SPATIAL AND TEMPORAL DEVELOPMENT OF INCIPIENT DUNES AT WHITE SANDS DUNE FIELD, NEW MEXICO, USA.

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Introduction: In zones of loose sand, the emergence of sand dunes results from a hydrodynamic instability coupling the properties of turbulent wind and sediment transport over an irregular sand bed. Linear stability analyses have been developed as a theoretical framework able to predict the wavelength, celerity and growth rates of the incipient pattern from wind and sediment grain properties [1,2]. Nevertheless, very few field studies of the early stage of dune growth exist [3-6] due the time and length scales involved, making in-situ monitoring of the topography and thus direct verification of the predictions difficult.

So far, all above studies have focused on spatially homogeneous conditions where dunes develop and grow everywhere simultaneously. However, non-homogeneous situations are also likely to occur, for example when boundary conditions introduce spatial discontinuities in sand availability. In this case, the instability is triggered at a specific point from which it grows and propagates downstream, resulting in a series of dunes of increasing height. This configuration can be found at the upwind border of large sand patches where the sediment starts to accumulate, but has never been investigated before.

Methods: Here we present the case of the upwind margin of White Sands Dune Field, a gypsum dune field exhibiting transverse, barchan and parabolic dunes shaped by an almost unimodal wind regime. We follow the development of incipient dunes over 4 years using high-resolution lidar-derived topography data and wind data from the KHMN weather station at the Holloman air base.

In addition to the dune wavelength, growth rate and celerity, we extract the characteristic length scale associated with the spatial growth of dunes on 75 transects, at 50-m spacing and aligned with the resultant flux direction (Fig. 1).

We also compute these four quantities from a spatial linear stability analysis of a sand bed, corresponding to a non-homogeneous case. Parameters related to the sediment are measured from grain samples, and those related to the sand flux inferred from wind data.

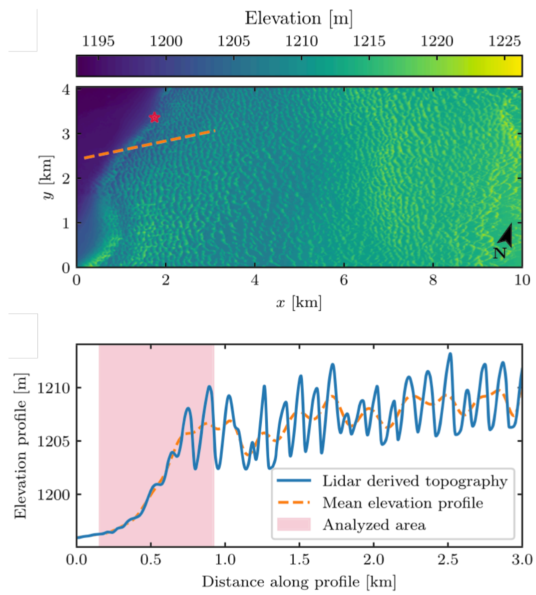

Fig. 1: *Dune field elevation and transect profiles*

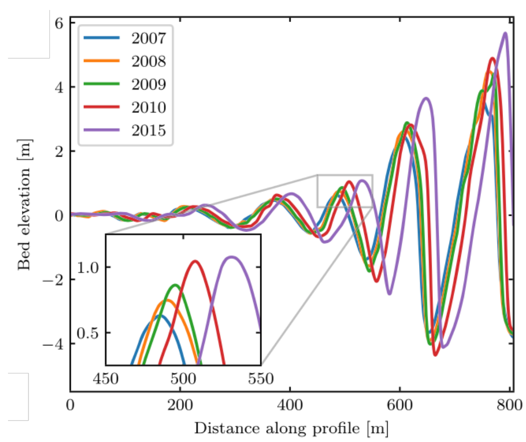

Fig. 2: *Detrended bed elevation profile along a transect of the dune field at four different dates, showing the dune propagation in time and exponential growth in space.*

