Report of Sabbatical Leave Activity, 2004-2005

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Overview

This document summarizes my activities and major accomplishments during my sabbatical leave for the 2004-2005 academic year. Briefly, I spent Fall Semester 2004 at Cornell University, collaborating with members of the Mechanical and Aerospace Engineering, and Physics Departments, and Spring Semester 2005 at the Leibniz Institute for Tropospheric Research (Leibniz-Institut für Troposphärenforschung) in Leipzig, Germany, collaborating with the Atmospheric Physics Division. The sabbatical leave was successful in allowing me to develop the intended collaborations and to carry out the proposed experiments. As a direct result of our work, one paper has been submitted for publication and four are in preparation. Furthermore, the collaborations fostered during my leave are continuing in the form of joint proposals for future work.

The major scientific accomplishments of the sabbatical leave can be summarized as follows: Using laboratory and computational facilities at Cornell University, and a helicopter-based platform at the Institute for Tropospheric Research (IfT), along with a newly developed instrument from Michigan Tech we studied the *spatial distribution* of droplets in turbulent clouds, as a function of droplet size and turbulence intensity. This clustering effect is directly relevant to collision rates of droplets in a turbulent cloud, and quantifying them will shed light on the exact physical mechanisms for particle-turbulence interactions. This, in turn, provides insight into the formation of precipitation in the earth's atmosphere, a problem of practical interest.

Cornell University, August-December 2004

I spent Fall 2004 as a Visiting Professor in the Sibley School of Mechanical and Aerospace Engineering and the Department of Physics at Cornell University. While there I collaborated with Professors E. Bodenschatz, L. Collins, and Z. Warhaft on theoretical, computational, and experimental studies of particle-turbulence interactions. Our primary effort was to carry out a laboratory experiment using an instrument recently developed by our group at MTU (in collaboration with P. Chuang, UC Santa Cruz, and W. Bachalo, Artium Technologies), known as Phase-Doppler Interferometer for Cloud Turbulence (PICT; see Fig. 1). The instrument measures arrival time, size, and longitudinal speed of particles that enter its measurement volume. The experiment was carried out in a 15-meter-long wind tunnel with sprays for injecting particles into the flow. Air entering the tunnel is actively mixed with an array of flaps that are randomly rotated, and therefore is highly turbulent. Qualitatively the random movement and mixing of particles in turbulence is analogous to that of atoms in a gas. Together with MTU Physics graduate student Ewe Wei Saw, we studied how small particles interact with the turbulent flow, with the goal of determining the collision rate inside this "particle gas." The experiments provide strong evidence that droplets cluster at small spatial scales in turbulence due to finite inertia:

essentially, they are flung out of vortices into more quiescent regions of the flow (see Fig. 2). This results in an increase in the mean collision rate, and therefore has implications for multiphase industrial and geophysical systems where turbulence is present. The first results of the study were recently presented at the Meeting of the Division of Fluid Dynamics, of the American Physical Society, and a paper describing the results is in preparation.

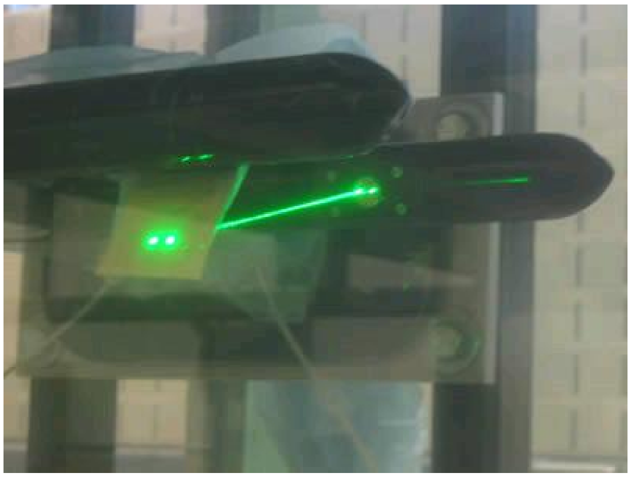

Figure 1: The Phase-Doppler Interferometer for Cloud Turbulence measuring droplets in the high-Reynolds-number, active grid wind tunnel at Cornell University.

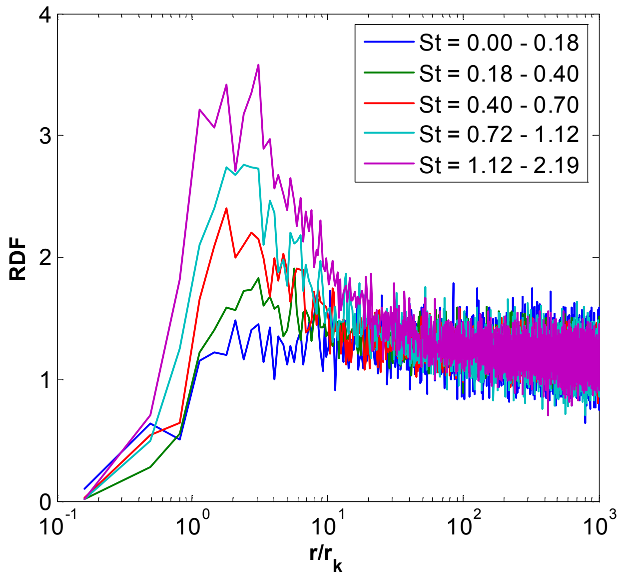

Figure 2: Radial distribution functions for droplets measured in the wind tunnel. Droplet clustering increases with droplet inertia and turbulence intensity, as quantified with the Stokes number.

Institute for Tropospheric Research, January-May 2005

Spring 2005 was spent at the Institute for Tropospheric Research (IfT) in Leipzig, Germany, where I collaborated with Dr. H. Siebert, MTU physics student E.W. Saw, and others on a project to take our PICT instrument into atmospheric clouds. This was accomplished using the unique Airborne Cloud-Turbluence Observation System (ACTOS; see Fig. 2) developed at IfT. ACTOS is equipped to measure air turbulence, cloud liquid water content, and aerosol properties, as well as to host other instruments such as PICT. During our experiments ACTOS was suspended on a 140-meter-long tether from a helicopter, and simultaneous measurements of cloud droplet properties and atmospheric turbulence were made with the highest resolution ever attained in clouds. The early data analysis tends to confirm the view that emerged from the controlled laboratory experiments at Cornell: highly turbulent regions show signs of strong interaction with droplets, and therefore enhanced droplet clustering and collision rates. Unlike the laboratory, however, turbulence in clouds is found to be extremely intermittent, with much higher chances of encountering patches of turbulence much more vigorous than the mean. This may imply that the earliest raindrops to form in a cloud originate in small pockets of highly turbulent air at the edges or tops of clouds.

Figure 2: The ACTOS instrument payload (top left) and the helicopter used for deployment (top right). ACTOS during takeoff (bottom left), and a view from the helicopter looking down on ACTOS in the clouds (bottom right).