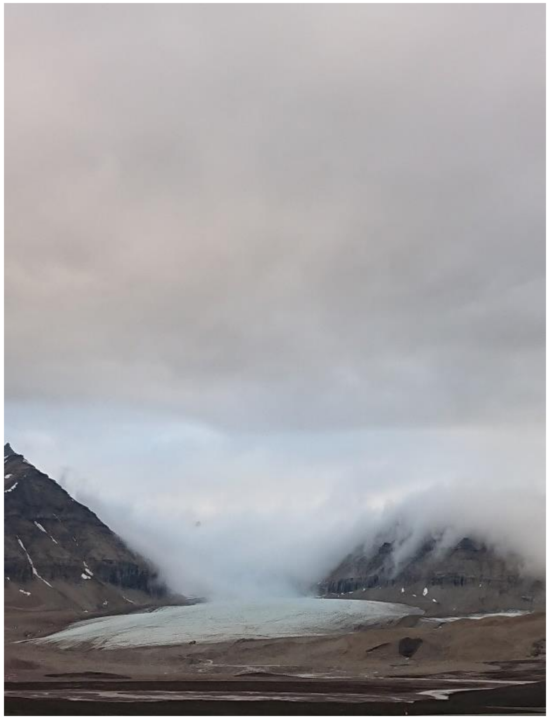
Variability of aerosols related to cloud formation over the Svalbard region

11th Virtual INP colloquium

9 March 2021



ArCS
Arctic Challenge for Sustainability
ArCS II Arctic Challenge for Sustainability II

Yutaka Tobo

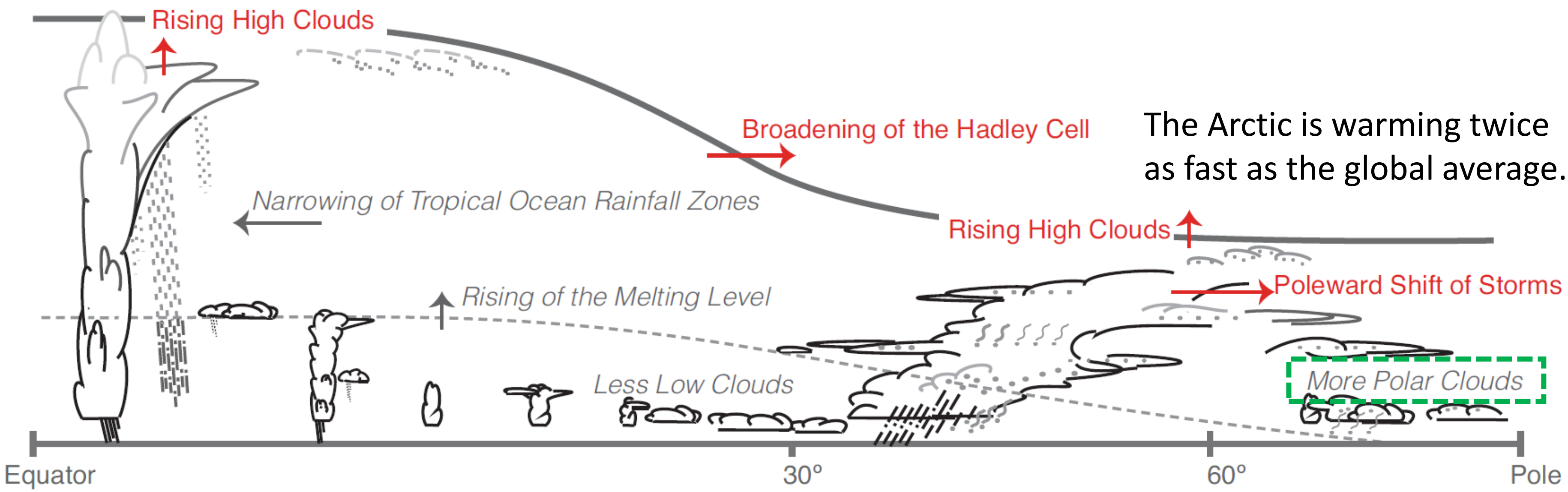
NIPR (National Institute of Polar Research, Japan)

NiPR National Institute of Polar Research

Contents

1) Arctic low-level clouds and atmospheric conditions

Robust cloud responses to greenhouse warming



The Arctic is warming twice as fast as the global average.

Figure 7.11 | Robust cloud responses to greenhouse warming (those simulated by most models and possessing some kind of independent support or understanding). The tropopause and melting level are shown by the thick solid and thin grey dashed lines, respectively. Changes anticipated in a warmer climate are shown by arrows, with red colour indicating those making a robust positive feedback contribution and grey indicating those where the feedback contribution is small and/or highly uncertain. No robust mechanisms contribute negative feedback. Changes include rising high cloud tops and melting level, and increased polar cloud cover and/or optical thickness (*high confidence*); broadening of the Hadley Cell and/or poleward migration of storm tracks, and narrowing of rainfall zones such as the Intertropical Convergence Zone (*medium confidence*); and reduced low-cloud amount and/or optical thickness (*low confidence*). Confidence assessments are based on degree of GCM consensus, strength of independent lines of evidence from observations or process models and degree of basic understanding.

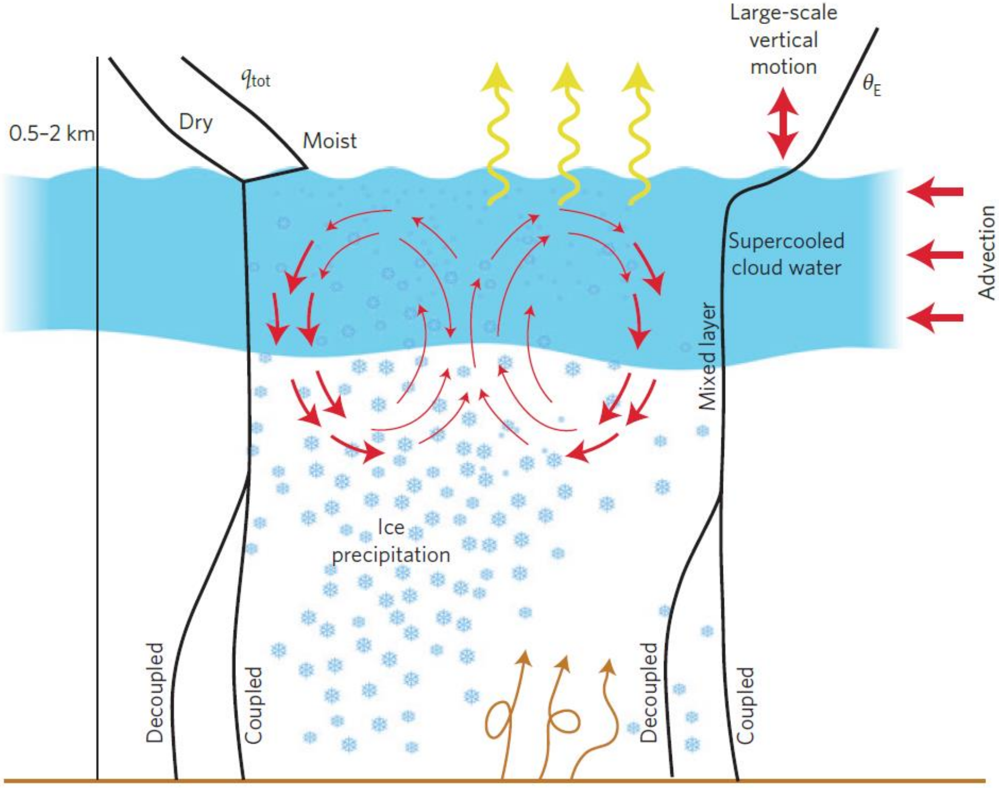
IPCC, Chapter 7 [2013]

Arctic low-level clouds

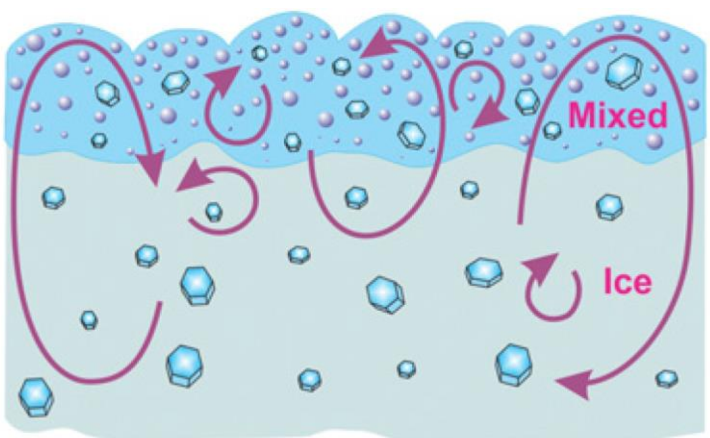
⇒ composed of supercooled liquid water and/or ice crystals.

⇒ Occur frequently in the lower troposphere (~0.5 to 2 km).

⇒ Often long-lived and can persist for several days

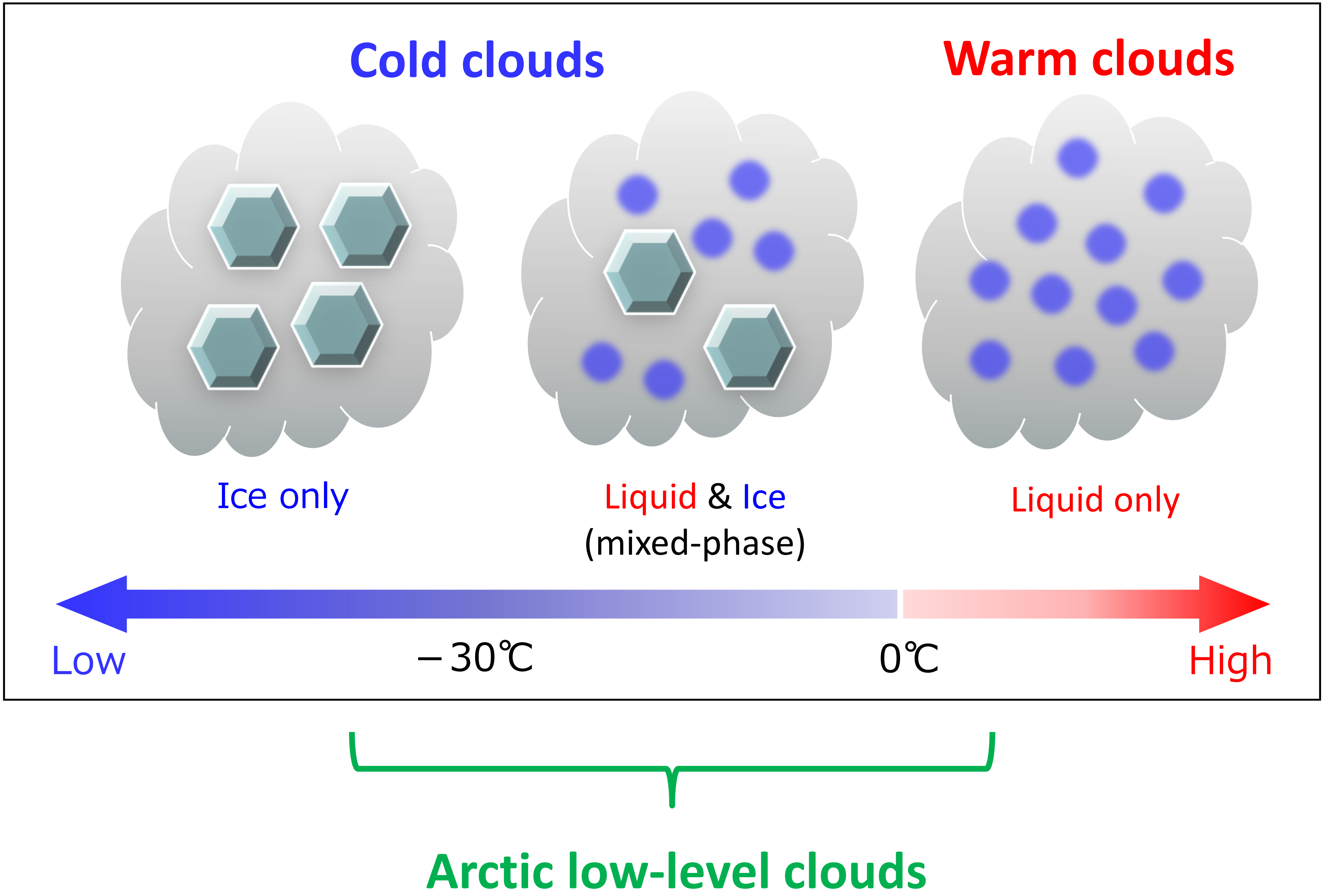


Morrison *et al*. [2012, *Nat. Geosci.*]



Korolev *et al*. [2017, *Meteorol. Monogr.*]

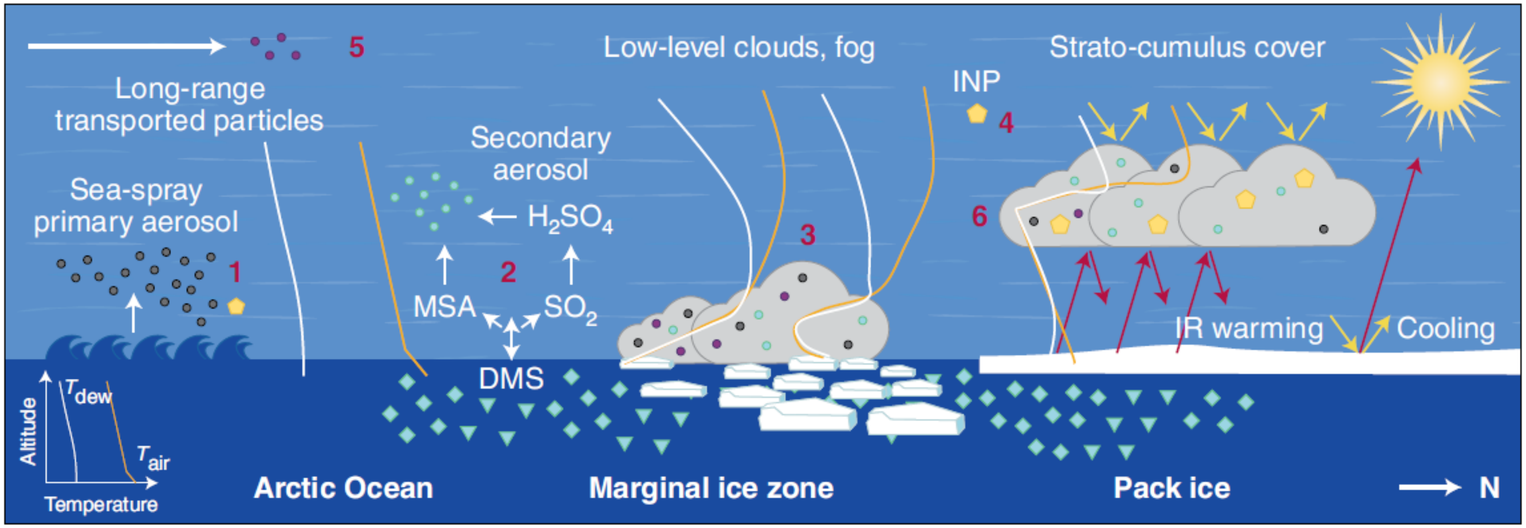
1) Arctic low-level clouds and atmospheric conditions



1) Arctic low-level clouds and atmospheric conditions

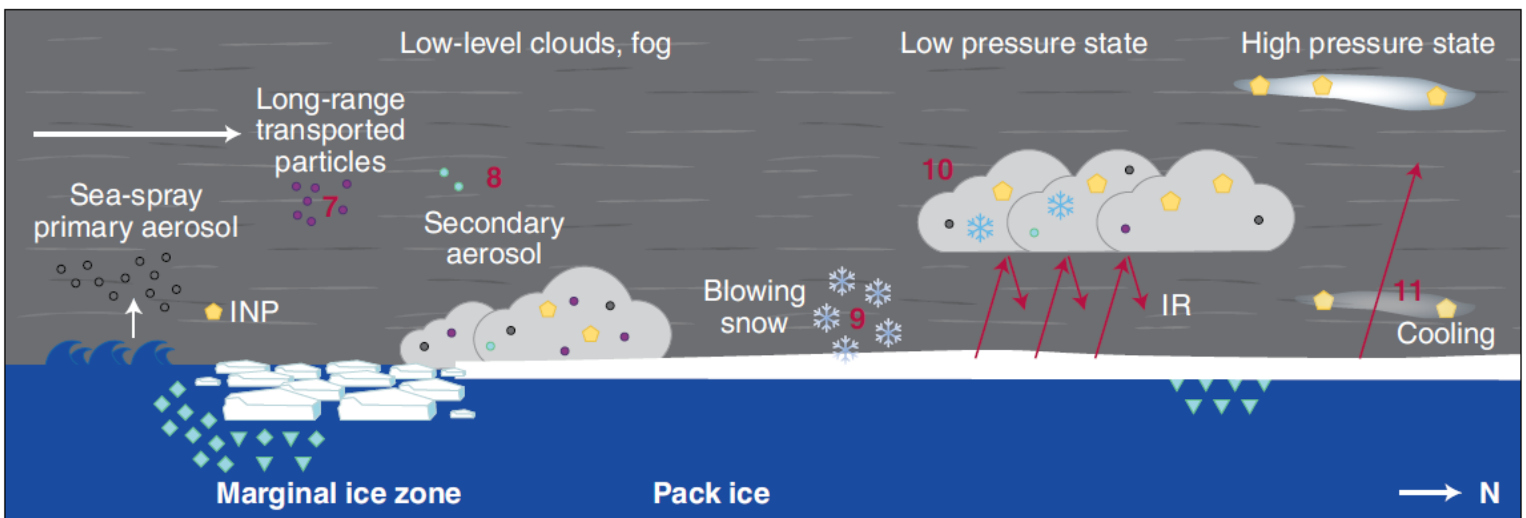
Aerosol processes related to Arctic low-level clouds

a



Polar day

b



Polar night

Schmale *et al.* [2021, *Nat. Clim. Change*]

