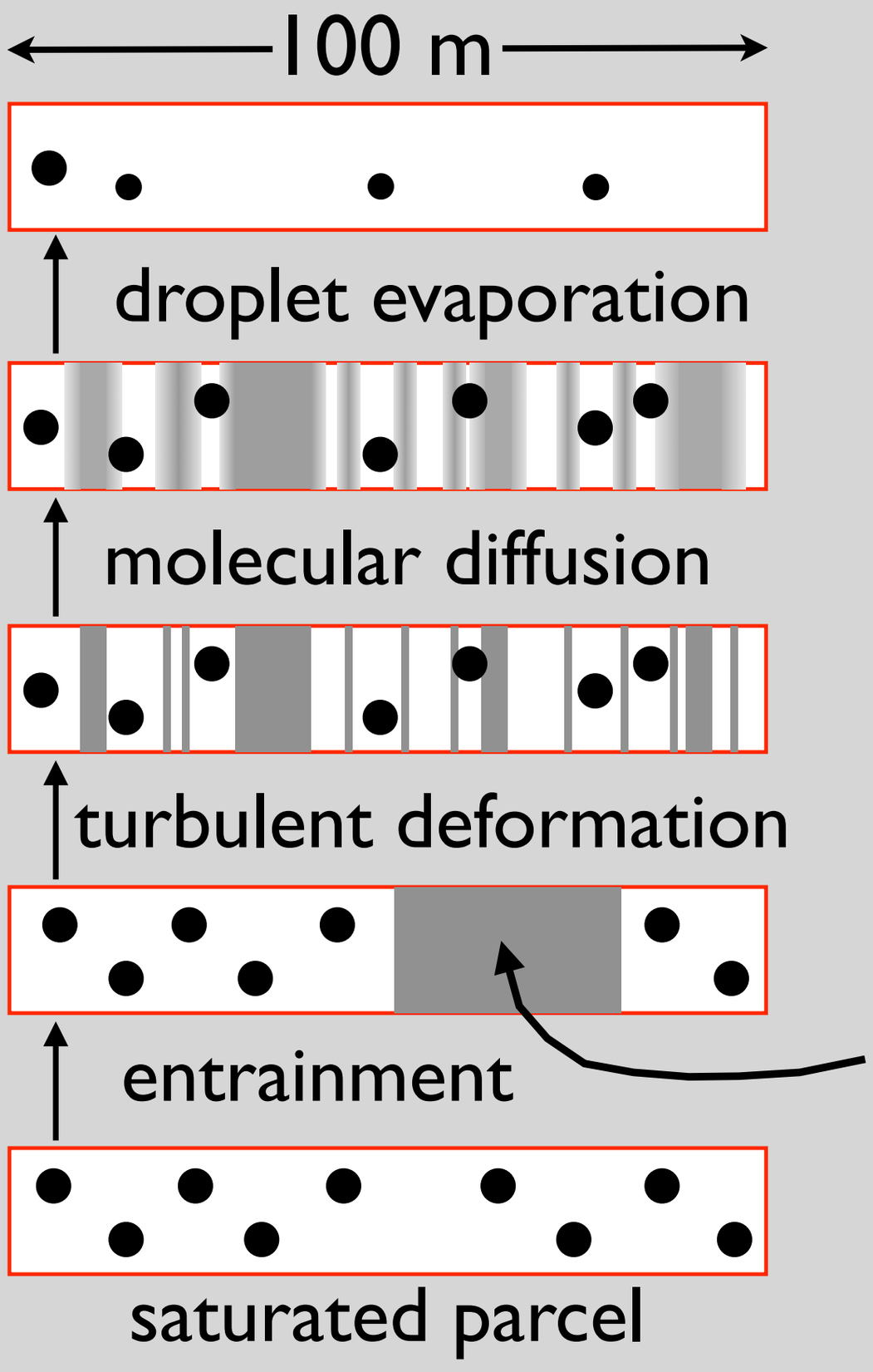
EMPM vs DNS results of Kumar, Schumacher, and Shaw (2014)

For same number of droplets (~ 9 million) and duration (30 minutes) as the DNS, the EMPM requires only 5 cpu hours.

