4AOP : A fast and accurate operational radiative transfer model for the infrared

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4A/OP Operational release for 4A

4A stands for Automatized Atmospheric Absorption Atlas.
4A is a fast and accurate line-by-line radiative transfer model particularly efficient in the infrared region of the spectrum.
4A/OP is a user-friendly software for various scientific applications, co-developed by LMD (Laboratoire de Météorologie Dynamique) and NOVELTIS with the support of CNES (the French Spatial Agency).

Abstract

NOVELTIS is in charge of the industrialization and the distribution of the LMD 4A radiative transfer model. NOVELTIS has created an "operational" version of this code called 4A/OP.
The 4A/OP software is a version of the 4A code for distribution to registered users. This version is regularly updated and improved and contains a graphical user interface and a reference documentation. The associated Website http://www.noveltis.fr/4AOP/ includes an on-line registration form.
4A/OP has the official support of CNES for radiative transfer applications in the infrared. This software is used by several research groups and can be integrated in operational processing chains. In particular, 4A/OP is the reference radiative transfer model for IASI level 1 Cal/Val and level 1 operational processing. Thanks to the computation of Jacobians, the model can also be coupled with an inversion algorithm for the atmospheric constituent retrieval.

What is 4A/OP?

The 4A/OP software package includes the radiative transfer model 4A, initially developed at LMD:

- **Atlases**

4A allows the **fast** computation of the transmittances and the radiances, thanks to the use of a comprehensive database, the atlases [1], of monochromatic optical thicknesses:

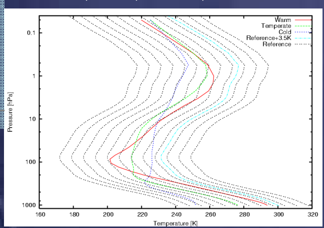
- ✓ for up to 43 atmospheric molecular species (reference mixing ratio profiles);
- ✓ for 12 nominal atmospheres (12 temperature profiles 7K distant);
- ✓ for a set of 40 pressure levels between surface and top of the atmosphere;
- ✓ for a $5\ 10^{-4}$ cm^{-1} nominal spectral step;
- ✓ separation into 15 cm^{-1} blocks for each gas: several matrices compressed in wave numbers / layer / temperature.

4A allows **accurate** computations: The atlases are created by using the line-by-line and layer-by-layer model, STRANSAC [2], with state-of-the-art physics. It uses spectroscopy from the latest edition of the GEISA spectral line catalogue [3]. Other spectroscopy databanks can be used.

level	Pressure (hPa)	level	Pressure (hPa)	level	Pressure (hPa)	level	Pressure (hPa)
1	0.05	11	7.43	21	131.20	31	471.86
2	0.09	12	11.11	22	161.99	32	525.00
3	0.17	13	16.60	23	200.00	33	584.80
4	0.30	14	24.79	24	222.65	34	651.04
5	0.55	15	37.04	25	247.87	35	724.78
6	1.00	16	45.73	26	275.95	36	800.00
7	1.50	17	56.46	27	307.20	37	848.69
8	2.23	18	69.71	28	341.99	38	900.33
9	3.33	19	86.07	29	380.73	39	955.12
10	4.98	20	106.27	30	423.85	40	1013.25

Table 1: Current 40-level vertical grid of the 4AOP optical thickness atlases

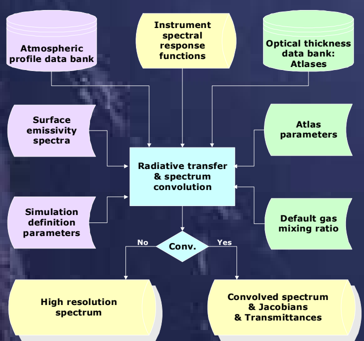
Atlas temperature discretisation (black) and user temperature profile examples (in colour)



- **Radiance computation**

To do a calculation, the compressed matrix is uncompressed and interpolated:

- to the correct temperature for each layer (interpolation between two adjacent temperature profiles);
- to the correct pressure levels (the nominal 40 pressure levels are not mandatory) scaled to the correct absorber amount and angle.

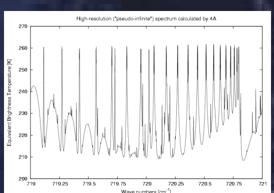


Absorption from each individual gas is added up and a transmittance calculation, as well as Jacobian calculations (these latter are optional), are performed.
Starting from these high spectral resolution optical depths, transmittance profiles, Jacobian profiles, radiances and brightness temperatures are generated (integration of the radiative transfer equation) and if necessary combined with a relevant convolution step to take into account the various instrument functions.
The computation is performed in a **spherical atmosphere**, at a user defined observation level for **zenith**, **nadir** or **limb** observations.

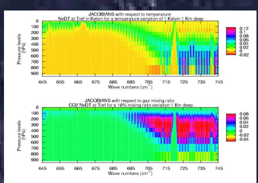
4A computes the radiance spectrum in a user-defined spectral domain in the **infrared region**; the usual domain is between 600 and 3,000 cm^{-1}.
4A can be used for a **wide variety of surface** and earth atmospheric conditions, including **solar contribution**.

