DYNAMIC SUB-GRID MODELLING OF AN EVOLVING CBL AT GREY-ZONE RESOLUTIONS

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Modelling **GREY** zone **B**oundary **L**ayer**S**

(GREYBLS)

Motivation

- Numerical Weather Prediction at O(100m) is now possible
- Dominant turbulence length scales ~ z_i (100 m – 3 km)
- Boundary Layer (BL) turbulence becomes partially resolved

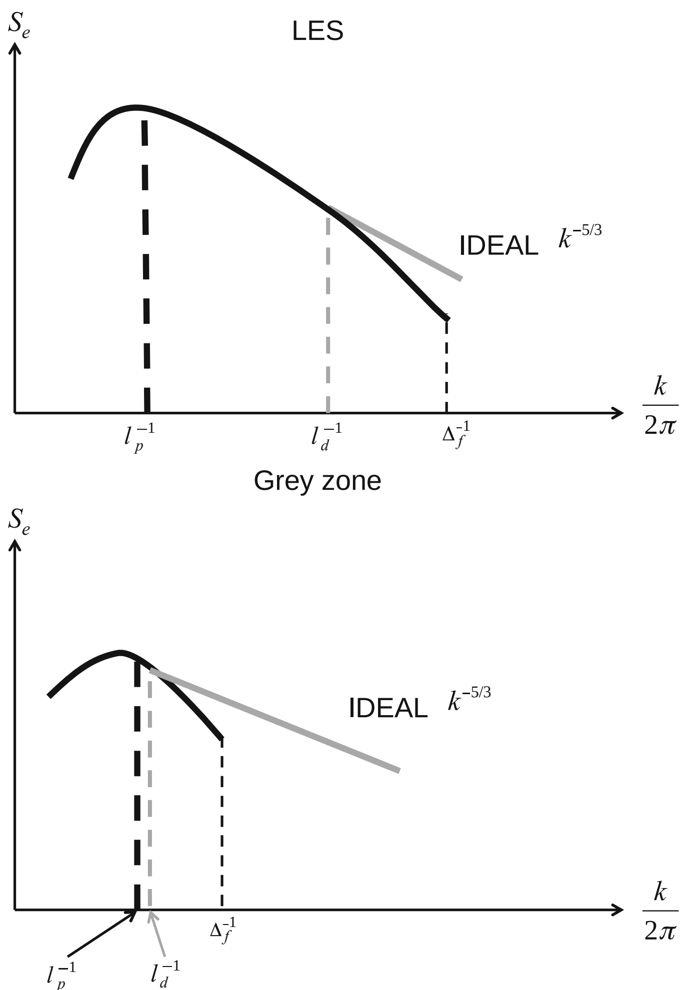
How do we parametrize sub-grid processes in the BL grey-zone?

Spectral view of the grey-zone (Beare, 2014)

- **LES** : Resolved field - scales for production (l_p) and dissipation (l_d) of TKE are well separated
- **Grey zone** : Dissipation has an impact on TKE production – Partially resolved field

