

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

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Historical perspective

Key field campaigns in mountain meteorology

- 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



Figures from the MAP Implementation plan (9/1999)

Mesoscale Alpine Programme

- Partners from AT/CA/HR/FR/DE/IT/SI/CH/UK/US
- Preparations began in 1995
- Field phase between 15 September and 15 November 1999
- 17 Intensive Observation Periods, 485 flight hours
- Approx. 220 articles on peer-reviewed journals in 1997-2006
- Approx. 45 doctoral dissertations in 1996-2007
- Peak of scientific production: 4-5 years after field campaign

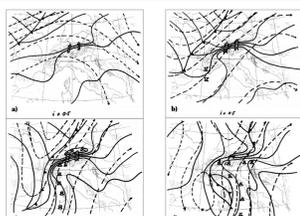


FIGURE 1.2. Schematic depiction of the time sequence of a major MAP event. Continuous lines are surface isobars with say 4hPa spacing, dashed are 500hPa contour lines with say 40gpm interval. Thick arrows indicate the flow direction over the mountain range, other symbols are conventional. It should be noted that with slowly moving, intensifying troughs the surface flow may very often consist of more than one flow which may modulate the flow direction considerably. Panel (d) denotes day 1 + 0.5 (onset of shallow Foehn in the Wipac valley), panel (c) approaching trough over France, panel (b) onset of heavy precipitation in the SW part, and panel (a) end of Foehn in the Wipac valley, onset of precipitation in SE part.

Primary scientific objectives ("MAP Design Proposal", 1/1995)

- To improve the understanding of orographically influenced precipitation events and related flooding episodes involving deep convection, frontal precipitation and runoff.
- To improve the numerical prediction of moist processes over and in the vicinity of complex topography, including interactions with land-surface processes.
- To improve the understanding and forecasting of the life cycle of Foehn-related phenomena, including their three-dimensional structure and associated boundary layer processes.
- To improve the understanding of three-dimensional gravity wave breaking and associated wave drag in order to improve the parameterization of gravity wave drag effects in numerical weather prediction and climate models.
- To provide data sets for the validation and improvement of high-resolution numerical weather prediction, hydrological and coupled models in mountainous terrain.

Sub-projects ("MAP Science Plan", 6/1998)

- Orographic precipitation mechanisms;
- Incident upper tropospheric PV anomalies;
- Hydrological measurements for flood forecasting;
- Dynamics of gap flow;
- Unstationary aspects of Foehn in a large valley;
- Three-dimensional gravity wave breaking;
- Potential vorticity banners;
- Planetary boundary layer structure.

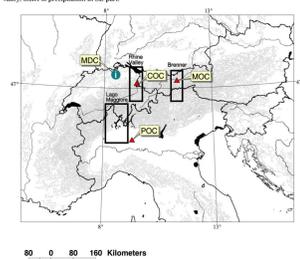


FIGURE 1.1. Key features in MAP. Three target areas (frames do not indicate "true" boundaries): MOC: Mannlicher Operation Center in Innsbruck; COC: Coordinated Center of Observations in the Wipac Valley in Bad Regebrunn; POC: Planetary Operation Center in Zurich.

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: CO₂

CO₂ 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 CO₂ flux modelling over land. Poorly represented exchange over orography may be one reason.

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.
- Exchange? Transfer of fluid properties through a surface, either at the boundary of the fluid or across an imaginary surface within the fluid.
- TEAMx focuses on interactions between mesoscale and boundary-layer processes. Even if the exchange of momentum, heat and mass (water, CO₂, 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 transport and exchange processes in the atmosphere over mountains – programme and experiment".

Why?

- 20 years after MAP, NWP products have much higher resolution (smaller spatial scales). Climate modelling (longer time scales) is mainstream science.
- 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, CO₂, 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 transport and exchange processes in the atmosphere over mountains – programme and experiment".

Who?

- The authors of this poster are the TEAMx "Coordination and Implementation Group".
- MWR: Chair. SS: Coordinator.

What comes next?

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

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.

