Title: Physics in Nature Presentation: Clouds - Formation and Self-Organizing Criticality

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Abstract:

Cloud Formation and Self-Organizing Criticality

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Perimter Scholars International

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What's so interesting about clouds?

- Local physical rules lead to large scale behavior
- Similar behavior found in other complex systems
- Phenomenon at the boundary between equilibrium and chaos

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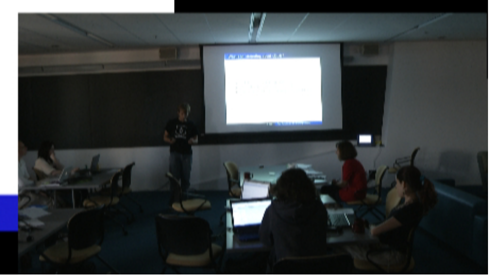

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Overview of discussion

- Basic physical model of formation
- Complexity in clouds
- Self-organized criticality
- Simple model of SOC

Condensation

- Most condensation occurs on the surface of a solute, such as *NaCl*
- Increased binding energy lowers the saturation required to produce droplets
- As water condenses on the solute, the vapor pressure required to sustain growth increases
- $C \propto \frac{1}{r^3}$ while $A \propto r^2$

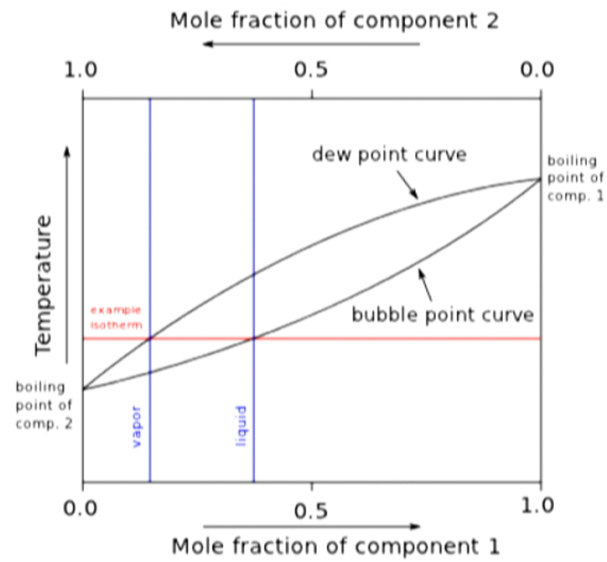

Figure: Sample phase diagra

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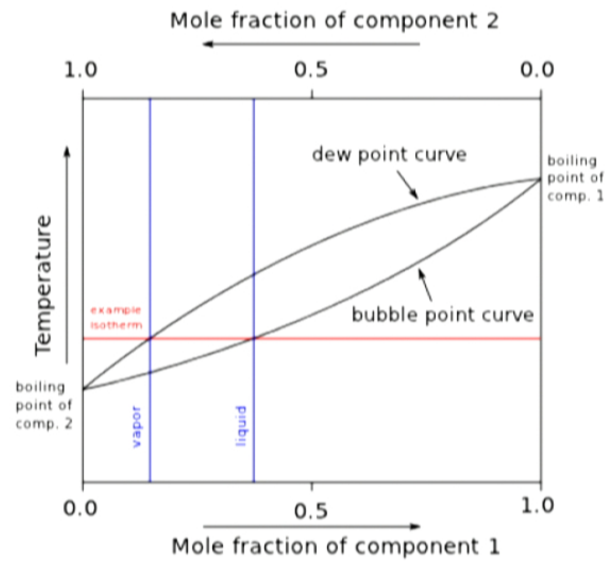

Figure: Sample phase diagra

A basic model for cloud formation

- During condensation a small amount of heat is released
- The increase in temperature leads to upward expansion
- Adiabatic cooling allows the cloud to sustain a feedback loop

$$N\Delta T = V\Delta P$$

$$\Delta P = -\rho g \Delta z$$

$$C_v \Delta T + P\Delta V = 0$$

Figure: Cloud

Structure of formation

- Air currents allow neighbors to be brought into the condensation cycle
- The result of this process is a scale invariant structure

