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A Numerical study of air-pollution and atmospheric fine-scale flow over the coastal complex terrain of Mt. Carmel

N. Haikin[1,2], P. Alpert[1], Y. Mahrer[3]

[1]Department of Geosciences, Tel-Aviv University, Israel
[2]NRCN, POB 9001 Beer Sheva, Israel
[3]Soil and Water Dept., Hebrew University of Jerusalem, Rehovot, Israel. (Emeritus)

Abstract
Haifa Bay, located on the Eastern Mediterranean, is densely populated by industrial facilities alongside inhabitants. The area is characterized by a complex terrain, mainly due to Mt. Carmel which rises up to 450 - 500 m (asl) over a short distance from the coast. The atmospheric models RAMS and HYPACT were employed with 0.5 km resolution on an air pollution episode in the domain. The simulations were used to better understand the evolution of the air-pollution episode and the complex atmospheric flow along it, where SO_2 served as a tracer. Simulated data of surface and upper air concentration profiles revealed a significant spatial and temporal variability, much more complex than was captured by the monitoring network.

Introduction
Haifa Bay is located on the Eastern Mediterranean coast. The region is densely monitored, with more than 20 monitoring stations within a 15 x 15 km^2 domain. The monitoring devices are mostly stationed in populated neighborhoods, in order to continually evaluate the air quality there, assuming they represent the air quality in their surroundings. However, in the complex environment of the study regime micrometeorology may cause very high variability of pollution patterns over short time and distance. Moreover, multi-pollutant environment can never be completely monitored for all components. Occasionally there are air-pollution episodes which are difficult to explain, sometimes events are sensed by the inhabitants even when or where no pollution is monitored. The local community complains about the high health risk concerning the air pollution in the region. Researchers have long been studying the health effects which were potentially caused by exposure to excess concentrations of air pollutants in the region (e.g. Goren et al., 1991; Paz et al., 2009; Eitan et al., 2010). Long-term observed data of emissions and ambient concentrations point at a decreasing trend of air pollution over the last decade, due to stricter regulation and enforcing. However, in recent years the region has been under focus of the public and the authorities (Israel MoEP, 2016), both struggle against air pollution sources and hazards. Yet, many parameters are still unknown. Atmospheric models may support spatial and temporal analysis of pollution dispersion and risk management, where they may supply additional unique information, especially in complex domain (e.g. Pielke et al, 1983; Schmitz R, 2005). Therefore, in the current work the models RAMS and HYPACT were employed on an air pollution episode which occurred in the Haifa region. Based on the simulation results, we studied the probable causes of the differences between simulated and monitored data, and analyzed the sensitivity of the monitoring locations to plume variations in the study domain.

Results and discussion
Several monitoring locations were selected for analysis of the pollutant plumes (Fig. 1). The sites were chosen to represent the mountainous part of the region, the bay, and the eastern foothills of Mt. Carmel. Meteorological fields simulated by RAMS demonstrated significant variability of which an example is

presented in Fig. 2. The adjacent sites 1 and 6 are less than 5 km apart from each other (direct line). The simulated temperature profiles over site 1 (representing the bay) presented an evolution of significant low level inversion during the day, while over the mountainous site (6) only a mild inversion appeared at that time. However, the 1300 UTC profile showed a similar inversion over site 1 and site 6, at about the same elevation above sea-level. It is therefore suggested that the midday inversion layer was leveled over the domain at that time. Throughout the air-pollution episode day the surface temperature difference between sites 1 and 6 reached 10°C. The profiles over the bay showed an evolution of ground-based and elevated inversion, of which only traces were demonstrated over the mountainous site.

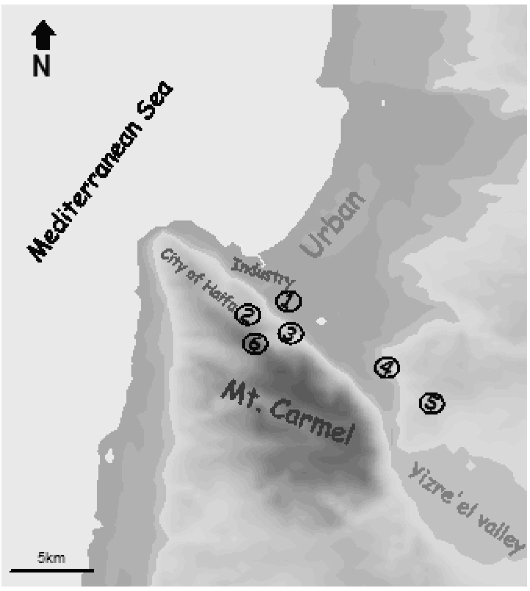

Figure 1: Haifa domain with selected monitoring (marked 1-5) and meteorological (marked 6) sites. Site 1 represents the bay, sites 2, 3, 6 are mountainous and sites 4, 5 represent the eastern foothills of Mt. Carmel.

