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Mesoscale wind speed simulation using CALMET model and reanalysis information: An application to wind potential

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ABSTRACT

This work presents a simple methodology to simulate the mesoscale wind field using dynamic modeling and complementary meteorological data. Meteorological information obtained from the project developed by the National Center of Environmental Research (NCEP) and the National Center of Atmospheric Research (NCAR), meteorological stations, a digital elevation model and a land use data were used in this study. All these data were input for the simulation of wind fields at three different heights (20, 30 and 40 m) through the CALMET model. Simulations were made for an area corresponding to the south central region of Chile, known as the Maule Region. The results show that the simulated spatial resolution (1 × 1 km) in the CALMET model yields good results, yielding an RMSE value near 1 m s^{-1} for all the heights simulated, with a greater RMSE at 40 m (1.15 m s^{-1}) and a lesser RMSE at 20 m (1.10 m s^{-1}). The direction of the simulated wind fields was also evaluated, yielding an RMSE near 31° at 40 m. The determination of the wind potential is presented as a direct application of the method shown in this work.

1. Introduction

Wind speed is the most important meteorological variable for determining wind potential. In effect, wind energy is based on the determination of wind fields to determine their potential. Spatial and temporal variability are also measured across layers of the atmosphere near the surface. This is why the determination of wind fields holds particular interest in the development of renewable energy sources, as is the case of wind power, which has experienced significant growth over the last two decades and has become a sustainable, reliable and efficient energy source [1]. However, the main barriers that arise when addressing the concept of wind potential are related to wind variability and the technical difficulty of identifying areas with good wind conditions [2]. The first obstacle comes from the fact that wind is considered one of the most difficult meteorological variables to model and predict due to its dependence on the specific characteristics of any given location, such as topography and surface roughness [3]. The second is related to surface coverage, mainly to the classification and definition of an area with high or low wind potential, which requires analysis of spatial and temporal variations in the speed and direction of the wind in a specific location and the vertical profile of the wind speed [4].

The most common way of characterizing wind speed is through in-situ measurements, which are not always available to the desired extent and only allow a specific point determination of the magnitude and direction of the wind [5]. In addition, use of these measurements is a major obstacle in developing countries, which do not have a dense network of meteorological stations [6]. As a result, the most common way to characterize the wind spatially is to interpolate point-specific measurements. However, this method has limited validity because, in many cases, interpolation can only be performed when the characteristics of the landscape are uniform and there is a dense distribution of wind speed measuring stations [7]. Therefore, a possible solution for the determination of the magnitude and direction of wind fields is utilization of different types of simulations, depending on the desired spatial resolution of the results, the number of in-situ measurements (meteorological stations), and the complexity of the landscape (topography and roughness of the surface), among others [8].

The models that allow simulation of wind fields are based on the integration of information from field measurements, land use data, a digital elevation model, and complementary information, such as vertical wind profiles, among others. For instance, there are

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different models, which differ in characteristics such as numerical formulation, assumptions, equation simplifications and type (diagnostic and prediction model). Prediction models solve the equations describing the atmospheric process and how the atmosphere changes with time [9]. Examples of these prediction models are MM5 [10], WRF [11], HIRLAM [12], and HRM [13]. On the other hand, diagnostic models represent the actual state of the atmosphere [14] (Hu et al., 2010). Examples of diagnostic models are AERMET [15], MCSCIPUF [16] and CALMET [17]. Other models used in wind energy assessment were analyzed in [18] and [19]. One of these models with interesting features is CALMET, which is a free distribution model that generates wind fields over complex terrain.

The precision of the simulation of wind fields, in CALMET, depends in large measure on the quality and quantity of in-situ measurements that are input into the model and on their spatial distribution [20,21], which makes it necessary to have different information sources to minimize sources of error. This integration of meteorological observations from different sources and at different resolutions (spatial or temporal) can come from satellite data or low-resolution global databases [22]. Within this context, one database meets these requirements is the NCEP/NCAR Reanalysis project (here-in-after NCEP-1), which was created in 1948 by the National Center of Environmental Prediction (NCEP) and the National Center of Atmospheric Research (NCAR). The available data represent global grids or meteorological information on different variables including wind speed, thus permitting spatial information to be obtained that complements data from meteorological stations for the CALMET simulation.

