TEAMx

Multi-scale Transport and Exchange processes in the Atmosphere over Mountains – programme and experiment

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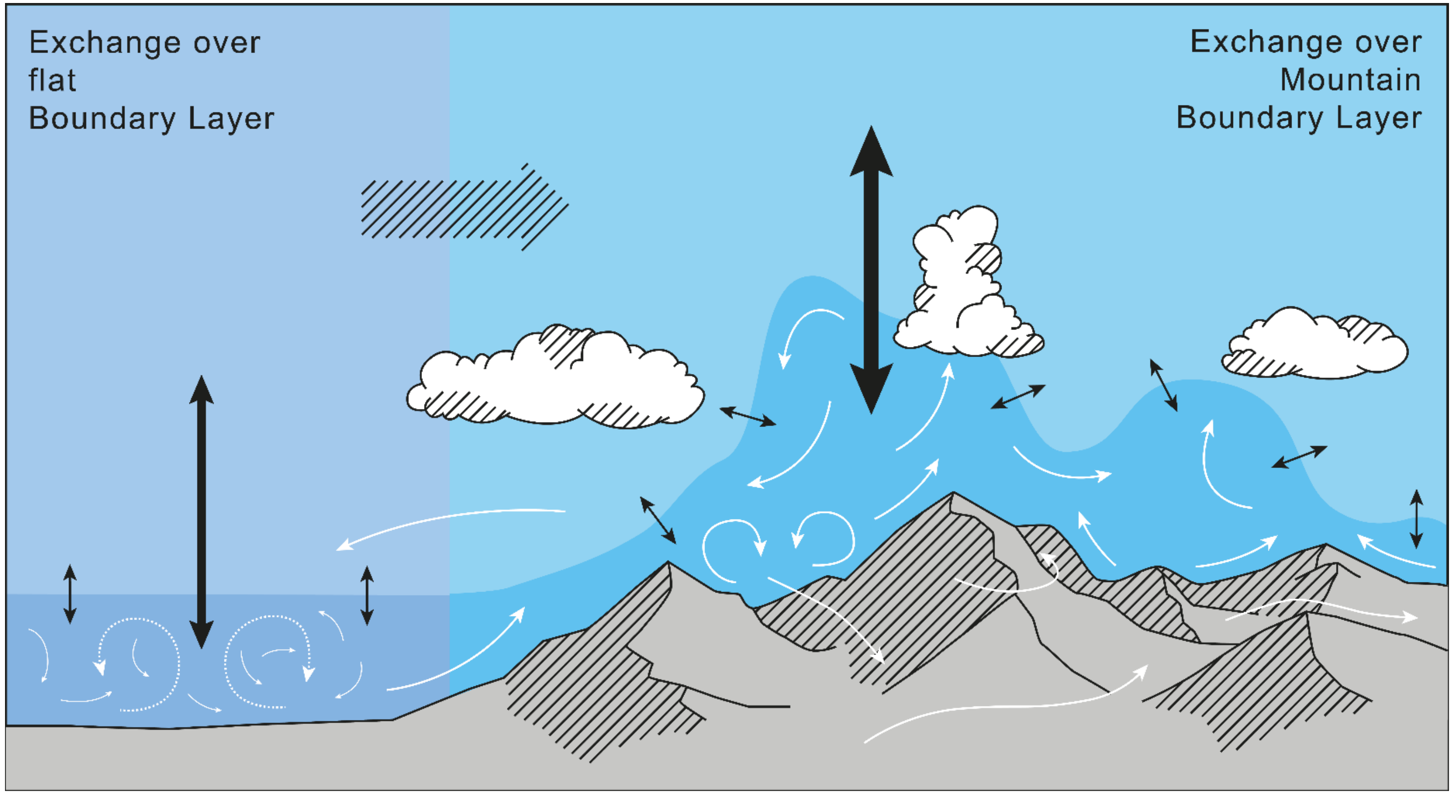
www.teamx-programme.org

TEAMx

- *Exchange processes induced by mountains*: Transfer of heat, momentum and mass (water, CO_2, aerosols) between the ground, the PBL and the free atmosphere.
- Special challenges over mountains: Spatial heterogeneity, wide range of relevant scales of motion.



TEAMx

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- Special challenges over mountains: Spatial heterogeneity, wide range of relevant scales of motion.

Ekhart, 1948

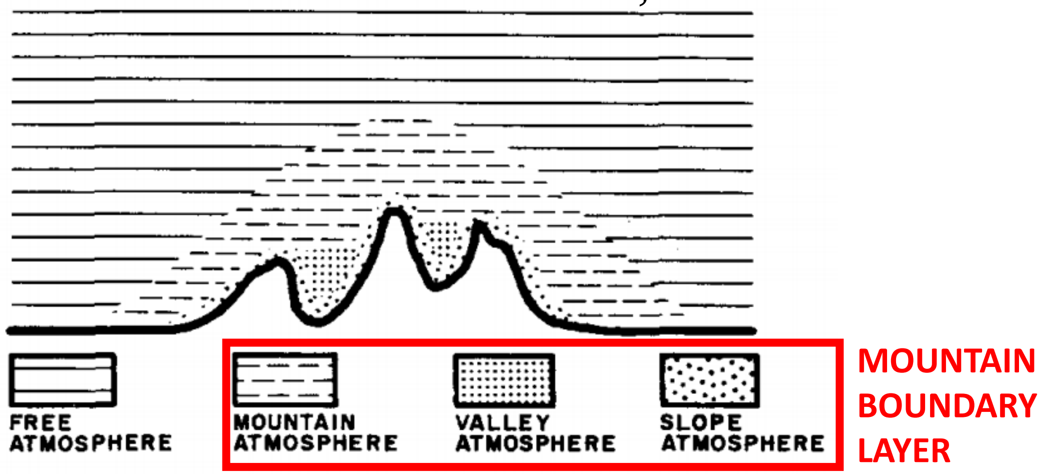
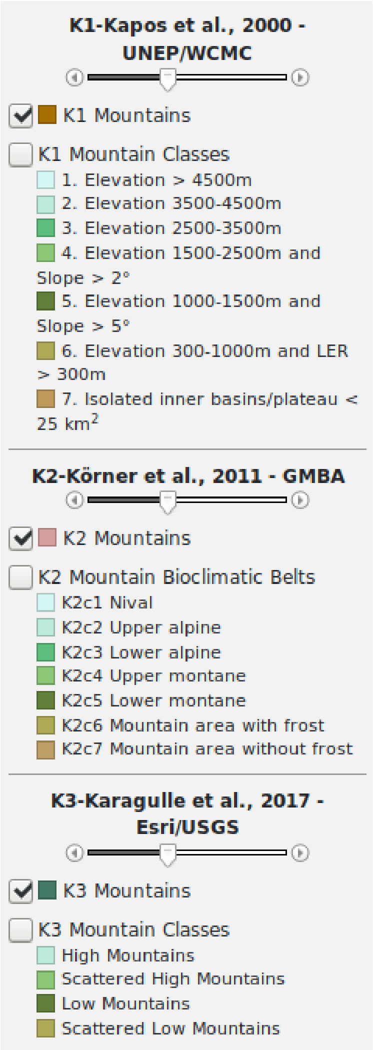
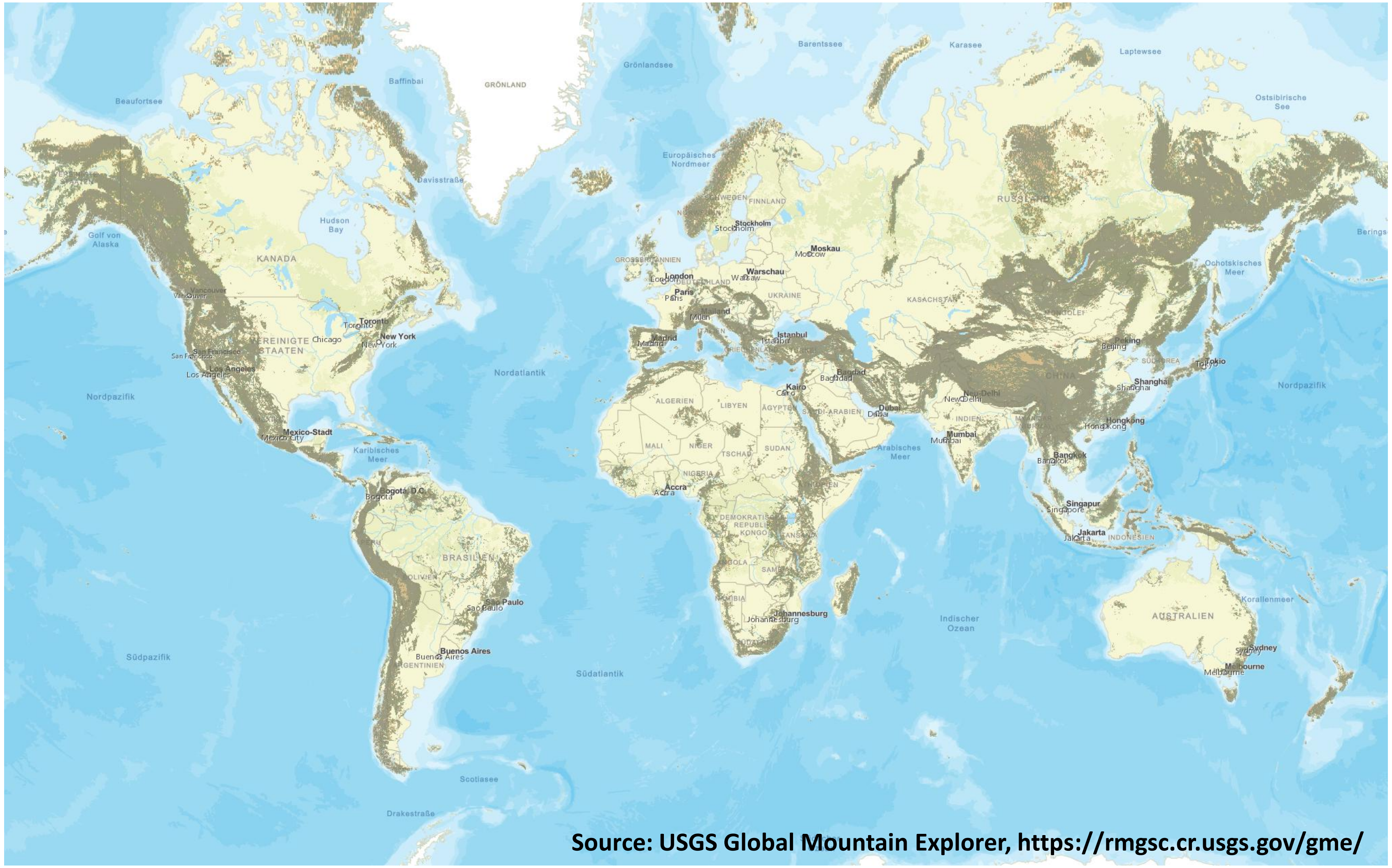


Figure 13: Diagram of the structure of the atmosphere above a mountain range.

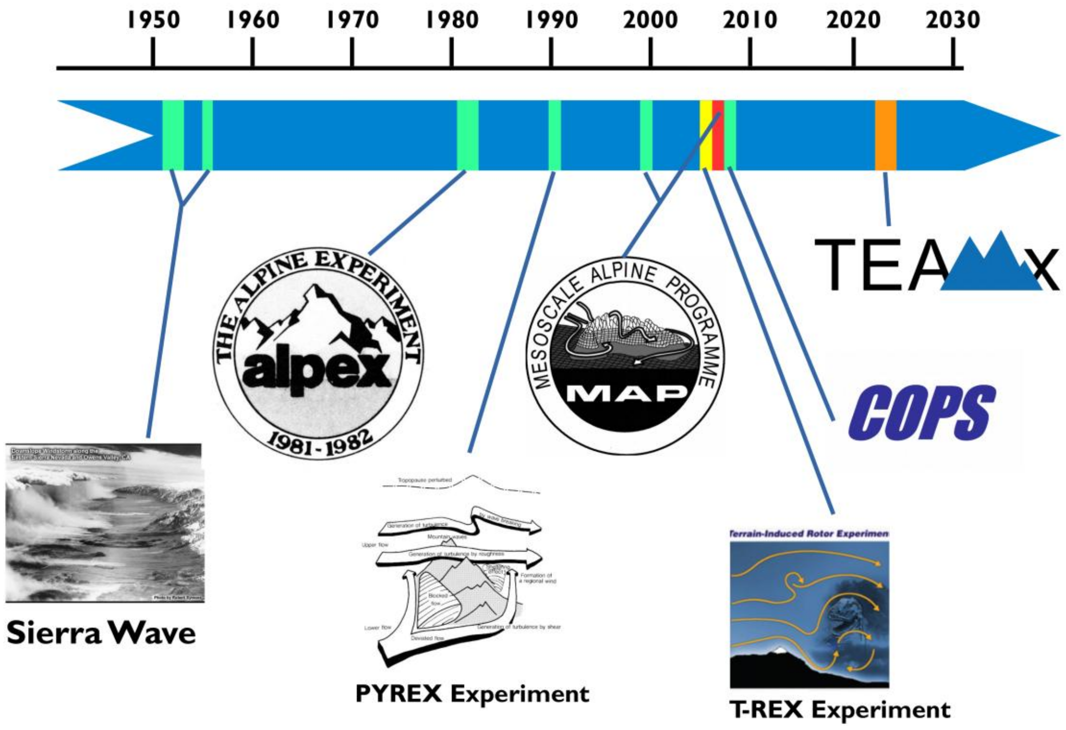
Global distribution of mountains





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

Major experiments in mountain meteorology



TEAMx technological drivers

- Observational advances w.r.t. historical campaigns:
  - Remote sensing: ground based (radar, lidar, boundary-layer profiling) 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 evaluation.

