

TEAMx



## The TEAMx Observational Campaign

Manuela Lehner and Mathias W. Rotach

with contributions from many of the TEAMx participants

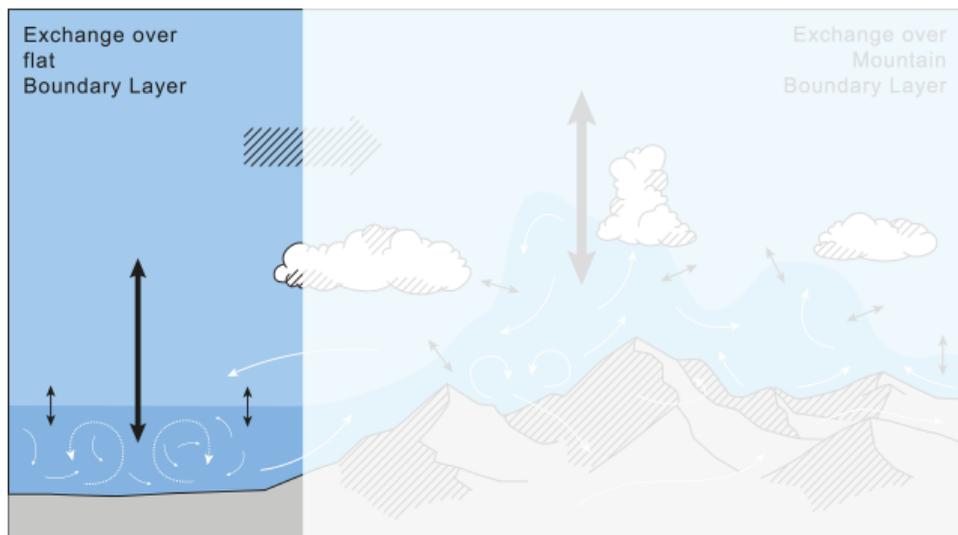
*ACINN Graduate Seminar, 12 November 2025*

# TEAMx

**Multi-scale transport and exchange processes in the atmosphere over mountains—programme and experiment**

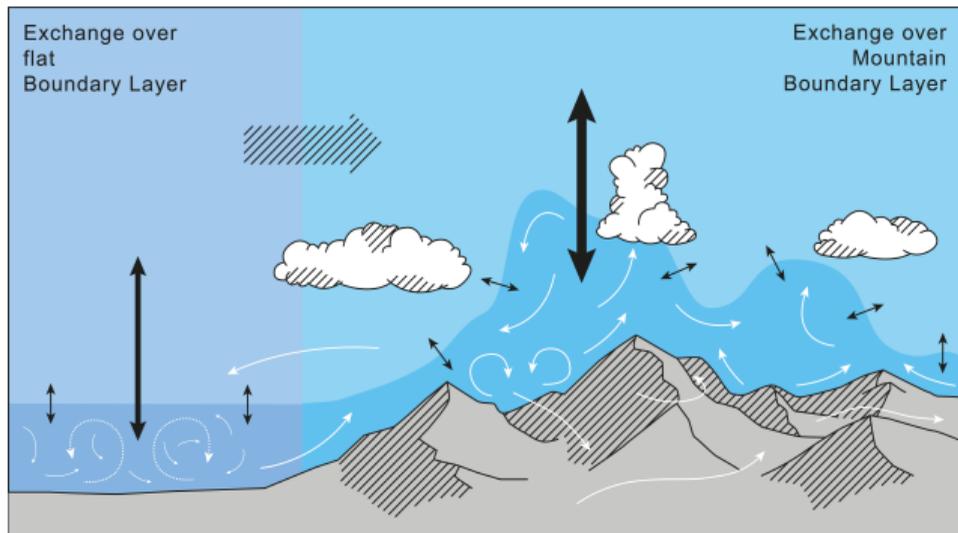
- ▲ international research programme with > 40 signatories of the TEAMx Memorandum of Understanding
- ▲ one-year long TEAMx Observational Campaign with > 25 participating institutions
- ▲ additional smaller measurement campaigns (e.g., HEFEX, PC22)

# Mountain Boundary Layer (MoBL)



- ▲ Horizontally homogeneous conditions
- ▲ Exchange due to vertical turbulent transport
- ▲ Turbulence parameterizations based on observations for flat and homogeneous terrain

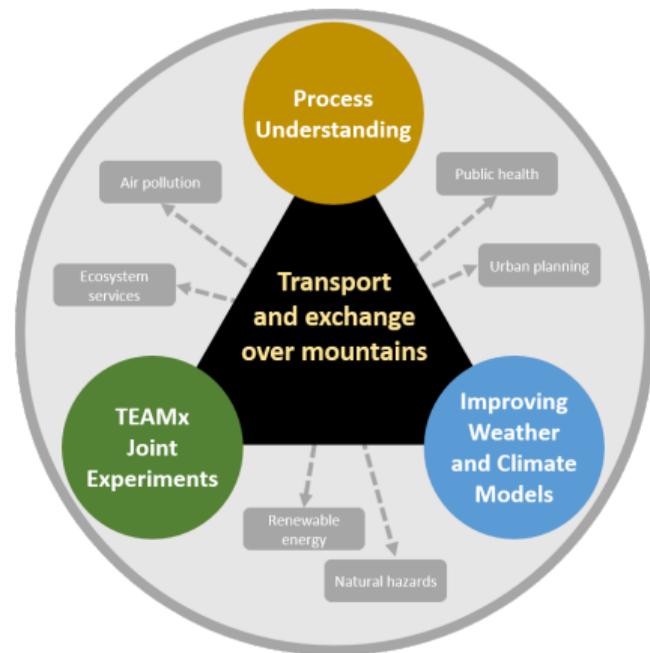
# Mountain Boundary Layer (MoBL)



- ▲ Wide range of scales
- ▲ Process interact
- ▲ 3D spatial variability
- ▲ Processes that are difficult to measure/model
- ▲ Questionable applicability of measurement/modeling techniques

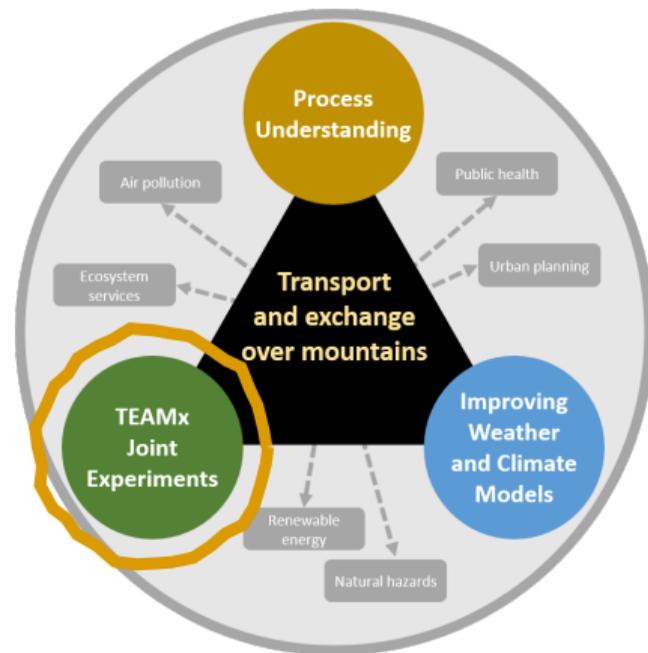
# TEAMx Goals

- ▲ Improving our understanding of transport and exchange processes between the surface and the atmosphere and within the atmosphere
- ▲ Evaluating and improving weather and climate models over complex terrain
- ▲ Collecting a unique dataset to study the transport and exchange processes
- ▲ Supporting weather and climate service providers

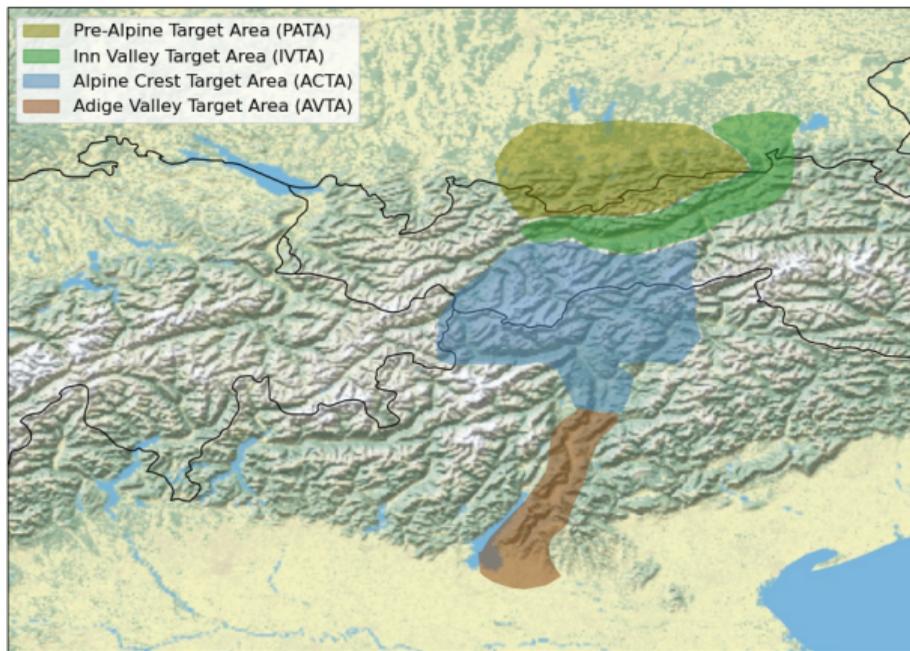


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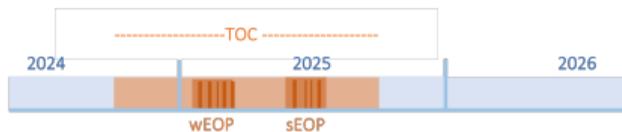
# TEAMx Observational Campaign (TOC)



## North-south transect through the Alps

- ▲ Pre-Alpine Target Area
- ▲ Inn Valley Target Area
- ▲ Alpine Crest Target Area
- ▲ Adige Valley Target Area

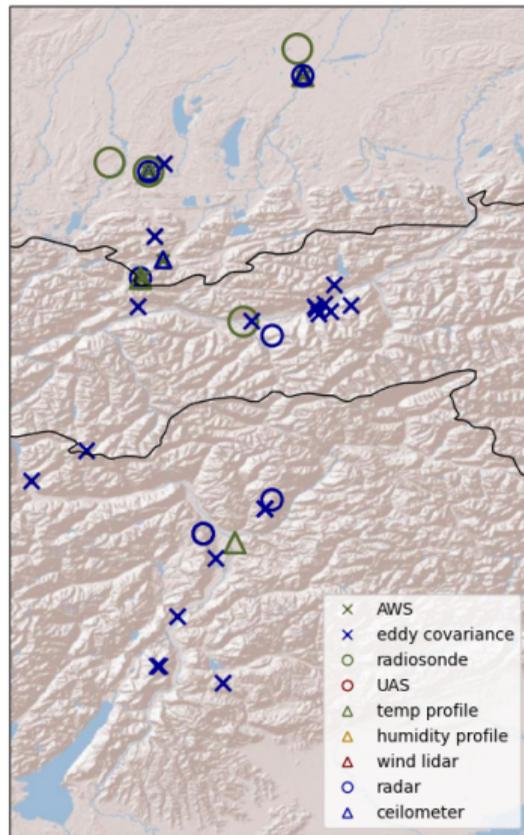
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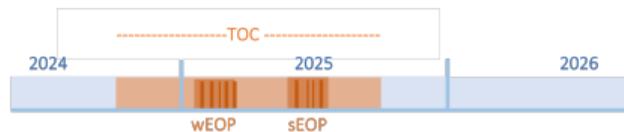
## One-year long TOC

