ICWE 16
August 27-31, 2023
FLORENCE - ITALY
16th International Conference on Wind Engineering

Estimation of near-ground wind velocity and temperature in the urban area around Tokyo Bay using local objective analysis data and the POD–LSE method

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SUMMARY:
Local objective analysis (LA) data are generally provided as a reanalysis database with a high spatiotemporal resolution for urban areas; however, currently, the period for which LA data can be provided is restricted. The near-ground meteorological observation data provided by observatory are valid for long-term statistical analysis; however, the observation data have a low spatial resolution. Thus, it is necessary to propose a strategy for constructing a long-term database with high spatial resolution to reproduce the statistical distribution of wind velocity and temperature for urban areas by combining near-ground meteorological observations (site-specific data) and LA data (high spatial resolution). The purpose of this study was to investigate the feasibility of reproducing large-scale meteorological data using Proper Orthogonal Decomposition with Linear Stochastic Estimation (POD–LSE) method. Using LA data from the Tokyo Bay area as training data (snapshots) and local grid point LA data (assumed observation data) from the same location as the observatory as input data, the wind velocity and temperature distribution were estimated with high spatial resolution using the POD–LSE method. The results indicate that it is feasible to reproduce the wind velocity and temperature distribution in large-scale urban areas using the POD–LSE method.

Keywords: local objective analysis, urban wind environment, POD–LSE method

1. INTRODUCTION

Due to increase in urban population, there are serious environmental problems in urban areas, such as air pollution and heat, driving concerns for urban ventilation in urban design. Currently, a typical approach for estimating the urban natural ventilation efficiency, pedestrian wind environment, and urban heat island effect is statistical analysis based on long-term observation data at the nearest observatory as the inlet boundary of the microscale simulation. However, urban areas where observational data can be provided are very limited, and conducting long-term observations in urban-scale areas is difficult and expensive. Recently, local objective analysis (LA) data developed by the Numerical Weather Prediction System of the Japan Meteorological Agency (JMA) provided high-resolution data with a horizontal spatial resolution of 5 km and hourly temporal resolution for wind velocity, temperature, and relative humidity. The effectiveness and reliability of LA data as an urban wind database has been demonstrated (Wang et al., 2022). However, LA data have provided meteorological data in recent years for urban areas. LA data are not currently available for long periods of the past. Furthermore, there are little statistical analysis data to use as a reference for urban wind environmental design in urban areas where long term observations are not available. Thus, it is necessary to propose a method to produce long-term spatial distribution data as complementary data for areas where observations are limited. This study attempted to generate spatially distributed databases by combining long-term observatory observation data with spatial distribution characteristics of urban areas analyzed by LA data.

2. Database

The LA data is a type of meteorological reanalysis data that can provide high-resolution data on wind velocity (west–east (U) and south–north (V) components), temperature (TMP) with a horizontal spatial resolution of 5 km, and an hourly temporal resolution for the whole of Japan and the surrounding areas. More details are provided in the reference provided by JMA (JMA, 2022). In this study, wind velocity at 10 m and temperature at 1.5 m above the ground in the LA data from 2018 to 2021 were selected for further analysis. In the LA data, the horizontal projection is a Lambert conformal projection grid with a resolution of 5 km × 5 km (the grid of 633 (latitude) × 521 (longitude) from approximately 20°26.3’N, 119°23.6’E to 25°54.7’N, 152°21.9’E). The temporal resolution was 24 h a day (00, 01, 02, …, 22, 23 UTC).

