State of the Art In-Situ Turbulence Measurements With Unmanned Aerial Systems (UAS) in the ABL

Norman Wildmann, Jens Bange
Environmental Physics, Centre for Applied Geoscience (ZAG)
Eberhard Karls University Tübingen

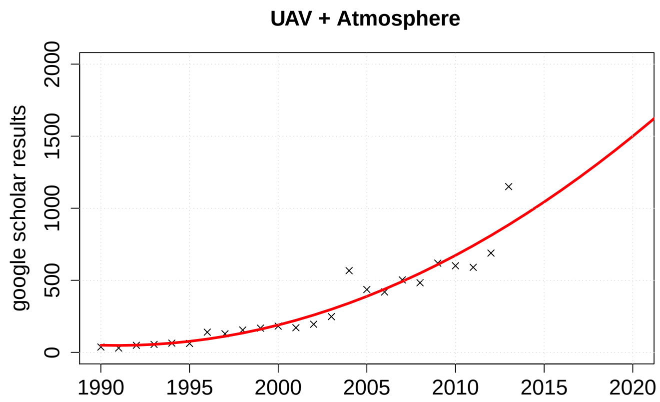
11 June 2014
AMS - BLT 2014, Vienna
Session 13A

Outline

1. Overview of Systems
2. Multi-purpose Airborne Sensor Carrier (MASC)
3. Sensor Equipment and Data Acquisition System for Turbulence Measurements
   (a) Flow Probe
   (b) Temperature Sensors
   (c) Humidity Sensors
4. Outlook

UAS for in-situ turbulence measurements

- Number of UAS for turbulence measurement in the lower atmosphere is increasing



- Selection of examples:

M2AV

SUMO

Manta

Tempest

- All examples from ISARRA members http://www.isarra.org
- Common strategy: Multi-hole probe measurements for turbulent flow
- Different size and weight classes allow different types of instruments

MASC: Multi-purpose Airborne Sensor Carrier

operated at **University of Tübingen**

(I told the designer, that I don't care about the colour, as long as it is well visible ...)

wingspan:	2.7...3.5 m
total weight:	$<$ 6 kg
incl. sci. payload:	1.5 kg
cruising speed:	25 m/s
endurance:	$\approx$ 1 hour
electrical engine	
autopilot:	ROCS

Autopilot System controlling MASC

Many thanks to Prof. Walter Fichter and his team at

iFR - Institut für Flugmechanik und Flugregelung

University of Stuttgart

`http://www.ifr.uni-stuttgart.de`

iFR

Research Onboard Computer System

rocs@ifr.uni-stuttgart.de
iFR – Institute of Flight Mechanics and Control
Universitaet Stuttgart

Experiments with the UAV MASC

More than 100 flights in over 20 days in 2013

Boundary Layer Meteorology

Turbulent transport

Transition phases

Wind Energy Research

Wake measurements

Turbulent structures

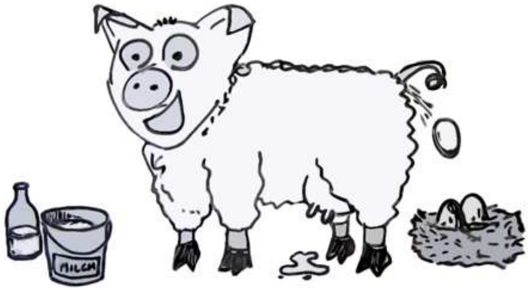
Airborne Sensor Requirements

Common requirements for sensors in airborne (UAV) applications:

1. Light weight / Small size
2. Fast response / Resolve small scale turbulence
3. Wide calibration range
4. Robustness
5. Good absolute accuracy / Long-term stability
6. Low cost
7. Allow measurements in clouds