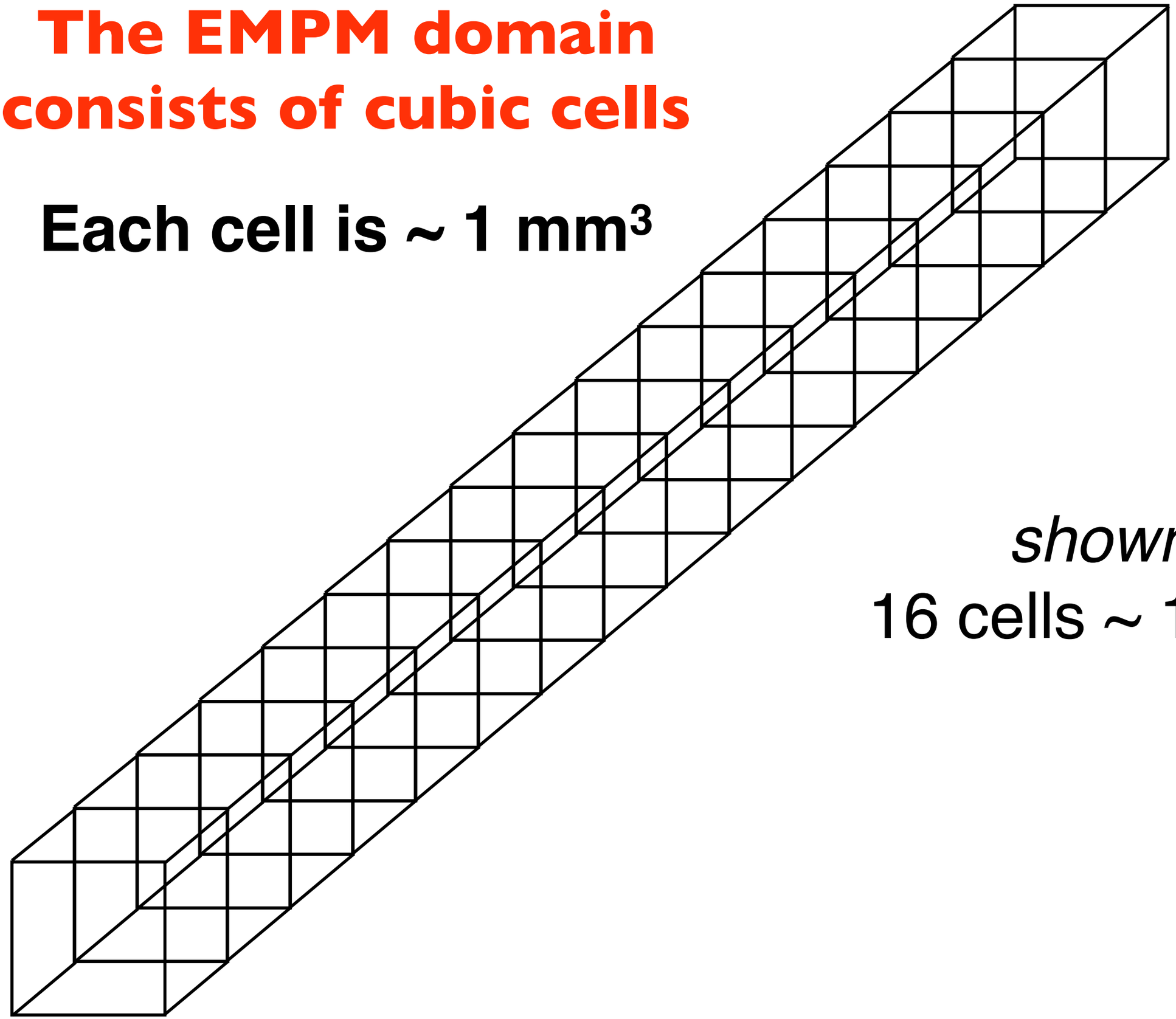
EMPM diagram

EMPM with droplets and entrainment



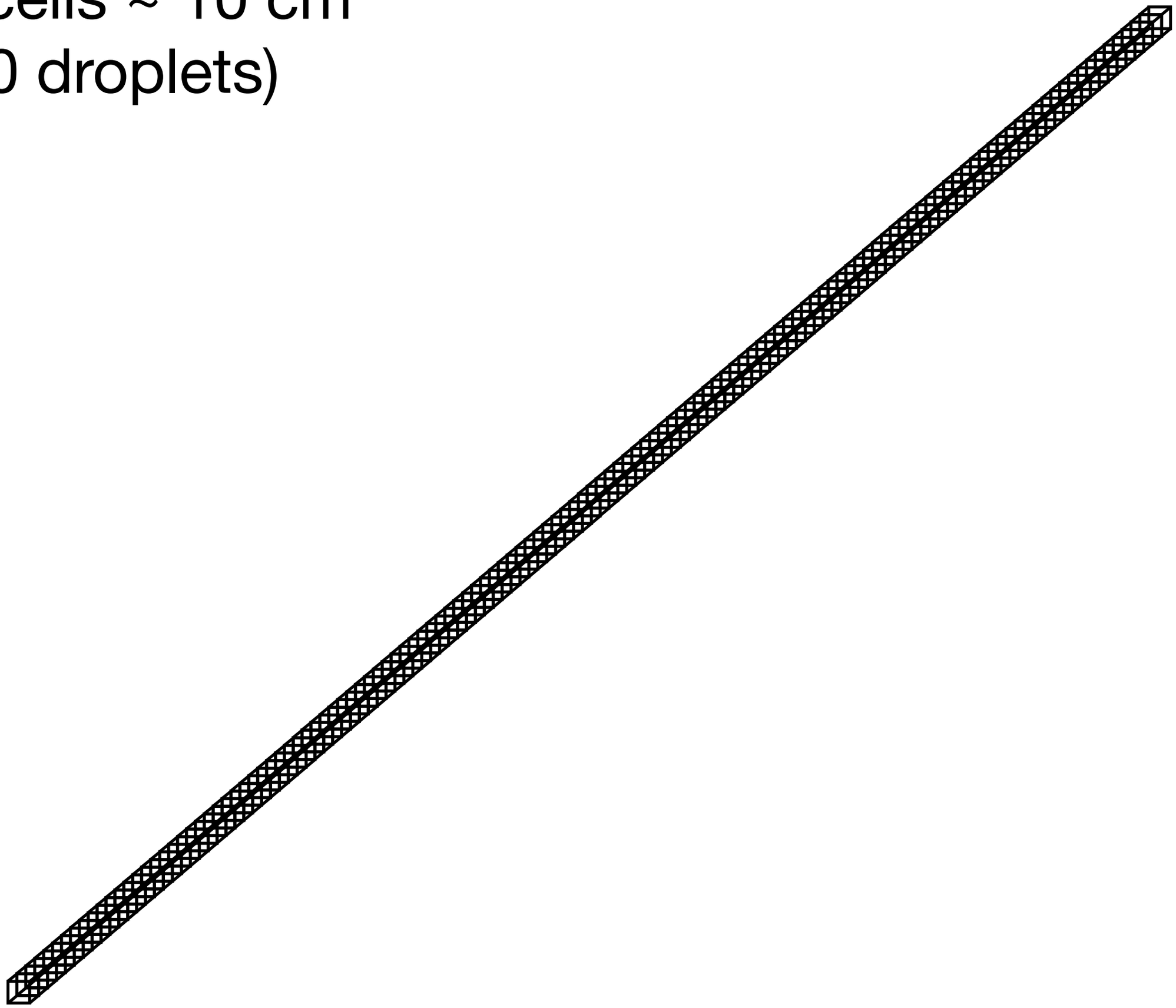
The EMPM domain consists of cubic cells

Each cell is ~ 1 mm^3

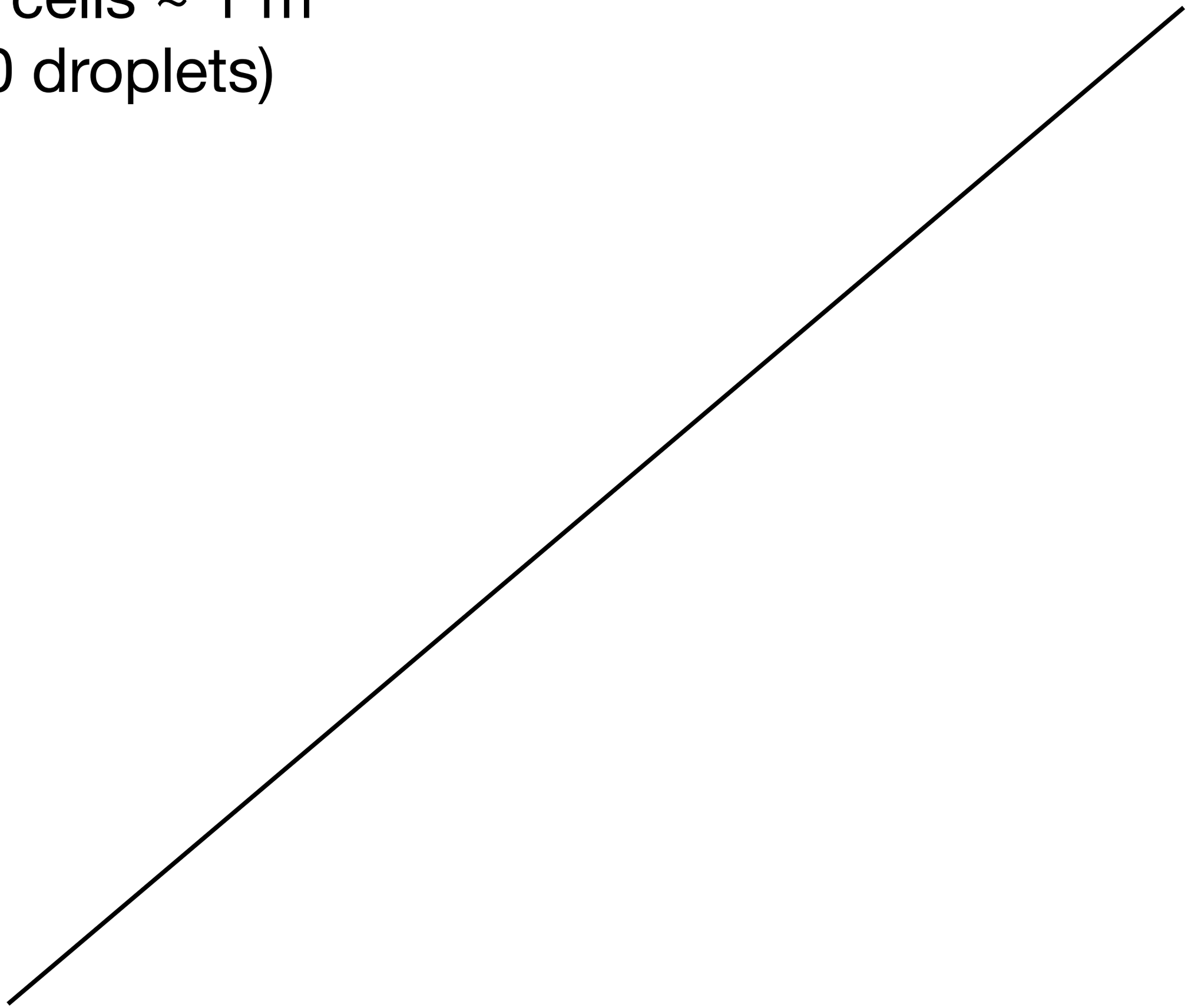


shown:
16 cells ~ 1.6 cm

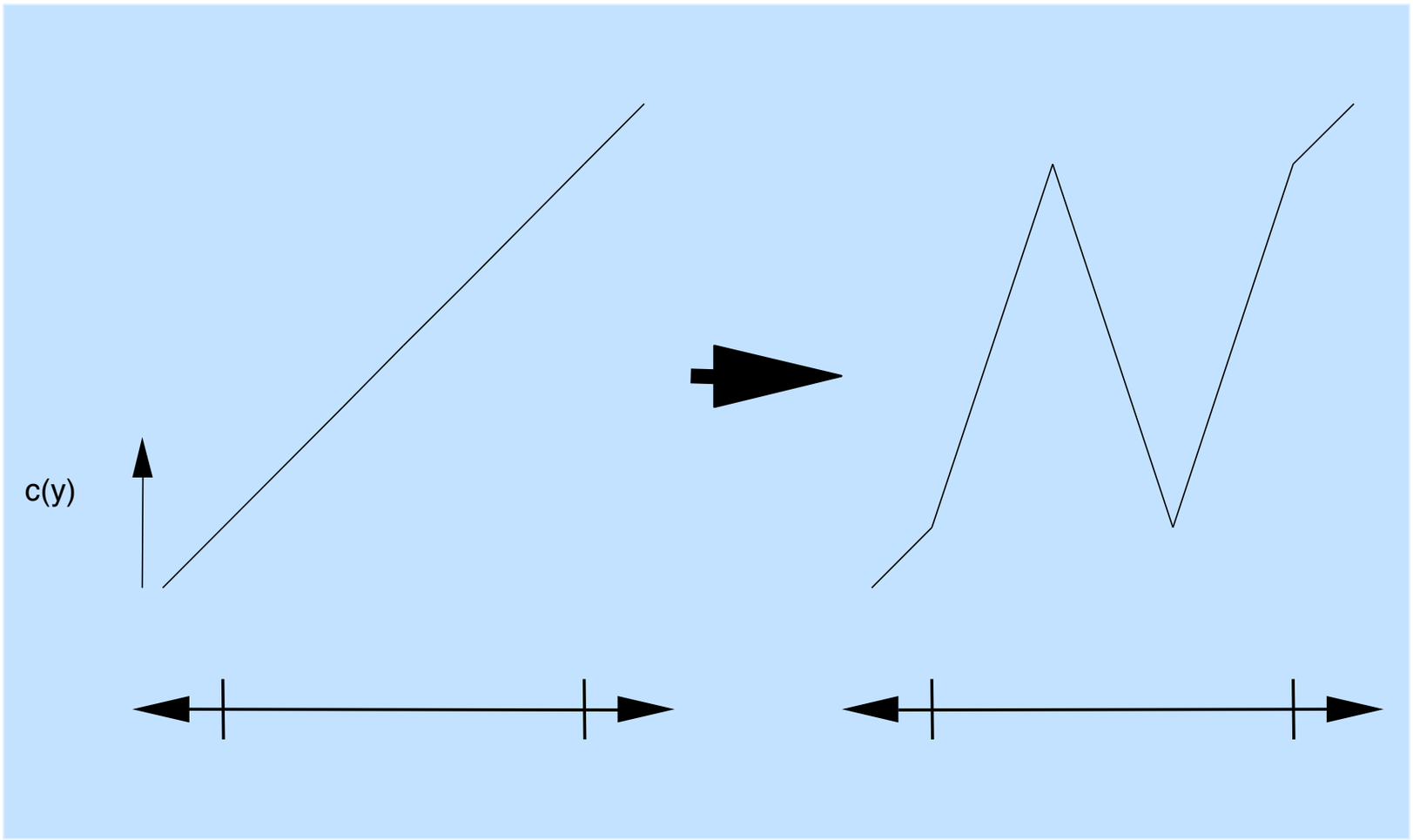
128 cells ~ 10 cm
(10 droplets)



1024 cells ~ 1 m
(100 droplets)



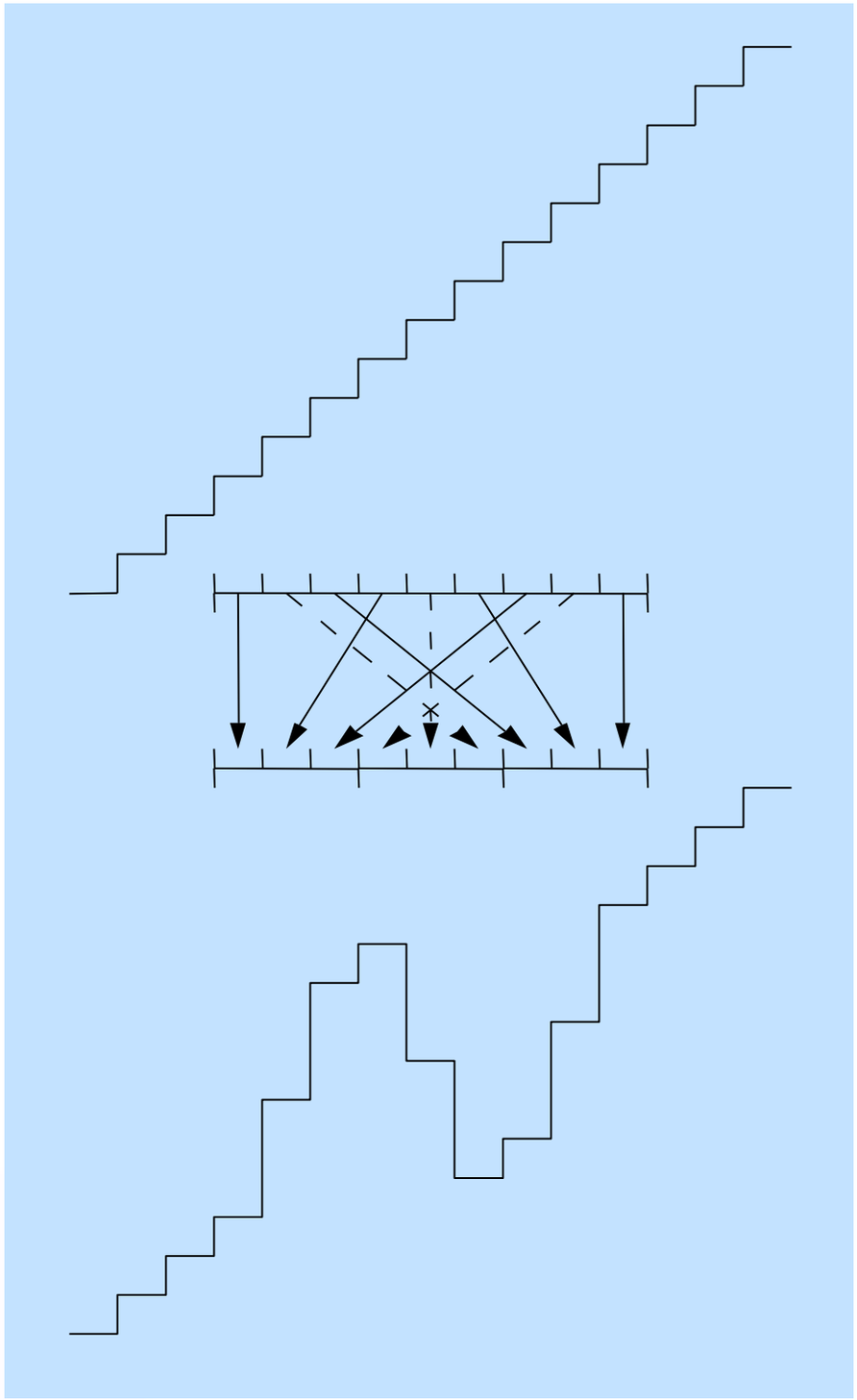
Turbulent motion of *fluid elements* is modeled as a sequence of **triplet maps** that preserve desired advection properties, even in 1D



Alan Kerstein

The triplet map captures compressive strain and rotational folding effects, and causes no property discontinuities.

