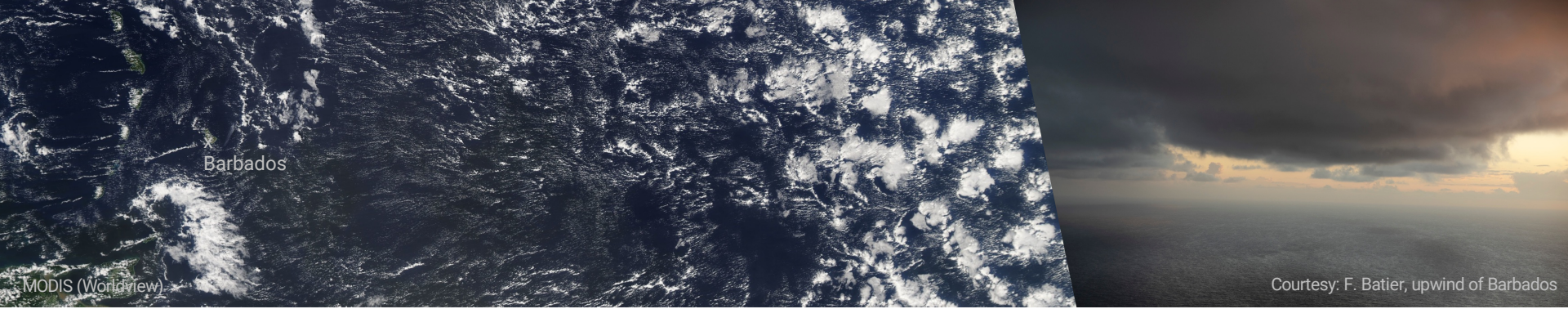
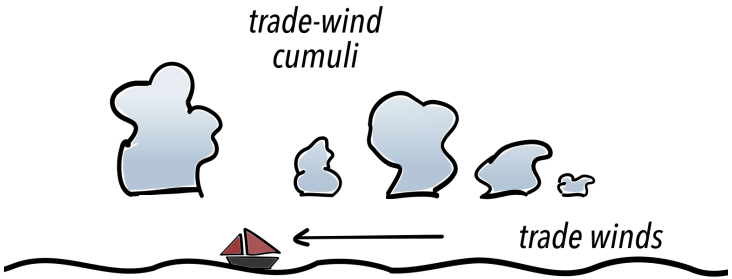


On the Relationship between Precipitation and Spatial Organisation in the Trades

Jule Radtke

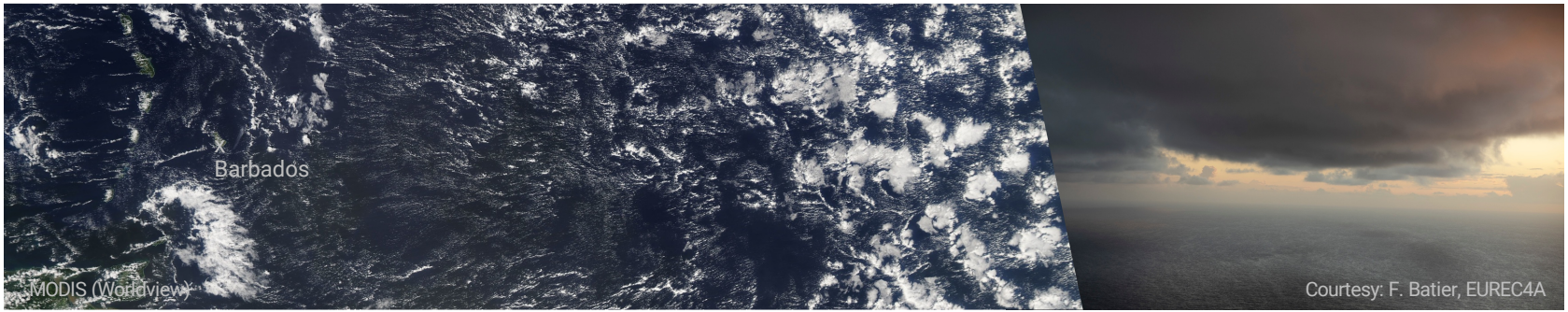
Raphaela Vogel, Felix Ament, Ann Kristin Naumann

Trade-wind clouds are more complex than thought



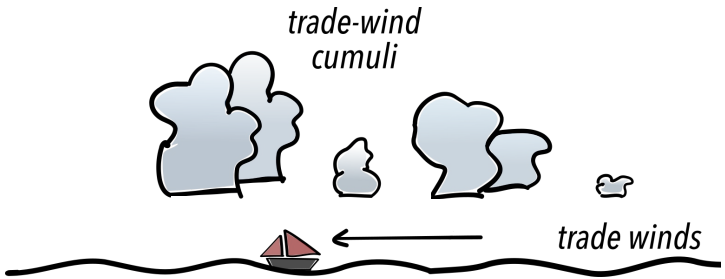
Betts, 1997; Siebesma, 1998; Stevens, 2005; ...

Trade-wind clouds organise into a variety of spatial patterns and rain



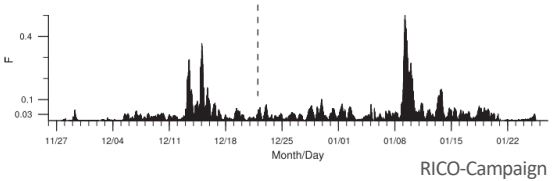
… an ignored cloud feedback component?

