7.2 FIRST CLIMATOLOGICAL ANALYSIS OF MOUNTAIN VENTING USING WATER VAPOUR PROFILES UP-WIND AND DOWN-WIND OF THE ALPS

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1. INTRODUCTION

Mountain venting during fair-weather episodes is one of the processes that influence the exchange of air including water vapour and air pollutants between the atmospheric boundary layer (ABL) and the free troposphere (FT) (Kossmann et al. 1999).

High altitude research stations in the lower troposphere are often influenced by air pollutants and water vapour from the polluted ABL (Baltensperger et al. 1997). At the Jungfraujoch (JFJ) high altitude research station in the central Swiss Alps (3580 m MSL) the amplitude of the diurnal variation of specific humidity q is about 1.7 g kg^{-1} and peaks at 1700 UTC within the summer season (Forrer et al. 2000). It is suggested that vertical transport in a certain catchment area influences the concentrations measured at mountain peaks (Seibert et al. 1998).

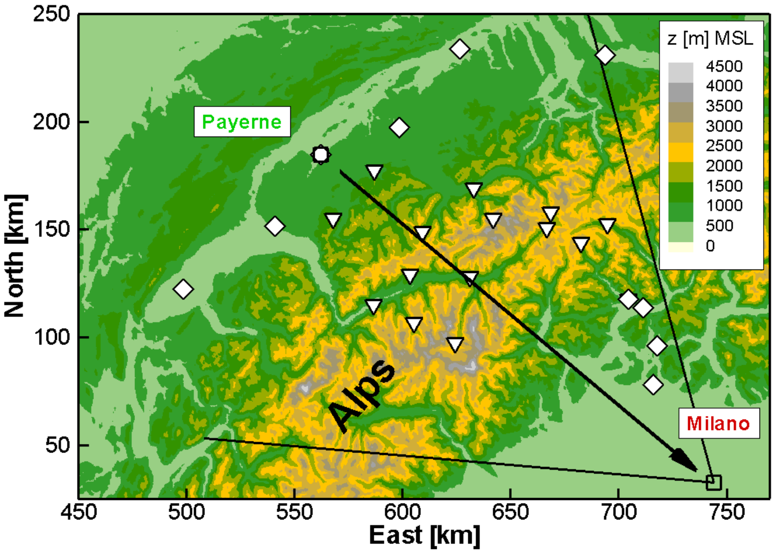

Figure 1: Overview of measurement sites and Alpine terrain. Sounding sites Payerne and Milano. Surface stations used for selection of fair-weather days (diamonds), surface stations used for lighting, rainfall, specific humidity in the ABL (triangles). Defined catchment area for Milano (solid line). Analyzed direction of advection (arrow).

So far, this vertical transport is only quantified for individual days within intensive field campaigns. 3 times the ABL air mass within deep Alpine valleys is injected into higher altitude layers (typically 2000 to 4000 m MSL) during day-time, fair-weather summer conditions (Henne et al. 2004b). It was suggested that a large fraction of this injection layer would leave the Alpine area with the synoptically driven wind and would be incorporated into the lower FT. Individual lidar and total precipitable water observations support this hypothesis (Nyeki et al. 2002;Ohtani 2001).

In this study we used 12 years of water vapour sounding data to assess the effects of mountain venting in a more climatological manner.

2. METHODS

A comparison of specific humidity on the windward and the leeward side of the Alps was done for the radio sounding sites Payerne, Switzerland, and Milano, Italy (see Figure 1) for a 12 year period. Surface data and radio soundings were combined in the study.

The first data set contains standard meteorological parameters measured at stations of the automated surface station network ANETZ. For the period 1991 to 2002 hourly data were available. The data is used to select fair-weather days. If a day showed more than 9 hours of total sunshine duration at stations north and south of the Alps (diamonds in Figure 1) it was selected as a fair-weather day. Lightning activity and precipitation was measured at stations within the Alps (triangles in Figure 1). Days that showed lightning activity or rainfall were separated for the analysis.

The second data set contains radio sounding data of temperature, pressure, humidity, wind speed and direction for Payerne and Milano. Within the period 1991 to 2002 at least two soundings with the full parameter set were available per day (00 and 12 UTC). The distance between Payerne and Milano is 273 km. An air parcel would have to travel with 5.5 m s^{-1} from one station to the other within 12 hours.

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The sounding data was analysed in vertical bins of 100 m thickness for each fair-weather day. Specific humidity at altitudes that showed advection from Payerne towards Milano (dd ± 35°, ff < 10 m s^{-1}) was averaged for all selected cases.

