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Atmospheric convection with condensation of the major component

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In Martian atmosphere, atmospheric major component, CO2, condenses. In current Martian polar regions, CO2 ice clouds are known to exist, and there is a possibility that these clouds are formed by convective motion (Colaprete et al., 2003).
Studies on the early Mars suggested that large amounts of CO2 ice cloud existed in the thick atmosphere, and that the scattering greenhouse effect of CO2 ice cloud had a significant effect on the climate (Forget and Pierrehumbert, 1997: Mitsuda, 2007).

In a system whose major component condenses, the degrees of freedom for thermodynamic variables degenerate when supersaturation does not occur. Due to degeneracy of degree of freedom, temperature profile of ascent region must be equal to that of descent region, and air parcel can not obtain buoyancy.
Colaprete et al. (2003) performed calculations by using a vertical one-dimensional model and showed that moist convection develops when critical saturation ratio (Scr) is greater than 1.0, because the supersaturation will permit the temperature profile to deviate from the thermodynamic equilibrium.
However, in the vertical one-dimensional model, there is an uncertainty in the parameterizations related to the effects of entrainment and so on.

In this study, we perform a direct numerical calculation of cloud convection using cloud convective model developed by ourselves (e.g., Odaka et al., 2006: Sugiyama et al., 2009:
http://www.gfd-dennou.org/library/deepconv/index.htm.en)
in order to investigate the properties of flow field and cloud distribution in the case of Scr = 1.0.
The used model is a two-dimensional cloud convection model that incorporates condensation of the major component, CO2.

The governing equations in our model are the quasi-compressible equations by Klemp and Wilhelmson (1978) with additional terms representing the major component condensation (Odaka et al., 2005).
Gravitational settling of cloud particle and drag force due to cloud particles are not considered.
We assume that cloud particles grow by diffusion process.
We formulate the cloud microphysics by using the equation of diffusion growth of cloud particles as Tobie et al. (2003).
In this formulation, conversions from the vapor to the cloud occur within finite time scale.
We do not calculate radiation transfer explicitly, but we give horizontally uniform body heating near the surface and horizontally uniform body

cooling in the troposphere.
As initial temperature profile, we give the profile in which temperature follows the dry adiabatic lapse rate in the lower layer, and follows the saturated vapor pressure in the upper layer.
As initial perturbation, random noise is added to the lowest layer of atmosphere.
Integration time is 10 days.

Our result shows that moist convection develop in the case of Scr = 1.0. This result is different from that of Colaprete et al. (2003). In the quasi-equilibrium state, The updrafts that occur above and below the CO2 condensation level are connected at the condensation level. The downdrafts are also connected at the level. Maximum vertical velocity in both dry and cloud layer are about 15 m/s. Ascending air parcels experience positive and negative buoyancy below and above the CO2 condensation level, because they are warm compared to surrounding air under the level and they are cold above the level.
On the contrary, descending air parcels are warm in cloud layer, and cold in dry layer.
Since time scale of conversions from vapor to cloud is finite, temperature deviates from the saturated one in the cloud.
The reason why moist convection develops is that positive buoyancy in dry layer is sufficiently large compared to negative buoyancy in cloud layer when air parcels go up.

Keywords: condensation of major atmospheric component, carbon dioxide ice cloud, cloud convection model