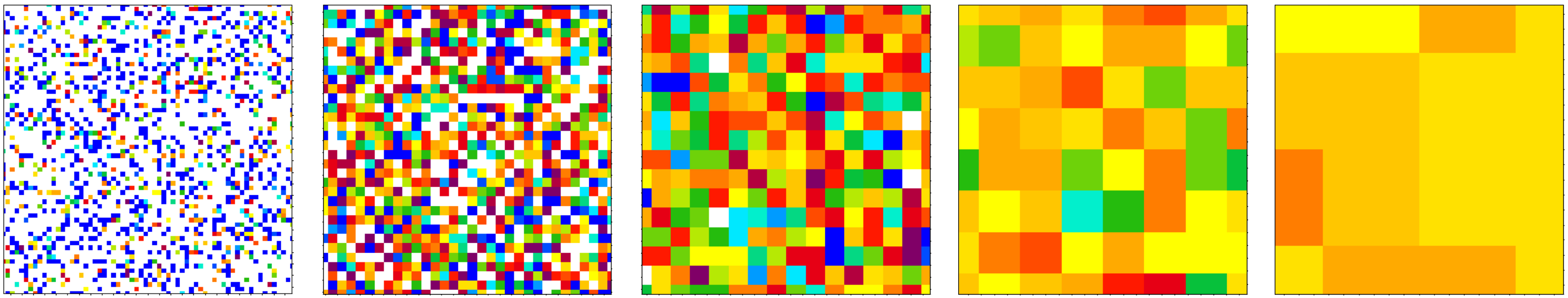
Shallow cumuli ensemble statistics for development of a stochastic parameterization



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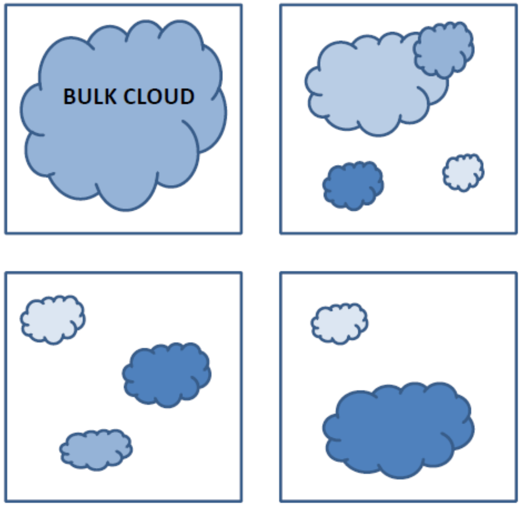
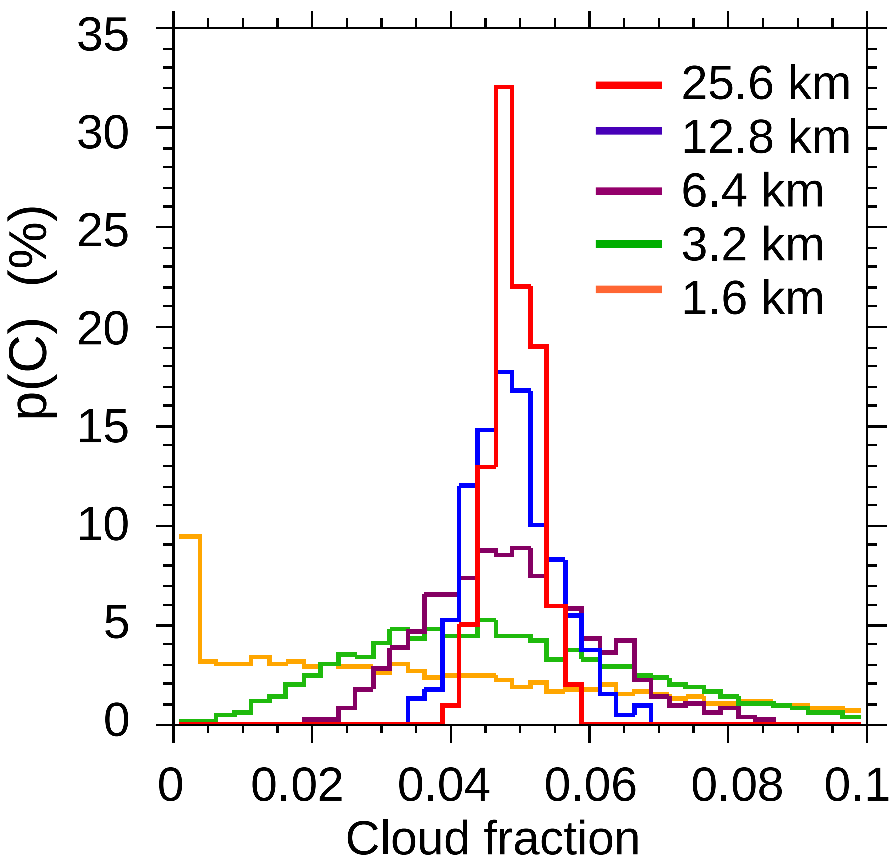
Clouds and Convection (Hans Ertel Research Group)

Stochastic approach to represent convective variability

- conventional schemes assume a deterministic relation
  - different realisations of subgrid convection can correspond to a given large scale forcing

(Plant and Craig, 2008)