Figure: Clouds

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Simulation of the condensation cycle

- K Nagel and E Raschke (1991) implemented a discretized version of this model in three dimensions
- Simulation produced scale invariant cloudlike structures as desired
- Although this may seem like a coincidence, many scale invariant systems exist in nature
- Scale invariant systems are called "$\frac{1}{f}$"

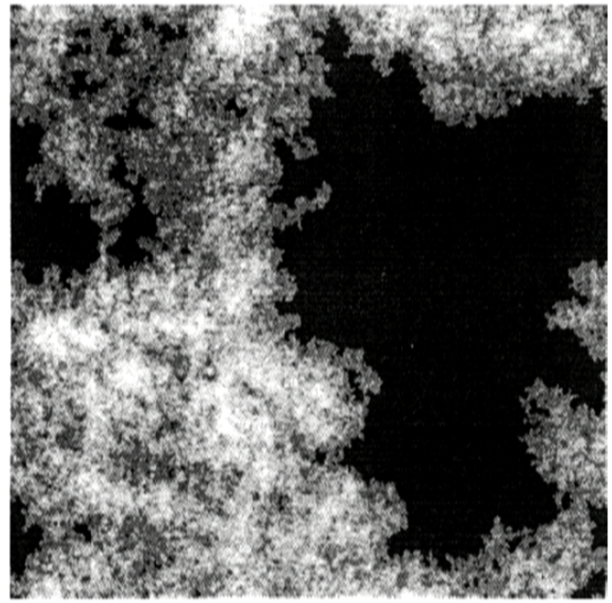

Figure: Clouds as simulated by Nagel and Raschke

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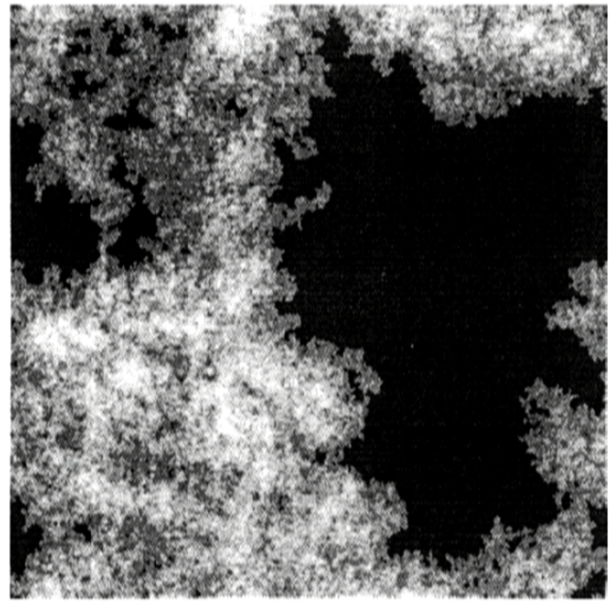
