P1.11 Ultrafast thermometer UFT-M and high resolution temperature measurements during Physics of Stratocumulus Top (POST)

Wojciech Kumala *, Krzysztof E. Haman, Marta K. Kopec and Szymon P. Malinowski

University of Warsaw, Institute of Geophysics, Warsaw, Poland

1. INTRODUCTION

UFT-M - a prototype of a new thermometer from UFT family (Haman et al. 1997, 2001) was used on the board of CIRPASS Twin Otter aircraft in Physics of the Stratocumulus Top (POST) field campaign in July and August 2008 (Gerber et al., 2010). Modernized sensor confirmed to be much more reliable that the former UFT-F, providing a large set of unique data. It allows to analyse thermal structure of Stratocumulus topped boundary layer with resolution of few centimetres. This note brings out improvements in the sensor construction (section 2), discusses data processing procedure (section 3) and documents UFT-M performance (section 4). Selected examples of small-scale temperature fluctuations which confirm the importance of deeper insight into details of mixing process of cloud and environment are shown.

2. Description of the UFT-M thermometer

2.1 *Construction of the sensor*

The sensing element in all thermometers of UFT family is a platinum coated tungsten wire 2.5µm thick and 5 mm long, working as a thermoresistive element in an electronic circuit. In UFT-F it is soldered to insulated copper wires hidden inside a fork-like support, made of stainless-steel tube. A small diameter and large length to diameter ratio of the sensing wire immersed in the airflow result in low thermal inertia and negligible heat transport along the wire (Haman et al., 1997, 2001).

The sensing wire is located 6.5 mm behind a shielding rod which protects it against impact of droplets and wetting. The hollow, 23mm long rod is aerodynamically shaped and has 0.35mm wide slots along its side surfaces which are connected to Venturi nozzle exposed to the airflow. Pressure deficit from the nozzle results in suction of the surface layer from the rod, damping pressure and temperature fluctuations in the wake and removing water collected by the shield. The sensor and the protecting rod are mounted on a rotatable vane adopting to the local airflow, held by a stiff frame. Since delicate wire could be easily broken, two UFT-F thermometers were usually installed, though distance between them hardly could be then smaller than few decimetres, making their indications not fully compatible.

The modifications introduced to UFT-M (Fig.1) are:

- two sensing wires close together on a single support (redundancy: continuation of measurement in case one of the wires gets broken);

- an improved miniaturized electronic circuit inside the vane to reduce the length of the signal cables in order to minimize interferences with aircraft avionics;

-a stiffer vane holding frame and improved bearings to reduce vibrations.

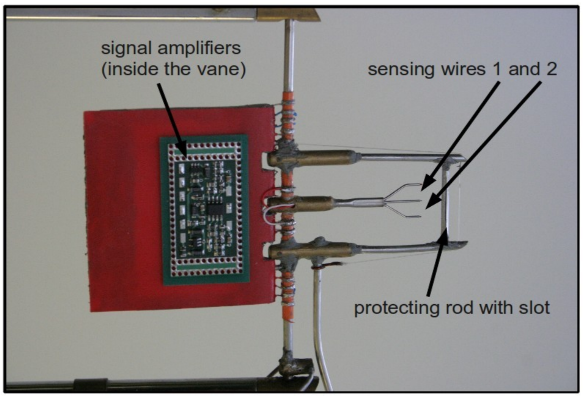

Fig. 1. *UFT-M as used in POST. The printed circuit with electronics is shown out of the vane.*

* Pasteura 7, 02-093 Warsaw, Poland, kumala@igf.fuw.edu.pl

Two sensing wires are now in front of a trident-like support made of ∅0.8mm stainless-steel tubes. Wires are soldered to the tips of teflon-coated copper connectors sheltered inside these tubes. The middle dent (common to both sensing wires) is connected to the common ground of the amplifiers located in the vane; signals are collected from outer dents. OPA 2365 operational amplifiers with 68-fold amplification and frequency response up to 20kHz are used. They are located on a specially designed printed circuit, small enough to be hidden inside the vane. The whole circuit is screened there with copper foil and the stainless tubes of the trident. Screening is important, since signal level from the sensors is very low due to reduced to 2mA current in the sensing wires in order to minimize Ohm heating. This implies that resolving temperature fluctuations with desired 0.1K precision requires voltage resolution better than 0.035mV. Such weak signal is easily affected by electromagnetic fields e.g. from aircraft radar, radio and avionic systems. After amplification the output signal sensitivity is better than 20mV/K and thermal drift of the output signal is less than 0.25mV/C. Since the UFTM is designed to measure temperature fluctuations rather than absolute temperature values, such drift is acceptable.

