Literature list accompanying presentation by Heike Wex et al., on

<u>Ice nucleating particles (INP) in the atmosphere</u>

Held online on March 16 2022,

as part of the Virtual lecture series-Cloud and Precipitation Physics and Dynamics.

First, citations from the oral presentations are given. Below, starting on page 7, are citations touched upon during the discussion.

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Additional details related to the discussion:

1) A paper discussing the influence of INP from the surface on Arctic clouds: “above -10°C, heterogeneous ice formation in Arctic mixed-phase clouds occurs by a factor of 2–6 more often when the cloud layer is coupled to the surface.”

Griesche, H. J., K. Ohneiser, P. Seifert, M. Radenz, R. Engelmann, and A. Ansmann (2021), Contrasting ice formation in Arctic clouds: surface-coupled vs. surface-decoupled clouds, Atmos. Chem. Phys., 21(13), 10357-10374, doi:10.5194/acp-21-10357-2021.

2) Addition of ammonium sulfate to mineral dust suspensions increased the ice activity:

Worthy, S. E., A. Kumar, Y. Xi, J. W. Yun, J. Chen, C. S. Xu, V. E. Irish, P. Amato, and A. K. Bertram (2021), The effect of (NH4)(2)SO4 on the freezing properties of non-mineral dust ice-nucleating substances of atmospheric relevance, Atmos. Chem. Phys., 21(19), 14631-14648, doi:10.5194/acp-21-14631-2021.

3) Model studies showing that wildfire activity can create sufficient aerodynamic conditions to lift also soil/dust particles during the combustion process:

Wagner, R., Jähn, M., & Schepanski, K. (2018). Wildfires as a source of airborne mineral dust–revisiting a conceptual model using large-eddy simulation (LES). Atmospheric Chemistry and Physics, 18(16), 11863-11884.

Wagner, R., Schepanski, K., & Klose, M. (2021). The Dust Emission Potential of Agricultural-Like Fires—Theoretical Estimates From Two Conceptually Different Dust Emission Parameterizations. Journal of Geophysical Research: Atmospheres, 126(18), e2020JD034355.

4) Indirect, spaceborne evidence that ice-nucleating particles influence clouds was given in an INP colloquium at ETH, and while the presentation-slides are not available online, it seems one can request a preprint of a paper for that topic here:

https://www.researchgate.net/publication/358159002_Spaceborne_evidence_that_ice-nucleating_particles_influence_cloud_phase

5) There is a monthly ETH-INP colloquium: https://iac.ethz.ch/group/atmospheric-physics/research/ice-nucleation-colloquium.html

For some past presentations, the slides are available there, and you can be added to the mailing list to get information about the monthly presentations.

7) If you want to get the monthly summary on new INP literature from Naruki Hiranuma, e-mail him:

nhiranuma@wtamu.edu

8) Thara sent me a few more publications on ice activity of soot. And even more can be found in the abovementioned review paper by Kanji et al. (2017), Fig. 1.7 (I, Heike, made that one 😉.)

After having had a look at these additional papers, in general, the argument I made during the presentation would not change, that anthropogenic pollution does not contribute INP for immersion mode in the mixed-cloud temperature regime. Below are these publications together with some remarks, mainly taken from their abstracts:

Laboratory studies which found no ice activity in soot samples:

https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2017JD027831 (Vergada-Temprado et al., 2018)
They present new experimental results for immersion mode ice nucleation by BC from two contrasting fuels (n-decane and eugenol), and observe no significant heterogeneous nucleation by either sample. They show that BC contributes at least several orders of magnitude less INP than feldspar and marine organic aerosol.

https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019GL086764 (Kanji et al., 2020)
Fossil fuel soot and commercially available hydrocarbon BC is inactive as immersion freezing nuclei for atmospherically relevant particle sizes and surface areas. Instead, temperatures <235 K are necessary for freezing droplets with immersed soot particles, implying homogeneous freezing, rather than immersion freezing by soot.

https://www.mdpi.com/2073-4433/12/9/1173/htm (Falk et al., 2021)
Laboratory study using miniCAST soot generator and measured with a CFDC (-41°C to -32°C, 10% RHw). All samples exhibited low to no heterogeneous immersion freezing. They conclude that it does not appear possible in general and in any straightforward way to link observed soot particle physico-chemical properties to the ice-nucleating ability using the online instrumentation included in this study.

Laboratory study which found ice activity in biomass burning samples, for measurements at roughly < -20°C:

https://www.science.org/doi/pdf/10.1126/sciadv.abd3440 (Jahl et al., 2021)
Aerosol from burning grass, needles and wood-logs: examined altering of ice activity of biomass-burning smoke using simulated atmospheric aging in a chamber reactor, sampled particles on filters and measured INP (roughly below -20°C) with a microfluidic device. Depending on type of aging, increase of ice activity by roughly 1 order of magnitude (decrease for dark ozonolysis).

Laboratory study using deposition mode ice nucleation - they indeed observed ice activity, which may be interesting in the light of Marcolli (2014) and related newer studies (pore condensation and freezing):

https://pubs.acs.org/doi/abs/10.1021/acs.jpcc.9b08715 (Ikhenazene et al., 2020)
Measured deposition ice nucleation activity of graphite flakes and aircraft soot analogues, in the −15 to −45 °C temperature range. All carbon-bearing samples were found to be active at nucleating ice at low ice saturation ratios.

Laboratory studies examining the cirrus cloud regime:

https://pubs.rsc.org/en/content/articlehtml/2020/em/c9em00525k (Mahrt et al., 2020)
They sampled two propane flame soots referred to as brown and black soot, characterized as organic carbon rich and poor, respectively and investigated how the ice nucleation activity of these particles changed through aging in water and aqueous acidic solutions, using a continuous flow diffusion chamber operated at cirrus cloud temperatures (T <= 233 K).

https://acp.copernicus.org/articles/19/12175/2019/ (Nichman et al., 2019)
They examined ice nucleation on BC particles under water subsaturated cirrus cloud conditions.

Atmospheric study on biomass burning aerosol, finding INP contribution. In that respect, fire induced lofting of dust may be interesting to look at (see Wagner et al. (2018, 2021), cited above):

https://www.pnas.org/doi/10.1073/pnas.2001674117 (Schill et al., 2020)
Measured the contribution of BC to INP concentrations ([INP]) in real-world prescribed burns and wildfires. They found that BC contributes, at most, 10% to [INP] during these burns.

Atmospheric deposition mode ice nucleation:

https://www.sciencedirect.com/science/article/pii/S0169809514002610?via%3Dihub (Patade et al., 2014)
Deposition mode measurements from aircraft during CAIPEEX with a thermal gradient diffusion chamber.

Laboratory study on CCN:

https://acp.copernicus.org/articles/19/15545/2019/acp-19-15545-2019.pdf (Friebel et al., 2019)
miniCAST soot generator; examine particles acting as cloud condensation nuclei (CCN) after exposure to atmospherically relevant levels of ozone (O3) and humidity.