

Temporal Variability of Total Atmospheric Carbon Monoxide over St. Petersburg

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Abstract—Data obtained from seven years of measurements of the total content (hereafter, content) of carbon monoxide (CO) near St. Petersburg (59.88° N, 29.83° E, 20 m above sea level) are analyzed. Random errors of a single measurement and of daily means of CO content are about 5% and 1–4%, respectively. Comparisons of the measurement results for St. Petersburg, Ny Ålesund, and Zvenigorod have shown that the mean CO contents at the first two stations agree within 1%; for Zvenigorod, similar values are systematically higher by 15%. The annual mean CO cycle in the area of St. Petersburg for the period 1995–2001 has an amplitude of about 24%. Maximum values of the CO content occur in February, and its minimum values are observed in July–August. Analysis of a CO measurement series has revealed a sharp CO increase over St. Petersburg in November–December 1998. Maximum values of the CO content substantially (by 25%) exceed the mean CO content typical of the February maximum. Estimates of the rates of CO increase for St. Petersburg have demonstrated that the CO content in 1995–1998 increased at a rate of ~3.5% per year. The CO content began decreasing in 1998–1999. The rate of CO decrease in 1999–2001 was ~3.8% per year.

1. INTRODUCTION

Anthropogenic impacts on the atmospheric composition have enhanced particularly strongly over the past half century. They have stimulated an increase in measurements of greenhouse and photochemically active gases with the aim of studying the intensity of their sources and sinks and long-term trends and, eventually, of predicting their influence on the ozonosphere and climate of the Earth [1–3]. These measurements are carried out using various local and remote techniques, including those based on space technology [4–6]. Whereas satellite measurements previously allowed a sounding of mainly upper atmospheric layers, the launch and functioning of new instruments (for example, MOPITT, SCIAMCHY) have opened up possibilities of measuring gas concentrations in the troposphere [7].

Carbon monoxide is a photochemically active constituent playing a key role in the troposphere of the Earth. The oxidation of CO may cause both the production and destruction of O₃ in the troposphere, depending on the nitrogen oxide content. The close connection among CO, OH, and O₃ characterizes CO as an important gas constituent regulating the oxidizing ability of the tropospheric layers [1–4].

The main sources of carbon monoxide are incomplete combustion of fossil fuels, biomass burning, and photochemical oxidation of methane and other hydrocarbons in the atmosphere. Most CO sources are located on the continent, among which the most important are year-round anthropogenic emissions and biomass burning in the dry seasons in the tropics and in the

warm period at high latitudes. Photochemical oxidation of methane and hydrocarbons is an important source for tropical latitudes, as well as for high latitudes in summer. A major sink for atmospheric CO is the reaction with the hydroxyl radical, which leads to the production of CO₂ and destruction of O₃. Under the conditions of polluted industrial areas, nitrogen oxides may serve as a sink for CO, which leads to the production of CO₂ and O₃. At present, anthropogenic sources account for about half of all CO sources in the Northern Hemisphere [1–3].

Spectroscopic measurements of the total CO content (hereafter, content) have been performed at the Institute of Physics, St. Petersburg State University, since 1995 [8]. The measurements of the CO content have been analyzed to identify different components of its temporal variability: long-term, periodic, and various irregular disturbances. Long-term variations (trends) of climate-forming gases are of particular importance, because information about them is used in global atmospheric models for the prediction of climate change. The annual cycle, reflecting the nature of regional sources and sinks of the gas under study, can be used to assess their intensities by using regional atmospheric models. Analysis of so-called “anomalous” series inside the whole measurement series, along with additional information (meteorological, etc.), makes it possible to identify major factors that cause the observed changes in gas contents over northwestern Russia.

Table 1. Errors of the CO content in the spectral range 2140–2180 cm^{-1}

Error source	δw_{CO} , %
Random measurement errors	
1.5%	1.0
3.0%	2.0
4.0%	3.0
Error in specifying a zero signal level U_0	
0.5%	0.5
1.0%	1.0
Error in specifying the instrument function half-width ($\Delta\nu$) of the spectrometer	
1.0%	0.5
3.0%	2.5
Absence of information about $\Delta\nu$ (calculation of $\Delta\nu$ from the spectrum)	0.5
Uncertainty of spectroscopic information	3.5
Differences between the real vertical profile and the profile used for interpretation	
1. Temperature (by the linear shift $\Delta T = 1$ K)	<0.5
2. Carbon monoxide	–
	3.0
Total error of a single measurement	3–5

2. INSTRUMENTATION AND INTERPRETATION TECHNIQUE

To study the temporal variability of characteristics of the atmospheric composition (methane, water vapor, carbon monoxide, etc.), IR solar spectra have been measured near St. Petersburg (Peterhof, 59.88° N, 29.83° E, 20 m above sea level) since 1991. These spectra are recorded in a wavelength range from 3.15 to 4.55 μm with a resolution worse than 0.3 cm^{-1} by a grating spectrometer with a photoelectric system using the Sun as a light source. The total contents of atmospheric gases are determined using the IR spectrum interpretation technique based on minimizing the rms differences between measured and calculated values of a signal. A method of statistical regularization is used. The instrumentation and the interpretation technique are described in detail in [9], which focuses on the retrieval of methane content.

