Atmospheric Boundary Layer Flow at the Sand Interface

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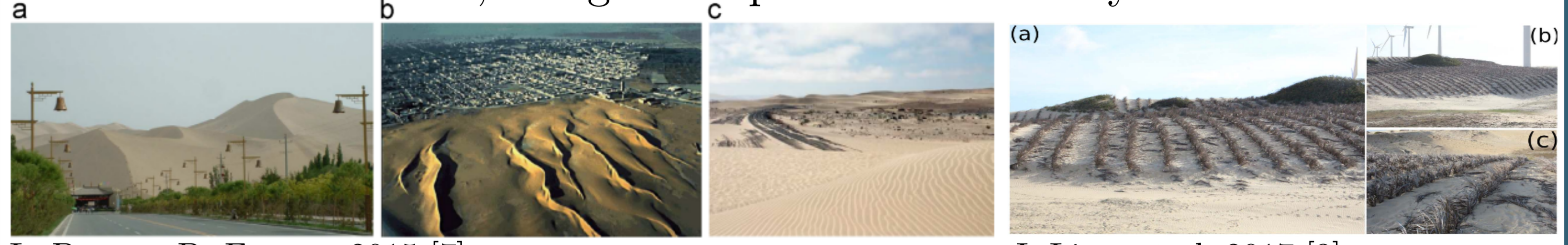
1. Motivation: desertification

Desertification and rising sea levels affect an increasing part of the world's population. Around 25% of the land surface and 1.5 billion people are affected by desertification at present[1]. Active dunes move several meters per year, the fastes dunes up to 100m per year[2], thereby threatening infrastructure and homes. At the same time, dunes protect us from flooding in the form of dykes along coastlines. How can we control dunes? One widely used option is to errect soil erosion fences.
In this poster we study how effective fences are at reducing wind shear stress near the surface, using a computational fluid dynamic model.



L. Bruno, D. Fransos 2015 [7]   I. Lima et al. 2017 [3]

2. Method: computational fluid dynamics

Model setup:
- software OpenFOAM: C++, finite volume numerical scheme
- air: incompressible, newtonian fluid
- Reynolds averaged standard k-epsilon turbulence model: steady state solver *porousSimpleFoam*
- 2D channel, x=40m, z=1m, refinement up to dx=2mm, dz=1.2mm

Boundary and initial conditions:
Turbulence caused by friction with the ground leads to *logarithmic profile* of wind velocity u in lower part of the atmosphere - the Atmospheric Boundary Layer (ABL). We implement the turbulence by using functions of the *atmBoundaryLayerClass*:

$$u = \frac{u^*}{\kappa}\ln\left(\frac{z-z_g+z_0}{z_0}\right),\quad k = \frac{(u^*)^2}{\sqrt{C_\mu}},\quad \epsilon = \frac{(u^*)^3}{\kappa(z+z_0)}$$

$$u^* = \left(\frac{\tau_w}{\rho}\right)^{1/2} = \frac{\kappa\, u_{\mathrm{ref}}}{\ln\left(\frac{z_{\mathrm{ref}}-z_g+z_0}{z_0}\right)}$$

u : velocity
k : turbulent kinetic energy
ϵ : turbulent dissipation
z_g: minimum z-coordinate (m),
z_0: surface roughness height (m),
u^*: friction velocity,
κ: von Karman's constant, κ=0.41
C_μ : model coefficient
τ_w : wall shear stress

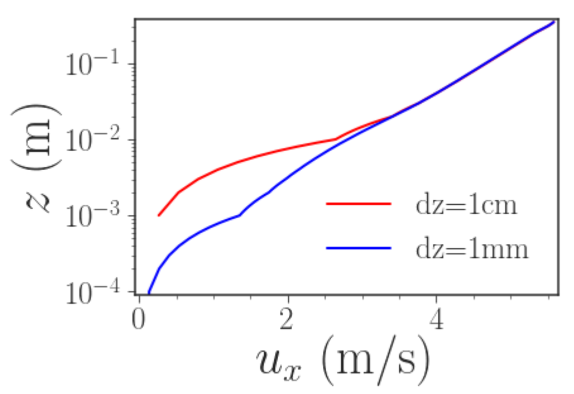
These equations are used for:
- inlet conditions for u, k, *epsilon*
- wall functions for lower wall for turbulent viscosity *nut*, k, *epsilon*
- and initial conditions for k, *epsilon.*

