Correlation between carbon dioxide sink from the atmosphere over Siberian boreal forests and variations of the ozonosphere

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Received April 14, 2005

The results of seven-year monthly airborne monitoring of the CO_2 concentrations at heights of 0.5, 1, 1.5, 2, 3, 4, 5.5, and 7 km, carried out during flights of the Optik-E flying laboratory of IAO SB RAS since 1997, are presented. The results show a steady growth of the CO_2 content in the atmosphere over Siberian taiga from year to year despite the fact that the intensity of industrial emissions was not high in this period. The annual variations of the CO_2 content with minimal values in summer are related with the changes in the activity of photosynthesis, peaking in the summer period. We compare annual variations of total ozone content (TOC) for the region of airborne measurements for two summer months (June and July) with the CO_2 concentrations at all heights. The correlation between CO_2 and TOC in these months was found to be the highest for a height of 1.5 km. It reached 94%, indicating that the photosynthetic sink of CO_2 to dark coniferous forests of Siberia strongly depends on TOC variations, governing the level of the UV-B radiation.

Introduction

Photosynthesis in plants is responsible for the main sink of carbon dioxide (CO_2) from the atmosphere over the land. As known, rainforests occupy the first place in this process, while the second place belongs to the boreal forests. More than a half of boreal forests are located in Russia, mostly in Siberian taiga.

The activity of chlorophyll in plant chloroplasts significantly depends on the level of the shortest-wave part of solar radiation reaching the Earth's surface, namely, the UV-B radiation of 290 to 320 nm wavelengths. The increase of the level of this radiation decreases the photosynthetic activity.[1] This effect is most pronounced in evergreen conifers, which are capable of accumulating the effect of the UV-B radiation.[2] Note that Siberian taiga mostly consists of dark conifers (fir, spruce, and cedar pine).

Deviations of the UV-B radiation level in the clear atmosphere are fully governed by the total ozone content in the atmospheric column, because it absorbs the most part of the UV-B radiation mostly in the stratospheric ozone layer – the ozonosphere, in which the main part of atmospheric ozone is concentrated.[3] The relation between the photosynthetic sink of CO_2 from the atmosphere and variations of the ozonosphere is realized just in this way.

Results of airborne measurements of CO_2 concentration over Siberian taiga

Regular measurements of the CO_2 concentration over the southern Siberian forests have been carried out since 1997 till now with the use of an An-30 Optik-E flying laboratory, of the Institute of Atmospheric Optics SB RAS.[4] Every month the ambient air is sampled at heights of 0.5, 1, 1.5, 2, 3, 4, 5.5, and 7 km into specialized glass bottles. The chemical analysis of these samples is carried out at certified analytical stands in Japan by the method of chromatography. In parallel, the CO_2 concentrations are measured with a LiCor 6262 gas analyzer. As a result, we obtain the CO_2 profiles, characterizing monthly variations of its vertical distribution. The lower part of these profiles up to a height of 3 km largely reflects regional variations, while the CO_2 content at heights higher than 3 km is largely attributed to the global processes.

Figure 1 shows the time behavior of the monthly mean CO_2 concentrations in the atmospheric layers at 0.5 to 2 and 3 to 7-km heights. It can be seen from Fig. 1 that in the period since 1997 through 2004 the CO_2 content in the atmosphere increased from year to year, though the intensity of industrial CO_2 emissions in Siberia, as well as in Russia as a whole, cannot be considered as high in this period. Against the background of the steady growth of the CO_2 content, we can clearly see (especially, in the lower atmospheric layer) the annual variations with the minimum in summer and maximum in winter, caused by the variations of the CO_2 sink, which, in their turn, are associated with the more active photosynthesis in the warm (growth) season.

The increase of the CO_2 sink in summer is most clearly seen from the comparison of the seasonal mean (summer, winter) vertical profiles of CO_2 (Fig. 2).

