Water Vapour Isotopologues Measurements From FORUM Observation Using KLIMA Retrieval Code

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Research Focus and Motivations

The Far-infrared Outgoing Radiation Understanding and Monitoring (FORUM) mission, selected for the ESA's 9th Earth Explorer (EE9) mission, will be launched in 2026. For the first time, spectrally resolved radiance observations covering the Far InfraRed (FIR) band from 100 to 667 cm^{-1}, as well as the Middle Infrared from 667 to 1600 cm^{-1}, with global coverage and with high spectral resolution and radiometric accuracy will be available. This spectral region is highly sensitive to upper-tropospheric–lower-stratospheric (UTLS) water vapour concentration. One of the tools used to support the FORUM proposal during the EE9 competition is KLIMA (Kyoto protocoL Informed Management of the Adaptation) retrieval code. KLIMA analyzed the synthetic FORUM observations in clear sky providing simultaneously the vertical profile of minor atmospheric gases (such as the water vapour), atmospheric temperature profile, surface temperature, and surface emissivity.

The feasibility of HDO retrieval from FORUM measurements has been investigated with KLIMA, with the objective of evaluating possible improvements coming from the exploitation of the synergy between IASI-NG and FORUM measurements. The information on water isotopologues is important because they depend on many climate factors such as water vapour source conditions, circulation, local precipitation and ambient temperature [1]. Moreover, the assimilation of water vapour isotopologues from IASI-NG has been proven to improve wind, humidity and temperature fields by more than 10% at mid-tropophere compared to only assimilating conventional non isotopic information [2].

Use of KLIMA

During the EE9 phase A selection, KLIMA code was employed in the following ESA studies, summed up also in Table 1: *FORUM-req* for the assessment of the FORUM mission requirements definition (see Fig. 1, where H2O average retrieved errors are shown for three different latitude bands and for different L1 requirements, threshold and goal); *FORUM-E2E* for the validation of the End-to-End Simulator (E2ES); *FORUM-FIRMOS* for the analysis of the ground-based observations of the FORUM prototype FIRMOS (Far-Infrared Radiation Mobile Observation System)(an example of profiles retrieved by FIRMOS is reported in Fig. 2).
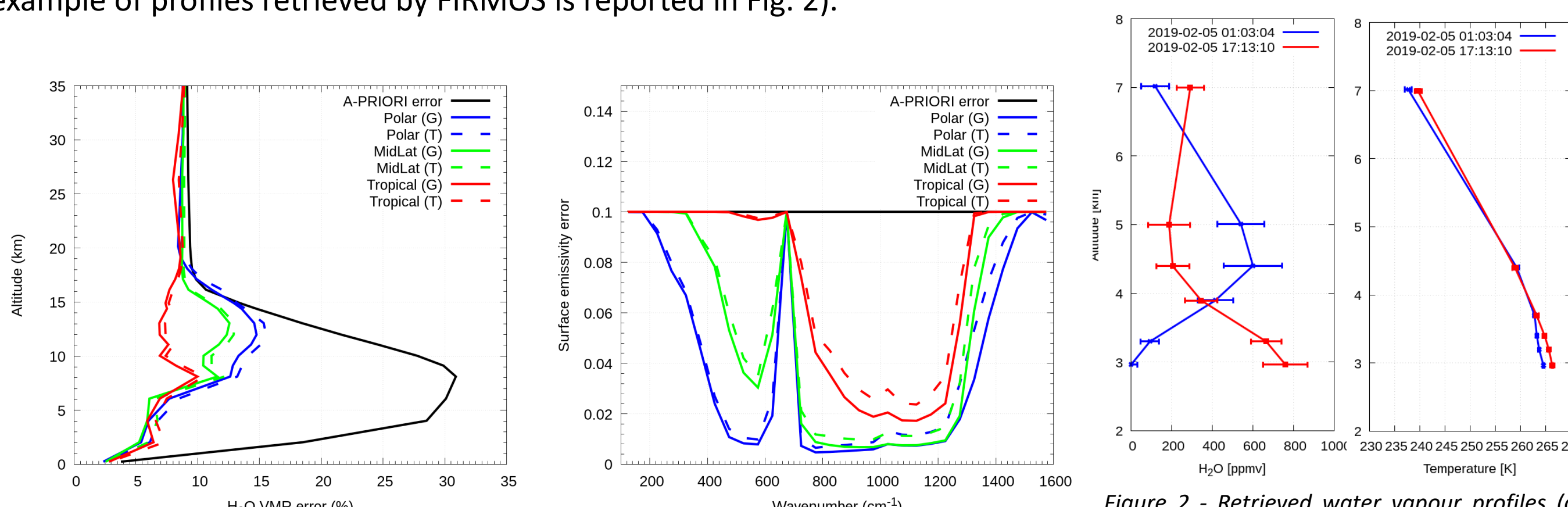
Table 1: Applications of the KLIMA code.