Dimensionless theoretical description:

$$z^+ = \frac{u^* z}{\nu},\quad u^+ = \frac{u}{u^*}$$

$z^+ < 5$: Viscous sublayer
$5 < z^+ < 30$: Buffer layer
$z^+ > 30$: Logarithmic layer

Resulting wind profile:



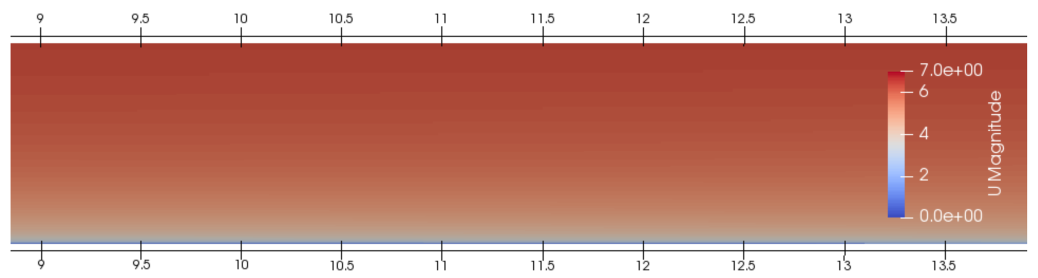
When using wall functions as described, logarithmic profile starts above first cell. Here z^+=30 equals z~1 mm.

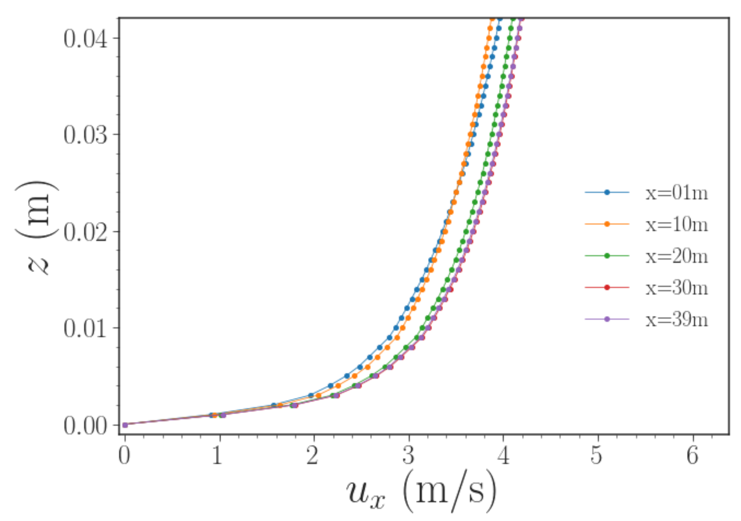
With this setup we successfully produce the logarithmic wind profile.

Implementation of Fences:
- fence height 0.1m, thickness 0.03m and 30 % porosity
- definition of porous cell zones, acting as momentum sink

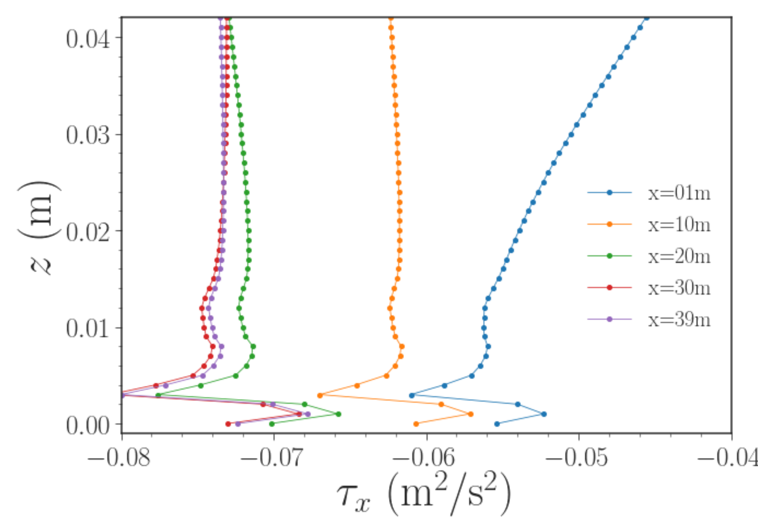
4a. Results: wind profile & shear stress

