Title: Cloud Physics Facility and Experiments for an Underground Laboratory

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At least 35 other scientists (nationally and internationally) have expressed interest in conducting experiments in such a facility, when it is functioning.

Program Description: In recent years there has been resurgence in the study of the detailed microphysical processes that result in the development of clouds and precipitation (rain, snow, sleet, hail, etc.). Studies of these processes in the last decade have been undertaken primarily through numerical modeling efforts, due to ever increasing computer power, while experimental laboratory cloud physics has declined. However, the results of numerical modeling have come to the point where the necessary knowledge of the interaction coefficients between different sized particles is the limiting factor. The detailed schemes in the models have outstripped knowledge of how individual and ensembles of cloud particles interact, limiting further advances. In addition, a recent study by the National Research Council (NRC), under the auspices of the National Academy of Sciences (NAS), has pointed out that better understanding of cloud microphysical processes is essential to resolving uncertainties in understanding global climate change (National Research Council, 2001). The report found that 60% of climate sensitivity was due to feedbacks involving, primarily, water vapor and clouds, with the remainder attributable to greenhouse gases and aerosols. One of the conclusions of this study was that "…uncertainties will remain until a more fundamental understanding of the processes that control atmospheric relative humidity and clouds is achieved."

Another study commissioned by the NAS and carried out by a committee of the NRC was one concerning issues surrounding weather modification research (National Research Council, 2003). The report looked at the status of the science underpinning weather modification and called for a national program to "…answer fundamental questions about basic atmospheric processes and to address other issues that are impeding progress in weather modification." The study concluded, in part, that there are "…critical questions about the microphysical processes leading to precipitation…" that need to be addressed. The committee recommended that "…a coordinated national program be developed to conduct a sustained research effort in the areas of cloud and precipitation microphysics, cloud dynamics, cloud modeling, and cloud seeding; it should be implemented using a balanced approach of modeling, laboratory studies, and field measurements designed to reduce the key uncertainties…". This proposal to create a cloud physics laboratory using a mineshaft in the Homestake mine as part of the Deep Underground Science and Engineering Laboratory (DUSEL) effort would work to reestablish the experimental laboratory branch of cloud physics needed to address the uncertainties brought to light in the two NRC reports.

Laboratory work related to the microphysical evolution (at the individual cloud particle level) has been carried out in the past in small-scale cloud chambers. However, the limited size of these chambers has not provided a sufficiently real cloud environment within which to fully test theories of cloud droplet and ice particle formation, growth, and interaction leading to the formation of precipitation (both liquid and frozen). One of the greatest unknowns in cloud physics is the nature of the transformation of small cloud particles to large precipitation particles on time scales of a few tens of minutes (including the influences of initial aerosol concentrations, turbulence, and electrical effects) as noted in National Research Council (2003). The creation of a Cloud Physics Facility within a mineshaft that extends for hundreds of meters would provide an environment where clouds could form naturally (on specified aerosol distributions) and be monitored over depths not achievable in normal laboratories. The ability to observe the vertical variation of cloud particles sizes and interactions over larger depths will give us the capacity to determine the details of the transformation to precipitation for the first time.

Some of the experiments that have already been identified through email contact with the cloud physics community for warm-cloud studies include: 1) examining individual particle interactions to determine the coefficients associated with collisions between different sized particles (collision and coalescence efficiencies), 2) effect of aerosol mixtures (organic and inorganic, combustion produced) on cloud properties, 3) turbulence effects (mm to cm length scales) on the evolution of cloud properties, 4) how precipitation forms (role of different aerosols and turbulence in the overall process), 5) hygroscopic seeding agent activity under varying cloud conditions, 6) comparison of 1D adiabatic parcel models with experimental observations, 7) cloud chemistry studies (longer time scales available compared with traditional laboratories), 8) instrument intercomparisons, 9) radiative transfer characteristics under various cloud conditions, 10) Lidar tests for different cloud conditions. Other experiments would come from the workshop held to help design the optimum laboratory.

There is one experiment that is a potential user of the Cloud Physics Facility already under review at NSF. As a part of the recent NSF EPSCoR Infrastructure proposal from South Dakota involving Nano-science, an experiment to develop nanoscale hydrogels that would act as condensation nuclei for cloud droplet formation was included. The experiment would be a joint venture of the Univ. of South Dakota and the SD School of Mines & Technology. The unique aspect of these hydrogels is that they would fluoresce upon becoming wet. The emitted light would make the particles much more visible in the context of a cloud chamber, making the tracking and visualization of interactions much easier than in traditional experiments. The particles would be tested initially in condensation nucleus counters, but their utility in a large-scale cloud chamber would need to be tested as part of the proposed science. The proposed Cloud Physics Facility would be ideal for these initial tests and success of the tests would lead, not only to the development of new proposals for the Facility, but also a new technology for improving visualization of the experiments that would be conducted.

<u>Estimate of Space Requirements</u>: We propose to construct the cloud physics facility using the Number 5 shaft and its surface access at the Homestake mine in Lead, SD. Initially, the shaft would be refurbished and surface facilities installed to undertake warm-cloud studies, where the cloud forms through condensation and precipitation forms

through coalescence (no ice process present). Ultimately, the facility could be outfitted with cooling equipment so that the air and shaft chamber could be cooled below 0°C in order to allow for the formation of ice crystals so that ice processes leading to precipitation could also be studied. The initial infrastructure development would be undertaken with the creation of a laboratory at the base of the shaft (excavated room) for experiment preparation, equipment maintenance, and monitoring; the refurbishing of the shaft for experimental use; and modification of facilities at the surface access to the shaft to accommodate experiments. Additionally, creation of the Facility would require the installation of equipment 1) to control the airflow in the shaft, 2) to precondition the air entering the shaft and monitor and modify its aerosol content, 3) to monitor the progress of experiment (video and other instrumentation hardened against the wet environment), 4) for computer recording and archiving of data as well as modeling studies of airflow behavior, 5) for communications links to the School of Mines for data analysis and permanent archiving, and 6) other equipment that is identified as necessary for the conduct of experiments. One of the first tasks to be undertaken would be to convene a workshop of potential users to identify potential experiments that could be done in the facility as well as the necessary generalized instrumentation to carry them out (other than very specialized equipment that would be experiment dependent). By tapping into the international user community, the facility can be designed to accommodate as many experimental ideas as practical, thereby making it a very attractive facility and guarantee its continued use.

Access Requirements: The experiment involving hydrogels would begin sometime in 2006, depending on NSF funding timelines. It is likely that the material would be ready for testing in the Cloud Physics Facility by the end of 2007 or certainly during 2008. It is likely that the refurbishment of the mine shaft and development of the Cloud Physics Facility would not be complete until the end of 2007, indicating that the experiment would be ready when the Facility was ready. The proposed Facility would usher in a new era in cloud physics research that could have profound affects on our understanding of climate and climate change. It would provide the data needed for models to improve their predictive capabilities and improve our ability to forecast weather on various time scales. Based on already-expressed interest, the Facility would become a world center for experimental cloud physics research that would fully complement modeling and field studies.

References

National Research Council, 2001: *Climate Change Science: An Analysis of Some Key Questions*, National Academy Press, Washington, DC, 36 pp.

National Research Council, 2003: *Critical Issues in Weather Modification Research*, National Academy Press, Washington, DC, 144 pp.