Meteorological fine structures of Thermals

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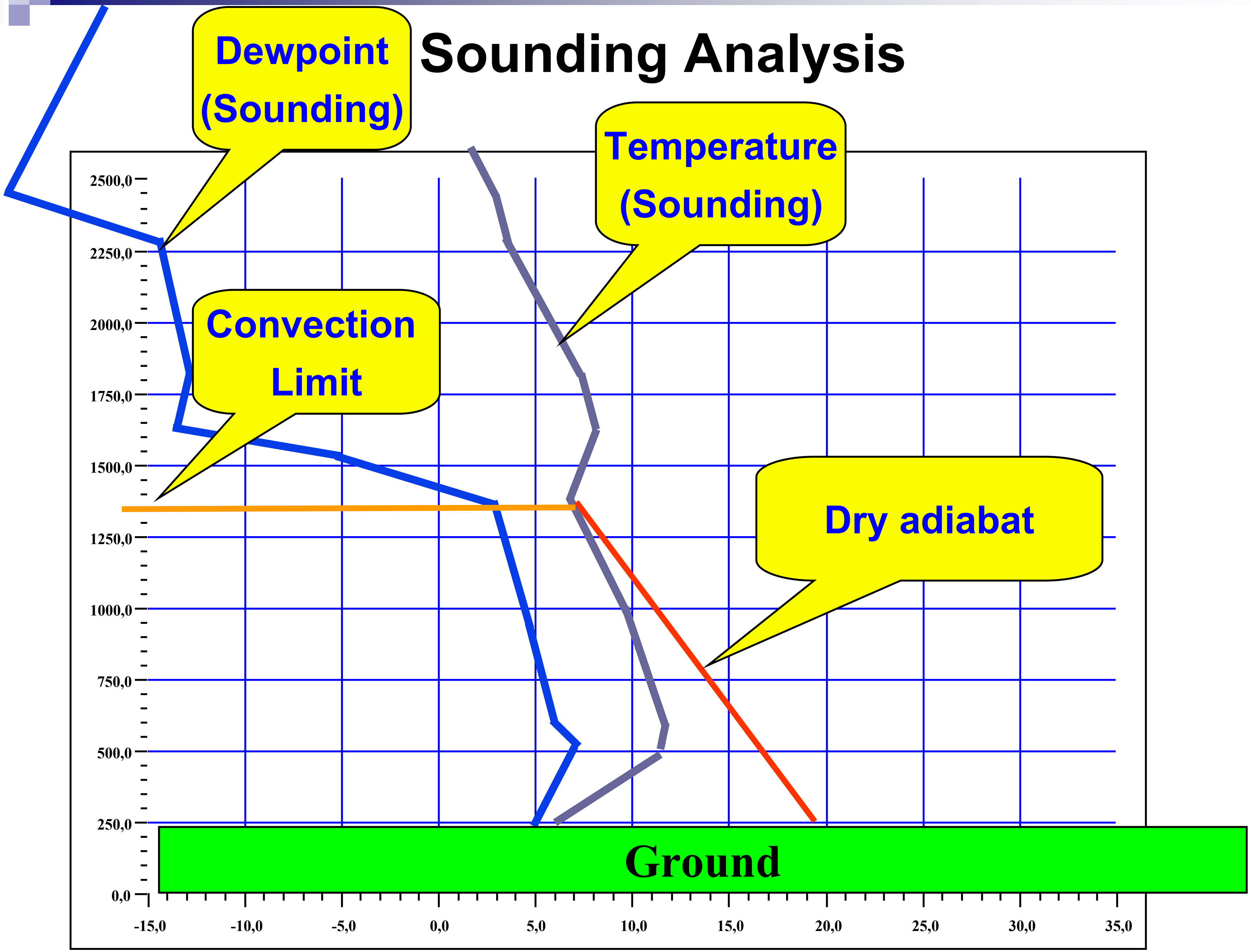
What is driving thermals?

- Classic point of view
- Thermal updraft is induced by temperature differences of air masses inside and outside of thermals:
  Warmer (lighter) air rises in surrounding colder (denser/heavier) air
- Based an analysis of atmospheric soundings

