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Application of Wind Measurements by Multicopter RPAS

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KNOWLEDGE

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Outline

- Motivation: Wind Measurement with Multicopters
- Requirements Analysis
- Types of Wind Sensor Setups
- Implementation and Characterisation
- Results

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Motivation

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Motivation

- Data acquisition for ABL measurements with multicopter RPAS has been proven to work reliably:
  - Temperature (air, surface)
  - Relative humidity
  - Chemistry (CO_2, aerosols, …)
- Good replacememt for captive ballons
- Wind would be nice to have ➔ real vertical profile of T, RH and wind
- But: Multicopter RPAS create downwash – more or less

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Our requirements analysis

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Requirements Analysis

- Suitable for multicopter operation, no impact of downwash
- No preferred flight direction (vertical profiles)
- Accurate wind measurements including low wind speeds: 0.1 m/s – 15 m/s
- Easy handling
- Easy integration into existing DAQ systems (not only I^2C, SPI bus)
- Integration of IMU, T and RH into wind sensor module
- Short and well defined tubes, sensors placed beneath the holes
- 1st stage: wind with low temporal resolution, 2nd stage: also high temporal resolution

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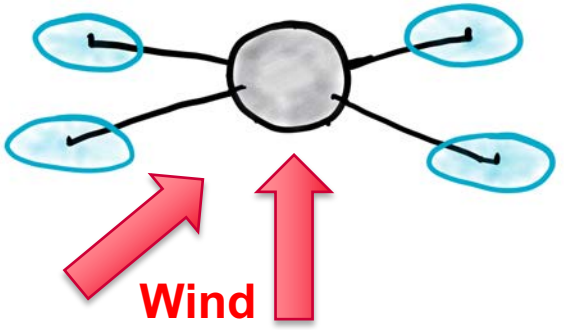
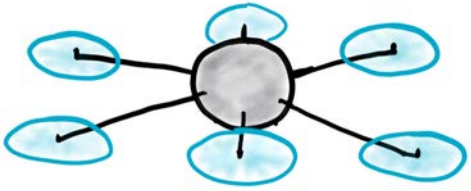
Possible Types of Wind Sensor Setups

Wind Sensor Setups (1): IMU-based System - 2 D wind information

- Multicopter RPAS responds to wind
- Its orientation depends on wind speed, wind direction
- Orientation is continuously measured by IMU/autopilot
- ➔ calculate wind speed and direction from IMU data
- Requires calibration and some estimations
- Errors [J. Moyano Cano, 2013; P. P. Neumann & M Bartholmai, 2015]
  - Wind speed approx. 1 m/s @ 5 m/s
  - Wind direction error approx. 15 °





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Wind Sensor Setups (2): IMU-based System plus flow sensor

- As before, but wind speed measured by a simple flow sensor
  - Error for direction still approx. 15°
  - Wind speed error << 0.1 m/s
- Also only 2D wind information

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Wind Sensor Setups (3): 3 D-wind from flow/pressure sensors

- See 5-hole probes for fixed wing RPAS
- Normal (differential) pressure sensors not suitable for low wind speeds (< 10 m/s) ➔ hot wire technology
- There is no preferred flight direction ➔ needs sensors for all directions (at least while flying vertical profiles)
- 5-hole probe design might work, but
  - can be improved and
  - take into account different true air speeds (fixed wing vs. rotary wing)

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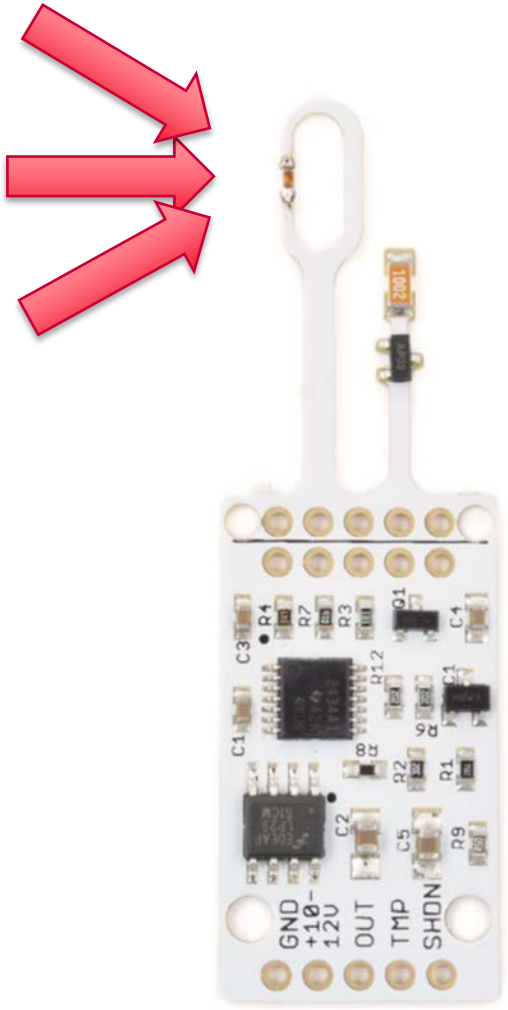
Implementation

