Department of Meteorology

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# ParaCon at Reading: New approaches for modelling convection

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## Introduction

**The UK ParaCon project, a collaboration between four UK universities and the Met office, seeks a step change in the representation of convective processes in models. Novel theoretical approaches in the areas of mass flux parametrization, high-order turbulence modelling and multi-fluid modelling are being developed with insights from analyses of high-resolution (order 100 m grid) reference simulations of idealized regions of convection. A few examples from work at the University of Reading are discussed below.**

## Mass Flux Approaches

Most mass-flux schemes are based on the "top-hat" assumption or "segmentally constant approximation". Neglecting the sub-plume variability underestimates the vertical transport of thermodynamic variables (e.g. $\theta_l$, $\theta_v$) up to 30%~50% using the bulk plume approximation. Assumed joint PDF of vertical motion and transported variables could be used to recover the sub-plume variability but introduces high-order moments that need to be estimated through high-order closure. Investigation of joint distribution reveals consistency between distributions among clouds with different sizes and at different heights using a 100 m grid BOMEX simulation and a 400 m grid deep convection RCE simulation (Figure 1). To some extent, distributions of different variables agree better in deep clouds because there is less of a shell structure from cloud evaporation at cloud boundaries. This suggests that the sub-plume variability could be simplified by the assumption of common distributions of normalised vertical motion and other variables. A composite study of cloud structure is performed to confirm this idea and shows its potential implication for the representation of sub-plume variability. Based on this idea, only the maximum values of variables and the common distribution with cloud radius would be needed.

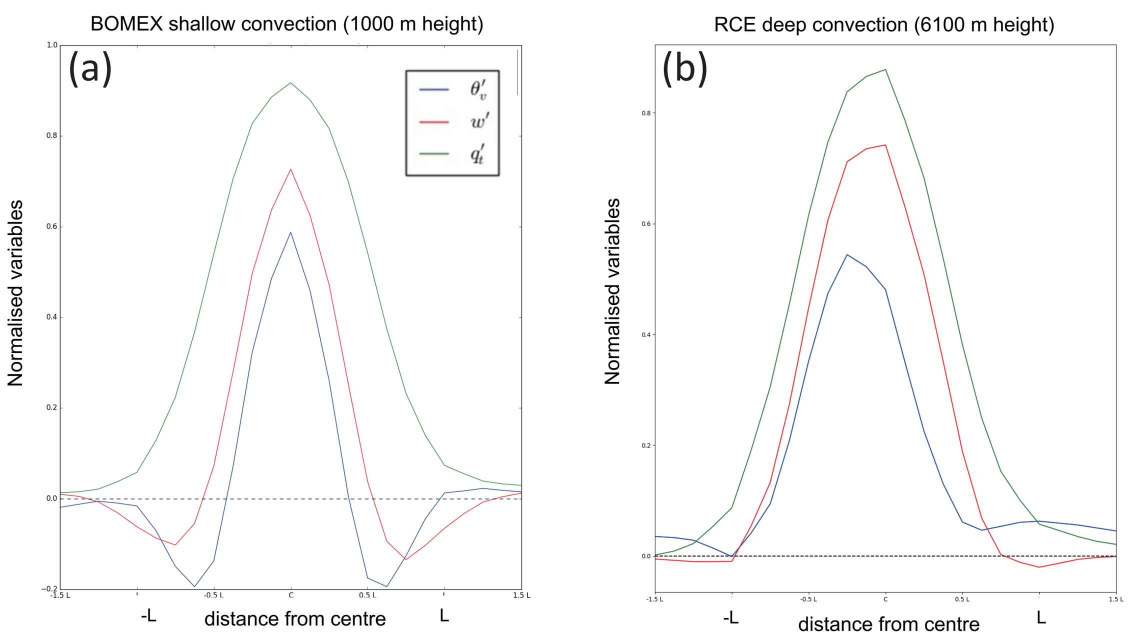


**Figure 1**. Composite distribution of several quantities within the cloud in (a) BOMEX at the height of 1000 m and (b) RCE simulation at the height of 6100 m. The x-axis represents the normalized distance to the cloud centre. L represents the approximate diameter of cloud. The y-axis represents the distribution of different variables normalized by their maximum values within each cloud object.

## High-order turbulence modelling

BOMEX simulations have been run using MONC at 100 m resolution, and a Mellor-Yamada-Nakanishi-Niino 2nd order level 2.5 TKE scheme has been implemented to compare with the pre-existing 2nd order level 2.0 scheme (Smagorinsky). Smagorinsky uses viscosity and diffusivity derived from assuming no transport terms and local equilibrium in the TKE budget (Smag. nu - coral). An equivalent TKE can be diagnosed (Smagorinsky diagnostic - dashed). In a run using Smagorinsky viscosity and diffusivity a TKE (Circle-A passive prognostic - solid) can be derived using the prognostic TKE budget. Indeed a viscosity and diffusivity can be derived from the prognostic TKE budget assuming local equilibrium with dissipation (L2.5 nu - olive). The difference between the prognostic to diagnostic Smagorinsky lines (solid to dashed, coral) shows the TKE is close to equilibrium in the surface layer but diverges aloft. Spikes in TKE attributed to cloud base, mid level cloud and cloud top are present. The prognostic (solid) is in effect a smoothed diagnostic (dashed) as evident from the graphic.

