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INVESTIGATION OF OBSERVED AND MODELLED NOCTURNAL WIND AND TEMPERATURE OSCILLATIONS IN AN ALPINE VALLEY

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1. INTRODUCTION

The study is based on measurements carried out in the Inn Valley, Austria (see Fig.1a), during winter 2005/2006 in the context of the European Interreg IIIB project ALPNAP[**](Heimann et al., 2007). The measurement sites where all located in the Inn Valley (see section 2.1), at the foot of the valley slopes .

We found some interesting recurrent events and fluctuations manifesting in sudden nocturnal temperature drops. We are trying to understand the causes of these phenomena by investigation of the observations and used additionally simulations with MM5 which may help to understand these fluctuations.

Similar kinds of simulations have been carried out by Hornsteiner and Zängl (2004), who modelled a local “mini-föhn” using MM5 and in Zängl and Vogt (2006) who compared valley wind characteristics in the Rhine Valley whereas Monti et al. (2002) investigated fluctuations in katabatic flows at the foot of a slope in the Salt Lake Basin, to mention only a some of the large number of and interesting literature.

2. DATA AND METHODS

2.1 *Measurements*

Three mast sites have been operated by BOKU located between Stans and Jenbach (see Fig. 1b). The locations of the measurement sites have been chosen with respect to investigations of the Prandtl layer and sound propagation in an Alpine valley. Therefore the stations are all located a bit above the valley bottom on the slopes as the railroads and the Inntal motorway follow the course of the Inn river (see Fig. 1b). Fig. 1b shows that the stations Stans and Buch are influenced by the houses of the nearby villages, Stans for the direction southwest and Buch for the direction northeast whereas the site Tratzberg is in a free location.

At all the three sites wind and temperature measurements were carried out and additionally an ultrasonic anemometer, RM Young 81000, has been operated at Stans to get accurate and highly resolved wind and temperature measurements. These measurements are needed for a better interpretation of atmospheric boundary layer processes and sound propagation. The sonic has been operated at a height of 2.5 meters with a recording resolution of 10 Hz to capture all turbulence characteristics, including surface fluxes of heat and momentum. The sensors used at the masts where light propellers for wind with icing problems, and temperature sensors at three, respective two different heights. In Tratzberg and Buch a 5 m and in Stans a 10 m mast have been used. Table 1 gives an overview of the measurements. Except for 24 missing days in the sonic, the data at the three sites are available for the whole measurement period starting on 28 November 2005 and ending on 6 March 2006.

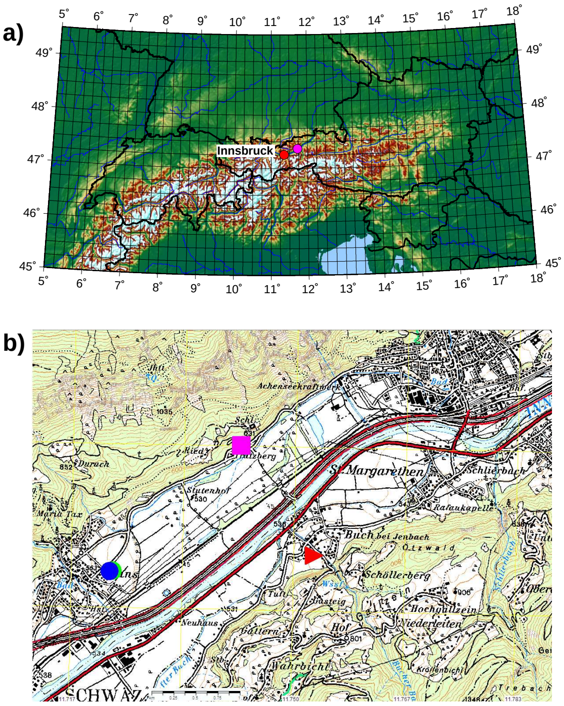

FIG. 1: a) Location of the measurement site in magenta, capital of Tyrol, Innsbruck, is marked with a red dot. b)Location of the three measurement sites, Tratzberg with the box in magenta, Stans sonic with the green dot, Stans mast with the blue dot and Buch with the red triangle. The Inntal motorway (red outline and black inner lines) is located on the northern bank of the Inn (in blue), the railroad can be found a bit above marked by a black line.

