Multiple equilibria in a cloud resolving model

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Multiple Equilibria

Definition

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- supports persistent precipitating deep convection
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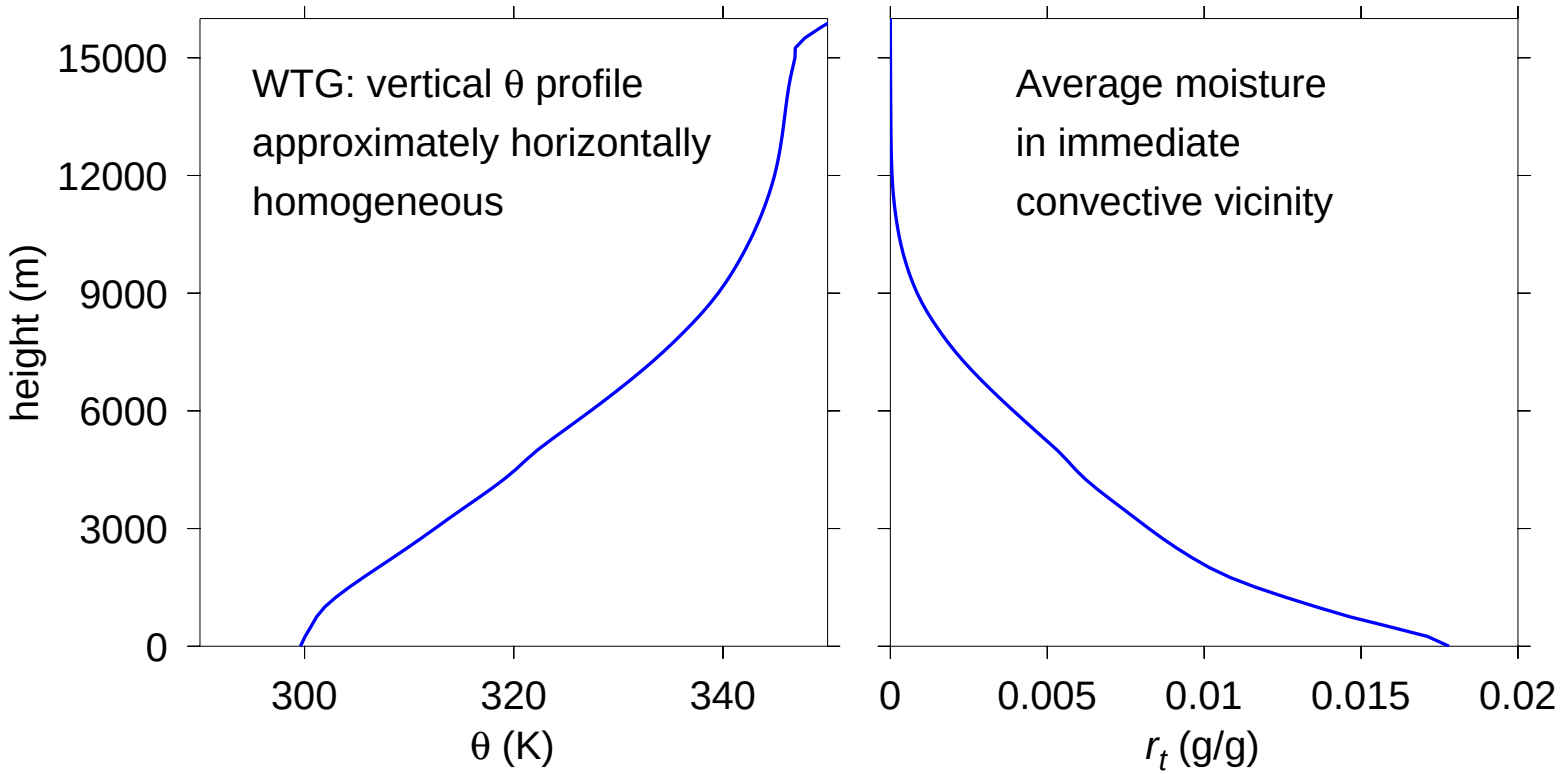
- Exists in
  - single column model (Sobel, Bellon & Bacmeister, 2007)
  - cloud resolving model (Sessions, Sugaya, Raymond & Sobel, 2010)
- Depends on the initial tropospheric moisture

