Protodunes formation under a bimodal wind regime

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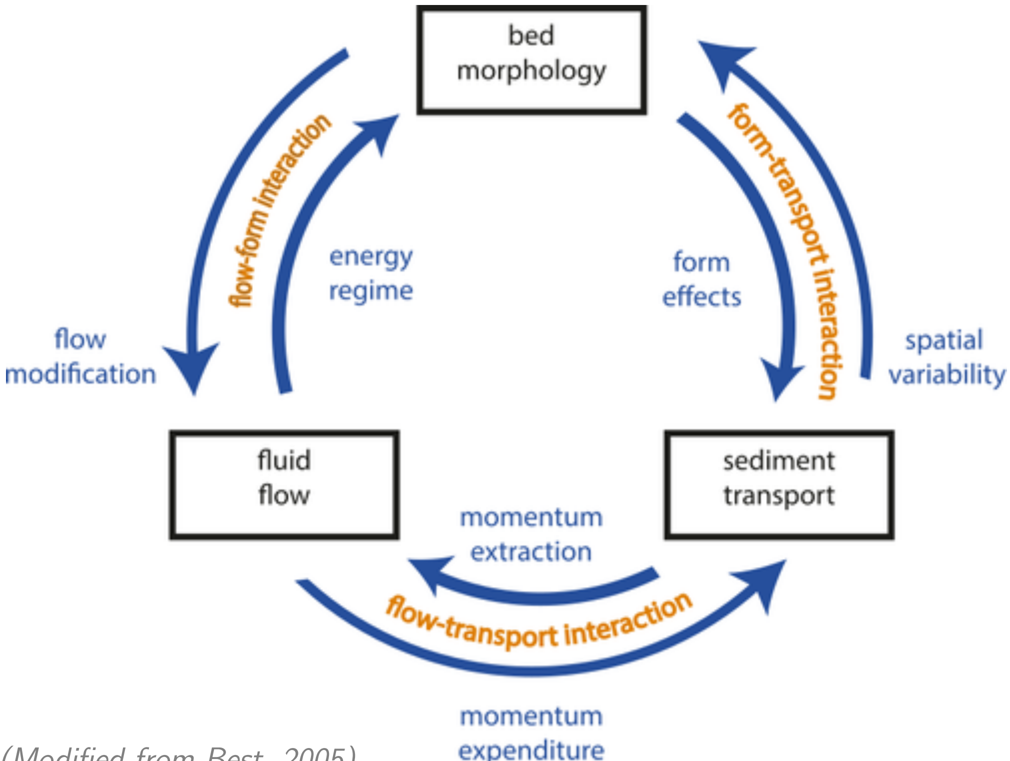
Dune formation



(Modified from Best, 2005)

Dunes grow from complex interactions between flow, form and sediment transport.

It is therefore necessary to quantify these parameters in the field.

This quantification, however, remains very challenging over proto-bedforms.

Flat sand bed

On a flat erodible bed, dunes grow from the bed instability mechanism. In this case, the bedform is fed by the sand coming from the erodible interdunes (white strips).

We investigated the emergence of protodunes under a bimodal wind regime, in a natural aeolian environment.

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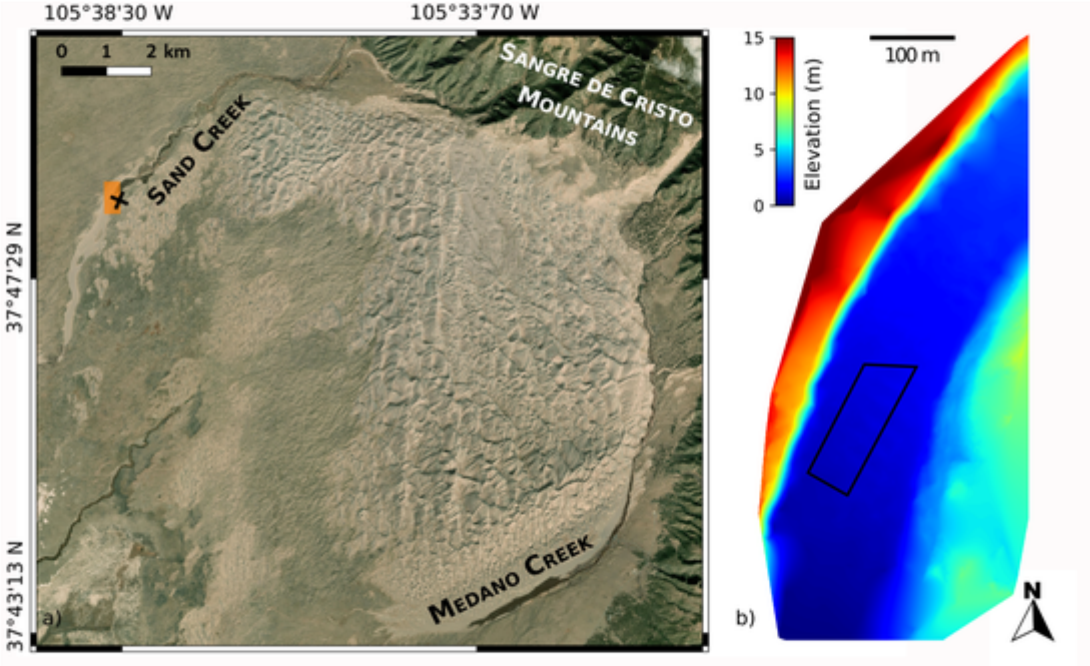
Great Sand Dunes National Park



