A dynamical statistical downscaling procedure for wind climate assessment and its verification

Takeshi Ishihara[a], Atsushi Yamaguchi [b], Yozo Fujino [c]

[a,b]Institute of Engineering Innovation, School of Engineering, The University of TOKYO
2-11-16 Yayoi Bunkyo TOKYO 113-8656, JAPAN
[c]Department of Civil Engineering, School of Engineering, The University of TOKYO
7-3-1 Hongo Bunkyo TOKYO 113-8656, JAPAN

ABSTRACT: A Dynamical Statistical Downscaling Procedure (DSDP) was proposed and verified at Tappi Cape, north of Japan. This method first dynamically predicts the regional wind by mesoscale atmospheric model with horizontal resolution of 1km. Next, regional wind is statistically analyzed to determine regional wind climate. Then, regional wind climate is downscaled to local wind climate with horizontal resolution of 10m. The advantage of this procedure is to predict an accurate micro wind climate in mountainous area and to take the effect of local circulation such as sea-land breeze and mountain-valley wind into account. Local wind climate predicted by the new procedure works with nonlinear micro wind prediction model MASCOT and Idealizing and Realizing Approach. Local wind climate predicted by this approach shows good agreement with the measurement and prediction error of the annual mean wind speed at Tappi Cape is 4.6%.

KEYWORDS: Wind Climate Assessment, Dynamical Statistical Downscaling, Mesoscale Model

1 INTRODUCTION

A lot of method for wind resource assessment was investigated so far as reviewed by Landberg et al.[1)]. Among them, the most widely used method is the WAsP methodology.[2)] In this approach, first, onsite measurement is carried out for one year near the wind farm to be constructed, then observed wind climate is collected to any point in the wind farm using the model that can take the effect of local terrain and roughness into account. The main disadvantage of this method is that it requires onsite measurement for at least one year.

The progress in computer hardware and meteorology made the wind resource assessment possible without onsite measurement. Several methods with mesoscale atmospheric model have been investigated. One of them is KAMM/WAsP approach[3)], which is based on the statistical dynamical downscaling procedure proposed by Frey-Bunnes et al.[4)]. Since quasi-steady state is assumed in this approach, the effect of local circulation is not taken into account. However, the local circulation can be an important factor in mountainous countries, where local circulation is dominant. Nesting is the most accurate approach, in which regional fine mesh model is embedded in and time dependently driven by the global circulation model. Furthermore, micro wind prediction model with even finer mesh is embedded in a regional model. LAWEPS[5)], the wind resource assessment system developed by New Energy and Industrial Technology Development Organization, Japan (NEDO), adopts this approach. In order to save computational efforts, however, LAWEPS only simulates the wind for four hours a day and one day (i.e. four hours) per every six days. It is obvious that this approximate approach cannot provide an accurate seasonal and diurnal variation of the micro wind.

2 THE CONCEPT OF PROPOSED METHOD

In this study, a Dynamical Statistical Downscaling Procedure is proposed to avoid the problems in previous methods. This procedure consists of three steps, as shown in figure 1. First, regional wind with the horizontal resolution of 1 to 2 km is dynamically simulated by mesoscale model. The mesoscale model is embedded in the global circulation model having the resolution of about 50km and time dependently driven for one year. Next, the predicted wind field is statistically analyzed to obtain regional wind climate, which is represented by the Weibull distribution and probability for each wind direction. Finally, regional wind climate is downscaled to the micro wind climate by the non-linear micro wind prediction model MASCOT with Idealizing and Realizing Approach (IRA). Figure 2 shows the concept of IRA. In this method, micro wind climate in the real terrain is estimated by correcting the difference between the effects of coarse terrain used in the regional atmospheric model and the fine terrain in the micro model. In this study, it is assumed that the effect of small terrain does not depend on atmospheric stability. First, a simulation by the non-linear model MASCOT is performed with the coarse terrain and roughness used in mesoscale simulation. Using the result of this simulation, regional wind climate is converted into the idealized wind climate at the upstream virtual region, where terrain is flat and roughness is constant (Fig.2a). Then, a simulation with real terrain and roughness is performed to convert the idealized wind climate to micro wind climate (Fig.2b). The final estimated wind climate has the horizontal resolution of about 10m, fine enough to represent the topographic features of complex terrain.

