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INSTITUTE OF ATMOSPHERIC AND CRYOSPHERIC SCIENCES

Turbulence Kinetic Energy Characteristics in the Inn Valley

A Model Evaluation Study with High-Quality Turbulence Measurements

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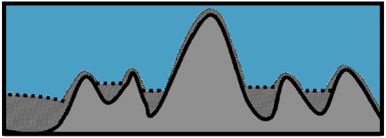
Motivation

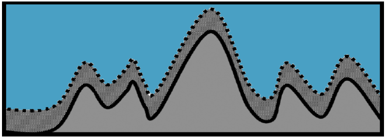
Simulation of boundary-layer processes in complex terrain with high-resolution NWP models

Mountain boundary layer



Rotach and Zardi (2007)

NWP model (Δx= 1 km)



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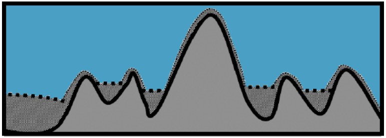

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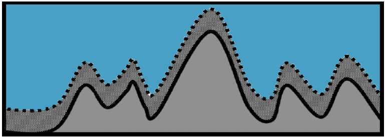
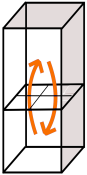


Rotach and Zardi (2007)

Challenges:

- High-resolution input data necessary
- Correct terrain representation
- Parameterizations (developed for hhf terrain):
  e.g. Turbulence scheme (gray zone, 1D turbulence)



after Honnert et al. (2013)

Mesoscale NWP Model COSMO

How does the model perform in complex terrain?

- COSMO - **CO**nsortium for **S**mall-scale **MO**deling
  Initially developed at DWD (German Weather Service)

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- Pre-operational setup of MeteoSwiss (minor differences)

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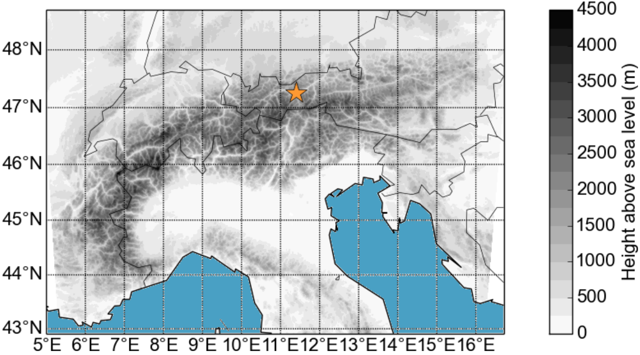
How does the model perform in complex terrain?

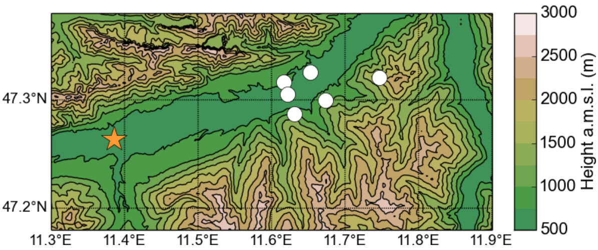
- COSMO - **CO**nsortium for **S**mall-scale **MO**deling
  Initially developed at DWD (German Weather Service)
- Pre-operational setup of MeteoSwiss (minor differences)
- Turbulence parameterization: 1.5 order TKE closure
  buoyant production **vertical shear** **dissipation**
  Other options: TKE Advection; 3D TKE scheme

Mesoscale NWP Model COSMO

- Inner model domain:
  - Δx=1.1 km
  - 80 vertical levels
  - Lowest model half-level at 10 m



i-Box Turbulence Measurements



6 flux towers at representative locations in complex terrain

- Turbulent fluxes
- Turbulence kinetic energy (TKE)
- TKE production terms:
  buoyant production, **shear production**, **dissipation**
- **and many more ...**

