Granular flow modeling: emergence of sand dunes and beyond

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Multi Scale Mechanics

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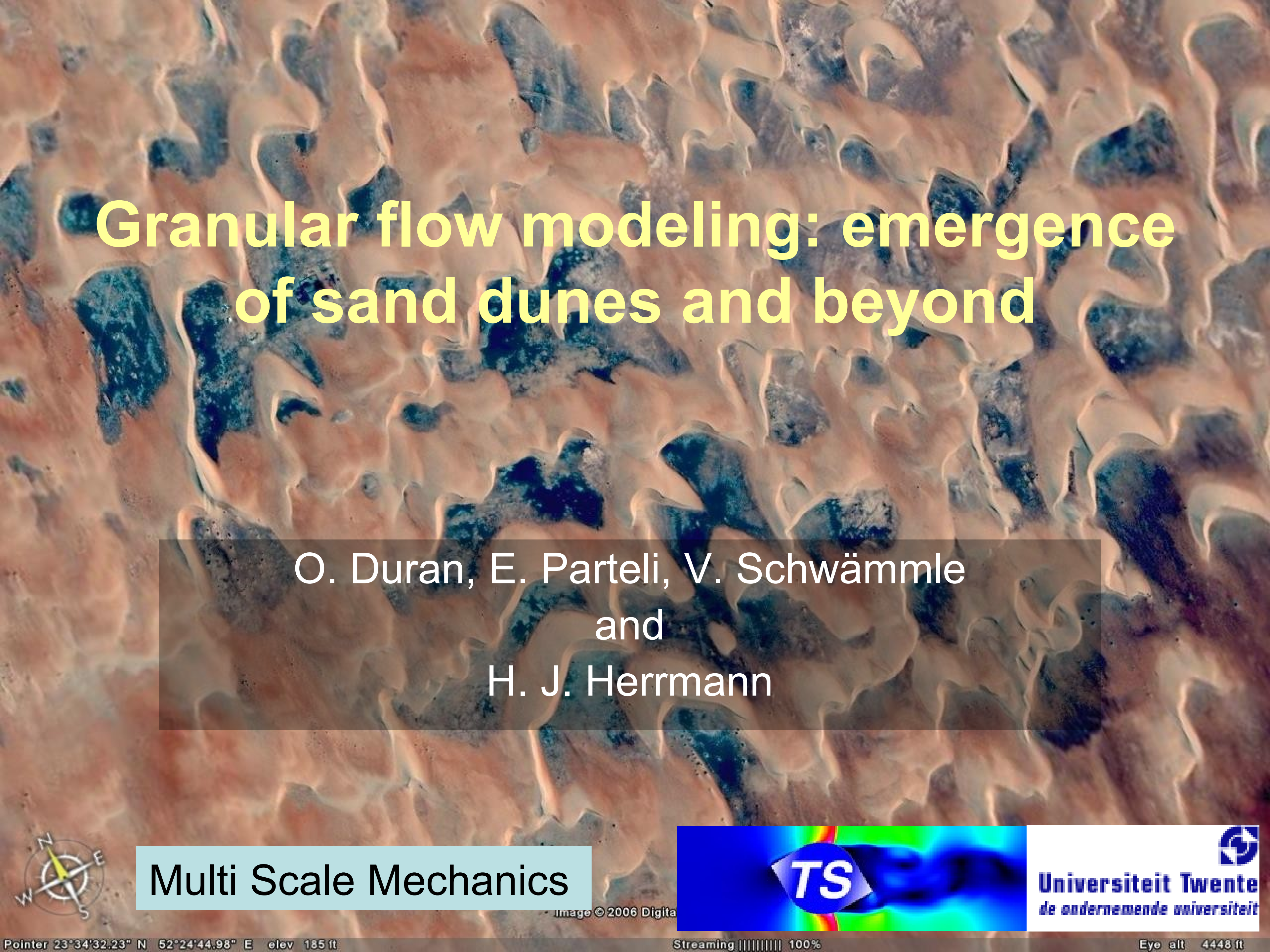
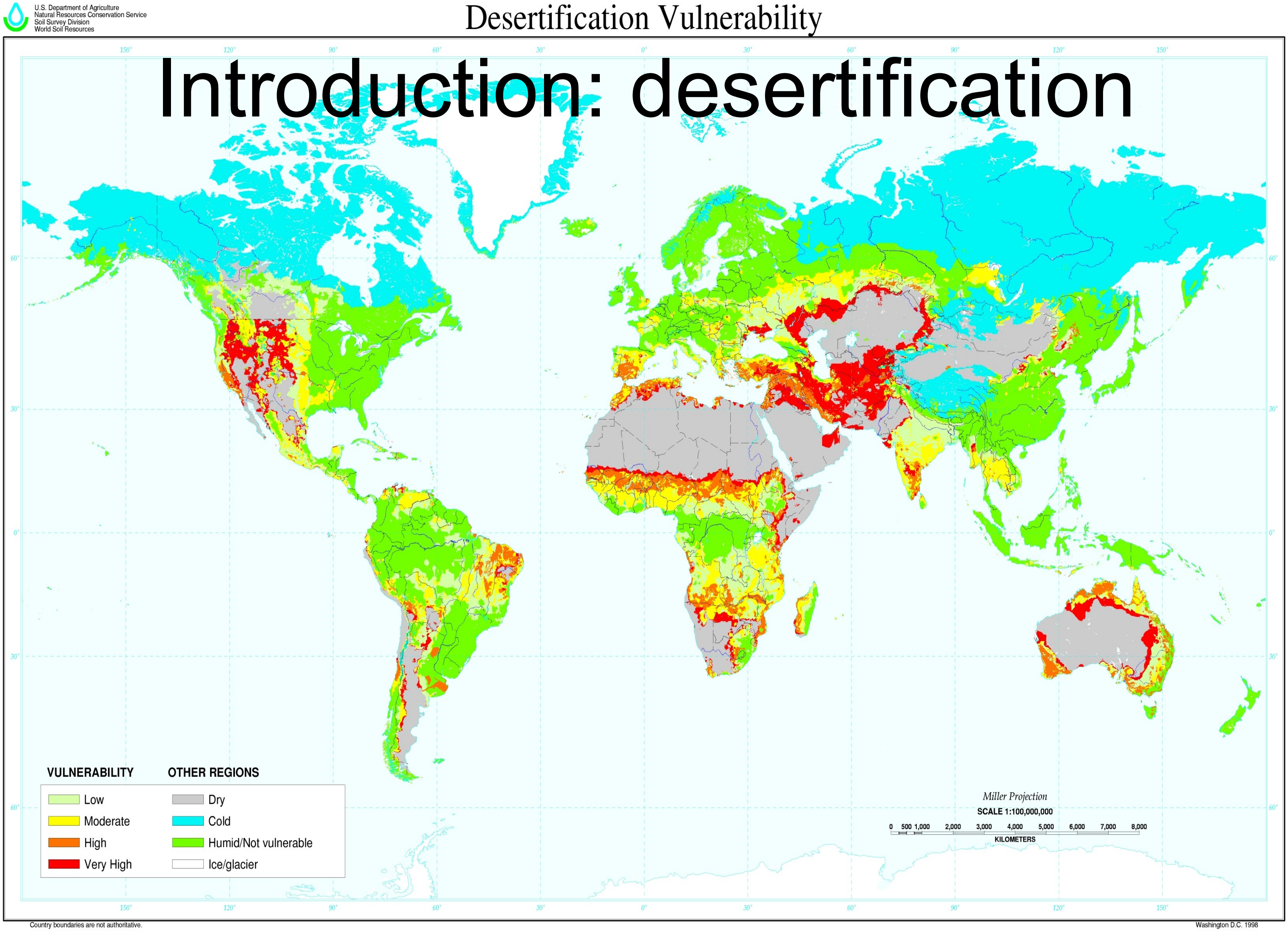


