II-3 Warm Clouds and Turbulence

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CLOUDS ARE dispersions of water droplets and ice particles embedded in and interacting with a complex and turbulent flow. Like other phenomena in the atmosphere, clouds are highly nonstationary, inhomogeneous, and intermittent. They embody an enormous range of spatial and temporal scales. Strong coupling across those scales between turbulent fluid dynamics and microphysical-chemical processes, e.g., evaporation and condensation, freezing and melting, deposition and sublimation are inherent to cloud evolution [1] (see figure 1). As discussed in [1], the effect of turbulence on clouds is largely unknown. A noticeable example is the rain formation in warm clouds. Cloud droplets are initiated by water vapor condensation on aerosol particles (cloud condensation nuclei, CCN). The growth of cloud droplets by condensation slows down with the increase of droplet size. It is believed that collision-coalescence dominates for droplets of size 10-20 μm and larger. When analyzing the growth rate by coalescence, the difference in gravitational settling velocities due to droplet size difference had long been regarded as the leading mechanism for raindrop initiation. However, this approach overestimates the time to rain formation by up to a factor of 10. Recent studies suggest that the collision rate among droplets could be greatly enhanced due to hydrodynamic interactions between droplets and turbulence [2, 3]. In addition, turbulence governs entrainment and mixing of dry, moist, and droplet-laden air. To a large extent, the difficulty in this problem lies in the fact that cloud turbulence spans a huge range of spatial and temporal scales. At present, it remains extremely difficult to mimic cloud conditions in laboratory experiments or numerical simulations. Field observations using state-of-the-art measurement techniques constitute one of the promising options.

We have been carrying out measurements of cloud-turbulence interactions at Umwelt Forschungsstation Schneefernerhaus (UFS) on the top of Zugspitze (2700 m above sea level). The wind at UFS is preferentially in the east-west direction, which helps reduce the complexity in the design of the measurement apparatus. Moreover, there is a relatively high probability to have clouds covering the observation site at UFS in the summer. Since August 2009, we have conducted 3 field campaigns at UFS. We have successfully set up ultrasonic sensor arrays to monitor the atmospheric turbulence and have conducted pilot Lagrangian particle tracking measurements of cloud droplets using a prototype device consisting of three high speed cameras installed in a stationary, water-proof box (figure 2). These measurements are complemented by simultaneous cloud microphysics measurements, including temperature, liquid water content, droplet number density, droplet size, and Eulerian air velocity measurements, carried out by our collaborators H. Siebert from Leipzig and R. Shaw from Michigan Tech. Analysis of these data is on the way. Currently, we are constructing an apparatus that will use a “sled” to drive our droplet-tracking system at the mean wind speed, by which we can follow cloud droplets for longer times. The droplet-tracking system, similar to the one tested in the prototype, will be driven by a linear motor with a speed up to 7.5 m/s along a 6.6 m long rail (see figures 2 & 3). In each run of the sled, the high-speed cameras can record up to 1 second of the motion of cloud droplets, which is equivalent to approximately 30 Kolmogorov times, more than enough to resolve droplet dynamics relevant to collision and coalescence.

In addition to field observations, we also conduct well-controlled laboratory experiments in our pressurized wind tunnel and in small-scale turbulence generators (e.g. the “soccer-balls” [4]), in which the turbulence properties can be fine tuned. By compressing gases, e.g., air, nitrogen, or SF_6 (an inert, heavy gas), to high pressure, we can reduce gas kinematic viscosities and the flow in the wind tunnel can reach a condition very close to that in natural clouds – much closer than those achieved in previous lab experiments. In these experiments, we can study not only the hydrodynamic interaction between droplets and turbulence; we can also change the microphysical properties of the flow, such as supersaturation and temperature. Moreover, we are working together with two numerical simulation groups to study the mixing and entrainment in cumulous clouds. S. Raasch from Hannover is modeling the dynamics of a complete cumulous cloud throughout its lifetime using LES together with Lagrangian droplets. J. Schumacher from Illmenau is modeling the detailed interaction between turbulence (resolved by DNS) and cloud droplets (treated as Lagrangian particles) at the interface between the cloud and clear air, including condensation and evaporation. The combined data, spanning a wide range of scales, from field observations, lab experiments, and numerical simulations would possibly elucidate the role of turbulence in clouds.

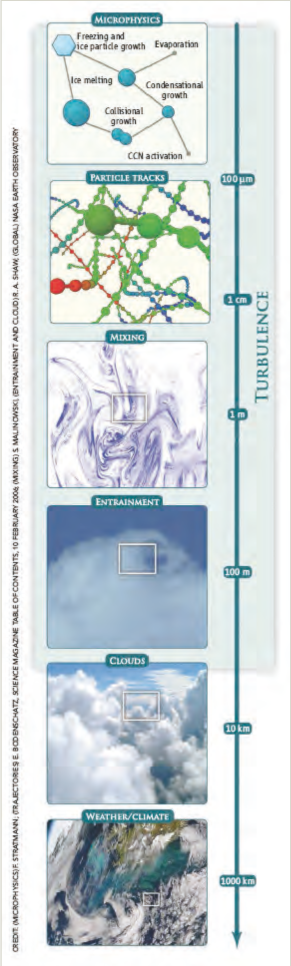

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Figure 1 (From Ref. [1])
The range of scales covered by clouds and the dominating phenomena/problems at different scales.

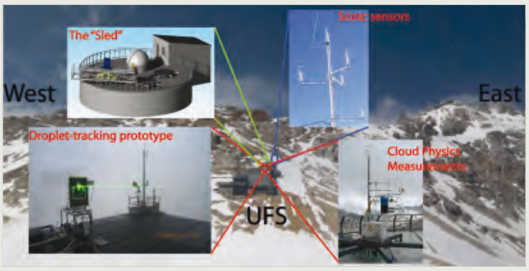

Figure 2
The topography of the UFS at Zugspitze, showing with the prototype of droplet-tracking device, the sonic sensors, and the future installation of the “sled”.

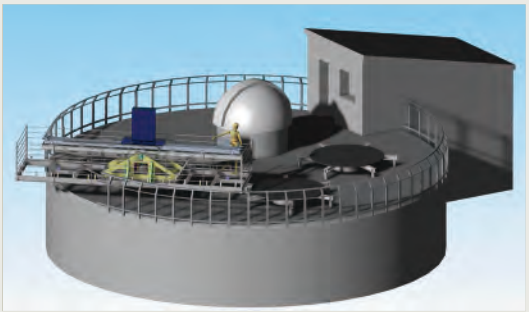

Figure 3
Computer generated image of the “sled”. The total length of the apparatus is 8 m long, with a 6.6 m long rail. A linear motor drives the droplet-tracking device at a speed of up to 7.5 m/s along the rail. The inclination of the sled can be adjusted within ±14° relative to the horizontal plane, according to the instantaneous mean wind direction measured by the sonic sensors.

[1] E. Bodenschatz, et al, *Science* **327**, 971 (2010)
[2] R. A. Shaw, *Annu. Rev. Fluid Mech.* **35**, 183 (2002)
[3] G. Falkovich, A. Fouxon, M. G. Stepanoc, *Nature* **419**, 151 (2002)
[4] C. Chang, G. Bewley, E. Bodenschatz, *under review*