Turbulent motion of *fluid elements* is modeled as a sequence of **triplet maps** that preserve desired advection properties, even in 1D



The triplet map is implemented numerically as a permutation of fluid cells.

Triplet Map for Fluid Elements

Each triplet map has a location, size, and time.

- *Location* is randomly chosen.
- *Size* l is randomly chosen from a distribution that matches inertial range scalings.
  - Smallest map (eddy) is Kolmogorov scale, η.
  - Largest eddy is L, usually domain size.
- Eddies occur at a *rate* determined by the large eddy time scale and eddy size range.

EMPM Fluid Variables

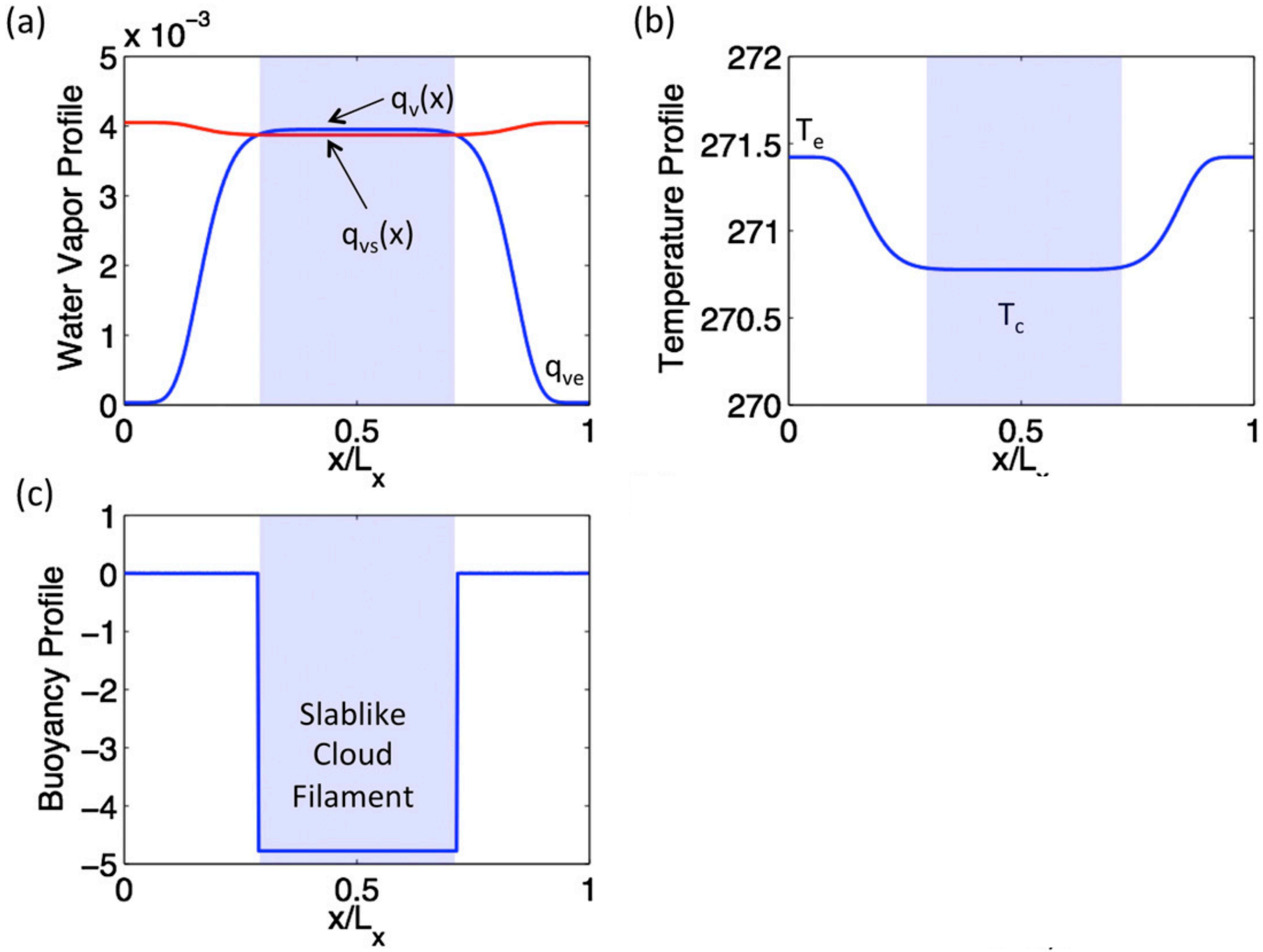
- Bulk microphysics:
  - Liquid water static energy
  - Total water mixing ratio
- Droplet microphysics:
  - Temperature
  - Water vapor mixing ratio

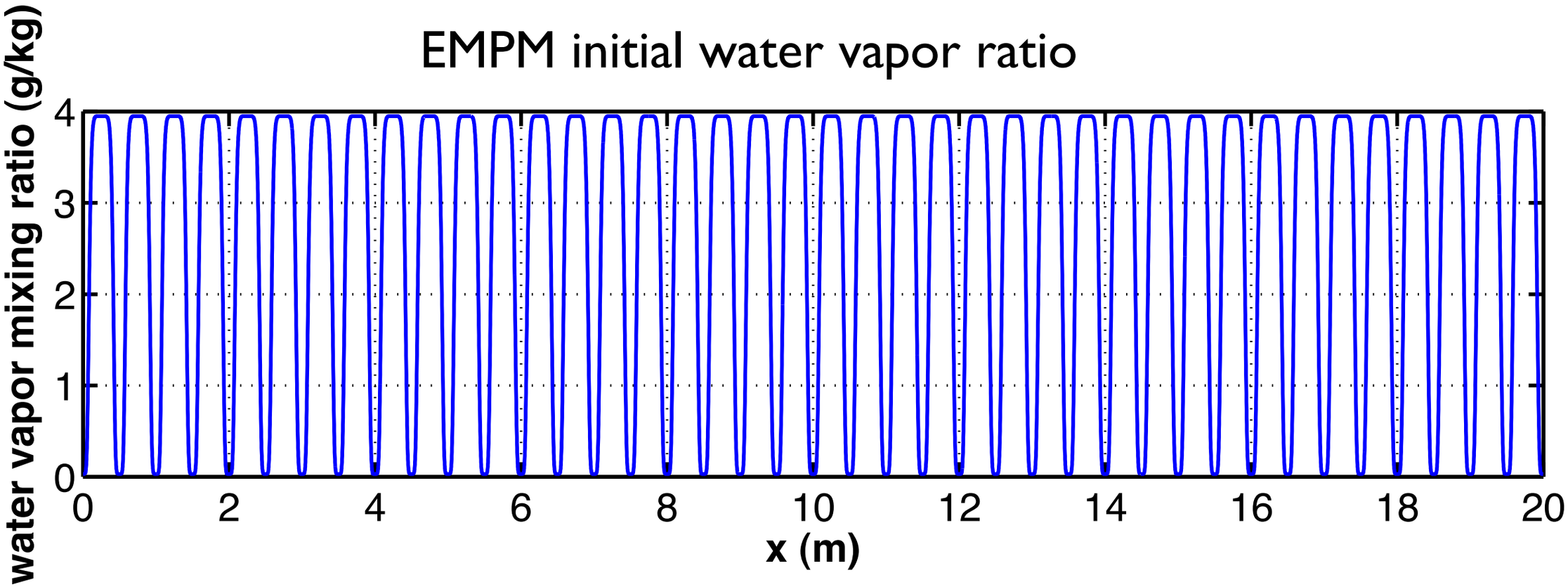
EMPM Droplet Variables

- **Location** (in one coordinate)
- **Radius** (droplet growth equation)
- CCN properties (specified)

In the EMPM, droplets move relative to the fluid at their terminal velocities.

Initial Configuration for DNS and EMPM





Domain size	20 m
Grid points	12,000
Grid size	1.67 mm
Smallest ‘eddy’ size	1 cm
Largest ‘eddy’ size	0.5 m
Number of droplets	1311
Duration	30 s

1000 realizations (1.3M droplets) takes 45 CPU minutes.

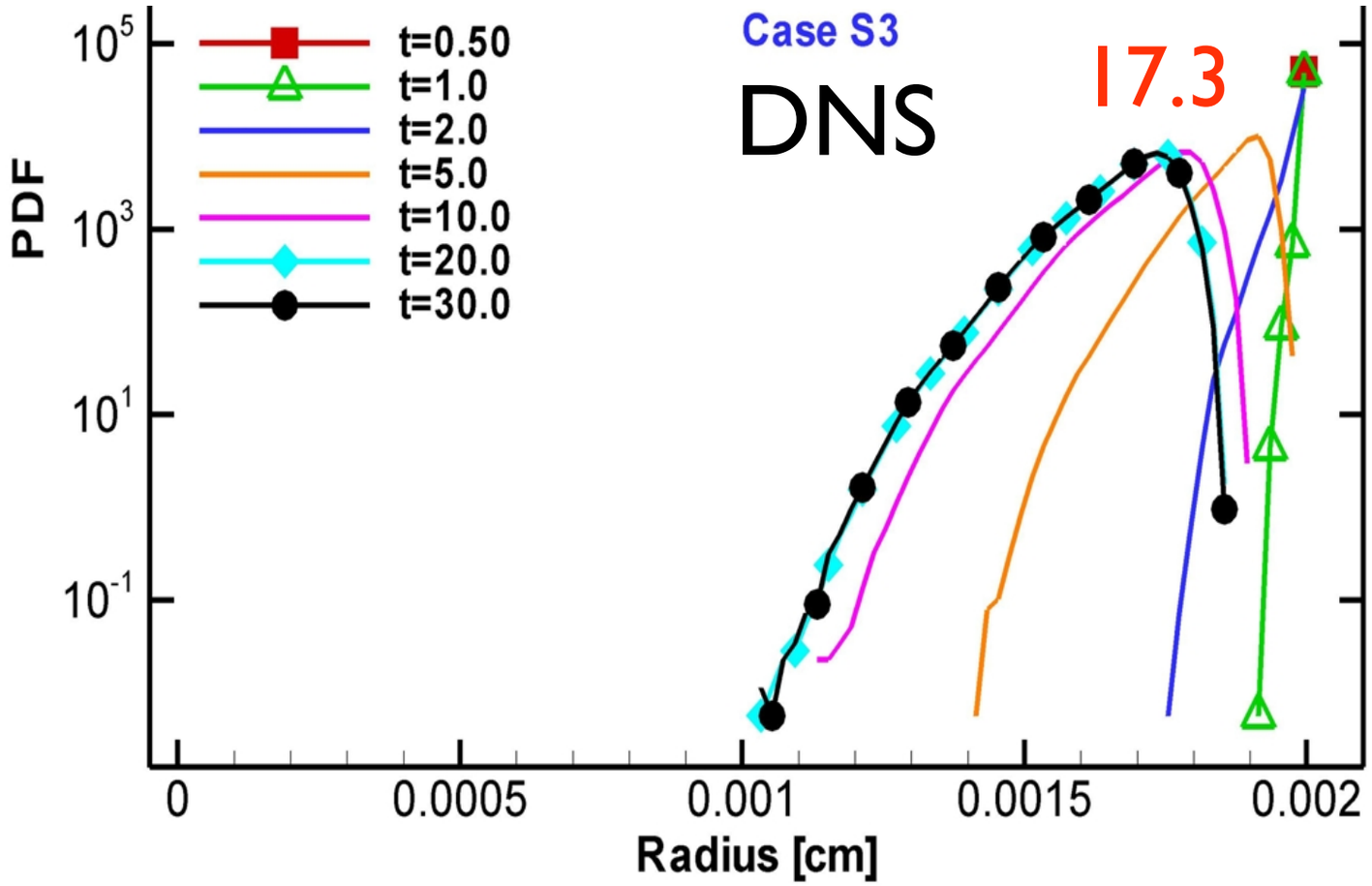
Some Potential Sources of Differences between the EMPM and DNS

