Micro-Siting Technique in Foreign Countries by Using the RIAM-COMPACT® CFD Model

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1. Introduction

In the past few years, the number of large-scale wind farm projects outside Japan which have taken into account the Clean Development Mechanism (CDM) defined in the Kyoto Protocol has been rapidly increasing. Simultaneously, our research group has conducted detailed micro-sitings for wind turbines (wind risk evaluations) outside Japan as well as within Japan, using the RIAM-COMPACT® natural terrain version software[1,2)].

The development of the RIAM-COMPACT® natural terrain version software has been led by RIAM-COMPACT Co., Ltd., an IT venture corporation that originated at Kyushu University, with cooperative efforts from West Japan Engineering Consultants, Inc., Environmental GIS Laboratory Co., Ltd., and FS Consulting Co., Ltd. The core of the software was mainly developed by one of the authors, Dr. Takanori Uchida of the Research Institute for Applied Mechanics of Kyushu University (also the director (technology development) of RIAM-COMPACT Co., Ltd.), and exclusive license of the software core has been granted to RIAM-COMPACT Co., Ltd. by Kyushu TLO Co., Ltd.

The present paper discusses case studies of wind simulations (wind risk evaluation) which were conducted with the RIAM-COMPACT® natural terrain version software with high accuracy for sites outside Japan. In addition, a method for acquiring the elevation data (topographical information) for sites outside Japan is also described.

2. Use of detailed terrain data generated from ALOS PRISM data

In order to accurately model the turbulence over terrain and objects on the surface in wind simulations, use of terrain data with high precision and accuracy is essential. In the past, detailed terrain maps for planned sites for wind turbine construction outside Japan were often not easily obtainable, and alternative terrain information was needed in such cases. Accordingly, we examine the use in wind simulations of elevation data that are created with high-resolution satellite data for sites outside Japan. Such satellite data are available at a uniform level of quality for worldwide locations. Out of a number of terrain datasets which have been created from satellite images and are available to the public, we use one created from PRISM stereo images. Specifically, the satellite data were produced on a made-to-order basis and sold by the Remote Sensing Technology Center of Japan. PRISM is a visible-spectrum sensor operating on the Earth observation satellite ALOS (Japanese name: DAICHI; launched in 2006 by the Japan Aerospace Exploration Agency (JAXA)) and is able to detect objects on the surface. The elevation data that have been prepared from the PRISM data are called a Digital Surface Model (DSM) and include data on buildings, roads, trees, and geometries of other objects on the surface as well as data on the surface terrain. In contrast, numerous grided elevation datasets such as those provided by the Geographical Survey Institute of Japan, called Digital Elevation Model (DEM) datasets, contain only ground surface elevation data. Therefore, DSM datasets, which allow accurate simulations of turbulence generated by objects on the surface, are more suitable than DEM datasets for use in wind simulations.

The ground resolution of the PRISM DSM data is approximately 10 m (Fig. 1). The horizontal and vertical location accuracies of the data are 20 m and 40 m, respectively, when no positional corrections are made with ground control points (GCPs). Furthermore, because the relative error of the DSM data is 5 m, the topological error of the terrain and objects on the surface is small, and the distortion of the terrain represented in the DSM data as a whole is small. For the wind synopsis analyses in the present study, the DSM data are extracted for simultion target areas and converted to a format which can be loaded onto RIAM-COMPACT®. The geographical coordinate system of the PRISM DSM data provided for the present study is ITRF97, in which the terrain data values are assigned to grid points in an equidistant latitude/longitude grid. This coordinate system is almost identical to the latitude/longitude coordinate system that is used in GPS. Therefore, the present DSM data can be used directly in the wind analysis of sites for wind turbine construction without the need for coordinate transformation.

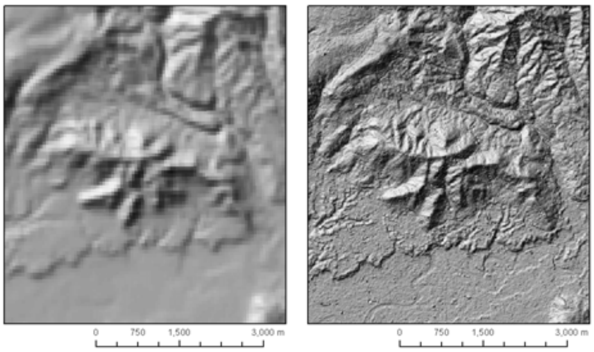


Fig. 1 Comparison between SRTM (Shutle Radar Topography Mission) data with 90-m spatial resolution (left) and ALOS DSM data with 10-m spatial resolution (right)

