Derivation of tropospheric carbon dioxide and methane concentrations in the boreal zone from satellite-based hyper-spectral infrared sounders data

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1. Objectives

- Improvement of the technique for column-average CO_2 mixing ratio (Q_{CO2}) retrieval in the upper troposphere from AIRS/EOS-Aqua data over Western Siberia
- Validation of Q_{CO2} retrievals against aircraft flask CO_2 observations (over boreal zone)
- Development and testing of the novel technique for tropospheric CH_4 column (Q_{CH4}) retrieval from IASI/MetOp and AIRS data.

1. AIRS Q_{CO2} Retrievals

2.1. The sensitivity studies based on synthetic clear-sky AIRS measurements (RTM SARTA simulations) resulted in the selection of 2 subsets of CO_2 dedicated channels (9 LW channels within the band 699-705 cm^{-1}; 6 SW channels within the band 1939-2107 cm^{-1}) with strong responses to CO_2 variations and minimum sensitivity to main interfering factors (inaccurate knowledge of state vector components, including atmospheric water vapor and ozone profiles, etc.).

Fig 1, 2 demonstrate the CO_2-Jacobians for LW and SW CO_2-channels. The AIRS radiances in CO_2 cnannels have maximum sensitivity to CO_2 variations in the mid-to high tropospheric layer and minimum sensitivity to variations of interfering factors.

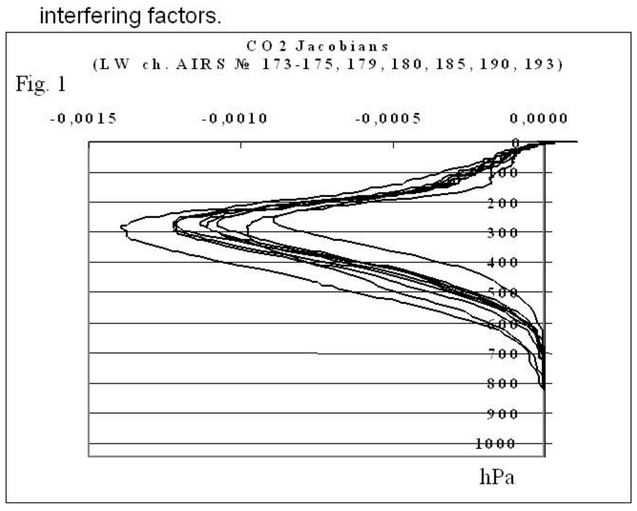


Fig. 1

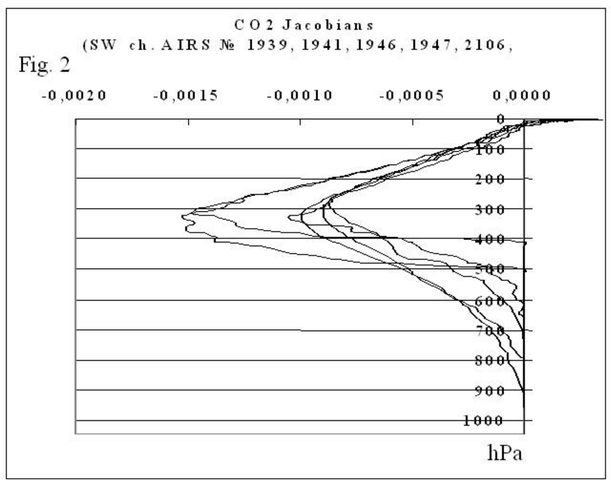


Fig. 2

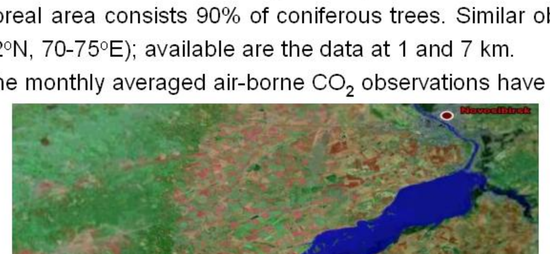
2.2. Improved technique for AIRS- based Q_{CO2} retrieval