Project	Role of KLIMA code
FORUM-req - FORUM consolidation of requirements and reference scenarios [3]	Assessment of the retrieval performances of temperature, water vapour and ozone profiles, surface temperature and emissivity using the KLIMA code.
FORUM (Far-infrared Outgoing Radiation Understanding and Monitoring) *End-to-End Simulator* (E2ES) [4]	KLIMA was used to validate the L2 algorithm within the FORUM E2E simulator and to prove that the performance of the retrieval algorithm of the E2ES are compliant with the project requirements in clear sky conditions.
FORUM-FIRMOS - Far-Infrared Radiation Mobile Observation System.	Clear sky measurements were processed using KLIMA in order to provide support to the development and characterization of the FORUM experimental apparatus.
FORUM-SCIENCE (Ongoing).	Generation of the OD, needed for the fast code σ-FORUM, using the KLIMA code.

Figure 1 – Average retrieval errors for goal (solid lines) and threshold (dashed lines) NESR and ARA requirements, at different latitude bands [3].

Figure 2 - Retrieved water vapour profiles (on the left) and temperature profiles (on the right) and retrieval errors. The profiles were obtained from two FIRMOS measurements with high (blue curves) and low (red curves) information content.
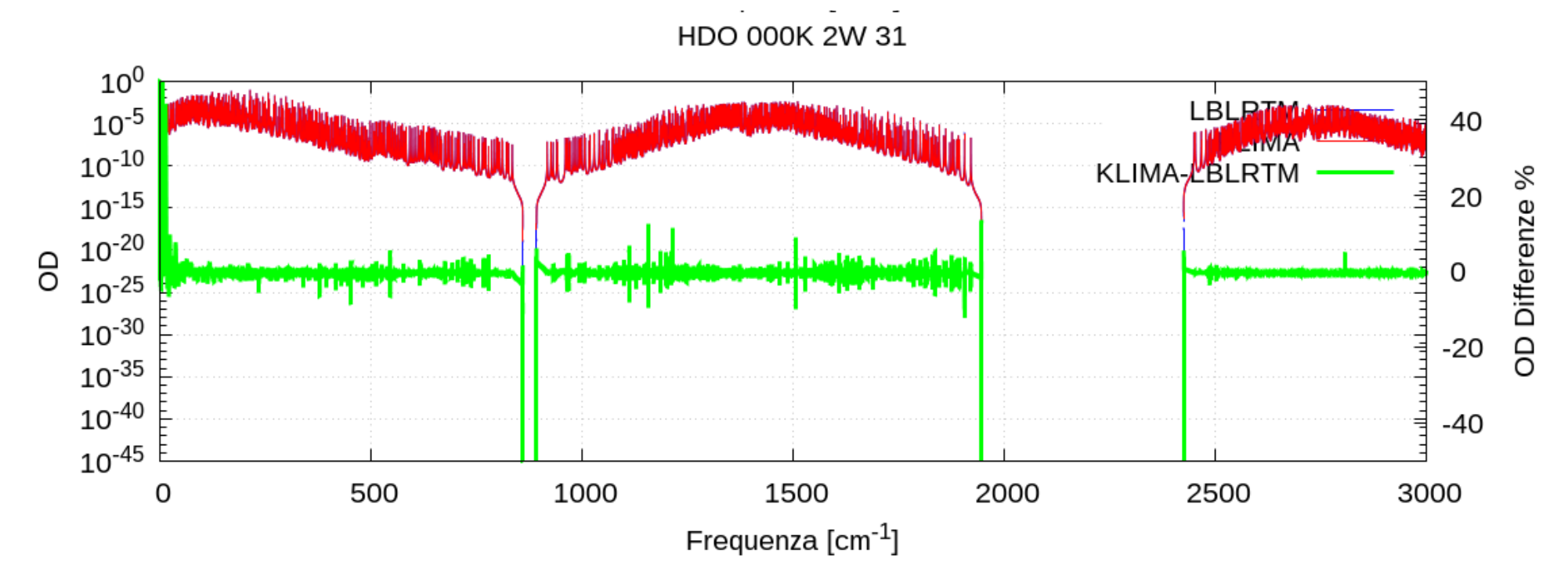

