Estimation of the influence of air pollution on extra emission of CO_2 by forests

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The increase of atmospheric CO_2 due to extra emission by forests has been simulated numerically using the obtained experimental data on dark respiration of plants at different levels of atmospheric pollution.

The increase of atmospheric CO_2 in recent years is one of the most urgent problems of geophysics and climatology. In this connection, it is especially important to determine possible sources and sinks of carbon dioxide and to estimate their productivity. The necessity of such estimates was emphasized at the Workshop on Biogenic Emission of Greenhouse Gases by Arable and Animal Agriculture – Measurement Technologies and Emission Factors (the Netherlands, 1997).[1]

Biological processes, such as respiration of soil and surface plants, are the potent contributors of CO_2 into the atmosphere.[2] These sources become more productive with time. For example, it was found[3] that the June–July-averaged night maximum of CO_2 under the canopy of pine forest at the mid-crown level has increased by 54% for 14 years (from 350 to 540 ppm).

In Refs. 4 and 5, we have shown that the action of gaseous pollutants (C_2H_4, CO, O_3) on grass and trees changes their dark respiration and, in most cases, significantly intensifies it. This increases the amount of CO_2 breathed out by plants.

Thus, we can assume that air pollution, including that due to human activity, may stimulate extra CO_2 emission by polluted plants.

In this paper, the possible increase of atmospheric CO_2 is estimated by numerical simulation. Some recommendations on local and remote detection of this increase are given.

Experimental data

The input data on the rate of CO_2 emission by plants were obtained by measuring the kinetics of dark respiration of needles of coniferous trees. These measurements were conducted under laboratory conditions by the method of laser photoacoustic gas analysis.[4] The object of study was two-years-old needles of 20-years-old pine trees. Sampling was conducted in two areas different in the degree of integral air pollution. As an experimental area, we took the Mikhailovskaya Grove (Tomsk). This grove is situated within the precincts of the city and is subjected to intense pollution by motor cars and industrial enterprises. The control area was in the Timiryazevo forest 15 km far from the city. In each area, we selected 10 trees of the same age. We analyzed identical experimental and control weighted samples of needles. Every sample included needles of 10 trees in equal amount. The prepared samples were placed in dark chambers. After exposition, the content of carbon dioxide was determined in the samples of air from the chambers. Figure 1 shows the diurnal kinetics of CO_2 emission by the experimental and control samples (the results are normalized to the sample weight).

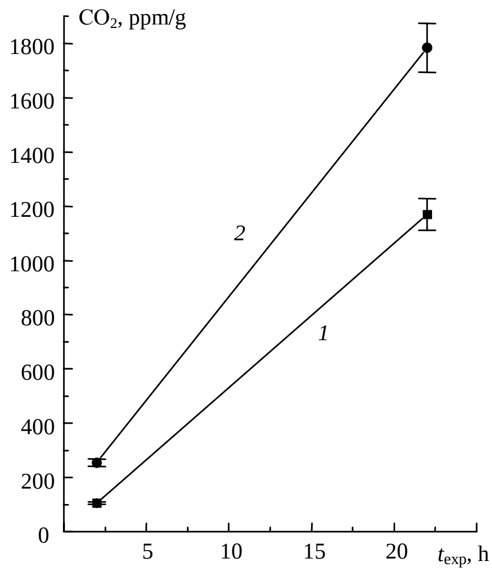

Fig. 1. Kinetics of CO_2 emission by control (*1*) and experimental (*2*) samples of needles.

To determine the rate of the CO_2 emission by a forest, we used averaged data on the following parameters: the number of trees of a dominating sort and a certain age,[6] weight of needles of a tree,[7] and fraction of needles of a certain age in the total mass of needles.[8] Taking into account the actual situations,

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these parameters were taken as having the following values: 1500 1/ha, 2.5 kg, and 34%, respectively. The obtained experimental results and the literature data allowed the rate of CO_2 emission by two-years-old needles of 20-years-old pine trees (above the background atmospheric content) to be estimated as follows: (a) $6.9 \cdot 10^3$ ppm/($m^2 \cdot h$) for the control area and (b) $12.8 \cdot 10^3$ ppm/($m^2 \cdot h$) for the experimental area.

