

Preliminary results from the ESA CH4TIR project: Spectroscopy and forward model improvement for CH₄ retrieval in the TIR

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Introduction

CH₄ atmospheric concentration retrievals from TIR nadir sensors exhibits significant biases compared to independent observations, or when intercompared between different TIR and SWIR/TIR sensors products. It is necessary to **analyze the possible causes** of biases and to investigate potential processing improvements and/or bias-correction for proper and consistent CH₄ measurements in the TIR. Results from Alvarado [2015] and De Wachter [2017] highlighted that **incomplete spectroscopic knowledge** could be a major source for these biases.

ESA CH4TIR Project

The CH4TIR project seeks to explore and consolidate the possible sources of CH₄ biases from TIR sensors, establish necessary actions and perform the work for mitigating biases. This will be achieved by performing the following tasks:

- Assessment and prioritisation of the expected impacts on the CH₄ retrieval due to 1) **incomplete spectroscopic knowledge**, 2) **forward/inverse model errors**, and 3) **instrument biases**
- Sensitivity study investigating the impact of these three types of errors on the final CH₄ systematic error by using **two different retrieval schemes** (ASIMUT and $\delta\text{-}\sigma$ -IASI) and **different instruments** (IASI and TANSO-FTS)
- Work plan and actions for implementing, performing and validating the mitigation of the CH₄ retrieval biases (in this study or in a follow-on activity)

Assessment of biases and prioritisation

From the discussion of the possible origin of biases and from published papers, the following research issues have been identified in the first phase of the project (by order of relevance):

- considering **line mixing** in the region around the Q-branch at 1306 cm⁻¹ as well as the impact of line-mixing among the CH₄ multiplets of the ν_4 band for the region of the P-branch
- the **accuracy of the spectroscopic parameters** describing the Voigt shape and their temperature dependence
- the contribution of the uncertainty of the **temperature profile** (if not retrieved simultaneously with the methane amount)
- the contribution/overlap of N₂O lines with those of CH₄
- the impact of the knowledge of the H₂O profile (if it is fixed or scaled) and/or if retrieved its contribution to the bias/uncertainty in the CH₄ column or partial columns

BISA CH₄ retrieval

The BISA CH₄ retrieval setup is outlined in Table 1 and typical retrieved profiles and averaging kernels (AK) are shown in Figure 1 for IASI and TANSO-FTS. Sensitivity of the CH₄ retrievals lies in the upper troposphere-lower stratosphere (UTLS).

Table 1 Description of the BISA CH ₄ retrieval setup for IASI and GOSAT	
Radiative transfer	ASIMUT—ALVL [Vandaele et al., 2006]
Retrieval	Optimal Estimation [Rodgers, 2000]
Spectral range	1210—1290 cm ⁻¹
Spectroscopy	HITRAN 2012
Vertical grid	23 altitudes
Emissivity	Zhou et al. [2011]
P, T, H ₂ O	ECMWF reanalysis
a priori	WACCM model
state vector	CH ₄ , T _s , H ₂ O, N ₂ O, CO ₂ total column
Correction	O ₃ , HNO ₃

The BISA CH₄ profiles are retrieved with the ASIMUT-ALVL software (Vandaele et al., 2006), which is a **modular** software for radiative transfer (RT) calculations and inversions in planetary atmospheres (Earth, Venus, Mars). The code has been developed with the objective to be as general as possible, accepting different instrument types and different geometries. ASIMUT-ALVL has been coupled to the SPHER/TMATRIX (Mishchenko and Travis, 1998) and LIDORT (Spurr, 2006) codes to include the complete treatment of the scattering effects into the RT calculations. The retrieval module is based on the formalism of the OEM (Rodgers, 2000). This tool is of particular interest for the ESA CH4TIR project as it is very **flexible** and can be used to easily and quickly investigate the effect of several parameters. Moreover, the recent addition of LUT capabilities

