Spontaneous aggregation of convective storms

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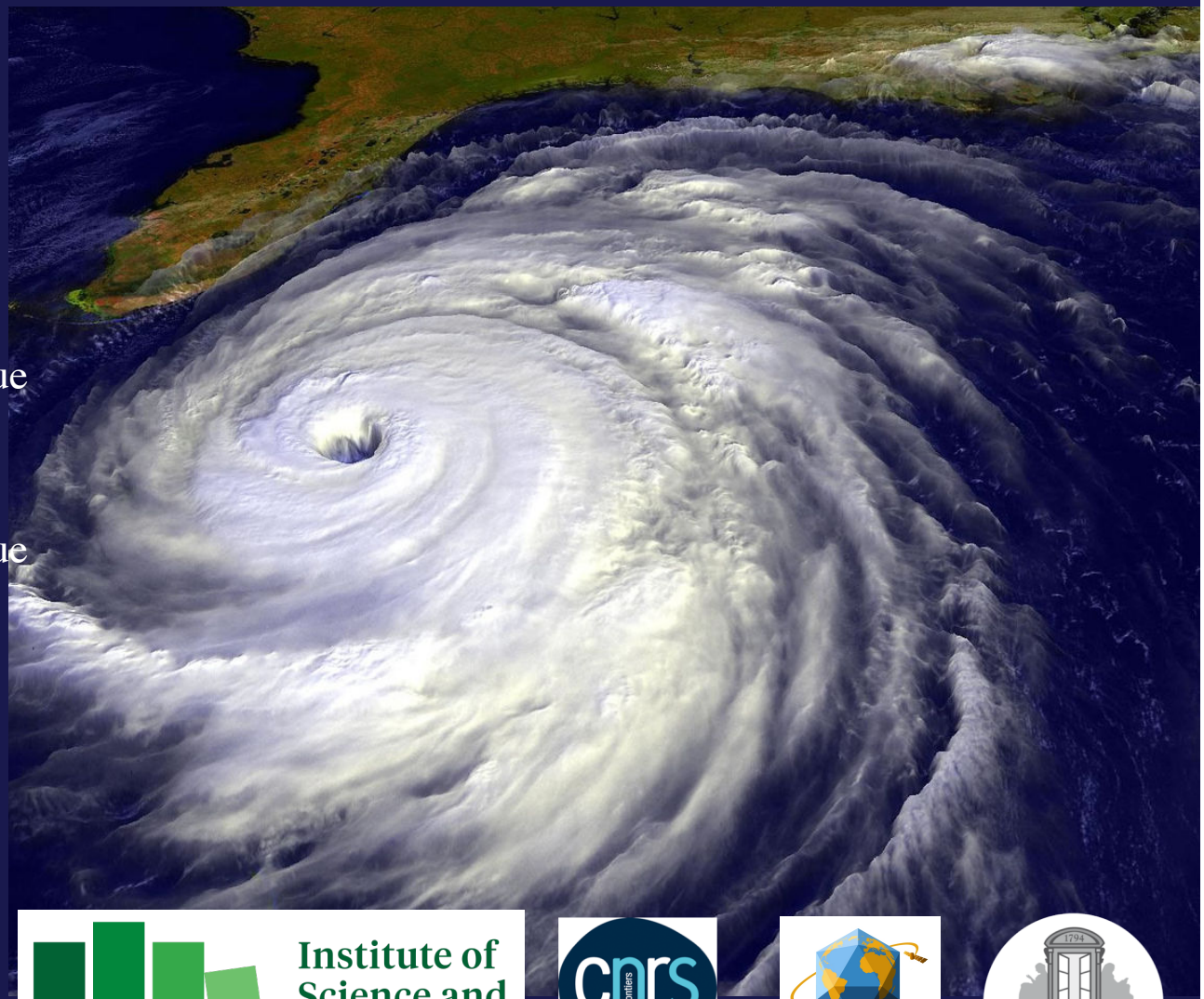

