High supersaturation in the wake of hydrometeors: Implications for ice nucleation and cloud invigoration

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Secondary nucleation occurs in the wakes of hydrometeors

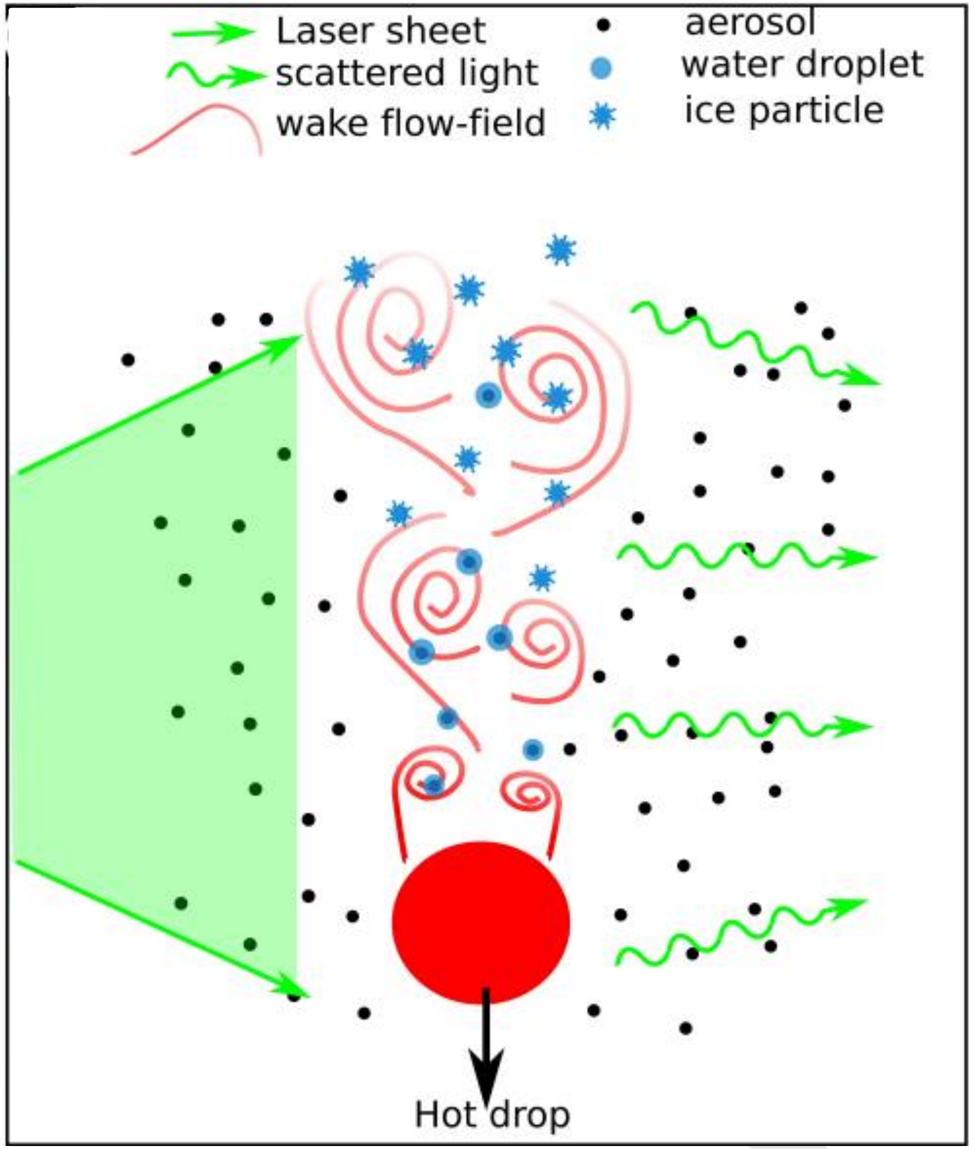
Here, "nucleation" equals activation of small aerosol particles or ice nucleating particles

Two essential aspects of the physics:

- Hydrometeors are not in thermal equilibrium with their environment (riming ice in supercooled convection or melting ice below the 0 C level)
- Hydrometeors are falling rapidly, leaving a turbulent wake that efficiently mixes water vapor and heat

