Journal of the Georgian Geophysical Society, ISSN: 1512-1127
Physics of Solid Earth, Atmosphere, Ocean and Space Plasma, v. 23(1), 2020, pp. 51 -56

Numerical Modelling of Dust Propagation in the Atmosphere of Tbilisi City: The Case of Background Eastern Fresh Breeze

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ABSTRACT

Dust propagation at Tbilisi city territory in case of strong background eastern winds is studied using the 3D regional model of atmospheric processes evolution and integration of the equation of admixtures transfer-diffusion. It is shown that dust propagation substantially depends on both the terrain of city and surrounding territories and on the magnitude and direction of background wind velocity. It is obtained that dust propagation process in case of strong background wind is characterized by time variation and spatial distribution peculiarities. High pollution zones as well as the reasons of their time variation and dust accumulation are determined. It is established that a high pollution level (1.2-2.0 MAC) is obtained in the time interval from 3 p.m. to 9 p.m. in the up to 50 m thick lower part of surface layer of the atmosphere.

Keywords: *numerical modeling, Tbilisi dust pollution, diffusion, strong wind.*

Introduction

The represented article is a continuation of studies started in [1] and dust pollution of Tbilisi city having complex terrain is studied in it via numerical modeling in case of strong background eastern wind. The magnitude of background eastern wind at 100 m height from earth surface (the upper boundary of the surface layer of atmosphere) equals to 10 m/sec and linearly increases up to 28.6 m/sec at 9 km altitude above sea level. It is assumed that the dust quantity dispersed in the atmosphere linearly depends on the traffic intensity. Time and space change of meteorological fields necessary for modeling is calculated according to numerical model described in [2, 3]. Meteorological situation corresponds to dry weather of June, when relative atmospheric humidity is 50%. Calculations are made along parallel and meridian with 300 and 400 m horizontal steps. Vertical step in the free atmosphere varies in time and equals 300 m in average. In 100 m thick surface layer of the atmosphere a vertical step varies from 2 to 15 m. Tbilisi city with a complex terrain is disposed in the center of modeling area.

Modeling results

In Fig. 1 there is shown a spatial distribution of dust concentration and wind velocity at 2, 100 and 600 m height over a ground at t = 0, 3 and 6 hours of the first day obtained via calculations. Dust content is given in units of one-off maximum allowable concentration (MAC = 0.5 mg/m^3). It is seen from Fig. 1 that at 2 m height from underlying surfaces a dust concentration value is less than 0.1 MAC. In the interval of time from

0.00 a.m. to 6.00 a.m. there is no dust emission in the city atmosphere. Wind takes a dust away from city territory, and the atmosphere self-purification process occurs, that's why dust concentration is getting smaller and by 6.00 a.m. its value in the surface layer of atmosphere is of order of 10^{-7}-10^{-6} MAC. In this time period dust distribution is featured by the fact that a concentration value at 600 m height is higher than that obtained at 2 an 100 m height.

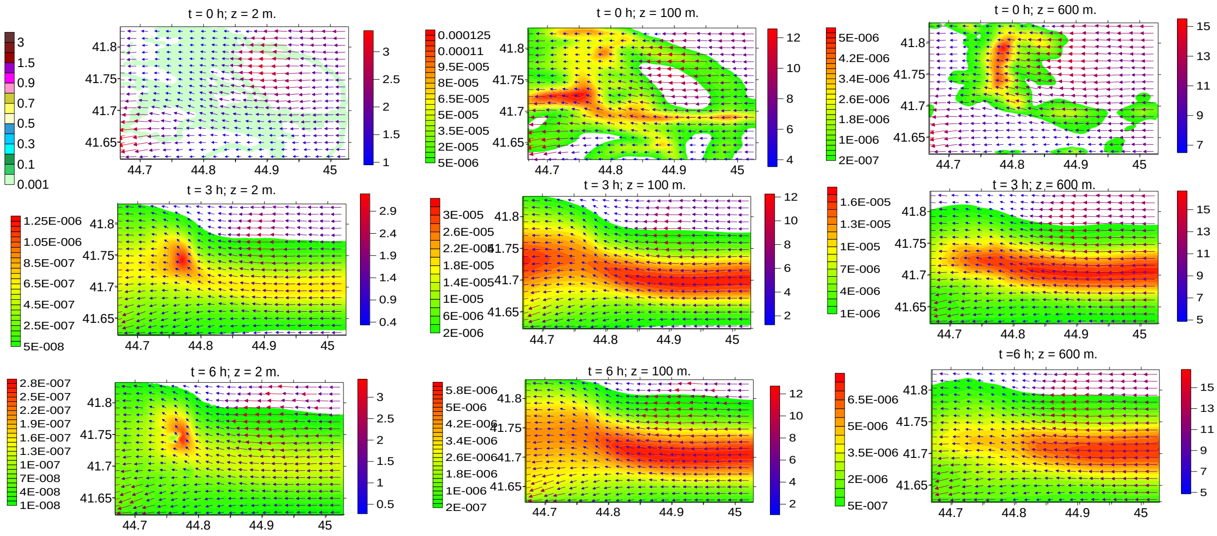

Fig. 1. Wind velocity (m/sec) and dust concentration (MAC) distribution, when t = 0, 3 and 6 h at 2, 100 and 600 m height over a ground

