NUMERICAL MODELING OF PM2.5 PROPAGATION IN TBILISI ATMOSPHERE IN WINTER. I. A CASE OF BACKGROUND SOUTH LIGHT WIND

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Summary: *Temporal and spatial variations of PM2.5 distribution originated resulting from motor transport traffic during background south light wind are studied via numerical modeling. PM2.5 high concentration zones at the territory of the city are established, and time intervals, where air high pollution forms or air self-purification process occurs, are determined. There is established a difference, which exists between PM2.5 spatial distributions in case of background south and north winds.*

Key words: *PM2.5 concentration, atmosphere pollution, numerical modeling.*

Introduction

Since the beginning of the XXI century a special attention is given to the study of microaerosol pollution of atmospheric air of industrial regions and large administrative centers. The problem became particularly topical in the course of last 2-3 years, since the transfer and diffusion processes of viruses getting on PM2.5 and PM10 can be considered as one of the main reasons of COVID-19 pandemic throughout a world [1].

The presented article is an extension of studies started in [2] the goal of which is to theoretically study Tbilisi city atmospheric pollution with PM2.5 in case of background south light wind using numerical model [3, 4]. At that, an assumption is made that the pollution source is a motor transport, and related PM2.5 emission rate in the atmosphere is calculated empirically [2].

Analysis of modeling results

In Fig. 1 there are shown the fields of wind velocity and PM2.5 concentration at 2, 100 and 600 m height from the Earth surface in winter season at 3AM and 6AM during background south light wind, which are obtained through numerical integration. Calculations showed that in case of time-constant background south light wind, due to terrain effect, at the major part of territory of the city a quasi-stationary south wind is formed, which velocity varies from 0 to 15 m/sec in 600 m thick lower layer of the atmosphere. Vertical change of wind velocity is especially large (from 0 to 12 m/sec) in 100 m thick surface layer of the atmosphere. Rugged terrain influence on wind velocity is mainly manifested in the northern and north-western parts of the city, where roughly 8 km diameter local, ground cyclonic vortexes are formed.

PM2.5 spatial distribution is not uniform in the atmosphere at t = 0h. Its concentration at 2 m height from the ground is within limits of 0.001-0.01 mkg/m^3 at the major part of the city. In the city center, at territories of Vake, Saburtalo districts, Tsereteli Avenue, in the vicinity of Kakheti Highway and trunk road connecting Tbilisi and Rustavi cities, PM2.5 concentrations vary from 1 to 5 mkg/m^3. In time interval from t = 3h to 6h a concentration change is virtually insignificant. At altitudes higher than 100 m a concentration decrease takes place and its value doesn't exceed 1 mkg/m^3 at 600 m height.

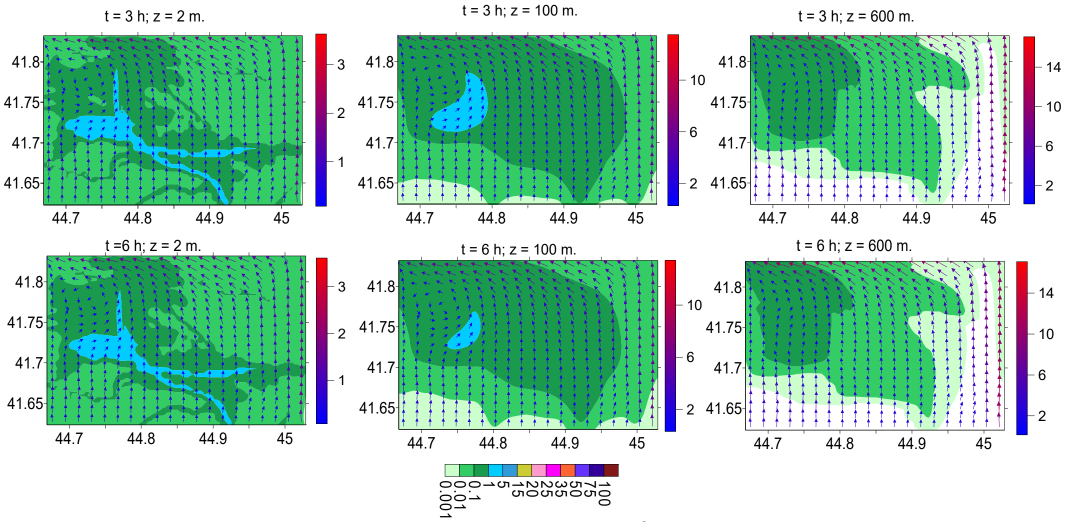

Fig. 1**.** Wind velocity (m/sec) and PM2.5 concentration (mkg/m^3) fields in surface and boundary layers of the atmosphere, when t = 3h and 6h