3. RESULTS AND DISCUSSION

Figure 2 shows vertical profiles of specific humidity for advection from Payerne, 12 UTC, towards Milano, 00 UTC (12 hours later). Specific humidity increased significantly (probability of error < 0.05) from Payerne towards Milano within a layer from 2400 – 4100 m MSL that includes about 80 cases. Specific humidity at Payerne itself increased only slightly within this layer. The average wind speed in this layer fulfilled the lagrangian requirement. Below 2400 m MSL direct flow from Payerne towards Milano was rather seldom.

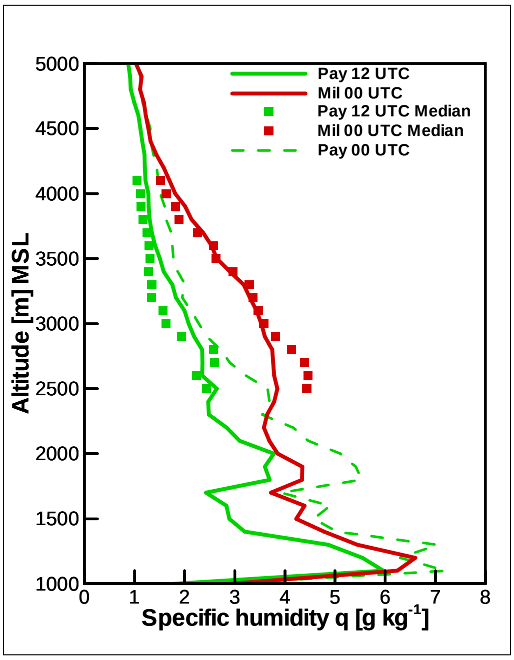

Figure 2: Vertical profiles of specific humidity *q* for fair-weather days, as measured in Payerne, 12 UTC (mean: solid green line, median at significant levels: green symbols), Milano, 00 UTC (red line and symbols), and Payerne, 00 UTC (dashed green line).

Thermal air flow is approximately active from 9 to 17 UTC in the Alps on fair-weather days during summer. An air parcel that arrives at 00 UTC over Milano therefore receives thermal plumes of ABL air injections over mountainous terrain from 13 – 17 UTC. An air parcel travelling with the same speed, but arriving at 12 UTC in Milano would not be influenced by thermal injections.

In the second case (night-time advection) specific humidity did not increase from Payerne to Milano for the same selection of fair-weather days (not shown).

The fraction of boundary layer air that reached a certain altitude was calculated by using the concept of relative increase (Prevot et al. 2000) for specific humidity observed in the Alpine ABL, the windward and lee side sounding. About 30 % of the air within the altitude range 2500 – 2500 m MSL originated from the ABL on fair-weather days with advection from Payerne towards Milano

Average potential temperatures θ (not shown) increased during day-time (12 – 00 UTC) transport from Payerne towards Milano by 2 K within the layer of significant specific humidity differences. Since injections and diabatic processes might be active in this altitude range, it was not possible to attribute the warming to adiabatic subsidence. Above 2500 m MSL θ increased less than 1 K. This corresponds to a downward motion of about 200 m within 12 hours if the warming was only caused by adiabatic subsidence. Therefore, we assumed that an air parcel returned to about its original altitude after crossing the Alps. Average relative humidity was lower than 40 % at the windward side and between 50 and 60 % in the lee, showing that diabatic warming due to condensation played only a minor role in the investigated cases.

A similar elevated layer of increased specific humidity in the lee of the Alps at Milano as observed on fair-weather days was also present in the average day-time profiles for the whole summer season (JJA). Only days with lightning, rainfall and high wind speeds were excluded.

Advection from Milano towards Payerne was very seldom. Only one summer day was suitable for the analysis of the day-time advection. It showed a broad layer with increased specific humidity in the lee side (Payerne in this case) sample, but no climatological conclusion can be drawn in this case.

4. CONCLUSION

An increase in specific humidity was observed for day-time advection from Payerne towards Milano. No increase could be observed during night-time advection. Mountain venting is therefore hold responsible for the vertical transport. The observed elevated layers were above the ABL height as identified over the flatlands surrounding the Alps. Mountain venting therefore enhances export of ABL air to the FT.

The results of this climatological analysis agree well with findings from previous field campaigns. Mountain venting was found to be the most important process for humidity increase in the lower free troposphere in the lee of the Alps during the summer season. Continental pollution budgets are therefore influenced by this mechanism that is up to now not adequately represented in global chemistry transport models.

A more detailed description of our analysis was submitted to the Journal of Applied Meteorology (Henne et al. 2004a).

5. ACKNOWLEDGEMENT

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