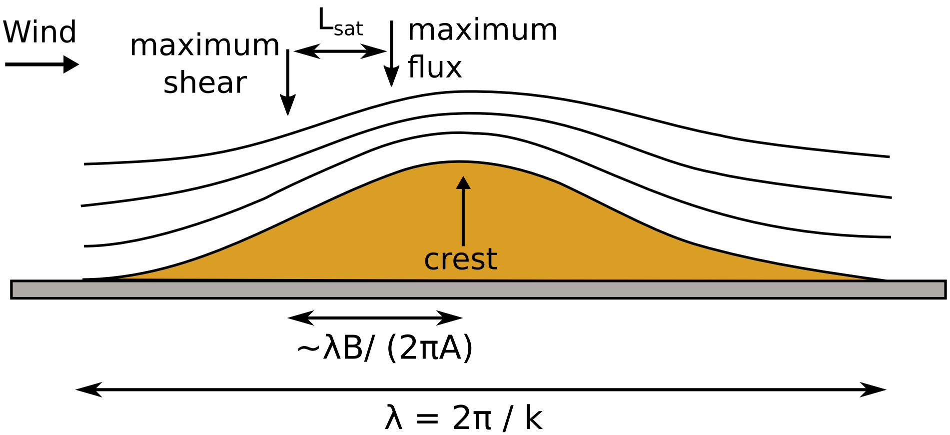
a) Satellite image of the Great Sand Dunes National Park, the orange rectangle indicates the field area (Source: Esri). b) TLS-derived digital Elevation Model of the Sand Creek study area. The black polygon limits the area used for the morphological analysis.

- Sand Creek bounds the North-West of the dune field
- The creek bed is flattened every summer during the ephemeral flooding
- The area experiences two main winds from the South West and the West

These characteristics make the area ideal to apply linear stability analysis

Bed instability mechanism

Above a small bump, the fluid is accelerated upwind of the crest and decelerated downwind, consequently, the maximum shear velocity is shifted upwind of the crest.



(Modified from Claudin et al., 2006)

- The upwind shift of the maximum shear stress is proportional to the wavelength and two hydrodynamical parameters A and B:

$$\sim \frac{\lambda B}{2\Pi A}$$

- The sand transport needs a distance to adjust to the wind velocity, the saturation length:

$$L_{sat} \propto \frac{\rho_s}{\rho} d_s$$

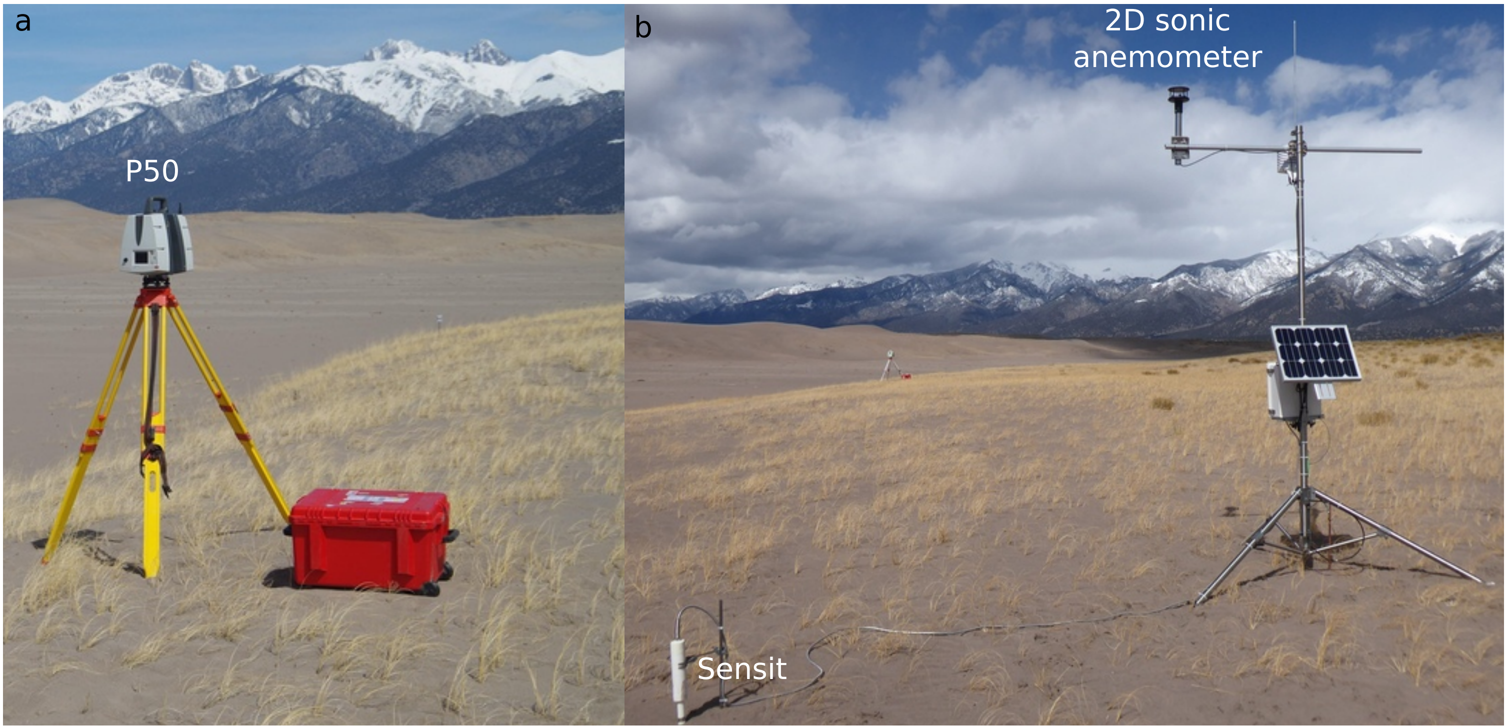
From these variables and the sediment flux Q we calculate the growth rate:

$$\sigma \propto Q k^2 \frac{B - A k L_{sat}}{1 + (k L_{sat})^2}$$

The emerging bedform is the one that maximizes the growth rate

Field monitoring

We monitored the Sand Creek area from March, 23^{rd} to April, 16^{th} 2019. We measured wind speed and direction at 3.17 m from the surface using a Gill 2D sonic anemometer and the sediment motion within 0.03 m from the surface using a Sensit. Additionally, 5 scans are performed with a TLS (27^{th} and 30^{th} of March, and 5^{th}, 12^{th}, and 16^{th} of April 2019).



