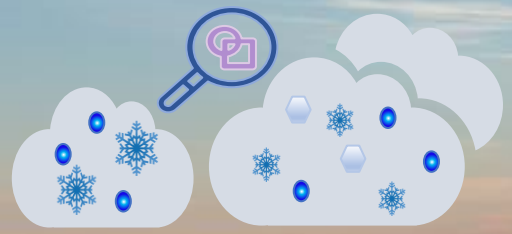
Parameterizing secondary ice production in Arctic mixed-phase clouds



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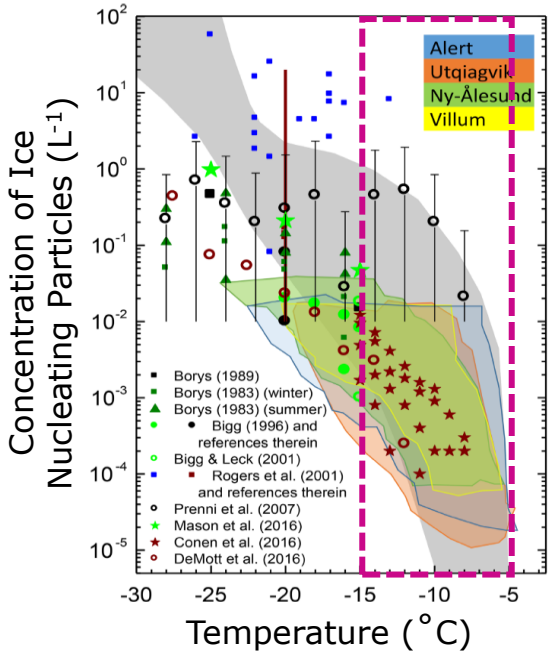
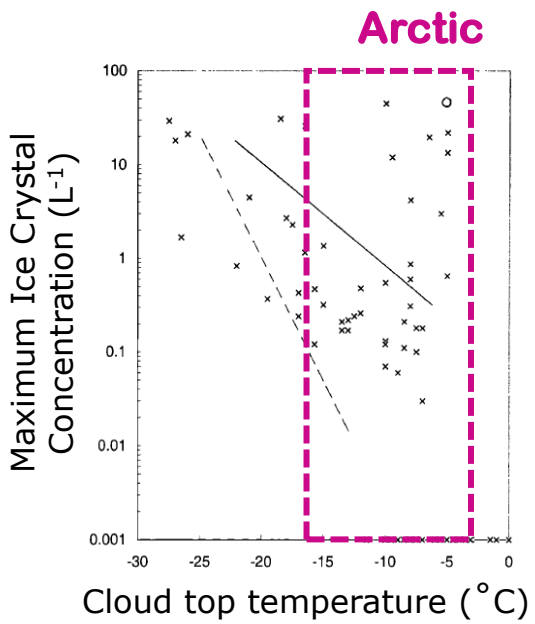
The source of ice crystals observed at polar clouds remains an enigma



(Wex et al., 2019)

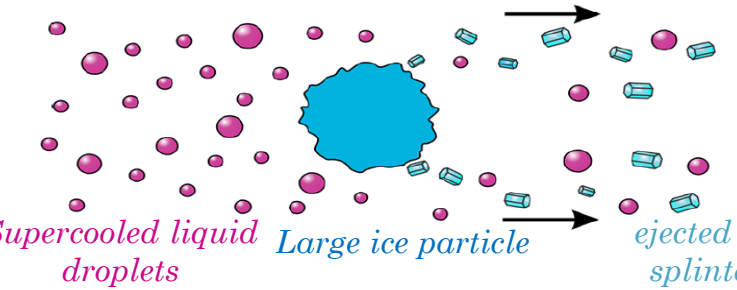


(Rangno and Hobbs, 2001)

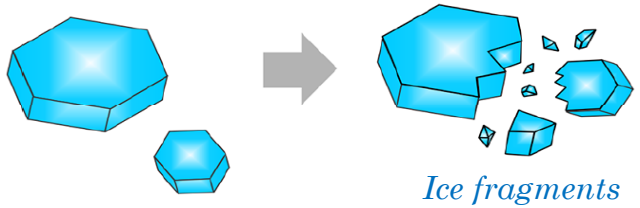
✓ Sparse Ice Nucleating Particles (INPs) in remote polar regions