With thanks to Yang Craig Cronin
Haerter Hohenegger Mapes
Randall Sherwood

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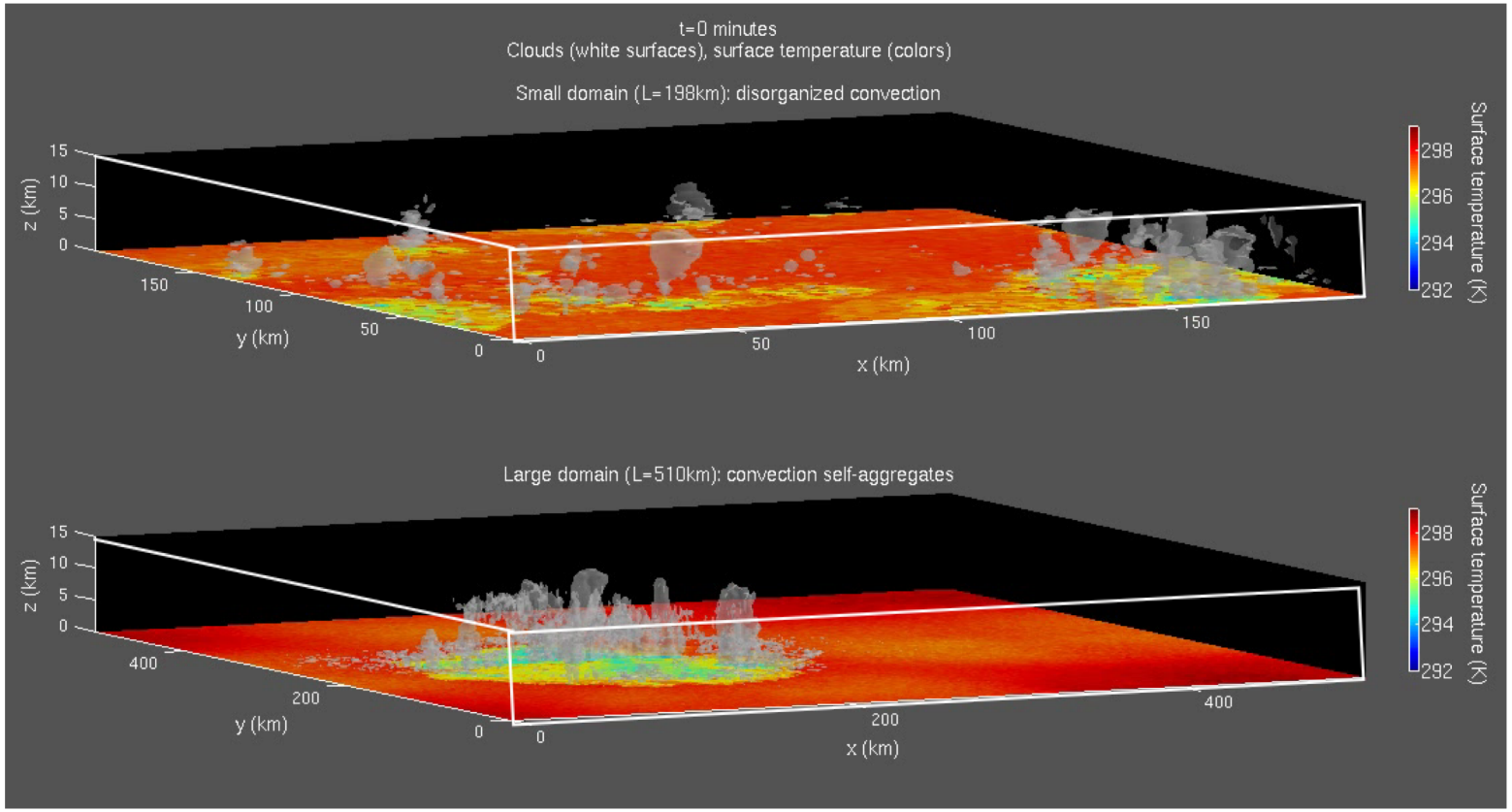
Self-aggregation

Clouds over near-surface temperature in cloud-resolving model SAM [Khairoutdinov & Randall, JAS 2003]



