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Recirculation bubbles behind dunes

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Fully developped dunes are rather flat objects with an aspect ratio of the order of a tenth. They however usually present a recirculation bubble on their stoss side. This detachment of the turbulent boundary layer is a non-linear effect at the origine of the formation of the avalanche slip face. It also plays a crucial role in the behaviour of these dunes in response to external forcing or perturbations (e.g. wind direction variations, dune collisions), and controls the dune growth in particular. To go beyond the present empirical description of the recirculation zone in dune models, we have generalized, within the Prandtl turbulent mixing length approach, the logarithmic 'law of the wall' induced by a homogeneous shear stress τ in the additional presence of a constant pressure gradient $\partial_x p$. Depending on the value of the non-dimensional parameter $\mathcal{A} = \frac{z_0 \partial_x p}{\tau}$ (z_0 is the aerodynamical roughness), the velocity vertical profiles can indeed present a change of sign. Assuming that the shear stress and pressure are locally homogeneous along the dune, we show that one can then find a dune 'envelope', defined as the highest streamline of vanishing wind flux, over which τ and p can be consistently computed by expressions deduced from the linear analysis of a turbulent flow over a wavy bottom.