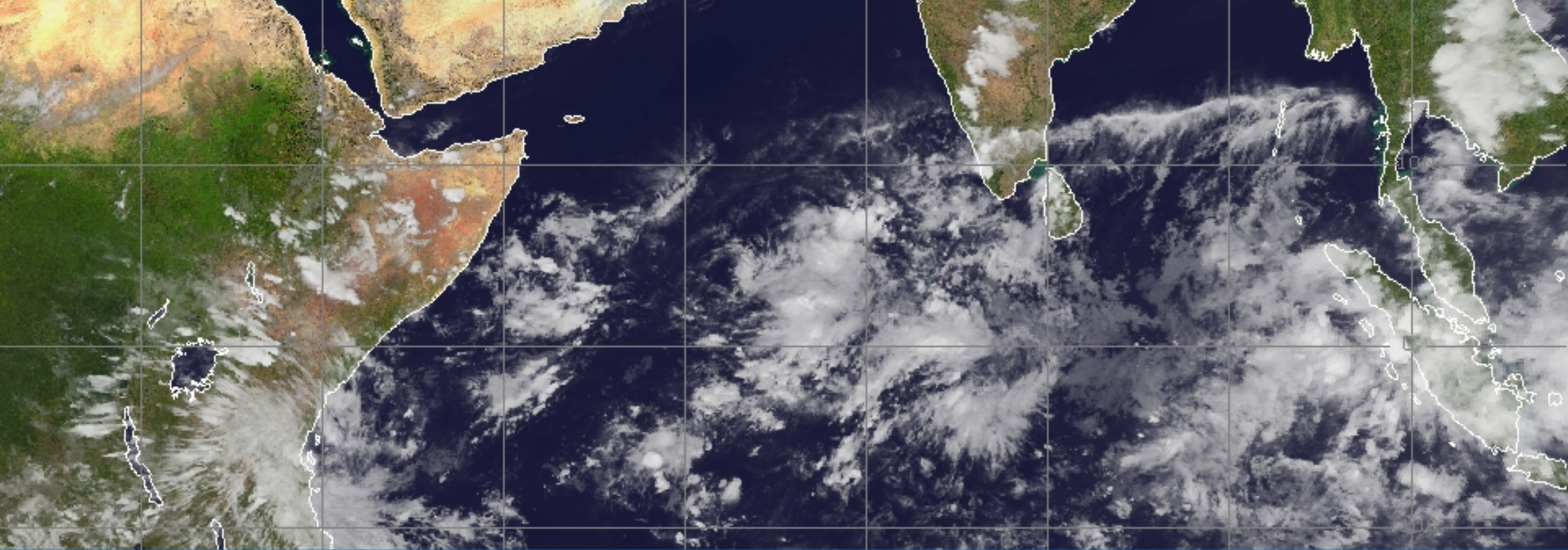

Evaluation of Parameterizations of Mesoscale Convective Organization in Earth System Models

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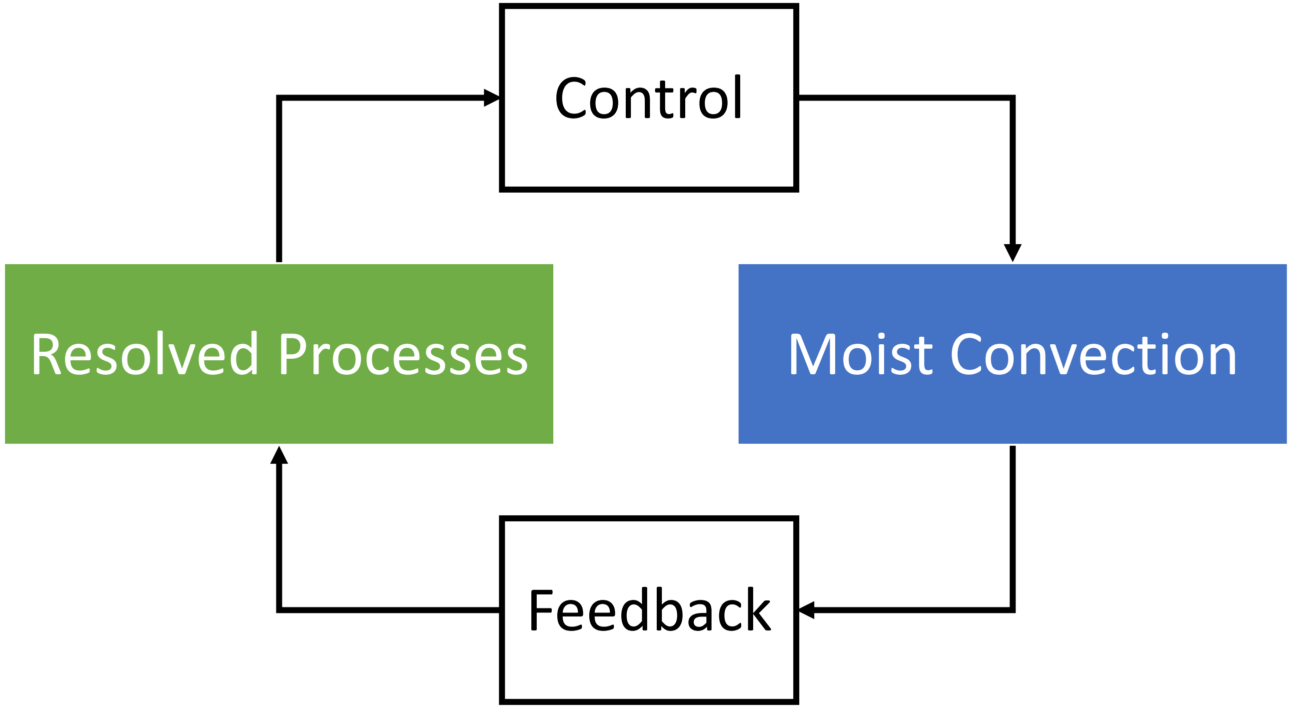
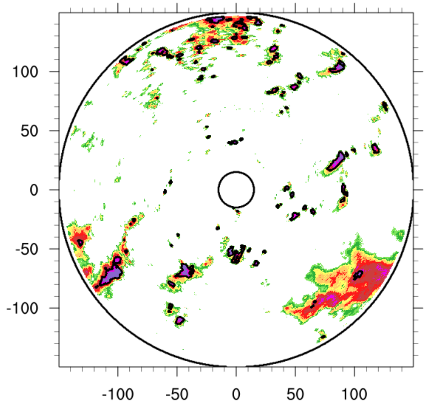
Yumin Moon[1], Min-Seop Ahn[1], and Sungsu Park[2]
[1]University of Washington [2]Seoul National University
June 10, 2019

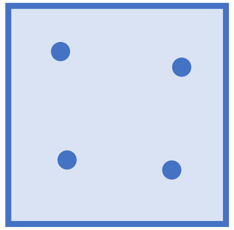
A Structural Error in Many (Most) Cumulus Schemes?

