Dynamics of orographic banner clouds

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Introduction

Banner clouds are cloud plumes which extend downwind of steep mountains or sharp ridges, even on otherwise cloudfree days. Examples are the banner clouds at the Matterhorn in the Swiss Alps or at Mount Zugspitze in the Bavarian Alps. Based on a set of time lapse movies taken on Mount Zugspitze, Schween et al. (2007) provided a detailed definition of what should (and what should not) be considered a banner cloud. According to their analysis, a banner cloud must simultaneously satisfy four criteria:

(1) the cloud should be in a fixed relation to the mountain and occur only on its leeward side;

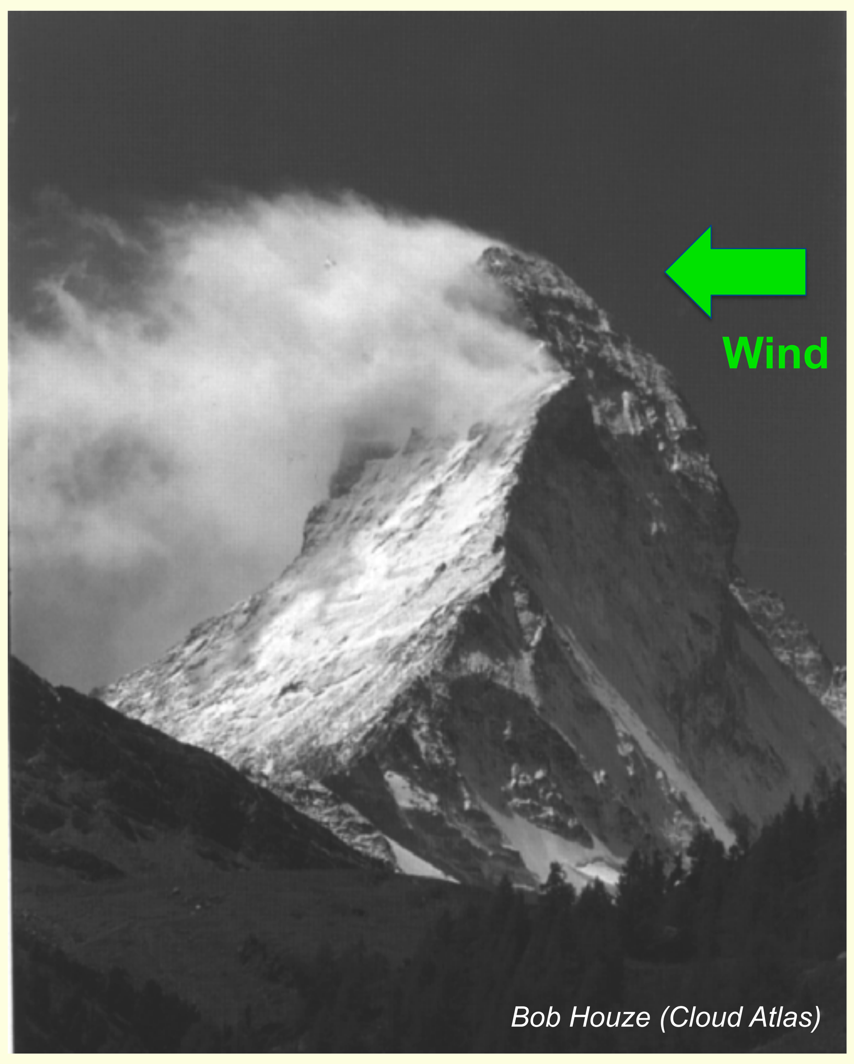
(2) the cloud should not be composed of snow crystals blown off the mountain by the wind;

(3) the cloud should be persistent;

(4) the cloud should not be primarily of convective character.

The picture to the right shows an example of a banner cloud at the Matterhorn.

Systematic observations of banner clouds were carried out by Wirth et al. (2012), revealing many interesting features of this cloud type at Mount Zugspitze.



