- ITSC-XX: Lake Geneva, Wisconsin, USA, 28 October-3 November 2015 -

poster 2p02

RTTOV GUI: Addition of 1D-VAR retrieval to RTTOV GUI

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Abstract

RTTOV GUI is a graphical user interface for the radiative transfer model RTTOV (1) developed in the context of the EUMETSAT NWP-SAF project and is included in the RTTOV package. The RTTOV GUI was designed for educational purposes and was used in the NWP-SAF's satellite data assimilation training course. The latest version of RTTOV GUI includes a 1D-VAR retrieval functionality. The algorithm is based on the NWP-SAF 1D-VAR retrieval package scheme. It allows the visualization of retrieved Temperature and Specific Humidity profiles from a user-defined profile and background and observation error co-variances. The latest version of RTTOV GUI also offers new enhancements corresponding to new RTTOV-V11.3 features (2).

1. Introduction

RTTOV GUI is a graphical user interface for the radiative transfer model RTTOV developed in the context of the NWP-SAF EUMETSAT project and is included in the RTTOV package (since version 11.2). It allows to run the RTTOV direct and Jacobian models and PC-RTTOV (direct as well as Jacobian) for one atmospheric profile and for all instruments permitted by RTTOV.

The RTTOV GUI was designed for educational purposes and is used in the NWP-SAF's satellite data assimilation training course. The last version of RTTOV GUI includes a 1D-VAR retrieval functionality based on the NWP-SAF 1D-VAR retrieval package scheme.

Historically, there was a graphical user interface for RTTOV version 9. This first software was written in C++ and used wxWidget. This software became hard to maintain. Therefore, for the 11th version of RTTOV, it was decided to rewrite the graphical user interface in Python.
Python is now a well used programming language in the scientific community (3) and comes with a lot of packages for numerical computations and visualization. It is an easy-to-use programming language which also allows an improved productivity for writing complex, easier to maintain, applications.
RTTOV GUI is written in Python 2.7 and uses:

- wxPython: an open source GUI framework based on the powerful wxWidget toolkit.
- NumPy: a Python package for scientific computing.
- matplotlib: a Python package for 2D plotting.
- F2PY: a Python extension tool which permits calling FORTRAN routines from Python (F2PY is part of NumPy).

- h5py: the interface between RTTOV and RTTOV GUI is working with HDF5 files:
  - profile.h5: contains vertical atmospheric profile and options for RTTOV.
  - surface.h5: contains RTTOV input/output surfave emissivity or BRDF values.
  - radr.h5: contains radiances and brightness temperatures (BT) or reflectances computed by RTTOV.
  - kmat.h5: contains the K-matrix computed by RTTOV.

2. Installation

An easy way to install Python 2.7 and all the Python required packages is to use the Anaconda distribution of Python packaged by Continuum Analytics http://continuum.io/downloads.
Anaconda already includes NumPy, matplotlib and h5py and by default is installed on your home directory. To do so, install Anaconda as instructed by Continuum Analytics and then, install the wxPython package with the conda command (which is part of Anaconda):

```
$ conda install wxpython
```

To continue the installation, follow the RTTOV installation guide (https://nwpsaf.eu/deliverables/rtm/docs_rttov11/users_guide_11_v1.4.pdf). The RTTOV GUI is provided as part of the RTTOV package in the gui/ directory.
In order to use RTTOV GUI, update the rttov_gui.env configuration file according to your environment.

To use RTTOV GUI, users need to provide input profile files in either HDF5 or ASCII files. These can be found in the rttov_test/profile-datasets-hdf/ and rttov_test/profile-datasets-py/ directories respectively.

To run the GUI, simply type the following commands:

```
$ cd <RTTOV_ROOT>/gui
$ source ./rttov_gui.env
$ ./rttovgui&
```

This last command launches the GUI.