“Degree” of convective organization/clustering is invariant

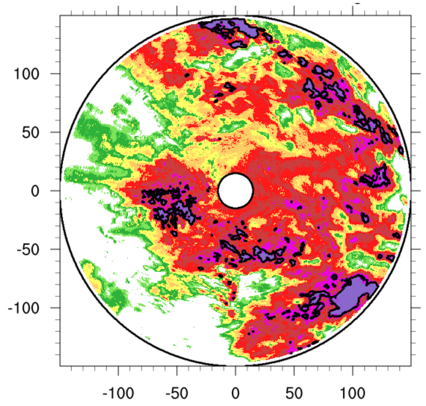




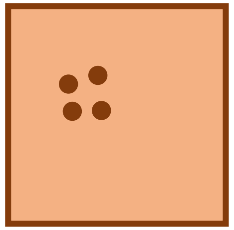
Scattered



e.g., newly developing cells with high rate of dilution



Organized

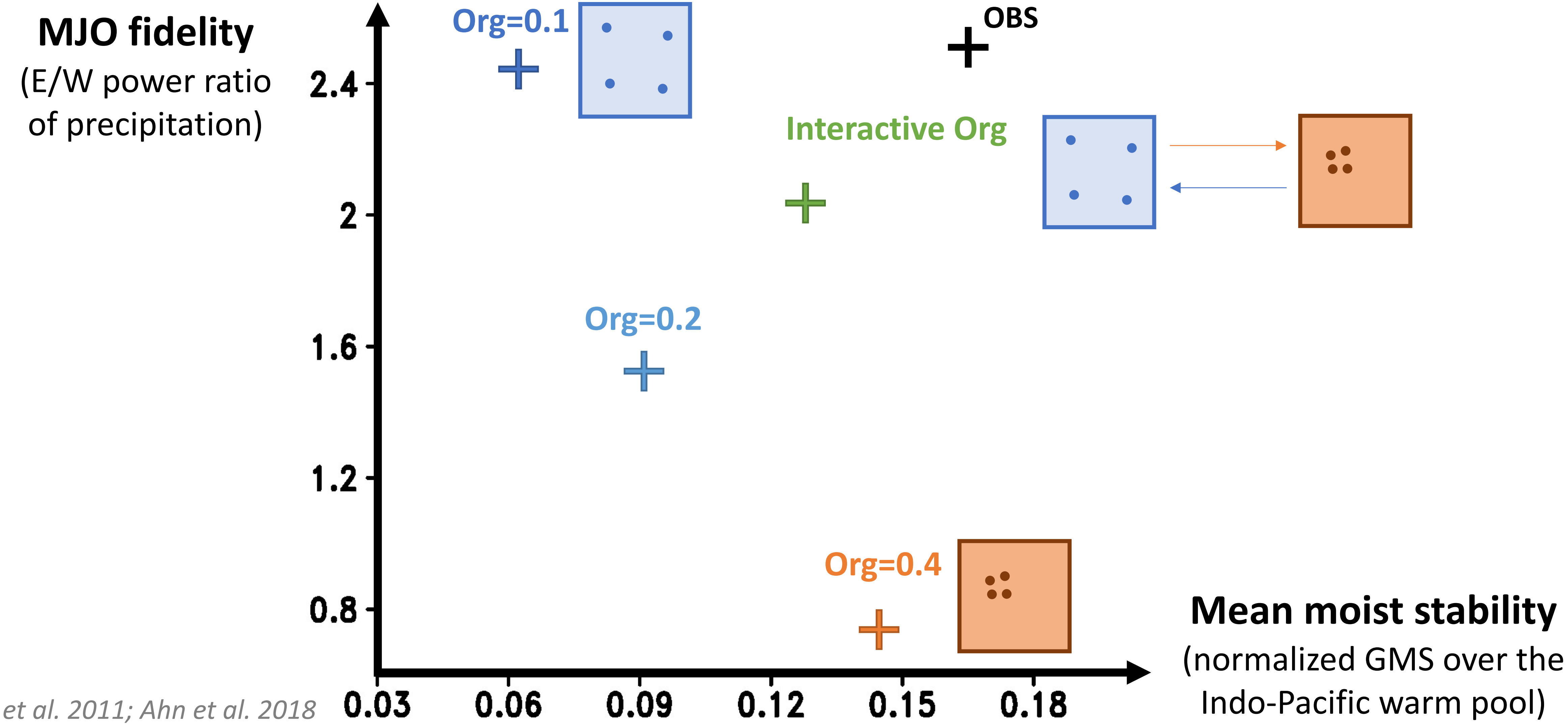


e.g., cells within a mature system with low rate of dilution

Arakawa 2004

Do ESMs Need It?

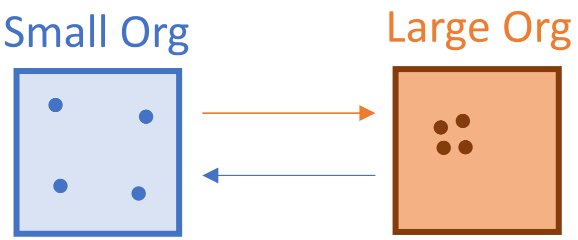
Situation-adaptive org. param. improves the MJO-mean state tradeoff syndrome



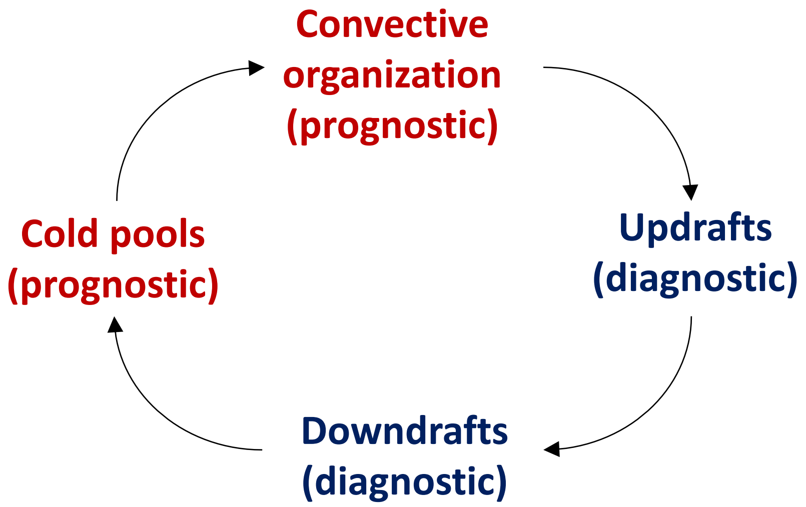
Kim et al. 2011; Ahn et al. 2018

Representation of Convective Organization in ESMs

Two-way feedbacks between convective updrafts and boundary layer cold pools



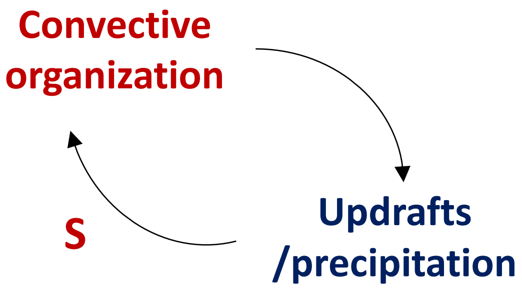
Ω (Org): degrees of organization



Mapes and Neale (2011) parameterization

$$\frac{\partial \Omega}{\partial t} = -(\boldsymbol{V}\nabla\Omega) - \frac{\Omega}{\tau} + S$$

