Aerosol standards for ice nucleating particle measurement methods – a preliminary set of thoughts

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Understand – the growing IN community has been very introspective on the topic of measurement comparability and is ready to embrace viable standards

- Upwards of 45 groups active in U.S. (16) and in Europe alone
- Many inter-comparisons, formally and informally in last several years
- Many data published for comparison for available materials,
  - General ability to test "activation temperature range" by one mechanism.
  - Less ability to produce conditions to establish active number per volume (air or water)
  - Some materials are labile in time or for certain means of aerosolization
- Recent exercises demonstrate that better protocols may need to be establishing in addition to distributing common samples for calibration
- Focused intercomparisons in one place offer the best chances of success
- Nano-IN and macromolecular standards may be possible (ideas welcome)
- For single measurement methods such as immersion freezing, protocols could be as important as the standard.

Calibration standards should perhaps represent some of the major categories of ice nucleating particles (INPs)

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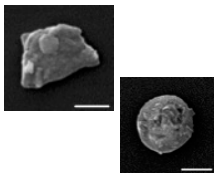
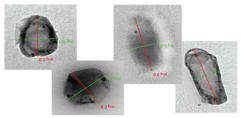
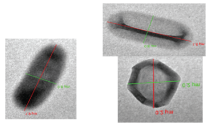
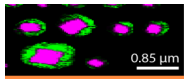


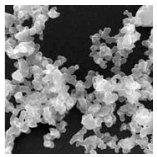




- Mineral dust
- Arable dust
- Biological INPs
- Marine INPs (from sea spray)



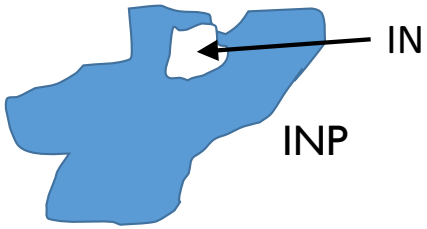
- Anthropogenic (soot, secondary organics) – most relevant to cirrus temperatures and will not be addressed here



Some sources within categories are unknown as yet, and complex

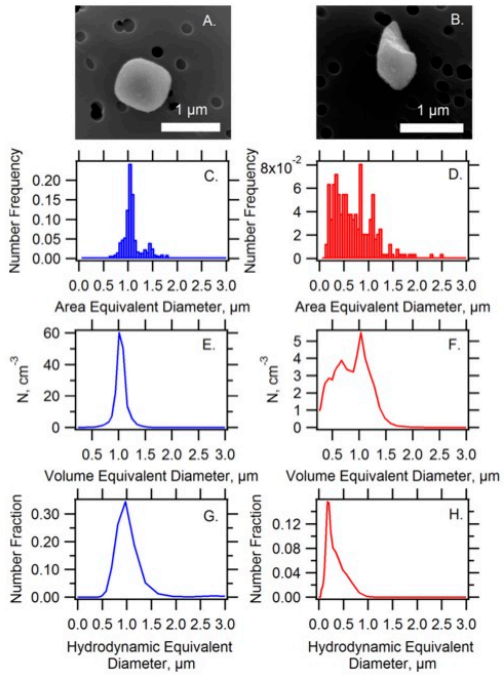
Complicating factors

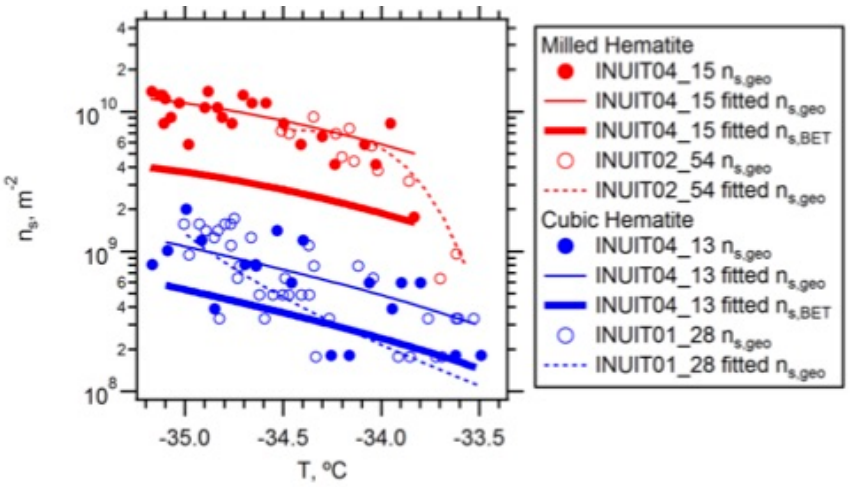
- Size range: 20 nm to 5 microns, although as individual particles that are INPs, sizes most likely to be larger than 100 nm
  - Macromolecular IN such as birch pollen washing water
  - Sea spray aerosol as INPs may contain elements this small



