Retrieval of minor atmospheric constituents from far-infrared FORUM measurements

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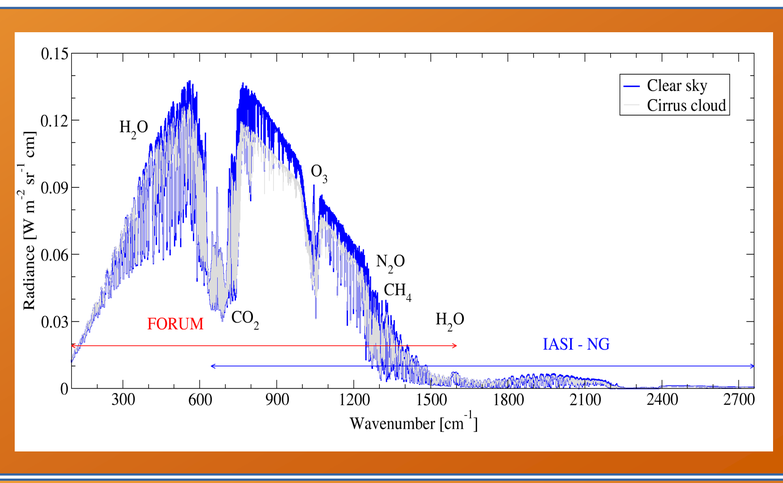
Background

FORUM (Far-infrared Outgoing Radiation Understanding and Monitoring) is a proposed experiment for the ESA Earth Explorer 9 mission. In December 2017 FORUM was approved for Phase-A studies. The core FORUM instrument is a FT spectrometer measuring, for the first time from space, the outgoing spectral radiance from the FAR- to the MID- infrared spectral regions, namely, from 100 to 1600 cm^{-1}. Far-InfraRed (FIR) spectral measurements are extremely important because approximately 40% of the outgoing Earth's radiation falls in this region.

The figure on the right shows a simulated spectrum at the top of the atmosphere. FORUM and IASI – NG spectral ranges are also indicated.
The main target parameters that will be retrieved from FORUM measurements are the H2O profile and cloud parameters. However, it will be possible to retrieve also profiles of other gases, such as: O3, CH4, N2O, HNO3, etc.. In this work we characterize the performance of the retrieval of these secondary gases from FORUM synthetic observations.



Impact of FIR observations

FORUM will allow obtaining:

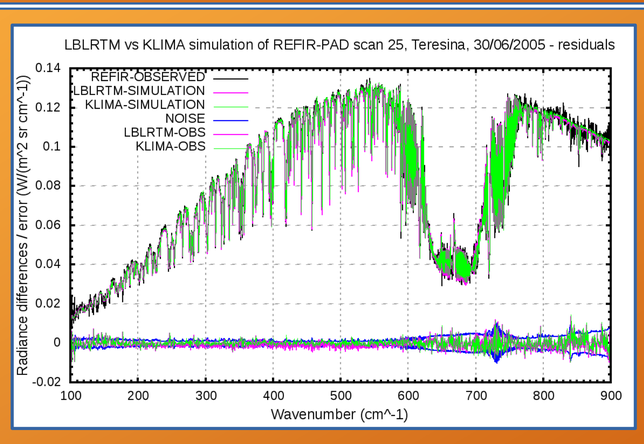
- Improved estimate of the **outgoing long-wave broadband flux** [Palchetti et al., 2008].
- Better estimate of the **emissivity of frozen surfaces** within the FIR region.
- Quantification of long-term effects of ongoing changes in greenhouse gases such as **CO2**, **CH4**, **N2O** and **O3** on the radiation field.
- A full verification of the **FIR water vapour spectroscopy.**
- Improved **water vapour retrievals** in the upper-troposphere as compared to retrievals from mid-IR measurements.
- FORUM measurements will contribute to improve **cloud parameterizations** (needed in climate and NWP models) and to characterize **radiative properties of ice clouds in the FIR.**

Forward and inverse modeling

For generation of synthetic FORUM measurements and test retrievals we use the KLIMA forward / retrieval model [Laurenza et al., 2014].

The KLIMA algorithm has been applied to FIR spectral observations acquired by the REFIR-PAD instrument during a stratospheric balloon flight from Teresina (Brazil) in 2005 [Palchetti et al.,2006].