After 6 in the morning, PM2,5 concentration increases throughout the territory of the city along with motor transport traffic growth. Concentration increase is not uniform (Fig. 2). It is especially high in the city center, Vake and Saburtalo districts. At this territory, by 9 in the morning concentration value changes within limits of 25-35 mkg/m^3 at 2 m height. In contradistinction from concentration field formed during background north light wind there is no PM2.5 concentration increase in the surroundings of Kakheti Highway.

After 9 in the morning concentration is dropped in the main pollution areas and a quasi-stationary distribution of microaerosols is established. The obtained distribution is characterized by slight positive vertical gradient in 100 m thick surface layer and by slight negative gradient at altitude above 100 m.

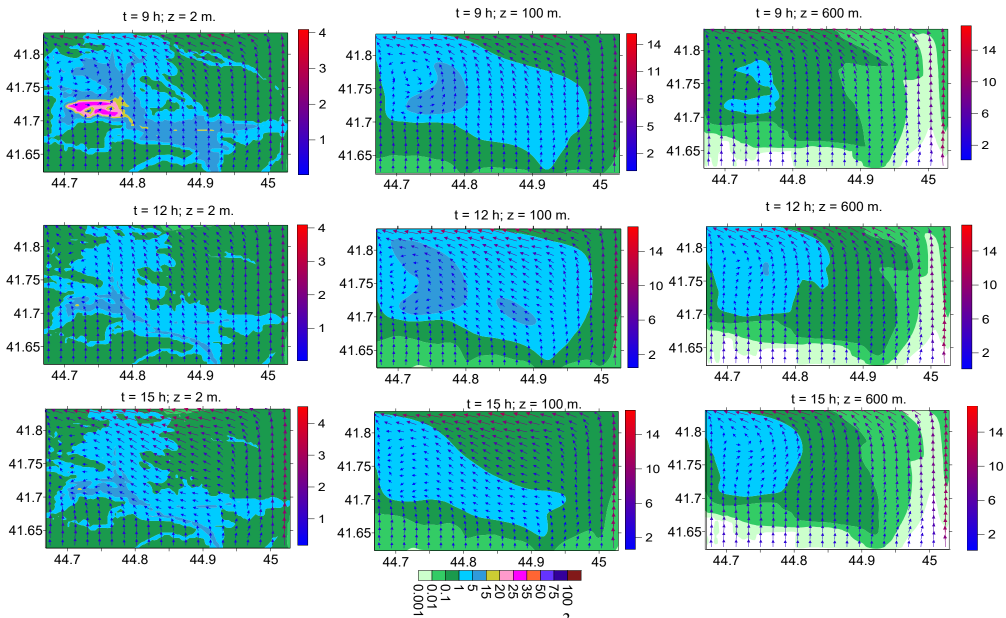

Fig. 2. Wind velocity (m/sec) and PM2.5 concentration (mkg/m^3) fields in surface and boundary layers of the atmosphere, when t = 9, 12 and 15 h

