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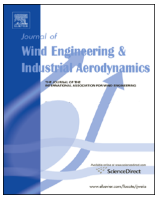

Short-term wind forecast for the safety management of complex areas during hazardous wind events

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ABSTRACT

This paper describes the short-term wind forecast system realised in the framework of the European Project “Wind and Ports: The forecast of wind for the management and safety of port areas”. The project's aim is to contribute improving the safety and accessibility to the harbour areas of the largest ports in the Northern Tyrrhenian Sea, which are frequently exposed to hazardous winds, in order to minimise the risks for users, structures, transport means, stored goods and boats within the ports. The short-term wind forecast system is based on a mixed statistical-numerical procedure, trained by means of local wind measurements and implemented into an operational chain for the real-time prediction of the maximum expected wind velocity corresponding to three forecast horizons (30, 60 and 90 min) and three non-exceeding probabilities (90%, 95%, and 99%). The local wind measurements used to train the forecast algorithms have been recorded from the 15 ultra-sonic anemometers installed in the Ports of Savona, La Spezia, and Livorno. This wind-monitoring network is used also to carry out the short-term forecast system a posteriori verification and validation.

1. Introduction

The short-term wind forecast, i.e. corresponding to time horizons from 1 h to 1 day, is very important for many human activities, e.g. for transport systems like navigation, air transport, and HS/HC rail transport, to estimate the impact of energy input from intermittent renewables into electric power supply systems, for the assessment of the atmospheric pollution due to fossil-fuel power plants or chemical plants, etc. During hazardous wind conditions, in particular, the transport systems can become very dangerous for human lives and goods. The present paper focuses on the short-term forecast system (hereafter STFS) realised in the framework of the European Project “Wind and Ports: The forecast of wind for the management and safety of port areas” (Solari et al., 2012). Such system is applied to a very complex anthropic context, i.e. the port areas, where a lot of people, working or in transit, are exposed to risks for their health under many different circumstances, like the ones depicted in Fig. 1. Note that in such a complex context, it is not possible to apply a unique definition of wind hazard, which is necessarily related to the considered terminal and dependent on its specific operational activities. For instance, in a Lo–Lo container terminal the threshold for the wind speed considered dangerous, e.g. for container overturning, is expected to be much higher than in a dry bulk plant, where coal or cereals are stored and their powders can be easily, i.e. during low wind speed conditions, re-suspended in the air. Yet, the height at which the threshold is chosen is different depending on the terminal, higher for container terminals and lower for multi-purpose or dry bulk plant terminals.

Following Lei et al. (2009), the techniques for realising short-term wind forecast systems can be divided into physical and statistical methods, depending on the application that they are targeted to and the time and spatial scales required.

Physical models, like meso-scale numerical weather prediction (NWP) models, require input data concerning both the geometry of the computational domain, e.g. topography and surface roughness, and the meteorological conditions of the atmosphere, e.g. wind velocity, temperature, pressure, and humidity. They are usually used for longer-term forecast, up to 2 or 3 days ahead, and larger spatial scales. Unfortunately, as far as the wind velocity forecast is concerned, the average precision of these models, even if coupled to higher-resolution micro-scale models, is still unsatisfactory for many applications related to safety, also at the shorter time scales. Al-Yahyai et al. (2010), for instance, have analysed several test cases available in the literature concerning NWP models uncertainties and reported in their conclusions that

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Fig. 1. Examples of wind-induced risks and damages in port areas: collapse of a harbour crane (a); containers overturning (b); collapse of lighting tower, fallen over a boat (c); the ferry boat Fantastic entering the Port of Genoa during a sea storm on 30th October, 2008 (d).

these models have typical wind speed biases, in the forecast horizon between +12 and +36 h, ranging from 0.25 m/s over flat terrain up to 2.5 m/s over complex terrain.

Statistical models provide a statistical relationship between past and future events and usually overcome NWP models for very short-term forecast applications. Torres et al. (2005), for instance, have shown that the root mean square error of an autoregressive moving average model does not exceed 1.5 m/s for forecast horizons of the order of 1 or 2 h, depending on the topographical complexity of the considered site.

Often, physical and statistical models are used together, where NWP forecasts and available measurements constitute the input variables and the statistical model is applied to improve the NWP output. Cassola and Burlando (2012), for example, developed a hybrid system consisting of a Kalman filter applied to NWP wind speed forecasts, obtaining an improvement of the order of 25% for a forecast up to 36 h ahead. Recently, some new statistical or hybrid methods based on the artificial intelligence techniques, as neural networks (Gong and Jing, 2010; Fadare, 2010) or fuzzy logic (Damousis et al., 2004), have been developed. See also Costa et al. (2008) for a review concerning the history of short-term wind forecast methods.

A universal forecasting model for all time horizons and all kinds of application does not exist. The choice of the most appropriate model depends on the required accuracy, algorithm's complexity, computational time, number and type of input variables and training data, etc. These features have to be set in a suitable way for each specific application from a practical perspective: for safety purposes, in particular, it is preferable to minimise the algorithm's complexity in order to reduce computational time and required input variables, to get fast responses to high-frequency wind speed variations. At the same time, the chosen model should provide forecasts with time horizons long enough to allow the terminals to apply their own safety protocols in case of dangerous wind conditions, e.g. the evacuation of the people working within the dangerous area.

Following the above considerations, the STFS implemented in the framework of the Project “Wind and Ports” is a quite simple statistical model based on the estimation of the conditional probability density function (CPDF) of the future wind speed given its present value. At, present, the model uses the wind measures that are registered by the anemometers installed in the monitoring networks of the three main ports of the Northern Tyrrhenian Sea, namely Savona, Livorno, and La Spezia (Italy), to forecast wind speed all over the ports with horizontal resolution equal to 80 m, at the heights of 10, 20, 50, and 100 m above ground level (AGL). The mentioned wind monitoring network, consisting of 11 tri-axial (Savona, Livorno) and 4 bi-axial (La Spezia) ultrasonic anemometers, is described in Section 2.

The statistical model that the forecast system is based on derives from a previous and somehow simpler formulation that has been applied extensively to the study of the wind conditions along the Italian HS/HC railway lines (Freda et al., 2009; Freda and Solari, 2010). It provides the Port Authorities of Savona, Livorno, and La Spezia with the mean and peak wind speed forecast corresponding to three time horizons (i.e. 30, 60 and 90 min ahead) and three non-exceeding probabilities (i.e. 90%, 95%, and 99%),. The STFS is based on two subsequent steps: firstly, the mean wind velocity (speed and direction) and turbulence intensity are forecasted at the anemometers position (Section 3.1); secondly, the mean and peak wind velocity forecasts are extrapolated from the anemometers to the grid points of the port areas (Section 3.2).

The mean wind speed forecast at the anemometers position is based on a conditional probability model of the future mean wind speed with respect to the present one (Section 3.1.1). The model parameters are estimated by means of the wind measurements recorded during a training period of, at least, 1 year, in order to account for the wind variability during the different seasons. Actually, it is expected that the longer the training period, the most reliable the model, as more extreme events can be considered in the parameters evaluation. Both the mean wind direction (Section 3.1.2) and turbulence intensity (Section 3.1.3) forecasts at