# Versatile systems for airborne environmental research


DIMO with16.5 m wing span and UMARS-2 with 5 m approximately to scale.
Photos Cyril Hertz and Marc Gerber

# On this background, I received this email 6 years ago:

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X-From_: Mathias.Rotach@meteoswiss.ch  Fri May 30 17:19:01 2008
Subject: FW: New COST Action "Unmanned aerial systems (UAS) in atmospheric research"
…

Lieber Bruno

ich habe diese Anfrage vom COST Büro bekommen. Ich weiss, du stehst eher auf die
bemannten 'aerial systems', aber trotzdem meine Frage: kennst du jemanden IN DER
SCHWEIZ, der sich mit den unbemannten befasst oder ein Interesse haben könnte dafür?
```

## Translation:

**Dear Bruno**

**I got this request from the COST office. I know you are rather involved in manned aerial systems, but, nevertheless my question: Do you know someone in Switzerland who deals with unmanned systems, or could be interested?**

umars

## Unmanned Meteorological Airborne Research System

**Bruno Neininger with Hanfried Hesselbarth,**
**the former assistants Oliver Ensslin,**
**Marc Gerber, and Manuel Metz, continued with**
**Thomas Matti, David Braig, Adrian Räz and more than 20 students**
**engaged in diploma theses, supported by internal funding of the**
**School of Engineering in Winterthur,**
**and COST Switzerland.