2D channel with dimensions: 40m x 1m:





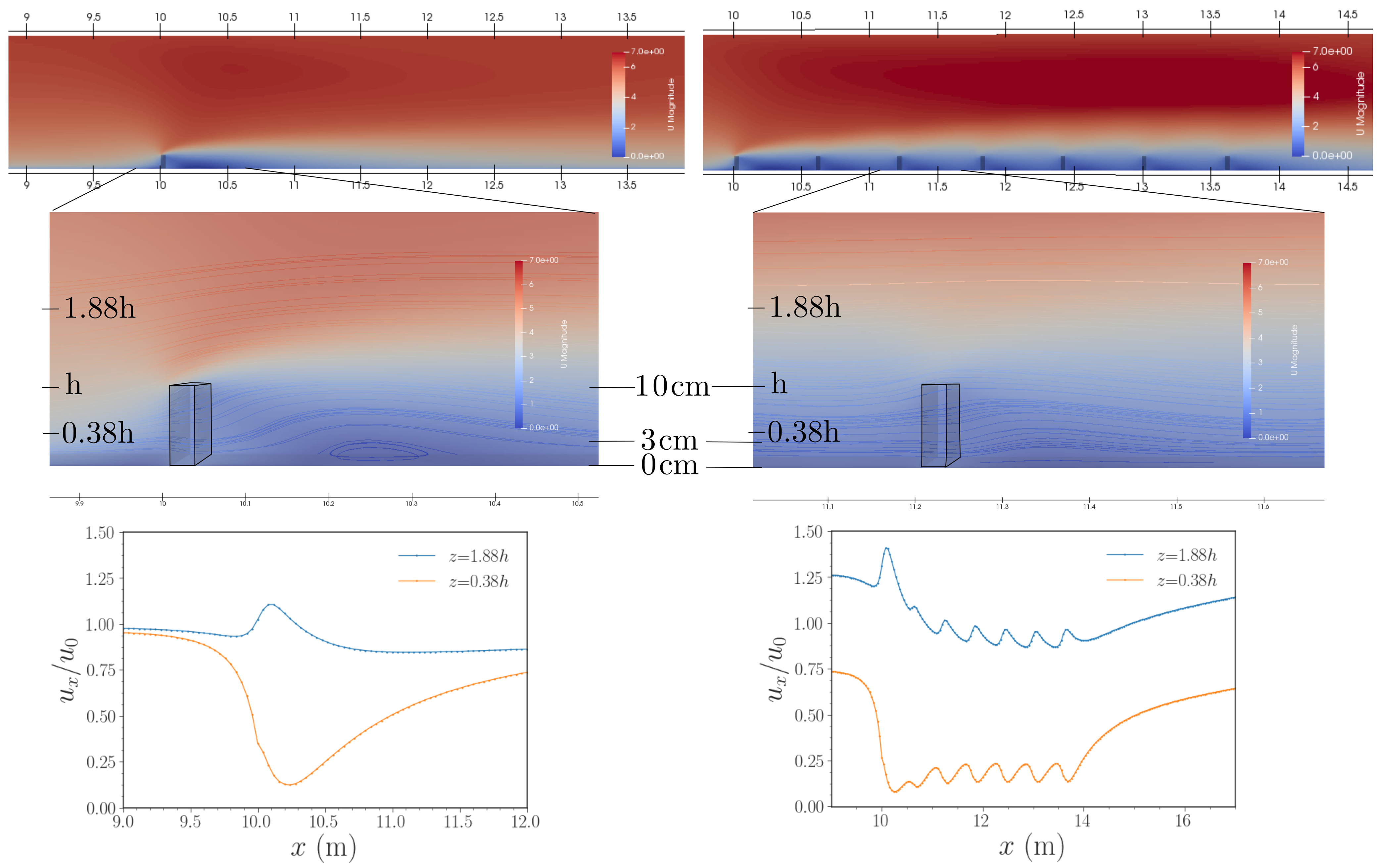
Wind shear stress over height



Shear stress varies in first three cells above ground but remains constant for several centimeters above. Velocity and shear stress profile remain approx. constant after >20m downwind channel.