Implementation: Wind Speed+IMU

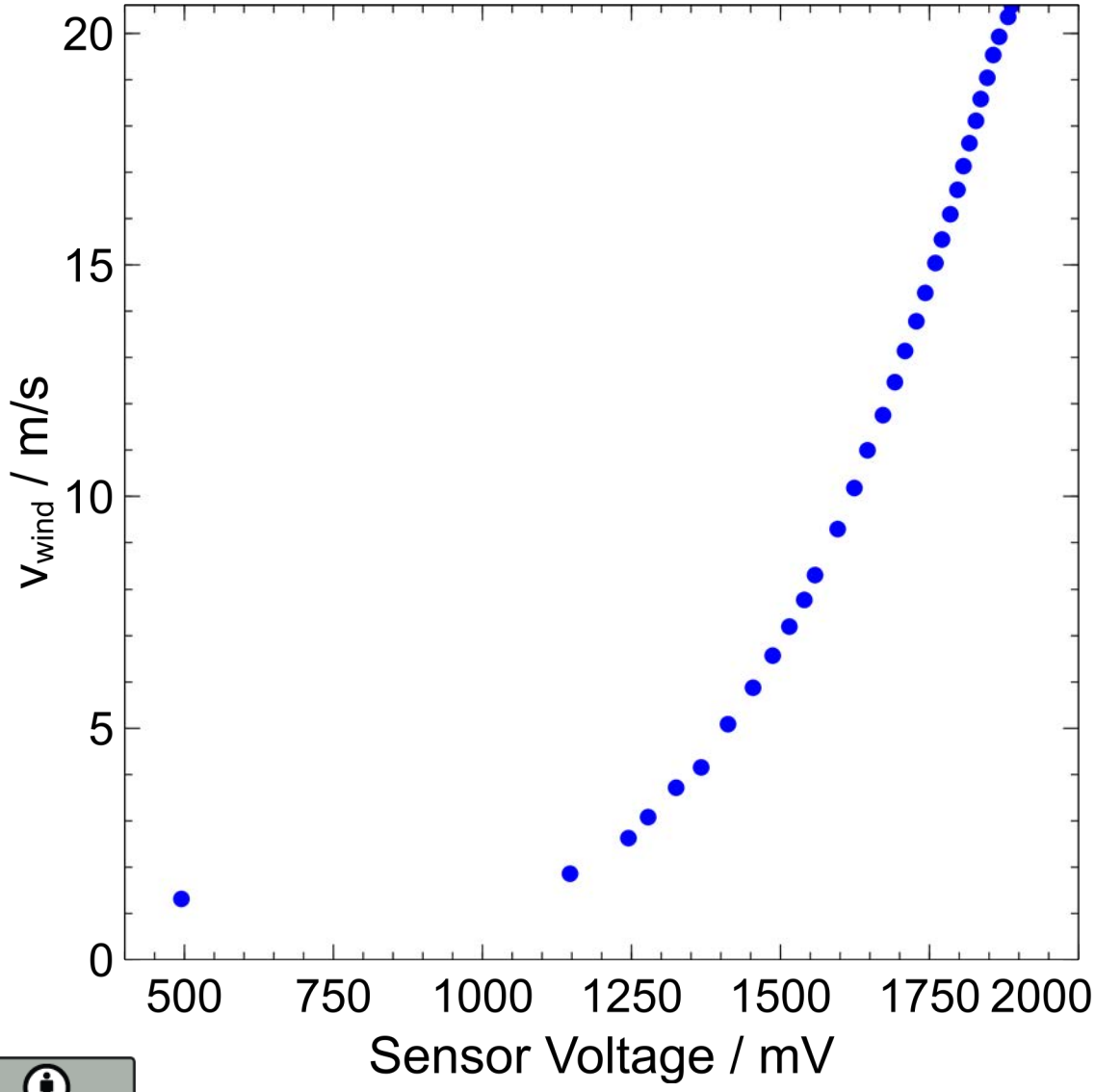
- Hot-element anemometer for wind speed: Modern Device (Rev. P)[1]
- Characterisation in wind tunnel:
  - Small dependecy on angle between wind and sensor orientation: ok for our operation
  - Mapping U_{sensor} ➔ wind speed
- Challenge: requires highly accurate power supply
- Intercomparison with 3D Ultrasonic and USAT during PABLS15 campaign for IMU wind direction estimations (2015)



[1] D. Prohasky and S. Watkins, 2014

Implementation: Wind Speed+IMU

- Wind tunnel:
  - 1.5-60 m/s
  - Low turbulence
- ➔ Mapping of sensor voltage to wind speed