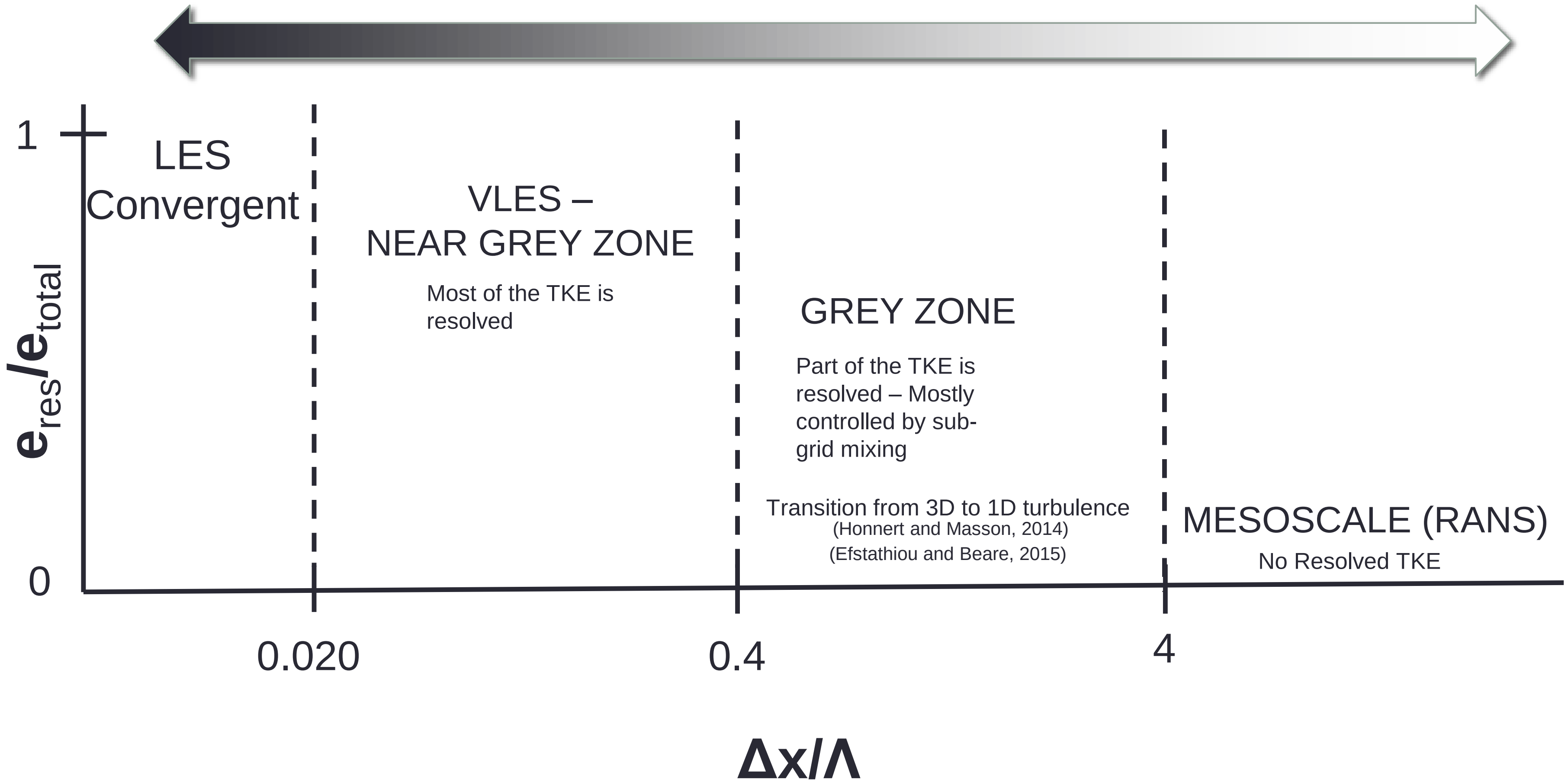
A working definition for the grey-zone

$$\frac{z_i}{l_d} < 0.7$$



(Beare, 2014)

Scales



(Sullivan and Patton, 2011) (Beare, 2014)

Research Tools

- Numerical simulations with the LEM (Large-Eddy Met Office Model)
  - Quasi-steady state CBL (z_i=1000 m)
  - Evolving CBL (Wangara case study)
  - A range of horizontal resolutions (LES-Greyzone-Mesoscale)
- Compare with filtered LES
- Smagorinsky type eddy-viscocity model

