TEAMx

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

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on behalf of the TEAMx *Coordination and Implementation Group*

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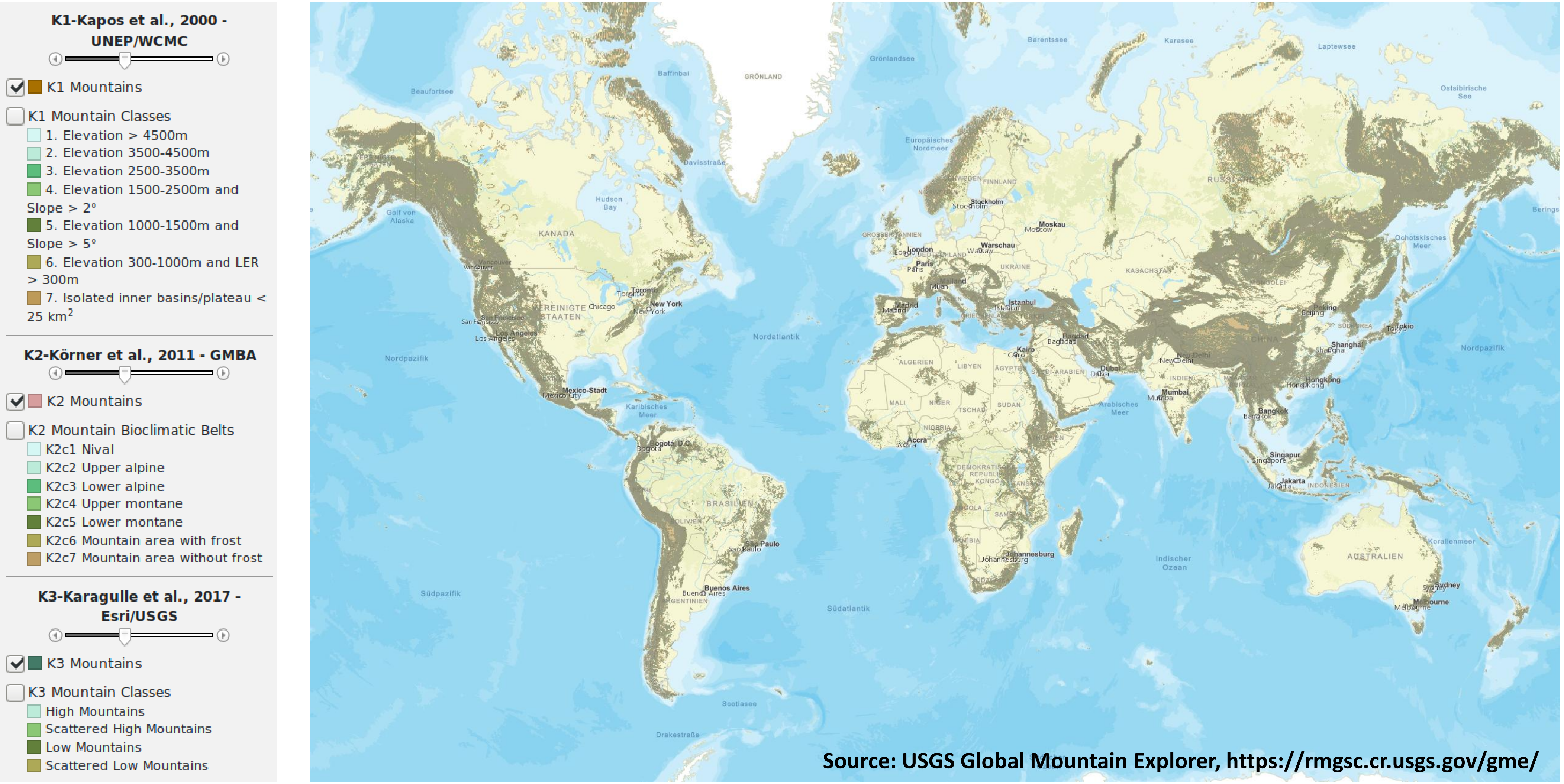
www.teamx-programme.org