**

## MANNED OR UNMANNED – DOES THIS REALLY MATTER ?

Part of this talk is about work and experience within the above-mentioned Institutions:

- Airborne Research Australia (at Flinders University, Adelaide)
- Metair AG – a spin-off of ETH Zurich (1990)

Both working with small (manned) aircraft

- Zurich University of Applied Sciences
  School of Engineering, with UAV «UMARS»
  Member of COST Action ES0802:
  «Unmanned aerial systems (UAS) in atmospheric research»

**The intention of my talk is to show – or at least to trigger a discussion about – that for some applications, manned aircraft are still easier to handle than UAV’s.**

**This is NOT against RPAS – we have our own (UMARS), admire the success with RPAS everywhere, and are convinced, that progress will continue.**

**It’s about discussing the short-term options which we have for the next few years.**

**It is also about combining the two types of systems.**

Manned airborne measurements are known to be expensive, and that the users are dependent from large, unflexible operators.

This is not the case if you are using or contracting SERAs: Small Environmental Research Aircraft, operated in teams of 2 to 4 people (including YOU if you wish!)

For many applications, the time between the integration of the system until getting a result is only a few days, and the costs per day of measurements are in the order of 10 to 20 k€, which can deliver Laser- or Hyper-Spectral Scanning of several 10 km$^2$ or any other application.

**By the way:**

**Some roots of this type of work started 30 years ago at ETHZ, within the Institutes for Geodesy, and for Atmospheric Physics, performing flights for refractive index measurements in terrestrial networks around 1985.**

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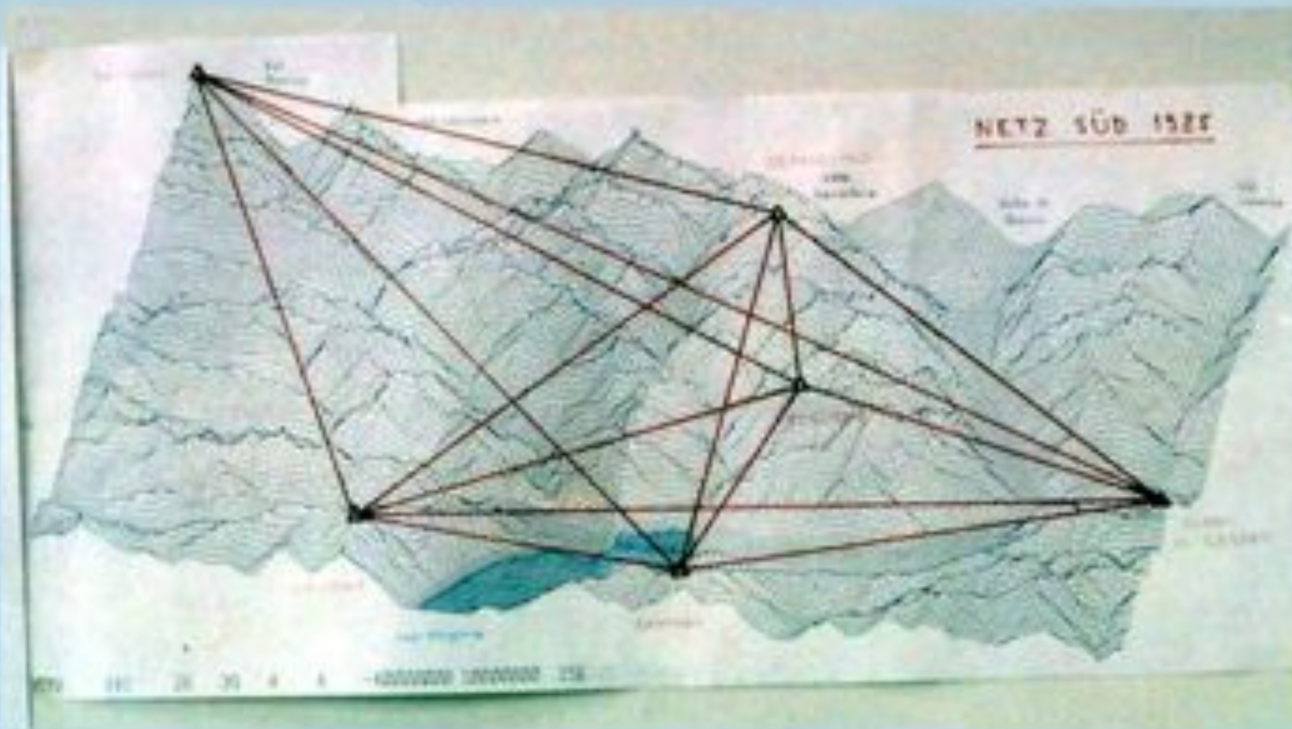
ZÜRICH, SCHWEIZ

# Refractive Index measurements for Geodesy

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Equipping and using several small and larger aircraft

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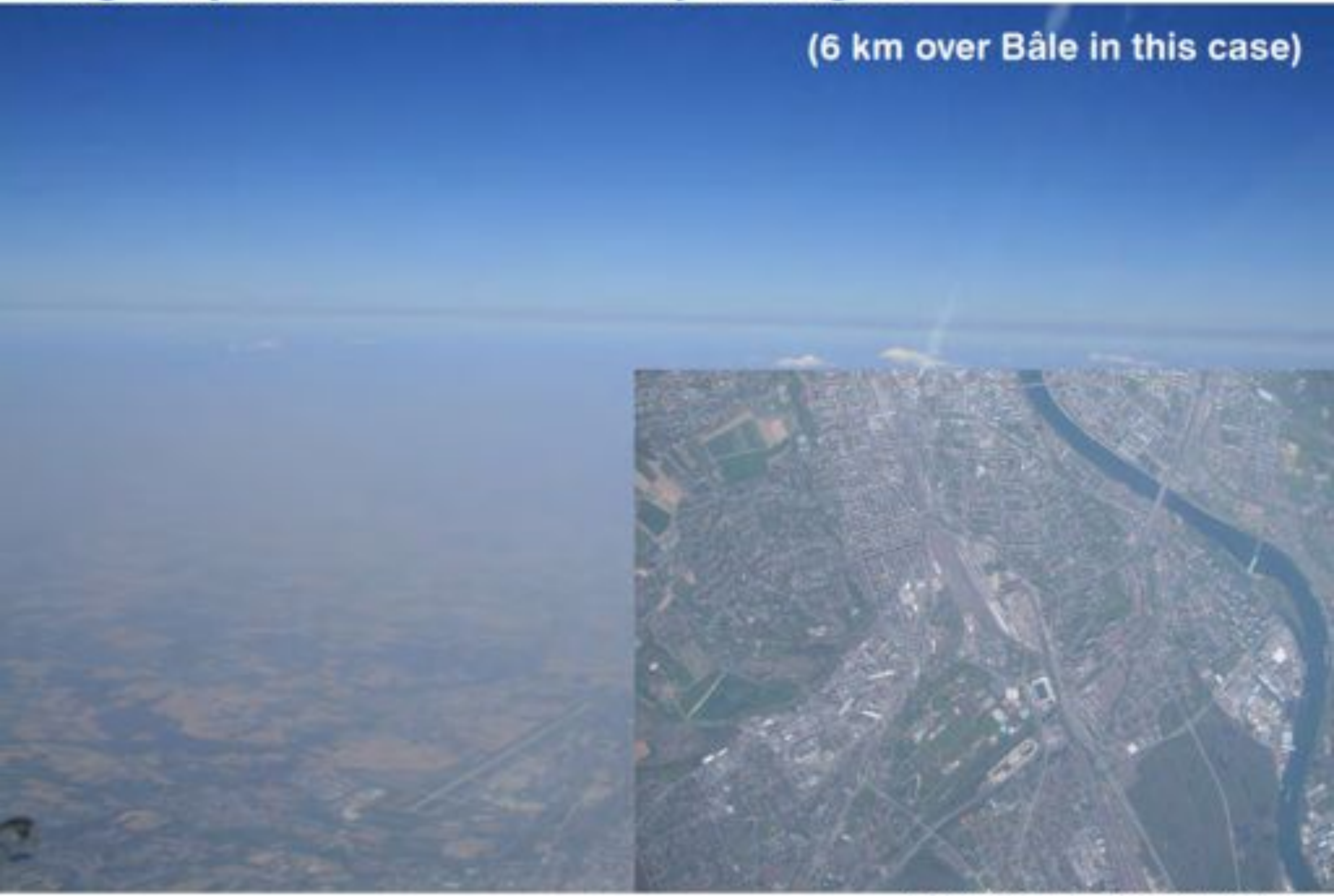
# Using today's small aircraft, we can fly both high …

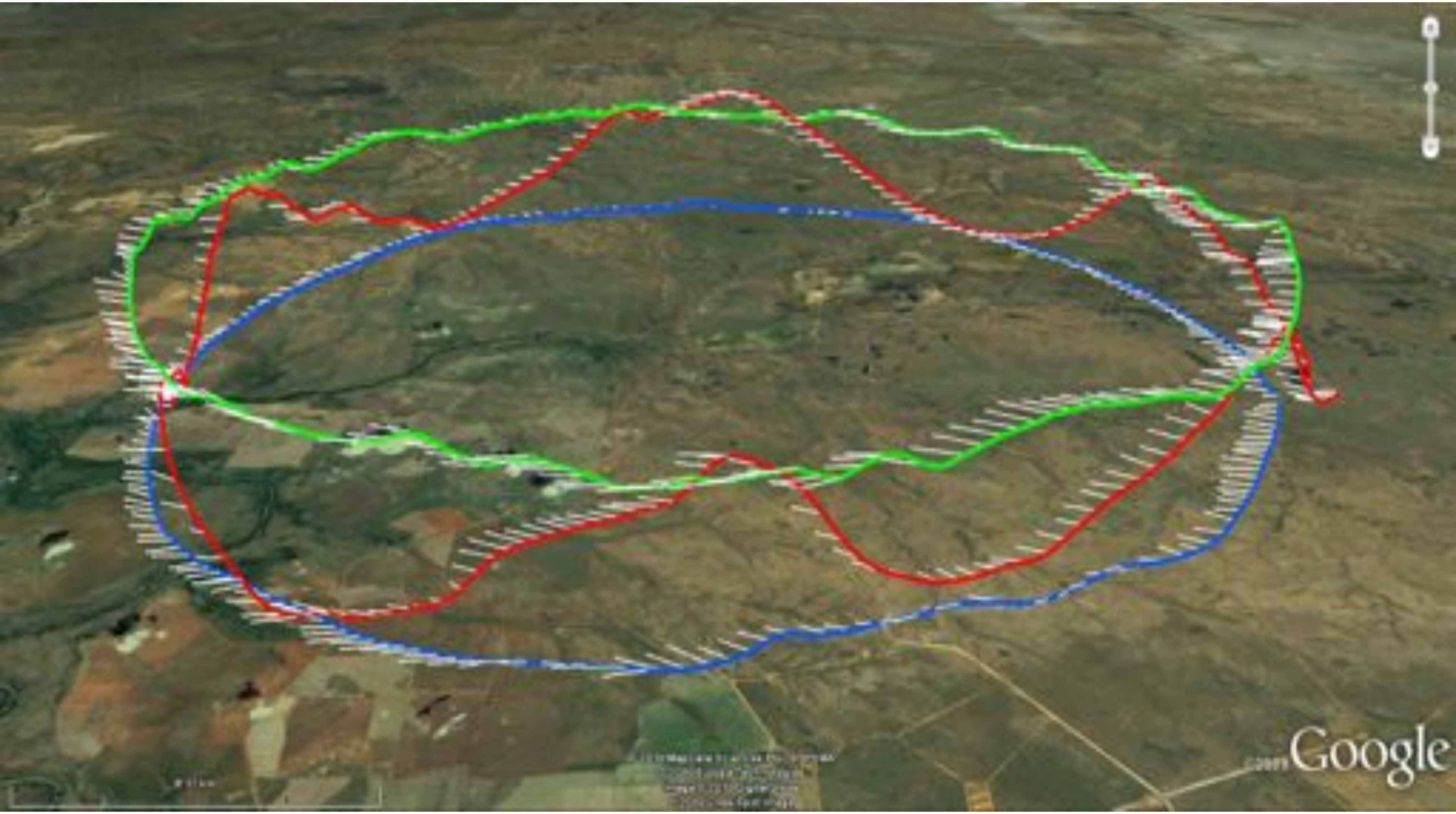



… or low

# … in Switzerland …

# … or in Australia

# This was one of the flight patterns (diameter 30 km)



## in order to get net budgets for $CO_2$ and $H_2O$

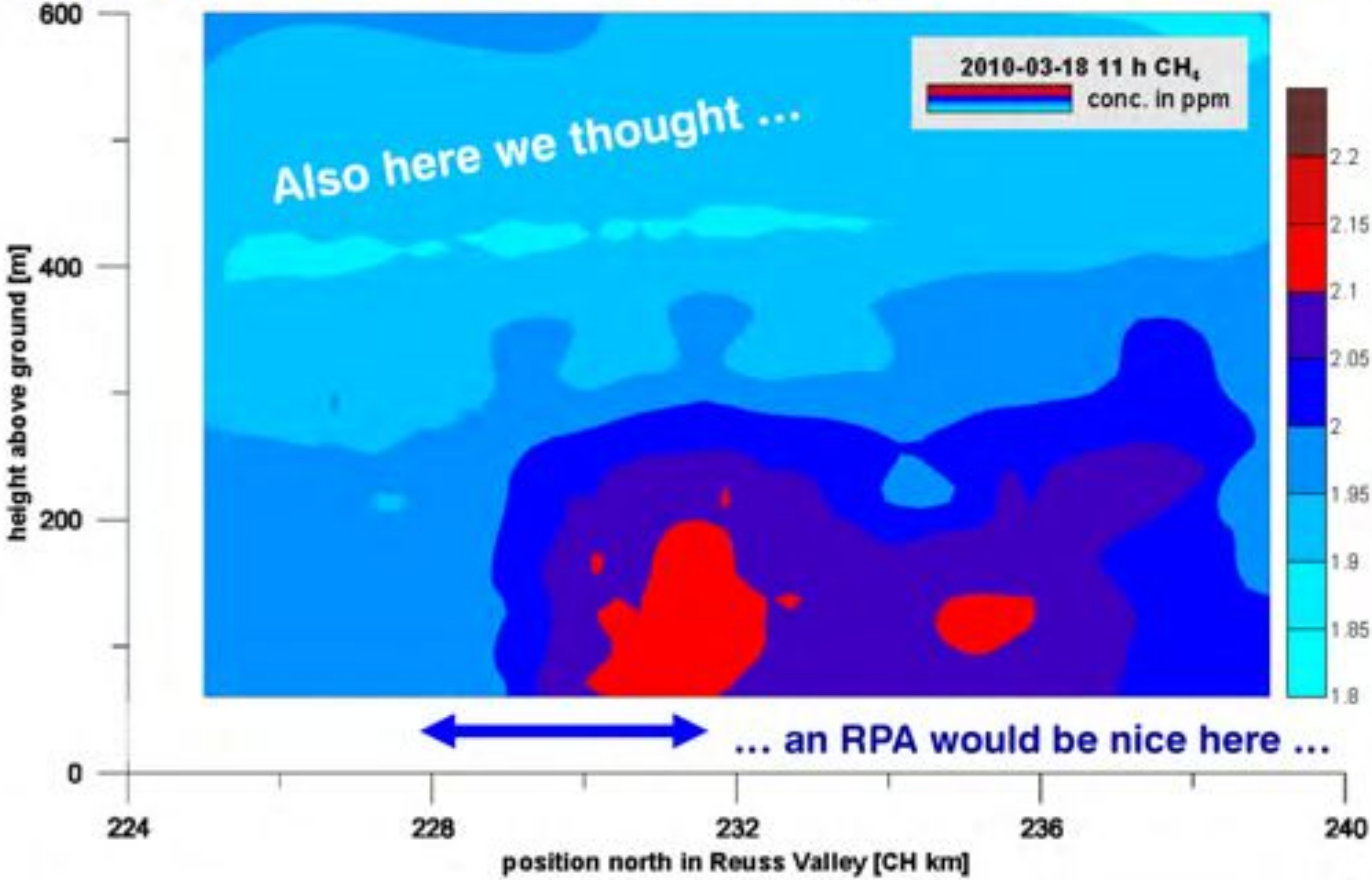
