Name of research institute or organization:

Leibniz-Institute for Tropospheric Research, Leipzig, Germany (IfT)

Title of project:

Sampling and physico-chemical characterisation of ice nuclei in mixed phase clouds

Project leader and team

Dr. Stephan Mertes, project leader
Hartmut Haudek, Stefan Günnel, Peter Glomb, Andrea Haudek, Werner Sarwatka†

Project description:

Ice nucleation in tropospheric, super-cooled clouds is the main initiation mechanism for precipitation in middle latitudes and moreover influences the radiative properties and the chemical multiphase processes of these clouds. Since homogeneous freezing of super-cooled droplets does only occur at temperatures below -38 °C, heterogeneous ice nucleation that is induced by a special subset of atmospheric aerosol particles named ice nuclei plays the decisive role in the middle and lower troposphere. But up to now, the physico-chemical properties of ice nuclei (size, number concentration, chemical composition) as well as the relevance of different heterogeneous freezing mechanisms (deposition, condensation, immersion or contact freezing) have been rather exclusively studied theoretically or in laboratory experiments but hardly inside tropospheric clouds themselves.

A sampling system based on the principle of a counterflow virtual impactor (CVI) has been developed (ICE-CVI) in order to characterize tropospheric ice nuclei that have formed ice particles in real clouds. Inside mixed-phase clouds the ICE-CVI separates ice particles smaller than 50 µm by pre-segregating large ice crystals, super-cooled droplets and interstitial particles. The collected small ice particles remain airborne in the vertical sampling system and are completely evaporated in a dry and particle free carrier air stream. In this way, the contained non-volatile aerosol particles are released as dry residuals which can be analysed by attached instrumentation downstream the evaporation tube. According to their small size and short life time, the sampled small ice particles do not incorporate particles by riming or aerosol scavenging, in contrast to large ice aggregates, i.e. the ice particle residuals can be considered as the original ice nuclei. Only when ice formation takes place via droplet freezing (immersion and contact freezing), the aerosol particle that formed the liquid droplet, the so-called cloud condensation nuclei) should be additionally measured. Using this information it should be possible to differentiate between ice formation via droplet freezing and additional ice particle nucleation (deposition and condensation freezing).

The novel ICE-CVI sampling system was deployed for the first time during the international field campaign CLACE-3 (cloud and aerosol characterization experiment) at the high alpine research station Jungfraujoch in February/March 2004. Downstream the ICE-CVI inlet several devices were connected to characterize the ice particle residuals in collaboration with other working groups. Number concentration and number size distribution of the ice nuclei were measured with a condensation particle counter (CPC, operated by IfT) and a scanning mobility particle sizer (SMPS, operated by the Paul Sscherrer Institute, Villigen). By means of a filter-based particle soot absorption photometer (PSAP, IfT) the mass concentration of graphitic carbon within the ice nuclei was determined. The mass concentration of major ions and organic carbon (OC) of the collected ice nuclei was derived by an aerosol mass spectrometer (AMS, operated by the Max-Planck Institute Mainz, Germany). Furthermore, an impactor (operated by the Technical University of Darmstadt, Germany) was connected for the off-line single particle analysis of the impactor samples using environmental scanning electron microscopy (ESEM, TU Darmstadt).

From the combination of the ICE-CVI sampler and the different sensors first features of the ice particle residuals are obtained, which are subsequently related to the aerosol properties of the total aerosol population measured downstream an independent whole air inlet. During a mixed-phase cloud event from the 24 March (11:00) to the 25 March (09:40) an ice nuclei concentration of 2 cm^{-3} was determined compared to a total particle concentration of 723 cm^{-3}, respectively. The small number of ice nuclei led to a particle mass concentration of 12 ng m^{-3} at a total particle mass concentration of 6180 ng m^{-3}, both obtained from the integration of the particle number size distribution. The ice nuclei contained a soot mass concentration of about 1 ng m^{-3} whereas the total aerosol particles included 92 ng m^{-3}. Relating the amount of soot to the aerosol mass for the ice particle residuals and the total aerosol particles yielded an enrichment of soot in the ice nuclei by a factor of 5, which is clear evidence that graphitic carbon promotes ice formation in tropospheric clouds. The number size distribution of the ice particle residuals revealed that a lot of ice nuclei were below a particle size of 100 nm. However, normalizing these size distributions by the number size distributions of the prevailing total aerosol particles, it was found that particles with diameters larger than 400 nm are favoured to act as ice nuclei. From the results of the aerosol mass spectrometer it could be concluded that the ice nuclei mass distribution does not consists mainly from major ions and organic carbon. The missing mass was not directly measured but it most likely consists of crustal material like mineral and desert dust. This hypothesis is strongly supported by the single particle analysis by means of electron microscopy. In smaller ice nuclei signatures of C and O were found and in larger ice nuclei Si became dominant. This is a first indication that small ice nuclei contain mainly organic and graphitic carbon whereas the larger ones are mineral dust particles.