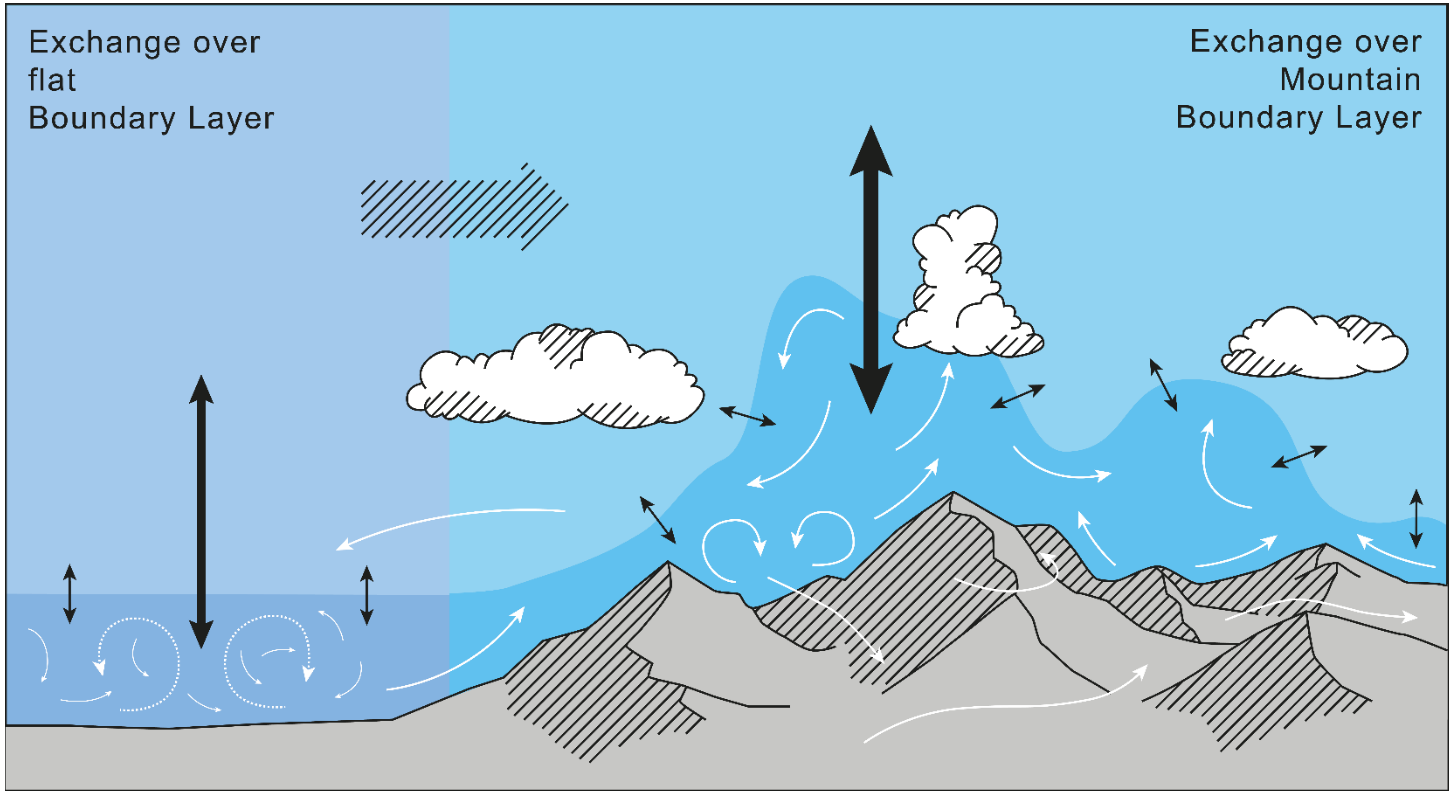
Global distribution of mountains



Source: USGS Global Mountain Explorer, https://rmgsc.cr.usgs.gov/gme/

The Mountain Boundary Layer (MoBL)

- *Exchange processes induced by mountains*: Transfer of heat, momentum and mass (water, CO_2, aerosols) between the ground, the PBL and the free atmosphere.
- High-resolution observation and modelling possible, but non-trivial. Model spatial resolutions outpacing observations.
- Special challenges over mountains: Spatial heterogeneity, wide range of relevant scales of motion.

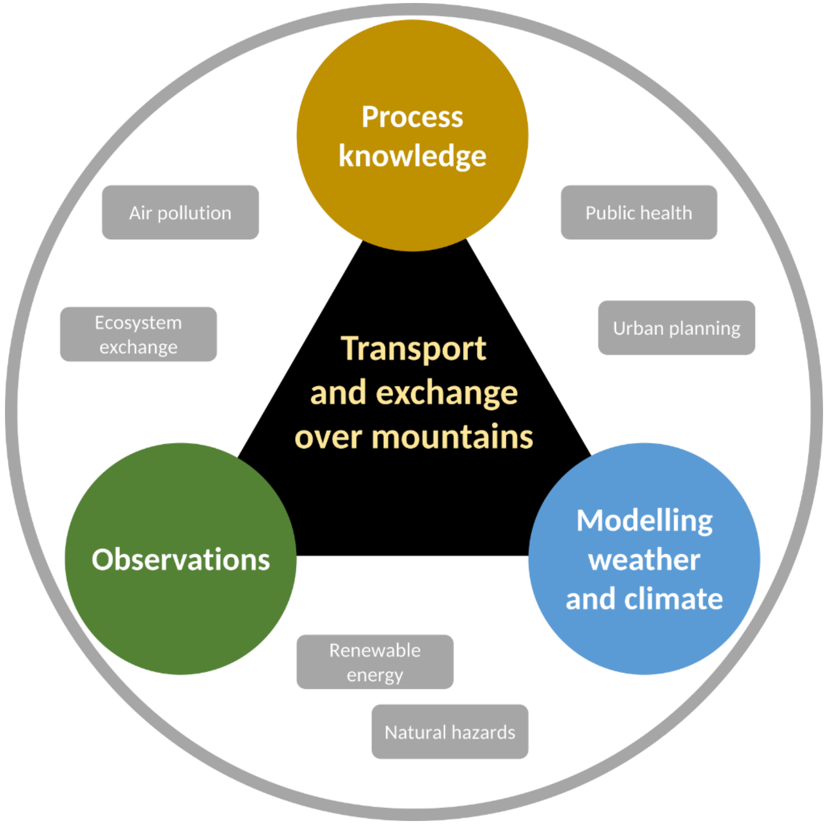


Exchange processes over mountains

Momentum	Atmospheric flow decelerates over mountains, due to orographic blocking and gravity wave breaking. Orographic drag parameterizations alleviate systematic biases in general circulation models.
Heat	At daytime, mountains heat the atmosphere at high altitudes above sea level, generating breeze systems that favor horizontal and vertical transport and mixing. At night, orography favors cold-air pooling.
Mass: water	Flow over mountains enhances stratiform and convective precipitation, drying up the atmosphere. Mountains are “water towers” for the surrounding plains.
Mass: CO_2	CO_2 uptake by the land surface is the most uncertain term of the global budget, and is often estimated as the residual from other terms. Systematic deviations between modelled uptake and estimated residual reveal inadequacies in CO_2 flux modelling over land. Poorly represented exchange over orography may be one reason.

TEAMx

- *Joint experimental efforts* to collect observations of exchange processes in complex-terrain areas. Use them for:
  - Model evaluation.
  - Parameterization improvement/development (SL, PBL, orographic drag, convection).
  - Process understanding.
- Field phase tentatively in 2023-2024, **European Alps**.



Memorandum of Understanding signed by 14 institutions.

Open to new partners.

