



What's the problem? And what is TEAMx?

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Outline

- ▲ What is TEAMx?
- ▲ Exchange processes over mountains: why does exchange matter?
- ▲ What are the challenges over mountains?

TEAMx – what is it?

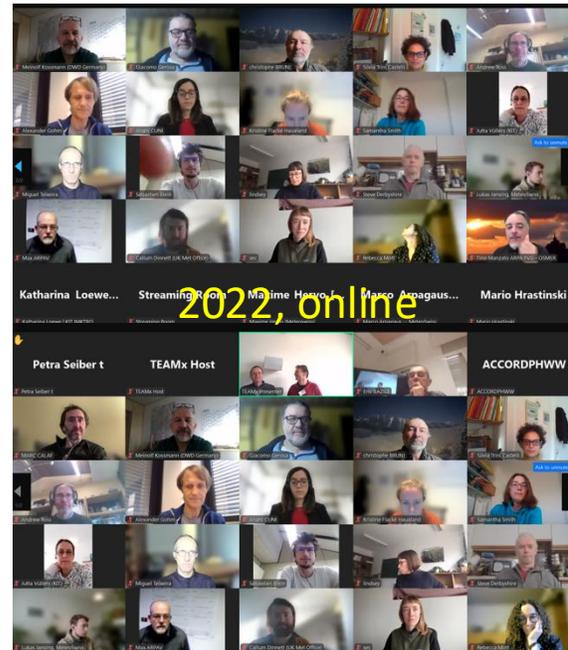


Multi-scale **T**ransport and **E**xchange Processes in the **A**tmosphere over **M**ountains Programme and **e**xperiment

