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THE ALPINE MOUNTAIN-PLAIN CIRCULATION: AIRBORNE DOPPLER LIDAR MEASUREMENTS AND NUMERICAL SIMULATIONS USING MM5 AND LM

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1. INTRODUCTION

The air in Alpine valleys is heated faster than over plains due to the smaller air volume in valleys (Steinacker 1984). On days with strong solar radiation this leads to a temperature difference between the foreland and the Alps, and a heat-low builds up in the mountains. The pressure gradient drives a flow from the foreland to the Alps within the boundary layer. This wind transports air and pollutants to the Alps, where they partly reach the free troposphere. The return flow in the troposphere is usually masked by stronger gradient winds (Burger and Ekhart 1937). The Alpine mountain–plain circulation occurs on about 30% of all days between April and September (Lugauer 2003).

This study investigates the structure and the mass transports of the circulation on 19 July 2002 using data from an airborne scanning 2 µm Doppler lidar system. The synoptic situation on 19 July 2002 was fairly typical for the development of a mountain-plain circulation. The high pressure system “Brian” caused a sunshine duration of up to 10 h, and weak pressure gradients at all levels.

The structure and the mass fluxes were compared to numerical simulations with the PennState/NCAR mesoscale model MM5, and the Local Model (LM) of the German Weather Service (DWD).

The measurements were taken during the VERTIKATOR campaign (“Vertical Transports and Orography”) in June and July 2002. The objective of the campaign was to study vertical exchange processes above gentle and steep terrain. The target regions were the northern foreland of the Alps and the Black Forest Region in Germany.

2. THE AIRBORNE 2 µm DOPPLER LIDAR

The system measures vertical profiles of the 3-dimensional wind vector beneath the aircraft with a vertical resolution of 100 m, and a horizontal resolution of up to 5 km. The profiles are obtained by the velocity-azimuth display (VAD) technique (Browning and Wexler 1968). This is done with a conical step and stare scan around the vertical axis with 24 positions. The accumulation time is one or two seconds at every position (500 and 1000 pulses respectively), which reduces the speckle noise. Furthermore, the 2 µm laser has a near Gaussian shape in spatial, temporal, and spectral domain, which minimizes the uncertainty of the Doppler estimates. The ground return can be used to calibrate the attitude angles and speed of the aircraft.

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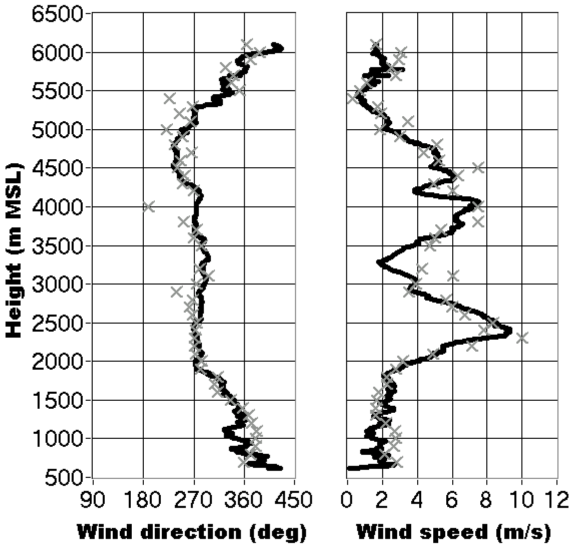

Figure 1: Vertical profile of wind direction (left) and wind speed (right) at 12.21°E and 47.94°N. Dropsonde data is shown with a black solid line and lidar data with gray x.

The lidar data of 19 July 2002 was compared to five dropsondes, which were launched on the same flight. One example can be seen in Figure 1. The statistical comparison of the horizontal velocities showed a standard deviation of 1.1 ms^{-1}, and an unknown bias of 0.09 ms^{-1}. However, the two instruments do not measure exactly the same: dropsonde data are line measurements, while the lidar data are volume averages along the flight track (about 5 km for one profile). This obviously leads to differences, which are not an error of one system.

3. MODEL DESCRIPTIONS

For the presented work we used two non-hydrostatic models: LM (Doms and Schättler 1999) and MM5 (Grell et al. 1995).

The LM was run with a horizontal mesh size of 2.8 km and 7 km. The model uses an Arakawa-C grid and has a generalized terrain-following coordinate system with 40 layers in the vertical. The initial and boundary fields were provided from the global scale hydrostatic model GME.

The MM5 was run with several interactively nested grids in a forecast domain covering most of Europe and the Mediterranean. The model uses a terrain-following coordinate system with 38 layers in the vertical. The initial fields were taken from the ECMWF analyses at 19 July 0000 UTC.

4. STRUCTURE OF THE CIRCULATION

The mountain-plain circulation on 19 July 2002 could be documented with three vertical cross-sections of Doppler lidar data (Figure 2): one cross-section parallel to the flow (north-south, black line on Figure 2), and two cross-sections perpendicular to the circulation (west-east, red and blue line on Figure 2). The northern west-east cross-section is shown in Figure 3.