3. RTTOV GUI Main features

The basic usage of RTTOV GUI can be described in 3 steps:

- Step 1-1: From the “File” menu of the main window (See Fig. 1), start by opening an ASCII or HDF5 profile file. These files contain atmospheric vertical profiles of temperature and gas concentrations, surface parameters, viewing angles and if needed aerosol and cloud vertical profiles. These files may also contain a dataset of logical flags and other settings to control various aspects of how the RTTOV model will be run: these are called the RTTOV Options.
- Step 1-2: (can be done before step 1-1) From the “Rttov” menu of the main window, choose a satellite instrument by selecting a coefficient file for RTTOV. This is mandatory for running RTTOV, as RTTOV is a fast radiative transfer model, it works only with precomputed coefficient files (with a Line by Line radiative transfer model). There are also optional coefficient files if you want to simulate clouds or aerosols. For the hyper-spectral instruments such as IASI or AIRS, there are also coefficient files which allow you to use the Principal Components algorithm of RTTOV (PC-RTTOV).

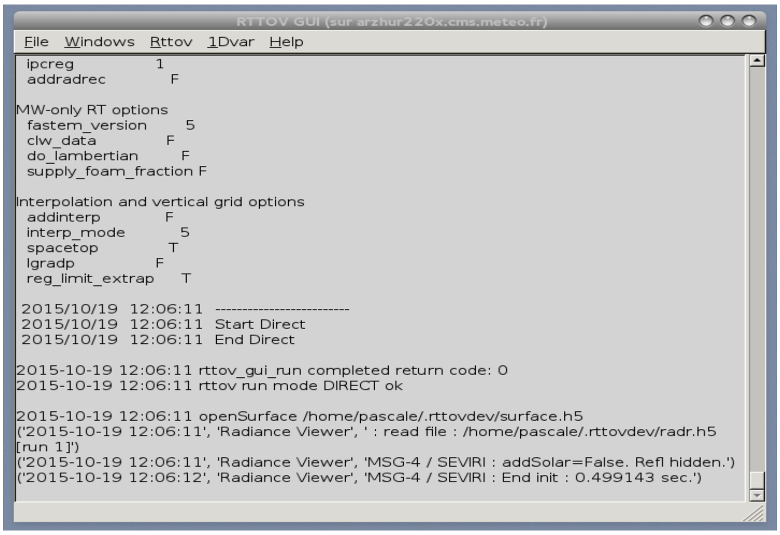


Figure 1: The main RTTOV GUI window.

- Step 2:

From the “windows” menu of the RTTOV GUI main window, 3 different windows can be opened to modify the RTTOV input parameters:

The “Profile editor” window (Fig. 2) for the vertical atmospheric parameters of the profile. This window allows users to see the shape of the atmospheric profiles where all different species are in separated tabs. Additionally, users can click on the right panel in order to modify the values of the profile. Furthermore, users can add or remove gases, aerosols or clouds. Users can also apply to a whole layer of a parameter a scaling factor and an offset (Edit Menu, “Change profile values” command). If users want to change the values of the profile, it is important to check that physical value of each input is consistent with RTTOV. A safe way, is to always have the “do_checkinput” option checked in the “Options” window (See Fig.4).