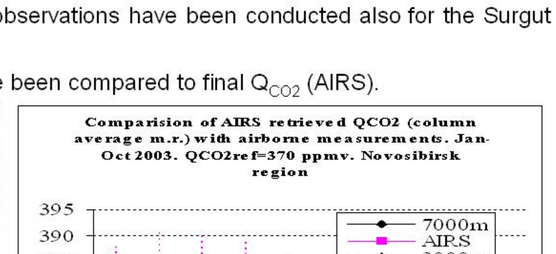
- Clear-sky and cloud-cleared radiances (brightness temperatures B_T^{obs}) measured in CO_2-dedicated channels are used for Q_{CO2} retrieval;
- Forward calculations of synthetic brightness temperatures, B_T^{calc}, are performed using RTM SARTA (in the range 370-385 ppmv) and ancillary information (AMSU-based temperature profile T(p) retrievals and AIRS L2 retrievals for other state vector components);
- Monthly averaged biases$\langle B_T^{obs}-B_T^{calc}\rangle$are specified beforehand for the RegionOf Interest (ROI);
- Estimating Q_{CO2} is carried out using physical inversion algorithm (Gauss-Newton iteration algorithm applied separately to bias-corrected AIRS data in LW and SW CO_2- channels in order to produce "independent" Q_{CO2}(LW) and Q_{CO2}(SW) retrievals);
- Spatial/temporal (median) filtering is performed for the clusters of {Q_{CO2}(LW)} and {Q_{CO2}(SW)} retrievals;
- The final monthly averaged estimate Q_{CO2} (AIRS) is produced as a linear combination of filtered Q_{CO2}(LW) and Q_{CO2}(SW) values (if they are consistent to each other);

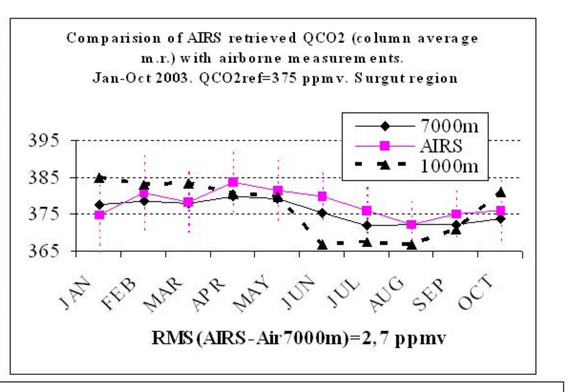
2.3. Validation exercise (CO_2 retrievals over Siberian boreal ecosystems)

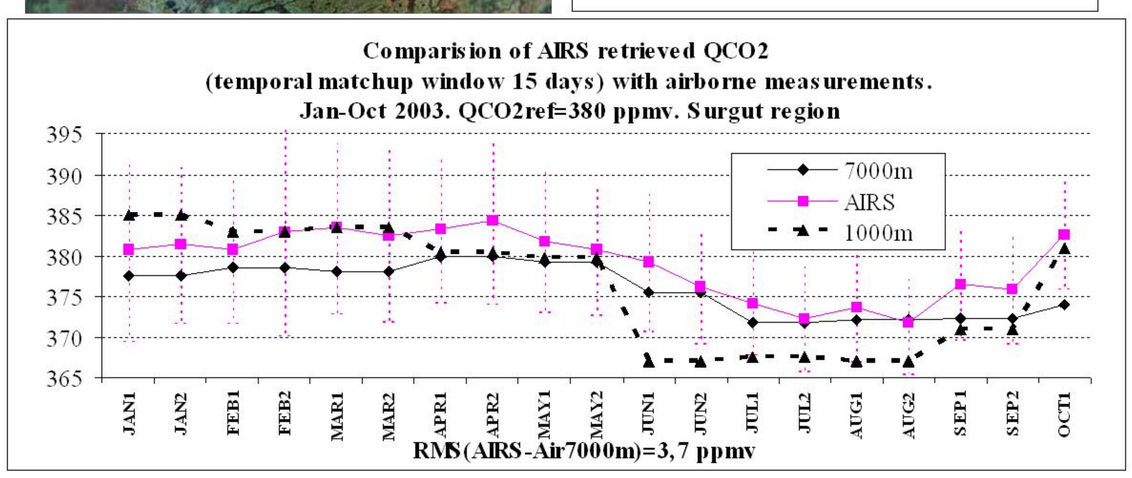
The series of retrieval experiments has been conducted for a sample of more than 600 granules of actual AIRS data that were downloaded together with AIRS L2 retrievals and AMSU-based T(p) retrievals for pre-selected area and time period between January and October 2003 (1-2 granules daily) from the site http://daac.gsfc.nasa.gov/data/dataset/AIRS/02_L2_Products/index.html. The Q_{CO2}(AIRS) retrievals are inter-compared with the results of air-borne measurements (Arshinov et al., 2005). The region of air-borne surveys is located at the right bank of the southern part of the 0b Reservoir. The air-borne measurements of CO_2concentration at heights of 0.5- 7.0 km (available are the data at heights of 1, 3, and 7 km) cover the region 54° 08'-54° 33' N, 81° 51'-82° 40' E., moreover the boreal area consists 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.

The monthly averaged air-borne CO_2 observations have been compared to final Q_{CO2} (AIRS).