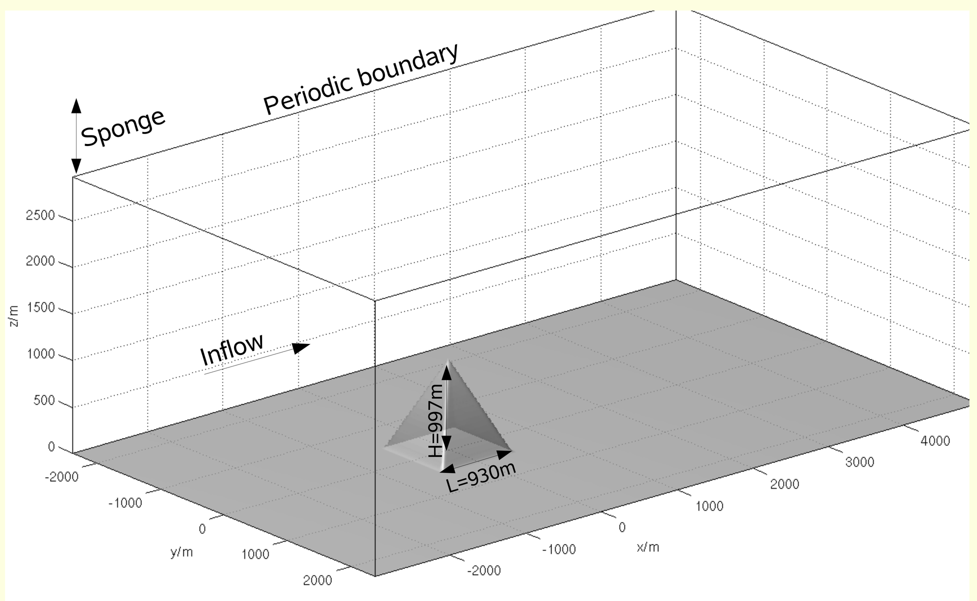
Simulations: Computational aspects

This poster reports results from the group of Prof. V. Wirth, which were obtained through **Large Eddy Simulations using the EULAG** numerical model (Prusa et al. 2008). This model parallelizes very well on multi-processor architectures. All simulations were performed on DKRZ computers.

The **model setup** represents an inflow-outflow geometry (see figure below). Profiles of wind, temperature and humidity are specified at the inflow boundary. The idealized orography is represented either through the method of immersed boundaries or through terrain following coordinates.

The **equations are discretized** on a 320 x 192 x 120 (x-y-z) grid with a resolution of 25 m in the two horizontal directions and a stretched vertical coordinate. Each model run (representing 2 hours simulated time) requires approximately 30,000 time steps with Δt = 0.25 seconds. Using 512 processors on 8 nodes this corresponds to a CPU time of about 4 hours.

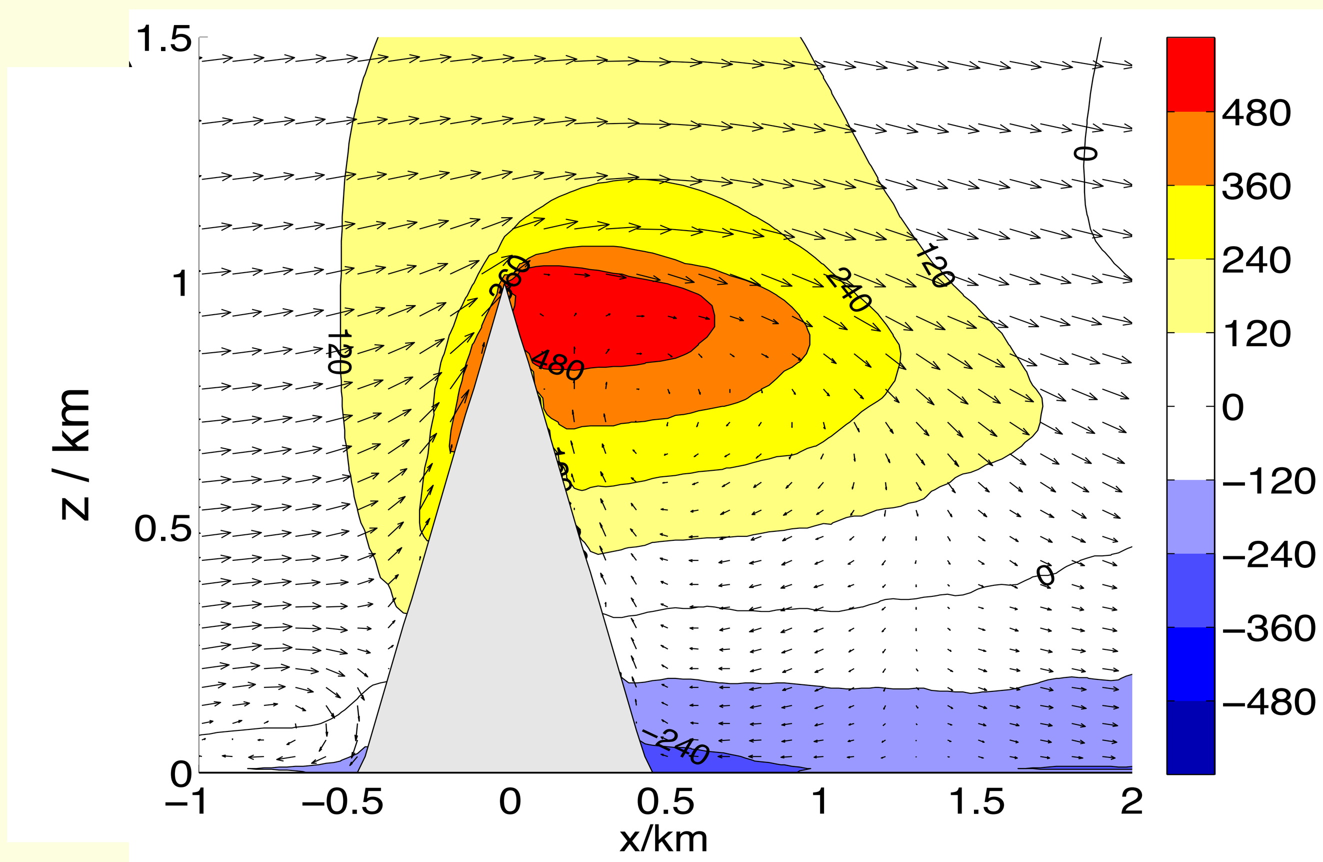
Doing **model output** every simulated minute produces over 100 Gbyte data.