In the period from t=15h to 21h there takes place PM2.5 concentration increase, which is related to the second “rush hour” of motor transport traffic (Fig. 3). A sharp increase of concentration at 2 m height from the ground is obtained in Vake and Saburtalo districts, when t=18h. Concentration varies within limits of 25-35 mkg/m^3 at these territories. Concentration growth is relatively smaller in some small-size areas of Rustaveli and Gorgasali Avenues, Kakheti and Rustavi Highways, and Ortachala and Ponichala. From t=18h to 21h PM2.5 concentration is dropped in the areas of relatively high pollution. Vertical turbulent and convective diffusion takes place with increase of ground-level concentration and therefore PM2.5 content increases at 100 and 600 m altitudes. Maximum concentration values at these levels become equal to 20 and 15 mkg/m^3 by t = 18h. After t = 18h at 2 m height a slow reduction of concentration begins, while at 100 m height its growth continues. This process lasts until t = 24 h. By t = 24h such vertical distribution of microaerosols is established, when PM2.5 concentration at 100 m height is more than concentrations obtained at 2 and 600 m altitude. As for time variation of pollution, after 24 h the process repeats on a quasi-periodical basis.

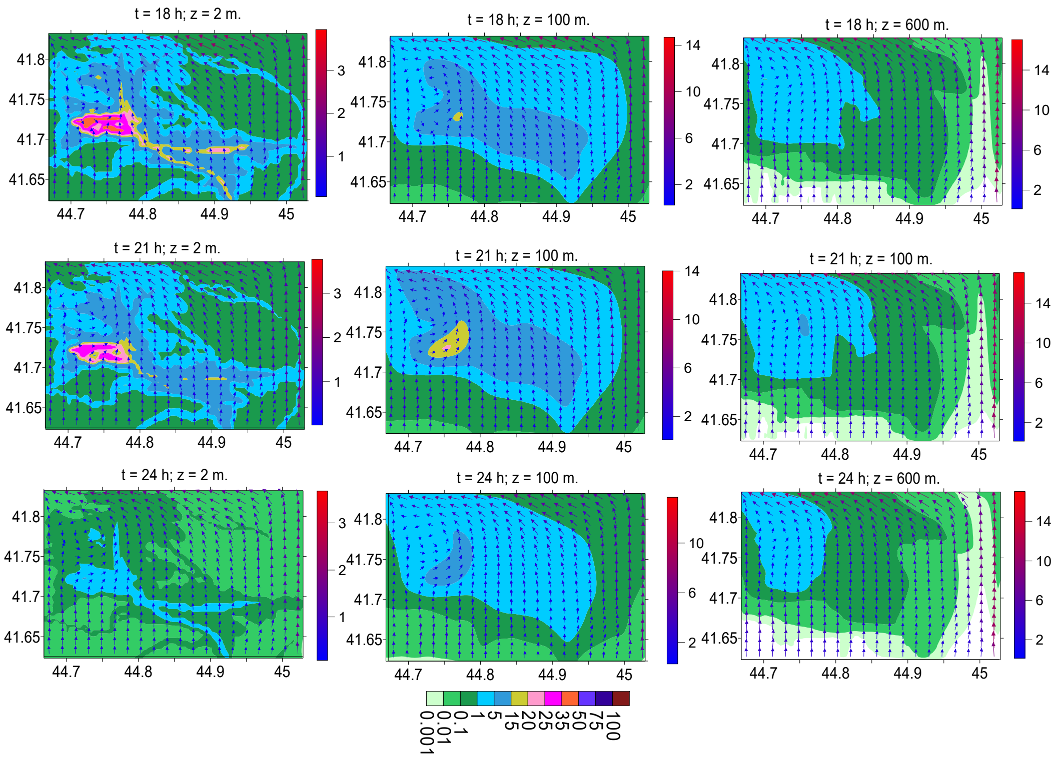

Fig. 3. Wind velocity (m/sec) and PM2.5 concentration (mkg/m^3) fields in surface and boundary layers of the atmosphere, when t = 18, 21 and 24 h

In Fig. 4 there are shown diagrams of PM2.5 concentration time variation in the surface layer at 2 m height. It seen from Fig. 4 that time evolution of concentration in case of background south light wind is qualitatively similar to temporal variation obtained for background north light wind (Fig. 8[2]) – there are obtained two periods of maximum and minimum pollution with corresponding time intervals.

