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Faculty of Geosciences
Physical Geography

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Modelling of wind flow over a beach-dune system

Introduction

Coastal dune systems are formed by aeolian (wind driven) processes. Similar to water, the flow of wind is influenced by topography. While advanced 3d models for water flow can be used to predict sediment behaviour and morphologic change, predictions of aeolian morphologic change in dunes are far less advanced. For example, often a regional wind speed and direction are used as input for aeolian transport models, neglecting the strong effect of foredune topography on the local (i.e., on the beach) wind field. Field measurements suggest that wind velocities decrease near the foredune; also, winds at the dunefoot appear to be more in alongshore directed than at the shoreline. Moreover, the intermittent character of aeolian sand transport (e.g., streamers) suggests that taking into account wind turbulence is important for accurate predictions of aeolian dune growth.

Objective: to investigate wind flow on the beach using Computational Fluid Dynamics
1) Decrease in wind speed
2) Steering near foredune

Streamers

Change of wind direction near dunes

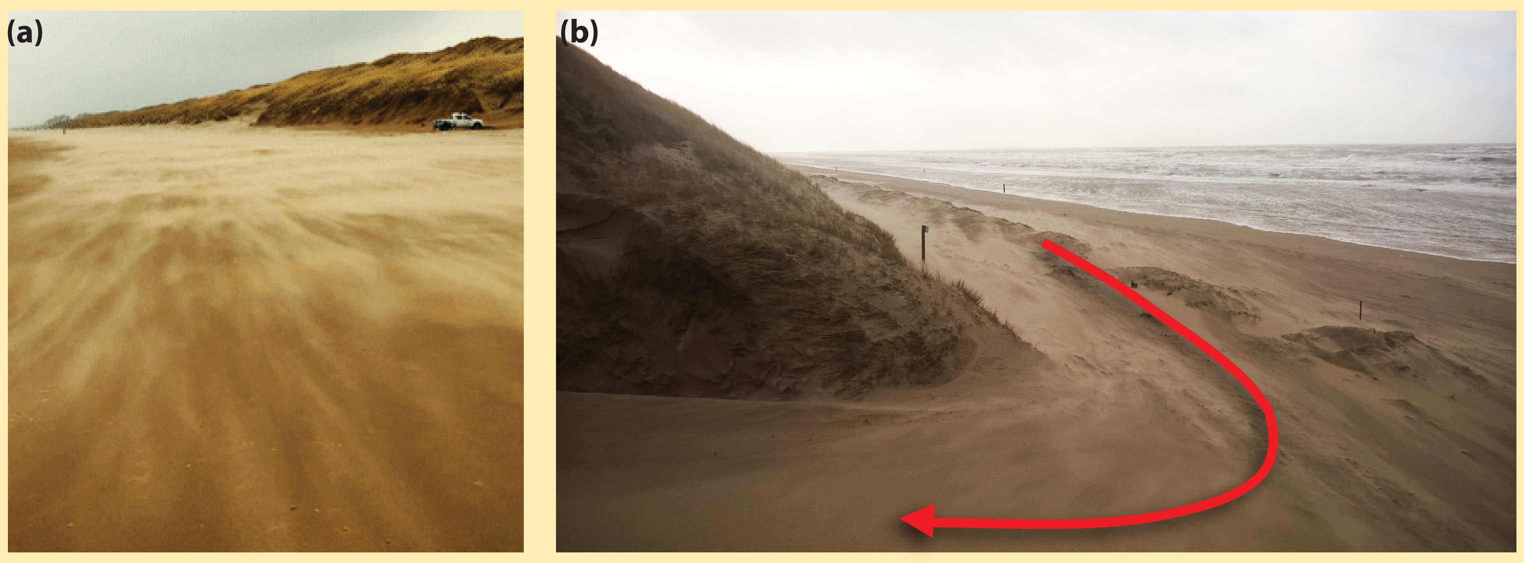


Figure 1 Aeolian transport on the beach (a) steamers or 'sand snakes' on the beach (Egmond, NL) and (b) rapid change of direction of aeolian transport near a blowout (Egmond, NL)

Methods

To model the effect of beach and coastal-foredune topography on near-bed wind characteristics we used the open source Computational Fluid Dynamics (CFD) package OpenFOAM. OpenFOAM incorporates a broad range of solving algorithms and turbulence parametrisations for the Navier-Stokes equations and includes tools for mesh generation. Here our model set-up is outlined.