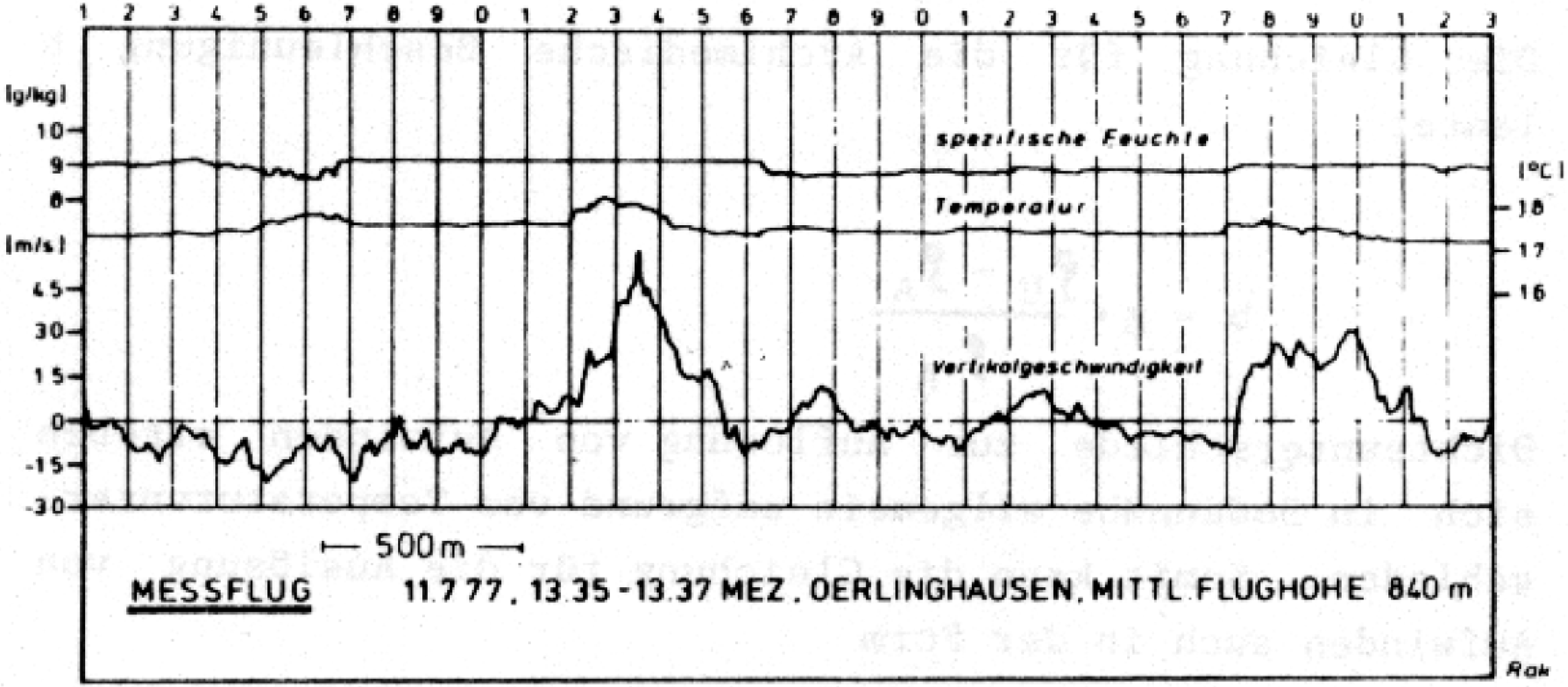
Sounding Analysis



Henry Blum's Hypothesis

- already 600 m AGL no more significant temperature difference between air masses inside and outside thermals, although updraft strength is strongest at or above that level
- derived from Carsten Lindemann's measurements
- at 200 m temperature differencs only ca 0.3 degrees
- thus thermals cannot be fed from temperature differences

