EFFECTS OF MOIST CONVECTION ON FLOW PAST 2D-TOPOGRAPHY

Oliver Fuhrer*, Christoph Schär
Institute for Atmospheric and Climate Science, ETH Zürich, Switzerland

1. Introduction

The type, distribution and intensity of orographically induced precipitation is strongly dependent on the stability and moisture content of the impinging airflow (Smith 1979, Cotton and Anthes 1989, Banta 1990). In the present study, consideration is given to quasi-steady stratified flow over a mountain ridge for a range of upstream profiles with different values of the convective available potential energy (CAPE). Recent studies have shown the importance of bulk or integral environmental quantities such as CAPE (e.g. Lin and Chiao 2001, Chu and Lin 2000) for the structure and intensity of orographically convective precipitation.

However, most cloud resolving studies of orographically induced precipitation focus on the impact of the environmental shear and/or use two-dimensional geometry. It has been noted by Soong and Tao 1980 that two-dimensional simulations do have some limitations; for example, artificially strong inhibiting effects on convection. It is thus desirable to investigate orographically induced precipitation for flow over a mountain ridge in a full three-dimensional model setup using CAPE as a regime control parameter.

2. Model and Methodology

Numerical experiments are undertaken with the Canadian non-hydrostatic mesoscale model MC2 (Benoit et al. 1997), using explicit warm-rain Kessler-type microphysics and a TKE-based turbulence scheme. The computational domain spans 500 km along the inflow direction and is 50 km wide. A horizontal resolution of 1 km should suffice to explicitly resolve the dominant convective processes (Weisman et al. 1997). In the vertical a stretched coordinate with 65 levels and level spacings ranging from 86 m at the lower boundary to 425 m at the model upper lid is applied. A timestep of 6 s is used for all simulations. The simulations are run until a quasi-steady state is reached.

All simulations are initialized with a sounding of uniform wind speed U=10 m s^{-1}, constant moist buoyancy frequency N_m=0.01 s^{-1} and constant relative humidity RH=0.95. The model orography is defined by a bell-shaped ridge of the form

$$h(x) = h_0 \frac{a^2}{a^2 + x^2},$$

where h_0=500 m and a=20 km are the mountain height and half-width. Thus, the mountain-induced wave response is expected to be linear to a good approximation for this setup.

Figure 1 illustrates the resulting values of surface temperature and specific humidity as a function of CAPE of the upstream sounding. Note that after a sharp decrease at low CAPE the level of free convection (LFC) is roughly constant at 350 m, which is well below the maximum ridge height.

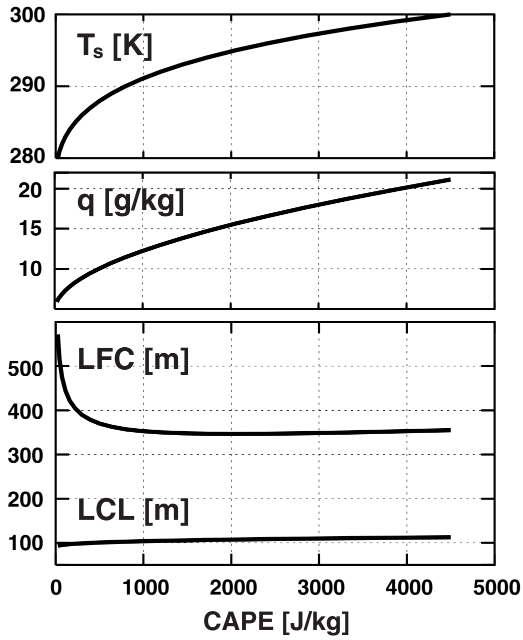

Figure 1. Surface temperature T_s, surface specific humidity q, lifting condensation level (LCL) and level of free convection as a function of convective potential available energy (CAPE) of the upstream sounding.

* *Corresponding author address*: Oliver Fuhrer, Institute of Atmospheric and Climate Science, ETH Zürich, Winterthurerstr. 190, Switzerland;
E–mail: fuhrer@geo.umnw.ethz.ch

The three simulations presented here were chosen to have surface temperatures of 280, 290 and 300 K and will be referred to by T280, T290 and T300, respectively. The soundings have CAPE values of approximately 25, 800, and 4500 J kg^{-1} corresponding to little or none, weak, and strong convective potential.

3. Results

The numerical experiments confirm that the CAPE of the incoming airstream is a good predictor for the nature of the flow. Experiment T280 (see *Figure 2a*) does not exhibit any convective precipitation. As the impinging airmass is stably lifted over the ridge it gives rise to a low-level cloud upstream and over the ridge. The maximum liquid water content is 0.6 g kg^{-1}, which suffices to produce light stratiform precipitation over a region of 20 km length shifted slightly upstream of the ridge (see *Figure 3a*).

In experiment T290 (not shown) the incoming airflow is sufficiently moist and unstable to trigger deep convective cells as airmasses are lifted over the ridge. The individual convective cells are mainly produced by the orographic forcing. They are on average 5 km in diameter and exhibit maximum updraft velocities of 10 m s^{-1}. *Figure* 3b shows that as the cells propagate downstream and decay in the lee of the mountain ridge, they give rise to a temporally and spatially highly variable field of intense precipitation (max. 100 mm h^{-1}). The cloud field is dominated by few cumulonimbus clouds to the lee of the ridge, reaching up to 7 km and being advected downstream by the mean flow. A quasi-stationary low-level stratiform cloud upstream and over the ridge is also present and produces substantial mean precipitation rates.

