Convective self-aggregation, cold pools, and domain size

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Convective self-aggregation, cold pools, and domain size

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[1] Convective self-aggregation refers to a phenomenon in cloud-resolving simulations wherein the atmosphere spontaneously develops a circulation with a convecting moist patch and a nonconvecting dry patch. All previous studies have found a sharp transition to aggregated convection when the domain size exceeds a critical threshold, typically in the range of 200–300 km. Here, we show that cold pools ble for this sharp transition. When cold pools l, self-aggregation occurs at all domain sizes. the aggregation strength decreases smoothly as size L is decreased below about 200–300 km. ction analysis reveals two distinct sources for ding into the dry-patch boundary layer: a moist, ulation and a dry, deep circulation. The deep cir- es with L, whereas the shallow circulation does l L, the shallow circulation dominates, thereby he aggregation. **Citation:** Jeevanjee, N., and D. 013), Convective self-aggregation, cold pools, and *Geophys. Res. Lett.*, *40*, doi:10.1002/grl.50204.

uction

ized convection, in which the spatial pattern of is fixed and persistent over time, has been h observations and numerical studies [*Houze* see *Bretherton et al.* [2005] and *Muller and Held* [2012] for details.

[3] These two papers also investigated the sensitivity of aggregation to various parameters, one of these being the domain size L. Both studies found that quasi-homogeneous states will only self-aggregate if $L \gtrsim$ 200–300 km. The goal of this paper is to shed light on this domain-size dependence.

[4] This work is motivated by the routine use of CRMs as a benchmark in the evaluation of convective parameterizations for global climate models. To improve the realism and statistics of CRM simulations, modelers have typically preferred the use of larger domains. Self-aggregation, however, presents a catastrophic failure of CRMs to converge as a function of domain size, casting doubt on the reliability of CRMs as a benchmark.

2. Numerical Simulations

[5] All simulations in this paper were performed using Das Atmosphärische Modell (DAM) [*Romps*, 2008]. DAM is a three-dimensional, fully compressible, nonhydrostatic CRM that uses the six-class Lin-Lord-Kreuger microphysics scheme. For this paper, we performed