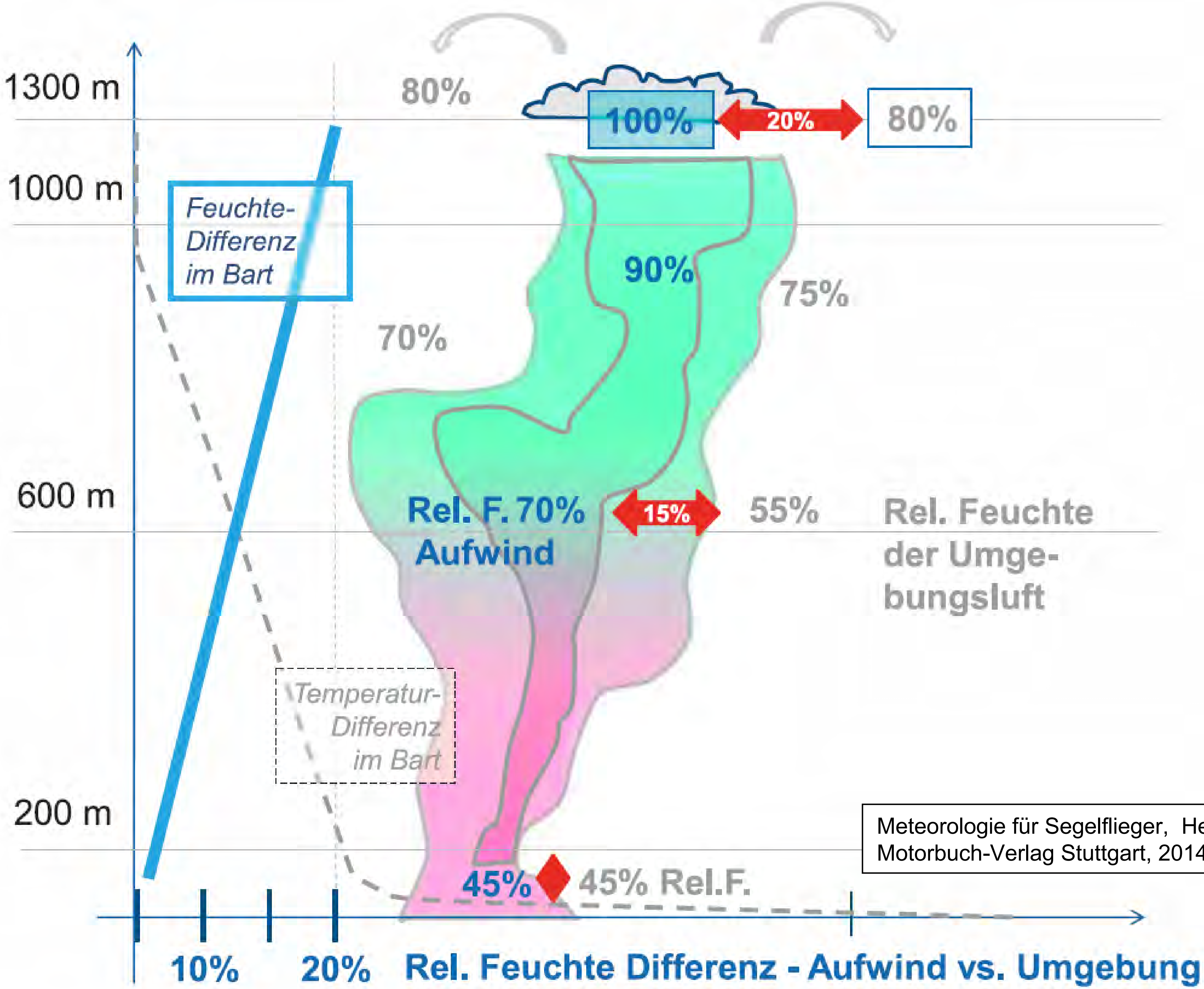
Carsten Lindemann's measurements



Meteorologische Aspekte des Streckensegelflugs,
Detlef Müller and Christoph Kottmeier, Universität Hannover, 1985

Henry Blum's Hypothesis

- Buoyancy in thermal updrafts is fed by humidity differences of air masses inside and outside thermals
- Humid air is lighter than dry air
- E.g. at 30°C air of 100% humidity (saturation vapor pressure 42 hPa) is 1.6% lighter than dry air (0% humidity)
- The same effect results from a temperature increase by 5° (virtual temperature 35°C).



Meteorologie für Segelflieger, Henry Blum, Motorbuch-Verlag Stuttgart, 2014

Blum's Hypothesis: Nothing New

Müller and Kottmeier have reported already in 1985:

Dichteunterschiede werden zwischen der aufsteigenden Luft und der Umgebungsluft aber nicht nur durch Temperaturunterschiede hervorgerufen, sondern in größeren Höhen auch durch Feuchtigkeitsunterschiede. Feuchtere Luft ist bei gleicher Temperatur leichter als trockene, da in dem Luft-Wasserdampf-Gemisch der Wasserdampf eine geringere Dichte als die Luft besitzt. Die feuchtigkeitsbedingten Dichteunterschiede sind Folge der mit der Höhe im Thermikkörper anwachsenden relativen Feuchte, die sich aufgrund der adiabatischen Abkühlung bei gleichbleibendem Mischungsverhältnis zwischen dem Wasserdampf- und Luftanteil der feuchten Luft ergibt. Die Dichteunterschiede können Werte erreichen, die einer Temperaturdifferenz von 0,5K entsprechen. Sie dürfen damit auf keinen Fall vernachlässigt werden und komplizieren die Formel für die Archimedische Beschleunigung.

Meteorologische Aspekte des Streckensegelflugs,
Detlef Müller and Christoph Kottmeier, Universität Hannover, 1985

Blum’s Hypothesis: Nothing New

Müller and Kottmeier have reported already in 1985:

"Density differences between rising and surrounding air are not only due to temperature differences, but at larger altitudes by humidity differences also. More humid air is lighter than dry air because in a water vapour air mixture water vapour has a smaller density than air. Humidity related density differences follow from the increase of relative humidity with altitude inside the thermal body which result from adiabatic cooling at a constant mixing ratio between water vapour and air fractions in the humid air sample. Density differences can reach values that correspond to a temeprature difference of 0.5 K. Therefore they must by no means be neglected and complicate the formula for Archimedean accleration."

