Evapotranspiration effects on mountain convection in ALADIN

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1. Introduction

Which meteorological processes determine if and where deep convection develops on a given day ? We need to address this question in order to improve the forecasting of convective precipitation. If synoptic-scale lifting mechanisms are weak or absent, meso-scale effects become important and topographically induced circulations and their convergence patterns become a major factor (e.g. Banta, 1990). With regard to the ALADIN model, this problem has been studied by Cordoneanu and Geleyn (1998). Another potentially important process is surface evapotranspiration. It partially compensates the afternoon drying of the PBL resulting from vertical mixing and thus has a direct effect on cloud base height and CAPE. Here we use the ALADIN model at high resolution (4 km) to investigate its contribution to convective rainfall in a mountainous area.

The effect of changes in Bowen ratio B=H/LE (H=sensible heat flux, LE=latent heat flux) on boundary-layer growth and convective cloud formation has been studied before (Rabin et al., 1990; Schrieber et al., 1996). It can be shown theoretically that, for a given total surface turbulent heat flux H+LE, the drier surface generates deeper convective boundary-layers and higher cloud bases (Haiden, 1997). How this affects cumulus cloud formation depends on stratification, among other things. Since the decrease in latent heat flux LE is linked to an increase in sensible heat flux H, the whole daytime boundary-layer evolution changes. Thus the specific effect of evapotranspiration as a water source cannot be isolated with this type of experiment. (It is however a very useful setup to study how deforestation affects convection, or how a prolonged dry spell reinforces itself through reduced convection.) Here we report on a different kind of experiment, where LE is set to zero only where it represents a water source for the atmosphere, but nowhere else. This is clearly an academic experiment because water gets 'lost' at the surface-atmosphere interface. However, it allows to directly quantify the effect of this water source on convective activity, without the complications due to a changed thermal structure, or changed flow patterns. Technically this was done by setting "`PDIFTQ(KLEV)=0`" in subroutine `ACDIFUS`.

2. Experimental setup

The area of investigation is a NW-SE running valley in Carinthia, Austria's southernmost province. The valley was chosen because it stretches along an almost straight line (an advantage for the evolution of a nearly ideal valley wind circulation) and because it is well covered by five stations, enabling a verification of the model output by observational data. The U-shaped, rather narrow valley is surrounded by mountains reaching well above 2000 m. At its lower end, it widens into the Klagenfurt basin, a large intra-alpine basin, at a height of about 500 m. The day of investigation, 10 August 2000, has been studied before (Haiden, 2001). The synoptic situation was characterized by high pressure with a weak northwesterly flow. On the lee side, i.e. in the southern part of the Alps, undisturbed diurnal circulations could evolve. The air mass was rather stably stratified and dry, so showers and thunderstorms formed only isolated over a few (also climatologically favoured) spots along the southeastern alpine rim, none of them inside the investigation area. The case is considered representative of a large number of days during summertime when convective conditions are rather suppressed but some thunderstorms and/or showers can form locally.

Two model runs of ALADIN (AL15) were carried out at a horizontal resolution of 4 km, the first with standard settings (further referred to as the reference run) and the second with evaporation set equal to zero (referred to as the experimental run). Results of the two runs were compared, especially with regard to the differences in the moisture patterns and simulated convective precipitation.

3. Results

In the reference run, convective precipitation starts in the late morning, around 09 UTC, and is at first strictly tied to orographical features. The first convective cells appear over the mountains framing the Klagenfurt Basin, where orographically induced convergence of the near-surface wind coincides with moisture advection from the basin. It takes two or three more hours until deep convection starts in the central parts of the Alps which do not experience humidity advection from adjacent basins or broad valleys. During the course of the afternoon, the correlation between precipitation and orographic features becomes weaker, giving way to a seemingly random precipitation pattern affecting parts of the valleys and subsiding in the evening hours. Total simulated rain amounts are low, large areas receive only some tenth of a millimeter and a few centres in the vicinity of effective "rain-producing" mountains get around 5 mm. Note that in the model much of the investigated area receives precipitation, whereas no precipitation was observed there by radar. The problem that the model generates convective precipitation too widespread and too often is well known, and is found in the operational forecasts (on 10 and 12 km resolution) as well. Figure 1a shows the areal distribution of convective precipitation generated by the reference run between 06 and 18 UTC.

