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Comparison between Satellite Spectrometric and Aircraft Measurements of the Gaseous Composition of the Troposphere over Siberia during the Forest Fires of 2012

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Abstract—The vertical profiles of the O_3, CO, CO_2 and CH_4 concentrations measured onboard the Optik Tu-134 aircraft laboratory and retrieved from data obtained with an IASI Fourier transform spectrometer operating aboard a MetOp satellite (European Space Agency) have been compared. This comparison shows that absolute differences between aircraft satellite ozone concentrations may vary from 55 to 15 ppb at the land surface and within the lower boundary layer and from 30 to –15 ppb at a height of 7000 m. Their relative differences range within 60 to 30% at a height of 500 m and 30 to –35% at a height of 7000 m. Absolute differences between aircraft and satellite carbon-monoxide concentrations may vary from 80 to 2300 ppb, while their relative differences range within –140 to 98%. For methane, the mean difference is maximal within the atmospheric boundary layer (90 ppb). According to the data on all profiles, the maximum and minimum differences reach 220 and 8 ppb, respectively, within the atmospheric boundary layer. Minimum differences range from zero at the land surface to –100 ppb in the upper troposphere. For carbon dioxide, the mean difference between the results of aircraft and satellite measurements ranges from –2 to –9 ppm. In the free troposphere, at a height of more than 3000 m, this difference is almost constant and amounts to –6 ppm. Over all flights, the maximum and minimum differences between aircraft and satellite CO_2 concentrations range from 14 to –4 ppm and from –7 to –16 ppm, respectively, within the atmospheric boundary layer. In this case, the maximum and minimum relative deviations over all flights amount to 3.4 and –4.2%, respectively, within the atmospheric boundary layer. These differences are significantly larger than those found earlier for the background conditions. It is necessary to improve the vertical gas distribution models used in the algorithms of satellite-data processing.

Keywords: atmosphere, gas, aircraft and satellite soundings, comparison

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INTRODUCTION

In recent several decades, the attention of the world community has been focused on both environment and climate changes. Numerical simulations using different scenarios related to increased emissions and, correspondingly, changes in atmospheric composition are widely used in order to estimate possible climate changes. The composition of the atmosphere is monitored by the network of the World Meteorological Organization (WMO). However, the WMO network of stations is not large, and these stations are nonuniformly distributed over the globe. This significantly complicates the simulation of climate changes and makes the interpretation of obtained results ambiguous.

Many scientists think that satellite monitoring of the atmosphere and the underlying surface is necessary to provide current climate change models with data. Currently, dozens of remote sensing satellites have been launched, remote sensing methods have been improved, and errors in measuring parameters have been estimated (Kramchaninova and Uspenskii, 2013; Kukharskii and Uspenskii, 2009, 2010; Polyakov et al., 2009, 2010, and 2012a; Upenskii et al., 2011; Safronov et al., 2012). Satellite sounding data on atmospheric composition can be used, if the measurement errors do not exceed 1–3% of the measurable value (Kramchaninova and Uspenskii, 2013; Kukhar-

† Deceased.

skii and Uspenskii, 2009, 2010). Satellite data are usually validated on the basis of data obtained from ground-based (Polyakov et al., 2012b) or aircraft (Kukharskii and Uspenskii, 2009, 2010; De Laat et al., 2012; De Wachter et al., 2012; Klonecki et al., 2012; Pommier et al., 2012; Tanaka et al., 2012; Kramchaninova and Uspenskii, 2013) measurements.

Thus, data obtained from measurements with an IASI Fourier spectrometer operating aboard a MetOp satellite (European Space Agency (ESA)) and from measurements aboard the aircraft laboratories WP-3D (NOAA, United States), DC-8 (NASA, United States), ATR-42 (CNRS, France), Falcon-20 (DLR, Germany), and AN-30 Optik-E (IAO SB RAS) within the framework of the POLARCAT Project were compared in (Pommier et al., 2012). It was shown that the errors in retrieving CO profiles amount to 21% for the lower troposphere and 10% for the upper troposphere. Comparisons of data on total CO for a SCIAMACHY instrument operating aboard the ENVISAT-1 satellite (ESA) yielded good results. In most cases, the discrepancies did not exceed 4–6% (De Laat et al., 2012). The authors of this work compared satellite and aircraft data on the gas composition of the troposphere over southwestern Siberia under background conditions (Arshinov, 2013). This comparison showed that the absolute differences in the concentrations of ozone between aircraft and satellite measurements may vary from 3 to 18 ppb at a height of 500 m and from –8 to –38 ppb at a height of 7000 m. Relative differences are within the ranges of 8 to 30% for a height of 500 m and –12 to 88% for a height of 7000 m. For CO profiles, absolute differences in the concentrations of CO between aircraft and satellite (IASI) measurements vary from 32 to 103 ppb at a height of 500 m and from –18 to 23 ppb at a height of 3000 m and relative differences are within the ranges –4 to 48% for 500 m and –8 to 20% for 7000 m. For methane, according to the data on all vertical profiles, the maximum and minimum differences reach 150 and –10 ppb, respectively, within the atmospheric boundary layer. The mean relative difference varies from 2.8 to –0.5%. According to the data on all flights, the maximum and minimum differences vary from 7.8 to 1.2% and from –0.4 to –3.4%, respectively. The mean difference in the concentrations of CO_2 between aircraft and satellite measurements lies within ±1.5 ppm, while individual vertical profiles are incomparable. According to the data on all flights, both maximum and minimum differences yield high values, namely, 10 and 12 ppm, respectively, within the atmospheric boundary layer. According to the data on all flights, the maximum and minimum relative deviations amount to 2.3 and –3.3% within the boundary layer, respectively. Above the boundary layer, relative deviations decrease to ±1.0%.

It should be noted that the results of these comparisons show noticeable disagreement with respect to seasons and regions. Therefore, verification of the results of satellite measurements for different regions is still urgent.

A similar situation was observed in European Russia in the summer of 2010 (Bondur, 2010, 2011a, 2011b).

The objective of this work is to compare satellite and aircraft data obtained under the conditions of large destructive forest fires on the territory of Siberia in summer 2012. This period was characterized by decaying atmospheric general circulation and weak trace-gas dissipation. A dense haze was observed in the atmosphere over most regions of Siberia. Therefore, the question as to the extent of smoke generation reflected in the satellite data is especially interesting.

