University of Basel

Towards parameterising concentrations of warm-temperature ice nucleating particles active at moderate supercooling

July 7, 2020; 3rd virtual Ice Nucleation Colloquium

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Goals

- Present to you the results of my manuscript submitted to ACPD*.
- Suggest improvements to predict warm-temperature ice nucleating particles (INPs).
- Encourage you to critically challenge my work.

Outline

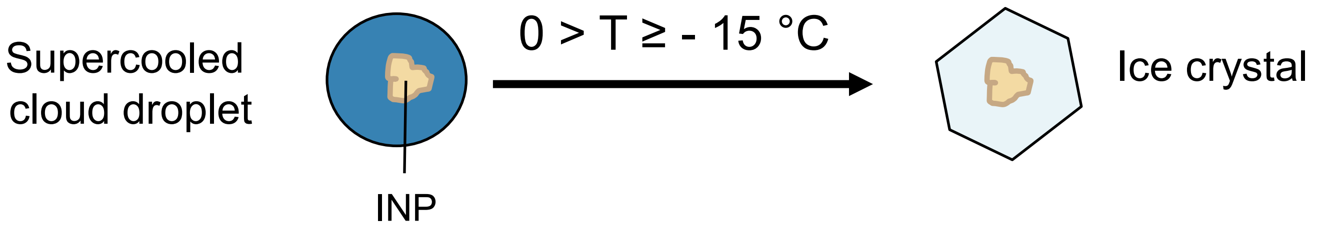
1. Introduction to ice nucleating particles and parametrisations.
2. Collection of data in the Swiss Alps.
3. Results, conclusion and take-home messages.

*now published: https://doi.org/10.5194/acp-21-657-202

revisions of the presentation made based on published paper

Warm-temperature INPs

- INPs active at -15 °C or warmer (i.e. $INPs_{-15}$)



Warm-temperature INPs

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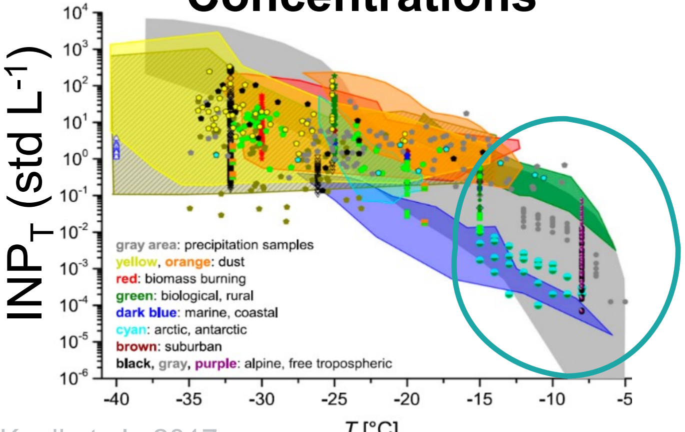
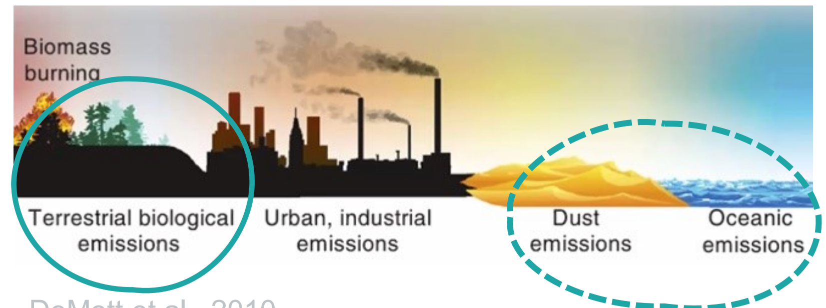
Concentrations



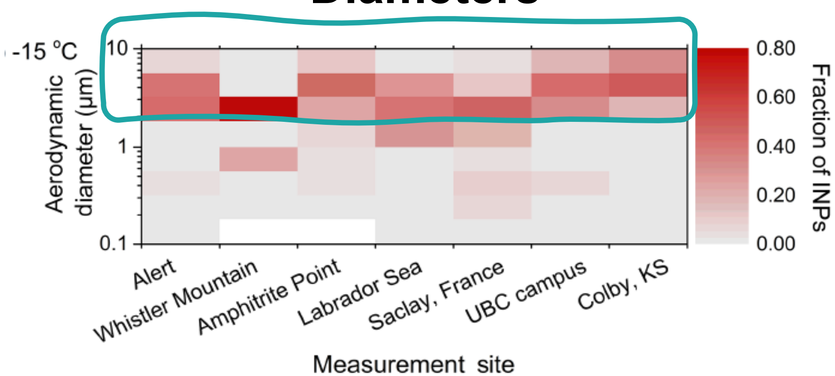
Kanji et al., 2017

Sources



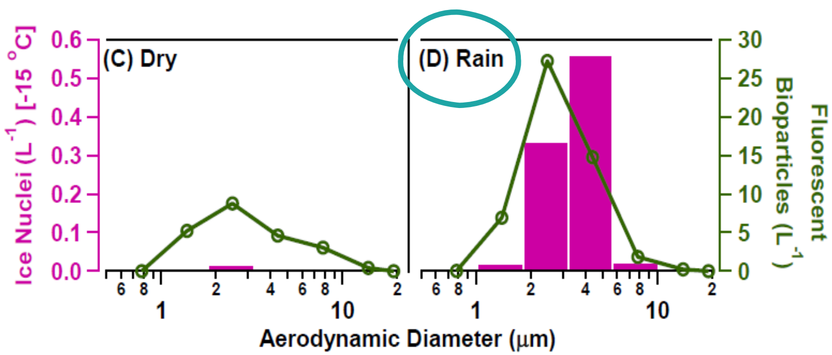
DeMott et al., 2010

Diameters



Mason et al., 2016

Abundances



Huffman et al., 2013

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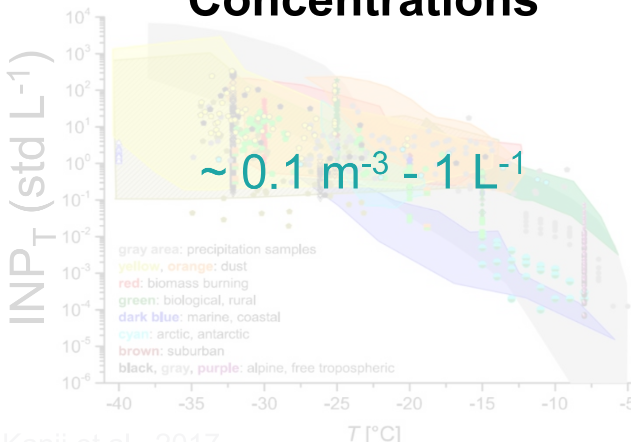


