universität innsbruck

TEAMx

TEAMx. Multi-scale Transport and Exchange Processes in the Atmosphere over Mountains - Programme and Experiment

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Outline

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

TEAMx – what is it?

Multi-scale Transport and
Exchange Processes in the
Atmosphere over
Mountains

Programme and experiment

- ...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)

TEAMx – what is it?

Multi-scale Transport and
Exchange Processes in the
Atmosphere over
Mountains
Programme and experiment

- Embedded in international programmes
  → Crosscutting project within the GEWEX Hydroclimatology Panel (GHP)
  → endorsement sought within WWRP (pending)
  → WMO High Mountain Summit
- 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)

  → Progamme Coordinator: Helen Ward (UIBK)

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....

TEAMx – 'who' is it?

- Coordination and Implementation Group (CIG)
- Individuals from (mostly) sponsoring insitutions
  - 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'

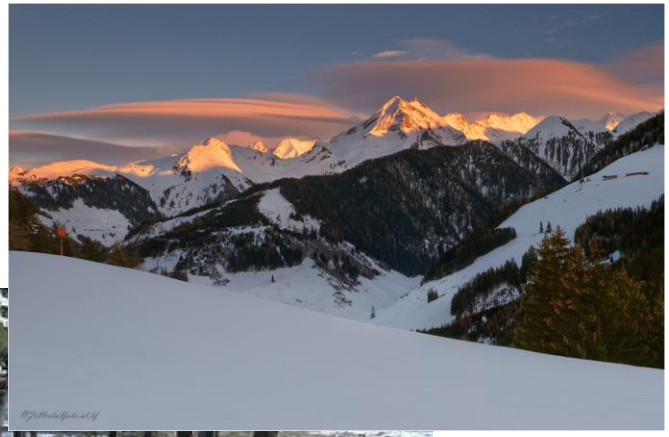
TEAMx – 'who' is it?

TEAMx – what do we do?

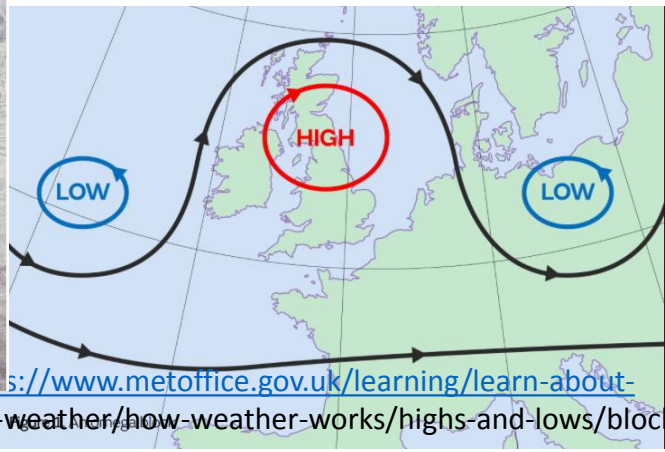
- foster research on **Multi-scale Transport and Exchange Processes in the Atmosphere over Mountains**

Mountain Weather and Climate

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



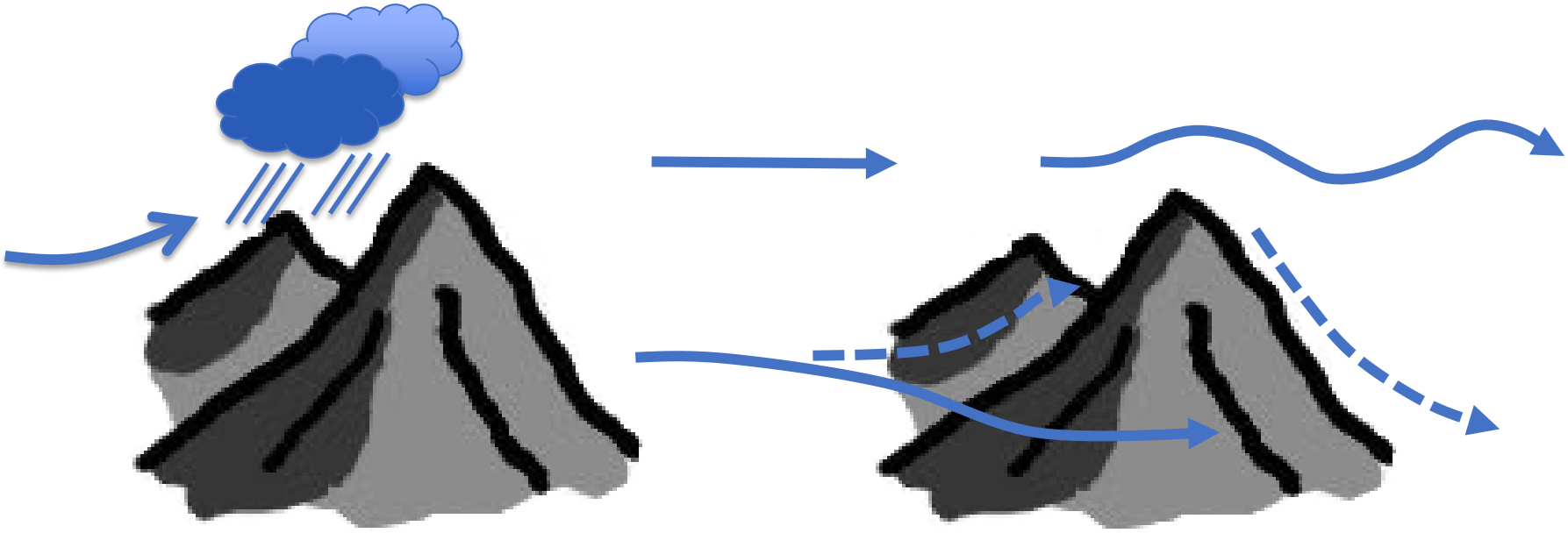
http://blog.weatherflow.com/gravity-waves-over-new-hampshirevermont/



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

Mountain Weather and Climate

- 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. ...



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

Mountain Weather and Climate

- 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

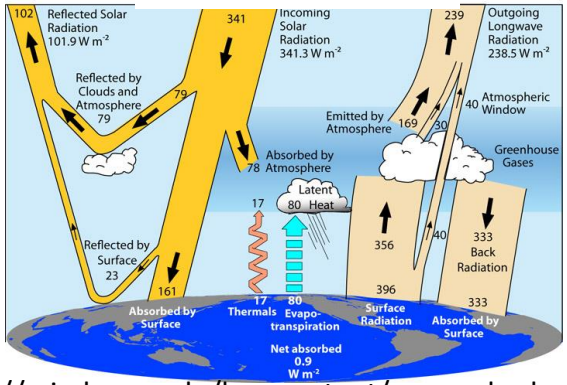

http://www.panoramio.com/photo/1724212

Exchange

- character of the surface
  → determines the *exchange* between the atmosphere and the earth
  → *coupling* of the atmosphere with the surface

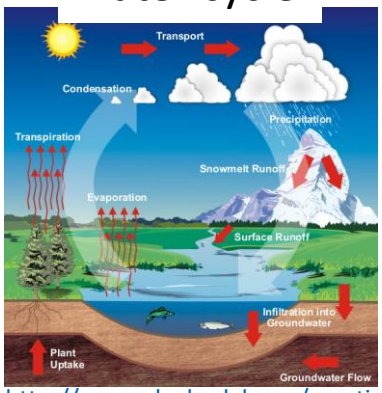
- mountain ⟷ atmosphere perspective
  → how does the atmophere – which has been modified by the mountain – execute this exchange?

energy budget



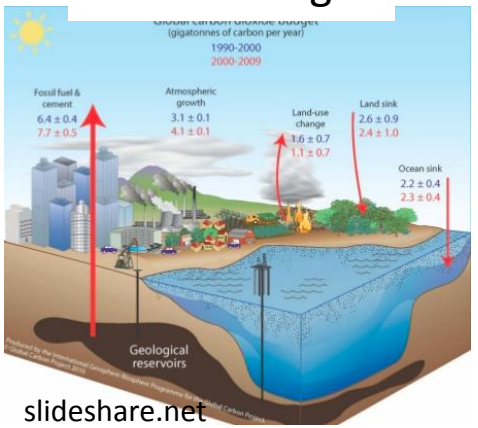
https://scied.ucar.edu/longcontent/energy-budget

water cycle



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

carbon budget



slideshare.net

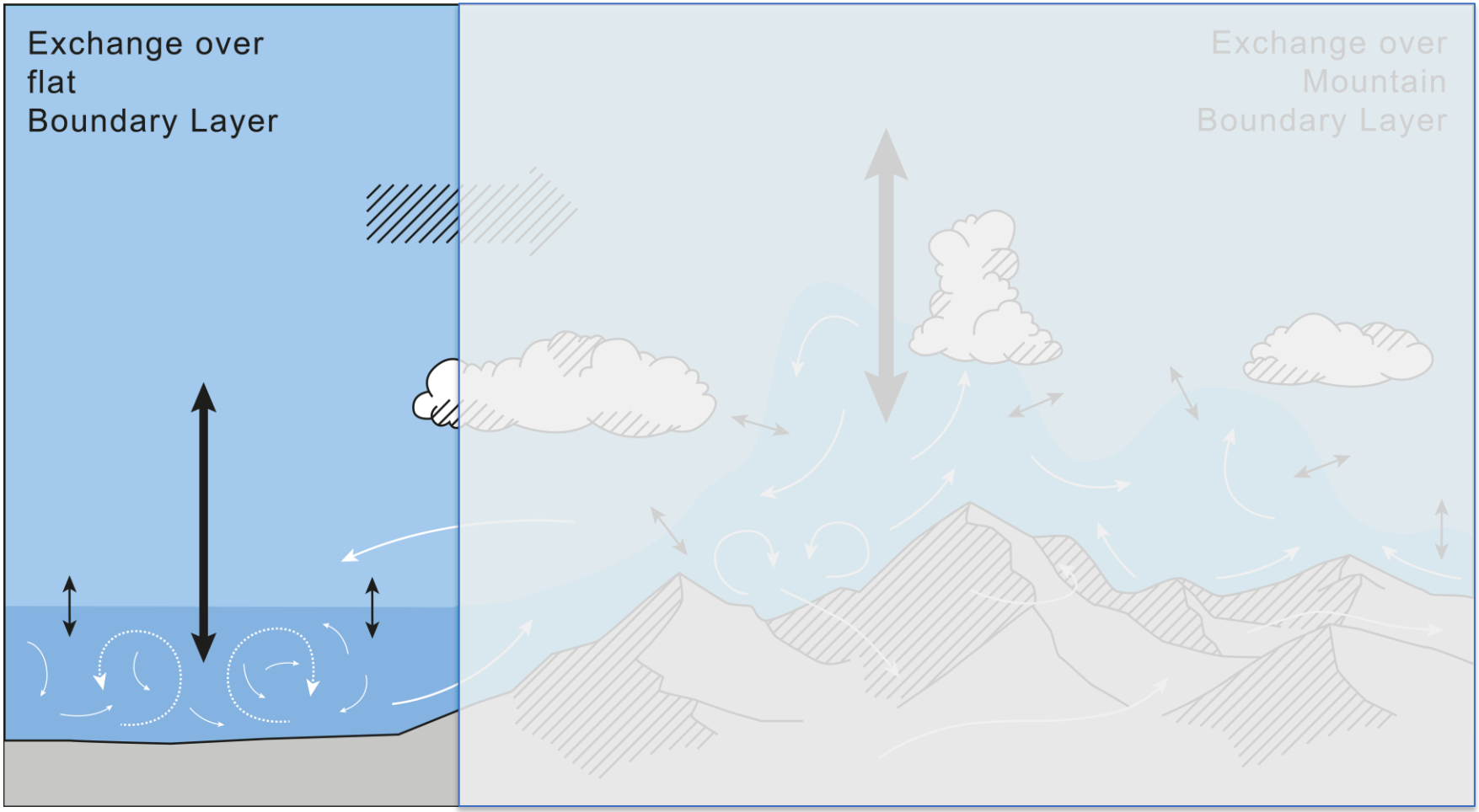
Exchange

- 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 atmophere – 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
flat
Boundary Layer
Exchange over
Mountain
Boundary Layer

Exchange over Mountains

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

Ekhart, 1948

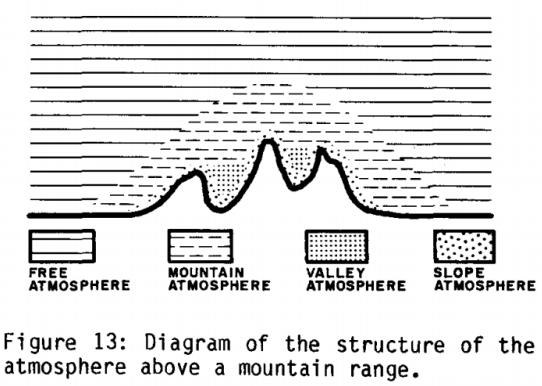


Figure 13: Diagram of the structure of the atmosphere above a mountain range.

