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Numerical analysis of the multi-fluid equations with applications for convection modelling

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Convection schemes are a large source of error in global models as modern resolutions are too fine to parameterize convection but are still too coarse to fully resolve it. Recently, numerical solutions of multi-fluid equations have been proposed for a more flexible and consistent treatment of sub-grid scale convection, including net mass transport by convection and non-equilibrium dynamics. The technique involves splitting the atmosphere into various fluid components which are defined by their physical properties, such as the stable environment or buoyant updrafts. The fluids interact through a common pressure and through transfer terms used to represent convective entrainment and detrainment. Without transfer terms the equations are ill-posed. Little is known about the numerical stability of the multi-fluid equations or the numerical properties of mass transfer terms between the fluids. This study therefore aims to provide an insight for these two topics:

1. We analyse the physical and numerical stability of the multi-fluid shallow water equations with a common height gradient. We show that the 2-fluid linearized equations are less stable than the 1-fluid case. However, the full non-linear equations have a greater numerical stability due to a direct energy cascade which removes energy from the most unstable modes.

2. We derive mass transfer terms which relabel the fluids and derive numerical properties of the transfer schemes including boundedness, momentum conservation and energy properties. We find 3 transfer schemes which possess desirable numerical properties, 2 of which are suitable for use on staggered grids.