Introduction: desertification



Introduction: global dune invasion

Introduction: local dune invasion

Overview

Model:

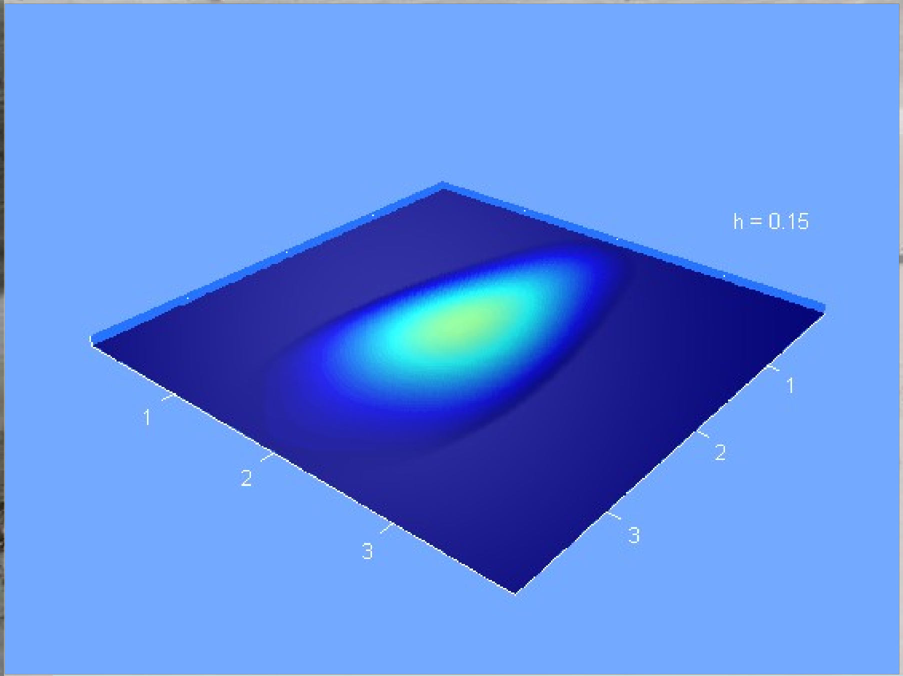
- Emergence of an isolated ‘barchan’ dune

Applications:

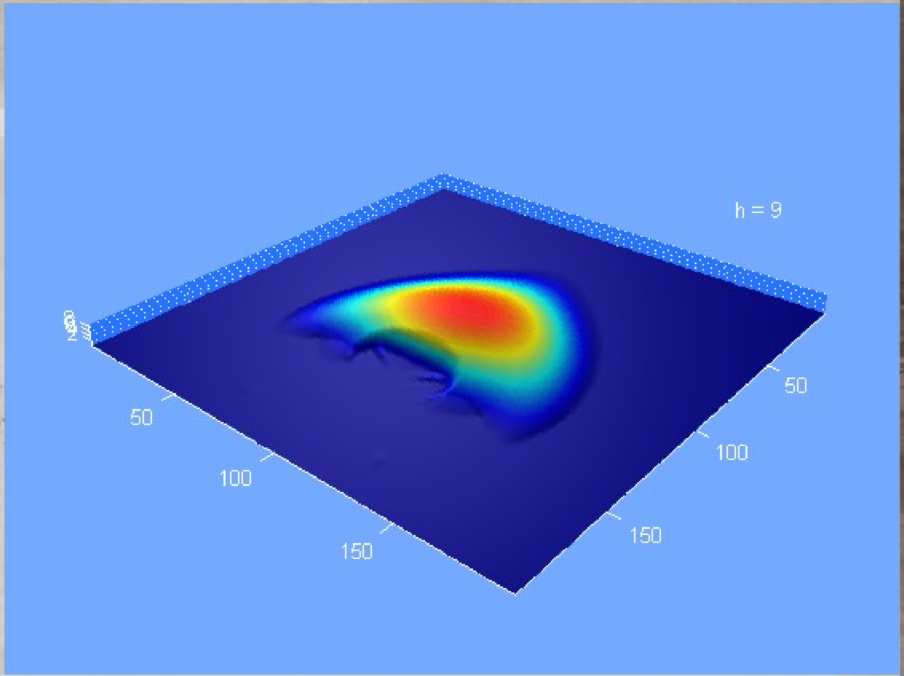
- Sand waves instabilities and the emergence of dune fields
- Dunes + Vegetation: stabilization of dunes

Emergence of isolated dunes: barchans

Small hill (h = 0.15m)



Large hill (h = 9m)



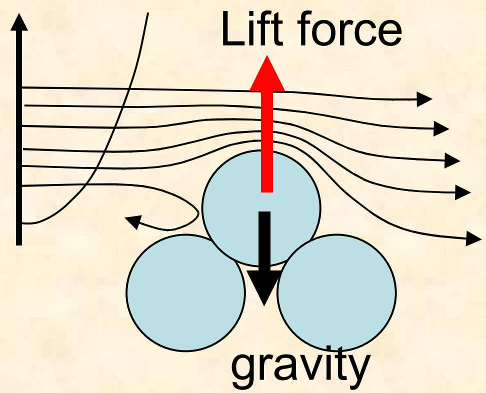
What are the mechanisms behind dune formation?

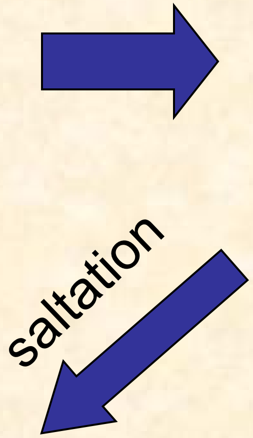
Mechanisms behind dune formation:

Aeolian sand transort

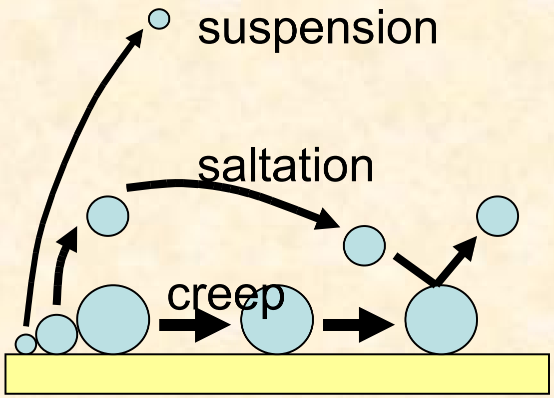
What happen when wind blows over a sandy surface?

