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LOCAL MIXING WITH EXTERNAL CONTROL IN THE MET OFFICE UNIFIED MODEL STABLE BOUNDARY LAYER

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1. BACKGROUND

The current first-order closure scheme for the Met Office Unified Model (UM) stable boundary layer (SBL) calculates eddy diffusivities in terms of a Richardson number (R_i) based on local gradients. Such an approach represents well the accepted localised behaviour of turbulence in stratified flows, but is limited in its ability to control the depth and vertically-integrated mixing characteristics of the SBL as a whole, and exhibits a high sensitivity to gradient errors which can be problematic in models with coarse vertical resolution. These characteristics sometimes lead to unsatisfactory fog prediction, severe surface decoupling, and noise in forecast quantities near the surface. Historically, the occurrence of such problems has been partially ameliorated via the use of modified stability functions, as is common in numerical weather prediction (NWP) models (e.g. Beljaars and Viterbo 1998). However, this continues to be an area in need of development.

The use of so-called “non-local” schemes for mixing in the SBL is becoming increasing popular in NWP models (e.g. Kim and Mahrt 1992; Holtslag and Boville 1993; Ha and Mahrt 2001). Such schemes directly prescribe profiles for the eddy diffusivities, scaling with the surface fluxes and a specified SBL depth, which is often estimated diagnostically from the model profiles using a bulk Richardson number criteria. This is a powerful way of imposing external controls upon the gross mixing characteristics of the SBL, and reducing sensitivity to local gradient errors. However, the form of the profile functions is completely empirical, and it is unclear how they relate to our physical understanding of SBL turbulence. In addition, the SBL height diagnosis requires the specification of a critical R_i, which has limited meaning and is therefore rather arbitrary. Finally, wind and temperature fields must be available on the same model levels, which can be a problem on staggered grids.

2. A NEW CLOSURE FOR SBL MIXING

A new scheme for the UM is currently being developed (see Figure 1), which attempts to retain the essential local scaling characteristics of stably stratified turbulence, whilst at the same time imposing a strong external control upon the gross SBL mixing behaviour.

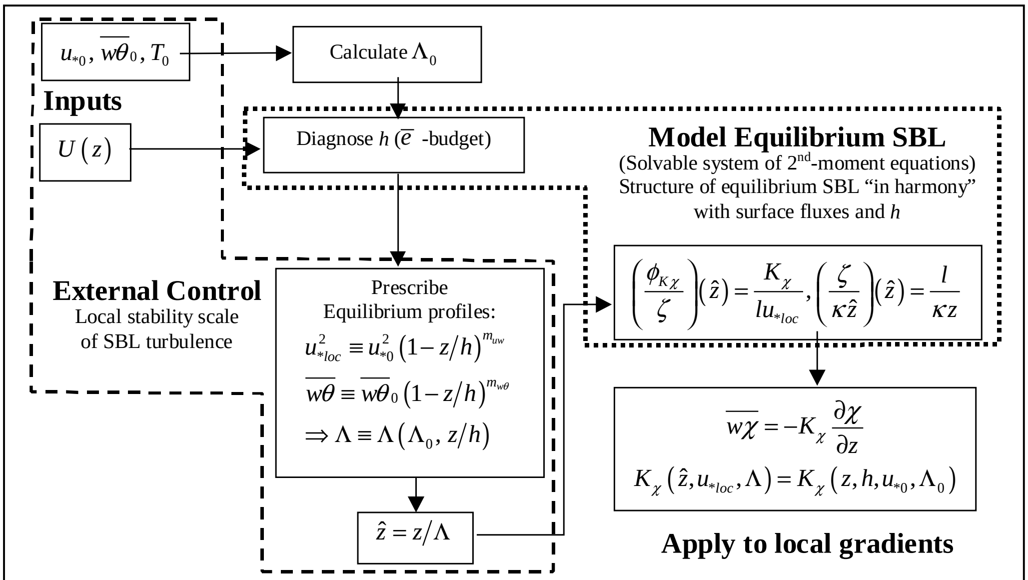

Figure 1: Concept for new stable boundary layer mixing scheme in the Met Office Unified Model (see text for details).

