Cloud-clear air interfaces: Population Balance Equation solutions by considering nucleation information from in-situ measurements, and by modeling the droplet growth on super-saturation fluctuation data from numerical simulation.

Mina Golshan[1], Federico Fraternale[1], Marco Vanni[1] & Daniela Tordella[1]
[1]*Dept. of Applied Science and Technology, Politecnico di Torino, Torino, Italy*

In this study we will present a preliminary analysis of the droplet population as hosted by a turbulent shear-less mixing air flow which is mimicking a cloud/clear-air interface. The interface is subject to density stratification and vapor density fluctuation under super-saturation conditions. We use the Population Balance Equation (PBE) as a tool to represent a few aspects of the droplet size dynamics by taking into consideration both turbulence results coming from in-situ and laboratory measurements and from numerical simulations. In particular, we use the PBE formulation proposed by Park and Rogak in 2004 [1]

$$\frac{\partial n(v,t)}{\partial t} + \frac{\partial (n(v,t)G(v))}{\partial v} = \frac{1}{2}\int_0^v \beta(v-\bar{v}\,,\bar{v})n(v-\bar{v}\,,t)n(\bar{v}\,,t)d\bar{v}\,,$$

where $n(v,t)$ is the numerical density of drops with volume v at the time t, $G(v) = dv/dt$ is the droplet growth/fallout and $\beta(v-\bar{v}\,,\bar{v})$ is the kernel describing the aggregation/coalescence interaction between drops of different size. Although, at the state of the art, fragmentation can be included in an approximate way in the global process of aggregation–breakage [2], we consider here the aggregation process alone because nowadays cloud simulations can take into consideration only aggregation (by single or multiple coalescence). The kernel $\beta(v-\bar{v}\,,\bar{v})$ depends on the size of colliding particles and the local turbulent dissipation rate according to the classical relationship by Saffman & Turner [3]. However, in the future we foresee to better this representation by exploiting the statistics on the collisions that can be directly deduced from the simulations.

We aim at observing the population distribution evolution by exploiting information both from numerical simulation of a turbulent cloud interface and in-situ/laboratory measurements. The first aim is reached: i) by using as initial condition for the PBE particle size distributions obtained from direct numerical simulations of cloud-clear air interfaces [4, 5] and ii) by introducing inside the growth/fallout rate, which is directly proportional to supersaturation variability, statistical information on the fluctuation of the supersaturation field at the various transient stages of the turbulence in the system portion we are actually simulating (a volume of 0.25 m x 0.25 m x 0.5 m across the cloud/clear-air interface, 512x512x1024 grid points). The model is based on a series expansion up to the fourth-order moment of the fluctuation. The second aim is reached by introducing via the boundary condition, always placed at the droplet nucleation size, information from the time derivative of the numerical density $n(v,t)$ observed in the in-situ experiment by Ovadnevaite et al., 2016 [6], and in CERN CLOUD laboratory experiment [7], http://cloud.web.cern.ch and
http://www.goethe-university-frankfurt.de/65418923/The_CLOUD_Experiment.
Starting from three different monodisperse distributions of 6, 18 and 25 microns in radius, the time broadening of the drop size distribution and the position and value of the peak of the distribution are characterized in terms of the supersaturation variability [8] and are contrasted with the available in-situ observations and numerical simulations.

References

[1] S.H. Park, S.N. Rogak. A novel fixed-sectional model for the formation and growth of aerosol agglomerates *J. Aerosol Sci.* **35**: 1385-1404, 2004.
[2] M.Vanni. Approximate population balance equations for aggregation-breakage processes, *J. Colloid Interf. Sci.* **221 :** 143–160, 2000
[3] P. G. Saffmann and J. F. Turner. On the collision of drops in turbulent clouds *J. Fluid Mech.*, **1**:16-30, 1956.
[4] D. Codoni, V. Ruggiero, D. Tordella. PRACE White Paper, Type C project 2010PA3699, 2018. http://www.prace-ri.eu/IMG/pdf/WP266.pdf
[5] D. Codoni et al., EGU General Assembly 2018, **20**, Geophysics Research Abstracts; D. Codoni et al. Euromech. Colloquium **596**, Numerical simulations of flows with particles, bubbles and droplets. 9 - 11 May 2018, Venice, Italy.
[6] J. Ovadnevaite et al. Surface tension prevails over solute effect in organic-influenced cloud droplet activation, *Nature*, **546**, 2017.
[7] J.Curtius. Nucleation of atmospheric particles *Eur. Phys. Journal Conferences* **1**: 199-209, 2009.
[8] K.K.Chandrakar et al. Aerosol indirect effect from turbulence-induced broadening of cloud-droplet size distributions, *PNAS*, **113**, 2016.