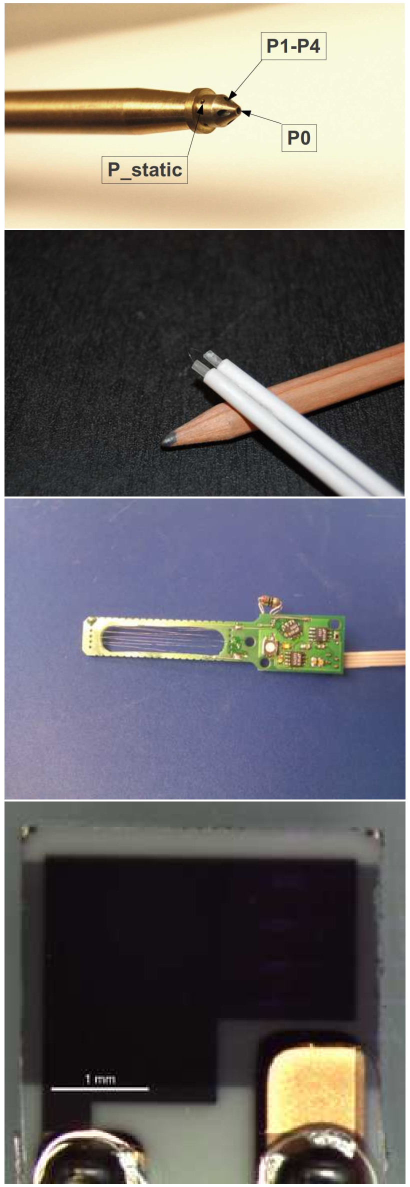
Special demands for polar research:

1. Low temperature stability
2. Resistance to icing
3. Easy handling with gloves

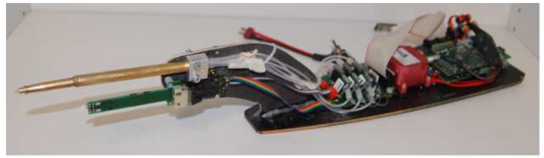


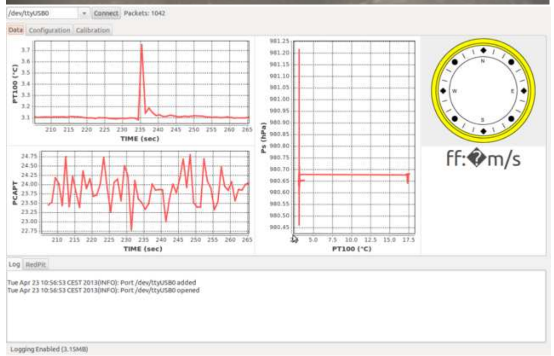
'Eierlegende Wollmilchsau'

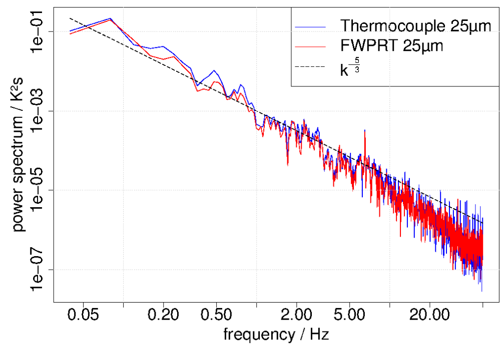
MASC sensor system



- complete thermodynamic sensor package:
  - thermocouple
  - fine wire resistance thermometer
  - capacitive humidity sensors
  - flow probe
  - inertial measurement unit (IMU)
  - GNSS position and velocity
- turbulence measurement up to 30 Hz
- live data observation on ground-station computer
- 100 Hz on-board log to SD-card

