Impact of the valley-wind system on the dispersion of passive tracers in the stably stratified atmosphere of an Alpine valley

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1. Introduction

In wintertime, mountain valleys frequently experience very stable atmospheric conditions, leading to air pollution episodes, especially when strong ground-based temperature inversions persist for several days. Under such conditions, the valley-wind system (consisting of thermally-driven down-slope and down-valley flows) is key to providing some degree of ventilation. The main objective of the present work is to improve our understanding of the behavior of pollutants emitted when the atmosphere is stably stratified. The tool selected to perform the simulations is the Weather Research and Forecasting (WRF) model.

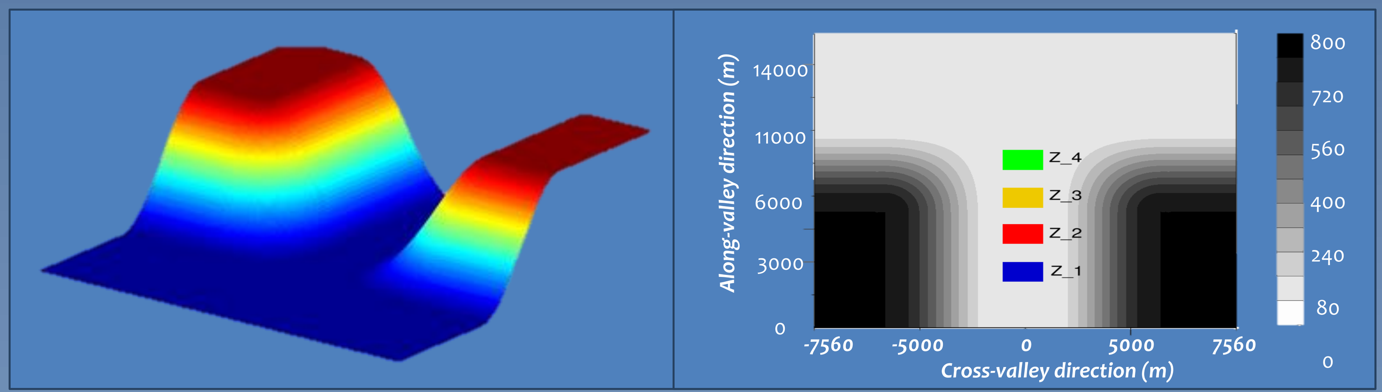

Figure 1. Left panel: 3D visualization of the topography. Right panel: contour plot of the terrain height for the inner domain. Each color area (Zi) corresponds to an emission source, all the areas have the same size. Four different tracers are emitted in each area at different levels (0, 95, 280 and 415 m above the ground). All tracers are emitted at the same rate.

A high resolution one-way nested simulation (two domains) has been performed using an idealized version of the Chamonix valley. The simulation starts one hour after sunset on a winter day using as initial condition a constant gradient 1.5 Km^{-1} with no forcing.