3. Methods

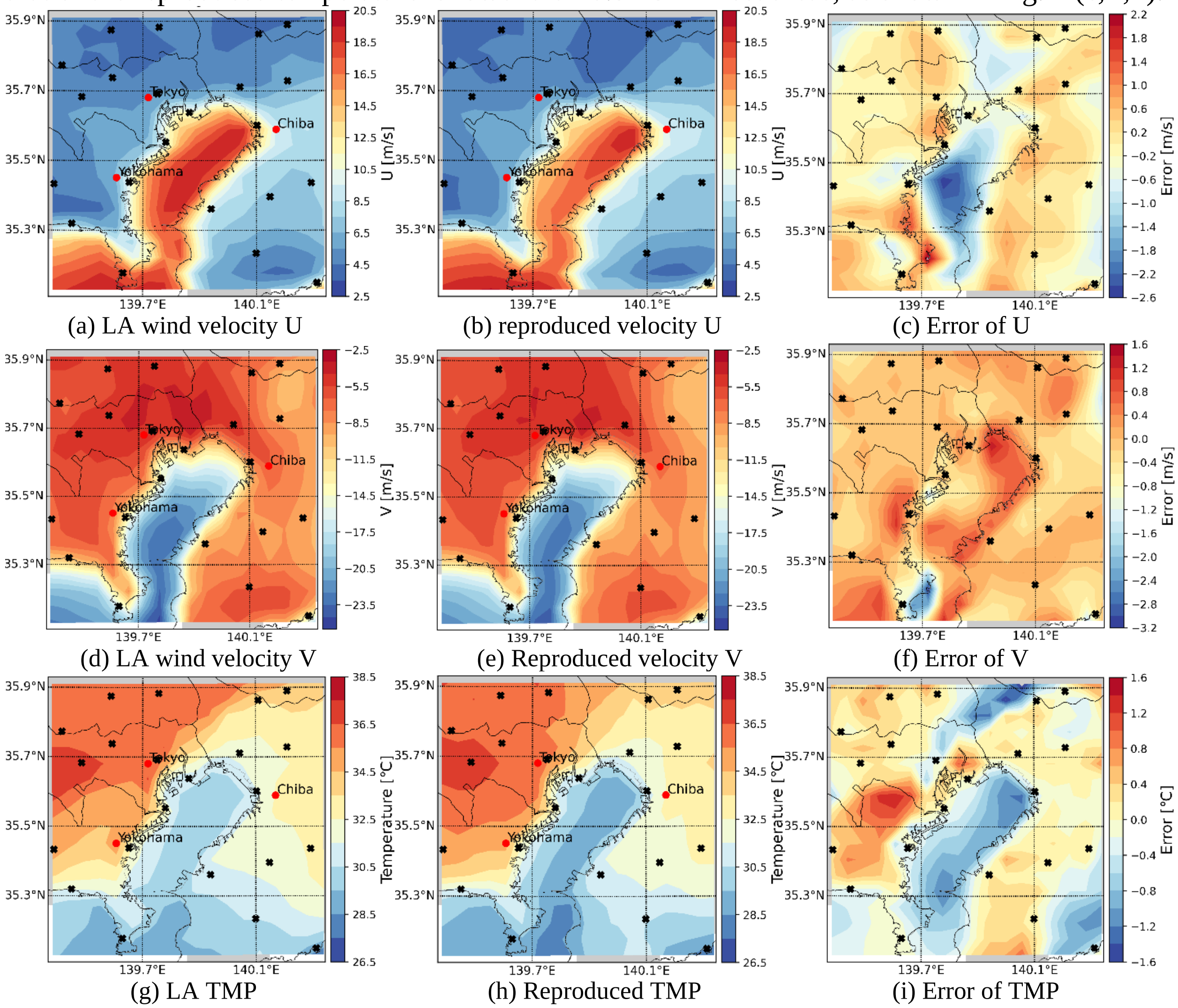
Proper orthogonal decomposition (POD) is a model reduction method for decomposing complex nonlinear problems into a series of optimal basis (modes) and coefficients. The linear stochastic estimation (LSE) uses conditional average statistics to linearly estimate the target quantity. In this study, POD was used to extract dominant features and trends in the spatial distribution of meteorological variables, such as wind velocity and temperature, from the LA data. The LSE was used to establish the relationship between the observational data and the POD temporal coefficient of the LA data. More detailed information on the POD–LSE method can be found in the previously published paper (Hu et al., 2022). Currently, only LA data from 2018 to 2020 were used as the training data to establish various parameters of the POD–LSE model. The grid point data of LA near the location of the observatory ("×" as shown in Fig. 1) in 2021 were extracted as assumed observation data to input to the POD–LSE model for the reproduction of spatial distribution data. Finally, the spatial distribution of LA data from 2021 was used as verification data to validate the feasibility of the model.

4. RESULTS

Fig. 1 compares the spatial distribution of wind velocity and temperature reproduced by the POD–LSE model and LA data that were used for verification at instant snapshots in the area around Tokyo Bay. The spatial average of the wind velocity magnitude and temperature in the investigated area was calculated to determine the time when the spatial average wind velocity magnitude or temperature was the largest to show the instant snapshot for comparison. The reproduced spatial distribution was shown in Fig. 1 (b, e, h) using the LA point data of the observation location ("×" in Fig. 1) as the input of the POD–LSE model. The error is defined as:

$$\text{Error}(i) = X_{\text{POD-LSE}}(i) - X_{\text{LA}}(i) \quad (1)$$

where $X_{\text{POD–LSE}}$ and X_{LA} represent the values reproduced by the POD–LSE model and the LA verification data, respectively. i is the index of the spatial coordinates. The results indicate that, although wind velocity and temperature were slightly underestimated in several local areas, the spatial distribution reproduced by the POD–LSE model was similar to the verification data (LA data) to some extent. The absolute error of the reproduced wind velocity is lower than 1 m/s, and that of the reproduced temperature is lower than 0.5 °C in most areas, as shown in Fig. 1 (c, f, i).