Bony et al., 2020



About 50% of clouds produce rain, 10-20% rain that reaches the surface

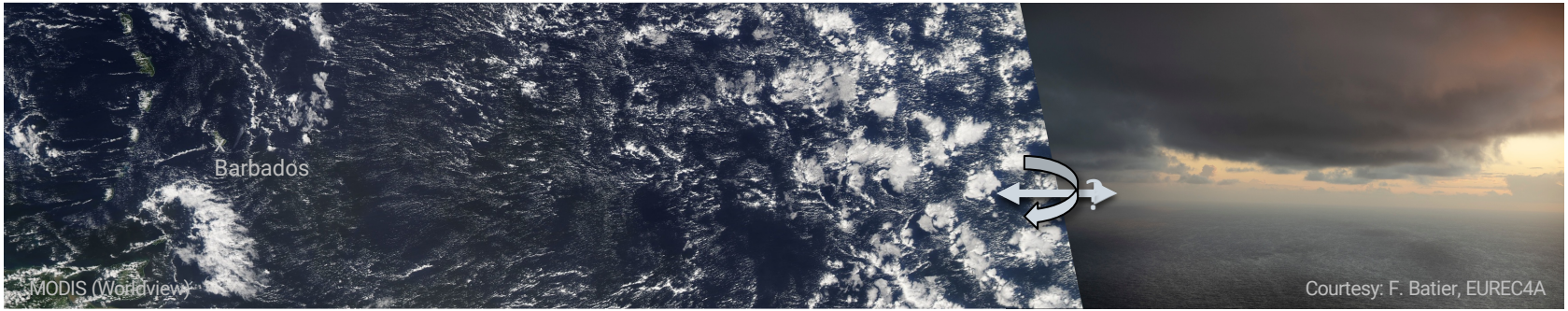
Nuijens et al. 2009, Kalesse-Los et al. 2023



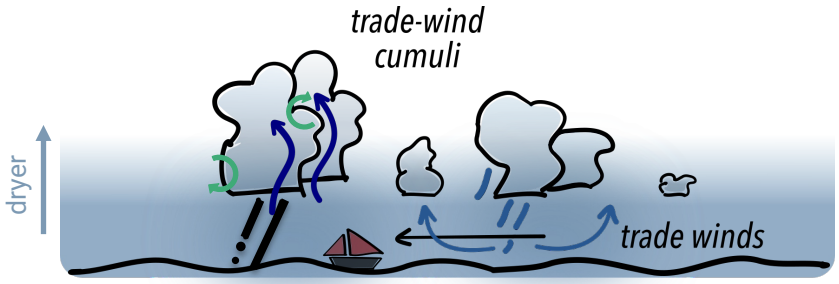
RICO-Campaign

Snodgrass et al. 2009; van Zanten et al., 2011, Vogel et al., 2016

(How) do spatial organisation and precipitation in the trades relate?



Is organisation to first-order responsible for differences in rain rates?



In the winter trades cold pools occur on 73% of days and are present about 7.8% of the time

Vogel et al., 2021, Touzè-Pfeiffer et al., 2021

Snodgrass et al., 2009; Seifert and Heus, 2013; Stevens et al., 2020, Schulz et al., 2021

1. How do occurrence, amount and intensity of rain in observations of the trades relate to the cells' clustering, size and number?

Radtke et al. (2022): The relationship between precipitation and its spatial pattern in the trades observed during EUREC^{4}A, QJRMS

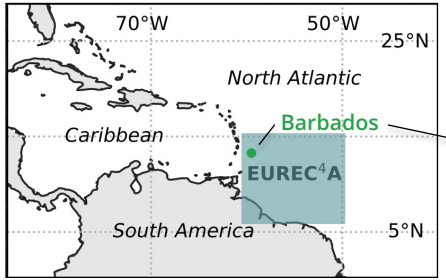
2. Does spatial organisation affect the pathway to precipitation in simulated trade-wind convection? How?

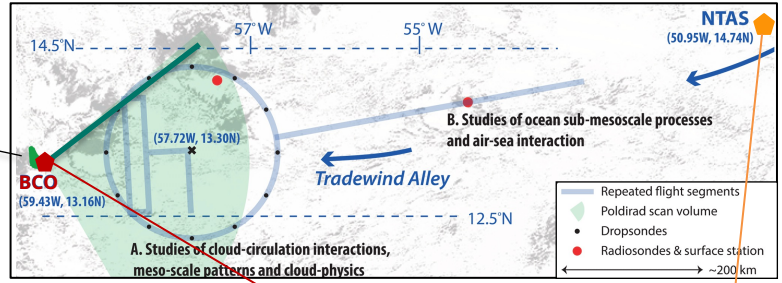
Radtke et al. (in press): Spatial organisation affects the pathway to precipitation in simulated trade-wind convection, GRL

EUREC⁴A field campaign

January, February 2020, North Atlantic trades

(Bony et al., 2017; Stevens et al., 2020)





Clouds representative across the trades

(Medeiros and Nuijens, 2016)

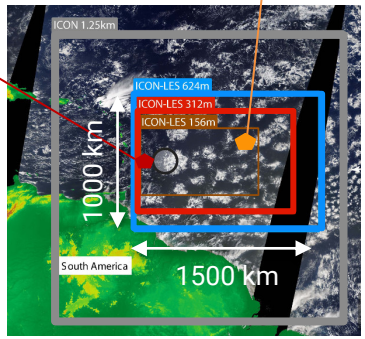
C-band rain radar

Poldirad

(Hagen et al., 2021)

Integrated water vapor @BCO

(Bock et al., 2021)