Key mechanism

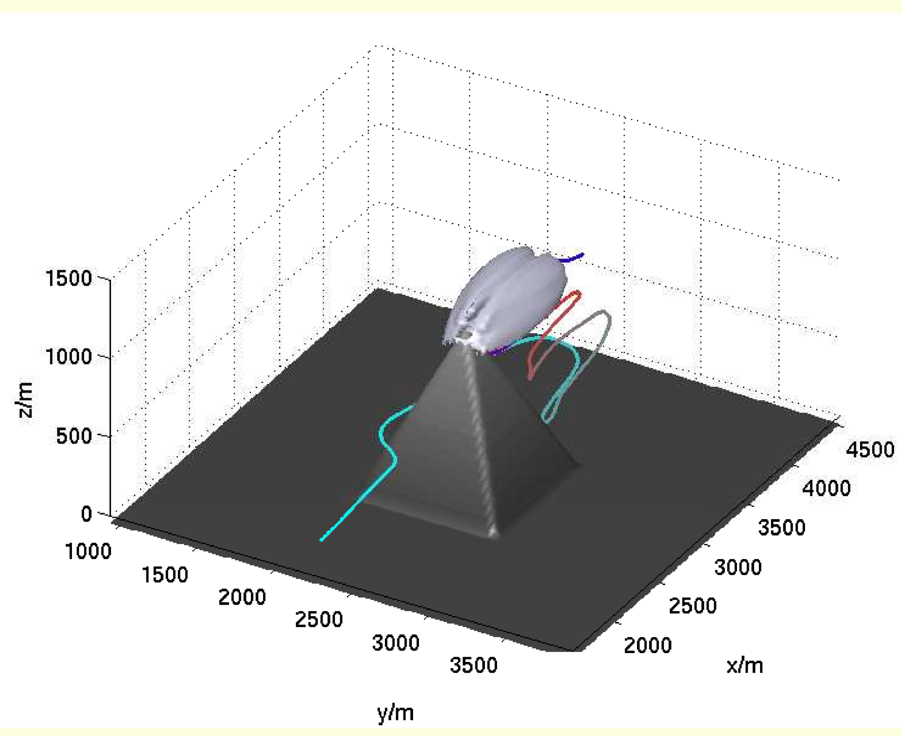
A key diagnostic in our analysis is the **Lagrangian vertical displacement** Δz of air parcels. It is computed through the advection of a passive tracer that contains information about the altitude of each air parcel at the inflow boundary (Reinert and Wirth, 2009). The figure below shows the time mean Δz (colors, in m) together with the time mean flow (arrows). Apparently, there is a clear windward-leeward asymmetry indicating that air parcels in the lee of the mountain have experienced a much larger uplift since they entered the domain than air parcels on the windward side. This suggests that a cloud occurs primarily on the leeward side.