~ 0.1 m^{-3} - 1 L^{-1}

Kanji et al., 2017

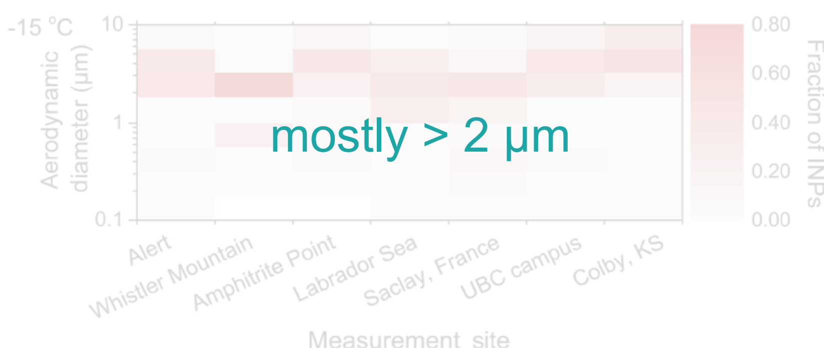
Sources

terrestrial biogenic

dust and oceanic

DeMott et al., 2010

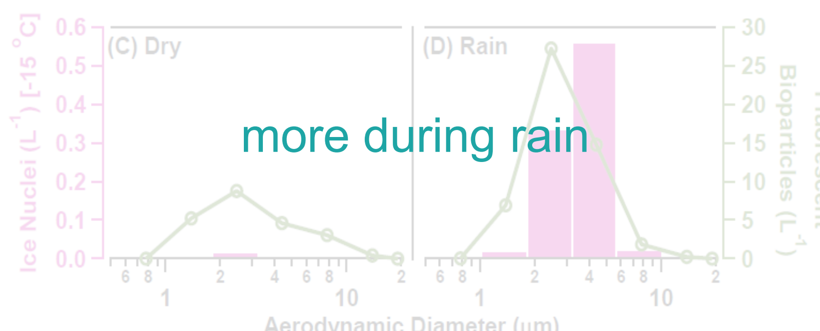
Diameters



mostly > 2 µm

Mason et al., 2016

Abundances



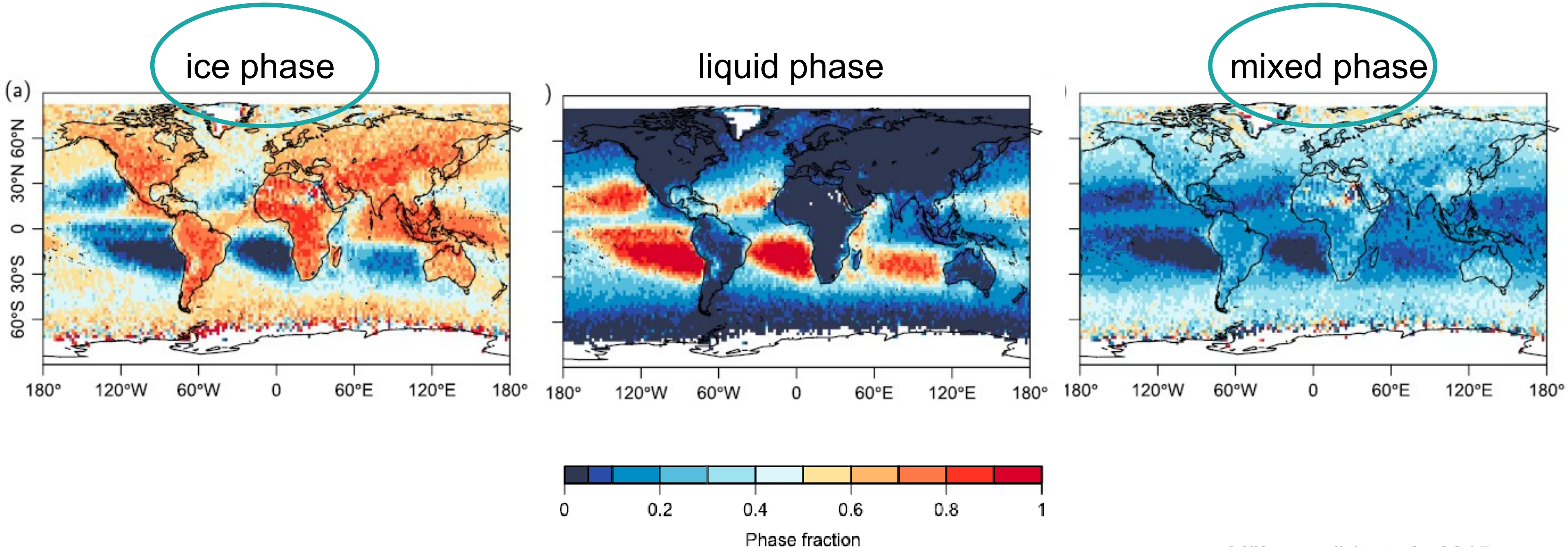
more during rain

Huffman et al., 2013

Warm-temperature INPs: their importance

In midlatitudes over land:

- the presence of ice is important for clouds to precipitate.



Mülmenstädt et al., 2015

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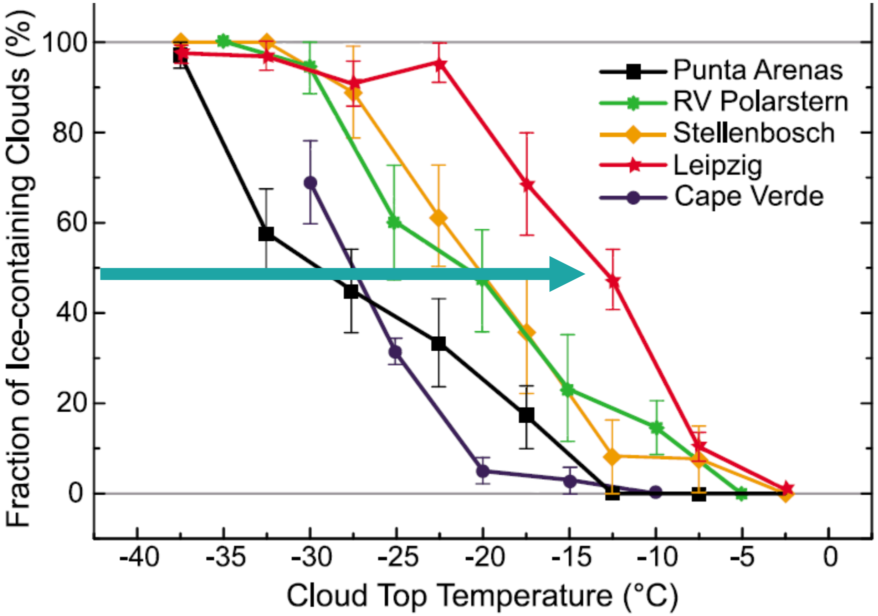
- 50% of the clouds contain ice > -15 °C.



Kanitz et al., 2011

Warm-temperature INPs: their importance

In midlatitudes over land:

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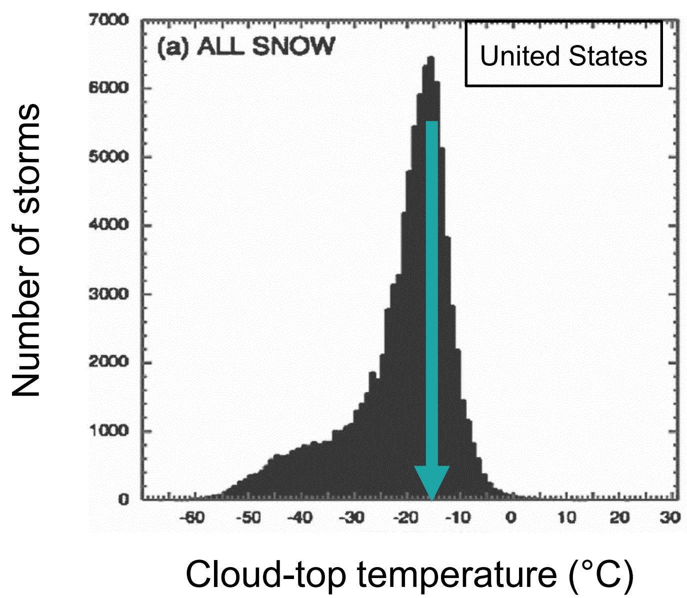
- Cloud-top temperatures associated with precipitation have a distinct temperature mode at around -15 °C.

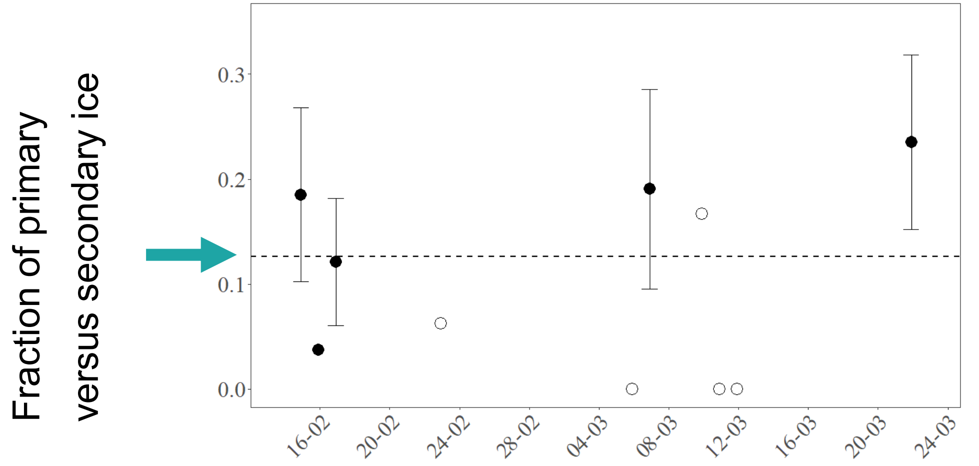


Hanna et al., 2008

Warm-temperature INPs: their importance

In midlatitudes over land:

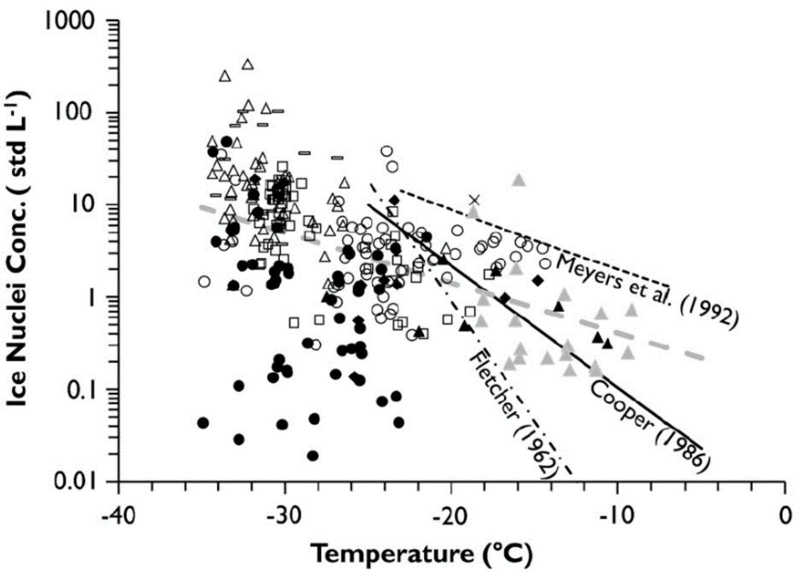
- the presence of ice is important for clouds to precipitate.
- 50% of the clouds contain ice > -15 °C.
- Cloud-top temperatures associated with precipitation have a distinct temperature mode at around -15 °C.
- Around -15 °C, primary ice multiplies by at least a factor of 10 above the Alps.