Large-domain, hectometer ICON large-eddy simulations

09.01.–19.02.2020

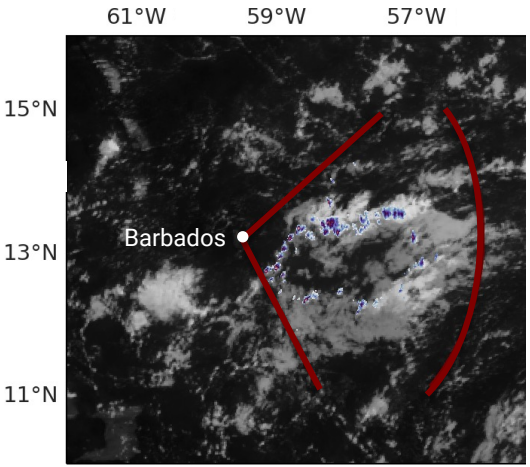
2mom microphysics

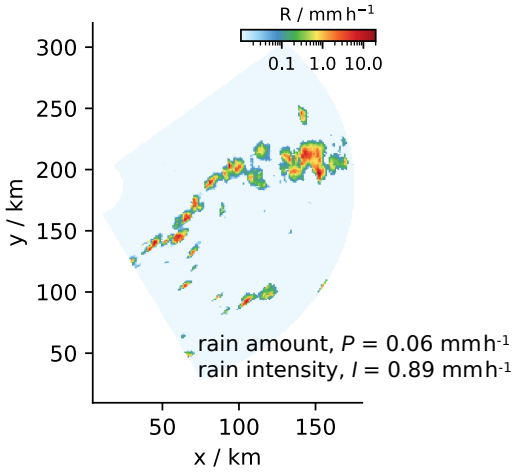
(Schulz et al., 2023)

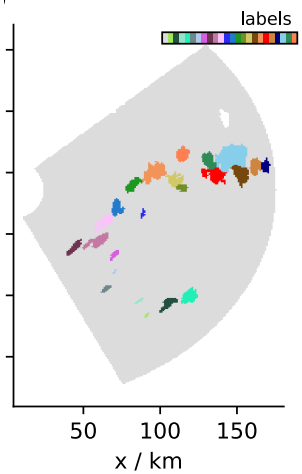
How do occurrence, amount and intensity of rain in observations of the trades relate to the cells' clustering, size and number?

Data: EUREC^{4}A campaign, C-band radar PoldiRad

radar reflectivity → rain rate (Z-R as in Nuijens 2009) + convective rain cells watershed segmentation (Brueck 2020)







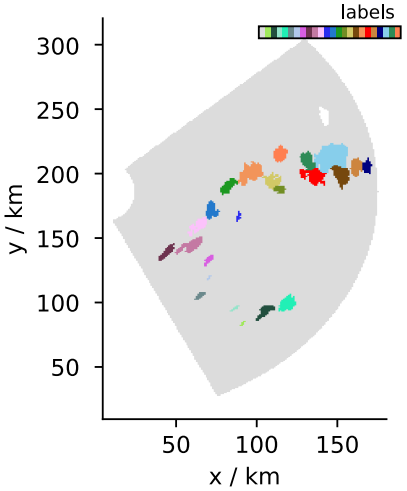
3 properties of spatial organisation:

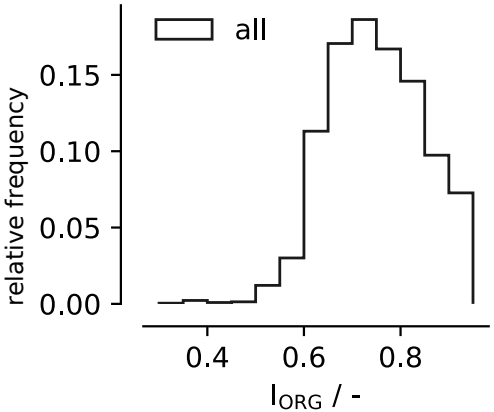
Cell number

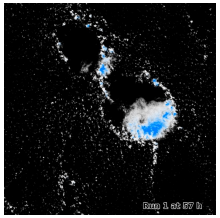
Mean cell size

Spatial distribution
I_{org}
(Tompkins 2017)
0 —— 1
regular < 0.5 < clustered

Occurrence of rain is almost always associated with clustering

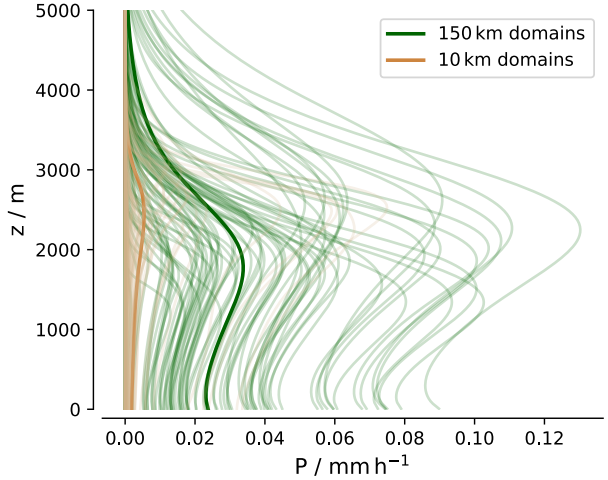






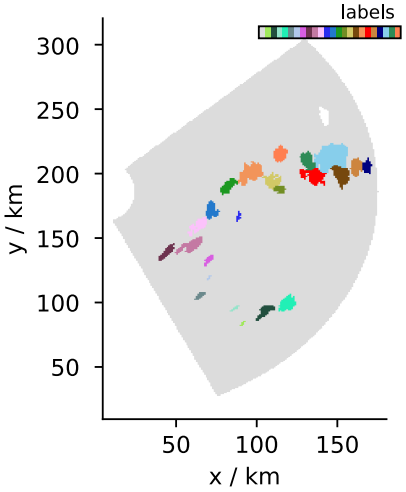
Cloud Botany

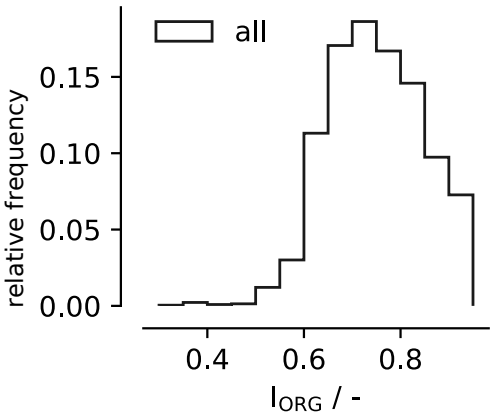
(Jansson et al., 2023)

