PHD-THESIS SYNOPSIS

Development of a two channel photoacoustic spectroscopy based hygrometer system for atmosphere research

By

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1 Introduction

Airborne hygrometry (measuring water vapor concentration and total water content) has a very important role in climate research as atmospheric moisture is responsible for circa 75% of greenhouse effect. High variety of humidity levels means one of the difficulties of such measurements: it can be as high as 40000 ppmV at ground level (namely at 1 bar pressure) at tropics and as low as 1.5 pmV at the upper troposphere-lower stratosphere (namely at 10-12 km altitude, at circa 200 mbar pressure). Moreover, atmospheric humidity is usually inhomogenously distributed both in time and space– one can think the rapidly varying meteorological circumstances. The MOZAIC project was launched 20 years ago to measure atmospheric water vapor concentration with capacitive sensors mounted on in-service aircrafts. The IAGOS project was recently launched to similarly to measure atmospheric water vapor concentration (besides several other compounds) similarly as it has been done within the MOZAIC project, but extending the measurements to total water content is also planned. Atmospheric water vapor concentration and total water content is regularly measured within the CARIBIC project with the measuring system developed at the University of Szeged, Department of Optics and Quantum Electronics, Research Group on Photoacoustic Spectroscopy, partially by myself.

An airborne water vapor concentration and total water content measuring system has to meet several expectations:

- It has to measure highly precise (at least 0.3 ppmV + 1% relative) and accurate (at least ±5% relative) at any pressures and concentrations possible during a flight.
- Measurement of water vapor concentration and total water content should be realized in one measuring system since this way small differences of the two quantities can be measured more accurately than with two separate systems.
- The high cruising velocity requires fast response time to provide high space resolution.
- The measuring system has to be small in size and light in weight to minimalize the operational costs.
- The system has to operate continuously in a fully autonomous way.
- Maintenance and recalibration interval should be at least half a year.
- The availability should be quasi continuous: 363 days a year (namely 99.54%) supposing 1 day maintenance every half year.
- Has to meet all the rigorous safety restrictions.

The data acquisition and control system that previously had been developed in the research group less and less met the state of the technology and science more and more limiting the broader applicability of our systems. This was also true in the case of airborne hygrometry, where besides the state of the art system control the los size and weight are also essential. The measuring system that had been developed at Szeged only partially met the requirements listed above, but was a good starting point for the improvements done by myself.

I joined the Photoacoustic Research Group at the beginning of my doctoral studies, duties were exploring the shortcomings of the system, finding and implementing solutions on them. Finally I had to prove that the developments achieved by myself result in a significant performance improvement.

2 Objectives and methods

My aim was improving the reliability and accuracy of the two channel airborne hygrometer developed at the University of Szeged and making it capable for autonomous operation while reducing its size and weight.

Within this:

I developed a new method for setting the wavelength of the laser applied in the system with high precision and accuracy.

I developed a new calibration and data processing technique, which determines the accuracy of the system that makes it traceable to the calibration reference within 2% at any pressures and concentrations in the operational range.

I prepared a new measuring system and proved the applicability of the previous developments and its reliability and accuracy through independent laboratory and in-flight inter comparison measurements.

I prepared a new data acquisition and control system to reduce the size and weight of the measuring system itself.

3 Novel scientific results

T1: Improvement of the accuracy of setting the wavelength of DFB diode lasers to the targeted one:

I managed to increase the precision and accuracy of the technique previously had been developed by the research group for setting the wavelength of DFB diode lasers by circa one order of magnitude through developing a data processing algorithm for the determination of the inflection point of the phase shift curve. Through experiments I proved that the uncertainty (1σ) of the new technique is 50 fm. I ascertained that the new technique requires pressure correction and determined its level: approximately 10 mbar pressure variation makes the correction necessary. Note: The precision of the new technique through its precision enables the study of the pressure dependent shift of absorption lines.

T2: Development of calibration and data processing technique for the two channel hygrometer system:

I developed a new calibration and data processing technique based on the determination of the calibration surface in the pressure-concentration- photoacoustic signal space: the photoacoustic signal as the function of concentration has to be determined at various but constant pressure levels. From the present photoacoustic signal and pressure using the constant pressure calibration curves I determine the concentration value using an interpolation technique. Using this technique the photoacoustic system is traceable to the calibration reference within noise level ±2% in the 0.5-25000 ppmV concentration and 100-1000 mbar pressure ranges. Previously this level of accuracy was not possible at various pressures. The data processing interval is only a few milliseconds therefore real-time data processing is possible now.

T3: Preparation of a new measuring system and proving its accuracy and reliability through laboratory and in-flight inter comparison measurements.