The lidar data showed a layer with northerly flow (flow towards the Alps) and wind speeds of about 1 – 4 ms^{-1} in the lower part of the boundary layer (Figure 3). Northerly flow extended about 80 km into the Alpine foreland to north of the Alps. The layer increased in depth from 800 m to the north to 1200 m at the rim of the Alps. The height of the boundary layer increased from about 2000 m MSL in the foreland to 4200 m MSL above the Alps. Westerly winds were observed above the boundary layer.

With the use of lidar wind data it was possible to quantify the mass flux through the west-east cross-sections. The density was calculated with the temperature and pressure data of five dropsondes. The calculated mass flux through the northern cross-section (Figure 3, length = 223 km) was 4.9 * 10^8 kg s^{-1}, the flux through the southern cross-section was 3.9 * 10^8 kg s^{-1}. This means that nearly the whole air in the lowest kilometer of the atmosphere between Munich and the Alps is transported to the Alps on a sunny day in summer.

Southwesterly winds were observed between 2000 and 3000 m MSL, which indicate the return flow.

5. EVALUATION OF SIMULATIONS

All simulations were able to reproduce the general circulation, the temperature, and the humidity field.

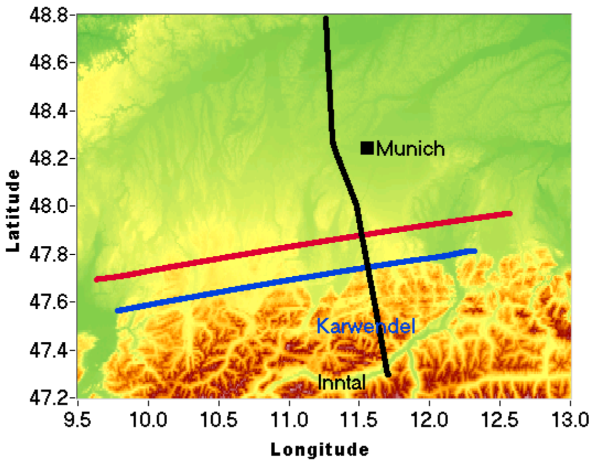

Figure 2: The investigation area at the northern Alpine rim with the location of Munich, the Inn Valley (Inntal), and the lidar cross-sections.

Even the two simulations with a coarse mesh of 6 km (MM5) and 7 km (LM) were able to reproduce a mass flux from the foreland to the Alps. At the northern west-east cross-section: the mass flux in all four model runs was within a range of 86 - 122% of the flux derived from the lidar data. On the southern cross-section the simulations overestimated the mass flux by up to 46%.

6. VERTICAL MOTIONS

It is possible to determine vertical velocities from airborne Doppler lidar measurements. With a fixed scanning angle the lidar can be used to measure the structure of updrafts and downdrafts (Figure 4). In the scanning mode the lidar measures mean profiles of vertical velocities (Figure 5). The magnitude of these mean vertical velocities (net rise/sinking) is very small (up to 0.1 ms^{-1}), which is a challenging task for airborne Doppler lidar. However, the speed of the ground return can be used to calibrate the aircraft attitude angles and speed. After this correction the mean vertical velocity of the ground return was –2 * 10^{-3} ms^{-1} on the southern cross-section and –7 * 10^{-3} ms^{-1} on the northern cross-section.

