CIFellows 2020-2021

Computing Innovation Fellows

Surface wind stress model for turbulent flows above ocean surface waves

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Introduction

- *About* ***two-thirds*** *of the surface of the Earth is covered by the* ***ocean****.*
- *The air-sea exchanges of mass, momentum, and energy over such a huge area play an integral role in determining the* ***sea state****,* ***weather patterns****, and* ***climate*** *and thus significantly impact many aspects of human life.*
- *Although we know that surface waves are critically important, we do not yet fully understand the fundamental physics of ocean waves.*
- *The current parameterizations of air-sea fluxes are limited, and that prevents us from, for example, making* ***accurate predictions*** *of* ***extreme wind events*** *such as tropical storms and hurricanes.*
- *The objective of this study is to develop an accurate wall-layer model for use in large-eddy simulations (LESs) that capture the salient features of air-sea fluxes.*

Large-eddy simulation of wind field

$\tilde{u} = u - u'$

$$\frac{\partial \tilde{u}_i}{\partial x_i} = 0$$

$\tau_{ij} = \widetilde{u_i u_j} - \tilde{u}_i \tilde{u}_j$

$$\frac{\partial \tilde{u}_i}{\partial t} + \tilde{u}_j \left(\frac{\partial \tilde{u}_i}{\partial x_j} - \frac{\partial \tilde{u}_j}{\partial x_i} \right) = -\frac{1}{\rho}\frac{\partial \tilde{p}}{\partial x_i} - \frac{\partial \tau_{ij}}{\partial x_j} + \frac{1}{\rho}\delta_{i1}\Pi + F_i$$

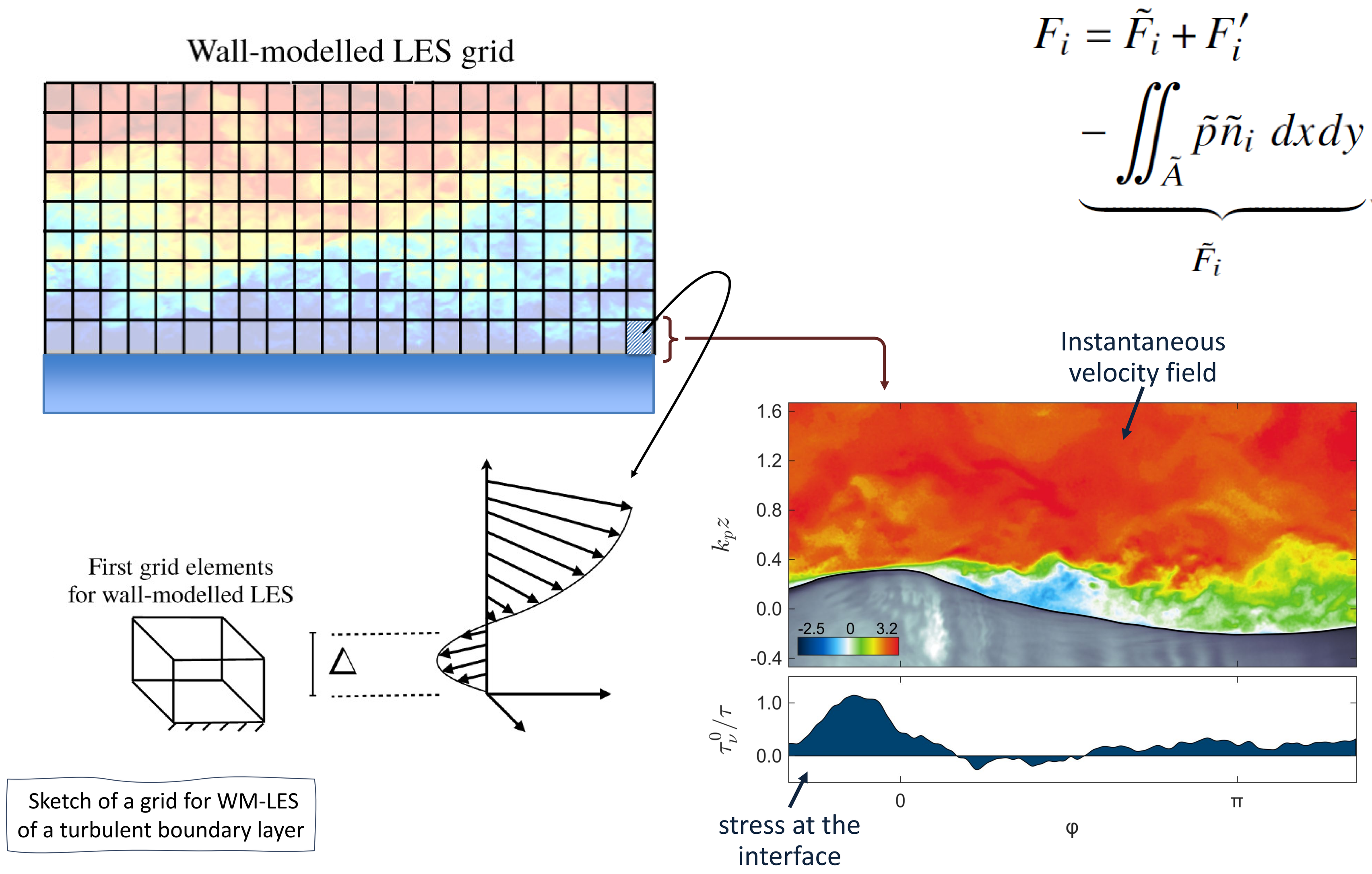
Here, $\tilde{u}$ is the filtered (or resolved) velocity, u' is the residual (sub-grid scale) component, τ_{ij} is the SGS stress tensor, F_i is a body force, and Π is the streamwise pressure gradient driving the flow:

$$\frac{1}{\rho}\Pi = -\frac{u_*^2}{L_z}$$

friction velocity (u_*)

height of the computational domain (L_z)

