EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

April 18, 2008

CERN-SPSC-2008-015 / SPSC-SR-032
18/04/2008

# 2007 PROGRESS REPORT ON PS215/CLOUD

*CLOUD Collaboration*

## 1 INTRODUCTION

In its Fourth Assessment Report, February 2007, the Intergovernmental Panel on Climate Change (IPCC) attributes more than 90% of the observed climate warming since 1900 to the rise of anthropogenic greenhouse gases in the atmosphere [1]. Aerosols and clouds are recognised as representing the largest uncertainty in the current understanding of climate change. The IPCC estimates that changes of solar irradiance (direct solar forcing) have made only a small (7%) contribution to the observed warming. However, large uncertainties remain on possible other solar-related contributions, such as the effects of changes of ultra violet radiation or galactic cosmic rays on aerosols and clouds. So far, no quantitative estimates of galactic cosmic ray-induced changes in aerosol and cloud formation have been reached. Experiments are planned for the CERN PS215/CLOUD facility to quantitatively address this discrepancy.

During 2007 the CLOUD activities have mainly involved 1) analysis of the 2006 beam data from the CLOUD Mk1 prototype, 2) preparation of the engineering design for the new CLOUD Mk2 prototype and 3) submission of funding proposals to the EU FP7 and national agencies. These activities are briefly summarised in this document, together with a request for CERN PS T11 beam time to set up and take physics data with the CLOUD Mk2 prototype.

## 2 ANALYSIS OF Mk1 PROTOTYPE BEAM DATA

During autumn 2006, the CLOUD Mk1 prototype was operated at the CERN PS both to provide technical design input and also to study the effect of ionising particle radiation on aerosol formation and early growth, in the presence of UV radiation and under atmospheric conditions. The aerosol chamber involved a $2 \times 2 \times 2$ m$^3$ stainless steel chamber built by the Danish National Space Center (DNSC). The ions were detected using an air ion spectrometer (AIS) from U. Helsinki, and the aerosol particles using an SMPS and a CPC battery from PSI and U. Mainz. Gas-phase $H_2SO_4$ was measured by a mass spectrometer (CIMS) of MPIK-Heidelberg. The chamber was filled with ultra-pure air obtained from the evaporation of cryogenic $N_2$ and cryogenic $O_2$ liquids, provided by CERN and U. Helsinki, to which were added water vapour and trace amounts of $O_3$ and $SO_2$. The trace gas concentrations and chamber conditions (T, RH, UV) were continuously measured during the run.

After extensive flushing and cleaning cycles with elevated $O_3$ concentrations (few $\times$ 100 ppb), extremely clean conditions could be achieved in the aerosol chamber, in terms of low particle background conditions (<0.1 particle/cm$^3$ above the 3nm detection threshold) and low pre-existing concentrations of $H_2SO_4$ (less than the detection limit of about 0.03 ppt). Aerosol nucleation bursts were generated and their characteristics analysed. Typical formation rates were about 10 cm$^{-3}$s$^{-1}$, and growth rates of about 10 nm/h. The corresponding $H_2SO_4$ concentration was around $10^6$ cm$^{-3}$. The observed nucleation rates are somewhat higher than observed at atmospheric conditions. However, the slope of the nucleation rate vs. $H_2SO_4$ concentration is similar to that observed at atmospheric conditions, supporting the idea that existing clusters are activated, probably by sulphuric acid. However, sulphuric acid is not able to explain