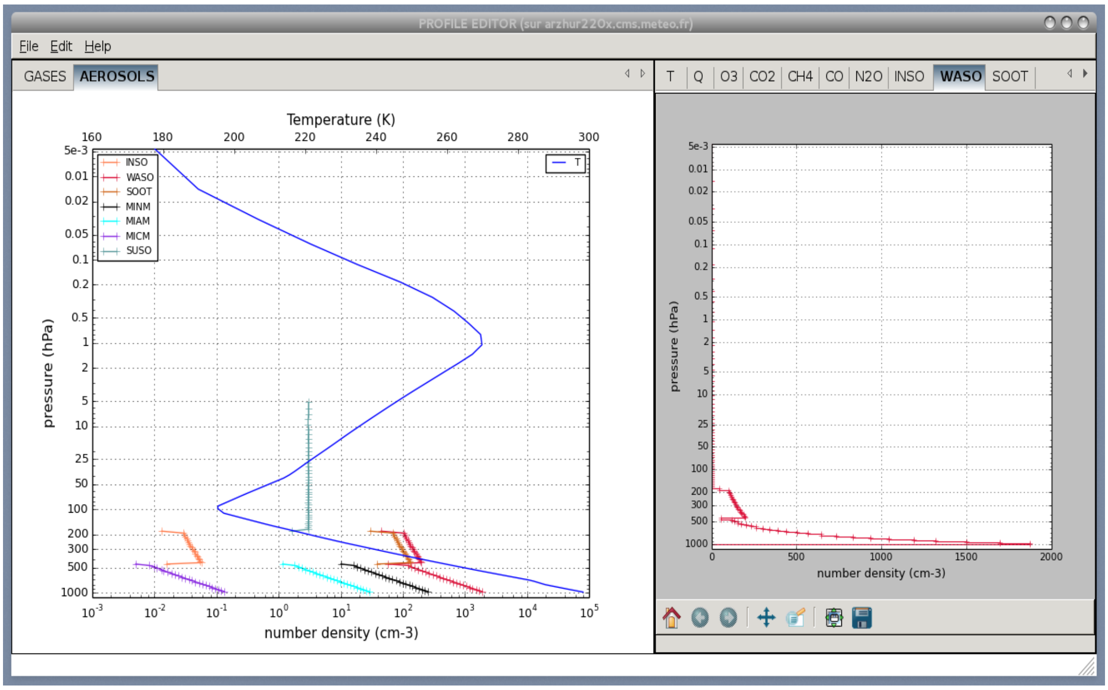


Figure 2: The Profile Editor window

The “Surface Editor” window (Fig. 3) allows the users to modify the surface parameters, the sun and satellite viewing angles and also load RTTOV surface emissivity or BRDF atlas. Finally, this window displays the Emissivity and the BRDF in each band of the selected instrument.

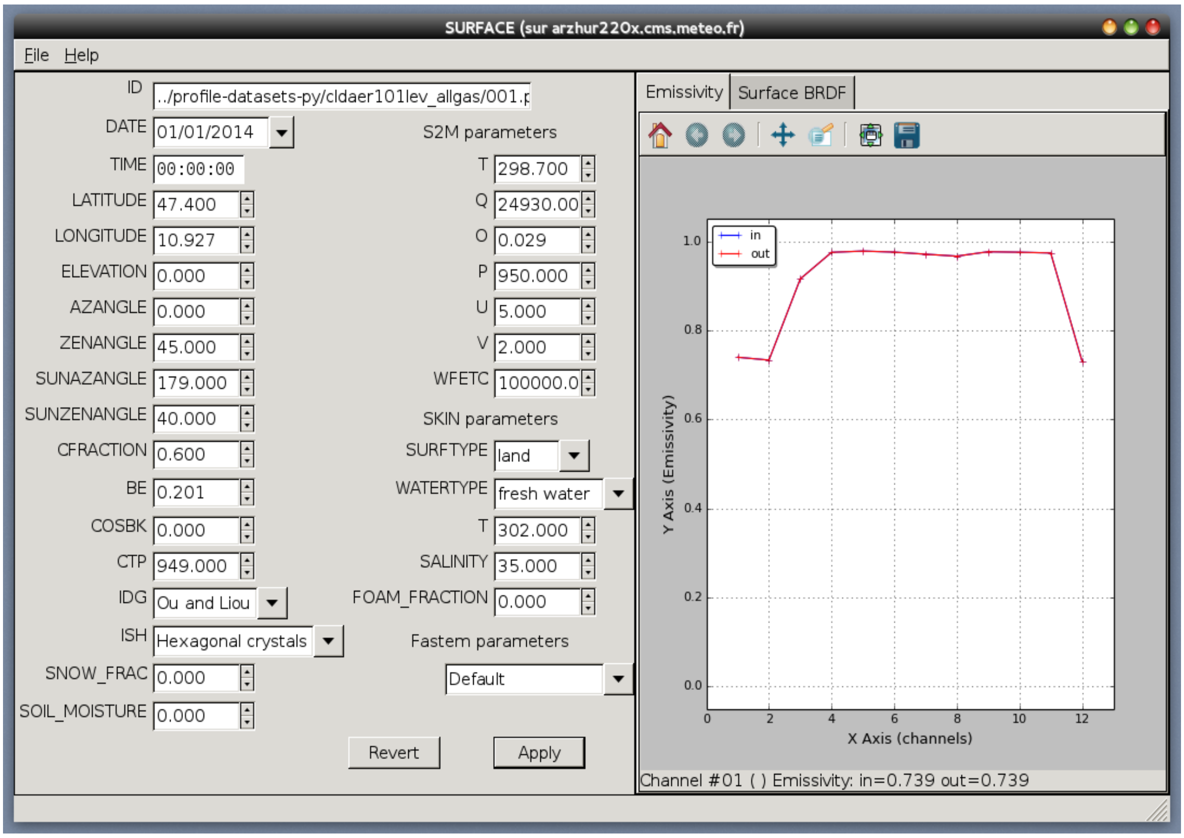


Figure 3: The Surface Editor window

The “Options” window (Fig. 4) allows the users to modify the RTTOV options. There are different kinds of options, some are of general scope (for example the interpolation mode), others apply only to a specific range of instruments.