The CO content is determined from measurements of direct solar radiation in the spectral range 2140–2180 cm^{-1} . The main absorbing gases in this range are CO, H_2O , and N_2O . The CO and H_2O contents were determined simultaneously when measured spectra were interpreted. Since N_2O is a long-lived and slowly varying atmospheric gas, its amount was fixed at the mean level of the N_2O content in the atmosphere (0.24 atm cm). As is shown by calculations, if the atmospheric N_2O content is known with an error no

greater than 10%, the additional contribution to the random error of the CO content due to the uncertainty in N_2O will not exceed 1%.

The analysis of the errors in the CO content was performed on the basis of numerical experiments by a closed scheme including the following:

(1) calculation of solar spectra in the range 2140–2180 cm^{-1} with the addition of measurement errors of a different kind;

(2) retrieval of CO content from calculated spectra using a spectral interpretation technique [9].

Thus, estimates have been calculated of the influence of the following factors on the error in the CO content: random measurement errors, the error in specifying a zero signal level, the error in specifying an instrument function half-width of a spectral device (or the accuracy of its calculation from the solution of an inverse problem), and the difference between the assumed and true vertical profiles of the temperature and mixing ratio of absorbing gases. Table 1 presents the errors in the CO content in the presence of random and systematic errors. Calculations were performed under typical experimental conditions: the noise level was 1–3%, the instrument function half-width was $\Delta\nu = 0.5$ –0.8 cm^{-1} , and seasonal mean vertical profiles of the atmospheric temperature and mixing ratio of CO, H_2O , and N_2O for the Northern Hemisphere midlatitudes (AFGL and NCAR models) were used. The absorption spectra of the gases under consideration were calculated using spectroscopic information from the HITRAN'96 database [10].

Analysis of the errors in the CO content has shown that the spectral range 2140–2180 cm^{-1} , in which the CO content is determined, is weakly sensitive to temperature (Table 1). Therefore, no rigid constraints are imposed on the vertical temperature profile.

An important feature of a spectroscopic technique of measurement of total contents of atmospheric gases at an average spectral resolution is the need to use an a priori (model) vertical profile of a mixing ratio. The estimates obtained from numerical modeling of the interpretation technique have shown that the shape of the vertical profile of the CO mixing ratio does not introduce any significant error into the CO content values [11].

As follows from Table 1, the main factors that determine the accuracy of spectroscopic CO measurements (δw_{CO}) are random noise, which can be minimized in replicate measurements during a day, differences between the real and assumed vertical CO profiles, and uncertainties of spectroscopic information. The last factor introduces systematic errors, which are unimportant in the analysis of CO variations.

Under typical conditions of the atmospheric state and a typical functioning of the instrument, random errors of a single measurement and of daily means of CO are about 5 and 1–4%, respectively. The daily mean

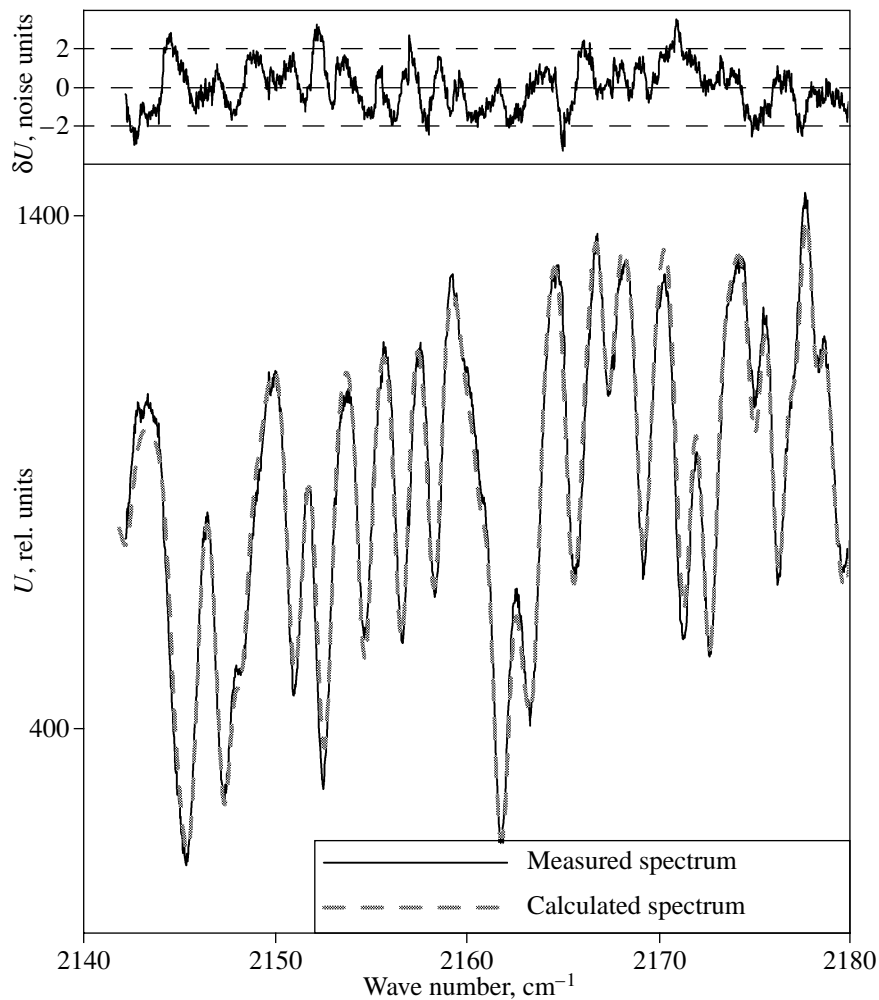


Fig. 1. Experimental, calculated, and difference spectra.

