INP at different ends of the world: results from two recent studies in South America and Northern Greenland

by

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Part 1: Significant continental source of ice-nucleating particles at the tip of Chile’s southernmost Patagonia region

1. Motivation & previous studies
2. Measurements & Methods
3. Results
4. Conclusion

Martin Radenz, Patric Seifert, Farnoush Ataei, Holger Baars, Boris Barja, Albert Ansmann, Heike Wex, Frank Stratmann, Silvia Henning

Gong et al., Atmos. Chem. Phys., 22, 10505–10525, 2022

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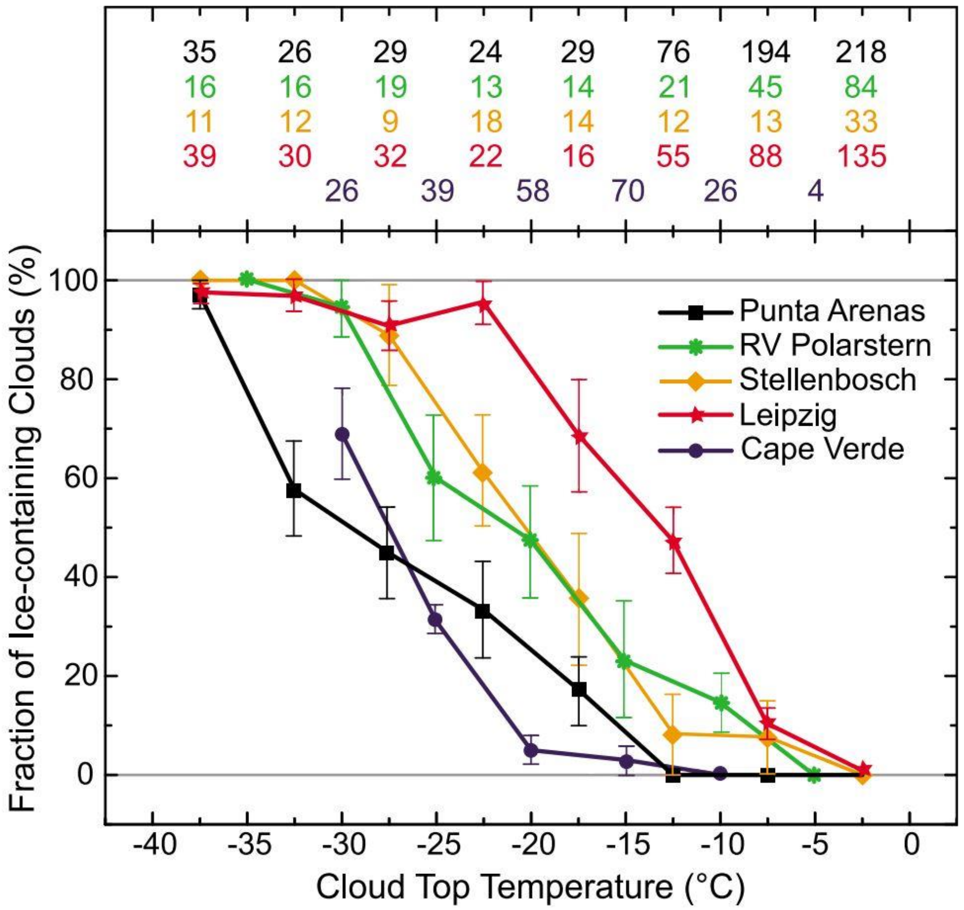
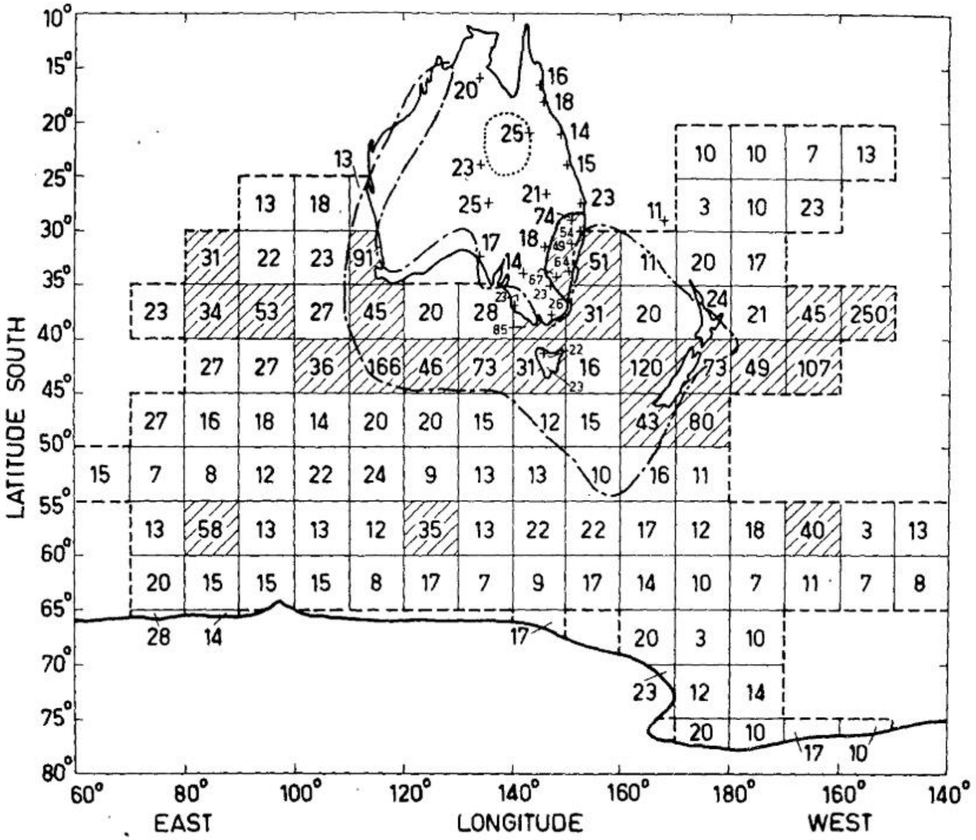
Contrasting Heterogeneous Ice Formation over North and South

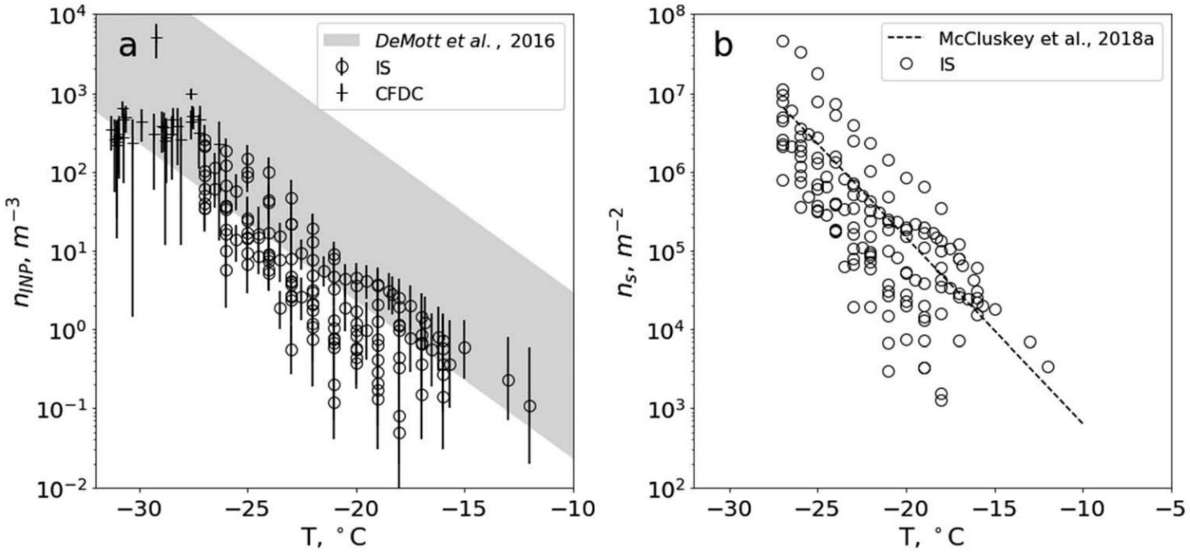


Kanitz et al. (2011), GRL
Radenz et al. (2021), ACP

I. The strongest increase in the ice-containing cloud fraction with decreasing temperature over Leipzig
II. While the lower ice-containing cloud for Punta Arenas
III. Measurement uncertainties, Lidar detection limits, and wave cloud in Punta Arenas

Previous INP Measurements in the Southern Ocean





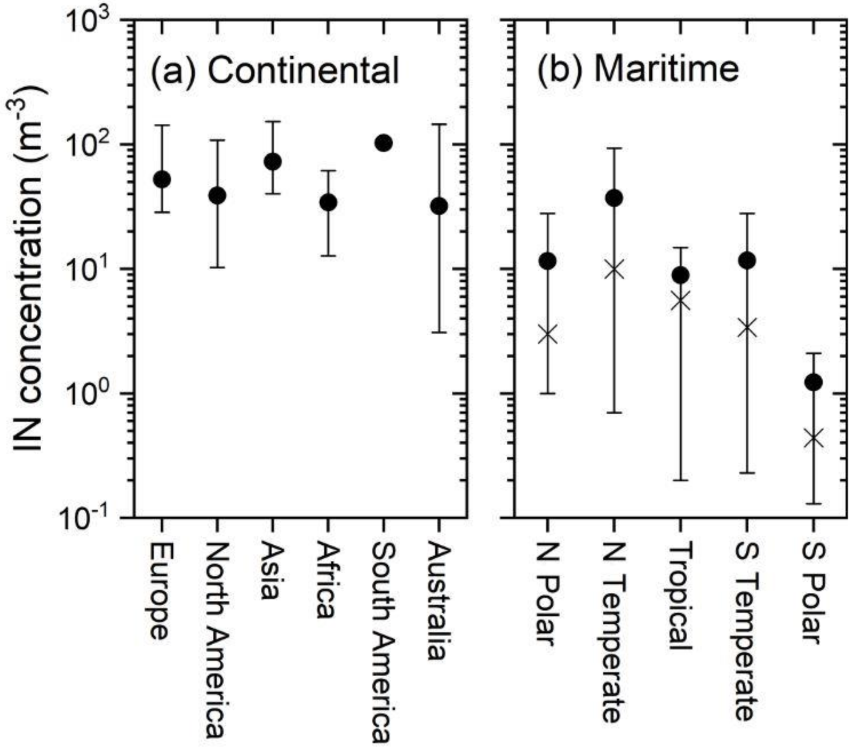
I. Aerosol transported from distant continents is the main source of INP (left).

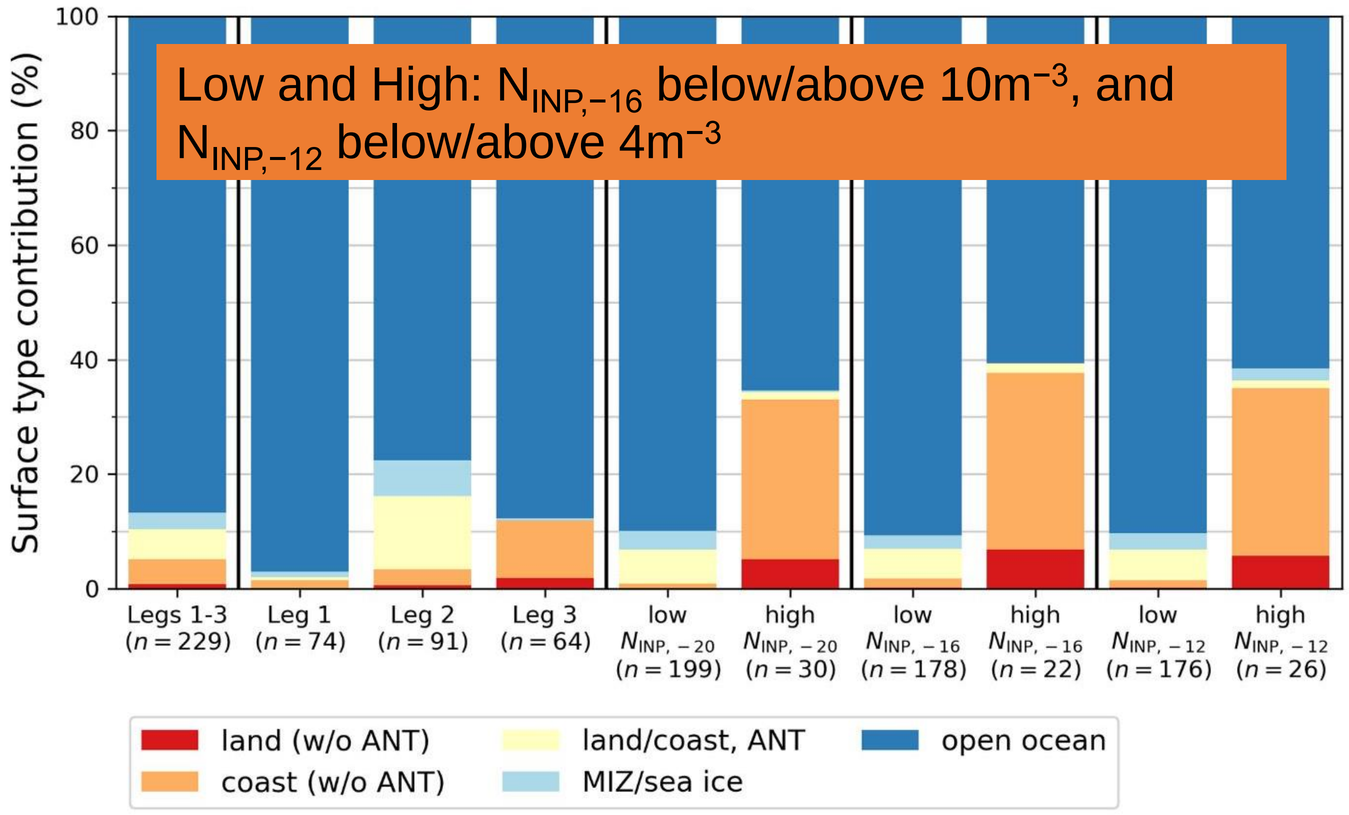
II. Lower N_{INP} in the Southern Ocean than previous studies; These INPs were mainly heat-stable materials (right).

