TNA User Report

The completed and signed form below should be returned by email to
eurochamp2020@lisa.u-pec.fr

Project title	Volcanic Ash Ice Nucleation in Clouds (VAINIC02)
Name of the accessed chamber	AIDA cloud simulation chamber
Number of users in the project	1
Project objectives (max 100 words)	The objectives of the project were to quantify the ice nucleating efficiency (INE) of volcanic ash and to relate this to ash physicochemical properties, primarily dictated by the magmatic conditions from which the ash derives. Specifically, the measurement campaign addressed the following research questions: i) What is the range of INEs exhibited by volcanic ash of varying physicochemical properties in the immersion nucleation mode (i.e. as relevant to mixed-phase clouds)? ii) Is there a link between the INE of volcanic ash in this mode and the ash chemical composition, mineralogy and/or crystallinity?
Description of work (max 100 words):	To address these questions, ice nucleation measurements were performed on fifteen volcanic ash samples that have been fully characterised and display a range of compositions, mineralogies and/or crystallinities as typically generated by explosive eruptions. Over the course of three weeks, a series of cloud expansion experiments with different starting temperatures were carried out using the AIDA cloud simulation chamber, accompanied by online measurement of parameters such as ash particle, water droplet and ice crystal number concentrations and size distributions, temperature and relative humidity, and complementary sample characterisation by SEM/TEM-EDS.

Principal Investigator's and group's information	
First name	Elena
Family name	Maters
Nationality	British, Canadian, American
Activity domain[1]	Earth Sciences & Environment
Home institution	University of Leeds
Institution legal status[2]	UNI
Email	e.c.maters@leeds.ac.uk
Gender	Female
User status[3]	PDOC
New user	Yes

[1] Physics; Chemistry; Earth Sciences & Environment; Engineering & Technology; Mathematics; Information & Communication Technologies; Material Sciences; Energy; Social sciences; Humanities.

[2] UNI= University and Other Higher Education Organisation;
RES= Public Research Organisation (including international research organisations and private research organisations controlled by public authority);
SME= Small and Medium Enterprise;
PRV= Other Industrial and/or Profit Private Organisation;
OTH= Other type of organization.

[3] UND= Undergraduate; PGR= Post graduate; PDOC= Post-doctoral researcher; RES= Researcher ENG= Engineer; ACA= Academic; TEC= Technician.

Trans-National Access (TNA) Scientific Report

The completed and signed form below should be returned by email to
eurochamp2020@lisa.u-pec.fr

Instructions

Please limit the report to max 5 pages, you can include tables and figures. Please make sure to address any comments made by the reviewers at the moment of the project evaluation (if applicable, in this case you were informed beforehand). Please do not alter the layout of the document and keep it in Word version. The report will be made available on the eurochamp.org website. Should any information be confidential or not be made public, please inform us accordingly (in this case it will only be accessible by the European Commission, the EUROCHAMP-2020 project partners, and the reviewers). Please include:

- Introduction and motivation
- Scientific objectives
- Reason for choosing the simulation chamber/ calibration facility
- Method and experimental set-up
- Data description
- Preliminary results and conclusions
- Outcome and future studies
- References

Name of the PI: Elena Maters
Chamber name and location: AIDA cloud simulation chamber, Karlsruhe Institute of Technology
Campaign name and period: Volcanic Ash Ice Nucleation in Clouds (VAINIC02), 23/04/2018 to 11/05/2018
Text:

• Introduction and motivation

The formation of ice exerts a major impact on the properties and lifetime of atmospheric clouds, yet remains one of the least well understood processes indirectly affecting the Earth's climate (Boucher et al., 2013). Ice may form homogeneously at temperatures below ~-36 °C from supercooled water droplets or heterogeneously at higher temperatures involving particles called ice nuclei (IN) (Pruppacher and Klett, 1997). Although the abundance of IN in the atmosphere is low, they exert a profound influence on cloud properties and lifetime, underlining the importance of research that seeks to quantify and explain the ice nucleating efficiency (INE) of different airborne particles.

This project aims to improve knowledge of the role of volcanic ash as IN in the atmosphere. While mineral dust from arid and semi-arid regions is considered to be one of the most important IN globally, the impact of volcanic ash from explosive eruptions on ice formation is increasingly recognised, with ash sporadically dominating IN populations (Murray et al., 2012). Existing field and laboratory measurements present conflicting evidence as to the INE of ash, and it is far from clear what drives this variation (Durant et al., 2008). Studies on dust suggest that chemical composition, mineralogy and crystallinity can influence the abundance of ice active surface sites (e.g. Atkinson et al., 2013; Freedman, 2015), and similar controls may apply to ash (Kulkarni et al., 2015; Schill et al., 2015). However, the importance of such physicochemical properties in dictating a particle's INE remains poorly understood, even for dust, and has not been systematically investigated for ash.