Results: After removing the large-scale topography, the remaining sediment bed elevation exhibits a sinusoidal profile of constant wavelength. Its amplitude increases exponentially in space (Fig. 2), corresponding to the predictions of the spatial linear stability analysis for dune emergence. Quantitatively, these detrended profiles take the form:

$$h(x,t) = C_0 e^{x/\Lambda} cos[2\pi(x-ct)/\lambda],$$

where λ is the dune wavelength, Λ the spatial dune growth and c the dune migration velocity. Their distributions (Fig. 3), measured with two different manners: a *global* method, where the oscillatory and exponential behaviors of the profiles are extracted by fits or auto-correlations; a *peak-to-peak* method, where the height and position of each dune is followed individually. These distributions exhibit clear dominant values, resulting in a wavelength, growth length and celerity of about 120 m, 160 m and 5 m/yr, respectively. Furthermore, the growth rate of individual bumps, of about 0.03 yr^{-1}, matches the ratio between celerity and growth length, in agreement with the theory.

Finally, these measurements also quantitatively correspond to the predictions of the spatial linear stability analysis, providing a small correction to account for the presence of the few reversing winds (Fig. 3).

Concluding remarks: The spatial increase in height of incipient dunes is field evidenced for the development of the flat bed instability. The quantitative agreement between the predictions of the spatial stability analysis and the field measurements confirms the validity of the linear theory in describing dune emergence in zones of loose sand.

Although applied to the boundary of a dune field, the spatial development of the dune instability is also ubiquitous on the back and flanks of pre-existing dunes, exhibiting similar upwind sand availability. In unidirectional wind regimes, superimposed bedforms trigger the breaking of barchan horns [4,5,7], while they are responsible for the transition from elongating linear dunes to trains of barchans in multidirectional wind regimes [8]. This study therefore provides a relevant framework to study the stability of large dunes.

More details on all this work can be found in [9] and its Suppl. Mat.

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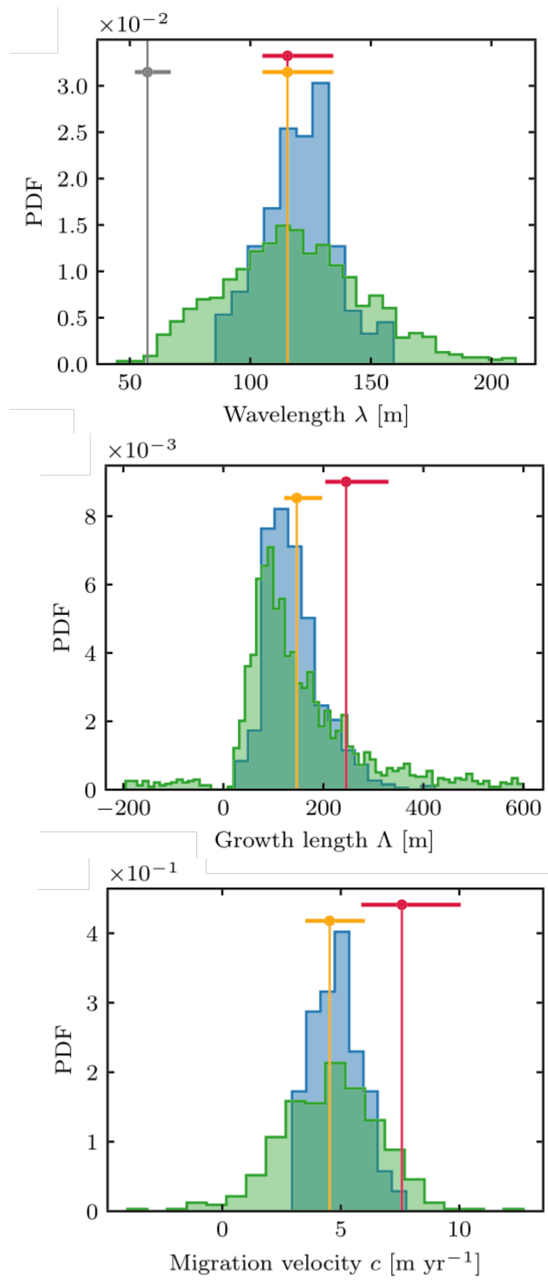

Fig. 3: *Distribution functions of the dune wavelength (top), growth length (middle) and propagation velocity (bottom). Blue: global analysis. Green: peak-to-peak analysis. Red: model prediction with the average wind. Orange: model prediction including reversing winds.*