Bigg et al. (1973), Journal of the Atmospheric Science

McCluskey et al. (2018), GRL

Previous INP Measurements in the Southern Ocean

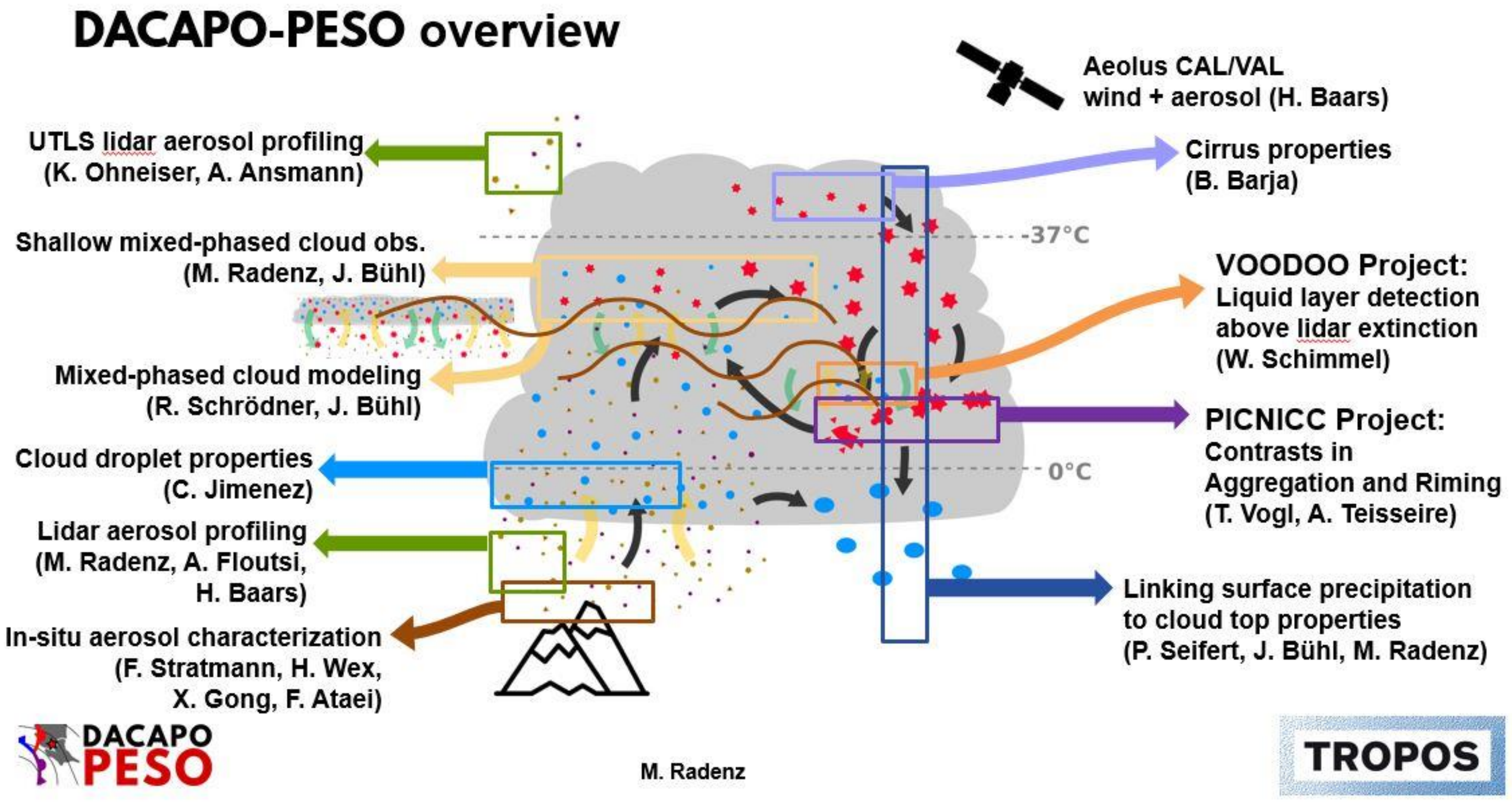




I. Continental N_{INP} higher than that in marine
II. Large variation of marine N_{INP}

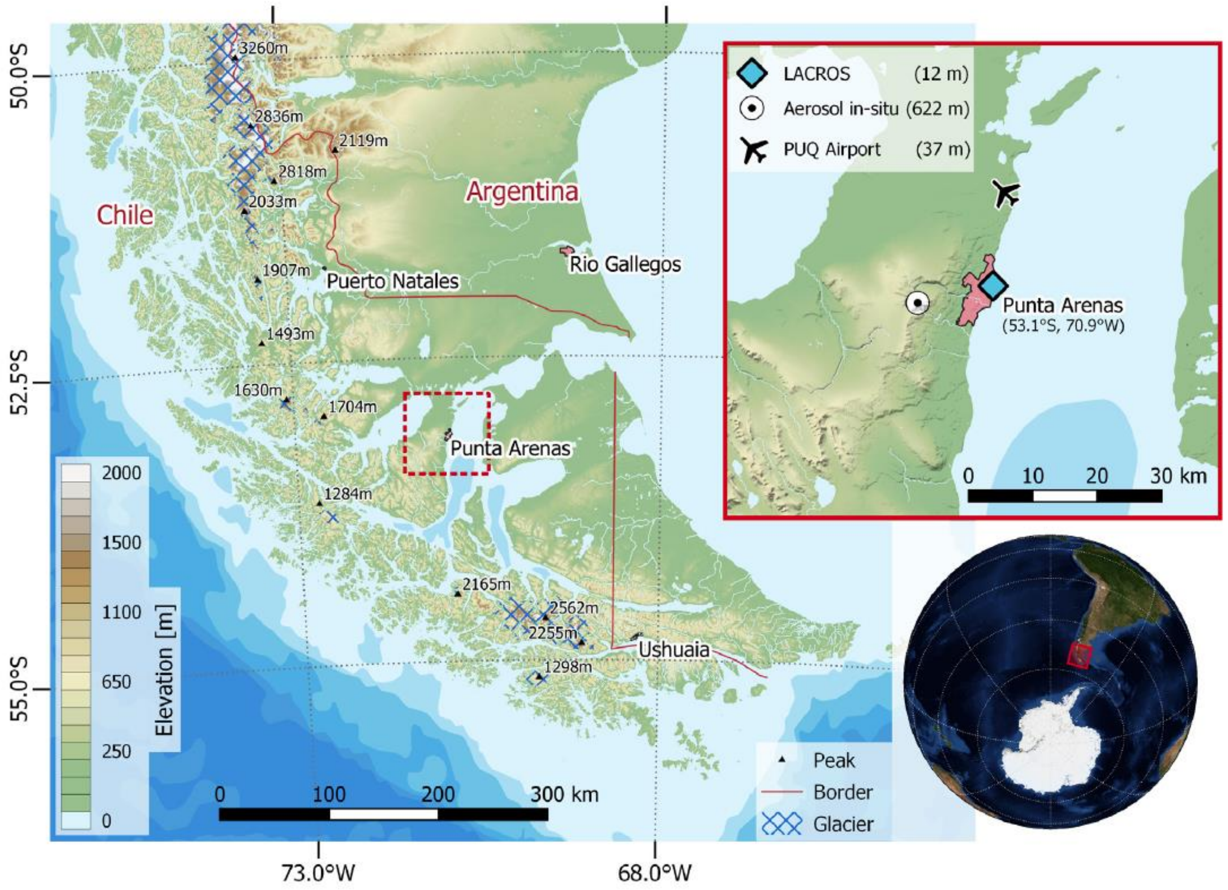
Welti et al. (2020), ACP
Tatzelt et al. (2022), ACP

Measurement Sites



Credit to Dr. Martin Radenz

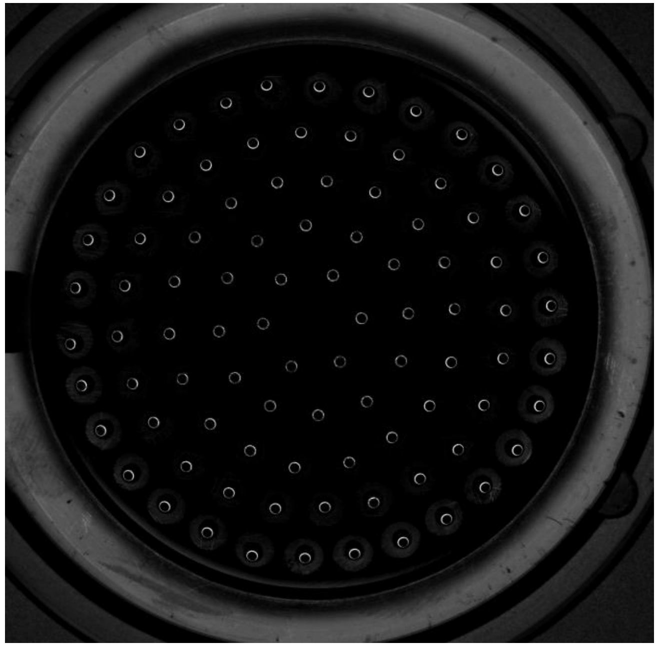
Measurement Sites

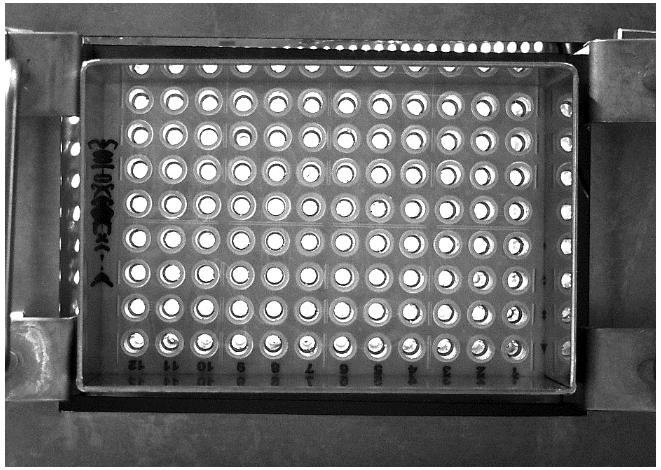


I. Filters collected at Aerosol in-situ station
II. Meteorology data collected in PUQ Airport
III. Lidar measurement preformed at LACROS

Credit to Dr. Martin Radenz

Off-line measurement (Cold stage/freezing array)





Leipzig Ice Nucleation Array (LINA)

V=1uL

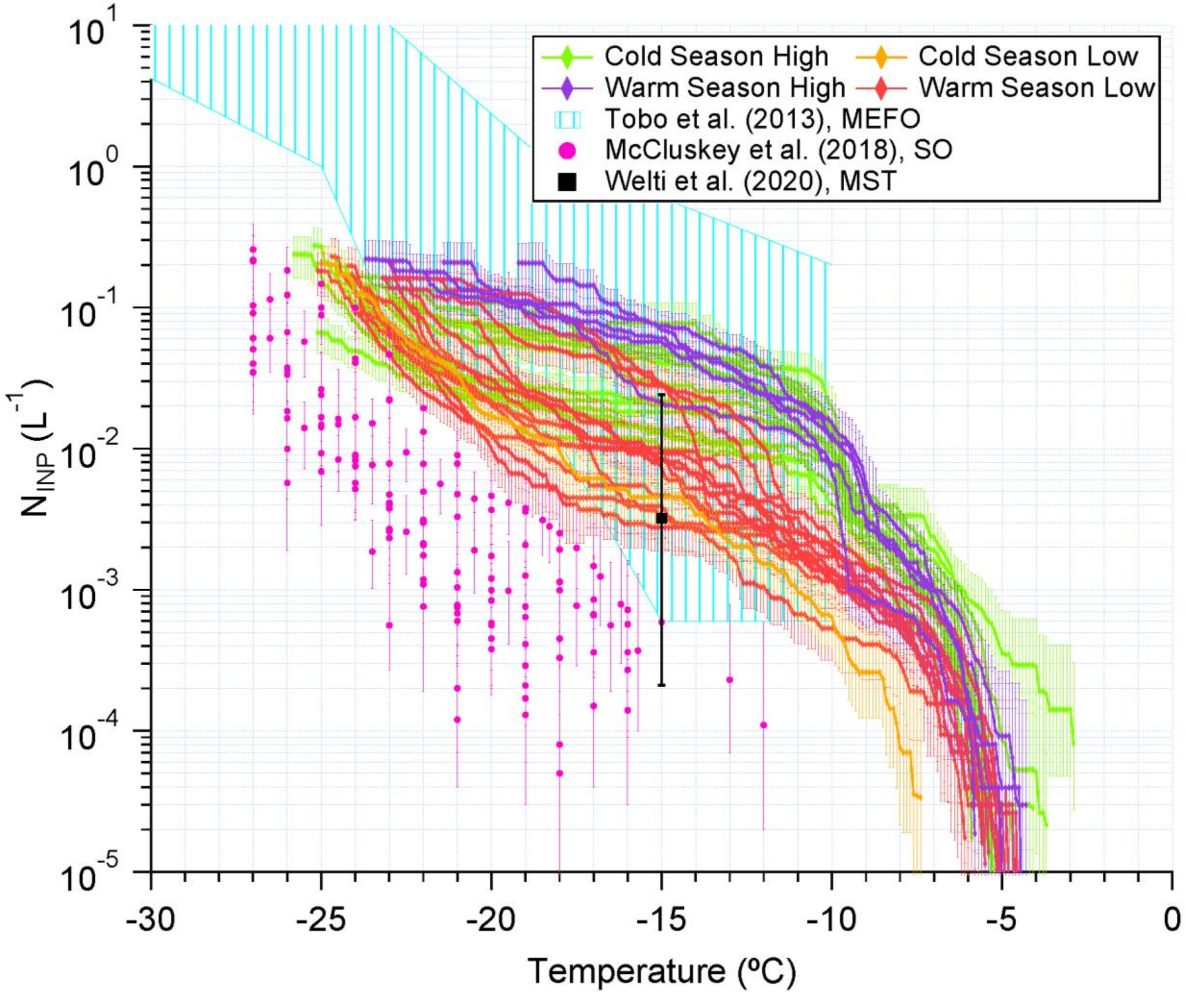
Ice Nucleation Droplet Array (INDA)

