Study of the organization of cumulus clouds using LES simulation

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In the context of global warming, the response of trade wind cumuli remains a major uncertainty. Moreover, it has recently been shown that these clouds can be organized in several regimes, from simple cumuli of less than one kilometer to shallow convective systems reaching tens of kilometers. To investigate these distributions, the EUREC4A field campaign used a research aircraft to measure the size of the clouds at their base. In addition, a numerical simulation was used to reproduce different cloud patterns.

Does LES well represent the cloud chord distribution change during the transition from a mesoscale pattern to another one ?

EUREC^{4}A: Elucidating the role of clouds-circulation coupling in climate

20 Jan - 20 Feb 2020, Barbados and Western Atlantic Ocean *[Stevens et al., 2021]*

- **Mesoscale organization of cumulus clouds in trade wind regions**

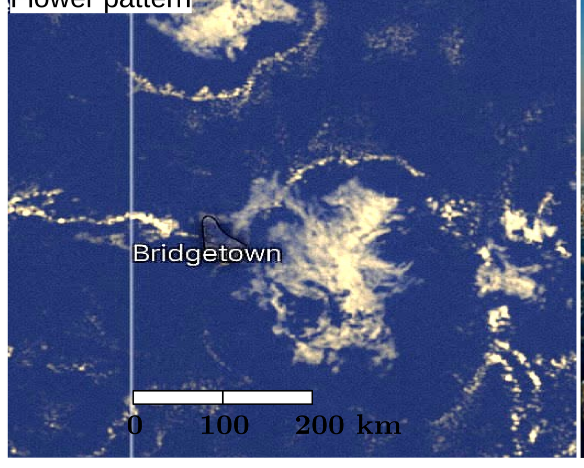
Several patterns have been documented in *Stevens et al., 2020* and *Bony et al., 2020*:

→ Sugar : Dominance of small shallow clouds

→ Gravel : Dominance of small and deeper shallow clouds formed along lines or arcs

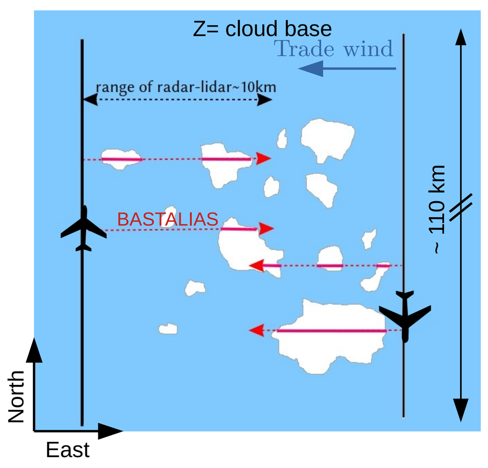
→ Flower : Large and deeper clouds associated with an anvil