Prabhakaran et al. GRL (2020)

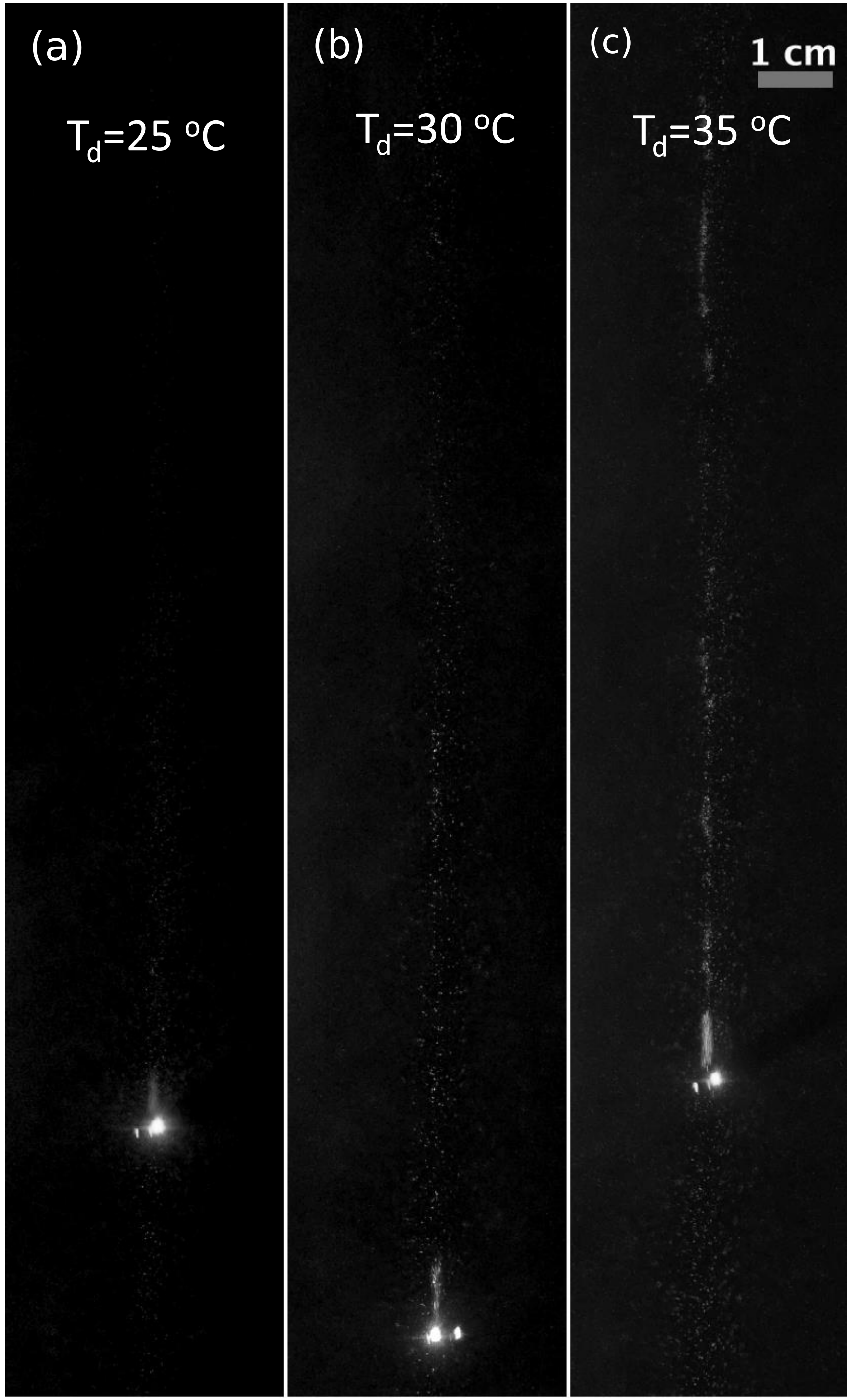
Concept was demonstrated in the Pi Chamber



Observe droplet activation or ice nucleation in the wake of large, warm falling drops.

Illuminate the wake with a laser light-sheet.