Direct entrainment

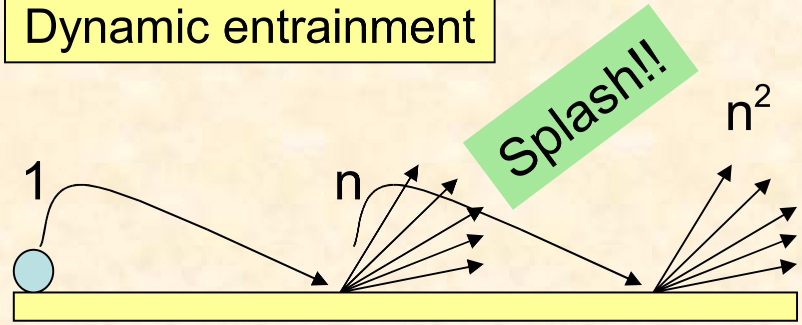




Transport regimes



Dynamic entrainment

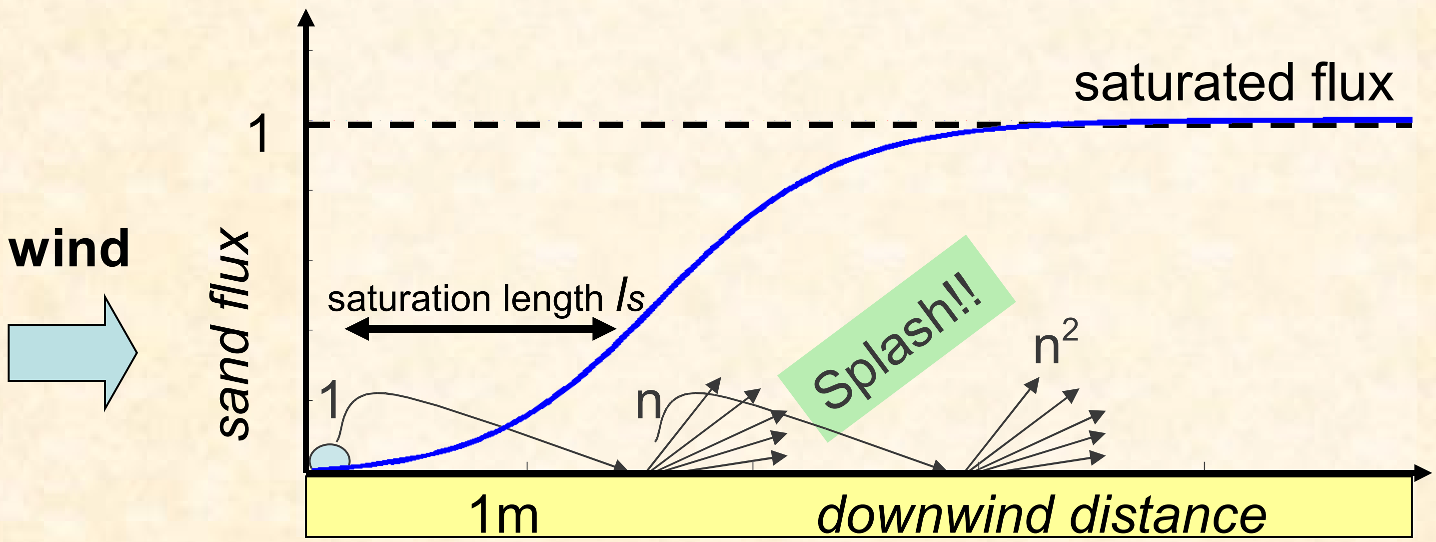


The number of grains entering the flow grows exponentially!

Mechanisms behind dune formation:

Aeolian sand transort

Relaxation of the sand flux toward the maximum: saturated flux

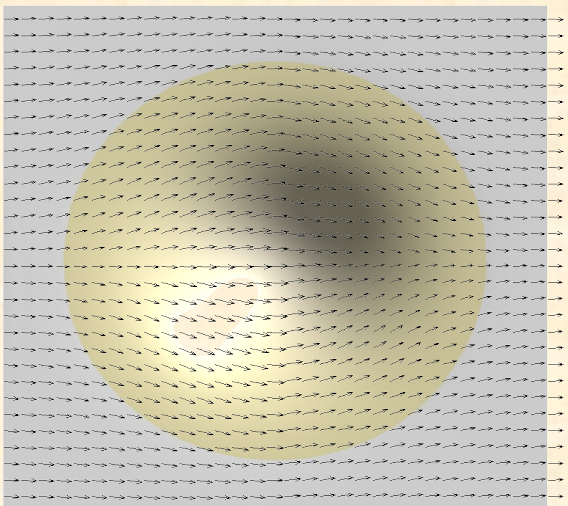


Mechanisms behind dune formation:
Surface wind

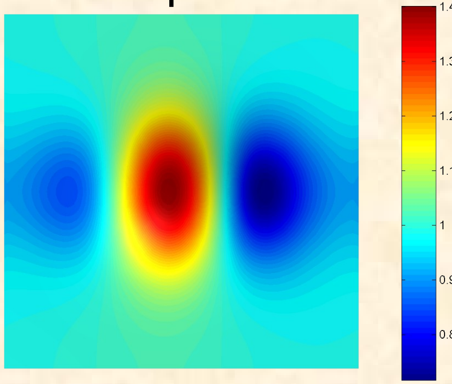
How the surface wind depends on the surface topology?

Example: Surface wind over a Gaussian hill

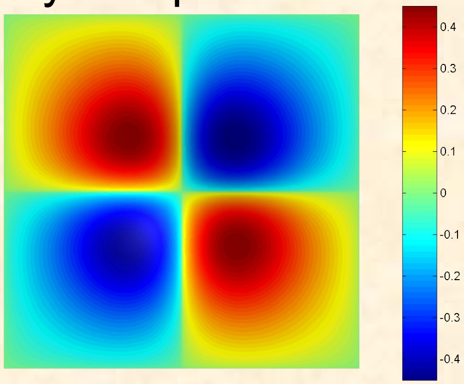
Surface wind is characterized by the shear velocity: $\mathbf{u}_*(x, y)$

