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

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Overview

- Historical perspective.
- What is TEAMx? First steps.
- What is TEAMx about? (Preliminary) science plan.
- What happens next?

Historical perspective

Mountain meteorology: key programmes

1981-1982: Alpine Experiment (ALPEX)

Lee cyclogenesis

1990: Pyrenees Experiment (PYREX)

Gravity wave drag

1999: **Mesoscale Alpine Programme** (MAP; first WWRP research and development project).

Heavy rainfall, PV streamers, gap flows

What is TEAMx?

TEAMx

- What?
  - TEAMx is an international research programme that aims at measuring exchange processes in the atmosphere over mountains and at evaluating how well these are parameterized in NWP and climate models.
  - TEAMx focuses on *interactions* between mesoscale and boundary-layer processes. Even if the exchange of momentum, heat and mass is often regarded as a boundary-layer meteorology issue, implications are far-reaching. Examples will be provided.

TEAMx

- Why?
  - 20 years after MAP, NWP products have much higher resolution (smaller spatial scales). Climate modelling (longer time scales) now resolve some mesoscale processes explicitly.
  - Today's challenge lies in observing, understanding and modelling correctly the interactions between processes at different scales (down to micro-).
  - The exchange of momentum, heat and mass (water, CO_2, pollutants) between the ground, the boundary layer and the free atmosphere is the key to understanding the impact of mountains on the atmosphere.
- From "*Mesoscale alpine programme*" to "*Multi-scale **t**ransport and **e**xchange processes in the **a**tmosphere over **m**ountains – programme and e**x**periment*".

TEAMx

- Where and when does it all begin?
  - In Innsbruck, after the 33rd ICAM (2015), upon initiative of Mathias Rotach.

- Who keeps things going at the moment?
  - A self-proclaimed *Coordination and Implementation Group*, meeting every few months (31.8.2017, 13.4.2018, next planned on 4.12.2018).

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TEAMx

- Has anything already happened?

❶ Promotion of a series of review articles on the MDPI journal *Atmosphere*, special issue "Atmospheric Processes over Complex Terrain" (editors M. Rotach and D. Zardi).
4 papers published, 5 more in preparation or under review.

Open Access | Review

Moist Orographic Convection: Physical Mechanisms and Links to Surface-Exchange Processes

by Daniel J. Kirshbaum, Bianca Adler, Norbert Kalthoff, Christian Barthlott and Stefano Serafin

Atmosphere **2018**, *9*(3), 80; https://doi.org/10.3390/atmos9030080

Received: 11 January 2018 / Revised: 15 February 2018 / Accepted: 21 February 2018 / Published: 25 February 2018

Cited by 2 | PDF Full-text (4422 KB) | HTML Full-text | XML Full-text

Abstract This paper reviews the current understanding of moist orographic convection and its regulation by surface-exchange processes. Such convection tends to develop when and where moist instability coincides with sufficient terrain-induced ascent to locally overcome convective inhibition. The terrain-induced ascent can be owing to [...] Read more.

(This article belongs to the Special Issue Atmospheric Processes over Complex Terrain)

▶ **Figures**

Open Access | Review

Exchange Processes in the Atmospheric Boundary Layer Over Mountainous Terrain

by Stefano Serafin, Bianca Adler, Joan Cuxart, Stephan F. J. De Wekker, Alexander Gohm, Branko Grisogono, Norbert Kalthoff, Daniel J. Kirshbaum, Mathias W. Rotach, Jürg Schmidli, Ivana Stiperski, Željko Večenaj and Dino Zardi

Atmosphere **2018**, *9*(3), 102; https://doi.org/10.3390/atmos9030102

Received: 29 January 2018 / Revised: 17 February 2018 / Accepted: 19 February 2018 / Published: 12 March 2018

Cited by 4 | PDF Full-text (1081 KB) | HTML Full-text | XML Full-text

Abstract The exchange of heat, momentum, and mass in the atmosphere over mountainous terrain is controlled by synoptic-scale dynamics, thermally driven mesoscale circulations, and turbulence. This article reviews the key challenges relevant to the understanding of exchange processes in the mountain boundary layer and [...] Read more.