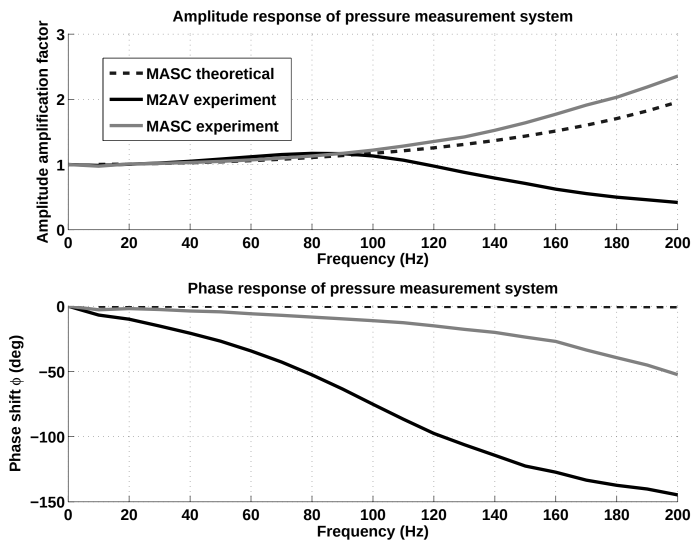






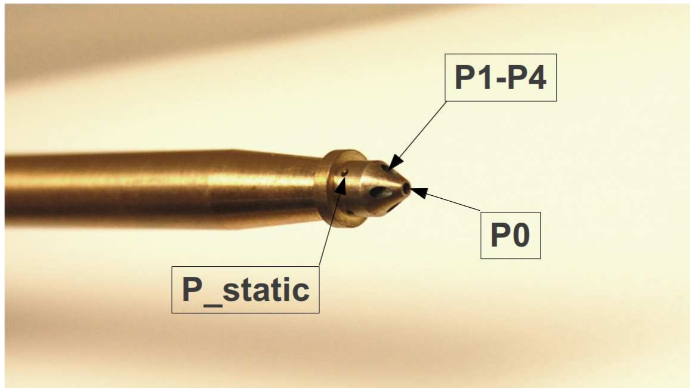
Flow probe

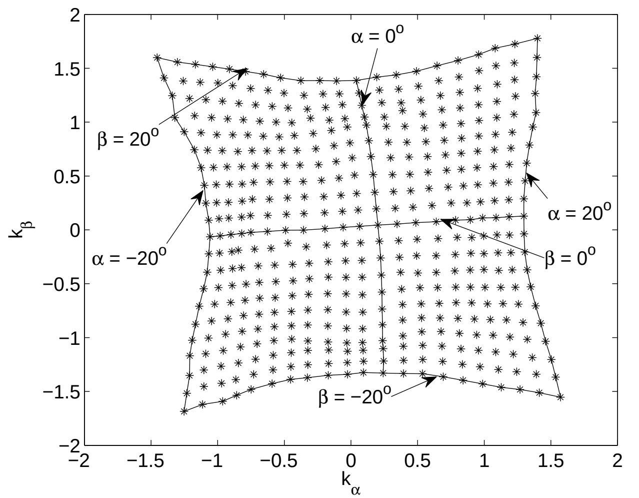
Five-hole probe, design considerations



Important:

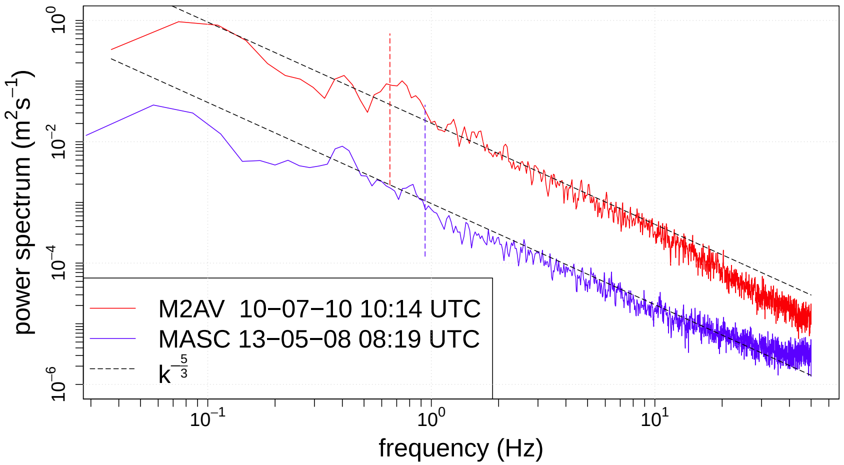
- Proper design of tubing system
- Choice of pressure transducers
- Wind tunnel calibration
- Analog and digital filtering

