# *The $CO_2$ retrievals from IASI, AIRS and SCIAMACHY data and their validation by in situ measurements*

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## Introduction

The development of space-borne hyper-spectral IR sounders (AIRS/EOS-Aqua, IASI/MetOp) as well as SCIAMACHY/EnviSat spectrometer opens new opportunities for detecting the variations of atmospheric carbon dioxide concentrations. The capabilities to retrieve atmospheric column-average $CO_2$ mixing ratio ($X_{CO2}$) from satellite measurements is of significant importance in the context of global carbon cycle research, climate change studies and due to sparse network of ground-based $CO_2$ observations. The main objectives of our research were as follows:

- Improvement of the technique for $X_{CO2}$ retrieval in the troposphere from satellite data over Siberia;
- Validation of $X_{CO2}$ retrievals from satellite data against aircraft flask $CO_2$ observations.

The report presents an updated status of $X_{CO2}$ retrieval scheme based on clear-sky or cloud-cleared AIRS inversion algorithm. The validation effort carried out with AIRS data for 10 months in two areas of the boreal zone of Western Siberia (Novosibirsk and Surgut regions) demonstrates the successful performance of proposed technique. It was shown that the average $CO_2$ mixing ratio in the mid to upper troposphere can be retrieved at the 1% precision level – as compared to collocated airborne in situ observations.

The $X_{CO2}$ retrieval scheme based on IASI measurements in the set of $CO_2$ dedicated channels has been developed and tested. The $X_{CO2}$ retrievals over Siberia were compared with correlative aircraft measurements including YAK-AEROSIB campaigns in 2007-08.

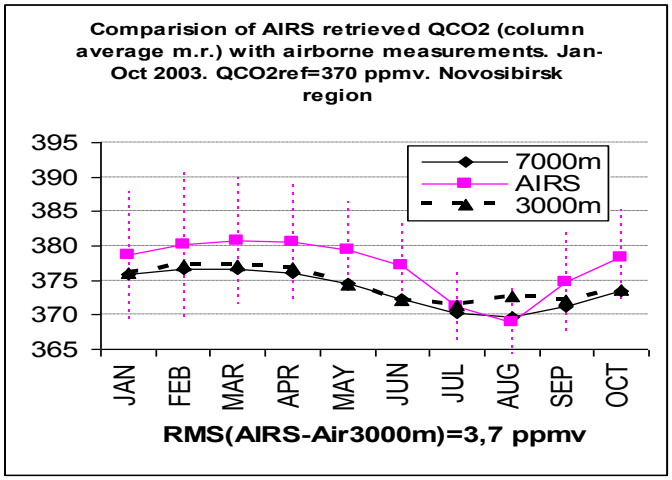
With the SWIR instrument SCIAMACHY we have designed a robust method which is largely independent of possible calibration problems (either spectral or radiometric) based on the ratio of optical depth differences at optimized wavelength channels in the 1.58 μm band of $CO_2$ and the 0.765 μm band of $O_2$ (necessary for reducing the sensitivity to clouds or aerosols). The method was also validated against aircraft measurements over two Siberian regions. Besides, the inter-comparison of AIRS- and SCIAMACHY-based $X_{CO2}$ estimates has performed to demonstrate the similarity of retrievals.

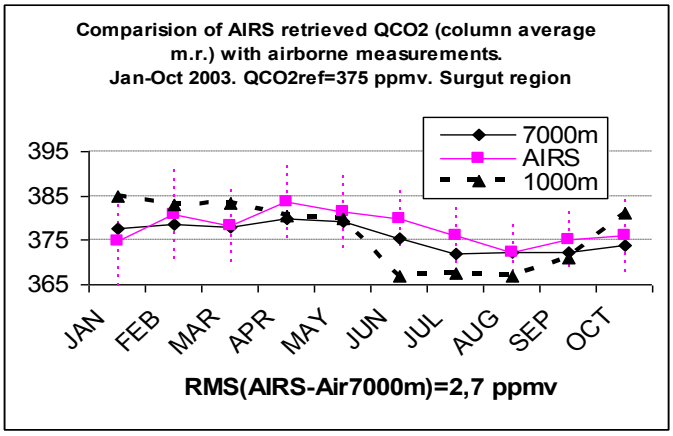
## AIRS

The detailed description of the methodology of AIRS data inversion and $X_{CO2}$ retrieval can be found in (Kukharsky, 2009).

