TNA User Report

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Project title	Performance of the UltraFast Thermometer 2 under turbulent cloudy conditions
Name of the accessed chamber	LEAK-LACIS
Number of users in the project	3
Project objectives (max 100 words)	Main goal is to explore the limits of application and performance of the UltraFast Thermometer 2 (UFT-2). This instrument is designed for high-resolution airborne temperature measurements in atmospheric turbulent warm clouds, onboard various flying vehicles. Specific objectives include calibration against reference thermometer, investigation of likelihood and importance of wetting, and examining the influence of sea salt aerosol on the properties and degradation of the sensing element. Because LACIS allows for precise control of temperature, humidity and generation of cloud droplets on salt nuclei, it is an ideal facility for carrying out such studies.
Description of work (max 100 words):	Experiments inside the LACIS chamber involved 6 different thermometers: 4 versions of the UFT, a commercial coldwire thermometer and a slow-response accurate reference. Under dry conditions, we performed calibration and intercomparison of the sensors, and investigated dependence of the UFT readings on the incidence angle with respect to the mean flow. Further, the instruments were exposed to water droplets at a series of angles to study collisional wetting. Condensational wetting was examined by placing clean and salt-exposed sensors in moist flow. Conditions inside the chamber were monitored with a reference thermometer and a dew-point hygrometer.

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[1] Physics; Chemistry, Earth Sciences & Environment; Engineering & Technology; Mathematics; Information & Communication Technologies; Material Sciences; Energy; Social sciences; Humanities.
[2] UNI= University and Other Higher Education Organisation;
RES= Public Research Organisation (including international research organisations and private research organisations controlled by public authority);
SME= Small and Medium Enterprise;
PRV= Other Industrial and/or Profit Private Organisation;
OTH= Other type of organization.
[3] UND= Undergraduate; PGR= Post graduate; PDOC= Post-doctoral researcher; RES= Researcher EXP= Engineer; ACA= Academic; TEC= Technician.
[4] Reproduce the table for each user who accessed the infrastructure

Trans-National Access (TNA) Scientific Report

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Please limit the report to max 5 pages, you can include tables and figures. Please make sure to address any comments made by the reviewers at the moment of the project evaluation (if applicable, in this case you were informed beforehand). Please do not alter the layout of the document and keep it in Word version.
The report will be made available on the eurochamp.org website. Should any information be confidential or not be made public, please inform us accordingly (in this case it will only be accessible by the European Commission, the EUROCHAMP-2020 project partners, and the reviewers). Please include:

- Introduction and motivation
- Scientific objectives
- Reason for choosing the simulation chamber/ calibration facility
- Method and experimental set-up
- Data description
- Preliminary results and conclusions
- Outcome and future studies
- References

Instructions

Name of the PI: Jakub Nowak
Chamber name and location: LEAK-LACIS, Leibniz Institute for Tropospheric Research, Leipzig, Germany
Campaign name and period: Performance of the UltraFast Thermometer 2 under turbulent cloudy conditions, 19 Aug – 6 Sep 2019
Text: scientific report

Introduction and motivation

Reliable in-situ measurements of temperature in clouds and their neighborhood remain a challenge, mostly due to the significant speed of the airborne vehicles and the wetting by water droplets. High spatial resolution, desired to study atmospheric phenomena such as cloud microphysics – turbulence interaction or cloud – clear air mixing, is limited by flow velocity and probe response time. Quick heat exchange comes at the cost of exposing sensing elements to harsh conditions, including cloud droplets, aerosol particles or insects. UltraFast Thermometer 2 (UFT-2) is a new family of instruments created with ambition to improve the state of the art in this domain.

Scientific objectives

As relatively new device, UFT-2 requires precise characterization under controlled conditions. Laboratory tests are desired to verify accuracy, response, stability, efficiency of anti-droplet protection measures, importance of wetting, influence of sea salt aerosol, and eventually to improve the current design and outline appropriate data processing schemes.

Specific experiments at LACIS-T were planned in order to:

- calibrate UFT-2 against a reference thermometer; inspect accuracy, response and orientation dependence in turbulent flow by comparison with commercial sensors,
- examine the character and likelihood of wetting under cloudy conditions and estimate its dependence on the incidence angle,
- investigate the influence of salt deposition on wetting and instrument performance.