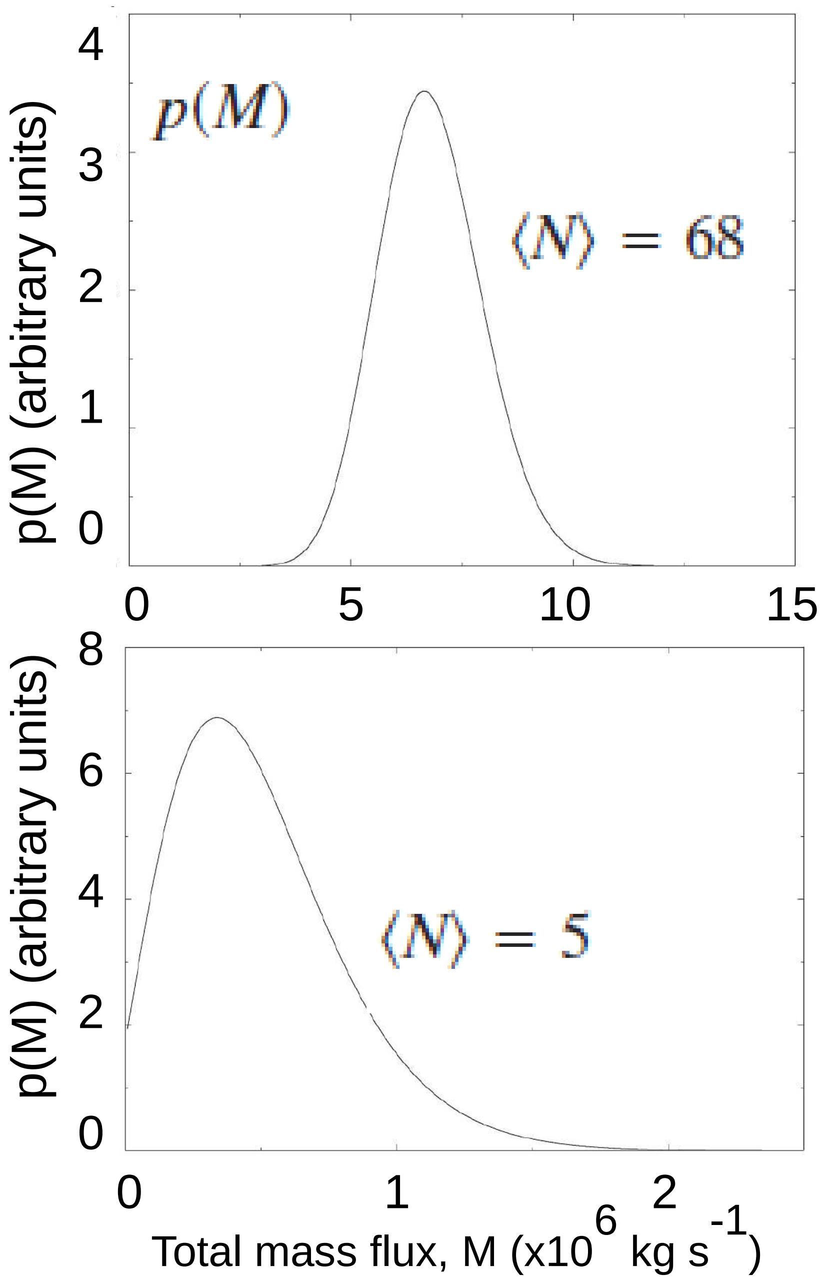




- variability of convection is scale-dependent
  - smaller grid box → fewer clouds → higher variability

Fig: Coarse-grained LES

Gibbs canonical ensemble: generalization to cloud fields



- **Fluctuations in an Equilibrium Convective Ensemble** (*Craig and Cohen, 2006)*

number of clouds in an area – *n:*

$$p_N(n) = \frac{\langle N\rangle^n e^{-\langle N\rangle}}{n!} \quad \text{for} \quad n = 0, 1, \ldots .$$

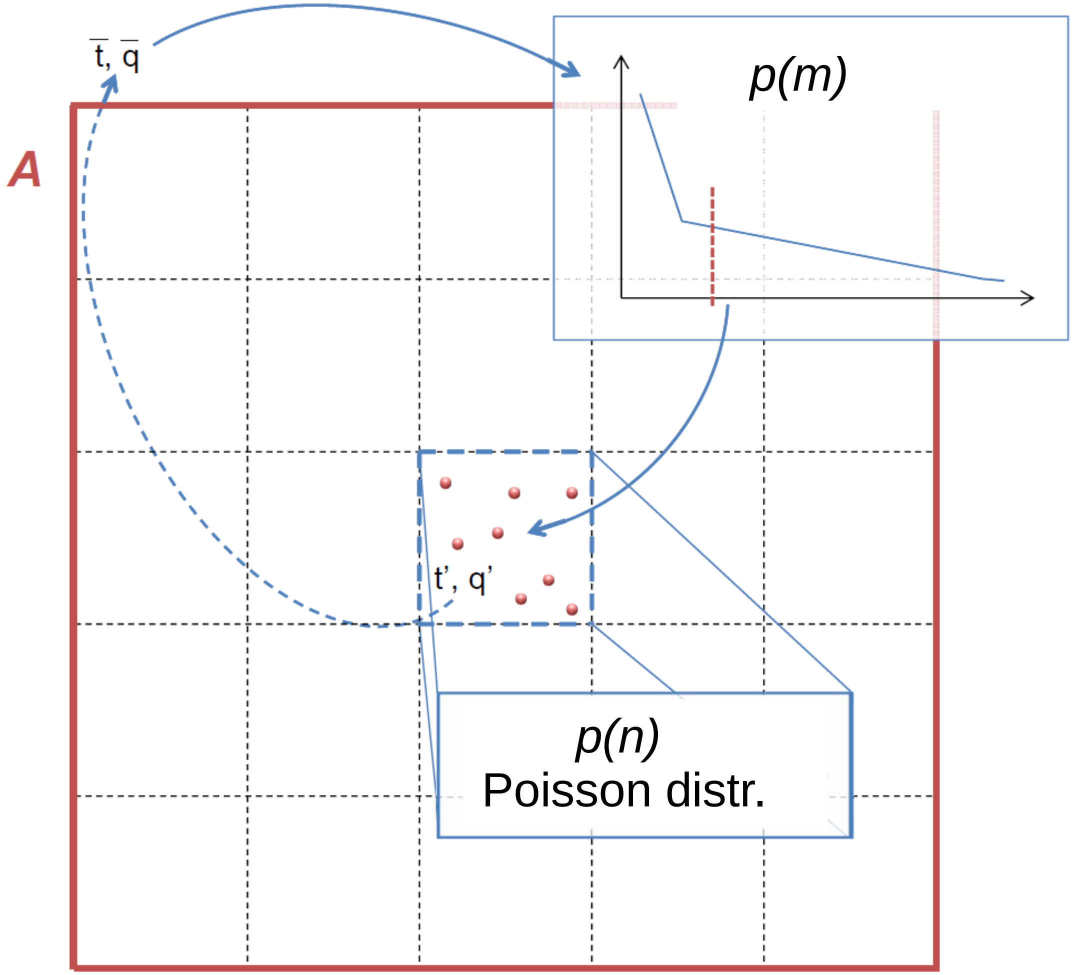
cloud mass flux – *m:*

$$p(m)\, dm = \frac{1}{\langle m\rangle} e^{-m/\langle m\rangle}\, dm$$

PDF of **total mass flux** (in a grid box), *M*:

$$p(M) = \left(\frac{\langle N\rangle}{\langle m\rangle}\right)^{1/2} e^{-\langle N\rangle} M^{-1/2} e^{-M/\langle m\rangle} I_1\left(2\sqrt{\frac{\langle N\rangle}{\langle m\rangle} M}\right).$$

