SURFACE WIND MODELLING AT THE EXOMARS LANDING SITE, OXIA PLANUM, MARS: AEOLIAN SEDIMENT TRANSPORT POTENTIAL UNDER MULTIPLE WIND DIRECTIONS.

D.W.T Jackson[1]; M. Beyers[2], M.R. Balme[3], E.A Favaro[3], S.R. Lewis[3]. [1]School of Geography and Environmental Sciences, Ulster University, Coleraine, U.K. d.jackson@ulster.ac.uk, [2]Klimaat Consulting and Innovation Inc. Guelph, Ontario, Canada; [3]School of Physical Sciences, Open University, Walton Hall, Milton Keynes, UK

Introduction: The main objective of the ExoMars Rover mission is to examine the Martian subsurface to seek evidence of ancient life. Examining wind-driven processes operating at Oxia Planum (Fig.1), the *Rosalind Franklin* rover landing site, is an important element in helping achieve this. A 3-billion-year history of aeolian activity has played a central role in dictating patterns of erosion and deposition on Mars' surface and therefore we must better understand patterns of wind activity (past and present) to help isolate locations where signs of life could be better preserved in the lithic record.

In the absence of established *in situ* wind data in advance of landing, we rely on wind modelling to provide forcing information to better understand resulting aeolian landforms at Oxia Planum. Traditionally, large scale Global Circulation Models (GCMs) and relatively finer resolution mesoscale models, have provided only basic wind information at landing sites on Mars. Recently, very-high resolution models of surface wind flow using Computational Fluid Dynamics (CFD) have provided better insights into how surface winds are adjusted to local morphology and terrain on Mars [1,2].

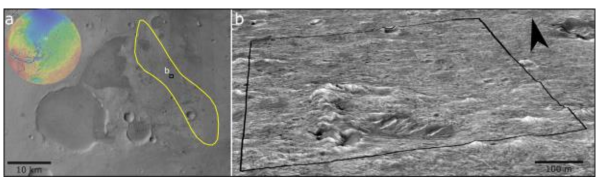

Figure 1. (a) Global and regional context of the Oxia Planum landing site. The 1-sigma landing ellipse envelope is outlined in yellow, and encompasses (b), the site chosen for Large Eddy Simulations. There is a 3x vertical stretch applied to the DTM in (b).

This study investigates local-scale turbulent airflow at a site in the 1-sigma landing ellipse by using CFD Large Eddy Simulation (LES) techniques. The CFD modelling uses small-scale topography, to resolve turbulent eddies and vortices that are missed by global or mesoscale and steady state CFD models. Using representative output from larger scale atmospheric models as input characteristics for the LES, we examined the microscale dynamics of wind flow and its corresponding variability in time and space of surface shear stress and potential sediment flux at the surface close to the proposed landing location of ExoMars rover.

Methods:

Large-scale, background winds were derived from GCM experiments run with a typical horizontal resolution of 225 km and with 35 or 70 vertical levels extending from the surface to about 100 km altitude, with the lowest ~4 m above the ground. Wind data was interpolated to the ExoMars site. For the present day simulations, winds were taken from Mars Year 33, a year with no strong global dust event, from the OpenMARS database that is formed by assimilation of recent spacecraft thermal and opacity observations into the GCM [3]. For past climate runs, the same GCM was integrated at differing values of planetary obliquity from 5–45 degrees (but with all other orbital parameters unchanged) for 20 Mars years each, with wind data extracted from the last year only.

Large Eddy Simulations

For the LES, the open-source CFD software OpenFOAM® was ran with inflow turbulence boundary conditions generated by means of a random flow turbulence generation method that approximates a three-dimensional inflow velocity profile, turbulence spectra and spatial coherence based on specification of assigned atmospheric boundary layer input. The inflow turbulence characteristics are generated offline, creating a time series of 3D velocities at the inflow plane using the mean flow direction and wind speed profile output from the GCM models. The methodology as coded and applied here for the inflow turbulence generation, is similar to Melaku et al. [4], Veers [5], among others.

For the current simulations, the GCM outputs were filtered to isolate mean wind speeds and directions representing the 95% percentile wind speeds for different GCM model scenarios. From this filtered GCM set it was evident that the stronger winds approach the site from the NNW, SSE, SW and W. These wind directions were subsequently chosen for the LES and their mean wind profile characteristics used as input for the inflow turbulence generation.

The LES computational domain covers a region of 700m x 700m (horizontal) and 350m (vertical) with the bottom boundary conforming to the HiRISE DEM terrain surface resolution with higher vertical resolution of the mesh near the terrain surface. The computational domain is centred within the ExoMars landing ellipsis.