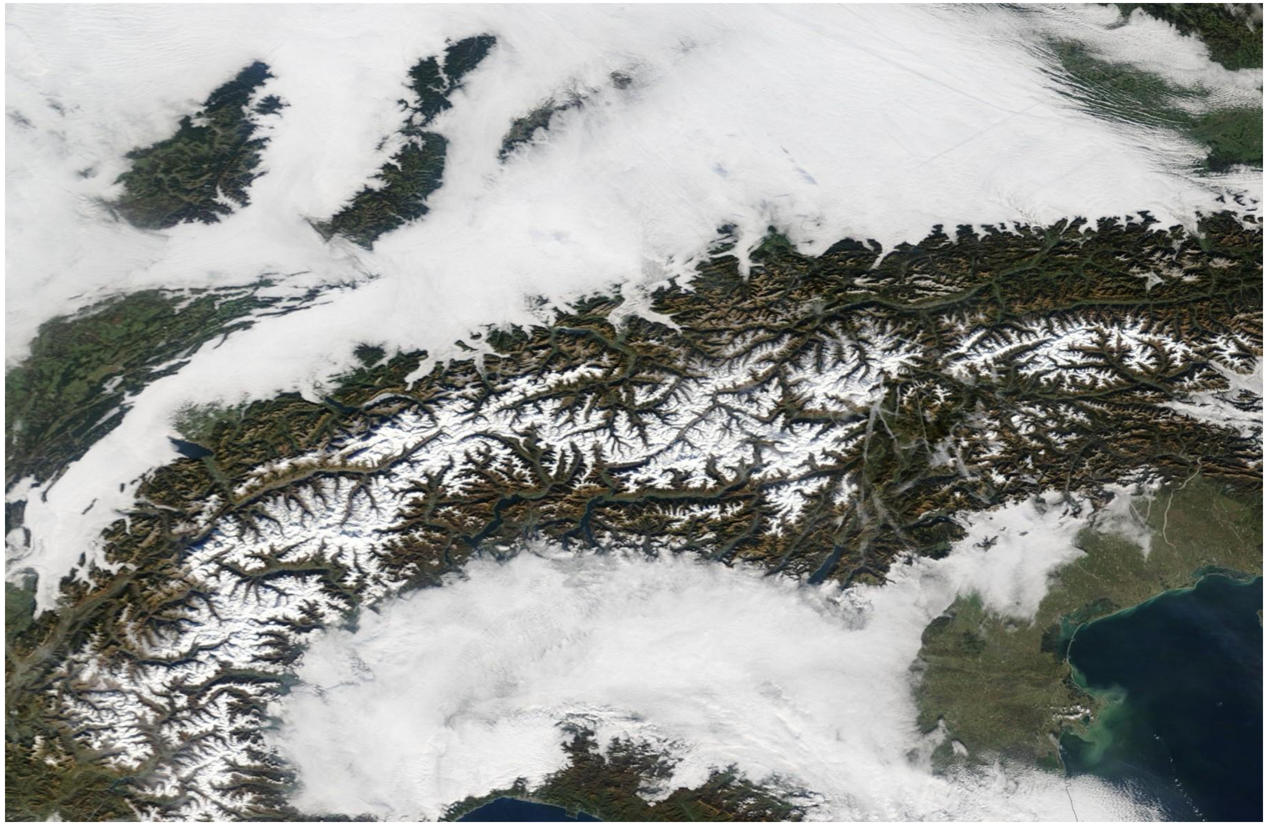
Atmosphere special issue on "***Atmospheric Processes over Complex Terrain***" (editors M. Rotach and D. Zardi). 8 papers published, 1 in preparation.

First TEAMx Workshop
28-30 August 2019
Rovereto (Italy).
92 participants from 11 countries.

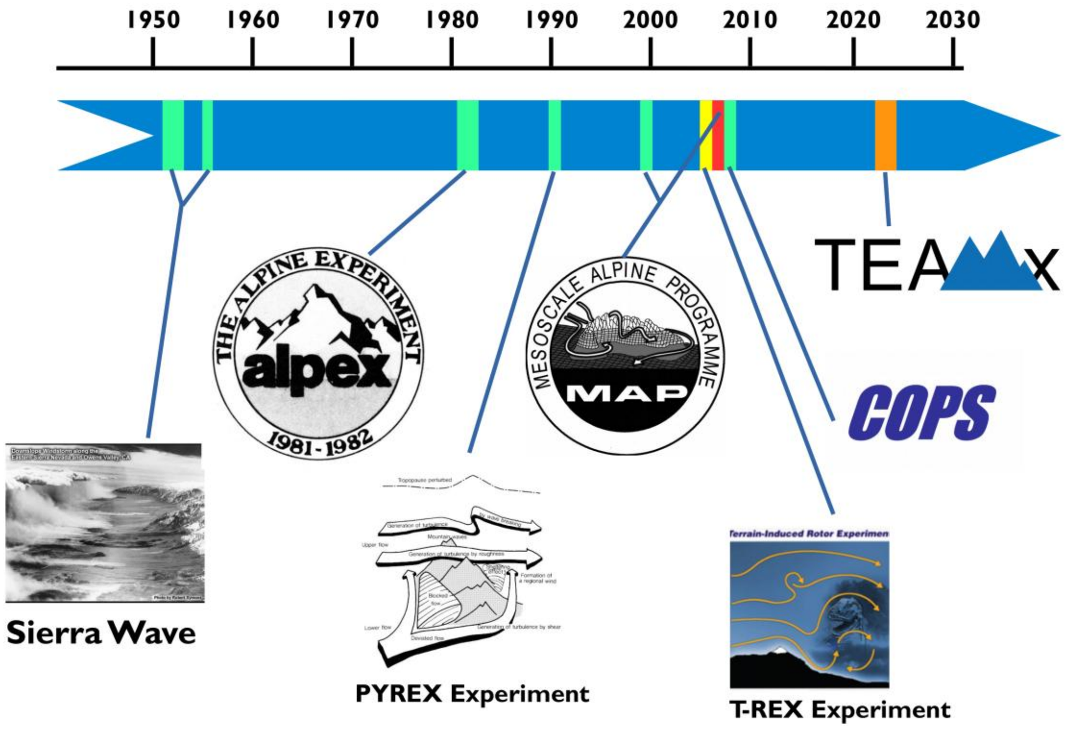
White Paper being finalized.

Why the Alps?

- Midlatitude region with abundant moisture supply.
- High spatial heterogeneity in small area.
- Dense measurement network.
- Existing semi-permanent micrometeorological observatories, numerous high-altitude observatories.
- High population density, many stakeholders, impact-oriented modelling important.



