Project Title: International Workshop on Comparing Ice Nucleation Measuring Systems 2014 FINAL REPORT
PI: Daniel Cziczo
Awardee: Massachusetts Institute of Technology
Award Number: DE-SC0014487
Award Ends: 4/30/2016 *Note extension due to supplement
Program Officer Name: Ashley Williamson
Program Officer Email Address: Ashley.Williamson@science.doe.gov

Project Final Report

The relationship of ambient aerosol particles to the formation of ice-containing clouds is one of the largest uncertainties in understanding the Earth's climate. The uncertainty is due to several poorly understood processes and measurements including, but not limited to: (1) the microphysics of how particles nucleate ice, (2) the number of ice forming particles as a function of atmospheric properties such as temperature and relative humidity, (3) the atmospheric distribution of ice forming particles and (4) the role of anthropogenic activities in producing or changing the behavior of ice forming particles. The ways in which ice forming particles can impact climate is also multi-faceted. More ice forming particles can lead to clouds with more ice crystals and different optical properties than clouds with less ice forming particles. More effective ice forming particles can lead to ice at higher temperature and/or lower saturation, resulting in clouds at lower altitude or latitude which also changes the Earth's radiative balance. Ice nucleation also initiates most of the Earth's precipitation, even in the mid- and low-latitudes, since cloud-top temperatures are often below freezing. The limited measurements and lack of understanding directly translates to restrictions in our ability to model atmospheric ice formation and project changes into the future. The importance of ice nucleation research is further exemplified by Figure 1 which shows the publications per decade and citations per year on the topic of ice nucleation [DeMott et al., 2011]. After a lull at the end of the last century, there has been a dramatic increase in both publications and citations related to ice nucleation; this directly corresponds to the importance of ice nucleation on the Earth's climate and the uncertainty in this area noted by the Solomon [2007].

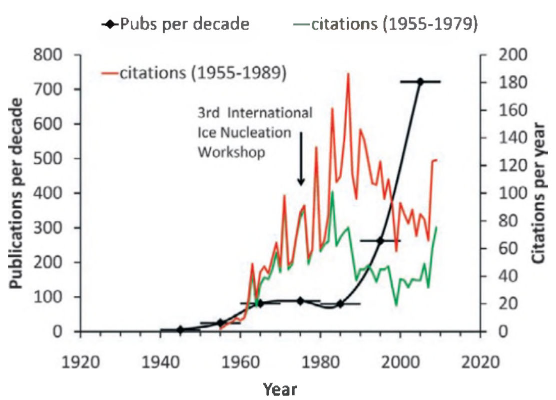

Figure 1. Web of Knowledge (Thomson Reuters) publications per decade and citations related to the terms "ice nuclei," "ice nucleation," "freezing nuclei," "sublimation nuclei," and "deposition nuclei" that are filtered for atmospheric-related studies from 1950–79 and 1950–89, demonstrating the 1970s–80s research lull and the interest in early publications that have recently begun to surge. Reproduced from DeMott et al. [2011].

The purpose of the funded workshop was to answer these questions by co-locating the world's leading groups currently addressing the formation of ice in atmospheric clouds. Those groups then undertook a course of research to determine if our current technology is in agreement and where disagreements lie. When disagreements occur, the workshop attempted to determine solutions that would lead to better future measurements.

Activities Conducted

This DOE Grant, along with a grant from NSF, funded three distinct workshops on the topic of atmospheric ice nucleation. The first activity, that addressed by this grant, was an intercomparison of instruments to determine the composition of ice forming particles in a controlled laboratory setting. This took place in fall, 2014 in the location of the last ice nucleation instrument intercomparison: the Aerosol Interaction and Dynamics in the Atmosphere (AIDA) chamber located at the Karlsruhe Institute of Technology (KIT; see http://www.imk-aaf.kit.edu/73.php). AIDA is the world's foremost facility for ice nucleation research and offered unequalled facilities for the intercomparison [Moehler et al., 2006].

The second activity, which took place in spring, 2015, was an intercomparison of instruments used to determine cloud formation conditions. This activity also took place at AIDA. Both workshops leveraged the ability to use the AIDA chamber as 'truth' where known particles and conditions could be sampled from all instruments. Thus, real 'apples to apples' comparisons were possible in a manner not possible at any other facility that we are aware of.

