The Daytime Boundary Layer in the Inn Valley

A Model Evaluation Study with High-Quality Turbulence Measurements

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① Motivation and research question

- The correct simulation of the boundary layer structure is crucial for high-resolution NWP models.
- Especially in complex terrain parameterizations may be inappropriate since they were developed for horizontally homogeneous and flat (HHF) terrain.
- **How does a high-resolution, modern NWP model simulate the boundary layer in a region with truly complex terrain such as the Inn Valley?**

② Measurements

The i-Box:

- Turbulence measurements:
  6 flux towers at representative sites in mountainous terrain located in the Inn Valley
- Remote sensing:
  HATPRO (temperature and humidity profiler) and Doppler wind lidar located in Innsbruck

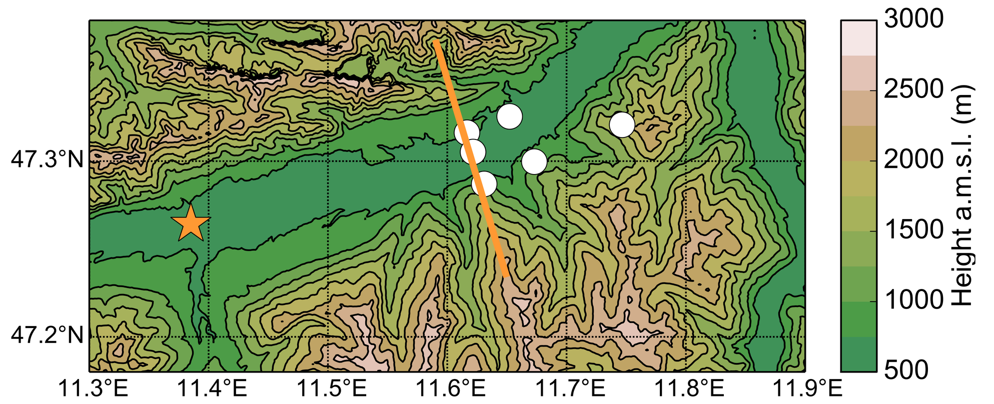

Figure 1 : The i-Box target area: Spatial distribution of flux-tower stations in the Inn Valley (white dots). The orange star indicates the city of Innsbruck, where the two remote sensing devices are located. The orange line shows the cross-section through the valley in Fig. 3. Coloured contours indicate the topography (interval: 250 m).

③ NWP model COSMO

Challenges for the model in complex terrain

- Turbulence closure (developed for HHF conditions)
- Correct terrain representation on the model grid (Fig. 2)

Model Setup
(similar to MeteoSwiss)

- COSMO (Consortium for Small-Scale Modeling)
- Outer domain: over Europe with Δx=7.7 km
- Inner domain: 800 × 600 grid points spans main Alpine range
  80 vertical levels
- Δx=1.1 km
- Vertically stretched grid
  (lowest level at z=10 m)
- Simulations for 24 h for specific days
- Turbulence parameterization:
  1.5 order TKE closure

