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Short Communication

Cyclic Characteristics of CO_2 Chronologies for Scots Pine Discs

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Abstract

The results obtained from photoacoustic measurements of vacuum-extracted gas samples show that porous wood structure is capable of annual accumulation of stem gas components that include plant cell-respired carbon dioxide. An analysis of the vacuum-extracted carbon dioxide in Scots pine tree ring wood has revealed that the CO_2 chronologies are associated with interannual variations in the total pressure of the gas components in the root rings and are characterized by short-period cycles.

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INTRODUCTION

Researchers exploring the role of forests as potential sinks of atmospheric carbon dioxide and investigating CO_2 balance in the biota-atmosphere system fail to pay due attention to the fraction of plant cell-respired carbon dioxide (C-CO_2) retained in tree stems. Wood is a porous hygroscopic biological material. We believe that owing to the fact that porous wood structure is capable of annual sorption of water and CO_2 dissolved in water, the capillary tree ring system can retain the interannual distribution pattern of the gas components even in a dead tree. Hydroxyl groups of wood polymers are known to be the main chemical components attracting water molecules to form the surface layer of bound water whose diffusion is very slow as compared to that of water vapor in porous wood structure [1].

A laser photoacoustic (PA) gas analysis of gas samples vacuum-extracted from disc treering wood furnishes an opportunity to construct long chronologies for gas components, such as CO_2 and H_2O, and to measure interannual variations in the total pressure in the samples studied. While the PA technique has long and profitably been in use for different applications, we were the first to employ this approach for investigating the behavior of CO_2 and H_2O in annual disc tree rings of different coniferous species (see, for example, [2-4]). We have repeatedly pointed to the existence of cyclic processes in the experimentalCO_2 (and H_2O) chronologies (see, for example, [3,4]).The focus of this article is on the presence of identical cycles in the disc wood of the Scots pine stem and root. Information about the CO_2 behavior in the tree ring wood is of interest to experts dealing with CO_2 balance and estimation of CO_2 fluxes between terrestrial ecosystems and atmosphere.

MATERIALS AND METHODS

We analyzed dry and a newly sawn disc, as well as in the Scots pine root. The dry Scots pine disc was sawn at a height of 1.4 m above the ground, and the newly sawn disc was sampled at a height of 70–80 cm above the ground from a pine tree broken by the wind in the spring of 2011. Part of the pine tree root was sampled from a depth of 20 cm below the Earth's surface. The sample was obtained from the stump of a pine tree sawn a year before. The root was ~8 cm in diameter and 22 cm in length. All discs were sawn near Tomsk (56°26'N and 85°03'E, West Siberia, Russia). Since the dry disc was stored under laboratory conditions over a long period of time, the wood material can be considered to be room-dried. Notably, the measurements on the broken pine disc were performed immediately after the tree had been broken. The time series studied spanned 104 years for the dry Scots pine disc, 55 years for the newly sawn pine disc, and 61 years for the pine root.

The present investigations rely on a laser PA technique and an automated tunable CO_2 laser-based gas analyzer. Our experimental system and a procedure for measuring the CO_2 and H_2O content in the gas samples vacuum-extracted from disc tree rings were described elsewhere (see, for example, [3,5]). The measurements were performed using a computer-controlled PA spectrometer with a frequency-tunable waveguide CO_2 laser. The PA spectrum was found to correlate with the optical absorption spectra of the sample. Once the system is calibrated, i.e. the absorption of gases with known concentrations is measured, the calibration coefficient is found, and the absorbing component concentration in the gas sample studied is found. The laser emits more than 70 lines within a tuning spectral range of 9.2–10.8 μm with an output power of 0.3–3 W in the single-mode single-frequency regime. The laser line tuning and detector signal recording and preliminary processing (averaging of the data and determination of the signal ratio) are performed by means of dedicated software. The measured results are stored in a file for associated laser lines, providing an analog of the absorption spectrum for the sample. Information about the measured spectrum is displayed on a computer monitor to visualize the spectrometer data. The system is pre-calibrated using a CO_2-N_2 reference mixture containing a known amount of CO_2. The ultimate absorption coefficient sensitivity of the spectrometer used was 2 $*10^{-5}$ cm^{-1} for a laser power of 70 mW, and the calibration measurement error was no more than ±5%. A further increase in the sensitivity was obtained for a total PA cell detector pressure of ~100 Torr, therefore air was added to attain this pressure.

The pinetree ring wood was planed off with special chisels, placed in four sealed exposure chambers pumped out for a short time to stimulate sorbed gas diffusion, and allowed to stand for 20 min. for subsequent measurements. In a recent experiment, samples of the annual tree ring wood of approximately the same weight were placed in the exposure chambers whose evacuation was controlled by a manometer so that the same minimum pressure in the chambers was maintained during all the measurements. In the experiments, the extracted gas pressure in each of the chambers for a 20 min. exposure time was also measured by the manometer. Each series of the gas absorption measurements on the samples extracted from the tree ring wood was accompanied by determination of the background air absorption. The information obtained from the difference between the gas sample absorption and that of air enabled the relative content of the absorbing component (CO_2 or H_2O) in the sample to be measured for each of the rings, using a calibration curve. The measurements were performed in four lines of the tunable waveguide 10.6 μm CO_2 laser: P (20, 16, and 14) and R (20) coinciding with the CO_2 absorption lines, ethylene absorption line P (14), and water-vapor absorption line R (20). In our experiments, the PA signal was absent in the P (14) line, which is why ethylene was not detected in the gas samples. The CO_2 content was averaged over the values obtained for the three laser lines, and their associated correlation coefficients were 0.85–0.9. Measurements in the R (20) line allowed for detection of the signal from the sum of the gas components (CO_2 + H_2O), and on subtraction of the CO_2 signal the data about H_2O distributions over the tree rings were acquired.