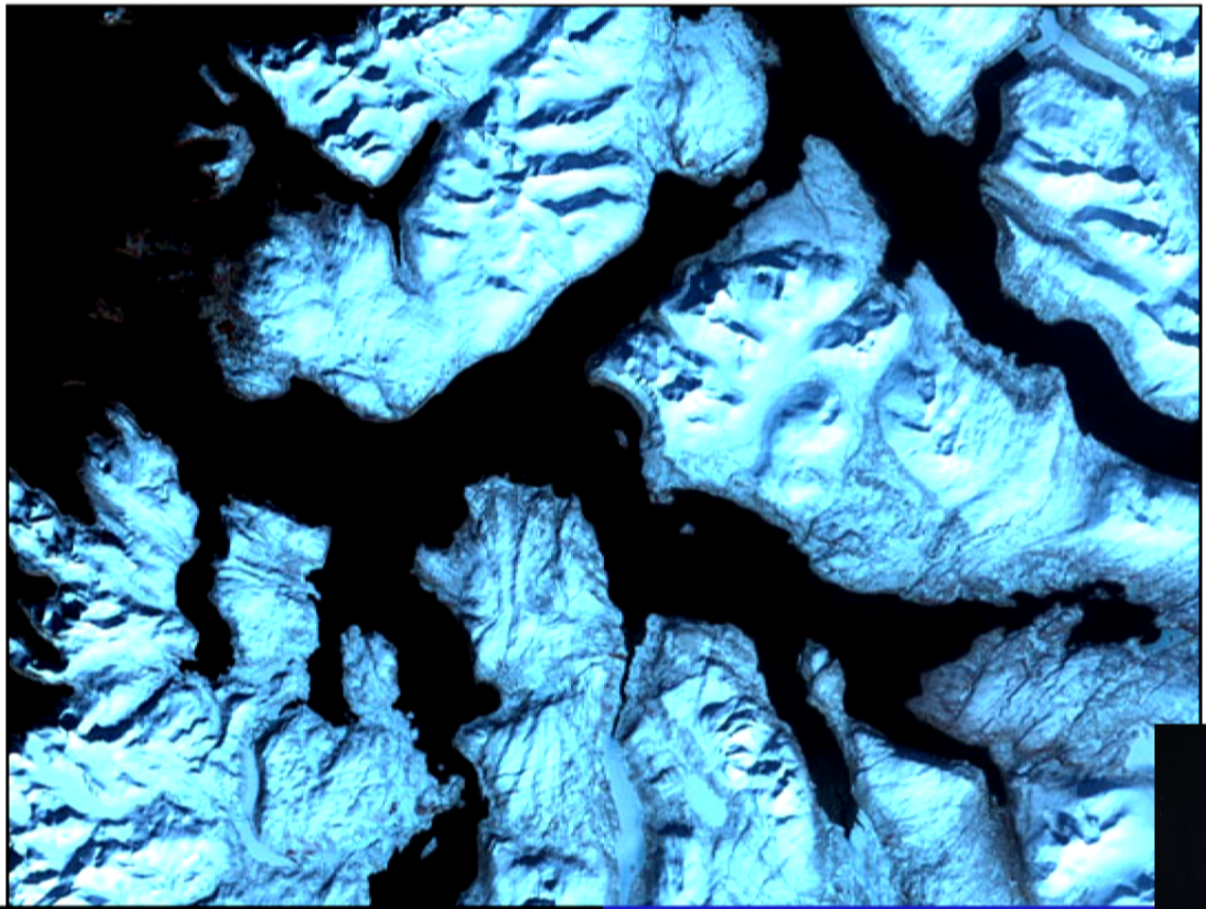


Figure: Clouds as simulated by Nagel and Raschke

Fjords of Norway display scale invariance



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Example of $\frac{1}{f}$ noise: Average Temperature

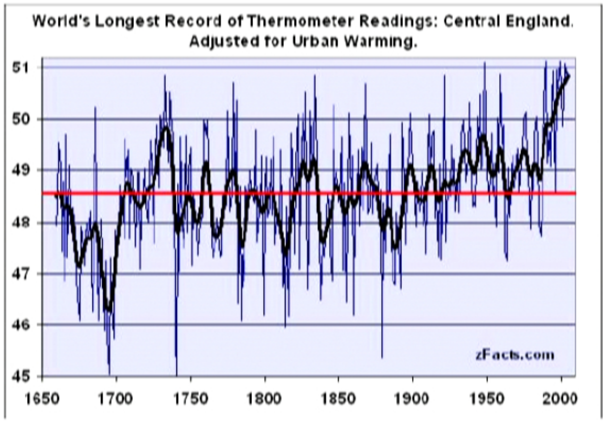

Figure: Average temperature in central England by year

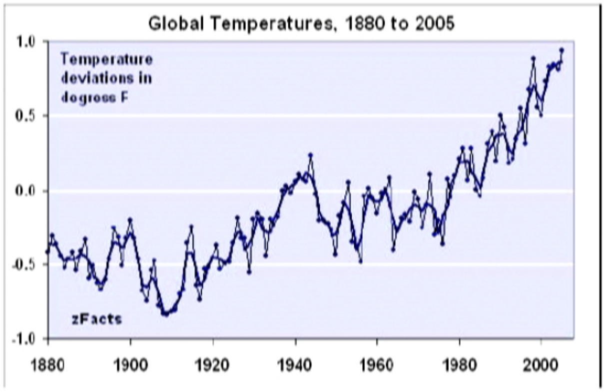

Figure: Average global temperature by year

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Self-Organized Criticality as an example