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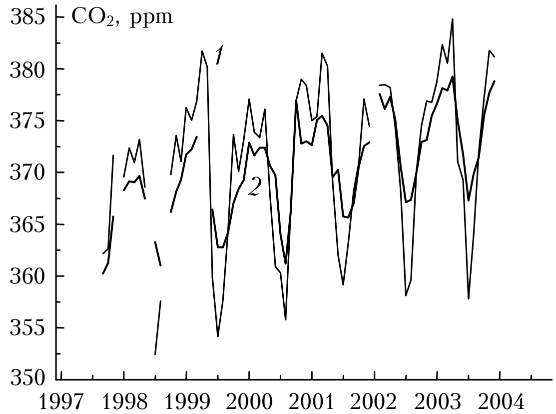

Fig. 1. Time behavior of the monthly mean CO_2 concentration in the atmospheric layers of 0.5 to 2 (*1*) and 3 to 7-km heights (*2*), obtained from monthly airborne measurements from onboard the An-30 Optik-E flying laboratory over forests of Southwestern Siberia.

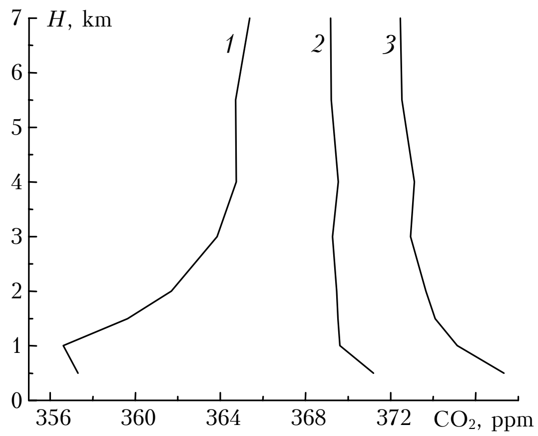

Fig. 2. Comparison of seasonal mean (summer, winter) and annual mean vertical profiles of CO_2 obtained from the results of airborne measurements: summer (*1*), annual mean (*2*), winter (*3*).

In summer, in the lower (0.5 to 2 km) atmospheric layer, a dip is seen in the CO_2 profile due to the active photosynthesis in the plant biota. The intense sink leads to the general decrease of the CO_2 concentration at any height as compared with the winter period. In winter, in the absence of active CO_2 sink and with the additional emissions of CO_2 in the heating season, CO_2 is accumulated in the atmosphere. The shape of the winter-mean CO_2 profile determines the shape of the annual mean CO_2 profile, which is also shown in Fig. 2, since most of boreal forests are actively photosynthesizing for the shorter part of a year.

Analysis of correlations between atmospheric CO_2 concentration and TOC

Figure 3 shows the vertical CO_2 profiles averaged over June–July for every year of the airborne measurements since 1997 through 2003. As can be seen from Fig. 1, these months are characterized by the lowest CO_2 concentrations due to the active CO_2 sink at the maximum seasonal insolation. The TOC values for the region of airborne measurements are taken from TOMS satellite data; they were also averaged over these two months.

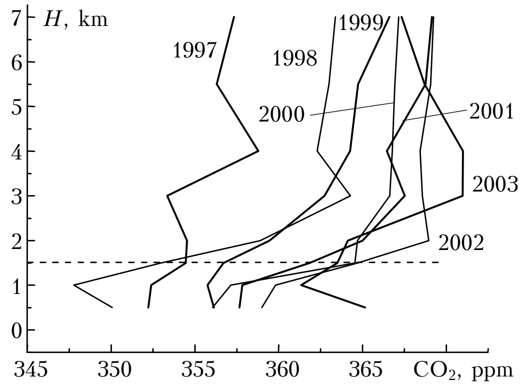

Fig. 3. Vertical CO_2 profiles (the horizontal dashed line shows the level of 1.5 km).

We have considered the correlation of TOC with the CO_2 concentration at all the height levels. The maximum correlation was revealed for the level of 1.5-km height. Figure 4*a* illustrates the pronounced correlation between the annual behaviors of the CO_2 concentration at the height of 1.5 km and TOC, averaged over June–July of every year. If we subtract the linear trends from these series and convert them into dimensionless quantities by subtracting the mean and normalizing to the rms deviations, then the coefficient of negative correlation between the TOC and CO_2 indices achieves 94% (Fig. 4*b*).

