Numerical simulation and analysis of transient Ekman boundary layers using a stochastic turbulence model

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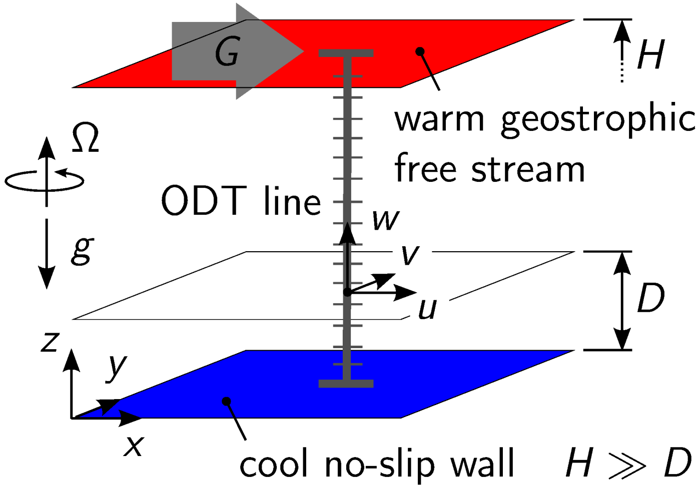
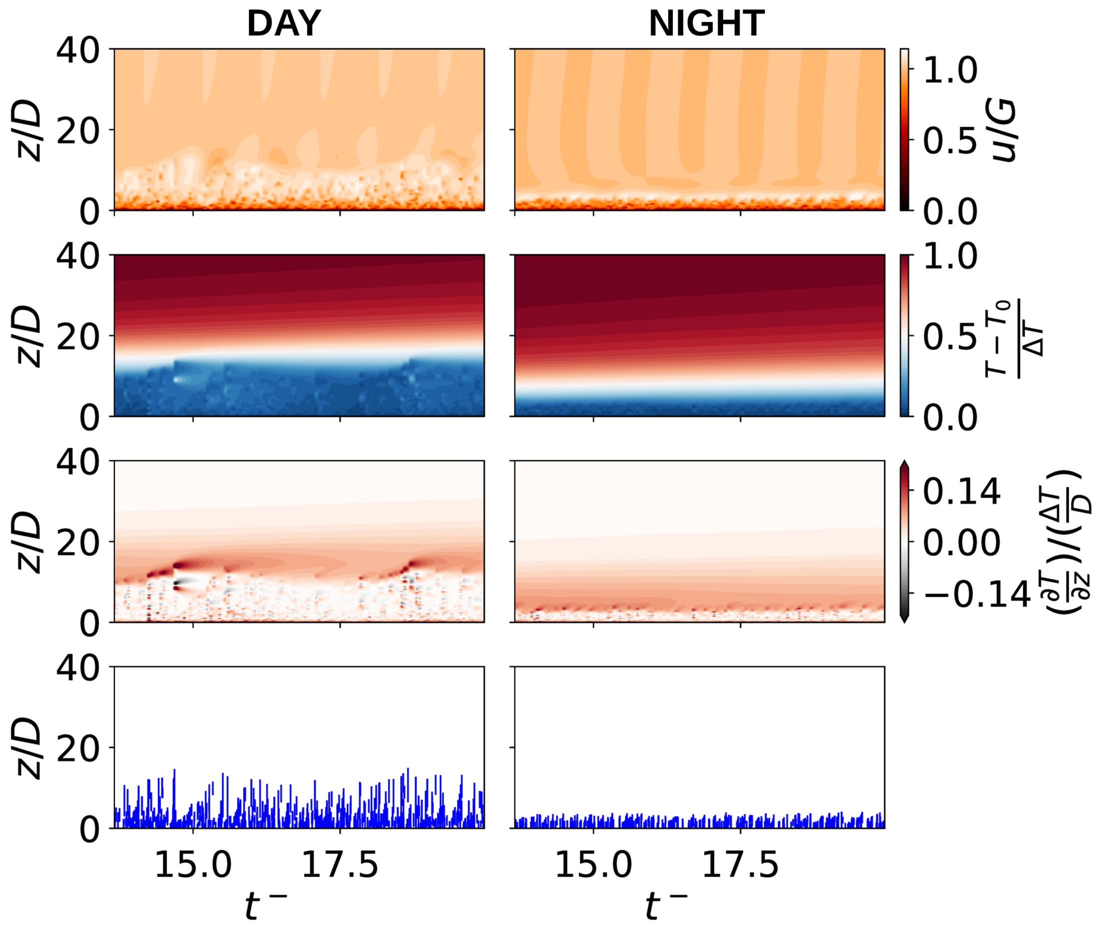
ODT application to atmospheric boundary layers





