



On the Mountain Boundary Layer (MoBL) height

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Overview



- problem statement
→ rather than new results
- unstable vs stable conditions
- greatest challenges

Mountain Boundary Layer (MoBL)

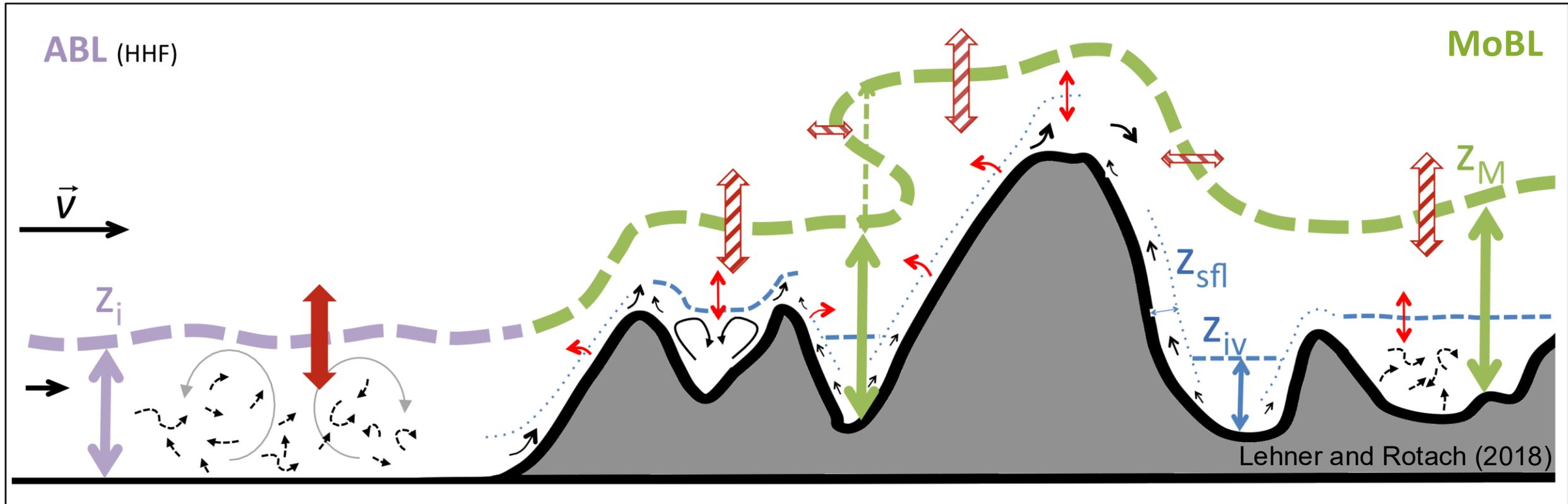
Definition

The Mountain Boundary Layer (MoBL) is *the lowest part of the troposphere that is directly influenced by the mountainous terrain, responds to surface **and terrain forcings** with timescales of one to a few hours ($\mathcal{O}[1 \text{ h}]$), and **is responsible for the exchange of energy, mass, and momentum between the mountainous terrain and the free troposphere.***

Lehner and Rotach (2018)

Mountain Boundary Layer (MoBL)

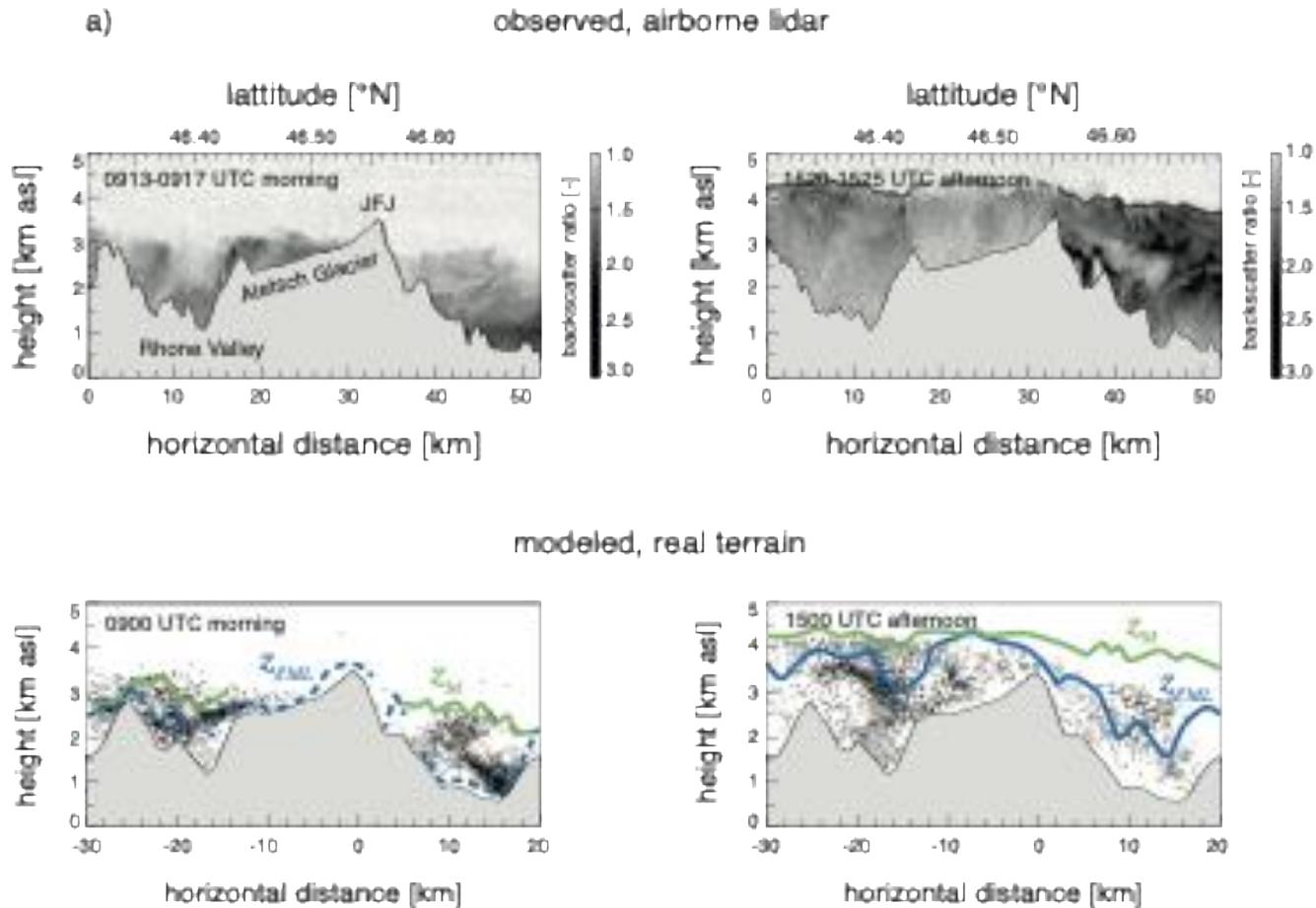
a) unstable stratification (daytime)