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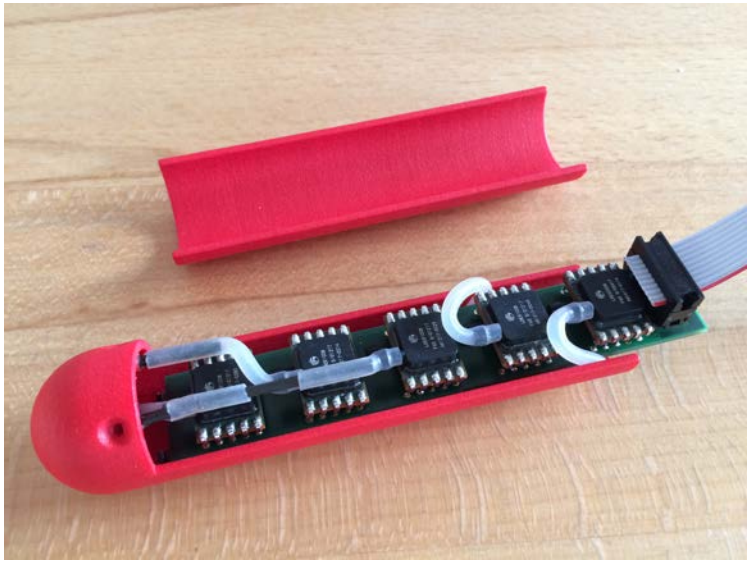
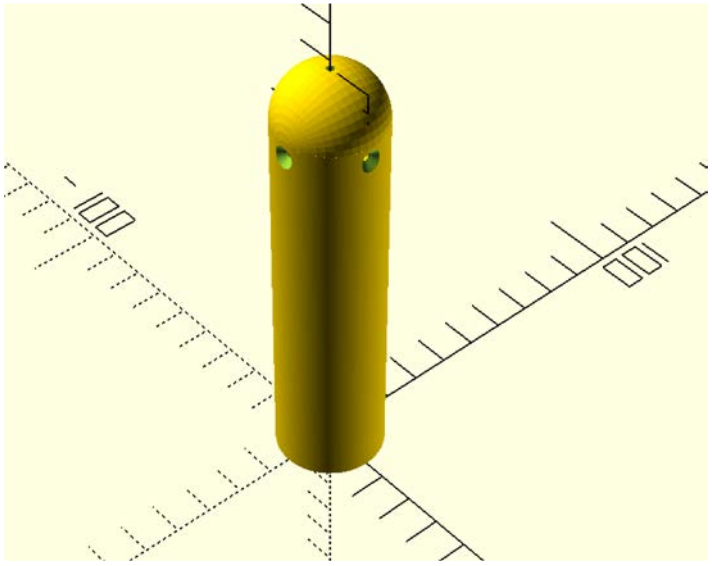
Implementation: 3D Wind Sensor

- Based on hot-element differential pressure sensors
- Requires IMU data ➔ IMU integrated
- One 5-hole probe looking „forward“, one looking „backward“
- Approx. 60 g incl. IMU





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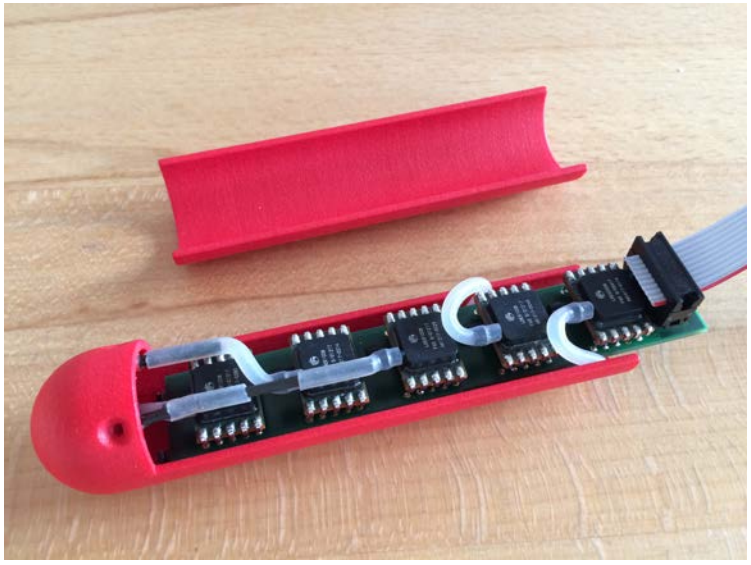
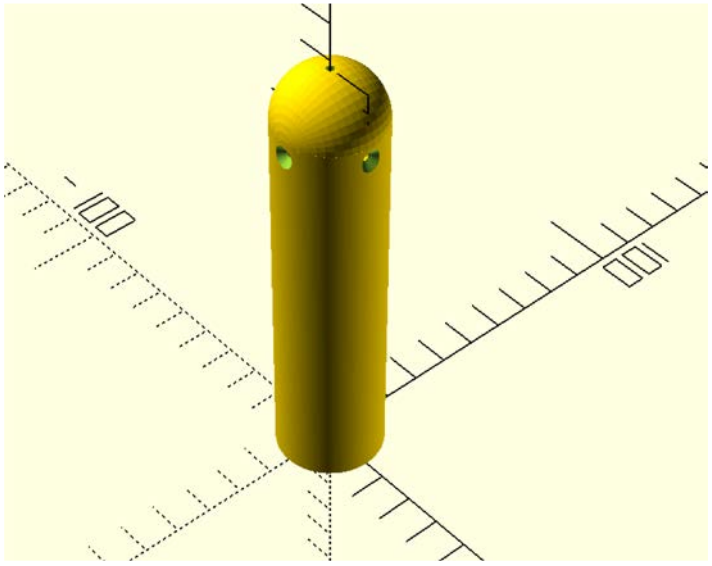
Implementation: 3D Wind Sensor