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

Parameterizing exchange processes

- Two examples of gaps between the state-of-the art in parameterizations and the state of knowledge about exchange processes over mountains:
  1. Scaling laws in the surface layer
  2. Planetary boundary layer

Example 1: Scaling laws (MOST)

How parameterizations work

- SL parameterizations assume that the first model level lies within the constant-flux layer.
- Under this assumption, *surface* fluxes are estimated from model-level variables using bulk transfer relationships.
- Bulk transfer coefficients include adiabatic corrections, based on MOST (Ψ, ζ=z/L).

$$\overline{u'w'}_s = -C_d u_1 U_1$$
$$\overline{v'w'}_s = -C_d v_1 U_1$$
$$\overline{w'T'}_s = -C_h U_1 (T_1 - T_s)$$

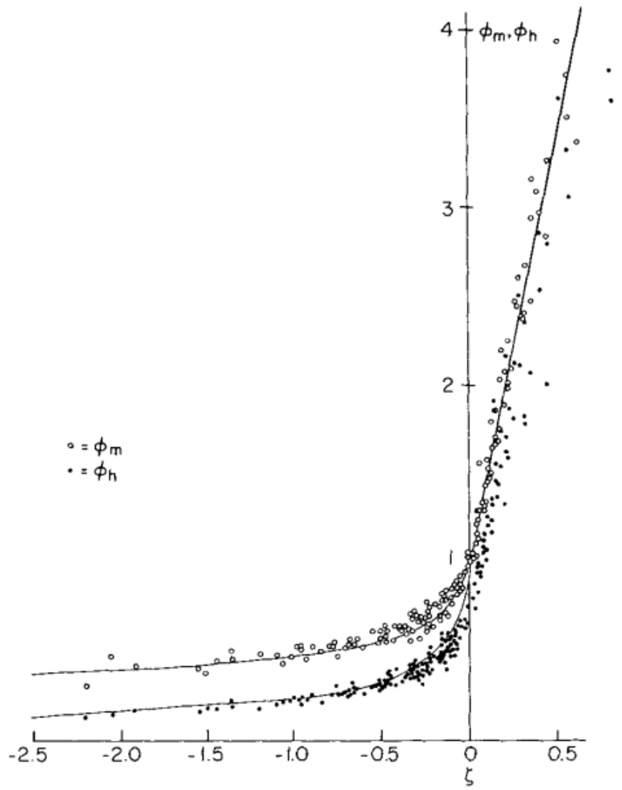


FIG. 6.5. The dimensionless wind gradient ϕ_m and temperature gradient ϕ_h as function of the dimensionless height. For $\zeta < 0$ the solid lines are $\phi_m = (1+\gamma\zeta)^{-1/4}$ and $\phi_h = (1+\gamma\zeta)^{-1/2}$. For $\zeta > 0$ the solid line is $\phi_m = \phi_h = 1 + \beta\zeta$.

Fleagle and Businger (1971)

$$C_d = k^2 \left[\log\left(\frac{z_1}{z_0}\right) - \Psi_m\left(\frac{z_1}{L}\right)\right]^{-2}$$

$$C_h = k^2 \left[\log\left(\frac{z_1}{z_0}\right) - \Psi_m\left(\frac{z_1}{L}\right)\right]^{-1} \left[\log\left(\frac{z_1}{z_0}\right) - \Psi_h\left(\frac{z_1}{L}\right)\right]^{-1}$$

Example 1: Scaling laws (MOST)

What we know

- Over slopes, turbulent fluxes may change considerably with height above ground.
- Even using *local* scaling, flux-profile relationships are often reported to match observed fluxes and gradients very poorly over complex terrain.
- The example refers to a steep mountain slope.

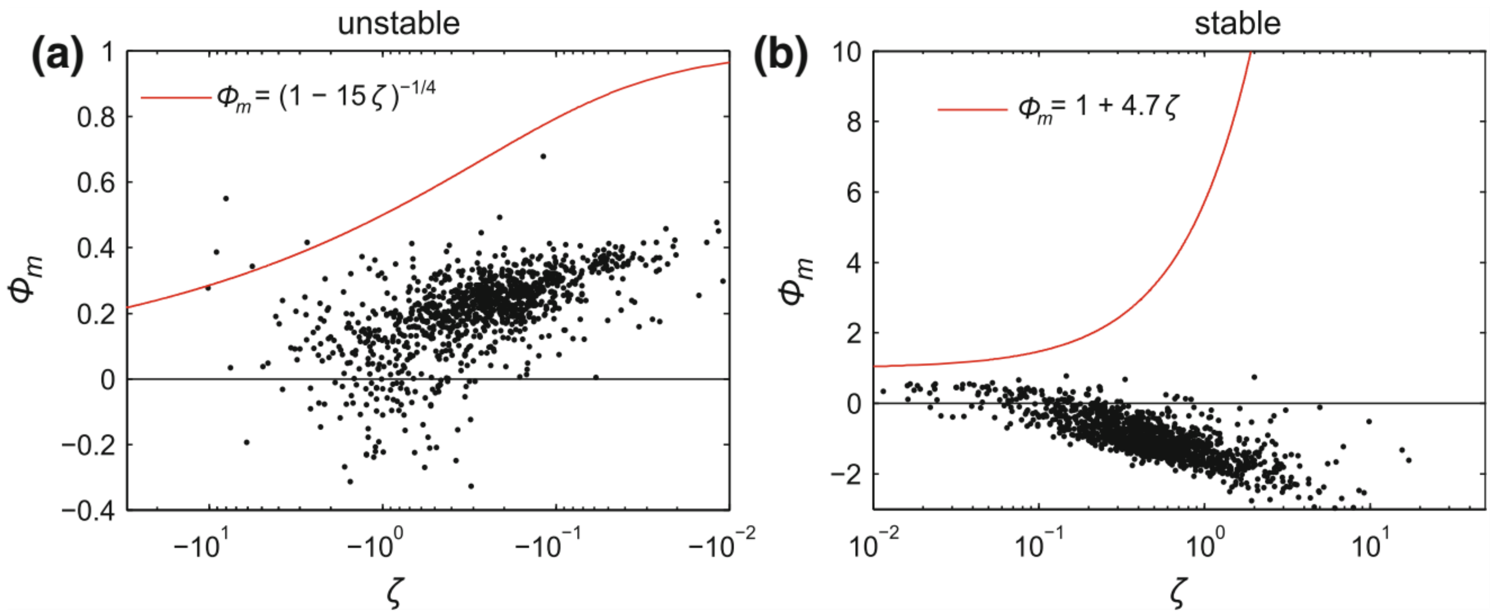


Fig. 10 Dimensionless wind shear ϕ_m for **a** $\zeta < 0$ and **b** $\zeta > 0$ at site T2, 1.5 m normal to the surface. The *solid red lines* represent the Businger–Dyer flux–profile relationships determined over flat and homogeneous surfaces (Businger et al. 1971; Dyer 1974)

Nadeau et al (2013)

Example 2: PBL structure

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).

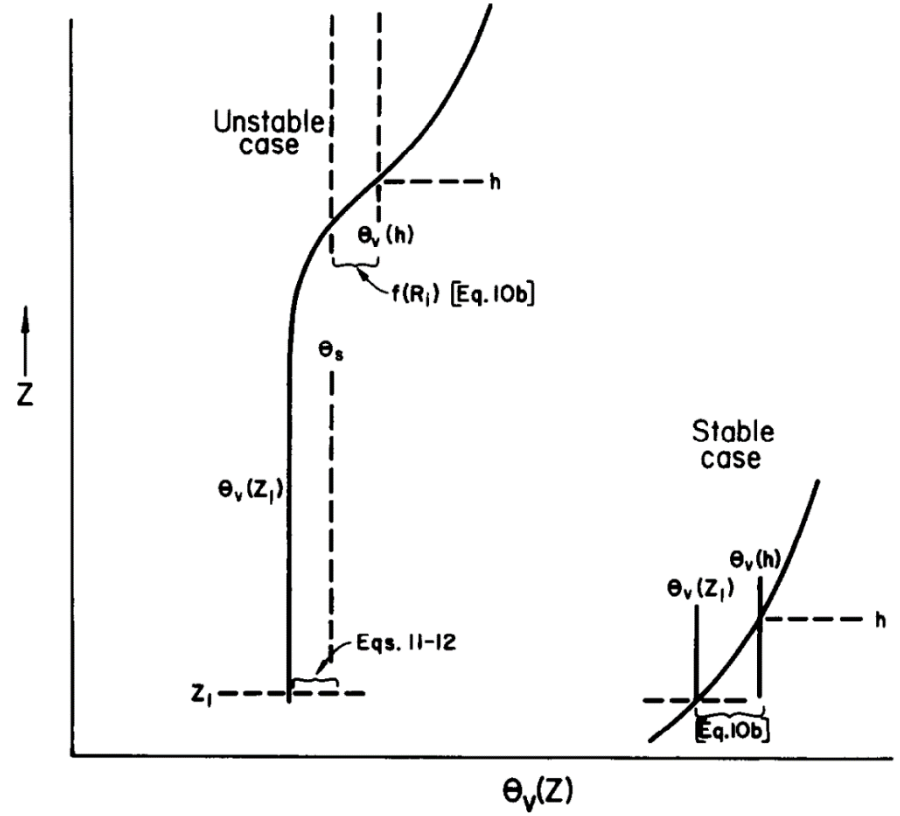


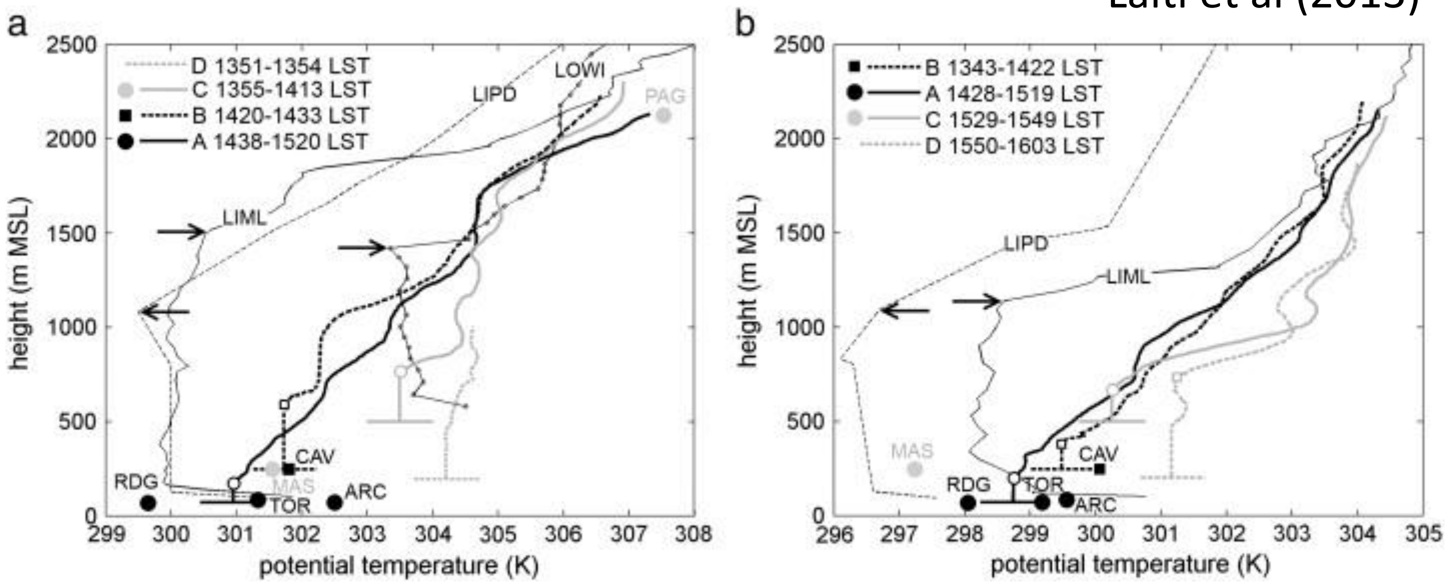
Fig. 1. Geometric sketch of the boundary-layer depth relationship to the profile of potential temperature above the surface layer (solid profile). For the unstable case, the first vertical broken line to the right of the profile indicates the potential temperature after enhancement due to the temperature 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.

Example 2: PBL structure

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.