- ▲ Observations over a longer timescale than most field campaigns
- ▲ Increase the density of the existing observational infrastructure

operational sites excluding AWS networks



# TEAMx Observational Campaign (TOC)



## One-year long TOC

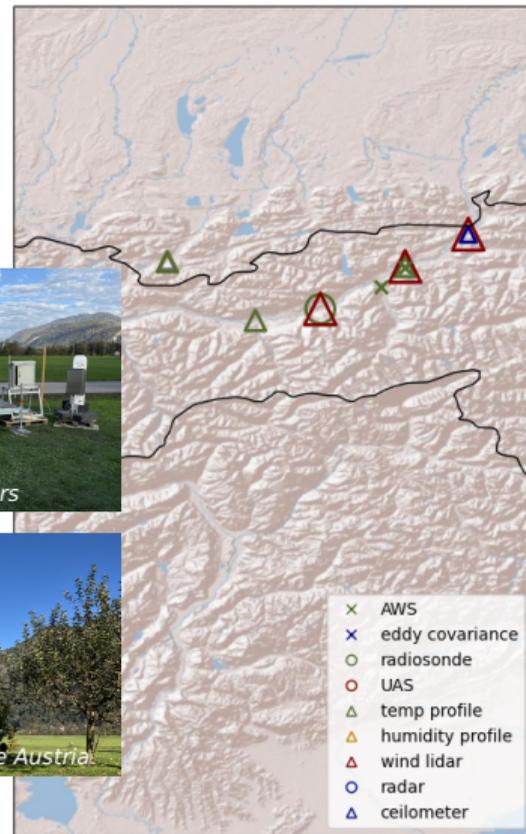
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Photo: B. Saunders

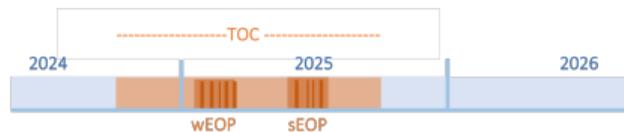


Photo: GeoSphere Austria



instruments deployed for the TOC

# TEAMx Observational Campaign (TOC)

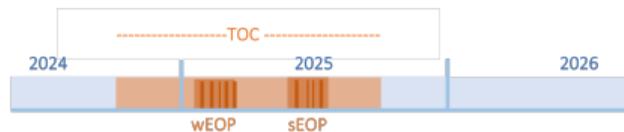


## Extended Observational Periods

▲ Focus on individual processes

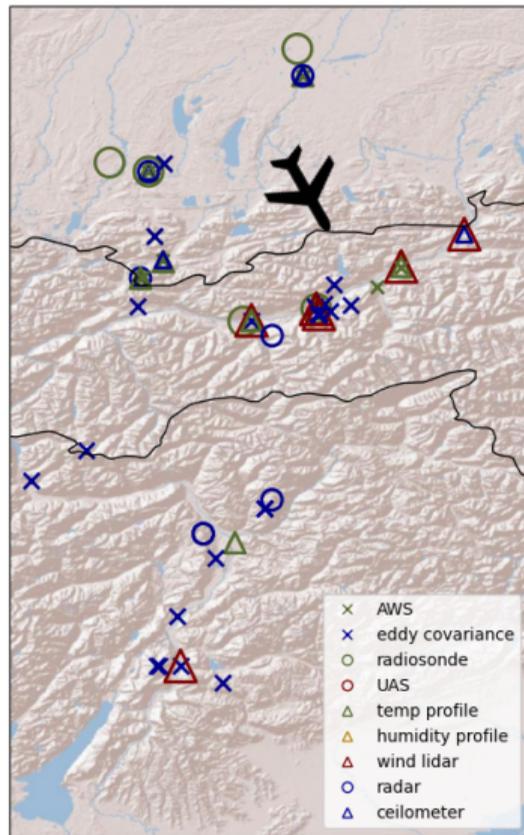


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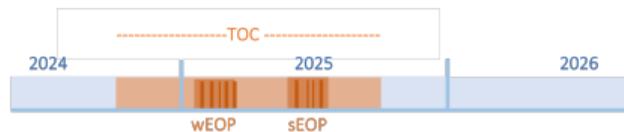


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- ▲ Winter EOP (wEOP): 20 Jan–28 Feb

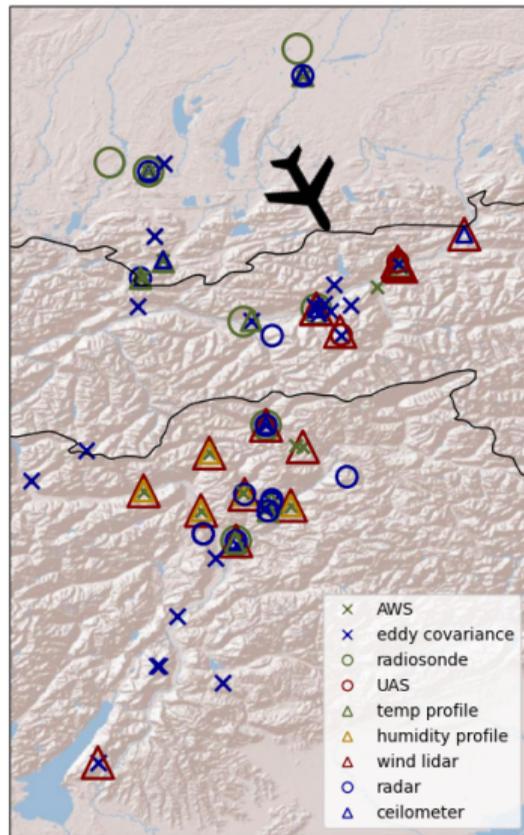


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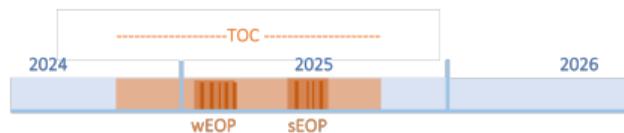


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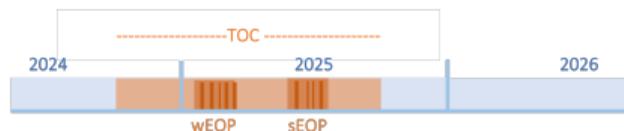


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## 3 research aircraft

- ▲ NCAS FAAM BAe146
- ▲ DLR Cessna Caravan
- ▲ TU Braunschweig Cessna F406



# ACINN activities during IOPs



# Daily weather briefings

- ▲ Daily meetings during the EOPs
- ▲ Weather briefings by four **ACINN student forecasters** (Leo Schlagbauer, Stefan Müller, Loren Schäffler, Andreas Friesinger)
- ▲ **Scientists in Charge** leading the meetings and compiling IOP summaries and information on the status of field instrumentation



Photo: D. Anderson

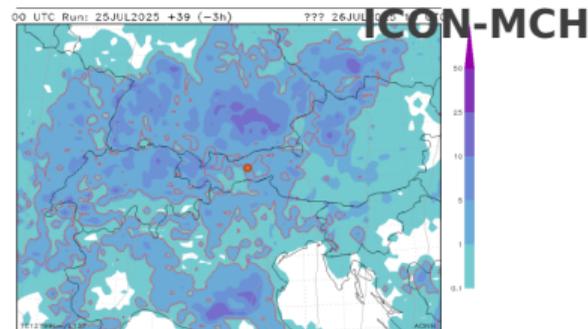
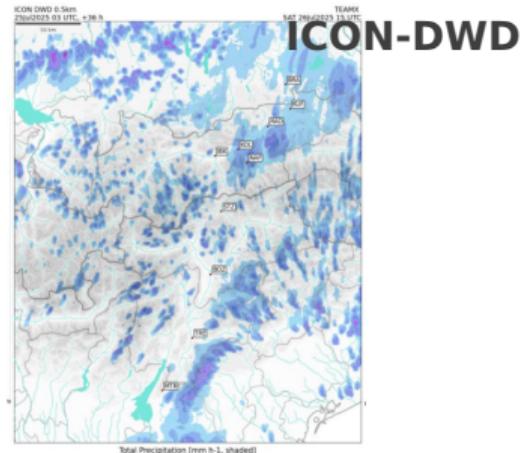
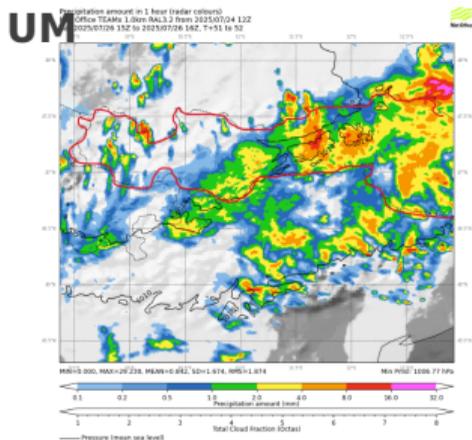


Photo: M. Lehner

# High-resolution NWP forecasts

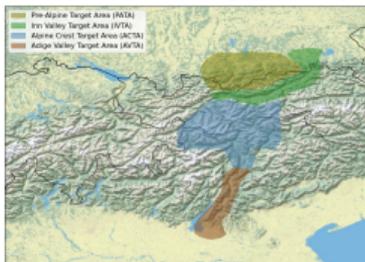
Daily forecasts supported by

- ▲ 500-m ICON runs from DWD
- ▲ 1-km ICON runs from Meteo Swiss
- ▲ 1-km UM runs from the Met Office

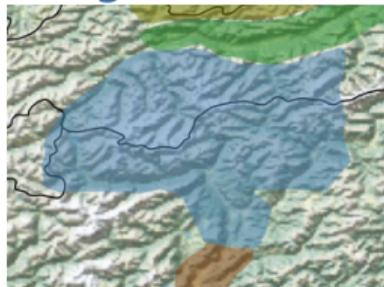


# Multi-scale processes

## Alpine scale



## Regional scale



## Valley scale



## Local scale



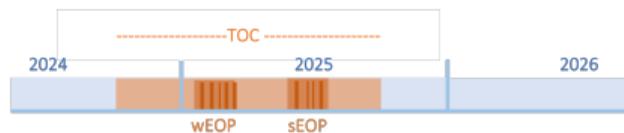
- ▲ Mountain waves
- ▲ Mountain-plain wind

- ▲ Orographic convection
- ▲ Foehn

- ▲ MoBL structure
- ▲ Valley winds
- ▲ Mountain venting
- ▲ Fog/low stratus

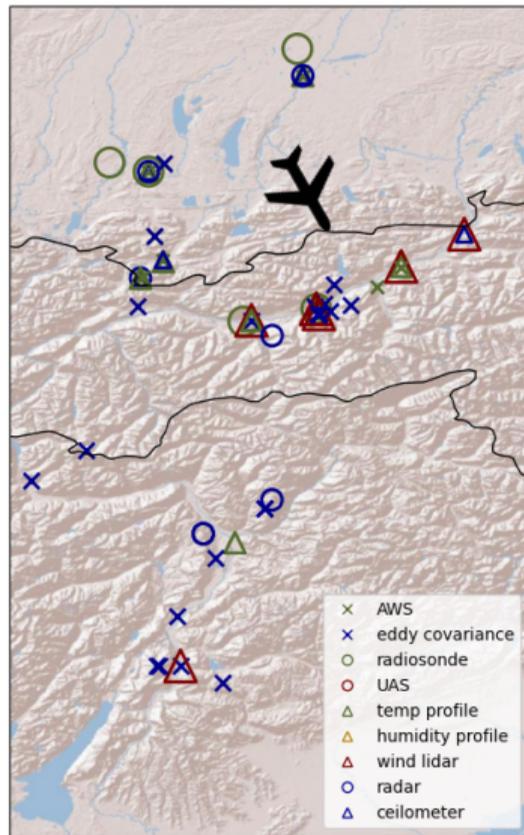
- ▲ Slope winds
- ▲ Turbulence

# Winter EOP (wEOP)

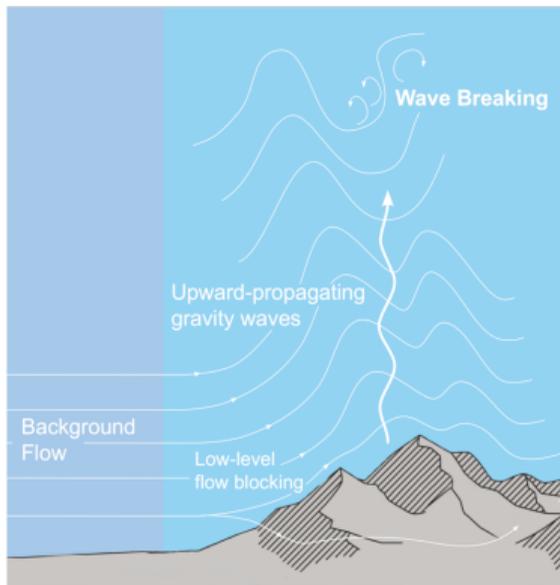


## Extended Observational Periods

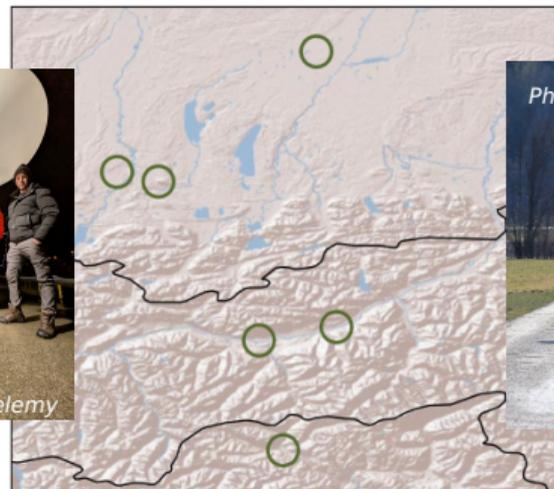
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# Gravity waves



