Investigating the Mechanism of a Local Windstorm in the Swiss Alps Using Large-Eddy Simulations

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1 Introduction

The Laseyer windstorm is a local and strong wind phenomenon in the narrow (1 - 1.5 km wide) Schwende valley in northeastern Switzerland. The phenomenon has raised the interest of meteorologists as it has led to derailments of the local train. It is characterised by easterly to southeasterly winds during strong northwesterly ambient wind conditions (Sprenger et al., 2018). However, the mechanism behind the flow reversal is not yet understood.

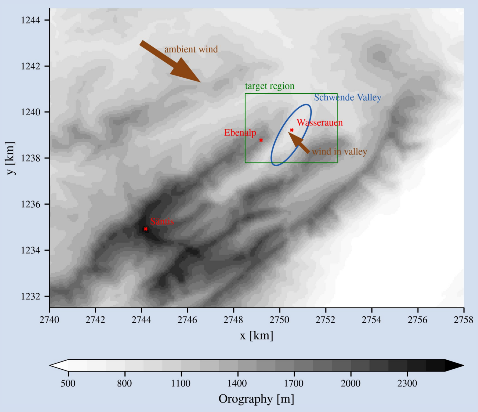

Figure 1: Topography of the Alpstein region in northeastern Switzerland. Marked are the three location of the measurement stations, the Schwende valley and the dominant wind direction during Laseyer events.

Figure 2: View towards north-east at Wasserauen and the Schwende valley.

2 FVM-LES numerical laboratory

We perform large-eddy simulations (LES) with **FVM**. This model has the following characteristics and implemented parameterizations:

- Fully implemented in **Python** leveraging the **domain-specific language GT4Py** to enable **high performance** on CPUs and GPUs (see related PASC poster Ubbiali et al.)
- Fully compressible equations efficiently solved by **semi-implicit integration** and multi-dimensional flux-form non-oscillatory advection (Smolarkiewicz et al., 2014; Kühnlein et al., 2019)
- Terrain-following vertical coordinate with finely tuned smooth level specification under complex orography
- Dynamical core, diffusion, and surface fluxes thoroughly implemented for robust and **accurate handling of steep orography**
- **Prognostic TKE** sub-grid scale turbulence scheme

3 Simulation setup

We performed LES with the following specifications:

- Only surface fluxes of momentum, no cloud microphysics and no radiation
- Lower boundary condition (topography, roughness length) from real fields
- Horizontal **grid spacing of 60 m** over a domain size of 30 km x 25 km; 101 vertical levels with a vertical grid spacing of 20 m close to the surface stretched towards the model top at 20 km; absorbers at the lateral (2 km) and upper (6 km) boundary
- Idealized initial and boundary conditions:
  - Constant wind speed and direction
  - Constant stratification of N = 0.011 s^{-1}
- Simulations performed over 3 h, where first hour is considered spin-up, 15 s temporal resolution of output

4 Sensitivity to ambient flow conditions

We performed a set of LES with ambient conditions conducive to the occurrence of the Laseyer (wind wind speeds of 12 m s^{-1} to 21 m s^{-1} and wind directions of 300° to 330°; Figs. 3 & 4).
The flow in the valley shows strong sensitivity to the ambient wind conditions and large variability over time (Fig. 5).
The strongest gusts occur for ambient wind conditions of 310° and at least 18 m s^{-1} and reach up to 26.6 m s^{-1} (~25% more than the ambient wind speed).

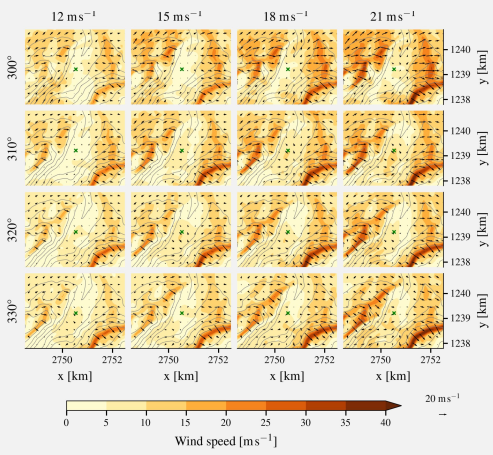

Figure 3: Mean flow in the target region. Gray contours show the height of the orography and green crosses mark location of wind roses (Fig. 4).

