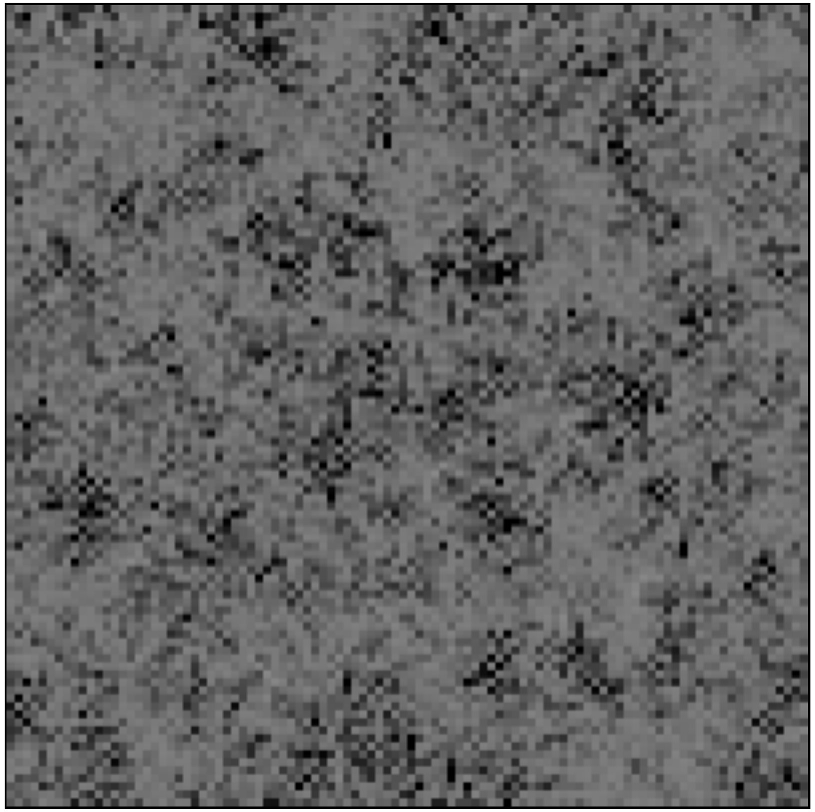
A minimal model of diurnal self-aggregation



Radiation constant

r : 0,03

Convection constants

threshold, τ : 33

intensity α : 3

f_{up} : 0,2

Diurnal cycle

amplitude, A : 0,1

Colormap limits

vmin : 65

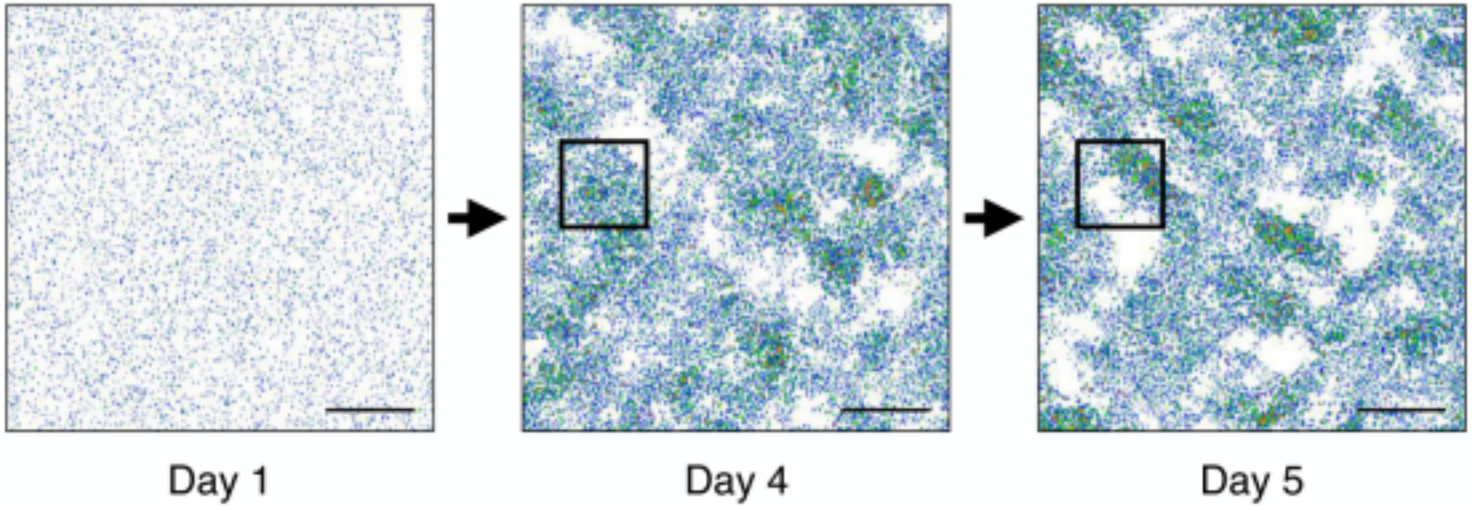
vmax : 67

start fps: 1 time : 29d 8h

OBS: You can reload the page to restart the simulation with a new random initial condition.

