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# Wave influenced wind and the effect on offshore wind turbine performance

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**Abstract**

In this paper the effect of wave influenced wind on offshore wind turbines is studied numerically. The wave is seen as a dynamical roughness that influences the wind flow and hence the wind turbine performance. An actuator line representation of the NREL's 5 MW offshore baseline wind turbine is placed in a simulation domain with a moving mesh that resolves the ocean waves. These wave influenced wind turbine simulations, WIWiTS, show that the wave will influence the wind field at the turbine rotor height. Both the produced power and the tangential forces on the rotor blades will vary according to the three different cases studied: wind aligned with a swell, wind opposing the swell and wind over a surface with low roughness (no waves).


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## 1. Introduction

Ocean surface waves develop due to the frictional drag over the water's surface. Momentum from the air is transported to the ocean during the wave development, but the waves themselves will also influence the wind field. This process is often ignored, both in weather forecasting and in the field of offshore wind energy [1]. Different sea states affect the wind field in various ways. Wave shape, wave age and wave direction are important for upward momentum transfer in the marine atmospheric boundary layer (MABL) [2]. It is common to divide the wave regime into two parts: wind-waves are locally generated by the wind and swells are waves that have propagated away from the source origin. While wind-waves are often aligned with the wind, the swell direction is not necessarily correlated with the wind direction. Occasionally, swells will oppose the wind field, and this is known to give rise to interesting situations with increased turbulence levels over the sea surface [3]. Although it is known that fast moving waves in a low wind regime will influence the whole depth of the MABL, it is still uncertain to what extent the wave induced wind field will affect an offshore wind turbine or a wind farm [1].

In this paper, we present a numerical study of the possible effects wave states may have on the wind field and the following indirect effect on an offshore wind turbine. This is done by using computational fluid dynamics (CFD). In these CFD simulations the air flow does not influence the waves themselves. The wave is prescribed as a solid moving ground. Therefore this is a study of the wave *influenced* wind and the possible effect on offshore wind turbine performance.

## 2. Wave influenced wind

The wind profile over a surface is influenced by the roughness of the surface and the atmospheric stability. Wind observations at different heights are limited in offshore environments. Therefore wind speed profile models are frequently used to extrapolate the wind speed observations at lower levels to the wind turbine hub height or the swept rotor area. Small deviations from the real wind speed will significantly influence the anticipated wind power levels which are proportional to the cube of the wind speed. Different wind profiles will also give rise to different loads on the blade and the rotor nacelle assembly [4]. Therefore a correct description of the wind profile is of outmost importance for both for wind turbine design, wind assessment and wind energy harvest.

Expression for the wind profile can be found by using Monin-Obukhov similarity theory (MOST). MOST is valid in the constant flux layer (where the fluxes are assumed to vary little with height). Under neutral atmospheric stability conditions MOST theory leads to the logarithmic wind profile [5]:

$$U(z) = \left(\frac{u_*}{k}\right) ln\left(\frac{z}{z_0}\right) \tag{1}$$

where k = 0.4 is the von Kármán's constant, $z_0$ is the roughness length (defined as the height where the wind speed equals zero) and $u_*$ is the friction velocity. The friction velocity is defined as [5],

$$u_*^2 = \frac{\tau_0}{\rho}, \tag{2}$$

where $\tau_0$ is the force per unit area exerted by the ground surface on the flow and ρ is the density of the air. The roughness length, $z_0$ , can be derived from wind speed measurements. The literature contains different recommendations for selection of $z_0$ for different surfaces. In the field of offshore wind industry the sea surface is generally considered as levelled and smooth, and, therefore, a low $z_0$ value of 0.0002 m is often chosen [6]. This is also the value of the roughness used in the simulations described later in this paper.

Atmospheric stability is of importance when studying the wind profiles and it has also been documented that both energy yield and fatigue damage on a wind turbine differ when atmospheric stability is taken into consideration [7,8]. Nevertheless, in this study, we have assumed neutral atmospheric stratification; hence there will be no heat exchange between the sea surface and the overlying air.