The KLIMA forward model has been validated against state of the art radiative transfer codes such as LBLRTM (AER, see plot on the right).



Observed vs KLIMA/LBLRTM simulated clear sky spectrum.

KLIMA is first used to generate **synthetic FORUM observations**:

- the instrument line-shape is assumed to be a *sinc* function with 1/2L = 0.3 cm^{-1}.
- Random noise is added to the simulated spectrum according to FORUM noise specifications.

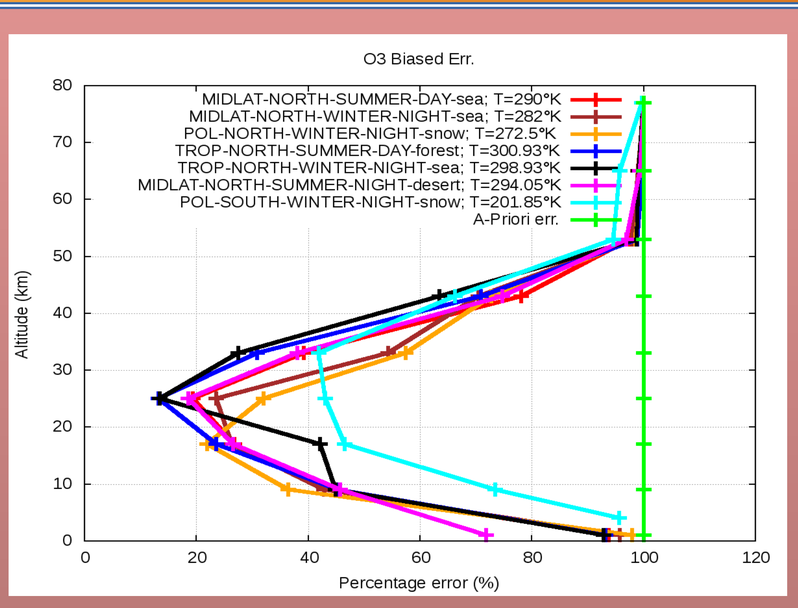
KLIMA is then used to **retrieve vertical gas** profiles with the optimal estimation method:

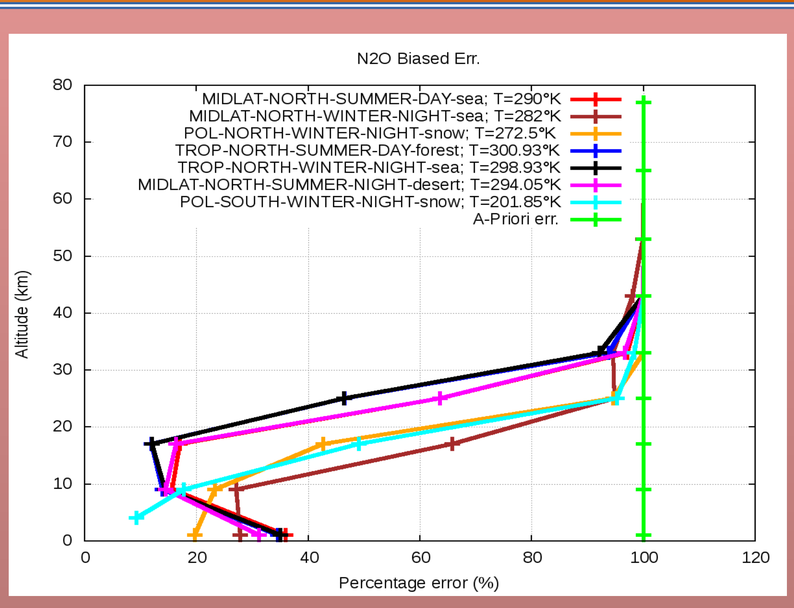
- The retrieval error is estimated as:
- $\mathbf{S_x} = (\mathbf{K}^T \mathbf{S_y}^{-1} \mathbf{K} + \mathbf{S_a}^{-1})^{-1}$
- The averaging kernels (AKs) are computed as:
- $\mathbf{A} = (\mathbf{K}^T \mathbf{S_y}^{-1} \mathbf{K} + \mathbf{S_a}^{-1})^{-1} \mathbf{K}^T \mathbf{S_y}^{-1} \mathbf{K}$