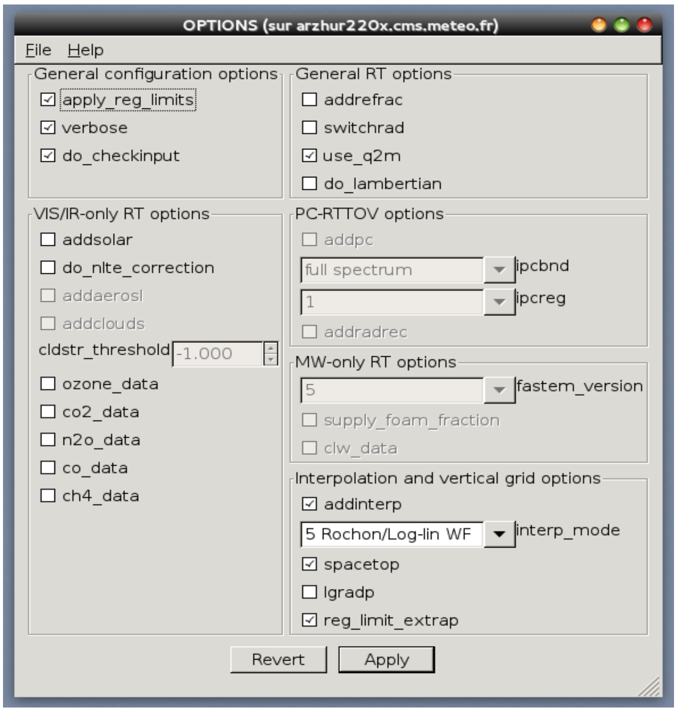


Figure 4: Options window

- Step 3:

Everything is now ready to run the RTTOV model: from the “Rttov” menu of main window, you may now run the direct model (Run RTTOV direct) or the Jacobian model (Run RTTOV-K).

The “Radiance” window (Fig. 5) appears when you run the direct model. This window displays the result of RTTOV: users can visualize radiances, brightness temperatures and reflectances (if the “addsolar” option is selected) computed by RTTOV and visualize the difference between 2 runs.
It is also possible to make channel combinations.

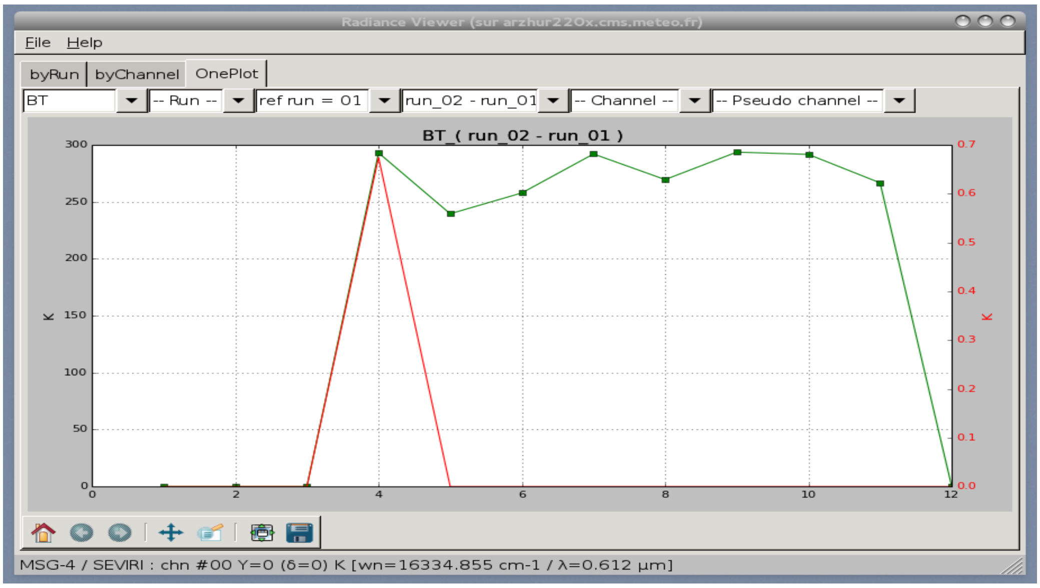


Figure 5: Radiance window for MSG4 SEVIRI instrument

For an hyper-spectral instrument, the “Radiance” window (Fig. 6) displays the spectrum of radiances, brightness temperatures and reflectances in wave numbers.