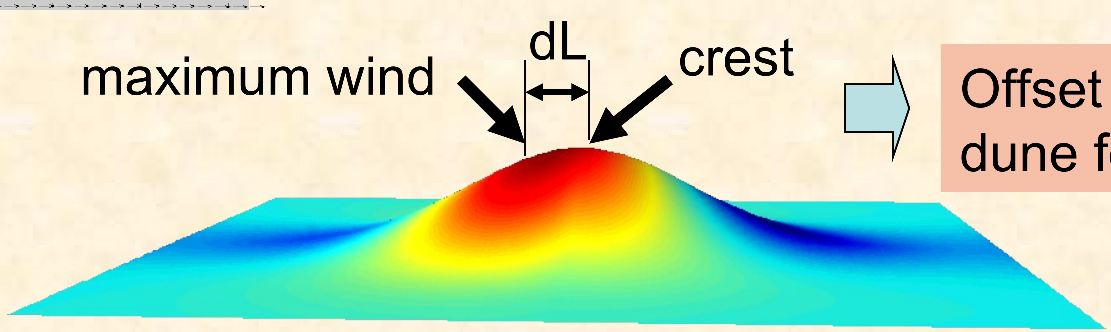


x-component



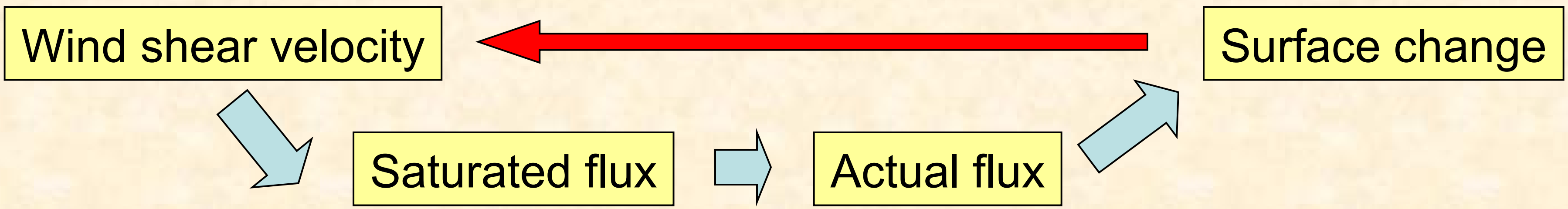
y-component

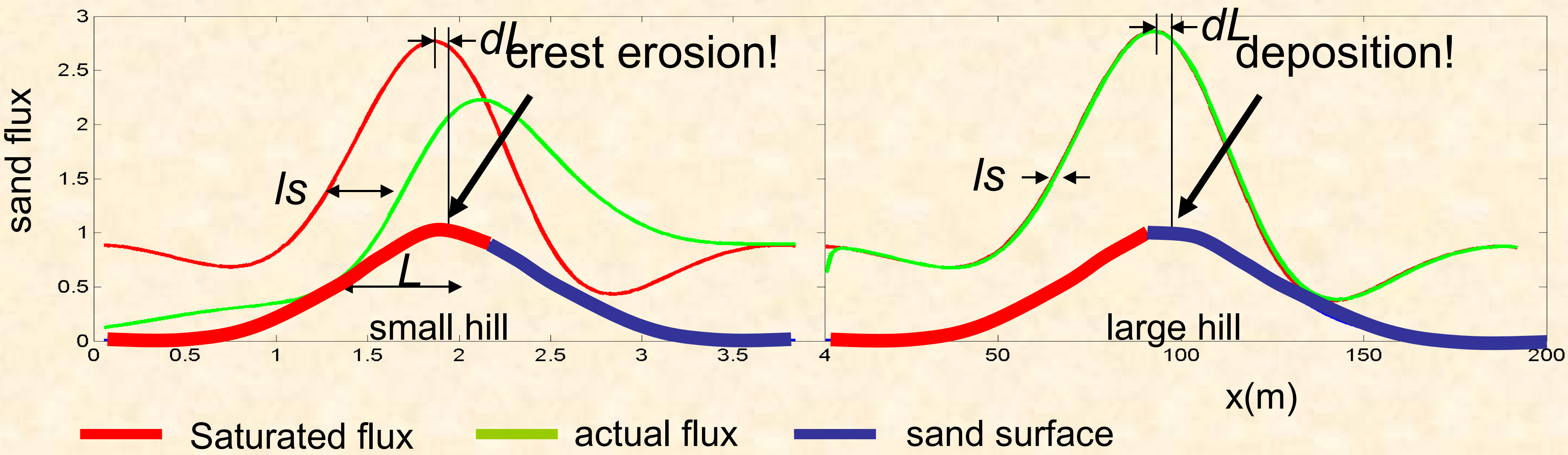




Offset is crucial for dune formation!!!

Mechanisms behind dune formation:
Surface wind + sand transport





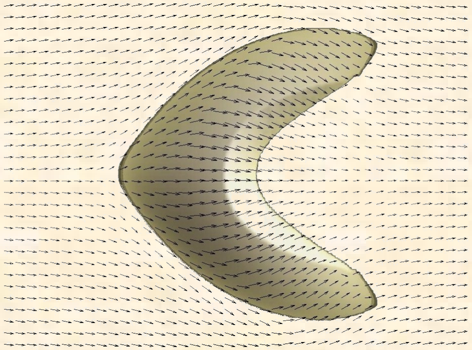
Since: dL ~ L / C → Condition for dune formation: L > C * ls

Sand transport model (summary)

Perturbed flow field

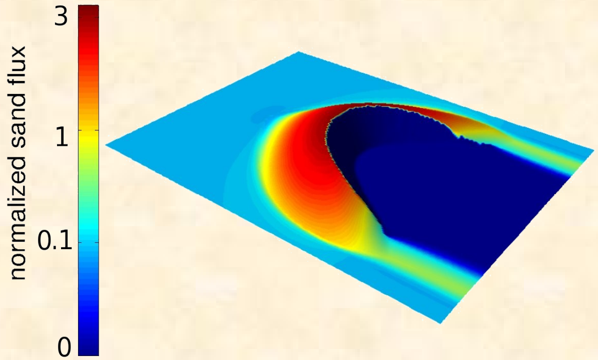
$$\boldsymbol{\tau}(x,y) = \boldsymbol{\tau}_0 + |\boldsymbol{\tau}_0|\delta\boldsymbol{\tau}(x,y)$$

$$\mathbf{u}_*(x,y) = \frac{\sqrt{|\boldsymbol{\tau}(x,y)|}}{\rho}\,\mathbf{e}_\tau(x,y)$$



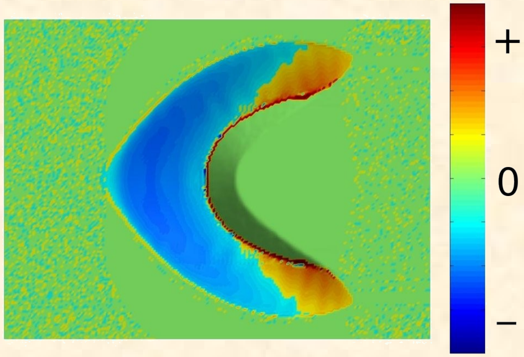
Sand transport equation:

$$\nabla\cdot\mathbf{q}(x,y) = \frac{q(x,y)}{l_s(x,y)}\left(1-\frac{q(x,y)}{q_s(x,y)}\right)$$



Evolution of the surface:

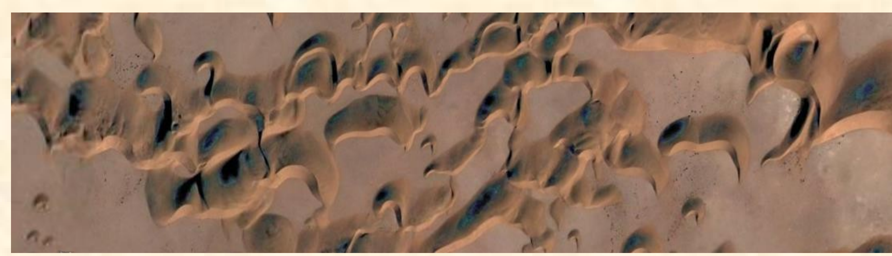
$$\frac{\partial h}{\partial t}(x,y) = -\nabla\cdot\mathbf{q}(x,y)$$