CO content depends on both the number of measurements taken in a day and the natural CO variability during the measurement period. The maximum scatter of the CO contents measured during the day was generally within 5–6%, in agreement with the estimated errors of a single measurement.

Figure 1 shows an example of the experimental, calculated (U , expressed in relative units), and difference (δU) spectra of a measured signal after the solution of an inverse problem: finding the CO content (August 23, 2001). The difference spectrum δU is given in units of standard deviation (SD) of measurement noise and demonstrates a good consistency between the modeling and experimental data: the discrepancies, as a rule, are no greater than the doubled values of SD of random measurement noise.

For an independent indirect testing of the quality of instrument functioning and of the interpretation technique used for CO retrieval, the total water vapor con-

centration was determined from measurements of solar radiation by the same instrument in the same spectral range and with the same interpretation technique. The spectroscopic H_2O measurements were compared to the results of the atmospheric radio sounding performed in March and August 1999. The sounding was carried out at noon (Greenwich mean time) at the weather station of Voeikovo, about 50 km from Peterhof [12]. Data of spectroscopic H_2O measurements were also sampled for the interval of 12 ± 1 h (Greenwich mean time). The H_2O contents measured by radiosonde (p) and determined from IR spectra (c) are compared in Fig. 2. The standard deviation of these values is 0.007 g/cm^2 , or $\sim 2\%$ of the minimum H_2O content (observed in 1999). This is lower than the estimated errors in determining the H_2O content by the spectroscopic method ($\sim 6\%$). The results of comparisons of the H_2O content determined by independent methods indirectly support the estimated error of the spectroscopic CO measurements.

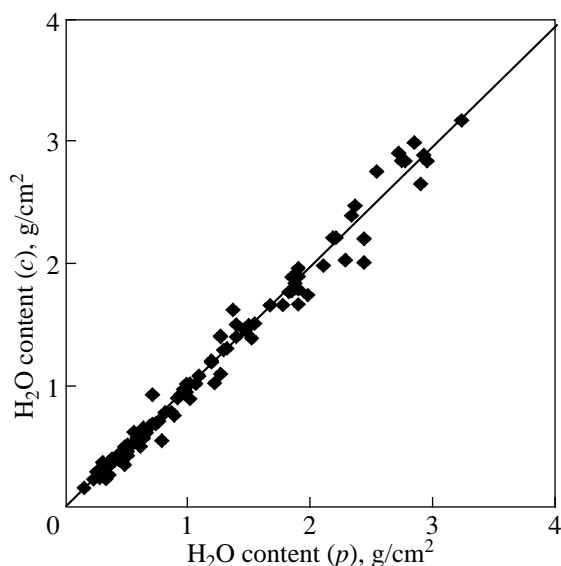


Fig. 2. Comparison of H₂O contents measured by radio-sonde (p) and determined from IR spectra (c).

3. ANALYSIS OF MEASUREMENTS OF THE TOTAL CO IN THE ATMOSPHERE

To determine CO contents, we used IR solar spectra measured from 1995 through 2001. The days of measurements are distributed unevenly throughout the year and are determined by the statistics of sunny days in St. Petersburg. The months that have the largest number of measurements are March, June, and August. Measurements are scarce in the period from November to Janu-

ary. The CO content series comprises about 200 daily means (Fig. 3). Each of them was calculated as a weighted mean of single CO measurements during the day. The values inversely proportional to the mean-square differences between measured and calculated spectra were used as weights.

3.1. Variability of CO content. Atmospheric carbon monoxide exhibits a strong temporal variability. This is due to its high chemical activity and, as a consequence, to its relatively short lifetime (from a few weeks to one year depending on geographic location and season) in the atmosphere [13]. Extreme values of the daily means of the CO content for St. Petersburg from 1995 through 2001 were as follows: a minimum of 0.134×10^{19} mol/cm² in August 1997 and a maximum of 0.390×10^{19} mol/cm² in December 1998. The mean value over the entire period of observations was 0.236×10^{19} mol/cm².