- uController translates from SPI and I^2C to USB ➔ DAQ software may run on Linux incl. Raspi, Windows and Mac OS X.
- Sensor placed approx 1 m from center ➔ well beyond downwash (specific for our RPAS setup!)
- Resolution of hot element sensor : < 1 cm/s





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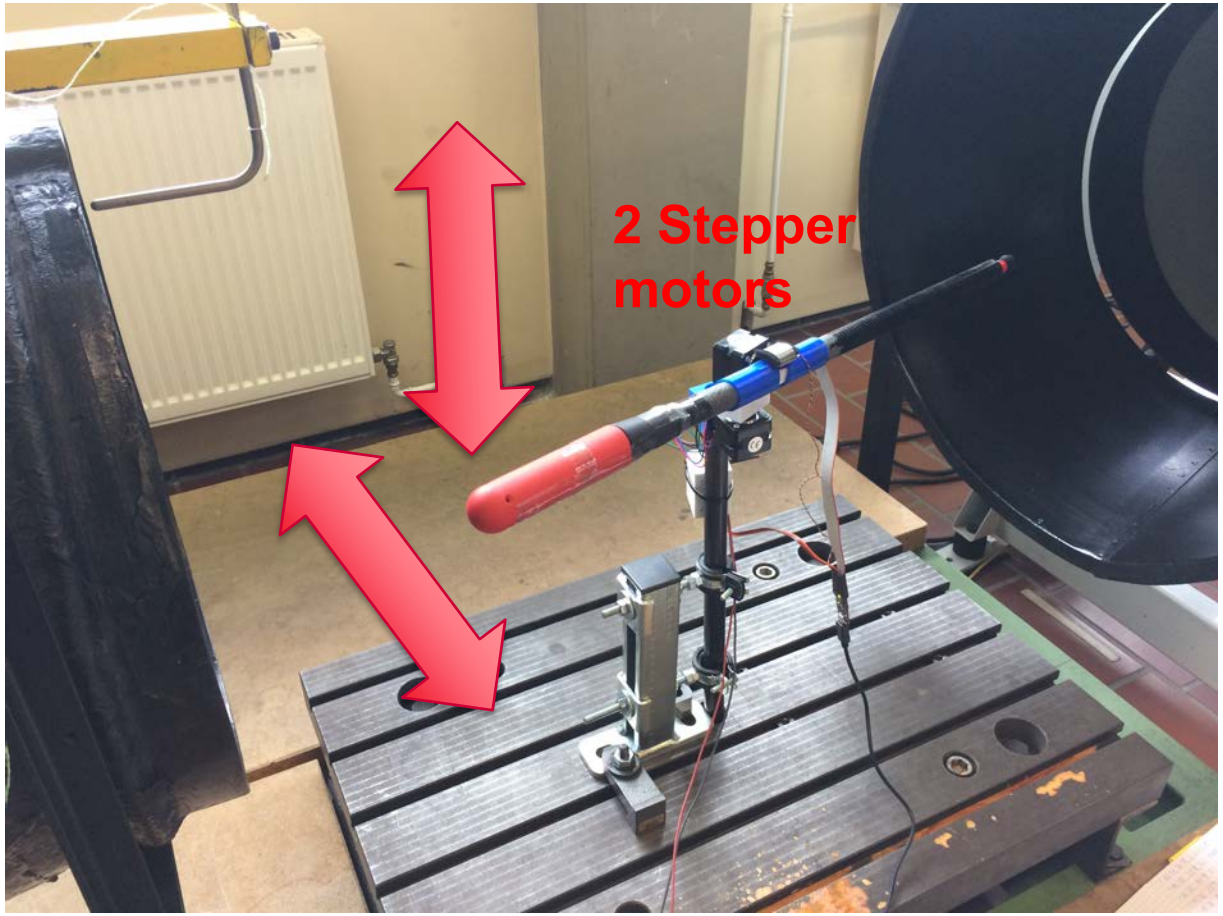
Characterisation: Wind Tunnel Setup



