Double-moment cloud microphysics scheme for the deep convection parameterization in the GFDL AM3

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Motivation

- Contributing to the major FASTER goals: "improvement of parameterizations of key cloud processes/properties (e.g., convection, microphysics and aerosol-cloud interactions), thus narrowing the range of treatments of fast processes that exert strong influences on model sensitivity so as to better constrain climate sensitivity."
- Number and size of detrained hydrometeors from deep convective towers affect moisture content in the upper troposphere and the tropical cirrus, resulting in impact on climate sensitivity.
- Cloud-aerosol microphysical processes in deep convective towers play an important role in influencing cumulus dynamics through latent heat release and condensate loading. For example, increasing number of aerosols available for activation in deep convection leads to invigoration of convection by virtue of delaying formation of precipitation in warm parts of the cloud and increased relative importance of ice processes and the related increased latent heat release; causes stronger downdrafts due to enhanced evaporation from smaller droplets; stronger downdrafts may intensify subsequent convection (Fig. 1).
- This motivates incorporation of treatment of the microphysical processes in to the parameterization of the deep convection that would be capable of capturing of these effects. Namely, parameterization of rates microphysical processes should include dependence on the number of activated cloud droplets and crystals, as well as rain and snow number concentrations, as opposed to using only mass mixing ratios of these hydrometeor species.