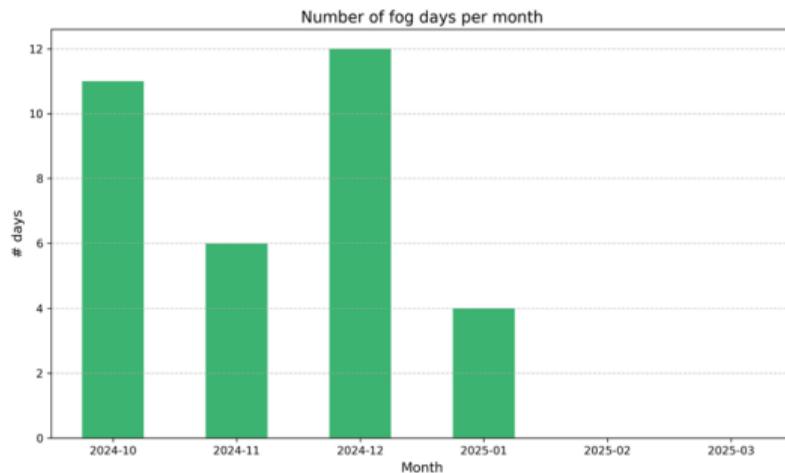
*Credit: Andrew Orr*



- ▲ Improve process understanding (especially gravity-wave drag)
- ▲ Improve understanding of how drag is resolved and parameterised in NWP and climate models at all scales

# Fog and low stratus

Karlsruhe Low-Cloud Exploratory Platform (KLOCX): Life-cycle phases of **low-level stratiform clouds and fog**



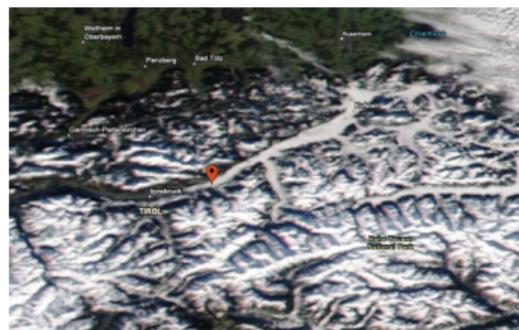
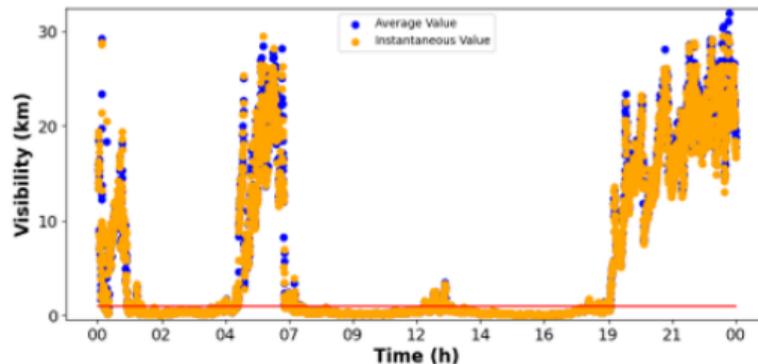
*Credit: Jutta Vüllers*

# Fog and low stratus

Karlsruhe Low-Cloud Exploratory Platform (KLOCX): Life-cycle phases of **low-level stratiform clouds and fog**



Case study—17 Dec 2024



Credit: Jutta Vüllers

# wEOP: Katabatic winds over a snow-covered slope



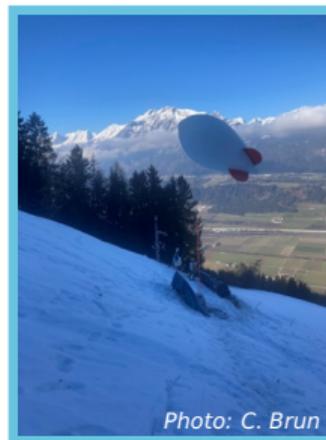
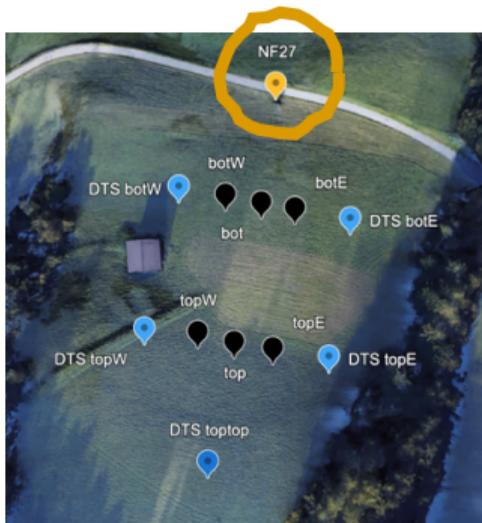
3D structure of **mean and turbulent flow properties**



*Credit: I. Stiperski, A. Gohm, L. Pfister, C. Brun*

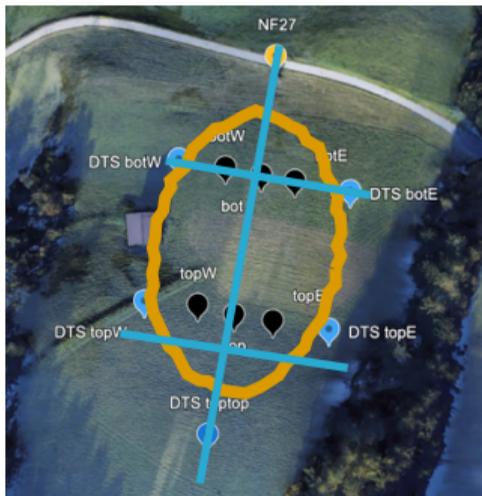
# wEOP: Katabatic winds over a snow-covered slope

## Vertical profiles



*Credit: I. Stiperski, A. Gohm, L. Pfister, C. Brun*

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## Spatial structure

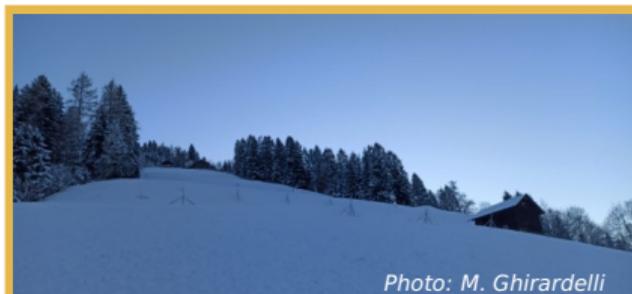
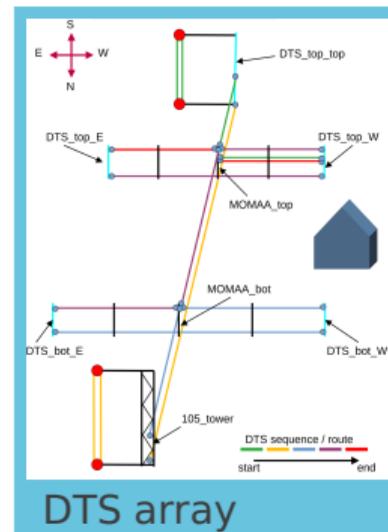


Photo: M. Ghirardelli

Station network



Credit: I. Stiperski, A. Gohm, L. Pfister, C. Brun

# wEOP: Katabatic winds over a snow-covered slope

## Turbulence

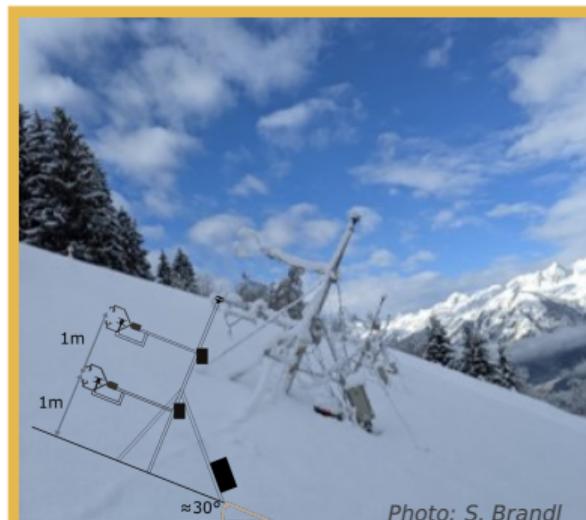


Photo: S. Brandl

Turbulence station

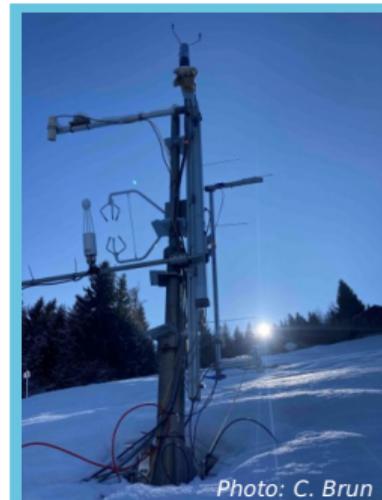
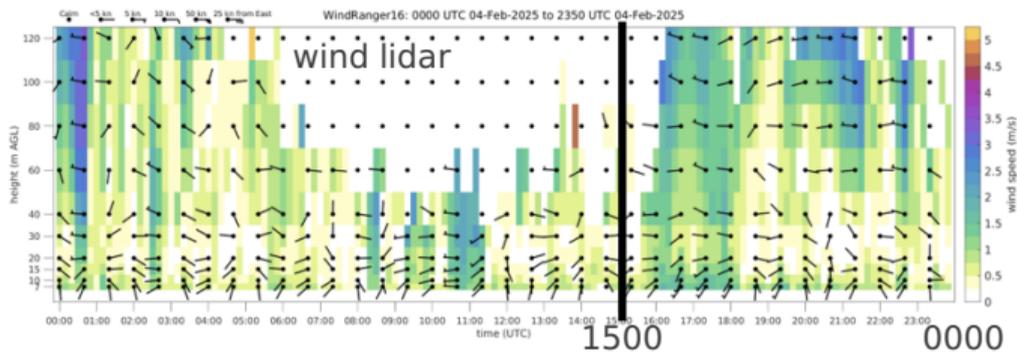


Photo: C. Brun

Station with  
Pitot tube

Credit: I. Stiperski, A. Gohm, L. Pfister, C. Brun

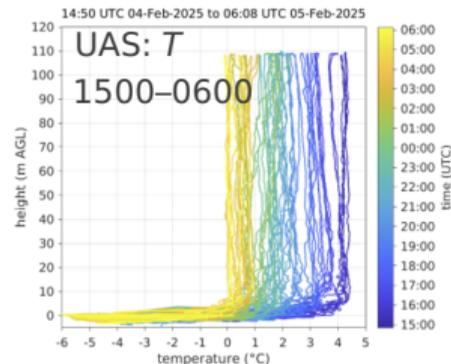
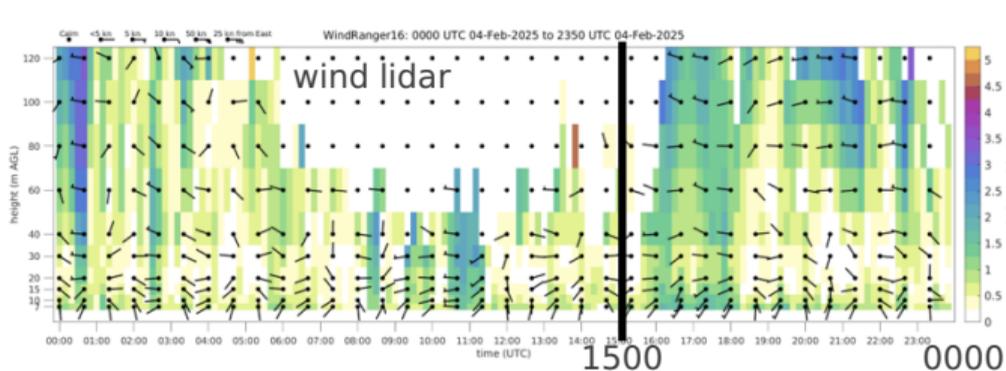
# Katabatic winds—Vertical profiles



