Cloud Formation and Dynamics: a Field-Theoretic Approach

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The formation of clouds and their dynamics are highly complex processes occurring in atmospheric physics. A cloud is made of water droplets and vapour, whose interplay through condensation, evaporation and sedimentation determines the cloud's evolution. In this project, we employ a novel combination of the Doi-Peliti and Martin-Siggia-Rose (MSR) field-theoretic frameworks to model cloud formation processes [1] [2]. Our approach offers a complete analytical formulation for interacting particle systems with time-evolving background fields. Its application to cloud microphysics represents a new perspective in atmospheric science, where most current models rely heavily on numerical simulations and large usage of data [3].

In our initial simplified model, we describe cloud formation using a Master Equation to a coupled Langevin equation: the former governing droplet formation as a discrete stochastic process, and the latter describing vapour dynamics as a continuous background field. These processes are mutually coupled through feedback. We cast these dynamics into a combined Doi-Peliti and MSR action. We analytically characterise statistical properties of the water droplets such as its expected number, fluctuations, and its correlation with the vapour field in a perturbation expansion about weak coupling. The results of this perturbative approach are supported numerically using Monte Carlo simulations. Our theoretical approach can be applied to other systems where particle-field interactions play an important role. This is the case, for instance, in the formation of amyloid aggregates that cause Alzheimer's disease [4] [5].

References

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