Secondary Ice Production
vs.
Primary Ice Nucleation

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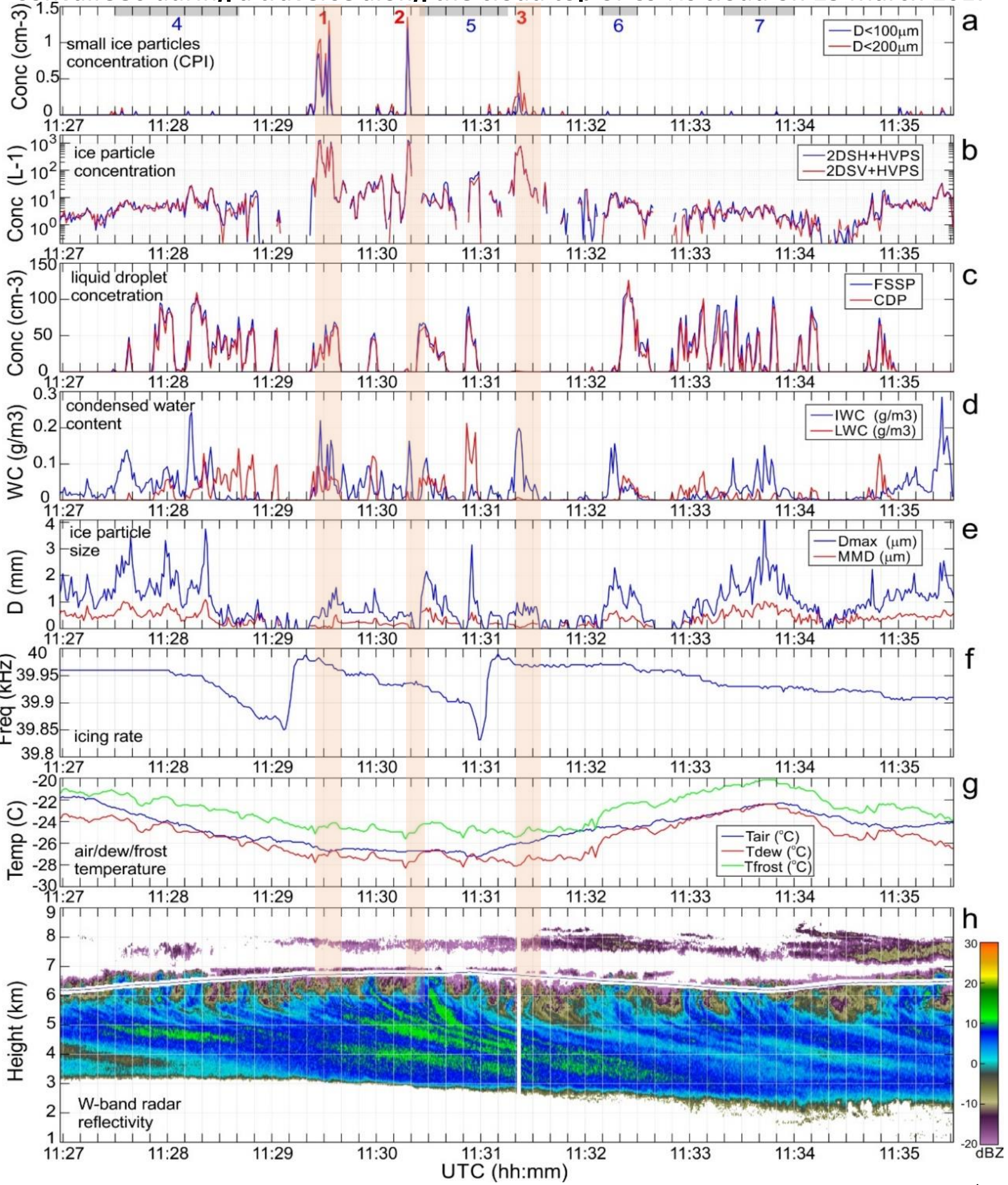
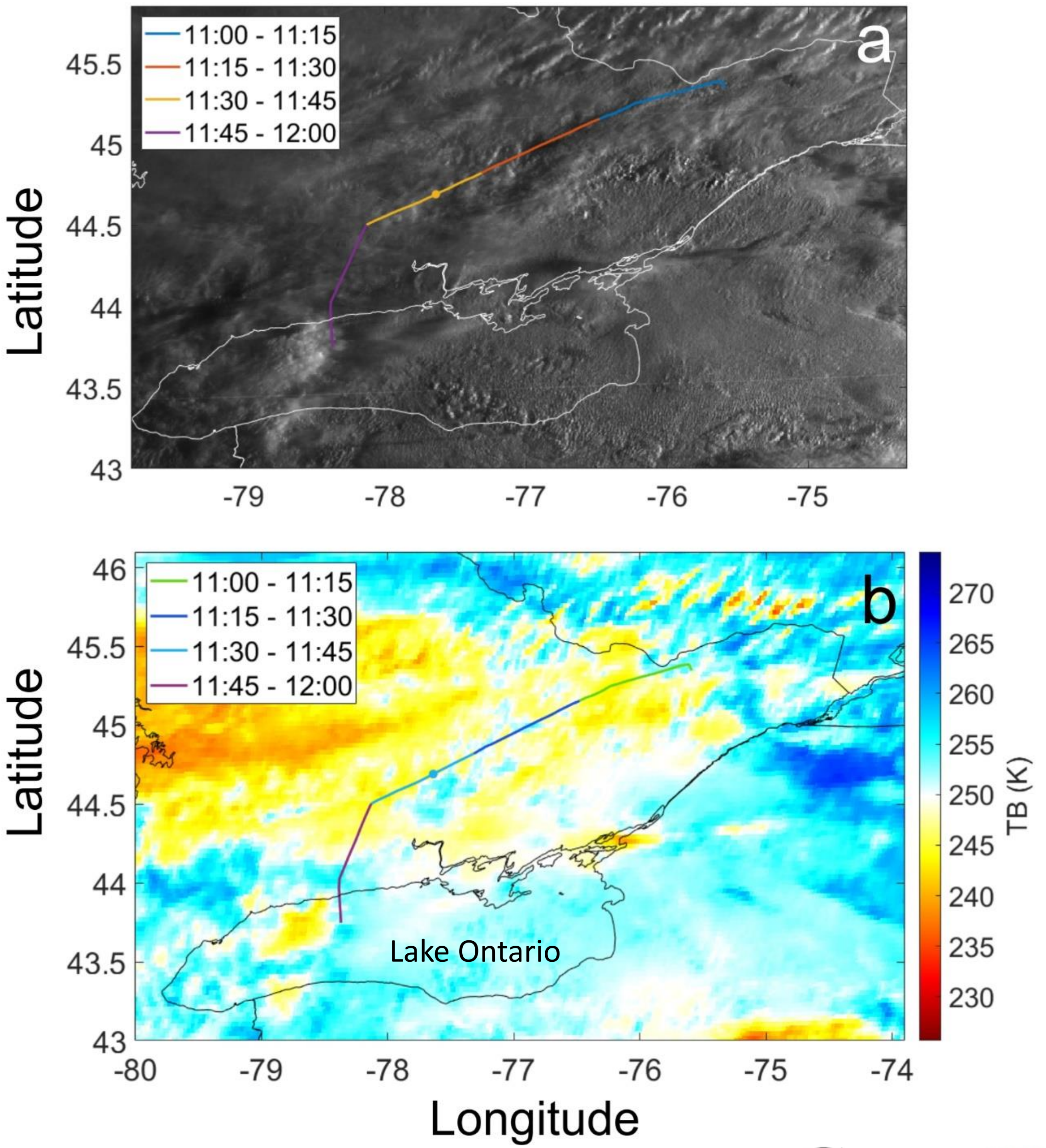
Objectives

To set a discussion on the relative roles of primary and secondary ice production in clouds (PIP vs SIP).