(This article belongs to the Special Issue Atmospheric Processes over Complex Terrain)

▶ **Figures**

Open Access | Article

Challenges and Opportunities for Data Assimilation in Mountainous Environments

by Joshua Hacker, Clara Draper and Luke Madaus

Atmosphere **2018**, *9*(4), 127; https://doi.org/10.3390/atmos9040127

Received: 15 February 2018 / Revised: 16 March 2018 / Accepted: 21 March 2018 / Published: 27 March 2018

Cited by 1 | PDF Full-text (45478 KB) | HTML Full-text | XML Full-text

Abstract This contribution aims to summarize the current state of data assimilation research as applied to land and atmosphere simulation and prediction in mountainous environments. It identifies and explains critical challenges, and offers opportunities for productive research based on both models and observations. Though [...] Read more.

(This article belongs to the Special Issue Atmospheric Processes over Complex Terrain)

▶ **Figures**

Open Access | Review

Current Challenges in Understanding and Predicting Transport and Exchange in the Atmosphere over Mountainous Terrain

by Manuela Lehner and Mathias W. Rotach

Atmosphere **2018**, *9*(7), 276; https://doi.org/10.3390/atmos9070276

Received: 8 June 2018 / Revised: 9 July 2018 / Accepted: 14 July 2018 / Published: 18 July 2018

PDF Full-text (4270 KB) | HTML Full-text | XML Full-text

Abstract Coupling of the earth's surface with the atmosphere is achieved through an exchange of momentum, energy, and mass in the atmospheric boundary layer. In mountainous terrain, this exchange results from a combination of multiple transport processes, which act and interact on different spatial [...] Read more.

(This article belongs to the Special Issue Atmospheric Processes over Complex Terrain)

▶ **Figures**

TEAMx

- Has anything already happened?

❷ Drafting of a *Memorandum of Understanding* between the institutions of the CIG members. Signed by **7** institutions. Expected signature by **3** more.
Open to new partners.

University of Innsbruck / MeteoSwiss / Meteo France / University of Virginia / McGill University / University of Trento / ETH-C2SM / NCAR / NCAS / KIT.

TEAMx

- Has anything already happened?

❸ Establishment of a programme coordination office at the University of Innsbruck (UIBK), supported by seed money (enough for 2 years) committed by a few partners. Negotiations for bilateral agreements with UIBK are in progress.

University of Innsbruck (50 k€) / MeteoSwiss (30 k€) / Meteo France (10-25 k€) / ETH-C2SM (10 k€) / NCAS (20 k€) / KIT (20 k€) / ZAMG (5 k€).

What is TEAMx about?

Exchange processes

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.

Parameterizing exchange processes

- The following slides provide 3 examples of gaps between the state-of-the art in parameterizations and the state of knowledge about exchange processes.
    1. Orographic drag
    2. Scaling laws in the surface layer
    3. Planetary boundary layer

Example 1: Orographic drag

How parameterizations work

- Two components: blocked-flow drag and gravity-wave drag.
- Both are estimated from vertically-averaged values of U, N and ρ, e.g. in the layer between σ and 2σ (of the SGS orography).
- Consequence: orographic drag parameterizations are unaware of low-level wind shear and inversion layers.

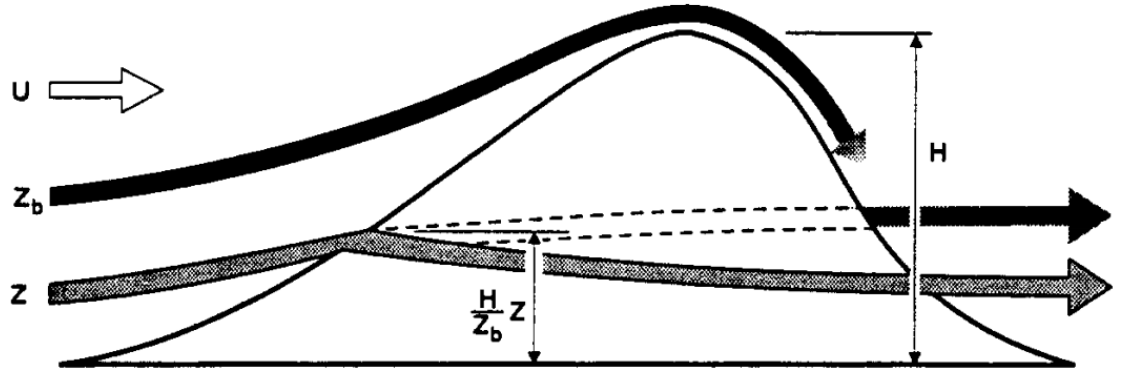

Figure 1. Schematic representation of the low-level flow behaviour parametrized in the new scheme (see text for details.

