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# Consistent and Flexible Thermodynamics in Atmospheric Models Using Internal Energy as a Thermodynamic Potential

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Approximations in the moist thermodynamics of atmospheric models can often be inconsistent. Different parts of numerical models may handle the thermodynamics in different ways, or the approximations may disagree with the laws of thermodynamics. To address these problems all relevant thermodynamic quantities may be derived from a defined thermodynamic potential; approximations are then instead made to the potential itself - this guarantees self-consistency, as well as flexibility. Previous work showed that this concept is viable for vapour and liquid water mixtures in a moist atmospheric system using the Gibbs potential. However, on extension to include the ice phase an ambiguity is encountered at the triple-point. To resolve this ambiguity, here the internal energy potential is used instead. Constrained maximisation methods on the entropy can be used to solve for the system equilibrium state. However, a further extension is necessary for atmospheric systems. In the Earth's atmosphere many important non-equilibrium processes take place; for example, freezing of super-cooled water, and evaporation into subsaturated air. To fully capture processes such as these, the equilibrium method must be reformulated to involve finite rates of approach towards equilibrium. Here the principles of non-equilibrium thermodynamics are used, beginning with a set of phenomenological equations, to show how non-equilibrium moist processes may be coupled to a semi-implicit semi-Lagrangian dynamical core. A standard bubble test case and simulations of cloudy thermals are presented to demonstrate the viability of the approach for equilibrium thermodynamics, as well as the more complex non-equilibrium regime.