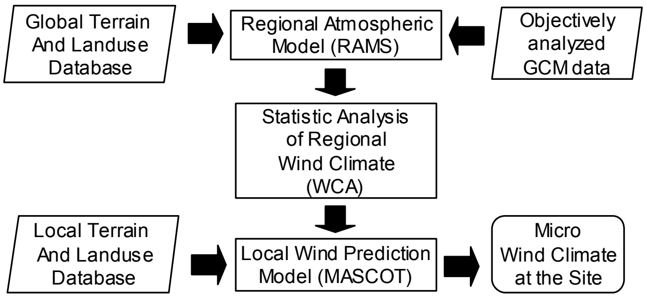


Figure 1. The flow of dynamical statistical downscaling procedure

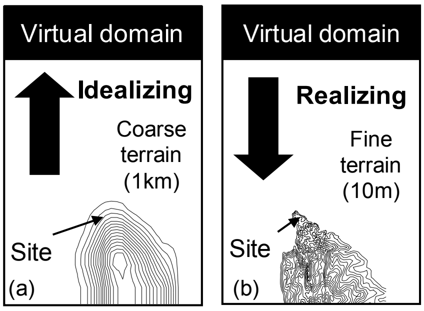


Figure 2. The concept of Idealizing and Realizing Approach

3 THE MODELS

3.1 *Mesoscale atmospheric model (RAMS)*

As a mesoscale atmospheric model, RAMS (Regional Atmospheric Modeling System)6) developed by Collorado State University was used in this study. RAMS is based on non-hydrostatic Reynolds-averaged primitive equations. The governing equations are equation of motion, thermodynamic equation, water species mixing ratio equation and mass continuity equation.

3.2 *Micro wind prediction model (MASCOT)*

As a micro wind prediction model, MASCOT (Microclimate Analysis System for COmplex Terrain) developed by the authors is used in this study. The basic ideas and the characteristics of MASCOT are as follows:

1) This model adopts the generalized non-orthogonal coordinate system so that it can be used for any slope angle. It also adopts the zooming mesh to concentrate the grid to the region of interest.
2) As a discretization method, finite volume method was adopted, which satisfy mass and momentum conservation and SIMPLE algorithm was used as a numerical scheme.
3) Standard or modified k-e turbulent model was used to accurately predict not only the mean wind speed but also the standard deviation of fluctuating wind speed.
4) To minimize the effect of boundary, a new boundary treatment method was adopted.
5) A new solution algorithm for linear equations was proposed and the prediction of the micro wind with one million grids can be done within two hours by a PC.

The detail of the model is described by Ishihara et al.7), 8).

4 REGIONAL WIND CLIMATE

The performance of Dynamical Statistical Downscaling Procedure was examined at Tappi Cape, north of Japan (Fig.3), where strong wind blows all through the year, and the terrain is very complex and steep. A lighthouse is located at the tip of the cape, where ten minutes averaged wind speed and direction is measured. A wind farm owned by Tohoku Electric Power Co. Inc. (Tappi Wind Park) is located at the south to the lighthouse (Fig.3). Wind speed and direction measured at the top of the nacelle at each wind turbine in 1997 were also used for the verification.

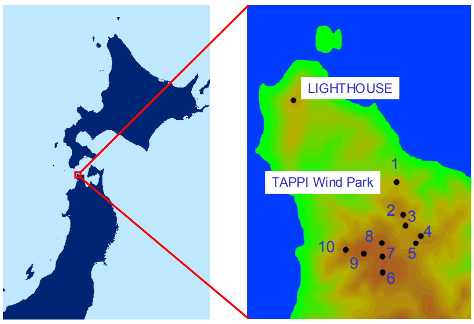
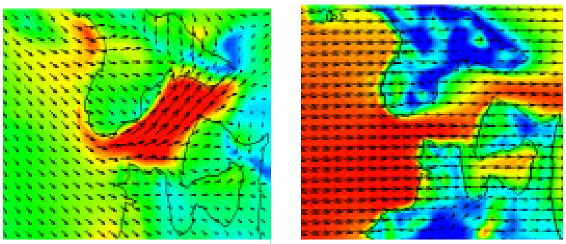


Figure 3. Location of Tappi Cape



SUMMER
1997/07/17 07:00 UTC

WINTER
1997/01/25 18:00 UTC

Figure 4. Wind field predicted by regional atmospheric model at Tsugaru Strait, north of Japan

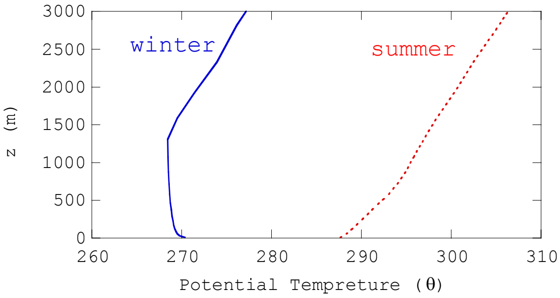


Figure 5. Vertical profile of potential temperature at Tappi

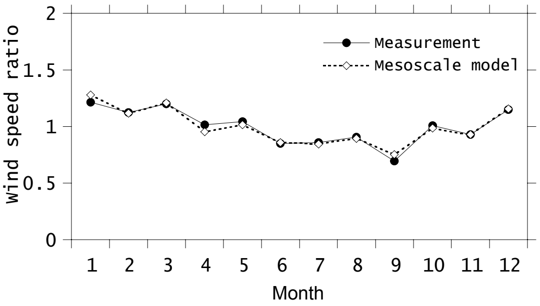


Figure 6. Non-dimensional monthly mean wind speed at the Tappi lighthouse

The wind flow is strongly affected by atmospheric stability and is well predicted by mesoscale model. Figure 4 shows the wind field predicted by regional atmospheric model for a typical winter and summer day. The contours in the figures show the mean wind speed, which shows seasonal variation. On a summer day, the wind direction is forced to change along the Tsugaru Strait. On the other hand, in winter, the wind tends to blow over mountain. This seasonal variation is caused by the difference in the atmospheric stability. Figure 5 shows the vertical profile of the potential temperature in the summer and the winter day denoted by dotted and solid line respectively. In summer, the atmosphere is stable and this makes the wind direction to be changed rather than blow over the terrain. On the contrary, in winter, the atmosphere is neutral near the surface and causes the wind to blow over the terrain. This is why strong wind is observed at Tappi Cape all through the year.

