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On the interaction of fast traveling Ocean Waves and the Atmospheric Boundary Layer:
A Mechanistic Approach combining Field Measurements and High-fidelity Simulations.

In coastal areas, the wind energy industry migrates to the offshore environment, where huge spaces are still available in stronger and better behaved wind conditions. The offshore environment imposes new challenges to a well established wind energy industry. It is imperative to accurately predict and describe the offshore wind resource in order to design cost efficient solutions. The concerned flow is characterized by a turbulent Atmospheric Boundary Layer (ABL) where the ocean's dynamics significantly alter the atmospheric flow through higher heat capacity and complex wind-wave interactions important in fairly common situations.

So this Thesis reviews and extends the current knowledge regarding Wind-Wave interactions in the lower part of the Marine ABL (MABL), where they are possibly significant in the characterization of the wind resource. The MABL is investigated through physical and numerical experiments, to reveal the role of Wave Induced (WI) motions transferred from the sea into the atmosphere. Thanks to the use of complementary physical and numerical experiments, new insights on the wind-wave interaction processes are obtained.

A scanning Light Detection and Ranging (LiDAR) system is deployed to observe the propagation of WI motions approximately 18 m above the ocean. The sLiDAR registers high resolution space-time maps of the Radial Wind Speed (RWS), allowing an original two-dimensional (2D) spectral analysis rarely possible in the field. Unlike more conventional methods, the upward turbulent energy transfer from the waves to the wind is evident and well distinguishable from the atmospheric turbulence in the 2D wave-number-angular-frequency (k-w) spectra. This is a first to demonstrate the applicability of sLiDAR systems to measure k-w dependent turbulent spectra in the Offshore Environment.

The MABL is investigated employing a Large Eddy Simulation (LES) solver. The test cases are built to investigate the WI disturbances above fast traveling waves, propagating under comparatively slow wind conditions in a situation commonly described as *old seas*. An original method is proposed to control the Wind Speed at a certain height above an arbitrary sea-state. The WI disturbances are investigated as function of varying Wave Age conditions in monochromatic wave scenarios. Non-monochromatic waves are also investigated, leading to the comparison between physical and numerical experiments in a level of detail rarely observed in the literature.

Recent developments in measuring and modelling techniques open path to a mechanistic approach, i.e., one that seeks the characterization of certain phenomena in purely physical or deterministic terms. Applied to the investigation of wind-wave interactions it consists in the direct estimation of WI velocities and pressure in the atmosphere, rather than the inference of WI disturbances in vertical wind profiles, total momentum fluxes, or TKE budget. An original methodology is proposed to characterize WI motions from the measurements in instantaneous velocities. The definition of a *Wave Related* flow is extended from *Wave Coherent* (WC) to *Wave Induced* (WI). If the waves travel with velocities sufficiently greater than the mean wind speed, that leads to WC and WI decompositions that for the first time allow their quantification in the field without any previous sea-state knowledge required.

Mots-clés : offshore environment, ocean engineering, atmospheric boundary layer, turbulence, wind-wave interactions, microscale, wind resource, large eddy simulation, remote sensing.