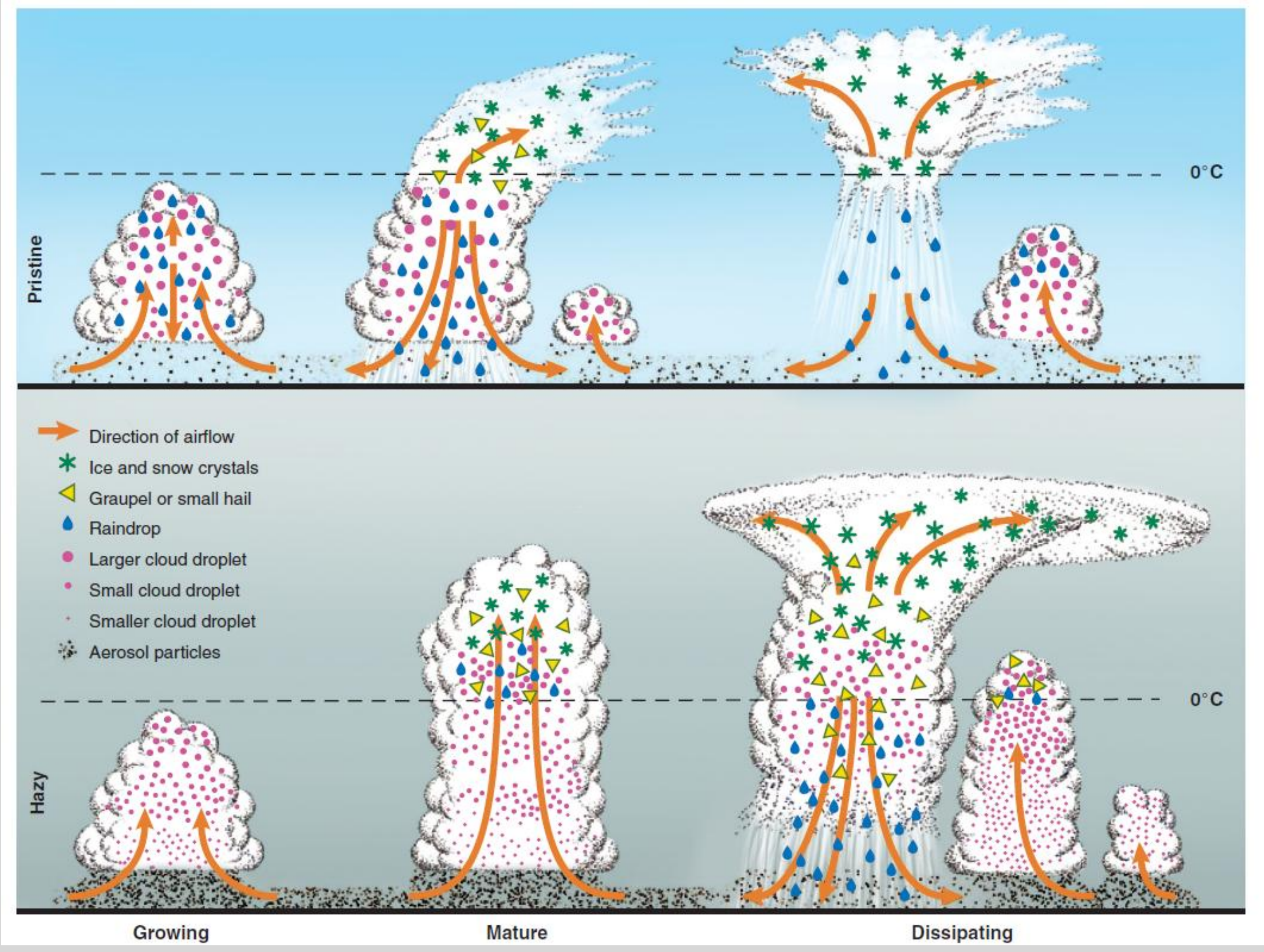

Fig 1. (From Rosenfeld et al (Science, 2008)) "Evolution of deep convective clouds developing in pristine (top) and polluted (bottom) atmosphere."

Parameterization of deep convection in the GFDL AM3

- Based on Donner (1993), Donner et al (2001), and Wilcox and Donner (2007).
- Incorporates cumulus updraft scale vertical momentum dynamics by explicitly solving a steady state equation for vertical velocity that includes effects of entrainment, condensate loading, and buoyancy. Rates of microphysical properties in cumulus cells are strongly dependent on vertical velocity.
- Cloud ensemble consists of a spectrum of plumes each with its own entrainment coefficient and radius.
- Mass flux at the cloud base is determined from the CAPE relaxation closure.
- Convective scheme includes a representation of dynamically active mesoscale circulation with semi-empirical partitioning between mesoscale components of the liquid and ice detrained from convective cells. The partitioning is based on observational studies of Leary and House (1980).
- Mesoscale updraft redistributes vapor detrained from cells, deposits vapor to ice, and detrains to large-scale clouds. Sublimation and evaporation occur in mesoscale and convective scale downdrafts. (Fig. 2)