- **4A/OP output**

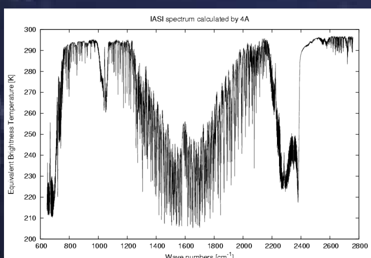
- ✓ High spectral resolution spectra (nominal spectral resolution: 5.10^{-4} cm^{-1})
- ✓ Convolved spectra with various types of instrument functions;
- ✓ Jacobians on user-defined layers: Partial derivatives of the radiance with respect to the temperature, gas mixing ratio and emissivity. They allow the model coupling with an inversion algorithm for the atmospheric constituent retrieval from infrared radiance measurements.



High-resolution spectrum example



Temperature (top) and CO_2 (bottom) Jacobians – IASI 1c (645-745 cm^{-1})



IASI 1c spectrum example

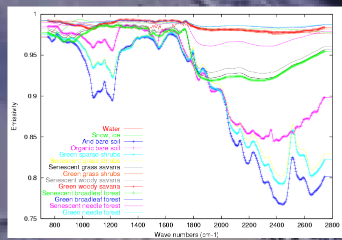
4A/OP enhancement

NOVELTIS is now in charge of the industrialization and the distribution of 4A, in accordance with a convention signed between CNES, LMD/CNRS and NOVELTIS:
Current version 4AOP2006v2.1 (11/2007)
The 4A/OP software is a version of the 4A code for distribution to registered users. The available operational version includes:

- Regular updating and improvements
- Graphical User Interface (GUI)
- Reference Documentation
- Website http://www.noveltis.fr/4AOP/ including an on-line registration form
- Distribution with maintenance and assistance; the full software package is available as a freeware product for academic and scientific research
- Additional scientific functions:
  - User-defined spectral emissivity functions
  - Spherical atmosphere
  - Solar contribution

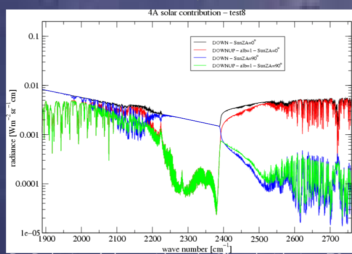
- **Emissivity = f(v)**

The 4A/OP code can take surface properties constant as well as function of the wave number. At the moment, the emissivities of Snyder (1998) have been introduced and the user can define other emissivity functions.



- **Solar contribution**

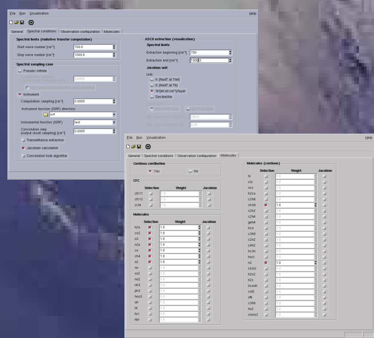
The solar component has been added to the 4A/OP radiative transfer computation in order to simulate day-time conditions.



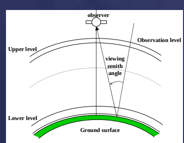
IASI daytime (solar zenith angle 0°) and nighttime TOA radiance spectra for a white surface (green and red, respectively) in comparison to corresponding surface daytime and nighttime spectra (black and blue, respectively) for wave numbers above 1890 cm^{-1}.

Graphical User Interface

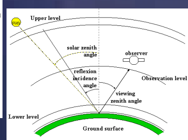
The 4A/OP GUI allows the user to create a basic 4A/OP input file by selecting values with buttons, pull-down menus, and text fields.
The GUI has been developed in Tcl/Tk.



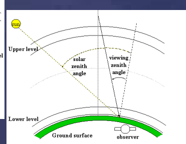
Different observation configurations



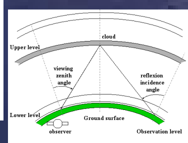
Nadir viewing



Viewing with ground surface reflection



Zenith viewing



Viewing with cloud reflection

Run time examples

Machine	IASI spectrum alone	IASI spectrum + 4 Jacobians
Linux Xeon Bipro 3.4 GHz	about 28 s	about 5 min
Unix Sun V880 900 MHz	about 110 s	about 30 min

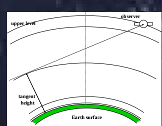
Running 4A/OP

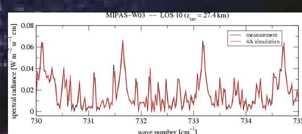
4A/OP runs on any platform with Fortran 90 compiler (tested on Sun and Linux PC).

In progress

A new version of 4A/OP will be released by mid 2008. It will include:

- Scattering for aerosol contribution (coupled with DISORT);
- Limb viewing including refraction.





4A/OP-limb simulation (red) over MIPAS level 1b spectrum (black). LOS: 27.4 km. Spectral domain: 730-735 cm^{-1}

References

[1] Scott, N.A. and A. Chedin, 1981: A fast line-by-line method for atmospheric absorption computations: The Automatized Atmospheric Absorption Atlas. J. Appl. Meteor., 20,802-812.
[2] Scott, N.A., 1974: A direct method of computation of transmission function of an inhomogeneous gaseous medium: description of the method and influence of various factors. J. Quant. Spectrosc. Radiat. Transfer, 14, 691-707.
[3] Jacquinet-Husson, N. et al., 1999: The 1997 spectroscopic GEISA data bank. J. Quant. Spectrosc. Radiat. Transfer, 62, 205-254.

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