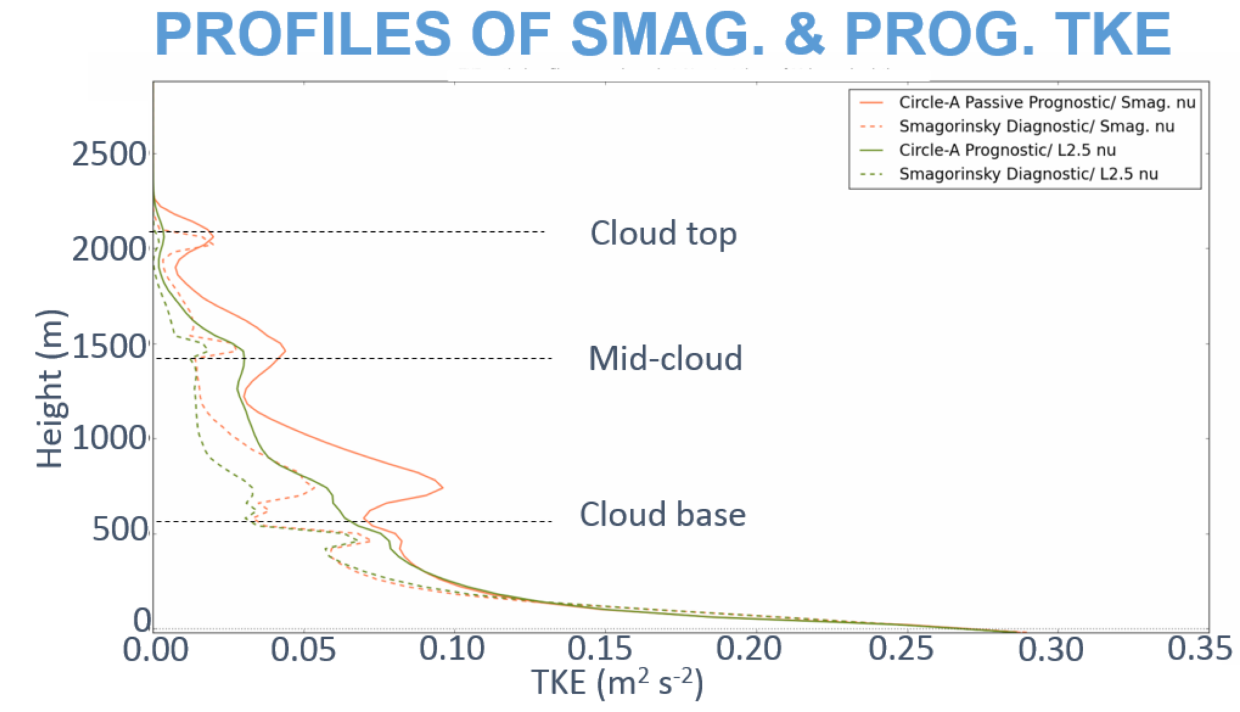


**Figure 2**. Profiles of Turbulence Kinetic Energy (TKE) from two prognostic and two diagnostic schemes for 100 m MONC simulations with a BOMEX configuration.

## Multi-Fluid Modelling

The multi-fluid method has been proposed for convection modelling due to the possibility of consistent treatment of resolved and sub-grid convection, whilst also representing net mass transport by convection and non-equilibrium dynamics (Thuburn et al., 2018; Tan et al., 2018; Weller and McIntyre, 2019). The method involves dividing space into various defined fluids, each with their own physical properties (Thuburn et al., 2018). In the case of convection, one could use fluid 0 as the neutrally buoyant air, fluid 1 as convective updraft regions and fluid 2 as downdraft regions. However, Stewart and Wendroff (1984) and Thuburn et al. (pre-release: 2019) note that the multi-fluid Euler equations are ill-posed when sub-filter terms are ignored, and little is known about the numerical properties of solutions to the multi-fluid equations. Mcintyre et al (2019) present numerical analysis of the 2-fluid shallow water equations (SWEs) to inform the treatment of the multi-fluid Euler equations for convection modelling which are numerically unstable (Fig. 3). Using linear stability analysis, we find the 1-fluid SWEs have an expected stability restriction of $|c|+|cg| \leq 1$ (Anmala and Mohtar, 2011) - the net Courant number (advection + gravity wave) is less than one, represented by the dotted line in Fig. 3. The 2-fluid stability is found to be weaker relative to the 1-fluid system (the numerically stable white region is smaller than the dotted line in the figure). Numerical simulations verify this behaviour (cyan contour). However the full, non-linear 2-fluid SWE simulations (orange contour) are more stable than the linear equation set. This is due to a stabilizing effect of the non-linear advection terms which remove energy from the unstable modes in the linear equation set. The multi-fluid equations are therefore more stable than analysis of the linear equations suggests. This study could be used to choose a drag or diffusion coefficient to stabilize the multi-fluid Euler equations.