Schematics of the 'Polar Dome' in the Arctic

⇒ The Arctic lower troposphere is isolated towards lower latitudes, by a transport barrier called the 'Arctic front'

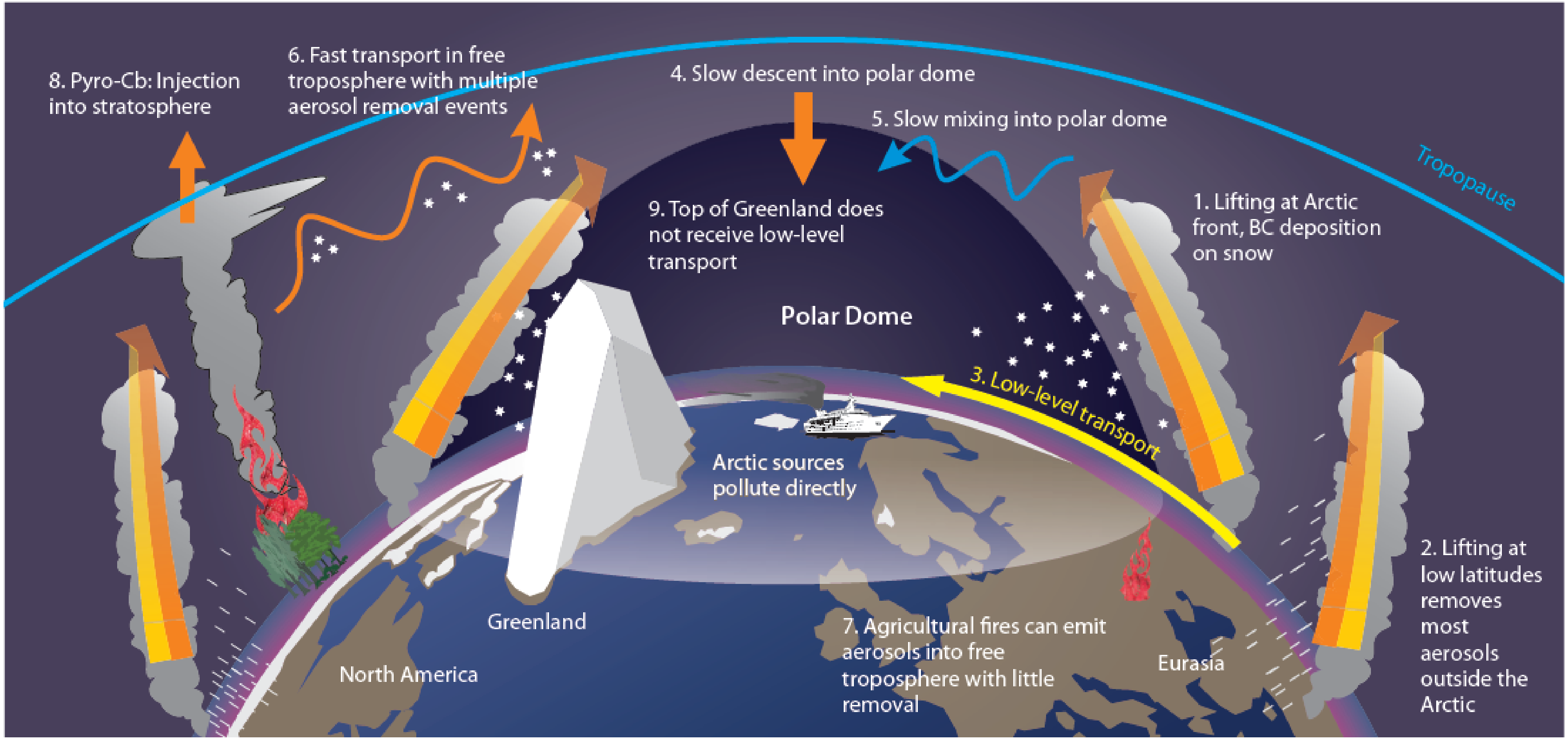


Figure 6.1 Schematic illustration of processes relevant for transport of trace pollutants into the Arctic based on the study by Stohl (2006), from AMAP (2011). In reality, the polar dome is asymmetric and its extent is temporally highly variable. In addition, its southernmost extent is greatest over Eurasia. The placement of the polar dome is more typical of the winter/spring situation, whereas in summer the dome is much smaller. Also note that the dome is not homogeneous but is itself highly stratified with strong vertical gradients.

AMAP Assessment [2015]

Seasonal variation of the position of the 'Polar Dome'

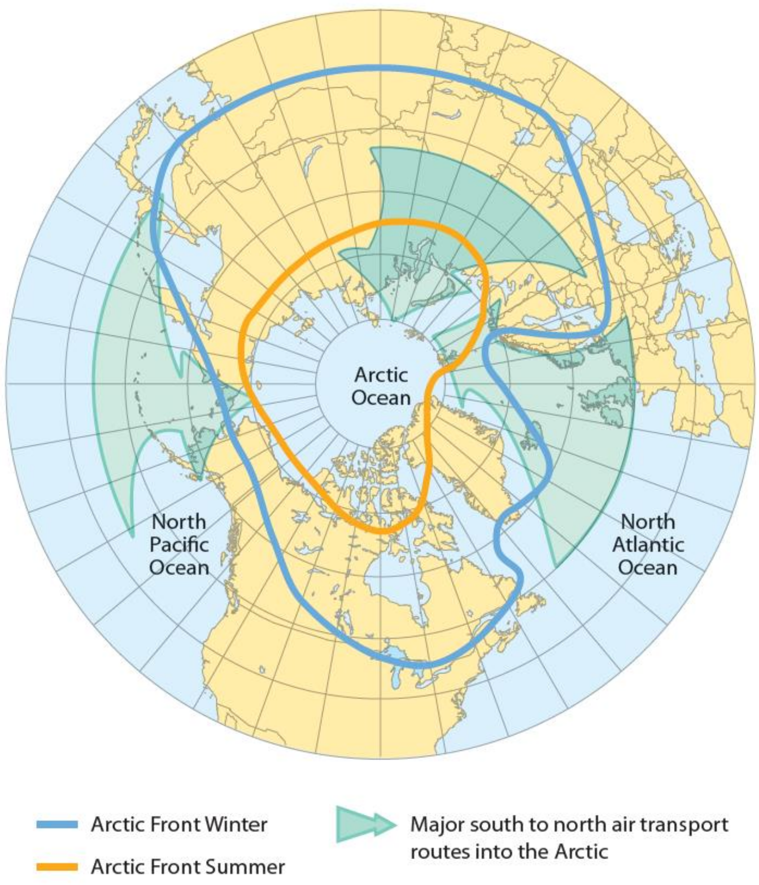


Figure 6.2 The mean position of the Arctic air mass in winter (January) and summer (July) according to Li et al. (1993), superimposed on the frequency of major poleward transport routes (Iversen 1996).

Winter

- **The Polar Dome becomes larger**

  => The Polar Dome extends over terrestrial areas (northern Eurasia and America).

  => The Arctic region tends to be effectively influenced by air pollution within the Polar Dome.

AMAP Assessment [2015]

Seasonal variation of the position of the 'Polar Dome'

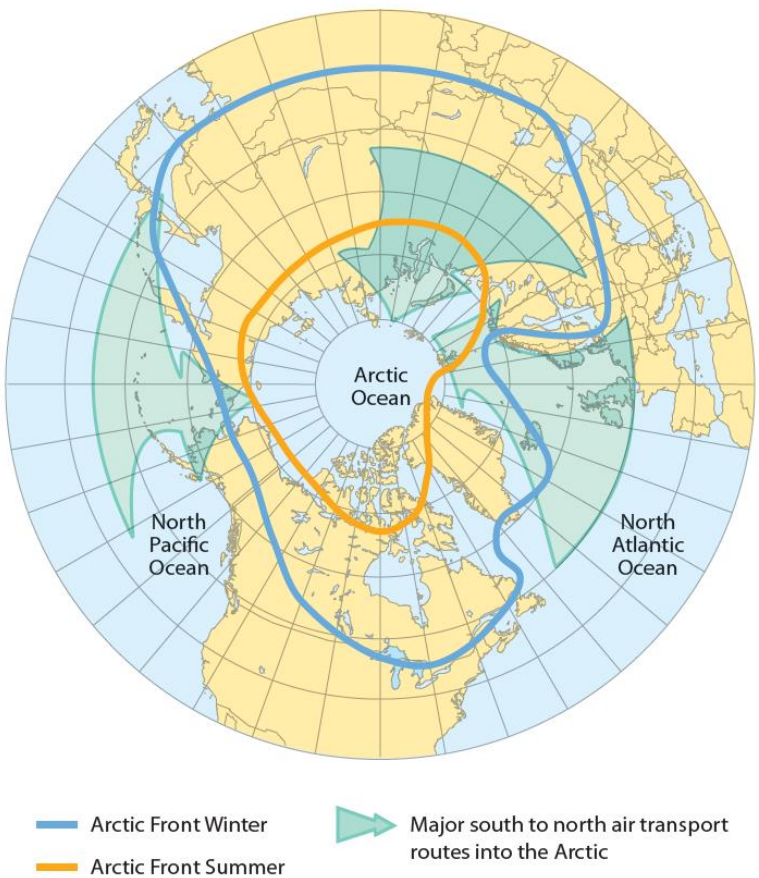


Figure 6.2 The mean position of the Arctic air mass in winter (January) and summer (July) according to Li et al. (1993), superimposed on the frequency of major poleward transport routes (Iversen 1996).

Summer

- **The Polar Dome becomes smaller**

=> The Arctic region is isolated towards lower latitudes.

=> The Arctic region tends to be less influenced by polluted air from lower latitude.

=> The influence of emissions within the Arctic region is more important.

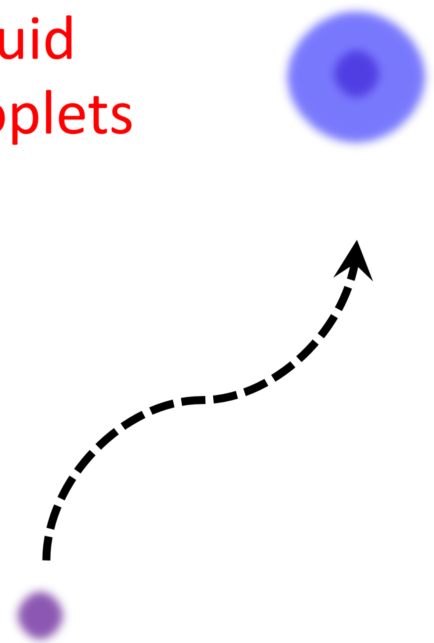
AMAP Assessment [2015]

1) Arctic low-level clouds and atmospheric conditions

Cloud condensation nuclei (CCN)

=> 10 ～ 1,000 cm^{-3}

Liquid droplets

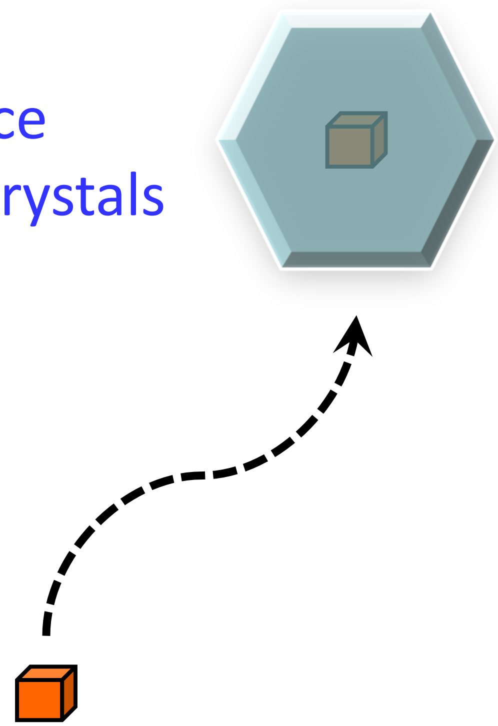


(**CCN**: Cloud Condensation Nuclei)

Ice nucleating particles (INPs) [immersion mode]

=> <10 cm^{-3} (<10,000 L^{-1})

Ice crystals



(**INPs**: Ice Nucleating Particles)

CCN and INP number concentrations (low-mid latitudes)

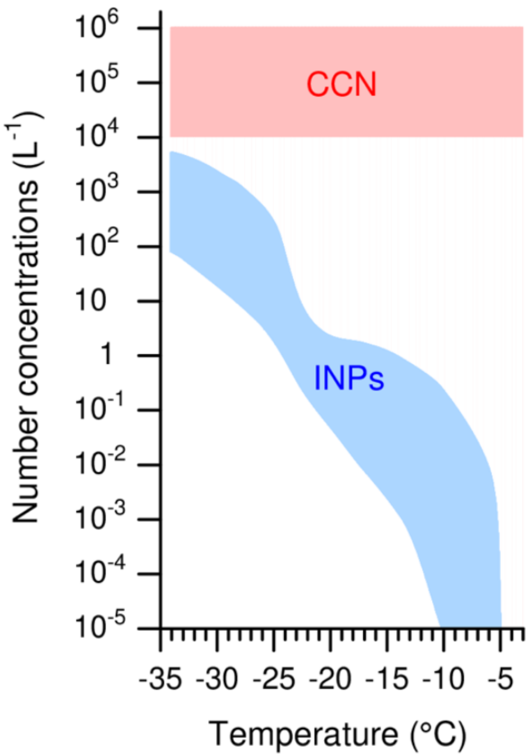
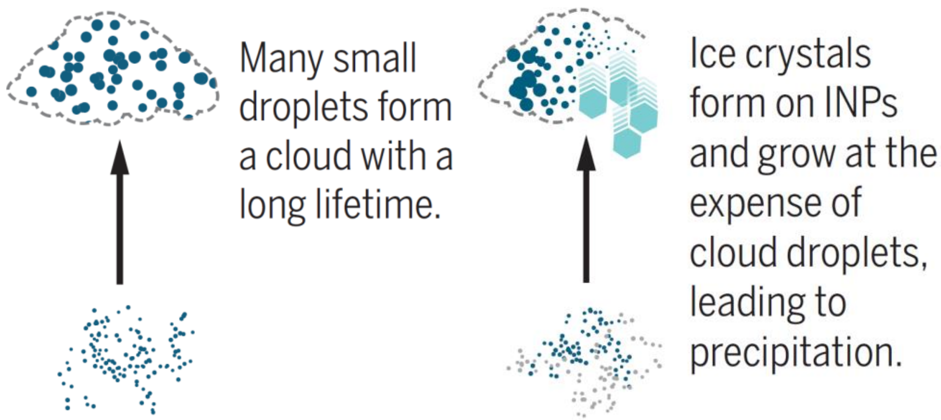


図 2 大気中における雲凝結核（CCN）や氷晶核（INPs）として働く微粒子の濃度分布。INPs の濃度は，世界の各地（主に北米とヨーロッパ）で報告されてきている観測値の範囲をまとめたもの［*Petters and Wright*, 2015］。

Tobo [2019, *AACR* (in Japanese)]



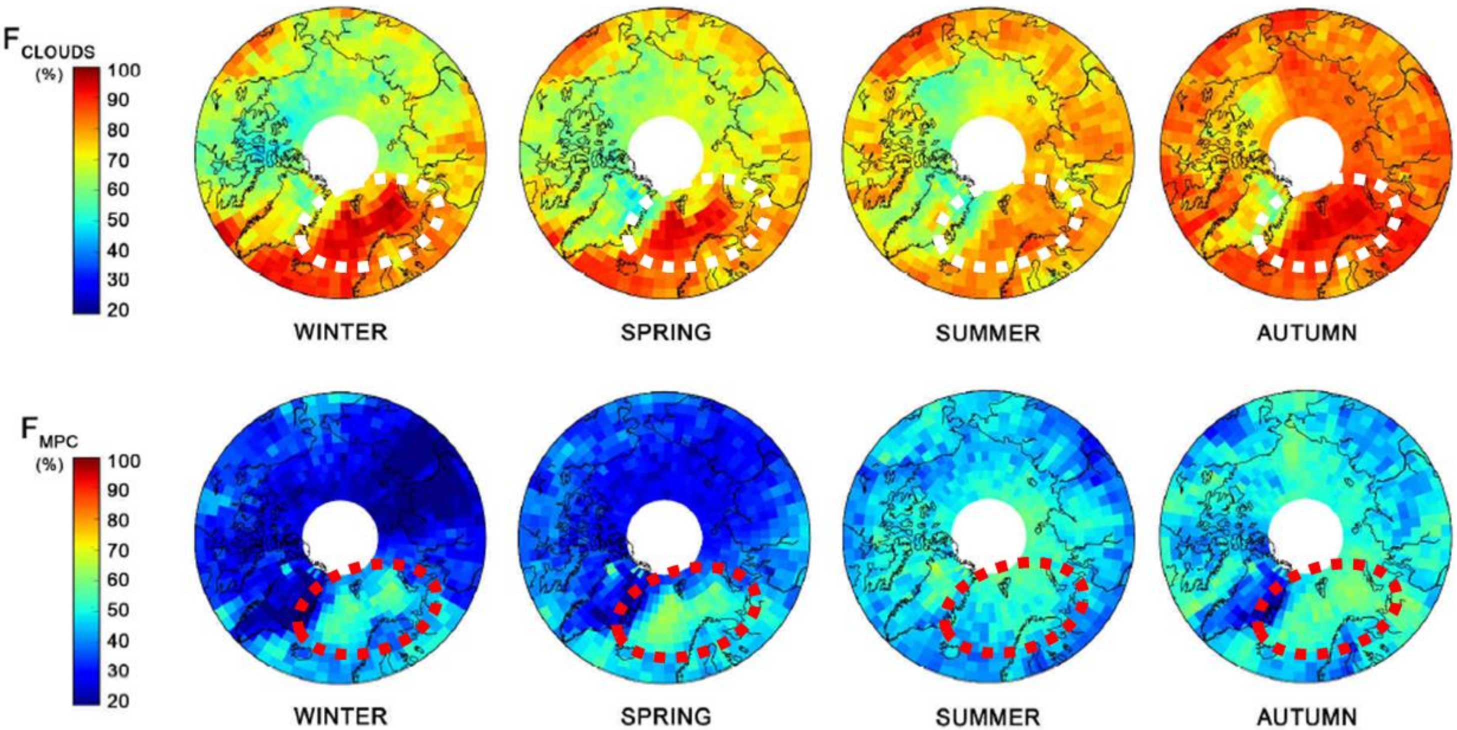
Murray [2017, *Science*]

How about CCN and INPs in the Arctic (high latitudes)?

