To what extent does the radiative effect of low-level clouds depend on an accurate description of their vertical structure?

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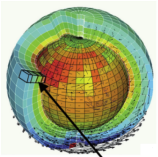
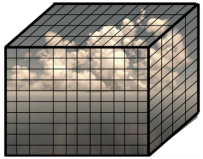
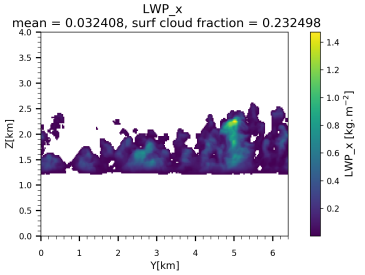
Jean-Louis Dufresne
Najda Villefranque

Improvement and calibration of clouds in models

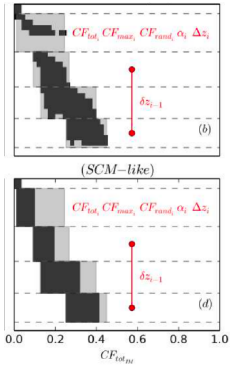
Aim of the current work





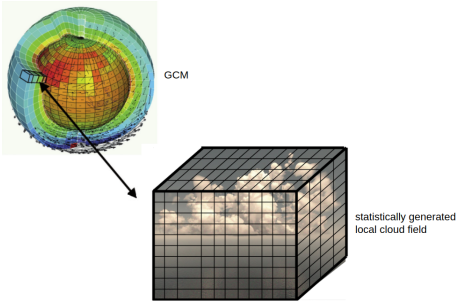


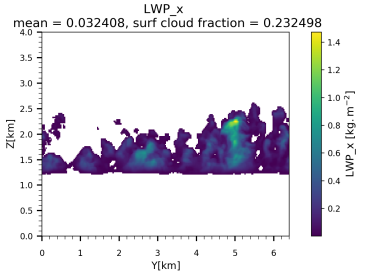
ARMCumulus (h=10) LES

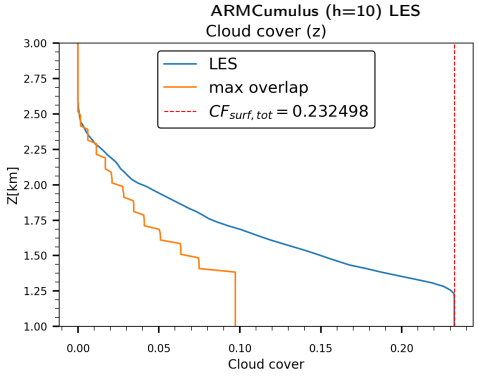