S: rain re-evaporation



Mapes and Neale 2011; Park 2014; Del Genio et al. 2015; Baohua and Mapes 2017

Representation of Convective Organization in ESMs

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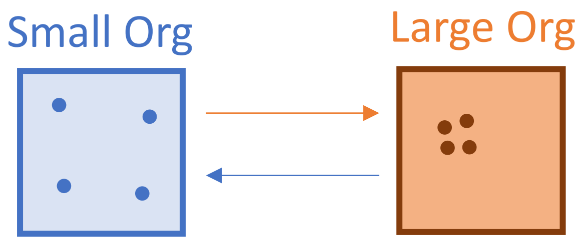
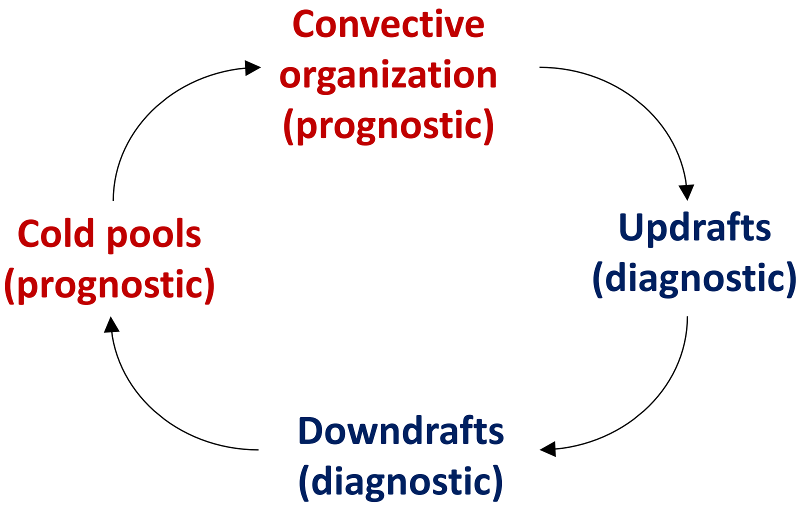


Ω (Org): degrees of organization



Unified convection scheme (UNICON, Park 2014)

$$\frac{\partial a_U}{\partial t} = -U_{\mathrm{PBL}}\frac{\partial a_U}{\partial x} - V_{\mathrm{PBL}}\frac{\partial a_U}{\partial y} + (\delta_c - \epsilon_c) - \frac{g}{\Delta p_h}\left(\sum_i \hat{M}_h^i - \sum_j \check{M}_{U,h}^j\right) - \frac{g}{\Delta p_h}\left[\sum_j (\check{M}_{D,h}^j + \check{M}_{U,h}^j) - \sum_i \hat{M}_h^i\right] a_U,$$

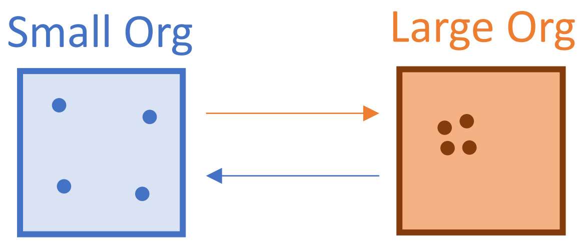
$$\frac{\partial a_D}{\partial t} = -U_{\mathrm{PBL}}\frac{\partial a_D}{\partial x} - V_{\mathrm{PBL}}\frac{\partial a_D}{\partial y} + (\epsilon_c - \delta_c) + \frac{g}{\Delta p_h}\sum_j \check{M}_{D,h}^j - \frac{g}{\Delta p_h}\left[\sum_j (\check{M}_{D,h}^j + \check{M}_{U,h}^j) - \sum_i \hat{M}_h^i\right] a_D,$$

$$\begin{aligned}\frac{\partial}{\partial t}(\Delta\phi_U) = &-U_{\mathrm{PBL}}\frac{\partial}{\partial x}(\Delta\phi_U) - V_{\mathrm{PBL}}\frac{\partial}{\partial y}(\Delta\phi_U)\\ &- \frac{g}{\Delta p_h}\left\{\sum_j\left[\check{M}_{D,h}^j(\check{\phi}_{D,h}^j - \phi_{\mathrm{PBL}}) - \frac{a_D}{a_U}\check{M}_{U,h}^j(\check{\phi}_{U,h}^j - \phi_{\mathrm{PBL}})\right] + \frac{a_D}{a_U}\sum_i \hat{M}_h^i(\hat{\phi}_h^i - \phi_{\mathrm{PBL}})\right\}\\ &+ g\left\langle \frac{a_D}{a_U}\sum_i \hat{M}^i\hat{S}_\phi^i + \sum_j\left(\frac{a_D}{a_U}\check{M}_U^j\check{S}_{\phi,U}^j - \check{M}_D^j\check{S}_{\phi,D}^j\right)\right\rangle_0^h + \langle (S_{e,U} - \overline{S}_e)_\phi\rangle_0^h\\ &- \left\{\frac{\delta_c}{a_D a_U} + \frac{g}{\Delta p_h}\left[\sum_j\left(\check{M}_{G,h}^j + \frac{1}{a_U}\check{M}_{U,h}^j\right) + \rho_s C_d V_s + \rho_h W_{e,h} - \frac{1}{a_U}\sum_i \hat{M}_h^i\right]\right\}\Delta\phi_U, \quad \text{and}\end{aligned}$$

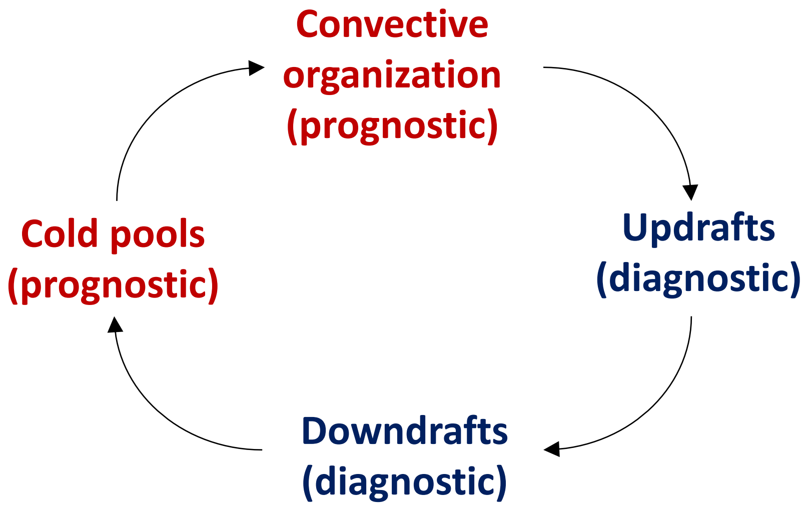
$$\begin{aligned}\frac{\partial}{\partial t}(\Delta\phi_D) = &-U_{\mathrm{PBL}}\frac{\partial}{\partial x}(\Delta\phi_D) - V_{\mathrm{PBL}}\frac{\partial}{\partial y}(\Delta\phi_D)\\ &+ \frac{g}{\Delta p_h}\left\{\sum_j\left[\frac{a_U}{a_D}\check{M}_{D,h}^j(\check{\phi}_{D,h}^j - \phi_{\mathrm{PBL}}) - \check{M}_{U,h}^j(\check{\phi}_{U,h}^j - \phi_{\mathrm{PBL}})\right] + \sum_i \hat{M}_h^i(\hat{\phi}_h^i - \phi_{\mathrm{PBL}})\right\}\\ &+ g\left\langle \sum_j\left(\frac{a_U}{a_D}\check{M}_D^j\check{S}_{\phi,D}^j - \check{M}_U^j\check{S}_{\phi,U}^j\right) - \sum_i \hat{M}^i\hat{S}_\phi^i\right\rangle_0^h + \langle (S_{e,D} - \overline{S}_e)_\phi\rangle_0^h\\ &- \left\{\frac{\epsilon_c}{a_D a_U} + \frac{g}{\Delta p_h}\left[\sum_j\left(\frac{1}{a_D}\check{M}_{D,h}^j + \check{M}_{G,h}^j\right) + \rho_s C_d V_s + \rho_h W_{e,h}\right]\right\}\Delta\phi_D,\end{aligned}$$