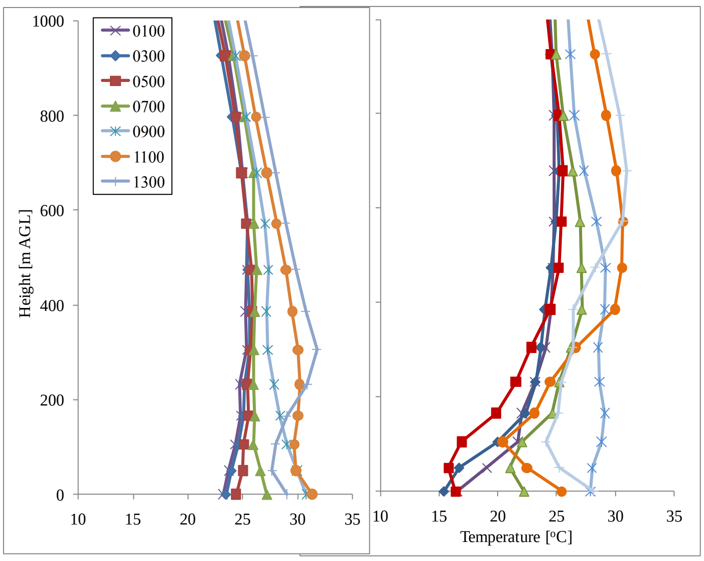

Figure 2: Simulated temperature profiles over Mt. Carmel, at about 450 m (asl) elevation (left) and over the bay starting from sea-level (right); each line represents a different hour (UTC)..

Air pollution concentrations throughout the case study episode showed an early morning peak which was observed over the mountainous site, and later peak concentrations which were observed over the eastern foothills (Fig. 3 (a)). The models were able to capture the air pollution episode by time-length and amplitude. However, a thorough look reveals that the afternoon simulated peak appeared both over the foothills and the mountainous sites (Fig. 3 (b)), with even higher concentrations than the observed ones. Another morning peak was also simulated over a foothills, bellow the mountainous sites (not shown here). Since both the observed and the simulated concentrations were attained from discrete sites, differences between the observed and the simulated data may have strongly been effected in this case by westerly shift of the simulated plume towards the mountain, and/or by misdetection of the plume by the monitors. It is suggested that in the current case the plume may have missed the monitoring sites by only short horizontal or vertical distance (Haikin et al, 2016).

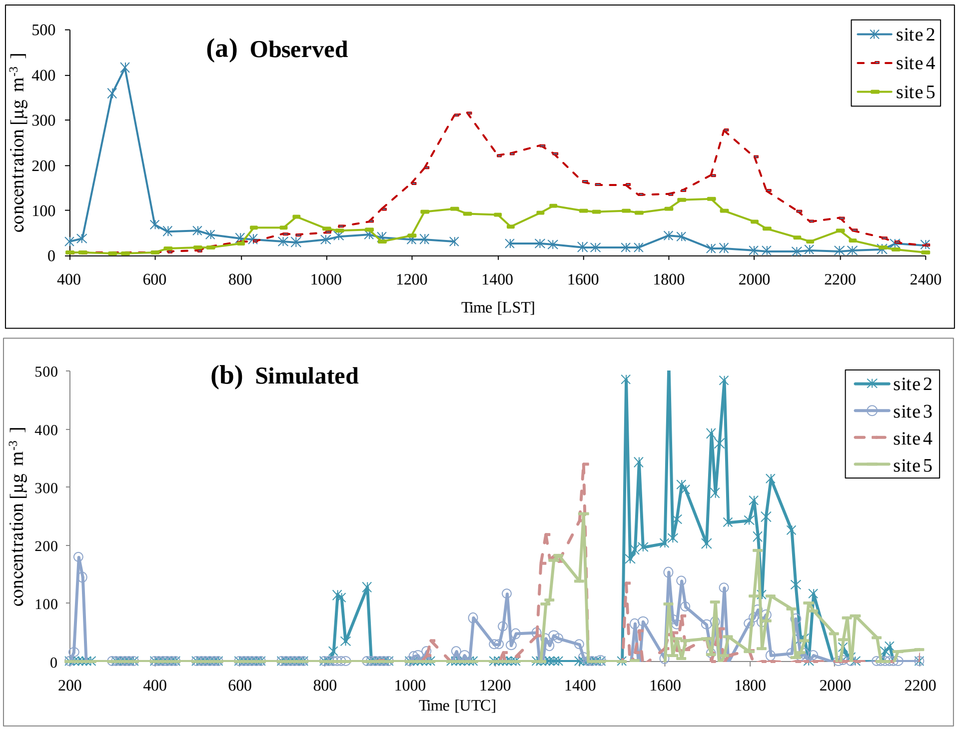

Figure 3*:* Observed (a) and simulated (b) concentrations along the case study episode. Each line denotes concentrations over a different site.

Conclusion

An air pollution episode was used to study the variability of pollution dispersion in a complex domain, where the employed models added unique information about the spatial and temporal evolution of the pollution plume. It was demonstrated that even adjacent sites presented significantly different simulated patterns of meteorological parameters and of pollution. Further simulations are needed, to assist with analysis of various air-pollution cases, as an addition to the observations.

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