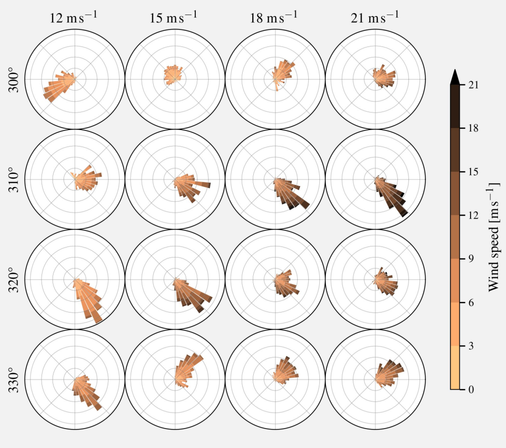

Figure 4: Wind roses for the 481 output times from 1 h to 3 h simulation time at the location marked in Fig. 3 for the 16 simulations.

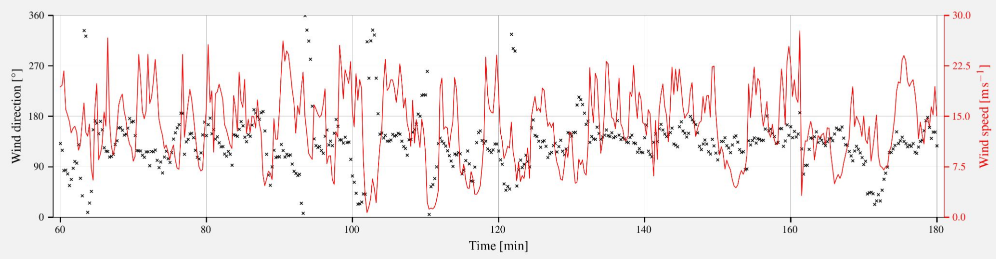

Figure 5: Temporal evolution of wind direction (black) and wind speed (red) for the simulation with ambient wind conditions of 21 m s^{-1} and 310° at the location marked with the green cross in Fig. 3.

5 Mechanism of the Windstorm

- One simulation with reversed flow investigated in more detail (ambient wind conditions of 21 m s^{-1} and 310°)
- Calculation of composite based on the strongest gusts at a point location in the valley (green cross in Fig. 6) selected using on a directional window (65° - 165°) and a wind speed threshold (20 m s^{-1}); composite encompasses 11.7% of the output time steps
- Composite shows a radially spreading pulse of higher wind speeds emerging from the lower part of the downstream escarpment (Fig. 6)
- Gusts can be explained by the positive pressure anomaly created by anomalously high wind speeds at higher elevations (Fig. 7)

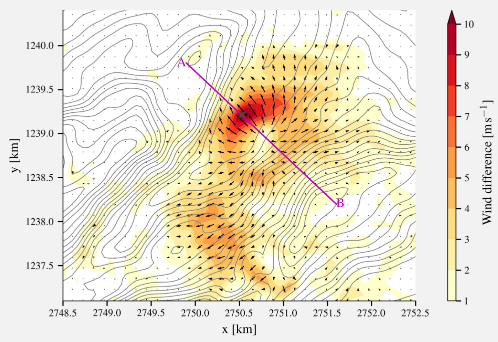

Figure 6: Surface wind deviation of the gust composite from the mean flow. The gray contours show the height of the topography.

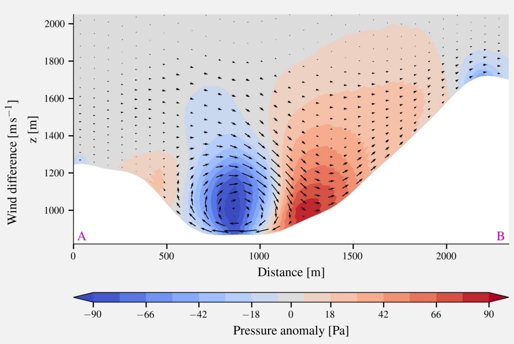

Figure 7: Wind (arrows) and pressure (colors) deviation of the gust composite from the mean flow. The location of the cross-section is shown by the magenta line in Fig. 6.

6 Conclusion

- FVM is able to simulate flow in very steep and complex terrain
- With the LES, we can show the high variability of the flow in the valley in both space and time and get a better understanding of the involved mechanisms
- The sensitivity study shows the observed flow characteristics at the location of the measurement station in the valley for suitable flow conditions

Related Posters

- Ubbiali et al.: Towards a Python-Based Performance-Portable Finite-Volume Dynamical Core for Numerical Weather Prediction.
- Bianco et al.: GT4Py: A Python Framework for the Development of High-Performance Weather and Climate Applications.

References

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Smolarkiewicz et al. (2014): A consistent framework for discrete integrations of soundproof and compressible PDEs of atmospheric dynamics. *Journal of Computational Physics*, 263, 185-205.

Sprenger et al. (2018). The Laseyer wind storm – case studies and a climatology. *Meteorologische Zeitschrift*, 27(1), 15-32.