From regional variability of the morphology of dunes to a new method of their classification

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ABSTRACT: Dunes exist in all the sand environments. Most of dune classifications come from observations in desert which have been adapted to the marine environment, with profiles and side scan sonar images. During the last years, Multibeam Echo Sounders (MES) have showed a great diversity of morphologies, for example, trochoidal dunes present 3D features which are not completely described by the height and wavelength. This leads us to return to in situ environments to study the various forms of dunes and their characteristics in terms of physical properties. This paper presents some examples of dunes which seem to be specific of the marine environment and proposes a reflection on a more complete classification of marine dunes.

1. INTRODUCTION

Dunes exist in many environments: deserts, rivers, oceans, on other planets, and at every depth in sandy marine environments. For example, small dunes, fully comparable to those observed in shallow water, had been photographed at depths greater than 3000 metres (Lenôtre, 1977). As terrestrial field is more accessible, dune classification has been defined on the basis of desert observations and has been used for marine dunes. But the dune heights are different in aeolian and hydrological environments, star dunes are exclusively founded in deserts and seif dunes are very rare in seas.

The symposium 'Classification of large flow transverse bedforms' led to the general adoption of the classification proposed by Ashley (1990). This empirical classification concerns sand structures generated by unidirectional currents, alternating currents, and combinations of both. Flemming (2000) established a compilation of descriptive parameters for 1500 dunes from various marine environments throughout the world (with nearly one-third of the data acquired near the coasts of South Africa) and thereby proposed a continuous statistical model for sand structures ranging from ridges to giant dunes with the following characteristics: dune height comprised between 0.001 and 20 meters, wavelength ranging from 0.01 to 1000 meters, mean dune height with respect to spacing λ: $H_{mean} = 0.0677 \lambda^{0.8098}$, maximum dune height: $H_{max} = 0.16 \lambda^{0.84}$. According to Ashley, the dunes are classified by wavelength, and Flemming's diagram can then be used to obtain their corresponding heights. To enhance this classification it is possible to use four parameters derived from measured profiles: wavelength (L), amplitude (H), stoss slope angle (α) and lee slope angle (β) to calculate four shape parameters : flattening index = λ/H, symmetrical index = $\lambda_{am}/ \lambda_{sv}$ (equal to one for symmetrical ridges), linearity index = ld/d, bifurcation index = LB/λ. These results were obtained before the appearance of multibeam echo sounders, and all these parameters came from profiles spaced of 100 meters or more and the studies on dunes had always focused on their crests and their slopes.

2. MORPHOLOGY OF DUNES

The dunes are oriented almost perpendicularly to the principal direction of the currents with angular variations of up to 20º (Le Bot, 2001). They are situated in environments were bottom currents are between 50 cm/s and 1m/s (Belderson et al., 1982). Granularity of sediments, current transport capacity and availability of sands are the three main parameters defining the shape and the volume of the dunes. The shape of dunes can be used to qualify sedimentary processes. As currents increase, an evolution is observed from linear dunes (rectilinear or anastomosed) to sigmoid or barchanoid dunes. The barchans dunes are for some authors symptomatic of slopes, of a sediment deficit or of a high velocity of currents. Knaapen (2004) observe a correlation between the migration speed and the symmetrical index. According to several authors, dunes with linear crests have the lowest migration velocity, and barchanoid dunes have the highest. Superposed, juxtaposed and interference dunes have been also described since half a century in desert and since less than twenty years in shallow water. As noted by Bartholdy (2004), the mere existence of superposed dunes contradicts the relationship between dune height and depth proposed by preceding authors. The presence of these superimposed structures is important and could be the main agent of sand migration (Idier et al, 2002) and by consequence of marine dune dynamics. As Flemming noted, H / λ models depend on the hydrodynamic conditions, so in theory the morphology of dunes could be used to estimate the intensity of dune dynamics. The variability of dunes comes from the granularity, heterogeneity, composition and availability of sediment, and in addition to hydrodynamic forcings. The dynamics of the dunes integrates the impact of tidal currents and swell at different time scales applied on a complex mixture of particles. The morphology of dunes can be seen as a synthesis of all these processes.

3. CLASSIFICATION TO MAP VARIABILITY OF DUNES

All these elements show a relationship between the morphology of the dunes and their dynamics. The observation of hundreds of marine dunes in 2D, thanks to high-resolution (MES), shows that dune fields are not always constituted by regular transversal dunes. And it seems necessary to construct a classification which must at least include a two input table with shape and height (or wavelength) of dunes. In fact in the marine environment, we observe dunes with different shapes: barchans, rhomboidal, trochoidal and transverse. Foremost, a dune classification must distinguish the environment; *i.e.* must differentiate isolated dune, fields of dunes and superimposed dunes (Figure 1). Then it must differentiate the morphology because transverse, trochoidal dune or barchan, do not reflect the same granular and hydrodynamic characteristics and peculiarities (Figure 2). For transverse dunes specification could be associated to specify the dune morphology, the availability of sediment could be associated with this classification (Figure 3).

