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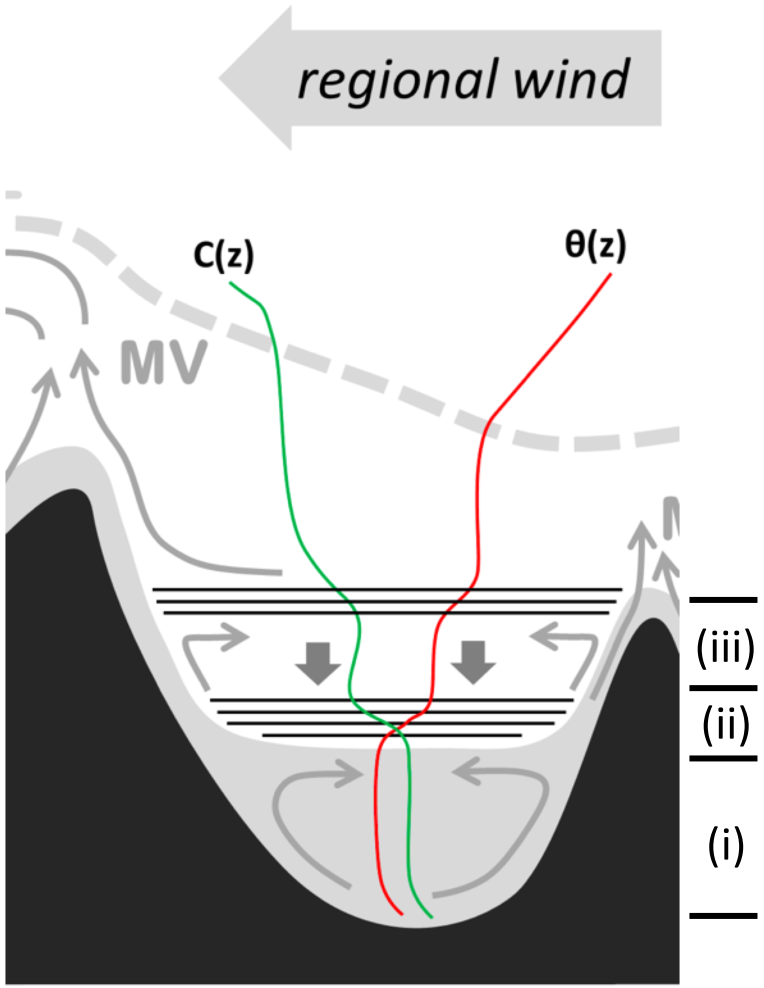
CIRES

The CROSSINN Field Campaign on the Three-Dimensional Flow Structure in the Inn Valley, Austria: Overview and Selected Results

Bianca Adler, Alexander Gohm, Norbert Kalthoff, Nevio Babić, Manuela Lehner, Mathias W. Rotach, Maren Haid and many others

Atmospheric boundary layer (ABL) structure in a valley during daytime



Serafin et al. 2018, Atmosphere

When thermally driven flows are dominant:

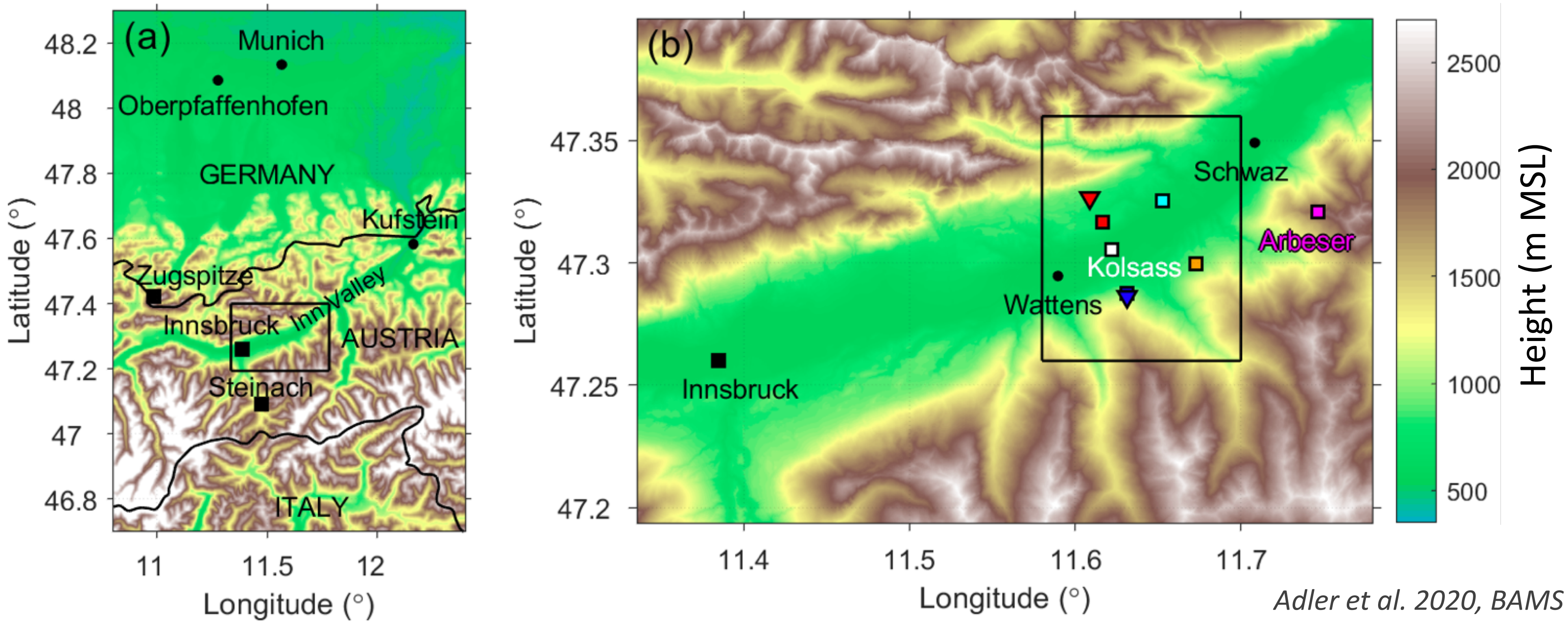
- Three-layer thermal structure with lower (i) and upper (iii) well-mixed layer separated by inversion (ii)
- Likely caused by two vertically stacked circulations cells which form due to partial redirection of the upslope flow towards the valley center when stability increases with height

Observational studies under fair weather conditions mainly based on profile and aircraft measurements

→ **Continuous area-wide measurements of the flow field in valleys under different large-scale conditions still rare**