Time series of microphysical and state parameters measured from the NRC Convair580 during a traverse along the cloud top of Cs-Ns cloud on 25 March 2017



25 March, 2017; NRC Convair580 flight track



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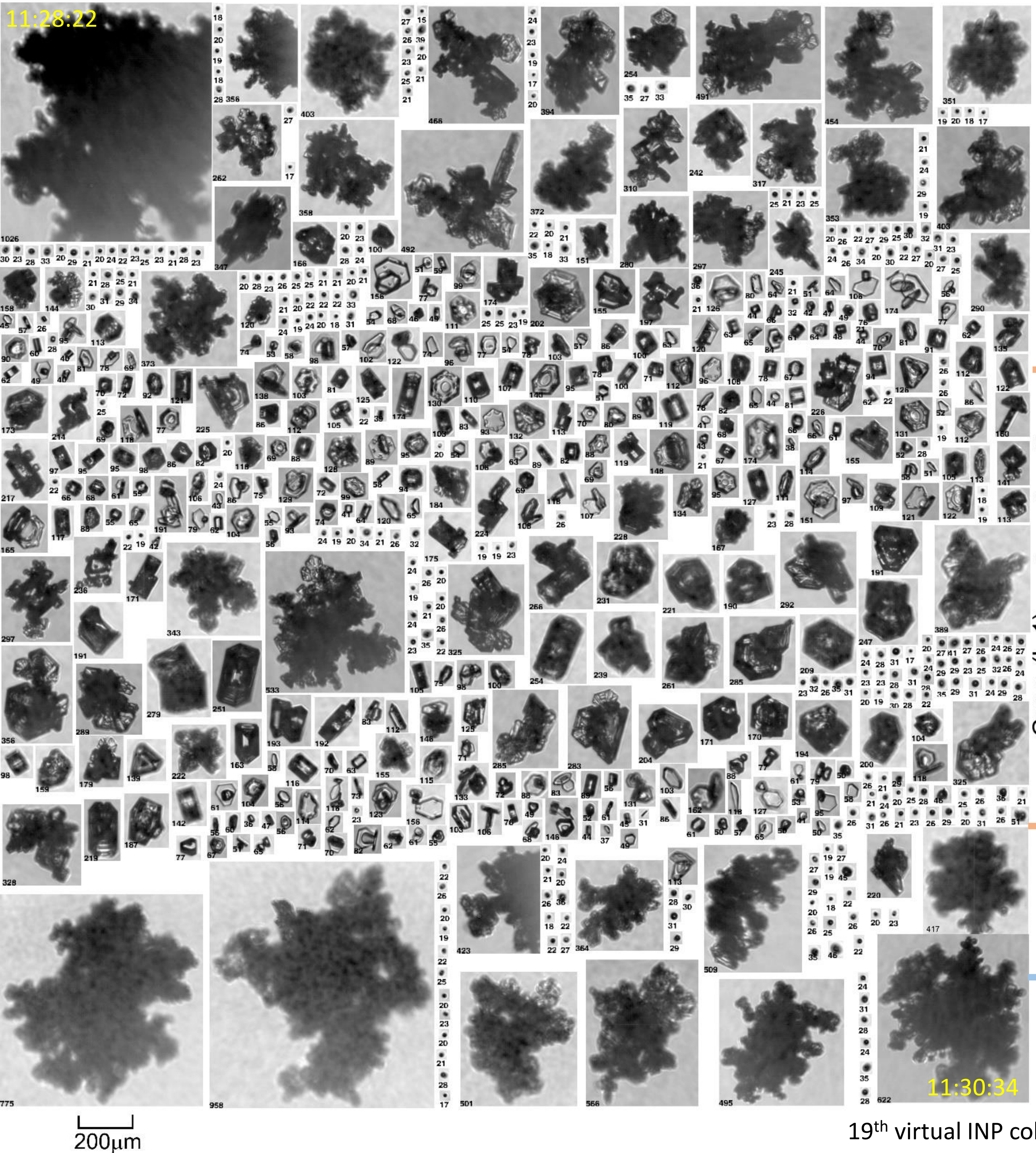
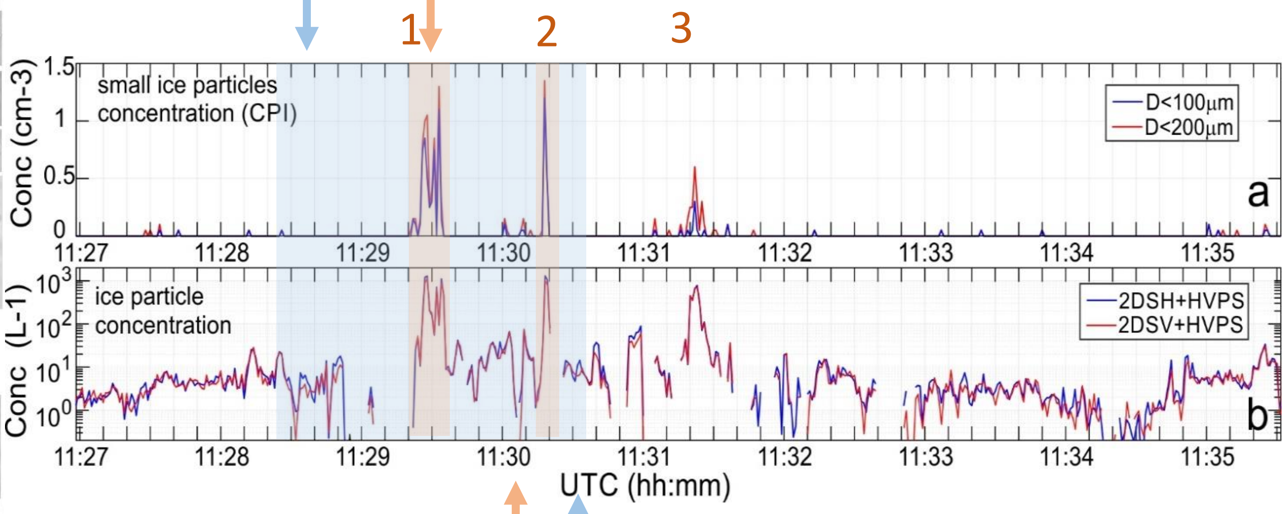
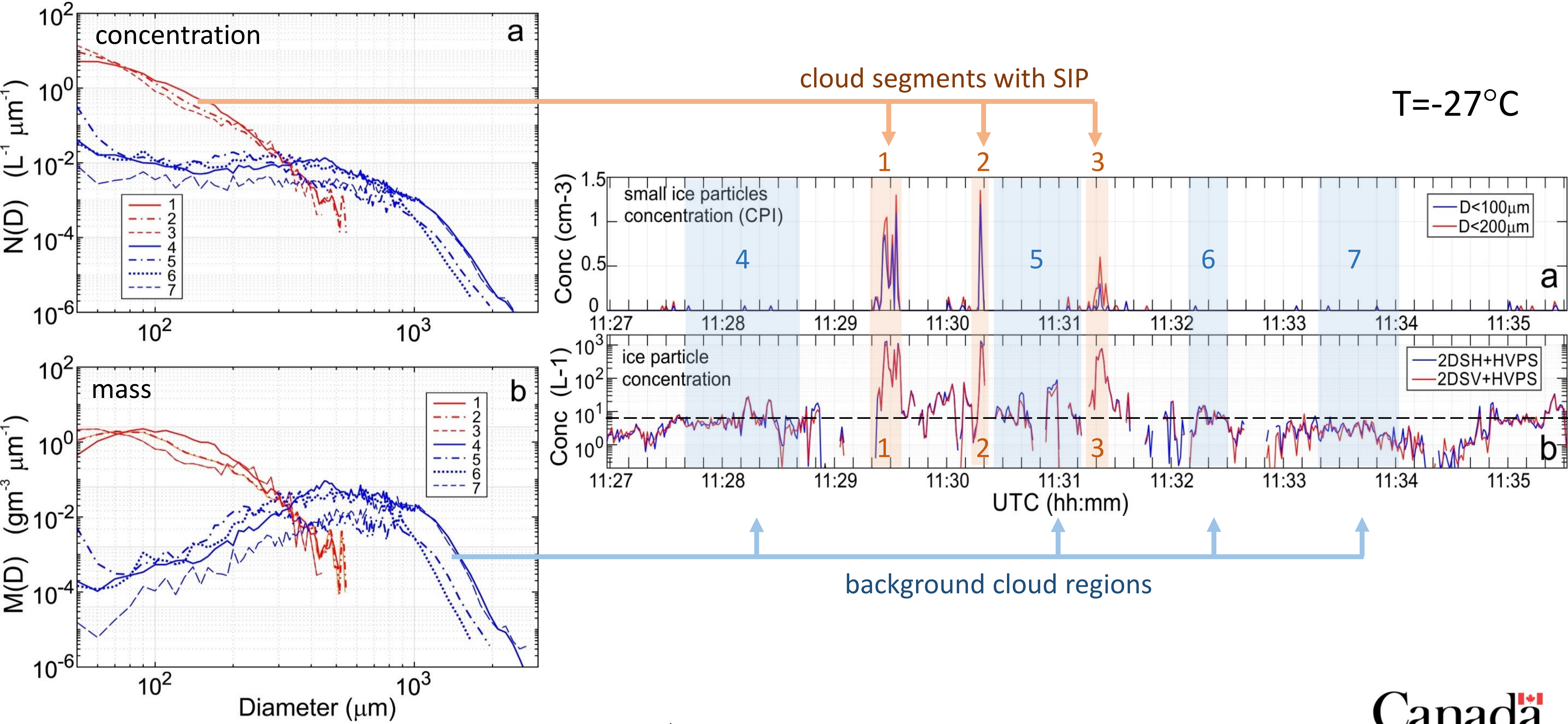
Succession of CPI particle images when passing cloud segments #1 and #2