INSTRUMENTATION AND OBSERVATION REGIONS

Aircraft sounding of the atmosphere over Siberia has been carried out by the authors of this work since the early 1980s. At first, measurements to determine the vertical distribution of atmospheric gases and aerosols were taken from board the Optik-E AN-30 aircraft laboratory (Zuev et al., 1992; Antokhin et al., 2012). Then, all instrumentation was transferred to the Optik Tu-134 aircraft laboratory (Anokhin et al., 2011).

A Li-6262 instrument (Li-Cor, United States), a nondispersive infrared gas analyzer modified at the LSCE (France), was used for measuring CO_2. This instrument includes a system that regulates the temperature, flow, and pressure of the air under analysis. The outboard air inflowing into this instrument was dried using magnesium perchlorate. The frequency of data recording was 0.5 Hz. During flights, this instrument was calibrated every 30 min using reference gas mixtures with three highly accurate concentrations. These gases are in high-pressure cylinders marked as high, low, and reference mixtures. The concentrations of these gases were previously verified at the LSCE (France); these concentrations correspond to the WMO-CO_2 primary standards established by the NOAA/ESRL (United States): 370.60 ± 0.01, 380.47 ± 0.01, and 409.76 ± 0.01 ppm, respectively.

Carbon oxide (CO) was measured with a correlation gas analyzer of the 48CTL model (Thermo Environmental Inc., United States) within the ranges 0–500, 1000, 5000, and 10000 ppb. This instrument was modified at the Laboratoire d'Aérologie (France) and was described in (Nédélec et al., 2003). This instrument is fully automatic and makes it possible to take measurements with an accuracy of 5 ppb. Its modified version verifies the instrument zero every 20 min. For this purpose, a new IR sensor with better cooling and temperature control is used.

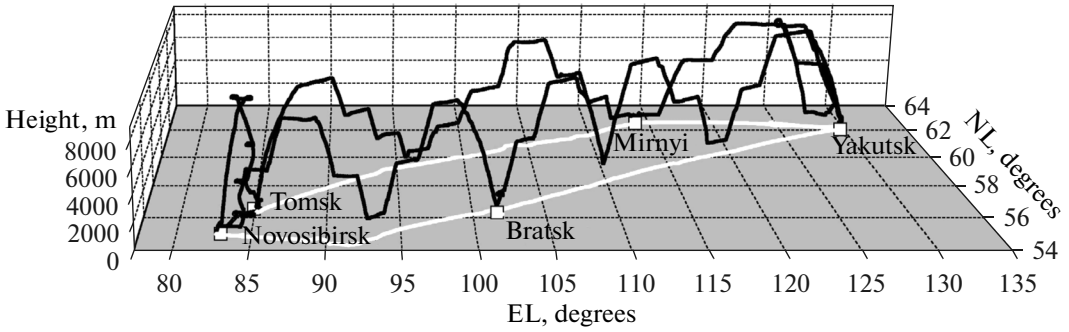

Fig. 1. Scheme of the Optik Tu-134 aircraft laboratory flights during measurements.

Since there is a problem related to ozone measurements under conditions that differ from the background ones (Arshinov et al., 2001; Dunlea et al., 2006), three ozonometers were simultaneously operating aboard the aircraft laboratory: a 3-02P chemiluminescent ozonometer developed and manufactured at the OPTEK Close Corporation (St. Petersburg, Russia) and two 49C ultraviolet models (Thermo Environment Inc., United States). These ozonometers were calibrated using a GS-2 ozone generator manufactured at the OPTEK Close Corporation. Air flowed in and out of the instruments through Teflon tubes.

In 2011, the instrumentation installed aboard the Optik Tu-134 aircraft laboratory was supplemented with a precision instrument of the G2301-m Picarro model (United States) to measure the carbon dioxide (CO_2), methane (CH_4), and water vapor (H_2O) concentrations in the atmosphere. The measurement ranges were 0–1000 ppm for CO_2, 0–20 ppm for CH_4, and 0–7 vol % H_2O at a dew-point temperature of 39°C. The measurement errors were as follows: $CO_2 <$ 200 ppb, $CH_4 < 1.5$ ppb, and $H_2O < 150$ ppm. The measurement interval was 1.2 s.

Data obtained within the framework of the YAK-AEROSIB Russian–French Project were used in this work. The Optik Tu-134 aircraft laboratory was in flight over Novosibirsk–Tomsk–Mirnyi–Yakutsk–Bratsk–Abakan–Novosibirsk on July 31–August 1, 2012. The generalized profile and track of this flight are given in Fig. 1.

It follows from Fig. 1 that the experiment was carried out by conducting five flights with different route lengths. The flight profile was variable, which made it possible to obtain 20 vertical profiles over different regions of Siberia.

As was noted above, during this period, a large number of forest fires were observed on a significant part of the territory of Siberia, which resulted in severe air pollution due to combustion products. The fire situation can be judged from both tabular and graphic data obtained for July 31 and August 1, 2012, at the Krasnoyarsk Branch of the National Crisis Management Center (Table 1, Fig. 2).

Vertical gas-concentration profiles measured during the entire flight were used in this work. These profiles were compared with data obtained with the IASI Fourier spectrometer installed aboard the European MetOp satellite. Standard spectral-data processing methods described in (Crevoisier et al., 2009; August et al., 2012) were used, as well as the resource http://www.class.ngdc.noaa.gov/saa/products/welcome.

The spatial resolution of the IASI instrument frame depends on the angle of observation. The nominal (during nadir measurements) spatial resolution amounts to 12 km, and, at the end of scan, the pixel is 39 × 20 km. It is clear that it is not easy to reach an accurate coincidence of profiles (in space and time) obtained from both satellite and aircraft soundings. Therefore, cases with maximum agreement between aircraft and satellite data were chosen for comparison. It is seen from Fig. 3 how critical it is. Figure 3 gives the vertical profiles measured from onboard the aircraft laboratory and retrieved from satellite data in three pixels for the corresponding coordinates and time.

