Raindrops, buoyancy

Droplets: microns
Cloud box: centimetre

the Indian monsoon

Rama Govindarajan
ICTS

Work done (mainly) in ICTS

5 Jan 2018
ICTS@10

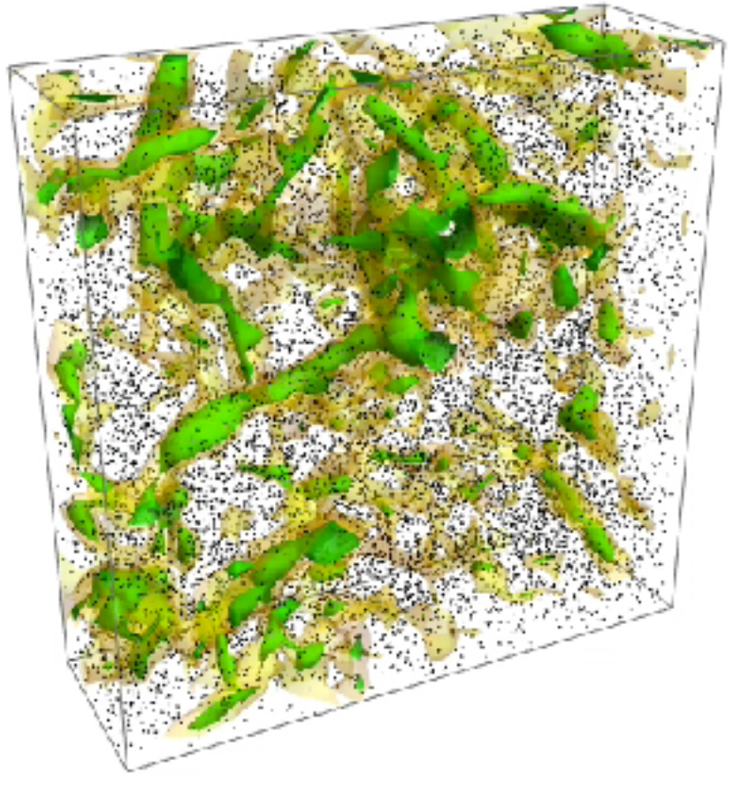
Raindrops, buoyancy

Priyanka

S Ravichandran

Sankar Ray

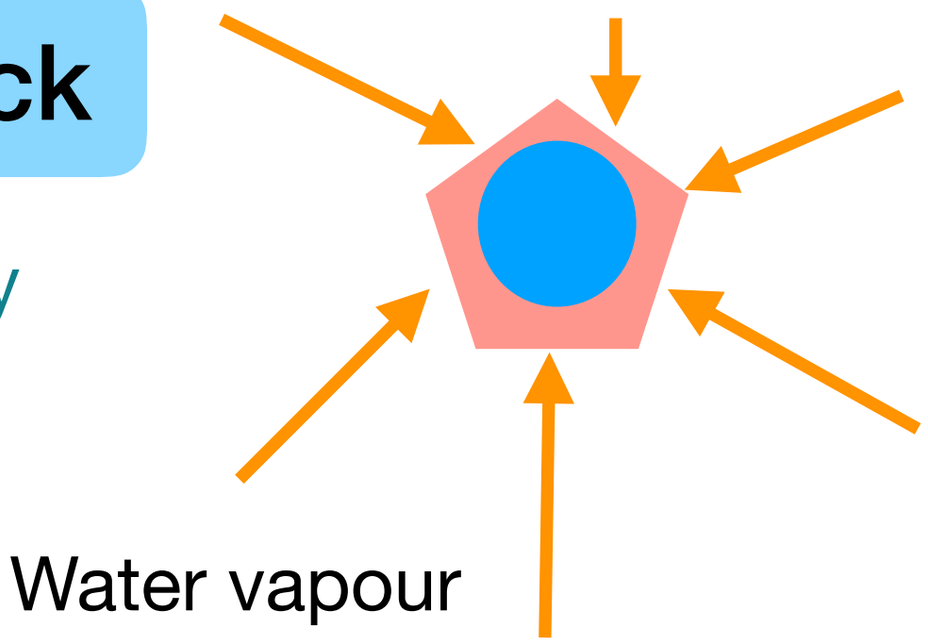
Jason Picardo



Lokahith Agasthya

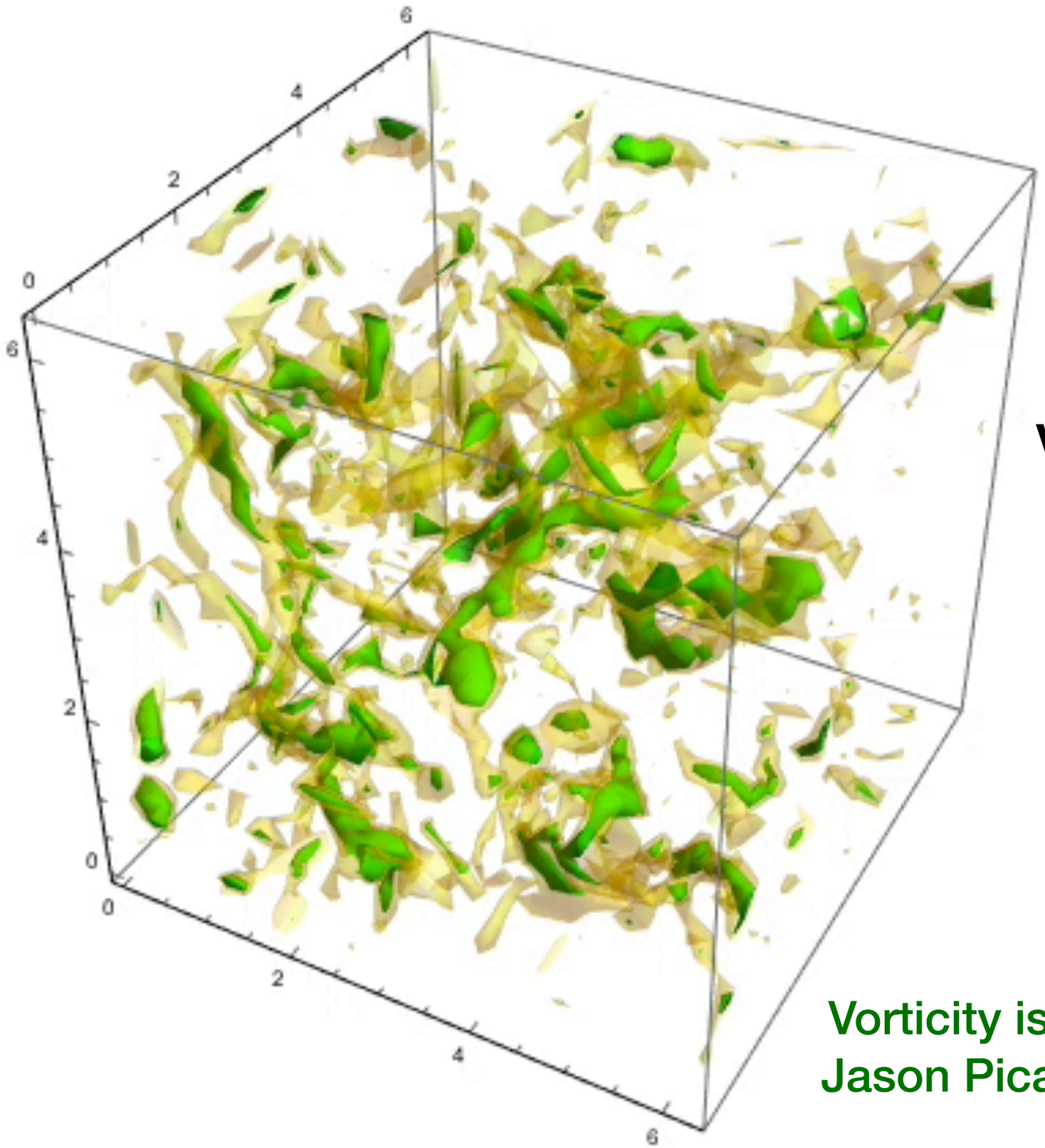
Droplet growth bottleneck

Collisions: rare and necessary



Is cloud turbulence different from “normal” turbulence?

Turbulence: a vorticity picture



$$\omega \equiv \nabla \times u$$

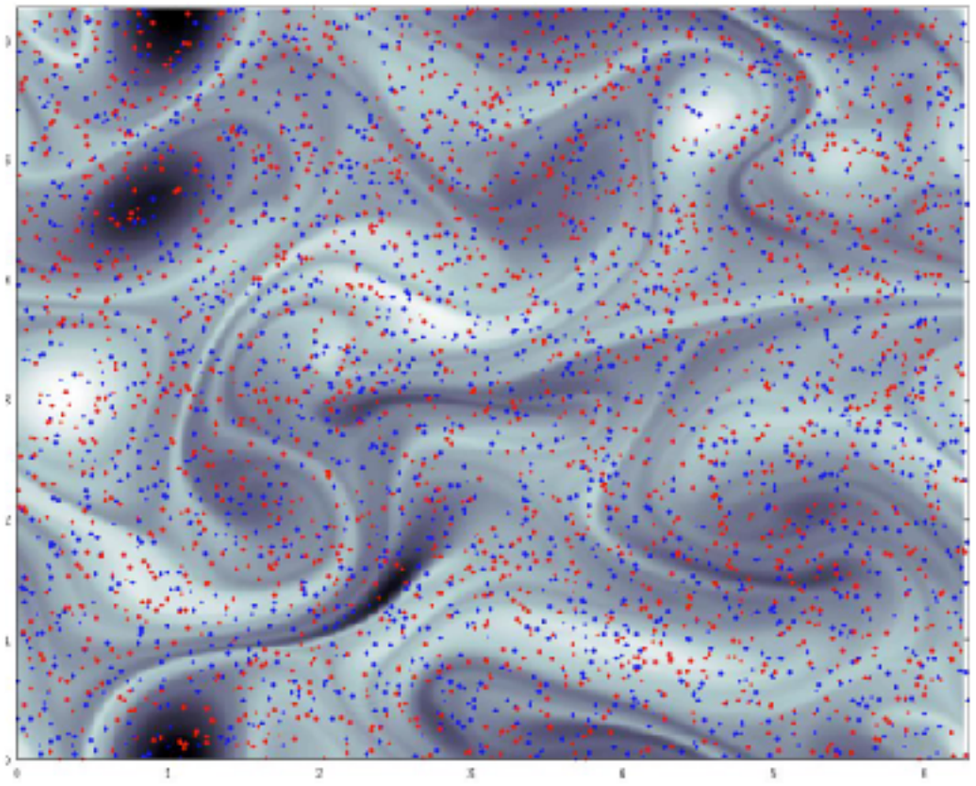
Vortices stretching, tilting, inducing velocity