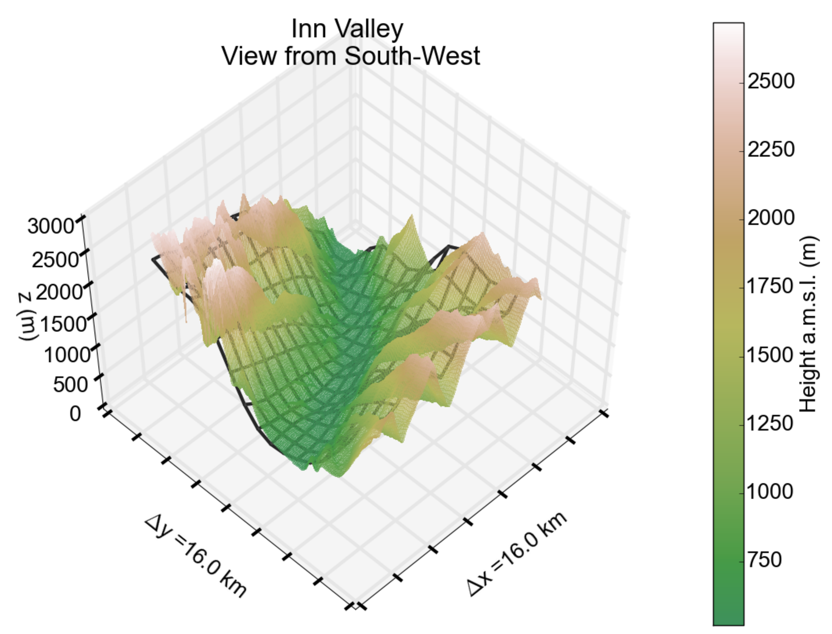

Figure 2 : Real topography (colors) and model topography (black grid) of the Inn Valley at the location of the i-Box stations.

④ Thermally-driven winds at i-Box stations

Case study for Sept. 16, 2014

12 UTC:

- Established slope wind circulation
- Growing mixed layer and weak winds

15 UTC:

- Up-valley wind onset after midday
- Asymmetric structure towards south-facing slope

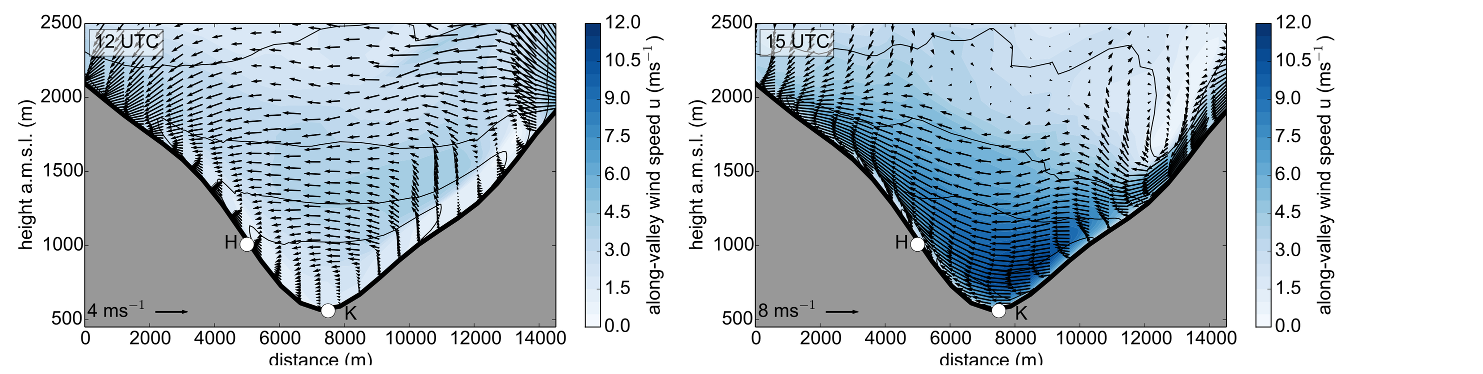

Figure 3 : South-north cross-section from model output along the line shown in Fig. 1 in the Inn Valley. The colors show the along-valley wind speed, while the black contours show potential temperature (interval: 1 K). Arrows are calculated from the cross-valley component v and the vertical velocity w. White dots mark the location of the stations Kolsass and Hochhäuser.

⑤ Valley wind – TKE interaction

Valley floor (Kolsass):

- Valley wind and TKE maximum at same time
- Overall underestimation of TKE production terms by model
- TKE production in the afternoon clearly dominated by shear

North-facing slope (Hochhäuser):

- Only weak influence of valley wind on TKE
- No clear maximum in TKE timeseries
- TKE production equally distributed between budget terms
- Lower values of TKE and production terms than at the valley floor