Major experiments in mountain meteorology



TEAMx technological drivers

- Observational advances w.r.t. historical campaigns:
  - Remote sensing: ground based (radar, lidar, boundary-layer profiling, tomographic) and satellite-based (resolution, parameters retrieved).
  - Airborne sampling and remote sensing.
- Model advances:
  - Steadily increasing resolution.
  - High resolution implies challenges in model initialisation, parameterization of sub-grid-scale physical processes, model evalution.

TEAMx Science Plan

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

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Focus: The MoBL

- The state-of-the art in parameterizations does not reflect the state of knowledge about exchange processes over mountains.
- Examples:
    1. Scaling laws in the surface layer
    2. **Planetary boundary layer (MoBL)**
    3. Orographic drag

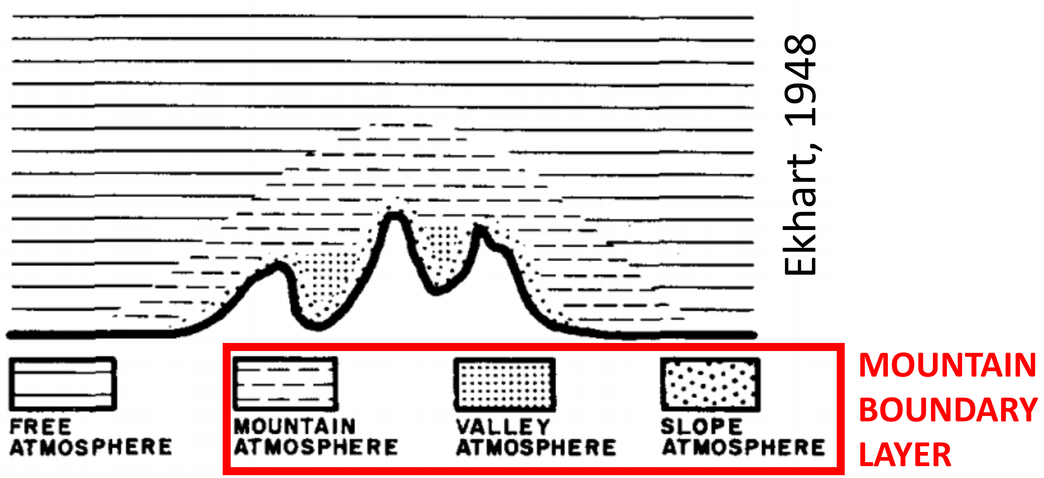


Figure 13: Diagram of the structure of the atmosphere above a mountain range.

Focus: The MoBL

Troen and Mahrt (1986)

How parameterizations work

- Regardless of the closure type (K-profile or TKE-based), the BL height (z_i) is a key parameter in determining the eddy transfer coefficients.
- z_i is determined in a variety of ways (e.g., gradient or Ri_b methods).
- PBL closures are often 1D (they only model vertical exchange).