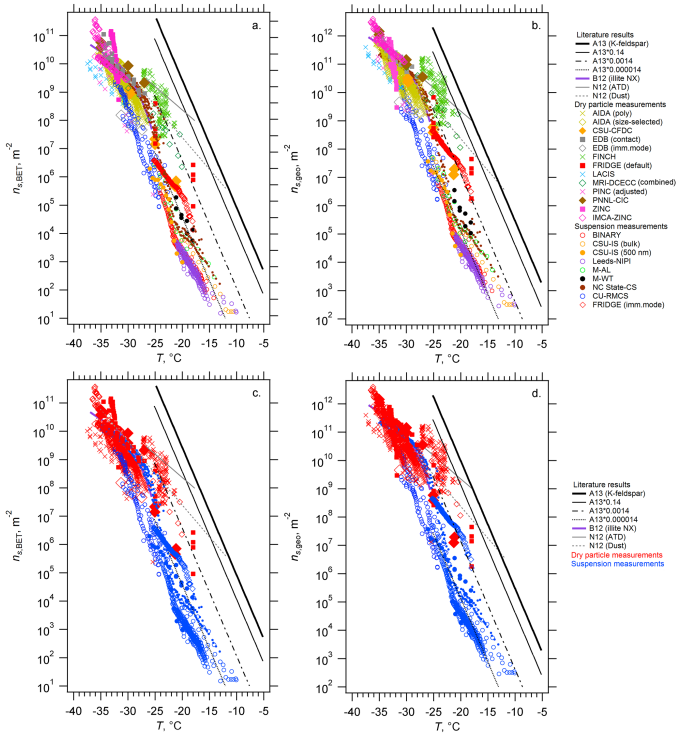
- Hydrophobic versus hygroscopic
- Varied nucleation mechanisms
  - "deposition" nucleation which may really be pore condensation freezing
  - immersion freezing
- Methods that include real-time measurements of particles in air versus bulk particles in water (standards for each type)

Hiranuma (2014) hematite – even particles uniform in appearance are not always unique for ice nucleation (possible role of surface active sites)





Hiranuma et al. (2015) illite NX: consistency in some regards, but not in others - sharing samples broadly does not always work well



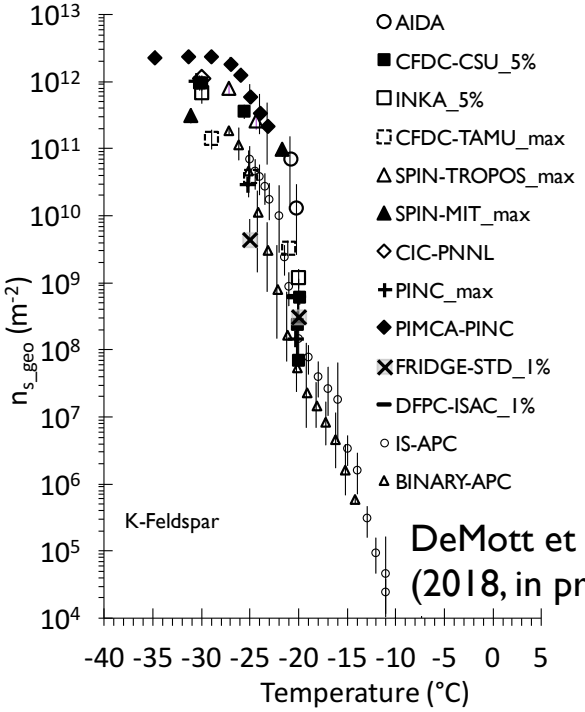
Particles in air

Particles in water suspensions

Differences between methods in water versus in air still a topic of great interest.

