EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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2011 PROGRESS REPORT ON PS215/CLOUD

CLOUD Collaboration

1 FIRST RESULTS

The first physics results from CLOUD [1] were published in Nature, August 2011 [2]. The measurements represent the most rigorous laboratory evaluation yet accomplished of binary, ternary and ion-induced nucleation of sulphuric acid/ammonia aerosol particles under atmospheric conditions. Several new findings were reported. Firstly, CLOUD has shown that the most likely nucleating vapours, sulphuric acid and ammonia, cannot account for nucleation in the lower atmosphere. The nucleation observed in the chamber occurs at only one-tenth to one-thousandth of the rate observed in the lower atmosphere (Fig. 1). In view of the CLOUD results, the treatment of aerosol formation in climate models will need to be substantially revised since all models assume that nucleation is caused by these vapours and water alone. Secondly, CLOUD has found that cosmic ray ionisation can substantially enhance nucleation of sulphuric acid/ammonia particles—by up to a factor of 10. Ion-enhancement is particularly pronounced in the cool temperatures of the mid-troposphere and above, where CLOUD has found that sulphuric acid and water vapour can nucleate without the need for additional vapours.

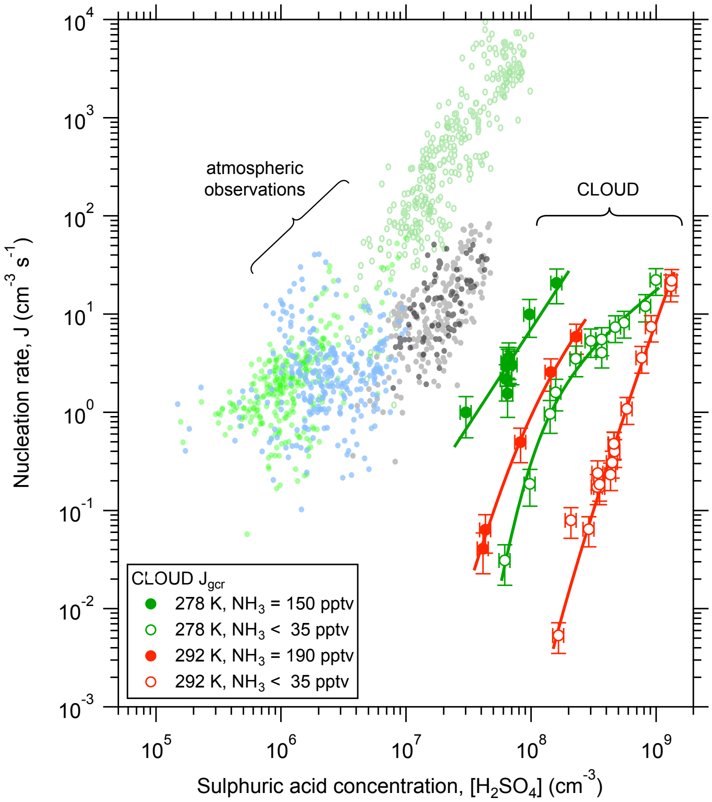

Fig. 1: Comparison of the nucleation rate of new particles as a function of [H_2SO_4] measured by CLOUD (large red and green circle symbols) with atmospheric boundary layer observations (small dot and circle symbols) [2]. The measurements at 278 K and 292 K bracket the typical range of boundary layer temperatures.

Fig. 2: View of CLOUD in the East Hall T11 zone during the June-July 2011 run to study neutral and ion-induced nucleation involving organic vapours.

2 CLOUD RUNS

There were two physics runs for CLOUD in 2011, with the following aims:

CLOUD4: June - July 2011: Neutral and ion-induced ternary nucleation involving organic vapours (dimethylamine and pinanediol, a precursor of oxidised organic species from the important biogenic vapour, alpha-pinene). The CLOUD experimental configuration in the T11 zone during the June-July run is shown in Fig.2.

CLOUD5: October - November 2011: Neutral and ion-induced binary ($H_2SO_4-H_2O$) and ternary ($NH_3-H_2SO_4-H_2O$) nucleation over the entire tropospheric temperature range (to -65°C).

3 CLOUD DETECTOR

Upgrades of the CLOUD facility in 2011 included:

- Completion of the thermal housing and precision thermo-regulation system (to -65°C).