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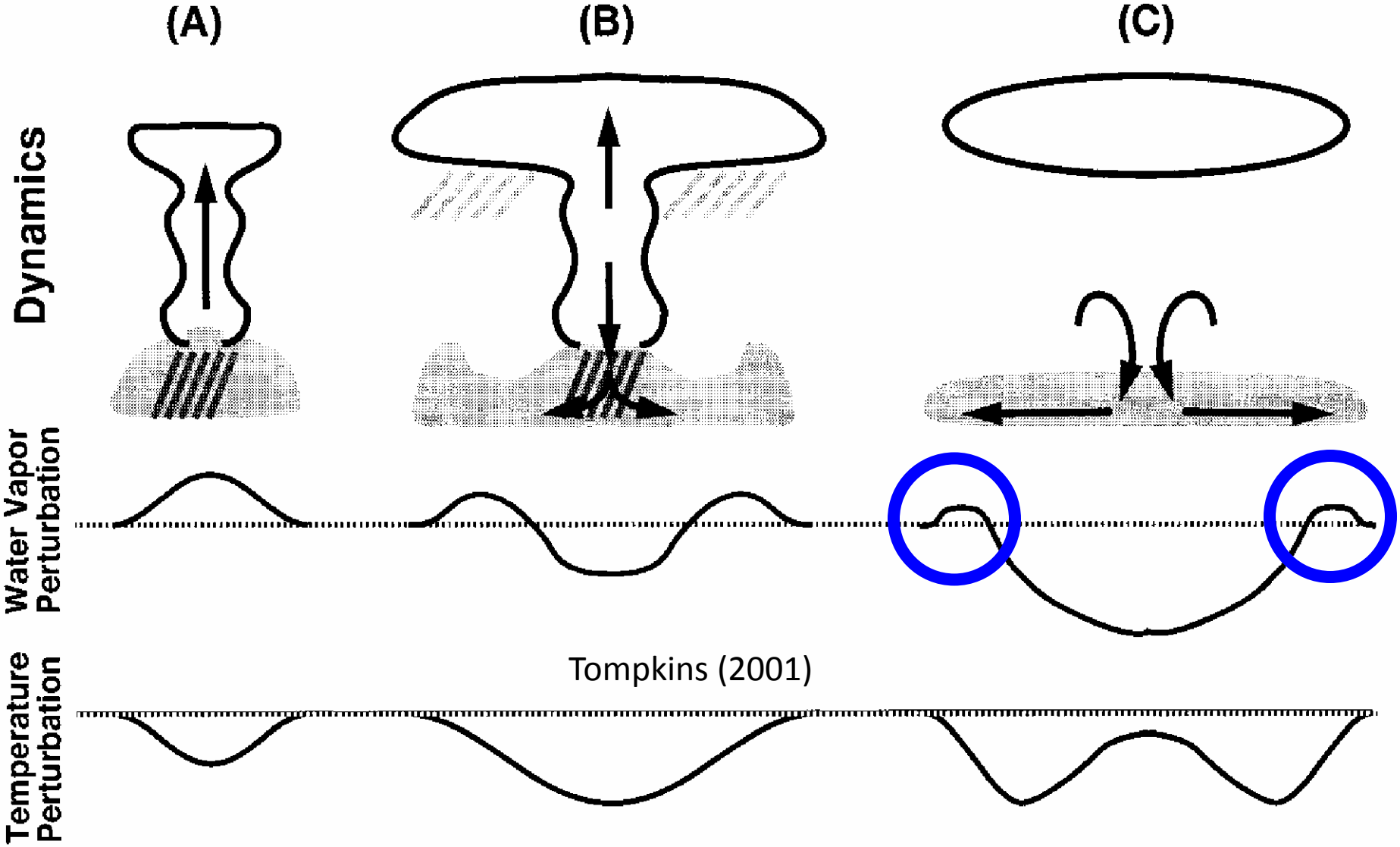
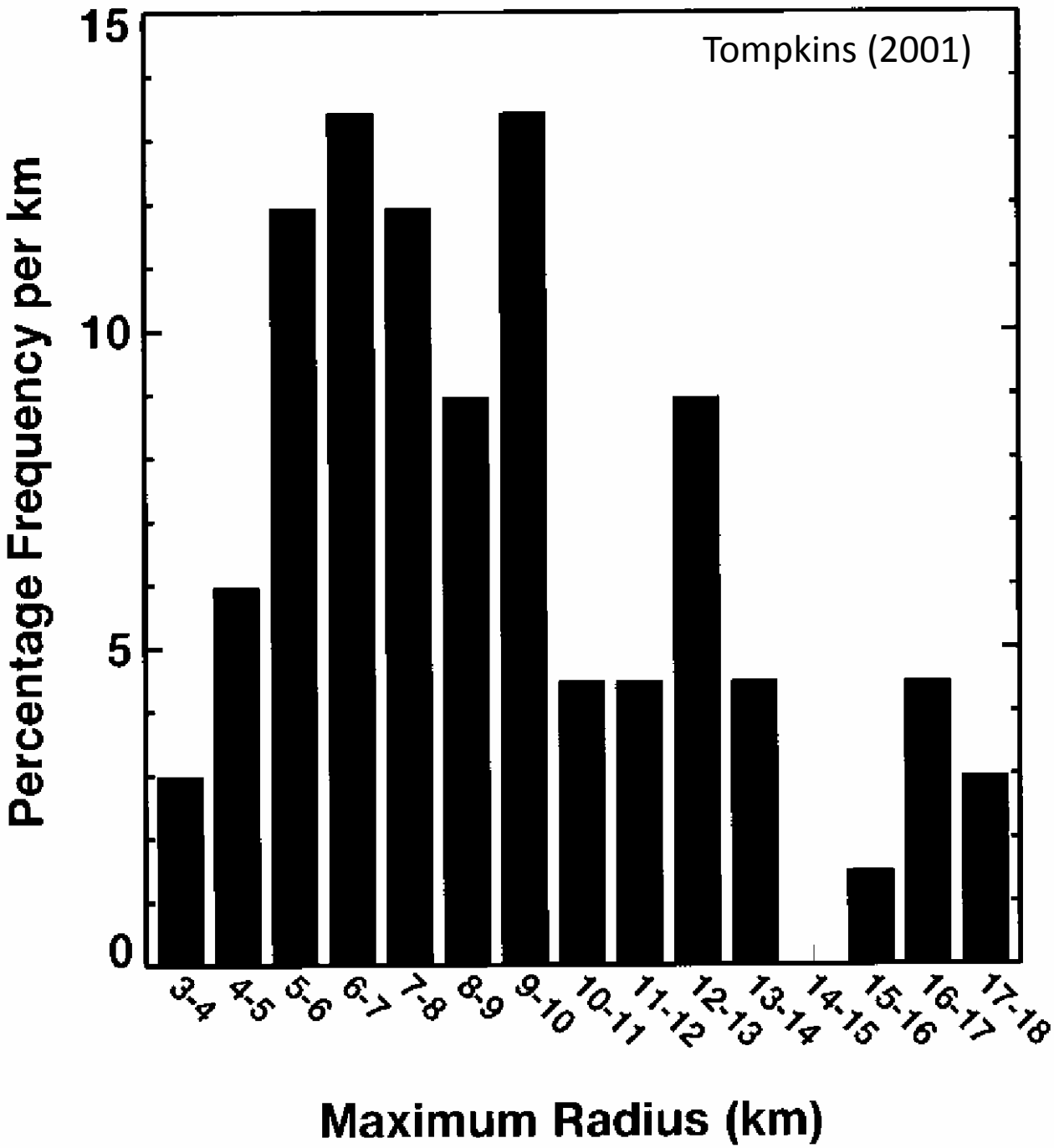


Tompkins (2001)

Cold pools inhibit convection where convection just occurred, but they promote convection some distance away.



Cold pools grow to be no larger than about 10 km.

Yet, we will see that they have an influence well beyond that length scale.

