Karlsruher Institut für Technologie

Ice Nuclei Research Unit

Parameterising Contact Ice Nucleation

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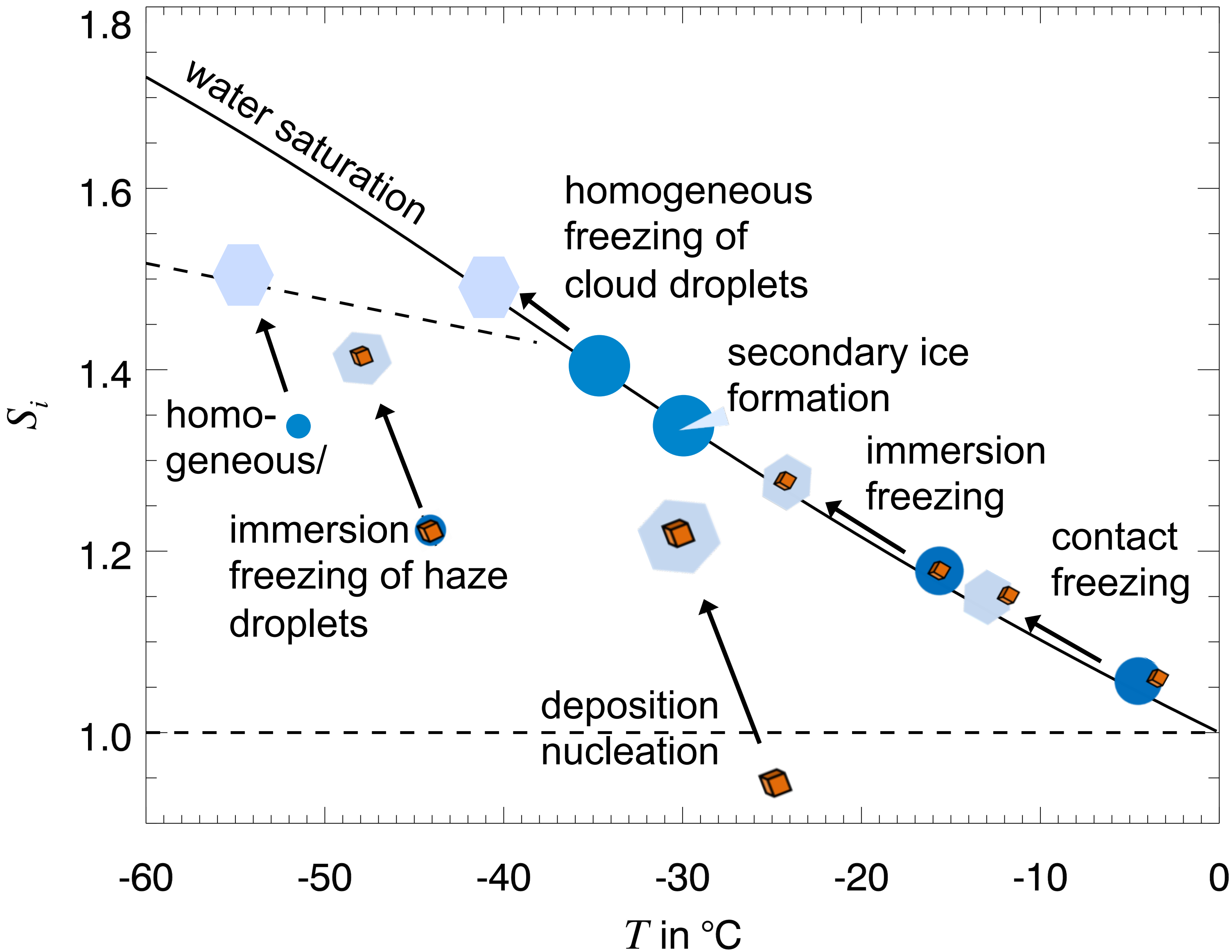
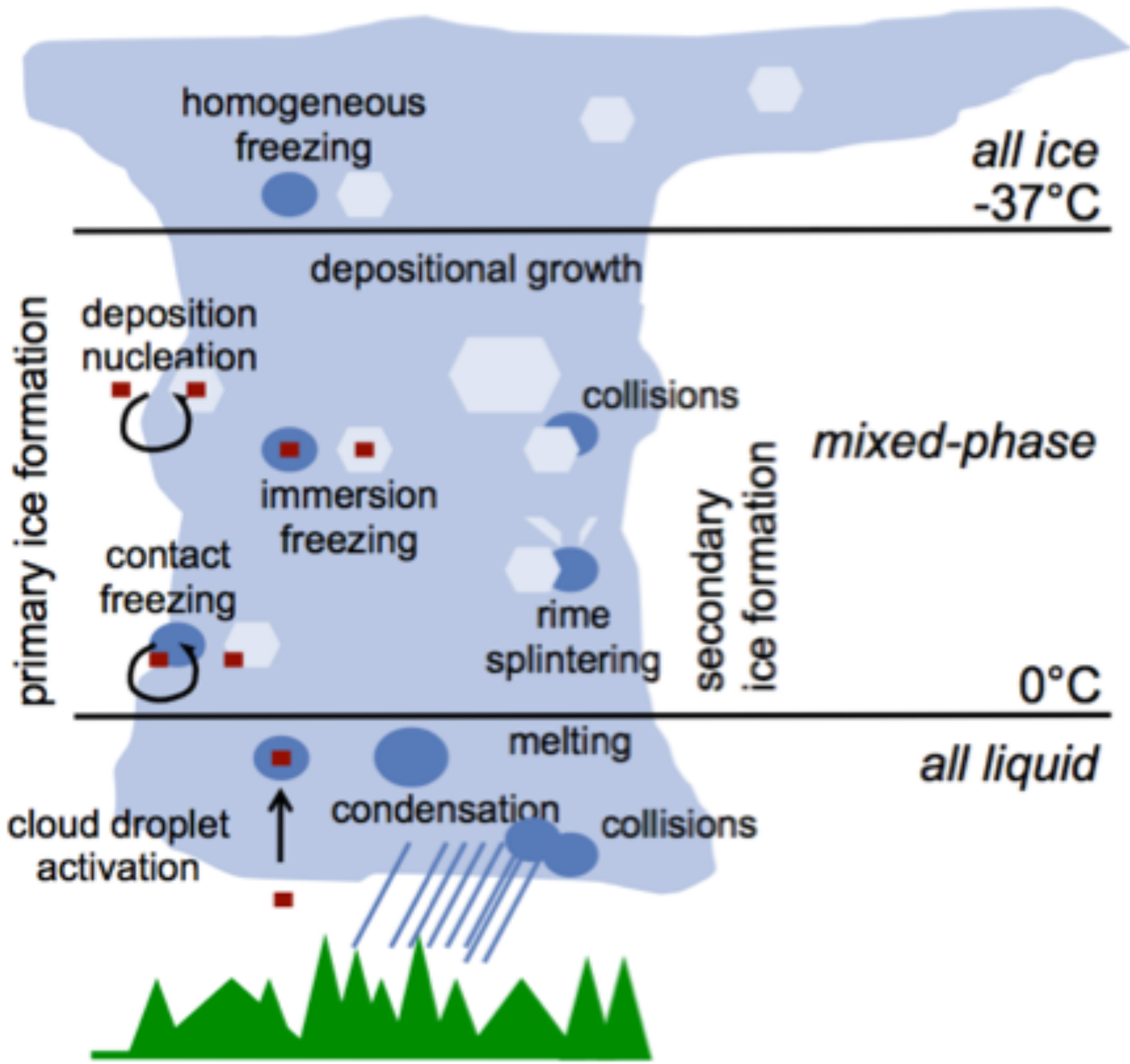
INSTITUTE OF METEOROLOGY AND CLIMATE RESEARCH

Heterogeneous Ice Nucleation Modes



Heterogeneous Ice Nucleation

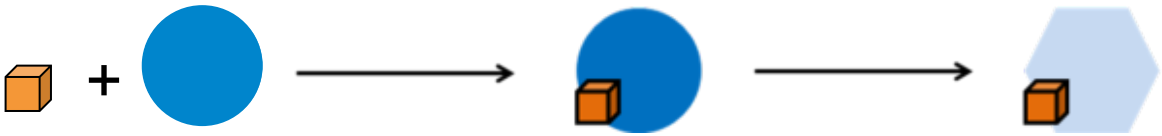


Aims of INUIT (Ice Nucleation Research Unit) RP5

- Investigate **the frequency of occurrence and location** of the various heterogeneous ice nucleation mechanisms in **different mix-phase cloud regimes** over Europe.

- Existing aerosol-dependent parameterisations:
  - Niemand et al. (2012) / Ullrich et al (subm.) for **immersion freezing** on dust.
  - Steinke et al. (2015) / Ullrich et al (subm.) for **deposition nucleation** on dust and soot
  - What about **contact nucleation**?

Parameterising contact nucleation



$$\frac{dN_{INP}}{dt} = \iint K_{coll} \times N_r \times nFE \times A_a \times N_a \, da\, dr$$

$$K_{coll} = \pi(r+a)^2 \times CE \times |V_r - V_a|$$

Parameterising contact nucleation

Karlsruhe Institute of Technology

Normalised Freezing Efficiency:

Temperature dependent fit from laboratory data.

$$\frac{dN_{INP}}{dt} = \iint K_{coll} \times N_r \times nFE \times A_a \times N_a \, da\, dr$$

$$K_{coll} = \pi (r+a)^2 \times CE \times \left| V_r - V_a \right|$$

Collection Efficiency:

Theoretical expressions including **Brownian motion**, **Phoretic forces**, **inertial impaction**, **electrical effects**.