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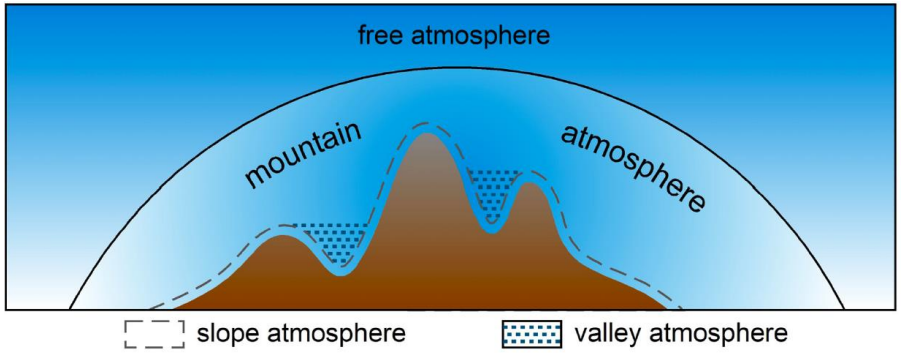
DeWekker and Kossman (2015)



Mountain Boundary Layer (MoBL)

Traditionally, the boundary layer is defined…

'The *Atmospheric Boundary Layer* is that part of the troposphere that is **directly influenced** by the presence of the **earth's surface**, and responds to surface forcing with a **timescale of about an hour or less**'.

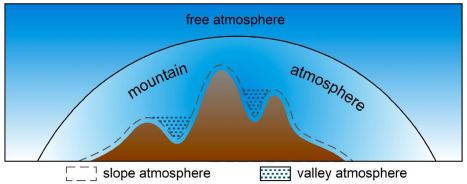
Stull (1988)

Suggested definition **Mountain Boundary Layer** (MoBL)

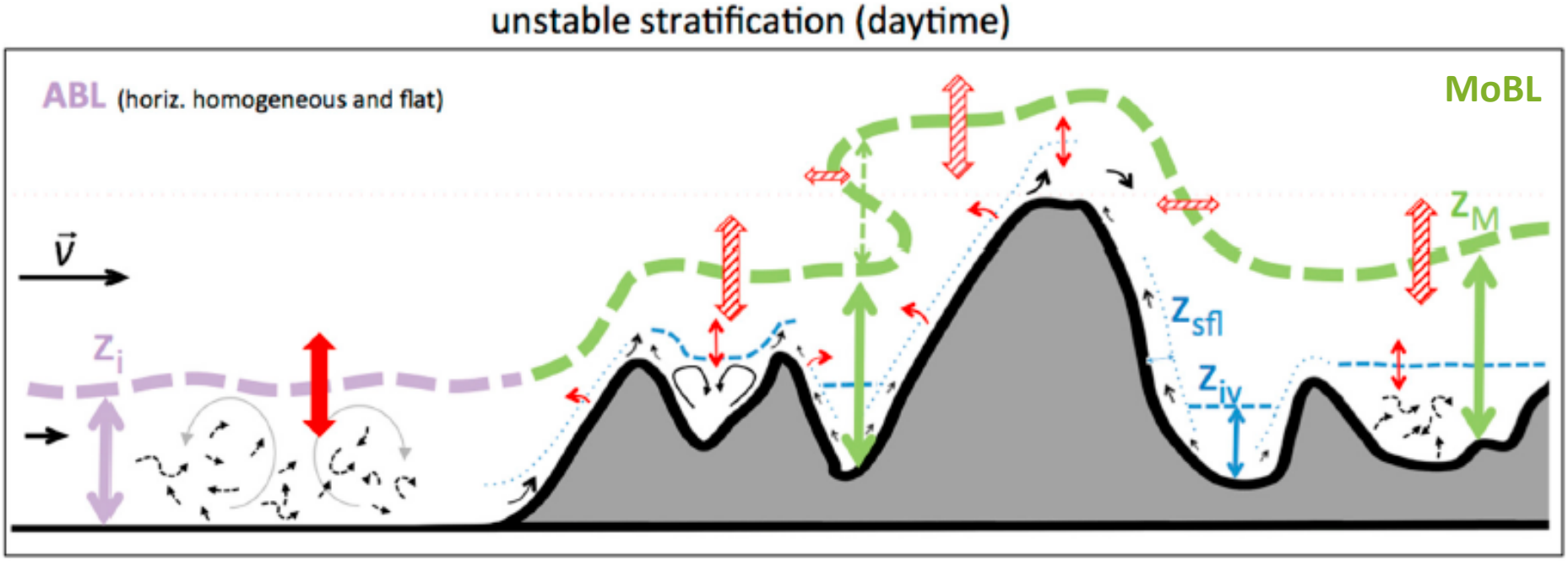
The Mountain Boundary Layer is *the lowest part of the troposphere that is directly influenced by the mountainous terrain, responds to surface and terrain forcings with timescales of about one to a few hours, and is responsible for the exchange of energy, mass, and momentum between the mountainous terrain and the free troposphere.*

Lehner and Rotach (2018)

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



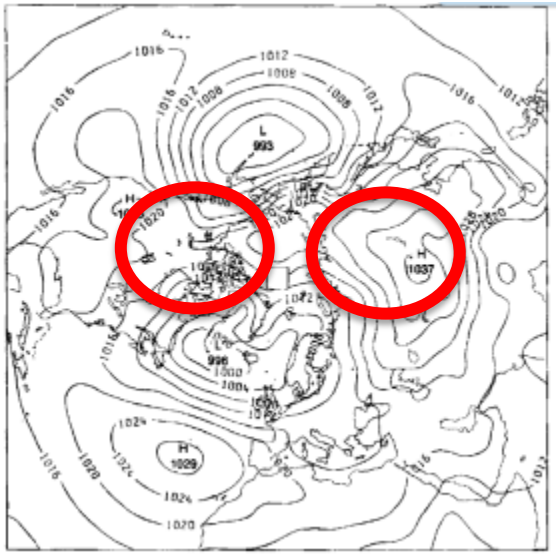
Lehner and Rotach (2018)

Exchange over Mountains

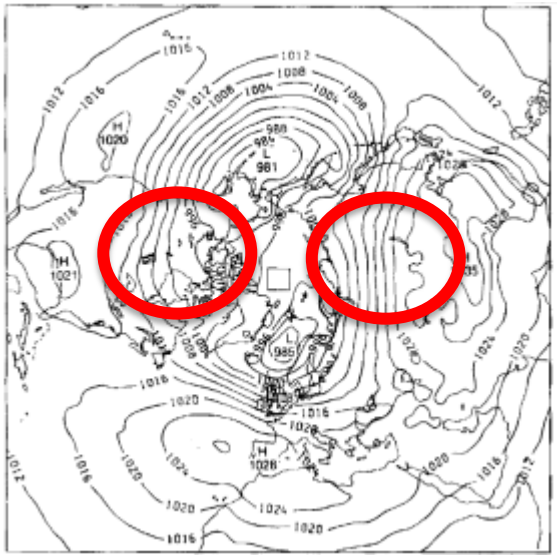
- Impact on global cycles (mass, momentum, energy)
  → hence atmospheric modeling
  → prominent example: gravity wave drag

Momentum exchange

observed



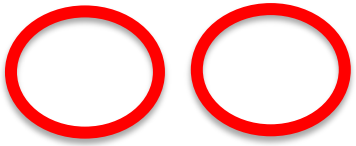
modeled



Palmer et al 1986 (QJ)

mean Jan NH SLP (84-86)

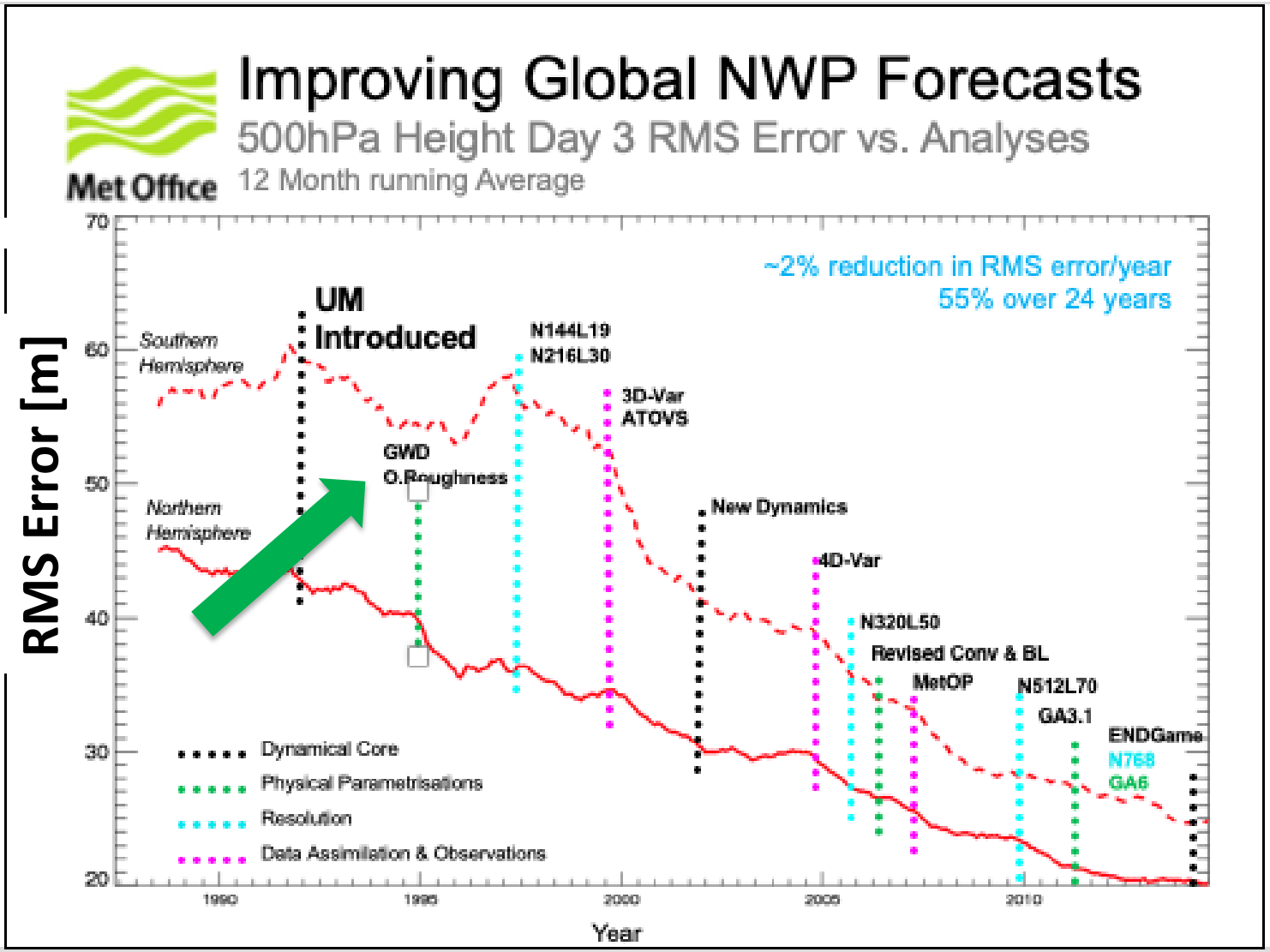
no gravity wave drag



→ **total exchange:** subgrid-scale contribution para-meterized

Momentum exchange

Andi Brown‘s talk yesterday (IAMAS centennial session)



