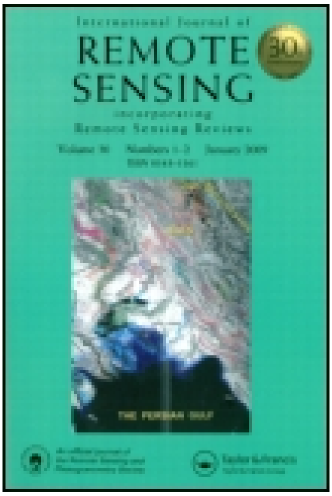

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The first results of the water vapour total column (WVTC) Fourier Transform Infrared (FTIR) measurements carried out over West Siberia (near Tomsk) in the framework of the combined experiment (22 May 2012) are presented. Direct solar radiation spectra with high spectral resolution were recorded by ground-based FTIR spectrometer Bruker IFS-125M. New spectral intervals (the advantage of this spectral band is that observations could be performed without cooling the interferometer's detector) were tested and then used to retrieve the H_2O total columns in the atmosphere by SFIT2 v3.92. Ground-based measurements of the WVTC and aerosol optical thickness in the atmosphere were carried out by means of the automated sun photometers (SP series). Sun photometer and FTIR observations were performed under clear-sky conditions. During this study, we compared data obtained from ground-based remote sensing systems to the results of infrared atmospheric sounding interferometer (IASI) MetOP-A satellite measurements and airborne measurements with the use of the Tu-134 aircraft laboratory. Comparison shows that FTIR observations could give reasonable agreements with sun photometer data within 1%. This value is less than the combined error (1.2%) of both techniques. The average values of total H_2O obtained for three measurement systems were as follows: 1.50 and 1.49 g cm^{-2} for the Fourier spectrometer and sun photometer, respectively, and 1.84 g cm^{-2} for IASI.

1. Introduction

Water vapour is one of the most important trace gas species, and determines the radiative balance and energy processes of the Earth's atmosphere. Continuous measurements of water vapour content are needed to investigate global climate change (Schneider et al. 2012). Radiosounding, GPS, Fourier transform infrared (FTIR), Cimel, and spaceborne remote-sensing systems (e.g. the Infrared Atmospheric Sounding Interferometer (IASI), MetOP) are the main means through which the majority of data on water vapour content and its vertical distribution in the troposphere are provided (Pałm et al. 2010). The question on comparability of these observational systems remains open because of the use of different types of sensors (Miloshevich et al. 2009; Schneider et al. 2010). On the other hand, ground-based spectral measurements

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performed with standard equipment (e.g. the Network for the Detection of Atmospheric Composition and Change (NDACC) and Total Carbon Column Observing Network (TCCON)) give highly accuracy atmospheric transmission spectra and thus information on different gas components of the atmosphere, including water vapour (Schneider and Hase 2009; Schneider et al. 2010).

In the present study, new spectral intervals were used for H_2O total column retrievals in the atmosphere from FTIR observations. The advantage of this spectral band is that registration of direct solar radiation by the Bruker IFS-125M could be performed without cooling the interferometer's detector. The proposed FTIR technique was tested in the framework of the combined experiment with the participation of several research groups of the Institute of Atmospheric Optics, The Siberian Branch of Russian Academy of Sciences (IAO SB RAS), engaged in atmospheric composition studies. The entire experiment started on 17 May and ended on 23 May 2012 in Tomsk (Tomsk, 56.48° N, 85.04° E,160 m above sea level) and its surroundings. The airborne sounding was performed over the background area (60 km west of Tomsk) on 22 May 2013 with the use of the 'Optik' TU-134 aircraft laboratory (Anokhin et al. 2011).

Processing details and intercomparisons with the calibrated sun photometer were used for confirmation of the consistency of our FTIR retrievals. Upper air soundings (radiosonde and airborne) and IASI satellite data for 22 May 2012 were additionally involved for the analysis of ground-based remote sensing measurements of water vapour content in the atmosphere over West Siberia (near Tomsk).

Tomsk is situated in the southeast of the West Siberian lowland, on the right bank of the Tom river, 60 km from its confluence with River Ob. The River Tom flows in a direction close to meridional around the city from the southwest and west. The relief of the town and the surrounding region is heterogeneous. Behind the eastern outskirts of the city, the terrain rises, merging with the spurs of the Kuznetsk Alatau and the Salair ridge. On the right bank of the Tom is a zone of transition from the dark coniferous taiga to pine and birch forests and forest meadows.

The weather conditions on 22 May 2012 were determined by the low-gradient high-pressure field linked to weak variable wind. During the day, the weather was observed to be partly cloudy with a predominance of solid cloud. Before noon, clouds were observed in the upper and middle tiers (altocumulus and cirrus clouds) and with the development of turbulence in the afternoon appeared cumulus clouds (cumulus humulus (cu hum)).

