11th European Turbulence Conference

Role of turbulence for droplet condensation

Antonio Celani[a] Andrea Mazzino[bc]
Agnese Seminara[ac] Marco Tizzi[bc]

[a]Centre National de la Recherche Scientifique, Institut Non Linéaire de Nice

[b]Università di Genova, Dipartimento di Fisica

[c]Istituto Nazionale di Fisica Nucleare, sezione di Genova

Porto, Wednesday 27th June 2007

outline

condensation crucial role

three consecutive stages

- heterogeneous nucleation
- condensation
- collision and coalescence
- . . . precipitation

during condensation stage

- droplet radii spectrum broadens

condensation crucial role

three consecutive stages

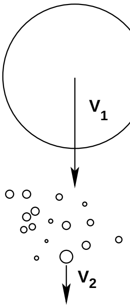
- heterogeneous nucleation
- condensation
- collision and coalescence
- . . . precipitation

during condensation stage

- droplet radii spectrum broadens

condensation crucial role

three consecutive stages



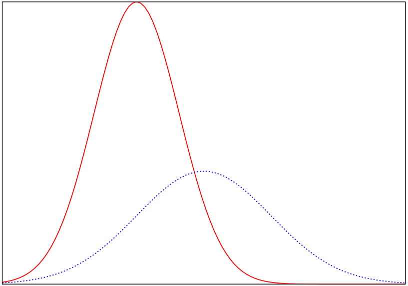
- heterogeneous nucleation
- condensation
- collision and coalescence
- . . . precipitation

during condensation stage

- droplet radii spectrum broadens

condensation crucial role

three consecutive stages



- heterogeneous nucleation
- condensation
- collision and coalescence
- . . . precipitation

during condensation stage

- droplet **radii spectrum broadens**

classical model failure

description hypotheses for condensation

- *mean field* type description
- evolution of an ascending small *fluid parcel*

$$\frac{d}{dt}R^2 = 2A_3 s$$

$$\sigma_{R^2}(t) = \sigma_{R^2}(0)$$

results

- no broadening size spectrum

classical model failure

description hypotheses for condensation

- *mean field* type description
- evolution of an ascending small *fluid parcel*

droplet evolution law

$$\frac{d}{dt}R^2 = 2A_3 s$$

$$\sigma_{R^2}(t) = \sigma_{R^2}(0)$$

results

- no broadening size spectrum

classical model failure

description hypotheses for condensation

- *mean field* type description
- evolution of an ascending small *fluid parcel*

droplet evolution law

$$\frac{d}{dt}R^2 = 2A_3 s$$

$$\sigma_{R^2}(t) = \sigma_{R^2}(0)$$

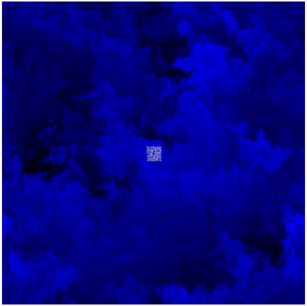
results

- **no broadening size spectrum**

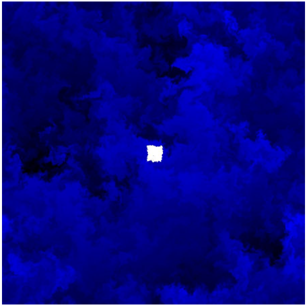
turbulence in a fluid parcel

temporal and local fluctuations are not enough

confined droplets



free droplets



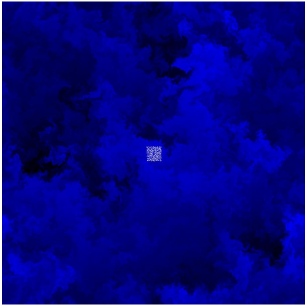
droplets are transported in the whole cloud

- the fluid parcel is not a proper tool

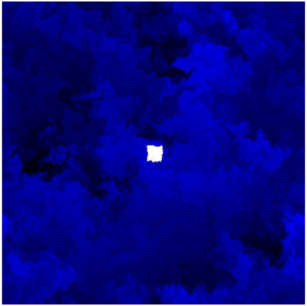
turbulence in a fluid parcel

temporal and local fluctuations are not enough

confined droplets



free droplets



droplets are transported in the whole cloud

- the **fluid parcel** is **not** a **proper tool**

a global approach

2d A. Celani, G. Falkovich, A. Mazzino, A. Seminara 2005
Europhys. Lett. **70** ***6***