It follows from Fig. 3 that the results of aircraft and satellite measurements may differ significantly, because the results of satellite measurements do not contain data on variations in the concentrations of the indicated gas components in the atmospheric boundary layer. On the basis of satellite measurements (in the absence of cloudiness), one can retrieve two–three parameters of the vertical distribution of ozone (because their informative content with respect to tropospheric-ozone variations is low) and one "integral" parameter individually for CO, CH_4, and CO_2. Figure 3 shows the vertical profiles with the most significant differences. Moreover, in the cases under consideration, coincidence in time is nonobligatory. In both

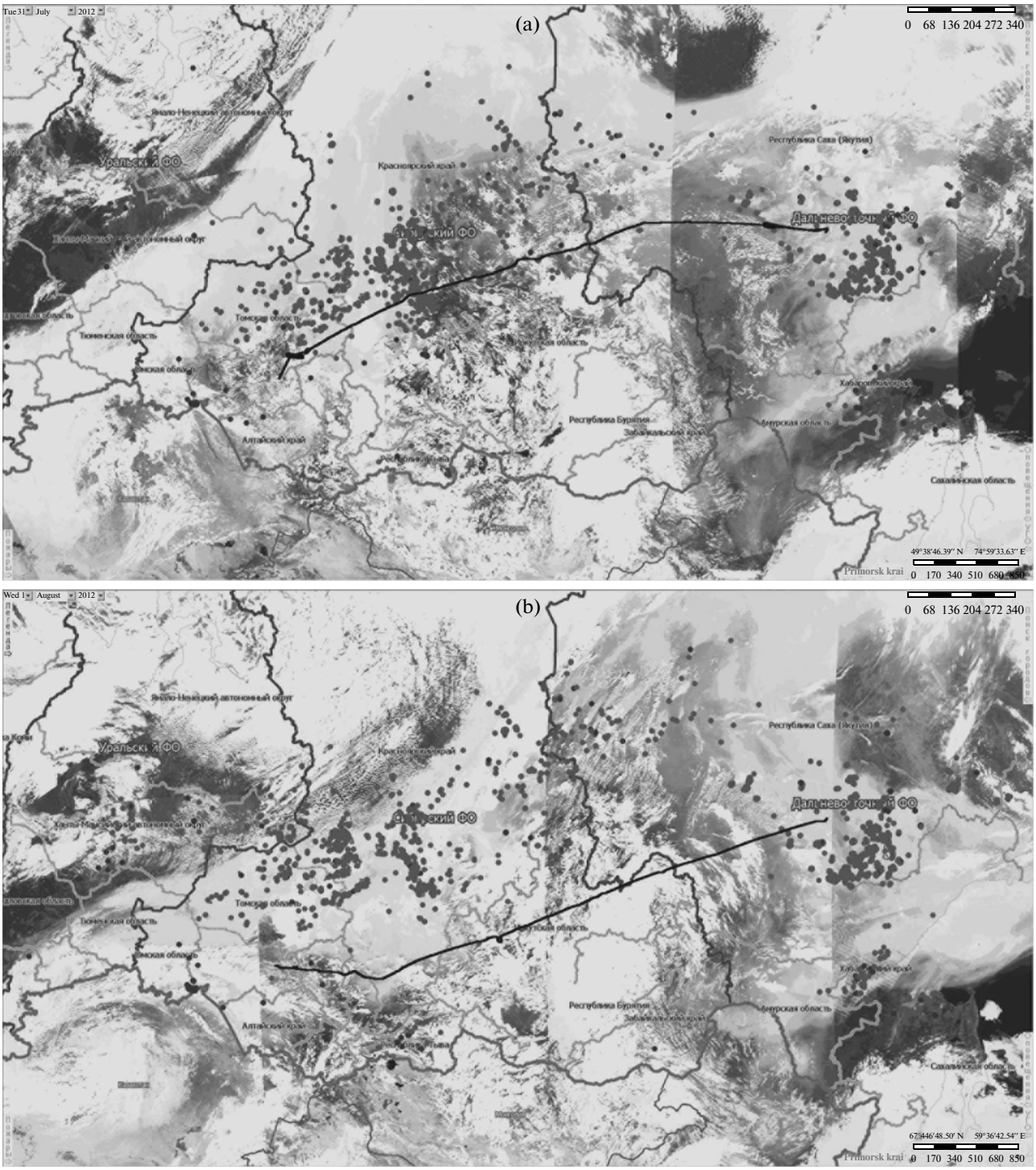

Fig. 2. Map of thermal points and smoke from fires (a) on July 31 and (b) August 1, 2012. The black lines denote the flight track (Novosibirsk–Yakutsk–Novosibirsk) of the aircraft laboratory.

cases, the profiles retrieved from satellite measurements taken later are in better agreement. Therefore, vertical profiles that disagreed with aircraft data to a lesser degree were used in finding mean differences.

Table 2 gives the coordinates of the flight track of the aircraft laboratory, the satellite pixels used for analysis, and the time of sounding.

It follows from the data given in Table 2 that the latitudinal gridding of the aircraft and satellite measure-

Table 1. Fire-hazardous situation in Siberia on July 31 and August 1, 2012

Federal district	Region	Number of thermal points	Number of fires	Area of fire seats, ha	Combustion area, ha
July 31, 2012					
Siberian Federal District	Novosibirsk oblast	2	1	4258	31709
Siberian Federal District	Tomsk oblast	54	21	15215	145660
Siberian Federal District	Krasnoyarsk krai	733	220	263303	2360094
Siberian Federal District	Irkutsk oblast	20	8	14522	17722
Far Eastern Federal District	Sakha Republic (Yakutia)	744	164	428675	1560742
August 1, 2012					
Far Eastern Federal District	Sakha Republic (Yakutia)	800	200	531521	1847748
Siberian Federal District	Irkutsk oblast	29	13	22659	32203
Siberian Federal District	Krasnoyarsk krai	274	118	109395	1796093
Siberian Federal District	Khakass Republic	2	1	309	352
Siberian Federal District	Kemerovo oblast	1	1	207	558
Siberian Federal District	Novosibirsk oblast	n.d.	n.d.	n.d.	n.d.