Reason for choosing the simulation chamber / calibration facility

LACIS-T is an ideal infrastructure for testing UFT thermometers, as it provides turbulent flow with precisely controlled temperature and humidity. Moreover, two streams differing in thermodynamics can be mixed to resemble intensive fluctuations present in some parts of the atmosphere and to create supersaturation. The facility allows for the generation of cloud droplets of reproducible concentration and size distribution. They grow on aerosol particles, e.g. salt, and the objects inside can be also exposed to those, which might simulate research flight close to the sea surface.

Method and experimental setup

Four types of the UFT were used in different arrangements and experiments:

- UFT-M with two independent sensing wires spanned on a trident-shape support, designed for Twin Otter research aircraft (Kumala et al., 2013),
- UFT-2-0 with two sensing wires connected in parallel circuit, spanned on a trident-shape support behind a steel protection rod, designed for ACTOS helicopter-borne platform (Nowak et al., 2018),
- UFT-2-A with one sensing wire spanned perpendicular to the flow on straight prongs, designed for balloon-borne measurements,
- UFT-2-B with properties similar to UFT-2-A but the wire spanned along the direction of the flow on bended prongs.

Additionally two supporting thermometers were applied for comparison: fast-response ColdWire (Dantec Dynamics 55P71) and slow-response but highly accurate PT100 (see all in in Fig. 1).

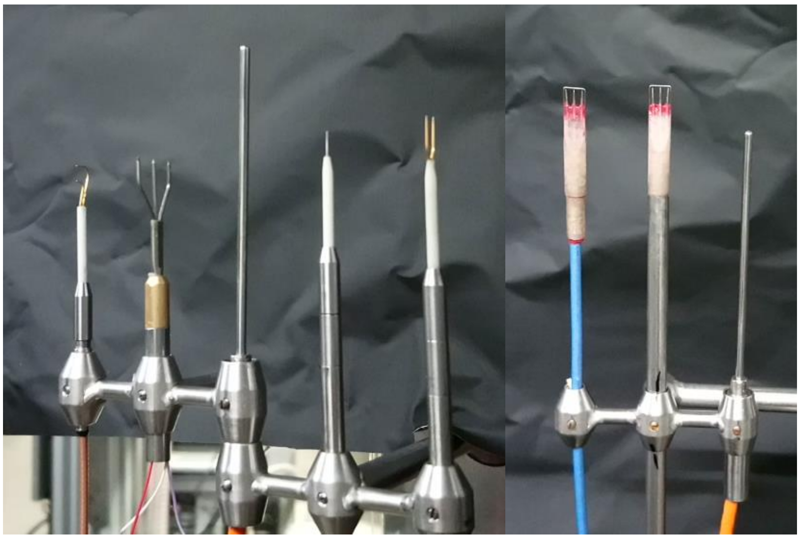

Fig.1. Thermometers participating in the experiments within the project (from left to right): UFT-2-B, UFT-M, PT100, ColdWire (Dantec Dynamics 55P71), UFT-2-A, UFT-2-0, UFT-2-0, PT100.

LACIS-T is a closed loop turbulent wind tunnel consisting of two branches, independently controlled with respect to temperature and humidity. Two streams mix while entering the cuboidal measurement section of the size 80 cm x 20 cm x 200 cm (Niedermeier et al., 2017). The conditions are close to uniform along the longer dimension and usually highly non-uniform across. Where the two streams come into contact, aerosol particles can be isokinetically injected to form cloud droplets provided that supersaturated air is encountered.

Data description

Collected data consist of a number of 5-120 min long timeseries: voltage for UFTs and ColdWire (3 kHz), temperature for PT100 (0.2 Hz). When needed, the humidity inside the tunnel was monitored with a dew-point mirror (1 Hz). The voltage was converted into temperature by calibrating the thermometers against the PT100. The sampling frequency of 3 kHz was chosen taking into account constant mean flow of 1.3 m/s, the length of the UFT sensing wire (3-5 mm) and its response time estimated with infinite cylinder model (about 0.24 ms).

Preliminary results and conclusions

<u>Calibration</u>

All UFTs were calibrated against the reference thermometer (PT100) assuming linear relationship between temperature and voltage on the sensing wire. Two methods were employed independently:

- uniform conditions (UNI): equal temperature in both branches of the LACIS tunnel which was changed in steps while keeping the sensors in a fixed position,
- mixing conditions (MIX): temperature settings different between the branches created mixing zone downstream their connection and were kept constant, the sensors were moved in steps across the mixing zone.

