Study marine dunes in an offshore windfarm context

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ABSTRACT:

Mobility of the sedimentary substrate, both through the flow of sedimentary particles and through the migration and evolution of sedimentary structures, has direct implications on the design, implementation, longevity, and safety of ORE (ocean renewable energy) devices. Marine dunes are very present on the English Channel and North Sea coast where most of the future Europeans offshore windfarms (OWF) are located and planned to be constructed. Cable installation and foundations for OWF in this environment is a challenge due to the seabed mobility. This mobility can bring risks of cable over-burying or un-burying and uncertainties about foundations scouring conditions. Consequently, there is a need to anticipate variations in sediment thickness to limit damage to infrastructure and to design anti-scouring protection and better anticipate OWF costs. Furthermore, marine dunes are areas of high ecological importance. It is therefore important to understand the effect that the installation of MRE infrastructure can have on dune morphodynamics to limit the impacts on the ecosystem. To address all these issues for OWF industry, two research and development collaborative projects have been set up: DUNES & MODULLES. The first project (DUNES) aimed at collecting *in situ* data on seabed, hydrodynamics and ecosystem via bathymetric surveys, current measurements and biological sampling. The second one (MODULLES) aims to model the influence of these dunes on offshore wind farms at different spatio-temporal scales from a few seconds and centimeters to several years and kilometers *via* numerical and physical modeling. During MARID, marine dunes issues for ORE sector will be depicted. An overview of the DUNES and MODULES projects will be given to present how we address these issues with research and development project.

1 MARINE DUNES AND OFFSHORE WINDFARM

Marine dunes are among the most dynamic sedimentary bodies and are very present on the English Channel and North Sea. At the end of 2021, offshore wind turbines represented 28.3 GW of installed capacity in Europe, almost all of it in the North Sea. The European Commission aims to have 300 GW of installed capacity by 2050 (Figure *1*).

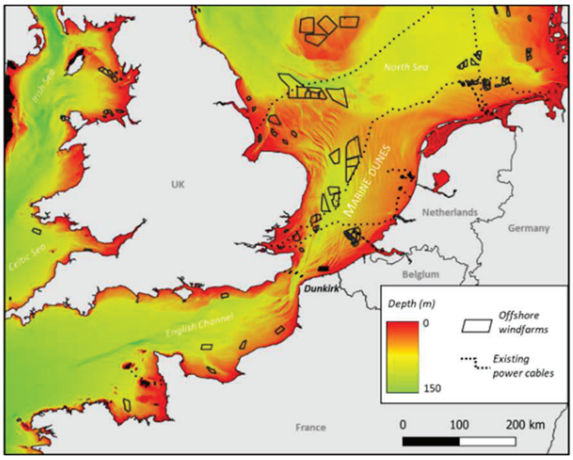

Figure 1 : Bathymetry of the North Seas (North Sea, English Channel, Irish Sea, Celtic Sea), planned and in operation Offshore Wind Farms (OWF) and power cables (data from EMODNET)

Cable installation and foundations of OWF in this environment is a challenge due to the high seabed mobility. This mobility can bring risks of cable over-burying or un-burying and uncertainties about foundations scouring conditions (Figure 2). It is therefore important to anticipate variations in sediment thickness to limit damage to infrastructure (heat transfer diffusion, exposition to fishing) and to design anti-scouring protection.

Marine dunes are essential functional areas as feeding and breeding grounds for many species. They are classified by the Marine Strategy Framework Directive (MSFD) and by Natura 2000 as key habitats. The French Ministry in charge of the environment therefore asks developers to assess particularly the impact of offshore wind farms on the habitat of marine dunes and their ecosystem.

In this context, it is important to address the following question: how to study marine dunes in an offshore windfarm context.

