Data-driven identification of drag-relevant roughness scales

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Surface roughness in flow-related applications typically has an irregular multi-scale nature posing challenges to development of predictive tools for roughness-induced skin friction. To address this issue, it is essential to understand the detailed influence of roughness topography on skin-friction drag and to identify roughness scales contributing to it. We have developed a data-driven model trained by a wide variety of roughness samples that predicts the equivalent sand grain size k_s of an arbitrary roughness based on the probability density function (PDF) and power spectrum (PS) of its topography. The training samples are selected based on an 'active learning' strategy and a testing data set comprising 45 artificial and realistic surfaces is used to establish an average error of less than 10%. Each training or testing data point is the result of a direct numerical simulation. Subsequently, the model is used to further analyse the physics of roughness-induced drag augmentation, and particularly, to identify roughness scales contributing more to drag. To this end, the model predictions are interpreted utilizing the layer-wise relevance propagation technique (LRP). LRP enables assessing contributions of different input features to the predicted value. Hence, the contribution scores of the PS input are analyzed to identify the range of roughness wavelengths that dominate the drag. A high-pass filter is then applied to exclude the less contributing scales (here those with negative LRP). A representative case is displayed in Fig. 1 showing the original and filtered roughness samples (a), the pre-multiplied PS colored by contribution scores of different wavelenghts and the position of the filter (b), and a comparison of the mean velocity profiles of flow in a periodic channel over filtered and unfiltered samples (c). Results clearly show that excluding the scales with less contribution, based on LRP analysis, does not meaningfully affect the shift in logarithmic region of the profile. Therefore, the positive contribution scores can be associated with the drag production, while the negative contribution scores mainly manifest themselves as surface undulation without significant influence on the drag.

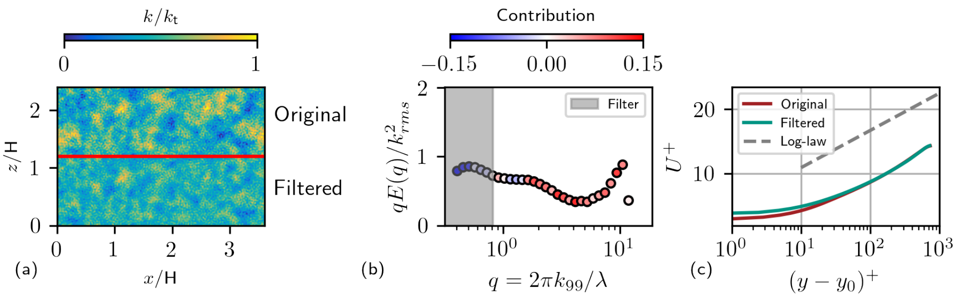

Figure 1: Roughness height maps, power spectrum and mean velocity profiles.

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