<https://www.teamx-programme.org>



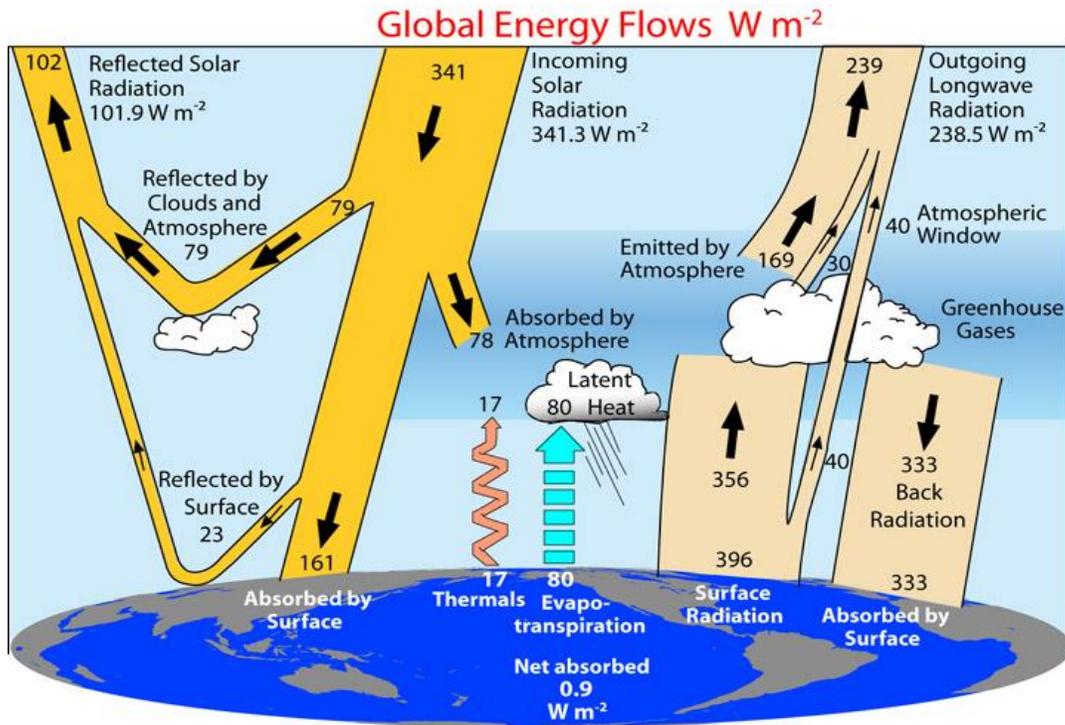
2019, Rovereto



2024, Innsbruck - hybrid

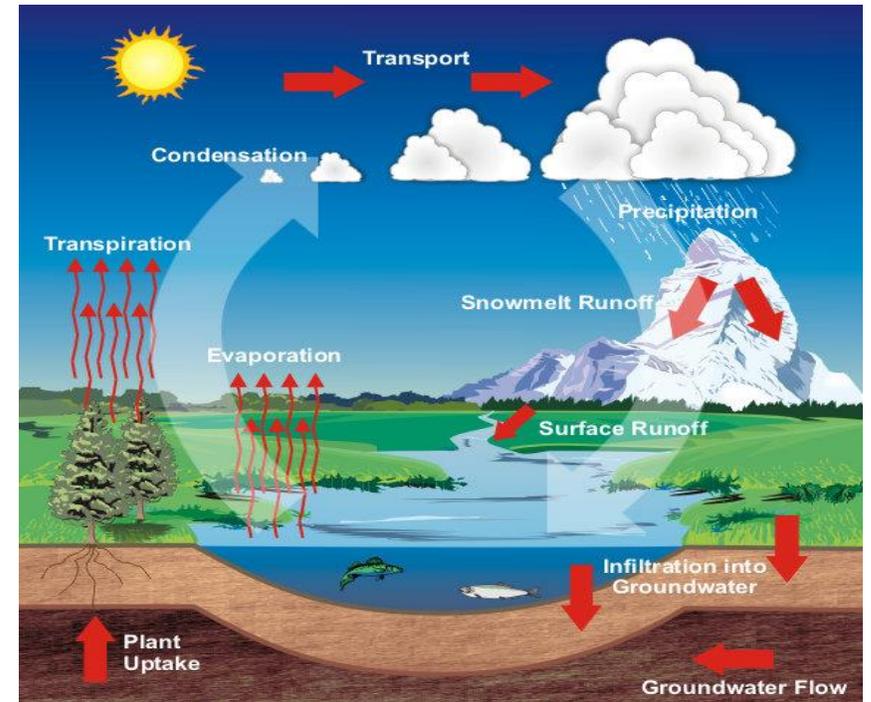
Exchange – why does it matter?

Global energy budget



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

Water cycle



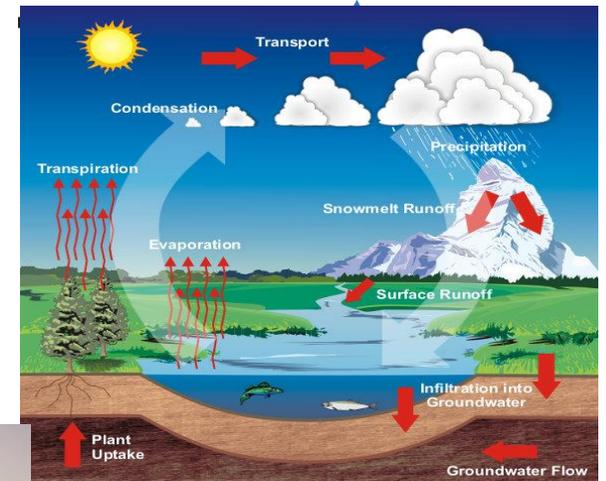
http://www.algebra.org/practice/practice.aspxfile=Reading_WaterCycle.xml

→ energy, mass (H_2O , CO_2 , ...), momentum

Exchange – why does it matter?