Methods

- No classical model verification

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- **Process-oriented analysis** – Case studies:
  Focus on boundary-layer processes for selected days

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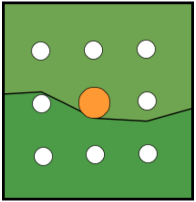
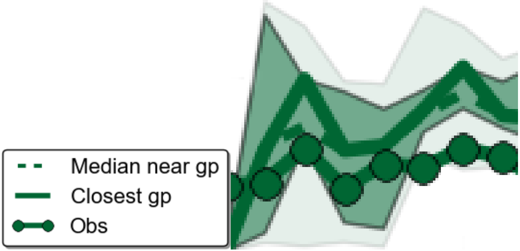
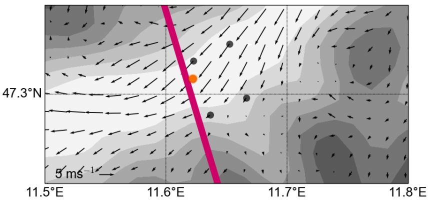
Comparison model - measurements

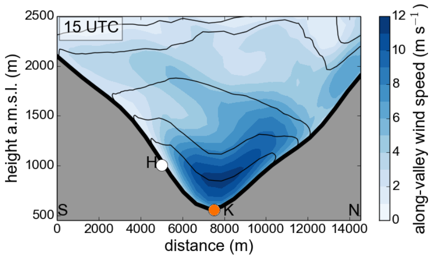
Gridpoint “ensemble”:





Daytime valley wind (July 1, 2015)





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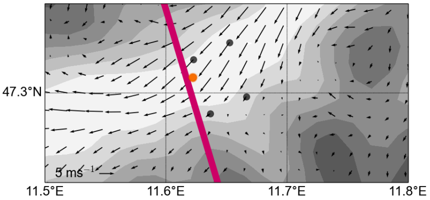