An (extremely) brief history of aggregation research

Held et al. (1993) discover aggregation in 2D cloud-resolving simulations

Radiative–Convective Equilibrium with Explicit Two-Dimensional Moist Convection

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(Manuscript received 7 December 1992, in final form 29 April 1993)

ABSTRACT

Radiative–convective statistical equilibria are obtained using a two-dimensional model in which radiative transfer is interactive with the predicted moisture and cloud fields. The domain is periodic in x, with a width of 640 km, and extends from the ground to 26 km. The lower boundary is a fixed-temperature water-saturated surface. The model produces a temperature profile resembling the mean profile observed in the tropics. A number of integrations of several months' duration are described in this preliminary examination of the model's qualitative behavior.

The model generates a QBO-like oscillation in the x-averaged winds with an apparent period of ~60 days. This oscillation extends into the troposphere and influences the convective organization. In order to avoid the associated large vertical wind shears, calculations are also performed in which the x-averaged winds are constrained to vanish. The convection then evolves into a pattern in which rain falls only within a small part of the domain. The moisture field appears to provide the memory that localizes the convection.

If the vertical shears are fixed at a modest nonzero value, this localization is avoided. Comparing calculations with surface temperatures of 25° and 30°C, the planetary albedo is found to decrease with increasing temperature, primarily due to a reduction in low-level cloudiness.

1. Introduction

As computer resources have increased, some cloud modelers have moved from the investigation of indi-

Radiative–convective equilibrium models have proven to be invaluable in studies of climatic sensitivity. Following the classic study of Manabe and Strickler (1964), in these models one assumes the existence of

An Energy-Balance Analysis of Deep Convective Self-Aggregation above Uniform SST

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(Manuscript received 26 August 2004, in final form 11 April 2005)

ABSTRACT

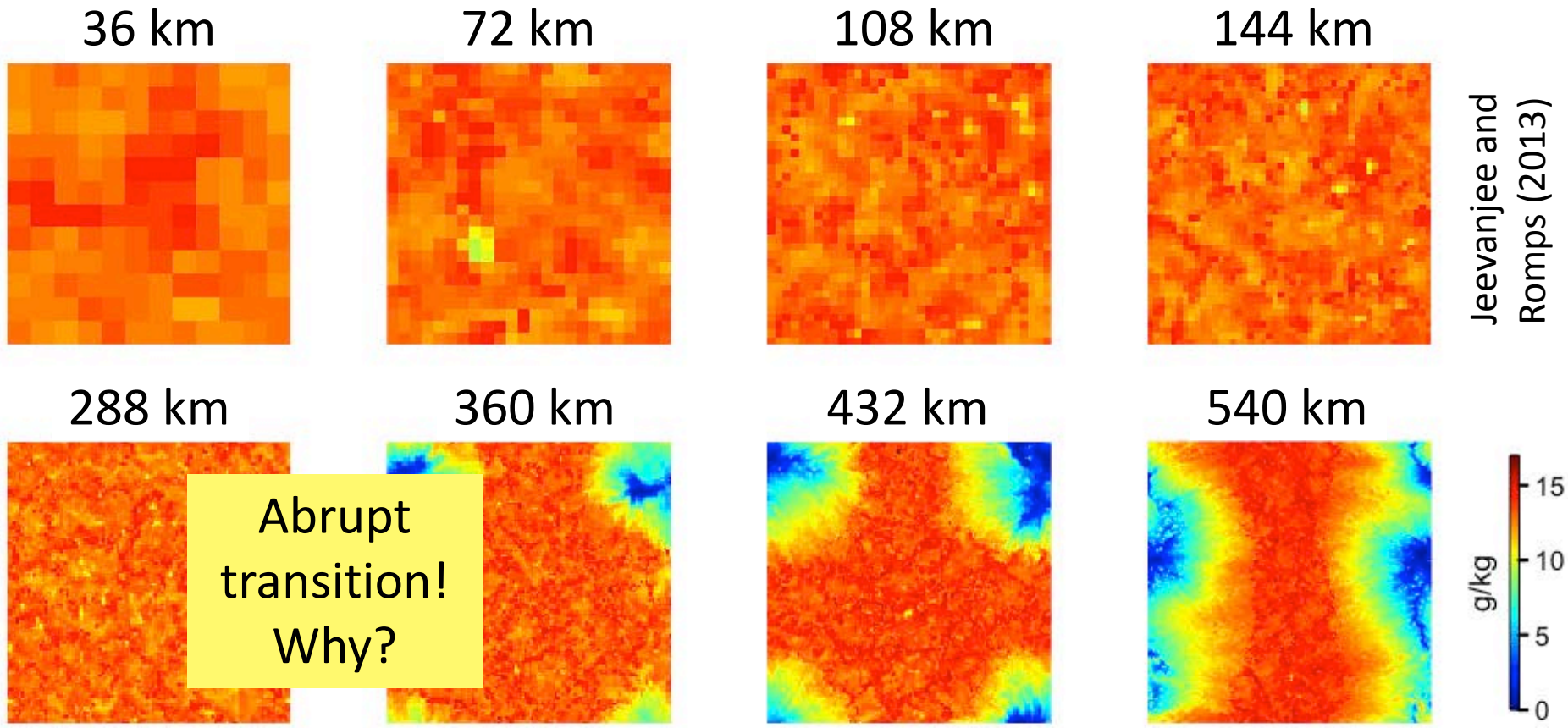
The spatial organization of deep moist convection in radiative–convective equilibrium over a constant sea surface temperature is studied. A 100-day simulation is performed with a three-dimensional cloud-resolving model over a $(576\ \mathrm{km})^2$ domain with no ambient rotation and no mean wind. The convection self-aggregates within 10 days into quasi-stationary mesoscale patches of dry, subsiding and moist, rainy air columns. The patches ultimately merge into a single intensely convecting moist patch surrounded by a broad region of very dry subsiding air.