Contents

2) Studies of clouds and aerosols in Svalbard

Seasonal occurrences of all clouds and mixed-phase clouds in the Arctic



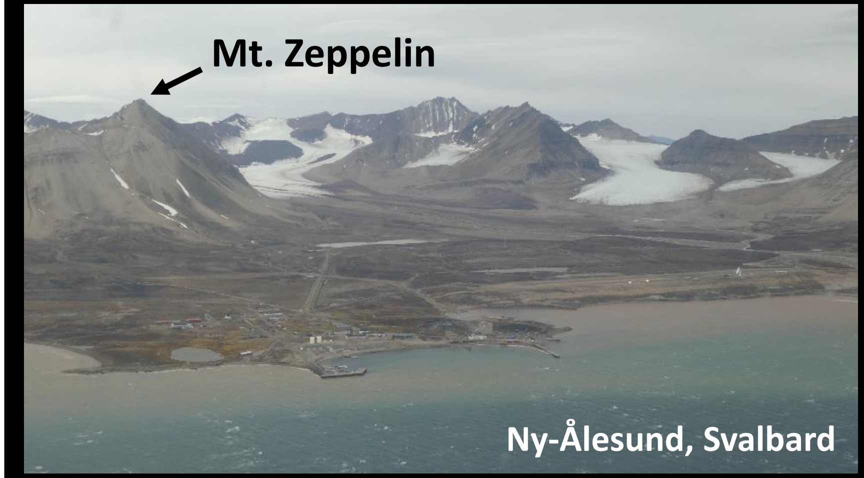
All clouds

Mixed-phase clouds (MPCs)

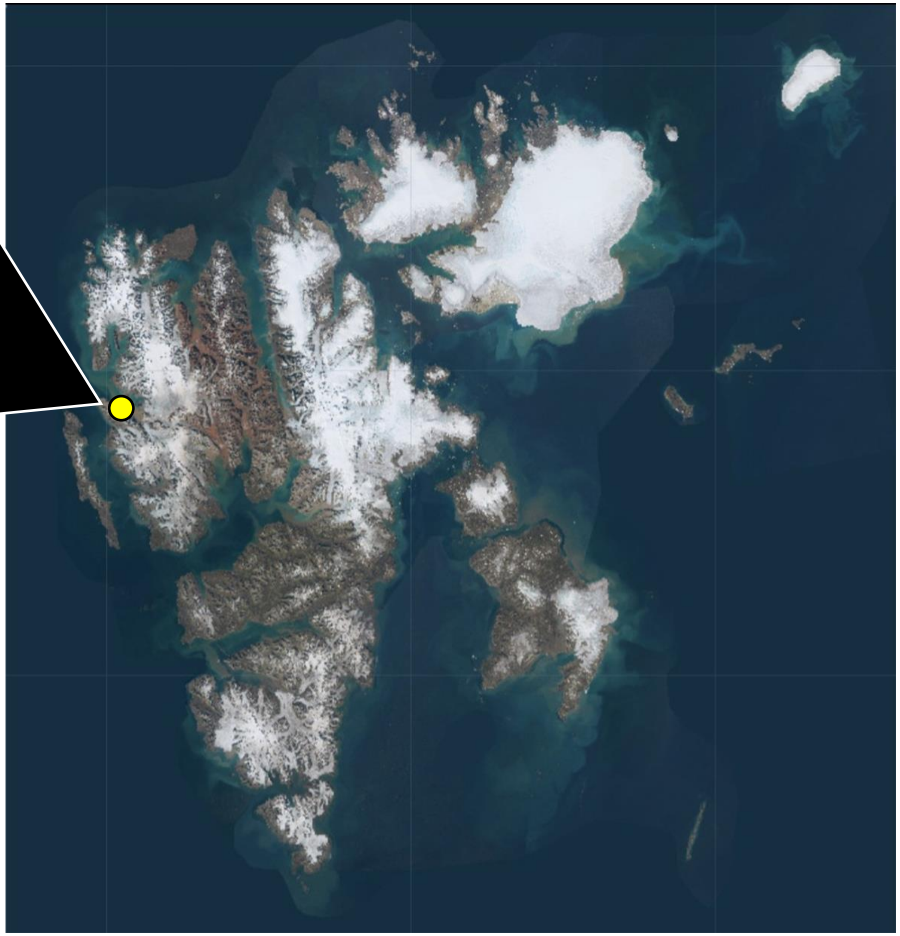
Svalbard region → Frequent occurrences of mixed-phase clouds (MPCs) during all seasons (~55%)

Mioche *et al*. [2015, *ACP*]

Aerosol and cloud measurements in Ny-Ålesund, Svalbard



Summer



https://toposvalbard.npolar.no/

NIPR Observatory in Ny-Ålesund

- **Rabben (1991 to 2019)**
- **Veksthus (2019 to present)**

Photo by Y. Tobo (July 2019)

INP studies in Ny-Ålesund (by NIPR)

- 2015 to present

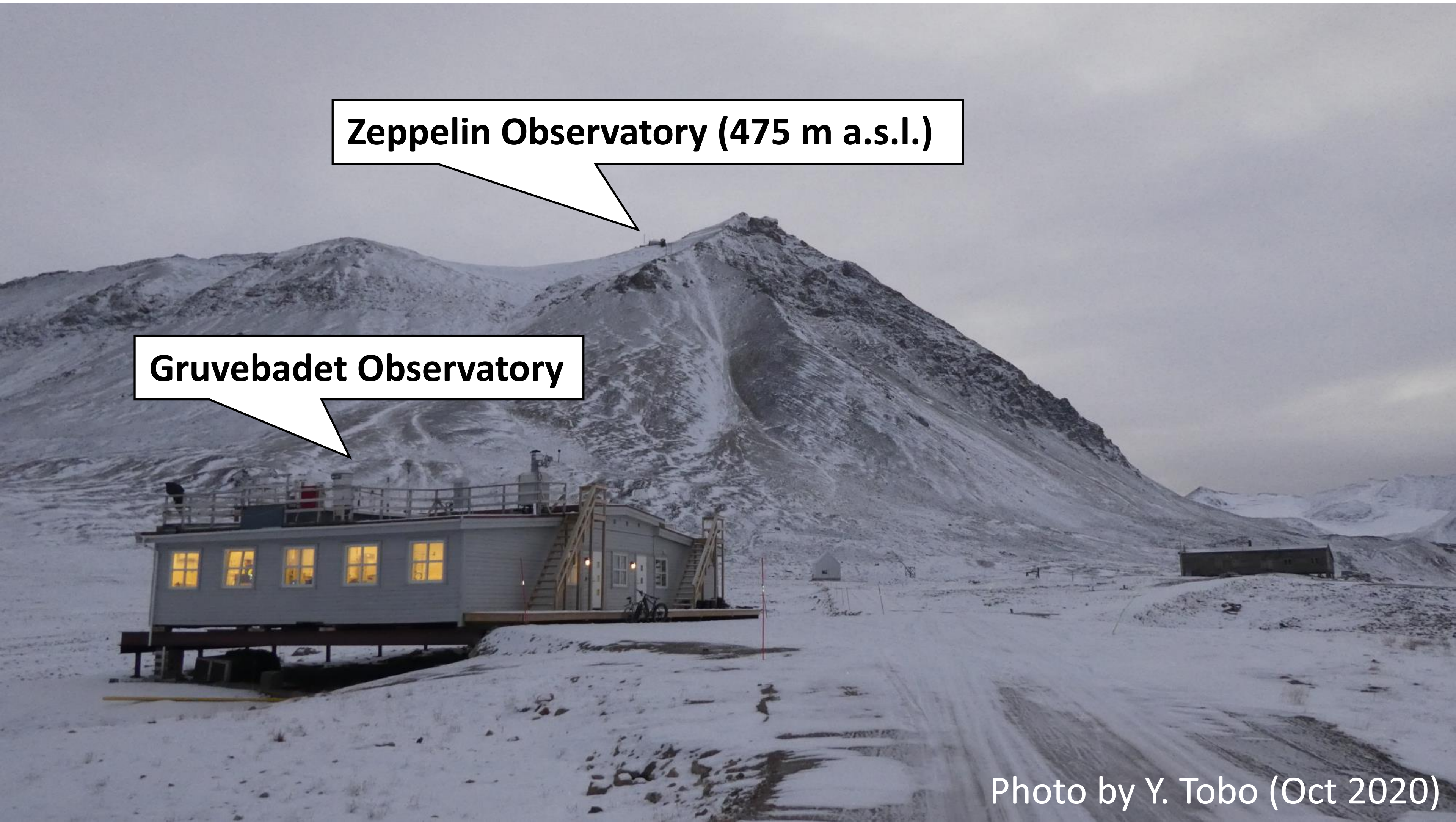


Photo by Y. Tobo (Oct 2020)

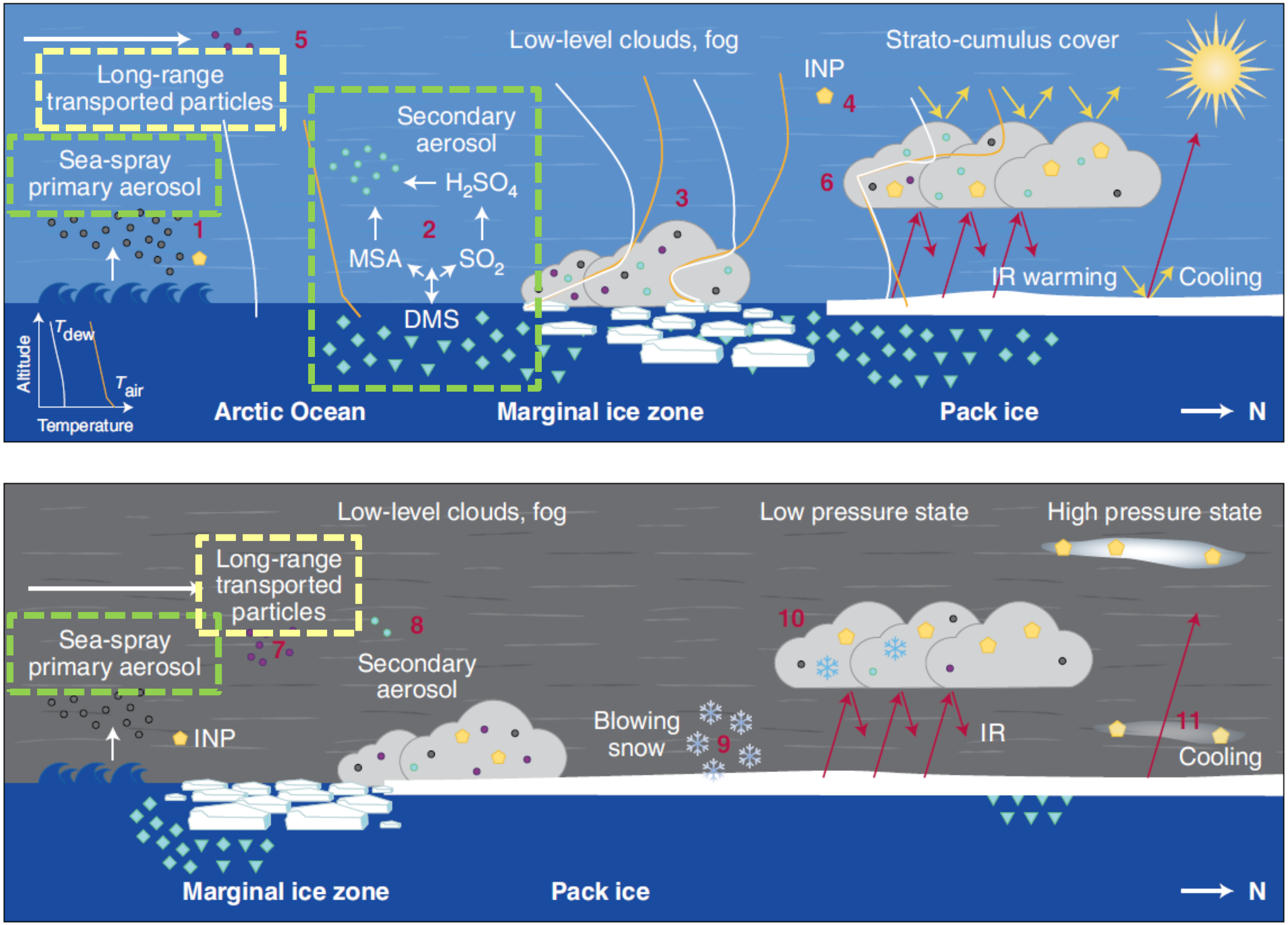
Contents

3) CCN measurements in Svalbard

Possible sources of CCN in the Arctic

a

b



Polar day

Polar night

Schmale *et al*. [2021, *Nat. Clim. Change*]

3) CCN measurements in Svalbard

Annual variation of CCN number concentrations measured at the Zeppelin Observatory

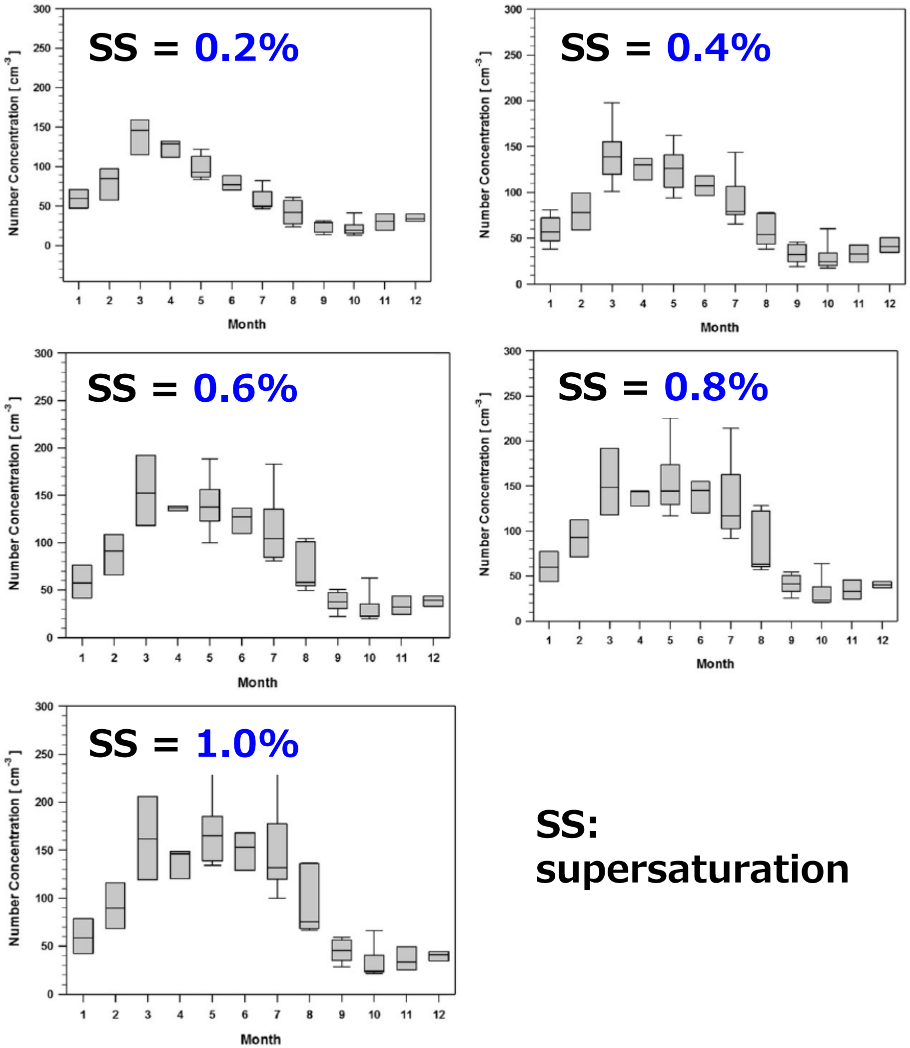


Fig. 3. Box plot of Monthly median CCN number concentration at various supersaturations (SS): April 2007–March 2013.

