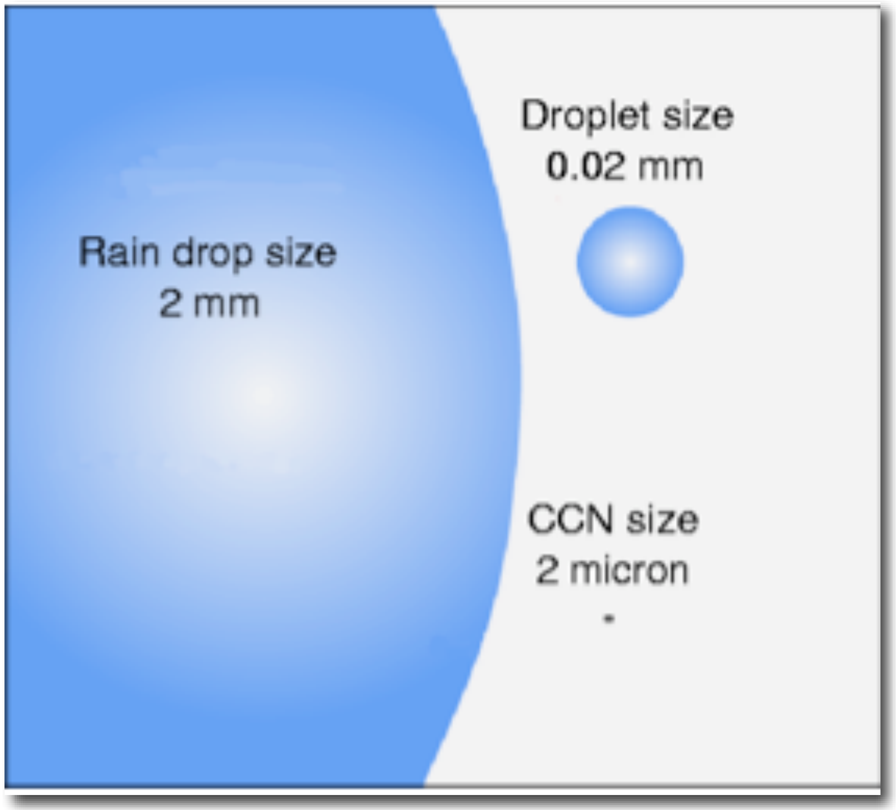
Condensation of cloud microdroplets in homogeneous isotropic turbulence