**The idea using RPAS was born during a joint campaign in Sept 2008 with Jorg Hacker from Airborne Research Australia, where we flew two manned DIMOs up to five hours over the Savanna south of Darwin**

**Also in Switzerland, we were active with a project needing low flying in the Reuss Valley in order to study the sources and distribution of Methane in the atmosphere.**
**(Nina Buchmann et al., ETHZ)**

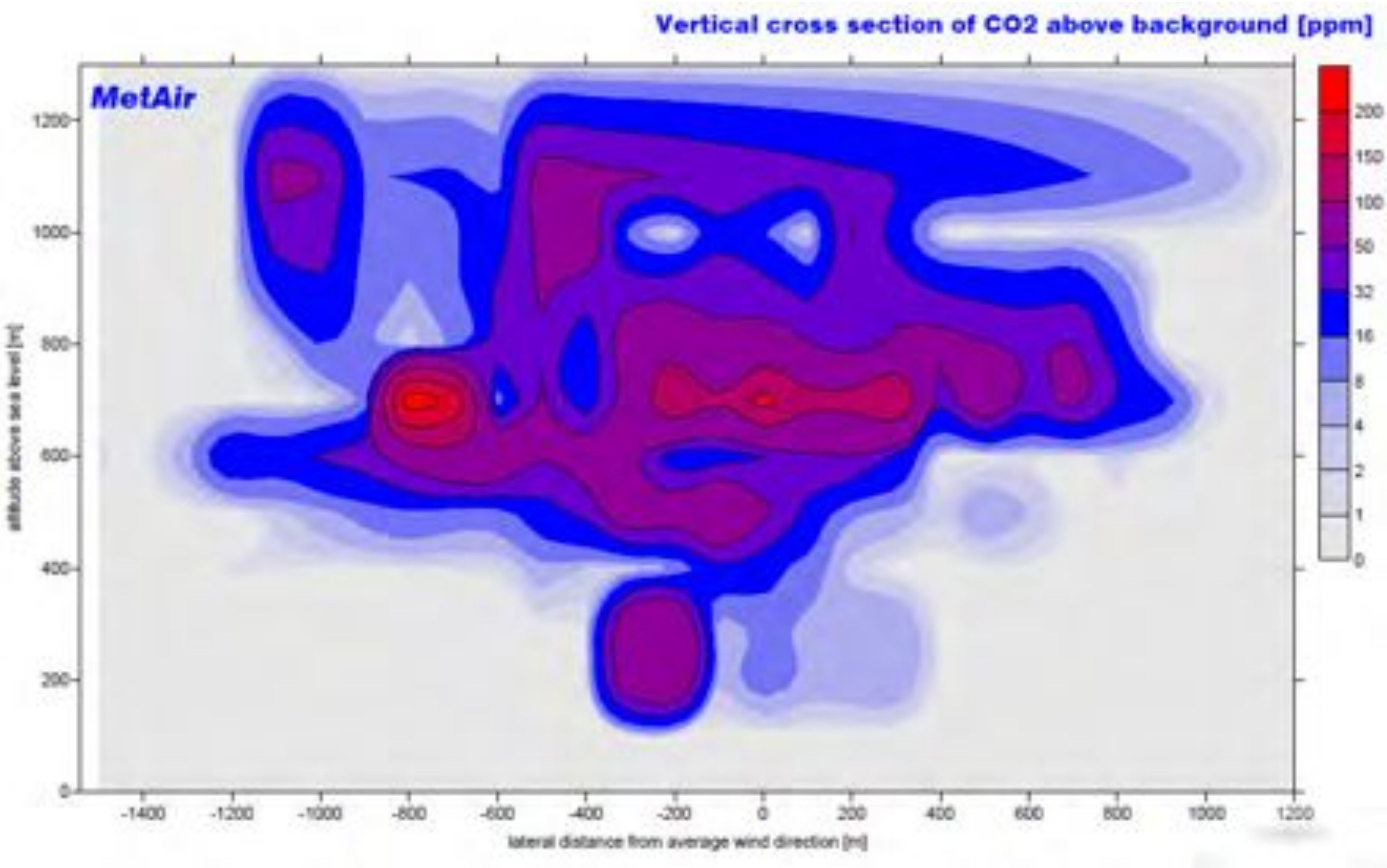
# These were the methane sources:

# The focus was on $CH_4$ along this rural valley and the advection from the surroundings

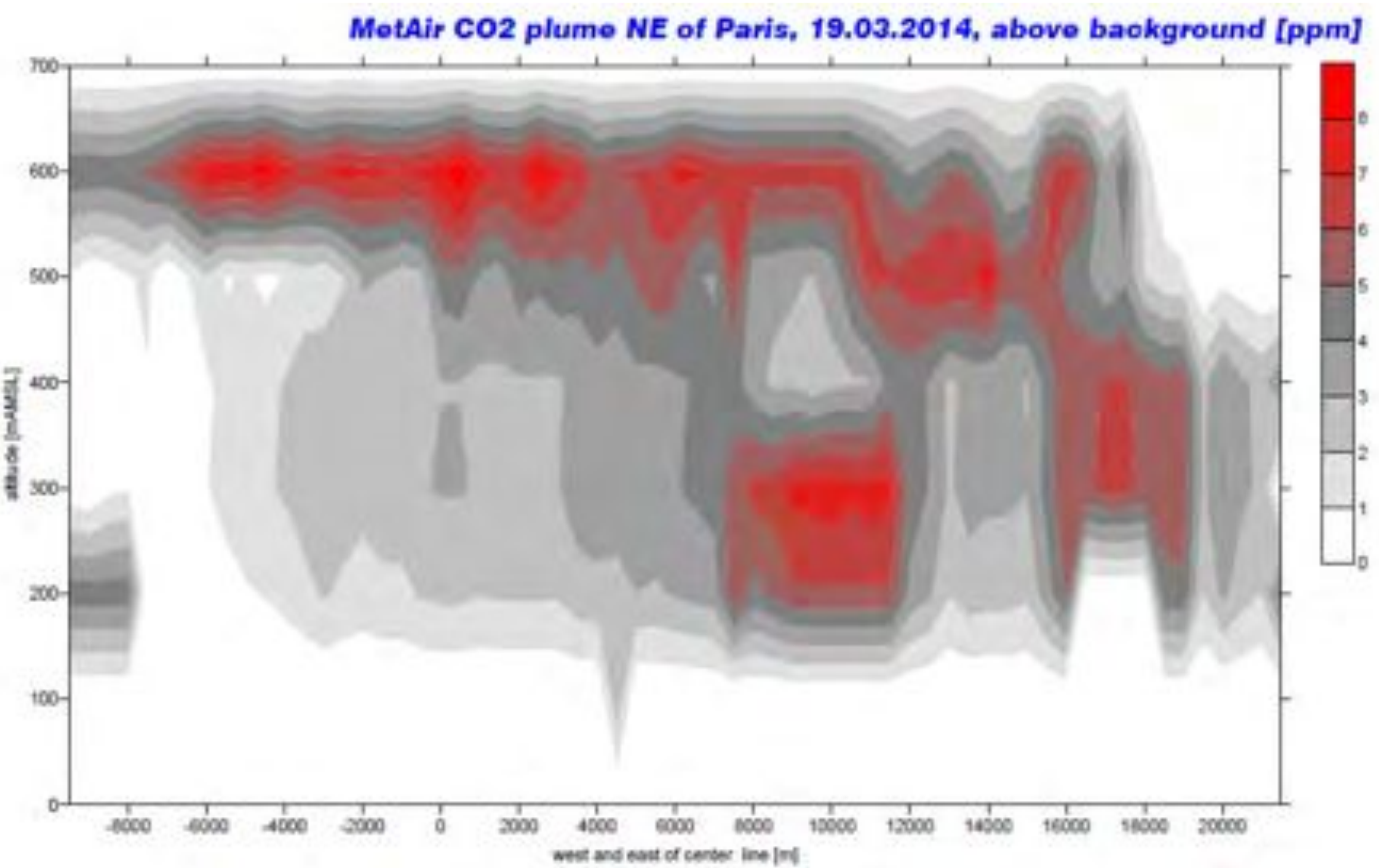
MetAir



# With the same technique, we can also measure emissions e.g. from a large coal power plant (Aug. 2012 in Germany) …



# … or from a city like Paris (March-19, 2014)



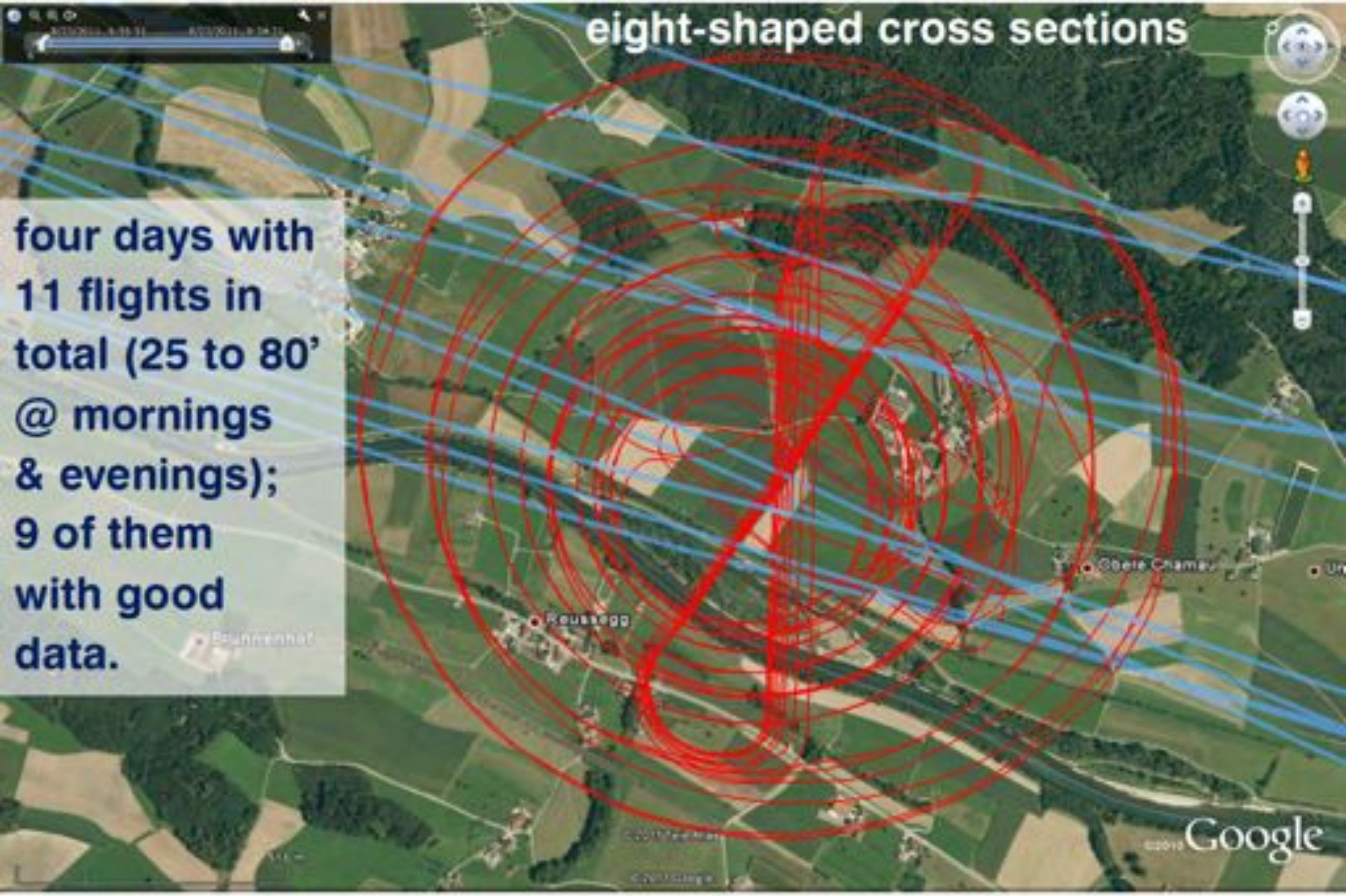
# We started a first test using RPAS in August 2011

# This was the flight pattern of the manned aircraft

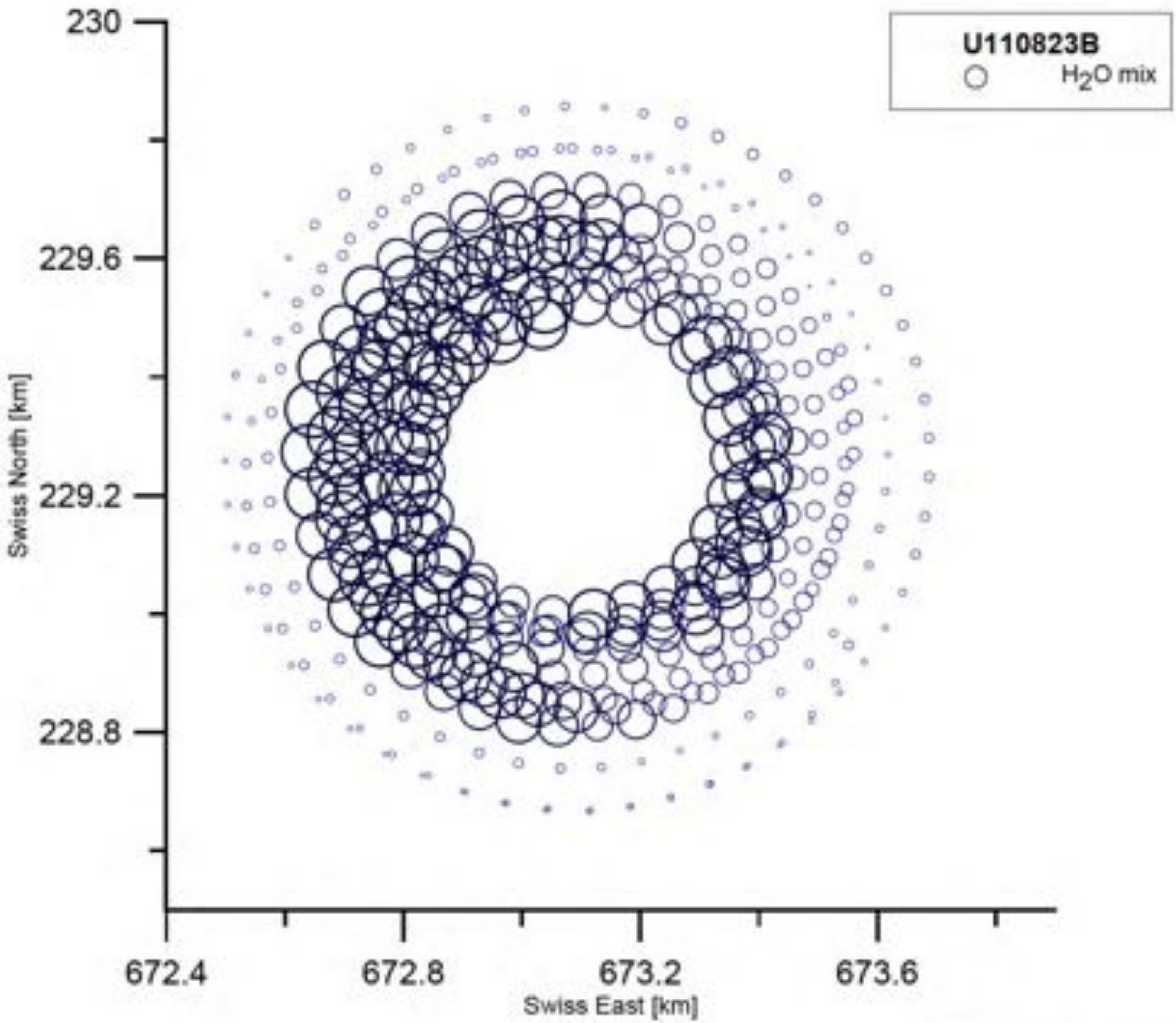

**(with a scale also in the order of 20 to 30 km)**

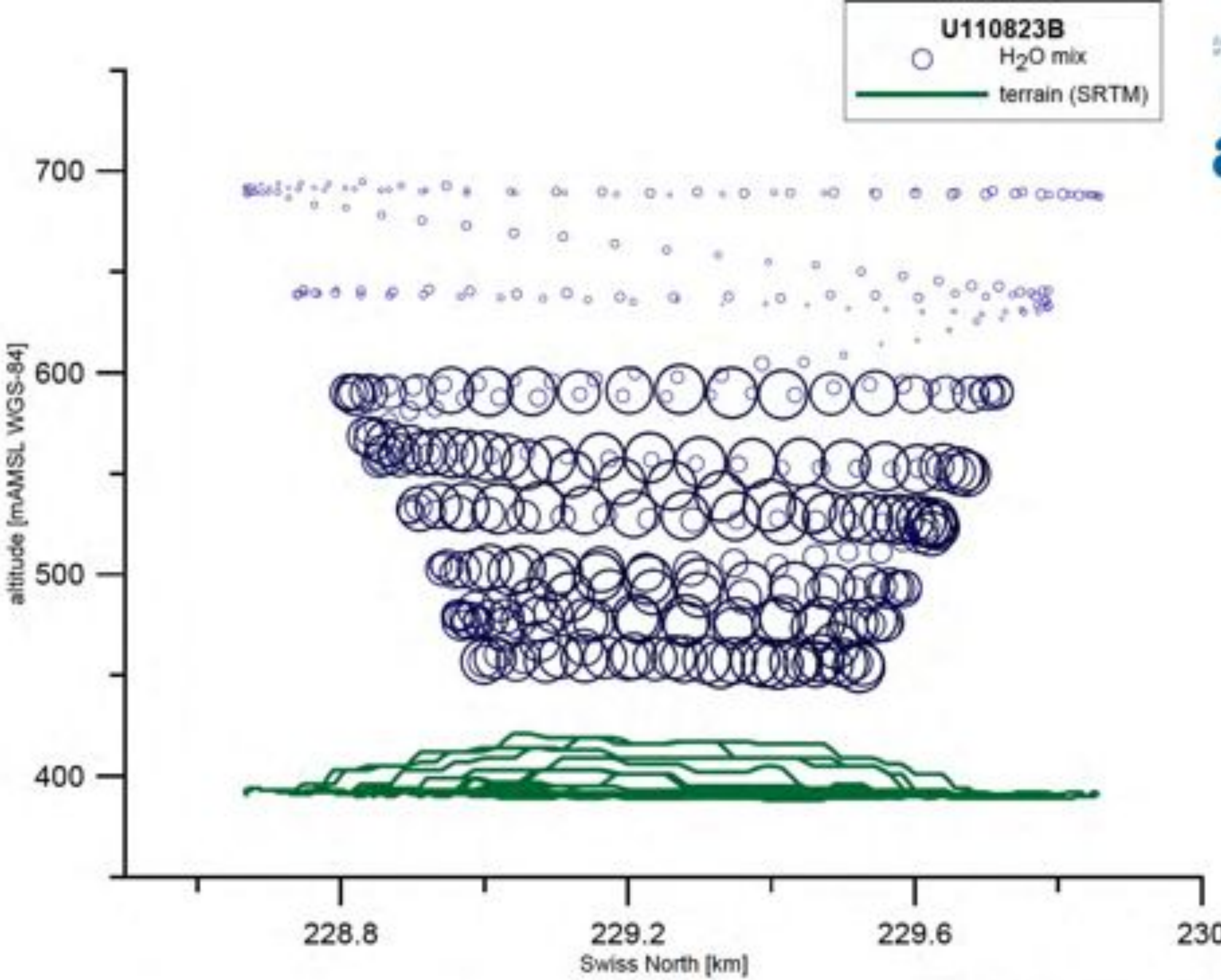
# … while this funnel was flown by UMARS

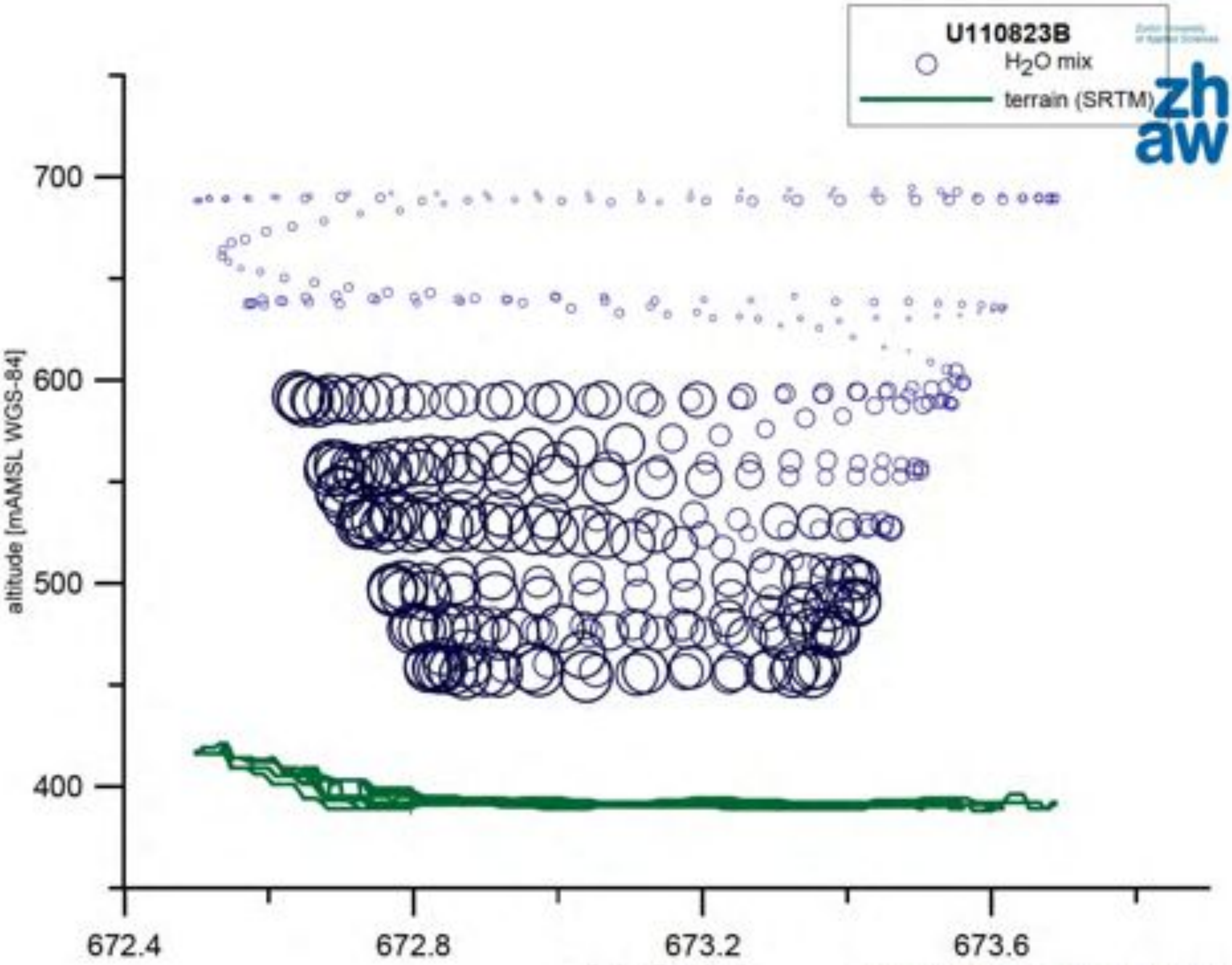
## …sometimes supplemented with one or two eight-shaped cross sections




four days with 11 flights in total (25 to 80’ @ mornings & evenings); 9 of them with good data.