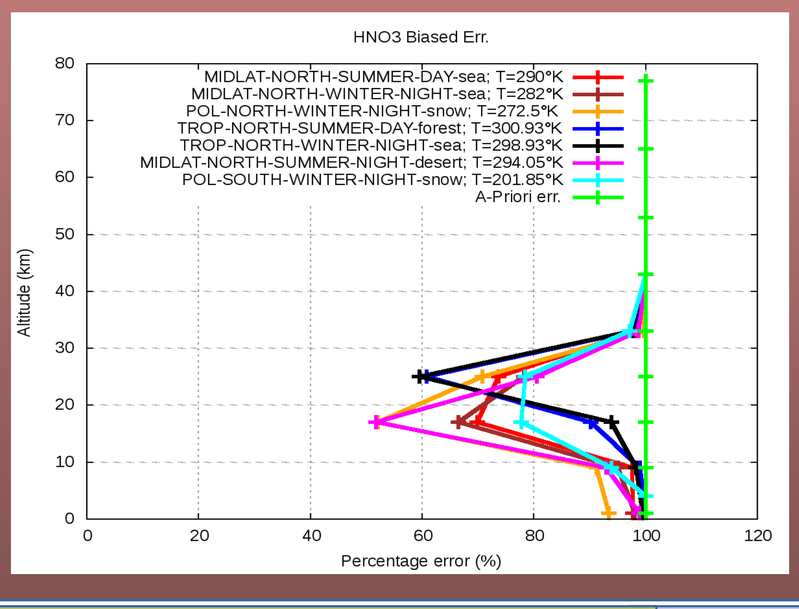
Noise-induced retrieval error

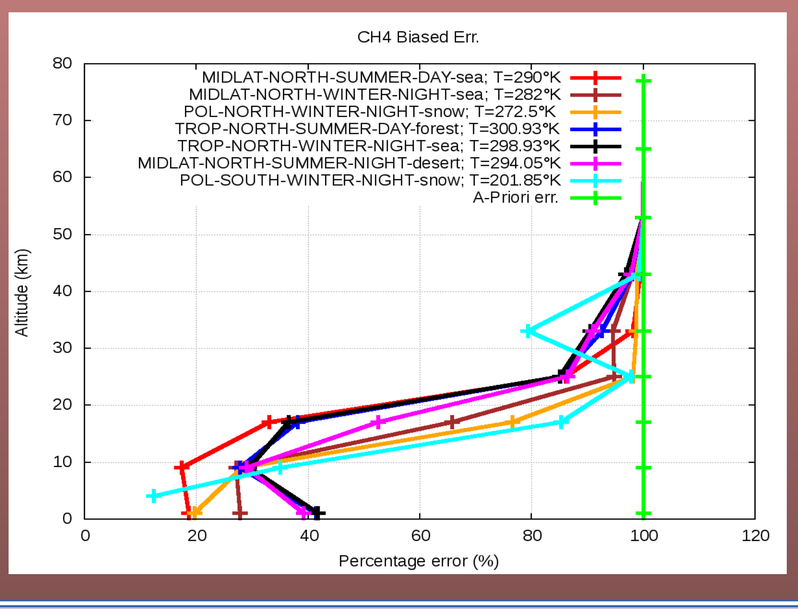
Noise retrieval errors vs altitude, for various clear-sky observational scenarios as indicated in the plot's key. The plots refer (from top-left to bottom-right) to O_3, N_2O, HNO_3 and CH_4 retrievals for seven clear sky scenarios.