Theoretical Collision Efficiency

- Sum of forces due to:
  - Brownian motion
  - Inertial impaction and interception
  - Electroscavenging
  - Phoretic forces: Thermophoresis and Diffusiophoresis

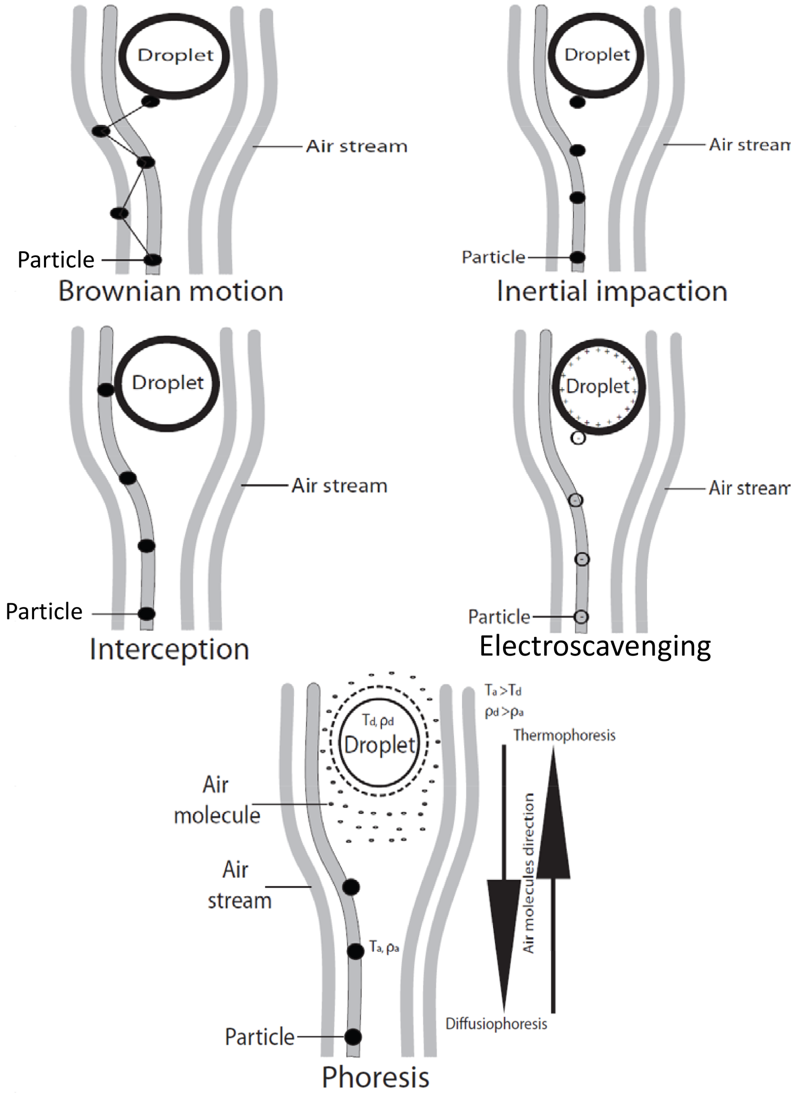
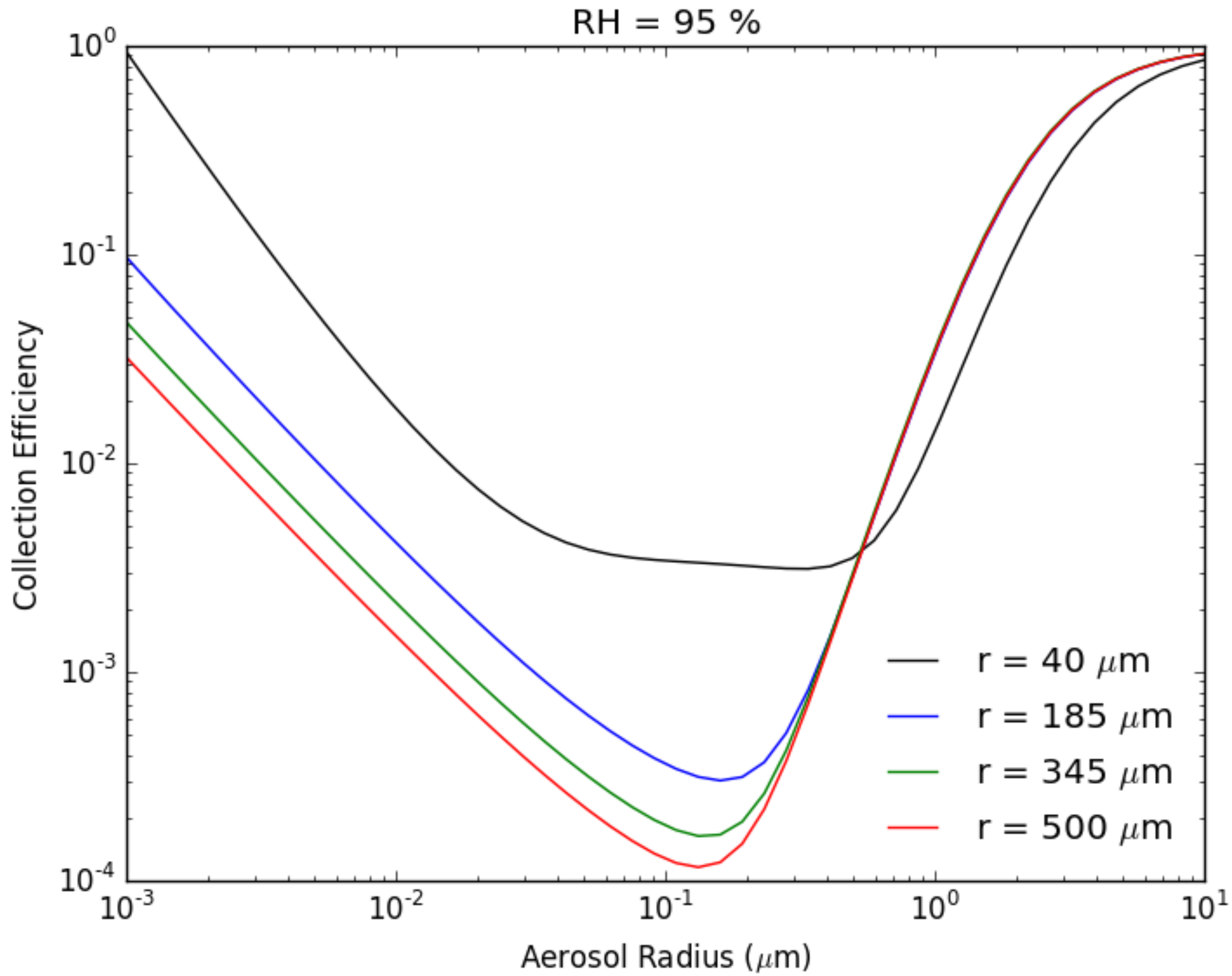


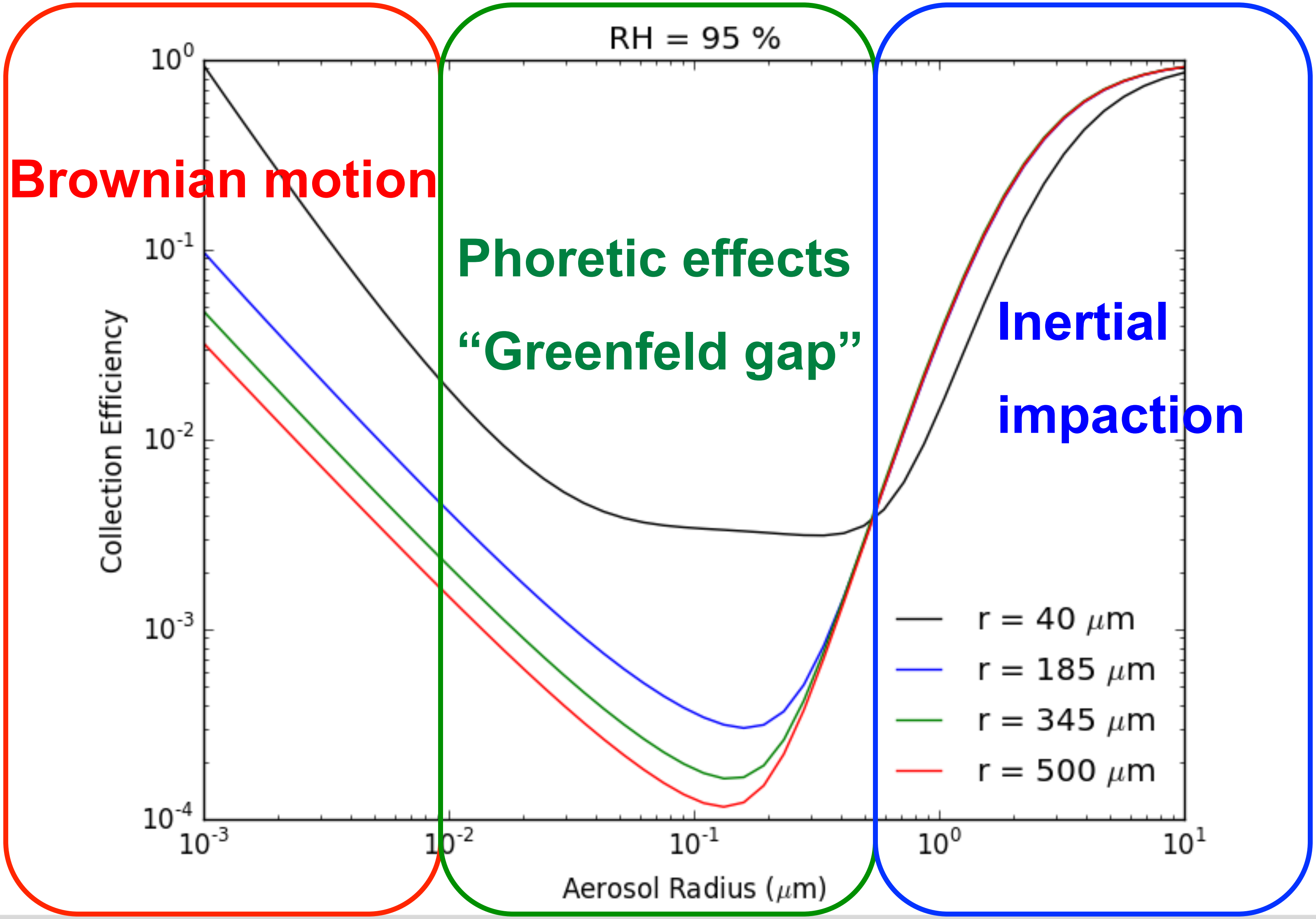
Figure from Ladino et al. (2013)

