COMPARISON OF MESOSCALE MODEL WITH SODAR WIND AND RADIOMETER TEMPERATURE PROFILER MEASUREMENTS OVER AN URBAN AREA

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ABSTRACT

In the framework of the project "Development and evaluation of a high resolution atmospheric urban canopy model for energy applications in structured areas" of the Archimedes program funded by the Greek Ministry of Education and Religious Affairs, wind and temperature measurements were conducted in the atmospheric boundary layer (ABL) over the urban area of Kozani, Greece for a time period of about one year using an acoustic sounder (sodar, up to 300 m above ground) and a radiometer profiler (up to 600 m above ground), respectively,. The purpose of this campaign was to evaluate the performance of a mesoscale model (The Air Pollution Model, TAPM, of CSIRO Marine and Atmospheric Research) and more specifically its surface layer and ABL turbulence parameterizations. The TAPM model uses surface similarity and urban parameterizations of various surface parameters (like roughness length and displacement height) to estimate surface turbulent fluxes, and the standard E-ε model for the estimation of eddy diffusivity in the ABL. The comparison was limited to selected days that were representative of different conditions of atmospheric wind intensity and atmospheric stability with low acoustic noise, which affects the range of sodar measurements. The comparison showed that the TAPM model forecasts generally performed well with respect to the thermal structure (temperature profiles and ABL height), but overestimated wind speed at the heights of comparison (mostly below 200 m) up to 3-4 ms^{-1}. Also, friction velocity and less heat fluxes estimation by the model were generally overestimated by the model when compared (excluding time periods when the forecast didn't predict accurately large scale atmospheric changes) to the corresponding estimates derived by fitting the similarity relations to measured profiles. These differences are probably due to the selected values of the surface parameters or noise problems of the sodar measurements in the quite noisy urban environment.

Keywords: Urban boundary layer, Ground based remote sensing, Profiles of temperature and wind velocity, mesoscale model.

1. Introduction

The atmospheric boundary layer (ABL) relates surface and atmospheric processes. It is the region of large vertical transport of heat and water (Hennemuth et al., 2006). These processes could be simulated properly in models which are used not only for forecast, but also in energy applications. In this study comparison of several parameters in the atmospheric boundary layer derived from the meteorological component of the mesoscale model TAPM and from observations over an urban area is presented and the ability of the model to simulate the boundary layer processes is discussed.

2. Measurements and modeling

The instrumentation used for wind and temperature measurements in the atmospheric boundary layer (ABL) over the urban area of Kozani, Greece, was an acoustic sounder (SODAR) and a radiometer profiler (MTP-5), respectively. Both measurements were conducted for a period of one year.

2.1. Wind measurements

Acoustic sounder system “Doppler Sodar PCS.2000-16/MF” was used for the vertical profile measurement of wind direction and velocity. The measuring principle of the mobile system is similar to echo sounder or RADAR technique. The SODAR transmits short and high power acoustic pulses of a certain frequencies into the atmosphere. A small fraction of the acoustic energy is scattered back from density fluctuations of the atmosphere, with the corresponding frequencies being a factor of the wind component parallel to the propagation of the acoustic waves. By means of the propagation time of the acoustic wave and the acoustic velocity the distance (or the height range) of the measuring volume can be evaluated (PCS.2000/MF, User Manual, copyright 2005 METEK GmbH).

The SODAR was installed, after calibration, on the terrace of a building in the city of Kozani (Figure 1) at a total height of 707m (including the height of the building) above sea level and 30m horizontal distance from the road (40.301718°, 21.800835°). Wind measurements up to 300m above ground were conducted from 02/2014-01/2015.

Figure 1. Satellite image of Kozani showing the installation site of SODAR.

2.2. Temperature measurements

MTP-5 R.P.O “ATTEX” was used for temperature profile measurements. MTP-5 is a remote sensing instrument that measures radiation emitted from the lower 1000 m of the atmosphere, within the Planetary Boundary Layer. Atmospheric radiation is measured by scanning in angular steps from horizontal to vertical and the operating software processes the data into vertical height and temperature information. The data is stored and profiles are displayed graphically every 5 minutes, typically showing the temperature at 50 m height intervals.

The instrument was installed on a building in the city of Kozani at coordinates 40.298809°, 21.799331°. Temperature measurements up to 600m were carried out from 02/2014-01/2015.

