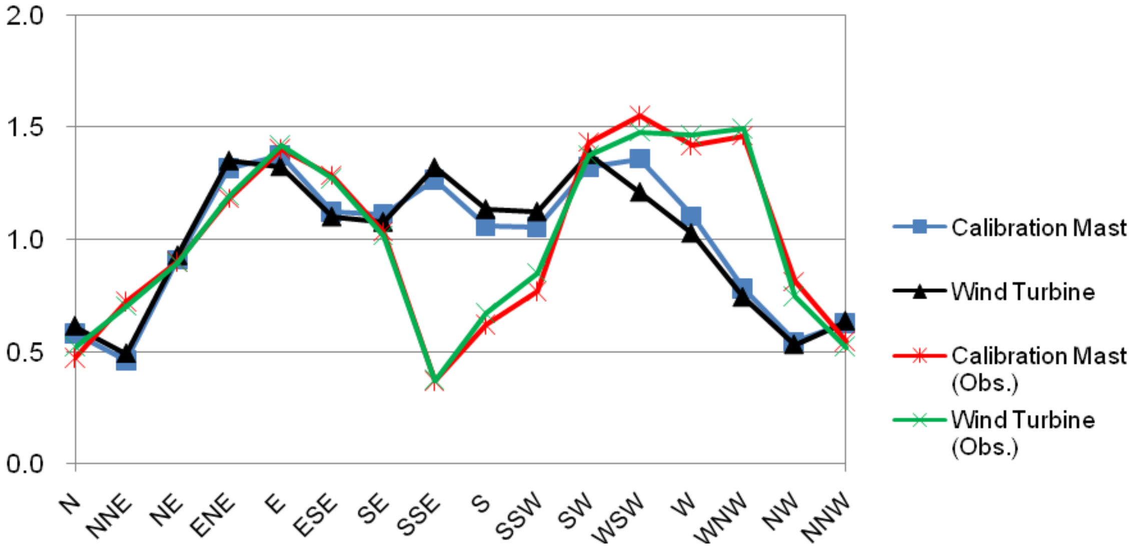


Fig. 5 Sectorwise distribution of the ratios of average wind speed variation