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On the boundary layer structure over mountainous complex terrain

Mathias W Rotach & Ivana Stiperski

Leopold Franzens University Innsbruck, A

…and Alexander Gohm, Johannes Wagner, Daniel Leukauf, Brigitta Goger, Matthias Reif, …

Outline

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- point of departure
- where/what is the ‘Boundary Layer’?
- how to treat it…
  → as a whole?
  → local (near surface)?

in this presentation
…more **?** than anything else…

Boundary Layer approximation

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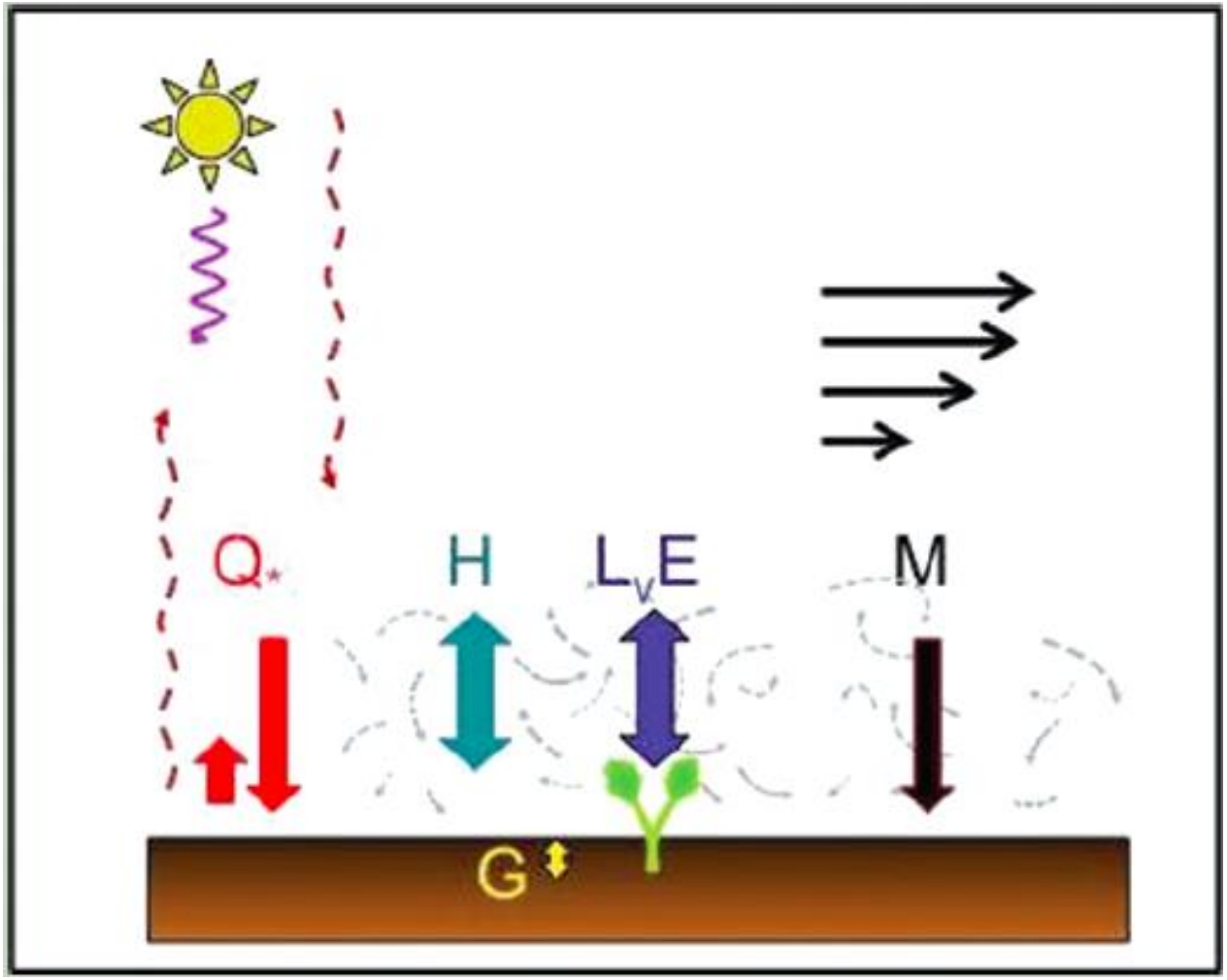

(Rotach et al 2014)

Mathias Rotach (mathias.rotach [at] uibk.ac.at)

Boundary Layer approximation

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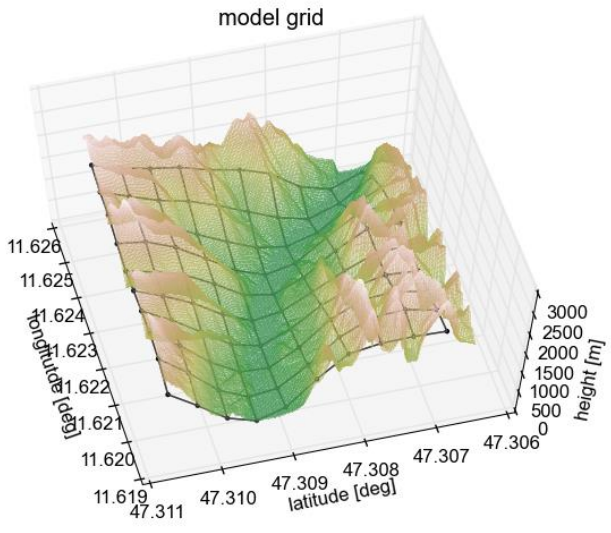
Overall:

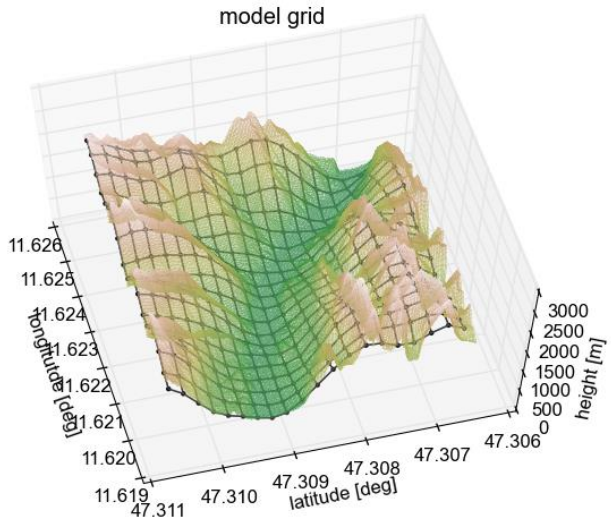
→ one (vertical direction

→ NWP…

COSMO-2



COSMO-1



(courtesy Brigitta Goger, IMGI)

→ what is the boundary layer?

→ 1d vs 3d turbulence

→ scaling approaches

PBL in ct

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The atmospheric boundary layer (ABL) is that part of the atmosphere, which is directly affected by the presence of the Earth's surface and responds to forcing at the surface within a timescale of an hour or even less (Stull, 1988)

- 'at the surface'

  → topography scales become important
  → not 'only' turbulent exchange
  → thermally /dynamically driven flows

Boundary layer height

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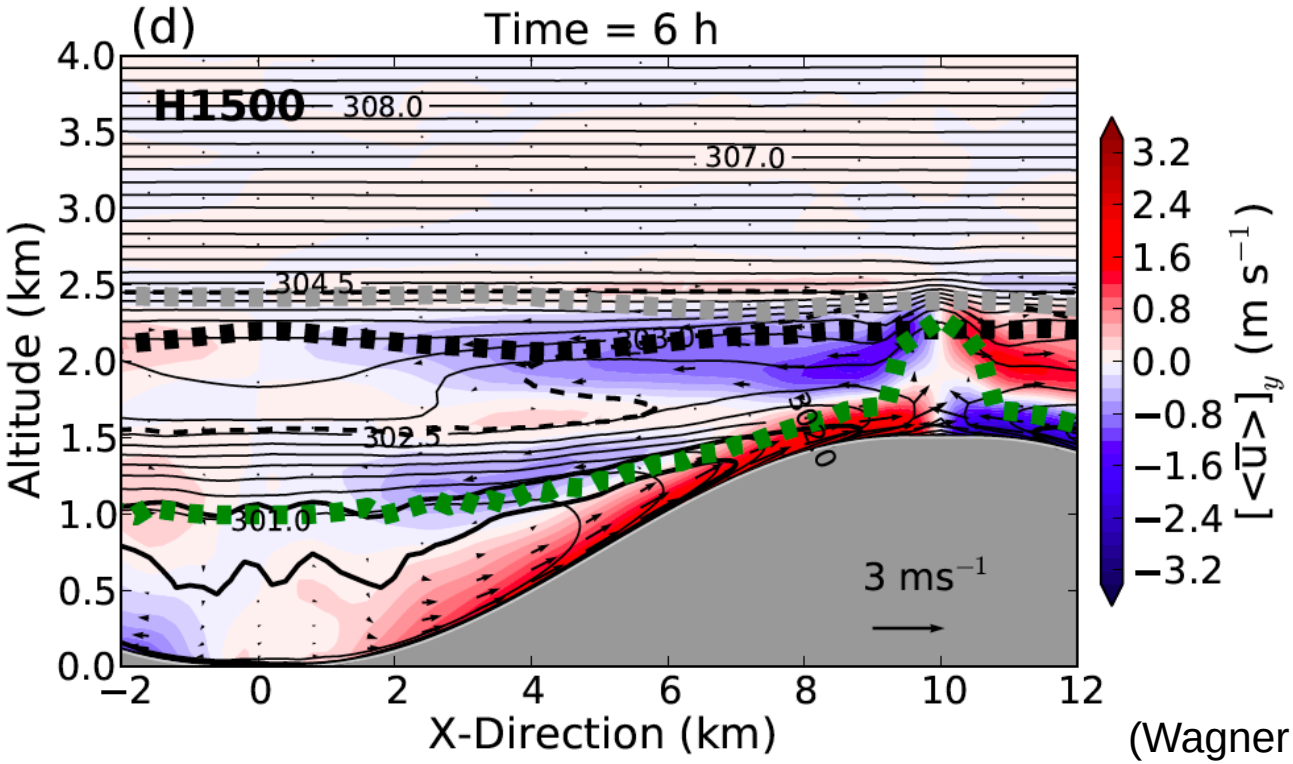

(Wagner et al. 2014, QJ)

PBL1 (θ gradient > 0.001 Km^{-1} from sfc)

PBL2 (θ gradient > 0.001 Km^{-1} from above)

PBL3 (θ gradient maximum)

Idealized wrf simulations

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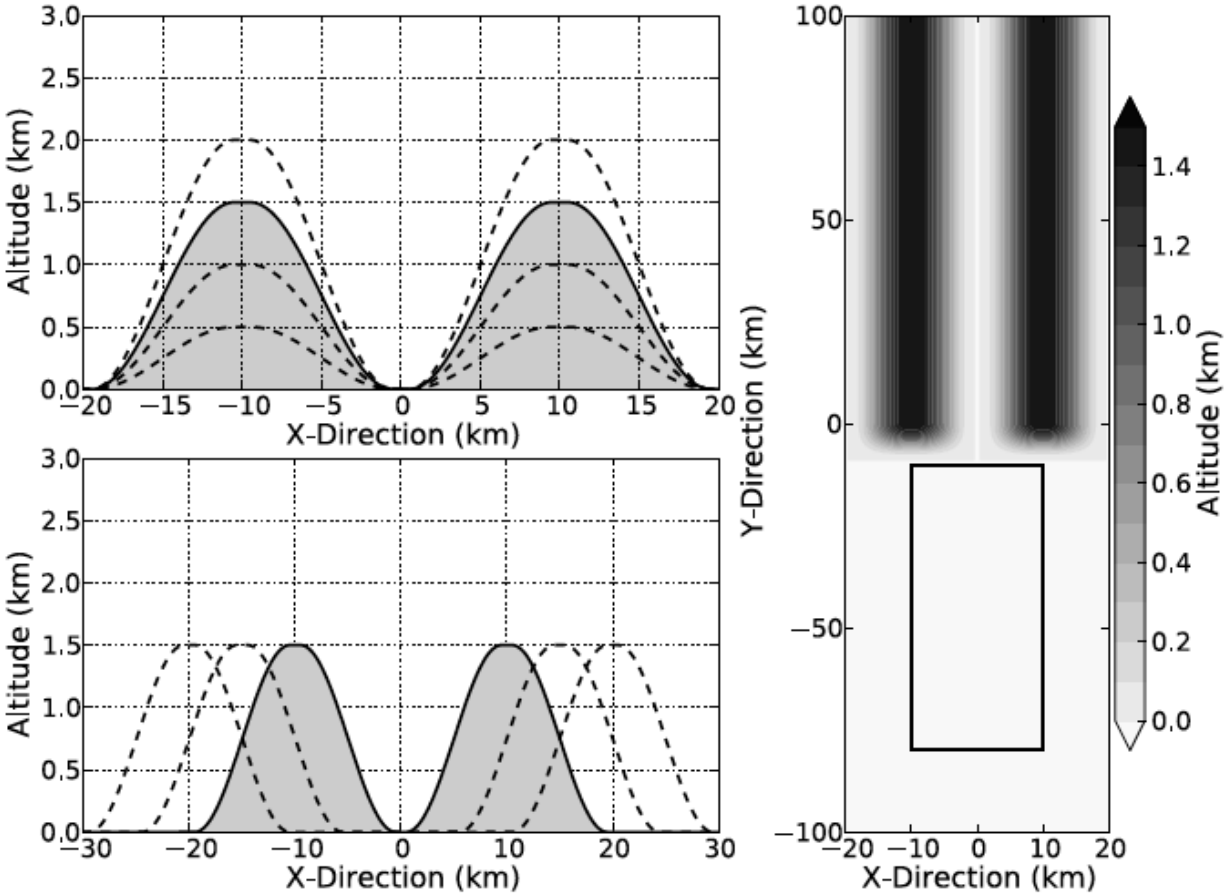

