APPLICATION OF CELLULAR MODEL TO EL FANGAR DUNE SYSTEM DYNAMICS

Fernando Barrio-Parra[1*], Pedro Molina Jimenez[2], Inmaculada Rodriguez Santalla[1], Juan Miguel Ramirez-Cuesta.

[1] Área de Geología, Dpto. de Biología y Geología, ESCET, Universidad Rey Juan Carlos, C/Tulipán s/n, 28933 Móstoles, Madrid, Spain
E-mail: fernando.barrio@uric.es

[2] Departamento de matemática aplicada a los recursos naturales, Universidad Politécnica de Madrid, C/Alenza 4, 28003, Madrid, Madrid, Spain.

The littoral dunes have importance into an ecological and natural coastal defense point of view. Characteristics of El Fangar (the North hemidelta of Ebro river,Tarragona, Spain) dune ecosystems are conditioned by sedimentary dynamics and these are mostly determined by wind field and sediment properties. This ecosystem provides a nesting place for birds which colonizes the dune field in the spring and summer seasons (Rodríguez-Santalla et al., 2009). The dune field surveying is an important methodology in order to assess if a dune field is increasing or decreasing its volume so it is a good net sediment budget estimator (Andrews et al., 2002; Anthony et al., 2006; Saye et al., 2005; Sánchez-García, 2008; Sánchez-García et al., 2007). When the dunes behaves as aeolian sediment sinks (p.e.foredunes), and the beach is the unique sediment source, it is quiet easy to establish the beach dune interaction. At El Fangar spit dune system, the active dunes behaves as aeolian sediment sinks and sources at the same time, trapping the sand from different sources and transferring it to the littoral drift. The dunes are also eroded by wave action. In this dynamic context, the dune system surveying and the net sediment budget estimated is not enough to characterize the interaction between sediment sources and sinks, being due using modeling alternatives that allow reproducing the dune dynamics and the estimation of sediment flows in and out and then, the evolution of the abiotic system.

Barrio-Parra et al. (2012) reviewed the actual dune dynamics models and concluded that the easiest way to model real dune field dynamics is the application of cellular models(Barchyn and Hugenholtz, 2011; de Castro, 1995; Katsuki and Kikuchi, 2011; Katsuki et al., 2011; Narteau et al., 2006; Nishimori and Tanaka, 2003; Werner, 1995). These models can be resumed in two main processes: saltation and avalanche. The saltation algorithm (Equations 1&2) consist in the movement of a sand height (q_s) in a Digital Elevation Model (DEM) array from a cell (erosion) and its deposition on a downwind cell at a saltation length (L_s) at each time step.The avalanche algorithm represents the slide down processes that occur when a repose angle is exceeded. Then the sand volume that produces an unstable slope in the highest cell is reallocated to the nearest lowest cells in order to obtain a slope that not exceeds the repose angle.

$$h(x,y,t) \rightarrow \qquad h(x,y,t+1) \qquad -q_s \qquad (1)$$

$$h(x+L_s,y,t) \qquad \rightarrow \qquad h(x+L_s,y,t+1)+q_s \qquad (2)$$

The work presented here shows the results of the application of a cellular model to a surveyed area of El Fangar dune system in order to reproduce its morphological evolution and obtain the sediment input and output that generates the observed net sediment budget.

The cellular model had been developed based on the models reviewed by Barrio-Parra et al. (2012) and in the improvements needed for its application to El Fangar dune system mentioned in their text. The model is an *R Script*(R Development Core Team, 2011), freely available by demand, intended to its free use, improve and develop. It incorporates, as a novelty to the cellular models, algorithms that introduce wind data to estimate the

variability of the sand flux with the dune height due to the shear stress changes produced in the windward dune profile by aerodynamic processes (Kroy et al., 2002a, 2002b) introducing q_s as a function of the initial height and the wind intensity on a level surface (Momiji and Warren, 2000). The wind data is also employed to evaluate if a cell is exposed to a wind (and susceptible to be eroded) or not due to its relative aspect to the incident wind. The speed up effect (Momiji and Warren, 2000)is introduced as a saltation length function of the dune height (Katsuki and Kikuchi, 2011; Katsuki et al., 2011) and as a function of the wind velocity components.

