Analysis of the Consistency Between FIR Spectroscopic Data and Airborne Measurements: Support to FORUM-EE9 Mission

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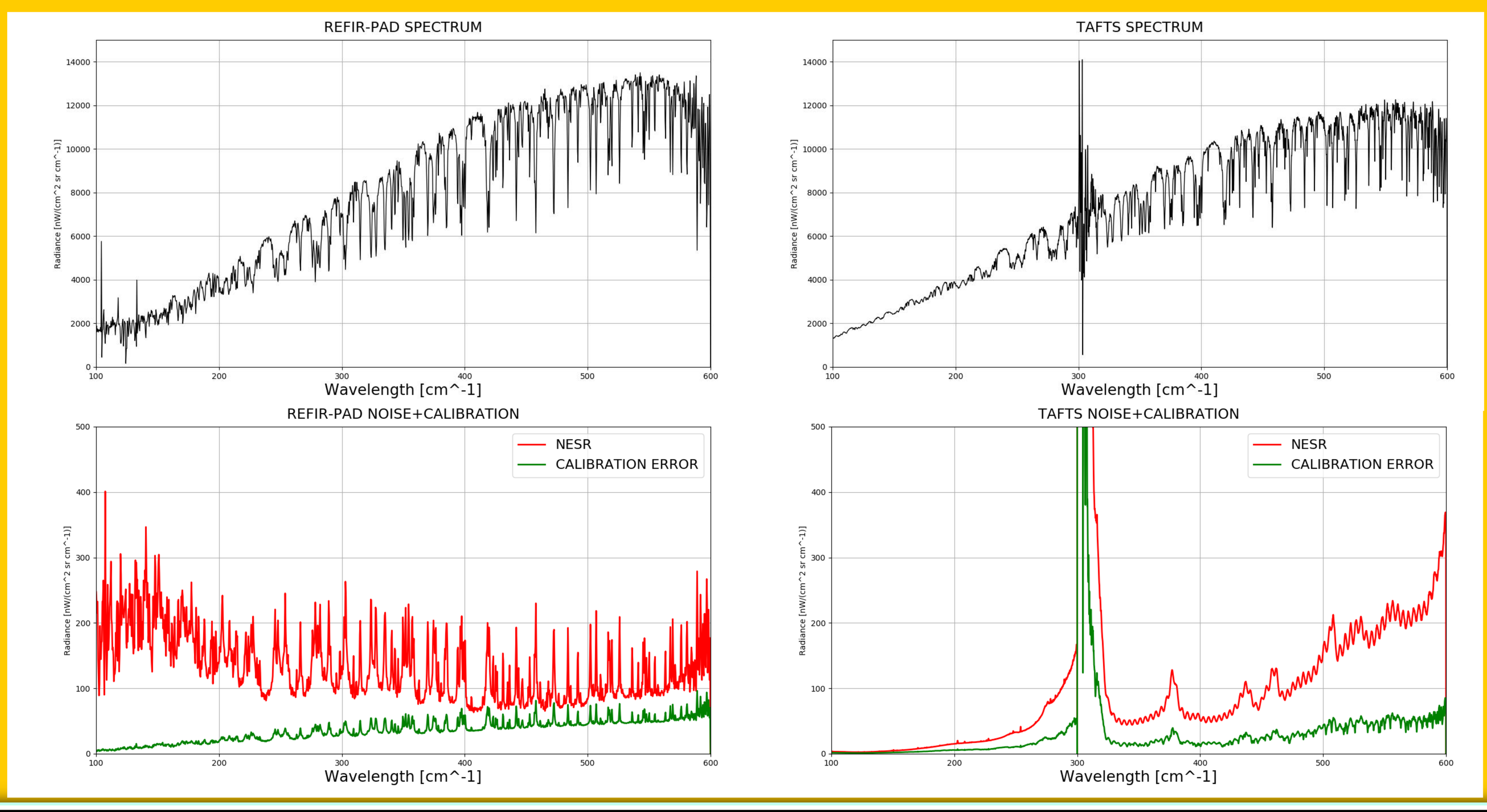
Introduction