- ▲ Shallow katabatic jet: peak < lowest lidar level
- ▲ Transition from downslope (S) to down-valley (W) winds

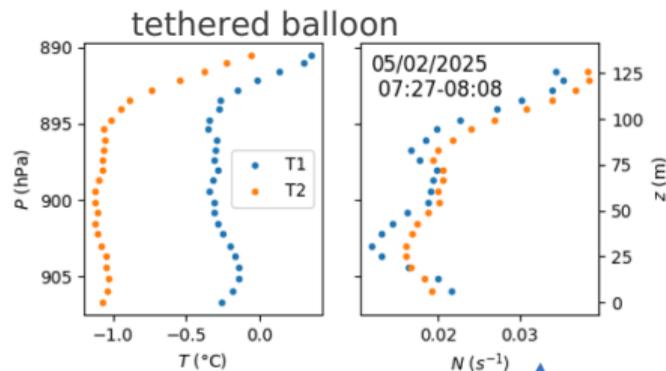
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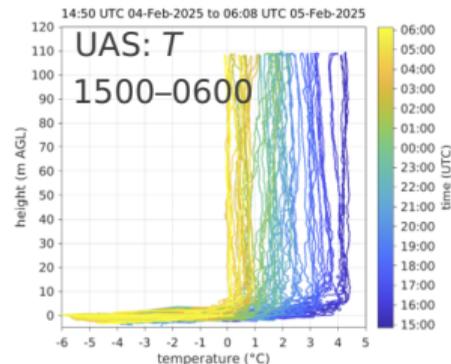
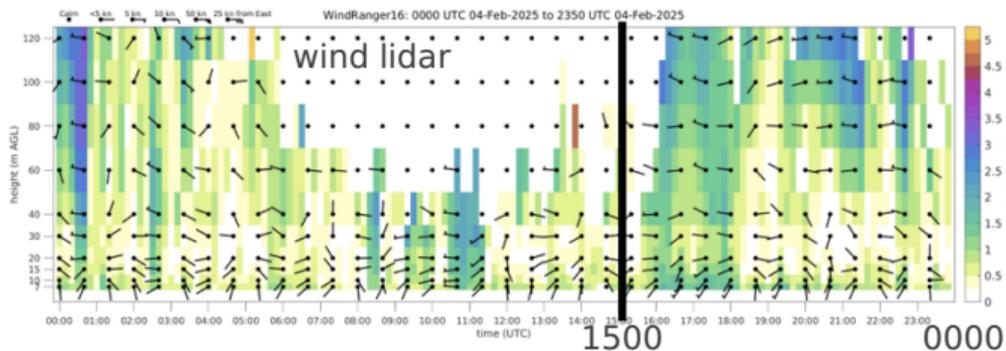


- ▲ Shallow katabatic jet: peak < lowest lidar level
- ▲ Transition from downslope (S) to down-valley (W) winds
- ▲ Shallow temperature inversion: 5–10 m

*Credit: A. Gohm, C. Brun, L. Pfister*

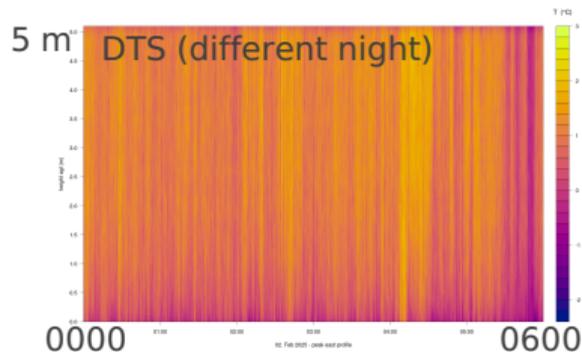


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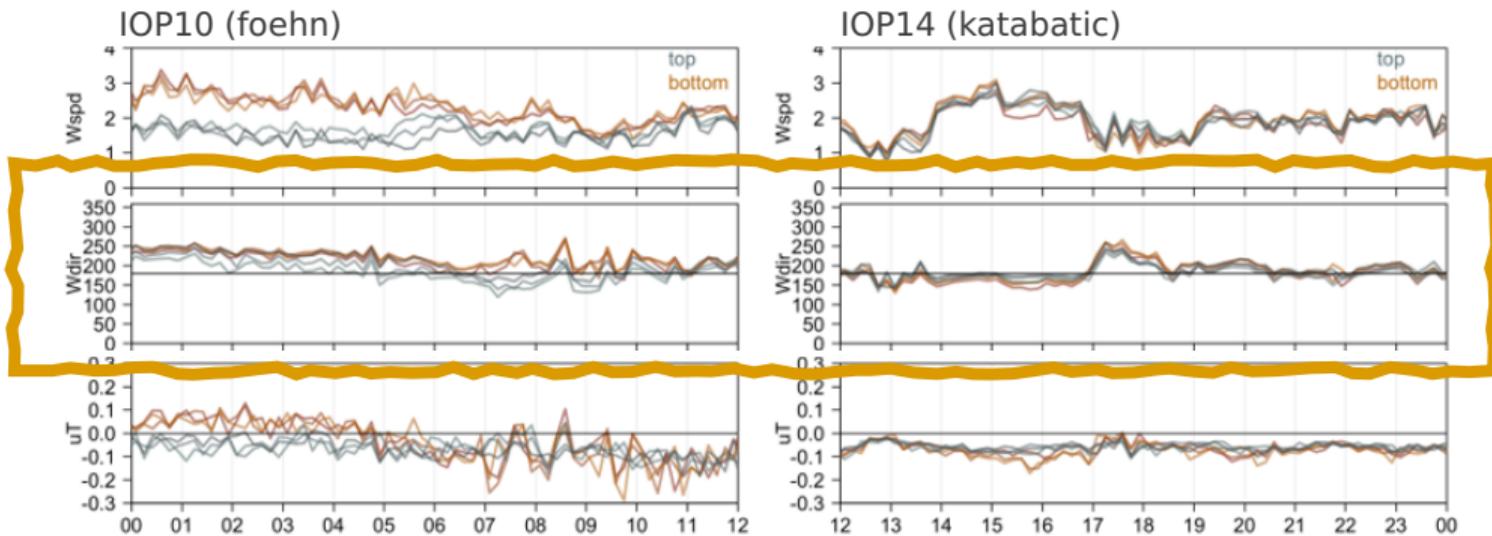


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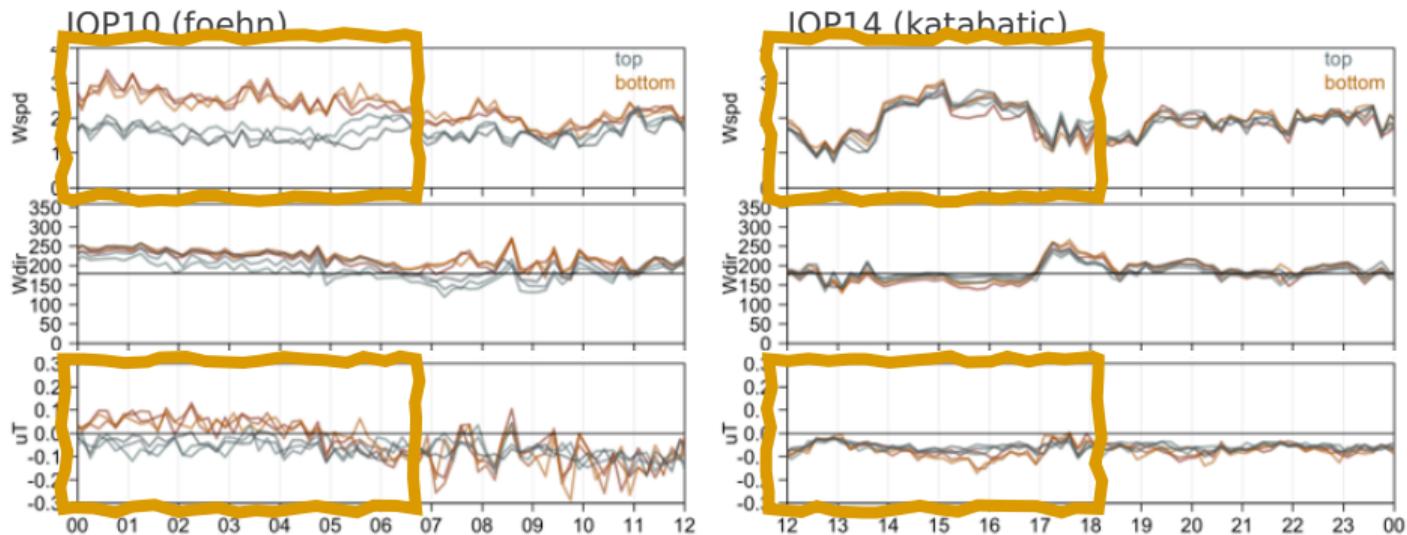
# Katabatic winds—foehn influence



▲ Southerly flow during both katabatic flow and foehn

*Credit: I. Stiperski*

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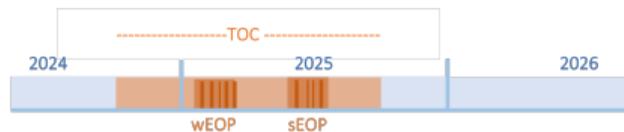


▲ Katabatic flow: jet < 1 m

▲ Foehn: jet < 1 m at top transect; jet > 1 m and stronger winds at bottom transect

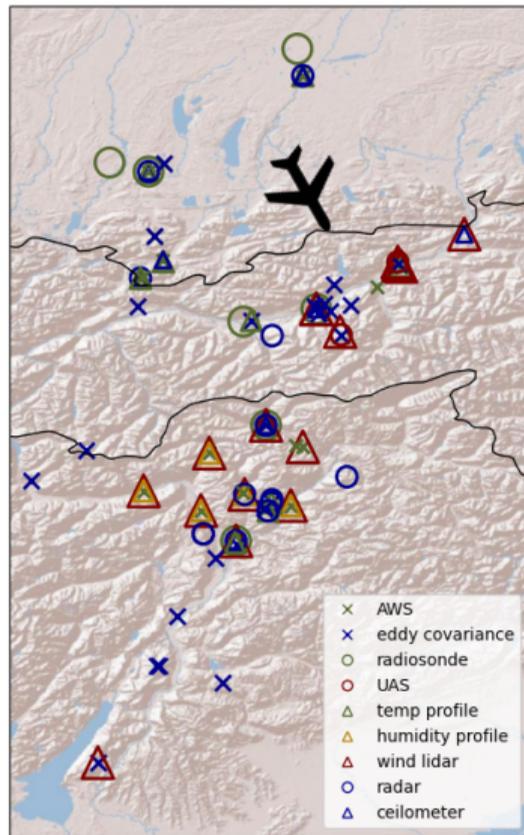
*Credit: I. Stiperski*

# Summer EOP (sEOP)



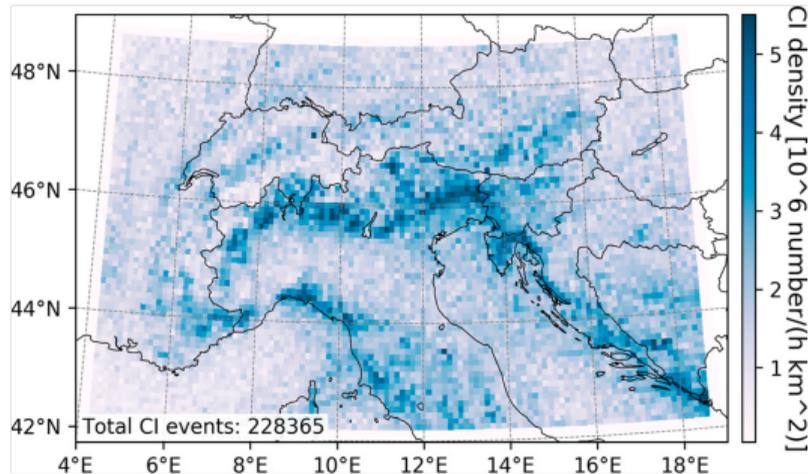
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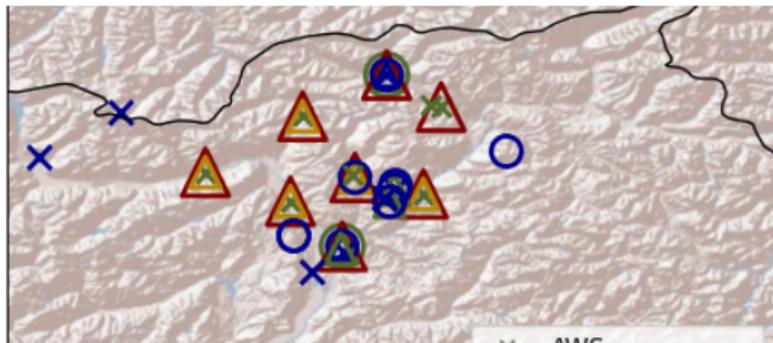
# sEOP: Convection

## Sarntal Alps: Hotspot of convection initiation



Manzato et al. (2022) : A pan-Alpine climatology of lightning and convection initiation. *Monthly Weather Review*.