(Wagner et al. 2014, QJ)

Boundary layer height

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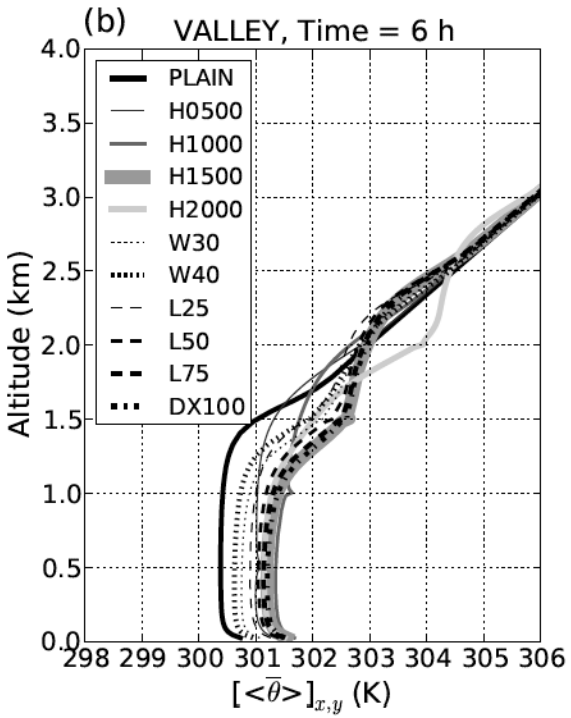
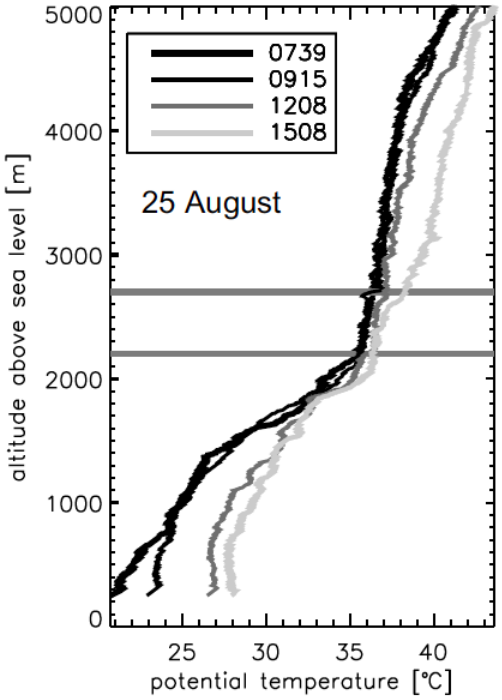
simulated, LES, ideal



(Wagner et al. 2014, QJ)

measured, real



(Weigel and Rotach 2004, QJ)

→ can have two valley circulation cells (valley inversion)

→ impacts total (vertical) exchange

Mathias Rotach (mathias.rotach [at] uibk.ac.at)

Total heat transport

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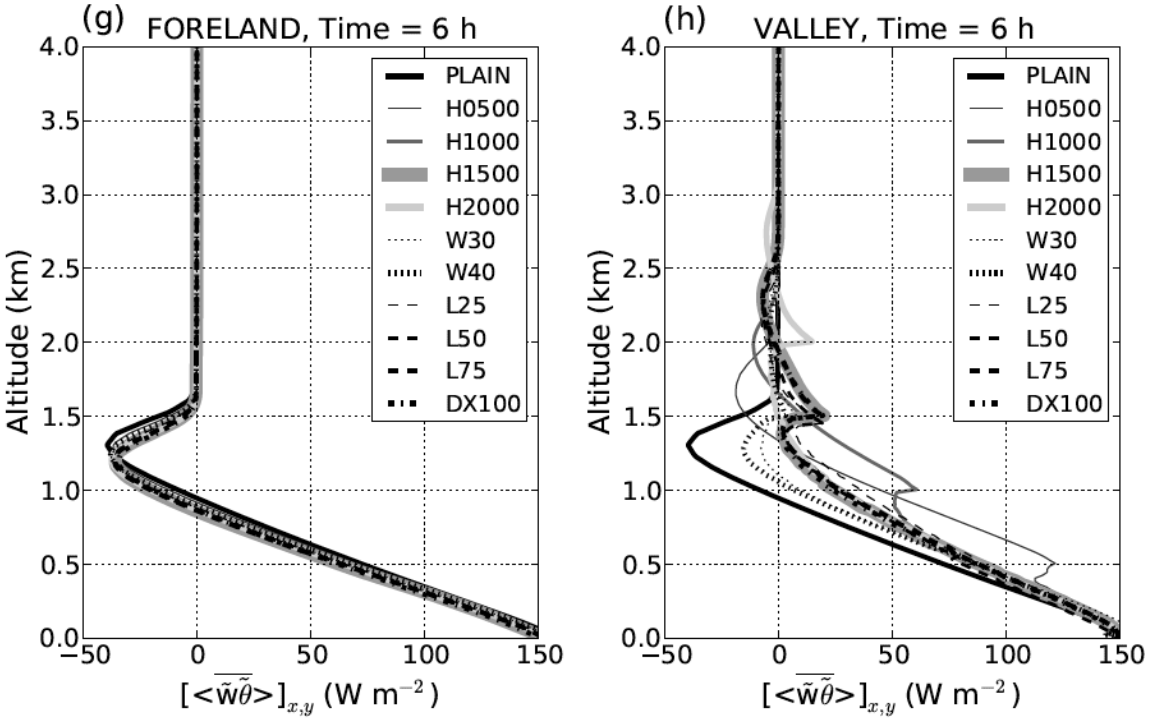
simulated, LES (wrf), ideal



(Wagner et al. 2014, QJ)

→ dependent on geometry

→ enhanced heat transport (↑) @ mtn top

→ weak entrainment from aloft

Exchange processes

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(i.e., …the 'role' of PBL in numerical models…)

numerical model usually has:

- **boundary layer parameterization**
  - → turbulent 'part'
  - → but not mean resolved part
  - → at least for large-scale models: need additional SGS parameterization
- **surface-atmosphere exchange parameterization**
  - → assumes MOST
  - → HHF

MOST or MOST$_{ct}$?

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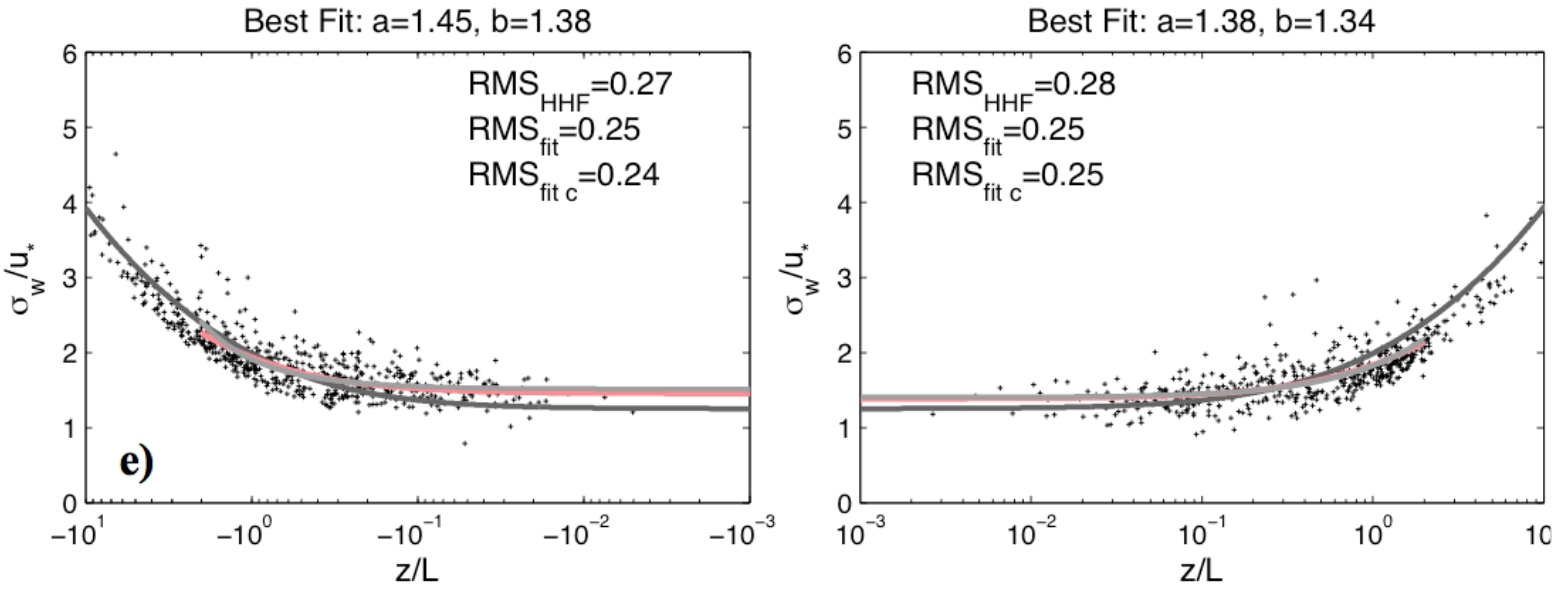
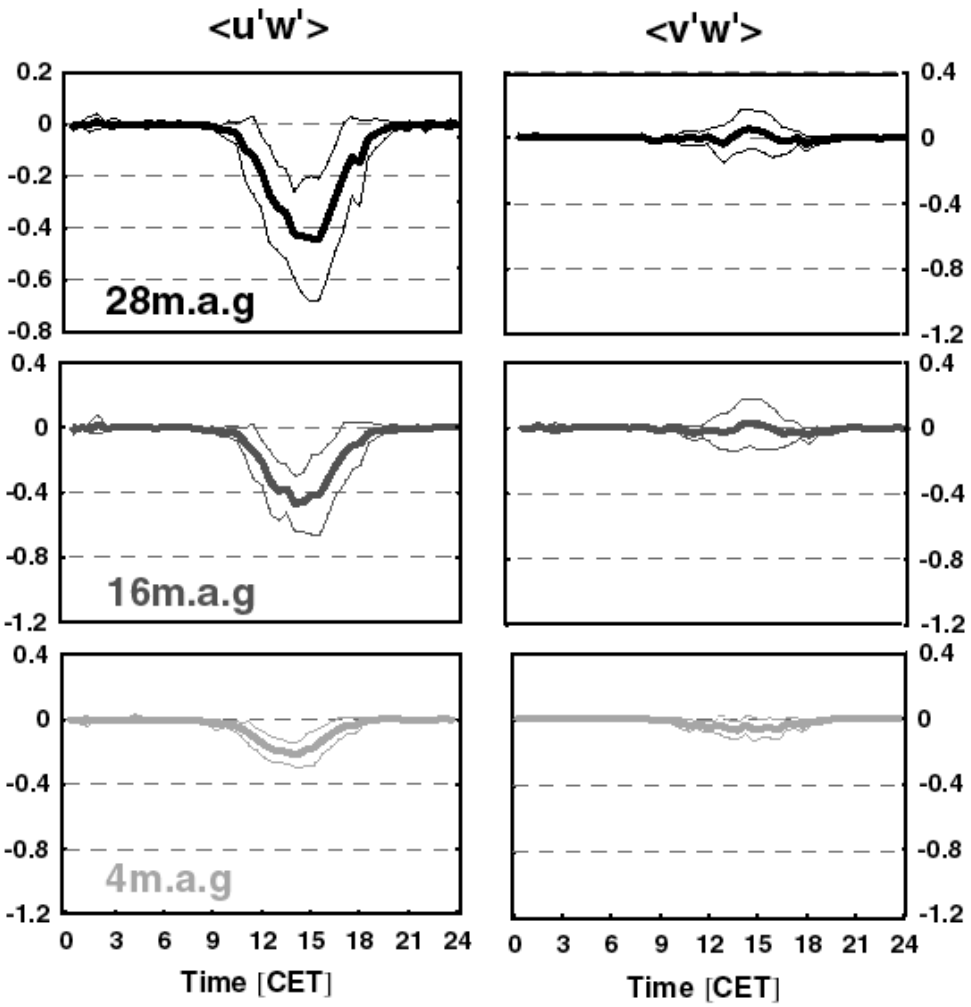
- impact of pre-processing of turbulence data in ct
  → different post-processing options, different quality criteria, corrections, etc
- are there sufficiently 'homogeneous' conditions?
- are sufficiently general 'extensions' possible at all?