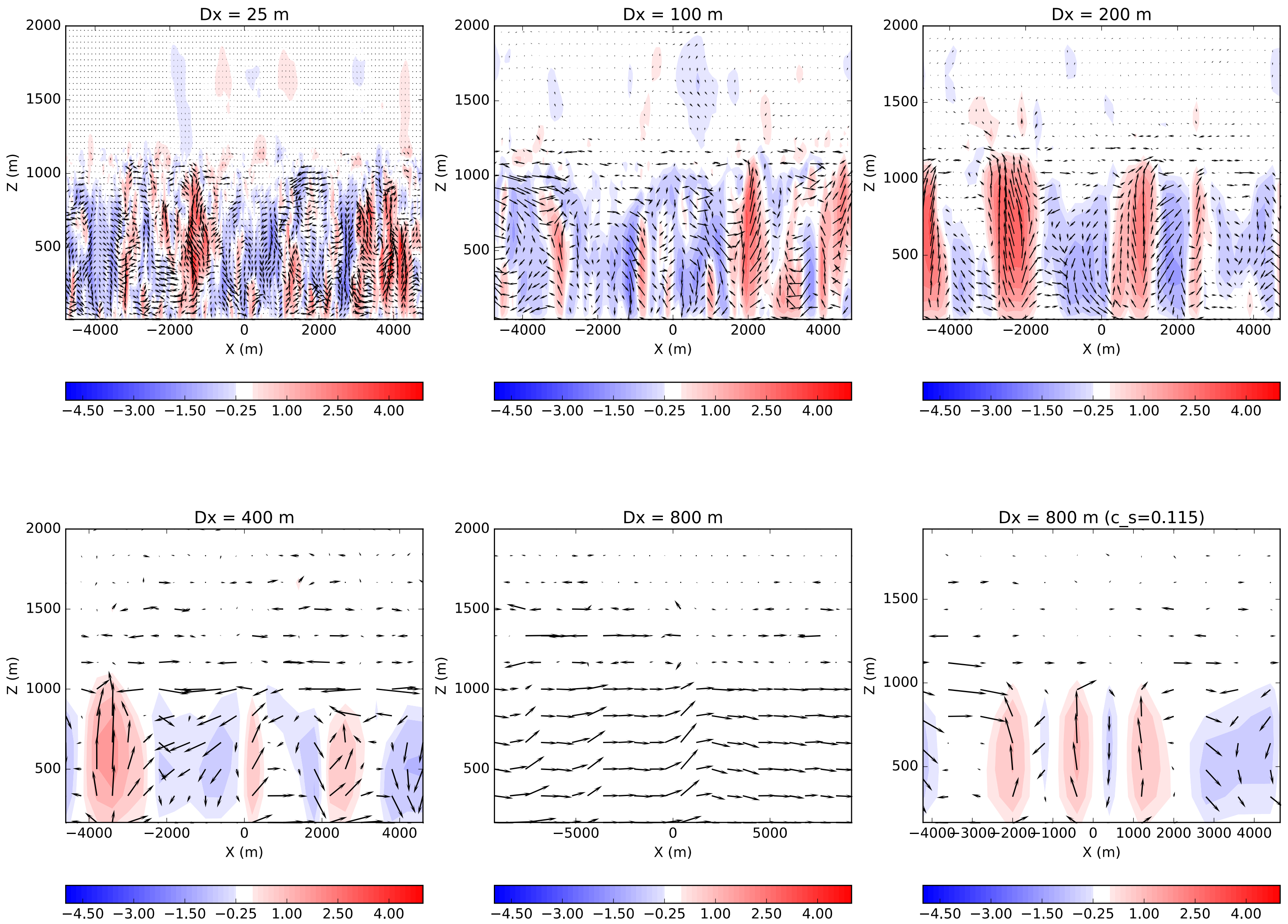
$$K_{M,H} = l^2 \, S \, f_{M,H}\,(Ri)$$

$$l^{-2} = (k\,z)^{-2} + \lambda_0^{-2}$$

$$\lambda_0 = c_s \, \Delta x$$

Control : $c_s = 0.23$

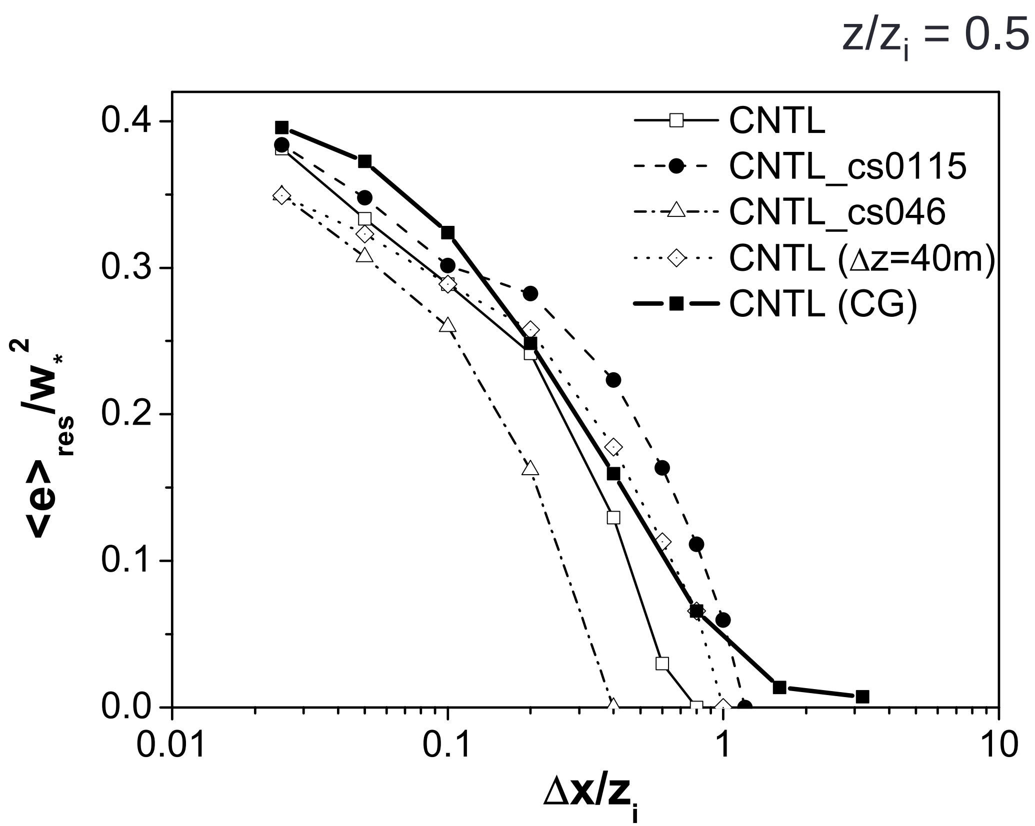
Steady State Simulations (Free Convection)



Quantifying sub-grid diffusion in the grey-zone

- Reducing sub-grid diffusion ?
- Increasing vertical resolution ?

How much resolved TKE?