2. Flow dynamics: Down-slope and down-valley flows

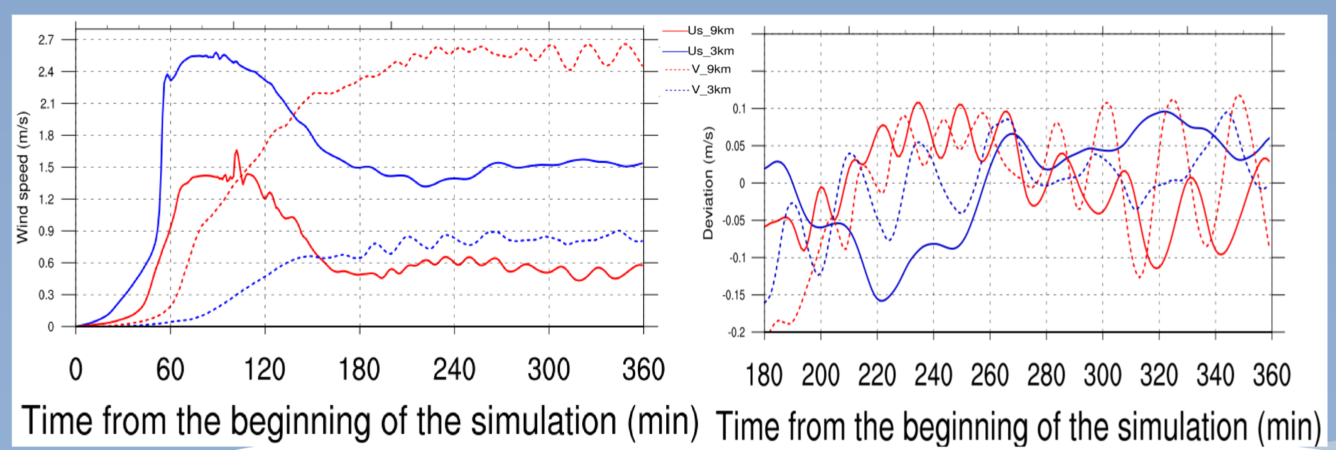

Figure 2. Left panel: Time series of the down-slope wind (Us) at 1.5 km from the valley center (10 m above the ground level) at two locations in the Y direction (3 and 9 km) and the down-valley wind (V) on the valley center at 20 m above the ground. Right panel: Time series the deviation from the mean state after both flows have reached the quasi-steady state (180 min) up the end of the simulation (6 hours).

During nighttime a negative buoyant flow is detected over the valley sidewalls. The generation of this down-slope flow is produced by a sign reversal in the surface radiative budget over the valley, generating a cold-air pool (CAP) at the valley bottom. These flows dominate the valley atmosphere for the first 150 min (figure 2). The formation of the CAP inside the valley induces a horizontal temperature gradient which creates a pressure difference that drives the down-valley flow (figure 3 right).

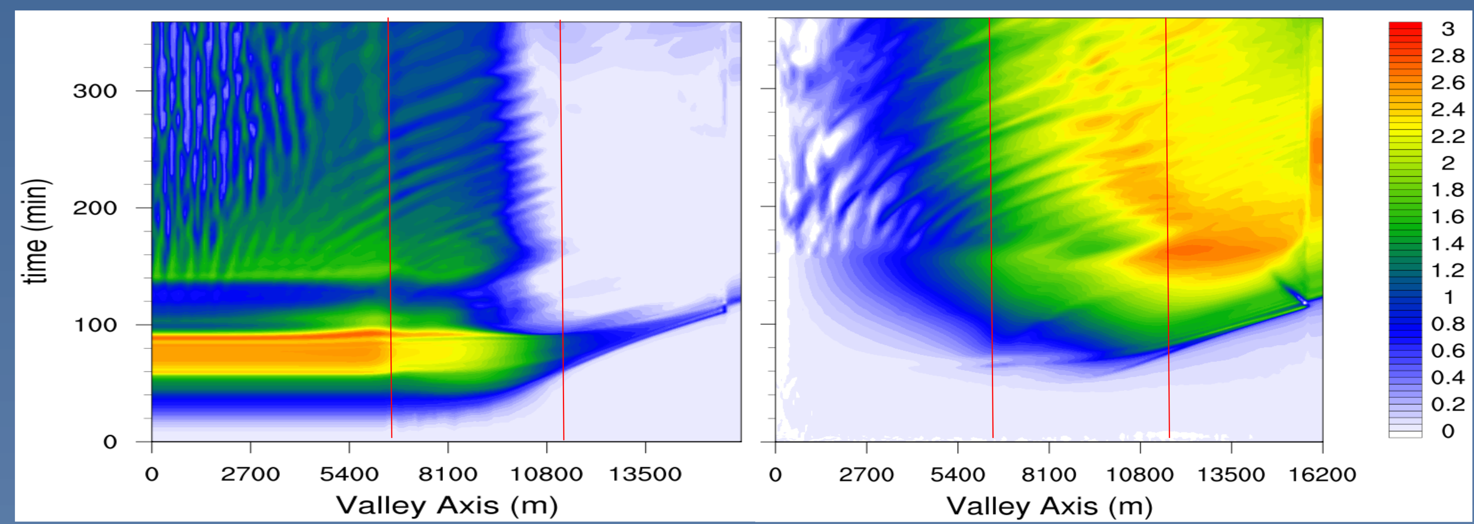

Figure 3. Left panel: Hovmoller plot of u component of the velocity field at 1500 m from the valley center along the valley axis. Right panel: v component of the velocity field at the valley center at 20 m above the surface. The units of the color scale are m s^{-1}. The red lines in the figures correspond to the end of the plateau (6km) and the end of the valley (11km).

McNider (1982) stated that oscillations in nocturnal drainage flows over complex terrain come from stratification effects; a simple analytical model to predict the frequency of these oscillations was proposed: $f_{McNider} = \frac{N \sin(\alpha)}{2\pi}$. In our calculations, α=8.4° (slope local angle where oscillations were stronger) and the N (Brünt-Väisäla frequency) is computed by taking the averaged of the temperature from the end of the flow layer until 80m above the ground (at the same point, 1.5 km from the valley center).

