Dunes morphodynamics superimposed on sand banks in a shallow macro-tidal environment: the example of the Haut Fond de Ouessant

P. Daguinos *UMR 6538 GEO-OCEAN, UBO, UBS, CNRS, Ifremer, 29280 Plouzane, France– paul.daguinos@univ-brest.fr*
N. Le Dantec *UAR 3113 IUEM et UMR 6538 GEO-OCEAN, UBO, UBS, CNRS, Ifremer, 29280 Plouzane, France– nicolas.ledantec@univ-brest.fr*
P. Le Roy *UMR 6538 GEO-OCEAN, UBO, UBS, CNRS, Ifremer, 29280 Plouzane, France– pascal.leroy@univ-brest.fr*
D. Menier *UMR 6538 GEO-OCEAN, UBO, UBS, CNRS, Ifremer, 56017 Vannes, France– david.menier@univ-ubs.fr*
G.Jouet *UMR 6538 GEO-OCEAN, UBO, UBS, CNRS, Ifremer, 29280 Plouzane, France– gwenael.jouet@ifremer.fr*
A.Ehrhold *UMR 6538 GEO-OCEAN, UBO, UBS, CNRS, Ifremer, 29280 Plouzane, France– axel.ehrhold@ifremer.fr*
M.Franzetti *UMR 6538 GEO-OCEAN, UBO, UBS, CNRS, Ifremer, 29280 Plouzane, France*
A.Trotot *UMR 6538 GEO-OCEAN, UBO, UBS, CNRS, Ifremer, 29280 Plouzane, France*

ABSTRACT: This study investigates the morphological parameters and migration rates of dune systems associated with a set of banner banks located at intermediate depths (50 m to 120 m) in the context of a highly dispersive shelf, offshore Brittany (Western France). The work mainly focuses on the Haut Fond d'Ouessant bank. New geophysical data (bathymetry, seismic, reflectivity) from Speedunes (2015) and Bankable (2019) cruises are analysed. We examine how the large range in basal surface depth over which the bank lies affect the dune morphodynamics. We also characterize sediment fluxes between these sediment structures, toward an overview map of sediment pathways across the Iroise shelf, in relation with the straits and the irregular shelf bottom.

1 INTRODUCTION

Submarine sand banks (or sand ridges) and dunes are the main bedforms of tide-dominated continental shelves. These structures are developed in response to variations hydrodynamic factors, but also sedimentary characteristics and long-term sea-level fluctuations (Allen 1968). The understanding of these morphodynamics variations and their roles on the sediment transport pathways is crucial for many applications such as marine resources exploitation, ecosystems protection, safety of marine infrastructures (Trentesaux 1993; Bajjouk et al. 2015). Nevertheless, assessing sediment fluxes in the context of submarine dunes and sand banks is still a scientific challenge due to the difficulty in collecting in-situ morphodynamic measurement. Some recent studies carried on marine dunes superimposed on banks allowed a better understanding of these systems (e.g., Franzetti et al. 2013; Homrani 2020 for submarine dune systems in Brittany). But surveys in intermediate bathymetric depth range (from 50 to 120 m) are still uncommon. Here we consider four sand banks located at intermediate depths on the Iroise Sea shelf in Western Brittany (France). The shelf is subject to large storms and under a macrotidal regime, with tidal range from 3 to 6 meters (Mariette et al. 1982). These banks consist mainly of biogenic sand and are associated with superimposed dunes. Here we focus on the *Haut Fond de Ouessant* Bank located at the south of Ouessant (Ushant)

Island, Southwest of the Fromveur channel. Dunes are located on the flanks of the bank while they are absent at the top. Two diachronic bathymetric datasets are used in this study to characterize the morphodynamics of these dunes superimposed on the bank, as well as to explore potential sedimentary pathways on the shelf.

2 STUDY ZONE

The study zone, named the Iroise Sea, is located in Western Brittany (France), between the Molene archipelago to the North, the Pointe du Raz and the Raz de Sein to the South and the Rade de Brest to the East (Fig. 1). The area is characterised as a highly dispersive shelf, at the confluence between the Atlantic Ocean and the English Channel, subject to strong tidal current and large swells. Due to this localisation, the Iroise Sea is also directly impacted by the English Channel's discharge (Kenyon and Stride 1970). Tidal currents are accelerated at straits (or "raz") and channels, generating alternating currents with maximum velocity exceeding 4m.s^{-1} (Hinschberger 1963; 'Service Hydrographique de La Marine (Ed.), 1957), and average current velocity slightly over 1m.s-1 during spring tides, especially at the proximity of the Fromveur and the Molene archipelago (Guillou and Chapalain 2018).