- Cold racks (to -25°C) for the sampling instruments.
- Completion of the final manhole covers and magnetic mixing fans.
- UV sabre for a) rapid aerosol growth and b) suppression of organic contaminants.
- Gas system upgrades for precision supply of organic vapours with low saturation vapour pressures.
- Commissioning of synthetic ultrapure water system.

4 PUBLICATIONS

The publication of the first CLOUD results in Nature [2] attracted wide interest in the media and scientific press, including articles in The Economist [3], Wall Street Journal, CERN Courier [4], Nature News, and Nature Geoscience [5]. The results were also reported at numerous scientific meetings, including an invited plenary talk at the European Aerosol Conference, EAC2011, Manchester, September 2011.

The CLOUD4 and CLOUD5 runs in 2011 have revealed a number of important new findings which are currently being analysed. Several high profile (Nature/Science) manuscripts are in preparation. At least two of these will be submitted for publication before 31 July 2012. This date marks the submission deadline for papers to be eligible for inclusion in the 5th Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), which is due to be completed by the end of 2013. For the first time, a chapter in AR5 will be devoted to "Clouds and Aerosols", and it will contain a section on the influence of galactic cosmic rays.

In addition to the high profile manuscripts, a further 20 papers are in preparation for submission to Atmospheric Chemistry and Physics, an open access—and highly popular—Journal of the European Geosciences Union. Several papers have already been published [6, 7, 8, 9] and about ten more are expected to be submitted by mid 2012. Fourteen CLOUD abstracts have been submitted to the European Aerosol Conference, EAC2012, Granada, September 2012.

5 COLLABORATION

Several new partners joined CLOUD during 2011, with special expertise as indicated:

Karlsruhe Institute of Technology, Germany: laboratory measurements of aerosols, liquid- and ice clouds (AIDA facility).

University of Stockholm, Sweden: atmospheric aerosol growth from organic vapours.

Carnegie Mellon University, USA: atmospheric organic chemistry and aerosol growth.

The Memorandum of Understanding for the maintenance and operation of CLOUD has been finalised and signed by the CERN Director for Research and Computing. It is currently being signed by the 19 CLOUD partners (U Innsbruck, U Vienna, U Helsinki, Finnish Meteorological Institute, U Eastern Finland, U Frankfurt, Karslruhe Institute of Technology, Institute for Tropospheric Research - Leipzig, U Lisbon, Lebedev Physical Institute - Moscow, U Stockholm, CERN, PSI, U Leeds, U Manchester, Caltech, Carnegie Mellon, Aerodyne Research - Billerica and TOFWERK - Thun).

During 2011, CLOUD Collaboration meetings and data workshops were held at the University of Vienna, 14–18 February and Goethe University of Frankfurt, 25–30 September.

6 PHYSICS AIMS AND BEAM REQUEST 2012

The beam requests and experimental aims for 2012 are as follows:

CLOUD6: 4 June - 2 July 2012 (4 weeks): Commissioning of the adiabatic expansion system to operate CLOUD in a classical Wilson expansion chamber mode for generation of liquid and ice clouds. Instruments will be attached to CLOUD to measure, for the first time, the formation of liquid droplets and ice particles inside the chamber. The purpose of this run is to prepare for future studies of the so called "near-cloud" mechanism by which cosmic rays may directly influence cloud microphysics rather than through the production of cloud condensation nuclei (Fig. 3) [10]. Three spills per supercycle are requested.

CLOUD7: 1 October - 3 December 2012 (9 weeks): Ion-induced and neutral nucleation and growth of sulphuric acid particles in the presence of oxidised organic vapours from pinanediol and alpha-pinene (Fig. 4). This represents a follow-up investigation of the new processes discovered during the CLOUD4 run, and a new study of aerosol growth up to the size of cloud condensation nuclei (CCN). Three spills per supercycle are requested.