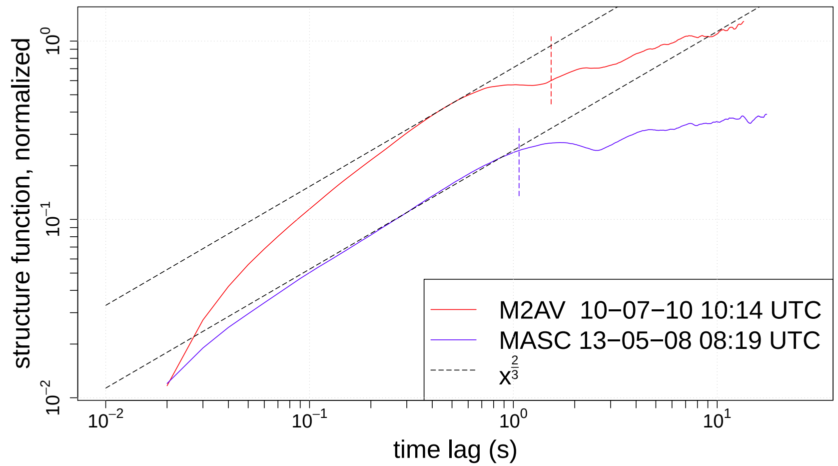




Flow probe

Five-hole probe, capabilities

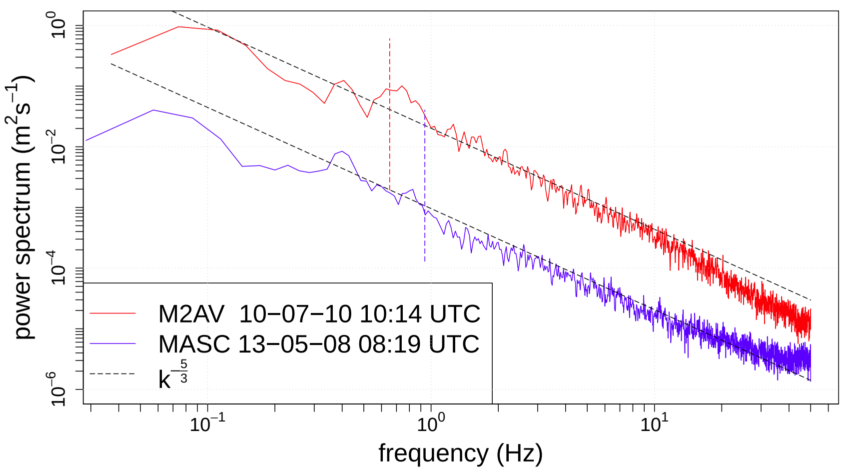


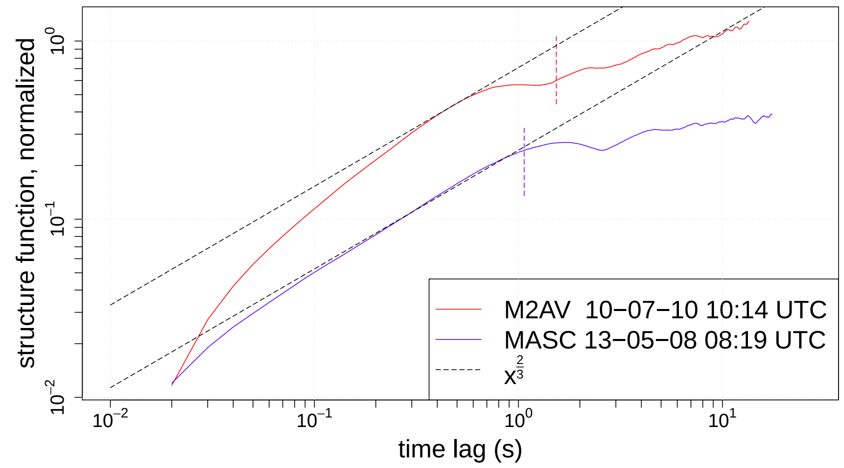


- Small scale turbulence in flight is captured mainly by airspeed measurement with the 5HP
- Careful design of the setup can improve results with standard 5HPs significantly