The ultrasonic raw data have been preprocessed using our own routines and further investigated for calculation of turbulence characteristics and mixing heights using the eddy covariance software package (ECPACK) of the University of Wageningen (Van Dijk et al., 2004). The format needed as input to the ECPACK is netcdf, therefore the sonic data had to be converted using the csi2ncdf software of the University of Wageningen. Processed data of the sonic is available in 1 minute, 5 minutes and 30 minutes means of wind speed, wind direction and acoustic temperature as well

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as 5 minutes and 30 minutes means, standard deviations and fluxes of the turbulence quantities. Here results of the 1 min and 5 min means are investigated and shown.

2.2 *Modelling*

The PSU/NCAR mesoscale model MM5 (Dudhia, 1993; Grell et al., 1996) version 3.7.4 was used in this study with the modifications based on G. Zängl's Alpine MM5 version (Zängl, 2003). Due to lack of time and hardware resources results presented here do not contain the measurement period but a 10–day high pressure winter smog period with stable stratification in the valley and diurnal cycles of the valley wind during January and February 2004.

Out of this 10-day period a 60 hour simulation in February 2004 was carried out. The simulation produced output every 5 minutes with a resolution of 0.27 km x 0.27 km in the innermost nest, domain 6. The ETA–ABL scheme, 2-way nesting and FDDA nudging on the outermost grid towards the ECMWF analysis (horizontal resolution = 1°, temporal resolution = 3 hours) have been used in addition to Zängl's z-diffusion scheme and orographic shadowing. The Noah land surface model, USGS 30'' elevation data and the built–in land–use and surface property data were used. One should note that this leads to a terrain representation at 0.27 km grid size which is smoother than what would be obtained with better terrain elevation data. Reisner 1 moisture scheme, Kain-Fritsch 2 cumulus parameterisation and cloud radiation scheme have been applied. Model top was at 50 hPa, and 35 sigma levels have been used.

3. CASE STUDY

3.1 *Observations – March 2 2006*

Several events of nocturnal temperature and wind oscillations can be found in the data sets of all three sites. The most interesting case took place during the night from March 1 to March 2, 2006. The synoptic conditions on March 1 where determined by a cut-off low located over the North Sea pushing cold polar air towards the Alps. This resulted in very cold air at the Inn Valley during the night.

In Fig. 2a the 1 min means of the temperatures of March 2, 2006 at all three measurement sites are shown. Additionally, 30 min mean of a measurement site operated by the University of Innsbruck near Schwaz located at the valley bottom is shown in black for the same period. A diurnal cycle can be identified at all sites, highest temperatures during the day can be found at Tratzberg, lowest temperatures during day at Buch. During nighttime and late afternoon temperatures at the three stations do not differ much. Measurements of Schwaz show that the air at the valley bottom is colder than the air at the foot of the slopes. The interesting nocturnal temperature oscillations which we wanted to investigate are displayed in Fig. 2b. During the first 6 hours of March 2 in total seven strong decreases of temperature can be found at Tratzberg and Stans and five at Buch, which lies on the opposite side of the valley. Three of this rapid drops in temperature, denoted P1 to P3, will be further investigated with a closer focus on the stations Tratzberg and Stans.

