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Results of monitoring of the vertical carbon dioxide flux in the atmospheric surface layer of a background region of Western Siberia

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ABSTRACT

Vertical fluxs of carbon dioxide have been calculated with the use of data measured at a high measurement tower located at the territory of the Fonovaya Observatory of IAO SB RAS. The measurements have been carried out in the period from August 2015 to December 2018.

Keywords: vertical carbon dioxide flux, atmospheric surface layer, measurement tower

1. INTRODUCTION

The carbon dioxide dynamics is now studied actively in different regions of Russia. Carbon dioxide is one of the main greenhouse gases, the increase of whose concentration is associated with climate change. From this point of view, it is important to know which regions are sources of carbon dioxide and in which regions its sink is observed. Western Siberia is a region of prevalent carbon dioxide sink from the atmosphere. Therefore, it is important to have estimates of the vertical carbon dioxide flux, which can be used in global and mesoscale climatic models for theoretical investigations. The goal of this study is to obtain the annual distribution of the vertical carbon dioxide flux for the background region of Western Siberia.

2. MEASUREMENT DATA AND CALCULATION METHODS

The vertical flux of carbon dioxide gas was calculated from the data of monitoring. The monitoring was carried out at a high measurement tower situated at the territory of the Fonovaya (Background) Observatory of IAO SB RAS, which is located in the background area of the Tomsk Region (56°25' N, 84°04' E, 80 m above the sea level, http://lop.iao.ru). The measurements were conducted since August 2015 till December 2018. The measurement instrumentation is listed in Table 1. For flux calculation, we used the results of meteorological measurements at heights of 10 and 40 m and measurements of the gas composition at heights of 10 and 44 m. Meteorological parameters were recorded every hour. The gas composition was measured in the following way: the high-level concentration was measured from 0 to 30 minutes and the low-level concentration was measured from 30 to 60 minutes. For measurement time matching, the linear interpolation between neighboring times was used. The values of the concentration for the upper level were interpolated.

The vertical fluxes of carbon dioxide and methane were calculated by the gradient technique based on the MoninObukhov similarity theory, which is described in detail in [1]. According to this technique, the gas flux is calculated by Eq. (1) as

$$F_s(z_m) = -K\frac{\partial S}{\partial z} \tag{1}$$

where $F_s(z_m)$ is the vertical flux of a substance, K is the turbulent diffusion coefficient, $\frac{\partial S}{\partial z}$ is the gradient of the substance concentration, $z_m = \sqrt{z_1 z_2}$ is a reference height, for which the flux is calculated, $z_2 = 30$ and $z_1 = 10$ are the heights of the upper and lower measurement levels, respectively.

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Table 1. Measurement instrumentation.

Device/sensor	Parameter	Range	Error	Time constant
Vaisala HMP155	t °C	-40...+60	± 0.1 C	1 s
Vaisala HMP155	f,%	0...100	±2%	1 s
Young model 85004	dd, deg	0...360	± 10°	1 s
Young model 85004	V, m/s	1,2...40	±(0.5+0.05V)	1 s
Young model 61302V	P, hPa	150...1150	± 1.5	0.1 s
Picarro G2301-m	CO_2, ppm	0...1000	< 0,2 ppm	1 s
	CH_4, ppm	0...20	< 0.0015 ppm	1 s
	H_2O, ppm	0...70000	< 150 ppm	1 s

The following rule is used in the calculations: the vertical gradient $\frac{\partial S}{\partial z}$ along with the flux $F_s(z_m)$ is positive (directed upward), if the concentration decreases with height ($\Delta S < 0$), and negative (directed downward), if the concentration increases with height ($\Delta S > 0$).

For parameterization of the turbulent diffusion coefficient, equations with allowance for stratification (ζ) of the atmospheric surface layer were used. For unsteadily stratified surface layer, equations (2-5) were applied.