First application: emergence of dune fields

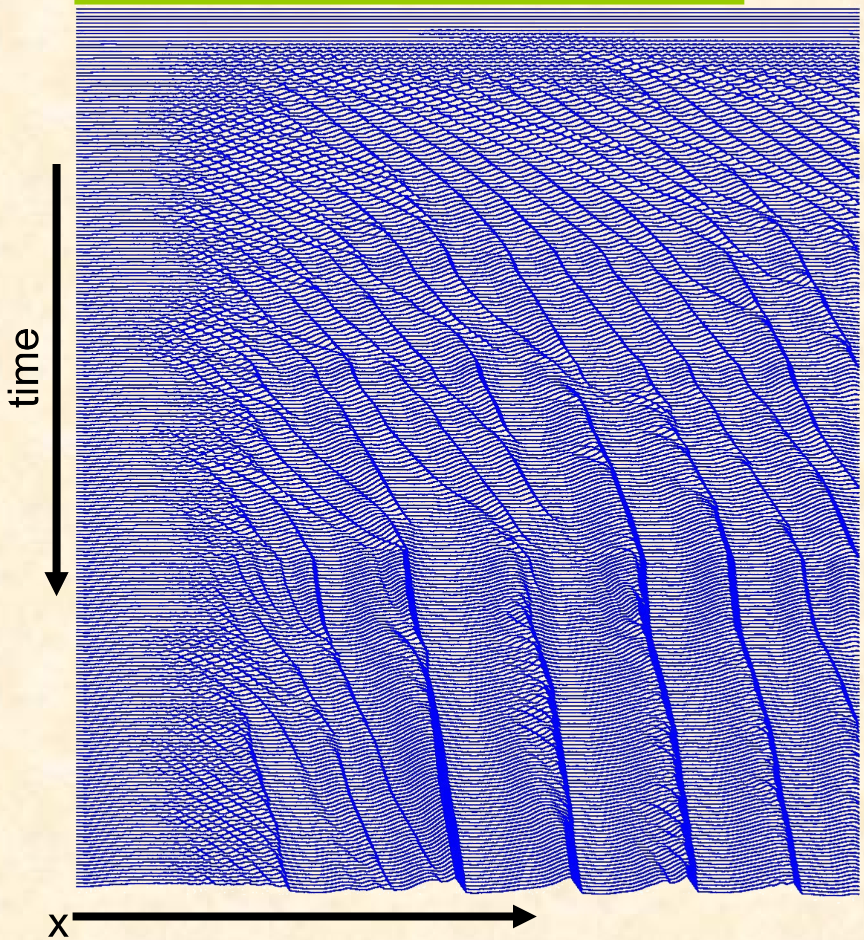
Open Boundary

Periodic Boundary

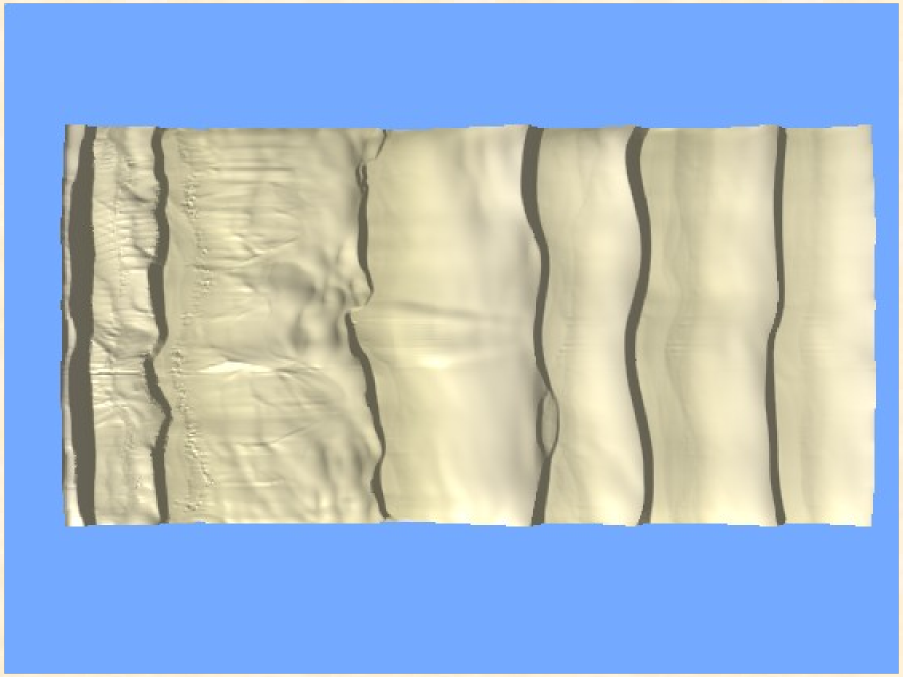


Sand waves instabilities: emergence of transversal dune fields

'longitudinal' instability

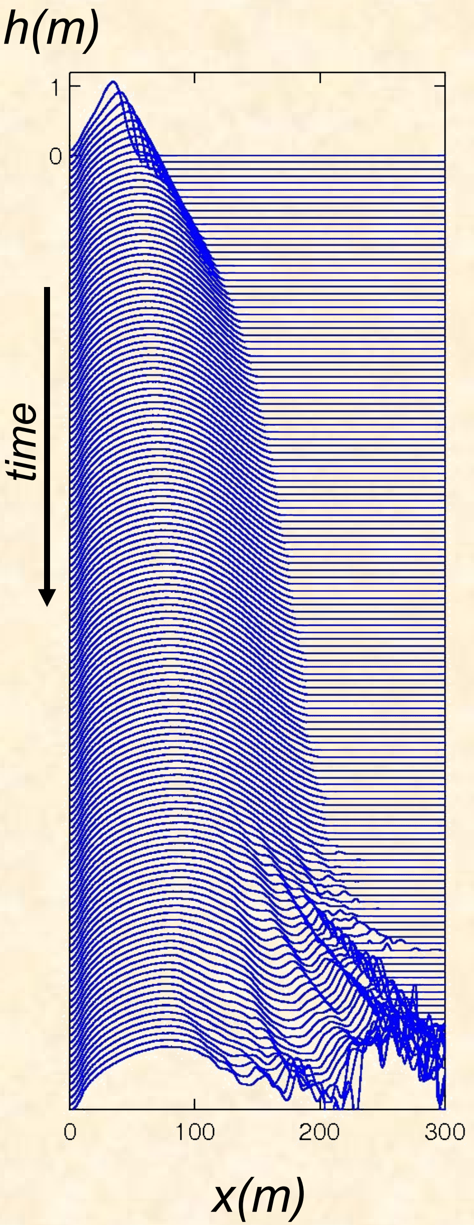


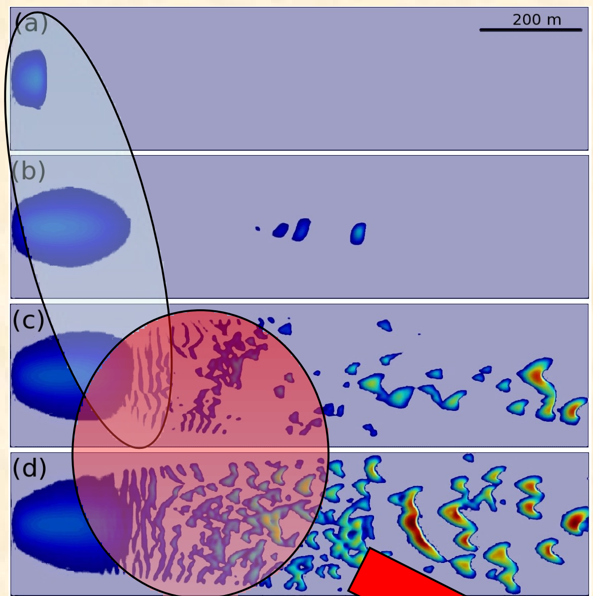
periodic boundaries



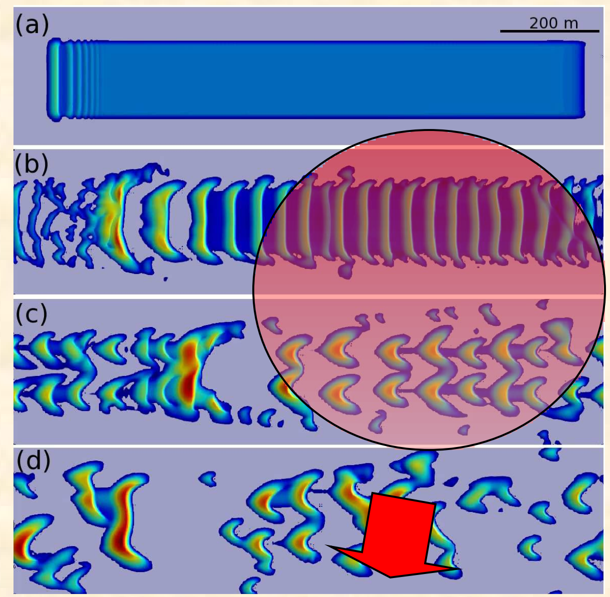
1 km long

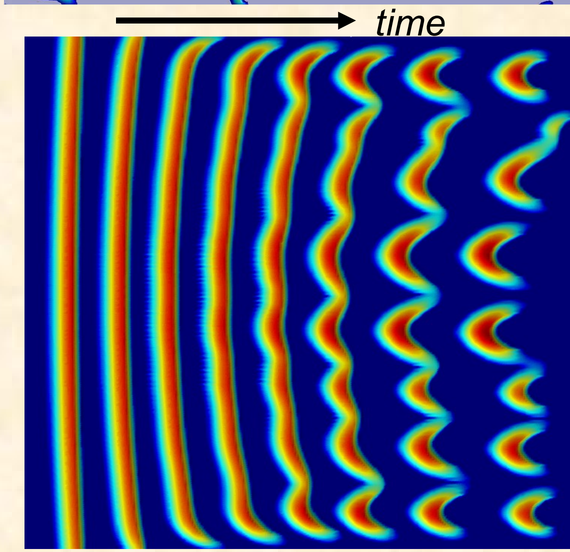
Sand waves instabilities: emergence of barchan dune fields