230
229.6
229.2
228.8
Swiss North [km]
672.4
672.8
673.2
673.6
Swiss East [km]
U110823B
$H_2O$ mix


U110823B
$H_2O$ mix
terrain (SRTM)
700
600
500
400
altitude [mAMSL WGS-84]
228.8
229.2
229.6
230
Swiss North [km]


U110823B
H2O mix
terrain (SRTM)
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altitude [mAMSL WGS-84]
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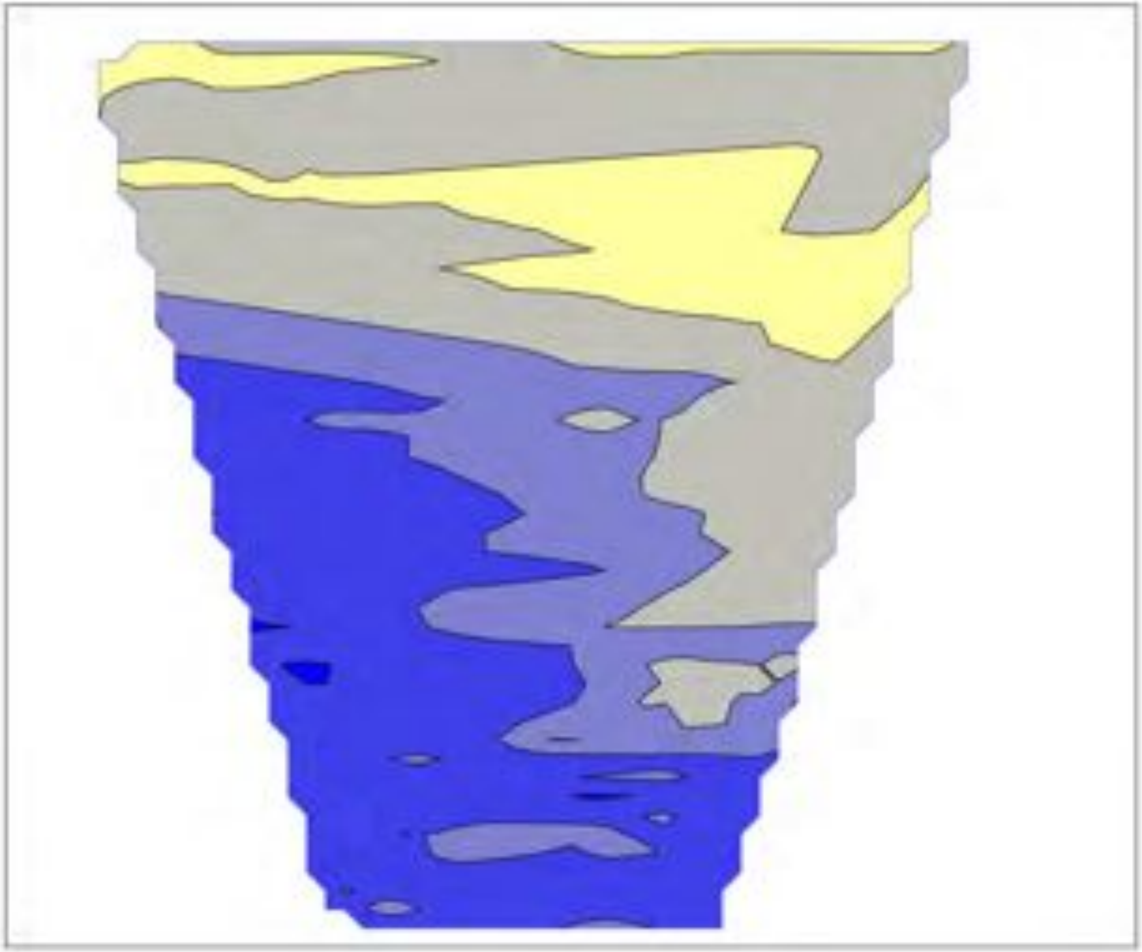
673.6
Swiss East [km]



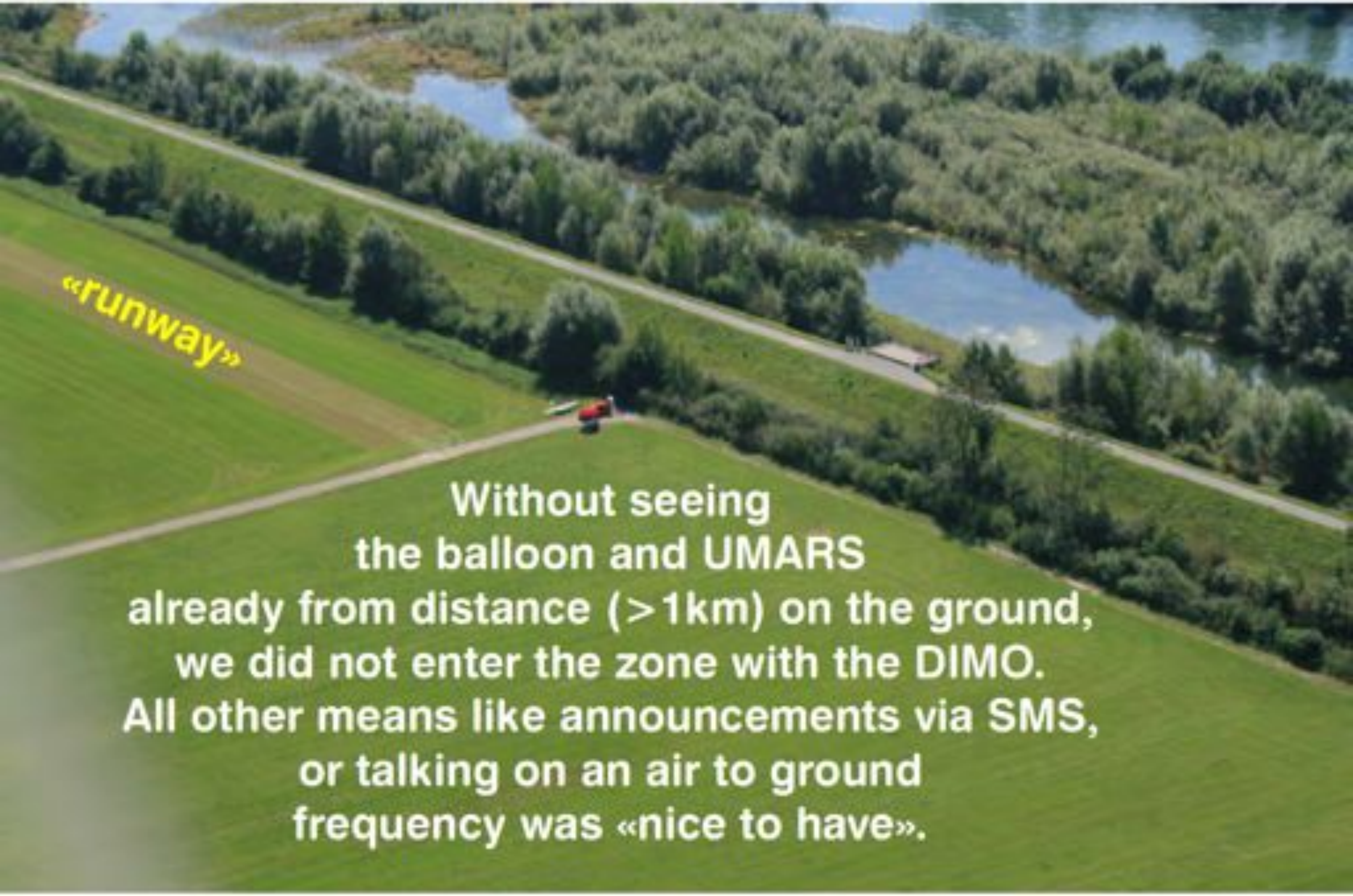
# Even a third airborne system was active:

# … a tethered balloon system with p,T,u,wind, and $CH_4$

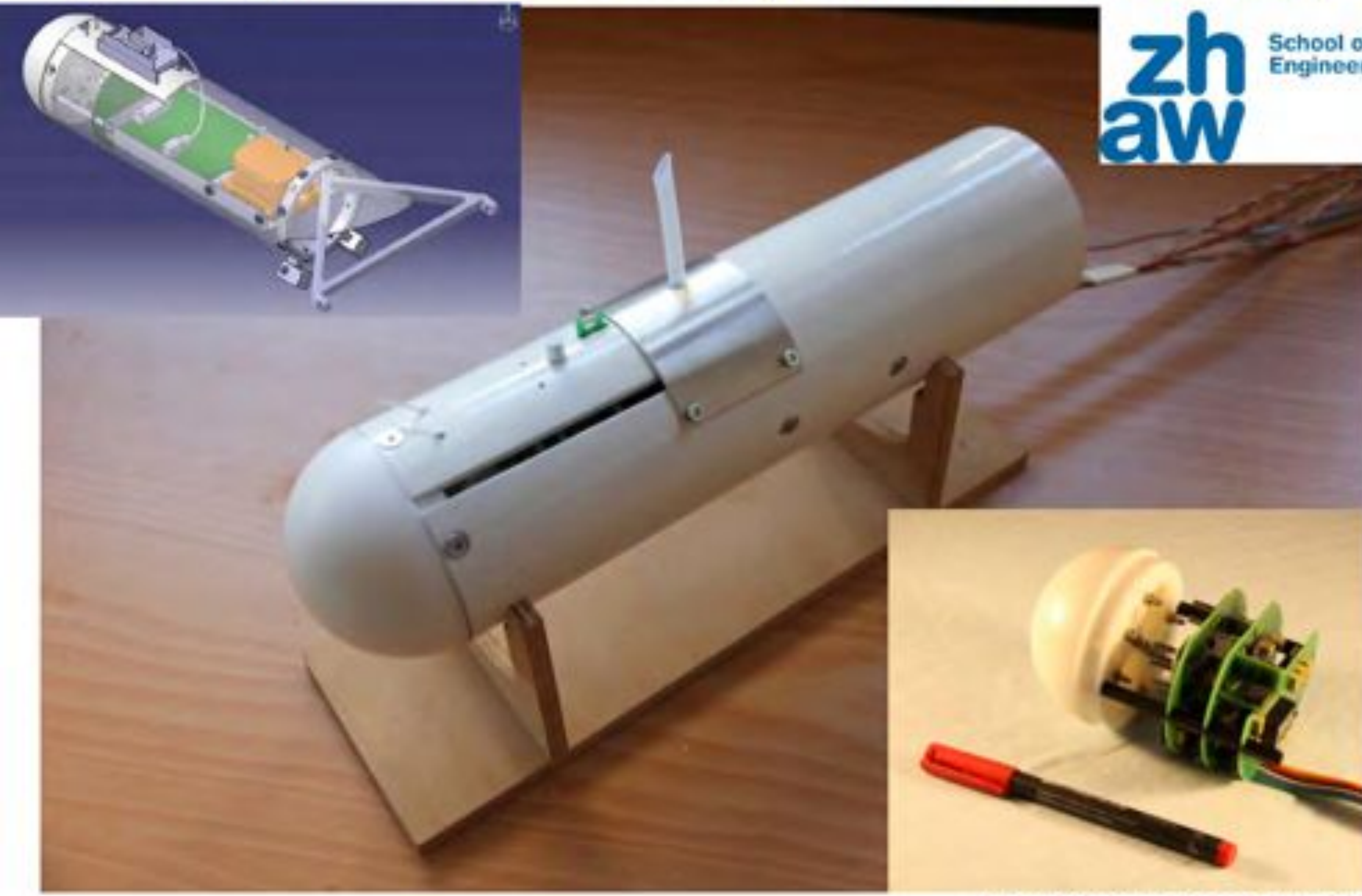
The procedures which we had to follow in order to coordinate the DIMO (manned), UMARS (unmanned) and the tethered balloon were quite reasonable, i.e. we could define them on our own, and then FOCA confirmed that this is acceptable.

