Validation of the IASI operational CH_4 and N_2O products using ground-based Fourier Transform Spectrometer: preliminary results at the Izaña Observatory (28ºN, 17ºW)

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Abstract

Within the project VALIASI (VALidation of IASI level 2 products) the validation of the IASI operational atmospheric trace gas products (total column amounts of H_2O, O_3, CH_4, N_2O, CO_2 and CO as well as H_2O and O_3 profiles) will be carried out. Ground-based FTS (Fourier Transform Spectrometer) trace gas measurements made in the framework of NDACC (Network for the Detection of Atmospheric Composition Change) will serve as the validation reference. In this work, we present the validation methodology developed for this project and show the first intercomparison results obtained for the Izaña Atmospheric Observatory between 2008 and 2012. As an example, we focus on two of the most important greenhouse gases, CH_4 and N_2O.

I. INTRODUCTION

Reliable Earth observation data sets are needed for understanding the processes driving climate change and for supporting decisions on climate change mitigation strategies. Atmospheric remote sounding from space is an essential component of this observational strategy, since it allows for a global coverage. In this context, the sensor IASI (Infrared Atmospheric Sounding Interferometer) is a key instrument for EUMETSAT's contribution to climate monitoring, since it offers a unique combination of high quality (very good signal to noise ratio and a high spectral resolution), excellent horizontal resolution (nadir pixel size of 12 km^2), global coverage and long-term data availability. It operates from the meteorological polar satellite MetOp/EUMETSAT (first MetOp-A launched in October 2006), provides operational data since 2007, and its mission is guaranteed until 2020 (on board MetOp-A, MetOp-B and MetOp-C). All these features are very promising for observing highly variable tropospheric gases (e.g., water vapour) or more uniform but less abundant gases (e.g., carbon monoxide) with good precision and consistently during many years. Indeed, IASI operationally provides water vapour profiles and ozone partial columns below ~16 km as well as total column (TC) amounts of water vapour, ozone, methane, nitrous oxide, carbon monoxide and carbon dioxide. However, for a correct scientific interpretation of these observational records it is fundamental that the quality of IASI products is well documented. So far validation activities have been mostly performed in the context of campaigns of a few days, weeks or months or have been focused on specific atmospheric parameters (e.g., Viatte et al., 2010; Schneider and Hase, 2011). By such campaigns alone it is not possible to assess IASI's potential for long-term climate change studies.

The project VALIASI, supported by EUMETSAT, will perform the first comprehensive and scientific long-term validation of IASI's operational atmospheric trace gas products. To this end, ground-based FTS (Fourier Transform Spectrometer) trace gas measurements, made in the framework of NDACC (Network for the Detection of Atmospheric Composition Change, www.acd.ucar.edu), will be used as a reference data set. A ground-based FTS system can observe total column amounts and profiles of many different atmospheric trace gases often with an unprecedented precision. There are about 25 globally distributed NDACC FTS experiments in operation since many years. They cover different geographical locations (subtropical, middle and polar latitudes) and different surface conditions (land and ocean). VALIASI will document the quality of the whole IASI-A time series (2007-2012) for three different NDACC FTS sites, covering different geographical and atmospheric conditions: Izaña Atmospheric Observatory (IZO, Spain) at the subtropics, Karlsruhe (Germany) at the mid-latitudes, and Kiruna (Sweden) at the Arctic. In this work, the preliminary results of VALIASI project for IZO are presented, showing the validation strategy and the first intercomparison results for two of the most important greenhouse gases: CH_4 and N_2O.

IZO (www.izana.org), run by the Spanish Meteorological Agency (AEMET), is a subtropical high mountain observatory in Tenerife island (28.3ºN, 16.5ºW, 2.37 km a.s.l.). It is located above a trade-wind temperature inversion layer acting as a barrier for local pollution, so it offers excellent conditions for remote sensing of the atmosphere. IZO FTS contributes to the NDACC since 1999.