Starting with 6.00 a.m., the dust pollution level of the atmosphere in city streets is getting higher (Fig. 2). Concentration increase is associated with beginning of intense vehicular traffic. As a result, by t = 9.00 h we get a state when dust is propagated throughout a city. Large magnitudes of concentration are obtained at Gldani and Temka mains, their crossing areas, Guramishvili Avenue, Saburtalo and Vake mains, Heroes Square, and at separate sections of Gorgasali Avenue and Kakheti Highway. Concentration is within 0.8-1.0 MAC at mentioned territories. Despite the fact that the vehicle traffic intensity at Georgian Military Road, Tsereteli Avenue, and both sides of Mtkvari river embankment is roughly the same as at city mains with high pollution level, the concentration in their vicinity is relatively less and varies within limits of 0.5-0.8 MAC. The mentioned effect is obtained due to orography and thermal impact of underlying surface. In particular, along the Mtkvari river gorge, during the mentioned time interval, wind velocity direction changes by 90-180 grades and air stream convergence zone forms. The counter air flow brings along an originated dust and increases its concentration in Gldani, Temka and Nadzaladevi districts. In Vake and Saburtalo districts a dust brought by eastern flow, at high altitudes meets resistance of Mama Daviti ridge, cannot overcome it and increases dust pollution level in the mentioned districts. Dust horizontal distribution is such that dust concentrations are approximately within a limit of 0.3-0.5 MAC at 2-5 km distance from heavy pollution areas, while at more distances concentrations drop to 0.1-0.001 MPC. It should be noted that in morning hours dust pollution occurs mainly in the 50 m thick lower part of surface layer of the atmosphere. As for higher altitudes, concentrations are small there and are within a range of 0.1-0.3 MAC. From t = 9 to 21 h the quantity of dust dispersed in the atmosphere, doesn't change. At the same time, this time interval can be divided into two periods according to concentration changes:

First, from t = 9 to 18h, when concentration changes insignificantly; Second, from t = 18 to 21 h, when dust pollution level increases in the central and western parts of the city and reduces in the eastern part (Fig. 2 and Fig. 3). In these periods dust concentration in high pollution zones reaches 1.5-2 MPC at 2 m height.