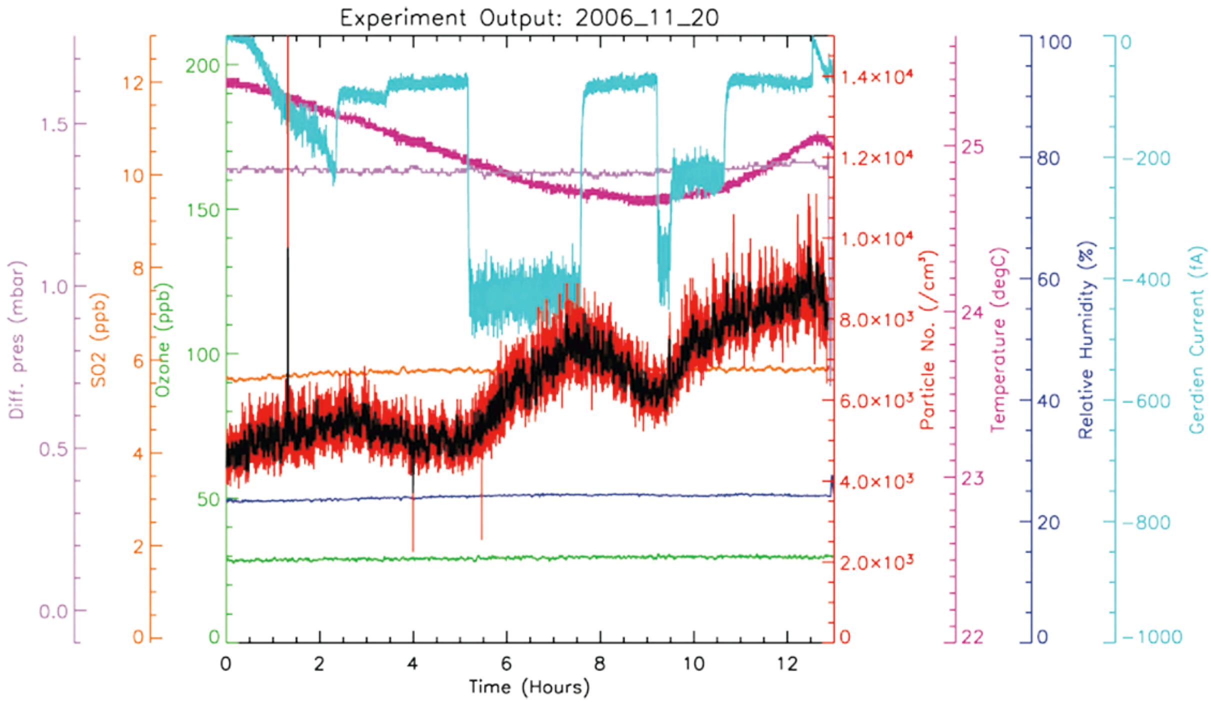


**Fig. 1:** On-line plot from the Mk1 2006 beam data showing indications of ion-induced nucleation events. The figure shows the progression of various aerosol chamber parameters over a 13-hour period ($x$ axis). Each parameter is indicated by its corresponding colour-coded $y$ axis label. The red/black curve shows the aerosol number concentration (3 nm threshold size). The cyan curve shows the conduction current of air samples extracted from the aerosol chamber and passed through a Gerdien counter (note inverted scale). This directly measures the ion pair concentration due to varying beam intensities, which produce the observed steps. The beam was first turned on at 00:00 but, due to a charging effect in the Gerdien counter, it did not record a reliable reading until about 02:00. No other chamber parameters were changed during this period, although temperature variations of the chamber due to variations of the East Hall temperature can be seen in the purple curve. Variations of the aerosol number—both increases and decreases—appear to be initiated by changes of the beam intensity. Note that the increase of the chamber temperature after 10:00 hours indicates that the data were unreliable after that time.

the observed growth, suggesting the possible presence of additional trace gases in the chamber that were not measured.

Interestingly we were able to observe different kinds of new particle formation events. Some of the events are related to ion induced nucleation and ion-ion recombination to form neutral clusters. In these cases, up to as much as half of new particle formation can be explained by ion processes (an on-line example is shown in Fig. 1). However, during some nucleation events less than 1% of new particle formation can be explained by ion processes. These results are being prepared for conference presentation.

In summary, the Mk1 tests confirmed the feasibility of the CLOUD experiment and provided important input for the technical design, as well as providing initial indications of ion-induced nucleation events.

