



**Introducing**  
**the international cooperation programme TEAMx:**  
**Multi-scale Transport and Exchange Processes in**  
**the Atmosphere over Mountains**  
**Programme and Experiment**

**Mathias W. Rotach<sup>1</sup>, Marco Arpagaus<sup>2</sup>, Joan Cuxart<sup>3</sup>, Stephan De Wekker<sup>4</sup>, Vanda Grubišić<sup>5</sup>, Norbert Kalthoff<sup>6</sup>, Dan Kirshbaum<sup>7</sup>, Manuela Lehner<sup>1</sup>, Stephen Mobbs<sup>8</sup>, Alexandre Paci<sup>9</sup>, Elisa Palazzi<sup>10</sup>, Stefano Serafin<sup>1</sup>, Dino Zardi<sup>11</sup>**

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<sup>5</sup>NCAR EOL, <sup>6</sup>Karlsruhe Institute of Technology, <sup>7</sup>McGill University <sup>8</sup>National Centre of Atmospheric  
Sciences, <sup>9</sup>Meteo France, <sup>10</sup>ISAC CNR, <sup>11</sup>University of Trento

**Nowcasting and Mesoscale Research**  
**Working Group**  
**21 October 2020**

# Outline

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- TEAMx in a (pretty big) nutshell
  - what is it?
  - 'who' is it?
  - what do we do?
- Research questions
- Field experiment
- Numerical experimentation

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Multi-scale **T**ransport and  
**E**xchange Processes in the  
**A**tmosphere over  
**M**ountains  
Programme and **e**xperiment

- ...a bottom-up financed research programme on weather, climate & air pollution in mountain areas
- In the 'tradition' of international mountain meteorology programmes (ALPEX, PYREX, MAP)
- Institutional 'crowd funding' for a **Programme Coordination Office** (*PCO* - @ UIBK)

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## Multi-scale **T**ransport and **E**xchange Processes in the **A**tmosphere over **M**ountains

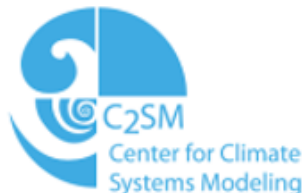
### Programme and **e**xperiment

- Embedded in international programmes
  - [Crosscutting project](#) within the GEWEX Hydroclimatology Panel ([GHP](#))
  - endorsement sought within WWRP (pending)
  - WMO High Mountain Summit (Geneva Oct. 2019)
- Coordination with other international activities
  - e.g., COST action PROBE

# TEAMx – ‘who’ is it?



- A group of institutions...
- ‘crowd funding’ for a Programme Coordination Office (PCO)
  - **sponsors:** Karlsruhe Institute of Technology KIT, Météo France, MeteoSwiss, National Center for Atmospheric Science (NCAS), University of Innsbruck, University of Trento, ZAMG, Center for Climate Systems Modeling (C2SM)
  - Programme Coordinator: Helen Ward (UIBK) (formerly Stefano Serafin)

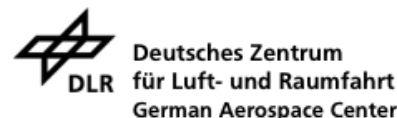


# TEAMx – ‘who’ is it?



- A group of institutions...
- Memorandum of Understanding
  - signed by interested institutions
  - support research topic, liaise projects, contribute to discussion, workshops, .....
  - open for signature (contact Helen)

*presently....*



- 
- Coordination and Implementation Group (CIG)
  - Individuals from (mostly) sponsoring institutions
    - Marco Arpagaus, MeteoSwiss
    - ❖ Joan Cuxart, Universitat de les Illes Balears
    - ❖ Stefan De Wekker, University of Virginia
    - ❖ Vanda Grubišić, NCAR
    - ❖ Norbert Kalthoff, Karlsruhe Institute of Technology (KIT)
    - ❖ Daniel Kirshbaum, Mc Gill University
    - ❖ Manuela Lehner, University of Innsbruck
    - ❖ Stephen Mobbs, University of Leeds (NCAS)
    - ❖ Alexandre Paci, Meteo France (CNRS)
    - ❖ Elisa Palazzi, ISAC CNR
    - ❖ Mathias Rotach, University of Innsbruck (chair)
    - ❖ Stefano Serafin, University of Innsbruck (former PC)
    - ❖ Dino Zardi, University of Trento
  - ,runs the programme‘

# TEAMx – ‘who’ is it?



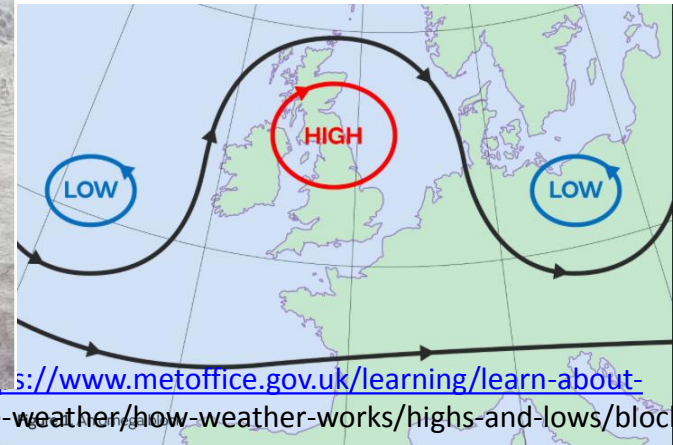
- 
- foster research on **Multi-scale Transport and Exchange Processes in the Atmosphere over Mountains**

# Mountain Weather and Climate

- long tradition
  - orographic precipitation
  - gravity waves, ~ breaking
  - blocking
  - Föhn, Bora & co
  - dynamic features
- Alpex, Pyrex, MAP