The Earth Explorer 9 – FORUM (Far-infrared Outgoing Radiation Understanding and Monitoring) mission will sound the underexplored FIR (Far-Infrared) part of the Outgoing Longwave Radiation (OLR), a relevant part of the thermal emission spectrum of the Earth+atmosphere system. This region is strongly influenced by key climatological parameters such as the water vapor concentration in the Upper Troposphere / Lower Stratosphere (UTLS). The analysis of the Levels 1 and 2 products of the forthcoming mission will require the exploitation of accurate Radiative Transfer Models making use of spectroscopic data. Therefore the quality of the spectroscopic data is a fundamental issue for FORUM results. Water vapor spectroscopy in the FIR region is particularly important, as the water vapor absorption accounts for almost the total atmospheric extinction in clear sky conditions. The water vapor spectroscopic parameters reported in the current spectroscopic databases show differences that may lead to large differences when the simulations using them are compared to both other simulations or the measured spectra. In this work we compare the clear sky airborne measurements of FORUM-like sensors as REFIR-PAD and TAFTS from 100 to 600 cm^{-1} to simulations performed with the GBB-Nadir+LIDORT RTM (Radiative Transfer Model) using spectroscopic data from some of the most used databases. The analysis will allow to get an indication on whether and how changes introduced in the water vapor FIR spectroscopy are going in the right direction. Furthermore, it will highlight the role of EE9-FORUM in the future improvements of the FIR spectroscopy

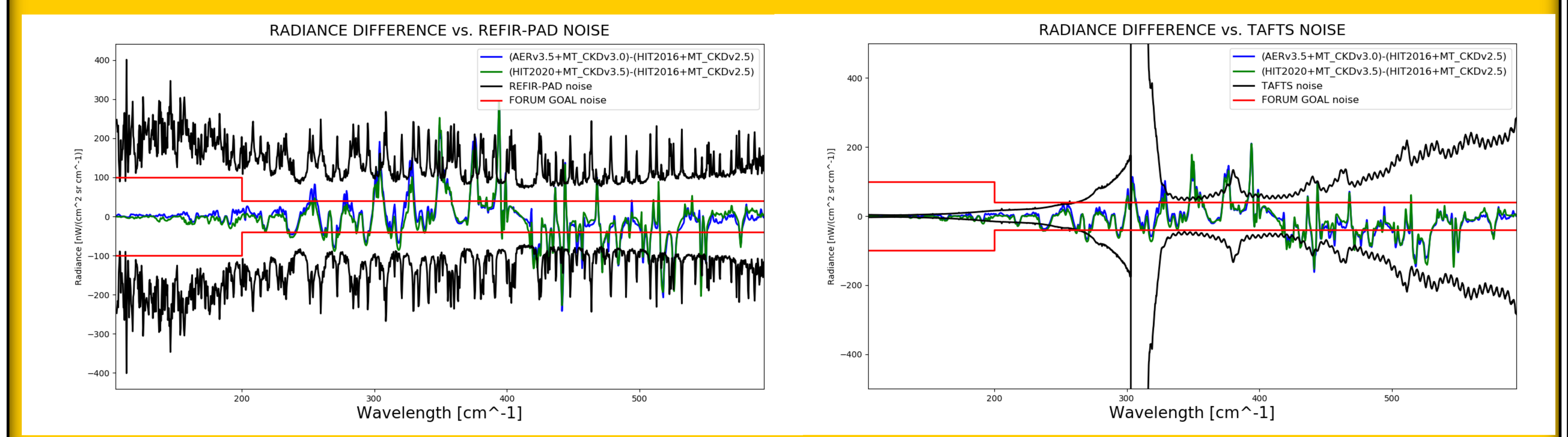
Observations

- The Tropospheric Airborne Fourier Transform Spectrometer (TAFTS) is a Martin-Puplett interferometer, it collected more than 150 spectra from 80 to 600 cm^{-1} on board the FAAM-BAE aircraft on 03/13/2019 above the North Sea in the frame of the PIKNMIX-F campaign. Dropsondes measuring humidity and temperature were released during the flight
- The Radiation Explorer in the Far-InfraRed – Prototype for Application and Development (REFIR-PAD) flown on board the Laboratoire de Physique Moleculaire pour l'Atmosphere et l'Astrophysique (LPMAA) balloon during the Equatorial Large Balloons Campaign (ELBC, Teresina (Brazil), 06/30/2005). It collected more than 50 spectra from 100 to 1400 cm^{-1} during the flight
- We selected 10 REFIR-PAD spectra measured close to 12UTC and 10 TAFTS spectra close to Dropsonde 8 launch from 100 to 600 cm^{-1}. Examples of REFIR-PAD and TAFTS spectra in the FIR range are shown below with noise and calibration errors



Spectral residuals compared to instrumental noise.