T=-27°C



Comparisons of concentration and mass size distributions of ice particles in cloud segments affected by SIP and background clouds



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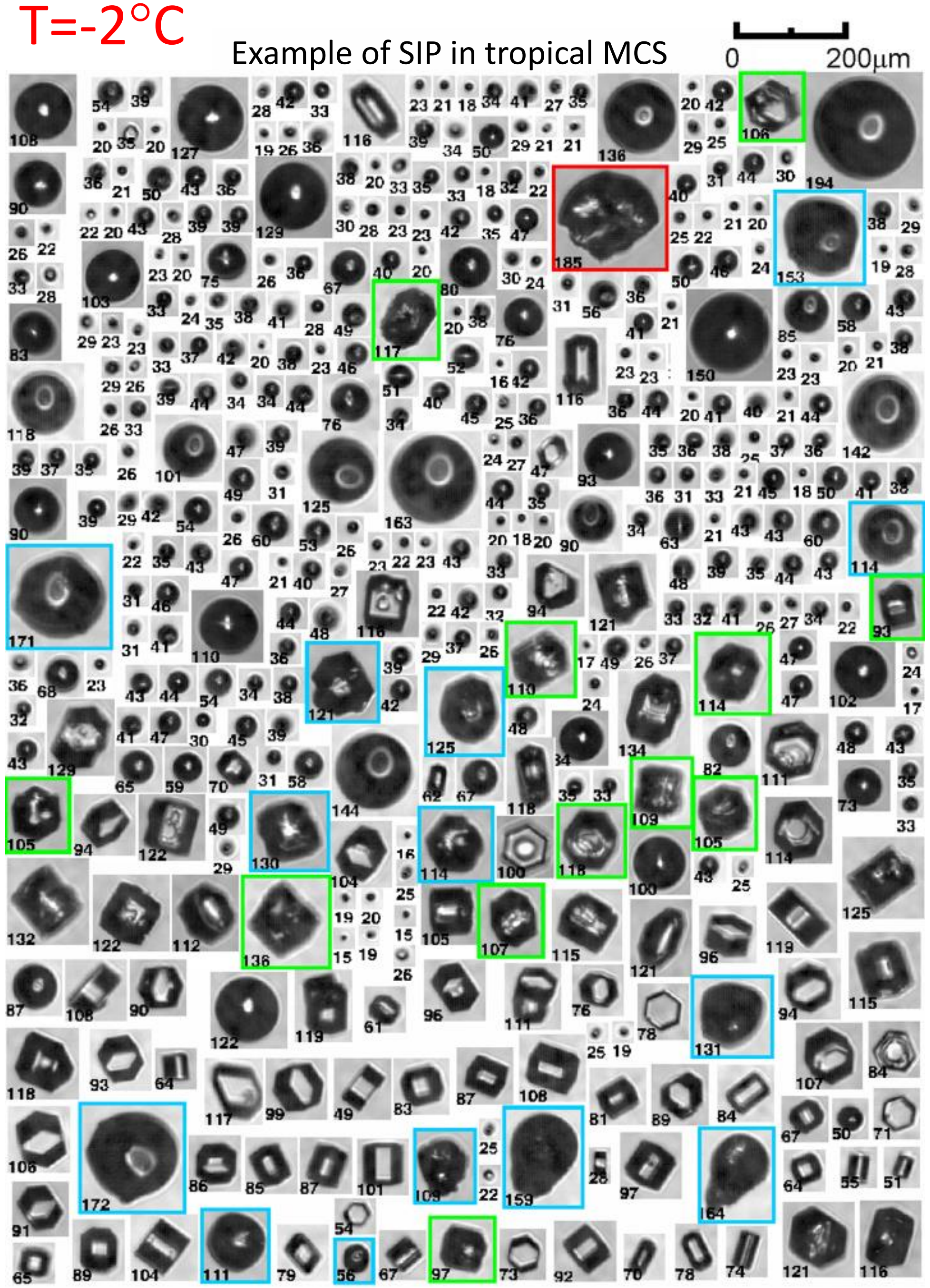
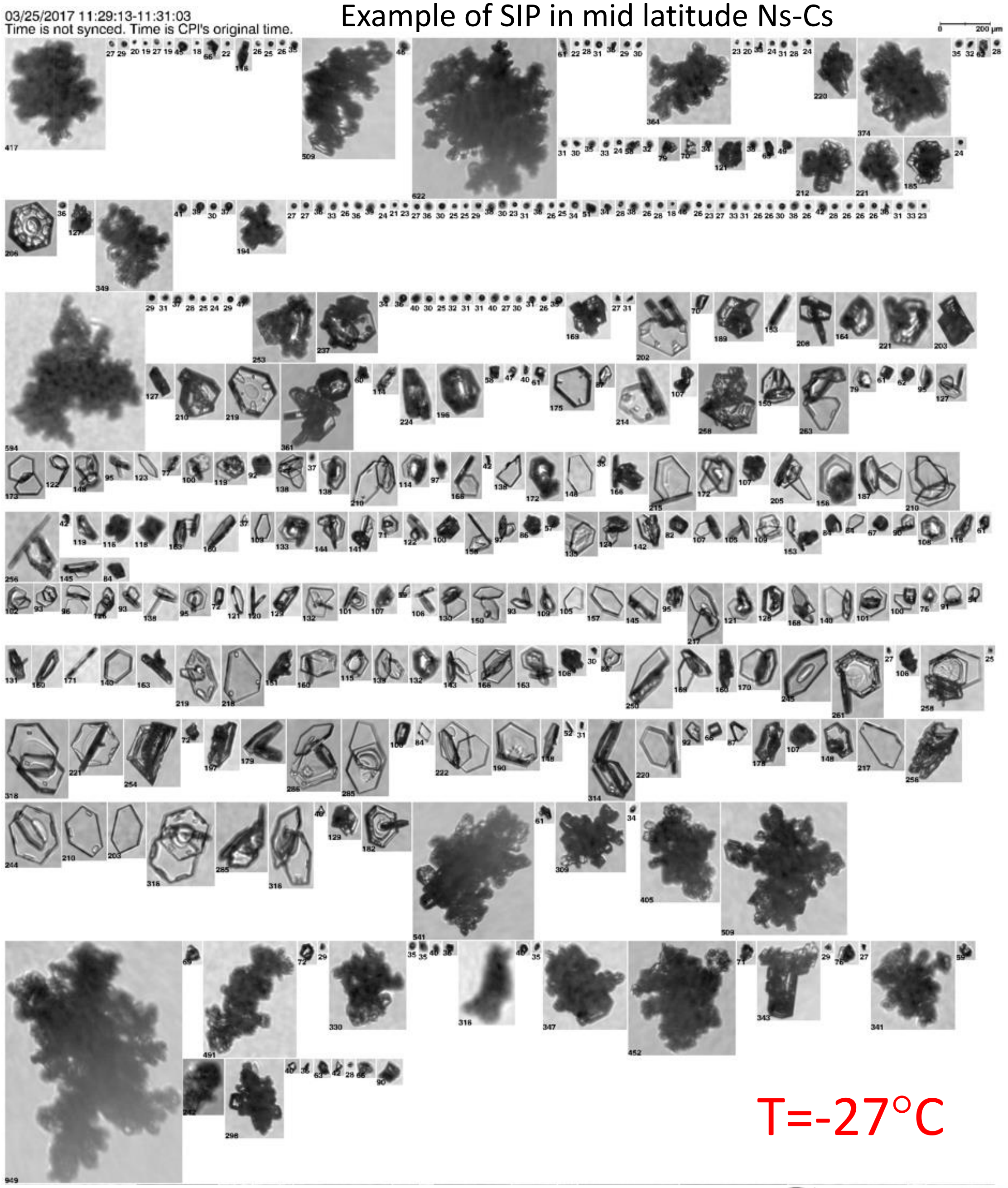
T=-2°C