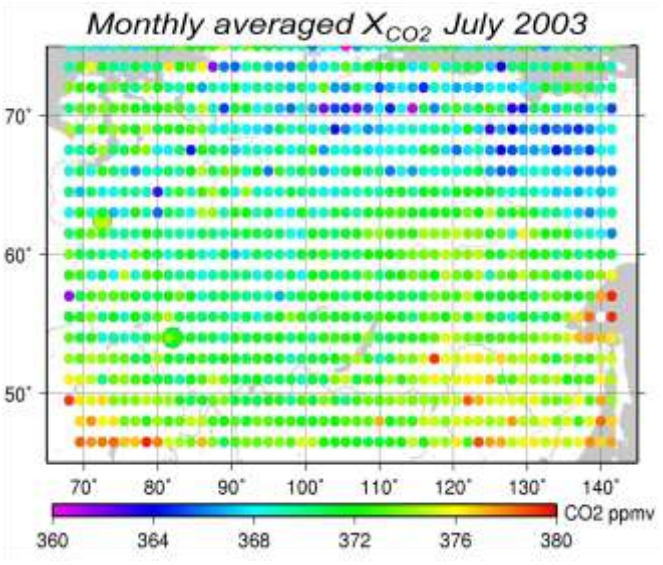
The series of retrieval experiments has been conducted for a sample of more than 600 granules of actual AIRS data together with AIRS L2 retrievals and AMSU-based T(p) retrievals for preselected area and time period between January and October 2003 (1-2 granules daily). The $X_{CO2}$(AIRS) retrievals are inter-compared with the results of air-borne measurements. The region of air-borne surveys is located at

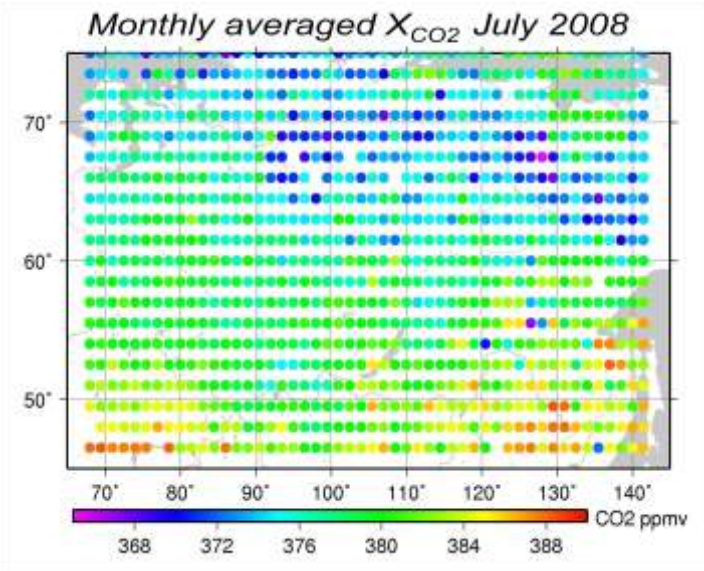
the right bank of the southern part of the Ob Reservoir. The air-borne measurements of $CO_2$ concentration at heights of 0.5-7.0 km cover the region 54° 08'-54° 33' N, 81° 51'-82° 40' E., where the boreal area consists on 90% of coniferous trees. Similar observations have been conducted also for the Surgut region (60-62°N, 70-75°E); available are the data at 1 and 7 km.




Similar methodology has been applied for the generating monthly averaged maps of $X_{CO2}$ over Siberia region and two summer months-July 2003 and July 2008.