2. Methods

2.1. The ground-based FTIR measurement technique

2.1.1. Tomsk FTIR system

Detailed descriptions of the experimental setup and procedures have been given previously (Vasilchenko, Serdukov, and Sinitsa 2013). Briefly, the recording of direct solar radiation spectra was performed using the Fourier spectrometer Bruker IES-125M. The conditions of spectrum recording are given in Table 1.

The spectrometer allowed us to conduct measurements at an aperture diameter of 0.85 mm (then the signal-to-noise ratio (S/N) increased by a factor of 2 or 3). However, in this case, the convolution (distortion) of spectra in the high-frequency range of 400–500 nm was observed. The radiation was injected in the spectrometer using an optofibre solar tracker described in Vasilchenko, Serdukov, and Sinitsa (2013).

Table 1. The spectrometer parameters.

Spectral range	25,000–8,000 cm^{-1} (400–1250 nm)
Photoreceiver	Silicon photodiode
Divider	Quartz
Resolution	0.05 cm^{-1}
Rate of scanner	20 RHz
Aperture diameter	0.6 mm
Time of one measurement	10 min
Number of accelerated scans	36
Aperture diameter measurement	0.6 mm

Rough calibration of the frequency scale of the Fourier spectrometer was performed using a stabilized He-Ne laser. Descriptions in details of the frequency scale calibration and spectrometer tuning are given by Vasilchenko, Serdukov, and Sinitsa (2013). The analyses of the recorded solar radiation spectrum revealed sinusoidal noise with periods 17–18 cm^{-1} (amplitude ~1% of the max signal) and about 9 cm^{-1} (amplitude ~0.3% of the max signal). The presence of such noise is apparently connected with use of optical fibre cable for radiation induction in the solar tracker.

2.1.2. FTIR measurements processing and data evaluation

FTIR measurements were carried out from 8:30 until 18:00 under cloudless conditions. A typical example of the recorded solar spectra is presented in Figure 1.

The peculiarity of our FTIR spectra recording is in the fact that a non-standard spectral range was chosen. The NDACC (http://www.ndsc.ncep.noaa.gov/) and the TCCON (http://www.tccon.caltech.edu/) networks use spectral intervals which are located commonly in the more long-wave IR-range (~700–5000 cm^{-1} and ~4000–9000 cm^{-1},

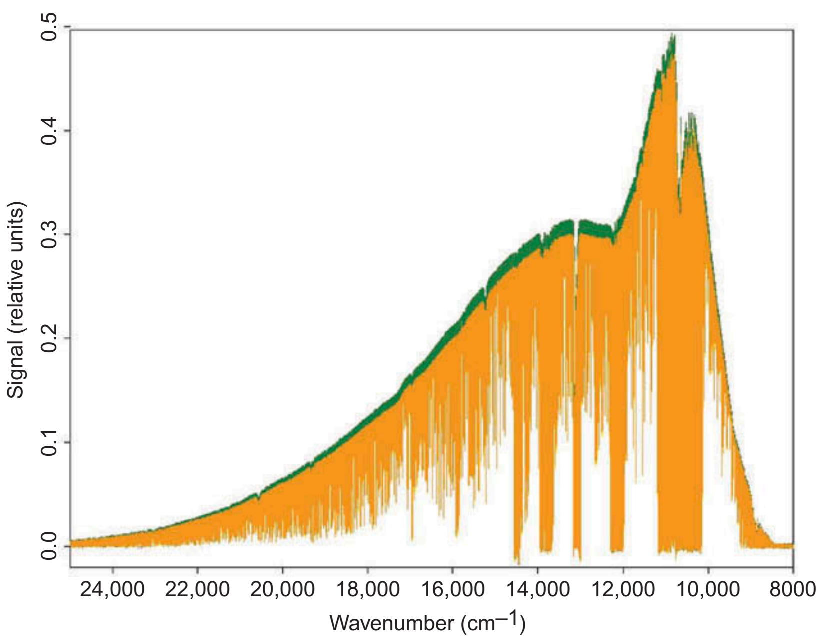

Figure 1. Experimental Fourier transform solar absorption spectra recorded on 22 May 2012 (local time 8:48; 8:59, and 9:09) in the spectral range of 8000–25,000 cm^{-1}.

respectively), where absorption bands of chemically and climatically active gases (e.g. CO_2, CH_4, N_2O, CO, HCl, HF, $ClONO_2$ etc.) are observed. In our case, the shift of measurement ranges to the short-wave range significantly reduces the list of determined gases to water vapour and molecular oxygen.

Procedures for the retrieval of total columns of gases in the atmosphere developed and unified specially for NDACC and TCCON network measurements provide for the use of a set of standard spectral ranges and unified input information (http://www.tccon.caltech.edu/; Sussmann et al. 2011). Thus, we avoid systematic mismatches of the results of total contents measurements for various stations, which may occur, for example, due to incorrect spectroscopic data (Sussmann et al. 2011). The TCCON network commonly uses nine spectral intervals in the 1.87 μm H_2O absorption band to determine the total water vapour column in the atmosphere (http://www.tccon.caltech.edu/).

