P7.6 THE ROLE OF THE HELICOPTER-BORNE TURBULENCE PROBE HELIPOD IN JOINT FIELD CAMPAIGNS

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1. INTRODUCTION

The increasing efforts in numerical climate and weather prediction require precise knowledge of atmospheric exchange processes. In the beginning 1990s this requirement was the approach for the development of a completely new airborne turbulence probe named Helipod. The idea was to increase the accuracy of airborne near-surface turbulent flux measurements by one order of magnitude. The development of the Helipod was completed in 1994 and since this time the Helipod participated in several field campaigns.

Apart from some exceptions the Helipod always operated in joint field campaigns like the LITFASS-Experiments (**L**indenberg **I**nhomogeneous **T**errain - **F**luxes between **A**tmosphere and **S**urface: a Long-Term **S**tudy, (Beyrich *et al.*, 2002)). Helipod's data was often compared with ground-based measurements, remote sensing, and numerical models. Furthermore the Helipod measurements were used for reference, cross-validation, and initialization.

This article describes the Helipod and its future modernization as well as the comparison of results from Helipod flights with other measurement systems.

Fig. 1: *The helicopter-borne turbulence probe Helipod*

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2. MEASUREMENT SYSTEMS

The Helipod (Fig. 1) is a unique measurement system. It is an autonomously operating sensor package, constructed to be carried by almost any helicopter on a rope of 15 m length. At a typical ground speed of 40 ms^{-1} (Fig. 2) the Helipod is outside the downwash area of the rotor blades. The Helipod itself is a container of about 5 m in length, 0.5 m in diameter, and 250 kg in weight. It carries its own navigation systems, power supply, data storage, and fast responding sensor equipment. The system was especially designed for in situ measurements of the turbulent fluctuations of wind, temperature, humidity, and the turbulent fluxes (e.g., Bange *et al.*, 2002a; Bange and Roth, 1999).

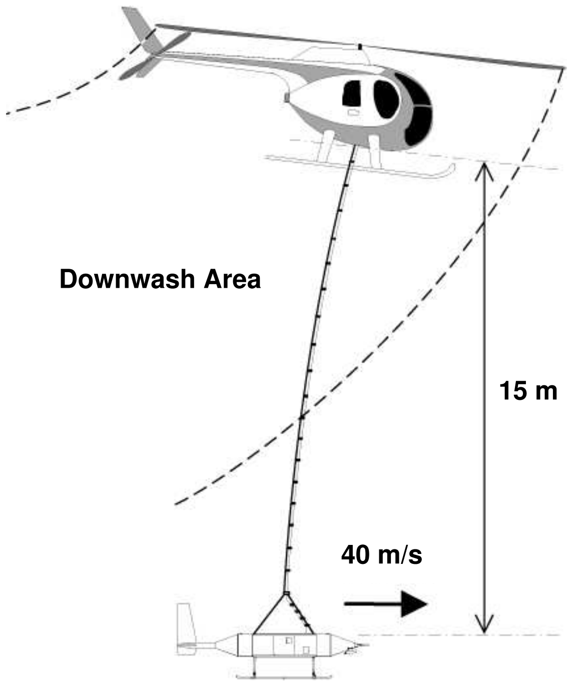

Fig. 2: *The principle of the Helipod-flight: At a true airspeed of 40 ms^{-1} the system is out of the downwash area.*

To achieve a high temporal resolution, the Helipod measures each meteorological parameter with at least two different types of instruments: One that has a short response time, but the disadvantage of a temporal drift, is sampled at 100 Hz to 1000 Hz internally. The other type responds slowly but is very accurate on a large time scale, and is sampled at 20 Hz. To achieve a large frequency range, the data sets are united by complementary filters. The results are 100 Hz time series of the meteorological parameters, equivalent to one measurement point every 40 cm. Due to its small fuselage, and the absence of wings and propulsion Helipod's influence on the atmosphere is small compared to an airplane. Apart from this the Helipod is no subject to approval (FAA, JAA) and is in general allowed to perform low-level flights at less altitude than an airplane.
The Helipod is demountable and can be transported in boxes around the world on a ship or by commercial aircraft. This makes missions in tropical areas or polar regions possible. The system participated several arctic expeditions since 1995. These missions, a specialty of the Helipod, were started from the helicopter deck aboard a research sea vessel, e.g. the Polarstern (Fig. 3).