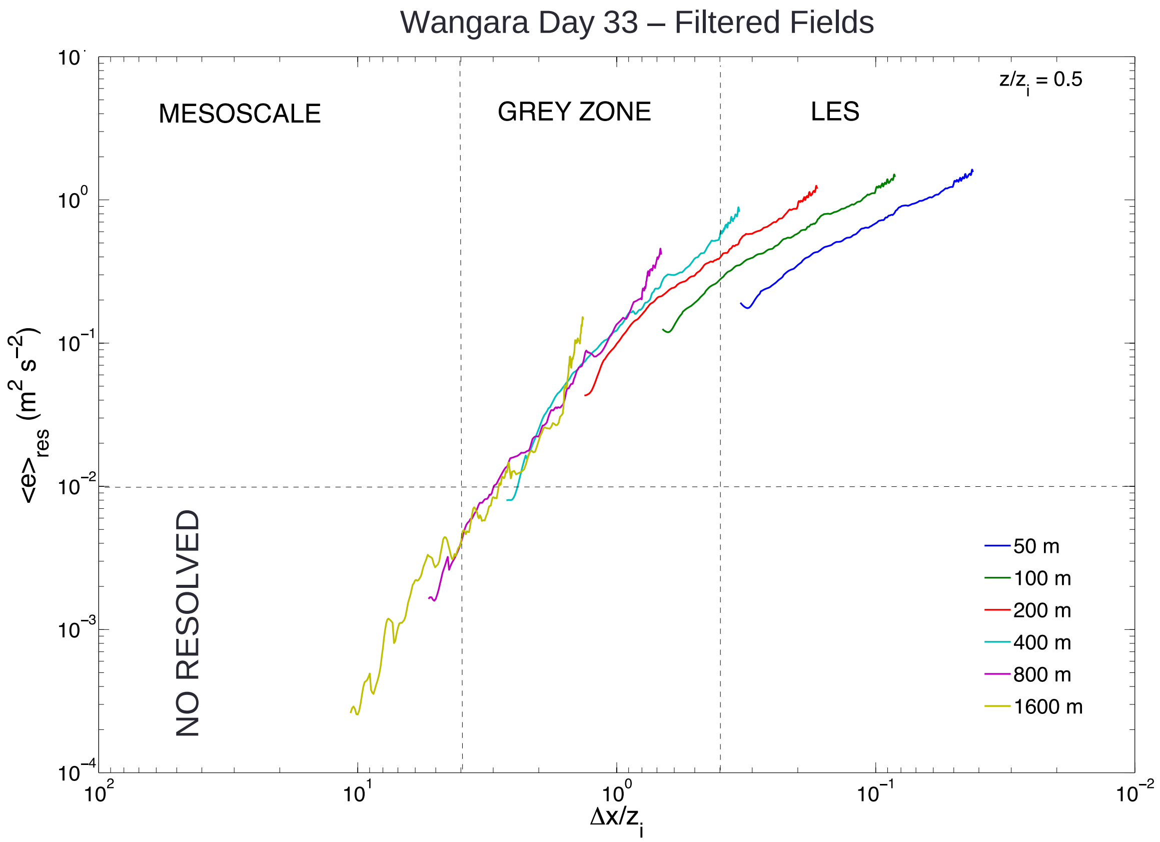


(Efstathiou and Beare, 2015)

Parametrization approaches

- Modifying Smagorinsky
  - BOUND approach (Efstathiou and Beare, 2015)
  - Dynamic Smagorinsky Modelling
  - Dynamic Blending (Preliminary results)

Evolution of Scales – Wangara CBL



During the morning CBL development simulations of different Δx go through different regimes

(Efstathiou et al., 2016)

Dynamic sub-grid modelling

- Using "resolved" scales to estimate C_S
- Apply a test filter ($G_{\alpha\Delta}$) to diagnose sub-filter scales

$$\tau_{ij} = -2(C_s\Delta)^2|\overline{S}|\overline{S}_{ij}f(Ri)$$

τ : sub-grid stress

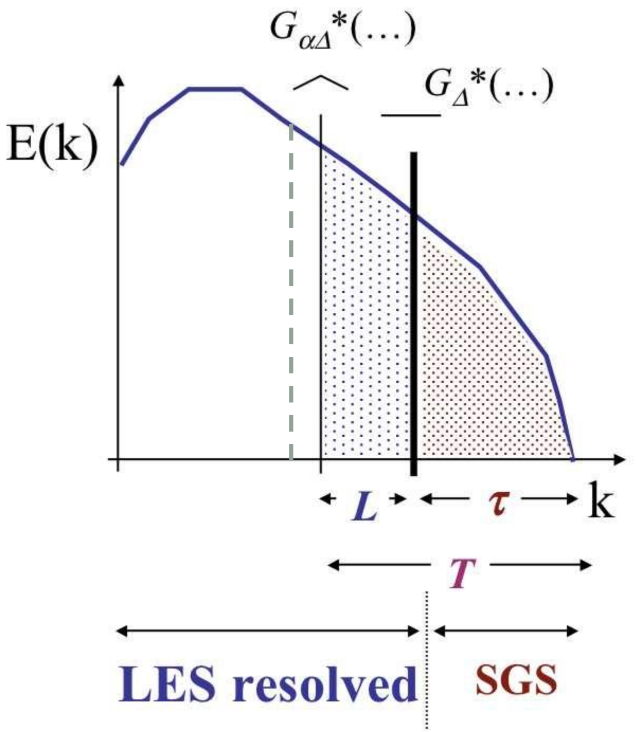
T : interactions between sub-grid - sub-filter

L : "smallest" resolved scales (Leonard stress)

C_S averaged over path lines (LASD)