$$Re = \frac{G\,D}{\nu} \qquad Pr = \frac{\nu}{\kappa} \simeq 1$$

$$D = \sqrt{\frac{\nu}{\Omega}} \qquad Fr = \frac{G^2}{g\,D\,\beta\,(T_{\mathrm{bulk}} - T_{\mathrm{wall}})}$$

M.K. & H.S. (2022) *Adv. Sci. Res.* **19**:117–136

Langevin-like stochastic conservation equations

$$\underbrace{\frac{\partial T}{\partial t}}_{\text{rate}} + \underbrace{\mathcal{E}_T(u,v,w,T)}_{\text{time sequence of eddies}} = \underbrace{\kappa\frac{\partial^2 T}{\partial z^2}}_{\text{diffusion}} + \underbrace{s_T}_{\text{sources}} \qquad \underbrace{\rho = \rho_0\left[1 - \beta\,(T - T_0)\right]}_{\text{Boussinesq approx.}}$$

$$\underbrace{\frac{\partial u_i}{\partial t}}_{\text{rate}} + \underbrace{\mathcal{E}_i(u,v,w,T)}_{\text{time sequence of eddies}} = \underbrace{\nu\frac{\partial^2 u_i}{\partial z^2}}_{\text{diffusion}} + \underbrace{s_i}_{\text{sources}} - \underbrace{2\Omega\,\epsilon_{i3k}\,(u_k - G\,\delta_{1k})}_{\text{nongeostrophic Coriolis forces}}$$