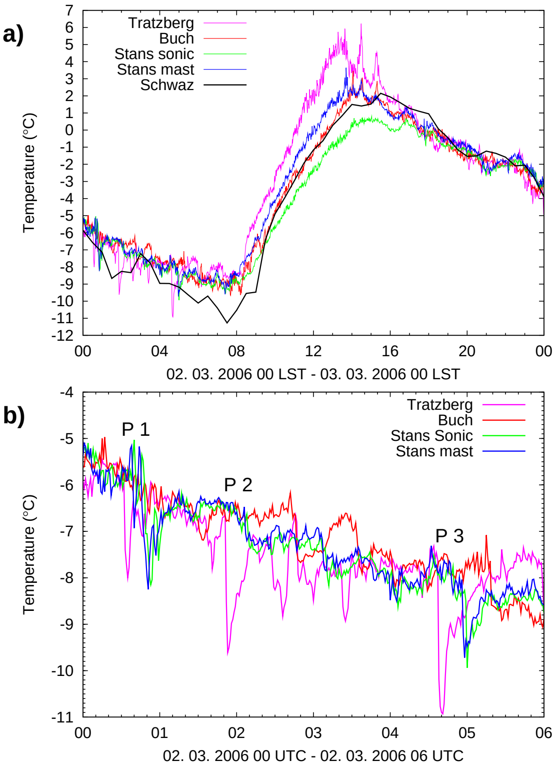

FIG. 2: a) 1 minute means for March 2 2006 00 – 24 LSTof the temperature for Tratzberg (magenta), Buch (red), Stans mast (blue) and Stans sonic (green) and 30 minutes mean of the temperature at a mast station near Schwaz at the valley bottom (black). b) the same as in a) but whithout Schwaz for March 2 00 – 06 LST.

The first interesting event, P1 (see Fig. 3), started at 0:32 LST and ended at 0:35 LST whith a temperature drop from –5.9° C to –8.0° C. At the same time the wind turned from north, down–slope, to south, up–slope from the valley bottom, wind with low wind speeds. At Stans, another temperature decrease occurred 14 minutes later, starting at 0:46 LST with –5.4° C and ending at 0:52 LST with –8.1° C as the lowest temperature. At Stans the wind turned from northerly flow (downslope) to easterly flow bringing the cold valley bottom air towards the station with low wind speed.

The second major event, P2 (see Fig. 4), ocurred at 1:51 LST at Tratzberg starting with a temperature of –6.6° C, 1:52 with –8.5° C and at 1:53 with –9.6° C. Again, the wind turned from northerly to easterly flow, too a direction bringing the cold air from the valley bottom to the station Tratzberg. Opposite to P1, the temperature drops more rapidly due to higher wind speed when the wind turns into the easterly flow. Also at Stans a temperature decrease, about 17 minutes later than the Tratzberg event, can be observed but not that strong as in P1. Here the wind direction changes from westerly, alongslope, to a southerly flow. At Buch we can observe about an hour later, at 2:46 LST, a temperature decrease from –6.6° C to –7.6° C at 2:50 LST with wind direction turning from a southeasterly flow, here at Buch down–slope, to a northerly/northeasterly flow, upslope, with cold valley air.

Station	height	type	parameters and levels		time
		T	dd,ff	resolution	
Buch	567 m	mast	2 m, 5 m	5 m	10 min, 1 min
Tratzberg	542 m	mast	2 m, 5 m	5 m	10 min, 1 min
Stans	548 m	mast	2 m, (5 m,) 10 m	2 m, (5 m,) 10 m	10 min, 1 min
Stans	548 m	sonic	2.5 m	2.5 m	10 Hz

Table 1: Overview of measurements. The levels in parenthesis did not provide useful data.

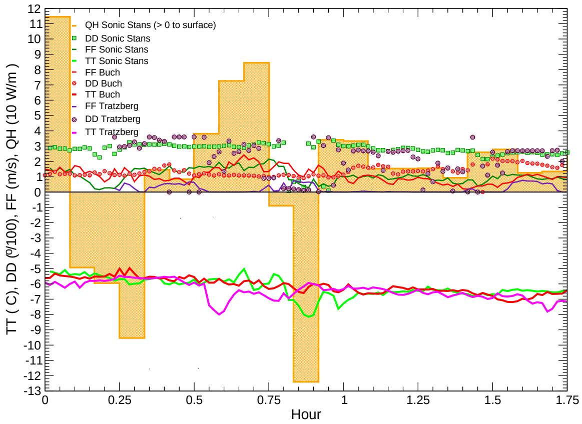

FIG. 3: 1 min means of temperature (lines), wind direction (filled squares and dots) and wind speed (lines) for the stations Tratzberg (magenta and violet), Buch (red) and Stans sonic (green) and 5 minutes mean of the sensible heat flux, positive towards the surface, in orange steps of Stans sonic. Shown here is the time 0:00 – 1:45 LST of 2 March 2006.