The third activity was conducted in fall, 2015. Because ice nucleation predominantly takes place at the low temperatures found at high altitude a critical requirement for the third workshop was a facility that offers access to free tropospheric airmasses with minimal local particle sources. We used the Desert Research Institute's recently renovated Storm Peak Laboratory (SPL; see http://stormpeak.dri.edu/) located in north-central Colorado. The SPL renovation was under a grant from NSF and we highlight our ability to leverage this recent expenditure from NSF for the benefit of this workshops We conducted the third workshop for two reasons: (1) many important IN measurements take place not in the laboratory but in the field, e.g. the determination of ambient IN concentration and composition and (2) the low number density of atmospheric IN offers measurement challenges that are not encountered in the laboratory where arbitrarily large particle concentrations can be produced.

We note that the date of this final report was due to a supplement for the third activity (August, 2016).

Impact

A three-part international workshop was completed in full and improved our understanding of atmospheric ice formation. The first activity addressed the characterization of ice nucleating particle size, number and chemical composition by co-locating groups performing mass spectrometry in the laboratory and field. This activity The intellectual merit of the first activity was a comparison of state-of-the-art instruments for characterizing ice forming aerosol and result in an ability to compare past and future data between them. The second activity addressed the determination of ice nucleating particle number density by co-locating international groups making these measurements. This activity also take place at AIDA which will serve as a reference point and source of particles. Groups modeling ice nucleation joined the second activity and provided insight on measurements critically needed to model atmospheric ice nucleation. The performance of the ice chambers intercompared was also modeled. The third activity took place at the Desert Research Institute's Storm Peak Laboratory. As a result of the third activity the performance of instruments in the field has now been quantified and compared.

Results

Three distinct results of the grant are noteworthy. First, the goal of this proposal was to bring together international groups making ice measurements that have not been able to intercompare instruments and this was successfully completed. Graduate students and post doctoral fellows from the groups were involved in all three activities.

Second, we partnered with "Science for the Public", a WGBH television and multimedia production, to document and disseminate the results of this workshop. This video, documenting the first and second activities, was successfully completed and can be viewed here :

http://www.scienceforthepublic.org/speakers-guests/meet-dan-cziczo-phd/

Third, we have already disseminated results to the broader atmospheric sciences community. The workshop organizers, Dan Cziczo, Paul DeMott and Ottmar Moehler have now completed invited presentations at the 2015 Fall AGU (2 presentations) and 2016 AMS Annual Meeting (2 presentations), EGU (3 presentations), ICCP (4 presentations) and EAC (3 presentations). Further presentations on the workshops are scheduled at the 2016 AGU Meeting. We have organized a special issue to present workshop results in Atmospheric Chemistry and Physics and anticipate first submissions in fall, 2016.

Final Participant List

Here we provide a list of participants. Note that 1 corresponds to the AIDA mass spectrometer workshop, 2 the AIDA cloud chamber workshop and 3 the SPL workshop.

USA
1. P. DeMott, CSU 1,3
2. D. Cziczo, MIT 1,2,3
3. G. Kulkarni, PNNL 2 (Directly DOE funded)
4. M. Petters, N.C. State 2,3
5. S. Brooks, Texas A&M 2,3
6. K. Prather, UCSD 1
7. D. Murphy / K. Froyd, NOAA 1,3 (unfunded)
8. A. Zelenyuk, PNNL 1 (Directly DOE funded)

Germany
1. O. Moehler, AIDA / KIT 1,2 (German funding)
2. J. Curtius, H. Bingemer. Frankfurt 1,3 (German funding)
3. F. Stratmann, Leipzig 2 (German funding)
4. M. Ebert, Darmstadt 1 (German funding)
5. J. Schneider, MPI 1 (German funding)

Canada
1. J. Abbatt, Toronto 3 (Canadian funding)

UK
1. H. Coe, Manchester 1 (UK funding)
2. B. Murray, Leeds 2 (UK funding)

Switzerland
1. U. Lohmann, ETH-Zurich 1,2 (Swiss funding)

Austria
1. A. Wonaschutz, Vienna 1 (Austrian funding)

References

DeMott, P. J., et al., Resurgence in ice nuclei measurement research, *Bull. Amer. Meteor. Soc.*, **92**, 1623-1635, doi:10.1175/2011BAMS3119.1 (2011).

Moehler, O., et al., Efficiency of the deposition mode ice nucleation on mineral dust particles, *Atmos. Chem. Phys.*, **6**, 3007-3017 (2006).

Solomon, S. Ed., *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, (Cambridge Univ. Press, Cambridge, 2007.