<http://blog.weatherflow.com/gravity-waves-over-new-hampshirevermont/>



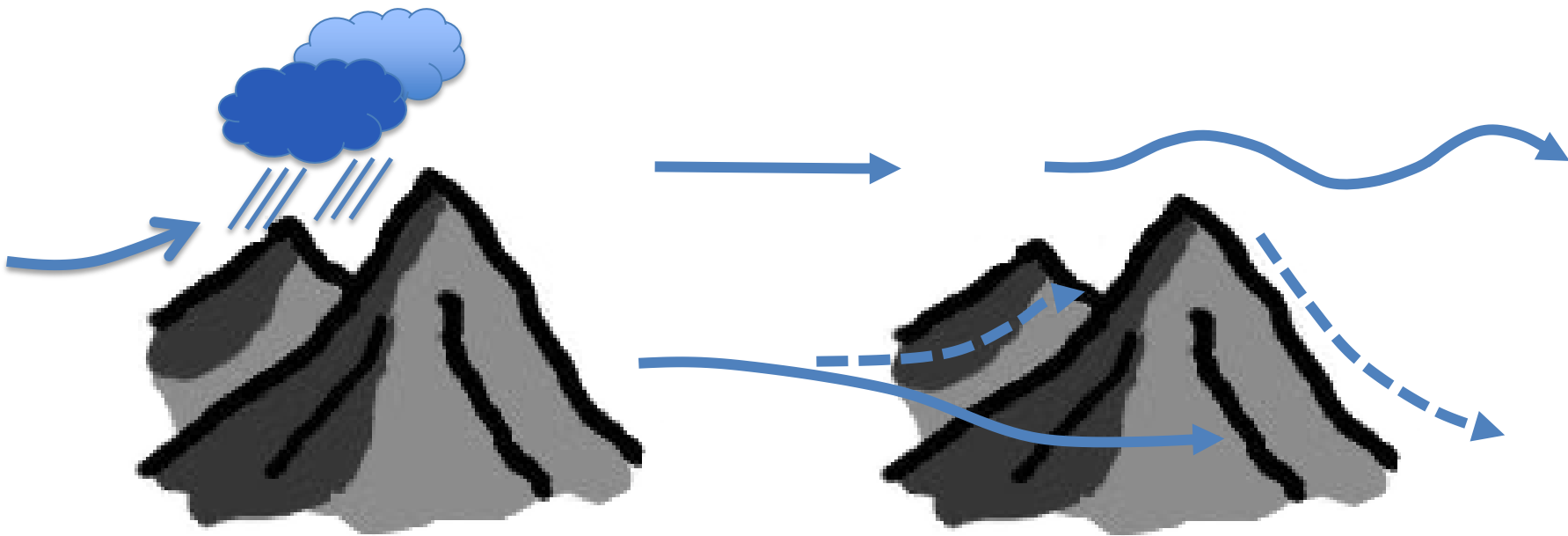
<https://www.metoffice.gov.uk/learning/learn-about-the-weather/how-weather-works/highs-and-lows/blocking>

# Mountain Weather and Climate

## ➤ common interest, traditional

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- impact of mountains on state of the atmosphere
- e.g., how does 'a mountain' change the production of rain?
- how does 'a mountain' modify the flow?
- etc., etc. ...



**Which effect has the presence of the mountain on the atmosphere?**

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# Mountain Weather and Climate

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- common interest, traditional
  - impact of mountains on state of the atmosphere
  - e.g., how does 'a mountain' change the production of rain?
  - how does 'a mountain' modify the flow?  
etc., etc. ...
- mountain → atmosphere perspective
- from a global point of view:
  - 'mountain' is part  
of the surface
  - character of the surface

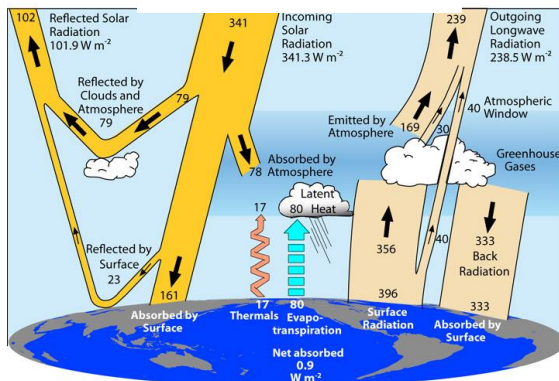


<http://www.panoramio.com/photo/1724212>

# Exchange

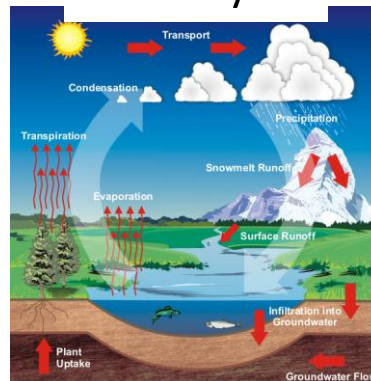
- character of the surface
  - determines the *exchange* between the atmosphere and the earth
  - *coupling* of the atmosphere with the surface
- mountain ↔ atmosphere perspective
  - how does the atmosphere – **which has been modified by the mountain** – execute this exchange?

energy budget



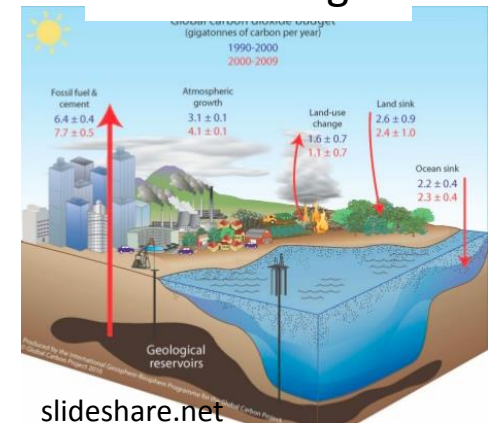
<https://scied.ucar.edu/longcontent/energy-budget>

water cycle



[http://www.algebralab.org/practice/practice.aspxfile=Reading\\_WaterCycle.xml](http://www.algebralab.org/practice/practice.aspxfile=Reading_WaterCycle.xml)