« pop corn »
convection

Larger domain

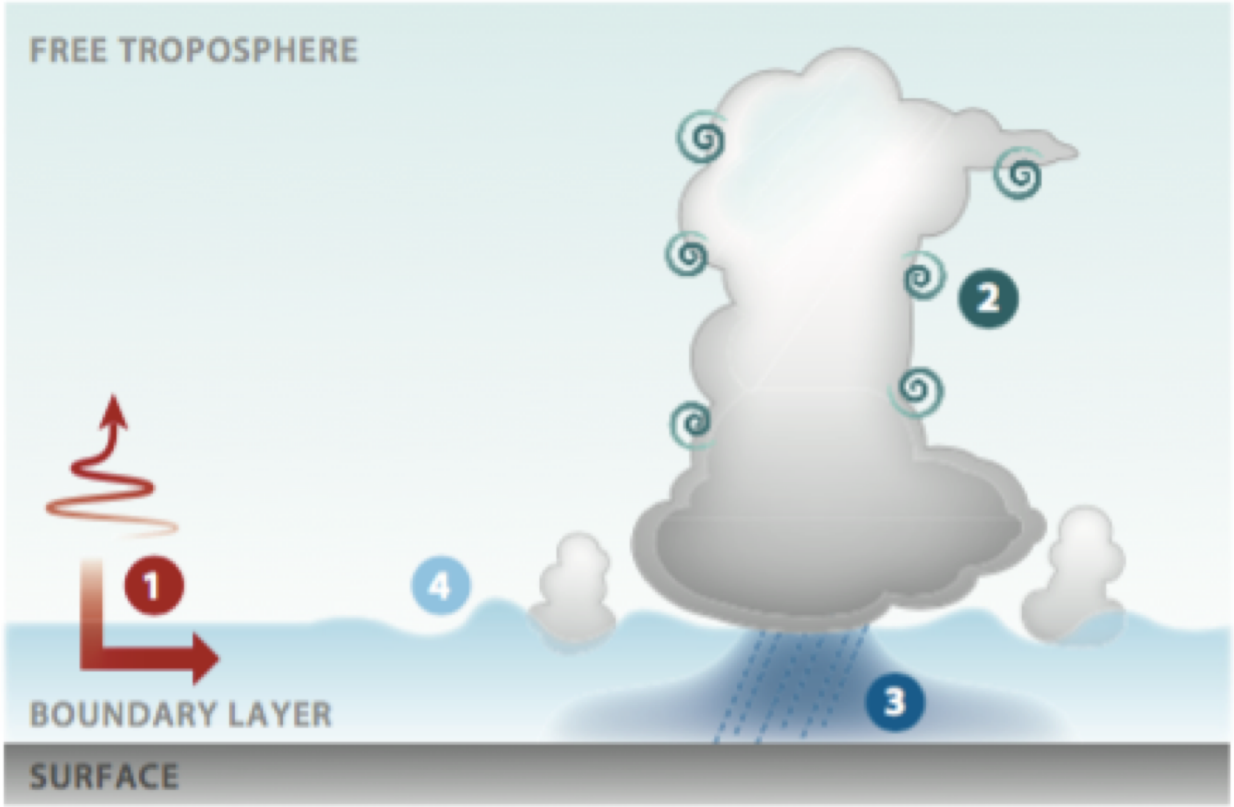
Self-aggregates

- SST=300K uniform
- Doubly periodic
- No Coriolis (f=0)
- No large-scale forcing

Self Aggregation = Instability of disorganized Radiative-Convective Equilibrium “pop corn” state

[Bretherton, Blossey, Khairoutdinov, 2005; Muller, Held 2012; Emanuel, Wing, Vincent 2013; Wing Emanuel 2013; Jeevanjee Romps 2013; Khairoutdinov Emanuel, 2013; Shi Bretherton 2014; Tobin, Bony, Roca, 2012; Tobin et al, 2013; Muller Bony 2015; Arnold Randall 2015; Coppin Bony 2015; Mapes 2016; Holloway Woolnough 2016; Tompkins Semie 2017; Wing Holloway Emanuel Muller 2017; Becker Bretherton Hohenegger Stevens 2018; Muller Romps 2018; Fildier et al 2021; Muller et al 2022 ARFM …]

Self-Aggregation: physical processes involved?

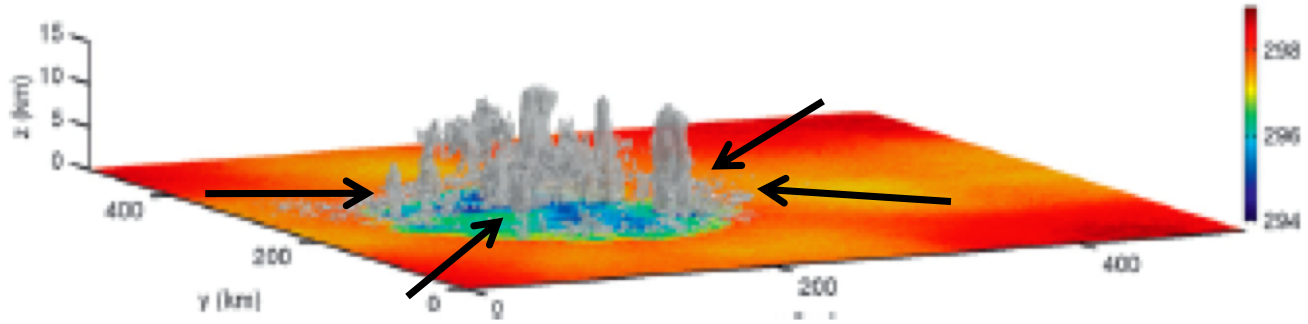


(1) **Radiative cooling in dry regions** and associated shallow divergent circulation (red arrow)
(2) Turbulent entrainment of environmental air at the edge of clouds
(3) Evaporation-driven cold pools
(4) Wave emission

[Muller Yang Craig Cronin Fildier Haerter Hohenegger Mapes Randall Shamekh Sherwood ARFM 2022]

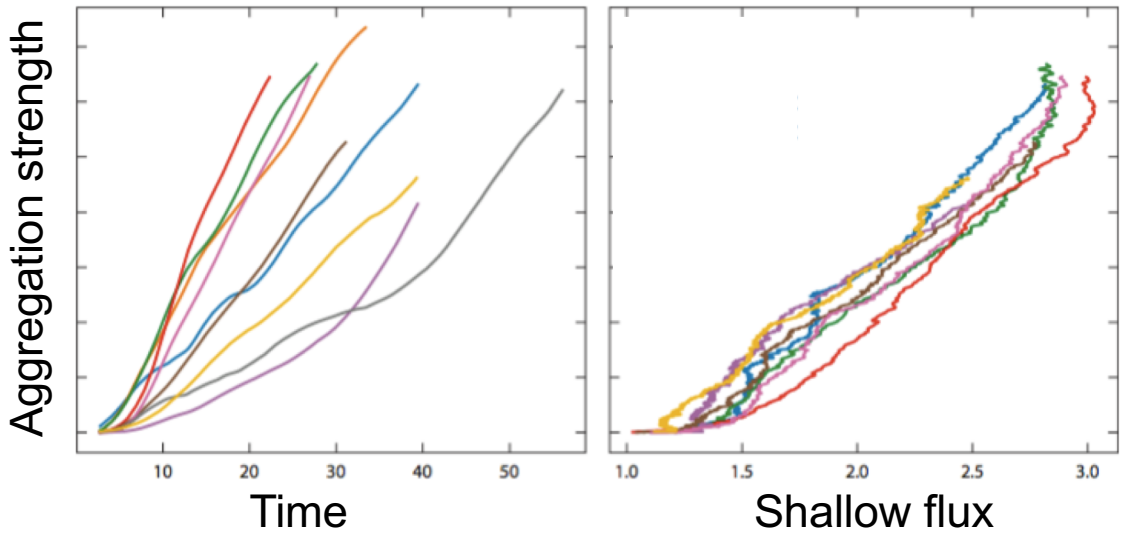
Why does interactive longwave cooling lead to aggregation?