Example of SIP in tropical MCS



Korolev et al. ACP, 2020

Example of SIP in mid latitude Ns-Cs



T=-27°C

Korolev et al. ICCP, 2021

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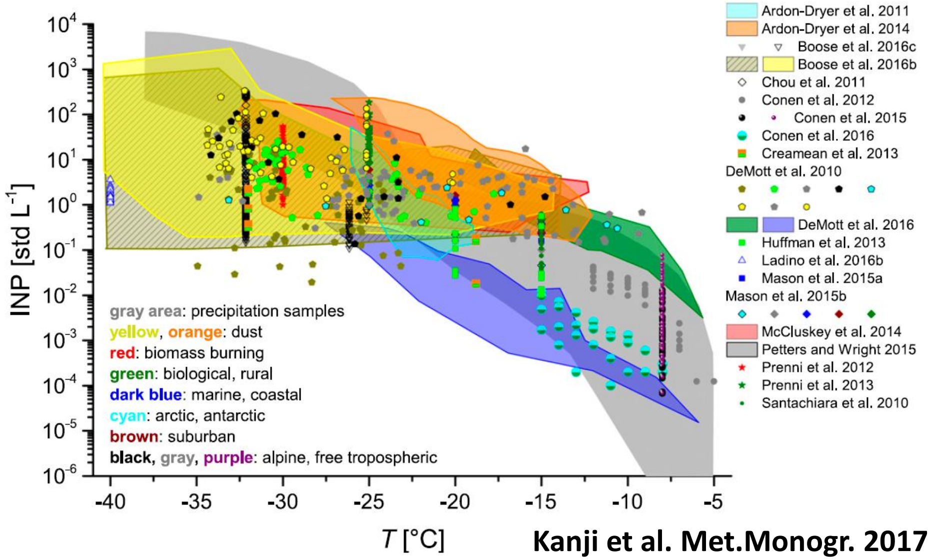
Brief summary

(a) SIP is an omnipresent phenomenon in clouds.
(b) SIP is observed in clouds from polar regions to tropics.
(c) SIP was documented in clouds at temperatures ranging from -2C to -27C.
(d) SIP may be a strong source of ice depending on the environmental conditions. In SIP cloud regions ice concentration may enhance up to $10^3 L^{-1}$.

Items (a)-(d) are equally relevant to PIP.



Kanji et al. Met.Monogr. 2017

Could PIP and SIP contributions in ice particle concentrations be identified and segregated?

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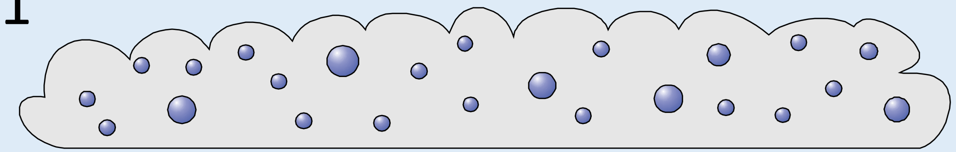
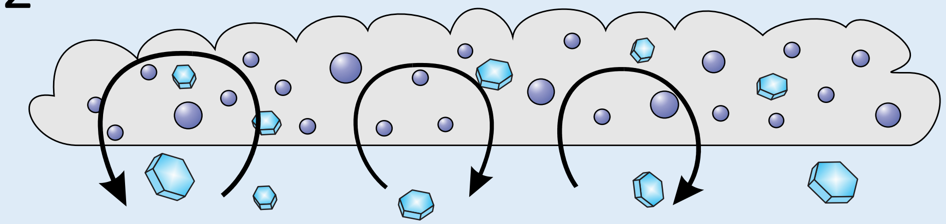
Documented observations of three types of liquid-containing supercooled clouds

1



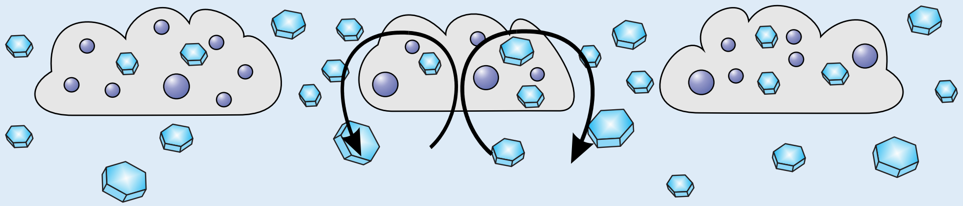
Persistent supercooled liquid clouds
(typically T>-20°C, N_{ice}=0)

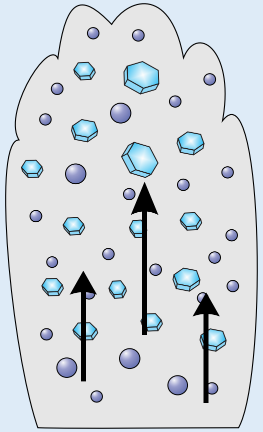
2



Persistent mixed-phase clouds
(typically T>-20°C, N_{ice}<$10L^{-1}$)

3





Unstable mixed-phase clouds
(T>-40°C, 10^1<N_{ice}<10^3L^{-1})

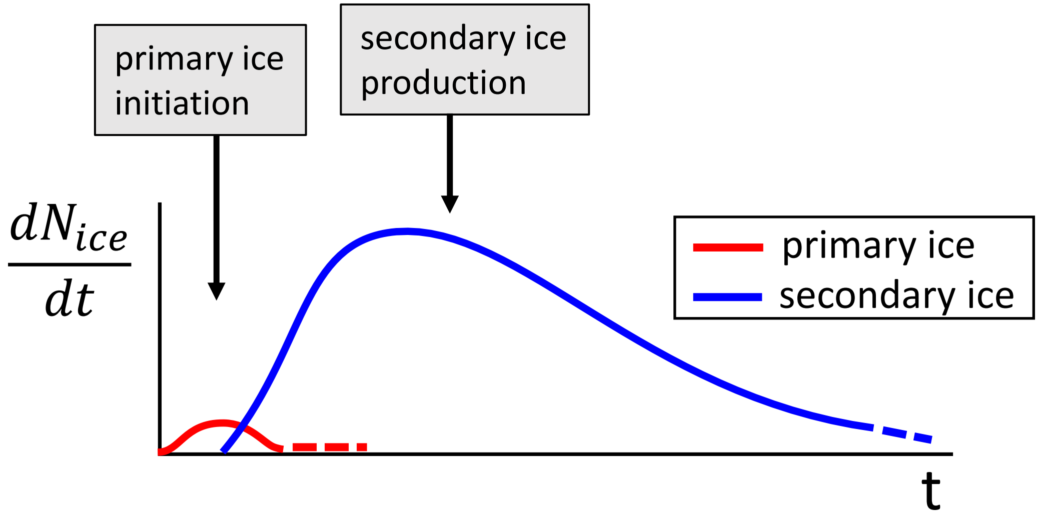
Primary ice production
heterogeneous/homogeneous nucleation of INPs

→ **Secondary ice production** → ?

What is the role of PIP in ice formation after SIP initiation?

Possible scenarios of primary and secondary ice production

(conceptual consideration)

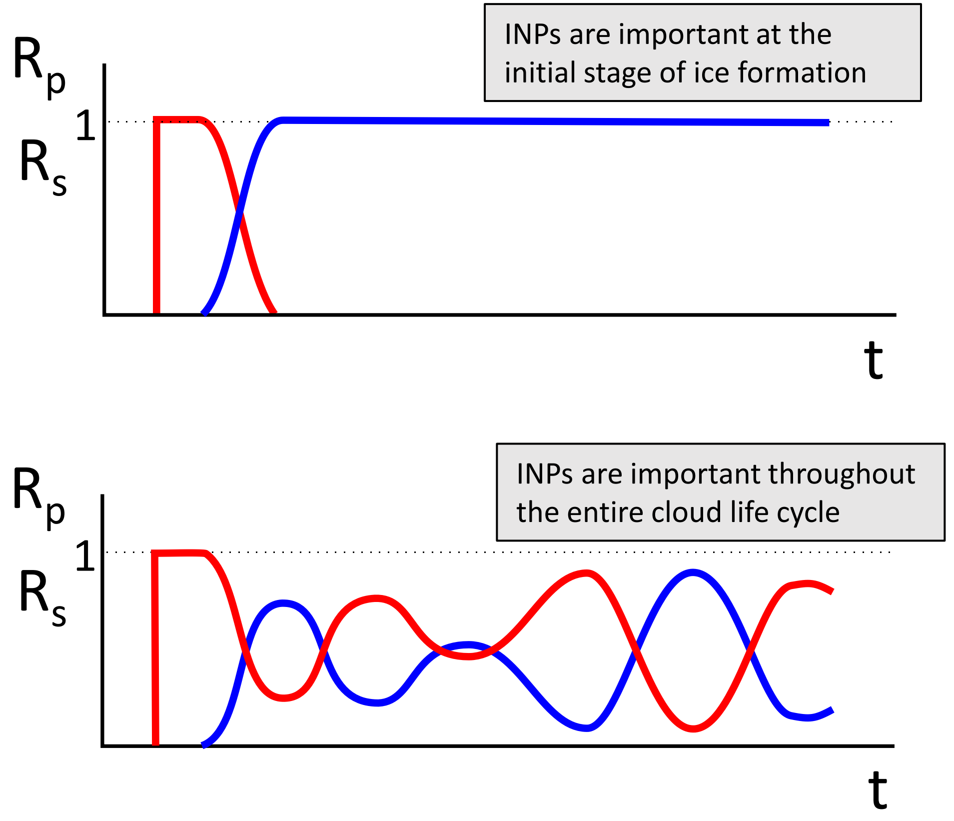


$$R_p = \frac{dN_{prim\ ice}}{dt} \Big/ \frac{dN_{tot\ ice}}{dt}$$ PIP rate ratio