Lott and Miller (1997)

Example 1: Orographic drag

Teixeira (2014)

What we know

- Gravity wave drag depends heavily on a number of variables and processes that conventional linear hydrostatic theory cannot capture.
- These include wind shear, the presence of critical levels, temperature ducts, lee-wave interference, boundary-layer dissipation, moisture.
- Most of these effects have been described analytically.

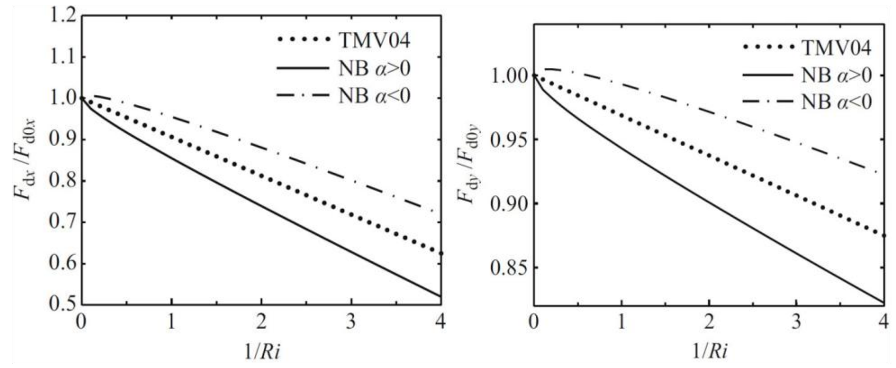

FIGURE 4 | Normalized x (left) and y (right) components of the drag as a function of Ri for the wind profile (45). The solid and dash-dotted lines correspond to non-Boussinesq calculations (with different signs of α – see legend), and the dotted line is the original Boussinesq result (46). Reproduced from Figure 1 of Tang et al. [69] with kind permission from Springer Science and Business Media.

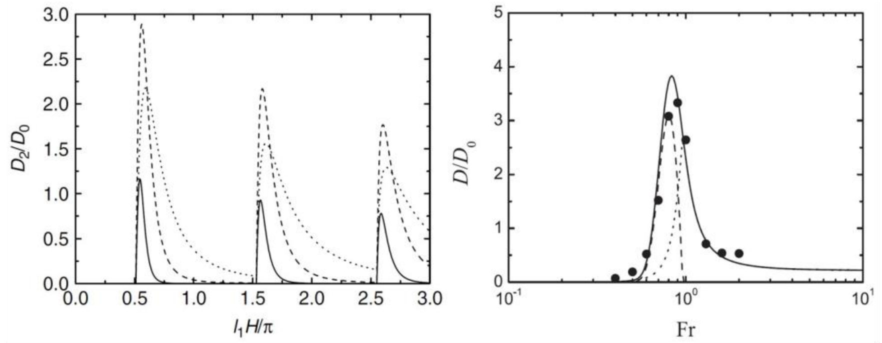

FIGURE 11 | Left: trapped lee wave drag (here denoted by D_2) normalized by (30) as a function of $l_1 H/\pi$. Solid line: $l_1 a = 10$, dashed line: $l_1 a = 5$, dotted line: $l_1 a = 2$. Reproduced from Figure 6 of Teixeira et al. [111]. Copyright © 2012 Royal Meteorological Society. **Right:** Drag normalized by (30) as a function of Fr for $l_2 H = 0.5$ and $l_2 a = 1$. Solid line: total drag, dotted line: internal gravity wave drag, dashed line: trapped lee wave drag, all from theory; symbols: numerical simulations. Reproduced from Figure 9 of Teixeira et al. [112]. © American Meteorological Society. Used with permission.

Example 2: MOST scaling laws

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).

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

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

Example 2: MOST scaling laws

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 provide a poor match to observed fluxes and gradients over complex terrain.
- The example refers to a steep mountain slope.