Parameterization framework



- ***Plant and Craig (2008)*** parameterization of deep convective clouds

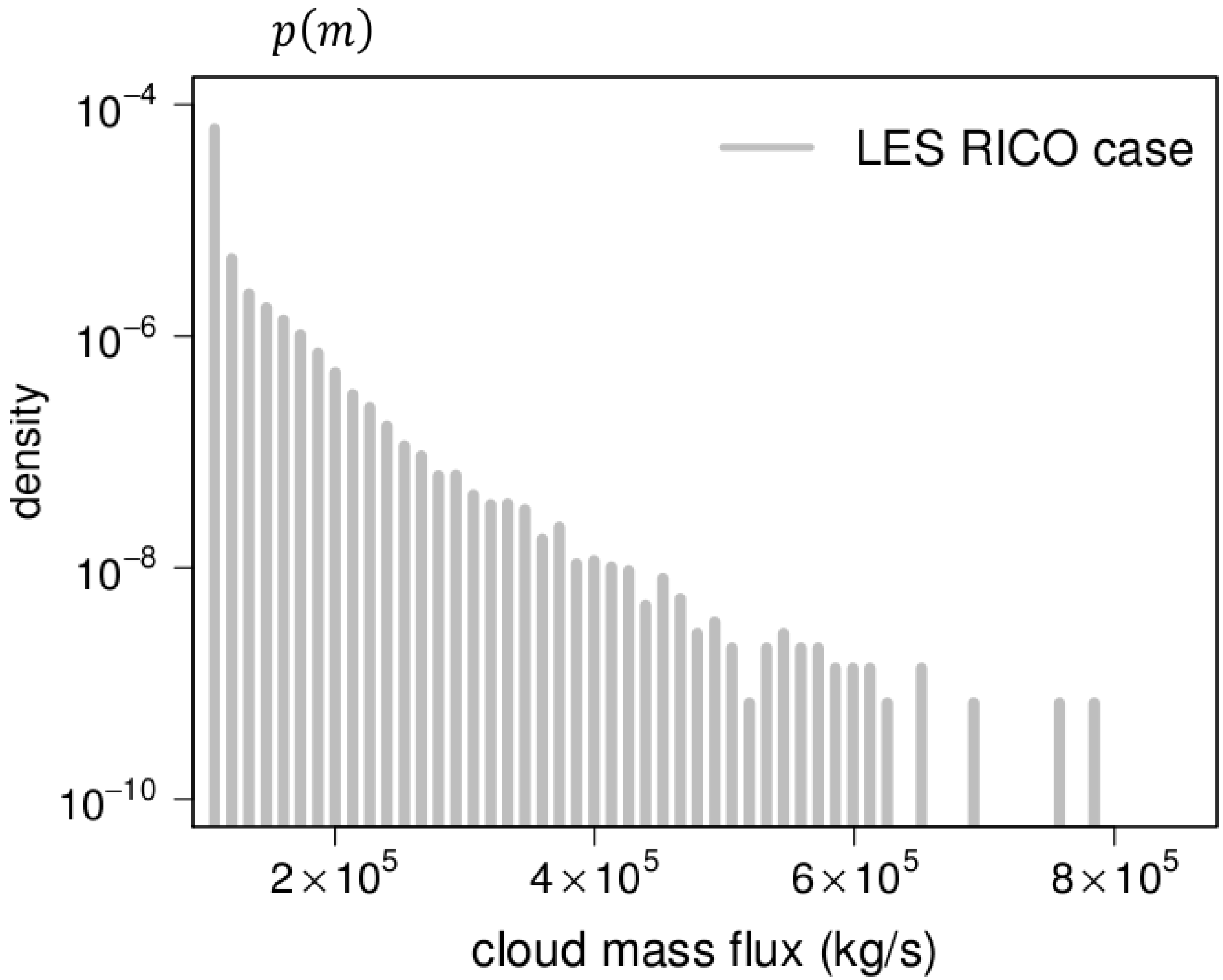
- we have constructed a stochastic stand-alone model for shallow clouds based on this framework

- Model grid box is a smaller region containing a **subset** of the cloud ensemble, and is represented as **one of many possible states** that correspond to the large scale forcing

- Can we extend the theory of fluctuations of Craig and Cohen (2006) to shallow convection and support it by the findings from LES

  and how?

Cloud-base mass flux distribution after the cloud tracking - LES



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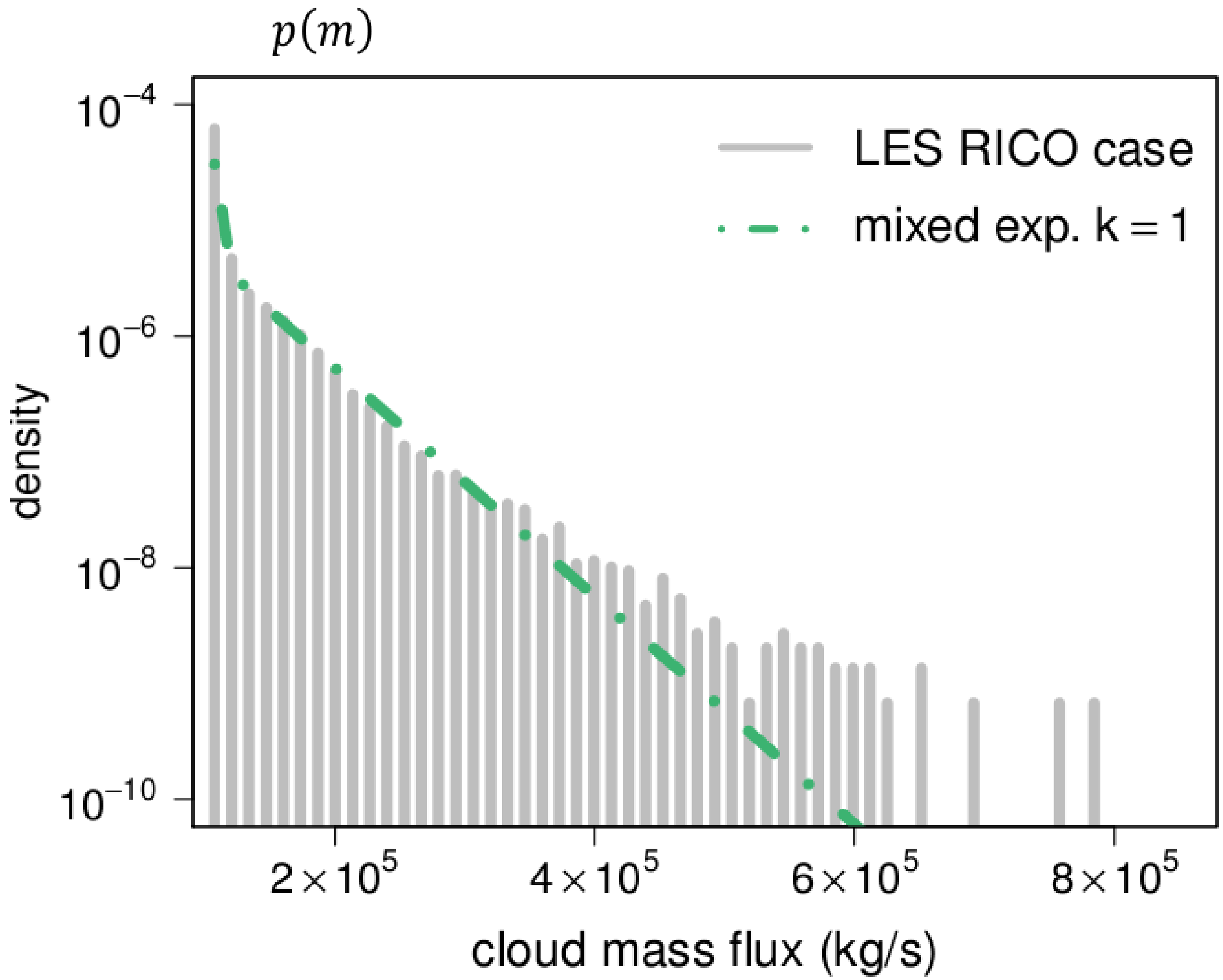