Measurements of CO content were performed during a ship cruise between 60° N and 45° S in the central Atlantic in October 1996. The measurements were carried out using a high-resolution Fourier transform spectrometer [14]. In Table 2, the mean CO contents for the latitude zone 55°–60° N in the Atlantic are presented in comparison with the October means (1996) for St. Petersburg and Zvenigorod. All three areas lie in the same latitudinal zone; however, as is evident from Table 2, the CO content values for the Atlantic and St. Petersburg are very close to each other, with a difference of ~3%, while the Zvenigorod values are 40% higher. Thus, the CO measurements over St. Petersburg agree well with Atlantic measurements. A comparison

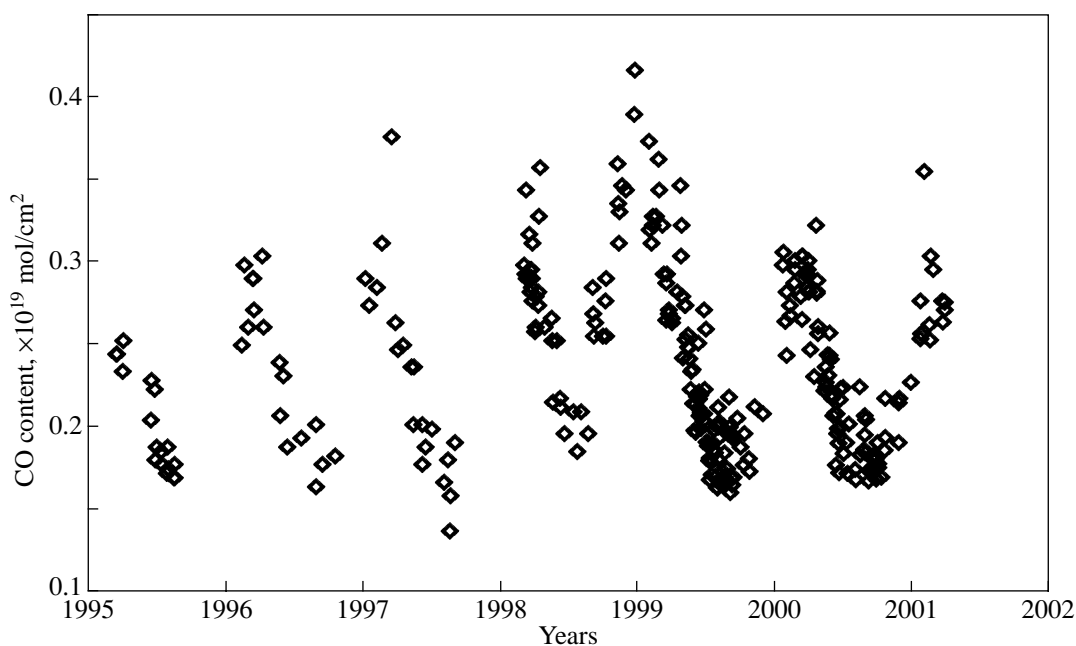


Fig. 3. Daily means of CO content over St. Petersburg.

with the CO data for northern high latitudes (Ny Ålesund), given in [15], also shows a good consistency.

There are significant discrepancies with the Zvenigorod CO contents. This may be caused, first, by spatial variations in the CO field (the influence of intense local and other continental sources) and, second, by the fact that the modifications of spectroscopic techniques used for CO measurement were not intercalibrated. The importance of the latter factor is emphasized in [16], where the intercalibration of spectroscopic CH₄ measurements is discussed.

3.2. Annual cycle of CO content. Atmospheric carbon monoxide has a clearly defined annual cycle, whose amplitude can reach ~30% of the mean value. Maximum amounts of CO occur between late fall and early spring and correspond to its gradual accumulation in the atmosphere, when the OH concentration assumes the smallest values there. In April–June, the reaction with OH destroys CO rapidly. As a result, the amount of CO in the atmosphere decreases to its annual mean.

The annual mean cycle of CO (d) over 1995–2001 and its year-to-year variability (s_d) for St. Petersburg are illustrated in Fig. 4. The values of s_d are lower during summer than in the other seasons. Minimum values of s_d for St. Petersburg occur in July. As can be seen from Fig. 4, the 1995–2001 annual mean cycle of the CO content has an amplitude of about 25%, with a maximum in February and a minimum in July–August. The annual cycle and the year-to-year variability of atmospheric CO content are attributed to the temporal behavior of the intensities of CO sources and sinks. The analysis of the influence of different sources and sinks on the global distribution and time variation of CO was performed using a Geophysical Fluid Dynamics Laboratory three-dimensional global chemical transport model (NOAA GFDL GCTM) in [13]. The results of calculations of the global distribution of CO mixing ratios are shown in comparison with measurements of surface CO mixing ratios at certain NOAA network stations. In particular, contributions of different CO sources to the annual cycle of the CO mixing ratio are presented for each station. The analysis of the simulated surface mixing ratios of CO for European and Arctic NOAA stations closest to St. Petersburg (for example, Baltic Sea station, 55°30' N, 16°40' E, 7 m above sea level; Heimaey station, Iceland, 63°15' N, 20°09' W, 100 m above sea level) indicates that the main source responsible for the annual cycle of CO mixing ratios at these stations is fossil fuel (coal, oil, gas). The maximum of the annual CO cycle at these stations manifests itself from January to April and the minimum is distinct from June to August. Probably, the character of the annual CO cycle for St. Petersburg, which agrees with the annual cycle of CO mixing ratios (at the NOAA stations), is also explained by extensive use of fossil fuel (particularly in cold periods for heating). It should be noted that comparisons of the gas contents and surface mixing ratios must be handled with

Table 2. Results of spectroscopic CO measurements for different geographical sites in October 1996

	Central Atlantic, 55°–60° N	St. Petersburg	Zvenigorod
CO content (October 1996), 10 ¹⁹ mol/cm ²	0.189	0.183	0.266

care, because the mixing ratio is a local characteristic and the total content is an integral parameter containing information about all atmospheric layers. However, for as well-mixed a gas as CO, most of which is found in the troposphere, it is tropospheric variations in mixing ratios that have a decisive influence on the total content.