2.2 Mounting of the sensor

During POST campaign the UFT-M frame was mounted on a special stiff stainless-steel tube located below the nose of the CIRPASS Twin Otter research aircraft (Fig.2) in proximity of fast-response instruments: PVM-100, hygrometers and 5-hole turbulence probe. Tube was tilted back in order to compensate the typical angle of attack during the measurements.

Access to the tube through the front baggage compartment allowed for adjustment of the tube length in order to keep the sensor in undisturbed flow and minimize vibrations. It also permitted fast replacement of the tube with the sensor even in field conditions.

Amplified signals from both sensors of the UFT-M were transmitted to conditioning filters and A/D converter with double-shielded cables. Data were collected at the rate of $20*10^3$ samples per second (20kS/s) in each channel. Additionally time sync signal was recorded. Typically ~10GB of raw data was collected during each flight.

Fig.2. *UFT-M thermometer (red vane) mounted below the nose of CIRPASS Twin Otter research aircraft.*

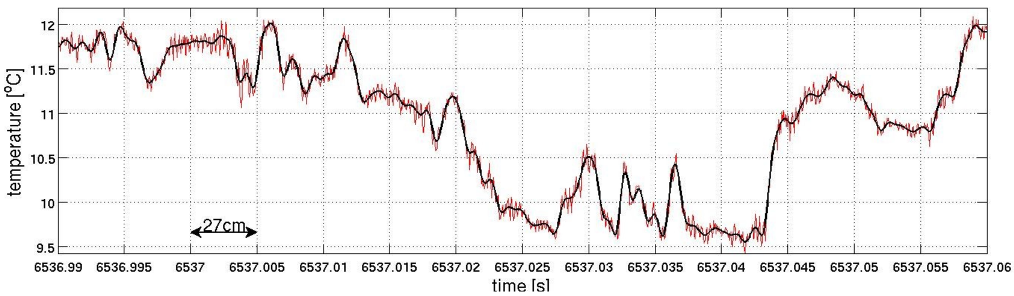

Fig.3 *Example temperature record from UFT-M. Red line – raw, unfiltered signal. Visible temperature fluctuations in vortices shedding from the anti-droplet protecting rod. These fluctuations of order of 0.1 K are effectively filtered with 20th order low-pass Butterworth filter of 2.5 kHz cut-off frequency without phase shift (black line).*

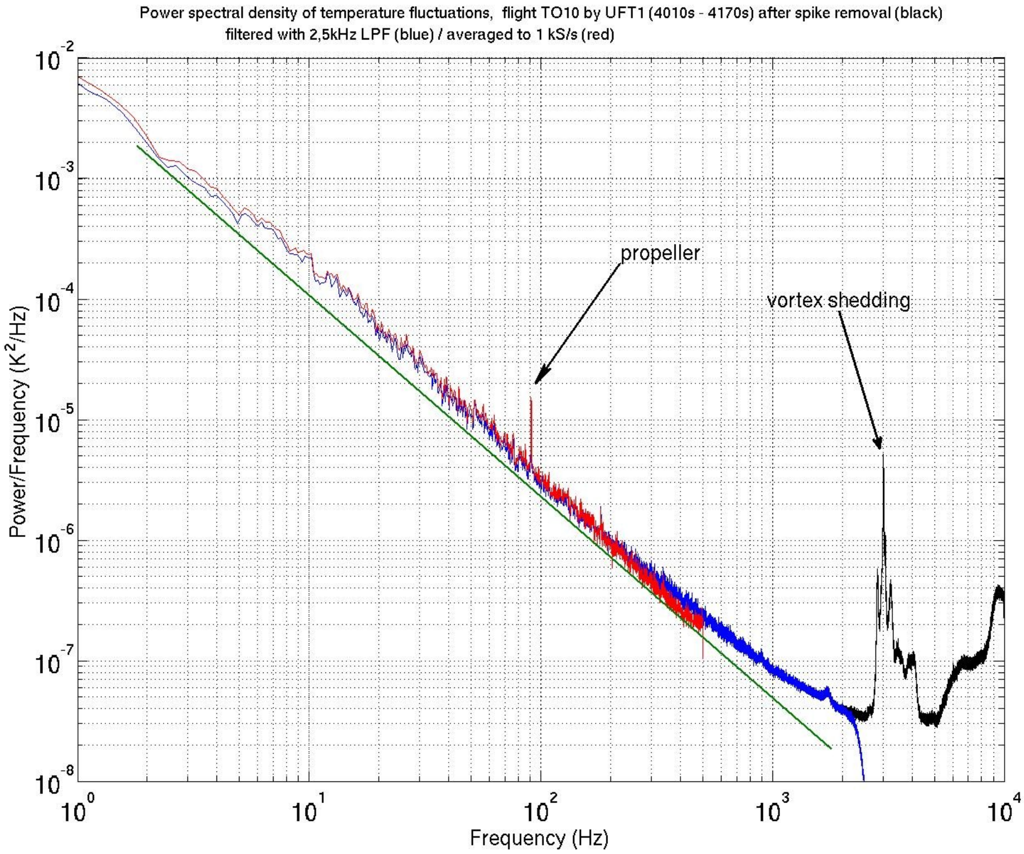

Fig. 4 *Power spectral density of temperature fluctuations in clod-top region. -5/3 slope plotted for reference. Black: 20kS/s data after spike removal, blue: 20kS/s data low-pass filtered with 2.5 kHz cut-off frequency, red: 1KS/s data stored in the database http://www.eol.ucar.edu/projects/post/.*