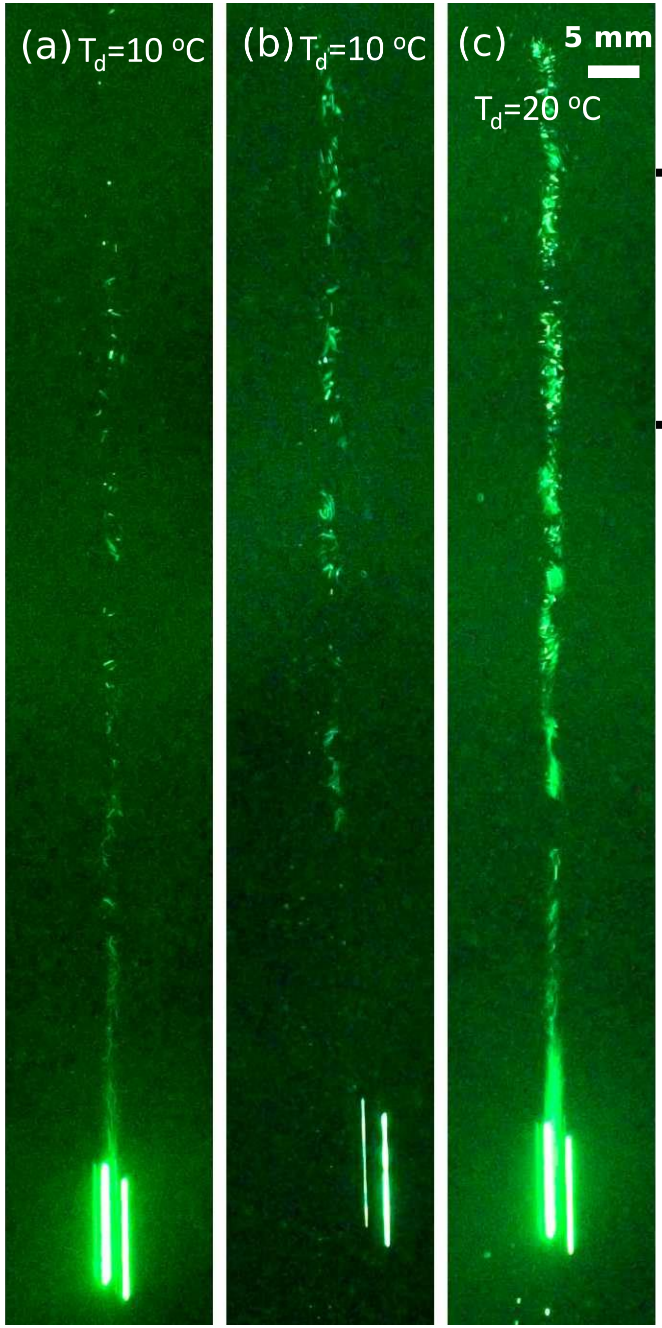
Prabhakaran et al. GRL (2020)



$T_a \approx 11\ ^oC$
RH≈90%
$N_{CN} \approx 2x10^4$ per cm^3

NaCl aerosol

Cold condition experiments



T_a≈-18 °C
RH≈60%
N_{CCN}≈10^4 per cm^3
Snomax aerosol

T_a≈-18 °C
RH≈80%
N_{CCN}≈10^4 per cm^3
AgI aerosol

Rate at which cloud is exposed to high wake supersaturations

- Volume (rate) swept by a hydrometeor = $\varepsilon\sigma u$

ε = wake growth factor, cross-sectional area $\sigma = \pi r^2$, u = fall velocity