Theoretical Collision Efficiency: Drop Radius



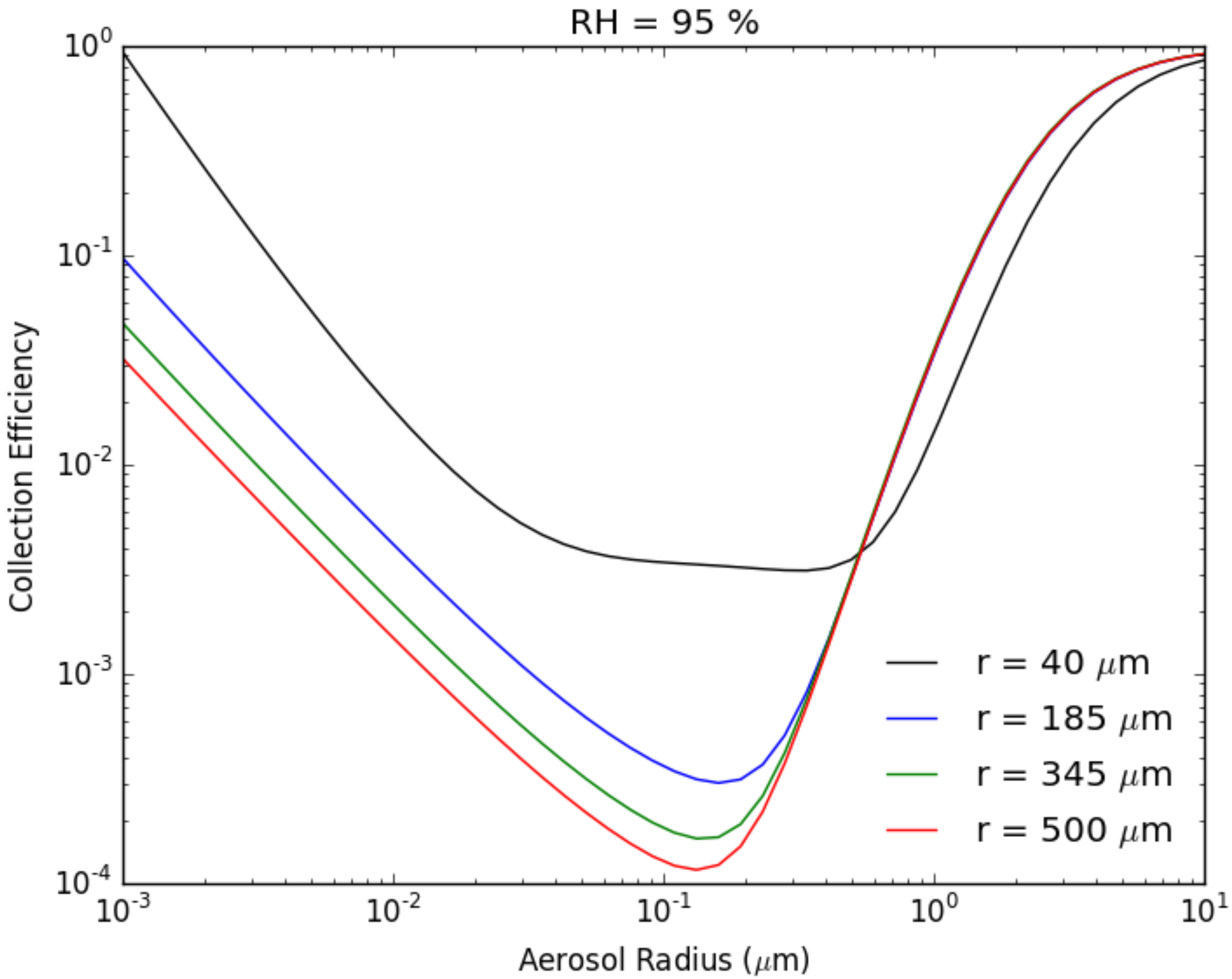
Wang et al (1978), Park et al (2005), Wang et al (2010)

Theoretical Collision Efficiency: Drop Radius



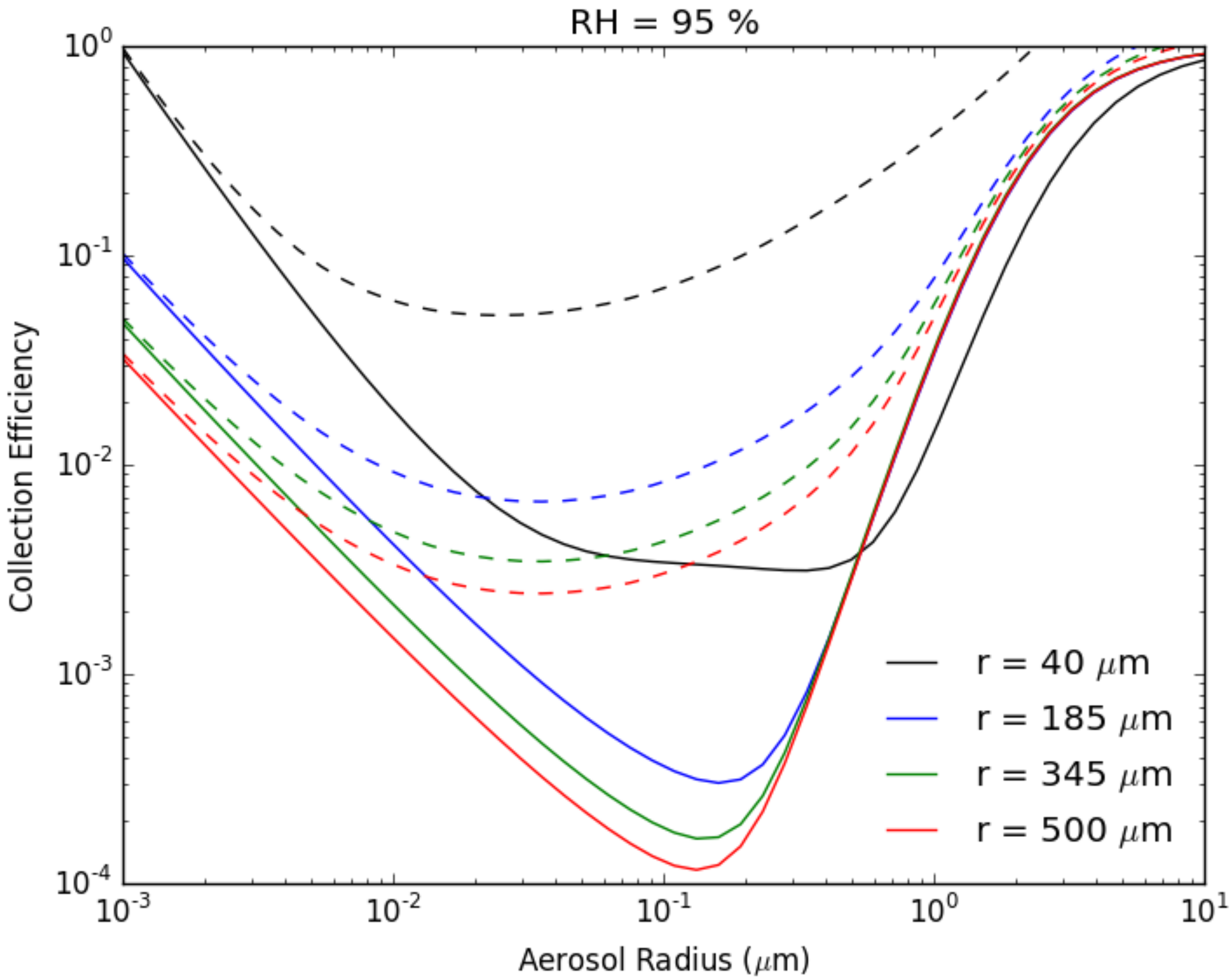
Wang et al (1978), Park et al (2005), Wang et al (2010)