SS: supersaturation

Low CCN periods (~20 to 50 cm^{-3})

⇒ Autumn (Sep-Nov)

Jung *et al*. [2018, *Tellus B*]

3) CCN measurements in Svalbard

Annual variation of CCN number concentrations measured at the Zeppelin Observatory

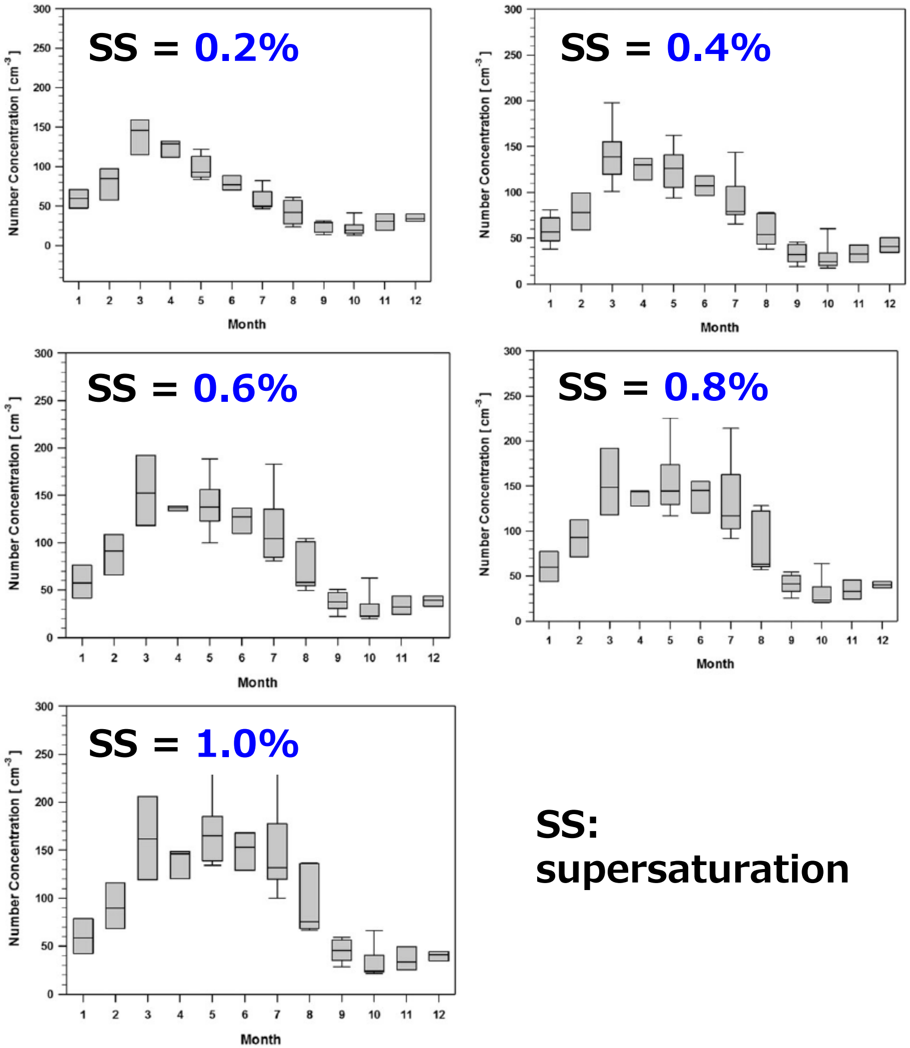


Fig. 3. Box plot of Monthly median CCN number concentration at various supersaturations (SS): April 2007–March 2013.

SS: supersaturation

High CCN periods (~100 to 200 cm^{-3})

⇒ Change depending on supersaturation state

SS = 0.2-0.4%

- **Peak: Spring (Mar-Apr)**

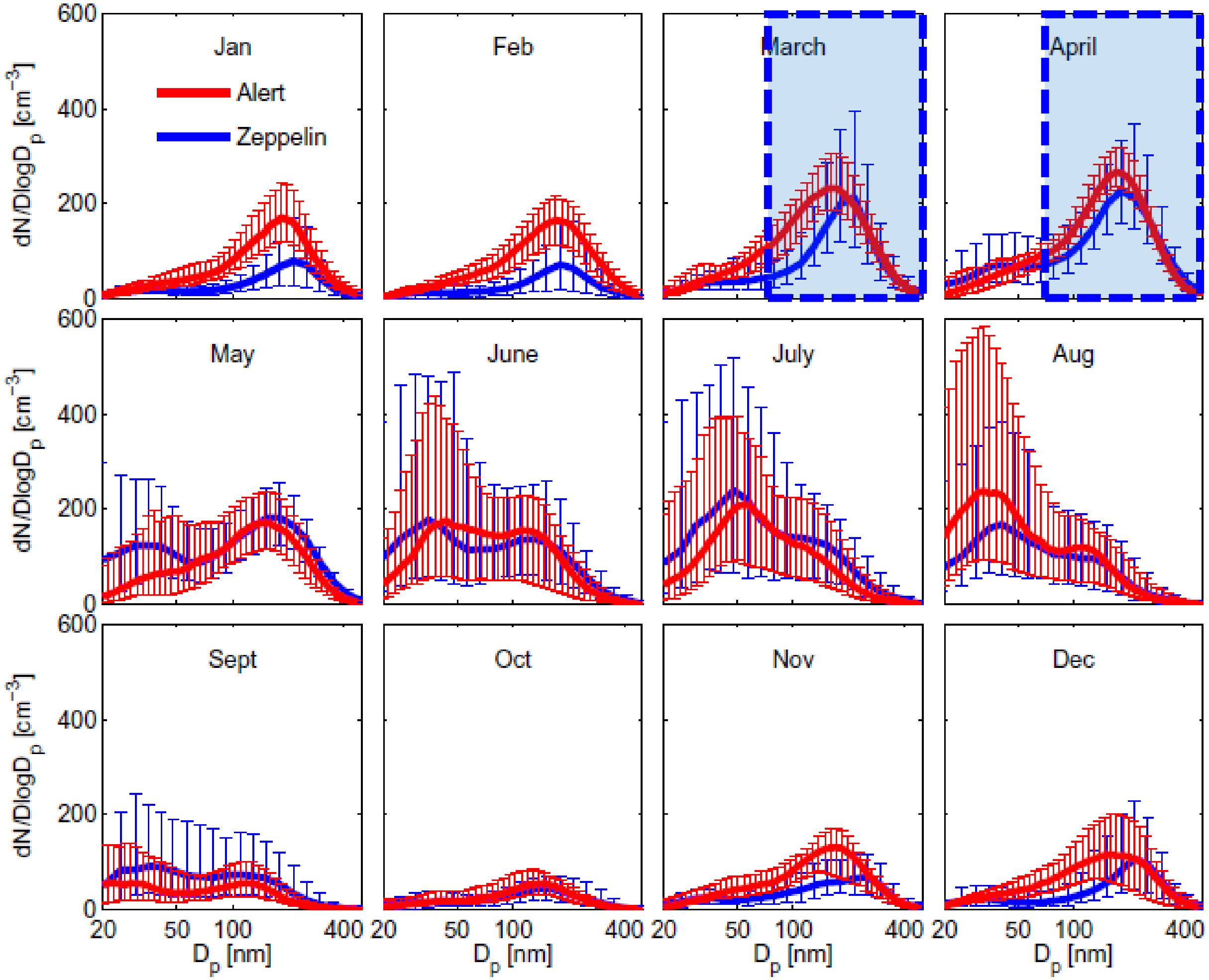
SS = 1.0 %

- **Peak: Spring to summer (Mar-July)**

Jung *et al*. [2018, *Tellus B*]

3) CCN measurements in Svalbard

Number-size distribution ($dN/d\log D_p$) of aerosol particles measured at the Zeppelin Observatory



CCN (SS = 0.2-0.4%)

- ➢ **Peak: Spring (Mar-Apr)**

Accumulation mode

(~70 to 400 nm)

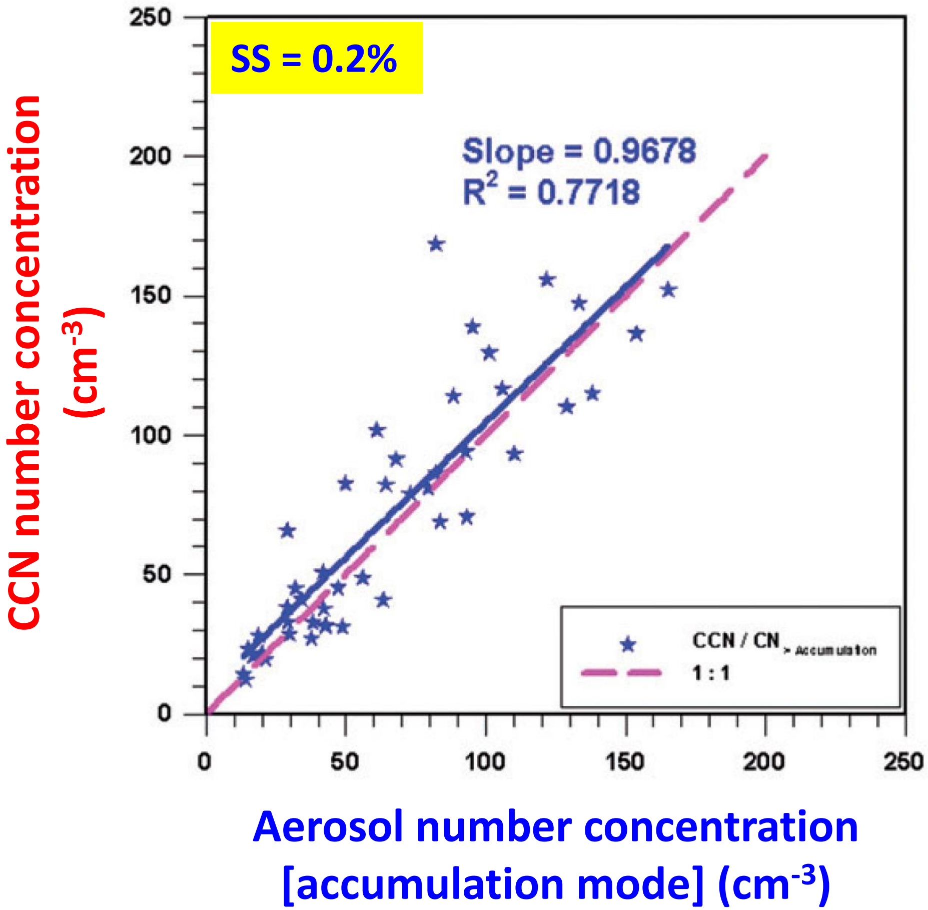
- ➢ **Peak: Spring (Mar-Apr)**
- ➢ Transport of polluted air? (Polar Dome is relatively large in this period.)

Croft *et al*. [2016, *ACP*]

3) CCN measurements in Svalbard

Relationship between accumulation mode aerosol particles and CCN at the Zeppelin Observatory

⇒ Change depending on supersaturation



SS = 0.2-0.4%

⇒ CCN are almost consistent with accumulation-mode particles

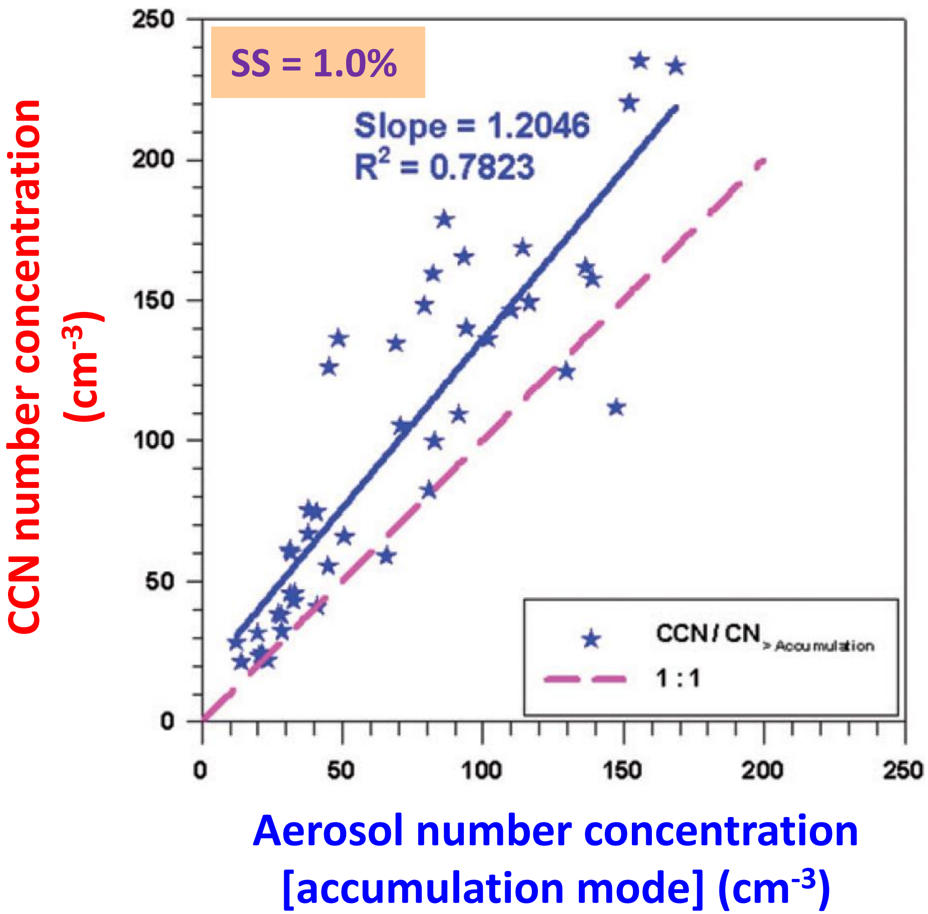
⇒ CCN can change depending on the variation of accumulation-mode particles

Jung *et al*. [2018, *Tellus B*]

3) CCN measurements in Svalbard

Relationship between accumulation mode aerosol particles and CCN at the Zeppelin Observatory

⇒ Change depending on supersaturation



SS = 1.0%

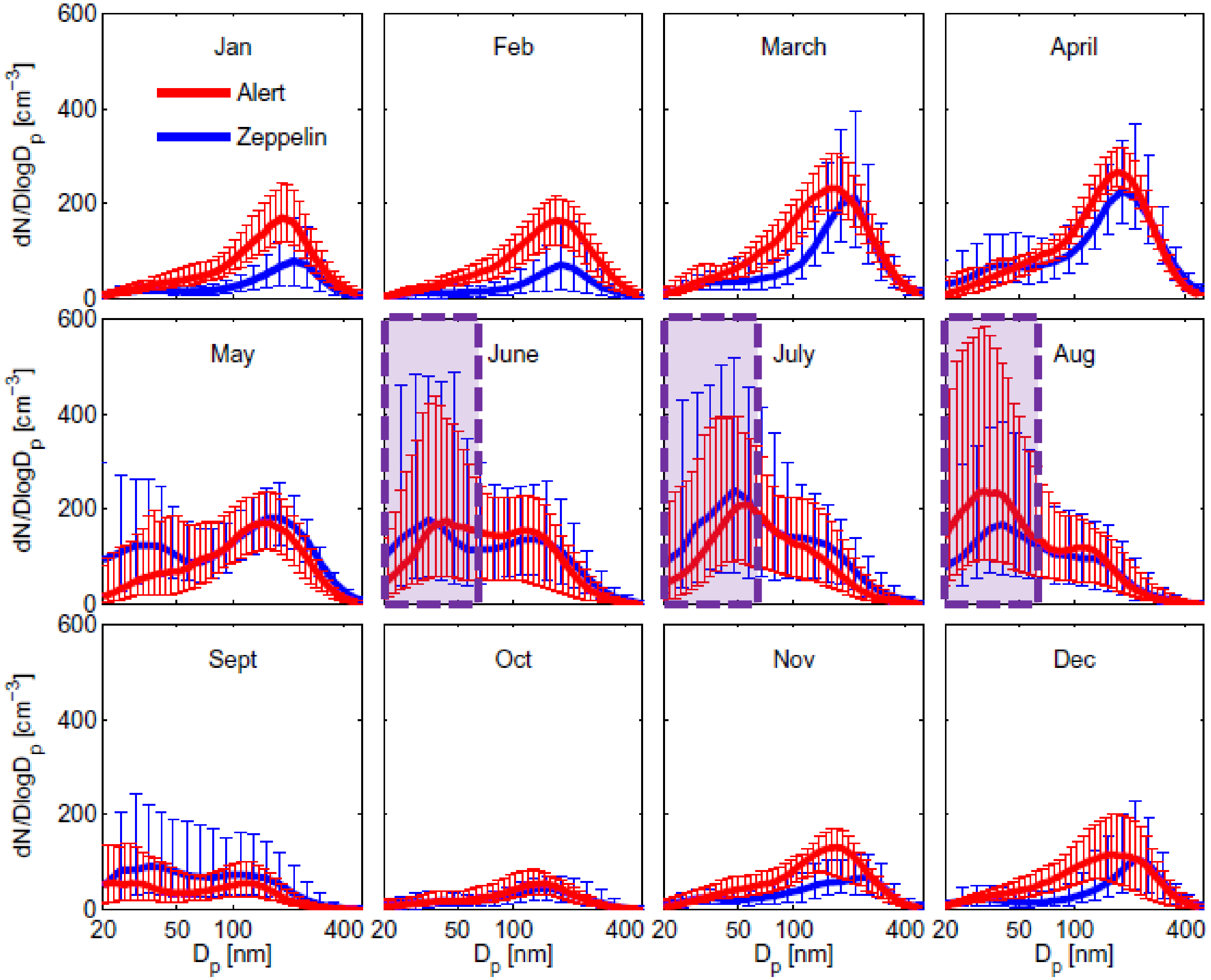
⇒ CCN seem to exceed accumulation-mode particles

⇒ CCN cannot be explained by the variation of only accumulation-mode particles

Jung *et al*. [2018, *Tellus B*]

3) CCN measurements in Svalbard

Number-size distribution ($dN/d\log D_p$) of aerosol particles measured at the Zeppelin Observatory



CCN (SS = 1.0%)

- **Peak: Spring to summer (Mar-July)**

Aitken mode (< ~70 nm)

- **Peak: Summer (Jun-Aug)**
- New particle formation

Croft *et al.* [2016, *ACP*]

3) CCN measurements in Svalbard

Monthly variation of new particle formation (NPF) events measured at the Zeppelin Observatory

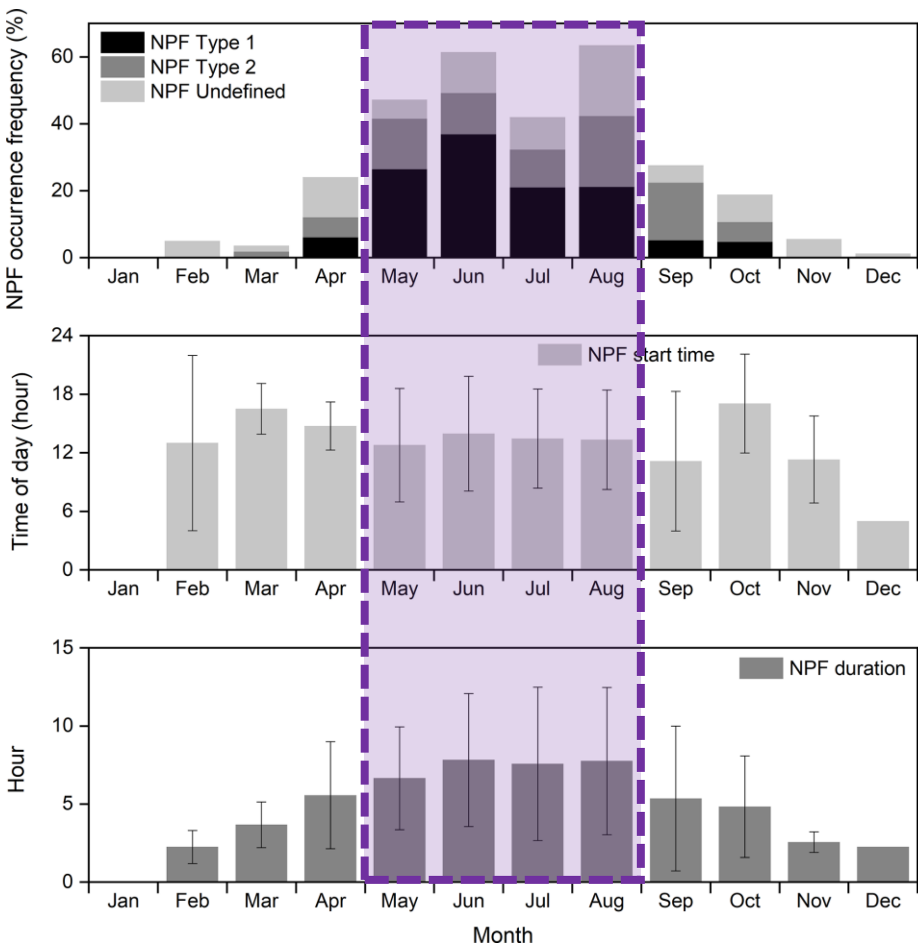


Figure 5. Monthly variations in NPF occurrence, start time (local time), and duration; the error bar represents standard deviation.