• Scientific objectives

The objectives of this project were to i) quantify the INE of a wide range of volcanic ash samples and, ii) investigate if there is any relationship between INE and specific properties of the ash including its chemical composition, mineralogy and crystallinity.

• Reason for choosing the simulation chamber/ calibration facility

The AIDA cloud simulation chamber has a unique capability to operate from 0 to -90 °C and at relative humidities covering the entire mixed-phase and cirrus cloud conditions, which is not possible with the cold stage set-up at the University of Leeds. Moreover, the AIDA chamber offers a more realistic simulation of cloud conditions and particle dispersion for ice nucleation studies, and benefits from online measurements by many aerosol instruments simultaneously.

• Method and experimental set-up

Cloud expansion (and thereby ice nucleation) experiments were performed with the volcanic ash samples at starting temperatures ranging from approximately -17 °C to -30 °C (i.e. mixed-phase cloud conditions). The ash particles were injected into the AIDA chamber using a Rotating Brush Generator in tandem with two cyclones to control particle size (≤ 3 μm). The dispersed particle size distribution was measured simultaneously by APS and SMPS, and the particle number concentration was measured with two CPCs. Prior to each expansion experiment, three sub-samples of dispersed ash were collected on filters for analysis on the INSEKT and by SEM-/TEM-EDS. The particle optical properties were characterised by a well-established SIMONE instrumentation. All water-related (e.g. relative humidity) parameters were measured by MBW, APict, APet and TDL. An FT-IR instrument was also operated alongside the experiment to quantify the water profiling of the chamber. Throughout the experiment, the size and optical properties of the ice particles formed were quantified using two WELAS systems.

• Data description

The project typically consisted of two cloud expansion experiments per day utilising one volcanic ash sample and two different starting temperatures. A large amount of data was generated over the three-week period including parameters relating to aerosol numbers and size distributions, water droplet and ice crystal concentrations as a function of temperature and relative humidity, as well as complementary data characterising the physicochemical properties of the different ash samples.

• **Preliminary results and conclusions**

The preliminary data treatment is ongoing and is being conducted on the side of collaborators of the project at Karlsruhe Institute of Technology, namely Dr. Nsikanabasi Umo and Dr. Romy Fösig, who have strong expertise in compiling and processing the different types of data generated by the AIDA chamber facility. An example plot of the various measurements recorded during a cloud expansion experiment is shown in Figure 1. In this particular experiment, ice nucleation in the immersion mode by volcanic ash from the 1999 eruption of Soufrière Hills volcano, Montserrat was measured over the temperature range of approximately -26 °C to -35 °C:

The top panel shows the controlled decrease in pressure (p, black line) within the AIDA chamber and the resulting decrease in gas temperature (T_g, blue line).

The second panel shows the corresponding increase in saturation within the AIDA chamber with respect to supercooled water (h2o liquid, dashed blue line) and ice (h2o ice, solid blue line).

The third panel shows the number concentration of aerosol (black line) and ice (light blue circles, dark blue triangles) detected by the two WELAS optical particle counter systems associated with different cut-off diameters.

The bottom panel shows a scatter plot (light and dark blue dots) of ash particles, supercooled water droplets and ice crystals detected by the two WELAS systems. During the cloud expansion experiment, once the liquid water saturation reached 100% within the AIDA chamber, the ash particles activated to supercooled water droplets as indicated by the onset of scatter at larger diameters (e.g. > 5 µm) relative to the baseline, and then formed ice crystals as indicated by the scatter at even larger diameters (e.g. > 20 µm). The light blue horizontal line represents an optical threshold size used to distinguish water droplets from ice crystals.

Altogether, fifteen volcanic ash samples were studied with cloud expansion experiments performed at two different starting temperatures in the AIDA chamber, generating no less than thirty experimental datasets. Since the preliminary processing of this large amount of data by Dr. Nsikanabasi and Dr. Fösig is still in early stages, as of yet no statements can be made regarding a specific influence of ash composition, crystallinity and/or mineralogy on INE. One thing that can be noted at this point, however, is that clear variations were visually observed in ice nucleation by the different ash samples, with some producing much higher concentrations of ice crystals than others at comparable temperatures. Moreover, three different ash samples from the same volcano but produced by discrete eruptive events (SH1- 1996 dome collapse, SH2- 1999 phreatic explosion, SH3- 2010 dome collapse) showed various behaviours during the cloud expansion experiments (Figure 2), suggesting that the physicochemical properties of ash may be more important than the source volcano in dictating its INE.