‘Beach’ instability

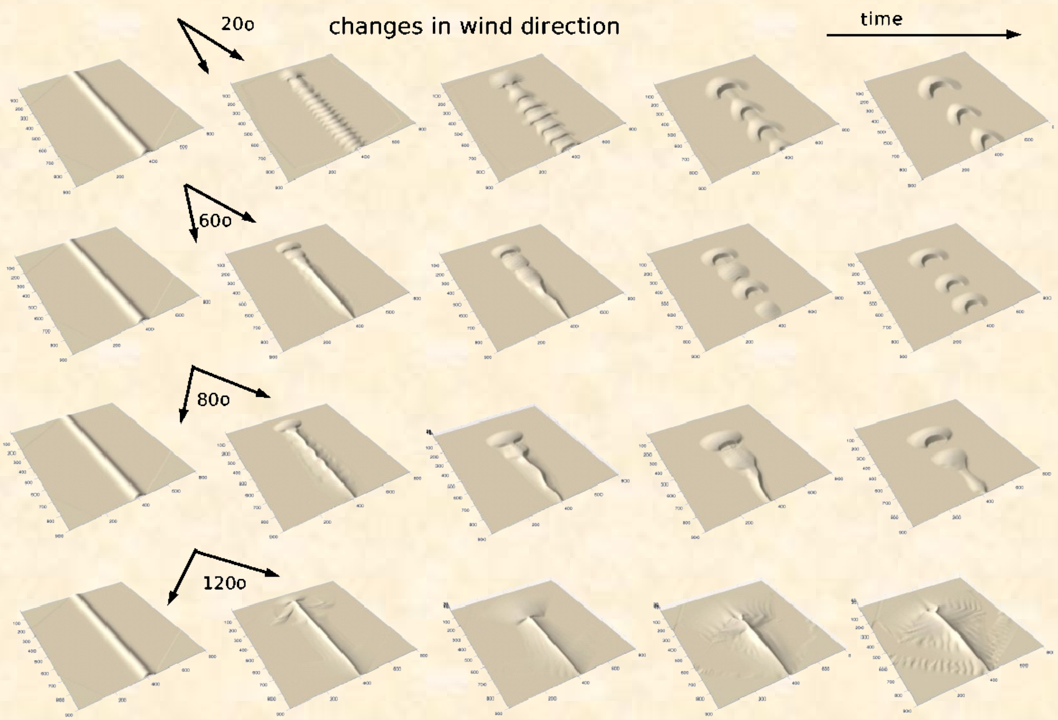




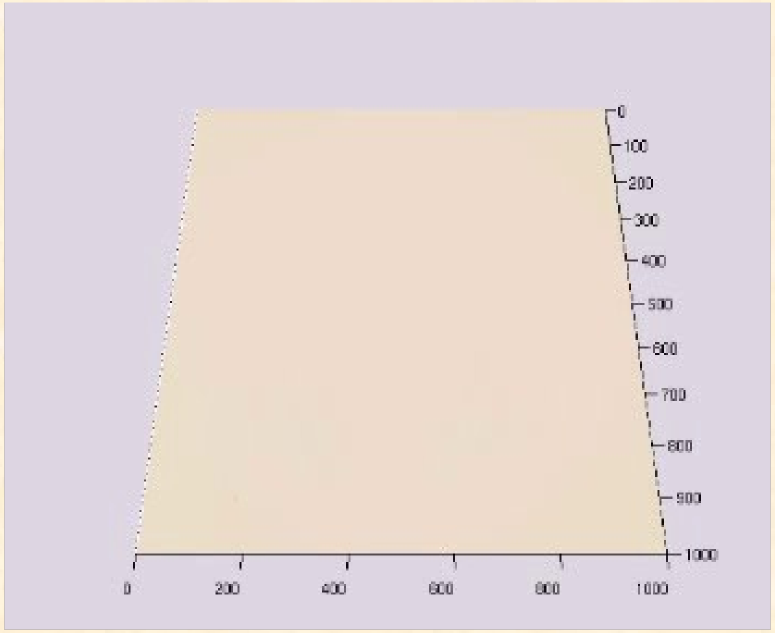
‘Transversal’ instability

Sand waves instabilities: emergence of liner dune fields

Isolated linear dunes

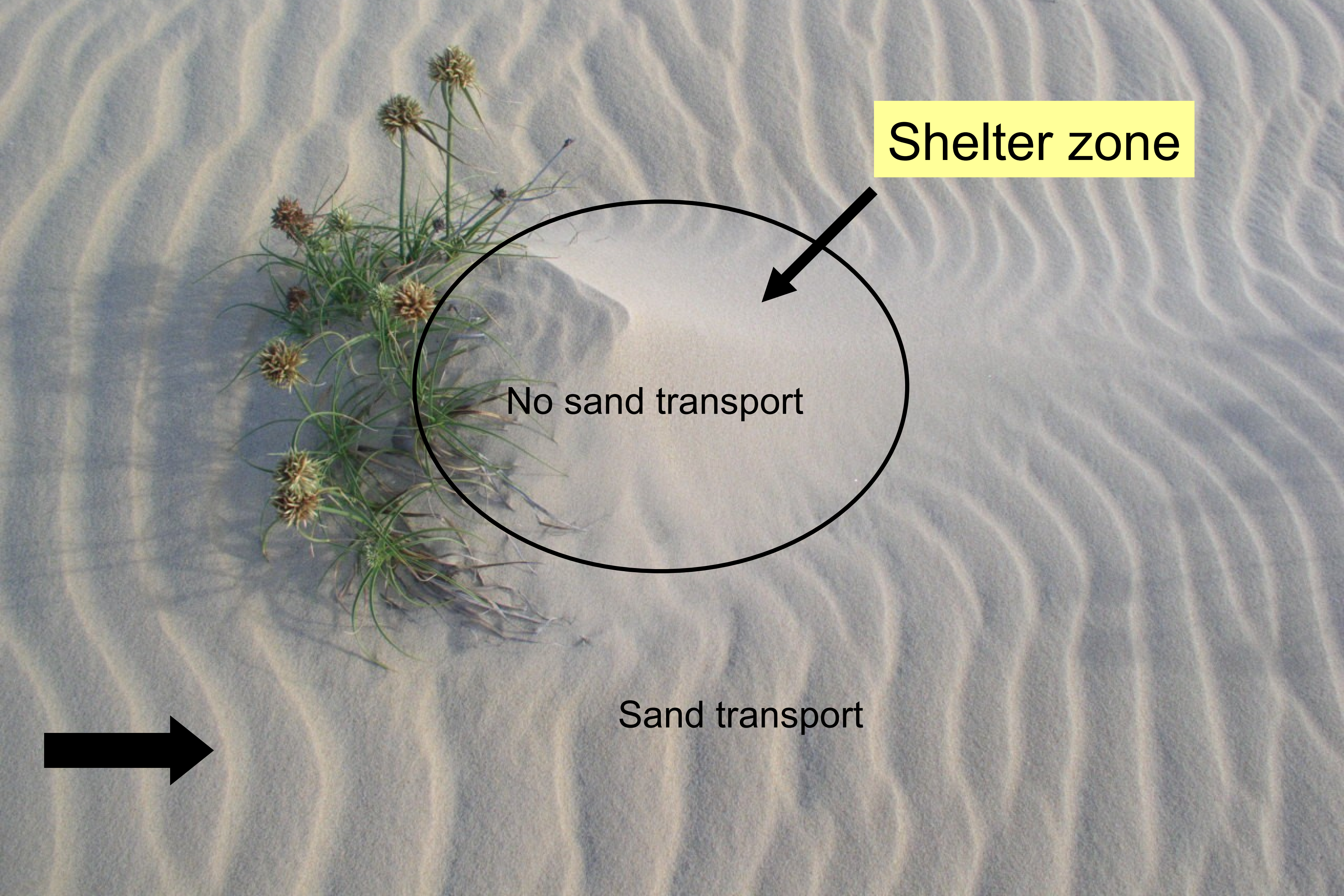


