



Multi-scale **T**ransport and **E**xchange processes in the **A**tmosphere over **M**ountains – programme and **e**xperiment

Mathias W. Rotach and Manuela Lehner

TEA  X

Overview

- ▲ TEAMx
 - a little bit of history
 - science background
 - activities
- ▲ TEAMx-UIBK
- ▲ Student opportunities

A little bit of history

- ▲ discussion started: after ICAM-2015
- ▲ Coordination and Implementation Group established (9/2017)
- ▲ eight institutions formed 'TEAMx-Seed'
 - joint financial support for setting up a PCO (COSMO consortium joined later)
 - establishing a TEAMx community (MoU)
- ▲ Project coordinators



Stefano Serafin



Helen Ward



Stephanie
Westerhuis



Manuela
Lehner

TEAMx

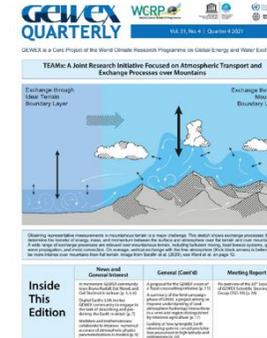
A little bit of history

- Review papers in Atmosphere, special issue
- White Paper
→ overview of the scientific scope of TEAMx
- GEWEX Quarterly, BAMS Essay, ...



Serafin et al 2020, ISBN 978-3-99106-003-1

available from:
www.teamx-programme.org



TEAMx is...



...endorsed by WWRP

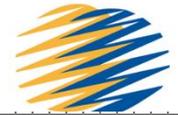
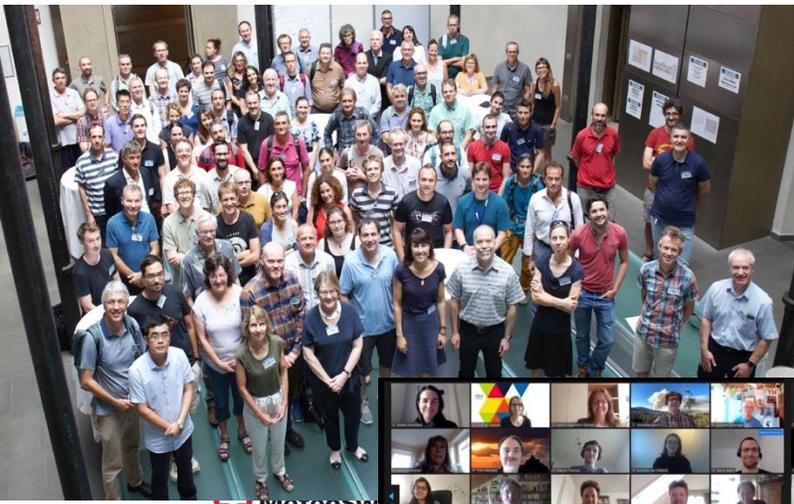


..a cross-cut project of the GEWEX
Hydroclimate Panel

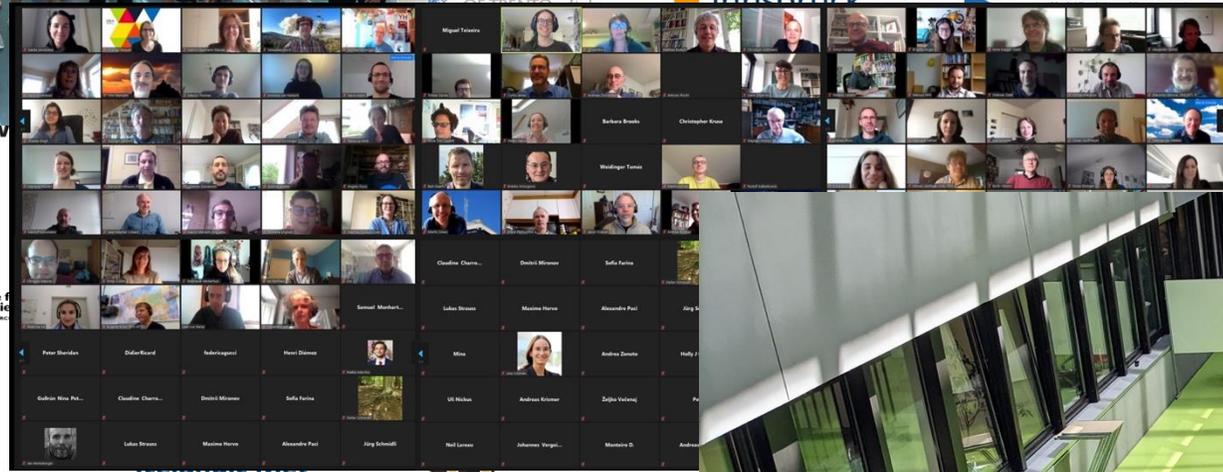


who is it?

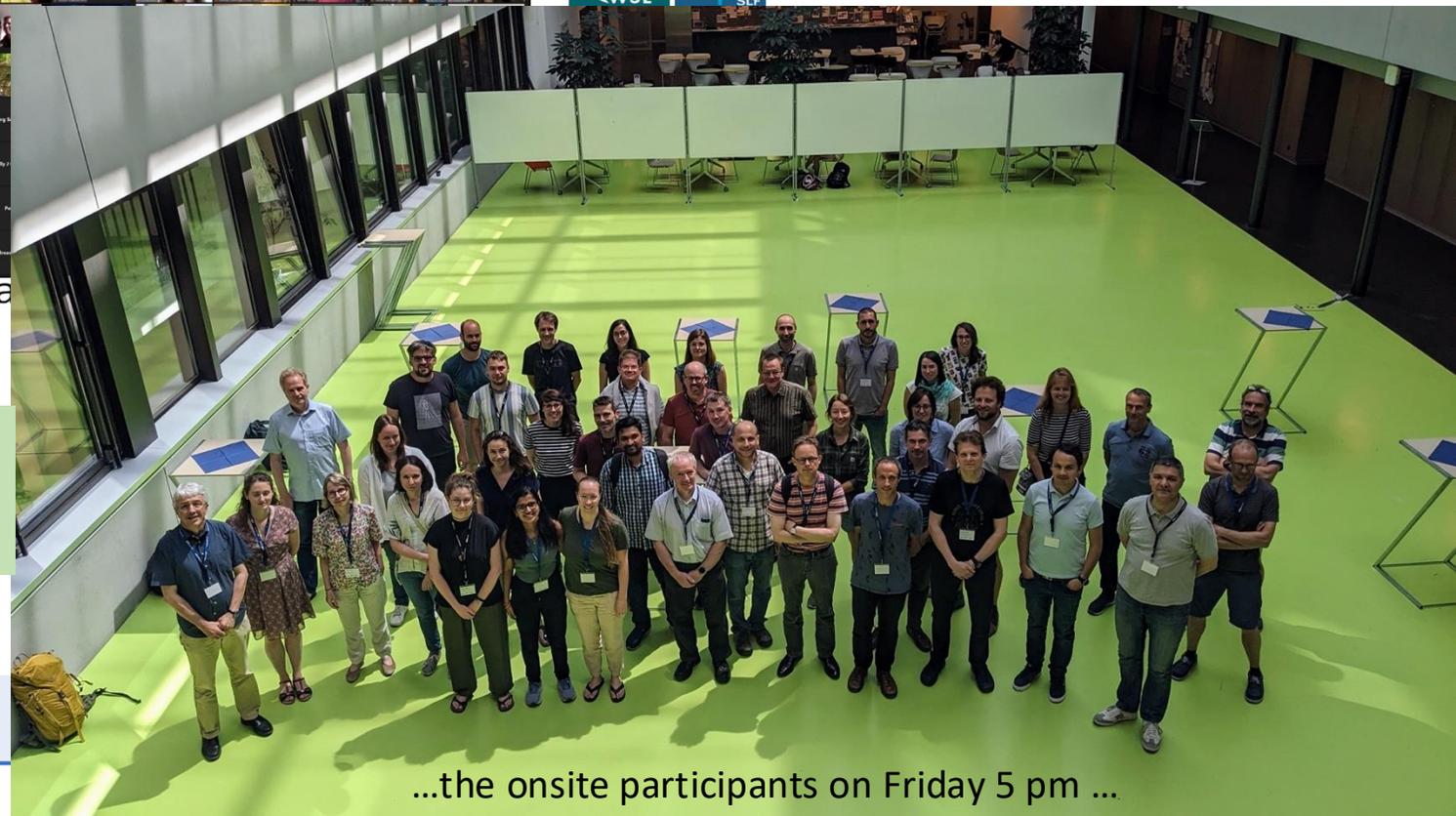
The first TEAMx workshop 2019 fully on site 2019



The second TEAMx workshop 2021 fully online



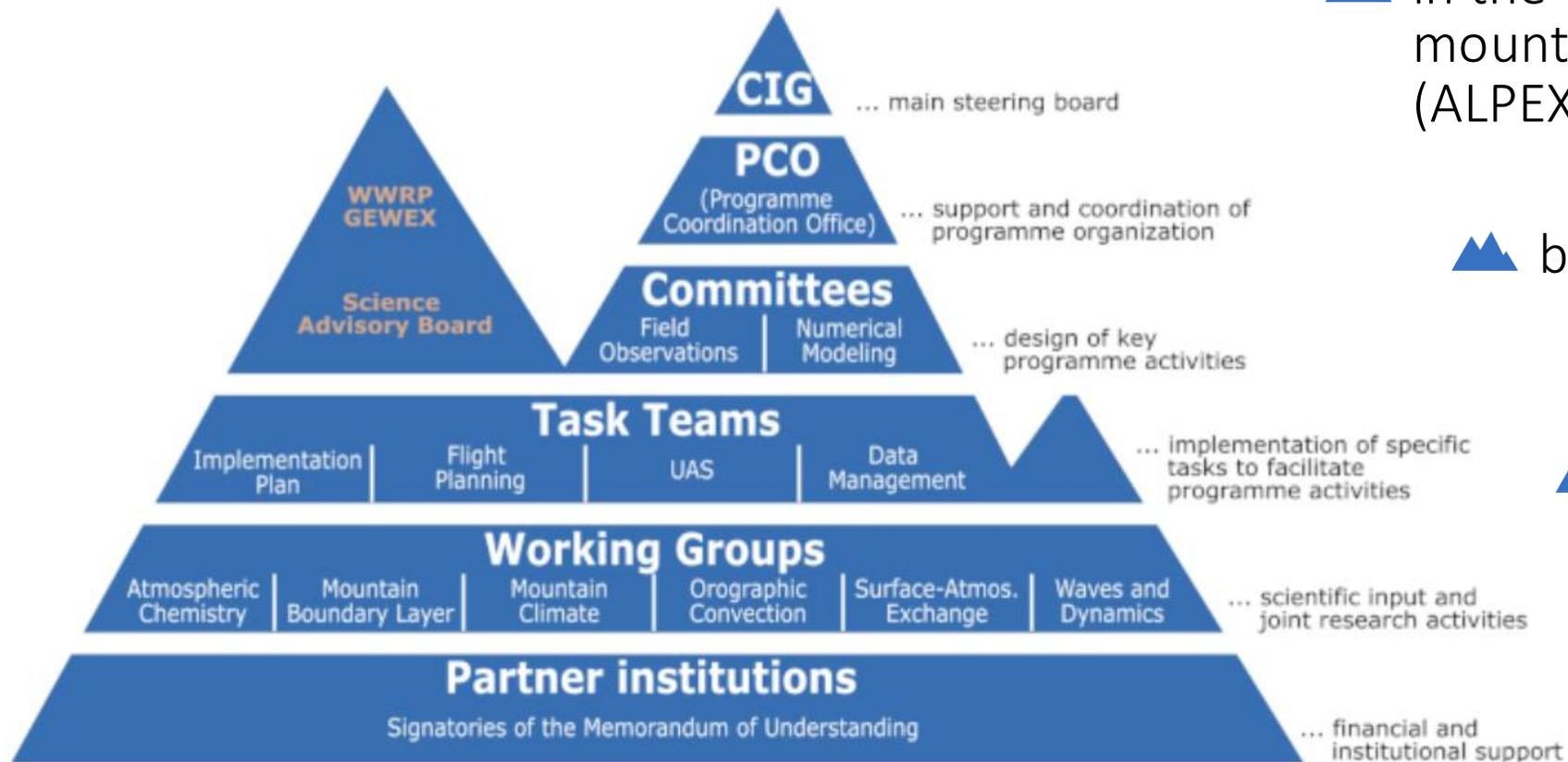
The third TEAMx workshop last week fully hybrid 2023



...the onsite participants on Friday 5 pm ...