- ABL:
 - height of turbulent layer
 - or: layer influenced by turbulence
- turbulence = mixing agent

- MoBL:
 - height of surface influence
 - or: layer influenced by mixing
- mixing agent: turbulence & mesoscale flows

Mixing.....



▲ airborne aerosol measurements
→ mountain venting & slope
wind circulation

▲ simulation (RAMS [1km] &
LPDM)
→ local Mixed Layer ($z_{\ell ML}$)
≠
→ MoBL height (z_M)

Rotach and Holtslag (2025), based on De Wekker et al. (2004)

Detection of MoBL height

Traditional

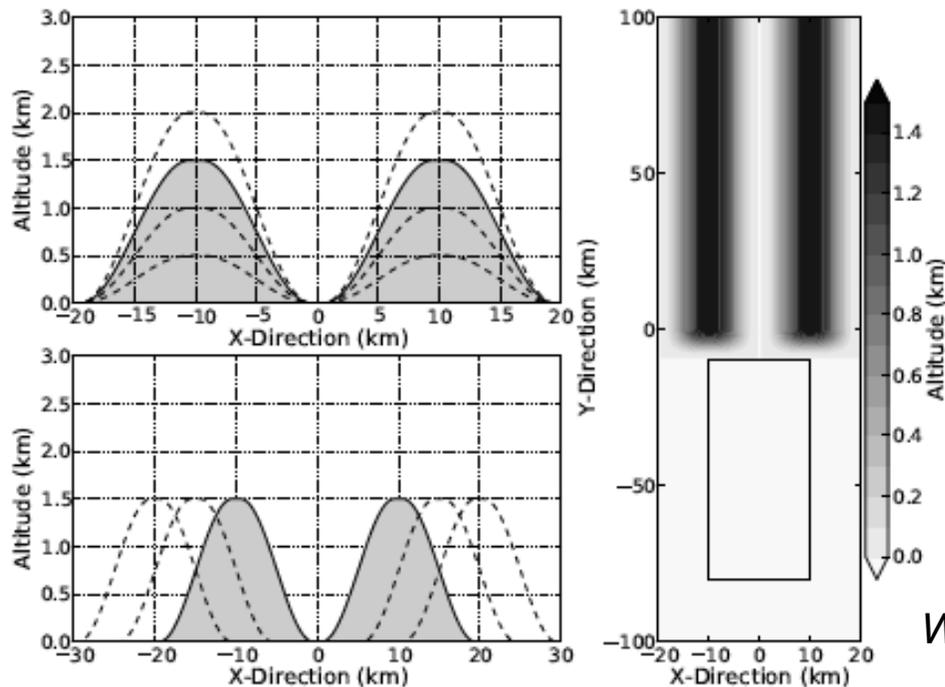
- Result of mixing
 - $\bar{\theta}$ profile
 - unstable (CBL)

MoBL?

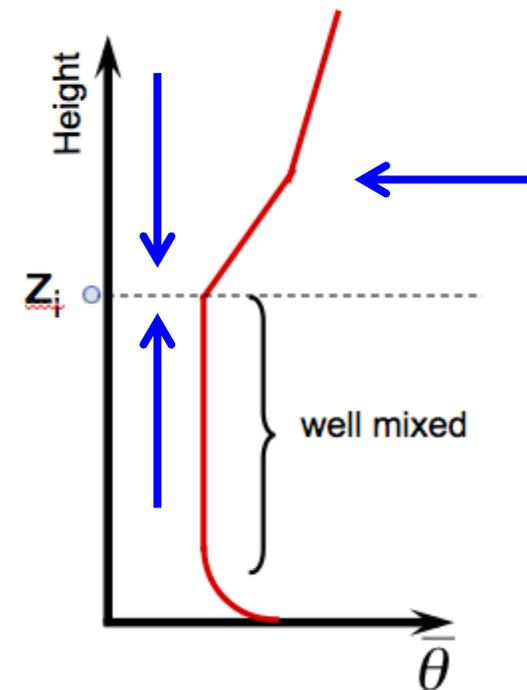
MoBL height detection

consider: convective valley BL

→ diagnose ABL height:



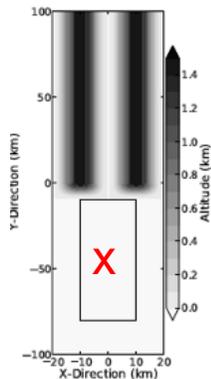
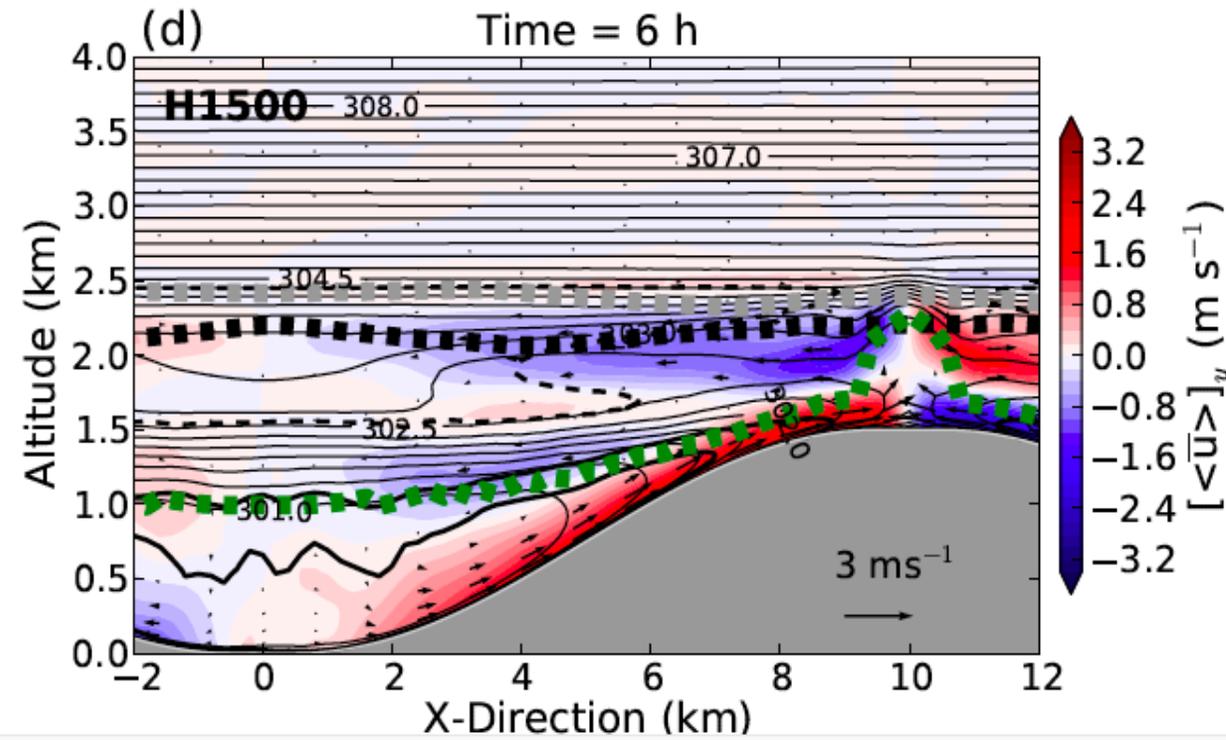
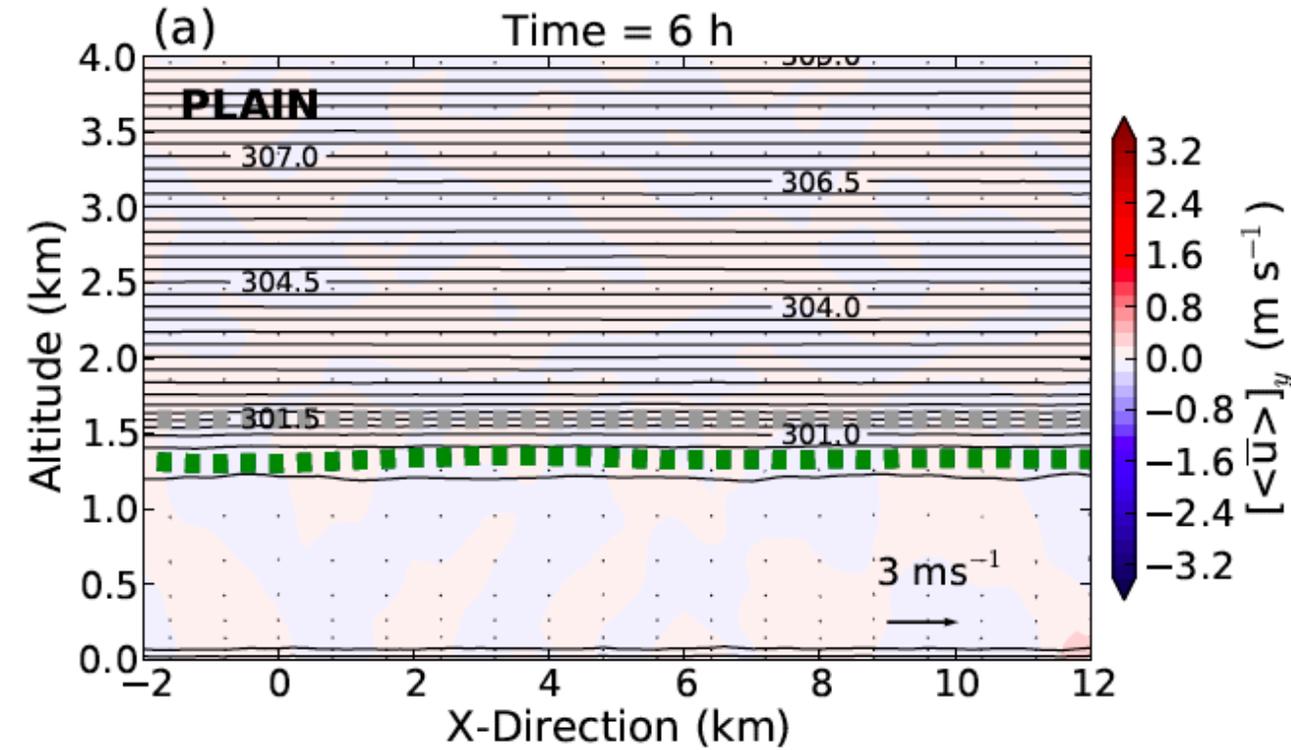
Wagner et al (2015)