The number of stations where CO measurements are performed is small compared to the network for observations of surface mixing ratios. They provide the bulk of CO data. The longest series of CO measurements is available at the Institute of Atmospheric Physics, Russian Academy of Sciences [17]. The series contains observations at the Zvenigorod Research Station (55.4° N, 36.5° E) from 1970 to the present time. Monthly means of the CO content in this series from 1995 to 1999 were received courtesy of E.I. Grechko and A.V. Dzhola of the Institute of Atmospheric Physics [17]. Another very close geographical point where regular CO measurements are performed is the polar station in Ny Ålesund, Spitsbergen (Network for Detection of Stratospheric Change, 78.9° N, 11.9° E) [14]. Table 3 lists the following data for all three stations:

- (1) measurement periods used (accessible) for analysis,
- (2) annual mean cycle amplitudes (A_{ann}),
- (3) mean CO contents (w_m) for the corresponding measurement periods,

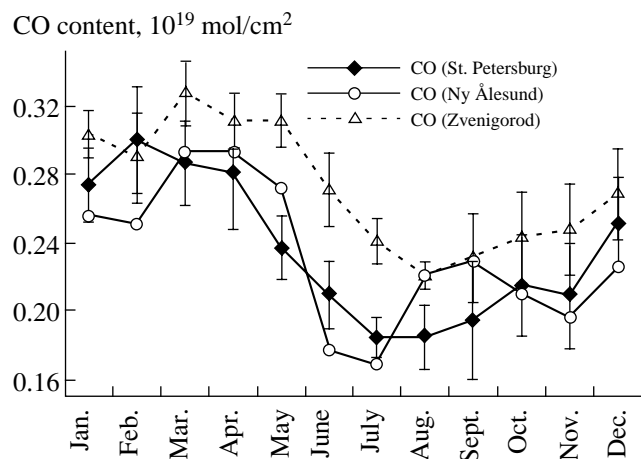


Fig. 4. Annual mean CO cycles for St. Petersburg, Ny Ålesund, and Zvenigorod.

Table 3. Amplitudes of the annual mean cycle (A_{ann}), mean CO contents (w_m) for corresponding measurement periods, and difference $\Delta_m = w_m$ (Zvenigorod, Ny Alesund) – w_m (St. Petersburg) for Ny Alesund, Zvenigorod, and St. Petersburg

	Station		
	Zvenigorod	St. Petersburg	Ny Ålesund
Latitude, °N	55.4	59.88	78.9
Period	1995–1999	1995–2001	1992–1995
A_{ann} , %	20	24	26
w_m , 10^{19} mol/cm ²	0.272	0.236	0.233
Δ_m , %	+15	–	–1

(4) difference $\Delta_m = w_m$ (Zvenigorod or Ny Ålesund) – w_m (St. Petersburg).

It can be seen from Table 3 that the amplitudes of the annual cycle increase with latitude. For the three stations listed in increasing order of latitude, the amplitudes are 20, 24, and 26%.

The values of Δ_m in the last row of Table 3 characterize the systematic difference in CO content between St. Petersburg, Zvenigorod, and Ny Ålesund. It is seen that the mean CO contents for St. Petersburg and Ny Ålesund agree within 1%, while similar values for St. Petersburg are systematically higher by ~15%.

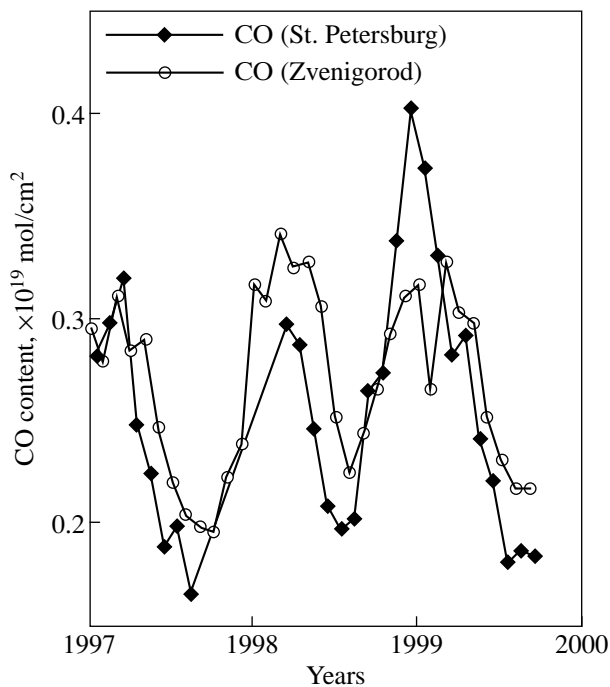


Fig. 5. Monthly means of CO content for St. Petersburg and Zvenigorod in the period from 1997 to 2000.