Meteorologische Aspekte des Streckensegelflugs,
Detlef Müller and Christoph Kottmeier, Universität Hannover, 1985

Seen by the eye of a physicist

Rising air needs buoyancy, i.e. difference in air mass densities inside and outside of thermals

Air is an ideal gas: $pV = nRT$

p: pressure, V: volume, n: amount of substance, R: universal gas constant, T: temperature

Mass density ρ: $\rho = m/V = nM/V = Mp/RT$

ρ: mass density, M: molar mass

Proportionality to 1/T: $\rho \sim 1/T$

Proportionality to M: $\rho \sim M$

For given pressure buoyancy can be created by reducing the mass density of the air via 1) increasing the temperature T (classic) or 2) decreasing the molar mass M (Blum) [or both].

An aside: Air is not a sponge.

- **Please avoid saying: "Warm air can hold a large amount of water"**
- **Air is not a sponge!**
- **The maximum amount of water in the gas phase exclusively depends on the temperature of the liquid, whether there is air around or not.**

- *The notion of air "holding" water vapor or being "saturated" by it is often mentioned in connection with the concept of relative humidity. This, however, is misleading—the amount of water vapor that enters (or can enter) a given space at a given temperature is independent of the amount of air (nitrogen, oxygen, etc.) that is present. Indeed, a vacuum has the same equilibrium capacity to hold water vapor as the same volume filled with air; both are given by the equilibrium vapor pressure of water at the given temperature. (Wikipedia)*

Where do we stand?

- Everybody agrees that temperature and humidity are both relevant quantities for generating buoyancy forces
- There is a vivid discussion as to what is the dominating factor
- We discuss several minutes of experimental data obtained some 40 years ago.

What should we do?

- Go out and get data!

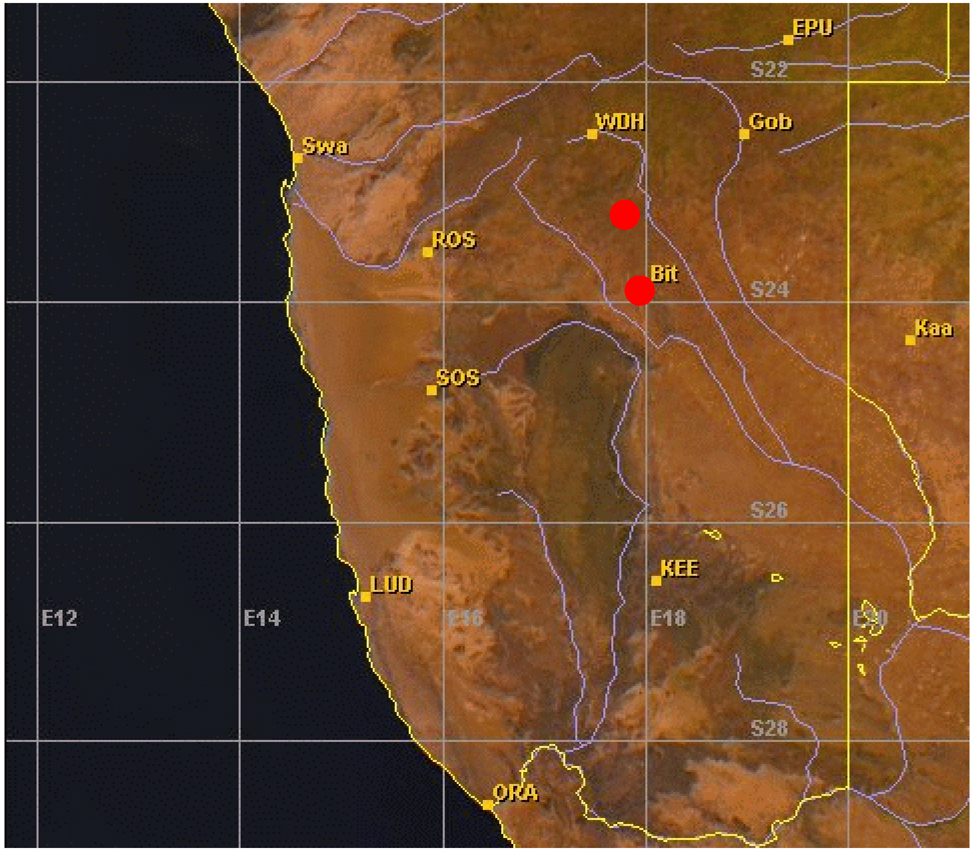
What have we already done and found out?