3d A. Lanotte, A. Seminara, F. Toschi 2007
submitted to *J. Atmos. Sci.*

- turbulent field fluctuations were considered

$$\overline{w}, \overline{s} \quad \longrightarrow \quad \boldsymbol{v}(\boldsymbol{x}, t), s(\boldsymbol{x}, t)$$

- the whole cloud core was analysed

$$L \sim 1\ \mathrm{m} \quad \longrightarrow \quad L \sim 1\ \mathrm{km}$$

results

- there is a **correlation** between **trajectories and supersaturation**
- a **broadening size spectrum** is observed

a global approach

2d A. Celani, G. Falkovich, A. Mazzino, A. Seminara 2005 *Europhys. Lett.* **70 *6***

3d A. Lanotte, A. Seminara, F. Toschi 2007 submitted to *J. Atmos. Sci.*

- turbulent field fluctuations were considered

$$\overline{w}, \overline{s} \longrightarrow \boldsymbol{v}(\boldsymbol{x}, t), s(\boldsymbol{x}, t)$$

- the whole cloud core was analysed

$$L \sim 1\ \mathrm{m} \longrightarrow L \sim 1\ \mathrm{km}$$

results

- there is a **correlation** between **trajectories and supersaturation**
- a **broadening size spectrum** is observed

a global approach

2d A. Celani, G. Falkovich, A. Mazzino, A. Seminara 2005 *Europhys. Lett.* ***70 6***

3d A. Lanotte, A. Seminara, F. Toschi 2007 submitted to *J. Atmos. Sci.*

- turbulent field fluctuations were considered

$$\overline{w}, \overline{s} \quad \longrightarrow \quad \boldsymbol{v}(\boldsymbol{x}, t), s(\boldsymbol{x}, t)$$

- the whole cloud core was analysed

$$L \sim 1 \text{ m} \quad \longrightarrow \quad L \sim 1 \text{ km}$$

results

- there is a **correlation** between **trajectories and supersaturation**
- a **broadening size spectrum** is observed

a strongly coupled system

more realistic cloud dynamics

turbulent convective motions

$$\partial_t \boldsymbol{v} + \boldsymbol{v} \cdot \boldsymbol{\partial} \boldsymbol{v} = -\frac{1}{\rho} \boldsymbol{\partial} p + \Big(1 - \beta\big(T - T_{\mathrm{m}}\big)\Big) \boldsymbol{g} + \nu \partial^2 \boldsymbol{v}$$

$$\partial_t T + \boldsymbol{v} \cdot \boldsymbol{\partial} T = -\Gamma w + \varkappa \partial^2 T$$

$$\partial_t s + \boldsymbol{v} \cdot \partial s = A_1 w - \frac{s}{\tau_{\mathrm{s}}\big(\boldsymbol{X}_i(t), R_i(t)\big)} + D \partial^2 s$$

$$\frac{d}{dt} \boldsymbol{X}_i(t) = \boldsymbol{v}\big(\boldsymbol{X}_i(t), t\big) + \sqrt{2D}\, \eta_i(t)$$

$$\frac{d}{dt} R_i^2(t) = 2 A_3 s\big(\boldsymbol{X}_i(t), t\big)$$

a strongly coupled system

local vapour absorption by droplets

droplet local feedback on vapour

$$\partial_t \boldsymbol{v} + \boldsymbol{v}\cdot\boldsymbol{\partial}\boldsymbol{v} = -\frac{1}{\rho}\boldsymbol{\partial}p + \Big(1 - \beta\big(T - T_{\mathrm{m}}\big)\Big)\boldsymbol{g} + \nu\partial^2\boldsymbol{v}$$

$$\partial_t T + \boldsymbol{v}\cdot\boldsymbol{\partial}T = -\Gamma w + \varkappa\partial^2 T$$