$$(u_i) = (u,v,w)^{\mathsf{T}} \quad i,k \in \{1,2,3\}$$

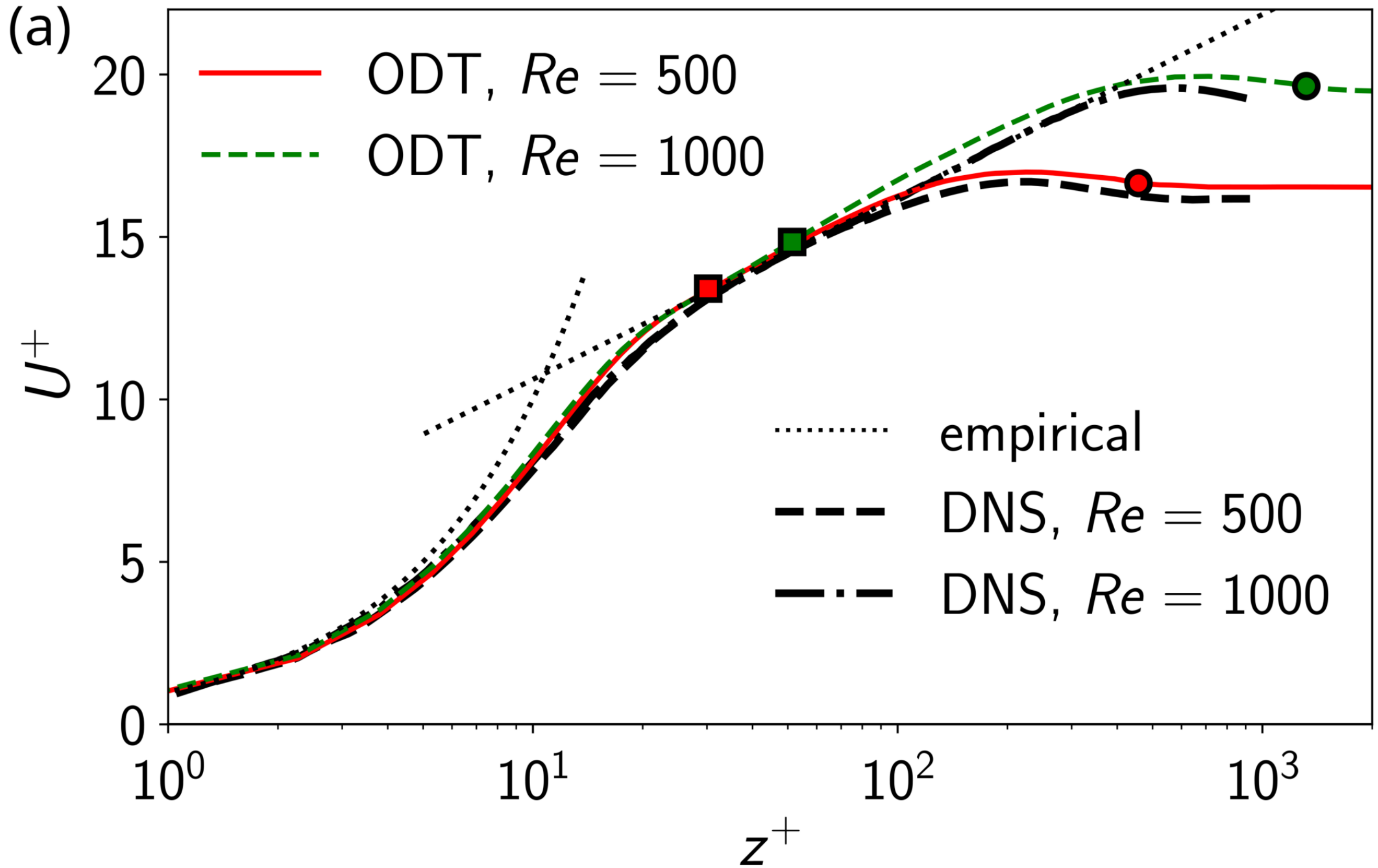
Flow profile modification due to a turbulent eddy

$$\mathcal{E}_T: \quad T(z) \to \underbrace{T\big(f(z)\big)}_{\text{turb. advection}}$$

$$\mathcal{E}_i: \quad u_i(z) \to \underbrace{u_i\big(f(z)\big)}_{\text{turb. advection}} + \underbrace{c_i(u,v,w,\rho)\,K(z)}_{u\text{–}v\text{–}w\text{–buoyancy couplings}}$$

Extension of Kerstein & Wunsch (2006) *Boundary-Layer Meteorol.* **118**:325–356

Boundary layer structure



$$U^+ = \frac{U}{u_\star}$$

$$z^+ = \frac{z u_\star}{\nu}$$

$$u_\star = \sqrt{\nu \left. \frac{\mathrm{d}\sqrt{U^2 + V^2}}{\mathrm{d}z} \right|_{z=0}}$$

ODT: M.K. & H.S. (2022) *Adv. Sci. Res.* **19**:117–136
DNS: Ansorge & Mellado (2014) *Boundary-Layer Meteorol.* **153**:89–116

Summary

- **One-dimensional turbulence (ODT)** is a physics-based reduced-order *flow model* that aims to resolve *all* relevant scales in a reduced dimensional setting.
- ODT *models* **turbulence phenomenology** obeying physical **conservation principles**.
- ODT has **regime-independent modeling capabilities** *bridging the gap* between idealized cases and applications.
- ODT provides **detailed fluctuation statistics** across atmospheric boundary layers, *replacing* wall-function parameterizations.