Mapes and Neale 2011; Park 2014; Del Genio et al. 2015; Baohua and Mapes 2017

Evaluation of Conv. Org. Parameterizations in ESMs



Ω (Org): degrees of organization



1. How can "degrees" of observed convective organization/clustering be quantified?
2. How can individual parameterized processes be tested against observations?

Mapes and Neale 2011; Park 2014

Quantification of Convective Clustering

Organization Index (I_{org}) of Tompkins and Samie (2017)

$I_{org} < 0.5$:

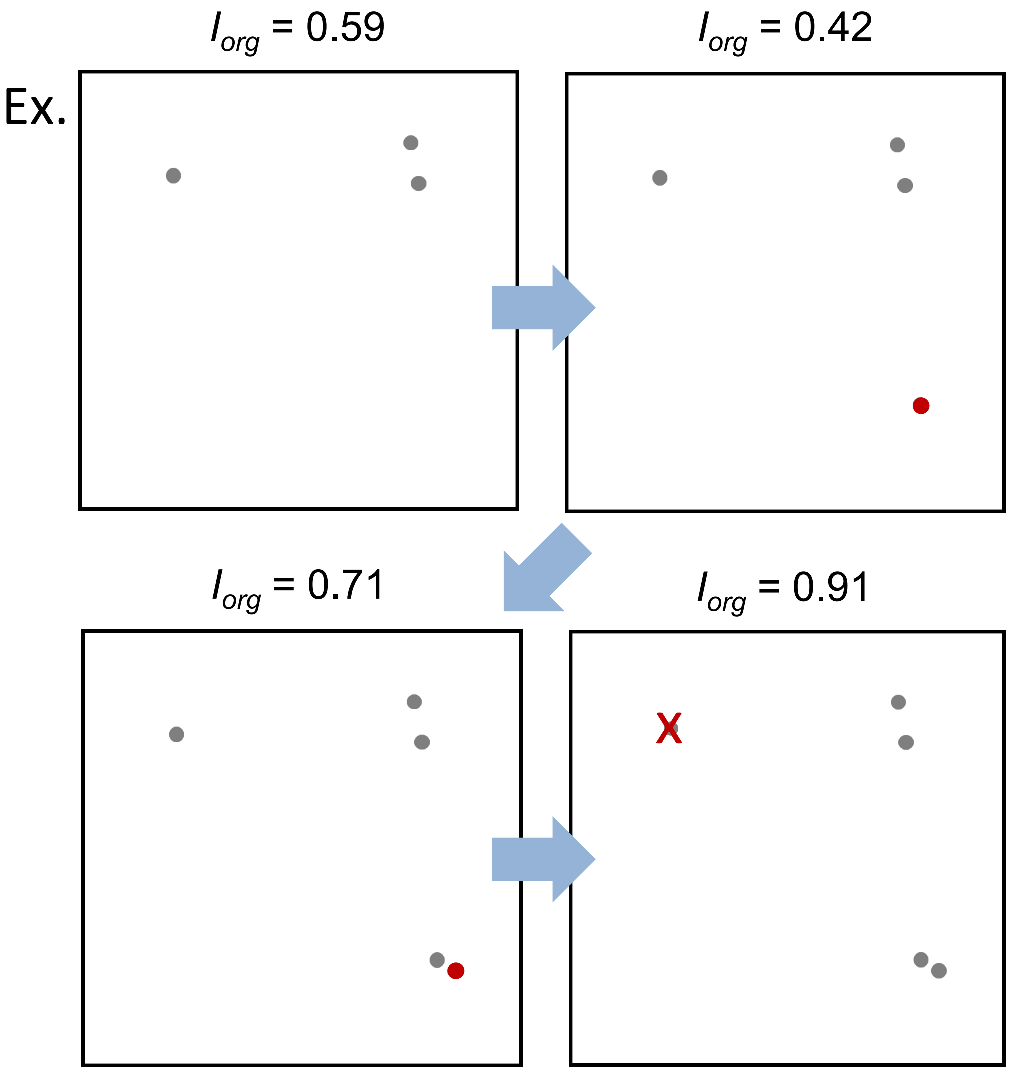
scattered distribution

$I_{org} = 0.5$:

random distribution

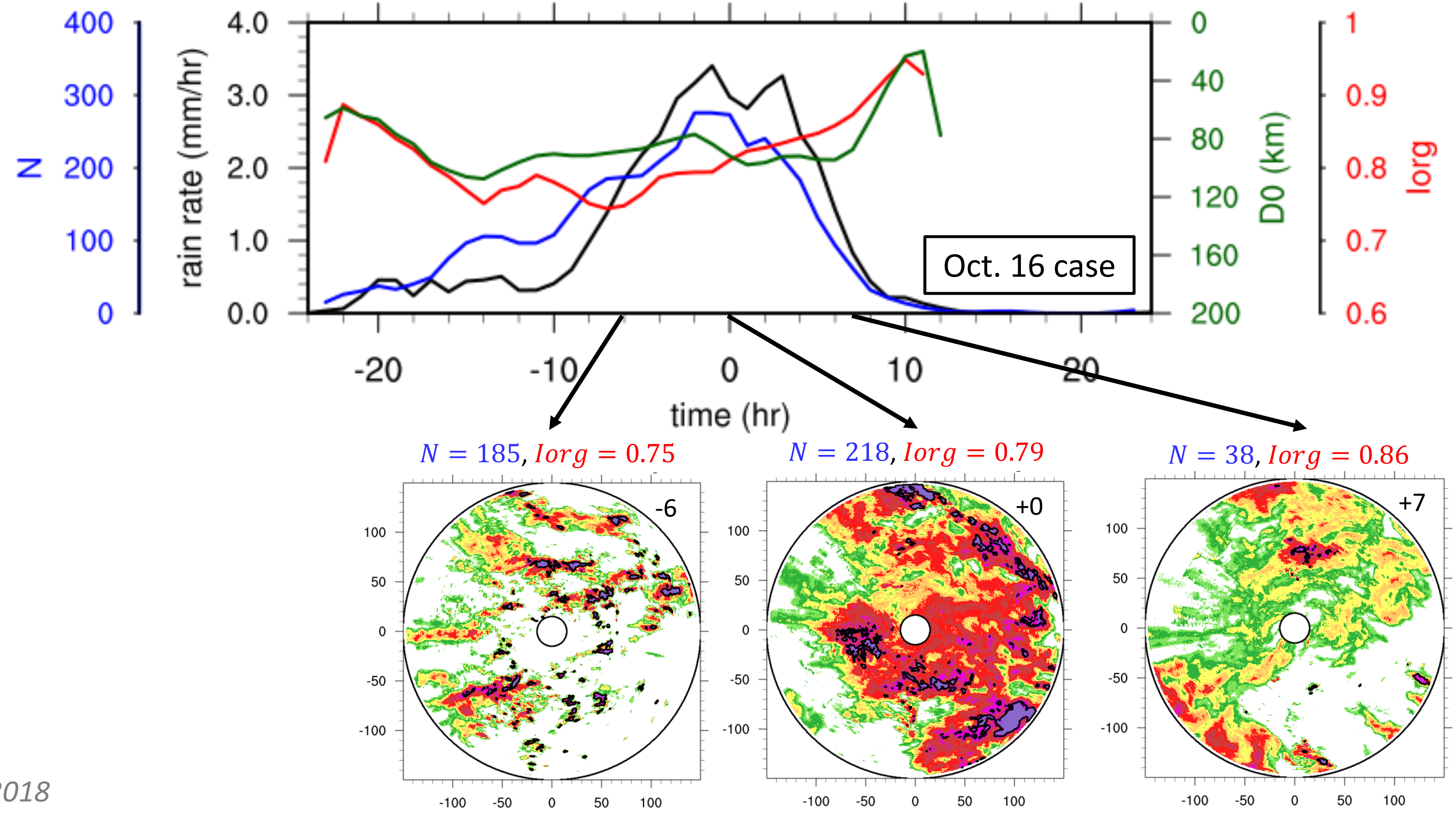
$I_{org} > 0.5$:

clustered distribution



AMIE/DYNAMO 2-day rain events

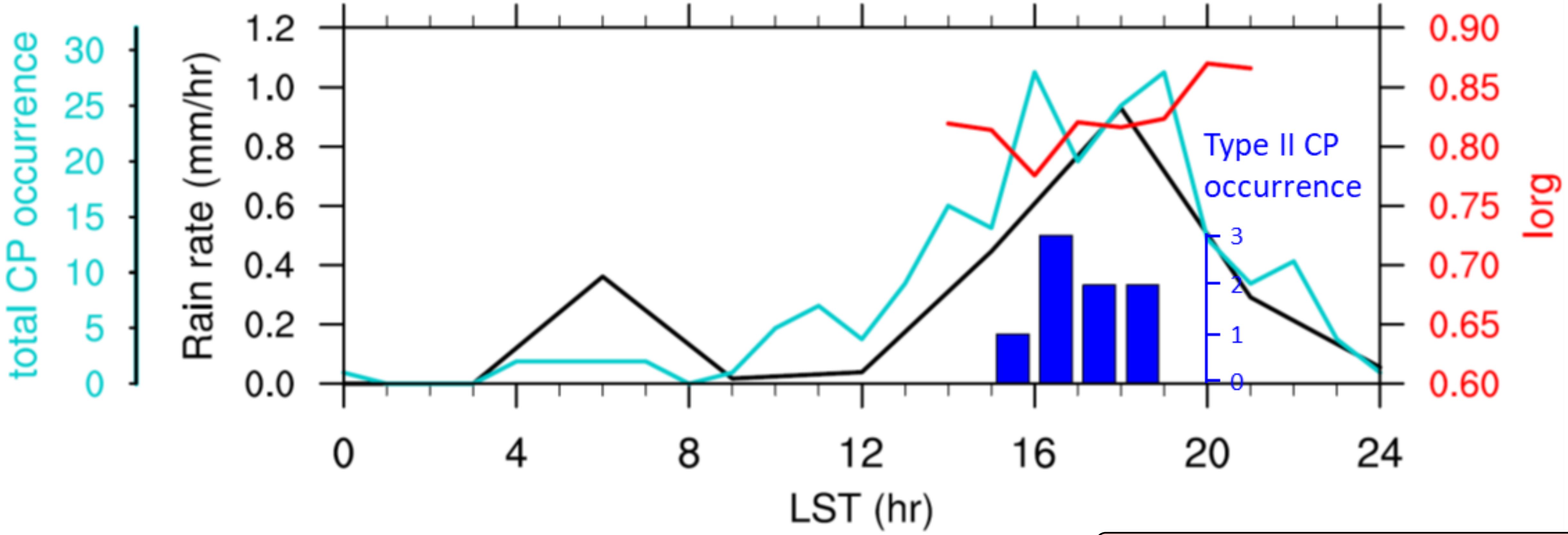
I_{org} captures the observed clustering of tropical convection



Cheng et al. 2018

MC3E May 23rd rain event

I_{org} captures the clustering within the locally developed system

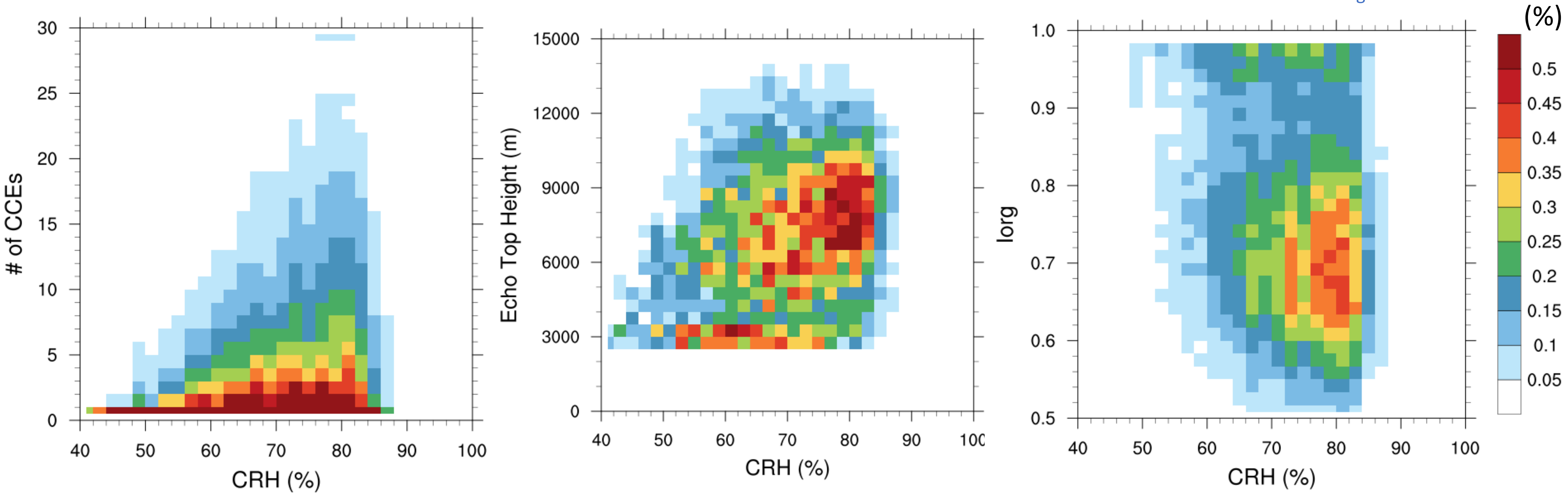


Poster (Wei-Yi Cheng et al, tomorrow afternoon)

