Project	**664**
Project title	**Dynamik orographischer Wolkenbildung im Hochgebirge**
Project lead	**Prof. Dr. Volkmar Wirth**
Institution	Johannes Gutenberg University, Institute for Atmospheric Physics
Report period	1.1.2016 – 31.12.2016

During the allocation period we continued using DKRZ's resources to carry out various model runs using the EULAG model (Eulerian/semi-Lagrangian fluid solver, see Prusa et al., 2008) . The majority of these runs adressed issues directly connected to the project title, i.e. formation of banner clouds on the leeward side of steep obstacles.

While the work programme during the previous allocation period mostly consisted of sensitivity studies on mountain geometry, applying EULAG to idealized topographies as regular pyramids or cosine-shaped mountains, in 2016 we intensified simulations for realistic topographies, i.e. the Zugspitze mountain located at the german – austrian border in southern Bavaria.

Results were published in journals and have been presented at conferences and workshops, see reference list below. The PhD thesis on banner clouds, funded by the German Research Foundation (DFG), is almost completed, the project will be finished right after the PhD student's return from parental leave. Additional publications will then be finalized and submitted as well.

We plan to apply for funding for a follow-up project during 2017.

Some important results of this and previous year's work are:

Sensitivity studies on domain size, mountain geometry and inflow conditions: In addition to our previous studies, non-symmetric topographies have been examined regarding their potential for banner cloud formation. Also, the studies for bell shaped and pyramid shaped mountains have been extended and completed, a publication is going to be prepared in 2017.

Figure 1 shows the model setup for the comparison of symmetric and non-symmetric idealized pyramids.

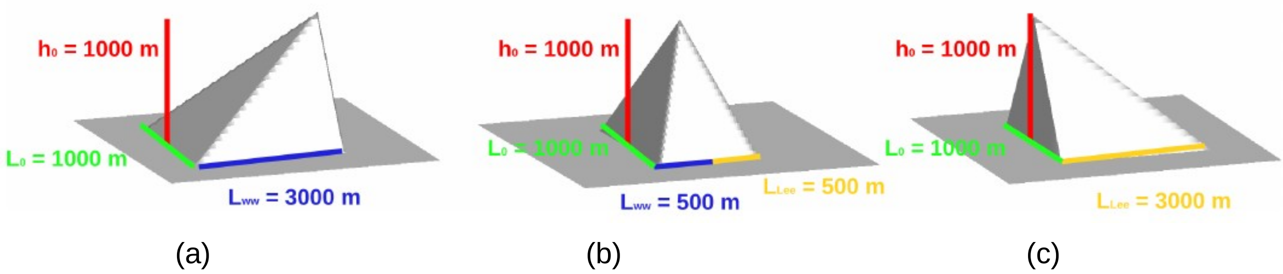

Figure 1: Mountain geometries for sensitivity studies for non-symmetric obstacles.

Case (a) yields the greatest likelihood of banner cloud formation, which can easily be verified by a comparison of the vertical displacement of the flow (Fig. 2, left panels) as well as the resulting distributions of relative humiditay (Fig. 2, right panels). Additionally, in case (a) results indicate a longer duration of the banner cloud occurrence compared to the symmetric pyramid (b).

As mountain type (a) is roughly similar in shape to the Zugspitze mountain for a southeasterly inflow. For this inflow, the number of banner cloud observations was highest in comparison to other directions. Simulations adopting the real topographic structure of the Zugspitze were performed systematically to evaluate EULAG's capability to reproduce this phenomenon.

Studies of banner clouds at the Zugspitze mountain: EULAG simulations have been carried out for the region around Zugspitze, located on the border between southern Bavaria and Austria. Long term observations at this mountain indicate two favoured wind directions for banner cloud