## 3 Mk2 DESIGN

A new 3m aerosol chamber—the CLOUD Mk2 prototype (Figs. 2–4)—has been designed for the next CLOUD run at the CERN PS. The chamber is constructed from stainless steel and will operate near

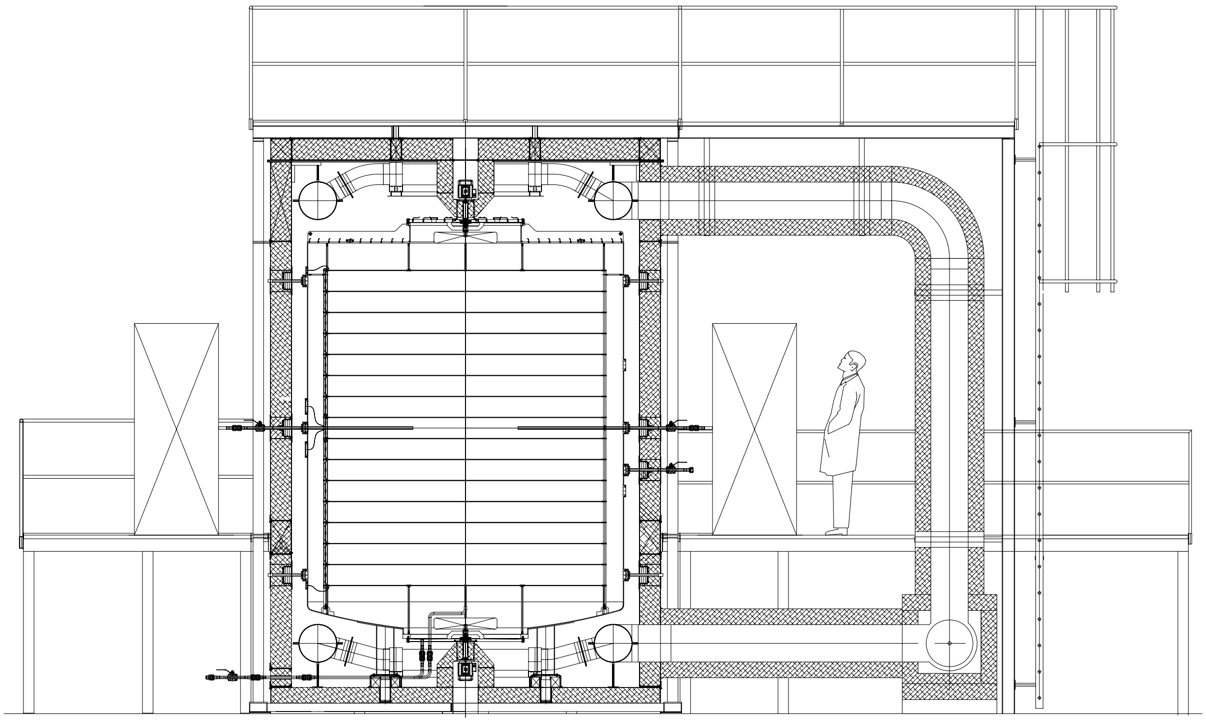

**Fig. 2:** Vertical section through the CLOUD Mk2 prototype showing the 3m aerosol chamber and its thermal control housing. Also shown are the field cage, fibre-optic UV illumination (through the roof plate), circulation fans, sampling probes, racks housing the analyser instruments and a typical man (1.75m).

1 atm pressure, but can accommodate modest (around 10%) adiabatic pressure reductions to allow for droplet activation. It will be operated between about -50°C and 40°C. In comparison, the Mk1 chamber operated strictly at 1 atm pressure and room temperature. The Mk2 prototype incorporates many design improvements that were learnt during the Mk1 beam run in 2006, among which are:

- **Temperature stability:** Reliable nucleation measurements require a temperature stability for the chamber of around 0.1°C. This will be achieved with a thermally-insulated housing through which precisely-temperature-controlled air will circulate. All thermal sources (electronics, etc.) are located outside this enclosure. The temperature of the inlet gas will be equalised with the chamber, before entry. Furthermore, a new design for the UV system has been developed based on optical quartz fibres which eliminates the large thermal load present in the Mk1 prototype from the bank of UV lamps. This should allow UV burst experiments to be carried out without any appreciable temperature rise in the chamber

