Spatial organisation affects the pathway to precipitation in simulated trade-wind convection

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Motivation

Field studies and satellite imagery have shown that **trade-wind convection organises into a variety of spatial structures** – often associated with **precipitation development** (Snodgrass et al., 2009; Stevens et al., 2019; Schulz et al., 2021; Radtke et al., 2022). Whereas it is known that precipitation, e.g. via cold pool interactions, can help pattern cloud fields, little attention is paid towards the relationship between spatial organisation and the rain development process. Here, we investigate **whether and how the formation of surface precipitation differs with spatial organisation** in **large-domain hectometer simulations** of the North Atlantic trades (Radtke et al.; in review, see QR code for a preprint).

Simulations and Methods

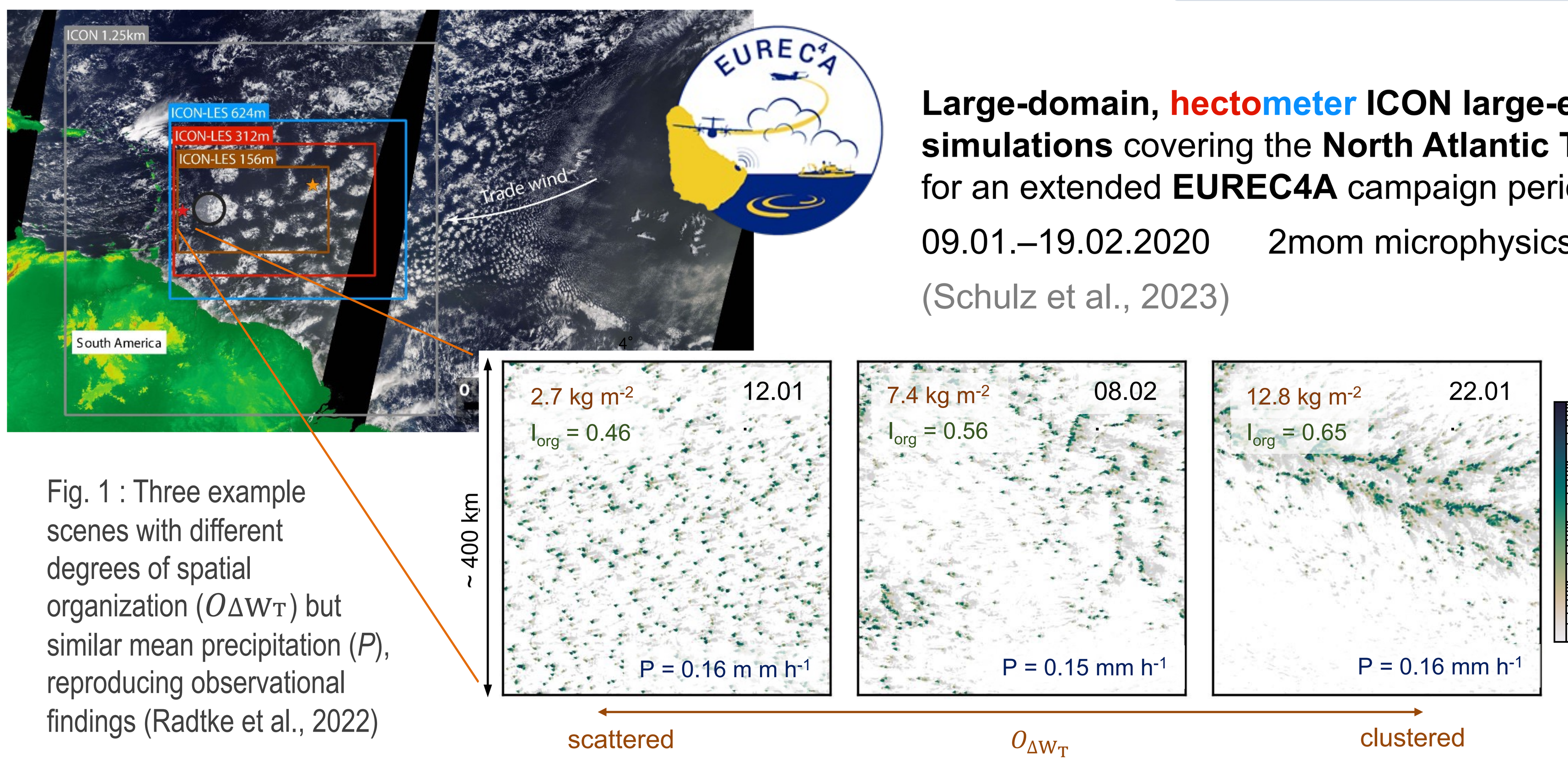

Fig. 1 : Three example scenes with different degrees of spatial organization ($O_{\Delta W_T}$) but similar mean precipitation (P), reproducing observational findings (Radtke et al., 2022)

Large-domain, hectometer ICON large-eddy simulations covering the North Atlantic Trades for an extended **EUREC4A** campaign period

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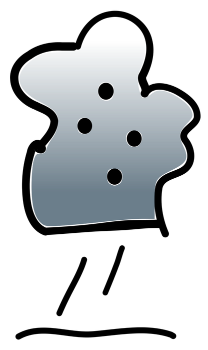
(Schulz et al., 2023)

We **decompose the formation of surface precipitation** into **two phases**:

(following Langhans et al., 2015)



Production: cloud $\xrightarrow{C_R}$ rain, $= C_{Auto} + C_{Acc}$

Sedimentation: rain falls towards the ground while some if it evaporates

P – Precipitation
W_L – Cloud liquid water path

C_R – rain production rate
C_{auto} – autoconversion rate
C_{acc} – accretion rate

and define:

Conversion Efficiency $\epsilon_{conv} = \frac{C_R}{W_L}$

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

Precipitation Efficiency $\epsilon_P = \frac{P}{W_L}$

***Do* the production and sedimentation efficiencies of rain differ with organisation?**

If so, *why* do they differ with organisation?

Results

When organisation strengthens, rain is *less* efficiently produced and sediments *more* efficiently

