Aerosol-Cloud-Precipitation Interactions in a Self-Organizing System

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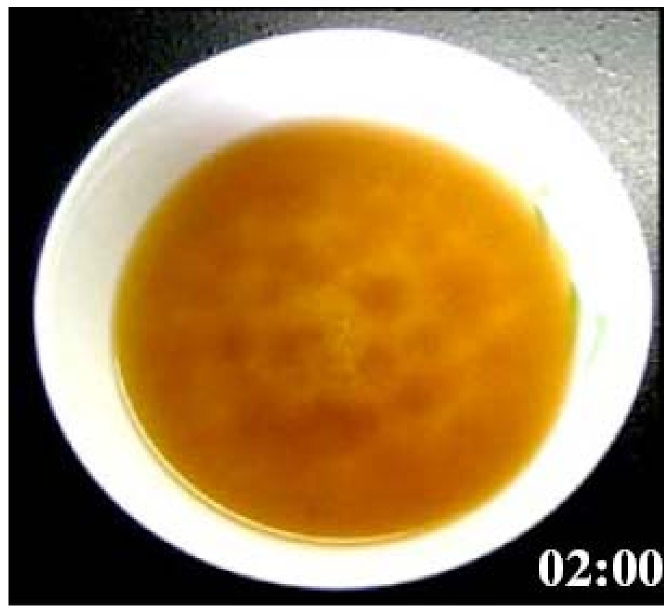
Miso Soup

Warm currents rise; Cold surface currents sink; Opposite movements cannot take place at the same time without self-organization;

Cellular structures emerge; Benard cells

Spontaneous creation of globally coherent patterns out of local interactions



Convectional and sedimentation dissipative patterns of Miso soup Tsuneo Okubo. Colloid Polym Sci (2009) 287:167–178

Questions/Objectives

- Can we simulate the transition from closed to open cells?
- What role does the aerosol life cycle play in maintaining closed cells or closing open cells?
- Explore concept of self-organization
- Model-observational comparisons to further understanding of POC-related processes (Hailong Wang et al.)

Model

- The Weather Research and Forecasting (WRF) model
- Two-moment (bulk) cloud microphysics
- Monotonic advection
- Cyclic boundary conditions
- Aerosol Budget
- Nocturnal simulations: DYCOMS-II
- 60 km (180 km) x 60 km domain
  ($\Delta x = \Delta y = 300$ m; $\Delta z = 30$ m; $\Delta t = 3$ s)

Aerosol Effects on Cloud Morphology via Drizzle

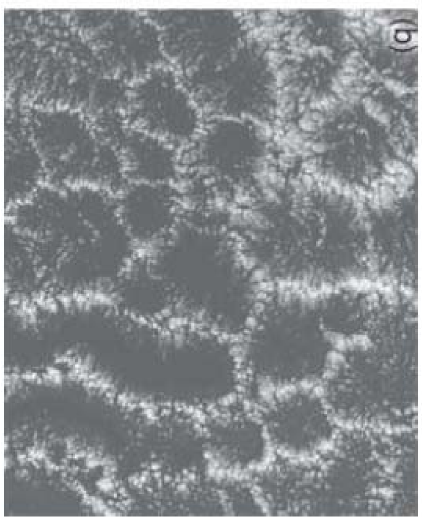
Albedo

Closed-cell
Albedo ~ 0.6
(non-precipitating)

→ high aerosol

*Onset of **drizzle** results in transition to open-cell convection*

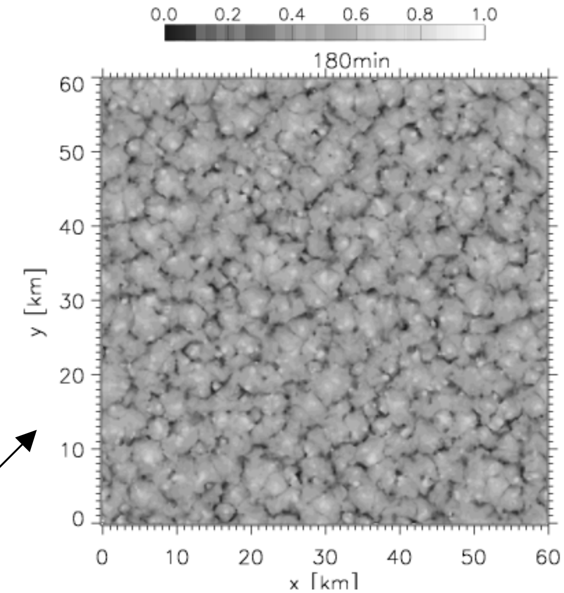
WRF Model
+ 2-moment μphysics;
60 km domain;
$\Delta x = \Delta y = 300$ m
$\Delta z = 30$ m

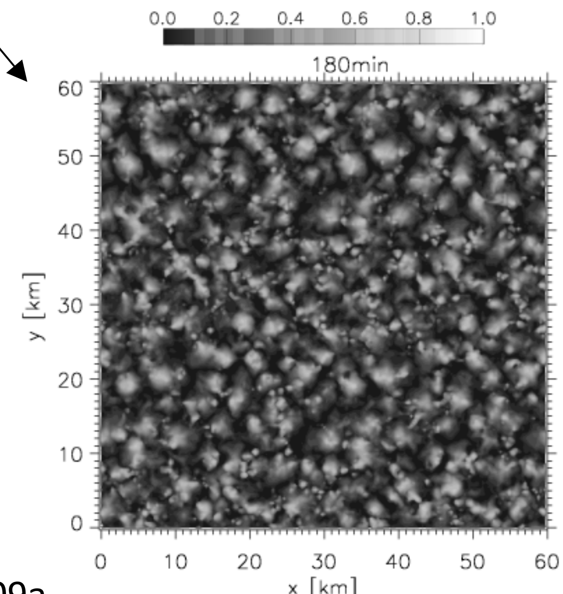


Open-cell
Albedo ~ 0.2
(precipitating)