carbon budget

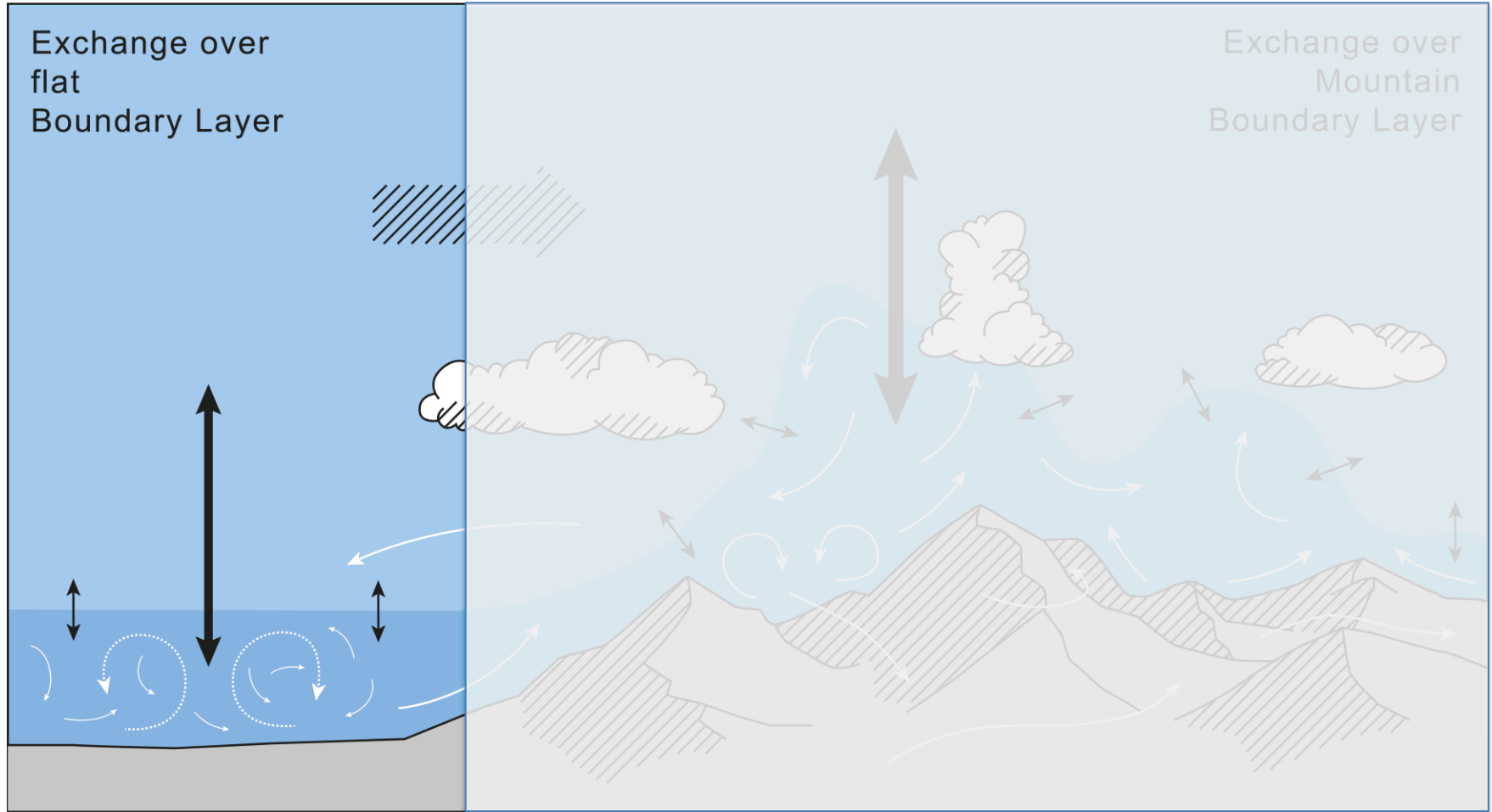


# Exchange

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- character of the surface
  - determines the *exchange* between the atmosphere and the earth
  - *coupling* of the atmosphere with the surface
- mountain ↔ atmosphere perspective
  - how does the atmosphere – **which has been modified by the mountain** – execute this exchange?
  - traditionally: this is the role of the *boundary layer*
  - exchange of heat, mass and momentum *at the surface*
  - transport to the ground / away from the ground
  - coupling earth - atmosphere

# Exchange



# Exchange over Mountains

- More than 'traditional boundary layer'
  - interaction with meso-scale ('mountain- induced' flows)
  - largely inhomogeneous in space
- **Mountain Boundary Layer (MoBL)**

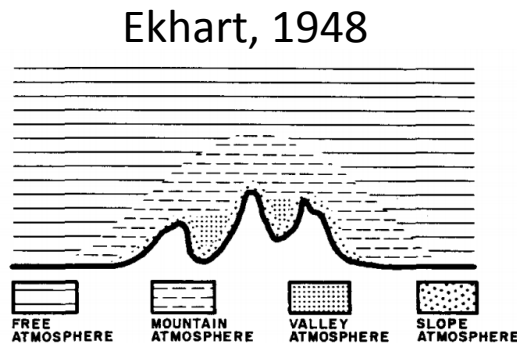
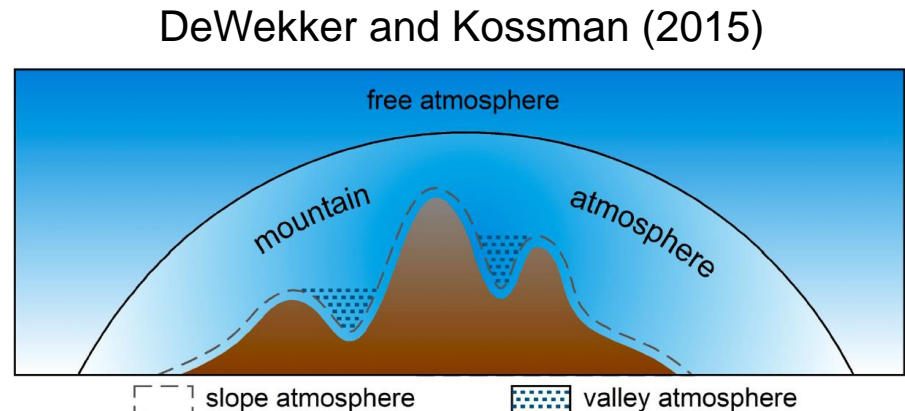
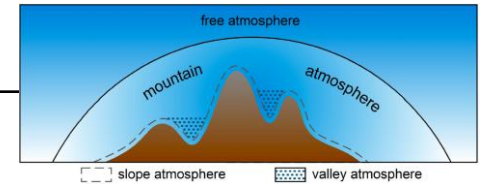


Figure 13: Diagram of the structure of the atmosphere above a mountain range.