Table 2. Coordinates and time for the Optik Tu-134 aircraft laboratory and the MetOp (IASI) satellite pixels used

Region	Aircraft laboratory		MetOp (IASI) satellite	
	time	av. coordinates	time	coordinates
Novosibirsk–Tomsk	02:57–03:15	N55.656 E83.498	05:05	N56.249 E84.436
Landing in Tomsk	03:25–04:20	N56.232 E84.736	05:05	N56.249 E84.436
Takeoff—Tomsk	05:44–06:07	N56.659 E86.126	05:05	N57.327 E88.779
Descent—Eniseisk	06:18–06:56	N58.626 E92.844	05:05	N57.327 E88.779
Ascent—Vanavara	07:10–07:55	N60.157 E100.779	05:02	N61.062 E103.899
Descent—Mirnyi	08:06–09:02	N61.534 E109.065	13:17	N61.072 E104.724
Takeoff—Mirnyi	11:13–11:56	N62.576 E117.974	11:35	N62.251 E123.257
Descent—Magaras	12:13–12:41	N62.273 E127.477	11:35 11:35	N62.251 E123.257 N62.080 E124.733
Ascent—Magaras	12:52–13:05	N62.367 E126.217	11:35 11:35	N62.251 E123.257 N62.080 E124.733
Descent—Yakutsk	13:08–13:41	N62.231 E128.367	11:35 11:35	N62.251 E123.257 N62.080 E124.733
Takeoff—Yakutsk	03:34–03:54	N61.877 E128.465	03:02	N61.502 E125.350
Descent—Olekminsk	04:09–04:35	N60.631 E121.495	03:02	N61.502 E125.350
Ascent—Olekminsk	04:44–05:16	N59.673 E116.291	03:02	N58.959 E113.221
Descent—Kirensk	05:28–05:42	N58.459 E110.637	03:02	N58.959 E113.221
Ascent—Kirensk	05:42–05:59	N57.999 E108.770	03:02	N57.556 E106.176
Descent—Bratsk	06:11–06:49	N56.776 E103.471	03:02	N57.556 E106.176
Takeoff—Bratsk	08:04–08:26	N56.261 E100.560	04:44 12:53	N56.209 E97.696 N55.552 E97.919
Descent—Artemovsk	08:36–09:00	N55.368 E95.487	04:44 12:53	N56.209 E97.696 N55.552 E97.919
Rising—Artemovsk	09:10–09:37	N54.554 E91.250	04:44 14:35	N54.829 E88.652 N54.615 E88.328
Landing—Novosibirsk	09:51–10:34	N54.849 E85.243	04:44 14:35	N54.829 E88.652 N54.615 E88.328

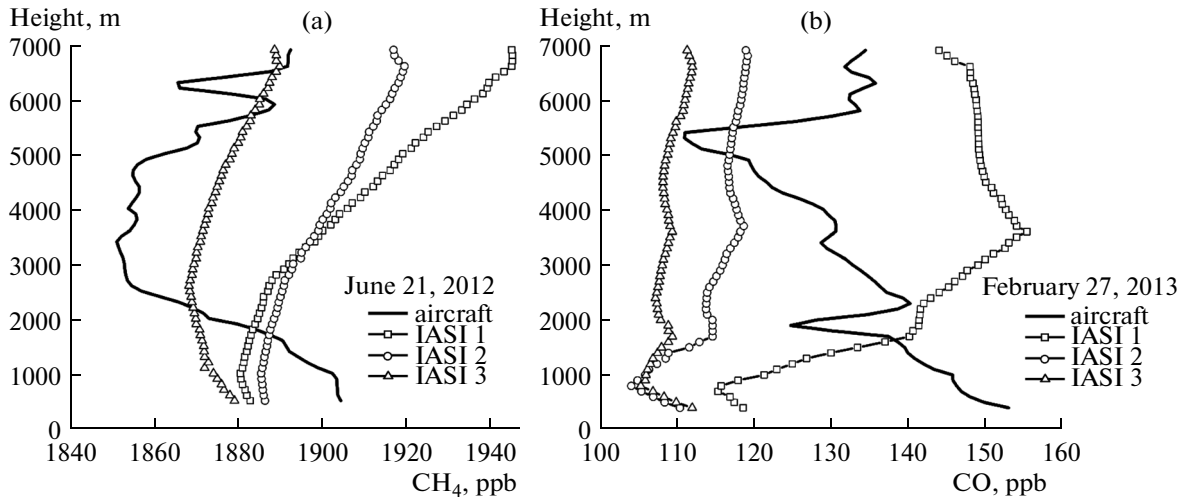

Fig. 3. Vertical gas distributions according to aircraft and satellite (IASI 1, IASI 2, and IASI 3) data obtained in the Novosibirsk region for (a) methane and (b) carbon monoxide.

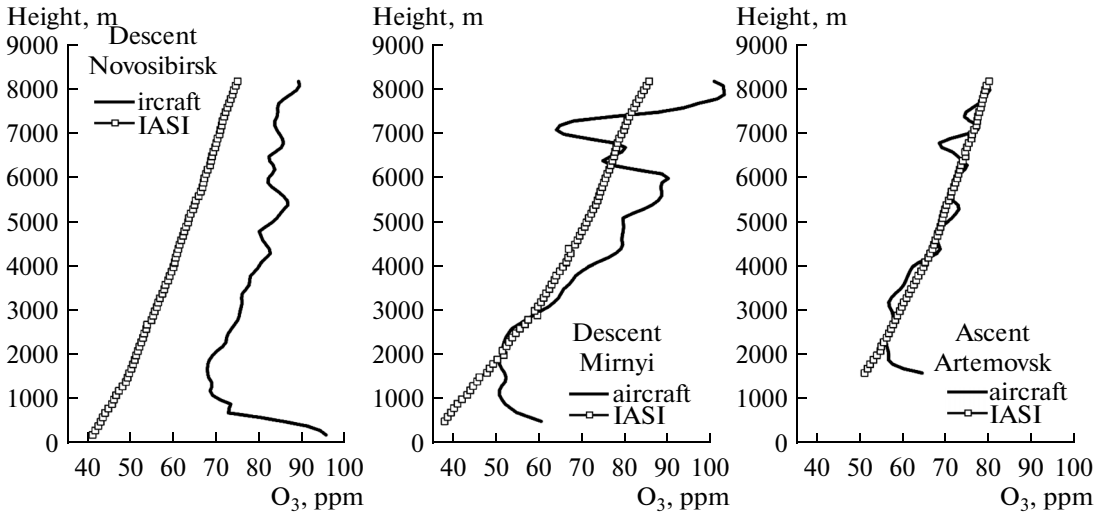

Fig. 4. Vertical ozone distribution according to aircraft and satellite (IASI) data.

ments is sufficiently strict (within 1°). As for longitude, it is impossible to reach such accuracy: for some profiles, their differences reach 5°. The time reference of data may vary from 0 to 6 h.

