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A dynamic extension of the pragmatic blending scheme for scale-dependent sub-grid mixing

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One approach to the boundary-layer grey zone is to blend a mesoscale and a Smagorinsky LES formulation. We extend this idea to use a scale-dependent dynamic Smagorinsky scheme. It improves the simulation of the transition from the shallow morning to the deep afternoon boundary layer by better controlling the spin-up of explicit turbulence.

Approaching the grey zone

- Simulations of the evolving convective boundary layer are run with (dynamic) Smagorinsky in the Met Office LEM for Wangara day 33.
- Reference LES at Δx=25m well matched at Δx=50m.
- Smagorinsky has excessive diffusion and a delayed onset of resolved turbulence leading to errors in the mean temperature profile beyond Δx~100m.
- By varying C_S the dynamic model reproduces mean fields and basic statistics of the filtered LES fields until Δx~400m. It then suffers from insufficient mixing in the shallow BL.

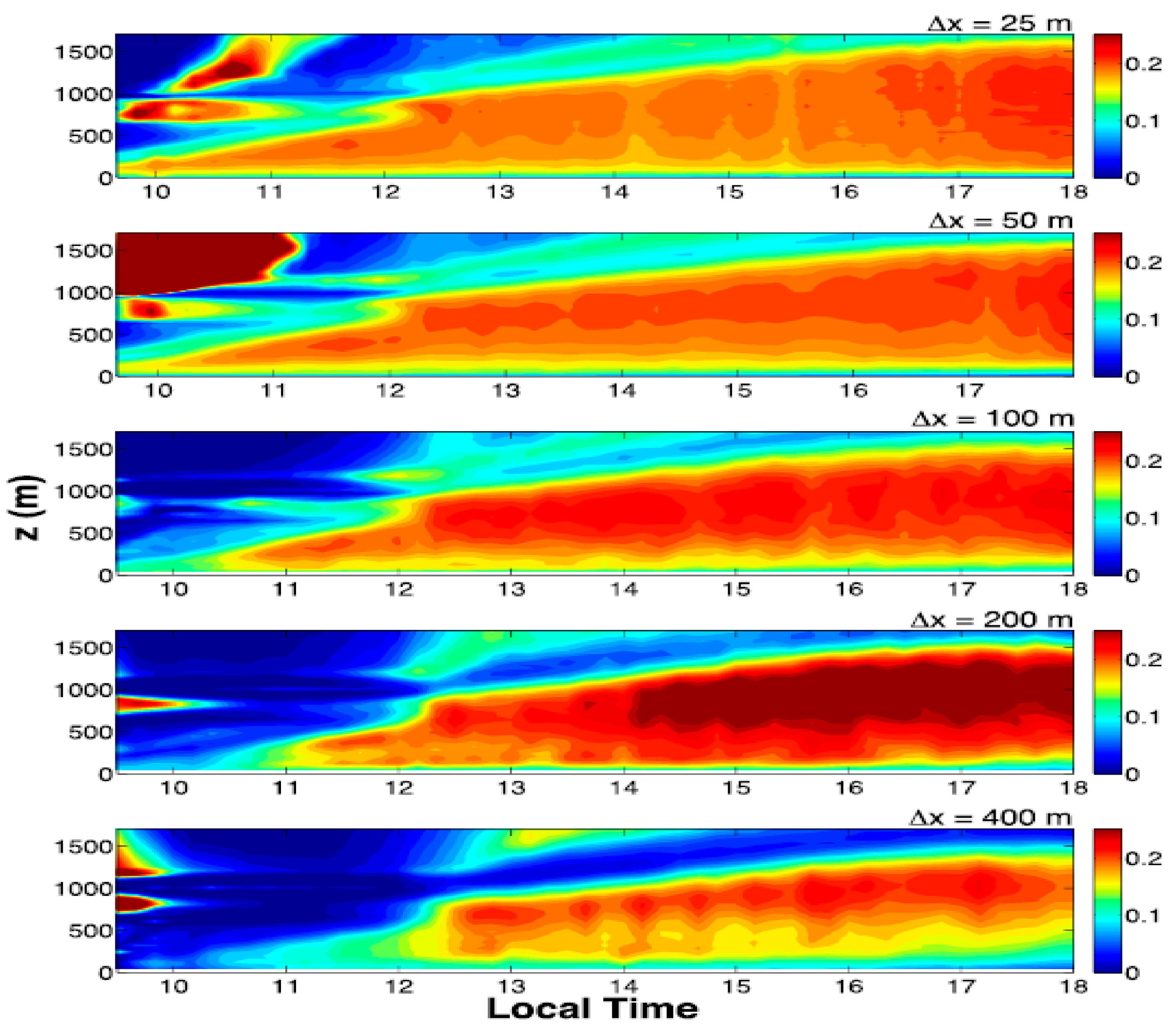

FIG. 10. Time–height sections of the horizontally averaged Smagorinsky coefficient C_S from the LASD simulations with Δx ranging from (top) 25 to (bottom) 400 m.