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

PBL1: first time $\partial\bar{\theta}/\partial z > 0.001 \text{ K m}^{-1}$ from below
PBL2: first time $\partial\bar{\theta}/\partial z < 0.001 \text{ K m}^{-1}$ from above
PBL3: height where $\partial\bar{\theta}/\partial z = \max$

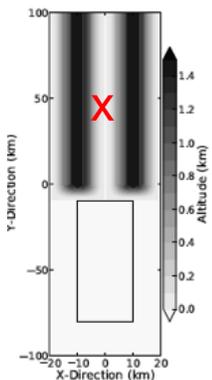
MoBL height detection



PBL1: → local ML height

PBL2: → MoBL height (?)

PBL3:



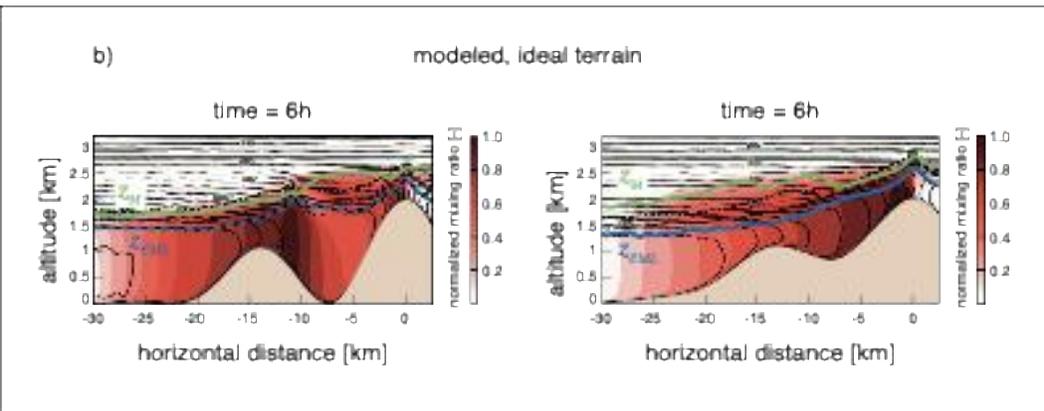
Wagner et al (2015)

Detection of MoBL height

Traditional

- Result of mixing
 - $\bar{\theta}$ profile
 - unstable (CBL)

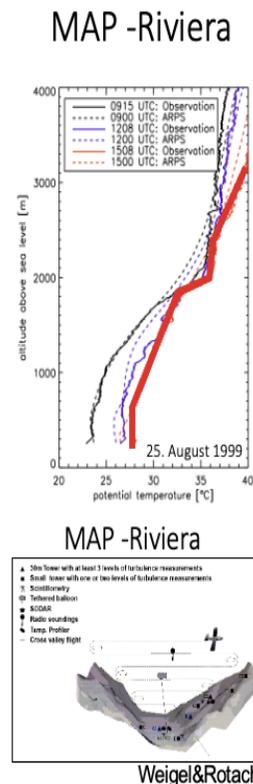
- ▲ also for more complicated terrain
 - e.g., Lang et al (2015)



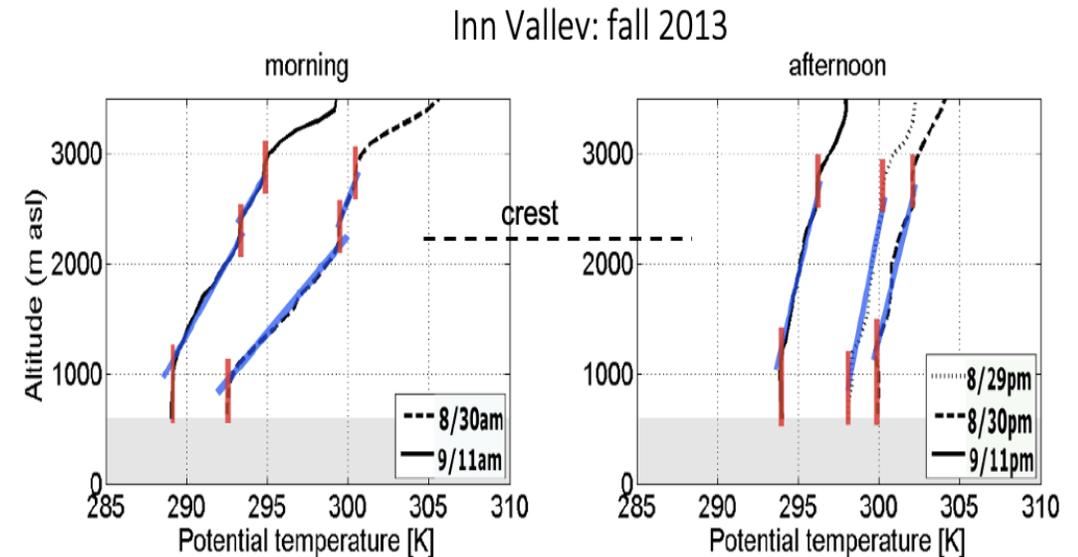
Rotach and Holtslag (2025), based on Lang et al (2015)