To answer this question, France Energies Marines initiated two collaborative projects: DUNES (2019-2022) and MODULLES (2021-2024). These projects aim to deepen our knowledge of the marine dunes field off Dunkirk where an OWF is planned in 2027 *via:*

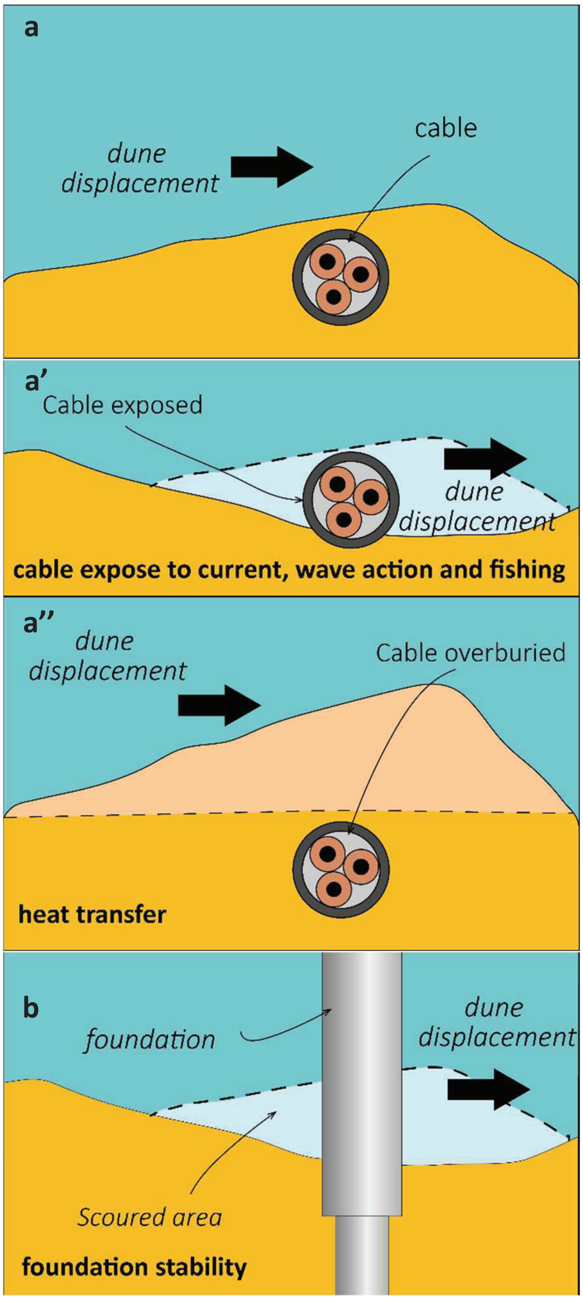

Figure 2 : Effect of marine dunes on OWF component: a) cable under marine dunes; a’) unburied cable after a marine dunes displacement, a’’) overburied cable under a marine dune experiencing heat issue, b) OWF foundation experiencing stability issue due to scouring.

- *in situ* morphodynamic observation and analysis,
- Marine dunes numerical and physical modelling,
- Thermal modelling,
- Ecosystem characterisation.