For our case, the NDACC and TCCON standard spectral intervals were outside the measurement range; therefore, to define the H_2O total column, we selected a number of new spectral intervals. It should be noted that the SFIT v.3.92 software (Rinsland et al. 1998; Hase et al. 2004) which has been used for spectra processing has a 10,000 cm^{-1} limitation on the wave numbers.

We have tested 10 spectral intervals of different width (from 35 to 0.6 cm^{-1}) within the 9900–9999 cm^{-1} band (e.g. 9930–9965 cm^{-1}, 9943.6–9944.7 cm^{-1}, 9973.5–9974.1 cm^{-1} etc.) which contain the water vapour lines. Selected ranges 9979.4–9981.15 and 9941–9958 cm^{-1} are characterized by minimum values of random errors of total H_2O column in the atmosphere.

Meteorological information (on temperature T(z) and pressure P(z) profiles, where z is the height), which was necessary for spectra processing, was taken from the upper air soundings (stations Kolpashevo, WMO N29231; 58.31°N, 82.95°E; Novosibirsk, WMO N29634; 54.96° N, 88.96° E) and IASI satellite measurements (IASI, satellite METOP, and http://smsc.cnes.fr/IASI/index.htm). WACCM (whole atmosphere community climate model) profiles of gas mixing ratios in the atmosphere were used as *a priori* profiles (Garcia et al. 2007).

Information on parameters of the fine structure of molecular absorption lines was taken from the HITRAN 2004 spectroscopic data base (Rothman et al. 2005).

Water vapour total columns (WVTCs) were retrieved by simultaneous processing of two spectral ranges 9979.4–9981.15 and 9941–9958 cm^{-1}. A peculiarity of the 9941–9958 cm^{-1} spectral range consists in the necessity of taking into account the sinusoidal noise in the spectrum (so-called channelling effect). For this purpose, we processed the broader range of 9930–9965 cm^{-1} first (see Figure 2).

Practically sinusoids with 'periods' 17–18 cm^{-1} (amplitude ~1% of maximum signal) and about 9 cm^{-1} (the amplitude ~0.3% of maximum signal) were observed. We suppose that sinusoids are determined by the overtones of the calibration laser.

In the process of spectra processing, the initial value of the signal-to-noise ratio was determined using spectral intervals with total absorption. Then, after the first processing of spectra (by SFIT software), the signal-to-noise ratio was corrected in accordance with the obtained value of mismatch between measured and calculated spectra (RMS value), then the spectra were processed again. Examples of measured and calculated spectra as well as the residuals between them for ranges 9979.4–9981.15 and 9941–9958 cm^{-1} are given in Figures 3 and 4.

The estimate of the random error of the WVTC is of 0.6% (or ~3×10^{20} mol cm^{-2}). The systematic error of WVTC because of possible errors in meteorological inputs (temperature profiles in the atmosphere) can reach ~2%.

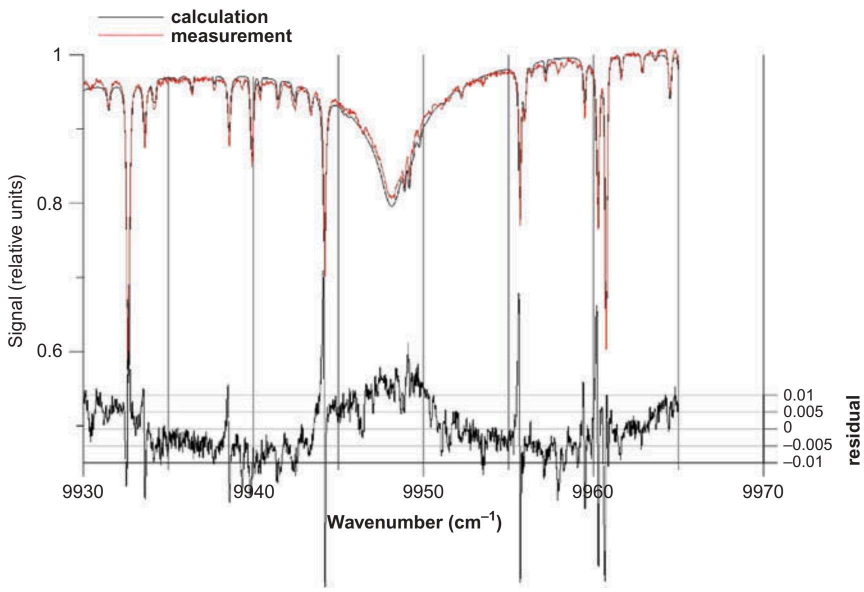

Figure 2. An example showing the presence of sinusoidal noise with the period of 17–18 cm^{-1} in the residual (8:48, 22 May 2012).