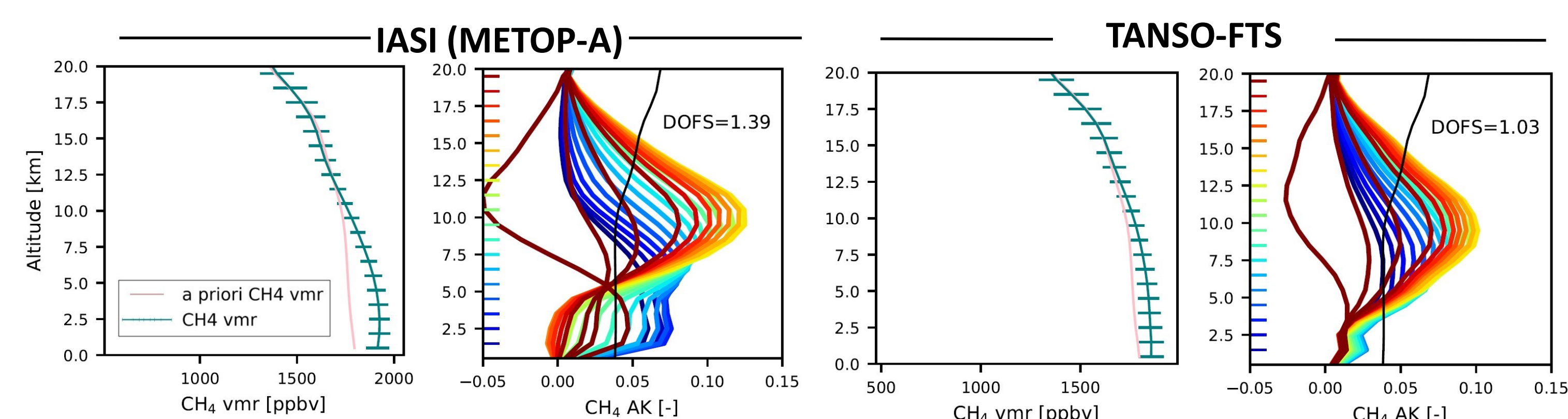


Figure 1 Examples of BISA CH₄ retrievals and a priori for IASI and TANSO-FTS

Preliminary analysis and discussion of the retrieval residual

A first step for improving the BISA CH₄ retrieval is to focus on the radiance residuals. Residuals from the initial retrieval setup (see Figure 2) clearly show structures around 1246 cm⁻¹, which is a complicated mixture from CH₄, N₂O, CO₂. Other signatures are clearly visible, such as CF₄ and HNO₃, and possibly some weak O₃ lines.

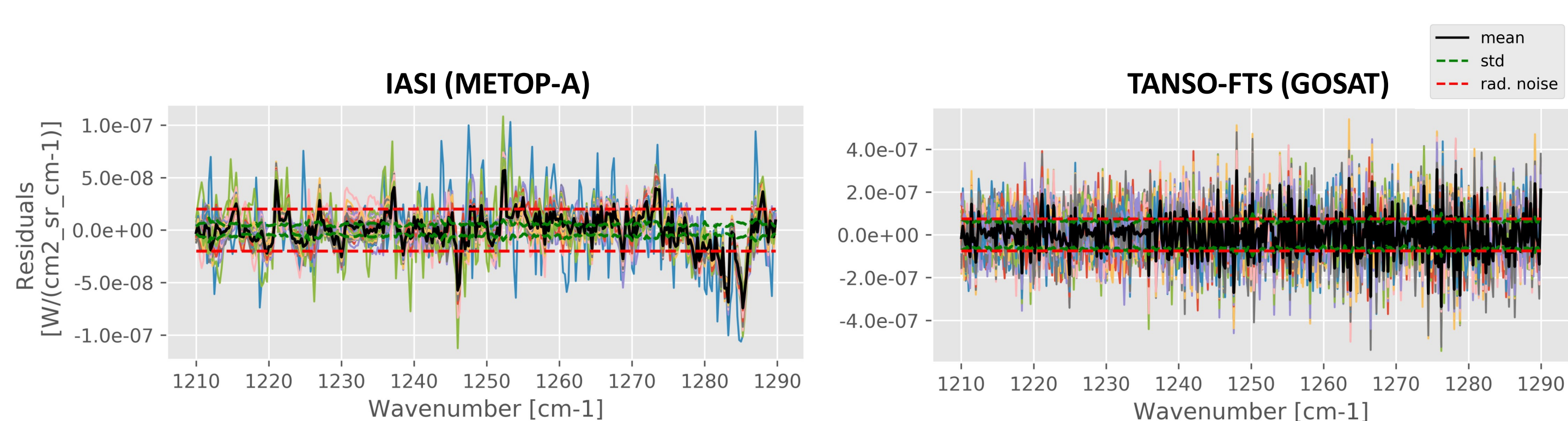


Figure 2 IASI and TANSO-FTS residuals for observations made in July 2012 near Mauna Loa.

