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AIR POLLUTION DYNAMICS ALONG A LOW-LEVEL-JET EVENT IN COMPLEX TERRAIN: A HIGH-RESOLUTION STUDY EMPLOYING RAMS

Nitsa Haikin[1,2], Silvia Trini Castelli[1]

[1]CNR-ISAC Torino, Italy
[2] NRCN, Israel

Abstract

Air pollution is a major issue of densely populated zones, where in many occurrences it is difficult to accurately evaluate and trace the sources and the dispersion patterns. On top of local complexities which characterize many inhabited areas, unique atmospheric flows may result with high concentrations - some of which may be very local. Such a unique flow is the low-level jet (LLJ). In this study, an event of LLJ over a coastal complex terrain was considered to investigate its effect on the dispersion of potential pollutants in the domain. The RAMS model was employed with a high vertical resolution close to the surface, in order to allow a detailed analysis of the flow and to characterize the specific features of the LLJ. After a sensitivity analysis and a comparison with the measured meteorological variables, numerical experiments were performed adding a scalar tracer. As first test, the tracer was distributed homogeneously in the whole domain to follow the dynamics of the LLJ and its effect on the tracer transport. Then, virtual sources were included, with continuous releases, and this approach enabled the identification of some expected and unexpected "hotspots" of tracer accumulation, due to very local circulations and convection cells that developed as a result of the LLJ flow. Here, we use several examples to demonstrate possible applications of this approach.

Key words: *High-resolution modelling, Low-level-jet, RAMS*

INTRODUCTION

An episode of LLJ was detected over the complex domain of Haifa Bay in the Eastern Mediterranean during a radiosounding campaign, in the morning of January 7, 2010. The RAMS model was employed to investigate the dynamics of potential pollutants dispersion under such particular conditions in complex terrain, and specifically the effect of the LLJ on it. The wind speed profiles detected a LLJ at 0700 and 0800 local time (UTC+2). RAMS was employed with four nested grids with resolution from 32 km to 500 m. A high vertical resolution in the inner grid was achieved with as many as 20 levels below 600 m, using a vertical nesting with a rather novel approach not frequently adopted (Haikin and Trini Castelli 2021). This resolution enabled a better description of the LLJ characteristics and its development in time, which were studied with respect to their implication on the dispersion pattern. This study intends to provide a contribution to the investigation of pollutant dispersion processes through all the boundary-layer and in the particular condition of inversion in presence of LLJ. The final aim is to provide indications about the importance of capturing and well resolving the LLJ when simulating the pollutant dispersion in the atmosphere, which could be of interest not only for research purposes but also for model developers and users. In this sense, this work is a contribution in promoting original approaches and in establishing consistency in methods. In the following section we present and briefly discuss some flow and dispersion results. A schematic map of the domain is shown in Fig. 1.

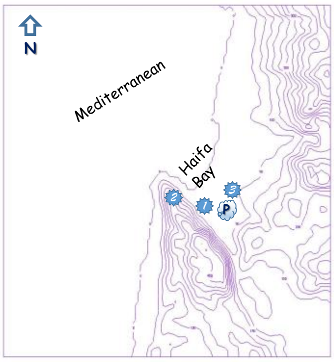

Figure 1. The study domain of Haifa Bay, locations of sites 1, 2, 3 and the point source P are shown.

RESULTS AND DISCUSSION

Flow simulation

After testing the configuration of the model and optimizing it, the model was verified against the available meteorological observations, then it was used for studying the spatial-temporal evolution of the LLJ in the study domain. For example, we investigated the elevation of the LLJ "nose" above the mountain top and above its downwind lee, with respect to its elevation over the main LLJ-route over the valley aside the mountain. The simulation shows that in two adjacent sites 1 and 2 (see Fig. 1), one at sea level and another on the mountain slope, the LLJ "nose" was found at similar height above sea-level (Fig. 2). The simulation suggests that the LLJ episode in this case lasted about nine hours, from build-up to break-up, and the peak strength of 10-12 ms^{-1} for the wind speed occurred along 4 hours (0500 to 0900 UTC, see in Fig 3). The attained high vertical resolution in the lower boundary layer, namely 20 levels below 600 m agl, enables a detailed study of the spatial-temporal LLJ evolution.