Vertical exchange surface – atmosphere:

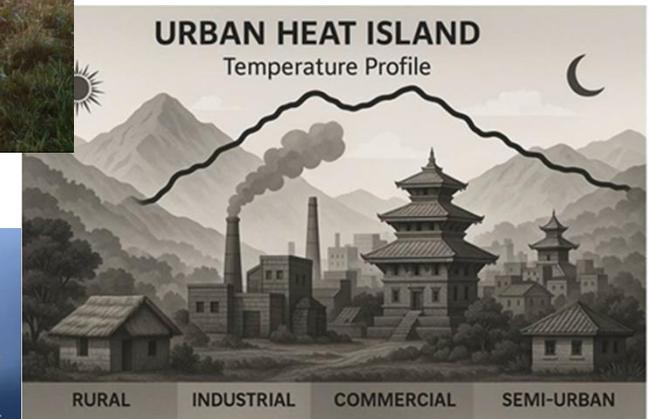
- ▲ how much water gets ‘into the clouds’? (evaporation → condensation)
- ▲ (heat) energy re-distribution → baroclinicity → circulation
- ▲ how effectively is the flow decelerated through friction @sfc



http://www.algebra.org/practice/practice.aspx?file=Reading_WaterCycle.xml



<https://stock.adobe.com/at/search?k=dew+morning>

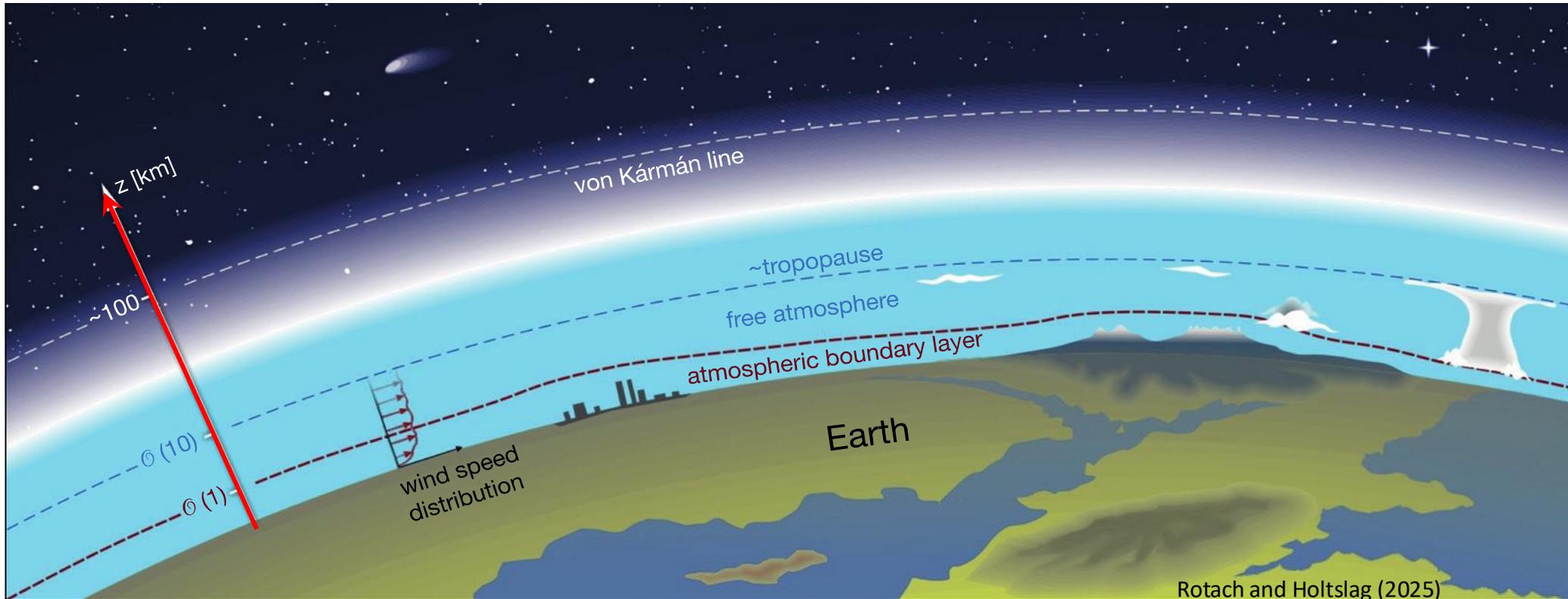


<https://english.pardafas.com/urban-forests-parks-and-ponds-can-cool-kathmandu-by-up-to-1-6c-study-finds/>