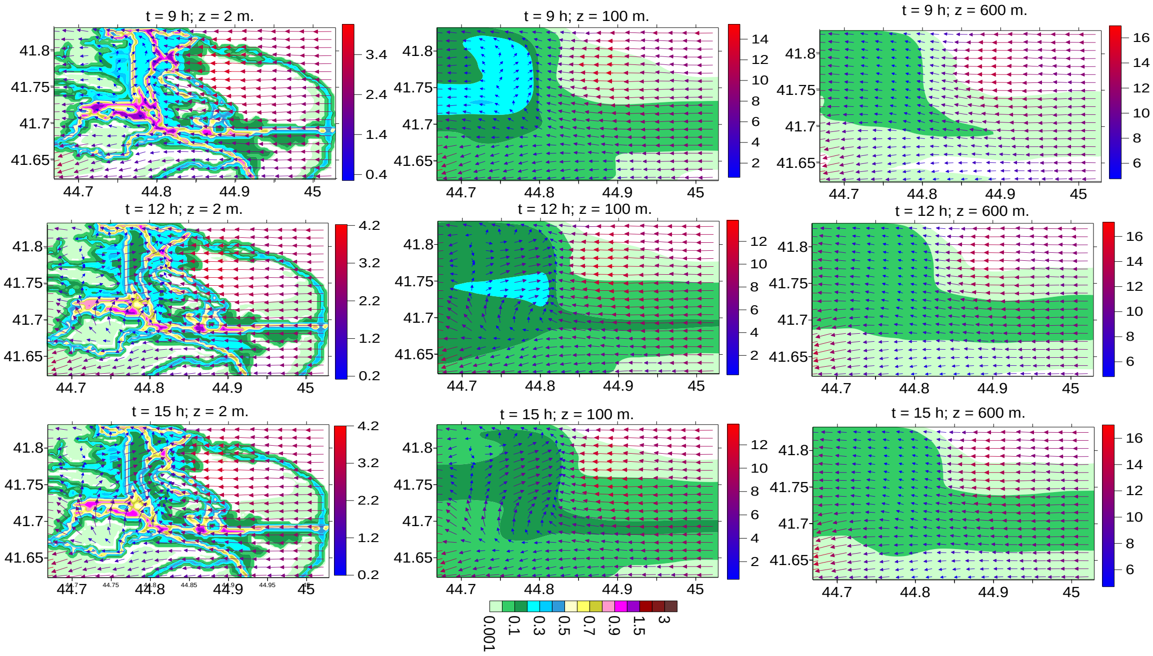

Fig. 2. Wind velocity (m/sec) and dust concentration (MAC) distribution, when t = 9, 12 and 15 h at 2, 100 and 600 m height over a ground

In both periods, dust pollution pattern changes depend on diurnal variation of wind velocity. During the first period there takes place increase of western wind in the western part of the region and convergence band shift to the east by 1.5-2.0 km distance. Starting with t = 16 h there takes place western wind weakening in the surface layer of atmosphere, convergence band breakup and eastern wind formation in the western part of the region. As a result, accumulation of local dust and dust taken by advection, and respectively its concentration increase occurs to the west of city, nearby the Mama Daviti piedmont slopes.

Two mutually opposite processes of dust pollution take place in the upper part of surface layer of the atmosphere and in the atmospheric boundary layer. At 100 m height over a ground from t = 9 to 15 h dust concentration reduces and afterwards, from 15 to 18 h it increases. The mentioned effect is obtained in the atmospheric boundary layer at 600 m height, as well, though with less obviousness.

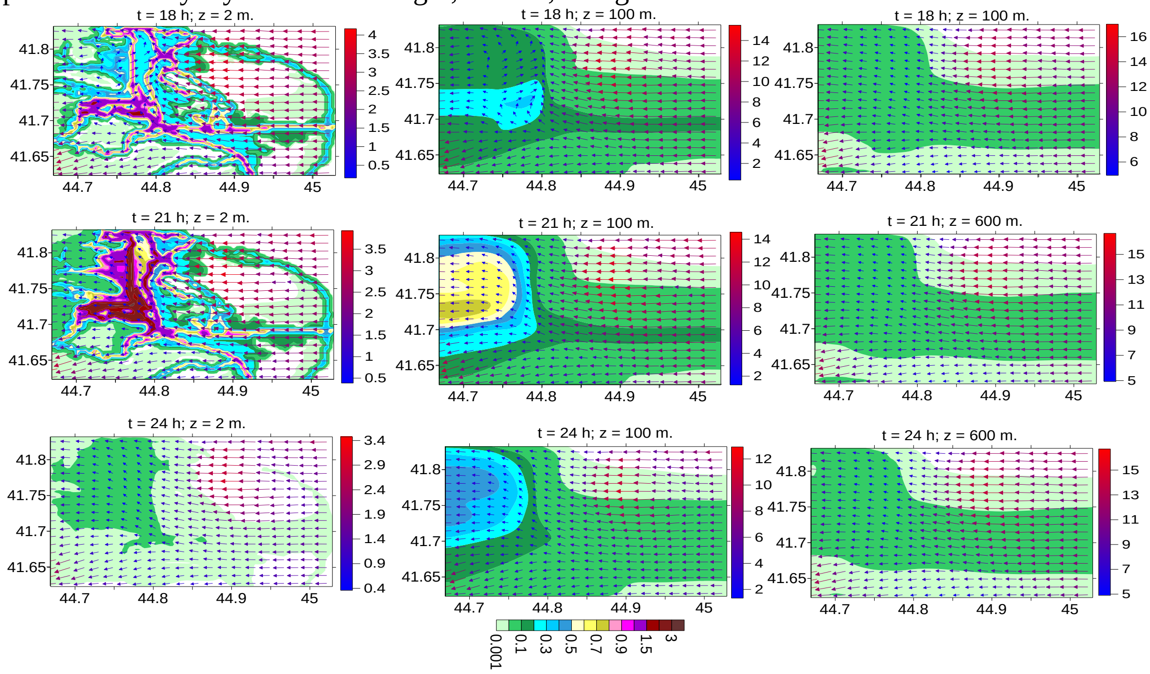

Fig. 3. Wind velocity (m/sec) and dust concentration (MPC) distribution, when t = 18, 21 and 24 h at 2, 100 and 600 m height over a ground

From t = 21 to 24 h a sharp decrease of vehicular traffic intensity takes place. As a consequence, the quantity and concentration of dispersed dust at 2 m height reduces. At this time, the wind velocity and vertical turbulence are high in the lower part of a surface layer that causes powerful vertical diffusion and advective transfer of near-the-ground dust. So, we get a steady state, when maximum dust concentration at 100 m height (0.7 MAC) exceeds the concentrations that are obtained at 2 and 600 m heights (0.1 MAC).

