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Ice-nucleating Macromolecules from Alpine Forests as Possible Contributors to Cloud Glaciation Processes

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Biological ice-nucleating macromolecules (INMs) allow plants in boreal and alpine areas to cope with harsh low-temperature conditions (Burke et al., 1976, Sakai and Larcher, 1987). These INMs are available at the plant surface and are soluble or suspendable in rain water and thus can be washed off from these surfaces (Pummer et al., 2012).

Laboratory experiments have determined the amount of removable material and have determined chemical nature, molecular weight and sizes of theses INMs (Felgitsch et al., 2018, Pummer et al., 2012, Dreischmeier et al., 2017). We suggest biological ice nucleation to be triggered by proteins, sugars or glycoproteins smaller 100 kDa, that form aggregates which act as ice-nucleating particle.

Field experiments show that rain distributes the INMs into the environment. Rainwater collectors find INMs directly below the trees in concentrations of 10^{11} to 10^{13} per m² of forest, but do not collect INMs when a few meters away from the outermost branches (Seifried et al., 2020 (in prep.), Display: D3133). Aerosol measurements in forests find evidence that there is correlation between humidity and ice nucleation activity and autofluorescence of these aerosols. Both latter characteristics increase by about two orders of magnitude directly after rain events (Huffman et al., 2013, Rathnayake et al., 2017).

Laboratory experiments in a water tank spiked with ice nucleation active pseudomonas syringae show wind-driven droplet production allowing ice nucleation active materials to cross the air-water interface (Pietsch et al., 2018). Measurements with high-speed cameras find evidence for mechanical mechanisms how leaves can pitchfork droplets into the atmosphere (Joung et al., 2017).

Recent measurements with un(wo)manned aerial vehicles (UAV) find first-time evidence for biological materials of different size categories collected directly above canopy of a birch forest next to the alpine timberline ((Bieber et al., 2020), Display: D3134)). Some of these materials were found to be ice nucleation active.

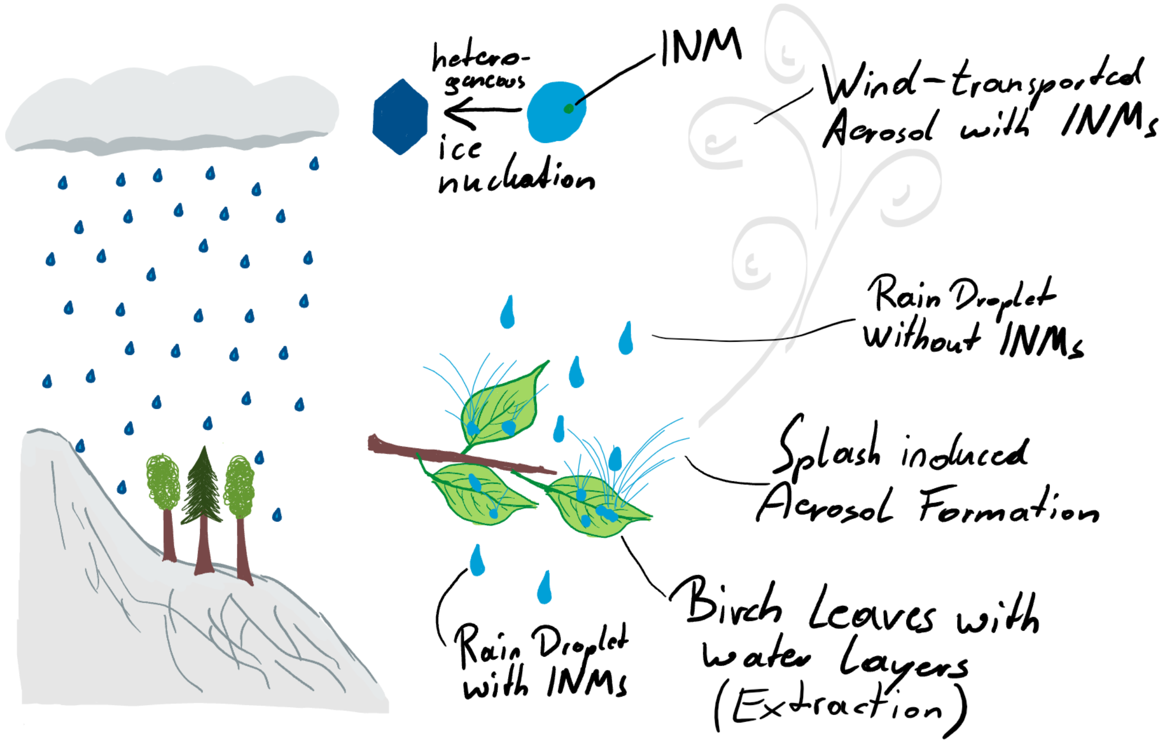

Figure 1: Release and transport phenomena of INMs

Several open questions remain, which we intent to discuss with the scientific community (Figure 1):

a) How do INMs find their way from the plant surface into the aerosol phase?
b) Can these INMs leave the forest and are they detectable above canopy?
c) How stable are INMs against reactive oxygen species of the atmosphere?
d) What distance can INMs be transported form the source?
e) Can INMs reach high altitudes to be active ice nuclei in clouds?

Here we propose some field and laboratory studies which could help to answer some of these questions. We intend to discuss these experiments with the scientific community:

a) In-Chamber rain experiments with birch and pine branches carrying leaves and needles respectively. Sampling of the aerosol and measuring INMs.
b) Studying the interaction between falling droplets and surfaces. How much INMs can be taken up?
c) Finding spectroscopic signatures or trace substances which will allow to set-up trustable analytics in the field searching for INMs of different origins.
d) Developing detectors for in-situ fluorescence detection of INMs which are portable by UAV.
e) Analyzing the surfaces of mineral dust samples from the field with the aim to understand a possible carrier mechanism for INMs.
f) Aerosol chamber experiments investigating the photochemical aging of biological INMs.

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