**SCIAMACHY**

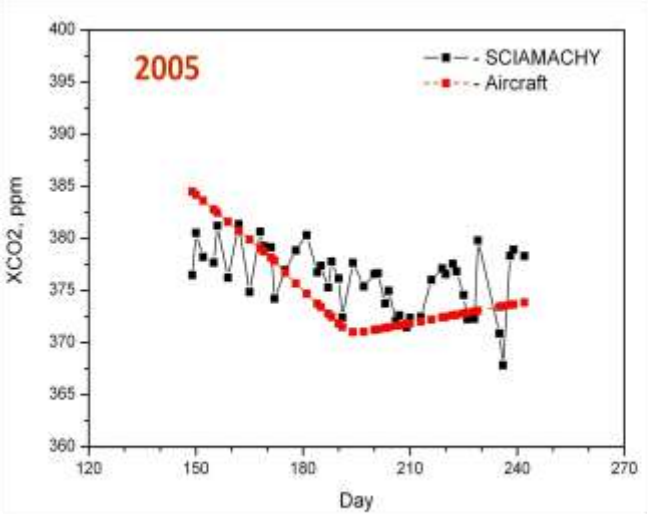
The main feature of the suggested retrieval method (Rublev, 2008) is calculation the relative spectral optical thicknesses $\tau_i$ for several channel pairs in $CO_2$ & $O_2$ absorption bands, i.e.:

$$\tau_i^{CO_2} = \mathrm{abs}\left[\ln\left(R_{i_1}^{CO_2} \Big/ R_{i_2}^{CO_2}\right)\right], \quad \tau_i^{O_2} = \mathrm{abs}\left[\ln\left(R_{i_1}^{O_2} \Big/ R_{i_2}^{O_2}\right)\right], \quad R_i^{gas} = \frac{r_i - R_W(\lambda_i)}{R_W(\lambda_i)} \times 100,$$

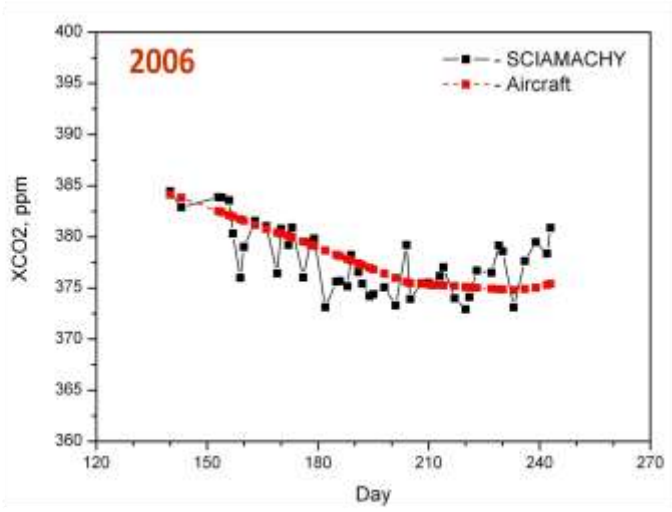
$r_i$- a sun-normalized reflection coefficient corrected to $R_W(\lambda_i)$ in the i-channel, $R_W(\lambda)$ regression, received by the least-squares method on the local maxima corresponding to atmospheric microwindows. The $CO_2$ concentration is determined as linear combination:

$$XCO2 = a_0 + \sum_i a_i \frac{\tau_i^{CO_2}}{\tau_i^{O_2}}$$

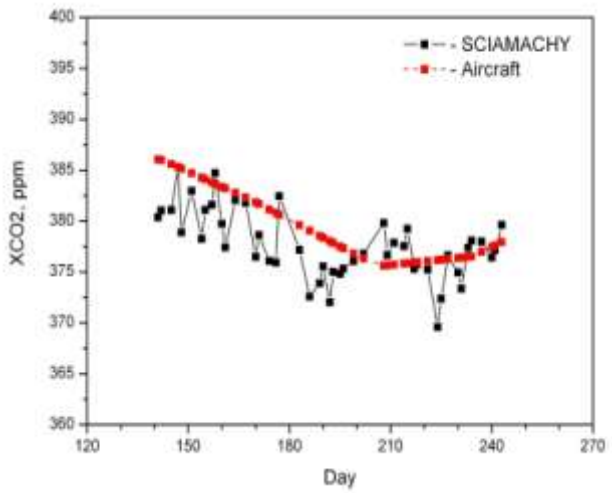
For this linear combination, two appropriate pairs of oxygen and carbon channels have been found using real $CO_2$ aircraft measurements over Surgut in 2003.



