4AOP : A fast and accurate operational forward radiative transfer model

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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. 4A is a fast and accurate line-by-line radiative transfer model for the computation of transmittances, radiances and Jacobians, particularly efficient in terms of accuracy and computation time. NOVELTIS has developed an "operational" version of this code called 4A/OP available for distribution to registered users. This software is used by several research groups and can be integrated in operational processing chains including inverse problems processing.
The operational version of 4AOP is regularly updated and improved. It also contains a graphical user interface and 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. In particular, 4A/OP is the reference radiative transfer model for IASI level 1 Cal/Val and level 1 operational processing.

What is 4A/OP?

The 4A/OP software package includes the radiative transfer model 4A, initially developed at LMD. The 4A calculation relies in particular on a multi-dimensional interpolation using a pre-built optical thickness database called "Atlases" [1].

· Atlases

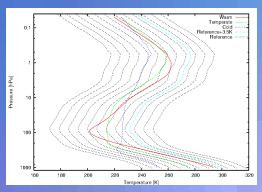
4A allows the fast computation of the transmittances and the radiances, thanks to the use of a comprehensive database, the atlases, of monochromatic optical thicknesses:
- ✓ for up to 43 atmospheric molecular species (reference mixing ratio profiles);
- ✓ for 12 nominal atmospheres (12 temperature profiles 7K distant);
- ✓ for a set of 44 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 and up-to-date spectroscopy from the latest edition of the GEISA spectral line catalogue [3] and also http://ether.ipsl.jussieu.fr

Level	Pressure (hPa)	Level	Pressure (hPa)	Level	Pressure (hPa)	Level	Pressure (hPa)
1	0.0026	12	3.33	23	106.27	34	471.86
2	0.0069	13	4.88	24	131.20	35	525.00
3	0.0240	14	7.43	25	161.99	36	584.80
4	0.0500	15	11.11	26	200.00	37	651.04
5	0.0900	16	16.60	27	222.65	38	724.78
6	0.1700	17	24.29	28	247.87	39	800.00
7	0.3000	18	37.04	29	275.95	40	848.69
8	0.5500	19	45.73	30	307.20	41	900.33
9	1.0000	20	56.46	31	341.99	42	955.12
10	1.5000	21	69.71	32	380.73	43	1013.25
11	2.2300	22	86.07	33	423.85	44	1050.00

New current 44-level vertical grid of the 4AOP optical thickness atlases

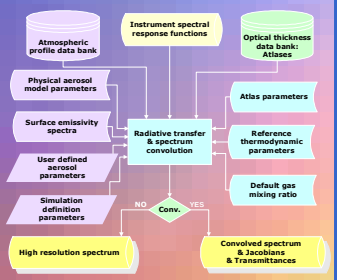
Atlas temperature discretisation (black) and user temperature profile examples (in colour)



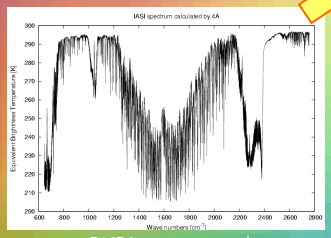
· Radiance computation

To do a calculation, the model reconstructs the optical thickness profile for any given atmospheric condition by interpolating in the atlases.
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.

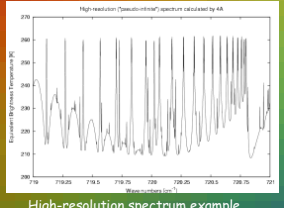
4A computes the radiance spectrum in a user-defined spectral domain in the **infrared region**; the usual domain is between 600 and 3,000 cm^{-1}.
4A can be used for a **wide variety of surface** and earth atmospheric conditions, including **solar contribution**.