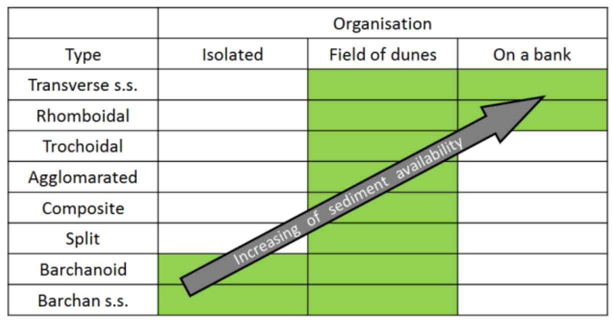

Figure 3. Morphological classification of marine dunes

Then, dune parameters such as height, wavelength, granularity, depth, the flattening, symmetry, linearity and bifurcation index must be characterized. Sediments must be translated by several elements (Mean Grain Size, Sorting, Skewness, or even percentage of each granular classes) to carefully consider the heterogeneity. To be complete, these 2D morphologies must be added to the four shape parameters and to the height (the more important for hydrography) or the wavelength (the easiest to measure). Finally the direction of dune movement and the annual average speed can complement the description of the dune or at least of the dune field if that information per unit is missing. The last element concerns superimposed dunes or megaripples. These structures are highly mobile and can move at speeds about one meter per hour, are fleeting, and can appear or disappear at the whim of storms. This information is thus highly dependent on the resolution of the acquisition system as well as hydrodynamic conditions preceding the survey. Nevertheless, it appears that these features should be retained because it carries information related to the splitting of the dunes, and can be associated with non-unique ridges, or complex dunes, which complicate the automatic calculation of dunes settings.

4. CONCLUSIONS

Synthesis on the different physical processes affecting the dynamics of the dunes (Naqshband and 2014, Doré 2015 ...) show how numerous are the phenomena and he importance of their links; but they also show how much progresses have been huge in the last 20 years. However, as in the study of the morphodynamics of beaches, progresses seem much less perceivable in the consideration of sediment. The work seems to be now on the angle of measurement of sediments which must provide descriptions of the dunes variation at the resolution of physical models. What about the variability of the average sediment grain size or of the sediment heterogeneity when models used grids of some meters on the profile of a dune. From measures in a water tank, Dréano (2009) proposes that barchans are due to fine sand, when resource in sediment is limited and for strong currents. In contrast when the sand is coarser and the resource important dunes are transverse and linear. But frequently dunes of different shapes appear in the same environment. It is the case of barchan and transverse dunes of Portsall, of trochoidals dunes often neighbouring transverse dunes, and more frequently cited, of megaripples superimposed on the dunes. The improvement seems to come back to field measurements to be at resolutions and scales of the processes described precisely by physics.

The mapping of dunes with a classification based on morphology and shape parameters could be a product adapted to estimate the areas were dunes are more or less actives. This kind of map could be useful for hydrographic survey strategy, in particular in areas where only one MES survey has been done. It could be a tool to studying the impact of wind or tidal turbines and for all models and applications concern by dune dynamics.

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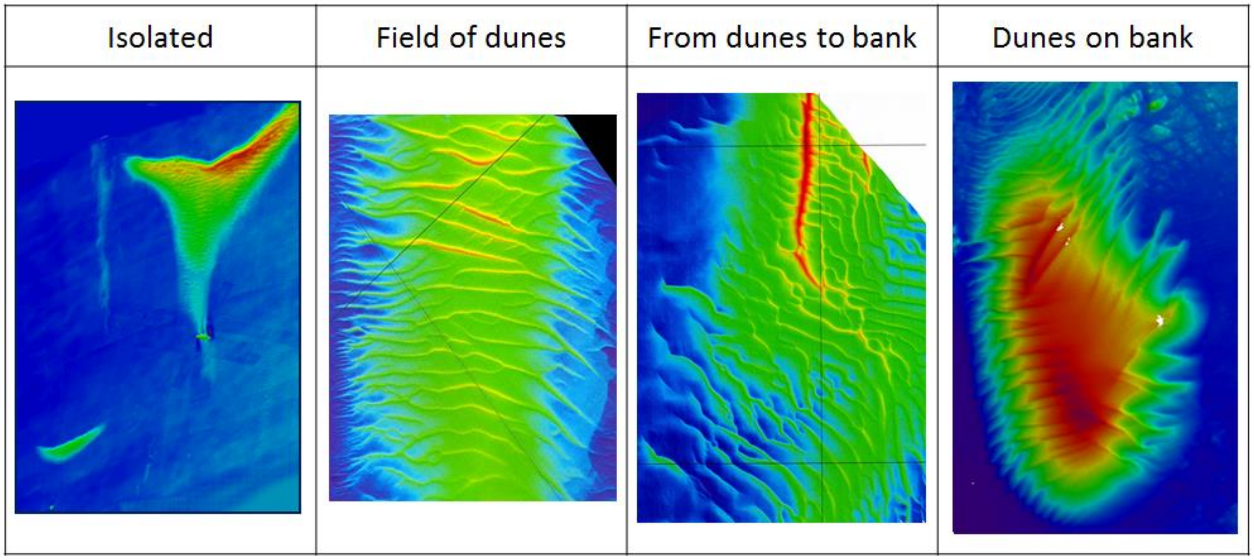

