EPSC Abstracts
Vol. 11, EPSC2017-445, 2017
European Planetary Science Congress 2017

The microphysical formation process of mesospheric clouds on Earth and Mars

M. Nachbar (1), D. Duft (2) and T. Leisner (1, 2)

(1) Institute of Environmental Physics, University of Heidelberg, Heidelberg, Germany
(2) Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology – KIT, Karlsruhe, Germany
(Mario.nachbar@kit.edu)

Abstract

Mesospheric water ice clouds are a phenomenon frequently occurring on Earth at mid to high latitudes during summer. Surprisingly, similar clouds consisting of CO_2 ice were also detected at low latitudes in the mesosphere of Mars. Both types of clouds are believed to form by heterogeneous nucleation on nanometer size Meteoric Smoke Particles (MSPs). However, describing cloud formation is still flawed by high uncertainties due to a lack of experimental data regarding the nucleation process. We present measurements on heterogeneous nucleation and subsequent growth of H_2O and CO_2 on sub 3nm silica, iron oxide and mixed iron silicates as analogues for MSPs. The experiments were performed at conditions which are relevant to the mesosphere of Earth and Mars. We show measured desorption energies and critical saturations of H_2O and CO_2 for the different particle materials. Using Classical Nucleation Theory (CNT), we infer the contact parameter resulting in a full parameterization of the nucleation process. We conclude that the same parameterization may also be valid for Martian Dust Particles [MDPs] and predict conditions at which H_2O and CO_2 clouds form in the mesospheres of Earth and Mars. The results are discussed in comparison with atmospheric observations.

1. Introduction

Mesospheric water ice clouds, often referred to as Noctilucent Clouds (NLCs), are a phenomenon frequently occurring on Earth at mid to high latitudes during summer [e.g. 5, 10]. Similar clouds were also detected at low latitudes in the mesosphere of Mars. These clouds mainly occur during post- and pre-aphelion season [e.g. 2, 7, 8]. In contrast to Earth, the majority of the martian mesospheric clouds consist of CO_2 ice. Both types of clouds have in common that they are believed to form by heterogeneous nucleation on nanometer size Meteoric Smoke Particles (MSPs) during gravity wave induced supersaturated conditions [e.g. 1, 4, 11]. If the conditions needed for cloud formation would be well known, cloud observations could be used as a tracer for the thermodynamic conditions of the observed region. Unfortunately, predictions for cloud formation still struggle with high uncertainties due to a lack of experimental data regarding the nucleation process at realistic mesospheric conditions of Earth and Mars and regarding realistic nuclei materials.

Recently, we introduced a novel experimental setup [3, 6] specifically designed for the investigation of adsorption, nucleation and subsequent depositional growth of H_2O and CO_2 on nanoparticles with MSP material compositions. With the new setup we are able to determine the desorption energy and contact parameter which are key parameters describing the nucleation ability of the aerosol particles at realistic mesospheric conditions of Earth and Mars [3, 9].

2. Experimental Method

Singly charged nanometer size MSP analogues are produced in a microwave plasma particle source. The particles enter into the TRAPS vacuum system [6] in which we are able to select particles with radii between 1 and 3 nm. The size selected particles are then accumulated in the novel MICE-ion trap [3]. In MICE, the particles are exposed to realistic mesospheric conditions in terms of background pressure and temperature as well as CO_2 and H_2O vapor concentrations. From MICE we extract a small amount of the trapped particle population at periodic time steps and analyze their mass distribution with a time-of-flight mass spectrometer. As a result, we observe the adsorption process of CO_2 and H_2O on the MSP analogues. Depending on the conditions in MICE, adsorption is followed by nucleation and subsequent growth of CO_2 and H_2O ice particles.

3. Results and Discussion

Figure 1 shows an exemplary series of H_2O deposition on 2.6nm Silica particles. Here, the H_2O concentration has been kept constant to 5E15 m^{-3} and the particle mass is shown as a function of trapping time for 4 different particle temperatures.

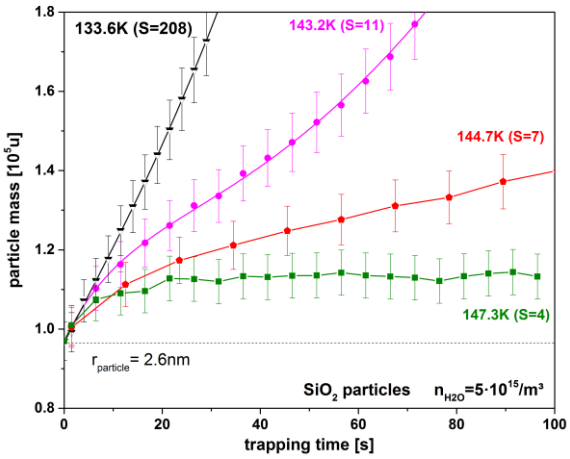

Figure 1: Exemplary dataset of an H_2O deposition experiment on 2.6nm SiO_2 particles used for desorption energy (green curve), critical saturation (red curve) and growth rate (black curve) analysis.

