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Boundary layer dynamics in the Grenoble valley during strongly stable episodes

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In a valley environment, serious air pollution episodes develop mostly when the boundary-layer flow is not subject to any strong synoptic forcing. Such a decoupling occurs when the boundary layer is capped by an inversion layer and the atmosphere is stably stratified. In this case, the pollutants are confined into the shallow layer up to the inversion level, increasing dramatically near-surface pollutant concentrations. Such a situation is the focus of the present study, for the Grenoble valley. Although the Grenoble area is one of the most populated areas in the Alps, there has been no detailed study of such situations.

We first analysed ground temperature data within the valley, provided by Meteo-France, at altitudes ranging between 220 m (valley bottom) and 1730 m during 5 months, November to March, of winter 2006-2007. Our purpose was to detect strongly stable episodes, these being defined by the episode-averaged vertical gradient of the absolute temperature being positive over at least five days. Five episodes were selected from this criterion. We also analyzed air quality data recorded by the Grenoble air quality agency to detect strongly polluted events for PM10 and found that the five episodes were also strongly polluted episodes. To perform a more detailed analysis of those five episodes, we reproduced their dynamics with the numerical code Meso-NH. Four nested domains were used, the horizontal resolution being 333 m; from comparison with ground temperature data, we found that the vertical resolution above ground level in the innermost domain (containing the Grenoble valley) had to be as low as 4 meters.

The boundary layer dynamics in the numerical simulations was found to be decoupled from the (anticyclonic, weak) synoptic flow, consistent with the value of the Froude number associated with the inversion layer. These dynamics result from thermal winds flowing from the higher altitude valleys which surround Grenoble. Remarkably, the same flow pattern was found in the valley during the five episodes, both horizontally and vertically, implying that this pattern solely depends upon the geometry of the topography once a strong enough thermal inversion has formed. A detailed analysis of one such episode was next conducted. We found that the wind displays a strong vertical veering shear as a result of the superposition of the katabatic winds flowing from the different valleys. This may result in vertical ventilation if turbulence occurs in maximum shear locations. In the horizontal direction, the relative importance of ventilation and stagnation regions close to valley bottom was quantified through the computation of indices as defined by Allwine and Whiteman (1994), providing in particular a clear view of the stagnation regions which are critical for air quality.