A dynamic extension of the pragmatic blending scheme for scale-dependent sub-grid turbulent mixing in the boundary layer grey zone

Robert S. Plant | George A. Efstathiou

Overview

One approach to parameterized turbulent mixing in the boundary-layer grey zone is to blend between schemes for a mesoscale model and a Smagorinsky LES formulation. We extend the approach to use a scale-dependent dynamic Smagorinsky scheme. This improves the simulation of the transition from the shallow morning to the deep afternoon boundary layer by better controlling the spin up of resolved turbulence.

Boundary-layer grey zone

Numerical weather prediction is moving towards the boundary-layer grey zone where turbulence is neither fully parameterized or fully resolved (Fig. 1).

Blending scheme

The sub-grid sensible heat flux has local and weighted non-local contributions (based on Hong et al. 2006)

\[
\begin{align*}
\overline{w'\theta'} &= -K_T \frac{\partial \theta}{\partial \zeta} + \delta_w W' K_{TY} + w' \theta' I_{KL} \left( \frac{z}{z_R} \right)
\end{align*}
\]

while momentum fluxes are treated locally:

\[
\begin{align*}
\overline{u'v'} &= -K_M \frac{\partial \theta}{\partial \zeta} + \delta_{u,v} \frac{\partial \theta}{\partial \zeta} 
\end{align*}
\]

The blending function is:

\[
W = 1 - \tanh \left( \frac{b \zeta}{\delta} \right) \max \left( 0, 1 - \frac{\zeta}{\delta} \right) \text{ with } b = 0.15
\]

Simulations in the grey zone

We focus on grey-zone simulations with \( \Delta = 400 \text{m} \), using blending with either standard (PGB) or dynamic (DNB) Smagorinsky. At early times, \( W = 1 \) and the NWP scheme captures the temperature profile well with little resolved motion. By 1140 both of the blended parts of the scheme become important. Using standard Smagorinsky, there is a delayed onset of resolved turbulence (Fig 4), despite the reduction in the NWP part of the eddy diffusion (Figs. 3, 5) leading to a temperature profile that is slightly superadiabatic throughout the BL. There is insufficient non-local mixing at this time.

Blending with Smagorinsky contribution (Fig 5b). By 1240, explicit turbulence has developed in PGB producing a non-local heat flux that does produce a well-mixed BL with appropriate turbulent statistics.

For simulations with \( \Delta = 800 \text{m} \), similar results occur but with turbulence initiated around 1 hr later.

Conclusions

- A new blending approach has been demonstrated for the turbulent grey zone, using a scale-dependent dynamic Smagorinsky model.
- There is little difference when the blending function is strongly weighted to the NWP scheme.
- The dynamic approach 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 \( C_z \).

References


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Contact information

- Department of Meteorology, University of Reading, RG6 6BB
- Email: r.s.plant@reading.ac.uk
- www.met.reading.ac.uk/weather/