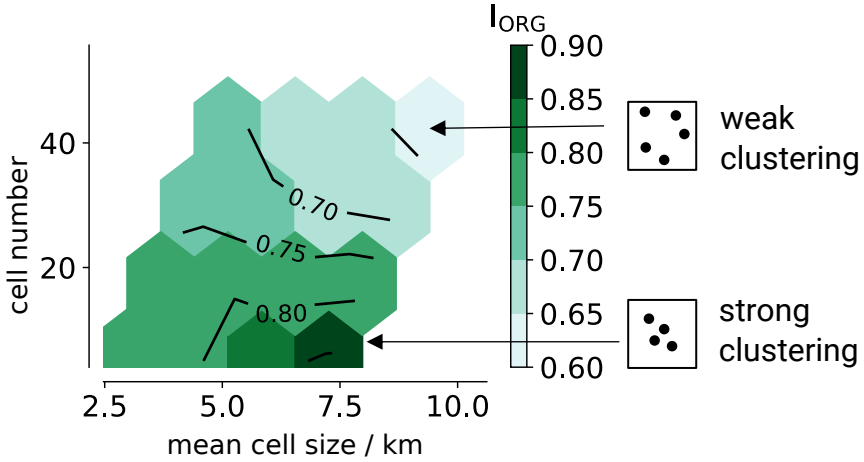


I_{org} – clustering index

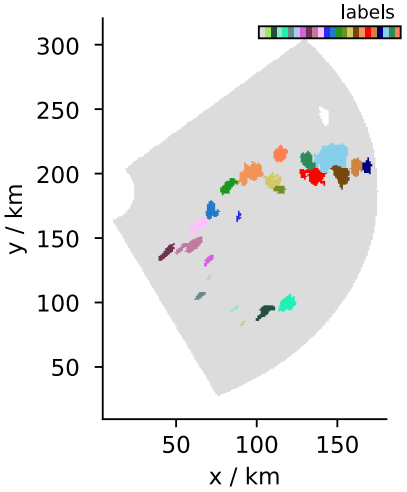
Degree of clustering highest in scenes containing few, large cells

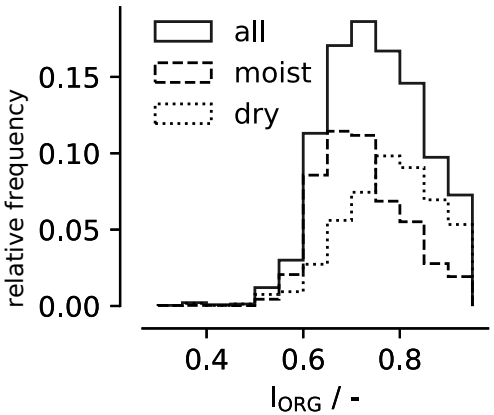


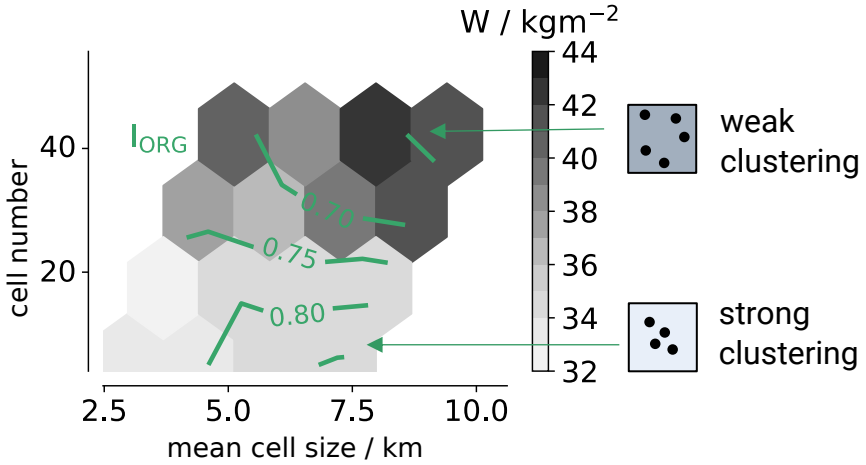




Degree of clustering highest in scenes containing few, large cells





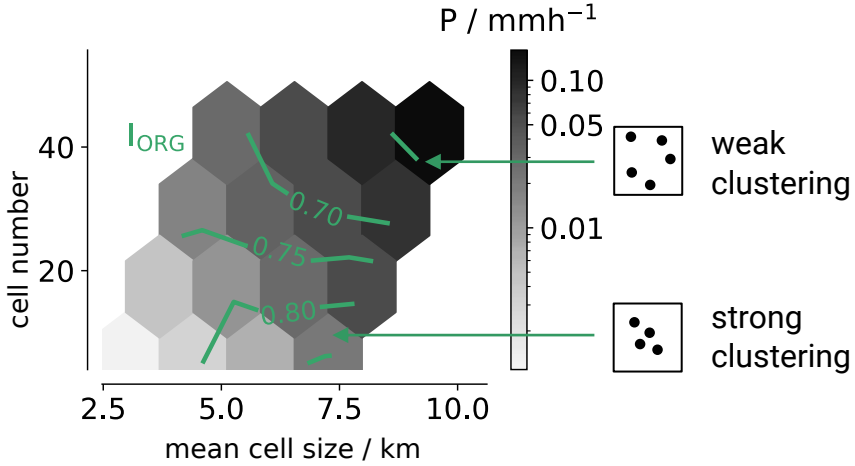


… that are typically dryer (low W)

… suggesting similarities to the spatial organisation of deep precipitating convection (Louf 2019, Brueck et al., 2020, Retsch et al., 2020)