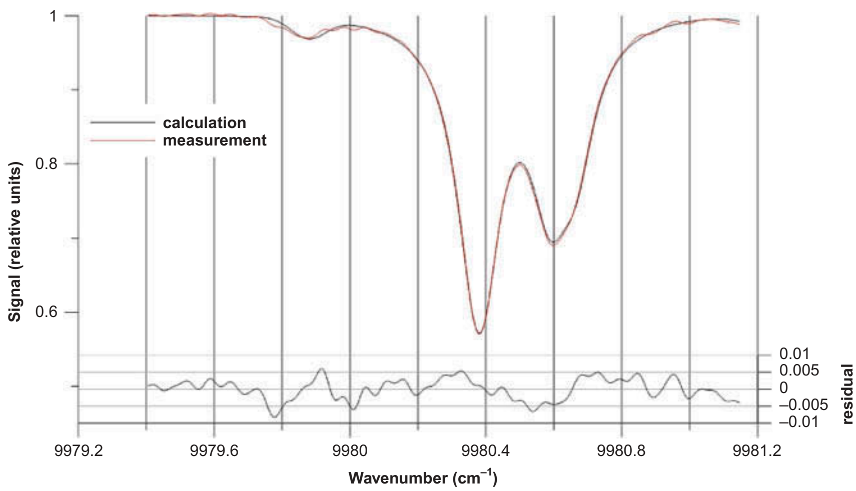

Figure 3. Measured (08:48, 22 May 2012) and calculated spectra for 9979.4–9981.15 cm^{-1} spectral interval.

2.2. Photometric measurements

The measurements of the WVTC and the aerosol optical thickness (AOT) in the atmosphere are carried out at IAO SB RAS by automated sun photometers (SP series) (Sakerin et al. 2004, 2012). Year-round WVTC and AOT monitoring is performed with an interval of 1 min under clear-sky conditions. The definition of WVTC is carried out according to the ratio of the signals in water vapour absorption band centred at

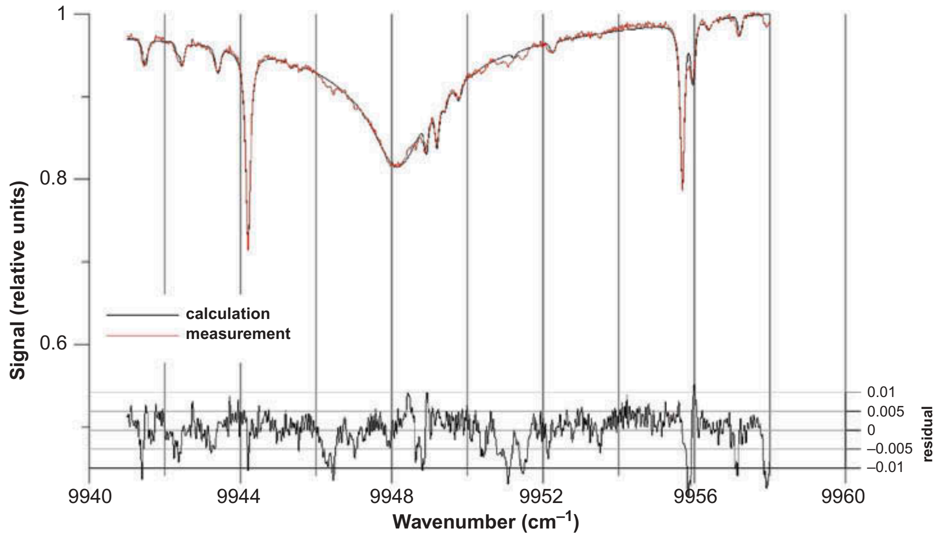

Figure 4. Measured (09:09, 22 May 2012) and calculated spectra for 9941–9958 cm^{-1} spectral interval.

0.94 µm and outside the band at 0.87 µm. The half-width of the interference filters is 0.01 µm. Dependency of the transmittance relationship $T_{0.94}/T_{0.87}$ from absorbing masses used for retrieving total water vapour column is calculated using HITRAN-2000 spectral database (Rothman et al. 2003) taking into account the instrumental functions of the spectral channels. The measurement error of WVTC derived from sun photometer observations is no worse than 0.2–0.5%. The technique of the SP calibration as well as AOT and atmospheric WVTC retrieving is described in more details by Kabanov and Sakerin (1997) and Kabanov et al. (2009).

2.3. *Aircraft measurements*

During this experiment, the 'Optik' Tu-134 research aircraft was used to carry out continuous *in situ* measurements of key atmospheric gases and aerosol particles within the tropospheric layer from 500 to 7000 m. The flight in the vicinity of Tomsk was performed on 22 May 2012. The 'Optik' Tu-134 research aircraft was equipped with a number of gas analysers, aerosol particle spectrometers, a temperature and relative humidity sensor, and a navigation system as well.

