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Effects of different wind data sources in offshore wind power assessment

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ABSTRACT

Currently, approximately 5.3% of electricity production in Europe comes from wind energy. The increase of the size and the improved efficiency of wind generators have permitted their utilization offshore, leading to exploitation of offshore wind energy. Although offshore wind farms are well established in northern European countries, in the Mediterranean Sea they are still in their infancy. It is expected that within the next few years, offshore wind farming will grow considerably in this area. The accurate estimation of the wind speed fields is of most importance for the assessment of offshore wind energy resources. In this work, the effects of alternative wind data sources on the wind climate analysis are examined along with the offshore wind power density estimation in four locations across the Aegean Sea. In order to develop correction relations for satellite and model wind data, taking as reference the buoy measurements, the data are analysed and calibrated using the Error-In-Variables approach. The effects of the different data sources on the wind climate analysis and the estimation of the mean wind power density before and after the calibration procedure are presented and discussed. The Error-In-Variables approach performed better and reduced significantly the uncertainties of the alternative data sources.

1. Introduction

Greece, with an approximately 16,000 km long coastline, has a high wind potential over the Aegean and Ionian Seas [1,2]. Although the Aegean is not a large open sea area and is shaped by the presence of island complexes, it has certain hot-spots where wind power may reach high values. Advancing offshore wind farms (OWF) development in areas like the Aegean Sea is a challenging task that certainly requires reliable and accurate wind resource maps. Usually, the collection of wind data at an offshore location is performed by installing a meteorological mast[1] or deploying a buoy on site for a relatively short period (e.g., one year). Even though the obtained observations are useful, they have sparse spatial coverage, poor extent in the time scale, and are generally not representative, when a larger candidate region is considered. When only short-term measurements in a candidate offshore place are available, one of the most important problems refers to the lack of information regarding the interannual variability of the wind speed; this issue renders the measurements incomplete. To deal with the lack of measured long-term wind data in offshore areas and to reliably describe the corresponding wind climate characteristics, various methods have been developed and proposed in the scientific literature. These methods utilize the short-term wind measurements in the candidate area combined with co-located in time (concurrent) wind measurements in one or more neighbouring coastal or offshore reference areas. The wind climate of the reference areas is considered as known, since, usually, long-term wind measurements are available, e.g., from meteorological stations or oceanographic buoys operating for long periods of time. In this way, the wind time series data from the candidate site are extrapolated to longer time intervals acquiring long-term data for the site.

The relationships between the short-term wind data in the candidate area and long-term data in the reference area(s) are either linear or of probabilistic nature, see Ref. [4]. The relevant methods for this analysis are known as measure-correlate-predict (MCP); linear regression (and variants or generalizations of it) is the primary theoretical framework. For a recent review on MCP methods see Ref. [4] and references cited therein. The fundamental principle for the most common MCP methods refers to the establishment of a linear relation between the long-term wind speed at a

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[1] For offshore locations, in-situ installation of a mast is a very costly procedure. In addition, wind fields obtained from offshore meteorological stations close to the coasts, could be very different compared to the wind fields obtained from neighbouring coastal meteorological stations; see e.g., [3].

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candidate (C) and a reference (R) site, when long-term data are available for the R site and only short-term data for the C site. The simplest form of the sought-for relationship is

$$u_C^{LT} = a + bu_R^{LT}, \qquad (1)$$

where u_C^{LT} is the mean long-term wind speed at the C site and u_R^{LT} is the mean long-term wind speed at the R site. Various regression approaches in the context of MCP analysis, including higher than first order linear, as well as non-linear methods are also described in Ref. [4].