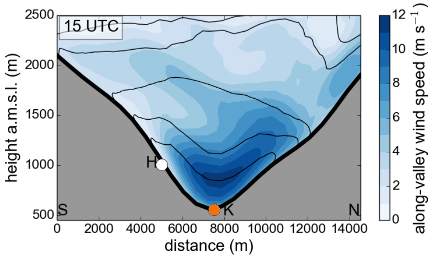

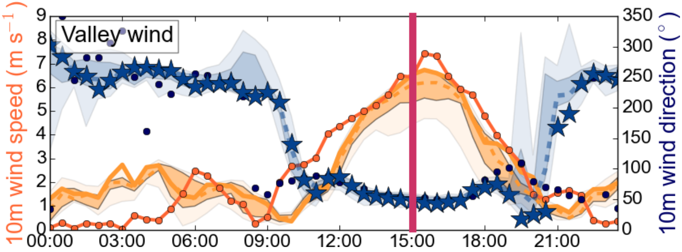

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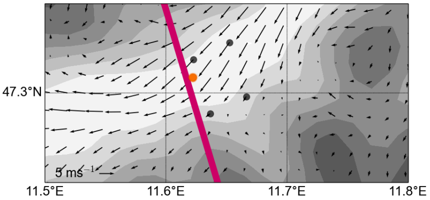
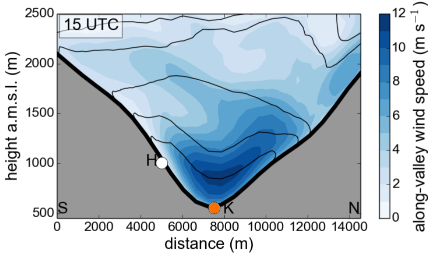
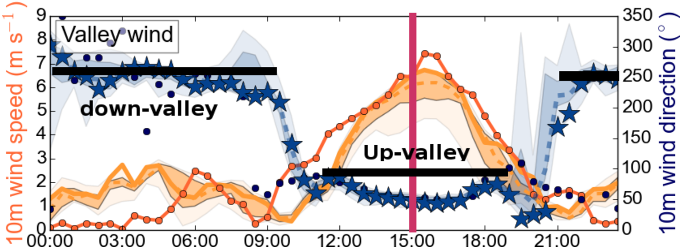
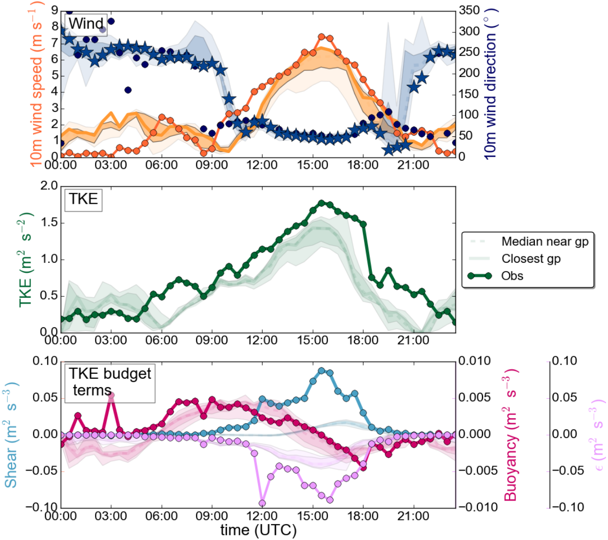
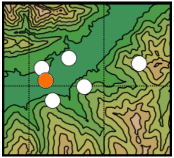






Daytime TKE (valley floor)





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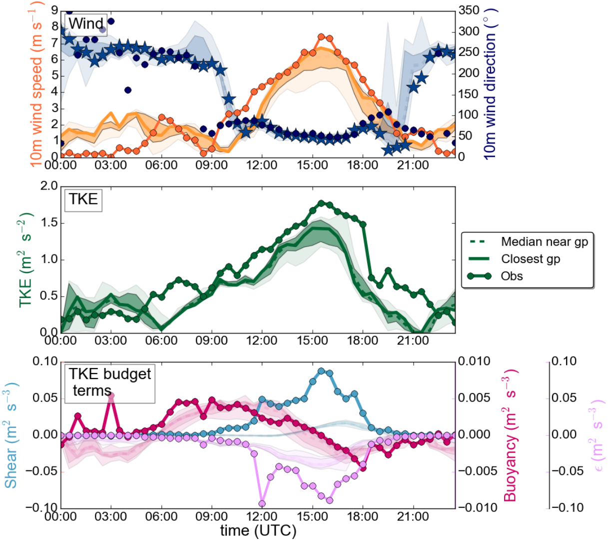

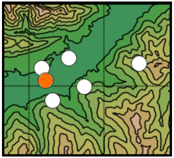

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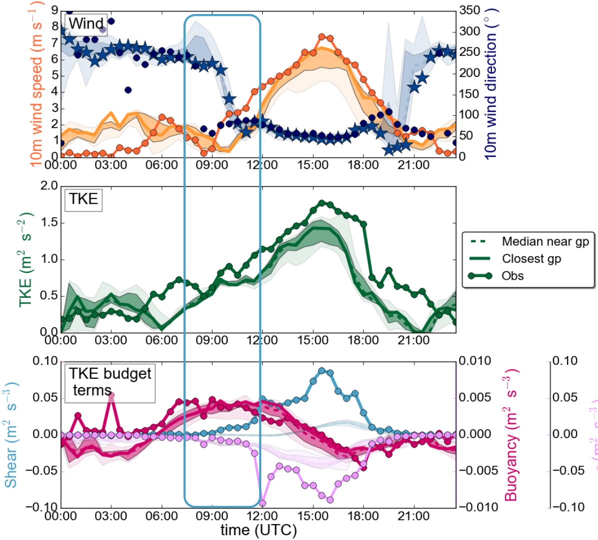
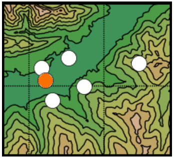