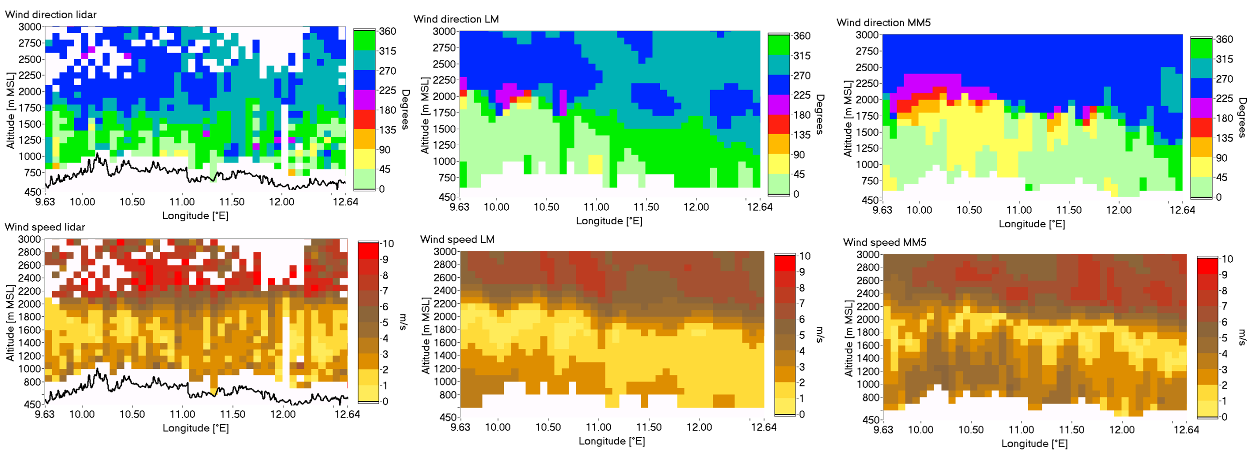

Figure 3: Vertical cross-sections of wind direction (top) and wind speed (bottom) along the red line on Figure 2: lidar data (left), LM run with mesh size 2.8 km (middle), and MM5 run with mesh size 2 km (right).

Furthermore the vertical velocities above the boundary layer, which should be close to zero in the present synoptic situation can be used as a quality control for the lidar data.

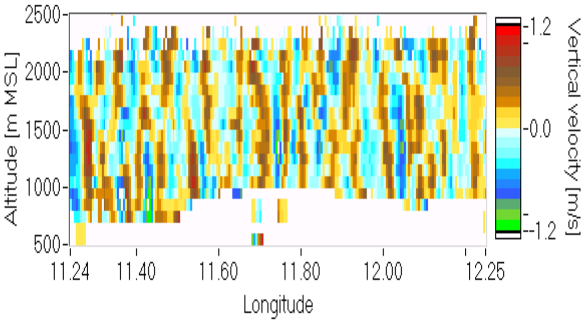

Figure 4: Vertical cross-section of the fluctuations in the line-of-sight velocity along the eastern part of the southern west-east cross-section (blue line on Figure 2).

The fluctuations of the line-of-sight velocity (Figure 4) were used to investigate the structure of convection. The wave length of convection (width of one updraft and one downdraft) was about 3 km. In contrast the convective wavelength in the simulations was about 30 km with a mesh size of 2 and 2.8 km, and 60 km with 6 and 7 km mesh size.

In many aspects the convective structures are similar to previous measurements (e.g.: Cohn et al. 1998). But in contrast to other studies no broad regions with weak sinking motions were observed. At a height of 1500 m MSL 48% of the area was covered with updrafts, 46% with downdrafts, and 6% were missing values. It was concluded that this difference to previous measurements is due to the location of the cross-section in the vicinity of the Alps, where the lidar measured a net rise (Figure 5), and a horizontal convergence.

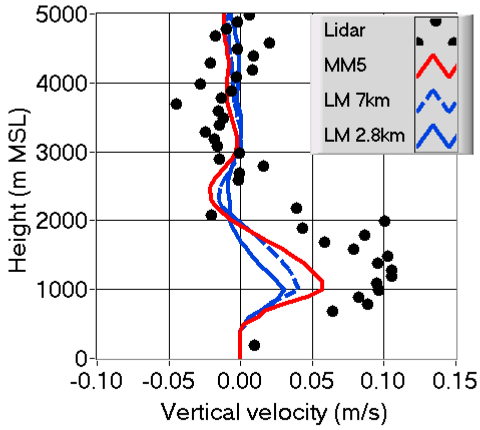

Figure 5: Vertical profiles of the mean vertical velocity averaged along the blue line on Figure 2.

The profiles of the mean vertical velocity measured by the Doppler lidar (Figure 5) show a net rise of up to 0.1 ms^{-1} on the southern cross-section. In general they have a similar structure as the mean profiles in the numerical simulations. The magnitude of the mean rise is about 2 – 3 times higher than in the simulations, which agrees with the finding that the horizontal convergence between the northern and the southern cross-section is smaller in the simulations than in the lidar data (Section 5).

7. CONCLUSIONS

The Alpine mountain plain circulation could be documented with airborne Doppler lidar data. The flow towards the Alps extended about 80 km into the Alpine foreland to the north of the Alps. It increased in depth from about 800 m in the north to 1200 m at the rim of the Alps. The mass flux could be quantified with two cross-sections parallel to the northern rim of the Alps.

Numerical simulations with LM and MM5 were able to reproduce the general circulation. The mass flux in the simulations was within a range of 86 to 146% of the mass flux derived from lidar data.

The lidar also measured vertical velocities. A cross-section with a fixed scanning angle was used to investigate the structure of convection. The horizontal wave length of convection was about 3 km. In contrast the convective wave length in the simulations was between 30 km and 60 km (increasing with mesh size). It is concluded that a significant reduction of the mesh size would be necessary in order to actually resolve convection (approximately 100 or 200 m).

Cross-sections with a scanning mode were used to calculate vertical profiles of the mean vertical velocity. Although these values are only up to 0.1 ms^{-1}, they agree well with the horizontal mass budget. This new method of measuring mean vertical velocities seems to deserve future attention.

8. REFERENCES

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