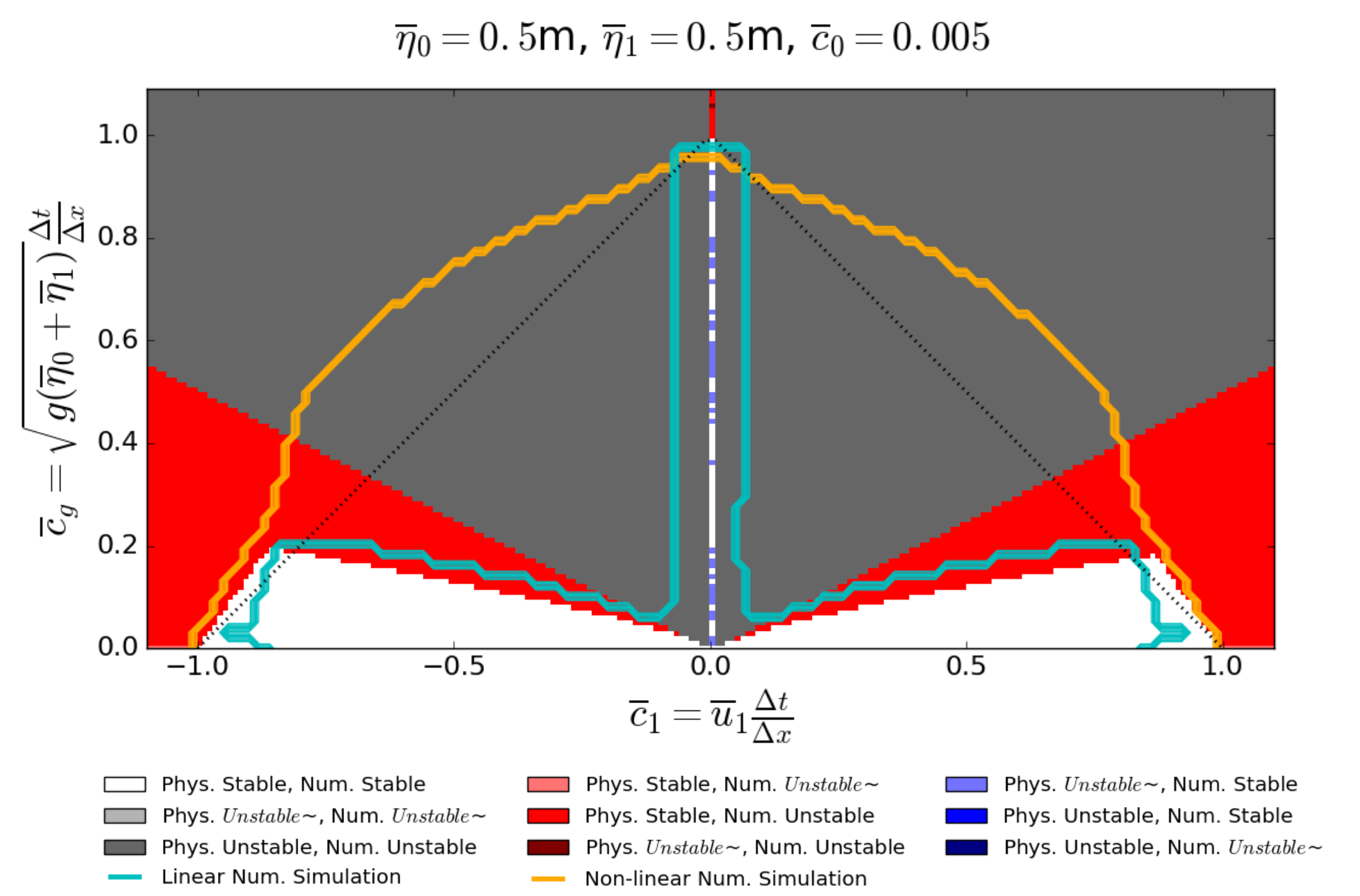


**Figure 3**. The physical (red and white) and numerical (blue and white) stability regions of the 2-fluid linearized shallow water equations. Dark grey regions indicate a physically and numerically unstable system. Also included are unstable regions which are within rounding-error of the stability condition (denoted by ~ u n s t a b l e ) and are given by the different shades of red, blue or grey. The stable regions for the numerical simulations are contained within the cyan (linear simulations) and orange (non-linear simulations) contours.

## Summary

- The ParaCon projects at Reading are developing novel approaches to the representation of convection in models. Here, we show examples of current directions, including representations of sub-grid variability in mass flux formulations, tests of high-order turbulence parametrizations, and stability analysis of a multi-fluid method.

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