Motivation for **CROSSINN** (Cross-valley flow in the Inn Valley investigated by dual-Doppler lidar measurements) field campaign in 2019 (August-October)

Investigation area: Inn Valley in the Tyrolean Alps, Austria



Adler et al. 2020, BAMS (under review)

- Well suited from scientific point of view, e.g. layered ABL structure, thermally driven circulations (Vergeiner and Dreiseitl 1987, MAP)
- About 2 km deep, valley floor 2-3 km wide, ridge-to-ridge distance about 20 km → can be captured with ground-based Doppler lidars and probed by research aircraft in cross-valley direction
- Existing network of surface flux towers (i-Box, Rotach et al. 2017, BAMS) and good infrastructure

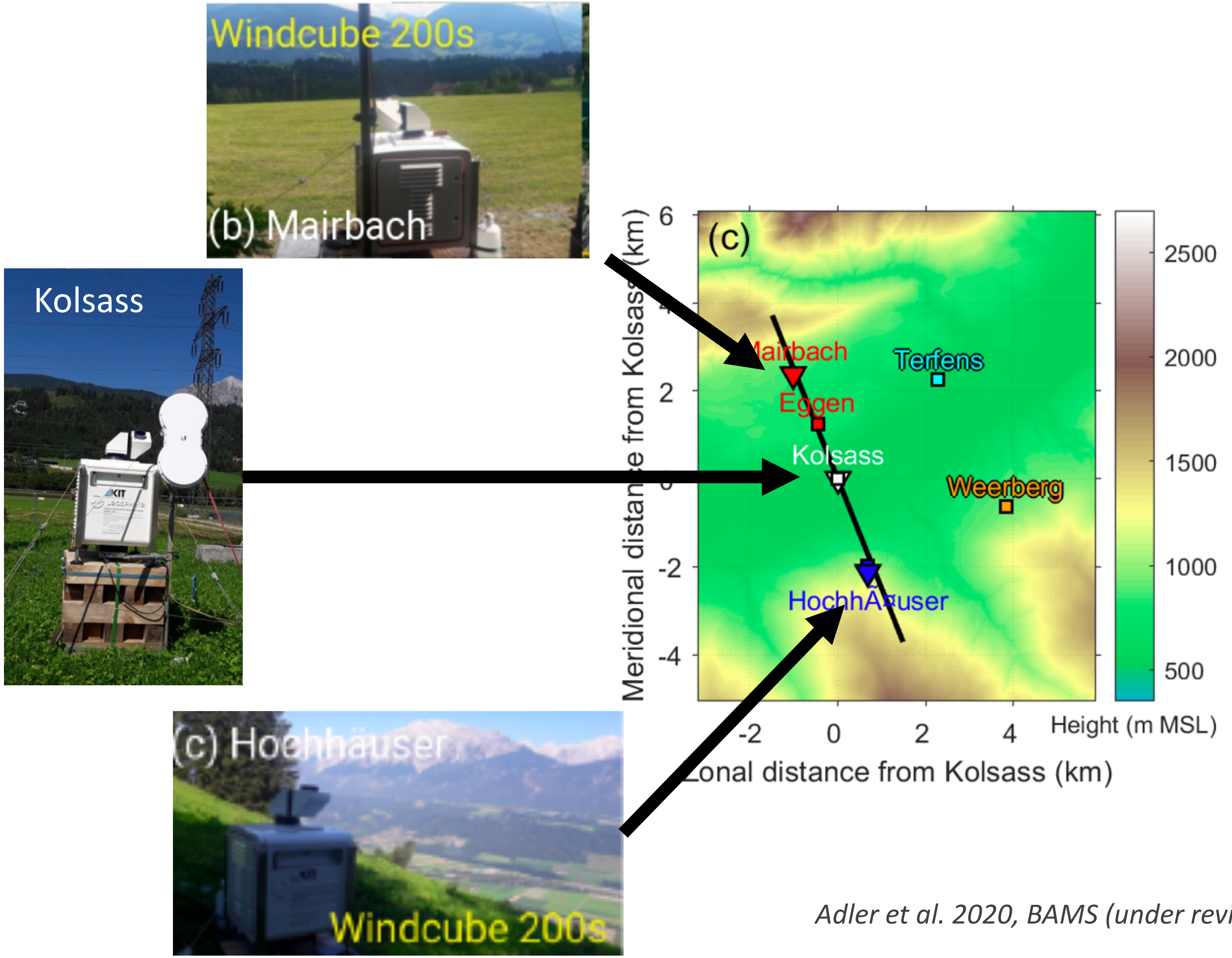
CROSSINN project– research questions and approach

<u>1. Kinematic flow structure</u>

- Spatial flow structure across the valley
- Variability along the valley axis
- Relationship between across and along valley flow

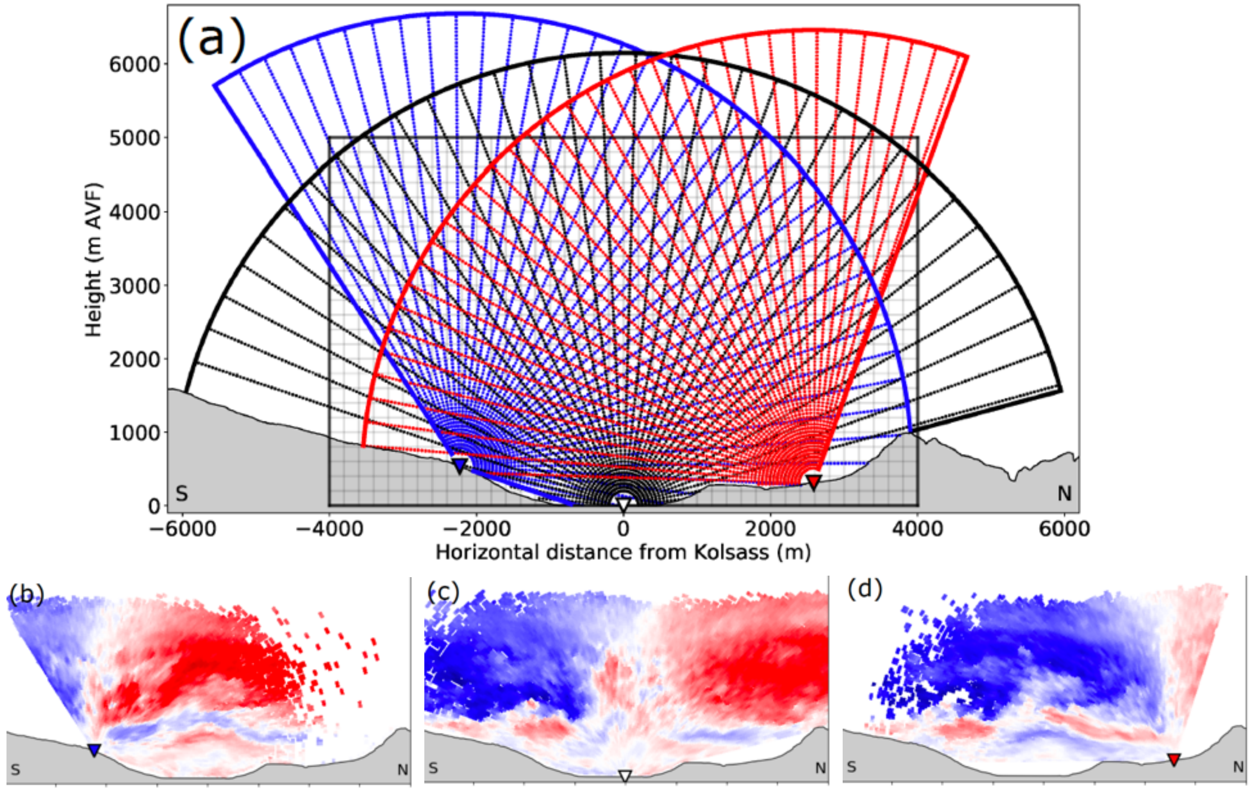
Doppler lidars:

- synchronized vertical scans across the valley
- horizontal and vertical wind profiles in valley center
- near-horizontal scans for horizontal variability



Adler et al. 2020, BAMS (under review)

Retrieval of the two-dimensional wind across the valley



- Coplanar radial velocity fields from synchronous vertical scans from 3 lidars
- Duration 60 s
- Range gate length 50 m

- Radial velocity, *rv*, is projection of 3D wind vector, ***v***, on lidar beam direction:

$$
\begin{aligned}
rv &= \hat{\boldsymbol{r}} \cdot \boldsymbol{v} \\
&= u \cos el \sin az + v \cos el \cos az + w \sin el \\
&= u_v \cos el + w \sin el = \widehat{\boldsymbol{r}_v} \cdot \boldsymbol{v}_v
\end{aligned}
$$

- Cartesian grid with lattice length *Δl*=50 m
- For each grid point:

i. Assign *N* *rv* values from 3 lidars within $R = \Delta l/\sqrt{2}$

ii. System of *N* linear equations is solved by minimizing cost function:

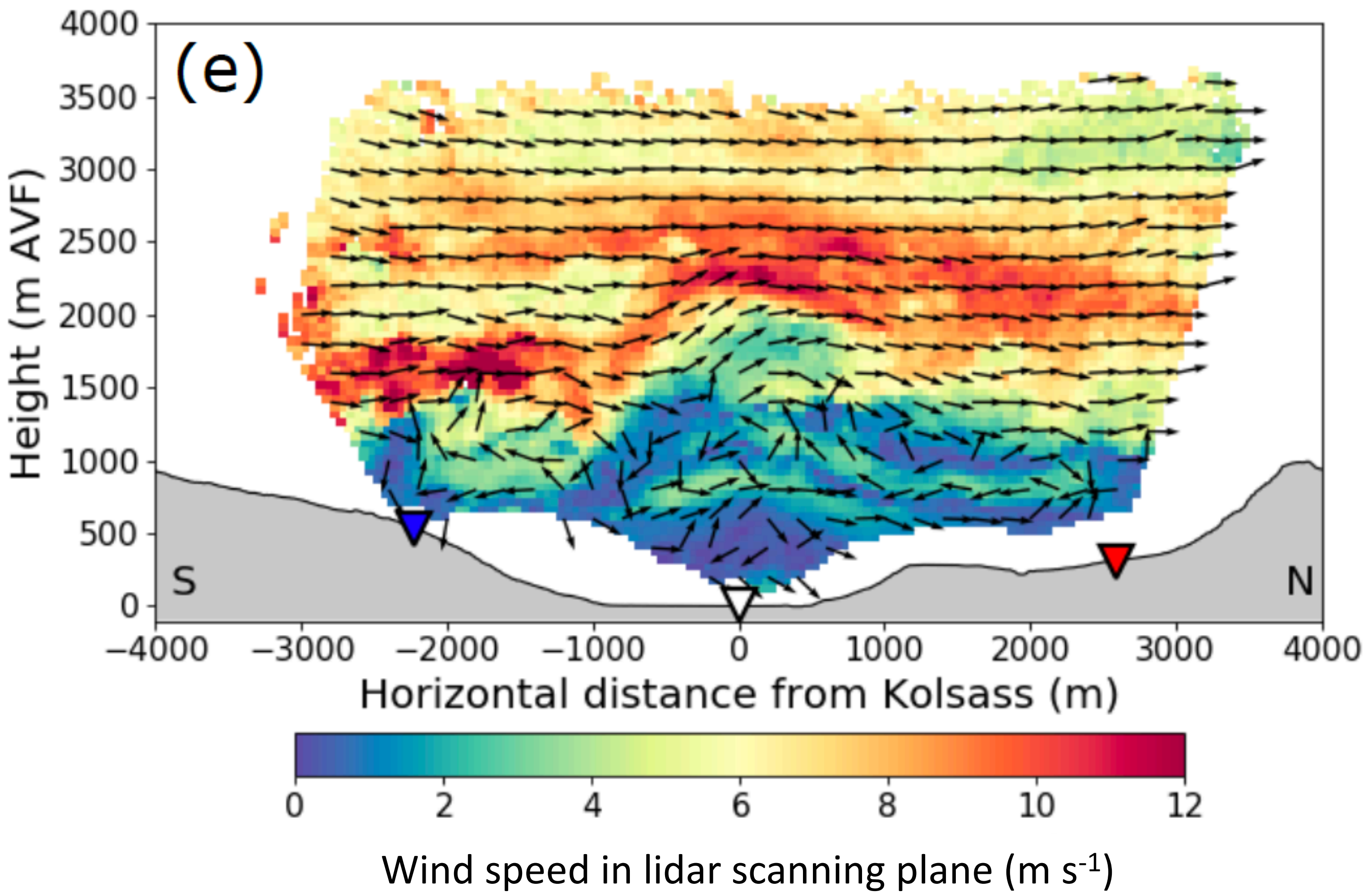
$$J = \sum_{n=1}^{N} (rv_n - \hat{\boldsymbol{r}}_{v,n} \cdot \boldsymbol{v}_v)^2$$

iii. Intersection angles between 30 and 150 degree

→ Two-dimensional wind field in a vertical plane across the valley (area around 6 km x 3 km)

Adler et al. 2020, BAMS (under review)