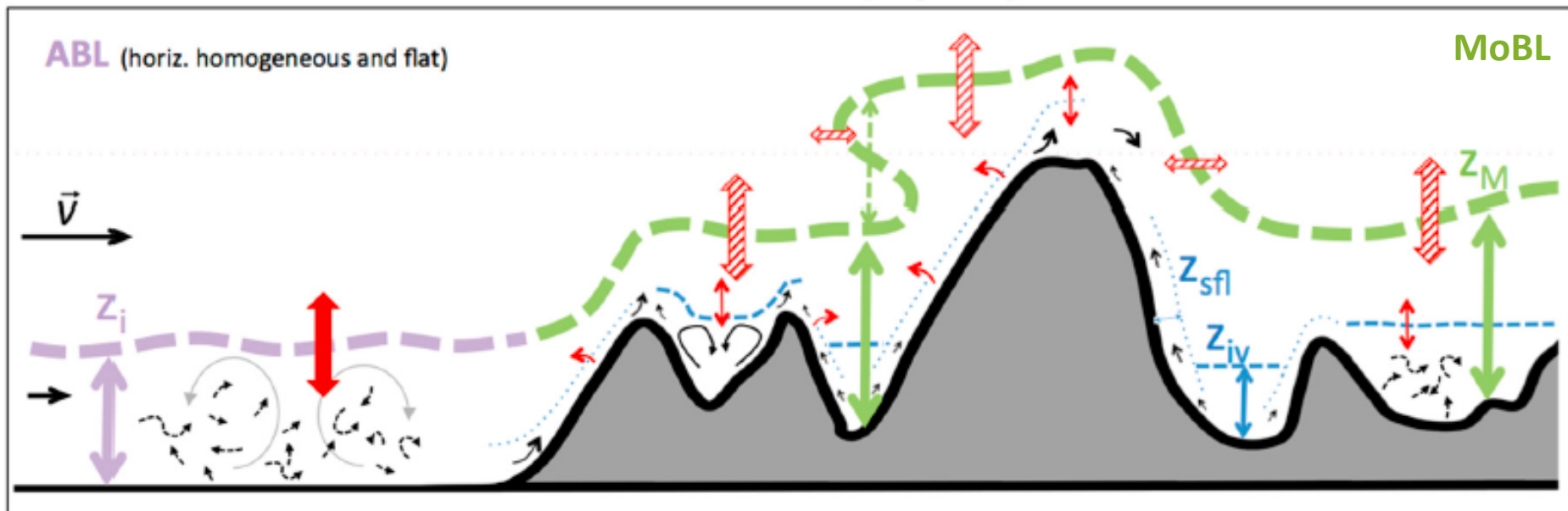


# Mountain Boundary Layer (MoBL)

- ‘layer influenced by mountain surface’
  - not only *surface character* (turbulence)
  - interaction with meso-scale flow (valley / slope winds)
  - interaction with synoptic flow



unstable stratification (daytime)



Lehner and Rotach (2018)

# Exchange over Mountains

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- Impact on global cycles (mass, momentum, energy)
  - hence atmospheric modeling
  - prominent example: gravity wave drag

# Exchange over Mountains

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- Impact on global cycles (mass, momentum, energy)
  - hence atmospheric modeling
  - prominent example: gravity wave drag
- better weather forecast and climate scenarios?
  - certainly yes for momentum
  - should also be the case for heat, mass...
- In particular
  - better (more realistic) near-surface flow (point forecast )
  - required for *impact modeling*
  - air pollution, hydrological, agricultural, energy (wind/solar power), avalanche, health, ..... modeling

right for the right reason

# TEAMx – what do we do?

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- Knowledge gaps (processes understanding)
  - special issue *Atmosphere: Atmospheric Processes over Complex Terrain* (Eds Rotach and Zardi)
  - White Paper (Serafin et al. 2020), on the TEAMx website
  - working groups on specific processes (land-exchange, MoBL, convection, mountain climate chemistry, Waves and Dynamics)

Stefano Serafin, Mathias W. Rotach, Marco Arpagaus,  
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Vanda Grubišić, Norbert Kalthoff, Thomas Karl, Daniel J. Kirshbaum,  
Manuela Lehner, Stephen Mobbs, Alexandre Paci, Elisa Palazzi,  
Adriana Raudzens Bailey, Jürg Schmidli, Georg Wohlfahrt, Dino Zardi

## **Multi-scale transport and exchange processes in the atmosphere over mountains**

**Programme and experiment**

# Knowledge Gaps



## Working groups

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### Working group on Atmospheric Chemistry

Investigating atmospheric transport and atmospheric chemistry in mountainous terrain

**Leaders:** Martin Graus (University of Innsbruck) and Marcus Hirtl (ZAMG)

### Working group on Mountain Boundary Layer

High-resolution modelling experiments, development of an observation strategy for the MoBL

**Leaders:** Sebastian Hoch (University of Utah), Manuela Lehner (University of Innsbruck) and Stefano Serafin (University of Vienna)

### Working group on Mountain Climate

Improving understanding and modelling of the processes by which mountains are shaping regional climates

**Leaders:** Nikolina Ban (University of Innsbruck) and Sven Kotlarski (MeteoSwiss)

### Working group on Orographic Convection

Studies of convective triggering due to mechanical and thermal orographic forcing