The former results in almost ideal linear dependence, the latter involves slight departures from linearity caused by the influence of tunnel walls on the flow (see summary in Fig. 2). The *uniform* method should be reagared as more precise, yet it is quite time-consuming. In contrary, the *mixing* method allows to simultaneously study the properties of the mixing zone (example in Fig. 3). Calibrated UFTs stay in good agreement, both in terms of absolute values as well as the variances. Except for close to the walls, the results follows the reference thermometer with good accurary. The variances exceed those measured with the commercial coldwire which might indicate better frequency response of our instruments.

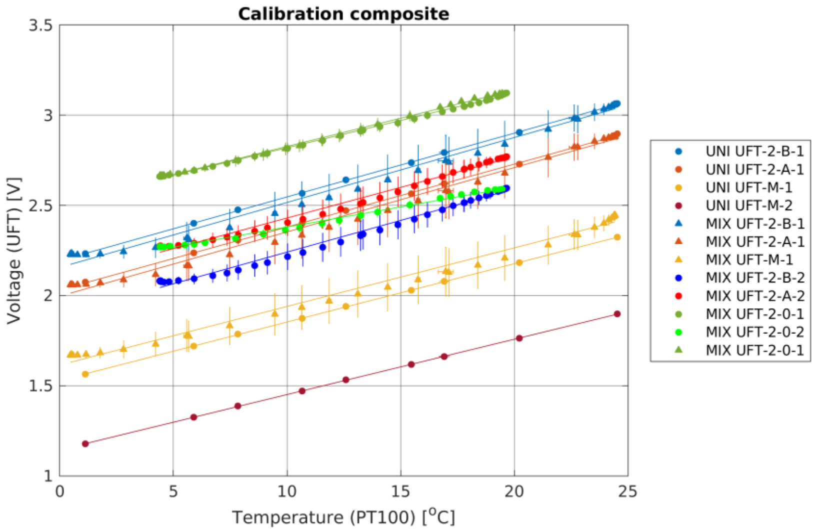

Fig. 2. UFT calibration curves for a number of instruments and two experimental procedures (UNI: uniform conditions, MIX: mixing zone between two streams). Errorbars show standard deviation within 5 min long record taken at each point.

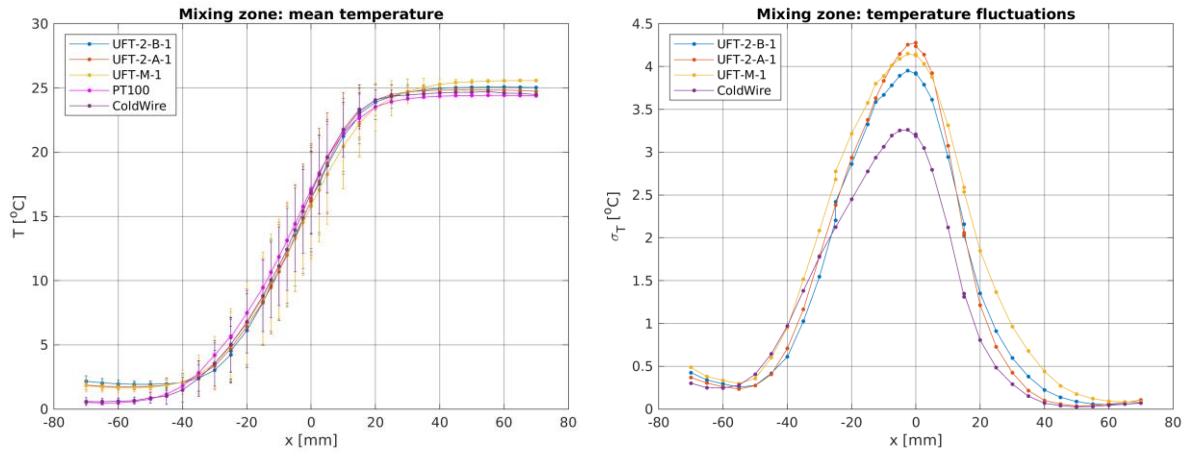

Fig. 3. Calibration with MIX method: profile through the mixing zone of two streams differing in temperature: mean temperature (left) and standard deviation within 5 min long records taken at each point(right).