Comparing this mechanisms with two other mechanisms, Voigt and Wirth (2013) argue that the vertical uplift in the lee vortex can be expected to be the key mechanisms of banner cloud formation in most cases.



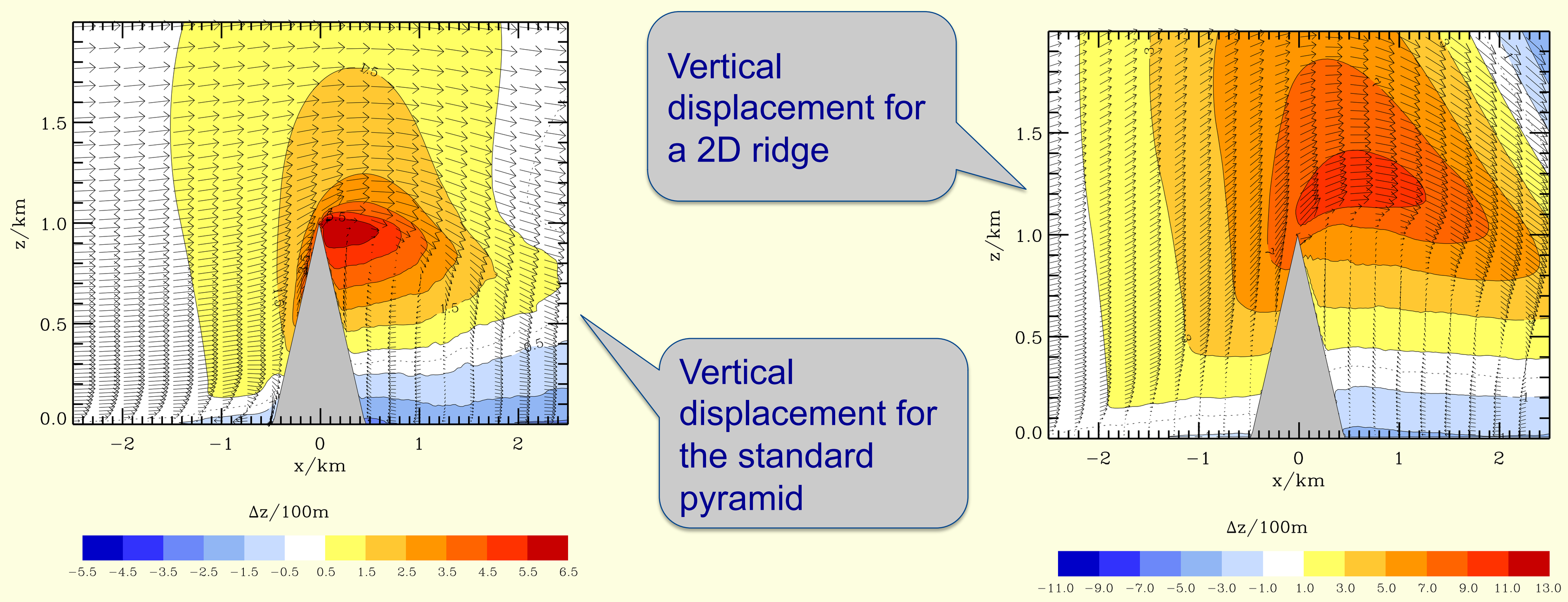
Trajectory analysis

Computing a large number of trajectories reveals that the **flow geometry is rather complex**. Some parcels (not shown) flow over the mountain and become part of the banner cloud (gray) through mixing. Other parcels (shown in the figure) travel around the mountain and become caught in the so-called bow-vortex in the lee of the mountain. They can recirculate through the cloud several times before they leave the domain.



Sensitivity studies

Numerical modeling lends itself to sensitivity studies of all kinds. Here we given an example of the sensitivity with respect to orography.



References

Schween, J. H., J. Kuettner, D. Reinert, J. Reuder, and V. Wirth, 2007: Definition of “banner clouds” based on time lapse movies. Atmos. Chem. Phys., **7**, 2047–2055.
Prusa, J. M., P. K. Smolarkiewicz, and A. A. Wyszogrodzki, 2008: EULAG, a computational model for multiscale flows. Computers and Fluids, **37**, 1193–1207.
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Voigt, M., and V. Wirth, 2013: Mechanisms of Banner Cloud Formation. *J. Atmos. Sci.*, submitted.