- The EMPM's largest "eddy" (triplet map) size, *L*, should be set by matching the scalar variance decay time scale of the DNS.
    - For these comparisons, *L* was simply set to the DNS domain size.
- In the EMPM, droplets fall parallel to the scalar gradients, thereby over-estimating the effects of droplet sedimentation.
    - Not allowing droplets to fall underestimates sedimentation's impacts.
    - We therefore performed simulations with and without sedimentation.

Some Potential Sources of Differences between the EMPM and DNS

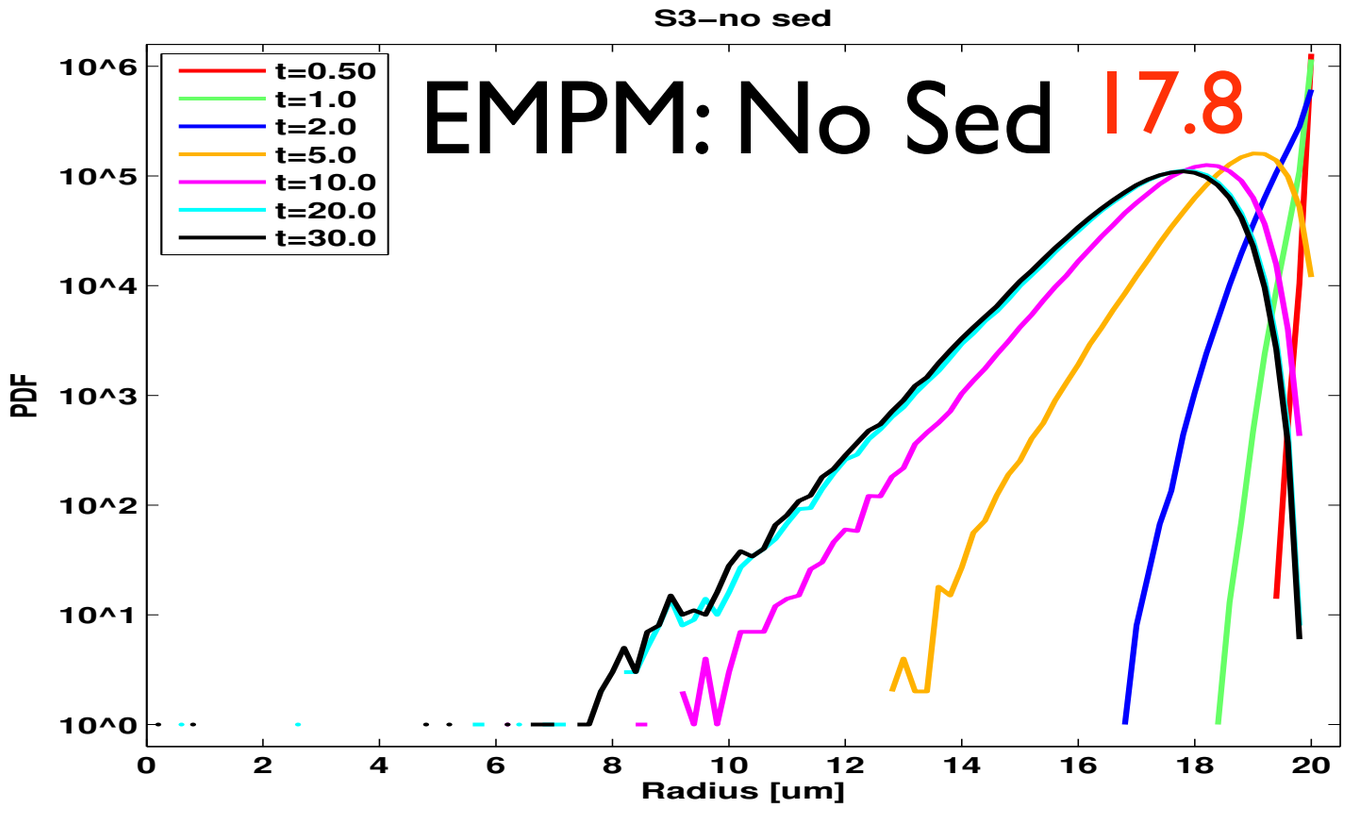
(Those listed below are not expected to be significant)

- The EMPM's turbulence properties are specified.
  - They do not evolve in response to buoyancy due to droplet evaporation.
    - Such buoyancy had a minor effect on mixing in the DNS.
- The EMPM's droplets have no inertia, unlike those in the DNS.
  - The effects of droplet inertia on mixing should be much less than those of sedimentation.



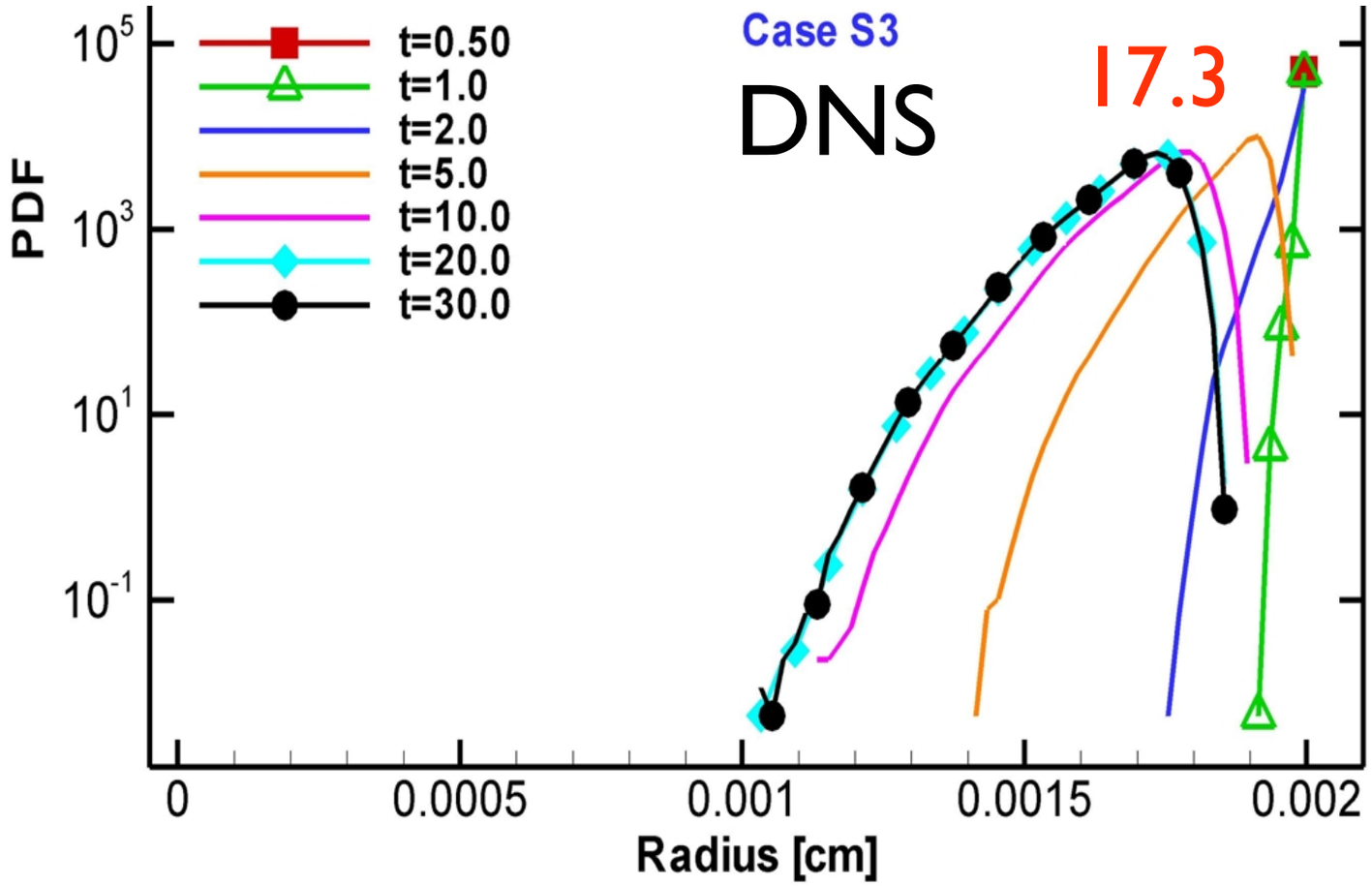
Initial droplet radius = 20 microns

No droplets completely evaporate.