The self-aggregation is analyzed as an instability of a horizontally homogeneous convecting atmosphere driven by convection–water vapor–radiation feedbacks that systematically dry the drier air columns and moisten the moister air columns. Column-integrated heat, water, and moist static energy budgets over $(72\ \mathrm{km})^2$ horizontal blocks show that this instability is primarily initiated by the reduced radiative cooling of air columns in which there is extensive anvil cirrus, augmented by enhanced surface latent and sensible heat fluxes under convectively active regions due to storm-induced gustiness. Mesoscale circulations intensify the later stages of self-aggregation by fluxing moist static energy from the dry to the moist regions. A simple mathematical model of the initial phase of self-aggregation is proposed based on the simulations.

In accordance with this model, the self-aggregation can be suppressed by horizontally homogenizing the radiative cooling or surface fluxes. Lower-tropospheric wind shear leads to slightly slower and less pro-

Bretherton et al. (2005) report a strong domain-size dependence of aggregation

Plan view of near-surface humidity in equilibrium CRM runs.



Jeevanjee and Romps (2013)

We thought we had a good theory for this transition.

We were wrong.

But, we learned we were asking the wrong question.

Instead of:

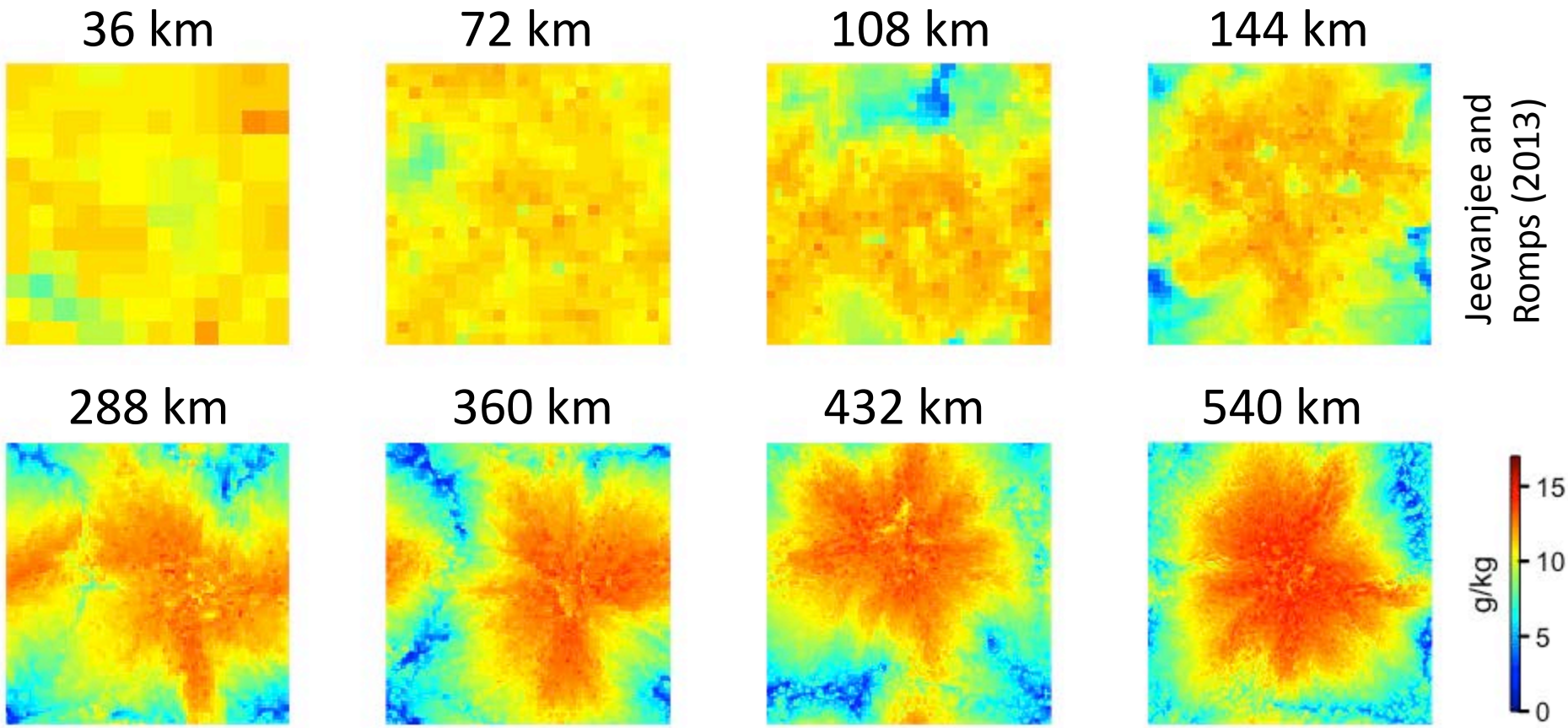
> "Why does convection aggregate
> in domains larger than 300 km?"