Wall-layer model for sea surface stress



$$F_i = \tilde{F}_i + F_i' \\ -\underbrace{\iint_{\tilde{A}} \tilde{p}\tilde{n}_i \, dxdy}_{\tilde{F}_i} - \underbrace{\iint_{A'} p' n_i' \, dxdy}_{F_i'}$$

$$\tilde{F}_i = -\rho \iint_A C_D \tilde{u}_i R\left(\tilde{u}_{r,j}\frac{\partial \eta}{\partial x_j}\right) \mathrm{d}x\mathrm{d}y$$

$$C_D \approx \left(\kappa \ln^{-1}\frac{\delta_z}{\alpha_w \sigma_\eta^\Delta}\right)^2$$

$$F_i' = -\rho \iint_A \left[\frac{\kappa}{\log(\delta_z/\alpha_w \sigma_\eta^\Delta)}\right]^2 \|\tilde{\boldsymbol{u}}_r\| \tilde{u}_{r,i} \, \mathrm{d}x\mathrm{d}y$$

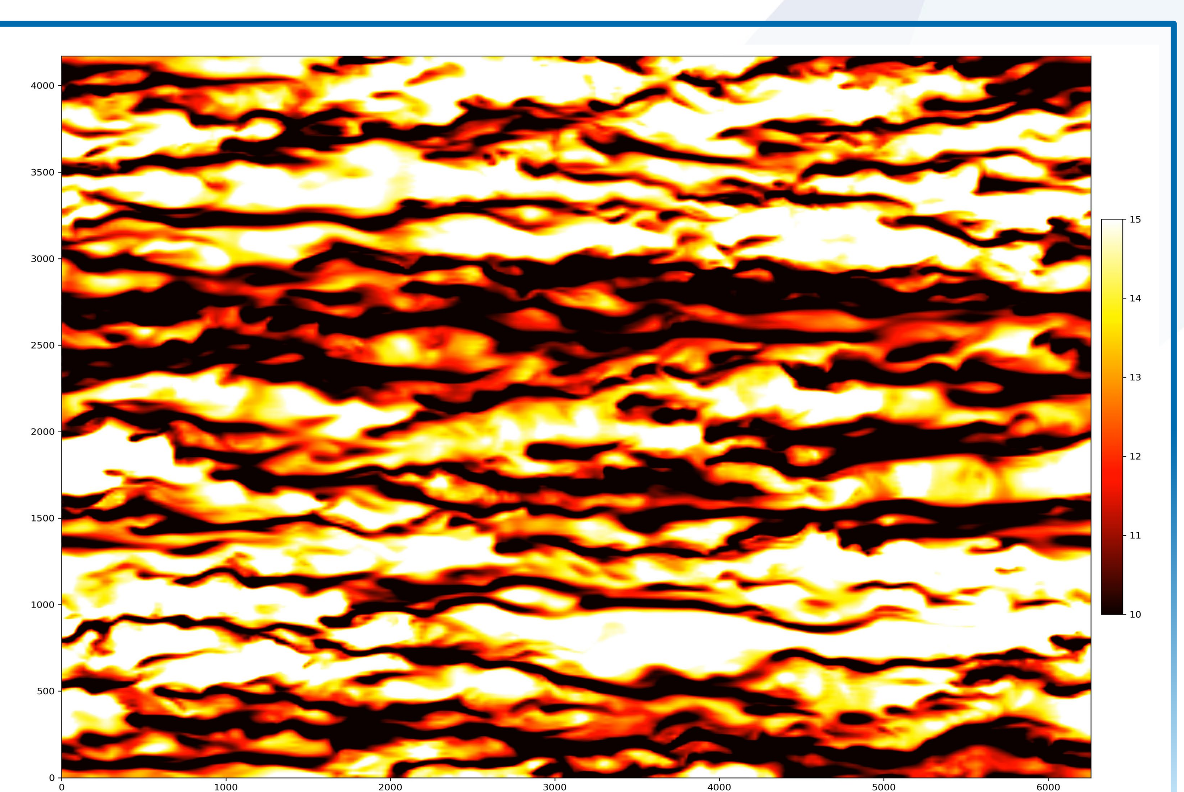
$$F_i = \tilde{F}_i + F_i' = -\rho \iint_A \left(\kappa \ln^{-1}\frac{\delta_z}{\alpha_w \sigma_\eta^\Delta}\right)^2 \tilde{u}_i R\left(\tilde{u}_{r,j}\frac{\partial \eta}{\partial x_j}\right) \mathrm{d}x\mathrm{d}y \\ -\rho \iint_A \left[\frac{\kappa U_r(x,y,\delta_z)}{\log(\delta_z/\alpha_w \sigma_\eta^\Delta)}\right]^2 \frac{\tilde{u}_{r,i}(x,y,\delta_z)}{U_r(x,y,\delta_z)} \mathrm{d}x\mathrm{d}y$$

Scale invariant constraint

The scale invariant constraint requires the total ***drag force*** *to be* ***independent of the*** **resolution**. Thus, we dynamically obtain the drag by filtering F_i equation at two different filter scales: one is the LES filter scale of Δ and the other is a test-filter scale of $a\Delta$, where $a > 1$.

$$F_i = \tilde{F}_i + F_i' = \tilde{\tilde{F}}_i + \tilde{F}_i'$$

filtering at scale Δ — *filtering at scale* 2Δ



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* This is the current state of our work, with the underlying theory finalized. Additional processing and analysis of the **results are ongoing**.