Incidentally, the use of PRISM DSM data is only possible for a potential site for wind power generation if images of the site and its surrounding area have been captured by PRISM from three directions. In some areas outisde Japan, the required data are not available because of the limited number of images in the image library. Because production of terrain data relies on images in the visible spectrum, information about the ground surface cannot be obtained with clouds present. In this case, the elevations of the area of interest cannot be evaluated, and missing value flags for the elevation will be entered in the DSM dataset. Therefore, for subtropical regions, in which clouds are frequently observed throughout the year, the amount of data which can be used for terrain construction tends to be limited. However, the amount of data is expected to grow in the future with continued observation of the Earth's surface by PRISM, and PRISM DSM data will likely become available for more extensive areas than those for which the data are currently available. It is anticipated that the use of highly detailed satellite imagery-based terrain information (Fig. 2) for wind power development projects will increase in regions such as developing countries, in which terrain information is highly limited at the present time. The readers are advised to refer to http:// www.alos-restec.jp/products2.html for details of the ALOS data.

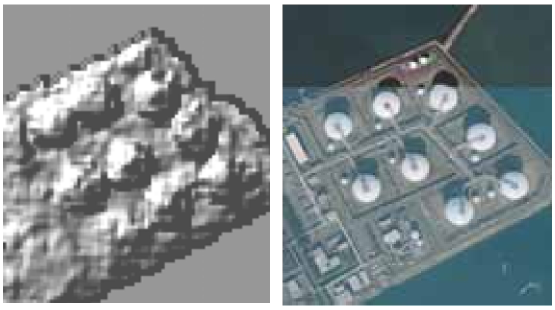
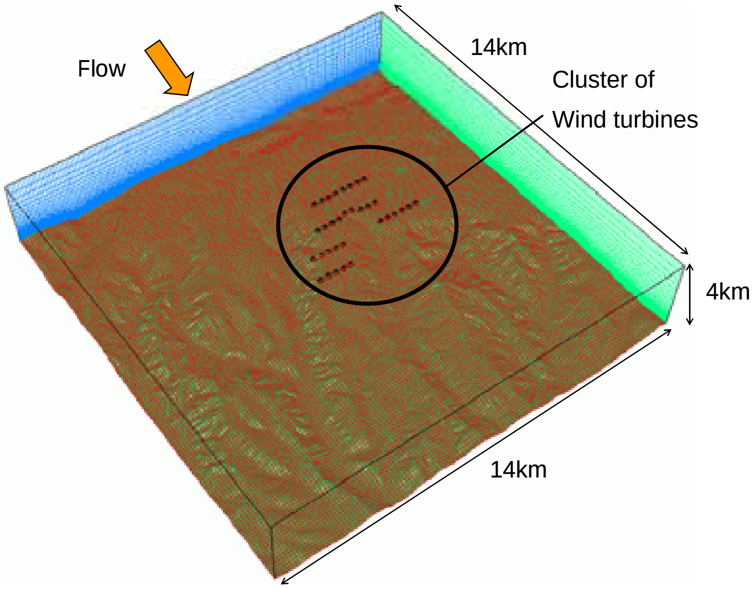


Fig. 2 Examples of reconstructed terrain and objects on the surface

3. Case studies of wind synopsis evaluations by RIAM-COMPACT®

(1) China Wind Power Generation Project Site

First, a case study for wind synopsis evaluation is illustrated for a planned site for wind power generation in the China Wind Power Generation Project managed by the Kyushu Electric Power Co., Inc. ("the present project" hereafter). The present wind synopsis evaluation was conducted as a part of the work performed for the Nishinippon Environmental Energy Co., Inc.



- Computational domain：14km×14km×4km
- Number of grid points: 141×141×51 points (approx. one million points)
- Wind speed aloft: 10 m/s (1/7 exponential law)

Fig. 3 Birds-eye view of the computational domain

The development scale for the present project is 50,000 kW (2,000 kW / wind turbine × 25 wind turbines). The planned site for wind power generation is at an elevation of approximately 1,700 m, and part of the surrounding terrain is characterized as complex terrain which includes valleys.

For the present project, wind synopsis simulations are performed for 16 wind directions using RIAM-COMPACT®, in order to evaluate wind conditions for the wind farm area and at the individual wind turbines. The numerical simulations involved approximately one million grid points in a domain which includes the planned site for wind turbine deployment as shown in Fig. 3.