Intermittency:
very strong vortices

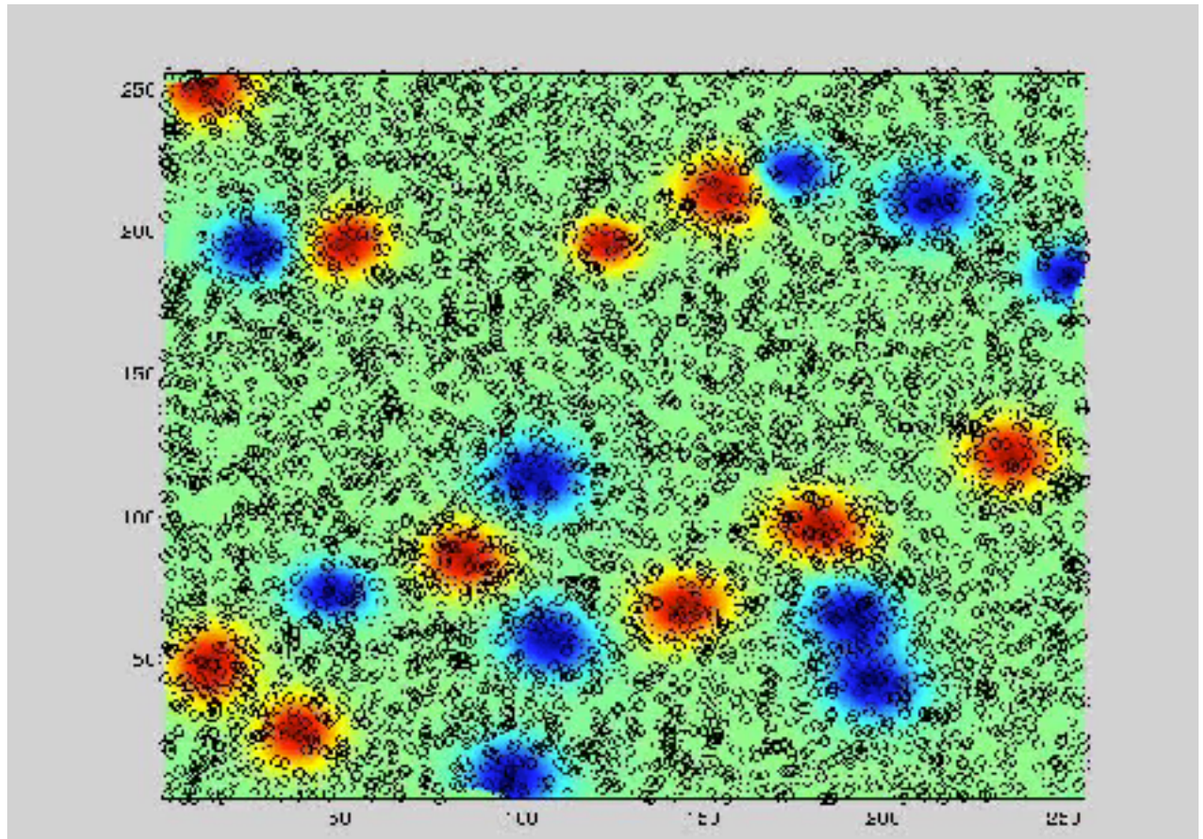
Vorticity isosurfaces: two magnitudes
Jason Picardo's simulation

Droplets are not sugar in your tea

Large droplet inertia



Small droplet inertia



Mohit Gupta & Samriddhi Sankar Ray’s simulations

Further, in clouds, industrial applications
(catalytic reactions, combustion) …..

Droplets/ aerosols are condensation nuclei

Entrainment of external fluid

Water vapour field inhomogeneous

Temperature field inhomogeneous

Supersaturation: sink for water vapour (if nuclei)
source term for liquid water

Evolution with phase change

$$\frac{D\omega}{Dt} = \omega \cdot \nabla u + \frac{1}{\mathrm{Re}} \nabla^2 \omega + \frac{1}{Fr^2} \nabla \times \left[\theta \hat{e}_y \right]$$

$$\frac{D\theta}{Dt} = \frac{1}{Pe_\theta} \nabla^2 \theta + H \left[\alpha \left(\frac{\rho_v - \rho_s}{\rho_s St_s} \right) \right]$$

$$\frac{D\rho_v}{Dt} = \frac{1}{Pe_v} \nabla^2 \rho_v - H \left[\left(\frac{\rho_v - \rho_s}{\rho_s St_s} \right) \right]$$

$$\frac{\partial \rho_l}{\partial t} + \nabla \cdot \left(v \rho_l \right) = \frac{1}{Pe_l} \nabla^2 \rho_l + H \left[\left(\frac{\rho_v - \rho_s}{\rho_s St_s} \right) \right]$$

$$v = u - St_p \frac{Du}{Dt}$$ **or Maxey-Riley**

$$H = 1 \text{ if } \rho_v > \rho_s \text{ or if } \rho_v < \rho_s, \rho_l > 0$$

$$a \frac{da}{dt} = \frac{1}{C \rho_w} \left[\frac{\rho_v}{\rho_s} - 1 \right]$$

$$\mathrm{Re} = \frac{\Omega_0 d_0^2}{\nu}$$

$$Fr^2 = \frac{\Omega_0^2 d_0}{gAt}$$

$$\alpha = \frac{L_v \rho_s^0}{C_p \Delta T}$$

$$St_p = \Omega_0 \tau_p$$

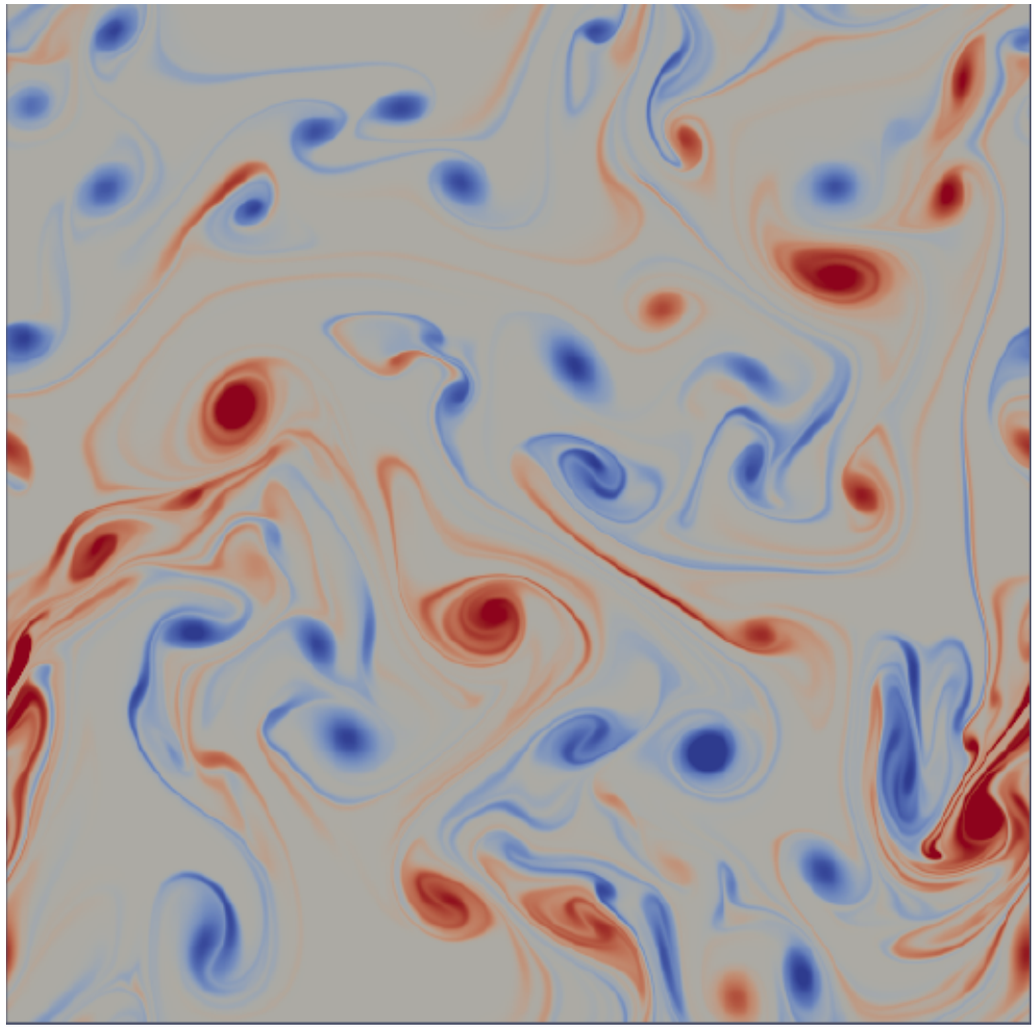
$$St_s = \Omega_0 \tau_s = \Omega_0 \frac{C \rho_s^0}{4 \pi a n}$$

Need: intermittency

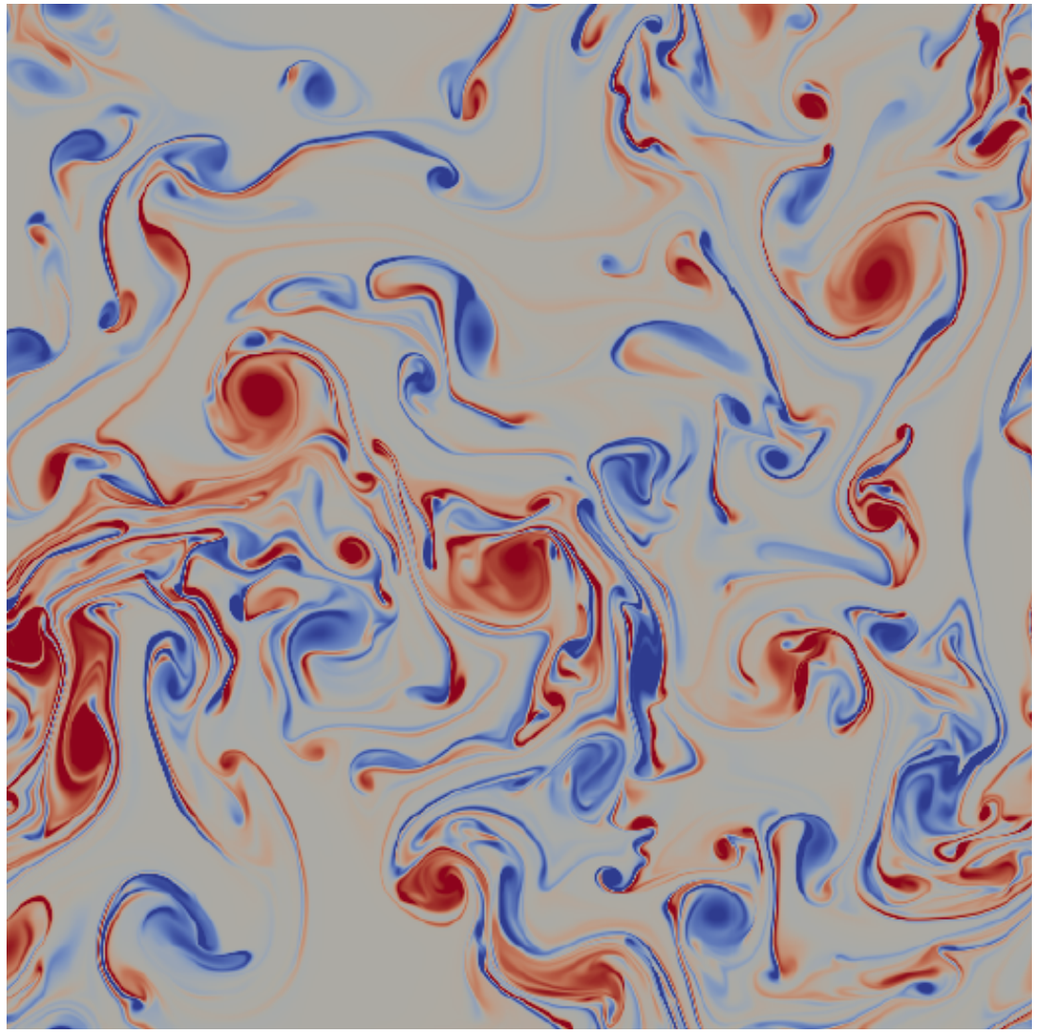
$$At_{eff} \approx St_p^{1/2} St_s^{1/2}$$