**Leaders:** Daniel Kirshbaum (McGill University) and M. Marcello Miglietta (ISAC-CNR)

### Working group on Surface-Atmosphere Exchange

Description not available yet

**Leaders:** Helen Ward (University of Innsbruck) and Lorenzo Giovannini (University of Trento)

### Working group on Waves and Dynamics

Description not available yet

**Leaders:** TBD

# Exchange of energy, momentum & mass

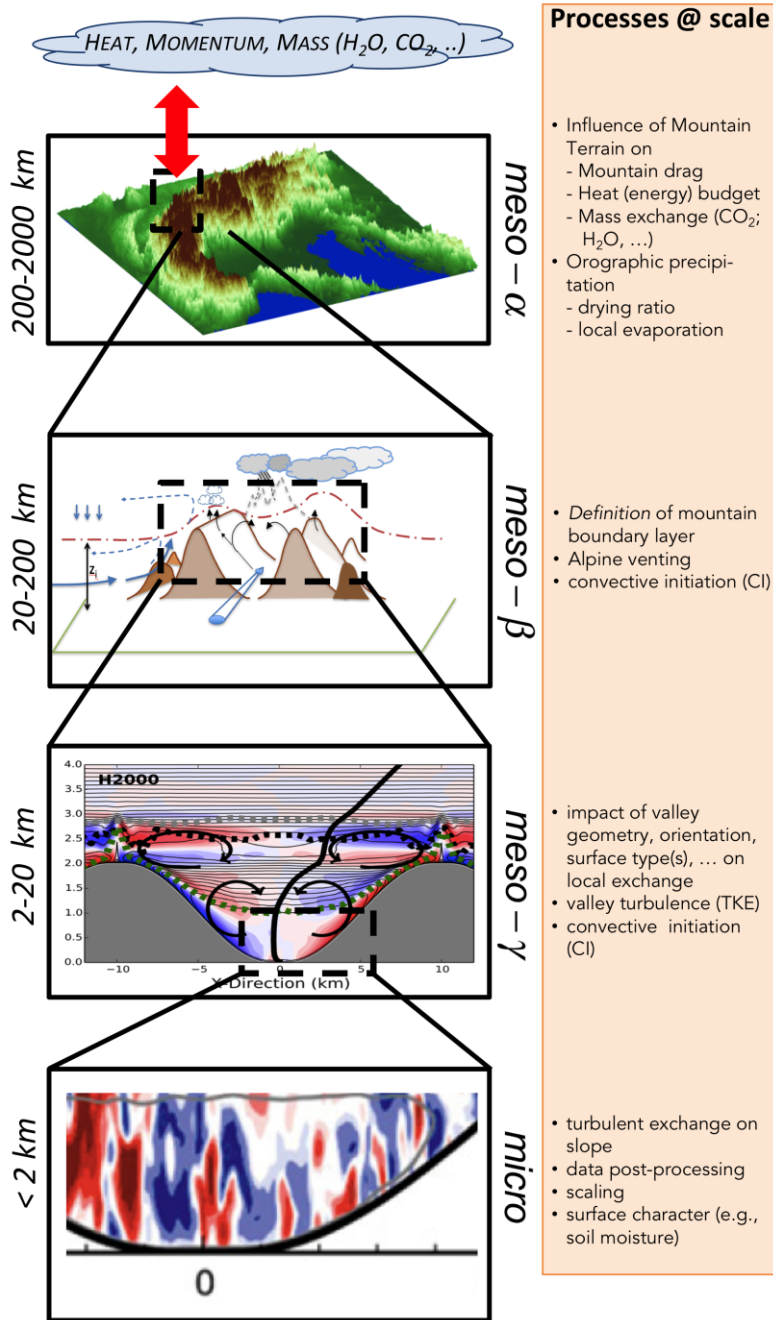
## Scale interactions

- cyclogenesis, instability
- PV generation
- blocking

- impact of synoptic flow
  - stability/ strength/ direction
- interaction between flows in different valleys
- CO<sub>2</sub> uptake
- moisture export

- interaction orog. precip. - valley drainage
- ridge-area turbulence
- impact of background flow on exchange
- chemistry-dynamics

- interaction slope flow - turbulent exchange
- radiation - turbulence
- turbulence-chemistry



## topics:

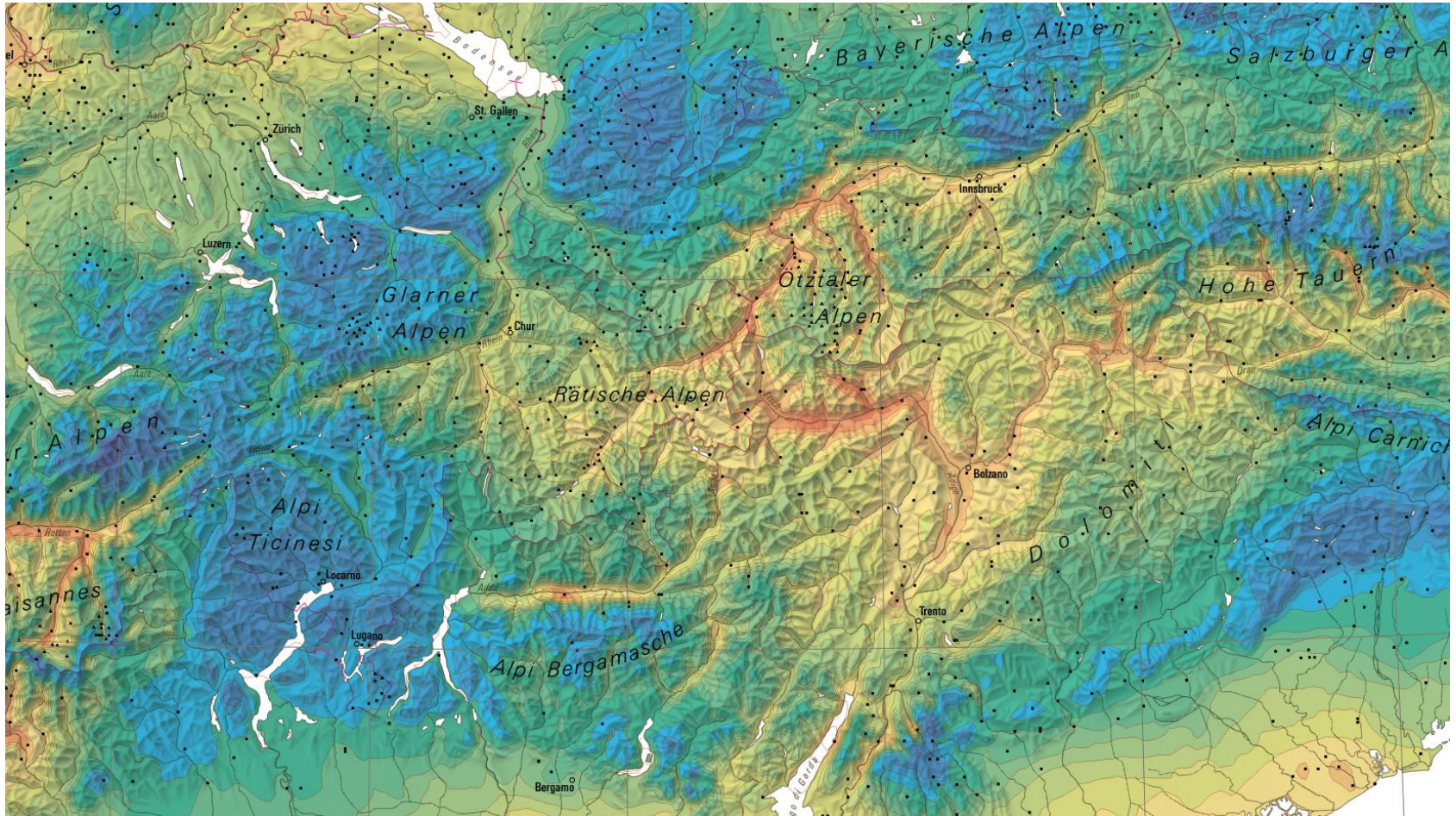
- BLs in complex terrain
- thermally driven flows
- dynamic transport (waves, breaking, ...)
- convection & orography
- stable BLs
- pollutant transport and dispersion