<https://www.zmescience.com/other/feature-post/how-windturbines-work-21072021/>

Exchange surface ↔ atmosphere



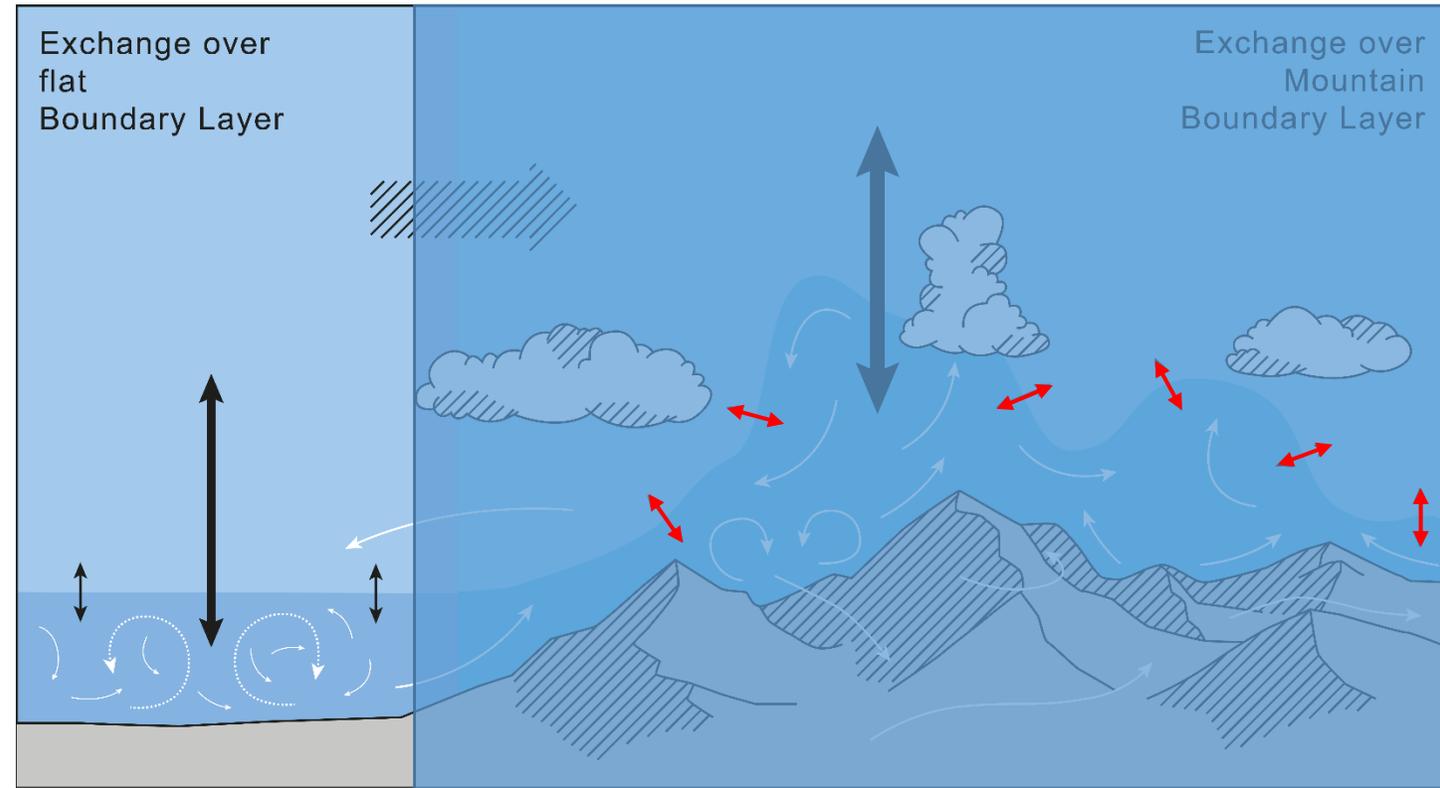
▲ traditionally, earth-atmosphere exchange through the Atmospheric Boundary Layer