Simulation using HITRAN2016+MT_CKDv2.5 is considered as the reference



Residuals among simulations performed with different spectroscopic data are of the order of the instrumental noise of REFIR-PAD and TAFTS.
REFIR-PAD and TAFTS NESR are larger than the FORUM NESR

Simulations

The GBB (Geofit Broad-Band) Nadir version is a line-by-line code computing optical depths using the selected input atmosphere and spectroscopic parameters. It is coupled with the LIDORT RTE solver for the calculation of high resolution spectra. It was originally built for the ESA MIPAS instrument and then adapted for simulation in the nadir line of sight. It can use spectroscopic data from many different database.
For the analysis we selected:

Spectroscopic Databases
- **HITRAN (2016 and 2020 versions)**
- **GEISA (**Gestion et Etude des Informations Spectroscopiques Atmospheriques) **2015 version**
- **AER (Versions v3.5 and v3.8)**

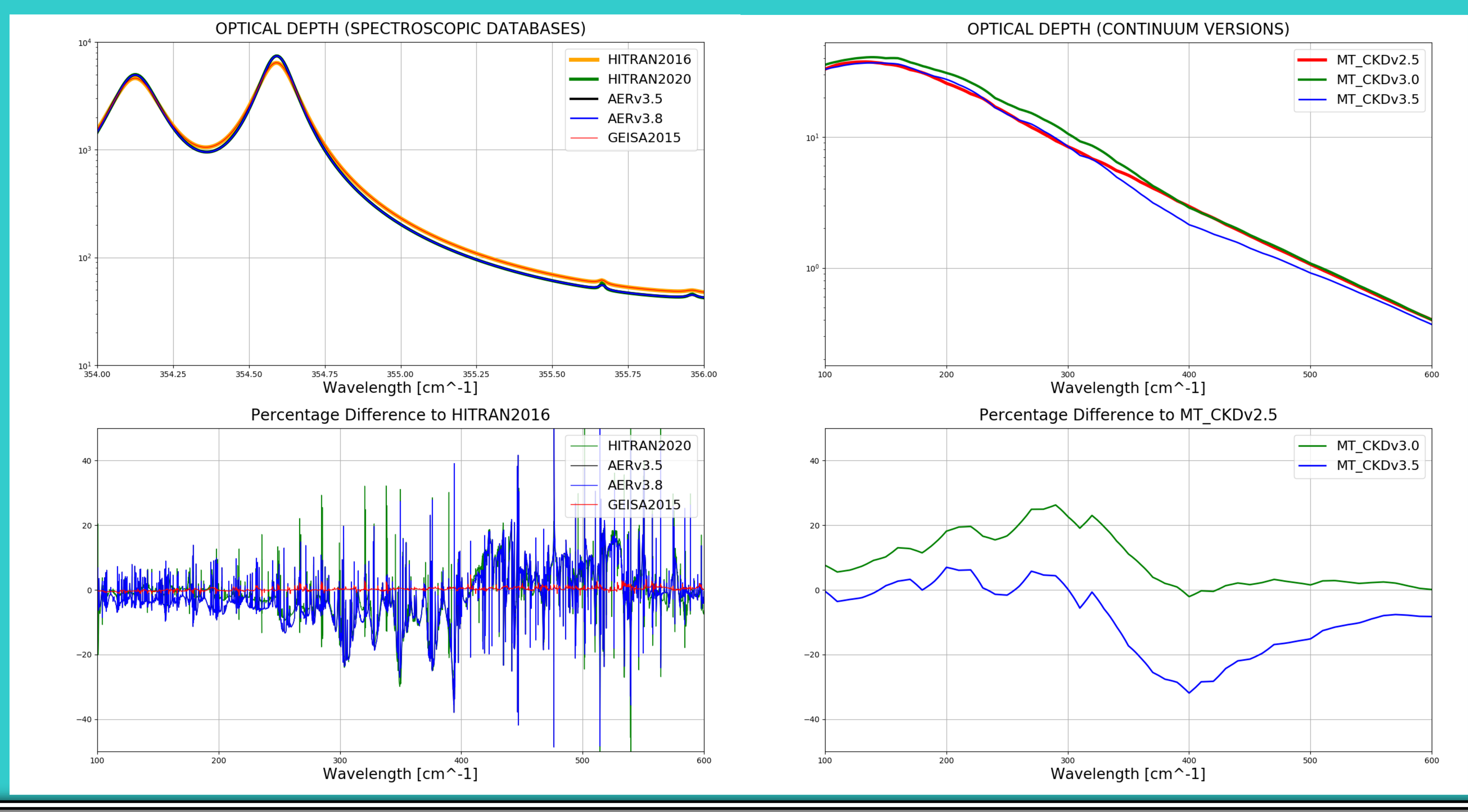
Each database is coupled to different MT_CKD models of continuum absorption (Mlawer et al., 2012)
For continuum absorption we selected MT_CKD versions 2.5, 3.0 and 3.5.