Recently, the capacity factors of some wind farms within Japan have fallen below their initial projections, and the significant reduction in power output at these wind farms has become a significant concern. Turbulence which is generated locally by small undulations near wind turbines (terrain-induced turbulence) is commonly considered to be the cause of the low capacity factors. Accordingly, for the present project, the wind synopsis evaluation is made with a focus on the influence of the terrain-induced turbulence on wind power generation. Subsequently, some of the major analyses and results from the numerical wind synopsis evaluation will be discussed.

First, the existence of the influence of terrain-induced turbulence on the flow around the wind turbines is visually examined. For the visual examination, an animation is created so that air parcels with large terrain-induced wind velocity fluctuations can be tracked. Fig. 4 shows the wind velocity vectors (instantaneous field) at the wind turbine hub heights. Furthermore, a contour plot of the fluctuating streamwise velocity from the wind field in Fig. 4, $|u'|$ $(= |u - U_{ave}|)$, is illustrated in Fig. 5.

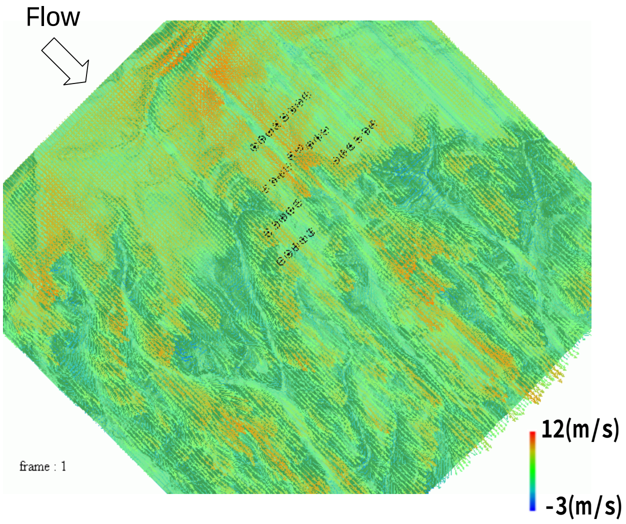


Fig. 4 Wind vectors at the wind turbine hub-heights

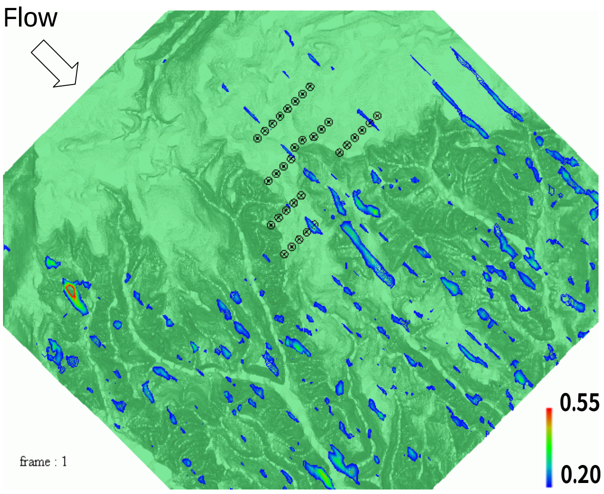


Fig. 5 Distribution of the fluctuating streamwise wind velocity component at the wind turbine hub-heights

Because turbulent flow conditions are hard to identify in these still images, spatial and temporal variation in the terrain-induced turbulence has been confirmed with the use of the animation described earlier. The temporal change in the fluctuating streamwise wind velocity component of the terrain-induced turbulence as described in this case study can be investigated as a result of the non-stationary wind synopsis simulation. Moreover, our wind synopsis evaluation which is based on RIAM-COMPACT® allows visualization of turbulence as well as complex wind flows, and thus enables wind turbine deployment planning which takes into account the three-dimensional airflow conditions.

Second, a statistical analysis is performed on the simulated wind data. Figs. 6 and 7 show the vertical profile of the mean normalized horizontal wind speed and that of the streamwise turbulence intensity, respectively, from four of the wind turbine deployment locations at the China Wind Power Generation Project Site. The vertical axis indicates the height above the ground in full scale, z (m). The horizontal axes in Figs 6 and 7 indicate the non-dimensional wind speed and the turbulence intensity, respectively, which have been normalized by the inflow wind velocity, U_{in} The two figures also include an illustration of the rotor diameter. As part of the evaluation procedure for determining the deployment location of a wind turbine, essential criteria include that neither the horizontal wind speed shear nor the wind speed deficit is large in the vertical profile of the horizontal wind speed. The evaluation procedure also examines the vertical profile of turbulence intensity to determine if the values of turbulence intensity exceed a unique reference value. When the wind turbulence