Satellite image from GOES ; 3 february 2020 Flower pattern

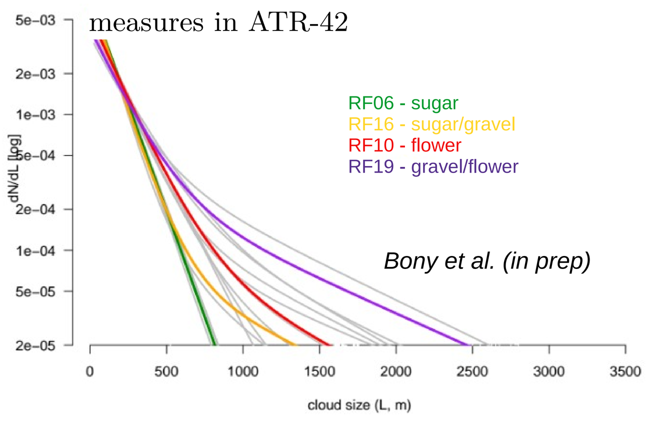


Picture of cold pool and flower from HALO

- **ATR-42 observations at cloud base**

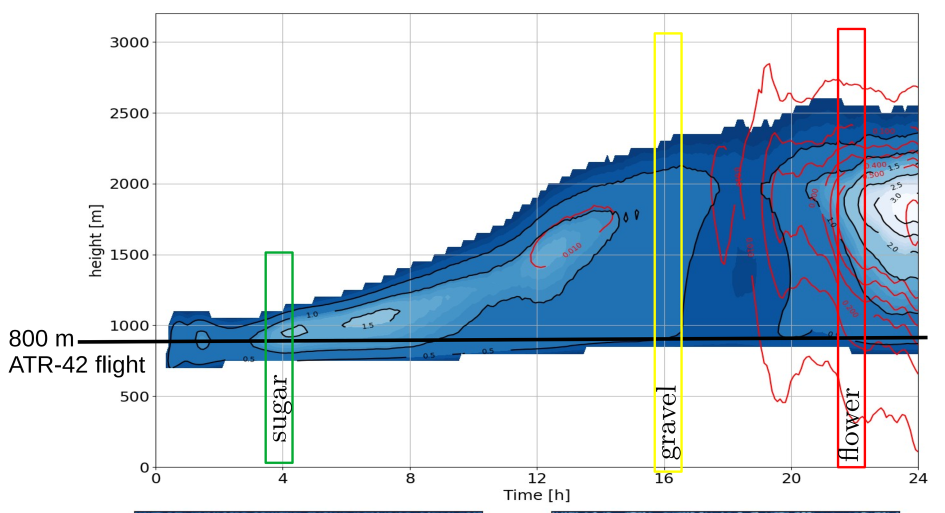


Distribution of cloud chords from lidar/radar measures in ATR-42



SIMULATION: SAM lagrangian Large-Eddy simulation of the 2-3 February 2020

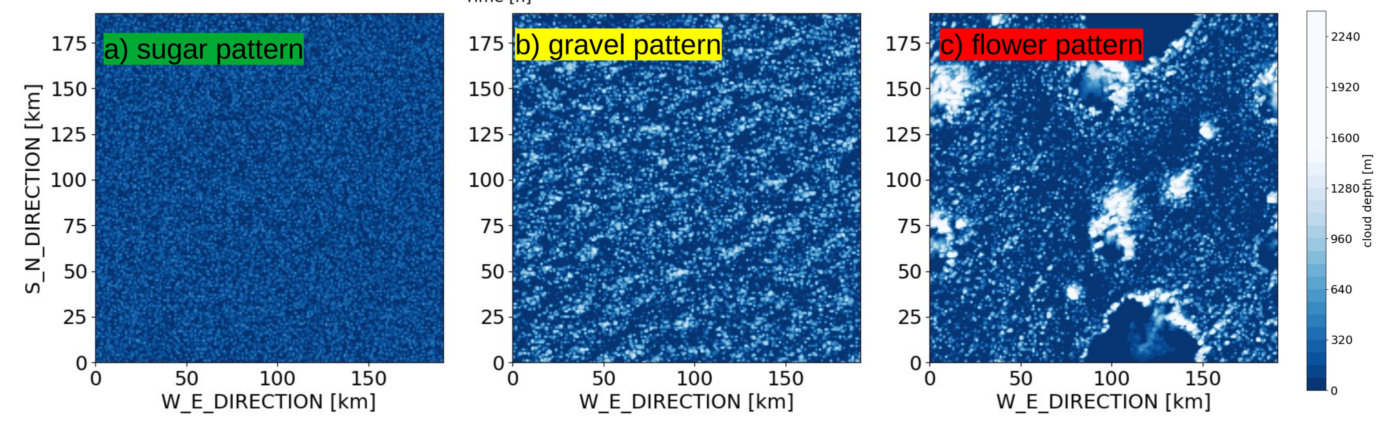
Narenpitak et al. (2021) have simulated the transition between sugar to flowers pattern with a LES. LES simulations can both help test the representativity of the aircraft sampling, and interpret the observational results.