- Overlap
- Subgrid variability

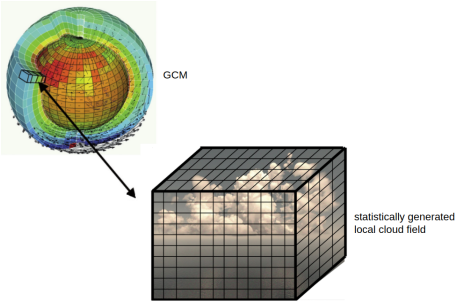
Aim of the current work

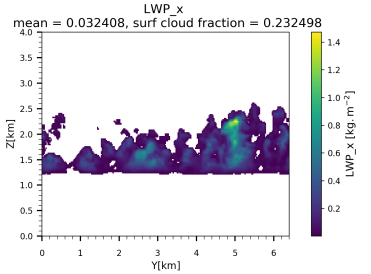


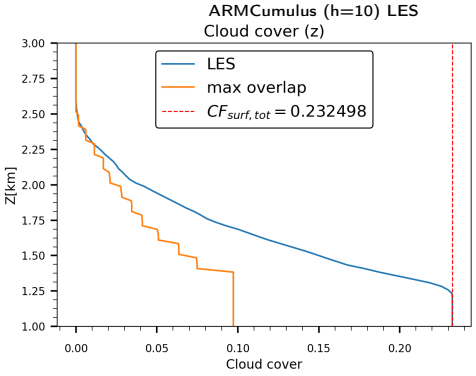




Aim of the current work

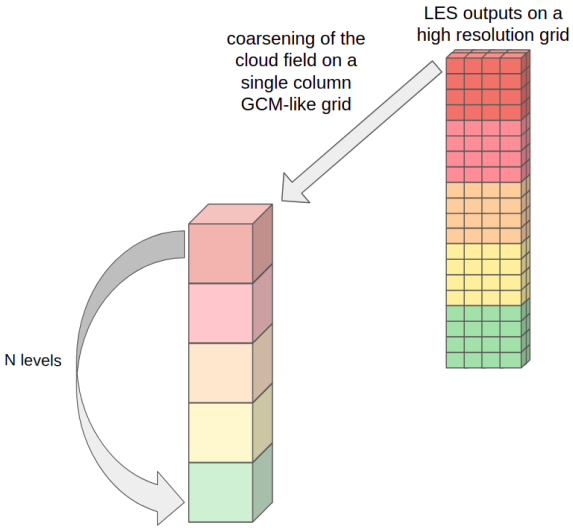






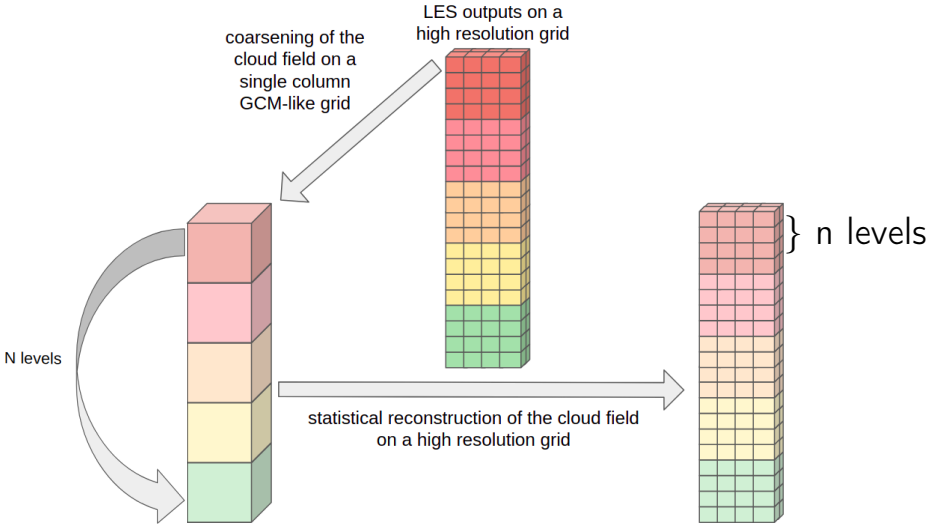
With a given cloud cover CF_{surf}, what is the effect of subgrid heterogeneity and overlap on the radiative properties of shallow clouds ?

Methodology



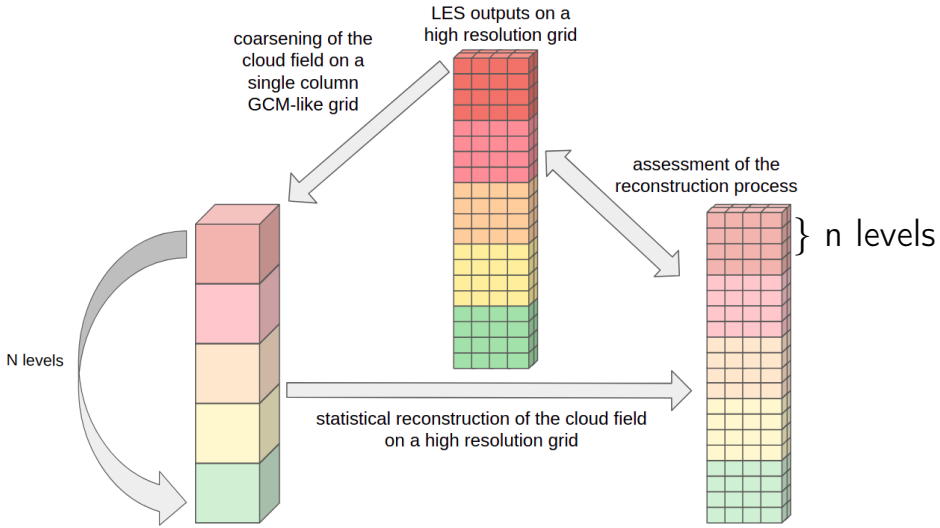
Sub-grinding a $1 \times 1 \times N$ column to a $N_x \times N_y \times (N \times n)$ one.