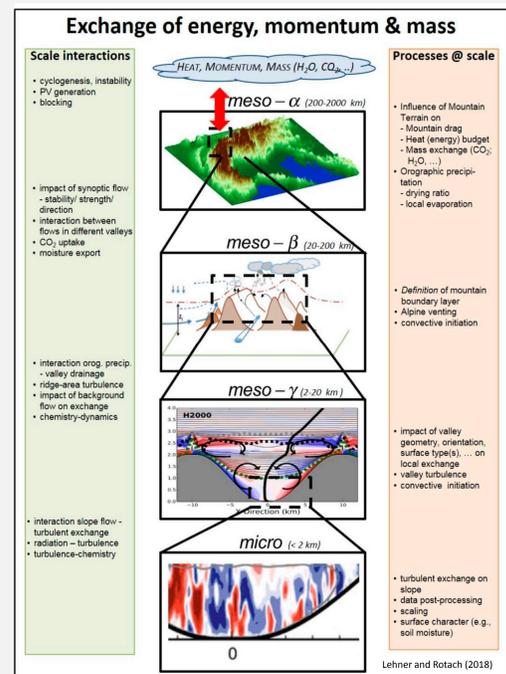


Figure 5. Different scales in mountainous terrain, atmospheric processes on these scales (right bar) and interactions (left bar). The top panel in the middle column shows the Alps at 1 km horizontal grid spacing. The middle two panels are from Rotach et al. [6], the lowest panel from Schmidli [69] © Copyright (2013) American Meteorological Society (AMS).

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.

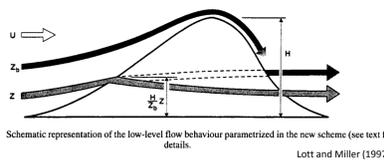


Figure 1. Schematic representation of the low-level flow behaviour parameterized in the new scheme (see text for details). Lott and Miller (1997)

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.

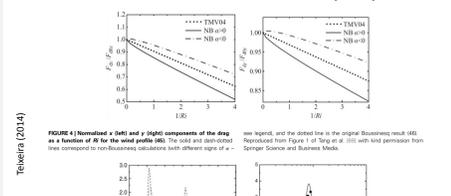


FIGURE 4. Normalized x and y (right) components of the drag as a function of N for the solid profile (left). The solid and dashed lines correspond to non-hydrostatic calculations with different steps of σ . The legend, and the dashed line in the original Boussinesq result (left) are reproduced from Figure 1 of Tang et al. [5] with kind permission from Springer Science and Business Media.

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 Monin-Obukhov Similarity Theory, MOST (Ψ , L).

$$\overline{w'w'_s} = -C_d u_1 U_1$$

$$\overline{w'w'_s} = -C_d v_1 U_1$$

$$\overline{w'\theta'_s} = -C_h U_1 (\theta_1 - \theta_s)$$

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

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

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.

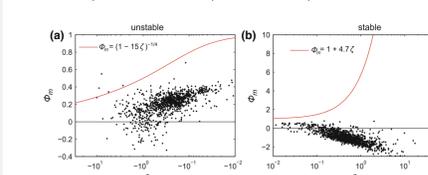
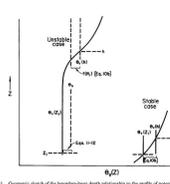


FIGURE 10. Dimensionless wind shear ϕ_w for $a < 0$ and $b > 0$ at site T2, 1.5 m normal to the surface. The solid red lines represent the Businger-Dyer flux-profile relationships determined over flat and homogeneous surfaces (Businger et al. 1971; Dyer 1974).

PBL structure

How parameterizations work

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



Troen and Mahrt (1986)

What we know

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

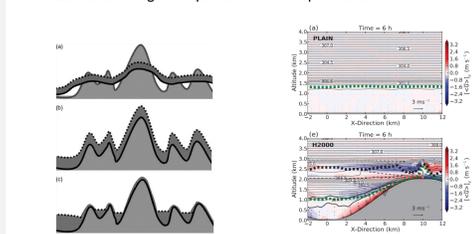


Figure 5. Vertical cross-sections of potential temperature (thin contour lines), cross-wind (thick dashed) and along-wind wind speed (thick contour lines). The panels show cross-sections at different times: (a) 06:00, (b) 12:00, (c) 18:00. The x-axis is the cross-wind direction (km) and the y-axis is the along-wind direction (km). The z-axis is the vertical coordinate (km). The panels show the evolution of the boundary layer structure over time.