Ravichandran & RG, Journal of Fluid Mechanics, 2017

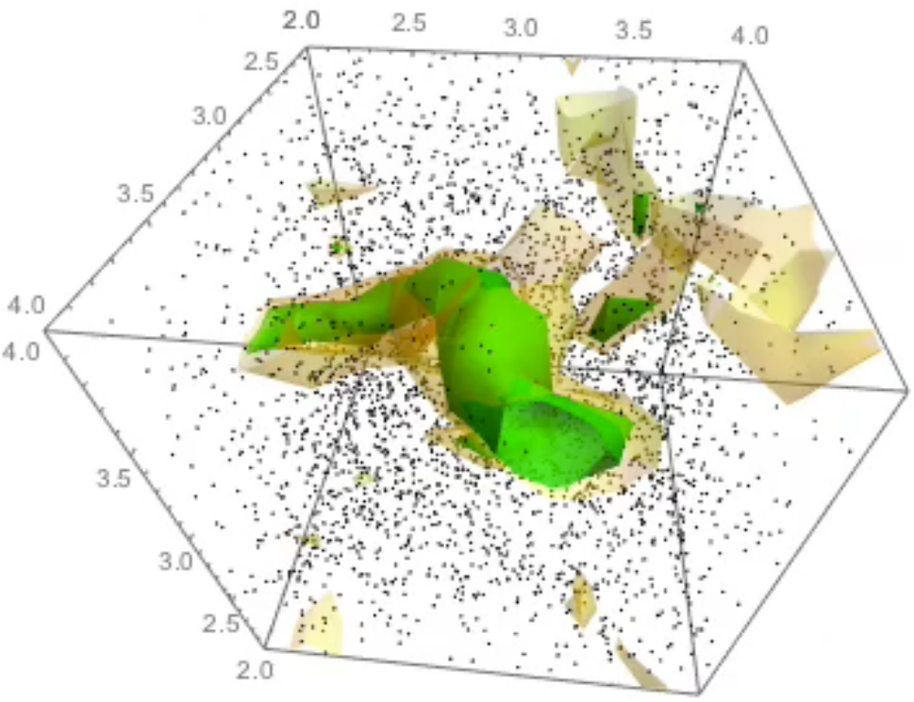
“Plain” flow



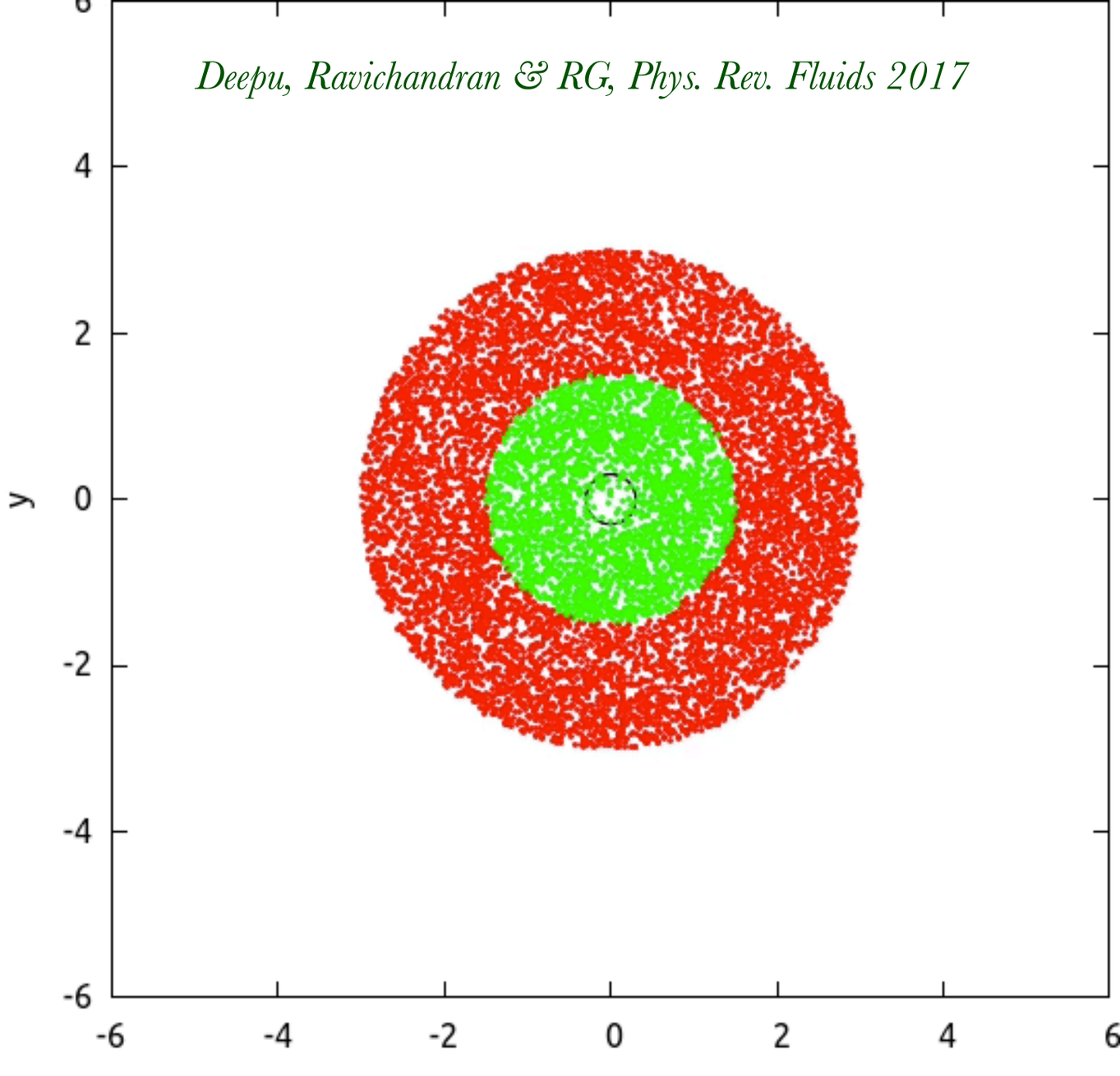
“Cloud” flow



Ravichandran & RG, Journal of Fluid Mechanics, 2017



Jason's simulation



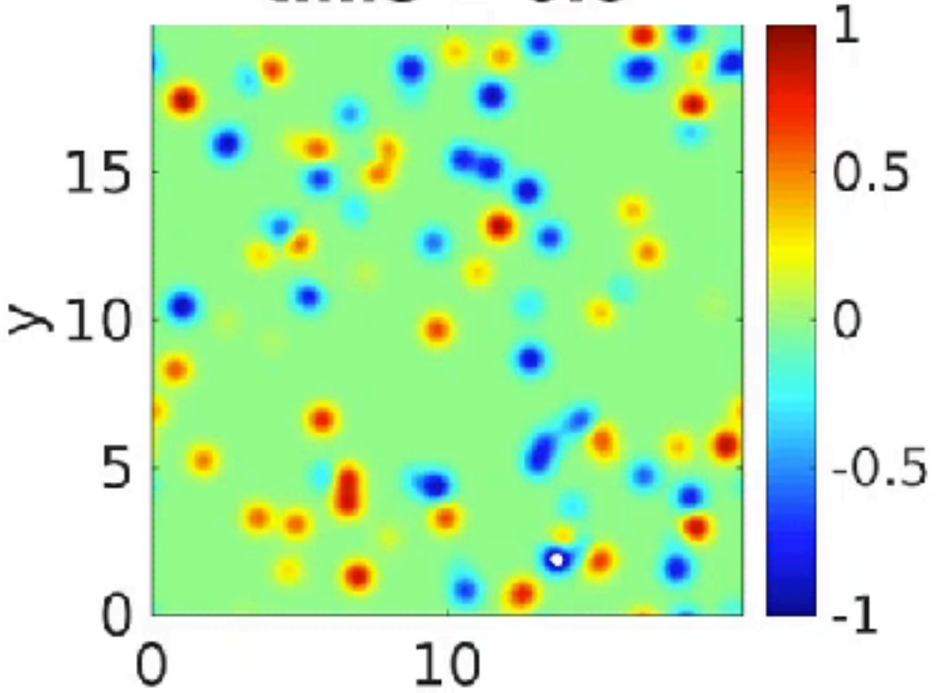
$$L = \left(\tau\Gamma\right)^{1/2}$$

Ravichandran & RG, Phys. Fluids 2015

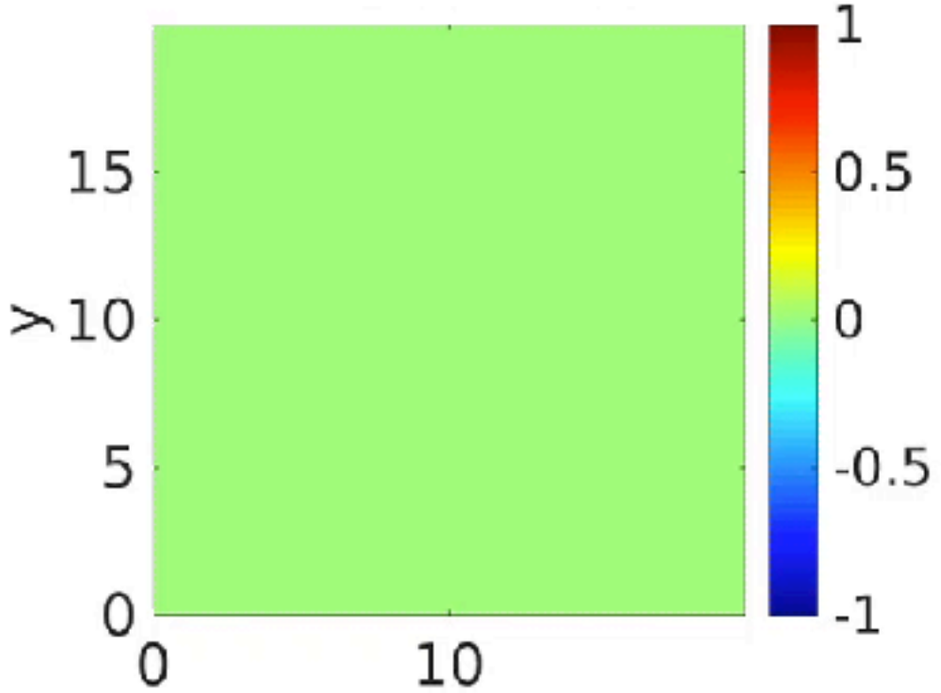
Singular perturbation problem
Inner: ballistic evacuation
Outer: low compressibility

$$P(a_q,r') = \int_{r'_{q-1}=r'_c}^{r'} \int_{r'_{q-2}=r'_c}^{r'_{q-1}} \cdots \int_{r'_2=r'_c}^{r'_3} \int_{r'_1=r'_c}^{r'_2} \prod_{j=1}^{q-1} [S(r'_j,r'_{j-1}) f_j] S(r',r'_{q-1}) \prod_{k=1}^{q-1} dr'_k$$