Gathering detailed dune topography

Surface model is generated from aerial photographs

- Aerial photographs obtained with an UAV
- Georeferenced using 21 ground control points
- Structure-from-Motion workflow in AgiSoft Professional
- Resuling 3d point cloud converted into 3d surface model

- Surface model is imported into Blender (3D creation suite) and converted into a solid dune model.

Creating the model grid

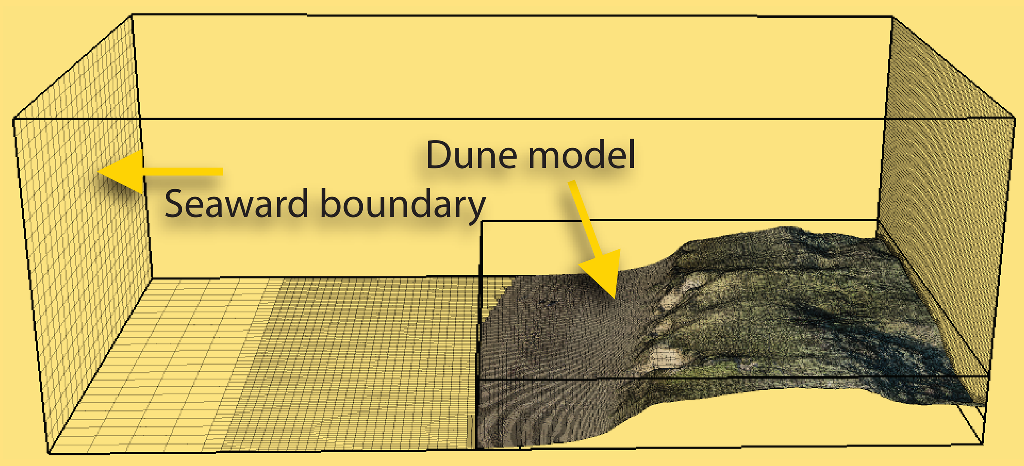


Figure 2 Outline of model grid with location of dune model

Grid is generated using openFOAMs pre-processing tools

- Model is rotated to test for different wind directions
- Basic 3D grid defined using BlockMesh
- SnappyHexMesh places dune model in the basic 3D grid
- Grid density is increased near the beach-dune surface

Model settings and runs

Boundary conditions:
- Logarithmic wind speed (u) profile at the seaward boundary:

$$u\,(z) = \frac{u_*}{\kappa}\ln\left(\frac{z+z_0}{z_0}\right) \qquad (1)$$

- Wind speed at 10 m used for reference (u(10))
- Surface roughness (z_0) fixed to 0.1 m
- Zero pressure gradient at boundaries

Numerical methods:
- Turbulence parameterized using renormalized group κ - ε method.
- Steady state solving algorithm SimpleFoam

Model runs:
- Different cross-shore wind speeds u(10) = 4 -20 m/s
- Under 10 different angles 2.8 - 47.8° at u(10) = 15 m/s