V=50uL

Measurement methods

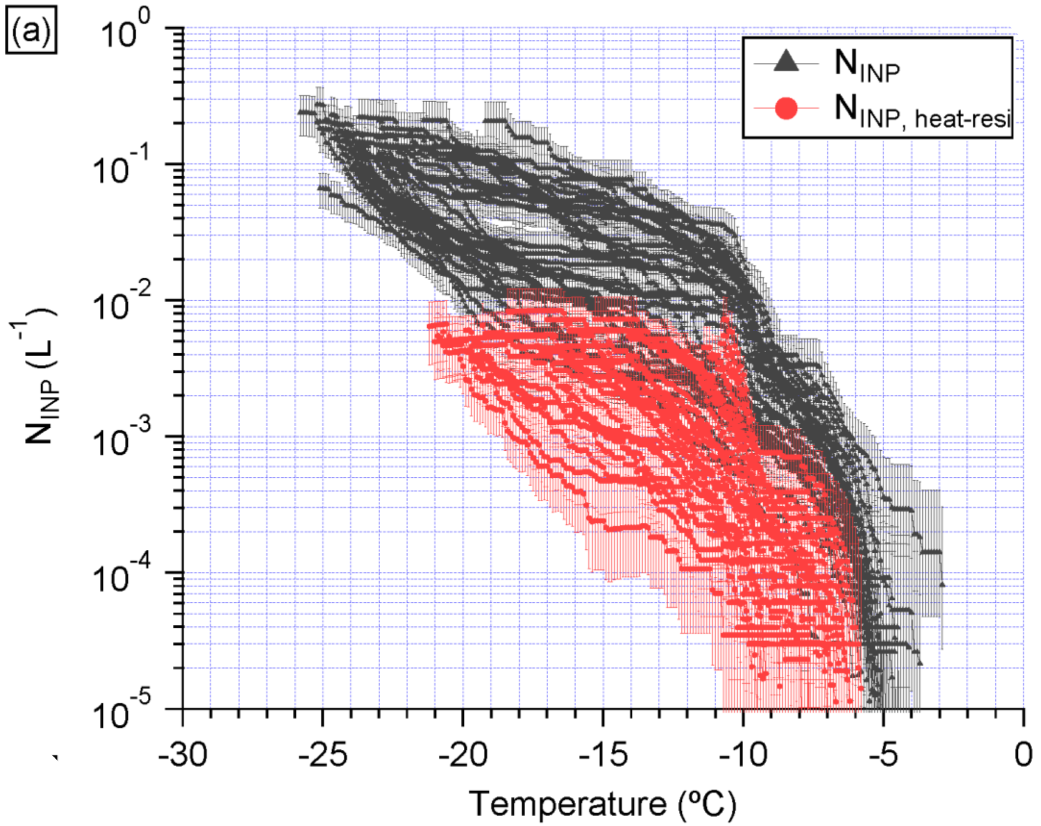
- f_{ice}: ice fraction
- $N_{INP}=-LN(1-f_{ice})/V$

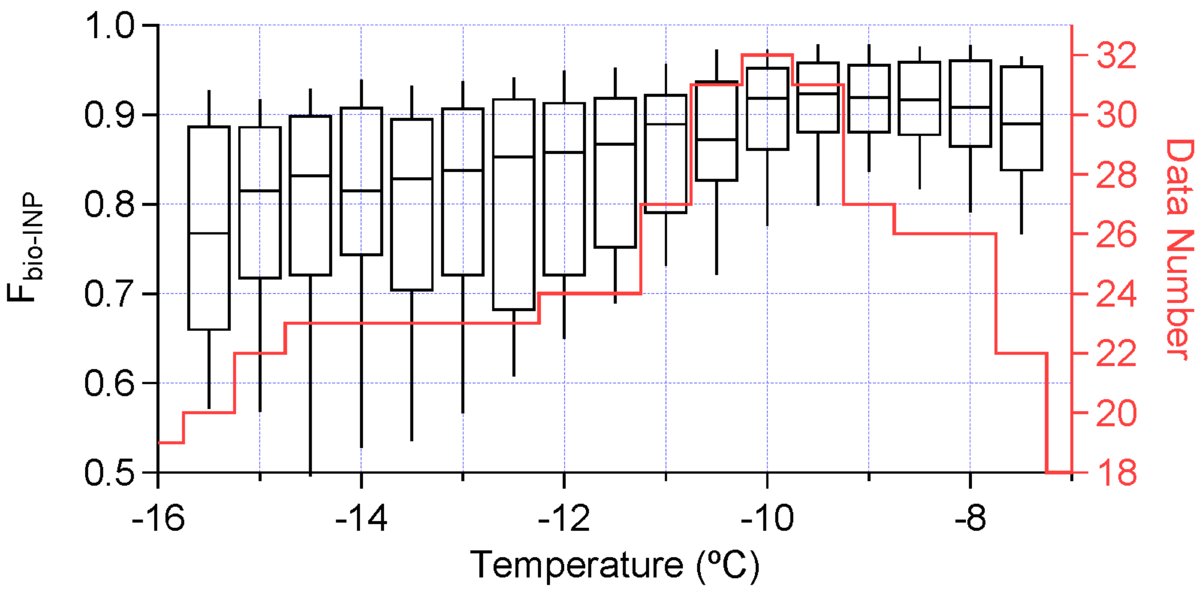
Temperature Spectra of N_{INP}



I. N_{INP} generally span a broad concentration range at any temperature
II. Relatively high and sharp increase of N_{INP} at >-10 °C
III. Comparable to land source N_{INP}, higher than marine N_{INP}
IV. Classify samples into groups, discriminating them by concentration, depending on N_{INP} at −11 °C

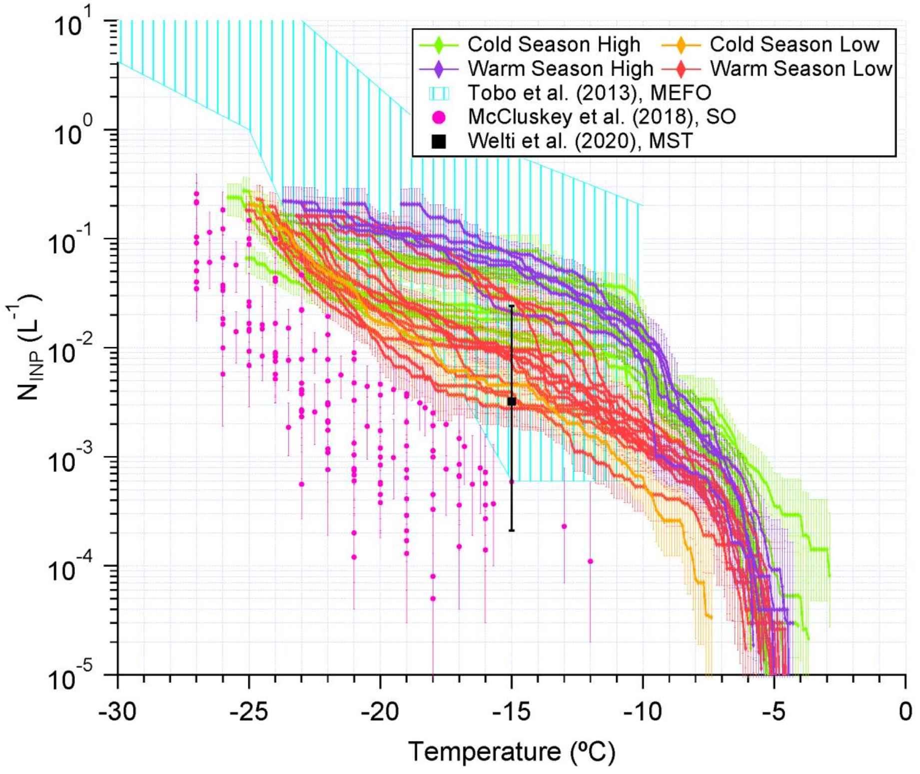
Contribution of Biogenic INPs

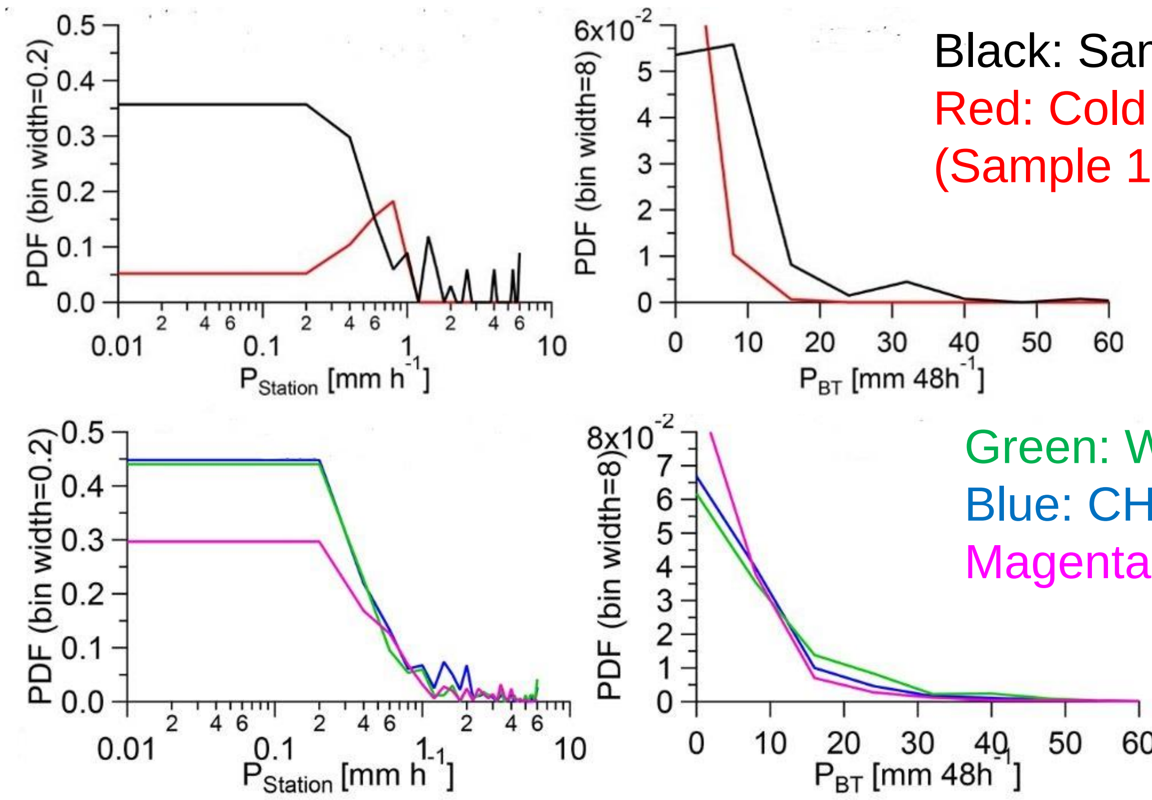




I. Heated to 95 °C for 1 h
II. Above −10 °C, more than 80% of all INPs were of proteinaceous biogenic origin.
III. From −10 °C to lower temperatures, a decreasing trend in biogenic INP fraction

Processes Controlling N_{INP}





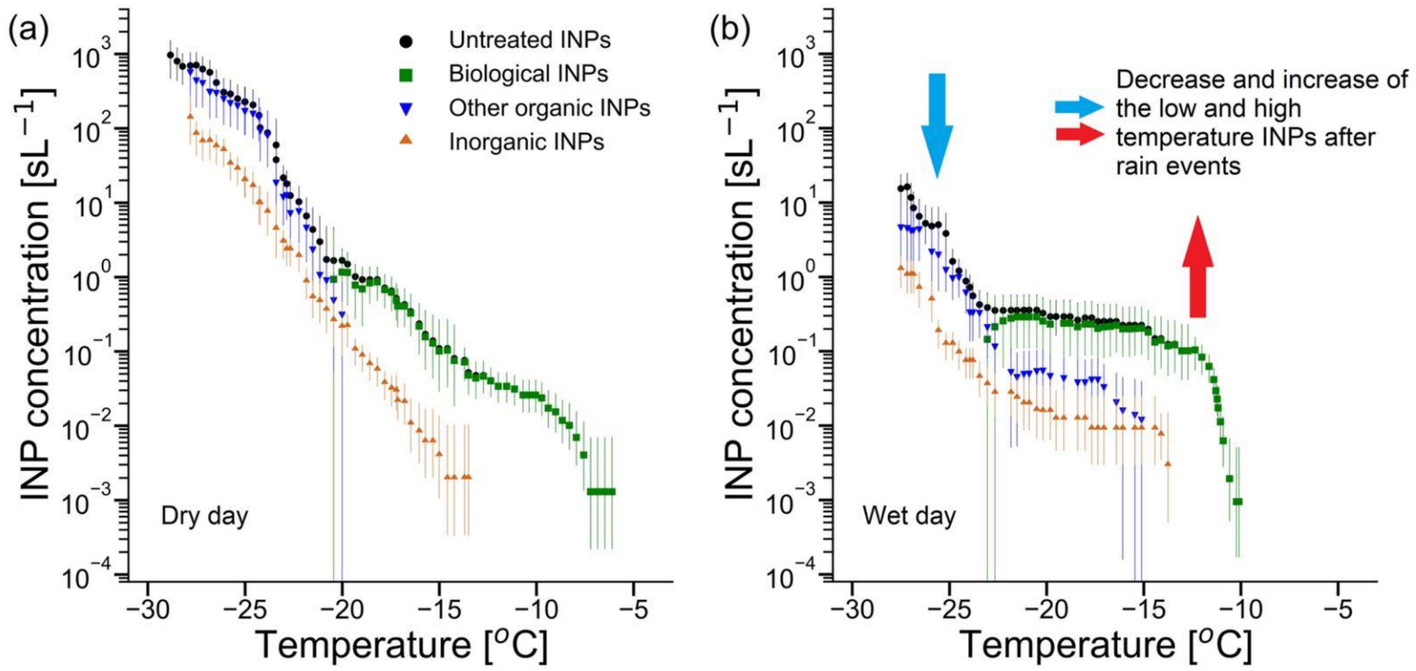
Black: Sample 12
Red: Cold Low (Sample 11)

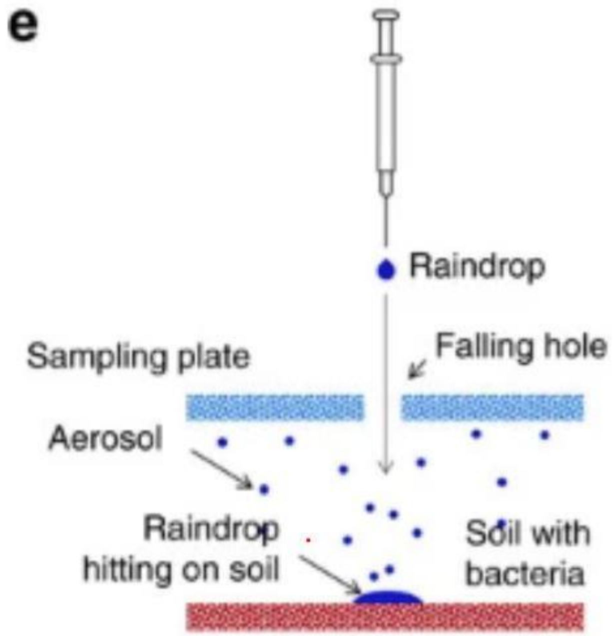
Green: WH
Blue: CH
Magenta: WL

I. Strong precipitation is one of the most important parameters to enhance the N_{INP} in both cold and warm seasons.

II. Other parameters are not directly related to N_{INP}. (Temperature, RH, cloud height, cloud cover, wind speed, wind direction, air masses, particle surface area, vertical particle backscatter).