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

$$u_* = \frac{k z_m}{\varphi_m\left(\zeta_m\right)} \frac{\partial U}{\partial z} \tag{3}$$

$$\varphi_m\left(\zeta_m\right) = \left(1 - 16\zeta_m\right)^{-\frac{1}{4}}, \zeta_m < 0 \tag{4}$$

$$\varphi_h\left(\zeta_m\right) = \left(1 - 16\zeta_m\right)^{-\frac{1}{2}}, \zeta_m < 0 \tag{5}$$

where $u*$ is the friction rate [2], $k = 0.4$ is the von Karman constant, ζ is the stability parameter, $\varphi_h\left(\zeta_m\right)$ are the universal differential functions of heat and angular momentum [3] .

The stability parameter ζ_m is calculated by the iterative method with the use of the Richardson gradient number Ri by equation (6) [1]:

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

$$Ri(\zeta_m) = \begin{cases} \frac{\zeta(0.74+0.47\zeta)}{(1+4.7\zeta)^2} & \zeta > 0 \\ 0.74\zeta\left(\frac{1-15\zeta}{1-9\zeta}\right)^{0.5} & \zeta < 0 \end{cases} \tag{7}$$

If the surface layer was steadily stratified, then ($\zeta_m > 0$), and equations (8-14) from [4] were used for the calculation.

$$K = u_* l_z \tag{8}$$

$$u_* = \sqrt{2\Psi_\tau E_z^{1/2} l_z \frac{\partial U}{\partial z}} \tag{9}$$

$$\Psi_\tau = 0.228 - 0.08 Ri_f \tag{10}$$

$$\Psi_3 = 1 - 2.25 Ri_f \tag{11}$$

$$Ri_f \approx 1.25 Ri \frac{(1+36Ri)^{1.7}}{(1+19Ri)^{2.7}} \tag{12}$$

$$l_z = z_m Ri_f \left(1 - \frac{Ri_f}{Ri_f^\infty}\right)^{4/3} \tag{13}$$

$$E_z = \left(l_z \frac{\partial U}{\partial z}\right)^2 \frac{2C_k Cr \Psi_3 \Psi_\tau}{3(1+C_r)} \left[1 - \left(\frac{3}{C_r \Psi_3} + 1\right) Ri_f\right] \tag{14}$$

where $C_k = 1.08$, $C_r = 3$, Ri_f is the Richardson flux number, E_z is the energy of fluctuations of the vertical velocity. The use of different schemes of turbulent closure, depending on the stability regimes, made it possible to obtain a full annual flux of vertical fluxes. For the calculation of averaged characteristics, we took only the values falling within the 3 range with respect to the average value.

3. RESULTS

Figures 1 and 2 shows the results of calculation of carbon dioxide fluxes. The vertical flux of carbon dioxide is directed downward. The maximum is observed in the summer months, while the minimum occurs in winter. The maximal flux value can achieve -40 μmol/m^{2}s.The diurnal variation of the fluxes is observed in the summer. In the daytime hours it is directed to the bottom, to the night up. This completely coincides with the cycle of respiration of vegetation.