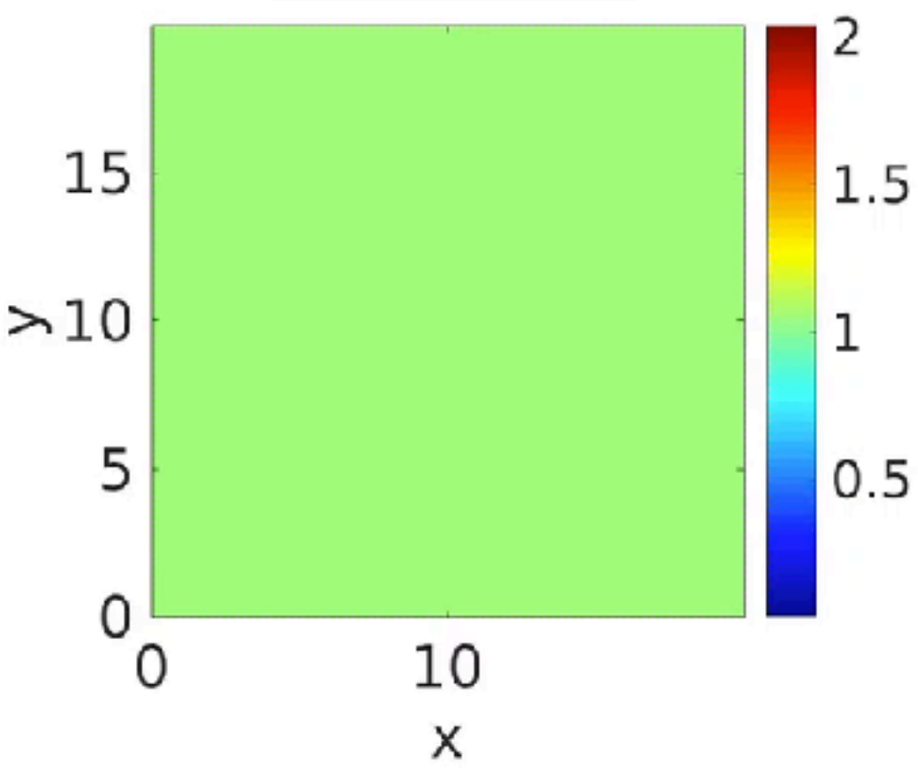
Vorticity



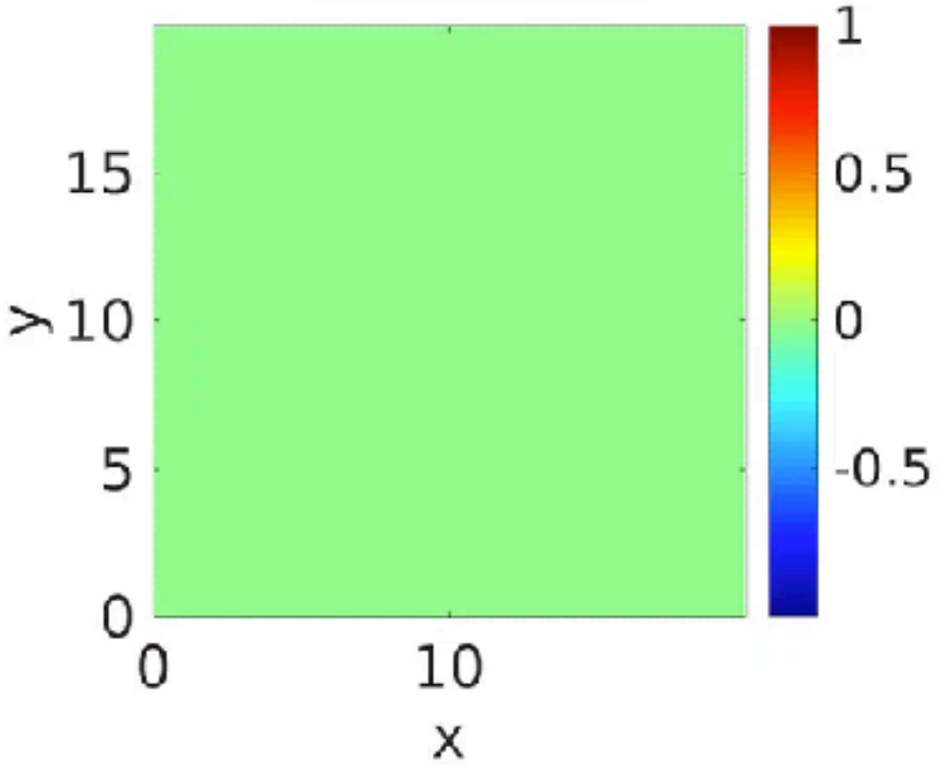
Temperature



Water vapour

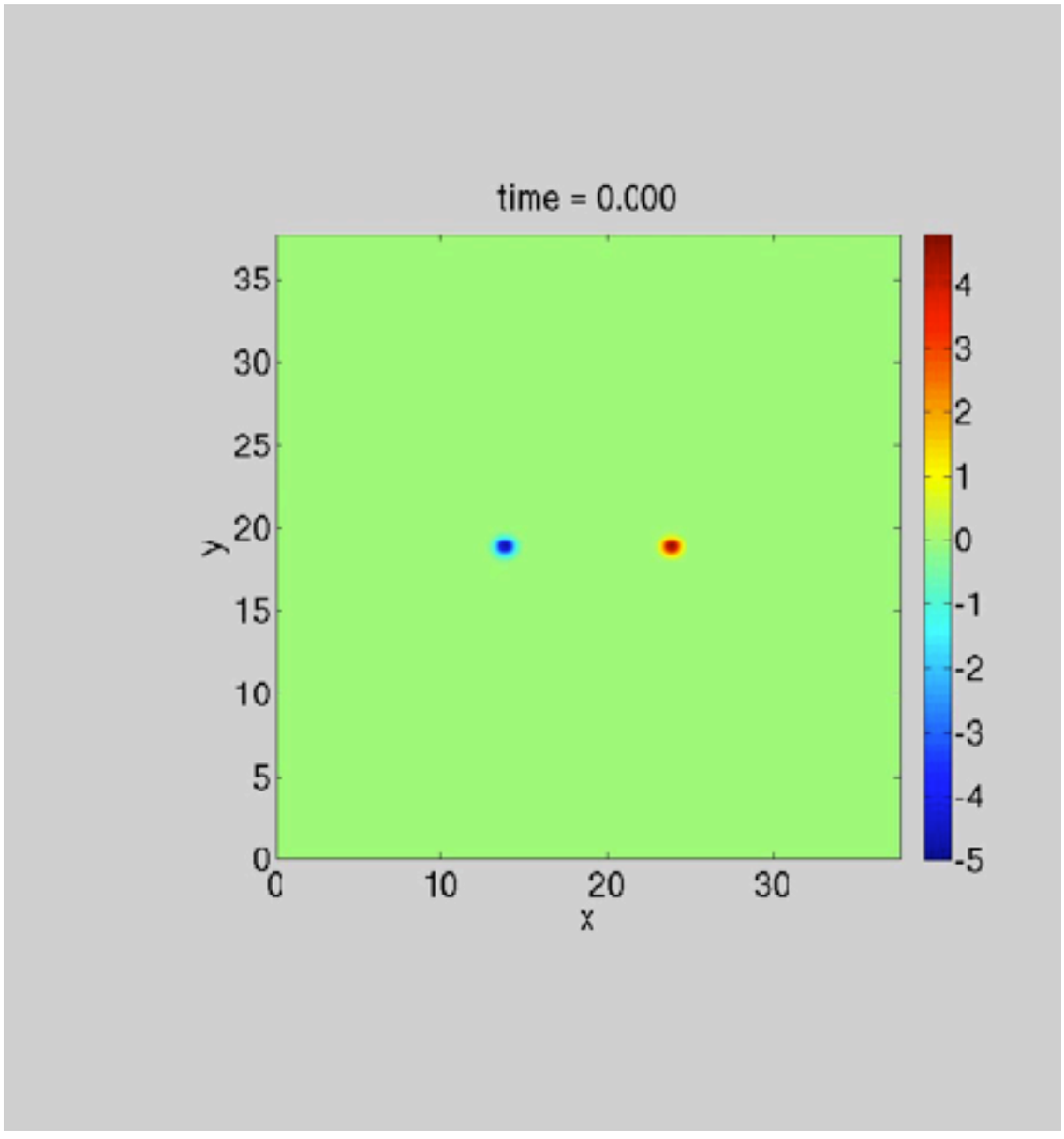


Liquid water

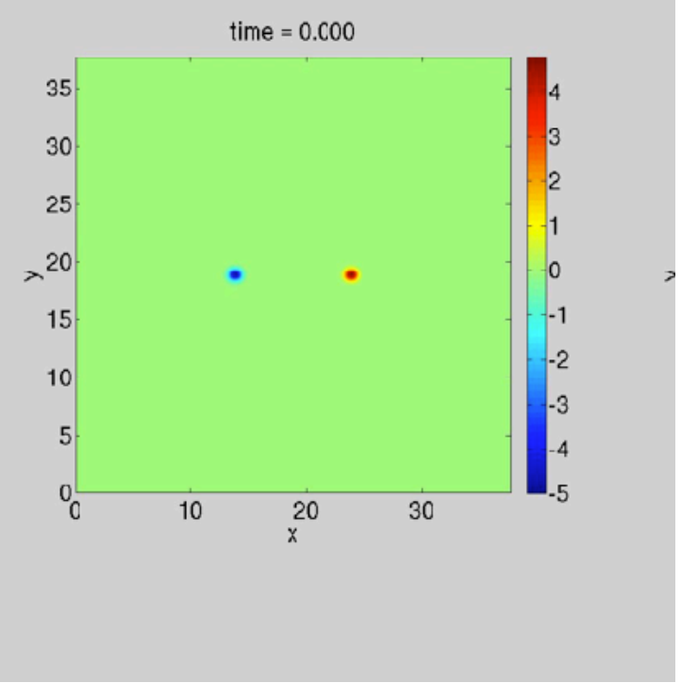


Ravichandran & RG, Journal of Fluid Mechanics, 2017

Vortex pair



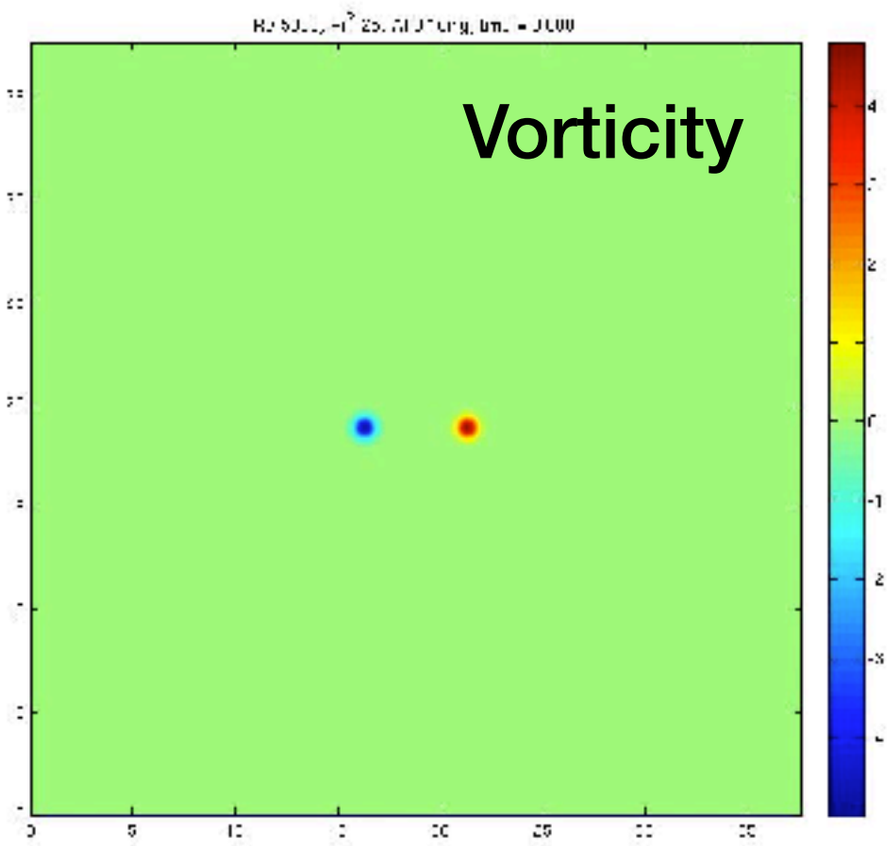
Biot-Savart Law

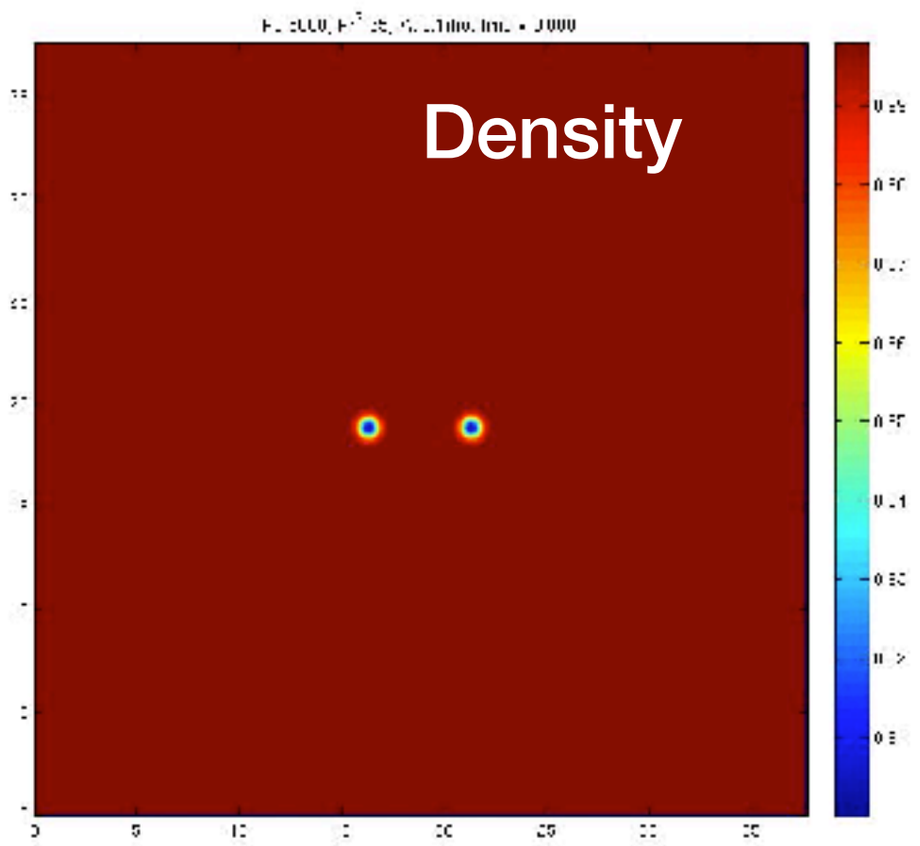


Vortex pair

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