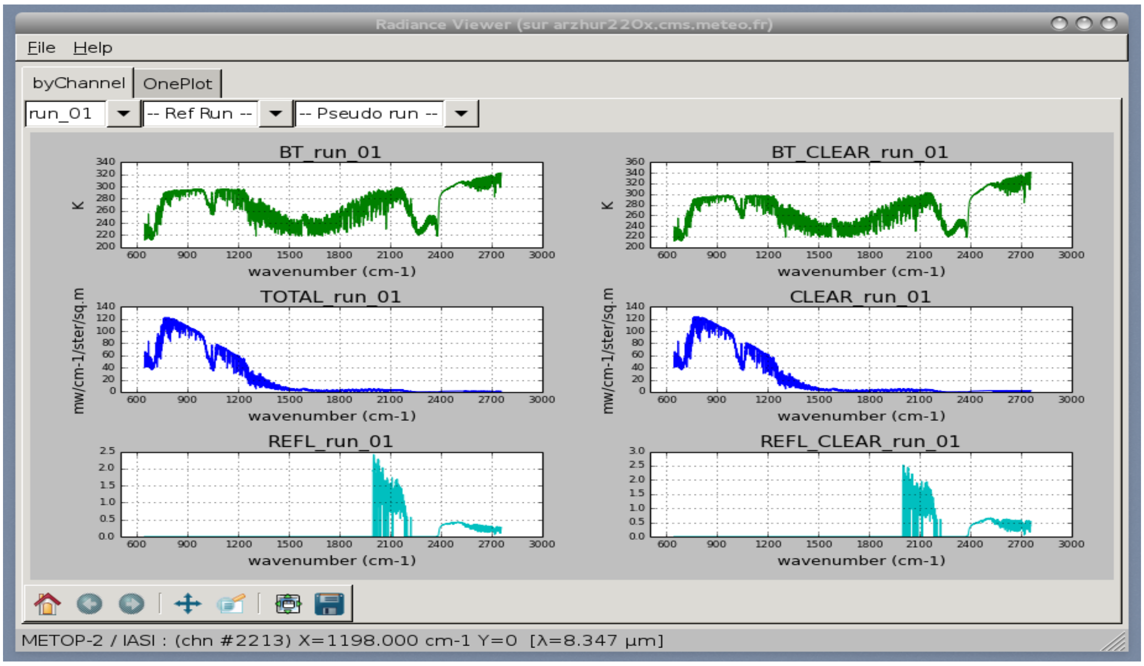


Figure 6: Radiance window for an hyper-spectral instrument

4. The 1D-VAR functionality

This new functionality was added to RTTOV GUI for the 2015 SAFNWP-ECMWF satellite data assimilation course. Its purpose is to demonstrate to a student how the 1D-VAR retrieval works.
The 1D-VAR functionality uses Background and Observation error covariance matrices. These matrices are inherited from the NWP-SAF 1D-VAR retrieval package and they can be customized if necessary: see the NWP-SAF 1D-VAR retrieval package documentation. (https://nwpsaf.eu/deliverables/nwpsaf_1dvar/index.html).

In order to use the 1DVAR functionality, you must use RTTOV GUI with a 54 levels profile. This profile, once opened from the file menu of the RTTOV GUI main window, will be considered as the background profile. It can be modified with the “profile editor” window.
The covariance observation error matrices come from the 1Dvar. Therefore the number of permitted instruments for the RTTOV GUI 1Dvar functionality is restricted: AMSUA, MHS, ATMS, HIRS, AIRS, CrIS, IASI, SSMIS. Choose a 54 levels coefficient file among these instruments.
With this 2 prerequisites, the “Configure 1Dvar” command of the “1Dvar” menu of the main window becomes available: select it .