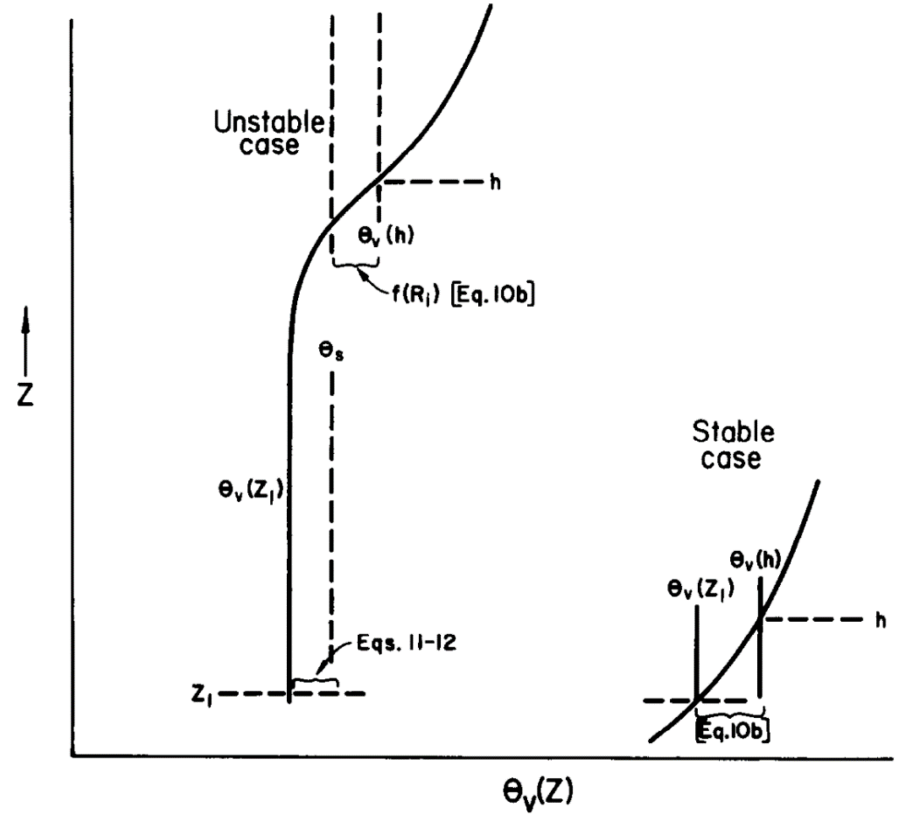


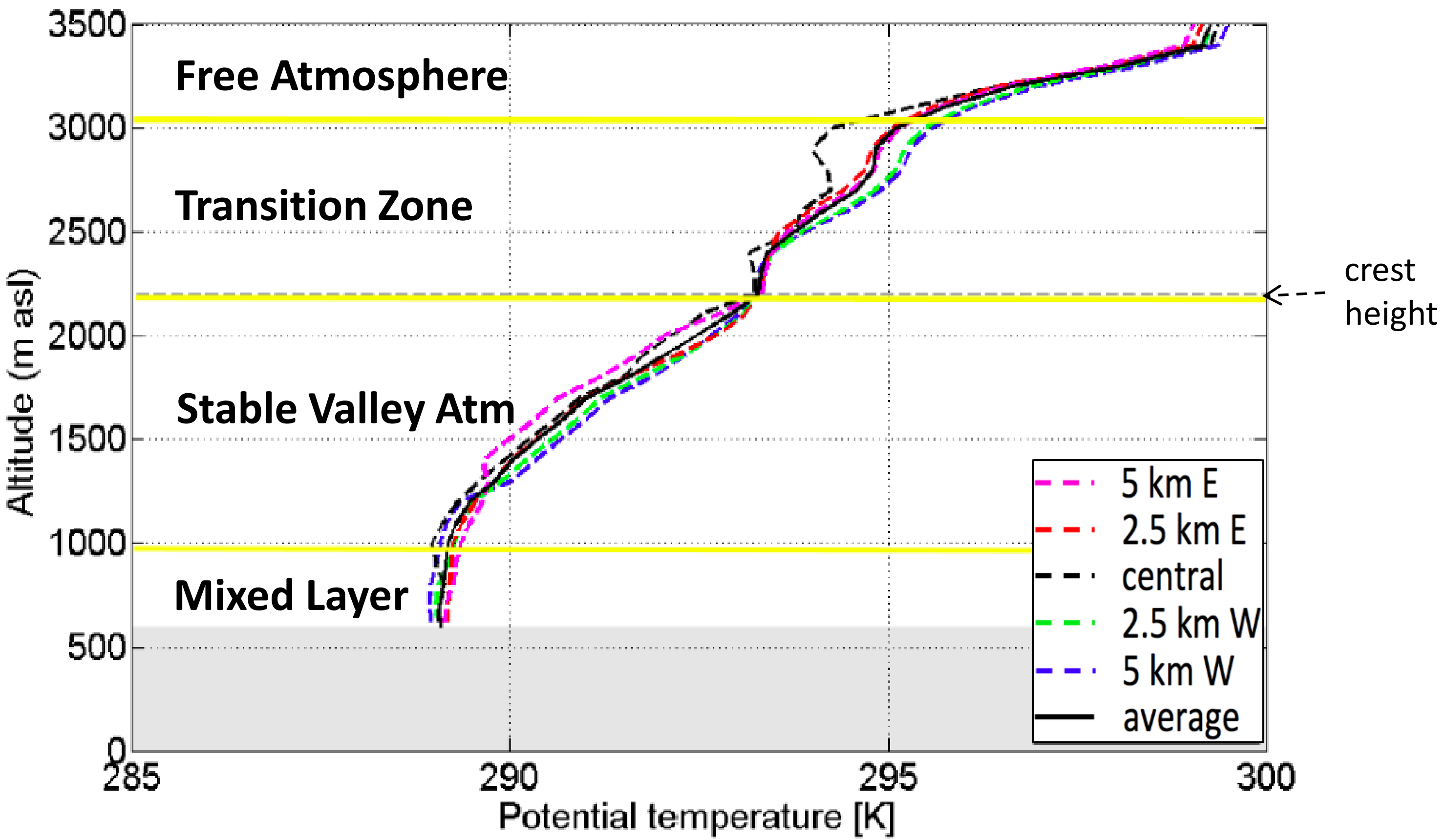
Fig. 1. Geometric sketch of the boundary-layer depth relationship to the profile of potential temperature above the surface layer (solid profile). For the unstable case, the first vertical broken line to the right of the profile indicates the potential temperature after enhancement due to the temperature excess associated with surface heating (11–12). The vertical broken line on the right indicates the potential temperature at the boundary-layer top after deepening due to shear-generated mixing as formulated in terms of a modified bulk Richardson number (10b). The latter mechanism completely determines the depth of the stable boundary layer.

Focus: The MoBL

What we know

- The vertical structure of the MBL is more complex than that of the CBL (evidence from both *observations* and numerical modelling).
- Different ways to estimate z_i perform very differently over complex terrain.
- Horizontal exchange is important over complex terrain.

Markl et al (2017)



Wagner et al (2015)

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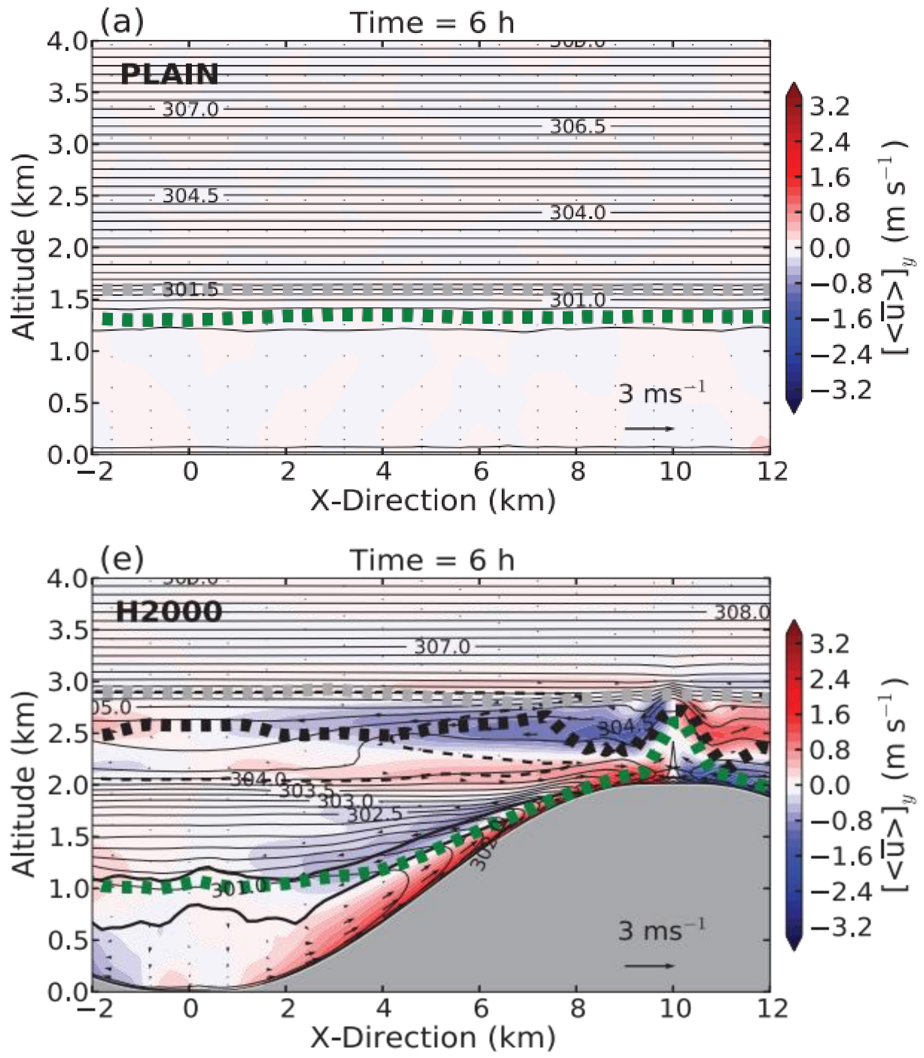