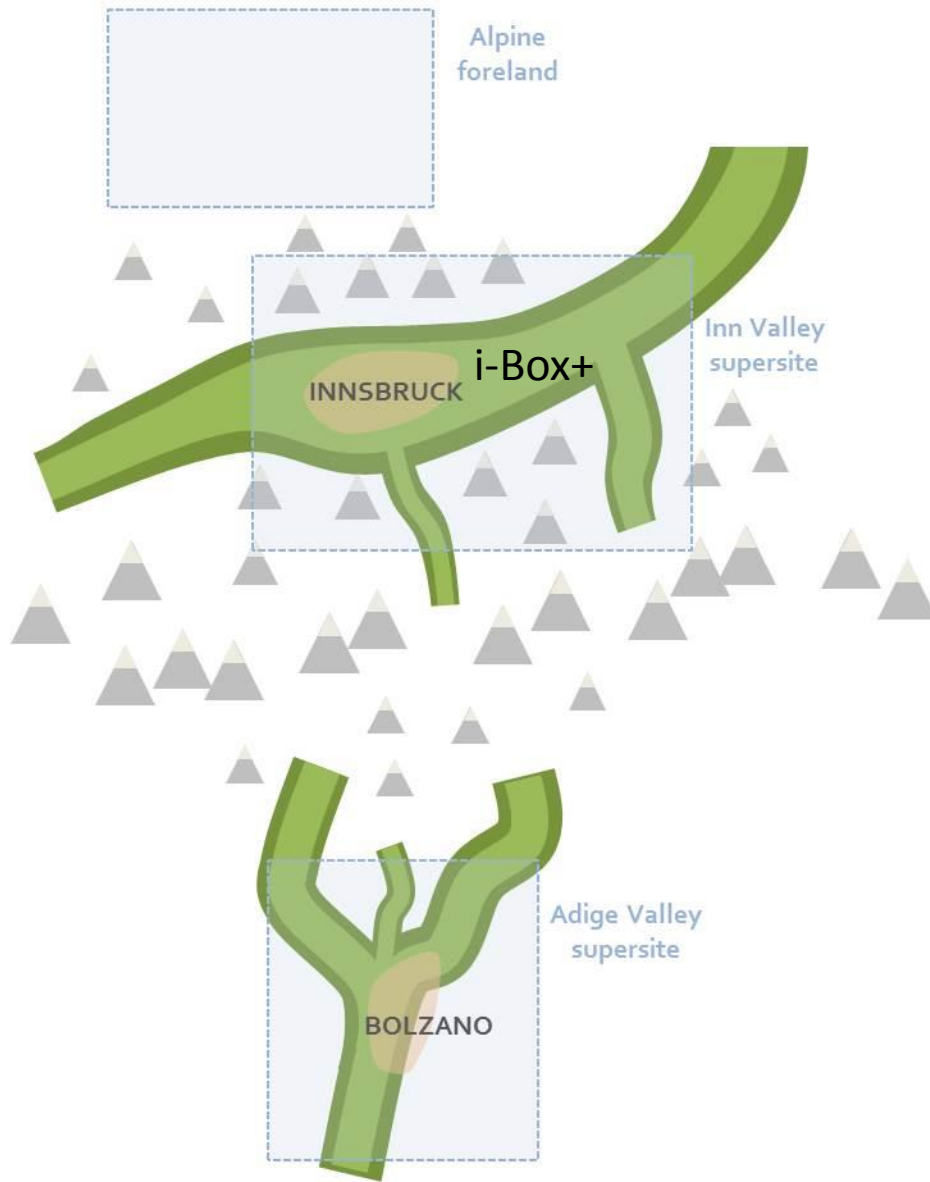
→ *and their interactions*

- 
- Knowledge gaps (processes understanding)
    - special issue Atmosphere
    - White Paper (Serafin et al. 2020), on the TEAMx website
    - working groups on specific processes (land-atmosphere exchange, MoBL, convection, mountain climate, atmospheric chemistry, Waves and Dynamics)
  - Prepare for a joint field experiment
    - 2023-2024, yearlong observational programme
    - summer and winter IOPs
    - 3 'super boxes' (target areas) – north/south of the Alps
    - seek obs. support from outside Europe

# Broader Target Area

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3 super sites / target areas