→ low aerosol

Albedo

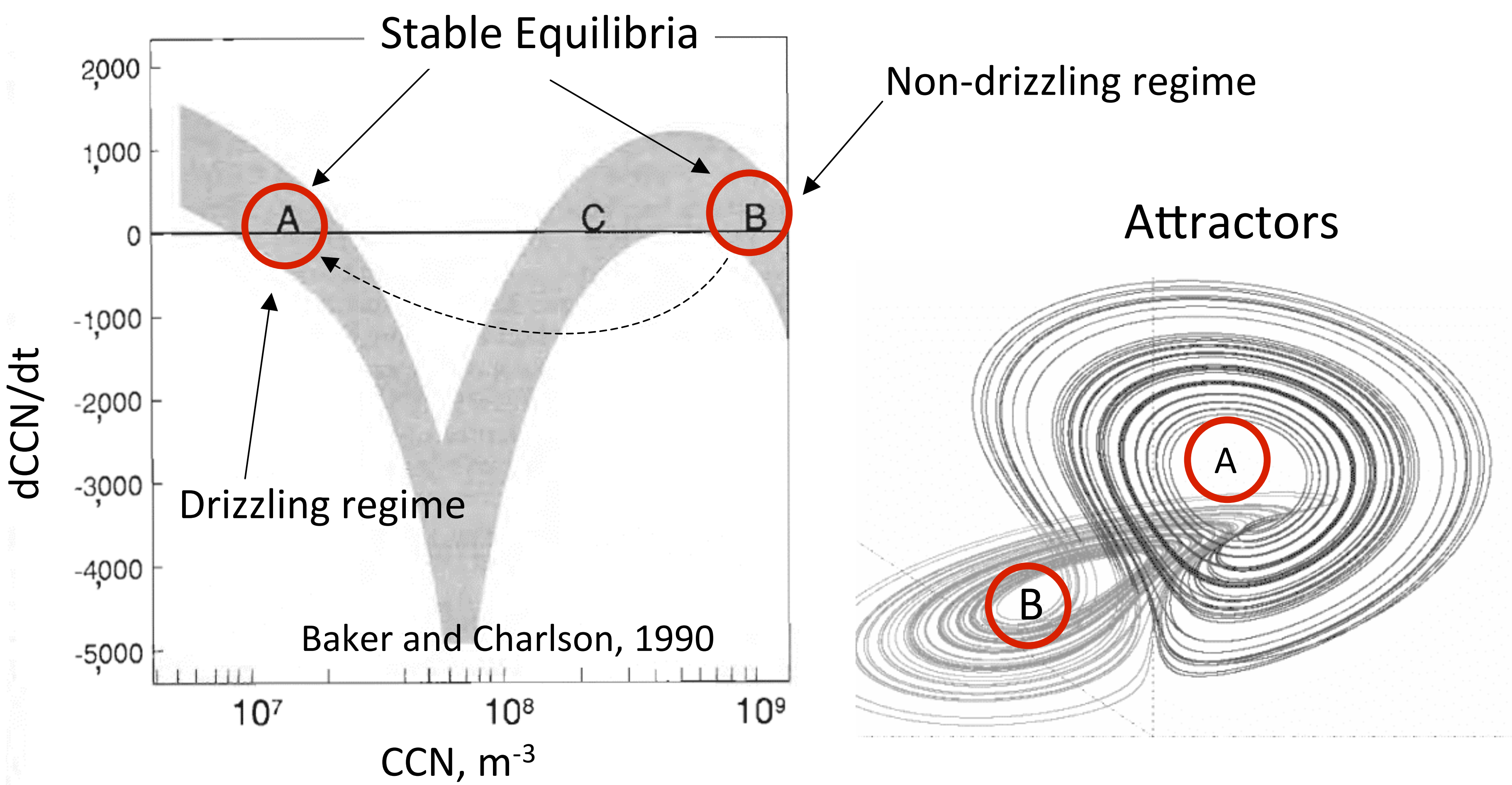




Garay et al. 2004, MISR Satellite images

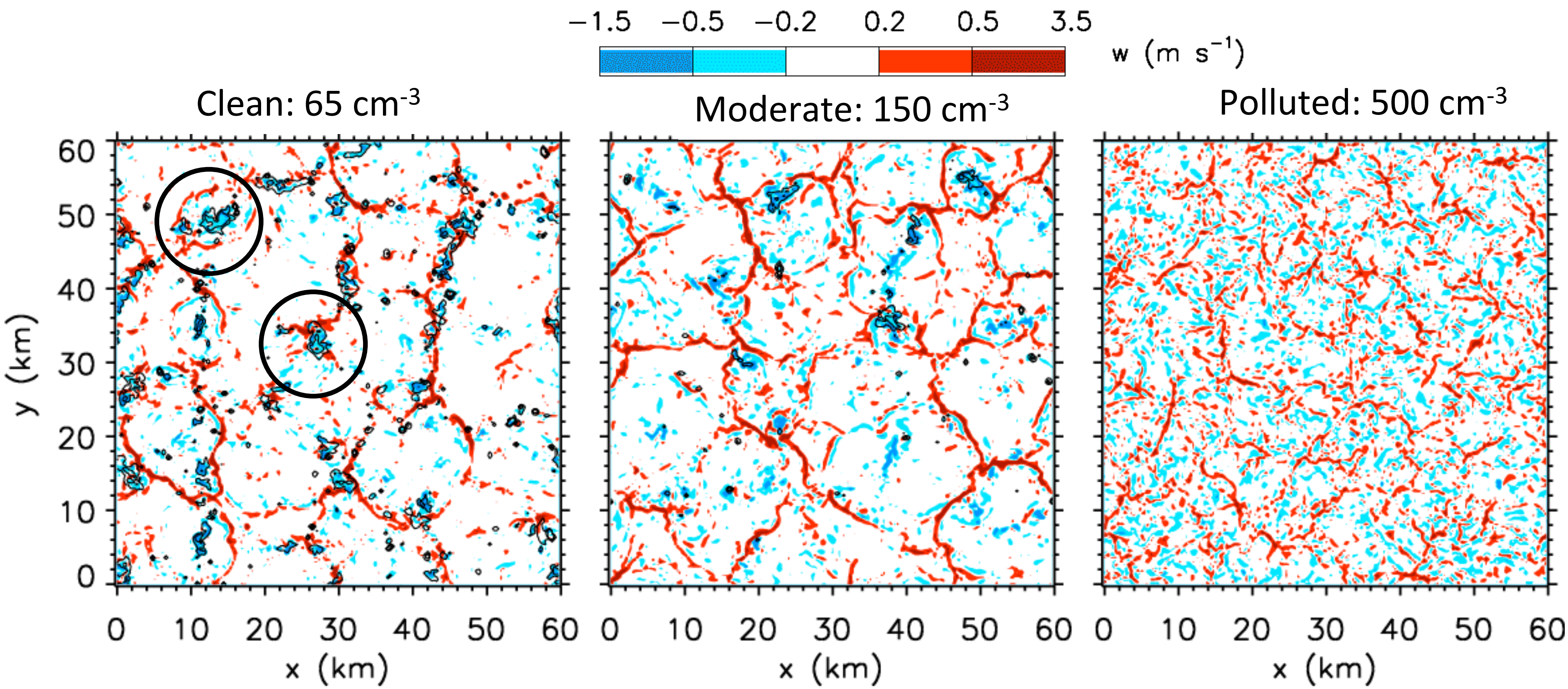
Wang and Feingold, 2009a

Stable Equilibria: Attractors



- *The process of transition starts with a positive feedback (precip)*
- *Once in equilibrium it enters a stable equilibrium*

Vertical Velocity



near-surface vertical velocity

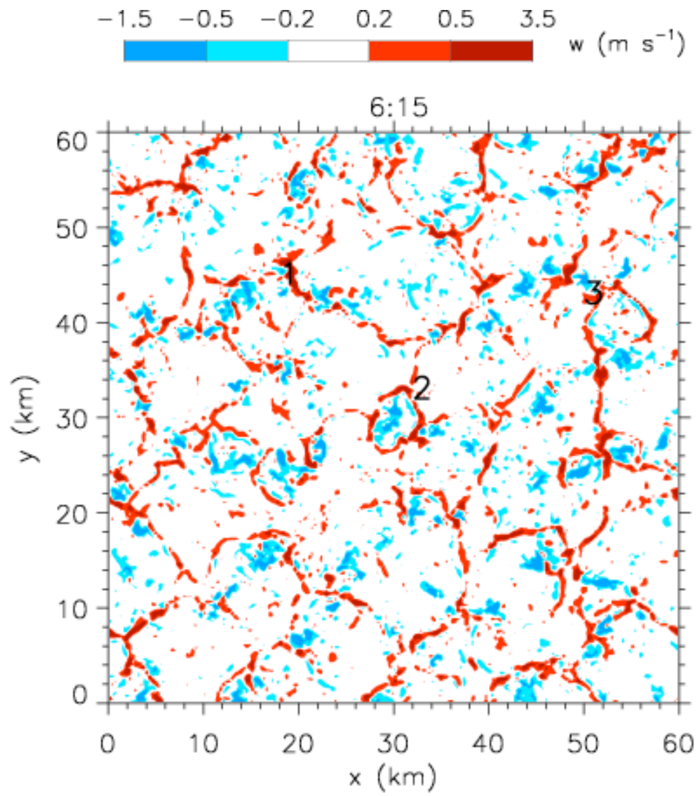
Red: Updrafts/surface convergence

Blue: Downdrafts/surface divergence

Black contours: Drizzle

Wang and Feingold 2009b

Global Order from Local Interactions



200-m vertical velocity from
t = 6:15 to 9:15

Cells compete or cooperate while interacting with their shared physical environment