MoBL?

- ▲ Use 'PBL2 / PBL 3'?
 - in real terrain not (always) obvious
 - elevated ML has been observed



Weigel&Rotach 2004



Markl et al, 2017

- characteristic θ - profile: ,shallow' ML
- ,stable valley atmosphere' aloft
- ,elevated ML'

Detection of MoBL height

Traditional

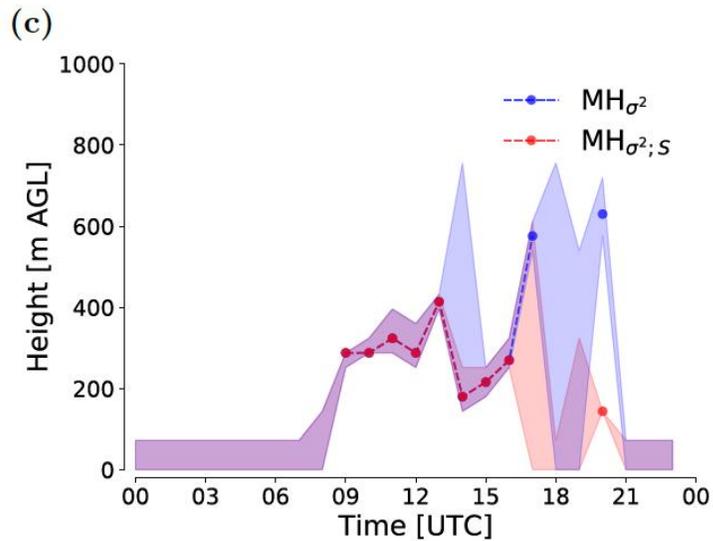
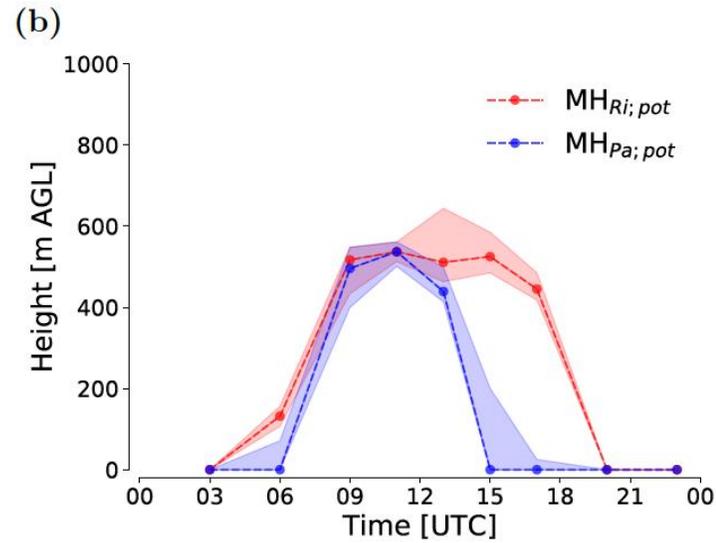
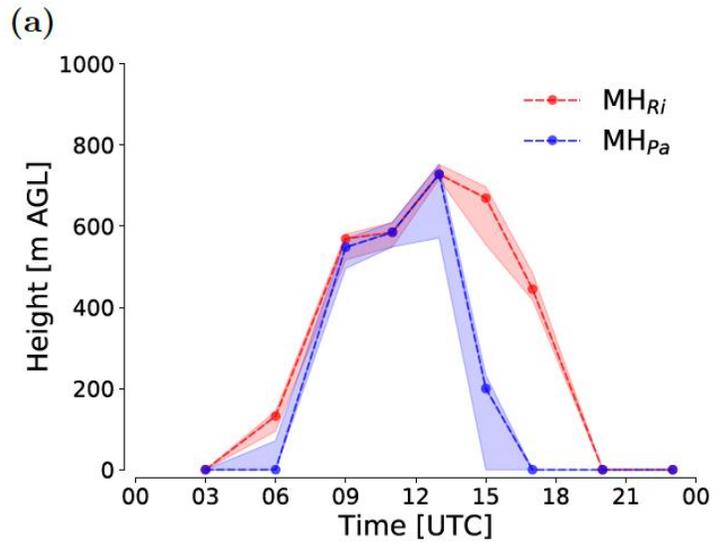
- Result of turbulent mixing
 - $\bar{\theta}$ profile
 - unstable (CBL)

- Turbulence itself
 - Ri criterion
 - TKE threshold
 - σ_w & Sk_w (e.g., Adler and Kalthoff (2014))

MoBL?