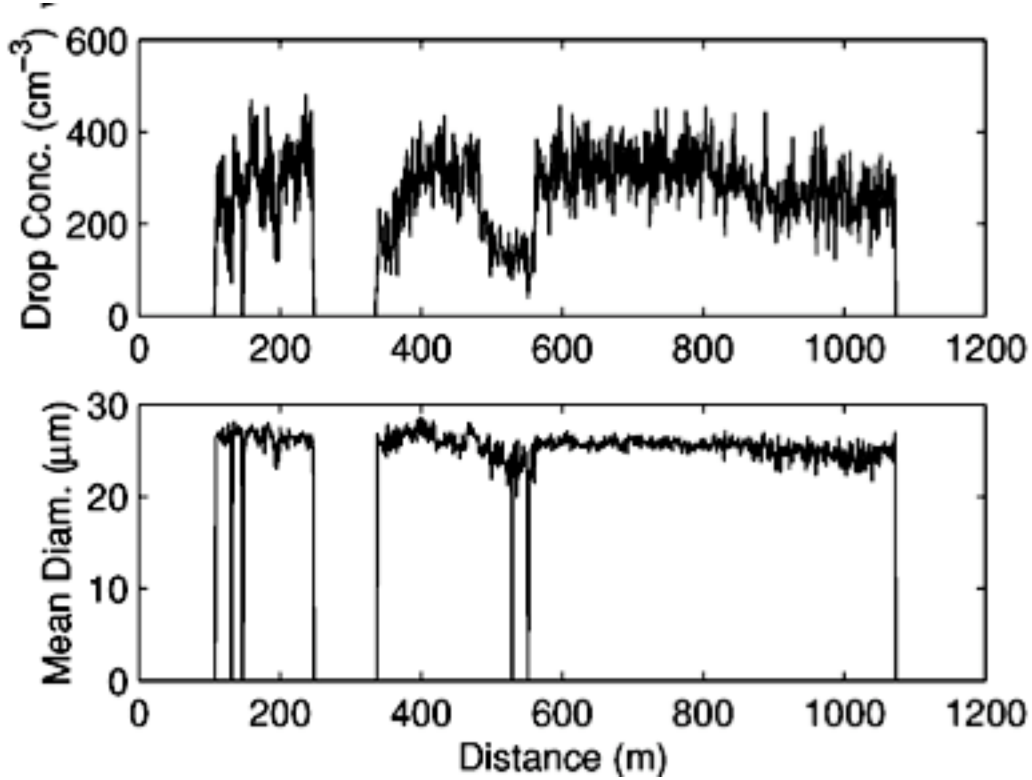
Alessandra Lanotte

CNR ISAC, Rome, Italy

Informal KITP talk

A traverse through a warm cloud

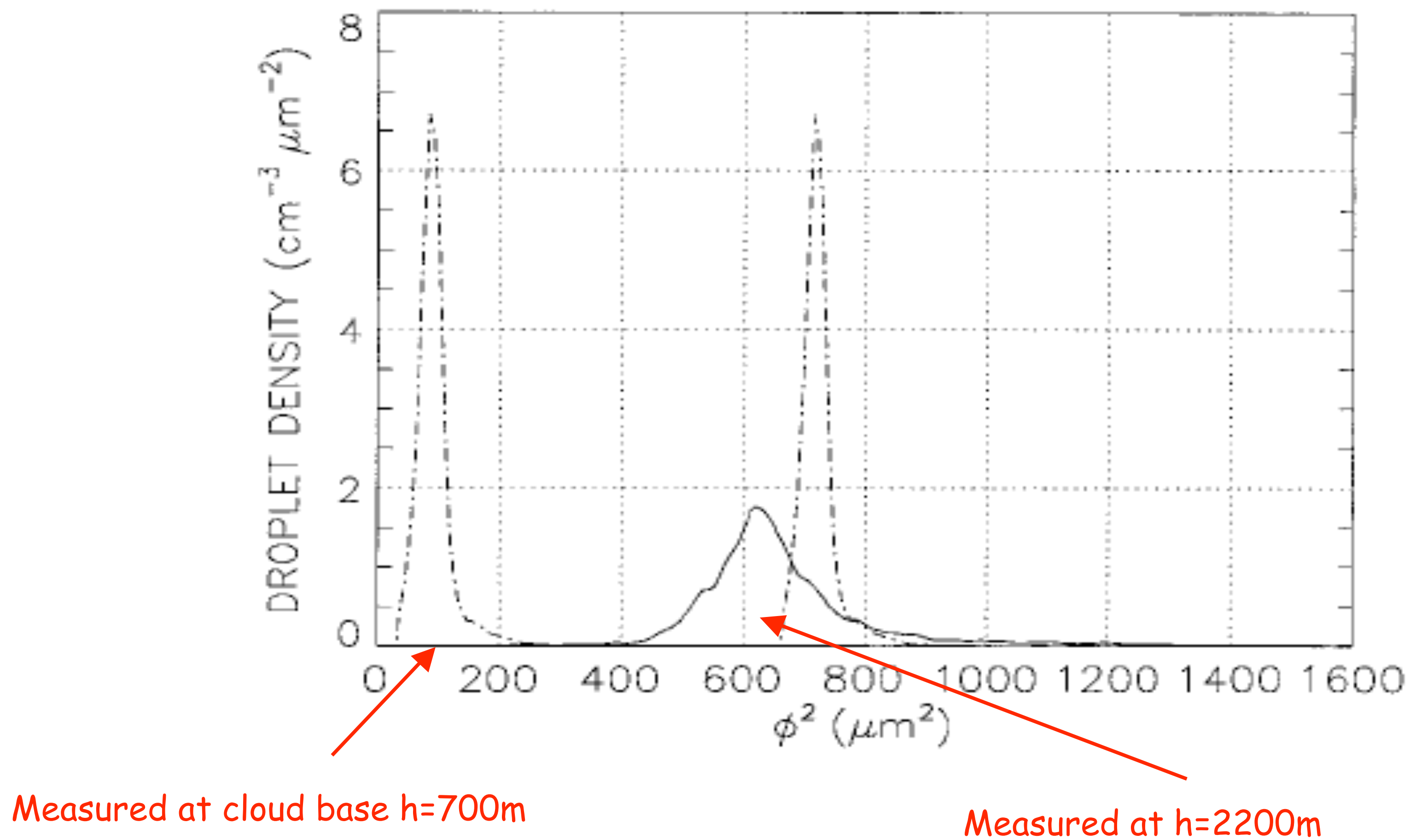
From R. Shaw, Ann. Rev. Fluid Mech 2003



- Drop concentration is not at all homogeneous in space.
- Fluctuations of mean radius down to zero means that dry and cloudy air are segregated during mixing.