Stiperski and Rotach, later this morning

Mathias Rotach (mathias.rotach [at] uibk.ac.at)

Valley floor – momentum transport

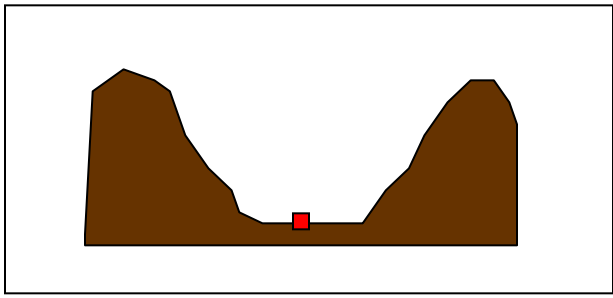


(Rotach et al. 2008)

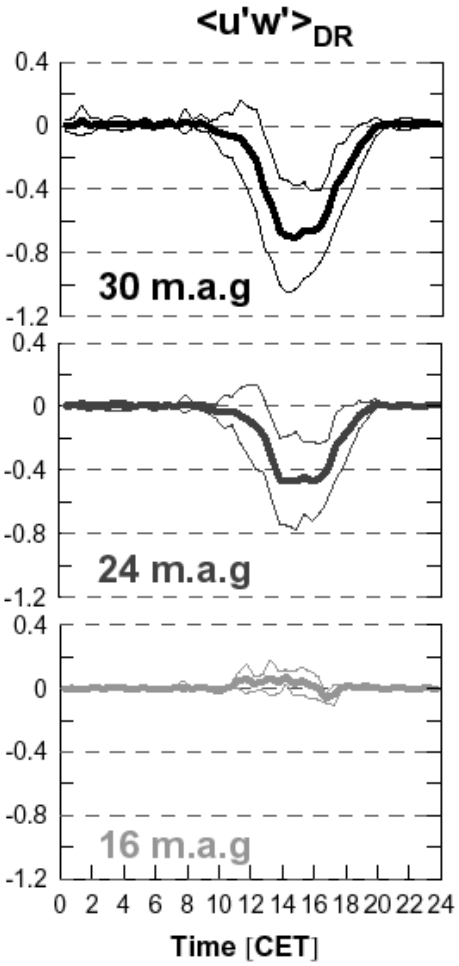
15 ‘Valley wind days‘

frictional stress $\overline{u'w'}$

Bosco di Sotto



Local circulation & turbulent exchange

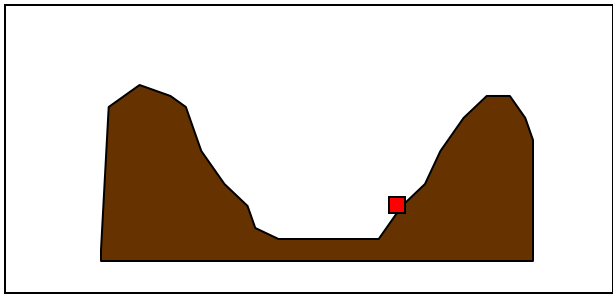


(Rotach et al, 2008)

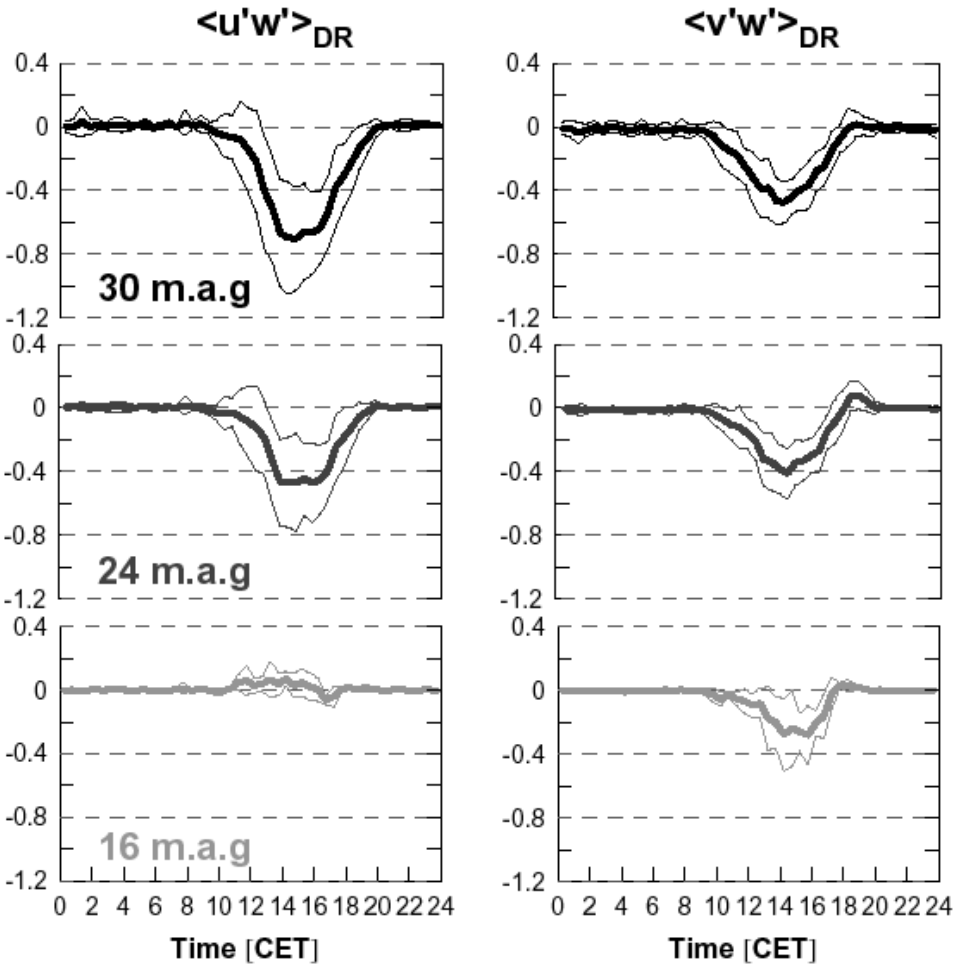
15 'Valley wind days'

frictional stress $\overline{u'w'}$

Rored



Local circulation & turbulent exchange



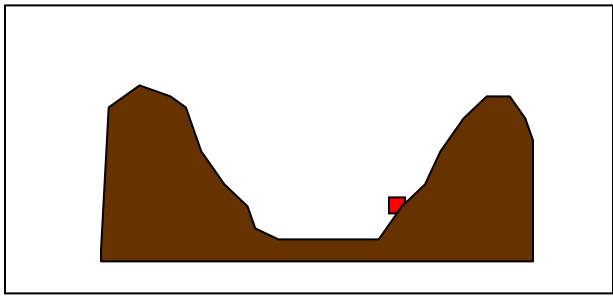
15 'Valley wind days'