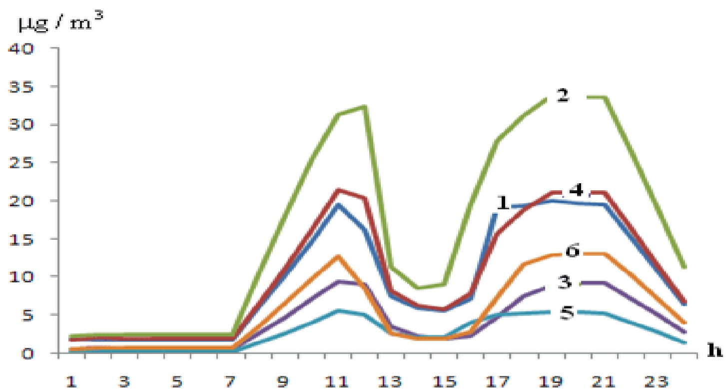

Fig. 4. Temporal variation of PM2.5 concentration in 6 points of modeling area: 1 – Ponichala, 2 – Vazha Pshavela Ave., 3 – Akhmeteli Theater, 4 – Freedom Square, 5 – Tskhneti, 6 – Digomi

Despite the fact that aerosols are emitted according to one and the same regularities in different pollution areas (points), temporal variation of formed concentrations is different, namely: the moments of reaching a maximum concentration, time variation gradients, concentration values in points located in the central and peripheral parts of the city etc.

In Fig. 5 there is shown a diurnal variation of concentration differences obtained via calculations in 6 modeling points at 2 m height in case of background south and north light winds. It is seen from Fig. 3 that in Ponichala, in the surroundings of Freedom Square and Digomi, in case of background south wind, during rush hours, concentration values are 1-20 mkg/m^3 higher than those obtained for north wind cases. On the contrary, at Vazha-Pshavela Avenue and in the vicinity of Akhmeteli Theater – in case of background north wind concentration is approx. 3-10 mkg/m^3 higher than concentrations obtained for south wind cases. As for concentrations in points located outside the town, the differences between them are small.

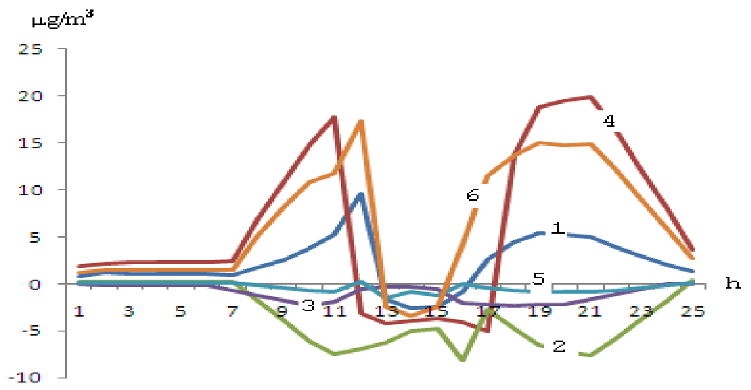

Fig. 5. Temporal variation of PM2.5 concentration differences in cases of background south and north light winds in 6 points of modeling area:
1 – Ponichala, 2 – Vazha-Pshavela Ave., 3 – Akhmeteli Theater, 4 – Freedom Square, 5 – Tskhneti, 6 – Digomi

A vertical distribution of PM2.5 concentration in three vertical sections drawn along the parallel to the surface layer of the atmosphere is shown in Fig. 5, from where is seen that in the period from t = 3h to 6 h, PM2.5 concentration in surface layer of the atmosphere is ≤ 5 mkg/m^3 and is characterized by a slight reduction trend. After t = 6 h, aerosols concentration in the surface layer increases along with motor transport traffic intensity and by t=9h the zones of average and high pollution are formed. They are of quite large vertical and horizontal sizes and cover almost the entire surface layer. In the period from t=9h to 15h, despite a constant quantity of aerosols getting on atmosphere (t = 9-12h) and its small reduction (t = 12-15h) (Fig. 2) a significant drop of concentration and air quality improvement take place. A sharp increase of ground-level concentration is obtained in the time interval from t=16h to 21h. In this time period a maximum concentration value reaches 50 mkg/m^3 at small area near the earth surface. If we analyse PM2.5 concentration vertical distribution in different points of time, we can come to conclusion that in case of background light wind the prevailing mechanisms of aerosols propagation are represented by vertical and horizontal turbulent diffusion in the surface layer of the atmosphere. Turbulent flows transfer aerosols from surface layer to boundary layer, where an advective transfer causes pollution dissipation at large areas and air self-purification.

