Main results of Carbon Dioxide comparison between IASI, TANSO-FTS and HIPPO products

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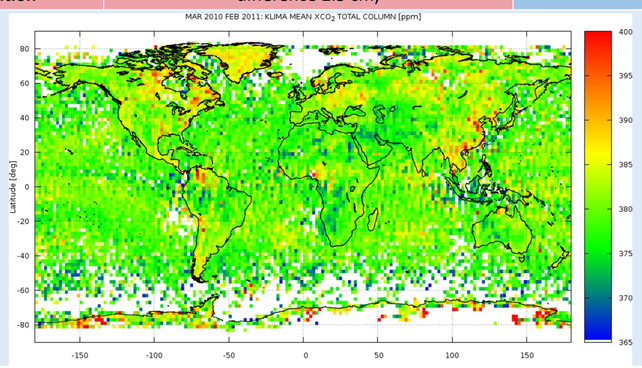
A great effort is undertaken by the scientific community to investigate carbon dioxide amounts and vertical distribution and to characterize its sources and sinks. In this context, the development of CO_2 retrieval models in the Thermal InfraRed (TIR) spectral range is effective for the characterization of the CO_2 distribution in the mid-to-upper troposphere because of the profiling capabilities of the TIR with peak sensitivity in these altitudes. The research project "Application of KLIMA Algorithm to CO_2 Retrieval from IASI/METOP-A Observations and Comparison with TANSO-FTS/GOSAT Products" had the main purpose to investigate the performances of KLIMA algorithm applied to the Infrared Atmospheric Sounding Interferometer (IASI) observations. The Thermal And Near infrared Sensor for carbon Observation (TANSO)-FTS on board of the Greenhouse gases Observing SATellite (GOSAT) can measure CO_2 column amounts from the ShortWave InfraRed band (SWIR) and CO_2 profiles from the TIR band, simultaneously. SWIR observations are more sensitive to CO_2 near the earth surface, but they have a lower capability to resolve the vertical profile than TIR observations. Thus, the use of the SWIR and TIR combined data provide the possibility to estimate the amounts of CO_2 in the boundary layer accurately and consequently may produce a useful dataset for the study of CO_2 sources and sinks. The main goal of the HIAPER Pole-to-Pole Observations (HIPPO) project is to provide the first high-resolution vertically resolved global survey of trace gases and aerosol investigating the Carbon Cycle and greenhouse gases annual cycle throughout various altitudes of the western hemisphere by aircraft measurements. In order to provide additional evidence to the ongoing discussion on the measurement of carbon dioxide from space, we performed a comparison between temporally reduced dataset of collocated IASI, GOSAT TIR and HIPPO data. In this work, we present the main results from this activity, developed as part of the collaboration between IFAC-CNR and the GOSAT team.

The overall activity of the research project **"Application of KLIMA algorithm to CO_2 retrieval from IASI/METOP-A observations and comparison with GOSAT/TANSO-FTS products"** aimed at the application of the KLIMA inversion algorithm, integrated into the ESA G-POD (Grid Processing On-Demand) operational environment, to processing of IASI/METOP-A spectra and at the retrieval of carbon dioxide columns and profiles for comparison and cross-validation with GOSAT TANSO-FTS SWIR and TIR products. According to the original planning, the activities of the project have been developed in two phases. In Phase 1 a prototype software for the retrieval of CO_2 columns from IASI data with performance suitable for the comparison with TANSO-FTS products and with basic features meeting the requirements of the integration on G-POD has been developed. The objectives of Phase 2, pursued in cooperation with JAXA, NIES and the MoE of Japan and continued beyond the end of the ESA project, were the procurement of a consolidated version of the KLIMA-IASI/G-POD retrieval code, the ***processing of IASI spectra and the comparison and cross-validation with TANSO-FTS CO_2 SWIR and TIR products***.

MetOp-A/IASI – GOSAT/TANSO-FTS (SWIR)

For the SWIR products we have analyzed 240000 IASI spectra acquired in the period from March 2010 to February 2011 using the KLIMA retrieval code developed by the IFAC group on the GRID Processing On Demand (G-POD) system at ESA-ESRIN both on land and on water and during day and night for a global geographical coverage.