In experiment T300 (see *Figure 2b*) the incoming airflow is very unstable and strong deep convection occurs 30 km upstream of the highest point of the ridge. Numerous new cells are mainly produced either by an upstream propagating density currents caused by evaporative cooling or gravity waves generated by other convective cells. The convective updrafts are up to 20 km in diameter and exhibit maximum updraft velocities of more than 20 m s^{-1}. The convective cells decay much more rapidly than in experiment T290. Figure 3c shows that precipitation is very intense (max. 230 mm h^{-1}) and confined to a band of 100 km width centerd 20 km downstream of the ridge. The dense cluster of convective updrafts leads to

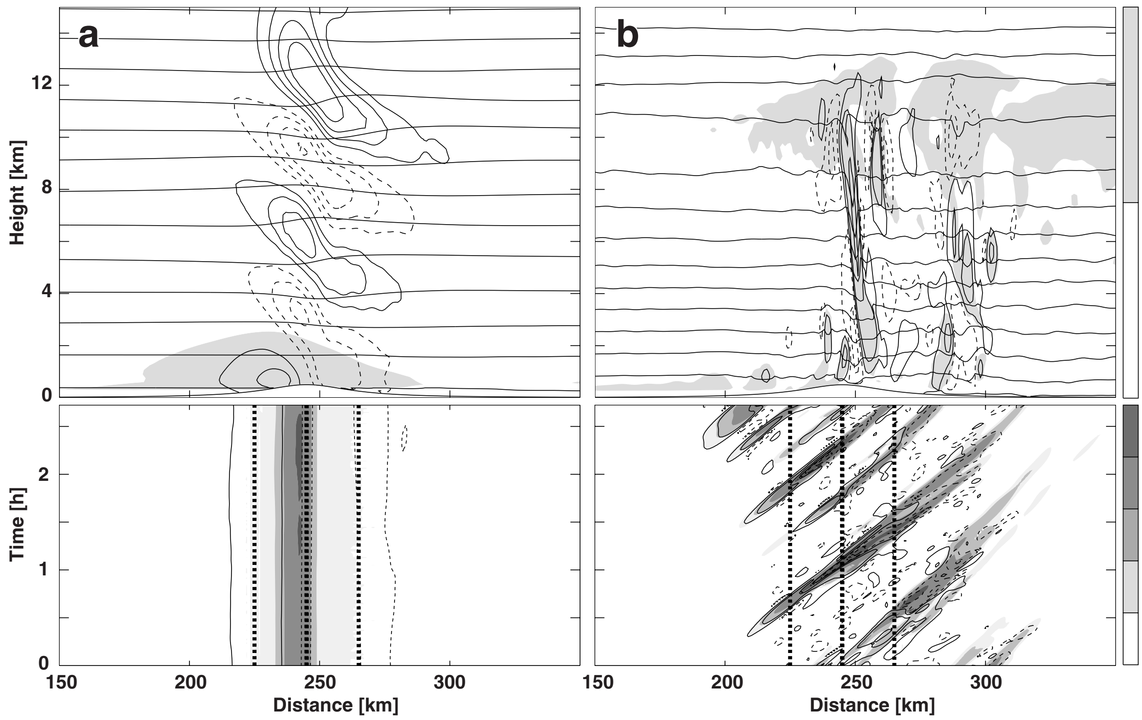

Figure 2. Overview of experiments T280 and T300 (see text). The upper row are xz-sections after one day of integration, the lower row are xt-diagramms close to the surface. Shown are the vertical velocity (thin contours; Panel a: +/-0.05, +/-0.1, +/-0.15, +/-0.2 m/s; Panel b: +/-0.5, +/-2, +/-10), potential temperature (upper panels, thin contours every 4 K), clouds (light grey shading), precipitation (lower panels, filled contours; Panel a: 0 to 0.2 mm/h; Panel b: 0 to 20 mm/h) and topography (lower panels, thick, dotted line at 250 m and 500 m).

the formation of a large cumulonimbus cloud with the cloud anvil located at 13 km, which is advected downstream by the mean flow.

5. Conclusion and Outlook

The experiments suggest that CAPE is a useful parameter for describing different regimes of orographically induced precipitation. At a low value of CAPE, precipitation is observed to be purely of stratiform type. As the CAPE of the upstream profile is increased solitary convective cells are triggered by upslope lifting and propagate downstream with the mean flow. At an even higher value of CAPE, a quasi-stationary, complex system of vigorous convective cells develops over the ridge and leads to intense and localized precipitation.

Further study and simulations will address the presence and role of embedded convection for settings close to the regime boundary between stratiform and convective precipitation (cf. Smith 1979). The sensitivty of the results presented to the shape of the topography and environmental shear will be investigated.

6. References

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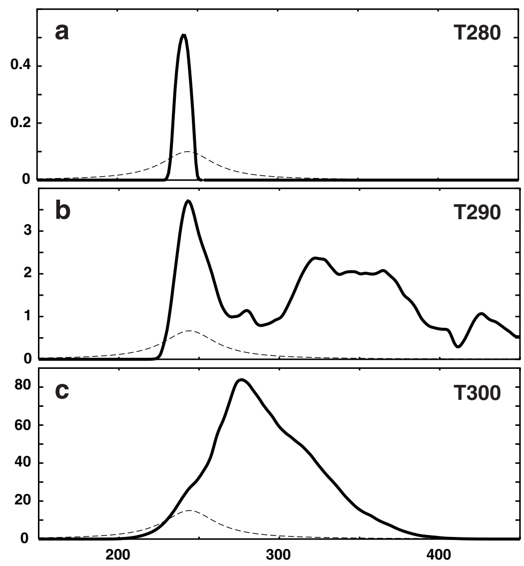

Figure 3: Total precipitation over 5 hours in mm averaged over the whole width of the computational domain. Dashed and in arbitrary units is the mountain ridge outline.

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