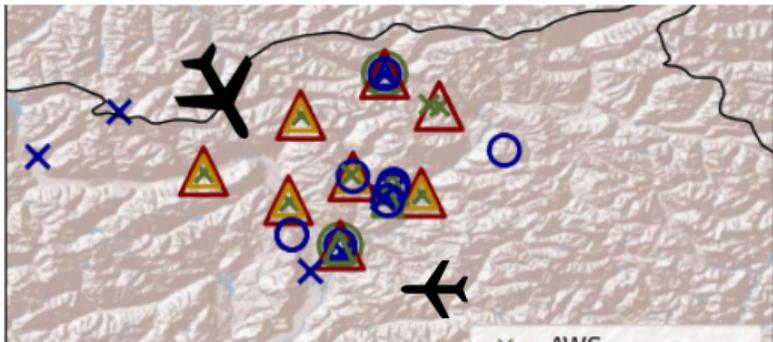
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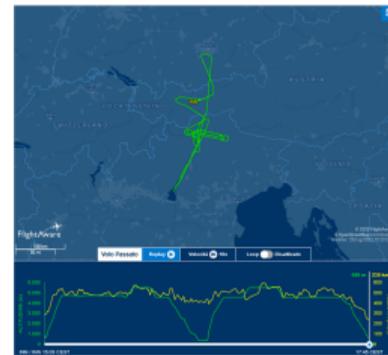
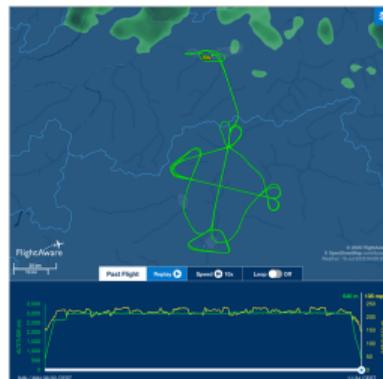
▲ Dense network of remote-sensing instrumentation + radiosoundings



# sEOP: Convection



- ▲ Dense network of remote-sensing instrumentation + radiosoundings
- ▲ Aircraft: TU Braunschweig Cessna + NCAS FAAM



# sEOP: MoBL + thermal winds

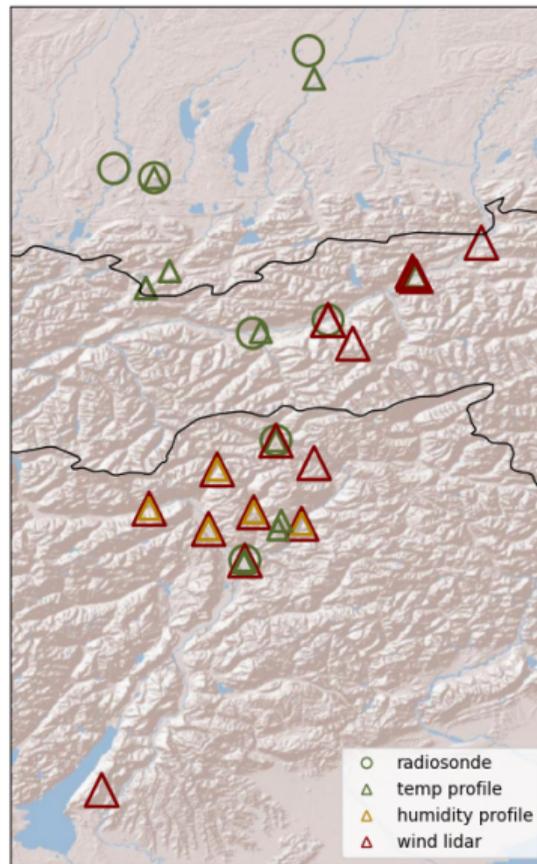
## Spatially distributed vertical profiles

### Radiosoundings



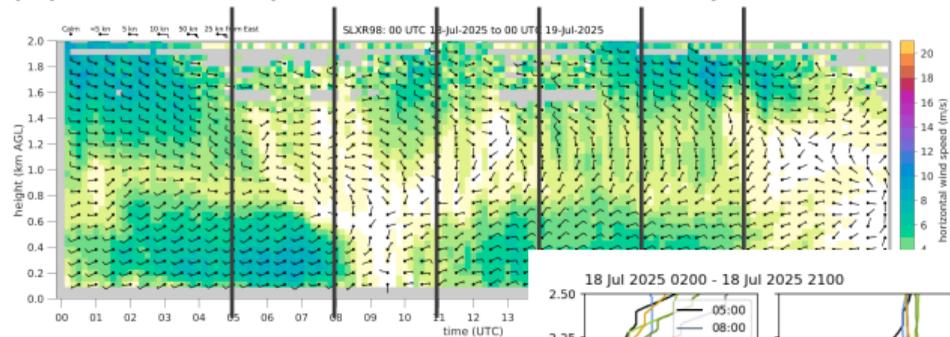
### Wind lidars

### T/RH profilers

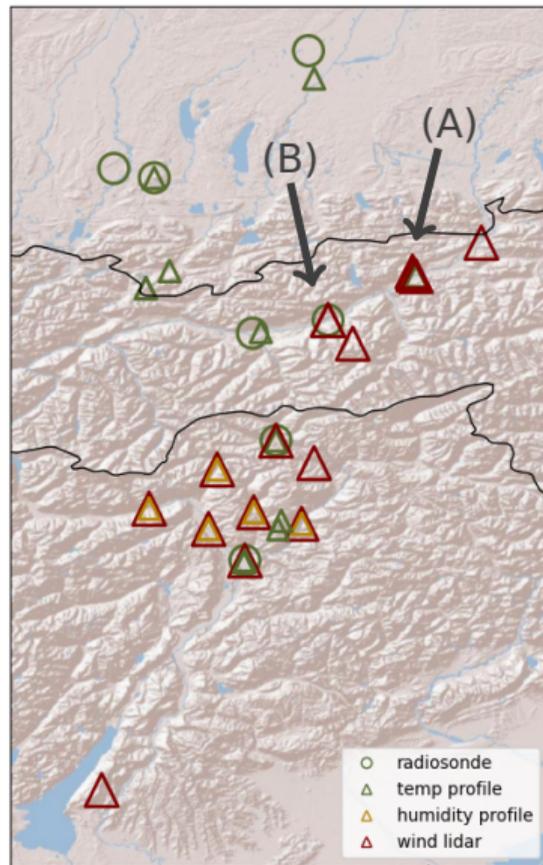
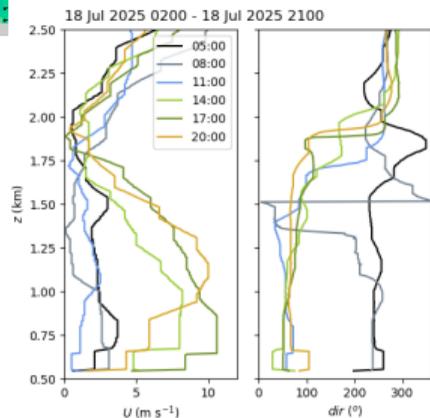


# sEOP: MoBL + thermal winds

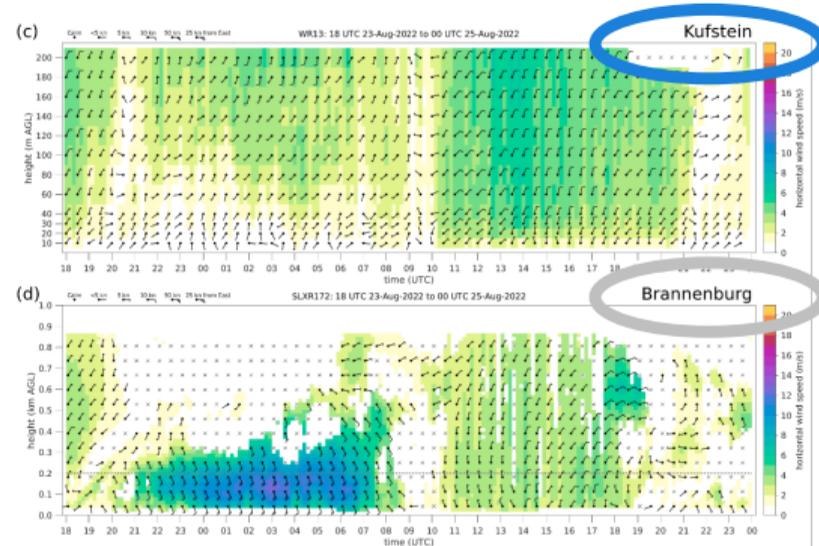
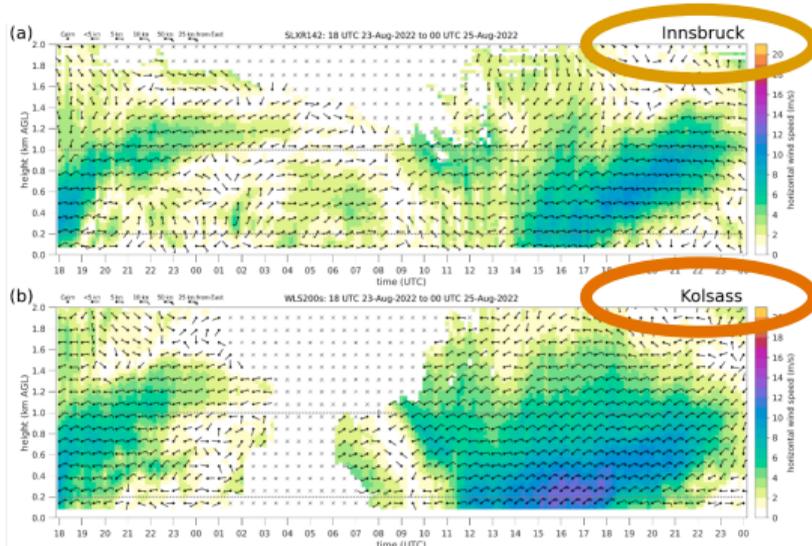
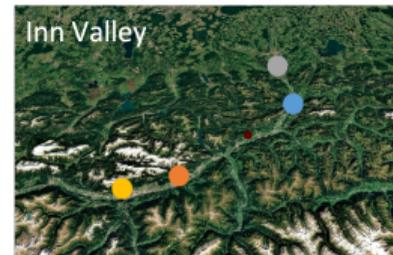
(A) Wind lidar (Credit: Alexander Gohm)



