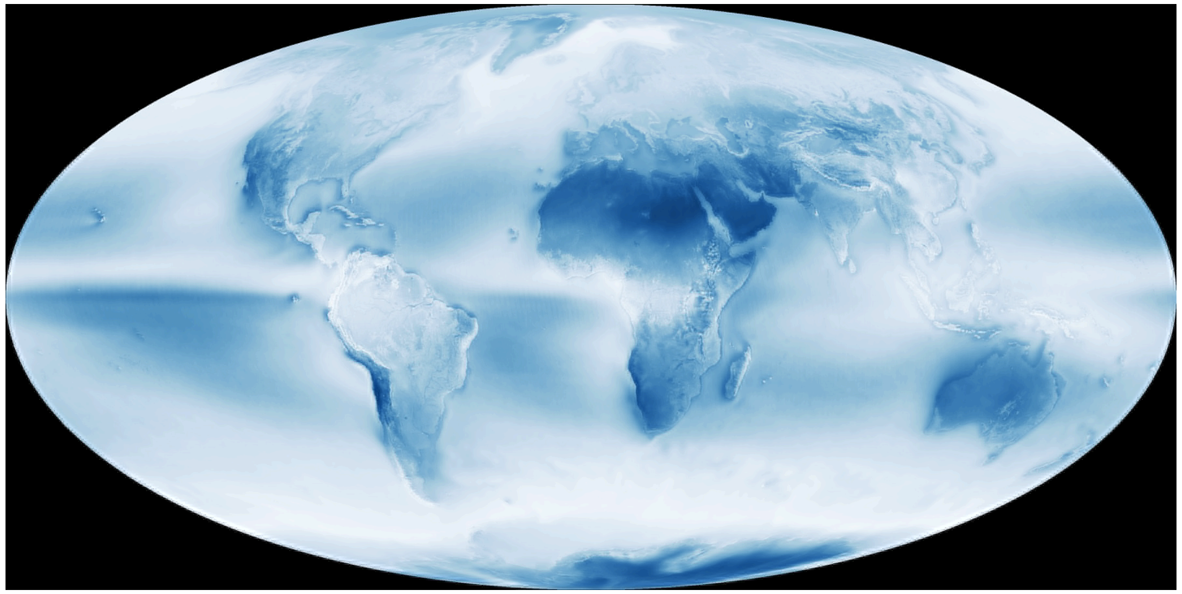
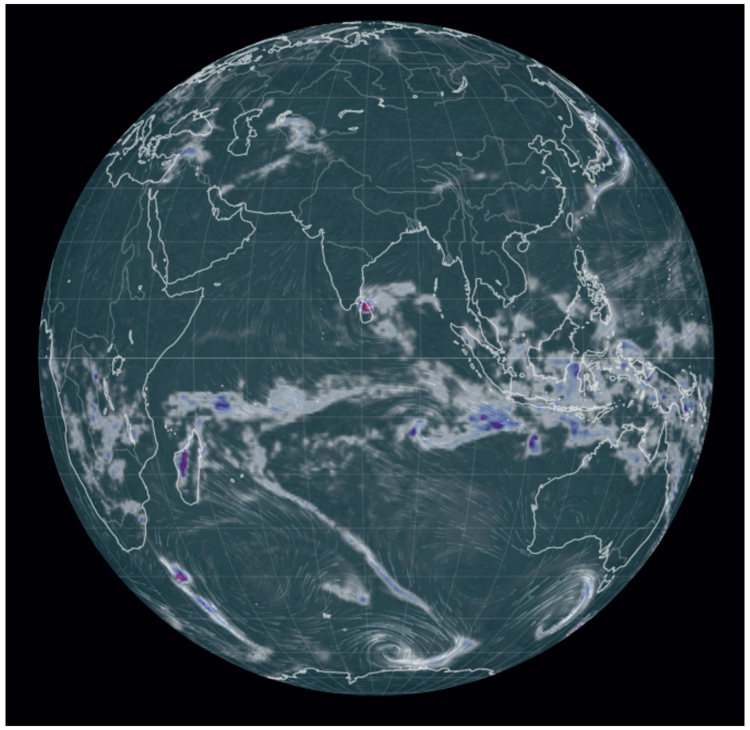
Most clouds don't rain



