1 Introduction

Background:
- Understanding the ice formation pathways in mixed-phase clouds remains crucial for climate models.
- Heterogeneous ice formation (≥ 38 °C) relies on ice nucleating particles (INPs).
- Organic aerosols are ubiquitous and a source of INPs, but their complexity hinders detailed IN activity (INA) characterizations.
- The biopolymer lignin is a subcomponent of organic aerosols and serves as proxy for organic matter.

Research Questions:
- What is lignin’s ability to act as an ice nucleating particle in mixed-phase clouds?
- What are the effects of...
  - A. typical IN laboratory treatments
  - B. atmospheric processing
    - on lignin’s INA?

2 Methods – Ice Nucleation Setup

Freezing Ice Nuclei Counter (FINC) (Müller et al., 2020)

- 288 freezing events per experiment
- Visualization methods:
  1. Frozen Fraction (FF) vs Freezing Temp. (FrzT)
  2. n_{INA} normalization to carbon content
  3. biopolymers: mean 260-750 μl

3 Lignin’s Ice Nucleating Ability

Lignin’s INA is relevant for mixed-phase clouds, but lower than INA of complex dissolved organic matter (DOM)

- n_{INA} range from 1 to 10^4 INPs/mg C (–7 °C to –26 °C)
- 50% FF at –18.7 °C for 200 mg C/L
- Relative INA with – concentration, – interactions with water

4 Laboratory Treatments

1. Sonication:
   - No change in INA
   - Extraction tool for particulates on aerosol filters, radical reactions may affect chemical structure (Miljevic et al., 2014)

2. Heating:
   - INA decrease
   - Volatilization of organic material by pyrolysis
   - Experiment: heating of lignin as powder, then H₂O addition to 200 mg C/L
   - INA with Heating T, FrzT of H₂O reached after heating to 260 °C
   - Relative INA after removal of insoluble fraction, as mass loss

3. H₂O₂:
   - INA decrease
   - Oxidative removal of organic material
   - Experiment: reactions with varying ratios of mL H₂O₂ (35 w%) : g lignin, then dilution with H₂O to 200 mg C/L
   - INA with ratio of H₂O₂ to lignin, FrzT of background with H₂O reached after ratio 400:1

5 Atmospheric Processing

1. Ozonation:
   - No change in INA
   - Experiment: bubbling of 0.1 L/min O₃ (100 ppb – 1 ppm) through bulk solution of 20 mg C/L up to 6.5 h

2. Photochemistry:
   - Minimal INA decrease
   - Experiment: up to 25 h (6.5 days atmospheric equivalent) of UVB irradiation on 20 mg C/L solution
   - Small – trend in lignin’s INA through photochemistry, however less than observed for complex DOM (Borduas et al., ACP, 2019)
   - Max. – 1 °C decrease at 50% FF after 22 h compared to 0 h

Measurement of UV/Vis spectra (200 – 400 nm)

- Absorbance after exposure to ozone or UVB irradiation
- Decay of chromophoric components in lignin’s structure
- The INA activity is mostly retained despite this decay, so these chromophores are not decisive for the biopolymer’s INA

6 Conclusions

Lignin’s INA ability:
1. is relevant for mixed-phase clouds
2. is robust and lasts the aerosols’ lifetime
3. is minimal change through atmospheric processing (exposed to up to 1 ppm O₃, up to 25 h of UVB light with an atmospheric equivalent of 6.5 days sunlight)
4. is retained after structural changes in the biopolymer’s chromophoric structure

References:

- A. Müller, K. Brennan, C. Miljevic, J. Wieder, A. Zepolt, and Nadine Borduas-Dedekind, 2020, manuscript in preparation