In the experimental run only few areas receive precipitation (Figure 1b). This is because cloud bases are significantly higher (by up to 1 km) than in the reference run, and CAPE (not shown) almost reduced to zero. Note that the areas that still get some rainfall are close to the basin at the eastern boundary of the area, whereas in the inner-mountain areas rainfall is completely absent. Thus, the switching off of evaporation as a moisture source *everywhere* has shut down convection especially in the *inner parts* of the mountainous area. In the experimental run, the evaporation that maintains the valley's humidity excess compared to the surrounding mountains is missing as the most important humidity source. During the course of the day, boundary-layer moisture is completely mixed out by convection and not replenished. The usual structure with humid valleys and dry mountains gradually vanishes and turns into a smooth, rather homogeneous field. Reduced cumulus cloudiness allows stronger daytime heating over the mountains and intensifies the baroclinicity which drives the slope wind system. It is an interesting result that the convergence of the slope winds over the mountain tops is even slightly larger in the experimental run, and that is why also the convection's initial upward pulse is stronger. The overcompensation of this baroclinic enhancement of the convective cells by the higher condensation level is, however, sufficient to limit precipitation to those few places which offer the best conditions for deep convection.

Figure 2 shows the diurnal course of 2-meter specific humidity at the station Mallnitz (11260) situated in the upper part of the valley. The green line represents observational data and the white and red line show the results of the reference and experimental model runs, respectively. The negative bias of the reference model output is mainly due to the fact that the station height is 1185 m whereas the corresponding gridpoint in ALADIN is located at 2045 m. This is also why the operational run generates a curve with a marked single wave rather resembling a slope station whereas the observations, despite the station's rather high altitude, show weak characteristics of a broad valley with an indicated second humidity maximum in the morning. This second maximum, which was found at all stations in the valley, is due to advection of moisture by the up-valley wind. The experimental run shows a minimum late in the morning, when convective activity has mixed out the little boundary-layer moisture, before humidity increases again with the onset of the valley wind. Another interesting detail is that the model curves come close to each other again during the evening hours. A likely explanation is that the commencing mountain wind advects air from above the PBL, which has similar humidity in both experiments. Observed specific humidity, however, is much higher in the evening, presumably because a shallow valley inversion manages to decouple from overlaying air layers. This process is not simulated by the model due to its smooth topography which gives the location the characteristics of a slope rather than a valley floor.