- ▲ use 'PBL2 / PBL 3'?
 - in real terrain not (always) obvious
 - elevated ML has been observed
- ▲ if no elevated ML exists?
 - valley too wide / shallow
- ▲ only convective conditions....
- ▲ yields local *turbulent* BL
 - methods not always consistent

Based on Turbulence itself



▲ Sept 13, 2019
→ CROSSINN
(Adler et al 2020)
→ VWD

▲ No return during stable
(nighttime) conditions

Ladstädter, 2020

Detection of MoBL height

Traditional

- result of turbulent mixing
 - $\bar{\theta}$ profile
 - unstable (CBL)
- turbulence itself
 - Ri criterion
 - TKE threshold
 - σ_w & Sk_w (e.g., Adler and Kalthoff (2014))
- turbulence from Doppler spectrum width
 - Babić et al (2024)

MoBL?

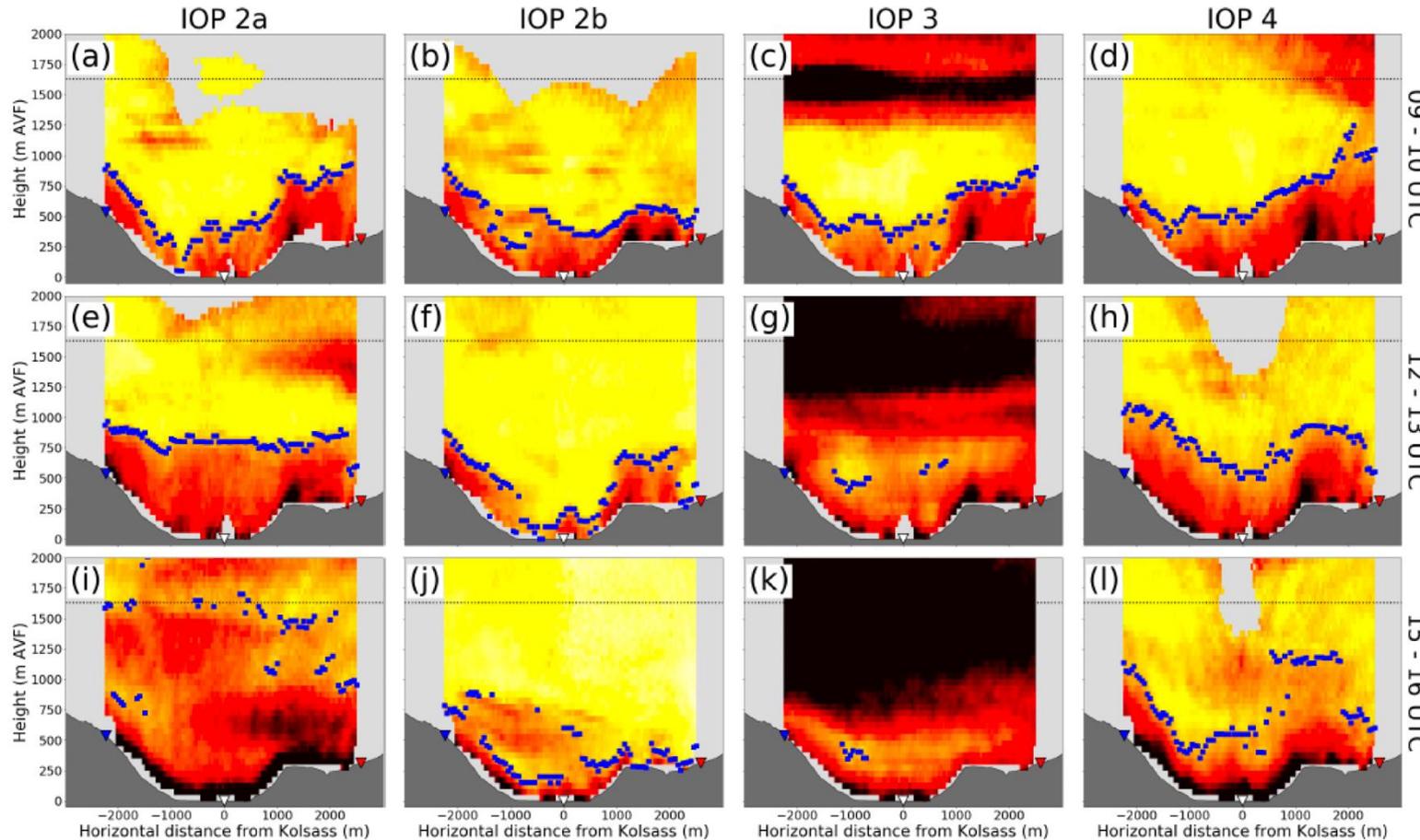
- ▲ use 'PBL2 / PBL 3'?
 - in real terrain not (always) obvious
 - elevated ML has been observed
- ▲ threshold?
- ▲ If no elevated ML exists?
 - valley too wide / shallow
- ▲ yields local turbulent BL
 - methods not always consistent
- ▲ yields turbulent BL (\neq MoBL in general)
 - could possibly be extended to airborne (top-down)
 - example: local CBL (in a valley)

Detection of MoBL height

CROSSINN IOPs (Adler et al 2021)

- (local) CBL top
- ↑ bottom-up diagnostic

- ▲ similar start
- ↓
- ▲ valley wind timing, stability aloft, presence of dynamic influence (föhn)
- ↓
- ▲ different late afternoon structure