The results of validation exercise performance can be summarized as follows:

The inversion of actual AIRS data for 2 areas (Western Siberia) enables to retrieve Q_{CO2} values that agree reasonably with seasonal trend of those identified from *in-situ* air-borne measurements and have a precision of about 1% (comparing to air-borne measurements at 7 km). The temporal match-up window between 2 weeks-1 month is suitable for Q_{CO2} retrievals averaging.

3. IASI- and AIRS-based CH4 concentration retrievals: first results

3.1. Selection of IASI CH4-dedicated channels and super-channels

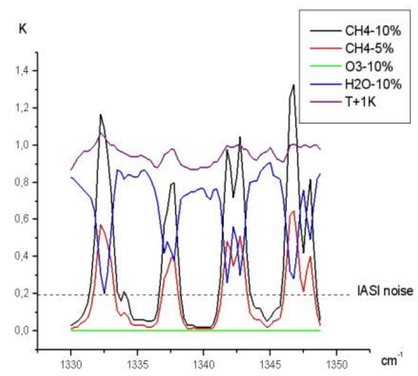
Sensitivity studies carried out with synthetic clear-sky IASI measurements (RTM LITMS) enabled to select subset of 4 CH4-dedicated channels within the methane absorption band around 7.7 μm. The plots of CH4-Jacobians for these channels show maximum sensitivity to the CH4 variations in the troposphere with a peak around 10 km. The plots of averaging kernels obtained for CH4 column retrievals demonstrate strong sensitivity to the CH4 concentration in the layer between 7 and 15 km.

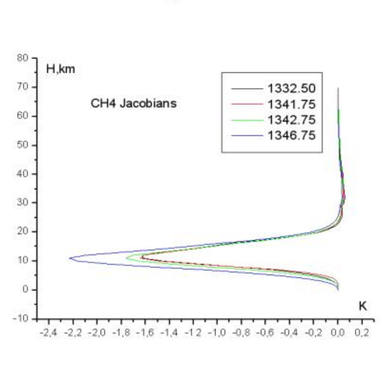
Besides, four CH4-dedicated super-channels have been built in order to reduce the effect of profile T(p) uncertainties on the accuracy of Q_{CH4} assessment.

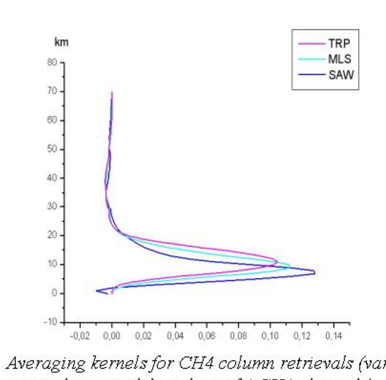
3.2. Methodology Q_{CH4} retrieval from IASI or AIRS data

The CH4 retrieval approach is based on the physical inversion and utilizes clear-sky IASI data in several super-channels (differences of signals in T- and CH4-dedicated channels) as well as *a priori* specified T- and water vapor profiles. Similar inversion algorithm is applied to AIRS data.

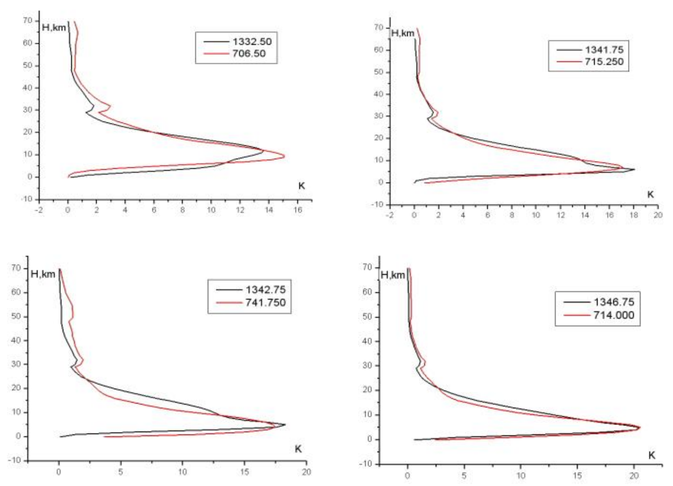
Sensitivity studies



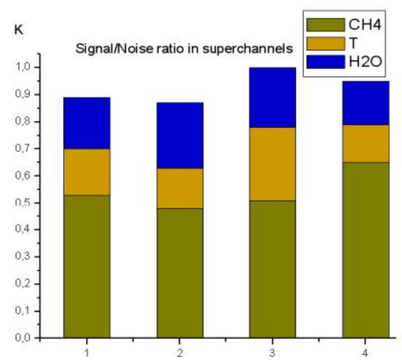




Averaging kernels for CH4 column retrievals (various atmospheric models, subset of 4 CH4-channels)