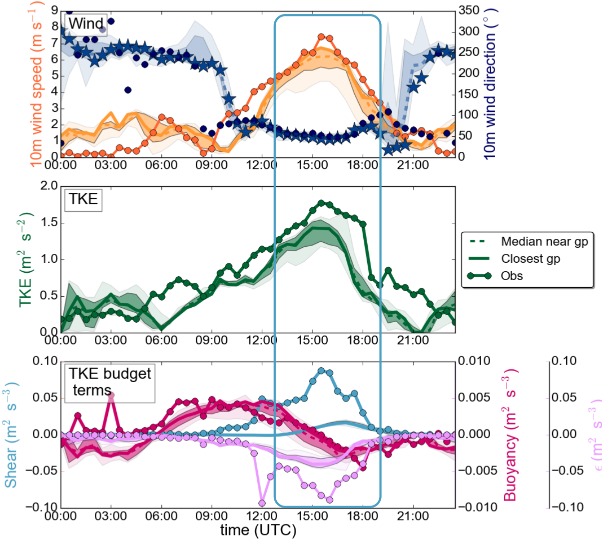


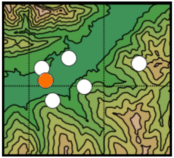
Before noon:

Buoyant production dominates

TKE well simulated by the model

Daytime TKE (valley floor)



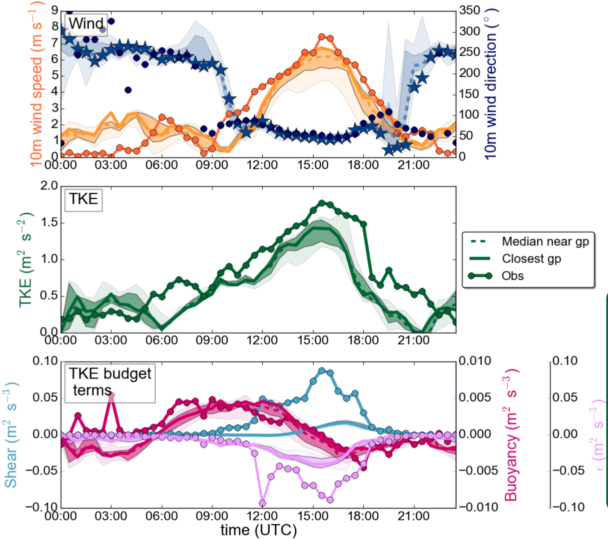


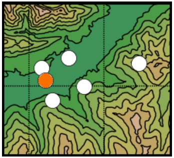
Afternoon:

Vertical shear generation together with valley wind

Shear term drastically underestimated (missing horizontal contributions)

Daytime TKE (valley floor)





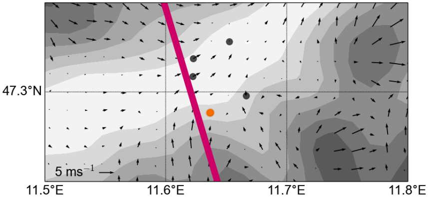
TKE:

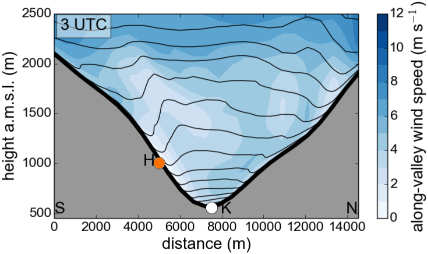
Simulation captures contributing processes

Daytime-dependent

Process-dependent

Nighttime down-valley flows (July 1, 2015)