Interactive presentation available at: https://sid.erda.dk/share_redirect/abelL26XEZ

Motivation



Diurnal self-aggregation of rain activity in cloud-resolving simulation.
Figure copied from: https://arxiv.org/pdf/2001.04740.pdf

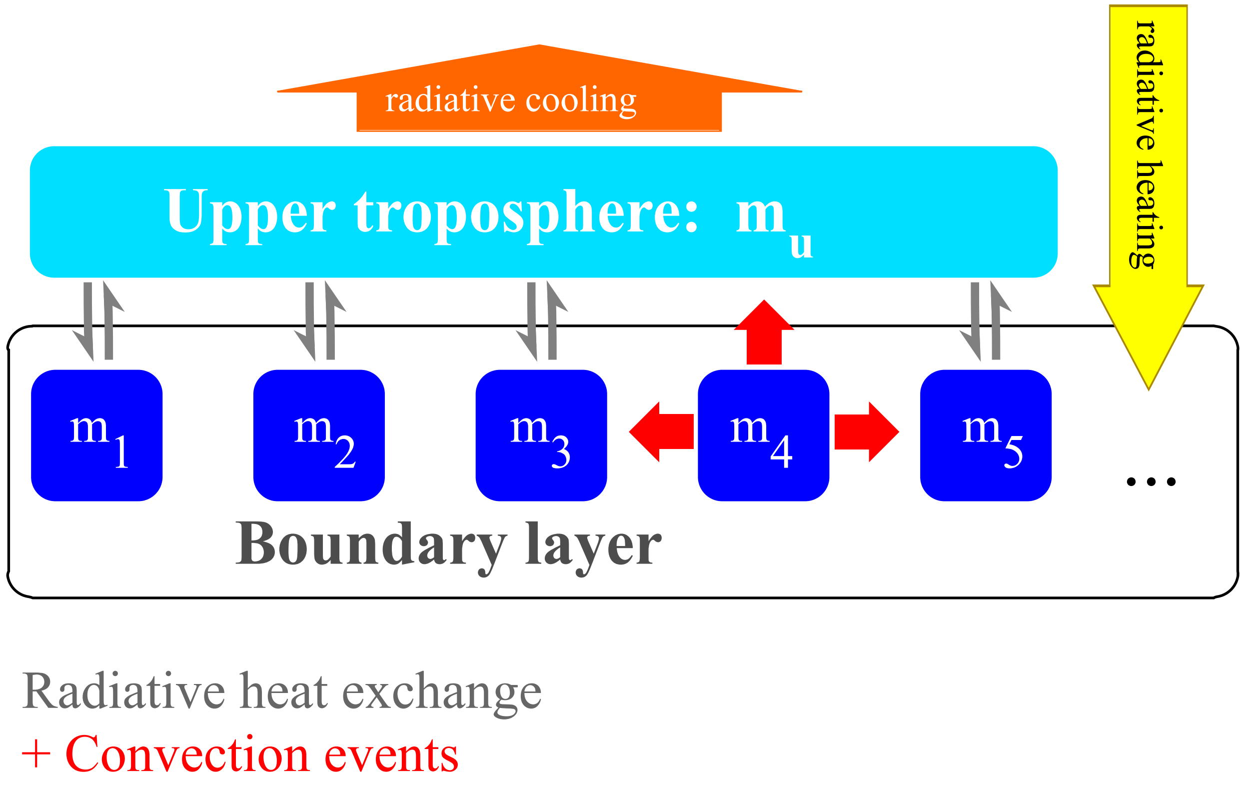
The figure shows daily rainfall in a stylized cloud-resolving simulation where the surface temperature is varied sinodially with an amplitude of 5K to mimic the diurnal cycle. Further information about these results can be found in Jan Härter's presentation.