THE RESULTS OF COMPARISON BETWEEN AIRCRAFT AND SATELLITE DATA

Ozone

All cases of comparison between vertical ozone profiles measured onboard the aircraft laboratory and retrieved from satellite data can be divided into three groups (Fig. 4).

The case presented in Fig. 4a belongs to group 1, which includes approximately 30% of all the cases under analysis (6 of 20 profiles). This group is characterized by almost complete disagreement between the vertical ozone distributions measured in these two different ways.

Group 2 includes profiles with agreement between data on ozone concentrations throughout the most tropospheric layer (see Fig. 4b). Such cases amount to 40%.

Group 3 includes cases when the concentrations of ozone differ within the error ranges of these two measuring methods. Such cases amount to 30% (Fig. 4c).

The results of comparison between ozone concentrations measured under the conditions of smoke generation proved to be much better than between those measured under the background conditions in the atmosphere over Siberia (Arshinov et al., 2013). Satis-

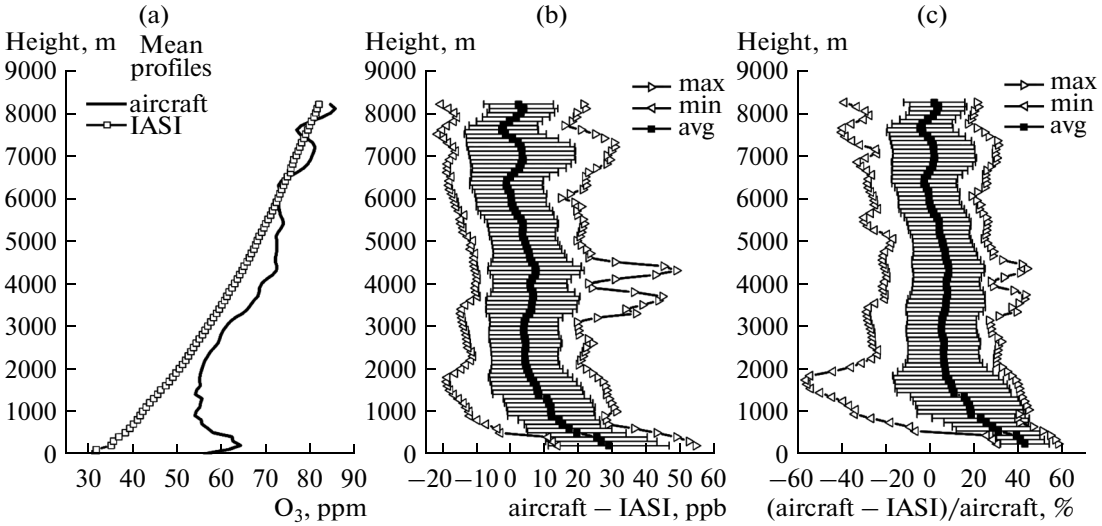

Fig. 5. (a) Mean vertical ozone profiles measured onboard the aircraft laboratory and retrieved according to satellite (IASI) data, their (b) differences in absolute units and (c) relative differences (aircraft – IASI)/aircraft.

factory agreement can be noted between aircraft and satellite data in 70% of cases for the conditions of smoke generation and only in 50% of cases for the background conditions.

When comparing aircraft and satellite data, it was concluded (Uspenskii et al., 2011) that differences between these data can significantly be decreased through averaging over a large space. Data averaged over the entire flight track of the aircraft, i.e., over 20 vertical profiles, are given below (Fig. 5).

The mean ozone profiles plotted on the bases of aircraft and satellite data show that ozone concentrations within the atmospheric boundary layer are significantly underestimated during satellite sounding (Fig. 5a). According to satellite data, the concentrations of ozone are underestimated also within the middle troposphere. Only in the vicinity of 6000 m, the concentrations of ozone become close to one another, and this closeness continues in the upper troposphere up to a maximum height of 8500 m for the aircraft laboratory.

The mean difference between the aircraft and satellite concentrations of ozone varies from 30 ppb in the vicinity of the land surface and in the lower boundary layer to –5 ppb at a height of 6000–8000 m (Fig. 5b). The maximum differences over all vertical profiles amount to 55 ppb at the land surface and 20 ppb within a layer of 6000–8000 m. The minimum differences over all profiles vary from 15 to –20 ppb within the same height range.

Since the annual variation of ozone is noticeable, in order to obtain relative errors in measuring its concentrations with the IASI satellite instrument, the difference between its concentrations was normalized to its values obtained from board the aircraft laboratory (aircraft–satellite)/aircraft. These data are given in Fig. 5c.

It follows from Fig. 5c that the mean relative difference is positive within the boundary layer and the middle troposphere and varies from 30% at the land surface to zero at a height of 6000 m; above this level, it varies in the vicinity of zero. The maximum relative difference varies from 60 to 20% within a layer of 0–6000 m. The minimum relative difference over all profiles amounts to 30% at the land surface, reaches –60% in the vicinity of the upper limit of the atmospheric boundary layer, and decreases to –20% above this level.

Thus, this comparison shows that the absolute differences between aircraft and satellite ozone concentrations vary from 55 to 15 ppb at the land surface and within the lower boundary layer and from 30 to –15 ppb at a height of 7000 m. The relative differences are within the ranges 60 to 30% at a height of 500 m and 30 to –35% at a height of 7000 m. These differences are significantly larger than those found in (Parrington et al., 2012; Pommier et al., 2012; Zyryanov et al., 2012). It seems likely that the vertical ozone distribution model used in the algorithm of data processing needs correction. At least, the results of ozone measurements performed by us earlier show that there is a pressing need for this correction (Belan et al., 2010; Antokhin and Belan, 2012).

Carbon Monoxide

Differences between the vertical profiles of carbon monoxide (unlike ozone) measured onboard board the aircraft laboratory and retrieved from satellite data are divided into four groups.

Only two profiles (10% of cases) belong to group 1, which is characterized by an almost complete disagreement between the vertical distributions of CO.