Work now from the “1D-VAR” window (Fig. 7):

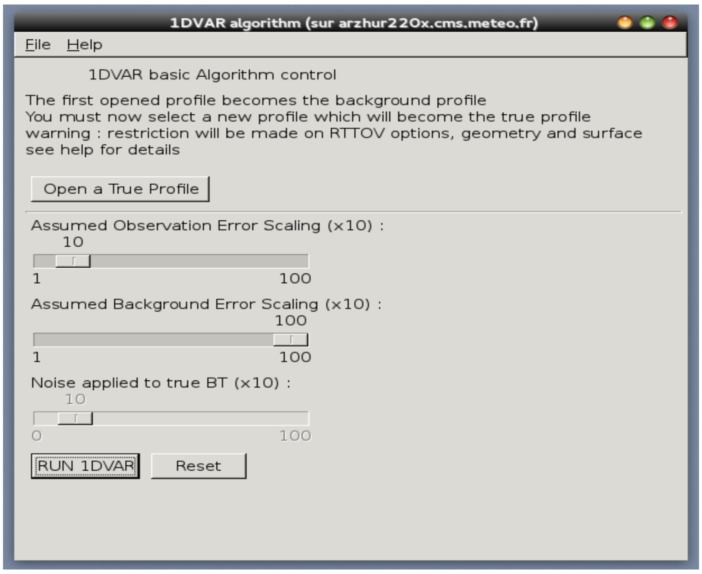


Figure 7: 1D-VAR window

1. Click on the "Open a true profile" in order to load what will be considered as the True profile (Xt): This true profile will be used to compute the simulated observed radiances, and to compare with the retrieved profile.
2. Change the value of the scaling factor (fb) for the background errors if necessary.
3. Change the value of the scaling factor (fr) for the observation errors if necessary.
4. Change the value of the maximum random noise if necessary.
5. Click on the RUN 1DVAR button.

The result is displayed in the Retrieved profile window (Fig. 7), the true profile is in black, the background in blue and the retrieval in red.

