The formation of ice in clouds and the impact on climate

[Prof. Ken Carslaw](#) (School of Earth and Environment, University of Leeds), [Prof. Ben Murray](#) (School of Earth and Environment, University of Leeds), and Prof Paul Field (Met Office and School of Earth and Environment, University of Leeds)

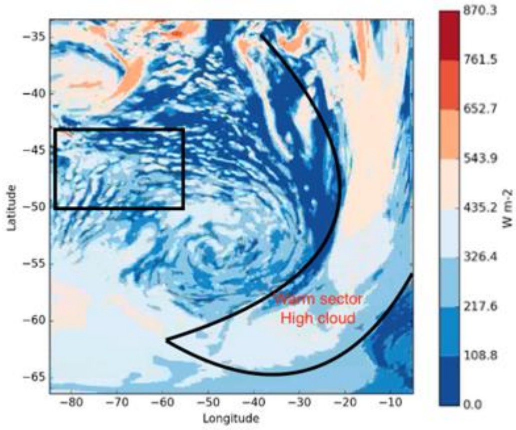
Contact Ben Murray or Ken Carslaw to informally discuss the project in advance of the application deadline: b.j.murray@leeds.ac.uk, K.S.Carslaw@leeds.ac.uk.

Project Summary

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 but they are currently very poorly simulated in global climate models. In particular, it is now recognised that ice formation in clouds influences the sensitivity of our climate to future changes in greenhouse gases.

A cloud growing out of a very dusty lower atmosphere. This aerosol contains ice-nucleating particles that cause some cloud droplets to freeze.

The aim of this PhD project is to understand how ice-nucleating particles affect clouds and climate

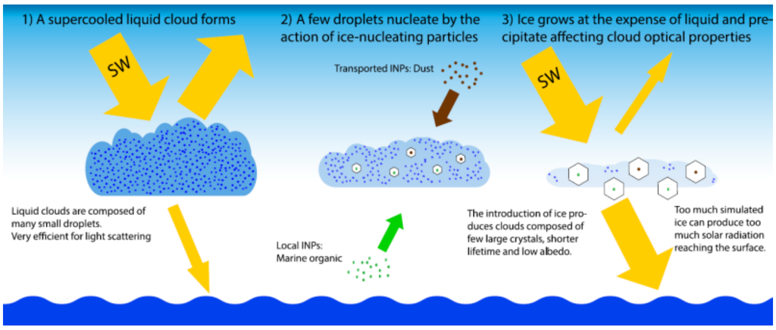


Simulation of a cyclone over the Southern Ocean using the CASIM model to be used in this project. The figure shows reflected shortwave (solar) radiation. Data produced by Leeds PhD student Jesus Vergara-

The project will use a combination of the latest laboratory measurements of ice-nucleating particle properties, new field observations of ice-nucleating particles, high-resolution model simulations, global climate model simulations and satellite observations.

Only very recently this kind of research was not feasible because our understanding of INP was too poor and our models were not sophisticated enough. We can now run very realistic high-resolution model simulations of clouds, and we have a good enough understanding of ice-nucleating particles from laboratory experiments to simulate them on a global scale.

Previous collaborative PhD research by this group of supervisors led to the discovery of how very low concentrations of ice-nucleating particles over the Southern Ocean can explain large climate model errors (Vergara-Temprado et al., 2018) – see Figure. The aim of this project is to extend the research to other cloud types and environments to understand how ice-nucleating particle concentrations influence cloud properties and climate.



Schematic representation of the effect of INPs on marine mixed-phase clouds.