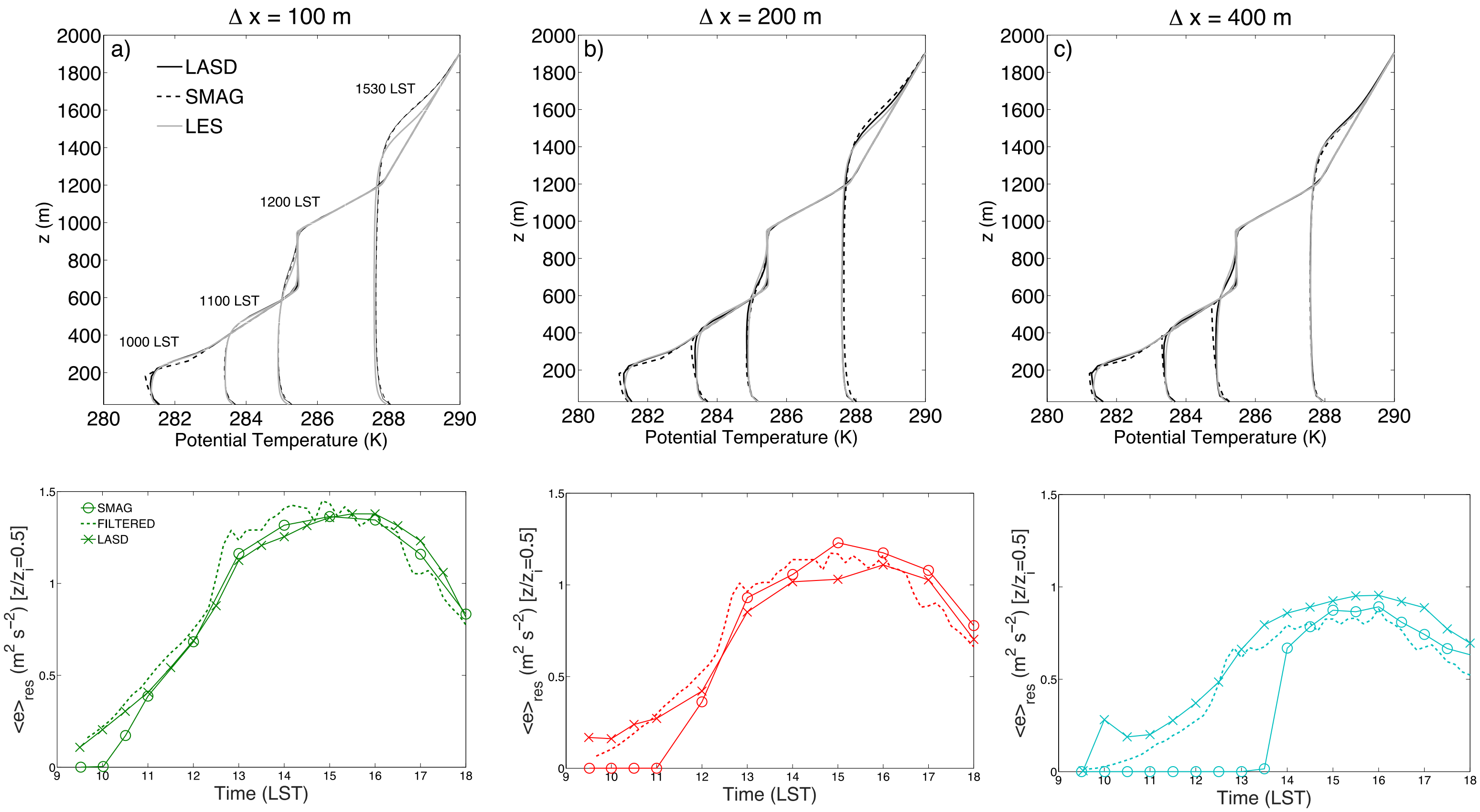
Second filter ($G_{2\alpha\Delta}$) to account for scale dependence

$$C_S(\Delta) \neq C_S(a\Delta)$$



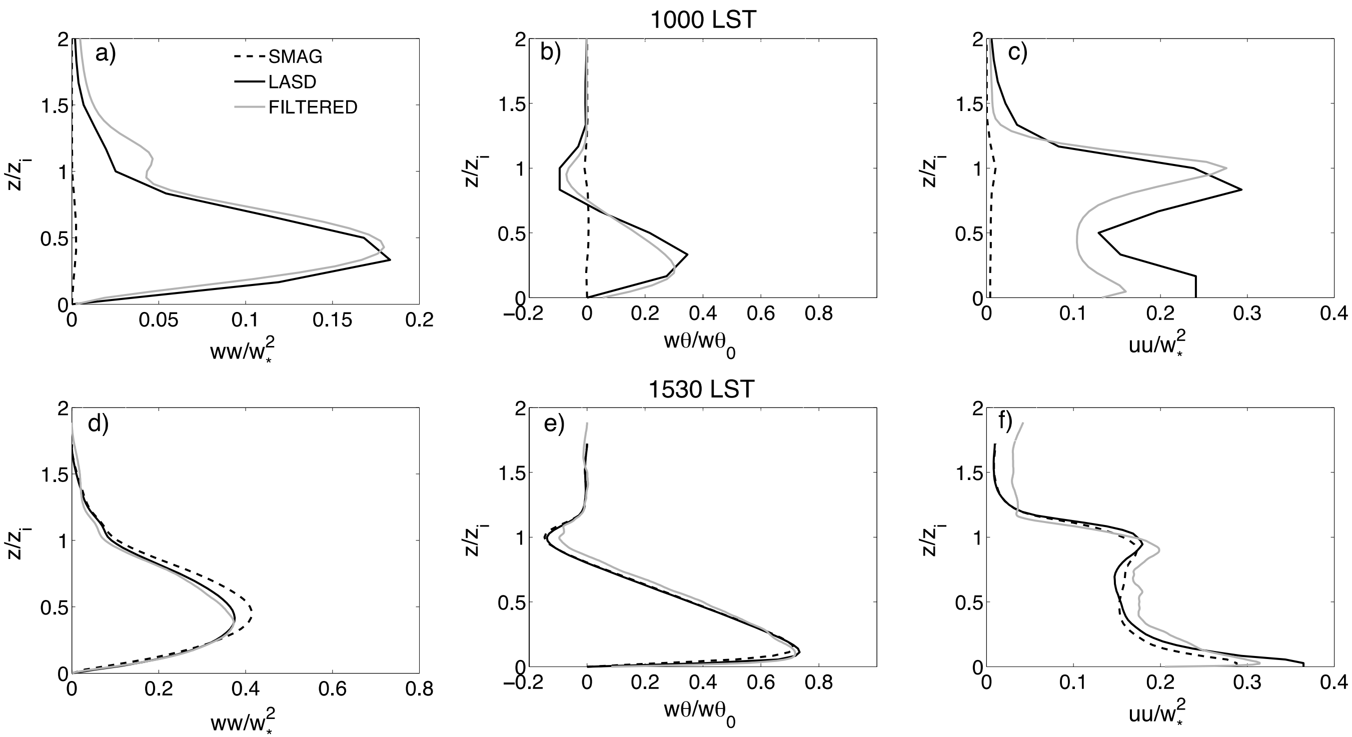
Charles Meneveau (2010), Scholarpedia, 5(1):9489.

