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Wind gust estimation by combining a numerical weather prediction model and statistical post-processing

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Abstract

The continuous rise of off-shore activities such as the development of wind farms requires a reliable operational support in order to minimize cost drawbacks and secure operations during the different stages of associated projects. One of the most important parameters for this kind of analysis is wind gustiness. The objective of the study is the development of a methodology for the surface wind gust estimation based on Numerical Weather Prediction Models and statistical post processing. The obtained method has been tested over the offshore west coastline of the United States and evaluated utilizing observational data from the NOAA's buoy network.

Keywords: wind, wind gust, Kalman filters, forecasting, numerical weather prediction models, operational meteorology

1. Introduction

The continuous rise of offshore and nearshore activities and the development of structures such as wind farms require the employment of state-of-the-art risk assessment techniques [1,2]. These techniques depend on environmental characteristics that affect the activities in question, such as wind speed and wave height. Risk analysis has a rather climatological character and sets the safety standards that should be followed on the structural design.

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Beyond the risk analysis that is performed a priori, a reliable operational support is also needed in order to minimize cost drawbacks and human danger during the construction and the functioning stage as well as during maintenance activities. One critical parameter for this type of analysis, is the presence and magnitude of surface wind gusts, which is defined as the maximum observed wind speed over a period of time [3,4]. More than one gust definitions are proposed in the literature for wind gusts. For example, Extreme Operating Gust (EOG) and Extreme Coherent Gust (ECG) are described within the IEC 61400 standard for wind energy [5]. Moreover, several parameterizations and formulas are applied for their description and estimation.

The purpose of this work is the development of a wind gust forecasting methodology combining a Numerical Weather Prediction (NWP) model and a dynamical statistical tool based on Kalman filtering. To this end, the methodology adopted in this work is based on a physical parameterization that takes into account all the processes in gust formation, namely Wind Gust Estimate (WGE) methodology [6]. This has been applied in a number of studies [7-12] with interesting and promising results and was implemented to function within the framework of the atmospheric modeling system SKIRON/Dust [13]. The model was run operationally for four selected months with a relatively coarse resolution (small resource demands). The results were evaluated using observational data from NOAA's buoy network in the West Coast of the United States. Furthermore, for selected cases a Kalman filter methodology [14,15] was used for the removal of systematic errors, giving a more accurate estimation of forecasted wind gusts.

2. Experimental design

2.1. SKIRON/Dust Modeling System

SKIRON/Dust is a modeling system developed at the University of Athens from the Atmospheric Modeling and Weather Forecasting Group [13,16] in the framework of National and European Union (EU) funded projects like SKIRON, MEDUSE (Mediterranean Dust Experiment), ADIOS (Atmospheric Deposition and Impact on the Open Mediterranean Sea), CIRCE (Climate Change and Impact Research) and most recently MARINA (Marine Renewable Integrated Application Platform). Recently the model was updated to include the Rapid Radiative Transfer Model– RRTMG [17-20]. Further details on the various model parameterization schemes and capabilities can be found in the above mentioned studies and the references therein.

2.2. Parameterization of Surface Wind Gusts in SKIRON/Dust

The processes leading to gust formation vary among boundary-layer turbulence, deep convection, mountain waves and wake phenomena [21]. These phenomena are difficult to be properly resolved by NWP systems [21,22] without the need of considerable computational resources. In addition, the subscale interactions are not always sufficiently described and generate errors or uncertainties.

In general, gust forecasting is based on semi-empirical formulas derived from experimental studies [23-25], statistical models (using observations, ex. MOS - Model Output Statistics [26,27]) and physical parameterizations that take into account atmospheric conditions in the processes of gust formation.

In this study an integrated methodology for the prediction of wind gusts is proposed based on a NWP model and a dynamical optimization statistical algorithm. The main gust forecasting scheme adopted is the WGE method as suggested by Brasseur [6]. According to this approach, the turbulent wind fields of the boundary layer can be considered as an overlay of a large number of eddies with different sizes. Larger eddies have the scale of the depth of the boundary layer, while the smaller ones rapidly dissipate through friction. This leads to momentum transportation both upwards and downwards. Under specific conditions, air parcels within eddies may deflect toward the surface, leading to gusty type wind fluctuations [7]. These processes have been incorporated in the SKIRON/Dust modeling framework, allowing the estimation of wind gusts at the surface.