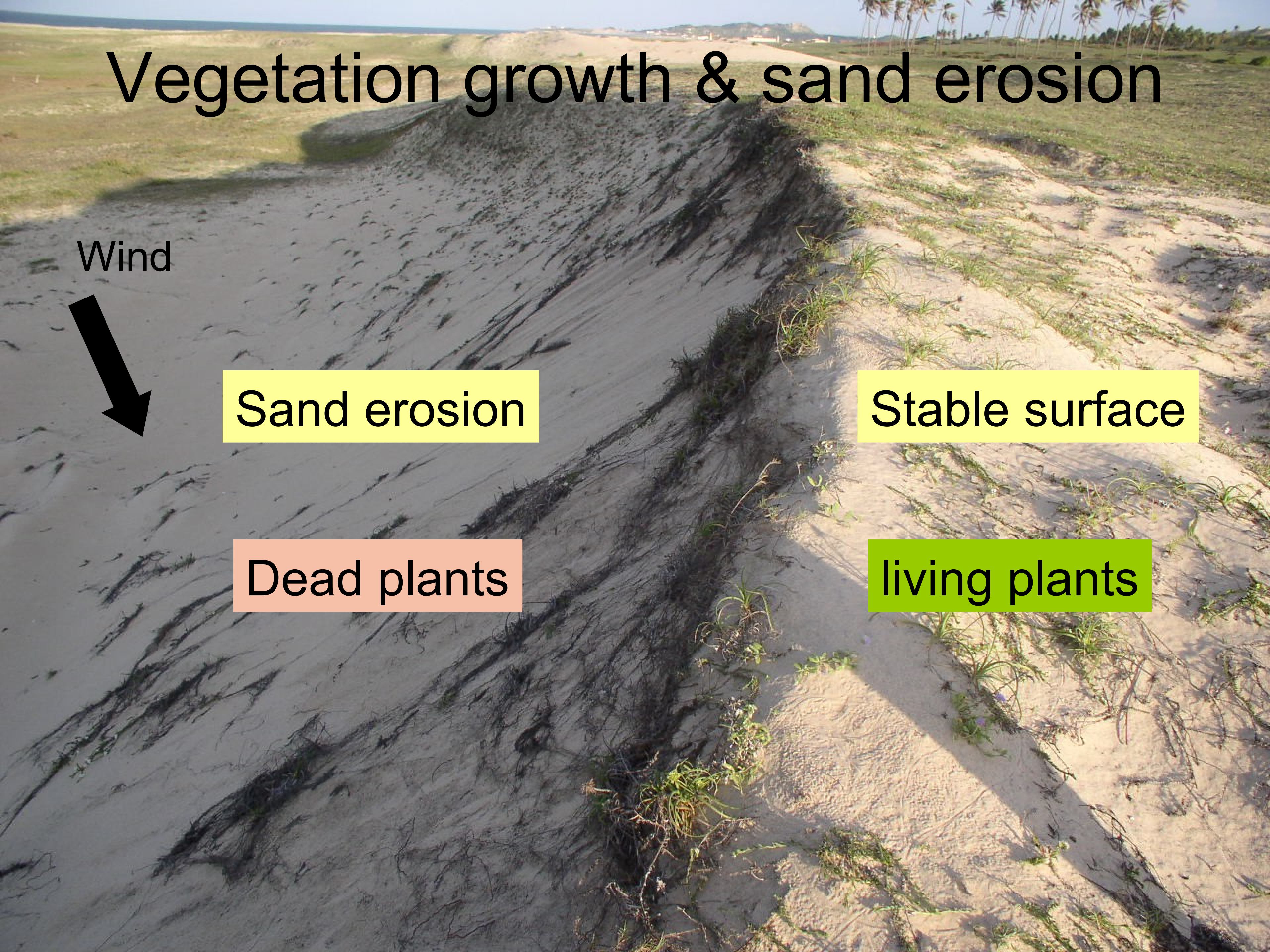
Linear dune field



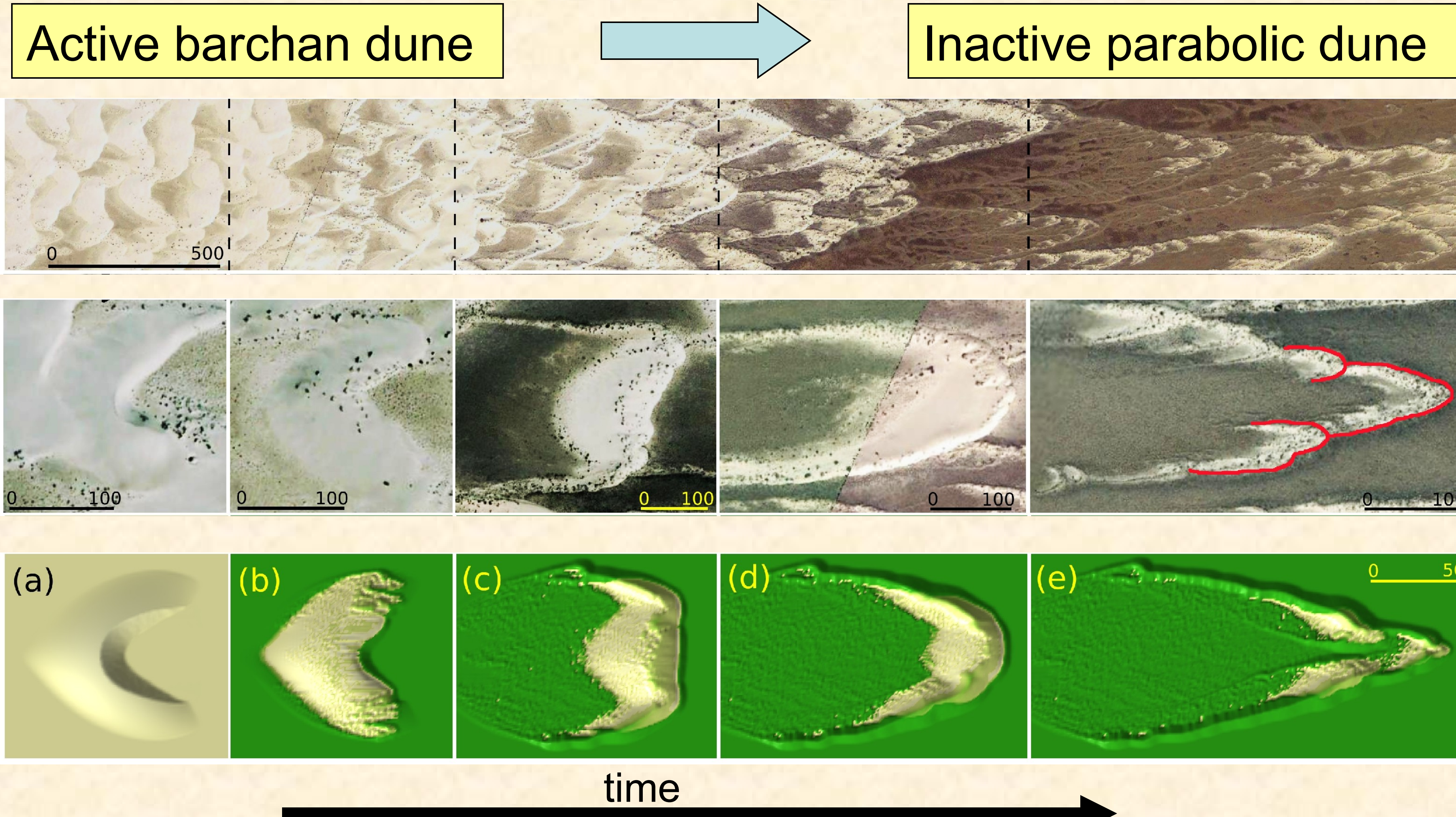
Second application: sand transport + vegetation growth (dune stabilization)

Vegetation effect: wind reduction



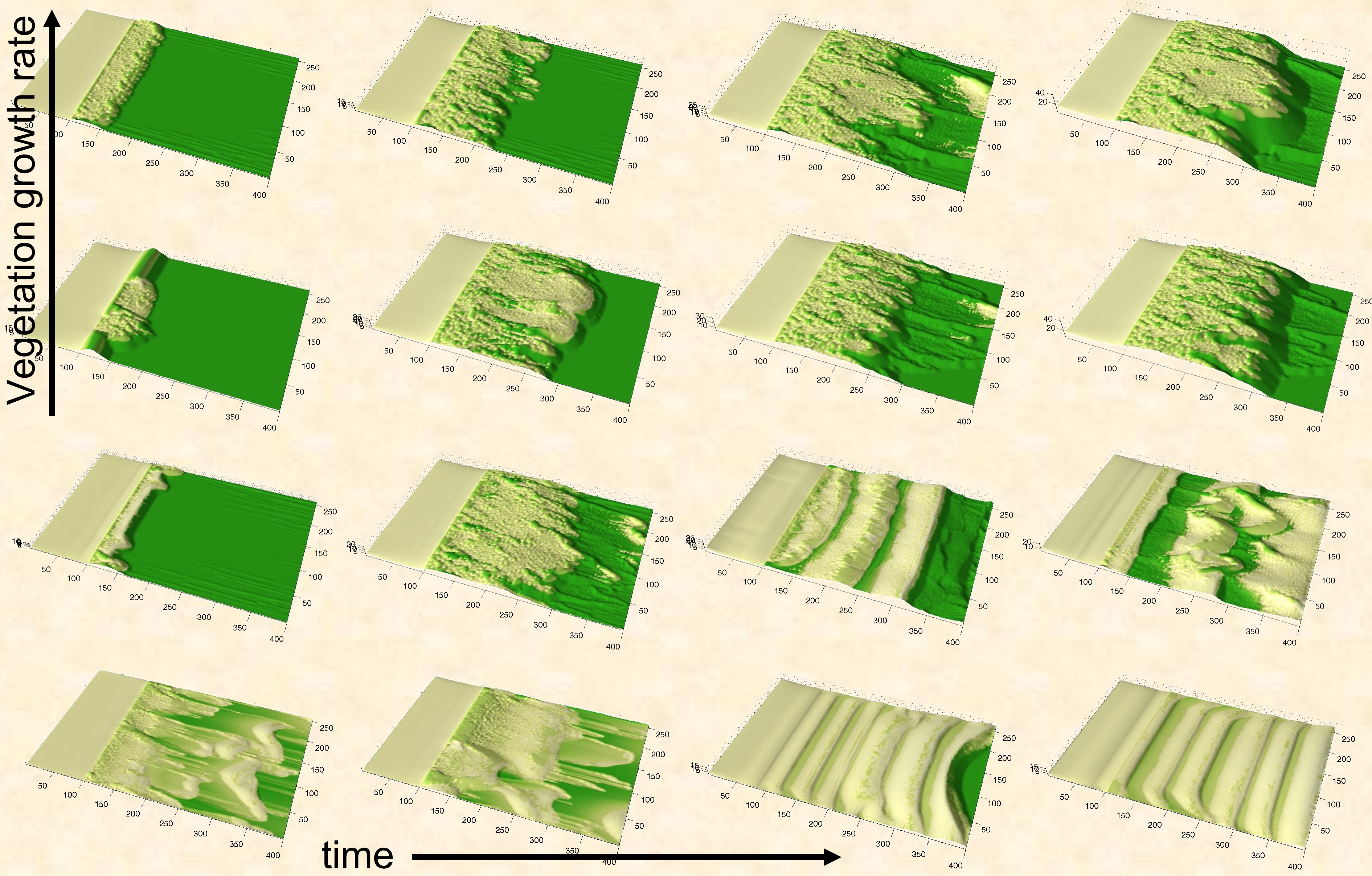

Vegetation growth & sand erosion
Wind
Sand erosion
Stable surface
Dead plants
living plants

Stabilization of barchan dunes: emergence of parabolic dunes



Duran and Herrmann, *Phys. Rev. Lett.* (2006)

Sand waves instabilities + Vegetation: Toward a model for coastal dunes




Thank you!