The sedimentary cover is very limited and heterogeneous, with the basement often at the seafloor. Sediments are principally characterised as biogenic sand. Sediment materials are organised in two main types of structures visible on the shelf: sandbanks with large dunes superimposed over them, and sediment draping. The shelf hosts 4 large sandbanks (10 to 50 sq. km): Four Bank, Armen Bank, Pierres Noires Bank, Haut Fond de Ouessant Bank), showing very contrasted morphologies but all having their base located at the same range of water depths (around 90 m). Except Pierres Noires

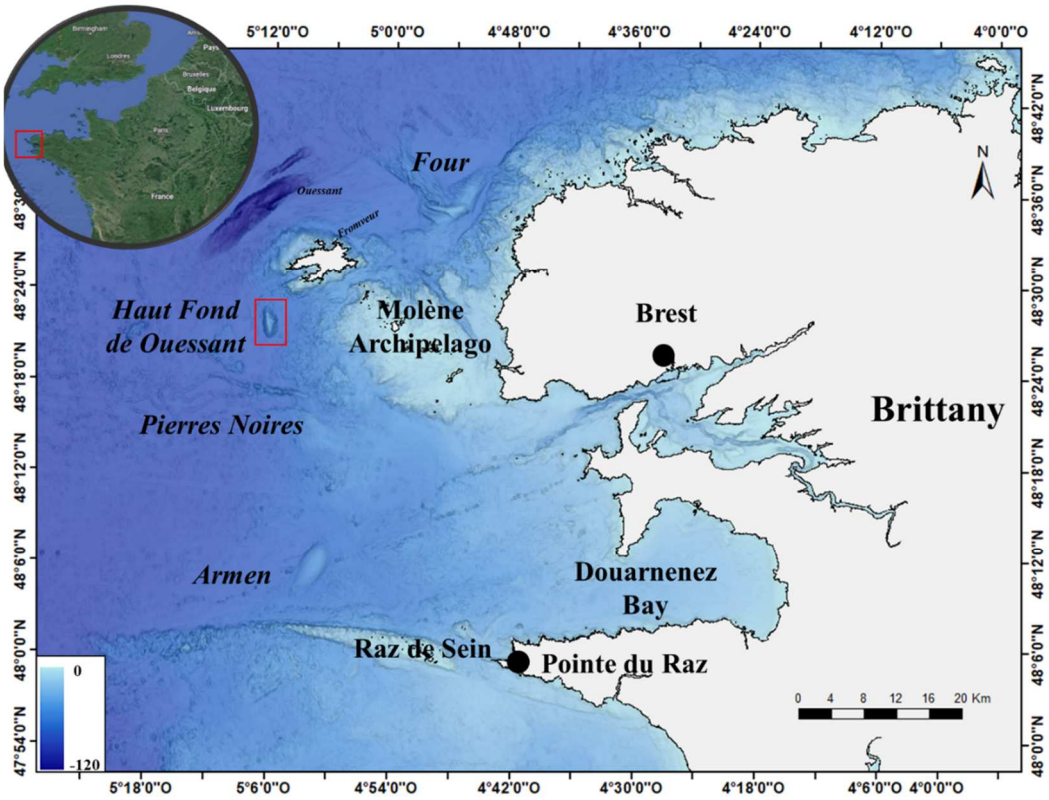

Figure 1: Localisation of the Iroise Sea, in red the Haut Fond de Ouessant Bank (insert: localisation of the Iroise Sea).

bank, they are considered as banner banks (Franzetti et al. 2013).The Haut Fond de Ouessant Bank, focus of this study, is an ellipsoidal bank with a length of 6 km and width of 2 km, and more than 45m high. It is associated with over 100 large dunes either superimposed on its flanks or in the dune field located directly north of the bank.

3 METHODS AND DATA

3.1 Dataset

The dataset used for this study consists of 2 Digital Elevation Models (DEM) obtained from research cruises in 2015 (Speedunes, RV Thalia) and 2019 (Bankable, RV Côtes de la Manche).

3.2 Methods

Data processing and analysis were realised on QPS (Qimera), ArcGIS and Matlab. Dunes crests were manually picked on GIS software, using the slope raster to identify them (Franzetti et al. 2013; Homrani 2020). Bathymetric profiles extracted from the DEM