$$\partial_t s + \boldsymbol{v}\cdot\boldsymbol{\partial}s = A_1 w - \frac{s}{\tau_{\mathrm{s}}\big(\boldsymbol{X}_i(t), R_i(t)\big)} + D\partial^2 s$$

$$\frac{d}{dt}\boldsymbol{X}_i(t) = \boldsymbol{v}\big(\boldsymbol{X}_i(t), t\big) + \sqrt{2D}\boldsymbol{\eta}_i(t)$$

$$\frac{d}{dt}R_i^2(t) = 2A_3 s\big(\boldsymbol{X}_i(t), t\big)$$

an undersaturated environment

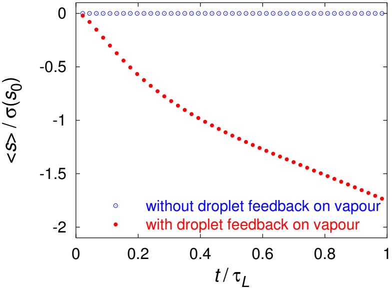
consequences of the Lagrangian feedback on vapour

- absorption frequency field

$$\frac{1}{\tau_s}(\boldsymbol{x},t) \propto \sum_i^{N(\boldsymbol{x},t)} R_i(t)$$

- mean supersaturation

$$\frac{d}{dt}\langle s(\boldsymbol{x},t)\rangle = -\left\langle \frac{s(\boldsymbol{x},t)}{\tau_s(\boldsymbol{x},t)} \right\rangle$$



negative mean supersaturation

- clue of correlation

an undersaturated environment

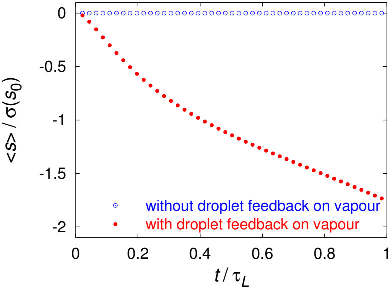
consequences of the Lagrangian feedback on vapour

- absorption frequency field

$$\frac{1}{\tau_s}(\boldsymbol{x},t) \propto \sum_{i}^{N(\boldsymbol{x},t)} R_i(t)$$

- mean supersaturation

$$\frac{d}{dt}\langle s(\boldsymbol{x},t)\rangle = -\langle \frac{s(\boldsymbol{x},t)}{\tau_s(\boldsymbol{x},t)} \rangle$$

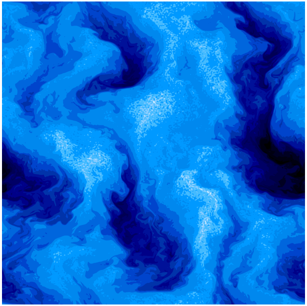


negative mean supersaturation

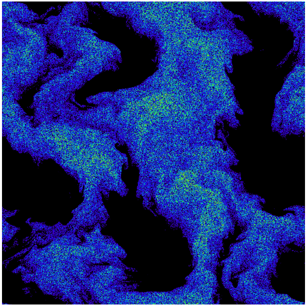
- **clue of correlation**

a selection mechanism

with convection and Lagrangian feedback



supersaturation



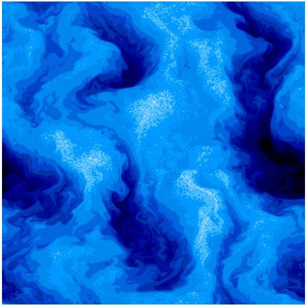
absorption frequency

droplets are in supersaturated regions

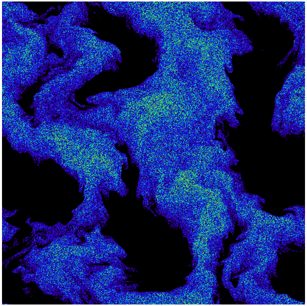
- there is correlation

a selection mechanism

with convection and Lagrangian feedback



supersaturation



absorption frequency

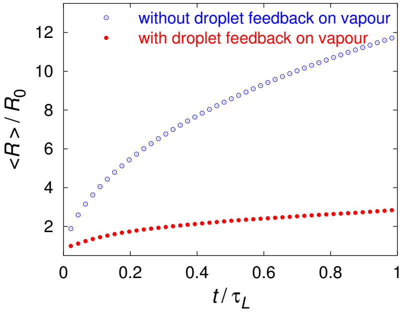
droplets are in supersaturated regions

- **there is correlation**

growth by condensation

bigger droplets absorb more vapour

$$\frac{d}{dt}\langle R_i^2\rangle = 2A_3\langle s\rangle_{\mathrm{lag}} \neq 2A_3\langle s\rangle$$



