# AIR FLOW AND SAND TRANSPORT PERTURBATION OVER A HUMAN-MADE FOREDUNE UNDER OFFSHORE WIND USING COMPUTATIONAL FLUID DYNAMICS

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## INTRODUCTION

Human activities grew rapidly until the 20th century in European coastal areas, disturbing the natural evolution of coastal dunes. This is epitomized in the Mediterranean region, which has seen a rapid expansion of tourism in the coastal zone. Many coastal dunes are experiencing human stabilization by fencing, vegetation planting or reshaping the dune profile, resulting in a modification of air flow and sediment transport patterns. For example, a taller and steeper dune may result in an increased zone of wind flow separation and deceleration, resulting in the reversal of flow and sediment transport to the dune toe from the backshore during offshore winds. (Walker and Nickling, 2002; Hesp and Smyth, 2019). Globally, the pattern of reversed or deflected flow plays a key role in dune evolution, particularly when an offshore wind regime is dominant (Bauer et al., 2012; Nordstrom and Jackson, 2018). Recently, Computational Fluid Dynamics (CFD) has given new insights to complex flow recirculation on the lee-side of heavily managed coastal dunes on developed coasts during onshore winds (Smyth and Hesp, 2015; Nguyen et al., 2022).

This research is the first to investigate wind flow and sediment transport dynamics on a anthropogenically constructed dune in offshore wind conditions. CFD simulations were completed for three offshore wind directions over a computational domain constructed from a 3D topographic LiDAR surface. Simulations were validated by a comparison with wind measurements on the field using 2D anemometers.

## STUDY SITE

The field site is situated in the south of the Gulf of Lion on the French Mediterranean coast. Leucate Beach is a microtidal (0.3 m at mean spring tide) and wave-dominated environment ($H_s$< 0.3m for 75% of the time) with a prevailing strong offshore wind (71.6 % of the time from 2015 to 2022). Offshore winds can reach more than 40 m/s 10 to 30 days per year, with one preferential direction of about 310° (38% of the time). The dune system is composed of a single foredune and is vegetated from the dune crest to the inland. This dune was totally human-made in 2003. The southern section of the dune is constructed from excavated materials from a road, which constitute the core of the dune's, which has then been covered by sand from harbor dredging, whereas the northern dunes are just composed of sand from the dredging (Figure 1).

## METHODS

Near surface wind flow was measured along a cross-shore profile with nine 2D ultrasonic anemometers at a height of 0.3 m. The sampling rate was 1Hz from which a 1-minute

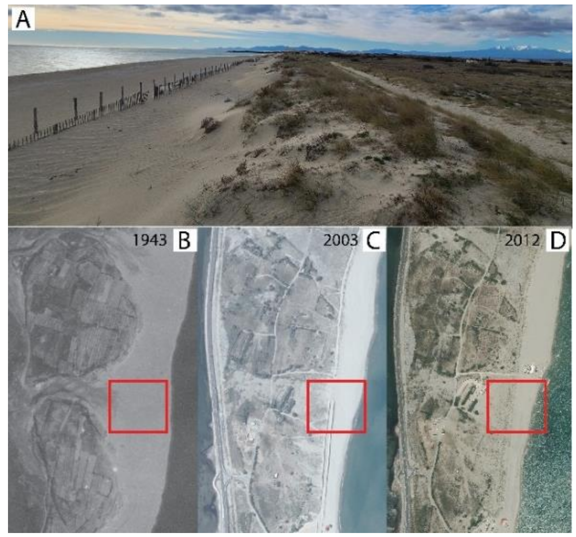


Figure 1 – A. Leucate beach and dune system. B., C. and D. aerial photography of the study site with evolution of the foredune creation, from natural evolution (1943), excavated rock (2003) and filled by sand (2012).

average was calculated and used to validate CFD simulations. All the simulations were performed using the open-source software OpenFOAM over a computational domain created with snappyHexMesh from LiDAR. The numerical calculations were performed with the incompressible air flow algorithm SIMPLE, producing a steady-state time averaged solution. Turbulence was modeled by the RNG k-ε model. This method has been validated in many publications on coastal dunes (e.g., Hesp et al., 2015).

