TNA User Report

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Project title	Exploring performance of the Fast Infrared Hygrometer across the range of environmental conditions
Name of the accessed chamber	Leipzig Aerosol Cloud Interaction Simulator (LACIS)
Number of users in the project	2
Project objectives (max 100 words)	Characterization and evaluation of Fast Infra-Red Hygrometer (FIRH) under well-defined and reproducible conditions (flow, humidity, temperature conditions) was performed in Leipzig Aerosol Cloud Interaction Simulator (LACIS). The information about spatial distribution of humidity in-homogeneities inside the LACIS tunnel was achieved. The results provided by the experiments will foster further development of FIRH as a reliable, fast-response optical system for measuring air humidity in variable atmospheric conditions, including airborne applications in clouds.
Description of work (max 100 words):	After installation of FIRH on LACIS tunnel a set of preliminary experiments was performed. That provided opportunity to determine a procedure of data collection and further compensation of secondary effect influencing the results. Then systematic investigation of air masses (and their mixtures) under controlled humidity and temperature were done. Cases of the air seeding by the monodisperse particles of controlled concentration were also observed. Spatial humidity distribution was determined using both optical and dew-point meter. Good coincidence among the results provided by these instruments was stated.

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Trans-National Access (TNA) Scientific Report

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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

Instructions

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

Name of the PI: Tadeusz Stacewicz
Chamber name and location: LEAK-LACIS, Leibniz-Institut für Troposphärenforschung, Permoserstrasse 15, 04318 Leipzig, Germany
Campaign name and period: *Exploring performance of the Fast Infrared Hygrometer across the range of environmental conditions*, 20.05 - 07.06.2019
Text: Scientific report

Introduction and motivation

Our prototype hygrometer - the Fast InfraRed Hygrometer FIRH [1] - is an optical system, measuring absorption of laser light tuned to a specific rovibronic absorption line of H_2O molecule. FIRH has been already tested in atmospheric conditions and proved satisfactory agreement with other hygrometers (including ultraviolet absorption one). However, its accuracy has not been verified independently, i.e. under controlled conditions with different humidity levels. The design of the Leipzig Aerosol Cloud Interaction Simulator (LACIS, [2,3]) from the Leibniz-Institut für Troposphärenforschung (TROPOS) allows for precise control of humidity, temperature and flow velocity. Thus, it is an excellent testbed for the FIRH sensor.

Scientific Objectives

The goal of our experiment was to characterize and evaluate FIRH under well-defined and reproducible conditions resembling those in the real atmosphere. This includes a set of combined investigations across the measurement section of LACIS to achieve data on spatial humidity inhomogeneities.

Reason for choosing the simulation chamber

LACIS is an ideal facility to test the FIRH since the temperature and water vapour field can be precisely controlled. It allows for detailed investigation of the instrument performance under broad range of well-defined and reproducible laboratory conditions. The width of the measurement section of LACIS corresponds well to the typical optical path in FIRH. Therefore, the measurement from outside the chamber is possible, which eliminates the influence on the processes inside (flow, mixing, temperature and humidity diffusion).

Method and experimental set-up

In FIRH, the determination of water vapor concentration is based on the measurement of laser light attenuation. Its wavelength is precisely tuned to the peak of specific absorption line of H_2O molecule (λ_m = 1364,6896 nm – see Fig. 1) [1]. This quenching is compared with the attenuation at the reference wavelength λ_{R1} = 1364,4620 nm, that is characterized by much smaller absorption cross section. In several cases a different reference wavelength λ_{R2} = 1364,767 nm was used. It is worth to point out that such measurement is sensitive for molecular water concentration, while the light scattering on dust or water droplets is ignored due to simultaneous registration at both λ_m and λ_R wavelengths.