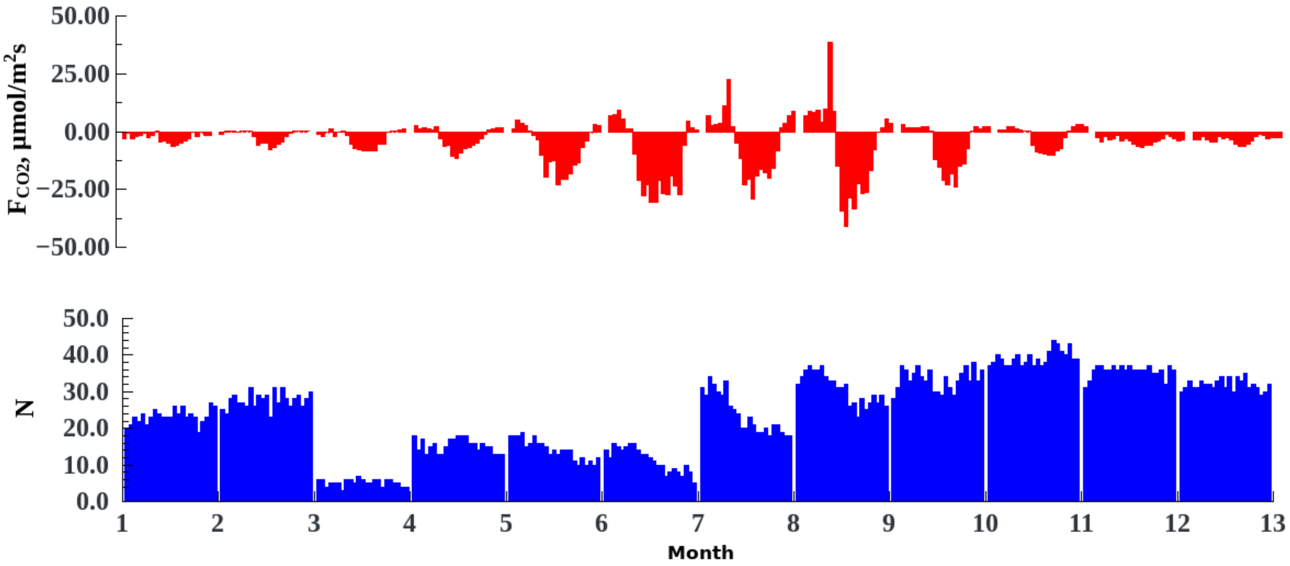
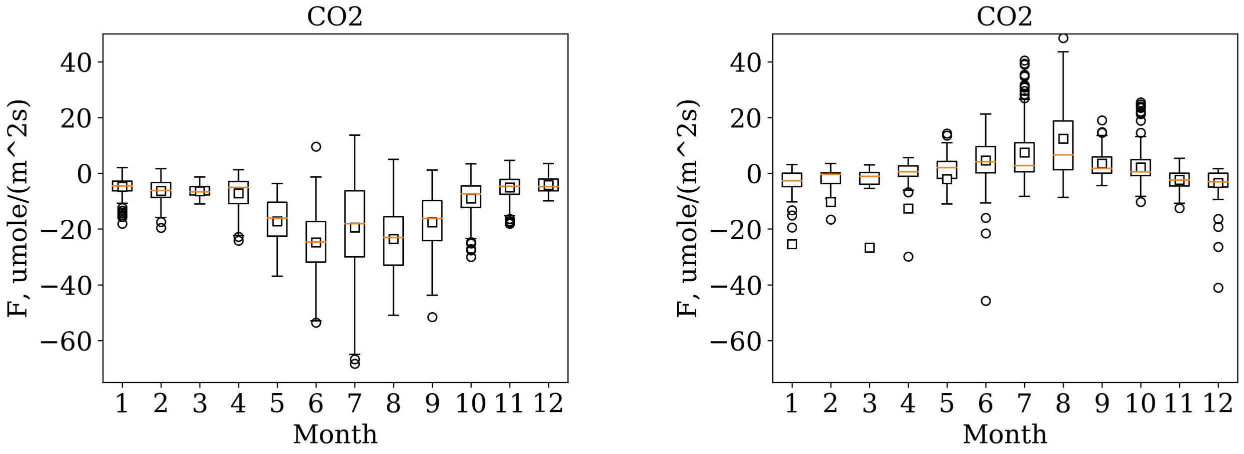


Figure 1. Median of the interannual variation of the vertical carbon dioxide flux (top), number of used measurements (bottom)



Day Night

Figure 2. Annual bechvior CO_2 day (left) and night (right) time

4. CONCLUSION

As a result of the study, it was shown that the vertical CO_2 flux has the pronounced diurnal dynamics in summer. The flux is mostly directed downward. which does not contradict the generally recognized theory and indicates in favor of the fact that Western Siberia is a region in which an intensive sink of carbon dioxide from the atmosphere takes place.

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