Journal of Wind Engineering & Industrial Aerodynamics 174 (2018) 411–423

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia

Optimisation technique for improving wind downscaling results by estimating roughness parameters

Gustavo Montero [a], Eduardo Rodríguez [a], Albert Oliver [a,*], Javier Calvo [b], José M. Escobar [a], Rafael Montenegro [a]

[a] University Institute for Intelligent Systems and Numerical Applications in Engineering, SIANI, University of Las Palmas de Gran Canaria, ULPGC[1] Campus Universitario de Tafira, 35017, Las Palmas de Gran Canaria, Spain

[b] Agencia Estatal de Meteorología, AEMET, Leonardo Prieto Castro, 8, 28040 Madrid, Spain

ARTICLE INFO

Keywords:
ALADIN-HIRLAM HARMONIE-AROME model
ECMWF model
Wind3D
Roughness length
Displacement height
Downscaling wind field models
Evolutionary algorithms
Land cover

ABSTRACT

The characterisation of the aerodynamic roughness length (z_0) and the displacement height (d) is critical when modelling the wind field using the log vertical profile. It is known that the values of these parameters depend on land coverage and weather conditions. Thus, many authors have studied their relationship, providing typical values for each land cover. In this paper, we have performed a comprehensive literature review to collect the intervals of z_0 and d values for each land coverage. Using these intervals, we estimate their values using an optimisation technique that improves the results of a downscaling wind model. The downscaling model is a 3D adaptive, mass-consistent finite element model (Wind3D) that takes values from the HARMONIE-AROME or ECMWF mesoscale numerical weather prediction models. The optimisation is carried out by a memetic algorithm that combines the Differential Evolution method, a rebirth operator and the L-BFGS-B algorithm. The fitness function to be minimised is the root mean square error (RMSE) against observed wind data. This fast procedure allows updating the aerodynamic parameters for any weather condition. Numerical experiments have been carried out to show the performance of the methodology.

1. Introduction

The influence of aerodynamic parameters in the modelling of wind field in the microscale and mesoscale, specially the wind velocity near the ground, is well known (Mahrt et al., 2001; Emeis and Knoche, 2009; Jancewicz and Szymanowski, 2016). Therefore, the accuracy of these parameters is critical to simulate the wind field used in wind power plants energy prediction, dispersion of air pollution, and wildland fire spread among others. In this paper we propose a strategy to improve the results of a downscaling wind model by estimating the values of the roughness length (z_0) and displacement height (d) using Differential Evolution (DE) and a rebirth operator (RO).

A downscaling wind model uses the prediction of a Numerical Weather Prediction (NWP) model as input wind field to compute a new one in a higher resolution mesh that better captures the terrain features. In this paper, the downscaling wind model is Wind3D (Rodríguez et al., 2012; Montero et al., 1998, 2005; Oliver et al., 2015), a diagnostic mass-consistent wind model, coupled with two different NWP models; specifically the European Centre for Medium-Range Weather Forecasts (ECMWF) model (Andersson, 2015) and the HARMONIE-AROME model (Bengtsson et al., 2017).

Diagnostic models apply conservation of mass, momentum, and energy singularly or fully, considering the terrain effects on an initial flow field. Although these models are used to obtain wind fields at a given time, the results usually represent winds of a time-averaged period. They are limited in comparison with prognostic models because they don't take into account the transient and thermal effects so they cannot simulate the evolution of the boundary layer; however, the computational requirements of the former are much lower than the latter. Diagnostic models can be classified into three different categories according to the conservation laws applied. The first category comprises the diagnostic models that are based only on the conservation of mass; see, e.g., (Sherman, 1978; Montero et al., 1998; Burlando et al., 2007). Mass-consistent models have been applied to the dynamical-downscaling

* Corresponding author.
E-mail addresses: gustavo.montero@ulpgc.es (G. Montero), eduardo.rodriguez@ulpgc.es (E. Rodríguez), albert.oliver@ulpgc.es (A. Oliver), fcalvos@aemet.es (J. Calvo), josem.escobar@ulpgc.es (J.M. Escobar), rafael.montenegro@ulpgc.es (R. Montenegro).

[1] http://www.dca.iusiani.ulpgc.es/proyecto2015-2017.

https://doi.org/10.1016/j.jweia.2018.01.011
Received 18 September 2017; Received in revised form 8 January 2018; Accepted 9 January 2018

of NWP models for local and regional scale wind forecasting, e.g., the WindNinja model (Wagenbrenner et al., 2016). The second category considers a linearised momentum equation (Walmsley et al., 1986; Mortensen et al., 1993); its computational cost is comparable to mass-consistent models with similar results (Walmsley et al., 1990; Barnard, 1991). Nevertheless, mass-consistent models are better suited for some atmospheric dispersion problems where a fast response is required (Homicz, 2002). The third type of diagnostic model applies conservation of both mass and momentum to some form of turbulence closure (Apsley and Castro, 1997; Maurizi et al., 1998; Uchida and Ohya, 1999; Lopes, 2003), and even conservation of energy (Montavon, 1998). The RANS RNG $k-\varepsilon$ turbulence model has handled non-linear flow effects better than mass-consistent models (Lopes, 2003) but it is computationally more expensive. The diagnostic model used in this paper is a new version of Wind3D, with an updated atmospheric parameterisation and wind profile proposed in (Zilitinkevich et al., 1992, 1998, 2012). Under this new profile, both z_0 and d determine the effect of the terrain on the near-surface airflow (Abtew et al., 1989), therefore it is important to have land use data available. In the last twenty-five years several projects on land cover mapping have been developed mainly using satellite images. In this paper we have used the land cover database of Spain (SIOSE) (National Technique Team SIOSE, 2011a).