- **Cleanliness:** CLOUD is measuring processes involving ppt concentrations of trace condensable gases. This requires extreme attention to inner surface cleanliness, to the absence of leaks in the detector and to the strict avoidance of unsuitable materials. The inner surface of the Mk2 chamber will be electropolished, as will the stainless steel sampling probes and the stainless steel pipes that supply the chamber gases. The successful Mk1 ultra-pure air system from cryogenic liquids will be re-used for the Mk2. A completely new gas system is being designed to humidify the ultra-pure air and add the trace gases. The homogeneity of the chamber contents has been optimised by the addition of two internal, magnetically-coupled, fans located at the top and bottom of the chamber (Fig. 2). No plastic materials will be used in the chamber or gas supply system. The chamber seams are welded, and metal seals are used on all access ports, windows and feedthroughs. All the

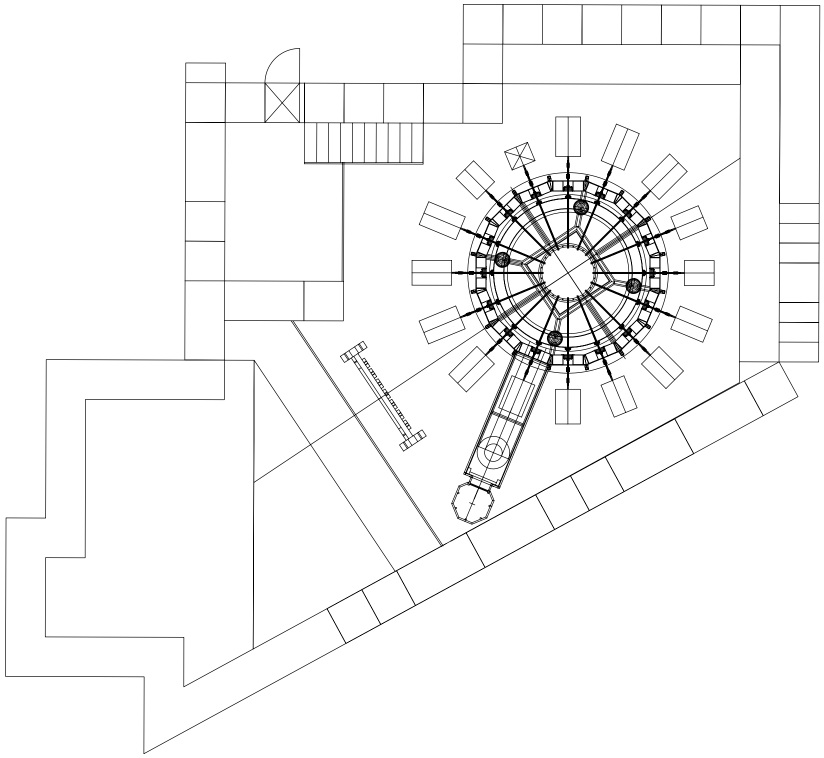

**Fig. 3:** Horizontal section through the 3m CLOUD Mk2 prototype. The East Hall T11 experimental area is shown after modifications for the 2009 beam tests (notably, suppression of the gas alcove).

**Fig. 4:** The bare 3m aerosol chamber, showing the ring of 16 sampling ports in the mid plane and the access hatches at the top and bottom.