$$R_s = \frac{dN_{sec\ ice}}{dt} \Big/ \frac{dN_{tot\ ice}}{dt}$$ SIP rate ratio

$$N_{tot\ ice} = N_{prim\ ice} + N_{sec\ ice}$$ total ice concentration

Possible scenarios



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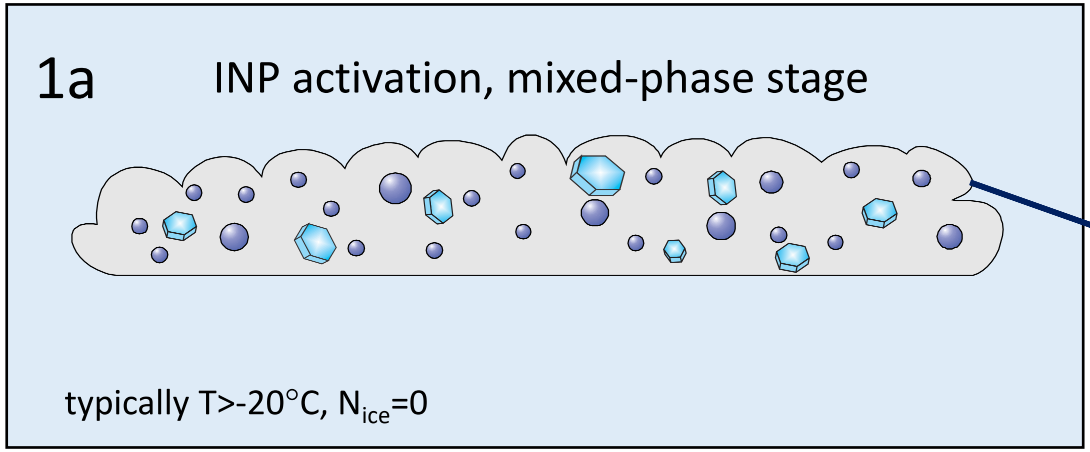
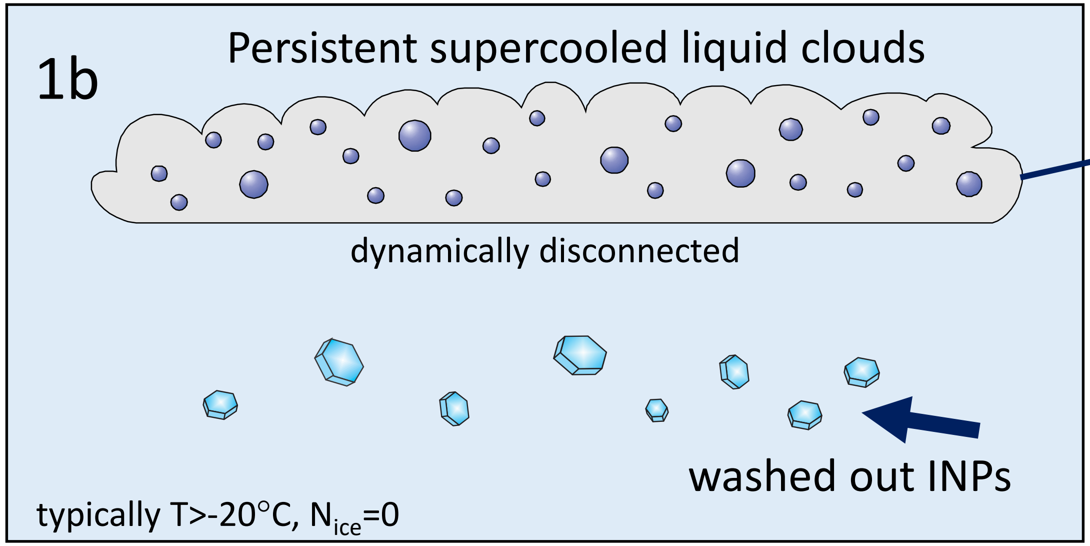
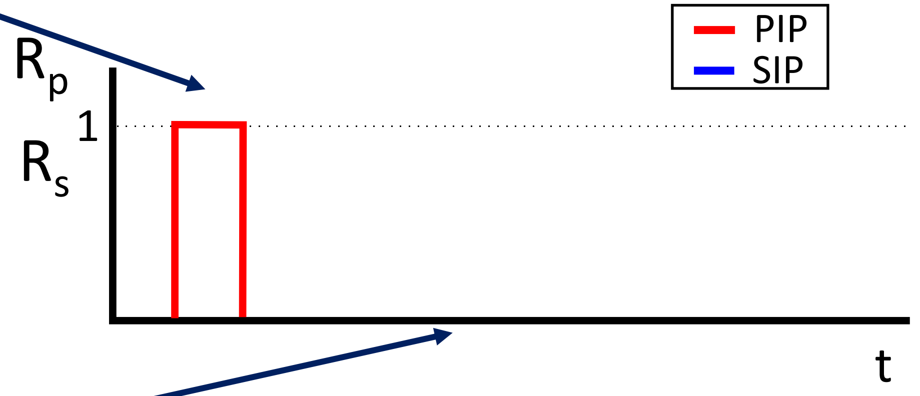
Possible scenarios of PIP and SIP in relation to the type of clouds
(conceptual consideration)







After primary ice nucleation ice particles precipitate out of the cloud. After that the cloud transforms into a persistent supercooled liquid cloud.