Equipment

- low cost sensor logger based on Arduino
- air pressure [hPa]
- air temperature [°C]
- relative humidity [%]
- x,y GPS coordinates
- z=altitude (GPS)
- time (UTC)
- total cost
- sampling rate 1Hz
- ca. 60 EUR

Namibia Campaign - Nov 2017 / Jan 2018

- Measurements
- Kritipotib / Bitterwasser + ca. 500 km East and South



East / km

Measurements

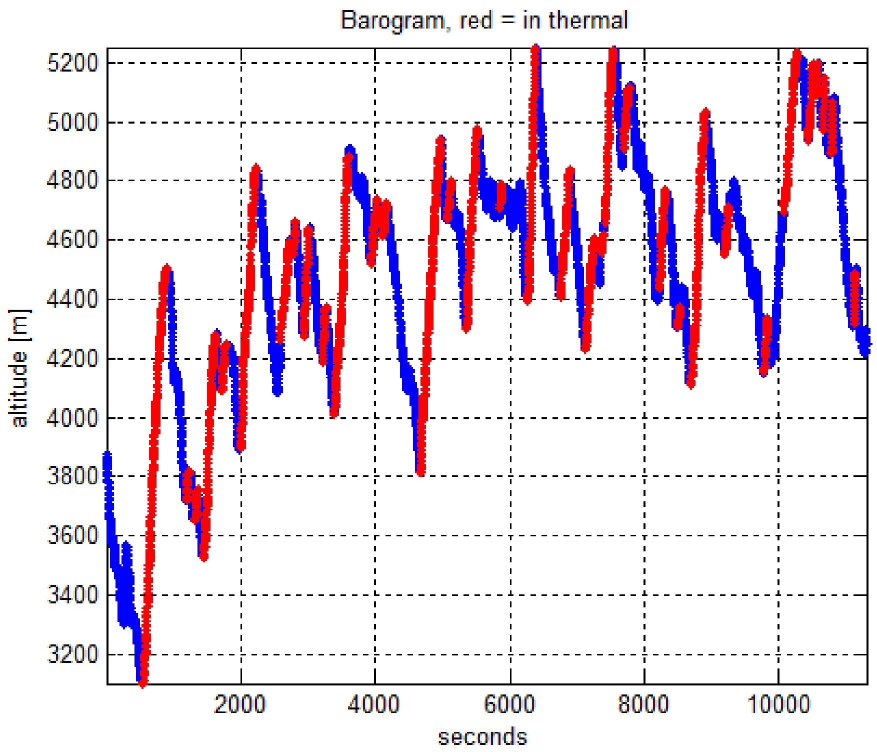
- 3 days with Clouds, cloud base up to 5000m
- 19.95h of measurements: n= 71.000 points (1/sec)

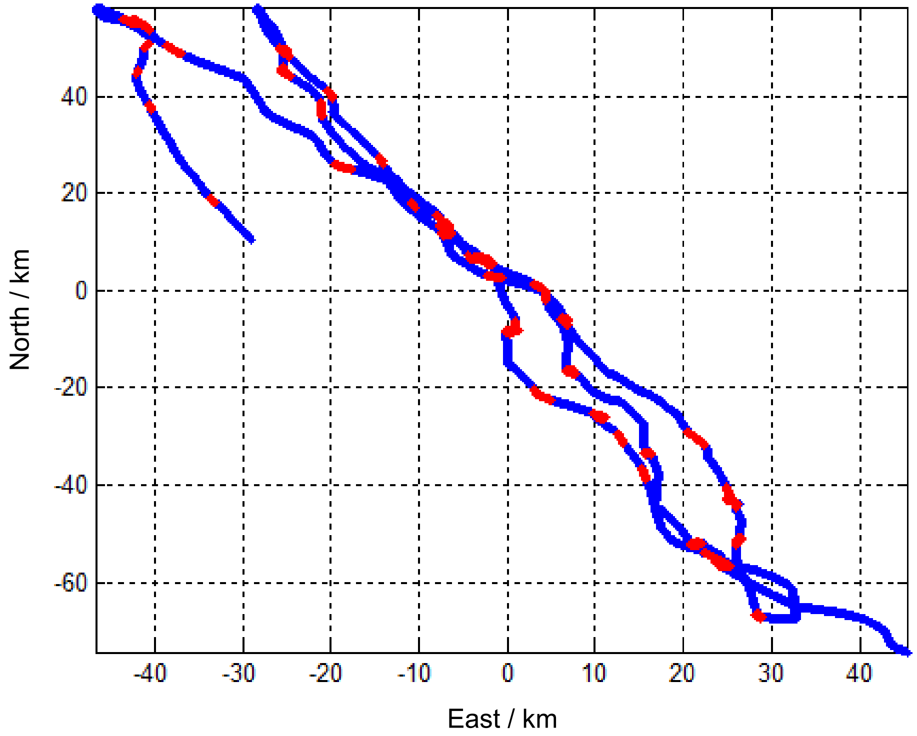
- 4 days with pure (blue) thermals, convection height up to 3000 m
- 17.5h of measurements: n= 65.000 points (1/sec)

- Meteorology: pressure, temperature, rel. humidy
- GPS: North, East, Altitude, Time
- second GPS source using IGC files

Sample Observation 1: Nov 13, 2017

- **red = in thermal,**
- **blue = between thermals (programmed classification)**