We shifted gears and asked:

> "Why does convection NOT aggregate
> in domains smaller than 300 km?"

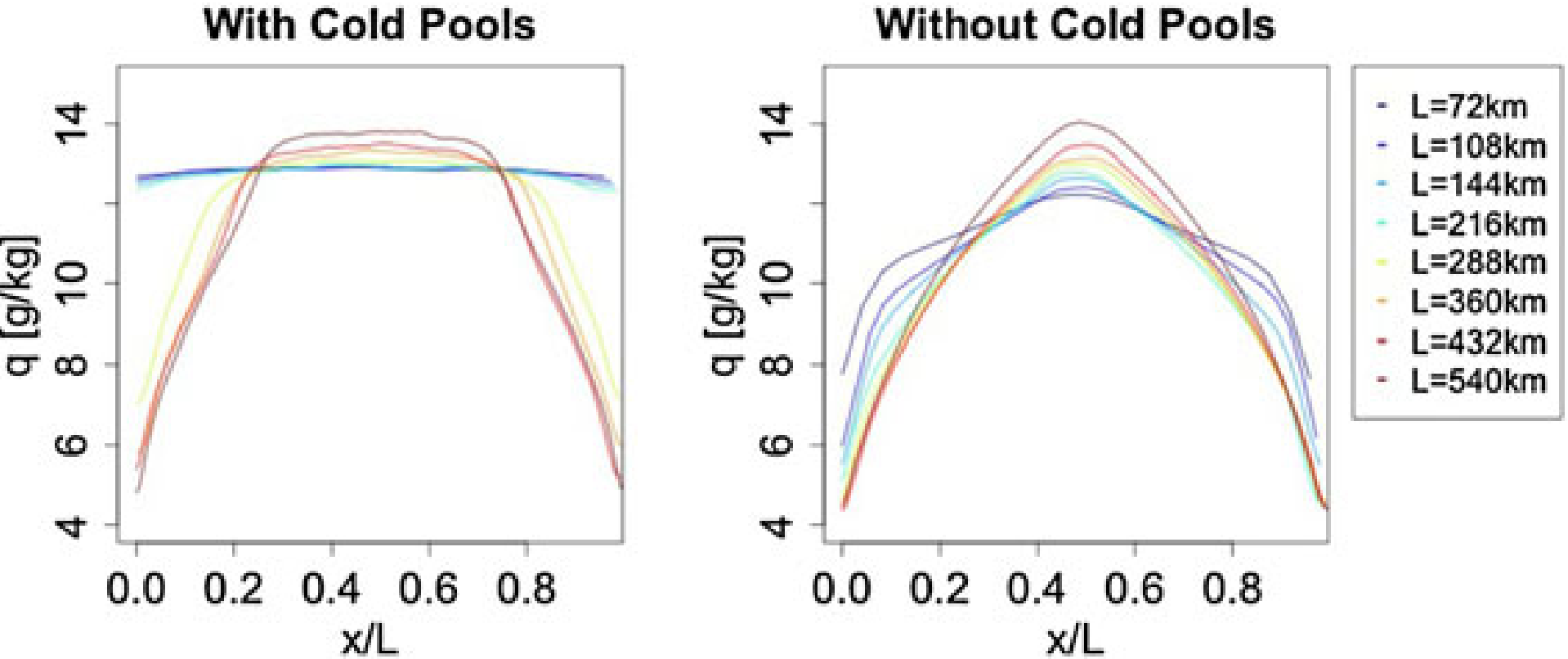
The answer: cold pools.

Same set of simulations as before, but with cold pools inhibited.