Methodology



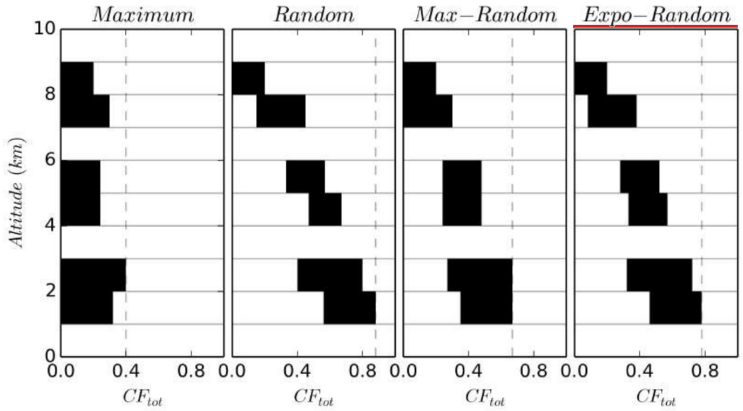
Sub-grinding a $1 \times 1 \times N$ column to a $N_x \times N_y \times (N \times n)$ one.

Methodology



Sub-grinding a $1 \times 1 \times N$ column to a $N_x \times N_y \times (N \times n)$ one.

Inter-layer overlap schemes

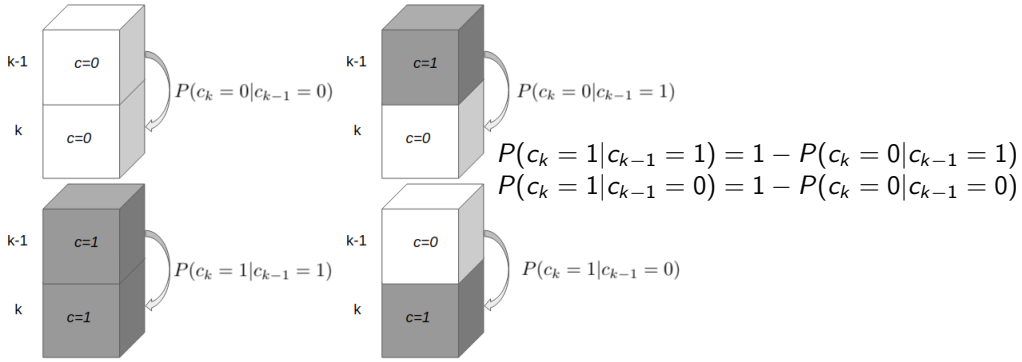


Four different overlap assumptions *Hogan & Illingworth,2000*

Overlap as a Markov chain

The cloud fraction overlap is a product of conditional probabilities :

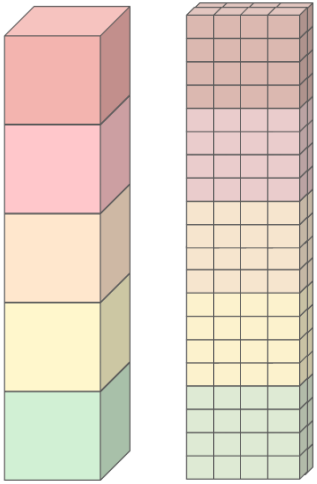
$$P(C=(c_k)_{k=1,N}) = P(C_1 = c_1) \prod_{k=2}^{N} P(C_k = c_k \mid C_{k-1} = c_{k-1})$$

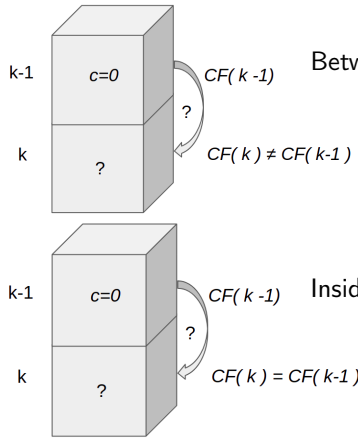


$$P(c_k = 1|c_{k-1} = 1) = 1 - P(c_k = 0|c_{k-1} = 1)$$
$$P(c_k = 1|c_{k-1} = 0) = 1 - P(c_k = 0|c_{k-1} = 0)$$