17-Year C-POL Data

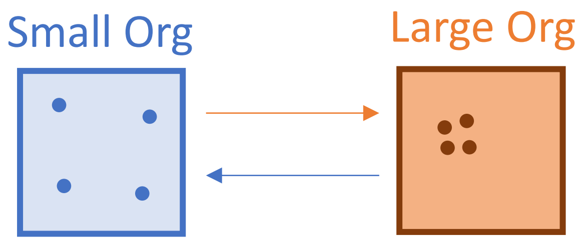
C-POL data provides statistics of I_{org} and its relationship with other variables

Joint PDF of column relative humidity (CRH) with number of CCEs (left), echo top height (middle), and I_{org} (right)



Data help acknowledgement: Robert Jackson and Scott Collis (ANL)

Evaluation of Conv. Org. Parameterizations in ESMs



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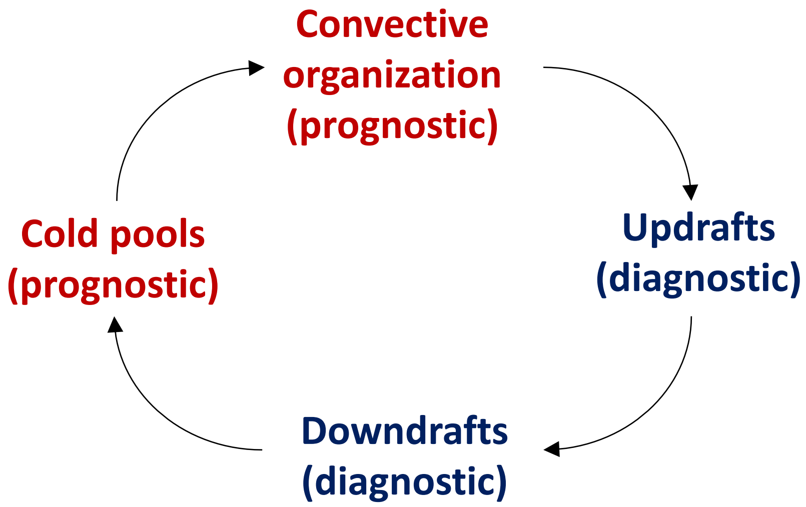

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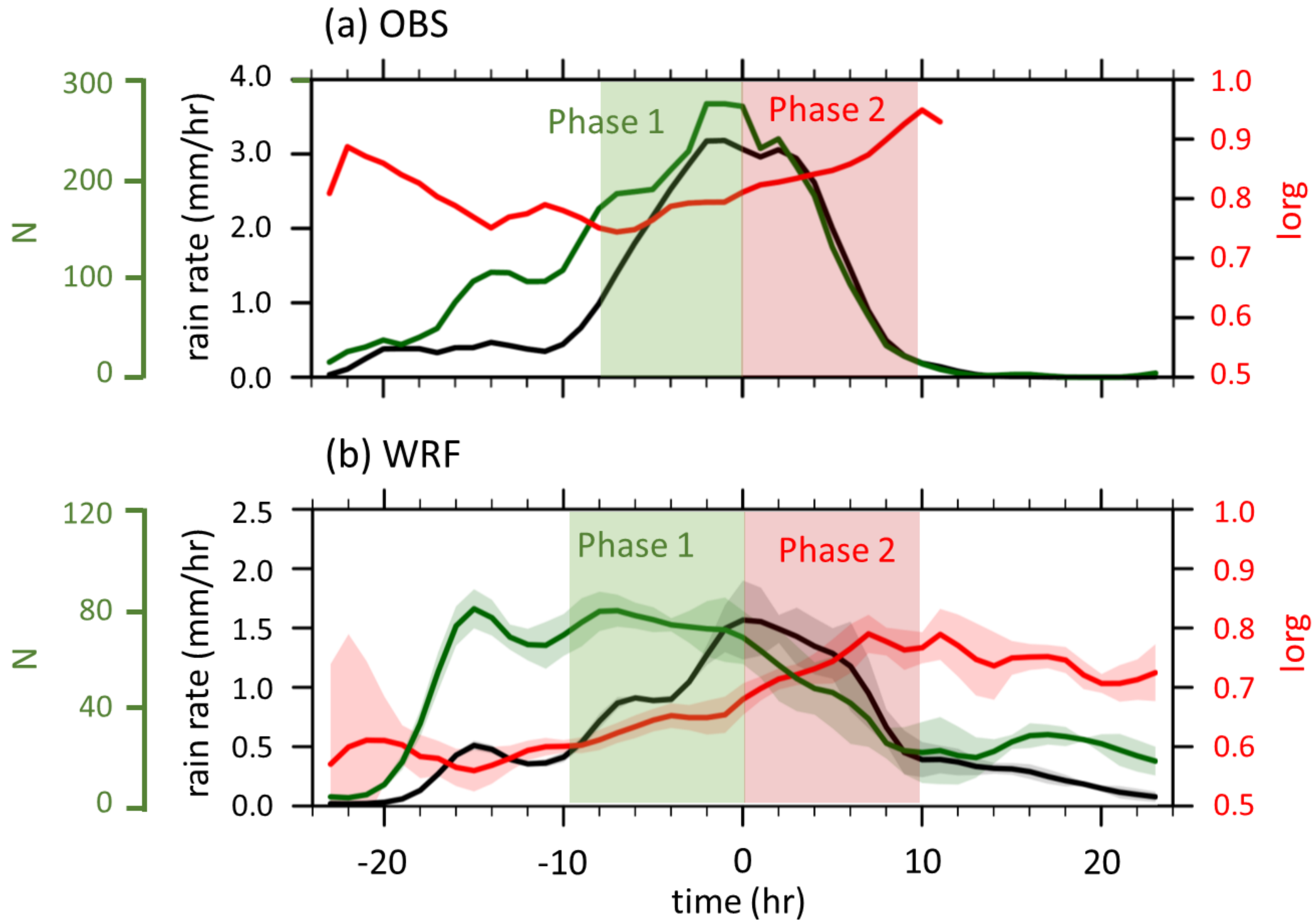
Mapes and Neale 2011; Park 2014