Dust vertical distribution for different moments is shown in Fig. 4. Concentration isozones in 3 cross-sections drawn along the parallels in the surface layer of atmosphere are depicted there. It is seen from Fig. 4 that from the beginning of a day in this period 0 h< t < 6 h dust concentration in the lower part of surface layer of the atmosphere is less than above it. After t = 6 h, with intensification of vehicular traffic, the high pollution areas shaped like convection clouds are formed in the near-the-ground surroundings of dust pollution sources. Starting with this moment, dust concentration in the lower 50 m thick part of surface layer substantially exceeds concentration values obtained above it. Afterwards, there takes place intensification of abovementioned dust pollution processes, which reaches its maximum by t = 21 h. After t = 21 h a self-purification process – dust pollution reduction occurs. Self-purification process lasts until 6.00 a.m.. Then, this process repeats on a quasi-periodic basis.

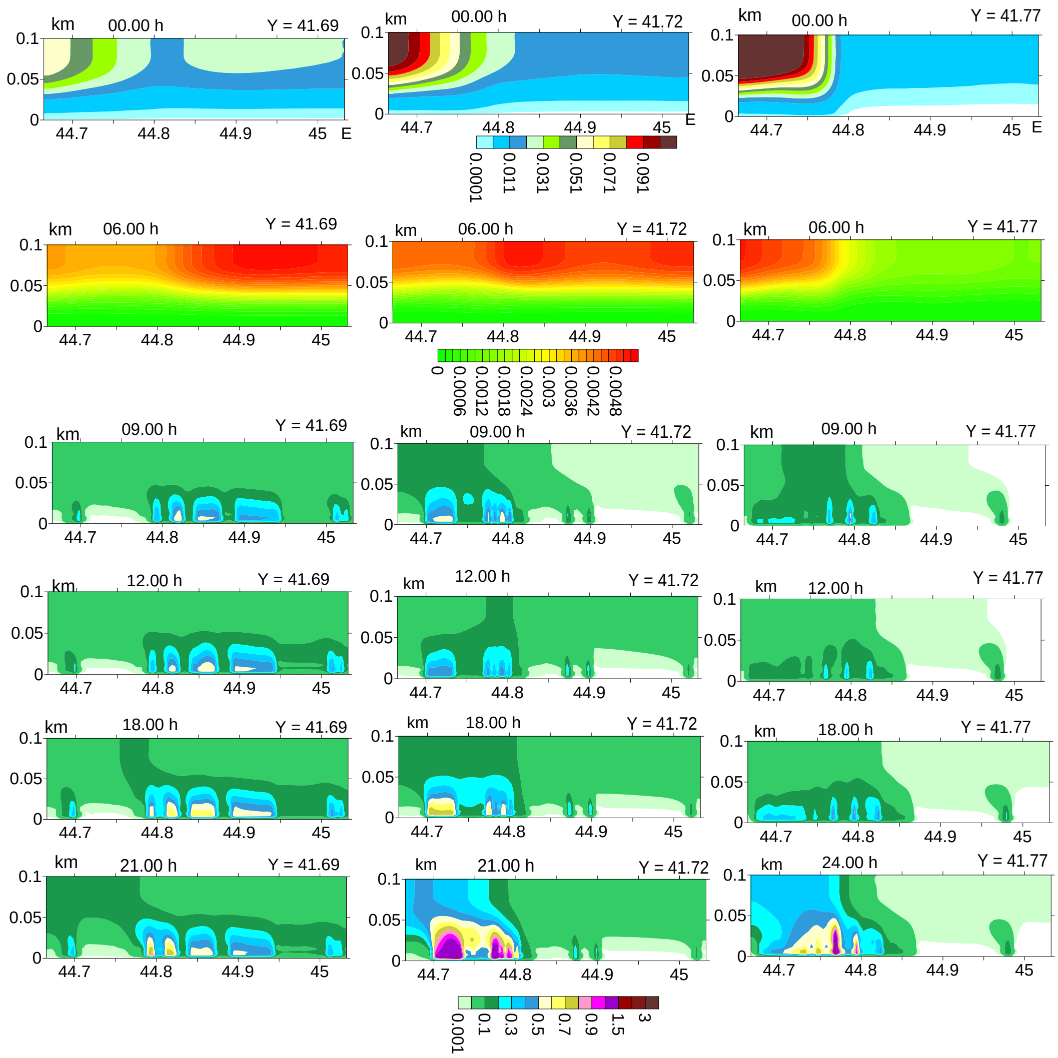

Fig. 4. Dust concentration vertical distribution (MPC) in three vertical sections (41,69^{O} N, 41,72^{O} N, 41,77^{O} N) drawn along the parallel in the surface layer of atmosphere

Conclusion.