Figure 1.Variation of Cs in simulations with the dynamic Smagorinsky scheme, ranging from LES (top) through the near-grey zone (centre) and into the grey zone proper (bottom).

Blending Scheme

The UK Met Office operationally blends between its NWP scheme and Smagorinsky (Boutle et al., 2014). We implement here a simple NWP scheme blended in the same way but with a Lagrangian-averaged scale-dependent dynamic Smagorinsky scheme (Bou Zeid et al 2005).

$$\overline{u_j'\theta'} = -K_H \frac{\partial \bar{\theta}}{\partial x_j} + \delta_{3j} W \left(K_H \gamma + \overline{w'\theta'}|_{z_h} \left(\frac{z}{z_h} \right)^3 \right)$$

$$\overline{u_i' u_j'} = -K_M \left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_I} \right)$$

The blending function is:

$$W = 1 - \tanh\left(b \frac{z_h}{\Delta x}\right) \max\left(0, 1 - \frac{\Delta x}{4 z_h}\right) \text{ with } b = 0.15$$

K_H and K_M compare a weighted NWP profile from Lock (2000) and a Smagorinksy formulation with a blended mixing length:

$$K_{M,H} = \max\left(W K_{M,H(NWP)}, l_{BLEND}^2 S f_{M,H}(Ri)\right)$$

$$l_{BLEND} = W l_{NWP} + (1 - W) l_{SMAG}$$

where l_{NWP} is from Lock (2000) and $l_{SMAG} = C_S \Delta x$ away from the surface. There is no wall damping with the dynamic model.

Simulations in the grey zone

- Grey-zone simulations with $\Delta x = 400$ and 800m, using blending with either standard (PGB) or dynamic (DNB) Smagorinsky.

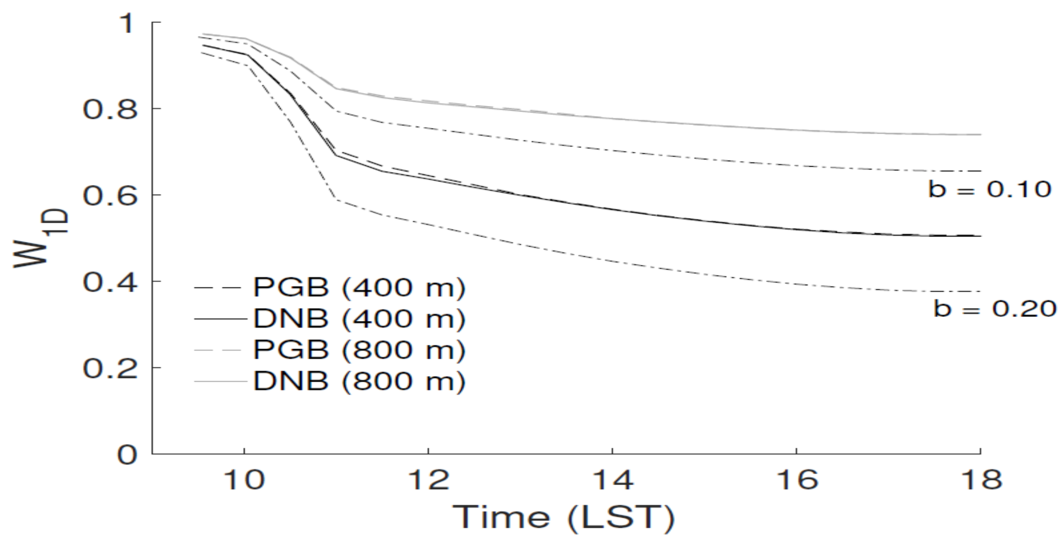

Figure 3.Time evolution of the weighting function W.

- At early times, $W \approx 1$. NWP scheme captures mean profile with no resolved motion.
- By 1140 both parts become important. Standard Smagorinsky gives a delayed onset of resolved turbulence, despite the reduction in the NWP part, and leads to a profile that is slightly superadiabatic throughout the BL. With the dynamic model, BL is well mixed with an appropriate level of resolved turbulence. It has significantly less mixing in the lower BL.
- By 1240, explicit turbulence has now developed in PGB producing a non-local heat flux that does produce a well-mixed BL with appropriate turbulent statistics.
- Qualitatively similar at $\Delta x = 800$m, but with turbulence initiated around 1 hr later.