Mignani et al., 2019

INP parametrisations

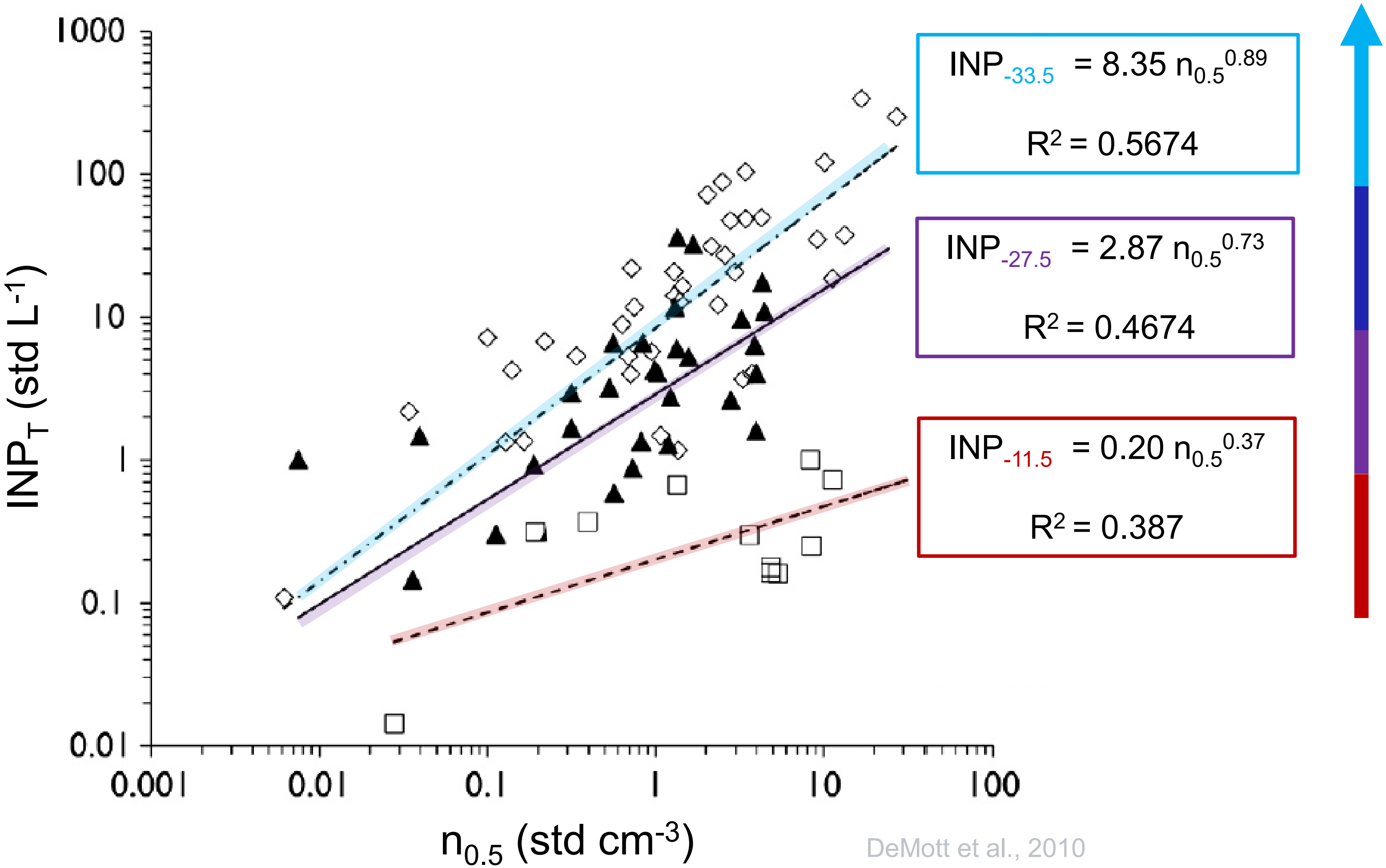
- Former parametrisations were temperature dependent (i.e. Fletcher, 1962).



DeMott et al., 2010

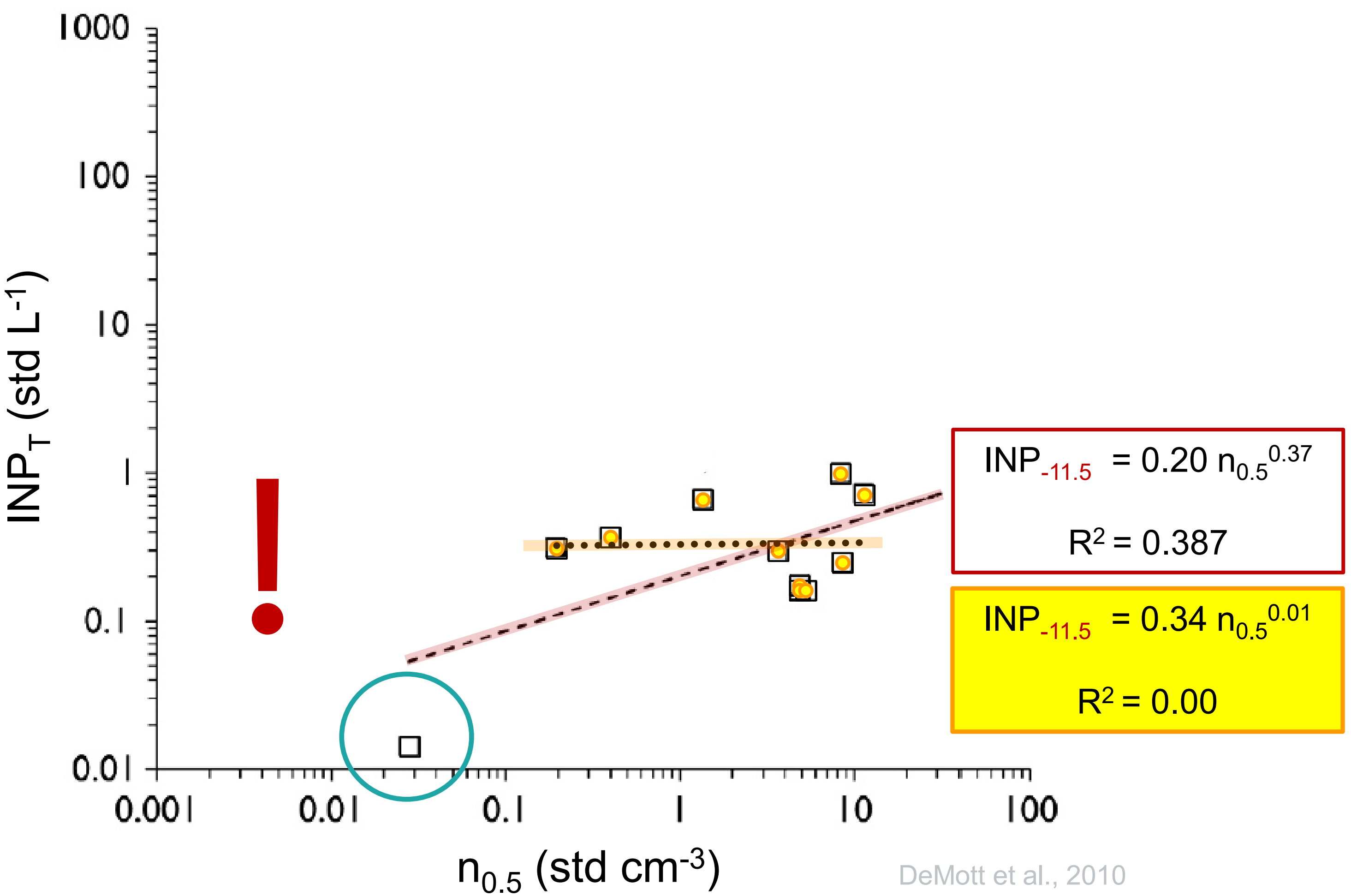
- More recently particle numbers were taken into account (i.e. DeMott et al., 2010).

Parametrisation considering aerosol particles



Relationship less good for warm-temperature INPs.

Parametrisation considering aerosol particles



Relationship disappears if deleting one data point.

Current atmospheric INPs predictions

- Empirical parametrisation established by DeMott et al. 2015 (D15):

$$\boxed{\mathrm{INP_T} = CF\, \mathrm{n}_{0.5}{}^{\beta}\, e^{\gamma\,(-\mathrm{T})+\,\delta}} \quad \text{(Eq. 1)}$$

CF, β, *γ*, δ	Empirically determined parameters
T	Temperature (°C)
$\mathrm{INP_T}$	INP concentration (std L^{-1}) at T
$n_{0.5}$	Number concentration of aerosol predominantly consisting of mineral dust particles with a physical diameter > 0.5 µm (std cm^{-3})

Current atmospheric INPs predictions, but…

- Empirical parametrisation established by DeMott et al. 2015 (D15):

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“ weakly constrained at temperatures > -20 °C, where much additional ambient […] data are needed ”

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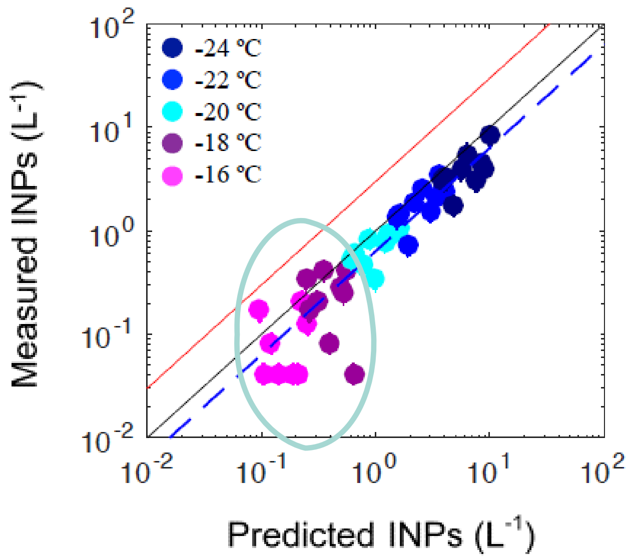
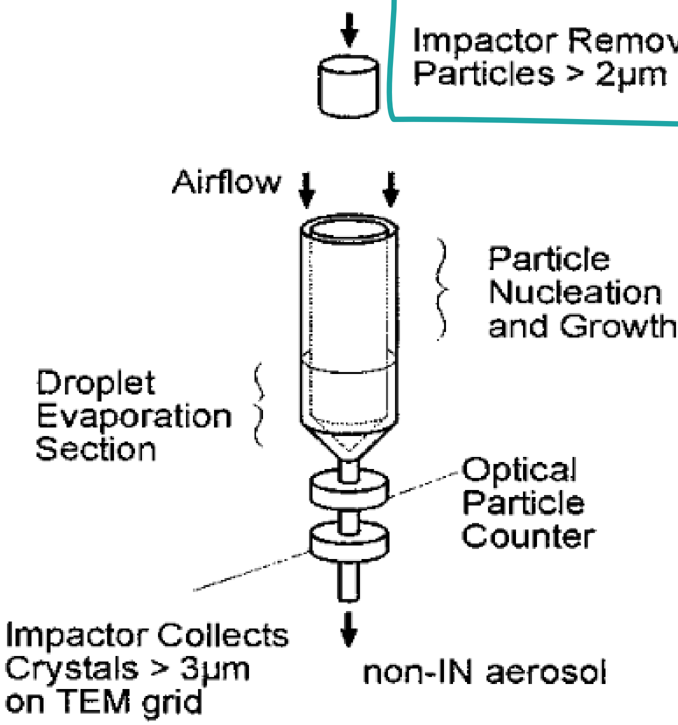
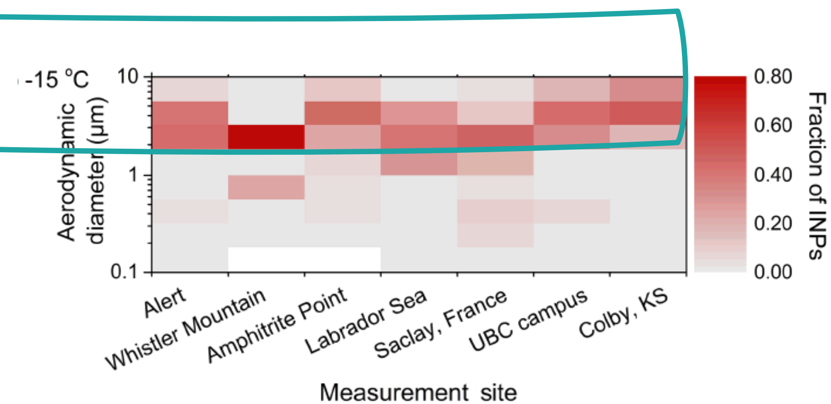


