The helicopter-borne ACTOS for small-scale cloud turbulence observations

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1. Motivation

Clouds play a major role in the Earth system and are relevant to many aspects of climate and daily weather forecast. The dynamics of clouds span a wide range of spatial scales from the macroscopic cloud extension itself down to the Kolmogorov microscale (typically in the mm range for atmospheric conditions). Since cloud microphysical properties on larger scales are controlled by processes taking place on smaller scales, measurements with high spatial and temporal resolution are essential for a better understanding of cloud processes.

The majority of airborne in-situ observations of clouds have been made by fast-flying research aircraft which limits the spatial resolution of most parameters to the meter scale or so. To overcome this limitation the Airborne Cloud Turbulence Observation System (ACTOS) has been developed which was originally designed for the use beneath a tethered balloon (Siebert et al. 2003, 2006b). Due to the low true airspeed (TAS) of such a balloon-borne system the spatial resolution of the measurements is much higher compared with aircraft data. In this paper the new helicopter-borne version of ACTOS is introduced (see also Siebert et al. (2006a)). However, compared to balloon–borne measurements, which also meet the slow–flying criterion, a helicopter is even more advantageous due to its longer cruising range and possible ceiling. A helicopter is more flexible in time and space than a balloon and can be chartered at different airfields. Furthermore there are fewer limitations with respect to possible payload (weight, size, available electrical power).

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Besides a technical overview of ACTOS the possibilities of using a helicopter for cloud research are discussed by showing measurement examples which clearly demonstrate the unique capabilities of the new system.

2. Experimental Setup

ACTOS is an autonomous measurement payload which can, in principle, be carried by different platforms such as balloons, blimps, Zeppelin, or helicopters. The system is equipped with sensors to perform high-resolution measurements of meteorological standard parameters such as wind vector, air temperature, and humidity but also cloud and aerosol microphysical properties such as liquid water content (LWC) and number concentrations of interstitial aerosol particles in boundary layer clouds.

To keep the load for the carrier platform as low as possible, a light-weight frame made from carbon-fiber and aluminum was designed. The total weight of ACTOS including the instruments is $\sim$ 200 kg. ACTOS is equipped with an autonomous power supply and data acquisition to be completely independent from its carrier platform. A data link between ACTOS and the helicopter cabin was installed to ensure on-line monitoring of standard parameters during the flights.

2a. *Sensor Equipment*

ACTOS was designed to provide collocated measurements of several types of parameters. All sensor outputs are sampled with a joint real-time data acquisition system to ensure precise temporal correlation between the different measured parameters. In the following a short list of all devices is given, for a more detailed discussion of sensor performance the reader is referred to Siebert et al. (2003, 2006b).

- The three-dimensional wind vector and the virtual air temperature are measured with an ultrasonic anemometer/thermometer (Solent HS, see also Siebert and Muschinski 2001).
- A combination of differential Global Positioning System (dGPS) and inertial sensors (optical fiber gyros and accelerometers) measure the attitude angles, angular rates, position, and the velocity vector of ACTOS with different time resolution and precision. A navigation computer combines all measurements and gives all parameters with 10 Hz resolution (100 Hz are optional) and with best precision.
- A special version of the so-called UltraFast Thermometer (UFT, Haman et al. 2001) allows air temperature measurements with 500 Hz resolution. The UFT is based on temperature-dependent resistance measurements of a thin wire which is protected against droplet impaction with a shielding rod in front of the wire.
- Humidity fluctuations are measured with a Lyman-α absorption hygrometer. A pre-impactor inlet prevents cloud droplets to enter the optical system which would lead to an irreversible bias of the signal.
- For air temperature and relative humidity measurements standard PT-100 resistance-wire thermometers and a capacitive hygrometer based on the Vaisala Humicap sensor serve as calibration standard for the UFT and Lyman-α, respectively.
- The LWC is measured with a Particle Volume Monitor PVM-100A (airborne version, Gerber 1991).
- The number concentration of interstitial aerosol particles is measured with two Condensation Particle Counter (CPC). Since the two CPCs have a different lower cut-off characteristics, the concentration of ultrafine particles in the size range between 6 and 12 nm is derived which is used as an indicator of freshly nucleated particles (Siebert et al. 2004).
- Cloud droplet microphysical properties are measured with a modified version of the Fast Forward Scattering Spectrometer Probe (M-Fast-FSSP, Schmidt et al. 2004; Lehmann et al. 2006). The M-Fast-FSSP counts each individual droplet and measures its size and the inter-arrival times. The size distribution, number concentration, and the LWC of the droplets is derived from the measurements.