Δx=Δy=2Δz=100 m
domain = 192 x 192 x 4 km²
Duration = 24h, timestep= 15min

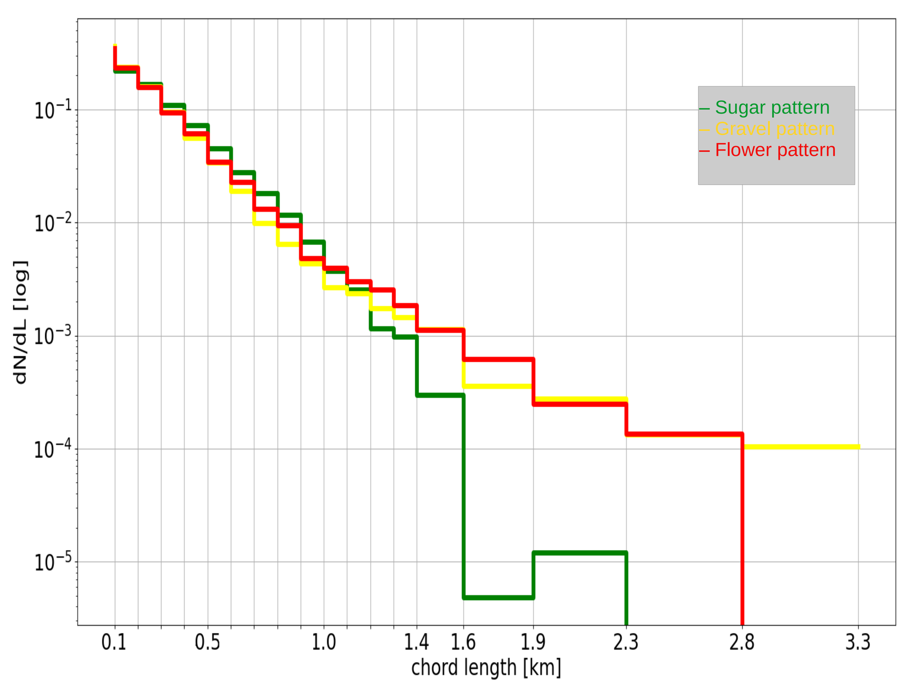
Isotropy of the horizontal clouds size properties

Virtual sampling in LES as ATR-42 at 50-100 m above cloud base ; Racetrack (~100 km) perpendicular to the advective wind



1 - How ATR-42 trajectory is representative of the mesoscale organization?

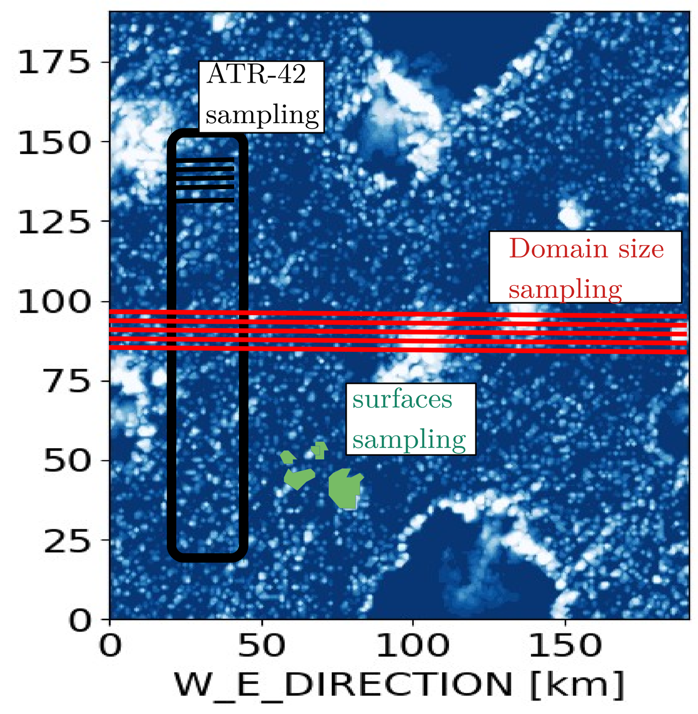
Distribution of cloud's base chords for the ATR-42 sampling in LES for the 3 patterns