The green curve at a particle temperature of 147.3K and a Saturation of S=4 represents a typical measurement below the nucleation threshold. The increase in mass reflects the adsorption/desorption equilibrium process of H_2O molecules on the surface of the particles under these conditions. From measurements like this we determine the desorption energies for the investigated vapors and nuclei materials. By decreasing the particle temperature and thereby increasing S we reach conditions at which nucleation and further mass aggregation takes place (red curve, T=144.7, S=7). By observing this transition, we are able to experimentally determine the critical saturations needed for cloud formation. Fitting nucleation theory to the determined critical saturations gives us the contact parameter of the particle material. In addition, measurements at high S values (black curve T=133.6K, S=208) allow us to investigate particle growth rates.

Overall, we present a full parameterization of the nucleation process of CO_2 ice between 64K and 74K and of H_2O ice between 128K and 155K on pure iron oxide, silica and mixed iron silicates as analogues for MSPs. We will discuss the differences in the nucleation ability of the materials in respect to CO_2 and H_2O ice and will show that the same parameterization may also be valid for the nucleation on Martian Dust Particles. Using this parameterization we will deduce the Saturations at which H_2O and CO_2 cloud formation is activated at conditions relevant to the mesosphere of Earth and Mars and compare the results to observations.

Acknowledgements

The authors thank the German Federal Ministry of Education and Research (BMBF, grant number 05K13VH3) and the German Research Foundation (DFG, grant number LE 834/4-1) for financial support of this work.

References

[1] Berger, U. and von Zahn, U: The two-level structure of the mesopause: A model study. J. Geophys. Res, Vol. 104(D18), 1999.

[2] Clancy, R. T., Wolff, B. A., Whitney, B.A., et. al.: Mars equatorial mesospheric clouds: Global occurrence and physical properties from Mars Global Surveyor […], J. Geophys. Res.-Planets, Vol. 112(E4), 2007.

[3] Duft, D., Nachbar, M., Eritt, M. and Leisner, T.: A linear ion trap for studying the interaction of nanoparticles with supersaturated vapors. Aerosol. Sci. technol., 2015

[4] Gonzalez-Galindo, F., Määttänen, A., Forget, F. and Spiga, A.: The Martian mesosphere as revealed by CO_2 cloud observations and General Circulation Modeling, Icarus, Vol. 216(1), pp. 10-22, 2011.

[5] Gumbel, J. and Megner, L.: Charged meteoric smoke as ice nuclei in the mesosphere: Part 1-A review of basic concepts, Journal of Atmospheric and Solar-Terrestrial Physics, Vol. 71(12), pp. 1225-1235, 2009.

[6] Meinen, J., Khasmiskaya, S., Rühl, E., Baumann, W. and Leisner, T.: The TRAPS Apparatus: Enhancing Target Density of Nanoparticle Beams in Vacuum for X-ray and Optical Spectroscopy, Aerosol. Sci. Technol., Vol. 44(4), pp. 316-328, 2010.

[7] Montmessin, F., Gondet, B., Bibring, J.P., et al.: Hyperspectral imaging of convective CO_2 ice clouds in the equatorial mesosphere of Mars, J. Geophys. Res. - Planets, Vol. 112, pp. E11S90, 2007.

[8] Montmessin, F., et al.: Subvisible CO_2 ice clouds detected in the mesosphere of Mars, Icarus, Vol. 183(2), pp. 403-410, 2006.

[9] Nachbar, M., Duft, D., Mangan, T.P., et al.: Laboratory measurements of heterogeneous CO_2 ice nucleation on nanoparticles under conditions relevant to the Martian mesosphere, J. Geophys. Res. Planets, Vol. 121, 2016

[10] Rapp, M. and Thomas, G. E.: Modeling the microphysics of mesospheric ice particles: Assessment of current capabilities and basic sensitivities, Journal of Atmospheric and Solar-Terrestrial Physics, Vol. 68(7), pp. 715-744, 2006.

[11] Spiga, A., Gonzalez-Galindo, F., Lopez-Valverde, M. A. and Forget, F.: Gravity waves, cold pockets and CO_2 clouds in the Martian mesosphere, Geophys. Res. Lett., Vol. 39, pp. L02201, 2012.