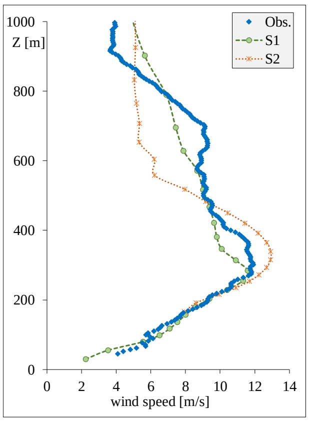

Figure 2. Wind speed profile showing an LLJ: observed (data from radiosonde at 0600 UTC) in blue diamonds, and simulated profiles over sea-level site (circles) and adjacent mountainous site (×).

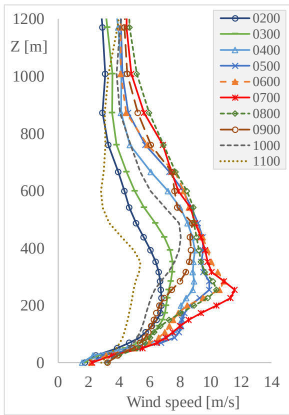

Figure 3. Simulated wind profile at site 1 from 0200 to 1100 UTC, showing the LLJ development and its break-up.

The analysis of the thermal vertical pattern resulted with two, and in some cases three, strong inversions from ground level up to 700 m agl, as shown in Fig 4. The high vertical resolution used in this study allows differentiating between separate inversion layers. In Fig. 4, the thermal profiles over sites 1 and 3 are shown. The profile over site 1 shows three inversions: the lower one is a very strong ground inversion (which disappears by 0800 UTC), the second one is at the LLJ-nose level and the highest inversion is above the LLJ level. Over the adjacent location of site 3 there is a shallow ground inversion at 0500 UTC, which integrates by 0600 into the stronger inversion above. A double-peak inversion (as defined by Haikin et al 2015) shows at 0700 UTC, with its stronger peak at the LLJ "nose" elevation. By 0800 the double-peak inversion is almost totally destroyed, and a new inversion is formed above the LLJ elevation.

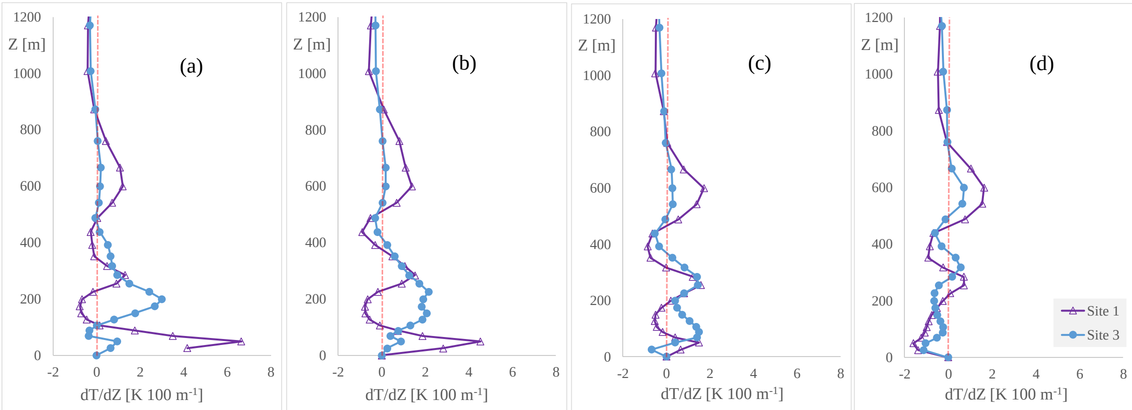

Figure 4. Thermal profiles over sites 1 (violet) and 3 (blue) during the LLJ event: (a) 0500, (b) 0600, (c) 0700, (d) 0800 UTC

Dispersion simulation

After analysing the dynamics induced by the LLJ and its interaction with the topography of the domain, the characteristics of the pollutant dispersion in the area, as subjected to this particular wind regime, were investigated with two main approaches, based on using RAMS as a Eulerian dispersion model (Trini Castelli et al. 2012 and 2017). In one approach we used each grid-point as a source, in order to have a homogeneous distribution of the tracer in the area. First, a tracer was released at each point of the inner grid for a single time step. Second, a tracer was released at each point of the inner grid as a continuous emission along the simulation time. In this way, the effect of the flow, and specifically the LLJ effect on tracer accumulation and sweep-off, could be studied. In Fig. 5 we present contour lines of the tracer for the main hours of the LLJ at different model levels. Accumulation zones at the lower heights are clearly discernible and there the tracer amounts increase in time, indicating the effect of the flow interaction with the topography. At the higher levels, as expected, the distribution of the tracer tends to become more homogeneous.