The kinematics of dust concentration change created by motor transport at the territory of Tbilisi and diurnal pattern of its spatial distribution in case of strong background eastern wind are studied. Via analysis of wind velocity and concentration fields it is obtained that spatial distribution of heavily polluted areas depends on city mains disposition, and local circulation systems formed under dynamic impact of terrain and diurnal change of thermal regime at the underlying surface. Maximum concentration 1.5-2.0 MPC is obtained in time interval of t = 15-21 h in the central and western parts of the city. At 600 m height from earth surface a maximum value of concentration reaches 0.7 MAC, when t = 21h.

Results obtained through modeling of time and spatial changes of dust concentration qualitatively correctly describe the true picture. From a quantitative viewpoint, modeling results are close to average characteristic data of observations [3].

Acknowledgment. The study was carried out under financial support of Shota Rustaveli National Science Foundation of Georgia [FR-18-3667].

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ქ. თბილისის ატმოსფეროში მტვრის გავრცელების რიცხვითი მოდელირება: ფონური აღმოსავლეთის ძლიერი ქარის შემთხვევა

ვ. კუხალაშვილი,ნ. გიგაური, ა. სურმავა, დ. დემეტრაშვილი, ლ. ინწკირველი

რეზიუმე

ატმოსფერული პროცესების ევოლუციის 3D რეგიონალური მოდელისა და მინარევების გადატანა-დიფუზიის განტოლების ერთობლივი ინტეგრირებით შესწავლილია მტვრის გავრცელება ქ.თბილისის ტერიტორიაზე ფონური აღმოსავლეთის ძლიერი ქარის დროს. მიღებულია, რომ მტვრის გავრცელების პროცესი ძლიერი ფონური ქარის შემთხვევაში ხასიათდება დროში ცვლილების და სივრცული განაწილების თავისებურებებით. ქარის სიჩქარისა და კონცენტრაციის ველების ანალიზით დადგენილია, რომ ძლიერ დამტვერიანებული არეების სივრცული განაწილება დამოკიდებულია ავტომაგისტრალების მდებარეობაზე, რელიეფის დინამიკური ზემოქმედების და ქვეფენილ ზედაპირზე თერმიული რეჟიმის დღეღამური ცვლილებით ფორმირებულ ლოკალურ ცირკულაციურ სისტემებზე. მაქსიმალური კონცენტრაცია 1.5 – 2.0 ზდკ ფორმირდება 15.00 – 21.00 საათის ინტერვალში ატმოსფეროს ქვედა 50 მეტრამდე ფენაში ქალაქის ცენტრალურ და დასავლეთ ნაწილებში. მიწის ზედაპირიდან 600 მეტრის სიმაღლეზე კონცენტრაციის მაქსიმალური მნიშვნელობა 21.00 საათზე აღწევს 0.7 ზდკ-ს.

ЧИСЛЕННОЕ МОДЕЛИРОВАНИЕ РАСПРОСТРАНЕНИЯ ПЫЛИ В АТМОСФЕРЕ г.ТБИЛИСИ: СЛУЧАЙ ВОСТОЧНОГО СИЛЬНОГО ФОНОВОГО ВЕТРА

В.Г. Кухалашвили, Н.Г. Гигаури, А.А. Сурмава, Д.И. Деметрашили, Л.Н. Инцкирвели

Резюме

С помощью региональной модели атмосферных процессов на Кавказе и уравнения переноса-диффузии примеси в атмосфере, изучено распространение пыли на территории г. Тбилиси при сильном фоновом ветре. Анализ полей скорости ветра и концентрации пыли показал, что пространственное распределение областей высоких концентрации зависит от расположения автомагистралей, динамического воздействия рельефа и локальных циркуляционных процессов, формированных изменением суточного термического режима на подстилающей поверхности. В нижней приземной 50-метровой зоне центральной и западных частях города максимальные концентрации 1.5-2.0 ПДК формируются во временном интервале от 15 до 21 часа. На высоте 600 м от поверхности земли максимальная концентрация 0.7 ПДК достигается к 21 часу.