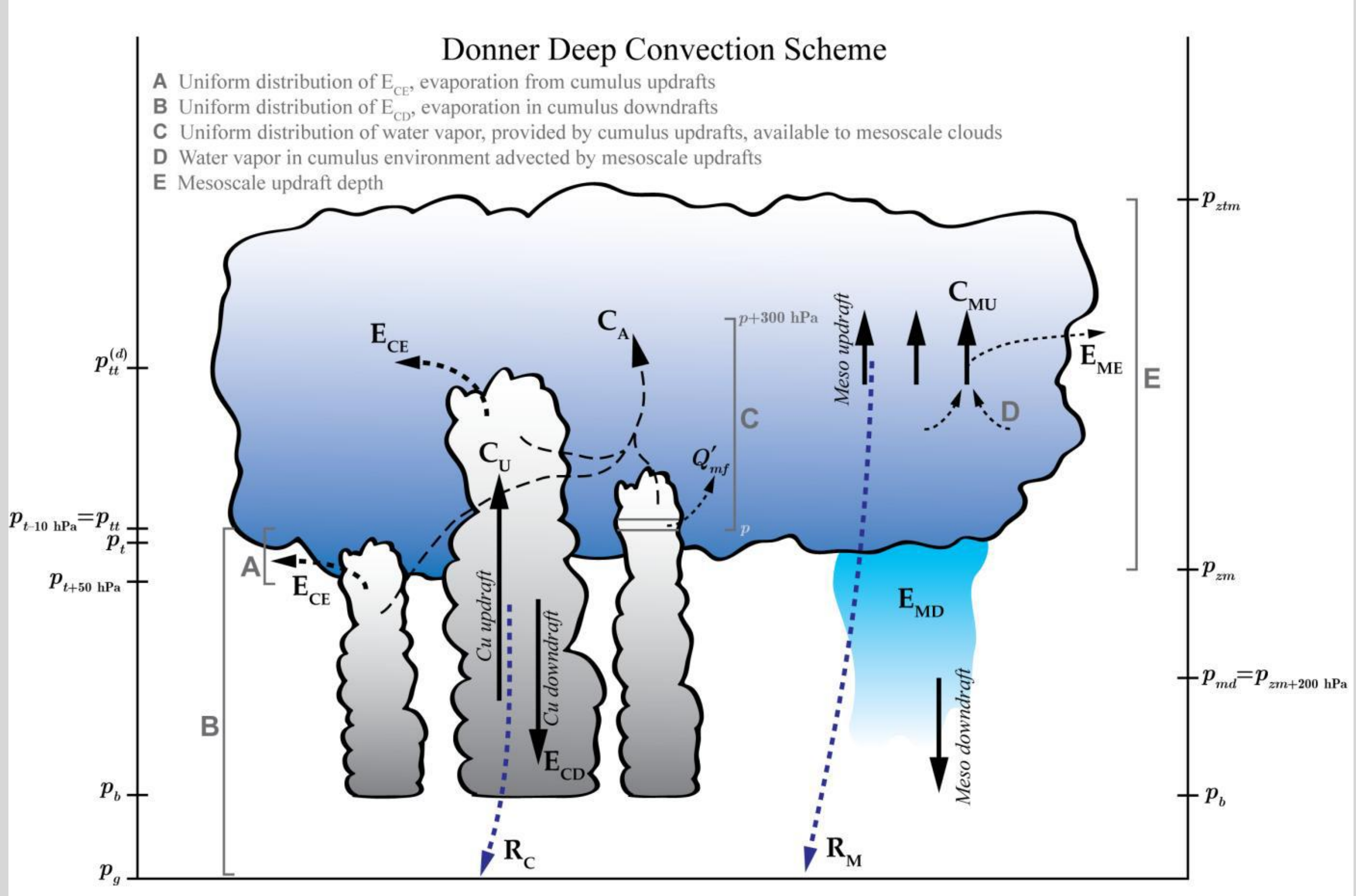

Fig. 2 (from Benedict at al. (2013)). "Diagram of selected physical processes represented in the Donner deep convection scheme. Clouds associated with the cumulus (mesoscale) parameterizations are shaded gray (dark blue). For any member of a spectrum of cumuli, condensate can be formed within convective updrafts (C_U), evaporated directly into the environment (E_{CE}) within the cloud-top zone, evaporated within convective downdrafts (E_{CD}), removed from the cloud as precipitation (R_C), or transported to a mesoscale anvil cloud as liquid (C_A) or vapor (Q'_{mf}). Water substance provided by cumuli to the subgrid-scale anvil can undergo phase changes: condensate can be formed within mesoscale updrafts (C_{MU}), removed as precipitation (R_M), or evaporated into the grid-scale environment from mesoscale updrafts (E_{ME}) or downdrafts (E_{MD})."

Parameterization of deep convection in the GFDL AM3 (cont.)