Weather conditions during the flight were determined by low gradient baric field. In the area of airborne sounding of the atmosphere, fair weather cumulus clouds were observed (cu hum, 4–6 cloud amount), and the system of the clouds had a chess structure, being evidence of the presence of convective cells in the lower troposphere.

To measure the main greenhouse gas concentrations, a high precision Picarro G2301-m gas analyser was used. The analyser was specially designed for aircraft continuous measurements, allowing simultaneous airborne measurements of carbon dioxide, methane, and water vapour to be carried out at 1 Hz data rate.

Its operation is based on the CRDS technique (Cavity Ring-Down Spectroscopy), that is applying a signal decaying with time within the cavity and allowing quantification of spectral features of gas phase molecules in an optical cavity. At present, the Picarro G2301-m instrument is the world's most advanced flight analyser for *in situ* measurements of greenhouse gases with the accuracy of measured concentrations of CO_2, CH_4, and H_2O < 200 ppb, <1.5 ppb and <150 ppm, respectively. More detailed information on aircraft measurement is available in the work of Matvienko et al. (2014).

3. Discussion of the results of measurements

In Figure 5, the total H_2O columns measured on 22 May 2012 by sun photometer and Fourier spectrometer are shown. The diurnal cycle of H_2O, which is driven by variable meteorology, was used as a convenient tool for the validation of FTIR-spectrometer measurements (against sun photometer) in dynamics, for the relatively wide range of H_2O TC.

In addition to the WVTC, the following measurements were involved in the analysis.

- Data on vertical distribution of H_2O obtained from the five nearest upper air sounding stations: Kolpashevo, Novosibirsk, Emeljanovo, Barabinsk (WMO routine observations at 7 am and 7 pm) and Tomsk (research mode of sounding, at 1 am on 23 May 2012).
- Aircraft measurements of the water vapour concentration carried out on 22 May 2012 in the Tomsk region during 11:40–13:00.
- MetOP-A satellite measurements (11:14 and 12:53).

All these total H_2O column values are presented in Figure 5 as well.

The following parameters are shown in Figure 6: the location of ground-based measuring stations which provided information on water vapour in the atmosphere, area of the aircraft laboratory flight, and the location of pixels of the European satellite IASI MetOP instrument from which WVTC data were obtained.

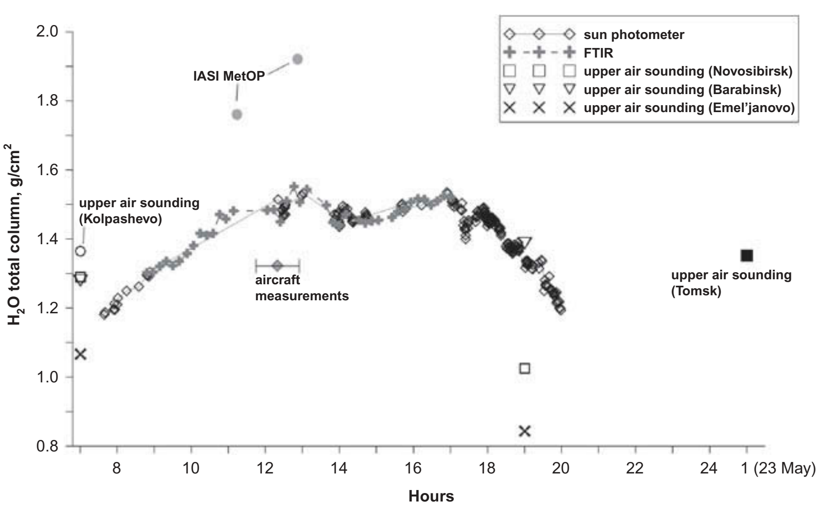

Figure 5. Results of total H_2O columns measurements.

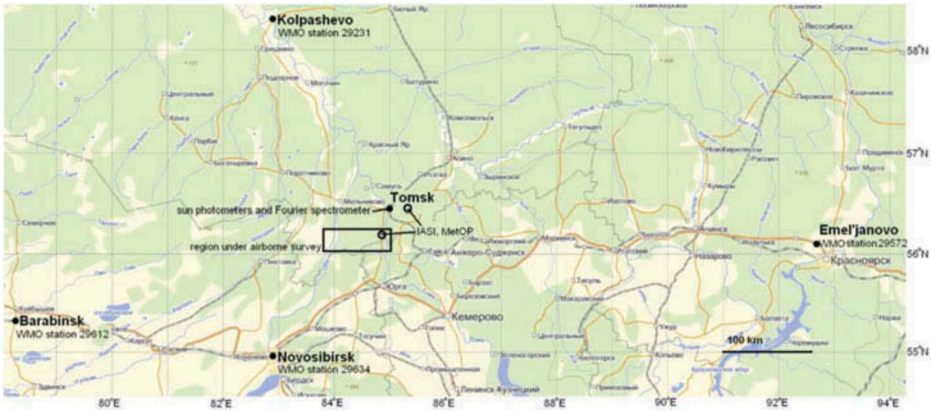

Figure 6. The location of ground-based measuring stations, area of the aircraft laboratory flight, and pixel arrangement of the European satellite IASI MetOP instrument.