The curves of the annual mean cycle are shown in Fig. 4 for all three stations. The annual cycles for St. Petersburg and Zvenigorod are shifted relative to each other by one month. While the maximum for St. Petersburg occurs in February, the maximum for Zvenigorod is in March, and, correspondingly, the minimum occurs in July in the first case and August in the second case. The annual CO cycle for Ny Ålesund is more complicated than for St. Petersburg or Zvenigorod. It has two maxima (in March–April and September) and two minima (one in November and a strong summer minimum in July, like that for St. Petersburg).

3.3. Irregular disturbances of CO content. The CO content series can be represented as a superposition of long-term changes, annual cycle, and irregular disturbances. Irregular disturbances may be significant and can be induced by natural variations in the intensities of CO sources. As an example, we consider the period from September 1998 to January 1999. In this period, a sharp CO increase was reported for St. Petersburg and Zvenigorod, and there was also an increase in CO mixing ratios over the entire Northern Hemisphere, particularly at high-latitude stations (Point Barrow, Alaska, 71.32° N, 156.61° W).

The CO peak for St. Petersburg and Zvenigorod was in November–December 1998 (see Fig. 5). It was stronger in St. Petersburg than in Zvenigorod. Maximum values of the CO content in St. Petersburg were $\sim(0.37\text{--}0.38) \times 10^{19}$ mol/cm², substantially higher (by 25%) than the mean CO amounts typical of a February maximum. In Zvenigorod, the peaks in November–December 1998 were at the level of a March maximum.

The anomalously high values of the CO mixing ratios in the period under study are illustrated in Figs. 6b and 6c. Figure 6b shows the series of residuals of the CO mixing ratios at Point Barrow, Alaska (71.32° N, 156.61° W) [14]. Figure 6c shows the series of residuals of globally averaged CO mixing ratios and those averaged over each hemisphere separately [4]. The residual series (of surface mixing ratios or content) is the set of original data from which the annual mean cycle was removed.

The analysis of the residual series of the CO content and surface mixing ratios given in Fig. 6 has shown the following.

(1) Anomalies in the CO content are found in all the data analyzed. The beginning and the end of the period with the anomalously high CO content coincide with those for surface mixing ratios.

(2) Maxima in the residual series of CO content (peaks) for St. Petersburg (and for Zvenigorod) were observed about one month later than those for the surface CO mixing ratios at Northern Hemisphere stations (at Point Barrow, in particular). It is unclear why this shift occurs in the peaks. One may suppose that the cause of this shift is the time of transport of CO-rich air masses or the inertia of the CO content compared to surface mixing ratios.