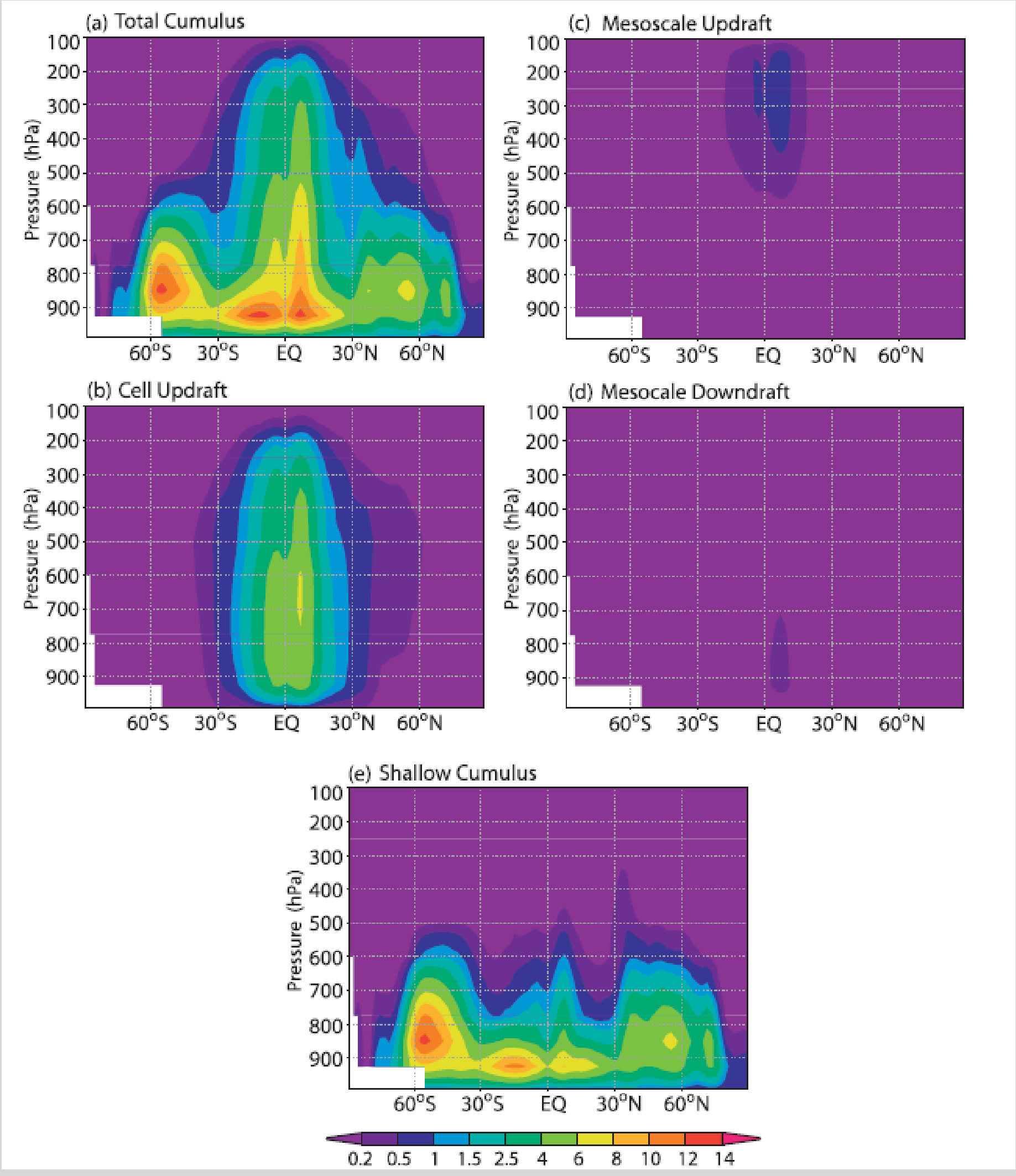

Fig. 3 (from Donner et al (2011)) AM3 annual-mean, zonally averaged cumulus mass fluxes ($g\ m^{-2}\ s^{-1}$) for (a) all convection (except MAA), (b) cell updrafts, (c) mesoscale updrafts, (d) mesoscale downdrafts, and (e) shallow cumulus.

Double Moment Microphysics

- A double-moment cloud microphysical scheme originally developed by Morrison and Gettelman (2008) for the stratiform clouds and later adopted for the deep convection by Song and Zhang (2011) is being implemented in to the GFDL AM3.
- The scheme treats cloud drop, cloud ice, rain, and snow number concentrations and mixing ratios as diagnostic variables and incorporates processes of autoconversion, self-collection, collection between hydrometeor species, sedimentation, ice nucleation, drop activation, homogeneous and heterogeneous freezing, and the Bergeron-Findeisen process (Fig 4).