The largest decrease in temperature in a short time range can be found in P3 (see Fig. 5). In this period, the temperature at Tratzberg decreases within 1 minute, at 4:37, by –7.6° C, by 2.6 K to –10.2 at 4:38 and within 4 minutes, at 4:41 with –10.9° C, the temperature decreased by 3.3 K. This rather large drop of temperature is again caused by the turning of the wind from northwesterly to easterly flow.

At the same time with the decrease of temperature the wind suddenly drops to 0 m/s and with the turning into the easterly direction it goes up to ∽1 m/s. The increasing of the temperature shortly afterwards, starting at 4:42 LST, is caused by downslope wind, which is warmed adiabatically. At Stans the temperature decreases from –8.5° C at 4:59 to –9.9° C at 5:00. Whereas in the previous cases the wind direction changes and temperature decrease go nearly hand in hand, here the case is not that clear. The wind turns from southeasterly to northwesterly direction, which is in fact outvalley flow from a small valley (see Fig. 1b) northwest of Stans, the Wolfsklamm. So, the first small temperature decrease of ∽0.5 K at 4:49 is caused by turning from alongslope to upslope wind whereas the second decrease at 4:59 is caused by outvalley wind from the Wolfsklamm.

3.2 *Modelling – A brief overview*

As mentioned before only a short period was modelled which also did not include the observation period (see section 2.2). Results of this simulation show that high

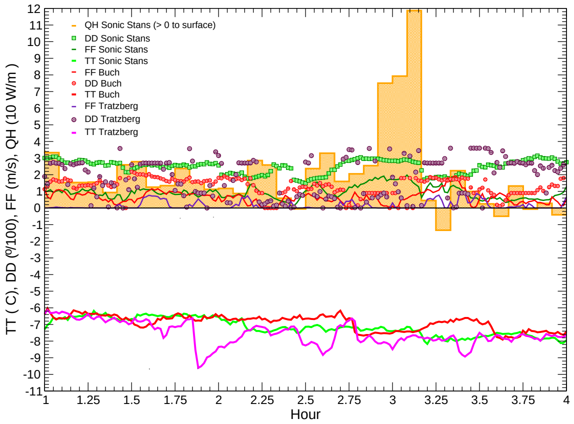

FIG. 4: The same as Fig. 4 but for P2, 1:00 – 4:00 LST of 2 March 2006.

resolution modelling, temporal and spatial, is possible with MM5 but high resolution terrain and land–use data is required.

In general, the synoptic flow is well simulated as well as in–valley and out–valley flows. The daily temperature cycle is captured well but nocturnal temperatures are simulated to high during the night. During the simulation period the valley bottom was covered with snow but due to fast melting in the outermost domains with temperature downscaling of 0.6 K now snow can be found at the valley bottom in the innermost 2 domains. This influences temperature as well as stability in the valley. Wind direction is well simulated but wind speed is underestimated at the mountain tops and ridges and overestimated in the valley.

The modelled results (Fig. 6a) show that inhomogeneities at the valley bottom in the meteorological fields as moving bubbles with higher wind speed and flushing of cold air are in good agreement with the observed recirculating events. Fig. 6b shows that during the night a thin cold air pool remains at the valley bottom. A temporal output every 5 min and a horizontal resolution of less than 1 km are sufficient in reproducing nocturnal oscillations and typical features of the valley wind system but high resolution terrain input and land–use data are required as well as correct initialisation of snow.