**It was mainly «see and avoid»**

# And this was basically the safety concept:

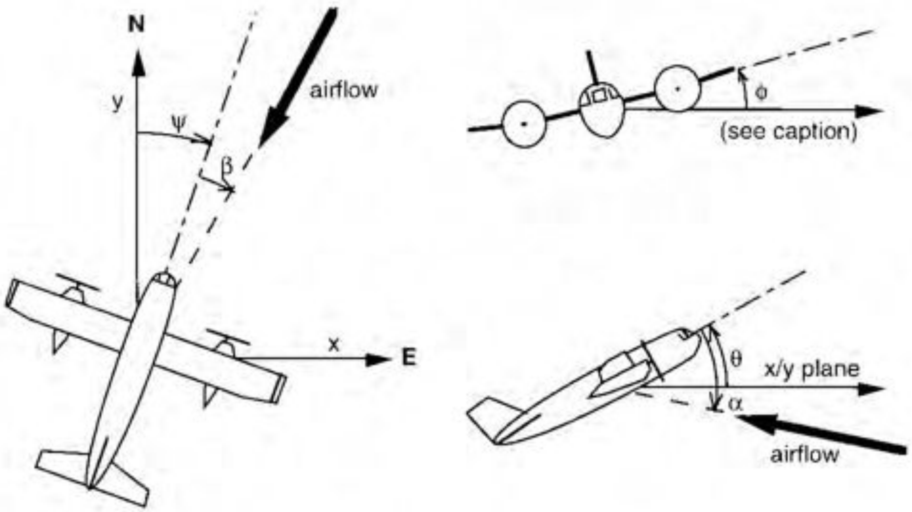


# This was the only sensor in this campaign: the new turbulence probe «Z_probe» for fast 3-d-wind, temperature and humidity



School of Engineering

# Calculating wind after Lenschow, 1986, corrected by Hans Richner, ETHZ, 1987)




Definition of attitude and flow angles for wind computations. ψ is the yaw, θ the pitch , and φ the roll angle; α the angle of attack and β the sideslip. In the front view (top right frame), the horizontal reference axis is the intersection of the plane perpendicular to the aircraft's longitudinal axis with the horizontal plane in the earth-fixed coordinate system. (After Lenschow, 1986. Please note that in the original drawing the angle of attack is shown falsely, the explaining text, however, is correct.)

$$u = \frac{-U_a}{D}[\sin\psi\cos\theta + \tan\beta(\cos\psi\cos\phi + \sin\psi\sin\theta\sin\phi) + \tan\alpha(\sin\psi\sin\theta\cos\phi - \cos\psi\sin\phi)] + u_p - l(\frac{d\theta}{dt}\sin\theta\sin\psi - \frac{d\psi}{dt}\cos\psi\cos\theta)$$

$$v = \frac{-U_a}{D}[\cos\psi\cos\theta - \tan\beta(\sin\psi\cos\phi - \cos\psi\sin\theta\sin\phi) + \tan\alpha(\cos\psi\sin\theta\cos\phi + \sin\psi\sin\phi)] + v_p - l(\frac{d\psi}{dt}\sin\psi\cos\theta + \frac{d\theta}{dt}\cos\psi\sin\theta)$$

$$w = \frac{-U_a}{D}[\sin\theta - \tan\beta\cos\theta\sin\phi - \tan\alpha\cos\theta\cos\phi] + w_p + l\frac{d\theta}{dt}\cos\theta$$

with $D = \sqrt{1 + \tan^2\alpha + \tan^2\beta}$

where $U_a$: the true airspeed and
$l$: the distance between the navigation platform and the air sensing platform along the longitudinal axis of the aircraft
$u_p, v_p, w_p$: the components of the aircraft velocity in the earth-fixed coordinate system (obtained, e.g. from an inertial platform or from GPS navigation).

## The principle of the wind measurements:

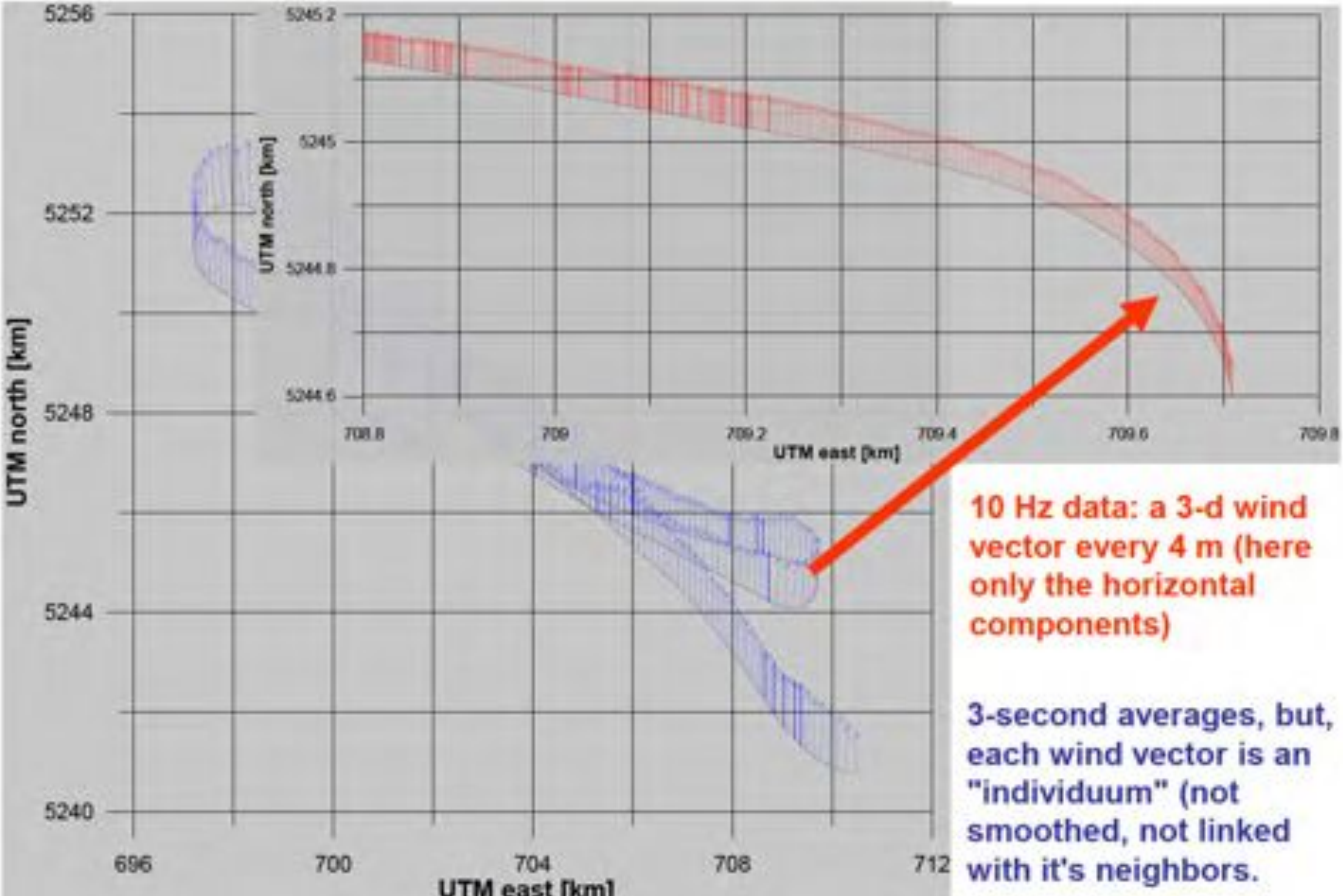
Measuring the speed of the aircraft in the earth-fixed system by GPS (Doppler), the fine movements by 3-axis accelerometers, the true air speed with the two flow angles (up/side) by five-hole probe. The difference is the 3-d wind.

Measuring the attitude angles (true heading, pitch and roll) by carrier phase detecting GPS (prec/acc/res 0.2°/0.5°/5 Hz)



A newer technique combining GPS (two antennas) and accelerometers in one box (2.4 kg, 24 x 12 x 8 $cm^3$, but 40 kEUR) improved all specs by an order of magnitude (0.02° / 0.05° / 100 Hz).