II. IASI AND FTS MEASUREMENTS

Both the IASI and the FTS instruments share the same working philosophy: both are Fourier Transform spectrometers and the total amounts and profiles of atmospheric gases are determined by using radiative transfer and inversion algorithms [Hase et al., 2004; August et al., 2012]. To do so, IASI records thermal infrared emission of the Earth-atmosphere system between 645 and 2760 cm^{-1} with a spectral re-solution of 0.5 cm^{-1} twice per day. On the other hand, the FTS systems provide high quality direct solar absorption spectra between 700 and 9000 cm^{-1} (high spectral resolution of up to 0.0036 cm^{-1} and signal-to-noise ratio of about 2000) and offer a high measurement frequency (up to hourly).

The IASI N_2O and CH_4 Total Columns (TC) are obtained by an Artificial Neuronal Network algorithm [August et al., 2012], with a target uncertainty of 20%. For this preliminary validation study, we use the Level 2 (L2) N_2O and CH_4 TCs, operatively disseminated by EUMETSAT, from IASI on MetOp-A: Version 4, V4, from 2008 to September 2010 and Version 5, V5, from September 2010 onwards. From this dataset we have selected the best quality IASI measurements: over sea, cloud-free and with the highest level of quality and completeness of the IASI retrieval (IASI quality flag equal to 5, for more details please refer to the EUMETSAT Technical Note "IASI Level 2 Product Guide", EUM/OPS-EPS/MAN/04/0033).

For ground-based FTS, the N_2O and CH_4 Volume Mixing Ratio (VMR) profiles are retrieved by using the algorithm PROFFIT [Hase et al., 2004] from NDACC FTS solar absorption spectra between 2480-2945 cm^{-1} (measured with a spectral resolution of 0.005 cm^{-1}). The spectroscopic line parameters for N_2O and CH_4, as well as for all interfering species considered, are taken from HITRAN 2008 database (www.cfa.harvard.edu/hitran). Then, the FTS N_2O and CH_4 TCs are calculated by integrating the FTS VMR profiles from the IZO altitude (2.37 km) to top of the atmosphere, with a theoretical precision of better than 1%. The partial column missed by the FTS (from sea level to the IZO altitude) will be not crucial in the intercomparison, since IASI has a weak sensitivity below IZO for the target species, as observed in Figure 1. This figure shows the IASI CH_4 averaging kernels (avks) from the IASI_MUSICA retrieval [Schneider and Hase, 2011; Schneider et al., 2013] (not IASI_L2 retrieval, since not operationally available) and the FTS CH_4 avks for typical measurement conditions at IZO.

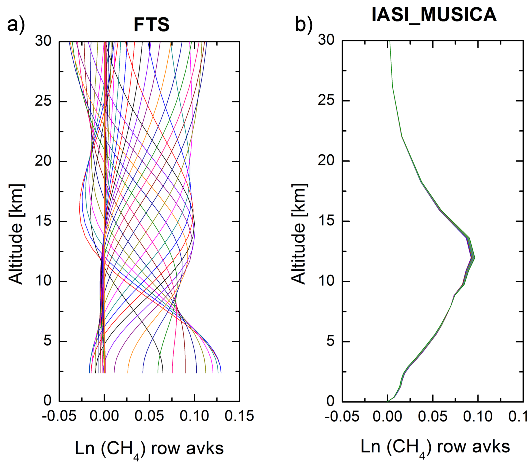

Figure 1. Rows of the CH_4 averaging kernel matrix, avks, expressed as ln(CH_4), on 31 January 2012 at IZO: (a) FTS and (b) IASI overpass from MUSICA retrieval (IASI_MUSICA).

We observe that the IASI maximum sensitivity is located about the tropopause region (~12 km) and only one CH_4 layer is well detected around this region (degrees of freedom for signal, DOFS, ~1), whereas the FTS system detects two independent CH_4 partial columns (DOFS~2.5), corresponding to the troposphere and the stratosphere. This difference in the IASI and FTS vertical sensitivity has to be considered when interpreting the intercomparison results. Note that the FTS profiles are not smoothed by the IASI avks, since they are not operationally available. However, smoothing the FTS profiles would not allow us to analyse the influence of the different sensitivities on the IASI validation.

III. IASI AND FTS INTERCOMPARISON

III.A. VALIDATION STRATEGY

To intercompare the IASI and FTS measurements we define a validation box of 1°x1° centred in IZO. As observed in Figure 2.a, the relative differences between IASI and FTS observations (CH_4 as example) show no significant spatial distribution in the validation area. As temporal criterion we consider all the FTS measurements taken within ±1hour of the IASI overpass. The temporal criterion is so restrictive to guarantee optimal validation conditions, since the dispersion of the relative differences depends on the coincidence time used (Figure 2.b).