Figure 3 - Comparison of the HDO ODs (187 hPa). In blue the LBLRTM ODs and in red the KLIMA ODs. ODs are reported in the left logarithmic scale. The percentage differences are reported in green and are referred to the linear scale on the right.

Furthermore, in the framework of the ASI FORUM-SCIENCE project, KLIMA was used for the generation of gases optical depths (ODs) used by the fast code σ-FORUM to parametrize the atmospheric gas absorption, so far generated using LBLRTM, on three different latitude bands (an example is reported in Fig. 3, where the HDO ODs generated by LBLRTM are compared with the ones generated by KLIMA).

KLIMA has been recently upgraded to retrieve also the concentration of the isotopologues of the atmospheric gases and has been used for the first time to retrieve the concentration of the water vapour isotopologue HDO from simulated FORUM observations under different measurement conditions.

Retrieval Procedure and Results

KLIMA has been used first to simulate FORUM (100 - 1600 cm^{-1} range) and IASI-NG (645 - 1400 cm^{-1} range) observations according to the instrument requirements and taking into account both the NESR and the calibration errors [3], then to retrieve water vapour isotopologues. Details of the retrieval and the considered quality estimation parameters are provided in Fig. 4. The contribution of the HDO spectral lines to the total spectral radiance, compared with the NESR, is shown in Fig. 5. DOFs, retrieval errors, and [retrieved-true] values differences for three fitting configurations (FORUM alone, IASI-NG alone, synergy of IASI-NG and FORUM) and three different scenarios (Polar, Midlat, and Tropical) are reported in Fig. 6 and Fig. 7 using the results of a single retrieval and the average of 100 observations, respectively.
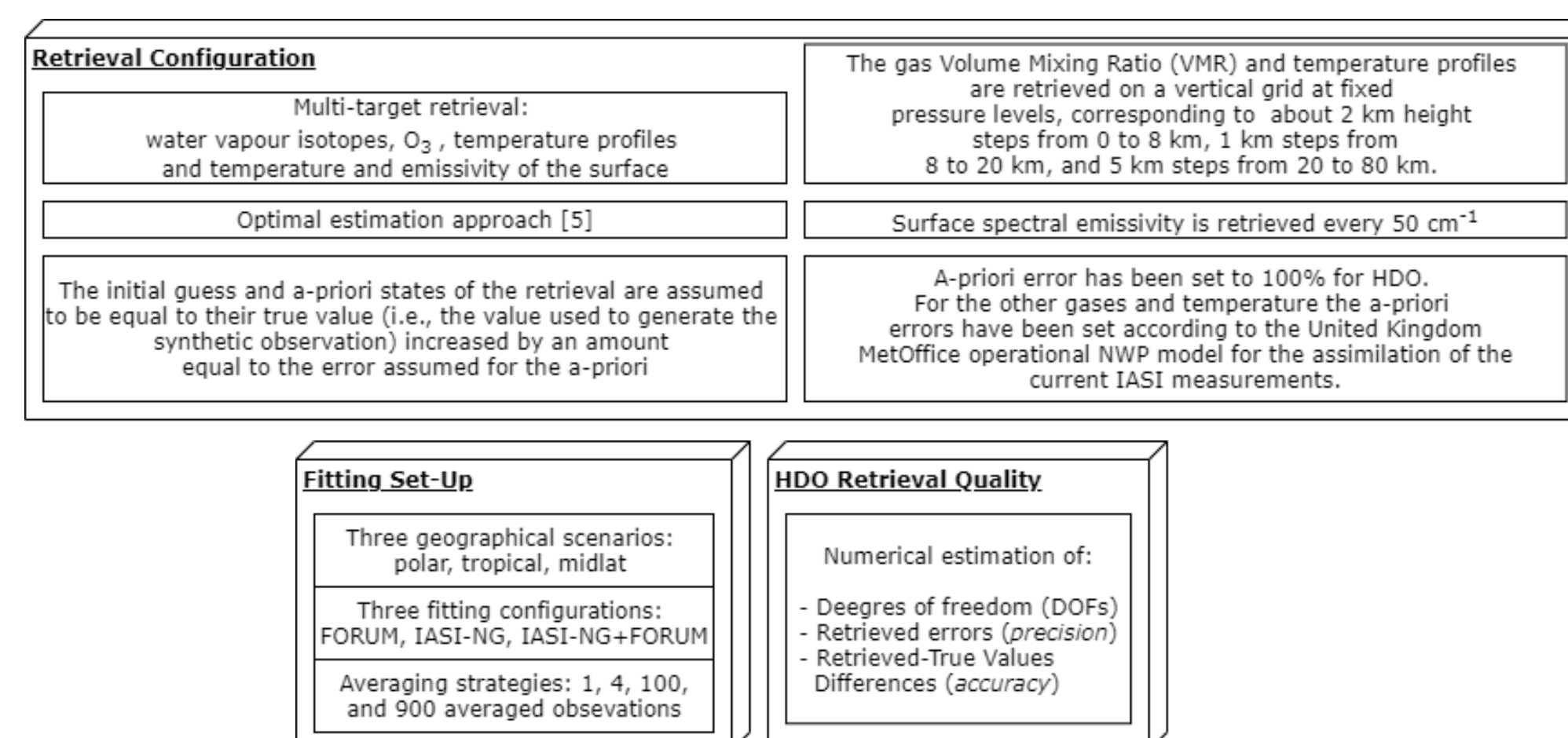