Schrod et al., 2016

Why are warm-temperature INPs less predictable?

Particles > 2 µm are poorly represented in empirical data:





Mason et al., 2016

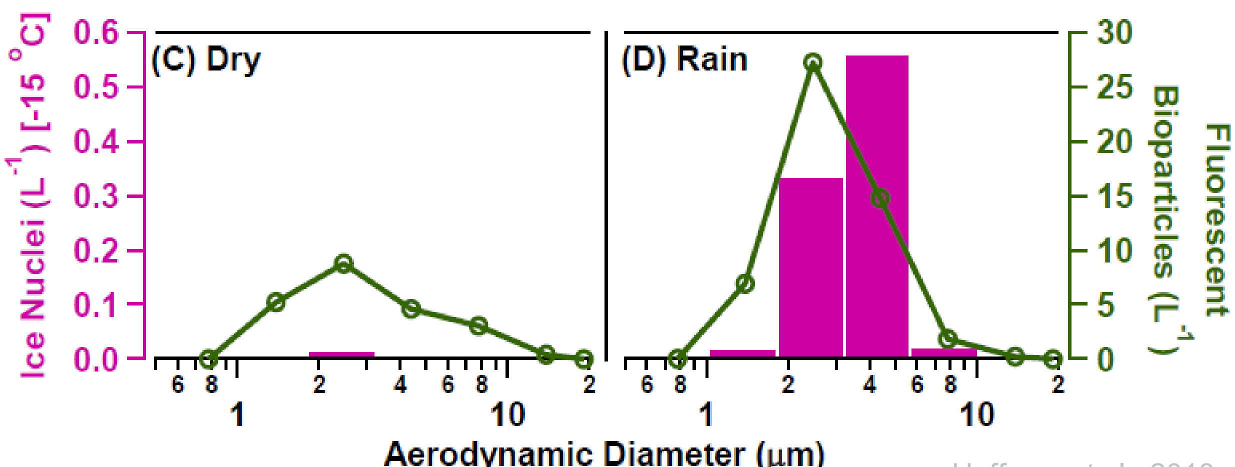
Continuous Flow Diffusion Chamber

Rogers et al., 2001

Why are warm-temperature INPs less predictable?

Particles > 2 µm are poorly represented in empirical data:

- Instrumental reasons: Particles > 2 µm are removed before measuring INPs (Rogers et al., 2001).
- Large particles activate and deposit earlier than other (smaller) INPs → shorter atmospheric lifetime and higher variability.
- Large variance of the IN-active fraction in bioaerosols.



Huffman et al., 2013

Aim of our study

Test whether the two fundament aspects of warm INPs

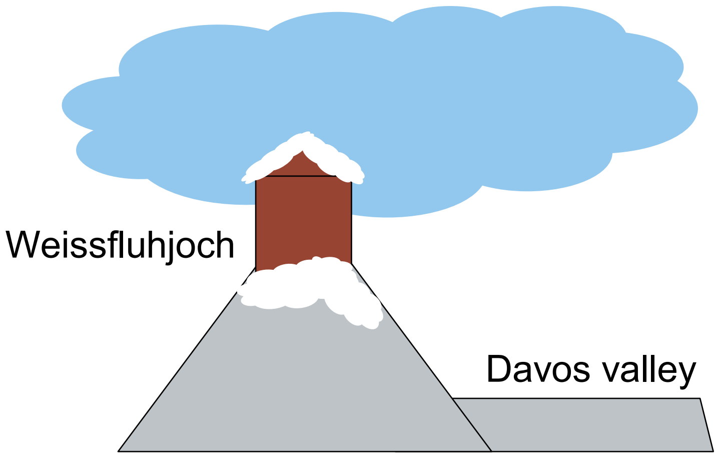
– increased abundance during precipitation and size –

can be reconciled with the general approach of parametrising INPs

(i.e. predicting INPs as a function of particles > a certain size)

Measurement site

- Weissfluhjoch 2’671 m a.s.l.
- Feb – Mar 2019
- “Role of Aerosols and Clouds Enhanced by Topography on Snow” (RACLETS) campaign
- Average air temperature: -7.1 (s.d. ± 4.3) °C
- Site: snow covered, lowland: snow-free



Instrumental setup

1. INP concentrations [INP]

Liquid impinger + droplet freezing assay

Stopelli et al., 2014

- 124 samples
- 6 m^3 per sample
- No cut off size (!)
- INPs at -15 °C (INP_{-15})

2. Aerosol particle concentrations [n]

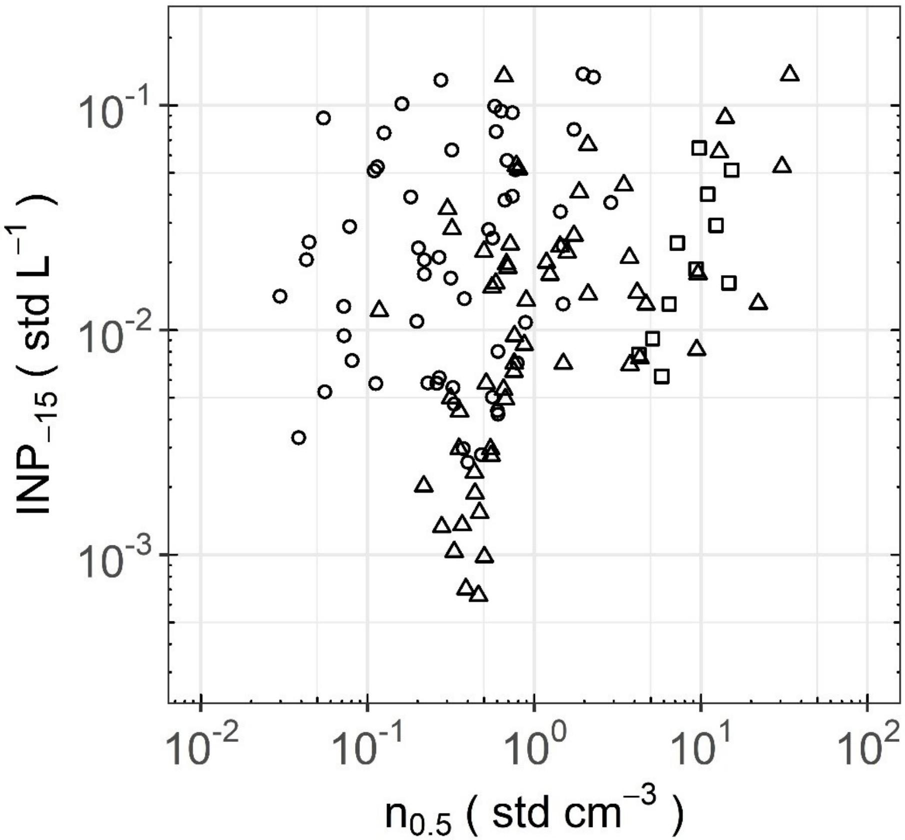
Aerodynamic Particle Sizer (APS) spectrometer