A little bit of history

Organization



▲ in the 'tradition' of earlier mountain meteorology programs (ALPEX, PYREX, MAP → TEAMx)

▲ bottom-up financed

▲ WGs & TTs

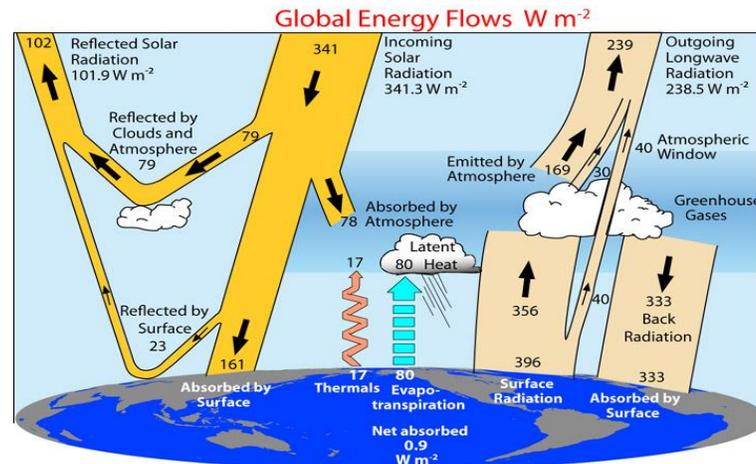
It is about... exchange processes over mountains

Momentum



- ▲ orographic blocking
- ▲ gravity wave breaking
- ▲ orographic drag parameterisations in general circulation models

Heat

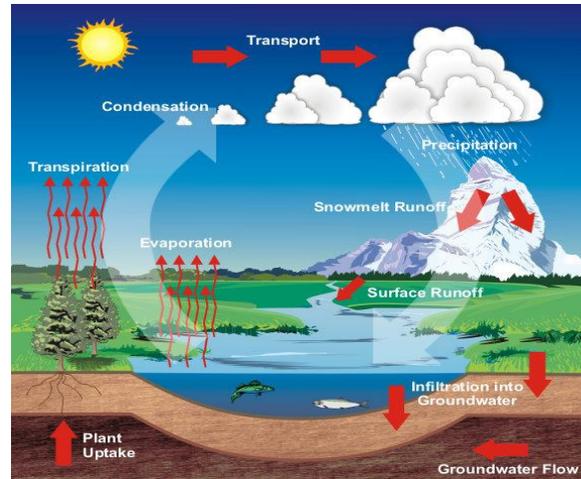


- ▲ thermally driven breezes
- ▲ cold air pooling
- ▲ Interaction meso- local scales
- ▲ no parameterisations

<https://scied.ucar.edu/longcontent/energy-budget>

It is about... exchange processes over mountains

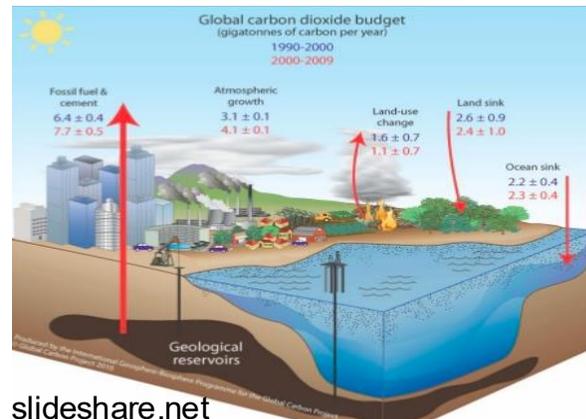
Mass: water



http://www.algebra.org/practice/practice.aspxfile=Reading_WaterCycle.xml

- ▲ orographic precipitation
- ▲ triggering of convective precipitation (CI)
- ▲ 'water towers' for the surrounding plains

Mass: CO₂
(trace gas)

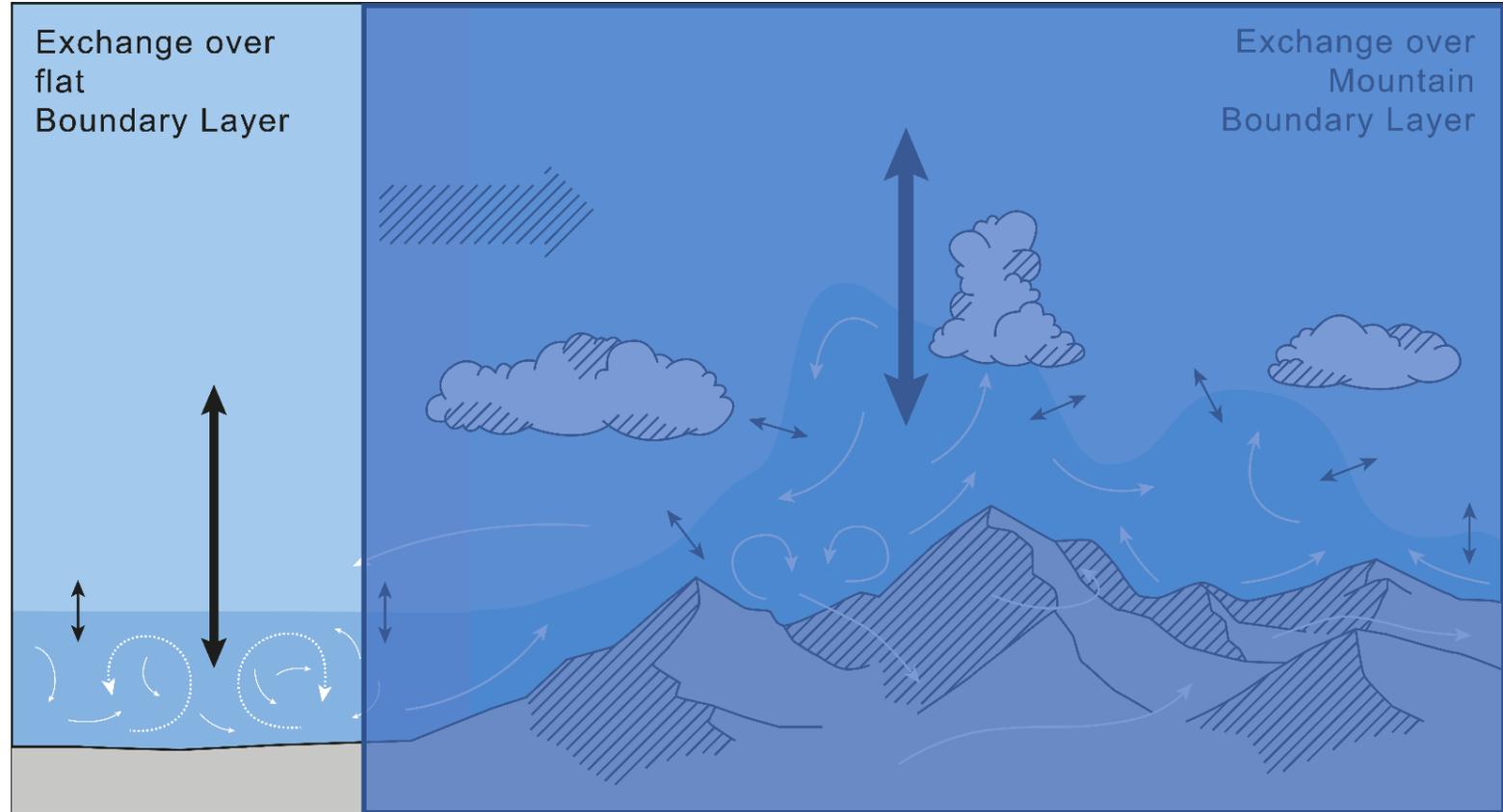


slideshare.net

- ▲ global (regional) budgets most uncertain over land
- ▲ poorly represented exchange over orography may be one reason for 'missing sink'

The Mountain Boundary Layer (MoBL)

- ▲ traditionally, earth-atmosphere exchange through the Atmospheric Boundary Layer
→ vertical
- ▲ over mountains: interaction with mesoscale flows
→ thermally driven
→ dynamically forced
→ multi-scale!
- ▲ 3-dimensional: Mountain Boundary Layer: MoBL
- ▲ spatially inhomogeneous



TEAMx Science Plan

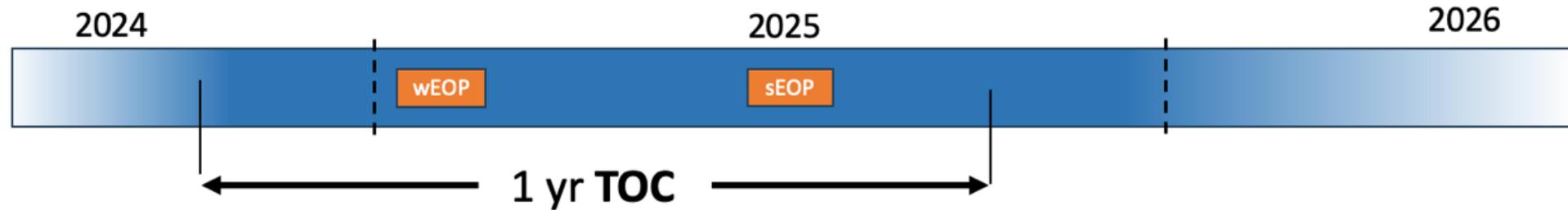
Objective	Primary Focus	Target
Process understanding	Micro- and meso-scale processes within and above the <i>mountain boundary layer</i> (MoBL); Interaction between scales.	Quantitative understanding of momentum, energy and mass exchange over mountainous terrain
TEAMx Joint Experiment(s)	Collaborative use of multi-platform instrumentation to sample the spatial heterogeneity of turbulence and mesoscale circulations over and near mountains	Quality-controlled observational data pool, available for process investigation, high-resolution model verification, parameterization development
Improving Weather and Climate Models	<i>Models right for the right reason</i> , i.e., identification and reduction of model biases and uncertainties over complex terrain	Weather forecasts and climate simulations over mountains as good as over flat terrain, and less reliant on model output post-processing
Support to Weather and Climate Service Providers	Air pollution, hydrology, climate change scenarios (e.g., elevation-dependent climate change).	Smaller uncertainty of impact models, due to reduced errors in weather and climate information.

Serafin et al. 2020



Joint TEAMx Observational Campaign (TOC)

Autumn 2024 - autumn 2025 (EOPs and IOPs):