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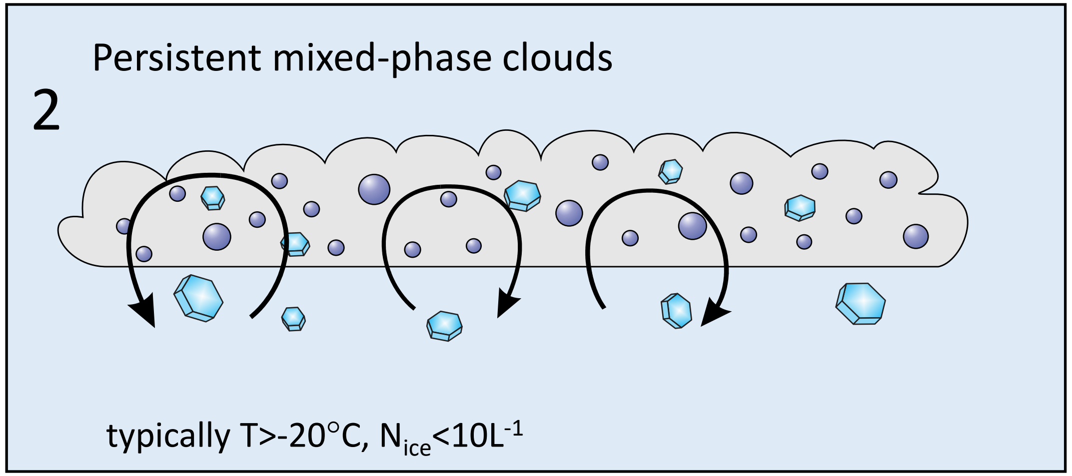
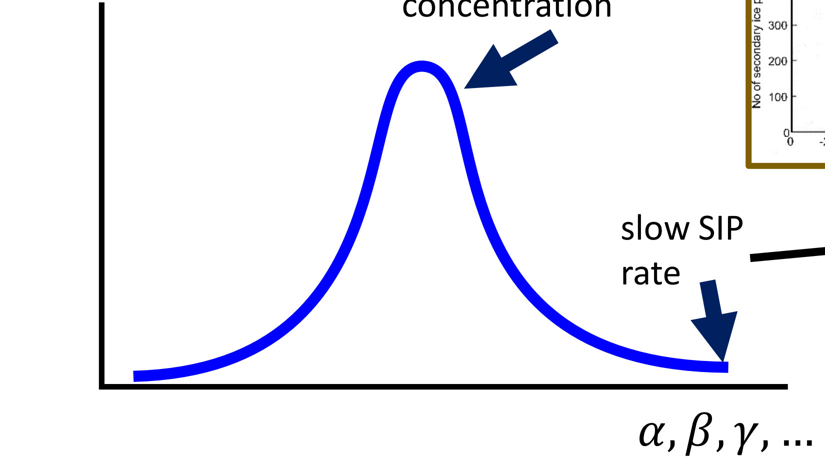
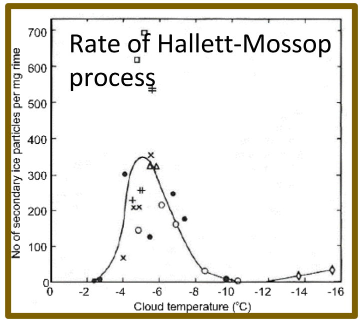
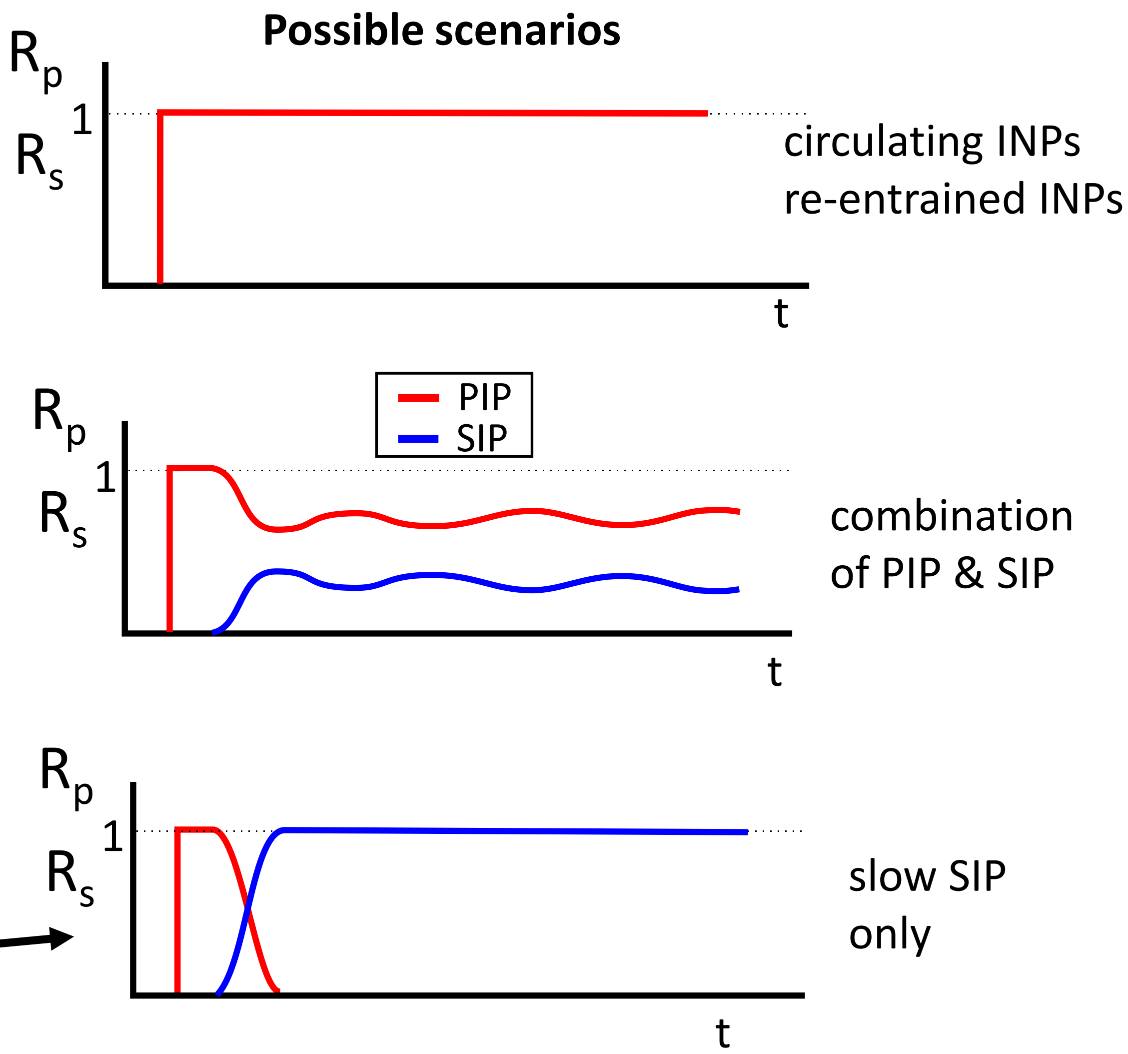
Possible scenarios of PIP and SIP in relation to the type of clouds
(conceptual consideration)









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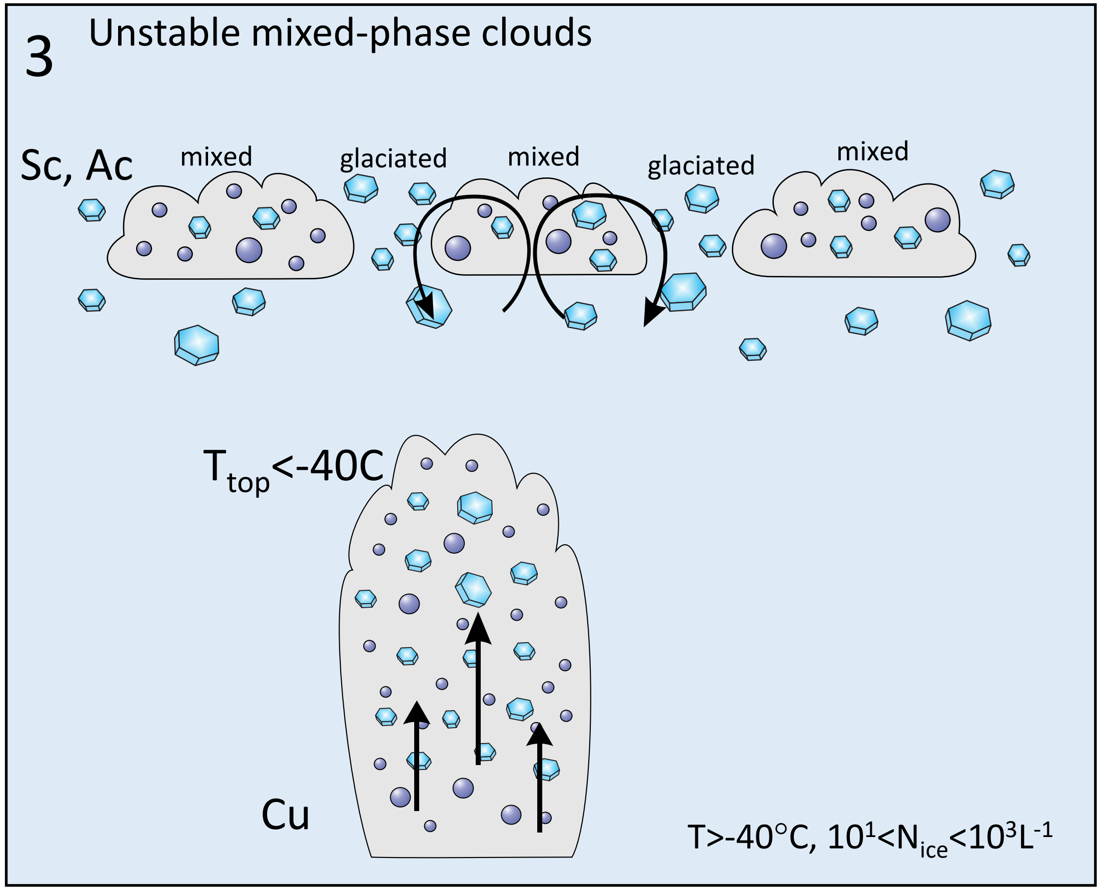
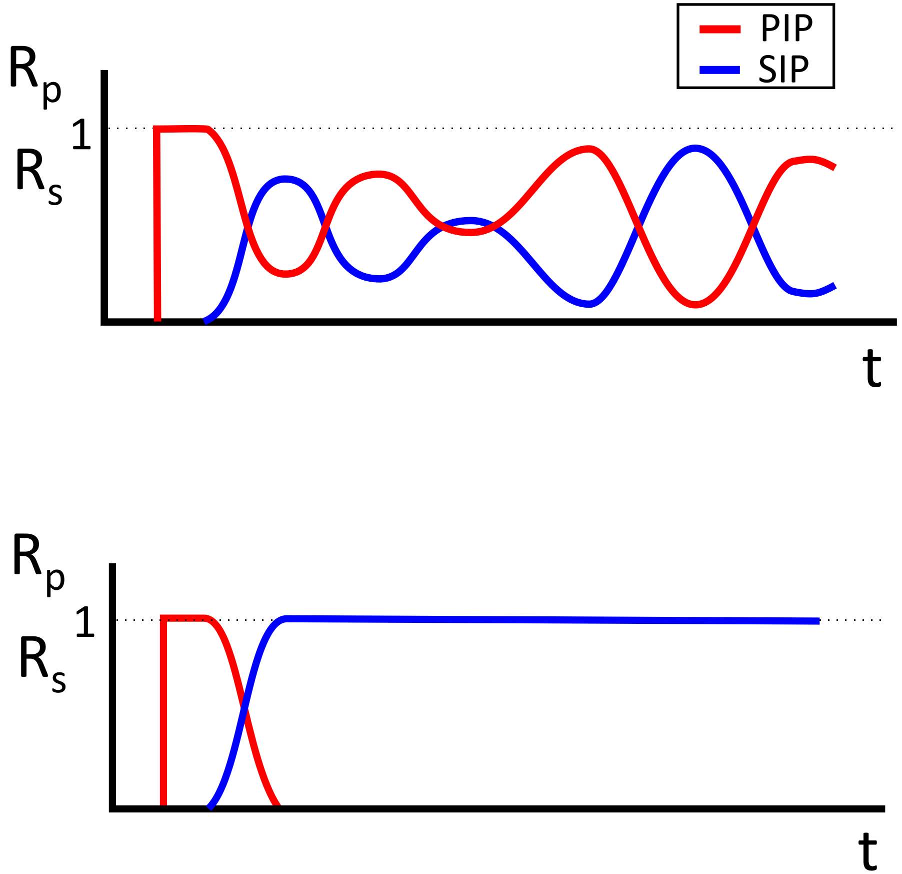
Possible scenarios of PIP and SIP in relation to the type of clouds
(conceptual consideration)