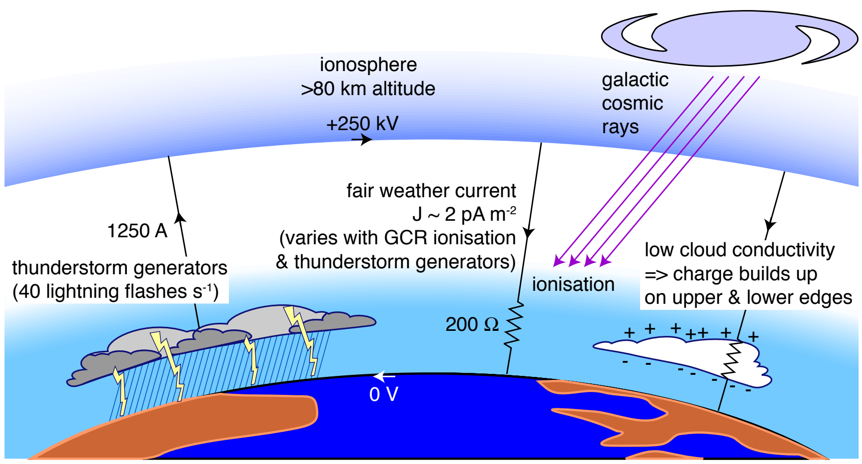

Fig. 3: The ion-aerosol "near-cloud" mechanism [10]. Highly charged aerosol particles develop at cloud boundaries due to the build-up of space charge from the fair weather current. These charged aerosol particles may then become entrained by clouds and possibly enhance the formation of ice particles.

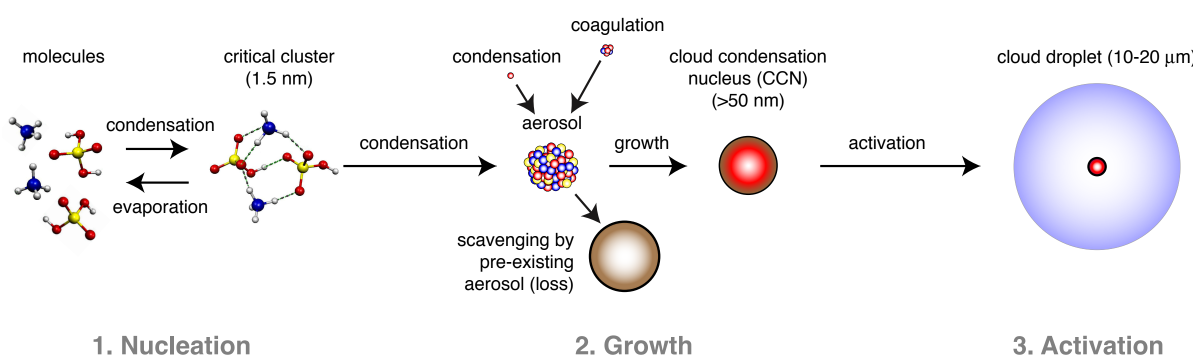

Fig. 4: Aerosol nucleation and growth to cloud condensation nuclei (CCN). Around half of global CCN are thought to originate from this process but many aspects are poorly understood, including the participating vapours, nucleation rates, growth rates at different aerosol sizes, and effect on these processes of ionisation from galactic cosmic rays.