Light vortices





Summary so far

Droplet growth enhanced by rapid evacuation near vortices

A mechanism by which microscopic droplets affect big structures

Future: real clouds

Movie by Karthik Menon

Indian Monsoon

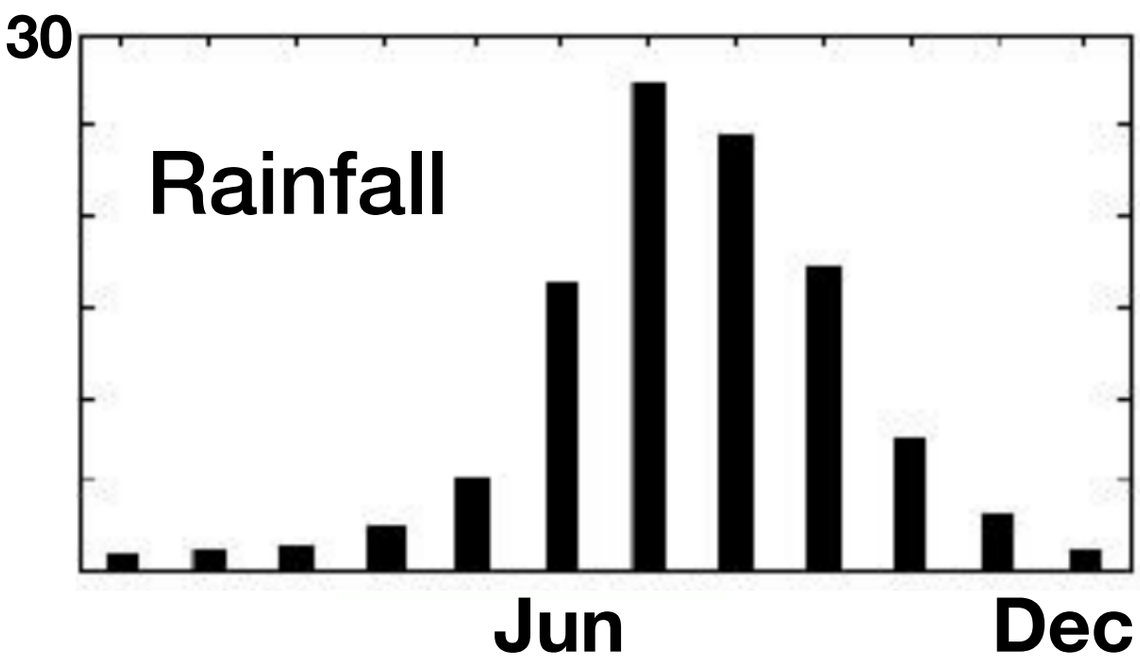
Amit Apte

Vishal Vasan

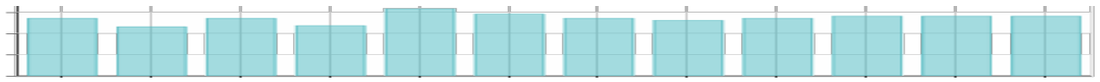
Adway Mitra

Sreekar Vadlamani
TIFRCAM

Data, not fluid dynamics yet

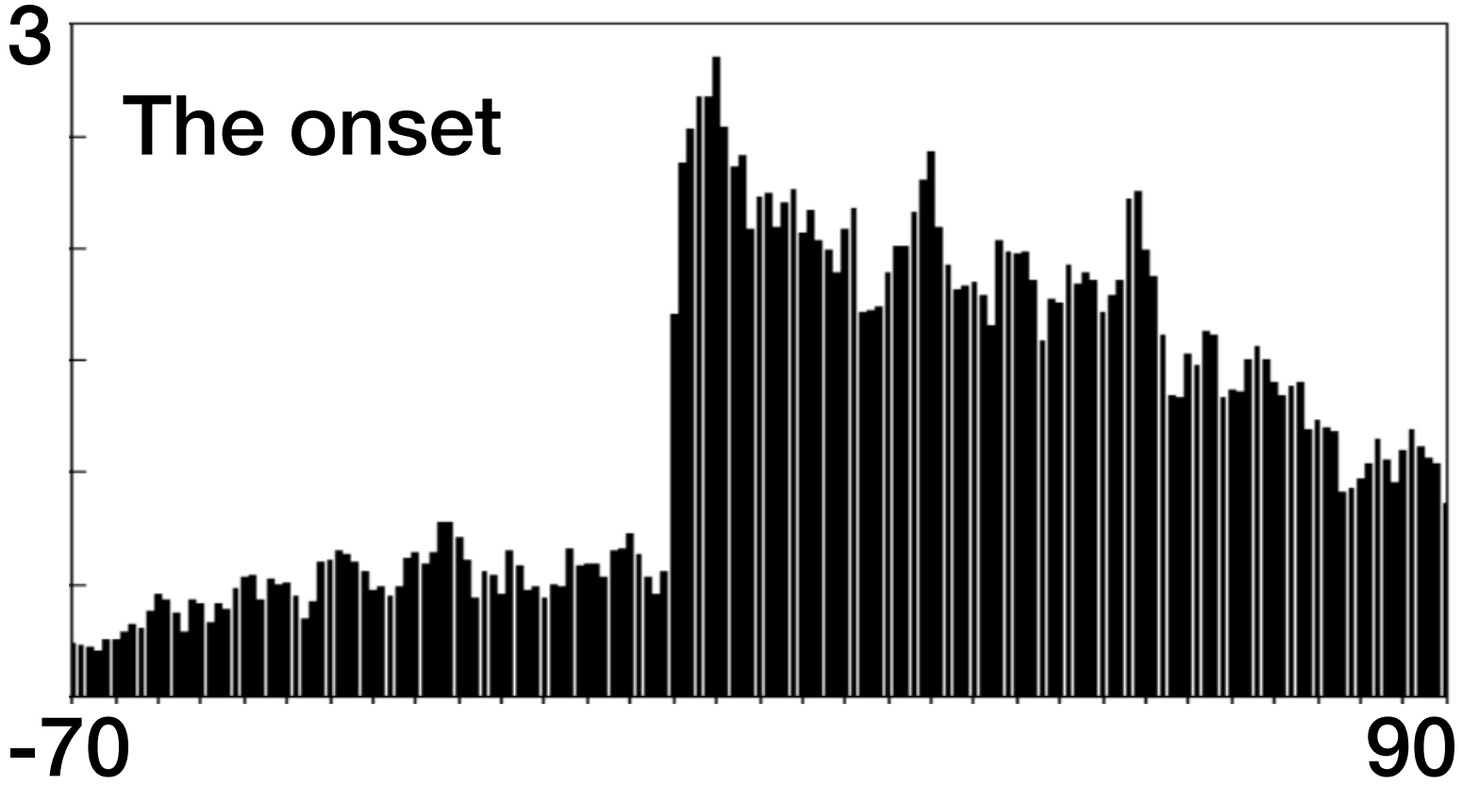