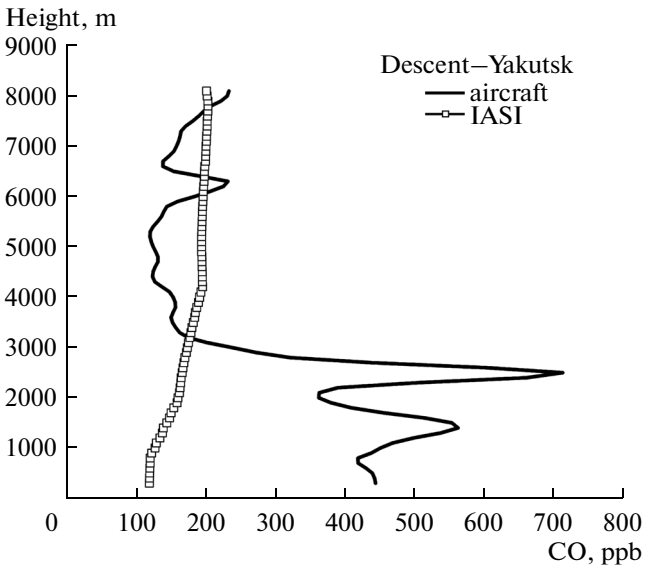

Fig. 6. Vertical carbon-monoxide distributions measured onboard the aircraft laboratory and retrieved according to satellite (IASI) data and the difference between aircraft and satellite carbon-monoxide concentrations (aircraft – IASI) for Yakutsk.

Group 2 includes three profiles (15% of cases) with CO concentrations coinciding throughout the most troposphere.

Group 3 includes six profiles (30% of cases) with CO concentrations differing within the error ranges for these two methods.

Group 4 includes 9 profiles (45% of cases) characterized by the presence of layers with increased CO concentrations, which are not in the least reflected by the algorithms of satellite-data processing (Fig. 6).

It follows from Fig. 6 that, there are two smoke plumes from forest fires with CO concentrations of 560 and 740 ppb within the atmospheric boundary layer at heights of 1700 and 2200 m. The profiles retrieved on the basis of satellite data do not reflect this fact.

It follows from Fig. 7a that the mean carbon-monoxide concentrations measured onboard the aircraft and retrieved from satellite data significantly differ within the atmospheric boundary layer up to a height of 1700 m. This difference reaches 1100 ppb. Then, this difference begins to decrease up to a height of 4000 m. Above this level, variations in the CO concentration measured by these two methods are similar and close in absolute values.

The mean difference between aircraft and satellite data has a similar behavior (Fig. 7b). It is seen that this difference reaches 400 ppb at a height of 500 m and decreases to 100 ppb in the vicinity of 2200 m. The mean difference varies within the range 30–50 ppb within a layer of 2000 to 4000 m.

The maximum difference found over all vertical profiles varies from 2300 ppb at a height of 300 m to 80 ppb at a height of 5000 m and then remains almost constant. The minimum difference over all profiles lies within the range 30 to –180 ppb.

As one passes to relative values, the situation significantly changes (Fig. 7c). The mean relative difference is maximal at the land surface and reaches 62% of the CO value measured onboard the aircraft laboratory. Then, this difference decreases to –20% in the vicinity of a height of 4000 m and varies only slightly above this level. The maximum relative difference found over all vertical profiles varies from 98% at a height of 300 m to 50% at a height of more than 5000 m and then increases again up to 60% at a level of 7000 m. The

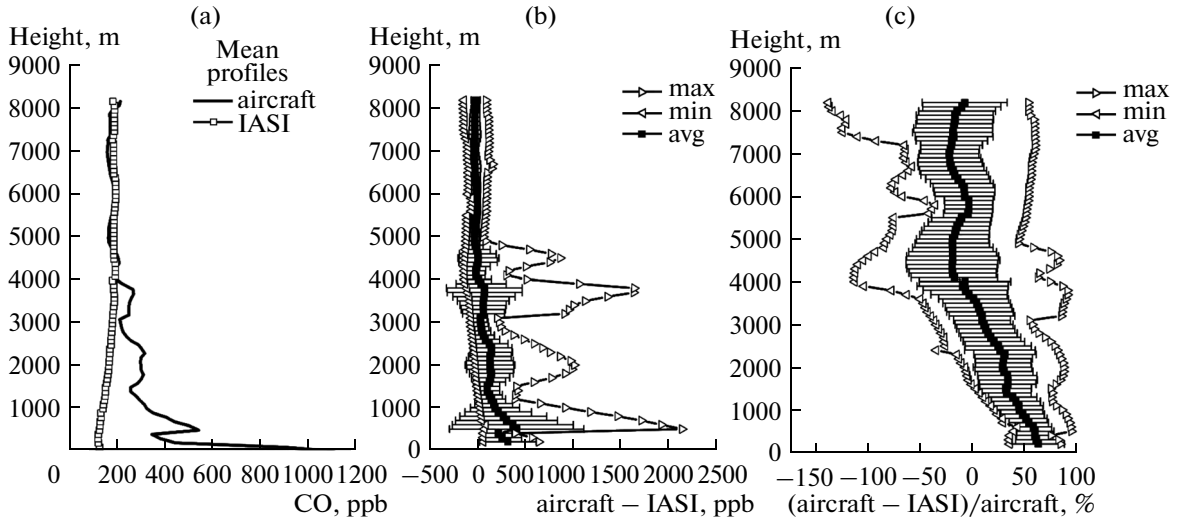

Fig. 7. (a) Mean vertical carbon-monoxide profiles measured onboard the aircraft laboratory and retrieved according to satellite (IASI) data, their (b) differences in absolute units and (c) relative differences (aircraft – IASI)/aircraft.

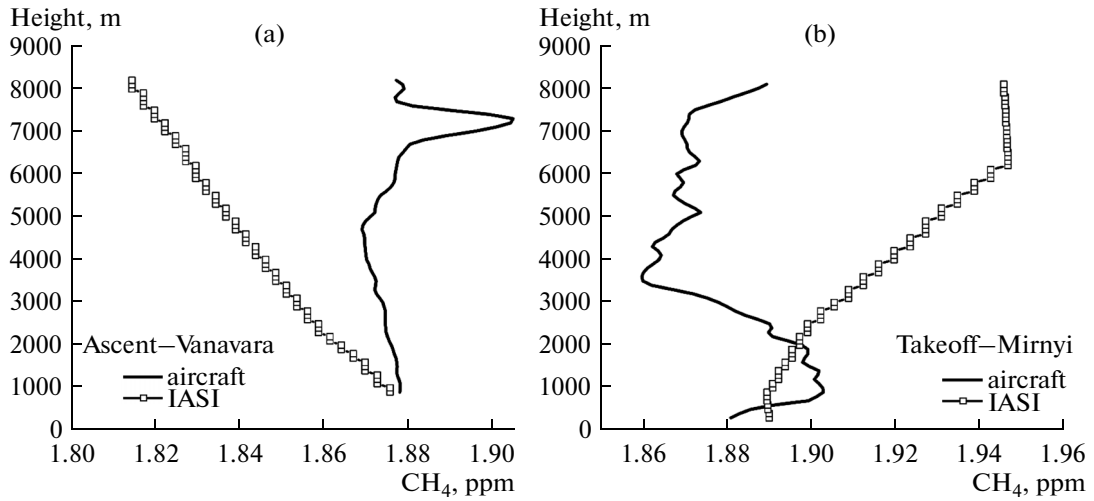

Fig. 8. Vertical methane distributions measured onboard the aircraft laboratory and retrieved according to satellite (IASI) data for the Vanavara (a) and Mirnyi (b) regions.

minimum relative difference over all profiles lies within the range 35 to –140%.