Fig. 3: *Start of the Helipod during an arctic mission from the German research vessel Polarstern*

During the LITFASS experiment in 2003 the Helipod performed 65 hours of measurement flights and additional 40 hours during the STINHO-2 (**ST**ructure of the turbulent transport over **IN**-**HO**mogeneous surfaces) experiment in 2002 (Spiess *et al.*, 2003). In these two measurement campaigns many other groups were involved. In 2003 a total of 13 micro-meteorological stations were installed on different surface types like forest, lake, rape, wheat, corn, etc. Furthermore, 7 Laser Scintilometer, 4 long-distance Scintilometer, a 99 m meteorological tower, a wind profiler/RASS system (Engelbart and Bange, 2002), a SODAR, a differential absorption LIDAR (DIAL) system (Bösenberg and Linné, 2002), and other systems performed simultaneous measurements simultaneously.
The first time ever a Tornado aircraft of the German Air Force (Fig. 4) participated a meteorological experiment in Germany. The Tornado was equipped with an infrared camera for surface photography. Due to its high speed the Tornado covered the experimental site of 20 km $\times$ 20 km in less than thirty minutes. The aim was to get a map of the surface temperature over the whole area in high resolution. Because these photographs were not calibrated, they have to be compared with the ground measurements and the data of the Helipod which measures the surface temperature along its line of the flight pattern. For better comparison and calibration the Helipod mostly made its measurements at the time when the Tornado was flying.

Fig. 4: *The Tornado Aircraft of the German Air Force*

3. FLIGHT PATTERN

To achieve the goals in the LITFASS framework the Helipod performed various flight patterns that were individually designed to meet particular questions of the research project.
For the comparison with the DIAL a vertical grid pattern was flown. It consisted of several straight legs of 12 km length oriented in the mean wind direction at different altitudes. In general the flights took place between noon and the early afternoon. The flight pattern is shown in Fig. 5.

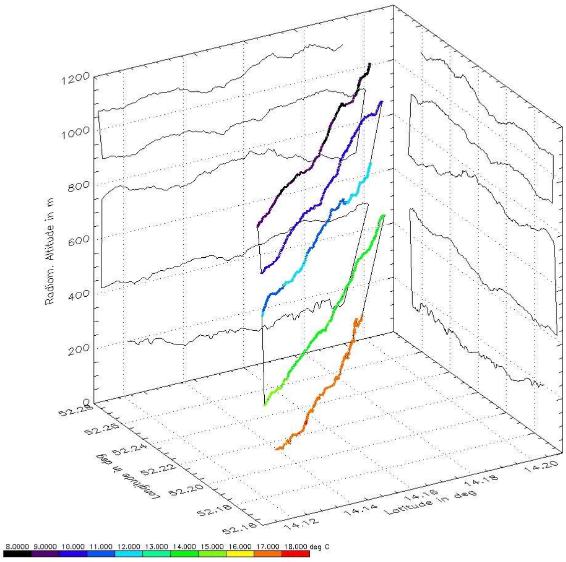

Fig. 5: *The Helipod flight pattern 'Vertical Grid'. The color of the line is the measured static temperature.*

Another flight pattern was called 'Stations' and was especially concepted for the comparison between Helipod flights, ground-based measurements, and the data of a long distance scintilometer. In this context the Helipod data was intended to be a reference for the other systems. The flight pattern consisted of several straight legs of varying length, positioned over the micrometeorological ground stations. One leg was oriented west-east along the measurement line of the long distance scintilometer (see Fig. 6). The flights were performed only at low altitude, between about 80 m and 100 m above the ground.

Similar to the 'Stations' flights was the 'Catalog' pattern (Fig. 7). The difference was that the legs of the 'Catalog' were positioned above specific surface types like forest, lake, grassland and agriculture, and mixed surface. This flight pattern was performed around noon or during the early afternoon at different altitudes. With theses flights one of the aims of the project EVA-GRIPS (Regional **Eva**poration at **Gri**d/**P**ixel **S**cale over Heterogeneous Land Surfaces) within the German climate research program (DEKLIM) was achieved. The turbulent fluxes and the turbulent flow above specific surface types were analyzed. The results can be used for the initialization and verification of numerical prediction models.