In LES as in OBS: dependance of the cloud chord distribution on the mesoscale pattern

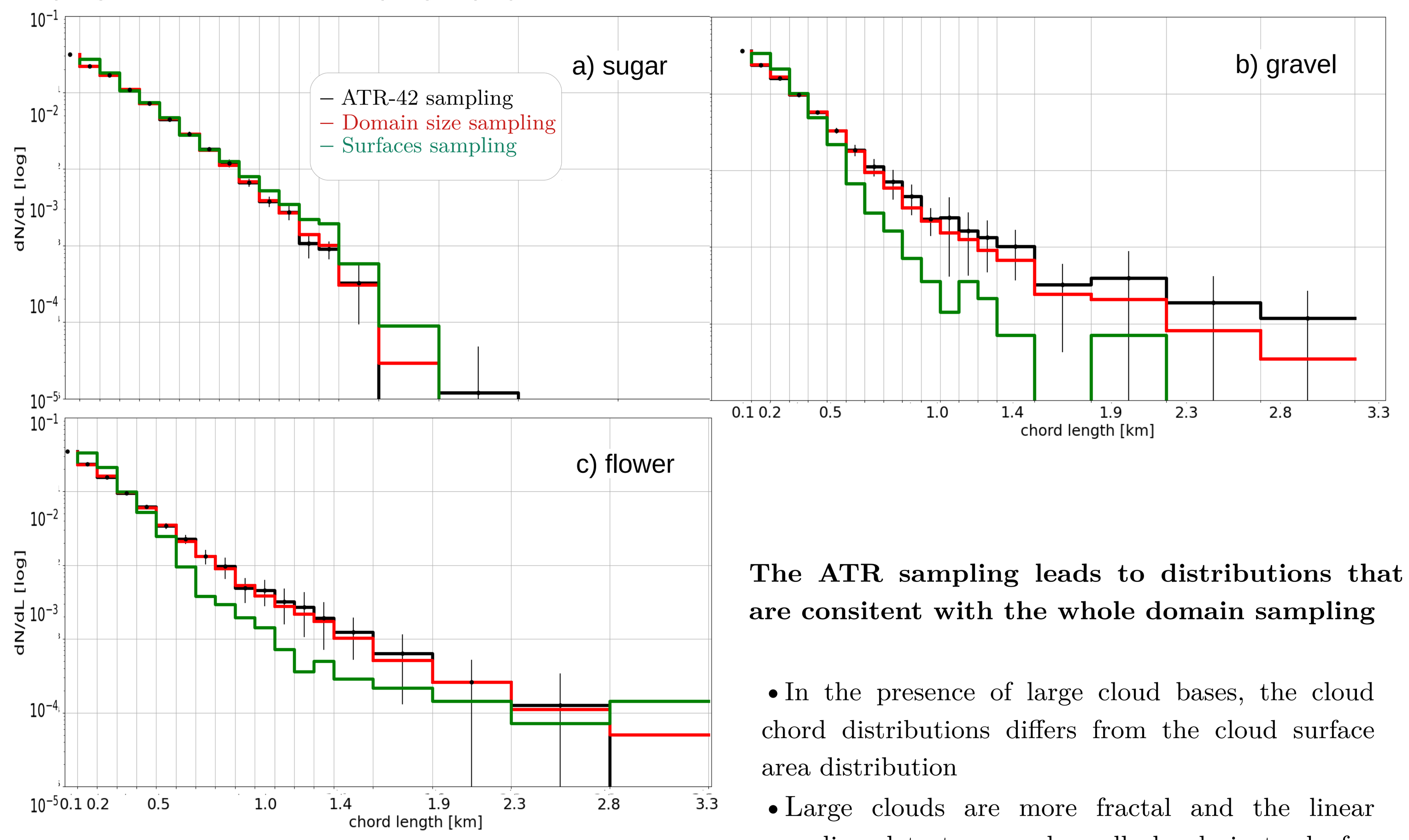
- First cloud mode (d<1km): present in the 3 patterns and representing almost all the sampled clouds.
- Second cloud mode (d>1km) : present in the gravel and flower patterns, with stronger chord lengths for this last one

