ÉCOLE DOCTORALE
SCIENCES DE LA TERRE ET DE L'ENVIRONNEMENT ET PHYSIQUE DE L'UNIVERS, PARIS

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Subject title:

DUNE GROWTH MECHANISMS IN PRESENCE OF VEGETATION AND COHESION

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Host lab/ Team : **IPGP- Geophysical Fluid Dynamics – UMR7154**

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Context Dunes occupy a special position in geophysics because they occur in various environments (aeolian, subaqueous, extraterrestrial), where they exhibit a wide variety of shapes, sizes and orientations that are constantly evolving and migrating in response to transporting flows. Thus, dunes are not only an invaluable source of patterns to study the physics of sediment transport and morphogenesis, they can also be used as a proxy for environmental flows, especially In terrestrial deserts and other planetary bodies where they are key indicators for past and present climate.

State of the art In the middle of the last century, Bagnold [1] laid the foundation for quantitative research on aeolian transport by linking granular physics and fluid mechanics to dune studies for the first time. This subject has aroused more interest among physicists over the last twenty years, such that there are now well-established theories and transport laws for developing new quantitative methods to disclose fundamental information about aeolian systems [2,3]. Among them, the dune instability provides a size-selection mechanism leading to the emergence of periodic dune patterns [4]. There is indeed a minimum length-scale for the formation of dunes, which has been estimated to be of the order of 10 m in aeolian systems on Earth based on the smallest wavelength of the superimposed bedforms observed on the flanks of larger dunes [5,6]. This characteristic length-scale is regulated by the balance between a destabilizing process associated with the turbulent flow response to the topography and a stabilizing process due to transport inertia, which can both be measured in the field [4]. Such an understanding of this small-scale dynamics that constantly generates new dunes and reshapes older ones is critical to evaluate transport properties over short times.

Depending on sand availability, it was also shown that the same multi-directional wind regime can lead to two different dune orientations, which reflect two independent dune growth mechanisms [7-10]. Over an unlimited layer of loose sand, periodic patterns of linear dunes grow in amplitude and wavelength as they migrate and interact from defect propgation or collisions. In areas of limited sediment supply, dunes adopt crescentic shapes that can also elongate by depositing at their tips the sediment that is transported along their crests. As expressed by their elongation and/or migration rate that can be quantified in the field, these two dune growth mechanisms rely differently on sand fluxes perpendicular to the crest. Together they explain the coexistence of different types of dunes or the development of superimposed bedforms with different orientations [11]. The apparent complexity of dune fields can then be used to reconstruct the wind regimes over the characteristic timescales of the dunes under consideration, from a decade to tens of thousands of years [12].

Methods and objectives The objective of the PhD is to investigate dune growth in different geophysical contexts in order to elucidate the morphodynamics of a variety of bedforms for which the mechanism of elongation and migration have not yet been distinguished. Using numerical simulations and field data analysis, this will include (1) vegetated dune fields and (2) cohesive bedforms. In practice, the objective is to inject new levels of complexity into the 3D cellular automaton dune model developped in IPGP [13].

For vegetated dune fields, the new dune model integrating vegetation growth and the effect of sediment transport on plants will be used to identify transitions between erosion and deposition in drylands or coastal areas (progress in model development 100%). The first study will focus on the barchan/parabolic dune transition under unidirectional wind regimes of constant strength. By isolating the stability conditions of these dune patterns, it will be possible to determine the dynamic equilibrium states (e.g., shapes, migration velocities, sand flux) as a function of wind speed and dune size. Using these steady states, the relationship between the dune migration velocity and the intensity of vegetation growth processes will be an original result allowing, as was the case for the non-vegetated dunes, to better understand the non-stationary character of natural dune fields. These results can be extended to the analysis of transgressive dunes in order to quantify the maximum size of coastal dunes as a function of climatic conditions.

To account for cohesion in the dune model, we will introduce a new field into the structure associated with sedimentary cells (progress in model development 50%). Transitions between the non-cohesive and the cohesive substates will be governed by a characteristic timescale, reflecting the underlying mechanism of cohesion, cementation by evaporites in hot deserts, and snow sintering in cold deserts. According to this timescale, we will analyze the longitudinal or transverse orientation of the different generations of dunes. We will focus first on snow dunes in Antarctica, a zone of net deposition at a continental scale, and in mountainous areas for applications to Alpine environments at smaller scales. We will also try to quantify the time scale of the cohesion mechanisms likely to produce the indurated linear dunes in the Qaidam Basin, China, where field measurements can be envisioned.

Thanks to the modular nature of the numerical model, it will be possible to couple the vegetation and cohesion modules in order to focus on soil formation in arid areas or along sandy coastlines. Thus, we will be able to revisit the stability of vegetated dune fields in drylands, as well as the formation of giant coastal dunes in humid environments (e.g., the Pilat dune, France). These new models will be the first numerical simulations coupling dune pattern formation and their long-term evolution under hardening conditions.

The purpose of the PhD is also to provide a broad picture of the impact of multidirectional wind regimes on aeolian landforms (shape, orientation, wavelength) based on the two dune growth mechanisms associated with elongation and/or migration. Using the predictions of global climatic reanalysis to inject natural wind conditions in the models, the PhD candidate will contribute to the development of a worldwide database on the morphodynamics of aeolian landforms, a critical resource for estimating their resilience to changes in wind regimes, precipitations or vegetation cover.

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