I designed and prepared a new two channel hygrometer system in which I also implemented the techniques introduced in T1 and T2. I tested the system through blind laboratory and in-flight inter comparison measurements. At both tests due to the high dynamic range I had to use two reference instruments one at low and one at high concentrations. The measuring system was performing reliably during the tests, in comparison to the reference instruments it measured values typically with 5% or less relative deviation. During the development of the system similar result never had been achieved previously.

T4: Designing and preparing the hardware of a data acquisition and control system for photoacoustic spectroscopic measurements:

In order to extend the application area of the airborne measurements the improvement of the entire measuring system became necessary. Therefore, to replace the controlling electronics based on an industry standard embedded controller (NI SBRIO9642) I designed and prepared a new small in size and low in weight data acquisition and control system. As part of the system I also designed and prepared all the necessary peripherals such as voltage controlled laser driver, PI control based laser temperature stabilization, differential microphone amplifier, and other sensor signal conditioning circuits. I managed to achieve significant advancement in the laser temperature stabilization: reduced the uncertainty from 1 m°C to 0.21 m°C and in the dynamic range (without sensitivity change): I increased it from 3.5 to 5.8 orders of magnitude. Furthermore, based on this new data acquisition and control system the measurement system probably can be prepared 40% smaller in size and 50-70% lighter.

T5: Designing and preparing the software of a data acquisition and control system for photoacoustic spectroscopic measurements:

I designed and prepared the software of the new data acquisition and control system in LabVIEW development environment: It defines the functionality of the hardware including all the analogue and digital in/output channels, digitalizing and lock-in evaluating the signals of the microphones even using 2(n)f technique. The implemented lock-in amplifier is based on PLL (phase locked loop) signal generation and demodulation. I implemented two signal generators (laser control signals) and the data evaluation of two input channels (microphone amplifiers): Any of the signal generators can be assigned to any of the input channels in parallel using 1f or 2f lock-in data processing. Without significant modification of the software the system can be extended for more signal generators and input channels as well even at higher harmonics. The usage of the system resources is low (60%) therefore new functions measuring routines can be implemented upon need.

4 Related publications:

T1:

D. Tátrai, Z. Bozóki and G. Szabó

Method for wavelength locking of tunable diode lasers based on photoacoustic spectroscopy

Optical Engineering 59 096104.

doi:10.1117/1.OE.52.9.096104

IF: 0.958

Z. Bozóki, **D. Tátrai**, G. Szabó:

Eljárás és összeállítás hullámhossz-hangolható hullámhosszának stabilizálására abszorpciós spektroszkópiai jeldetektálás alapján

Magyar szabadalom

Bejelentve: 2011.12.23.

Elfogadva: 2015.05.27.

Lajstromszám: 230073

T2, T3:

D. Tátrai, Z. Bozóki, H. Smit, C. Rolf, N. Spelten, M. Krämer, A. Filges, C. Gerbig, G. Gulyás, and G. Szabó

Dual-channel photoacoustic hygrometer for airbornemeasurements: background, calibration, laboratory and in-flight intercomparison tests

Atmos. Meas. Tech., 8, 1–10, 2015

doi:10.5194/amt-8-1-2015

IF: 3.206 (2013)

T4, T5:

D.Tatrai, Z. Bozoki, G. Gulyas, G. Szabo

Embedded system based data acquisition and control system for photoacoustic spectroscopic applications

Measurement, Volume 63, March 2015, Pages 259-268

doi:10.1016/j.measurement.2014.12.028

IF: 1.526 (2013)

5 Other publications

5.1 Journal articles

2015

Christian Rolf, Jessica Meyer, Cornelius Schiller, Susanne Rohs, Nicole Spelten, Armin Afchine, Martin Zöger, Nikolay Sitnikov, Troy D. Thornberry, Andrew W. Rollins, Zoltan Bozóki, **David Tátrai**, Volker Ebert, Benjamin Kühnreich, Peter Mackrodt, Ottmar Möhler, Harald Saathoff, Karen H. Rosenlof, Martina Krämer
Two decades of water vapor measurements with the FISH fluorescence hygrometer: a review
Atmospheric Chemistry and Physics Discussion 15, 7735-7782, 2015
doi:10.5194/acpd-15-7735-2015

2013

Z. Gyori, V. Havasi, D. Madarász, **D. Tátrai**, T. Brigancz, G. Szabó, Z. Kónya, A. Kukovecz
Luminescence properties of Ho3+ co-doped SrAl2O4:Eu2+, Dy3+ long-persistent phosphors synthesized with a solid-state method
Journal of Molecular Structure, Volume 1044, 24 July 2013, Pages 87-93
doi:10.1016/j.molstruc.2012.11.008
IF: 1.643

