Filtering of LM-Orography

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1 Introduction

High resolution models often suffer from unrealistic forecasts in precipitation fields in mountainous areas. The LM exhibits large maxima in precipitation amount on the top of the mountains and conversely valleys are dry desert areas. In turn, the hydrological cycle will be modified in a strange way. This model behaviour is not confirmed by observations and obviously a fault.

Dynamics govern the precipitation forecast. We should test the dynamics on reliable flow fields in mountainous areas. In a study we examine four test cases. First, a mountain (height: 1500 m) is represented by only one gridpoint on a 7 km grid. Successively, the horizontal mesh size is reduced and the mountain is represented by more and more gridpoints. This refinement is done until the flow pattern doesn't change any longer. This state will be recognized as truth. From this study we deduce the height stucture of a mountain that gives a reliable forecast.

With this result, we know whether the orography of the mountain should be smooth in some way. We can apply a filtering operation to the orography for the flow field will develop in a numerical clean way. As a result, the precipitation forecast should improve significantly. But this filtering operation should not damage meteorological important and correct information.

We examine the problem of horizontal resolution in relation with the precipitation field. Other problems with orography should also be mentioned. The circulation in valleys represented by only one gridpoint does not develop in a right way. Sometimes in winter, these gridpoints are completely decoupled from the dynamics and forcing is only done by radiation and horizontal diffusion. This may lead to unrealistic cooling in the valley.

2 Idealized Experiments

2.1 Configuration of Experiments

The configuration of idealized experiments is shown in the table below.

Number	Resolution	dlam dphi	zda	ie_tot	dt	i(hmax)
1	1*	0.0625	0.5	32	60	17
2	2*	0.03125	1	32	40	17
3	4*	0.015625	2	64	20	33
4	8*	0.0078125	4	128	10	65

Following values are used for all calculations.