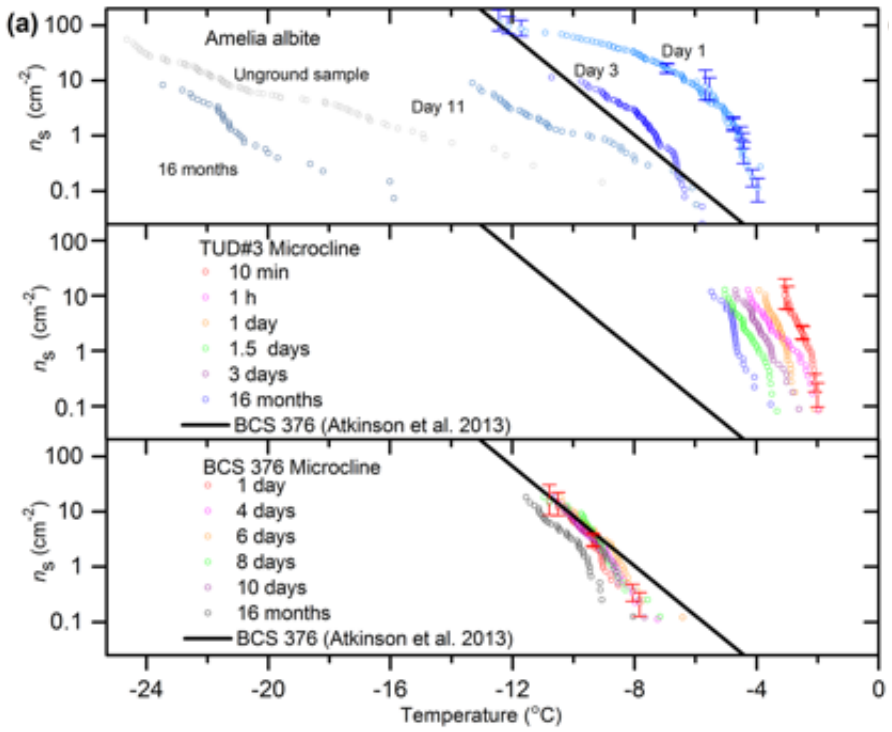
Various feldspars, though some have issues with ion-etching in water

Steep activity curve with temperature, so can specify a temperature "range" < -20 ° C and maximizing below -25 ° C



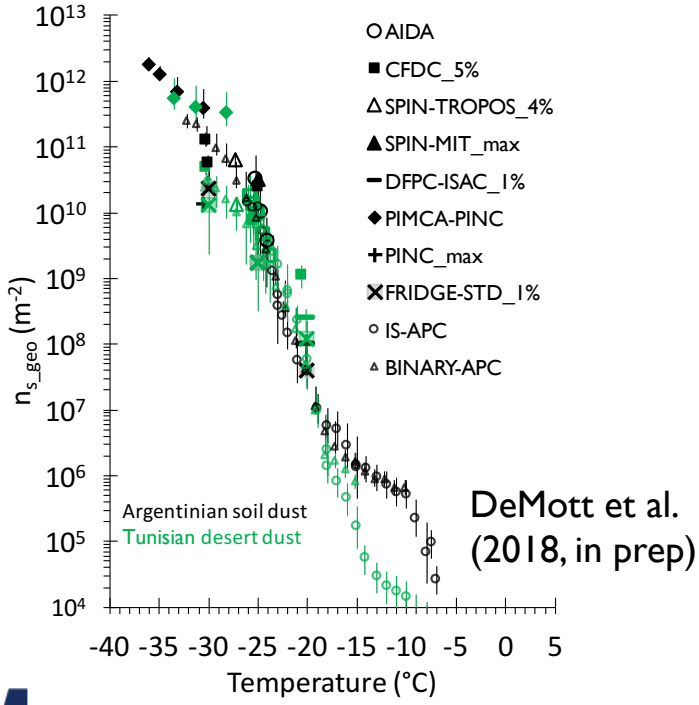
DeMott et al. (2018, in prep)

Harrison et al. (2016)



Also suitable standards for arable dusts?