For each land cover, the actual values of z_0 and d can be computed using, as a rule of thumb, a ratio of the height of the surface morphology characteristics (h). For instance, for a crop or forest canopy (Brutsaert, 1982), proposes a value of d between 0.67 h and 0.75 h, and a value of z_0 about 0.12 h. However, this approach does not hold for non-homogeneous surfaces and a more detailed analysis is required (Kondo and Yamazawa, 1986). Different authors have carried out this analysis resulting in diverse values of z_0 and d for the same land cover. For this reason, we have performed a literature review to construct a table with all the ranges for each land coverage in the SIOSE database.

In addition, the values of z_0 and d can be affected by land coverage variations, wind speed and direction, and atmospheric stability (Bosveld, 1997). So, the values of z_0 and d have to be known for each weather condition and a general value for each land coverage is not enough to predict the wind field reliably.

To this end, we propose an optimisation algorithm to estimate the values of the aerodynamic parameters for a downscaling wind model. This strategy has been applied to a particular region (Canary Islands) using the SIOSE land cover database and the Wind3D downscaling wind model. We want to remark that the values of z_0 and d obtained in the numerical experiments are not representative values for a given land cover; they only represent the optimal solution compared to the available wind measurements for the land covers in the domain of interest. However, the general methodology can be applied to any combination of regions, databases, and downscaling wind models. So, the final aim of the proposed strategy is to improve the results of a downscaling wind model by estimating the optimum aerodynamic parameters values.

The content of the paper is organised following the steps of DE. This algorithm generates a random population from the ranges of z_0 and d for a given point. So, as a first step, we need to know the different land covers of our region that, in this case, are given by the SIOSE database described in Sect. 2. Then, we identify the possible range of values for z_0 and d for each land cover; these ranges are given in the literature review performed in Sect. 3. For a given region there exists a combination of different land covers, so we need to compute the actual value of each aerodynamic parameter by using the formula presented in Sect. 4. Then, with these values and the forecast wind field of the NWP models described in Sect. 5 we simulate the resulting wind field with the Wind3D model (Sect. 6). The last step of the algorithm is to compute the fitting function (the root square mean error between the predicted and the observed wind in meteorological stations) and generate the next population of the optimisation algorithm (Sect. 7). Numerical experiments in a test problem and a realistic case in Gran Canaria Island are described in Sect. 8 and the results are discussed in Sect. 9. Finally, the conclusions of this work are summed up in Sect. 10.

2. SIOSE land cover database

In 1990, the first land cover database encompassing the whole national territory was constructed in Spain on a scale of 1 : 100.000. It was developed in the framework of the CORINE Land Cover (CLC) European project (Bossard et al., 2000). After successive updates in 2000, 2006 and 2012, it became Image & CORINE Land Cover. In short, it consists of an inventory of land cover in 44 classes. The project SIOSE (Spanish acronym for Information System of Land Cover of Spain) was created in 2005 to integrate the local information available from the Autonomous Communities and the General State Administration. Since the requirements at the Spanish national level were higher than those supplied by the European project, the SIOSE generated a new land cover database for all the country on a 1 : 25.000 scale. It was based on reference images from 2005, with a MUM of 0.5–2 ha (SIOSE, 2005) and a planimetric accuracy of 5 m or better. The project was updated in 2009 and 2011; see (National Technique Team SIOSE, 2011a). Other important differences with the CLC are the land classification and the hierarchy levels, which are much more simplified in the CLC than in the SIOSE.

The SIOSE database consists of different basic and compound coverages. A compound coverage is made up of a combination of basic or compound coverages. Specifically, it considers eight general groups of basic coverages (Crops, Grassland, Forest, Scrubs, No Vegetation, Artificial Coverage, Wet Coverage and Water Coverage) that are further refined into forty specific classes of basic land coverage; see. e.g., (National Technique Team SIOSE, 2011b).

3. Roughness length and displacement height: literature review

To obtain the appropriate values of z_0 and d, the search space of each one must be defined. In this section, we present a methodology to generate a table with the ranges of z_0 and d values for each land coverage. Particularly, it is applied to Gran Canaria Island, but it is suitable to any other location.

To find the ranges of possible z_0 and d values for each land cover, we have carried out a literature review. Table 1 summarises it, and the specific references are listed in the caption. The first and second columns show the SIOSE code and a description for each of the distinct land coverages. The third and fourth, and the fifth and sixth columns present the nominal value and the range of the parameter z_0 and d, respectively. When data are not available, we have used the rule of thumb to obtain the z_0 and d values from the canopy height h; see (Brutsaert, 1982). Also, it is worth remarking that d is assumed to be zero for all the water surfaces (ACU, AEM, AES, ALC, ALG, AMO and LAA classes). The z_0 intervals for these water bodies verify the Charnock's formula for typical wind values, i.e., any estimation of z_0 with Charnock's formula will be within the proposed ranges. In the case of hurricane force winds, the z_0 maximum range may be increased if necessary. In such case, the Charnock approach does not apply and the resistance law appears to be more accurate; see, e.g., (Makin, 2005).

We have searched in the literature the minimum and the maximum values of each parameter and canopy. In addition, the values most used by different authors have been selected as nominal values, but these are not used in our approach. In fact, we used the ranges of Table 1 as searching space for the solution of each parameter in the characteristic wind situations shown in Table 3. Then, we performed an extended literature review on the assigned values to the roughness parameters of each coverage. For this reason, in general, we think that the proposed ranges completely cover the variation interval of z_0 and d corresponding to each coverage, respectively, not only for the region studied in this paper, but also for any region if the specific coverage is included in that literature review. Nevertheless, some ranges have been defined according to the local characteristics of certain coverages. This is the case of the high sea cliffs in Gran Canaria, for example, where the range of z_0 and