4b. Results: flow over porous fences

Flow over single fence **Flow over array of fences**

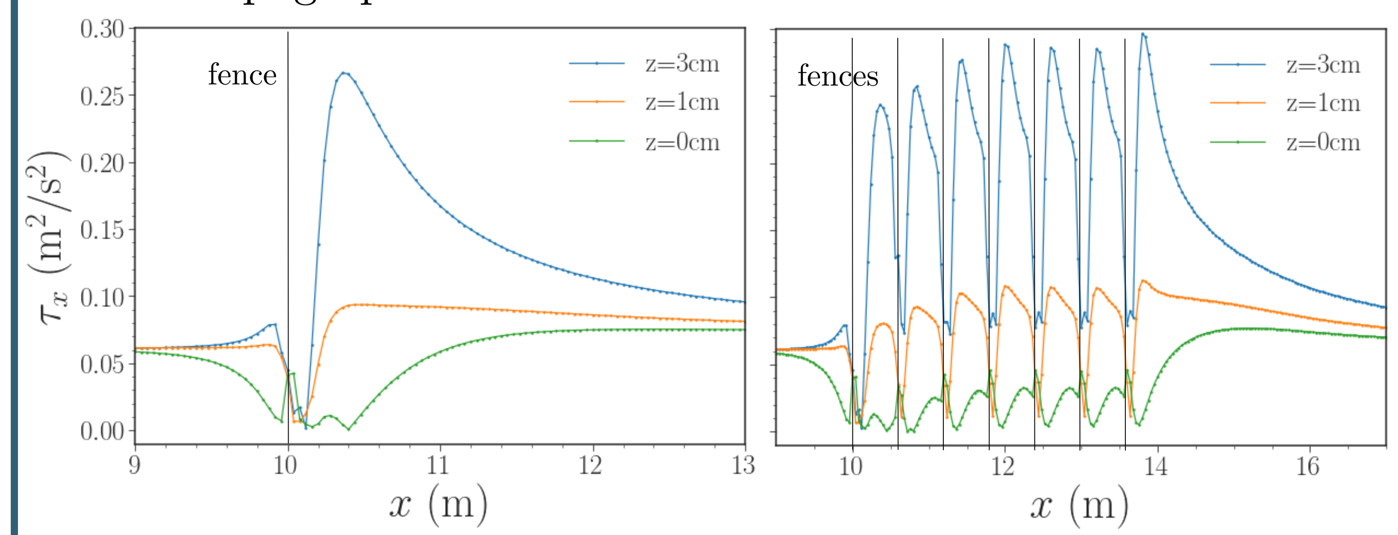


Velocity along channel at heights z=0.38h and z=1.88h as Santiago et al 2007 [4].
Velocity u_x normed by velocity u_0 at inlet of channel at same height. Results for single fence as well as array of fences are in good qualitative agreement with earlier results of our group by Lima et al. [3] and results of Fang et al. [5].

Flow over single fence and array of fences can be simulated with the chosen solver, boundary conditions and grid resolution. Velocity decreases significantly in the vicinity of fences at z=0.38h.

4c. Results: shear stress over fences

Shear stress along channel in x direction at heights z=0cm, 1cm, 3cm to examine shear stress right at the bottom wall and inside the saltation layer, which has a height of ~3cm over smooth topographies.



Shear stress constant over height upwind of fence, but varies strongly near and downwind of fence. Overall, fences reduce shear stress close to ground, but lead to increase above z~1cm.

5. Conclusions & Outlook

- Grid resolution is important for wall functions of atmospheric boundary layer flow. First cell at the bottom should have a size of z^+~30 to resemble ABL flow over smooth surfaces.
- Wind velocity and wall shear stress decrease substantially up- and downwind of fences. Shear stress inside saltation layer above ~1cm height, increases right before and downwind of fence.
- Flow over array of fences leads to recirculation bubble behind the first fence that becomes smaller behind subsequent fences - for given velocities, dimensions and spacing.
- Outer layer stabilizes after second or third fence of array (in good aggrement to Lima et al. [3]).

Outlook:
Couple OpenFOAM simulation of atmospheric wind with sand transport model [6], to simulate dunes with fences and examine the efficiency of fences for aeolian sand erosion.

6. References & Acknowledgements

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