(a) LA wind velocity U (b) reproduced velocity U (c) Error of U

(d) LA wind velocity V (e) Reproduced velocity V (f) Error of V

(g) LA TMP (h) Reproduced TMP (i) Error of TMP

Figure 1. Comparison of spatial distribution characteristics between reproduced results (POD–LSE) and verification data (LA data) at instant snapshots (UTC time: 2021/01/07 5 am for U; 2021/10/01 3 am for V; 2021/08/10 5 am for TMP.) ("×" is the observation location; Red dots are the positions of the three cities around Tokyo Bay)

Fig. 2 compares the reproduced hourly wind velocity and temperature with the verification data (LA data) for 2021 at the Tokyo site. The results indicated that the reproduced wind velocity and temperature were consistent with the verification data for the entire year. Fig. 3 demonstrates the probability density and cumulative distribution of the reproduced results and LA data at the Tokyo site. For the reproduction of wind velocity, the reproduced results of the frequency of small wind velocity magnitude are slightly lower than those of the LA data. However, the reproduction of large wind velocity magnitudes was almost consistent with that of the LA data. For temperature, the reproduced distribution was largely consistent with LA data.

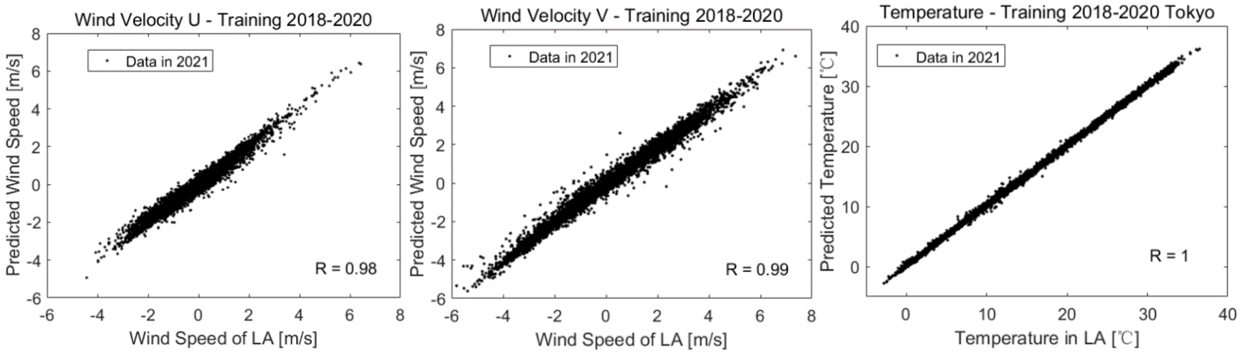


Figure 2. Comparison between reproduced results (POD–LSE) and LA data during 2021 at the Tokyo site

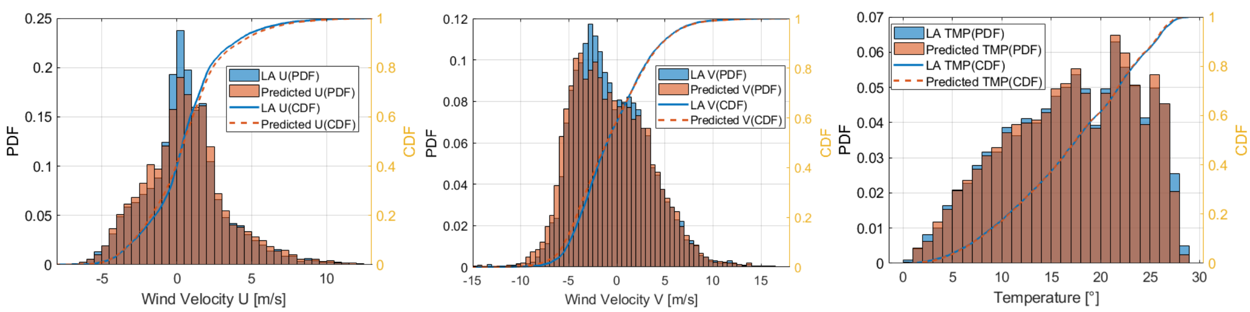


Figure 3. Probability density (PDF) and cumulative distribution (CDF) between reproduced results (POD–LSE) and LA data during 2021 at the Tokyo site

5. CONCLUSION

In this study, the POD–LSE model, which was based on several local point data and LA spatial distribution characteristics was feasible for reproducing the urban wind velocity and temperature distribution. In particular, for the probability density distribution of wind velocity, the frequency of a larger wind velocity magnitude can be accurately reproduced. In future research, we will attempt to use long-term meteorological observation data provided by the observatory as input data to reproduce the long-term spatial distribution of urban wind velocity and temperature for statistical analysis.

ACKNOWLEDGEMENTS

A part of this work was supported by the Japan Society for the Promotion of Science KAKENHI Grant Number 20H02308 and 22K04448. In addition, the first author is grateful for financial support from the Chinese Scholarship Council (CSC).

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