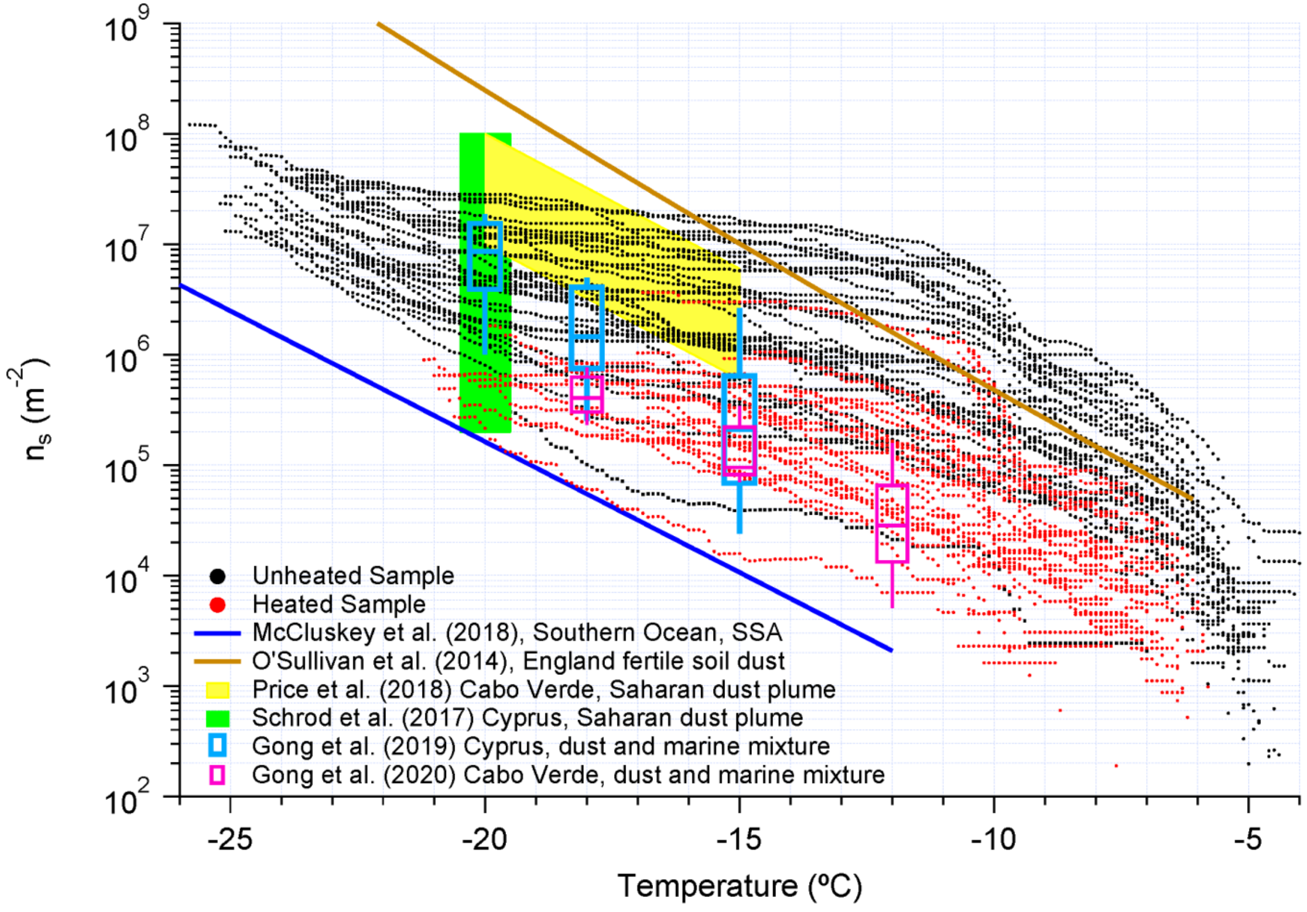
Special Effect of Rain on the INPs





Testa et al. (2022), JGR Atmospheres
Joung et al. (2017), Nat. Commun.

Ice Active Surface Site Density

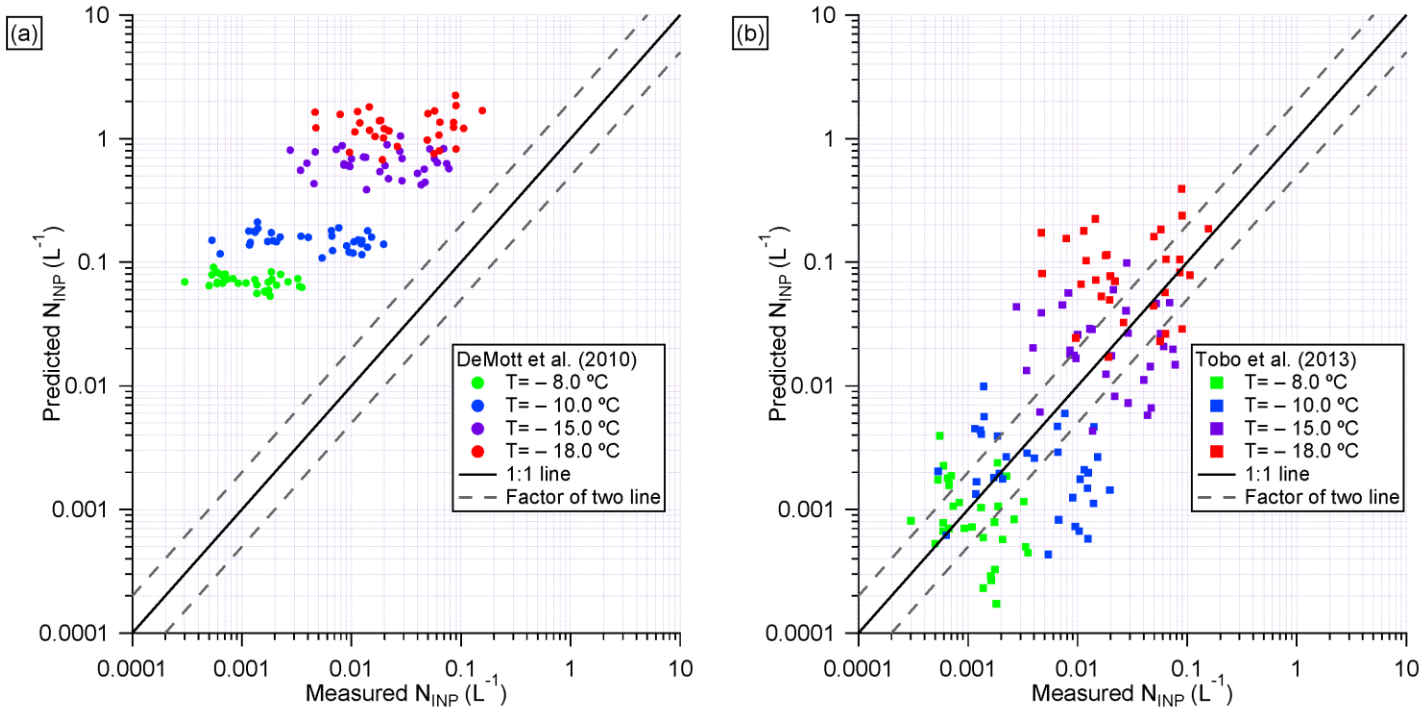


I. Unheated samples n_s above ~ −15 °C are higher than n_s of other INPs.

II. Unheated samples n_s below ~ −15 °C are comparable to n_s of soil/mineral INPs.

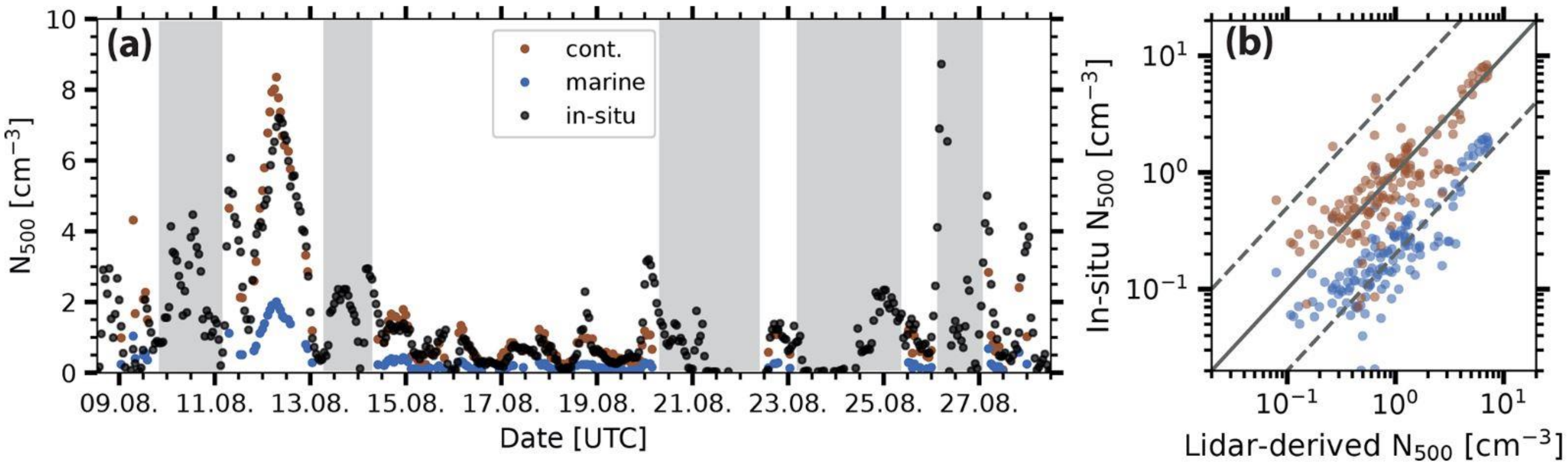
III. Heated samples n_s are comparable to mineral/soil INPs.

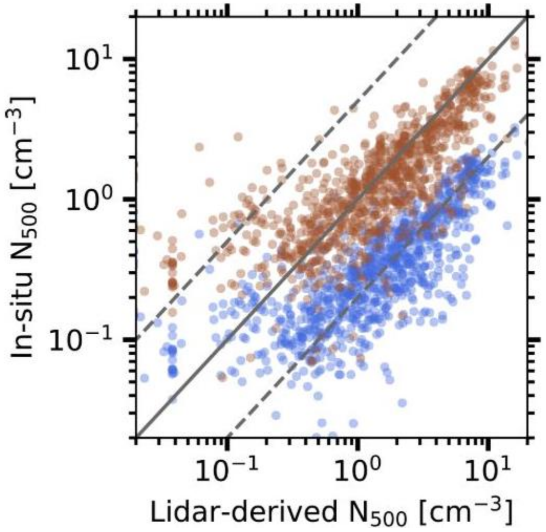
Parameterization of N_{INP} ($N_{>500nm}$)



I. Parameterization based on "global" average (not include SSA) overestimates N_{INP} in this study.
II. Parameterization based on measurements in a forest ecosystem fits N_{INP} is this study.

Relationship Between in-situ Measured $N_{>500nm}$ and Lidar Data





I. Values retrieved when assuming continental aerosol fit well with the in-situ data.

II. N_{INP} valid throughout the boundary layer may generally be derived based on lidar data.

Take-home Messages

1. The N_{INP} in this study is higher than that in the Southern Ocean, but comparable with land source.
2. Roughly 90% of all INPs were proteinaceous and hence of biogenic origin. This fraction lowered to ~ 70% between −10 and −16 °C.
3. Ice active surface site density (n_s) support the conclusion that major INPs are land source.
4. Strong precipitation is the parameter to enhance the N_{INP}.
5. Lidar-retrieved $N_{>500nm}$ and parameterization extend our tools to get N_{INP} in the boundary layer.

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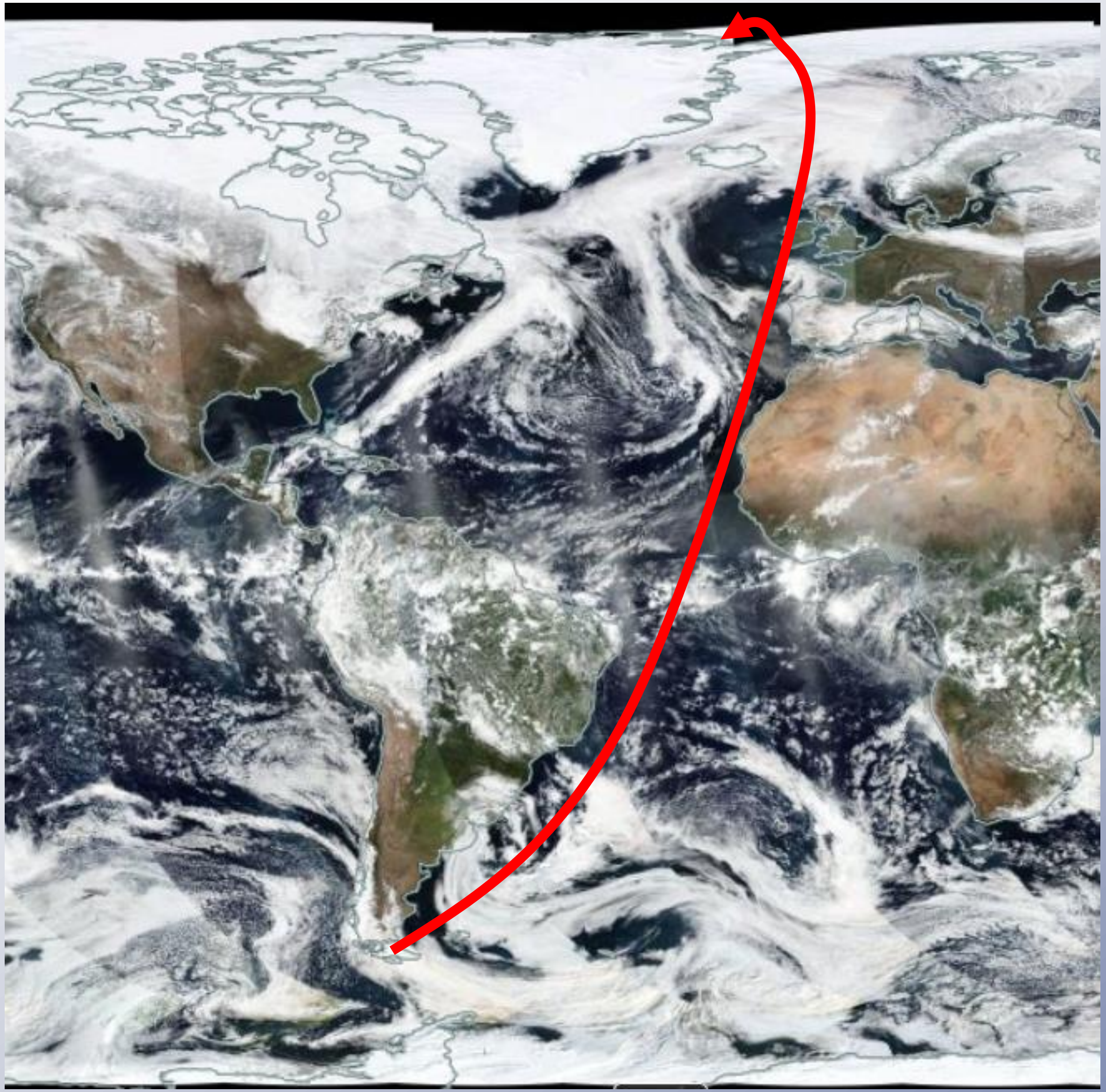
Going North: Villum Research Station in Northern Greenland