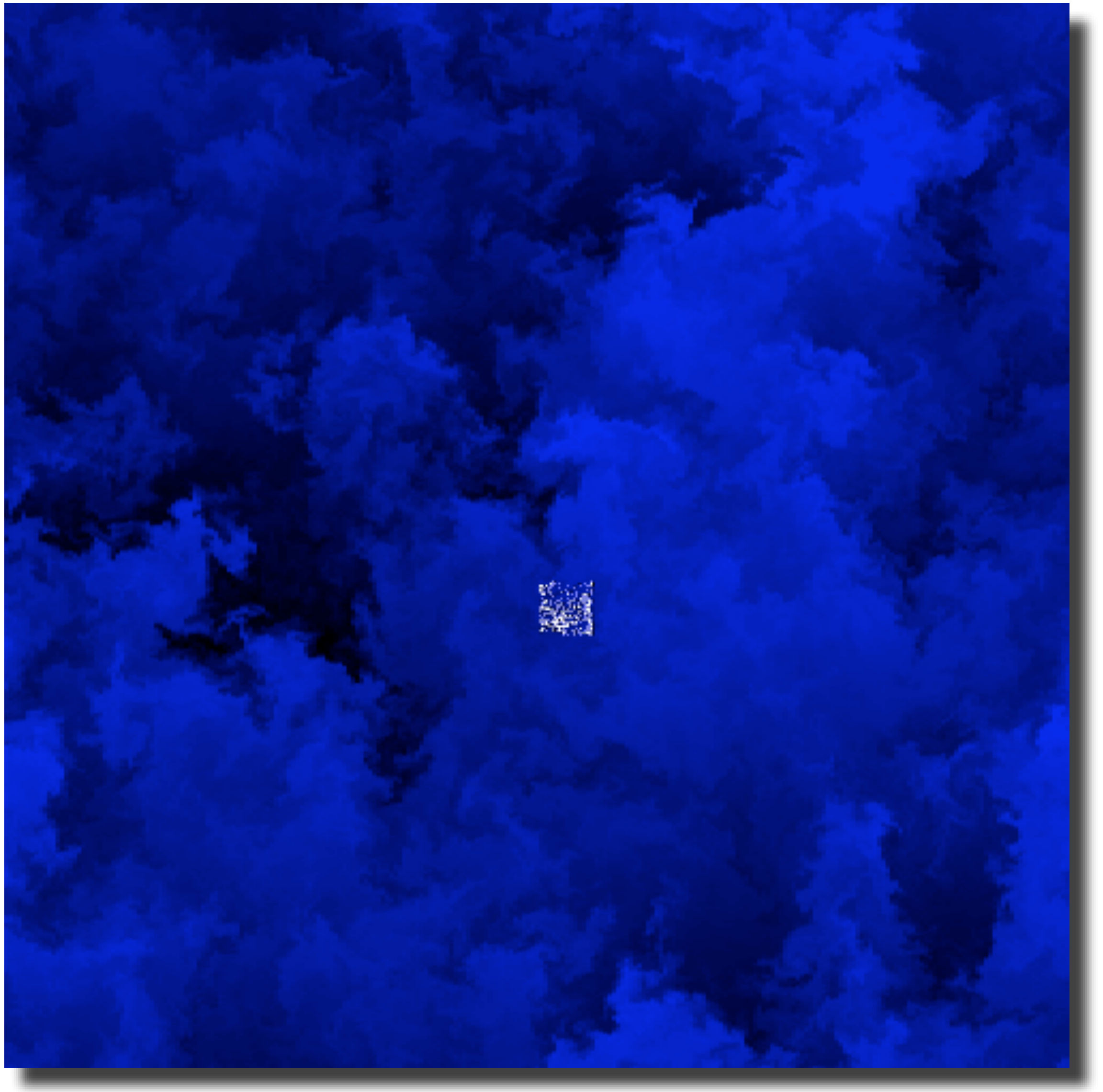
Droplet size spectrum

From JL. Brenguier & L. Chaumat, JAS 2001

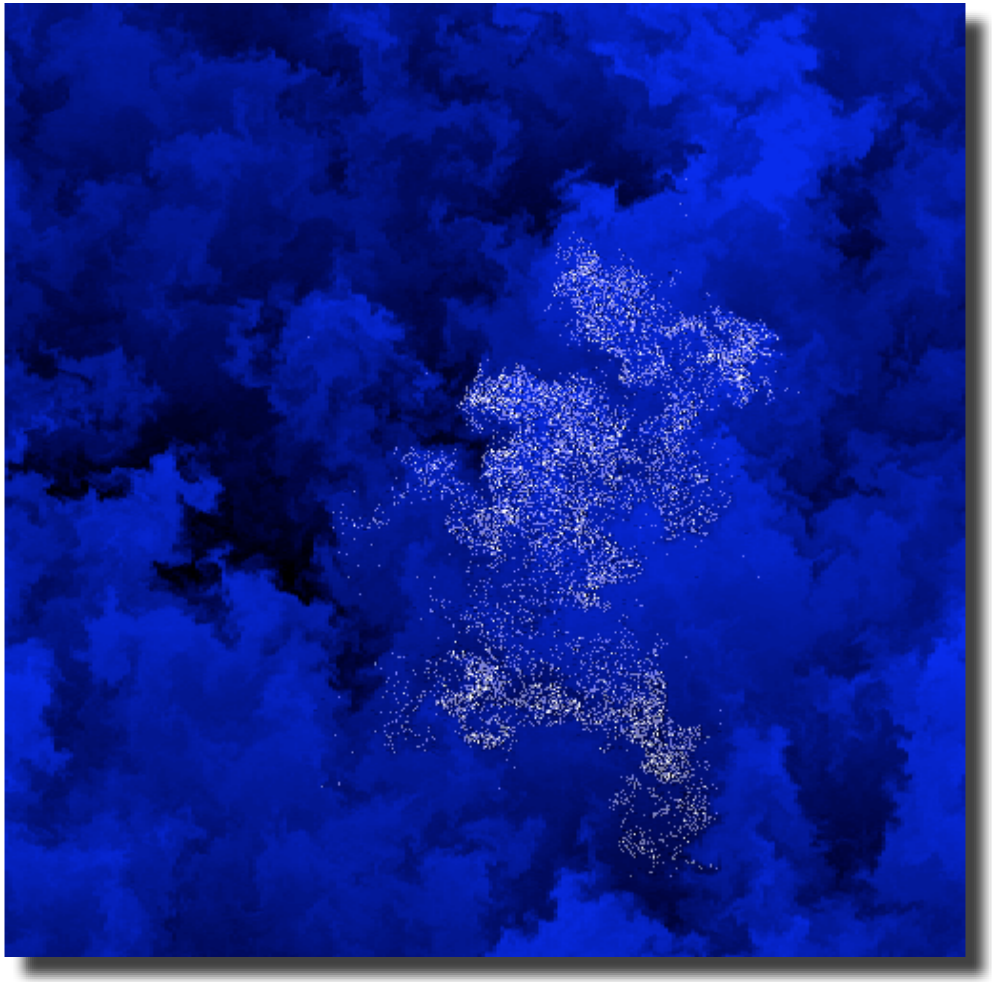


average LWC= 2.5 gr/m^3; average #drops= 250 drops/cm^3

Parcel Model



Beyond air parcel model



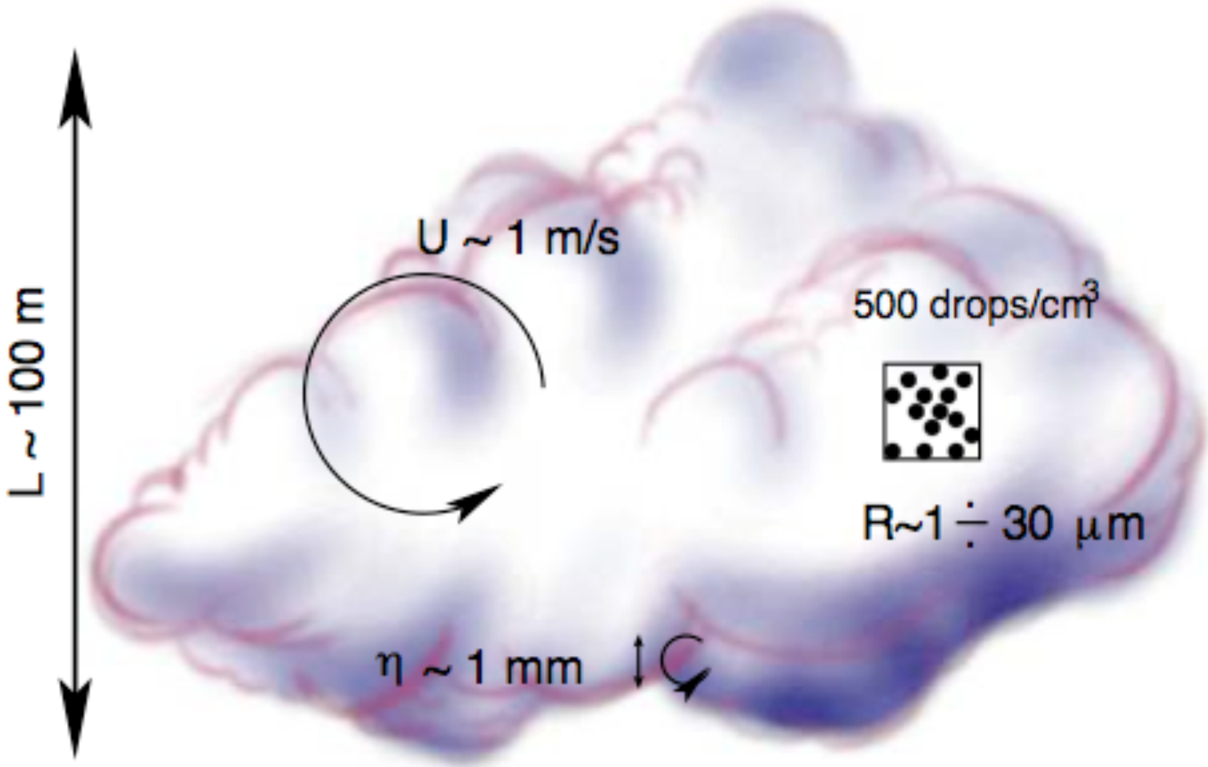
Role of flow & vapour turbulence
for droplet spectrum broadening
during condensation

$$\langle (\mathbf{X}_1(t) - \mathbf{X}_2(t))^2 \rangle \simeq \epsilon t^3$$

$$\rightarrow < r^2 >^{1/2} \sim (3-100)m,\ t = (10-100)s, \epsilon = 10^{-2} m^2/s^3$$

Warm non-precipitating cloud

τ_η= 0.1 s; ε= 10^{-3}-$10^{-2}m^2/s^3$; Re=10^7; concentration 150-500drops/cm^3



Note: Typical Stokes numbers: St ≈ 0.001 ÷ 0.9 for R ≈ 1 ÷ 30 μm

Generalized Twomey's model equations

(Twomey, Geofis. Pura Appl. 43, 1959)

$$s(\mathbf{x},t) = e/e_s(\mathbf{x},t) - 1$$

- $$\partial_t \mathbf{u} + u \cdot \nabla \mathbf{u} = -\nabla p + \nu \Delta \mathbf{u} + f$$
  $$\partial_t s + u \cdot \nabla s = A_1 u_z - \frac{s}{\tau_s} + \kappa \Delta s$$

$$\tau_s^{-1} \sim n < R >$$

supersaturation absorption time

$$\frac{dX}{dt} = V(t)$$

- $$\frac{dV}{dt} = -\frac{V(t) - u(X(t),t))}{\tau_d} + g$$
  $$\frac{dR^2}{dt} = A_3 s(X(t),t)$$

