AIRCRAFT TOWED SENSOR SHUTTLE (AIRTOSS): A TANDEM MEASUREMENT PLATFORM FOR CLOUD-RADIATION STUDIES

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1 INTRODUCTION

Clouds play a significant role in regulating the radiation balance of the Earth-atmosphere system. Therefore, it is important to investigate the influence of cloud particle properties on radiative transfer by in-situ measurements. Cirrus clouds are challenging in particular because they may cool or warm the atmosphere [Solomon et al., 2007]. In order to investigate the radiative impact of (cirrus) clouds simultaneous observations above and below the cloud are required to obtain optical layer properties and radiative budget quantities of the clouds. In this regard the close coordination of the radiation measurements above and below, and the microphysical measurements within the clouds is crucial. Usually this is attempted by using several aircraft in stack as for example in the CRYSTAL-FACE (2002) or TC^4 (2007) experiments. However, the aircraft usually have different speeds which makes it hard to obtain truly simultaneous measurements around and in the clouds. Also there are often series flight safety regulations which additionally complicate aircraft coordination. Moreover, using several aircraft is expensive. Therefore, a new tandem measurement platform has been developed and applied within a measurement campaign funded by the Collaborative Research Center SFB641 *The Tropospheric Ice Phase*. This tandem platform consists of (1) a Learjet 35A aircraft mainly equipped with radiation instruments and (2) the AIRcraft Towed Sensor Shuttle (AIRTOSS) equipped with instrumentation to measure cloud microphysical properties. The AIRTOSS sonde is detached from, towed by, and retracted onto the Learjet. By varying towing-cable length (maximum length is 4 km) and air speed, the horizontal and vertical distance between the AIRTOSS and the research aircraft can be varied, providing possibilities for different vertical profile flight patterns. In this way the measurements conducted on the aircraft and on the AIRTOSS are truly collocated, which has not been possible in earlier coordinated aircraft experiments.

By comparing the microphysical properties derived from a combination of radiation measurements and radiative transfer modelling (e.g. using the Library for Radiation Transfer calculations (LibRadtran) model [Mayer and Kylling, 2005]), closure studies of the radiative effect of cirrus clouds can be performed. Furthermore,

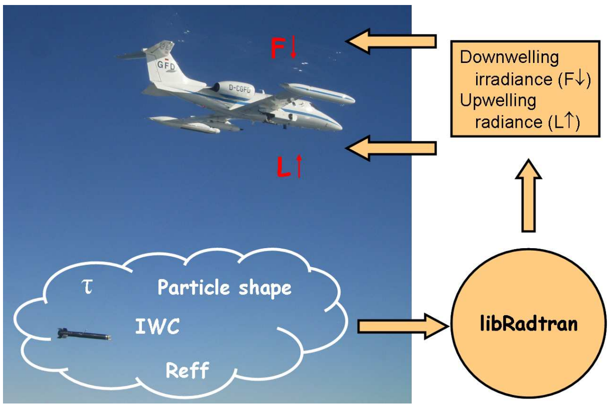

Figure 1. Illustration of AIRTOSS operating mode.

the microphysical cloud properties (such as effective particle radius and/or optical thickness of the cloud) can be retrieved and compared to the simultaneous microphysical measurements conducted with AIRTOSS.

1.1 Campaign

A 'proof-of-concept' campaign was conducted in September 2007 from Hohn, Northern Germany. Three test flights with AIRTOSS have been made, whereof the first flight was accompanied by a second aircraft to closely watch the flight attitude of the AIRTOSS drag-body. The duration of the test flights was about two hours each. Due to safety regulations, flying with the AIRTOSS sonde underlies some flight restrictions when not attached to the winch, as for example, not flying through mixed-phase clouds due to possible icing and flying over restricted military area in a maximum height of 25.000 feet. Beyond testing the flight characteristics of AIRTOSS, first measurements with AIRTOSS were performed within low marine stratus clouds.
For measurements of cirrus inhomogeneities two additional flights without AIRTOSS were made in order to be able to fly at higher altitudes.

2 INSTRUMENTATION

The instrumentation for radiation and cloud microphysics is described in the following section. Figure 2 shows the locations of the instruments within the tandem platform.