Weak temperature gradient (WTG) approximation

- Charney (1963) scaling analysis: $\delta\theta_{horiz} \sim 10^{-3} \times \theta$ in the tropics
- Sobel & Bretherton (2000) used this to parameterize the large scale tropical environment in a single column model (SCM)
- Raymond & Zeng (2005) adapted WTG to a cloud resolving model (CRM)

Implementing WTG in a cloud resolving model

Radiative-convective equilibrium (RCE) profiles of θ and r_t are used to represent ambient environment



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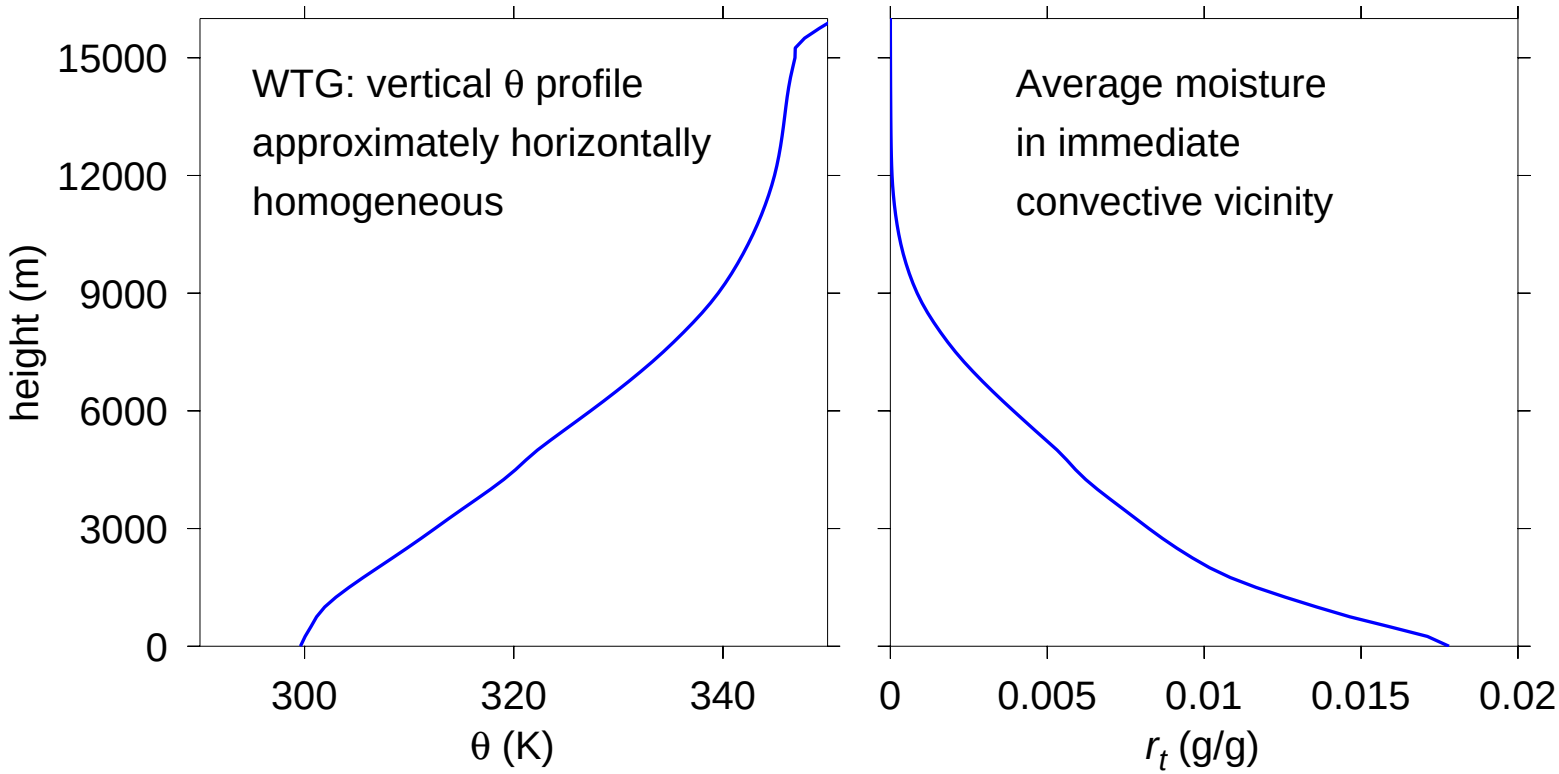