Exp-rand overlap parameter α and sub-griding

$$CF_{tot}(k,k-1) = \alpha CF_{max}(k,k-1) + (1-\alpha) CF_{rand}(k,k-1)$$





Between coarse grid layers :

$$P_{diff,k,k-1}(\alpha)$$

Inside coarse grid layers :

$$P_{id,k,k-1}(\alpha)$$

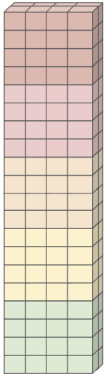
Determining α to match the total cloud cover

Probability to generate a free-sky sub-column :

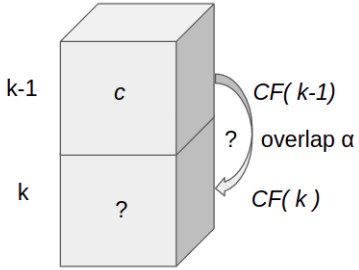
$$P_{\emptyset}(\alpha, N, n, CF) = \prod_{k=1}^{N} \left[P_{\text{diff},k}(0|0) \prod_{1}^{n-1} P_{id,k}(0|0) \right]$$

$$CF_{surf,ERO} = 1 - P_{\emptyset}(\alpha, N, n, CF)$$

$$\boxed{\alpha = P_{\emptyset}^{-1}(1 - CF_{surf,LES}, N, n, CF)}$$



Generating a subcolumn cloud fraction knowing α

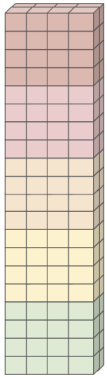


▽ **maximum overlap** (with probability α) :

$$\begin{cases} P_{max}(1 \mid 1) = \dfrac{CF_k + CF_{k-1} - \max(CF_k, CF_{k-1})}{CF_{k-1}} \\ P_{max}(1 \mid 0) = \dfrac{\max(CF_k, CF_{k-1}) - CF_{k-1}}{CF_{k-1}} \end{cases}$$

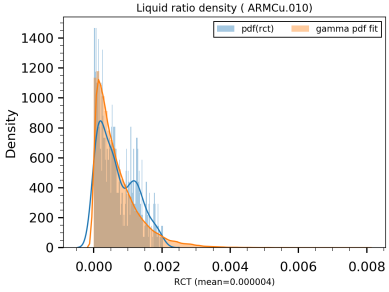
▽ **random overlap** with probability $(1 - \alpha)$:

$$P_{rand}(c_k = 1) = P_{rand}(1 \mid 0) = P_{rand}(1 \mid 1) = CF_k$$

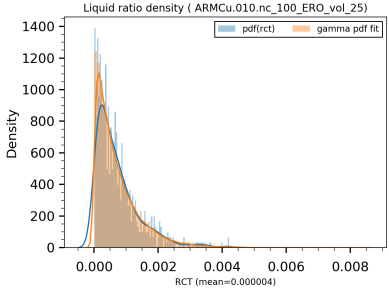


Liquid Water Content : γ-distributions

$\rightarrow$ Quantile correlation for adjacent layers, with α. (Raisanen et al, 2004)



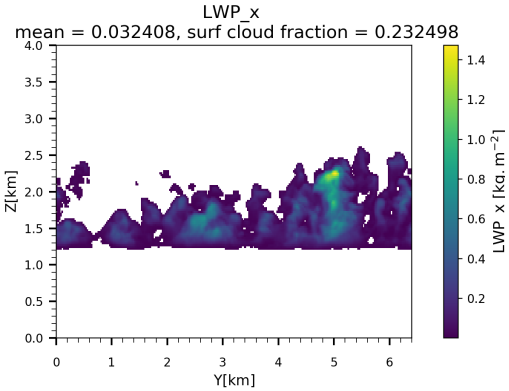
Pdf of the LWC
z=2.25km



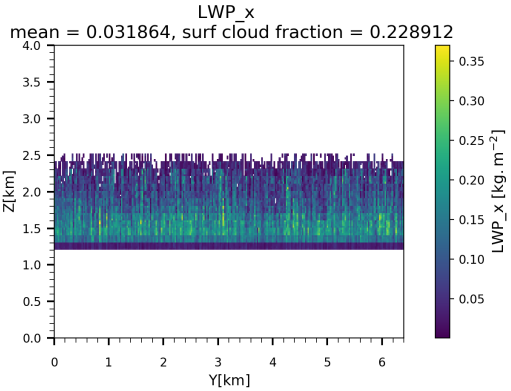
Pdf of the LWC
after generation z=2.25km

$$f(x,a) = \frac{x^{a-1}\exp(-x)}{\Gamma(a)} \qquad \gamma(x,a,loc,\beta) = f(\frac{x-loc}{\beta},a)$$