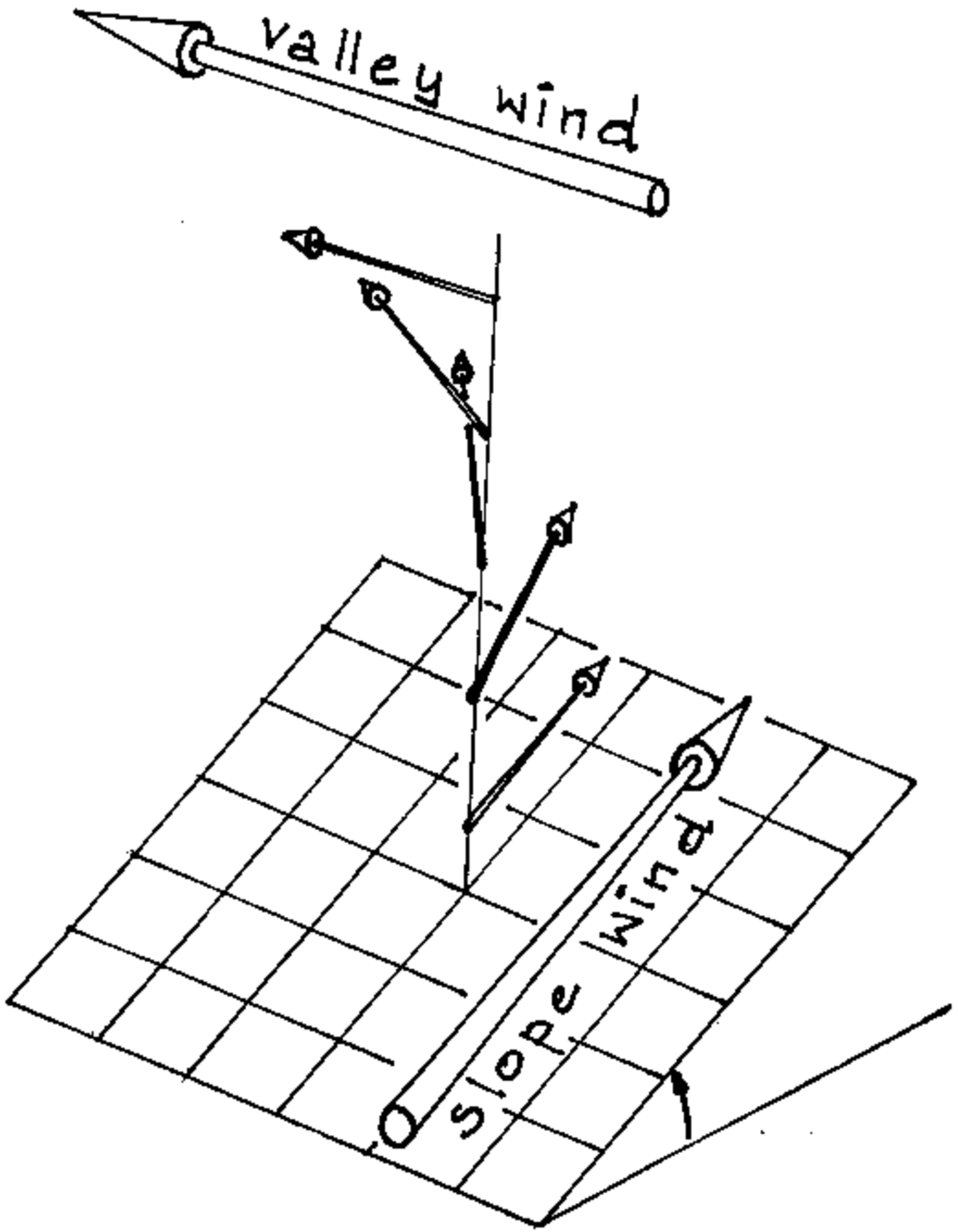
frictional stress $\overline{u'w'}$

+

directional stress $\overline{v'w'}$

Rored





Rotach et al, 2008

Slope site – into canopy

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z/h=1.74

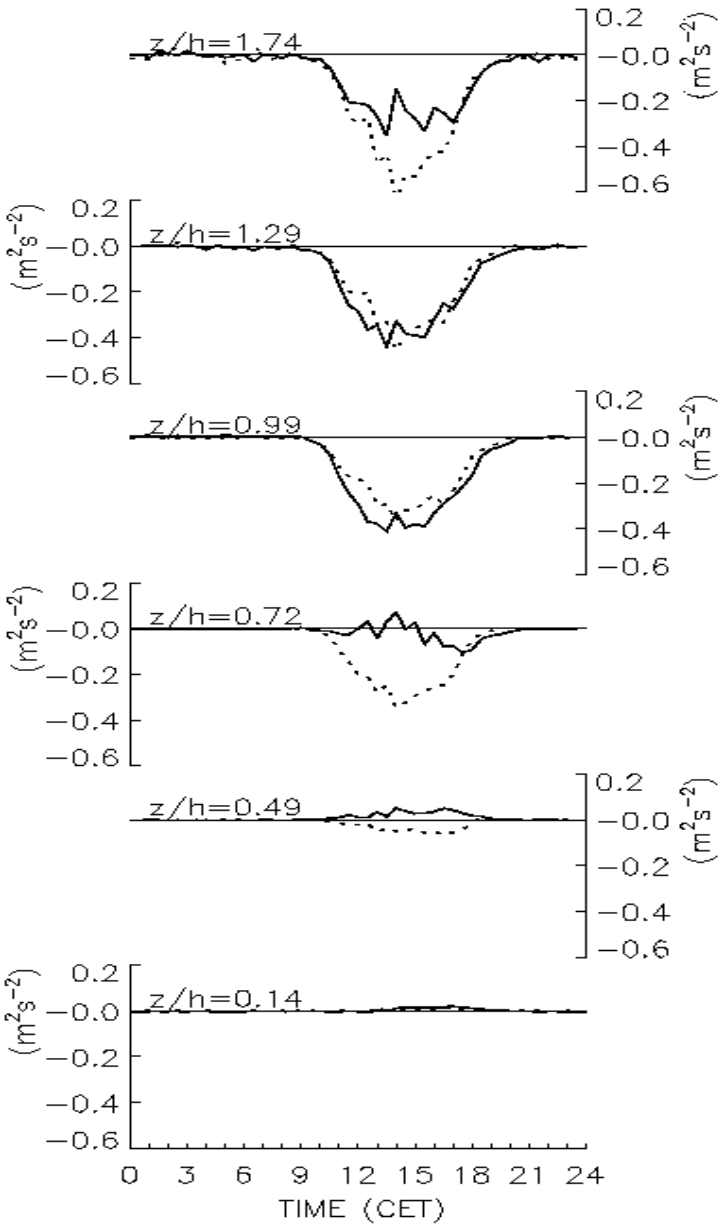
z/h=1.29

z/h=0.99

z/h=0.72

z/h=0.49

z/h=0.14



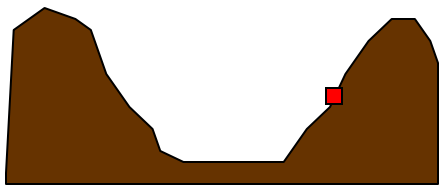
Average daily cycles

frictional: $\overline{u'w'}$ ——

\+

directional stress: $\overline{v'w'}$ - - - -

Monte Nuovo



van Gorsel et al. (2002)

Scaling Velocity

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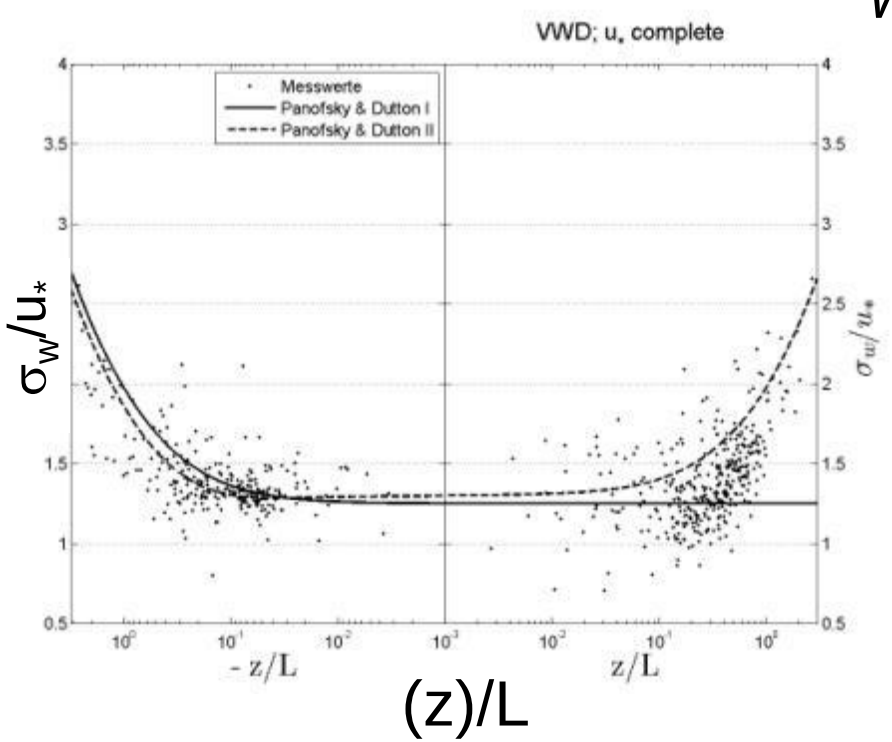
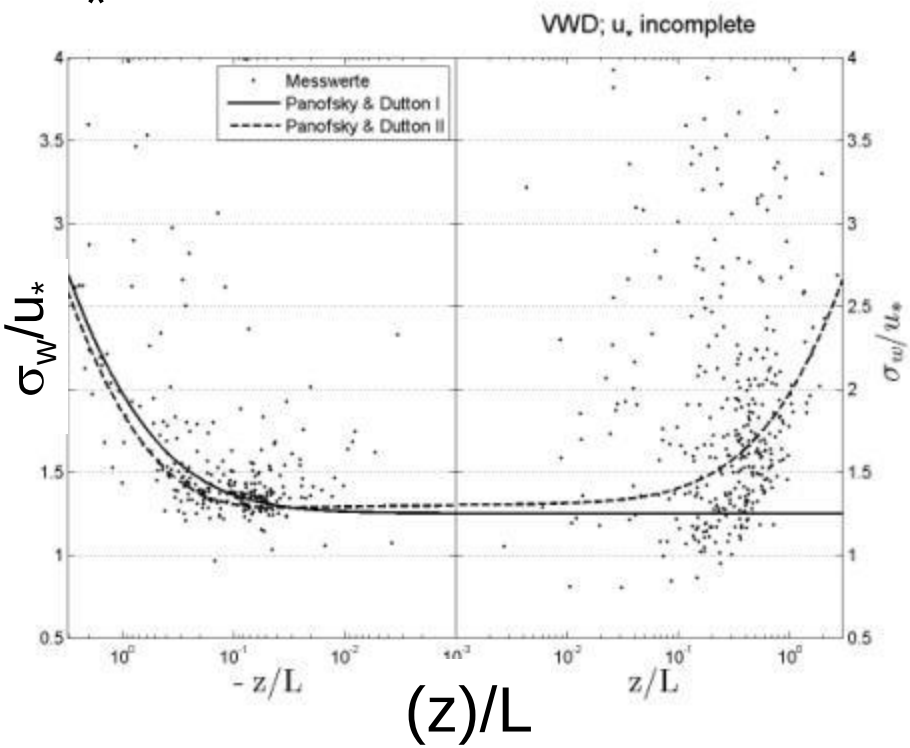
$$s_w / u_*$$



(z)/L



(z)/L

$$u_* = \left(\overline{u'w'}^2 + \overline{v'w'}^2 \right)^{1/4}$$

$$u_* = \left(-\overline{u'w'} \right)^{1/2}$$

MOST or $MOST_{ct}$?

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- there *are* systematic, terrain-related issues
- sufficiently general?
  → impact of slope?
  → tractable?
- how about 'Boundary Layer scaling regimes'?
  → aspect of PBL_{ct} structure
  → TKE example

Stiperski and Rotach, tomorrow

TKE scaling

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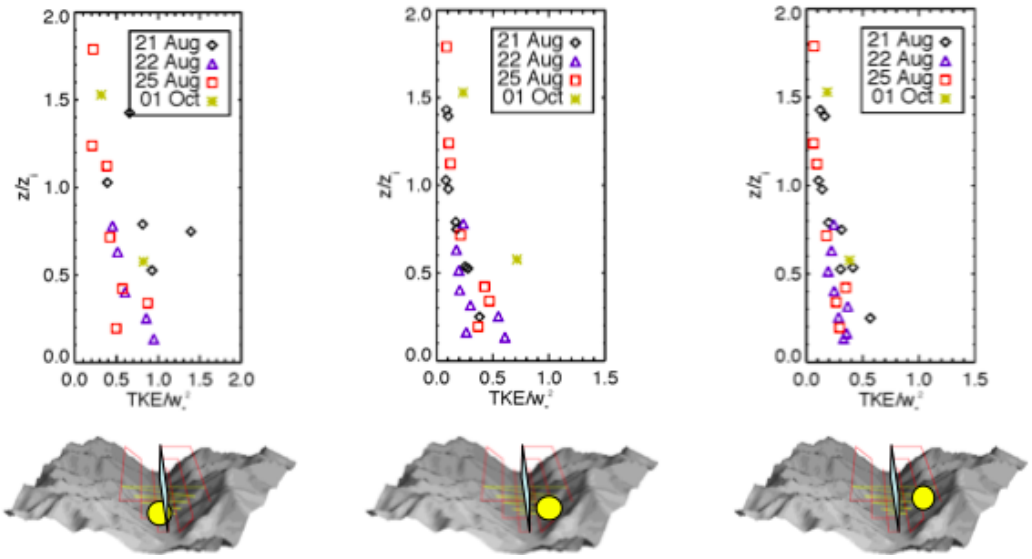
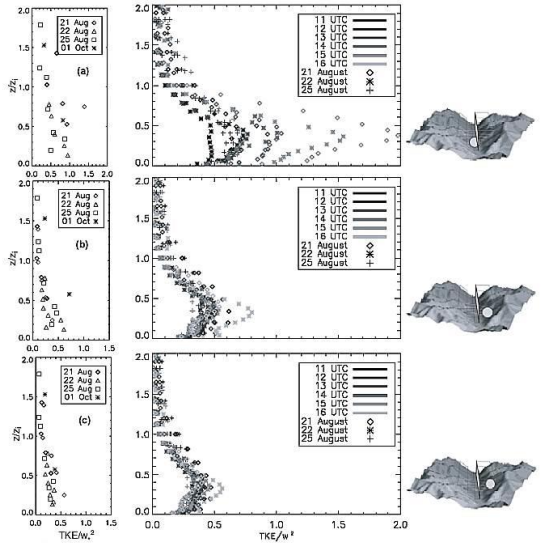
Scaled profiles of TKE - measured



simulated, ARPS



Weigel et al 2007

- *can be reproduced by ARPS*
- TKE due to *horizontal* shear production (valley wind core)
- dependent on ‘strength of valley wind’
- reproducible?

Summary

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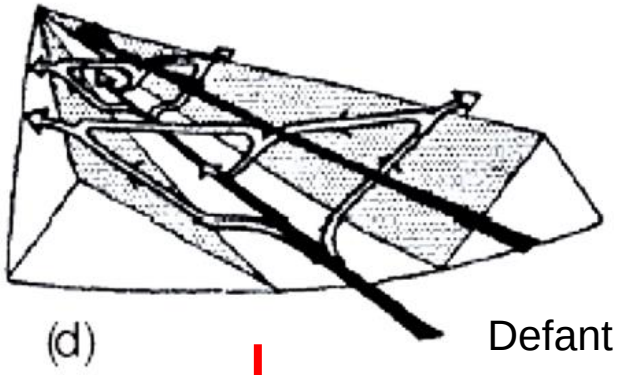
topography scales

- ➢ vertical structure
- ➢ definition of PBL_{ct}
  → only convectively driven so far
- ➢ revised conceptual picture



Defant 1949

?

turbulence / flow structure

- ➢ near-surface treatment
  → $MOST_{ct}$?
- ➢ PBL_{ct} scaling?