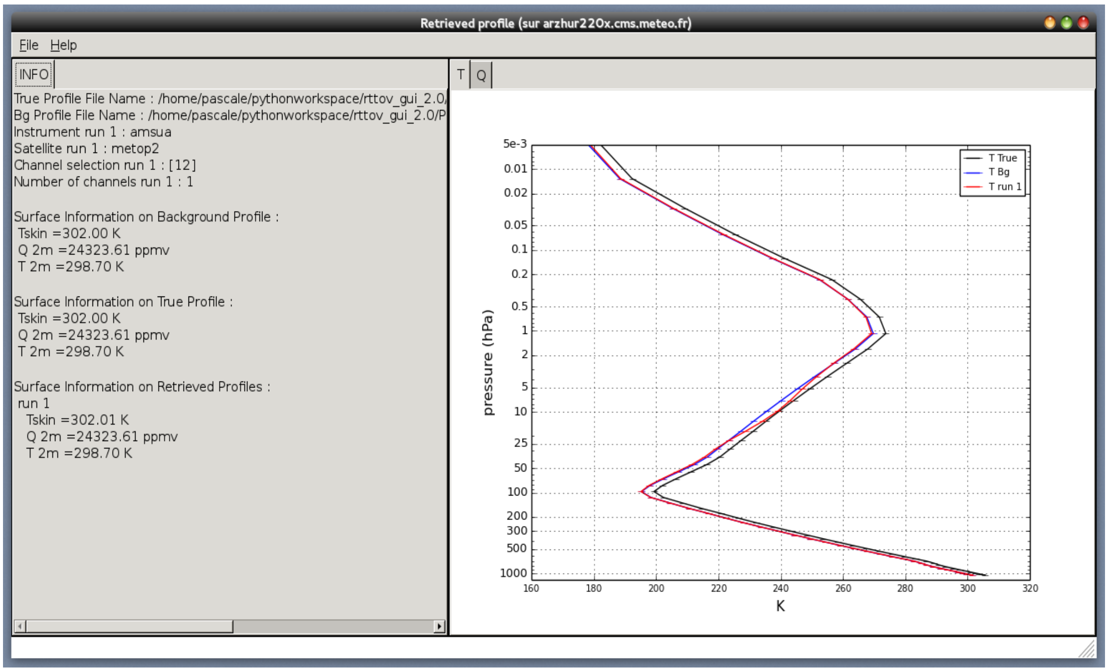


Figure 8: Retrieved profile window

RTTOV GUI allows you to perform a channel selection on the instrument, this functionality can be very useful if you want to “see” the retrieval in “action”.
In order to visualize at which level a specific channel of a instrument may be useful for the retrieval process, you can run RTTOV-K for all channels of an instrument from the Rttov menu of the main window. Then, RTTOV GUI shows a window called the K-Matrix Viewer. This window displays the results of the Jacobian model for the different channels for the temperature and for the gas concentrations. In this example (Fig. 8) of a K-matrix viewer for the METOP 1/AMSUA instrument, one can easily see that the influence of a slight modification of the temperature may be of some importance at the level where the Jacobian is the largest.

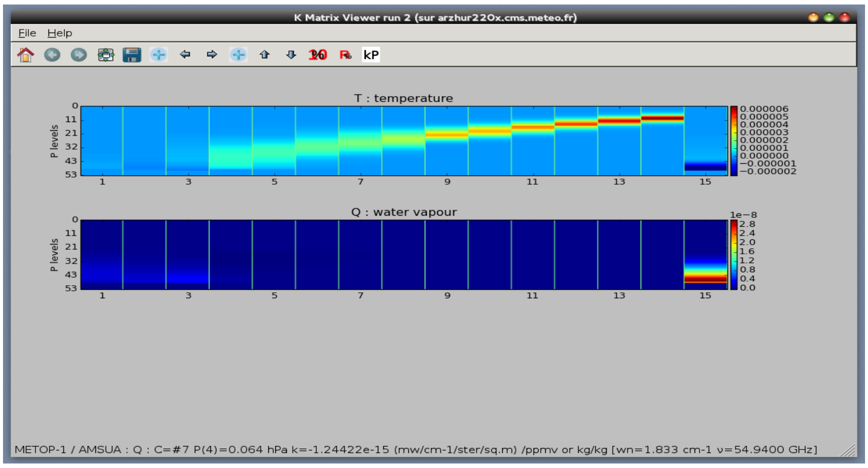


Figure 9: K-Matrix Viewer, this window is shown when one runs the Jabobian model (RTTOV-K).

From the K-matrix viewer, the user can, with the “kP button”, select a channel in order to display the K profile. In the figure 9, displaying the K profile window for channel 12 of METOP-1/AMSUA, one can see that the Jacobian of temperature has its peak around 10 hPa (see Fig. 7), and one can deduce that this channel will add some important information in the retrieval process at this level.