Test of three methods to compare ATR-chord sampling, full-domain chord sampling or projected cloud area size



Definition of cloudy mesh: LWC > 10^{-2} g.m^{-3}

- Application of cloud identification method *[Maury et al., 2022]* to isolated cloud. ⇒ derivation of equivalent diameter (D_e)
- Cloud chord defined as a sum of meshes transected by artificially reproduced nadir pointing lidar along the racetrack



The ATR sampling leads to distributions that are consitent with the whole domain sampling

- In the presence of large cloud bases, the cloud chord distributions differs from the cloud surface area distribution
- Large clouds are more fractal and the linear sampling detects several small chords instead of a single large chord

2 - How clouds density distribution can be fitted?

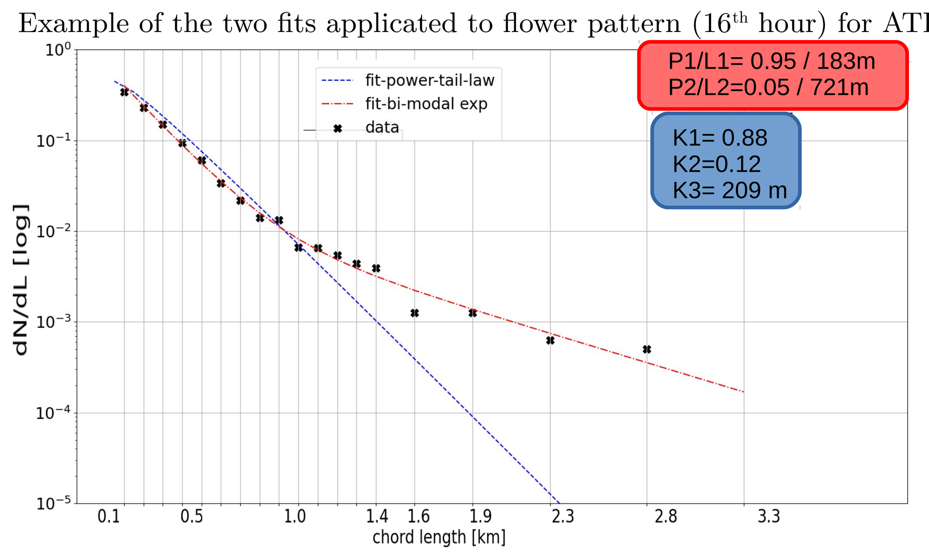
- **Power law with an exponential tail distribution** *[Neggers et al., 2019]*:

$$dN/dL = K_1 L^{K_2} e^{\frac{-L}{K_3}}$$

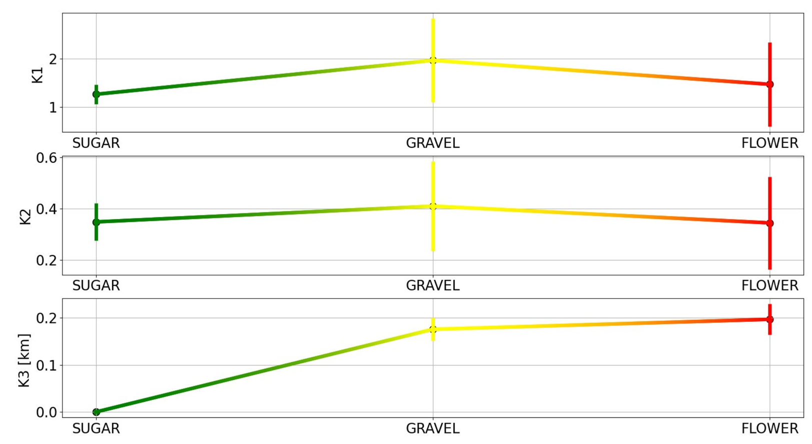
- **Sum of two exponentials distributions** *[Rochetin et al., 2014]*:

$$dN/dL = \frac{P_1}{L_1} e^{\frac{-L}{L_1}} + \frac{P_2}{L_2} e^{\frac{-L}{L_2}}$$

Example of the two fits applicated to flower pattern (16th hour) for ATR data



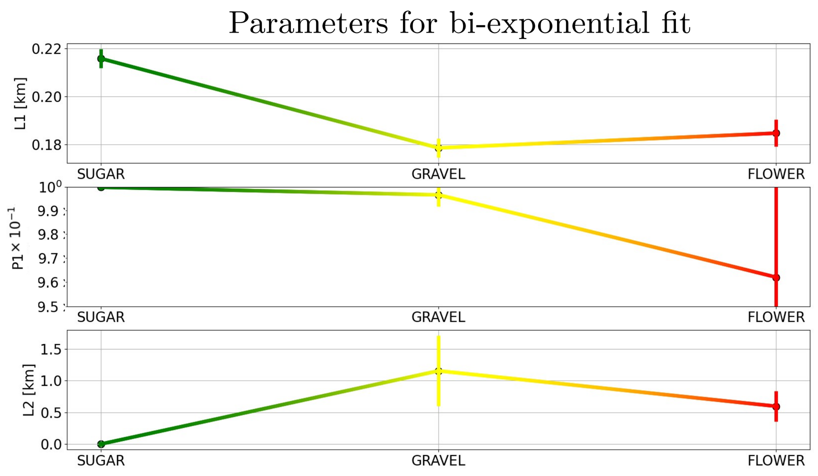
Parameters for power-tail fit



Parameters of power-tail fit consistent with previous study of shallow cumulus:

- For sugar pattern, the fit becomes a simple power law (k3~0)
- For gravel/flower pattern, K3~L1)