The aeolian sand flux and the transport threshold velocity are estimated by the measured sand flux-wind velocity correlation found bySánchez-García (2008) in the same site. The algorithm assumes that the saltation length is proportional to the number of times that the observed transport threshold velocity is exceeded. The variability of the sand flux with the dune height is described in Eq. 3. The speed up effect **(Momiji and Warren, 2000)** is introduced with the saltation length dependence with the dune height (Eq. 4)(Katsuki et al., 2011; Katsuki and Kikuchi, 2011). The terms *a* to *d* in equations 3 and 4 are call phenomenological variables (Katsuki et al., 2011) and are the object of calibration.

$$q_s = q \cdot (a + b \cdot h(x,y))$$
(3)

$$L_s = \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad l_0 \cdot (c + d \cdot h(x,y))$$
(4)

A small zone of El Fangar dune system was surveyed twice in 15th and 18th April 2012 using DGPS in order to obtain the initial and final stage of dune migration (**Fig 1**). During the survey high mobility of the dunes was observed associated to high wind intensity. The volumes difference between the surveyed DEMs yield a net sediment budget of 194 m^3. The wind direction and intensity data comes from a meteorological station located in the Port of L'Ampolla(about 6 km from the El Fangar dune field). These dataare freely available by the *Red deInstrumentosOceanográficos y Meteorológicos (XIOM) of Generalidad de Cataluña*. The data is provided for every 10 min. The mean wind conditions during the dune survey were 8 m/s speed and 283º North direction.
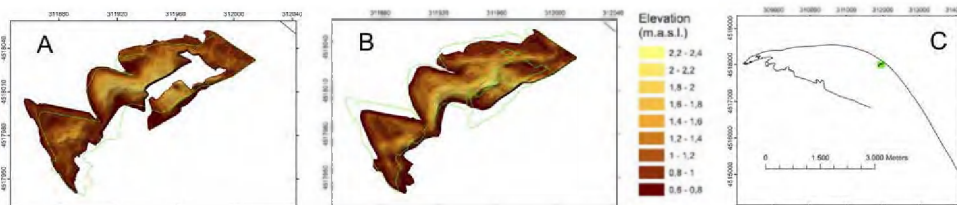

Fig 1. Surveyed dune initial (A) and final (B) states and its location in the North Hemidelta (C)

To assess the role and the sensibility of each model parameter on the morphology produced, a 5X5 factorial design is proposed in which five combinations of phenomenological parameters related with erosion (*a&b*) are faced to five combinations of saltation parameters (*c&d*) (Fig.2). For this issue we pay special attention on witch parameters yields DEM which fits the observed dune final state (i.e. dune migration and crest position) and which yields non desired formations (i.e. sand ripples in the dune windward side, lost of dunar morphology or strong erosion).
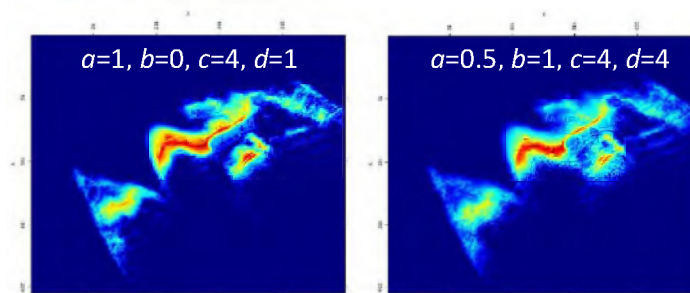
Fig 2. Examples of simulations results

The observed pattern showed a higher migration of the top of the dune, forming a flat region between the original foot and the new crest. The employ of low values of saltation length parameters results in the ripple formation. This formation is rejected as it is a non observed phenomenon at the study scale. The combination of high values of *c* and *b* produces a lost of dune structure, with massive ripples and sand piles formation. The employ of high *a* values results in crest enhancing. The best result reproducing soft slopes, dune migration and observed morphology, is the produced by *a*=0.5, *b*=1, *c*=4 and *d*=4. The result of performing a simulation with the parameters that best reproduce the morphology achieved in a final state is used to estimate the sediment entry and exit that generate the observed sediment budget.The difference between the sand volume in the initial DEM and in the simulation result yield the sediment output of the system. The sediment input is estimated as the sand volume difference between the surveyed and simulated final dune state. The result of these estimations applied to the best morphological reproduction simulation is that that 232.4 m³of sand had leave the system and 426.3m³ had been trapped by the dune.