Exchange over Mountains

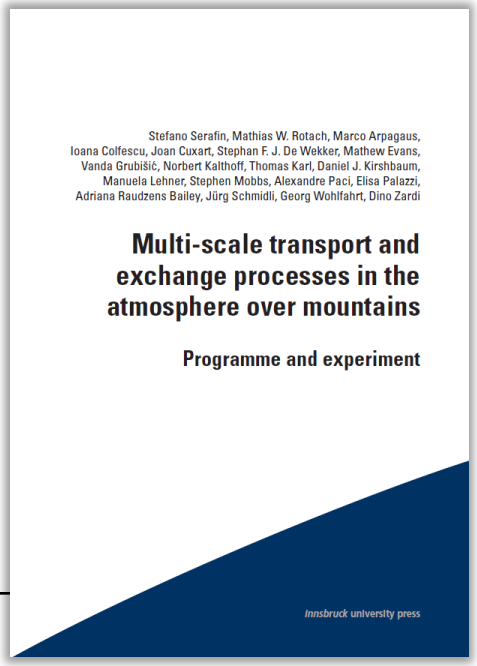
- Impact on global cycles (mass, momentum, energy)
  → hence atmospheric modeling
  → prominent example: gravity wave drag
- better weather forecast and climate scenarios?
  → certainly yes for momentum
  → should also be the case for heat, mass...
- In particular
  → better (more realistic) near-surface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

TEAMx – what do we do?

- 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-atmosphere exchange, MoBL, convection, mountain climate, atmospheric chemistry, Waves and Dynamics)



Knowledge Gaps

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*

Description not available yet
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)

Working group on *Waves and Dynamics*

Description not available yet
Leaders:

TEAMx

Overarching research questions

- how does mountainous terrain impact exchange to the free atmosphere of energy, mass and momentum? (which processes, interaction, abundance, ...)
- do we understand the relevant processes *quantitatively*?
- are current models (regional climate, NWP) able to adequately reproduce these processes?
- do we need a sgs-parameterization (*as for gravity wave drag*) for $\mathcal{O}$(10 km) grid spacing models?
- how does mountainous terrain affect air quality?

Exchange of energy, momentum & mass

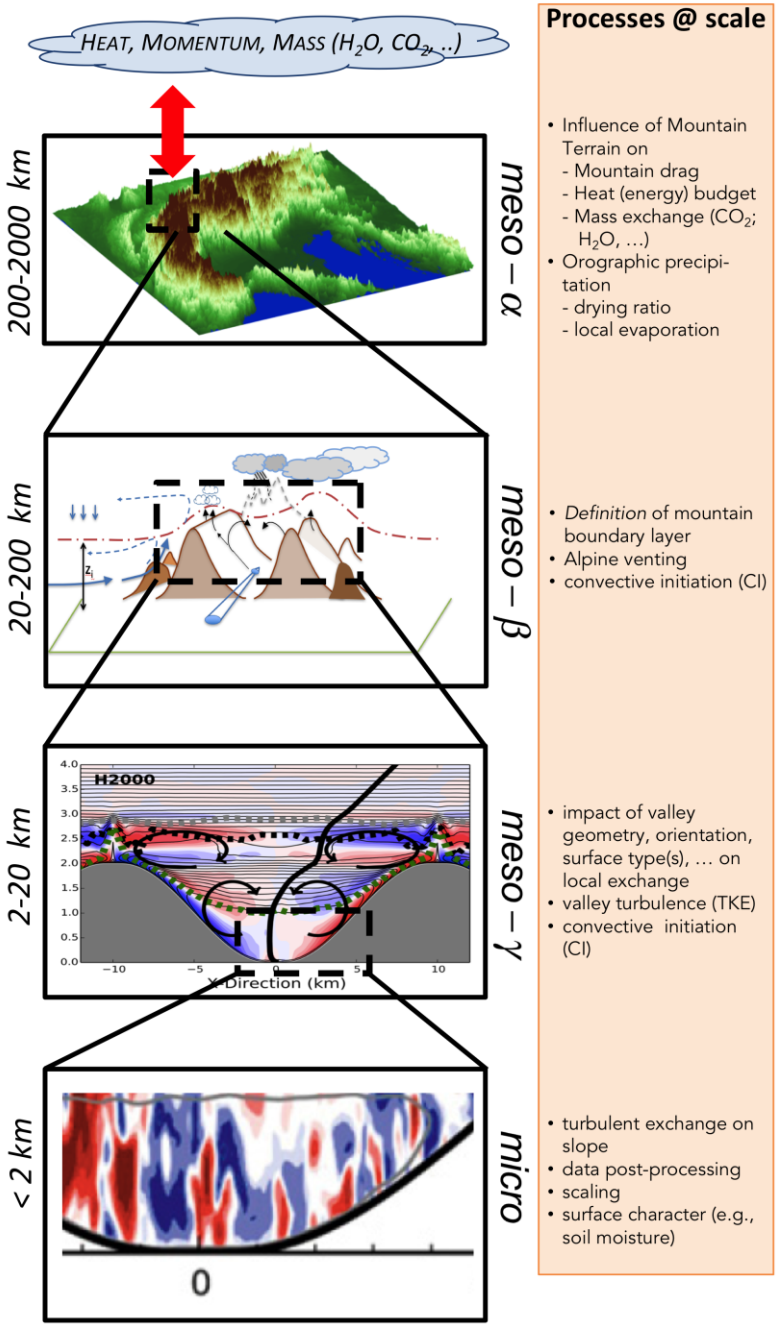
Scale interactions

- cyclogenesis, instability
- PV generation
- blocking

- impact of synoptic flow - stability/ strength/ direction
- interaction between flows in different valleys
- CO_2 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



Processes @ scale

- Influence of Mountain Terrain on
  - Mountain drag
  - Heat (energy) budget
  - Mass exchange (CO_2; H_2O, …)
- Orographic precipitation
  - drying ratio
  - local evaporation

- *Definition* of mountain boundary layer
- Alpine venting
- convective initiation (CI)

- impact of valley geometry, orientation, surface type(s), … on local exchange
- valley turbulence (TKE)
- convective initiation (CI)

- turbulent exchange on slope
- data post-processing
- scaling
- surface character (e.g., soil moisture)

topics:

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

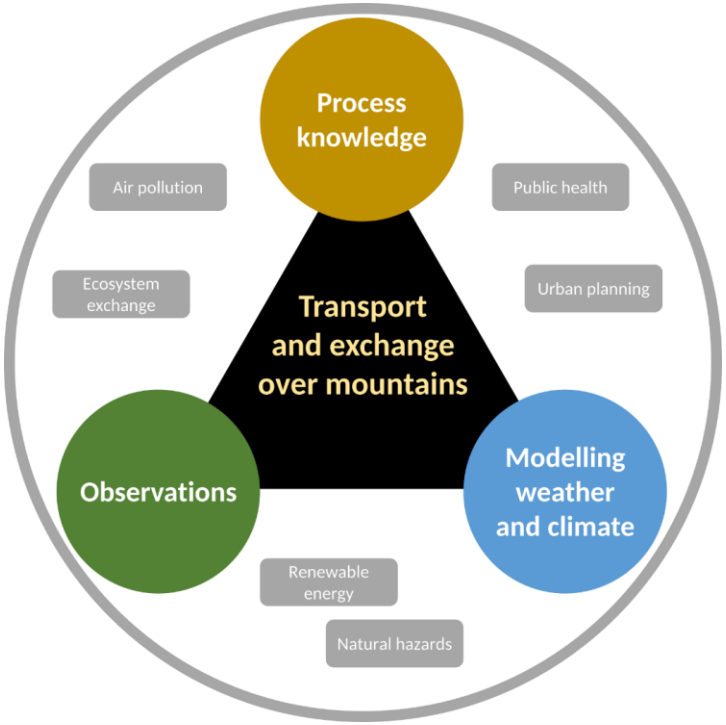
→ ***and their interactions***

Lehner and Rotach (2018)

Gaps of knowledge

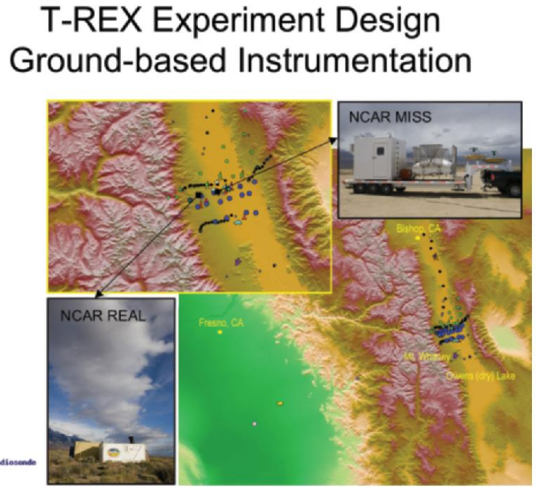
Example of knowledge gaps:

1. **Multi-scale interactions over mountains**
2. Shortcomings of parameterization schemes over mountains

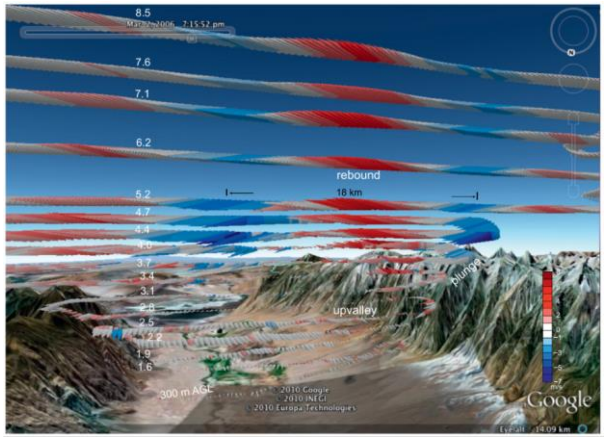


Example: a T-REX event

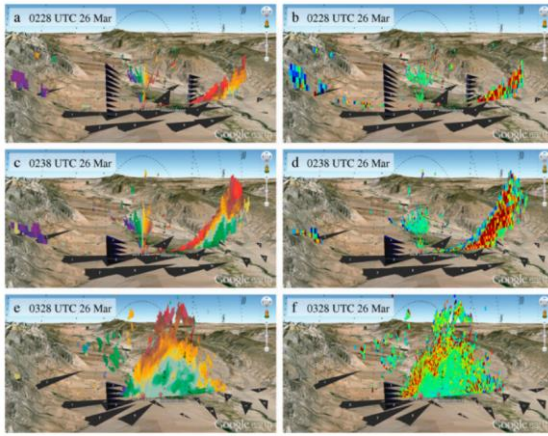
- T-Rex field phase in March-April 2006, Owens Valley (California)
  → example IOP6
- major focus: atmospheric rotors
  → Terrain-induced Rotor Experiment



Grubišić et al. (2008)