Typical for convective clouds

Hawker et al. ACPD, 2021

Lawson et al. JAS, 2017

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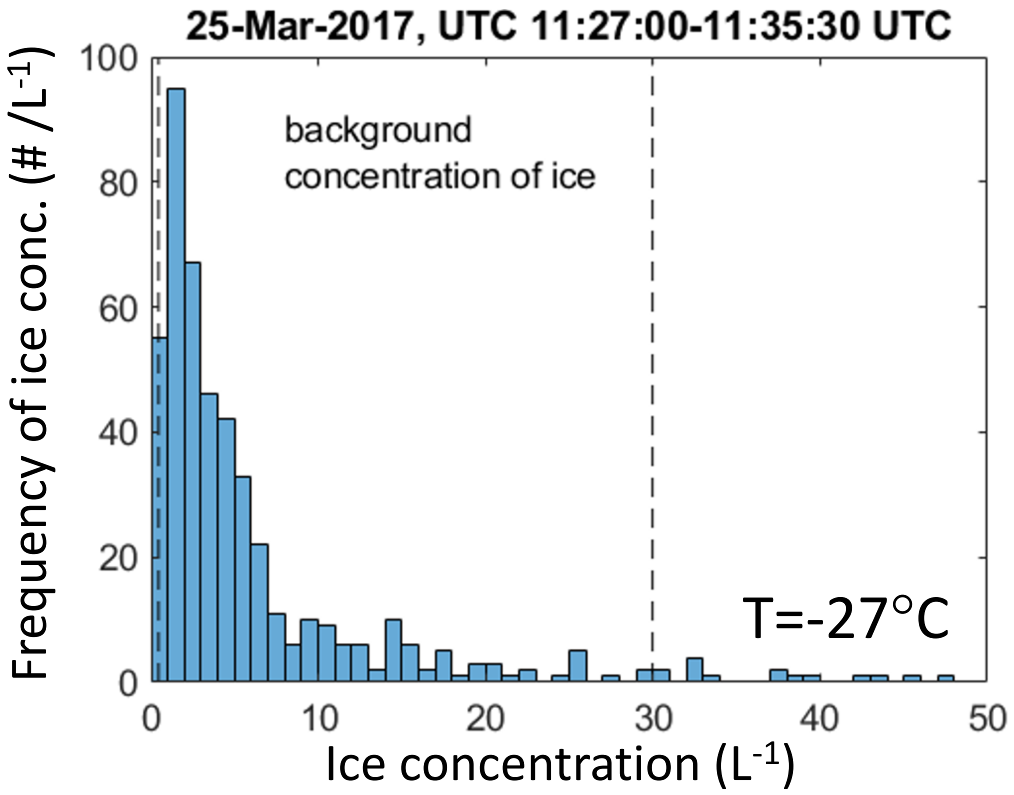
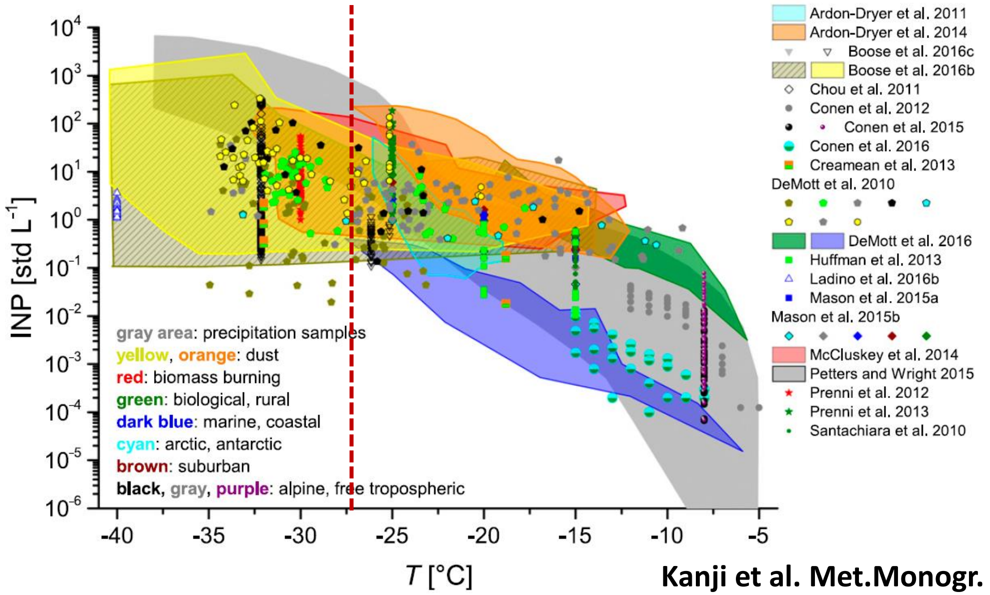
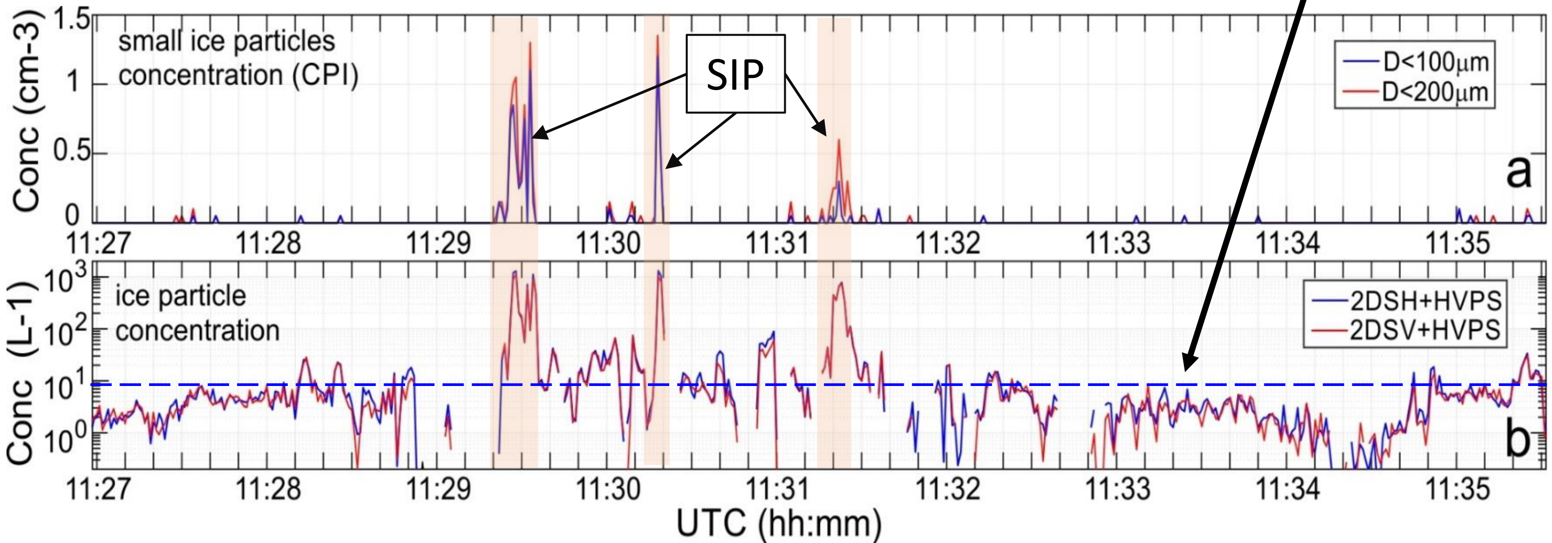