Position/attitude is not anymore the limiting factor, but, the flow measurement.

## The Result then looks e.g. like this (meandering in the valley)




10 Hz data: a 3-d wind vector every 4 m (here only the horizontal components)

3-second averages, but, each wind vector is an "individuum" (not smoothed, not linked with it's neighbors.

| **ECO-Dimona** | **UMARS** |
|---|---|
| **Transponder** | available |
| **position and attitude angles** | **xsens** |
| **data acquisition system** | **ZHAW** |
| **post processing** | **same** |
| **$O_3$ by UV absorption** | |
| **$NO_2$, NOx, NOy, $HNO_3$, PAN, Ox** | $NO_2$ opt. |
| **fast temperature (10 Hz)** | **thermocoup.** |
| **dew point (1 Hz, new 10 Hz)** | **SnowWhite** |
| wind (slow, horizontal) | **same** |
| **3-d-Wind (10 Hz)** | **Z_probe** |
| zGND (radar) | available |
| **zGND (laser, 100 Hz)** | |
| **Aerosols >0.3 / >0.5 μm** | available |
| Aerosol 0.3..20 μm | possible |
| Aerosol >10 nm | possible |
| **CO** | perhaps slow and inaccurate |
| **$CO_2$ etc. grab samples (flasks)** | |
| **$CO_2$ accurate (LI-6262 mod)** | |
| **$CO_2$ fast (LI-7500 mod)** | possible |
| **$H_2O$ fast (LI-7500 mod)** | possible |
| **Photometer (Irradiation)** | available |
| **fast $CH_4$ (5 Hz)** | perhaps slow and inaccurate |
| **vertical camera** | available |
| IR and/or NDVI | possible |
| LaserScanner RIEGL Q560 | no way |
| Hyper Spectral (Eaglet) | perhaps soon? |

Zurich University of Applied Sciences

zh aw

**There is space for more sensors. However, this capacity was not used yet in this first campaign. Measured parameters on board of METAIR-DIMO (left) and those that could be provided (carried) by ZHAW-UMARS in the near future (green: already done)**

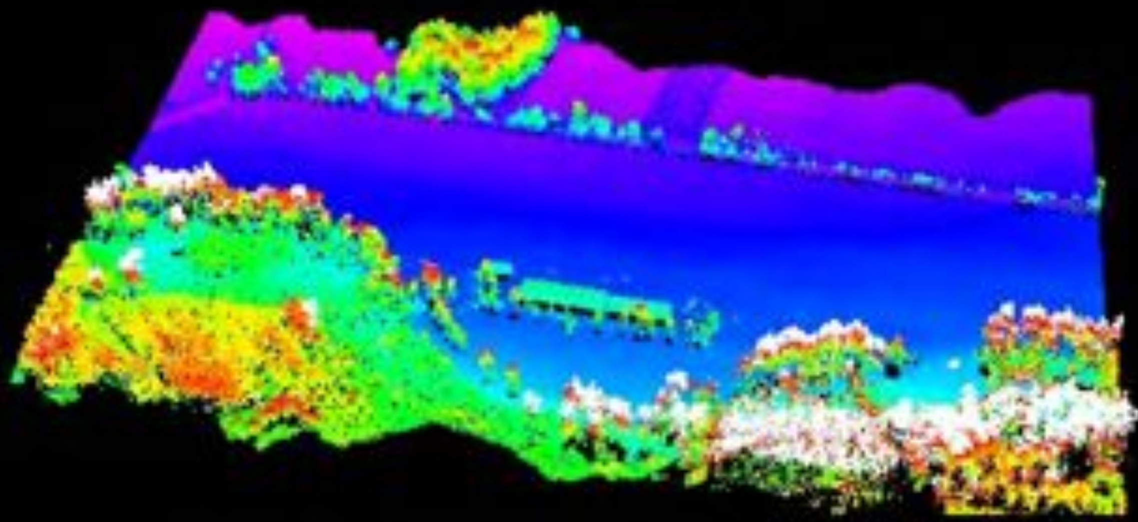
**That's what we promised:**
**Easy to handle.**

i.e. the same salaries as for the manned flights, with also the same efforts needed for the post-processing.

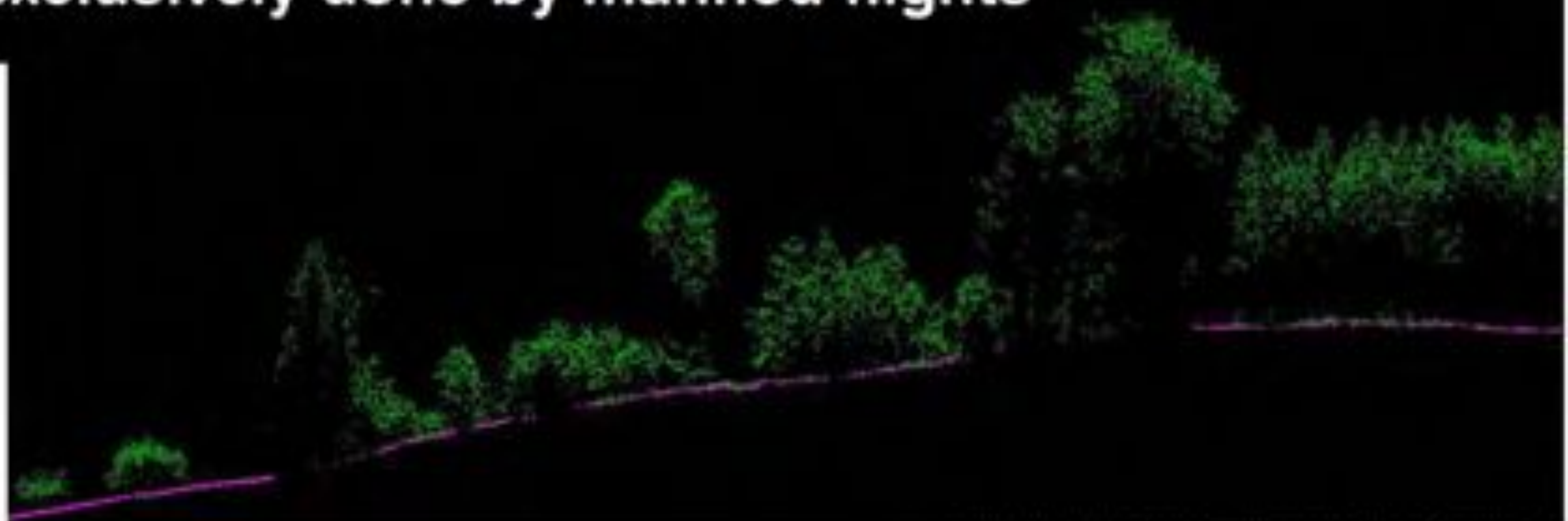
**And that's what we reached until now:**
**Two or three skilled and well trained people in the field.**

zh aw

# Our remote sensing applications until now …

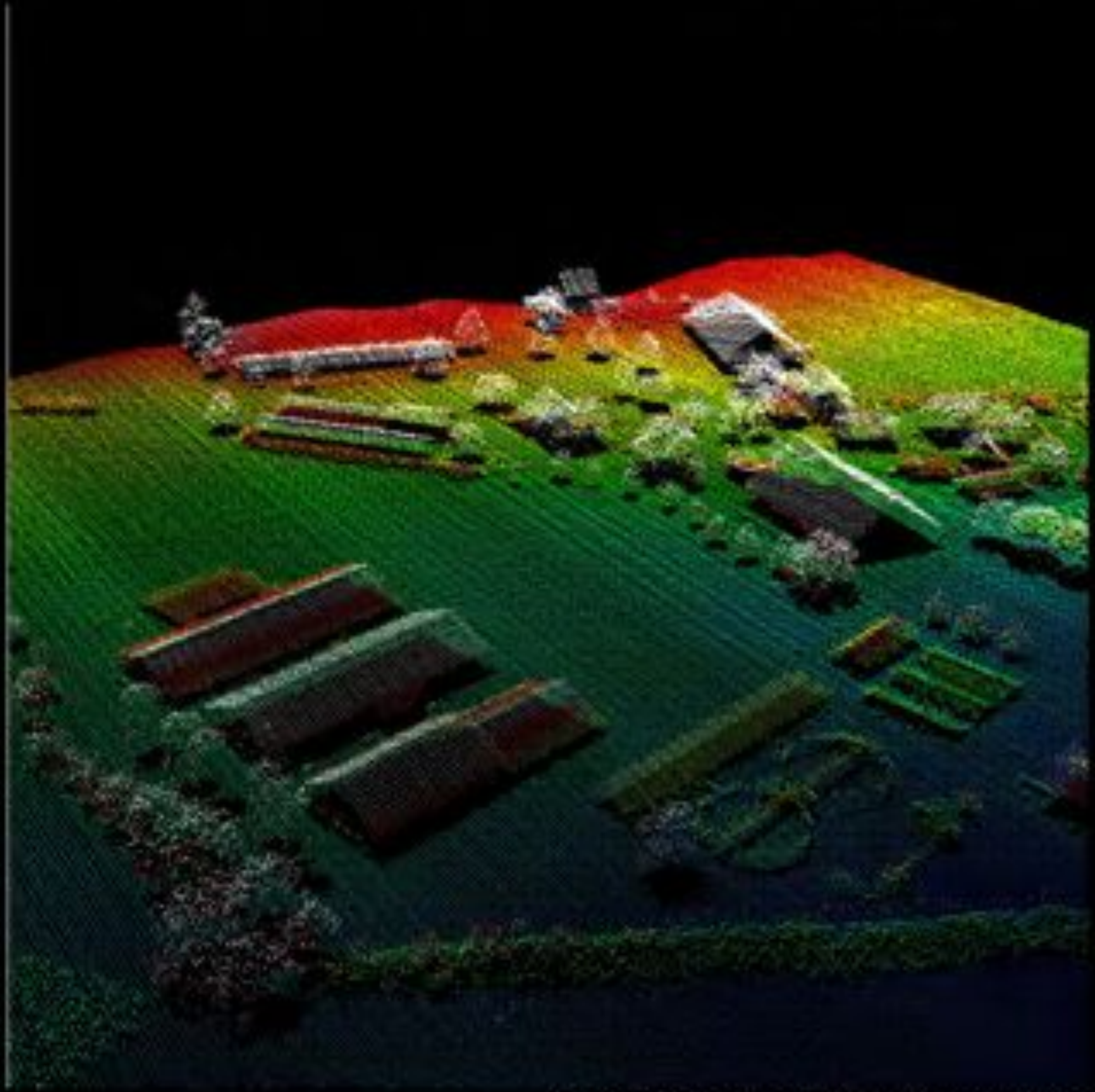


… were exclusively done by manned flights

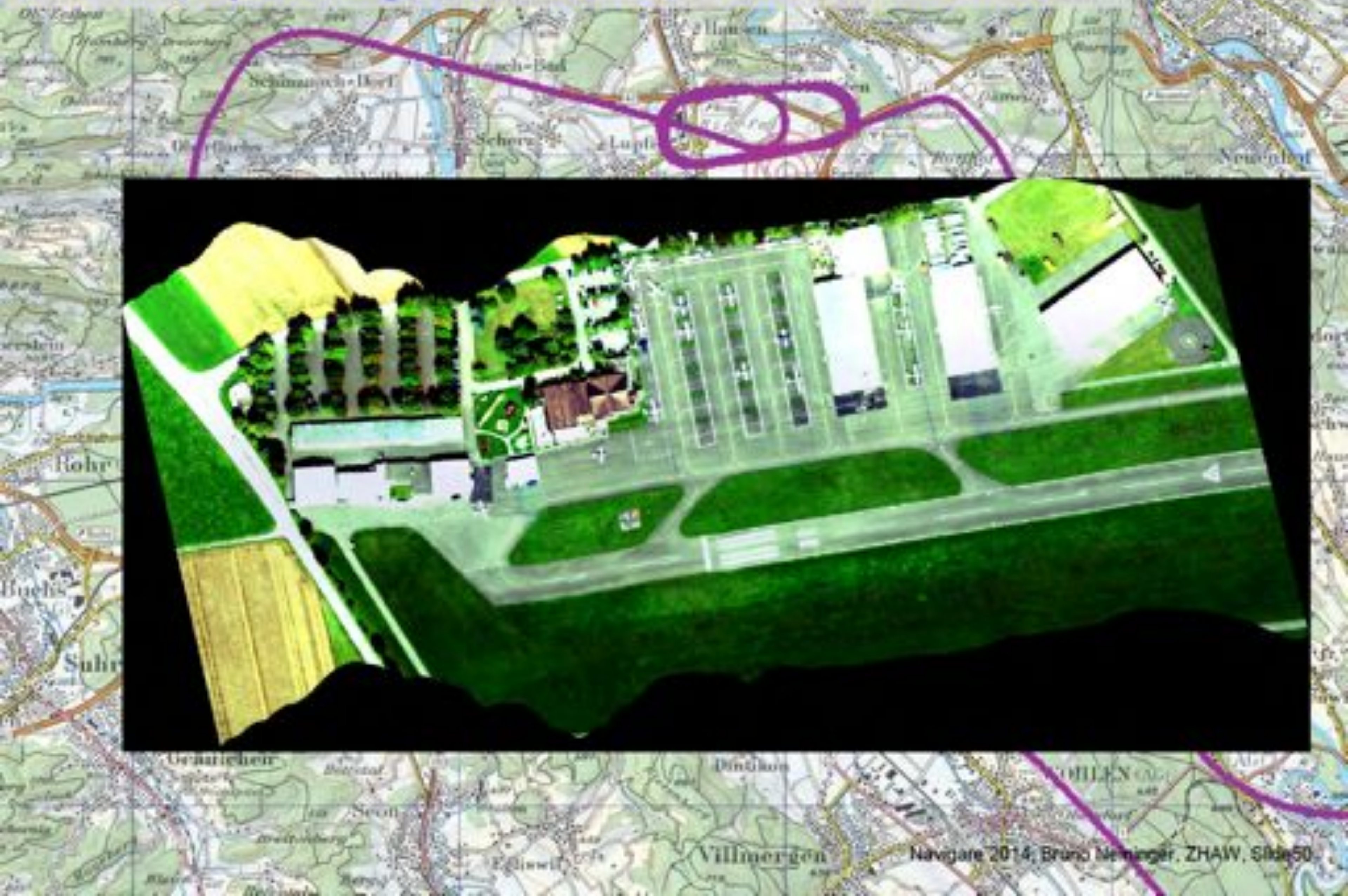


# ARA / Flinders, METAIR and

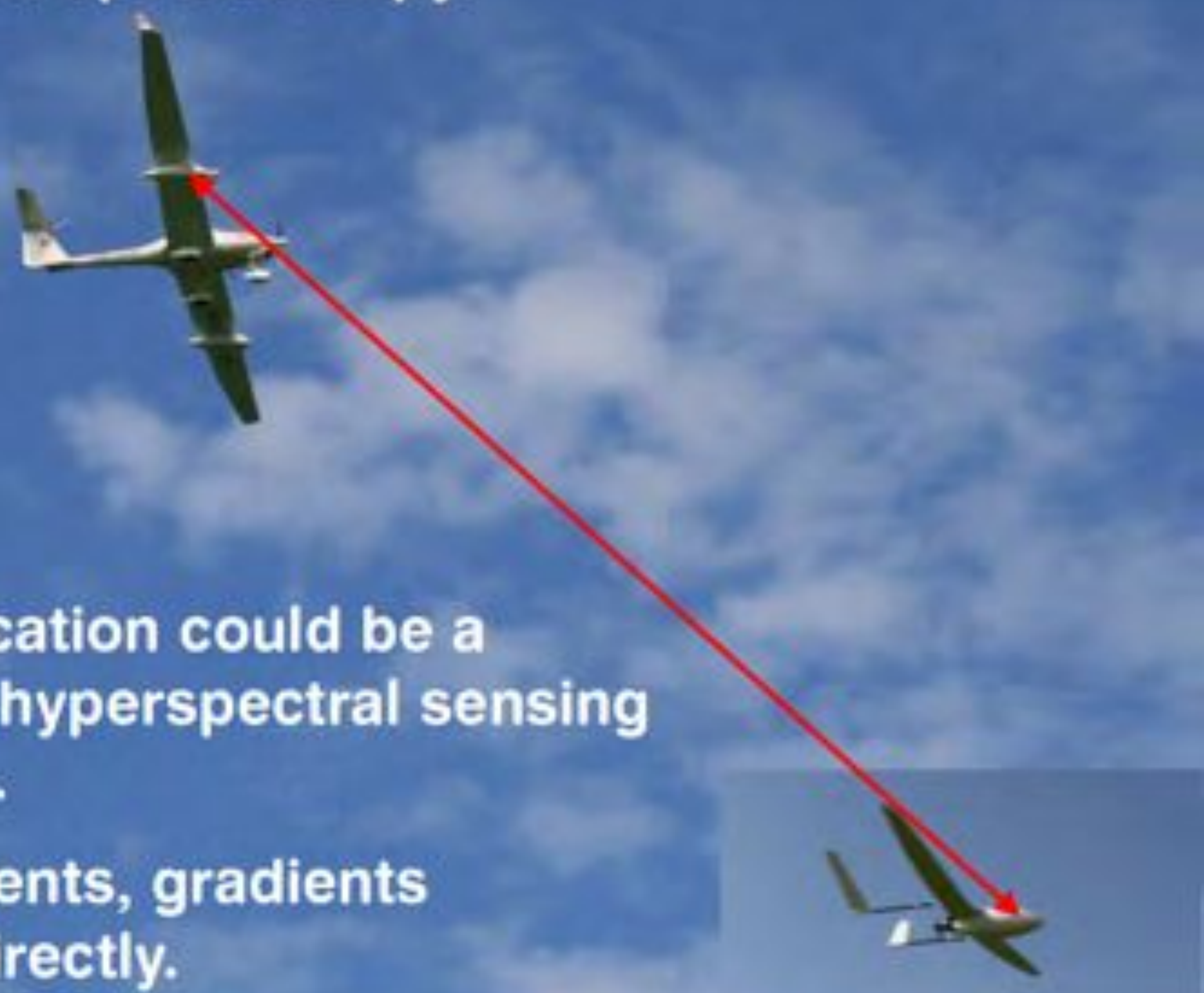