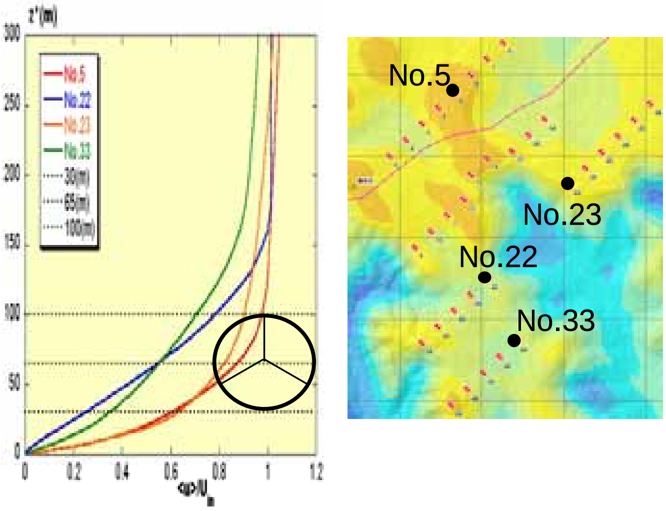


Fig. 6 Vertical profiles of the mean horizontal wind peed normalized by the inflow velocity

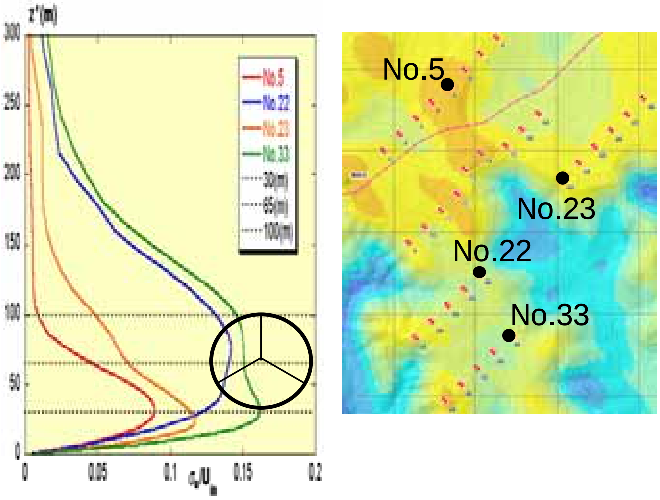


Fig. 7 Vertical profiles of streamwise turbulence intensity normalized by the inflow velocity

intensity is less than the reference value, the power output from the wind turbine does not decline significantly. The validity of the reference value has been confirmed using a large number of wind synopsis diagnostics for wind farms from our past research. Evaluations of the vertical profiles of the mean horizontal wind speed and turbulence intensity enable wind load mitigation on wind turbines, which can also lead to a reduction in the frequency of wind turbine malfunctions.

For the present case study, inter-comparisons of turbulence statistics (vertical profiles of the mean horizontal wind speed and streamwise turbulence intensity) among some of the planned wind turbines were illustrated. Evaluations of the turbulence statistics suggested that stable operations of most of the examined wind turbines could be expected. The investigated wind turbine arrangement was one of the arrangements under consideration, and was not the final arrangement adopted for the site.

(2) Palm Springs Wind Power Generation Site

In this section, a case study of wind evaluation for a large-scale wind farm in the Palm Springs area in California, U.S.A. is discussed. As described earlier, the acquisition of elevation data (terrain information) is necessary for conducting wind synopsis simulations for sites outside as well as within Japan. Currently, while our research group mainly uses the above-mentioned terrain data based on data from the Earth observation satellite ALOS, we also use Space Shuttle SRTM terrain data together with the ALOS terrain data. Accordingly, a case study that uses SRTM and ALOS terrain data will be described below.

The Shuttle Rader Topography Mission (SRTM) is an effort to generate detailed three dimensional topographic data of the entire globe using an on-board radar. At present, there are two three-dimensional SRTM topographic datasets available to the public: SRTM-1 and SRTM-3. The SRTM-1 data are available only for the United States, and their resolution is 1 arc second (approximately 30 m). The resolution of the SRTM-3 data is 3 arc seconds (approximately 90 m), and the data are available for the entire globe. Readers are advised to refer to http://srtm.usgs.gov/index.html for details of the two datasets. In the present study, the computational mesh is generated using SRTM-1 data.

For analysis, a computational domain is defined with a size of 20km×10km×7km in the streamwise (x), spanwise (y), and vertical (z) directions, respectively. The number of computational grid points is 201(x) ×101 (y) ×41 (z). The other settings used for the analysis are identical to those used for the China Wind Power Generation Project site.