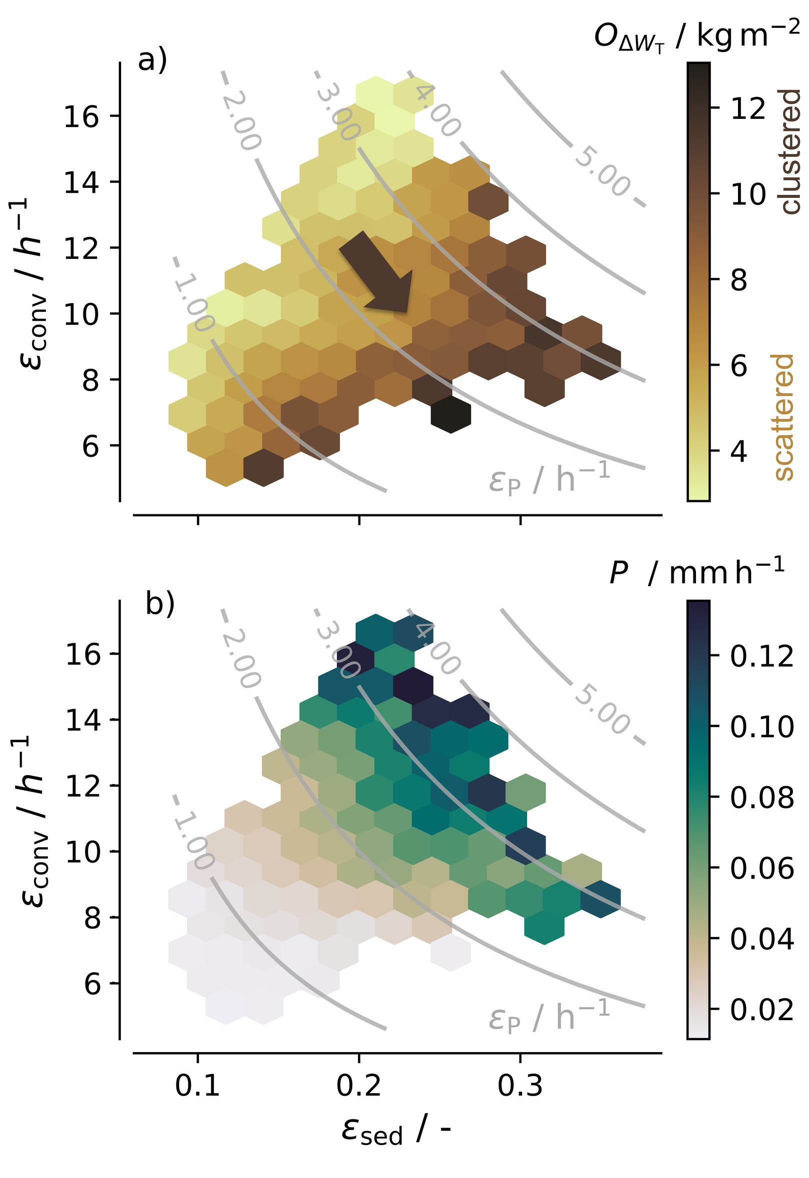


Fig. 3: How a) the degree of organisation and b) precipitation varies with conversion, sedimentation and precipitation efficiency.

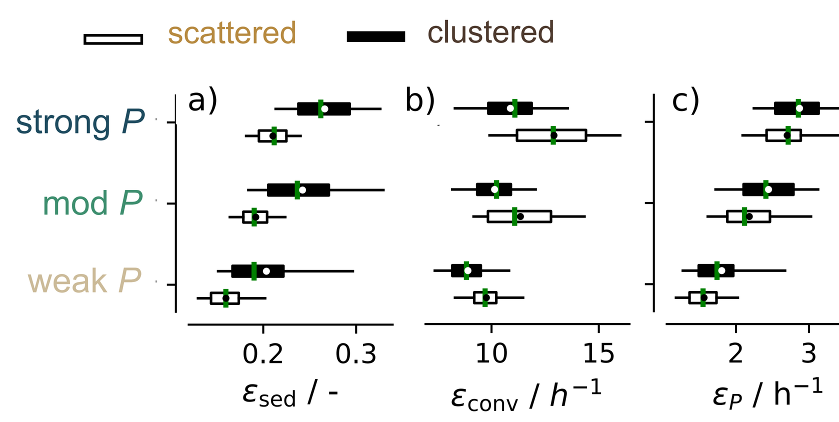


Fig. 4: Sedimentation, conversion and precipitation efficiency in scattered compared to clustered scenes for three precipitation regimes.