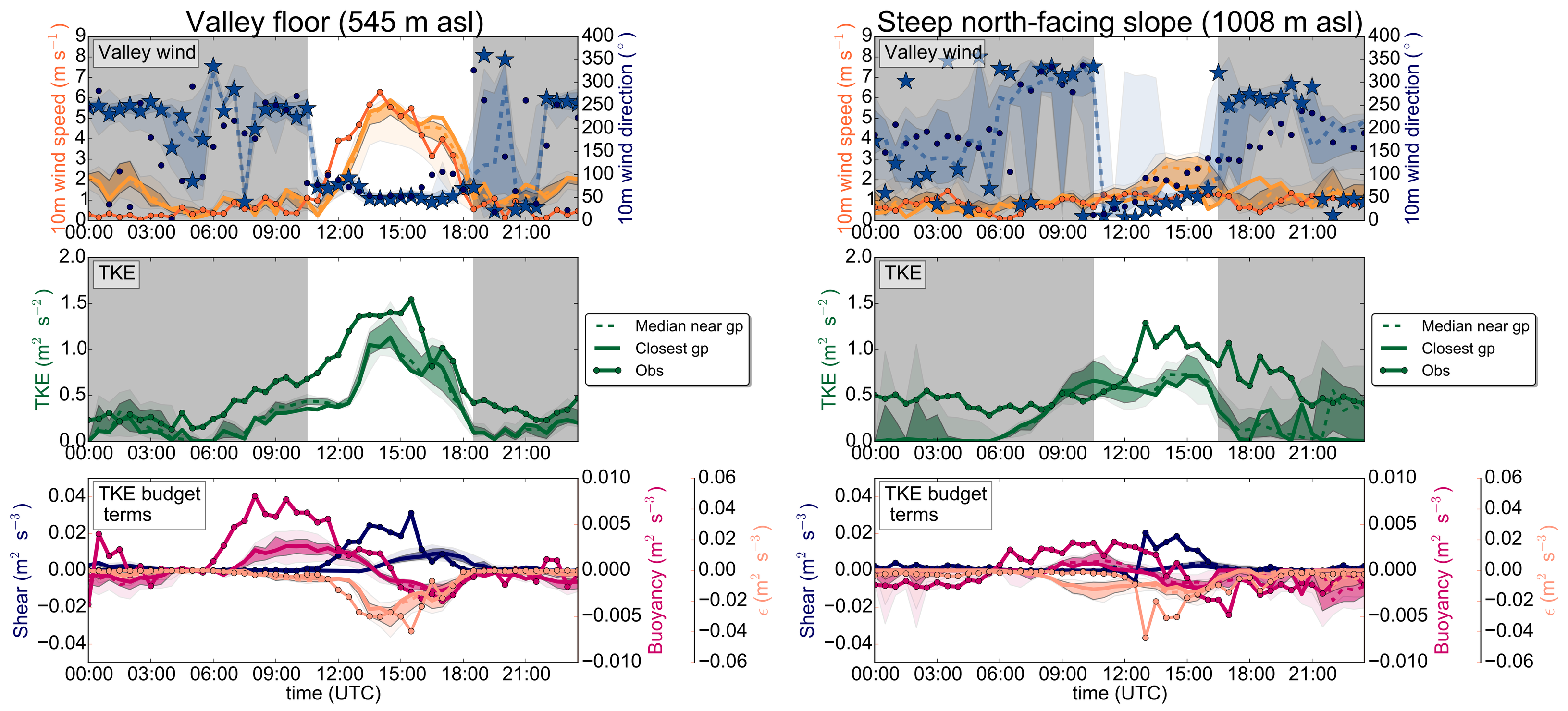

Figure 4 : Time series of the valley wind, TKE and TKE budget terms for two i-Box stations. Lines with dots indicate the observations (⊶), while full lines (—) or stars (⋆) show the model output. The valley wind period is marked in white.

⑥ Vertical profiles of boundary layer evolution at valley floor

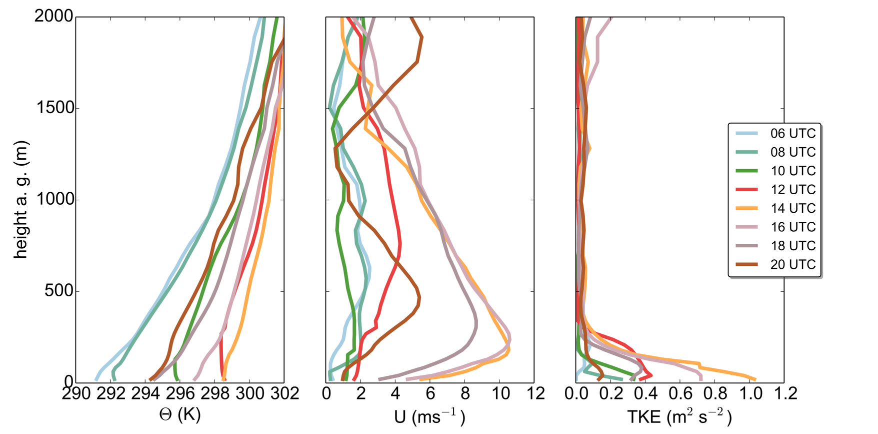

Figure 5 : Vertical profiles at various times from the model output at the closest gridpoint to the valley floor station.