Theoretical Collision Efficiency: Drop Radius



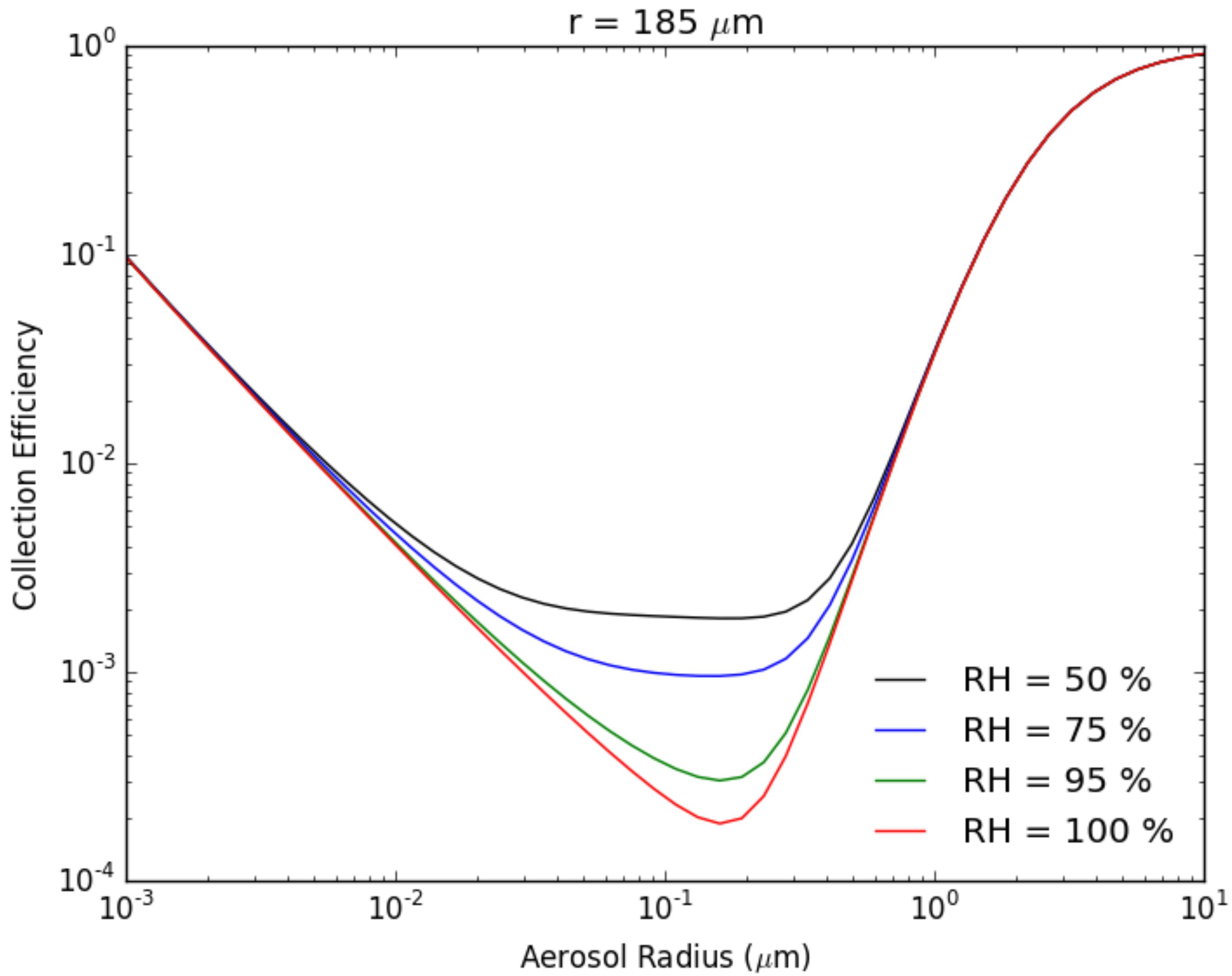
Wang et al (1978), Park et al (2005), Wang et al (2010)

Theoretical Collision Efficiency: Charge Effect



Wang et al (1978), Park et al (2005), Wang et al (2010)

Theoretical Collision Efficiency: RH



Wang et al (1978), Park et al (2005), Wang et al (2010)

Parameterising contact nucleation

Normalised Freezing Efficiency:

Temperature dependent fit from laboratory data.

$$\frac{dN_{INP}}{dt} = \iint K_{coll} \times N_r \times nFE \times A_a \times N_a dadr$$

$$K_{coll} = \pi(r+a)^2 \times CE \times |V_r - V_a|$$

Collection Efficiency:

Theoretical expressions including **Brownian motion**, **Phoretic forces**, **inertial impaction**, **electrical effects**.

Parameterising contact nucleation

$$nFE = \frac{1}{A_a} \frac{\#\,freezing\ events}{\#\,collisions}$$

$$A_a : aerosol\ surface\ area$$

Normalised Freezing Efficiency:

Temperature dependent fit from laboratory data.

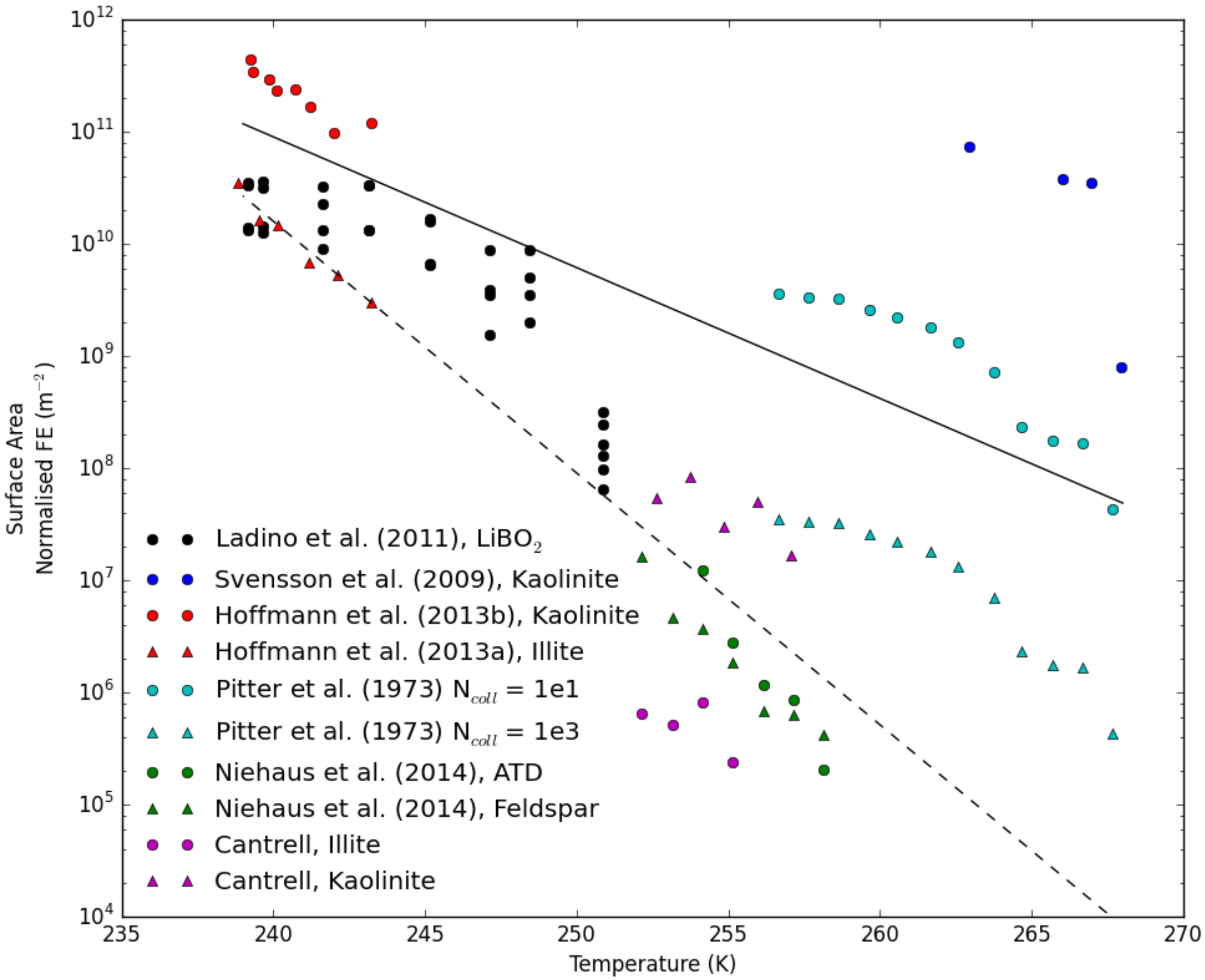
$$\frac{dN_{INP}}{dt} = \iint K_{coll} \times N_r \times nFE \times A_a \times N_a\, da\, dr$$

$$K_{coll} = \pi (r + a)^2 \times CE \times |V_r - V_a|$$

Collection Efficiency:

Theoretical expressions including **Brownian motion**, **Phoretic forces**, **inertial impaction**, **electrical effects**.