Conservation of the vertical profile of liquid water content and total cloud cover, but no horizontal structure.

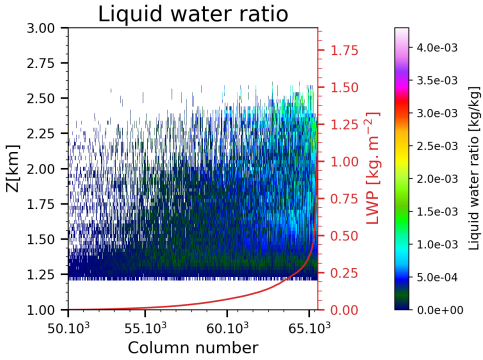


LWP integrated horizontally
LES

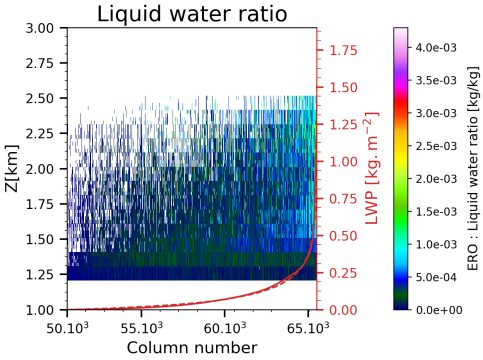


LWP integrated horizontally
after ERO generation

Distribution of the Liquid Water Path

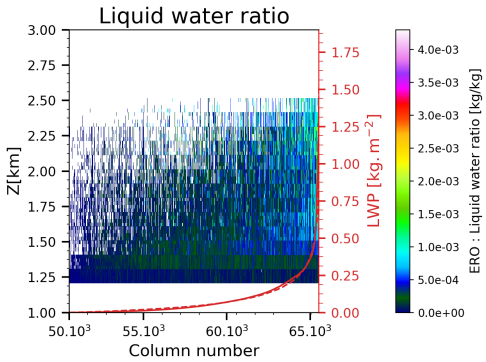


LWC, columns are sorted by LWP (LES)

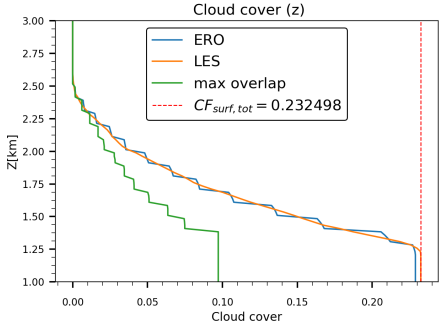


LWC, columns are sorted by LWP (after ERO generation)

Distribution of the Liquid Water Path and vertical cloud cover distribution

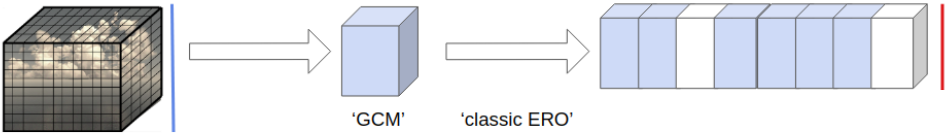


LWC, columns are sorted by LWP after ERO generation

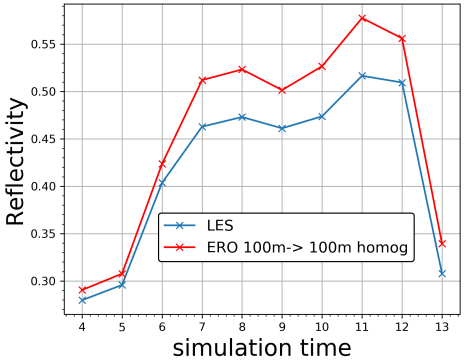


Vertical cloud cover : LES vs max overlap vs ERO

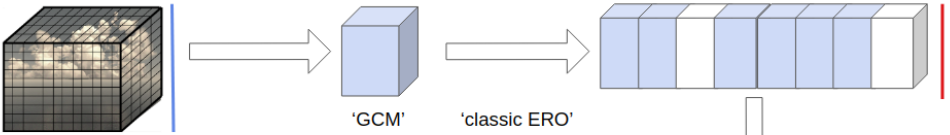
Radiative transfer : Impact on the SW reflectivity