Indian monsoon
85 cm rain



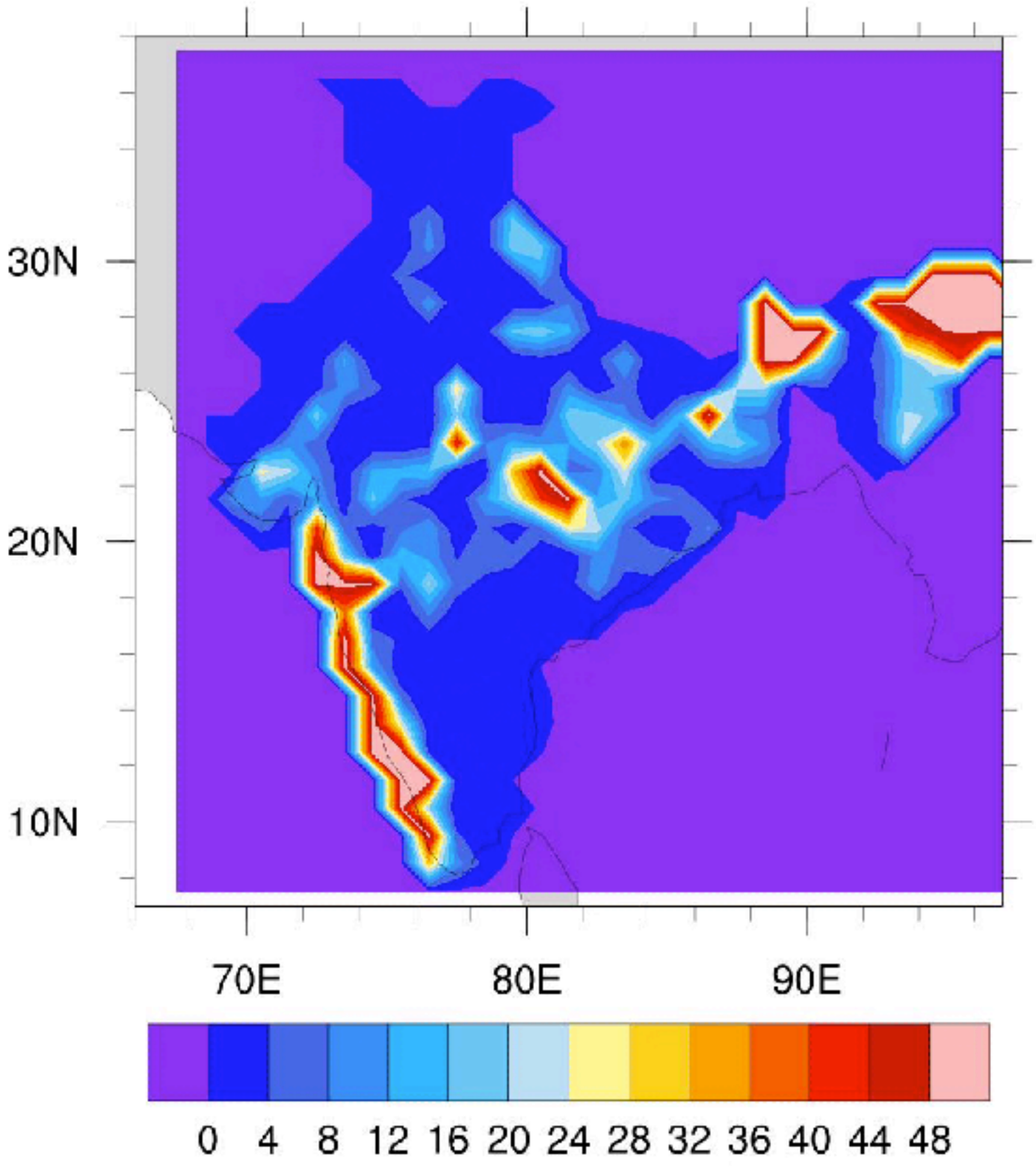
Food for a billion people

Paris



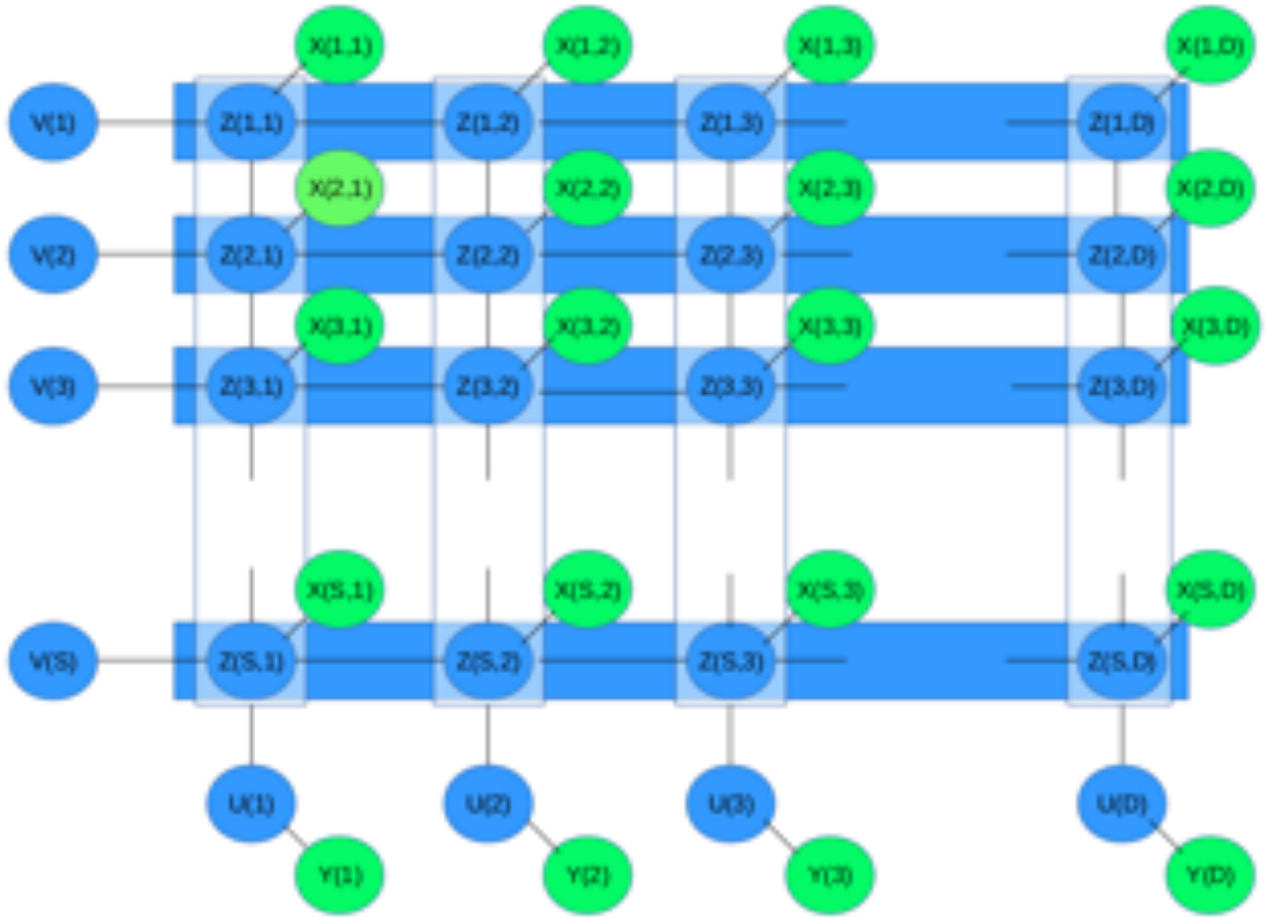
Source: *Sulochana Gadgil*, *Annual Review of Earth and Planetary Sciences, 2003*

Rainfall, Monsoon of 2008

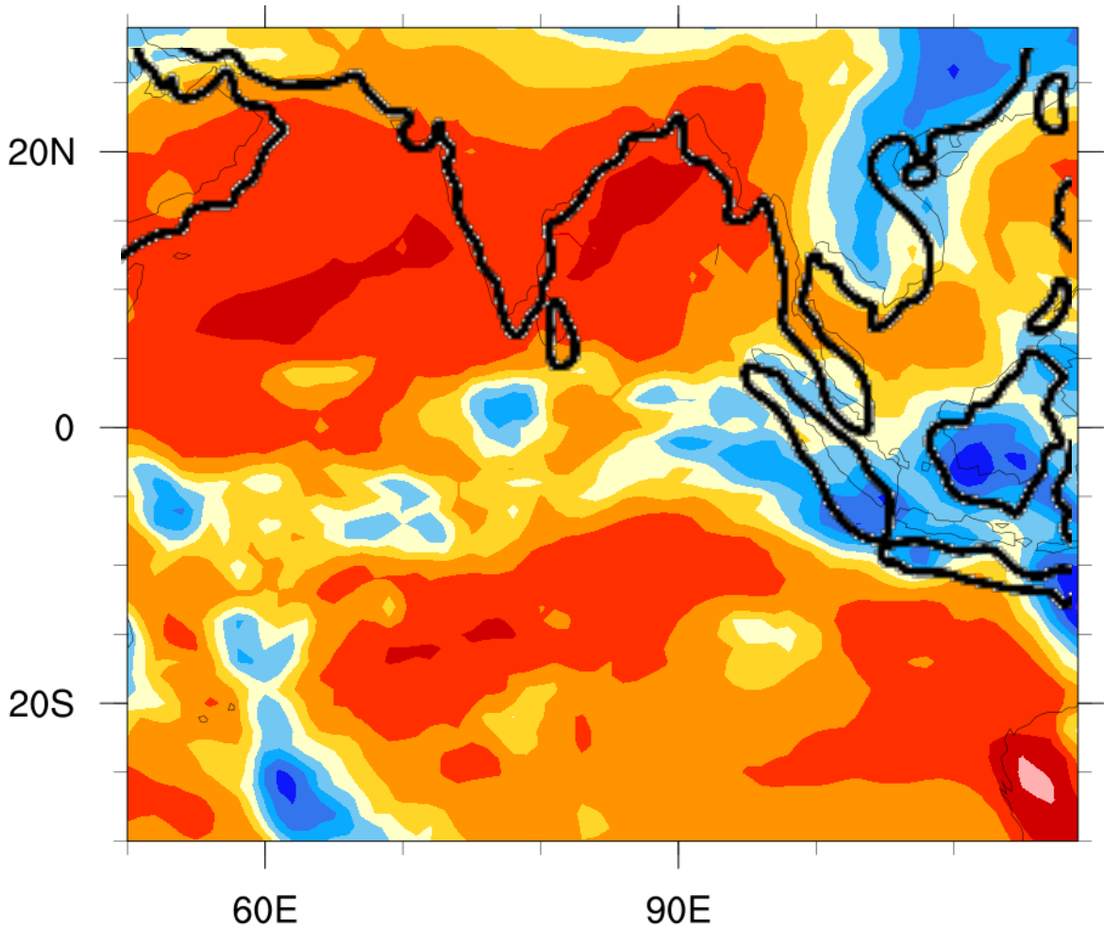


Underlying dynamics → Probabilistic manifestation

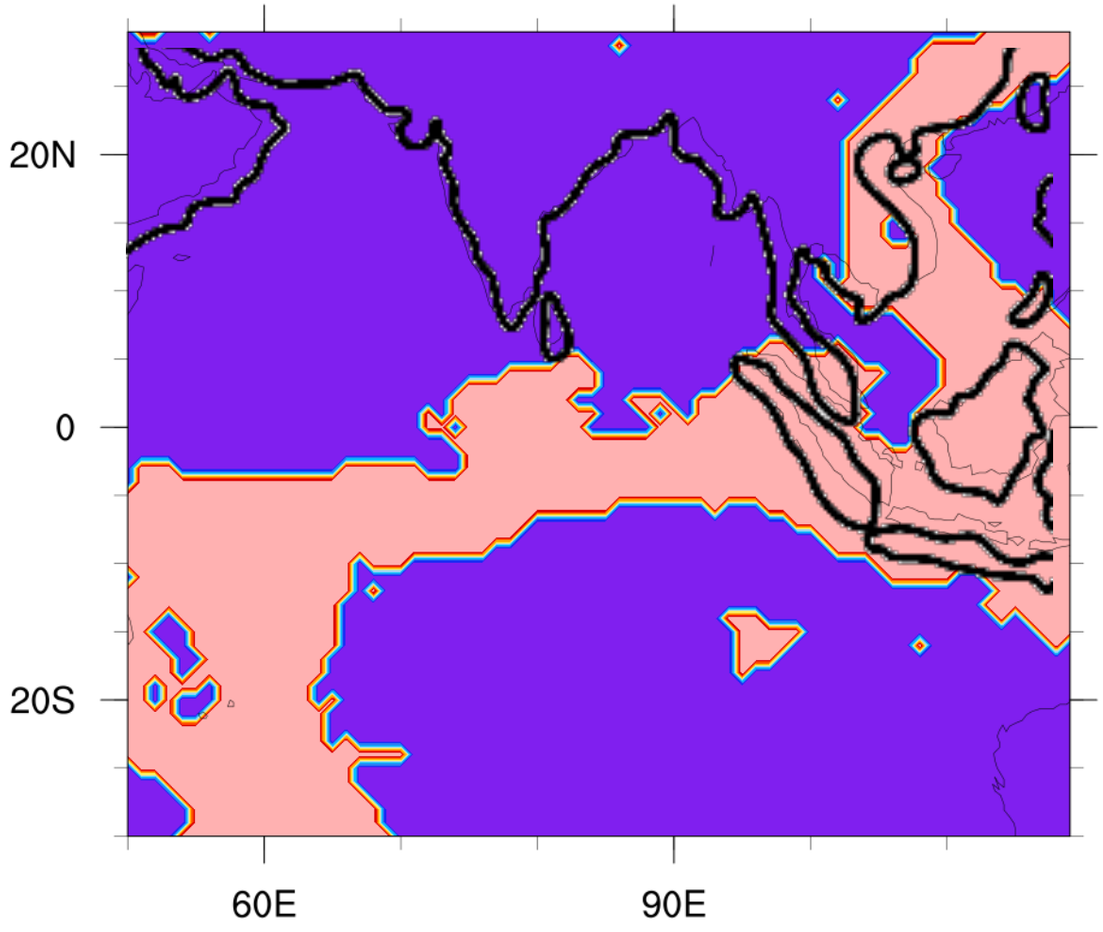
Markov Random Fields
discrete probabilistic representation



