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Vertical ozone flux in the near-surface layer of a background region of Western Siberia in 2016

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ABSTRACT

Vertical flux of ozone and the dry deposition rate have been calculated with the data measured at a high weather tower installed at the territory of Fonovaya (Background) Observatory of IAO SB RAS. The measurements were conducted in the period from February till July of 2016. It is shown that there are well pronounced diurnal dynamics of the vertical ozone flux and the dry deposition rate, which are inverse with respect to each other.

Keywords: vertical ozone flux, surface layer, ozone, deposition rate

1. INTRODUCTION

Ozone is the fifth main greenhouse gas and has the powerful oxidation potential in the atmosphere. This gas exerts the negative effect on the human health, vegetation and materials. Therefore, its spatial distribution and temporal dynamics are actively studied in many countries.

The dynamics of the spatiotemporal ozone distribution is determined by the advection of ozone and ozone-forming substances, as well as by the balance of their sources and sinks. One of the main components of the ozone balance in the surface layer is the vertical transport (flux) determining the ozone income from the upper layers, as well as sink to the surface. In this study, the vertical ozone flux was estimated experimentally for a background region of Western Siberia.

2. MEASUREMENT DATA AND CALCULATION METHODS

To assess the vertical ozone flux in the surface layer, the ozone concentration and meteorological parameters were measured from the high tower installed in the Fonovaya (Background) Observatory of IAO SB RAS. This observatory is located in a background region of the Tomsk Oblast (56°25' N, 84°04' E, 80 m above the sea level, http://lop.iao.ru). In this study, we used the data obtained for the period from April till July of 2016.

The tower meteorological measurements were conducted at four height levels of 10, 20, 30, and 40 m above the surface. Temperature and humidity sensors (Vaisala HMP155) and ultrasonic anemometers (Young Model 85000) were installed at every level. In addition, the near-surface pressure was additionally measured (Young Model 61302V). The ozone concentration was measured at two heights of 10 and 30 m by the 3.02P-A device made

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by OPTEK, Russia. The relative error of measurements was 20% in the concentration range of 30-500 μg/m^3. The air sample handling and distribution system was made of the chemically neutral fluoroplastic material (pipe with an outer diameter of 12 mm and wall thickness of 1 mm, pump of 20 liter/min, receiver with volume of 0.7 liter). The measured results were recorded every hour.

To calculate vertical ozone fluxs, we used the gradient technique based on the MoninObukhov similarity theory [1]. According to [1], a gas flux is calculated by Eq. (1)

$$F_{O_3}(z_m) = -K\frac{\partial O_3}{\partial z} \tag{1}$$

where, $-\frac{\partial O_3}{\partial z}$ - vertical gradient ozone concentration, K - coefficient of turbulence, $z_m = \sqrt{z_1 z_2}$ is the reference height, for which the flux is calculated, $z_1 = 10m$ $z_2 = 30m$ are the heights of the upper and lower measurement levels, respectively.

In the calculations was made following rule: vertical gradient$-\frac{\partial O_3}{\partial z}$, and flux $F_{O_3}(z_m)$ with it, positive (directed upwards), if concentration reduces with height ($\Delta O_3 < 0$) and negative (directed downwards), if concentration increases with height ($\Delta O_3 > 0$).

For parameterization of the coefficient of turbulent diffusion, Eqs. (2-5) were used with allowance made for the stratification (ζ) of the surface layer

$$K = \frac{k z_m u_*}{\varphi_h(\xi_m)} \tag{2}$$

$$u_* = \frac{k z_m}{\varphi(\zeta)}\frac{\partial U}{\partial z} \tag{3}$$

.

$$\begin{gathered}\varphi_m(\xi_m) = 1 - 5\xi_m, \xi_m \geq 0 \\ \varphi_h(\xi_m) = 1 - 5\xi_m, \xi_m \geq 0\end{gathered} \tag{4}$$

$$\begin{gathered}\varphi_m(\xi_m) = (1 - 16\xi_m)^{\frac{-1}{4}}, \xi_m < 0 \\ \varphi_h(\xi_m) = (1 - 16\xi_m)^{\frac{-1}{2}}, \xi_m < 0\end{gathered} \tag{5}$$

where $\varphi_h(\xi_m)$ are universal differential functions of heat and angular momentum [2], ζ is the parameter of stability, u_* is the friction rate [3], $k = 0.4$ is the von Karman constant, $\frac{\partial U}{\partial z}$ is the wind velocity gradient.

The parameter of stability ζ is calculated by the iterative method with the Richardson gradient number Ri_m by Eq. (6) [1]

$$Ri_m = \frac{g}{\theta_0}\frac{\frac{\partial\theta}{\partial z}}{\left(\frac{\partial U}{\partial z}\right)^2} \tag{6}$$

$$Ri_m = \begin{cases} \dfrac{\zeta(0.74 + 0.47\zeta)}{(1 + 4.7\zeta)^2}, & \zeta > 0 \\ 0.74\zeta\left(\dfrac{1 - 15\zeta}{1 - 9\zeta}\right)^{0.5}, & \zeta \leq 0 \end{cases}$$

The dry deposition rate was calculated by Eq. (8)

$$v_{O_3} = -F_{O_3}/O_3 \tag{7}$$

As usual, deposition rate results are in centimeters per second (cm/s), what is more positive value means that exchange goes from top to bottom, then negative means contrariwise.

3. RESULTS

Figures 1 and 2 show the diurnal average dynamics of the ozone flux and the dry deposition rate, respectively. To calculate the average values of the fluxs, we used the range from -3 to 4 μg/(m^{2}s), which was obtained from the statistical processing of the entire series. The results presented differ insignificantly from the data reported in [4]. This is likely caused by the fact that the data were complemented with new measurements and the iterative procedure was introduced for the calculation of ζ.

