

Regeneration of occurrence frequencies and vertical profiles of wind velocity by WRF calculation

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ABSTRACT: We intend to use the WRF (The Weather Research and Forecasting Model) to prepare standard wind data at high altitude for the assessment of pedestrian wind environment, and also to investigate urban heat island phenomena. Before doing these investigations, it is necessary to confirm the prediction accuracy of WRF. In this study, the measured occurrence frequencies and vertical wind velocity profiles obtained by Doppler Soda at Minami-senju (inland area in Tokyo) were compared with those calculated by the WRF model. In order to well regenerate the vertical profile of wind velocity by WRF, appropriate surface roughness should be given to the WRF calculation. Thus, we used GIS data to appropriately classify land-use categories and to give a roughness length to the WRF calculation. The WRF calculation results using GIS data were compared with those of WRF using default values. The occurrence frequency and the vertical profiles of wind velocity calculated by WRF using GIS data agreed very well with those of the observation data. The calculated results of WRF using GIS were much better than those of WRF using default values.

KEYWORDS: WRF, vertical profile of wind velocity, occurrence frequency of wind velocity

1 INTRODUCTION

To assess the pedestrian wind environment around tall buildings based on occurrence frequencies of wind velocities we need reliable statistical wind observation data from near their construction sites. However, wind observatories are not always located near construction sites. Even if they do, the observation height is sometimes not high enough and the wind data are affected by surrounding buildings. Meso-scale simulation can be an alternative to direct observation. The authors intended to use the WRF (The Weather Research and Forecasting Model), a meso-scale simulation model, in order to prepare standard wind data at high-altitude for the assessment of the pedestrian wind environment. We also plan to use WRF for research on urban heat island phenomena, which is becoming serious in large cities in Japan. One of the effective countermeasures against heat island phenomena is to lead cool air of sea breeze into urban canopies. This strategy strongly depends on the vertical profile of wind velocity and the temperature of the sea breeze. Before doing these investigations using WRF, it is necessary to confirm how WRF can correctly regenerate the occurrence frequencies and vertical profiles of wind velocities. For this validation, observation data measured by Doppler Sodar in the Minami Senju district in Tokyo (Miyashita et al. 2002) were used. In order to well regenerate the vertical profile of wind velocity by WRF, it is considered that an appropriate surface roughness should be given to the WRF calculation. However, the default setting of WRF based on USGS (United States Geological Survey) expresses urban areas as only by one category and gives a uniform roughness length regard-

less of building densities and heights. Thus, we used GIS (Geographic Information System) data to appropriately classify urban land-use categories and to give roughness lengths to the WRF calculation. We conducted two cases of WRF calculations using a default setting and using GIS data, and the results were compared with the observation data.

2 OUTLINE OF CALCULATIONS

2.1 Calculation Period, Initial and Boundary Conditions, Physics Scheme

Calculations were carried out for a period of one month from May 1 to May 31, 2000. To set initial and boundary conditions we used FNL (Final) Operational Global Analysis data from the NCEP (National Center for Environmental Prediction). Table 1 gives an overview of the Physics Schemes used for these calculations.

Table 1: Physics Schemes

Physics scheme	microphysics	WRF 6 graupel class
	Longwave	Rapid Radiative Transfer Model
	Shortwave	Gudhia showtwave
	Surface layer	Monin-Obukhov (Janjic Eta) scheme
	Land surface	Noah land surface model
	Planetary boundary layer	Mellor-Yamada-Janjic scheme (2.5 level closure model)
	Cumulus	no
	Urban canopy	no

2.2 Calculation Domains and Grid Intervals

The calculations were conducted using three-stage, two-way nesting grids. The calculation domains and grid resolution are shown in Table 2 and Figure 1. The Minami Senju district, used for the comparison between observation and WRF calculations, is included in Domain 3.

Table 2: Computational Domain and Grid Resolution

	Domain (km) $X \times Y \times Z$	Grid Size $X \times Y \times Z$	Horizontal grid intervals (km)
Domain 1	$450 \times 450 \times 20$	$50 \times 50 \times 60$	9
Domain 2	$180 \times 180 \times 20$	$60 \times 60 \times 60$	3
Domain 3	$60 \times 60 \times 20$	$60 \times 60 \times 60$	1

※We used unequal intervals for the vertical grid and small intervals for areas near the ground surface.