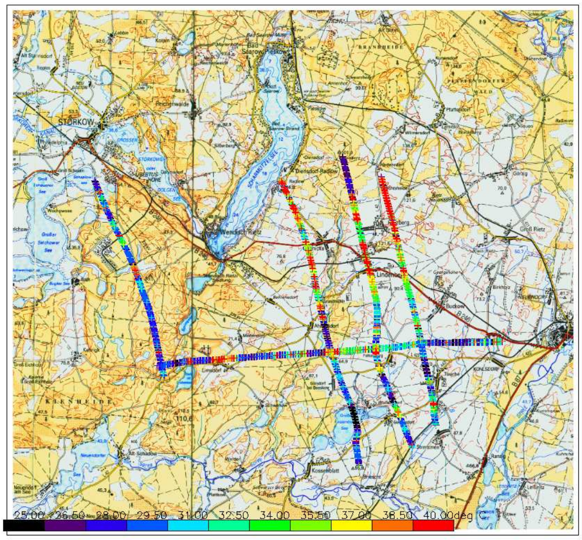

Fig. 6: *The Helipod flight pattern 'Stations'. The color of the line is equal to the measured surface temperature.*

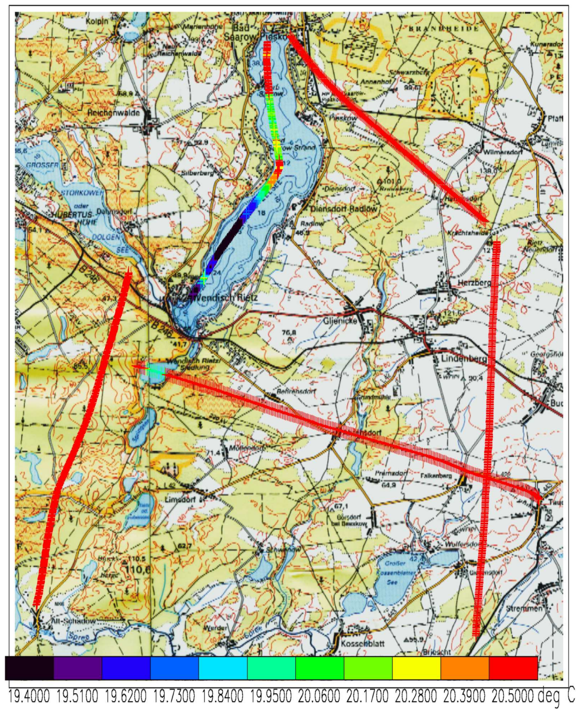

Fig. 7: *The Helipod flight pattern 'Catalog'. The color of the line is equal to the measured surface temperature. There are differences in the surface temperature of the lake concerning to its depth.*

For the determination of area averaged turbulent fluxes and for the calibration of the infrared surface temperature photos, made by the Tornado aircraft, a flight pattern that covered the experimental site area-wide was required. Helipod's 'Extended Big Grid' flight pattern consisted of 16 straight legs of 14 km length, 8 of them oriented in north-south direction, the other 8 legs in west-east direction (Fig. 8). Those legs were flown at altitudes between 80 m and 100 m above the ground. About the same time the Tornado aircraft flew at 1500 m above the ground for making the infrared photographies.

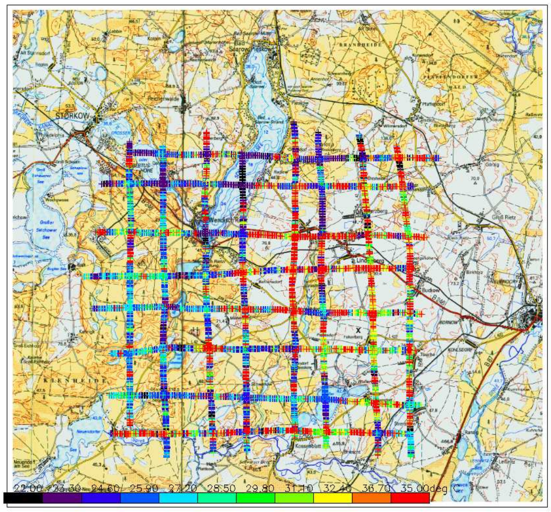

Fig. 8: *The Helipod flight pattern 'Extended Big Gird'. The color of the line is equal to the measured surface temperature.*

4. RESULTS

Using to the 'Catalog' flight pattern turbulent fluxes above different surface types at three altitudes were calculated (Fig. 9). At the lowest level there were significant differences in the measured sensible heat fluxes depending on the surface type. As expected the forest area had the largest heat flux due to its large roughness length. Of course the lake produced just the smallest sensible heat flux due to its low temperature and smooth surface. In agreement with the convective boundary layer theory, the heat flux decreases linearly with increasing height. What is remarkable: Every individual surface type seemed to develop its own linear flux profile. This may start a discussion about: 'How mixed is the mixed layer?'

