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

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
  \((\Delta x = \Delta y = 300 \text{ m}; \Delta z = 30 \text{ m}; \Delta t = 3 \text{ s})\)
Aerosol Effects on Cloud Morphology via Drizzle

Albedo

Closed-cell
Albedo $\sim 0.6$
(non-precipitating)

Onset of
drizzle
results in
transition
to open-cell
convection

Open-cell
Albedo $\sim 0.2$
(precipitating)

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

high aerosol

low aerosol

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

Clean: 65 cm$^{-3}$
Moderate: 150 cm$^{-3}$
Polluted: 500 cm$^{-3}$

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

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

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

Wang & Feingold 2009b

Strongest rain closest to boundary between clean and polluted
Ship Tracks: Self organizing systems are resilient to change

(a) clean

(b) polluted

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

Ship tracks filling open cells ??
Open cellular convection

Stevens and Feingold 2009
Conclusions

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

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

Aerosol gradients $\rightarrow$ precipitation gradients $\rightarrow$ mesoscale circulations that act to remove the gradient

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

60 cm⁻³

(a) t=3 h
Cloud albedo

150 cm⁻³

(b) t=6 h

Wang and Feingold 2009b

Contours: rain
Shading: ship particles

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

Cell sizes tend to achieve equilibrium

Median cell size

Initial rapid growth of large cells
Effect of resolution

Coarse resolution runs also exhibit poorer vertical mixing.