Example of retrieved two-dimensional wind field



Adler et al. 2020, BAMS (under review)

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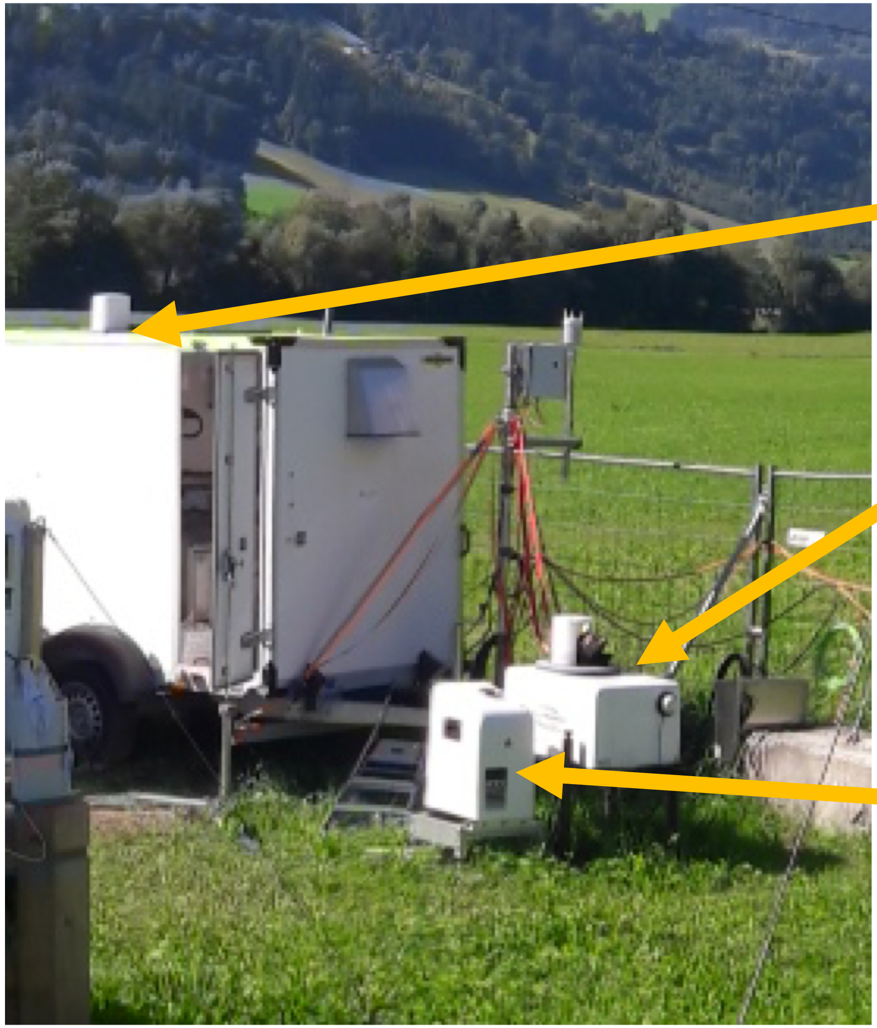
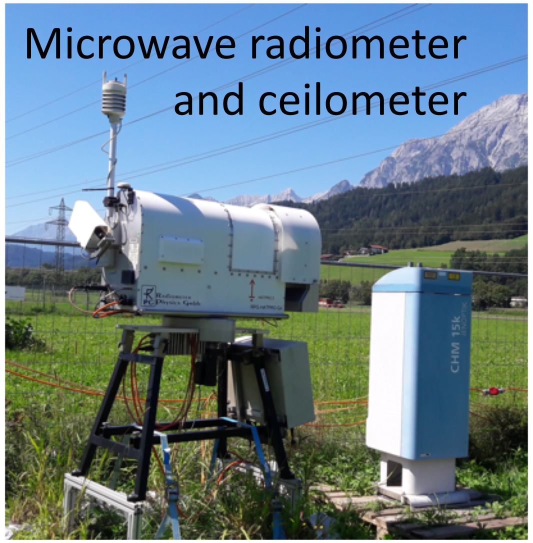


Stream Line XR
- Vertical wind profiles
- VAD every 30 min
- Low-elevation PPI

Stream Line
- Continuous VAD

Wind Ranger (Metek)
- Continuous VAD for 3D wind profiles (<10 – 100 m)

CROSSINN project– research questions and approach



Microwave radiometer and ceilometer

Temperature lidar

2. Impact of the flow on ABL

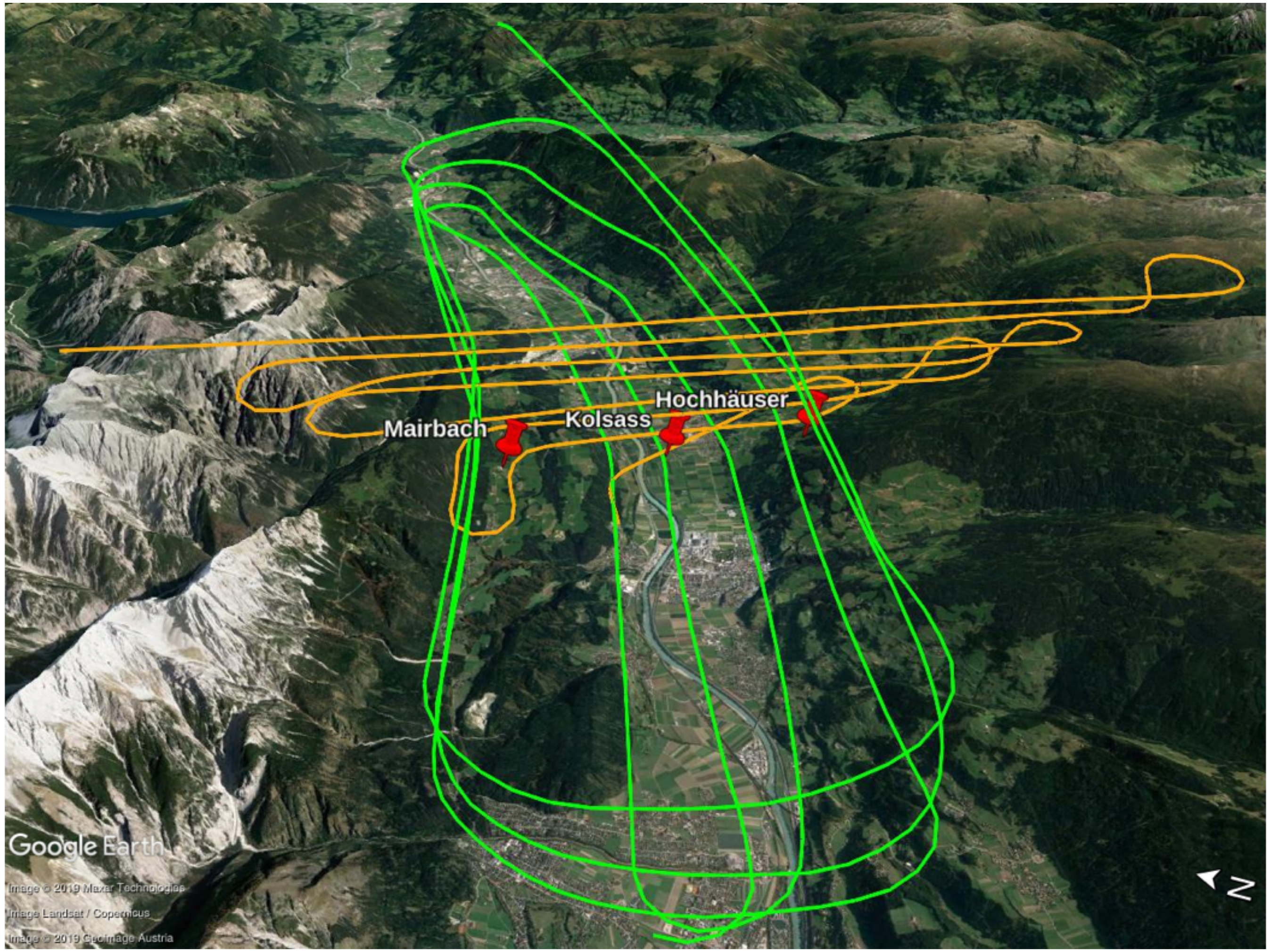
- ABL characteristics (e.g. stratification, layering, turbulence)
- ABL depth