Laiti et al (2013)



Wagner et al (2015)

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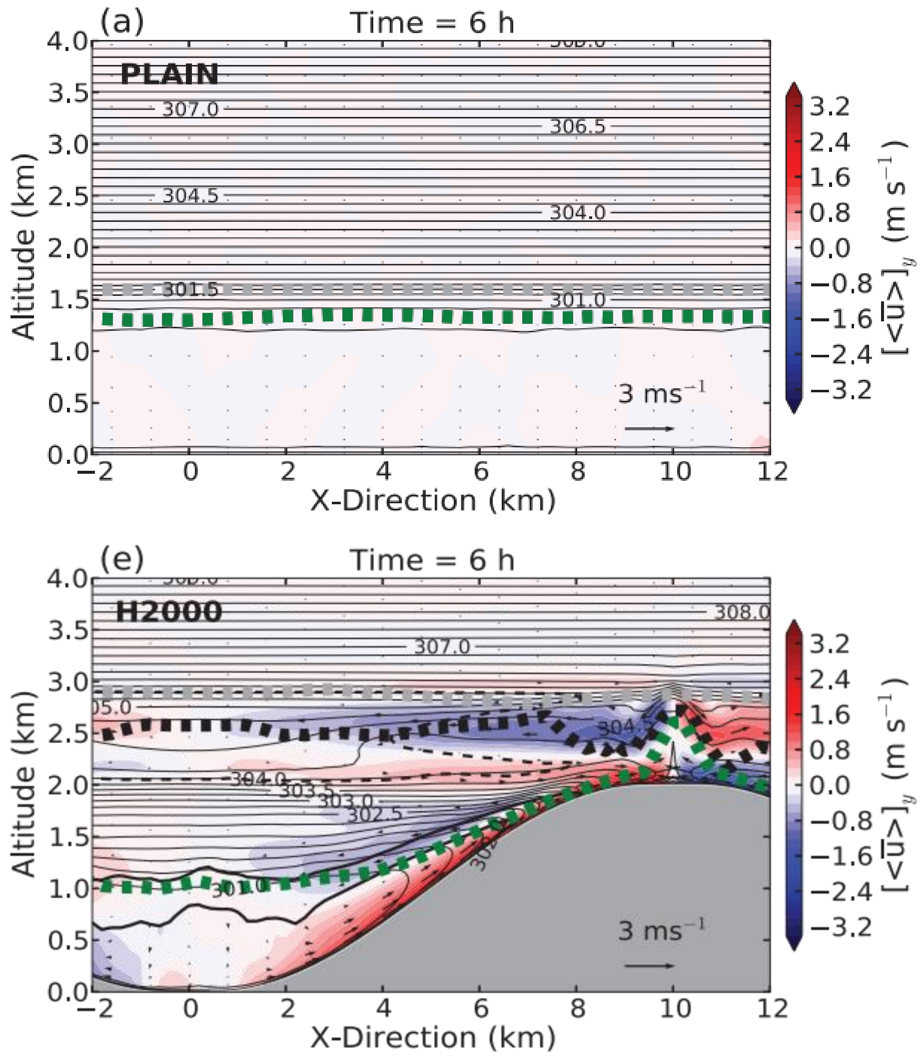

Figure 4. (a)–(e) Cross-sections of potential temperature (thin contour lines), cross-valley (colour shading) and along-valley wind speed (thick contour lines, negative values dashed, interval 1.0 m s^{-1}, the zero line is not shown) averaged between $y = 5$ and $y = 15$ km after 6 h of simulation.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

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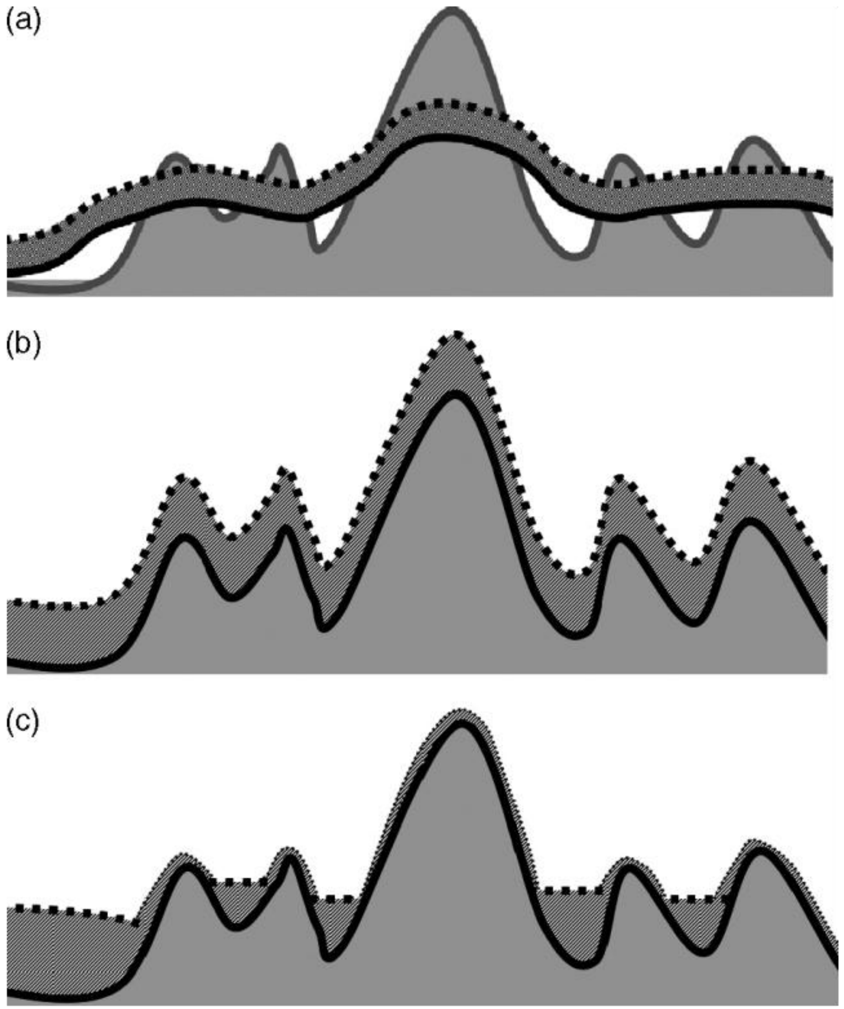


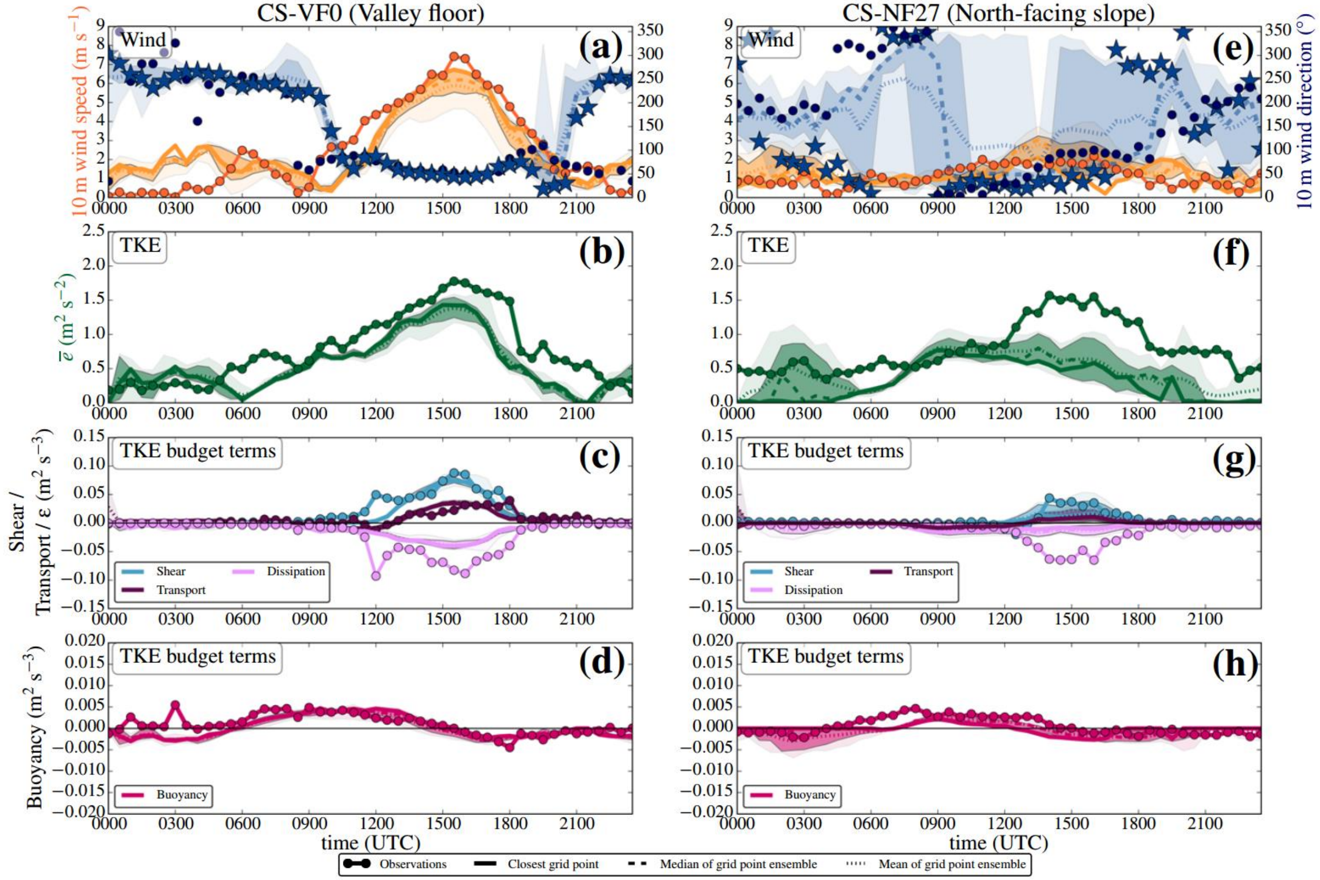
Figure 5. Schematic representation of the boundary layer in (a) a low-resolution numerical model, (b) a high-resolution operational numerical model, and (c) the turbulent boundary layer as found from different MAP boundary-layer studies.

Goger et al (2018)

Horizontal exchange

Impact of horizontal shear production on the modelled TKE budget

$$\underbrace{\frac{D}{Dt}\left(\frac{q^2}{2}\right)}_{\text{tendency}} = \underbrace{-K_H \frac{g}{\theta}\frac{\partial \theta}{\partial z}}_{\text{buoyancyproduction /consumption}} + \underbrace{K_M\left[\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right]}_{\text{vertical shear production}}$$
$$+ \underbrace{\frac{1}{\overline{\rho}}\frac{\partial}{\partial z}\left[\alpha_{\mathrm{TKE}}\overline{\rho}\lambda_l q \frac{\partial}{\partial z}\left(\frac{q^2}{2}\right)\right]}_{\text{vertical turbulent transport}} - \underbrace{\frac{q^3}{B_1 \lambda_l}}_{\text{dissipation}} .$$

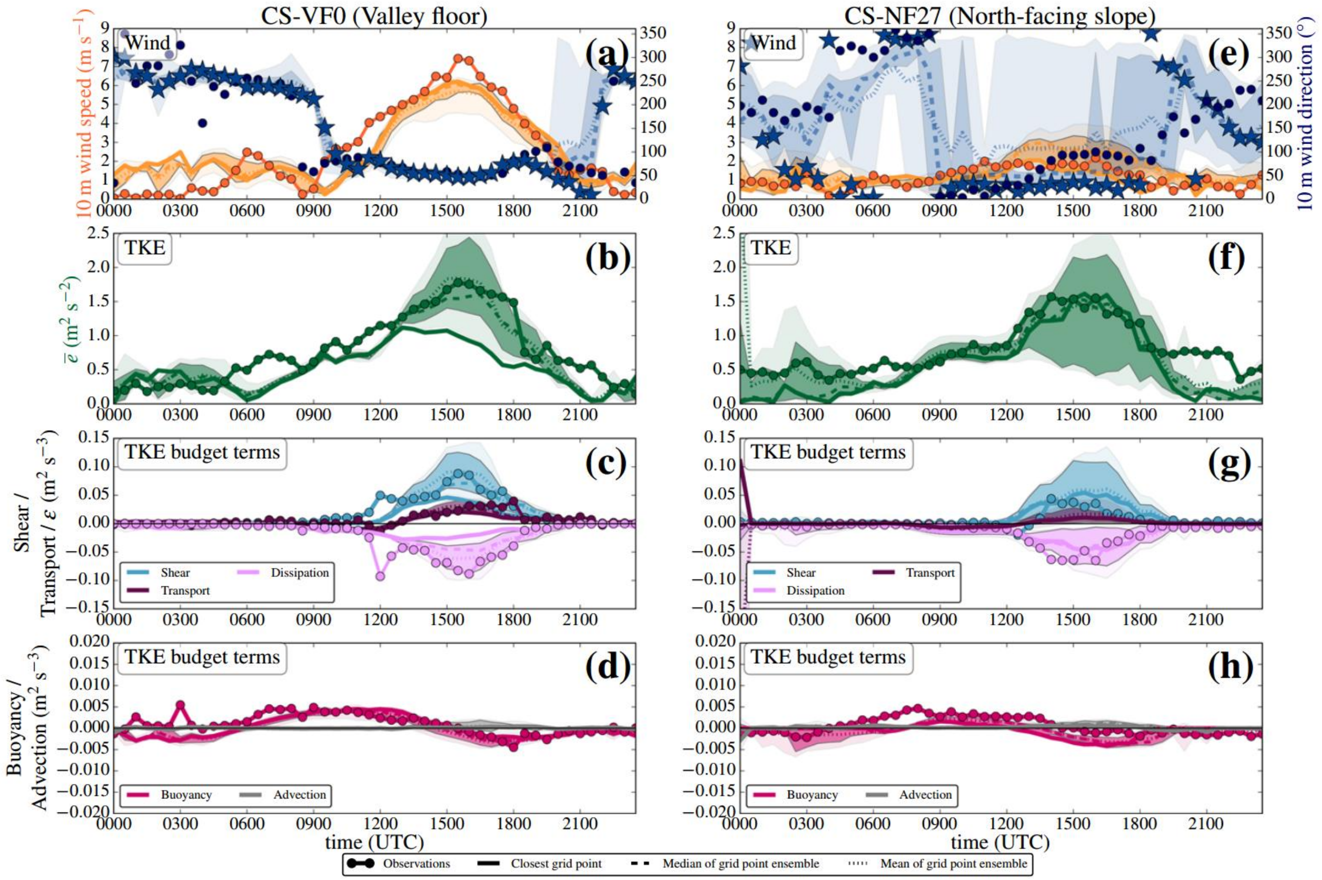


Goger et al (2018)