Cloud Cover, 20 Jan 2016



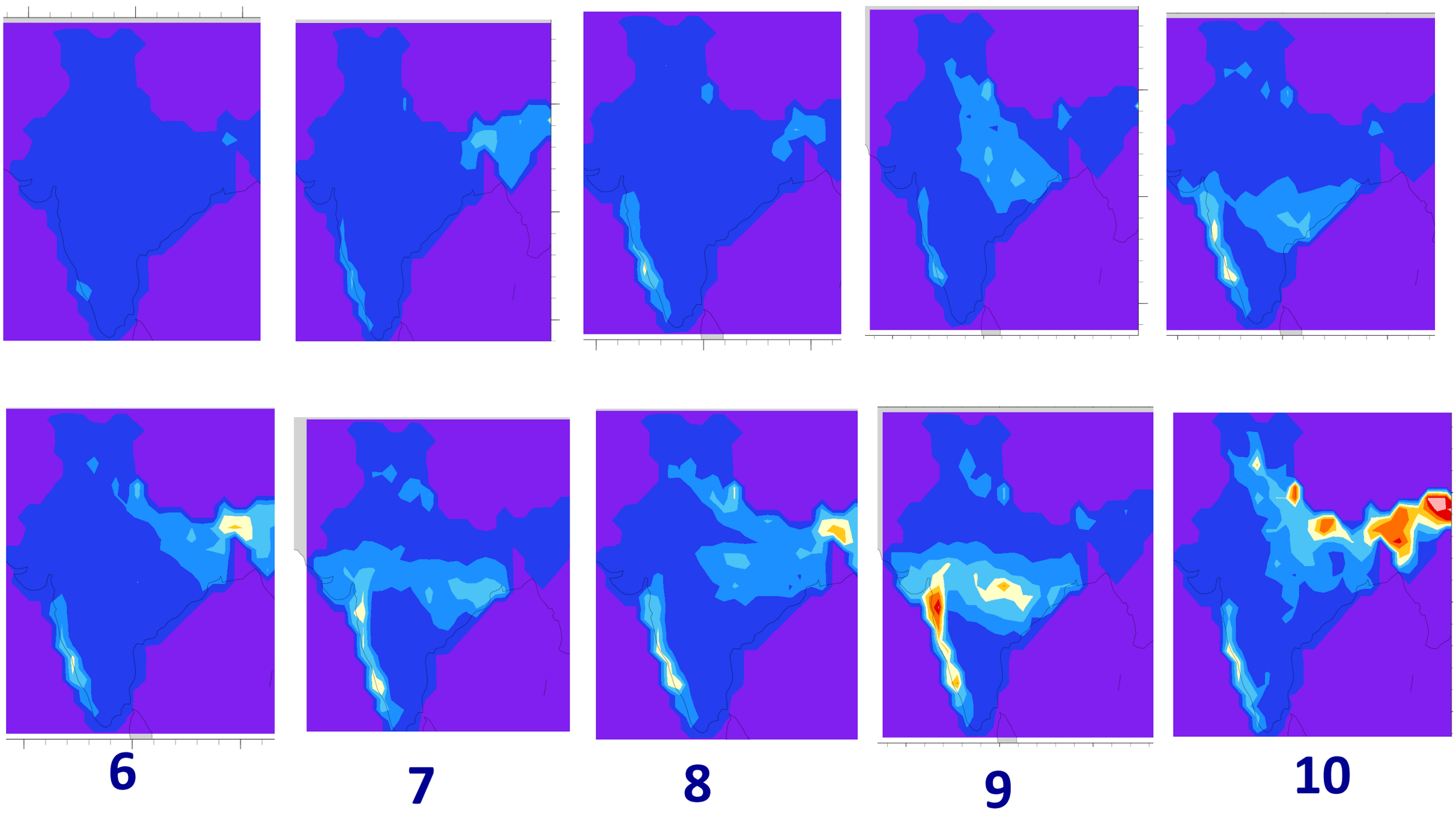
Raw data



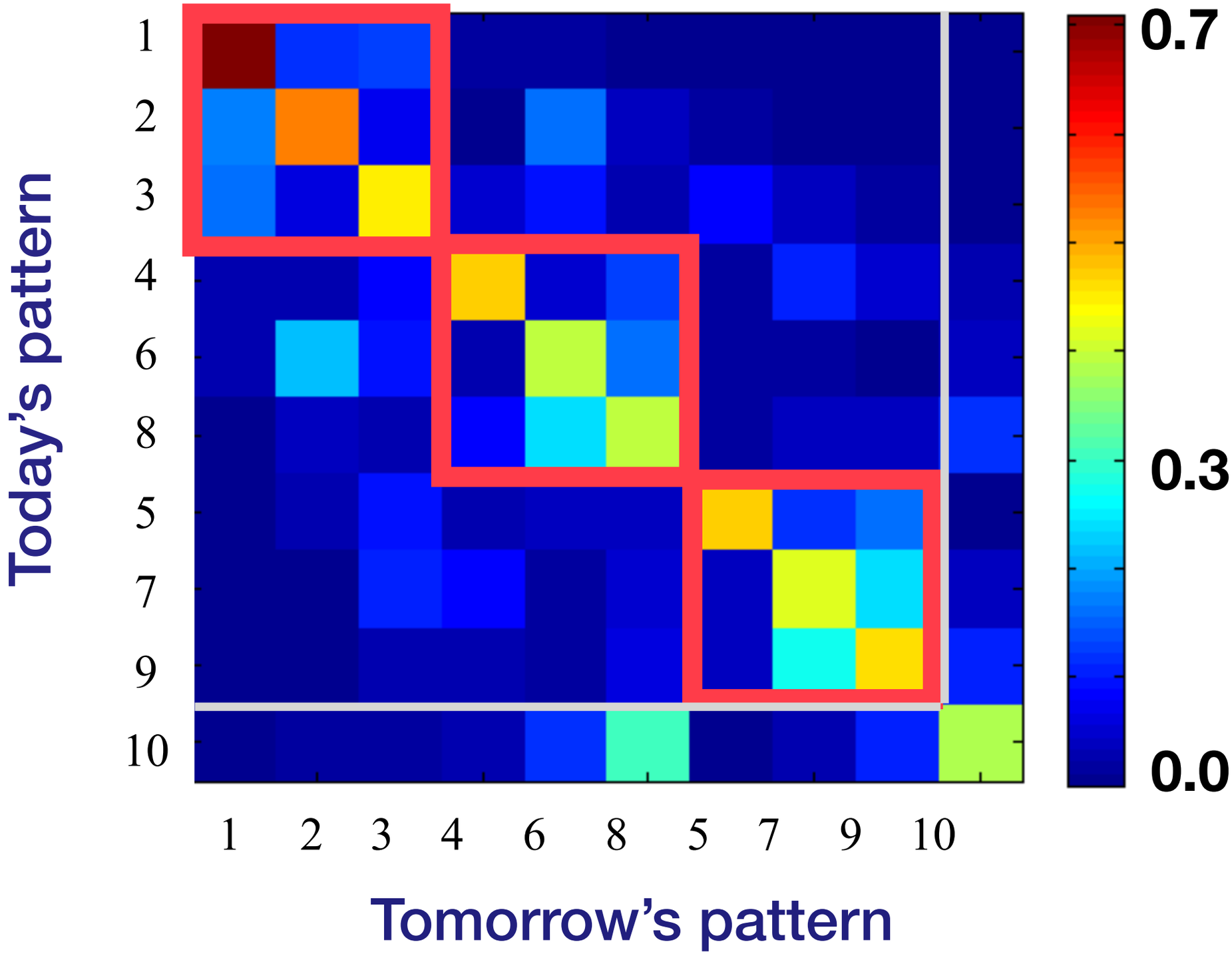
MRF description

Prominent Patterns (one per day)

Determined over 8 years, valid for 111 years



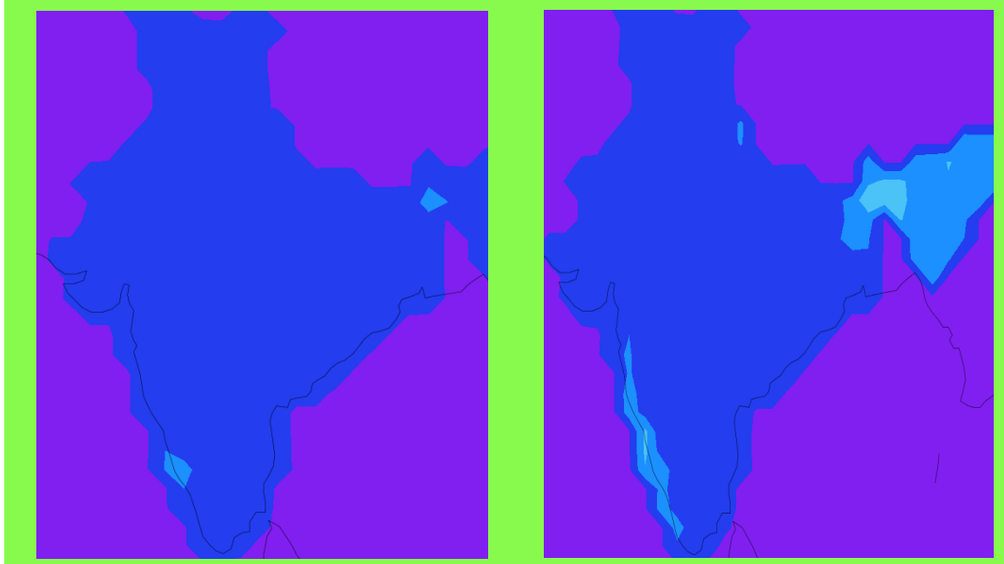
Transition probabilities



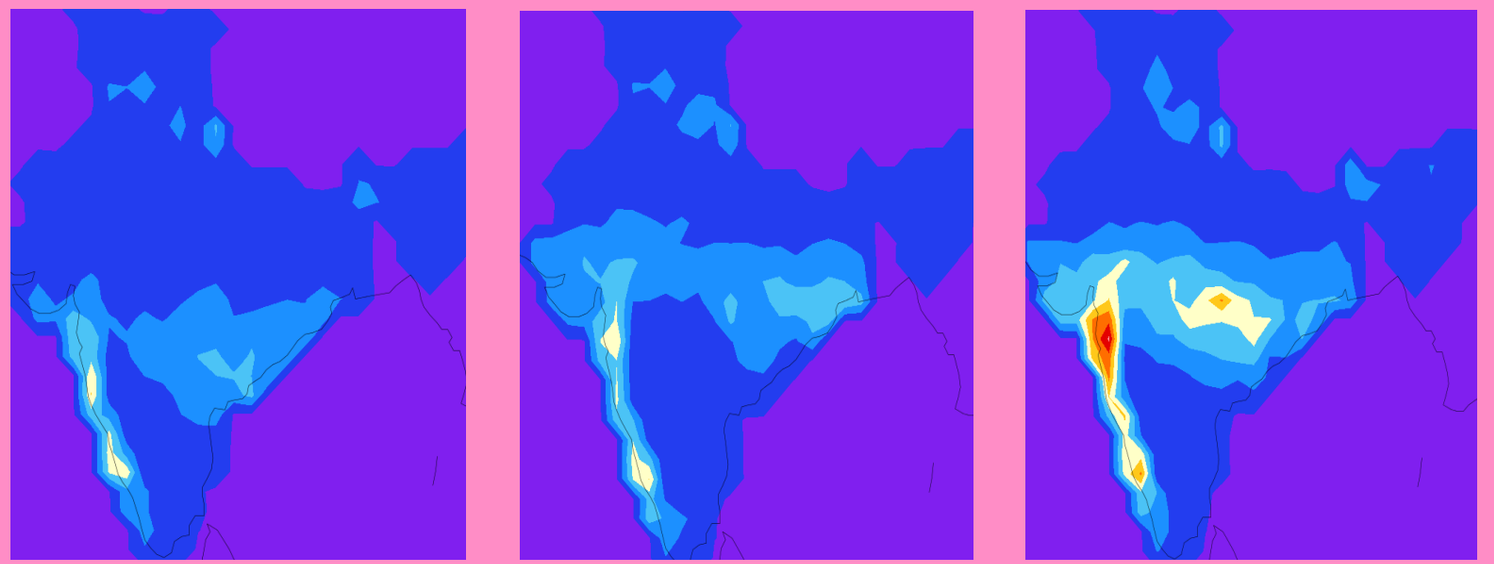
Mitra et al., 2018

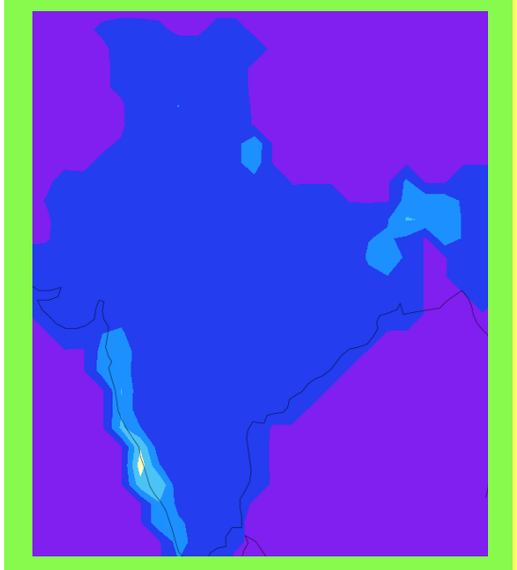
Sticky families

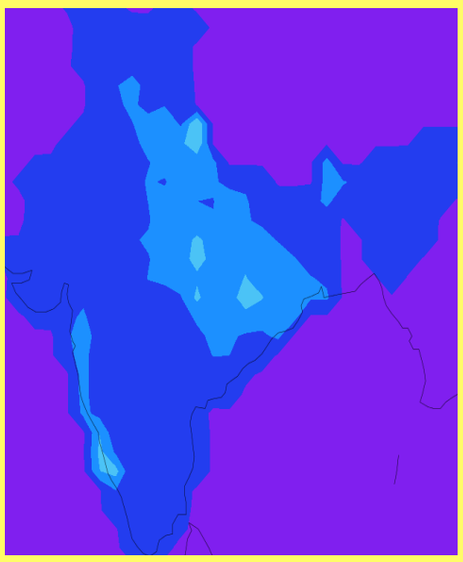
Relatively dry (5 days)