- Microwave radiometer, temperature lidar for thermodynamic profiles
- Ceilometer for clouds and backscatter profiles
- Radio soundings
- Research aircraft


Radiosonde


DLR Cessna Grand Caravan 208b

Flight pattern of DLR Cessna Grand Caravan



- Combination of cross-valley (orange) and along-valley pattern (green)
- Each pattern twice per flight
- 2 flights per day

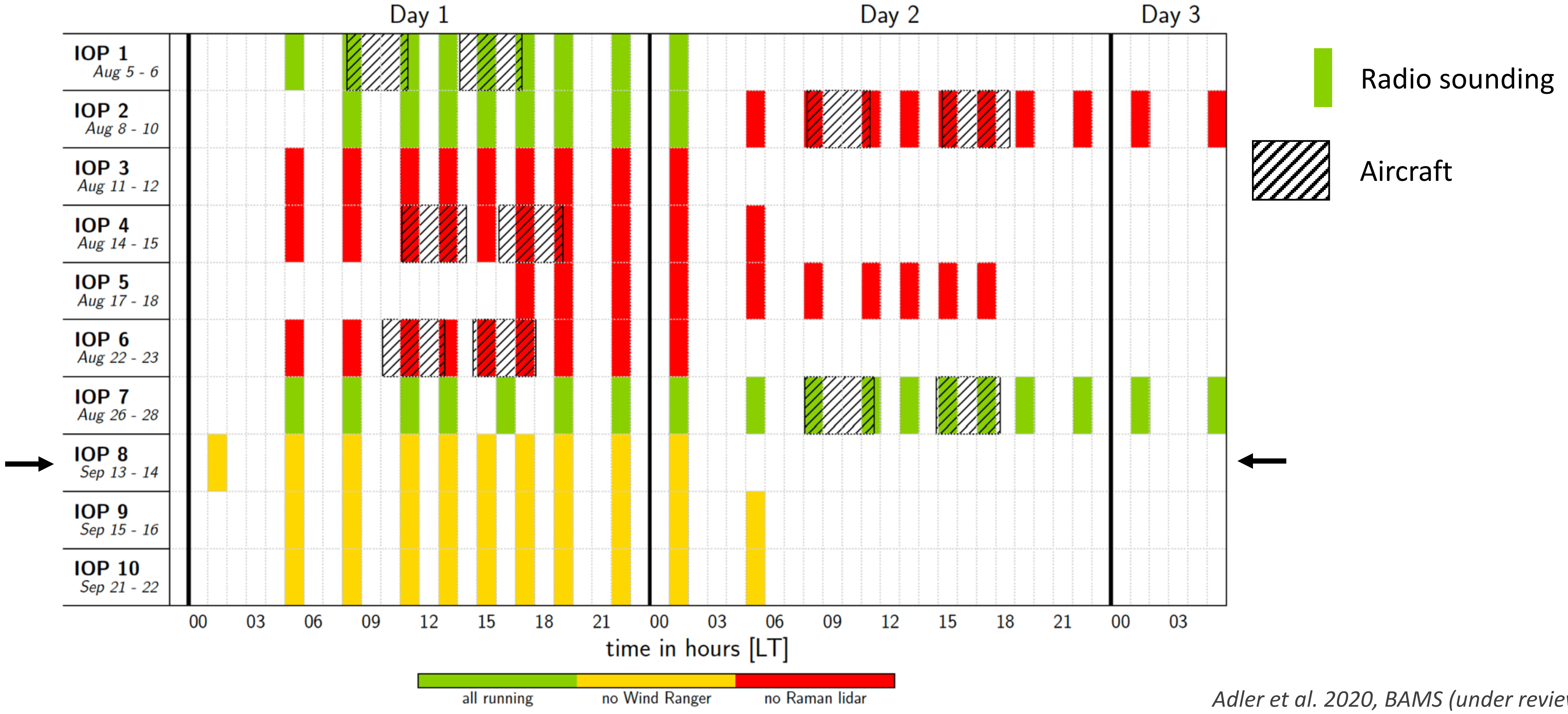
CROSSINN project– research questions and approach

3. Synoptic scale and surface impacts

- Dependence on large-scale conditions and surface energy exchange
- Interaction with foehn

