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Wind shear stress over Gale Crater, Mars, from CFD simulations

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Abstract

Wind is one of the most important geological agents on today's Mars and is responsible, for instance, for planet-wide migration of ripples and dunes. However, the significance of local topography for regional sand-moving wind patterns is still poorly understood. Here, we investigate the average turbulent surface wind shear stress over Gale Crater, Mars, by means of Computational Fluid Dynamics (CFD). Our results reveal how topographic effects at different scales affect local wind systems, thus contributing to understand present-day Aeolian activity throughout the crater. By coupling CFD to morphodynamic simulations of the sand landscape, we develop a numerical tool for modelling dune fields in Gale crater and in other Aeolian settings affected by strong local topography on Mars.

Introduction

The quantitative understanding of the genesis and dynamics of Martian dunes — which, in the Martian Sourthern Hemisphere, occur mainly in craters — has implications to reconstruct the climatic and geologic history of Mars. However, intra-crater dune processes on Mars are substantially affected by topographic effects on local winds, which cannot be fully resolved in Mars Circulation Models [1, 2, 3, 4]. Indeed, the Mars Science Laboratory on board of Curiosity rover landed at a crater of strong local topography (Gale crater). This crater hosts various dune fields [5] surrounding a central mountain (Aeolis Mons) that rises 5.5 km high from the crater floor. Although data on wind direction and speed are available for Curiosity landing site [1, 2], further modelling is needed to elucidate regional patterns of Aeolian shear stress driving the formation of dune fields over Gale crater. Here we conduct such a modelling by means of CFD as summarized below.

Numerical experiments

We compute the average turbulent surface wind shear stress over Gale crater's digital terrain model (50 m resolution in horizontal direction) from the High Resolution Stereo Camera of Mars Express. The fluid (Martian air) is regarded as incompressible and Newtonian, and FLUENT Inc. commercial package is used to solve the Reynolds-averaged Navier-Stokes equations with the SST-k-ω turbulence model and hydrostatic pressure. For every incident wind direction considered, a logarithmic wind profile is imposed over the pre-crater surface level at the inlet, assuming a surface roughness of 7 mm and wind shear velocity values in the range from 0.2 m/s to 1.0 m/s (comparable to today's winds on Mars).

Results and discussion

Fig. 1 displays results obtained by assuming south and east winds, each with wind shear velocity 1.0 m/s or upwind shear stress 0.019 Pa (resolution of CFD simulation is 250 m). Average values of shear stress predicted for Curiosity landing area are comparable to the minimal threshold shear stress for sustained transport predicted from models (0.3 − 1.0 cPa; see Ref. [7]). Our simulations could thus help to constrain upwind values of shear stress from wind observations in the landing site. However, we also identify areas of strong backward flow and regions to the east and west of Aeolis Moons in which the shear stress is below threshold without regard of the incident wind direction. Such regions may play an important role for sand deposition. Therefore, we are downscaling the simulations to 50 m resolution in dune field areas [5] to get a better understanding of local topographic effects. Furthermore, we extended a morphodynamic dune model to include an interface to CFD programs and study the dune effect [8] on the shear stress. This effect can be resolved by adding the shear stress perturbation (obtained through an analytical model, as reviewed in Ref. [7]) to the forcing, local shear stress predicted with CFD. Our coupled simulations will be helpful, for instance, as a means for testing hypotheses on (upwind) regional flow directionality and the history of sediment transport in Gale crater, as well as in other areas where strong local topography could affect dune field processes.

Acknowledgements

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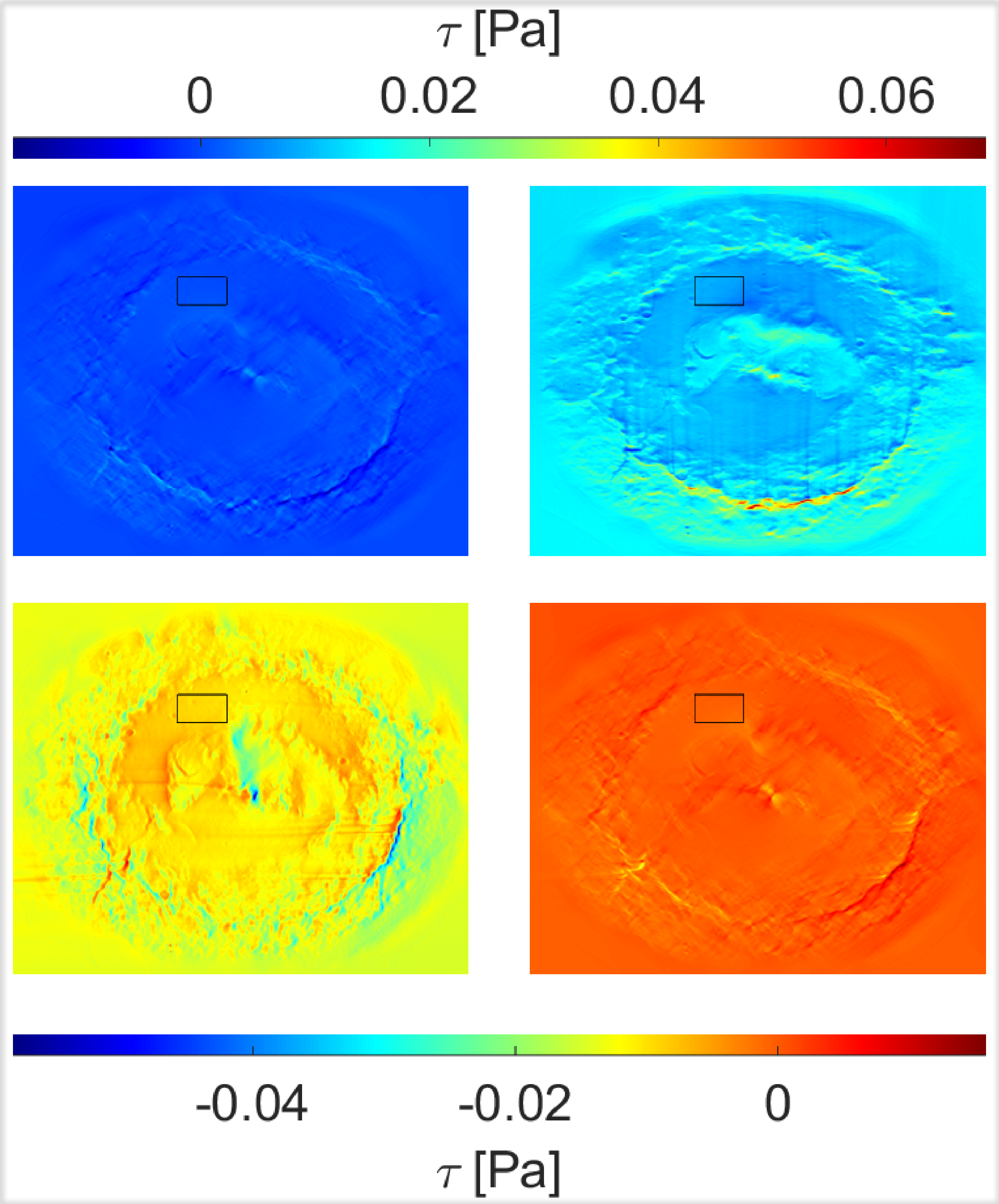

Figure 1: Shear stress (τ) over Gale crater for a south (top) and east (bottom) incident wind (shear velocity 1.0 m/s). Shown are the shear stress components in the west-east (on the left) and south-north (on the right) directions. Each subfigure has dimensions 220 x 220 km, and the rectangle indicates Curiosity's landing area.