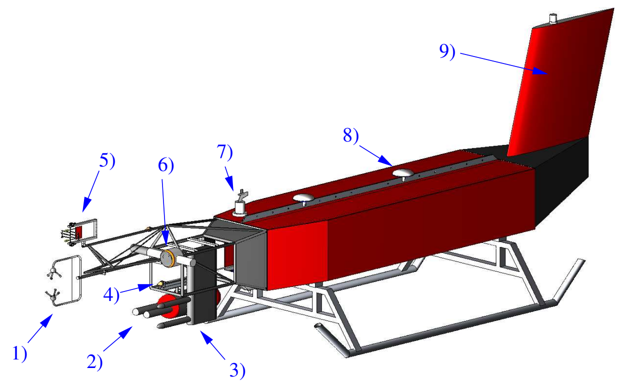

Figure 1: Schematic sketch of ACTOS with numbered devices. The system can roughly be divided into three parts (i) the tail unit (9), (ii) the main body consisting of five covered 19"-inch racks including electronics, data acquisition, power supply, and dGPS antenna (8) and (iii) an outrigger made of carbon-fiber tubes with all sensor and sampling inlets: 1) Sonic anemometer, 2) M-Fast FSSP, 3) PICT, 4) Impactor Inlets, 5) UFT, 6) PVM-100A, and 7) Nevzorov probe.

In addition to the standard equipment a second cloud spectrometer called PICT (Phase-Doppler Interferometer for Cloud Turbulence) was installed beside the M-Fast-FSSP for this experiment. The PICT instrument measures the radius, longitudinal velocity component, and time of arrival of droplets that enter its sampling volume. The sampling volume is defined by the region in which two laser beams intersect: light scattered from the two beams by a droplet is detected at several angles, providing temporal interference patterns (Doppler bursts) related to the droplet size and speed (Bachalo and Sankar 1996). The sampling frequency is sufficiently high that there is no dead time and therefore inter-droplet distances as small as the beam cross section can be determined. An advantage of PICT is that droplet sizes ranging from newly activated cloud droplets to drizzle can be detected with a single instrument ($1 \leq r_d \leq 100$ μm). Furthermore, at low TAS, such as in the experiment described below, the instrument provides a measure of the longitudinal turbulent velocity component.

Figure 1 depicts a schematic sketch of the current version of ACTOS. The setup is divided into three major parts: i) the 1.5 m long outrigger on which all sensors and inlets are attached, ii) the main body consisting of five covered 19” standard racks including the sensor electronics, data acquisition and power supply, and iii) the tail unit which keeps ACTOS in the mean flow direction. A rough skid system with shock absorbers ensure a safe take-off and landing procedure. The side covers can easily be removed for final settings before take-off.

2b. *ACTOS Carried by Helicopter*

Using the Helipod system Bange and Roth (1999) and Muschinski et al. (2001) demonstrated that state-of-the-art turbulence measurements with a payload carried by helicopter as external cargo are possible. With the appropriate combination of TAS and length of the rope, measurements are unbiased from the influence of the helicopter downwash which is deflected backwards. However, these measurements were done under cloud-free conditions and no experience was available concerning helicopter flights with an external cargo in clouds. After clarification of the flight regulations under such conditions first test flights with a mock-up version of ACTOS were successfully performed in 2004 and 2005. Hereby, ACTOS was dipped into the clouds from above whereas the helicopter remains outside the clouds such that it can be flown under visual flight regulations (VFR). For this reason a 140 m long rope was used which is much longer than the 15 m rope used for the Helipod but has also the advantage of allowing lower TAS of 15 $\mathrm{m\,s^{-1}}$ instead of 40 $\mathrm{m\,s^{-1}}$ without being influenced by the downwash. Figure 2 shows a sketch of the combination of ACTOS and the helicopter.

The conditions and requirements for measurement flights with ACTOS are summarized in Tab. 1.

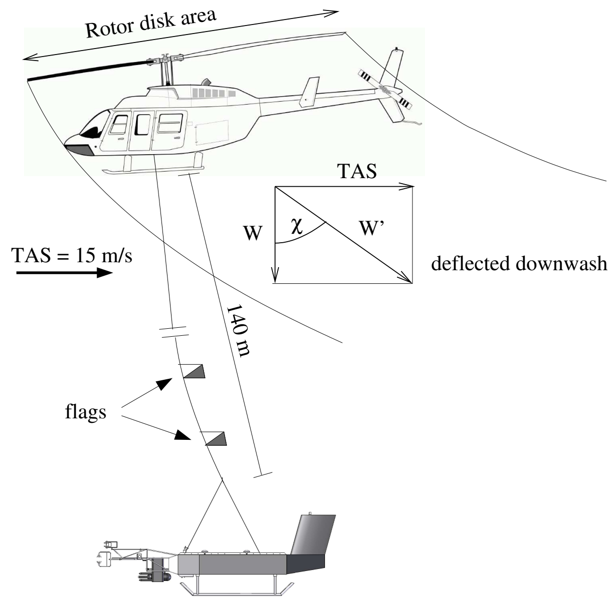

Figure 2: Sketch of ACTOS suspended from the helicopter of type BELL LongRanger. The rope is 140 m long, several flags are attached to the rope to increase the visibility. The downwash from the main rotor blades is deflected backwards, thus, turbulence measurements on ACTOS are safely unbiased. The sketch is not in scale.