Flow probe

Five-hole probe, capabilities

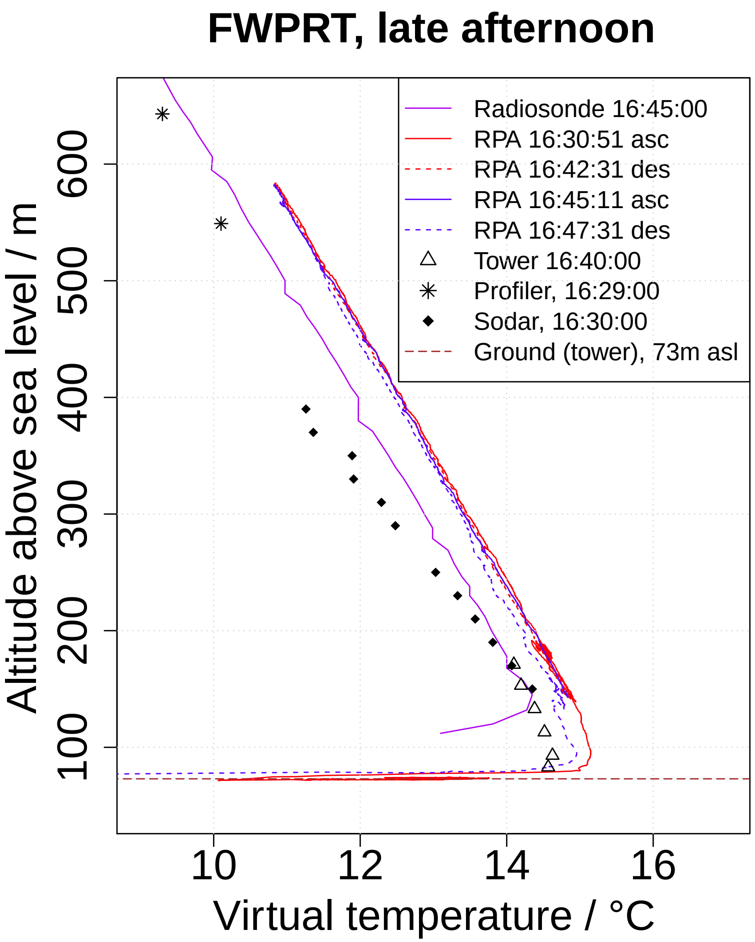




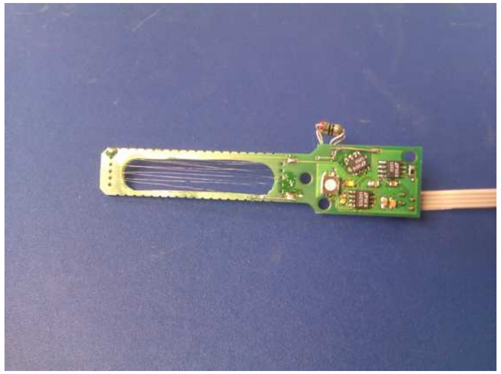
- Small scale turbulence in flight is captured mainly by airspeed measurement with the 5HP
- Careful design of the setup can improve results with standard 5HPs significantly
- Future: Fast response probes for kHz-response?