$$\tau_d \sim R^2/(\nu\beta)$$

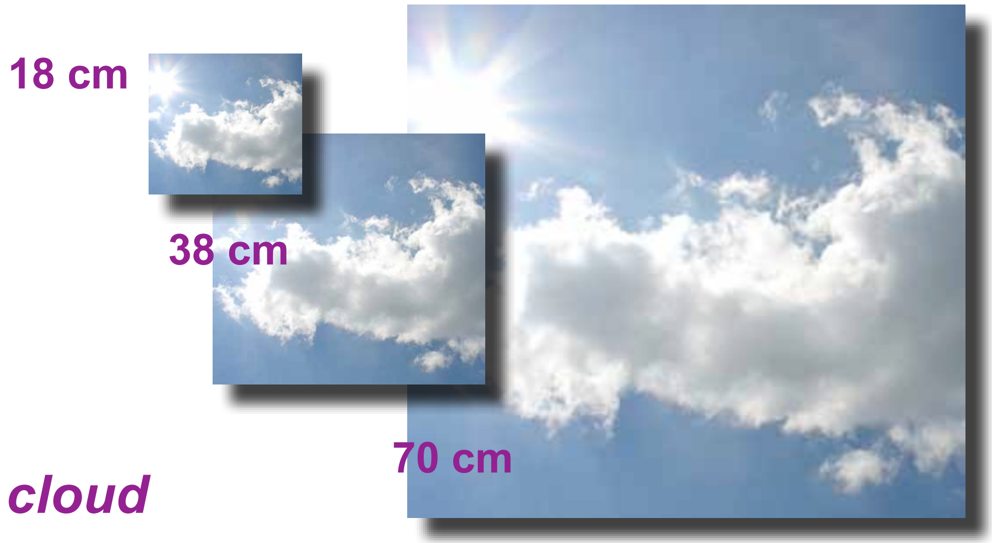
particle Stokes time

DNS for droplet condensation in turbulent flows

# = 130 drops/cm^3, ε = 0.001 m^2/s^3; v_rms=0.1 m/s; η =1mm
LWC= 0.07; 1.2 g/m^3; R0= 5; 13 μm ; St= 0.005; 0.035

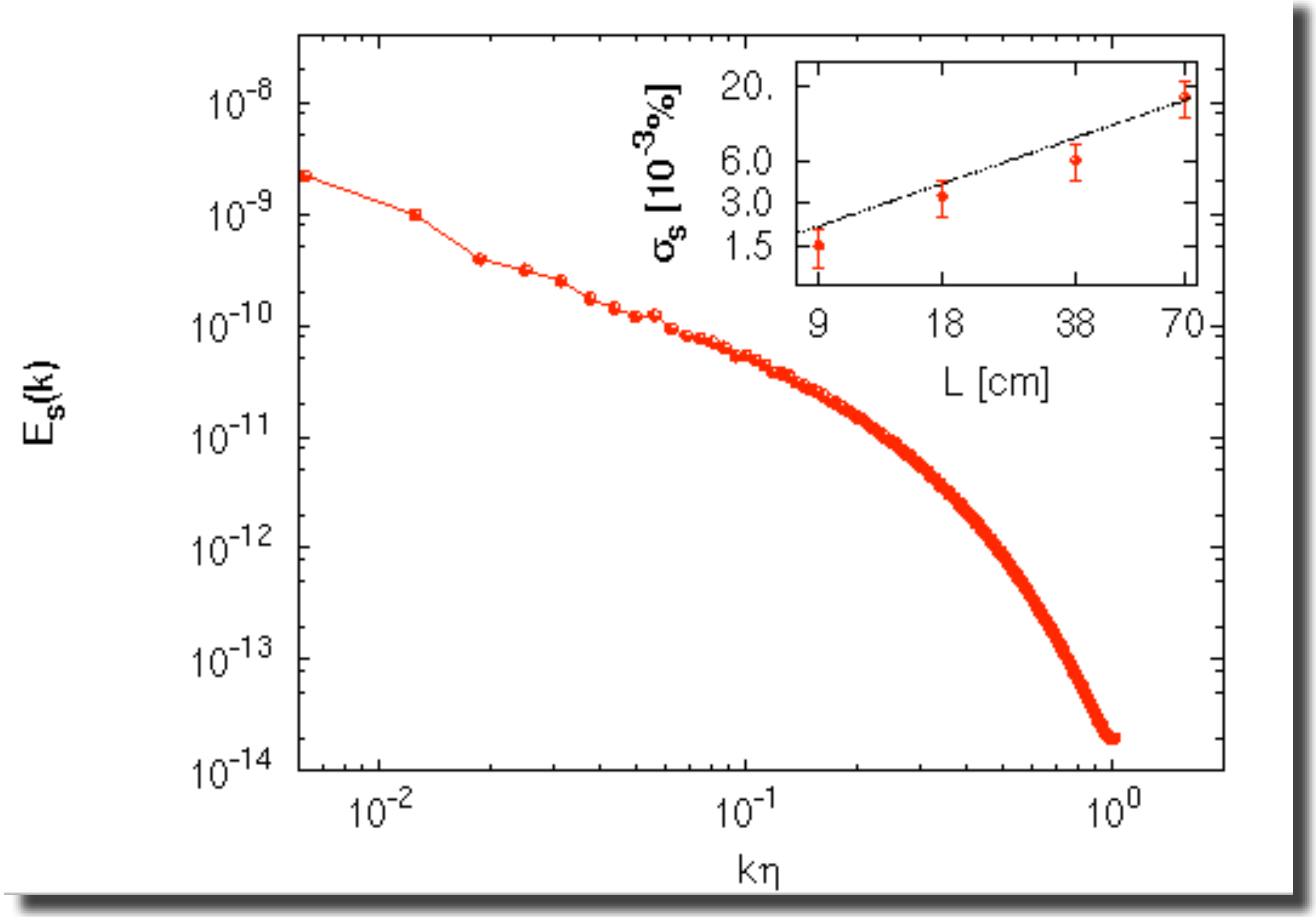
N^3	L	Re_λ
64^3	0.09m	40
128^3	0.18m	65
256^3	0.38m	105
512^3	0.70m	185
….	….	….
…	100m	~10^3