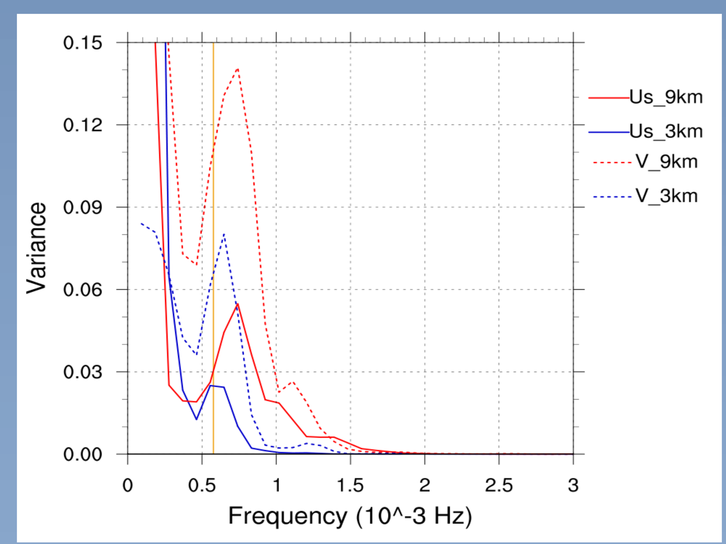

Figure 4. Power spectrum of the time series displayed in figure 2. The vertical orange line denotes the theoretical frequency of oscillation in the down-slope flow predicted by McNider (1982).

3. Structure of the down-valley flow

Once the flow is fully developed it is possible to observe a jet-like structure in the vertical profile of the V component of the velocity field. Three different layers driven by the temperature structure are detected inside the jet structure. The first layer extends from the ground to the height of the first jet maximum. The top of the second layer coincides with the top of the inversion layer, where $^{dT}/_{dz}$ changes its sign and becomes negative, finally, the third layer extends from the end of the second layer to the top of the CAP.

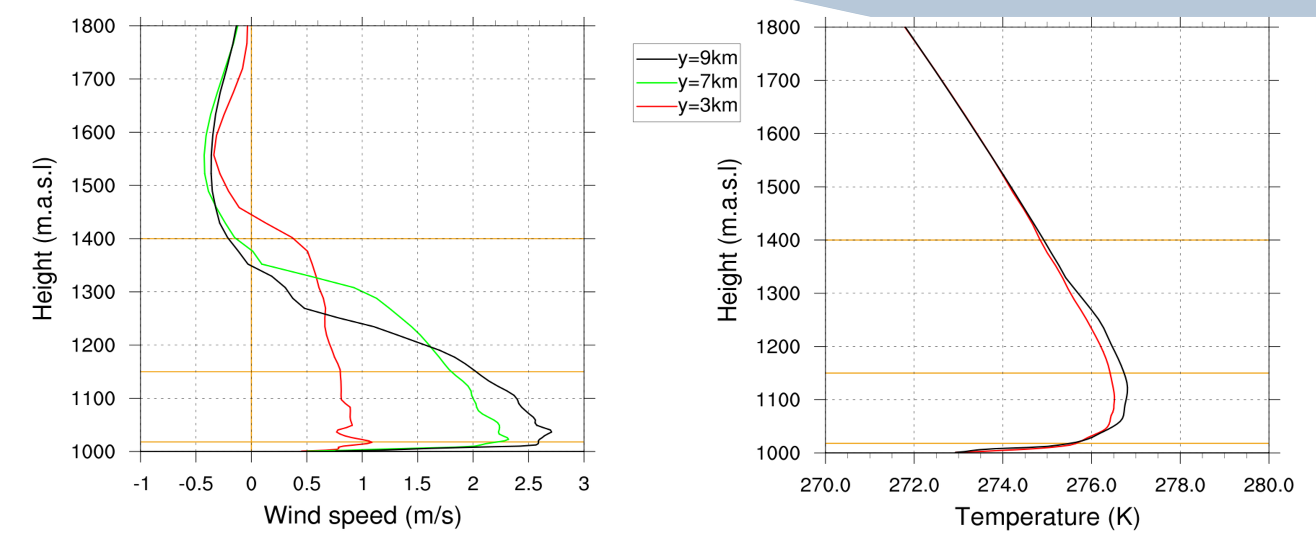

Figure 5. Left panel: Vertical profile of the down valley wind speed. Right panel: Vertical structure of the temperature after six hours.