WRF Simulation Driven by ARM Large-scale Forcing Data

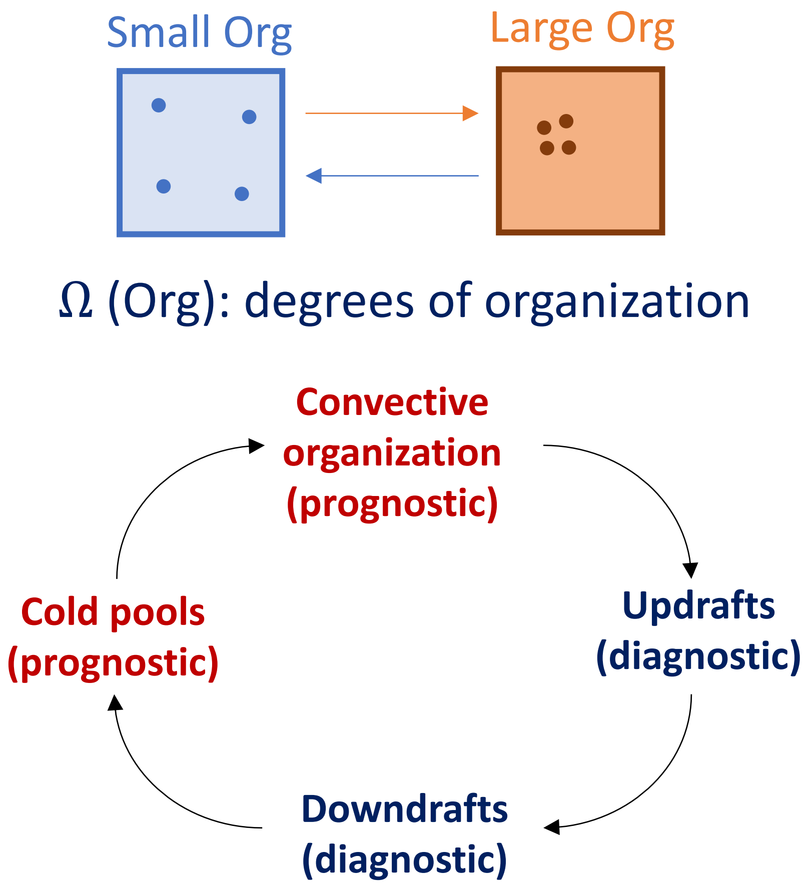
The observed convective clustering is reasonably reproduced



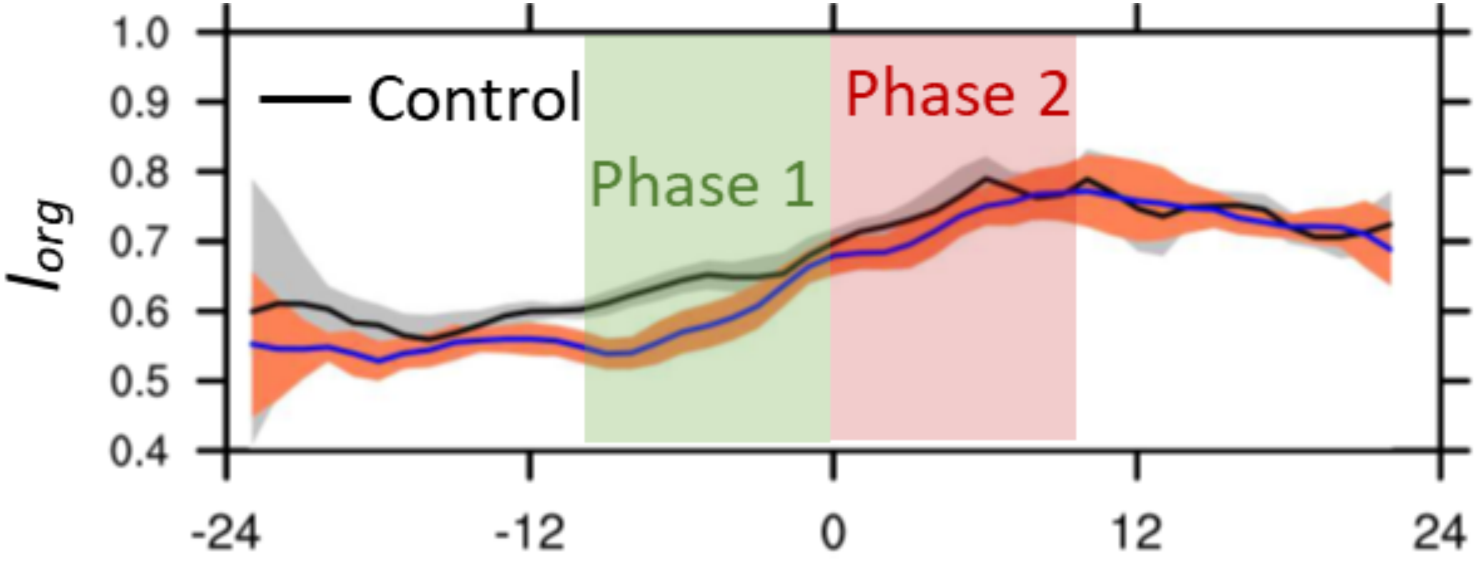
Cheng et al. 2019

CRM Intervention Experiment

Convection is less organized with weaker boundary layer cold pools

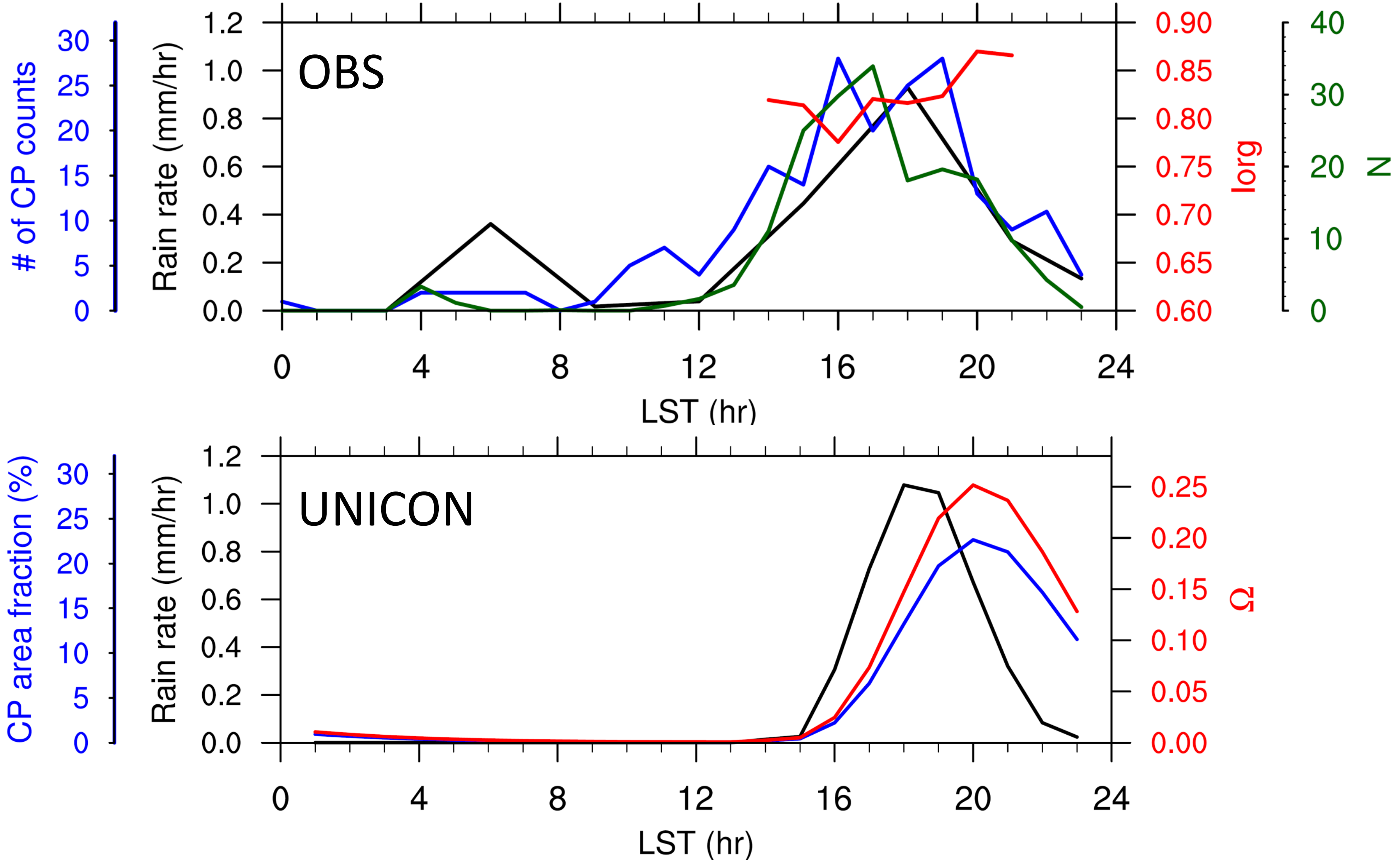


Boundary layer temperature is nudged toward the domain mean at each time step (AMIE/DYNAMO Oct 16th rain event)