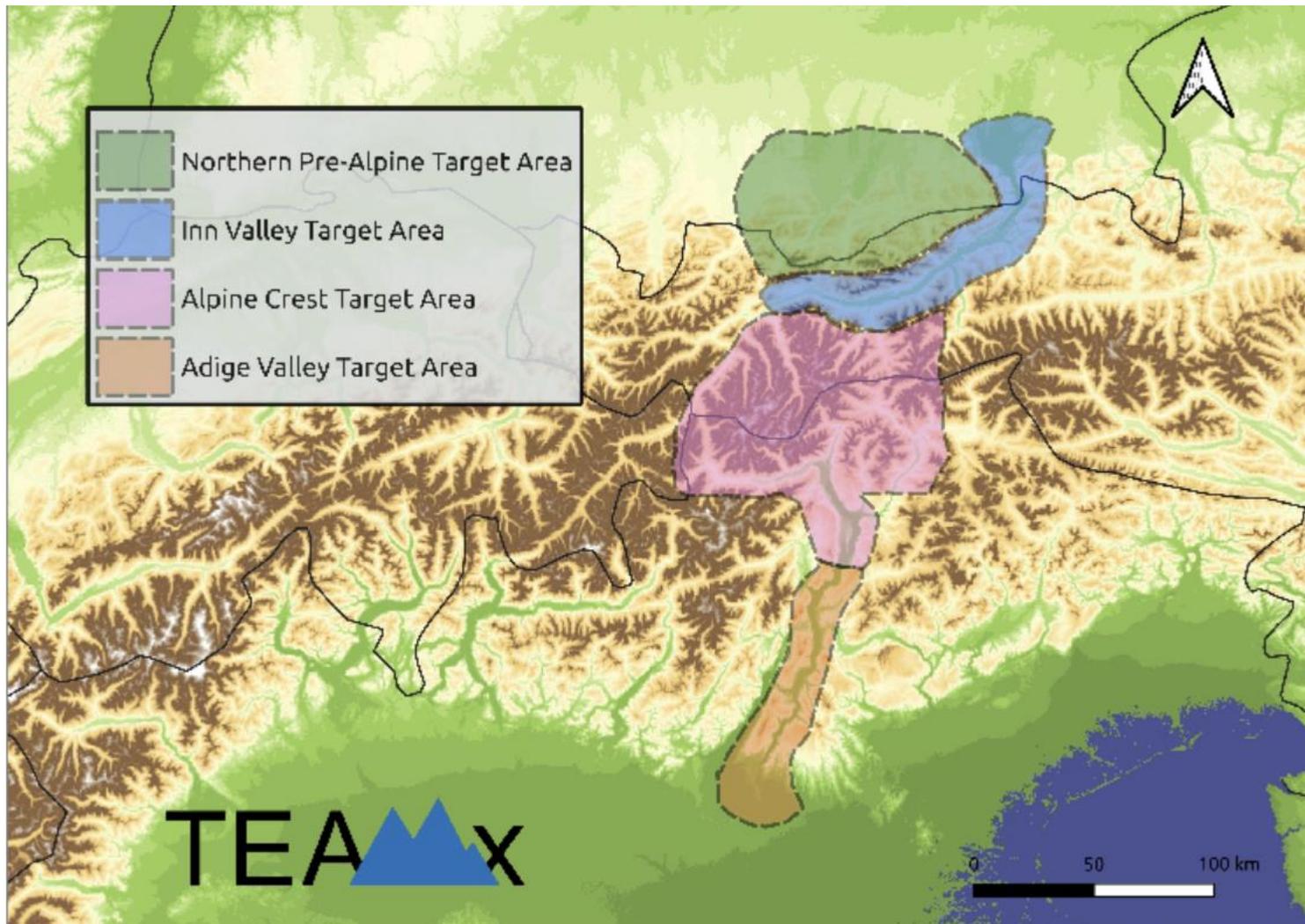


Winter EOP (wEOP)
specified dates: Jan 20 2025 – Feb 28 2025



Summer EOP (sEOP)
specified dates: June 16 2025 – July 25 2025

Joint TEAMx Observational Campaign (TOC)



Northern Pre-Alpine TA
→ Stefan Kneifel (LMU)
→ Hannes Vogelmann (KIT Alpin)

Inn Valley TA
→ Manuela Lehner (UIBK)

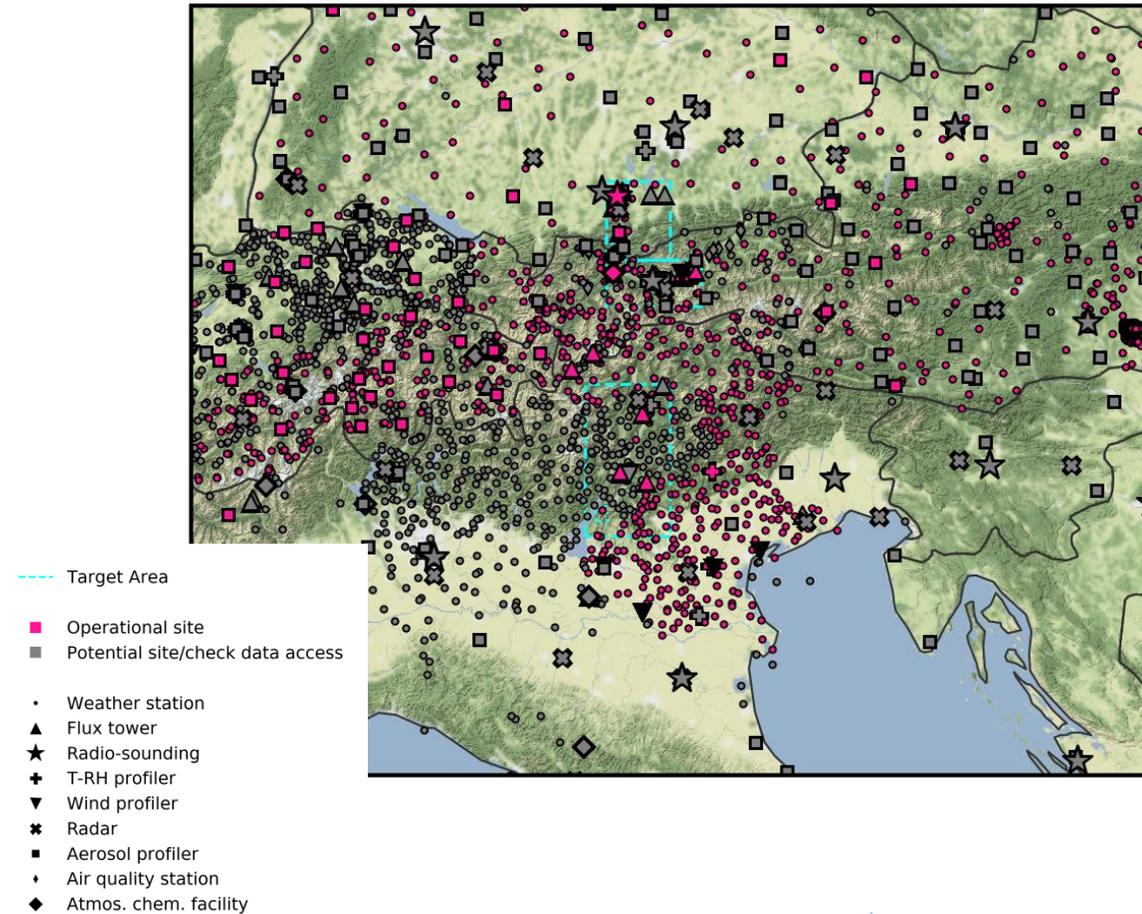
Alpine Crest TA
→ Charles Chemel (NCAS)

Adige Valley TA
→ Nadia Vendrame (Unitn)

Joint TEAMx Observational Campaign (TOC)

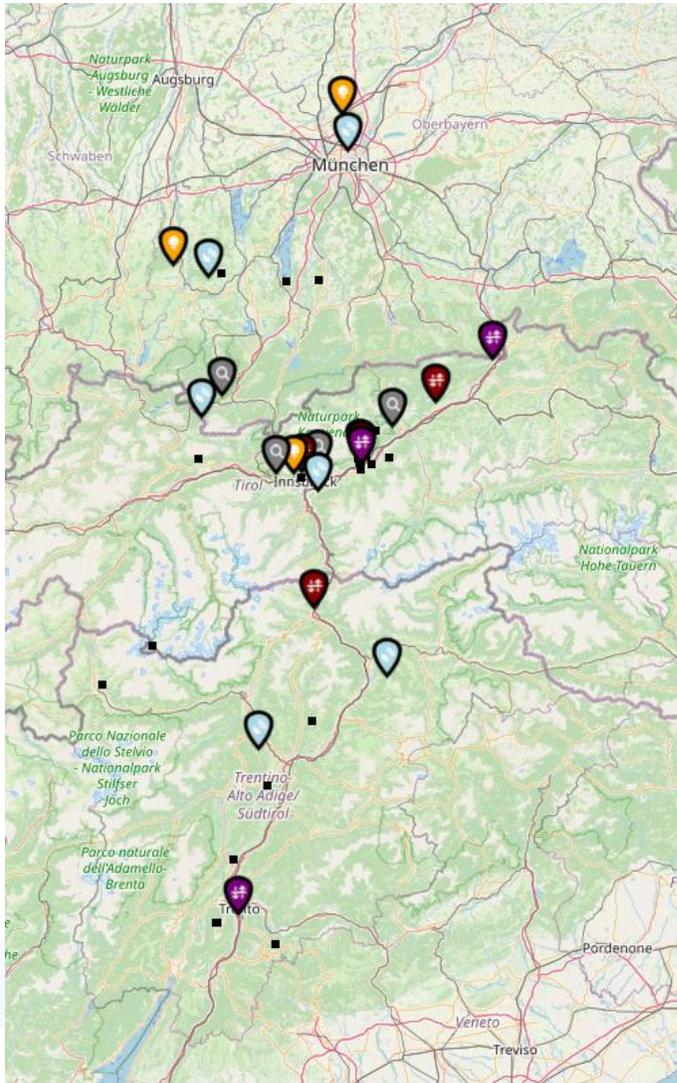
- TOC
- ▲ (semi-) operational observations
 - AWS, ceilometers, air quality
 - lidars, radars, MWRs
 - radio sounding
 - flux sites
 - ▲ additional deployments
 - additional profile sites (lidar, radars, MWR)
 - flux sites (Mezzolombrano)

All stations

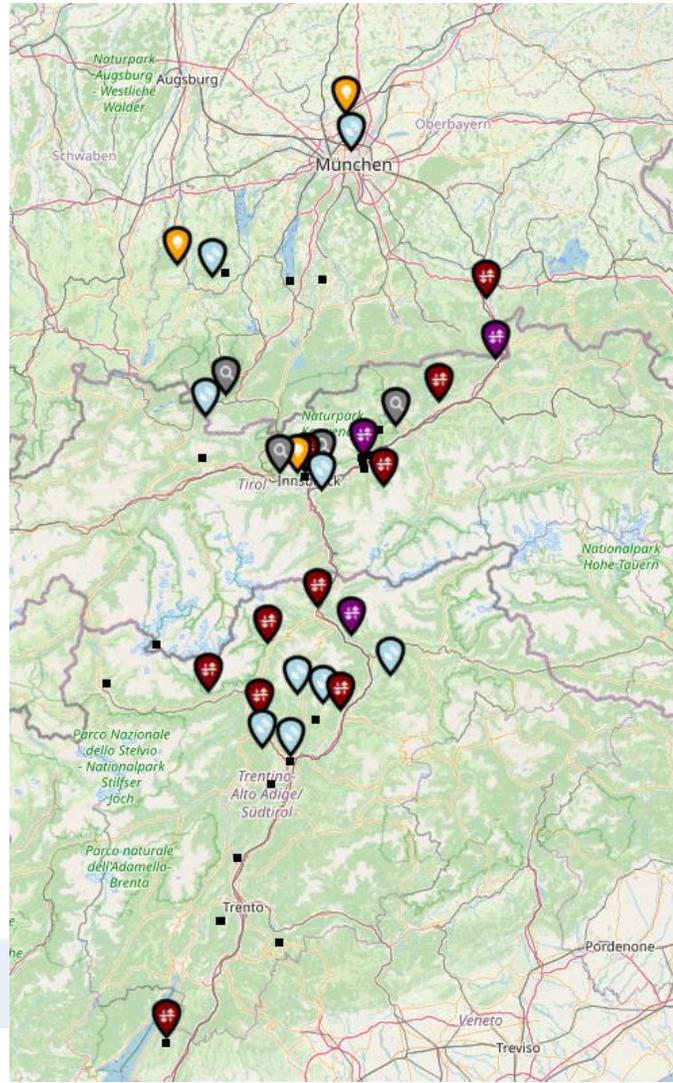


EOPs - backbone

wEOP



sEOP



profile site

→ lidar, MWR



radar



radio sounding



EC site

many 'supersites'

→ additional profiles (U, T, H)

→ radar (rain, cloud, MRR)

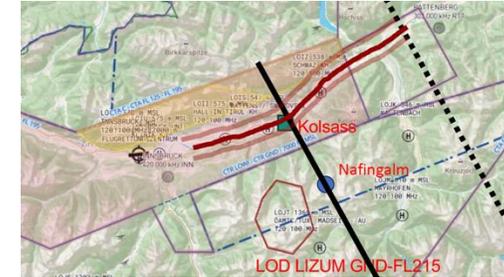
→ other (SEB, drones, ...)