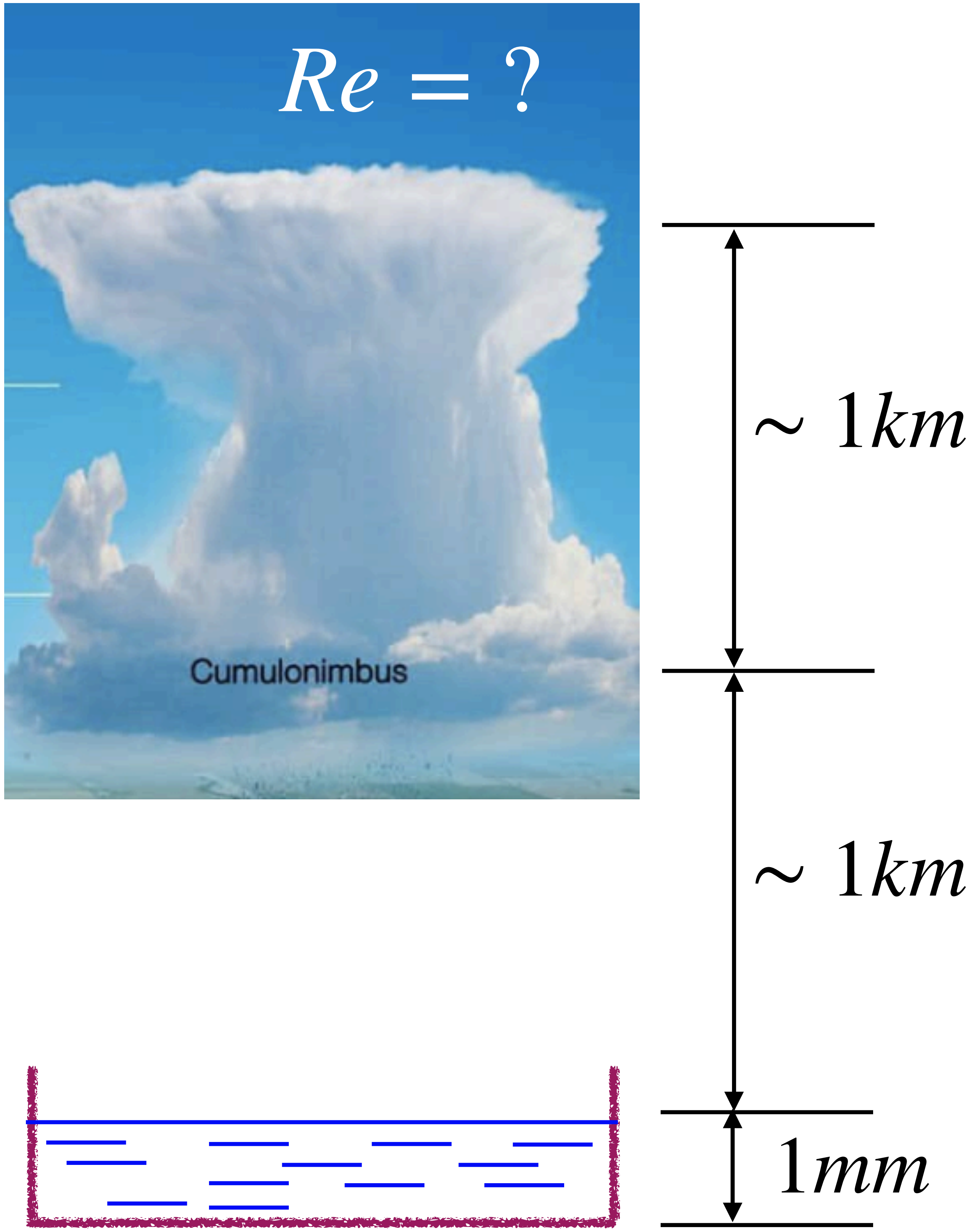
https://eoimages.gsfc.nasa.gov/images/imagerecords/85000/85843/globalcldfr_amo_200207-201504_lrg.jpg



earthhttps://earth.nullschool.net/#current/wind/surface/level/overlay=precip_3hr/orthographic

How turbulent should a cloud be?