The used model and calculated results

To calculate the concentration of carbon dioxide under the canopy of the pine forest, we used the equation of turbulent diffusion.[9,10] For simulation of carbon dioxide transport over the forest, the Gauss model was applied.[10] The turbulent exchange coefficient depends on the wind velocity, altitude distribution of temperature, and some other parameters. Several classes of stability of the surface air were separated out according to the Pasquill classification.[10] This allowed us to take typical values of the turbulent exchange coefficient, as well as vertical and horizontal components of air mass motion. In simulation, we considered the conditions close to equilibrium by the Pasquill classification (the 4th class). It was assumed that advection under the forest canopy can be neglected. In the case of convective conditions, the turbulent exchange coefficient accepts the values k_1 = 0.1–0.2 m/s at the altitude of 1 m and increases linearly with altitude.[10] In simulation we took k_1 = 0.1 m/s. The vertical component of the wind velocity was w = 0.2 m/s. The forest height was assumed equal to 10 m, and the rate of carbon dioxide generation was taken equal to 2 or 3.5 ppm/s and constant in the altitude range from 2 to 10 m. The wind speed at the altitude of 10 m was taken, according to the Pasquill classification, 4 m/s. The forest area had the size of 1 × 1 km.

In nighttime, if the concentration of CO_2 increases markedly, then plants breath out less amounts of CO_2. Thus, for example, as the concentration of CO_2 in air increases up to 720 ppm, the intensity of dark respiration halves.[11] In this work, we considered a simplified model that constant extra emission of carbon dioxide occurs under the stress effect. Therefore, we have chosen the stratification, at which convective conditions are observed and there is no marked accumulation of carbon dioxide under the forest canopy.

The results of simulation are shown in Fig. 2. Curve *1* corresponds to the control case of ordinary dark respiration, and curve *2* corresponds to the intensified emission under the stress effect.

The obtained estimates show that even under convective conditions the content of carbon dioxide under the forest canopy is markedly higher as compared to ordinary dark respiration. The concentration at low altitudes is sufficient for reliable measurement by a photoacoustic gas analyzer. It is also seen from Fig. 2 that the concentration of carbon dioxide above the forest fast decreases down to the background value.

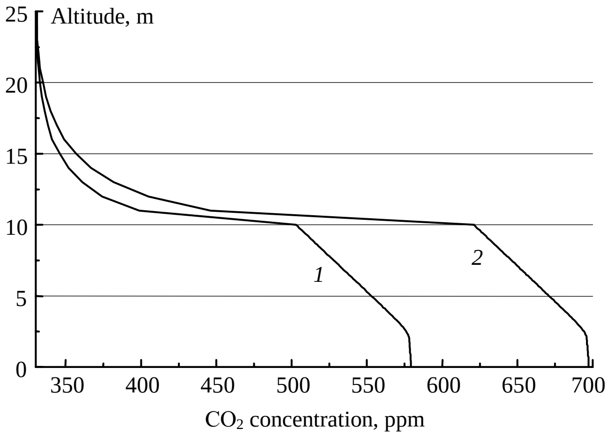

Fig. 2. Vertical profile of CO_2 concentration; the 4th class of stability by Pasquill; wind speed of 4 m/s at the altitude of 10 m: 2 ppm/s (*1*) and 3.5 ppm/s (*2*); k_1 = 0.1 m/s; w = 0.2 m/s.

Acknowledgments

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References

1. A. Freibauer, U. Dammgen, M. Kaltschmitt, et al., in: *Proceedings of the Workshop on Biogenic Emission of Greenhouse Gases Caused by Arable and Animal Agriculture – Measurement Technologies and Emission Factors* (Stuttgart, 1998), pp. 166–174.
2. G.V. Dobrovol'skii and G.S. Kusta, Priroda, No. 10, 53–63 (1996).
3. A.S. Shcherbatyuk, L.V. Rusakova, G.G. Suvorova, and L.S. Yankova, *Carbonic Acid Gas Exchange of Coniferous Trees in the Baikal Region* (Nauka, Novosibirsk, 1991), 135 pp.
4. B.G. Ageev, T.P. Astafurova, Yu.N. Ponomarev, and V.A. Sapozhnikova, Atmos. Oceanic Opt. **10**, Nos. 4–5, 270–277 (1997).
5. B.G. Ageev, A.B. Antipov, T.P. Astafurova, et al., Atmos. Oceanic Opt. **11**, No. 4, 355–358 (1998).
6. M.D. Korzukhin and V.N. Sedykh, in: *Problems of Ecological Monitoring and Simulation of Ecosystems*, (Gidrometeoizdat, Leningrad, 1982), Vol. 5, pp. 91–102.
7. V.A. Usol'tsev, A.V. Usol'tsev, and V.V. Kirillova, Lesovedenie, No. 2, 55–68 (1998).
8. N.V. Semenyuk and A.A. Rudkova, *Problems of Ecological Monitoring and Simulation of Ecosystems*, (Gidrometeoizdat, Leningrad, 1988), Vol. 11, pp. 143–149.
9. *Atmosphere*. Handbook (Gidrometeoizdat, Leningrad, 1991), 510 pp.
10. M.E. Berlyand, *Prediction and Regulation of Atmospheric Pollution* (Gidrometeoizdat, Leningrad, 1985), 272 pp.
11. S.B. Idso and B.A. Kimball, J. Plant Physiol. **141**, 166–171 (1993).