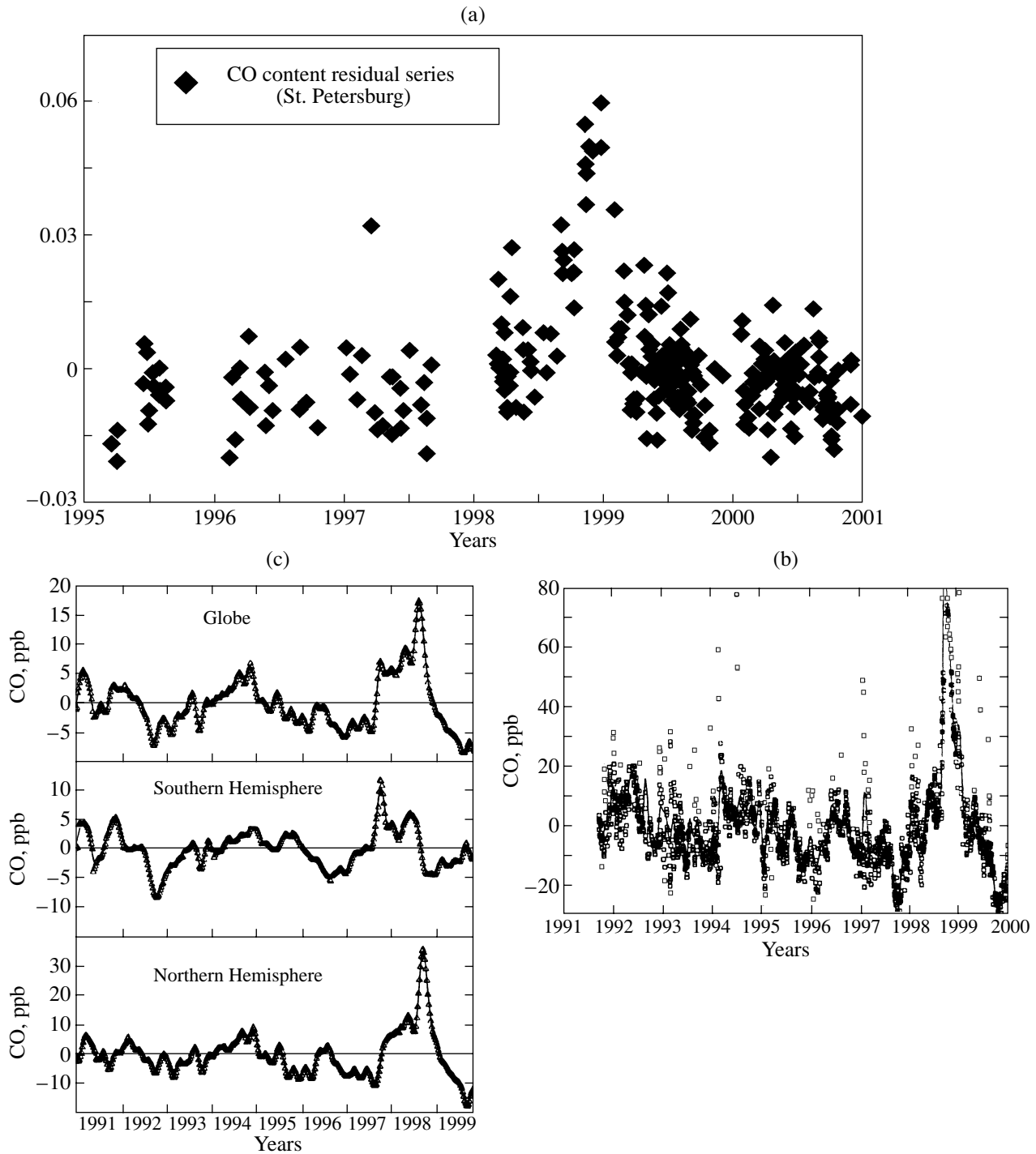


Fig. 6. Residual series of (a) CO content for St. Petersburg; (b) surface CO mixing ratios at Point Barrow, Alaska (71.32° N, 156.61° W) [4]; and (c) globally averaged CO mixing ratios (NOAA network) [4].

(3) The surface mixing ratios at maximum for the high latitudes of the Northern Hemisphere were considerably (twofold) greater than the hemispheric average (Fig. 6).

The stations located farther north recorded stronger maxima in both the content and the surface mixing ratios of CO. Presumably, forest fires in northern high

latitudes were the primary cause of the CO increase in the period September 1998–January 1999.

3.4. Long-term CO trends. In recent decades, much attention has been given to estimates of long-term CO trends. These estimates are based on the measurements of both the contents and surface mixing ratios of CO (Table 4). The gas chromatographic analysis of air

Table 4. Estimates of long-term CO trends in the atmosphere

Station	Measurement type	Altitude above sea level	Measurement period	Trend, % per year	Trend SD, % per year	Atmospheric layer, km
Zvenigorod Research Station (IFA RAN)	Spectroscopy	0.2	70–82	1.3	0.8	0.2–10
			80–95	0.2	0.2	
			84–95	0.4	0.2	
			84–97	0.02	0.18	
International Scientific Station Jungfraujoch	Spectroscopy	3.58	50–87	0.85	0.08	>3.5
			84–95	–0.18	0.16	
			84–97	–0.53	0.18	
Kitt Peak Observatory	Spectroscopy	2.09	78–97	–0.27	0.17	2.1–14
Northern Hemisphere, 20 NOAA/CMDL stations	Gas chromatography	0–0.2	90–95	–2.0	0.2	Oceanic boundary layer
Southern Hemisphere, 2 NOAA/CMDL stations	Gas chromatography	0–0.2	81–86	0.8	0.7	Oceanic boundary layer
			87–92	–1.4	0.9	

bubbles preserved in Greenland ice has shown that the atmospheric CO content in the period of 1850–1950 increased at a rate of $\sim 0.3\%$ per year [18]. The results of spectroscopic and gas chromatographic measurements show a positive CO trend from the 1950s to the mid-1980s. The CO contents measured in Zvenigorod were characterized by an increase of $\sim 1.3\%$ per year in 1970–1982. The spectra in the CO absorption band from the Jungfraujoch station, measured irregularly by Migeotte in 1950–1951, were reprocessed by Zander and compared with analogous measurements of 1985–1987. The trend was estimated to be $\sim 0.85\%$ per year [18]. However, as can be seen from Table 4, the esti-

mates of CO trends have considerably changed since the mid-1980s for CO contents as well as for surface mixing ratios. The estimates of the CO trends for the Southern Hemisphere boundary layer in 1987–1992 showed a decrease at a rate of $\sim 1.4\%$ per year. An even faster CO decrease ($\sim 2.0\%$ per year) was found (also in the boundary layer) in the Northern Hemisphere for the period of 1990–1995. The main cause of the CO decrease in the atmosphere is believed to be the Pinatubo eruption in 1991, which triggered the following chain of atmospheric processes: a decrease in the amount of O_3 in the stratosphere \Rightarrow a deeper penetration of UV radiation into the troposphere \Rightarrow the increase in OH (a major sink for CO). The low level of CO emissions into the atmosphere due to biomass burning could also be partly responsible for the observed sharp CO decrease [18].