Y-shaped surf
is region favou

↓

Precipitation i

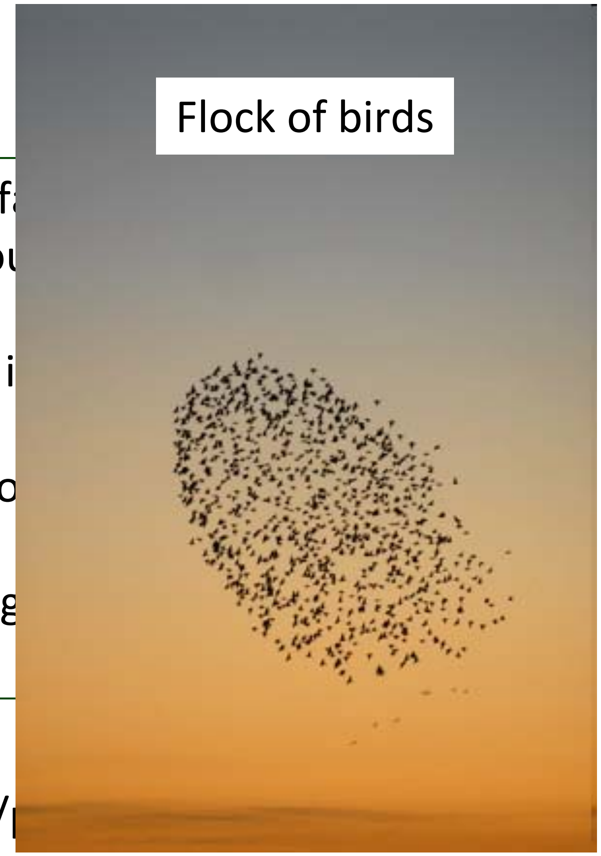
↓

Downdrafts, o

↓

Surface diverg

Red: Updrafts
Blue: Downdrafts/

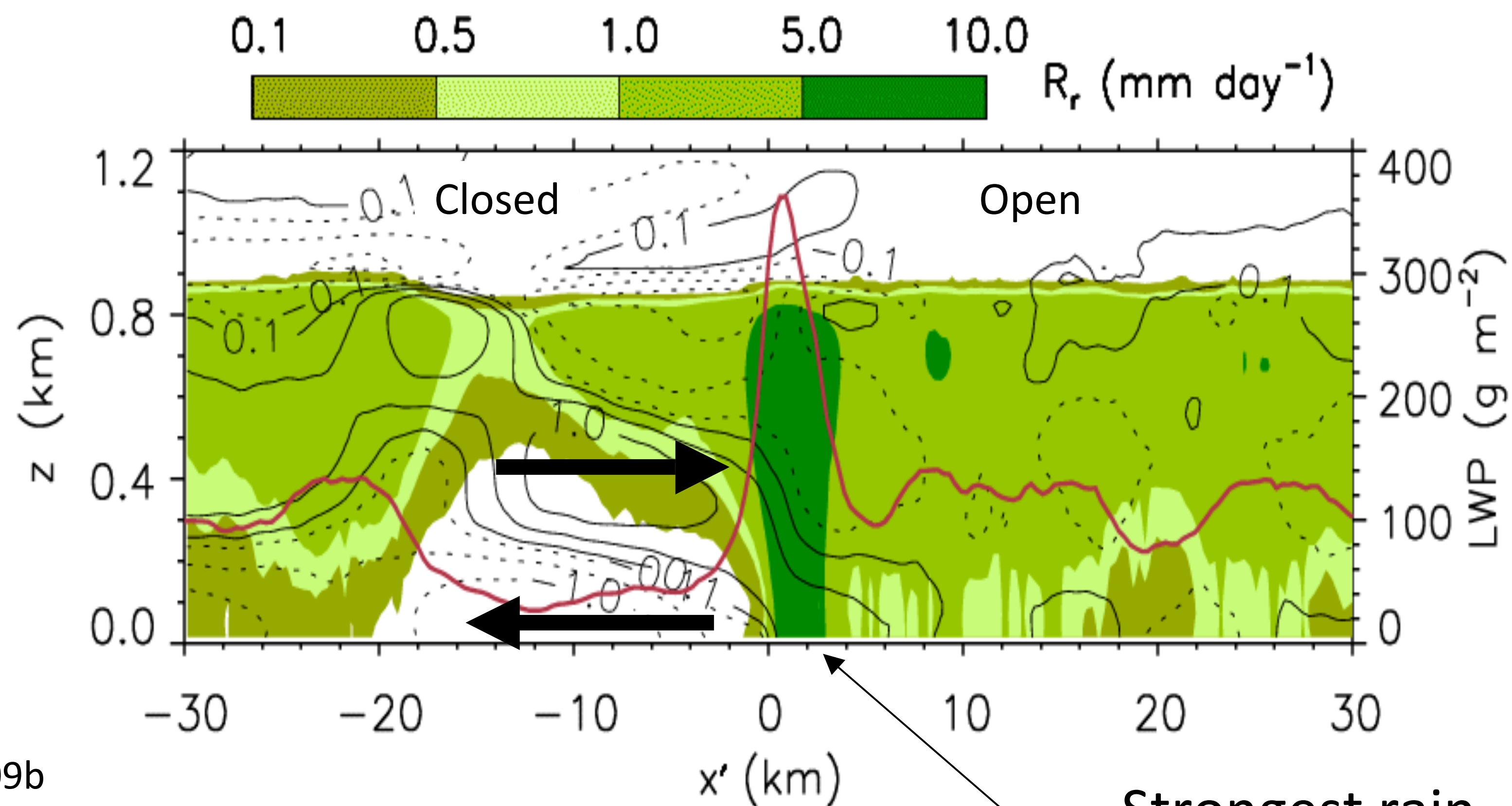


Behaviour can be reproduced numerically with following rules:

1) *Keep a minimum distance from one another*
2) *Follow average direction of neighbour*

Open/Closed Cell Boundary:

Conditional composite relative to clean/polluted boundary



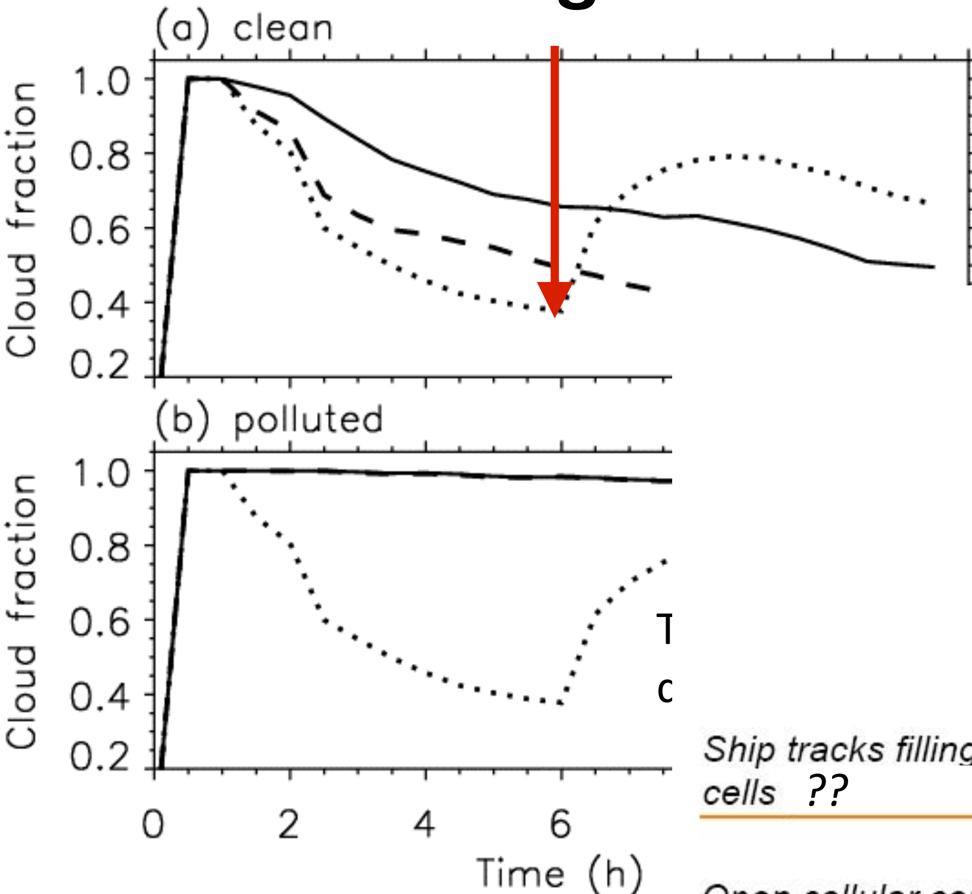
Wang & Feingold 2009b

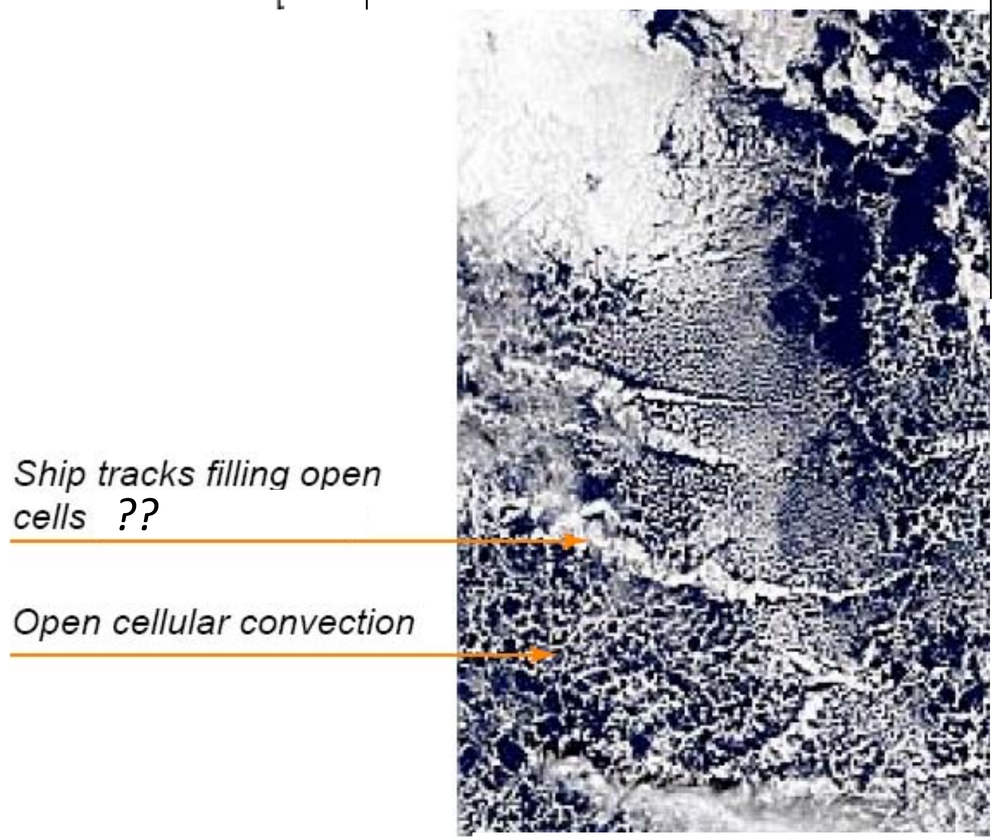
Strongest rain closest to boundary between clean and polluted

Contours: x-wind perturbation (+ve = solid)

LWP

Ship Tracks: Self organizing systems are resilient to change