work done by Kevin Cheuk Hang Sze

with contributions to the here presented plots from

Markus Hartmann
Frank Stratmann
Diego Villanueva
Heike Wex

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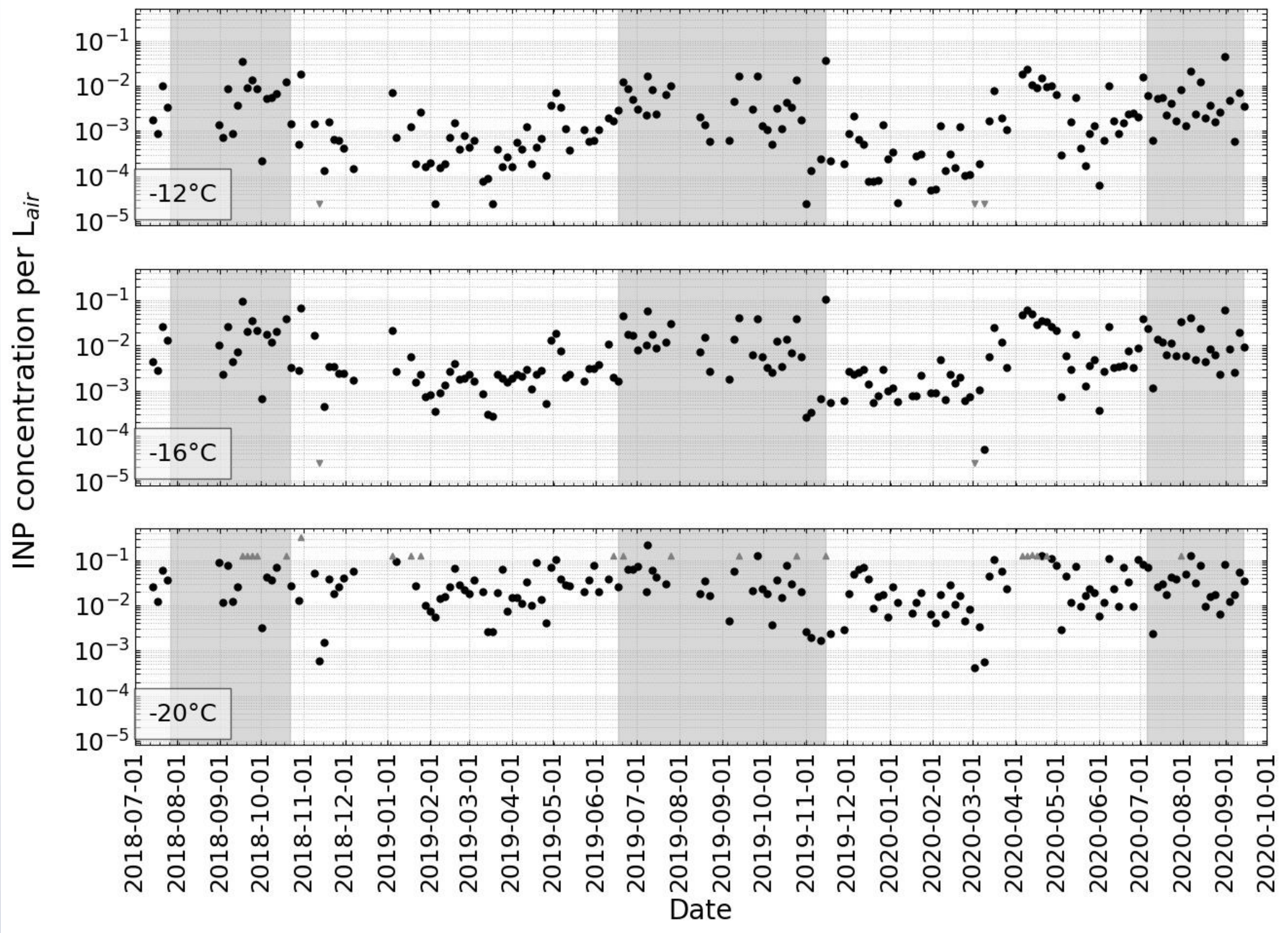
Going North: Villum Research Station in Northern Greenland

Villum Research Station (VRS)

- Low volume sampler with PM_{10} inlet and air flow of 21 L/min
- polycarbonate filters
- each filter sampled for 3.5 days
- 181 filters in total for this study in the course of two years

2 year long time series



2 year long time series (2nd year in parallel to MOSAiC) corroborates earlier results:

higher concentrations of highly ice active INP in summer

(white background -> ground is covered with snow

gray background -> ground is not covered with snow)

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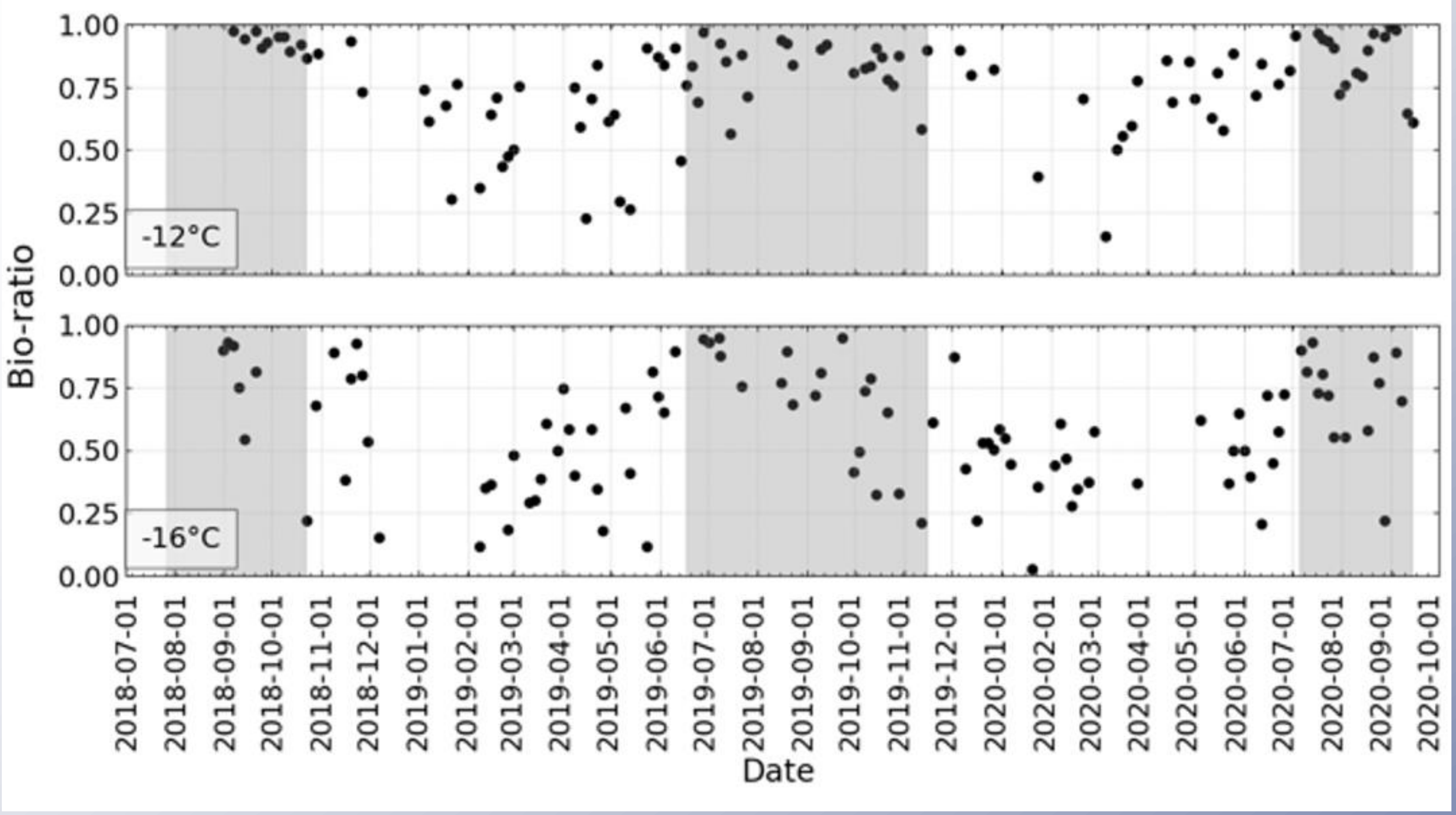
fraction of proteinaceous INP



heating the samples (90°C, 1h)

-> destruction of heat labile INP (proteins)

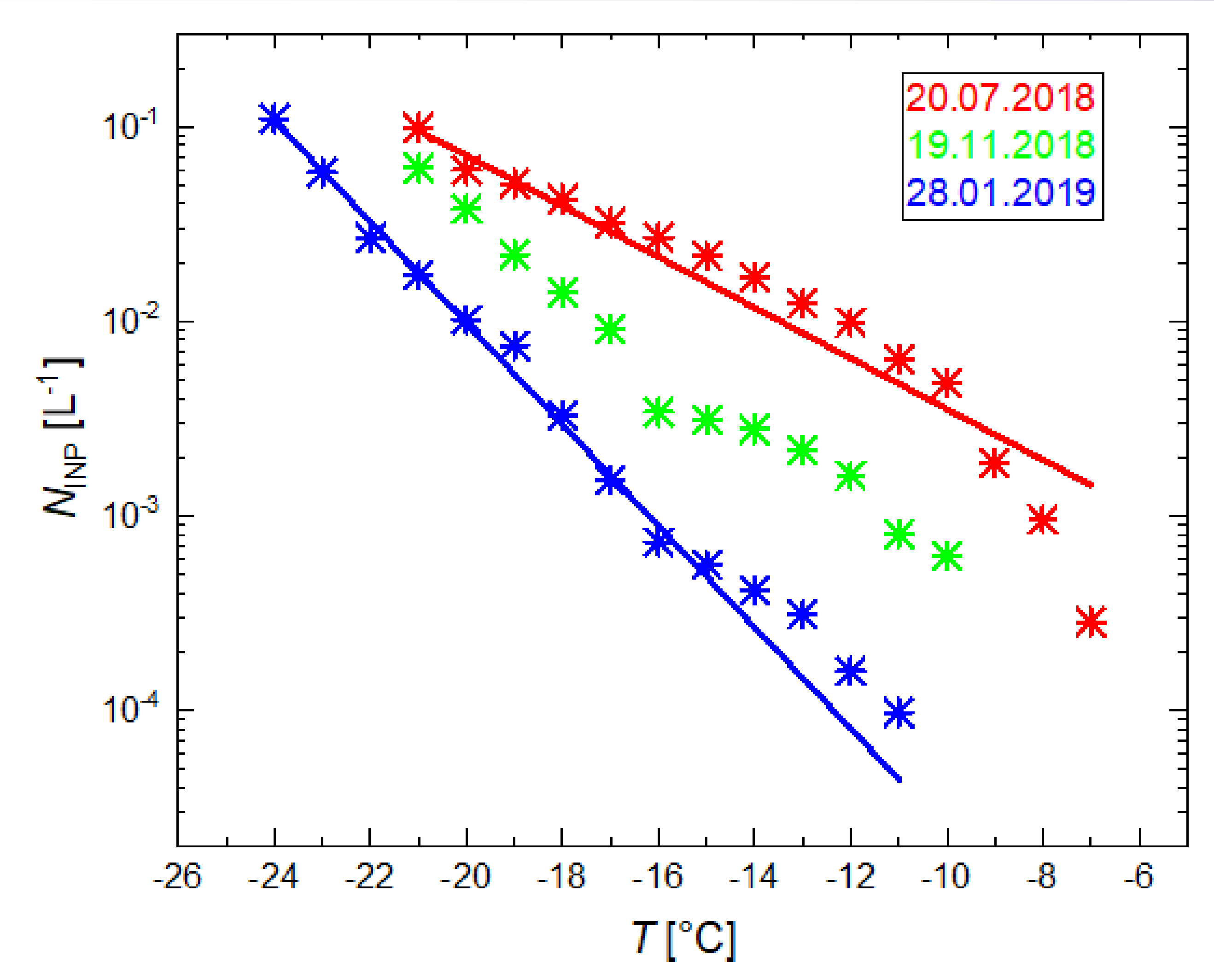
-> Bio-ratio:

$$(N_{INP} - N_{INP\text{-}heated})/N_{INP}$$

(fraction of heat labile INP)