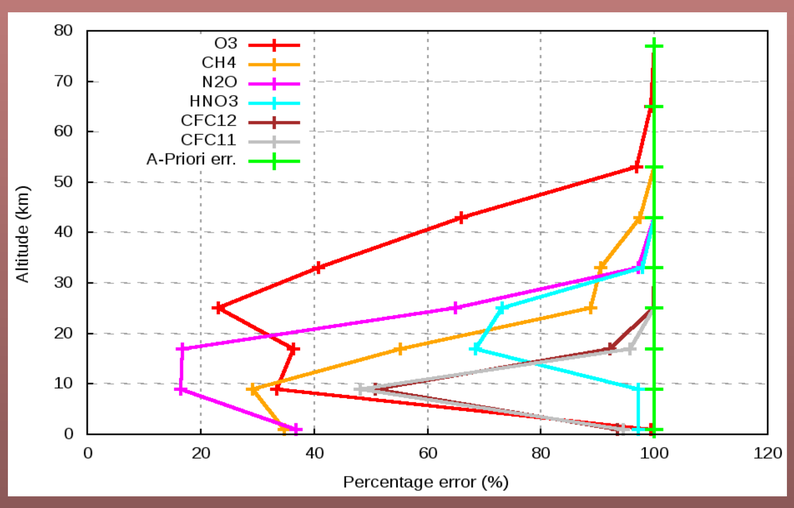
The rightmost-bottom plot shows the errors obtained for CFC-11 and CFC-12 retrievals in a mid-lat scenario, as compared to the errors of other species.







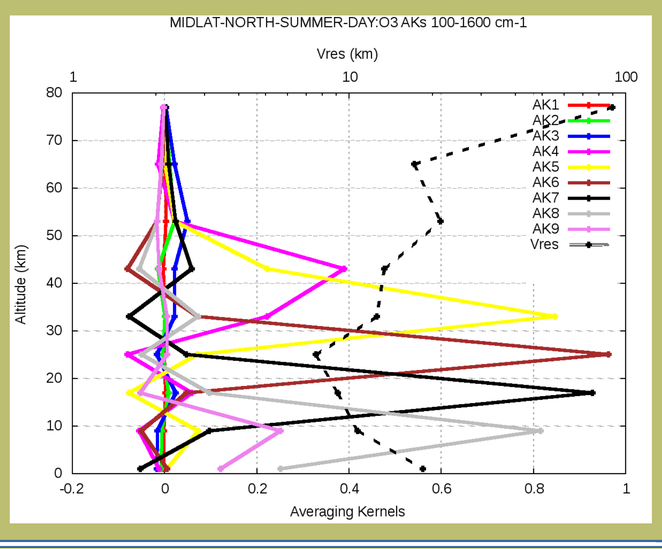




Example of noise retrieval error versus altitude for O_3, CH_4, N_2O, HNO_3, CFC-11 and CFC-12 for a mid-latitude observational scenario, in clear sky conditions.

Averaging Kernels (AKs)

AKs and vertical resolution vs altitude for the retrieval of O_3 in a mid-latitude atmosphere and clear sky conditions.



Summary table of performances

Min. err. (%) = minimum retrieval error achieved.
Min. Vres (km) = minimal (finest) vertical resolution, calculated as the FWHM of the averaging kernels.
Height (km) = altitude range where the minimal retrieval error and finest vertical resolution are achieved.
N_{DOF} = number of Degrees of Freedom of the retrieval, calculated as the trace of the AK matrix.
TC err (%) = percentage error on the Total vertical Column of the gas.

Species	Min. err. (%)	Min. Vres (km)	Height (km)	N_{DOF}	TC err (%)
O_3	15 - 20	7 - 10	20 - 30	4	2 - 3
CH_4 and N_2O	15 - 20	9 - 10	15 - 20	2.5 - 3.5	5 - 15
HNO_3	50	10 - 20	15 - 25	1	15 - 30
F11 and F12	50	13 - 15	9 - 11	1	55

We also tried to retrieve CO from the FIR simulated observations of FORUM, however the CO features are very weak as compared to the measurement noise. We found that the information gain on this gas is negligibly small.

Conclusions

- We find that, in general, the altitude regions with the largest AK peaks, corresponding also to a finer vertical resolution and smaller retrieval errors, are located close to the maximum concentration of the examined gas.
- The obtained results do not depend dramatically on the considered measurement scenario, except for the fact that in extreme Polar Winter conditions, the colder temperatures and air subsidence shift to lower altitudes the maximum of information on all the considered gases.
- The table on the left summarizes the average values of: minimal retrieval error, finest vertical resolution, altitude range for these minima, number of degrees of freedom of the retrieval and error on the total vertical gas column.
- The possibility to retrieve CO from FORUM individual measurements was also investigated, however results are not shown here. The intensity of CO spectral lines in the FIR is so small compared to the measurement noise that a meaningful retrieval is not possible.

References

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