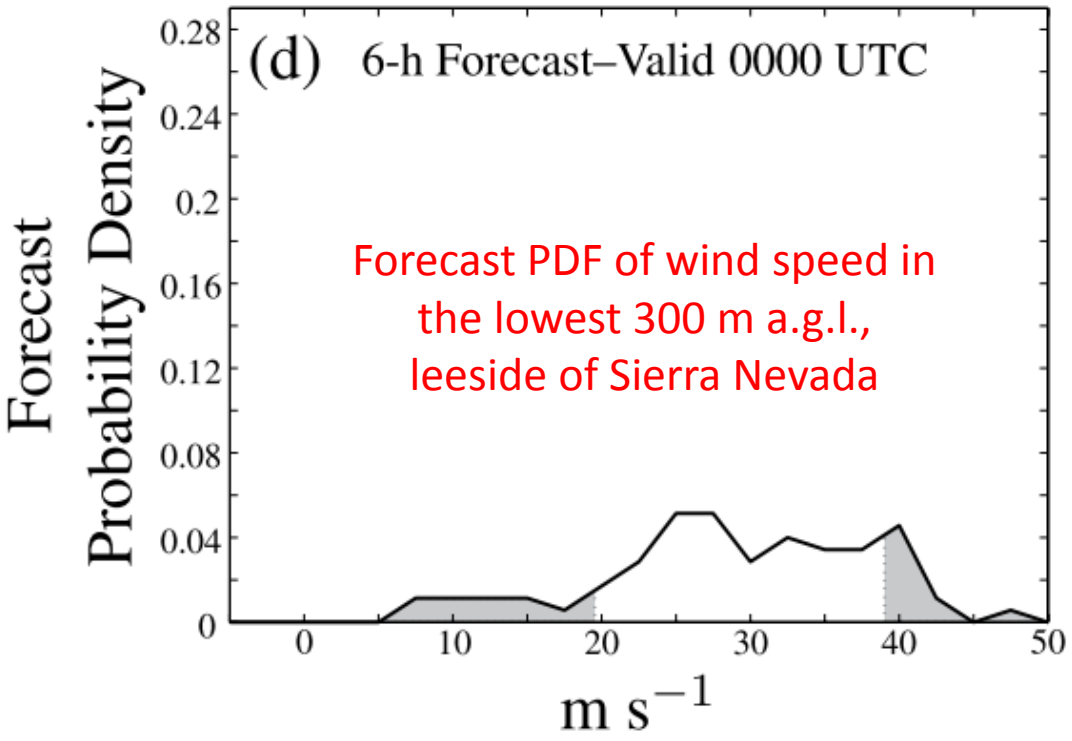


Mayr and Armi (2010)



Strauss et al. (2016)

Multi-scale interactions in orographic flows



Reinecke and Durran (2009)

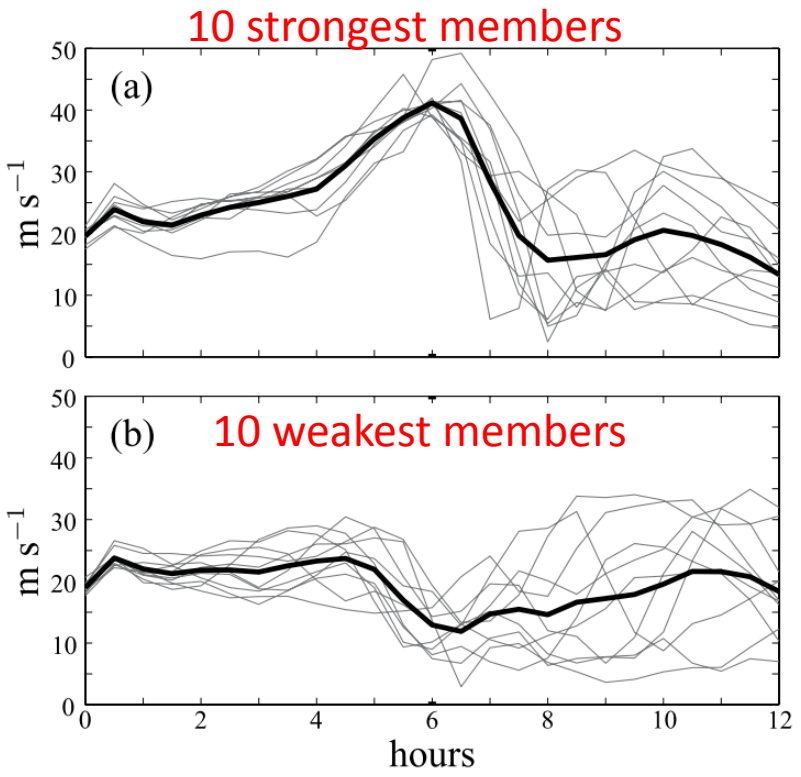
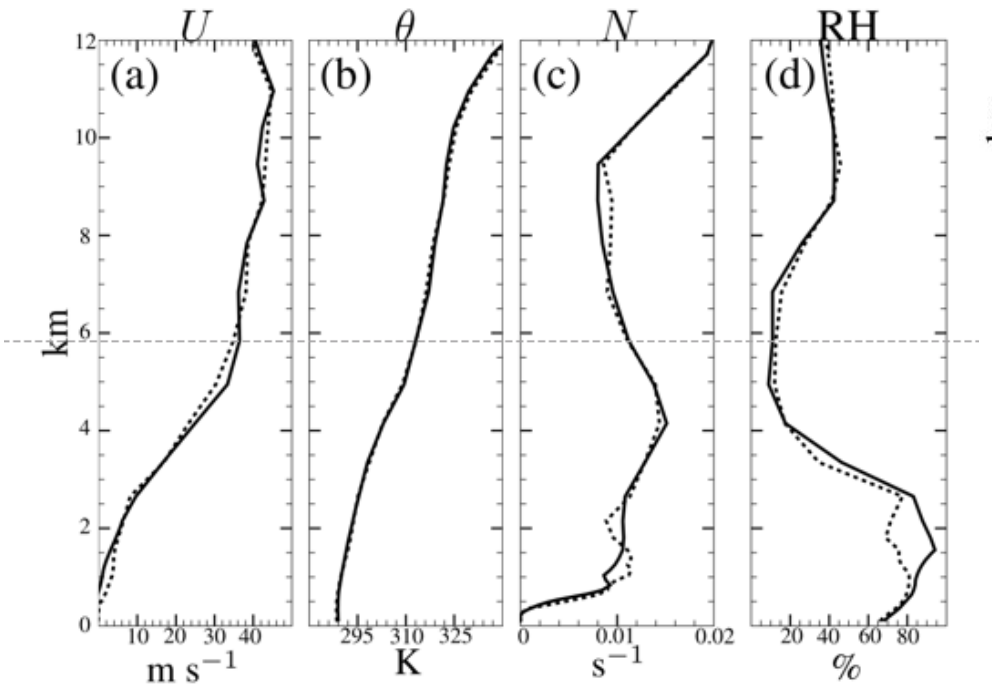


FIG. 7. The evolution of the zonal wind averaged over the Owens Valley metric box during the IOP 6 simulation for the (a) 10 strongest and (b) 10 weakest ensemble members. The thick line shows the mean of each 10-member subset.

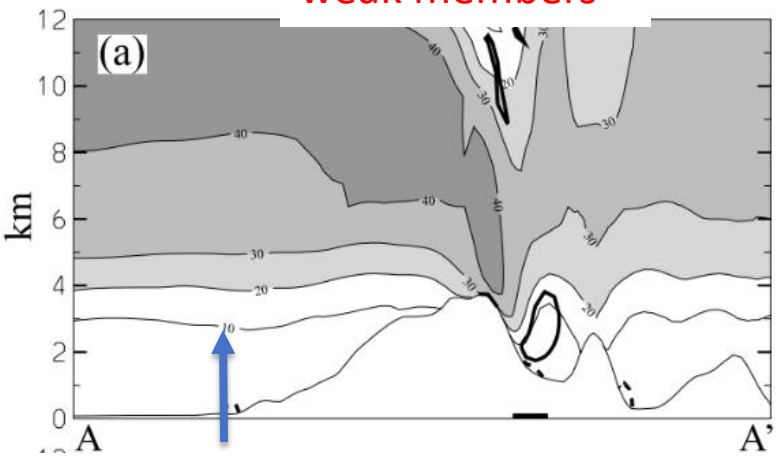
Multi-scale interactions in orographic flows

upwind composite soundings



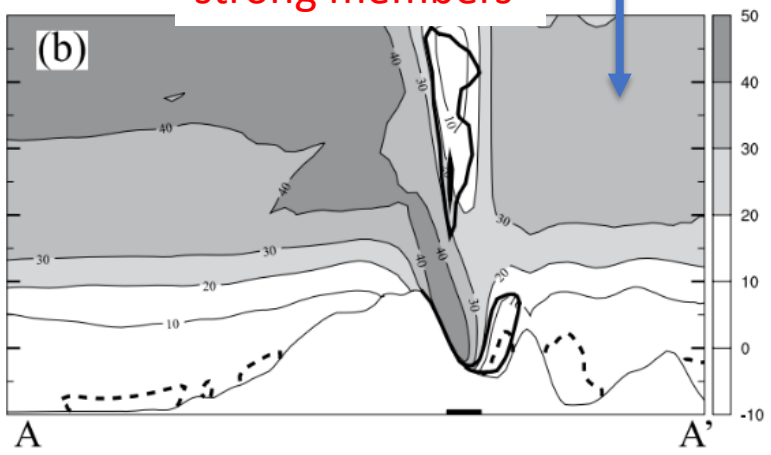
Reinecke and Durran (2009)

weak members



Different strength of wave breaking and thermal structure of the valley

strong members

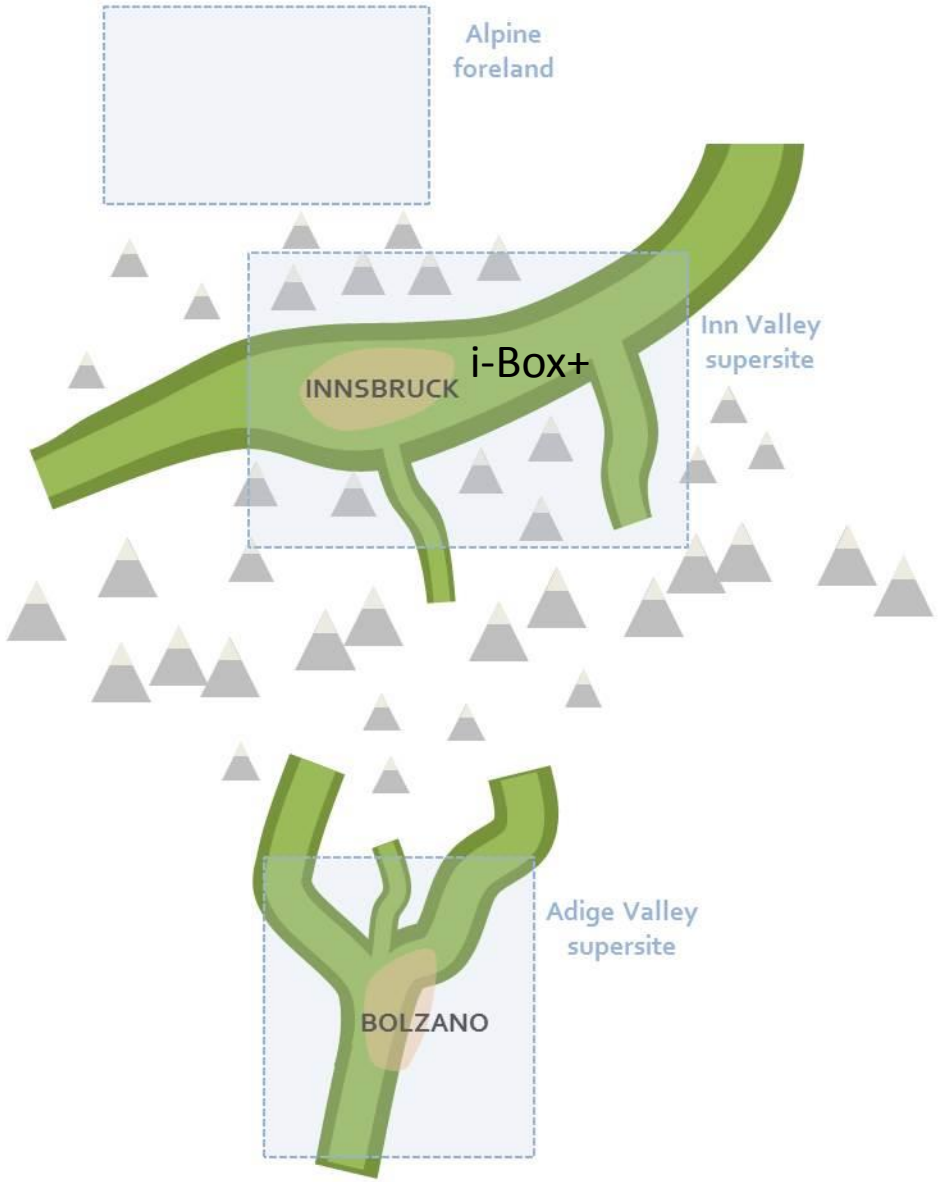


TEAMx – what do we do?