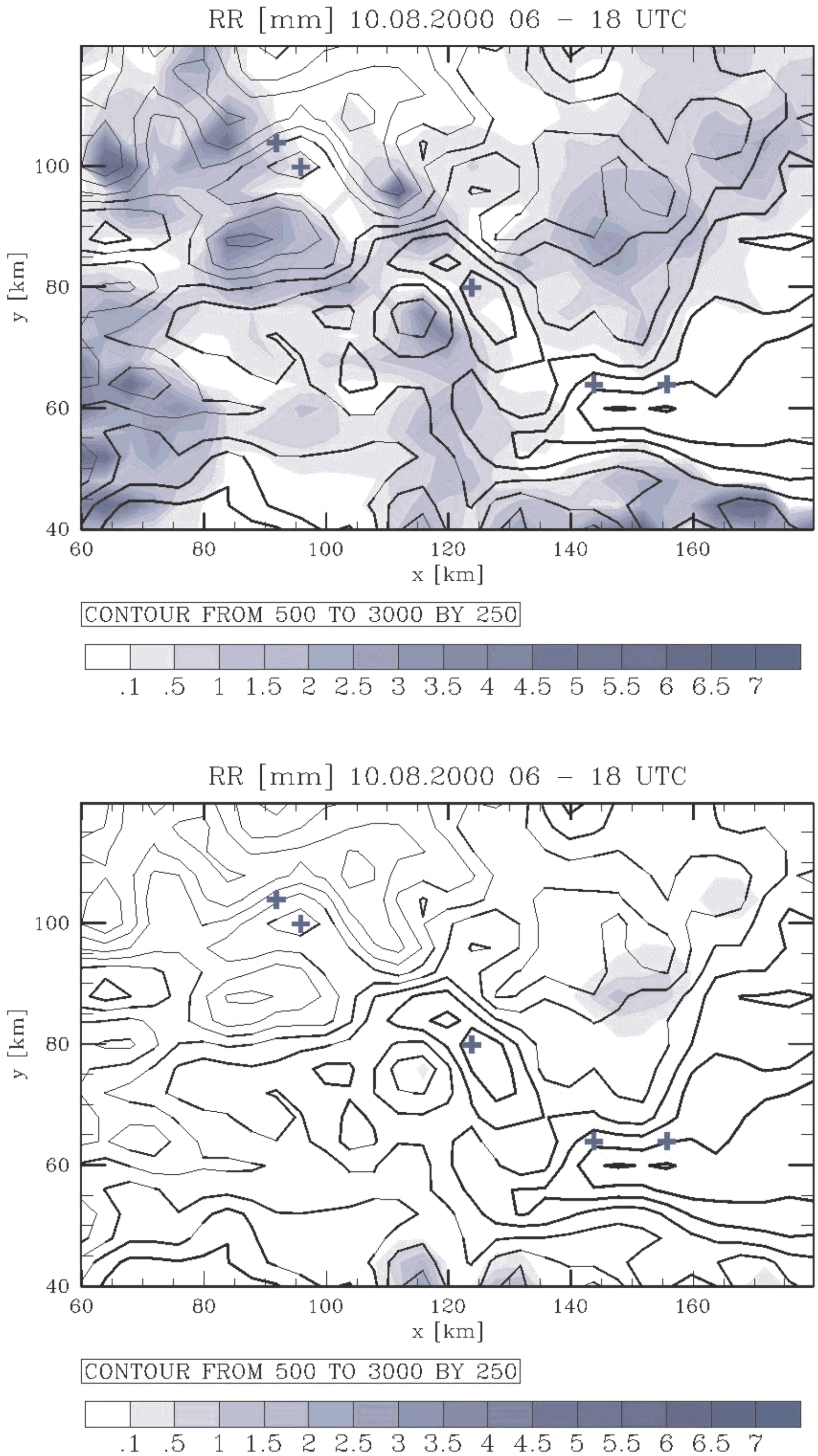

Figure 1 : Precipitation (in mm) generated by the reference model run (top) and the experimental run (bottom), on 10 August 2000 between 06 and 18 UTC. Isolines of the model topography are shown in black, the lowest being 500 m, the highest 2750 m and the spacing 250m; thicker lines represent lower elevations. The investigated valley runs from NW to SE through the area shown. Blue crosses represent the five stations covering the valley.

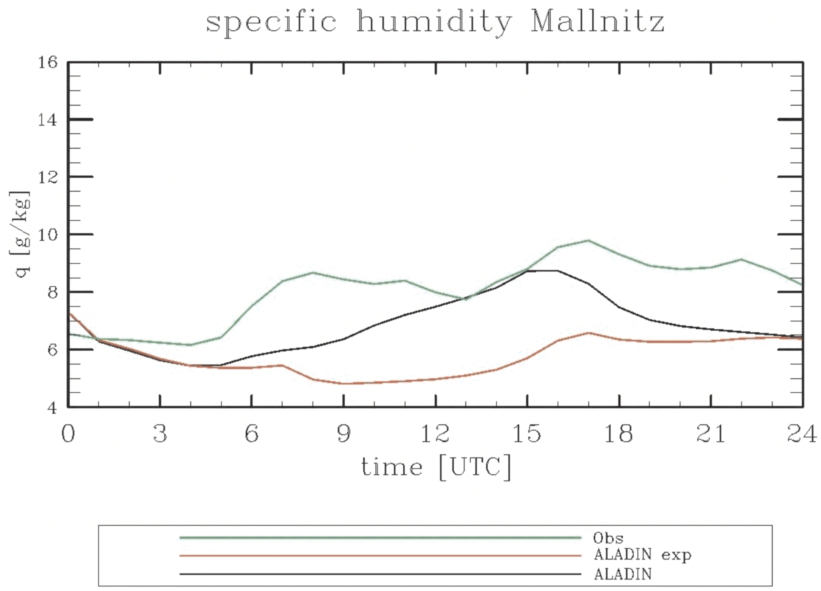

Figure 2 : Time evolution of 2-m specific humidity at the station Mallnitz (the westernmost station shown in Fig. 1), on 10 August 2000. The green line represents observational data, the black line the reference run and the red line the experimental run.

4. Conclusions

According to the model experiments, daytime surface evaporation has a large effect on convective rainfall in cases where convective activity is generally weak. Most of the areas that receive rainfall in the reference run remain dry in the experimental run. It is found that the inner, higher elevation parts of the domain are most sensitive to the lack of evaporation. With surface evaporation off, cumulus cloud bases were typically 500-1000 m higher, and CAPE decreased from 100-200 m^2/s^2 to near-zero values. The increase of 2m specific humidity during the day due to the up-valley wind is almost completely missing in the experimental run. This leads to a reduction of specific humidity in the valley of 2-3 g/kg. However, the experiment needs to be repeated (1) for a more unstable day with widespread convective activity, to see how much smaller the effect of surface evaporation is in those cases; (2) for a day where convective rainfall on the previous day has produced a distinct spatial pattern of surface evaporation that could directly affect the pattern of convective activity.

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