real cloud

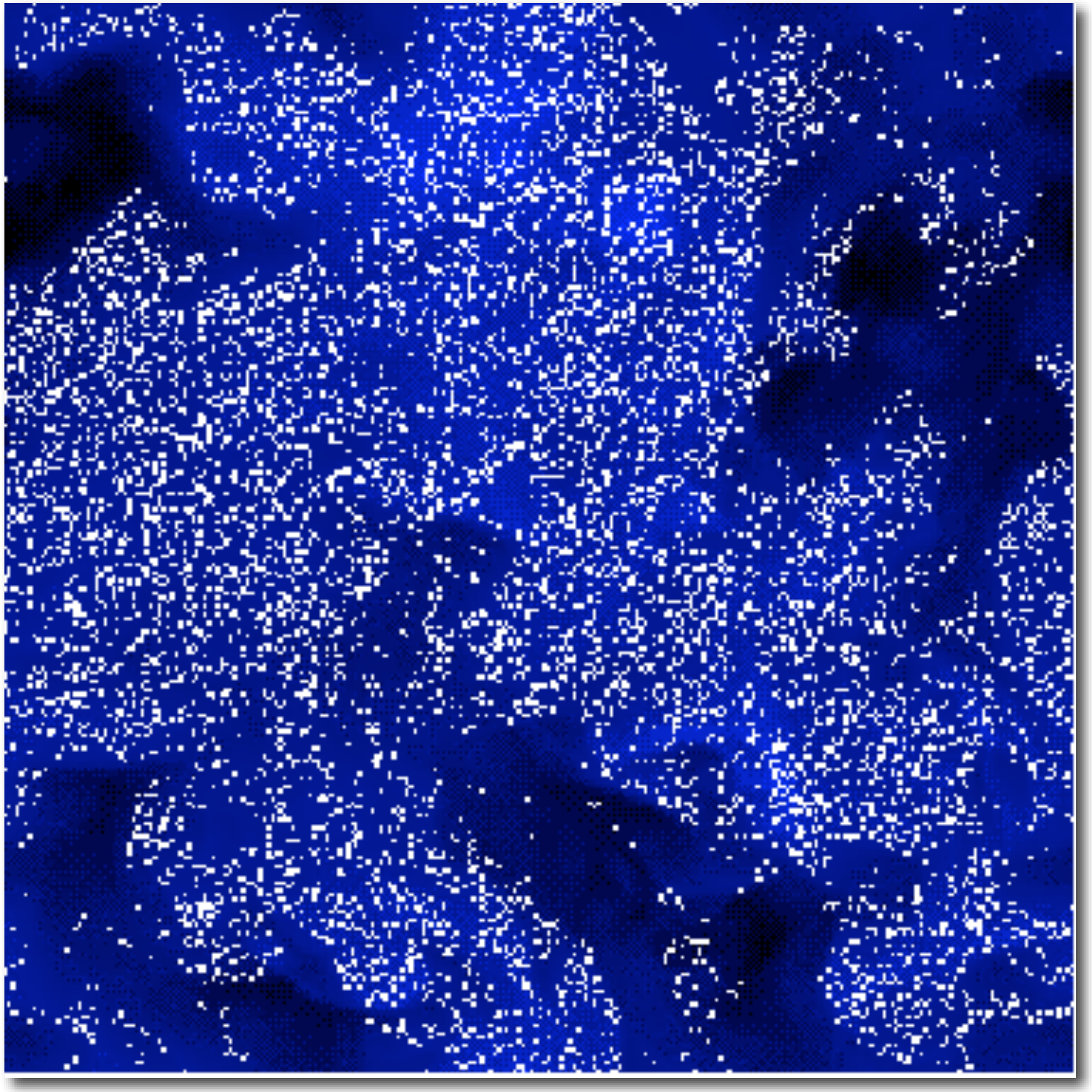


L=70 cm --> 32 Millions of droplets starting from a delta-function distribution in size