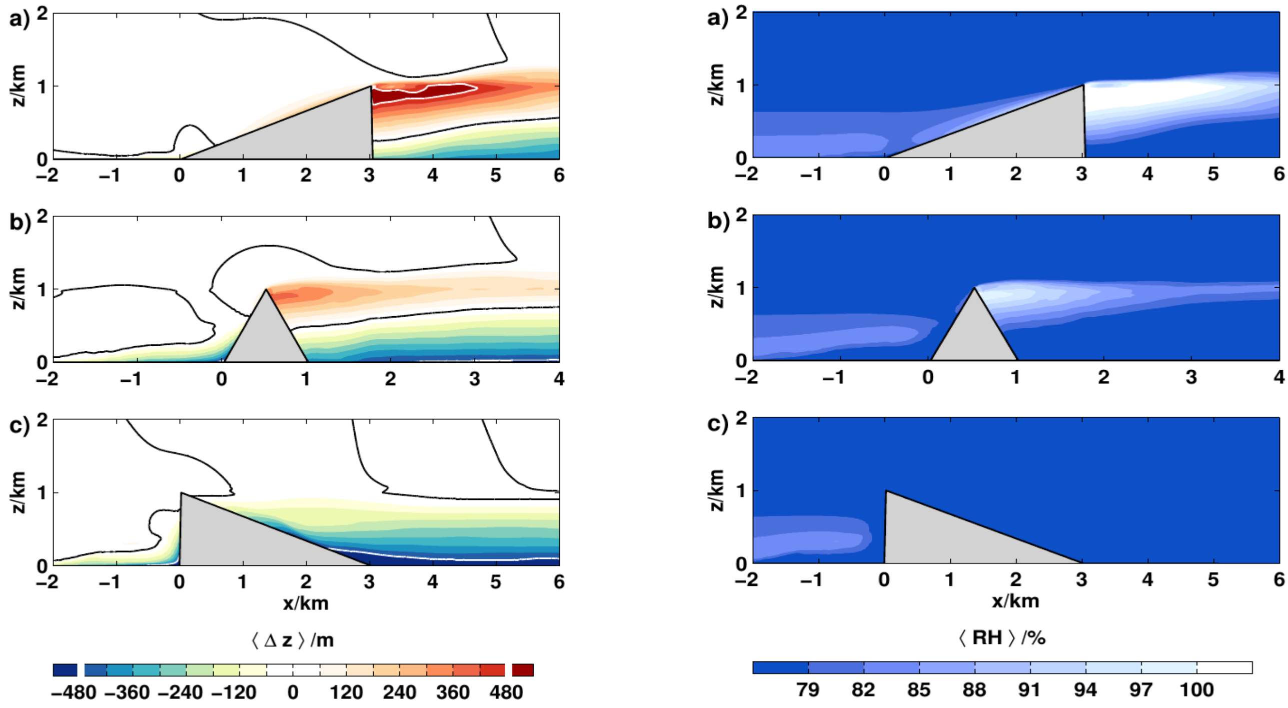

Figure 2: Lagrangian displacement (m, left panel) and relative humidity (%, right panel) for flow over idealized topographies.

formation, i.e. northerly and, to even greater extent, southeasterly wind.

Model results confirm the higher likelihood of banner cloud formation in case of south-easterly inflow. Plots of relative humidity (Figure 3) show the typical banner cloud structure of the humidity field especially in case of the southeasterly inflow (Fig 3a). Additional evaluations of the origin of air parcels being lifted into the banner cloud showed that most of the air mass in case (a) originated from the lee side of the mountain, this air mass is lifted by as much as 720 m leeward of the mountain peak. In contrast to this, for northerly wind displacements of similar magnitude are observed only right above the peak as well as a few km downstream.

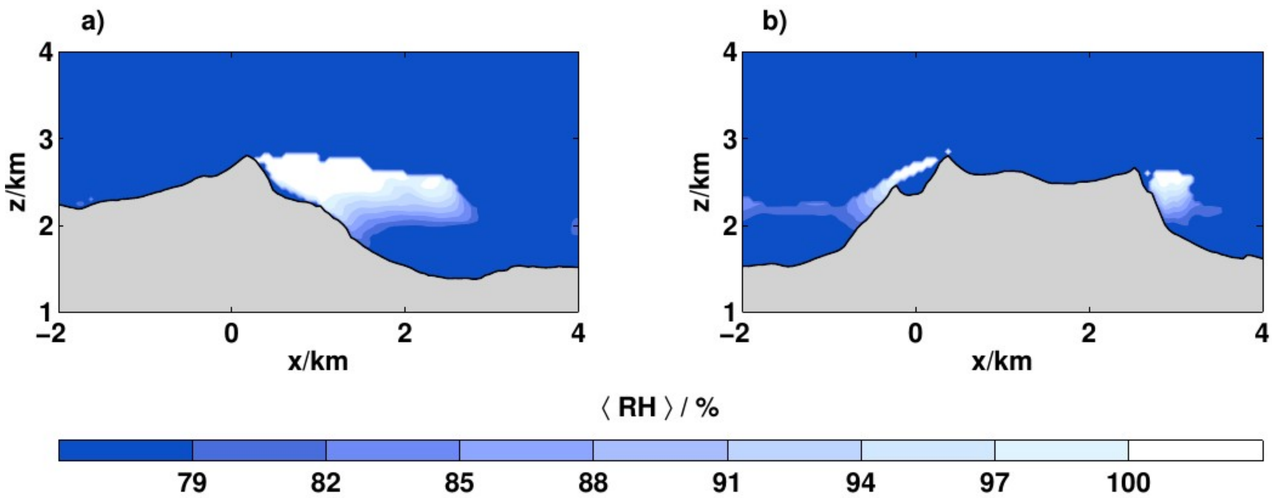

Figure 3: Relative humidity (%) at Zugspitze for southeasterly (a) and northerly (b) inflow.

Journal publication

Prestel, I. and V. Wirth, 2016: What flow regimes are conducive to banner cloud formation? *J. Atmos. Sci.,* **73**, 2385-2402.

Thesis work

During the report period a PhD thesis was prepared, publication is planned immediately after the student's parental leave will be finished:

Prestel, Isabelle (2016), Dynamik von Bannerwolken: Theoriebildung und Simulationen mit realistischer Orographie. PhD thesis, Institute for Atmospheric Physics, University of Mainz, Mainz, Germany.

References

Baines, P. G. (1995), Topographic Effects in Stratified Flows. Cambridge University Press, 482 pp.

Prusa, J. M., P. K. Smolarkiewicz, and A. A. Wyszogrodzki (2008), Eulag, A Computational Model For Multiscale Flows, Computers & Fluids, 37 (9), 1193-1207, doi: {10.1016/J.Compfluid.2007.12.001}.

Schween, J. H., J. Kuettner, D. Reinert, J. Reuder, and V. Wirth (2007), Definition Of Banner Clouds Based On Time Lapse Movies, Atmospheric Chemistry And Physics, 7 (8), 2047-2055.