W – water vapor path

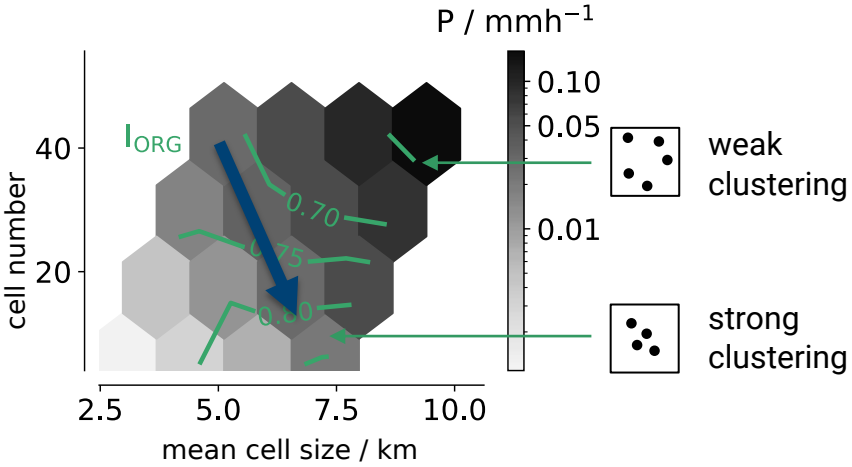
Rain amount follows cell number and size

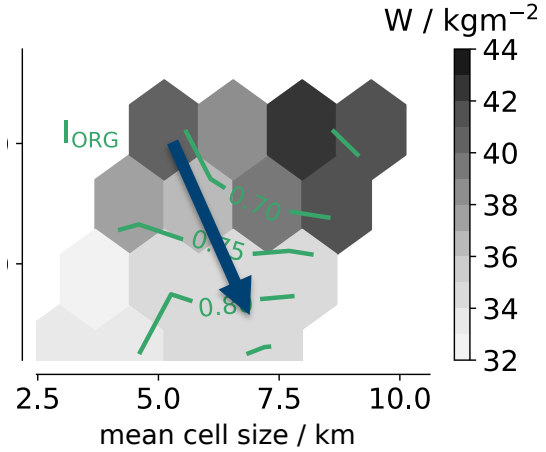


… such that it varies largely independently of the cells' degree of clustering.

> Hypothesized mechanisms such as enhanced cell interaction through clustering overall second-order role for increasing a scene's *rain amount*.

Degree of clustering could be important to maintain precipitation in dry environments

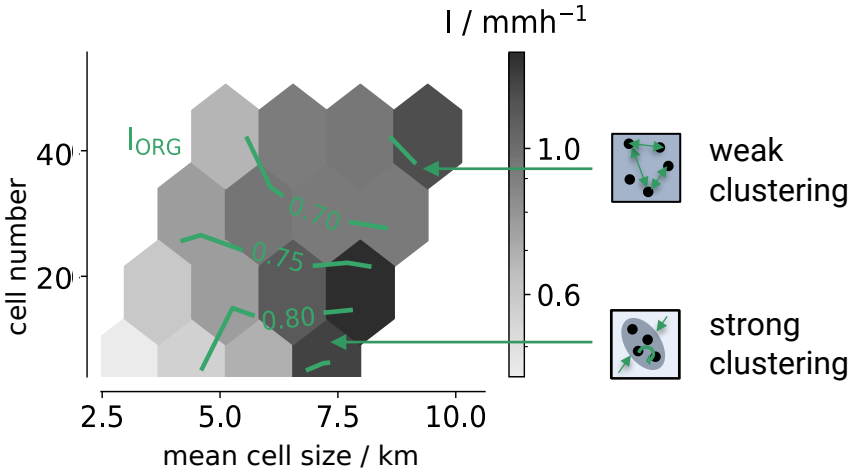




… possibly by protecting cells from entrainment in these hostile dry environments.

W – water vapor path

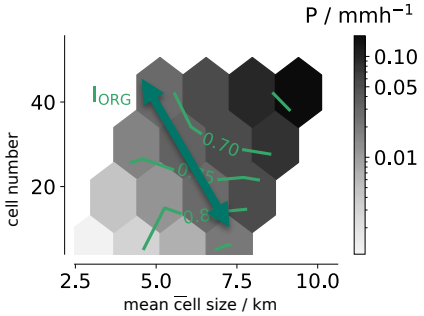
Rain intensity increases to first order with cell size



… and maximizes at high degrees of clustering.

1. How do occurrence, amount and intensity of rain in observations of the trades relate to the cells' clustering, size and number?