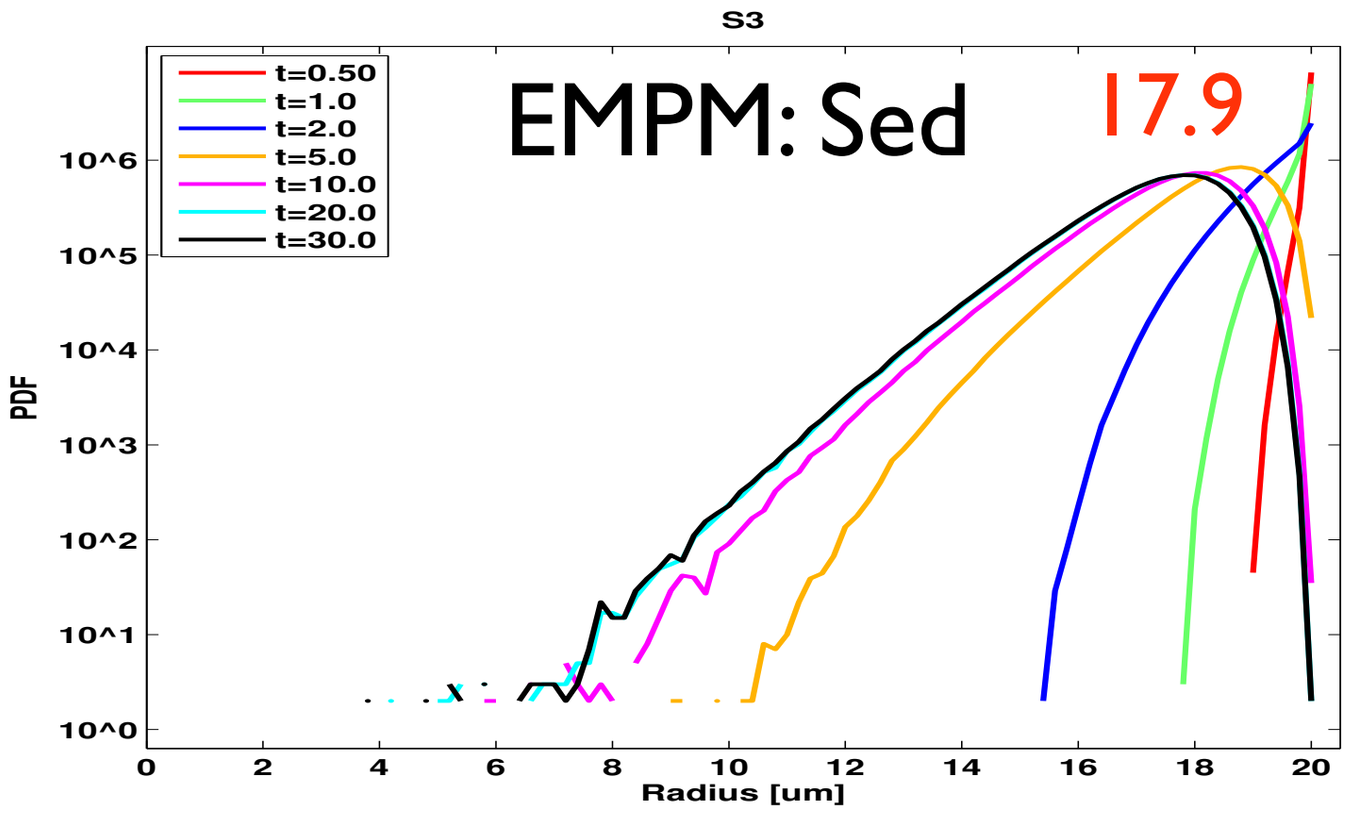
DSD evolution is essentially the same.

Slightly wider DSD at all times.

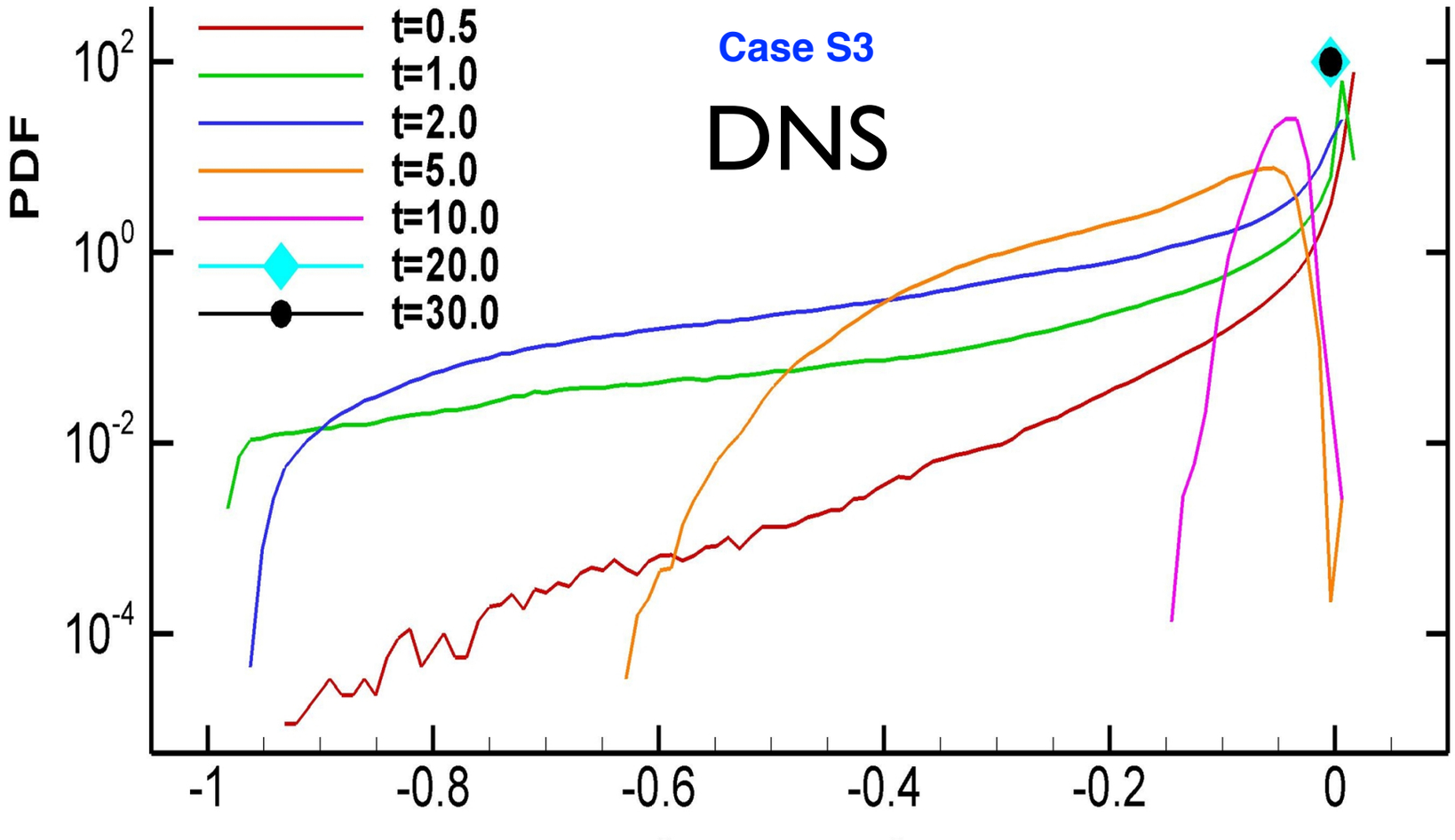


Initial droplet radius = 20 microns

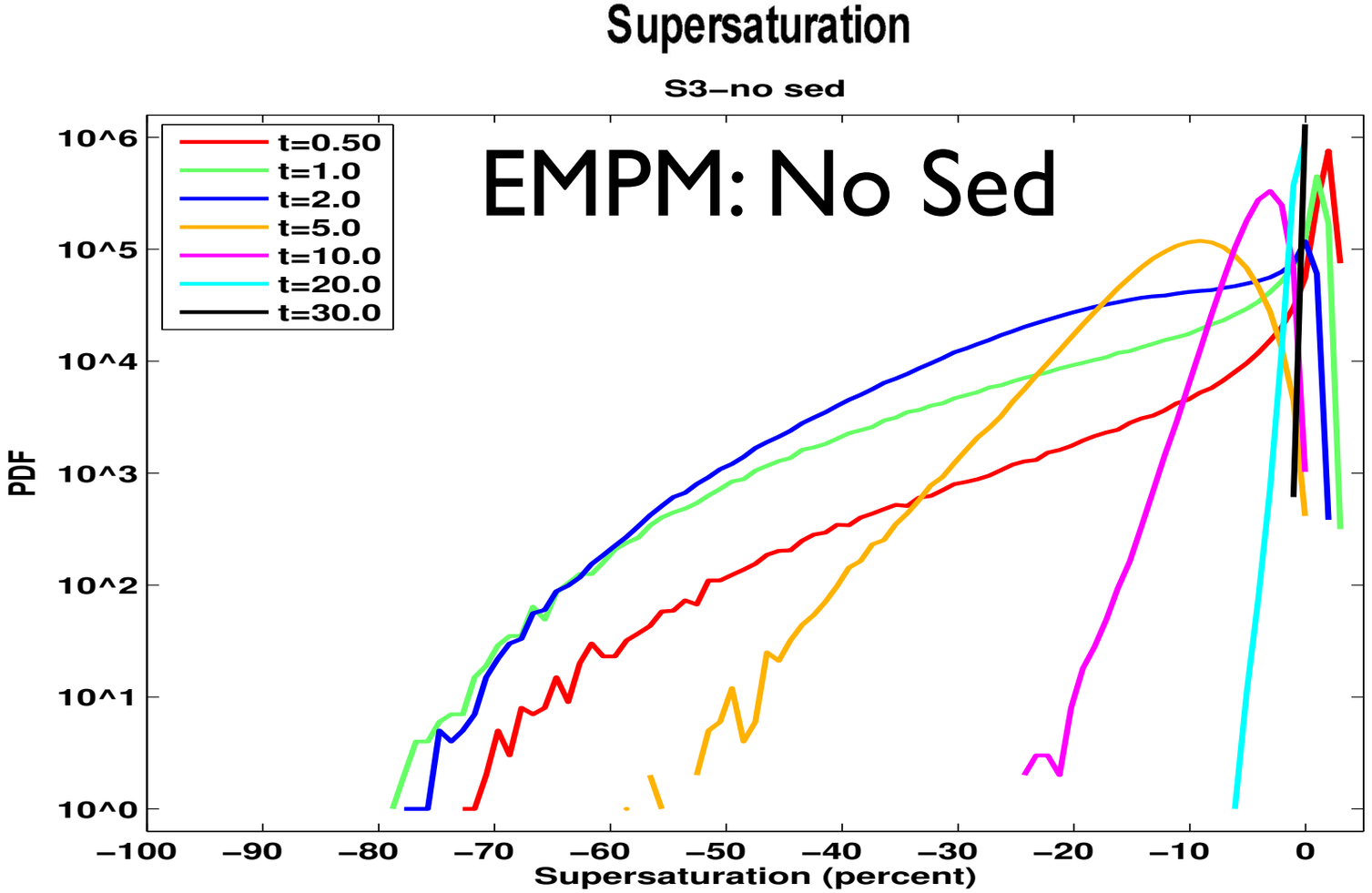
No droplets completely evaporate.