Radiatively-driven shallow circulation ⇒ upgradient MSE transport



[Muller&Bony, GRL 2015]

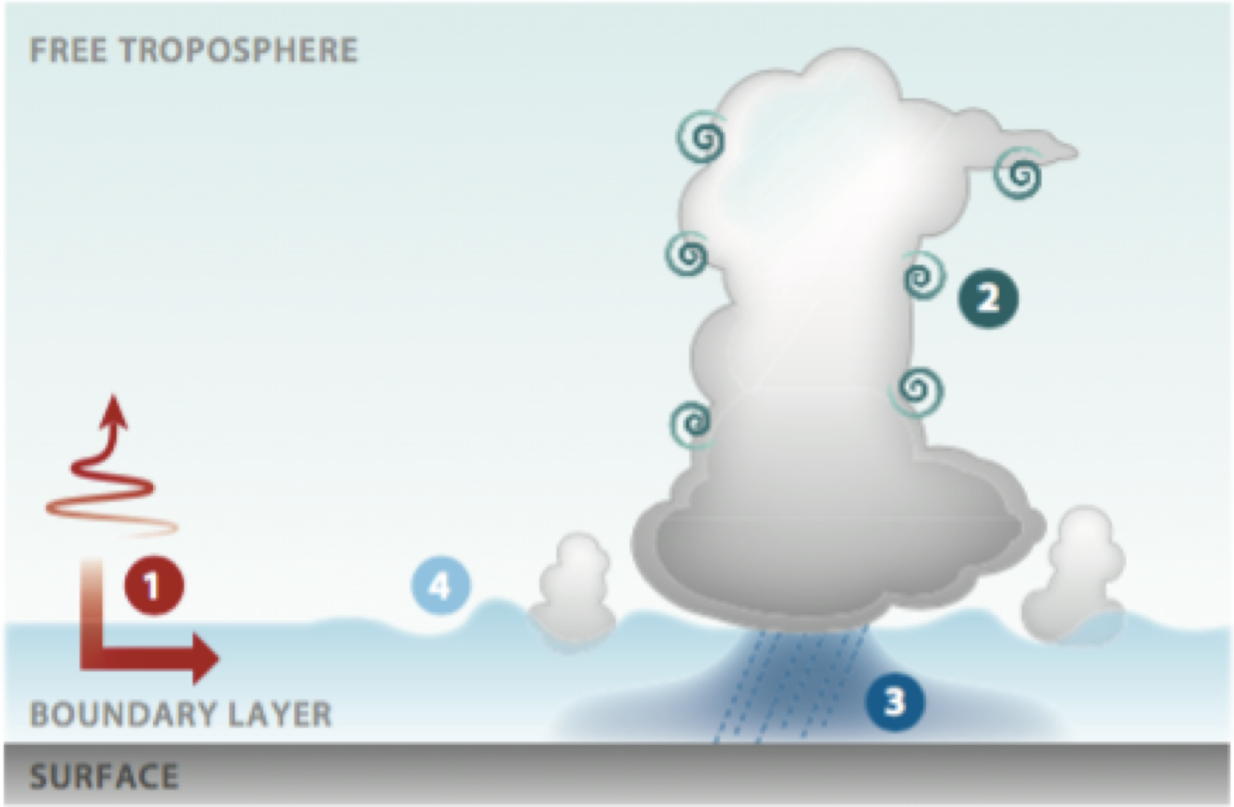
⇒ Aggregation evolution explained by strength of shallow circulation



[Shamekh et al 2020]

Formalized in water vapor perturbation stability analysis *[Emanuel et al 2014; Beucler&Cronin 2016]*

Self-Aggregation: physical processes involved?