✓ Secondary Ice Production (SIP) processes can explain the high Ice Crystal Number Concentrations (ICNCs) observed

Rime Splintering (RS) or the Hallett-Mossop process (H-M)



Collisional break-up (BR)



Droplet Shattering (DS) during freezing

The most important SIP processes

Korolev and Leisner, 2020

✓ Need for multiple liquid/ice species and interactions for explicit SIP calculations in models

✓ Global models do not always have this capability

Our approach to parameterize SIP in polar stratiform clouds

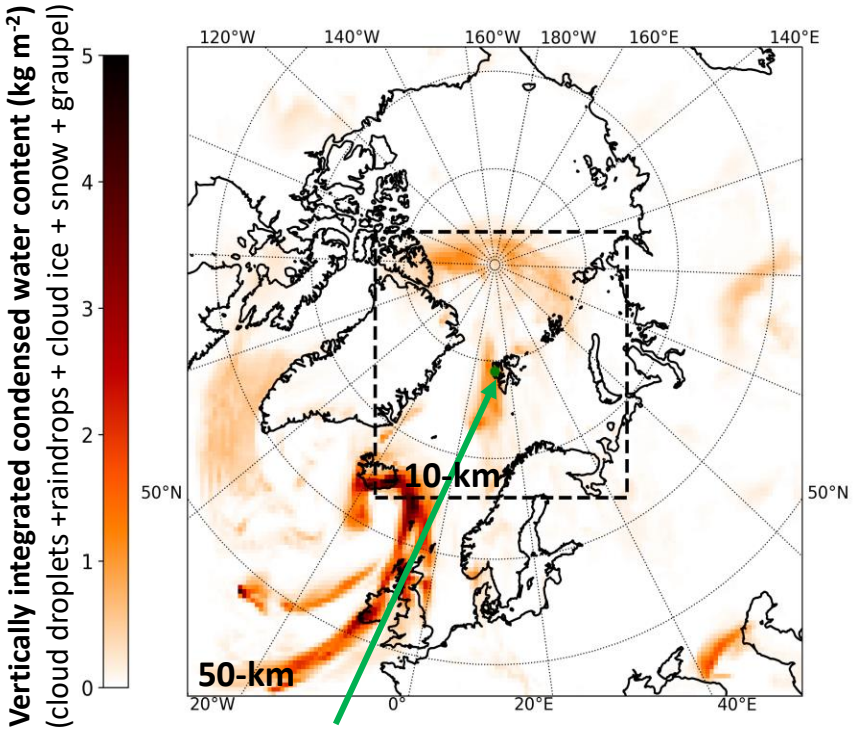
Total ice crystal number = **Primary ice** × **Ice Enhancement Factor (IEF)**

Primary ice production (PIP) described in all kind of models

Parameterized expression developed in this study

Perform "regional climate" simulations with the WRF model

- ✓ Focus on **Arctic mixed-phase clouds**
- ✓ 2-year simulation period: 2016-2017, Ny-Ålesund
- ✓ Ice processes in the updated version of WRF:
  - **i. Primary ice production** → Homogeneous freezing; Heterogeneous freezing
  - **ii.Secondary ice production** → Hallett-Mossop; Collisional break-up *; Droplet shattering **



Georgakaki et al., in preparation

* Phillips et al. (2017); implemented in Sotiropoulou et al. (2021), ** (Phillips et al. 2018; implemented in Georgakaki et al. (2022)