Temperature sensor

Fine Wire Pt Resistance Thermometer

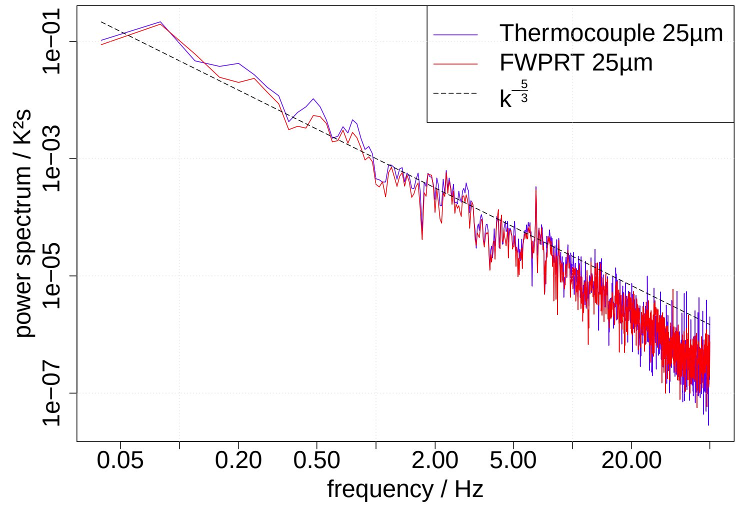


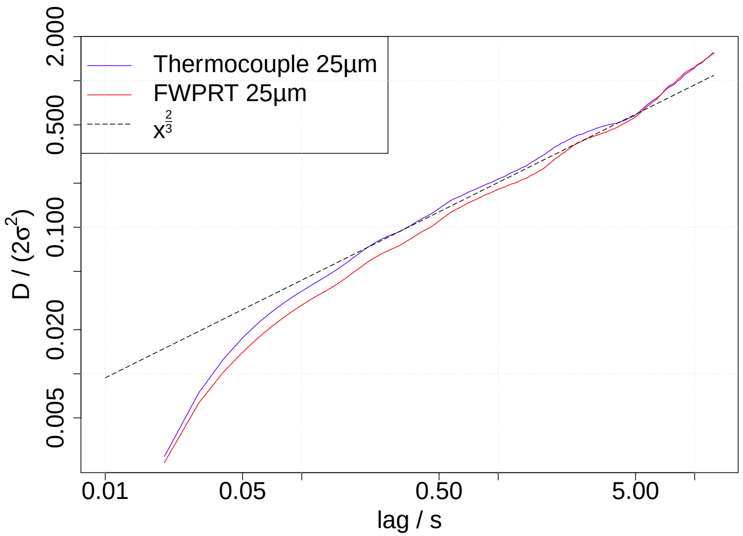
- 13μm or 25 μm wire
- Good comparison to radiosonde and tower measurements
- Tested for radiation effect, adiabatic heating and self-heating
- Accuracy up to 0.1 K (depending on calibration)
- Resolution and precision 0.01 K



Temperature sensor

Fine Wire Pt Resistance Thermometer

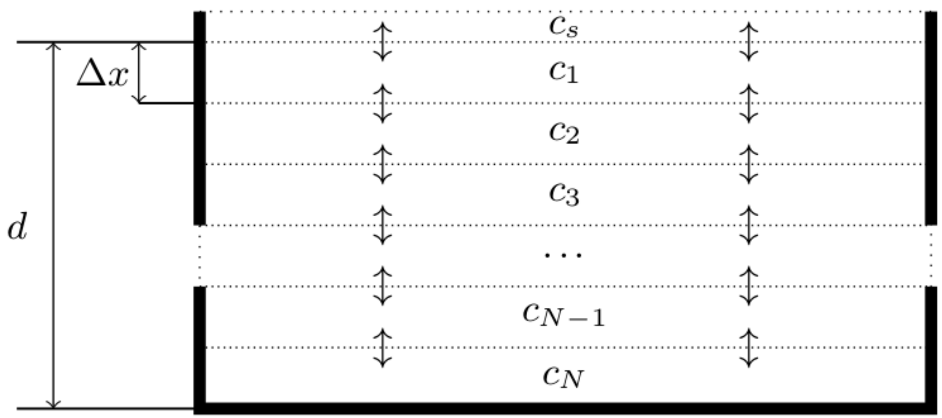




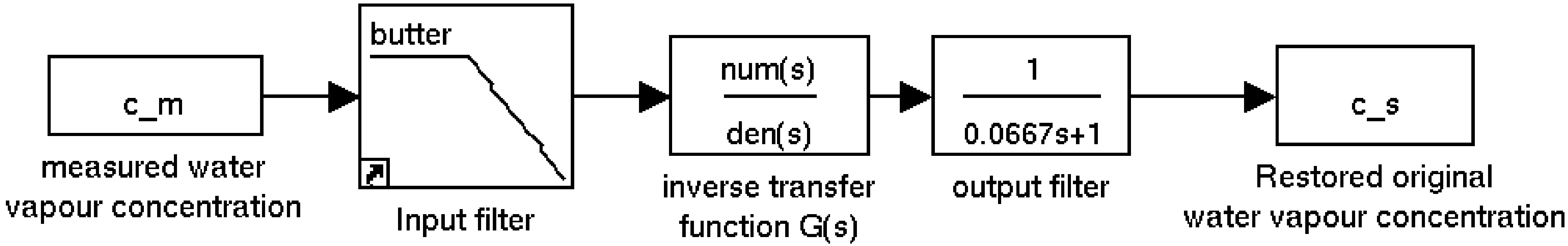
- 10 Hz response (after low-pass noise filter)
- Performance similar to thermocouple, but absolute temperature output
- First used in very low temperatures in Spring 2014 at Svalbard on a SUMO aircraft