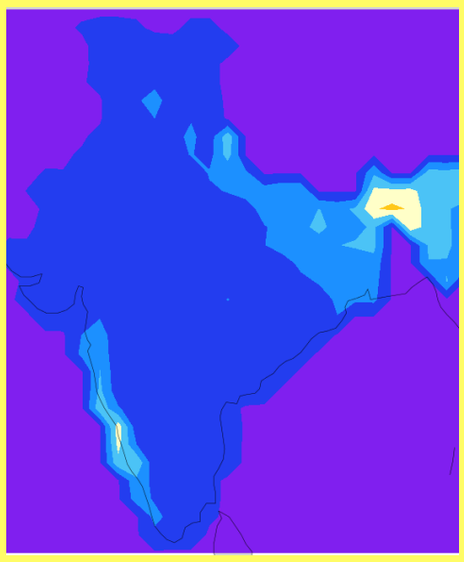


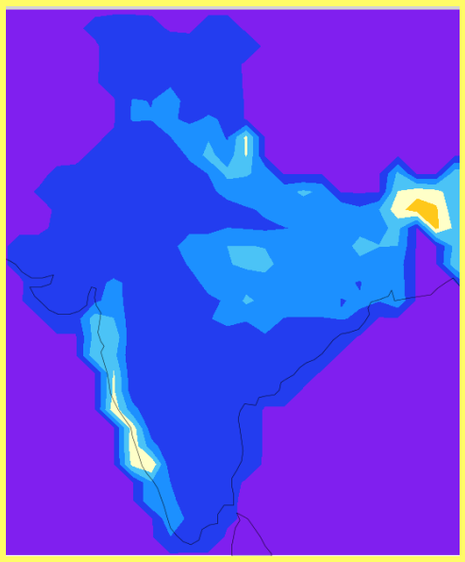
Wet 1 (2.7 days)

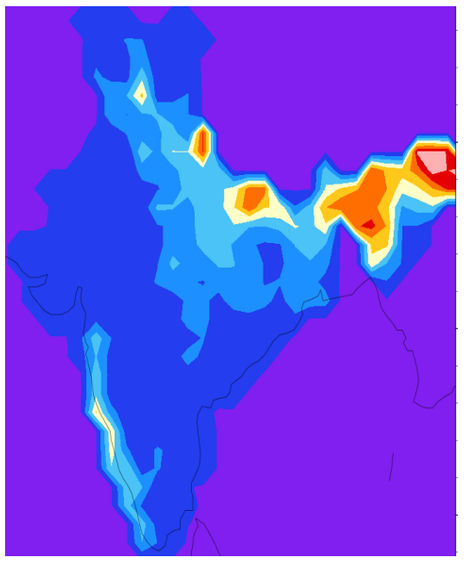




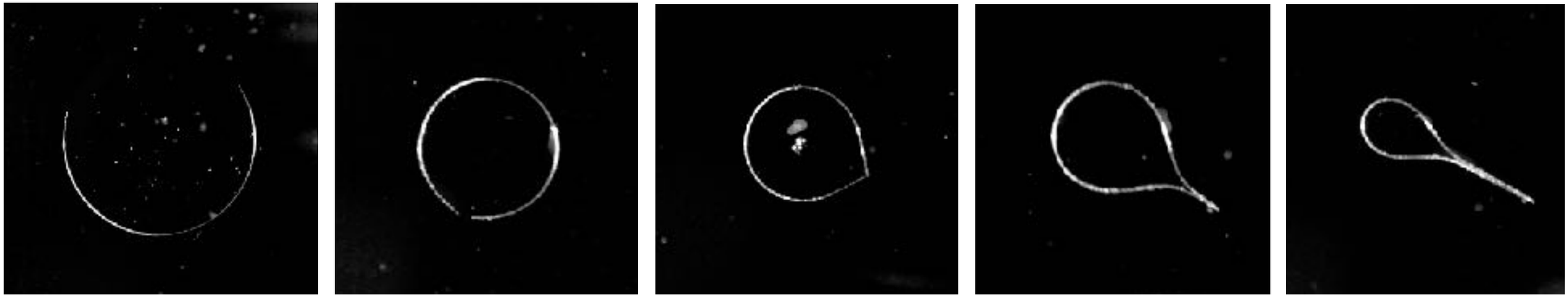








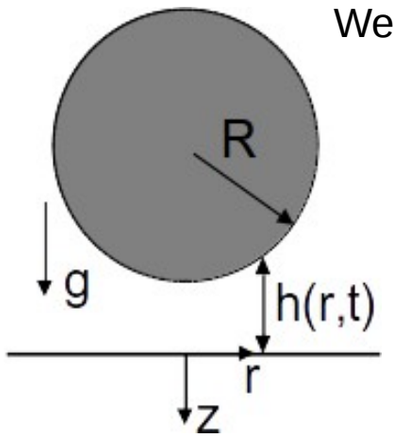
Wet 2 (2.5 days)



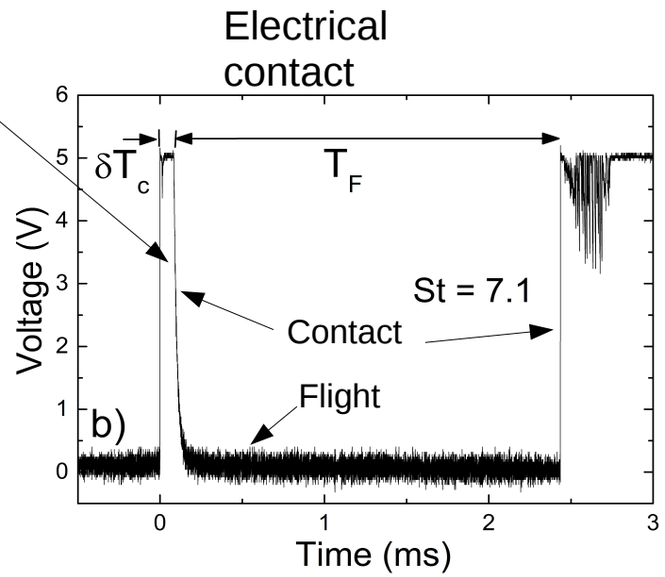
Mechanics of thin filaments

Lubrication theory says NO

We say YES!



Stokes Number, St = $\frac{2}{9}\frac{\rho_s u R}{\mu}$

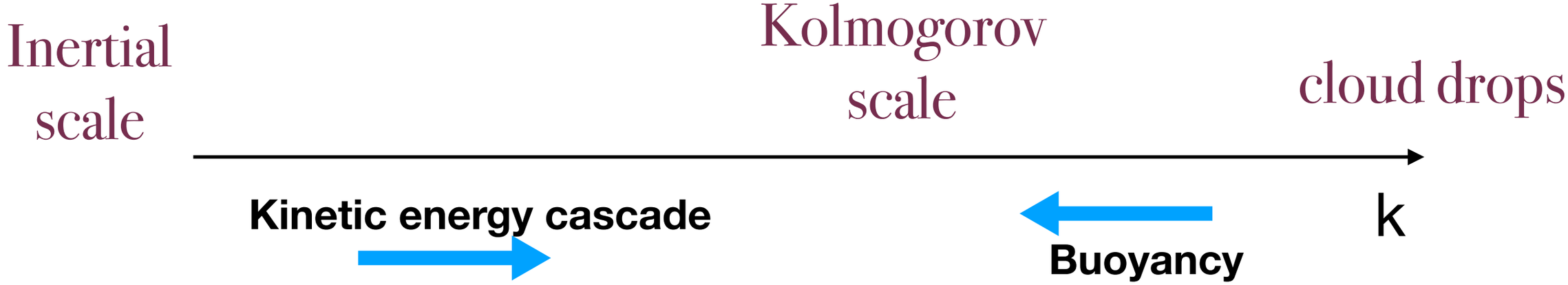


Contact dynamics in a sphere-wall collision in a viscous fluid

Summary and Thank you

Droplet growth enhanced by rapid evacuation near vortices

A mechanism by which microscopic droplets affect big structures

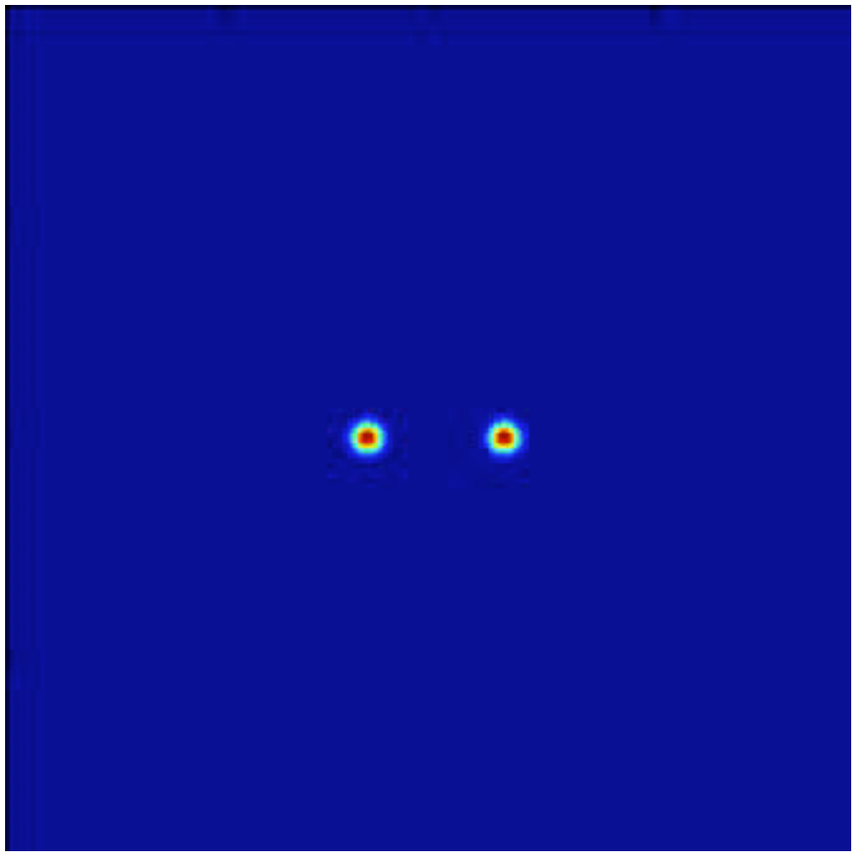


Future: real clouds

Indian monsoon: a promising beginning

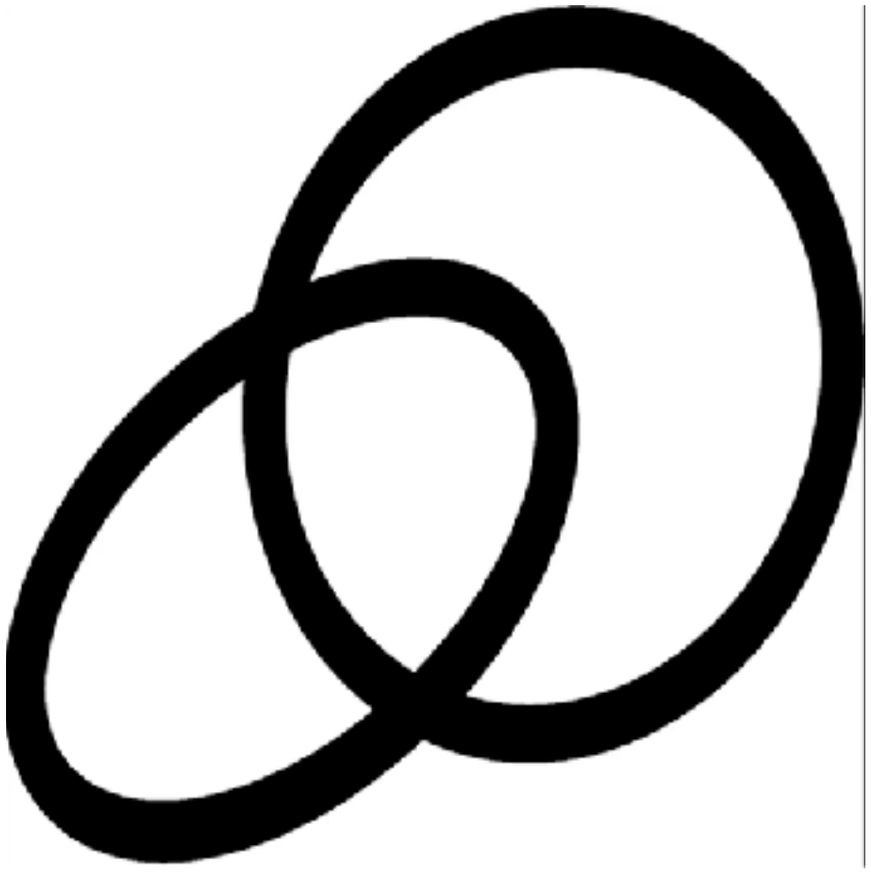
Movie by Karthik Menon

Vortex merger



Movie by Harish Dixit

Vortex reconnection



Movie by Karthik Menon