NPF (new particle formation)

⇒ Occur frequently in summer (May-Aug)

⇒ Related to the activation of marine biogenic activities (!?)

Lee *et al*. [2020, *ACP*]

3) CCN measurements in Svalbard

CN (condensation nuclei) measured at the Zeppelin Observatory

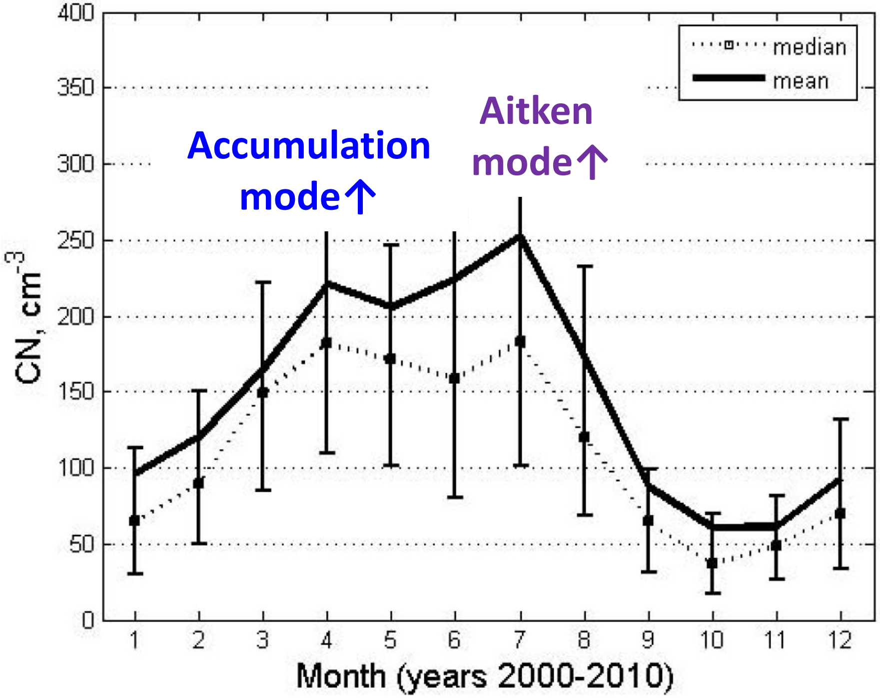
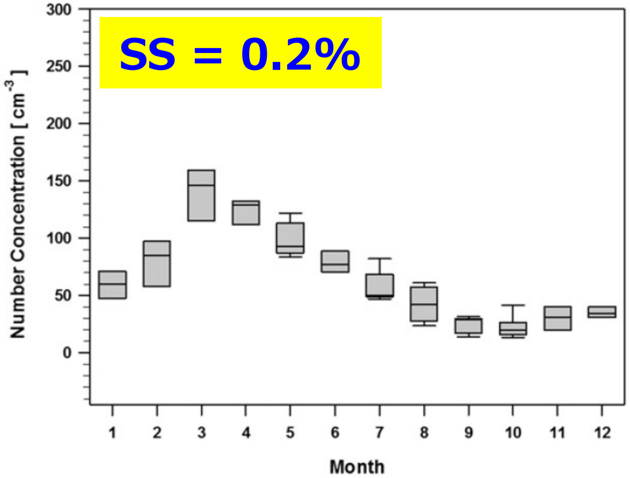
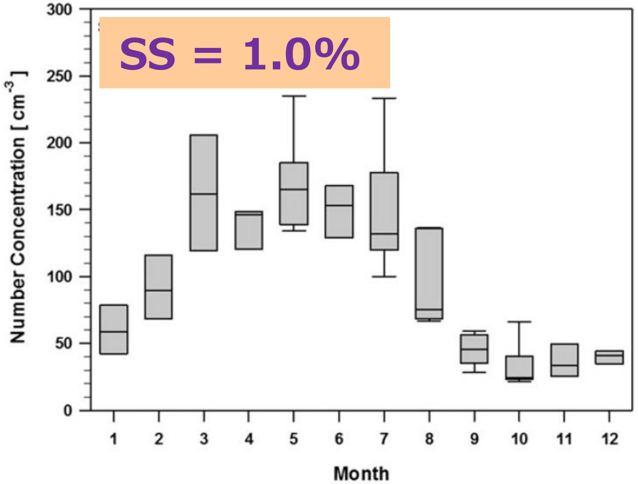


Fig. 5. Annual average variation of median and mean integrated number concentration per month March 2000–March 2010. 25–75th percentile ranges indicated by vertical "error bars".

Tunved *et al.* [2013, *ACP*]

CCN measured at the Zeppelin Observatory



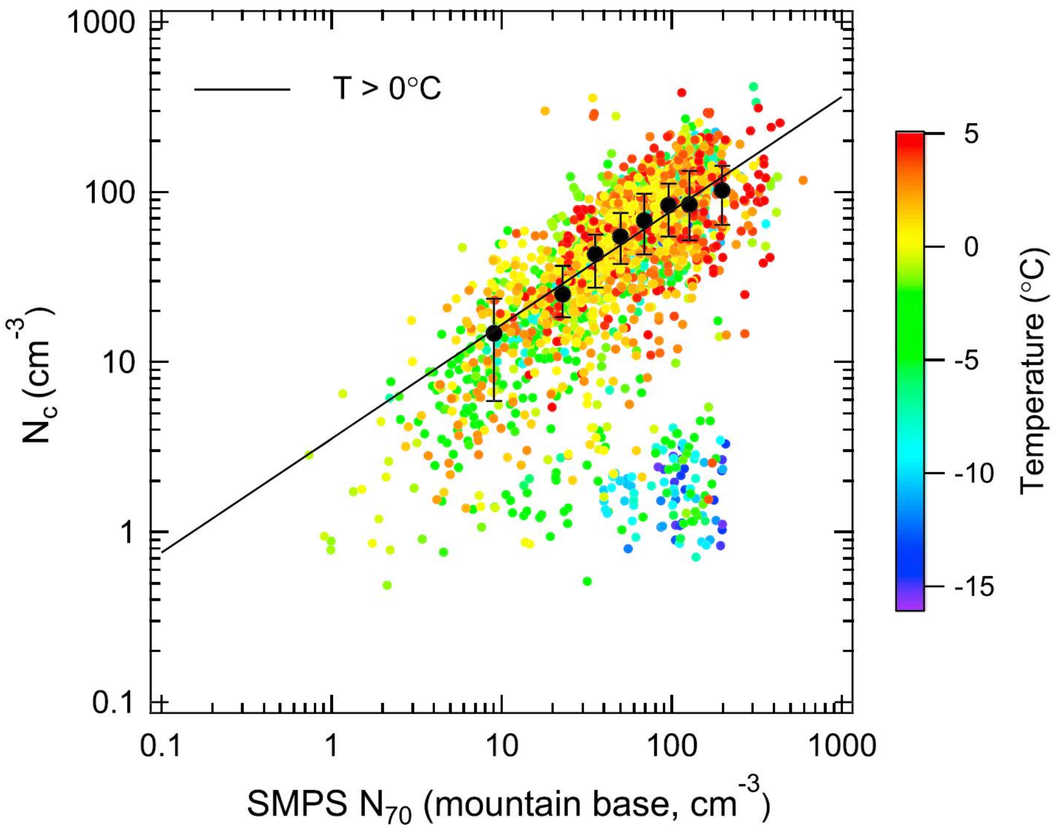


Jung *et al.* [2018, *Tellus B*]

3) CCN measurements in Svalbard

Relationship between accumulation-mode aerosol particles and cloud particles at the Zeppelin Observatory

⇒ Change depending on <u>temperature</u>



***T* > 0℃**

⇒ Positive Correlation

***T* < −10℃**

⇒ No clear correlation

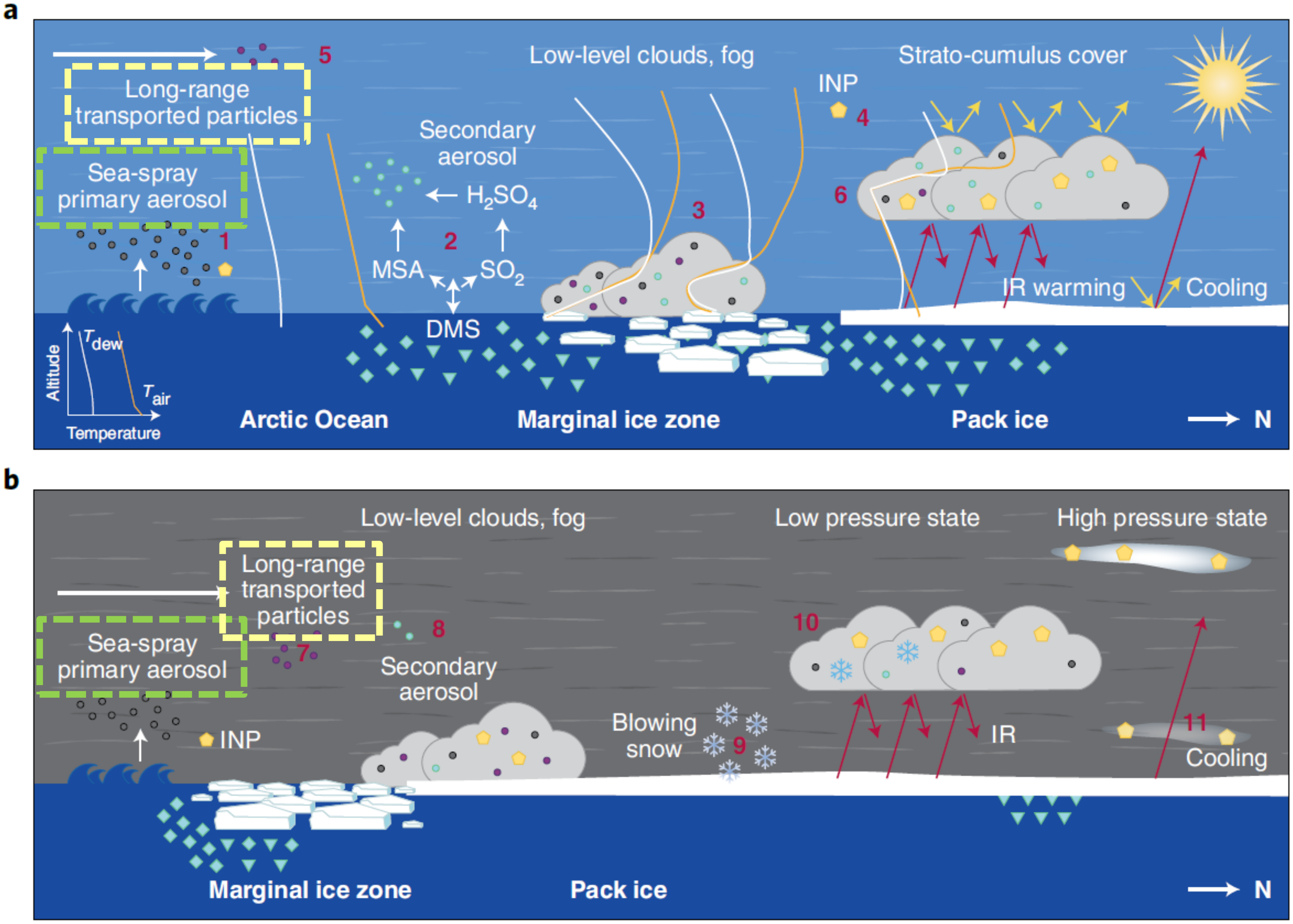
⇒ Probably, because of the formation of ice crystals

Koike *et al*. [2019, *JGR*]

Contents

4) INP measurements in Svalbard

Possible sources of INPs in the Arctic



Polar day

Polar night

Schmale *et al.* [2021, *Nat. Clim. Change*]

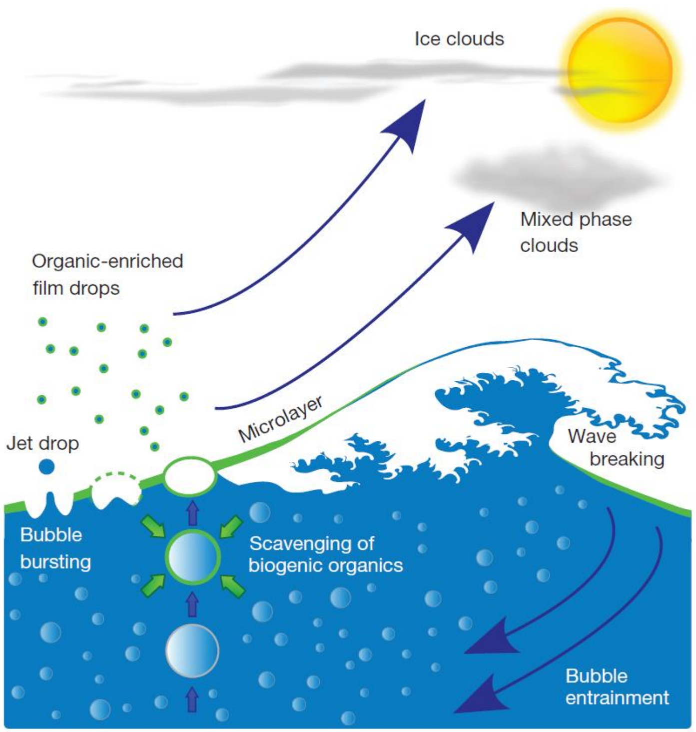
LETTER

doi:10.1038/nature14986

A marine biogenic source of atmospheric ice-nucleating particles

Theodore W. Wilson[1]*, Luis A. Ladino[2]*, Peter A. Alpert[3], Mark N. Breckels[4], Ian M. Brooks[1], Jo Browse[1], Susannah M. Burrows[5], Kenneth S. Carslaw[1], J. Alex Huffman[6], Christopher Judd[1], Wendy P. Kilthau[7], Ryan H. Mason[8], Gordon McFiggans[9], Lisa A. Miller[10], Juan J. Nájera[9], Elena Polishchuk[8], Stuart Rae[9], Corinne L. Schiller[11], Meng Si[8], Jesús Vergara Temprado[1], Thomas F. Whale[1], Jenny P. S. Wong[2], Oliver Wurl[12]†, Jacqueline D. Yakobi-Hancock[2], Jonathan P. D. Abbatt[2], Josephine Y. Aller[7], Allan K. Bertram[8], Daniel A. Knopf[3] & Benjamin J. Murray[1]

The amount of ice present in clouds can affect cloud lifetime, precipitation and radiative properties[1,2]. The formation of ice in clouds is facilitated by the presence of airborne ice-nucleating particles[1,2]. Sea spray is one of the major global sources of atmospheric particles, but it is unclear to what extent these particles are capable of nucleating ice[3–11]. Sea-spray aerosol contains large amounts of organic material that is ejected into the atmosphere during bubble bursting at the organically enriched sea–air interface or sea surface microlayer[12–19]. Here we show that organic material in the sea surface microlayer nucleates ice under conditions relevant for mixed-phase cloud and high-altitude ice cloud formation. The ice-nucleating material is probably biogenic and less than approximately 0.2 micrometres in size. We find that



Organics released from sea surface microlayer may be an important source of INPs in the Arctic (!?)