Horizontal exchange

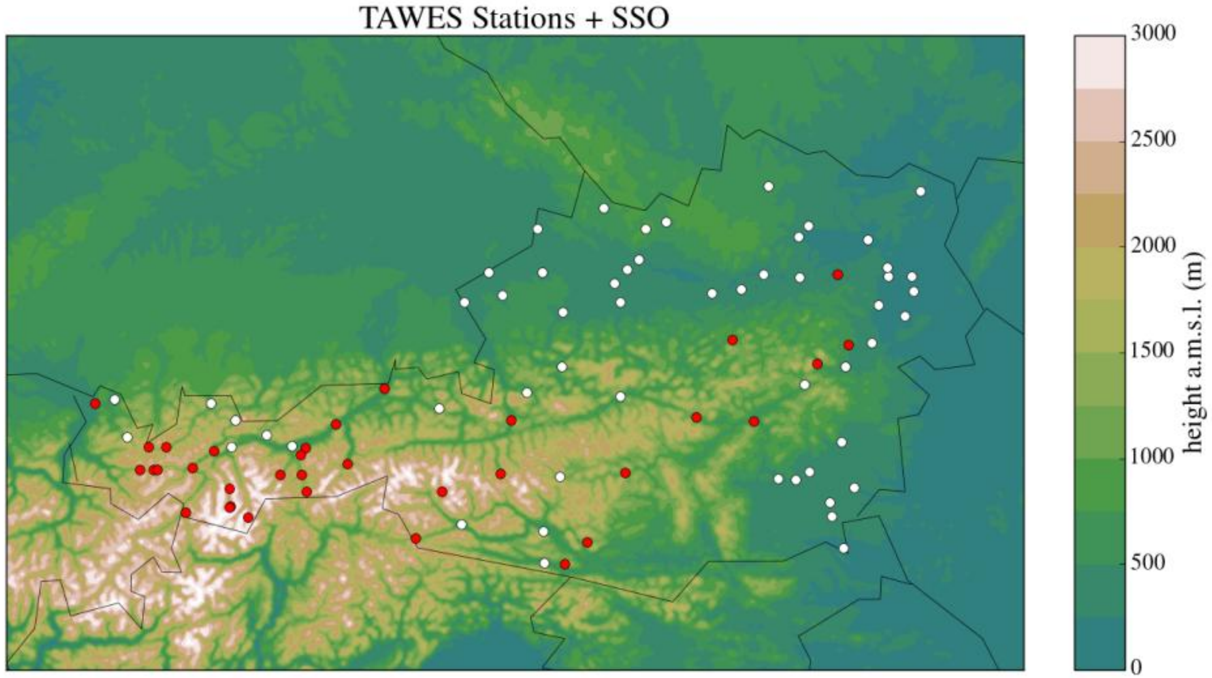
Impact of horizontal shear production on the modelled TKE budget

$$\frac{\partial}{\partial t}\left(\frac{q^2}{2}\right)_{\mathrm{HSP}} = (c\Delta x)^2\left[\underbrace{\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2}_{\text{confluence}}+\underbrace{\frac{1}{2}\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)^2}_{\text{shear}}\right]^{3/2}.$$



Horizontal exchange

Impact of hybrid 3D TKE parameterization on forecast skill for surface variables



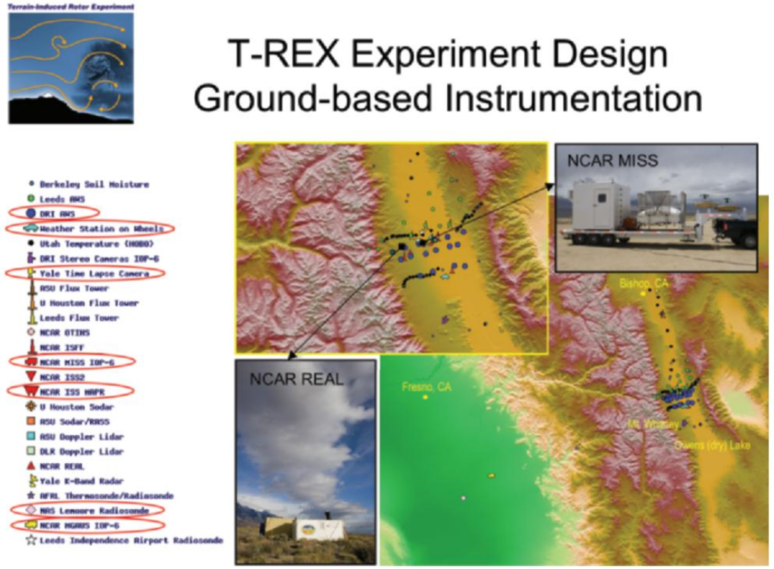
	Terrain	Rmse turb_1D	Rmse turb_hybrid	Rmse turb_pseudo3D
2-m temperature (K)	HCT	2.09	2.07	2.09
	Flat terrain	1.49	1.48	1.48
	Overall	1.72	1.71	1.71
2-m relative humidity (%)	HCT	10.95	10.58	10.40
	Flat terrain	8.92	8.91	9.17
	Overall	9.70	9.55	9.65
10-m wind speed ($m\,s^{-1}$)	HCT	1.12	1.12	1.14
	Flat terain	1.05	1.06	1.06
	Overall	1.08	1.08	1.09

Goger et al (2019)

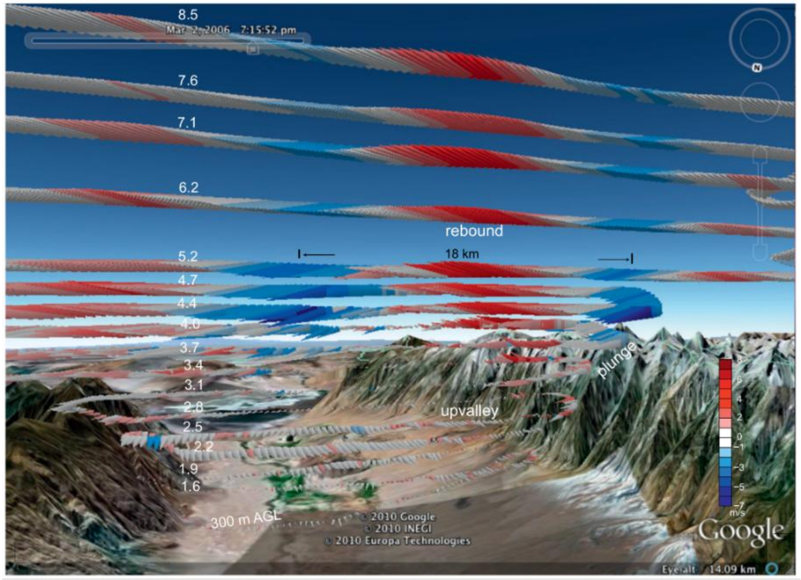
1. Shortcomings of parameterization schemes over mountains
2. **Multiscale interactions in orographic flows**
3. TEAMx

Downslope windstorms

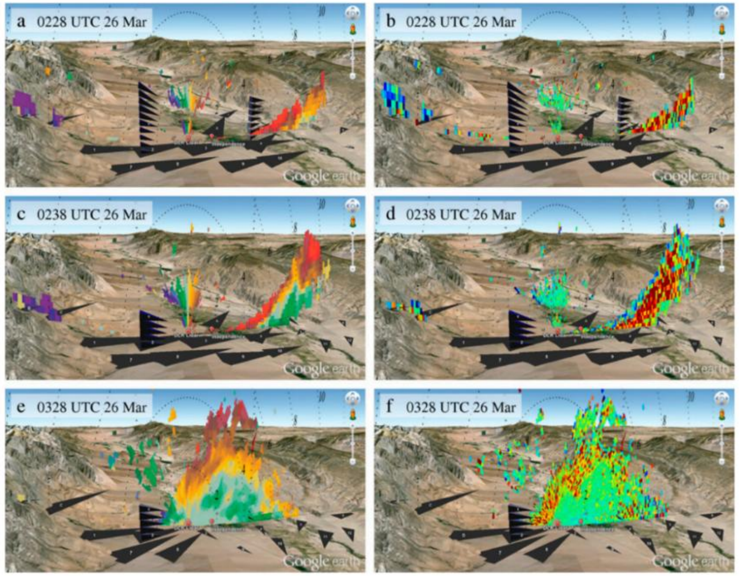
- T-Rex field phase in March-April 2006, Owens Valley (California).
- Major focus: Atmospheric rotors.



Grubišić et al. (2008)



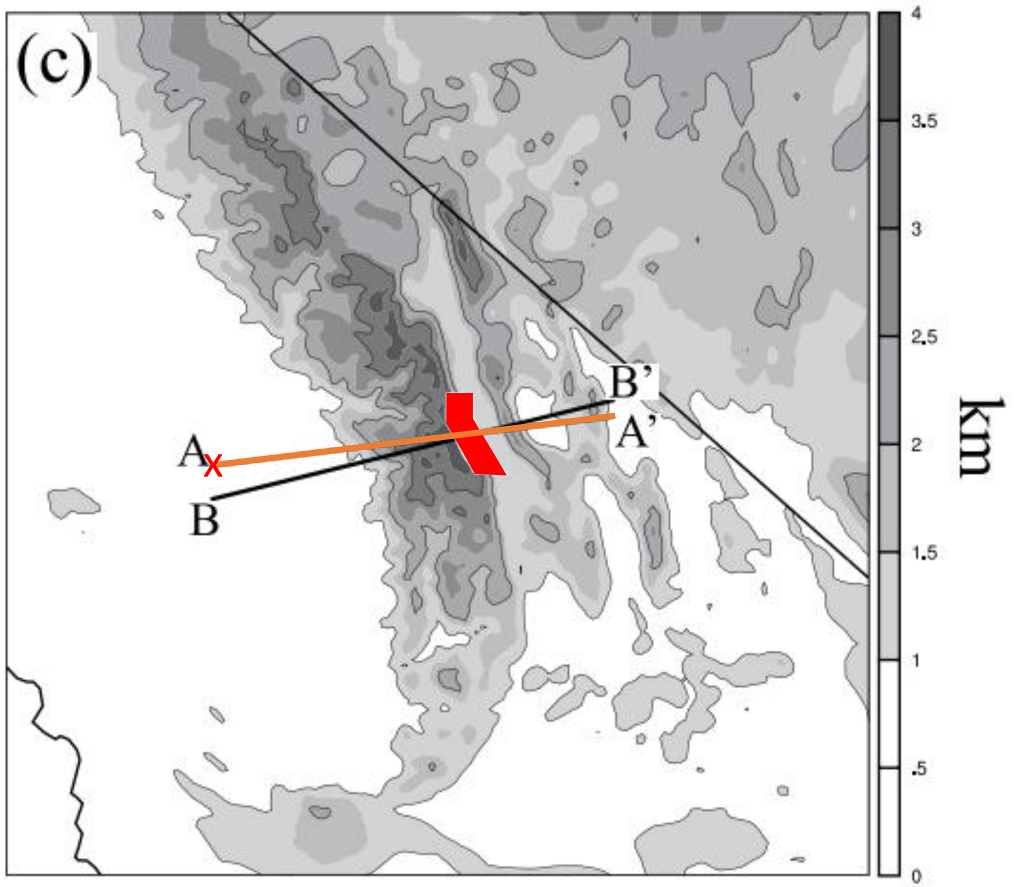
Mayr and Armi (2010)



Strauss et al. (2016)