Wangara CBL development



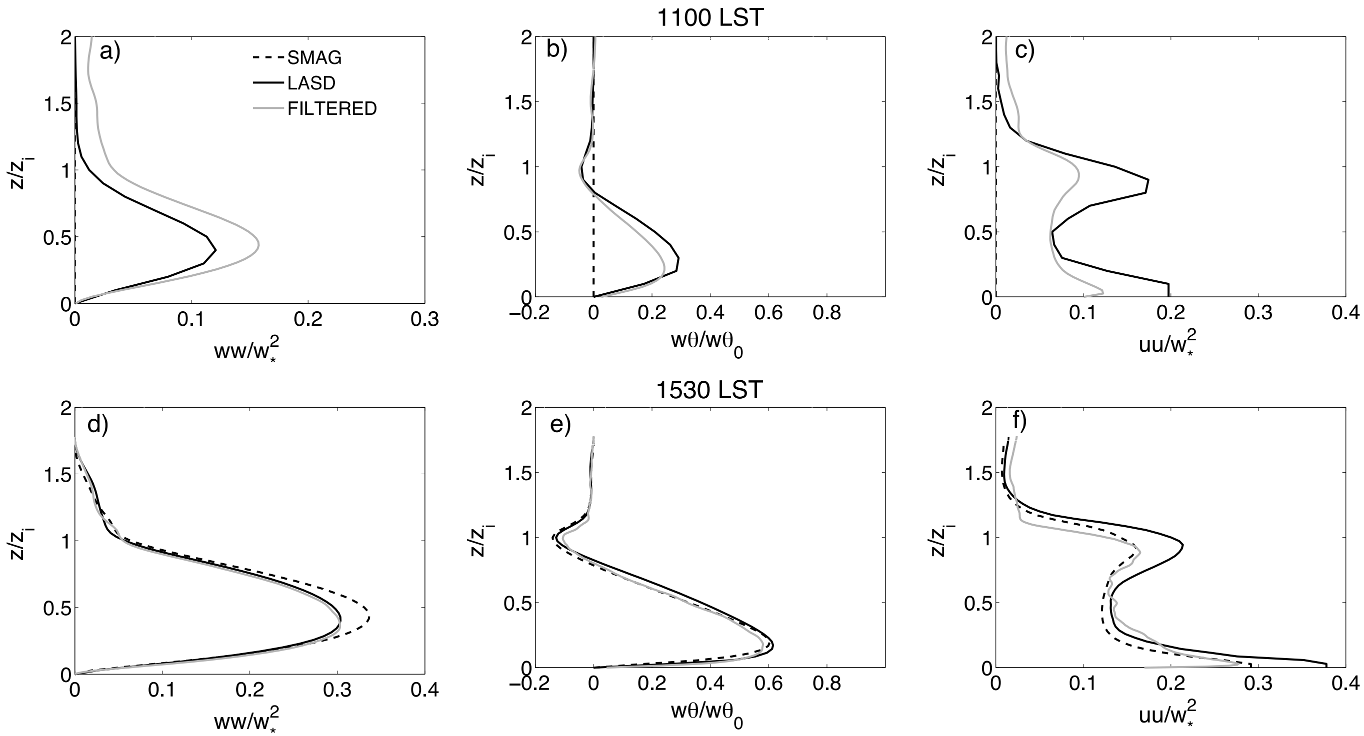
Comparison with the filtered fields

Δx = 100 m



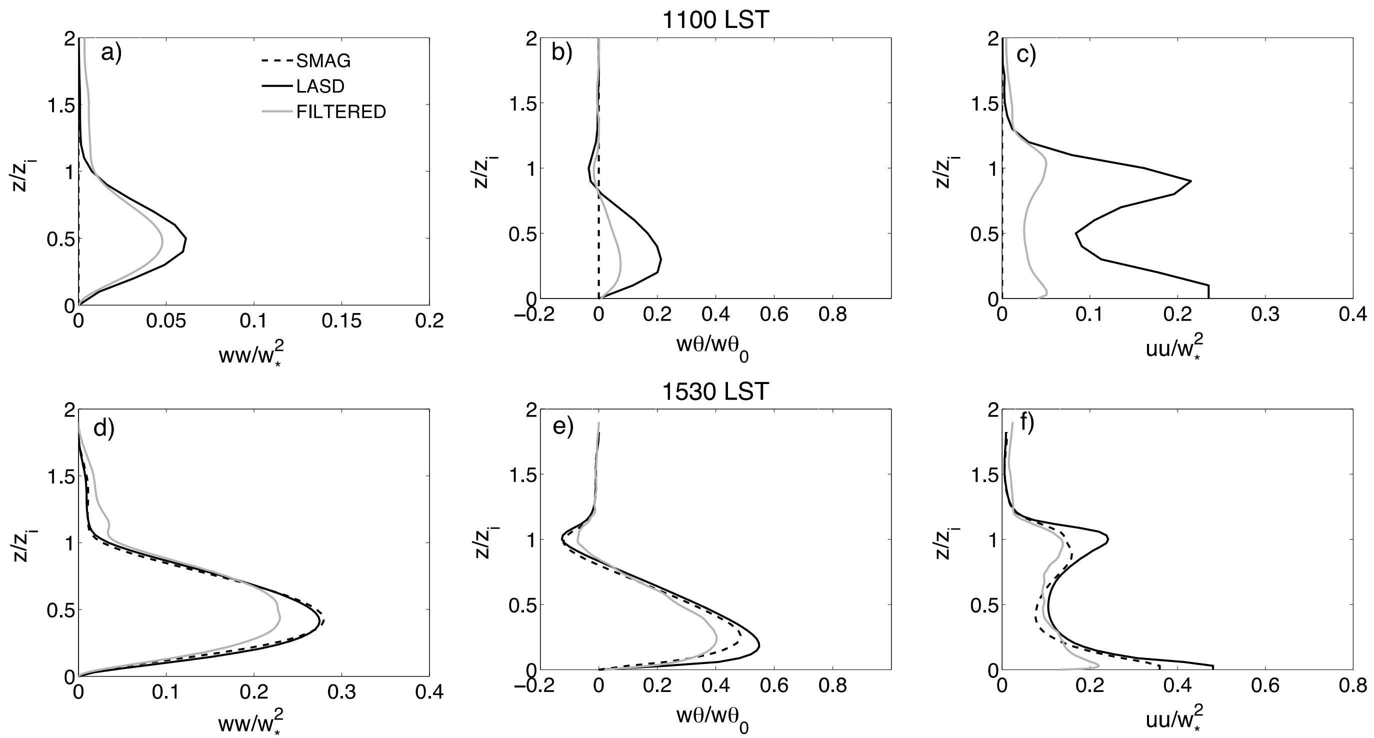
Comparison with the filtered fields

Δx = 200 m



Comparison with the filtered fields

Δx = 400 m



Met Office Blending Scheme

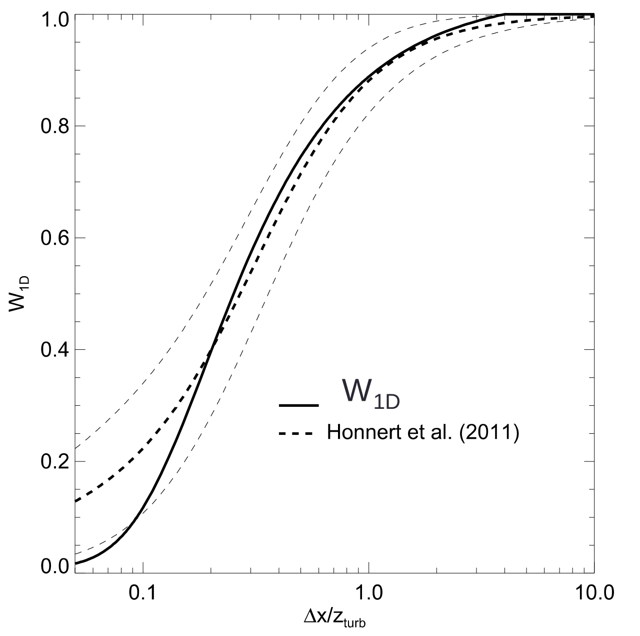
- Blending Scheme (Boutle et al., 2014)
- Implemented in the LEM (Efstathiou et al., 2016)

(based on Hong et al., 2006)