Both the NCEP-1 data and the CALMET model have been previously used for studies of wind as a resource. In the case of NCEP-1, the data have been used to visualize wind conditions in Canada [23,24] and also to develop the Wind Atlas Analysis and Application Program (WAsP), of the Risø National Laboratory of Denmark, which includes an extreme wind atlas [25]. CALMET has been used in combination with forecast models and has yielded good results for more detailed resolution of the evaluation of wind resources, for example with MM5 [22,26] or WRF [27,28]. This is because the model is suited to work on complex terrain [29] and long-term simulations [30].

The goal of this work is to present a simple method to simulate wind fields with data from the NCEP-1 project and the CALMET model. As an application of this methodology, the wind potential of an area in south central Chile, known as the Maule Region, that exhibits complex terrain with few meteorological stations was determined. This article is structured as follows: Section 2 describes the study area, the meteorological stations used and presents the main characteristics of the CALMET model and the NCEP-1 database. Section 3 presents the simulation methodology for the wind fields, its evaluation and the determination of the wind potential. Section 4 shows the results obtained from the model, the evaluation of data from a meteorological station, the wind potential maps and limitations of the proposed method. In addition, this section presents the analysis of these results, and, finally, section 5 presents the conclusions of this study.

2. Study area and data set

2.1. Study area and in-situ measurements

The study area covers the south central region of Chile, known as the Maule Region. This area is located between 34°41′ and 36°33′ south latitude and 70°18′ and 72°45′ west longitude, with a surface area of 30,269.1 km^2. The weather in this region is a typical Mediterranean semiarid climate, with a mean temperature of 17.1 °C between September and March (spring and summer). The mean annual precipitation in this region is approximately 676 mm, mainly concentrated during the winter months. The summer period is generally dry and hot (2.2% of the annual precipitation), whereas the spring is wetter (16% of the annual precipitation) [31]. In-situ measurements from five meteorological stations were used in this work. The measurements consisted of hourly records of the magnitude and direction of the wind. Fig. 1 shows the study area and the location of the meteorological stations.

Of all the stations, four were used as inputs for the modeling performed in CALMET. Two of these correspond to the Pahuil (35° 36′ S. − 72° 34′ W., 52 m.a.s.l.) and Putú (35° 12′ S. − 72° 16′ W., 8 m.a.s.l.) stations managed by the Dirección Meteorológica de Chile, with a recording period between May and October of 1992. The other two stations correspond to the meteorological station of the Cauquenes Experimental Center of the INIA (Instituto de Investigaciones Agropecuarias) (35° 58′ S. − 72° 17′ W., 140 m.a.s.l.), with a recording period between the years 2003 and 2005, and the Panguilemo experimental station (35° 23′ S. − 71° 40′ W., 102 m.a.s.l.) of the University of Talca, with a recording period between 2003 and 2006. The measurements performed by these four stations correspond to a height of 10 m. The remaining station is Faro Carranza (35° 32′ S. − 72° 35′ W., 21 m.a.s.l), which was used for evaluation of the modeling. This station provides wind speed measurements at 20, 30 and 40 m and wind direction at 40 m, with data records between January 29, 2006 and June 8, 2007. The area

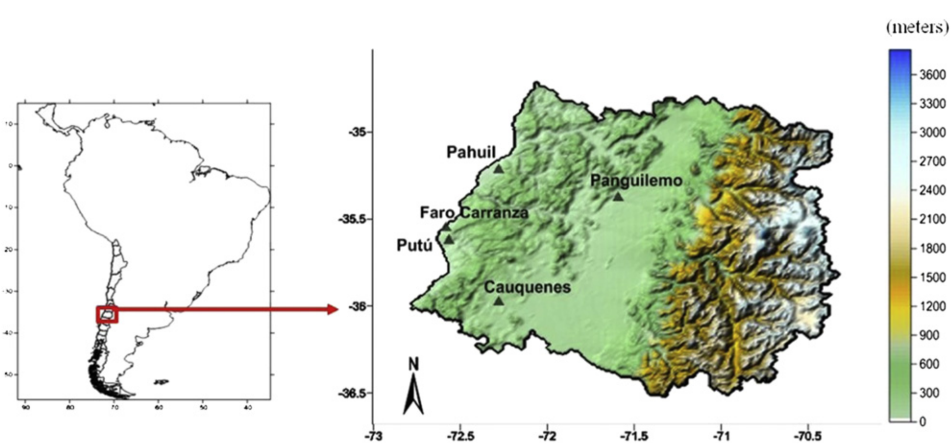

Fig. 1. Study area and location of the meteorological stations used in this work (black triangles) superimposed on a digital elevation model of the same region.