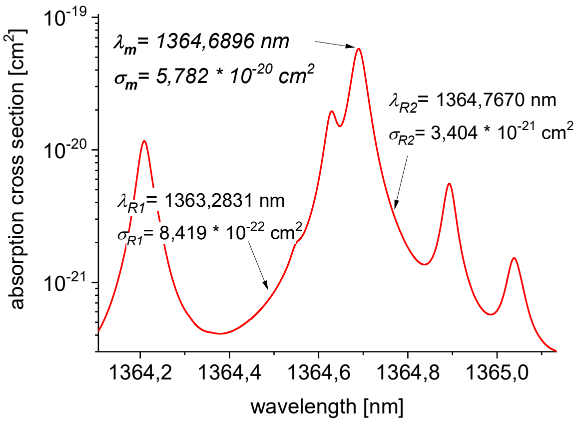

Fig. 1. H_2O absorption spectrum and the experimental wavelengths with relevant cross sections.

Scheme of the experimental setup is presented in Fig. 2. The laser beam was supplied to an optical transmitter by means of a fiber and then crossed the LACIS measuring section with a dimension 800 x 200 mm. A photodiode located in receiver was used to determine the light beam attenuation. Another photodiode (not shown in Fig. 2) was used for measurement of the intensity of laser light directed to the transmitter. Photodiode signals are analyzed with a two channel 16 bits AD converter. The laser light was AM modulated with the frequency of several kHz. Special software provided the opportunity of either *peak-to-peak* detection of the signals or their demodulation using *lock-in* approach.

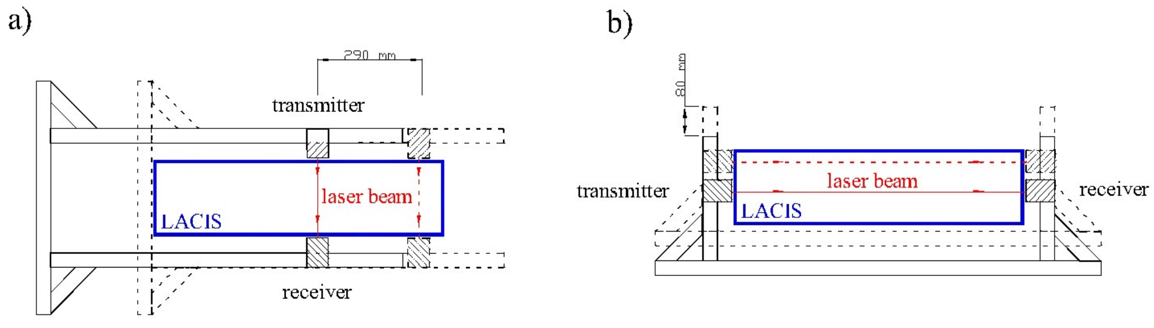

Fig. 2. Top-view section of LACIS-T tunnel and scheme of FIRH experiment for transverse (a) and longitudinal (b) investigation. The cross sectional dimension of the wind tunnel is 800 mm (longitudinal) x 200 mm (transverse). Dashed line drawings correspond to sleigh position displaced in respect to their initial location.

The transmitter and the receiver were mounted close to the opposite windows of the LACIS tunnel on rigid sleigh (constructed of Rexroth rails). Two kinds of sleigh, for transverse (Fig. 2a) and longitudinal air jet investigation (Fig. 2b) were used. Sleigh design allowed their displacement along a frame (not shown in Fig. 2) in respect to the tunnel. That provided the opportunity to study the spatial distribution of H_2O concentration. Possible displacement of the laser beam position was within 290 mm for transverse investigation and within 80 mm in the case of the longitudinal measurement.

Preliminary results and conclusions

The experiment was started on May 20th. Within the first day the FIRH as well as its frame and slays were installed at LACIS after their transport from Warsaw. Initial test measurements were performed. Then the experiment was continued till June the 7, when the equipment was packed and transported back to University of Warsaw. Altogether within almost 19 days of the stay in TROPOS, the experiment lasted 14 days (excluding weekends and holidays).