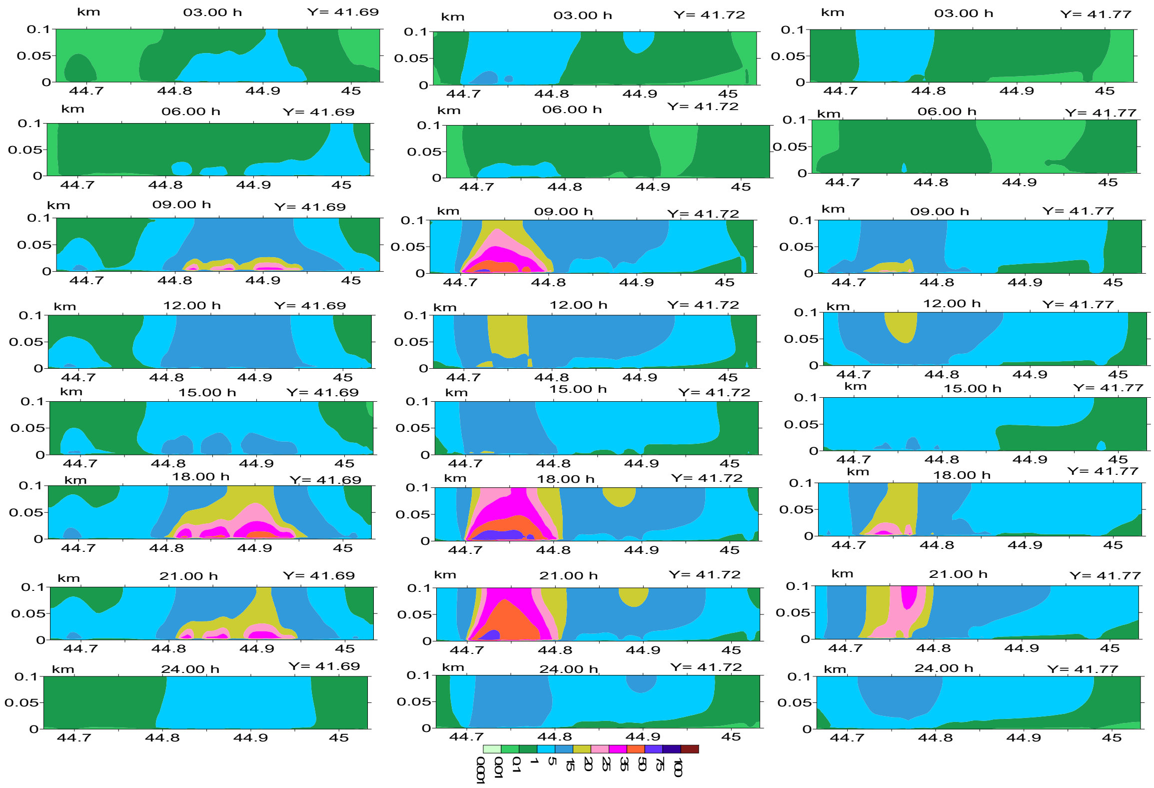

Fig. 6. PM2.5 concentration isolines in 100 m thick lower atmospheric layer in three vertical sections drawn along the parallels

Conclusion. Carried-out experiments showed that in case of background south light wind the city orography doesn't assist city aeration, so Tbilisi atmosphere pollution with PM2.5 is relatively high. In the vicinity of Freedom Square, Ponichala, Digomi maximum concentrations of PM2,5 are approx. 10-20 mkg/m^3 higher than those obtained during north wind. Ground-level concentrations from t=18h to 21h are high at the territories of Vake, Saburtalo, Ortachala and in the surroundings of Freedom Square. From midday to 6PM time period the concentration values obtained through calculation don't exceed 5 mkg/m^3.

Acknowledgement. The work is performed with funding from grant project №FR-3667-18 of Shota Rustaveli National Science Foundation.

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