Kanji et al. Met.Monogr. 2017

What is the origin of the "background" ice?



Average N_{ice}=7.5L^{-1}

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Questions:

1. *Liquid clouds*
    a. Why do persistent supercooled liquid clouds exist?
    b. What happens to INPs in persistent supercooled liquid clouds? What is the mechanism of INP removal from the cloud layer? Why do INPs not re-entrain the cloud layer?

2. *Persistent mixed-phase clouds*
    a. What is the mechanism of ice initiation in persistent mixed-phase clouds?
    b. Recirculating INPs (after ice sublimation)?
    c. Slow SIP?

3. *Unstable mixed-phase clouds*
    a. What are the necessary and sufficient conditions for SIP?
    b. Efficiency of SIP mechanisms?

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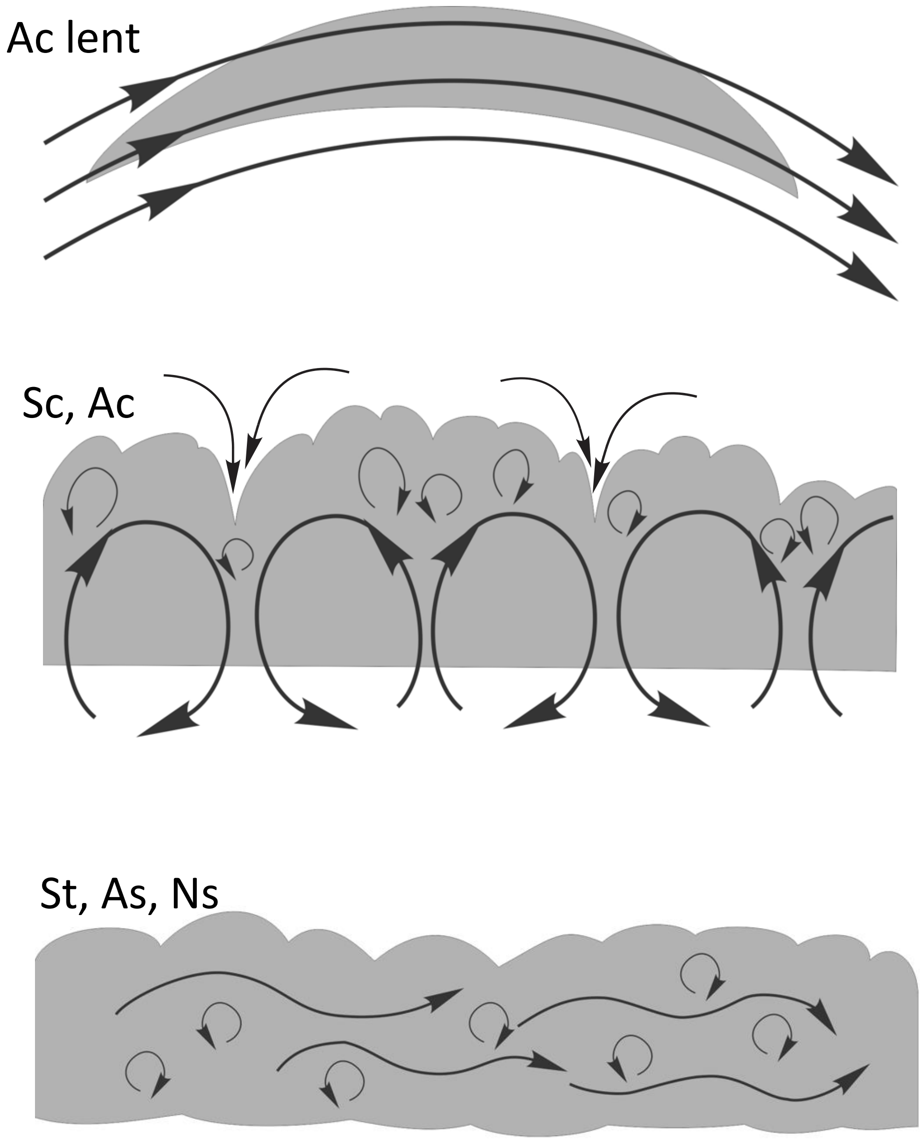


What is the role of dynamics on transport of INPs inside clouds?

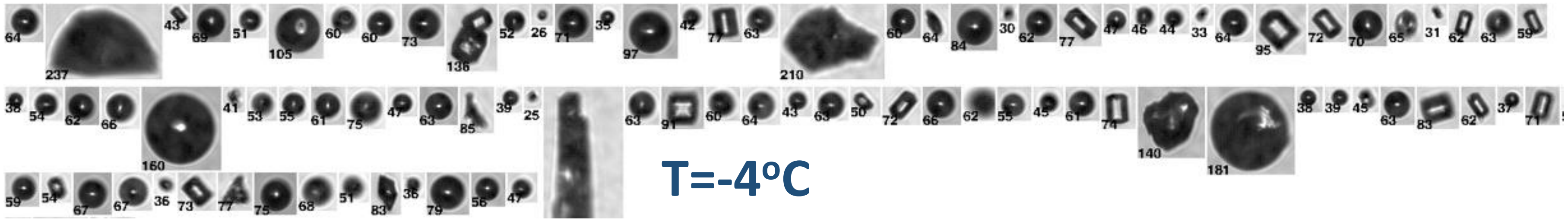
What is the effect of comparative the size of turbulent eddies and cloud depth on washing out INPs by precipitating ice?

Questions:

1. What is the overall significance of PIP and SIP in ice production on a global scale ?

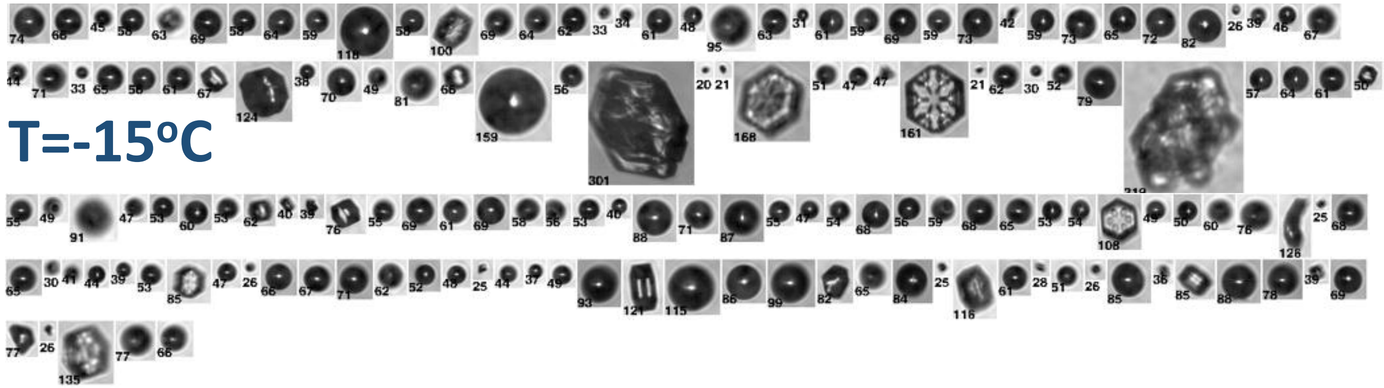
2. Is it possible to adequately simulate ice initiation at the present stage?

3. What is the missing knowledge to move forward?



T=-4°C

Discussion



T=-15°C