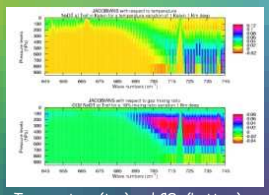
· 4A/OP output
- ✓ High spectral resolution spectra (nominal spectral resolution: 5.10^{-4} cm^{-1})
- ✓ Convolved spectra with various types of instrument functions;
- ✓ Jacobians on user-defined layers: Partial derivatives of the radiance with respect to the temperature, gas mixing ratio and emissivity.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



IASI 1c spectrum example



High-resolution spectrum example



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

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.
The current operational version 4AOP2009v1.0 (10/2009) includes:

Additional scientific functions:
- · User-defined spectral emissivity functions
- · Spherical atmosphere
- · Solar contribution
- · Scattering for aerosol contribution (coupled with DISORT)
- · Limb viewing geometry (including refraction)

Other functionalities :
- · Regular updating and improvements
- · Graphical User Interface (GUI)
- · Reference Documentation [4] and quick Start Guide
- · 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

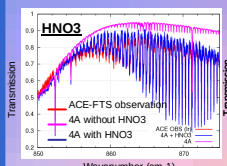
4A/OP validation at LMD

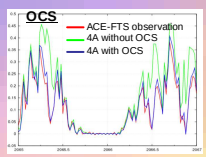
·Limb application: comparisons with the ACE-FTS

No "minor" constituents in limb-viewing!
Due to very long optical paths, number of molecules may impact the radiative transfer in a non-negligible way (NO, SO_2, NO_2, HNO_3, HF, HCL, OCS, HCN).

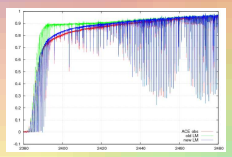
Limb-viewing observations, involving long optical paths, require high attention being paid to the radiative transfer modeling. They offer good opportunity to further validate R.T. models.

Update of the CO_2 line-mixing contribution





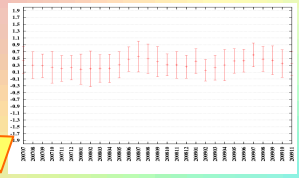
Comparison of transmittances : 4A/OP vs ACE-FTS at a geometric tangent of 11km



Comparison of transmittances : 4A/OP vs ACE-FTS at a geometric tangent of 22 km

Conclusions : The comparisons with ACE-FTS validate the use of 4A/OP in limb-viewing experiments

· Validation of 4A/OP through the analysis of Long Time Series of differences between simulated (4A/OP) and observed (IASI) Brightness Temperatures (« deltacs »),



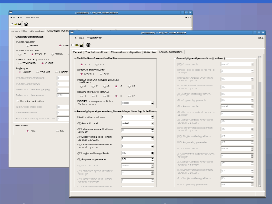
- · Instruments : IASI/AMSU-A/MHS (all channels)
- · Collocations (300km, 3 hours) of clear (**) satellite observations with the Analyzed RadioSoundings Archive
- ·Monthly statistics from, so far, July 2007 to November 2009: approximately 80 items per month for sea, night, tropical atmospheres

Example of the deltac values for one IASI channel in the 15 µm (722.25 cm-1) band showing variability due to the seasonal variation of the CO_2 concentration. The standard deviation is ~0.2 K.

Software features

· 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.



· Running 4A/OP

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

· Run time examples

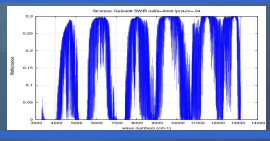
Machine	IASI spectrum alone	IASI spectrum + 4 Jacobians
Linux Xeon Bipro 3.4 GHz	about 28 s	about 5 min
Unix Sun V880 900 MHz	about 110 s	about 30 min

In progress …

· Acceleration of the time computing in scattering case

· Extension to the Short Wave Infra Red domain

4A-SWIR reflectance spectrum between 3000 and 13500 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., 2008: The GEISA spectroscopic database: Current and future archive for Earth and planetary atmosphere studies. J. Quant. Spectrosc. Radiat. Transfer, 109, 1043–1059.
[4] L. Chaumat, C. Standfuss, B. Tournier, R. Armante and N.A. Scott, 2009: 4A/OP Reference Documentation, NOV-3049-NT-1178-v4.0, NOVELTIS, LMD/CNRS, CNES, 309 pp.

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