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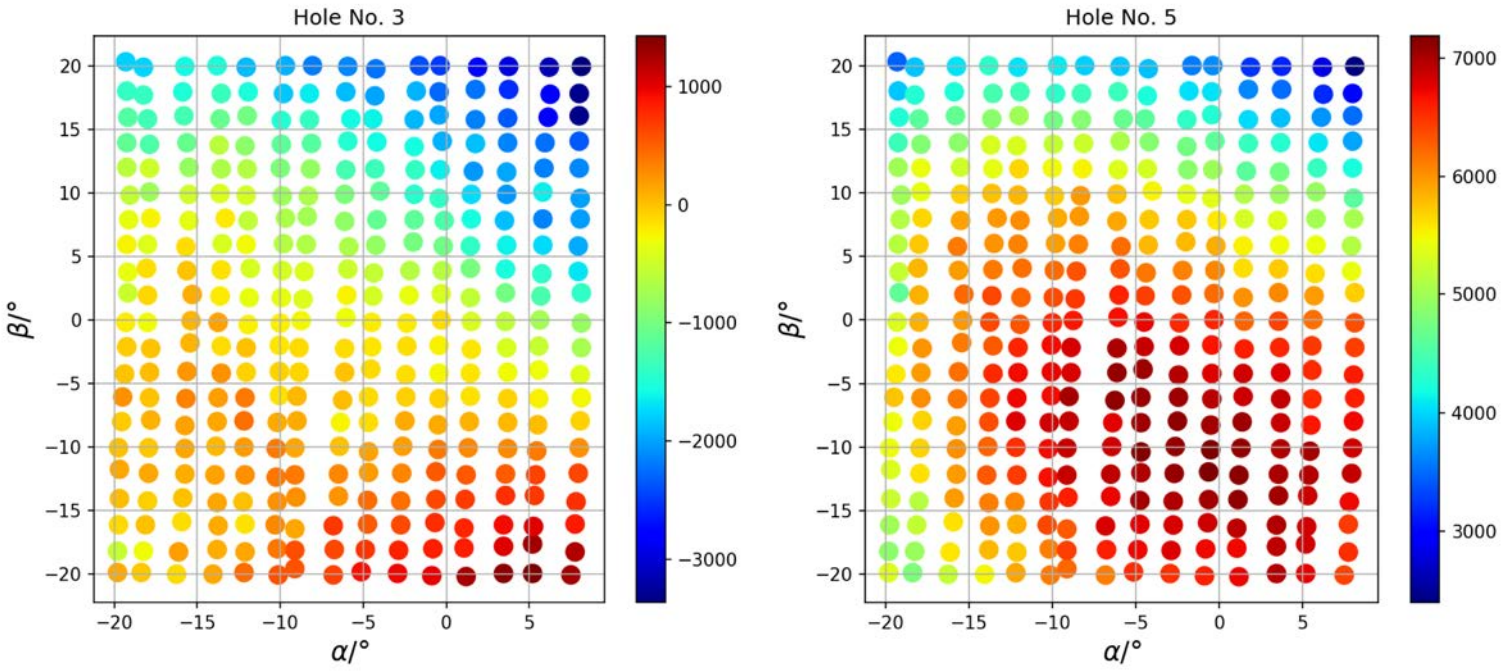
Characterisation: Wind Tunnel Results



- Windspeed in Windtunnel: v=4.95 m/s
- Required computations: raw data ➔ p ➔ wind speed
- Required corrections: take into account offsets