Excellent correspondence in sampling at one site, but same issue as for Feldspar (no "activation temperature")



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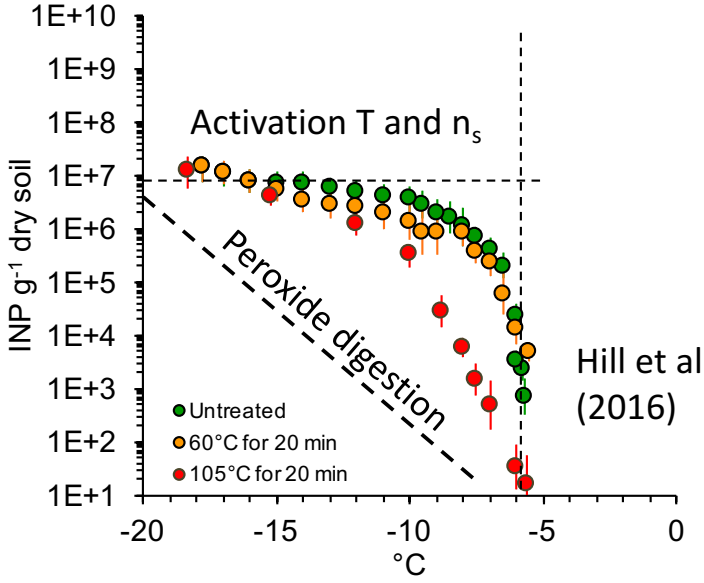
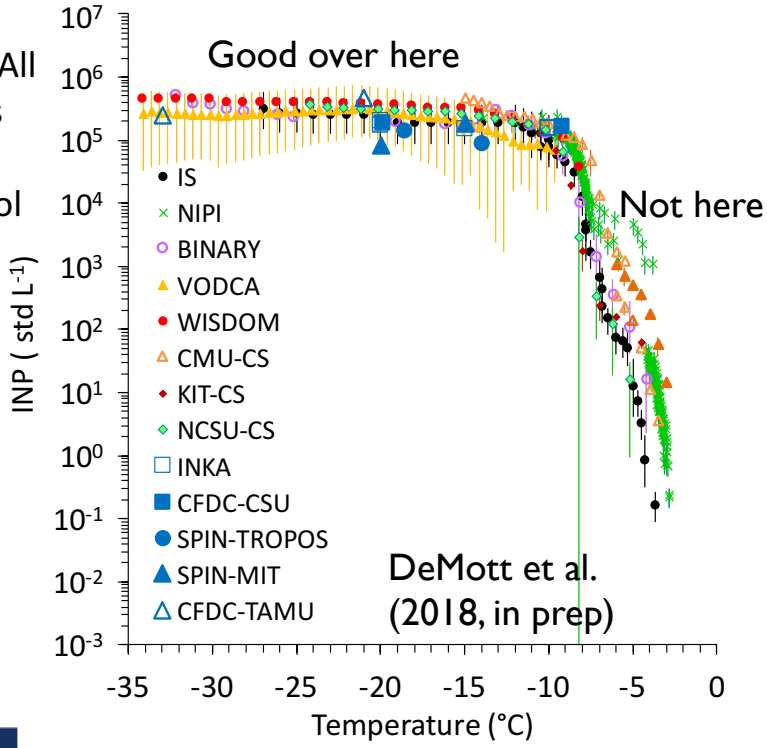
Some bulk soils dominated by highly organic INPs – similar to IN_bacteria and likely related to fungal content



Hill et al. (2016)

Biological particle standards (Snomax - P. syringae) – okay if take care of range of stability, shelf life

