Large Eddy Simulations to parameterize the Convective Cloud Field

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- The representation of clouds including convection, their interaction with the planetary boundary layer and large-scale dynamics remains a major source of uncertainty in models.

- Shear is known to be important in cases of deep convection, affecting both the momentum fluxes (e.g. Kershaw and Gregory, 1997) and in some cases the whole structure of the convection, as it may lead to the formation of organized systems (e.g. Thorpe et al., 1982).

- Large-eddy simulations performed for shallow convective clouds under varying shear by Brown (1998) showed that the scalar transports are largely unaffected by shear, while the momentum transport is strongly affected.

- The shear is observed to have an impact (e.g. on the diagnosed entrainment rates) in the most highly sheared cases, in which shear production of turbulence is more significant.

- The approach would be to improve the representation of clouds in convection parameterizations by improving the LES output at very high resolution (~100m grid length) .

Very high-resolution versions of the Met Office's UM use a Smagorinsky–Lilly type scheme (Halliwell, 2007) where the subfilter fluxes of momentum, τ, and conserved scalars χ, are parametrized as

$$\tau_{ij} \equiv \left[\widetilde{u_i}\widetilde{u_j} - \widetilde{u_i u_j} - \frac{1}{3}\left(\widetilde{u_k}\widetilde{u_k} - \widetilde{u_k u_k}\right)\right] = \nu_m S_{ij},$$

$$h_i^{\chi} \equiv \widetilde{u_i \chi} - \widetilde{u}_i \widetilde{\chi} = -\nu_h \frac{\partial \chi}{\partial x_i},$$

where, strictly,

$$S_{ij} = \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\frac{\partial u_k}{\partial x_k}\delta_{ij},$$

Where, u_i represents the i^{th} component of the velocities, τ_{ij} is the kinematic deviatoric stress, S_{ij} is the rate of strain tensor or deformation part of the velocity gradient, h_i^x is scalar flux, χ is the reference state, ν is the subgrid eddy-viscosity.

In the classical Smagorinsky–Lilly approach, the eddy viscosity coefficient, ν_m is defined as

$$\nu_m = (c_s \Delta)^2 \mathcal{S} = \lambda_0^2 \mathcal{S}$$

Where, velocity scale, $\mathcal{S}^2 \equiv \frac{1}{2} S_{ij} S_{ij}$.

c_s is an empirically determined constant, Δ is the maximum horizontal grid length, λ_0 is the mixing length.

The last term in S_{ij}, which removes the trace (i.e., the divergence of the flow), has not been included in operational code, and velocity components have been treated through simple diffusion.

- According to Lilly (1962), for isotropic mixing, λ_0 should have a dependence on the vertical grid length:

$$\lambda_0 = c_s(\Delta x \Delta y \Delta z)^{1/3}$$

and hence λ_0 depend on height in a model with a variable vertical grid spacing.

- Moeng *et al.* (2010) propose an extension to the Smagorinsky–Lilly scheme to be applied in the vertical.

- The second term on the right-hand side (referred to as the Leonard term and the Leonard term in has a very similar form to the tilting term.

$$\tau_{w\Phi} = -\nu_\chi \frac{\partial \Phi}{\partial z} + \frac{K_L}{12}\left(\Delta x^2 \frac{\partial w}{\partial x}\frac{\partial \Phi}{\partial x} + \Delta y^2 \frac{\partial w}{\partial y}\frac{\partial \Phi}{\partial y}\right)$$

- They proposed the Leonard has a very similar form to the tilting term,

$$\frac{3}{2} S_H^2 \lambda^2 = \frac{K_L}{12}\Delta x^2$$

- Leonard terms and K_L depends only on the stability function and c_s.

$$S_H = (1 + 2\ell / \Delta) C_K$$

- The relation between c_s and C_K is;

$$c_s \approx \frac{1}{\pi} \left(\frac{2}{3C_K}\right)^{\frac{2}{3}}$$

- In practice, values of λ_0 which correspond to $c_s \approx 0.23$ are usually used (UMDP28) and $C_K = 1.4$, the Smagorinsky constant is estimated to be $c_s \simeq 0.18$. In practical computations, a value of $c_s = 0.1$ has been found to yield more realistic results.

- Unfortunately, c_s appears to require adjustment for different problems (Nikolaos Katopodes, 2019)

- Hanley et al. (2015) showed that convective cells in the UM are very sensitive to λ_0 and, by increasing the mixing length in a smaller grid-length simulation, it is possible to produce a simulation with storm morphologies.

Thank You