- zhmax = 1500 m
- u = 10 m/s

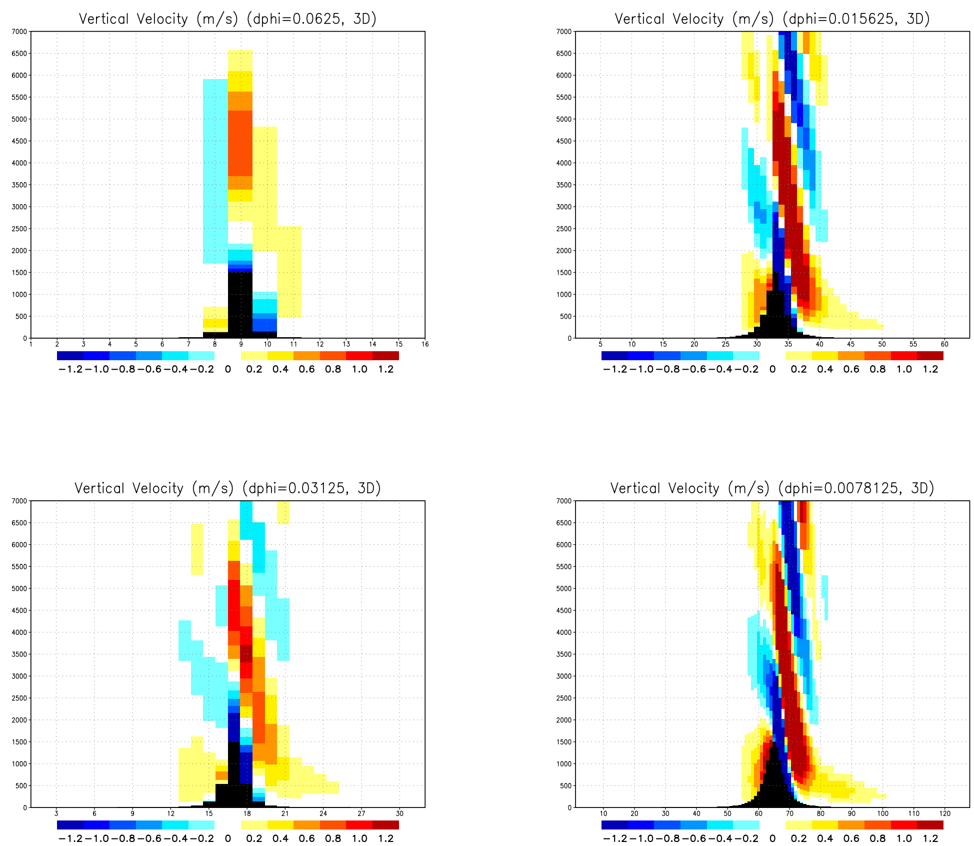

Figure 1: Vertical velocities for different resolutions

- TSL = 5 ^{o}C
- 95% relative humidity in middle troposphere
- 6.5 K decrease of temperature / 1000 m
- 12 h forecast time

The mountain is represented by a bell shaped profile.

$$H(x,y) = \frac{zhmax}{(1 + (\frac{x}{zda*dlam})^2 + (\frac{y}{zda*dphi})^2)^{\frac{3}{2}}} \quad (1)$$

In the coarsest grid resolution, the mountain is represented by more than one gridpoint, but the height of the surrounding points beside the peak is negligible.

2.2 Results

A lee wave should develop in all experiments. Figure 1 shows the vertical velocity w in a vertical cross section. Mean flow is coming from the left. In all cases lee waves are forming, but their

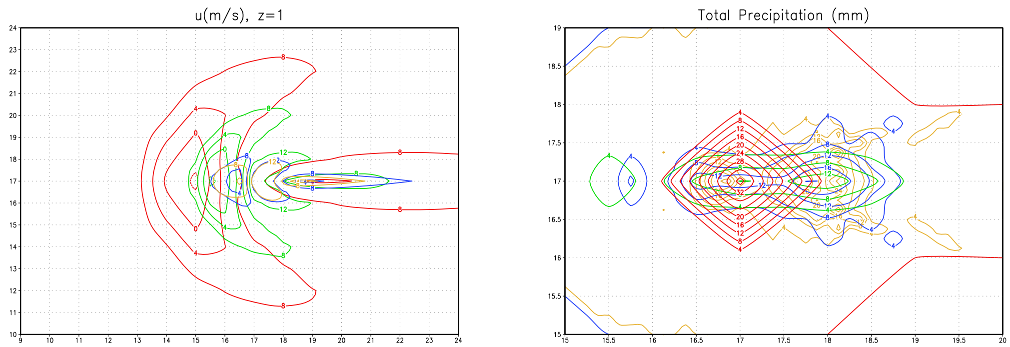

Figure 2: Horizontal velocity u in the lowest model layer and precipitation after 12 hours for different resolutions. red: dphi=0.625, green: dphi=0.03125, blue: dphi=0.015625, yellow: dphi=0.0078125

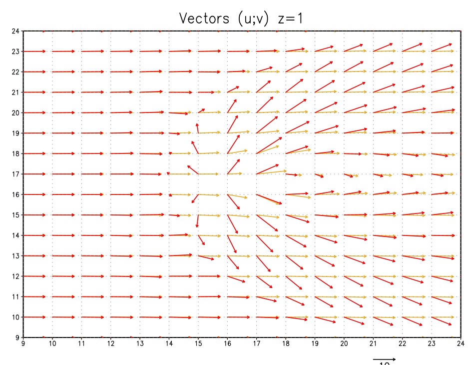

Figure 3: Vectors of horizontal velocity in the lowest model layer. Colors as in figure 2.

structures differ remarkably. Locations of maximum upwind areas in the two coarser resolution experiments do not coincide with the pattern formed with the finest resolution. But for the resolution with dphi=0.015625 the coincidence with the finest resolution flow is quite well. This is elucidated in figure 2 (left picture) showing the horizontal velocity u in the lowest model layer. Even negative u-values occur for coarser resolutions. The disturbed flow area is larger for coarser resolutions. Other model layers show similar results. The vectors of horizontal velocity in the lowest model layer (figure 3) give an impressive picture of different scales of the flow in different resolutions. In a coarse resolution, flow patterns are translated to a larger scale. This is not in common with the true solution.