Fig. 8 shows wind velocity vectors for the prevailing wind direction at the Palm Springs site. The wind velocity vectors displayed in this figure are from the heights which correspond approximately to the hub-heights. Mountain ranges extend in the east-west direction on both the north and south ends of the present computational domain, and the valley between the mountain ranges forms a wind path (see Fig. 8). Within this valley, multiple wind turbines have been constructed in a concentrated manner. The locations (latitude and longitude information) of some representative wind turbines out of the thousands within the valley are determined from visual inspections using Google Earth, and the location information is included in the simulation. Fig. 8 suggests that no large spatial variations exist in the wind direction in the valley in the middle of the computational domain (the area marked by dotted lines), thus the wind in this area flows steadily with little temporal fluctuation. It can be speculated that this area corresponds to a zone of wind convergence. On the other hand, complex wind patterns exist on the north and south sides of the computational domain outside of the region indicated by dotted lines.

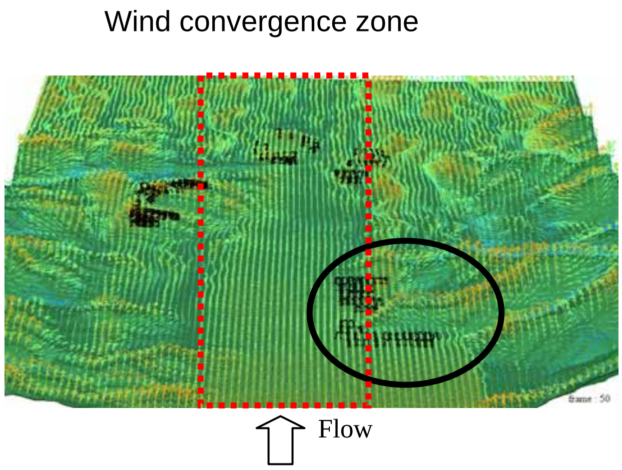


Fig. 8 Distribution of wind velocity vectors under the prevailing wind direction (westerly)

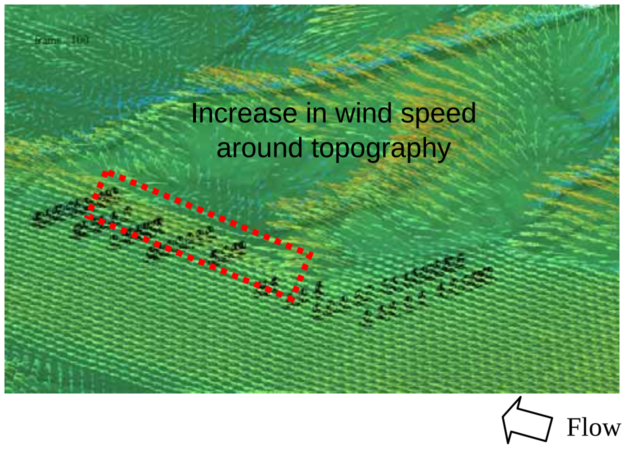


Fig. 9 Enlarged view of the area indicated by the black circle in Fig. 8

Fig. 9 illustrates a magnified view of the area indicated by the black circle in Fig. 8. Fig. 10 is a photograph of the same area. An examination of Fig. 9 reveals that the topography situated adjacent to the wind turbines affects the wind field in the area marked by dotted lines, that is, the wind speed increases locally at the locations where the wind flows around the topography, and the wind turbines in the area indicated by dotted lines are likely influenced by the wind with increased speed. Efficient power generation can be anticipated from wind turbines in such conditions.

Fig. 10 Photograph of the wind turbine site indicated by the black circle in Fig. 8. (photograph by one of the authors; December, 2008)

4. Conclusion

For wind turbine deployment planning, detailed investigations which include wind synopsis evaluations are necessary. Wind synopsis evaluations require a non-stationary wind synopsis technique and also a detailed terrain data construction technique which takes into account the latest terrain conditions. As for the visualization of the wind field, conventional wind mapping alone in which the stationary wind velocity distribution is visualized for the horizontal cross-section at the hub-heights is insufficient. In particular, the increasing size of wind turbine generators calls for evaluations of the wind velocity distribution along vertical cross-sections, thus, displays of vertical profiles of the turbulence intensity as well as those of the mean horizontal wind speed will likely become increasingly relevant from this time forward.

Further detailed investigations that use numerical simulations, wind-tunnel experiments, and field observation data are necessary for identifying the level of wind velocity fluctuation, above which there will be adverse effects on the power generation performance. These investigations will be addressed in our future research.

References

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