Our approach to parameterize SIP in polar stratiform clouds

Total ice crystal number = **Primary ice** × **Ice Enhancement Factor (IEF)**

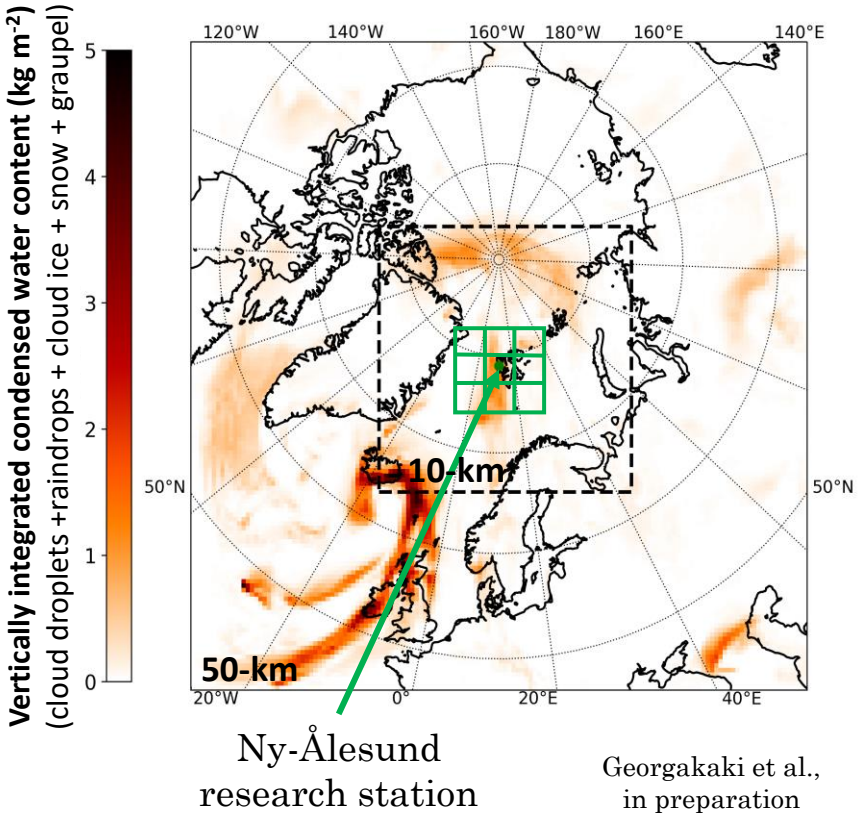
Perform "regional climate" simulations with the WRF model

- ✓ Outputs extracted from the 10 km-resolution (nest)
- ✓ IEF encompasses the effect of all 3 important SIP processes:

$$IEF = IEF_{BR} + IEF_{DS} + IEF_{HM}$$

$$IEF_i = 1 + \frac{SIP_i\ rate}{PIP\ rate}$$

How to parameterize IEF as a function of key meteorological & microphysical variables?



Georgakaki et al., in preparation

Developing SIP parameterization: Random Forest (RaFSIP) regressor

Inputs/ Features

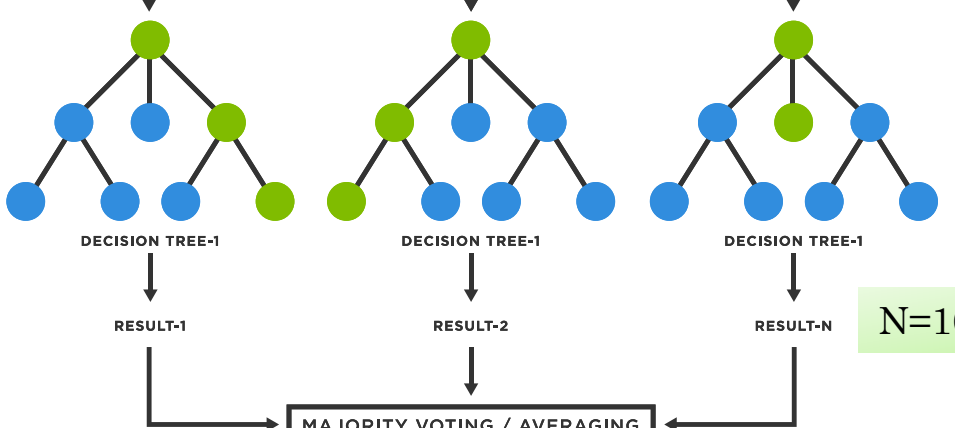
- Liquid water content
- Ice water content
- Temperature
- Relative humidity w.r.t ice (RHI)
- Cloud droplet riming
- Raindrop riming