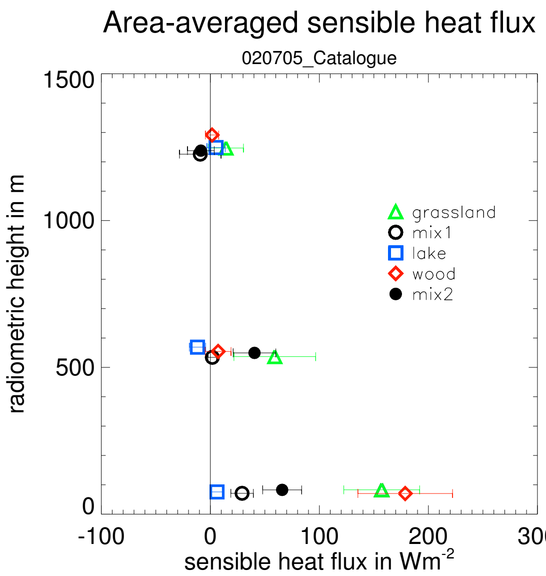

Fig. 9: *Area averaged sensible heat fluxes measured by the Helipod at three altitudes above different surfaces.*

From the 'Vertical Grid' pattern the area-averaged sensible heat flux within the convective boundary layer (CBL) was calculated. The linear interpolation of the measured fluxes in Fig. 10 agrees nicely with the theory of the CBL (e.g. Stull, 1988). The deviations at low altitudes may be caused by the influence of the strong heterogeneity of the surface. Additionally, the latent heat flux of the Helipod and the DIAL (Fig. 11) agree well at all altitudes. At the time of preparing this article, no error bars of the DIAL measurements were available.

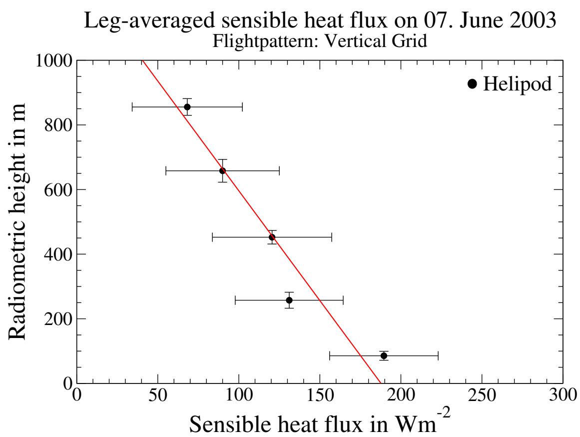

Fig. 10: *Leg-averaged sensible heat fluxes measured by the Helipod at different altitudes.*

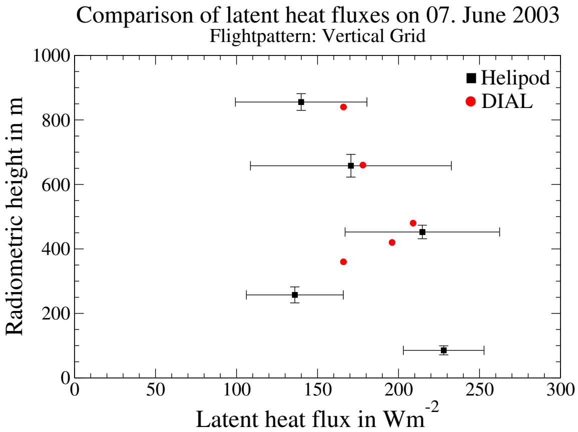

Fig. 11: *Leg-averaged sensible heat fluxes measured by the Helipod at different altitudes.*

Due to the simultaneous flights of the Helipod and the Tornado aircraft is was possible to calibrate the infrared photos of the Tornado. Figure 12 shows a part of Helipod's 'Extended Big Grid' flight pattern implemented to an infrared photo of the Tornado. The color of the line is the measured surface temperature.