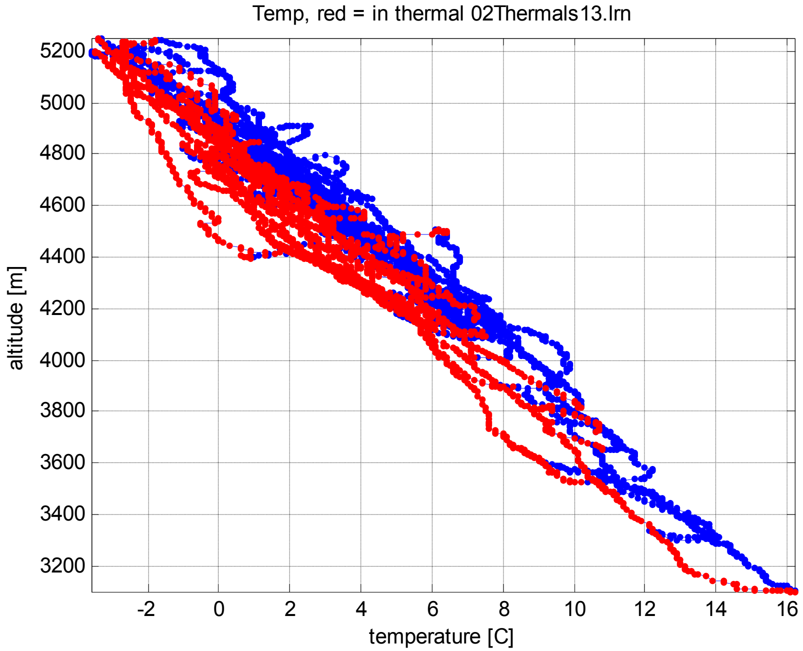




- **=> classification is quite good**

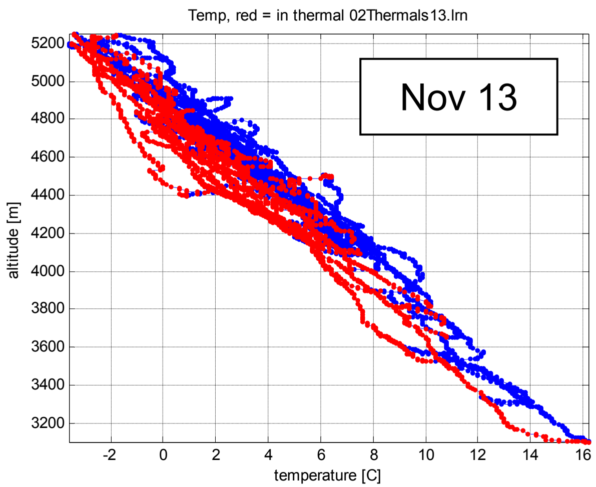
Temperature inside vs. outside of thermals

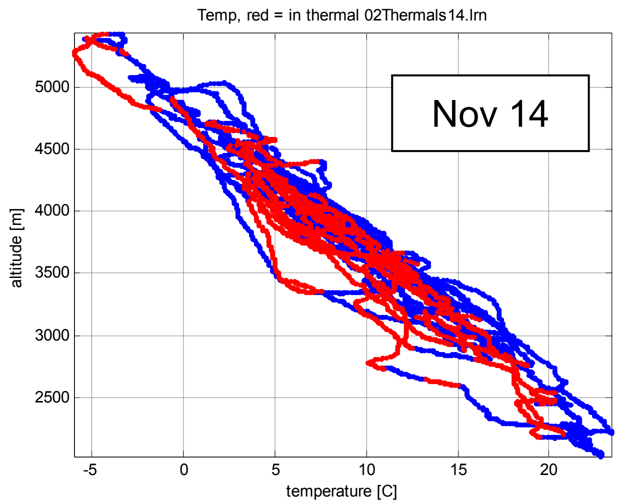
- **red = in thermal, blue = between thermals**