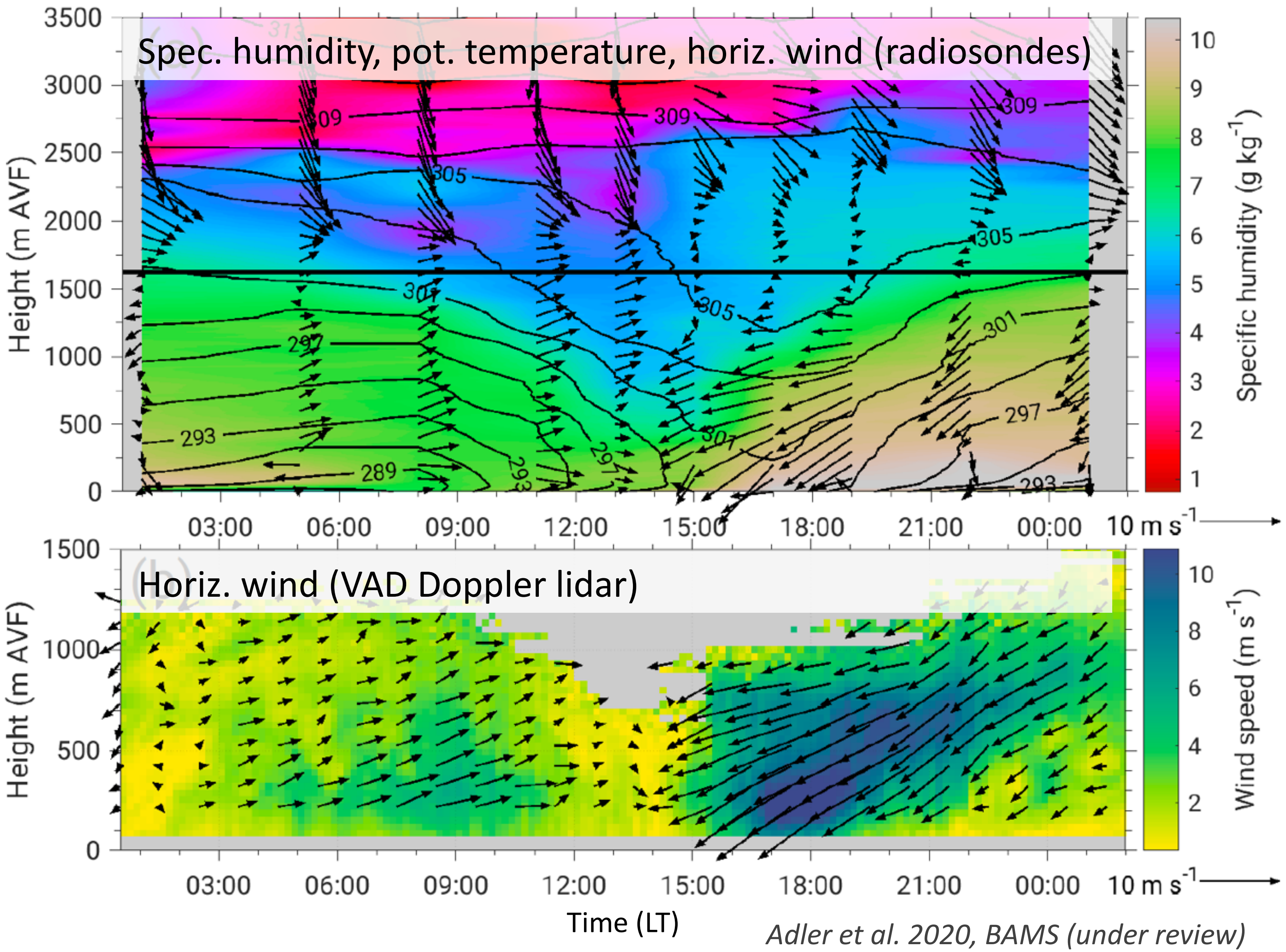
- Mountain top synoptic stations
- Operational radiosondes
- Surface flux towers

IOP overview



Adler et al. 2020, BAMS (under review)

Evolution of the vertical ABL structure in the valley center (IOP 8)



Adler et al. 2020, BAMS (under review)

Nighttime and morning:

- valley atmosphere stably stratified
- Downvalley wind until noon

Daytime:

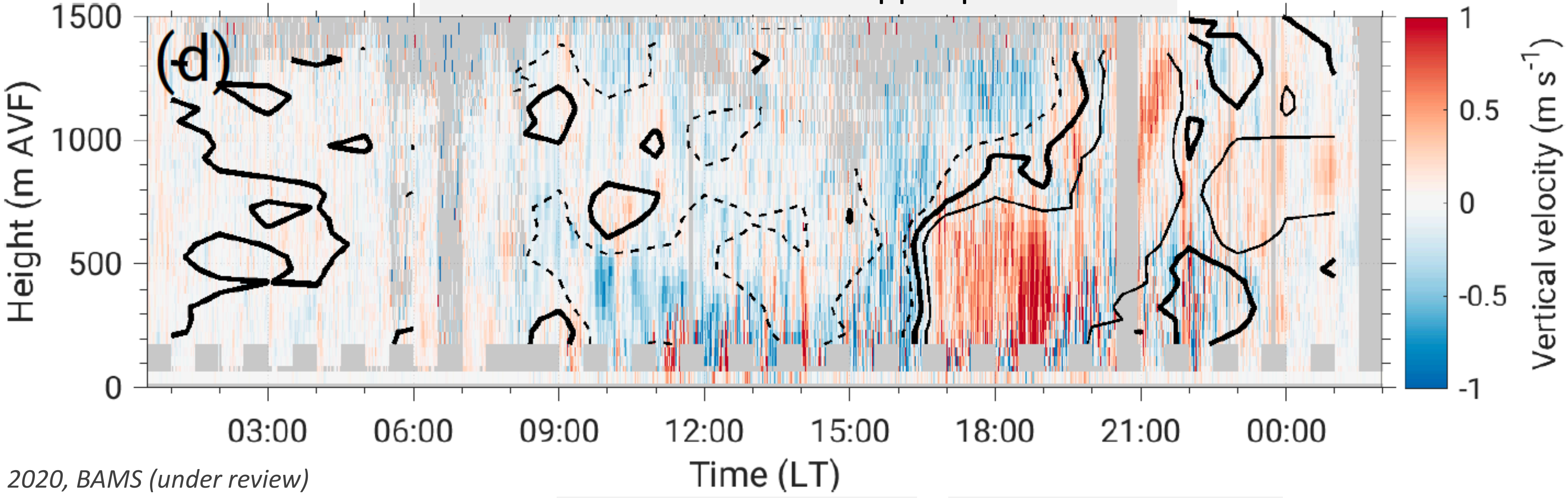
- Three-layer structure
- Dry air with low backscatter subsides into valley
- Upvalley wind after 14 LT (moist air with higher backscatter)

Evening:

- surface inversion forms and upvalley wind lifts

Vertical velocity in the valley center from Doppler lidar

Weak mean subsidence in upper part of ABL



Adler et al. 2020, BAMS (under review)

