# Low frequency temperature and velocity oscillations in katabatic winds

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## ABSTRACT

Temperature and velocity fluctuations are frequently observed features of drainage flows in the Riviera valley. They occur coherently at different stations at the slope and compressional warming seems to be one trigger mechanism of occurring upslope flows. A case study shows, that periods expected to result from internal gravity waves are somewht longer than those observed in the downslope flow. On the other hand, the down-valley flow in the bulk of the valley atmosphere exhibits a periodicity very close to that expectd for internal gravit waves. Consequently, interfering temperature fluctuations between the down-slope and the down-valley flows result in a secondary energy maximum in downslope flows, indicating that gravity waves may enhance / supress exchange mechanisms at the slope.

## 1. Introduction

Many observations of nocturnal drainage flows have indicated that surges or fluctuations are characteristic of katabatic winds. The periods of reported oscillations range from 10 min (e.g.: Stone and Hoard, 1989) to 90 min (Doran and Horst, 1981). While the basic mechanism for katabatic winds is fairly well understood the reason for the oscillations is not fully clear. They are mainly explained by the theory of compressional warming (Fleagle, 1950) or by modulations of the flow by gravity waves (Gryning et al., 1985).

Nighttime flows in the Riviera valley are characterised by wave like structures. Oscillations with periods of 10 to 25 min are a very common feature of the nighttime flow and they often occur coherently at several measurement stations.
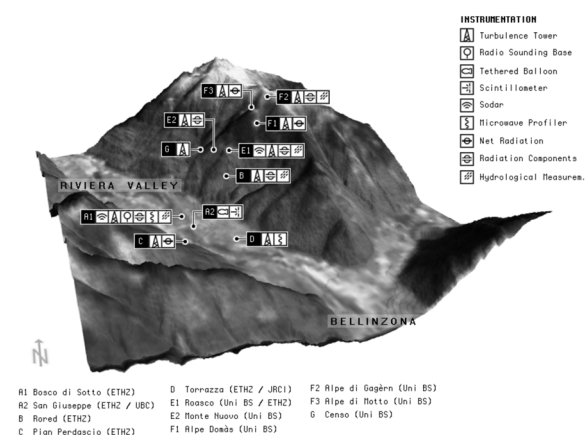
## 2. Sites and measurements



INSTRUMENTATION
- [A] Turbulence Tower
- [Q] Radio Sounding Base
- Tethered Balloon
- Scintillometer
- Sodar
- Microwave Profiler
- Net Radiation
- Radiation Components
- Hydrological Measures.

A1 Bosco di Sotto (ETHZ)
A2 San Giuseppe (ETHZ / UBC)
B Rored (ETHZ)
C Pian Perdascio (ETHZ)
D Torrazza (ETHZ / JRC1)
E1 Roasco (Uni BS / ETHZ)
E2 Monte Nuovo (Uni BS)
F1 Alpe Domàs (Uni BS)
F2 Alpe di Gagèrn (Uni BS)
F3 Alpe di Motto (Uni BS)
G Censo (Uni BS)

**Figure 1**: Topographical map based on the digital elevation model of the Riviera valley.

Scope of the MAP-RIVIERA project was the investigation of boundary layer processes in complex terrain. Mainly on the valley floor and on the westward exposed slope of the mountain range (30-35°) a number of permanent sites were installed. A detailed description of the measurements is given in Rotach et al. (2002). Measurements used here include the following stations: E1 (2 levels of turbulence measurements above a meadow), E2 (6 levels of turbulence measurements in and above a forest, with a horizontal distance of roughly 500 m to E1), A1 (radiosonds) and D (passive microwave temperature profiler MTP5).