3. Air mass differentiation

Lagrangian analysis tool LAGRANTO

Sprenger and Wernli, 2015

Predicting INP_{-15} based on $n_{0.5}$



Mignani et al., 2021

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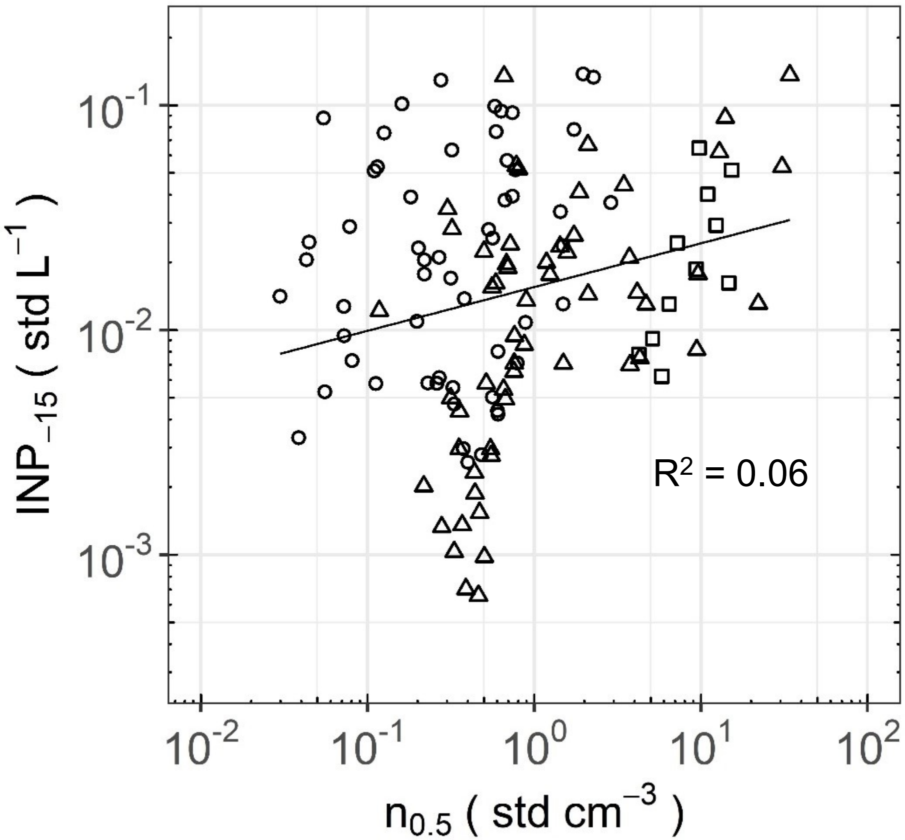
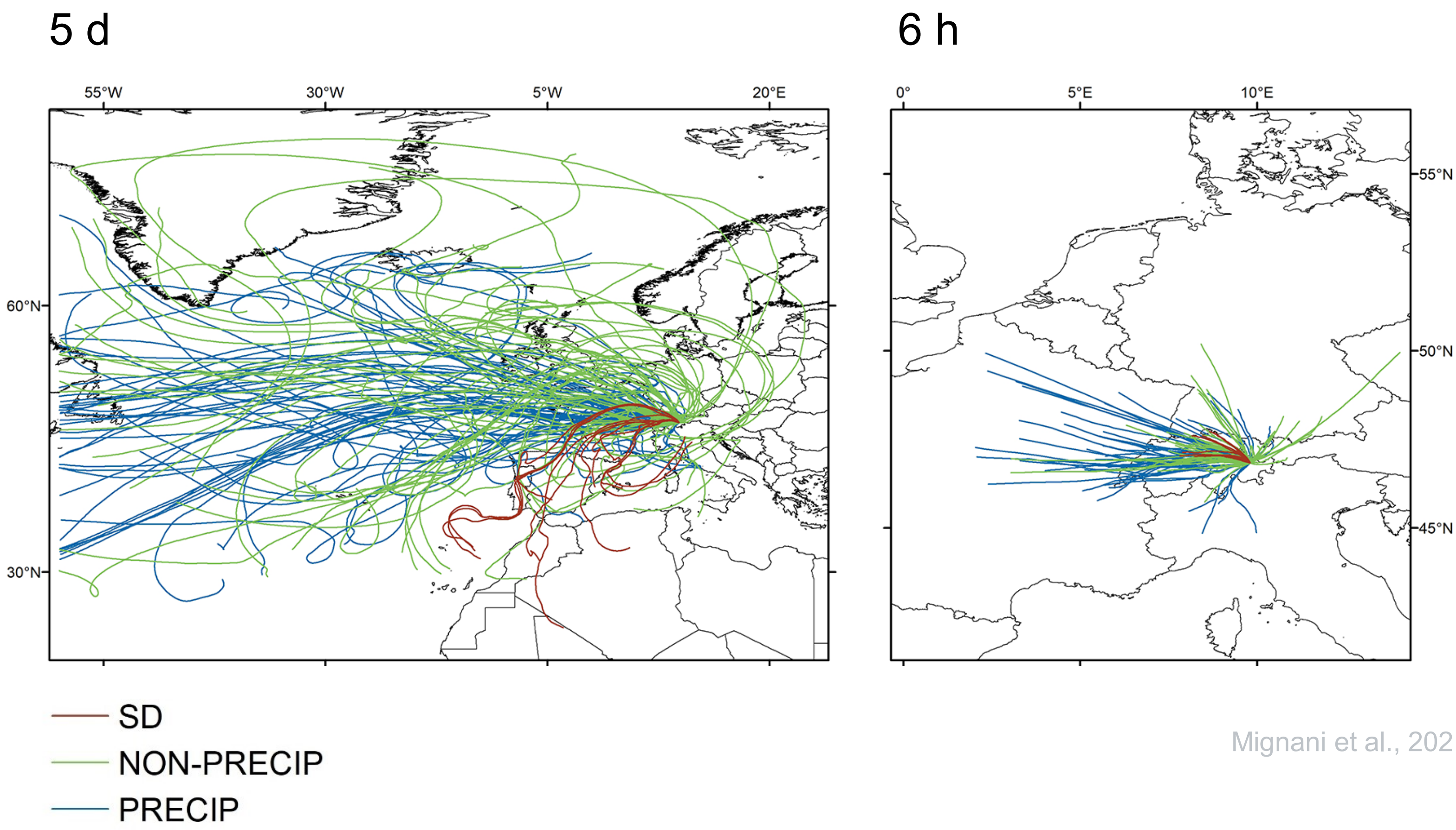


Mignani et al., 2021

Recent air mass differentiation



Mignani et al., 2021

Recent air mass differentiation

"non-precipitating"
(NON-PRECIP)

≤ 1.0 mm
precipitation 6 h
prior sampling

n = 57

"precipitating"
(PRECIP)

≥ 1.0 mm
precipitation 6 h
prior sampling

n = 56

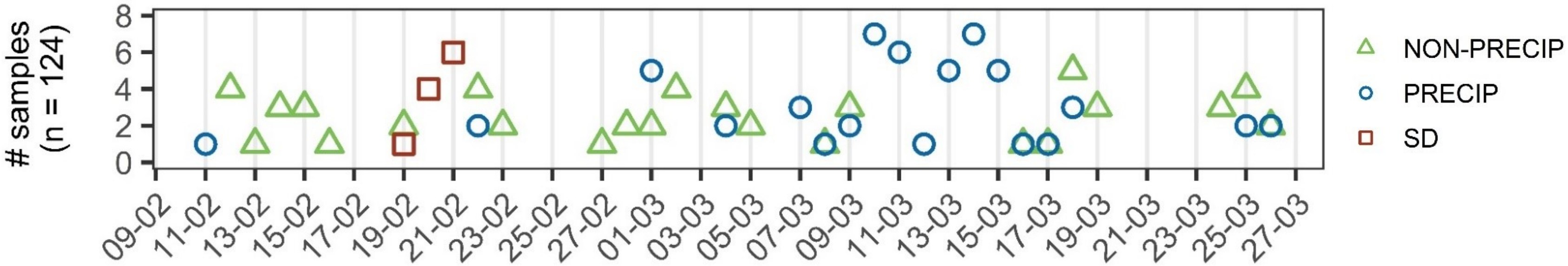
"Saharan Dust"
(SD)

carrying a
substantial fraction
of Saharan Dust

n = 11

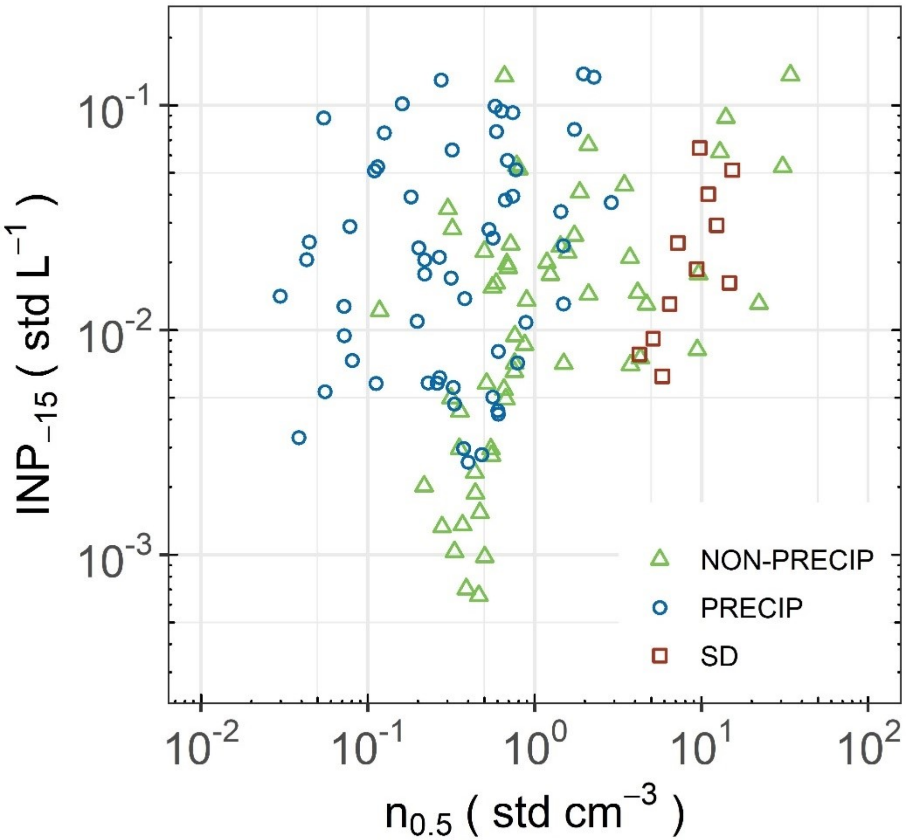
Recent air mass differentiation

"non-precipitating" (NON-PRECIP)	"precipitating" (PRECIP)	"Saharan Dust" (SD)
		