- Total volume swept by n hydrometeors = $n\varepsilon\sigma u$

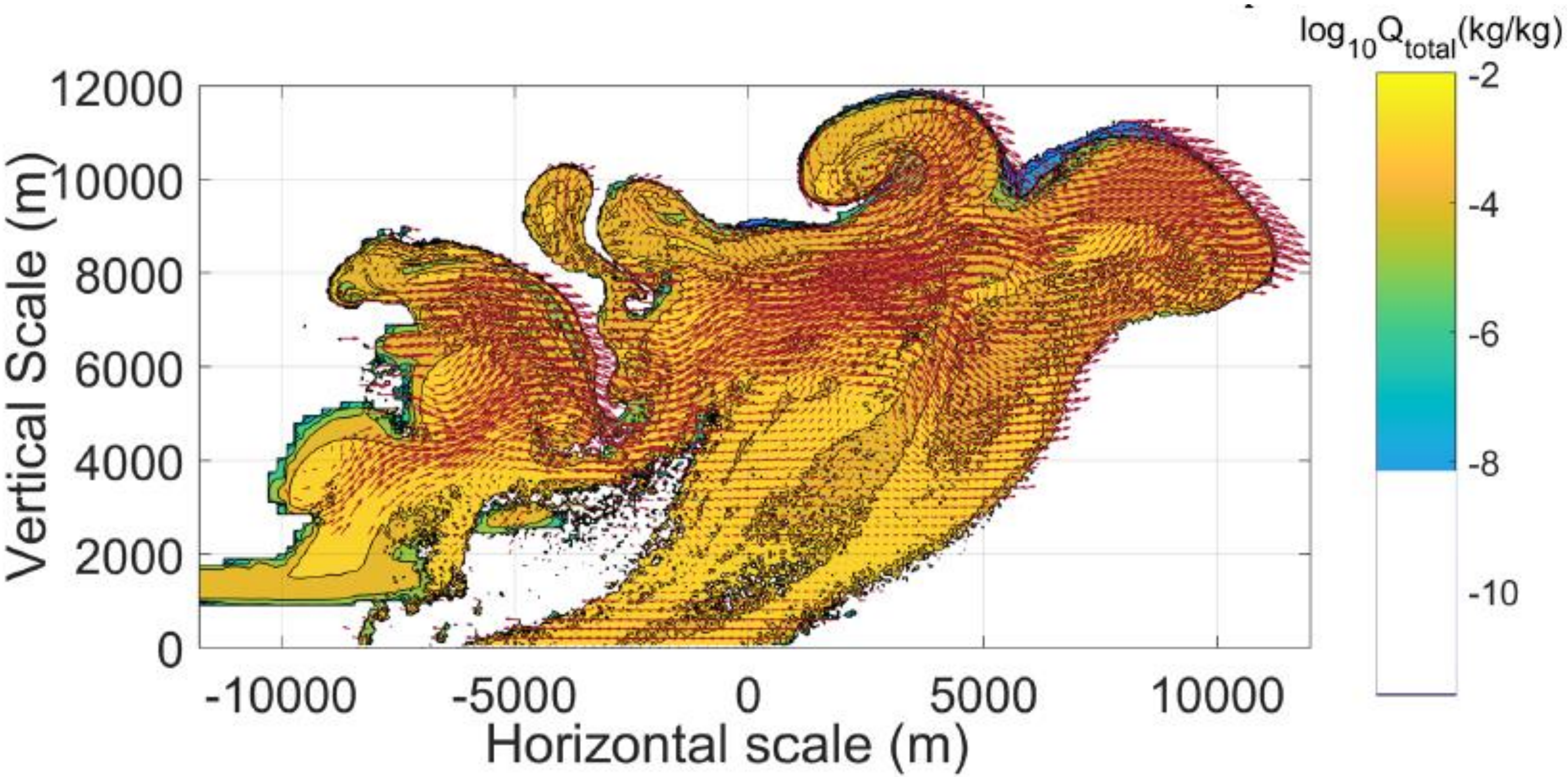
n = is the number density of the hydrometeors

$\Rightarrow$Total number of aerosol particles exposed to very high supersaturation (per sec) = $n^* \, n\varepsilon\sigma u$