Another effective way for acquiring long-term wind data is by using sea surface wind fields obtained from numerical weather prediction (NWP) models or gridded data obtained from remotely operating instruments such as radar altimeters, scatterometers and synthetic aperture radars (SAR). The model reanalyses are produced by assimilating measured surface data into model-generated surface wind fields through consistent numerical methods. The spatial resolution of NWP reanalysis wind data is usually rather coarse, describing only the large-scale features. To overcome this, dynamical or statistical downscaling techniques are applied to achieve the desired fine-scale fields. During the process of OWF site selection, it is usually necessary to understand the atmospheric flow patterns of the wider region, and, from this point of view, gridded wind data from NWP or remote instruments are of the utmost importance. In addition to this, NWP model wind data per-se are often used for the description of the wind climate in a candidate area; see Refs. [5–8]. However, NWP model wind data are subject to errors [9,10]. For calibrating the results of NWP models, techniques of a similar theoretical background as those described above can also be applied in principle. Model Output Statistics (MOS) is a family of post-processing techniques that use multiple regression equations to provide a statistical relationship between the forecast output of NWP models (predictors) and the observed (measured) variables (predictands). The MOS technique was introduced in the early 1970s; see Ref. [11]. MOS uses historical model output combined with the corresponding observations, quantifying in this way the uncertainty of the atmospheric forecasts. This is achieved by regressing historical measurements to historical predictions. The derived regression equations help to correct the actual weather forecasts of a NWP by minimizing prediction error and biases, as well as to provide the expected error of forecasts. The MOS technique is still widely used (e.g., in National Weather Service of the US National Oceanic and Atmospheric Administration, see also Refs. [12–16]). Though the MCP methods and MOS techniques aim at two essentially different goals, the underlying mathematical principles and tools for both methods are the same, i.e., to develop a single (or multiple) linear relationship between a dependent and one (or several) independent variables in order to either “predict” the dependent variable based on existing information for the independent or to “correct” the independent variable based on available information for the dependent.

A question that is closely related to the above discussion and accommodates the reliable estimation of the available wind power potential at a specific area, concerns the effect that different wind data sources may have on the estimation and modelling of the wind climate of the area. This question can be elaborated by means of the same principles and mathematical tools. In this respect, one of the main objectives of this work is to assess and quantify the effect that various wind data sources may have on wind speed statistics and on the preliminary analysis of wind climate and offshore wind energy resources for four offshore locations of the Aegean Sea.

The different wind data sources considered in this work consist of:

i) in-situ buoy wind measurements. The measurements are conducted from buoys of the POSEIDON marine monitoring network, at a height of 3 m above the sea surface; see Ref. [17].
ii) 10-km resolution NWP model generated wind fields at 10 m height above sea surface. The European Centre for Medium-Range Forecasts (ECMWF) ERA-40 global reanalyses at spatial resolution of approximately 125 km has been dynamically downscaled with the aid of the POSEIDON non-hydrostatic limited area NWP model, see Refs. [18,19].
iii) Seawinds blended satellite (BS) data at 10 m height above sea surface; the wind speed data are gridded on a global grid of 0.25° with a 6 h time step. The data are obtained by blending products from 6 different satellites utilizing the same retrieval algorithms, see Ref. [20].

Another main objective of this work is to establish realistic linear relationships between buoy wind measurements and gridded wind speed data from NWP simulations and satellite in order to homogenize and calibrate the latter data sets. A conceptual difference between the proposed analysis and MCP methods is that in the current work the final aim is to calibrate (correct) wind data from a less reliable source (target source, i.e., NWP model or satellite estimations) taking into consideration wind data from a reference source (buoy measurements). In this way, the available wind data for an area are enriched and homogenized and the wind climate analysis can be performed on a more secure ground.

In the next section, the wind data from the three wind data sources are presented. In section 3, the available wind speed time series are co-located first in the spatial domain (in reference to the locations of the buoys) and then in time (in reference to the common time frame). The obtained co-located wind data samples are compared by using ANOVA techniques and the corresponding deviations are estimated. In section 4, some elements of the simple linear regression (SLR) theory are provided along with the more general case of SLR, the Error-in-Variables (EIV) approach. In the same section, the calibration procedure of wind data originating from the BS and the NWP model is described analytically. In section 5, the calibration relations are provided for the examined offshore locations. The results derived from the EIV approach and SLR are compared and evaluated by adopting various statistic measures. Furthermore, the effects of the different wind data sources on the estimation of offshore wind power density in the examined locations, before and after the calibration procedure, are presented and discussed. Finally, section 6 includes some concluding remarks and proposals for future work.

2. Description of the available wind data sources

In this section, the wind data from the three different sources, namely wind data from buoy, BS and NWP model, are described. Furthermore, in subsection 2.4, the following preparatory procedures for the wind speed data are presented: i) the log wind profile used for the correction of buoy wind speed from 3 m to 10 m above the sea surface, and ii) the procedure for identifying the appropriate wind speed values from the gridded data sets in order to compare them with the observed values from the buoys. The latter is also known as spatial co-location procedure.

2.1. Buoy wind measurements

In 1999, the POSEIDON marine monitoring network was established in the Greek seas, comprising of 10 observation buoys, deployed in deep water locations, cf [17]. Since then, the buoys record various meteorological parameters (wind speed, gust and