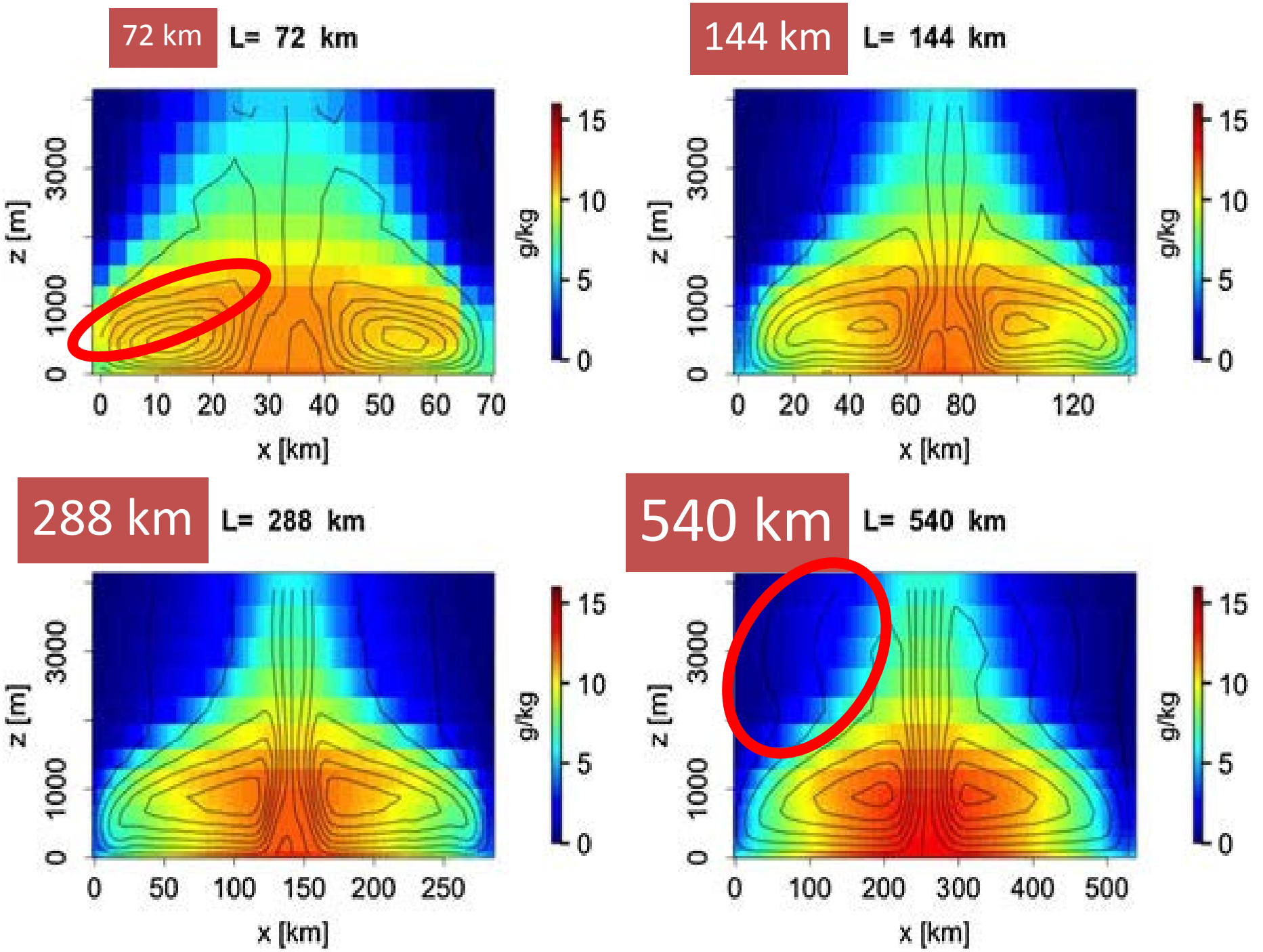


Now, there is aggregation for all domain sizes!

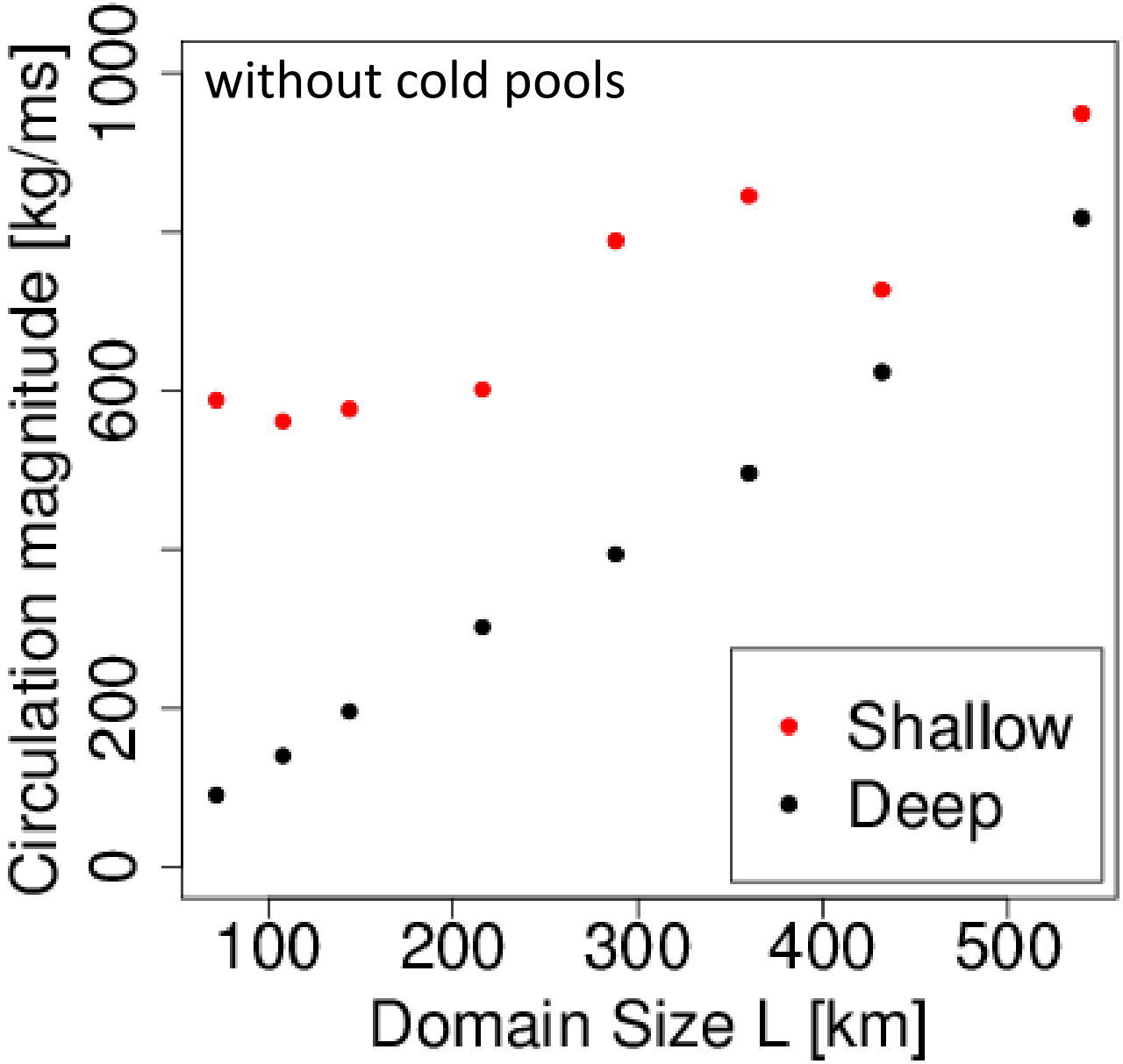
Not convinced? Here it is in 2D.