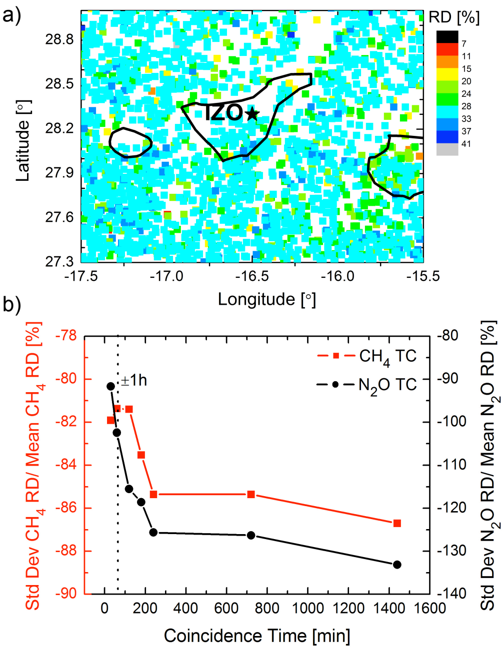

Figure 2. (a) Spatial distribution of the CH_4 Relative Difference (RD=(IASI_L2-FTS)/FTS, in %) in 1°x1° around IZO considering the whole IASI time series from 2008 to 2012 (V4 and V5) and (b) dispersion of the RD vs. the coincidence time for CH_4 and N_2O.

III.B. MEASUREMENT-TO-MEASUREMENT, MONTHLY AND ANNUAL CYCLE INTERCOMPARISON

Figure 3 summarizes the comparison between the CH_4 and N_2O TCs from FTS and IASI between 2008 and 2012 at IZO. Due to the weak sensitivity of IASI in the lower troposphere for CH_4 and N_2O, the variability of these species in this layer is expected not to be well captured by IASI. Therefore, we can assume that the partial column missed by the FTS only introduces a systematic bias between the FTS and IASI TCs. By removing such systematic offset of the relative differences (RD) time series (about 30% of the not smoothed TC observed by FTS), we observe that the IASI V5 significantly improves the CH_4 and N_2O IASI retrievals. The scatter (one standard deviation) of the RD time series between IASI and FTS TC relative to their corresponding inter-annual mean is reduced about half from IASI V4 to V5: from 4.3% to 1.4% for N_2O and from 5.6% to 2.0% for CH_4. It is important to highlight that the RD (and the found scatters) are strongly impacted by the different sensitivities of FTS and IASI instruments: while FTS captures tropospheric and stratrosheric CH_4 and N_2O variations, the IASI mainly reflects the variability of the tropopause (re-call Figure 1). In fact, as observed in Figure 3.d and 3.e, the IASI CH_4 and N_2O TC annual cycle are in good agreement with the annual cycle of the FTS CH_4 and N_2O VMR in the tropopause region (averaged between 10 and 14 km with a DOFS of about 0.5). Both IASI and FTS follow the annual shift of the tropopause's altitude and the peak-to-peak amplitude is similarly captured. This figure shows the annual cycle of the N_2O and CH_4 multi-year variability (multi-year monthly mean mines multi-year annual mean).