Stevens and Feingold 2009

- *a certain amount of random*
  than hinder, self-organization
- *possible implications for geoengineering*

Conclusions

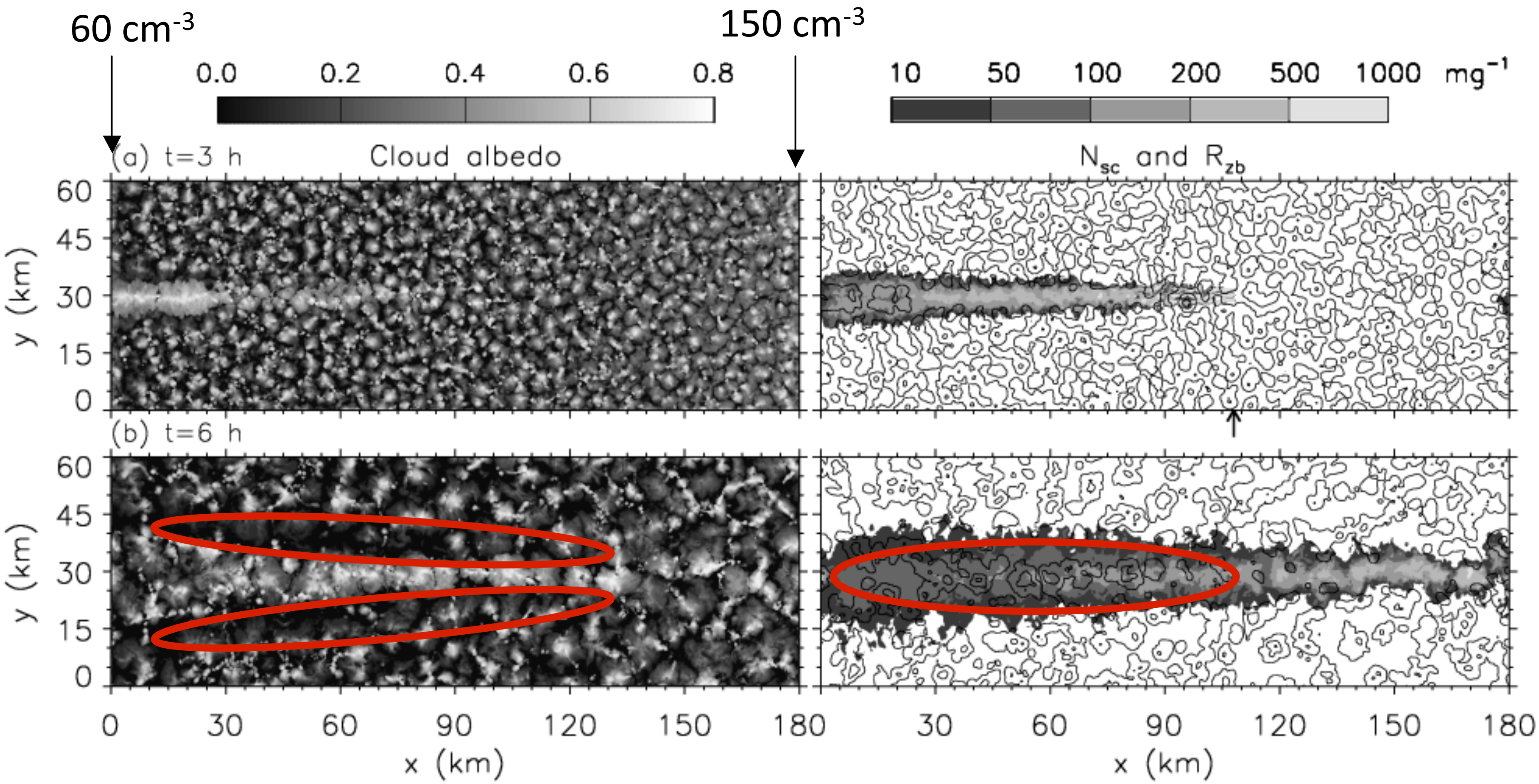
Closed/Open cellular structures exhibit the features of a self-organizing system; <u>two stable states</u> (Baker & Charlson)