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Clouds => moister atmosphere => clouds

Self-Aggregation: 2- turbulent entrainment at cloud edge

Formalized in simple model *[Craig&Mack 2013]*

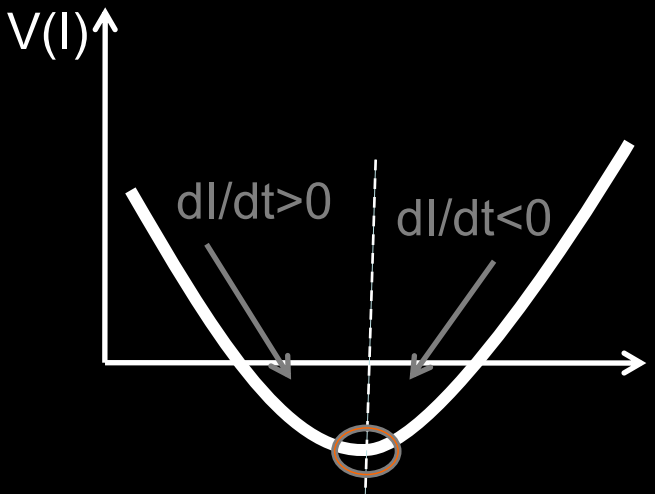
See also Biagioli&Tompkins

$$\left(I = \int q_v \; dz\right)$$

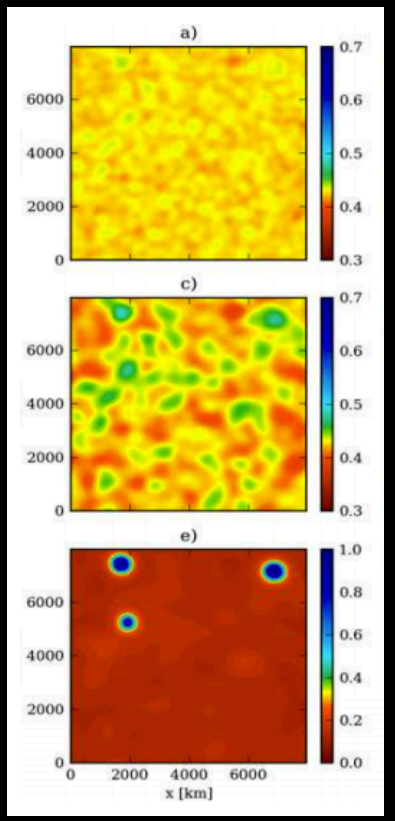
$$\frac{\partial I}{\partial t} = -\frac{\delta V}{\delta I}$$

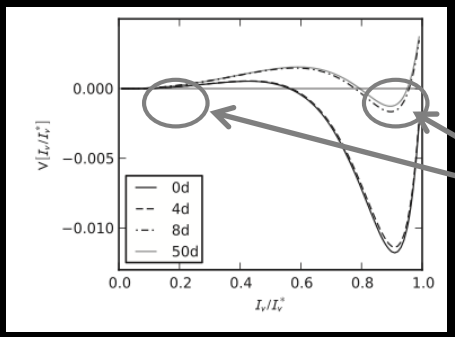
Includes source (convective moistening)
+Sink (subsidence drying)
+Horizontal diffusion (entrainment&transport)

If V(I) has a minimum, it is an attractor for I(t) :



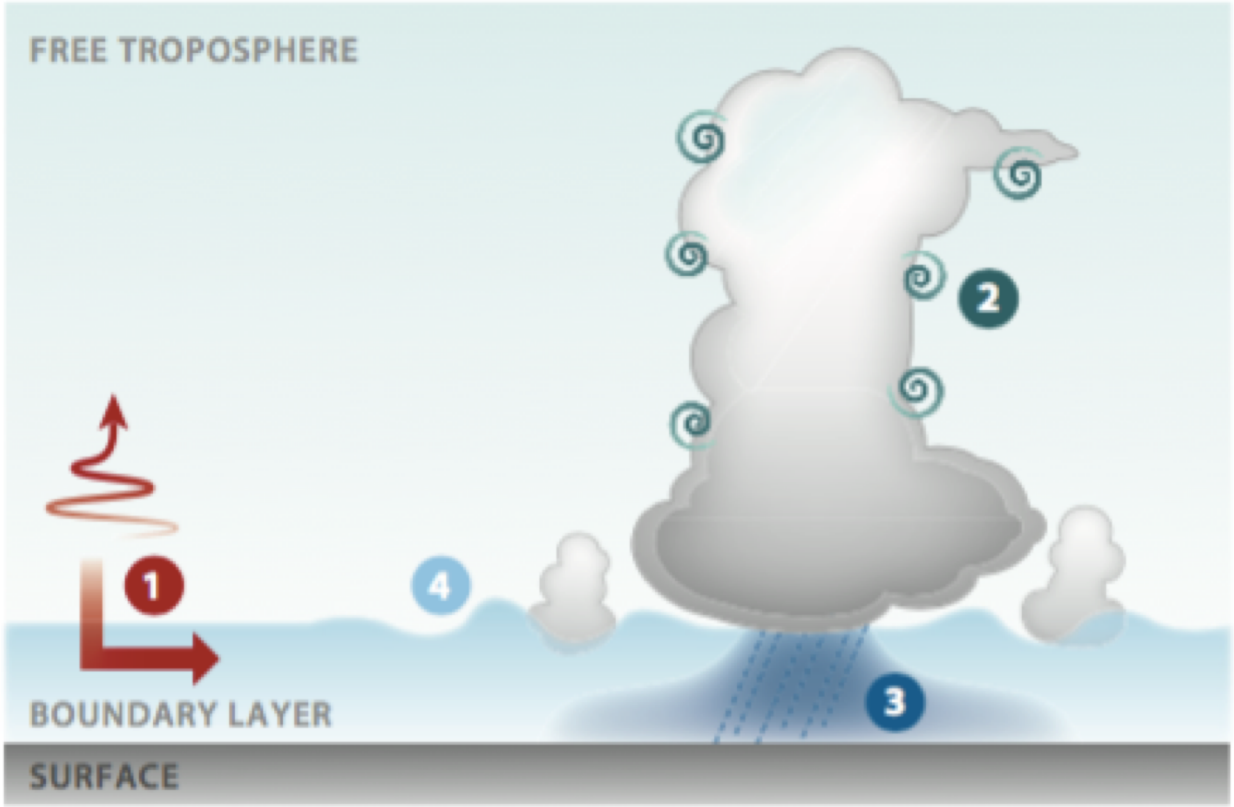
Time evolution of atmospheric humidity in simple model





Moist and dry equilibria

Self-Aggregation: physical processes involved?