2.3. The Air Pollution Model (TAPM)

TAPM is a three dimensional incompressible, non-hydrostatic, primitive equations model, with meteorological and air pollution components, which uses a terrain-following coordinate system. For computational efficiency it can be used in a telescoping nested configuration where higher resolution grids are successively placed inside coarser resolution ones. Model solution for each grid is one way interacting-information is passed from the coarser grid downwards [P. Zawar-Reza et al, 2005]. Data sets of the required important inputs for meteorological simulations accompany the model, allowing model set up for any region. However, user-defined data bases can also be connected to the model if desired. In any case, for meteorological and air pollution forecasts to be performed by the TAPM, emission information data have to be supplied by the user [S. Zoras et al, 2008]. The model uses surface similarity and urban parameterizations of various surface parameters (like roughness length and displacement height) to estimate surface turbulent fluxes, and the standard E-ε model for the estimation of eddy diffusivity in the ABL. TAPM solves fundamental fluid dynamics and solar transport equations to predict meteorology and pollutant concentration.

3. Results and conclusions

The purpose of this paper is to evaluate the performance of the Air Pollution TAPM Model and more specifically its surface layer and ABL turbulence parameterizations. The wind and temperature measurements were conducted in the atmospheric boundary layer (ABL) over the urban area of Kozani, Greece for a time period of about one year using an acoustic sounder (sodar, up to 300 m above ground) and a radiometer profiler (up to 600 m above ground), respectively. The comparison of model predictions to the experimental measurements was limited to selected days (9.2.2014, 17.2.2014, 28.3.2014, 9.8.2014, 21.12.2014 and 12.1.2015) from the period of the experiment (January 2014 - January 2015) that were representative of different conditions of atmospheric wind intensity and atmospheric stability with low acoustic noise, which affects the range of sodar measurements (only the results for one day, 9.8.2014, are presented in more detail).

Actually, on 9.8.2014, the vertical profile measurements of wind speed (U) and wind direction (dir) as measured by SODAR on 24h basis, of dynamic temperature (θ), as measured by MTP-5, and the corresponding TAPM forecasts up to the highest measuring height of either SODAR or MTP-5, showed that the wind measurements by SODAR exhibit high background at heights above 200m (presented as unusually high single wind values) while at heights below 200m the observed values, and especially those of wind speed differ from the forecasted ones. Figure 1 is a good representation of these remarks, presenting the daily trends of the aforementioned values near surface (lowest measuring height of SODAR and MTP-5). As shown in Figure 1, the dynamic temperature measurements from MTP-5 present a minor background while the thermal structure of the atmosphere is similar to the one predicted by the TAPM model. Finally, there is a good agreement between the MTP-5 temperature measurements and the corresponding model predictions (see Figure 1).

The processing and analysis of deviations between the observed and predicted values, showed a variance during the day (24hrs) with the lowest differences presented in the mid day. Wind speed predictions were overestimated by 3-4 m/s, with the random error increasing with height due to the corresponding background rise. A small systematic error (± 1K) was also presented in the predicted daily variations of dynamic temperature and the estimation of the atmosphere's thermal structure.

Figure 2 presents the vertical profile of wind speed and dynamic temperature measurements on 09-08-2014,13:30 LT (minus U_1 and θ_1 values, respectively) at the initial measuring height (lower than 200m) and their optimum fit (displacement length ≈ 3 m), according to the similarity theory..

Figure 3 presents the daily trends of the friction velocity (u_*), the surface turbulent heat flux (H_s) and the mixing height (Z_i) of the atmospheric boundary layer, as estimated by SODAR and MTP-5 measurements and TAPM predictions on 9.8.2014. From this figure it can be concluded that u_* και H_s values are in good agreement with the predicted ones. However, the model overestimates the lowest values of friction velocity and especially the highly negative values of heat flux and underestimates the mixing height.

In conclusion, the comparison showed that the TAPM model forecasts generally performed well with respect to the temperature profiles and ABL height, but overestimated wind speed (up to 3-4 ms^{-1}) at heights near ground level (mostly below 200 m). Also, friction velocity and less heat fluxes were generally overestimated by the TAMP model when compared to the corresponding estimates derived by fitting the similarity relations to measured profiles. These differences are probably due to the selected values of surface characteristics parameters or noise problems of the sodar measurements in the quite noisy urban environment.