Therefore, different tests were carried out by incrementally adding species and looking at the effect of the mean residual and variability. Finally, as outlined in the assessment of the priorities, the line mixing around 1306 cm⁻¹ will be investigated, and therefore the retrieval spectral range has also been extended to encompass this region. Results of these changes on the residuals are shown in Figure 3 and 4 for TANSO-FTS and IASI, respectively.

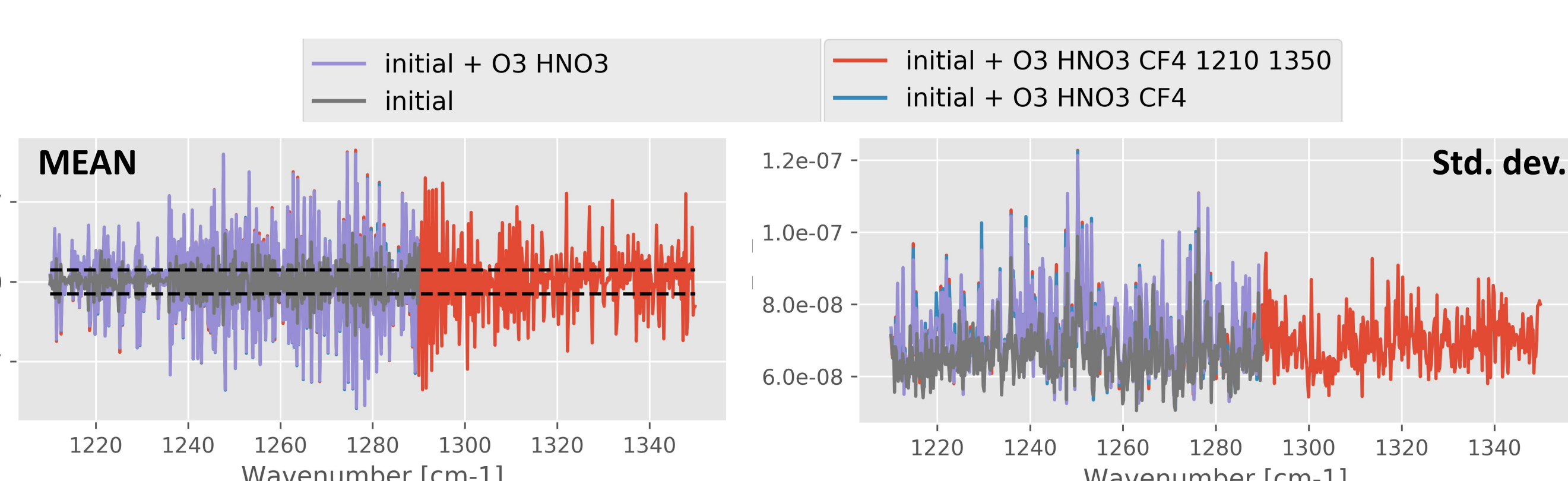


Figure 3 TANSO-FTS residual (mean and stdev, Nprofs =) after the addition of different species and the increase of the spectral range used in the retrieval: One can see that the residual does not improve with changes to the setup, and more work is needed.