Temperature Jacobians in "conjugated" IASI channels(CH_4 7.7 μm and CO_2 15 μm absorption bands)

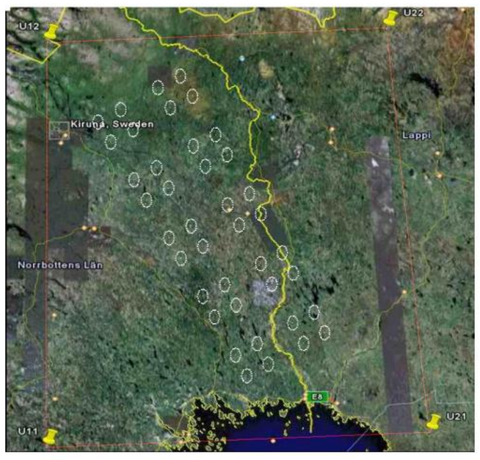


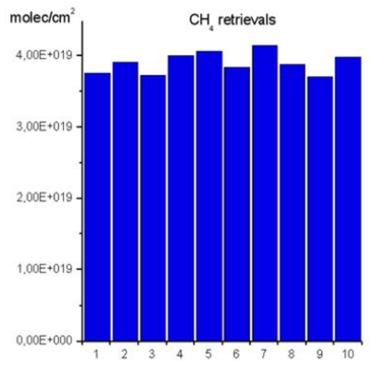
Signal/Noise ratio in 4 IASI superchannels (CH4-5%; H2O-10%, T+1K)

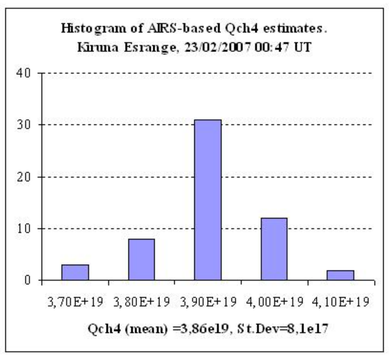
Superchannels: **I: 1332.50-706.50 II: 1341.75-715.25 III: 1342.75-741.25 IV: 1346.75-714.0**

4. Case study experiment

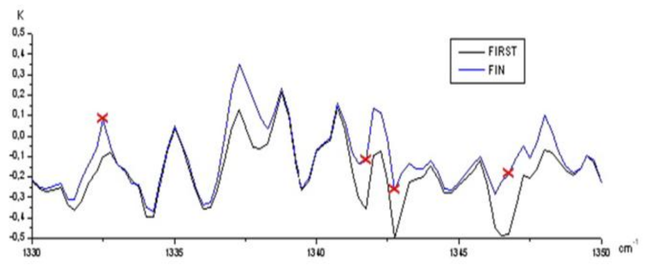
The performance of above retrieval algorithm was evaluated in a case study experiment using the dataset of IASI/MetOp, IASI balloon- borne instrument measurements together with ground based and radiosonde observations for Esrange (Kiruna, Sweden) area. This dataset is kindly provided by Dr Claude Camy-Peyret (Université Pierre et Marie Curie et CNRS Physics department, LPMAA, France) and later was complemented with quasi-synchronous and collocated AIRS data as well as with AIRS-based L2 retrievals.







Distributions of IASI-based (10 sub-pixels, Q_{CH4}(mean)=3.91e19, St.Dev.=1.45e18) and AIRS-based (about 60 FORs) Q_{CH4} retrievals



First guess and final residuals for IASI spectra, crosses mark the IASI channels used for CH4 retrievals

Experimental retrieval of QCO2 from AIRS data 21-23 Feb. 2007, Esrange/Kiruna

First guess, ppmv	SW channels			LW channels			SW+LW	
	Number of pixels	Std.d	QCO2	Number of pixels	Std.d	QCO2	Std.d	QCO2
375	184	10,7	387,5	227	9,8	393,4	7,2	390,7
380	206	12,0	389,3	229	9,6	393,6	7,5	391,9
385	222	13,3	390,5	228	9,6	393,8	7,8	392,7
390	225	13,8	391,1	226	9,5	394,0	7,8	393,1
395	219	13,6	391,4	224	9,3	394,0	7,7	393,2

Summary of a case study experiment performance:

The first experimental retrievals of Q_{CH4} and Q_{CO2} from AIRS and IASI data are consistent within their corresponding error bars.

Further work

Complete evaluation of AIRS-based retrieval algorithms performance

Comparisons Q_{CO2} (AIRS) – Airborne observations

Comparisons Q_{CH4} (IASI) and Q_{CH4} (AIRS)- Airborne observations

Adjust AIRS-based Q_{CO2} retrieval technique to IASI data

Acknowledgments

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