→ only in the vertical

▲ turbulent layer near the surface

Exchange surface ↔ atmosphere

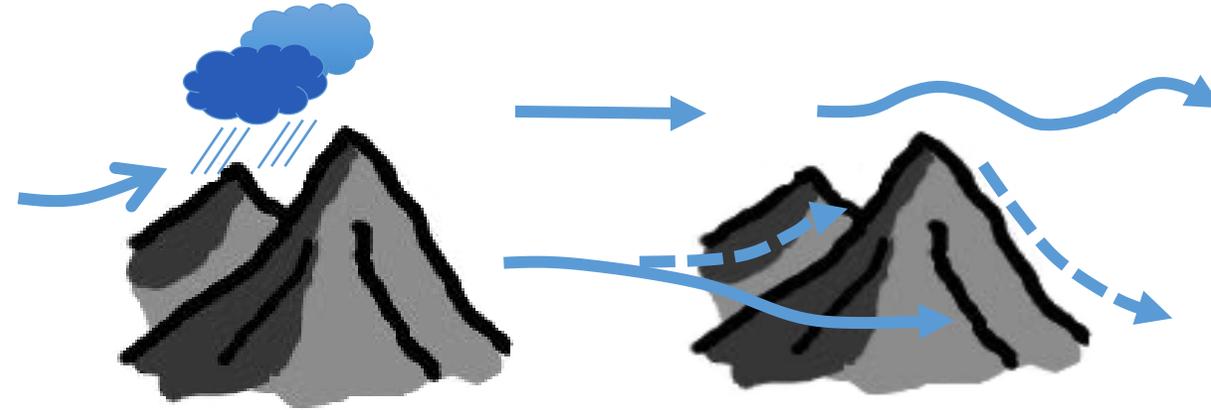
-  traditionally, earth-atmosphere exchange through the Atmospheric Boundary Layer
-  over mountains: interaction with mesoscale flows
 - thermally driven
 - dynamically forced flow
-  3-dimensional: Mountain Boundary Layer MoBL
-  spatially inhomogeneous



Serafin et al (2018)

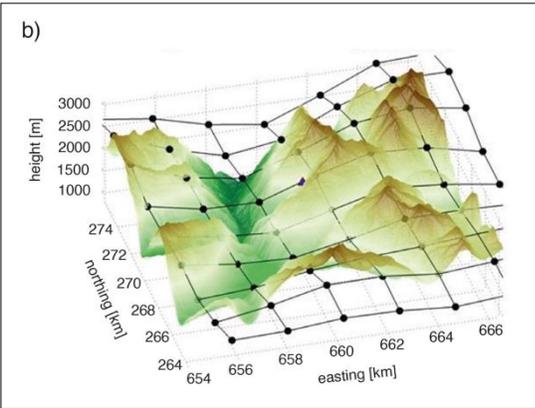
Challenges over mountains

- ▲ mountains produce 'their own' weather and climate
 - orographic precipitation
 - Föhn winds and other downslope windstorms
 - ...
- ▲ they also modify the flow - mainly at the surface...
- ▲ due to different spatial scales, there is not 'one solution to the problem'

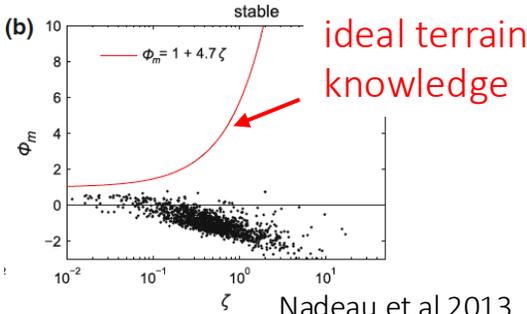
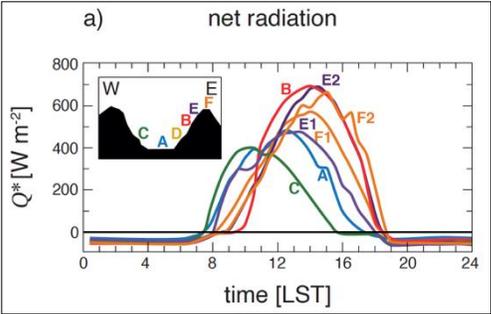
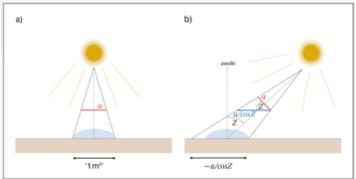
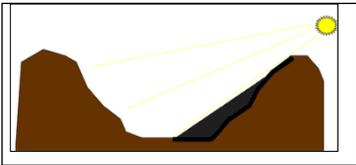