-> higher concentrations in summer in connection to proteinaceous INP

repetitive INP spectra



$$N_{INP} = A \cdot e^{s \cdot T}$$

s = -0.3

or

s = -0.6

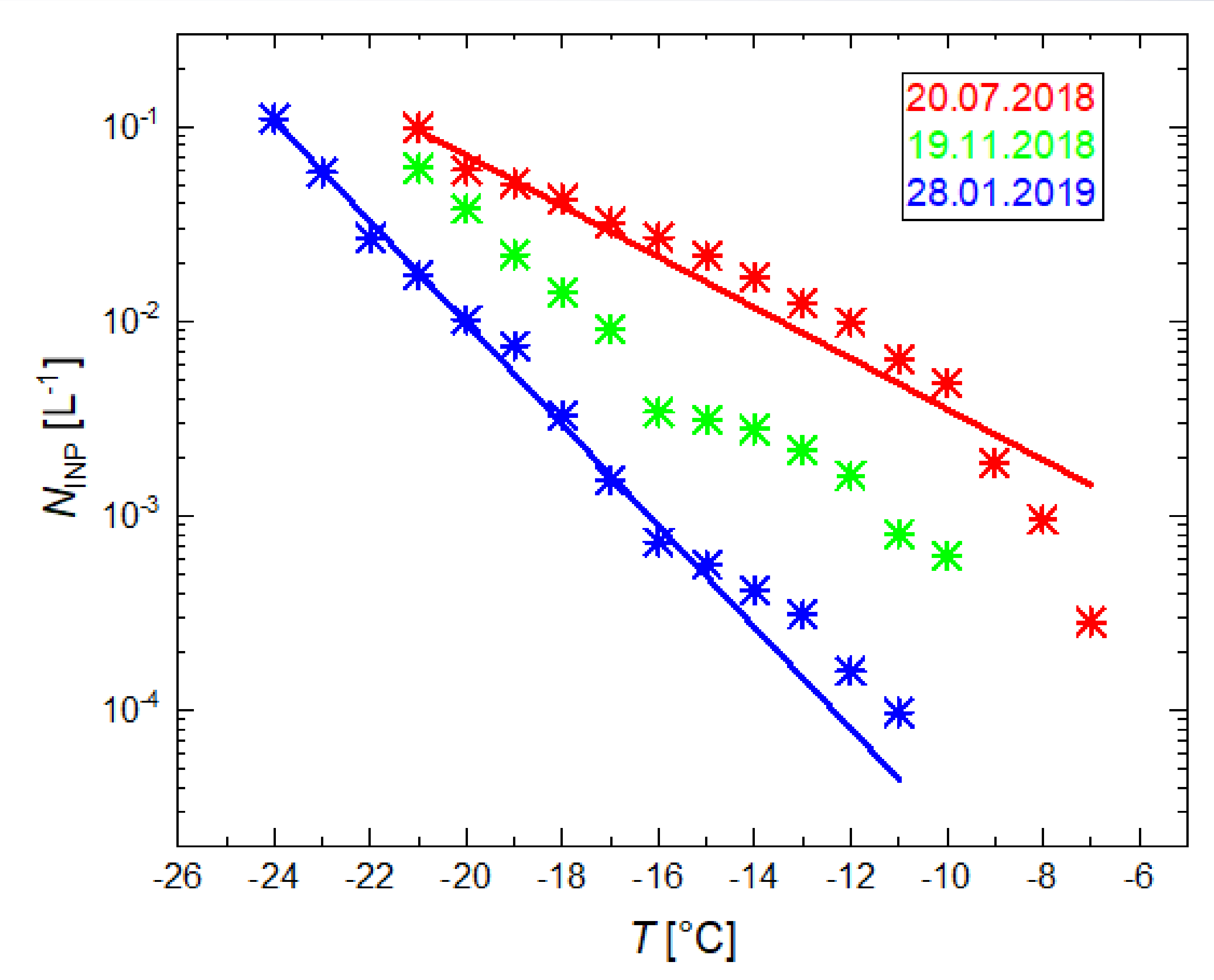
s : slope

A : y – intercept

T : temperature [°C]

N_{INP} : INP concentration [L^{-1} air]

repetitive INP spectra



$$N_{INP} = A \cdot e^{s \cdot T}$$

s = -0.3 Cooper (1986)

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s = -0.6 Fletcher (1962)

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mixture of both

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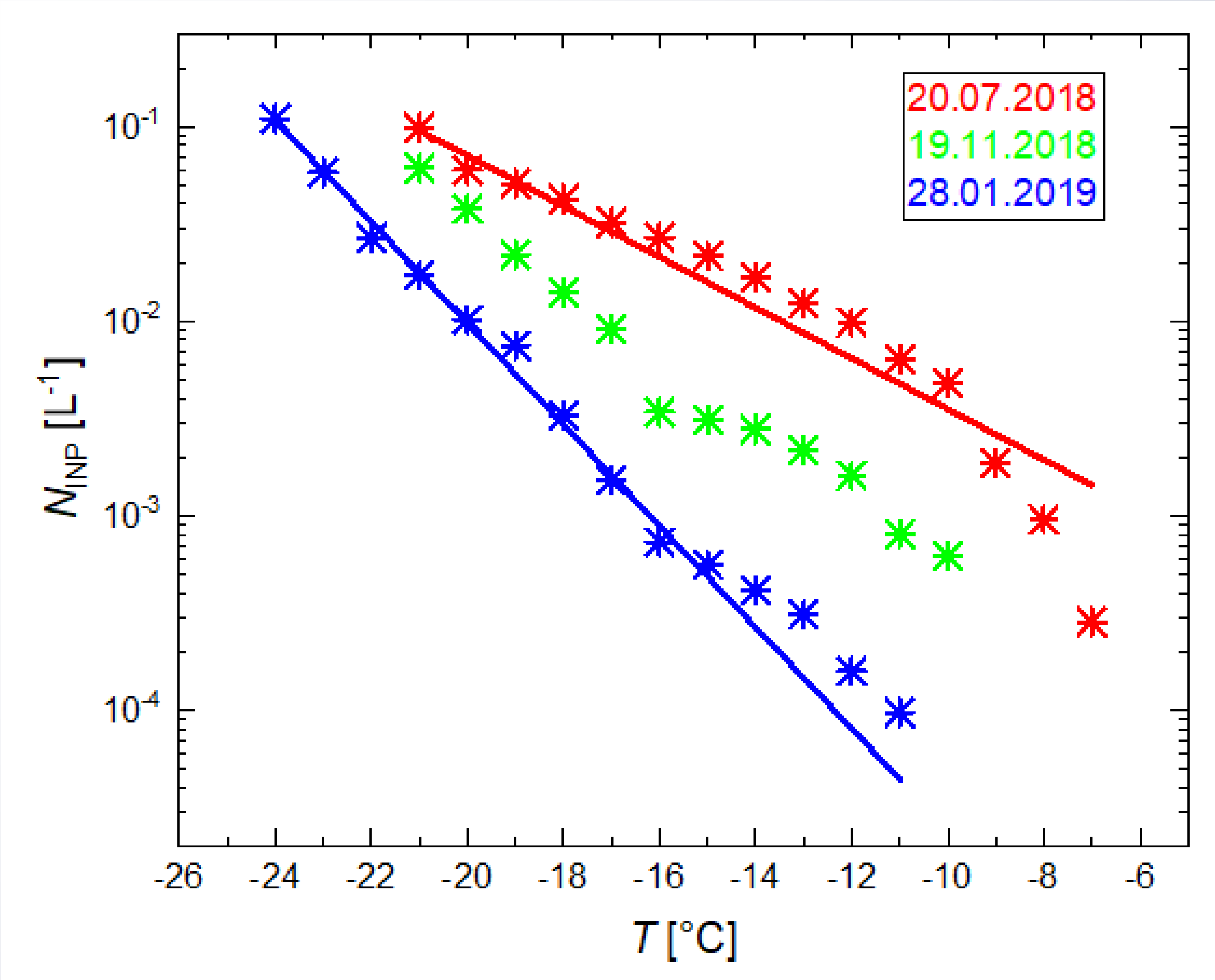

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-> similarity to these two sloples used to classify all cases

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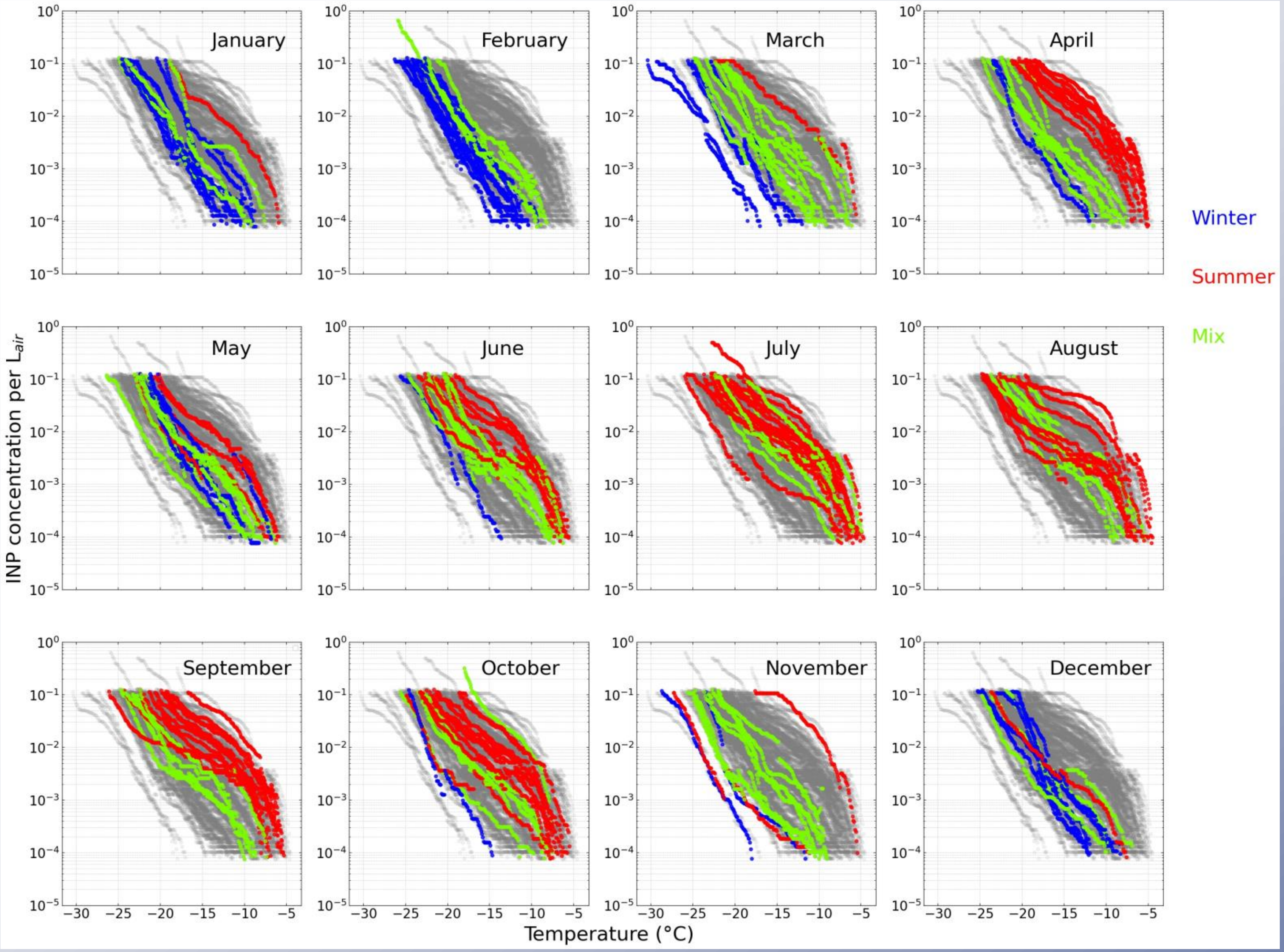
repetitive INP spectra



s = -0.3 Cooper (1986)
occurs in summer months
(60% of all cases from June to October)

s = -0.6 Fletcher (1962)
occurs in winter months
(60% of all cases from December to March)

mixture of both
occurs in ~40% of all cases throughout the year

transition months:
April, May and November

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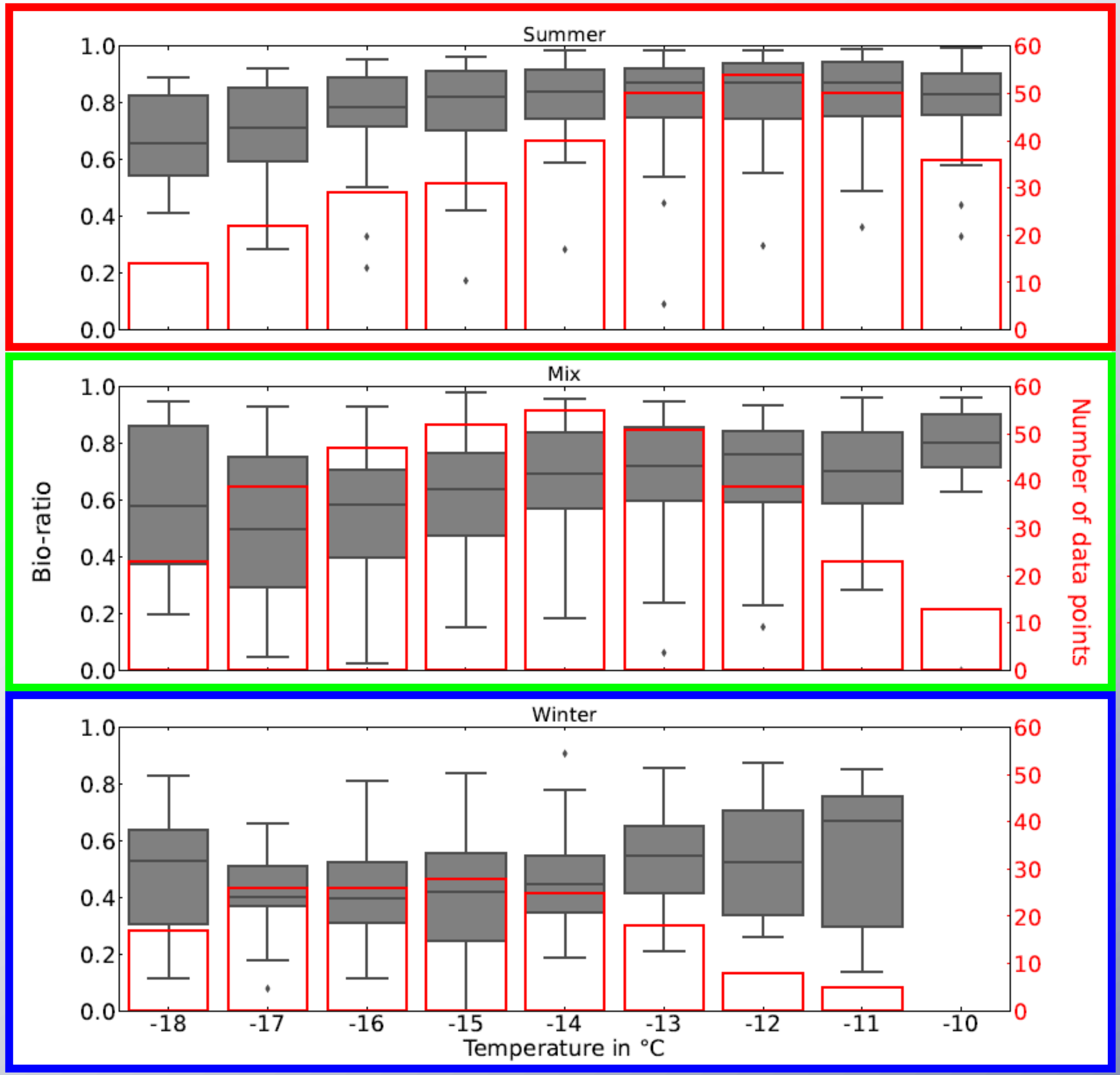
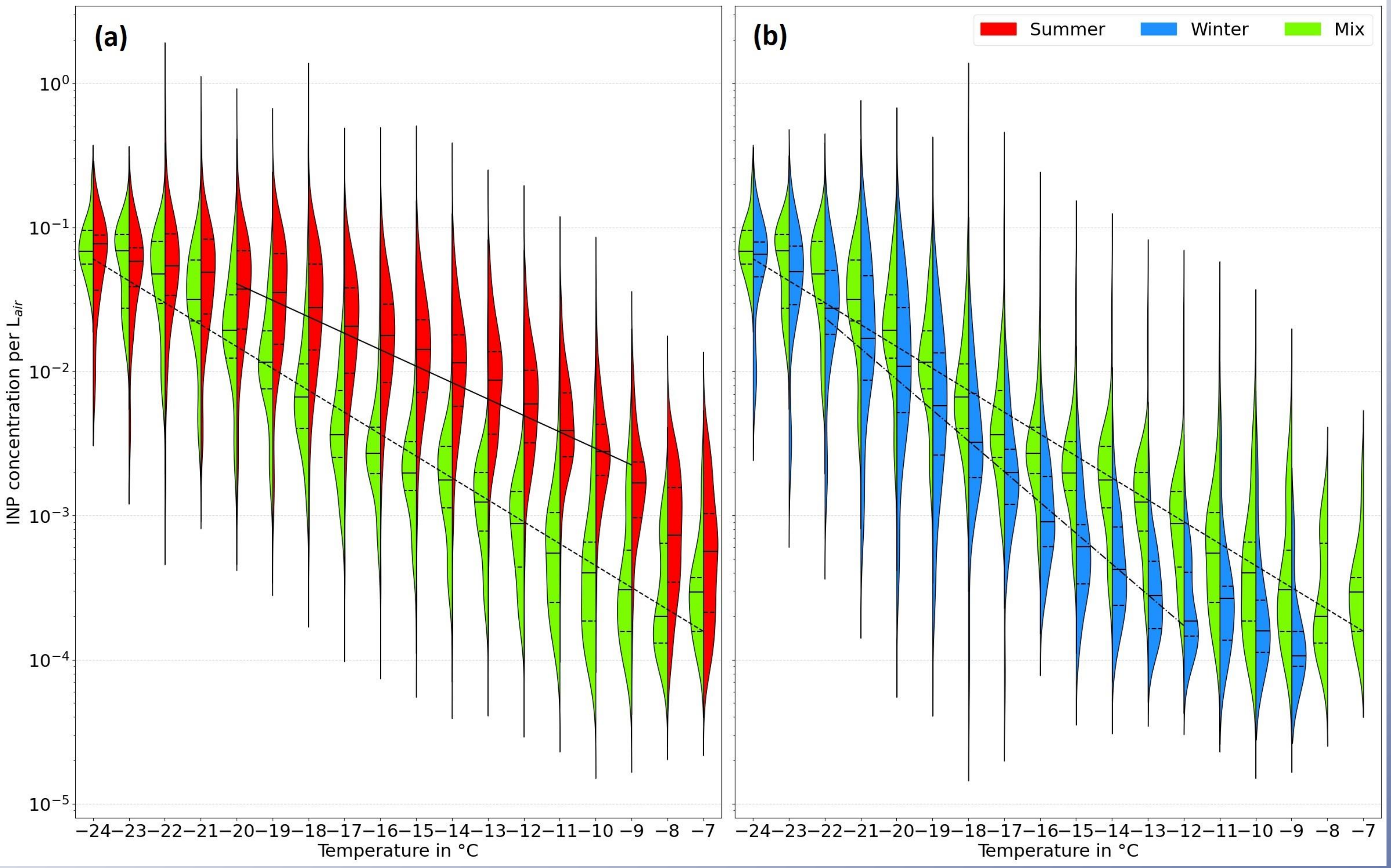
heat labile INP for the three cases