- Constrain θ profile to ambient profile by generating WTG vertical velocity, w_{WTG}, to exactly balance diabatic heating
- Moisture horizontally advected from immediate vicinity via mass continuity

Multiple equilibria experiments

Run parallel WTG experiments with

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- identical ambient environments (WTG reference profiles)
- initialize domain with ambient moisture or completely dry

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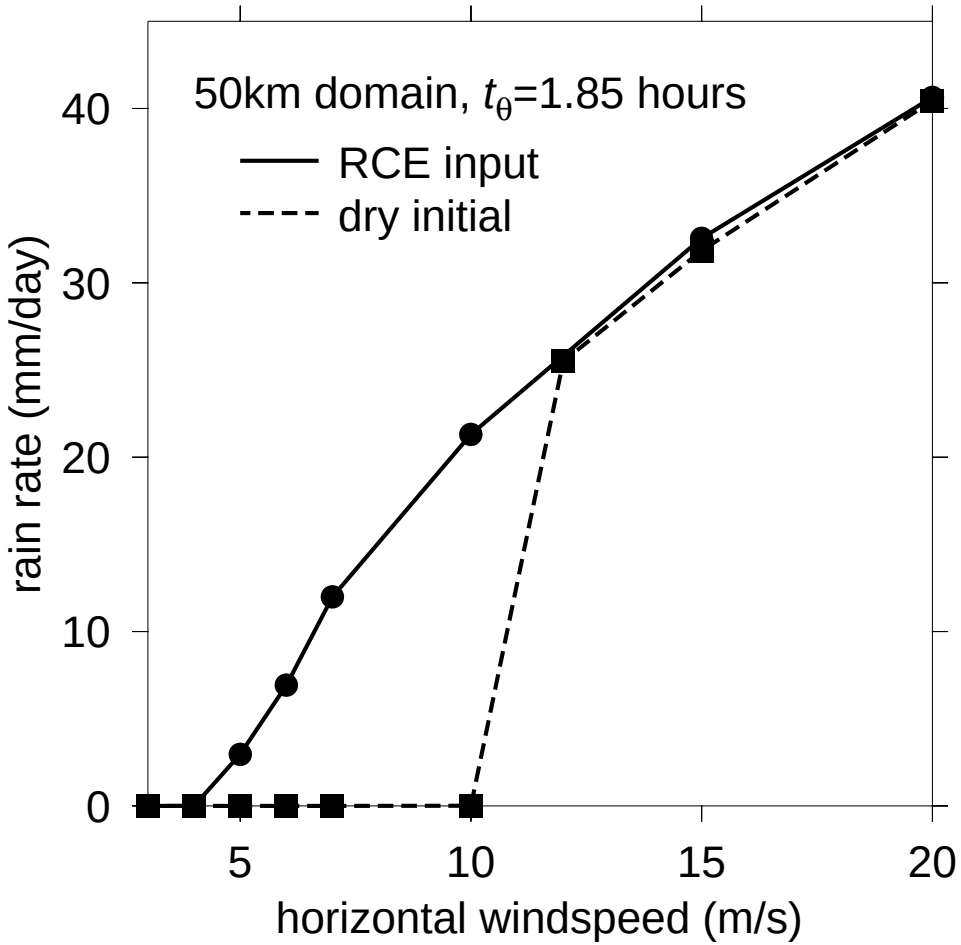
2D CRM, periodic boundary conditions

- horizontal domain sizes: 50-200 km (0.5-1 km resolution)
- 20 km vertical dimension (250 m resolution)
- statistics averaged over last 30 days of 4 month simulations