A 1-D quasi-equilibrium model has been developed along the lines of Nieuwstadt (1984) and others, in which a parametrized set of 2nd-moment budget equations (with transport terms set to zero) is expressed in terms of non-dimensional variables which are functions of the local stability parameter

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$\hat{z} = z/\Lambda$, where Λ is the local Monin-Obukhov length. This equilibrium model features improved parametrizations for dissipation and the master length scale, as well as incorporating "wall-effect" terms which improve matching with observed characteristics of the neutral surface layer. Independent parameters in the model have been tuned by comparison with large eddy simulations and observational data.

The critical hypothesis of the new SBL closure is that the "actual" eddy diffusivities, applicable for use within the UM, can be approximated as those of an "equivalent equilibrium SBL" in harmony with the surface fluxes and the SBL depth. For an *equilibrium* SBL, there is substantial observational evidence to allow estimation of a profile for the local Monin-Obukhov length Λ as an empirical function of the surface fluxes and a diagnosed SBL depth:

$$u_{*loc}^2 = u_{*0}^2 \left(1 - z/h\right)^{m_{uw}}$$

$$\overline{w\theta} = \overline{w\theta}_0 \left(1 - z/h\right)^{m_{w\theta}}$$

$$\Rightarrow \Lambda = -u_{*loc}^3 \Big/ \kappa \frac{g}{\Theta} \overline{w\theta}$$

$$\Rightarrow \hat{z} = z/\Lambda$$

The resultant $\hat{z}$ is then used as input to the 1-D equilibrium model to provide the required eddy diffusivities.

3. SBL DEPTH

The equilibrium model also provides a form of the turbulence kinetic energy budget that is used as the basis for the SBL depth (*h*) diagnosis. In this method, the UM wind profile is analysed to find the value for *h* which best satisfies the following budget equation:

$$\frac{\Delta U^{UM}}{u_{*0}} = G\left(\frac{h}{\Lambda_0}\right) = G_\varepsilon + G_B$$

where ΔU is a measure of the mean wind speed gradient across the outer layer, weighted towards the lower part of the profile:

$$\Delta U = \langle U \rangle - 0.9^{m_{uw}} U_{0.1h}$$

where $\langle U \rangle = m_{uw} \int_{0.1}^{1} U(\varsigma)(1-\varsigma)^{m_{uw}-1} d\varsigma$

and $\varsigma = z/h$.

The depth diagnosis represents a principle balance between *h* and the wind profile, with stability effects entering via $G(h/\Lambda_0)$. G_ε represents the stability effect on dissipation (primarily by contraction of the master length scale), whereas G_B represents the effect on buoyancy production (see Figure 2).

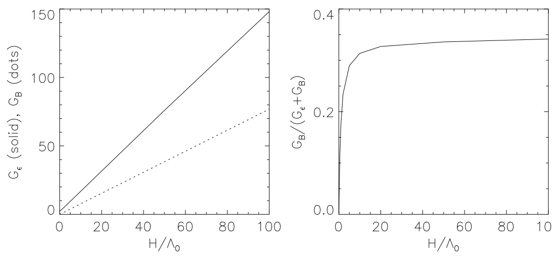

Figure 2: Functions in the SBL depth diagnosis (see text for details)

4. SUMMARY

The advantages of the new SBL closure scheme described above lie principally in:

- the clear definition of the assumptions made regarding the physics,
- the preservation of the firmly established local scaling behaviour of SBL turbulence, and
- the strong external controls imposed via the prescribed profile for Λ and the SBL depth diagnosis,

all of which will help substantially as the scheme is further developed in the future. Aspects of the concept and implementation of the new scheme will be discussed, along with illustrations of its performance in a single column version of the Unified Model.

5. REFERENCES

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