- **Potential temperature θ:**
  Before noon: Mixed layer development
  After valley wind onset: stabilization
- **Along-valley wind speed U:**
  Strong maximum in the afternoon
  Jet-like structure
- **TKE:**
  Maximum in the afternoon due to valley wind-related shear generation

⑦ Boundary layer structure in Innsbruck

- **Temperature profile:**
  Underestimation of temperature and boundary layer height by the model
- **Wind profile:**
  Model predicts too strong valley wind in higher altitudes

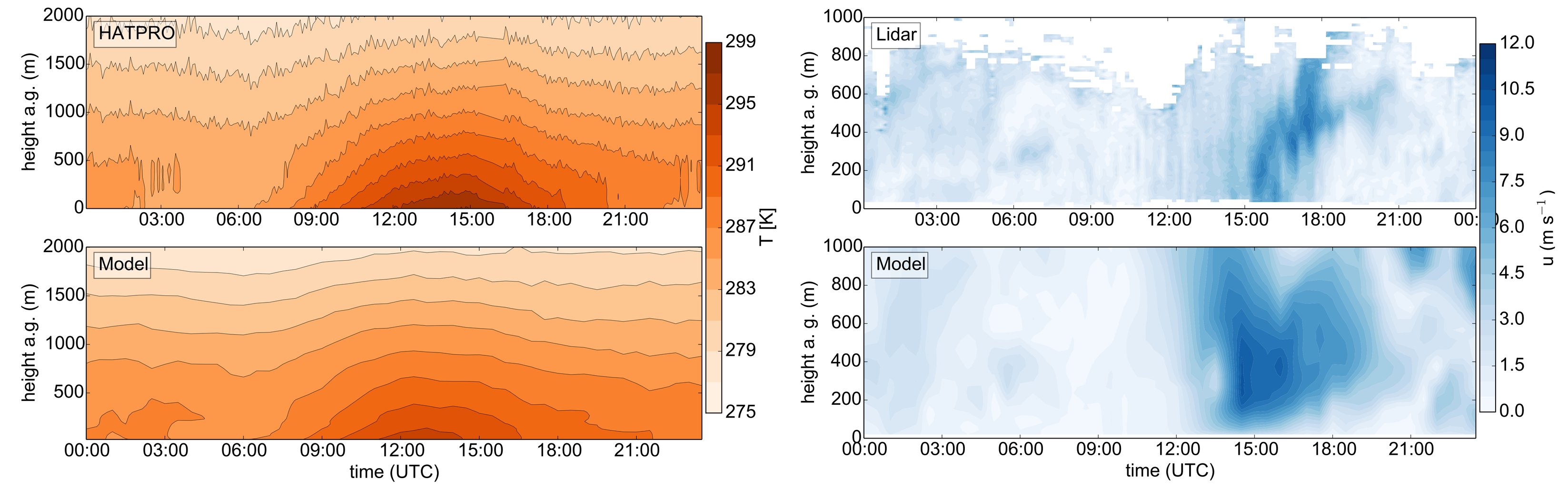

Figure 6 : The observations of the vertical boundary-layer structure of air temperature (Hatpro, left panel) and horizontal along-valley wind speed (Lidar, right panel) in Innsbruck.

⑧ Conclusions

- Overall, realistic representation of the valley boundary layer
- Strong interaction between valley wind and TKE structure in the afternoon
- Underestimation of TKE and its production terms by the model
- Contrary, overestimation of vertical valley wind structure

Outlook

- Start simulations with included TKE advection and a 3D TKE scheme
- Further case studies of other weather situations (e.g. Stable boundary layer, foehn winds) are planned.

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