2 IN SITU MORPHODYNAMICS OF MARINE DUNES

2.1 Data acquisition

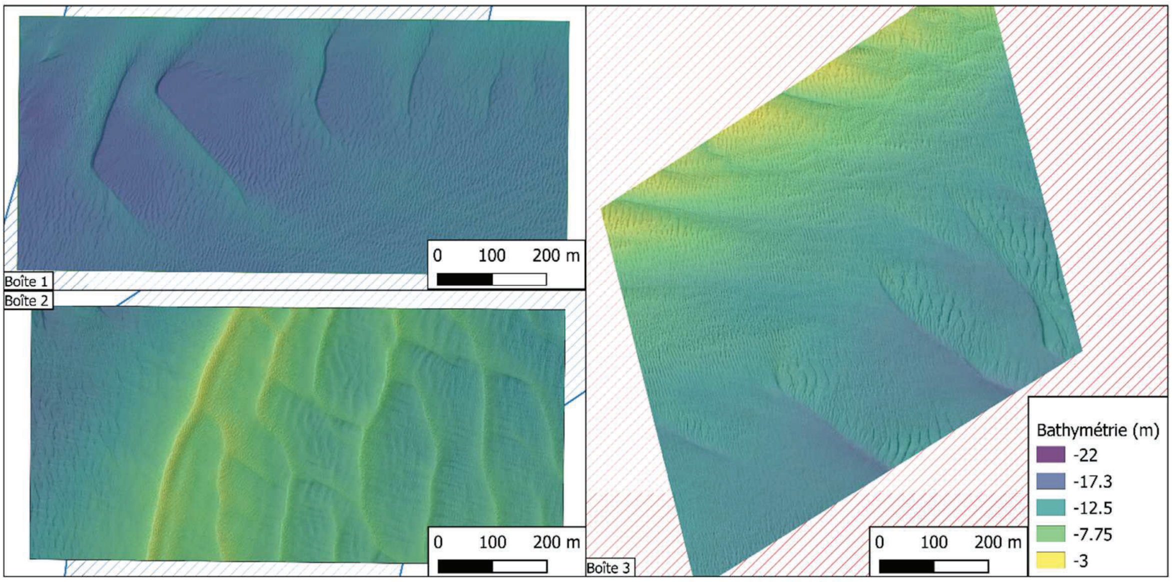

Figure 3 : Dunes morphologies off Dunkirk, bathymetric surveys realized in march 2020.

A protocol was implemented to acquire high spatial and temporal resolution data. To study the impact of forcing (wind, waves and current) on the marine dunes, it was necessary to perform numerous bathymetric surveys with a short time step. To allow this type of measurement and limit costs, three boxes were defined with an area of about 1 x 0.5 km (Figure 3). The boxes are located on the corridor of the connection cables and in the future OWF. They include different types of dunes: barchans, straight and three-dimensional dunes. Eight bathymetric surveys of these three boxes were carried out over a period of 21 months between November 2019 and July 2021.

The bathymetric surveys were complemented by an Acoustic Doppler Current Profiler (ADCP) campaign. Three ADCPs were deployed for 1.5 months in spring 2021 to measure the hydrodynamic. Two of them were positioned at the entrance and exit of box 1 near the buoys of the access channel of Dunkirk's harbour. The third ADCP was positioned north of box 3 in an area between two banks free of dune. The ADCPs were positioned on weighted cages that were launched and recovered by diver. The length of deployment was chosen to limit risks of silting while offering a relatively long timeframe.

2.2 Morphometric analysis

The acquired bathymetric data were processed to obtain a DTM (Digital Terrain Model) with a resolution of 0.5 m, which was used for a morphometric study and numerical modelling (Figure 3). The morphometric analysis has been performed for boxes 1 and 3 because dunes morphology of box 2 was judged too complex. DTM has been analysed as follow:

1) DTM filtering to smooth the roughness and limit the influence of secondary sedimentary figures (ripples and small dunes) in morphologies identification

2) Digitization of crest and troughs along transects perpendicular to the crest at 20 m intervals.

3) Measurement and calculation of morphometric parameters (bathymetry, height, wavelength, width, sinuosity) along these same transects.

4) Calculation of the migration speed (in m/year) of the crest along the same transects between two successive surveys.

Estimation of the associated sediment fluxes (in t/m/yr) has been done with the "Dune Tracking" method and three empirical equations (Hoekstra et al., 2004). “Dune tracking” uses morphometric indices of marine dune (height, wavelength, and width), sediment parameters (porosity and density) and migration velocities to approximate the volume of dune sediments that moves over time. All the figures obtained were compared to meteocean data (wind data at Dunkirk meteorological station and tidal data) to evaluate the influence of meteorological and oceanic forcing on the morphodynamic (see Le bot et al. 2023 in these proceedings for more details on the results).

Flux calculations were performed using realistic forcings and compared to the results of the "Dune Tracking" method. Then, the calculations were performed on an idealized case to refine the study of the influence of hydrodynamic processes (Michelet et al., 2022).

3 MARINE DUNES MODELLING

To better understand the dynamics of marine dunes and their interaction with OWF at different space and time scales (from days to years), marine dunes are modelled at different scales numerically and physically using bathymetric and current data acquired from 2019 to 2021.

3.1 Mesoscale numerical modelling

At mesoscale (from a dune to a dune field), two different numerical models are implemented using CROCO and TELEMAC-MASCARET modelling systems.

CROCO is a free-surface modelling system that solves the finite-difference approximations of the Reynolds-averaged Navier–Stokes equations. Space discretisation is performed with structured squares element. Waves are considered by coupling the spectral model Wave Watch 3 (WW3). The sediment dynamics is solved thanks to USGS sediment model (Blaas et al., 2007) (see Michelet et al. 2023, in these proceedings for results).