Objectives

The project will involve:

i) **Understanding the global distribution of ice-nucleating particles.** This will involve collation of atmospheric ice-nucleating particle measurement data from around the world in order to identify regions where we are missing important particle sources in the global model. The aim is to improve global model simulations with a view to incorporating these particles in climate simulations. The ice-nucleating particle fields will also be used to drive high-resolution regional model simulations.

iii) **Simulating the response of clouds to changes in ice-nucleating particles**. You will use an advanced meteorological model of clouds (based on the Met Office forecast model) to simulate how different types of clouds respond to changes in ice-nucleating particles. Simulations will be evaluated against satellite and other data. The aim is to work out which clouds are most sensitive to ice-nucleating particles and how they affect climate-relevant cloud properties like reflectivity. The project will explore ice-nucleating particle effects on various mixed-phase cloud environments, such as over remote oceans, deep convection, the Arctic or cyclones.

iii) **Exploring the potential implications for climate.** You will work with researchers at the Met Office using your results to understand how best to simulate ice-nucleating particles and their effects on a global scale in a future version of the UK's climate model.

Research environment

You will join the vibrant Atmospheric Composition and Cloud Physics research groups of 10 Academic Staff. There are about 80 PhD students across the Institute for Climate and Atmospheric Science (ICAS) covering 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.

The Met Office is a world class centre working across observations, climate processes, climate model development and assessment. This environment offers opportunities for the student to engage with a cross section of current weather and climate research (via regular seminar series and peer group meetings).

The collaboration between Leeds and the Met Office goes back over nearly 20 years and is now formalised as the Met Office Academic Partnership (MOAP: http://www.metoffice.gov.uk/research/partnership). There is therefore an active group of Met Office-facing scientists at Leeds. The co-supervisor, Prof Paul Field, was appointed as a joint Leeds-Met Office Professor in 2014 and has since set up a large research group of postdocs and PhD students who interact closely with the Met Office.

The supervisors have an outstanding track record of PhD student supervision, with students having won School of Earth and Environment PhD publication prizes in each of the last 6 years (out of 200 students) as well as several national and international prizes.

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.

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). Terrestrial biological INP are known to be important but are so far neglected in the global model.

Methodologies

The key modelling tool is the Global Model of Aerosol Processes (GLOMAP: http://www.see.leeds.ac.uk/aerosol) which was developed in Prof Carslaw's group. This is an advanced model that simulates the global formation, transport and removal of aerosol particles in the atmosphere. It has been used to study a very wide range of aerosol phenomena, including INP (Vergara-Temprado et al. 2017). You will also make use of new laboratory and field measurements of INP properties from Prof Murray's group in order to develop new descriptions of INP emissions in GLOMAP. You will also work with the Met Office's state of the art high resolution weather model to explore the effects of INP on weather and climate (see for example https://www.atmos-chem-phys.net/17/5155/2017/ and www.pnas.org/cgi/doi/10.1073/pnas.1721627115).

Requirements

Undergraduate training in any physical/chemical science, computing, mathematics or applied statistics would be appropriate.

Training

Students will receive training in running and visualizing global model results. The aerosol group has a dedicated research and support scientist who leads the technical aspects of the model development as part of the institute's new Centre of Excellence for Modelling the Atmosphere and Climate (CEMAC: https://www.cemac.leeds.ac.uk/) .

Co-supervision will involve regular 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

Atkinson, J. D., and Coauthors, 2013: The importance of feldspar for ice nucleation by mineral dust in mixed-phase clouds. Nature, 498, 355-358.

Murray, B. J., D. O'Sullivan, J. D. Atkinson, and M. E. Webb, 2012: Ice nucleation by particles immersed in supercooled cloud droplets. Chem. Soc. Rev., 41, 6519-6554.

Wilson, T. W., and Coauthors, 2015: A marine biogenic source of atmospheric ice-nucleating particles. Nature, 525, 234-238.

Vergara-Temprado, J., Murray, B. J., Wilson, T. W., O'Sullivan, D., Browse, J., Pringle, K. J., Ardon-Dryer, K., Bertram, A. K., Burrows, S. M., Ceburnis, D., DeMott, P. J., Mason, R. H., O'Dowd, C. D., Rinaldi, M., and Carslaw, K. S.: Contribution of feldspar and marine organic aerosols to global ice nucleating particle concentrations, Atmos. Chem. Phys., 17, 3637-3658, 2017.