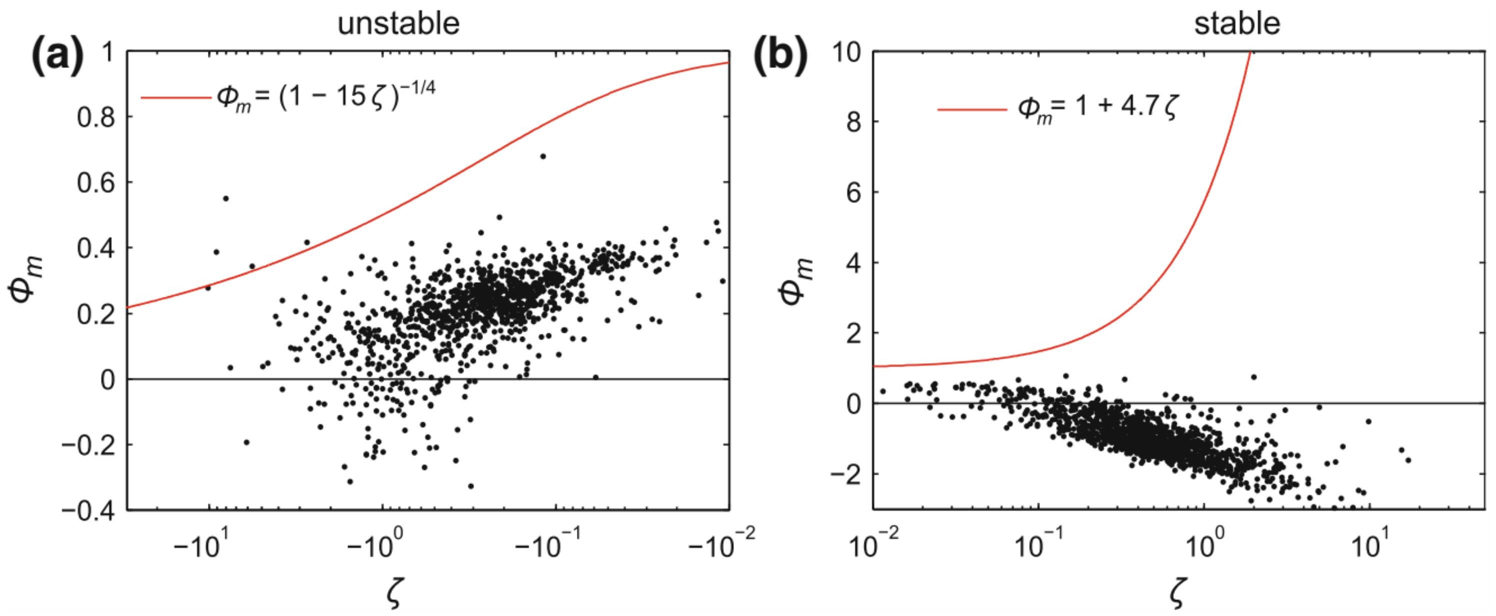

Fig. 10 Dimensionless wind shear ϕ_m for **a** $\zeta < 0$ and **b** $\zeta > 0$ at site T2, 1.5 m normal to the surface. The *solid red lines* represent the Businger–Dyer flux–profile relationships determined over flat and homogeneous surfaces (Businger et al. 1971; Dyer 1974)

Nadeau et al (2013)

Example 3: 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).