In Table 2, the values of H_2O total columns measured by Fourier spectrometer and a sun photometer during the matching or overlapping periods of time are given, and the different duration of measurements of Fourier spectrometer (~10 minutes) and a photometer (usually 1 minute) was thus considered.

The results for relatively short periods of time (~10–20 min) are compared in the first part of the table. The second part presents the average values of the WVTC measured for the periods of approximately an hour.

High-frequency temporal details of diurnal variations of WVTC can be clearly seen from simultaneous measurements of the calibrated sun photometer and Fourier spectrometer (see Figure 5). The correlation coefficient r for data from the first part of Table 2 is

Table 2. Total H_2O column values measured by Fourier-spectrometer and sun photometer as well as their normalized difference (δ).

Sun photometer		Fourier-spectrometer			
Time/number of measurements	H_2O total column (g cm^{-2})	Time/number of measurements	H_2O total column (g cm^{-2})	δ (%)	δ (g cm^{-2})
8:48–8:53 (4)	1.296 ± 0.006	8:48–8:59 (1)	1.303 ± 0.008	−0.5	−0.006
12:20–12:33 (11)	1.49 ± 0.01	12:14–12:34 (2)	1.47 ± 0.03	1.2	0.018
12:59–13:01 (2)	1.529 ± 0.005	12:56–13:06 (1)	1.51 ± 0.01	1.5	0.023
13:51–13:59 (7)	1.47 ± 0.01	13:49–13:59 (1)	1.45 ± 0.01	1.2	0.018
14:00–14:08 (7)	1.46 ± 0.02	14:00–14:10 (1)	1.44 ± 0.01	1.7	0.024
14:12–14:21 (5)	1.47 ± 0.02	14:11–14:21 (1)	1.47 ± 0.01	−0.3	−0.004
14:39–14:44 (6)	1.467 ± 0.007	14:32–14:52 (2)	1.450 ± 0.002	1.2	0.018
15:40–15:47 (5)	1.49 ± 0.01	15:35–15:46 (1)	1.48 ± 0.01	0.8	0.012
16:13 (1)	1.498 ± 0.007	16:07–16:17 (1)	1.52 ± 0.01	−1.3	−0.019
16:54–16:55 (2)	1.534 ± 0.003	16:50–17:00 (1)	1.53 ± 0.01	0.6	0.009
17:02–17:05 (9)	1.506 ± 0.007	17:00–17:10 (1)	1.52 ± 0.01	−0.9	−0.014
Average value				0.5	0.0071
12:20–13:01 (14)	1.49 ± 0.02	12:14–12:56 (5)	1.50 ± 0.04	−0.6	−0.009
13:51–14:44(27)	1.46 ± 0.02	13:49–14:42(5)	1.45 ± 0.01	0.9	0.013
15:40–17:06 (17)	1.50 ± 0.01	15:35–17:00 (9)	1.51 ± 0.02	−0.1	−0.002

equal to 0.97 (*r* is significant with confidence probability of 98%). Normalized and absolute differences between two types of spectral measurements (δ, % and g cm^{-2}, last two columns of Table 2) take both positive and negative δ values not exceeding 2% in absolute value. On average, for 22 May 2012, δ is about 0.5% (or 0.0071 g cm^{-2} in absolute value): photometric measurements usually provide higher WVTC values. The standard deviation of the differences between FTIR and photometer data is of ~0.015 g cm^{-2}.

The total random error for both types of measurement is approximately 1.1%. That is more than average value δ (0.5%) for the whole day, but less separate δ values, which exceeds this total error up to one and a half times.

We note that the maximum values of δ (1.2–1.7%) in the first part of the Table 2 are observed at maximum height of the Sun (at 12–14 hours). For example, for time intervals (12:14–12:34) and (12:56–13:06) (see the second and third rows in Table 2), δ makes 1.2% and 1.5% respectively. On the other hand, during the averaging of all data for a 40-min interval (~12:20–13:00, including two already mentioned above), δ changes sign (δ = −0.5%). This occurs because a large 40-min sample includes additional data on the H_2O column not being considered in the 10–20 min samples. Thus, under certain conditions (unstable state of the atmosphere, the mismatch between the periods of compared measurements), the value of the difference between the two types of measurements δ will be significantly influenced by inherent variability of atmospheric water vapour. Indeed, the assessment of the inherent variability of the H_2O total content in a period of about 12:20–13:00 derived from photometric and Fourier spectrometry measurements is about 2–3% (RMS), which is considerably higher than the total error of these observations.

Note that the processing procedures for both types of ground-based spectral measurements do not use the unified *a priori* information; for example, different versions of the HITRAN database may lead to a bias between results of FTIR and photometric measurements. In the case of FTIR measurements, we have evaluated the systematic differences in the values of the H_2O total column for various spectral ranges. This difference may make up to 2%.