Sensor position: horizontally outside dowswash

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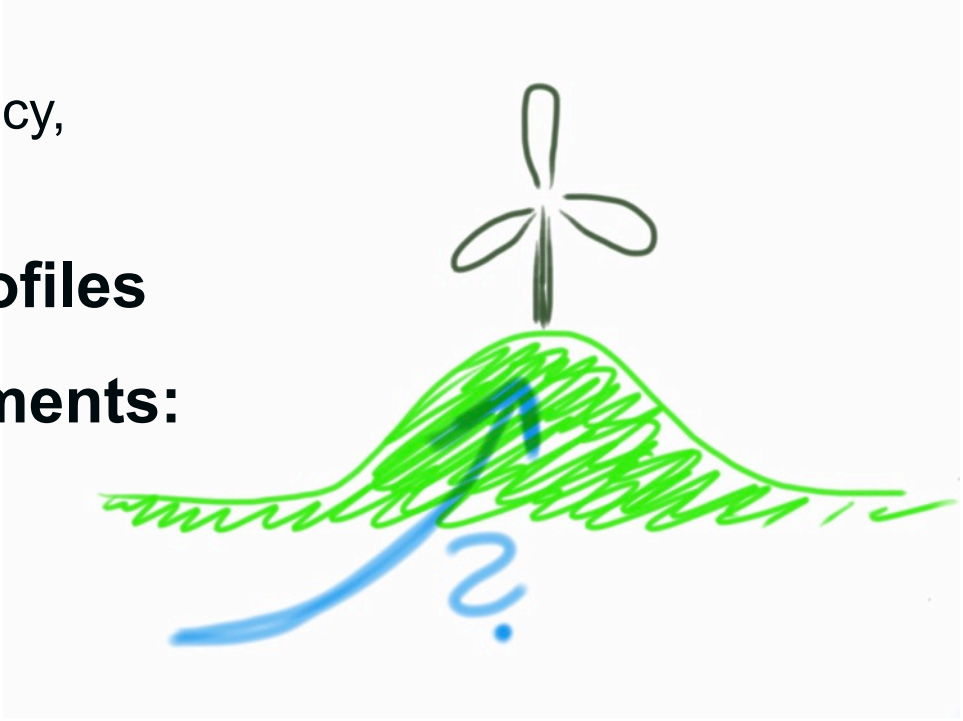
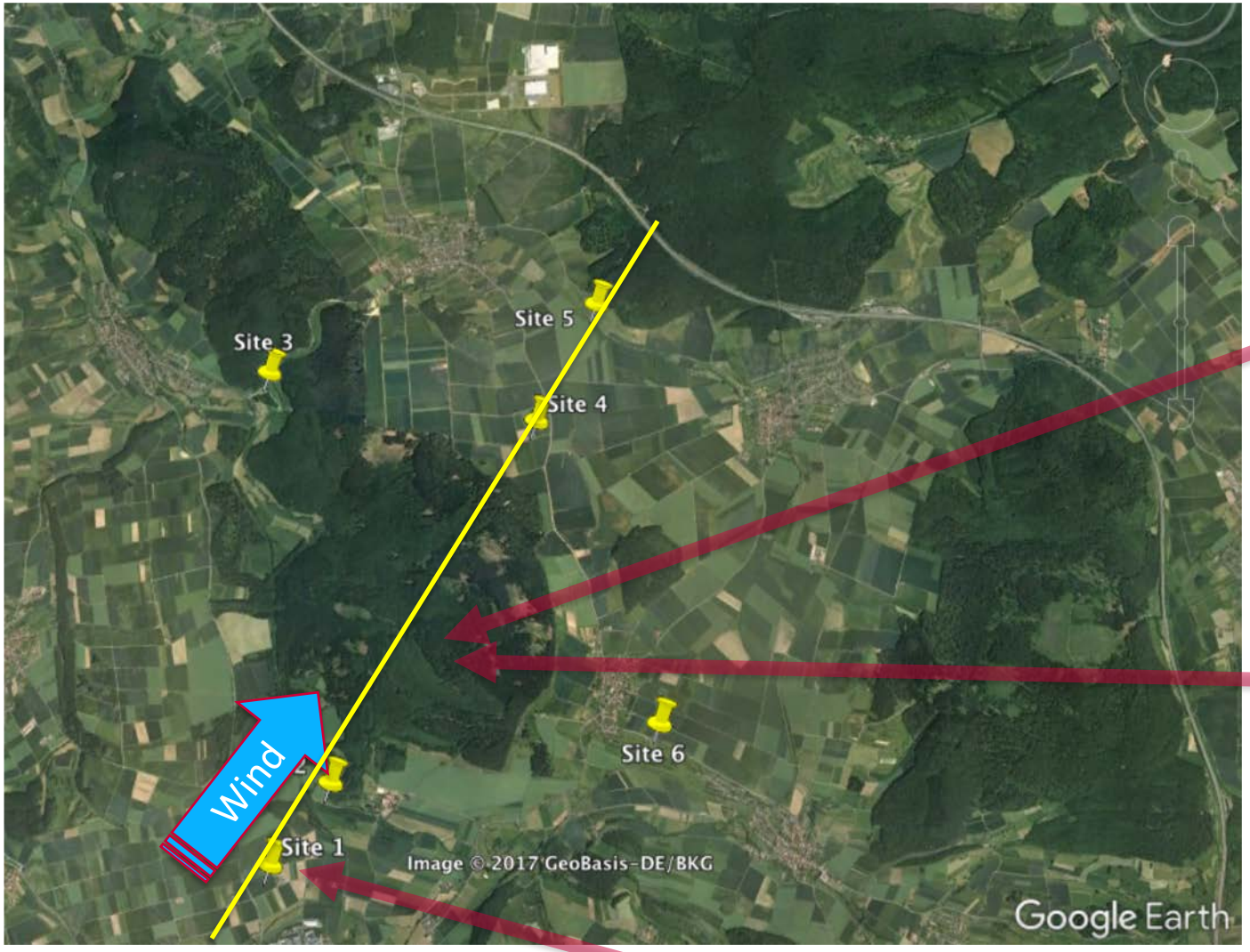
Results
Rödeser Berg (NEWA) 2016/17