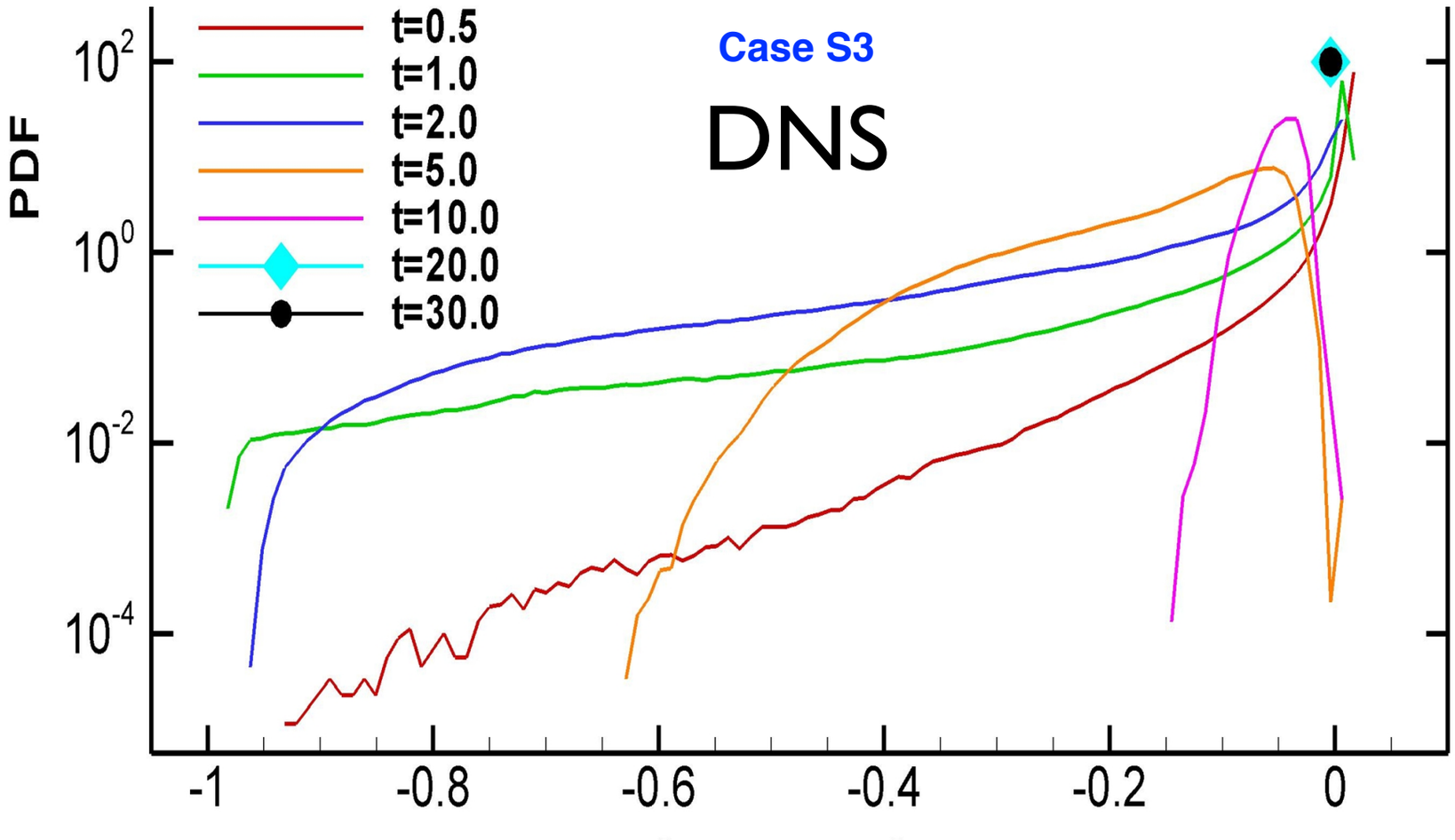
Slightly wider DSD than No Sed.



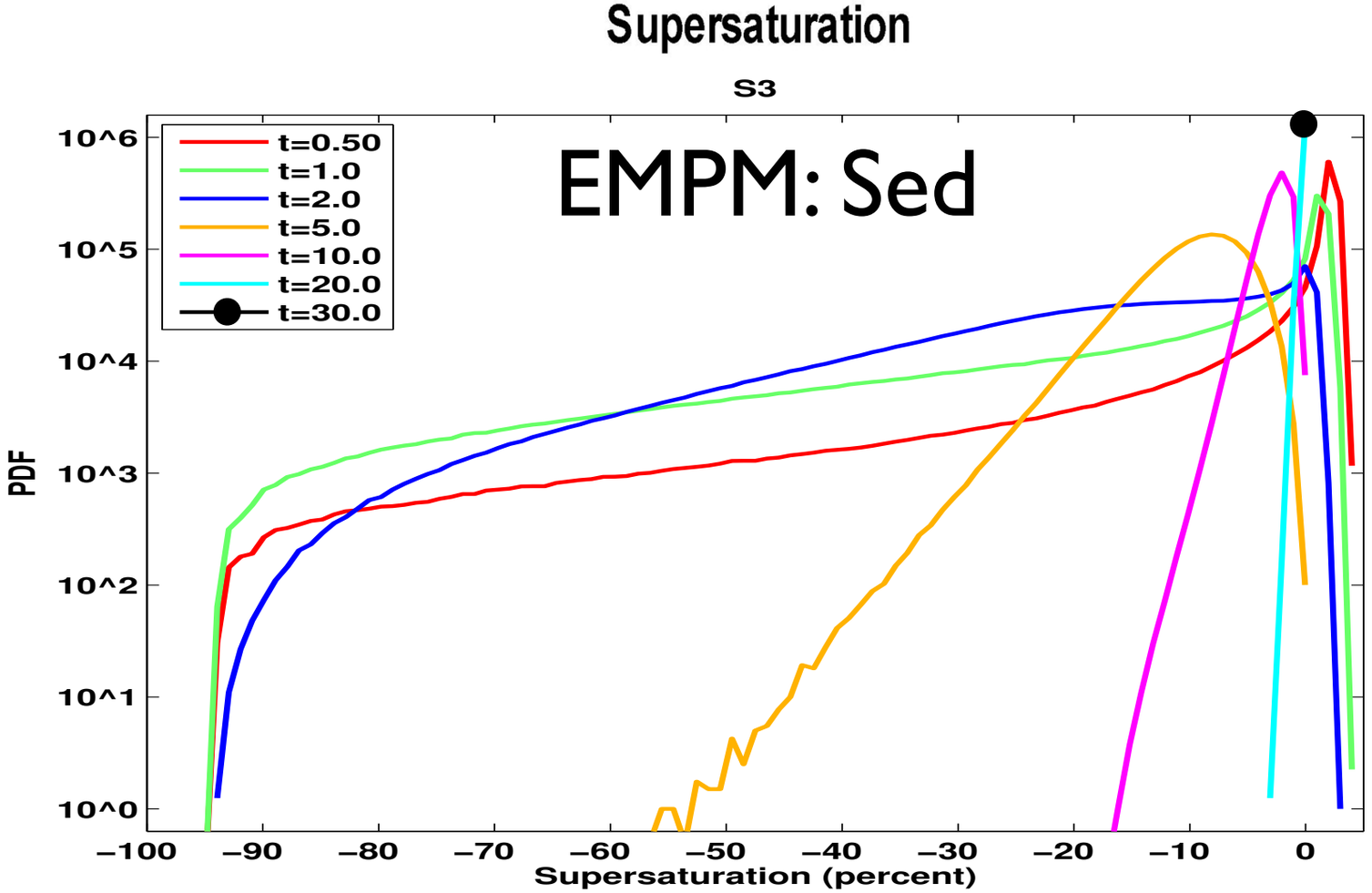
Super-saturation at droplets.



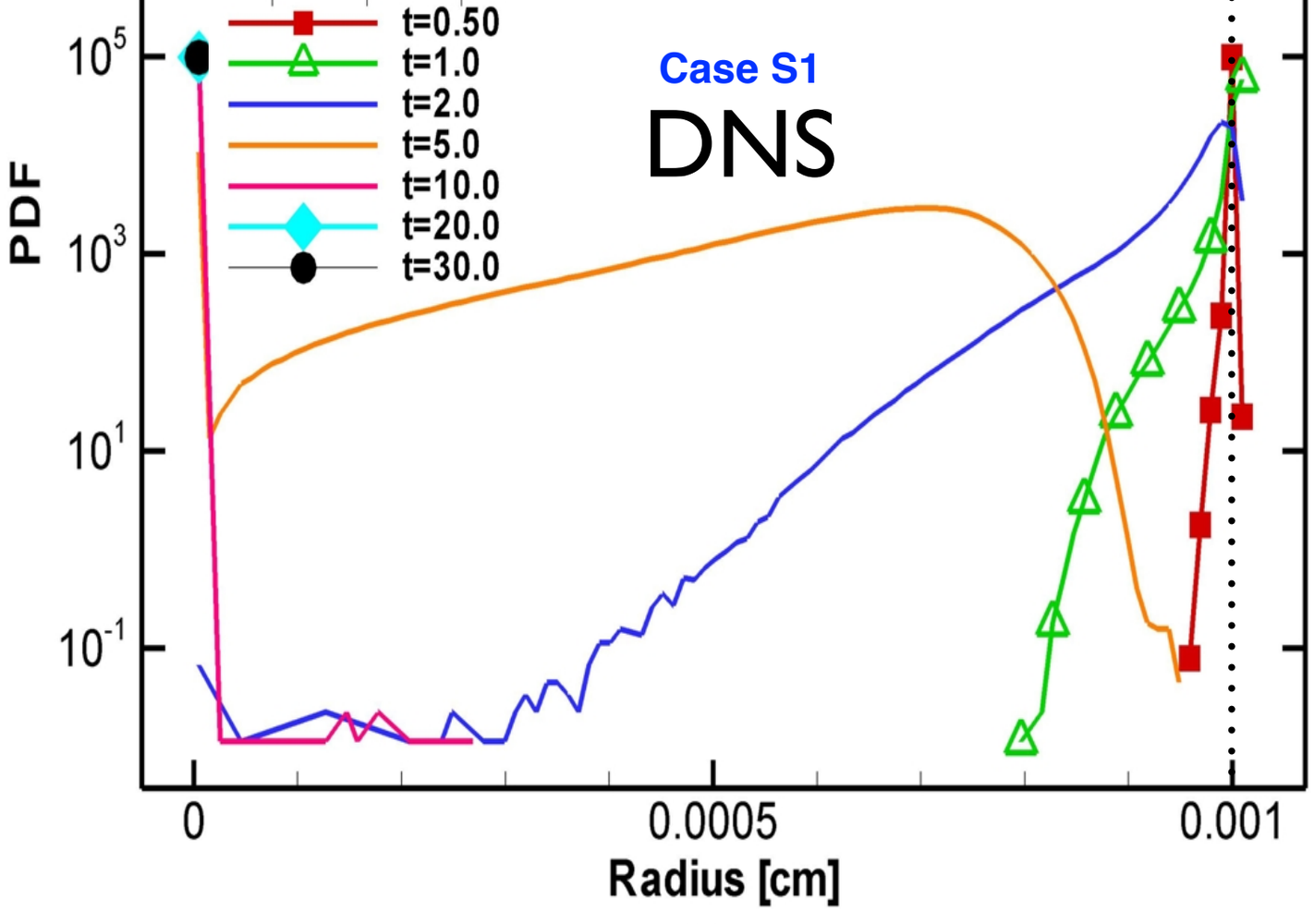
Droplets encounter less very dry air.