(B) Radiosounding



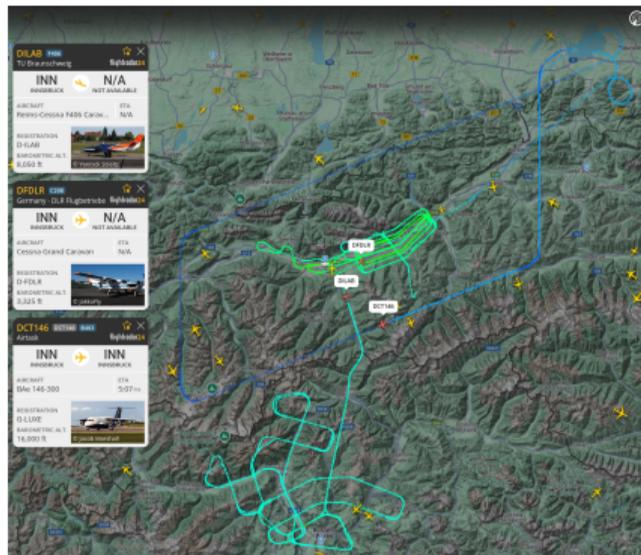
# sEOP: MoBL + thermal winds



Pfister et al. (2024): The TEAMx-PC22 Alpine field campaign—objectives, instrumentation, and observed phenomena. *Meteorologische Zeitschrift*

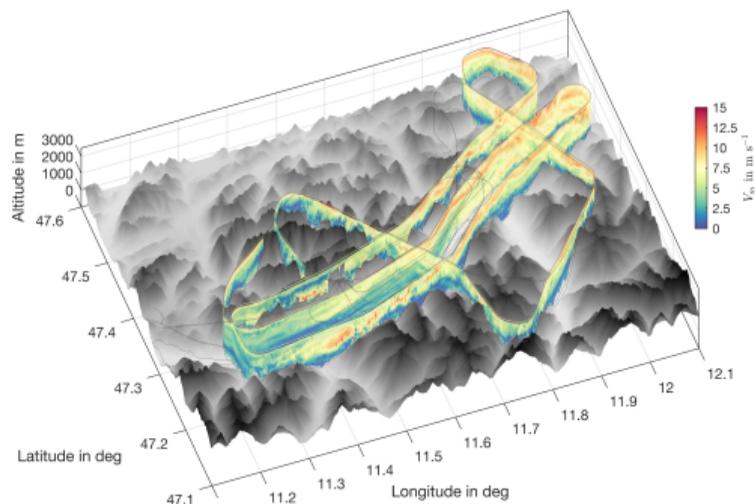
# sEOP: MoBL + thermal winds

## Airborne measurements



Source: flightradar24.com

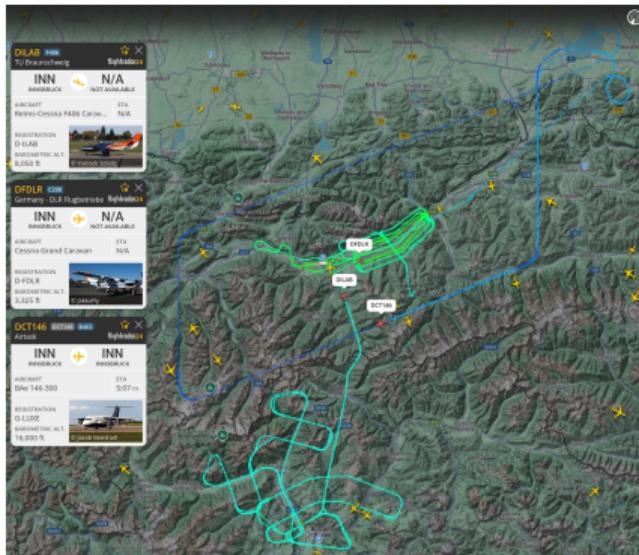
## Wind speed (TU Braunschweig Cessna)



Credit: Philipp Gasch

# sEOP: MoBL + thermal winds

## Airborne measurements

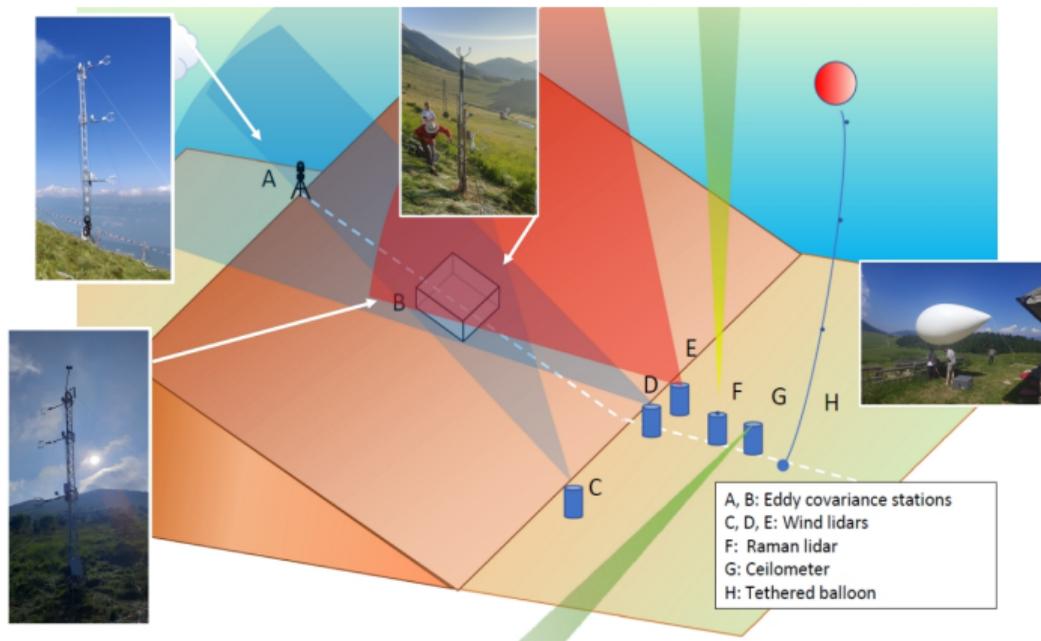


Source: flightradar24.com

**UAS:** vertical profiles + spatially distributed measurements



# sEOP: Slope winds

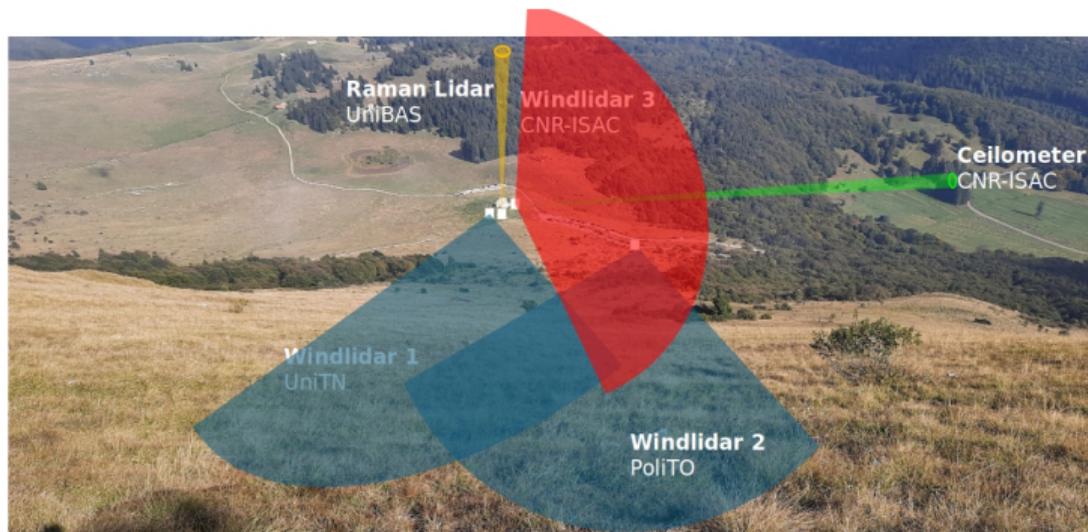


## Monte Baldo



*Credit: D. Zardi, L. Giovannini, G. Doglioni (Univ. Trento)*

# sEOP: Slope winds



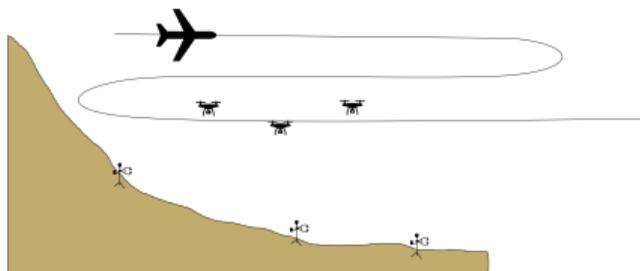
## Monte Baldo



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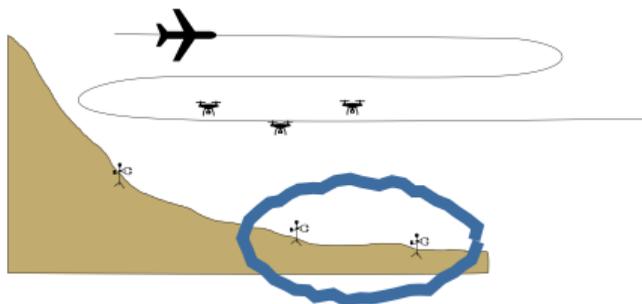
# sEOP: Turbulence in the MoBL

Observing turbulence throughout  
the valley atmosphere

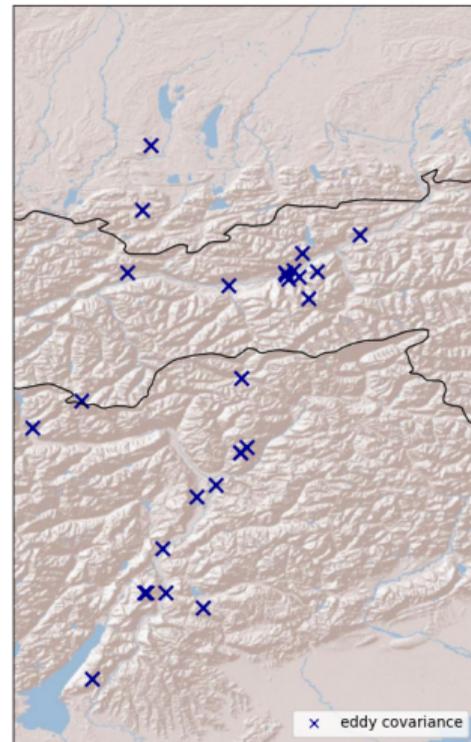


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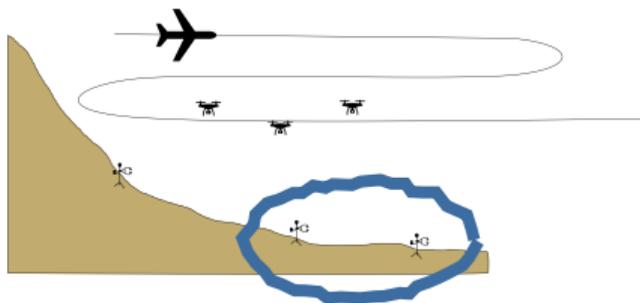


**Surface layer: (networks of) eddy-covariance stations**



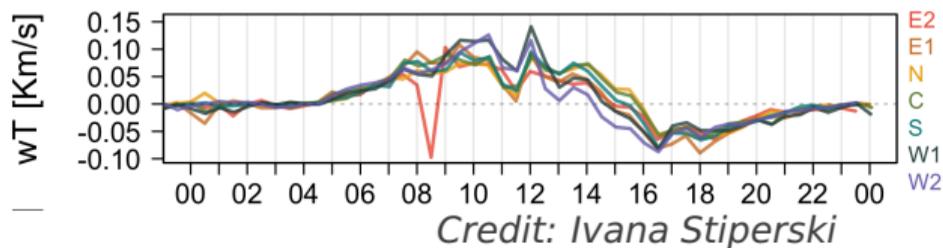
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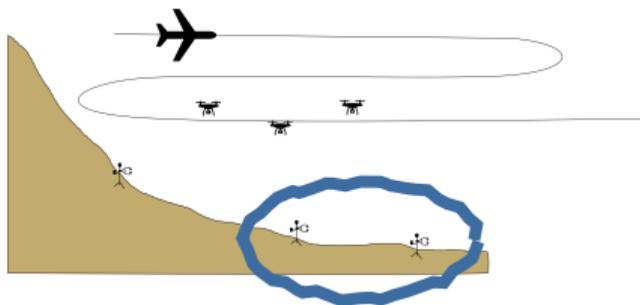
**Surface layer: (networks of) eddy-covariance stations**