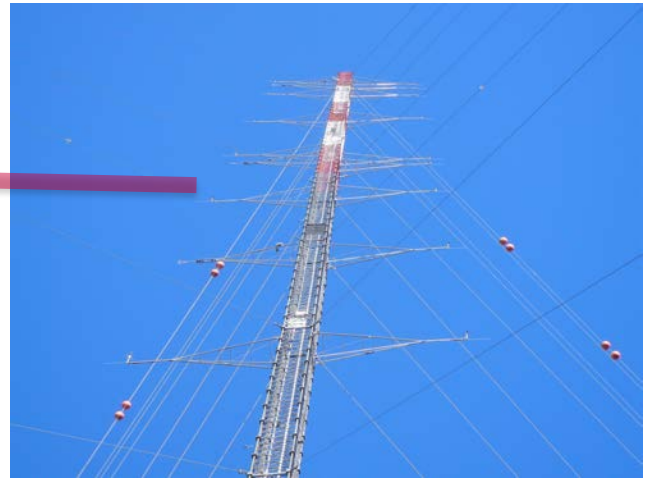
Context: New European Wind Atlas (NEWA) Project

- **Froude number Fr = U/(N h) ➔ upstream-propagating region of decelerated flow?**
  - U: wind speed
  - N=N(Θ_{va}, $\delta\theta_{va}/\delta z$): Brunt-Väisälä frequency,
  - h: height of the disturbance/hill
- **We need T, RH, Wind as vertical profiles**
- **Eliminate multicopter‘s own movements:**
  - Lateral
  - Vertical
  - Rotation



NEWA Site: Roedeser Berg, Kassel/Germany





40 m mast („reference“)

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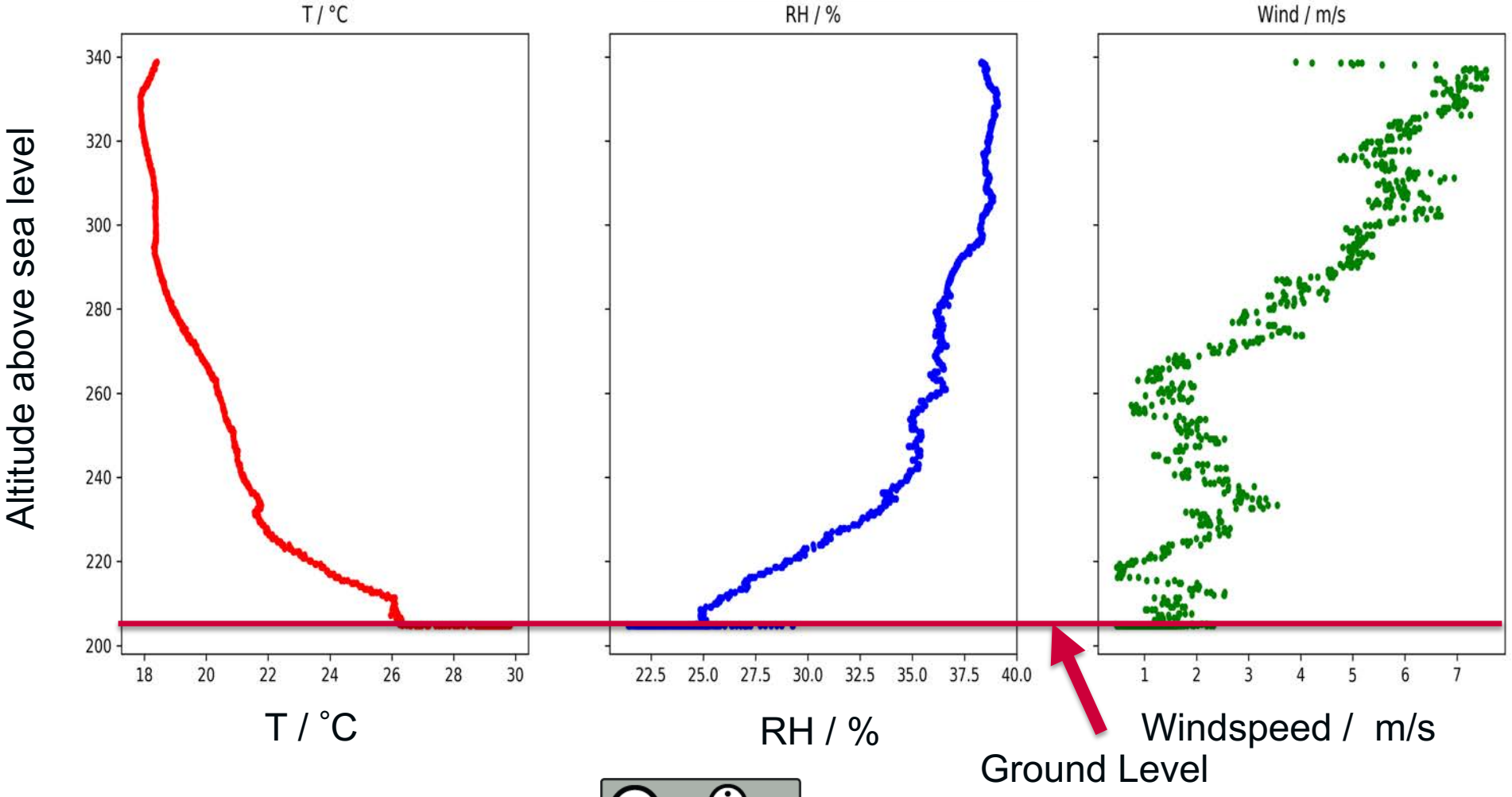
Results: Vertical Profiles 2017/07/14 10:44 UTC