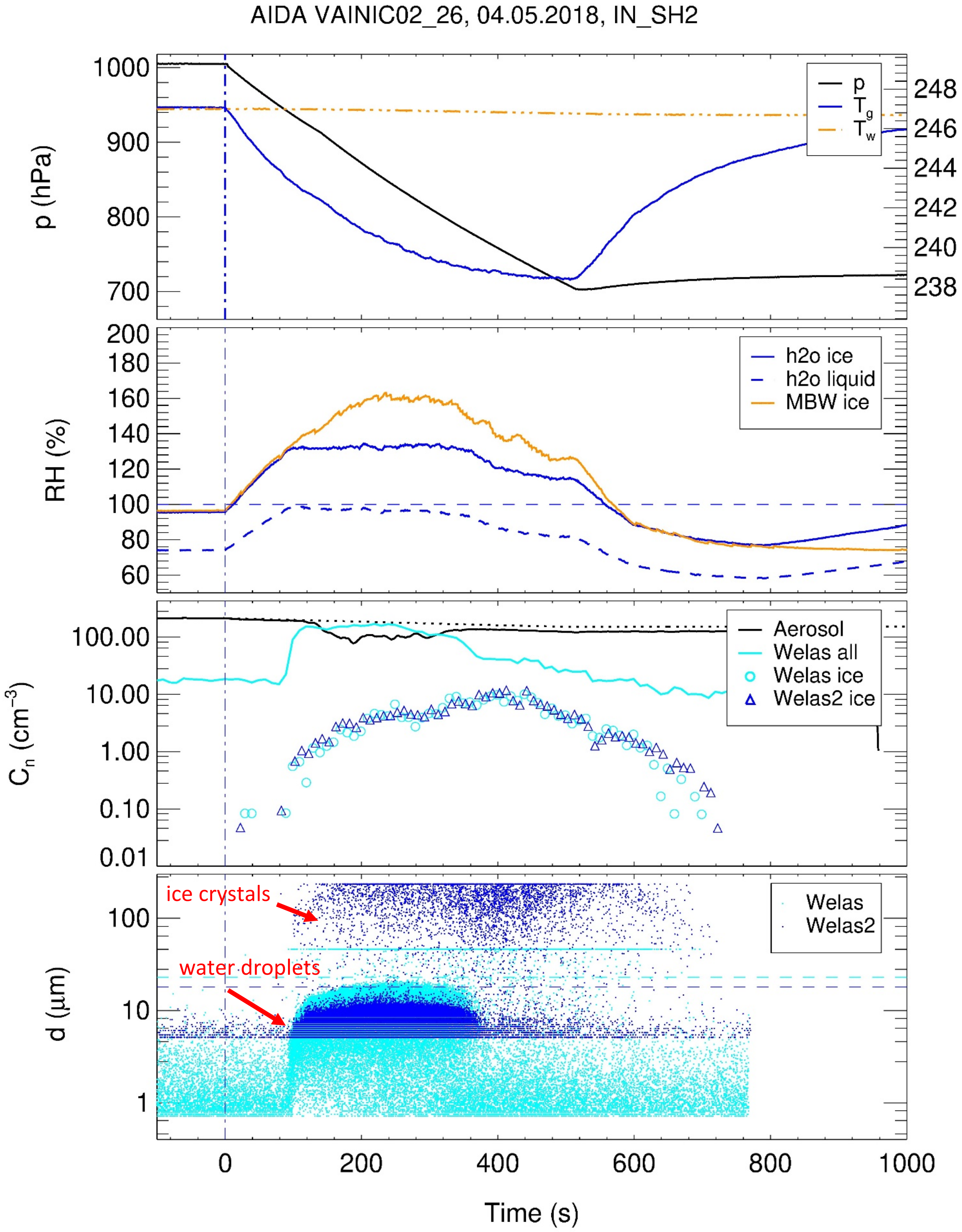

Figure 1. Various parameters measured during a cloud expansion experiment in the AIDA chamber with aerosolised ash particles from the 1999 explosive eruption of Soufrière Hills volcano, Montserrat. See the text for a description of the four panels.