$$W_{1D} = 1 - \tanh\left(\beta \frac{z_{turb}}{\Delta x}\right) \max\left(0, 1 - \frac{\Delta x}{4 z_{turb}}\right)$$

$$\overline{u_j'\theta'} = \overbrace{-K_H \frac{\partial \theta}{\partial x_j}}^{\text{local flux}} + \delta_{3j} W_{1D} \left[\overbrace{K_H \gamma}^{\text{non-local flux}} + \overbrace{\overline{w'\theta'}_{z_h} \left(\frac{z}{z_h}\right)^n}^{\text{explicit entrainment}} \right]$$

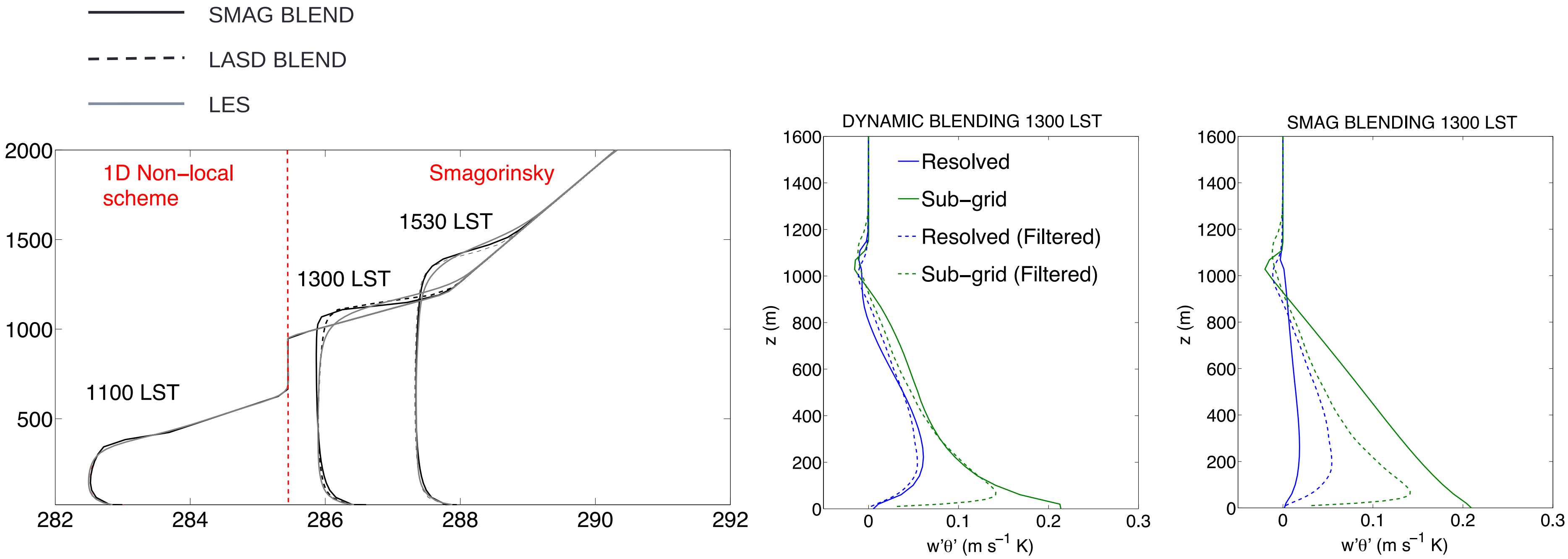
$$K_H = \max\left[W_{1D}\, K_H(1D),\, K_H(SMAG)\right]$$