To verify the fact that CO_2 in the samples studied was generated by the trees themselves and not supplied from the atmosphere, an isotope analysis of carbon CO_2 desorbed from several rings was performed using a Delta V Advantage mass spectrometer with a binary startup system. To estimate the periodic and temporal variations in the tree ring CO_2 and H_2O chronologies, we employed 1) a Fast Fourier transform (FFT) analysis with the use of ORIGIN software; 2) high-resolution spectral and cross-spectral analyses based on the maximum entropy technique, wavelet analysis, and digital filtration of the time series. Long-term trends were eliminated from the data being analyzed.

RESULTS AND DISCUSSION

It follows from the our experimental results that the porous structure of the pine disc wood annually retain the gas components of the tree stem among which are water vapor and plant cell-respired carbon dioxide [6]. Further investigations have shown that the pine root wood possesses the same properties [7]. The results of the FFT analysis of the CO_2 chronologies for the dry and newly sawn pine discs are illustrated in Figure 1. The trends were excluded from all the chronologies before the analysis.

It is evident from the figure that both of the chronologies exhibit high amplitudes of the 4-year cycle and lower amplitudes of the 2-year cycle. The CO_2-chronologies for the pine root were examined with the use of high-resolution spectral, cross-spectral, and wavelet analyses.

Figure 2 shows the power spectra of the CO_2 and pressure variations recorded for the pine root wood. The pressure variations exhibit a 4.5-year cycle similar to the 4-year cycle observed in the pine disc tree ring wood. The $CO_2$and pressure spectra illustrated in Figure 2 demonstrate variations with the 11-year cycle of the solar activity. A cross-spectral analysis of the CO_2 and pressure series as functions of the solar activity index has revealed that the CO_2 variations are in phase with the solar cycle, whereas the pressure variations are seen to be orthogonal to the solar cycle. In our publications, we have reported the measured results for the C isotope composition in CO_2 (see, for example, [4]). A similar analysis was performed for the pine root wood and showed $\delta^{13}C= -30$ ‰. The current C isotope ratio in atmospheric CO_2 is, on average, $\delta^{13}C= -8.5$ ‰, as showed by Rubino and colleagues (2013) [8] and thus the analyzed CO_2 is formed in the root rather than being transported from the atmosphere.

Carbon dioxide respired by plants is known to undergo

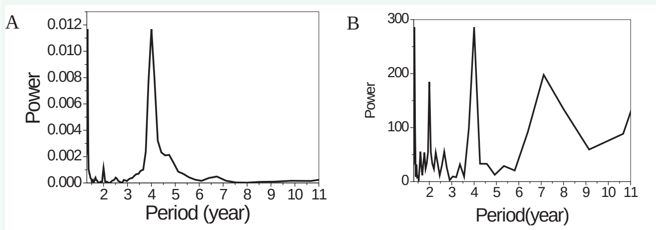

Figure 1 (A) –results of the FFT analysis of the CO2chronology for the drypine disc, (B) –results of the FFT analysis of the CO2chronology of a newly sawn pine tree obtained by the photoacoustic technique.

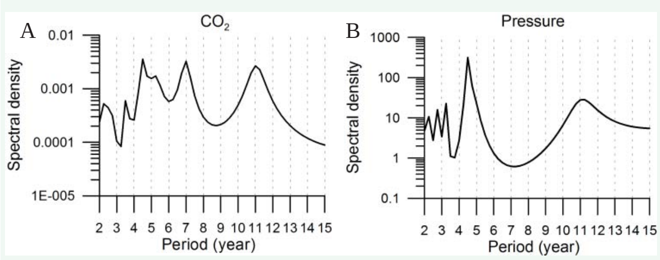

Figure 2 (A) – power spectra of the CO2 content, (B) –pressure variations in the Scots pine root wood.

diurnal and seasonal variations. The volume concentration of carbon dioxide in the ground air samples was measured in the European part of Russia in 1998–2014, using Fourier transform spectroscopy [9]. The measured results revealed additional cyclic variations in the background CO_2 concentration within 2–126 months: 1.7 and 4 years (stable parameters), 5.2 and 6.4 years (relatively stable parameters), and 10.5 years (stable parameters*).* Since the background CO_2 concentration is largely determined by the equilibrium exchange between the atmosphere and the biosphere, the 2- and 4-year cycles of the increase in the CO_2 concentration in the pine tree discs recorded in our investigations are likely to be responsible for the CO_2 contribution to the background concentration of atmospheric carbon dioxide. In our earlier work, it was shown that the experimental vacuum-desorbed CO_2 and H_2O chronologies exhibited correlation with the total pressure and were characterized by 4-year cycles. It can be assumed that enhanced diffusion of the gas components in the atmosphere due to increased pressure in the pine tree wood will also be observed with a periodicity of 4 years. Notably, the 3.9–4.4-year cycle was observed in almost all dendrochronological series. It was seen during different natural processes: in solar geomagnetic activity, repeatability of different atmospheric circulation manifestations, precipitation and ambient temperature trends, etc. The above-mentioned periodicity may be thought of as being the result of the action of the Moon-Sun tide-generating forces [10].

CONCLUSIONS

We have examined gas probes sampled from Scots pine tree ring wood. The results obtained are found to provide additional information about the behavior of cell-respired CO_2 and water vapor in the plant. Pressure variations in the pine root exhibit a cyclic pattern approaching a 4-year periodicity, which suggests a periodic increase in pressure in the tree stem and, accordingly, a periodic increase in the CO_2 and H_2O concentration in the tree stem rings.

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