Thus, for a more detailed study of the reasons for the observed discrepancy between FTIR and sun photometer measurements, we need to hold an additional series of simultaneous measurements and carry out data processing using uniform *a priori* information (for both types of ground-based spectral measurements).

Consistent results from ground-based measurements obtained by two independent spectral instruments may significantly differ from the values of the WVTC received by other observational systems (see Figure 5). Aerological stations are located at a considerable distance from Tomsk city (see Figure 6) and that may be the cause of differences in data measurements. At the same time, the area of the flight of the aircraft laboratory (that performed measurements of H_2O concentration profiles for the heights of ~0.4–7 km) and the pixels of satellite measurements of IASI are located near the venue of the ground-based measurements.

Meteorological data show that weather conditions for 20–22 May 2012 can be characterized as a calm or gentle/light breeze (not over 2 m s^{-1}) and partly cloudy. Backward trajectory analysis for the atmospheric layer of 0–3000 m agl (HYSPLIT model, Rolph 2013; Draxler and Rolph 2013) demonstrated that air masses have not changed during 20–22 of May when the slow southwesterly air transfer has been observed. Both aircraft measurements, which took place to the southwest of Tomsk, and spectrometry in Tomsk were carried out inside the same air mass. Detailed consideration of air mass transfer processes by means of trajectory analysis shows that air parcels which had started their travel from the area of aircraft measurements at noon (~0–1 pm) arrived at Tomsk at 4–5 pm. WVTC, which was obtained from aircraft measurements (11:44–12:55), was 8% lower than ground-based observations at 16:13–17:05 in Tomsk (see Figure 5). The relatively low value of WVTC for aircraft measurements (see Figure 5) occurs due to the lack of data for the lower 400 m layer. The estimates show that this layer may contain about 10–15% of the whole WVTC, and the part of the water vapour above 7 km height usually does not exceed 0.5%. After excluding the contribution (~12%) of the lower 400 m layer from the WVTC (retrieved from Fourier spectrometer measurements data), we obtain the H_2O partial column value for 0.4–7 km of 1.33 g cm^{-2}, which coincides within 1% with the estimate of the content in the layer of 0.4–7 km from aircraft measurements – 1.32 g cm^{-2}. Such a coincidence of the remote-sensing data with the direct aircraft measurements data can be considered good, as the inherent variability of TWVC already estimated above for the period of time ~16:13–17:05 is ~1%.

It can be seen that satellite values of WVTC, which were observed at 11:14 and at 12:53, are higher than the appropriate time spectral ground-based measurements by 20% and 25%, respectively. Most likely, such disagreement between IASI MetOP and ground-based observations can be attributed to a combination of atmospheric instability, influence of cloud cover, time, and space differences in data sets (satellite and ground-based) acquisition (Newman et al. 2012).

The profiles of H_2O mixing ratio for the measurements which are closest in time and coordinates derived from ground-based, satellite, and aircraft (11–13 hours of 22 May 2012) are shown in Figure 7.

Aircraft measurements (Figure 7) are presented in the form of raw data, smoothed moving average (1 min), and average values calculated for 500 m layers. Ground-based FTIR measurements are in good agreement with the aircraft observations up to

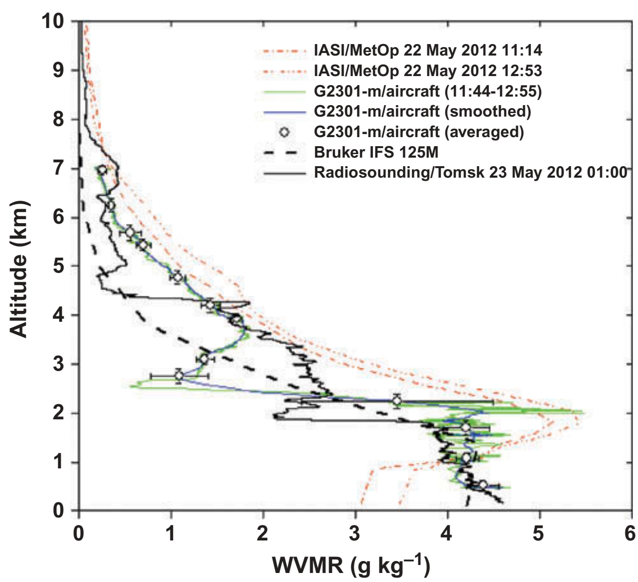

Figure 7. Vertical distribution of H_2O mixing ratio (WVMR) in the troposphere derived from satellite and aircraft sounding and Fourier measurements.

approximately 3 km, and satellite IASI measurements better reproduce the WVMR profile in the layers above 3–4 km. In addition to the reasons mentioned above (atmospheric instability, influence of cloud cover, etc.), discrepancies in vertical distributions (see Figure 7) could be also associated with different sensitivity of ground-based and satellite measurements to changes in water vapour content in the lower and upper troposphere (Schneider and Hase 2011). As was reported by Schneider and Hase (2011), near the surface, the IASI H_2O retrievals seem to be significantly less precise than in the middle troposphere. Schneider and Hase (2011) showed that close to the surface, the quality of the IASI H_2O data strongly depends on the uncertainties of lower tropospheric temperatures.