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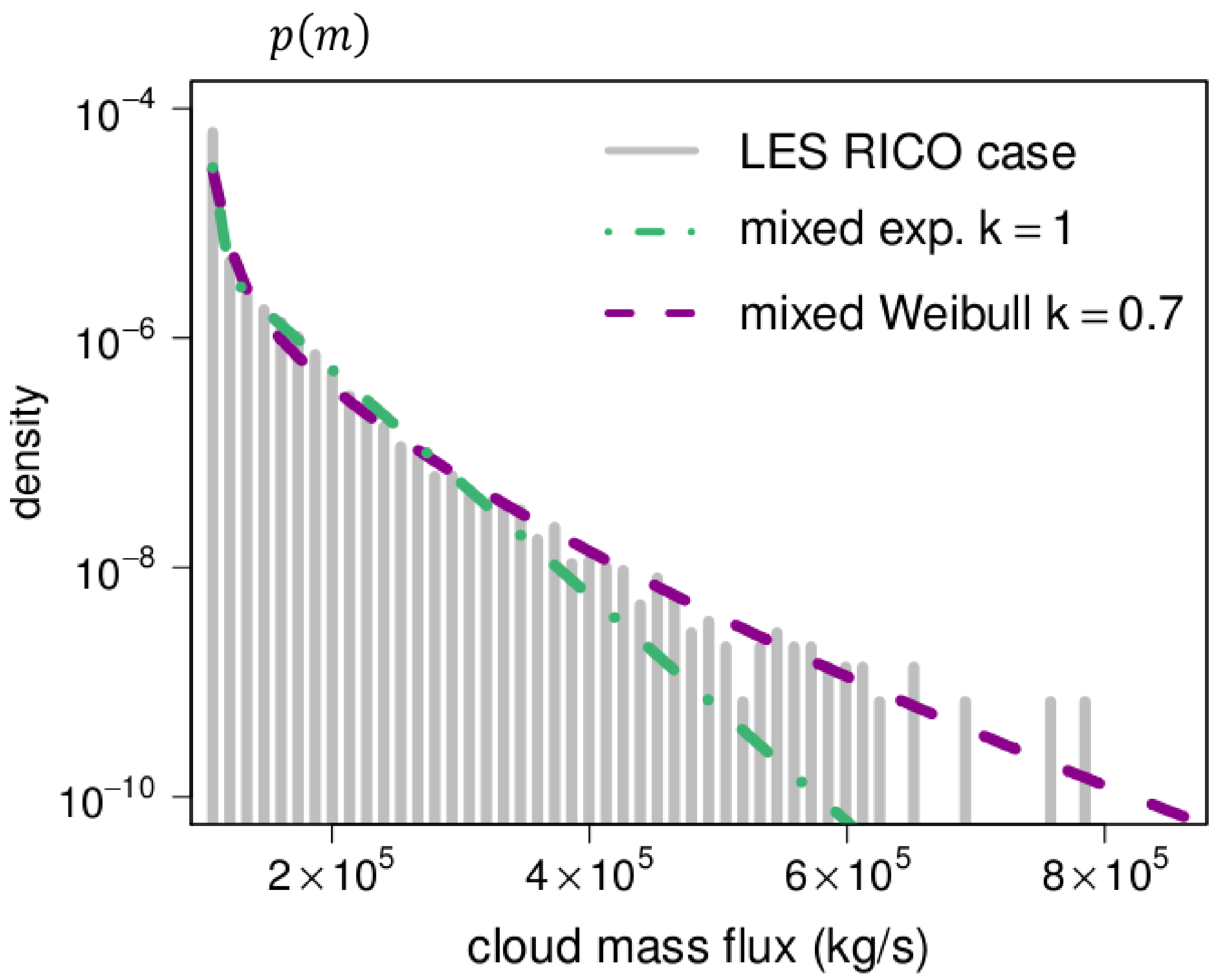
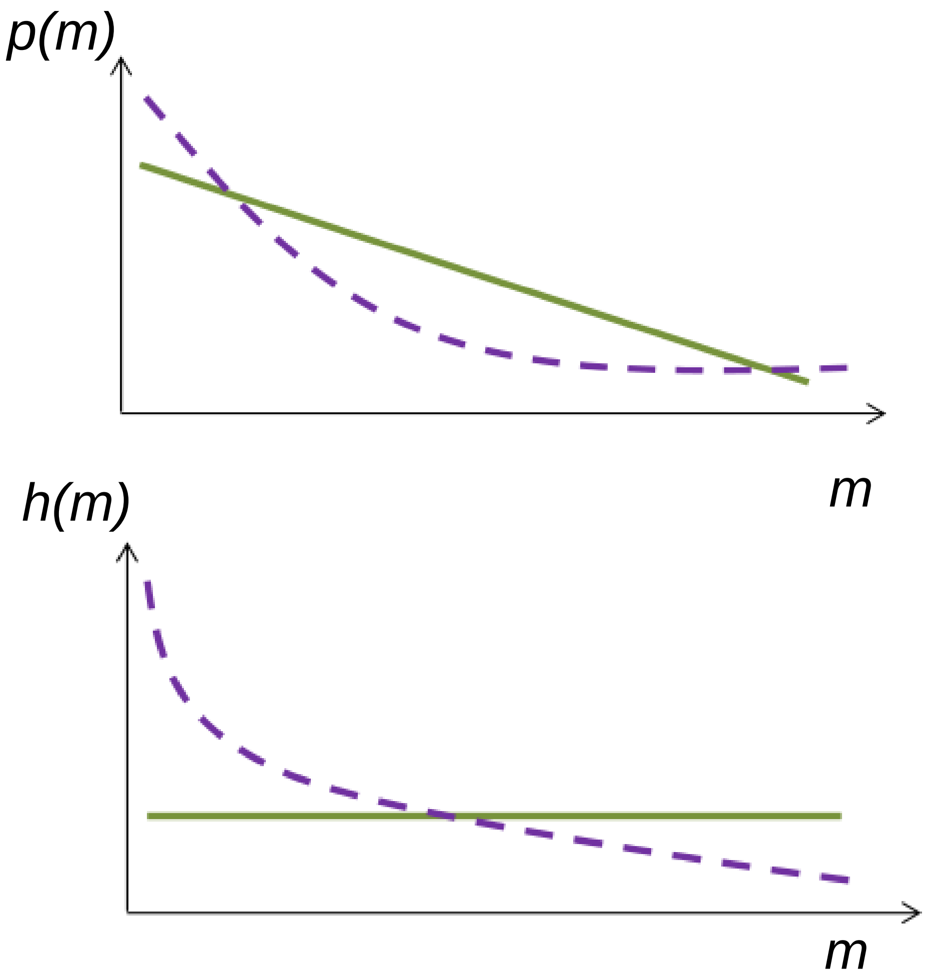


Generalization of the distribution of cloud-base mass flux – cloud memory

- shallow clouds are diverse in size and duration – memory effects of individual clouds are introduced through the diversity in lifecycles



failure rate **h(m)**:

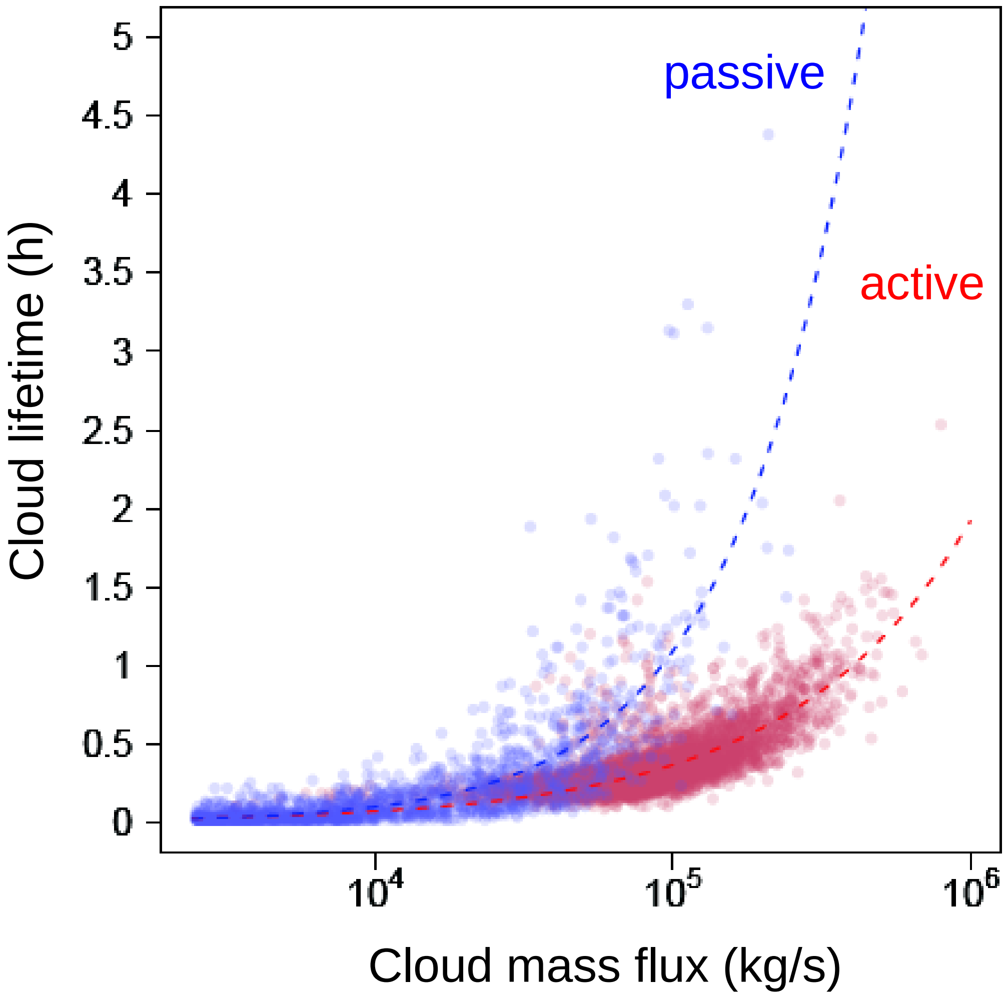
0 < k < 1 - - - - $p(m) = \boxed{\frac{k}{\lambda^k}\, m^{k-1}}\, e^{-\left(\frac{m}{\lambda}\right)^k}$

k = 1 ——— $p(m) = \boxed{\frac{1}{\langle m \rangle}}\, e^{-\frac{m}{\langle m \rangle}}$

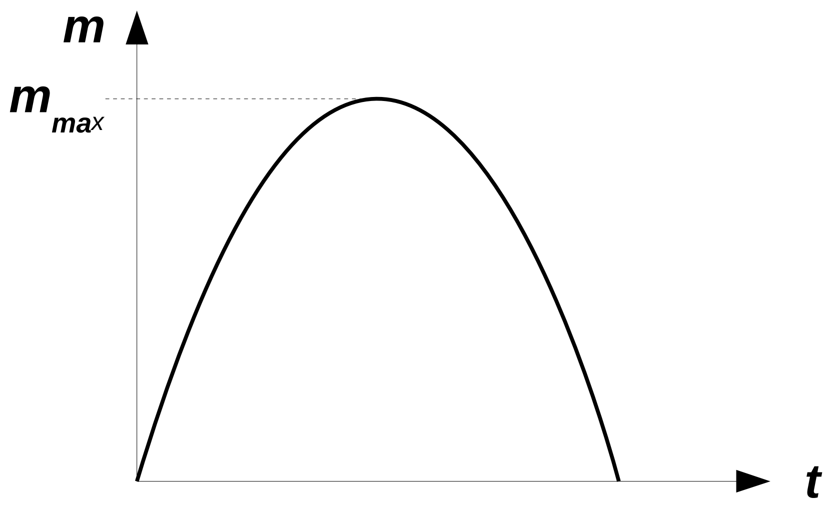
= *const.*

Generalization of the distribution of cloud-base mass flux – cloud memory

- Introduce the memory of individual clouds through the mass flux distribution and explicit and diverse cloud lifecycles



Cloud lifecycle:



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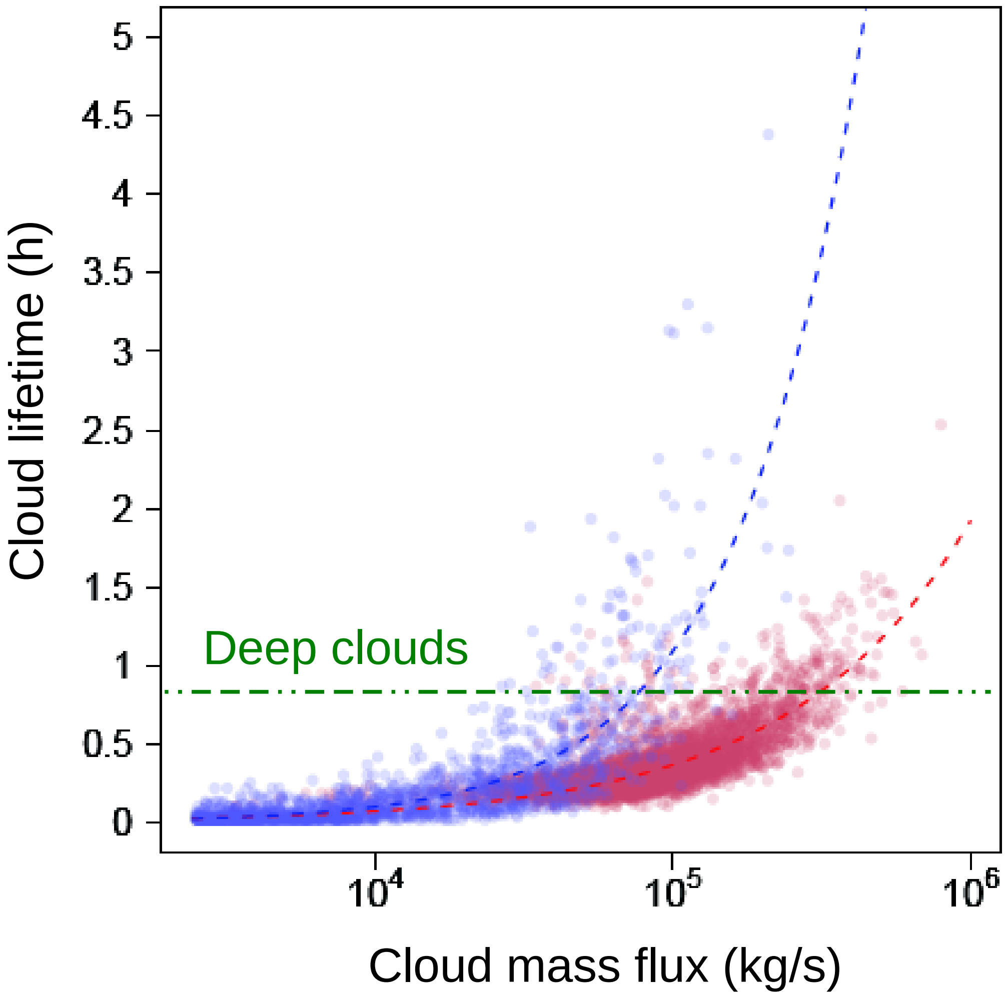
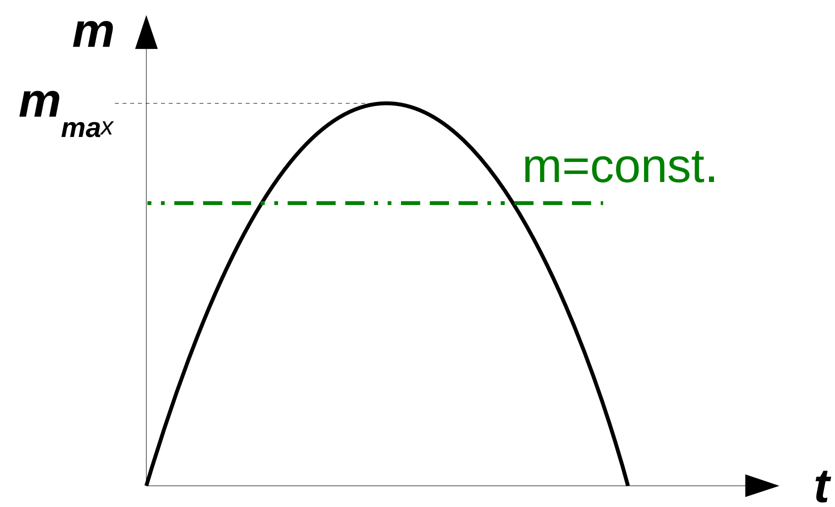
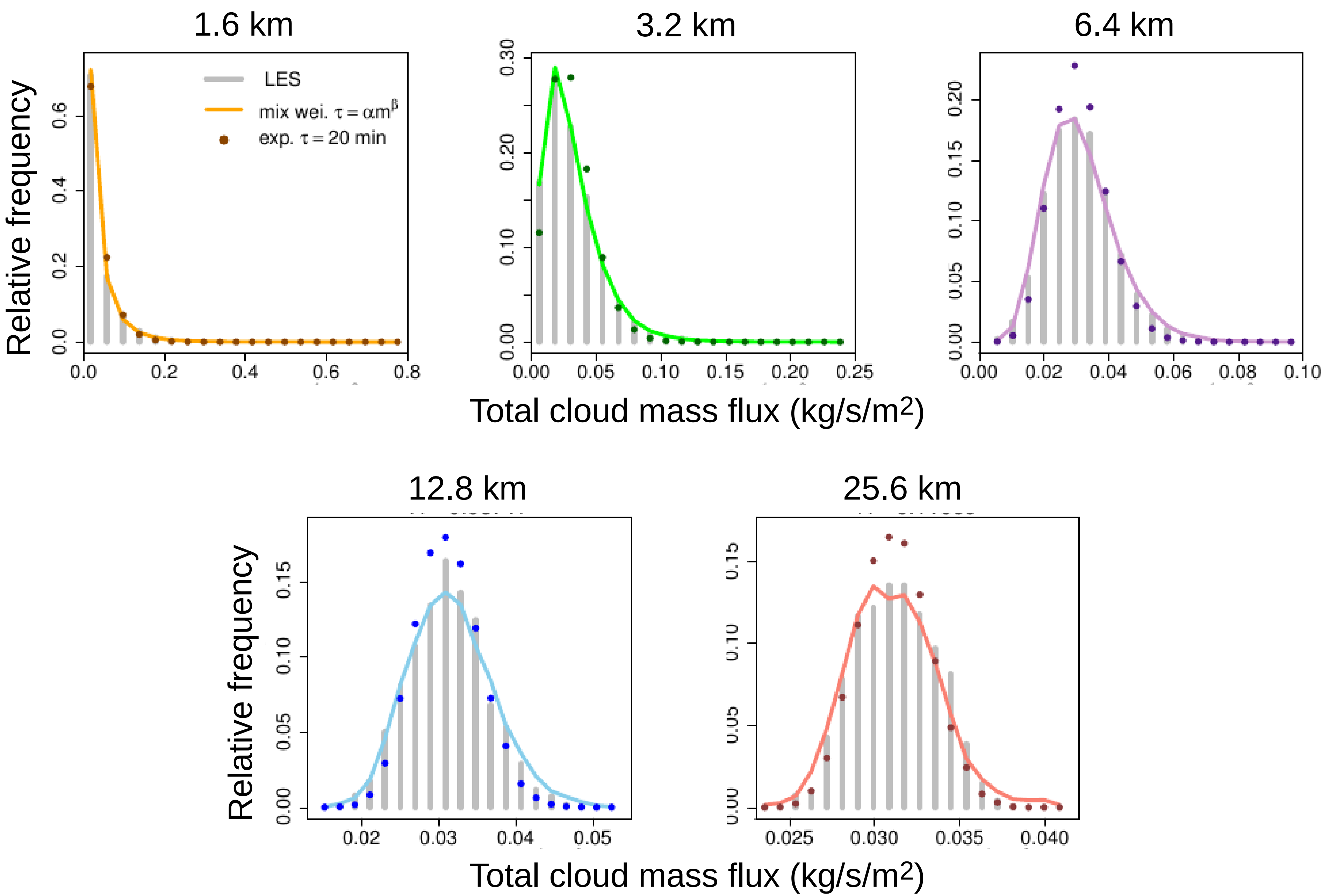


Cloud lifecycle:



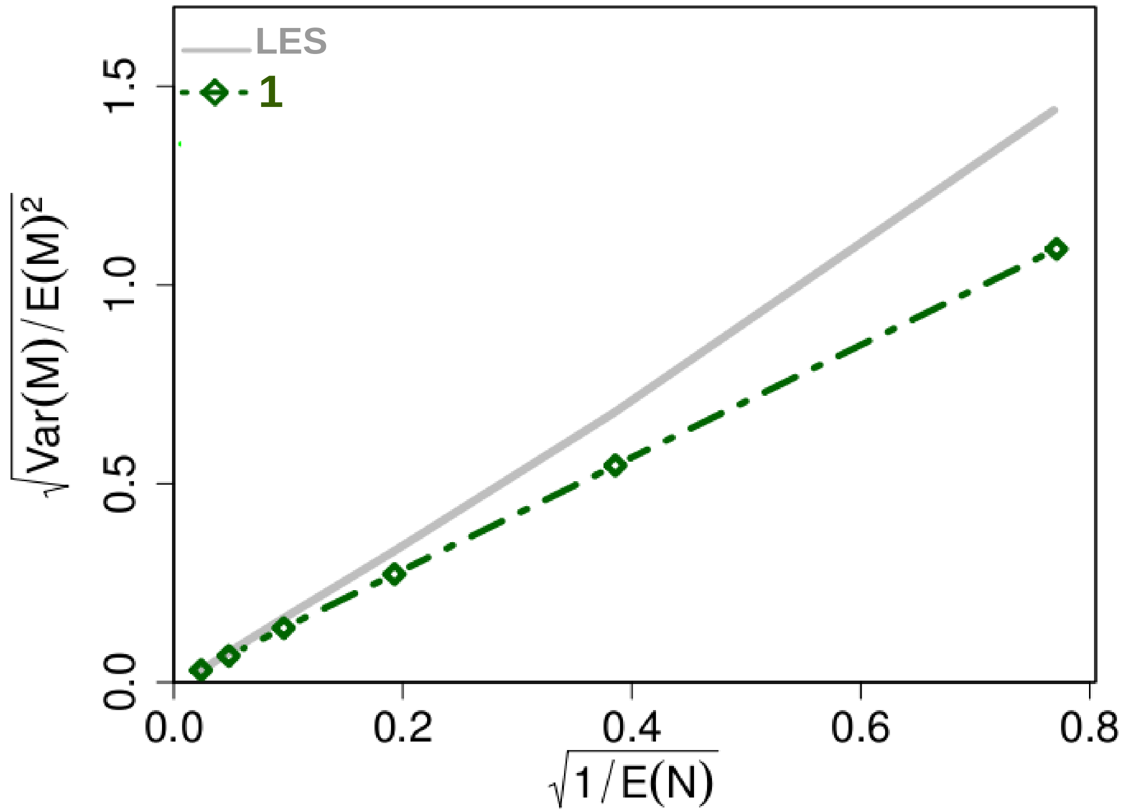
Resulting compound distribution of subgrid cloud-base mass flux $p(M)$