2010

Z. Győri, **D. Tátrai**, F. Sarlós G. Szabó, Á. Kukovecz, Z. Kónya, I. Kiricsi
Laser-induced Fluorescence Measurements On CdSe Quantum Dots
Processing and Application of Ceramics 4 [1] (2010) 33–38

5.2 Conference presentations:

2015

Atmospheric Ice Nucleation Workshop, Wien, Austria, 11, April

D. Tatrai, N. Bors, E. Zs. Jasz, G. Gulyas, Z. Bozoki, G. Szabo Two channel airborne hygrometer system for cloud water/ice content determination

Repüléstudományi konferencia, Szolnok, Hungary; 9, April

D. Tatrai, N. Bors, G. Gulyas, Z. Bozoki, G. Szabo

Kétcsatornás vízgőz-koncentráció-mérő rendszer repülőgépes alkalmazásokhoz

/Two channel hygrometer system for airborne measurements/

2014

UAV Workshop, Szolnok, Hungary; 21, November

Weidinger Tamás, Bottyán Zolt, Gyöngyösi András Zénó, Istenes Zoltán, Szabó Zoltán, Balczó Márton, Varga, Árpád, Bíróné Kircsi Andrea, Horváth Gyula, **Tátrai Dávid**, Bozóki Zoltán, Józsa János, Kiss Melinda, Bordás Árpád, Wantuch Ferenc, Gemma Simó Diego, Joan Cuxart Rodamilans, Burkhart Wrenger

A pilótanélküli repülőeszközök szerepe a határréteg kutatásban – nemzetközi mérési expedíció Szegeden

/Role of UAV-s in boundary layer research – international measurement campaign at Szeged/

Research Aircraft Operations Conference; London, UK, 5 November

Zoltan Bozoki, **David Tatrai**, Gabor Szabo

Dual channel hygrometer for atmospheric research

NIDays 2014 Budapest; Budapest, Hungary; 4, November

Tátrai Dávid

Fotoakusztikus spektroszkópiai mérőrendszer fejlesztése ipari-környezetvédelmi mérésekhez

MOZAIC-IAGOS Scientific symposium on atmospheric composition observation by commercial aircraft; Toulouse, France; 12-15 May

David Tatrai, Zoltan Bozoki, Andreas Zahn, Herman Smit, Gabor Szabo

Development of an airborne dual-channel hygrometer based on photoacoustic spectroscopy

ISARRA 2014; Odense, Denmark; 27, May

J. Cuxart, T. Weidinger, Burkhard Wrenger, M.A. Jimenez, G. Simo, D. Gomila, H. Warmers, A. Z. Gyongyosi, Z. Istenes, Z. Bottyan, **D. Tatrai**, M. Kiss, J. Josza

Joint Surface Budget Station, Tethered Balloon and RPAS Campaign SEABREEZE13 and PABLS13

2013

CPPTA 2013; Warsaw, Poland; 25-27 September

D. Tatrai, Z. Bozóki, G. Gulyas, A. Varga, G. Szabó

Photoacoustic spectroscopy based dual channel hygrometer for airborne applications

Avionics Europe; Munich, Germany; 21-22 March

Zoltán Bozoki, **David Tatrai**, Gabor Szabo

The Importance and Technology for MeasuringAtmospheric Humidity in Airborne Applications

2008

European Congress on Molecular Spectroscopy

Z. Győri, **D. Tátrai**, F. Sarlós G. Szabó, Á. Kukovecz, Z. Kónya, I. Kiricsi

Laser-induced Fluorescence Measurements On CdSe Quantum Dots

5.3 Conference posters:

2015

EGU 2015 Wien, Austria, 12-17, April

David Tatrai, Gabor Gulyas, Zoltan Bozoki, Gabor Szabo

Dual channel airborne hygrometer for climate research

EGU 2015 Wien, Austria, 12-17, April

Two decades of water vapor measurements with the FISH fluorescence hygrometer: A review

Christian Rolf, Jessica Meyer, Cornelius Schiller, Susanne Rohs, Nicole Spelten, Armin Afchine, Martin Zöger, Nikolay Sitnikov, Troy D. Thornberry, Andrew W. Rollins, Zoltan Bozóki, **David Tátrai**, Volker Ebert, Benjamin Kühnreich, Peter Mackrodt, Ottmar Möhler, Harald Saathoff, Karen H. Rosenlof, and Martina Krämer