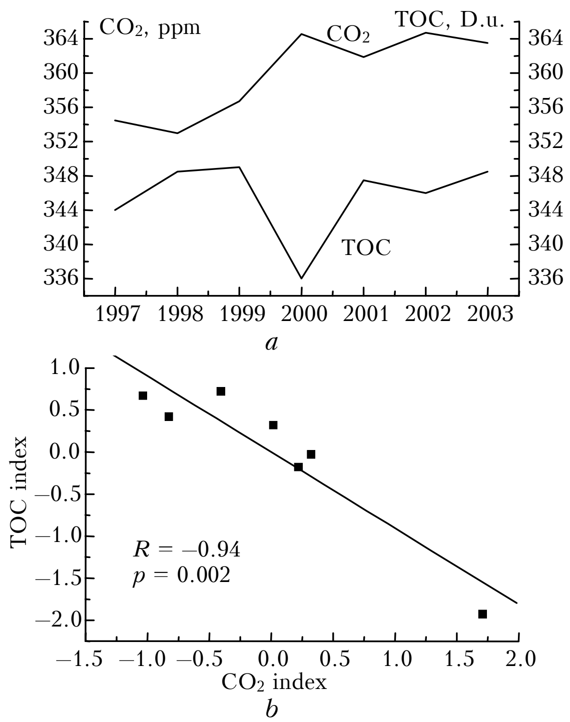

Fig. 4. Annual variations of the CO_2 concentration at the height of 1.5 km and TOC, averaged over June–July of every year (*a*) and the correlation between the TOC and CO_2 indices at this height (*b*).

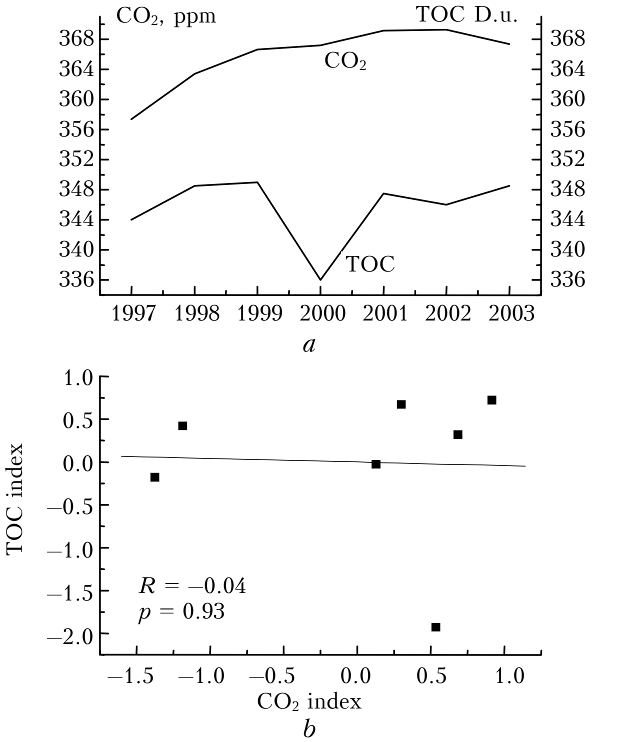

Fig. 5. Annual variations of the CO_2 concentration and TOC (*a*) and the correlation between the TOC and CO_2 indices at the height of 7 km (*b*).

It can be assumed that the summer CO_2 concentration at the level of 1.5 km reflects the resultant effect of taiga forests on the photosynthetic sink of CO_2 roughly on the same spatial scales as the averaging scales of the TOMS data. For lower heights, the correlation decreases due to local effects, but remains significant at the height of 1 km. At heights higher than 3 km, the processes of global scales are pronounced, and the correlation becomes insignificant. Figure 5 shows the annual behavior of the CO_2 concentrations at the maximum measurement height of 7 km and TOC, averaged over June–July of every year. The coefficient of negative correlation between the TOC and CO_2 indices in this case is about 4% as low.

Conclusions

The results of the correlation analysis presented above are indicative of significant correlation between the summer CO_2 concentration over Siberian forests and variations of the ozonosphere. This correlation is explained by the fast physiological response of plants to variations in the level of the UV-B radiation. The increase of this level suppresses the photosynthetic activity, and plants experience a stress. As a result, not only the CO_2 sink decreases, but also the emission of CO_2 increases due to the respiration of plants being in the stress state.

Acknowledgments

This work was partly supported by the Siberian Branch of the Russian Academy of Sciences within the Integration Project No. 95 and by the Russian Foundation for Basic Research (Grants No. 03–05–65105, No. 04–05–64559, No. 04–05–08010, and No. 05–05–98003–r–ob–a).

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