Figure 4 – Retrieval configuration, set-up, and quality estimation details.
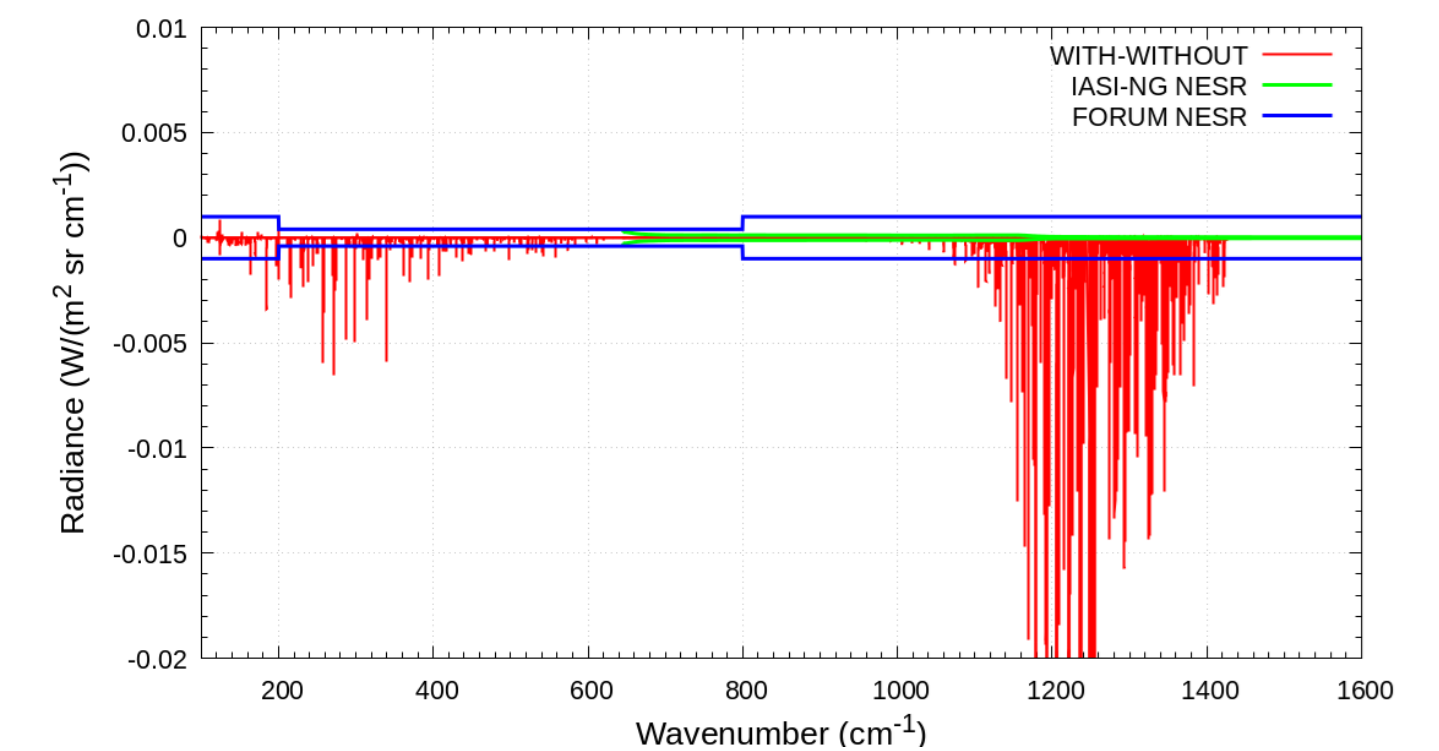