Thank you for your attention

Coarse models

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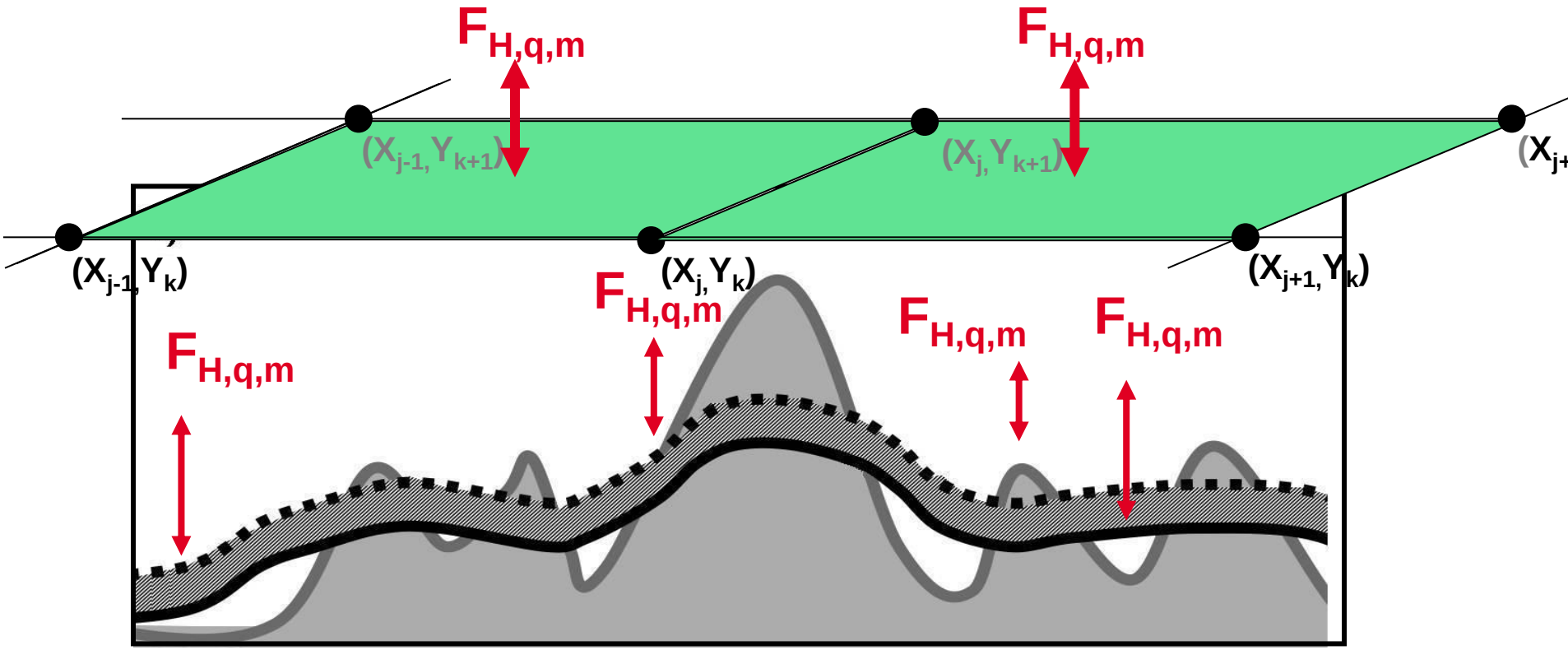
→ high spatial resolution required $\mathcal{O}$(100m)
→ global NWP $\mathcal{O}$(10km)
→ climate modeling: $\mathcal{O}$(100km) ….



Rotach and Zardi (2007)

Arbesser Kogl

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Mean Bias of 2 m air temperature (102 IMIS-Stations)

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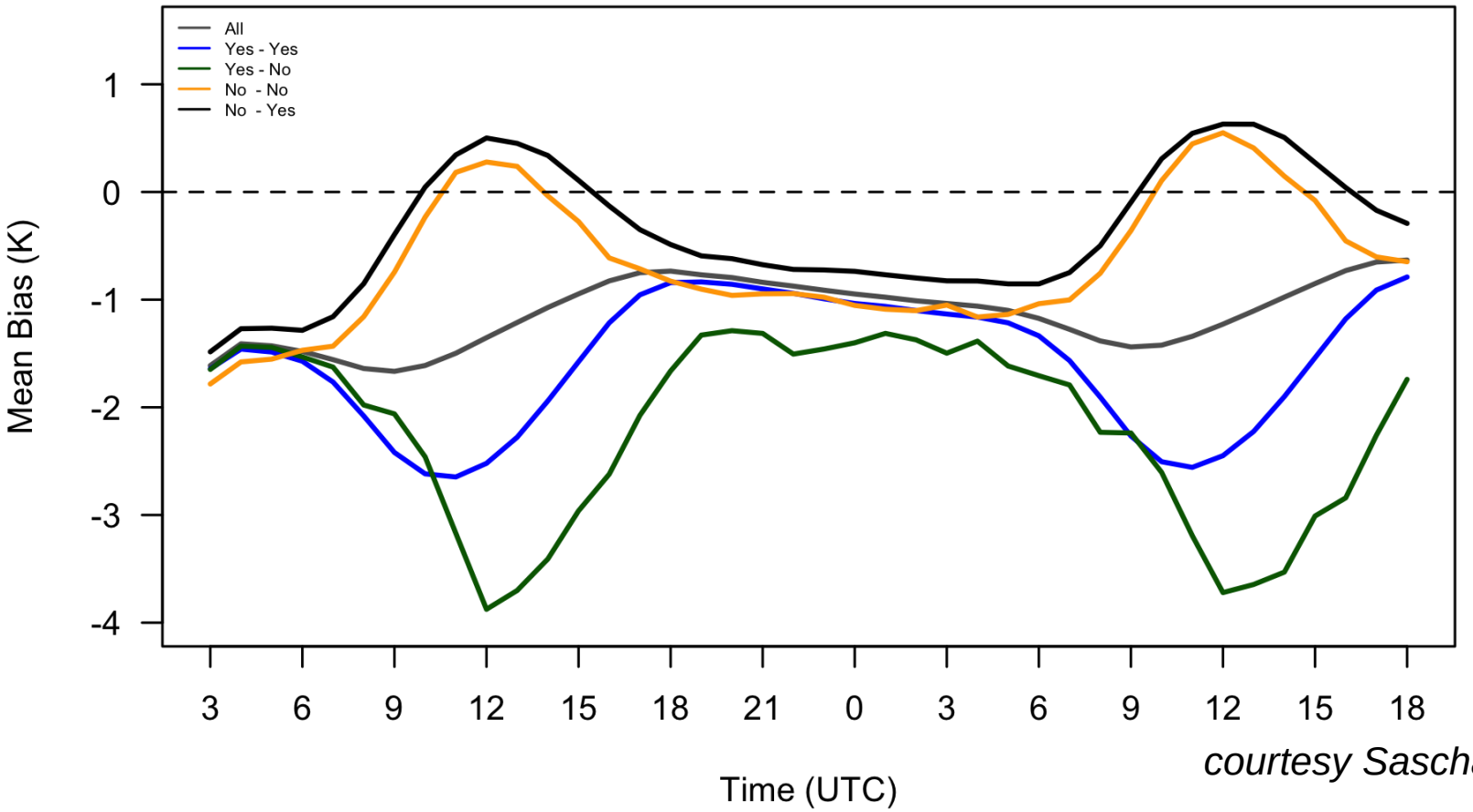

courtesy Sascha Bellaire

Yes - Yes

Yes - No

All

No - Yes

No - No

COSMO-1 simulations

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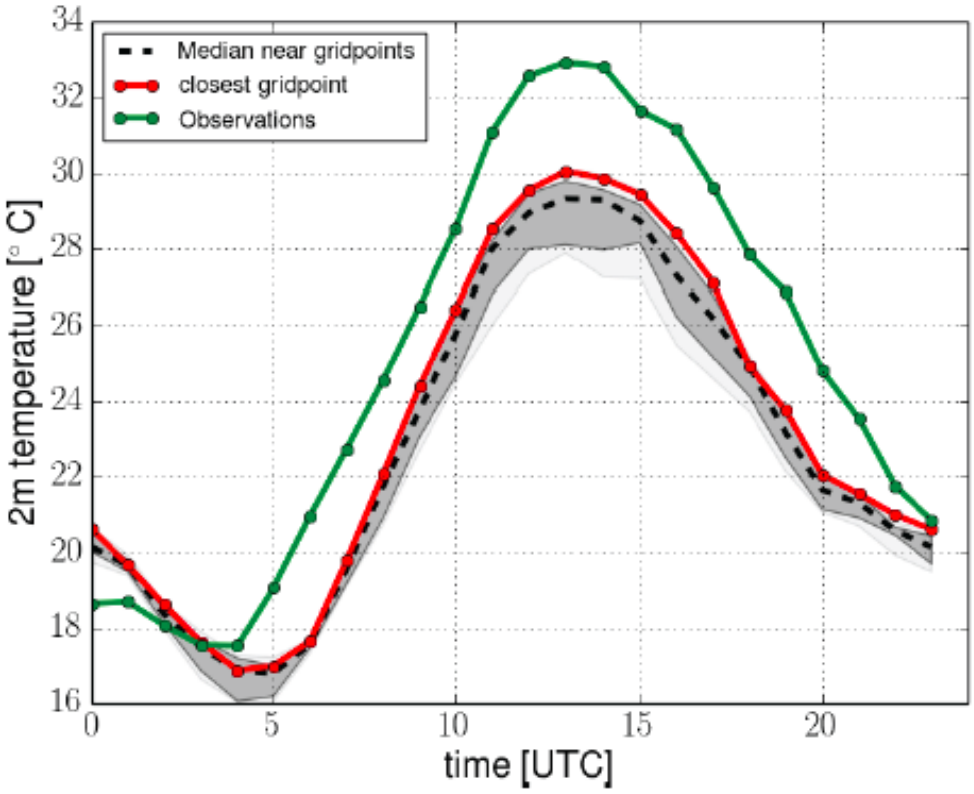
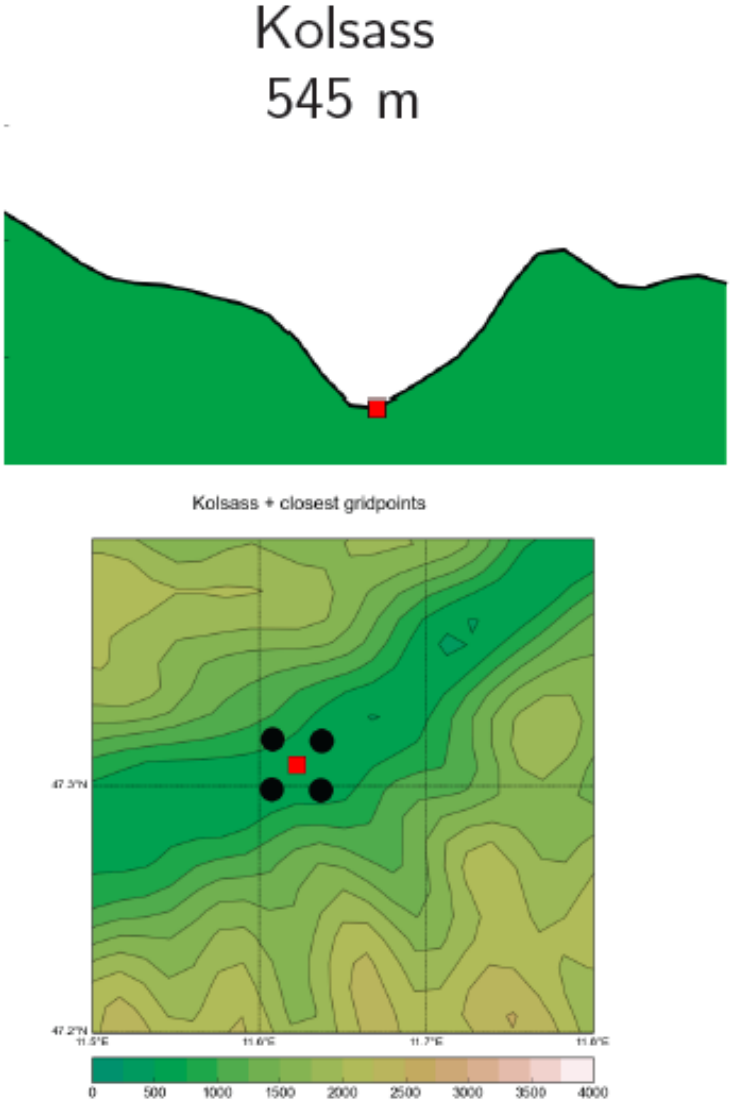