Developed using the RandomForestRegressor class from the **scikit-learn** package

WRF 2-year high-resolution outputs

90% → Training/validation dataset

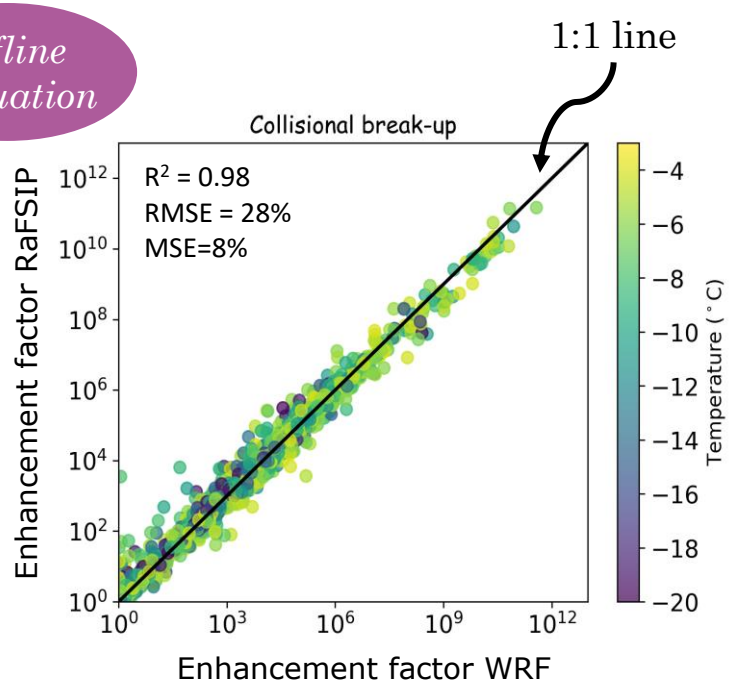
10% → Testing dataset



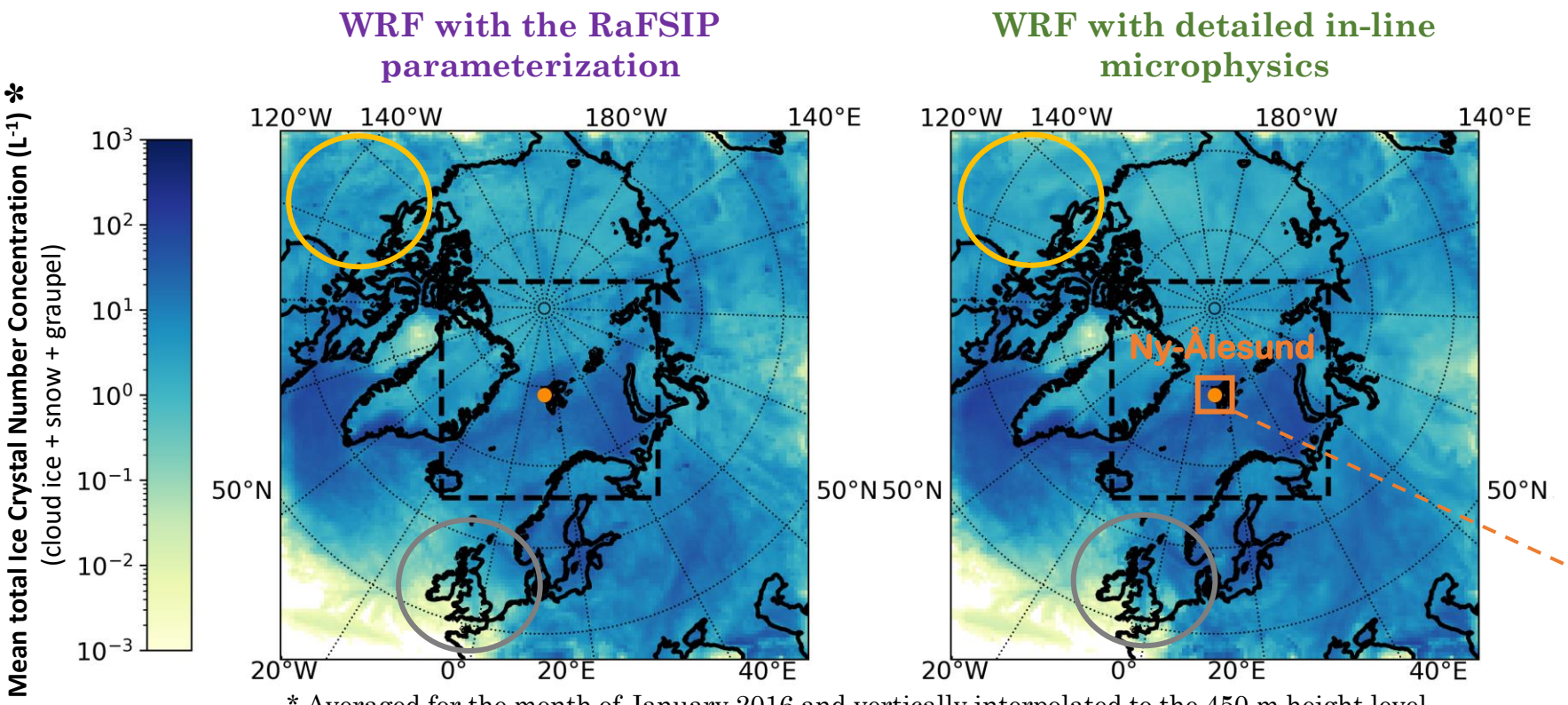
N=10 decision trees

- Enhancement factor due to BR
- Enhancement factor due to DS
- Enhancement factor due to HM
- Mass transferred from liquid droplets to cloud ice
- Mass transferred from raindrops to cloud ice

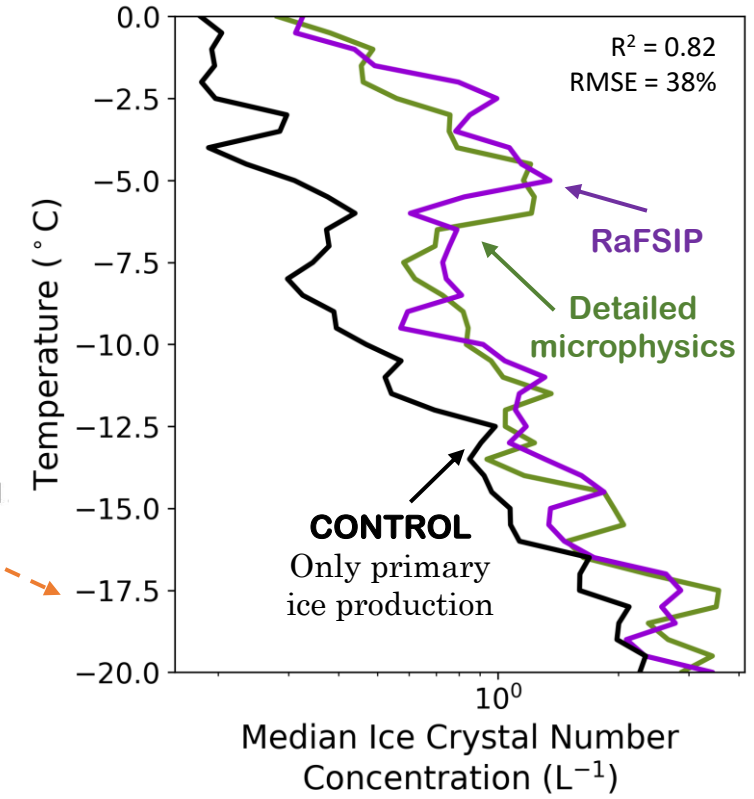
Offline evaluation



Online performance of the new RaFSIP parameterization



* Averaged for the month of January 2016 and vertically interpolated to the 450 m height level



✓ Overall, the main ICNC pattern is sufficiently well-reproduced

Georgakaki et al., in preparation

Take-home message

The ice enhancement factor is a robust way to parameterize SIP in mixed-phase clouds→ easy implementation in atmospheric models that do not have detailed microphysics or spatial resolution to support explicit treatment of SIP

Thank you for your attention!

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