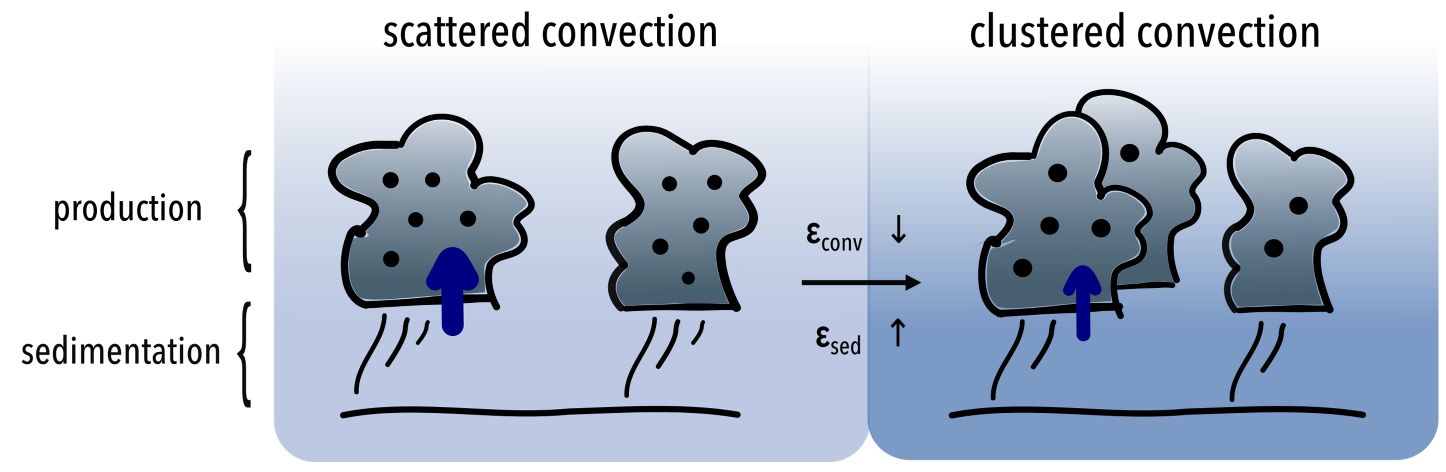


Fig. 2: Illustration of how organisation in the LES affects the formation of surface precipitation decomposed into a production and sedimentation phase.

In **clustered compared to scattered convection**:

- ϵ_{conv} decreases, **cloud condensate is less efficiently converted** (Fig. 3, 4b),
- ϵ_{sed} increases, **evaporation is reduced so that more rain reaches the ground** (Fig. 3, 4a).

> Opposing effects: The **pathway to precipitation differs with organisation**.

Organisation weakly affects how efficiently it precipitates in total (ϵ_P varies independently, Fig. 3, 4c).

As **underlying causes**, our analyses suggest that in clustered compared to scattered convection:

- rain falls through a **locally more humid environment** (Fig. 5a) > increase in ϵ_{sed}
- **raindrops** are likely **larger** as **accretion** contributes more to rain production (Fig. 5b) > increase in ϵ_{sed}
- rain forms in **weaker cloud vertical motions**, from **smaller mean cloud droplets** (Fig. 5c, d) > decrease in ϵ_{conv}

Changes in these properties explain large parts of the variability in ϵ_{conv} and ϵ_{sed}.

Organisation modulates the local moisture environment, cloud vertical motion & microphysical properties