The open-source TELEMAC-MASCARET modelling system (TMS) is an integrated modelling tool for use in the field of free surface flows. The space discretisation is performed with unstructured triangular elements, which means that it can be locally refined in the area of interest. The three-dimensional (3D) discretisation is performed by extruding each triangle along the vertical direction into linear prismatic columns, spanning the water column from the bottom to the free surface. In TMS, simulation modules can be internally coupled to simulate sediment transport and morphodynamics. Modules Telemac-3d and Tomawac solve respectively the current and wave fields to the sediment transport and bed evolution module Gaia (see Durand et al. 2023, in these proceedings for results).

The two models will test different scenarios in term of waves, current and anthropogenic structures (cables, foundations…).

Numerical results from both numerical tools will be compared with each other and with field and laboratory observations. A particular focus will be put on the strengths and limitations of each numerical approach and modelling strategy.

3.2 Fine scale numerical modelling

The aim here is to carry out small-scale modelling of the scouring phenomena around a ground-based structure (e.g., wind turbine foundation) lying over a sandy seabed, subject to wave and current actions at intermediate depths.

The two major scientific barriers identified in the simulations of small-scale modelling of scour around structures are: i) turbulence modelling and accurate simulation of flow hydrodynamics including vortices dynamics and ii) sediment flux modelling. To address the first point, hydrodynamic simulations are performed using different turbulence modelling approach ranging from LES (Large Eddy

Simulation) to RANS (Reynolds Averaged Navier Stokes) and Hybrid to accurately reproduce the Horse-Shoe-Vortex dynamics and the lee-wake shed vortices. Sediment flux modelling is performed *via* various two-phase flow simulations of scour around a cylinder using sedFOAM with the best turbulence modelling approach deduced from the hydrodynamic simulations. (see Gilletta et al. 2023, in these proceedings for results).

3.3 Flume modelling of marine dunes

Marine dunes are modelled in two different flumes: In one of them, the hydrodynamics will focus on the interaction between unidirectional currents and a complex wave spectrum, whereas in the other, tidal currents will be reproduced. These experiments will permit to: (i) extend the range of explored dimensionless quantities (such as Reynolds number or Shields parameter) to derive general formulation and deepen our knowledge of dune morphodynamics under complex forcings, (ii) investigate the influence of superimposed bedforms generated by combined flows on the overall bed roughness, and subsequently on flow properties and dune dynamics.

In a second set of experiments, a cylinder will be added to the experiment to better understand scouring in a marine dune's context (see Vah et al. 2023 and Abroug et al. 2023 in these proceedings for more details).

3.4 Modelling thermal diffusion in marine dunes

Dense grid of power cables is part of each OWF, connecting individual turbines to the substation. Export power cables are then used to reach the mainland. These cables are sensitive to heat as they are designed to work below a specific internal temperature, above which materials (specifically, the insulation) can be damaged. The thermal models for power cable sizing is well established for cables in open water or in air, or buried on land. The thermal boundary conditions of a subsea cable buried in the marine sediment are not so well controlled. Indeed, marine sediment is porous and contains a variable part of water that may influence heat transfers. Therefore, a set of numerical experiments is planned to simulate the impact of dune migration on the distribution between advective and conductive heat fluxes. Several models of varying complexity will be used and compared: 1D analytical model provided by IEC, 1D model not considering advection, 1D model considering advection, and 2D Finite Element Model taking all phenomena into account (see Morvan et al. 2023 in these proceedings for more details).

4 CARACTERISATION OF MARINE DUNES ECOSYSTEMS

The installation of the offshore wind turbines will change the local environment depending on the phase of the OWF project; the resulting pressures/changes will then influence dune ecosystems depending on the pressures/changes intensity and the resistance/resilience of dune systems. From a geomorphological point of view, the changes potentially induced in the shape of dunes, in grain size, in time of refilling after perturbation, all have effects on living communities; indeed, the communities living in sediment are strongly related to sediment characteristics (Robert et al., 2021), some are adapted to muddy environment and others to clean coarse sand.

