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Theoretical analysis of mixing in liquid clouds – Part 3: Inhomogeneous mixing

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Abstract. An idealized diffusion–evaporation model of time-dependent mixing between a cloud volume and a droplet-free volume is analyzed. The initial droplet size distribution (DSD) in the cloud volume is assumed to be monodisperse. It is shown that evolution of the microphysical variables and the final equilibrium state are unambiguously determined by two non-dimensional parameters. The first one is the potential evaporation parameter R, proportional to the ratio of the saturation deficit to the liquid water content in the cloud volume, that determines whether the equilibrium state is reached at 100 % relative humidity, or is characterized by a complete evaporation of cloud droplets. The second parameter Da is the Damkölher number equal to the ratio of the characteristic mixing time to the phase relaxation time. Parameters R and Da determine the type of mixing.

The results are analyzed within a wide range of values of R and Da. It is shown that there is no pure homogeneous mixing, since the first mixing stage is always inhomogeneous. The mixing type can change during the mixing process. Any mixing type leads to formation of a tail of small droplets in DSD and, therefore, to DSD broadening that depends on Da. At large Da, the final DSD dispersion can be as large as 0.2. The total duration of mixing varies from several to 100 phase relaxation time periods, depending on R and Da.

The definitions of homogeneous and inhomogeneous types of mixing are reconsidered and clarified, enabling a more precise delimitation between them. The paper also compares the results obtained with those based on the classic mixing concepts.

1 Introduction

Cloud physics typically investigates two types of turbulent mixing: homogeneous and extremely inhomogeneous (e.g., Burnet and Brenguier, 2007; Andrejczuk et al., 2009; Devenish et al., 2012; Kumar et al., 2012). The concept of extremely inhomogeneous mixing in clouds was introduced by Latham and Reed (1977), Baker and Latham (1979), Baker et al. (1980) and Blyth et al. (1980). According to this concept, mixing of cloud air and sub-saturated air from cloud surrounding results in complete evaporation of a fraction of cloud droplets, whereas the size of other droplets remain unchanged. The studies of extremely inhomogeneous mixing were closely related to investigation of different mechanisms underlying enhanced growth of cloud droplets and warm precipitation formation (Baker et al., 1980; Baker and Latham, 1982). The concept of homogeneous mixing suggests that all the droplets partially evaporate, so the liquid water content decreases while the droplet concentration remains unchanged (Lehmann et al., 2009; Pt1). The significance of the concepts of homogeneous and inhomogeneous mixing goes far beyond formation of large-sized droplets. In fact, these concepts are closely related to the mechanisms involved in formation of droplet size distributions (DSD) in clouds and to the description of this formation in numerical cloud models. A detailed analysis of the classical concepts of homogeneous and extremely inhomogeneous mixing is given by Korolev et al. (2016, hereafter Pt1).

Mixing in clouds includes two processes: mechanical mixing caused by turbulent diffusion and droplet evaporation accompanied by increasing relative humidity. The relative contribution of these processes can be evaluated by compari-

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Equations with Applications).E-mail: karan (at)aegean(dot)gr Ph. D. in Partial Differential Equations, Division of Mathematics (See Section II for details on invited talks in workshops and conferences) . CONTINUOUS DYNAMICAL SYSTEMS A 19 () no. . retirement, International Centre for Mathematical Sciences (ICMS), Edinburgh, 4- 5 April.Computational methods in fractional partial differential equations .. June , - Balikesir, Turkey malizair-ulm.com 19 . In Proceedings of the IEEE International Conference on Computer Vision, pp. Nonlinear differential difference equation and Fourier analysis, J. spaces [3,4,5].A first course in the numerical analysis of differential equations Discrete harmonic functions from local coordinates, Proceedings of the 12th IMA international conference on Mathematics of surfaces XII, p, conference on Chinese Control and Decision Conference, p, June , , Guilin, China.