Growth rate of open cells depends on strength of rain locally, and in surroundings - <u>coherent patterns from local interactions</u>

Aerosol gradients → precipitation gradients → <u>mesoscale circulations</u> that act to remove the gradient

Massive aerosol perturbations to an open cellular system increase the cloud cover/albedo but <u>do not change the cellular structure</u> to a closed state (robustness)

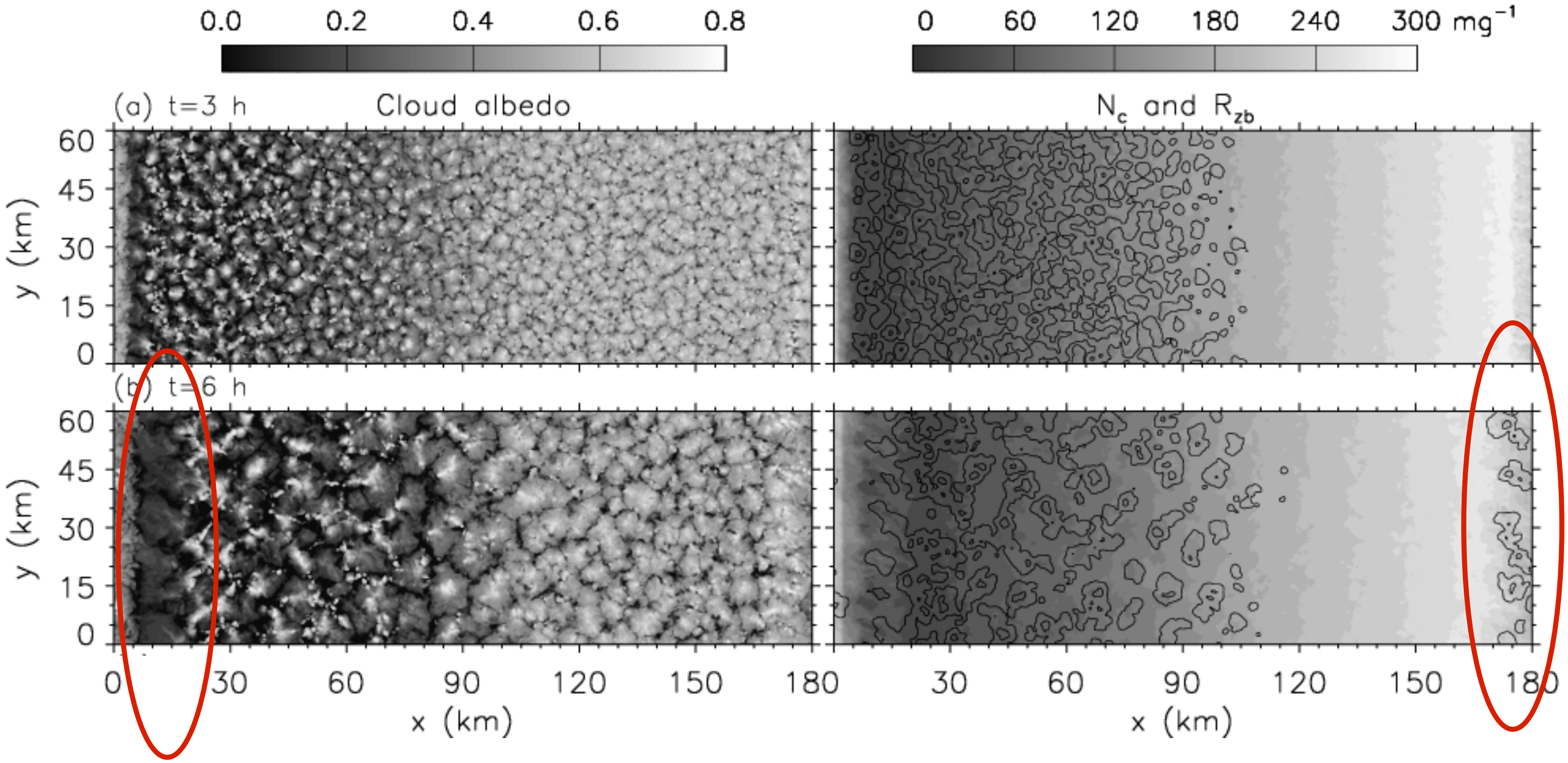
Ship Tracks



Wang and Feingold 2009b

Contours: rain
Shading: ship particles

- *Mesoscale circulation transverse to track strengthens LWP in track*
- *Clearing on either side of track*



Cloud Albedo

Aerosol concentration: shading
Rain at cloud base: contours

Mesoscale circulation at the strong aerosol gradient
- Enhances LWP in the closed cell (polluted side)
- Generates clearing near the boundary
(lack of counteracting outflow on the closed-cell side)

Wang and Feingold (2009b)

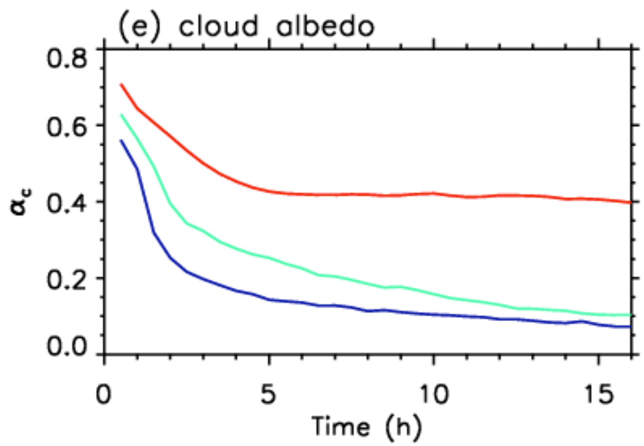
References:

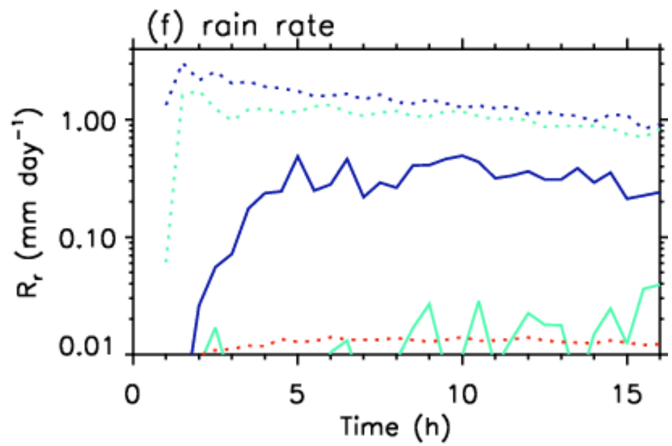
- Immanuel Kant, *Kritik der Urteilskraft*, 1790
- Francis Heylighen, *The Science of Self-Organization and Adaptivity*

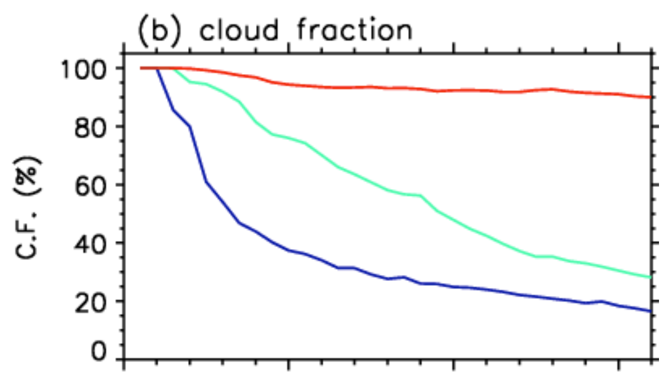
Clean: 65 cm^{-3}

Intermediate: 150 cm^{-3}

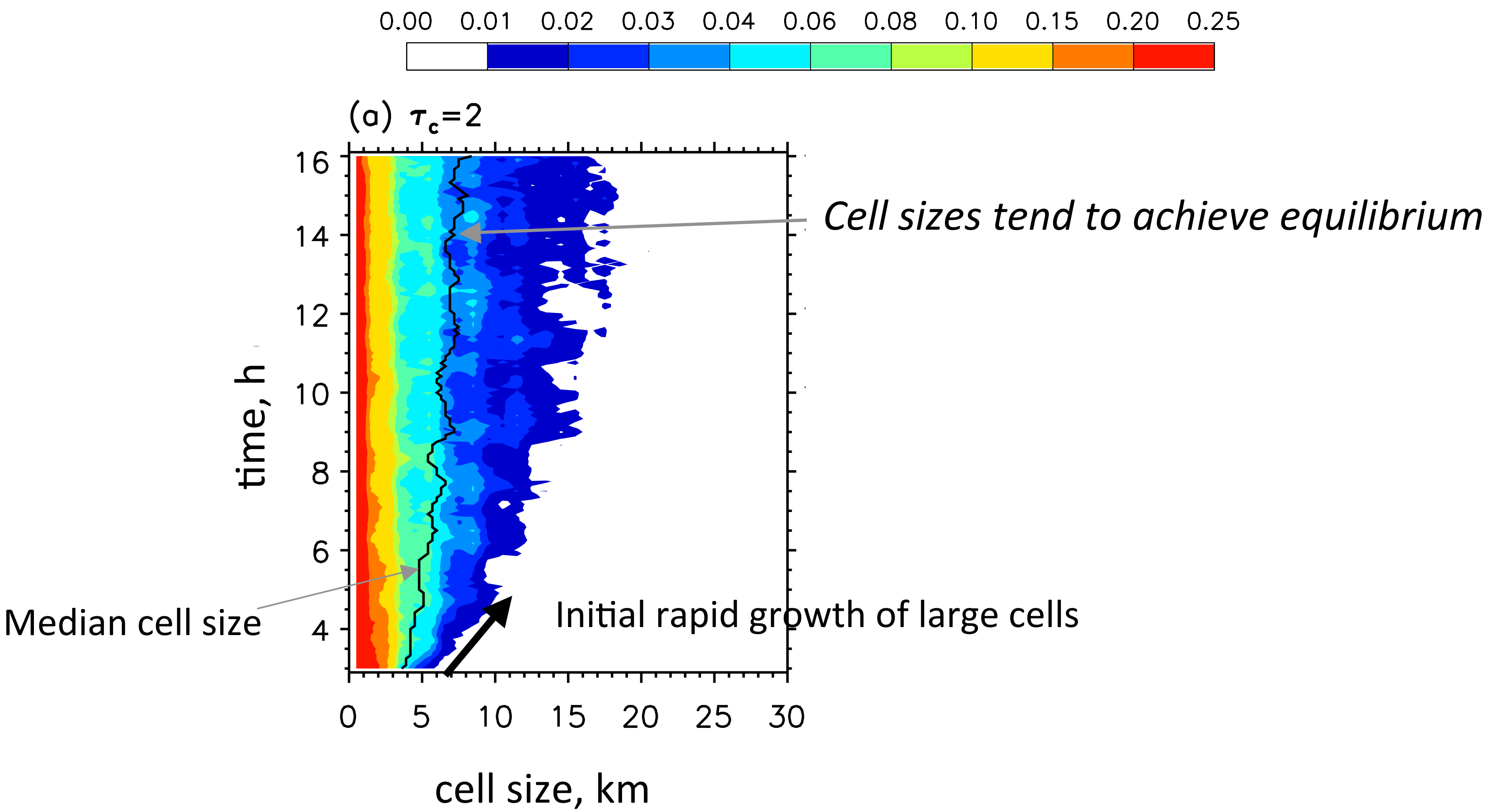
Polluted: 500 cm^{-3}