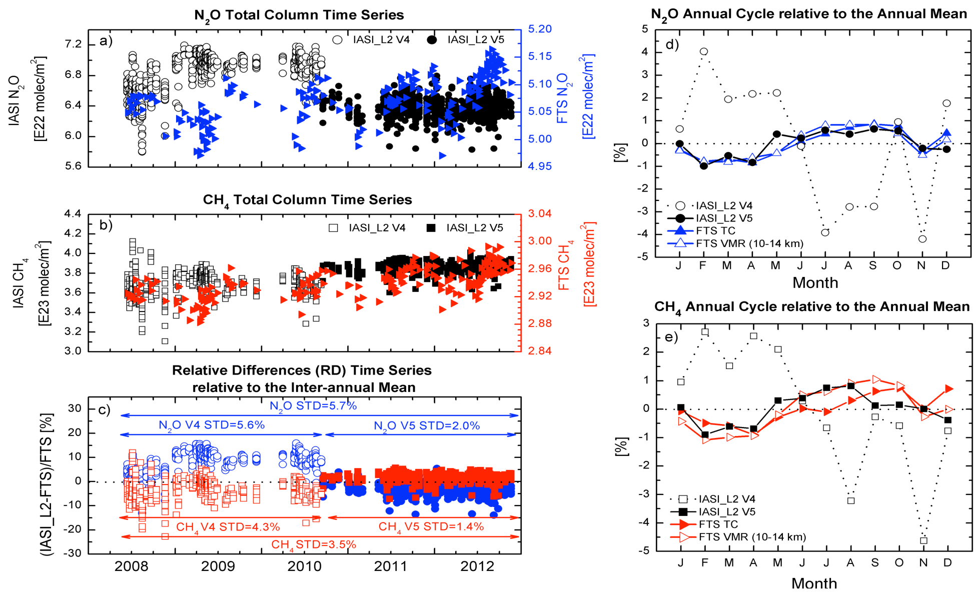

Figure 3. Consistency of N_2O and CH_4 TC time series as observed by IASI and FTS between 2008-2012 at IZO: (a) and (b) N_2O and CH_4 TC time series, (c) RD time series between IASI and FTS data relative to the inter-annual mean (in %). The standard deviation (STD) of the RD time series is shown considering the whole IASI time series and for the V4 and V5 datasets. (d) and (e) Annual cycle of the N_2O and CH_4 variability: IASI TC (V4 and V5), FTS TC and VMR (10-14 km).

The comparison between the monthly IASI and FTS also confirms that the IASI and FTS N_2O and CH_4 TC are not correlated (Figure 4). However, there is a reasonable correlation between CH_4 FTS concentrations in the tropopause region (10-14 km) and IASI TC (correlation coefficient about 0.80 for IASI V5). For N_2O it is only limited to about 25%.

IV. Summary and Conclusions

This work presents the first preliminary results of the experimental validation of IASI operational N_2O and CH_4 products within VALIASI project. To do so, the NDACC FTS trace gases measurements at the super-site Izaña Observatory between 2008 and 2012 have been used as reference.

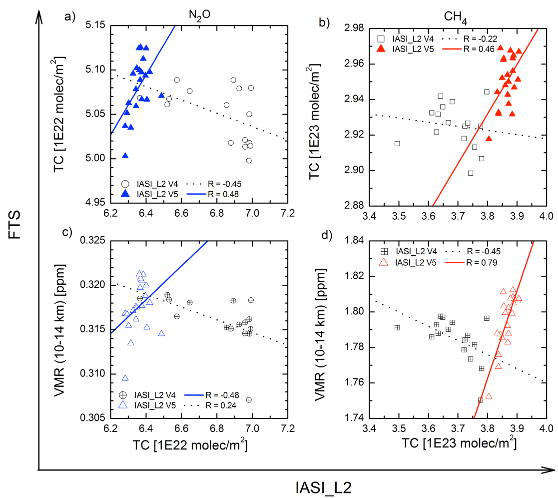

Figure 4. Monthly FTS N_2O and CH_4 TC (a and b) and monthly FTS N_2O and CH_4 VMR (averaged between 10 and 14 km, c and d) vs. monthly IASI N_2O and CH_4 TC.

The FTS system has demonstrated to be a powerful tool to validate IASI products: high precision, high measurement frequency and good vertical resolution.

The knowledge of the IASI vertical sensitivity is indispensable for its comprehensive validation, since the vertical sensitivity of IASI and FTS is significantly different in the subtropical region: IASI only detects variations in the tropopause region, while the FTS system distinguishes between tropospheric and stratospheric contributions. As a result, a reasonable correlation is found between IASI and FTS for the tropopause region (around 12 km) for CH_4, but total column amounts as observed by both instruments are not correlated (monthly values and annual cycles). Although the IASI new algorithm (V5, introduced in September 2010) significantly improves the quality of the IASI CH_4 and N_2O observations (i.e., it reduces the scatter in the IASI-FTS intercomparison), we can conclude that IASI mainly reflects the intra-annual variability of the tropopause region in the subtropical area.

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