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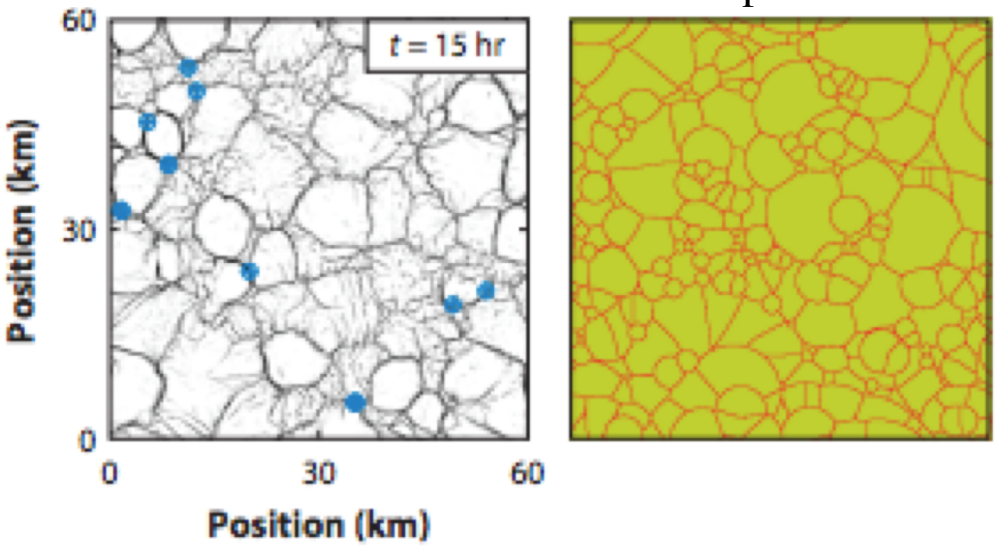
Self-Aggregation: 3- cold pools

Cold pool collisions : in simulations in conceptual model

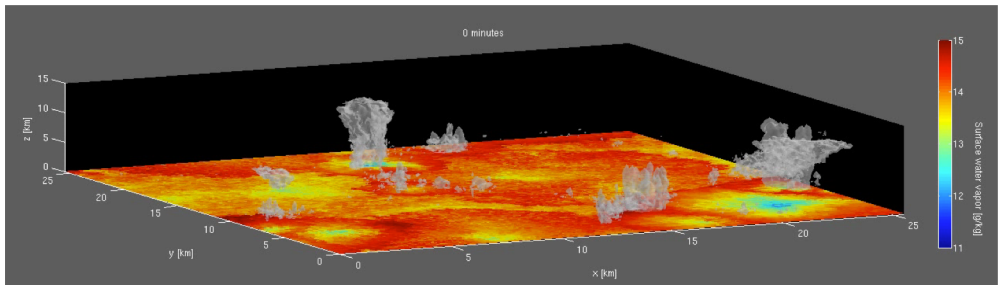


=> Cold pools can help organize convection by favoring convection nearby…

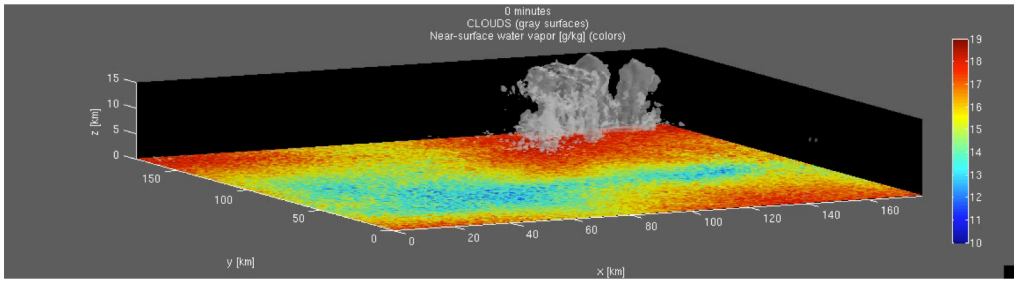
[Haerter et al 2019; Nissen & Haerter 2021]

... And cold pools can oppose organization via downdrafts !