3. Data Processing and evaluation.

Analysis of the signal after the first flight revealed that data were seriously affected by regular series of high amplitude spikes due to the interference with one of the avionics systems. Fortunately, this system could be switched off except for landing procedures. Some other spikes present in the signal were removed by post-processing. When the magnitude of spike exceeded certain selected threshold (corresponding to 0.15K), the arithmetic mean from neighbour points was substituted into the data.

After removal of spikes and other artefacts 20kS/s UFT-M signal was averaged down to 1000, 100, 10 and 1S/s. The 1S/s signal was used to calibrate the temperature record against the data from the reference thermometer (UCI Irvine probe in Rosemount housing). Calibration has been performed in each flight for each particular UFT-M sensor. Calibrated 1000, 100, 10 and 1S/s signals are available from the POST database maintained by NCAR's Earth Observing Laboratory.

A short section of UFT-M signal is presented in Fig.3 (red line). Characteristic temperature fluctuations of the amplitude of ~0.1K are caused by vortex shedding from the anti-droplet rod. They are discussed in detail in Rosa et al., 2005. These fluctuations are effectively filtered numerically with 20th order low-pass Butterworth filter of 2.5 Khz cut-off frequency without phase shift (black line in Fig.3).

An example of power spectral density (PSD) of temperature fluctuations in the cloud top region is given in Fig.4. Black line represents PSD of calibrated 20kS/s temperature signal after spike removal, blue line: PSD of the same signal digitally filtered and red line: PSD of the