Figure 5 – Effects of the HDO on the radiance calculation: spectral radiance absolute difference (with-without HDO contribution) and IASI-NG/FORUM relative NESR.
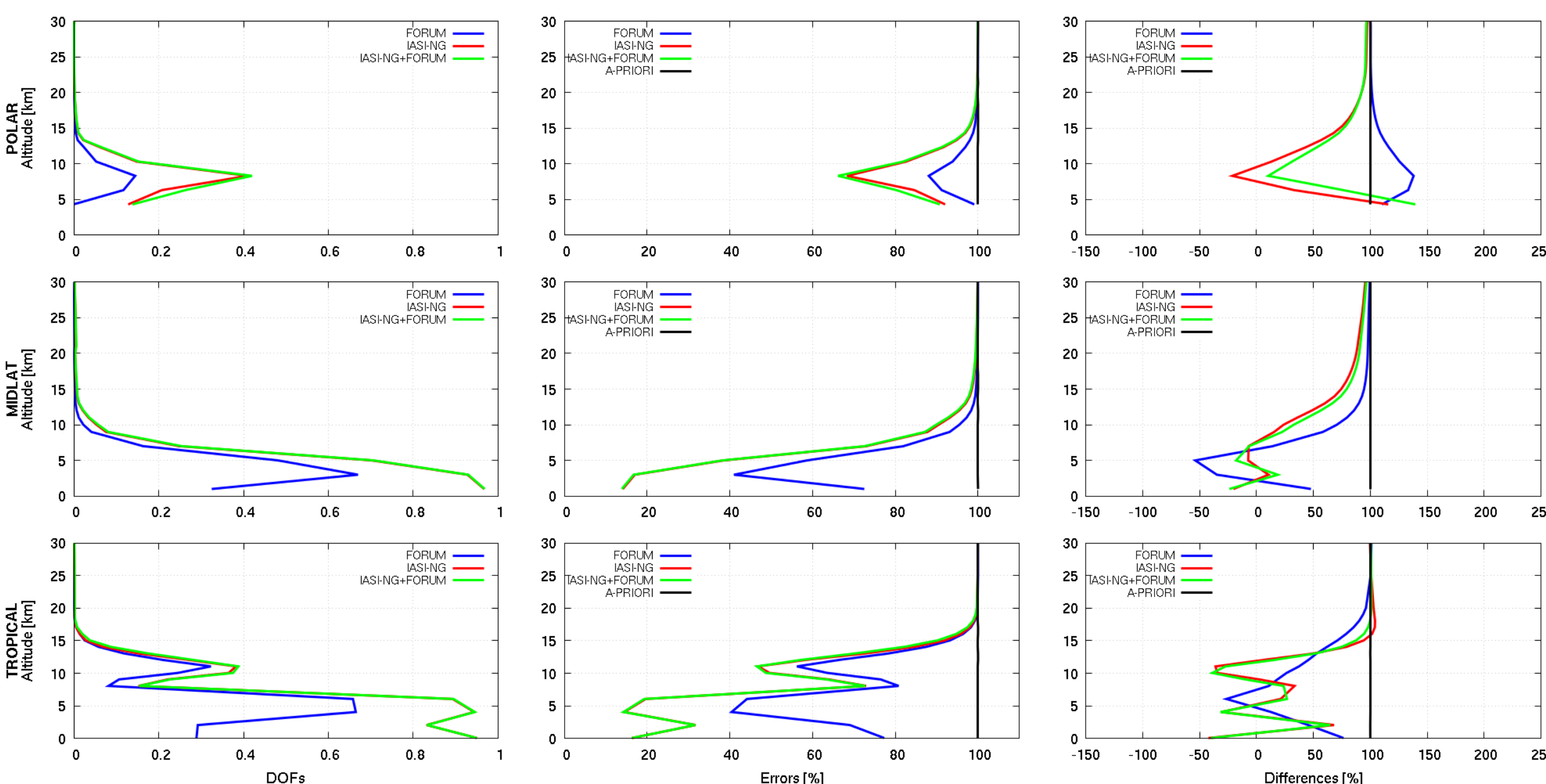