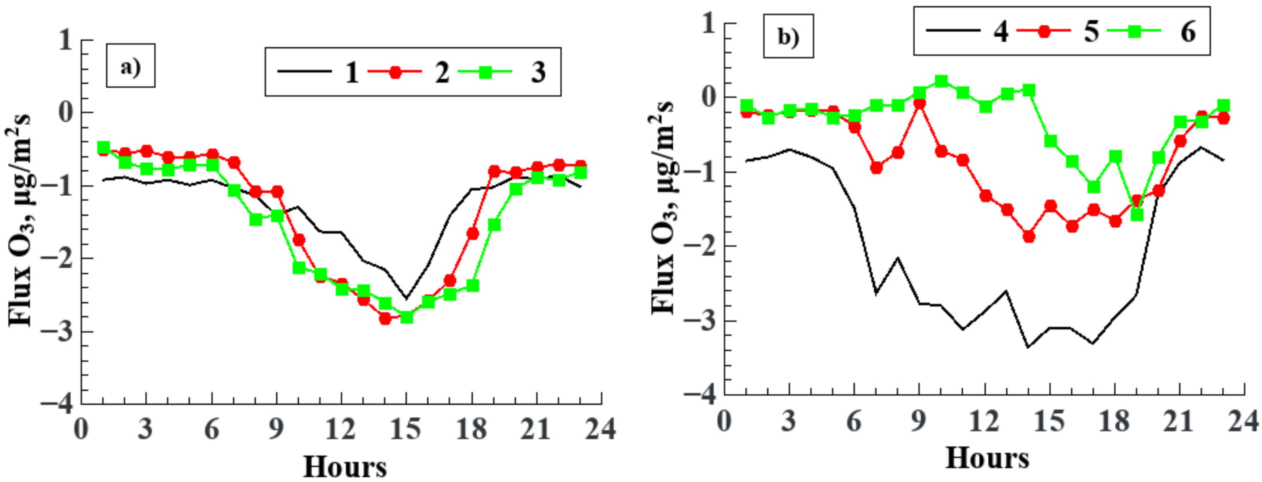

Figure 1. Temporal dynamics of the vertical ozone flux for the period from February to July of 2016: February (1), March (2), April (3), May (4), June (5), and July (6).

The diurnal average dynamics of the vertical ozone flux (Fig. 1a-b) has the same shape for all the months, although with some differences. The integral value of the ozone flux increases gradually from February to May and decreases in June and July. The maximum in the diurnal dynamics is observed in the afternoon from 14:00 to 16:00 Local Time. In addition, in July the maximum shifts in time to the period from 18:00 to 20:00 LT. The value of the diurnal average vertical ozone flux for February, March, April, May, June, and July is -1.29±0.5 -1.35±0.86 -1.53±0.8 -2.03±1.0 -0.84±0.61 -0.32±0.45 μg/(m^{2}s), respectively.

The diurnal dynamics of the dry deposition rate (Fig. 2-b) is inverse with respect to that of the vertical ozone flux. The value of the diurnal average dry deposition rate for ozone in February, March, April, May, June, and July is 2.23±0.81 2.27±1.38, 2.61±1.20, 3.87±1.70, 1.15±0.96 -0.68±1.19 cm/s, respectively.

The obtained results on the calculated diurnal average dynamics of the vertical ozone flux and the dry deposition rate are in agreement those reported in [5].

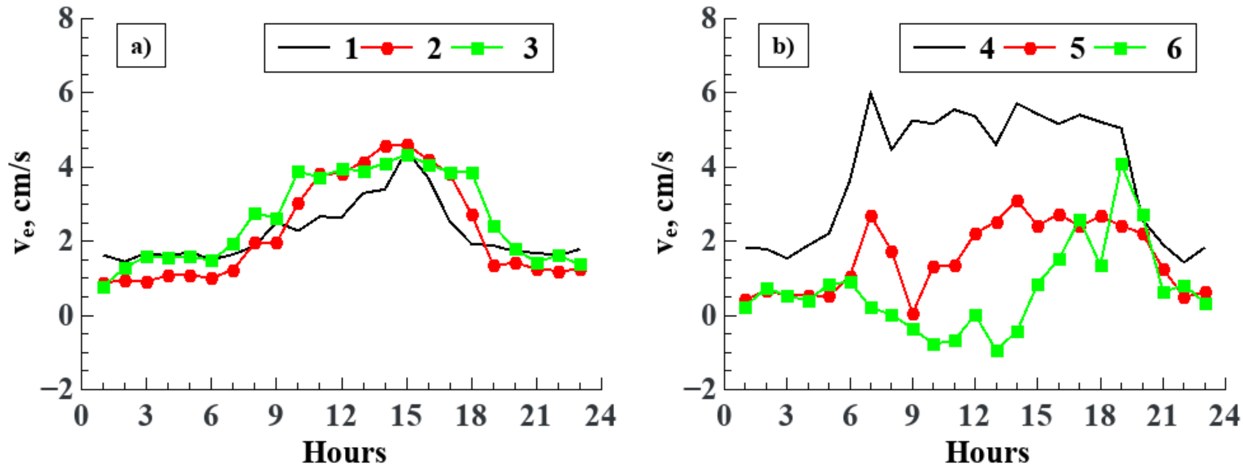

Figure 2. Temporal dynamics of the dry deposition rate for the period from February to July of 2016: February (1), March (2), April (3), May (4), June (5), and July (6).

4. CONCLUSION

As a result of the study, it was shown that the vertical ozone flux has the pronounced diurnal dynamics. The flux is mostly directed downward, which does not contradict the generally recognized theory and indicates in favor of the fact that the ozone source is located above the height of the upper measurement level.

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