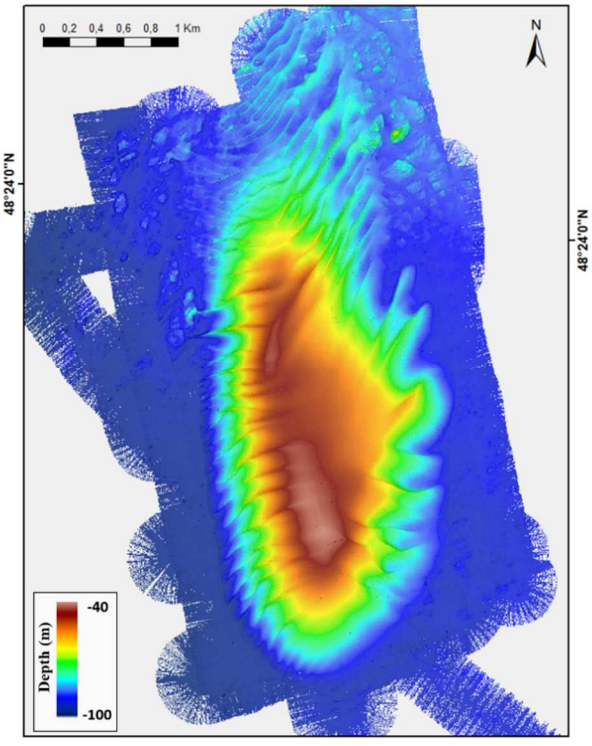

Figure 2: Bathymetric map of the Haut Fond de Ouessant Bank

were analysed to estimate the morphological parameters of the dunes: height H, stoss side length a, lee side length b, dune length a+b, stoss side angle α, lee side angle β, aspect ratio H/L and asymmetry A=(L-2b)/L (Berné et al. 1989; Le Bot 2001; Knaapen 2005). Migration distances of dunes between the two datasets were calculated using an ArcGis algorithm with the function Model Builder tool. Here the application was to measure the distance between crests on two diachronic rasters using the measuring tools of ArcGIS. First a raster with the Euclidian distance to the crest for each pixel was created for the first dataset. The intersect with the crest of the second dataset gave directly the distance covered by each dune during the time between the two surveys. Volume variation, erosion or accretion, was also defined by computing the difference between the two rasters. These morphodynamics analyses were linked to the migration of the sedimentary stock.

4 FIRST RESULTS AND DISCUSSION

The surface of the Ouessant bank area is composed of 137 sedimentary structures on the bathymetrics datas from the bankable survey (2019), define as dunes. The North part of the bank is characterised by a dune field directly on the basement, whereas the other dunes are on the flanks of the bank. From the morphodynamics analyses, the Bank was divided into six parts. Three of them are localised on the East flank (labelled from 1 to 3 for the South East, East, and North East parts), 2 on the West flank (North West and South West), and the last one is the dune field at the north of the bank. There are no dunes on the top of the bank, which is likely related to the large Atlantic storms.

4.1 Morphological parameters

Dunes heights on the Haut Fond d'Ouessant range between 1 and 14 meters and wavelength from 0 to 250 meters. The sector number 2, corresponding to the middle eastern part of the bank is composed of the 3 dunes with the maximal height. No correlation was observed between the size

and the depth of the dunes. Except in sector 2 where the mean asymmetry is 0.16, the dunes are globally not very asymmetric, with an overall mean asymmetry of 0.4. The highest dunes are the most symmetric on this bank.

4.2 Dunes morphodynamics

Between 2015 and 2019, the migration speed ranges from 0.9 to 26.15 $m.y^{-1}$ with a mean of 6.8 $m.y^{-1}$, and 90% of the dunes have a migration rate lower than 10$m.y^{-1}$. The Table 1 gives the migration rate and the direction of each sector. These dunes exhibit an anti-clockwise rotation around the banks, except for the North-Eastern part where they migrate in clockwise direction. The western flank evolved faster than the eastern one, where the large, rather symmetric dunes may in fact not be migrating presently.

Table 1: Migration rate by sectors

Sectors	Migration ($m.y^{-1}$)	Migration orientation
1	5.9	North
2	3.4	North-West
3	7.4	North-West/South-West
4	10.2	South
5	6.4	South
6	5.5	South

With a small volume, only 5.5%, of sediment in movement relative to the overall bank volume, he volume analysis highlights that the sediment remobilization is mainly superficial, corresponding to the morphodynamics of the superimposed dunes.

Tidal current analysis reveals the presence of a tidal gyre over the area (Guillou et al. 2018), characterized by anticlockwise currents. Moreover, Ehrhold and al. 2017 reported a circular sedimentary system around the Molene archipelago. This system could also connect the Haut Fond de Ouessant Bank with the Bank du Four through the Fromveur Channel. The signatures of eastward sediment transport from the eastern side of the bank are consistent with an outgoing sediment flux from the Haut Fond d'Ouessant through the Fromveur channel. The top of the bank does not show any superimposed structures, which is likely to be explained by the existence of large storm waves occurring on the Iroise shelf. The flow velocity on the seafloor under these waves could reach 0.8 $m.s^{-1}$, which is enough to remobilize sediment. These storms limit the aggradation at the top of banks, as described in some bank genesis models (Huthnance 1982a; Huthnance 1982b).