Precipitation amount should converge to the true solution if mesh size is refined. But if the flow is not in the correct scale, precipitation field (figure 2 right picture) is neither. But as with the flow field, convergence is achieved from the resolution of dphi=0.015625. Due to the false representation of vertical velocity maximum on the top of the mountain, the coarsest resolution has a peak in precipitation just there. The overall precipitation amount is very different in the two coarser resolution cases from that of the two finer resolution cases which have an almost equal precipitation amount. A table shows the overall precipitation amount after 12 hours related

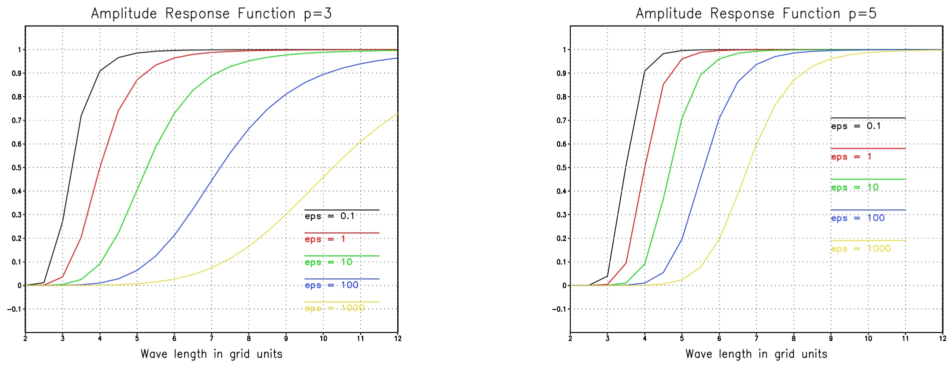

Figure 4: Amplitude response functions for different filtering parameters

to that of the finest resolution case (100%).

Number	Resolution	Precipitation amount [%] related to the finest resolution
1	1*	118
2	2*	60
3	4*	98
4	8*	100

We can conclude: A steep mountain represented by only one gridpoint is not able to produce a realistic flow pattern and, in turn, is not able to produce the right precipitation field. This error appears the more dramatic, the steeper the mountain is. Only a four times finer resolution can give a reliable solution, because it provides a sufficient number of degrees of freedom.

3 Filtering of Orography

The desired filter for orography should smooth all small scale structures until a grid size of $4\Delta x$. A suitable filter is the filter of Raymond (1988). It is very selective for short waves and does not damp the longer waves. This characterisic is controlled by the order of the filter and the filter parameter ϵ. The filter is defined by

$$[S^{2p}]u_n^F + (-1)^p \epsilon [L^{2p}] u_n^F = [S^{2p}] u_n. \tag{2}$$

In that, u_n are the original values of the field, u_n^F are the filtered values. The operators S and L are the sum operator and the finite difference operator of an order given by $2p$, ϵ is the filter parameter. From the amplitude response function

$$F(l) = \left(1 + \epsilon \tan^{2p}\left(\frac{\pi}{l}\right)\right)^{-1} \tag{3}$$

we know the properties of the filter. Here, the function is witten in dependency of l, the wave length in gridpoints. Figure 4 shows the amplitude response function for different orders and different filter parameters. A suitable configuration for our aim is a 10th order filter with $\epsilon = 10$.