Wilson *et al*. [2015, *Nature*]

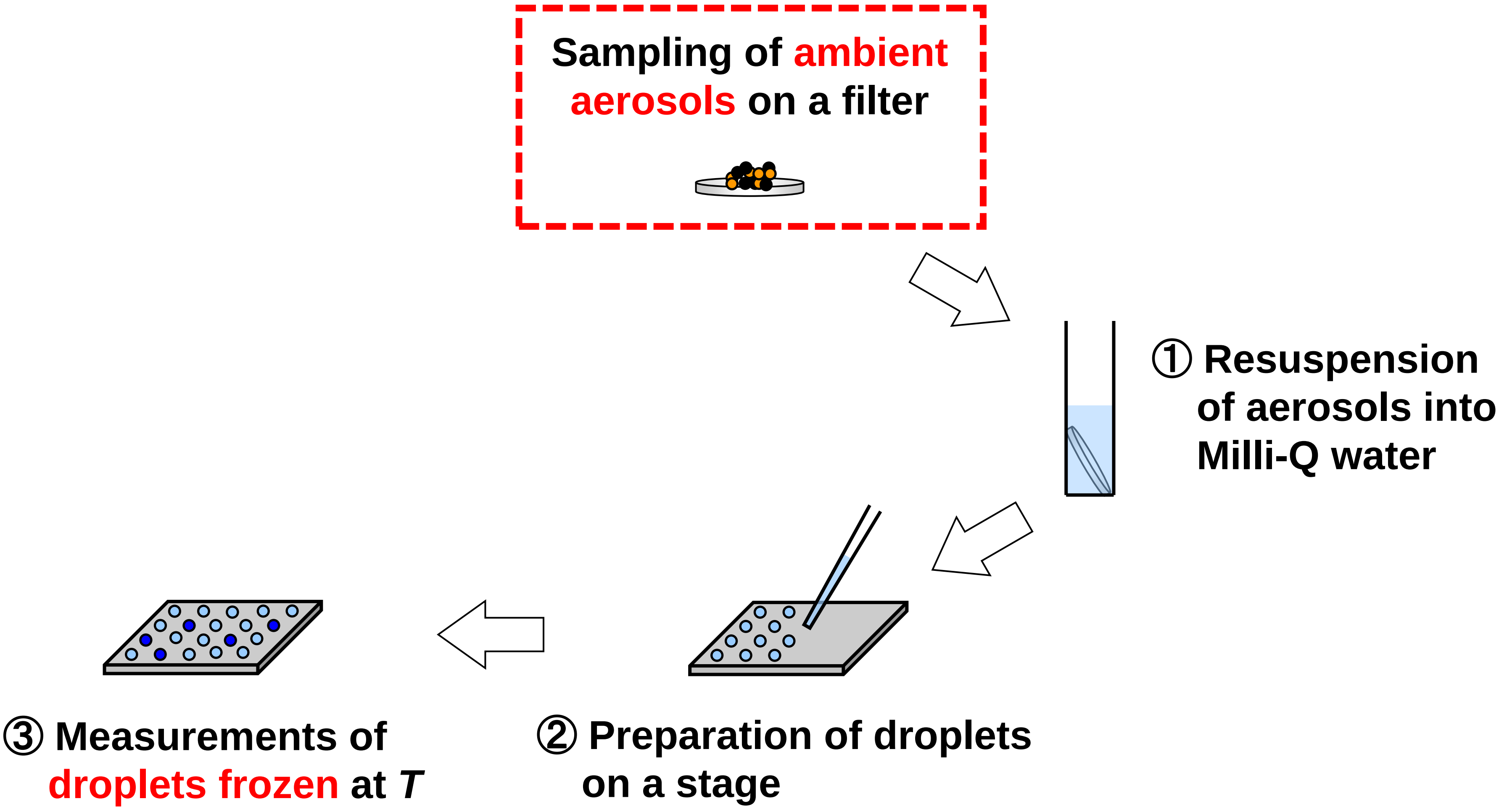
4) INP measurements in Svalbard

Intensive INP studies at the Zeppelin Observatory

- July 2016
- March 2017

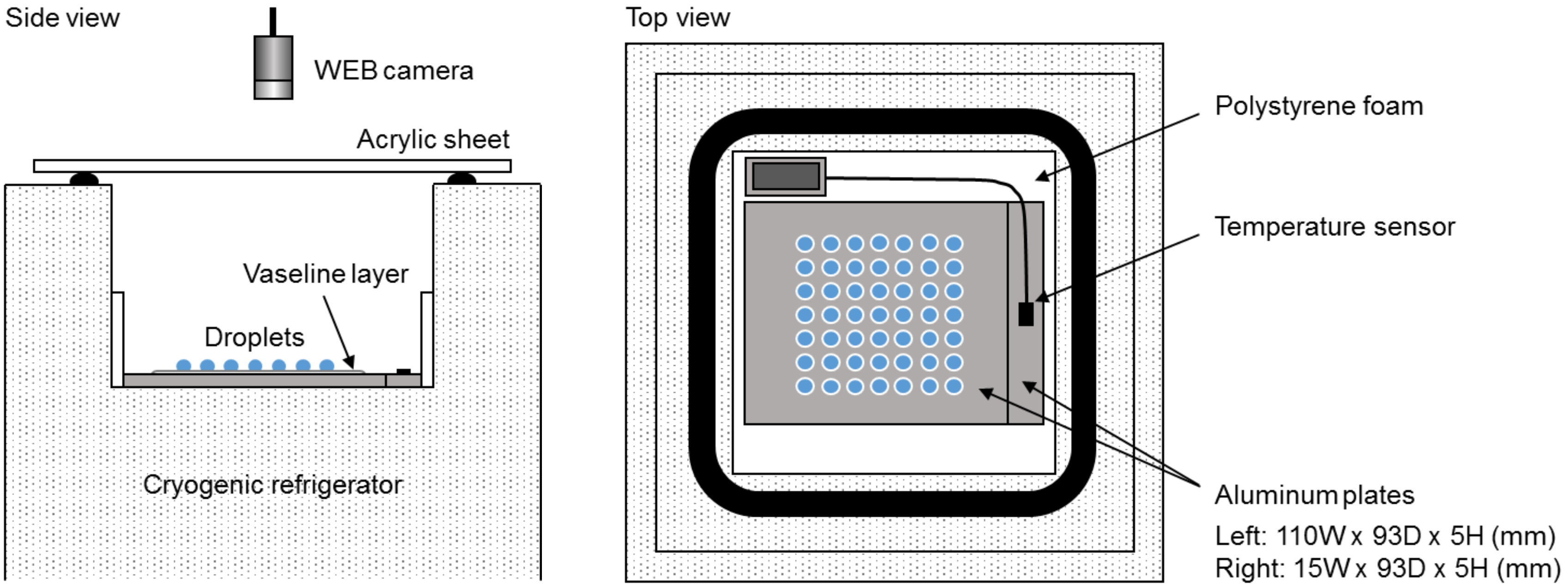
https://engr.source.colostate.edu/atmospheric-scientists-find-clues-to-climate-change-in-the-dust/

Methods for measuring INP number concentrations using ambient aerosol samples



CRAFT (Cryogenic Refrigerator Applied to Freezing Test)

[Tobo, 2016, *Sci. Rep.*]



Off-line measurements of INPs immersed in water droplets at a controlled temperature (-30°C < *T* < 0°C)

NiPR National Institute of Polar Research

Methods for measuring INP number concentrations using ambient aerosol samples

Number concentrations of INPs (N_{INP}) as a function of temperature [# L^{-1}]

$$N_{\mathrm{INP}}(T) = -\frac{\ln(f_{\mathrm{unfrozen}})}{V_{\mathrm{drop}}} \cdot \frac{d}{C}$$

f_{unfrozen} : Number fraction of droplets unfrozen

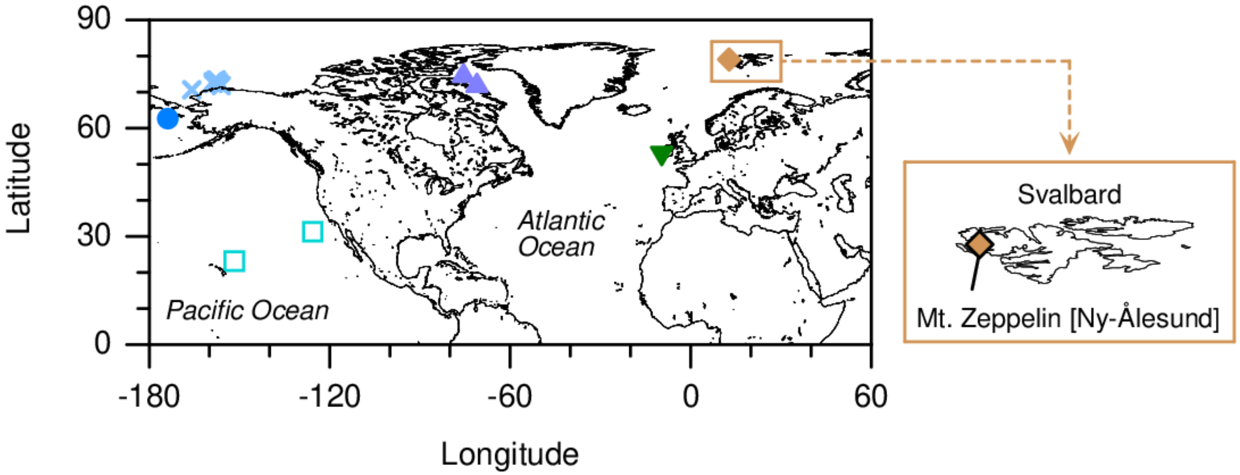
V_{drop} : Volume of a droplet (= 5 μL)

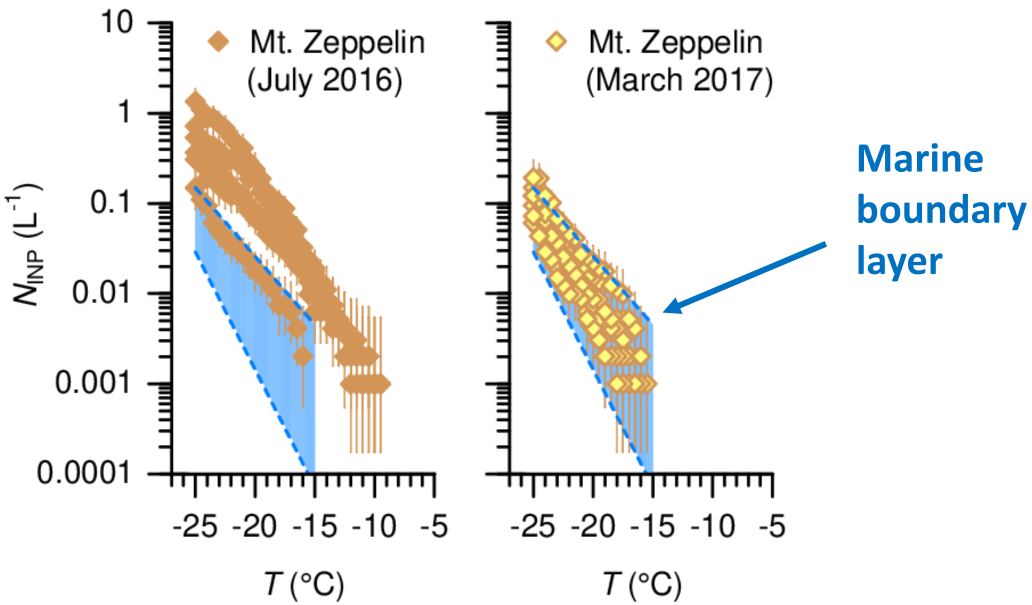
C : Volume ratio of the air sample to the initial suspension

d : Dilution ratio

4) INP measurements in Svalbard

INP number concentrations measured at the Zeppelin Observatory





INPs in July 2016

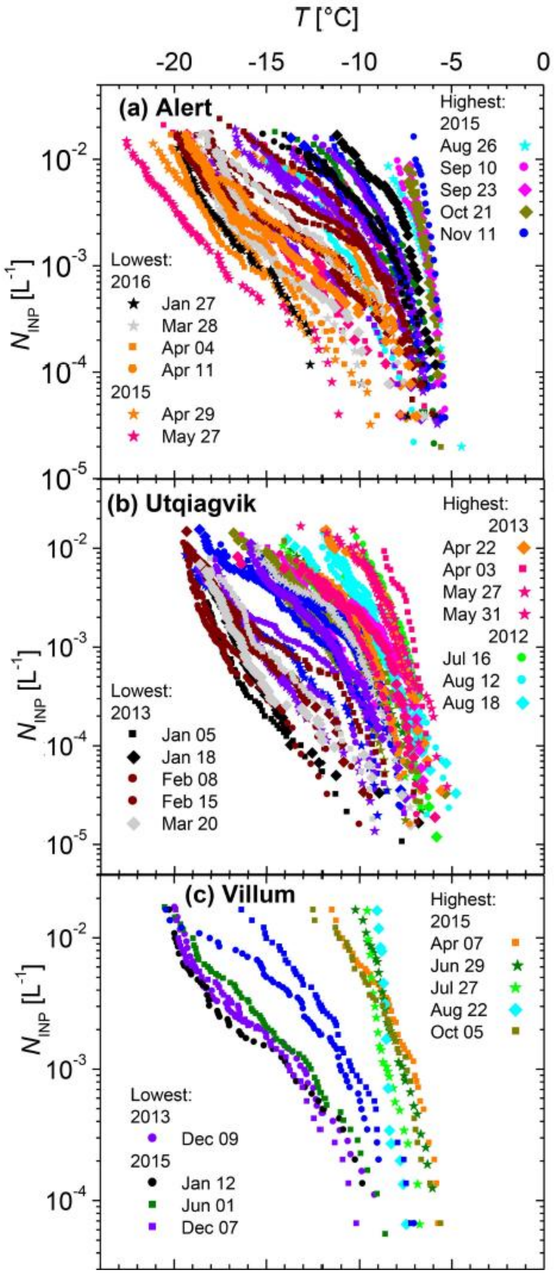
⇒ Enhanced (~1 order)

INPs in March 2017

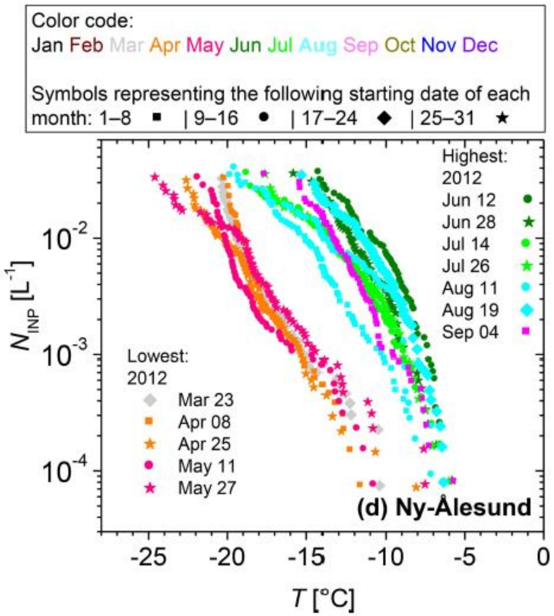
⇒ Similar to marine boundary layer)

Tobo *et al*. [2019, *Nat. Geosci*.]

4) INP measurements in Svalbard



INP number concentrations measured at terrestrial sites in the Arctic



INPs in summer

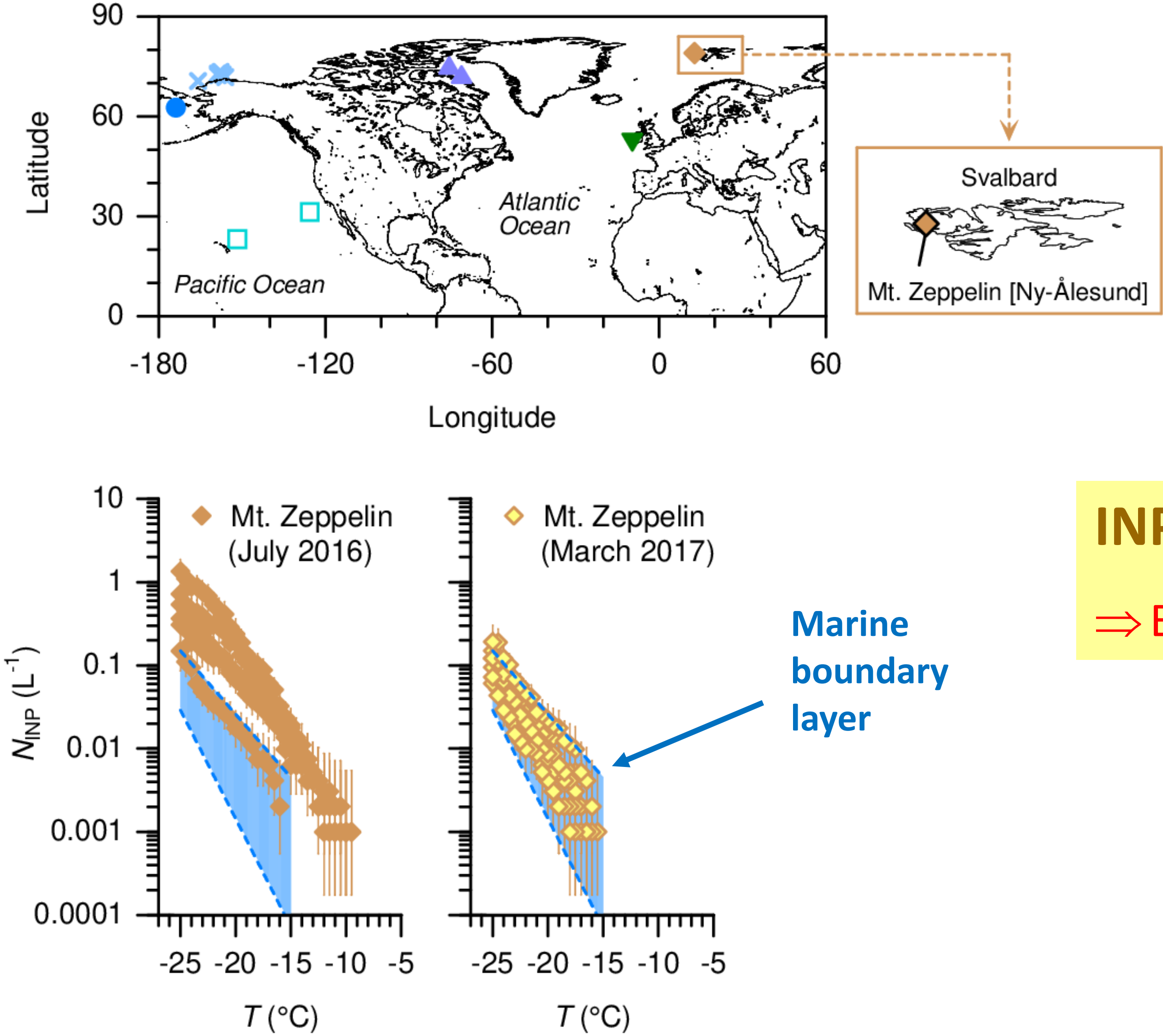
⇒ Enhanced at various locations in the Arctic