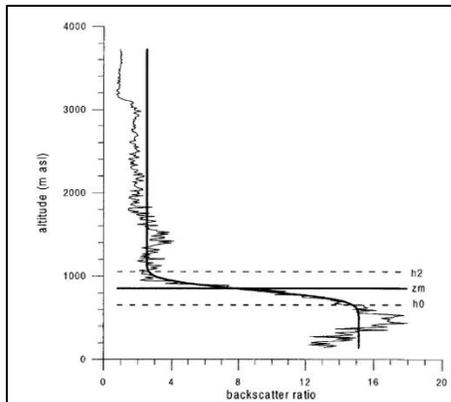


Babić et al (2024)

Detection of MoBL height

Traditional

- mixing of a constituent
 - water vapor
 - aerosol

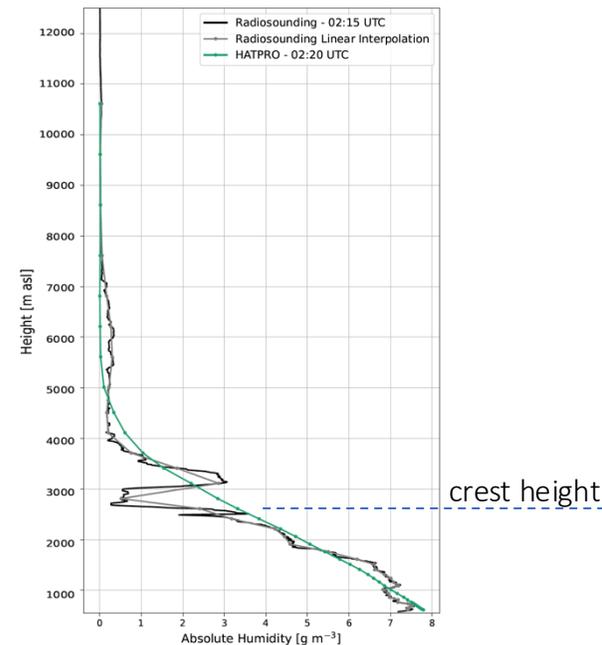


Hägeli et al. 2000

MoBL?

- should be from surface emission
 - advection aloft?

IBK airport 2021-09-23

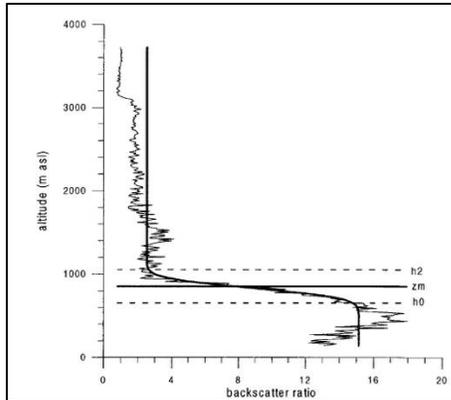


Scheiber (MSc. ACINN, in prep)

Detection of MoBL height

Traditional

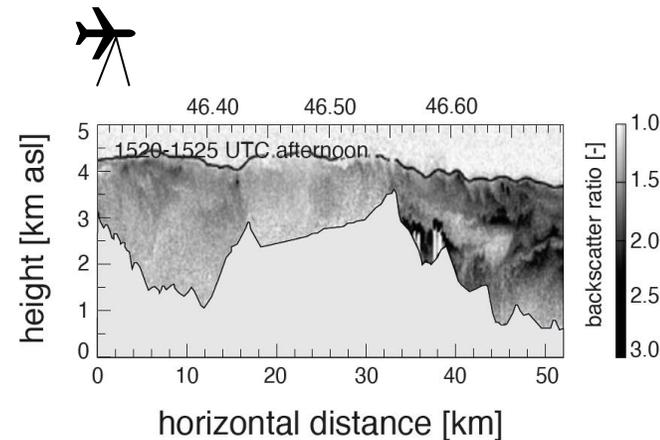
- mixing of a constituent
 - water vapor
 - aerosol



Hägeli et al. 2000

MoBL?

- ▲ should be from surface emission
 - advection aloft?
- ▲ lifetime of $\mathcal{O}(1 - 10 \text{ hr})$
 - secondary aerosols? (observation?)
 - could possibly reflect mechanical mixing
- ▲ airborne observation.....