IOPs - Personnel-intensive observations

DLR: Cessna Grand Caravan



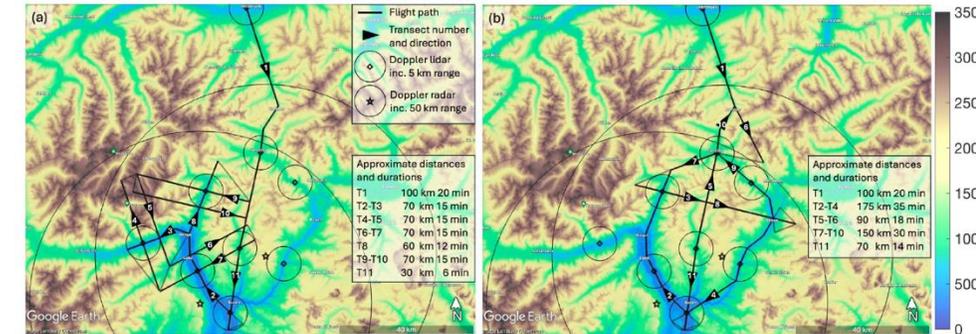
- ▲ IVTA (UIBK)
wEOP / sEOP
- ▲ cross-Alpine (DLR)



TUBS: Cessna F406



- ▲ Sarntal Alps (KIT)
sEOP
- ▲ IVTA (UIBK)
sEOP



TEAMx-UK:

FAAM BAe-146



- ▲ Cross Alpine (TEAMx-UK)
sEOP



IOPs - Personnel-intensive observations

Drones: swarm of drones

▲ Nafingalm (DLR/UIBK)
sEOP

drone

▲ Branneburg (IVTA) (DWD)
sEOP

drone

▲ Mezzolombrano (AVTA) (Eurac)
sEOP

RaSo: additional sites

▲ Sarntal Alps (NCAS / KIT)
(wEPO) / sEOP

▲ KOL (UIBK)
wEPO/sEOP

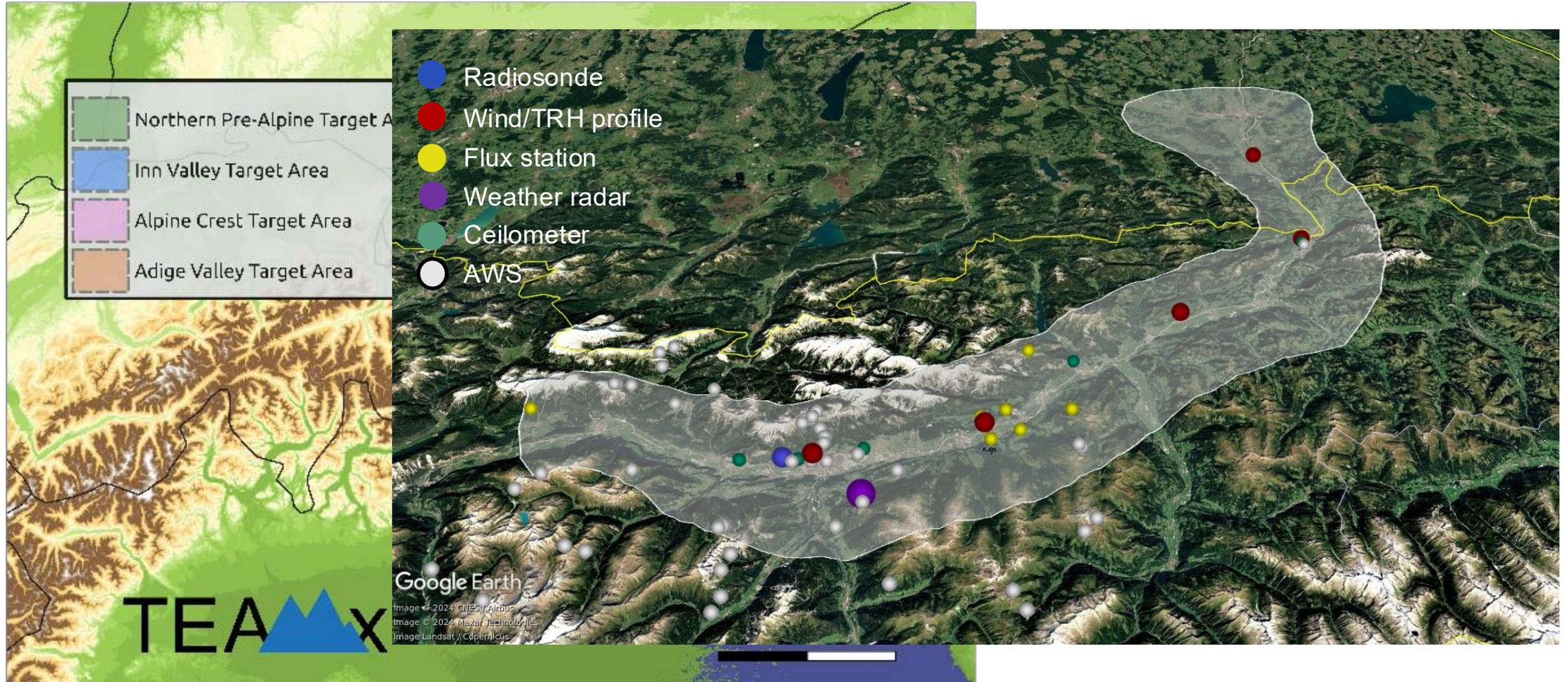
▲ Branneburg (DWD)
sEOP

▲ additional 'times' at Hohenpreißenberg, Altenstadt ,
Unterschleißheim (DWD)



training over snow...

Activities in the Inn Valley and at ACINN



Permanent Infrastructure Operated by UIBK



Valley Atmosphere

Innsbruck University (UIBK, KIT)



Photos: A. Gohm



Google Earth
Image © 2024 CNES / Airbus
Image © 2024 Maxar Technologies
Image Landsat / Copernicus

Kufstein
(GeoSphere Austria)



Radfeld (Meteo Swiss,
GeoSphere Austria)



Kolsass (UIBK, KIT)

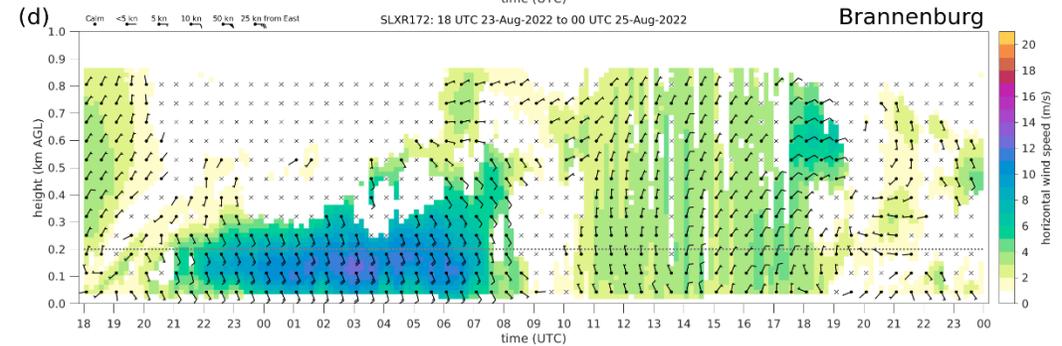
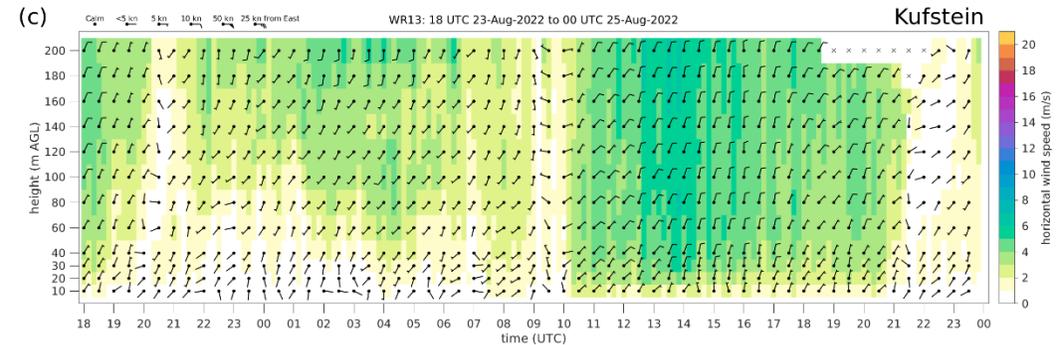
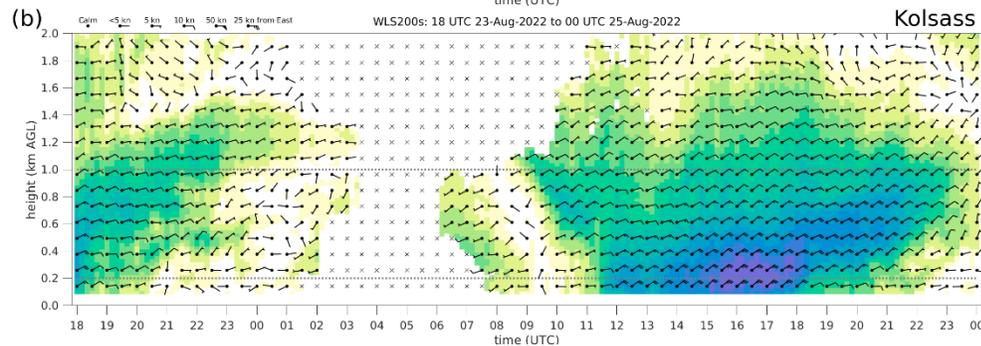
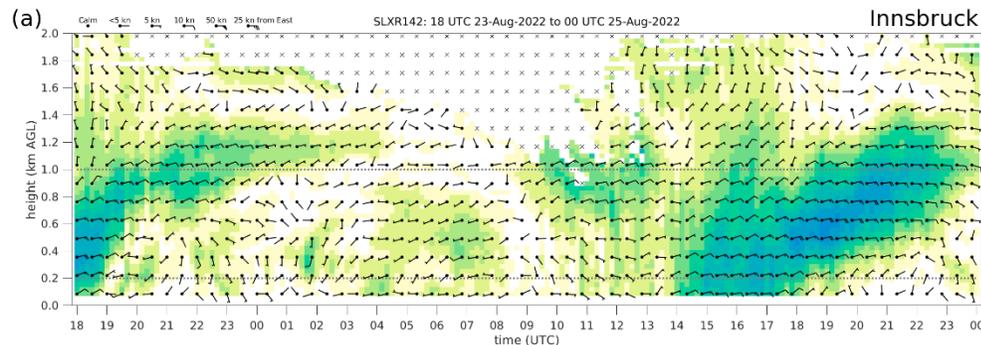