Thus, this comparison shows that the absolute difference between aircraft and satellite CO concentrations varies from 80 to 2300 ppb. The relative difference varies within the range –140 to 98%. These differences are significantly larger than those in (De Laat et al., 2012; De Wachter et al., 2012). The symmetry of aircraft and satellite deviations implies that the vertical CO distribution model used in the algorithm of satellite-data processing more adequately reflects CO actual profiles.

Methane

All cases of comparison between the measured and retrieved profiles of methane can also be divided into four groups.

Group 1 includes the measured and retrieved profiles of methane with opposite height variations (10 of 20 cases). Moreover, it follows from Fig. 8 that the concentration of methane in the middle and upper troposphere was underestimated (5 cases) and overestimated (5 cases) when compared to aircraft data, according to satellite data.

There is only one case (group 2), when the measured and retrieved profiles of methane coincide within the errors of the measurement methods (5% of the profiles under consideration).

Group 3 includes four of the profiles under comparison (20%), which partially coincide within the troposphere.

Group 4 includes five cases (25%) in which the aircraft profiles of methane reflect increased concentrations due to fire plumes, which is not reflected in the satellite data.

The pattern is somewhat smoothed out by averaging over the entire flight (Fig. 9a). It follows from Fig. 9a that the aircraft and satellite vertical profiles of methane are as if in antiphase. In this case, according to satellite data, the concentration of methane is underestimated in the boundary layer almost by 50 ppb and overestimated in the middle troposphere by 10 ppb.

Such disagreement between aircraft and satellite data is also reflected in the mean differences between aircraft and satellite methane concentrations (Fig. 9b). It is seen that the mean differences are maximal (50 ppb) within the boundary layer. Then, they decrease to –10 ppb within the middle troposphere. Above this level, the difference decrease is observed in the vicinity at a level of 7000 m. According to data on all profiles, the maximum and minimum differences reach 150 and –10 ppb, respectively, within the atmospheric boundary layer. For the middle troposphere, at a height of approximately 4000 m, the maximum and minimum differences amount to 60 and –63 ppb, respectively. In the upper part of the profile, at a height of 7000 m, they are almost equal: 42 and 38 ppb, respectively.

Figure 9b gives the relative differences normalized to the methane concentration measured onboard the aircraft laboratory. The mean relative difference varies from 2.8 to –0.5%. The maximum and minimum differences over all profiles vary from 7.8 to 1.2% and from –0.4 to –3.4%, respectively. These values are significantly higher than those required in (Kukharskii and Uspenskii, 2009 and 2010; Uspenskii et al., 2011). It is evident that the model used in the algorithm of data processing needs correction (Arshinov et al., Belan and Krekov, 2012).

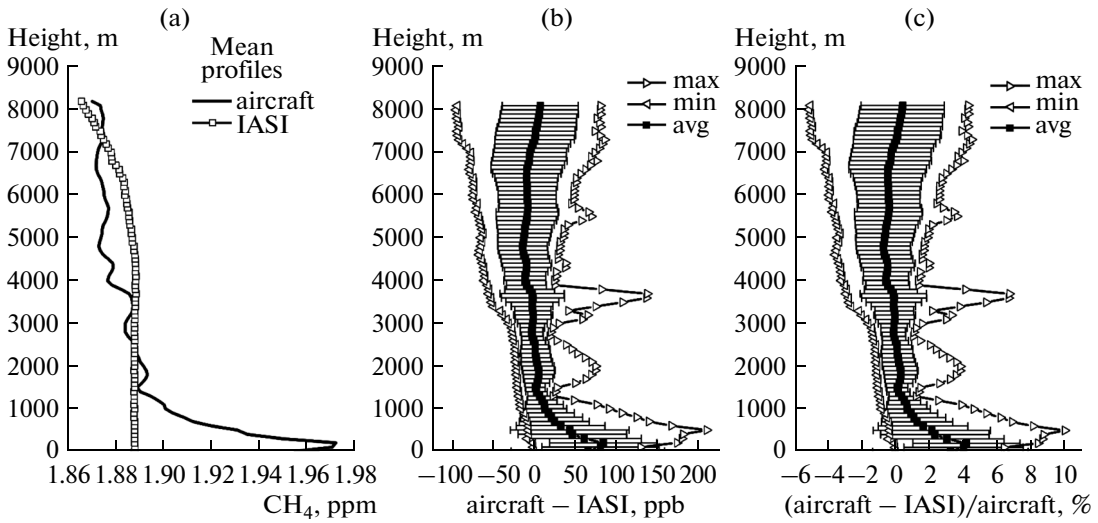

Fig. 9. (a) Mean vertical methane profiles measured onboard the aircraft laboratory and retrieved according to satellite (IASI) data, their (b) differences in absolute units and (c) relative differences (aircraft – IASI)/aircraft.

Carbon Dioxide

In (Arshinov et al., 2012; Belan and Krekov, 2012), it was also noted that the models of vertical CO_2 distribution needed correction. In support of this, let us consider Fig. 10, in which the vertical CO_2 profiles measured onboard the aircraft laboratory and retrieved according to satellite data (August 6, 2012) are given.

It follows from Fig. 10 that the vertical variations in the concentration of CO_2 are not reflected in the profiles plotted on the basis of satellite data, and its concentration is significantly overestimated when compared to that actually observed.

Averaging of the profiles does not improve the situation (Fig. 11). Figure 11a gives the mean (over all flights) profiles, which show that, according to satellite data, the concentration of CO_2 is overestimated by several ppm in the atmospheric lowest layers. Above the atmospheric boundary layer, such overestimation amounts to almost 10 ppm. In this case, the profile plotted on the basis of satellite data in no way corresponds to that actually observed. If the presence of plumes had been taken into account, the overestimation would have been more significant.