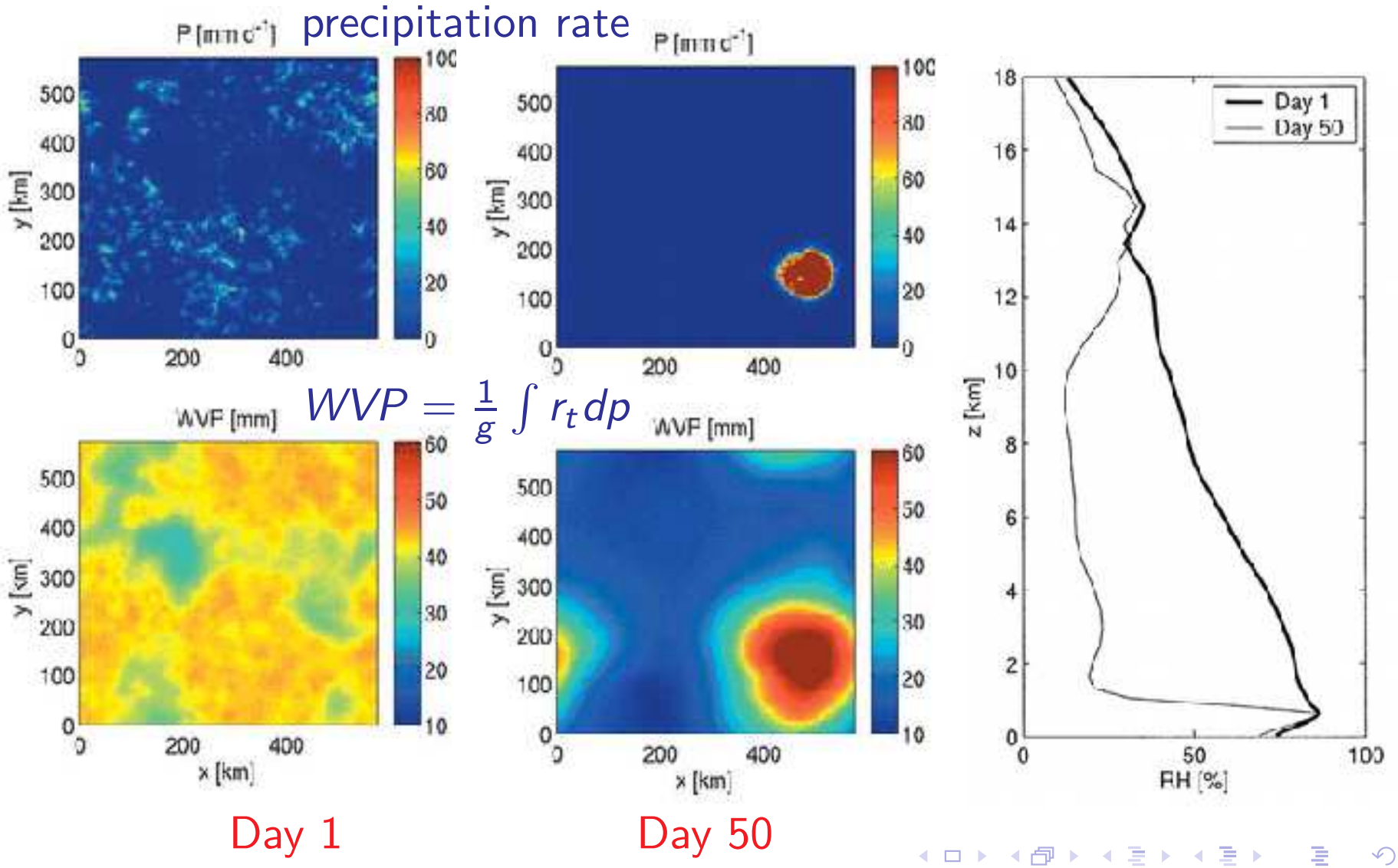
Multiple equilibria in a cloud resolving model

Sessions, Sugaya, Raymond & Sobel (2010)



Connection to self-aggregation

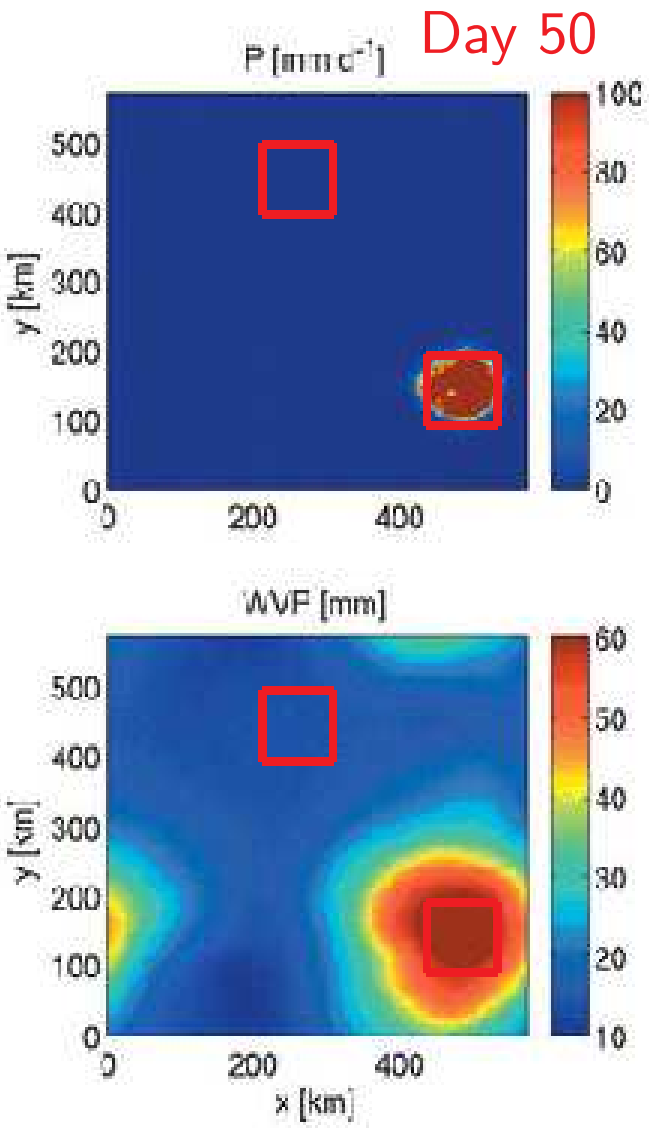
Bretherton, Blossey & Khairoutdinov (2005)