The offshore winds were simulated at different speeds (15, 20 and 25 m/s) and directions (290, 310 and 330°) at 10 m height in the computational inlet, in relation to the weather characteristics of the field site. The aeolian sand transport was calculated over the computational domain using the Lettau and Lettau (1978) equation, and shear velocity was computed at the surface of the CFD domain using the shear stress parameter. As the landward part of the dune is fully vegetated, only the sand transport from the seaward dune crest to the beach is represented.

## RESULTS

The comparison between the observed offshore wind and the CFD output shows a very good correlation ($r^2$ > 0.9) and the most turbulent zone on the lee side of the dune where eddy recirculation takes place was clearly illustrated. The simulated wind speeds showed an acceleration over the dune crest and a strong reduction on the lee (downwind and seaward) side of the dune, but these amplitudes are driven by the longshore difference of the dune shape (Dredge material and dredge and rock core profiles, Figure 2). When the incident wind was near perpendicular to the dune (290°), the acceleration at the dune crest was higher than for oblique 310° and 330° wind directions. This acceleration was marked by one peak in the dreg material profile and two peaks in the dredge and rock core one (Figure 2). Concerning the lee-side part of the dune, a very strong deceleration of the wind speed is observed in the dredge material profile, whatever the wind direction, while in the dredge and rock core profile, the deceleration is lower with the wind speed always above 8 m/s. Then, a rapid re-acceleration across the beach occurred as the distance from the dune increased.

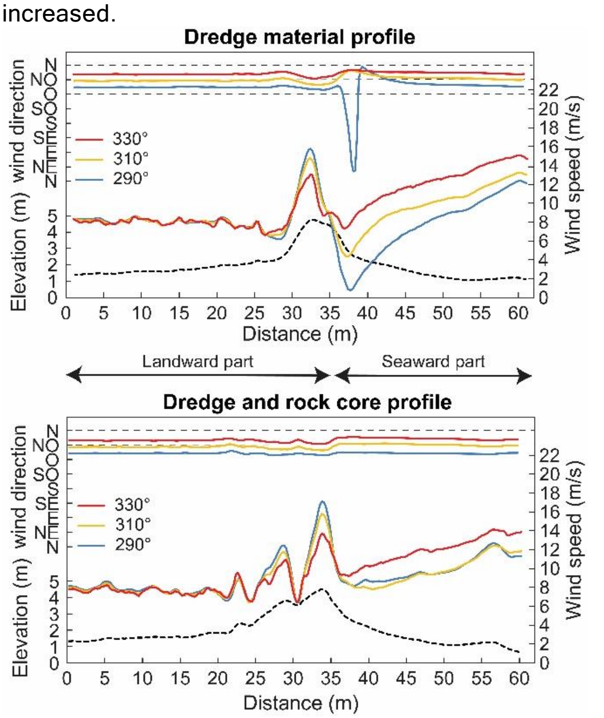


Figure 2 - Simulated wind speed (20 m/s) on the two profiles, dredge material and dredge and rock core. Dashed line shows ridge topography.

In regard to the wind direction, a slight steering to a more perpendicular wind was observed on the stoss slope for the three modeled directions for both profiles. The major differences appear on the lee-slope, where the dredge material profile shows a detached and reversed flow only for the near perpendicular 290° wind simulation (Figure 2) and a more deflected flow under oblique winds.

Because of a slower wind speed on the dredge material profile, the sand transport on the lee side was nonexistent (for the 20 m/s simulation presented here) under the near perpendicular 290° wind and very low for the oblique winds. It implied that no onshore transport occurred, even if there was reversed flow, because it was too weak to initiate sand transport. The trend is different in the dredge and rock core profile, where a moderate sand transport could occur on the top of the lee-slope and then decrease to the seaward dune toe.

CONCLUSION

The results of this study demonstrate that the choice of construction material for man-made dunes has a strong influence on dune geomorphology and thus patterns of offshore aeolian transport decades after construction. In this case the dune created with a hard rock core had a much more gradual gradient, thus preventing wind flow recirculation in the lee, potentially effecting aeolian sediment deposition at the seaward dune toe. This research demonstrates that seemingly minor differences in dune construction, may have long-lasting geomorphological implications for foredune dynamics and evolution.

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