➔ **Fr = 1.51**



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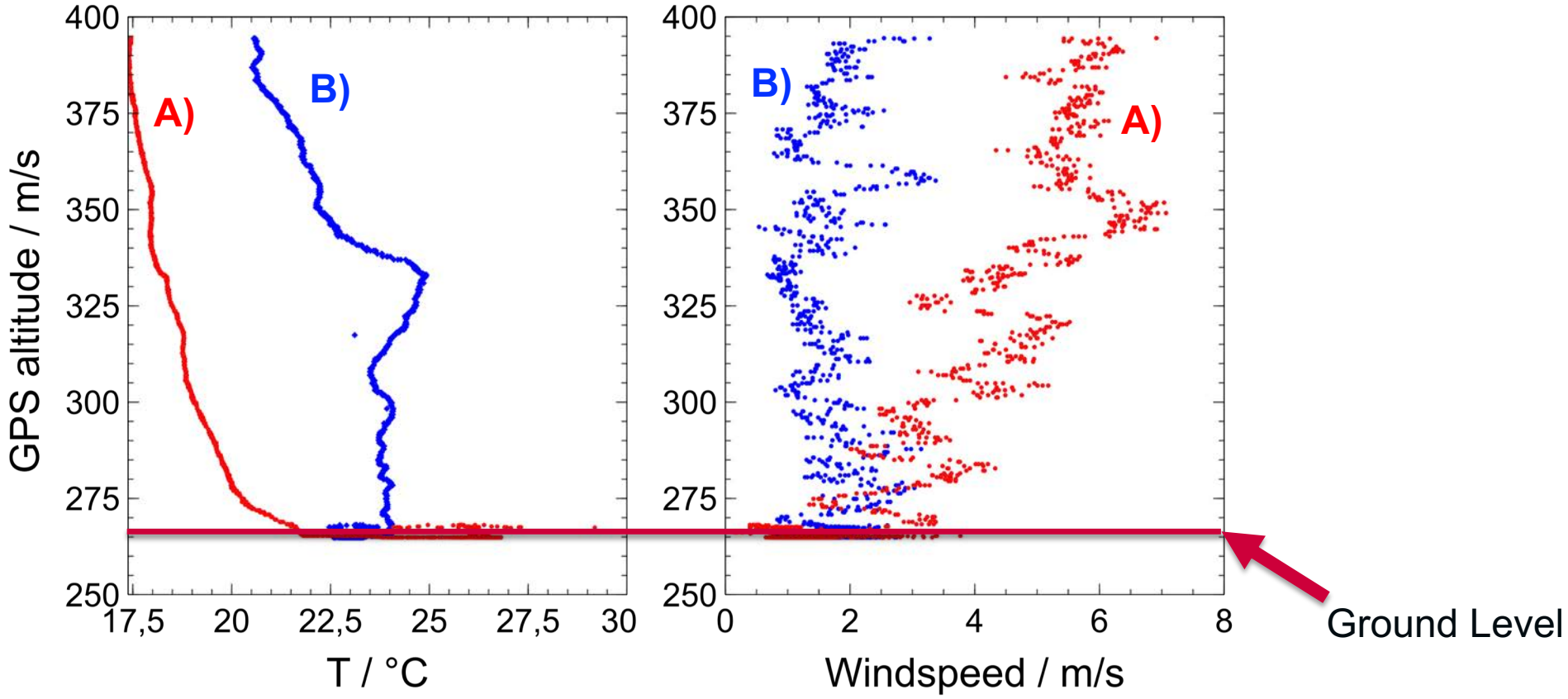
Results: Vertical Profiles T and Wind 2017/07/14



A) in front of hill
B) behind hill

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Conclusions and Outlook

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Conclusions and Outlook

- Wind measurements by multicopter RPAS very promising
- Mission scenario defines sensor setup.
- Hot element sensor modules are a good choice for low speed wind measurements.
- Extensive calibration (wind tunnel and in situ flights) required.
- Data analysis: work in progress

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