The difference in data at the altitudes of more than 3 km may also be due to the fact that under low air pressure, the Dicke narrowing of the spectral line profiles may occur, and neglecting this narrowing may lead to errors in the H_2O mixing ratio calculations. For a more correct calculation of this effect, we need more accurate data on spectral line profiles for other pressures, and we need to carry out measurements of a solar absorption spectrum with higher spectral resolution.

Ground-based and satellite remote sensing are usually unable to provide high vertical resolution, which can be received from *in situ* aircraft measurements. In some cases, spectral measurements allow us to define only the total column (single layer, an example of the sun photometer measurements), while in other cases, it is possible to retrieve gas content in multiple layers of the atmosphere (two to three layers for our Fourier spectrometric observations). It is clear that profiles which were retrieved from FTIR observations can only be viewed as smoothed approximation to the real profile of water vapour in the atmosphere (see Figure 7).

It should be noted that for more accurate comparison of H_2O profiles from direct measurements (upper air sounding or aircraft) and from remote sensing (ground-based or satellite), it is necessary to take into account averaging kernels for the chosen method of remote sensing (Rodgers 2000; Rodgers and Connor 2003) (at this stage of study such a task was not considered).

The vertical distribution of the water vapour mixing ratio can be very different depending on geographical location and time of day (Figure 8).

Figure 8 shows that the best similarity may be noted between the profiles obtained by means of the aircraft and radiosonde Vaisala RS92-SGP launched from the Siberian Lidar Station (IAO SB RAS SLS). The disadvantages of the data taken from the WMO aerological network stations can be attributed to low spatial resolution. Radiosounding on the basis of IAO SB RAS SLS was carried out in a research mode (Research PTU and wind sounding), making it possible to receive much more detailed information on stratification of the atmosphere.

4. Conclusions

A new technique which allows making FTIR measurements of H_2O total column without the cooling of the Fourier spectrometer's detector was tested during a one-day combined experiment.

Analysis of data on the WVTCs obtained during 22 May 2012 by various observing systems (ground-based, satellite, aircraft) for 22 May 2012 showed the following.

- Simultaneous independent ground-based spectroscopic measurements of WVTC carried out using Fourier spectrometer and sun photometer mainly agree within the

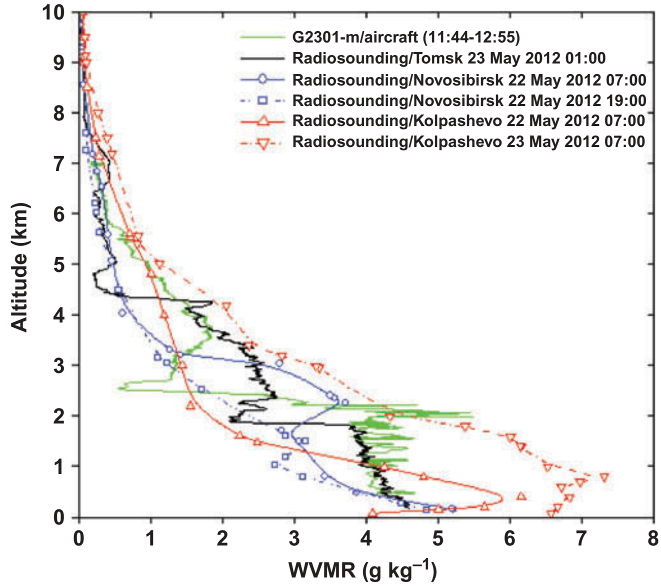

Figure 8. Vertical distribution of H_2O mixing ratio (WVMR) in the troposphere obtained during aerological and aircraft sounding.

total error of both types of measurements (about 1.1%). The bias between sun photometer and FTIR data is about 0.5% (photometric values of WVTC have higher values). Both types of measurements detected the same character of temporal variations of H_2O total column during the day of 22 May 2012. It is confirmed by statistically significant coefficient of correlation (r = 0.97) between FTIR and photometer data.

- The water vapour content in a layer of 0.4–7 km, derived from FTIR measurements (1.33 g cm^{-2}), is in good agreement with aircraft measurements for the same atmospheric layer (1.32 g cm^{-2}) with an accuracy of 1%.
- The data on WVTC for 11 am–1 pm on 22 May derived from IASI MetOP satellite measurements exceed the data received from ground-based measurements by 20–25%.
- To make detailed analysis of the WVTC, it is necessary to carry out measurements which exactly coincide in time and place. Sometimes, this is technically difficult to achieve. For example, it is impossible to launch the radiosonde at the same time as the plane departure for safety reasons.

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