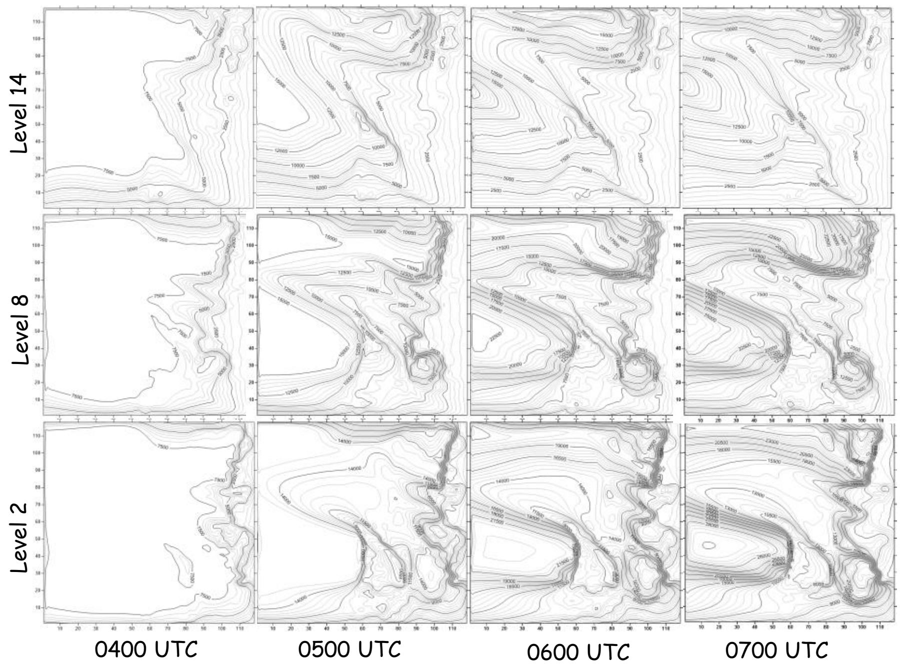

Figure 5. Tracer experiment: contours of tracer-amounts for continuous release from all points in the inner grid. Level 2, 8 and 14 of the model, correspond respectively to the heights of 13, 162 and 334 m agl.

In the second approach, we used one grid-point as an emission source, from which a continuous tracer emission was released. In this experiment we studied the impact of a release from two elevations, 60 and 138 m, at the site in the LLJ route (see point P in Fig. 1). The simulation showed that in both cases (release from the two elevations) the tracer clouds are forced to disperse close to the ground, until the LLJ structure breaks-up. The tracer cloud can develop upwards and gain a significantly larger volume, only after the LLJ breaks-up, as demonstrated in the vertical cross-sections in Fig. 6. Horizontal contours of the cloud are shown in Fig. 7 at different levels, presenting the pattern of the tracer dispersion in the inner grid. Similar dispersion patterns are found at the levels close to the surface, 13 m and 60 m, while the highest tracer-amounts are found at the level of the release, 138 m, and only spots of tracer appear at 334 m, which is above the LLJ peak.

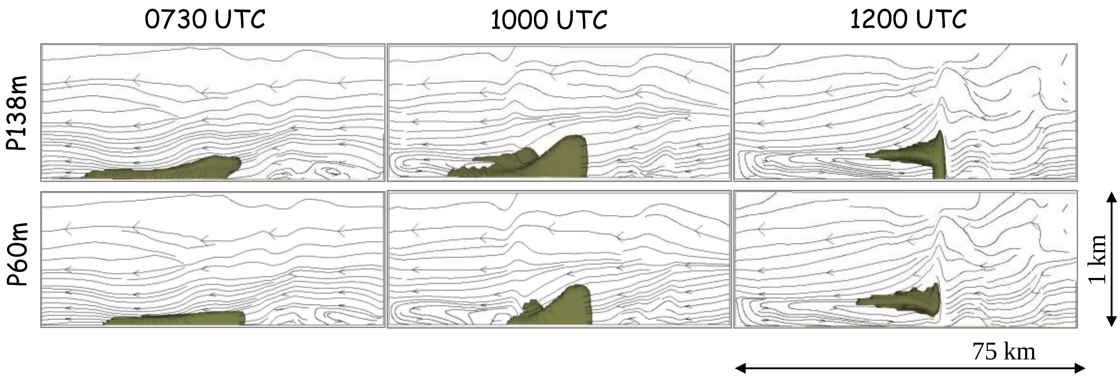

Figure 6. Vertical cross sections along the main route of the LLJ, with tracer clouds developing from point releases at two heights below the LLJ peak: 138 m agl (upper panels) and 60 m agl (lower panels). The vertical streamlines of the flow are also plotted, in between the hours of the LLJ simulated peaks, at 0730 UTC, after the major LLJ event, at 1000 UTC, and after the LLJ breaks up, at 1200 UTC.

