# Results from Cloud Physics Experiments

Eberhard Bodenschatz

Max Planck Institute for Dynamics and Self-Organization, Göttingen

In my talk I will touch upon two topics. One is on observations on the sling effect of inertial particles and the second is on observations from the Research Station Schneeferner Haus in the Bavarian Alps:

## (1) The sling effect

We report the first experimental support for the sling effect. We observed liquid water-alcohol droplets in a turbulent air flow, following their motions in three dimensions with two cameras. The turbulence was approximately isotropic with a Taylor Reynolds number of about 200. The resulting droplet Stokes numbers were between 0.1 and 0.7, depending on the intensity of the turbulence and the size of the droplets. We used two-droplet statistics to characterize the droplet velocity field and its gradient. The evidence in support of the sling effect includes: **1**. The existence of droplet velocity gradients that were large enough relative to the droplet response time for slings to occur, according to the theory. **2.** The observation that on average, large negative droplet velocity gradients grew increasingly sharp over time, consistent with the dynamics of a sling. 3. The observation that during these large gradients, the droplet motions were uncorrelated with those of the background flow.

*This work was conducted with Greg Bewley and Ewe-Wei Saw*

## (2) Schneefernerhaus as a cloud-turbulence research station: Flow conditions, large-scale turbulence, and turbulence induced 'cloud holes'

Cloud measurements are usually carried out with airborne campaigns, which are not only expensive, but are also limited by weather conditions and low spatial resolution. Ground based measurements at elevated research stations therefore play a complementary role in cloud study. Using the meteorological data (wind speed, direction, temperature, humidity, visibility, etc.) collected by the German weather service (DWD) over the last 10 years and turbulence measurements recorded by multiple ultrasonic sensors (sampled at 10 Hz) during the past two years, we show that the Umweltforschungsstation Schneefernerhaus (UFS) located in the German Alps, at a height of 2700m, is a well-suited station for cloud-turbulence research. The wind at UFS is dominantly in the east-west direction and nearly horizontal. During the summer time (July and August), there is about 25% of the time that the UFS station is immersed in warm clouds, which are either in the formation process, as moist air rises up from the valley in the east, or strongly convective as being advected by the wind from the west. Wind turbulence, as measured from the second and third order velocity structure functions that exhibit well-developed inertial ranges, possesses Taylor microscale Reynolds numbers between 1500 and 3500. In spite of the complex topography, the turbulence appears to be close to isotropic when evaluated on the “Lumley-triangle”.

Intense turbulence can cause inertial particles in the flow, such as water droplets in air, to cluster in certain regions of the flow field while avoiding other regions, and this mechanism may influence the growth rate of cloud droplets due to collisions, despite the relatively weak particle inertia and the settling by gravity. Previous studies of such effect focused on the interaction between cloud droplets and small-scale turbulence, i.e., below Kolmogorov scale. From images taken in our recent field campaign at Schneefernerhaus research station on top of Zugspitze we observe evidence of direct interaction between cloud droplets and tube-like structures in the turbulent flow. These worm-like structures have cores devoid of water droplets, which suggests that they are highly rotational. The typical diameter of these tubes, measured by the sizes of the voids, is about 5 cm, in accord with the Taylor microscale estimated from independent flow measurements. This is in contrast to the voids observed during cloud – clear air mixing, which exhibits a wide range of scales. We speculate that these cloud-free vortex worms are a manifestation of turbulence intermittency, suggesting that even for modest droplet sizes strong inertial response can be observed. If so, the observation provides support for mechanisms suggested to enhance droplet growth rates in clouds. While the shear due to the boundary effect of the mountain could certainly play a role in the generation of these structures, it has been shown that shear is also present in turbulent flows in free cumulus clouds.

*This work was conducted with Steffen Risius, Haitao Xu , Jonathan Bodenschatz, Hengdong Xi, Raymond Shaw, and Holger Siebert*