Figure 4. (a)–(e) Cross-sections of potential temperature (thin contour lines), cross-valley (colour shading) and along-valley wind speed (thick contour lines, negative values dashed, interval 1.0 m s^{-1}, the zero line is not shown) averaged between $y = 5$ and $y = 15$ km after 6 h of simulation. Boundary-layer heights PBL1, PBL2 and PBL3 are plotted with thick dashed green, black and grey lines, respectively.

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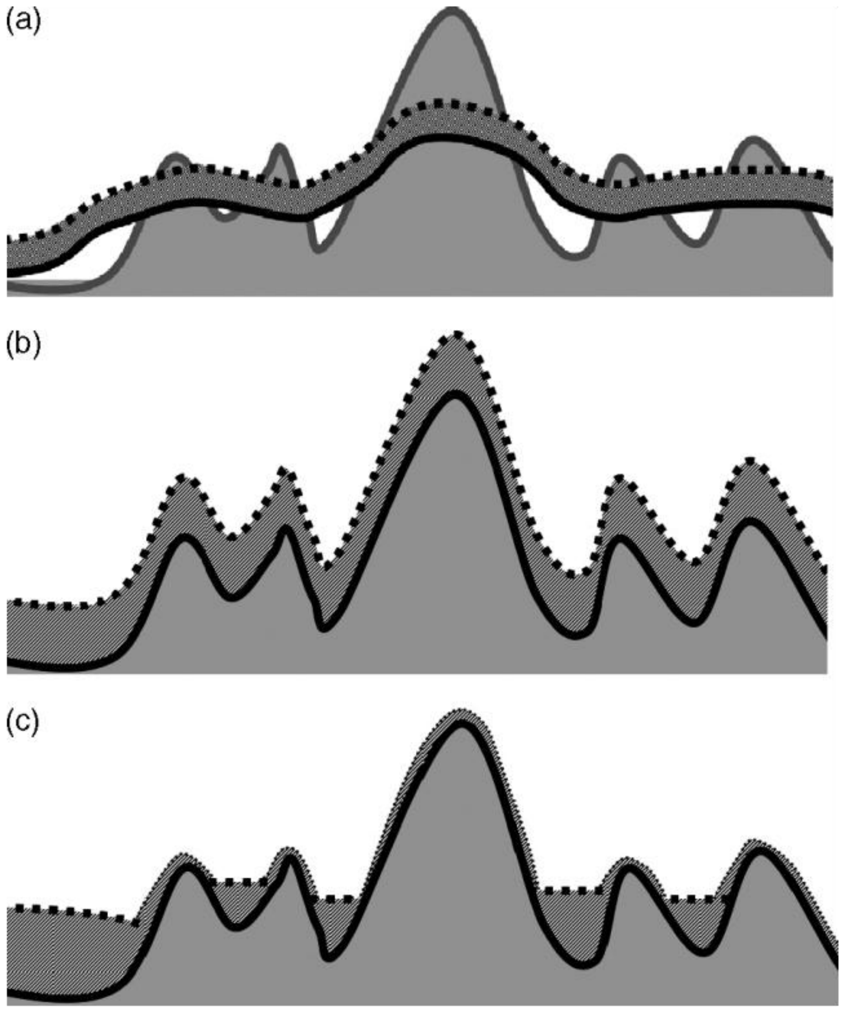