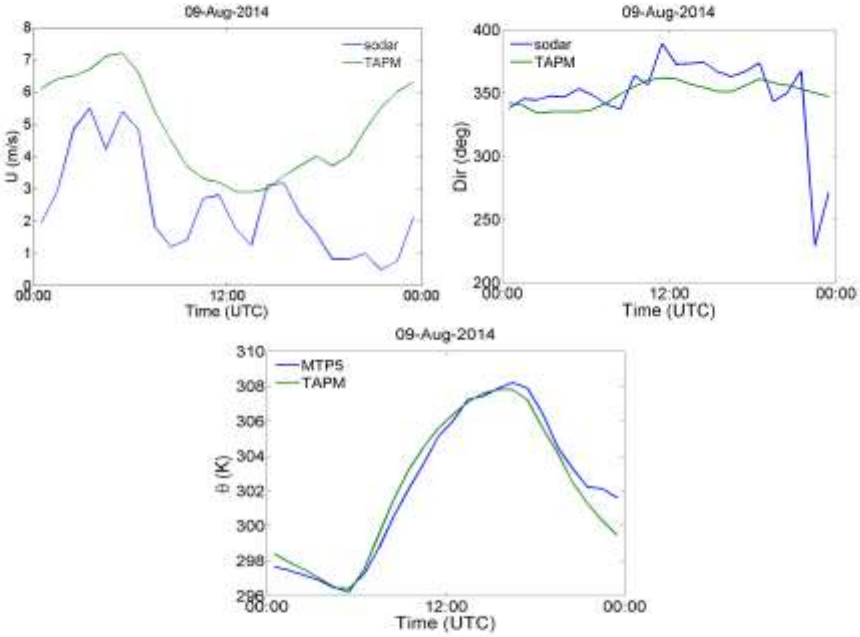


Figure 1. Daily trend of wind speed (U), wind direction (dir), dynamic temperature (θ) and the corresponding TAPM forecasts near surface (lowest measuring heights of SODAR and MTP-5) on 9.8.2014.

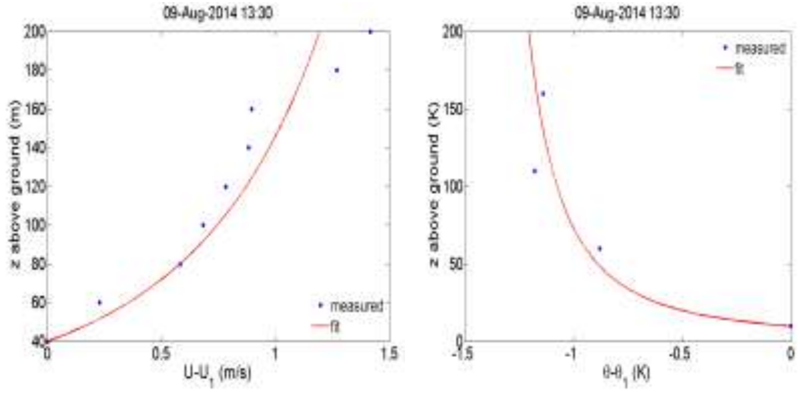
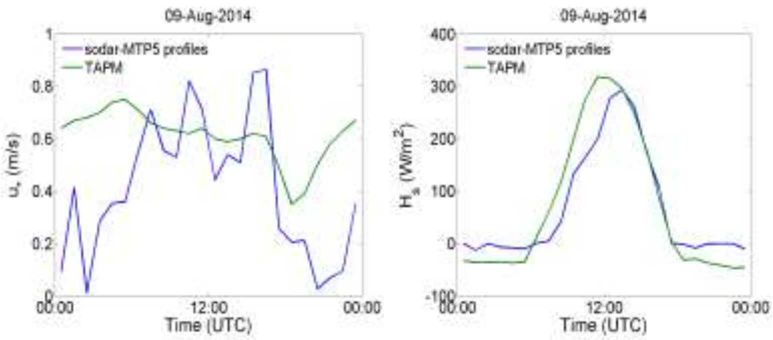


Figure 2. Wind speed ($U - U_1$) and dynamic temperature ($\theta - \theta_1$) vertical profile at heights lower than 200 m (near the atmospheric surface layer) and their optimum fit according to the theory of similarity.



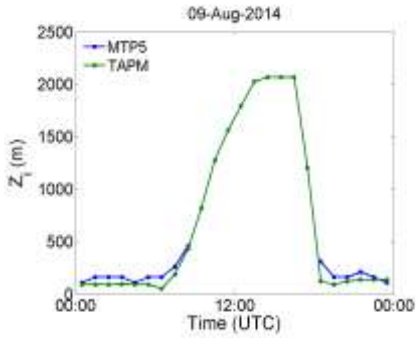


Figure 3. Daily trend of friction velocity, surface turbulent heat flux, mixing height of the atmospheric boundary layer and the corresponding model predictions near ground level on 9.8.2014.

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