Photo: J. Vüllers

- Radiosonde
- Wind/TRH profile
- Ceilometer

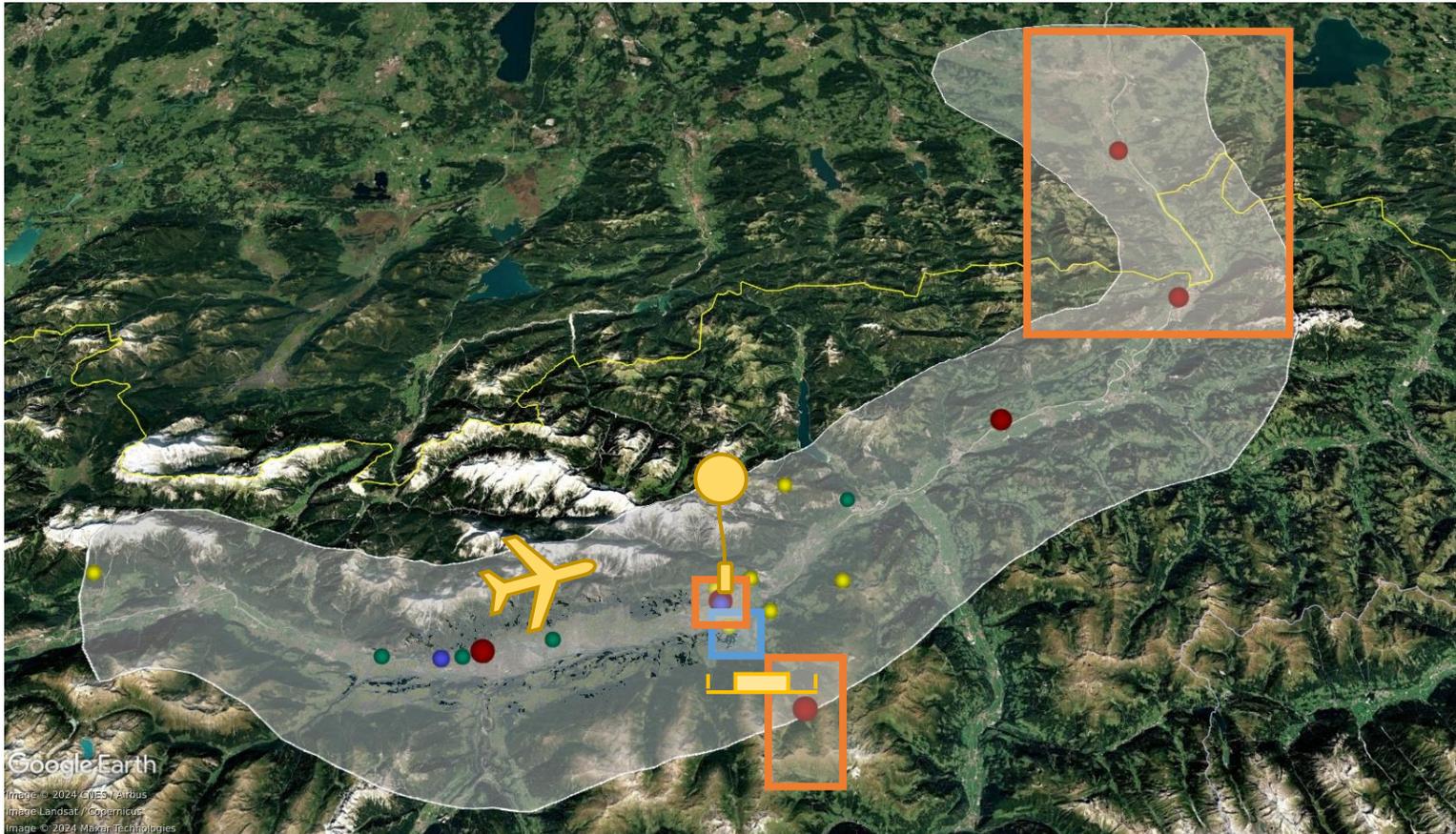
Valley Atmosphere

- ▲ 3D structure of the mountain boundary layer
- ▲ Thermal structure and wind field



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

Extended Observation Periods

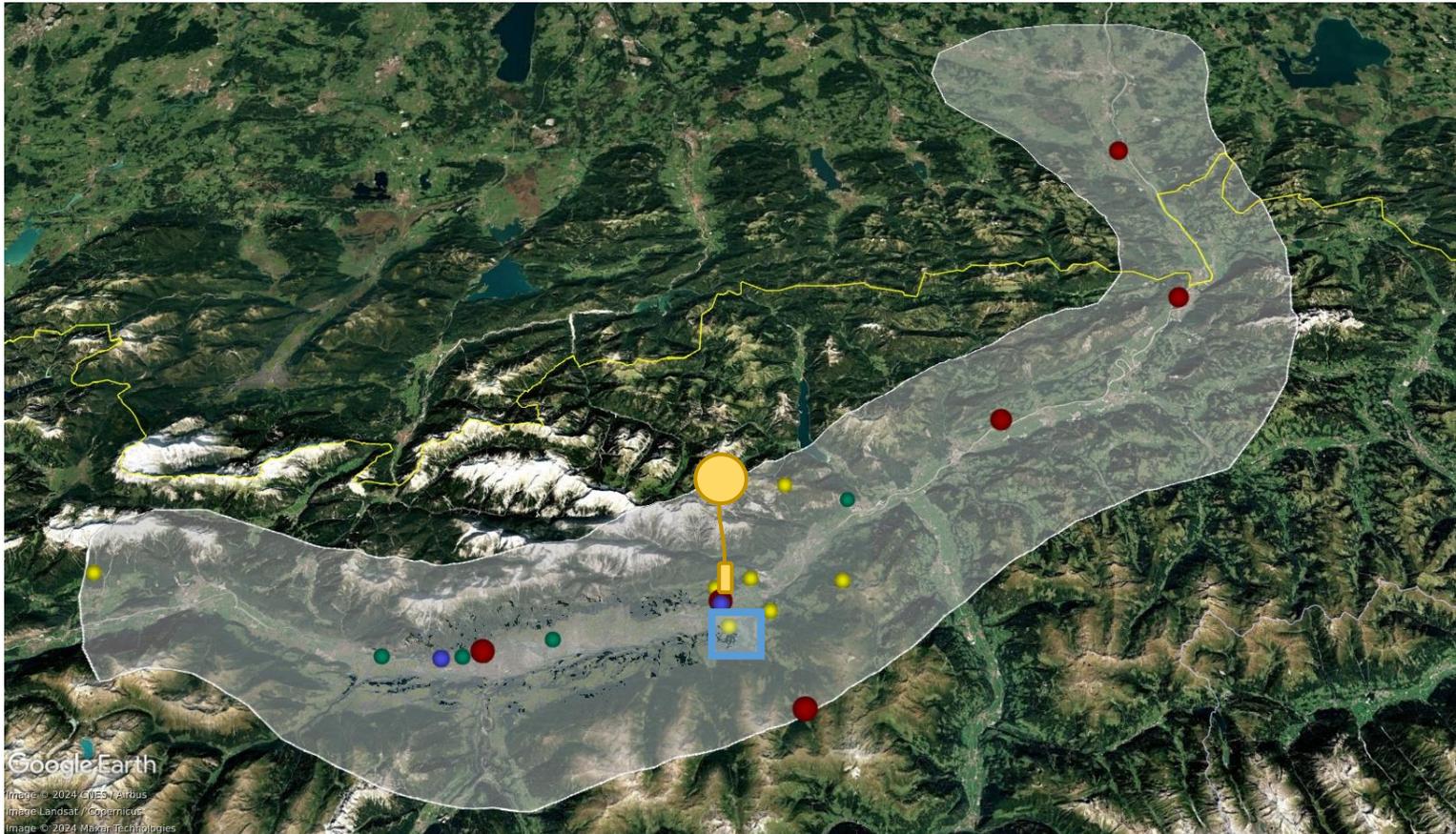


- Radiosonde
- Wind/TRH profile
- Flux station
- Weather radar
- Ceilometer

- wEOP
- sEOP

wEOP – Slope-Wind Experiment

UIBK, Université Grenoble Alpes



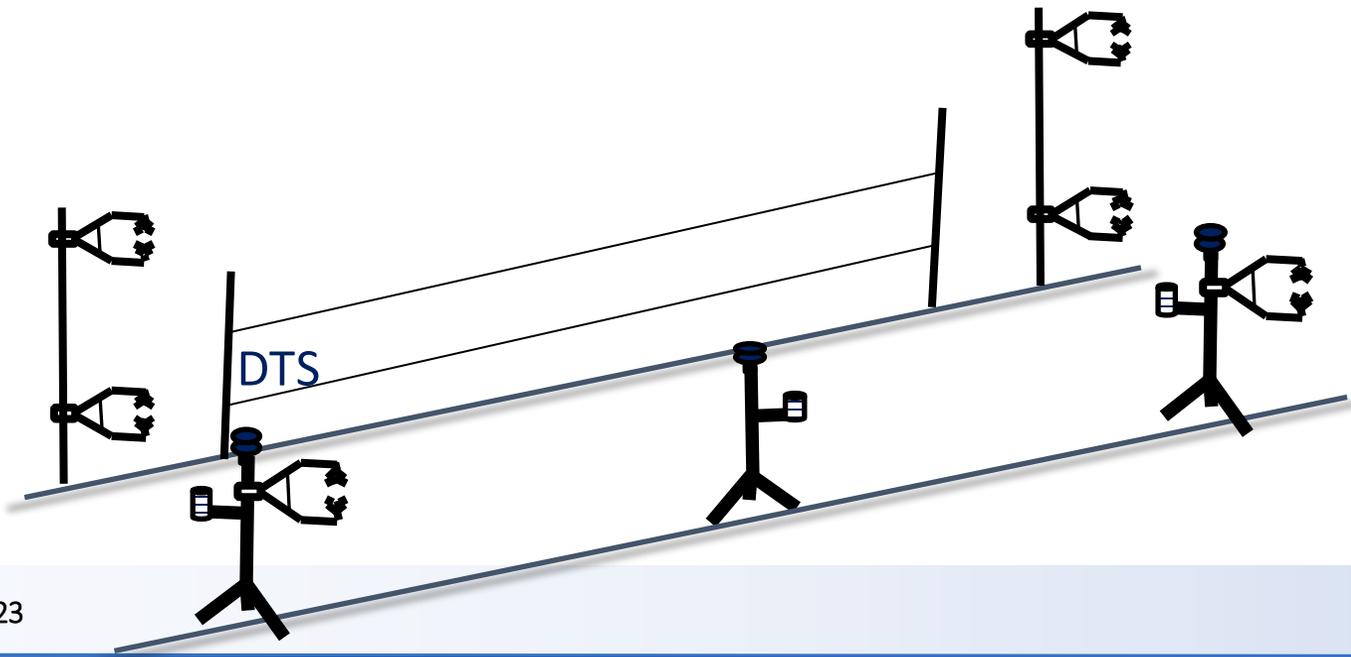
- Radiosonde
- Wind/TRH profile
- Flux station
- Weather radar
- Ceilometer

□ wEOP

wEOP – Slope-Wind Experiment

UIBK, Université Grenoble Alpes

- ▲ Turbulence characteristics of the katabatic flow
- ▲ Advection along and across the slope
- ▲ Heterogeneity of the mean and turbulent flow characteristics

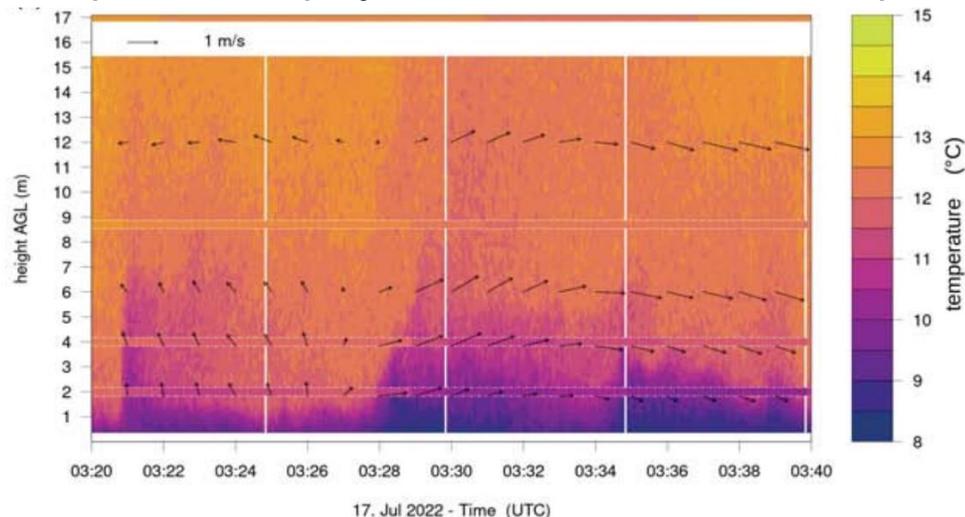


wEOP – Slope-Wind Experiment

UIBK, Université Grenoble Alpes

- ▲ Temperature structure at a high temporal and spatial resolution

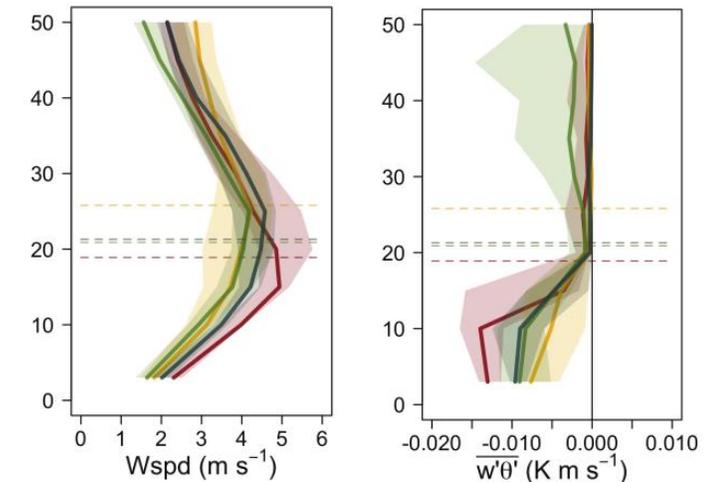
Example DTS deployment at Kolsass – vertical profile



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

- ▲ Vertical profiles of mean and turbulent flow characteristics

Example of deep katabatic flow profiles



Stiperski et al. (2020) : On the turbulence structure of deep katabatic flows on a gentle mesoscale slope. Quart. J. Royal. Meteorol. Soc.