The emergent spatio-temporal pattern is characterized by two qualitative features:

- Daily rain fall and convective activity is concentrated in spatially inhomogeneous patterns with a typical length-scale around 100-200km.
- The energent spatial pattern is anti-correlated from day to day.

Here we present a simple conceptual model, demonstrating how these two features can arise from simple energy-budged considerations.

Model description



Our model describes a single extensive variable, m, which can be thought of as moist static energy. Energy enters the system at the buttom of the system, at a sinodially varying rate, and leaves through the top. It is moved between the layers by two process: linearized radiation and non-linear convection events.

State

We consider a highly simplified model of the atmosphere separated into two layers.
The lower layer, which represents the boundary layer, is separated into N cells forming a square lattice. The

energy in the i'th cell is denoted by m_i.

The upper layer is modelled by a single variable m_u. This is equivalent to assuming that horizontal instant horizontal energy equilibration in this layer.

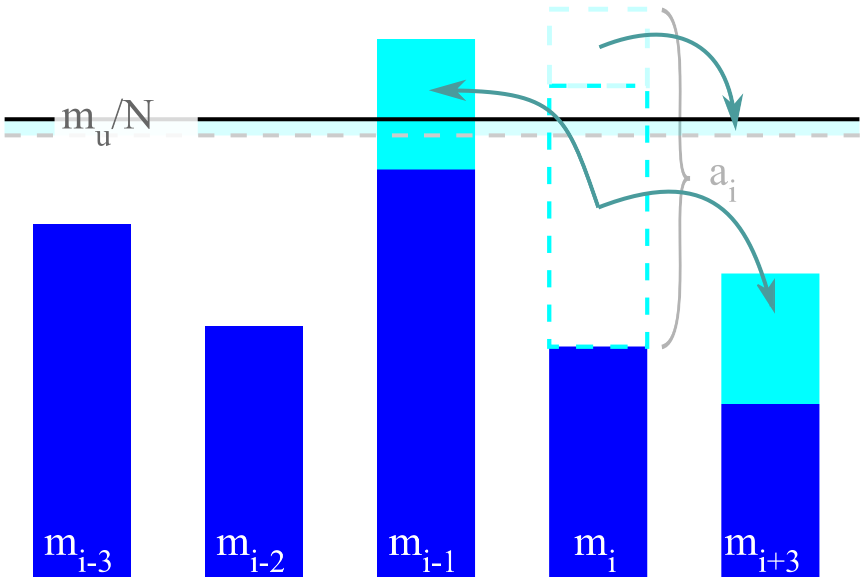
Dynamics

Energy can be transported by two types processes: radiation and convection events. We model this in discreete synchronous timesteps. Each timestep should be considered as the time of a typical convection event, which is around one hour.

Linearized radiation

In each timestep, each cell looses a fraction of its energy through linear radiation. The energy radiated out from the lower level is absorbed in the upper level. Half the energy radiated out from the upper level is distributed equally among the cells in the lower lever, while the other half escapes out of the system.

Convection events



Energy is added to the system at the lower level and leaves throught the upper layer. This gives rise to an energy imbalance. Convection events are triggered when the local energy imbalance exceeds a threshold τ. When a convection event happens at a cell *i*, the cell gives away some part of its energy proportional to how much the threshold was exceeded. A fraction of this energy, f_{up}, goes to the upper atmosphere, while the rest is distributed equally between the neighbouring cells. The horizontal distribution is supposed to represent the horizontal transport of moisture and kinetic energy driven by cold pools.

Combined equations

The dynamics described above are compactly described in the following equations:

$$\Delta m_i = r\frac{m_u}{N} - r\,m_i + 1 + A\cos\left(\frac{2\pi}{24}\,t\right) - a_i + \sum_{j\in\mathcal{N}_i}\frac{1-f_{up}}{\#\mathcal{N}_j}\,a_j$$

$$\Delta m_u = -2r\,m_u + \sum_i\left(r\,m_i + f_{up}\,a_i\right)$$

$$a_i = \max\left(\min\left(\alpha\left(m_i - \frac{m_u}{N} - \tau\right), m_i\right), 0\right)$$

m_u: Energy in upper troposphere
m_i: Energy in boundary layer cell 'i'
a_i: Convection activity at cell 'i'

r: Radiation rate
τ: Convection threshold
α: Convection intensity
f_{up}: Fraction of 'convection activity' sent to upper atmosphere
A: Amplitude of diurnal temperature surface flux oscillations

N: Number of boundary layer cells
$\mathcal{N}_i$: Boundary layer cells neighbouring cell 'i'