Turbulence Kinetic Energy Characteristics in the Inn Valley

A Model Evaluation Study with High-Quality Turbulence Measurements

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

Mountain boundary layer

NWP model ($\Delta x = 1$ km)

Rotach and Zardi (2007)
Motivation

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

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)
How does the model perform in complex terrain?

- COSMO - COnsortium for Small-scale MOdeling
  Initially developed at DWD (German Weather Service)
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- Pre-operational setup of MeteoSwiss (minor differences)
Mesoscale NWP Model COSMO

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- 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:
  - $\Delta x = 1.1$ km
  - 80 vertical levels
  - Lowest model half-level at 10 m
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
Methods

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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)
Daytime valley wind
Daytime valley wind

[Diagram of valley wind patterns with vector arrows and contour lines showing wind speeds and directions.]

17th Conference on Mountain Meteorology, Burlington, VT, 2016-06-28
Daytime TKE (valley floor)
Daytime TKE (valley floor)
Daytime TKE (valley floor)

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)
Nighttime down-valley flows
Nighttime down-valley flows

[Diagram of wind flow and topography]

Valley wind

down-slope

up-slope

10 m wind speed (m s⁻¹)
12:00 15:00 18:00 21:00 00:00 03:00 06:00 09:00
0 1 2 3 4 5 6 7 8 9

10 m wind direction (°)
0 50 100 150 200 250 300 350 400

ACINN

17th Conference on Mountain Meteorology, Burlington, VT, 2016-06-28
Nighttime TKE (slope)

Production terms: well-captured
Nighttime TKE (slope)

TKE: Drastically understimated by the model

Unresolved TKE production mechanisms
Nighttime TKE (valley floor)
Nighttime TKE (valley floor)

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 → 3D TKE scheme
Summary & Conclusions

Daytime TKE
- Correct simulation of the daytime TKE production mechanisms (buoyant production, vertical shear)
- Vertical shear production not sufficient → 3D TKE scheme

Nighttime TKE
- Missing TKE production mechanisms → TKE Advection
- Unresolved TKE production mechanisms → Simulations with higher horizontal grid spacing
TKE Equation

\[
\frac{\partial \bar{e}}{\partial t} + \bar{U}_j \frac{\partial \bar{e}}{\partial x_j} = \delta_{i3} \frac{g}{\theta_v} \left( \bar{u}_i' \bar{\theta}_v' \right) - \bar{u}_i' \bar{u}_j' \frac{\partial \bar{U}_i}{\partial x_j} - \frac{\partial \left( \bar{u}_j' \bar{e} \right)}{\partial x_j} - \frac{1}{\bar{\rho}} \frac{\partial \left( \bar{u}_i' \bar{p}' \right)}{\partial x_i} - \epsilon
\]

\[
\frac{\partial \bar{e}}{\partial t} \text{ ...Storage; } \bar{U}_j \frac{\partial \bar{e}}{\partial x_j} \text{ ... Advection}
\]

\[
\delta_{i3} \frac{g}{\theta_v} \left( \bar{u}_i' \bar{\theta}_v' \right) \text{ ... Buoyant production/consumption}
\]

\[
\bar{u}_i' \bar{u}_j' \frac{\partial \bar{U}_i}{\partial x_j} \text{ ...Shear production/loss}
\]

\[
\frac{\partial \left( \bar{u}_j' \bar{e} \right)}{\partial x_j} \text{ ... Turbulent transport; } \frac{1}{\bar{\rho}} \frac{\partial \left( \bar{u}_i' \bar{p}' \right)}{\partial x_i} \text{ ... Pressure correlation}
\]

\[
\epsilon \text{ ... Dissipation (Observations: calculation after Večenaj et al. (2010))}
\]
Stations

Kolsass (valley floor)

\[ h_{\text{a.m.s.l.}} = 545 \text{ m} \]
\[ h_{\text{Model}} = 579 \text{ m} \]
\[ h_{\text{Sensor}} = 8.6 \text{ m} \]
\[ h_{\text{Model Level}} = 10 \text{ m} \]

Hochhäuser (north-facing slope)

\[ h_{\text{a.m.s.l.}} = 1009 \text{ m} \]
\[ h_{\text{Model}} = 844 \text{ m} \]
\[ h_{\text{Sensor}} = 6.8 \text{ m} \]
\[ h_{\text{Model Level}} = 10 \text{ m} \]

\[ \alpha_{\text{real}} = 27^\circ \]
\[ \alpha_{\text{Model}} = 15^\circ \]