SMAG 1D BL

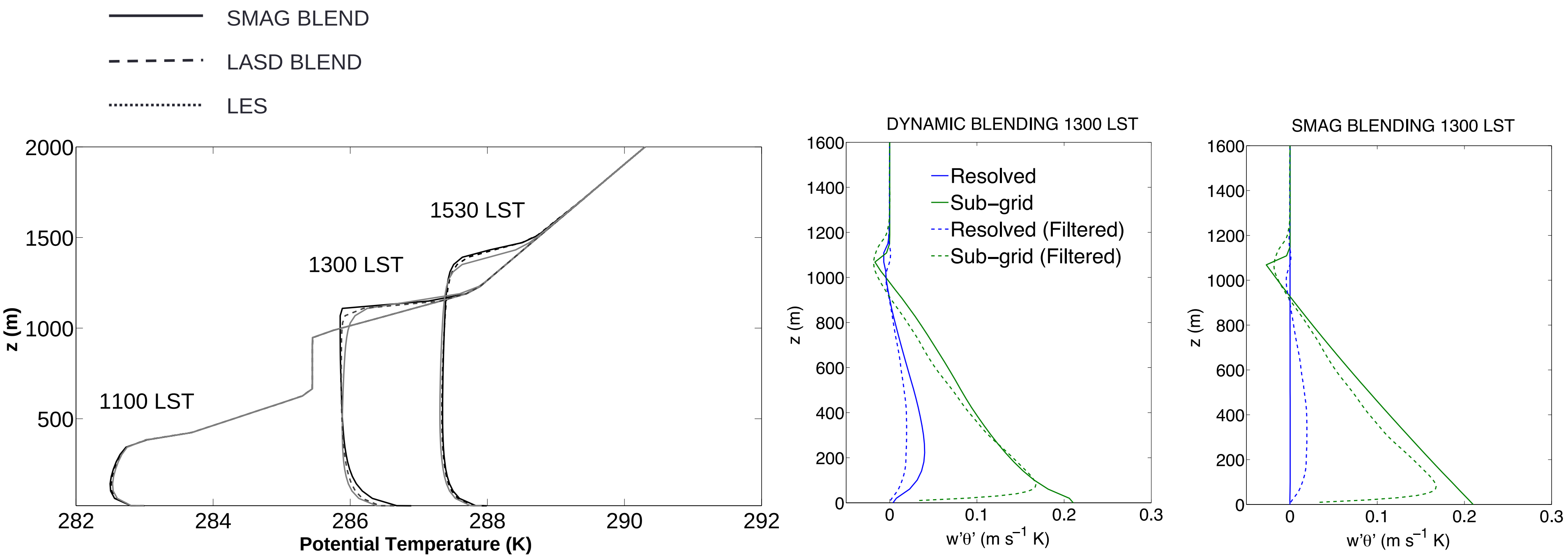
Wangara CBL development

Δx = 400 m



Wangara CBL development

Δx = 800 m



Summary

- *The grey-zone imposes practical limitations in very high resolution NWP*

  Should any convective overturning be allowed in the grey-zone?
- **Challenges**
  - Representing coherent structures
  - Quantify the resolved TKE – Energetics – TKE spin-up
  - Form of transition
  - Shape and form of the coherent structures in the CBL would affect the representation of shallow Cu convection
  - Implications with deep convection and convective parametrizations

- **Dynamic modelling of sub-grid diffusion at grey-zone resolutions**
  - Dynamic Smagorinsky a better alternative than Standard Smagorinsky
  - Improves spin-up / Representation of mean quantities and turbulence statistics
  - Relies on dynamics (unable to resolve for $\Delta x/z_i > 2$) – Usability limit
  - Modified 1D schemes suffer from delayed spin-up
  - Dynamic Blending extends the benefits of dynamic modelling further into the grey-zone

Papers

Beare, R. J., 2014: A length scale defining partially-resolved boundary-layer turbulence simulations. *Boundary-Layer Meteorol*. 151: 39–55.

Efstathiou, G. A. and R. J. Beare, 2015: Quantifying and improving sub-grid diffusion in the boundary-layer grey zone. *Quarterly Journal of the Royal Meteorological Society, 141, 3006–3017.*

Efstathiou, G. A., R. J. Beare, S. Osborne, A. P. Lock, 2016: Grey zone simulations of the morning convective boundary layer development, *Journal of Geophysical Research: Atmospheres*, 121, 9

Efstathiou, G. A., Plant R. S., and M. M. Bopape, 2017: Simulation of an evolving convective boundary layer using a scale-dependent dynamic Smagorinsky model at near grey-zone resolutions. *Journal of Applied Meteorology and Climatology*, submitted.