Laboratory Freezing Efficiency for different mineral dusts

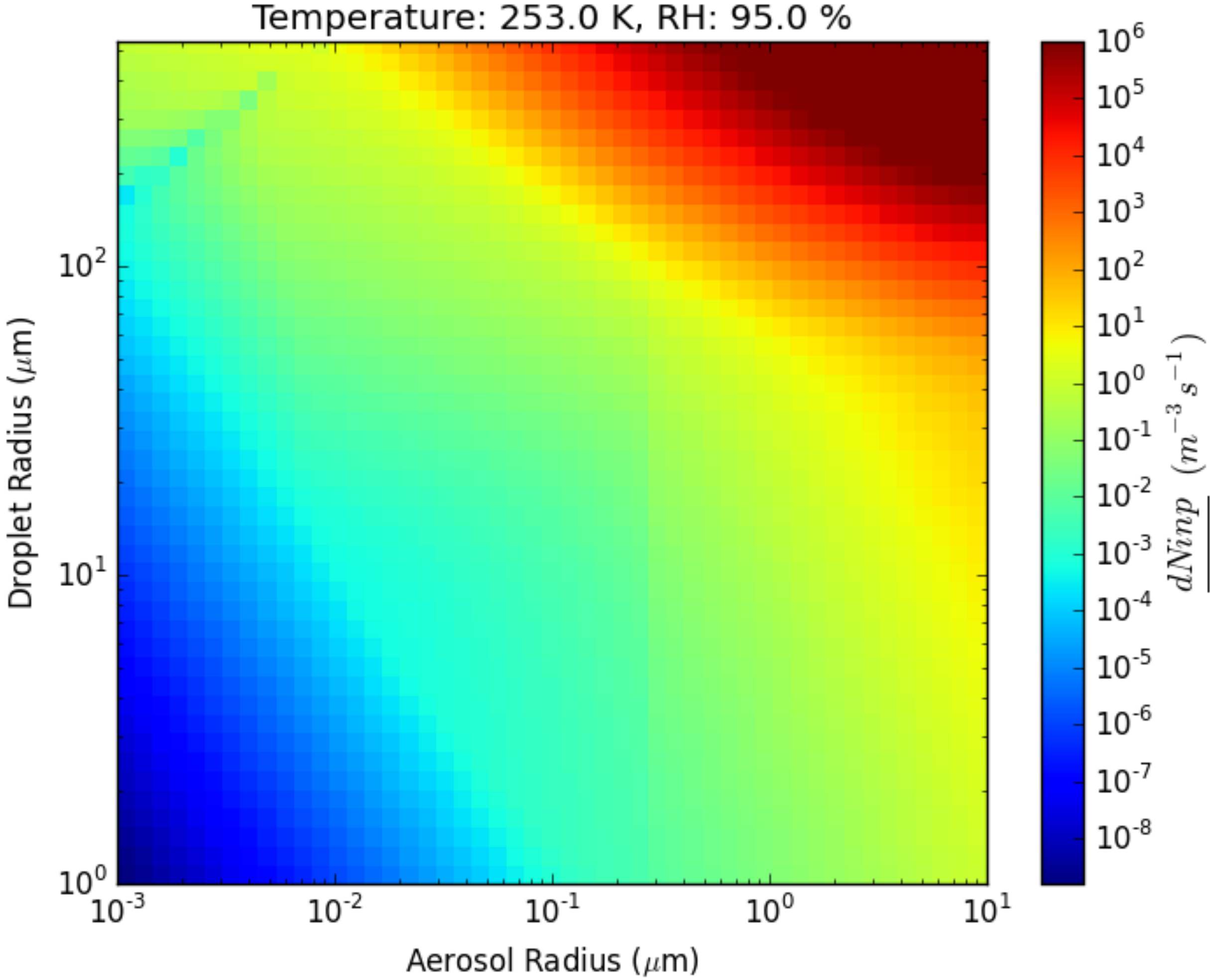


- Contact freezing experiments show enormous scatter
- **Solid line:**

$$nFE = A\exp(-B \times T)$$

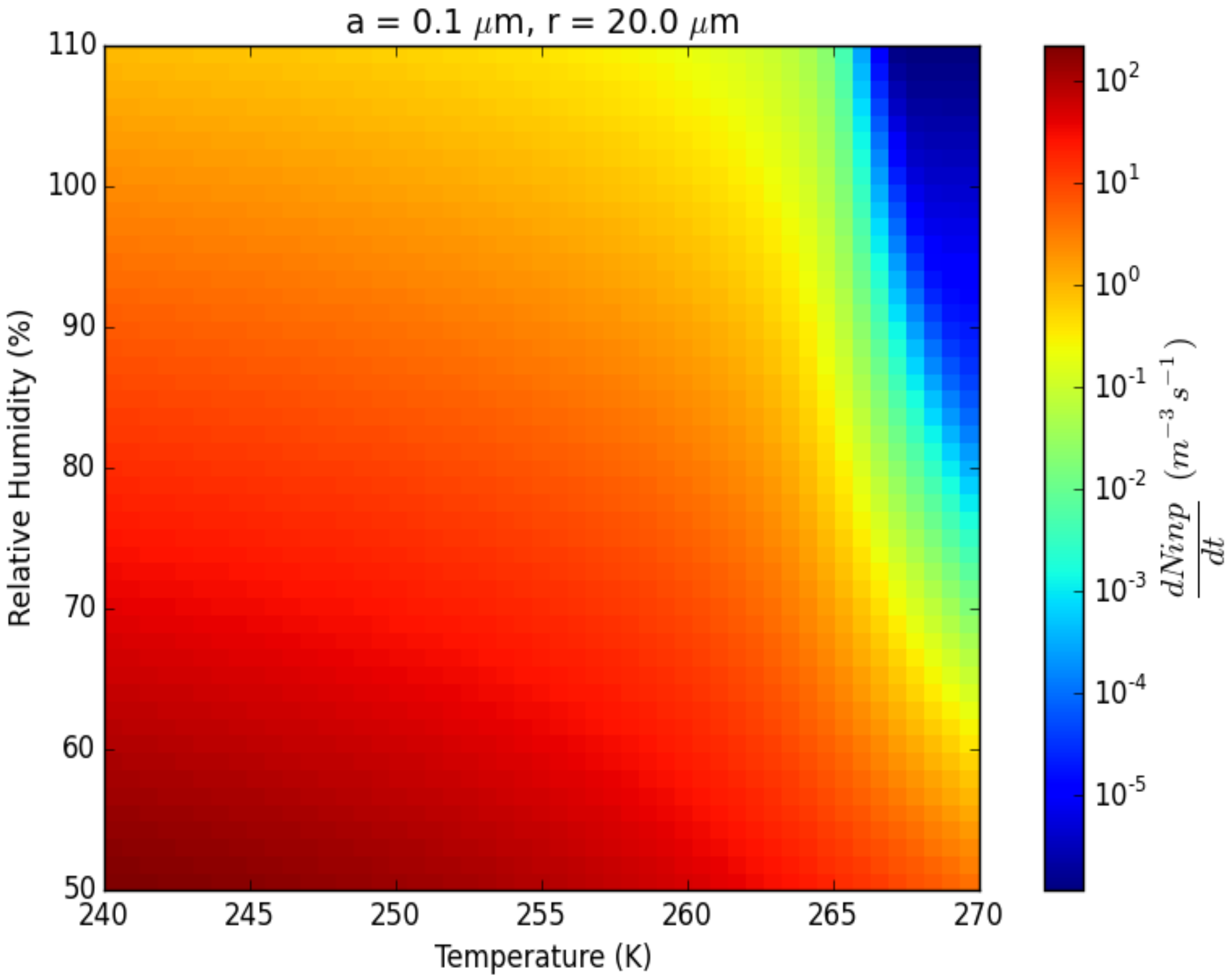
- **Dashed line:** Alternative fit for sensitivity studies

Contact Nucleation Rate: Drop & Aerosol Radius



- Highest nucleation rates for **large drop- large aerosol** interactions.
- **Small drop- small aerosols** have nucleation rate ~ 19 orders of magnitude lower.

Contact Nucleation Rate: Temp & RH

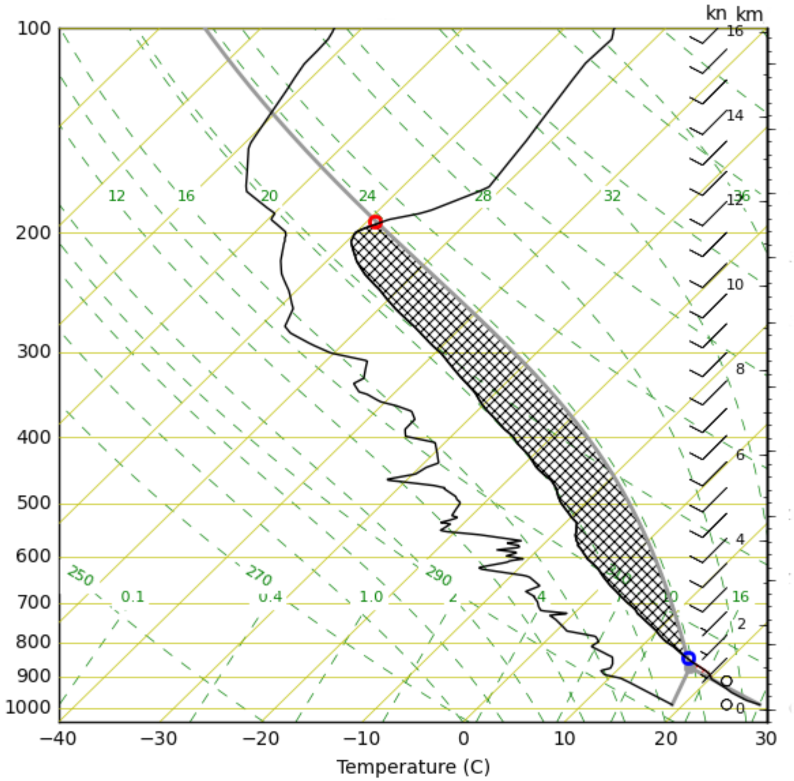


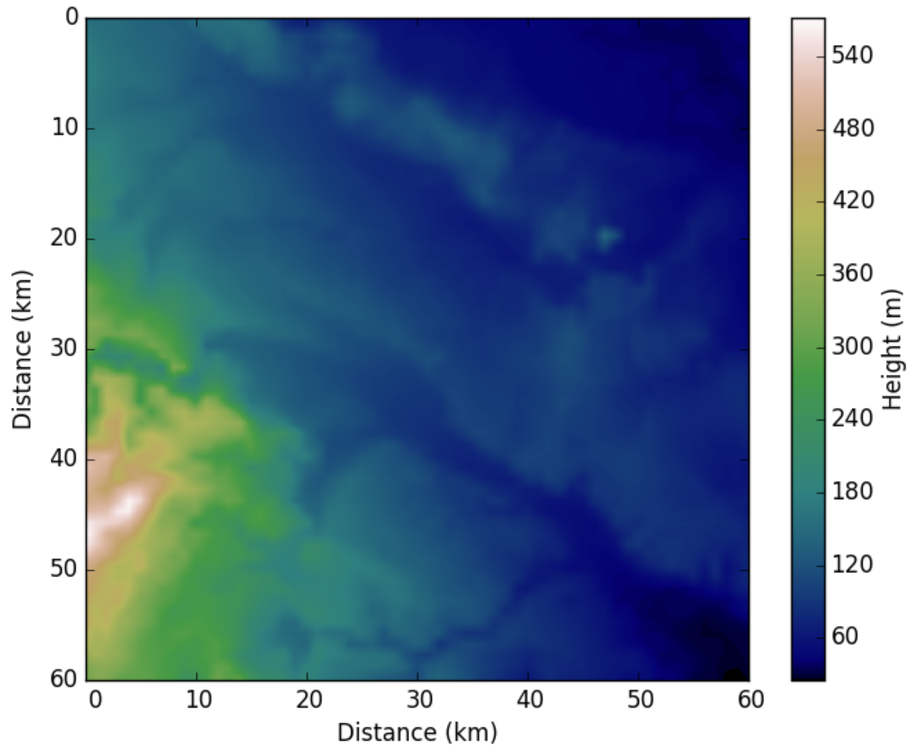
- Highest nucleation rates for **low RH conditions.**
- At higher RH, **nucleation rate is most sensitive to temperature.**

Preliminary results: Semi Idealised Convective Cloud

- COSMO model run **with very high horizontal resolution** (110 m) of a deep convective cloud.
- New **contact ice nucleation parameterisation**, Niemand et al. (2012) **immersion freezing**, and Steinke et al. (2015) **deposition nucleation** parameterisations.
- Sensitivity studies:
  - Soluble fraction of dust
  - Effect of electric charges
  - Temperature dependant fit
  - Comparison to other contact parameterisations