≤ 1.0 mm precipitation 6 h prior sampling	≥ 1.0 mm precipitation 6 h prior sampling	carrying a substantial fraction of Saharan Dust
n = 57	n = 56	n = 11



Mignani et al., 2021

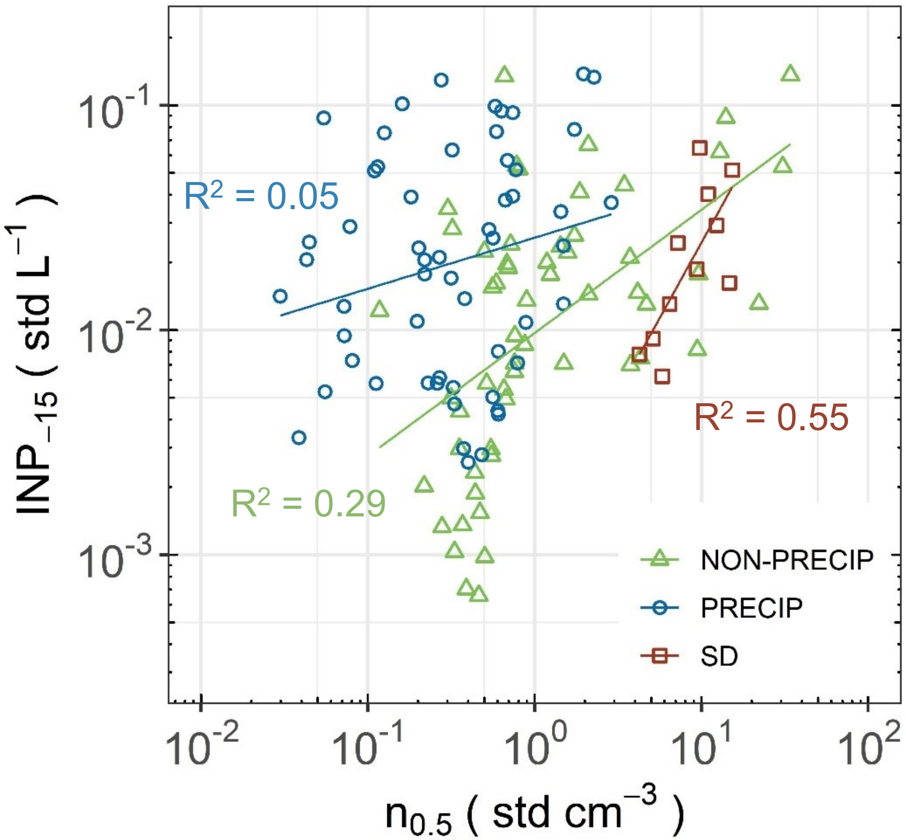
Recent air mass history structures data



Mignani et al., 2021

- [INP_{-15}] depends on recent air mass history.
- Known INP enrichment during precipitation, consistent with previous findings (e.g. Huffmann et al., 2013).

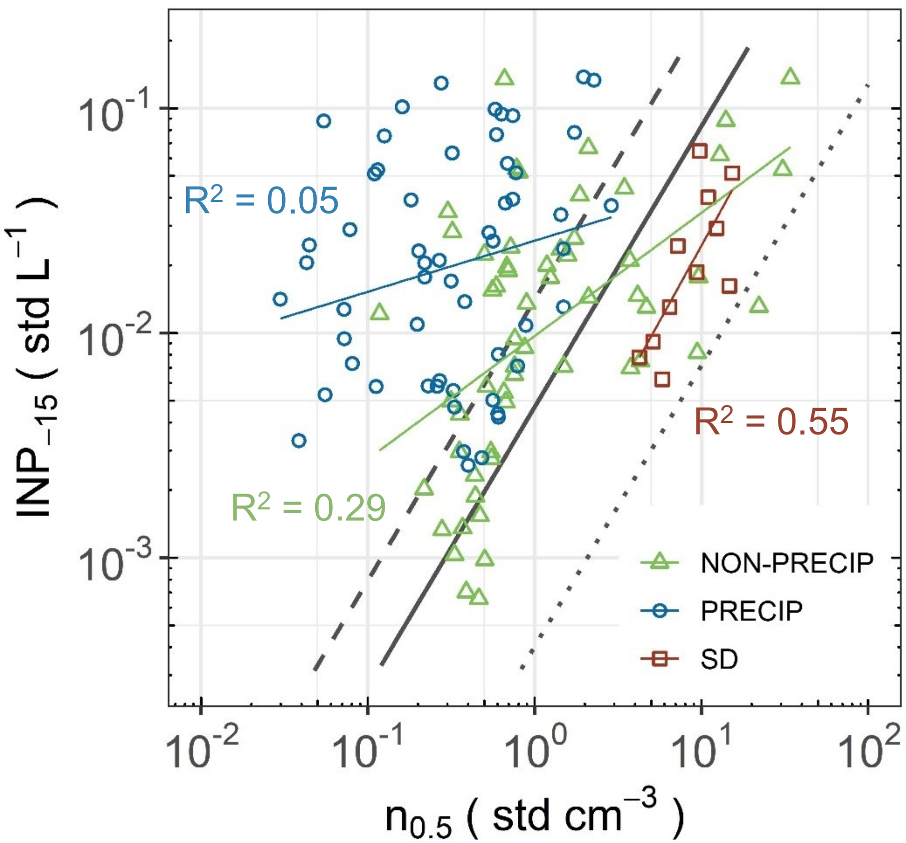
Recent air mass history structures data



Mignani et al., 2021

- Predictions improve when differentiating between air mass history.
- Predictions are best for SD and poorest for PRECIP air masses.

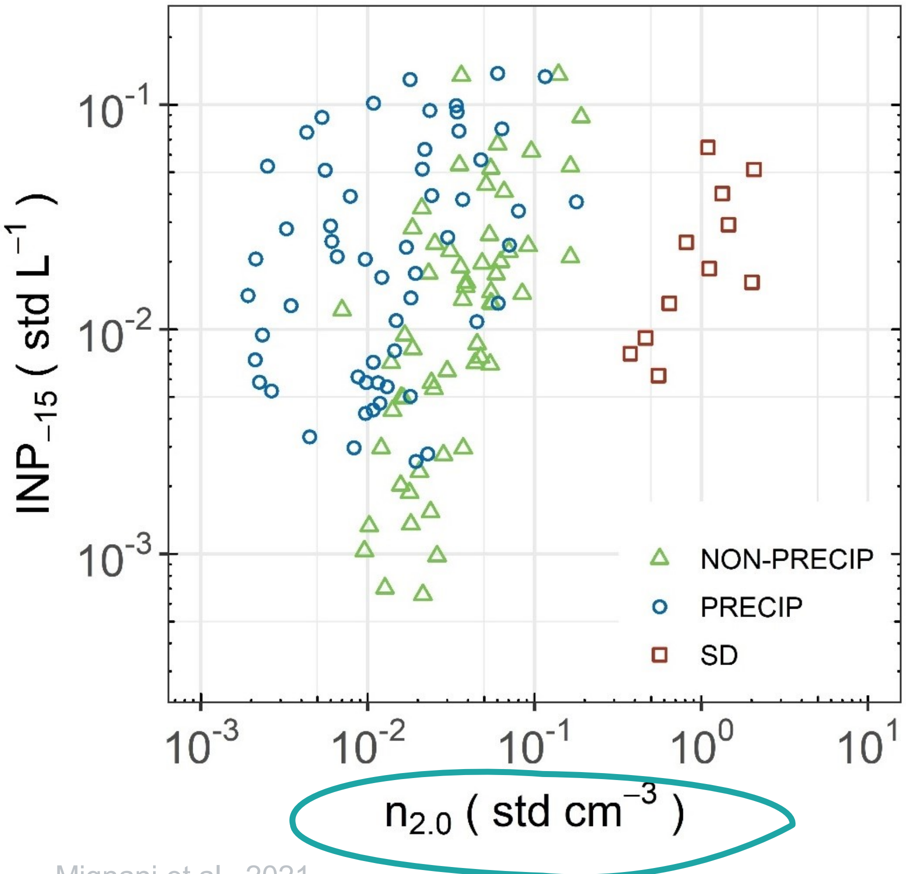
How does the D15 parametrisation?



Mignani et al., 2021

- Observed slope for SD air masses was the same as that predicted by the D15 parametrisation.
- Offset of the D15 curve depends on the calibration factor (CF, Eq. 1).

Can we predict INP_{-15} using larger aerosol particles?