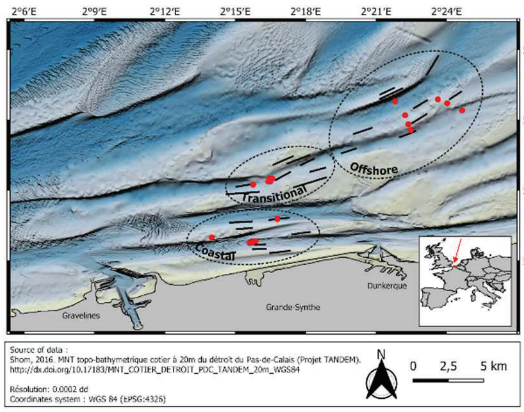

Figure 4 : Marine dunes sampling performed to study their ecosystem (Robert et al., submitted)

Marine dunes affect benthic species distribution (Robert et al., 2021). As we see above, OWF installation create marine dunes morphodynamic disturbance, which can cause effect on benthic habitat.

To study marine dune ecosystem and prevent effect of OWF construction, a sampling of all organisms from the water column to the sediment was performed (Figure 4).

Macrobenthic organisms (>1 mm) were collected with a Van Veen grab (0.1 m^2) whereas megabenthic organisms (> 10 mm) as well as fish species were collected with a commercial bottom-trawl. The latter was equipped with a reduced cod-end mesh of 20 mm stretched to improve the catch of juveniles and small fish. A total of twenty-three stations were sampled with grabs and twenty-six trawl hauls were performed. Stations were distributed in three boxes, according to a gradient of distance from the coast (coastal area, transitional area, and offshore area). This sampling strategy was performed both in Autumn 2019 (October) and Spring 2020 (May) to assess the seasonal variability of the benthic food web.

Organisms (meiofauna, macrobenthic organism and ichtyofauna) were then identified in the lab to establish a list of species for each compartment (Figure 5).

Then, stable isotope signatures of potential sources of carbon and nitrogen in the benthic ecosystem were gathered from an aliquot of sediment, extracted from grab samples (Sedimentary Organic Matter; SOM) and by filtering water on a GFF filter with a Niskin bottle (Particulate Organic Matter, POM). This isotopic analysis has permitted to understand the relation of each compartment of marine dunes ecosystem and decipher spatio-temporal variations in the food web structure (see Robert et al. 2023 in these proceedings for more details).

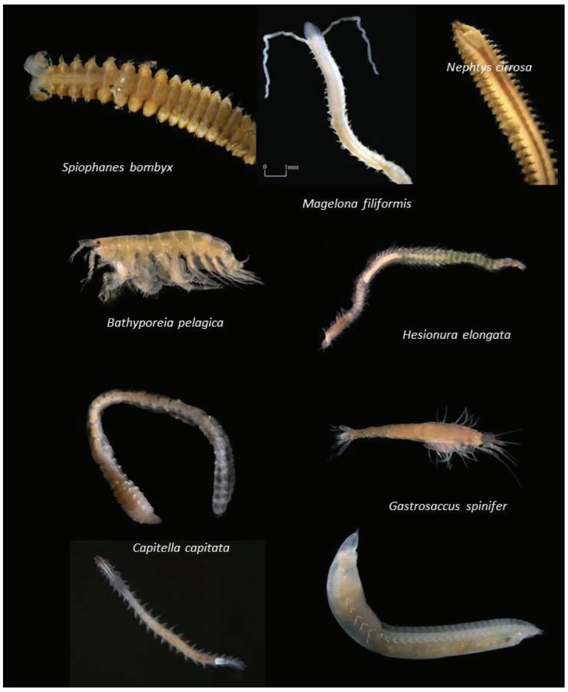

Figure 5 : binocular photographs of some characteristic invertebrates of the dunes off Dunkirk

5 CONCLUSION

Marine dunes are common in the North Sea where many OWF are planned. As they are very dynamic structures, OWF developers are closely interested in these sedimentary features to prevent their effect on components (cables, foundations).

To better our knowledge on relation between marine dunes and OWF off Dunkirk, we build an innovative multi-disciplinary approach including:

- In situ observation and analysis of morphodynamic and ecosystem of marine dunes
- Numerical modelling of marine dunes at two different scales (meso and finescale)
- Physical modelling of marine dunes in flumes
- Thermal diffusion modelling of heat produced by an export cable in marine dunes.

All these results will permit to help developers to better anticipate cost related to marine dunes and prevent effect of OWF on marine dunes and their ecosystem.

6 ACKNOWLEDGMENT

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