The model presented in this paper and the calibration methodology proposed are a very useful tool in assessing the dynamics of a dune system with a very low data entry demand in a wind variable dynamic context.This application will have a great impact in the study of El Fangar dune system as the dune system acts as a sink and a source of beach sediments depending on the dune system region and the transport conditions.

References

Andrews B., Gares P. A., Colby J. D. 2002. Techniques for GIS modeling of coastal dunes, 29th Binghamton Geomorphology Symposium: CoastalGeomorphology 48(1-3) : 289–308.

Anthony, E. J., Vanhee S., Ruz M.H. 2006. Short-termbeach–dune sand budgets on the northseacoast of France: Sand supplyfromshoreface to dunes, and the roleof wind and fetch, Geomorpholog 81(3-4) : 316–329.

Barchyn, T. E., HugenholtzC. H. 2011. A new tool for modeling dune fieldevolutionbased on an accessible, GUI version of the Werner dune model, Geomorphology 138(1) : 415–419.

Barrio-Parra, F., RodríguezSantalla I., Sánchez-García M. J., Montoya-Montes I. 2012. A BriefReview of Actual Dune Dynamics Modeling: Applicability to El Fangar Dune System (Ebro Delta-Spain), in: Huang Y., Wu F., Shi Z., and Ye B. (Eds.), New Frontiers in Engineering Geology and the Environment, Springer Geology 107–110.

de Castro, F. 1995. Computer simulation of the dynamics of a dune system, EcologicalModelling 78(3) : 205–217.

Herrmann, H.J. 2006. Pattern Formation of Dunes, Nonlinear Dynamics 44(1-4) : 315–317.

Katsuki A., KikuchiM. 2011. Simulation of barchandynamicswith inter-dune sandstreams, New Journal of Physics 13(6), 063049 (8pp)

Katsuki A., Kikuchi M., Nishimori H., Endo N., TaniguchiK.2011. Cellular model for sand dunes with saltation, avalanche and strongerosion: collisional simulation of barchans, Earth Surface Processes and Landforms 36(3) : 372–382.

Kroy K., Sauermann G., HerrmannH.J. 2002a. Minimal Model for Sand Dunes, PhysicalReviewLetters 88(5) : 054301.

Kroy K., SauermannG., HerrmannH.J.2002b. Minimal model for aeoliansand dunes, PhysicalReview E - Statistical, Nonlinear and Soft MatterPhysics 66(3 Pt 1) : 031302.

Momiji H., Warren A. 2000. Relations of sandtrappingefficiency and migration speed of transverse dunes to windvelocity, EarthSurface Processes and Landforms 25(10) : 1069–1084.

Narteau C., LajeunesseE., MétivierF., RozierO. 2006.Modelling of dune patterns by short range interactions, River, Coastal and EstuarineMorphodynamics 1035–1046.

Nishimori H., Tanaka H. 2003, Simple model for the complexdynamics of dunes, Concepts and Modelling in Geomorphology: International Perspectives Evans, IS; Dikau, R, 87–100.

R DevelopmentCore Team. 2011. R: A language and environment for statisticalcomputing.

RodríguezSantalla, I., Sánchez GarcíaM. J., Montoya MontesI., Gómez Ortiz D., Martín CrespoT., Serra RaventosJ.2009.Internal structure of the aeoliansand dunes of El Fangarspit, Ebro Delta (Tarragona, Spain), Geomorphology 104(3-4) : 238–252.

Saye S. E., van der WalD., Pye K., BlottS. J.2005. Beach–dune morphologicalrelationships and erosion/accretion: An investigation at five sites in England and Wales using LIDAR data, Geomorphology 72(1-4) : 128–155.

Sánchez García M. J. 2008.Evolución y análisismorfodinámicodel campo dunar de la FlechadelFangar (Delta del Ebro). Thesis. 185 pp., Departamento de Biología y Geología. Universidad Rey Juan Carlos, Madrid (Spain).

Sánchez-García, M. J., RodríguezSantallaI., Montoya-MontesI.2007. Short termcoastalduneevolution of FangarSpit (Ebro Delta, Spain). International Conferenceon Management and Restoration of coastal dunes. Santander.

Werner, B. T. (1995), Eolian dunes: computer simulations and attractorinterpretation, Geology 23 : 1107–1110.