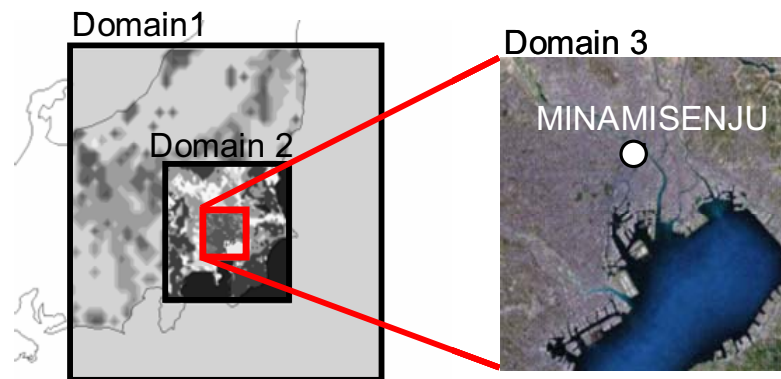


Figure 1: Computational Domain

2.3 Setting Land-Use Categories and Ground-Surface Parameters

Default setting of WRF employs the USGS's (United States Geological Survey) 24 categories of land use and their corresponding ground-surface parameters such as roughness length, albedo, and so forth. However, in the USGS, urban area is expressed by only one category and its roughness length is uniformly 0.8m regardless of building density and building height. Moreover, some areas that would be considered "urban" in reality are classified as pasture, grassland, and other categories in the USGS. Thus, the USGS does not sufficiently express the actual circumstances of Tokyo. For these reasons, we used the Digital Map 5000 and National Land Numerical Information Report (both referred to as "GIS" hereafter) published by the Ministry of Land, Infrastructure, Transport, and Tourism to appropriately classify land-use categories. Furthermore, we classified the urban area into three categories, "Low", "High", and "Commercial". We mainly used the Digital Map 5000, adding supplementary data from the National Land Numerical Information Report for places not covered by the former. The procedures for classifying land-use and determining ground-surface parameters are as follows.

Firstly, we netted the GIS in a $1\text{km} \times 1\text{km}$ mesh, which is the same size as the grid in Domain 3 of the WRF calculation. Then, the area for each land-use category in each $1\text{km} \times 1\text{km}$ grid was calculated, and the land-use category occupying the largest area within each grid was determined to be a representative land-use category in the grid.

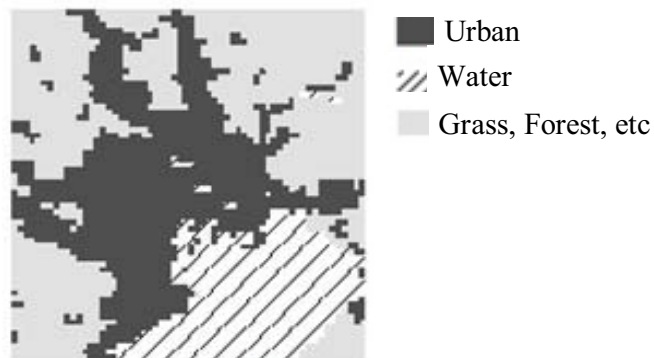
Secondly, we classified urban area into three categories to reflect the diverse urban configurations of Tokyo. (As described above, in the default setting of WRF with USGS, the urban area is expressed by only one category regardless of building density and building height.). We used land-use categories from the Digital Map 5000 and assigned them to three different urban categories: "Low," "High," and "Commercial". "General Low-Rise Residential area," "High-Density Residential area," and "Others" (including "Land for Public Facilities") in the Digital Map 5000 were assigned to the "Low" urban category; "Medium- and High-Rise Residential area" to the "High" urban category; and "Area for Commercial and Business Use" to the "Commercial" urban category. We totaled the areas occupied, respectively, by the Low, High, and Commercial category in each grid square, and the urban category with the largest area was determined to be a representative urban category for that grid square.

Finally, GIS land-use categories were corresponded to the USGS land-use categories, and surface parameters were determined as shown in Table 3. The USGS uses a uniform roughness length of 80cm for the urban area, but for this study we used 70cm, 100cm, and 150cm for Low urban area, High urban area, and Commercial urban area, respectively. We adopted these values

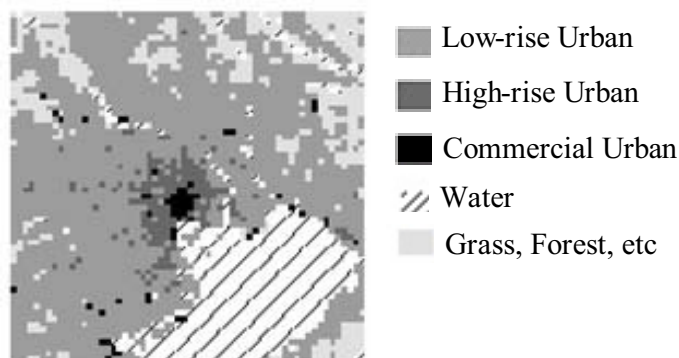
by referring to Grimmond and Oke (1999). Figure 2 shows land-use categories based on the USGS (Figure 2a) and the GIS (Figure 2b), which shows large differences between them.