Clouds over near-surface humidity

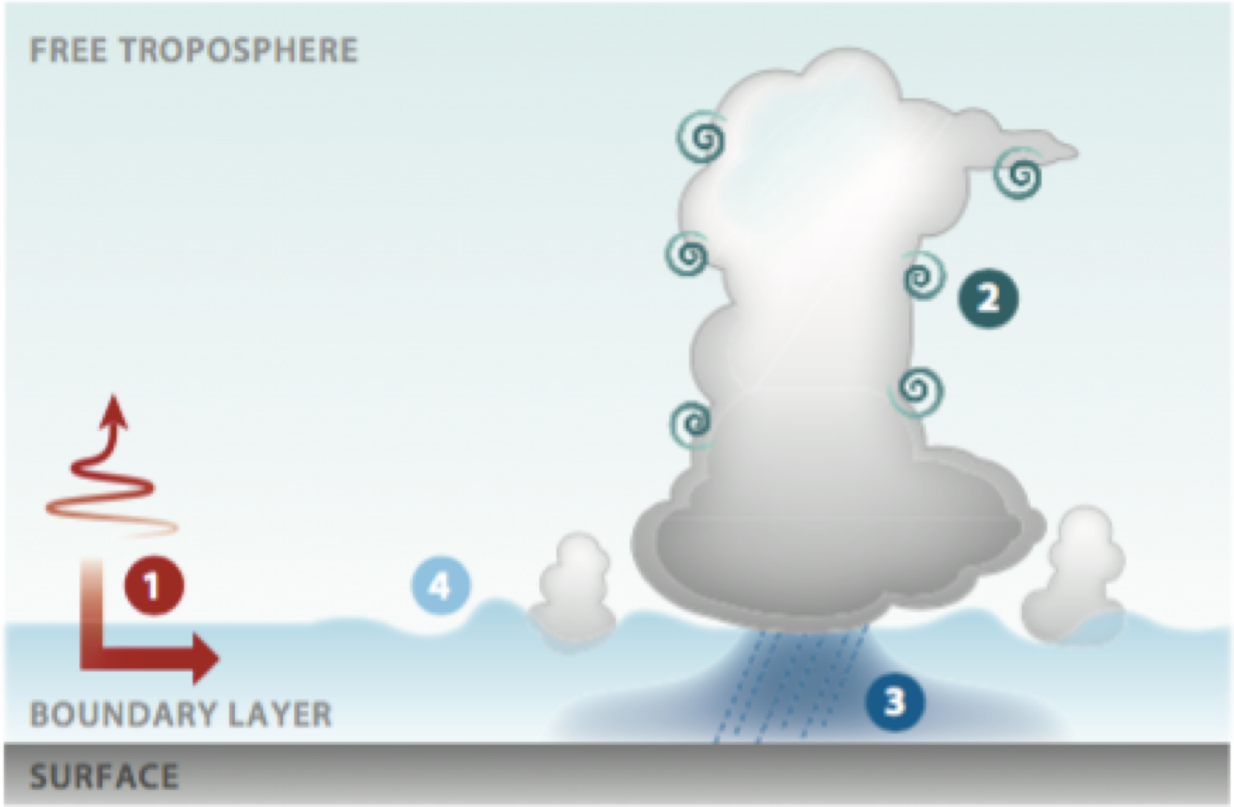


Control



No evaporation of rain <1km=> No downdrafts

Self-Aggregation: physical processes involved?