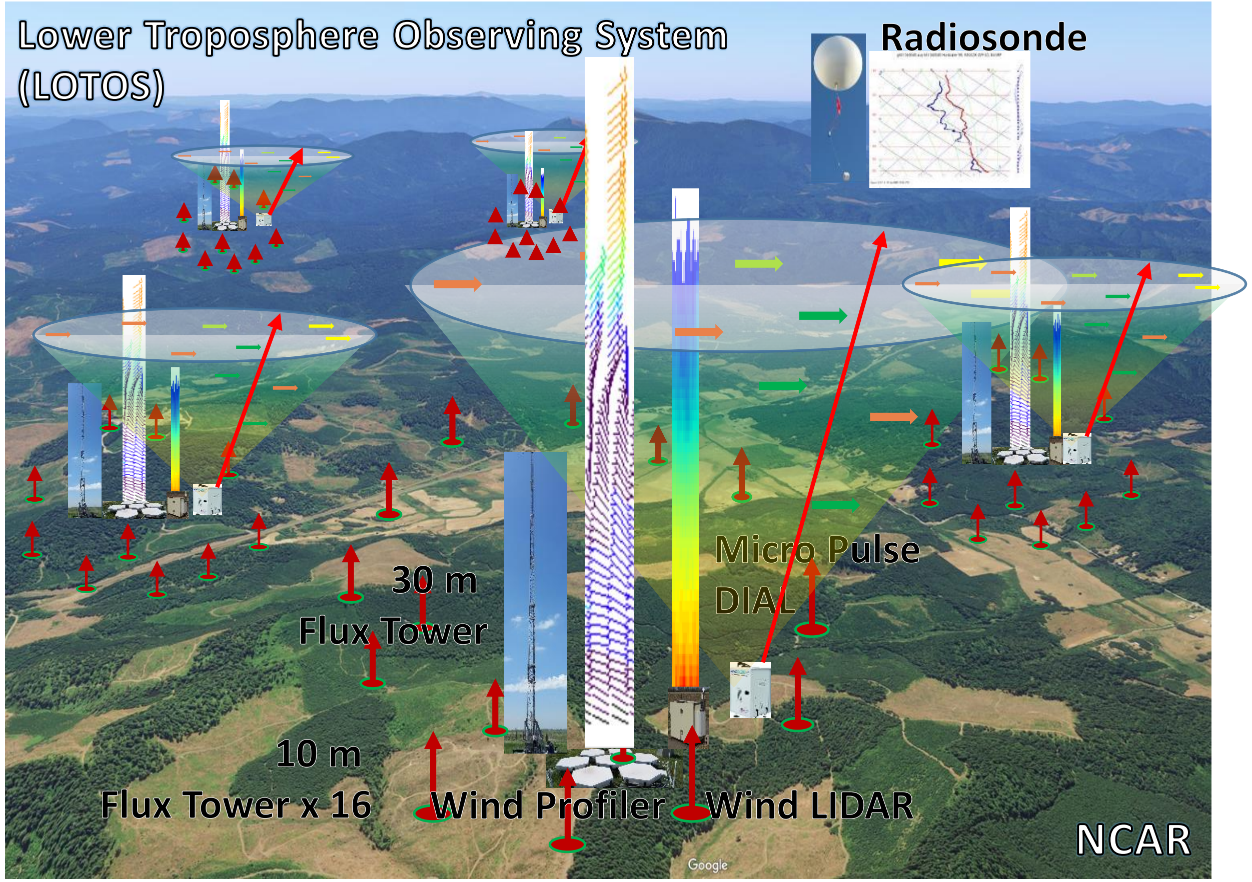
Figure 5. Schematic representation of the boundary layer in (a) a low-resolution numerical model, (b) a high-resolution operational numerical model, and (c) the turbulent boundary layer as found from different MAP boundary-layer studies.

Focus: The MoBL

TEAMx plan

- Comprehensive measurements of the MoBL
- Systematic evaluation of PBL parameterization over complex terrain
- Testing recent advances in numerics (e.g. immersed- and embedded-boundary methods to represent orography)
- Numerical modeling experiments including climate simulations