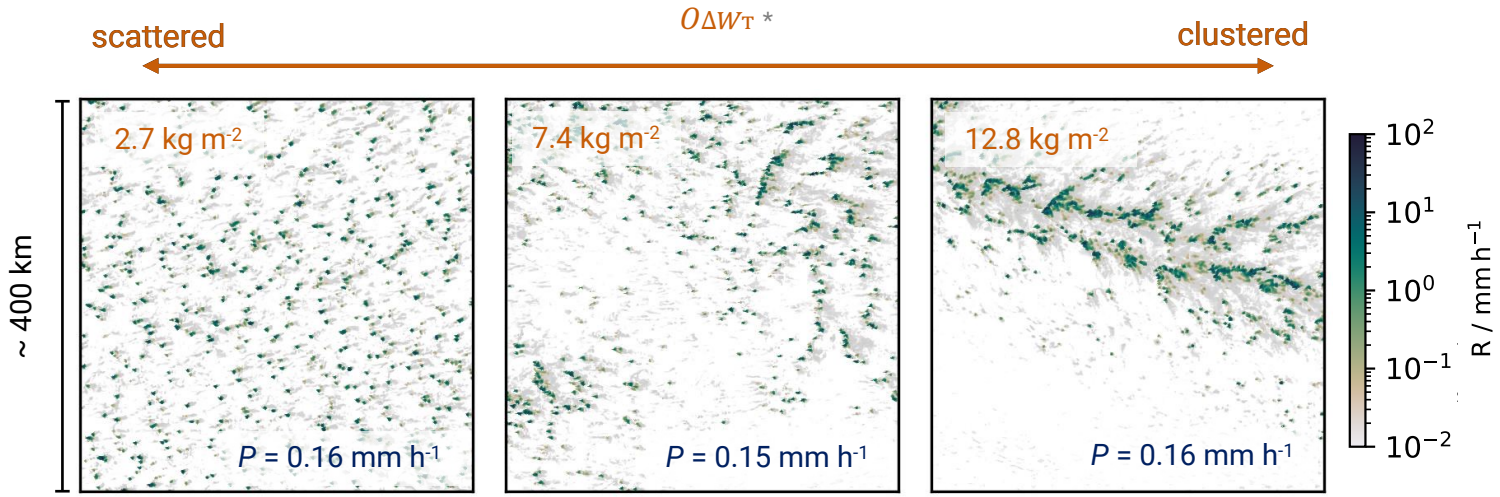
- Occurrence of rain is almost always associated with clustering.
- Cell number and size of first-order importance for a scene's rain amount, cell size for scene's rain intensity.
- Cells' clustering strength of second-order importance for rain amount across all regimes, important possibly to maintain precipitation in dry environments and for high rain intensities.



↷ Could spatial organization be a process to maintain precipitation in different environments, enabling a different pathway to precipitation?

Does spatial organisation affect the pathway to precipitation in simulated trade-wind convection? How?

ICON large eddy simulations (Schulz et al. 2023)

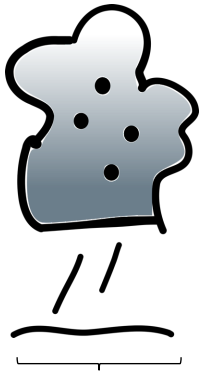


* (Narenpitak et al. 2021)

→ LES reproduce that similar rain amounts can be associated with different states of organisation

P – rain amount, $O_{\Delta W_T}$ – Organisation metric

Does spatial organisation affect the pathway to precipitation in simulated trade-wind convection? How?



Production (cloud $\xrightarrow{C_R}$ rain)
$= C_{Auto} + C_{Acc}$

Sedimentation (rain evaporates)

P – Precipitation
W_L – Cloud liquid water path

Conversion Efficiency: $\varepsilon_{conv} = \frac{C_R}{W_L}$

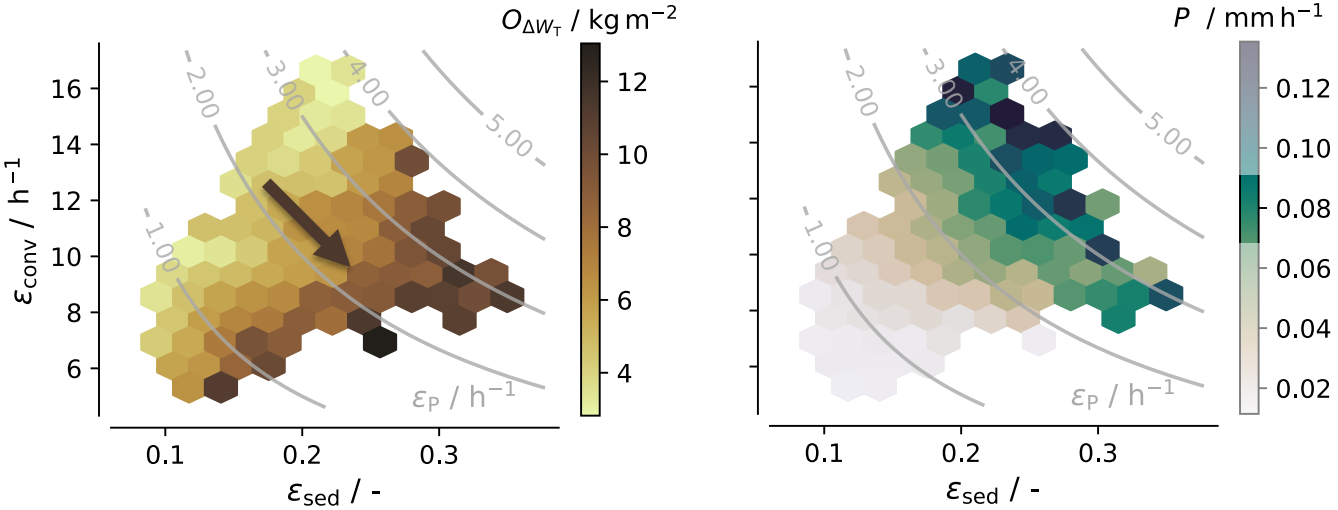
Sedimentation Efficiency: $\varepsilon_{sed} = \frac{P}{C_R} = 1 - \varepsilon_{evap}$

Precipitation Efficiency: $\varepsilon_P = \frac{P}{W_L}$

(following Langhans et al., 2015)

C_R – rain production rate
C_{Auto} – autoconversion rate
C_{Acc} – accretion rate

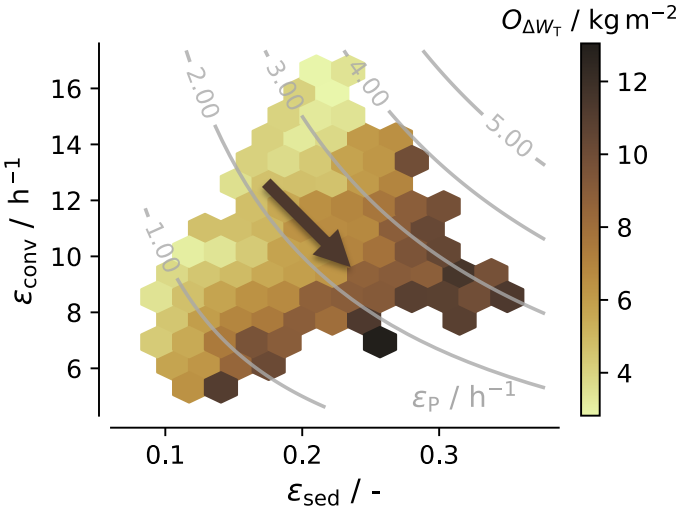
How does spatial organisation affect the conversion and sedimentation efficiency?