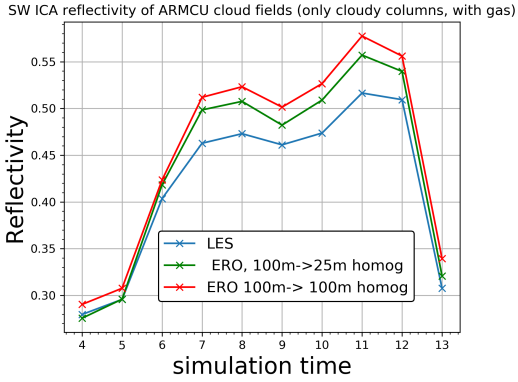


SW ICA reflectivity of ARMCU cloud fields (only cloudy columns, with gas)

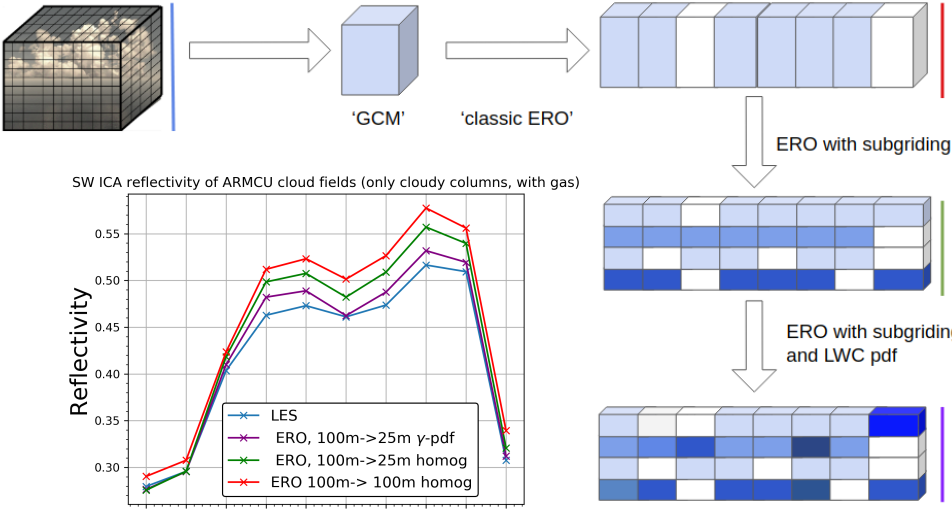


Radiative transfer : Impact on the SW reflectivity





Radiative transfer : Impact on the SW reflectivity



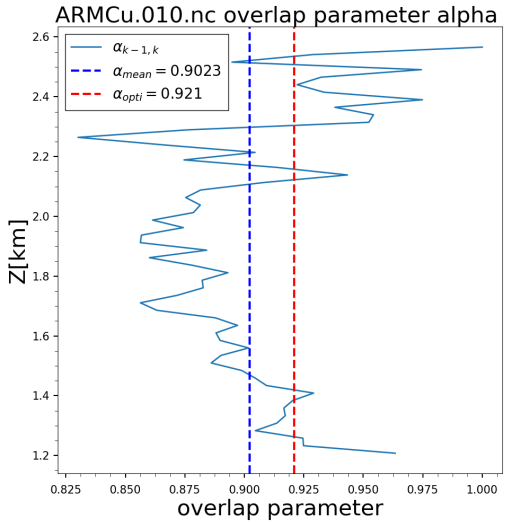
Conclusion

- The overlap parameter is computed to match the total cloud cover.
- This parameter allows a good reproduction of the vertical distribution of liquid water and cloud fraction.
- Vertical subgriding and liquid water distributions allows a better representation of the water content and of radiative properties (error reduced from 10% to 3%).
- This work as been done with the Independent Column Approximation, future work would be to consider 3D effects.