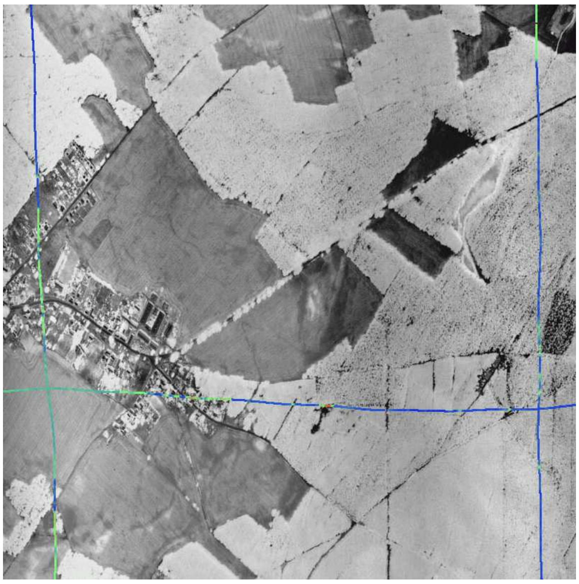

Fig. 12: *Flight path of the Helipod (thin vertical lines to the left and right of the picture, and the thin horizontal line in the lower third) implemented to an infrared photo of the Tornado.*

Due to the comparison of the Helipod temperatures with the gray scales of the Tornado data it was possible to allocate each grey scale with a temperature. The result is a colored and calibrated infrared surface temperature photo of the Tornado (Fig. 13). But these calibrated temperatures are not as exact as the measurements of the Helipod are. The reason for this is that the infrared surface temperature camera of the Tornado has a permanently varying lens aperture to achieve an optimum contrast. At this point it should be remarked, that the Tornado aircraft was initially equipped for military purpose.

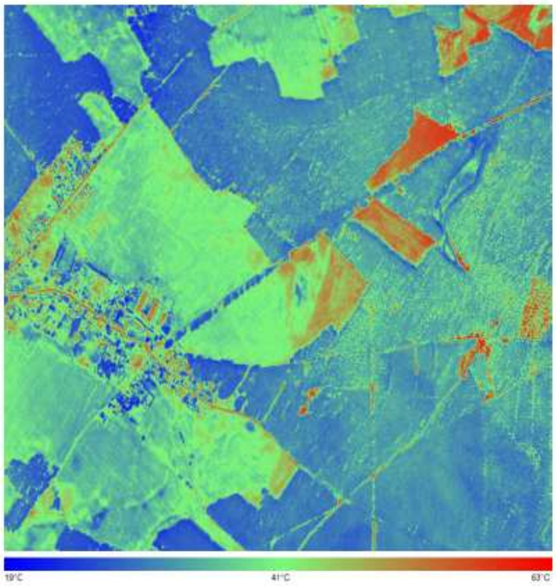

Fig. 13: *Calibrated infrared surface temperature photos of the Tornado aircraft.*

The differences in the grey scales due to the changing lens aperture had to be corrected. Because of the correction algorithms the absolute error of the calibrated Tornado photos is about a few Kelvin, which is rather large compared with the Helipod. But the relative error is with some tenth Kelvin in the same order as the Helipod measurements.
The results shown here are preliminary. The calibration of the infrared photos just started. Some systematical errors will be eliminated during the following months.

5. OUTLOOK

Currently the Helipod receives a complete upgrade that will be finished in 2004. The current main computer will be replaced by a single board computer with commercial industry components, temperature proofed to -30^{o}C (PowerPC, MEN Company, Nürnberg, Germany).

A real-time operating system of the Unix family, 'Real-Time Linux', will control the commercial input-/output modules. As there are 32 differential A/D-channels, ARINC interface for the LITEF inertial navigation system, 3 GPS receivers and antennas for complete attitude alignment, and a flash-storage. The choice of industry hardware components saved money and will make updates easier. The recording rate will increase to 500 Hz with an anti-aliasing low-pass filter at 100 Hz, and an oversampling of at least 3 kHz for noise reduction. This will increase the unmuted spatial resolution to 40 cm, which is in the order of the diameter of the Helipod. Instead of the former online data processing the data will be post processed for better complementary or Kalman filtering especially of the navigation data. Furthermore new measurement equipment will be integrated, like CO_2 sensors, ozone sensors, infrared- and optical cameras, etc.
Because the data of the ground-based measurements of the LITFASS Experiment in 2003 were not available by the time of writing there will be detailed analysis and comparison of Helipod and ground-based data in the early year 2004. It is expected that the agreement of the results of the different measurement systems will be as good as during the LITFASS experiment of 1998 (Bange *et al.*, 2002b).

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