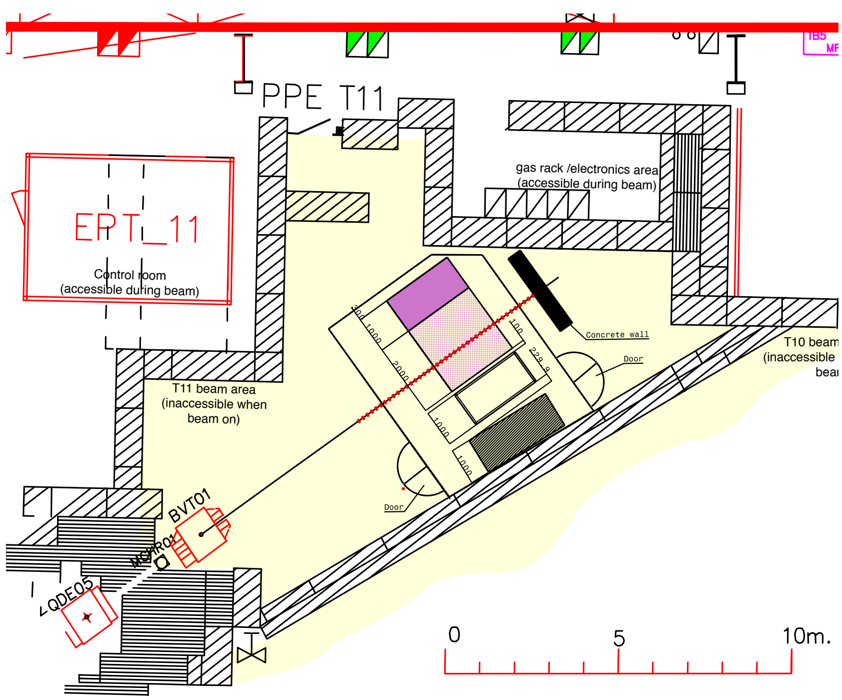


**Fig. 5:** East Hall T11 experimental area for the 2006 beam tests of the 2m CLOUD Mk1 prototype.

sampling ports/probes will be equipped with isolation valves (there were none for Mk1). The Mk2 chamber will be bakable to about 100°C and has the facility to be internally cleaned *in situ*.

- **Analysing instruments:** The Mk2 will allow up to 16 external analysers to be attached to the chamber via sampling ports (Figs. 3 and 4). The chamber will also be equipped with optical ports to view droplets and ice particles created inside the chamber during activation studies (adiabatic expansions). A more advanced range of analysers will be employed compared with the Mk1. Among the new instruments will be a proton-transfer-reaction mass spectrometer (PTR-MS) developed by U. Innsbruck for ultra-sensitive detection (ppt concentrations) of volatile organic compounds. In addition, new instruments are being developed in the collaboration to detect aerosols below the 3 nm size threshold of current commercial particle counters.

- **Space for analysing instruments and local electronics:** In order to avoid large transmission losses, the sampling lines into the analysing instruments must be not more than a few tens of centimetres in length. This implies that large instruments must be efficiently located in close proximity to the chamber. By rotating the chamber relative to the Mk1 orientation, and by suppressing the gas alcove in T11 (Figs. 3 and 5), a greatly-improved layout can be achieved for the sampling instruments. Discussions have taken place with the PS and East Hall coordinators on the T11 area modifications, which are planned to take place during 2008.

- **Beam size:** For the 2006 run, the T11 beam dimensions ($1 \times 1.2$ m$^2$) were significantly less than the chamber ($2 \times 2$ m$^2$). This should be much improved for future operations since the aperture of the final dipole has been increased by 50%, and CLOUD will be located further downstream, allowing the beam to diverge further. However, further development of the T11 beam optics is desirable to produce the largest possible beam size for CLOUD. For the next run, CLOUD will install a new counter hodoscope to measure the beam intensity and $x/y$ profile, and also a cosmic ray counter to monitor the hard and soft galactic cosmic ray components in the T11 experimental area.

## 4 PLANNING

### 4.1 Collaboration aspects

Full CLOUD collaboration meetings are held approximately twice each year. During the past year, the collaboration has met in Helsinki (2–4 April 2007), Salzburg (12 September 2007) and Frankfurt (7–8 February 2008). The experiment is led by the CLOUD Steering Committee, comprising six senior partners and chaired by the spokesperson. All major policy decisions are made by the Collaboration Board, which comprises each of the institute leaders within the collaboration. During 2007, and with the assistance of CERN management, a Collaboration Agreement was prepared and adopted for CLOUD. It provides the constitutional framework for the experiment and is based on similar documents for the LHC experiments.

Two new groups have recently joined the CLOUD collaboration: the University of Lisbon, Portugal (A. Amorim) and the Institute for Nuclear Research and Nuclear Energy (INRNE), Sofia, Bulgaria (J. Stamenov). Both groups are taking responsibilities in the Mk2 design and construction, namely in the UV system and DAQ (Lisbon), and in the Mk2 chamber and infrastructure (INRNE).