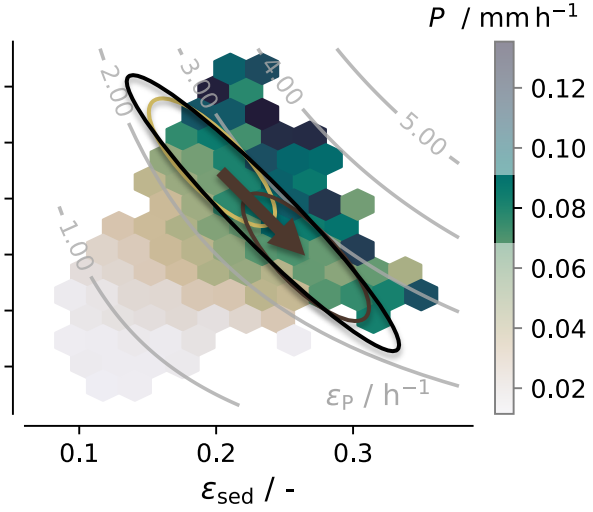


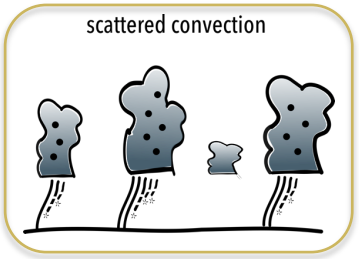
- As organisation strengthens:
  - evaporation is reduced so that more rain reaches the ground
  - cloud condensate is less efficiently converted to rain

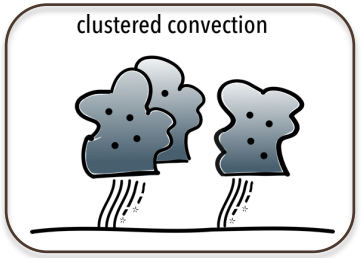
$O_{\Delta W_T}$ – organisation metric

The pathway to precipitation differs with spatial organisation









- As organisation strengthens:
  - evaporation is reduced so that more rain reaches the ground
  - cloud condensate is less efficiently converted to rain

Organisation can buffer rain development.

$O_{\Delta W_T}$ – organisation metric

How does organisation affect the sedimentation efficiency of rain?

$$\underbrace{\epsilon_{\text{evap}}}_{1-\epsilon_{\text{sed}}} \sim (1-\mathcal{R}_{\text{rain}}) \cdot t_{\text{fall}}^{*} = (1-\mathcal{R}_{\text{rain}}) \cdot \frac{h}{v}$$

raindrop size

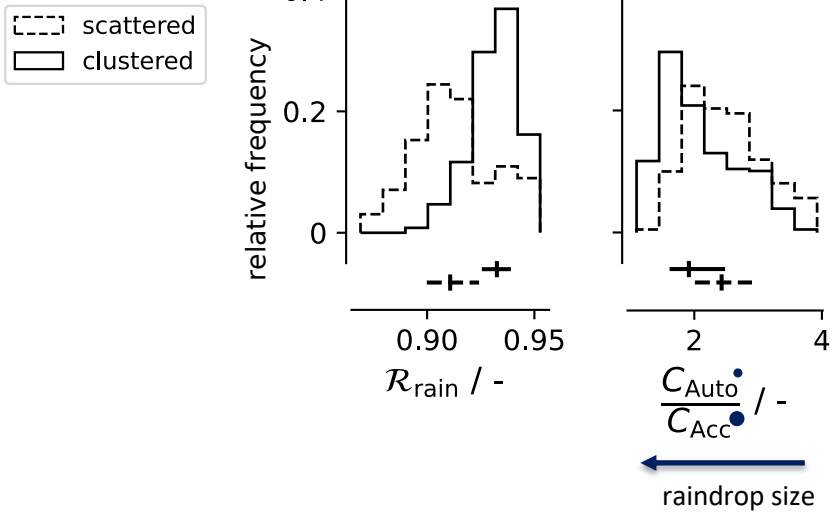
* following Lutsko and Cronin (2018)

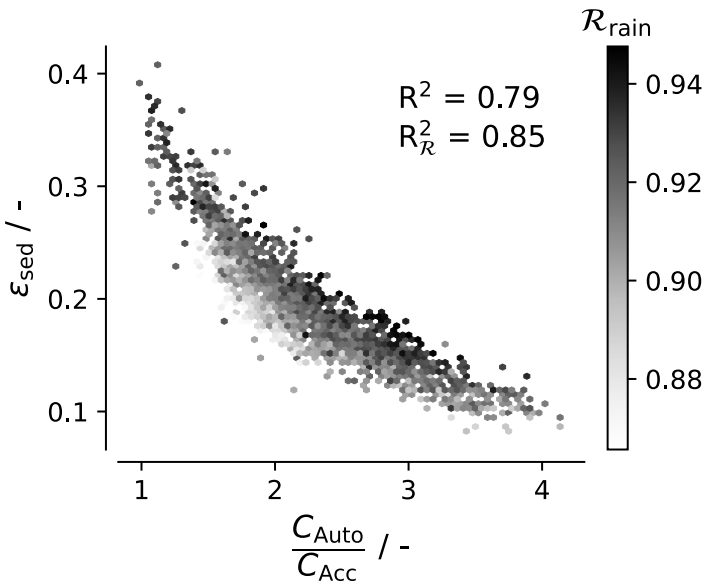
R_{rain} – rain-conditioned relative humidity, t_{fall} – fall time, h – fall height, v – fall velocity