Model Configuration



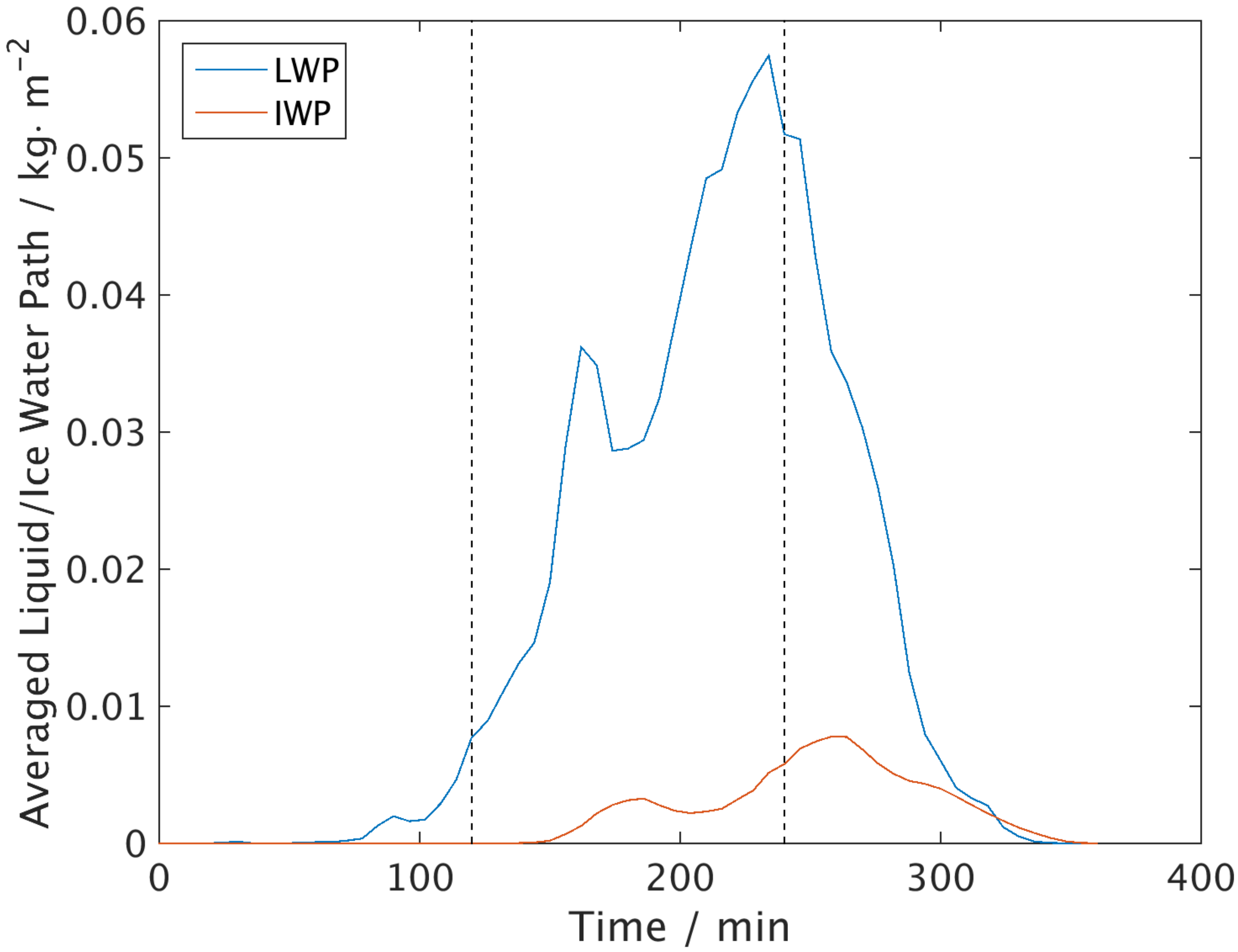


Initial sounding based on soundings at Idar-Oberstein, Essen and Beauchevain, 23.7.2013, with **1889 J/kg CAPE**

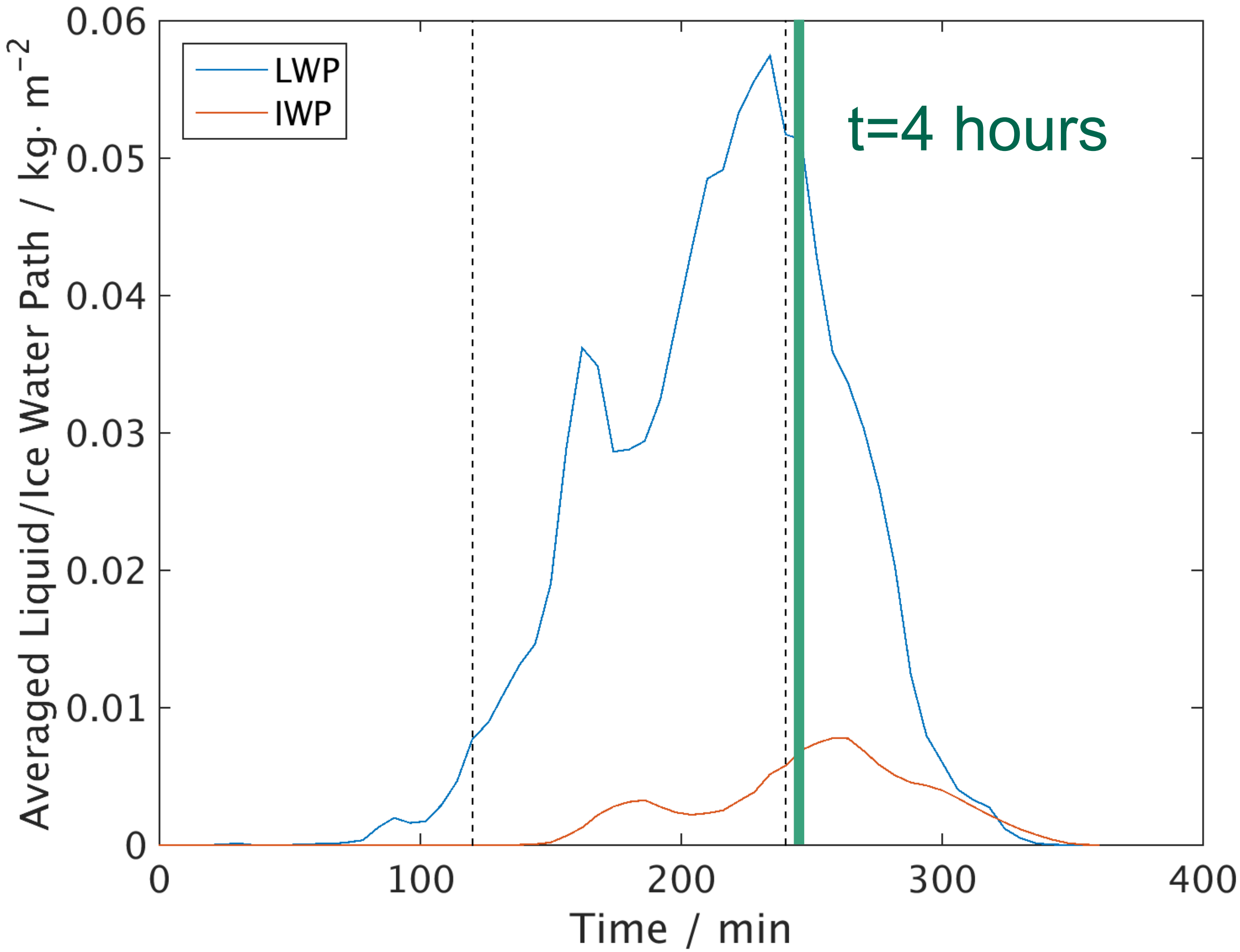
Real terrain from Juelich, Germany

Convection triggered by solar heating.