GOSAT/TANSO-FTS					MetOp-A/IASI
Spectral Band	1	2	3	4	1
Spectral range	VIS	SWIR	SWIR	MWIR/TIR	MWIR/TIR
Coverage(μm)	0.75	0.78	1.92-2.08	5.5-14.3	3.62-15.5
Spectral resolution	0.2 cm^{-1} both sides (maximum optical path difference 2.5 cm)				0.25 cm^{-1}



Global map of CO_2 averaged over the year (Mar 2010- Feb 2011) on a grid of 2°×2° pixels

COMPARISON ACTIVITIES

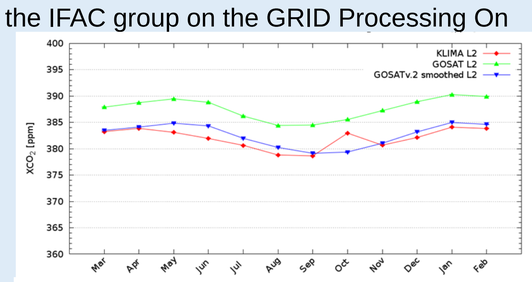
KLIMA IASI L2 vs. SWIR TANSO-FTS GOSAT L2 products

Three different strategies have been used:

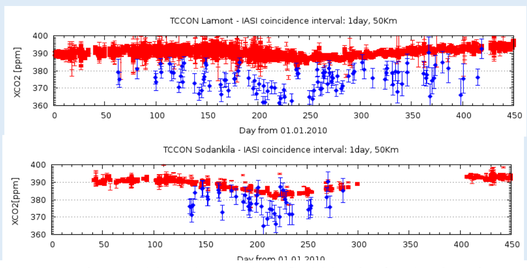
- ***Co-located comparison***: comparison of the CO_2 total column retrieved from observations of IASI and TANSO-FTS made in contiguous locations in time and space [Cortesi et al., 2013];
- ***Averaged comparison***: comparison of the CO_2 total column averaged on a suitable spatial and time interval (negative 7,3 ppm bias of KLIMA-IASI, with a standard deviation of 7 ppm and an un-accounted error of KLIMA-IASI of about 6 ppm with respect to the retrieval error and to the CO_2 atmospheric variability. Taking into account the different Averaging Kernels, the negative bias is reduced to 1,17)
- ***Seasonal variation comparison***: comparison of the seasonal variations of CO_2 from March 2010 to February 2011

KLIMA IASI L2 vs. TCCON products

As in the previous case, the comparison with TCCON stations shows a negative bias of the IASI measurements



Seasonal variation of the XCO_2 from March 2010 to February 2011 in the Northern Hemisphere.



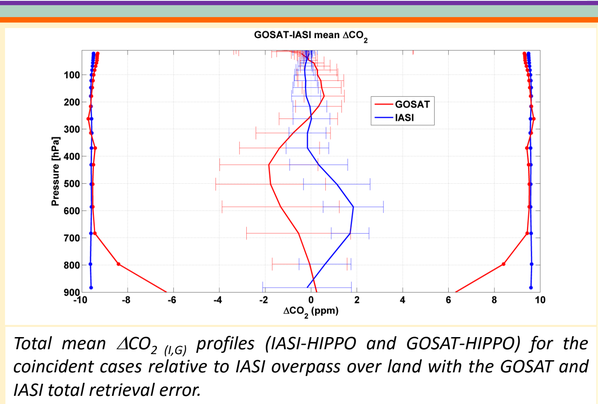
March 2010 to February 2011:time series of TCCON (red points) and averaged KLIMA IASI L2(blue points) XCO2[ppm] within 200 km and 1 hour

MetOp-A/IASI – GOSAT/TANSO-FTS – HIPPO3 (TIR)

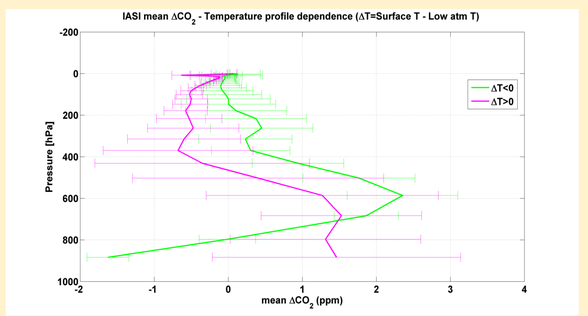
The KLIMA-IASI inversion code was used for processing IASI L1C data to retrieve CO_2 profiles with the aim of comparison with TANSO-FTS band 4 data. The GOSAT/TANSO-FTS CO_2 TIR operational products were obtained with the retrieval algorithm described in Saitoh et al. (2009, 2015). In order to validate the comparison results between IASI and GOSAT products, we considered CO_2 merged 10-second data product retrieved in the HIAPER Pole-to-Pole Observations (HIPPO) 3 aircraft campaign as reference to evaluate the results. The CO_2 profiles from GOSAT and IASI products have been compared with HIPPO 3 measurements for the coincidence cases of April 2010 (274 coincidence cases).