5 CONCLUSION

This study is focused on the morphological evolution of a submarine dune bank at intermediate depth, subject to strong tidal current and large storms. In 2015, it was composed of 137 dunes, localized on their flank and on a dune field directly to the north. These dunes had a migration rate around 6.8$m.y^{-1}$ between 2015 and 2019. They migrated in anticlockwise direction for the Western and SouthEastern parts, and both in anti-clock and clockwise directions (depending on the dune under consideration) for the NorthEastern part. We suggest that the migration directions are linked to the tidal residual current. A recent (Guillou and Chapalain 2018) revealed the existence of a tidal gyre over the Bank, in accordance with local hydrodynamics. The absence of dunes on the top of the Bank could be explained by the sediment remobilization process due to large storm waves that limits aggradation on the top (Huthnance 1982a; Huthnance 1982b). At the scale of shelf, the sand accumulation at the Eastern termination of the Bank allows transfer through the nearby Fromveur strait, suggesting a large sandy sediment recycling loop that connects several sand banks across the Iroise Sea.

ACKNOWLEDGEMENT

This work is supported by the UBS and the ARED UBO. The authors would like to give a special thanks to the crew on the Thalia during the Speedunes survey and the crew of the Bankable survey on the Cote de la Manche, in particular to Michel Lounge and

Alexandre Valance who joined the team on the Bankable survey.

6 REFERENCES

Allen, J. R. L. 1968. 'The Nature and Origin of Bed-Form Hierarchies'. *Sedimentology* 10 (3): 161–82.

Bajjouk, T., J. Duchêne, B. Guillaumont, M. Bernard, M. Blanchard, S. Derrien-Courtel, P. Dion, S. Dubois, J. Grall, and D. Hamon. 2015. 'Les Fonds Marins de Bretagne, Un Patrimoine Remarquable: Connaître Pour Mieux Agir. Édition Ifremer-DREAL Bretagne, 152 p'.

Berné, Serge, G. Allen, JEAN-PAUL Auffret, H. Chamley, J. Durand, and O. Weber. 1989. 'Essai de Synthèse Sur Les Dunes Hydrauliques Géantes Tidales Actuelles'. *Bulletin de La Societe Gèologique de France* 6: 1145–60.

Franzetti, Marcaurelio, Pascal Le Roy, Christophe Delacourt, Thierry Garlan, Romain Cancouët, Alexey Sukhovich, and Anne Deschamps. 2013. 'Giant Dune Morphologies and Dynamics in a Deep Continental Shelf Environment: Example of the Banc Du Four (Western Brittany, France)'. *Marine Geology* 346: 17–30.

Guillou, Nicolas, and Georges Chapalain. 2018. 'Annual and Seasonal Variabilities in the Performances of Wave Energy Converters'. *Energy* 165: 812–23.

Hinschberger, F. 1963. 'Les Hauts-Fonds Sableux de l'Iroise et Leurs Rapports Avec Les Courants de Marée'. *Bull. Sect. Géogr. Com. Trav. Hist. Scient.* 75: 53–80.

Homrani, Sabrina. 2020. 'Morphodynamique Des Dunes En Eau Peu Profonde et Transport Sédimentaire: Le Banc Du Creïzic (Golfe Du Morbihan)'. PhD Thesis, Brest.

Huthnance, J. M. 1982. 'On the Formation of Sand Banks of Finite Extent'. *Estuarine, Coastal and Shelf Science* 15 (3): 277–99.

Huthnance, John M. 1982. 'On One Mechanism Forming Linear Sand Banks'. *Estuarine, Coastal and Shelf Science* 14 (1): 79–99.

Kenyon, N. H., and A. H. Stride. 1970. 'The Tide-Swept Continental Shelf Sediments between the Shetland Isles and France'. *Sedimentology* 14 (3–4): 159–73.

Knaapen, M. A. F. 2005. 'Sandwave Migration Predictor Based on Shape Information'. *Journal of Geophysical Research: Earth Surface* 110 (F4).

Le Bot, Sophie. 2001. 'Morphodynamique de Dunes Sous-Marines Sous Influence Des Marées et Des Tempêtes : Processus Hydro-Sédimentaires et Enregistrement : Exemple Du Pas-de-Calais'. *Http://Www.Theses.Fr*. Thesis, Lille 1. http://www.theses.fr/2001LIL10016.

Mariette, V., G. Rougier, Jean-Claude Salomon, and B. Simon. 1982. 'Courants de Marée En Mer d'Iroise'. *Oceanologica Acta* 5 (2): 149–59.

'Service Hydrographique de La Marine (Ed.), 1957. Instructions Nautiques. France, Côtes Nord et Ouest, Impression Nationnale. Ed, Instrucutions Nautiques. Paris, France -

Trentesaux, Alain. 1993. 'Structure et Dynamique Sédimentaire Du Middelkerke Bank, Mer Du Nord Méridionale'. PhD Thesis.