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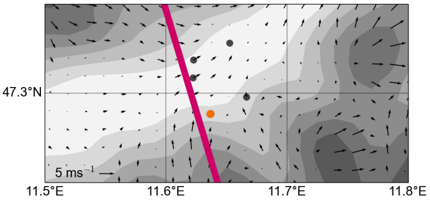

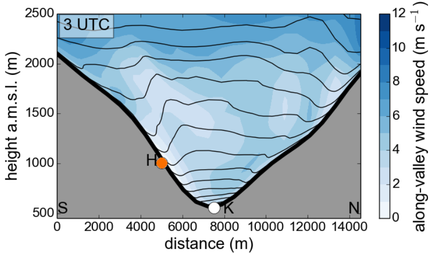

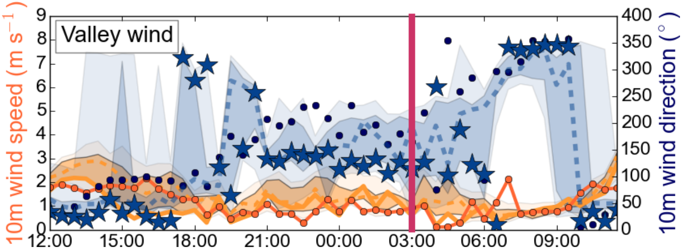

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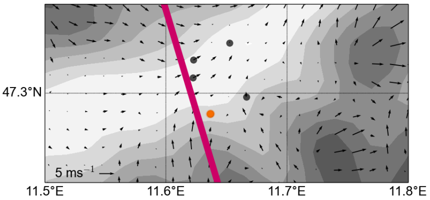
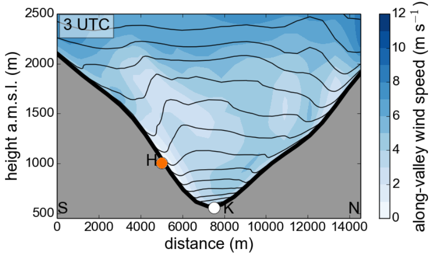
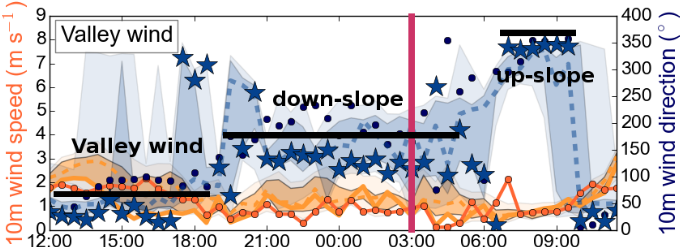
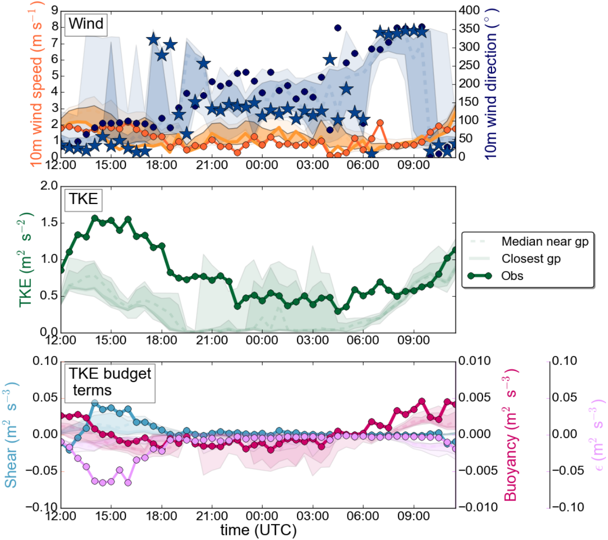
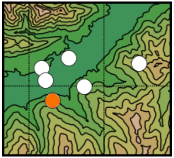






Nighttime TKE (slope)