CONCLUSIONS

In this study the RAMS atmospheric model was applied to reproduce and analyse a LLJ event over a complex domain. RAMS was used also as a Eulerian dispersion model, with an original approach, to study the tracer dispersion in the domain under LLJ conditions.

RAMS provided a reliable reproduction of the LLJ pattern, thanks to the increased vertical resolution, where the LLJ extension and the height of its peak were well captured. The temperature profiles were characterized by elevated inversions, where the LLJ was located at the bottom of such inversions. The effect of the LLJ on tracer dispersion was assessed and analysed with two approaches, homogeneous releases at all points of the 3D grid and emissions at single grid points. The homogeneous release allowed detecting the effect of strong local recirculation induced by the interaction between the LLJ and the complex topography. The LLJ acted on the tracer with an effective advection in the region above its maximum and with a trapping effect below it. The point release experiment showed that after the LLJ structure weakened, the tracer started to entrain the upper levels and to spread over a larger area at the ground. RAMS demonstrated to be a useful and reliable tool, for simulating not only the atmospheric LLJ dynamics but also the dispersion of potential pollutants released in the study area.

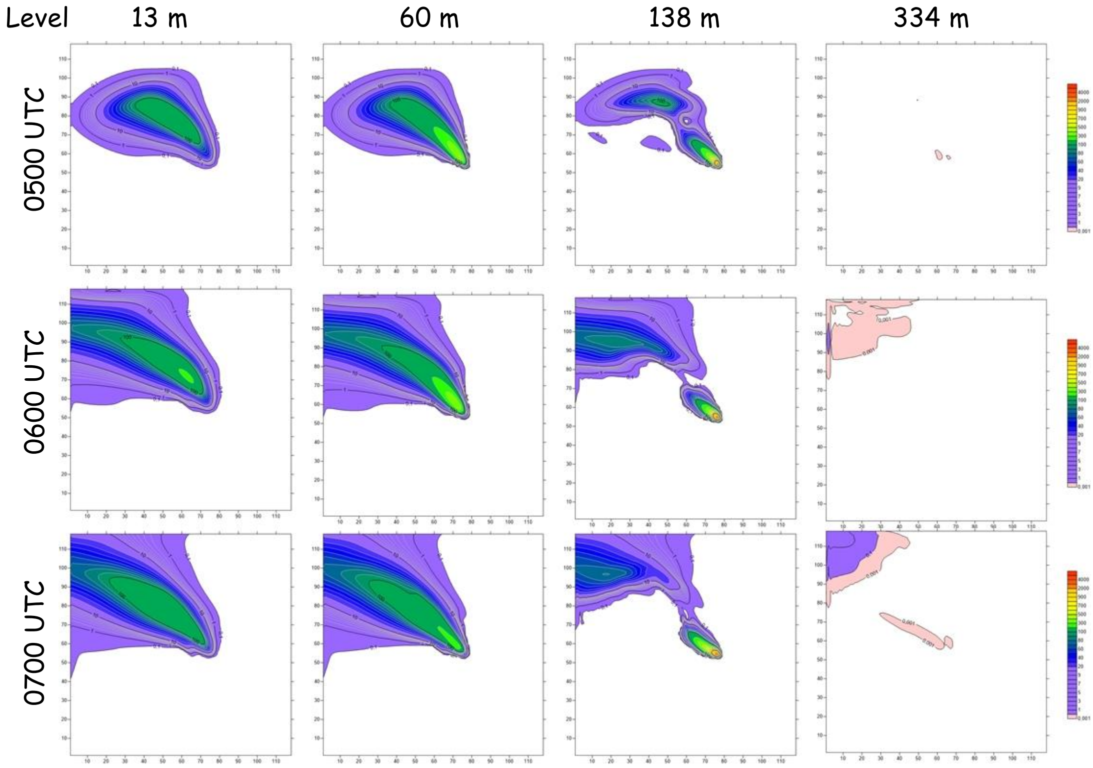

Figure 7. Point source experiment: tracer dispersion at four model-levels, 13 m, 60 m, 138 m and 334 m from left to right. The upper panels show contours of the tracer amount at 0500 UTC, the mid panels at 0600 UTC, and the lower panels show the contours of tracer-amounts at 0700 UTC

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