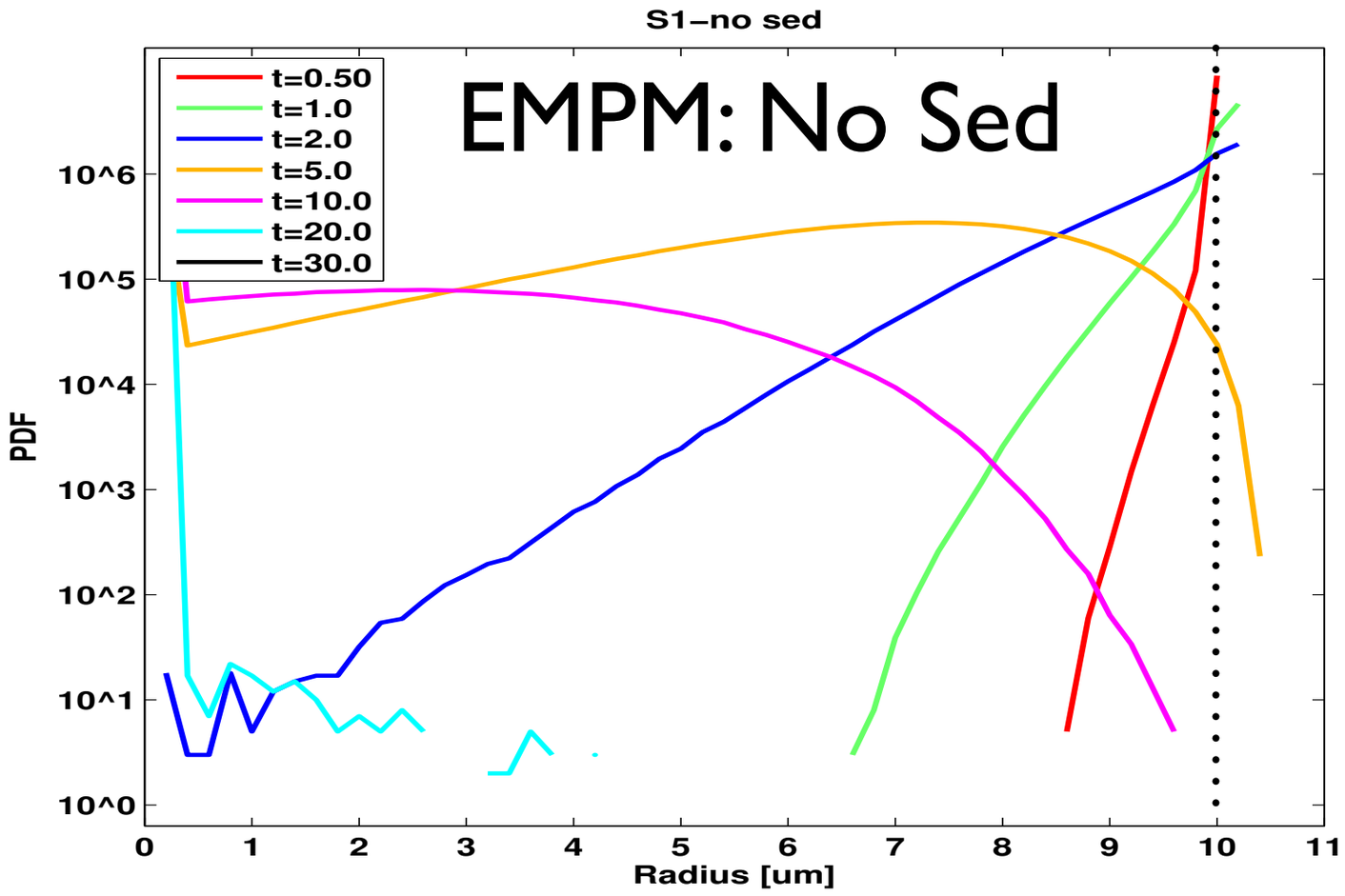


Super-saturation at droplets.



Droplets encounter more very dry air.





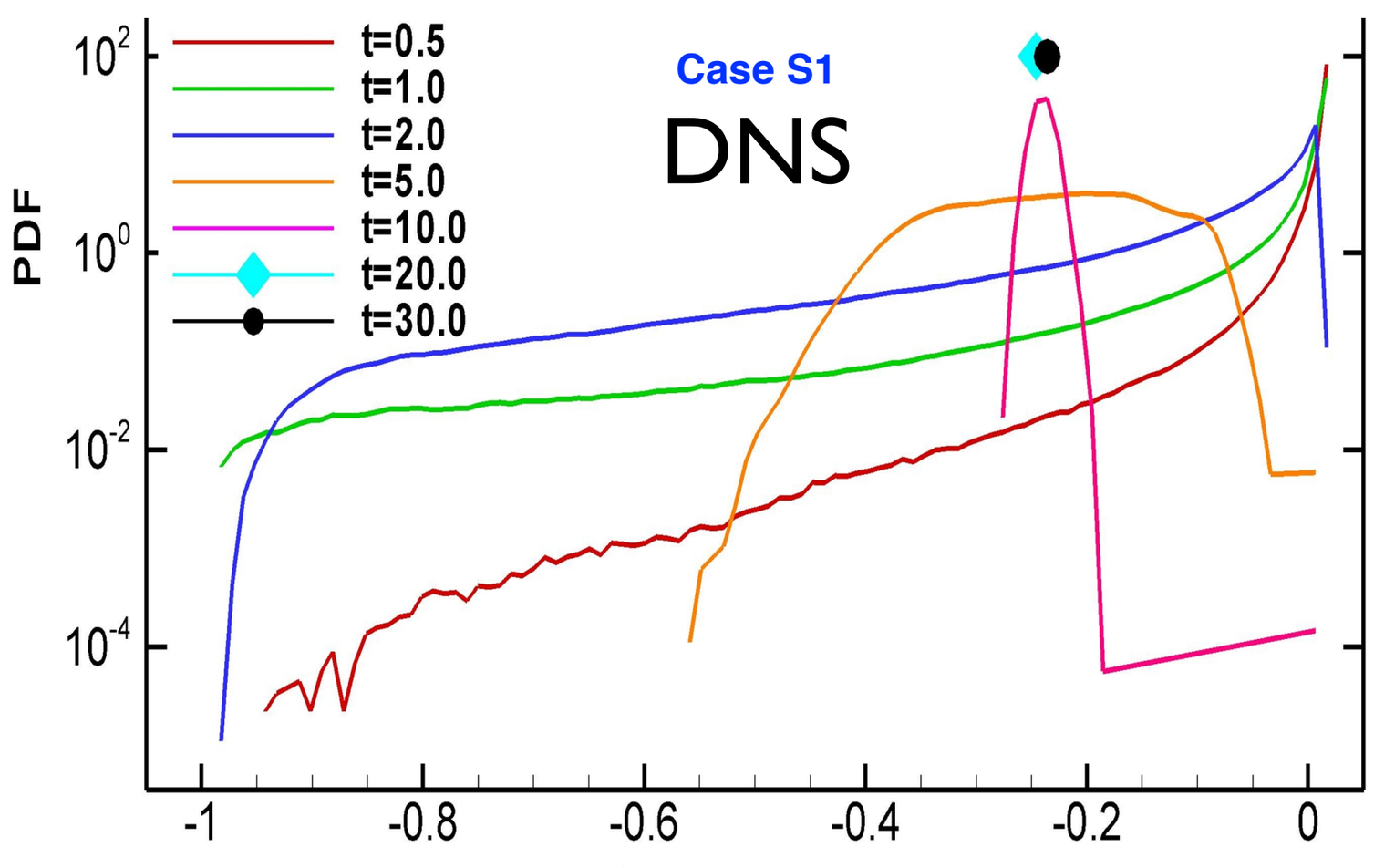
Initial droplet radius = 10 microns

All droplets completely evaporate by 30 s.

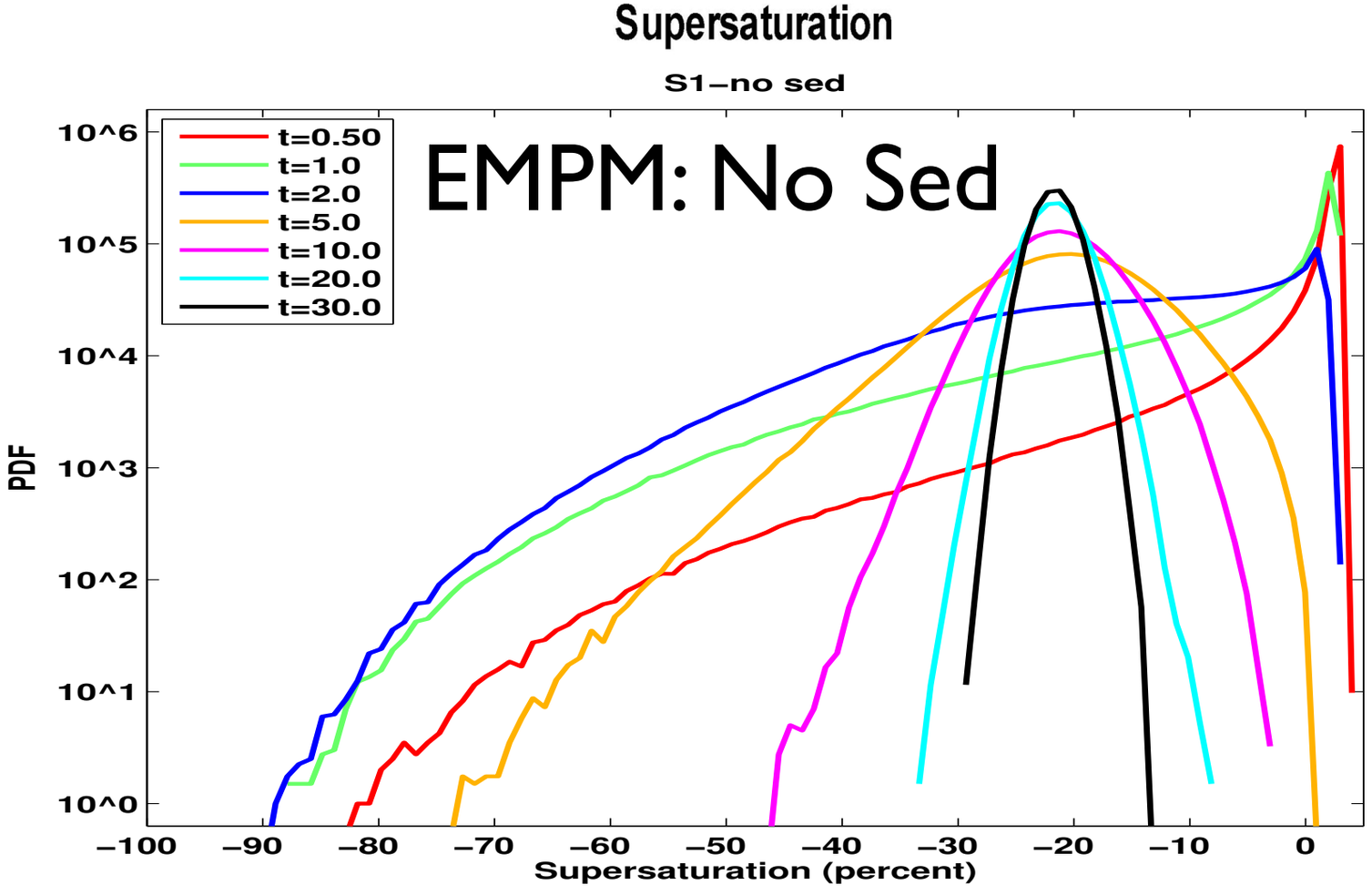
Some droplets grow initially in both.

In EMPM, droplets evaporate faster than in DNS to 2 s, then slower.

Wider DSD at all times



Super-saturation at droplets (including completely evaporated ones)



Droplets encounter less very dry air.

Slower mixing.

Example of EMPM results for larger scales not accessible to DNS.