### 4.2 Resources

**EU FP7 proposals:** Two EU Framework 7 proposals were submitted in 2007 to support CLOUD activities: CLOUD-DS (CLOUD design study in the Capacities–Research Infrastructures–Design Studies framework, 2.8 M€) and CLOUD-ITN (network of 10 Marie Curie fellows, 2.4 M€). The CLOUD-DS proposal was eventually rejected as being outside the scope of the call (CLOUD is considered by the EC as an experiment, not a research infrastructure facility). On the other hand, the CLOUD-ITN proposal was approved and the project will start in June 2008. It involves 8 Ph.D. students who will carry out their thesis research on the CLOUD Mk2 prototype and subsequent upgrades, plus 2 postdocs, for a period of 3 years (i.e. 30 person-years total). One of the postdocs will be permanently based at CERN.

**National funding:** All of the analysing instruments for the Mk2 prototype will be provided by the partner institutes, supported by their national funding agencies. The Lebedev Physical Institute has been awarded a research grant to support CLOUD activities by the Russian Foundation for Basic Research (RFBR) under the CERN-RFBR agreement on scientific cooperation. The design manpower for the CLOUD Mk2 facility (aerosol chamber, thermal housing, field cage, UV system, gas system and infrastructure) is being provided by PSI (10 person months engineering), CERN (engineering support and 6 person months designer) and, for the UV system, U. Lisbon. The construction costs of the CLOUD Mk2 facility will be paid from a common fund shared among the partner institutes and by in-kind contributions.

### 4.3 Beam request and schedule

At the Frankfurt CLOUD collaboration meeting, 7-8 February 2008, the design, construction and planning for the next CLOUD run in T11 was discussed. One of the key analysers is a CIMS (Chemical Ion Mass Spectrometer) that can measure $H_2SO_4$ concentrations at the sub-0.1 ppt level. There are only 3 groups in the world at present that are operating such CIMS (of which one is in CLOUD). Unfortunately, the CIMS will not be available for the previously-planned T11 run in September–November 2008. Since this device is critical for CLOUD, we decided at the Frankfurt meeting to postpone the fall 2008 run in T11 until PS startup in 2009. Since this run will be a major data collection period for the 10 Marie Curie fellows who will join CLOUD in the second half of 2008, a spring 2009 run will also better match their schedules. Furthermore, after discussions with several potential companies for construction and electropolishing of the Mk2 chamber, the new requested schedule of spring 2009 also well matches the construction schedule.

Our beam request is therefore as follows:

- Postponement of the PS215/CLOUD 10-wk run from Sep-Nov 2008 until PS startup in 2009. It is our understanding that the 2009 accelerator schedule is not yet defined but, if it is similar to this year, this would indicate a beam request of May–July 2009.

## 5 CONCLUSIONS

CLOUD made further good progress in 2007. The 2006 beam data from the CLOUD Mk1 prototype has been analysed and the first physics results from the experiment are ready for conference presentation. The engineering design for the Mk2 prototype has been prepared. The new detector incorporates many design improvements that were learnt during the Mk1 beam run in 2006, and represents a very large advance in performance relative to the first experiment. The financial and manpower resources for the experiment have developed significantly—in particular with the successful EU FP7 award of a network of 10 Marie Curie fellows who will carry out their thesis research on the CLOUD Mk2 prototype.

It is foreseen that the 3m CLOUD Mk2 prototype will be capable of a broad range of important physics measurements over a period of 2–3 years, and its performance and physics reach can be substantially developed over this period. After this time, it will be replaced with the final CLOUD facility, which will include an aerosol pressure chamber of around 4.5m diameter. This chamber will be too large for the T11 area and will require installation in the downstream half of an extended T9 or T10 beamline. Preliminary discussions have begun with the PS and East Hall coordinators on the long-term plans for the East Hall beamlines.

## References


[1] IPCC Fourth Assessment Report - Working Group 1 Report, "The Physical Science Basis" (2007). http://www.ipcc.ch/ipccreports/ar4-wg1.htm

[2] *CLOUD Collaboration,* A study of the link between cosmic rays and clouds with a cloud chamber at the CERN PS, CERN proposal SPSC-P317, SPSC-2000-021 (2000); CERN SPSC-P317 Add.1, SPSC-2000-030 (2000); CERN SPSC-P317 Add.2, SPSC-2000-041 (2000); CERN-SPSC-2004-023, SPSC-M-721 (2004); CERN SPSC-P317 Add.3, SPSC-2006-004 (2006); CERN SPSC-SR-019, SPSC-2007-014 (2007).