Analysis of banner cloud dynamics using a newly developed LES model

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Banner clouds belong to the class of orographic clouds. They are known to occur when sufficiently moist air flows across steep mountain peaks or quasi 2D ridges. The cloud is confined to the immediate lee of the mountain, whereas the windward side remains cloud-free. Preferred places of occurrence are e.g. the Matterhorn in the Swiss Alps or Mount Zugspitze in the Bavarian Alps. The cloud has a banner-like appearance with a characteristic (horizontal) scale of 1 km. It is attached to the mountain, while its downwind end flickers in the wind like a flag. The cloud is quasi-stationary and can often be observed for several hours. The underlying mechanisms of formation as well as the relative importance of dynamics versus thermodynamics for its formation and maintenance are not yet fully understood.

As a tool to investigate this phenomenon we developed a new Large Eddy Simulation (LES) model which can handle moist atmospheric flow above highly complex terrain. The model is able to treat orography with slopes up to 90° by applying the method of viscous topography. Furthermore, turbulent inflow conditions can be generated by using a modified perturbation recycling method. The model has been tested in detail and was validated against wind tunnel data.

Here we shortly present the new LES model including non-standard technical features like the new turbulence generator and the treatment of complex orography. We then focus on the dynamics of banner clouds as a typical area of application. Both dry and moist flow across an idealized pyramidal shaped obstacle is investigated, because observations suggest that pyramidal shaped mountain peaks are preferred places for banner cloud occurrence (e.g. Matterhorn).

The dry simulations reveal that the flow field is highly asymmetric regarding the Lagrangian vertical displacement: air parcels which are lifted in the upward branch of the induced lee vortex originate at lower levels than air parcels which are lifted on the windward side. As we will show, the upward displacement in the lee is sufficient to explain the occurrence of banner clouds. Due to the strong asymmetry of the flow field this is even true for horizontally homogenous initial conditions regarding both moisture and temperature. Simulations with moist physics switched on show that our model is able to simulate realistically shaped banner clouds downwind of a pyramidal shaped mountain peak. A comparison of model runs with the cloud model switched on and off indicates that thermodynamics (i.e. latent heat release) do not have a significant impact on the mean flow, even though they do increase the intensity of leeward turbulence. We conclude that banner clouds are primarily a dynamical phenomenon, with their dynamics only slightly modulated by thermodynamical processes.