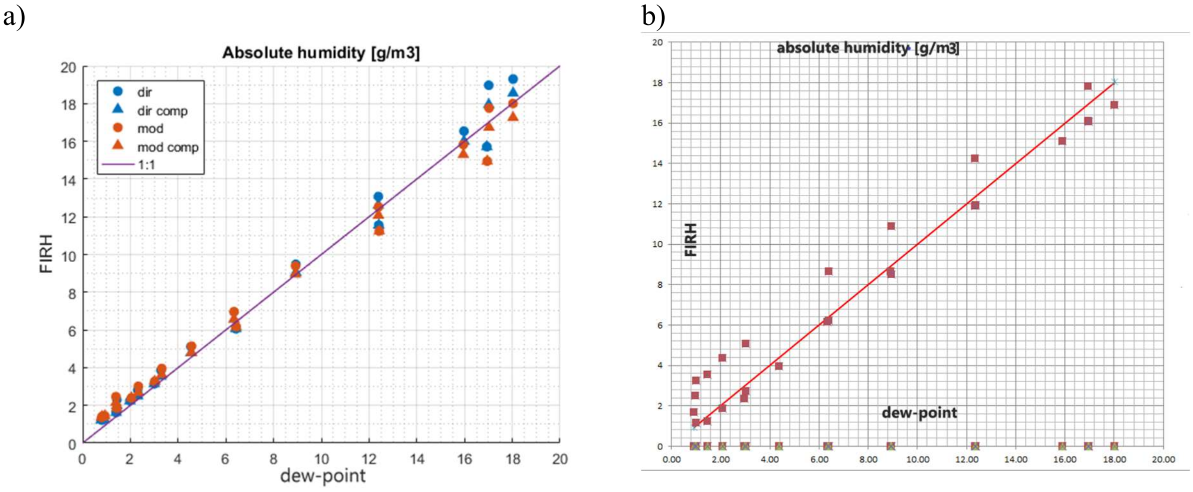

Fig. 3. Comparison of absolute humidity measurement for: a) longitudinal and b) transverse registrations. Lines – LACIS dew-point meter, dots - FIRH

After completing of the equipment, common humidity measurement using FIRH and LACIS dew-point meter was performed. Initially a constant air temperature in the tunnel (23 ºC) was applied while the dew-point temperature was changed from -20 to +20 ºC. FIRH investigation was done along the tunnel. The laser beam crossed it along the plane of symmetry, at the altitude approximately corresponding to the middle of the tunnel height. The comparison of the results is shown in Fig. 3a. The measurement was repeated several times and different methods of photodiode signal detection were tested. Better results were achieved for the *lock-in* detection (*mod* - red dots) than for the *peak-to-peak* registration (*dir* - blue dots). That is especially well seen at high humidity, when the optical signals were weak due to strong absorption. Good agreement between the dew-point meter and FIRH data was stated.

In the next days the investigation with FIRH was focused on transverse measurements. However, in this case the comparison of FIRH results with those from LACIS dew-point meter was not satisfactory. That is manifested in Fig. 3b by two series of the experimental points, approximately located on two parallel lines. Each series corresponds to different reference wavelength λ_{R1} and λ_{R2}.

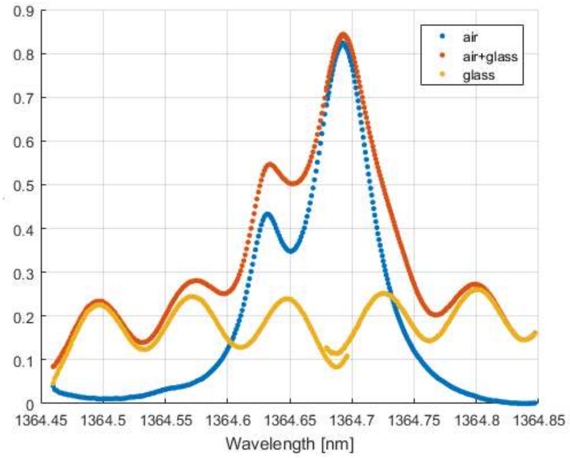

Fig. 4. H_2O absorption spectrum (blue line, HITRAN) and experimentally collected transmission spectrum of tunnel windows (yellow line). Red line represents an example of the resultant spectrum

Light interference in the tunnel glasses is responsible for such effect. The laser beam crossing the tunnel window reflects on the glass surfaces. The reflected beam interferes with forthcoming light beam, leading to its almost 15% modulation (which is dependent on the wavelength and the glass thickness). The effect is magnified by presence of two windows on the beam way. It causes a modification of the light spectrum transmitted through the tunnel (Fig. 4) and in this way it interferes the results. Its influence is much less important for longitudinal registration (Fig. 3a). In this case the light path through the tunnel is about 4 times longer than for the transverse measurement. Then the absorption by water molecules is stronger, so the contribution of spectrum modification by window transmission (fig. 4) is weaker.