Rama Govindarajan
ICTS



$$N \sim 10^9 \ m^{-3}$$

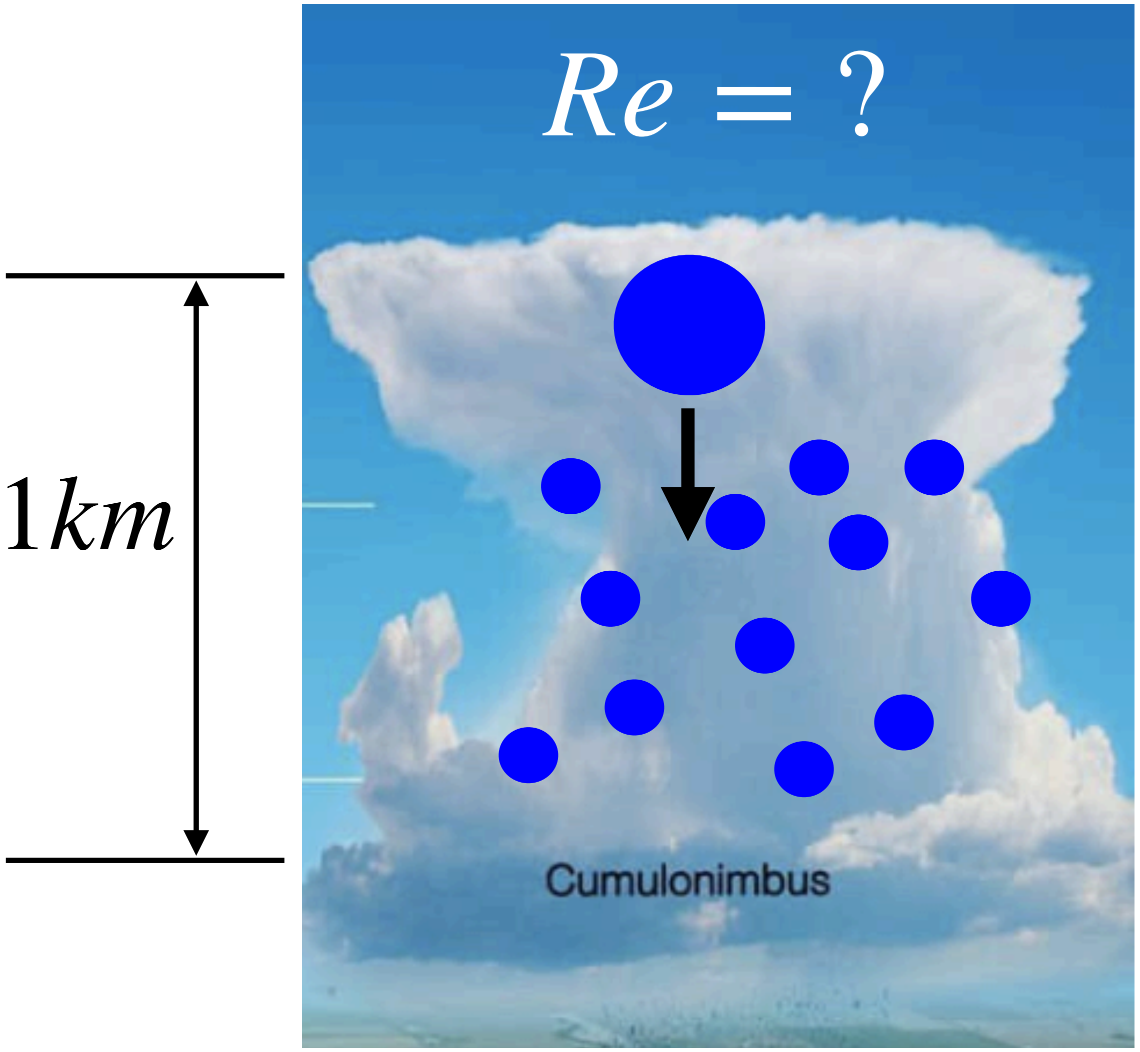
$$\text{Condensation} \Longrightarrow \ a_0 \sim 10 \ \mu m$$

$$q_L \sim 4 \cdot 10^{-3} \ m^3/m^2$$

$$t_{evap} = \frac{\mathscr{C}}{2} \rho_w a^2 \qquad t_{fall} = \frac{H}{v_p}$$

$$\chi \equiv \frac{t_{evap}}{t_{fall}} > 1 \ \Longrightarrow \ a > 70 \ \mu m$$

Need $\sim 10^6$ 1 mm drops per unit area



$$\frac{1}{2}c_D\rho_a v_p^2\pi a^2 = \frac{4}{3}\pi a^3\rho_w g$$

$$\frac{d}{dt}\left[\frac{4}{3}\pi a^3\right] = (v_p - v_{p0})(a + a_0)^2 N\epsilon\frac{4}{3}\pi^2 a_0^3$$

