Measuring the elusive particles that form ice in clouds

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This PhD is part supported by the CASE partner, Bilfinger Noell GmbH.

Project Summary

A cloud growing out of a very dusty lower atmosphere. This aerosol contains ice-nucleating particles that cause some cloud droplets to freeze. But our capacity to measure the concentration of ice nucleating particles is very limited.

The formation of ice in clouds is one of the least well understood aspects of the planet's climate system. Special aerosol particles, known as ice-nucleating particles, are needed to trigger ice formation but their sources, characteristics and distribution around the globe are very poorly defined. Once ice crystals form, there can be a cascade of processes leading to changes in precipitation, cirrus cloud coverage and cloud reflectivity. All of these changes are important for climate change. A major limitation in this field is the lack of instrumentation which can be used to measure INP concentrations on a semi-autonomous basis. In this project you will play a direct role in breaking this deadlock and revolutionising the field.

As part of a collaboration between Leeds, Karlsruhe Institute of Technology (KIT) and Bilfinger Noell GmbH, a new concept instrument for quantifying atmospheric ice nucleating particles has been developed. This new instrument, the **P**ortable expansion chamber for **I**ce **N**ucleating particles m**E**asurement (PINE), has been developed to work at conditions relevant for mixed-phase cloud conditions and is in the process of commercialization.

The aim of this PhD project is expand the use of the PINE chamber to temperatures and conditions relevant for cirrus clouds. This will involve taking a working instrument and adapting it for use at lower temperatures.

The project will involve working closely with the CASE partner (Bilfinger Noell GmbH) as well as Karlsruhe Institute of Technology. It will largely be a lab based project involving extended visits to Germany. Hence, it offers a fantastic opportunity to work in both academic and industrial settings in different countries. The experience gained will place you in an enviable position for future employment in either the industrial or academic sectors.

Objectives

The project will involve:

i) **Adapting the PINE chamber to operate at cirrus relevant temperatures below water saturation**. This will involve first learning how to use the instrument in its current configuration in Leeds before adapting it to work at lower temperatures and cirrus conditions. You will work closely with Dr Boffo at Bilfinger Noel to adapt the chamber for use at low temperatures. You will then work at Karlsruhe institute of technology where you will use the well-established AIDA cloud simulation chamber to calibrate the production of ice crystals in the PINE chamber below water saturation.

ii) Studying the effects of aging of dust aerosol under conditions relevant for cirrus in a set of laboratory experiments. This will be conducted in Leeds where aerosol will be generated in a chamber, processed in a controlled way to mimic atmospheric aging, and then sampled into the PINE chamber.

iii) Conducting some of the first long-term measurements of INP under cirrus conditions in the atmosphere. We are just starting to produce the first long-term (months long) datasets for INP concentrations relevant for mixed-phase clouds. You will make what might be the first ever long term measurements under cirrus conditions. For this, you will make use of the new Leeds Atmospheric Observatory, which is located in the countryside east of Leeds.

Research environment

You will join the vibrant Ice Nucleation group in the Institute for Climate and Atmospheric Science (ICAS). ICAS covers climate, air pollution, meteorology and climate impacts, with extensive programmes in observations, modelling and lab studies. Atmospheric science at Leeds is ranked 9th in the Centre for World University Rankings (http://cwur.org/2017) and 13th in the Academic Ranking of World Universities out of 400 (http://www.shanghairanking.com). Wider interdisciplinary experience is guaranteed through our new cross-campus Priestley Centre (http://climate.leeds.ac.uk). Peer exchange and learning occurs through frequent institute and group seminars, discussion meetings and paper review groups.

We also have formal partnerships with both the UK Met Office and also the Karlsruhe Institute of Technology. The KIT-ICAS partnership has led to exchange of students and staff and many joint publications. This project will build on the KIT-ICAS partnership and Dr Ottmar Möhler will be one of your supervisors (Murray and Möhler currently have a joint student, who has been very successful and have collaborated together for the past 10 years). The AIDA facility is on the KIT North campus which is a former research centre with several thousand scientists. The AIDA cloud simulation chamber is a unique facility which comprises an 84 m^3 chamber which can be cooled in a controlled way to -80^{o}C. You will work with a team of scientists and technicians to achieve your goals.

The supervisors have an outstanding track record of PhD student supervision, with students having won School of Earth and Environment PhD publication prize (out of 200 students), the Piers Sellers Priestly prize as well as several national and international prizes.