Due to the relatively short observation period (seven years) and because of the strong CO variability, the measurement series available for St. Petersburg provides only rough estimates of long-term changes in the CO content. Figure 7 presents estimates of the growth rate and of the error of its calculation for two periods: from 1995 to the first half of 1998 and from the second half of 1999 through 2001. These estimates were obtained from the analysis of the corresponding series of the residuals (δCO) of monthly mean CO contents (the annual mean cycle was subtracted from the monthly mean CO series). The period from the second half of 1998 to the beginning of 1999 was withdrawn from analysis, because it was characterized by a sharp CO increase, attributed to irregular disturbances, which was noted in the previous section. The rates of CO increase were $(3.5 \pm 2.3)\%$ per year in 1995 to early 1998 and $(-3.8 \pm 1.5)\%$ per year between the second half of 1999 and 2001. The increase changed to a decrease in late 1998–early 1999. Our estimates qualitatively agree with the results of the analysis of the glo-

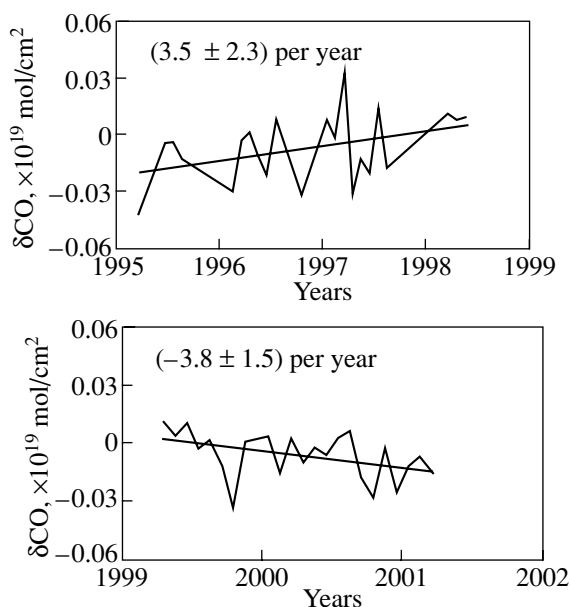


Fig. 7. Estimates of the rate of CO increase for St. Petersburg in the periods from 1995 to the first half of 1998 and from the second half of 1999 to 2001.

bal rates of increase of CO mixing ratios at the NOAA CMDL network for 1995–2001 [19]. The CO mixing ratios generally increased in the 1995–1998 period. This increase was followed by a decrease in 1998–1999. Quantitative estimates of the rates of increase are difficult to compare, because variations in the global rate of increase of CO mixing ratios relative to its zero level were significant during the given period and made up (± 15 – 20)% per year [19].

4. CONCLUSIONS

(1) Results of the spectroscopic CO measurements in St. Petersburg for 1995–2001 are presented. The accuracy of these measurements has been studied through numerical modeling of the measurement process and, indirectly, by comparing spectroscopic measurements of the total content of water vapor with radiosonde data. The errors in the daily means of the CO content are 1–4%, depending on the number of measurements in a day.

(2) The mean values of the CO content for St. Petersburg and Ny Ålesund agree within 1%, while analogous values for Zvenigorod are systematically higher by 15%. The results of CO measurements in the central Atlantic in October 1996 agree well with the CO contents recorded in St. Petersburg (within 3%). Significant discrepancies with the Zvenigorod data may be attributed, first, to spatial regional variations in the CO field (influence of intense local and other continental sources) and, second, to systematic errors in the proposed modifications of spectroscopic techniques of CO measurement.

(3) The annual mean CO cycle for St. Petersburg over the 1995–2001 period has an amplitude of about 24% of the average level. Maximum values of the CO content are observed in February, and its minimum values occur in July–August. The character of the annual mean CO cycle over St. Petersburg agrees with the annual cycle of the CO mixing ratios (at the NOAA network) and is explained by extensive use of fossil fuels, which substantially increases in the cold seasons.

(4) The comparison of the temporal behavior of the CO content for three stations (St. Petersburg, Zvenigorod, Ny Ålesund), where spectroscopic measurement are performed, has shown the following:

- (i) a one-month shift in the annual cycles for St. Petersburg and Zvenigorod,
- (ii) a more complicated annual CO cycle at Ny Ålesund than in St. Petersburg or Zvenigorod,
- (iii) an increase in the amplitude of the annual cycle with latitude for Zvenigorod (20%), St. Petersburg (24%), and Ny Ålesund (26%).

(5) The analysis of the series of the CO residuals (δCO), after the removal of the annual mean cycle, has shown a sharp increase in δCO for St. Petersburg, with a peak in November–December 1998. Maximum values were considerably ($\sim 25\%$) higher than the mean

CO content, typical of the February maximum. The results of CO measurements in Zvenigorod show a peak that coincides in time with that in St. Petersburg but has a smaller amplitude. The main cause of the observed anomalies in the CO content and in the surface CO mixing ratios is thought to be heavy forest fires in the high latitudes of the Northern Hemisphere.

(6) The rates of CO increase for St. Petersburg have shown that the CO content increased in 1995–1998 at $\sim 3.5\%$ per year. The CO decrease began in 1998–1999. The rate of decrease in 1999–2001 was $\sim 3.8\%$ per year. The results obtained are qualitatively consistent with the results of measurement of the surface mixing ratios in the atmosphere [19].

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