Fifth Ice Nucleation workshop: All instruments sample the same aerosol



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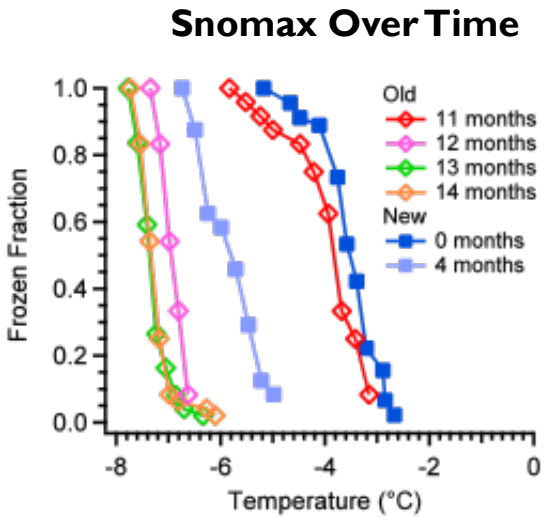
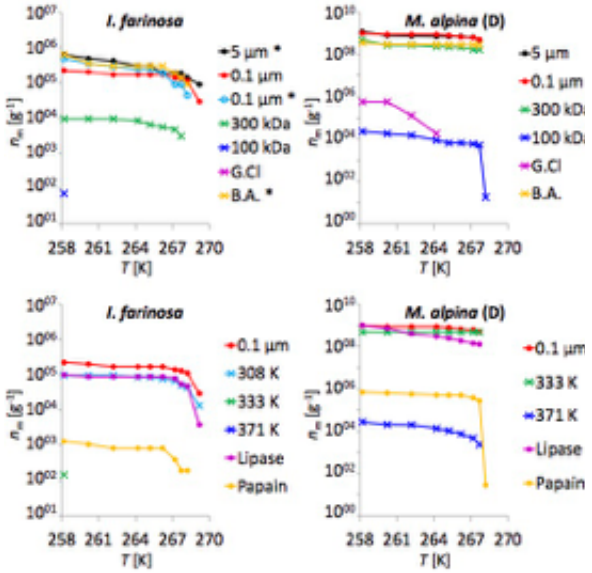


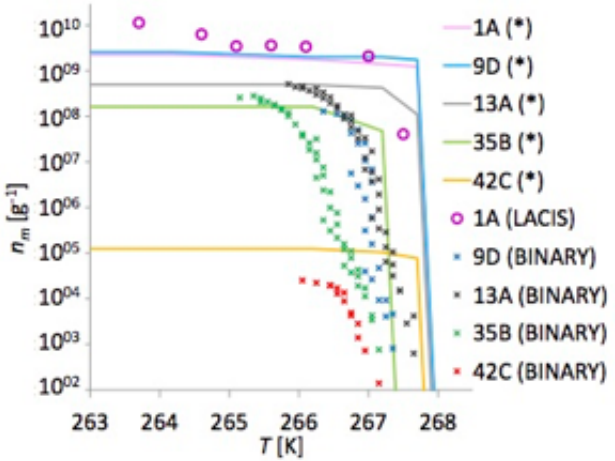
Polen, Sullivan, et al., JGR, 2016

Macromolecular IN from pollen, fungi: promising for immersion freezing studies?

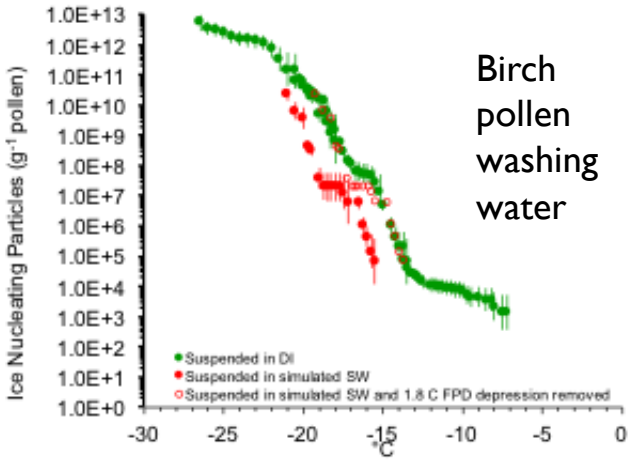
Fungi with range of activities



Three methods for assessment tested



Hill, unpublished 2018



Birch pollen washing water

Pummer et al. (2015, ACP)

Better INP Standards (Ryan Sullivan)

- Engineered nanoparticles from inert metal oxides or carbon nanomaterials may be ideal INP standards
- Need to control and characterize particle size distribution, surface area-to-mass ratio, surface properties, and pore sizes
- Tuning pore size could be effective way to produce INP standards for calibration in different freezing temperature ranges (Marcolli and others)
- Engineered nanoparticles as INP: Bai, PNAS, 2006; Alstadt, JPCA, 2017; Whale, Phys. Chem. Lett., 2015;

Summary and conclusions

- Some ice nucleation particle "standards" already exist, especially for use in immersion freezing methods
  - Minerals or bulk dusts
  - Bacterial and fungal units in water or sprayed and dried in air
- Few are ideal, so depends on what one is trying to test
- Some are too labile in their behaviors after storage or after time in water
- Could use work on highly refined standards
- Need to learn a lot more about molecular controls on ice nucleation simply to specify appropriate standards