- 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

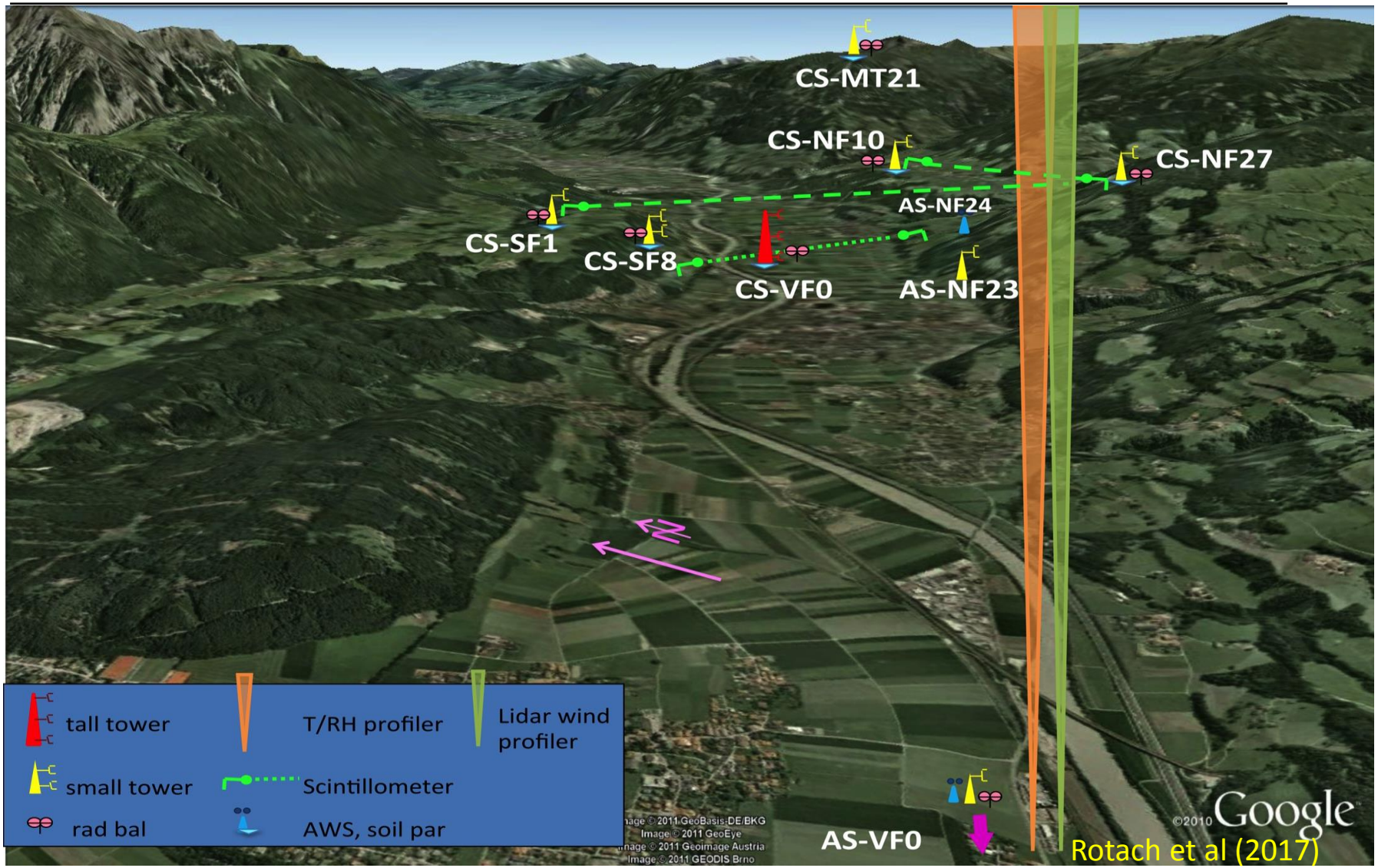
Field Experiment



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

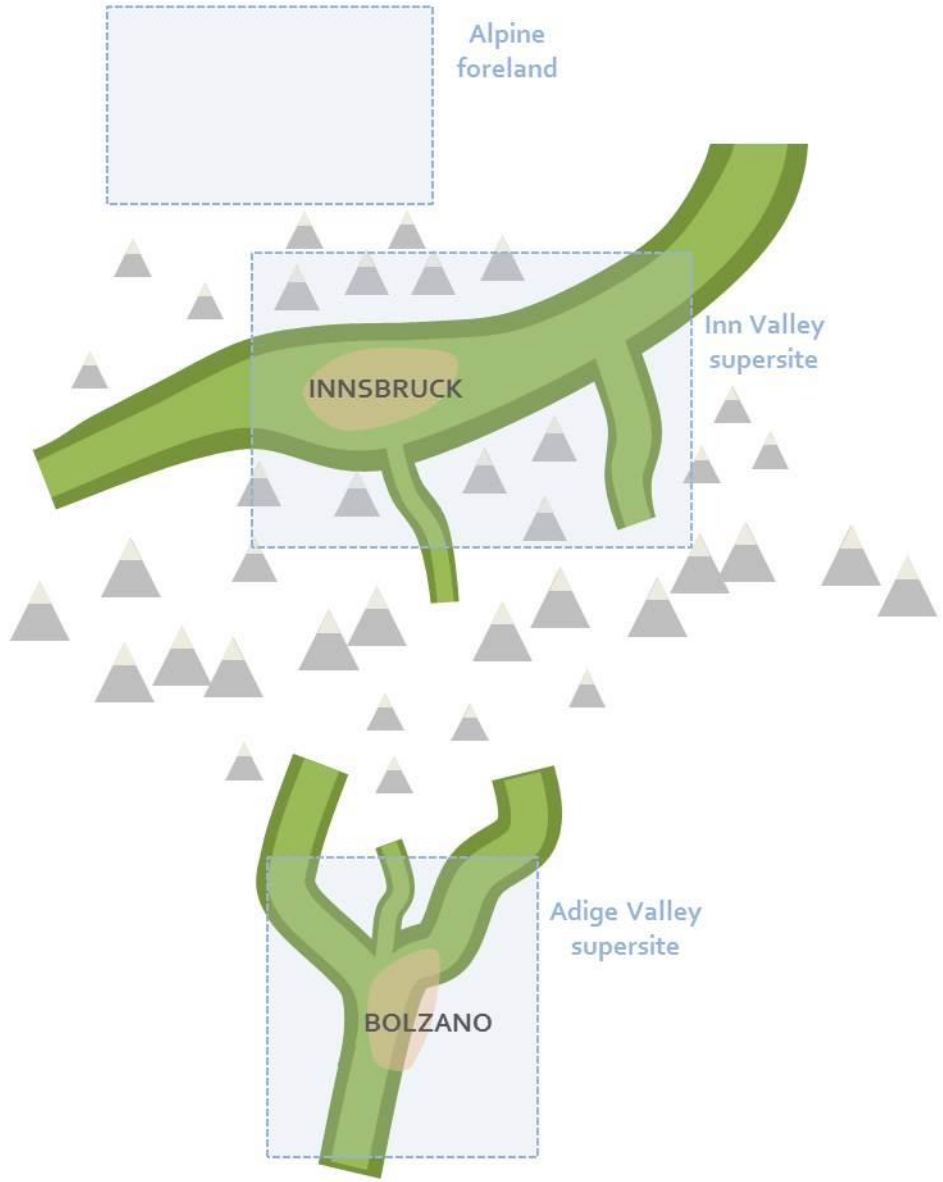
Backbone ….
→ e.g. i-Box
→ research partners add their instrumentation

i-Box



Rotach et al (2017)