in summer: the overwhelming majority of all INPs is heat labile

in winter: even then, a significant fraction of INPs is heat labile
-> not only mineral dust

parameterization for the three different cases



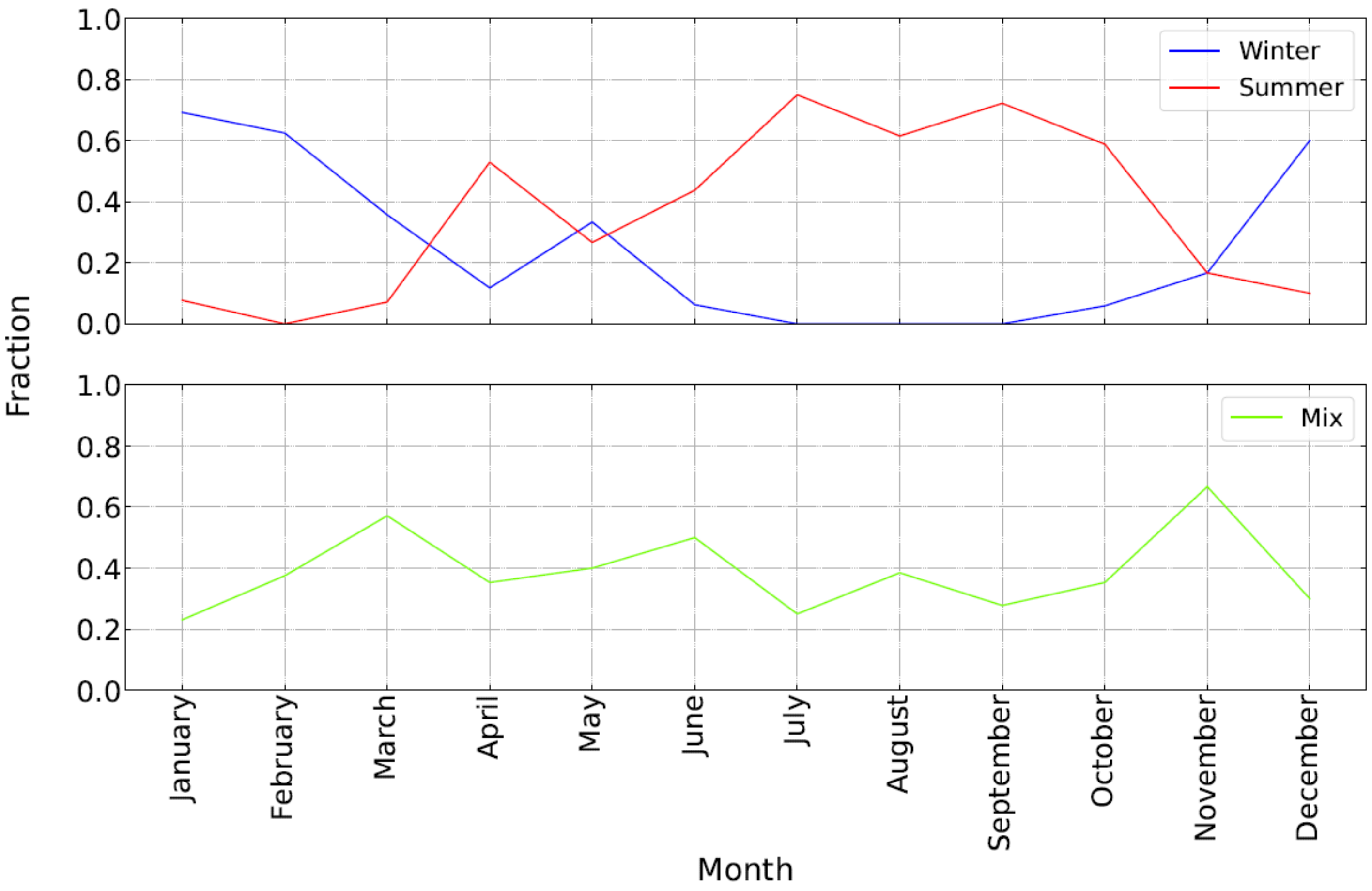
$$N_{INP} = A \cdot e^{s \cdot T}$$

Cases	A	s
Summer	$2.111 \cdot 10^{-4}$	-0.263
Winter	$4.710 \cdot 10^{-7}$	-0.492
Mix	$1.365 \cdot 10^{-5}$	-0.354

Temperature range of the fits
$-20 \leq T \leq -9$
$-22 \leq T \leq -12$
$-24 \leq T \leq -7$

parameterization for the three different cases

summer: ~ 60% of all cases from June to October
winter : 60% of all cases from December to March
mix: ~40% of all cases throughout the year
transition months: April, May and November



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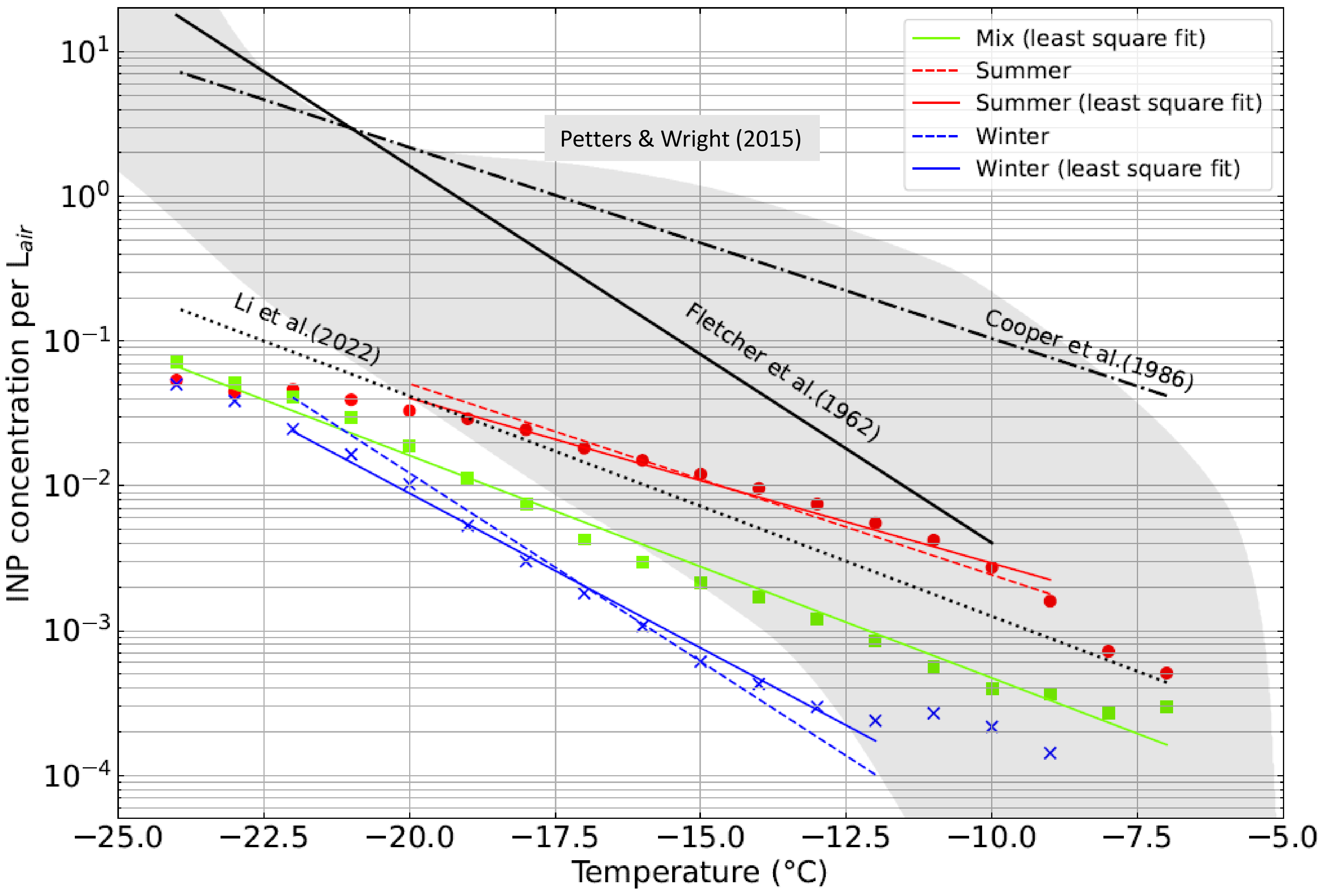