T_{2m}, 10.06.2014



courtesy Brigitta Goger

COSMO-1 simulations

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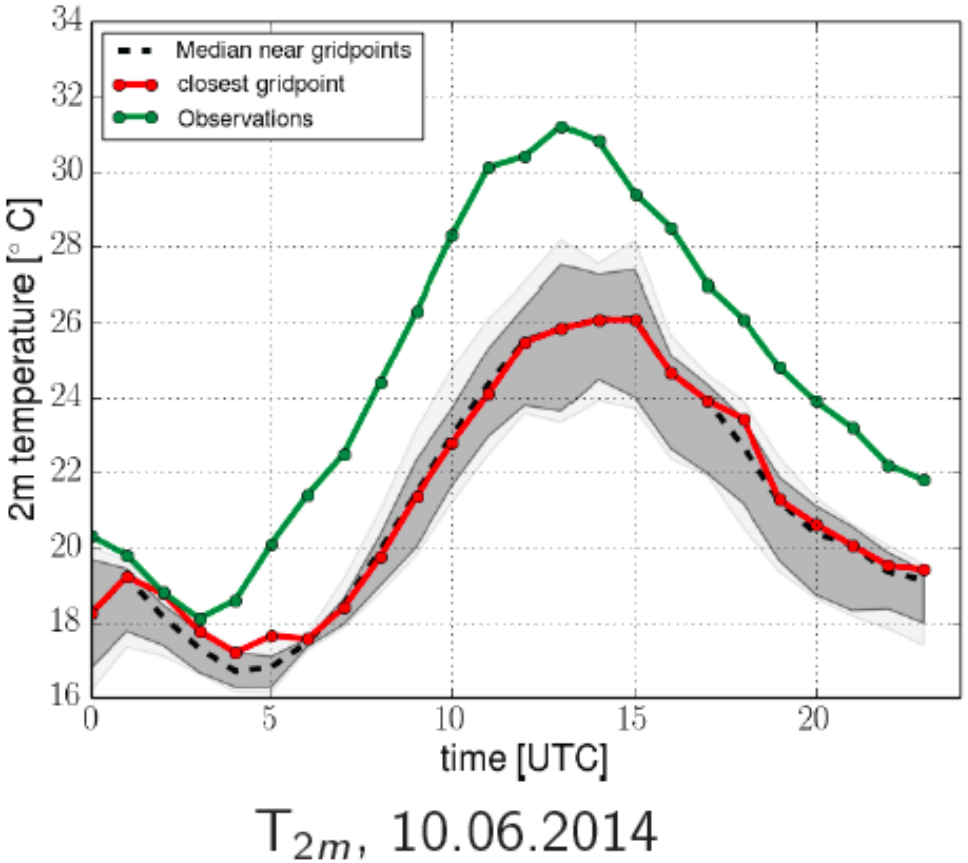
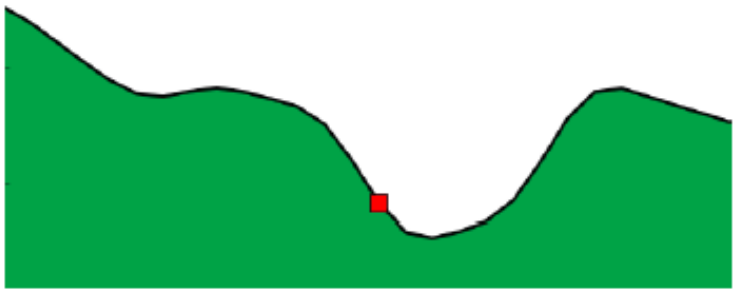


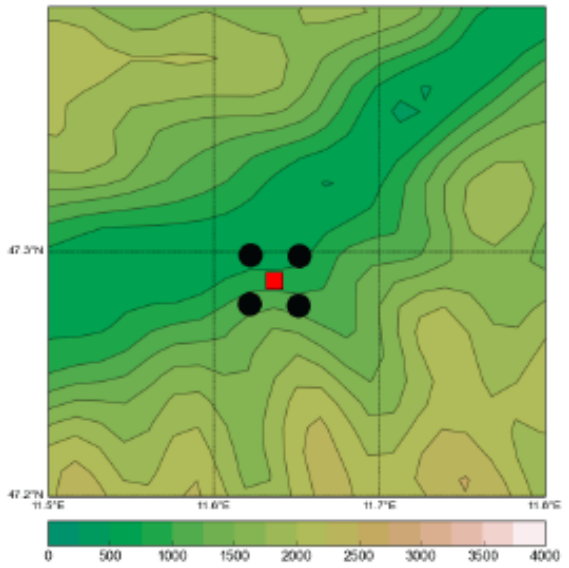
T_{2m}, 10.06.2014

courtesy Brigitta Goger

Hochhäuser
1009 m



Hochhaeuser + closest gridpoints



Wagner et al 2014

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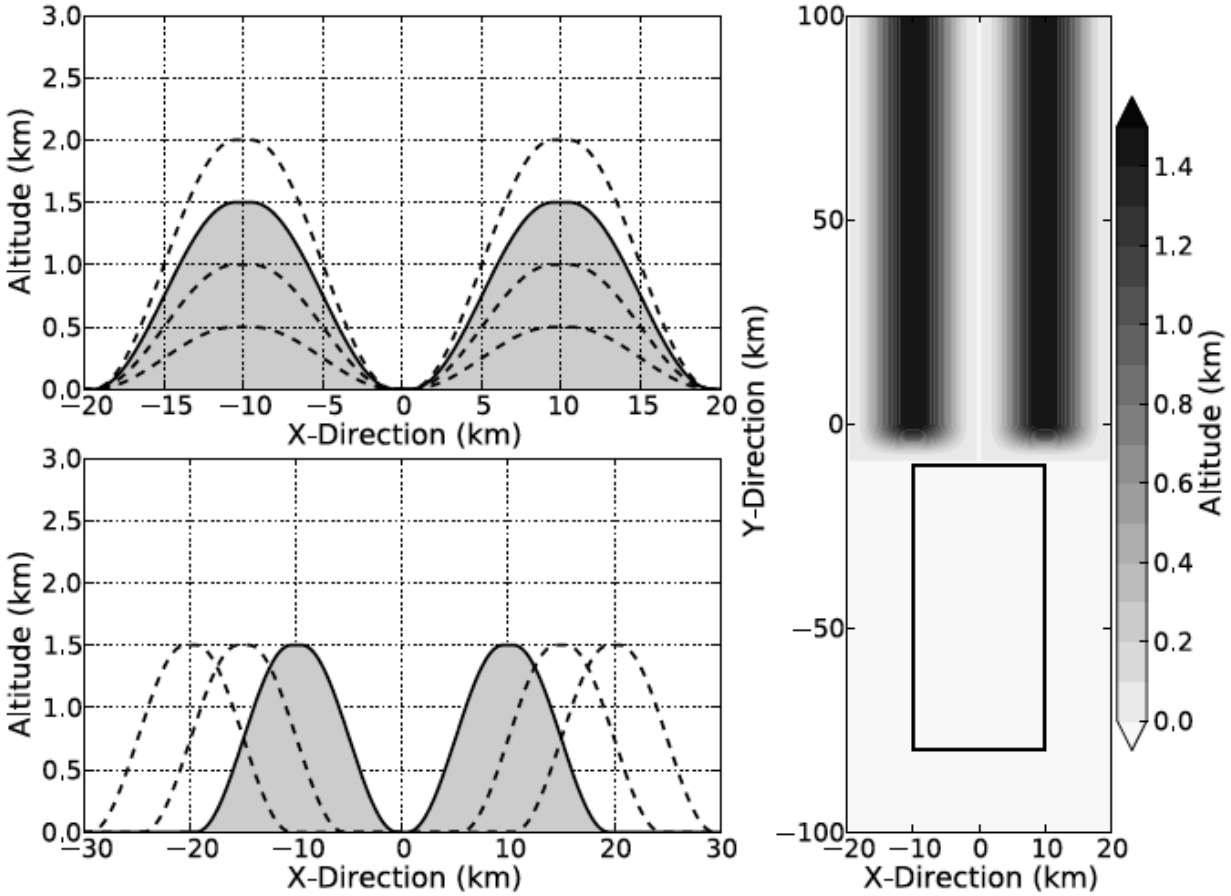

Wagner et al 2014

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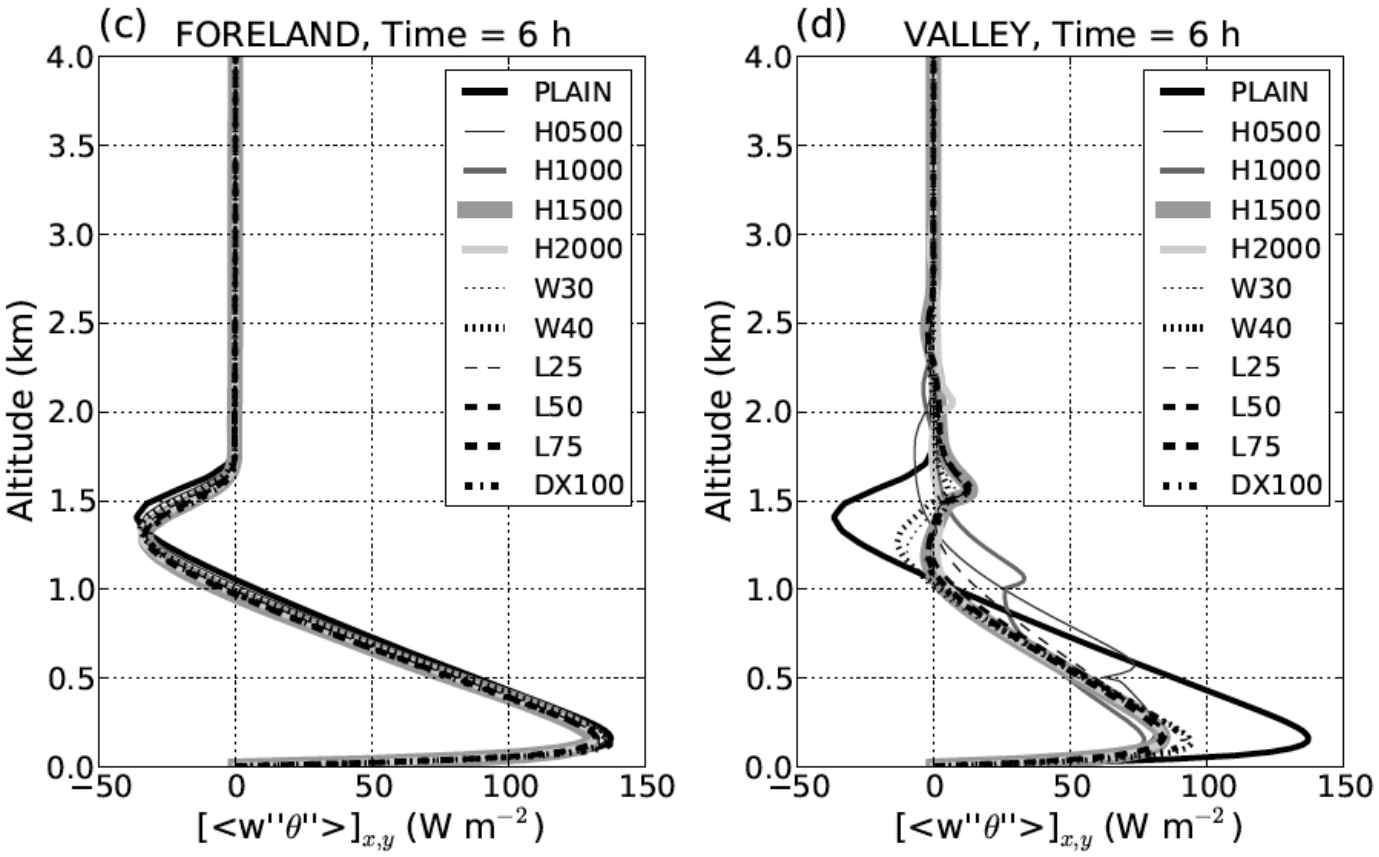