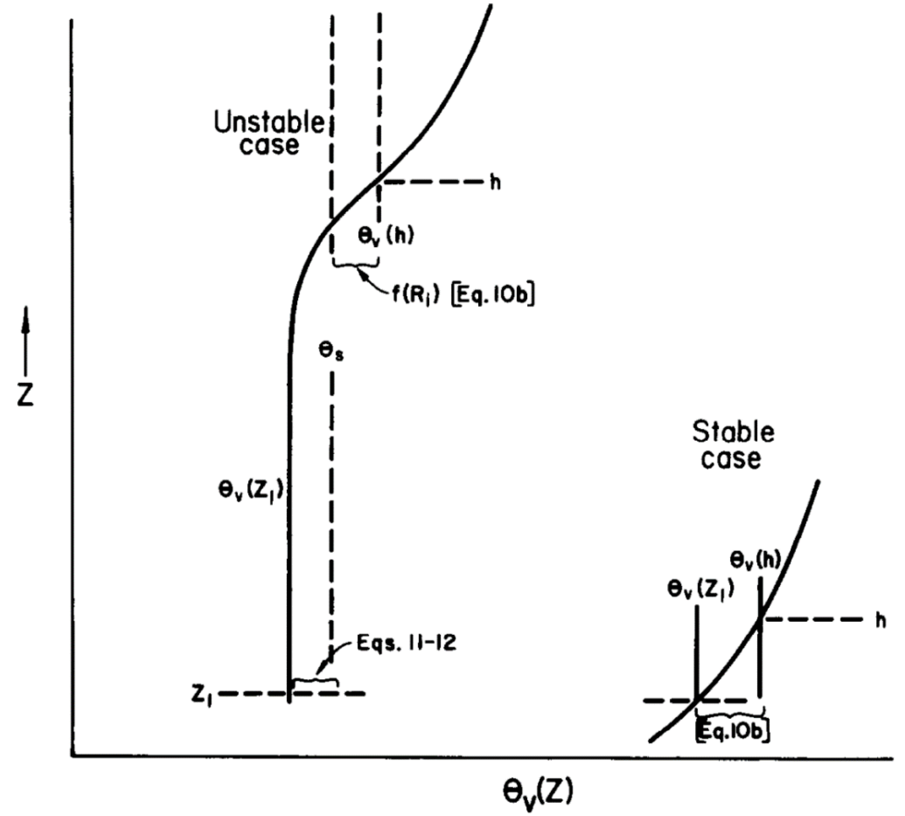

Fig. 1. Geometric sketch of the boundary-layer depth relationship to the profile of potential temperature above the surface layer (solid profile). For the unstable case, the first vertical broken line to the right of the profile indicates the potential temperature after enhancement due to the temperature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

Wagner et al (2015)

Example 3: PBL structure

What we know

- The vertical structure of the MBL is more complex than that of the CBL.
- Different ways to estimate z_i perform (very) differently over complex terrain.
- Horizontal exchange is important over complex terrain.

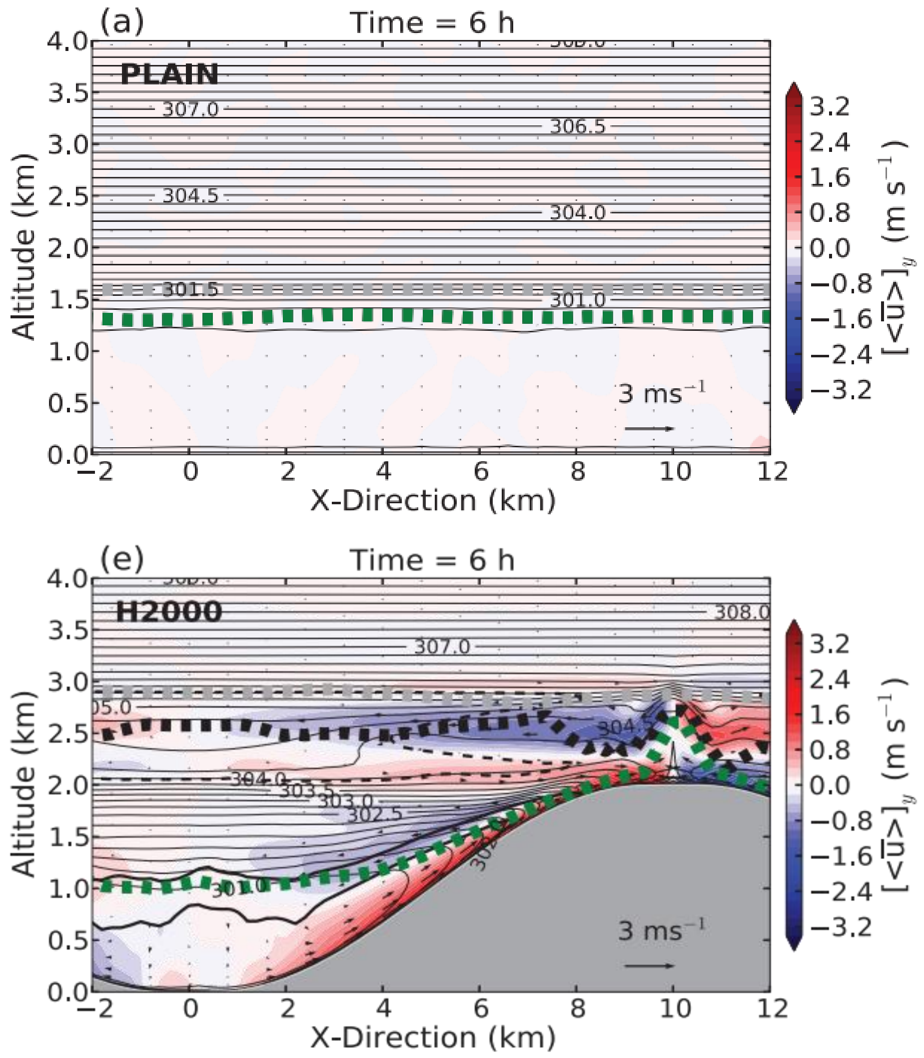

Figure 4. (a)–(e) Cross-sections of potential temperature (thin contour lines), cross-valley (colour shading) and along-valley wind speed (thick contour lines, negative values dashed, interval 1.0 m s^{-1}, the zero line is not shown) averaged between $y = 5$ and $y = 15$ km after 6 h of simulation.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