Initially a set of LES runs were performed for a similar computational domain but with flat terrain to assess whether the LES with inflow turbulence generation reproduces and maintains the assigned inflow turbulence spectra, velocity profile and terrain surface shear stress within the flow domain. Subsequent sets of simulations were performed for the Oxia Planum landing site for *four* different wind directions. Simulation output consisted of terrain surface shear stress and potential sediment flux maps as well as time series and statistical data for points locations within the flow domain to examine the influence of turbulent fluctuations on near surface air flow and surface shear stress. Surface shear stress maps and corresponding aeolian transport predictions were recast into a geo-referenced format for Geographic Information Systems (GIS) analysis, overlay and comparison with remote sensing observations.

Results

The LES and inflow turbulence generation method were capable of recovering the expected mean flow surface shear stress and velocity and turbulence profiles throughout the flow domain. It also resolved the assigned inflow turbulence energy spectra towards the domain centre (Figure 2) with limited inflow turbulence decay.

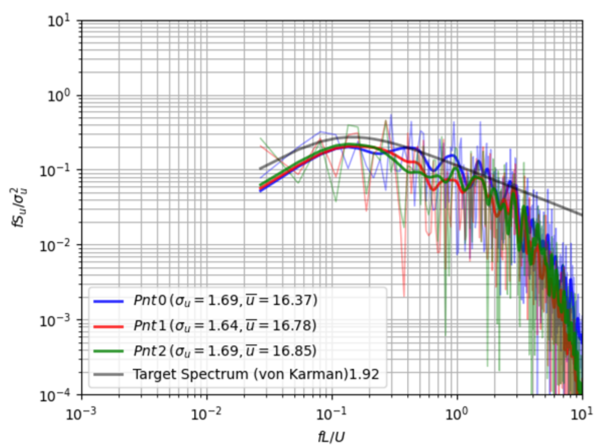

Figure 2: Simulated horizontal velocity spectra (normalised) for three interior domain data probes 40m above the terrain surface compared to the assigned theoretical inflow spectra.

Simulated mean surface shear stress maps (Fig. 3) highlight regions of high wind shear (near fluid thresholds for initiation of saltation) at terrain ridges and crests. Lower shear stresses (below fluid threshold) are predicted leeward of ridges, in crater valleys and in open relatively flat terrain areas. The LES also resolved turbulence fluctuations of the wall shear stresses indicating peak shear stresses that approach or exceed fluid thresholds often, even in areas where the mean wall shear stresses were well below the fluid threshold for saltation. These results and implications in understanding the landing site terrain and its aeolian sediment transport potential will be discussed in detail.

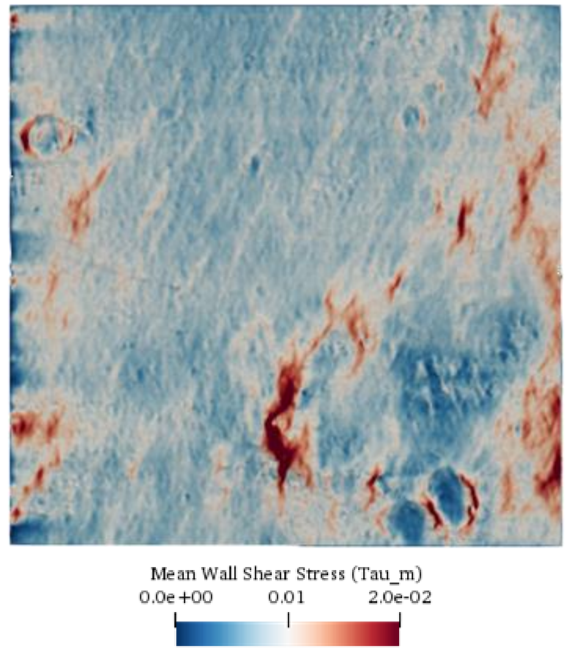

Figure 3: Mean wall shear stress (Pa) for a simulated North-northwest wind. Wind flow is from left to right. Red contours indicate fluid threshold surface shear stress ~0.02Pa based on an assumed fluid threshold shear velocity of 1m/s, and Mars air density of 0.02kg m^{-3}.

Acknowledgements: This is a contribution to UK Space Agency Grants ST/T001801/1, ST/T002913/1 and NERC Grant NE/F019483/1.

References:

[1] Cornwall, C., Jackson, D.W.T., Bourke, M.C., Beyers, M. and Cooper, J.A.G. (2018) Geophys. Res. Lett., 45, (18), 9498-9507.

[2] Jackson, D.W.T., Bourke, M.C. and Smyth, T.A.G. (2015) Nature Comms., 6:8796.

[3] Holmes, J.A., Lewis, S.R. and Patel, M.R., (2020) Plan. Space Sci. 188, 104962.

[4] Melaku, A.F., Bitsuamlak, G.T. (2021) *J. Wind Eng. Indust. Aerodynamics* , 212, 104580.

[5] Veers, P.S., (1984), Sandia Report, SAND83-1909, *Sandia National Laboratories.*