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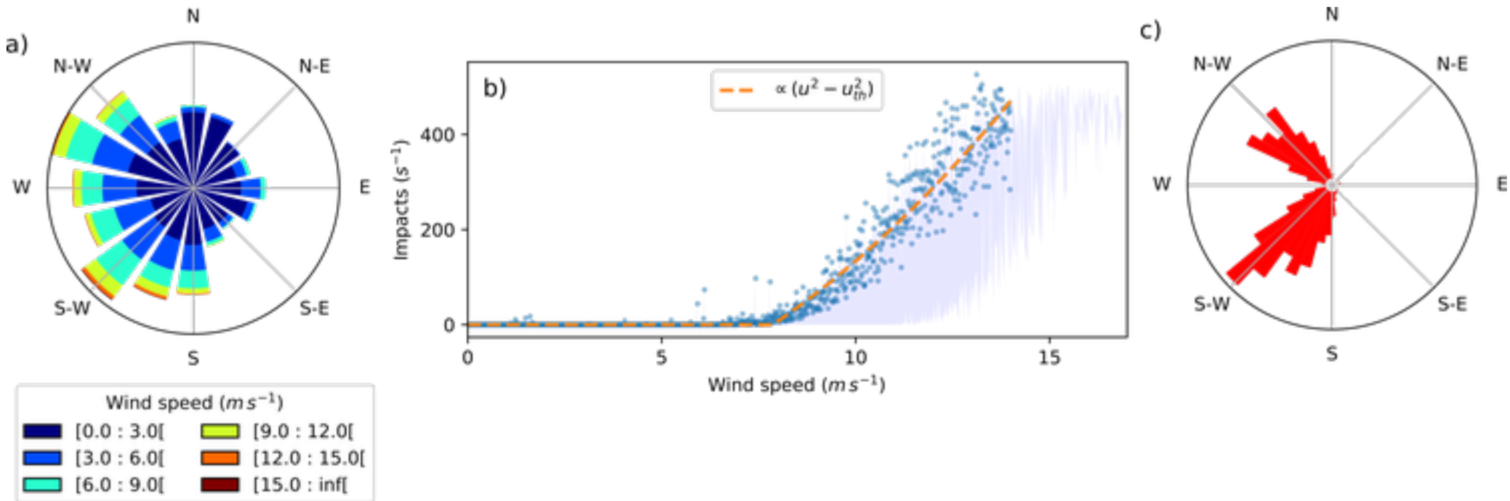
Wind and sediment fluxes



Wind data used to formulate a wind rose →

By combinig wind data with sand transport data, we can estimate the transport law,

$$Q_{sat} \propto (u_*^2 - u_{th*}^2)\ (u_{th} = 7.9\,\mathrm{m\,s^{-1}})$$

→ Sand comes from two main directions:

$\theta_1 = 218 \pm 15°$

$\theta_2 = 297 \pm 10°$

We use sand transport and wind data as an input for the linear stability analysis

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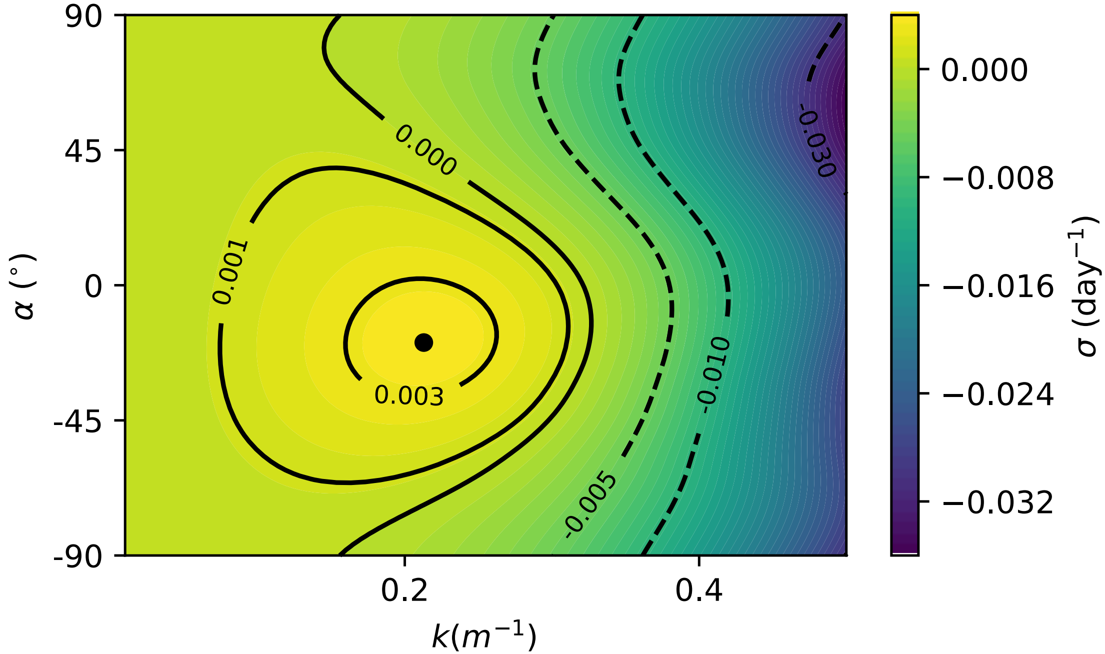
Maximize the growth rate

With a bimodal wind, we need to take into account the relative contribution of each wind. The orientation and wavelength of the emerging dune is the one that maximizes the growth rate.