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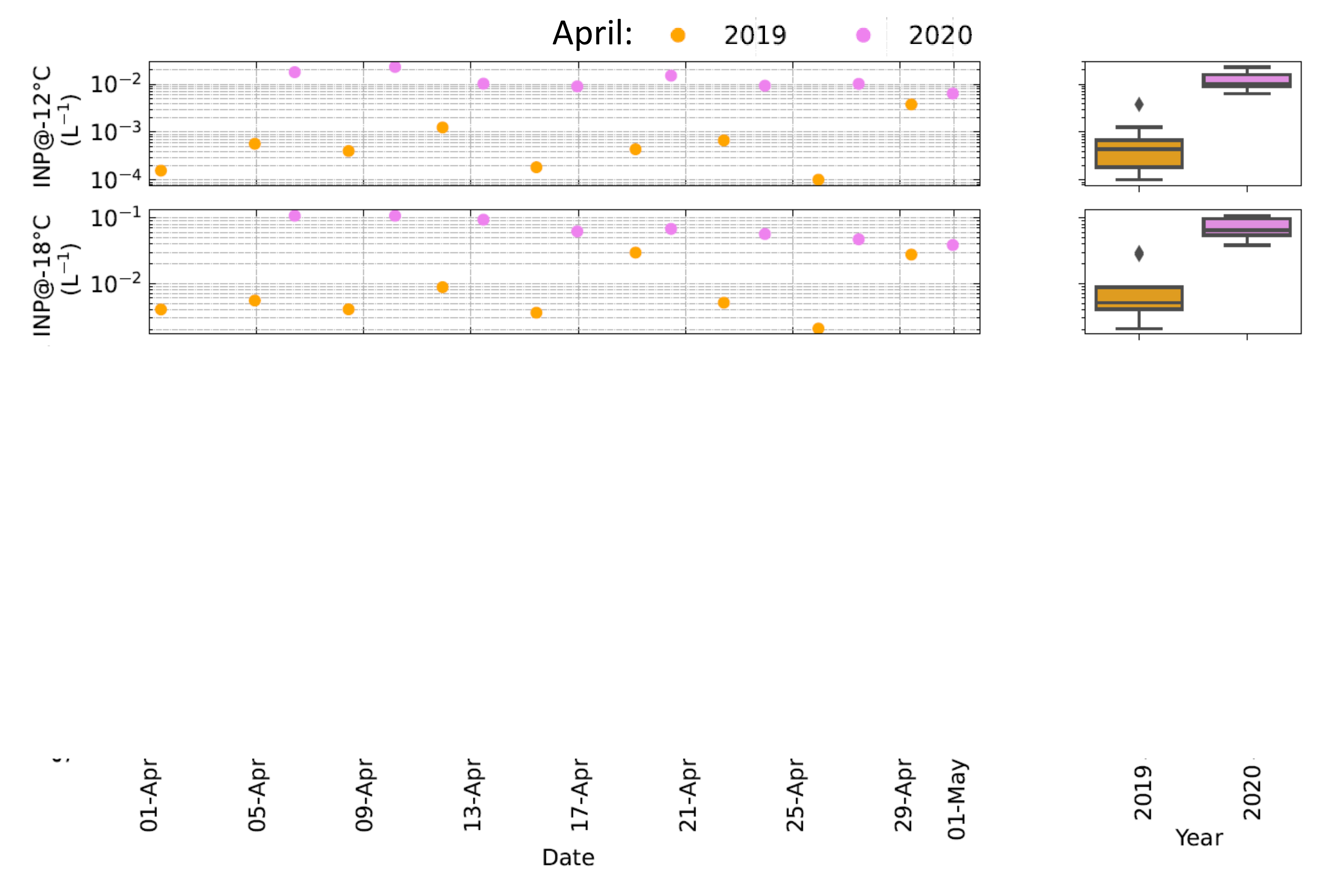
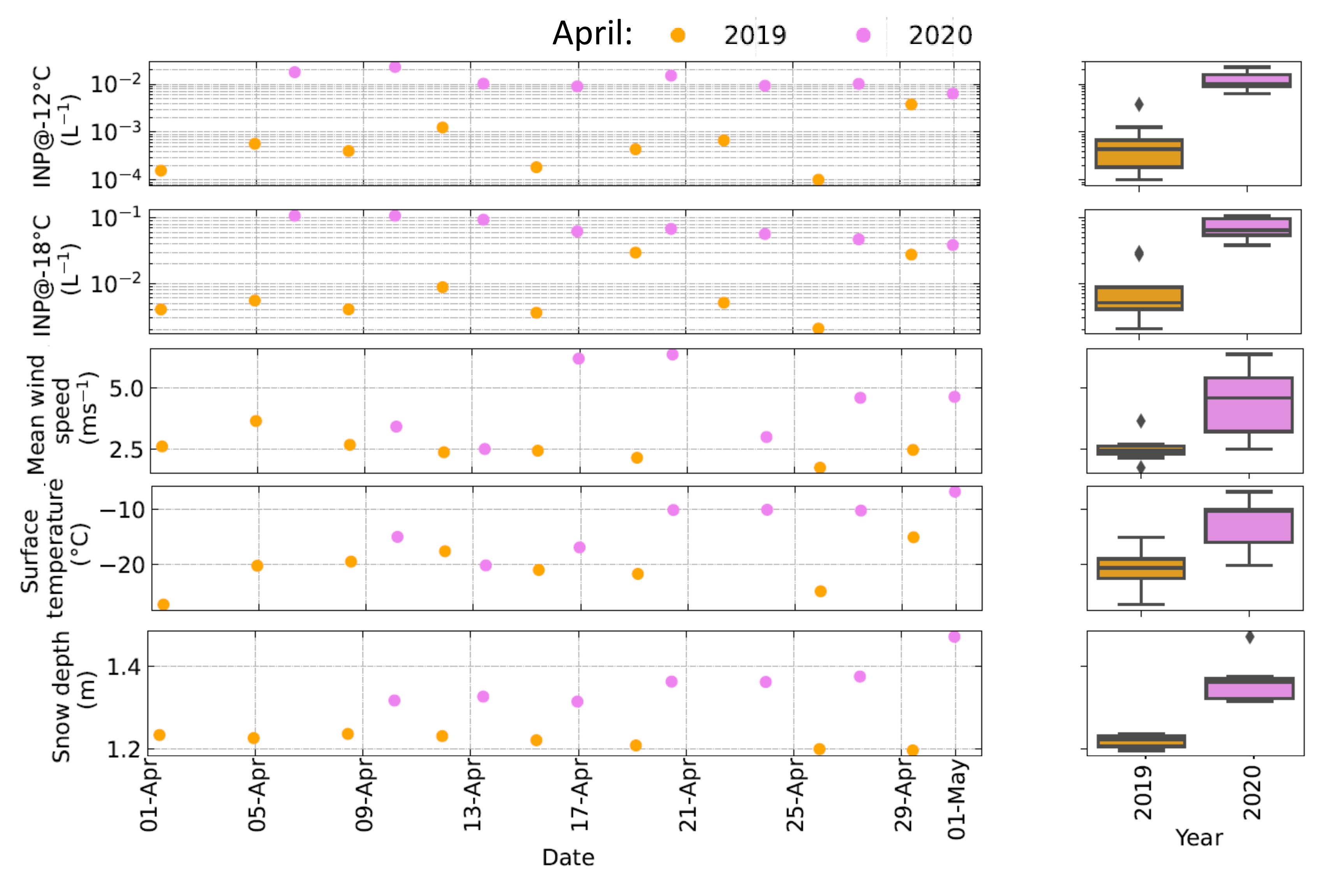
case study: a puzzle



VERY strong difference in INP concentrations between April 2019 and April 2020

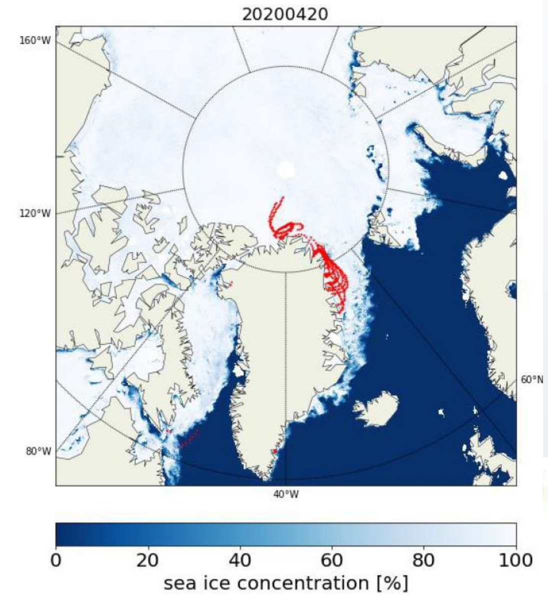
case study: a puzzle



- no significant differences observed in meteorological parameters that could explain our observation
- wind speed and surface temperature higher in second half of April 2020
- snow depth on average were higher in 2020

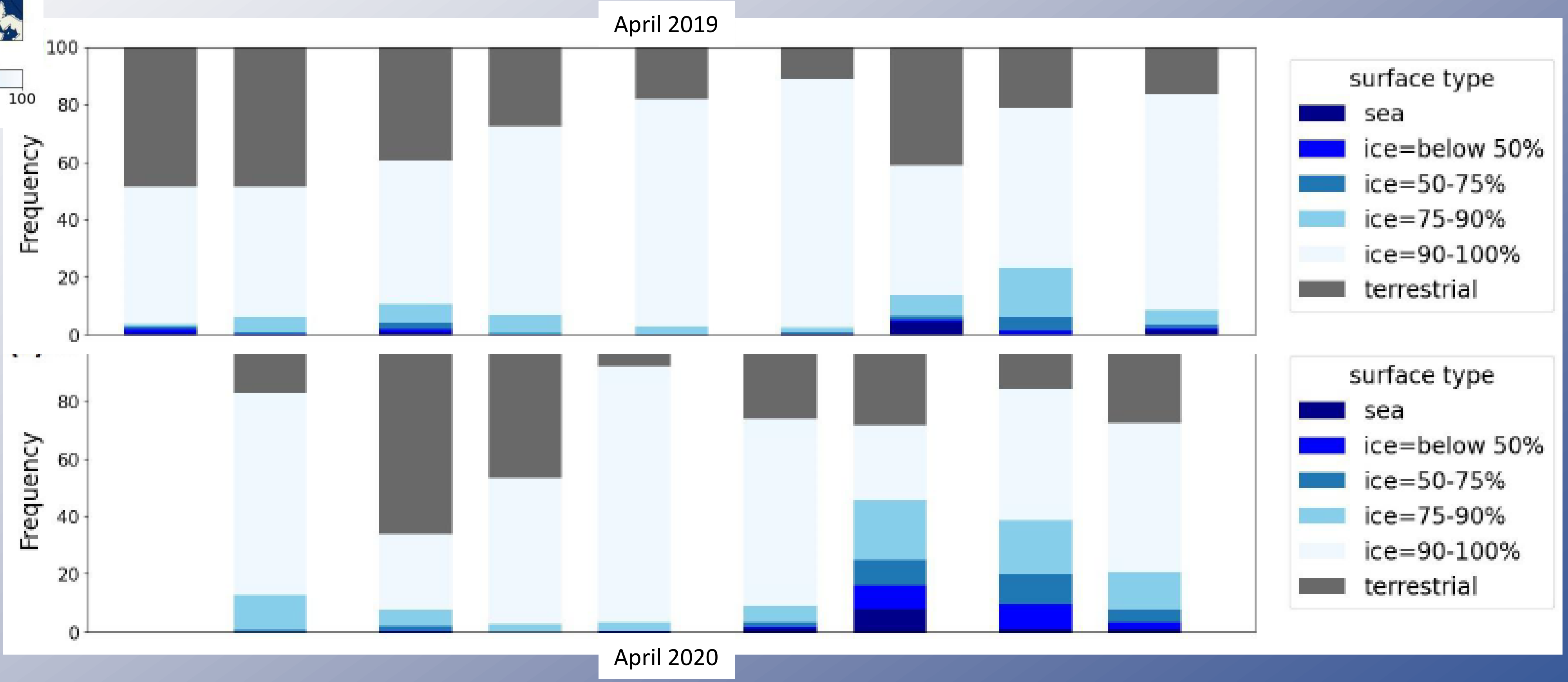
(paper on atmospheric river in April 2020, Dada et al., 2022)

case study: a puzzle

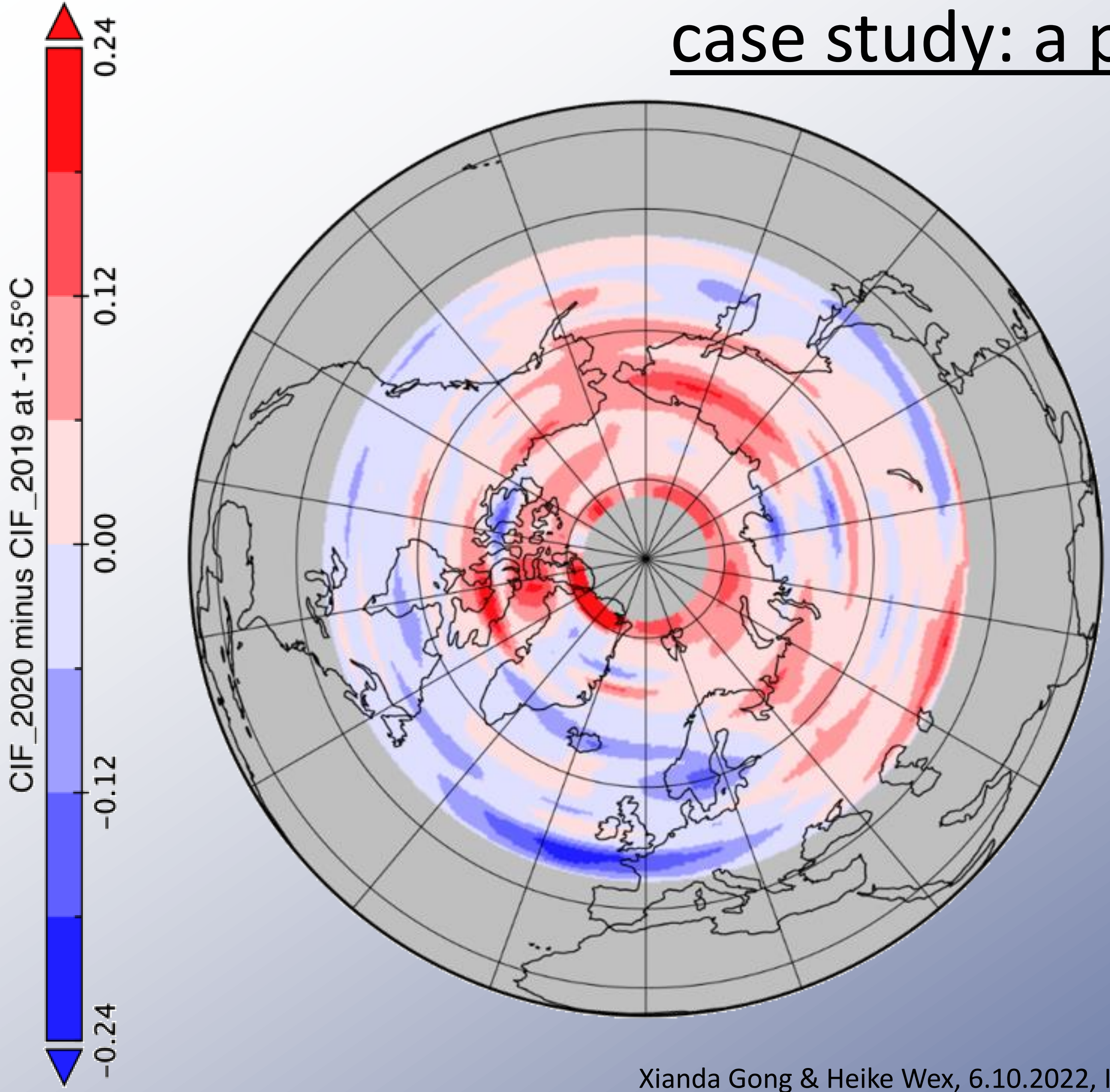


- no significant differences in surfaces crossed by air masses

(based on 5-day back-trajectories arriving at VRS at 50m with thres-hold heights below 250m)



case study: a puzzle



satellite data on cloud ice fraction (CIF) averaged for April 2019 versus April 2020

red: more ice in clouds in 2020

-> indeed higher CIF observed for the region close to VRS

summary for Villum Research Station

- 2 year long measurements of INP concentrations at Arctic station in Northern Greenland

- in summer: high concentrations of highly ice active INP and high fraction of proteinacious INP

- proteinaceaous INP fraction still not zero even in winter

- three parameterizations were derived:

  one for cases occuring in summer months only (June-Oct.), during 60% of the time

  one for cases occuring in winter months only (Dec.-March), during 60% of the time

  one for cases occuring 40% of the time throughout the year

  (transition months April, May and November)

(similarities in slopes to old literature: Fletcher (1972) and Cooper (1986))

- a case study comparing April 2019 to April 2020 could not shed light on INP sources

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- a case study comparing April 2019 to April 2020 could not shed light on INP sources

soon to be submitted to ACPD

overall summary

- fraction of proteinaceous INP high in both locations

- INP number concentrations particulary high for Southern Chile throughout the year, but also high in summer for Villum research station

- ground based INP measurements seem connected to boundary layer / clouds

- finding the sources or precise nature of the INP is always difficult

-> long-term and high time-resolution measurements of N_{INP} are needed in the future