2.1 Learjet

Instruments on the Learjet are either installed in the wingpod or on top of the fuselage. Here, the newly developed Stabilized Platform for Airborne Radiation Measurements (SPARM) is used for horizontal stabilization of the downwelling irradiance sensor (Fdw). Downwelling irradiances are measured in a wavelength-range of 350 – 2200 nm. The wingpod contains

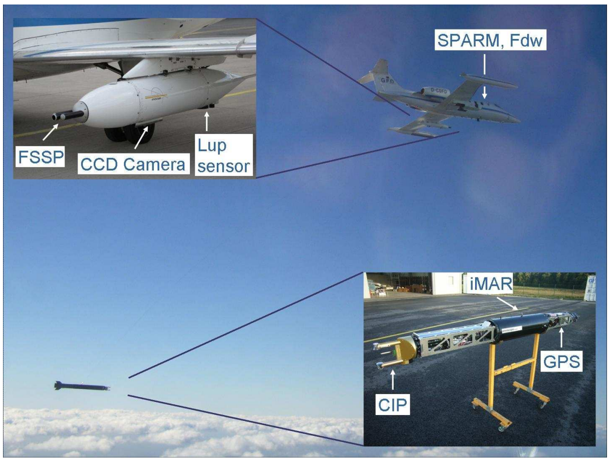

Figure 2. Instrumentation of Learjet/AIRTOSS tandem.

the Forward Scattering Spectrometer Probe (FSSP-100) at the front for measuring size distributions of particles in the size range of 2 – 45 μm [Dye and Baumgardner, 1984]. Also installed in the wingpod are the downward looking sensor for upwelling radiances (Lup) and the multispectral two-dimensional CCD camera [DuncanTech, 2002]. The CCD camera captures pictures at three different wavelengths: green (550 nm), red (660 nm), and near-infrared (880 nm) and has a viewing angle of 58.1°. Upwelling radiances are measured in a wavelength-range of 350 – 2200 nm, the viewing angle of the radiance inlet is 1.5°. The radiation sensors are described in Wendisch et al. [2001].

2.2 AIRTOSS

The AIRTOSS drag-body is equipped with the Cloud Imaging Probe (CIP), a Global Positioning System (GPS) and a System for Inertial Navigation, Guidance, Stabilization and Surveying (iMAR system) for measuring the attitude angles of the AIRTOSS. The CIP generates two dimensional shadow images of cloud particles with diameters between 25 and 1550 μm. From these images information about shape and size distribution of the cloud particles as water droplets or ice crystals can be obtained [Knollenberg, 1970]. For determining the exact position of the AIRTOSS a GPS

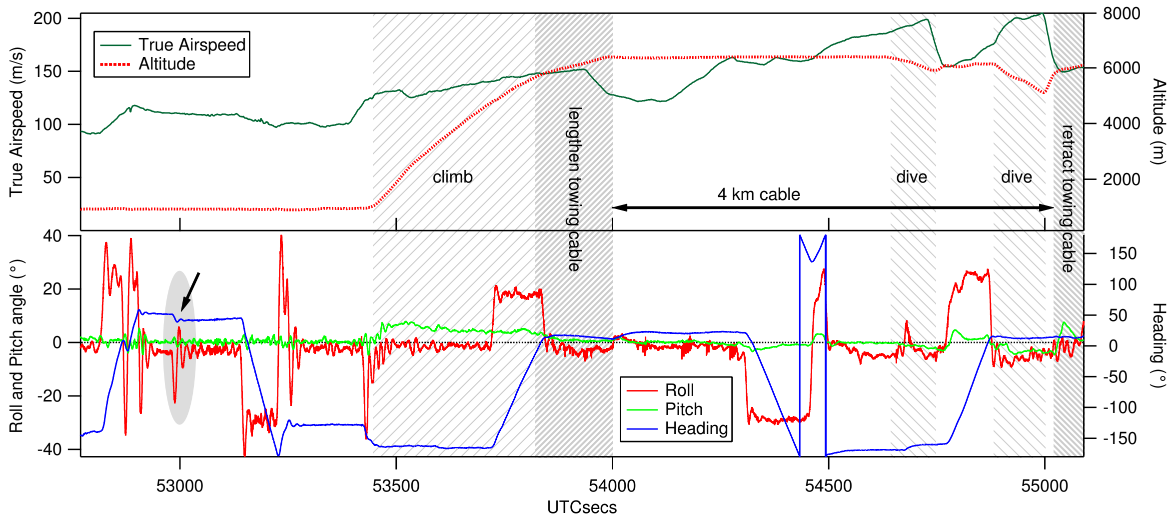

Figure 3. Flight characteristics on 6 of September 2007, shaded areas indicate climbing or diving of Learjet, lengthening and retracting of towing cable. The arrow in the ellipse denotes an example of a slight turn which causes a high amplitude in roll angle.