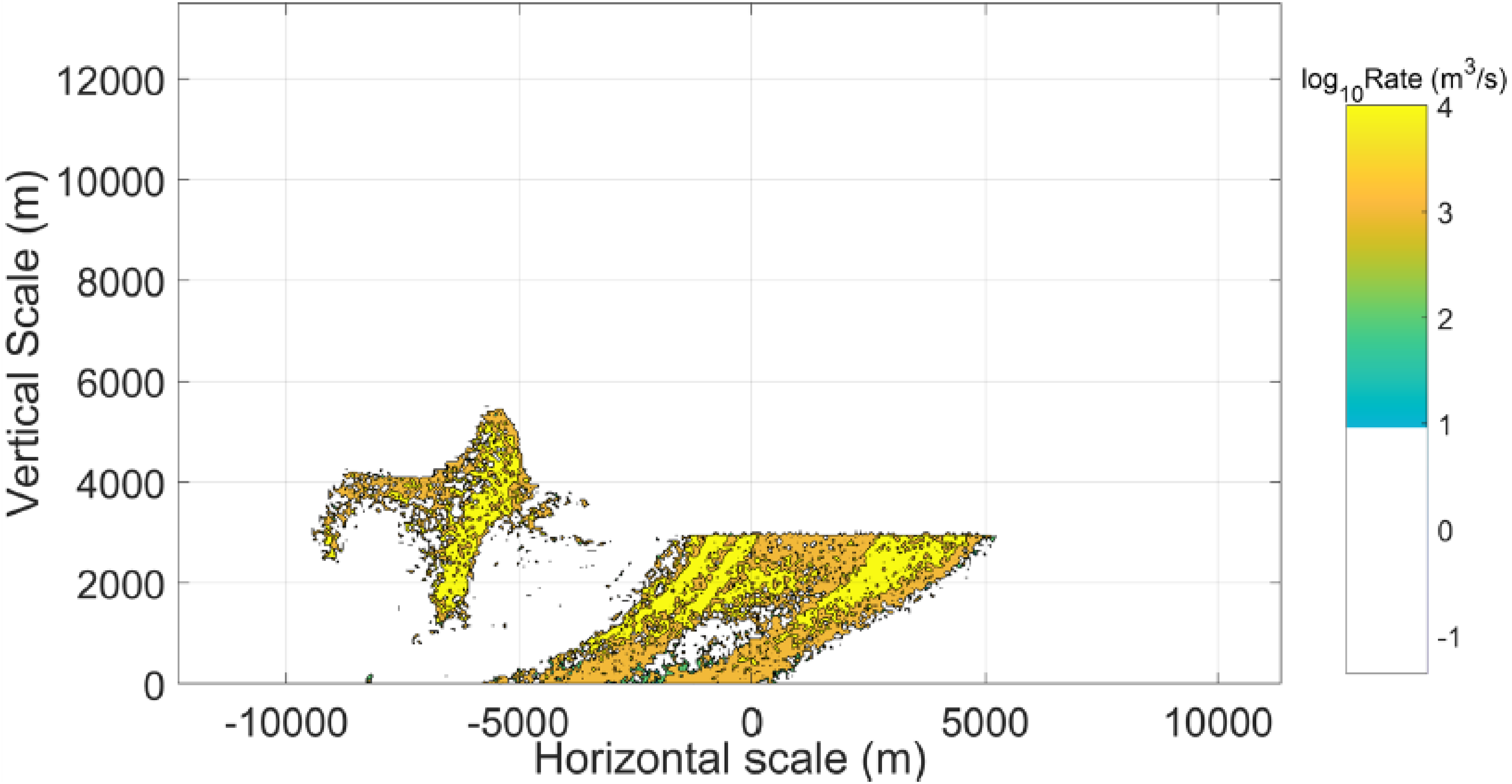
n* - is the number of unactivated aerosol

- $\tau = (n\varepsilon\sigma u)^{-1}$ is a time-scale for exposing cloud volume to the supersaturated wake
- Using realistic graupel size distribution, $\tau \approx$ 100-150 seconds

Squall line simulation with Lagrangian ice (McSnow)



Rate of exposure of cloud to wake supersaturation:
τ varies **between 1 and 7 minutes, same order as residence time in updraft**



Summary

- Aerosol activation and ice nucleation caused by evaporative supersaturation in the wake of a warm drop was observed under laboratory conditions.
- Estimates show that this mechanism is relevant in the wake of hydrometeors in wet convective clouds.
- Model calculations suggest that a significant volume of a convective cloud can be exposed to very high supersaturation within a few minutes.
- This is a mechanism for greatly increasing the number of activated droplets in deep convective clouds, and therefore has implications for invigoration.

See Prabhakaran et al. GRL (2020) for more details