Basing on these preliminary observations we established an experimental procedure which allowed us to collect valuable experimental data. It consisted on simultaneous registration of:
a) light intensities at the wavelengths λ_m and λ_R using both peak to-peak and lock-in detection,
b) windows transmission spectrum,
c) humidity of air in LACIS-T room (for compensation of laser beam absorption within their run outside of the tunnel).

The data collected in points *b)* and *c)* will be used during further results elaboration for compensation of the secondary effects described above.

After preliminary observations the systematic investigation was carried out. We were mainly focused on the observation of phenomena connected with the following situations:
a) mixing of the air masses of different humidity and temperature,
b) monodisperse particle seeding of the air masses at controlled humidity and temperature.

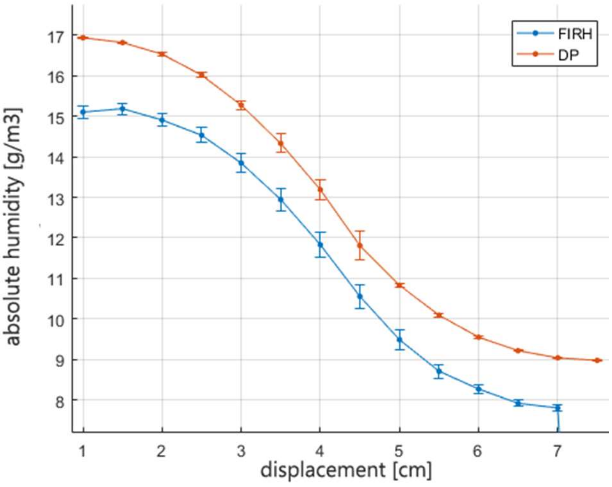

Fig. 5. Water vapor distribution in the tunnel - example

That leads to non-homogeneous spatial humidity distribution. Study of such effect was possible due to the displacement of laser beam against the tunnel.

An example of the results is presented in Fig. 5. In this case the measurement with FIRH was compared with dew-point humidity meter. The laser beam was sent along the tunnel. For each displacement against the apparatus symmetry plane the tunnel was opened and the position of the dew point meter head was agreed with the light beam. The discrepancy of the results provided by the both devices is about 10%. Analogous results for various conditions in the tunnel were registered in the transversal direction.

Outcome and future studies

Overall, within this experimental campaign about 0,5 TB of the data was collected due to coherent and fruitful collaboration of the teams from TROPOS and the Faculty of Physics from the University of Warsaw. As it was mentioned above careful elaboration of the data is necessary, including the compensation of secondary effects. That will be done in the nearest future. However, the measurement results will foster the further development of FIRH as an independent (i.e., no calibration needed), reliable, fast-response optical system for measuring air humidity in variable atmospheric conditions, including airborne applications in clouds. In summary, experiments carried out will help to explore and improve the capabilities of the FIRH system.

Second, the colleagues at TROPOS gained deeper knowledge concerning the design and application of the optical hygrometer system, which will influence future decisions with respect to possible instrumentation at LACIS.

We want to report the outcomes of this TNA on public conferences. It’s too early to judge, whether or not the investigations will result in a peer-reviewed technical publication of their own, but we are certain that they will find their way into future scientific publications, and EUROCHAMP 2020 will be definitely referenced therein.

References

1) J. L. Nowak, P. Magryta, T. Stacewicz, W. Kumala, S. P. Malinowski, *Fast optoelectronic sensor of* H_2O *concentration*, Optica Applicata 46, pp 607 – 618, 2016.

2) Voigtländer, J., D. Niedermeier, H. Siebert, R. Shaw, J. Schumacher, F. Stratmann (2017) : *LACIS-T – A humid wind tunnel for investigating the interactions between Cloud Microphysics and Turbulence,* 19th EGU General Assembly, proceedings from the conference, p. 6475, Vienna, Austria.

3) 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.