Results

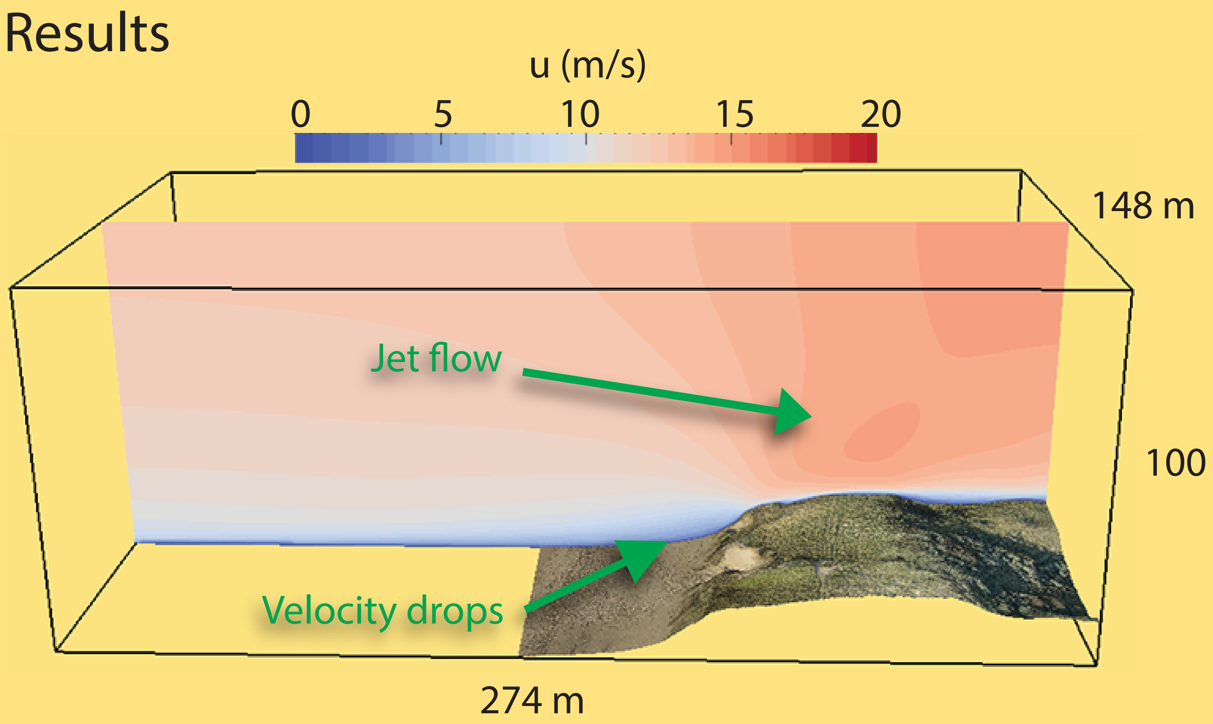


Figure 4 A cross-section of modelled wind speeds over a foredune. Results for a model run with a u(10)= 10 m/s and wind under an angle of 7.2° are shown. Highlighted are the velocity drop in front of the foredune and jet flow over the foredune.

1. Velocity decrease near the dunefoot

- Decrease in velocity towards dunefoot (F4)
- Increase in velocity over the foredune (jetflow) (F4)

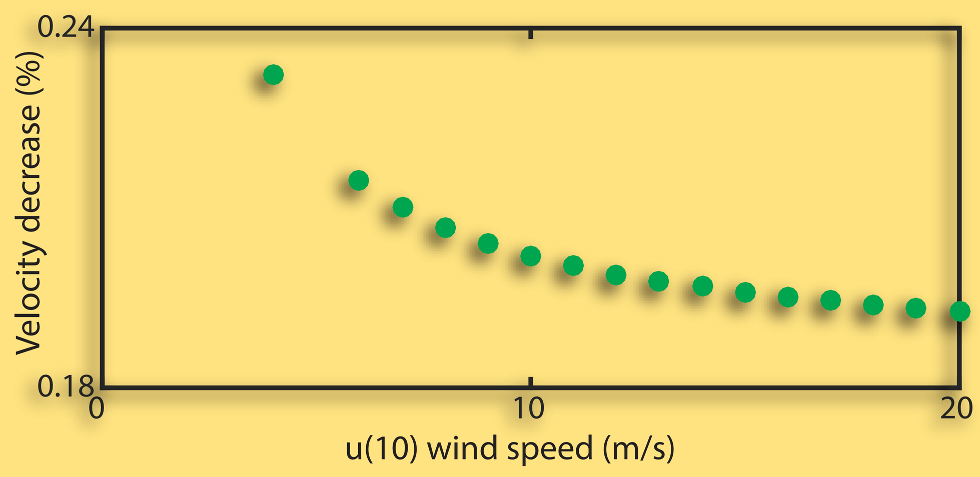


Figure 5 Modelled windspeed decreases between the shoreline (+0.5 line) and the dunefoot (+3 line).