Field Experiment



3 super sites / target areas
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Backbone ….
→ e.g. i-Box
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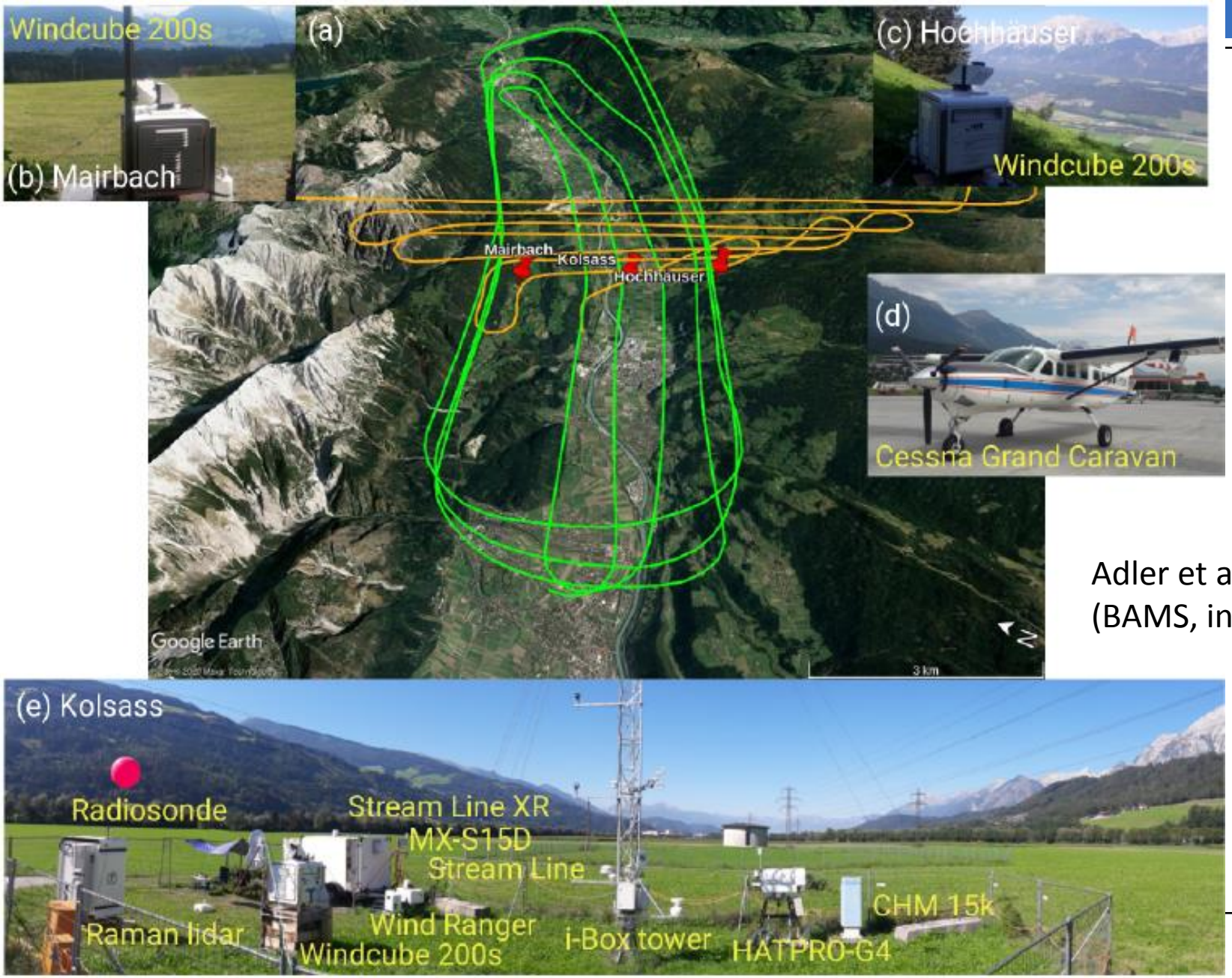
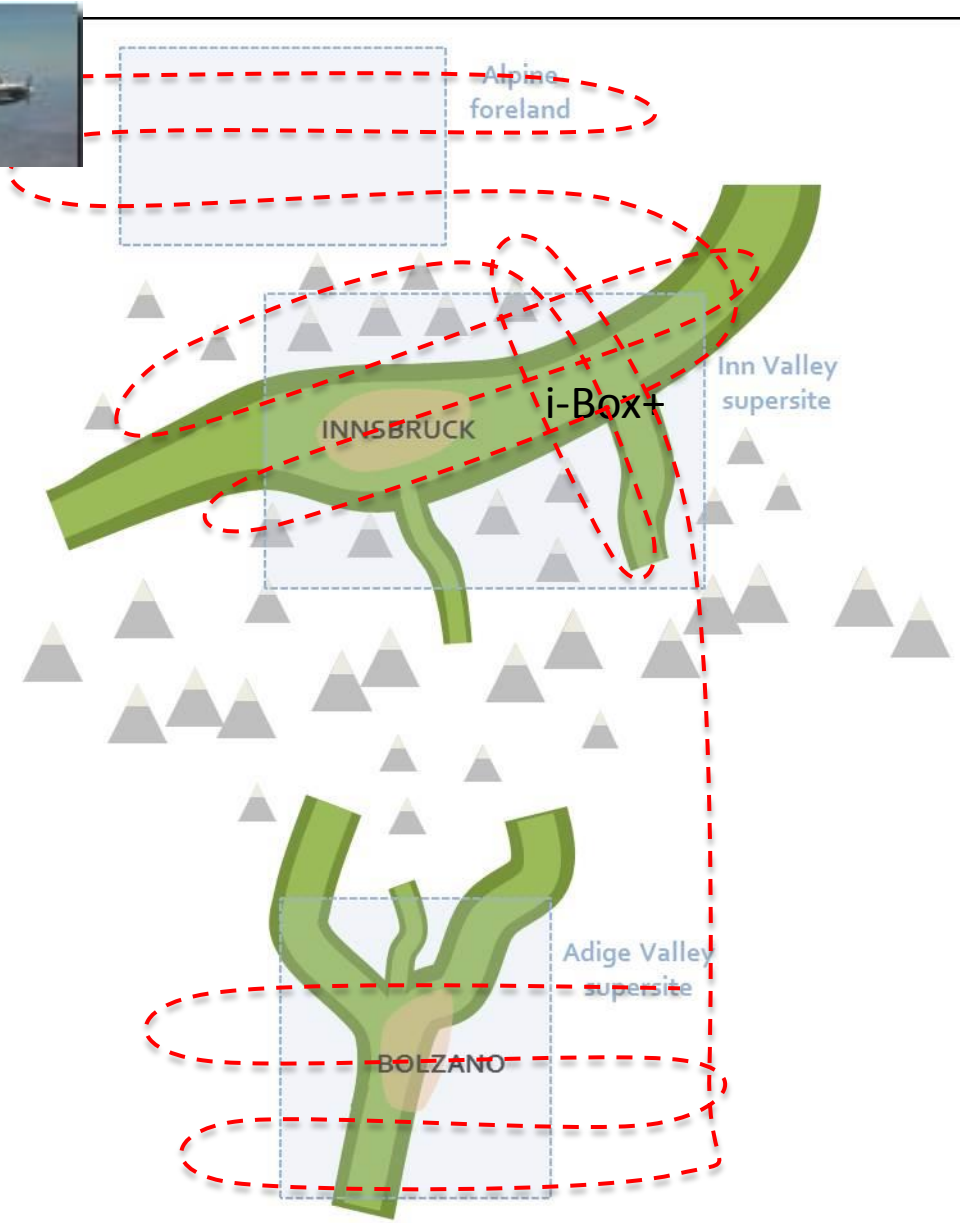
1 ‘test project’, 2019
- CROSSINN, Adler et al
- KIT&ACINN
- 3d flow structure in a valley

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

Field Experiment

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, …)

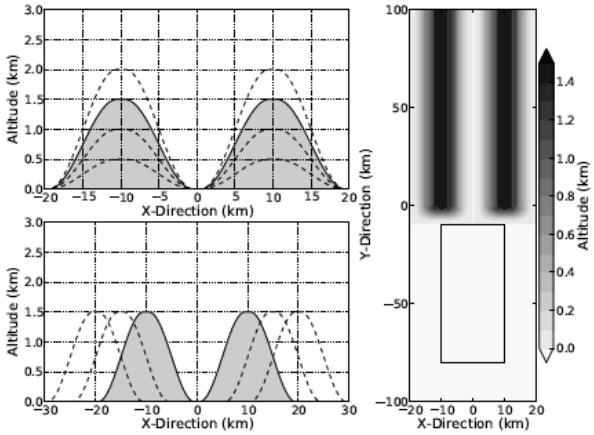
TEAMx – what do we do?

- Knowledge gaps
  - → 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 observational 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
- Numerical experimentation
  - → idealized & real-terrain modelling
  - → reference cases
  - → short and long time scales

Numerical Experimentation

Based on:

→ **ideal** & real terrain simulations

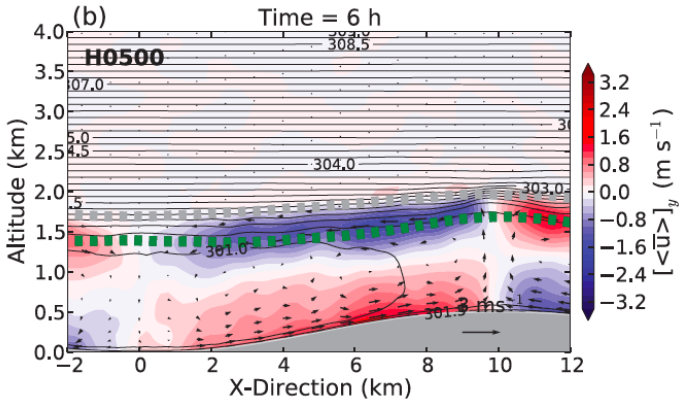


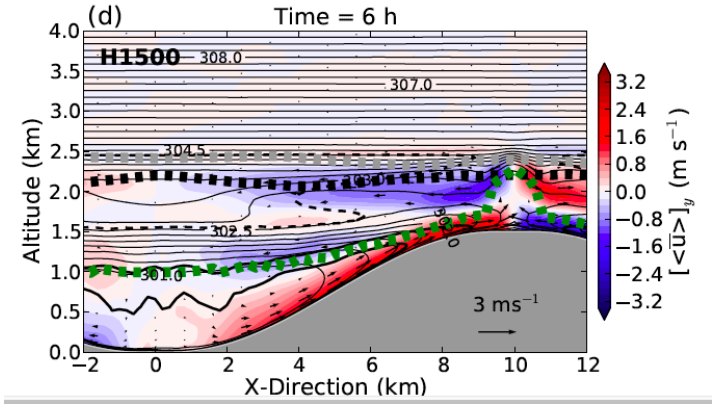
Wagner et al (2015)

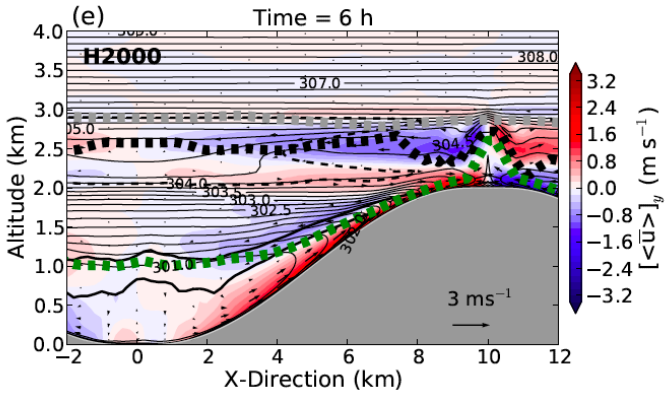
PBL1:

PBL2:

PBL3:







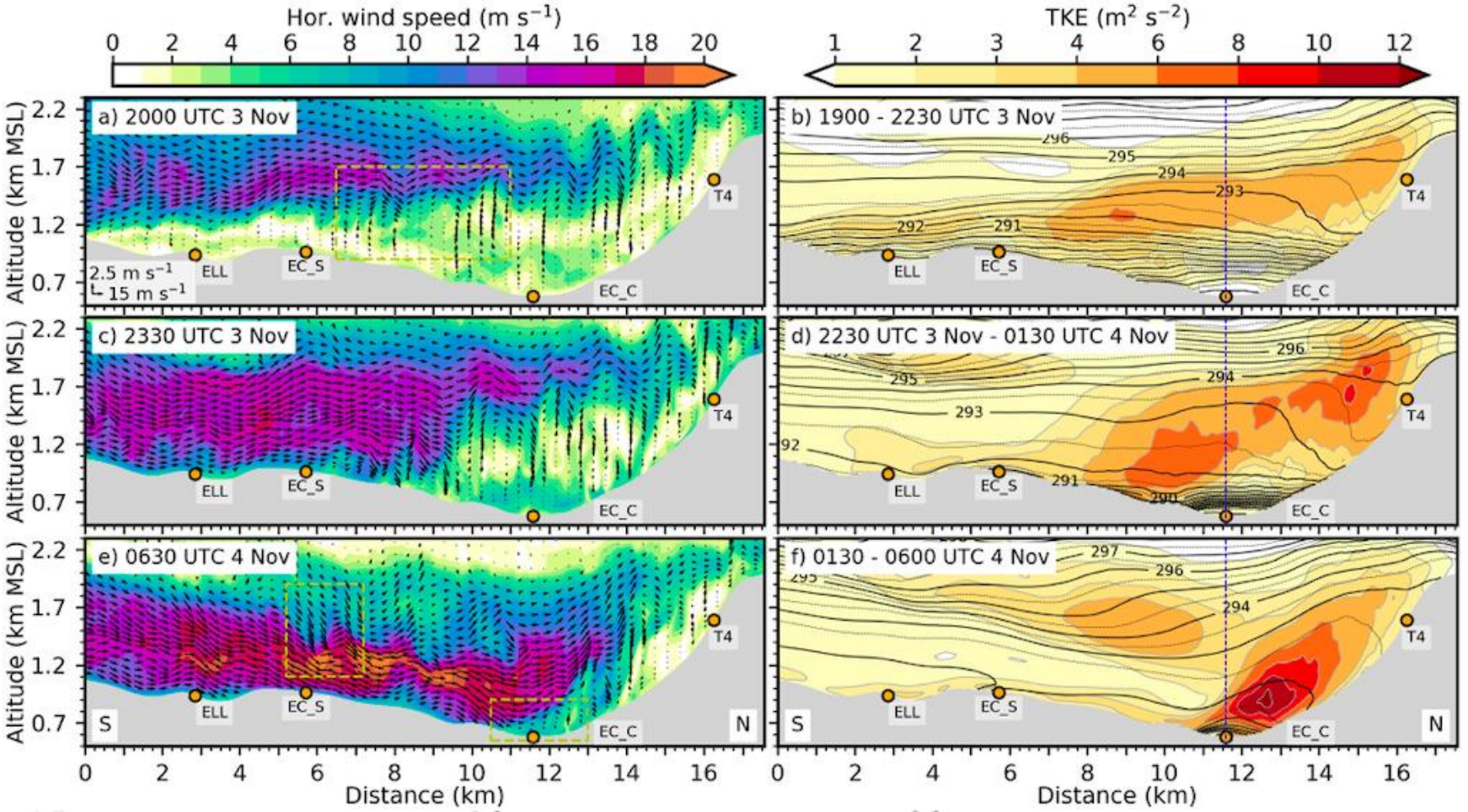
Numerical Experimentation

Based on:

→ ideal & **real** terrain simulations

→ Föhn development, Wipp Valley, WRF-dx40

Umek et al (subm)



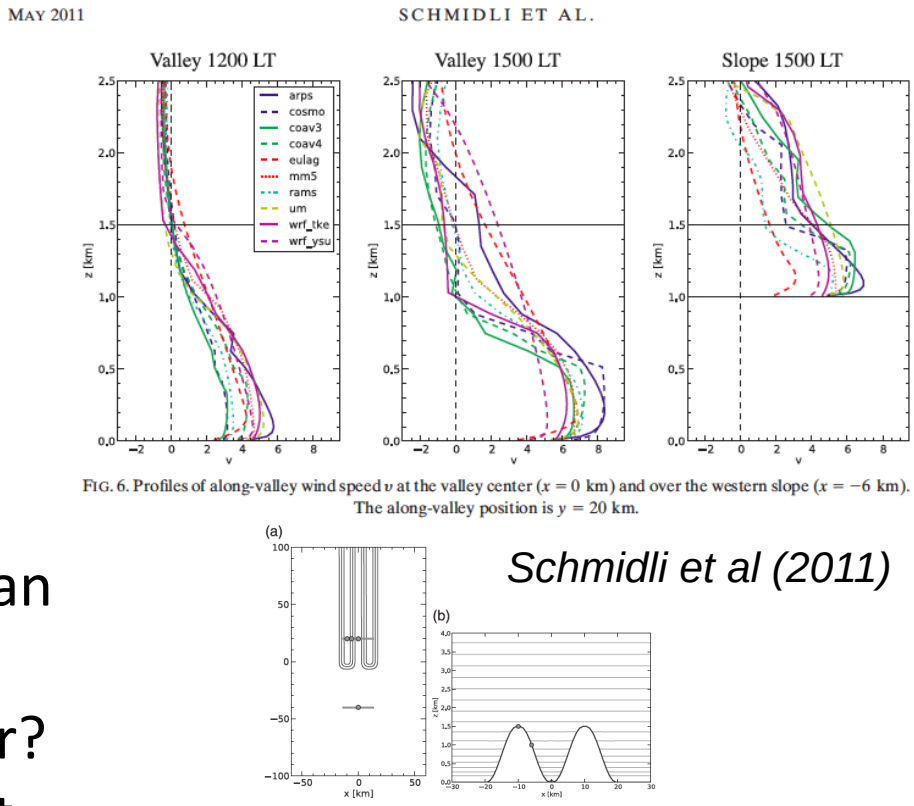
Numerical Experimentation

Based on:

→ ideal & **real** terrain simulations

TEAMx joint goals:

- reference case(s): lack of ‘analytical solution’
  → ‘GABLS type’ of experiment
- verification in complex terrain
  → worse in complex terrain than ‘HHF’?
  what is worse, what is better?
- Preparation of field experiment



Schmidli et al (2011)

Numerical Experimentation

Based on:

→ ideal & **real** terrain simulations

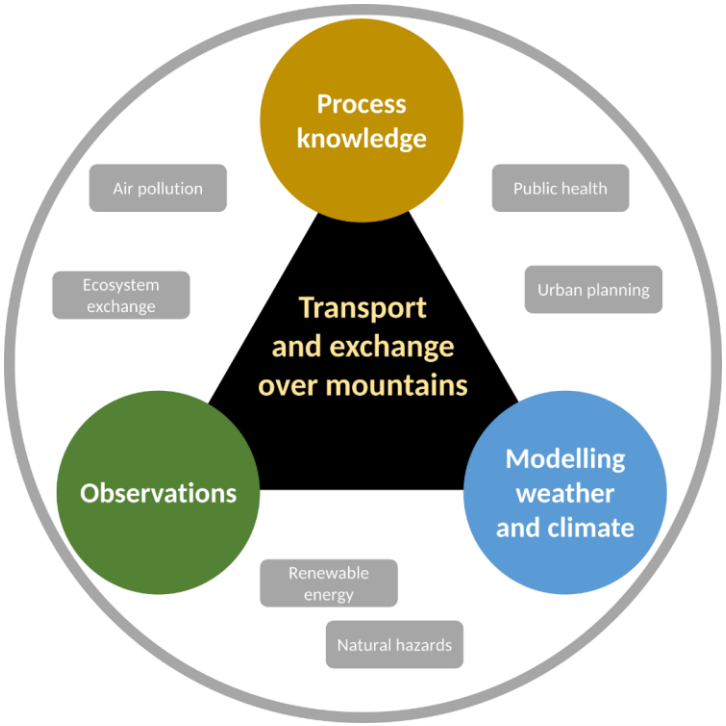
TEAMx coordination goals:

- coordination of / exchange of experience in case studies…
  → model stability, output options
- Mountain climate modeling: convection permitting (CORDEX FPS on Convection) Alps & Himalayas
- parameterizations…
  → for RANS: ‘boundary layer approximation’

Gaps of knowledge

Examples of knowledge gaps / topics:

1. Multi-scale interactions over mountains
2. **Shortcomings of parameterization schemes over mountains**

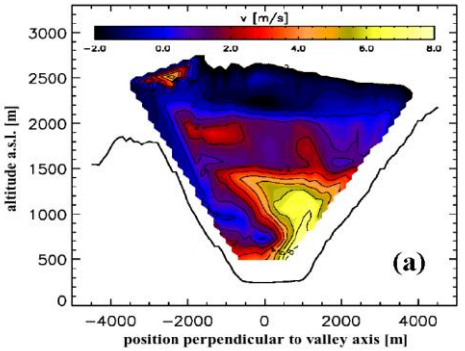


Numerical models

Turbulence parameterizations...

⟶ often ‘TKE schemes’, often 1d (only vertical)
⟶ TKE advection?
⟶ horizontal shear production?
⟶ horizontal (turbulent) transport?

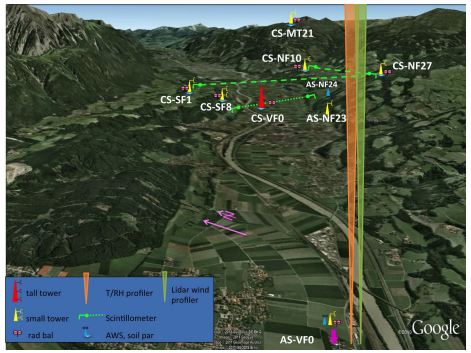
Along-valley wind
Observation



Weigel et al 2006

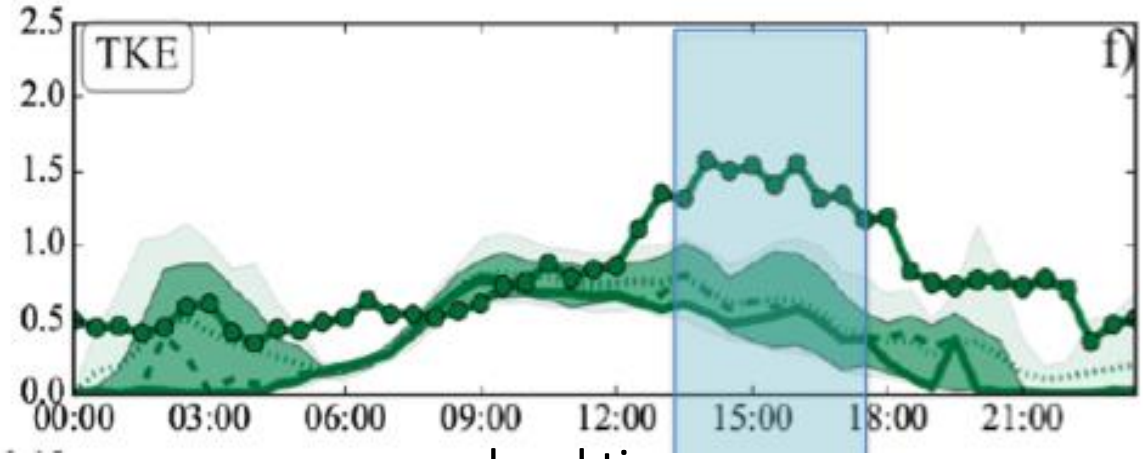
Example:
- use COSMO-1 (MeteoSwiss)
- add *horizontal shear production* and advection
- compare all the terms in the TKE eq. to obs. (i-Box)

i-Box sites

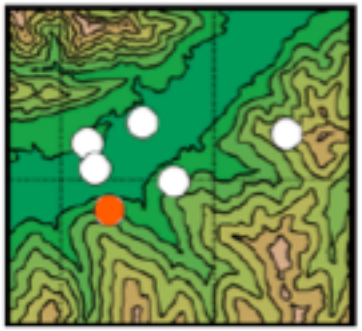


Turbulence parameterization

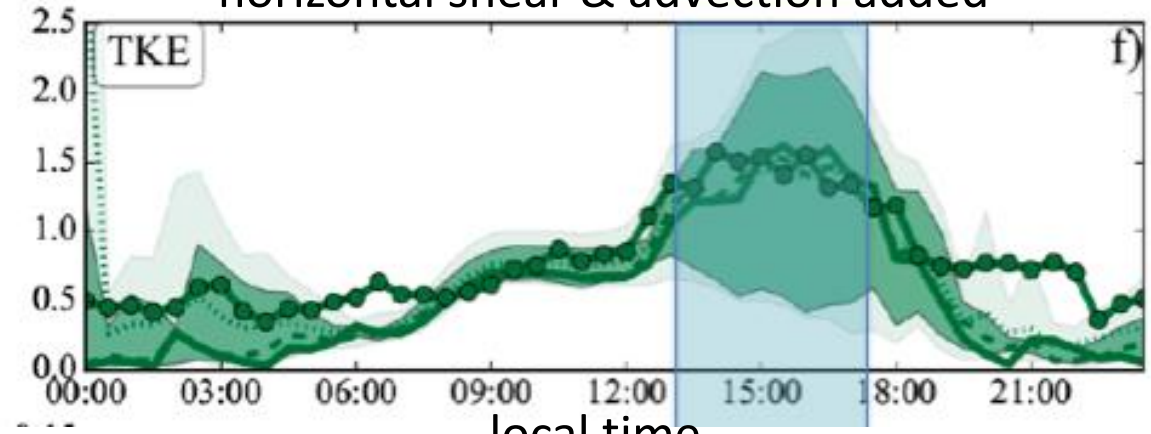
1-dimensional TKE closure



i-Box site CS-NF27



horizontal shear & advection added



Goger et al. (2018)

→ horizontal length scale!