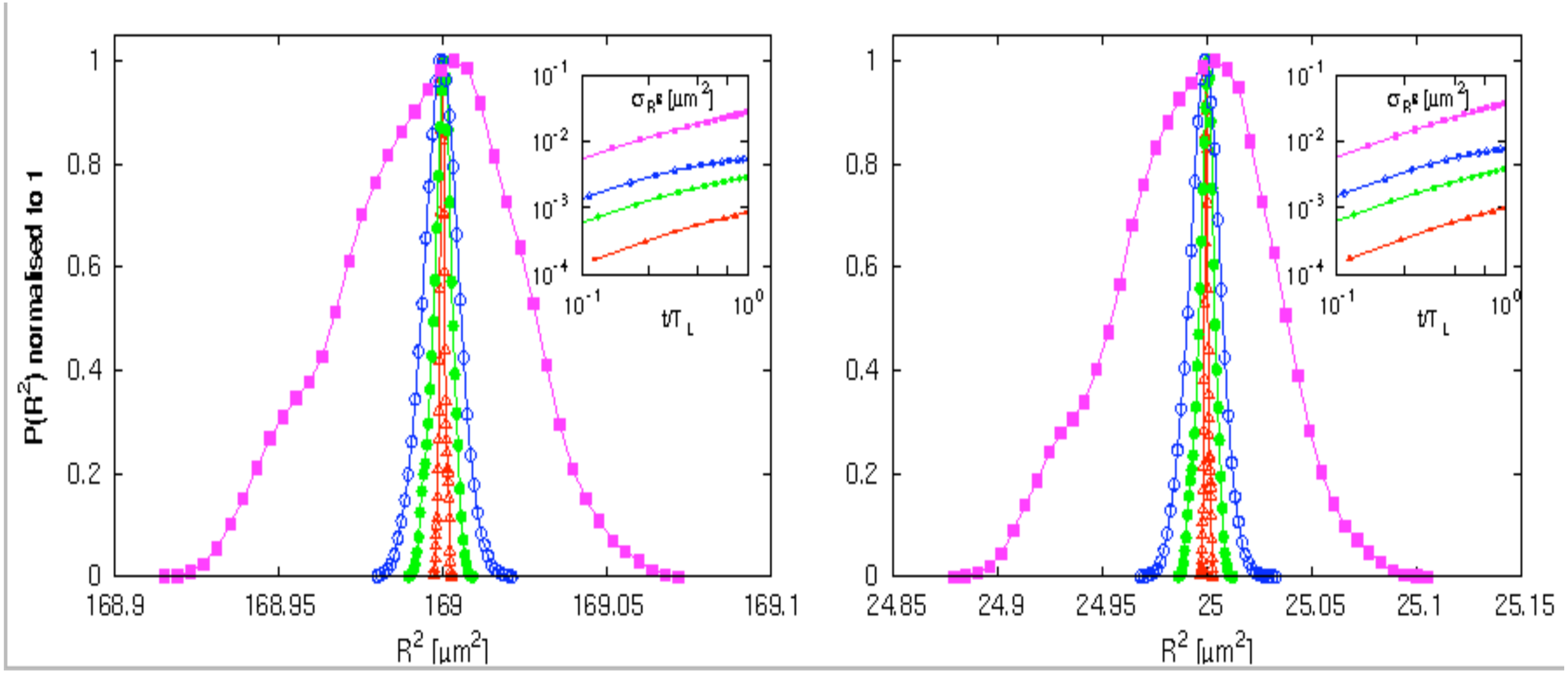
Supersaturation fluctuations



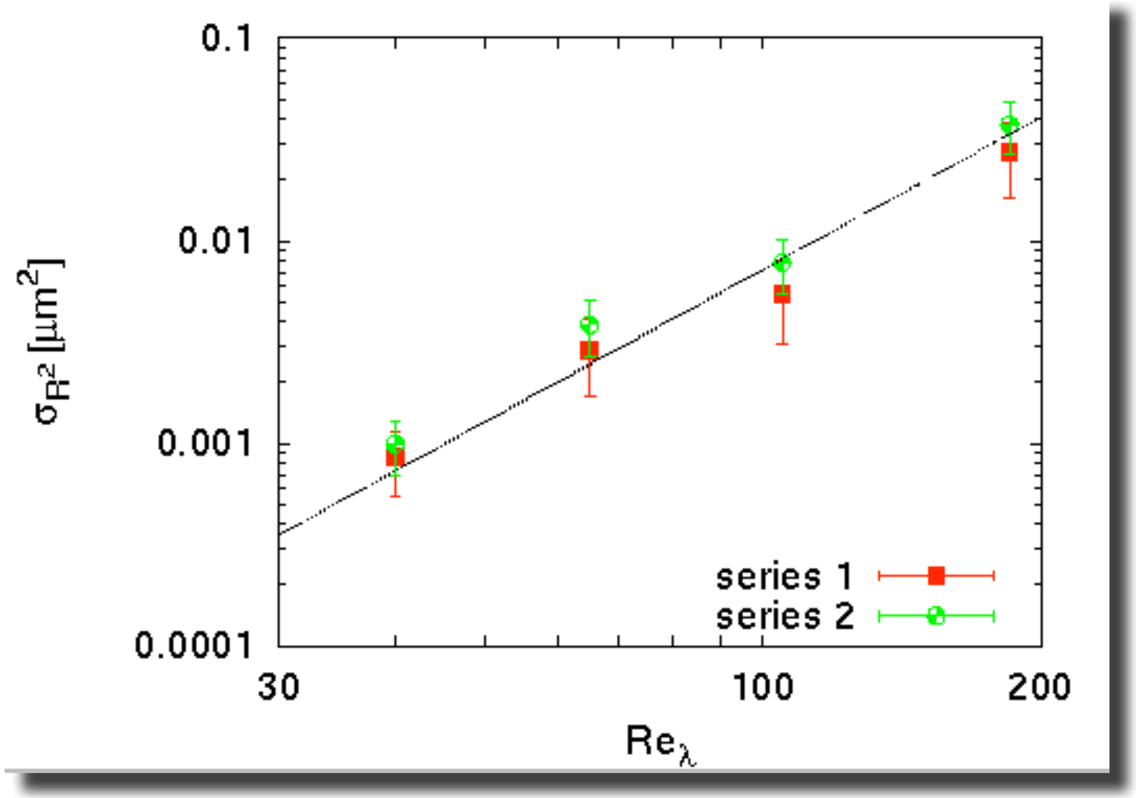
Istantaneous drops distribution in space