Aircraft Flights

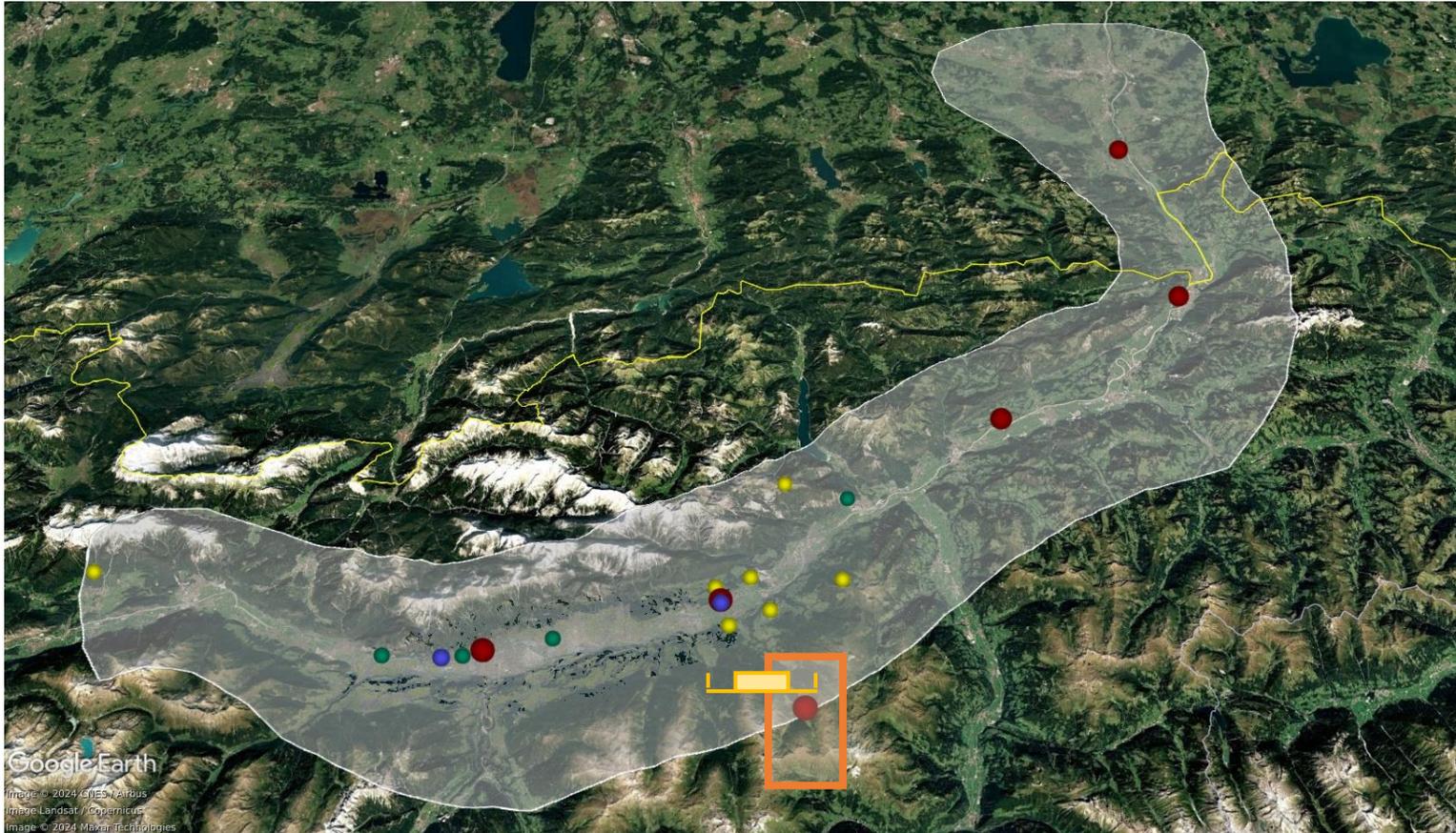
UIBK, DLR, KIT



- ▲ Aircraft flights during individual IOPs
- ▲ 3D structure of the mountain boundary layer
- ▲ Turbulence characteristics above the surface layer

sEOP - Nafingalm

DLR, UIBK



- Radiosonde
- Wind/TRH profile
- Flux station
- Weather radar
- Ceilometer

□ sEOP

sEOP - Nafingalm

DLR, UIBK

- ▲ Thermally driven slope and valley winds
- ▲ Flow interactions, e.g., foehn winds over a pass to the south and local thermally driven flows
- ▲ Swarm of UAS

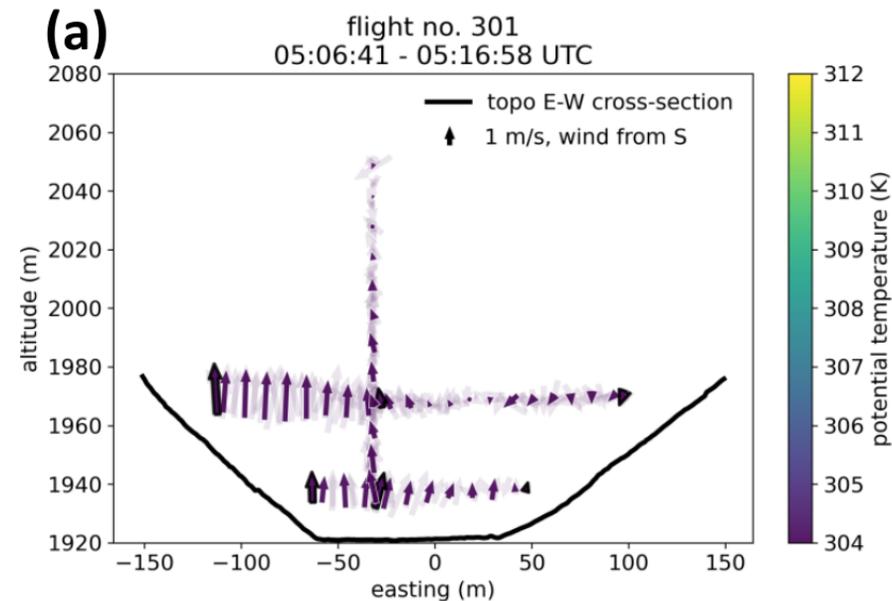
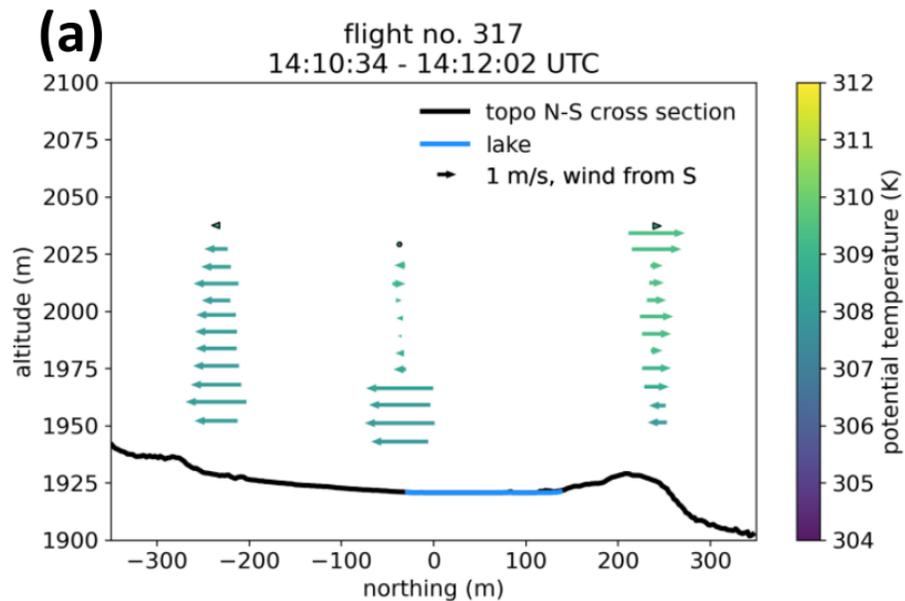
Photos: A. Gohm (test measurements 2024)



sEOP - Nafingalm

DLR, UIBK

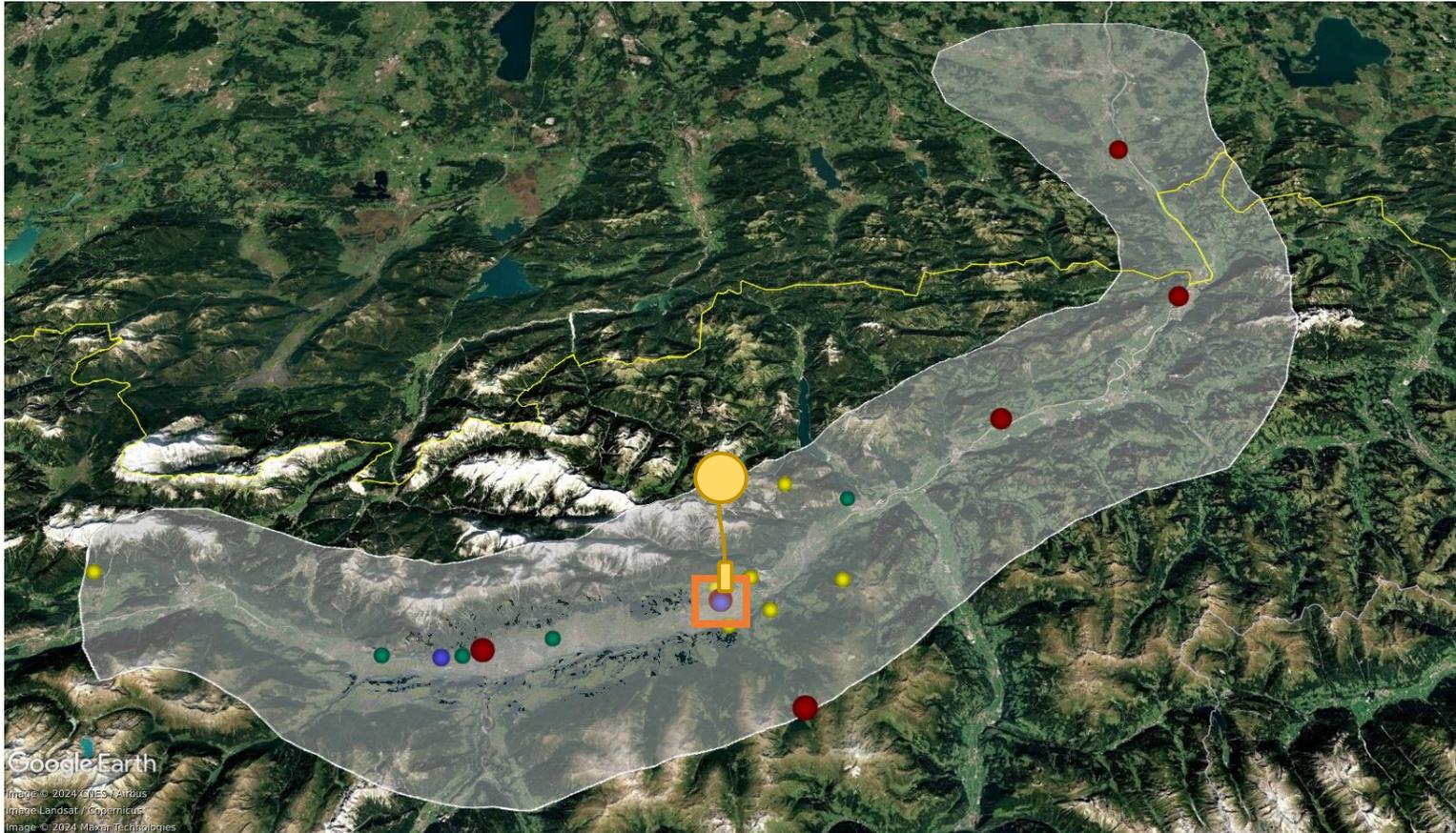
- ▲ Spatial structure of the temperature and wind field using UAS measurements
- ▲ Example from the pre-campaign 2022