The idealized mountain on the grid with dphi=0.0625 from the previous section will then be filtered in the following way. It will be represented by 5 gridpoints with a maximum height of 640

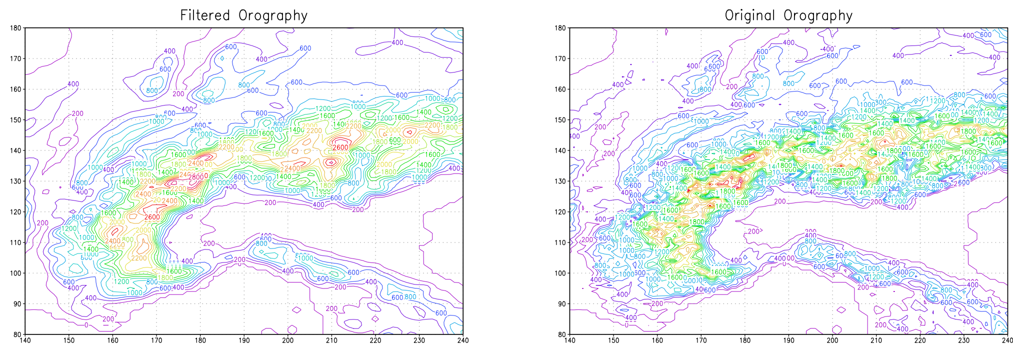

Figure 5: Orography of the Alps (mesh size 7 km)

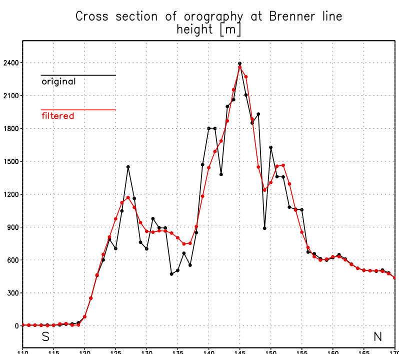

Figure 6: Cross section of orography in the Alps along the Brenner line

m. The structure is similar to that of the mountain in experiment 3 from the previous section, but on a larger scale. This height structure is sufficient to produce a realistic flow.

Figure 5 shows the original and the filtered orography of the Alps for the LM with the mesh size of 7 km. The original curve in Figure 6 is an example with a valley and a mountain represented by only one gridpoint each. After filtering, all valleys and all mountains provide enough degrees of freedom (gridpoints) for the proper flow field.

This filter produces, like many other filters, so called Gibbs phenomena. These oscillations near steep gradients have only a small amplitude, but can cause systematic errors. Consequently, the height of gridpoints over sea (land-see-mask smaller than 0.5) surrounded by at least 4 other sea gridpoints is set to the original value after filtering. Additionally, the sign of filtered orography should be the same as the original sign, otherwise height is set to the original value too.

4 Realistic experiments

We carried out an experiment for 8th of February 2000 and compared it with the routine run (figure 7). The routine run exhibits the well known features with unrealistic minima and maxima