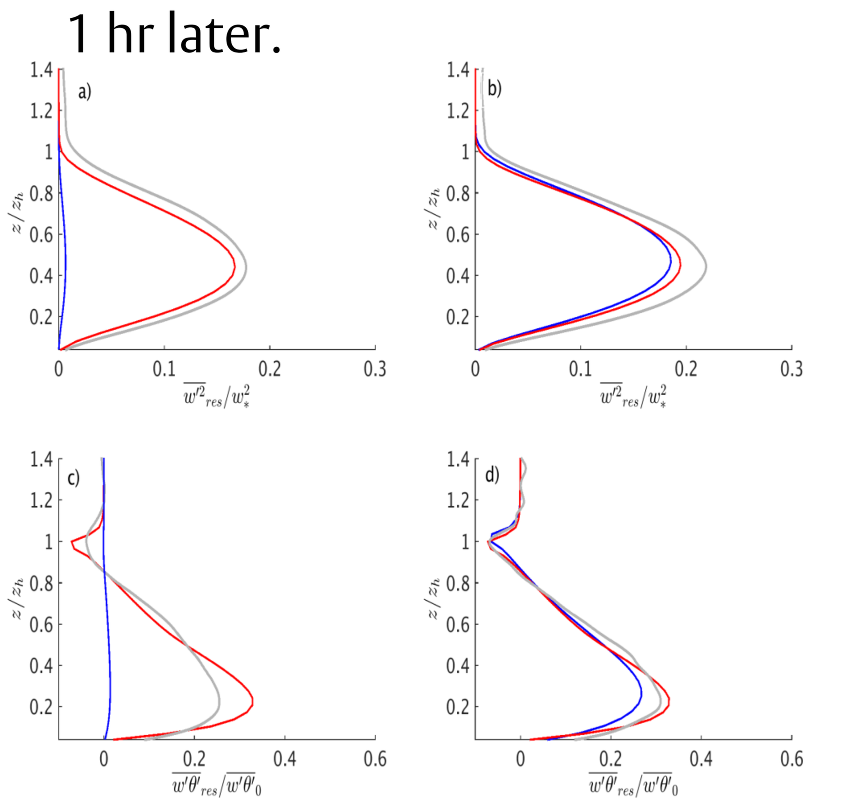

Figure 3. Normalized profiles of the resolved (a,b) w variance and (c,d) turbulent heat flux in the 400m simulation with PGB (blue) and DNB (red). (a,c) at 1140 and (b,d) at 1240. The coarse-grained LES profiles are in grey.

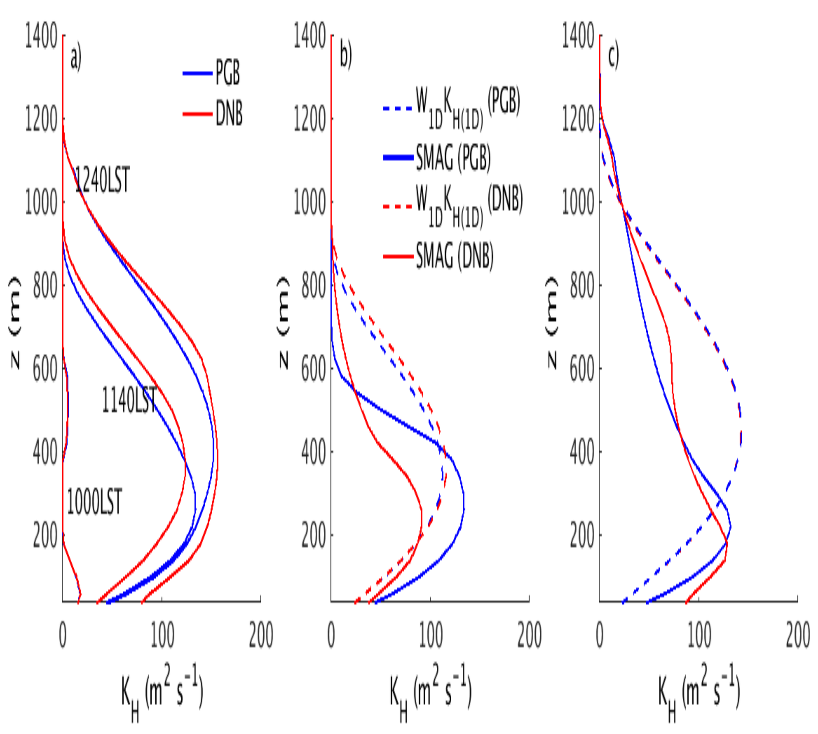

Figure 4. Profiles of eddy diffusion K_H using PGB (blue) or DNB (red) for (a) three different times and (b,c) decomposed into NWP (dashed) and Smagorinksy (solid) contributions at (b) 1140 and (c) 1240.

Conclusions

- A new blending approach has been demonstrated for the turbulent grey zone, using a scale-dependent dynamic Smagorinsky model.
- The dynamic aspect improves mean profiles and turbulence statistics during handover from an NWP to a LES treatment.
- The main advantage is an earlier onset of resolved turbulence.
- The dynamic approach also alleviates the need for a specified functional form of the Smagorinsky mixing length or for well-chosen C_S.

References

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