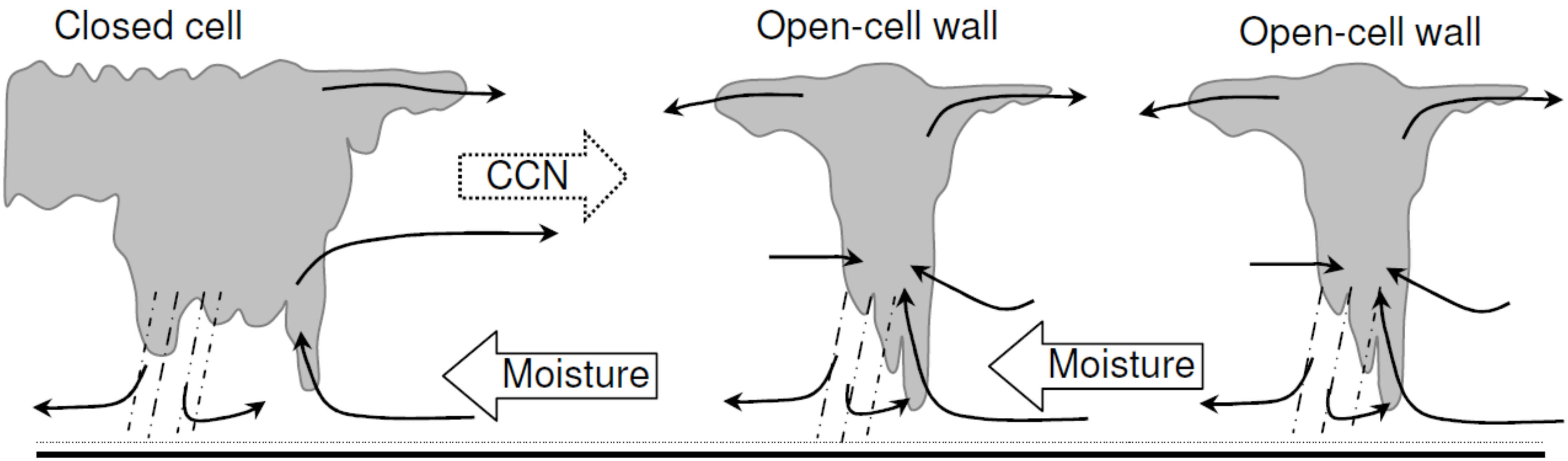






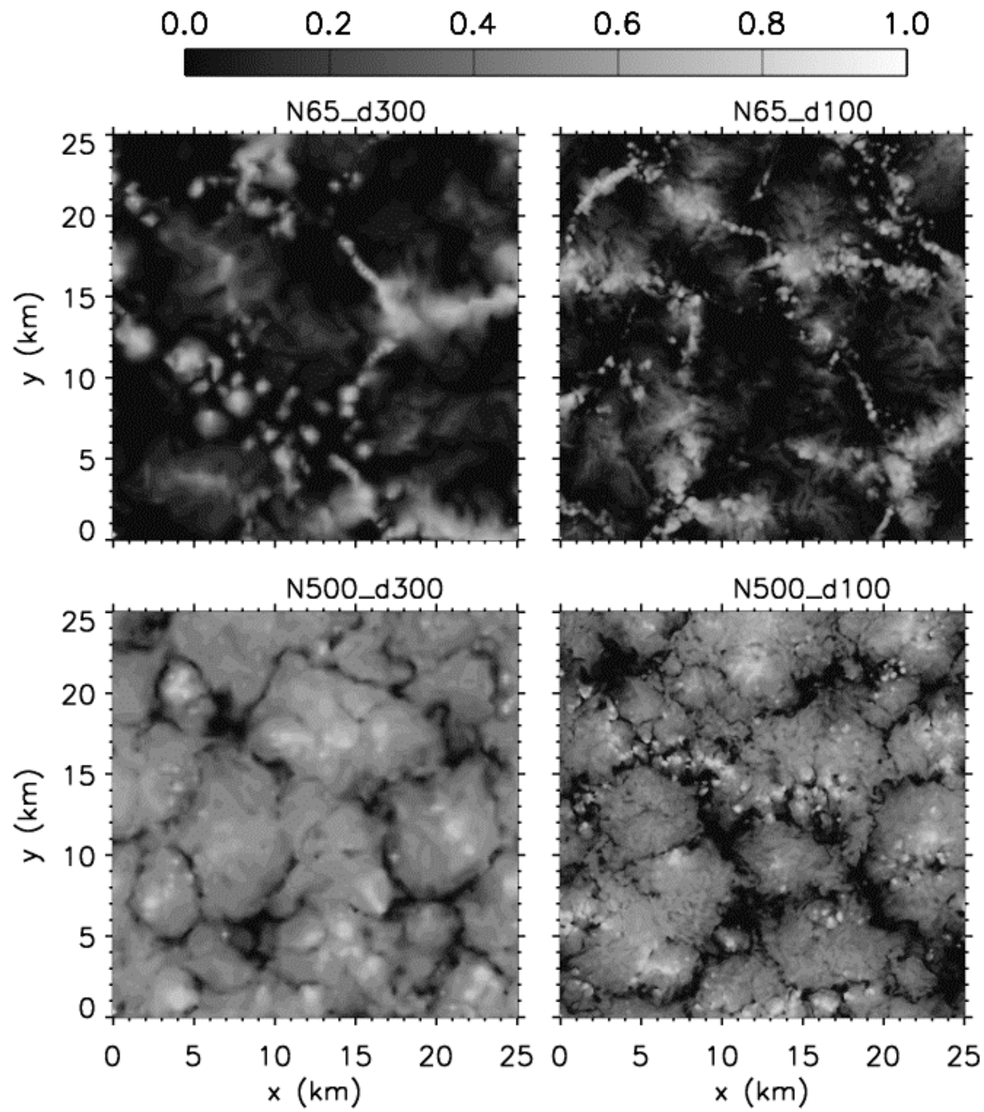
PDF of growth rates of a population of open cells





Closed cell
Open-cell wall
Open-cell wall
CCN
Moisture
Moisture

Effect of resolution



Low Resolution High Resolution

Coarse resolution runs also exhibit poorer vertical mixing