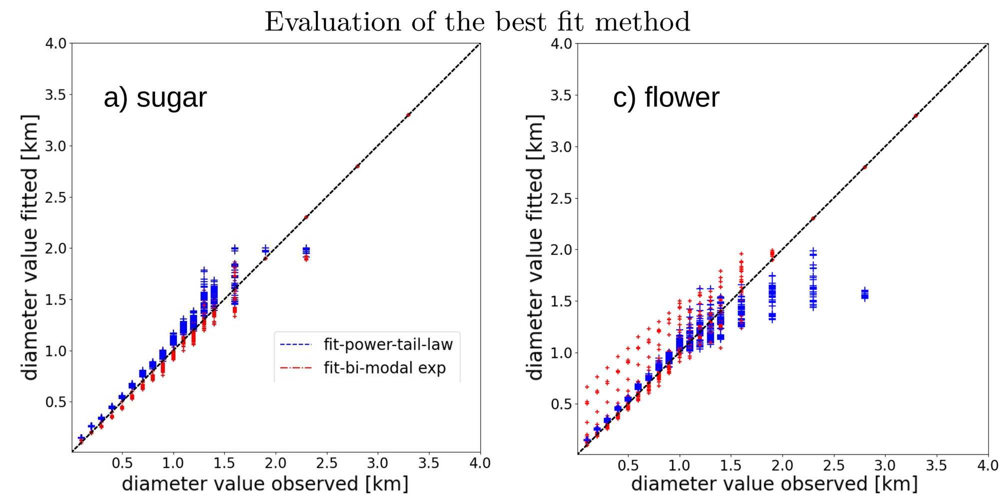
Parameters for bi-exponential fit

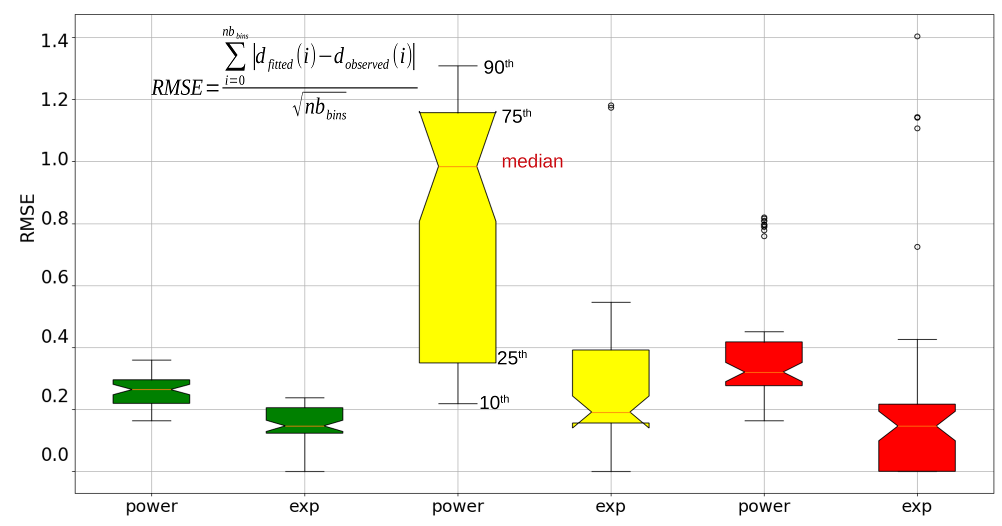


Parameters of bi-exponential fit consistent with EUREC^{4}A ATR-42 observations:

- L1 ~200m (1/4 z_{cloud_base}), L2~600-800m (z_{cloud_base})
- $P1_{flowers}$ ~96%

Evaluation of the best fit method





In the sugar pattern, both types of fits give good values with a slight improvement for the fit with the double exponential, while for the gravel and flower case, the fit with the double exponential is much better, the power tail fit does not represent the second mode correctly.

Conclusion

- Various virtual sampling tests show that the ATR-42 trajectory can accuratly reproduce the mesoscale pattern.
- The cloud chord distributions extracted from the LES reflect the observed influence of the mesoscale organization.
- The best fit to represent the transition is a bi-exponential distribution where the first mode remains quite stable around 20% of the cloud base height, i.e about 200 m-long chords.

Prospects

- Compare the LES outputs with other observations as HALO aircraft or GOES satellite data.
- Caracterize the organization with other parameters as Nearest Neighborg Size and link with thermodynamic characteristics of the mesoscale region (such as cold pools)

References :

Bony et al., 2020 : Sugar, Gravel, Fish, and Flowers: Dependence of Mesoscale Patterns of Trade-Wind Clouds on Environmental Conditions

Maury et al., 2022 : Use of large-eddy simulations to design an adaptive sampling strategy to assess cumulus cloud heterogeneities by remotely piloted aircraft

Narenpitak et al., 2021 : From Sugar to Flowers: A Transition of Shallow Cumulus Organization During ATOMIC

Neggers et al., 2019 : Power-Law Scaling in the Internal Variability of Cumulus Cloud Size Distributions due to Subsampling and Spatial Organization

Rochetin et al., 2014 : Deep Convection Triggering by Boundary Layer Thermals. Part I: LES Analysis and Stochastic Triggering Formulation

Stevens et al., 2020 : Sugar, gravel, fish and flowers: Mesoscale cloud patterns in the trade winds

Stevens et al., 2021 : EUREC4A

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