Example 3: PBL structure

What we know

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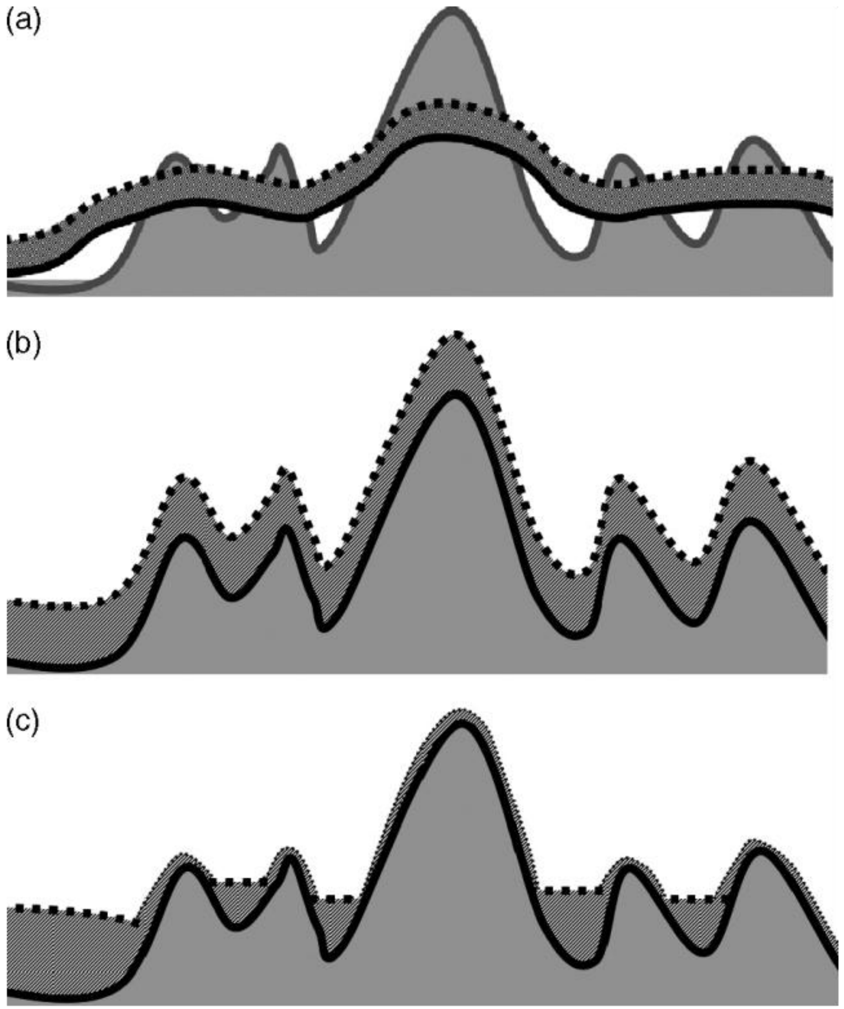
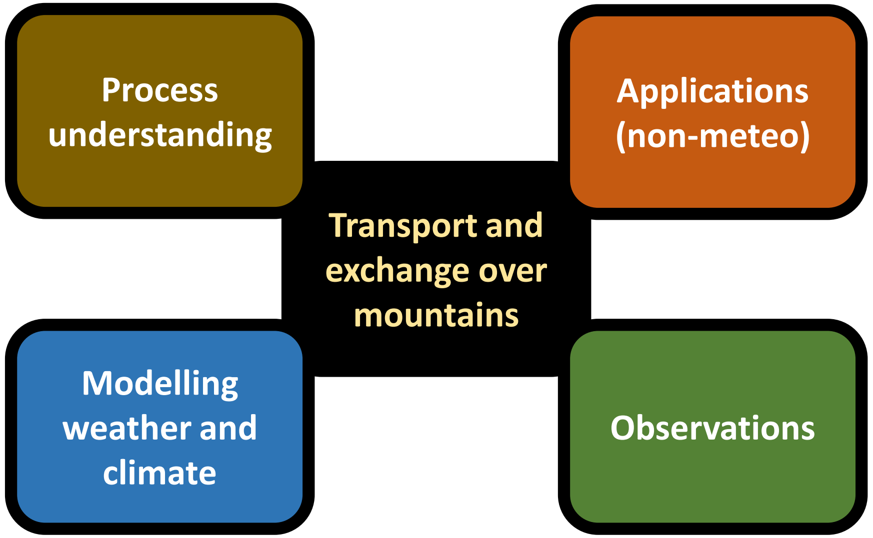
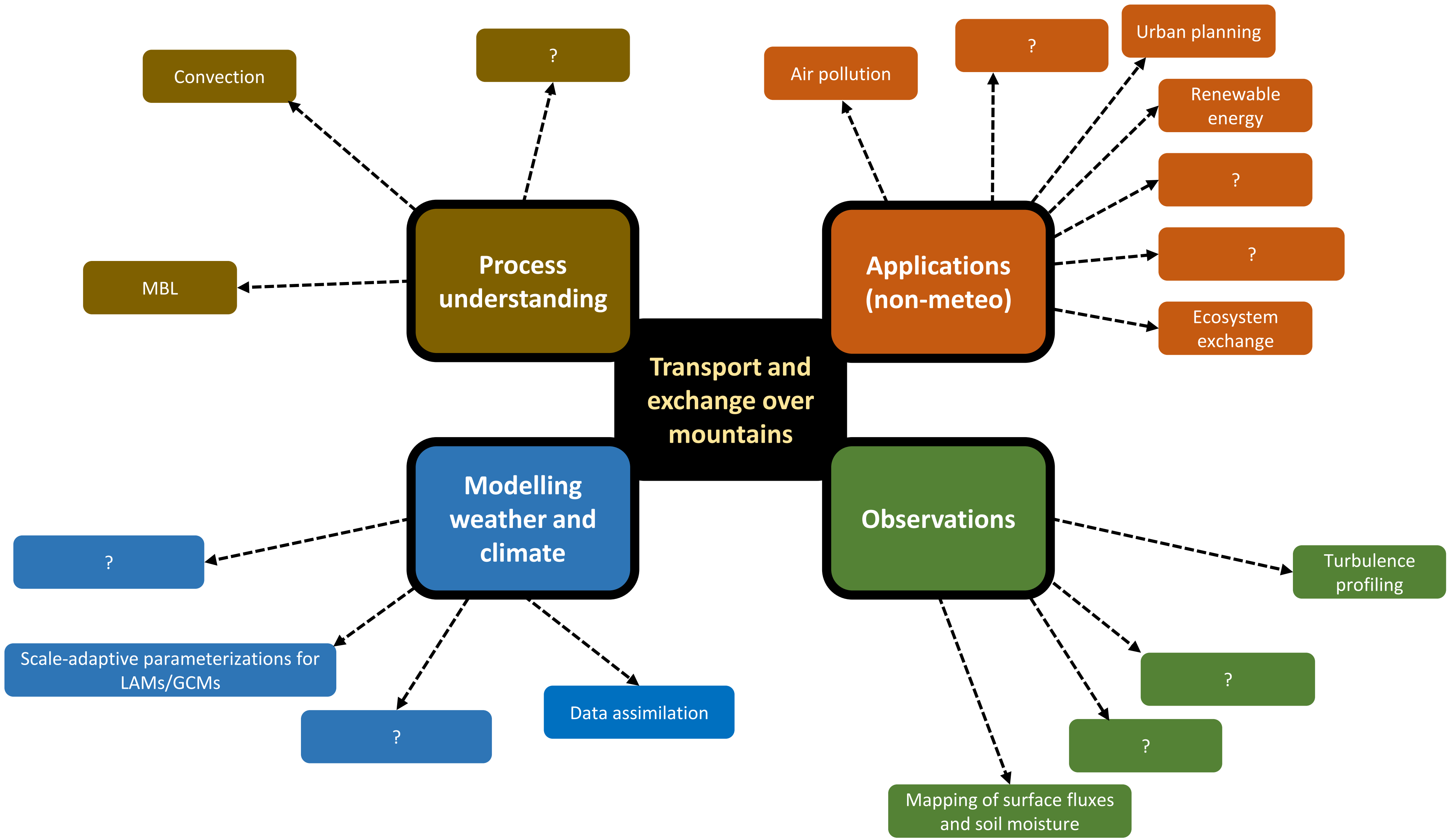


Figure 5. Schematic representation of the boundary layer in (a) a low-resolution numerical model, (b) a high-resolution operational numerical model, and (c) the turbulent boundary layer as found from different MAP boundary-layer studies.