Network of EC stations (IVTA)



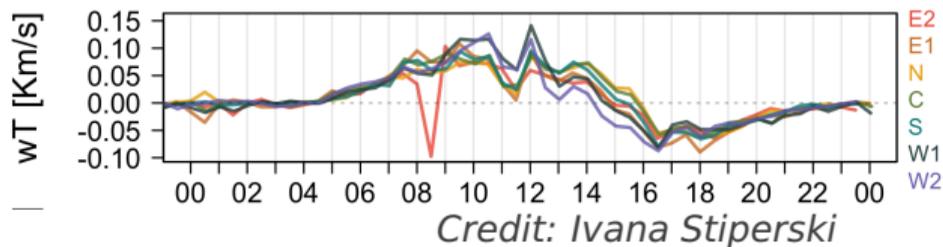
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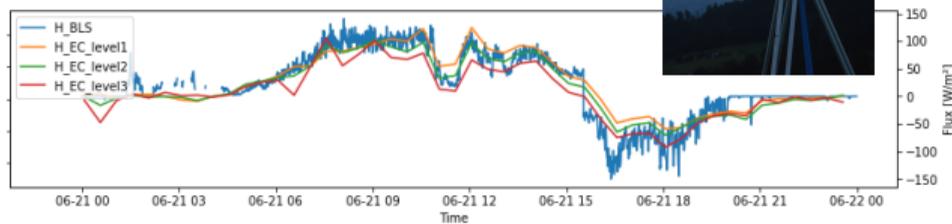


**Surface layer: (networks of) eddy-covariance stations**

Network of EC stations (IVTA)



Scintillometer

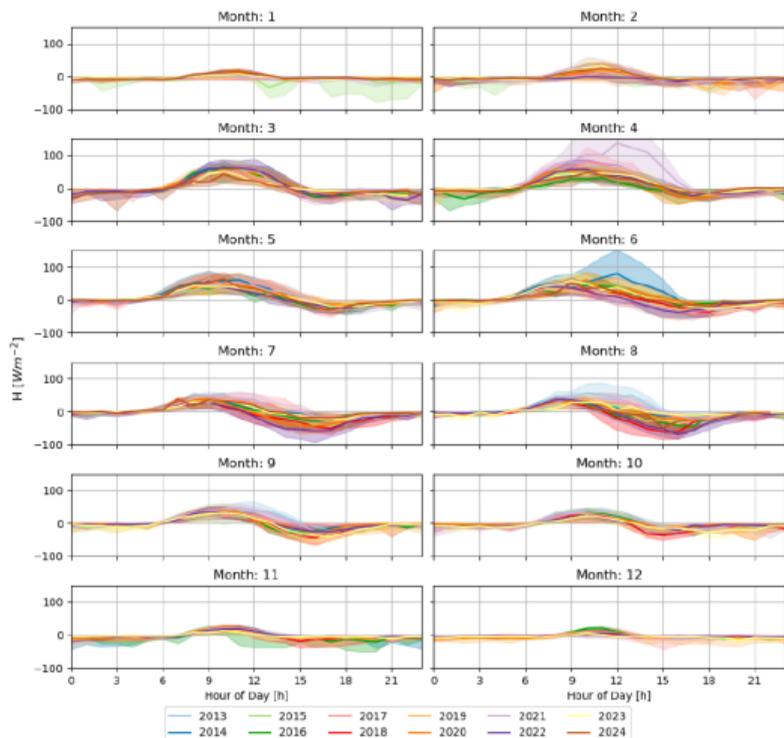


*Credit: Lena Zelger*

# Background: Climatology

- Similar diurnal cycles during most summer months, but
- interannual variability exists

*Linhard (2025), BSc*



# Background: Surface-energy budget

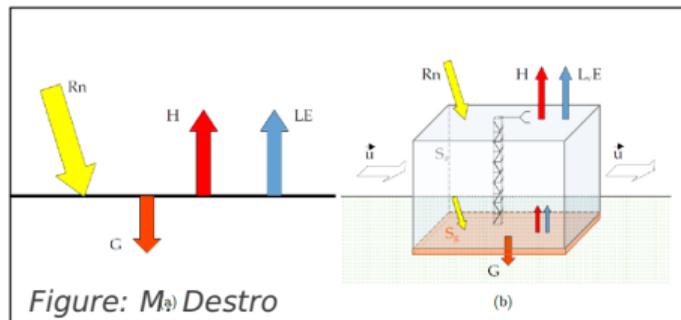
Impact of mesoscale flows on turbulence in the MoBL, e.g., the **surface-energy budget (SEB)**

# Background: Surface-energy budget

Impact of mesoscale flows on turbulence in the MoBL, e.g., the **surface-energy budget (SEB)**

SEB over ideal, horizontally homogeneous and flat terrain

$$R_n = H + LE + G$$



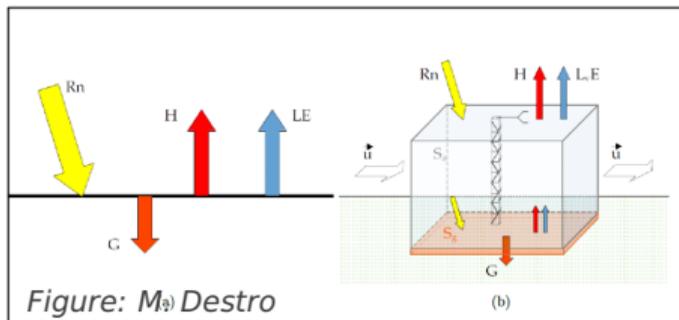
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## Assumption used in numerical models



# Background: Surface-energy budget

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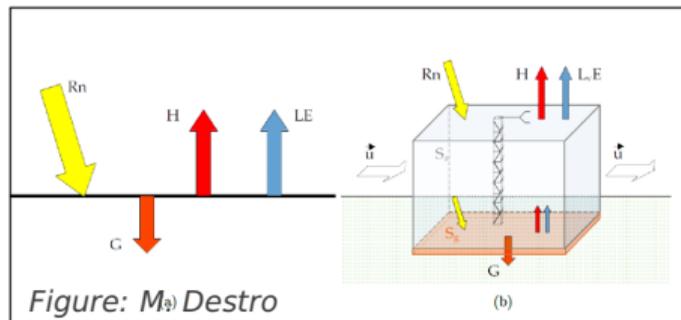
SEB over ideal, horizontally homogeneous and flat terrain

$$R_n = H + LE + G$$

In the MoBL:

$$Res = R_n - (H + LE + G)$$

## Assumption used in numerical models



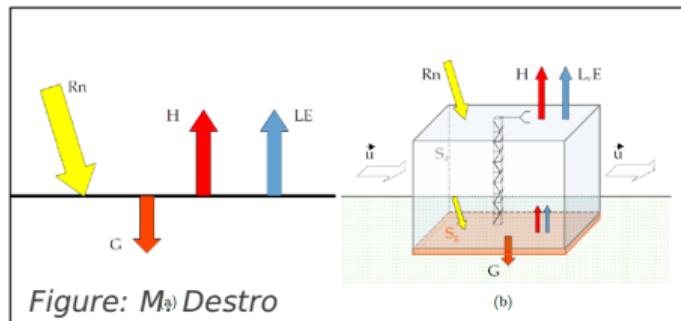
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## Assumption used in numerical models



In the MoBL:

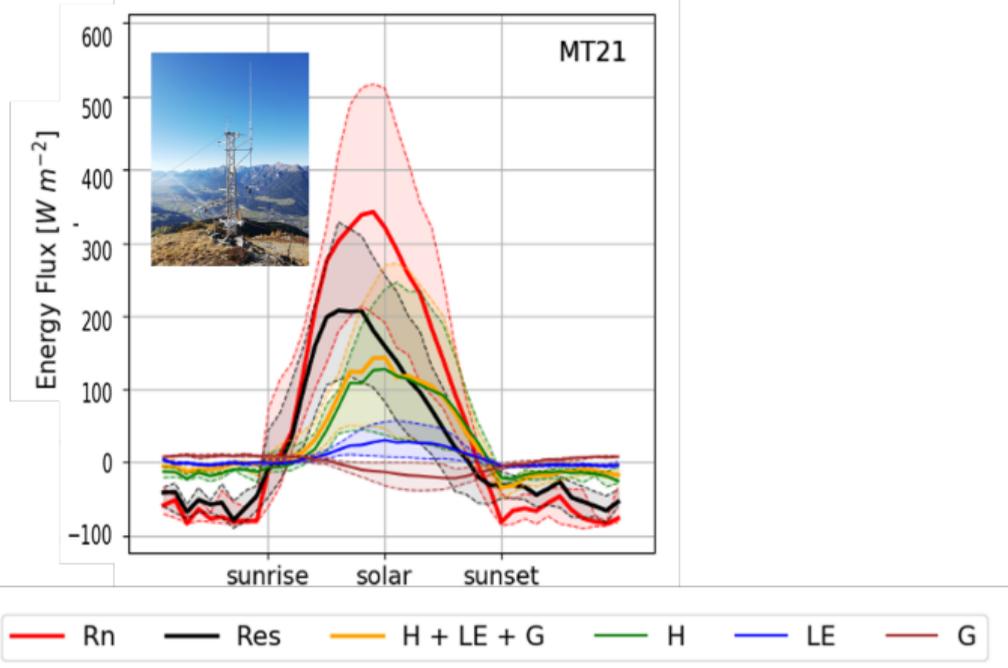
$$Res = R_n - (H + LE + G)$$

Processes contributing to the residual

- ▲ advection (horizontal and vertical)
- ▲ flux divergence
- ▲ storage
- ▲ chemical and biological processes
- ▲ ...