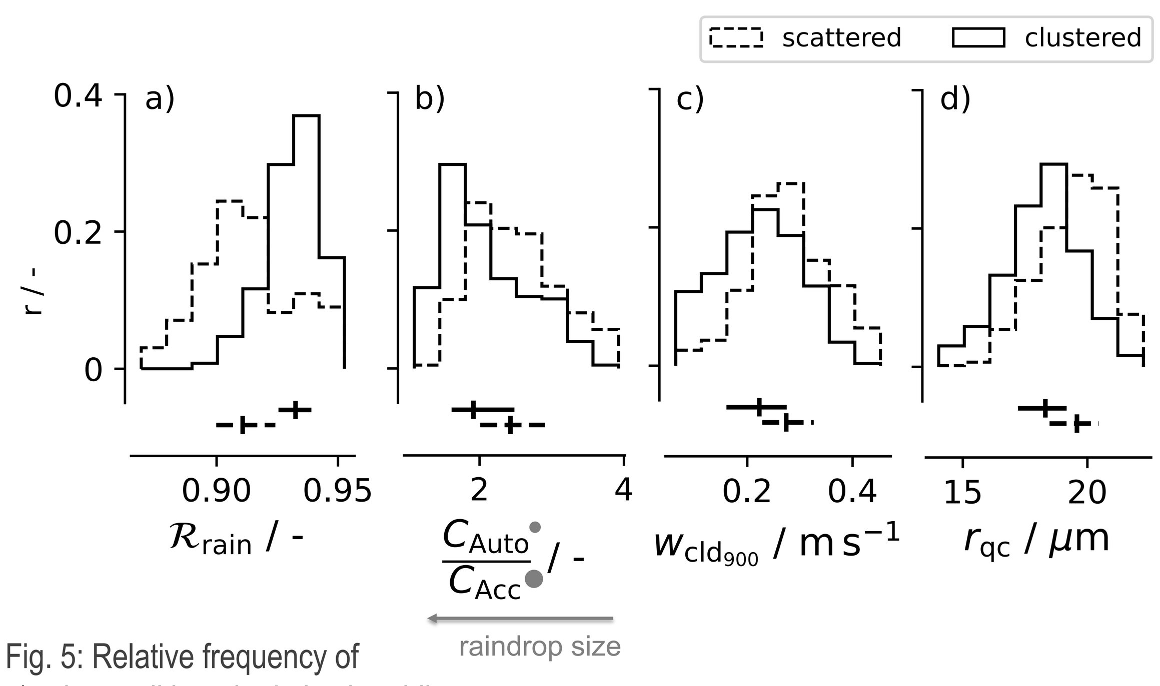


Fig. 5: Relative frequency of a) rain-conditioned relative humidity, b) ratio of autoconversion to accretion, c) cloud-conditioned vertical velocity at 900 hPa and d) mean cloud droplet radius in scattered compared to clustered convection.

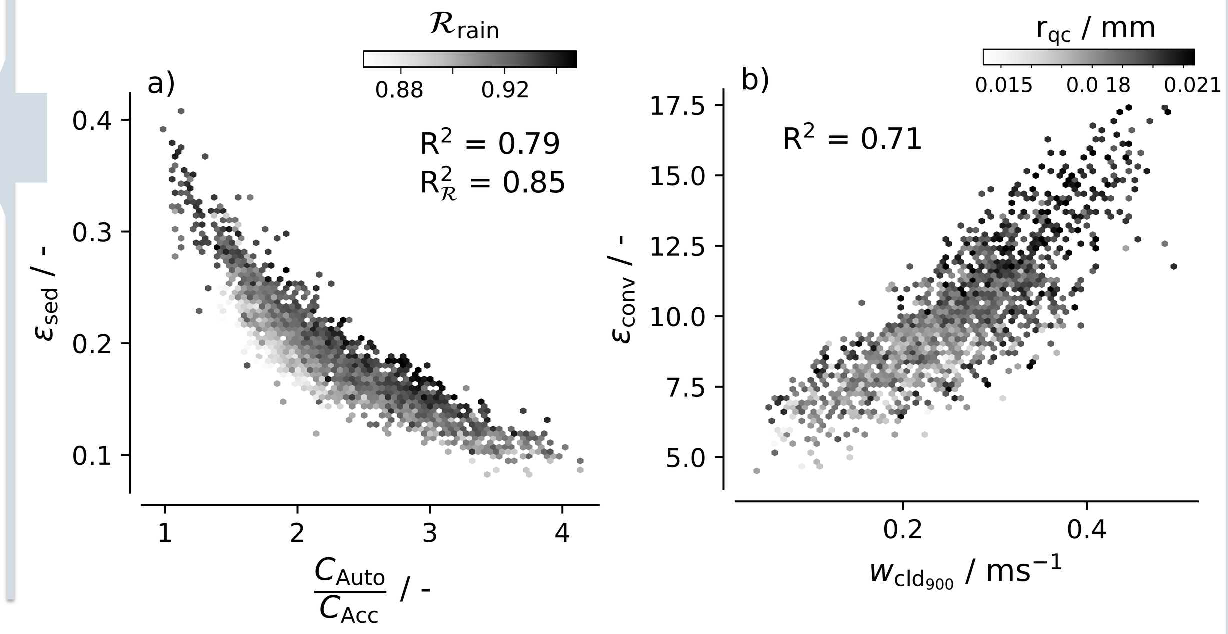


Fig. 6: a) Sedimentation efficiency as a function of the relative importance of autoconversion and accretion. Shading: rain-conditioned relative humidity. b) Conversion efficiency as a function of cloud-conditioned vertical velocity. Shading: mean cloud droplet radius.

Conclusions

- **Organisation** in simulated trade-wind convection **affects the formation of surface precipitation** decomposed into a production and sedimentation phase: In clustered convection, **evaporation is reduced so that more rain reaches the ground** compared to scattered convection, but **rain is less efficiently produced.**
- Organisation has an **opposing, stabilising influence** on rain formation.
- As **underlying causes**, our analyses suggest competing effects associated with organisation modulating **cloud vertical motion**, the **local moisture environment** and **microphysical properties**, possibly related to lifetime effects.

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