turbulent, resolved vertical heat flux

Wagner et al 2014

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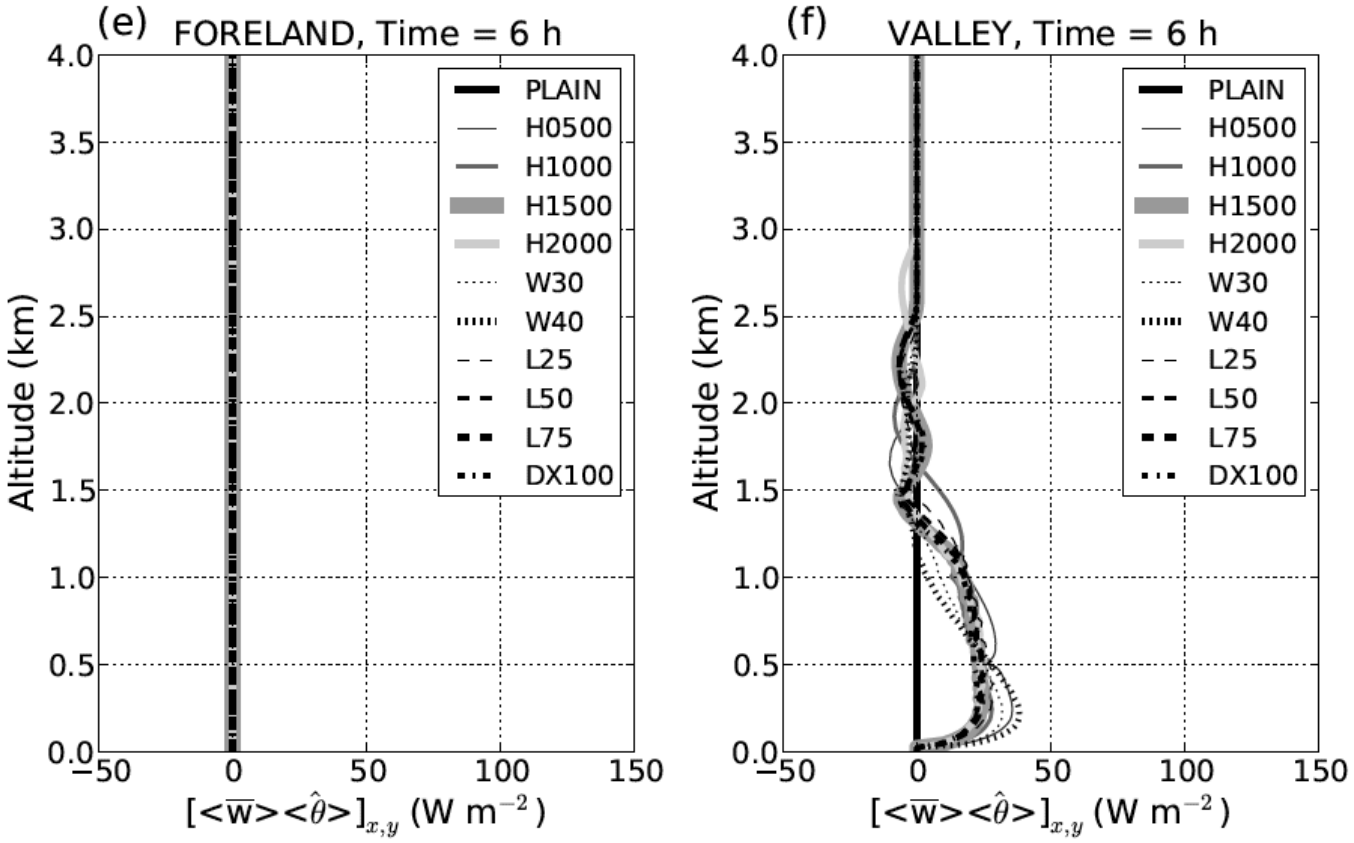
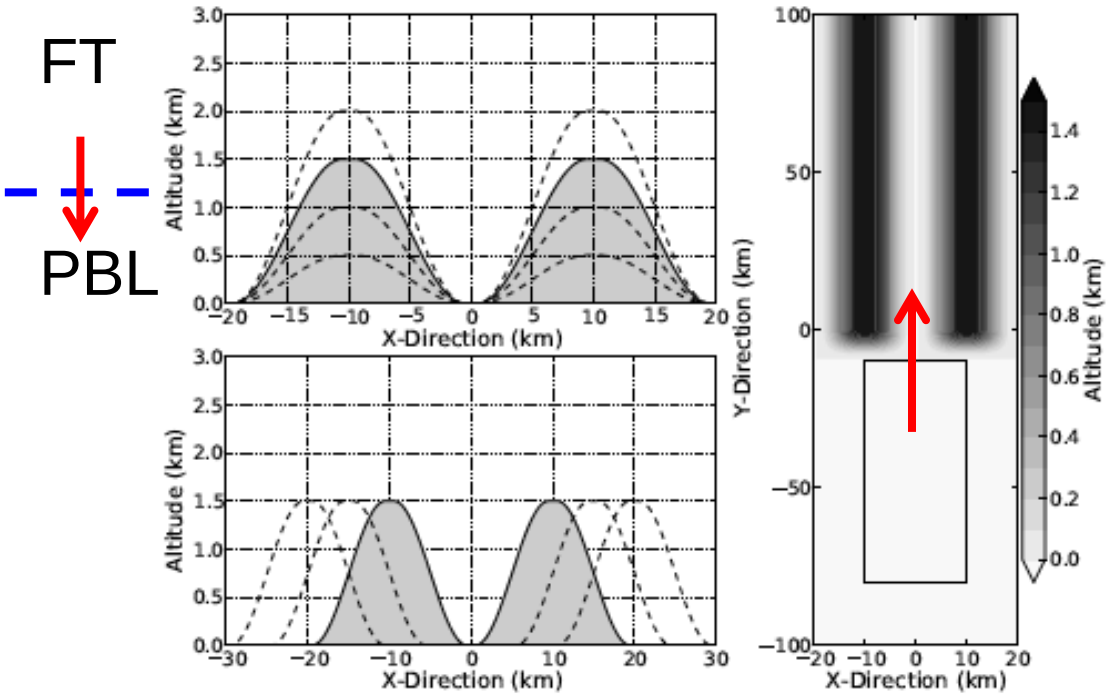


mean vertical heat flux

Mass exchange

- Idealized numerical modeling
- WRF, 200m horizontal mesh size
- different geometries



mass flux

- horizontal, ‘into the box=positive’
- vertical, PBL-FT
- all sides calculated

Wagner et al, 2014

Mass exchange

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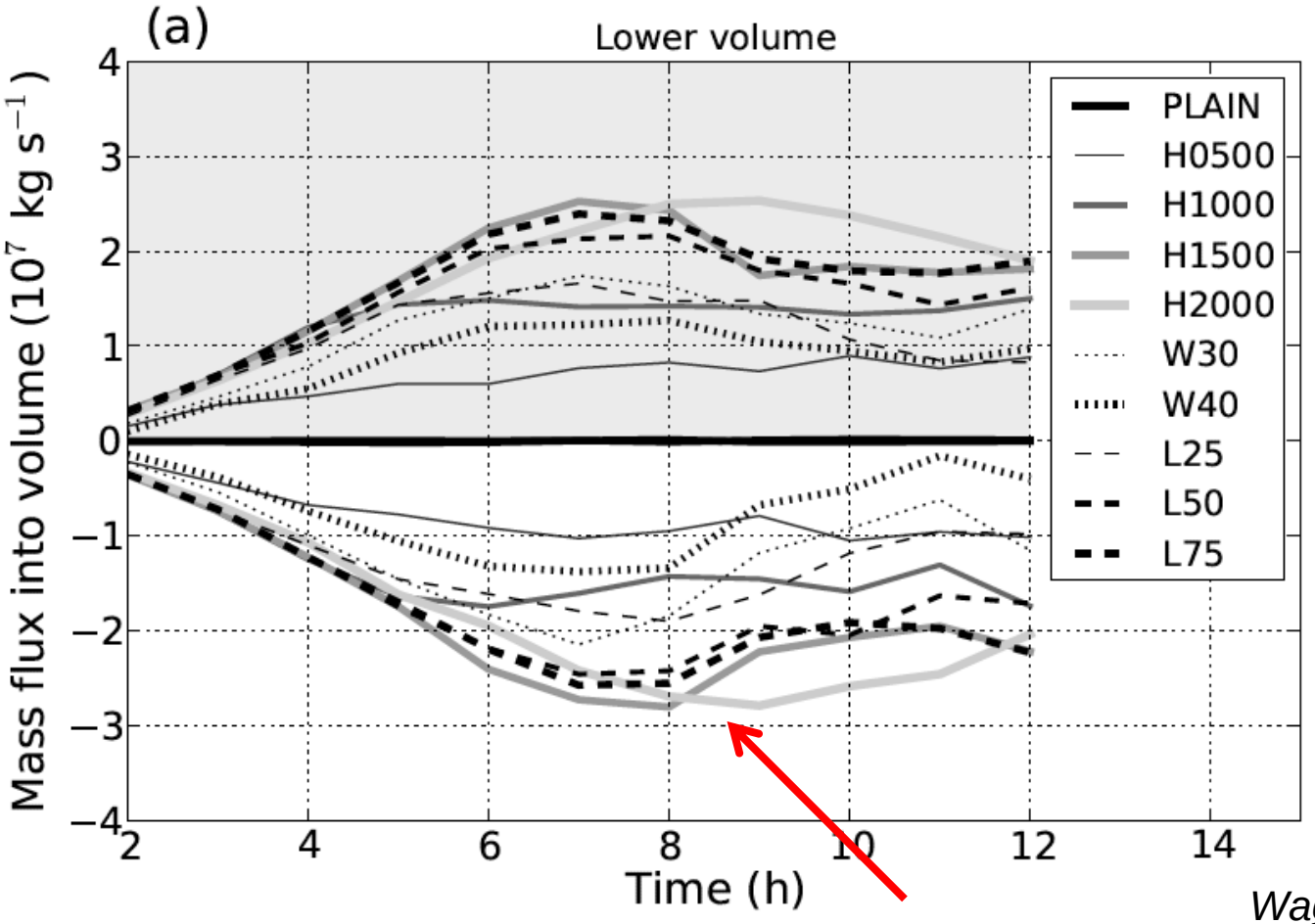
Net mass flux for LOWER volume over plain



vertical

horizontal

Wagner et al, 2014

Mass exchange

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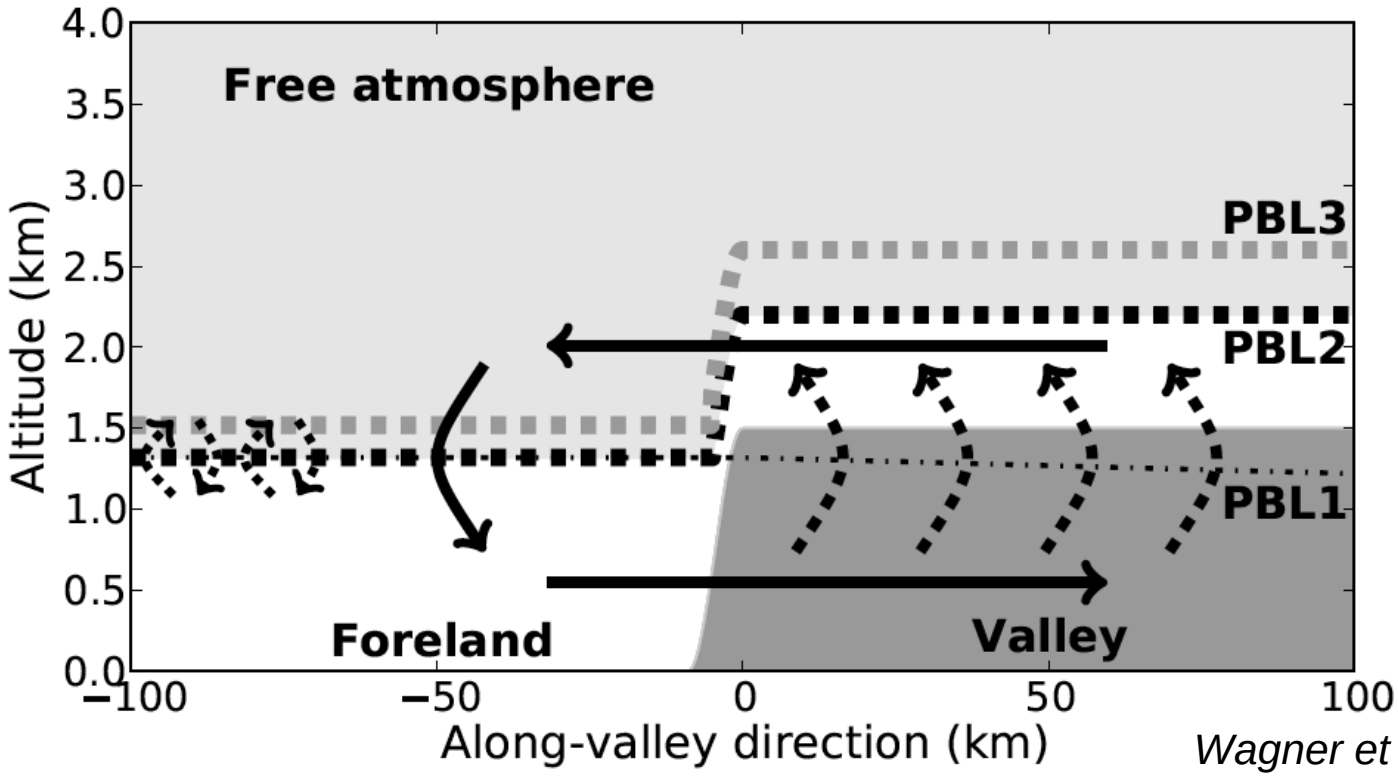

Wagner et al2014

PBL 1: dθ/dz first > 0.001K/m (Catalano and Moeng, 2010)
PBL 2: dθ/dz first < 0.001K/m (from above)
PBL 3: dθ/dz maximum (Sullivan et al. 1998)