Some updraft helps

A 1mm drop starts out as a $100\mu m$ one

Rain initiation needs enough “lucky” drops in a cloud

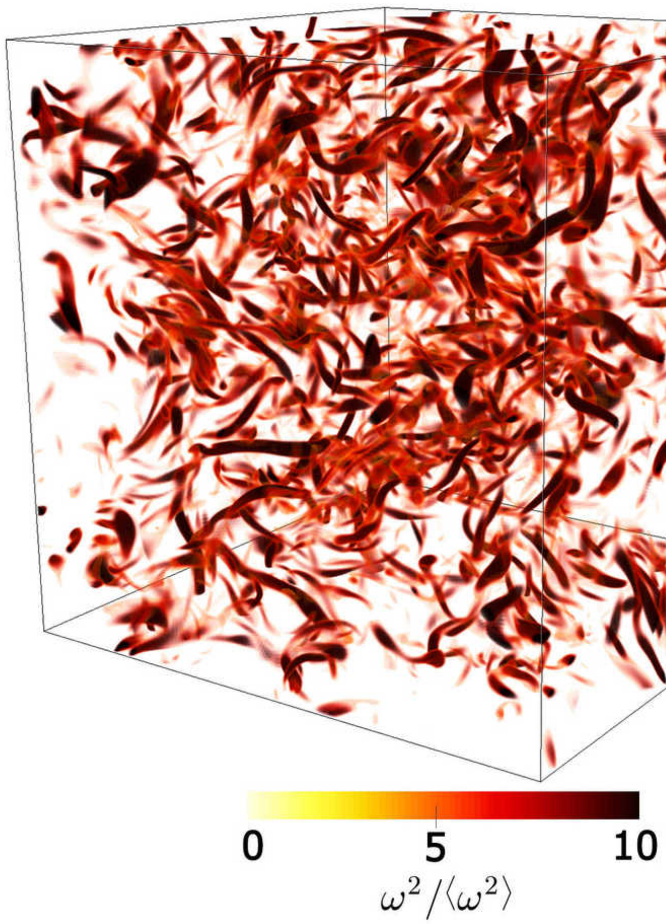
See e.g. Konstantin & Shaw, Bull. Am. Met. Soc., 2005

$10^6/1000m$ out of 10^{12}

“Lucky” (one in a million) drop:

Now lets go to the tiniest

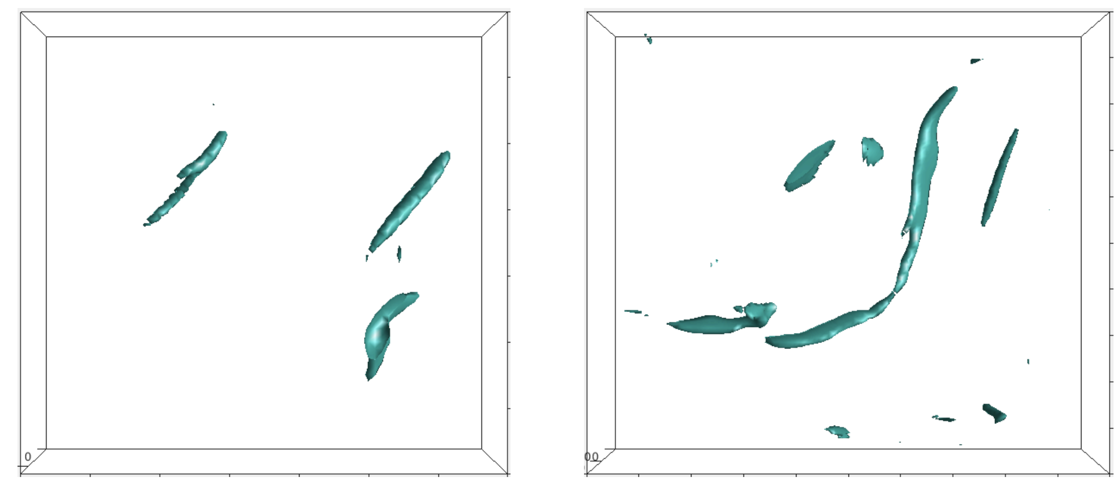
Lamb-Oseen vortices



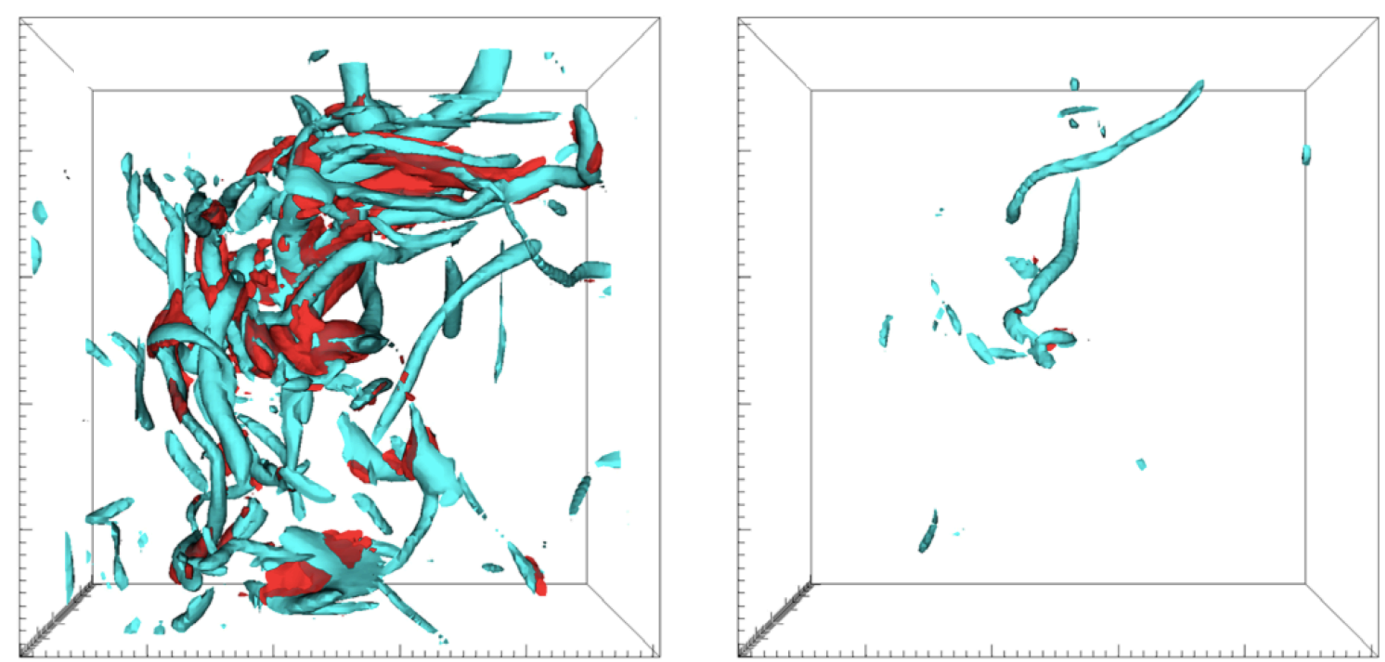
Simulation of Jason Picardo

Intense vorticity: tubular structures

→ R_λ



$R_\lambda = 1300$

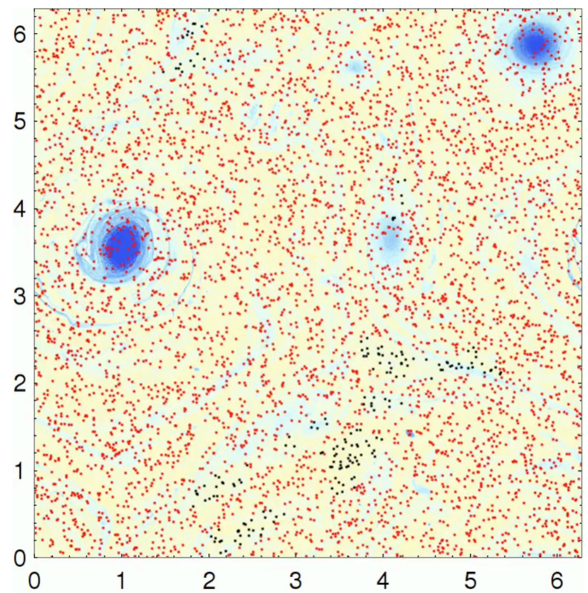


$\Omega\tau_K^2 = 500$ $\Omega\tau_K^2 = 4000$

Bhuaria & Pumir, Phys. Rev. Lett. 2022

Simplest form of Maxey-Riley equation