Connection to self-aggregation

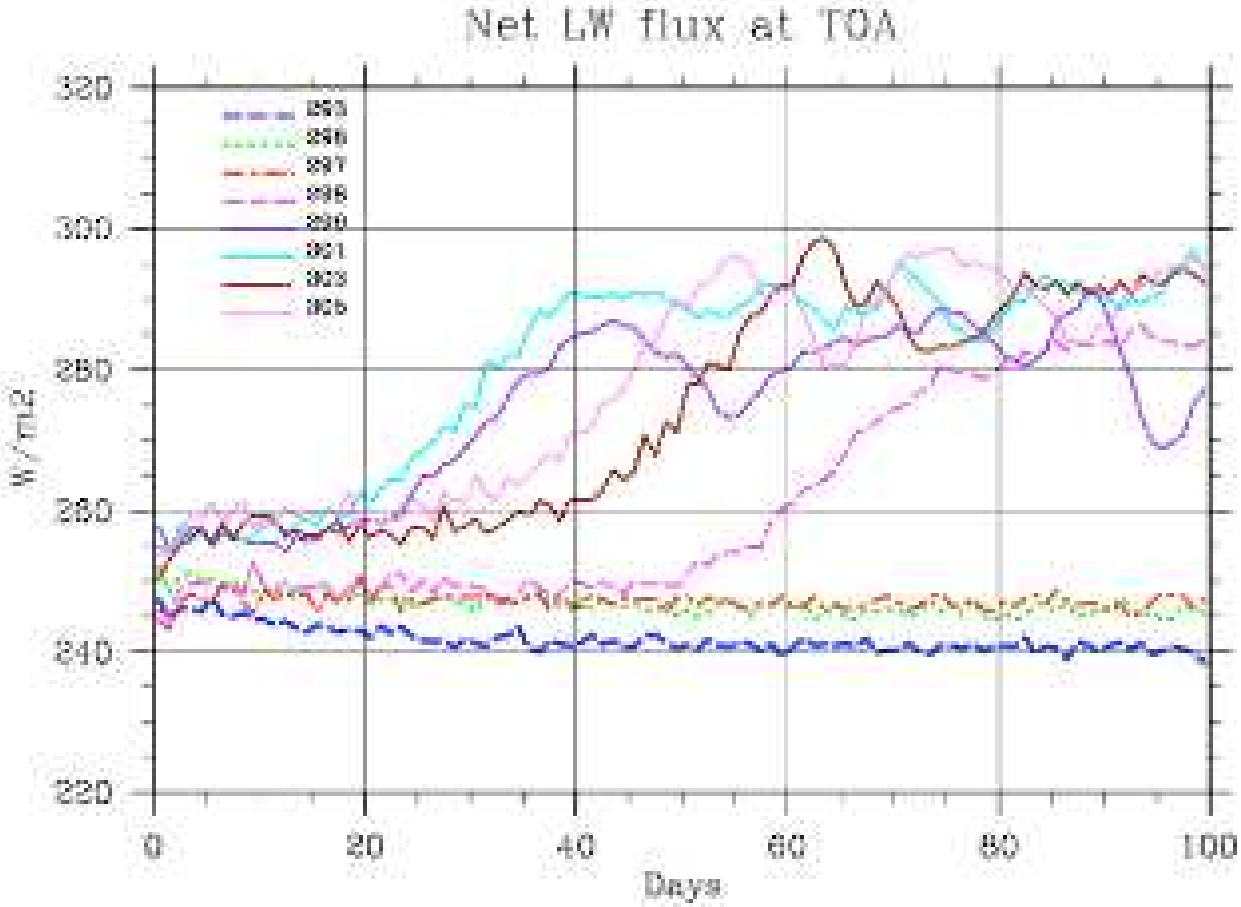
Hypothesis:

- Multiple equilibria in a small WTG domain is analogous to precipitating or dry regions of the larger RCE self-aggregated state
- Use WTG multiple equilibria experiments to identify conditions which permit self-aggregation



Self-aggregation dependence on sea-surface temperature

Khairoutdinov and Emanuel 2010

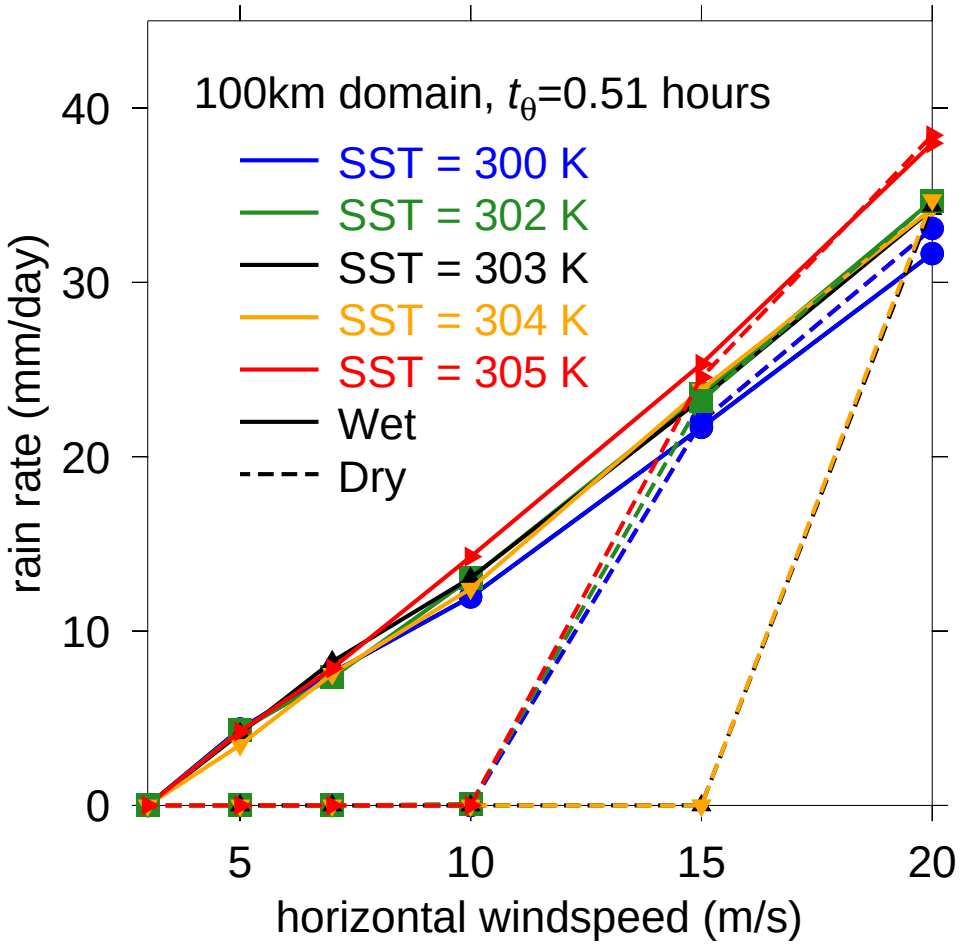


aggregated
(SST $\geq$ 298 K)

disaggregated
(SST $\leq$ 297 K)

Strong nonlinear dependence of self-aggregation on SST

Multiple equilibria dependence on changes in reference SST



- WTG reference profile generated for each SST
- WTG experiments have same SST as reference conditions
- Existence of multiple equilibria depends on SST

Summary

Multiple equilibria in small WTG domains may be a computationally economic way to investigate self-aggregation

Hypothesis:

- Conditions which permit multiple equilibria correlate to conditions which promote self-aggregation