Thank you !

Annex

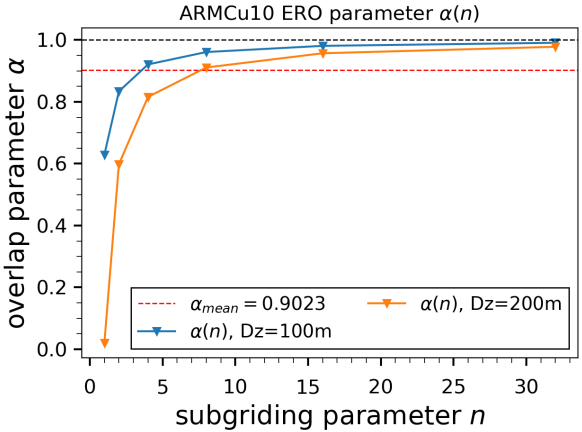
Two different overlap parameter ? α_{LES} vs α :



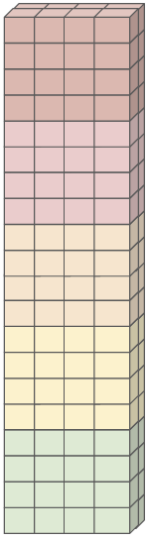
Overlap parameter computed from the LES : $\alpha_{k-1,k}$

$$CF_{tot} = \alpha CF_{max} + (1 - \alpha) CF_{rand}$$

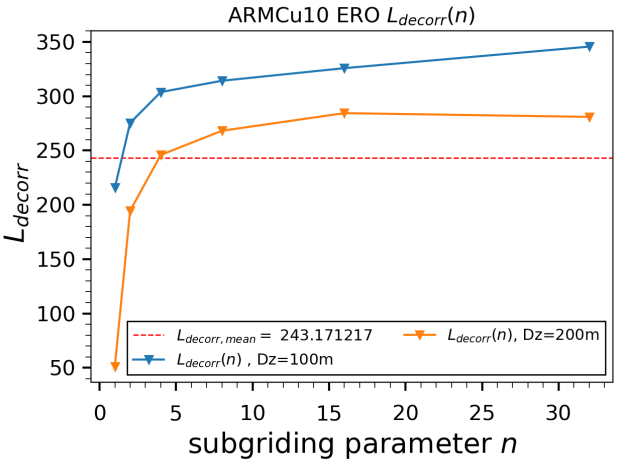
Two different overlap parameter ? α_{LES} vs α :



$$\alpha = P^{-1}(1 - CF_{surf,LES}, N, n, \bar{CF})$$



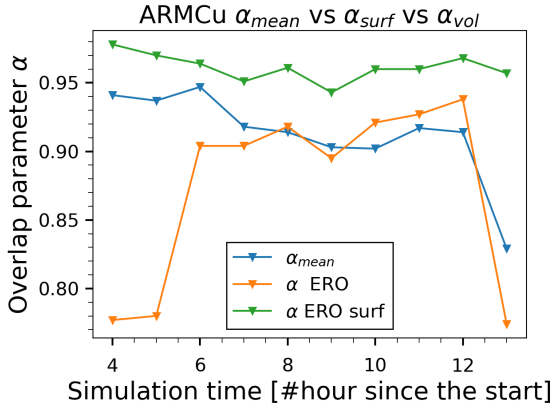
Decorrelation length

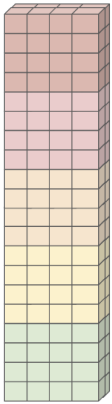


$$\alpha_{k,l} = \exp\left(-\int_{z_k}^{z_l} \frac{\mathrm{d}z}{L_{\mathrm{cf}}(z)}\right)$$

CF_{vol} vs CF_{surf} ?

$$c_{i,j,k} = \begin{cases} 0, & \text{for } x_{i,j,k} \leq 1 - \bar{CF}(k\%N) \quad (\text{ clear }) \\ 1, & \text{for } x_{i,j,k} > 1 - \bar{CF}(k\%N) \quad (\text{ cloudy }) \end{cases}$$





Overlap parameter α after volume or cloud cover dependant generation