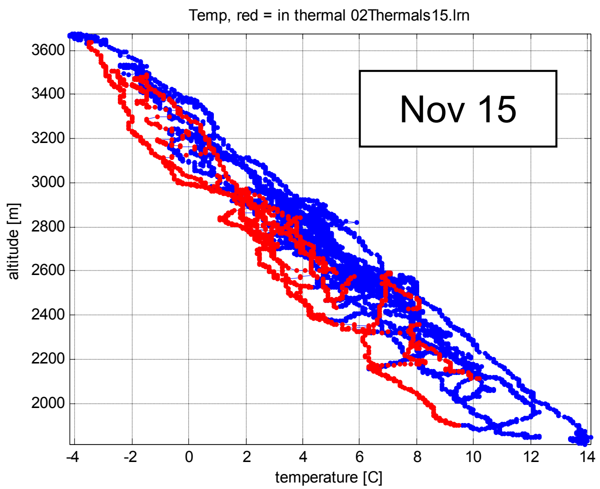


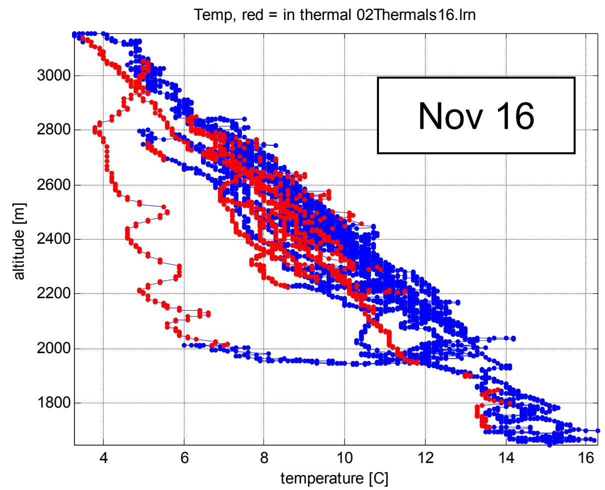
- **Surprise: air seems to be cooler inside thermals ???**
- **Experimental artefact?**