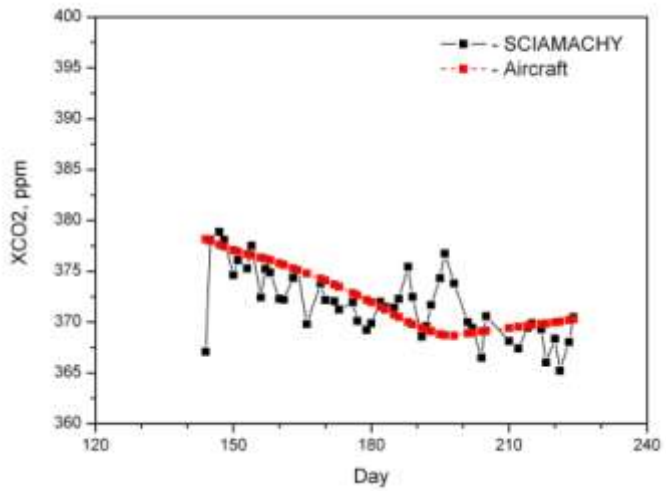

R=0.47 σ=3.8 ppm Δ(SCIA-aircraft)=0.8 ppm




R=0.66 σ=2.5 ppm Δ(SCIA-aircraft)=-0.2 ppm



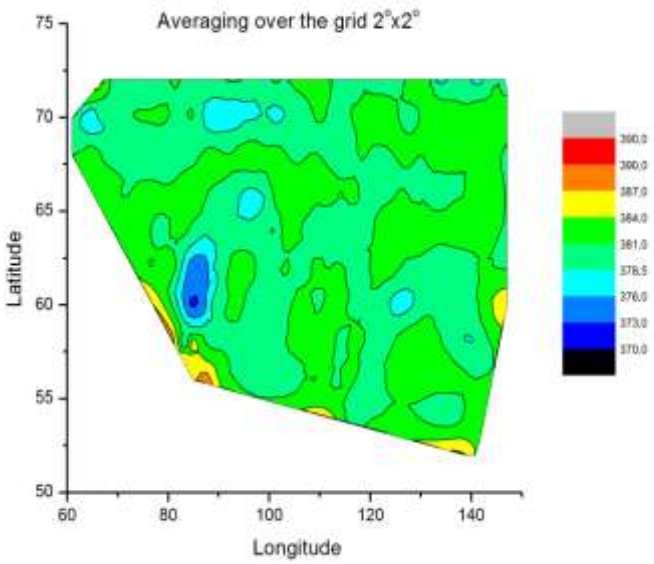

R=0.65 s=3.4 ppm D(SCIA-aircraft)=-1.9 ppm

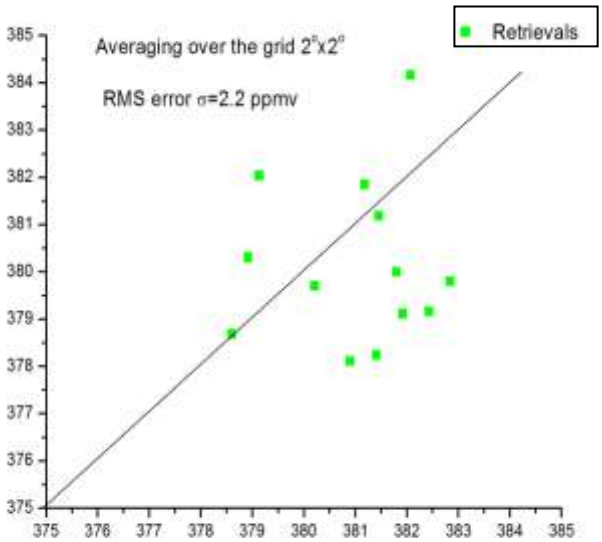



R=0.57 s=3.0 ppm D(SCIA-aircraft)=-0.6 ppm

**IASI**

$X_{CO2}$ retrievals from IASI measurements over Siberia for the date 07.07.2008 are validated from synchronous aircraft $CO_2$ measurements within the region shown below




The retrieval performed for more than 8800 clear sky pixels. The inversion procedure uses bias corrected IASI radiances in 5 preselcted $CO_2$ dedicated channels from 15 mm $CO_2$ band and is similar in basic to the method from (Kukharsky, 2009; Uspensky, 2008). Ancillary information about temperature and ozone profiles for each pixel necessary for forward modeling is obtained from IASI L2 product data. The $CO_2$ IASI retrievals averaged over the grid $2^o x 2^o$ are compared with aircraft $CO_2$ measurements performed during YAK-AEROSIB campaign (Paris, 2008)

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