## 3. Results

Nocturnal drainage flows are often accompanied by surges which manifest themselves as fluctuations of wind velocity. Figure 2 shows one time series of the slope wind component ($u_s$), wind direction and potential temperature ($\theta$). It gives a first impression of the flow characteristics observed at station E2 above the forest. One can easily make out three to four periods per hour in velocity and temperature signals, and spectral analysis indicates, that the peak frequency of temperature and $u_s$ is 15 and 14 min respectively. The wind direction is highly variable and winds are often directed slope upwards for several minutes. Connected with a positive slope wind component are decreasing temperatures and vice versa, which is supportive of Fleagles theory of compressional warming (Fleagle, 1950): radiative cooling of sloping surfaces causes the adjacent air to cool more than the free air at the same elevation, resulting in a downslope flow. However, as the air moves downslope, compressional warming reduces temperature deficit and pressure gradient. Adiabatic heating then exceeds radiative cooling and results in a reversal of the pressure gradient. As the air decelerates, friction decreases, and radiative cooling increases the pressure gradient. The cycle then is repeated.
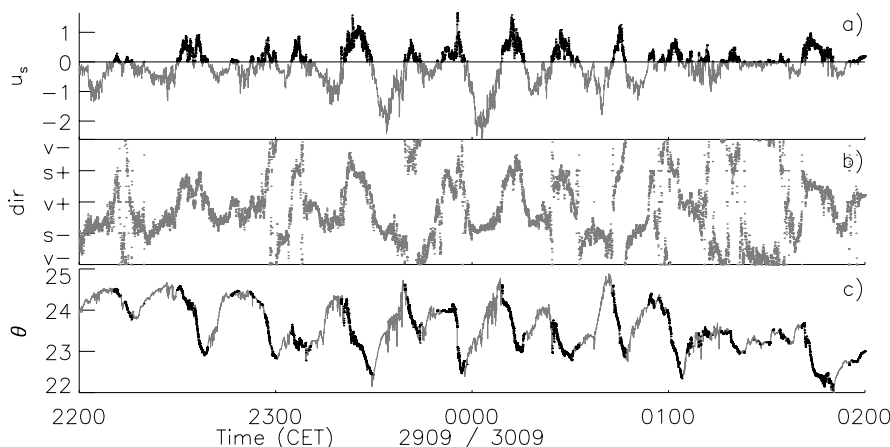


**Figure 2:** Time series showing 1 sec block means of station E2 of a) slope wind component (positive values: upslope), b) wind direction (v stand for valley, s for slope, + for up and – for down) and c) potential temperature. For easier orientation values where $u_s$ is positive are marked with black dots.

Having oscillations of relatively large scale we expect to find similar flow features at other stations. In order to get an idea of the frequency of occurrence calculations of the auto correlation (cross correlation) of station E2 (E2 / E1) were carried out and searched for a second maximum. The correlation of the temperature signal between the stations often reaches very high values (not shown) and it is confirmed, that these oscillations are a very common feature of the nighttime flow (occurrence in 70% of all nights) and that they often occur coherently at both stations (50%).

In the following the flow characteristics of the night from September 29 to 30 are further analysed. The choice of this time period is rather pragmatic as on the one hand during this night oscillations were observed and on the other hand additional data from radiosondes and MTP5 were available. Figure 4 shows measurements of the radiosonde of September 29 started at 2356 CET. One can discern three layers. From the valley floor up to 1250 m a.s.l there is a relatively strong temperature increase with height. The higher valley atmosphere is stratified more isothermal and above the mountain ridge there is a secondary increase in the potential temperature. Wind velocities in the valley are moderate and increase markedly only above mountain ridge height. Richardson numbers indicate that the atmosphere is susceptible to gravity waves (Ri<0.25). With a simple approach to
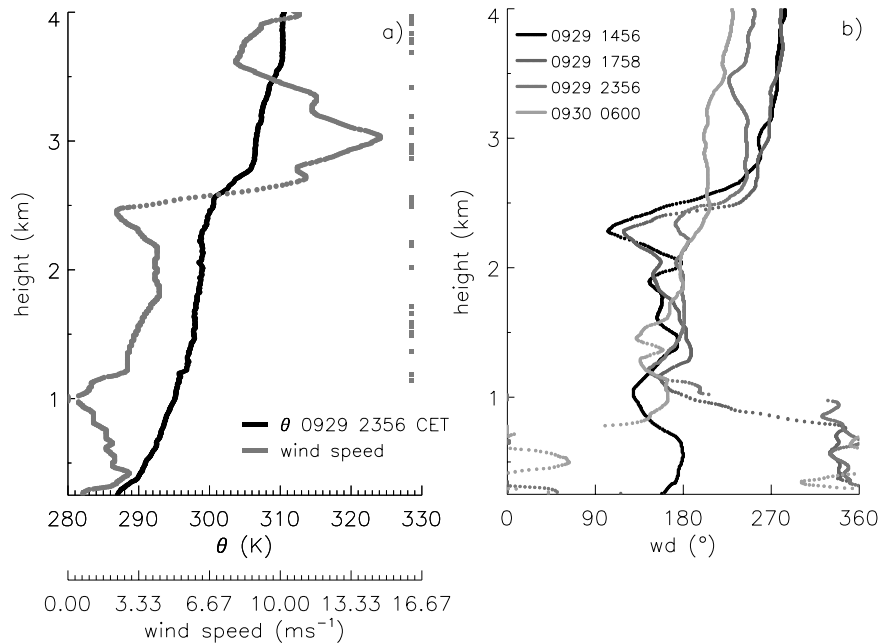
**Figure 3:** Vertical profile of potential temperature and wind speed from the radiosonde of September 29 2356 CET. Grey symbols at the very right indicate where the Richardson number is <0.25. b) Vertical profiles of wind direction.