Humidity sensor

Capacitive Humidity Sensor P14 Rapid, by IST

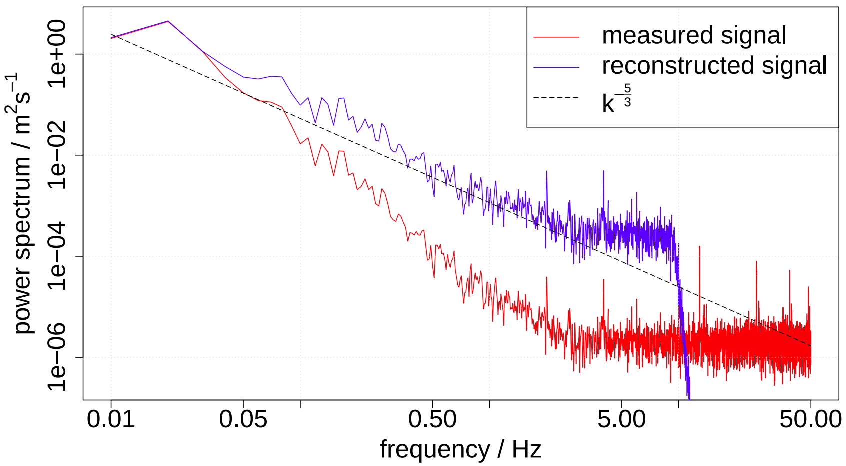


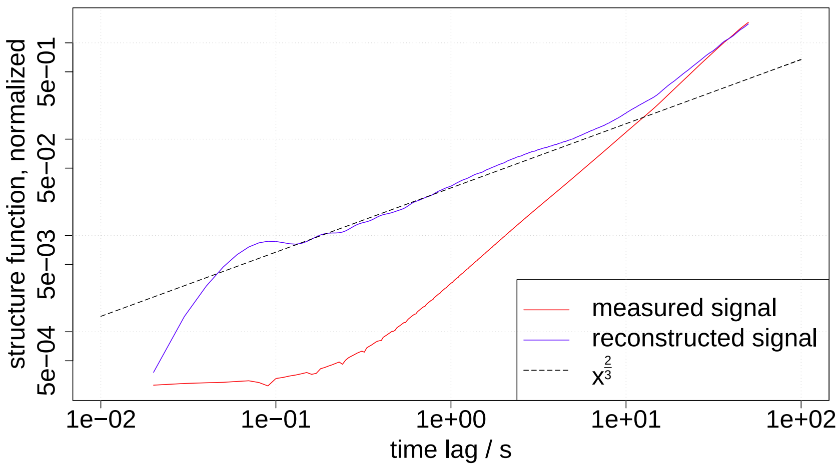
- Size and weight restrictions of small UAV only allow capacitive sensor
- Time response needs to be enhanced for turbulence measurements
- Model and signal restoration approach