EGU 2015 Wien, Austria, 12-17, April

David Tatrai, Gabor Gulyas, Ervin Jasz, Noemi Bors, Zoltan Bozoki, Gabor Szabo

Technical aspects of the development of a dual channel airborne hygrometer

Repüléstudományi Konferencia, Szolnok , Hungary, 9, April

Tamás Weidinger,. Cuxart, A. Z. Gyongyosi, B. Wrenger, Z. Istenes, Z. Bottyan, G. Simó, **D. Tatrai**, A. Jericevic, B. Matjacic, M. Kiss, and J. Jozsa

An experimental and numerical study of the ABL structure in the Pannonian plain

2014

Kvantumelektronika 2014; Budapest, Hungary; 29, November

A. Drozdy, Á. Börzsönyi, B. Kiss, M. Gstalter, N. Khodakovskiy, **D. Tátrai**, K. Osvay, M.P.Kalashnikov

Cross-correlator for 532 nm picosecond pulses based on optical parametric amplification

Kvantumelektronika 2014; Budapest, Hungary; 29, November

Tátrai Dávid, Gulyás Gábor, Bozóki Zoltán, Szabó Gábor

Fotoakusztikus spektroszkópiai vízgőz-koncentráció- mérő- rendszer repülőgépes légkörkutatáshoz

/Photoacoustic spectroscopic water vapor concentration and total water measuring system for airborne atmosphere research/

MMC 2014; Brdo, Slovenia; 15-18, September

D. Smorgon, N. Boese, V. Ebert and the **AquaVIT 2-B team**

Inter-comparison of airborne hygrometers and their laboratory-reference – The AquaVit2-B campaign –

21st Symposium on Boundary Layers and Turbulence; **Leeds, United Kingdom; 9 June**

Tamás Weidinger,. Cuxart, A. Z. Gyongyosi, B. Wrenger, Z. Istenes, Z. Bottyan, G. Simó, **D. Tatrai**, A. Jericevic, B. Matjacic, M. Kiss, and J. Jozsa

An experimental and numerical study of the ABL structure in the Pannonian plain (PABLS13)

MOZAIC-IAGOS Scientific symposium on atmospheric composition observation by commercial aircraft; Toulouse France; 12-15 May 2014

Christian Rolf, Martina Kraemer, Andreas Petzold, Nicole Spelten, Susanne Rohs, Patrick Neis, Rolf Maser, Bernhard Bucholz, Volker Ebert, **David Tatrai**, Zoltan Bozoki, Fanny Finger, and Marcus Klingebiel

Development and Evaluation of Novel and Compact Hygrometer for Airborne Research (DENCHAR): In-Flight Performance During AIRTOSS-I/II Research Aircaft Campaigns

EGU 2014; Wien, Austria; 1. May

David Tatrai, Daniella Nikov, Ervin Zsolt Jász, Zoltán Bozóki, Gábor Szabó, Tamás Weidinger, Zénó András Gyöngyösi, Melinda Kiss, János Józsa, Gemma Simó Diego, Joan Cuxart Rodamilans, Burkhart Wrenger, and Zsolt Bottyán

Study of surface energy budget and test of a newly developed fast photoacoustic spectroscopy based hygrometer in field campaign Szeged (Hungary)

EGU 2014; Wien, Austria; 28 April

Denis Smorgon, Norbert Boese, Volker Ebert and the **AQUAVIT2-B Team**

Airborne hygrometer calibration inter-comparison against a metrological water vapour standard

EGU 2014; Wien, Austria; 28 April

Herman G.J. Smit, Christian Rolf, Martina Kraemer, Andreas Petzold, Nicole Spelten, Susanne Rohs, Patrick Neis, Rolf Maser, Bernhard Bucholz, Volker Ebert, **David** Tatrai, Zoltan Bozoki, Fanny Finger, and Marcus Klingebiel

Development and Evaluation of Novel and Compact Hygrometer for Airborne Research (DENCHAR): In-Flight Performance During AIRTOSS-I/II Research Aircaft Campaigns

2013

Tempmeko 2013; Madeira, Porugal; October

D. Smorgon, O. Ott, N. Boese, V. Ebert and the **AQUAVIT2 B team**

Intercomparison of airborne hygrometers and their calibration reference against a traceable water vapor standard

EGU 2013; Wien, Austria; 9. April

Tibor Ajtai, Noémi Utry, Ágnes Filep, **Dávid Tátrai, Zoltán Bozóki**, and Gábor Szabó

Spectral characterisation of mineralogical components of dust, HULIS and winter time aerosol using multi-wavelength photoacoustic spectrometer. A laboratory and a field study

EGU 2013; Wien, Austria; 8. April

Zoltán Bozóki, **Dávid Tátrai**, Gábor Gulyás, Attila Varga, and Gábor Szabó

The Importance and Technology for Measuring Atmospheric Humidity in Airborne Applications