4. DISCUSSION AND CONCLUSION

Sound propagation and dispersion of pollutants in valleys are strongly influenced by valley and slope winds and the height of the top of cold pools of valley air. Observations in the measurement campaign carried out in the Inn Valley, Austria, show events with sudden drops of the nocturnal temperature are found by more than

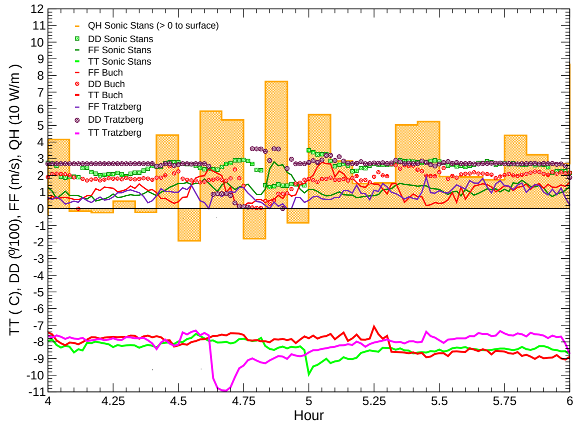

FIG. 5: The same as Fig. 4 but for P3, 4:00 – 6:00 LST of 2 March 2006.

1 K within 1 min. These events take place at all three stations but not necessarly at the same times. By a change of the wind direction from downslope to a direction towards the slope, advection of the cold air from the valley bottom can explain these sudden temperature drops. So we find here a microscale change of the air masses at the foot of both the slopes.

This feature is also relevant for transport of pollution and propagation of noise, which is especially interesting in the Inn Valley where major problems with transportation, train and road, and industrial sites exist. These small–scale events are also relevant for agricultur e.g. for fruit–growing which are very sensible to frost in spring.

MM5 simulations with 0.8 km resolution capture some interesting features such as oscillations in wind direction and lift–up of the wind from tributary valleys. When using 0.27 km resolution, many features of the nocturnal circulations such as inhomogeneities in the valley bottom wind field are simulated and agree in a qualitative way with the observed events. To obtain even better results with the model higher resolution, terrain and land–use data is needed, as well as high resolution temporal output of at least 5 min.

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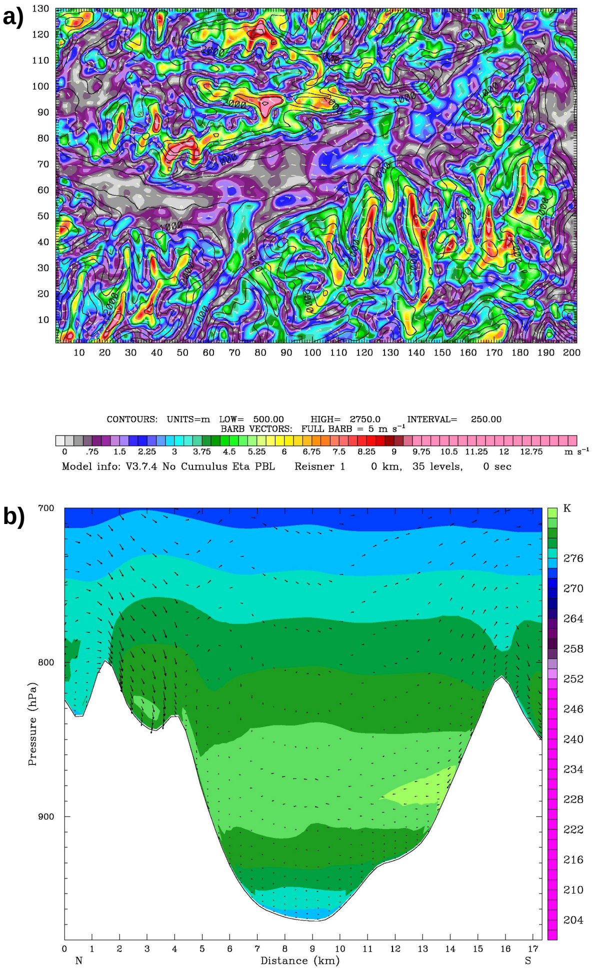

FIG. 6: a) Wind speed (coloured) and wind direction at 10 m height of the innermost model domain, every 4th grid points of the wind direction is plotted (white vectors). b) Cross-section plot at a point east of Innsbruck (at x = 90, ymin = 35, ymax = 100 in the upper image) showing the temperature and the wind vectors. Both plots show a result for February 5, 2004 at 5:05 UTC (6:05 LST).

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