Figure 6 shows non-dimensional monthly mean wind speed normalized by annual mean wind speed at the Tappi Lighthouse. The seasonal variation of regional wind is small and well demonstrated by the mesoscale model. It should be noticed that the annual mean wind speed of regional wind is less than that observed at the Tappi Lighthouse, indicating that the resolution of the mesoscale model is not enough for this site.

5 MICRO WIND CLIMATE

As seen in the previous section, wind climate estimated by RAMS differ considerably from micor wind climate due to the limitation of the horizontal resolution in the mesoscale model. It is clear that the finest grid with the horizontal resolution is not enough. In this study, a method called Idealizing and Realizing Approach

(IRA) is used as shown in Fig. 2. This approach remarkably improves the accuracy. The frequency distribution of wind speed shows a good agreement with the observation (Fig.7). The prediction error of annual mean wind speed is reduced from 29.8% to 4.6% in this case.

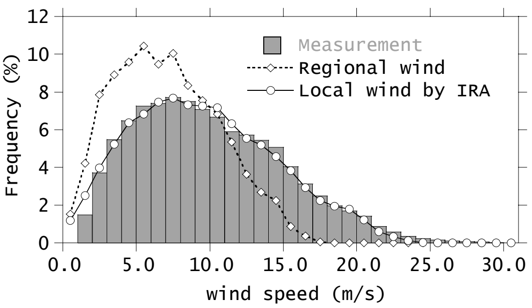


Figure 7. Frequency distribution of wind speed at the Tappi Lighthouse.

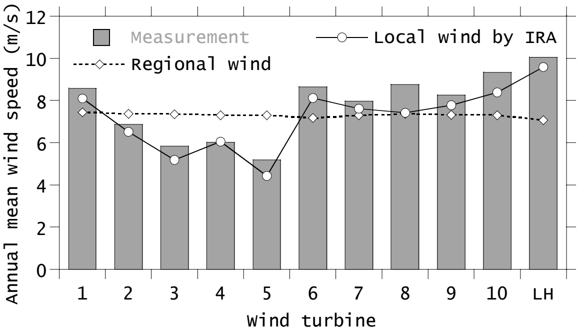


Figure 8. The annual mean wind speed at each wind turbine in Tappi Wind Park and at the Lighthouse

Finally, this approach was applied to Tappi Wind Park. Figure 8 shows the annual mean wind speed of each wind turbine and the lighthouse. The annual mean wind speed predicted by IRA (dotted line) shows good agreement with the measurement and well demonstrates the effect of the complex terrain compared with the regional wind climate interpolated to the location of wind turbine (dashed line)

6 CONCLUSIONS

A new concept, so-called Dynamical Statistical Downscaling Procedure (DSDP), for micro wind climate assessment was proposed and verified at Tappi Cape. Following conclusion was obtained.

1. Regional wind predicted by RAMS favorably simulates the effect of stratification and large scale terrain. However, it might contain large error due to the limitation in resolution.
2. Micro wind climate predicted by the proposed Dynamical Statistical Downscaling Procedure working with non-linear model MASCOT and IRA methodology shows good agreement with the observation.
3. The advantage of this procedure is to give an accurate micro wind prediction in mountainous area and to take the effect of local circulation such as sea-land breeze and mountain-valley wind into account.

References

1) Landberg, L., Wind Resource Estimation – An Overview, *Wind Energy*, 6, 261 – 271, 2003.
2) N. G. Mortensen, L. Landberg, I. Troen and E. L. Petersen, Risø National Labortory, Roskilde, Denmark, 1993.
3) Frank, H. P., Rathmann, O., Mortense, N. G. and Landberg, L., The Numerical Wind Atlas – the KAMM/WAsP Method, Risø National Laboratory, 2001.
4) Frey-Buness, F., Heimann, D. and Sausen, R., A Statistical–Dynamical Downscaling Procedure for Global Climate Simulations, *Theor. Appl. Climatol*. 50, 117 – 131, 1995.
5) Hayashi, H. et al., A New Wind Energy Prediction Model Based on the CFD Theory, World Wind Energy Conference 2002, 2002.
6) Pielke, R. A. et al., A Comprehensive Meteorological Modeling System – RAMS, *Meteorol. Atm,os. Phys.*, 49, 69-91, 1992.
7) Ishihara, T., Yamaguchi, A. and Fujino, Y., A nonlinear model MASCOT: development and application, European Wind Energy Conference 2003, 2003.
8) Ishihara, T. and Hibi, K., Numerical study of turbulent wake flow behind a three-dimensional steep hill, *Wind and Structure*, 5, 317-328, 2003.