Figure 1. Intermediate steps between dunes and sandbank

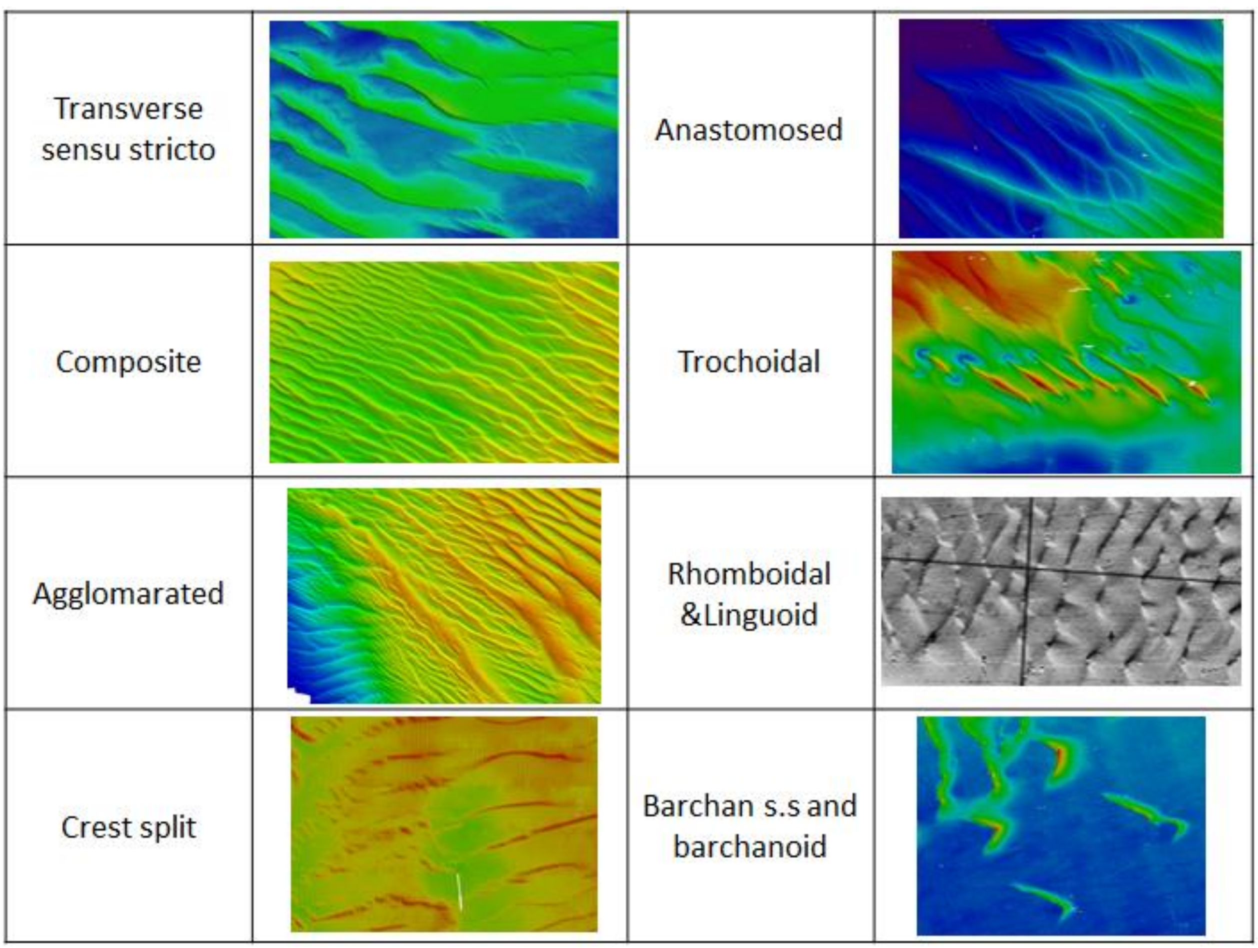

Figure 2. Examples of different dunes from a series of thousands of dunes of the English Channel and Celtic sea (SHOM, MES EM1002 & EM1002S).