Mass exchange

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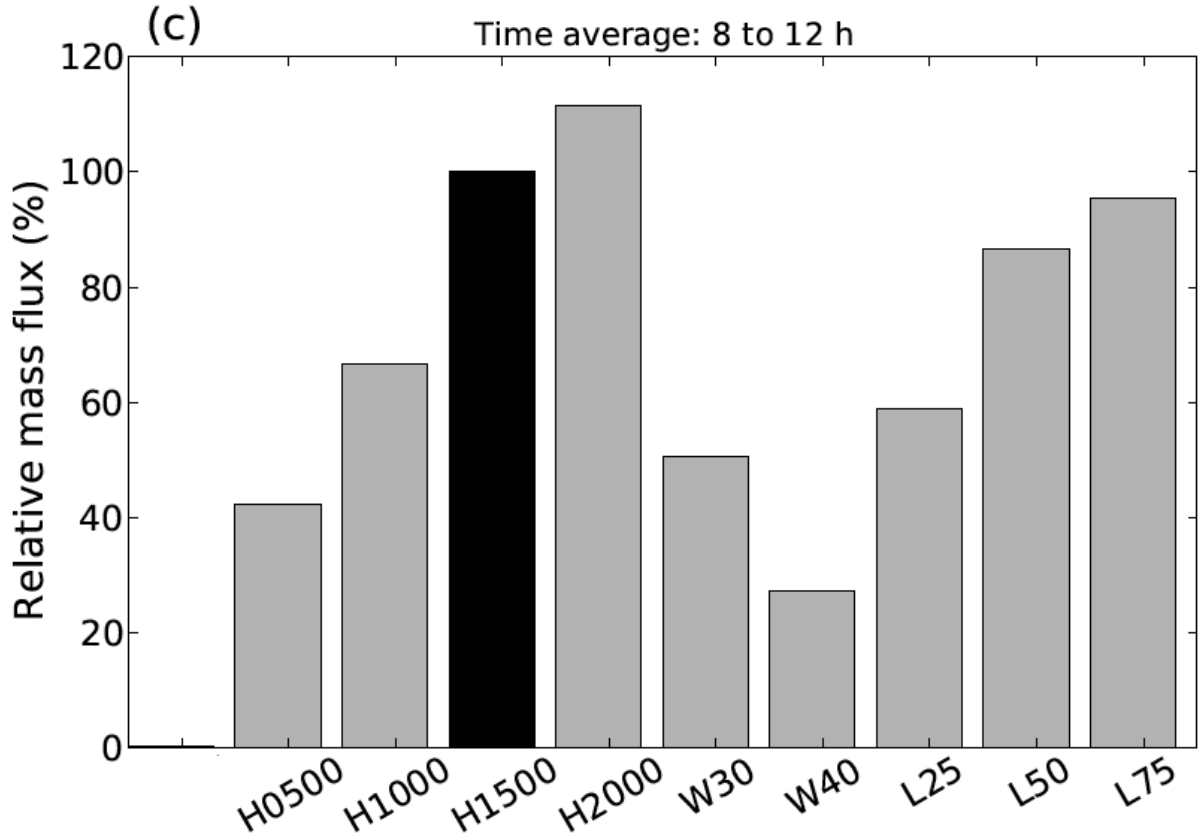
Geometry dependence

→ absolute value of mass flux *towards* the valley



Wagner et al, in rev QJ

Numerical Modeling

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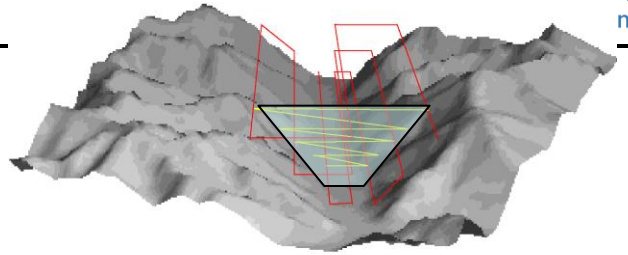
- MAP Riviera example
- three days with weak synoptic forcing
- ARPS, ‘LES’, high resolution, several nests

  → (very) good correspondence to observations

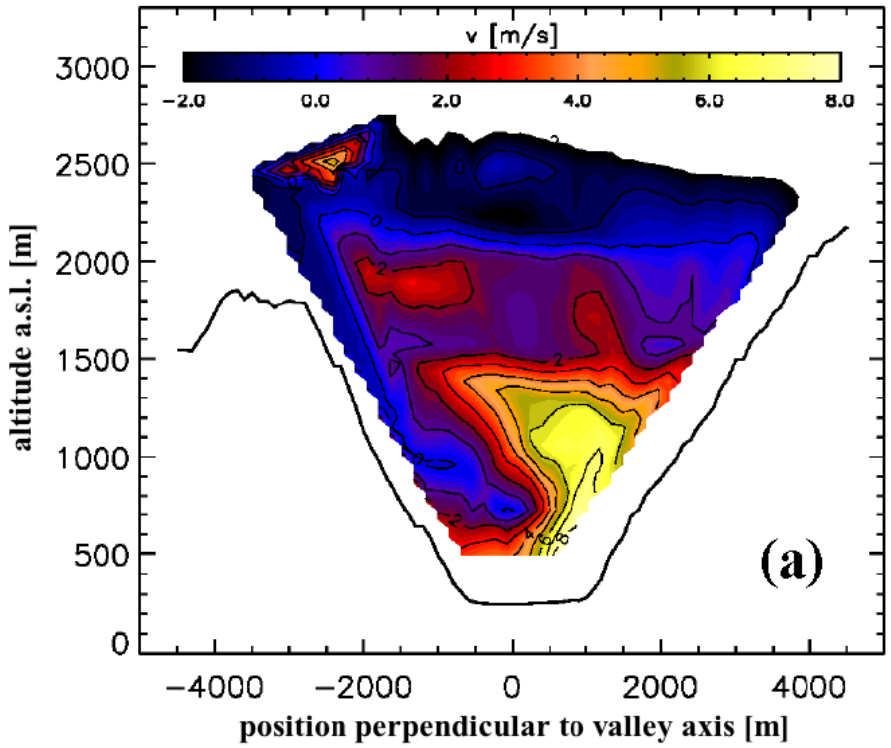
  → different (all) variables simultaneously in correspondence

Wind along valley

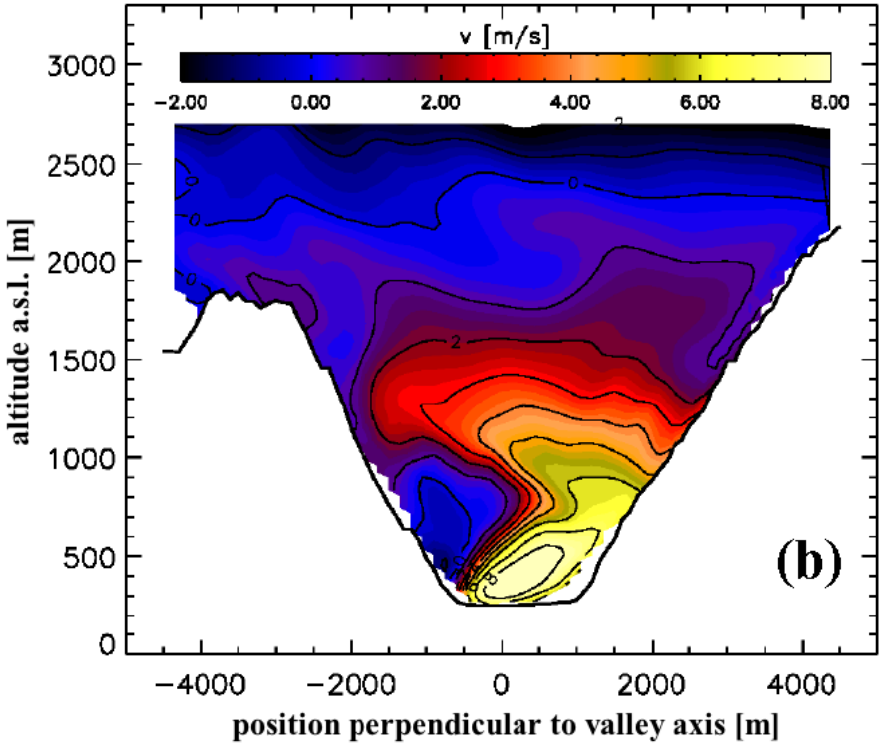


25. August (1300 UTC)

observation



simulation



Profile Potential Temperature

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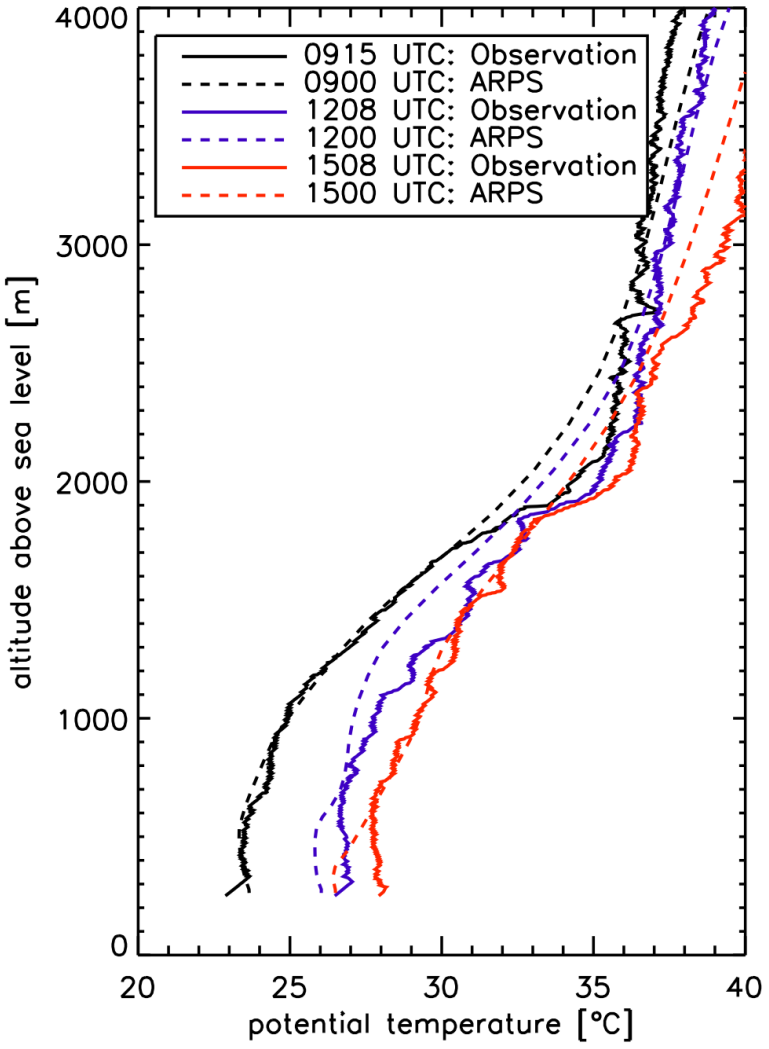

example:
25. August 1999

kinematic heat flux

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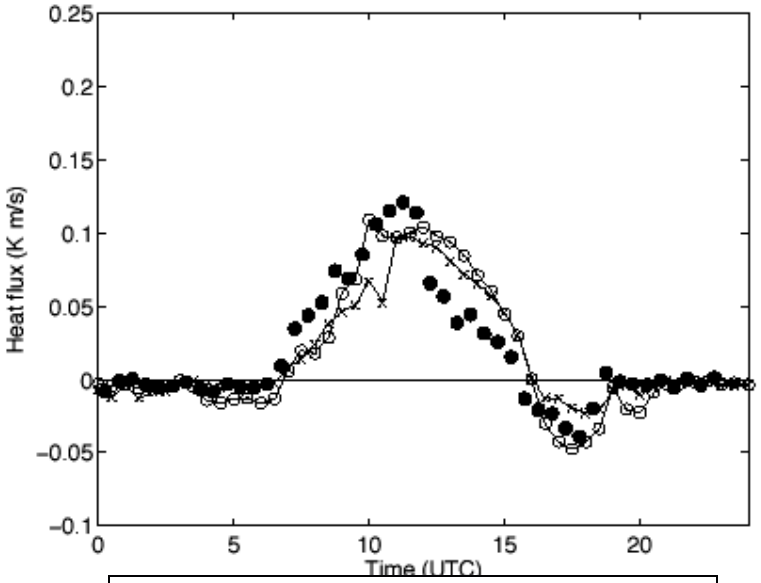
- ••• observation
- ××× simulation - reference
- ○○○ land use and soil moisture

Chow et al. 2006, JAM
Weigel et al. 2006, JAM



1d-Radiation

- Radiation needs to be normal to sloping surface

  & take care of shading topography
- e.g., Müller & Scherrer scheme (MWR 2005)
  in COSMO (Buzzi 2008)
- High resolution:
  → vertical direction is not enough