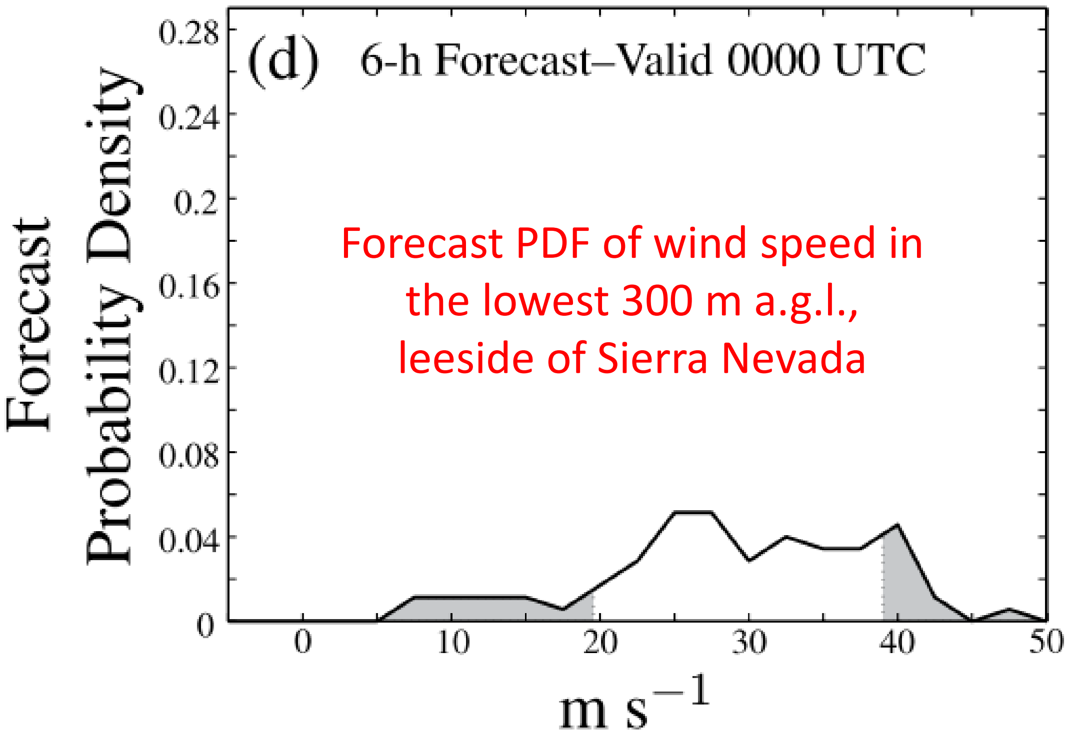
Downslope windstorms

- T-Rex IOP 6 simulated with a 70-member EnKF ensemble.
- Δx = 3 km in innermost domain
- 40 vertical levels
- Focus on downslope windstorms, lowest 300 m of atmosphere in the red area.
- Cross-sections along A-A’
- Upstream profiles at A



Reinecke and Durran (2009)

Downslope windstorms



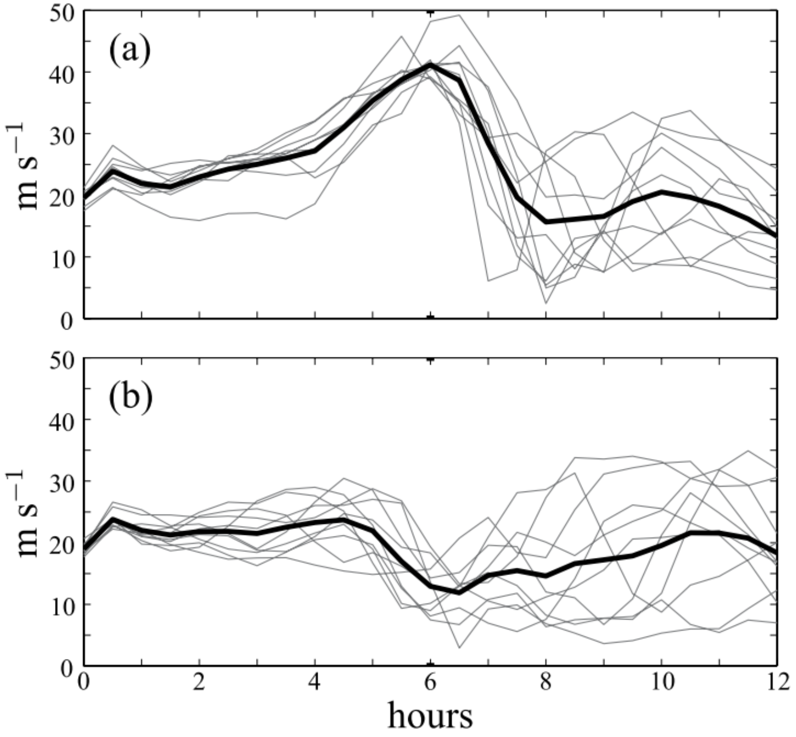


FIG. 7. The evolution of the zonal wind averaged over the Owens Valley metric box during the IOP 6 simulation for the (a) 10 strongest and (b) 10 weakest ensemble members. The thick line shows the mean of each 10-member subset.

Reinecke and Durran (2009)

Downslope windstorms

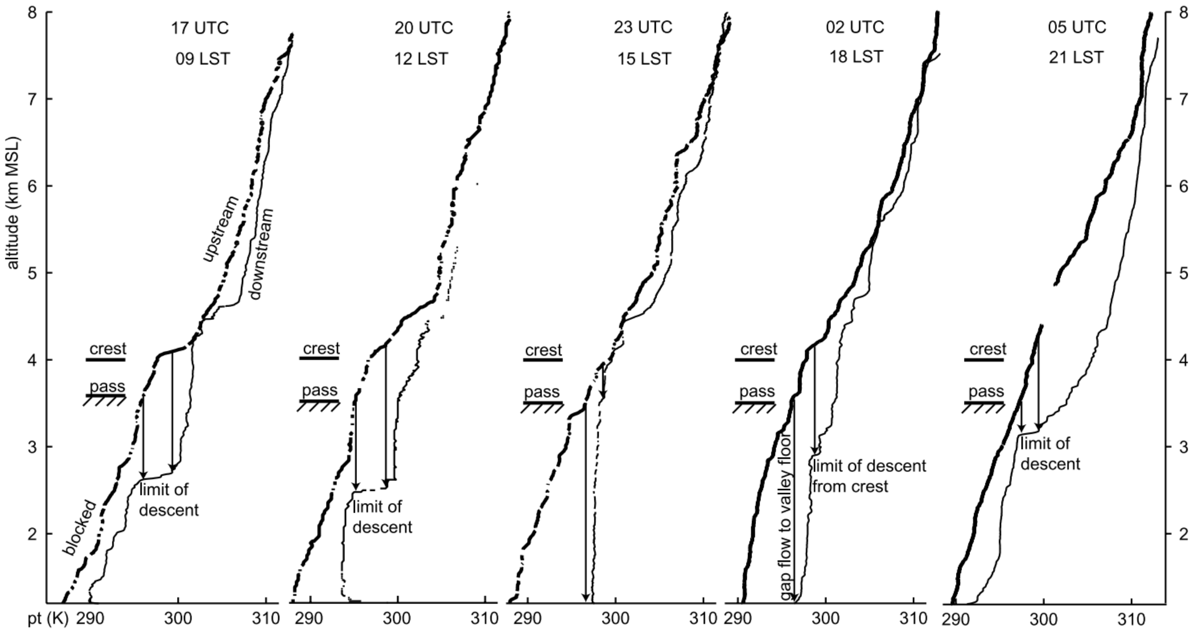


FIG. 4. Potential temperature of radio soundings upstream (thick) and downstream (thin) of the Sierra Nevada, with added altitude of the Sierra Nevada crest and Kearsarge Pass and launch times. Arrows show adiabatic descent of upstream air from gap and crest height, respectively, to the downstream air mass.

Mayr and Armi (2010)

IOP1

- A subtle interplay between large-scale and local-scale processes determines whether or not:
  - Foehn winds will break through to valley floors;
  - Mountain waves will reach large amplitude.

Downslope windstorms

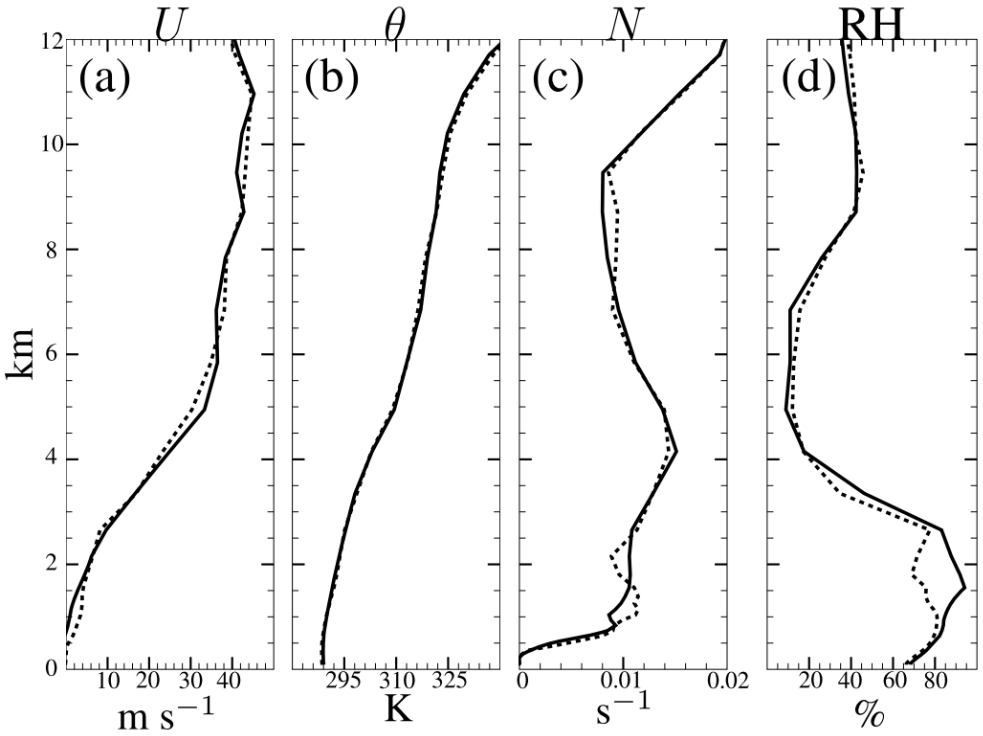
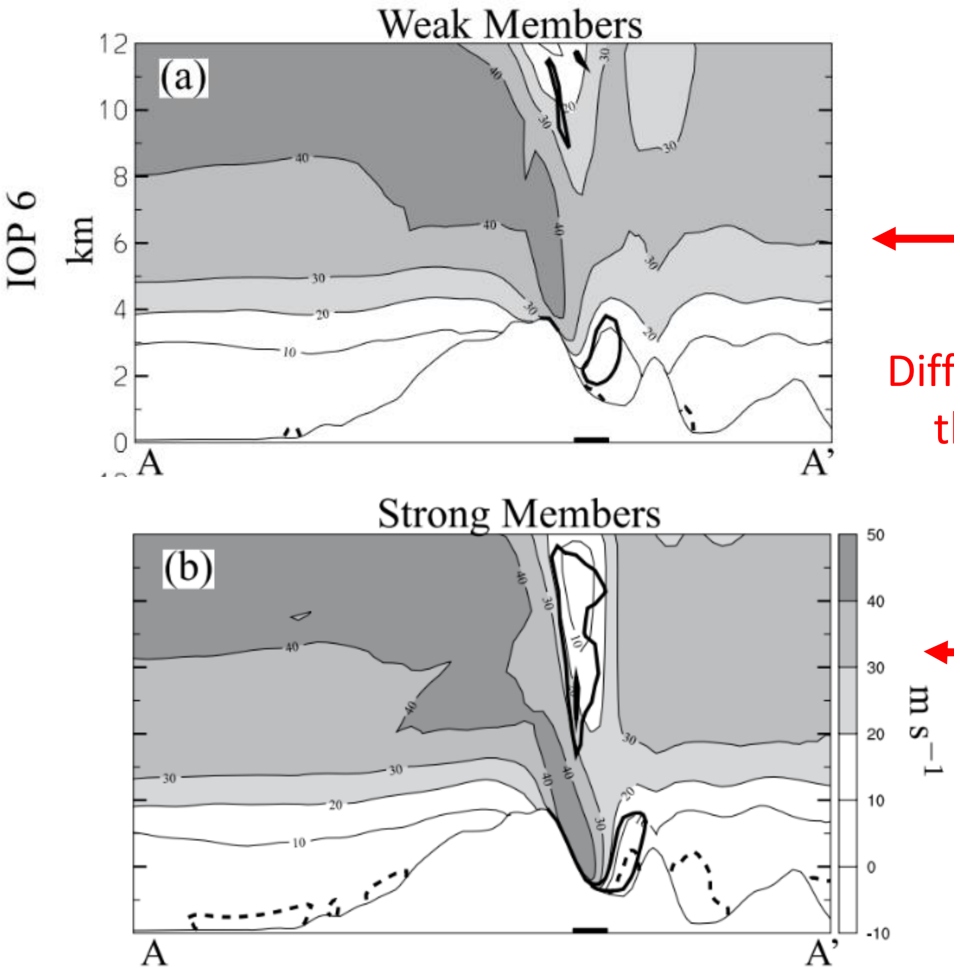