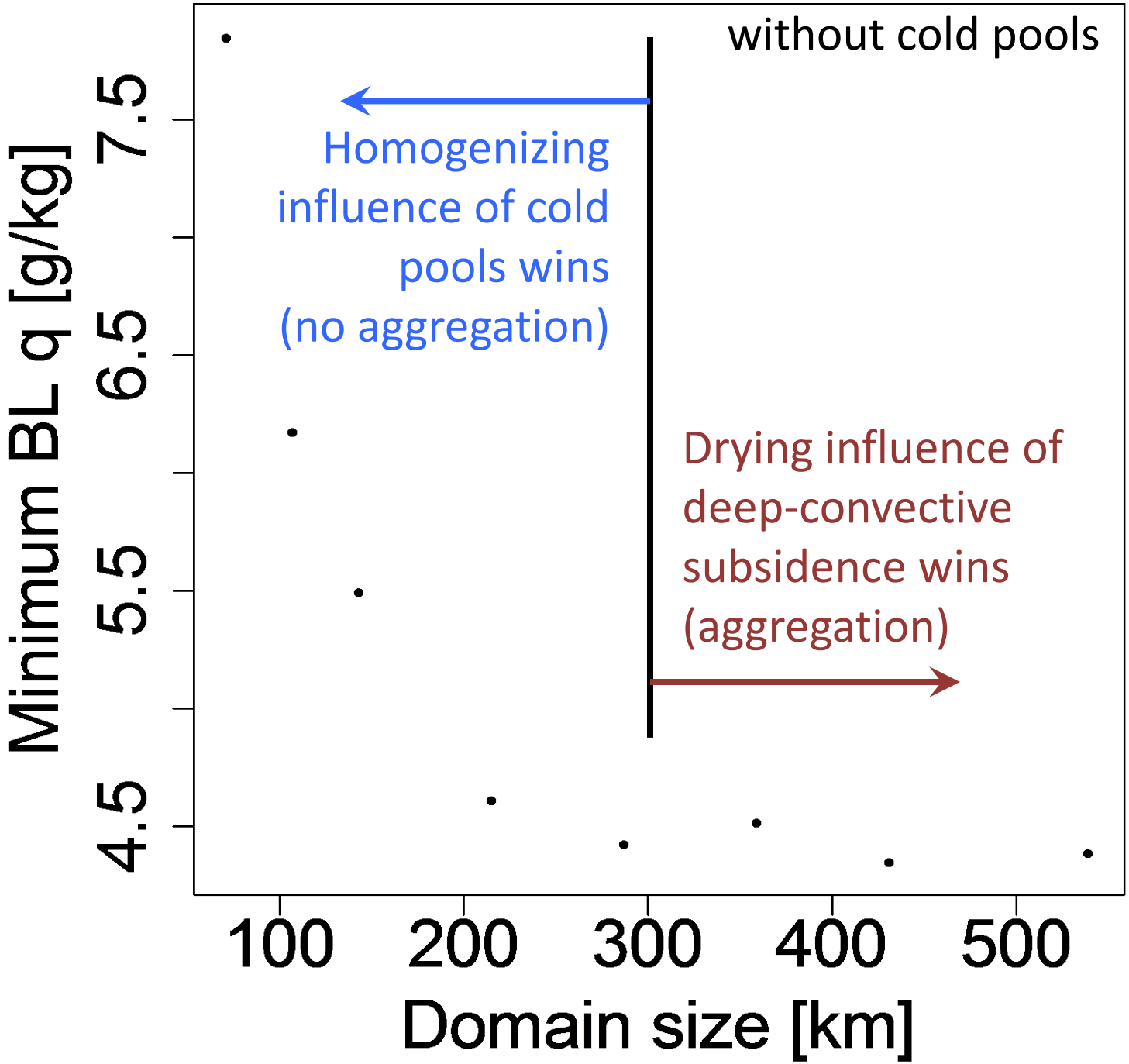
Cold pools prevent aggregation in small domains
(i.e., domains comparable to GCM grid box).