TAS_{meas}	15 $\mathrm{m\,s^{-1}}$
TAS_{car}	25 $\mathrm{m\,s^{-1}}$
Ceiling	10.000 ft (3.000 m)
Minimum Cloud Base	3.000 ft (1.000 m)
Endurance	1:45 h
Airfield	$\sim$ 50 m · 150 m

Table 1: Overview of flight parameters and conditions for the helicopter-borne ACTOS. TAS_{meas} is the true air speed during measurement flight conditions, whereas TAS_{car} is the maximum TAS for carrier flights with ACTOS to the measurement area.

For this study a single-engine helicopter of type Bell Long Ranger (BELL 206III LR) was used. For VFR flights one pilot and three scientists/operators can be on board the helicopter. Flights with the helicopter inside the clouds have to be performed under Instrument Flight Regulations (IFR) which are planned for 2006. The helicopter will be flown by two pilots and ACTOS will be operated by two scientist. This allows measurements in extensive stratiform cloud sheets which would not be possible under VFR and which will significantly extend the capabilities of ACTOS.

3. Measurement Example

The first field campaign with the helicopter-borne ACTOS was conducted in April 2005 at the airfield Koblenz/Winningen, Germany. Here, one example is shown to illustrate the unique possibilities of using a slow-flying helicopter-borne payload for cloud investigations. The data were taken on 27 April at a height of 2100 – 2300 m above ground level. Since the helicopter was not allowed to penetrate into the cloud, a constant flight level could not be maintained due to varying cloud top heights. Figure 3 depicts a 70 s long record of selected parameters for this flight leg. The LWC with maximum values $\sim 1\,\mathrm{g\,m^{-3}}$ indicates a cloud penetration close to cloud top. The vertical velocity shows strong downdrafts at cloud edges and updrafts with the same order of magnitude in the cloud core region. It is noteworthy that both downdraft regions at the cloud edges are still inside the cloud with a non-vanishing LWC. The temperature decreases rapidly when entering the cloud and drops from $-3°$ to $-5°$ C. Whereas inside the cloud core the fluctuations of T are comparable small, T shows much more fluctuations between the cloud regions.

An interesting feature is contained in the record of the aerosol particle number concentration N. Whereas N_{12} in the size range between 12 and 1000 nm is relatively constant over the entire record the second data set including the size range from 6 to 1000 nm, N_6 shows several significant peaks after the cloud penetrations with up to four times higher particle concentrations. The occurrence of so-called ultrafine particles in the size range between 6 and 12 nm is an indication for freshly nucleated particles. The cloud edges are a preferential region for new particle formation.

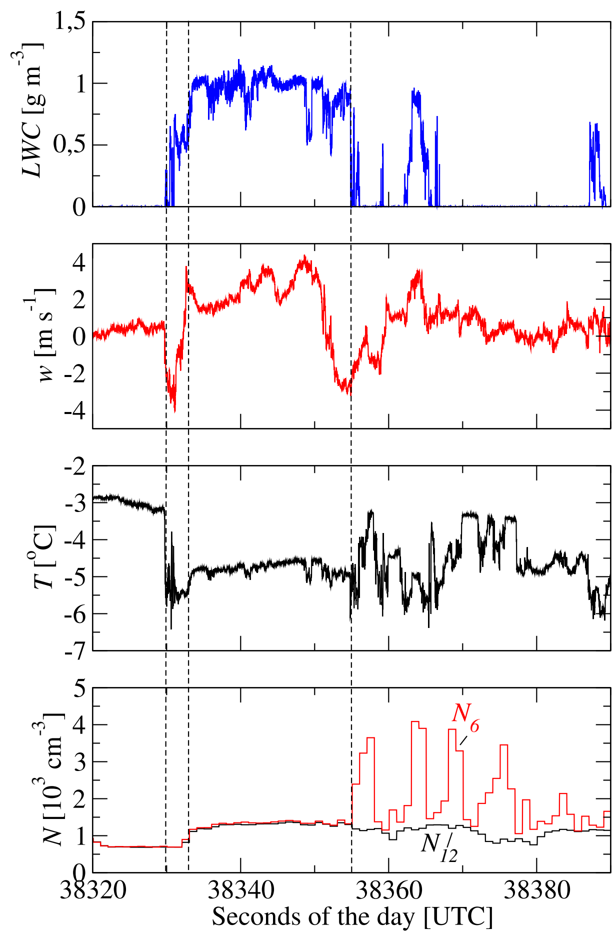

Figure 3: Measurements of liquid water content LWC, vertical wind velocity w, static air temperature T, and aerosol particle number concentration N in the size range 6 to 1000 nm (N_6, red curve) and 12 to 1000 nm (N_{12}, black curve). The true airspeed of the helicopter was 15 $\mathrm{m\,s^{-1}}$.

4. Summary

The approach of using a helicopter-borne measurement system for cloud research was introduced. The unique possibilities and limits of such a system for high resolution measurements were discussed and technical information of the payload ACTOS were given. A measurement example of a short cloud penetration illustrates the unique capabilities of the new system for high resolution cloud investigations.

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