Observation is reproducible

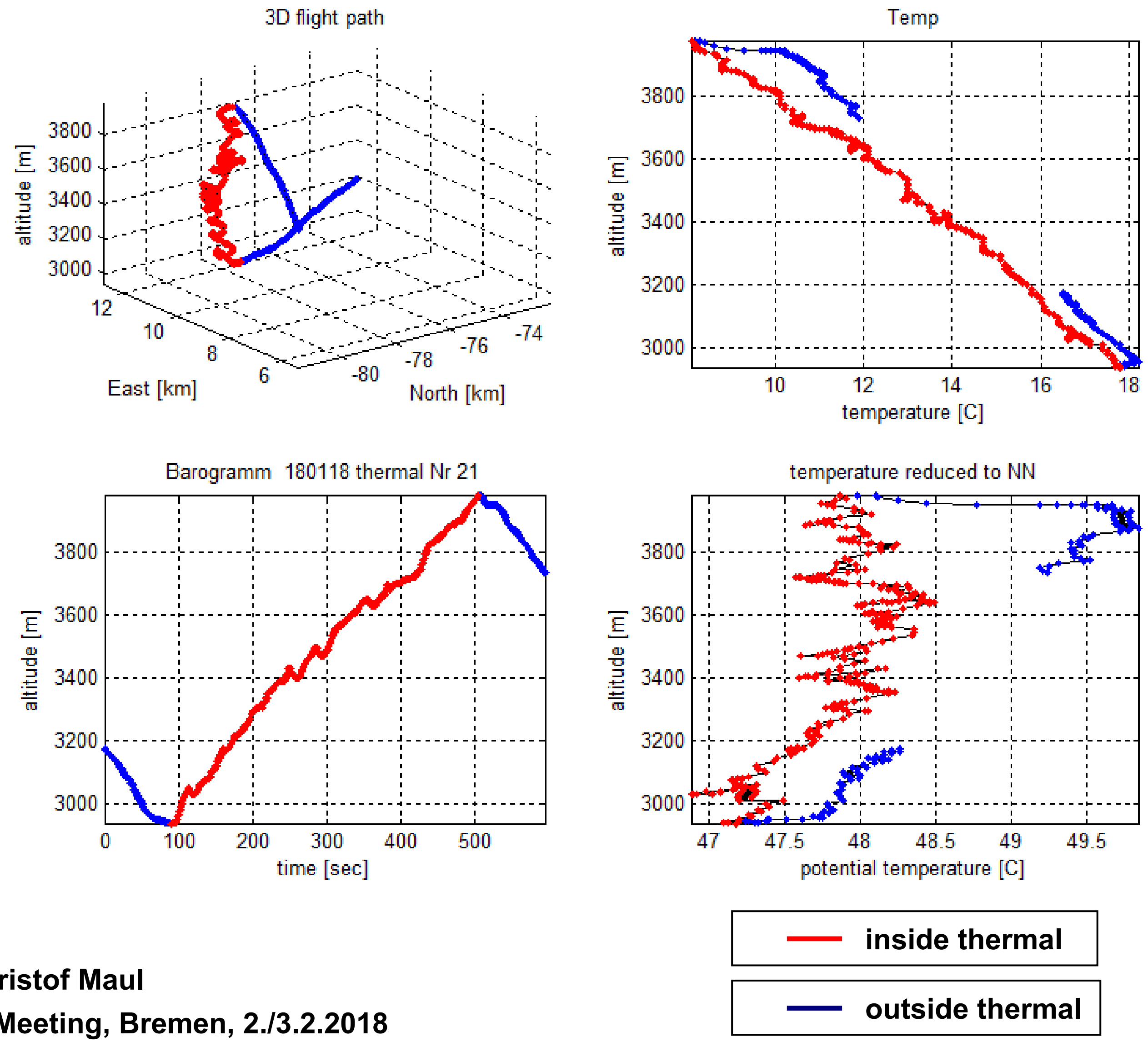




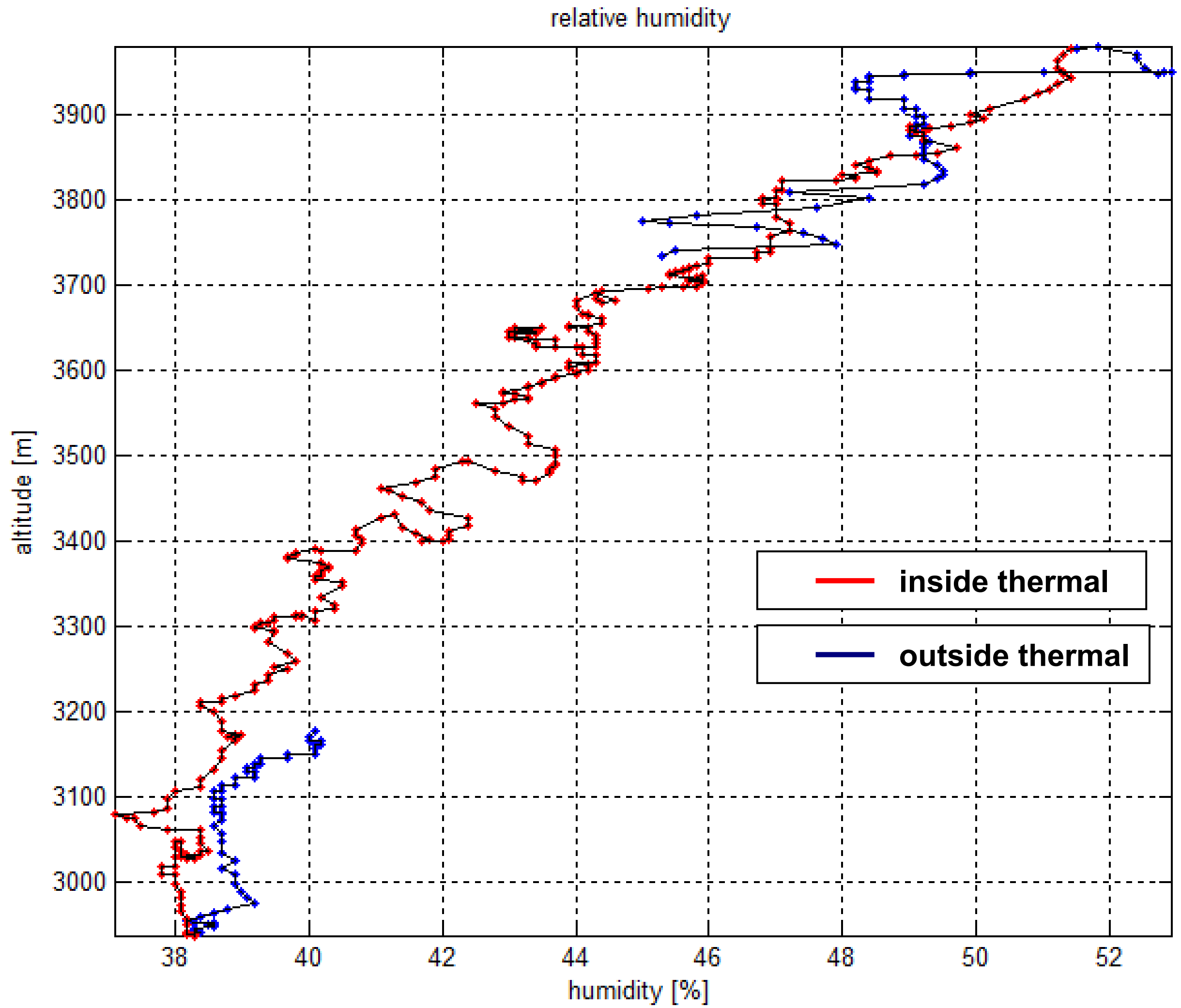




Thermal #21, Jan 18, 2018 - temperature



Thermal #21, Jan 18, 2018 - humidity



Conclusion

- successful proof of concept
- large number of experimental data
- preliminary analysis yields unexpected results ("cold thermals")
- more (new) questions, no good answers readily at hand. Suggestions welcome! ☺

To Do

- improve data sampling design to avoid biased sampling
- more data needed under different conditions
- more measuring devices needed in the gliding community

Philipps Universität Marburg

Technische Universität Braunschweig

Very Last Slide (post conclusion)

Call for participation

- Spread the news!
- Become part of a (global) measuring alliance yourself!
- Build your own device (design provided for free)! Or:
- Get a ready-to-use device (for compensation of expenses)!
- Contact: Alfred Ultsch
  wissenschaft@akaflieg-frankfurt.de

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