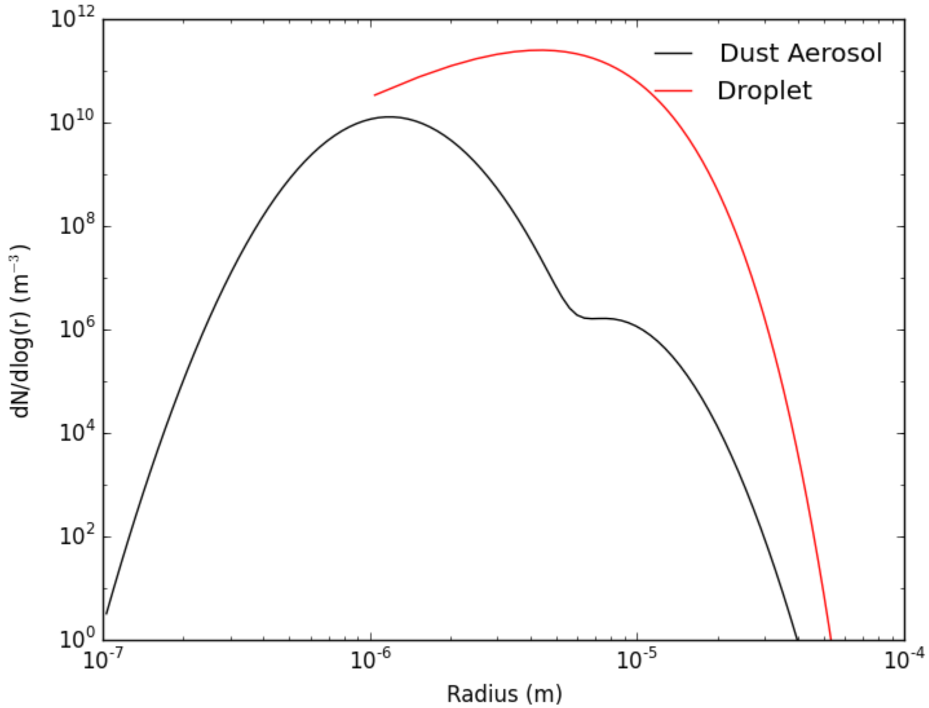
Cloud Evolution



Cloud Evolution



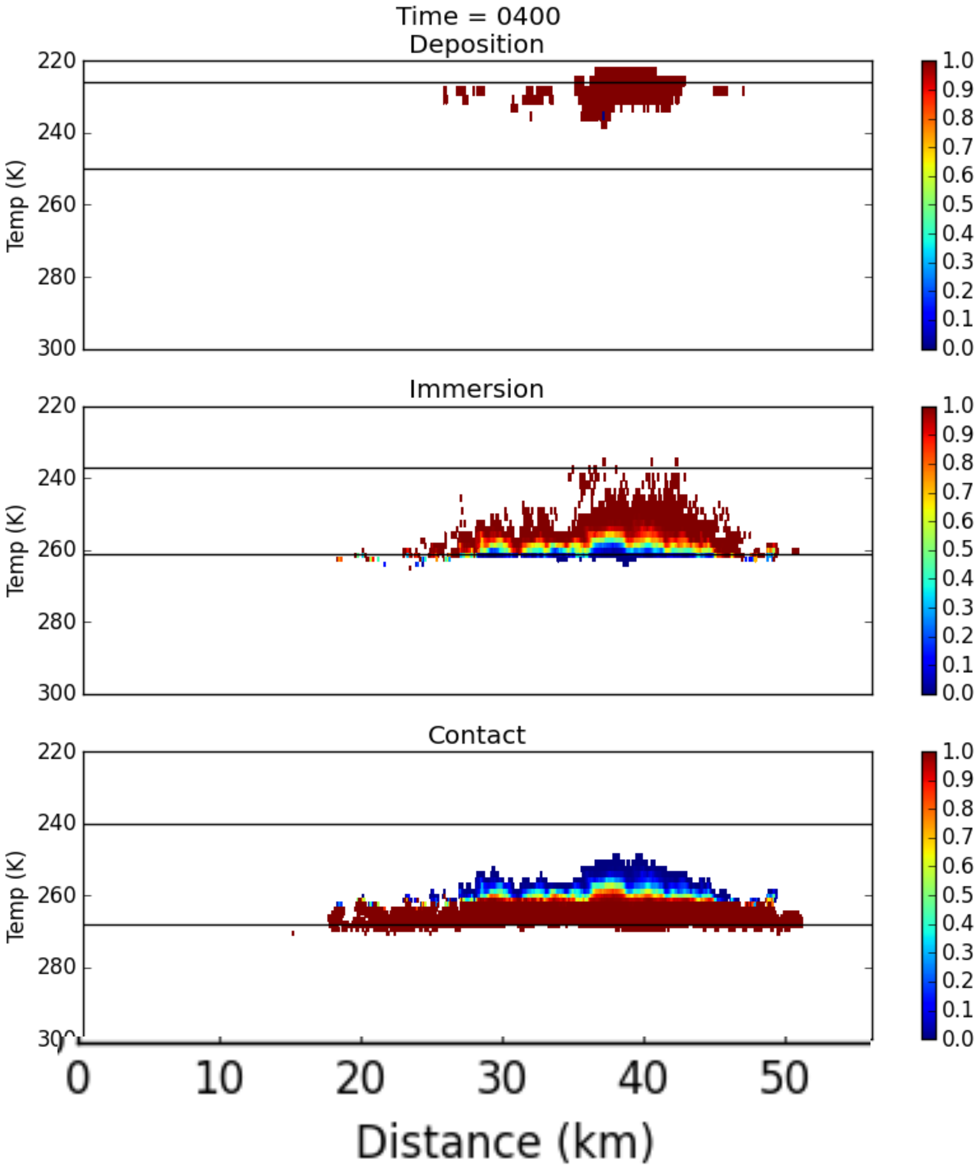
Dust and droplet size distributions



- **2 mode log-normal distribution** for dust aerosol particles (fitted to observations at JFJ; prescribed)
- **gamma distribution** for droplets predicted by the 2-moment scheme (in-cloud mean)

-> divided into 10 size bins for numerical integration

Modeled INP fraction

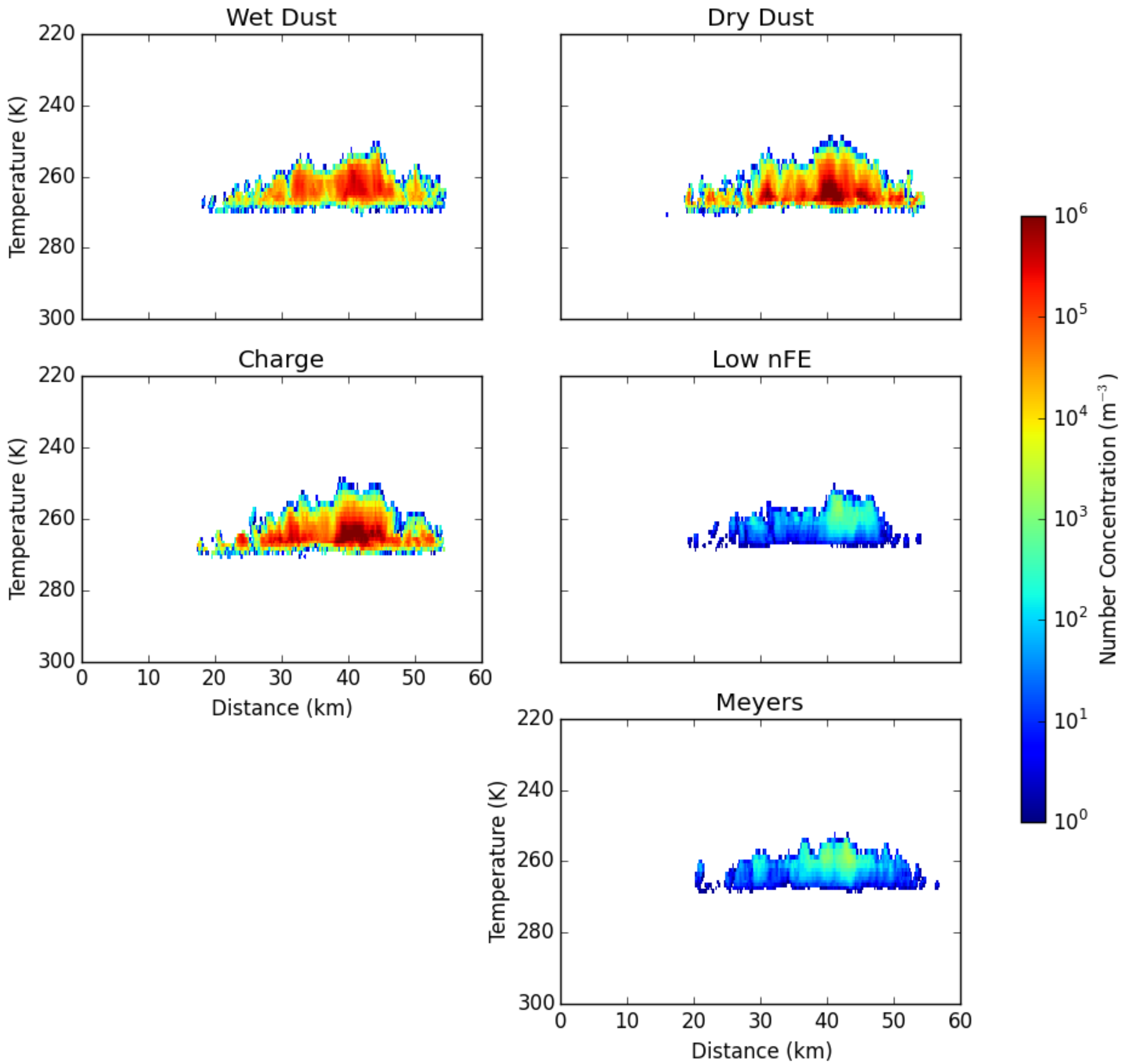


- At **~260 K, both contact and immersion freezing** contribute about 50%.

- At **~250 K, immersion dominates** (>80%) however **contact still occurs** (<20%).

- At **<230 K, supersaturation too small** for deposition nucleation to be significant.

Sensitivity experiments



- Soluble fraction of dust
  - 90:10 imm:contact
  - 10:90 imm:contact
- Effect of electric charges
  - ‘Thunderstorm’ level
- Temp dependent fit
  - Lower nFE fit
- Comparison to Meyers contact parameterisation