- We selected coincidences between HIPPO 3 campaign and both GOSAT TIR and IASI products, separately, considering the same criteria: 72 hours as time difference (Δt) and 300 km as space distance (Δs) between the centre of the GOSAT (or IASI) satellite acquisition and the location of the lowest HIPPO measurement point. We considered IASI and GOSAT overpasses both on land and on water and during day and night.
- A quantitative analysis of the differences between IASI and GOSAT Band 4 products and HIPPO 3 data taking into account the vertical sensitivity of the remote-sounding measurements from space, using the associated averaging kernel matrices, has been finally performed to obtain stringent comparison results. We calculated the differences between the GOSAT (or IASI) real and retrieved CO_2 profile $x_{G,I}$ and $\hat{x}_{G,I}$, to evaluate the differences with the HIPPO CO_2 measurements: $\Delta\, CO_{2_{(G,I)}} = x_{(G,I)} - \hat{x}_{(G,I)}$ where $\hat{x}_{G,I} = x_{a(G,I)} + A_{G,I}(x_{true} - x_{a(G,I)})$ is the GOSAT (or IASI) retrieved state as if they observed the air mass described by the aircraft profile (Rodgers et al, 2000). x_{true} is the Hippo profile, $x_{a(G,I)}$ and $A_{G,I}$ are the apriori state and averaging kernel matrix of GOSAT (or IASI), respectively.

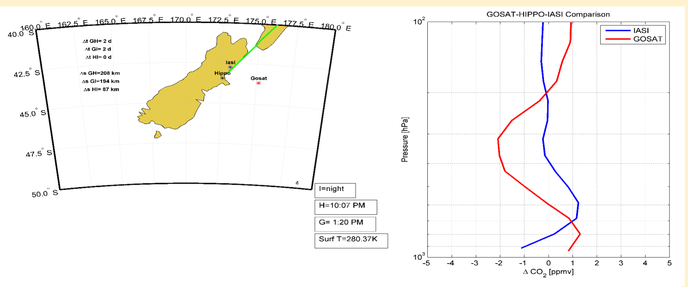
Every coincidence case has been considered singularly and then the results have been averaged to evaluate the dependence on the different variables considered about the satellite measurements: overpass time (day or night), overpass surface (water or land), and temperature profile.



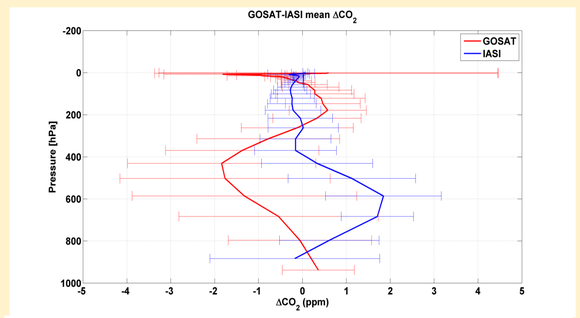
Total mean $\Delta CO_{2\ (I,G)}$ profiles (IASI-HIPPO and GOSAT-HIPPO) for the coincident cases relative to IASI overpass over land with the GOSAT and IASI total retrieval error.



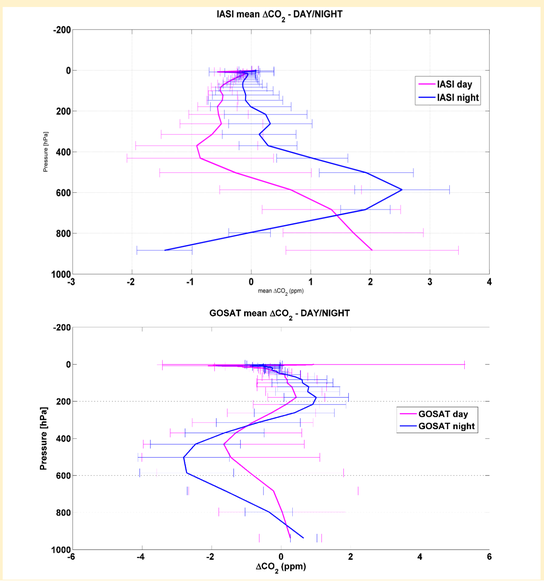
IASI total mean ΔCO_2 profiles for the coincident cases characterized by different thermal contrast between the surface and the near surface atmospheric layer (ΔT=surface temperature - lower atmospheric temperature). ΔT <0 (green) and ΔT >0 (magenta).