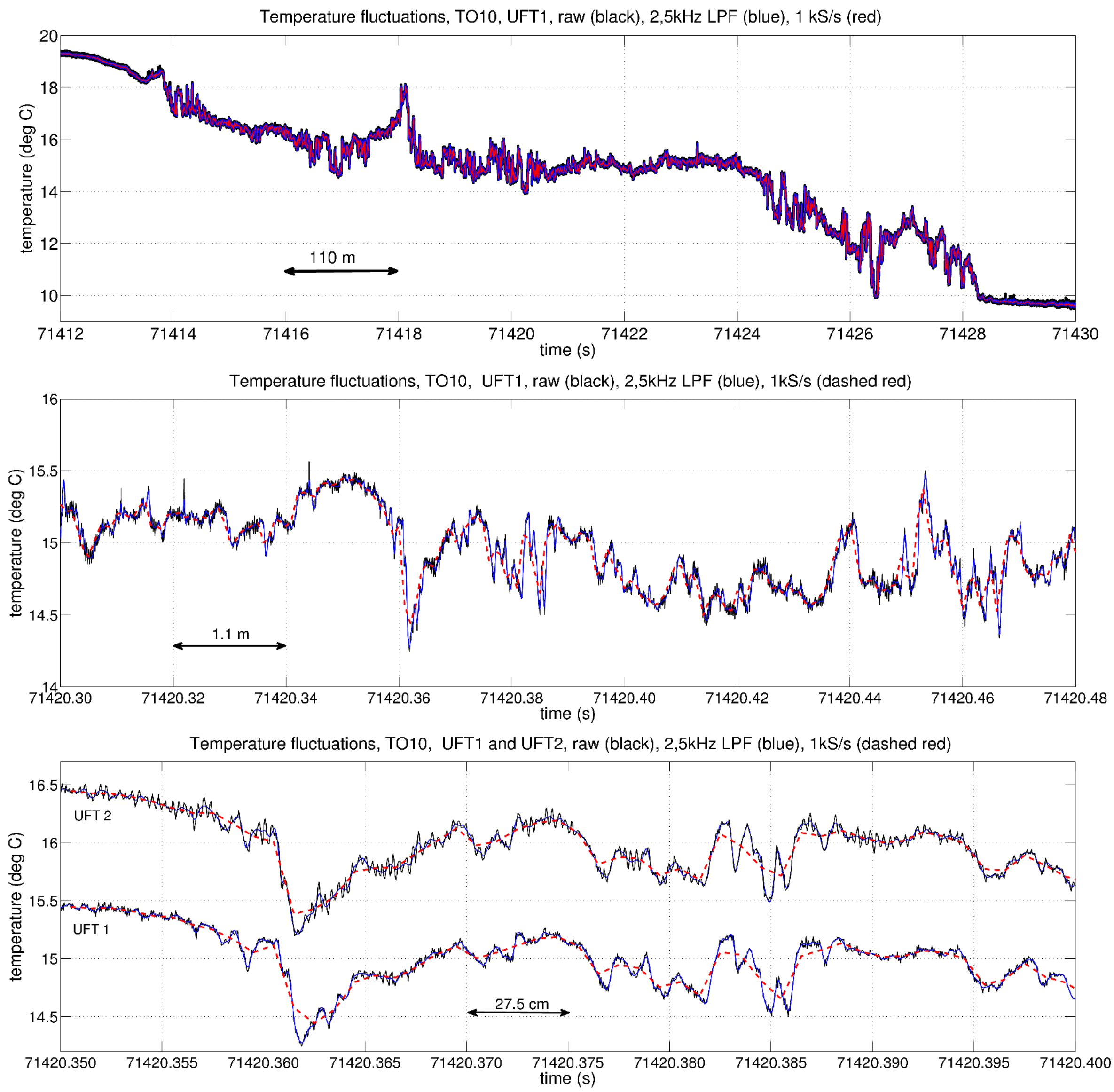

***Fig.5.** Examples of recorded temperature fluctuations in the cloud-top region. Upper panel shows full range of temperature fluctuations recorded during descent of Twin-Otter from capping inversion into Sc cloud. Middle panel presents temperature fluctuations as recorded by despiked, low-pass filtered and averaged signals. Lowest panel compares records from two sensing wires of the UFTM (shift between the records is artificial). Colour code as in Fig.4.*

signal averaged down to 1kS/s, as submitted to the POST database. Plots demonstrate that PSD follows -5/3 power law up to ~2kHz. Unfiltered, filtered and averaged signals overlap up to ~250 Hz. 1kS/S averaging slightly damps temperature fluctuations to limiting frequency of 500Hz. PSD of filtered and unfiltered 20kS/s records overlap up to 2kHz frequency. At higher frequencies vortex shedding from the rod produces temperature fluctuations which add energy to the power spectrum; these fluctuations are effectively damped by digital filter.

4. Example records

Fig. 5 presents raw, filtered and averaged temperature fluctuations recorded inside Entrainment Interfacial Layer (EIL, Gerber et al., 2005) close to the cloud top. Three successive blow-ups of the record show the performance of the sensor and effects of data processing. It can be seen, that averaging to 1KS/s efficiently damps noise, but also small-scale temperature fluctuations clearly seen in the low-pass filtered signal. In the region of high temperature contrast these fluctuations, visible over vortex-shedding noise, correspond to small filaments of inhomogeneously mixed air and give unprecedented insight into this important process. Minimum thickness of such filaments documented in Fig.5 is less than 5cm.

Let us notice that the lowest panel of Fig 5 shows that 2.5kHz LPF and 1kS/s averaged signals from both temperature sensors of UFT-M reveal similar shape of temperature fluctuations, while thermal noise due to vortex shedding is different for each wire. This suggests that small imperfections of sensor assembling and 3-dimensional effects of the airflow around the rod are important for generation of thermal noise. 2-dimensional modelling of the flow (as in Rosa et al., 2005) is not sufficient to explain all details of this process.

Acknowledgements:

This research was supported by the National Science Foundation with the grant ATM-0735121 and by the Polish Ministry of Science and Higher Education with the grant 186/W-POST/2008/0.
We thank H. Gerber for organizing POST, CIRPAS crew and all POST-ers for excellent collaboration.

References:

Gerber H., S.P. Malinowski, J-L Brenguier, F. Burnet, **2005**: Holes and entrainment in stratocumulus. *J. Atmos. Sci.,* ***62,*** 443–459.

Gerber H., et al., **2010**: POST—A New Look at Stratocumulus, *13th AMS Conference on Cloud Physics*, Portland, OR, 2010.

Haman K.E., A. Makulski, S. P. Malinowski, and R. Busen, **1997**: A new ultrafast thermometer for airborne measurements in clouds. *J. Atmos. Oceanic Technol.*, **14**, 217–227.

Haman, K. E., S. P. Malinowski, B. Strus, R. Busen, and A. Stefko, **2001**: Two new types of ultra-fast aircraft thermometer. *J. Atmos. Oceanic Technol.,* **18**, 117–134.

Rosa, B., K. Bajer, K.E. Haman, and T. Szoplik, **2005**: Theoretical and Experimental Characterization of the Ultrafast Aircraft Thermometer: Reduction of Aerodynamic Disturbances and Signal Processing. *J. Atmos. Oceanic Technol.*, **22**, 988–1003.