Figure 6 – HDO retrieval results - single observation: DOFs, retrieval errors, and [retrieved-true] values differences (respectively on the left, center, and right) at three different scenarios (Polar, Midlat, and Tropical).
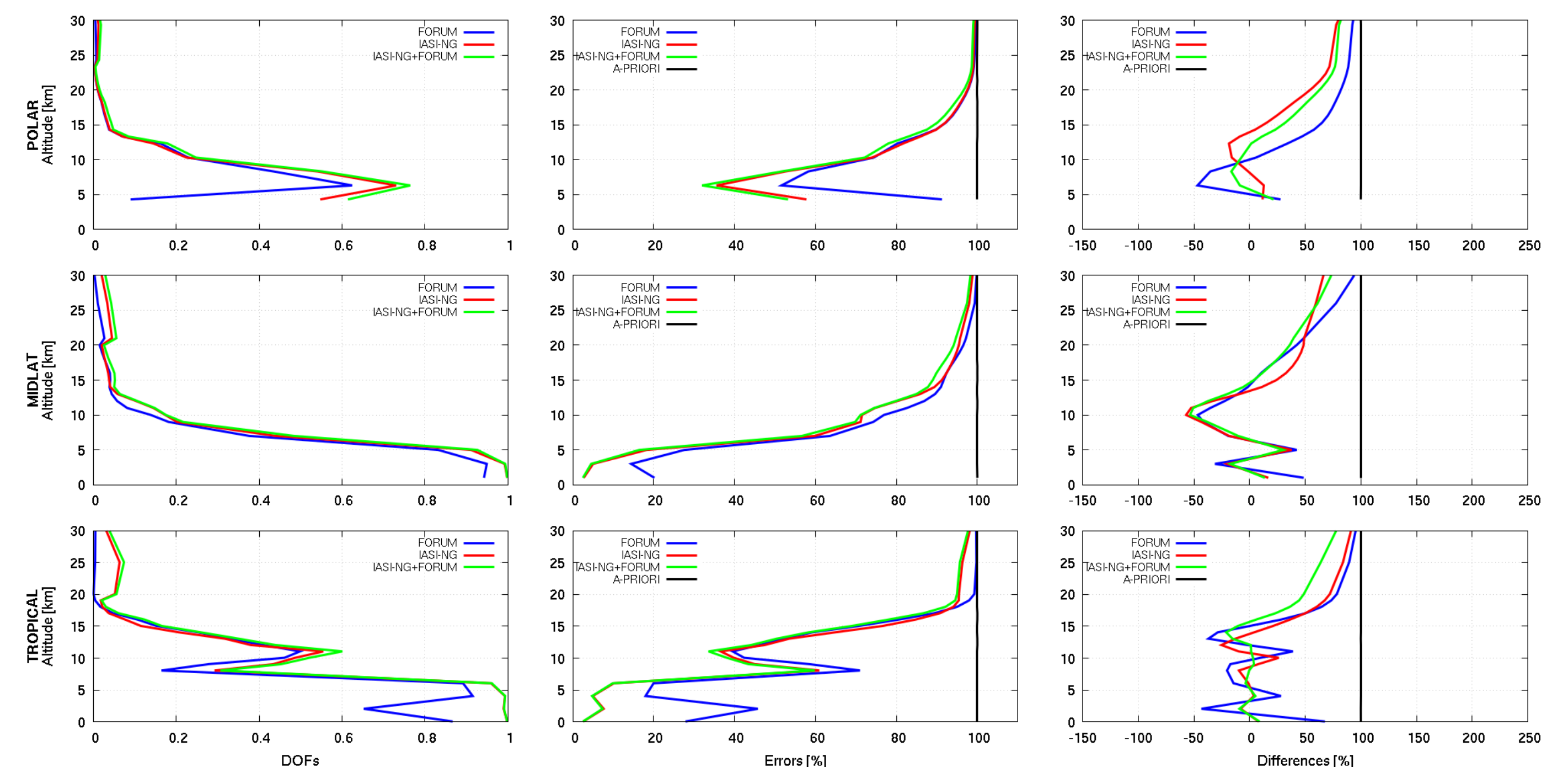

Figure 7 – HDO retrieval results - 100 averaged observations: DOFs, retrieval errors, and [retrieved-true] values differences (respectively on the left, center, and right) at three different scenarios (Polar, Midlat, and Tropical).

Conclusions

- This study provides a preliminary assessment of the feasibility of the retrieval of HDO profiles from FORUM measurements.
- KLIMA has been successfully upgraded to retrieve water vapour isotopologues, with the objective of determining their distribution in the upper troposphere and lower stratosphere. The contribution of FORUM measurements to the retrieval of HDO is small with respect to IASI-NG measurements but measurable, especially in the tropical scenario. The improvements coming from the synergistic exploitation of both IASI-NG and FORUM measurements are evident mainly in the accuracy plots of the averaged results.
- As the number of observations increases, both FORUM and IASI-NG HDO errors get reduced. Such effect is more evident in the case of FORUM. This can be explained considering the larger calibration error of IASI-NG which does not scale with the number of averaged measurements.
- The possibility of retrieving water vapour isotopologues also in the far infrared region will allow to evaluate the impact on the retrieved profiles of the different spectroscopic systematic errors affecting different spectral regions. Future developments of the presented study include the feasibility of retrieving the δ_D, as well as other water vapour isotopologues, from FORUM.

References

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