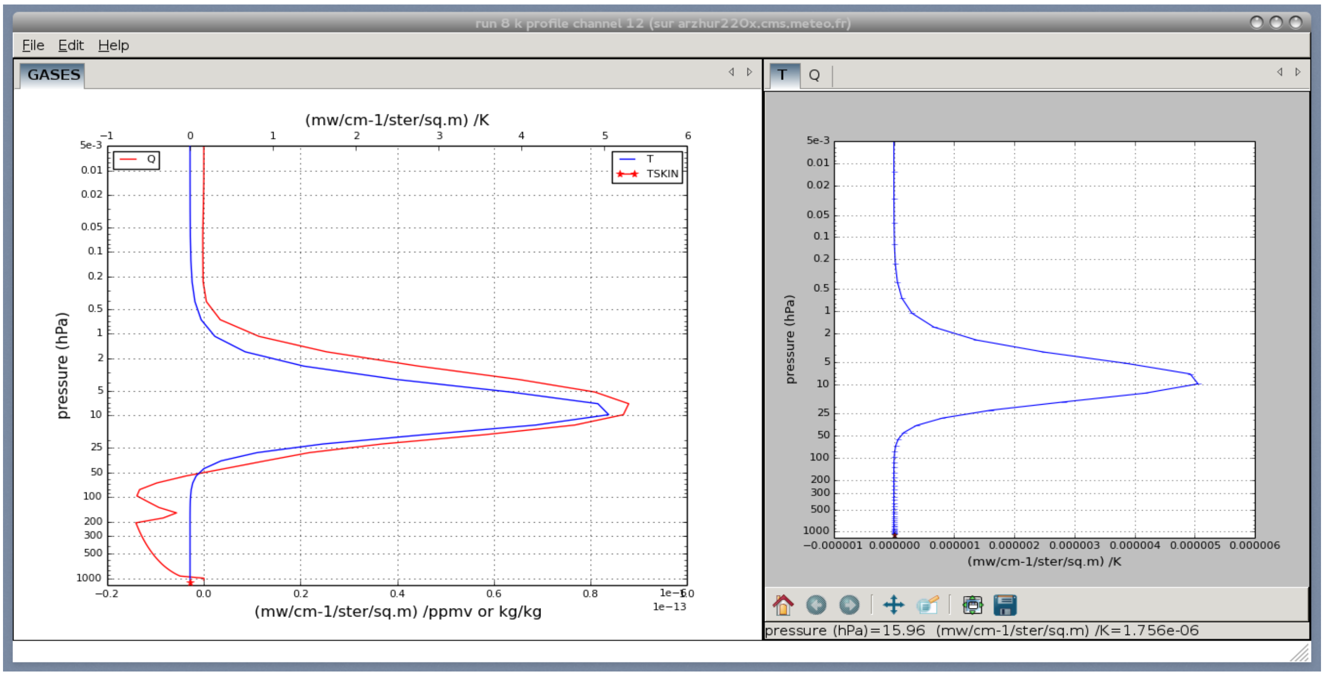
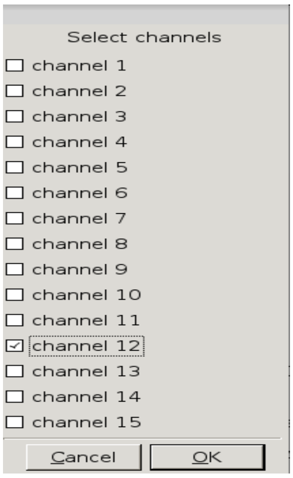


Figure 10 K: profile window displaying a Jacobian for METOP-1/AMSUA channel 12.

From the “Rttov” menu of the main window, the user can perform the channel selection, and choose the 12th channel.



In the figure 7, which is a retrieval for the METOP-1/AMSUA 12th channel, one can easily see that the retrieved curve for the temperature adjusts very nicely around 10 hPa.

Computations made by RTTOV GUI:

In the calculation below, X_t is the true vertical profile. This vertical profile is never known in the reality.
But the purpose is to show with RTTOV GUI, how it is possible to retrieved it from satellite observations. In the reality what are known are the observed brightness temperatures: they can be simulated in this experiment with the direct model of RTTOV from X_t :

The computation made by RTTOV GUI are:

1. Compute brightness temperatures Y_t from X_t (RTTOV direct model):

$$Y_t = RTTOV_{direct}(X_t) \quad [1]$$

2. Compute brightness temperatures Y_b from X_b (RTTOV direct model):

$$Y_b = RTTOV_{direct}(X_b) \quad [2]$$

3. Compute Jacobian matrix K and transpose K^T (RTTOV-K model):

$$K = RTTOV\text{-}K(X_b) \quad [3]$$

4. Apply scaling factor to background errors:

$$B = f_b\ B \quad [4]$$

5. Apply scaling factor to observation errors:

$$R = f_r\ R \quad [5]$$

6. Compute linear 1DVAR weights W:

$$W = B K^T [K B K^T + R]^{-1} \qquad [6]$$

7. Compute linear 1DVAR retrieved profile X_r:

$$X_r = X_b + W [(Y_t + N) - Y_b] \qquad \text{where } N = \text{random noise vector} \qquad [7]$$

5. Conclusion

RTTOV GUI is a great tool for learning about the radiative transfer in the atmosphere. It allows a neophyte user to use the radiative transfer model RTTOV in a very user-friendly way. It allows a student to understand how it is possible to retrieve an atmospheric vertical profile from satellite measures.

6. References

(1) RTTOV home page: https://nwpsaf.eu/deliverables/rtm/index.html

(2) ITSC-XX 2p.01. RTTOV development status
http://cimss.ssec.wisc.edu/itwg/itsc/itsc20/program/PDFs/28Oct/session2b/2p_01_hocking.pdf

(3) Why scientists should learn to program in Python
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