Square radius spectrum



Spreading vs Reynolds number



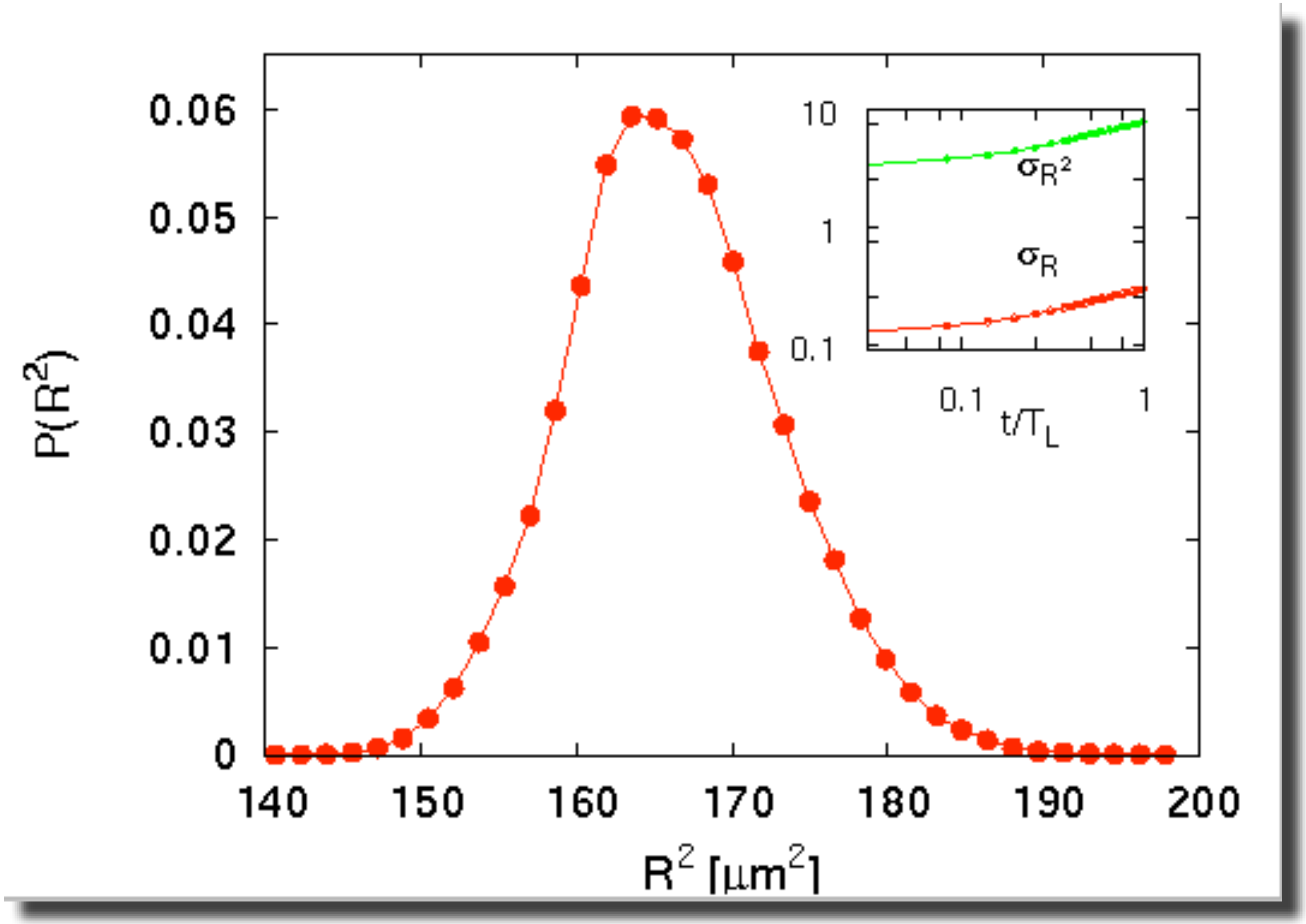
From dimensional argument:

σ (R^2) ~ c_1 $Re_\lambda^{5/2}$

---> With droplets feedback on supersaturation field,
the dimensional prediction becomes σ (R^2) ~ c_2 $Re_\lambda^{3/2}$

E.g. for physical parameters (L=100m; Re_λ~ 7000): σ (R^2) ~ (4 - 8) μm^2

Evidence from a large scale simulation



with

Agnese Seminara,
Harvard Univ., School of Engineering and Applied Math.

Federico Toschi
CNR-IAC, Rome, Italy

Preprint at:
http://climate08.wikispaces.com/References --> Clouds section