TEAMx scope


Process understanding
Applications (non-meteo)
Transport and exchange over mountains
Modelling weather and climate
Observations



Convection
?
Air pollution
?
Urban planning
Renewable energy
?
?
Ecosystem exchange
MBL
Process understanding
Applications (non-meteo)
Transport and exchange over mountains
Modelling weather and climate
Observations
?
Scale-adaptive parameterizations for LAMs/GCMs
?
Data assimilation
Turbulence profiling
?
?
Mapping of surface fluxes and soil moisture

A field campaign?

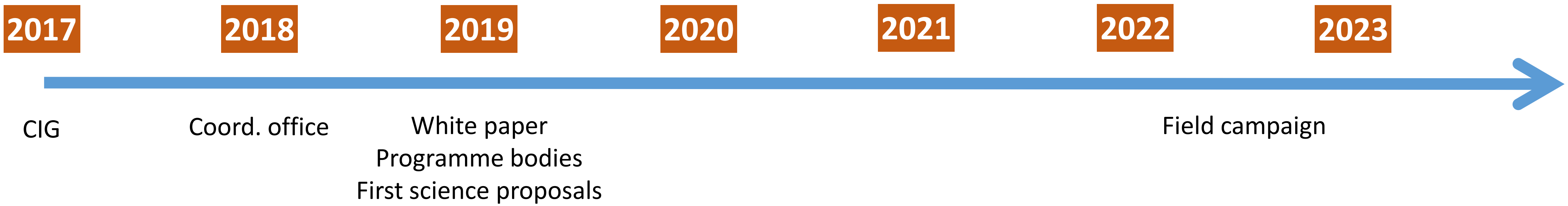
- Field campaigns like MAP are targeted at observing specific events (well-defined IOP prototypes).
- Exchange processes are “always on”, their observation cannot rely on IOPs only.
- A field campaign should contemplate two components:
  - A set of semi-permanent continuously operating observing platforms (e.g., i-Box) characterizing near-surface exchange in mountainous regions.
  - Intensive Observation Periods targeting *specific mesoscale processes* (mostly tbd) *tightly coupled to surface exchange* (e.g., convection initiation).

What happens next?

Next steps

- What happens next?

1. Expand the partnership, establish formal programme bodies.
2. Consolidate project science: White paper.
3. Seek international endorsement (e.g., WWRP, WCRP, EUMETNET).
4. Acquire funding from national and international agencies.



❶ Programme bodies

- Currently: only a *Coordination and Implementation Group*.
- Organization will have to be updated when the scientific core of TEAMx becomes better defined.
- Objectives:
  - Favour participation (“working groups” or “task teams”).
  - Help consolidate programme science, possibly formulate ideas for funding proposals.

❷ White paper

- Tentatively three parts: Motivation/Science/Implementation (Why/What/How).
- First draft available by the end of 2018; ample margin for successive updates.
- Starting point: MDPI *Atmosphere* issue on "Atmospheric processes over complex terrain".

1.	Lehner and Rotach: Overview	published
2.	Serafin et al: Boundary-layer processes	published
3.	Vosper et al: Mountain waves	under review
4.	Kirshbaum et al: Moist convection	published
5.	Emeis et al: Measurements	under review
6.	Chow and Schär: Numerical modeling	under review
7.	Hacker et al: Data assimilation challenges	published
8.	De Wekker et al: Applications	under review
9.	Giovannini et al: Air pollution	in preparation

4 Funding

- No big pot of money available. Bottom-up approach.
- Three pillars of support:
  - In-kind contributions, i.e., resources already available at participating institutions (e.g., i-Box, KITcube; HPC infrastructures; dedicated staff).
  - Getting access to existing facilities (EUFAR, NCAR/NSF-LAOF, EUMETNET, …).
  - Proposals for research projects (national, international, bilateral) and training/networking activities (e.g., MSCA-ITN, NSF-RCN, …)

Conclusions

Summary

- Broad international interest about TEAMx is already manifest.
- Ambitious plans.
- Core topic: exchange processes,
  - how they are affected by/affect meteorological processes at different scales,
  - how their parameterization can be improved,
  - how improved models can be used in practice.
- Scope and key scientific questions are not completely defined yet.
- A good moment to join.