During CLACE-3 the functionality of the ICE-CVI as a unique development to sample ice particles in order to analyse the ice initiating particles could be successfully verified. Based on this new technique it was feasible for the first time to carry out a characterization of ice nuclei that formed ice in tropospheric clouds in central Europe in 2004. The results from the field experiment confirm the assumption that hydrophobic aerosol substances that already possess a lattice structure are preferred to nucleate ice particles. More systematic and representative measurements of atmospheric ice nuclei and heterogeneous ice nucleation will be conducted at the high-alpine research station Jungfraujoch using the ICE-CVI technique.

Key words:

mixed-phase clouds, heterogeneous ice nucleation, ice nuclei

Internet data bases:

http://aerosolforschung.web.psi.ch/Clace3_Page/Clace3_Page.htm

Collaborating partners/networks:

Paul Scherrer Institute Villigen (PSI); Max-Planck Institute Mainz (MPI); Technical University of Darmstadt (TUD).

Scientific publications and public outreach 2004:

Conference papers

Mertes, S., A. Schwarzenböck, J. Schneider, S. Walter, M. Ebert, M. Inerle-Hof, B. Verheggen, J. Cozic, and E. Weingartner, Design and Operation of a Counterflow Virtual Impactor Inlet System to collect small Ice Particles out of Mixed-Phase Clouds at the high Alpine Site Jungfraujoch (3580 m asl), European Aerosol Conference, Budapest, Hungary, 6 – 10 September 2004, J. Aerosol Sci., 35, S167-S168.

Mertes, S., A Counterflow Virtual Impactor (CVI) System for Sampling of freshly formed Ice Particles in Mixed-Phase Clouds at the high Alpine Research Station Jungfraujoch (3580 m): Functionality and first results, Workshop on 'The Tropospheric Ice-Phase', Frankfurt, Germany, 10 – 11 November 2004.

Data books and reports

Mertes, S., Ice nuclei: field measurements on Jungfraujoch, colloquium of atmospheric and environmental sciences, Institut für Meteorologie und Geophysik, University of Frankfurt/Main, 15 July, 2004.

Magazine and Newspapers articles

"Gros plan sur la double vie climatique des aérosols", 24heures, April 1, 2004.

"Grosse Jagd auf kleine Teilchen", Berner Zeitung and Berner Oberländer and Thuner Tagblatt, April 1, 2004.

"Von Forschern, die sich Wolken wünschen", Tages-Anzeiger, April 7, 2004.

"Der Kern im Eiskristall", ETH Life, April 8, 2004.

"Ein Forscher jagt Wolken", Swissinfo, April 9, 2004.

"Particles cloud researchers' judgement", Swissinfo, April 27, 2004.

"Auf den Spuren der Wolkenmacher", Basler Zeitung, April 30, 2004.

"Ausser Puste", Frankfurter Rundschau, Mai 25, 2004.

"Zwischen den Wolken", Süddeutsche Zeitung, Mai 26, 2004.

Radio and television

"CLACE-3 Reportage" Interview with the atmospheric scientists Stefan van Eckeren, PSI Villigen, and Dr. Stephan Mertes, IfT Leipzig, Radio DRS 1 and DRS 3, "Rendezvous am Mittag", April 2 and 5, 2004.

Address:

Institut für Troposphärenforschung
Permoserstrasse 15
D-04318 Leipzig
Deutschland

Contacts:

Stephan Mertes
Tel.: +49 341 235 2153
Fax: +49 341 235 2361
e-mail: mertes@tropos.de
URL: http://www.tropos.de