is used. The iMAR system provides measurements of the flight attitude as roll and pitch angle as well as heading information of the AIRTOSS. Small changes in roll and pitch angle should not affect the accuracy of CIP measurements. Stable flight conditions are more crucial for the planned integration of radiation sensors into the AIRTOSS. The power supply for AIRTOSS is given by batteries.

3 OBSERVATIONS

3.1 AIRTOSS flight characteristics

The Learjet/AIRTOSS platform has been tested for altitudes up to 25.000 feet, aircraft speeds of 180 – 300 knots and a towing-cable length up to 4 km. While AIRTOSS is attached to the Learjet no measurements are carried out, in this time the batteries are disconnected in order to save battery power. The first test flight of AIRTOSS on 4 of September 2007 has been accompanied by a second Learjet to be able to closely watch the flight behaviour of the drag-body and thus to testify the operational capability of the Learjet/AIRTOSS tandem. No data have been collected on this flight. About 90 minutes of continuous data of the GPS, iMAR system, and CIP are available during the AIRTOSS flights on 6 and 7 of September 2007.

During the AIRTOSS flight on 6 of September 2007 tests were made for different flight altitudes and airspeeds as shown in Figure 3. Even slight turns cause high oscillations in roll angle as pointed out by the arrow. During the following straight on flight the oscillation diminishes. The coarse shaded areas denote climbing or diving of the Learjet which can also be seen in the pitch angle of AIRTOSS. Climbing causes a higher air resistance on the 'wings' at the end of AIRTOSS and thus a positive pitch angle as the front section looks up, diving of the Learjet a negative pitch angle, respectively. Narrow shaded areas denote a change in towing cable length which adds some noise to the attitude angles. In Figure 4 the attitude angles of the flight on 7 of September 2007 are displayed. The time segment shows a period with constant airspeed ($\sim$ 100 m/s) and AIRTOSS height ($\sim$ 500 m). After flying a turn the roll angle needs about 35 seconds to diminish its oscillation. Roll and pitch angles show absolute deviations up to 4° and 2°, respectively. The pitch angle is slightly positive at this airspeed.

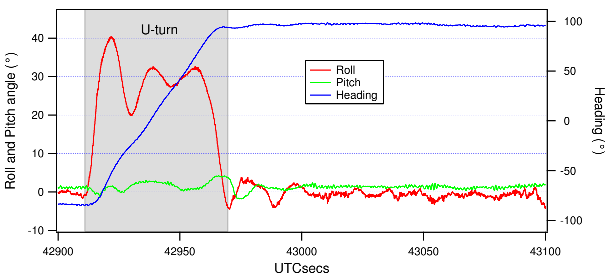

Figure 4. Flight characteristics on 7 of September 2007 in a period with constant aircraft speed and height.

3.2 Microphysics

During several flight legs on test flights on 6 and 7 of September 2007 the AIRTOSS sonde was dropped into marine stratus clouds. In-cloud measurements of size, shape, and size distribution of the cloud water droplets were made by the CIP. As Figure 5 demonstrates mostly small droplets with a size of about 39 μm in diameter were imaged. A mean number concentration of 12.9 particles per litre was observed in the clouds.

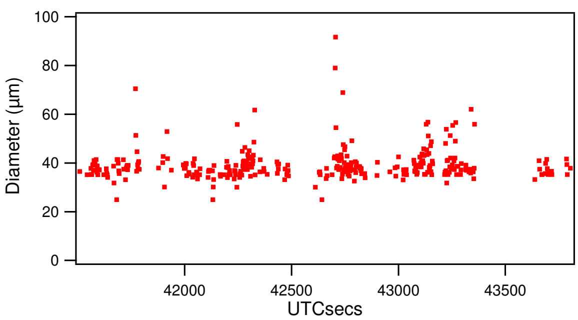

Figure 5. Mean diameter of cloud droplets measured on 7 of September 2007 in marine stratus clouds.