→ 3d MoBL structure

→ near-surface exchange

→ valley / slope / crest

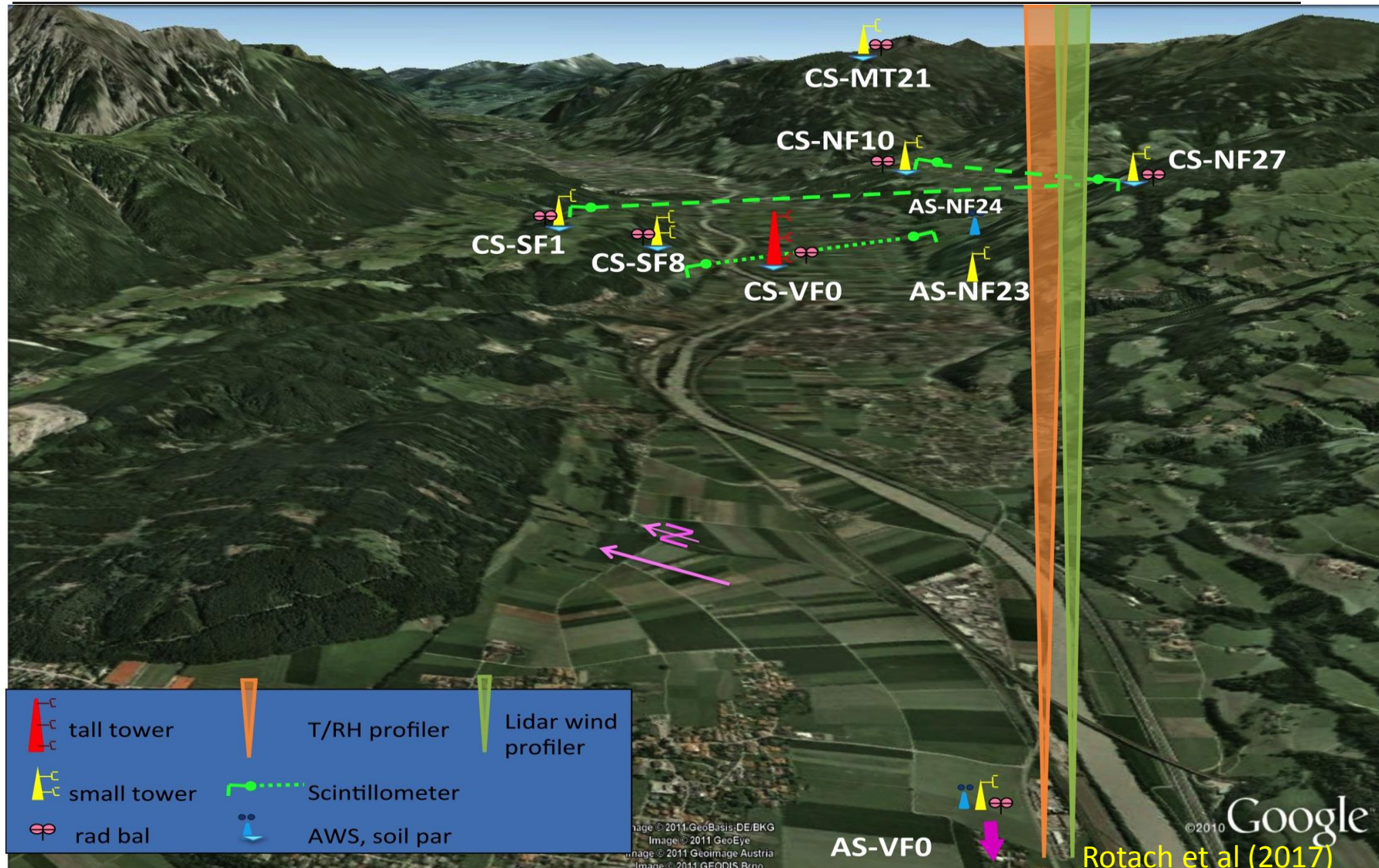
→ cold pools <-> air pollution

→ venting <-> air pollution

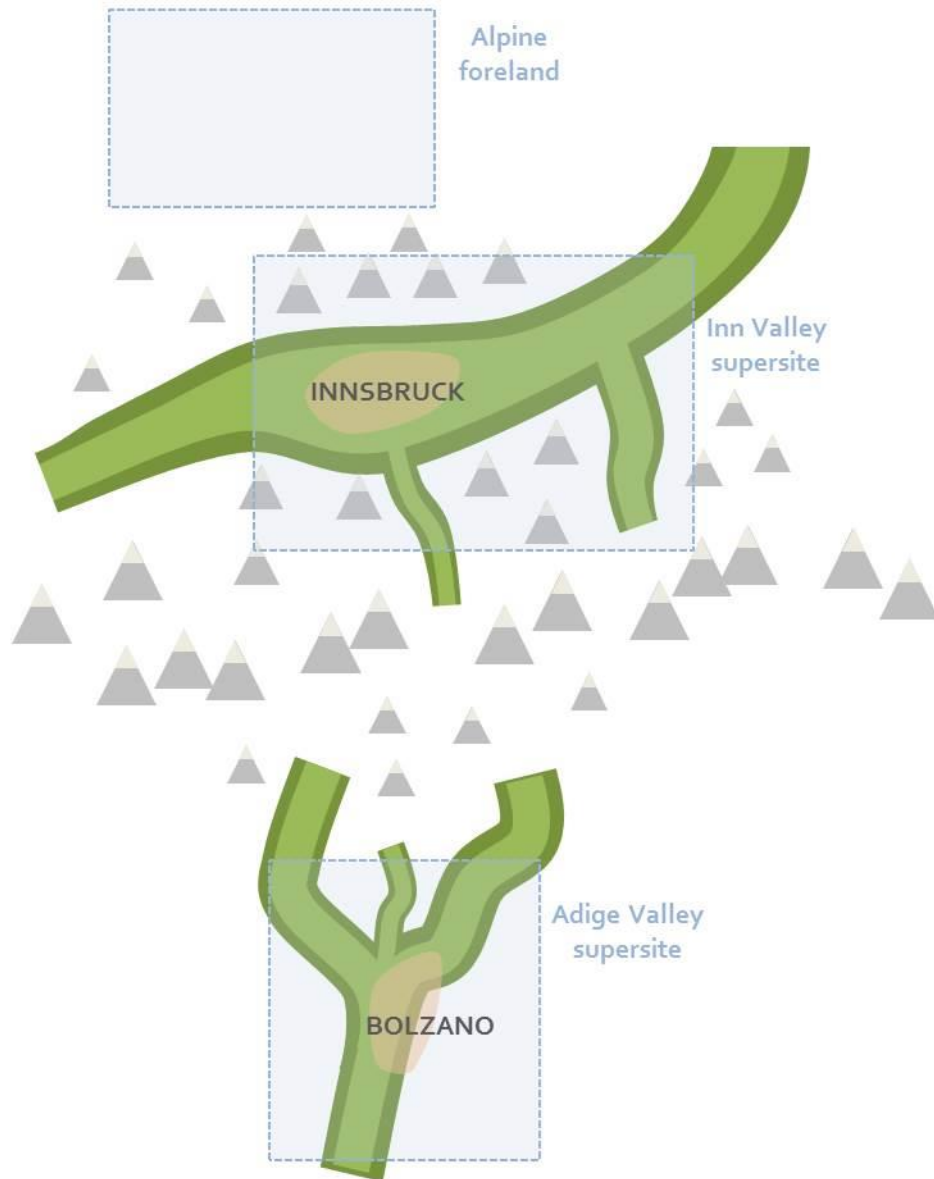
Backbone ....

→ e.g. i-Box

→ research partners add  
their instrumentation



# Field Experiment



- 3 super sites / target areas
- 3d MoBL structure
- near-surface exchange
- valley / slope / crest
- cold pools <-> air pollution
- venting <-> air pollution

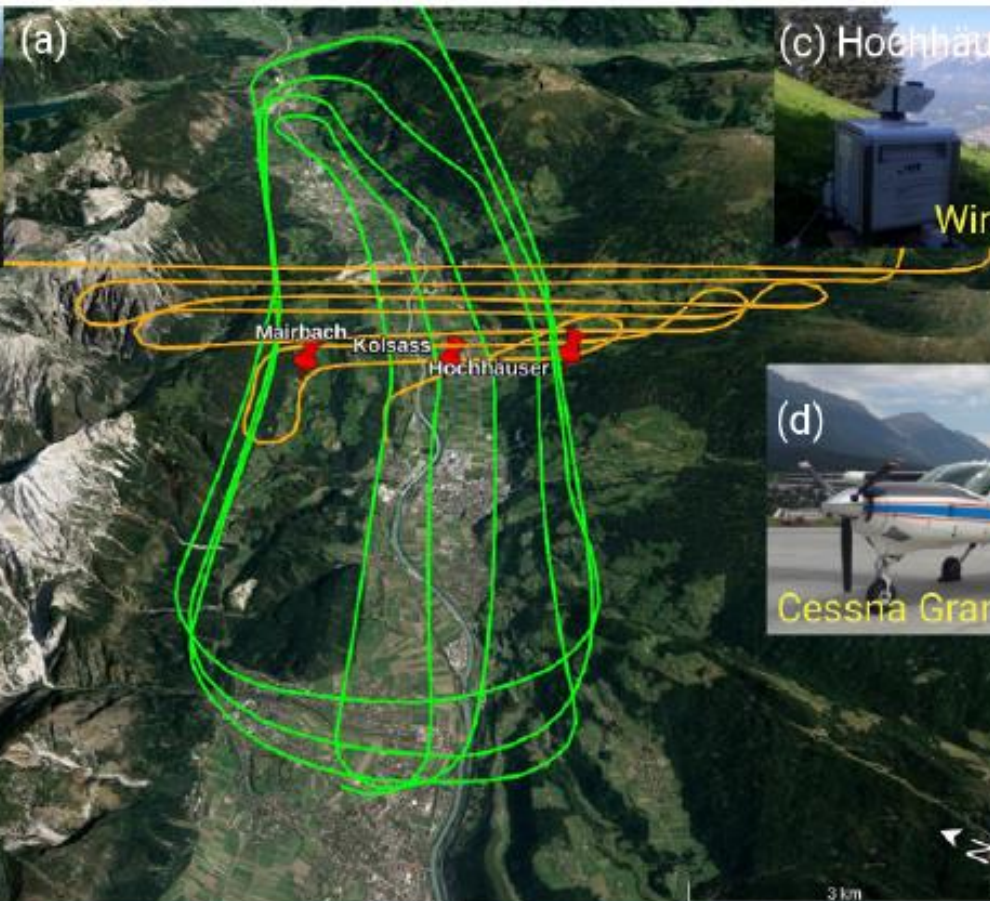
Backbone ....