Alexa, A. (2023): MS thesis

sEOP - Kolsass

UIBK



- Radiosonde
- Wind/TRH profile
- Flux station
- Weather radar
- Ceilometer

□ sEOP

sEOP - Kolsass

UIBK

- ▲ Turbulence characteristics (e.g., anisotropy) and scaling
- ▲ Role of advection in the surface-energy budget
- ▲ Heterogeneity at a scale of $O[100 \text{ m}]$

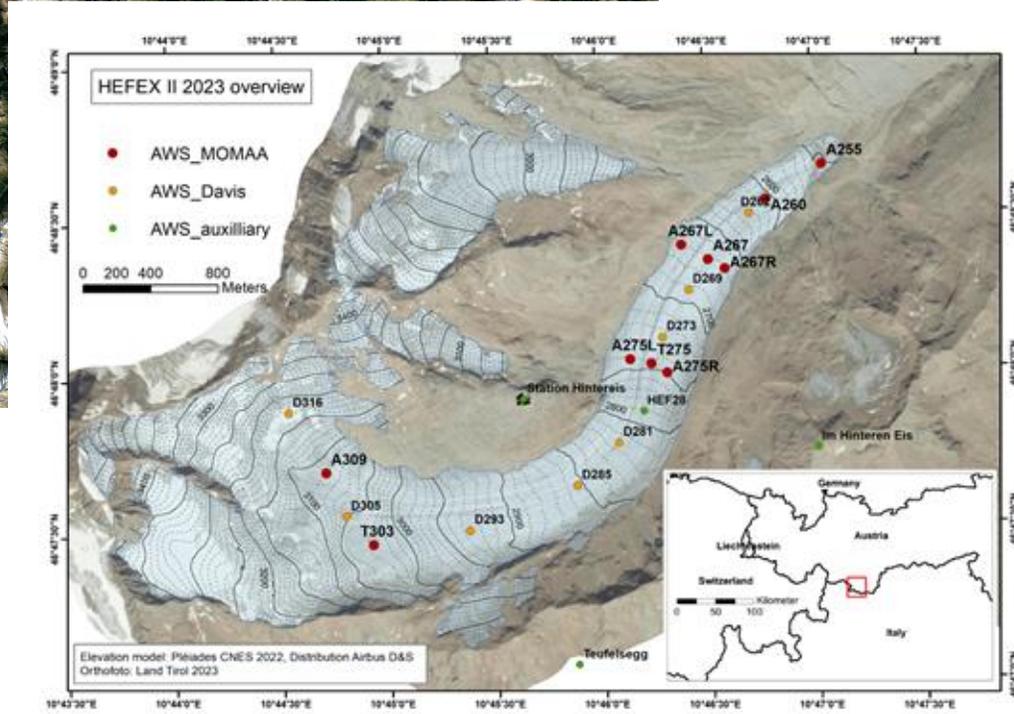
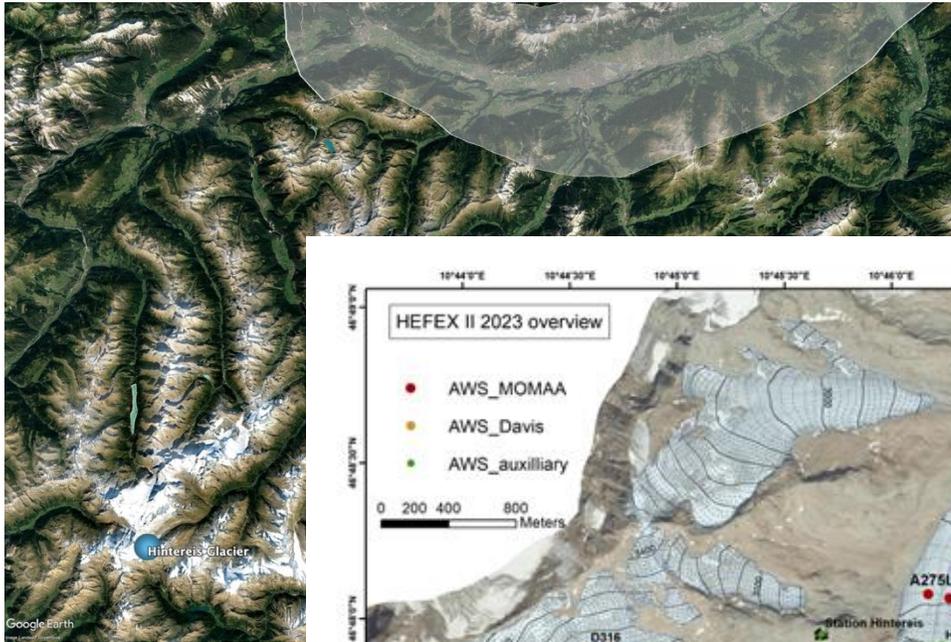


i-Box tower at Kolsass



Hintereisferner

UIBK, Humboldt-Universität Berlin, SLF, ...



HEFEX II campaign 2023

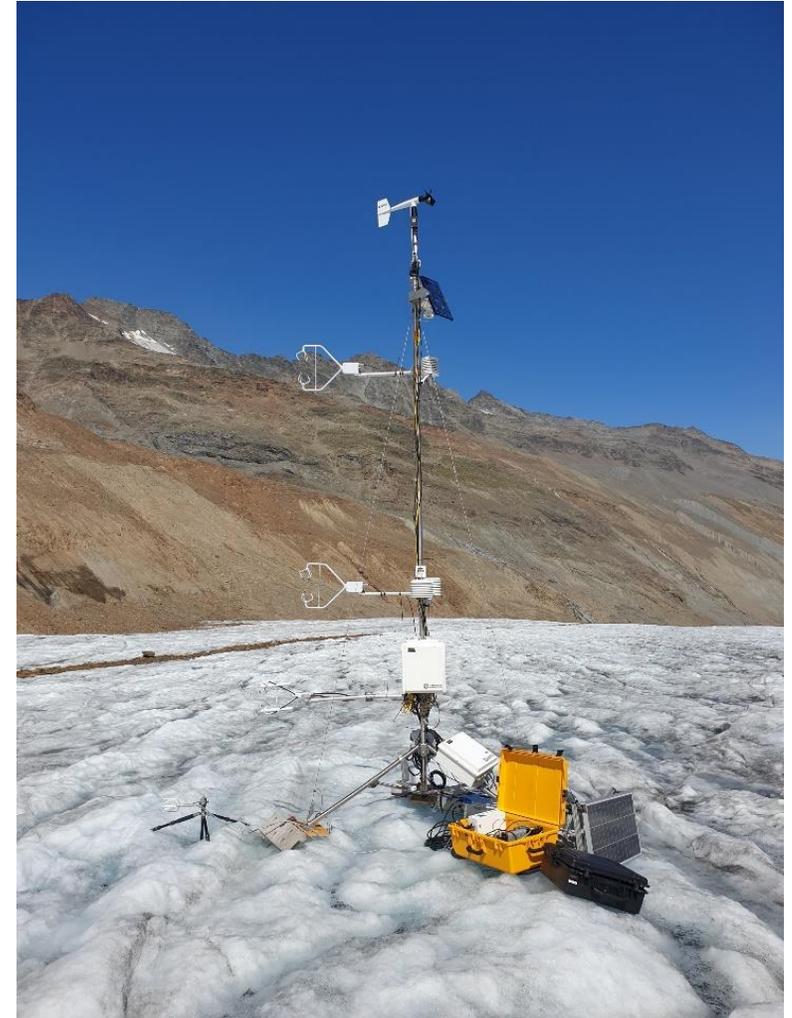


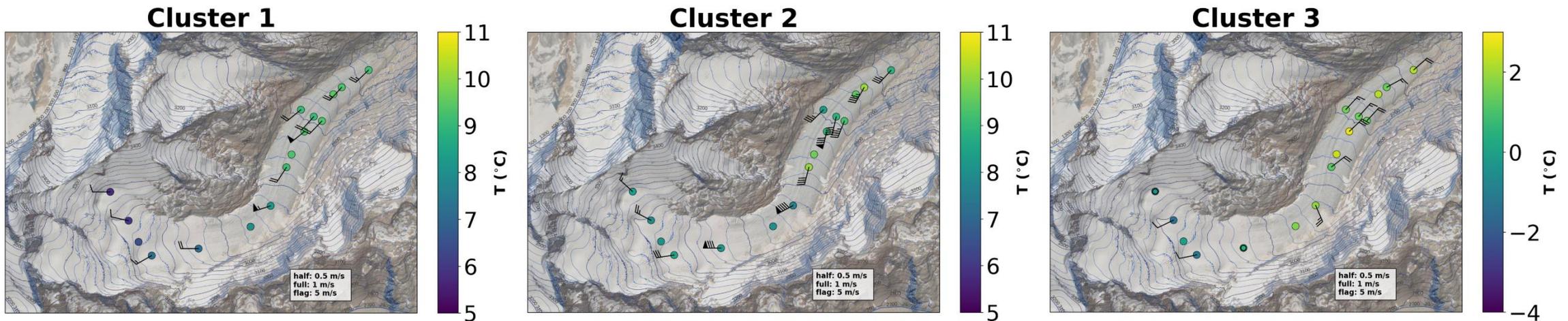
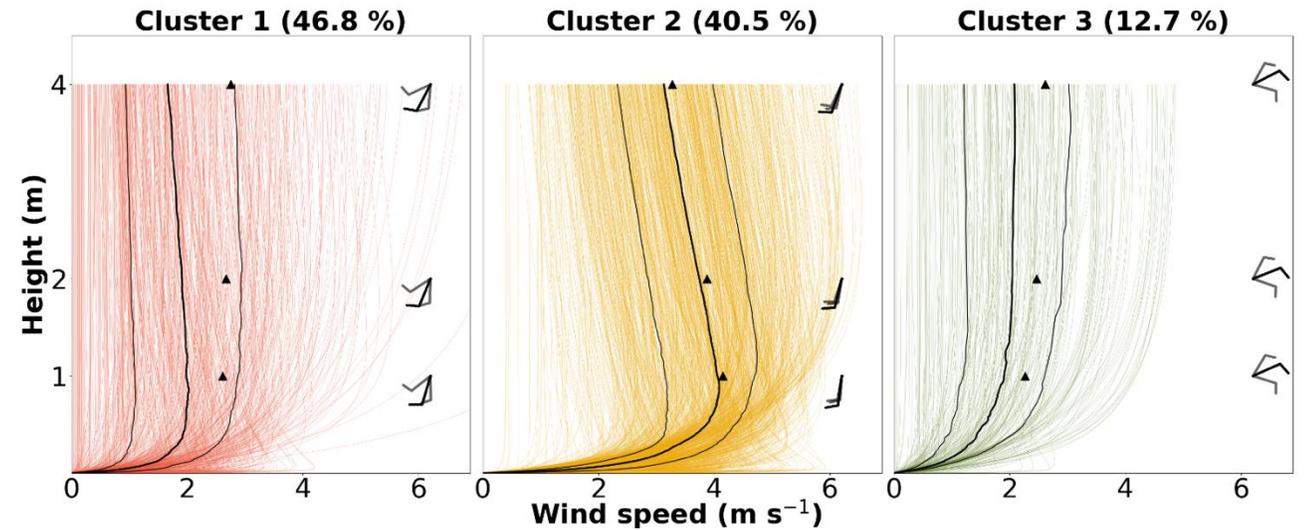
Photo: I. Stiperski

Hintereisferner

UIBK, Humboldt-Universität Berlin, SLF, ...