Humidity sensor

Capacitive Humidity Sensor P14 Rapid, by IST

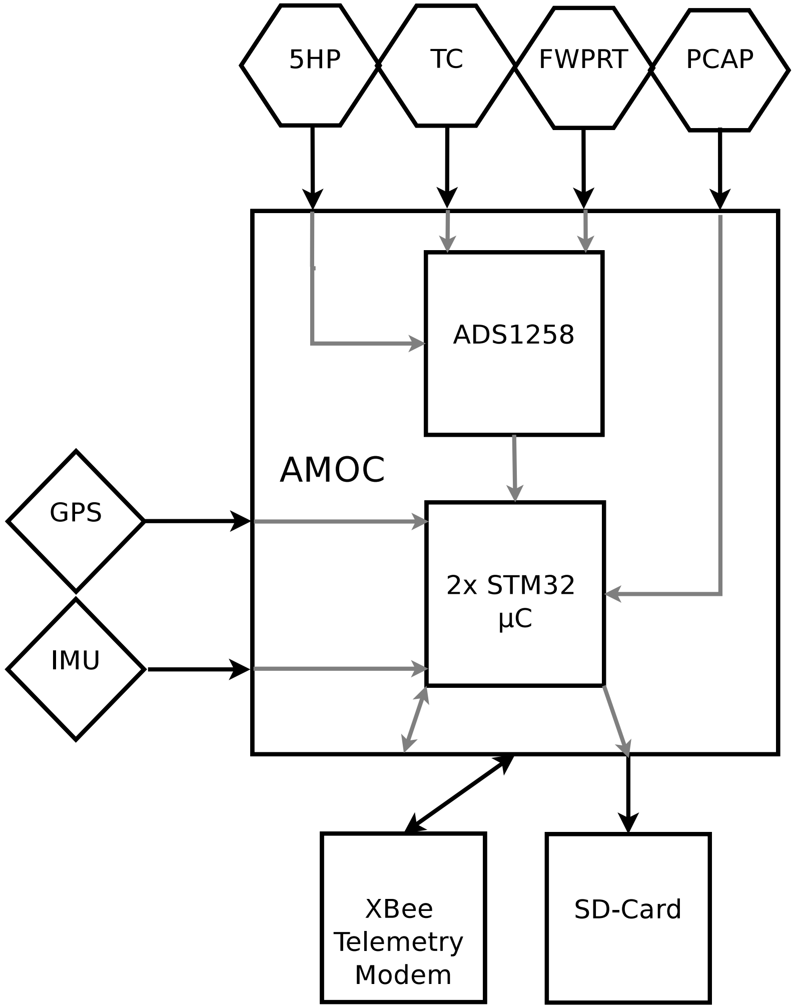




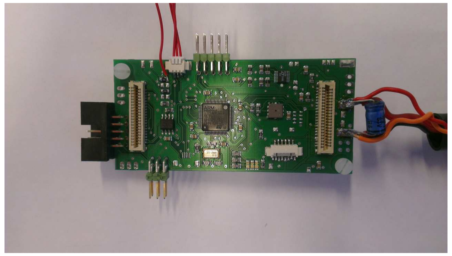
- Signal restoration is possible in defined conditions
- Noise in signal limits the achievable upper frequency
- Similar techniques are applied in multi-hole probe measurements and thermocouple measurements in gas turbines

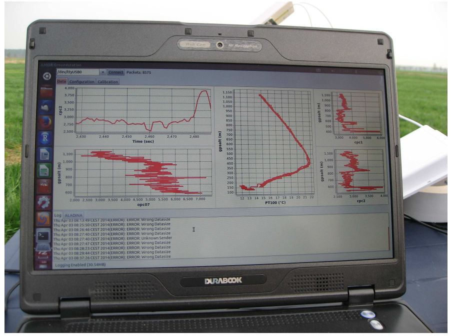
Data acquisition system

Airborne Meteorological Onbard Computer, AMOC



- Microcontroller Board with two STM32
- ADC, 24-bit, 16 channels for pressure transducers and temperature sensors
- digital interfaces for IMU/GPS, humidity sensor
- SD card log at 100 Hz
- Downlink to groundstation at 1 Hz





Outlook

- Boundary Layer research
  - DFG Aerosol project in cooperation with TU Braunschweig and IFT Leipzig
  - WESS groundstation network
  - Local cooperations with Uni Hohenheim

- Wind energy
  - Lidar Complex, WindForS (www.windfors.de)
  - KonTest, WindForS (www.windfors.de)
  - Owea Loads, ForWind cooperation

References

- Wildmann, N., Mauz, M., and Bange, J.: Two **fast temperature sensors** for probing of the atmospheric boundary layer using small remotely piloted aircraft (RPA), Atmos. Meas. Tech., 6, 2101-2113, doi:10.5194/amt-6-2101-2013, 2013.

- Wildmann, N., Ravi, S., and Bange, J.: Towards higher accuracy and better frequency response with standard **multi-hole probes in turbulence measurement** with remotely piloted aircraft (RPA), Atmos. Meas. Tech., 7, 1027-1041, doi:10.5194/amt-7-1027-2014, 2014.

- Wildmann, N., Kaufmann, F., and Bange, J.: An inverse modelling approach for frequency response correction of **capacitive humidity sensors** in ABL research with small unmanned aircraft, Atmos. Meas. Tech. Discuss., 7, 4407-4438, doi:10.5194/amtd-7-4407-2014, 2014.

- Wildmann, N., and Bange, J.: MASC - A small Remotely Piloted Aircraft (RPA) for **Wind Energy Research**., Adv. Sci. Res., 11, 55-61, doi:10.5194/asr-11-55-2014, 2014.

Thank you for your attention!