Wex *et al*. [2019, *ACP*]

Contents

5) Possible INP sources in Arctic summer

INP number concentrations measured at the Zeppelin Observatory



INPs in July 2016

⇒ Enhanced (~1 order)

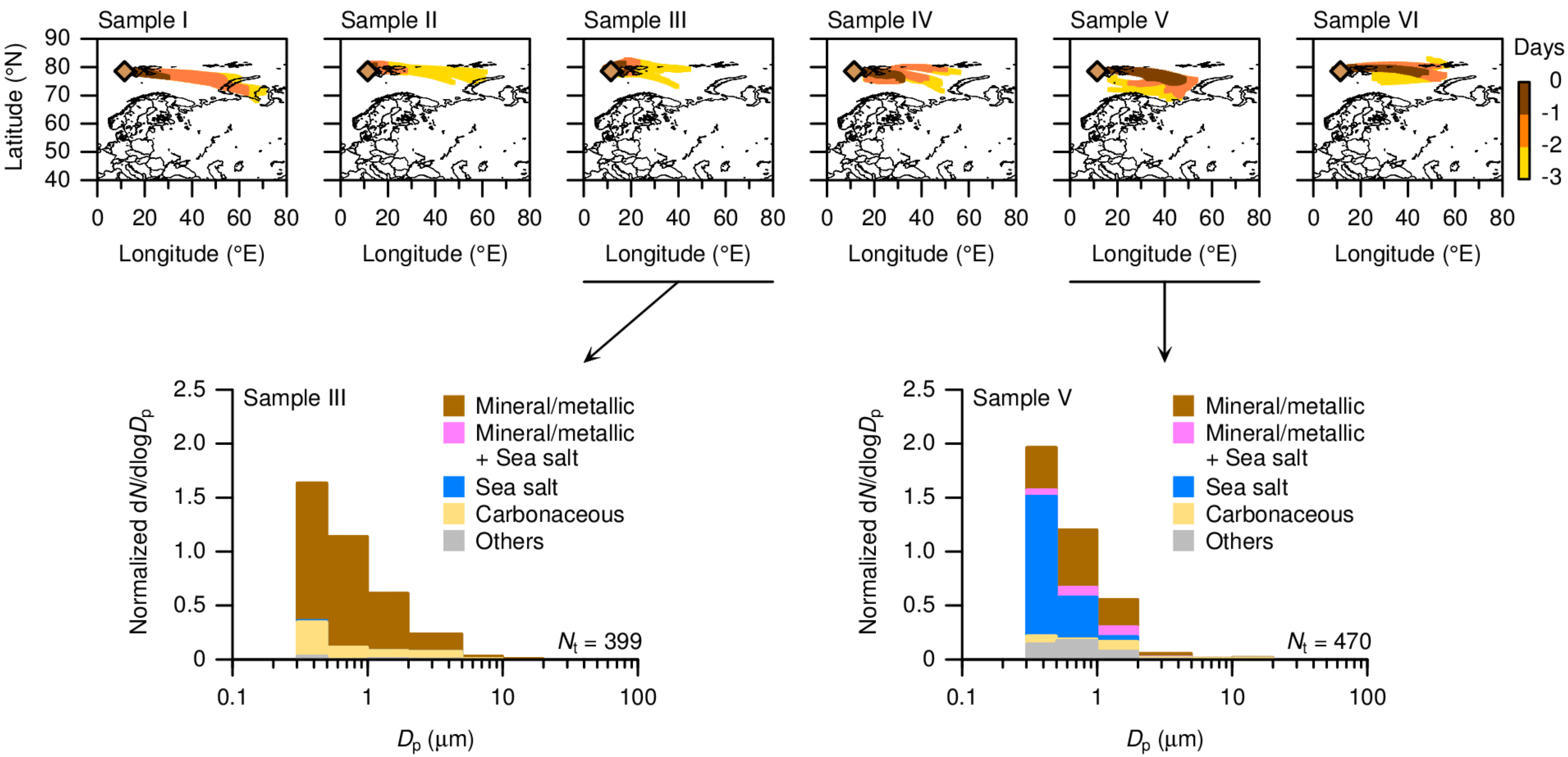
Why?

Tobo *et al.* [2019, *Nat. Geosci.*]

5) Possible INP sources in Arctic summer

3-day backward trajectory analyses (NOAA HYSPLIT model)

Mt. Zeppelin - July 2016

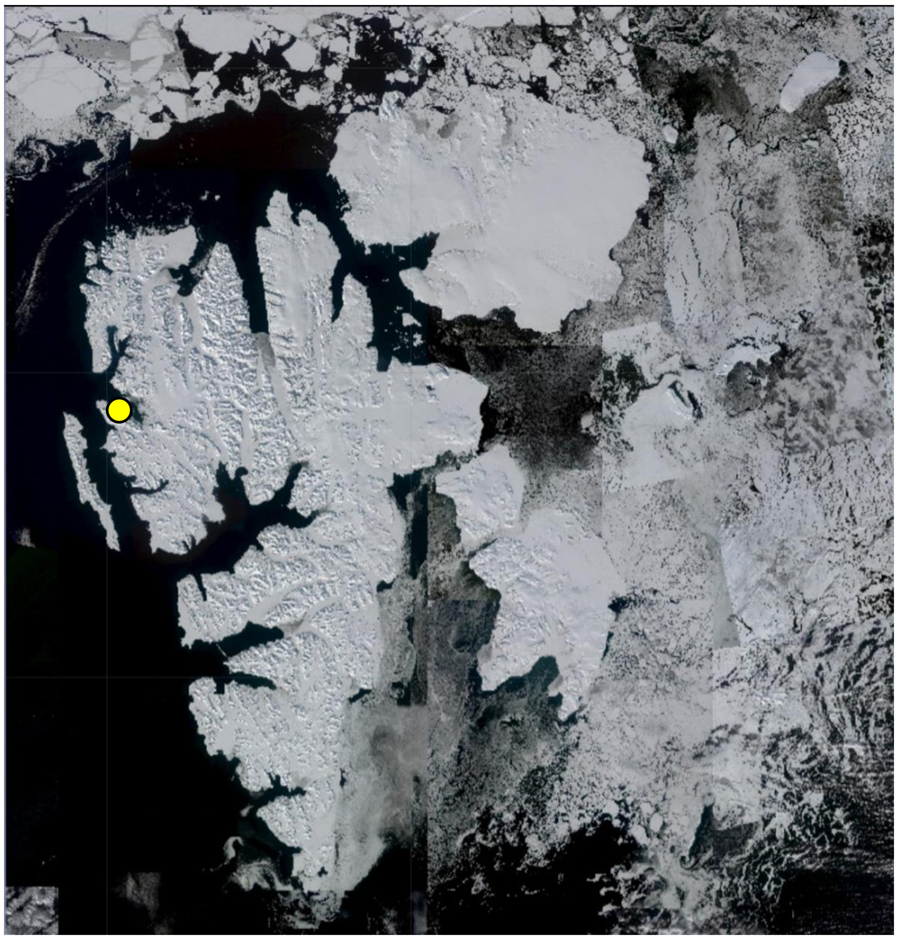


SEM/EDX analyses of ambient aerosol particles (>0.3 µm) collected on filters

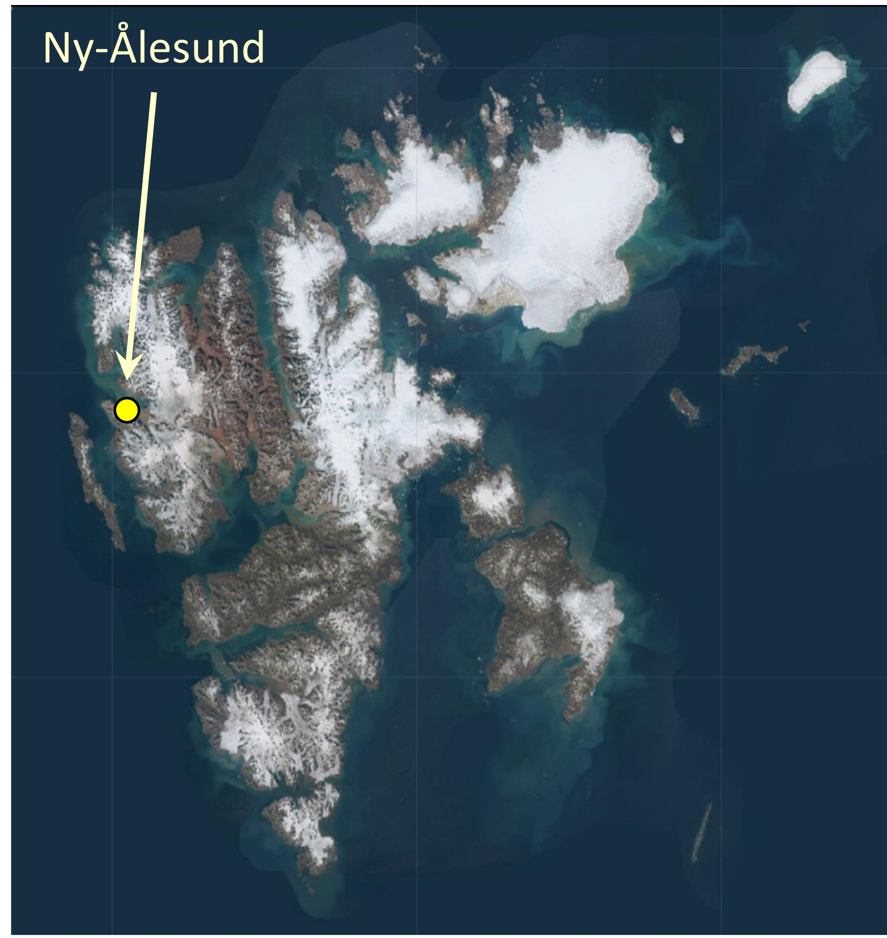
Tobo *et al*. [2019, *Nat. Geosci*.]

Satellite image of the Svalbard Islands

Winter



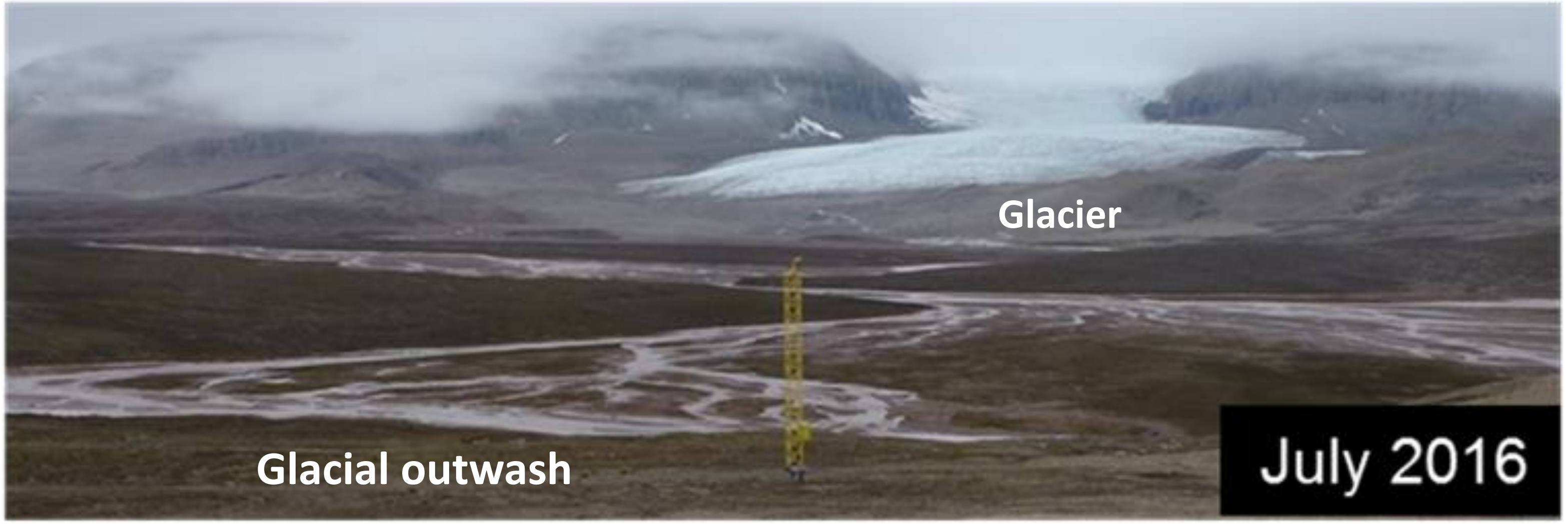
Summer

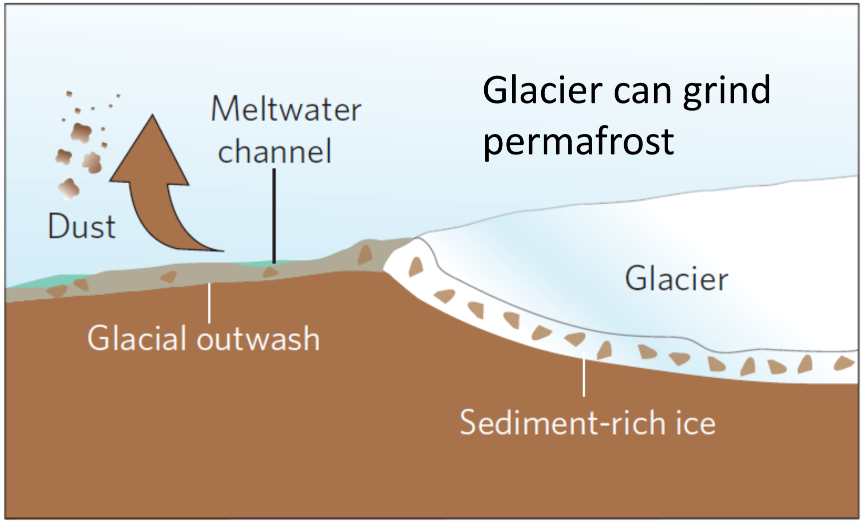


https://toposvalbard.npolar.no/

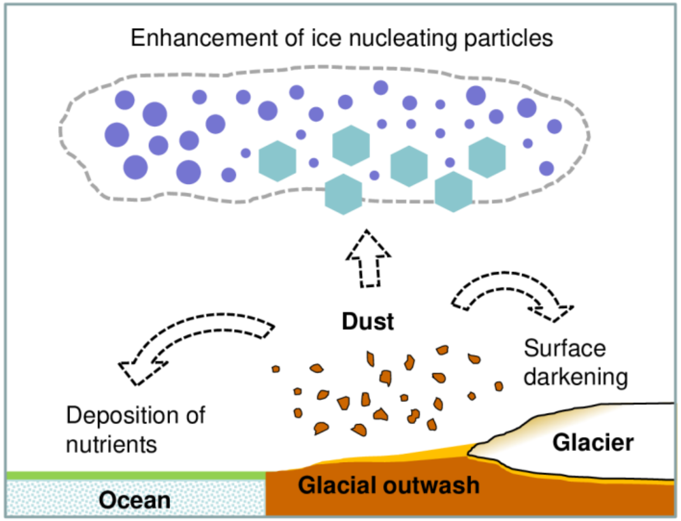
5) Possible INP sources in Arctic summer

The glacier Brøggerbreen near Ny-Ålesund, Svalbard





Ackert [2009, *Nature Geosci.*]



Koike *et al*. [in press, *Polar Sci.*]

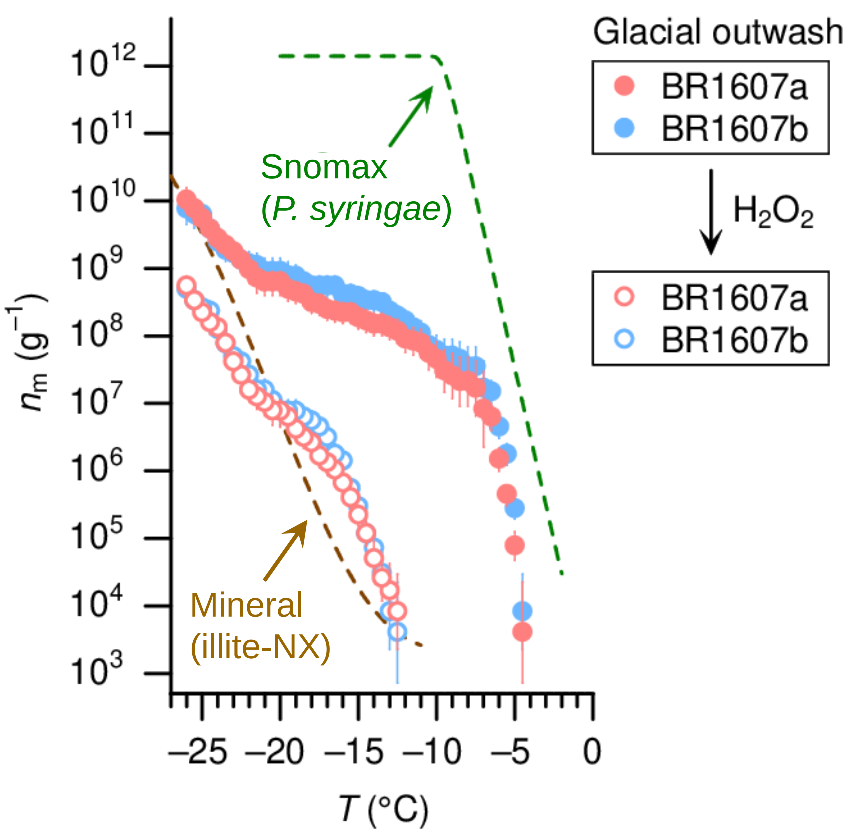
5) Possible INP sources in Arctic summer