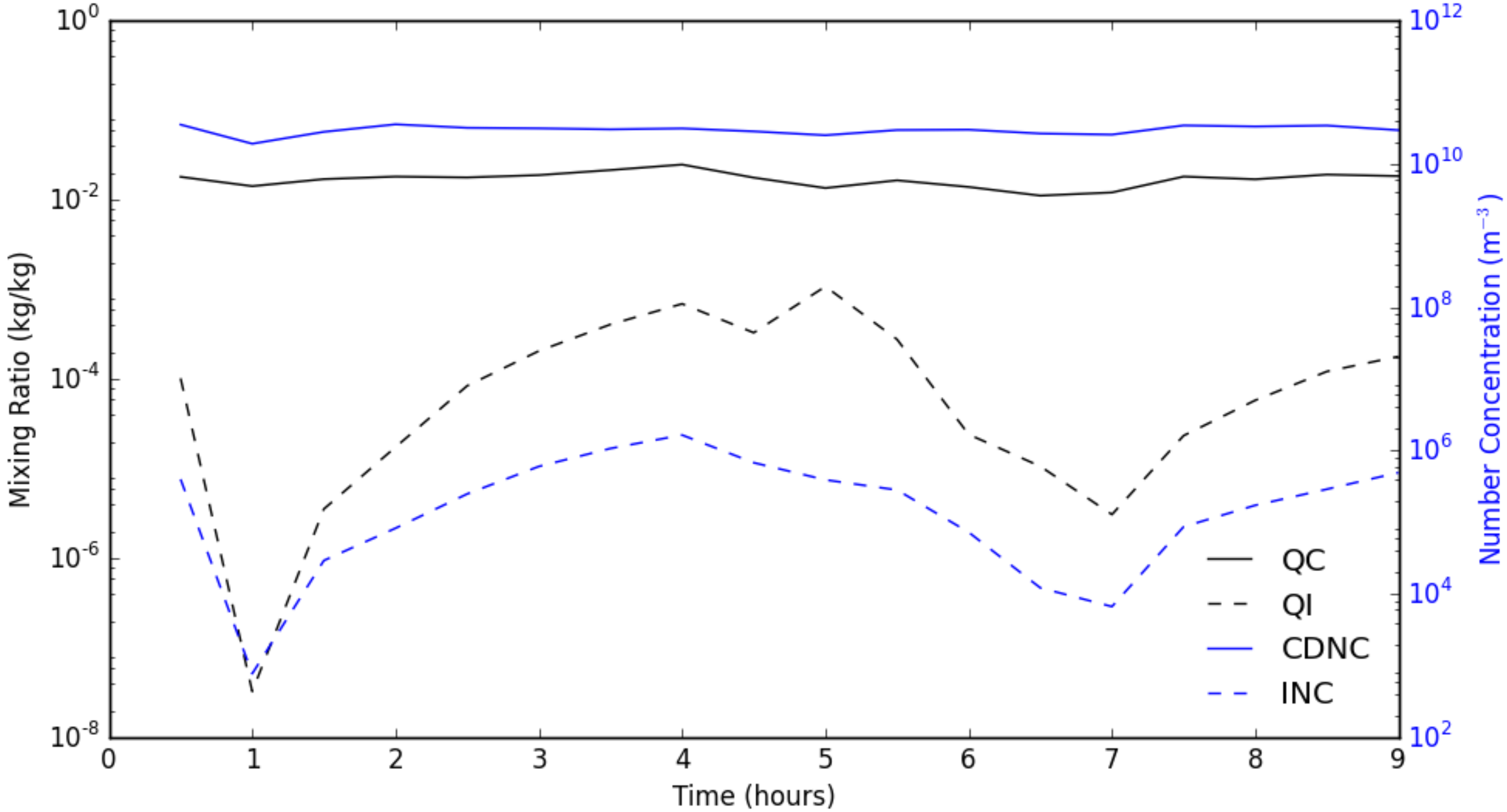
Sensitivity experiments

Name	Contact INP (m^{-3})	Immersion INP (m^{-3})	Deposition INP (m^{-3})
Wet Dust	2.42×10^4	2.63×10^6	8.30×10^1
Dry Dust	6.51×10^4	1.78×10^5	6.14×10^1
Charge	7.0×10^4	2.92×10^5	2.39×10^1
Low nFE	5.0×10^1	2.13×10^6	6.65×10^1
Meyers	6.6×10^1	2.00×10^6	8.23×10^1

Conclusions

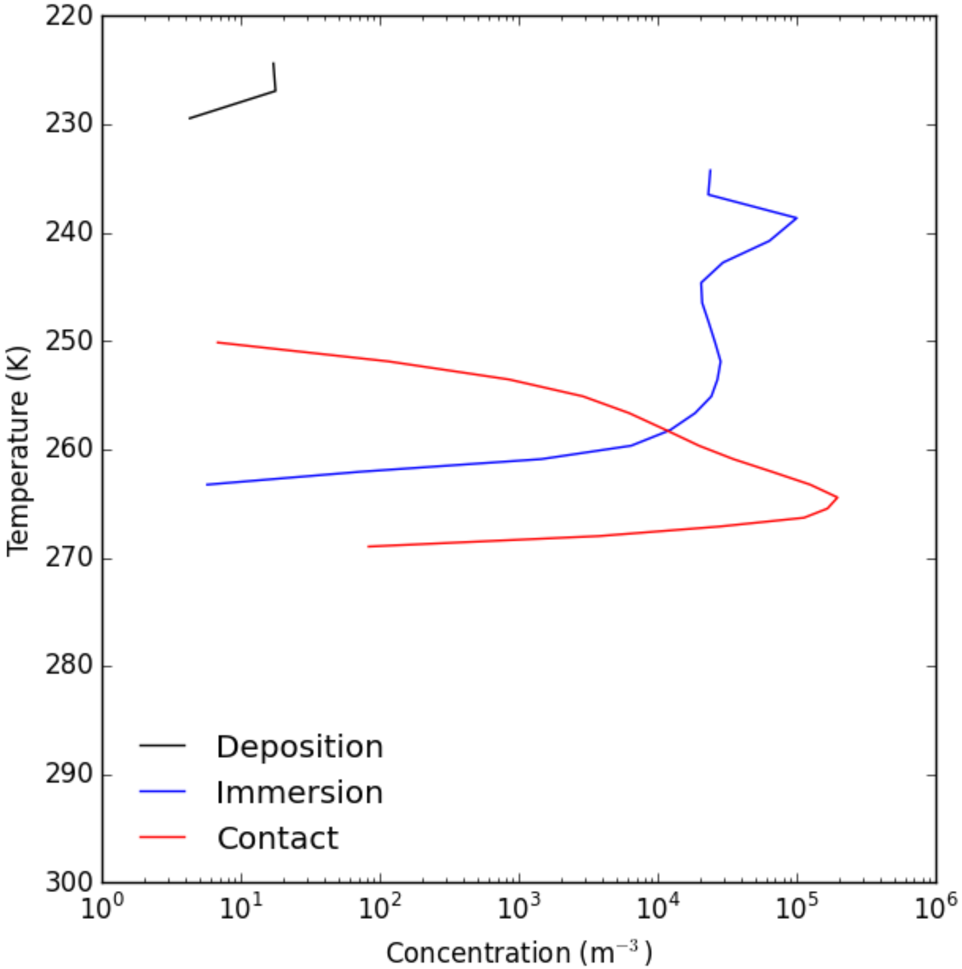
- A new aerosol-surface-area-dependent parameterisation for **contact ice nucleation** has been implemented into COSMO.
  - Dependencies on temperature, relative humidity, aerosol and droplet number, size, and electric charge.
  - Under certain conditions, **contact nucleation can dominate** over other modes.
  - To accurately estimate contact nucleation, **in-cloud aerosol** has to be treated explicitly.
- Preliminary semi-idealised **convective cloud simulations**:
  - Moderate sensitivity to **aerosol solubility**, low sensitivity to **electrical effects**, high sensitivity to **freezing efficiency** data.
  - Overall, **immersion freezing** dominates, followed by **contact nucleation**.
  - Not high enough supersaturations for **deposition nucleation** to be significant.

Cloud Evolution

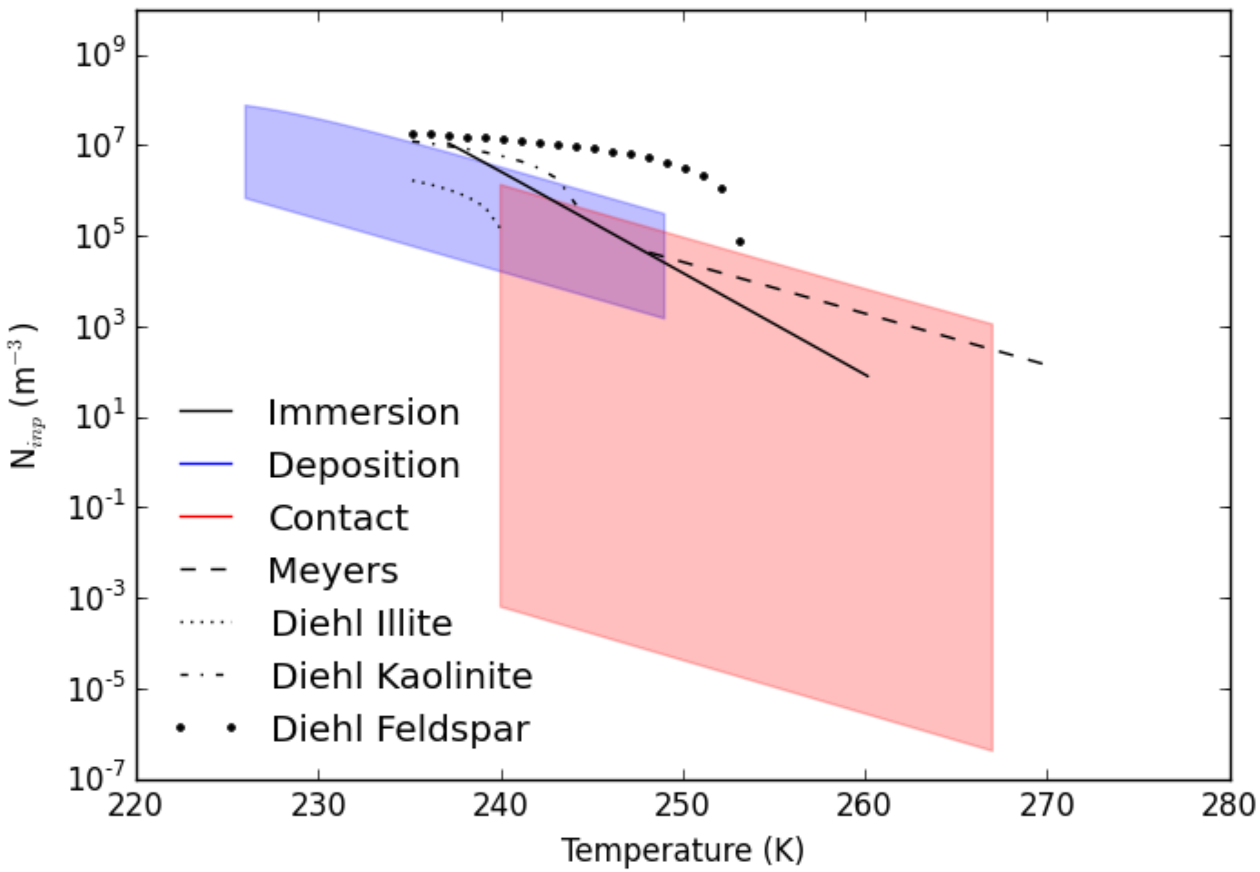


- Timeseries of **mean vertically integrated** cloud liquid and ice properties

Modeled INP concentrations



Heterogeneous Ice Nucleation Comparison



- **Aerosol radius:** 0.1 µm
- **Contact freezing rates are mostly lower** than immersion and deposition ice nucleation rates.
- Under certain conditions, **contact nucleation could dominate.**