→ based on integral time scale of turbulence

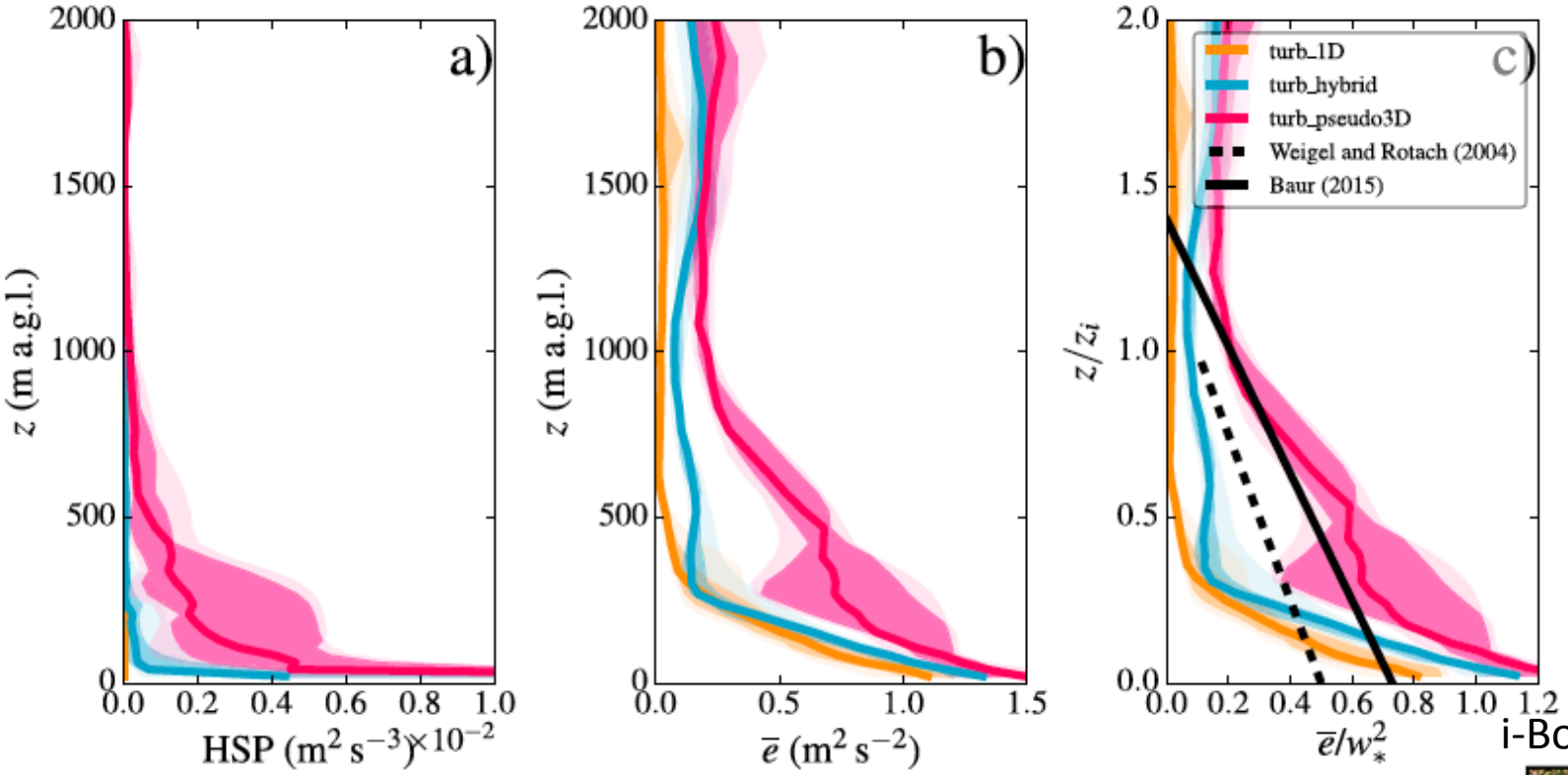
(Goger et al. 2019)

Turbulence parameterization

Horizontal shear production

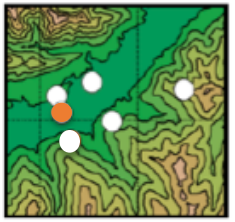
TKE

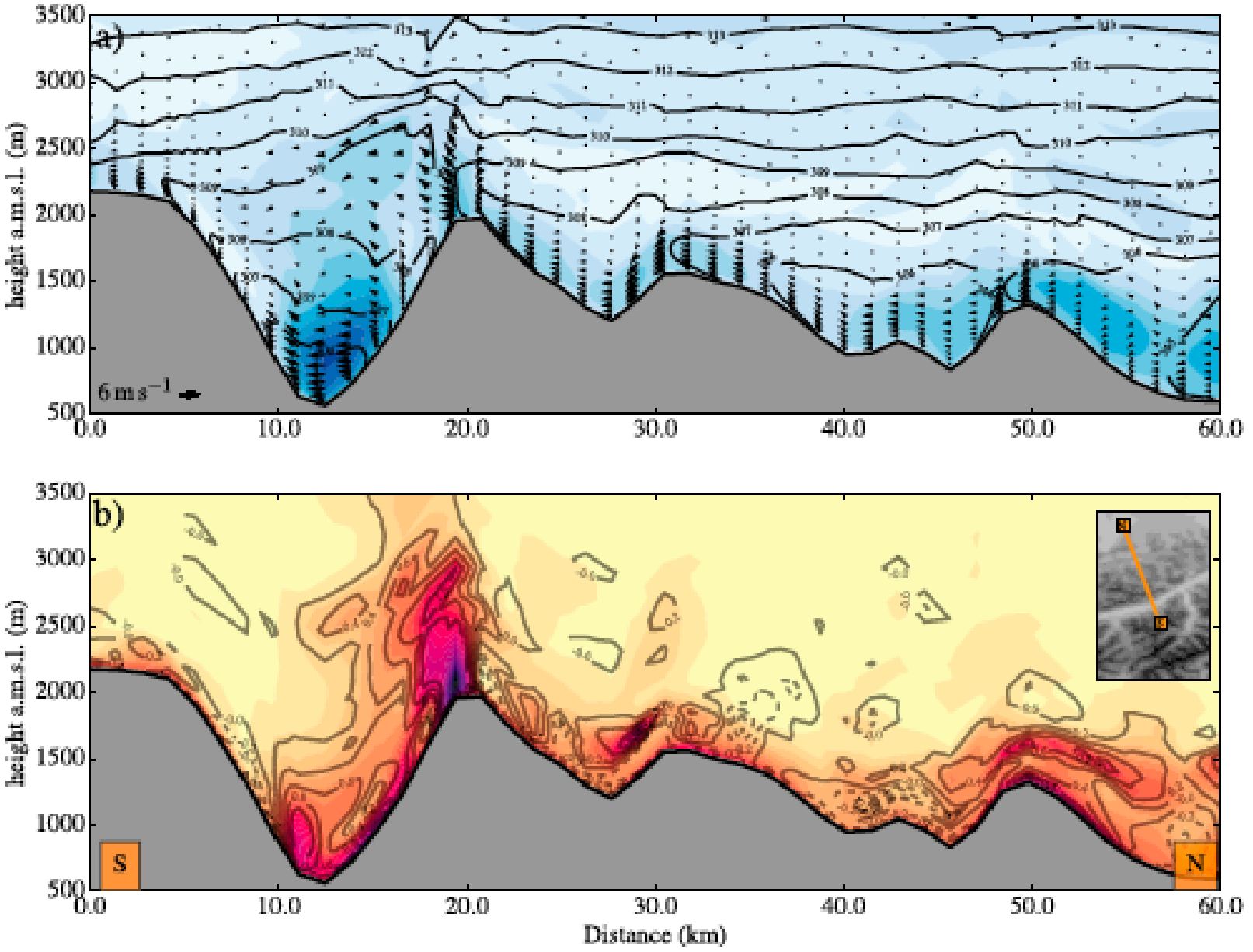
scaled TKE



Goger et al. (2019)

i-Box site VF-0





Goger et al. (2019)

Summary: Overarching objectives

Objective	Primary Focus	Target
Process understanding	Micro- and meso-scale processes within and above the *mountain boundary layer* (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	*Models right for the right reason*, 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.

Serafin et al. 2020, TEAMx-White Paper

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universität innsbruck

TEAMx

Thank you for your attention!

- TEAMx Website: http://www.teamx-programme.org
- PCO: Helen (→ see web site for contact information)

Funding

- TEAMx is bottom-up financed
- While applying for funding, project PIs may request TEAMx “endorsement”. Endorsement implies contributing and accessing to common data pool. Data policy in preparation.
- Projects can be individual, bi- or multi-lateral.
- TEAMx CIG/PCO supports coordination and initiation of new collaborative projects.

Exchange of energy, momentum & mass

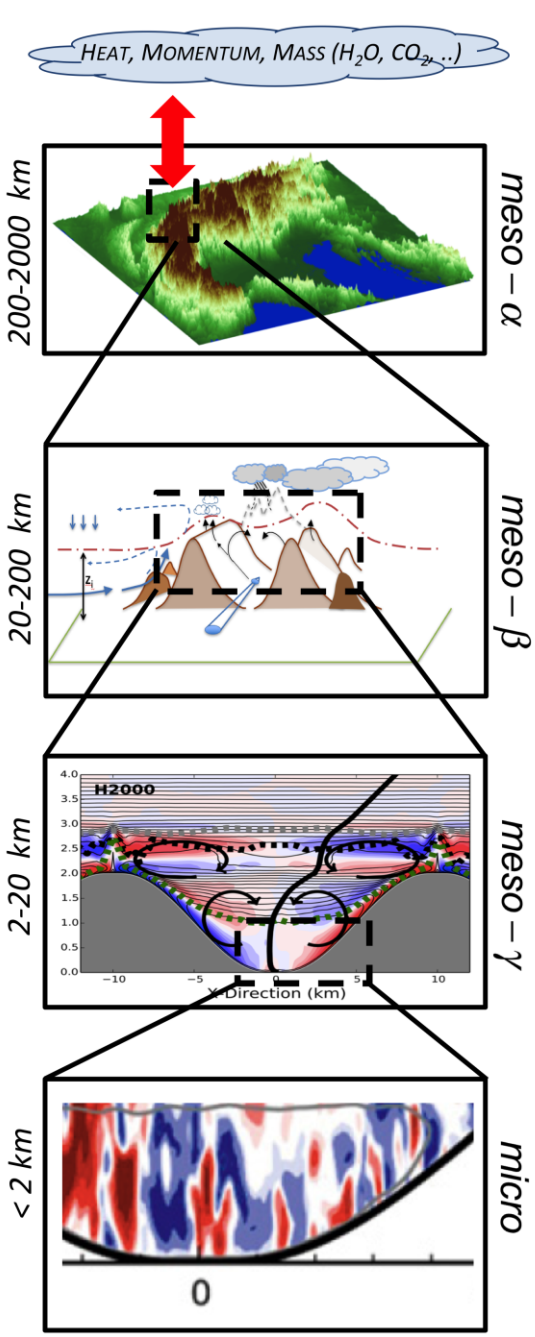
Scale interactions

- cyclogenesis, instability
- PV generation
- blocking

- impact of synoptic flow - stability/ strength/ direction
- interaction between flows in different valleys
- CO_2 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



Processes @ scale

- Influence of Mountain Terrain on
  - Mountain drag
  - Heat (energy) budget
  - Mass exchange (CO_2; H_2O, …)
- Orographic precipitation
  - drying ratio
  - local evaporation

- *Definition* of mountain boundary layer
- Alpine venting
- convective initiation (CI)

- impact of valley geometry, orientation, surface type(s), … on local exchange
- valley turbulence (TKE)
- convective initiation (CI)

- turbulent exchange on slope
- data post-processing
- scaling
- surface character (e.g., soil moisture)