Gradual generalization of the convective ensemble

◇ **1** exponential, no lifecycles
- deep convection (*Craig and Cohen, 2006*)

$$\frac{Var[M]}{(E[M])^2} = \frac{2}{\langle N \rangle}$$



N, Δx

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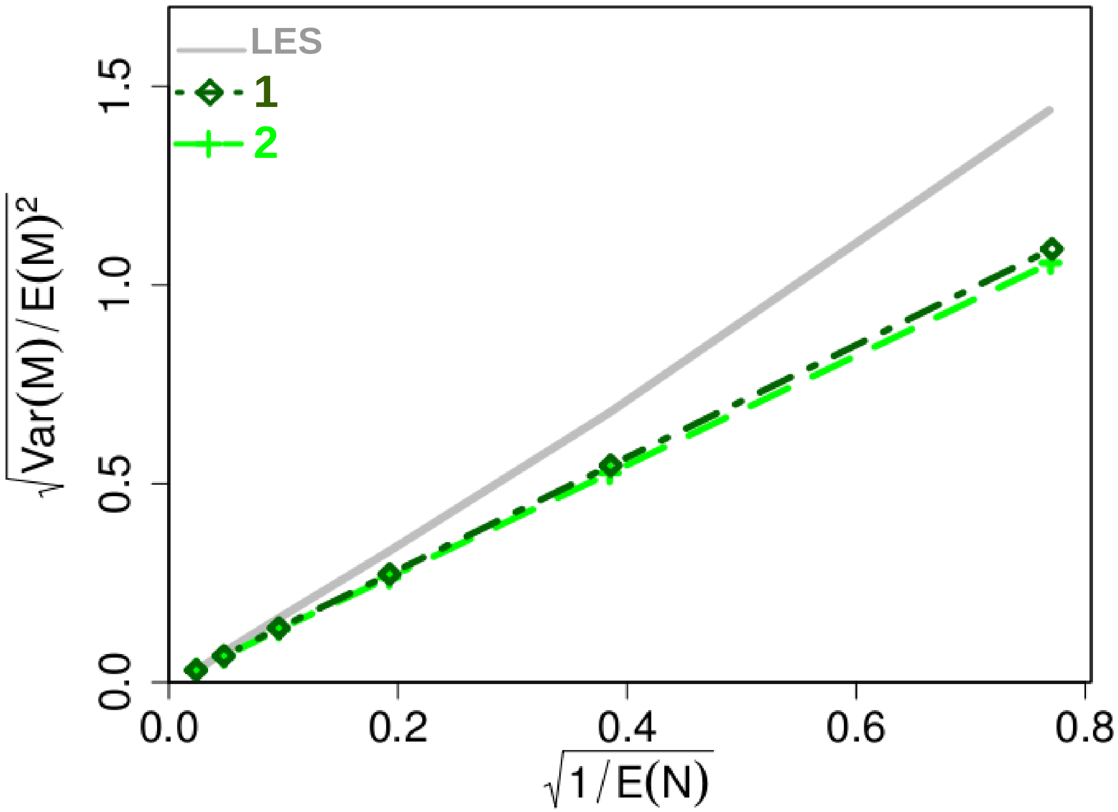
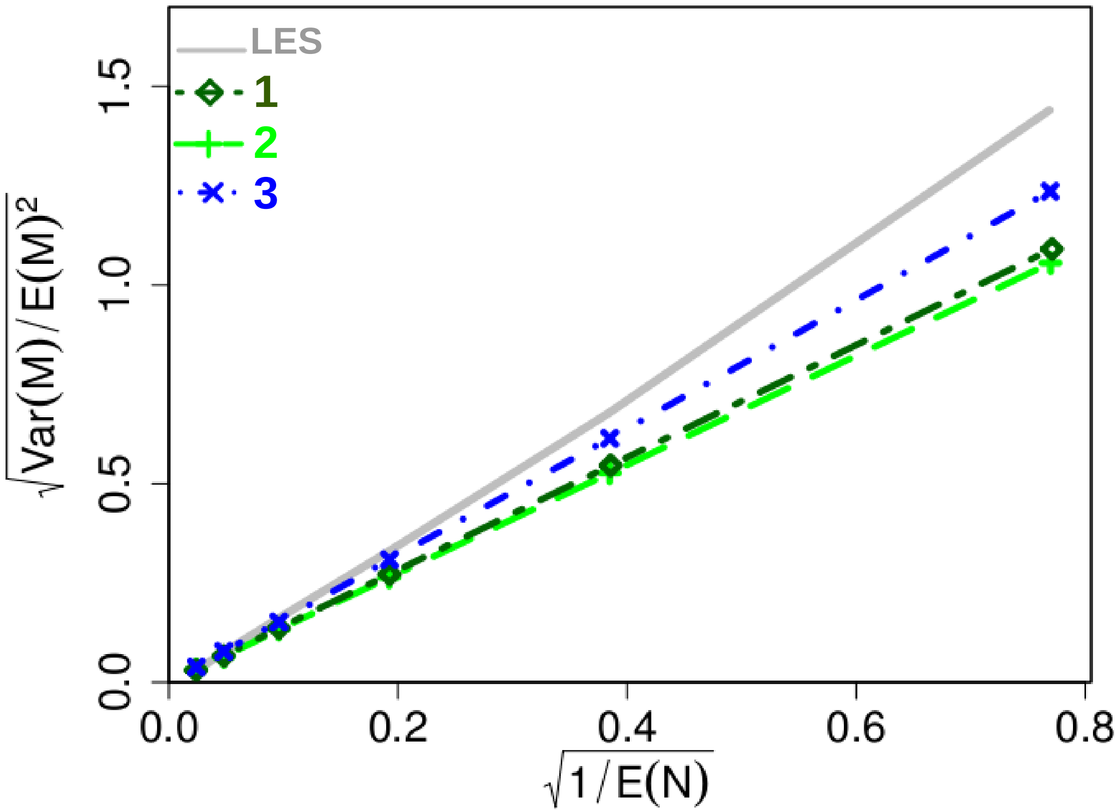