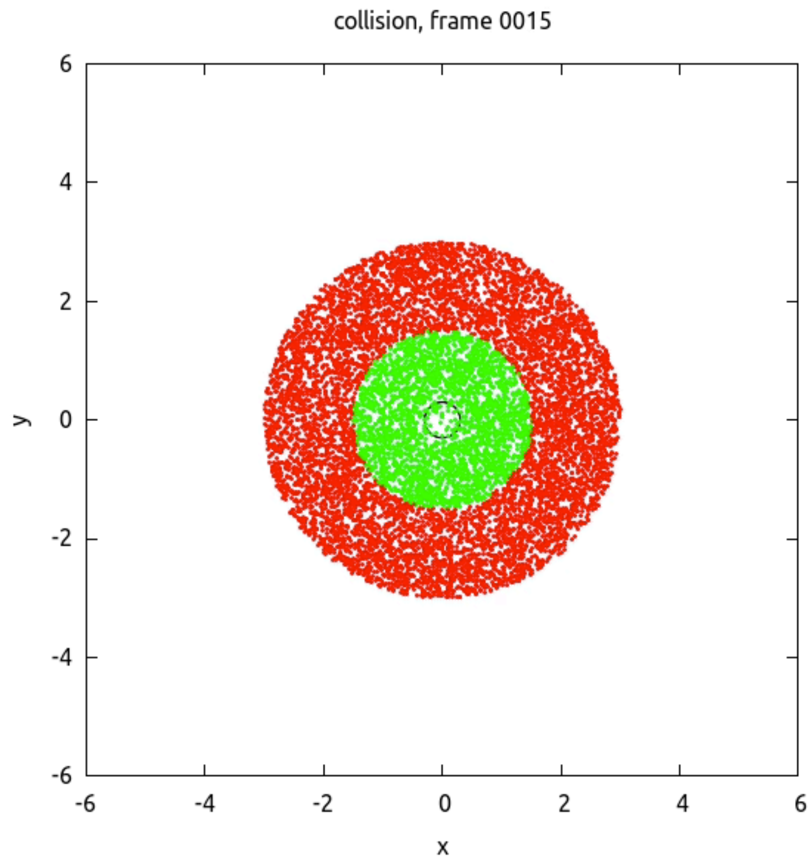
$$\dot{z} = v_p$$
$$\dot{v}_p = -\frac{1}{\tau}(v_p - u)$$



Simulation of Jason Picardo

Standard arguments not working

Dynamics near a single vortex



$$r_c \sim (\Gamma\tau)^{1/2}$$

Deepu, Ravichandran & RG, Phys. Rev. Fluids 2017

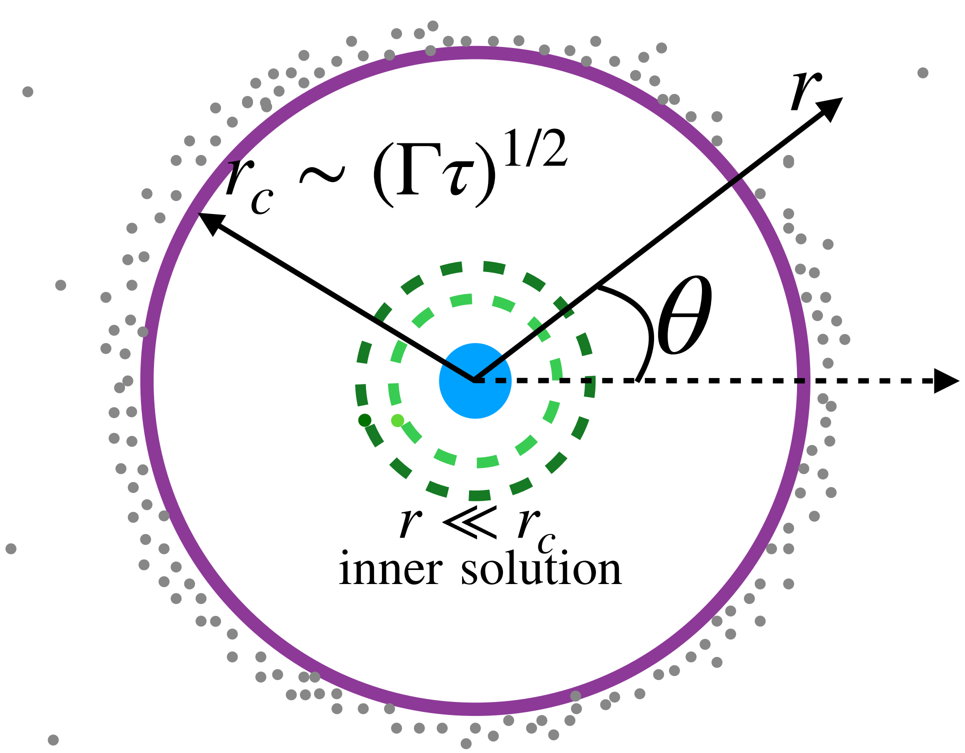
$$U_v = \frac{\Gamma}{r_v}\left[1 - e\right]$$