Convection in lower part of ABL

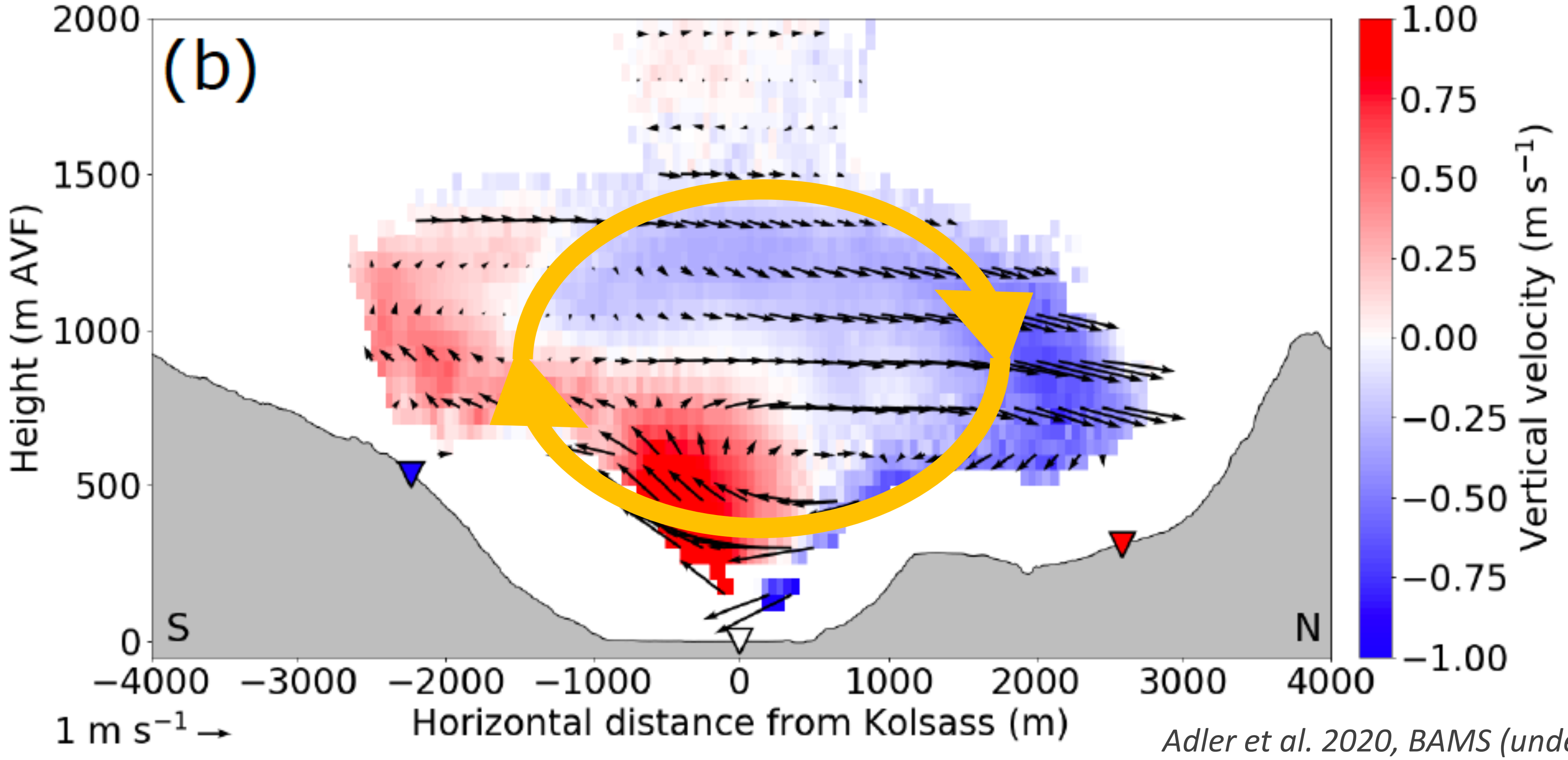
Persistent strong upward motion

??

At odds with classical textbook pattern!

What causes the persistent upward motion in the early evening?

Vertical velocity across the valley from coplanar Doppler lidar scans

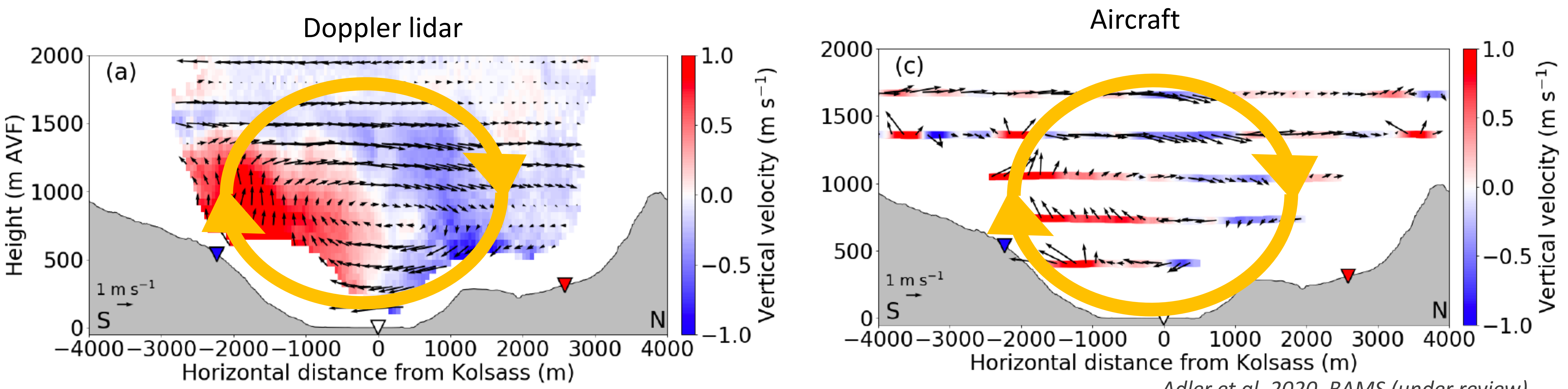


Adler et al. 2020, BAMS (under review)

- Closed circulation cell (vortex) with upward motion in southern part and downward motion in northern part of valley

Realistic?