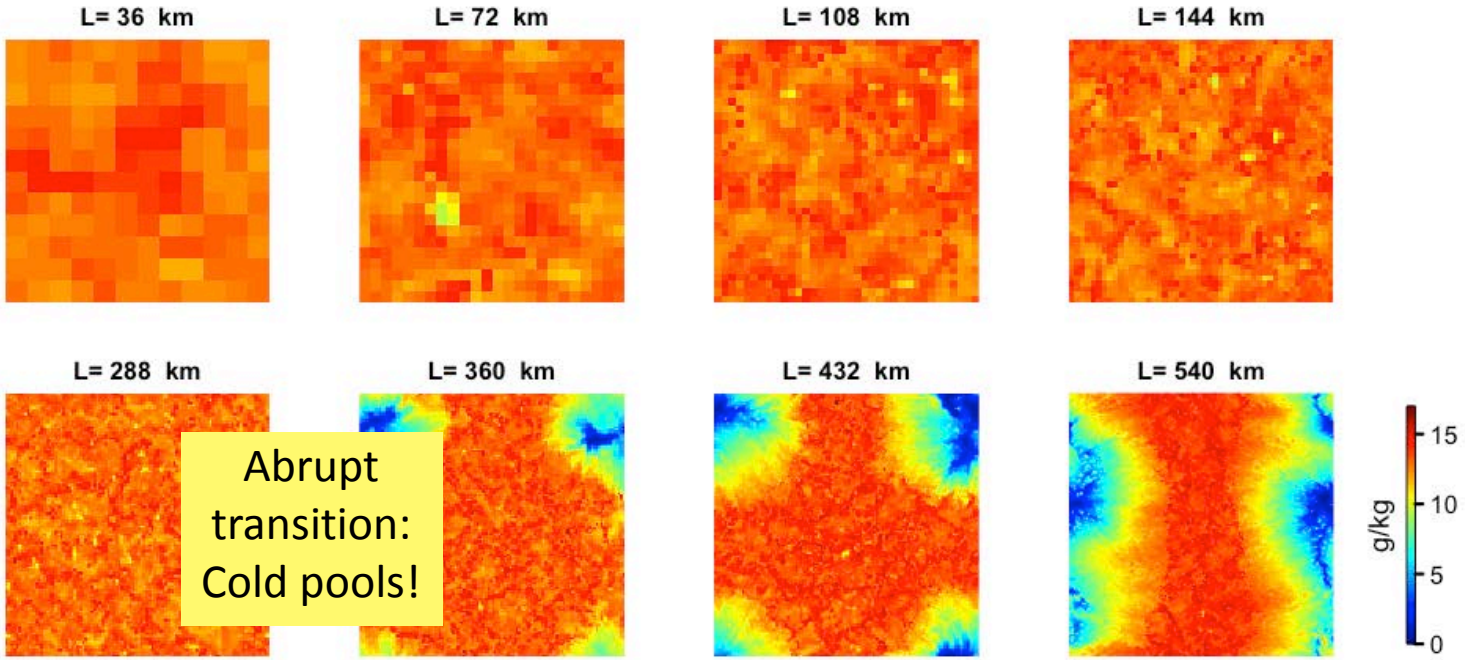

72 km
L= 72 km
144 km
L= 144 km
288 km
L= 288 km
540 km
L= 540 km
z [m]
x [km]
g/kg
0
1000
3000
0 10 20 30 40 50 60 70
0 20 40 60 80 120
0 50 100 150 200 250
0 100 200 300 400 500
0 5 10 15

Why the gradual strengthening of aggregation with domain size?



The competition between a drying deep circulation and a moistening shallow circulation.


without cold pools
Homogenizing influence of cold pools wins (no aggregation)
Drying influence of deep-convective subsidence wins (aggregation)
Minimum BL q [g/kg]
4.5
5.5
6.5
7.5
100
200
300
400
500
Domain size [km]



Plan view of near-surface humidity in equilibrium CRM runs.

Jeevanjee and Romps (2013)

Conclusions

Cold pools are responsible for the abrupt transition to aggregation at a critical length scale of about 300 km.

Collectively, cold pools can dramatically alter circulations that are much larger than the size of individual cold pools.