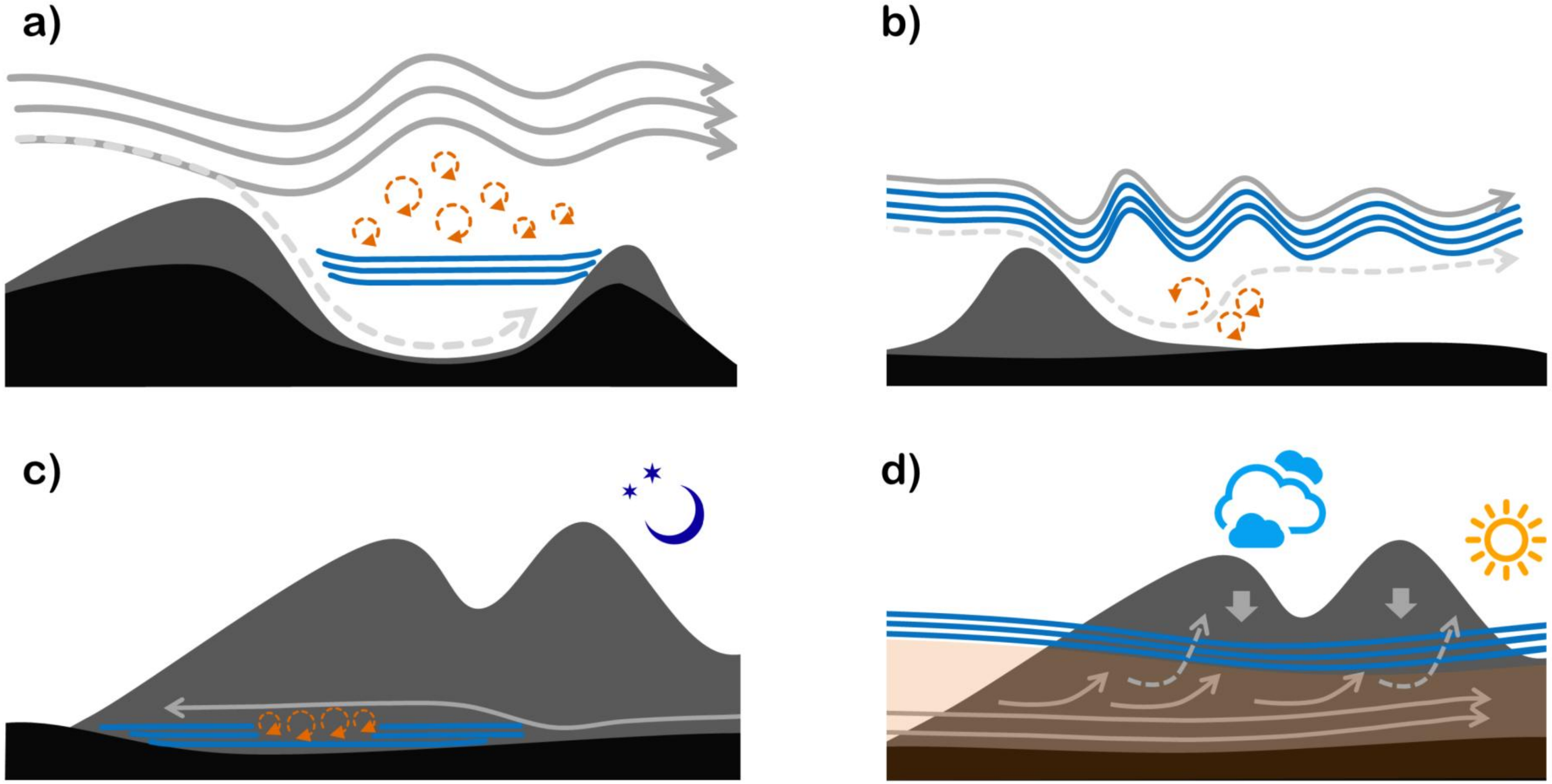
FIG. 11. Composite model soundings for the strong subset (solid) and weak subset (dashed) for IOP 6. The soundings are valid at forecast hour 5 (one hour before the time of maximum wind) and taken at the upstream edge of the A–A' cross section depicted in Fig. 1c. Plotted is the (a) cross-barrier component of the wind U, (b) potential temperature θ, (c) Brunt–Väisälä frequency N, and (d) RH.



Difference lies in the thermal structure

Reinecke and Durran (2009)

Multi-scale interactions

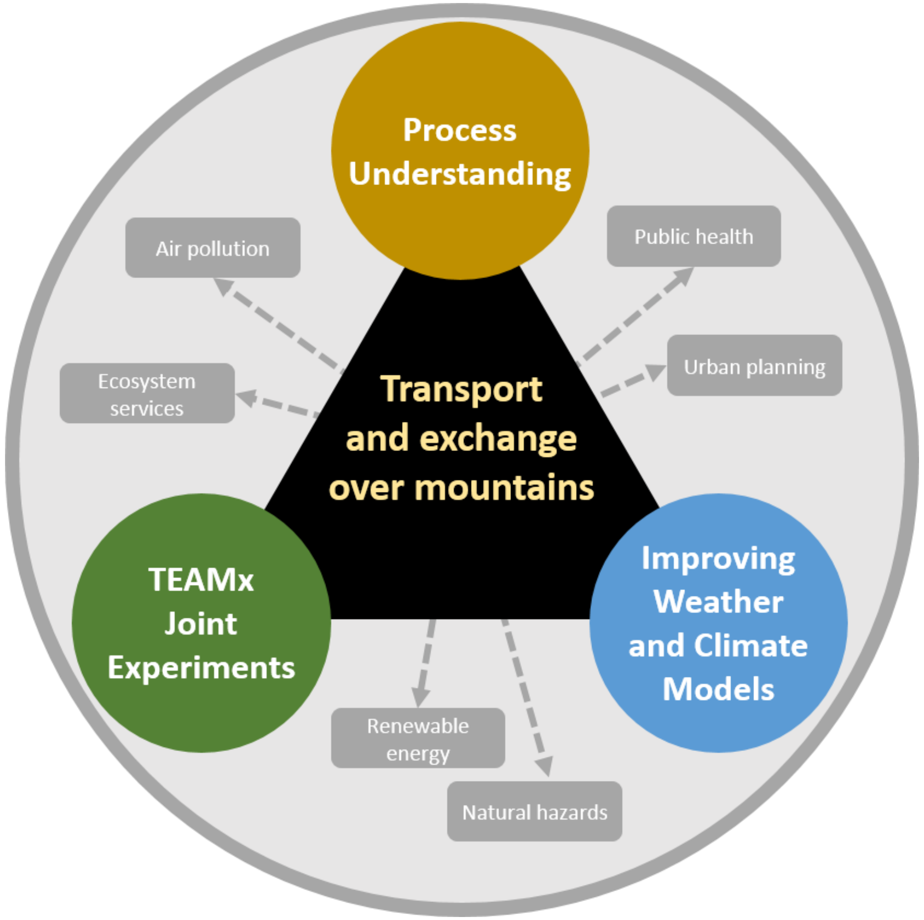


Serafin et al (2018)

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

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**.



Coordination and Implementation Group

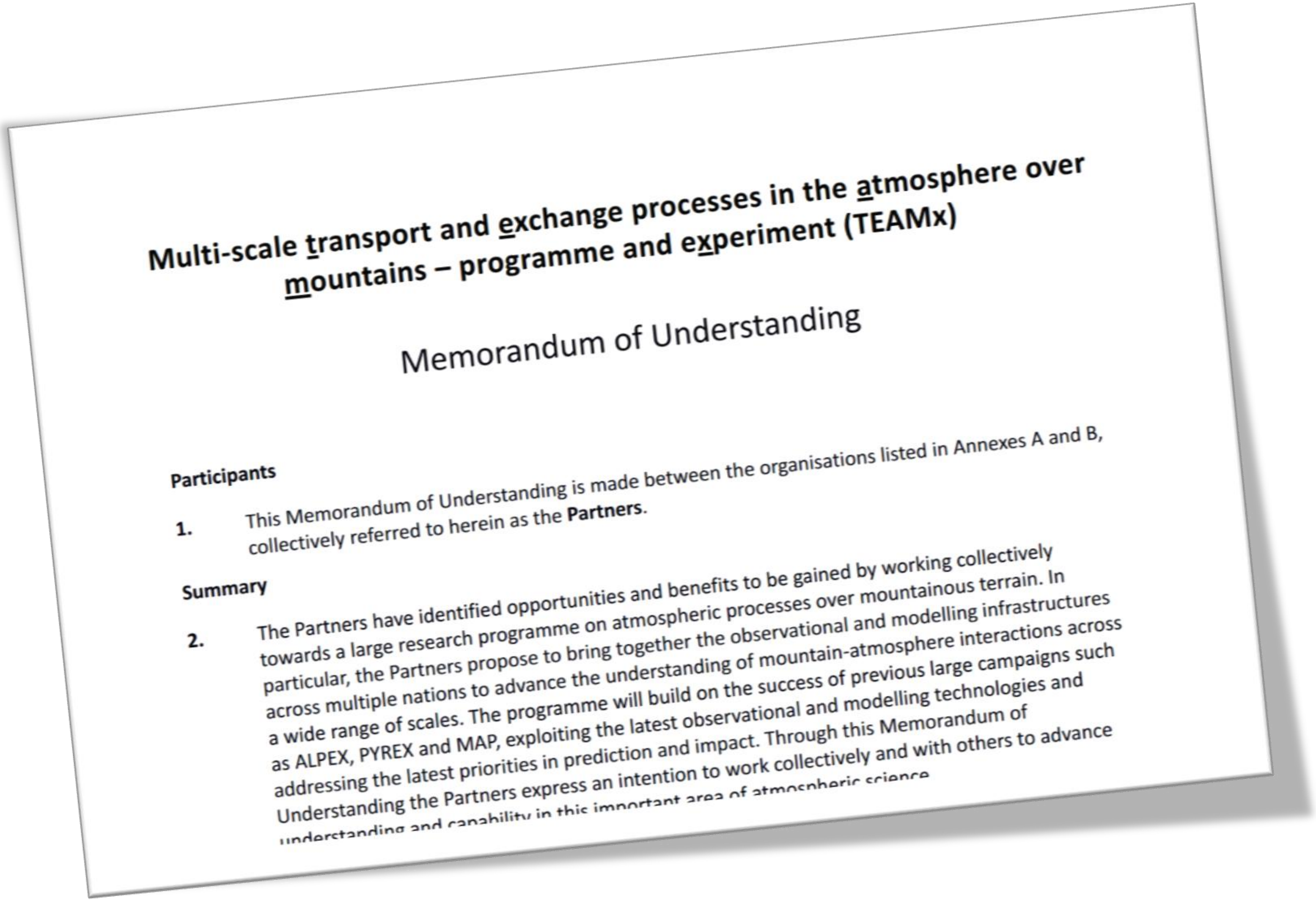
- **Mathias Rotach**, University of Innsbruck (Chair)
- **Marco Arpagaus**, MeteoSwiss
- **Joan Cuxart**, University of the Balearic Islands
- **Stephan De Wekker**, University of Virginia
- **Vanda Grubišić**, National Center for Atmospheric Research
- **Norbert Kalthoff**, Karlsruhe Institute of Technology
- **Daniel Kirshbaum**, McGill University
- **Manuela Lehner**, University of Innsbruck
- **Stephen Mobbs**, National Centre for Atmospheric Science
- **Alexandre Paci**, Meteo France
- **Elisa Palazzi**, National Research Council of Italy
- **Stefano Serafin** ⇦ Coordinator
- **Dino Zardi**, University of Trento

Programme Coordinator Office at the University of Innsbruck
Sponsored by C2SM, Karlsruhe Institute of Technology KIT, Météo France, MeteoSwiss, National Center for Atmospheric Science (NCAS), University of Innsbruck, University of Trento, ZAMG

Review articles

Goals
Solicit review articles on TEAMx topics
Basis for TEAMx White Paper

Memorandum of Understanding



Multi-scale transport and exchange processes in the atmosphere over mountains – programme and experiment (TEAMx)

Memorandum of Understanding

Participants

1. This Memorandum of Understanding is made between the organisations listed in Annexes A and B, collectively referred to herein as the **Partners**.

Summary

2. The Partners have identified opportunities and benefits to be gained by working collectively towards a large research programme on atmospheric processes over mountainous terrain. In particular, the Partners propose to bring together the observational and modelling infrastructures across multiple nations to advance the understanding of mountain-atmosphere interactions across a wide range of scales. The programme will build on the success of previous large campaigns such as ALPEX, PYREX and MAP, exploiting the latest observational and modelling technologies and addressing the latest priorities in prediction and impact. Through this Memorandum of Understanding the Partners express an intention to work collectively and with others to advance understanding and capability in this important area of atmospheric science