Table 3: Land-use Categories and Surface Parameters

No.	USGS/SIB Land-Use Category	GIS Land-Use Category	Urban Category	Surface Z0 [cm]	Albedo [%]	Soil Moisture [%]	Surface Emmissivity [%]
1	Urban Land	House and Public Building	Low	70	15	10	88
			High	100			
			Commercial	150			
2	Dryland Cropland and Pasture	Farm	-	15	17	30	98.5
3	Irrigated Cropland and Pasture	Paddy Field	-	10	18	50	98.5
7	Grassland	Park and Grass	-	12	19	15	96
15	Mixed Forest	Forest	-	50	13	30	97
16	Water	Lake and Sea	-	0.01	8	100	98
19	Barren or Sparsely Vegetated	Soil Surface	-	1	25	2	90



2a) USGS



2b) GIS

Figure 2: Land-use Categories in Domain 3

2.4 Calculation Cases

We carried out two kinds of calculations: one using the default setting of WRF with USGS (Case 1), and the other using the land-use categories and surface parameters based on GIS data as described in 2.3 (Case 2).

3 COMPARISON OF WRF-CALCULATED RESULTS WITH OBSERVATION DATA

3.1 Occurrence Frequencies of Wind Velocities at High Altitude

Figure 2 compares the probabilities of exceedance of mean wind velocity (10 minutes averaging 300m high) between the results of WRF and observation data. Case 1 and case 2 indicate WRF calculations using the default value and GIS data, respectively. The probability of exceedance of wind velocity calculated by Case 2 agreed very well with the observation data. The probability of exceedance calculated by Case 1 was higher than that of Case 2. However, the difference was not so large at this high altitude.

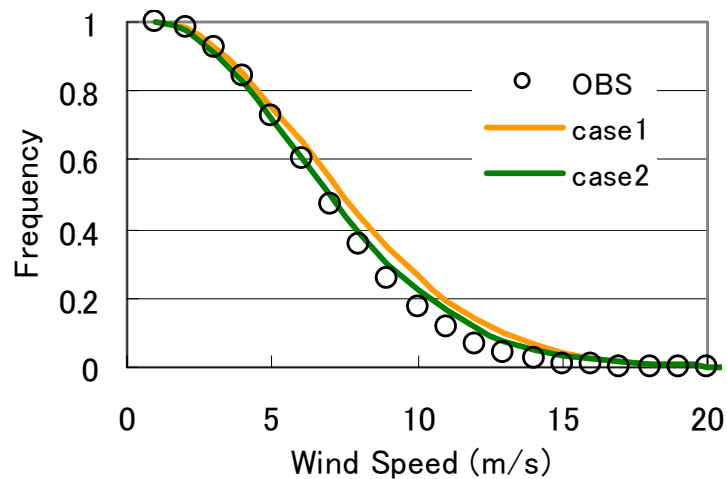


Figure 3: Probability of Exceedance for Mean Wind Speed

3.2 Vertical Profiles for Mean Wind Velocities

For this comparison, we firstly extracted southerly wind (wind direction= $180^\circ \pm 33^\circ$ at 200m high) for both observation and calculation. Then the vertical profiles of wind velocity of the observation data were classified into eight clusters by cluster analysis. Corresponding clusters of calculated results were made so that each cluster at the same time of the observation data became the same cluster.

Figure 4 shows vertical profiles of wind velocities in the eight clusters. Averaged values $\pm 1\sigma$ (standard deviation) at each height in each cluster are plotted in the figures. The value shown in the caption for each cluster is the occurrence frequency for that cluster. Except for Figure 4f (Cluster 6), there is a pretty good match between observation and calculated results. In particular, Case 2 using GIS is remarkably close to the observation values. Case 1 using the default setting of USGS generally show higher values than the observation data. The calculated wind velocities for Case 6 do not correspond with observation data because Cluster 6 includes many data obtained during rainy weather. In both Case 1 and Case 2, during rainy weather the WRF calculation tends to produce a higher wind velocity than the observations.