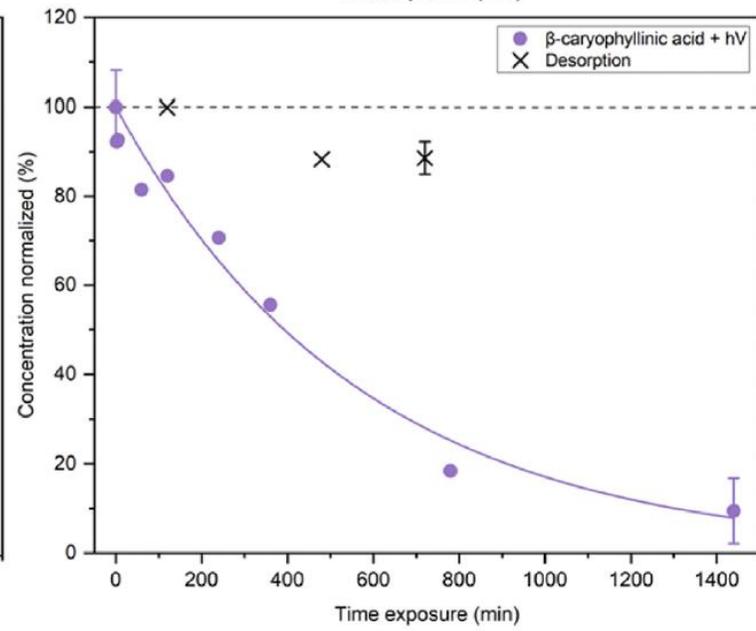
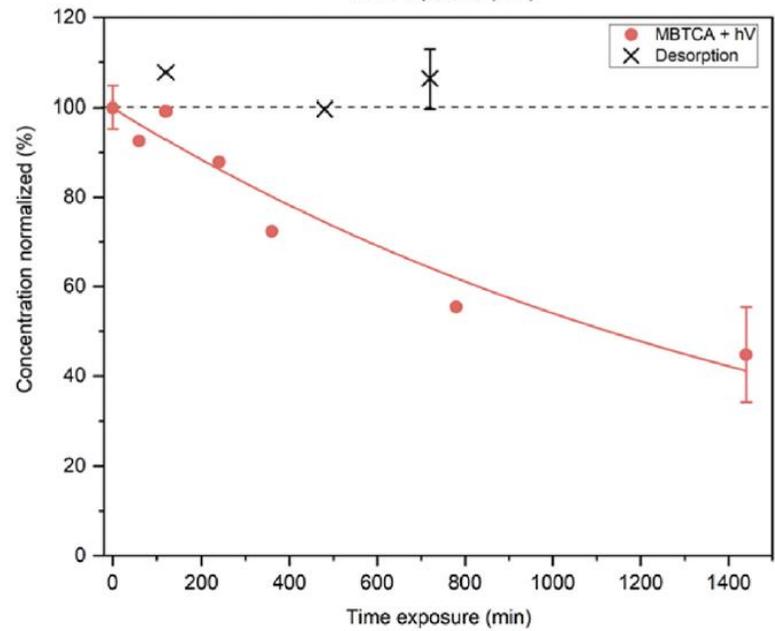
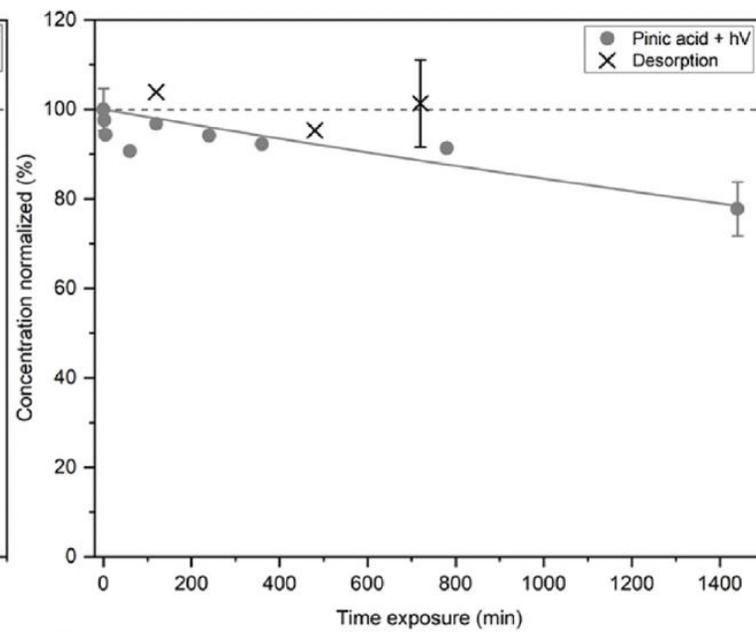
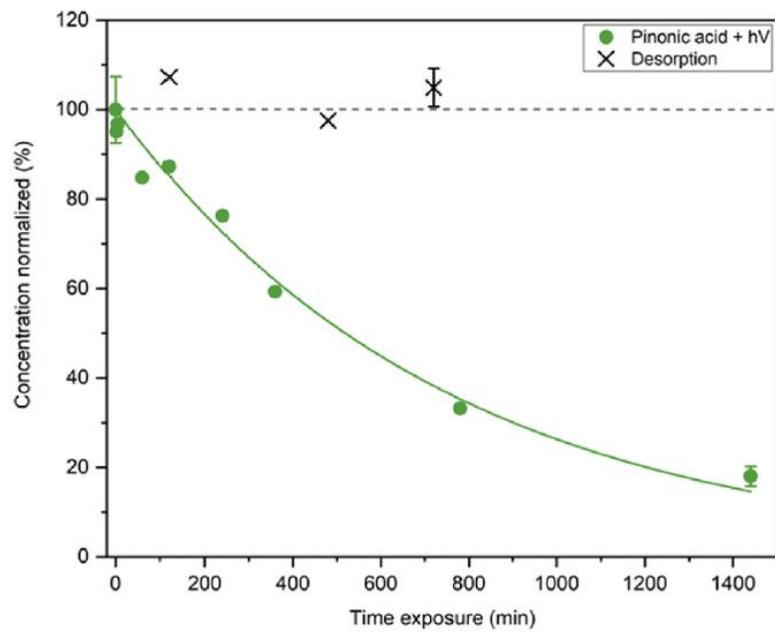
Wrap-up

- problem statement
→ more questions than answers....
- ideal:
→ surface emitted tracer
→ $O(\text{several hrs})$ lifetime
→ airborne observation...
- optimal:

Thank you for
your attention!
(more) questions?

References

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Exchange over
flat
Boundary Layer

Exchange over
Mountain
Boundary Layer

