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Multifractal subgrid-scale modeling within a variational multiscale method for large-eddy simulation of passive-scalar mixing in turbulent flow at low and high Schmidt numbers

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Multifractal subgrid-scale modeling embedded into a variational multiscale method is proposed for large-eddy simulation of passive-scalar mixing in turbulent incompressible flow. In this subgrid-scale modeling approach, subgrid-scale velocity and scalar field are directly approximated by a multifractal reconstruction process replicating the actual physics of turbulent flows. Problems from low to high Schmidt numbers (i.e., Sc $\approx$ 1 to Sc $\gg$ 1) are considered in this work. Starting from preceding work, in this study, multifractal subgrid-scale modeling is further detailed by refining the approximation process within the scalar field. Thereby, appropriate multifractal subgrid-scale modeling for passive-scalar mixing is derived in comprehensive form for the entire range of Schmidt numbers. The near-wall behavior of the multifractal subgrid-scale modeling approach is investigated for wall-bounded turbulent flows with passive-scalar mixing. The method is validated for passive-scalar mixing in turbulent channel flow for a broad range of Schmidt numbers in between 1 and 1000. Excellent performance is stated for all Schmidt numbers, in particular when comparing the results obtained with the proposed method to results provided by other methods widely used in the literature. An analysis of the subgrid-scale scalar-variance transfer highlights the influence of the multifractal subgrid-scale modeling within the variational multiscale method. The near-wall behavior of the proposed method is investigated via the transfer coefficient, for which results consistent with the theoretical correlation are obtained. © *2014 AIP Publishing LLC*. [http://dx.doi.org/10.1063/1.4874984]

I. INTRODUCTION

Turbulent mixing of passive-scalar fields is important for a wide range of environmental and engineering applications, such as ocean chemistry and electrochemical processes; see, e.g., Scalo *et al.*[1] and Bauer *et al.*[2] These examples already indicate that turbulent mixing constitutes a complex process, which is also reflected in Large-Eddy Simulations (LESs) of the respective situations. LES aims at resolving the larger flow structures, while modeling the influence of the smaller flow structures on the larger ones. There has been extensive research in the field of LES in the past decades; see, e.g., the reviews by Rogallo and Moin[3] in the 1980s, by Piomelli[4] in the 1990s as well as by Sagaut[5] in the 2000s. Passive-scalar mixing brings in additional challenges due to the substantially different length scales that may occur in both fields depending on the Schmidt number.

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