Partnership

New signatories welcome

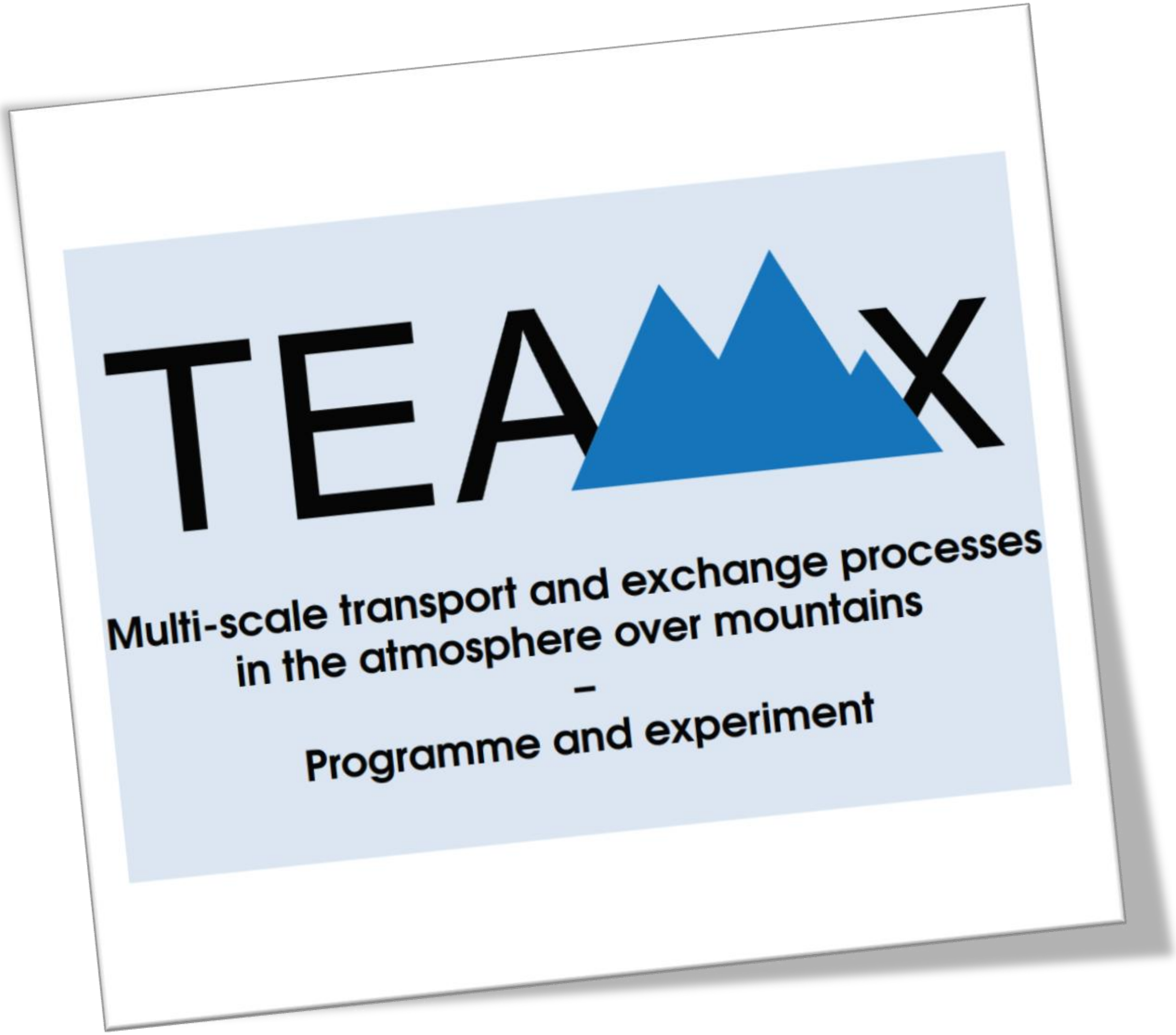
First TEAMx Workshop

28-30 August 2019
Rovereto
Italy

92 participants
11 countries

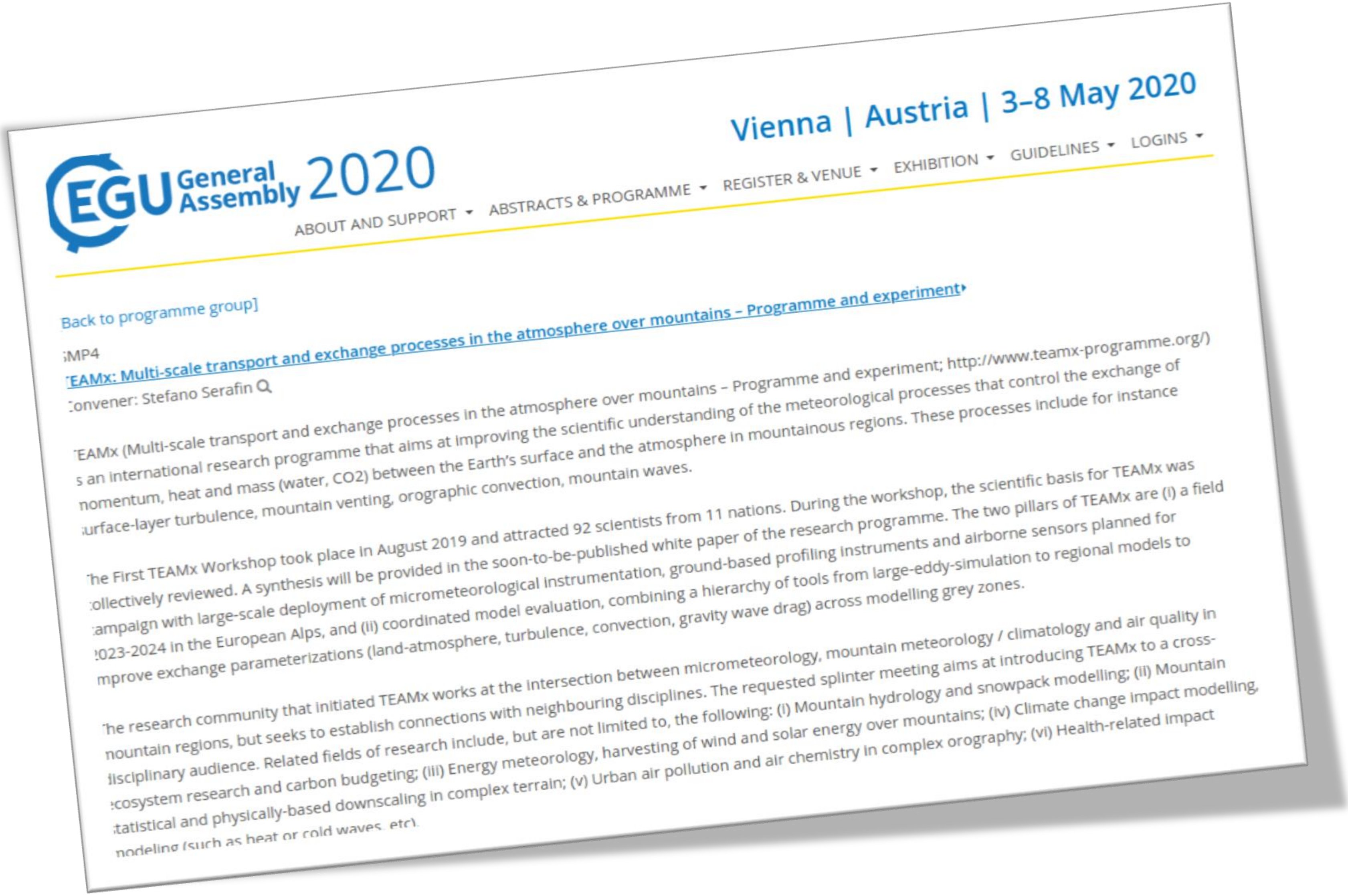
White paper

Recently finalized


TEAMx

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

EGU splinter meeting



EGU General Assembly 2020

Vienna | Austria | 3–8 May 2020

ABOUT AND SUPPORT ▾ ABSTRACTS & PROGRAMME ▾ REGISTER & VENUE ▾ EXHIBITION ▾ GUIDELINES ▾ LOGINS ▾

Back to programme group]

;MP4

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

:onvener: Stefano Serafin

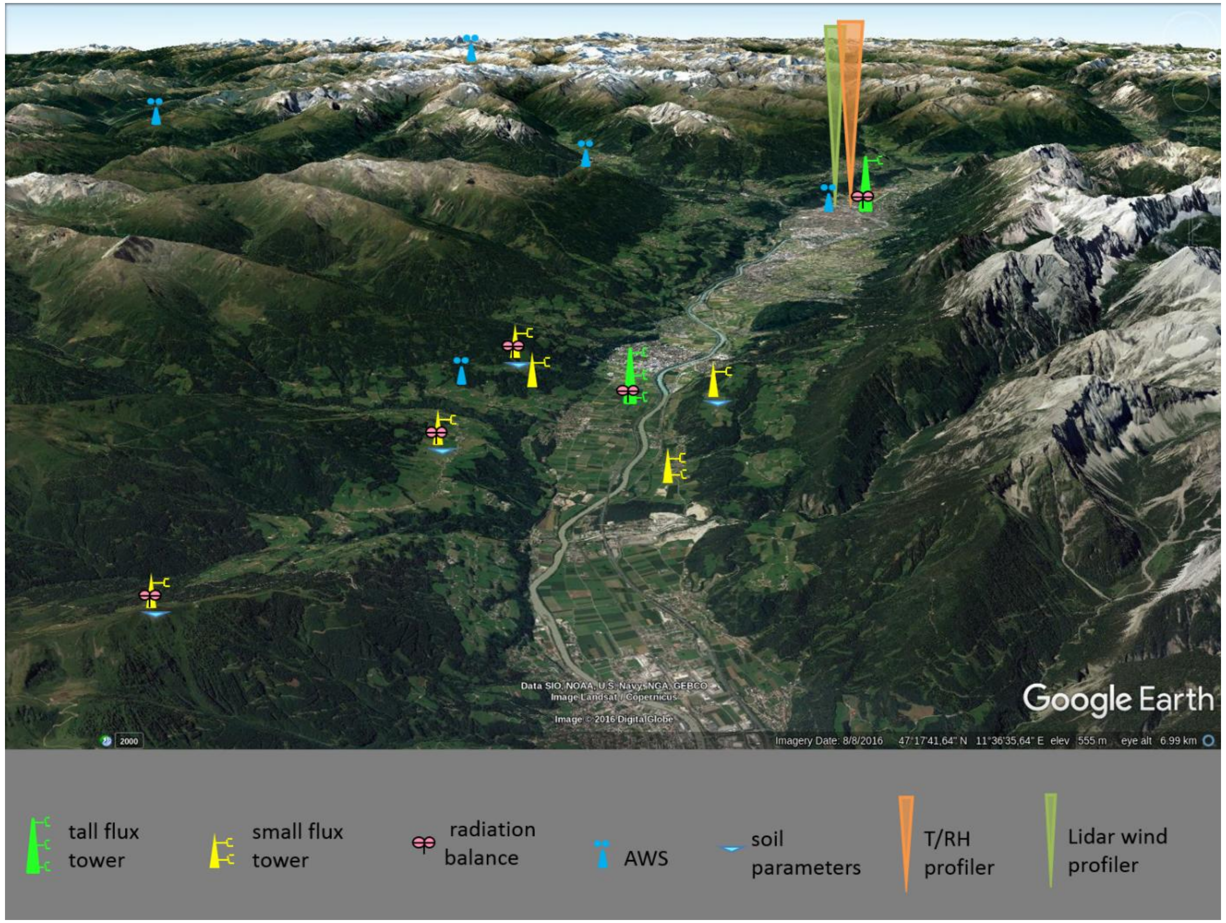
'EAMx (Multi-scale transport and exchange processes in the atmosphere over mountains – Programme and experiment; http://www.teamx-programme.org/) s an international research programme that aims at improving the scientific understanding of the meteorological processes that control the exchange of nomentum, heat and mass (water, CO2) between the Earth's surface and the atmosphere in mountainous regions. These processes include for instance ;urface-layer turbulence, mountain venting, orographic convection, mountain waves.

'he First TEAMx Workshop took place in August 2019 and attracted 92 scientists from 11 nations. During the workshop, the scientific basis for TEAMx was :ollectively reviewed. A synthesis will be provided in the soon-to-be-published white paper of the research programme. The two pillars of TEAMx are (i) a field :ampaign with large-scale deployment of micrometeorological instrumentation, ground-based profiling instruments and airborne sensors planned for !023-2024 in the European Alps, and (ii) coordinated model evaluation, combining a hierarchy of tools from large-eddy-simulation to regional models to mprove exchange parameterizations (land-atmosphere, turbulence, convection, gravity wave drag) across modelling grey zones.

'he research community that initiated TEAMx works at the intersection between micrometeorology, mountain meteorology / climatology and air quality in nountain regions, but seeks to establish connections with neighbouring disciplines. The requested splinter meeting aims at introducing TEAMx to a cross- lisciplinary audience. Related fields of research include, but are not limited to, the following: (i) Mountain hydrology and snowpack modelling; (ii) Mountain :cosystem research and carbon budgeting; (iii) Energy meteorology, harvesting of wind and solar energy over mountains; (iv) Climate change impact modelling, ;tatistical and physically-based downscaling in complex terrain; (v) Urban air pollution and air chemistry in complex orography; (vi) Health-related impact nodeling (such as heat or cold waves, etc).

Field experiment plans

- Observation of the components of the surface energy budget for extended periods in distributed observatories (e.g., i-Box).
- Fundamental investigations on turbulence properties in the atmosphere over complex terrain (e.g., anisotropy, generalization of scaling laws).
- Systematic evaluation of SL parameterization over complex terrain.