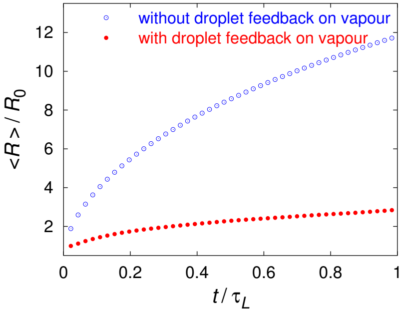
the mean radius

- still grows

growth by condensation

bigger droplets absorb more vapour

$$\frac{d}{dt}\langle R_i^2\rangle = 2A_3\langle s\rangle_{\text{lag}} \neq 2A_3\langle s\rangle$$

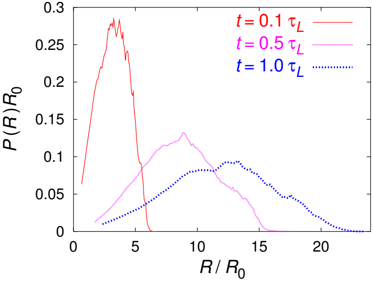


the mean radius

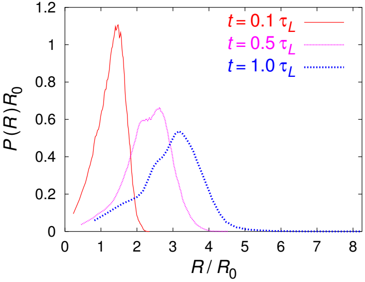
- still **grows**

a reduced broadening

size spectrum evolution



without feedback



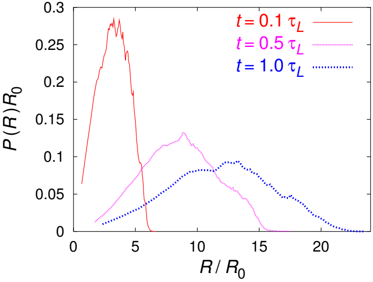
with feedback

size spectrum

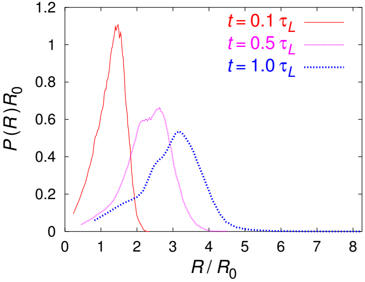
- broadens

a reduced broadening

size spectrum evolution



without feedback



with feedback

size spectrum

- **broadens**

conclusions

- very different conditions known by droplets
- correlation between trajectories and vapour field
- broadening size spectrum because of correlation
- effects reduced, not destroyed, by droplet feedback

A. Celani, A. Mazzino, A. Seminara, M. Tizzi 2007
J. Turbul. **8** ***17***

perspectives

- curvature and solute effects

$$\frac{d}{dt}R^2 = 2A_3\left(s - \frac{c}{R} + \frac{h}{R^3}\right)$$

- wet adiabatic cooling
- wet buoyancy
- more droplets
- coalescence stage

perspectives

- curvature and solute effects

$$\frac{d}{dt}R^2 = 2A_3\left(s - \frac{c}{R} + \frac{h}{R^3}\right)$$

- wet adiabatic cooling
- wet buoyancy
- more droplets
- coalescence stage

outline

1. an open problem
   - warm cloud development
   - the classical model
   - first turbulent models
2. model formulation
   - a global turbulent model
   - a convective turbulent model
3. two-dimensional numerical analysis
   - a correlation mechanism
   - spectrum broadening
   - conclusions and perspectives