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Towards a consistent treatment of cloudy air in ICON

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In simplified terms the atmosphere can be regarded as a two-component, multiphase system consisting of dry air and water, where each constituent moves with a different, constituent specific velocity $\mathbf{v}_k$. Based on this concept, Gassmann and Herzog (2008) formulated a general set of thermo-hydrodynamic equations for the air-water mixture, which is consistent with respect to energy and mass. This set of equations constitutes the basis for the ICON (Icosahedral Nonhydrostatic) model.

A key point when deriving equations for multi-component systems is the choice of an appropriate reference velocity. Gassmann and Herzog (2008) have chosen the barycentric velocity $\mathbf{v}_{bc} = \sum_k \rho_k \mathbf{v}_k / \sum_k \rho_k$, i.e. the velocity with which the center of gravity of the mixture moves. As detailed in Wacker and Herbert (2003), a key advantage of this particular choice is that the continuity equation for total air mass simplifies and becomes formally equivalent to the continuity equation for dry air (i.e. free from sources and sinks). This advantage, however is bought dearly since in the barycentric framework the vertical velocity w_{bc} at the surface generally deviates from zero due to contributions from evaporation and precipitation.

During the ICON development phase, some pragmatic approximations have been introduced into the governing equations concerning the treatment of moisture. E.g. by setting $w_{bc} = 0$ at the surface, the mass sink/source due to precipitation/evaporation is currently neglected in the continuity equation for total air mass. This approximation is questionable, especially for heavily precipitating systems. As a further consequence, ICON erroneously conserves the total air mass (dry + water) rather than the dry one.

In this work, we pinpoint the approximations currently in use, illustrate their consequences, and highlight the missing steps towards a consistent treatment of cloudy air in a barycentric reference frame. In a first step the lower boundary condition for w_{bc} has been fixed, which allows for the precipitation/evaporation mass sink/source to take effect. The dynamical effect of the precipitation mass sink will be investigated by taking the example of an idealized tropical cyclone.