4. Consequences of the valley-wind system on the dispersion of passive tracers.

Passive tracers have been released at different heights to investigate the influence of the stability in each region (inside the down-valley flow) on the diffusion and transport of tracers in the atmosphere. Figure 6 below shows that tracers emitted in the three layers identified from figure 5 remain completely decoupled over time and are transported toward the valley end. By contrast, the tracer emitted over the CAP remains trapped in the valley, being affected by the up-valley wind that develops from mass conservation.

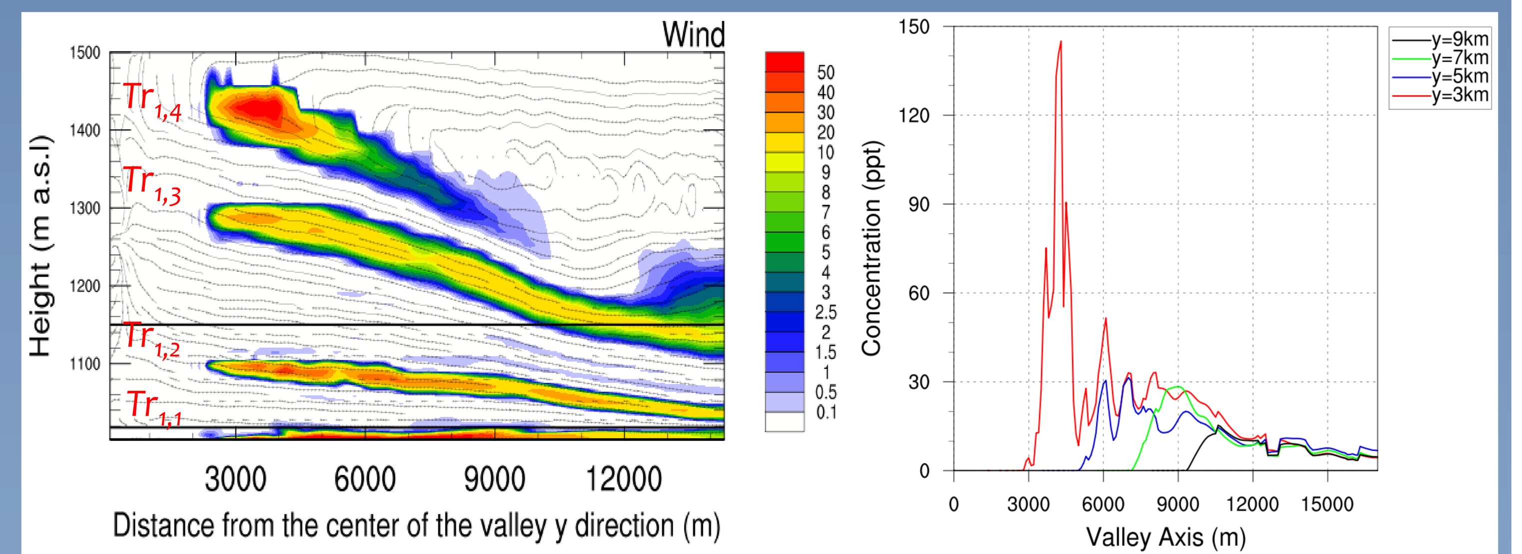

Figure 6. Left panel: Contour plots of tracer concentration (pptv) in the valley axis plane at t = 300min for tracers released at 3km from the beginning of the valley at different levels (Surface level, 100, 280 and 415 m above the ground) overlayed with streamlines. The emission of all the tracers start after 2.5 hr from the beginning of the simulation. Right panel: Tracer concentration averaged over the first layer inside the down-valley flow along the valley axis, at 300 min.

5. Conclusions

- Results show that temporal oscillations of the wind speed within the down-slope and down-valley flows provide a signature of the interactions between the two flows, which should affect the tracer concentrations in the along-valley direction.

- Tracers emitted at the ground level are trapped below the height of the jet maximum and mixed by shear turbulence within this layer. By contrast, turbulence is generally weak above the jet maximum, and so tracers released there are not mixed in the vertical and are transported down the valley by the down-valley flow.

References:

- Arduini, G., Staquet, C., Chemel, C., (2015). Interactions between the nighttime valley-wind system and a developing cold-air pool. Boundary Layer Meteorology.
- McNider, R. T. (1982). A note on velocity fluctuations in drainage flows. Journal of the Atmospheric 386 Sciences, 39(7):1658–1660.