3.3 Radiation

The radiation measurements focused on observations of cirrus clouds. The spectral upwelling radiance (Lup) measured above the clouds on 6 of September 2007 shows cirrus inhomogeneities (Figure 6). In the time series of Lup at 670 nm and 1600 nm wavelength the signal drops by about 50% within about 30 seconds (about 4.5 km flight path). The big differences in the radiances at the two wavelengths result from the fact that ice is almost not absorbing at 670 nm but strongly absorbing at 1600 nm.

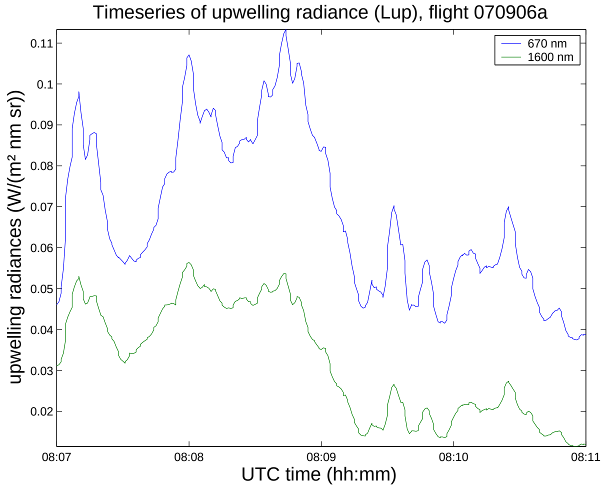

Figure 6. Upwelling radiances illustrating cirrus inhomogeneities measured on 6 of September 2007.

4 CONCLUSIONS AND OUTLOOK

The proof-of-concept campaign has shown that the principle of the tandem measurement platform worked out well. The AIRTOSS sonde was able to stabilize its flight after several flight manoeuvres. Thus, for future studies of the interaction between cloud microphysics and radiation AIRTOSS has proven to be a very useful platform. To achieve a preferably stable flight of the AIRTOSS airspeed, height, and towing cable length should be kept constant in straight on flight.

A wireless local area network (WLAN) connection between AIRTOSS and Learjet shall be made available for the next AIRTOSS mission, to gain inflight information whether the dragbody is in a cloud or not. This is of particular importance for measurements in thin clouds as for example cirrus clouds. For measurements of cloud-radiation interactions of cirrus clouds, the allowed maximum flight altitude has to be extended to 10 – 12 km. This shall be achieved until the next scientific campaign with the AIRTOSS which is planned for October

2008. For this campaign, the integration of instruments for radiation measurements into the AIRTOSS sonde is planned. Here, the same radiation sensors will be used as in the Learjet. These implementations will make the AIRTOSS an even more powerful tool for studies of interactions between cloud radiation and microphysics.

5 ACKNOWLEDGEMENTS

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6 BIBLIOGRAPHY

References

DuncanTech. *MS4000 and MS4100 High-Resolution Digital Color and Multispectral Camera*. DuncanTech, 11824 Kemper Rd. Auburn, CA 95603, 2002.

James E. Dye and Darrel Baumgardner. Evaluation of the forward scattering spectrometer probe. part i: Electronic and optical studies. *Journal of Atmospheric and Oceanic Technology*, 1(4):329–344, December 1984.

Robert G. Knollenberg. The optical array: An alternative to scattering or extinction for airborne particle size determination. *Journal of Applied Meteorology*, 9(1):86–103, February 1970.

B. Mayer and A. Kylling. Technical note: The libradtran software package for radiative transfer calculations - description and examples of use. *Atmospheric Chemistry and Physics*, 5 (7):1855–1877, 2005. ISSN 1680-7316.

S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, editors. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, U.K. and New York, USA, 2007.

M. Wendisch, D. Müller, D. Schell, and J. Heintzenberg. An airborne spectral albedometer with active horizontal stabilization. *Journal Of Atmospheric And Oceanic Technology*, 18(11):1856–1866, November 2001.