Challenges over mountains

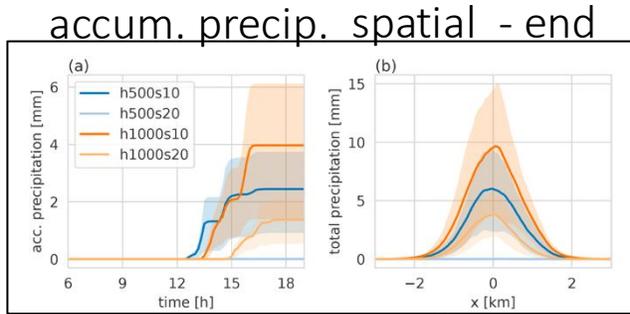
- ▲ numerical models require high resolution
→ expensive
- ▲ numerical instabilities over steep terrain
- ▲ most physical processes impacted [but in the models treated as over flat]
 - radiation (shading, angle)
 - turbulence
 - convection (initiation)
 - (surface) energy balance
 - sub-mesoscale circulations



Rotach and Holtslag (2025)



Nadeau et al 2013



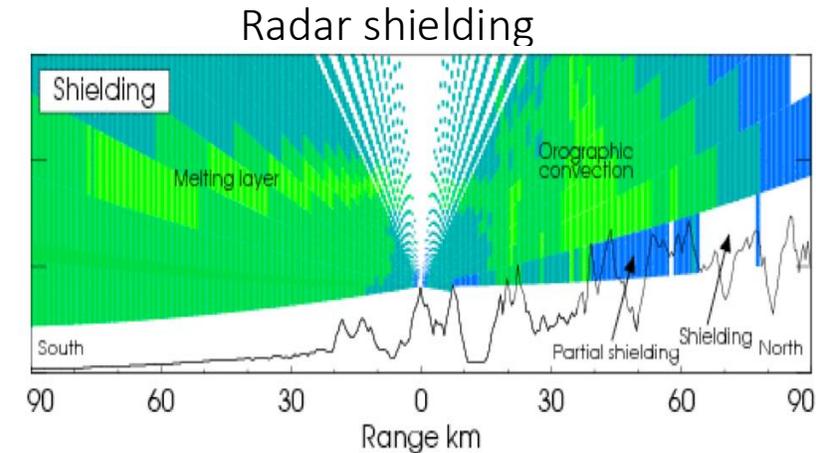
Göbel et al 2023

Challenges over mountains

- ▲ data from rough terrain
→ expensive maintenance
→ extra requirements
- ▲ often measurements principles not conform with steep terrain
- ▲ required: dense observational grid
→ large gradients over short distances
- ▲ actual: coarser observational grid
→ reasons above



Photo credit René Cattin



Germann et al 2006

Radiosoundings



- one operational radio sounding in the inner Alps
- critically lacking: thermodynamic profiles

TEAMx wants....



from the TEAMx Science Plan

- ▲ to better understand these exchange processes
- ▲ to make the models (weather and climate) better in the mountains
- ▲ to provide data to reach these goals
- ▲ to support weather and climate services in mountainous regions

Objective	Primary Focus	Target
Process understanding	Micro- and meso-scale processes within and above the <i>mountain boundary layer (MoBL)</i> ; 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

TEAMx is....