The mean difference between the aircraft and satellite profiles (Fig. 11b) varies from –2 to –9 ppm. Within the free troposphere, this difference is almost constant above the 3000-m layer and amounts to –6 ppm.

Over all flights, the maximum and minimum differences within the atmospheric boundary layer vary from 14 to –4 ppm and from –7 to –16 ppm, respectively.

The difference normalization to absolute value yields a mean deviation varying from –0.5 to –2.5% (Fig. 11c), which is significantly higher than that required in (Kukharskii and Uspenskii, 2009, 2010). In this case, the maximum and minimum relative deviations over all flights amount to 3.4 and –4.2%, respectively, within the atmospheric boundary layer.

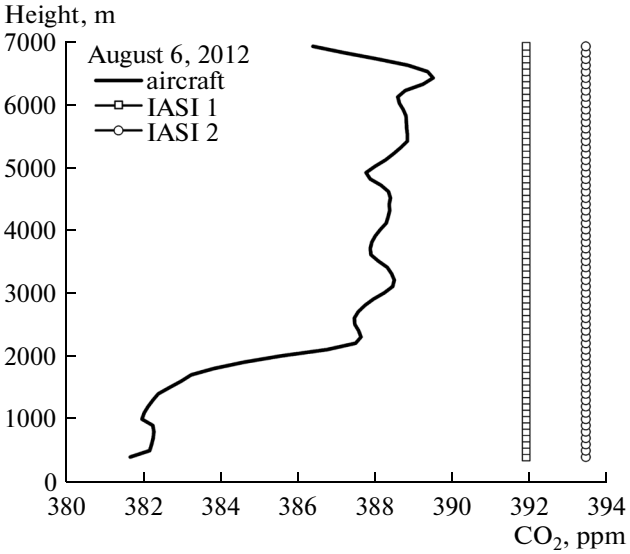

Fig. 10. Vertical carbon-dioxide distributions measured onboard the aircraft laboratory and retrieved according to satellite (IASI) data for the Novosibirsk region.

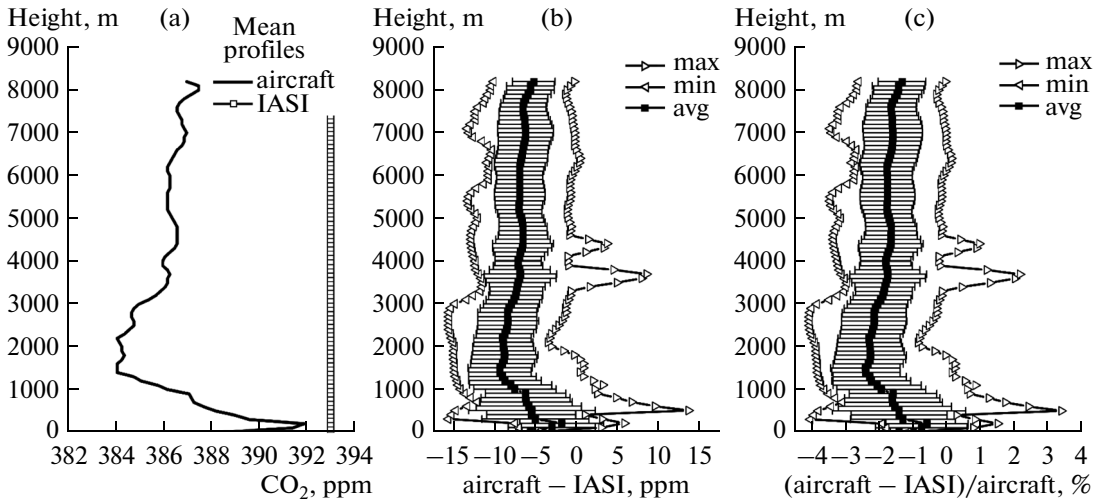

Fig. 11. (a) Mean vertical carbon-dioxide profiles measured onboard the aircraft laboratory and retrieved according to satellite (IASI) data, their (b) differences in absolute units and (c) relative differences (aircraft – IASI)/aircraft.

CONCLUSIONS

The comparison made shows that the absolute differences between ozone concentrations measured onboard the aircraft laboratory and retrieved from satellite data may vary from 55 to 15 ppb at the land surface and in the lower boundary layer and from 30 to –15 ppb at a height of 7000 m. Their relative differences are within the ranges 60 to 30% at a height of 500 m and 30 to –35% at a height of 7000 m.

The mean carbon-monoxide concentrations measured onboard the aircraft laboratory and retrieved from satellite data significantly differ throughout the atmospheric boundary layer up to a height of 1700 m. The absolute differences between aircraft and satellite CO concentrations vary from 80 to 2300 ppb and their relative differences are within the range –140 to 98%. These differences are significantly larger than those found in (De Laart et al., 2012; De Wachter et al., 2012).

For methane, the mean differences are maximal within the atmospheric boundary layer (90 ppb). They decrease to zero within the middle troposphere and increase up to 20 ppb within the upper troposphere. The maximum and minimum differences according to data on all profiles reach 220 and 8 ppb, respectively, within the atmospheric boundary layer. Minimum differences vary from zero at the land surface to –100 ppb within the upper troposphere.

The mean difference between CO_2 concentrations measured onboard the aircraft laboratory and retrieved from satellite data varies from –2 to –9 ppm. In the free troposphere, the difference is almost constant above 3000 m and amounts to –6 ppm. The values of maximum differences according to data over all flights are high and amount to 14 and –4 ppm for the atmospheric boundary layer. Minimum differences vary from –7 to –16 ppm. In this case, the maximum and minimum relative deviations over all flights amount to 3.4 and –4.2%, respectively, for the atmospheric boundary layer.

The differences obtained from this comparison are significantly larger than those found for the background conditions in (Arshinov et al., 2013). This implies that there is a pressing need for improving the algorithms of satellite-data processing especially under the conditions of severe forest fires. It is evident that the vertical gas distribution models used in these algorithms also need correction. At least, the results of gas measurements performed earlier show that there are significant differences between actual and model vertical gas distributions (Belan et al., 2010; Antokhin and Belan, 2012; Arshinov et al., 2012; Belan and Krekov, 2012).

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