Vertical velocity from Doppler lidar scans and aircraft (IOP 4)



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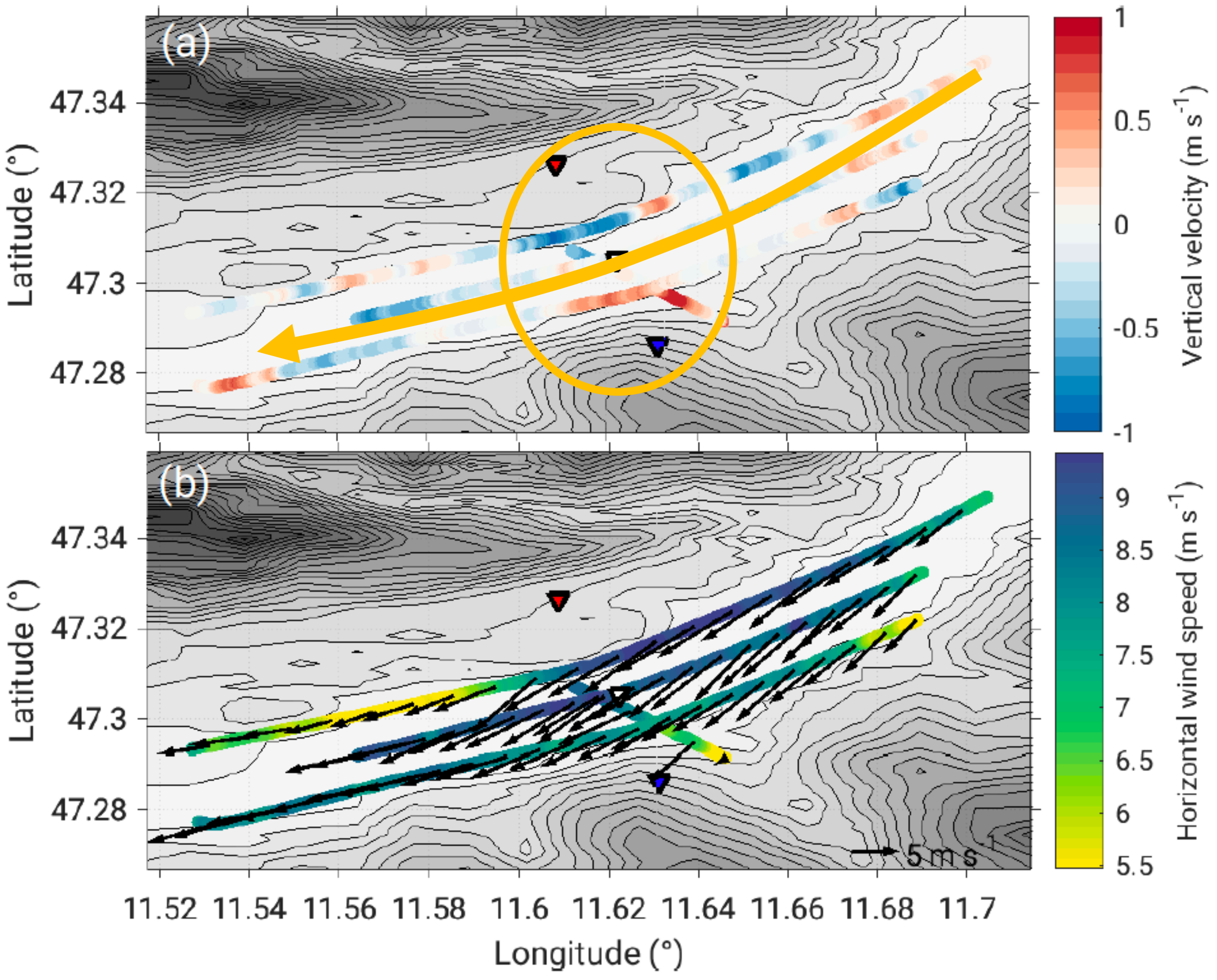
Aircraft measurements confirm closed circulation cell measured by Doppler lidar scans

Vertical velocity and horizontal wind along the valley



Adler et al. 2020, BAMS (under review)

- Vortices occur during upvalley wind
- Valley has slight curvature to the right in upvalley direction
- Upward motion in outer part of curve

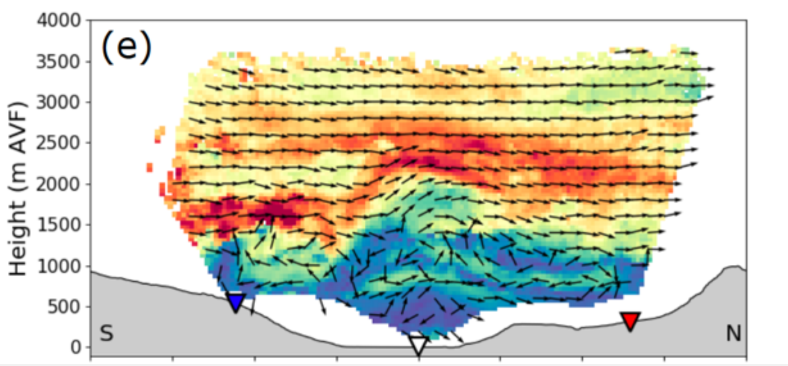
Further investigation:

- How regular are these cross-valley vortices?
- What are their characteristics?
- How do they relate to environmental conditions?
- What causes them?
- Differences to other cross-valley circulation observed in Riviera Valley (Weigel and Rotach, 2004, QJRS)?

Summary & outlook

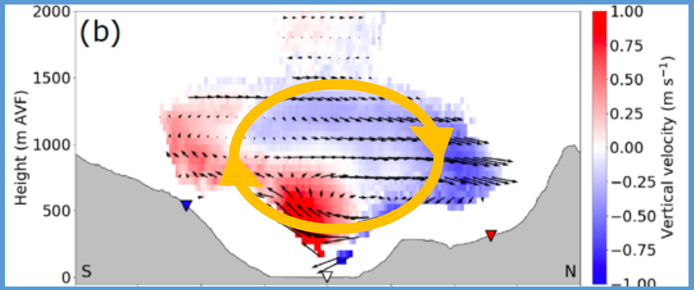
CROSSINN campaign

- 2.5-month long field campaign in the Inn Valley, Austria, with the aim to study the (i) **three-dimensional flow structure** and (ii) its **impact on the ABL** in the valley under **different synoptic conditions**
- Comprehensive set of ground-based in situ and remote sensing and airborne in situ measurements
- Continuous retrieval of the **two-dimensional wind field across the valley** with 3 scanning Doppler lidars



Cross-valley vortices

- Span the whole valley cross section
- Form regularly when the upvalley wind is strong
- Are related to valley curvature
- Depend on shape of upvalley wind profile



Outlook

- Continue data analysis of cross-valley circulation when (ii) thermally driven processes are dominant or (ii) foehn interacts
- High-resolution model simulations
- Facilitate planning of upcoming TEAMx field campaign (partly in Inn Valley)

Thank you for listening!

I am looking forward to your questions during the virtual conference or contact me directly at bianca.adler@noaa.gov

Inn Valley in Austria looking west