- ▲ international
- ▲ bottom-up financed
 - ‘institutional crowd - funding’
 - 3rd party funding
 - in kind
- ▲ ~ 20 M€ dedicated funding
- ▲ with a focus on the Alps



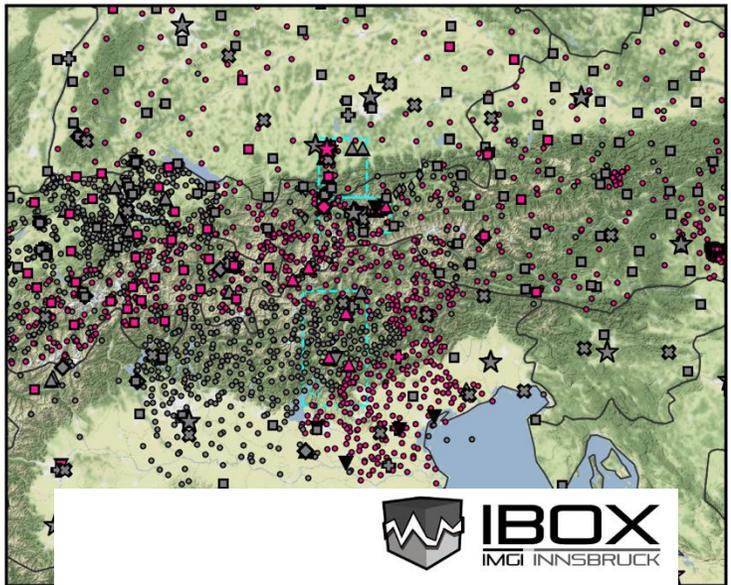
some
 ~250 scientists from
 ~ 40 institutions in
 13 countries



Why the Alps?

- ▲ dense *operational* networks
→ i.e., comparably dense
- ▲ especially Fluxnet sites
→ i-Box
→ 5 Italian sites
- ▲ diverse surfaces over small horizontal distances
→ urban areas, forests, pastures, bare rock, glaciated or snow-covered areas
- ▲ relatively large population affected
- ▲ long history..... (ALPEX, PYREX, MAP)

All stations



- Target Area
- Operational site
- Potential site/check data access
- Weather station
- ▲ Flux tower
- ★ Radio-sounding
- + T-RH profiler
- ▼ Wind profiler
- ✖ Radar
- Aerosol profiler
- ◆ Air quality station
- ◆ Atmos. chem. facility



Conclusions

- ▲ Mountain weather and climate is challenging
- ▲ If your research requires atmospheric data as input
 - look twice before you use it
 - is it representative?
 - does it reflect your needs?
- ▲ TEAMx addresses those challenges...
- ▲ The TEAMx observational campaign (talk by Manuela Lehner) has produced a wealth of additional data
- ▲ Will be used to make the models better (talk by Stefano Serafin)
- ▲ ...eventually will improve climate services (talk by Dino Zardi)

References

- Germann U, Galli G, Boscacci M, Bolliger M: 2006, Radar precipitation measurement in a mountainous region, *Journal of the Royal Meteorological Society*, **132**, (618) 1669-1692 <https://doi.org/10.1256/qj.05.190>
- Göbel M, Serafin S, Rotach MW: 2023, Adverse impact of terrain steepness on thermally driven initiation of orographic convection, *Weather Climate and Dynamics*, **4**, 725–745, <https://doi.org/10.5194/wcd-4-725-2023>
- Nadeau, D.F., Pardyjak, E.R., Higgins, C.W. et al. (2013) Similarity Scaling Over a Steep Alpine Slope *Boundary-Layer Meteorology* **147**: 401.
- Rotach MW and Holtslag AAM, (2025), *Ideal and Real Atmospheric Boundary Layers* Elsevier, Academic Press, ISBN 978-0-323-95957-5, 317pp.
- Serafin S, Rotach MW, Arpagaus M, et al: 2020, Multi-scale transport and exchange processes in the atmosphere over mountains. Programme and experiment, Innsbruck university press, 1st Edition, ISBN 978-3-99106-003-1, DOI 10.15203/99106-003-1, 48pp.