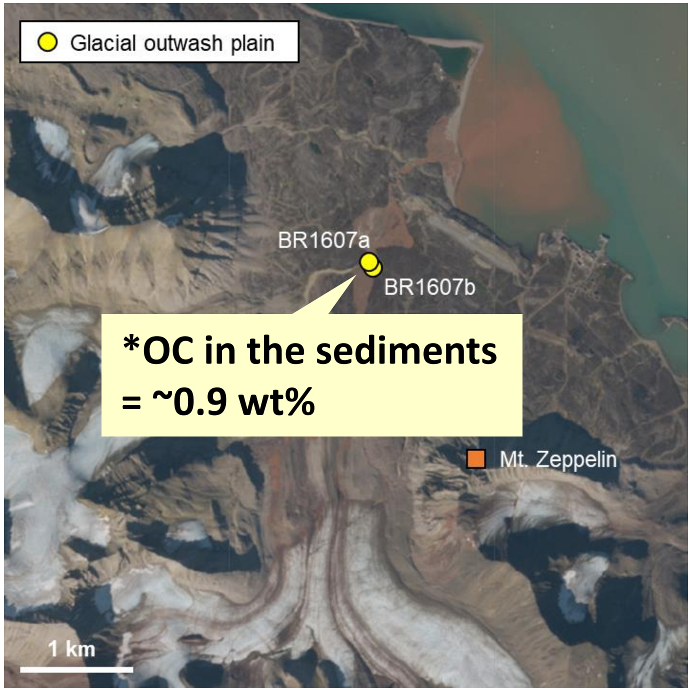
Sampling of glacial outwash sediments (a proxy for high-latitude dusts) near the glacier Brøggerbreen (Svalbard)

Photo: July 2016

5) Possible INP sources in Arctic summer

Ice nucleating ability (n_m) of glacial outwash sediments (<5 µm) in Svalbard





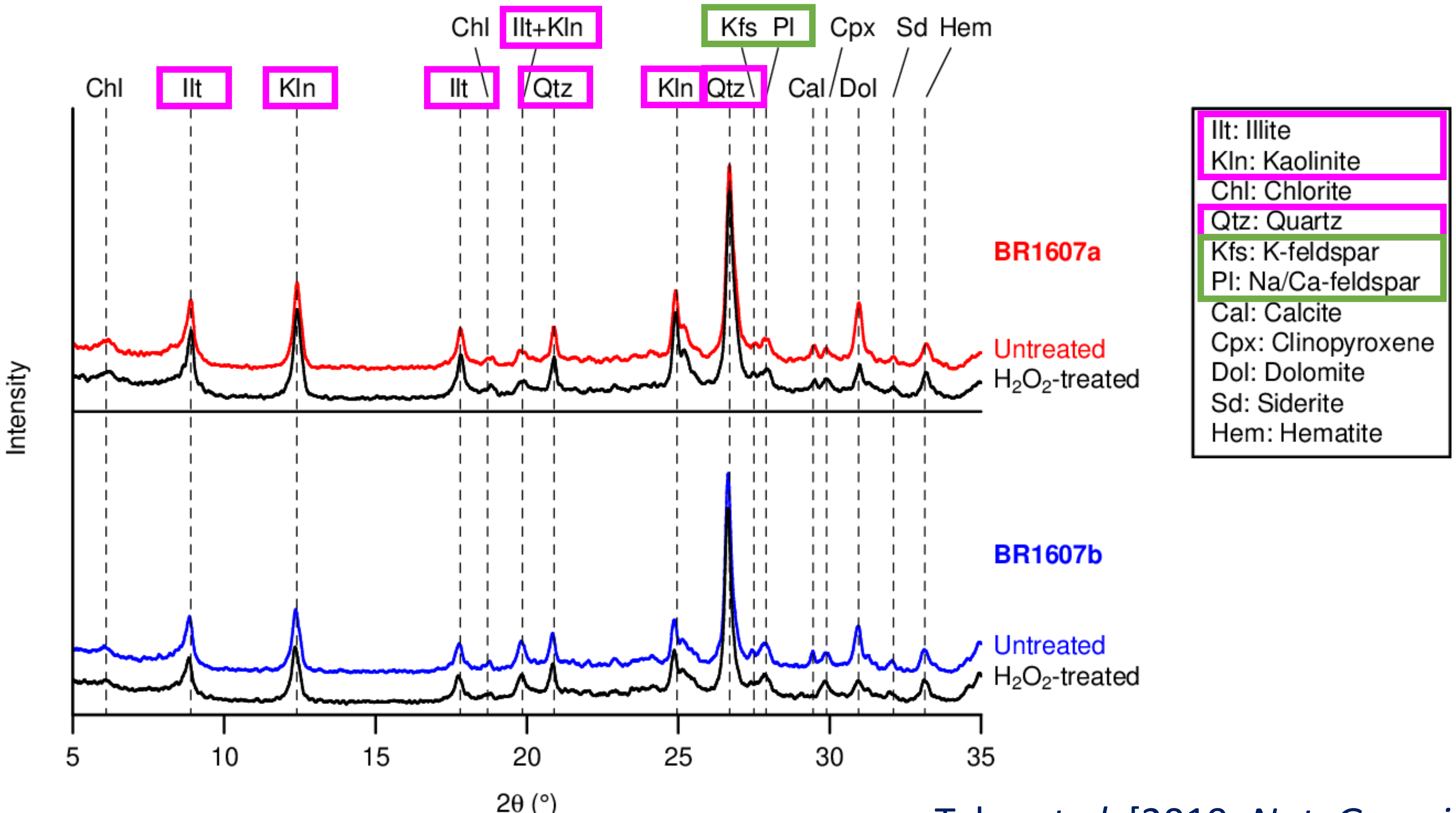
1) The **outwash sediments** have a very high ice nucleating activity

2) After removal of organic matter, the **outwash sediments** largely lost their ice nucleating ability…

Tobo *et al*. [2019, *Nat. Geosci*.]

5) Possible INP sources in Arctic summer

Mineral composition (XRD) analysis of glacial outwash sediments (<5 µm) collected from the glacier Brøggerbreen [Untreated, H_2O_2-treated]



Tobo *et al*. [2019, *Nat. Geosci*.]

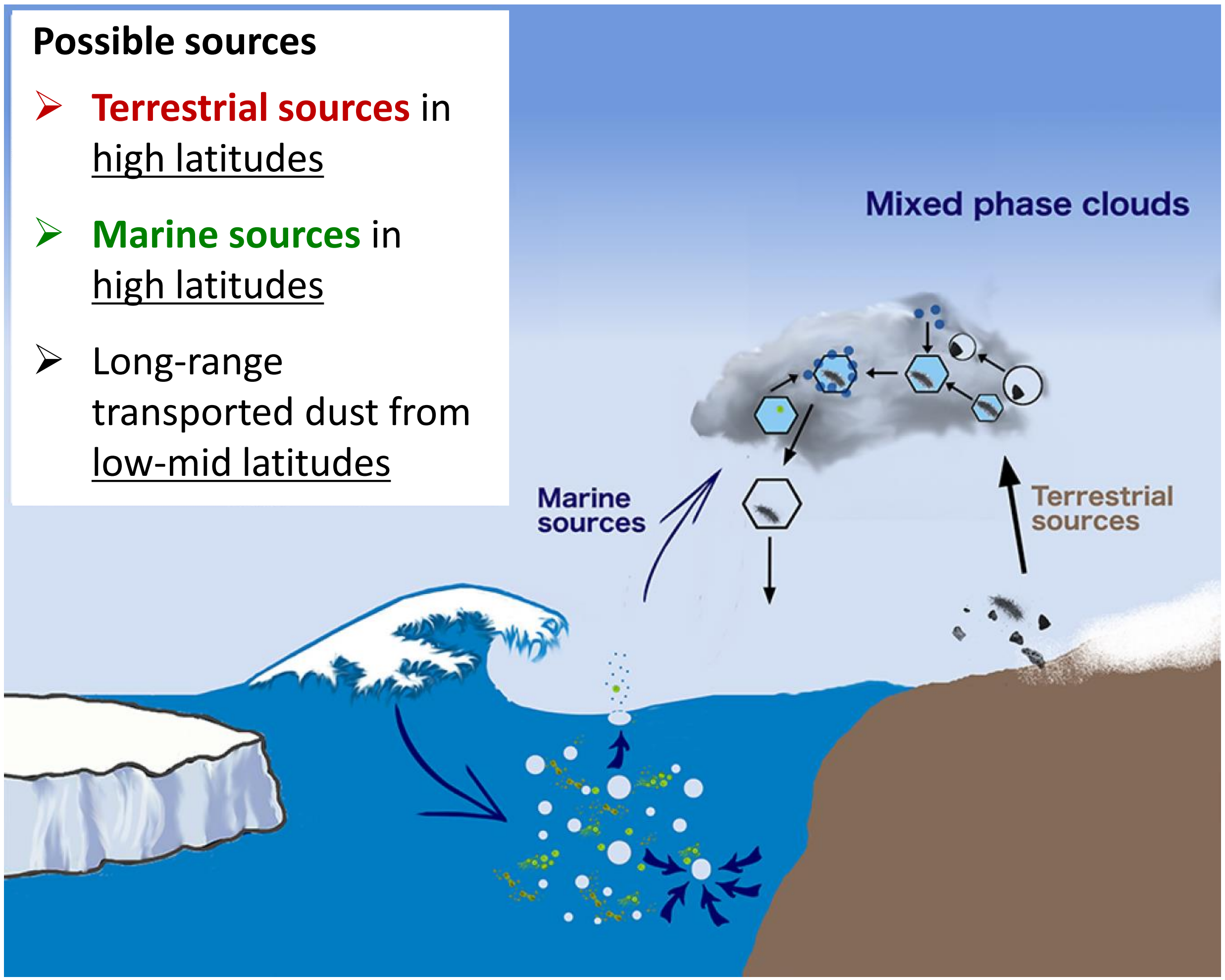
5) Possible INP sources in Arctic summer

Possible major sources of INPs in the Arctic

⇒ **High-latitude dust**, **organic matter** and/or **microorganisms** from local/regional sources might affect the INP population in the Arctic (!?)

Possible sources

- **Terrestrial sources** in high latitudes
- **Marine sources** in high latitudes
- Long-range transported dust from low-mid latitudes



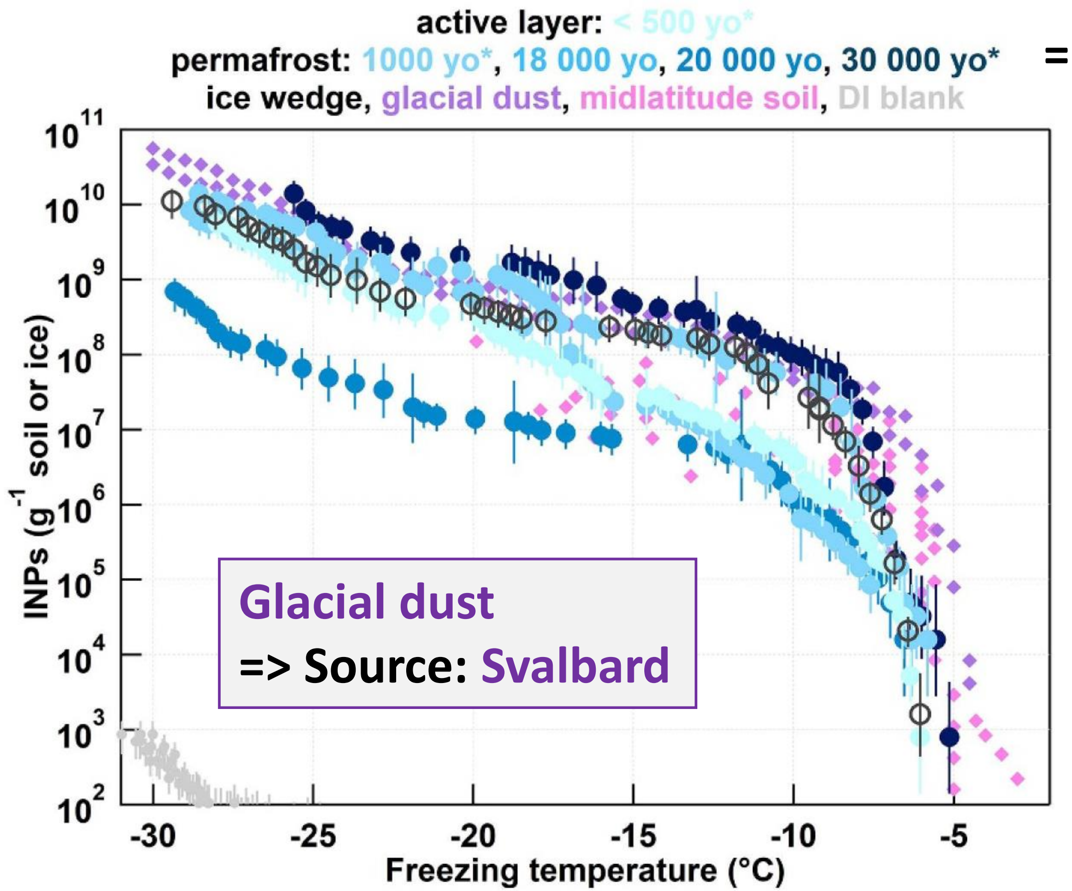
Šantl-Temkiv *et al.* [2019, *Environ. Sci. Technol.*]

5) Possible INP sources in Arctic summer

LETTER

Thawing permafrost: an overlooked source of seeds for Arctic cloud formation

Jessie M Creamean[1], Thomas C J Hill[1], Paul J DeMott[1], Jun Uetake[1], Sonia Kreidenweis[1] and Thomas A Douglas[2]



=> Source: Alaska

Creamean *et al.*
[2020, *Environ. Res. Lett.*]

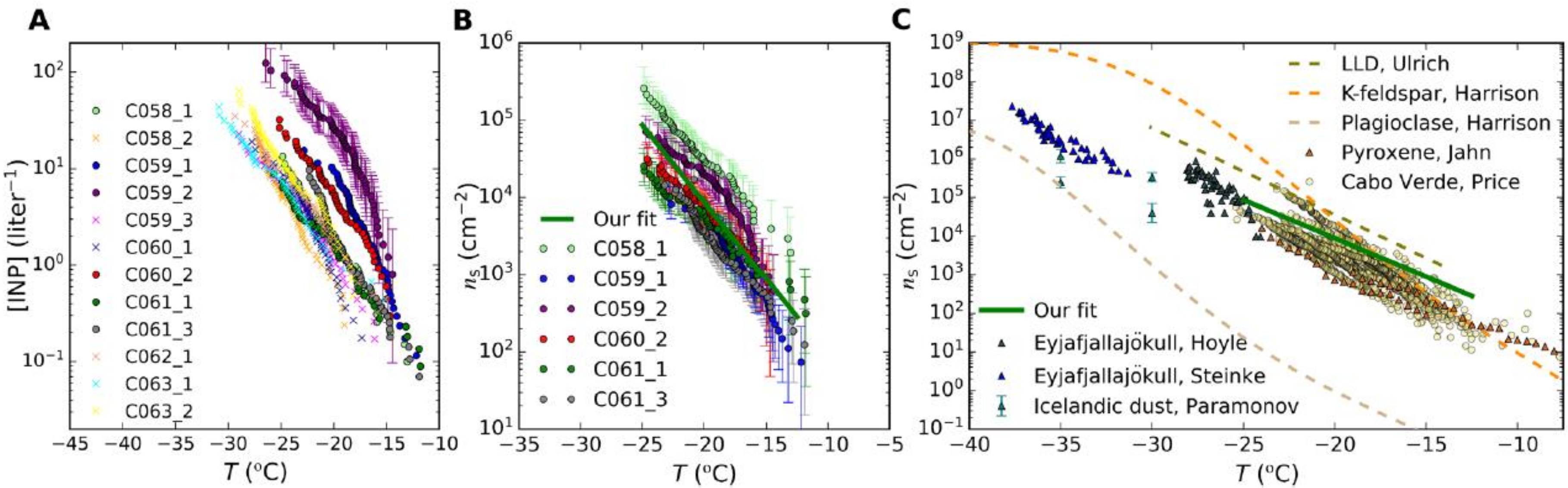
5) Possible INP sources in Arctic summer

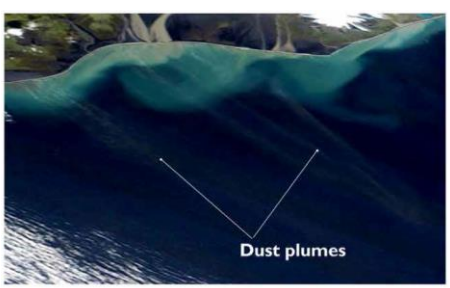
SCIENCE ADVANCES | RESEARCH ARTICLE

ATMOSPHERIC SCIENCE

Iceland is an episodic source of atmospheric ice-nucleating particles relevant for mixed-phase clouds

A. Sanchez-Marroquin[1]*, O. Arnalds[2], K. J. Baustian-Dorsi[1,3], J. Browse[1,4], P. Dagsson-Waldhauserova[2,5], A. D. Harrison[1], E. C. Maters[1,6], K. J. Pringle[1], J. Vergara-Temprado[7], I. T. Burke[1], J. B. McQuaid[1], K. S. Carslaw[1], B. J. Murray[1]





Sanchez-Marroquin *et al*. [2020, *Sci. Adv.*]

Summary

CCN (Cloud Condensation Nuclei) over Svalbard

- The CCN number concentrations tend to increase from spring to summer, while it depends on supersaturation (SS) state.

⇒ At lower SS (= ~0.2-0.4), the CCN reaches a maximum in spring, due to the increase in accumulation-mode aerosols.

⇒ At higher SS (= ~1.0), the CCN shows higher values even in summer, due to the increase in Aitken-mode aerosols.

Summary

INPs (Ice Nucleating Particles) over Svalbard

- The INP number concentrations (especially in the warmer temperature regime) tend to increase in summer when the ground surface appears due to snow melting.

⇒ The emissions of dusts and biogenic materials from terrestrial sources in high latitudes may play a key role.

⇒ Further studies will be necessary to understand the sources of aerosols causing the seasonal variation of INPs in the Arctic.


END
Photo by Y. Tobo