- e.g. i-Box
- research partners add their instrumentation

1 'test project', 2019

- CROSSINN, Adler et al
- KIT&ACINN
- 3d flow structure in a valley

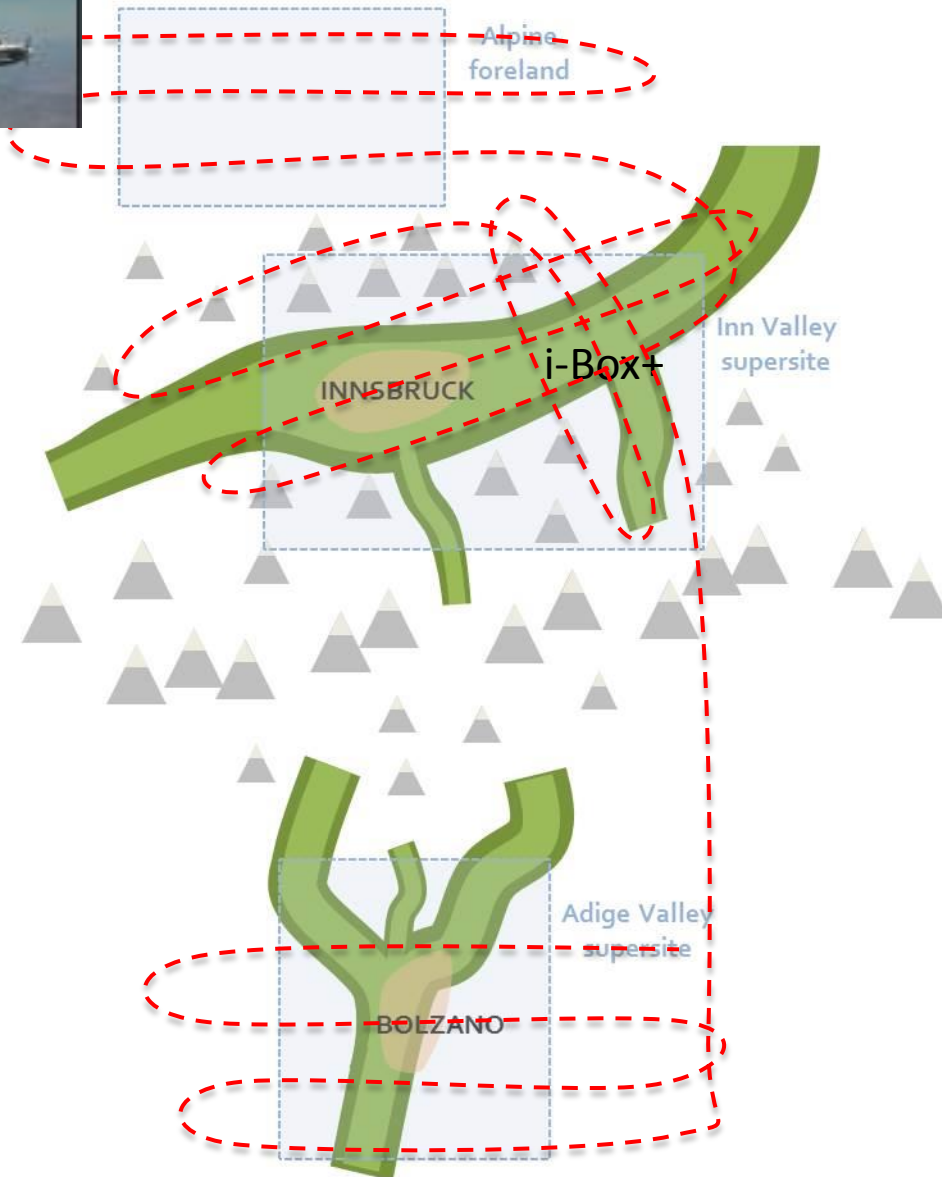
# CROSSINN



Adler et al.  
(BAMS, in review)



# Field Experiment



Meso-scale connection

→ meso-scale transport

→ air pollution

→ GWD

→ MoBL vertical extension  
(and structure)

Orographic convection

→ possibly with other needs

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Potential contributors:

- N Alps: i-Box (to be extended). plans to add a Sonnblick-'satellite site'
- pre-Alps: TERENO network
- yet to be coordinated 'single sites' & instruments in N Italy (U Trento)
- KIT cube
- MF / MCH / ZAMG: mobile facilities
- DOE's ARM facility (application pending)
- EOL (NCAR): LAOF (lower atm observing facilities): pre-application pending
- UK (via NCAS), incl FAAM aircraft
- US aircrafts (C130, King Air)
- individual groups / instruments (e.g., BOKU, ...)

# Numerical models

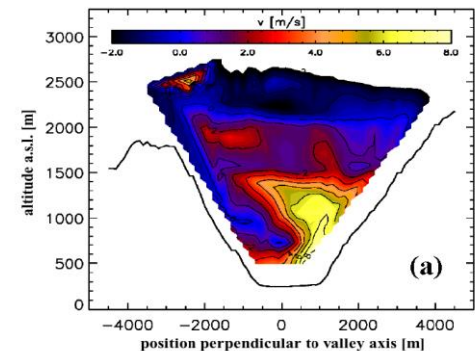
Turbulence parameterizations...

- often 'TKE schemes', often 1d (only vertical)
- TKE advection?
- horizontal shear production?
- horizontal (turbulent) transport?

Example:

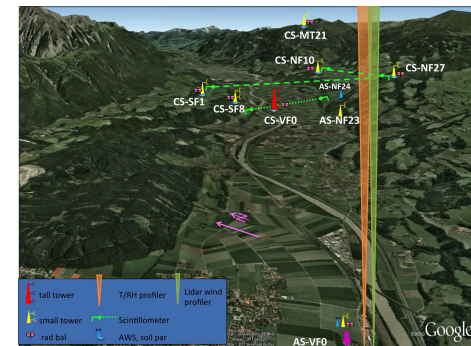
- use COSMO-1 (MeteoSwiss)
- add *horizontal shear production* and advection
- compare all the terms in the TKE eq. to obs.  
(i-Box)

## Along-valley wind Observation



Weigel et al 2006

## i-Box sites



# Summary: Overarching objectives

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 warming).	Smaller uncertainty of impact models, due to reduced errors in weather and climate information.

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**Thank you for your attention!**

➤ TEAMx Website: <http://www.teamx-programme.org>