2011 – ongoing

Field experiment plans

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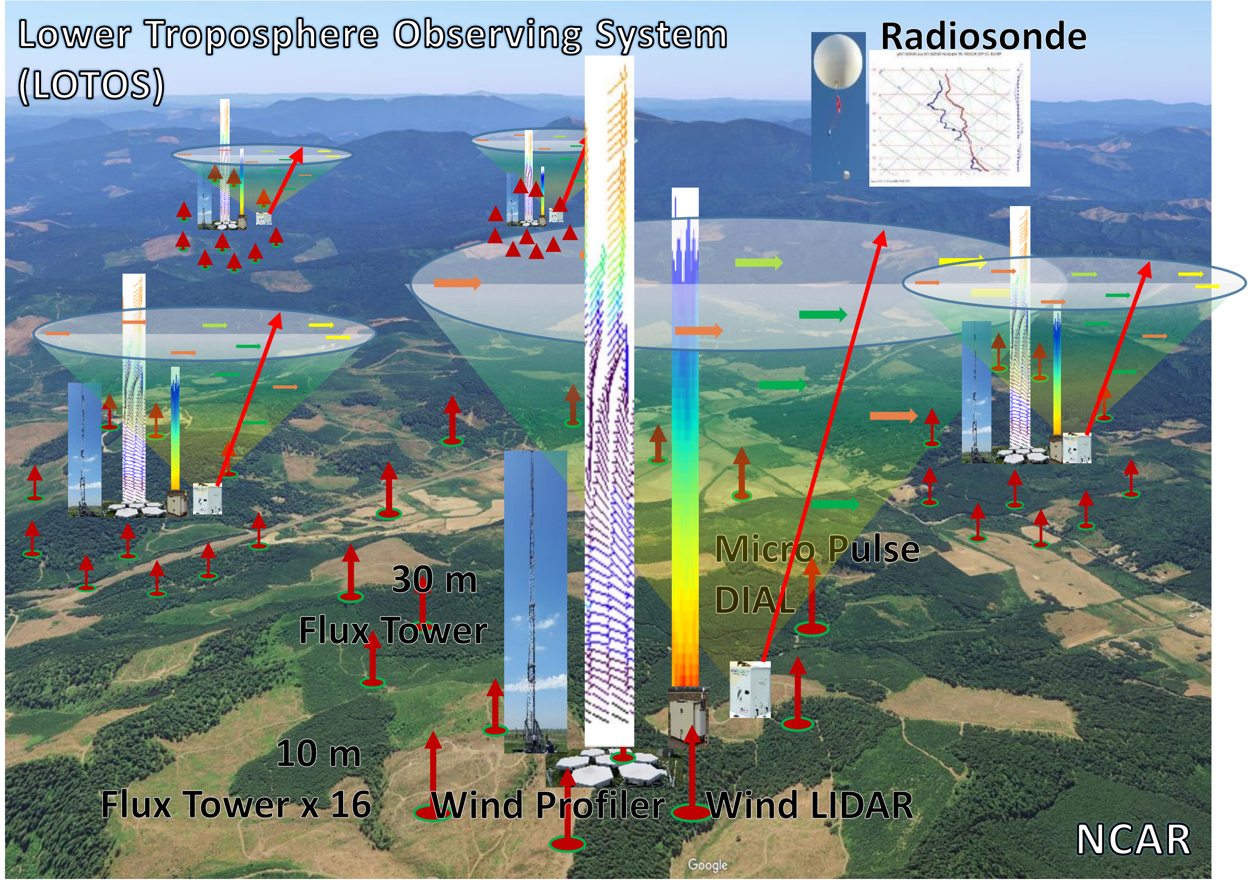
2011 – ongoing

Field experiment plans

- Comprehensive measurements of the MoBL: ground-based remote sensing to map 3D kinematic and thermodynamic structure and fluxes within PBL over valleys/mountains (flux towers+remote sensors; e.g. Doppler wind and Raman lidars, wind profilers).
- Possible use of light aircraft or UAVs for gap-filling measurements over wide areas.



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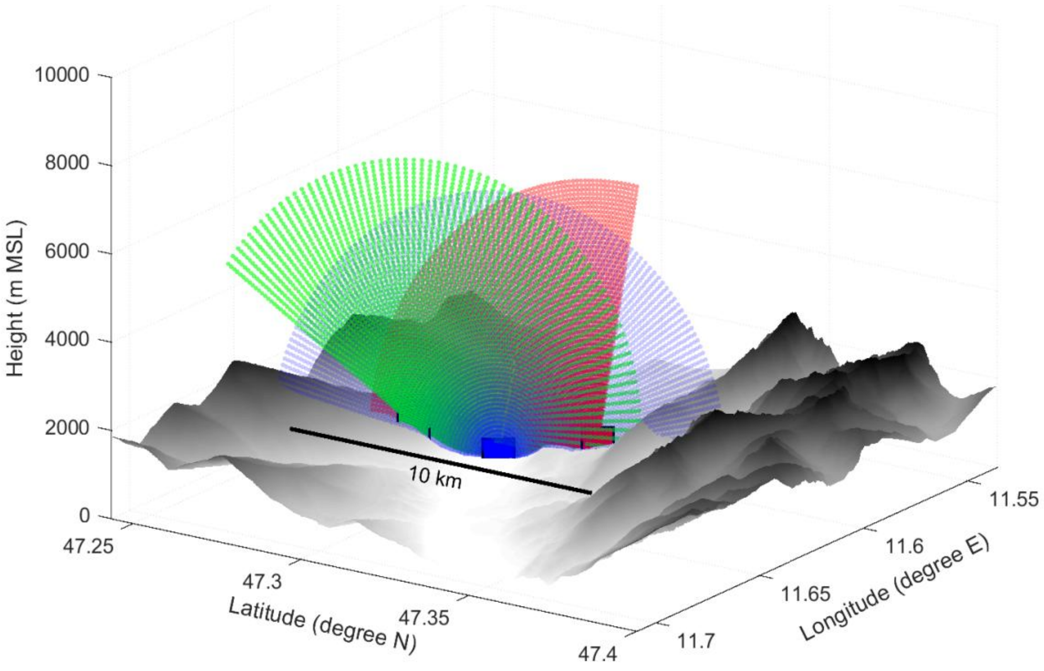
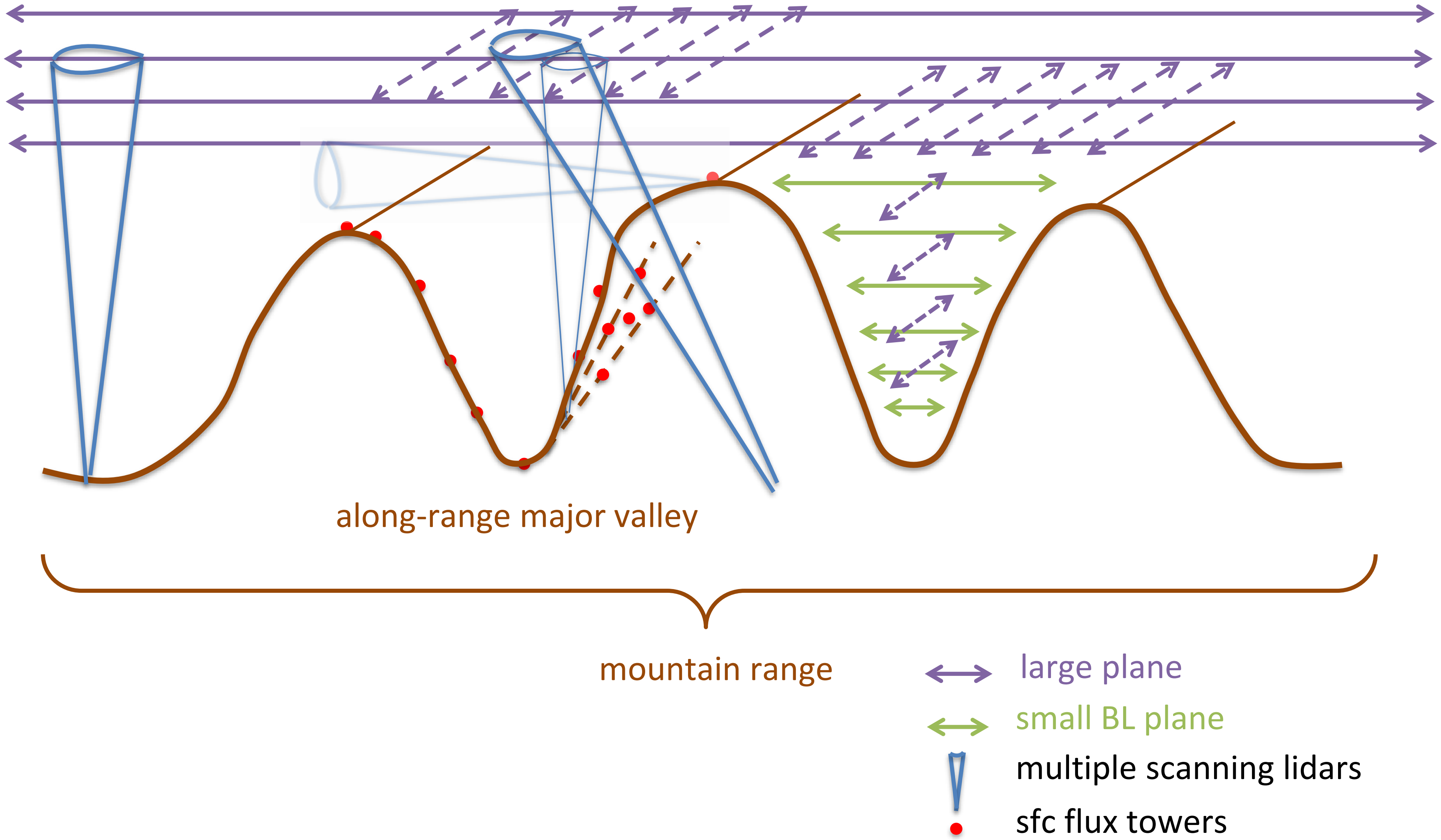


KITcube
integrated atmospheric observation system

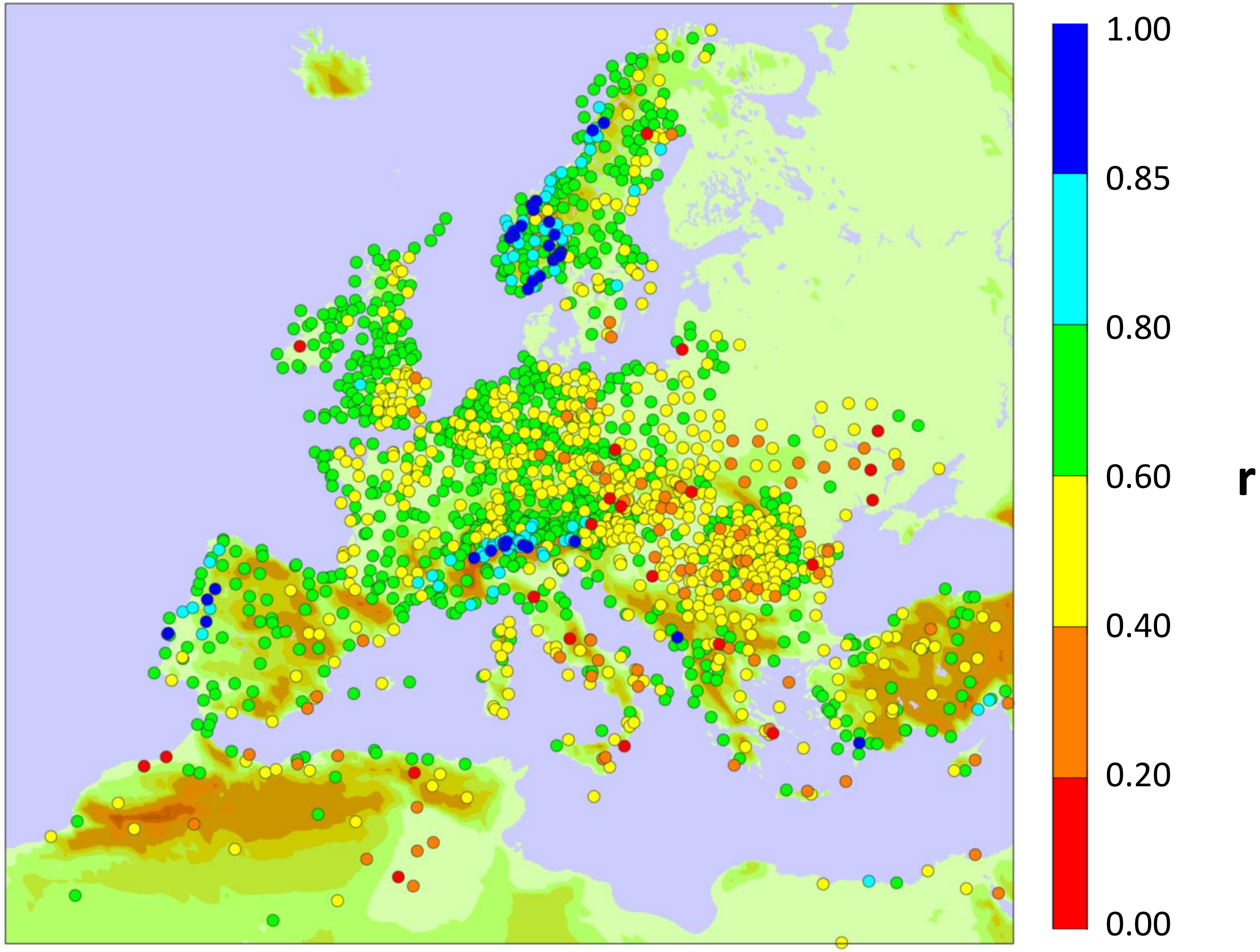


along-range major valley
mountain range
large plane
small BL plane
multiple scanning lidars
sfc flux towers

Modelling plans

- *"NWP and climate modelling is plagued by larger uncertainty and larger systematic errors over/near mountains".*
- True or not?

Precipitation forecast skill at day 3 (ECMWF IFS).
Courtesy of Thomas Haiden



2018

Modelling plans

GABLS1	GABLS2	GABLS3
		
LES as reference	Data (CASES99)	Data (CABAUW)
Academic set up	Idealized forcings	Realistic forcings
Prescribed T_s	Prescribed T_s	Full coupling *(SCM)* Prescribed T_s *(LES)*
No Radiation	No Radiation	Radiation included
Turbulent mixing	Diurnal cycle	Low levet jet + transitions

LES: Large Eddy Simulation; *SCM:* Single Column Model

Holtslag, 2011

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, white paper.
- Scientific focus on mountain-induced exchange processes.
- Aim: process understanding, observational evidence to better constrain parameterizations.
- Combination of field and modelling experiments.
- Plans for field campaign in 2023-2024 in the European Alps.
- Implementation details currently being defined.
- Funding: bottom-up approach, partners fund themselves.

TEAMx

https://worldview.earthdata.nasa.gov

Thank you!