The maximum growth rate, $\sigma_{max} = 0.005\,\mathrm{day}^{-1}$, is reached for:

$$k = 0.23\,\mathrm{m}^{-1} \rightarrow \lambda = 27\,\mathrm{m}$$

$$\text{and } \alpha = -19^\circ \rightarrow \text{Dune orientation } 136^\circ$$

with an associated celerity of: $c = 0.12\ \mathrm{m\,s}^{-1}$

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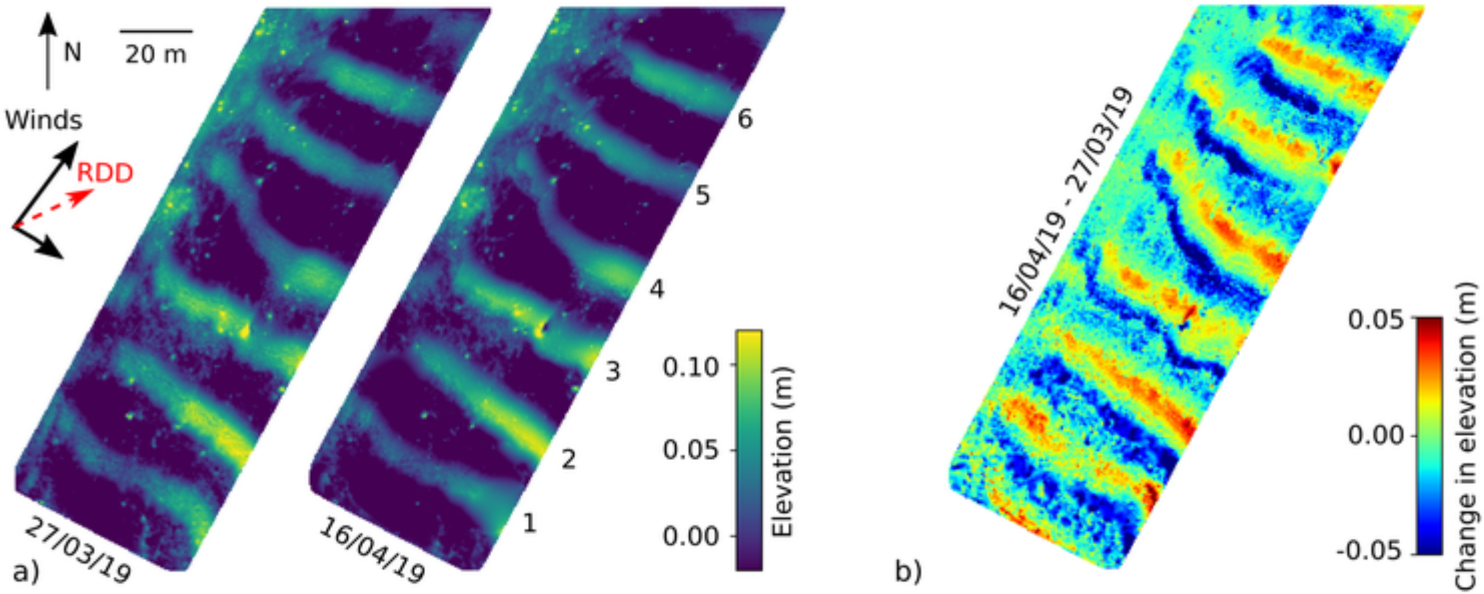
Comparison with topographic measurements



From the individual DEMs, we measure the dune wavelength and orientation:

$$\lambda = 25.7 \pm 0.5\,\mathrm{m} \text{ and dune orientaion : } 131 \pm 7^\circ$$

From the differential map, we measure the growth rate and migration celerity:

$$\sigma = 0.005 \pm 0.007\,\mathrm{day}^{-1} \text{ and } c = 0.084 \pm 0.07\,\mathrm{m\,day}^{-1}$$

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Take home message

Sand creek: ideal site to apply the bed instability model

- Flat sand bed resets every year
- Well constrain bidirectional wind

Bed instability (wind and sediment trasport) vs topography (TLS)

- Bed instaility: $\lambda = 27$ m and orientation $= 136^\circ$
- Topography: $\lambda = 25$ m and orientation $= 131^\circ$

For the first time the linear stability theory in a bimodal wind was tested in a natural environment and it works well