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Influence of Gaussian hill on concentration of solid particles in suspension inside Turbulent Boudary Layer

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Abstract

The soil erosion is a major problem that affects the agriculture, climate and health. It is therefore necessary to understand the phenomena that are its wheels in order to either predict or limit it. One of the main problem of this kind of study is the presence of high particle concentration that restricts measurements of either particle concentration or carrier flow rate. In so numerical simulations are essential for detailed studies. Nevertheless these numerical models have to be performant enough and validated with situations that if they are not realistic are representative of phenomena involved. So here we focused on the problem of the possibility of trapping the solid particles in the recirculation zones. We have reproduced in laboratory a configuration representative of sites with enough steep hills to generate recirculation zones during saltation regimes.

Measurements have been made of the dispersion of solid particles released from a rectangular area flushed at the ground of a flat plate on which evolved a turbulent boundary layer. The originality here is that it is flushed at the ground and push up the particles to continuously feed the ground at the same mean rate as the mean local erosion rate. One or more Gaussian hills were disposed transversally to the flow downstream the solid particle injection. Various Reynolds number where chosen to caracterise take-off regimes and recirculation regime behind the Gaussian hill(s). One optical system combined with CMOS camera is used successively to measure the velocity of career fluid or solid particles by PIV. Digital Image treatment is used to separate fluid seeding from solid particle images. Supplementary comparison was done to compare velocity field of the career flow for smooth and rough floor only for kinematic around the hill(s).

In this paper, in a first part we will present kinematic caracteristics of the flow whereas in a second part of this work, the data will provide some concentration profiles of solid particles. The results presented concerning the velocity and concentration field are related to streamwise vertical planes at the center of the wind tunnel at successive longitudinal positions. For velocity field we will report different regimes for smooth and rough plate. Only one regime will be presented for solid particles. We present in a first part the kinematic study and in the second part results on the concentrations of solid particles.

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1. Introduction

Understanding and predicting solid particle dispersion from ground level into the upper boundary layer strates, over desert landscapes or urban canopies continue to be a problem for prediction, for global earth nets of solid material transport or for stopping desertification progressions.

In spite of the increasing capabilities of experimental set-up and technics the problem is so complex that schematic process have still to be studied before built up complete physical process modeling for numerical predictions. Enough complete data basis is still necessary to validate the different modeling proposals. Laboratory flows, such as the one described in this paper, provide the controlled conditions needed to understand the underlying physics of the solid particle trapping processes over obstacles and to test predictive models, even though they have orders of magnitude lower gravity numbers and Reynolds numbers than for real desert atmospheric flows. The main problem is to correctly design hill shapes in order to preserves recirculation zones for take-off regimes of the present solid particles and roughness length. There are only a few techniques that have been developed to measure simultaneously particles (solid or droplets) velocity field and flow velocity field. Details of such technique for spray experiments and air/droplet mixing were developed in Boëdec and Simoëns[1] or directly for velocity measurements with submicronic solid particles by Simoëns et al.[2]. In the first one, investigated droplets were tagged with fluorescent dye and recorded simultaneously with a first CCD camera with a filter for fluorescent wavelength and by a second CCD camera for both droplets and smoke incense particles. By digital image treatment it was possible to remove droplet images from the images of the second CCD camera leaving only incense particles seeding air on the image. Velocity field of gas was obtained from these last images without taking into account for droplets images. From the first CCD camera droplet velocity was acquired. In so simultaneous droplets and gas velocity was obtained for the same locations. The same kind of digital image treatment was developed here to remove solid particle images from images where were also incense particle images. This was done with only one CMOS camera as the solid particles was 100 to 1000 time larger than incense particles, releasing thus more light intensity when present in the sheet of light necessary for PIV measurements.

In so it was possible to obtain velocity field from air in presence of solid particles behind the hill. The configuration of two dimensional Gaussian hill on the wall, perpendicular to the mean flow of an upstream turbulent boundary layer has been investigated relatively frequently in the litterature[3, 4, 5, 6, 7, 8]. In our case it is an ideal configuration for which solid particles tends to be trapped there and that could correspond to events with natural hills and not so far with static dunes. In function of the half hill width W to hill height H (giving the ratio R = W/H) and of the free-stream velocity of the flow, Ue, above the hill, first trends could be designed on the existence or not of recirculation zones responsible for trapping events. For large W/H, the recirculation zone tends to disappear removing any kind of trapping events. For large velocities the recirculation zone tends also to disappear prohibiting any kind of trapping events. Some uncertainties still exist concerning the fluctuating behavior behind the hill. Such process could considerably modify the modeling responsible for sweeping solid particles trapped behind the hill. An other parameter is clearly the roughness parameters that modify the recirculation behavior compared to the smooth cases. An other point is that with two dimensional case it is relatively easier to simulate numerically for validation of the models.

For this presentation we will only consider the Gaussian hill studies without detailing solid particle trapping problem. For roughness problem we will refer to Jimenez[9] that correctly describe the complexity of the problem that is largely enhanced as soon as we add the solid particle transport that, for any reptation, saltation or suspension regime modify the roughness wall structure permanently implying a large amount of supplementary difficulties for which numerical simulations have to account for such permanent wall or wall characteristic modifications.

Studies with three dimensional hill cases exist in the literature and we first refer to Zegadi et al. [12] for example for such case. More recent work by Ohba et al. [13] was carried out inside wind tunnel with an isolated three dimensional hill under neutral, stable and unstable conditions. Experiments results were compared with Direct Numerical Simulation for the neutral condition. Their objectives was linked with pollutant dispersion over complex terrain. For the neutral conditions they shown velocity field profiles all along a vertical plane aligned with the longitudinal axis of the wind tunnel and passing by the top of the hill. No recirculation zone was noted for the chosen regime Re =