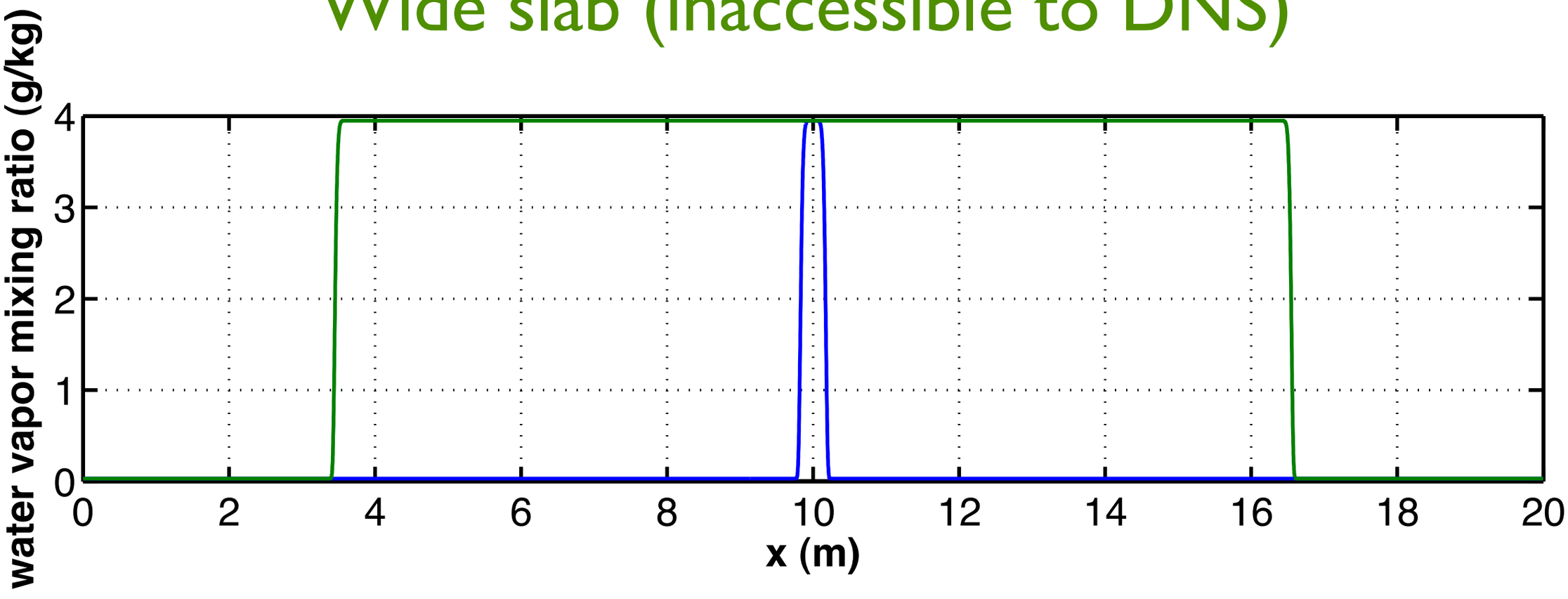
- DNS cost ~ N^3, EMPM ~N.

- Example: Increasing domain size from 0.5 m to 10 m is an increase of 20^3 = 8000 for DNS, but only 20 for EMPM.

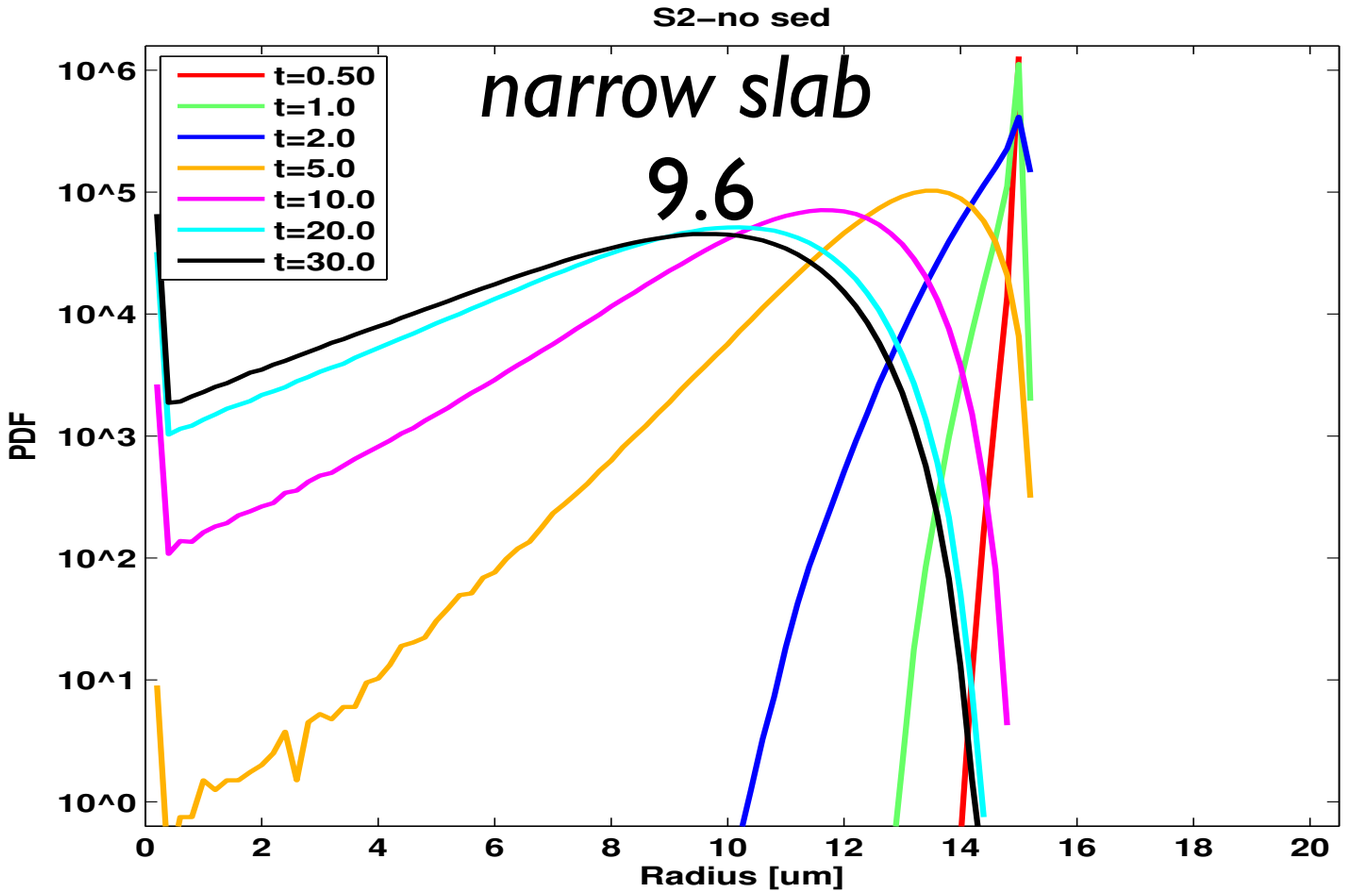
- Due to the increased mixing time, there is an additional factor of 20^(2/3)~7, for a total increase of 56,000, versus 140 for the EMPM.

[EMPM DNS case for 20-m eddy size?]

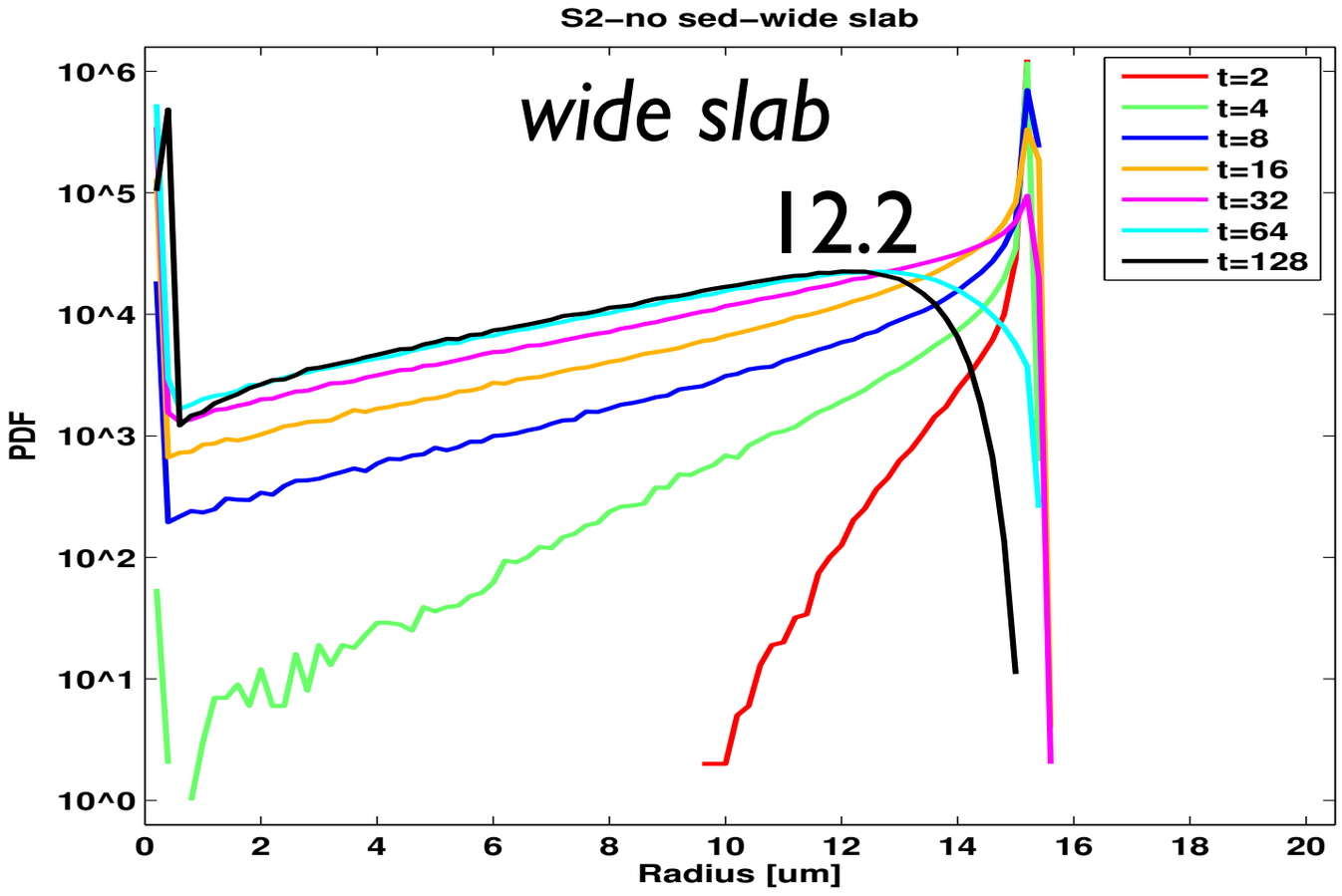
Wide slab (inaccessible to DNS)



Narrow slab (used in DNS)



Initial droplet radius is 15 microns.
Some droplets completely evaporate.



Similar but slower evolution.

Large droplet tail is less eroded.