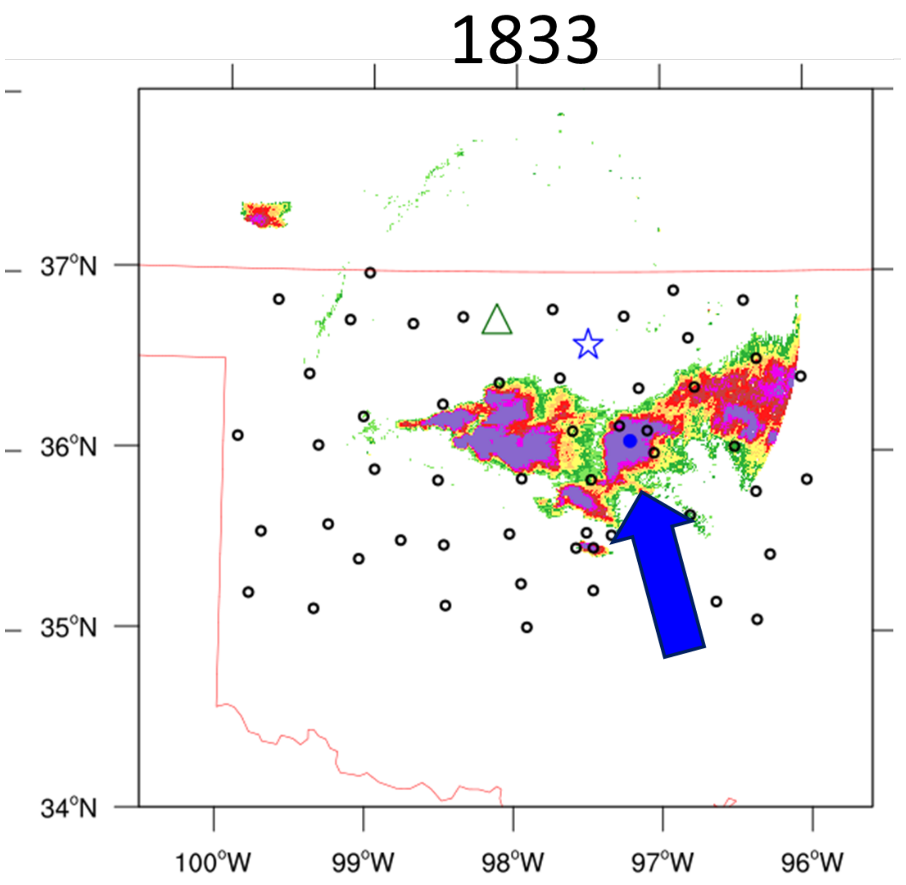


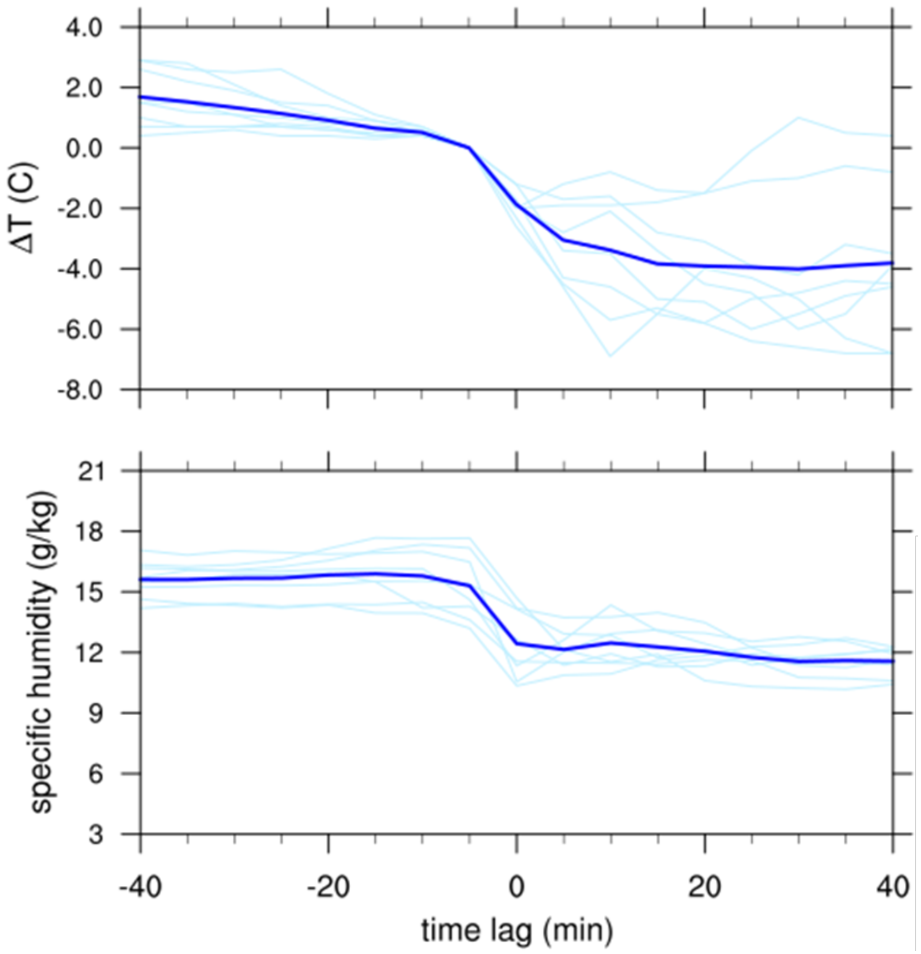
Cheng et al. 2019

SCM Simulation of the MC3E May 23rd Rain Event Driven by ARM Forcing Data



Cold Pools Properties (MC3E May 23rd rain event)





Poster (Wei-Yi Cheng et al, tomorrow afternoon)

Summary

- Parameterizations of mesoscale convective organization make plume properties situation-adaptive and thereby help ESMs better represent variability in the system (e.g., MJO).
- A few existing cumulus schemes represent two-way interactions between convective updrafts and boundary layer cold pools
  - None of them represents interactions with stratiform clouds; can ARM observations help develop such parameterizations?
- Spatial distribution of convective elements can be used to quantify the degree of convective organization/clustering
  - ARM scanning precipitation radar
- Process-level understanding of the underlying mechanisms of convective organization requires synergetic use of observations and cloud-system resolving model simulations
  - ARM large-scale forcing data
  - Characterizations of convective updrafts, downdrafts, and cold pools using ARM observations