model of internal gravity waves (e.g Haltiner, 1971) we calculate the oscillation period to be 18 min. The model relates the period $P$ of oscillations to the horizontal length scale ($L$) and the height of the valley ($H$) by $P=2\pi/N[1+(L/H)^2]^{0.5}$, where $N$ is the Brunt-Väisälä frequency and computed for the whole valley atmosphere. The wind direction in the valley (Fig. 4.b) changed from southerly flow in the afternoon of September 29 (upvalley wind) to northerly flow (downvalley wind) in the night while in the upper valley winds were directed upvalley during the whole time period. Above ridge height wind direction changed from a westerly to a more southern flow. The profiles of wind velocity and wind direction indicate strong shear between these three layers.
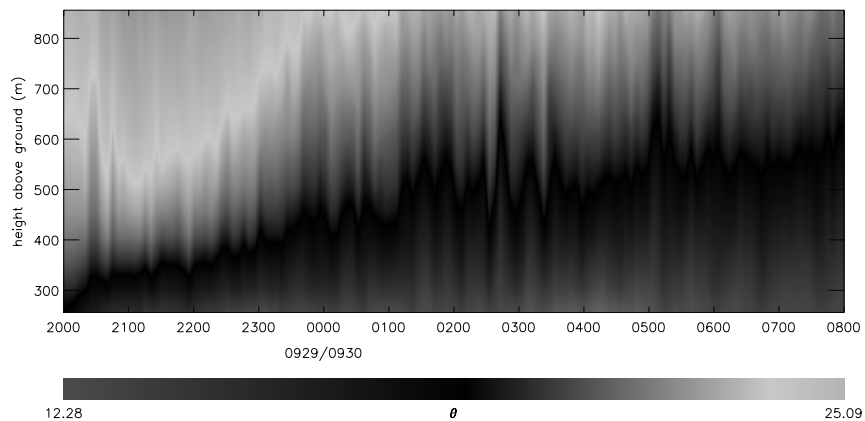


**Figure 4:** Contour plot of vertical profiles of potential temperature measured with MTP5
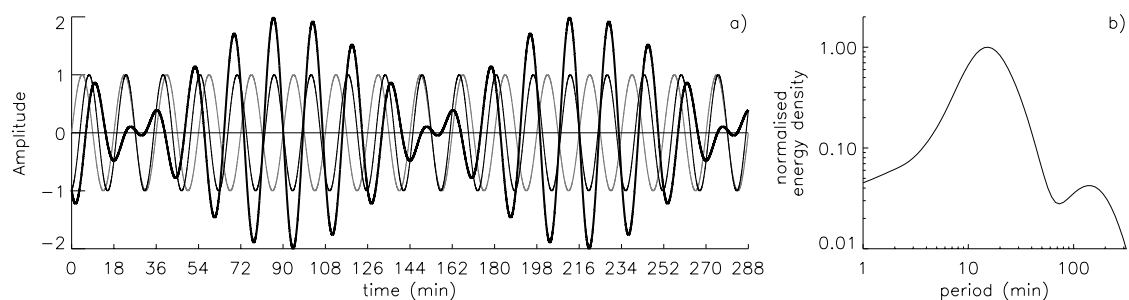
**Figure 5:** a) Schematic of interference between valley (grey line) and slope temperature (thin black line). The resulting temperature difference is given as black thick line. b) Global wavelet spectrum of slope wind component (E2).

Figure 4 shows vertical profiles of the potential temperature, measured with the MTP5. One can clearly see the growing of the cold air layer on the valley floor with time. More interesting are the wave like structures that are discernable in the valley atmosphere during almost the whole night. These structures are in phase through the whole layer and thus stationary relative to the ground, which is indicative for terrain generated waves. The period of these waves (18 min) is somewhat larger than those observed at the slope but is equal to the period modeled with radiosonde data. There is a phase shift of roughly 3.5 min between the valley and the slope temperature. Temperatures in the valley core and at slopes interfere such, that difference maxima are reached roughly every 120 min (Fig. 5). At approximately this period (130 min) a secondary maximum is found in the spectrum of slope winds. This indicates, that slope and valley flow oscillations are not independent and that waves may enhance or suppress oscillations caused by compressional warming.

## CONCLUSIONS

There is evidence for compressional warming being a cause of oscillations in katabatic flows in the Riviera valley. Radiosonde and MTP5 measurements however indicate that wave like structures in the valley core might be induced by dynamic instabilities. It is proposed that internal gravity waves may enhance / suppress slope boundary layer oscillations and by doing so strongly modify the exchange of momentum and scalars.

### LITERATURE

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