Mignani et al., 2021

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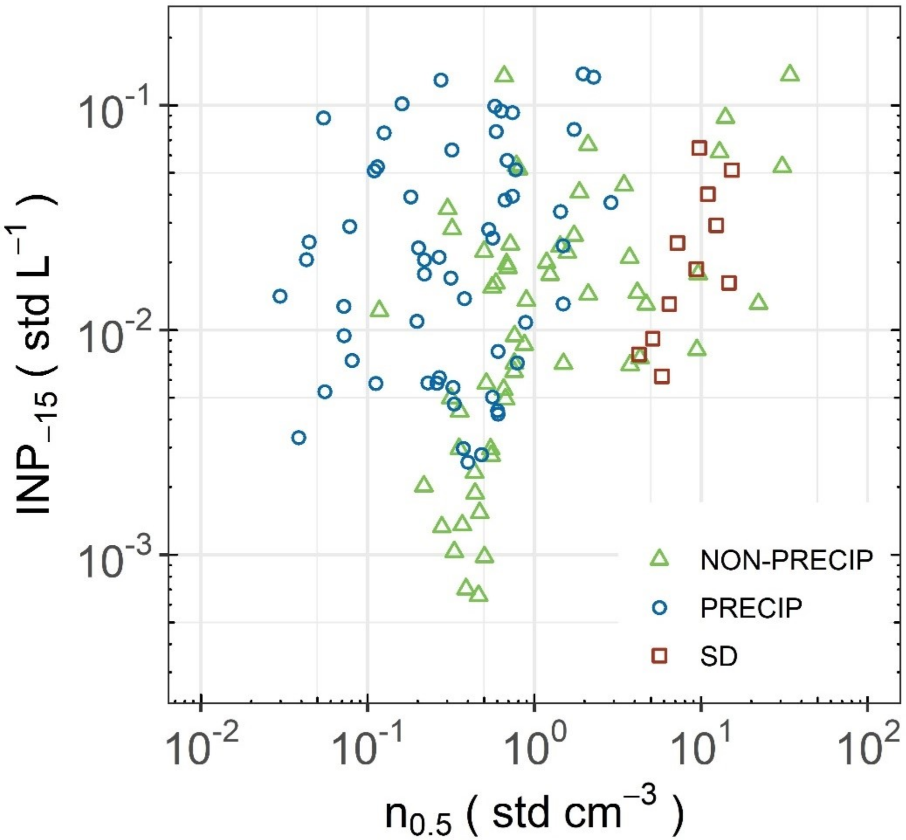

Mignani et al., 2021

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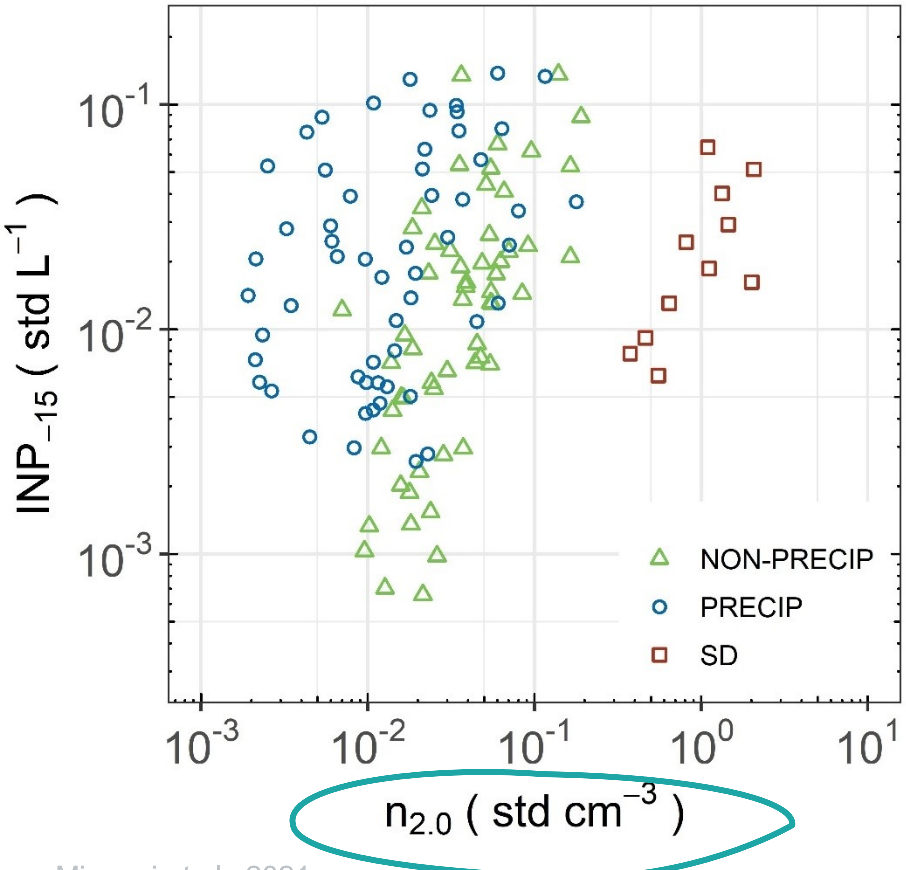
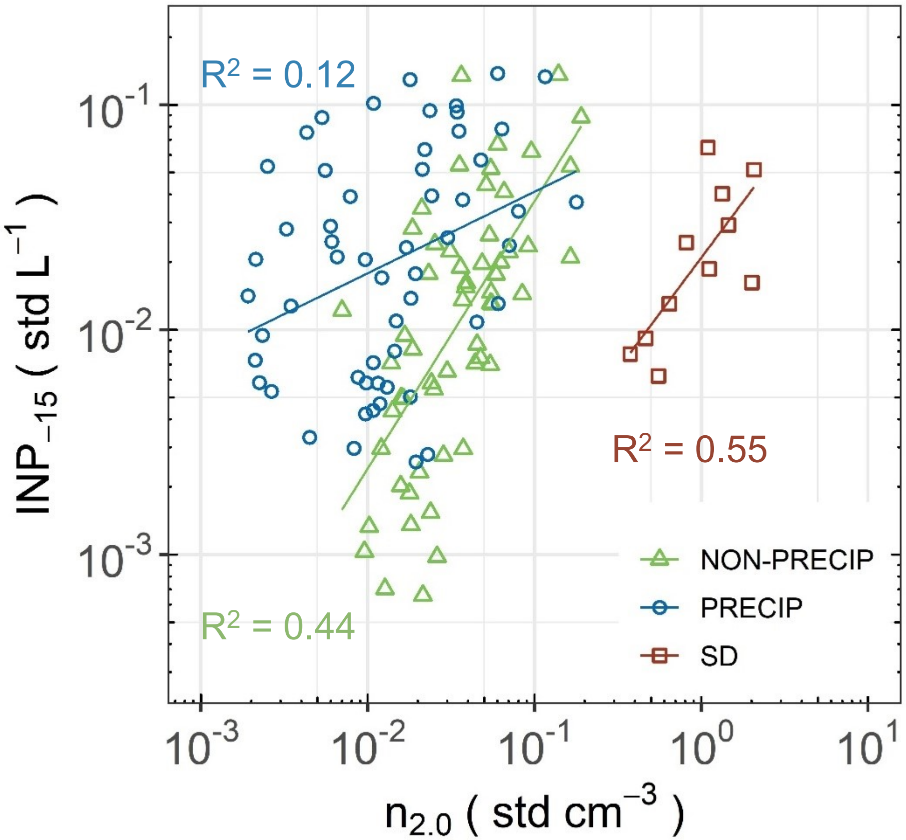


Mignani et al., 2021

- More distinct separation of $[INP_{-15}]$ to the different air masses versus $[n_{2.0}]$: SD data clearly separate from the rest with $n_{2.0}$.

Found parametrisation functions using $n_{2.0}$



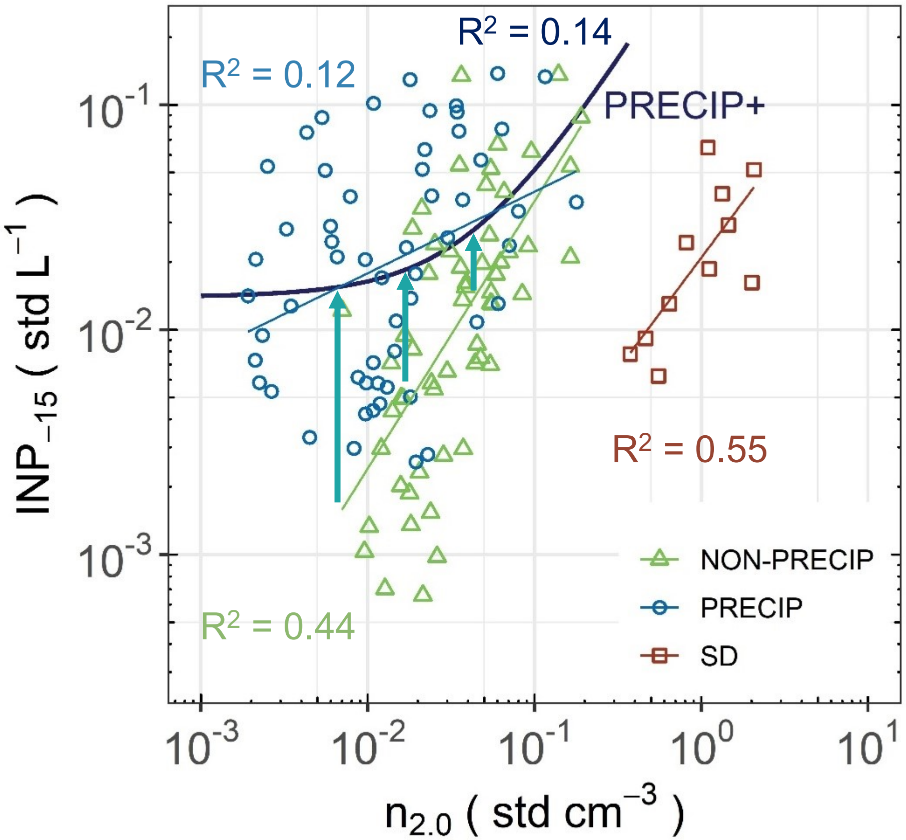
Mignani et al., 2021

- NON-PRECIP and SD slopes are similar, however PRECIP slope is less steep.