Courtesy of Vanda Grubišić

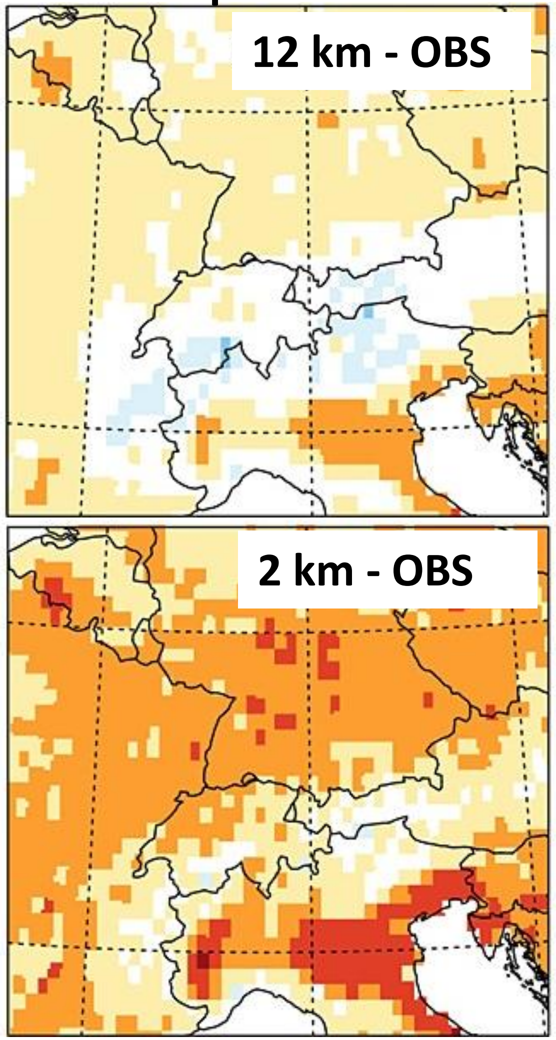


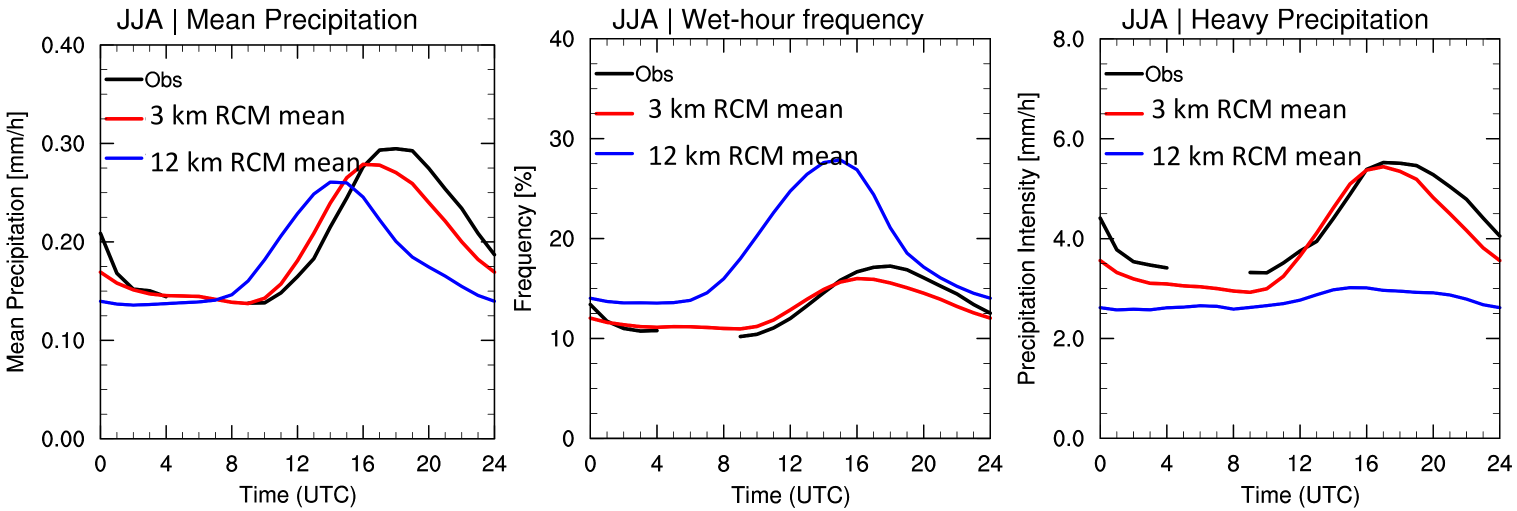
TEAMx relevance to climate modelling

Motivation

- Feasible to run high-resolution (km-scale) models at climate timescales
- However, the model physics is designed for coarse resolution models and starts to break down when going to a smaller grid spacing
- It is considered that km-scale models are entering the grey zone of turbulence (Chow et al., 2019) - need a better representation of turbulence and exchanges process

Temperature Bias





Ban et al. (In prep.)

Ban et al. 2014

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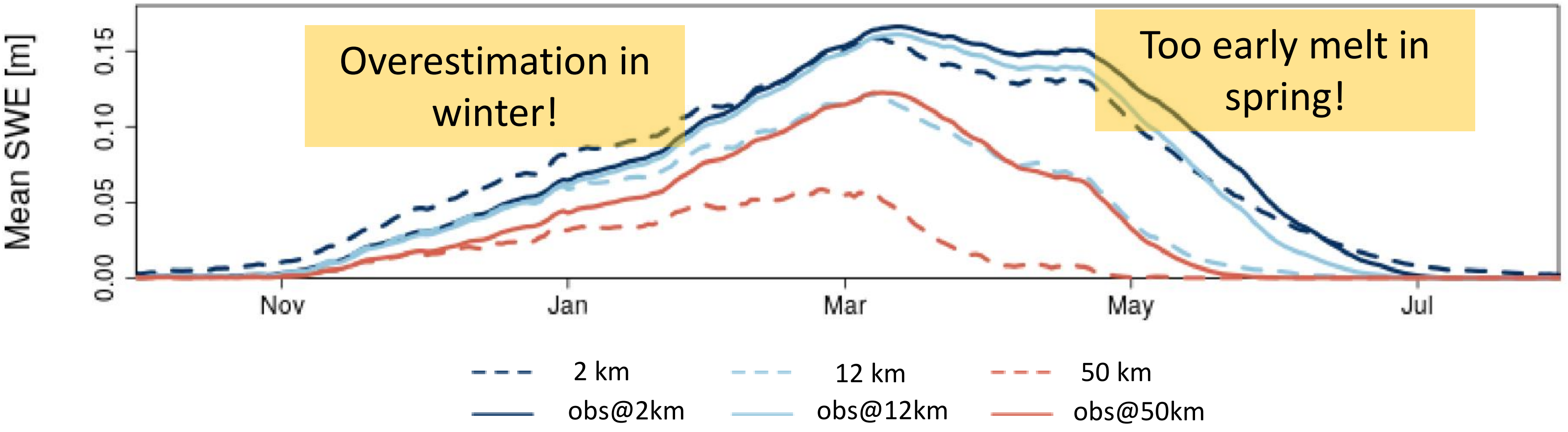
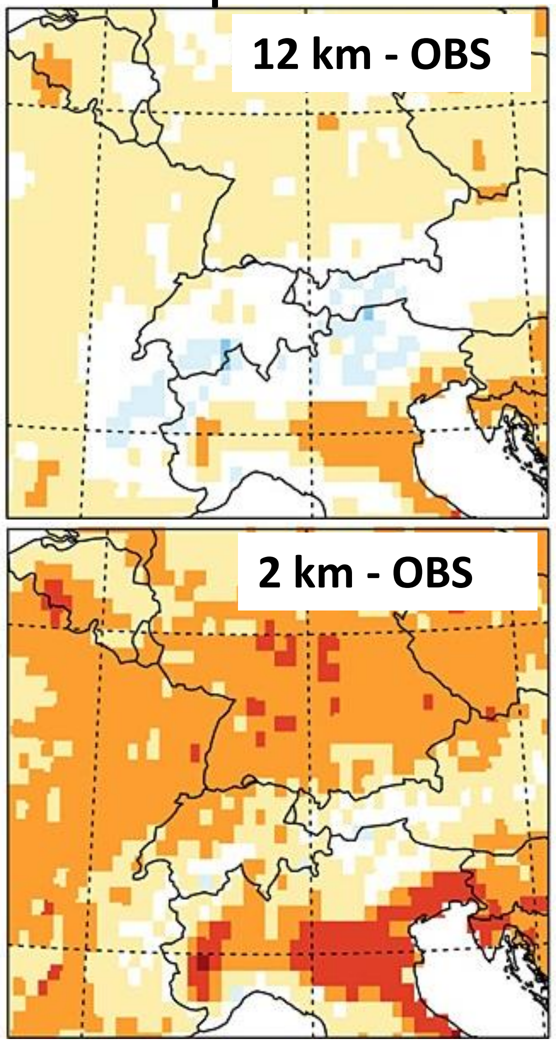
Snow Water Equivalent



Luethi et al. 2019

Temperature Bias



Ban et al. 2014

TEAMx relevance to climate modelling

Objectives

- Improve process fidelity in different models – GCMs, NWP, RCMs (LAMs), CRMs
- Understand the role of mountain for the global climate
- Recognize relevant climate processes and assess their changes with a warming
- Provide high fidelity and robust input to impact models – through Coordinated climate experiments on mountain climate (e.g., propose a CORDEX FPS on Mountain Climate)

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.

Conclusions

- TEAMx has started: MoU, review papers, workshop.
- Scientific focus on mountain-induced exchange processes. Broad scope including related disciplines such as air chemistry, climate science.
- Combination of field and modelling experiments.
- Plans for field campaign in 2023-2024 in the European Alps.
- Implementation details currently being defined.
- Bottom-up funding.
- ....


First TEAMx Workshop
Rovereto (Italy), 28-30 August 2019
Thank you!