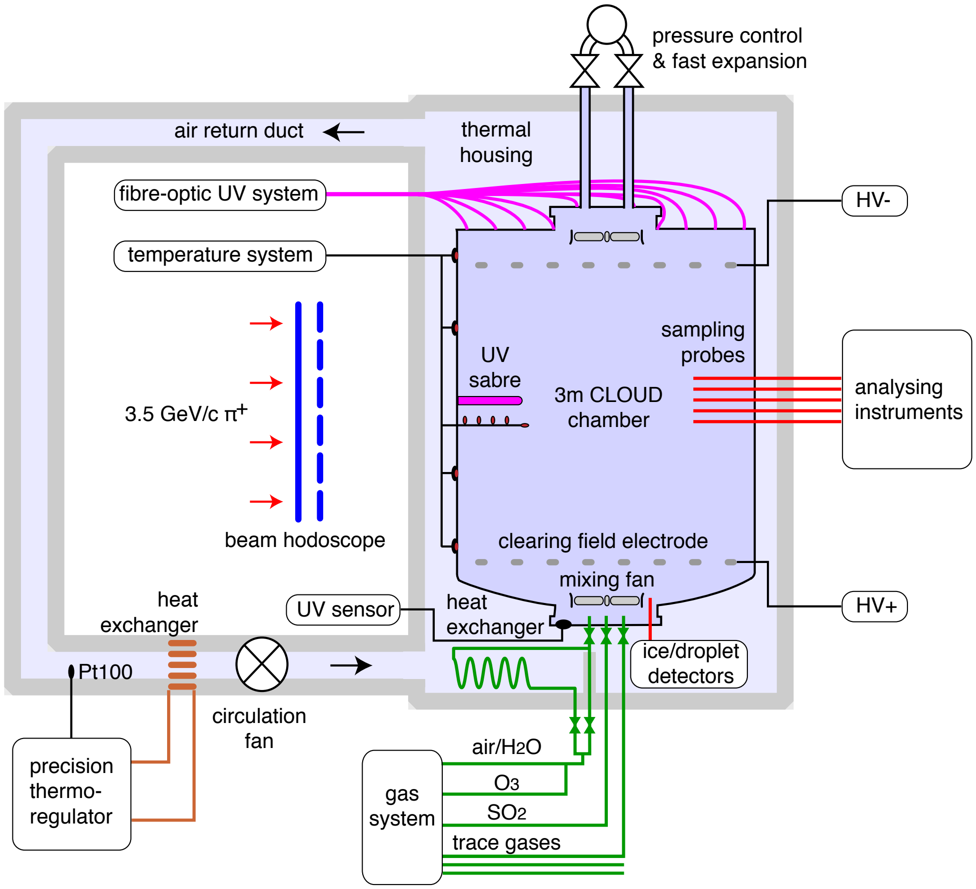

Fig. 5: Schematic of the CLOUD experiment in 2012.

7 FUTURE PLANS

CLOUD (Fig. 5) is tackling one of the most challenging problems in atmospheric science—to understand how new aerosol particles are formed and grow in the atmosphere, and the effect these particles have on the global atmosphere and climate. CLOUD also aims to answer definitively the question of whether or not galactic cosmic rays affect clouds and climate, either by affecting aerosols or by directly influencing the microphysics of liquid or ice clouds. The contribution of aerosols and clouds is recognised by the Intergovernmental Panel on Climate Change as the most important source of uncertainty in the radiative forcing of climate change.

The present poor experimental understanding of aerosol nucleation and growth is preventing the inclusion of physics-based mechanisms in global models, and limiting our understanding of how a major fraction of atmospheric aerosol will influence future climate. Development of reliable atmospheric models requires quantifying the fundamental physics and chemistry of nucleation in the laboratory, as well as a clear connection between the laboratory and the real world through these models.

In the near-term, the 2012 scientific goals for CLOUD are well-defined. During the 2013 shutdown of the CERN accelerators for the LHC energy upgrade, the CLOUD collaboration will likely devote a major effort into analysis of the large quantity of high quality data already collected during the last 3 years. Nevertheless, depending on the results obtained later in 2012, it is likely that CLOUD will operate at some stage during 2013 for special physics measurements that do not require a particle beam. We expect to begin normal data-taking operations for CLOUD when the PS beams return in 2014. The precise physics programme cannot be defined at this stage since it will depend on our findings during 2012–2103.

For the first time we have with the CLOUD facility at CERN an experimental chamber of the highest technological performance which has established itself as the world's leading experiment for these studies. CLOUD has also brought together a world-class team of atmospheric and modeling experts to conduct the experiments, analyse and interpret the data, and assess the impact of the results with global models. Nevertheless, a multi-parameter experimental phase space must be mapped, involving numerous variables such as temperature, relative humidity, trace gases and their concentrations, ionisation, nucleation rates, growth rates, droplet and ice particle activation, as well as liquid and ice cloud microphysics. CLOUD has been in operation for just over two years and we estimate around ten more years will be required to carry out the experimental programme.

The projected CLOUD experimental programme is therefore likely to extend well beyond the planned upgrade of the East Hall beamlines. After several year's experience in the T11 beamline we would like to request that T11 be retained for CLOUD in the new East Hall beamline layout, ideally with 1–2 m additional space in the experimental zone in the direction towards T10. A dedicated T11 beamline for CLOUD will maximise the efficiency and output of the experiment, and provide the maximum availability of the T9 and T10 beamlines for test-beam users.

Acknowledgements

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