$$\left[\frac{r_c}{r_v}\right]^2 = \frac{\tau}{T_v} = St$$

We need St > 1

$f_{void} \propto$ number of lucky drops

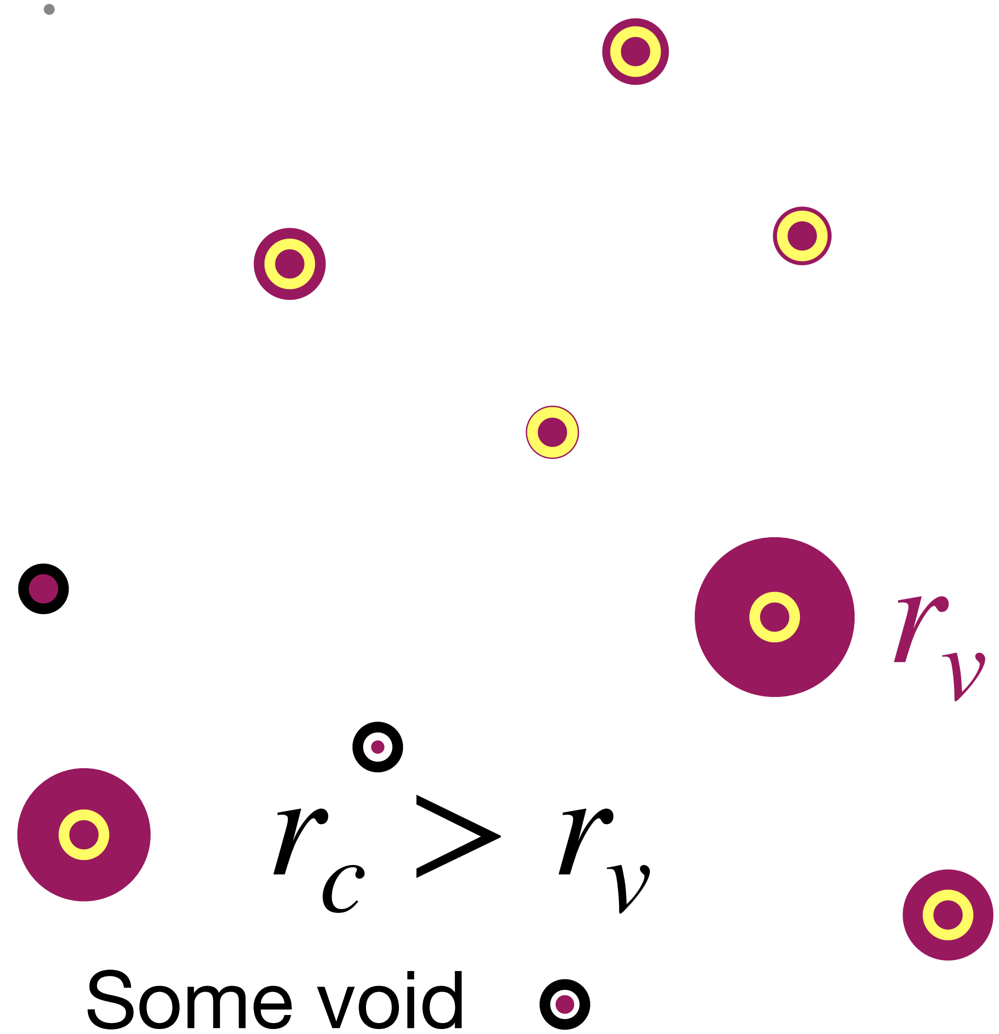
Calculation of void fraction in turbulence