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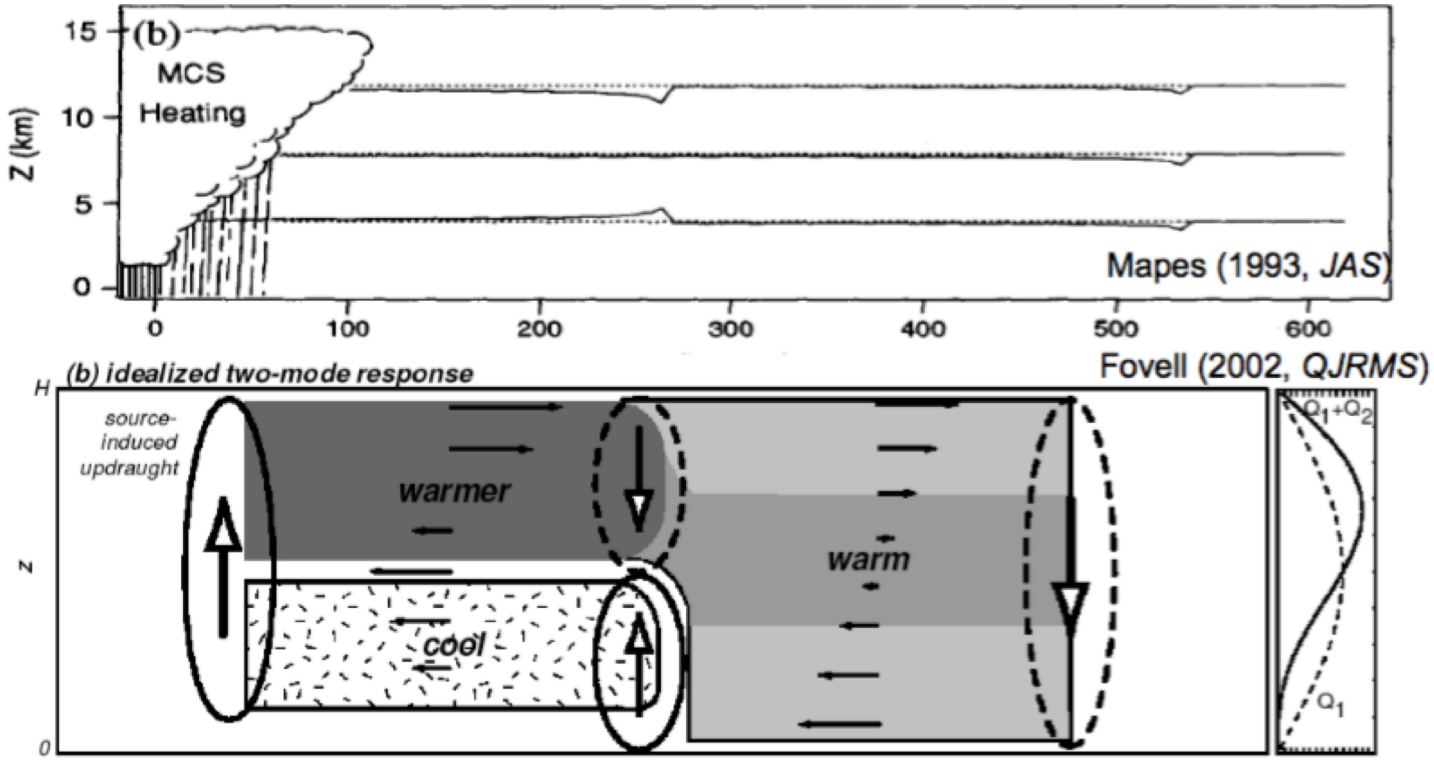
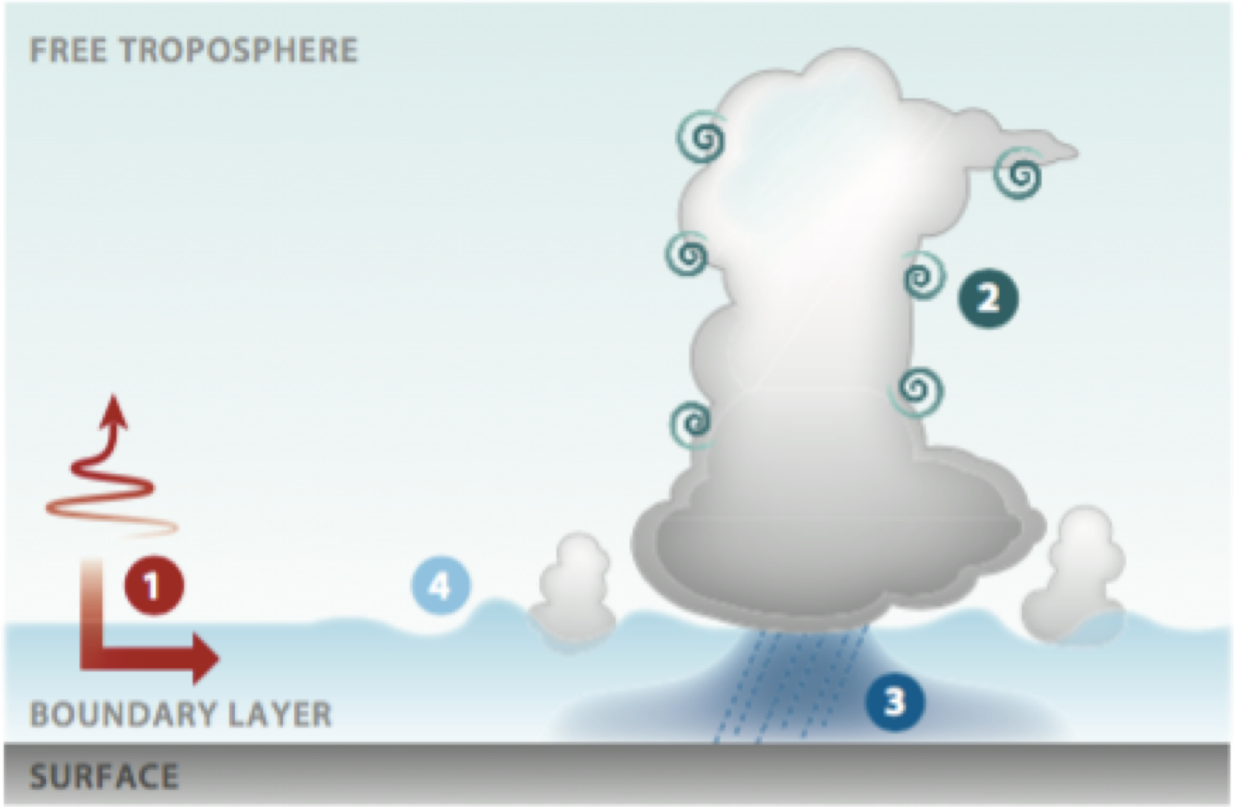
Mapes (1993, *JAS*) described tropical convection as 'gregarious'
Gravity waves destabilize cloud environment
$\Rightarrow$ promotes new convection



Formalized in linear shallow-water model *[Yang 2021]*

Self-Aggregation: physical processes involved?



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Similar feedbacks in shallow convection ? …