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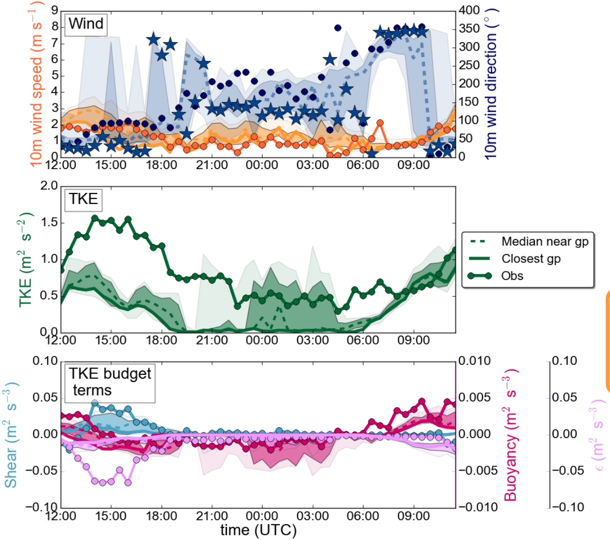

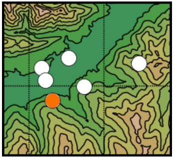

Production terms:
well-captured

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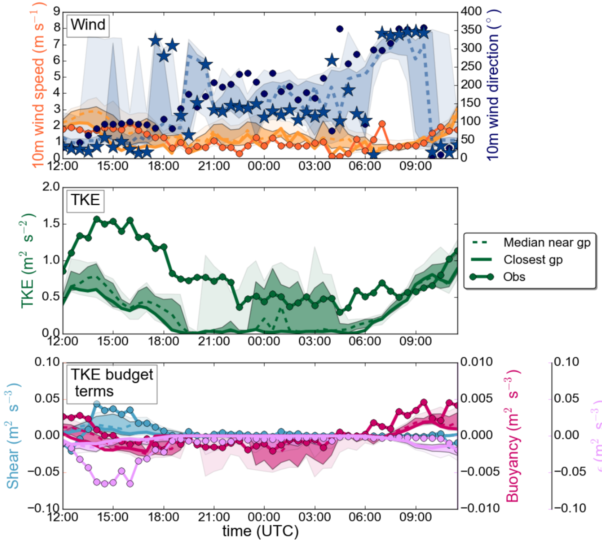
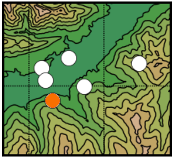


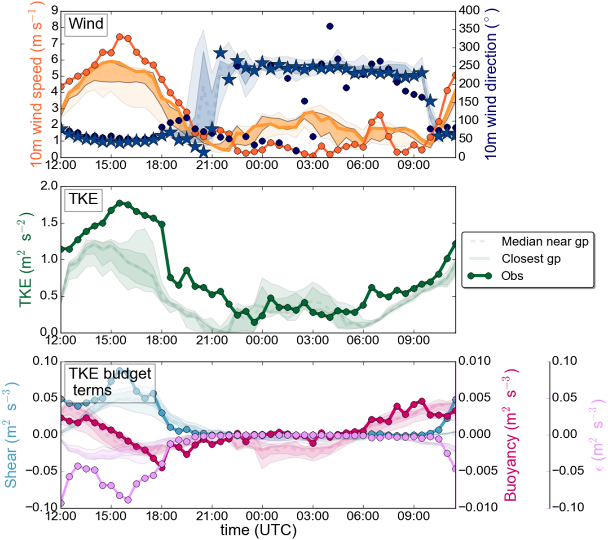


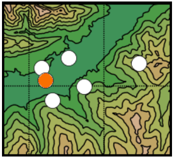
TKE:

Drastically understimated by the model

Unresolved TKE production mechanisms

Nighttime TKE (valley floor)