$$\Omega \equiv \omega_i \omega_i, \quad x \equiv \Omega t_K^2$$

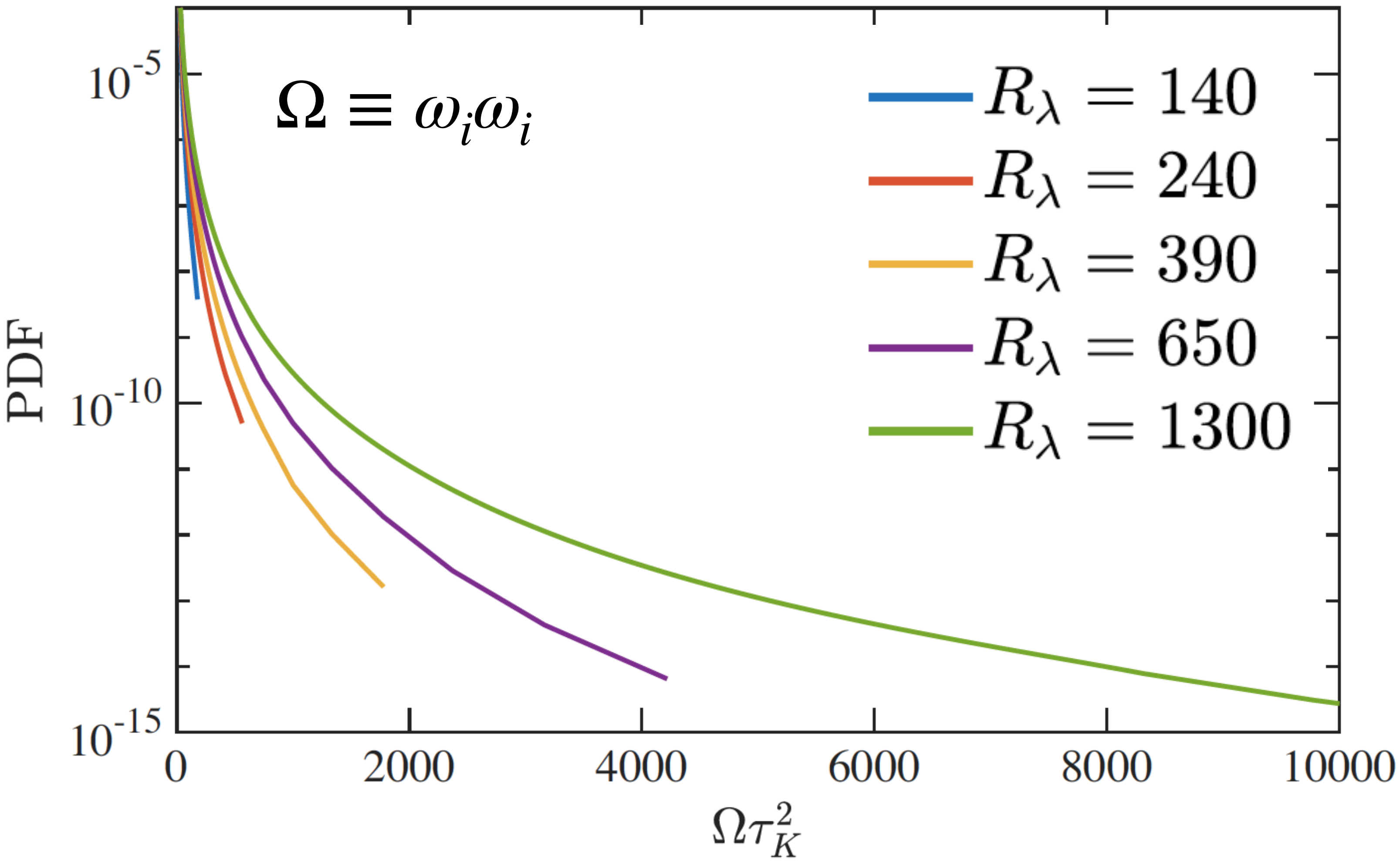
$$\Omega_{min} = \frac{1}{\tau^2}$$

$$f_{void} = \int_{x_{min}}^{\infty} p(x)\ \pi r_c^2\ dx$$

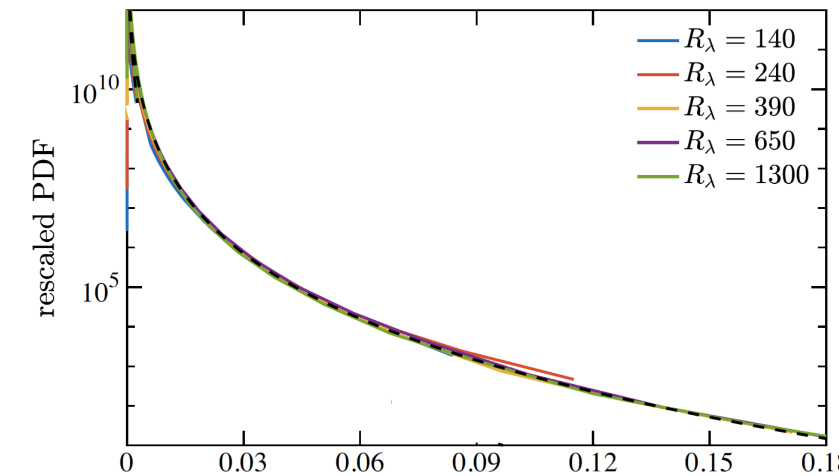


Need $f_{void} > 10^{-6}$

Ravichandran & Govindarajan
Phys. Rev. Fluids, 2022



Bhuaria & Pumir, Phys. Rev. Lett. 2022



$$p(x) \sim \exp\left(-bx^c\right)$$

$$\frac{r_v}{\eta_K} \simeq (\Omega t_K^2)^{-\gamma/4}$$

R_λ	t_K	η_K	$x_{min} = \Omega_{min} t_K^2$	f_{void}
650	$0.1s$	10^{-3} m	2500	$\sim 10^{-10}$
1300	$0.027s$	$5 \times 10^{-4} m$	200	$\sim 10^{-4}$
10^4	$10^{-2} s$	$3 \times 10^{-4} m$	25	$O(1)$

Summary

Single vortex caustics could be important
A threshold Reynolds number for rain formation is indicated

*Ref: Ravichandran & Govindarajan,
Phys. Rev. Fluids 2022*