Influence of the incidence angle

Some of the UFTs used in this study have nontrivial geometry intended to reduce the wetting of the sensing wire by impacting cloud droplets. Consequently, the local flow around the sensor depends on the exact incidence angle with respect to the mean velocity. To study this effect on temperature measurement, series of recordings were performed with the thermometers tilted by a chosen angle under mixing dry conditions inside the central zone of the LACIS-T.

The results accordingly corrected for slight non-uniformity in the tunnel, are summarized in Fig. 4. UFT of the simplest geometry (UFT-2-A) were used as reference since for its wire perpendicular to the flow, there should be no influence of the inclination. Comparison of the corrected variances implies that any kind of the protection reduces measured temperature fluctuations by the factor dependent on the angle whereas the orientation of the wire itself has almost no effect as long as it is outside the aerodynamic shadow.

Influence of wetting

To investigate the likelihood of sensor wetting, the thermometers were exposed to the stream of water droplets (of the mean diameter 2 um and concentration 1000 cm^{-3}) at a series of chosen incidence angles. Fig. 5 illustrates an example of such experiment. After an initial stoppage, the instruments were moved into the mixing zone where the droplets form. Significant wetting was observed in most cases even with the naked eye, with no clear systematic dependence on the angle.

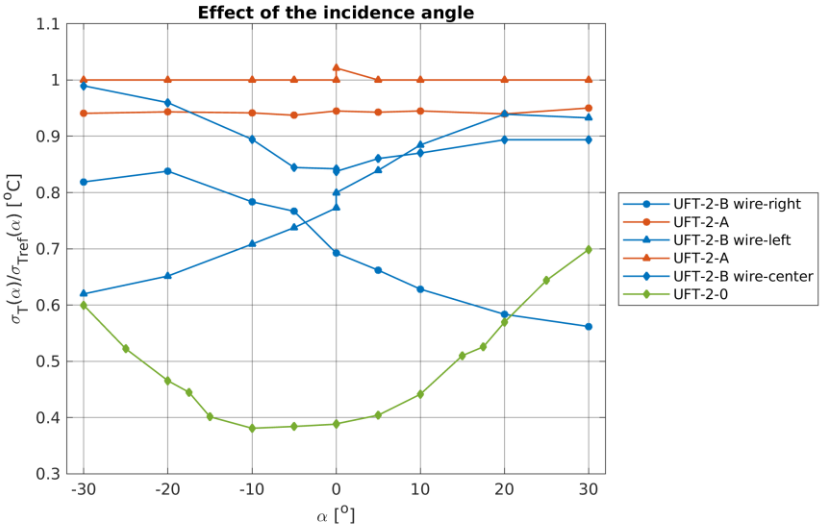

Fig.4. Standard deviations of the temperature records at different sensor orientation with respect to the mean flow, corrected for the non-uniformities in the tunnel. In case of UFT-2-B three positions are included: wire facing right is shadowed by the prongs for positive angles, facing left for negative, in the center - symmetrically for small angles.

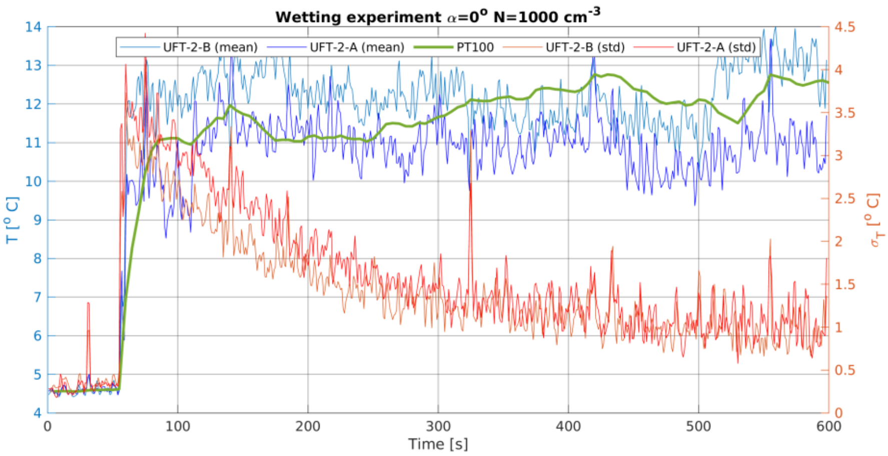

Fig.5. Example of the wetting experiment: timeseries of mean temperature (blue, green) and standard deviation (red), both calculated using the sliding window of 3 s, from the sensors exposed to the stream of water droplets inside the supersaturated mixing zone.