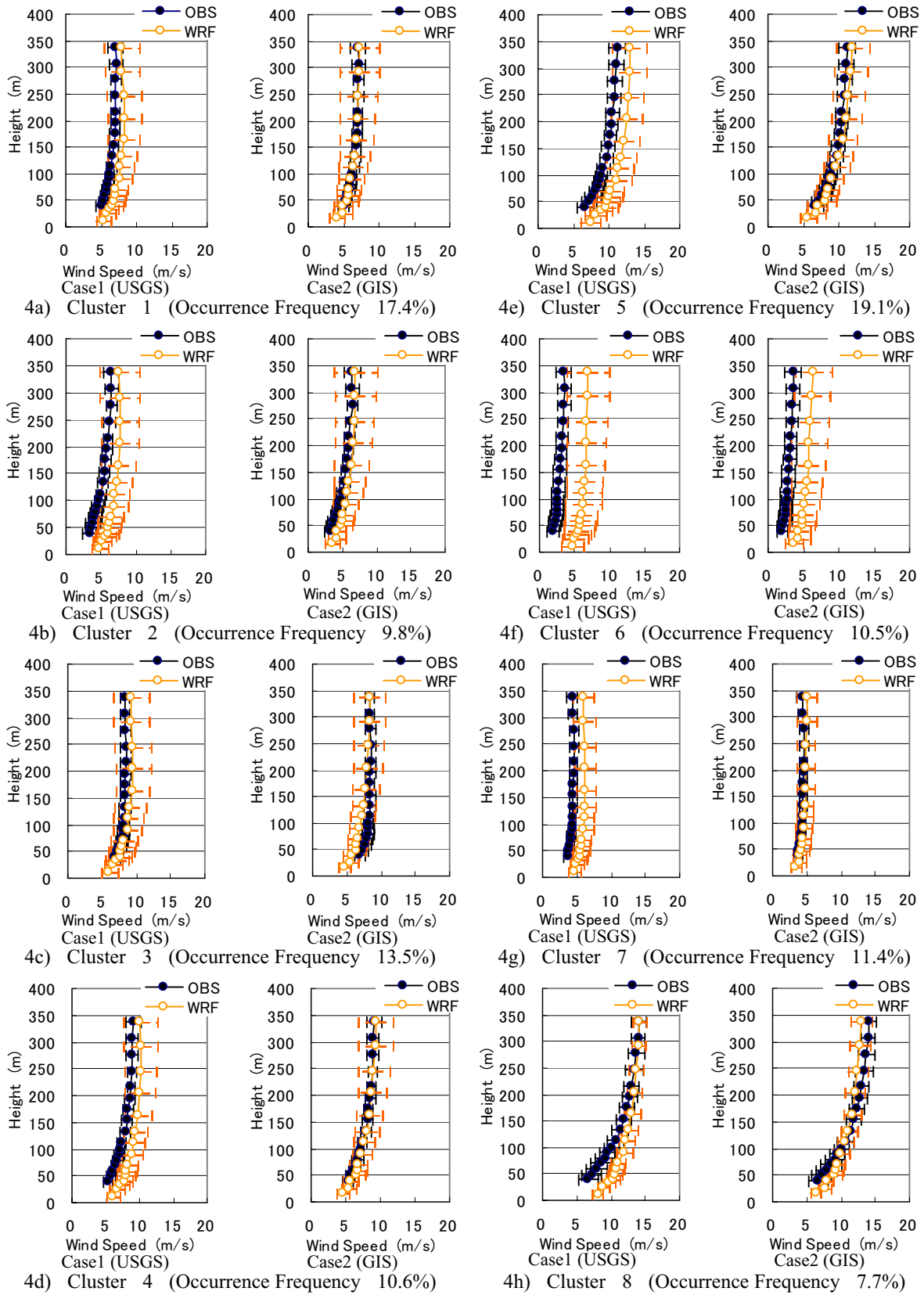


Figure 4: Vertical Profile of Mean Wind Speed

4 CONCLUSION

Two cases of WRF calculations were conducted using the default setting (Case1) and based on GIS-derived land-use categories and surface roughness lengths (Case2). The calculated results were compared with the observation data measured by Doppler Soda at Minami Senju. The calculated probabilities of exceedance of wind velocity at high altitude (especially Case2) corresponded very well with that of the observation. In addition, it was apparent that calculated vertical profiles of mean wind velocity of Case 2 were very close to those of the observation.

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