▲ Example from HEFEX II

▲ Clustering of katabatic flows

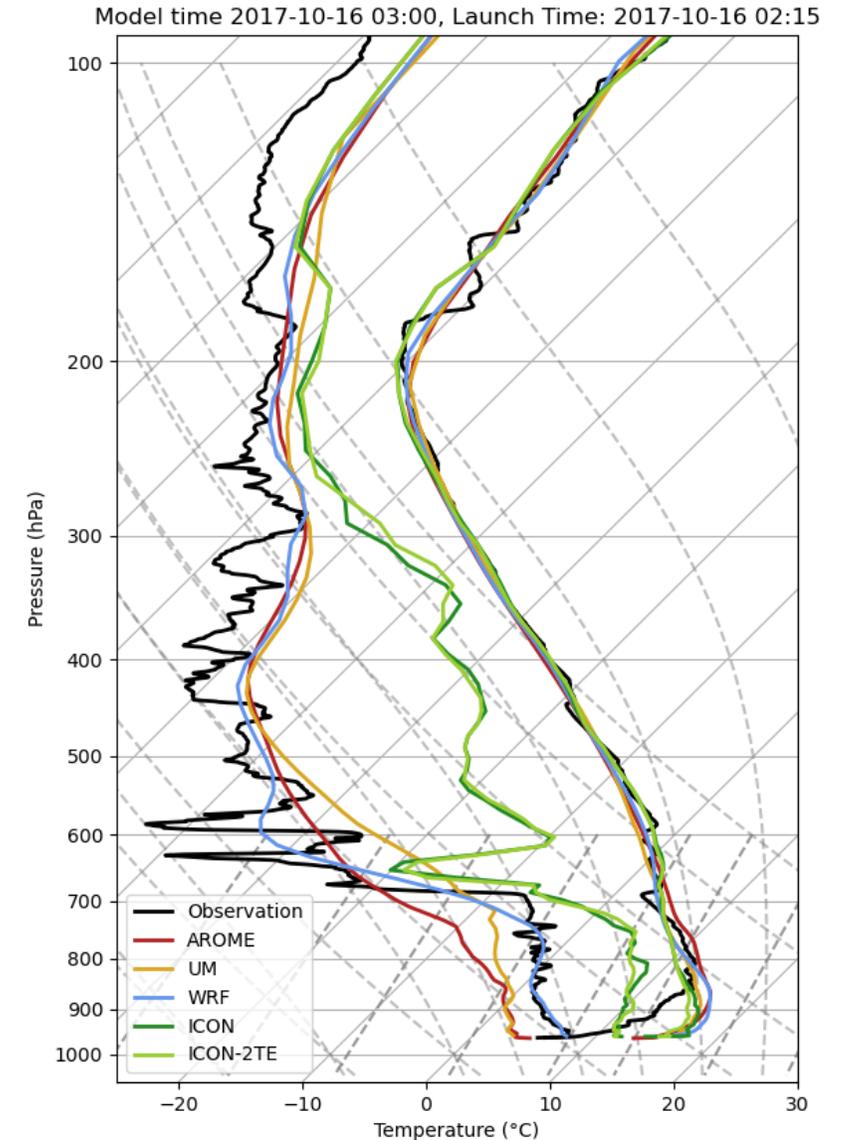


Nicholson et al. (2024), submitted to Bull. Meteorol. Soc. (figures G. Nitti)

Modeling Activities

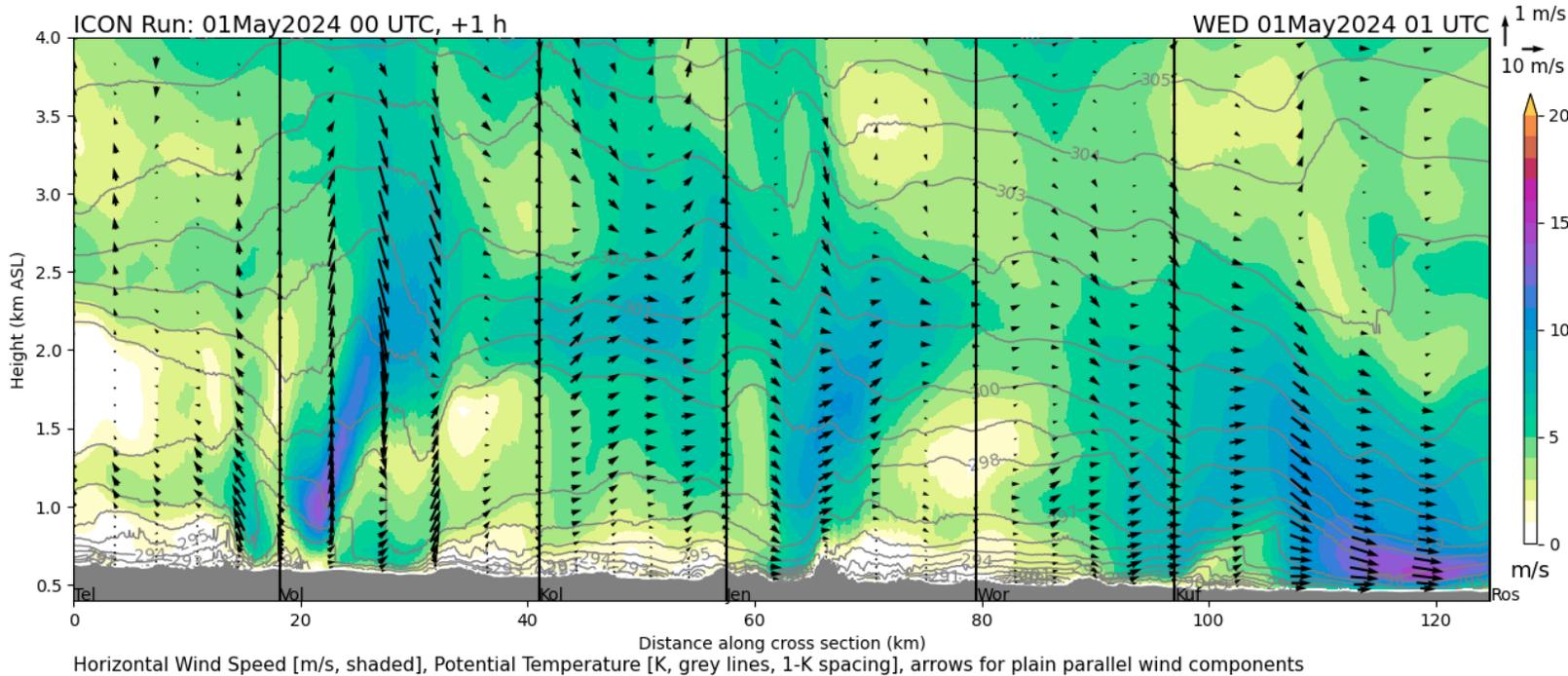
- ▲ Model intercomparison studies (e.g., thermally driven flows, convection, cold-air pools)
- ▲ Example: cold-air pool development in the Inn Valley

Model	Group
AROME	GeoSphere Austria
AROME	Météo-France
ICON	Goethe Universität Frankfurt
Meso-NH	Météo-France
UM	Met Office
WRF	University of Innsbruck
WRF	Université Grenoble Alpes



Modeling Activities

- ▲ NWP runs for daily weather briefings
- ▲ 6 European weather services
- ▲ 500-m high-resolution runs



Data Provider	Model	Mesh size
	AROME (C-LAEF)	2.5 km
	GeoSphere Austria	AROME (C-LAEF-1k)
	AROME	1.3 km
	Meteo-France	AROME
ISAC	MOLOCH	1.25 km
	ICON	500 m
DWD	ICON - D2	2.2 km
MeteoSwiss	ICON	500 m
UK Met Office	MetUM	1 km

Opportunities to get involved

We are looking for students to

- ▲ help with the fieldwork, e.g.,
 - ▲ setting up stations
 - ▲ checking on stations
 - ▲ launching radiosondes
- ▲ prepare weather forecasts for daily weather briefings

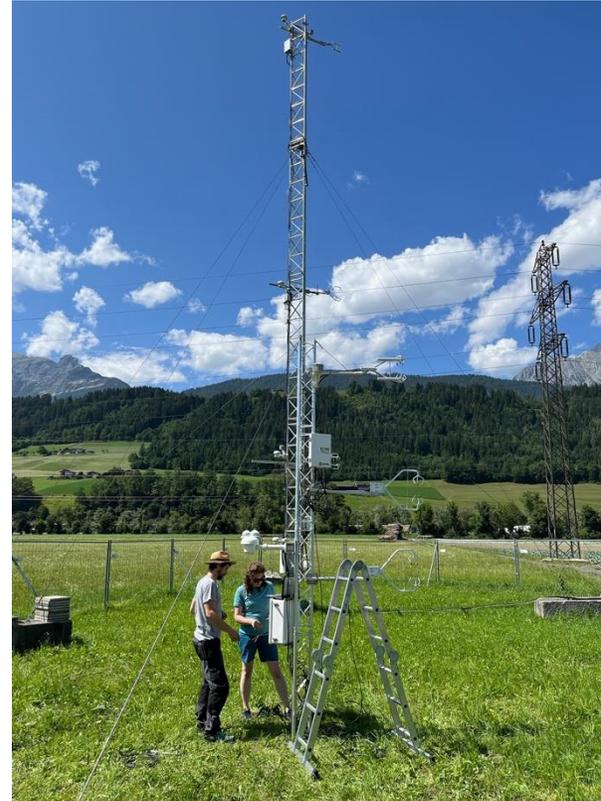


Photo: M. Lehner



Photo: E. Crosman

MSc and BSc Thesis Topics

Representation of cold-air pools in numerical models
– a TEAMx model intercomparison study

Manuela Lehner, Helen Ward

- output from multiple different models
- relate model performance to parameterizations, large-scale circulation, and surface characteristics

MSc and BSc Thesis Topics

Representa
– a TEAM

Manuela

- output
- relate
- large-
- chara

Turbulence climatology at the i-Box stations

Mathias Rotach

- climatology for the last 10 years
- reference for the one-year long TOC

MSc and BSc Thesis Topics

Representation of cold-air pools in numerical models

– a TEAMx model inter-

Manuela Lehner, He

- output from mu
- relate model per
- large-scale circul
- characteristics

Characterizing the boundary layer structure above Innsbruck with novel lidars

Alexander Gohm

- evaluation of new Raman lidar and DIAL
- document boundary-layer evolution over Innsbruck (temperature, humidity, wind)

MSc and BSc Thesis Topics

Representation of cold-air pools in numerical models
– a TEAMx model intercomparison study

Manuela Lehner, Helen Ward

- output from multiple sites
- relate model performance to large-scale circulation, and slope characteristics

Turbulence climatology at the i-Box stations

Characterizing

Mathias Rotach

Alexander

reference for the

evaluation

document

Innsb

Investigating the turbulent structure of katabatic flows with small quadrotor drones

Alexander Gohm

- drone measurements during the wEOP slope-wind experiment
- interaction between slope winds and larger-scale flow in the valley atmosphere

MSc and BSc Thesis Topics

Representation of cold-air pools in numerical models

– a TEAMx model intercomparison study

Manuela Lehner, Helen Ward

Manuela Lehner, Helen Ward

• output from multiple different models

• relate model performance to parameter

large-scale circulation, and surface

characteristics

• document bound

Innsbruck (temp

• intera

flow i

Hintereisferner summer surface energy balance

Lindsey Nicholson, Rainer Prinz, Emily Collier

- analyze the surface-energy balance and mass fluxes
- optimize a surface-energy balance model using the data

MSc and BSc Thesis Topics

Representation of cold-air pools in numerical models
– a TEAMx model intercomparison study

Manuela Lehner, Helen Ward
Turbulence climatology at the i-Box stations
Characterizing the boundary layer structure above

Manuela Lehner, Helen Ward
Investigating the turbulent structure of katabatic
flows with small-scale

- output from multiple different models
- relate model performance to parameterizations, large-scale circulation, and surface characteristics

Carbon fluxes over a glacier surface

Lindsey Nicholson, Rainer Prinz, Emily Collier

- compare observed carbon fluxes with published values in the literature
- how do carbon fluxes compare to recently deglaciated terrain

MSc and BSc Thesis Topics

Representation of cold-air pools in numerical models
– a TEAMx Turbulence climatology at the i-Box stations

 Watch out for more TEAMx thesis topics being added on OLAT over the next months

Master Thesis

→] Registration

▼  Restricted area

○ Topic assignment

 Completed Master th

Master Thesis in Atmospheric Sciences

Content: Information on the **Master thesis in Atmospheric Sciences** and assignment of thesis topics.

Note for students: Please register below for obtaining access to the restricted area.



Summary

TEAMx

... Multi-scale transport and exchange processes in the atmosphere over mountains – programme and experiment

- ▲ international research program
- ▲ large involvement of UIBK and ACINN
- ▲ ongoing one-year long observational campaign with two multi-week extended observations periods in the upcoming winter and summer
- ▲ many observational activities in the Inn Valley with ACINN participation
- ▲ many opportunities for students to get involved
- ▲ a lot of research expected to come out of TEAMx, including student theses