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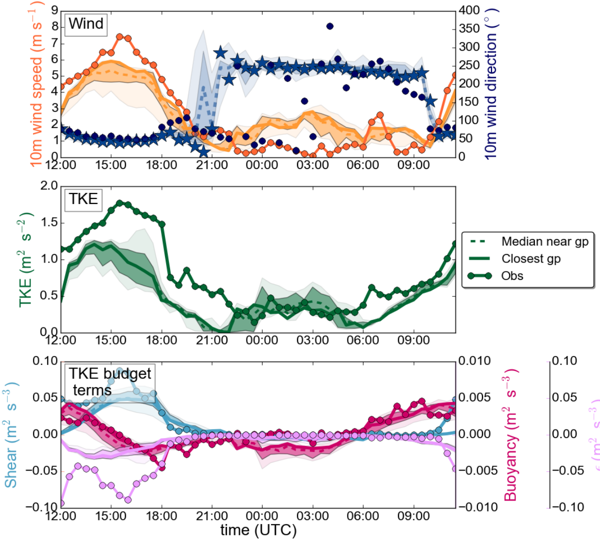
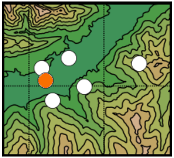




TKE:

Interaction with down-valley flow

Different TKE production mechanisms

Summary & Conclusions

Daytime TKE

- Correct simulation of the daytime TKE production mechanisms (buoyant production, vertical shear)
- Vertical shear production not sufficient $\rightarrow$ **3D TKE scheme**

Summary & Conclusions

Daytime TKE

- Correct simulation of the daytime TKE production mechanisms (buoyant production, vertical shear)
- Vertical shear production not sufficient $\rightarrow$ **3D TKE scheme**

Nighttime TKE

- Missing TKE production mechanisms $\rightarrow$ **TKE Advection**
- Unresolved TKE production mechanisms $\rightarrow$ **Simulations with higher horizontal grid spacing**

TKE Equation

$$\frac{\partial \bar{e}}{\partial t} + \overline{U_j}\frac{\partial \bar{e}}{\partial x_j} = \delta_{i3}\frac{g}{\overline{\theta_v}}(\overline{u_i'\theta_v'}) - \overline{u_i'u_j'}\frac{\partial \overline{U_i}}{\partial x_j} - \frac{\partial(\overline{u_j'e})}{\partial x_j} - \frac{1}{\overline{\rho}}\frac{\partial(\overline{u_i'p'})}{\partial x_i} - \epsilon$$

$\frac{\partial \bar{e}}{\partial t}$...Storage; $\overline{U_j}\frac{\partial \bar{e}}{\partial x_j}$... Advection

$\delta_{i3}\frac{g}{\overline{\theta_v}}(\overline{u_i'\theta_v'})$... **Buoyant production/consumption**

$\overline{u_i'u_j'}\frac{\partial \overline{U_i}}{\partial x_j}$...**Shear production/loss**

$\frac{\partial(\overline{u_j'e})}{\partial x_j}$... Turbulent transport; $\frac{1}{\overline{\rho}}\frac{\partial(\overline{u_i'p'})}{\partial x_i}$... Pressure correlation

ϵ... **Dissipation** (Observations: calculation after Večenaj et al. (2010))

Stations

Kolsass (valley floor)

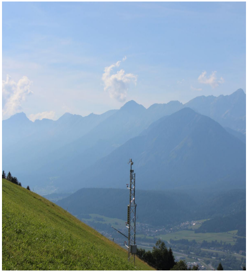
$h_{a.m.s.l.}$ = 545 m
h_{Model} = 579 m

h_{Sensor} = 8.6 m
$h_{ModelLevel}$ = 10 m

Hochhäuser (north-facing slope)

$h_{a.m.s.l.}$ = 1009 m
h_{Model} = 844 m

h_{Sensor} = 6.8 m
$h_{ModelLevel}$ = 10 m



$\alpha_{real} = 27^\circ$
$\alpha_{Model} = 15^\circ$