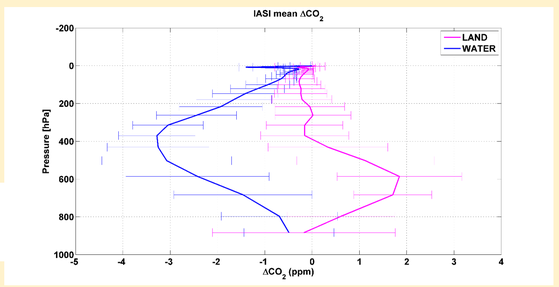
One coincidence case selected for the comparisons between CO_2 KLIMA and TANSO-FTS TIR products and HIPPO3 data (IASI and HIPPO over land, GOSAT over water; 40°-50° S and 170°-180° E). On the left: a map with the acquisition locations (red star:GOSAT, blue star:IASI, black star:HIPPO flight path lower point) and the relative HIPPO flight path



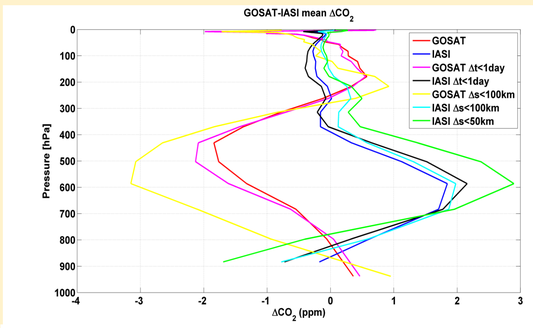
Total mean $\Delta CO_{2\ (I,G)}$ profiles (IASI-HIPPO and GOSAT-HIPPO) for the coincident cases relative to IASI overpass over land (215 cases)



IASI (top) and GOSAT (bottom) total mean ΔCO_2 profiles for the coincident cases relative to IASI and GOSAT daytime (magenta) and nighttime (blue) overpasses.



IASI total mean ΔCO_2 profiles for the coincident cases relative to IASI overpass over land (215 cases; magenta) and over water (59 cases; blue)



Total mean $\Delta CO_{2\ (I,G)}$ profiles (IASI-HIPPO and GOSAT-HIPPO) for the coincident cases relative to IASI overpass over land compared to the $\Delta CO_{I,G)}$ mean calculated selecting more strict coincidence criteria (time difference Δt< 1 day, spatial difference Δs <100 km).

Conclusions

MetOp-A/IASI – GOSAT/TANSO-FTS (SWIR)

- We obtained fits of good quality from KLIMA-IASI wide-band and multi-target analysis.
- The observed geographical and seasonal variability is often in good agreement with expectations.
- On average, we found a negative bias of KLIMA-IASI retrieved XCO_2 relative to other instruments. For the averaged comparison with TANSO-FTS, the bias is -7.3 ppm, reduced to -1.17 ppm with TANSO-FTS smoothed.
- The comparison with TANSO-FTS shows an unaccounted error of KLIMA-IASI of about 6 ppm with respect to the retrieval error and to the CO_2 atmospheric variability.
- The unaccounted error for TANSO-FTS XCO_2 product can be estimated to have an upper limit of 1.9 ppm.

MetOp-A/IASI – GOSAT/TANSO-FTS – HIPPO3 (TIR)

- The ΔCO_2 values ranges from 0 to 2 ppm and from -3.2 to 0 ppm for IASI data over land and water, respectively, while the range for GOSAT products is between -2 and 0.5 ppm, considering the complete dataset.
- IASI data over water (59 cases) demonstrate a different vertical trend in comparison with aircraft profiles, in these cases the mean difference between the two CO_2 datasets vary from -0.5 ppm (upper troposphere and near the surface) to -3.5 ppm (400 hPa).
- IASI daytime measurements overestimate HIPPO CO_2 data in the pressure levels near the surface (pressure levels grater than 700 hPa), while the behaviour is exactly reversed for nighttime overpass cases.
- For GOSAT/TANSO-FTS data, the mean ΔCO_2 trends for daytime and nighttime measurements are similar, with an increased underestimation of GOSAT CO_2 for pressures from 600 to 800 hPa for the nighttime overpasses.
- The definition of more strict coincidence criteria in time and space did not improve the comparison results, there is no relationship between ΔCO_2 values and Δs and Δt selection.
- The IASI and TANSO-FTS total retrieval error is close to 9.5 ppm, while the ΔCO_2 values vary from -3 to 3 ppm, considering all coincident cases (-2 to 2 ppm for mean values). So, the differences in CO_2 profiles between the two couples of TANSO-FTS-HIPPO and IASI-HIPPO measurements are within the total retrieval errors.

U. Cortesi et al. (2013) Finale Report of the Project 'Sensitivity analysis and KLIMA application oalgorithm to GOSAT and OCO validation' (ESA-ESRIN/Contract n. 21612/08/I-OL).
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Rodgers,C.: Inverse methods for Atmosferic sounding: Theory and practice, World scientific Publishing, Singapore, 2000