- P Bak, C Tang, and K Wiesenfield presented an explanation called self-organized criticality (1998)
- Complex systems evolve towards a meta-stable non-equilibrium self-organized "critical" state
- In this state a small fluctuation may initiate an "avalanch" in which a local effect propagates throughout the system

- Consider an grid with L (or LxL) positions
- Pieces of "sand" are placed randomly on the grid
- If sand is stacked too high at position N, some sand falls to $N-1$ and $N+1$ (if $Z_{N\pm1} = Z_N - 2$)
- Equivalent results may be found for coupled pendulums

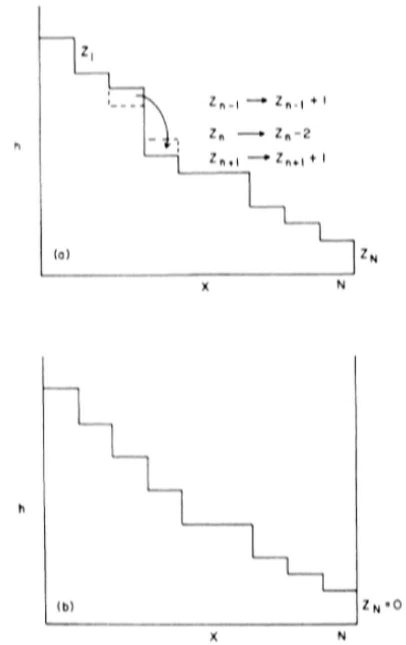

Figure: 1D sandpile as simulate
Bak et al.

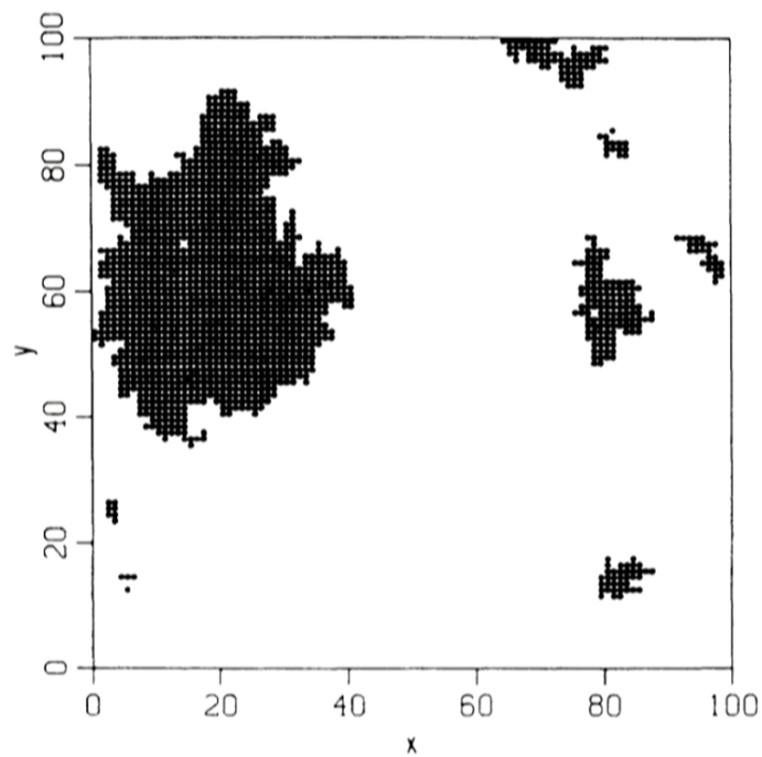

Figure: 2D avalanches as simulated by Bak et al.

Conclusion

- Self-organized critical behavior may be found in other complex dynamical systems
- May be applied to population growth, neurology, genetics, and many other complicated systems

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