The CASE partner

Bilfinger Noell GMBH (www.noell.bilfinger.com) is a major European engineering company based in Würzburg, Germany with around 200 employees. This PhD will give you the exciting opportunity to work with industrial engineers in a commercial environment, giving you unique experience and insight to the private-sector and placing you in an enviable position in terms of employability. As part of the project, you will spend a minimum of 3 months in total with the CASE partner. Part of this time will be spend working with Dr Cristian Boffo on the adaptation of the PINE chamber for low temperature cirrus cloud research. There will also be an opportunity to work on other projects related to the PINE chamber, for example we are discussing developing the system as a condensation particle counter and also have plans for a research aircraft version of the instrument.

In addition to having access to the expertise in Bolfinger Noell, you will also benefit from the enhanced funding from the CASE partner which will cover your expenses while at Bolfinger Noell.

Further background information

Atmospheric ice-nucleating particles (INP) are aerosol particles with special physical and chemical properties that enable them to induce the formation of ice crystals in clouds below 0°C. In the absence of INP, cloud droplets can supercool to below -33°C. Formation of ice in clouds is a fundamental process that initiates most of the global precipitation. It also has profound effects on the radiative properties of clouds and thereby influences the effect that clouds have on climate. For example, we recently demonstrated that the low INP concentrations above the Southern Ocean leads to clouds which persist in a supercooled state, but are extremely sensitive to changes in INP concentration (Vergara-Temprado, 2018).

There are different types of clouds in which ice is important, but the type and mode of action through which INP nucleate ice is distinct in the different cloud regimes. In the lower and mid troposphere at temperatures between 0 and -35°C clouds can exist as supercooled water, ice or a mixture of the two. In this regime, INP tend to be immersed in supercooled water before they can trigger freezing. In contrast, in the upper troposphere under cirrus conditions ice can form directly onto aerosol particles well below the supersaturation required to form a liquid cloud. In fact, different populations of aerosol serve as INPs in the different cloud regimes, hence measurements need to be made that distinguish between these different populations.

The prototype PINE chamber connected to the much larger AIDA chamber in Karlsruhe, Germanu

Despite decades of research on INP, our understanding of INP sources in the atmosphere, and hence their impact on climate, is in its infancy. Substantial developments are being made by characterizing INP in innovative laboratory and field experiments, and then carrying this new knowledge into atmospheric models. For example, the Leeds group discovered that a specific mineral group in desert dust particles can explain their ice nucleating properties, enabling a global model of these INP to be developed (Atkinson et al., 2013). Similarly, we quantified marine organic INP through field measurements in remote environments from research ships and then used our global model to represent the global distribution of these INP (Wilson et al. 2015; Vergara-Temprado et al. 2017). We have not yet extended our model or measurements to cirrus conditions.

Methodologies

The core element of PINE is an air tight vessel, several litres in volume, which can be cooled to a specified temperature. Air is drawn into the chamber through a valve at the top, and pulled through by a pump below. The pressure within the chamber is then reduced, causing the temperature to drop and an adiabatic expansion to occur. The chamber is temperature controlled, allowing for measurements to be taken between 0 and −60°C. The frost point within the chamber is measured, and the humidity within is controlled to ensure that frost build up does not occur on the walls of the chamber. Varying the temperature and humidity determines what nucleation mode will occur within the chamber. When the chamber is operated in the immersion mode, this will form a cloud within the chamber, as liquid cloud droplets form on the aerosol. If the aerosol is an INP, the water droplet will nucleate and an ice crystal will form and grow to much larger sizes than water droplets. When the chamber is operated in the ice-supersaturated regime below water saturation as to study cirrus conditions, water vapour will deposit directly onto aerosol particles as the temperature within the chamber decreases. These particles will again be distinct in size from the aerosol particles and hence detectable. Detection occurs by particles being drawn through an Optical Particle Counter (OPC) which records the particle count and particle diameter.

Requirements

Undergraduate training in any physical/chemical science or engineering would be appropriate.

Training

Students will receive highly transferrable training in aerosol science and technology as well specialist training in the field of atmospheric ice nucleation. Co-supervision will involve regular online meetings between all partners. In addition the successful PhD student will have access to a broad spectrum of training workshops put on by the Faculty that include an extensive range of supportive workshops in skills such as managing your degree to preparing for your viva (http://www.emeskillstraining.leeds.ac.uk/). There will also be opportunities to take part in field campaigns, international conferences, and training courses offered by other organisations such as the Aerosol Society.

References

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