# Background: Surface-energy budget

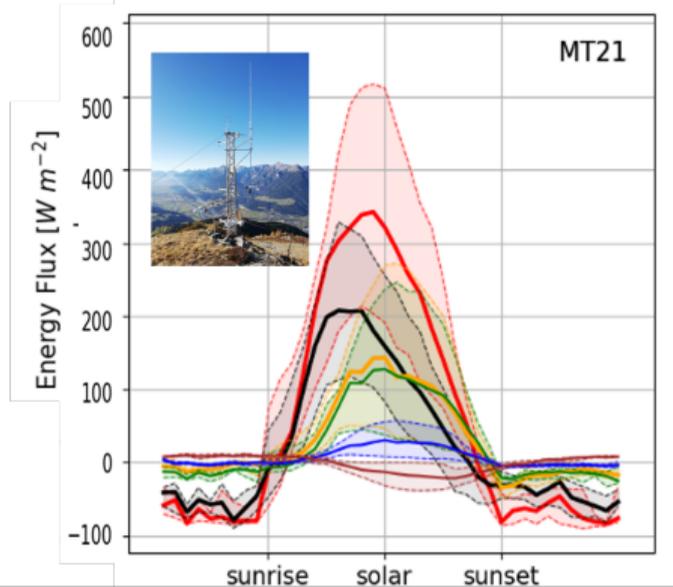
i-Box site Mt21



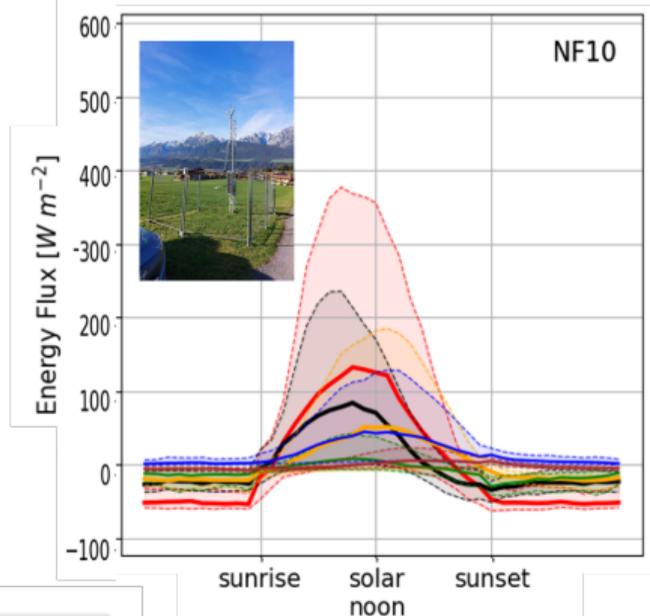
*Destro et al. (2025), submitted*

# Background: Surface-energy budget

i-Box site Mt21



i-Box site NF10



— Rn — Res — H + LE + G — H — LE — G

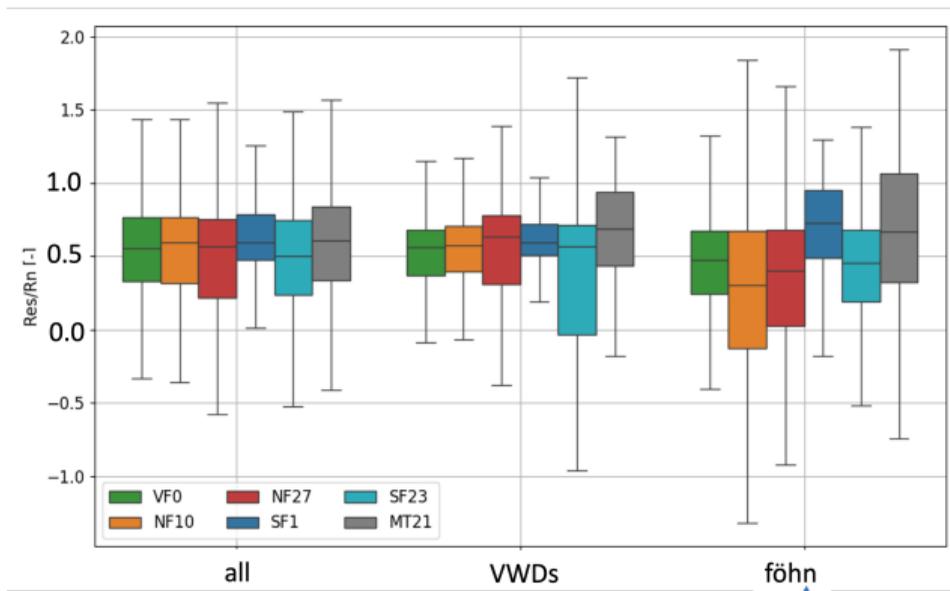
*Destro et al. (2025), submitted*

# Background: Surface-energy budget

Six i-Box sites, 10 years of data

▲  $Res/R_n > 50$

*Destro et al. (2025), submitted*



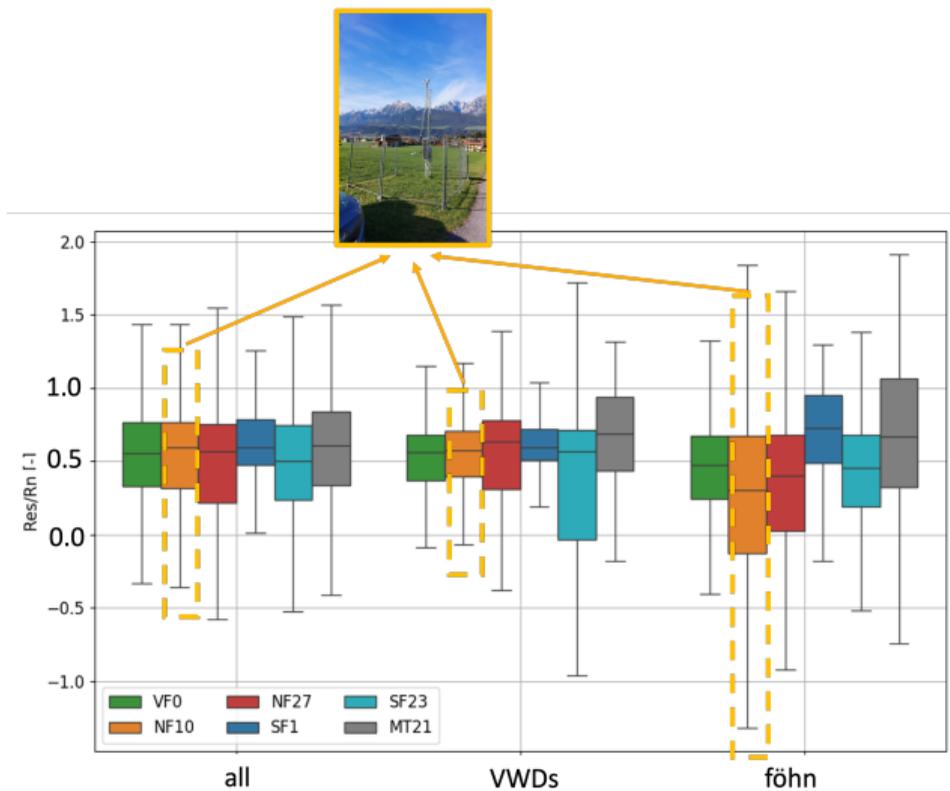
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▲ NF10: VWDs  $\sim$ , foehn  $\downarrow$

*Destro et al. (2025), submitted*

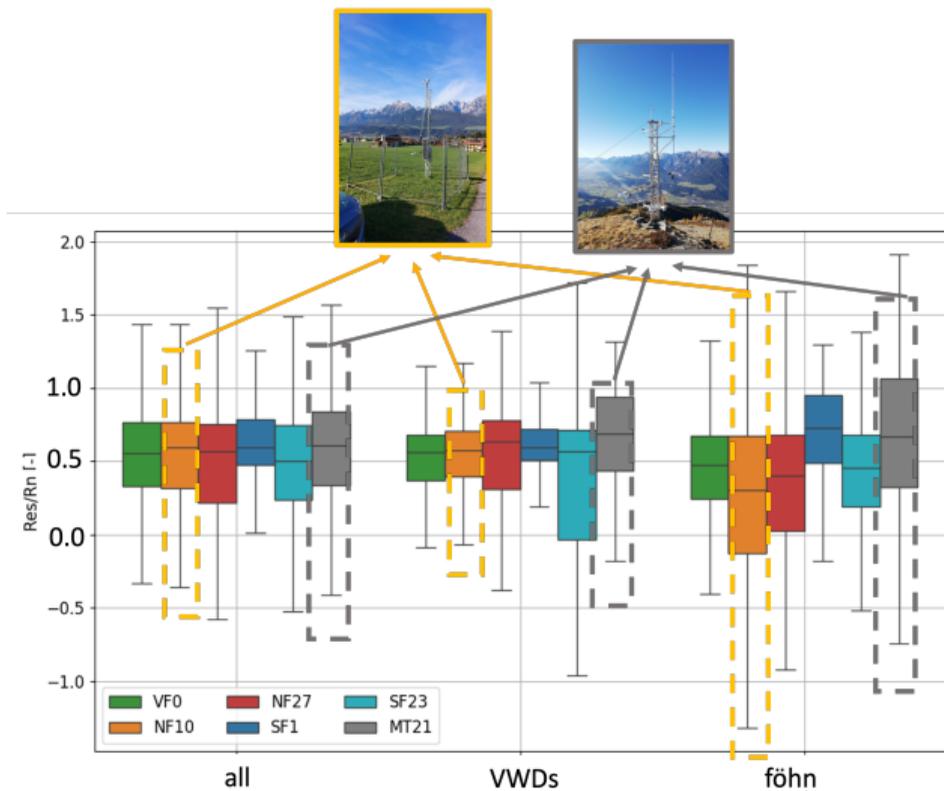


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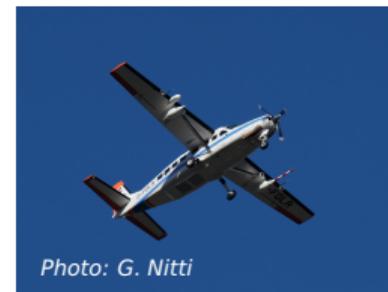
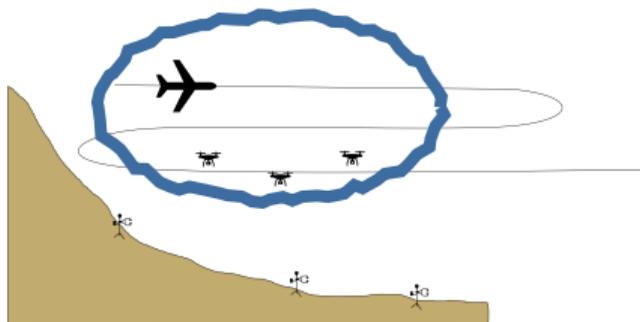
- ▲  $Res/R_n > 50$
- ▲ NF10: VWDs  $\sim$ , foehn  $\downarrow$
- ▲ MT21: VWDs  $\uparrow$ , foehn  $\uparrow$

*Destro et al. (2025), submitted*



# sEOP: Turbulence in the MoBL

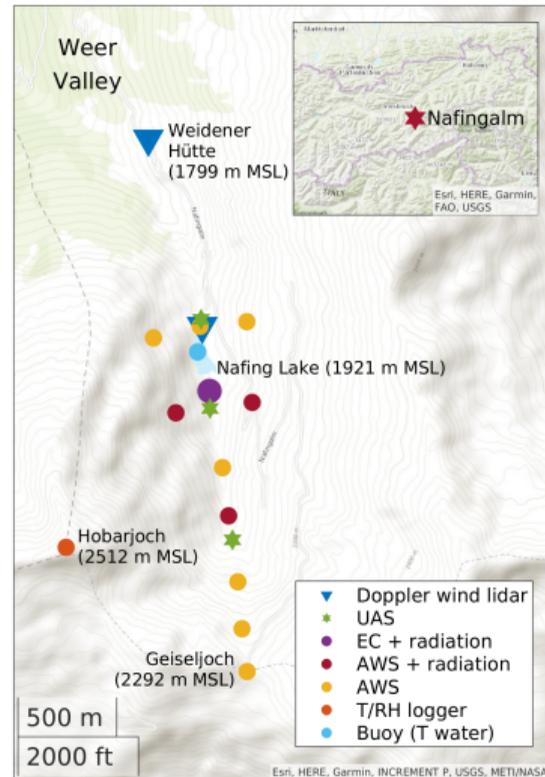
Observing turbulence throughout the valley atmosphere



**Valley atmosphere: aircraft + (swarms of) UAS**

# sEOP: Turbulence in the MoBL

Photos and map: A. Gohm

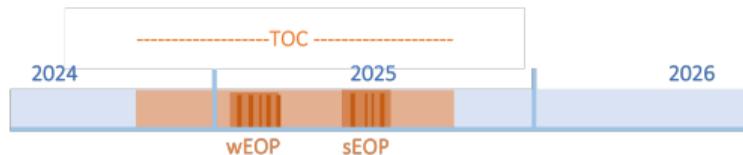
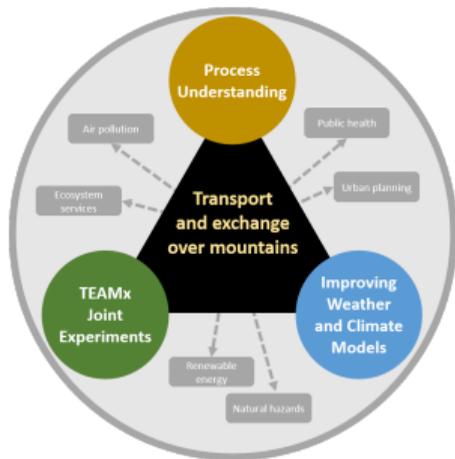


# TOC Summary

 > 25 participating institutions

<b>wEOP</b>	<b>sEOP</b>
6 weeks (20 Jan–28 Feb)	6 weeks (16 Jun–25 Jul 2025)
18 IOPs (gravity waves, MoBL, and katabatic winds)	24 IOPs (gravity waves, convection, MoBL, valley-exit jets, slope winds)
1 aircraft (24 flight hours on 3 days)	3 aircraft (>200 flight h on 21 days)
≈250 radiosoundings (4 sites)	≈550 radiosoundings (6 sites)
≈10 profiling sites	≈ 20 profiling sites
hundreds of UAS and tethered-balloon flights	
multiple AWS, eddy-covariance stations, ...	

# TEAMx Multi-scale transport and exchange processes in the atmosphere over mountains—programme and experiment



**TEAMx Observational Campaign:** one-year long campaign to collect a unique dataset to study transport and exchange processes over mountainous terrain

**ACINN** was a major contributor in the TOC and a wealth of data were collected

→ **MSc and BSc theses topics**



Photo: D. Anderson



Photo: M. Lehner

# Thank you to all TOC participants!