With clustering, rain falls through moister environments, faster

$$\underbrace{\epsilon_{\text{evap}}}_{1-\epsilon_{\text{sed}}} \sim (1-\mathcal{R}_{\text{rain}}) \cdot t_{\text{fall}}^{*} = (1-\mathcal{R}_{\text{rain}}) \cdot \frac{h}{v}$$

raindrop size





… explaining reduced evaporation

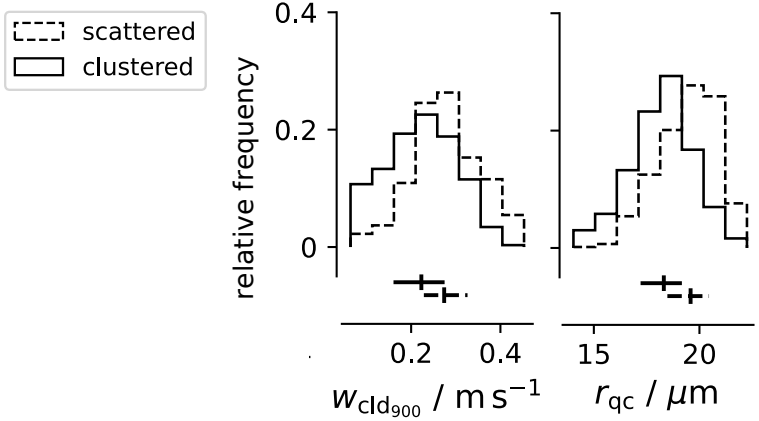
… variations in fall height are of minor importance

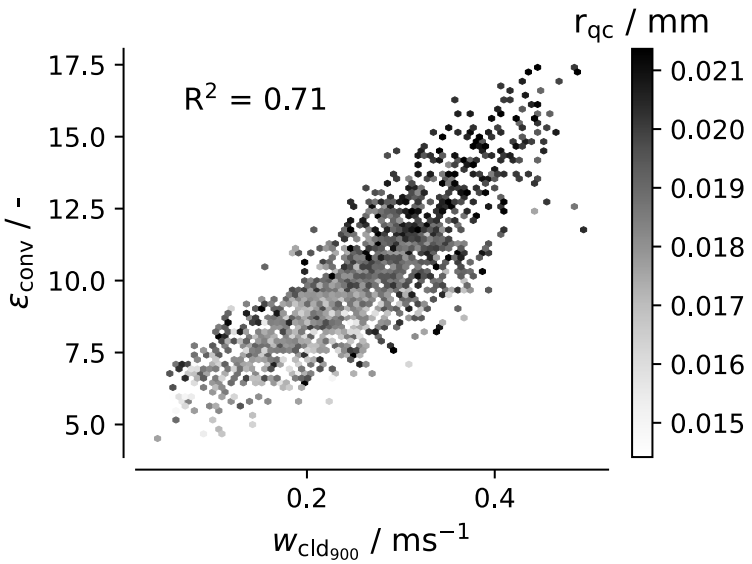
* following Lutsko and Cronin (2018)

h – fall height, v – fall velocity, C_{Auto} – autoconversion rate, C_{Acc} – accretion rate

How does organisation affect the production efficiency of rain?

With clustering, rain forms in weaker vertical motions from smaller cloud droplets





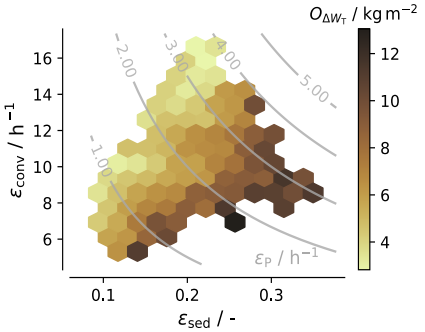
… explaining a reduced conversion efficiency

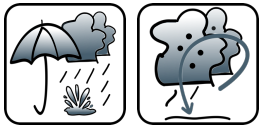
w_{cld900} – 900hPa cloud vertical velocity, r_{qc} – mean cloud droplet radius

2. Does spatial organisation affect the pathway to precipitation in simulated trade-wind convection? How?

The pathway to precipitation decomposed into a production and sedimentation phase differs with organisation:

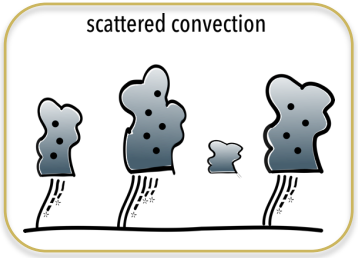
- As organisation strengthens, evaporation is reduced so that more rain reaches the ground, but rain is less efficiently produced,
- associated with changes in local moisture environment, cloud vertical motion & microphysical properties.

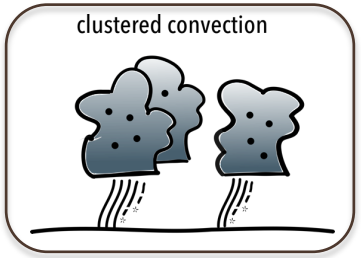




Conclusions

- Close relationship between trade-cumulus precipitation and organisation: Precipitation is almost always associated with clustering.
- Cell number and size of first-order importance for a scene's rain amount, cell size for scene's rain intensity.
- Cells' clustering strength of second-order importance for rain amount across all regimes, important possibly to maintain precipitation in different environments and for high rain intensities.
- Spatial organisation in simulated trade-wind convection affects the pathway to precipitation, altering how efficient rain is produced and how much evaporates,
- associated with changes in cloud vertical motion, the local moisture environment and microphysical properties.
- Rich relationship between precipitation and spatial organization in the trades – balancing rather than reinforcing?





Thank you!