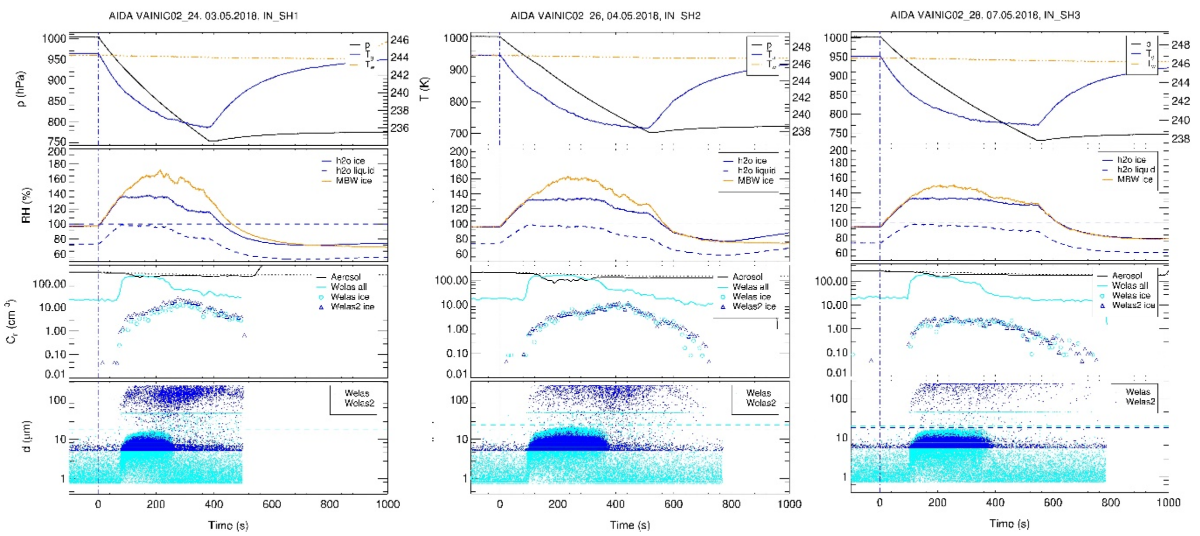

Figure 2. Contrasting data from cloud expansion experiments in the AIDA chamber with aerosolised ash particles from a 1996 (SH1), 1999 (SH2) and 2010 (SH3) eruptions of Soufrière Hills volcano, Montserrat.

• Outcome and future studies

The findings of this project will provide new qualitative and quantitative insights essential to constraining the potential influence of ash emissions on ice formation in clouds. Fundamental knowledge gained from this research concerning the effect of physicochemical properties on INE may also be relevant to other solid materials (e.g., mineral dust, glacial flour, coal fly ash). Further, laboratory data can eventually be parameterised for use in Earth System and climate models to quantify the importance of ash IN for atmospheric composition and climate. Such results can also have value for policy stakeholders outside of academia concerned with airborne ash, for example the London Volcanic Ash Advisory Center and UK Met Office Atmospheric Dispersion Group. The possibility of another measurement campaign using the AIDA cloud simulation chamber in 2019, aimed at investigating the effect of atmospheric aging (e.g. exposure to trace gases such as SO_2 and O_3) on the INE of volcanic ash, is currently being considered.

• References

Atkinson J.D. *et al.* (2013) The importance of feldspar for ice nucleation by mineral dust in mixed-phase clouds. *Nature* 498: 355-358

Boucher O. *et al.* (2013) Clouds and Aerosol. In *Climate Change 2013: Physical Science Basis*. Contribution of Working Group I to IPCC. Cambridge University Press

Durant A.J. *et al.* (2008) Ice nucleation and overseeding of ice in volcanic clouds. *J Geophys Res* 113: D09206

Freedman M.A. (2015) Potential Sites for Ice Nucleation on Aluminosilicate Clay Minerals and Related Materials. *J Phys Chem* Lett 6: 3850-3858

Kulkarni G.M. *et al.* (2015) Effects of crystallographic properties on the ice nucleation properties of volcanic ash particles. *Geophys Res Lett* 42: 3048-3055

Pruppacher H.R., Klett J.D. (1997) Microphysics of Clouds and Precipitation. Kluwer Academic Publishers.

Murray B.J. et al. (2012) Ice nucleation by particles immersed in supercooled cloud droplets. *Chem Soc Rev* 41: 6519-6554

Schill G.P. *et al.* (2015) Deposition and immersion-mode nucleation of ice by three distinct samples of volcanic ash. *Atmos Chem Phys* 15: 7523-7536