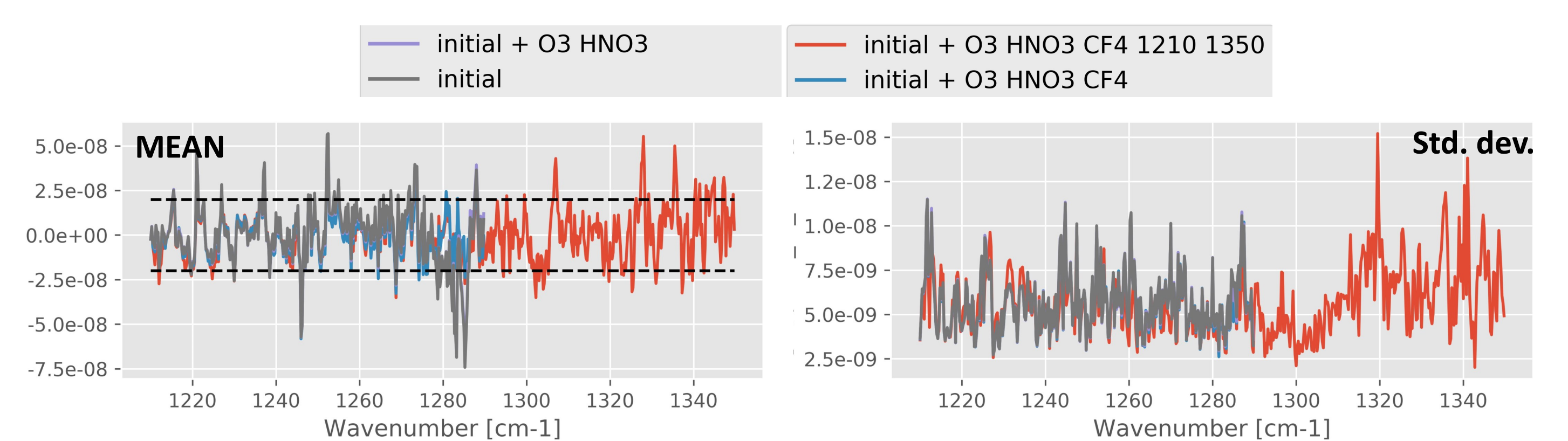


Figure 4 IASI Residuals after the addition of different species and the increase of the spectral range used in the retrieval, which does improve significantly with the addition of CF₄.

Spectroscopy: HITRAN 2012 vs 2016

Another aspect worth investigating was the effect of a different spectroscopic database on the retrieval. Therefore another retrieval exercise was carried out using HITRAN 2016 line parameters for all species and the results are compared on Figure 5.

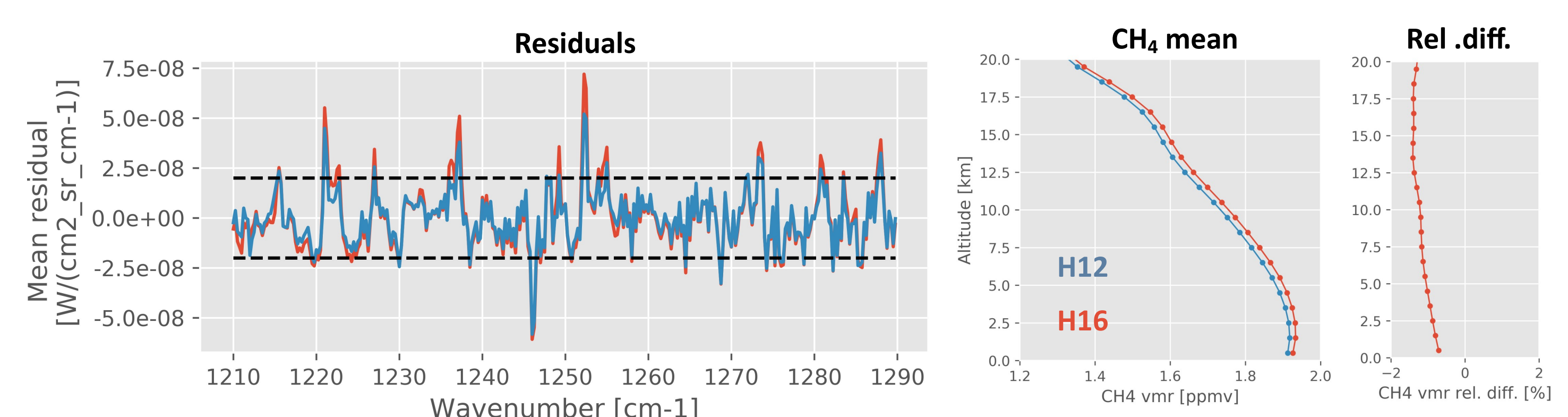


Figure 5 Effect of changing the spectroscopic database from HITRAN 2012 (blue) to HITRAN 2016 (red). Interestingly, the residuals are larger using the most recent version of the line parameters.