- Velocity decrease is nearly constant (20%) with wind speed (F5)

2. Wind steering near the dunefoot

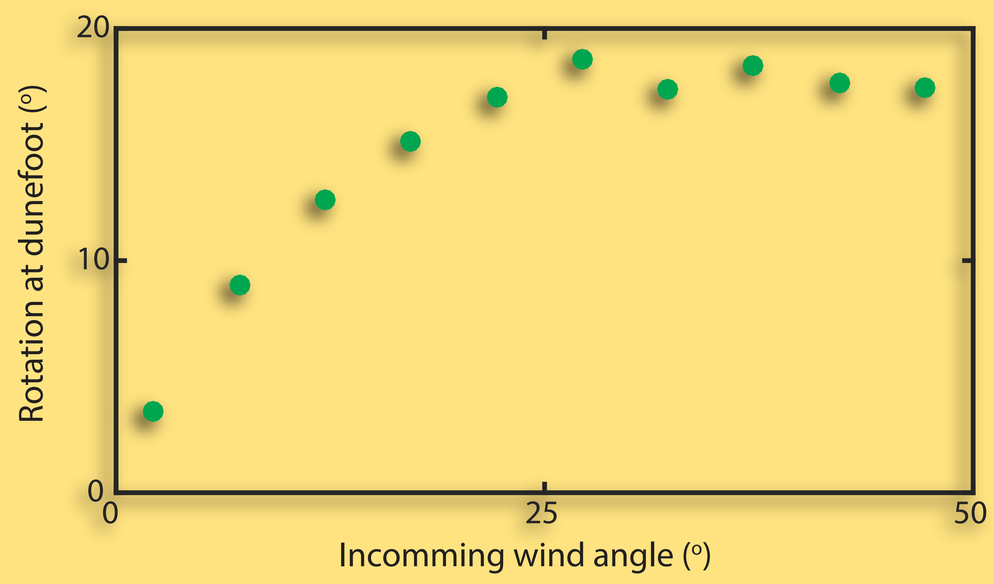


Figure 6 Rotation angle of wind to a more along shore direction with respect to the incoming wind direction (0° = cross-shore)

- Wind steering increases with wind direction (0 - 30°) (F6)
- Remains constant for more oblique winds (>30°) (F6)

Conclusions

1a) A 20% decrease in wind speed for on-shore winds.
1b) Small relation between drop and wind speed.

2a) Wind direction is more shore-parallel at dunefoot than at shoreline.
2b) Rotation increases with increasing angle up to 18° for (30-50°)

With OpenFOAM we can model the typical behaviour of the wind over a beach-dune ystem.

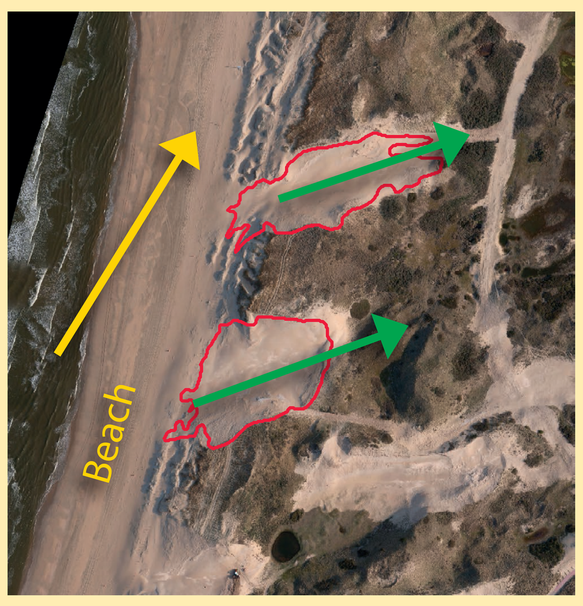
Outlook

Validate model

Wind measurements carried out in 2015 during the Aeolex field campaign.

- Use measurements to validate model for velocities and turbulence
- Optimize aeolian transport model with improved wind modelling.

Figure 7 Ultrasonic anemometer on the beach



Study tunneling effects near blowouts/ man-made trenches.

Trenches enhance aeolian transport and almost all sand is deposited landward of trenches.

- What is the best trench orientation?
- Determine optimal trench geometry

Figure 8 Man-made treches at Kennemerduinen. Arrows indicate regional (yellow) and local (green) wind direction. Red lines show trench edges.