Wetting explains the decrease in measured variance of temperature fluctuations since water deposited on the sensor increases its time response simply due to the growing heat capacity. For the specific thermodynamic conditions the wetting by colliding droplets was estimated to be negligible in comparison with condensation. The dominance of condensation is caused by relatively high supersaturation of 1.5 % (needed to efficiently form droplets on aerosol nuclei) and relatively small size of the droplets, in contrast to typical convective clouds. Indeed, no indications of intermittent hits were spotted in the signals while the gradual decrease of temperature variance implies rather continuous deposition.

Influence of salt

It was previously speculated that the salt deposited on the sensor might favor wetting through condensation as well as support sticking of the impacting droplets. In several experiments conducted to study this issue, thermometers in 3 different states were subject to increasing humidity level: completely clean and dry, wetted by droplet stream and dried afterwards, dipped in saturated salt solution and dried afterwards.

Hygroscopic growth of deliquesced salt particles was observed on the dipped ones, starting at the relative humidity of about 76 % which agrees with the previous studies (Niedermeier et al., 2017). No significant difference was noticed between clean and droplet-wetted sensors. In both cases the condensation started when saturation was reached, suggesting the deposition of salt by the cloud droplets is rather negligible from the point of view of temperature measurement. Nonetheless, intensive deposition of large salt particles, although unusual in the atmosphere, might lead to hygroscopic wetting even without saturation. Moreover, in the course of the project it was noted that salt exposure promotes mechanical damage of the instrument, e.g. by loosening the fine soldering of the sensing wire.

Conclusions

- All studied UFT versions provide accurate and consistent temperature readings when linearly calibrated against a reference. Accuracy and response of the UFTs allows for studying details of mixing between air masses differing in temperature.
- The effect of the incidence angle is negligible for mean temperature but significant for the fluctuations. Differences between UFT versions can be satisfactorily explained by the influence of the aerodynamic shadow behind the mounting prongs or the protection rod.
- In supersaturated air, condensation has major contribution to sensor wetting in contrast to collisions of droplets. The wetting manifests in decreasing time response due to the growing total heat capacity.
- Salt deposited on the sensor by cloud droplets does not exert measurable effect on temperature measurement and the probability of wetting. However, it might contribute to the mechanical deterioration of the instrument which results in floating calibration and intensifies the chance of entire damage. Excessive salt deposition, unlikely in the atmospheric conditions, can trigger hygroscopic condensation already at the relative humidity of about 76 % remarkably below saturation level.

Outcome and future studies

The study undertaken at LACIS-T facility within TNA activity has provided valuable information concerning the properties and performance of the whole family of the UFT thermometers. It has been the first experiment in which all the versions were systematically compared with a reference and between each other in controlled turbulent flow with well-defined thermodynamic conditions.

Further work involves building the set of thermometers for a tethered balloon as well as improving the design, in particular introducing the mechanism preventing the instrument from condensational wetting, e.g. with hydrophobic coatings or alternate heating in a double-sensor device to periodically evaporate collected water.

References

Haman, K. E., Makulski, A., Malinowski, S. P., and Busen, R.: A new ultrafast thermometer for airborne measurements in clouds, Journal of Atmospheric and Oceanic Technology, 14, 217–227, 1997.

Kumala, W., Haman, K. E., Kopec, M. K., Khelif, D., and Malinowski, S. P.: Modified ultrafast thermometer UFT-M and temperature measurements during Physics of Stratocumulus Top (POST), Atmospheric Measurement Techniques, 6, 2043–2054, 2013.

Nowak, J.L., Kumala, W., Kwiatkowski, J., Kwiatkowski, K., Czyzewska, D., Karpinska, K., and Malinowski, S.P.: UltraFast Thermometer 2.0 - new temperature sensor for airborne applications and its performance during ACORES 2017, Geophysical Research Abstracts, EGU2018-12492, 2018

Niedermeier, D., J. Voigtländer, N. Desai, K. Chang, S. Krueger, J. Schumacher, H. Siebert, R. A. Shaw, F. Stratmann (2017): LACIS-T - a moist air wind tunnel for investigating the interactions between cloud microphysics and turbulence, 70th Annual Meeting of the American Physical Society, Division of Fluid Dynamics, Denver, CO, USA