Ancillary data
REFIR-PAD → atmospheric data from ERA-Interim database
TAFTS → water vapour from Dropsonde 8 measurement.
Correction on atmospheric temperature → for both the datasets, atmospheric temperature is retrieved from the observations in order to cancel out possible bias due to not correct representation of the atmospheric state

Differences between computed ODs

REFERENCE: ODs simulated with HITRAN2016 and MT_CKDv2.5

First row → Computed ODs for T=297.6 K, P=980.7 hPa and X_{H2O}=1.16*10^{22} mol/(cm^2) using different databases (left, zoom between 354 and 356 cm^{-1}) and MT_CKD continuum versions (right)
Second row → Percentage difference between computed ODs using different databases and the reference one (left) and between computed ODs using different MT_CKD continuum versions and the reference one (right) for T=297.6 K, P=980.7 hPa and X_{H2O}=1.16*10^{22} mol/(cm^2)

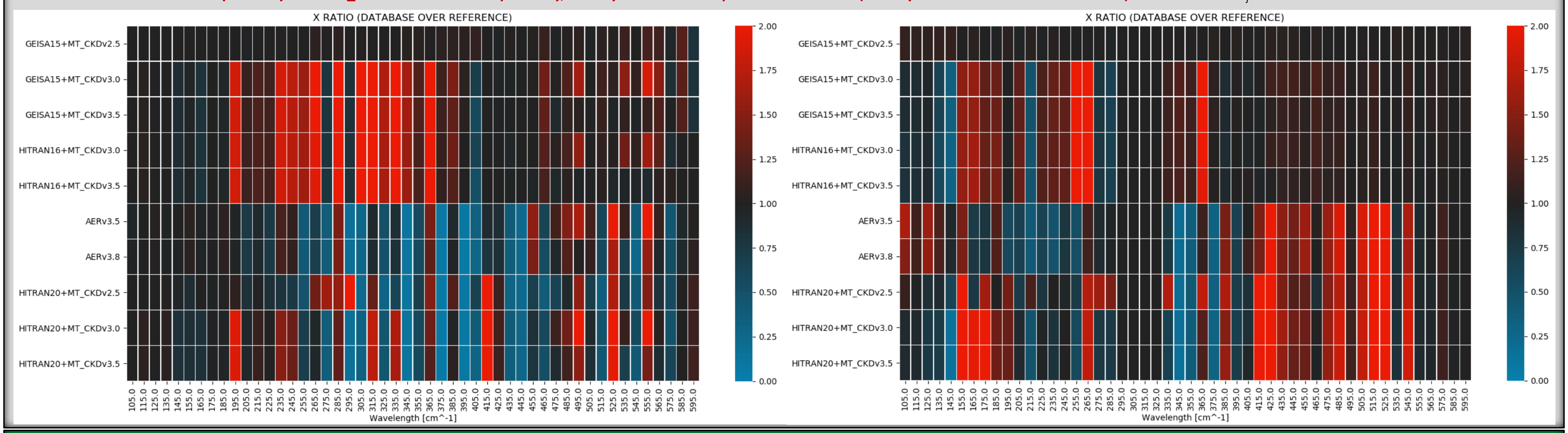


Results

We computed the reduced χ^2 (see Eq.1) between simulated and observed average spectra in spectral windows 10 cm^{-1} wide.
Here we report for REFIR-PAD (left) and TAFTS (right) the ratio between the reduced χ^2 values calculated using each database + continuum parametrisation and the reference HITRAN2016 + MT_CKDv2.5 → We choose one of the oldest database as the reference in order to check the improvement in the consistency between measured data and RTM simulations
N.B. AERv3.5 and v3.8 are coupled only with MT_CKDv3.0 and v3.5 respectively, as they have been coupled in the LBLRTM (Line-By-Line Radiative Transfer Model)

1. Reduced $\chi^2 = \frac{1}{N}\sum_{j=1}^{N}\frac{(Y_j - F_j)^2}{(\sigma_j)^2}$

N = # of points in a spectral microwindow
Y_j = observation at spectral point j
F_j = simulation at spectral point j
σ_j = noise at spectral point j



Conclusions

We performed our analysis studying the consistency between RTM simulations using different spectroscopic databases and airborne measurements of REFIR-PAD and TAFTS from 100 to 600 cm^{-1}. Our conclusions are listed below.
Common to both instruments:

1. The oldest databases (HITRAN16 and GEISA15) should be coupled only with continuum version MT_CKDv2.5
2. The AER database has introduced a consistent improvement in the FIR range with respect to the older HITRAN2016 database.
3. The HITRAN2020 reproduces the improvements introduced by the AER database, except for isolated MWs between 200 and 350 cm^{-1}

REFIR-PAD analysis → The AERv3.8 coupled to the updated continuum version MT_CKDv3.5 slightly improved the consistency between simulations and observations for wavenumbers > 450 cm^{-1}
TAFTS and REFIR-PAD spectra show different behaviour between 150 and 200 cm^{-1} (to be further investigated) and for wavenumbers > 420 cm^{-1} (probably due to problems affecting TAFTS aircraft measurements)
The large dataset of radiances provided by EE9-FORUM will help to verify the quality of the water vapour spectroscopy and trigger further improvements in the databases.