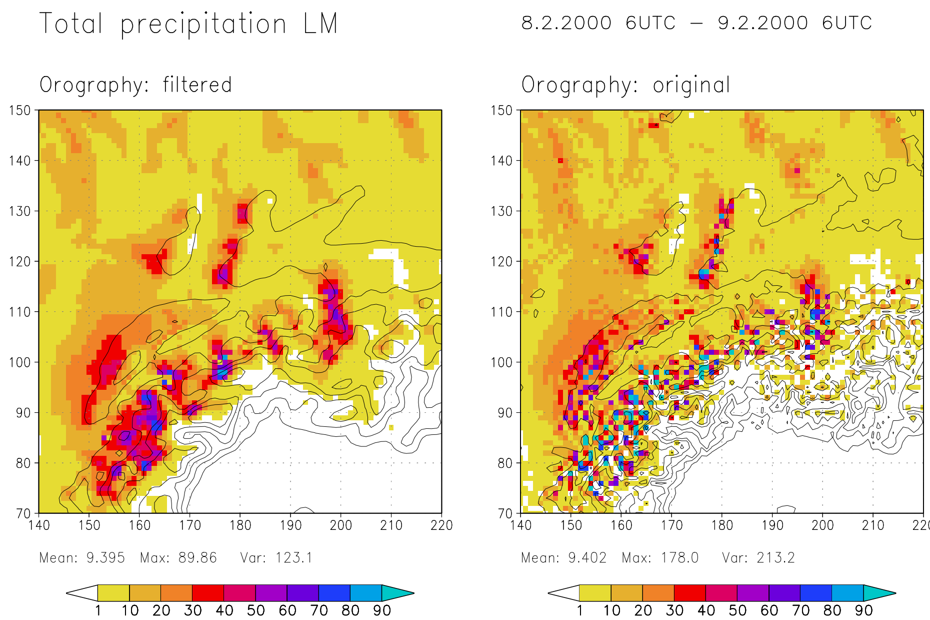

Figure 7: Precipitation fields of experiments with and without filtered orography.

in the precipitation field in the Alps. In contrary, a smooth field can be found in the experimental run. Larger scale precipitation patterns are the same in the experimental and the routine run. The mean value of precipitation in both runs is the same, whereas the maximum and the variance of precipitation drops to one half in the experimental run with filtered orography. The new field seems to be much more realistic than the routine one. There is no loss of reliable information. In regions outside the high mountains, differences are negligible. This filtering has a positive influence on the hydrological cycle and the prediction of precipitaion as well as on other dynamically driven processes.

Another test case was the Christmas storm "Lothar" on 26th of December 1999 (figure 8). Here, we wanted to test the LM with the filtered orography with an extreme weather situation. Provided the right boundary values, wind maxima and sea level pressure are as well recognized as in a comparable run. The local patterns of wind maxima seem reasonable and are similar to those in a comparable run. Filtered orography does not remove any meteorological relevant information.

5 Conclusion

This study gave us a positive result. The real numerical resolution of phenomena is on a larger scale than the grid scale. Forcing below the scale of numerical resolution is not only without any sense, it even causes errors by translating the response to larger scales. By filtering orography, the forcing scale is comparable to the numerical resolvable scale. Important information is retained and structures that could produce false information are not forced. There is a necessity to filter the orography.

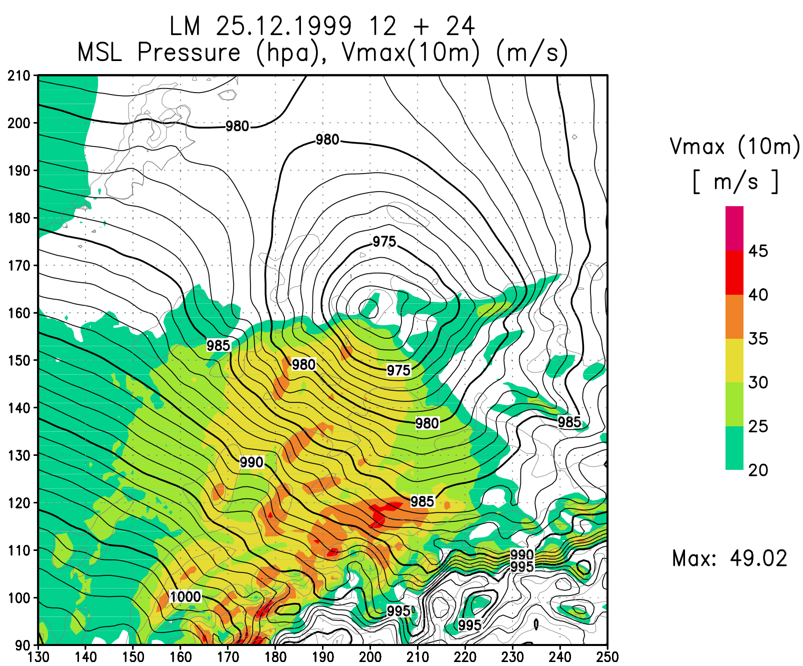

Figure 8: Christmas storm "Lothar"