This was
a Laser Scan
of the research area
Chamau / Reuss Valley
we have made
with RIEGL Q560
from ARA
on METAIR-DIMO
in August 2008



# And this was a demonstration during UAV-g 2011 in Birrfeld, operating the ‘EAGLET’ for the first time



## Outlook:
## The RPAS as passive reflector or active device (e.g. with a special light source) in order to use DOAS or other types of spectroscopy.



**Another optical application could be a «flying reference» for hyperspectral sensing of the earth's surface.**

**For in-situ measurements, gradients could be measured directly.**

**Therefore, we think, that one should check at least the following criteria before developing or investing in a UAV application:**

- ✓ Is the spatial scale adequate?
  Within the $km^2$ is fine, while a larger scale is questionable.
- ✓ Air spaces involved (ATC)?
- ✓ Do I have a chance to fulfill the legal constraints?
- ✓ Is it a routine application with many repetitions?
- ✓ Is it dangerous or impossible to fly with a manned aircraft,
  but feasible with a UAV?
- ✓ What is the value of the payload and the risk to damage or destroy it?
- ✓ What is the time of the day and the weather when I need my application?
- ✓ Do I have the experience and the capacity to overlook and organize everything from the concept and then the path via the campaign(s) to the results?
- ✓ What's about costs? Ask an operator of manned aircraft and compare;
  you know now at least two, but can look into www.eufar.net for more.

## We think, that the following is possible and useful during the next few years:

- joint flight patterns independently controlled (as done in the Reuss Valley)
- testing UAV equipment in underwing pods
- development of automatic control to follow a manned aircraft
- using the UAS as a retro-reflector for spectrometric methods
- extending flights into the night (mainly meteorology – less an issue for geomatics)
- near-field of measuring stations (mainly met. & chem. as well)

**Those who like UAV's mainly because they can apply their know-how and skills for robotics could help to extend the scope for cost-effective manned airborne applications, rather than trying to replace them all. (It's not because I like to fly – it's by rational reasoning.)**


*(photo Marc Gerber, ZHAW)*