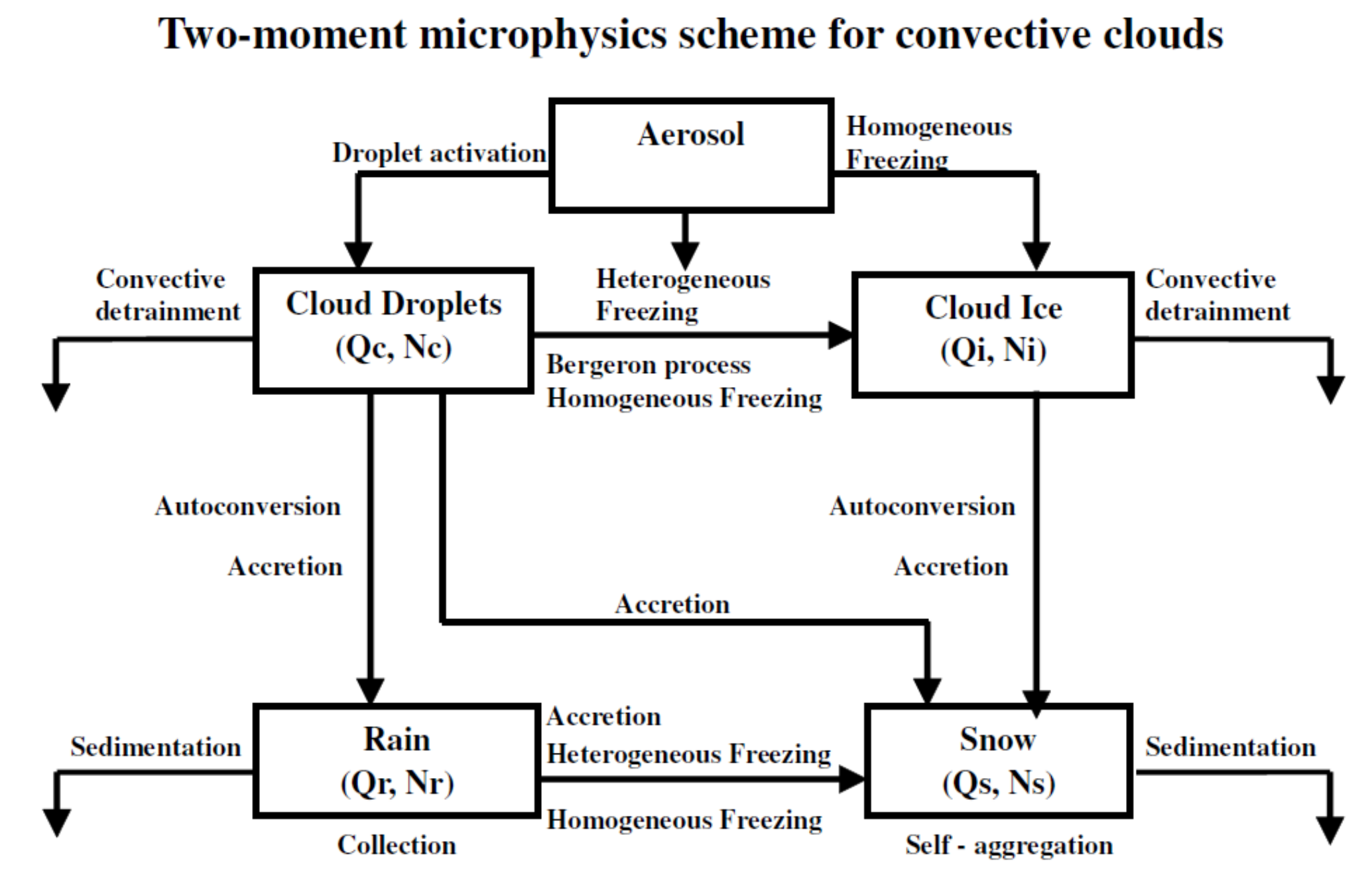

Fig 4. (from Song et al (2012)) Schematic diagram for scheme.

Work in Progress

- As a first step, the scheme is implemented in to the single column version of the GFDL AM3 and will be tested with DOE ARM SGP and TWP forcing data sets, along with others.
- Sensitivity to the details of implementation will be examined.
- Experiments with full GCM will be performed.