N, Δx

+ 2 exponential + lifecycles

Gradual generalization of the convective ensemble



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+ 2 exponential + lifecycles

x 3 mixed exponential + lifecycles

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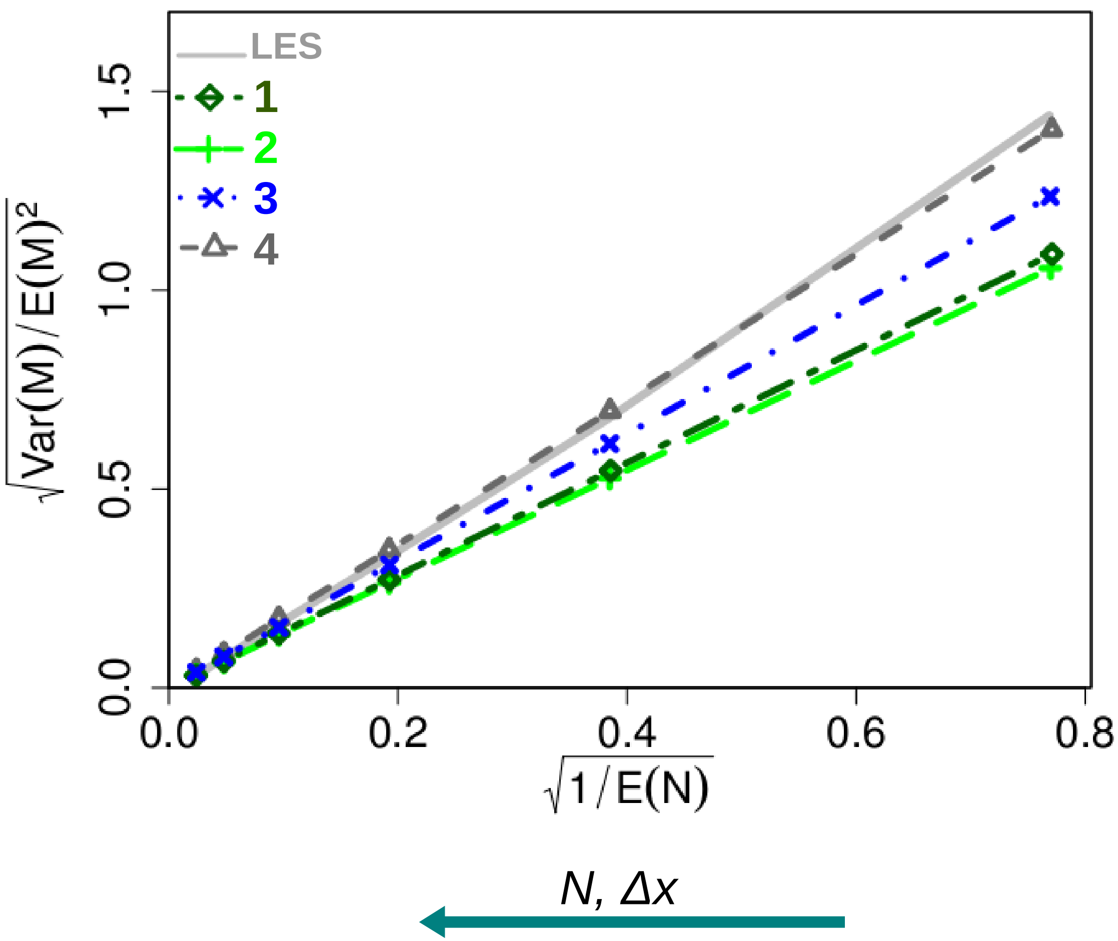

+ 2 exponential + lifecycles

x 3 mixed exponential + lifecycles

Δ 4 mixed Weibull + lifecycles

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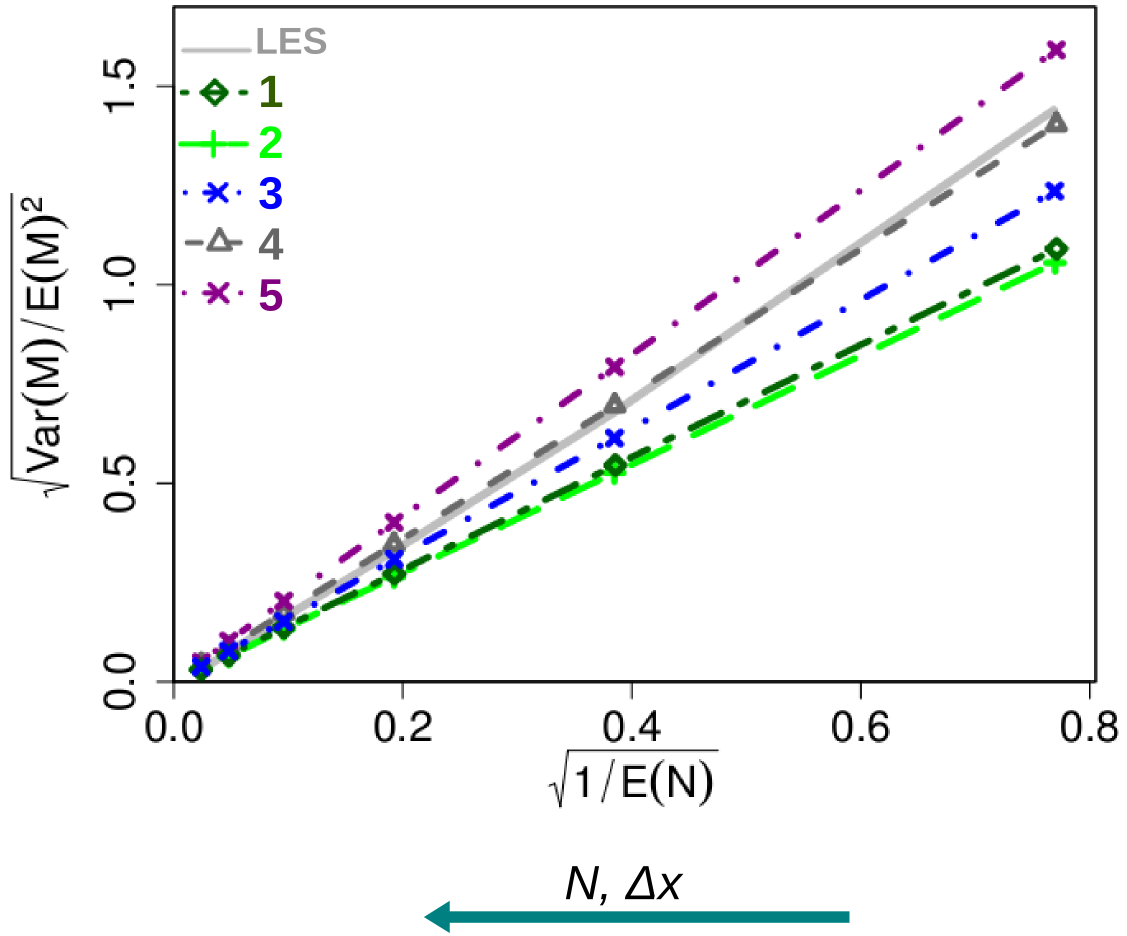

+ **2** exponential + lifecycles

x **3** mixed exponential + lifecycles

△ **4** mixed Weibull + lifecycles

x **5** mixed Weibull, no lifecycles

Conclusions

- we extend the theory of fluctuations in a convective ensemble to shallow convection by introducing cloud memory
- the shape of the cloud mass flux distribution deviates from exponential
  - diversity in cloud life cycles
- consistent model formulation:
  - Exponential distribution, no lifecycles
  - Weibull distribution, explicit and diverse lifecycles (memory)
- it is necessary to include the individual cloud memory to reproduce the correct variability in a shallow cumulus ensemble across the different scales

Thank you for your attention!