Functions: $INP_{-15} = b\ x^{a}$

Air mass type	n	x	b	a
PRECIP	56	$[n_{2.0}]$	0.09	0.36
NON-PRECIP	57	$[n_{2.0}]$	0.58	1.19
SD	11	$[n_{2.0}]$	0.02	0.99

Found parametrisation functions using $n_{2.0}$



Mignani et al., 2021

PRECIP+ function:

$$INP_{-15} = b\ x^{a} + c$$

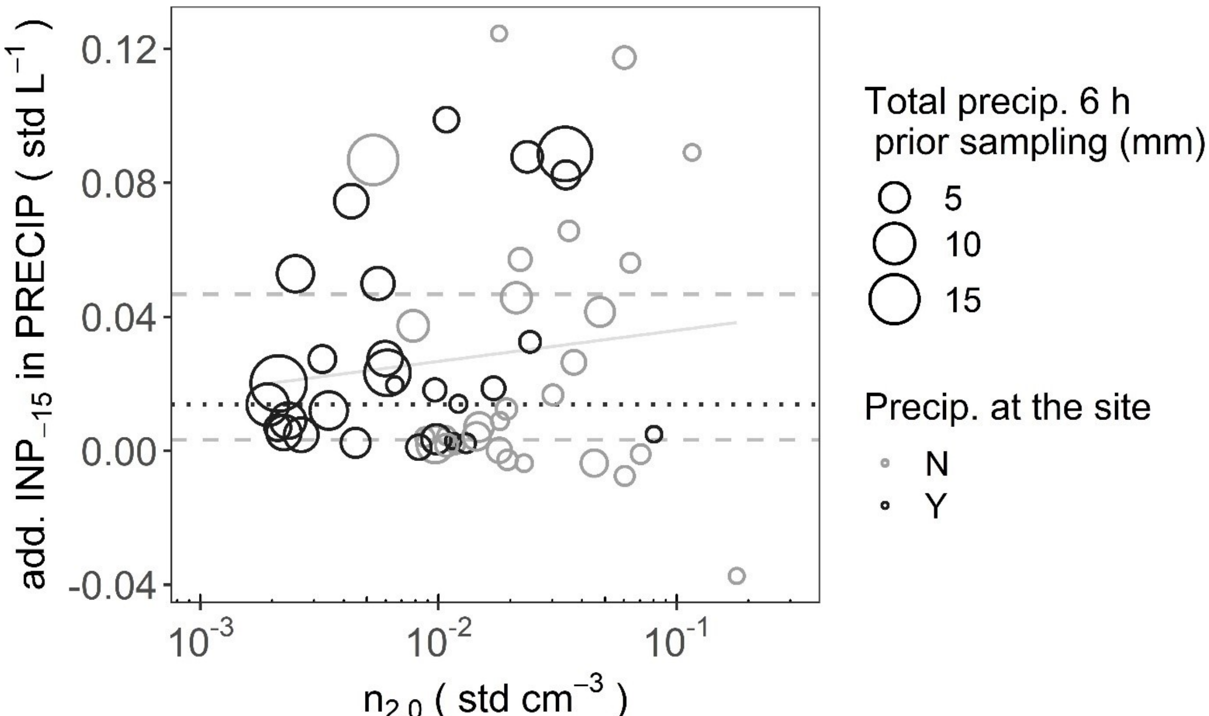
"background" NON-PRECIP function

Addition due to precip.

Air mass type	n	x	b	a	c
PRECIP+	56	$[n_{2.0}]$	0.58	1.19	0.014

- PRECIP+ more likely than PRECIP: rain splash (Joung et al., 2017) aerosolises INPs from snow-free surfaces upwind emitting INPs independent from the aerosol concentration.

Additional INP_{-15} during precipitation



Mignani et al., 2021

- The absolute value of additional INPs during precipitation is independent of $[n_{2.0}]$ supporting the 2-component function for precipitation air masses.
- Mean additional INP_{-15} in PRECIP air masses was 0.014 std L^{-1}.

Conclusion

Parametrisations based on aerosol particles can be improved > -15 °C:

- by considering larger particles (diameter > 2 µm).
- even greater improvement if additionally distinguishing between air mass history.

Outlook

Constrain these parametrisations in a wider geographical context while:

- paying attention to sample at cloud height,
- sampling a large enough volume *(remember André's thought experiment)*,
- including larger aerosol particles,
- distinguishing different air mass histories.

Take-home messages

1. It is okay to predict INP_{-15} as a function of aerosol particles.

2. We demonstrated the potential of differentiating between air masses.

3. The more differentiated parametrisations including air mass history and larger particles are promising ways *towards* predicting INPs > -15 °C.

Thank you for your attention!

Questions?

Contact: claudia.mignani@unibas.ch

Related publication: https://doi.org/10.5194/acp-21-657-2021

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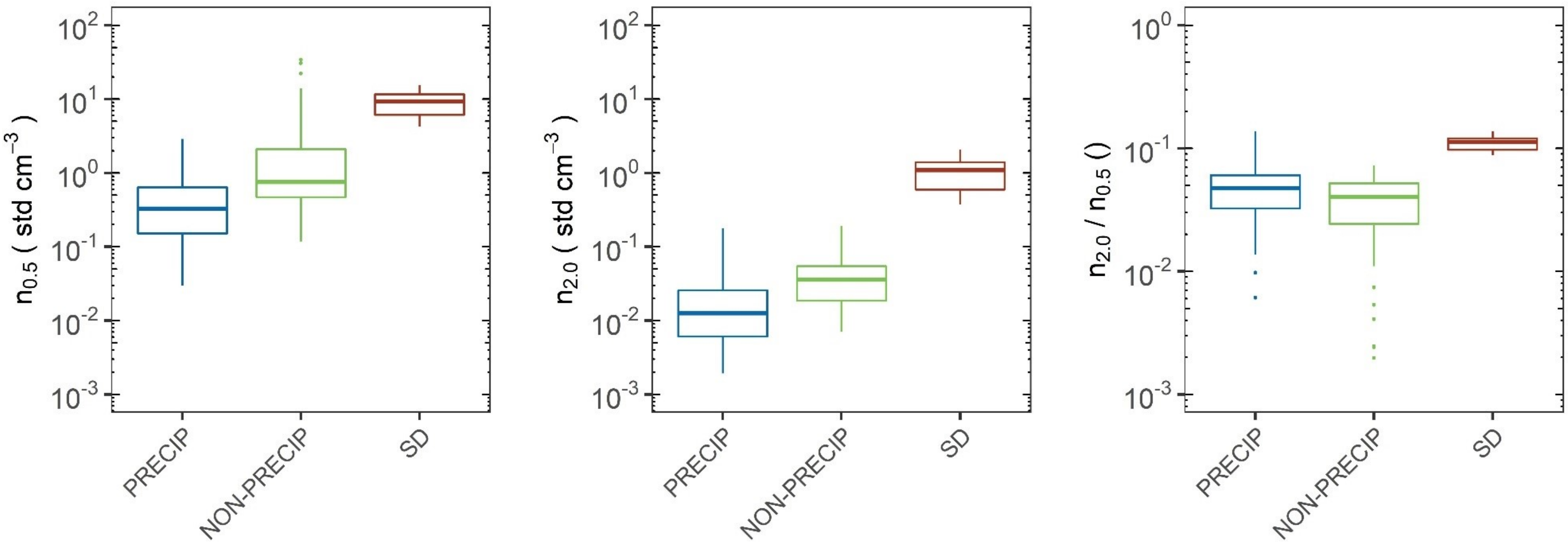
- Sprenger and Wernli, 2015: https://doi.org/10.5194/gmd-8-2569-2015
- Stopelli et al., 2014: https://doi.org/10.5194/amt-7-129-2014

Aerosol concentrations >0.5 and >2.0 µm

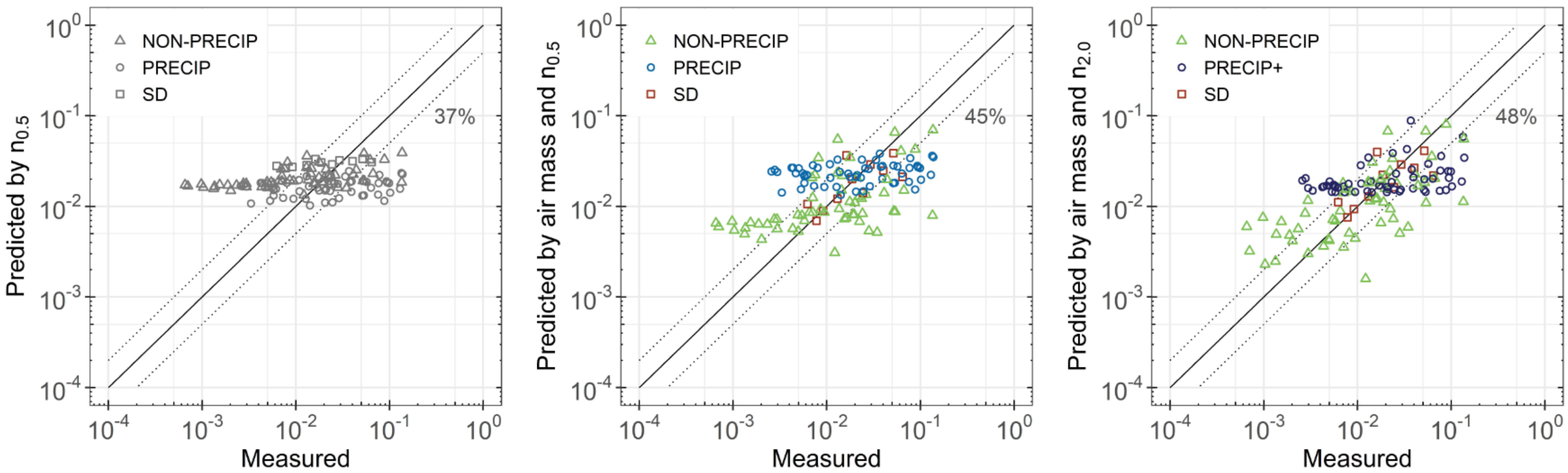


Mignani et al., 2021

$[n_{0.5}]$ and $[n_{2.0}]$

- Lowest concentrations found in PRECIP air masses
- Highest concentrations found in SD air masses

Predicted versus measured INP$_{-15}$ concentrations



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