



4AOP : A fast and accurate forward radiative transfer model

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4A/OP Operational release for 4A

4A stands for Automated 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

4A/OP is the operational user-friendly software - developed by NOVELTIS with the support of CNES - of the LMD 4A forward radiative transfer model. The 4A/OP package is regularly updated and improved. It also 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 is distributed to registered users. 4A/OP has the official support of CNES for radiative transfer applications in the infrared; in particular, 4A/OP has been chosen by CNES as the official radiative transfer model for the IASI level 1 Cal/Val and level 1 operational processing. This operational software is used by several research groups and can be integrated in operational processing chains including inverse problems processing.
Additional and strengthened capabilities of the new version - to be used by CNES in the Cal/Val of IASI/MetOp-B in 2012 - is presented. An outlook on ongoing developments, in particular the extension to the Short Wave InfraRed domain (reference code for Microcarb mission), is given.

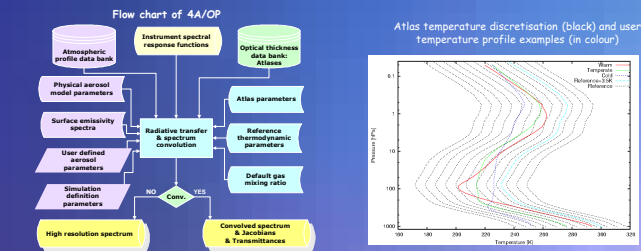
What is 4A/OP?

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 53 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 $5 \cdot 10^{-4}$ 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>

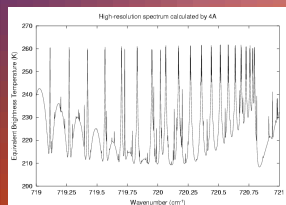


Radiance computation

1. Interpolation in the atlases → optical thickness profile for any given atmospheric condition.
2. Transmittance calculation.
3. Integration of the radiative transfer equation:
 - High resolution spectrum
4. If necessary, convolution with any instrument function (ISRF)
 - Convolved spectrum

4A/OP output

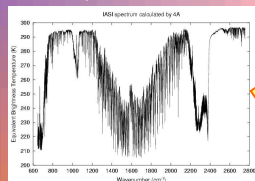
- ✓ High spectral resolution spectra (nominal spectral resolution: $5 \cdot 10^{-4}$ cm⁻¹)
- ✓ Convolved spectra with various types of instrument functions;
- ✓ Jacobians on user-defined layers: partial derivatives of the radiance with respect to the temperature, gas mixing ratio and emissivity. They allow the model coupling with an inversion algorithm for the atmospheric constituent retrieval from infrared radiance measurements.



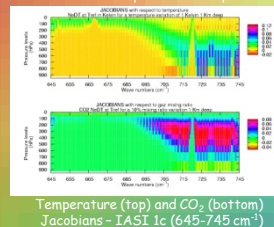
High-resolution spectrum example

The computation is performed in a spherical atmosphere, at a user defined observation level for zenith, nadir or limb observation.

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 and scattering by aerosols and cirrus (coupled with DISORT).



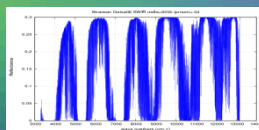
IASI 1c spectrum example



Temperature (top) and CO₂ (bottom) Jacobians - IASI 1c (645-745 cm⁻¹)

Extension to SWIR domain

- Main features
- ✓ Rayleigh scattering
- ✓ Any available solar spectrum
- ✓ Doppler shift of solar lines
- ✓ CO₂ line-mixing and CO₂ line broadening by H₂O
- ✓ O₂ Line-mixing effects + CIA contribution in O₂A-band
- ✓ Scattering module: DISORT, LIDORT or VLIDORT (including Jacobian calculation)
- ✓ Polarization with VLIDORT
- ✓ BRDF introduction (via LIDORT or VLIDORT)



Reflectance spectrum between 13500 and 3000 cm⁻¹ (from 0.74 to 3 μm)

Validation in progress

- ✓ Comparison with other RT codes
 - LBLDOM (from LOA, Lille, France)
 - Successive orders of scattering (CNES)
- ✓ Validation with real measurements
 - In-situ observations from TCCON network
 - GOSAT data
- Current use
- ✓ Microcarb preliminary design studies (CNES)
- ✓ Chosen by the PI as the reference code for Microcarb mission
- ✓ GOSAT retrievals / spectral calibration

In progress ...

- ✓ Next steps
 - GNU GPL license / On-line download
 - Migration of 4A-SWIR into operational version
- ✓ Scientific developments
 - Further validation with real measurements
 - CH₄ Line-mixing
- ✓ Technical developments
 - Speed up in scattering case
 - Graphical user interface to include SWIR features

References

- [1] Scott, N.A. and A. Chedin, 1981: A fast line-by-line method for atmospheric absorption computations: The Automated 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., 2011: The 2009 edition of the GEISA spectroscopic database : J. Quant. Spectrosc. Radiat. Transfer, 112, 2395-2445.
- [4] L. Chaumat, C. Standfuss, B. Tournier, E. Bernard, R. Armante and N.A. Scott, 2012: 4A/OP Reference Documentation, NOV-3049-NT-1178-v4.3, NOVELTIS, LMD/CNRS, CNES, 315 pp.

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4A/OP enhancement

NOVELTIS is in charge of the industrialization and the distribution of 4A, in accordance with a convention signed between CNES, LMD/CNRS and NOVELTIS.
The 4A/OP software is a version of the 4A code for distribution to registered users.
Current version: 4AOP2012v1.0 (03/2012)
The available operational version includes:

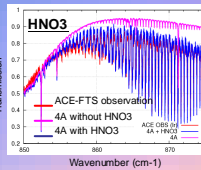
- Regular updating and improvements
- Graphical User Interface (GUI)
- Reference Documentation [4] and quick Start Guide
- Website <http://www.noveltis.fr/4AOP/> including an on-line registration form
- Distribution with maintenance and assistance; the full software package is available as a freeware product for academic and scientific research

New updates:

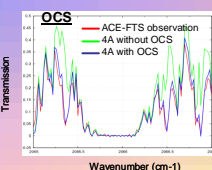
- Scattering for cloud (cirrus...) contribution
- New atlases of absorption optical thicknesses:
 - ✓ Improvement of CO₂ line-mixing
 - ✓ New GEISA 2009 spectroscopy
 - ✓ Pressure shift for H₂O, CO₂ and N₂O
 - ✓ Update reference gas mixing ratio profile
 - ✓ Improved TIPS' formulation
- Update and improved the GUI

4A/OP validation at LMD

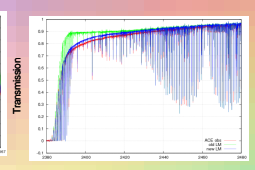
No "minor" constituents in limb-viewing!
Due to very long optical paths, number of molecules may impact the radiative transfer in a non-negligible way (NO, SO₂, NO₂, HNO₃, HF, HCl, OCS, HCN).



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



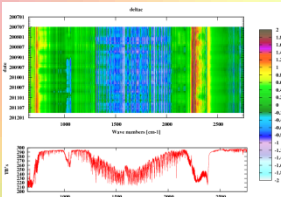
Comparison of transmittances: 4A/OP vs ACE-FTS at a geometric tangent of 22 km



Update of the CO₂ line-mixing contribution

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

• Validation through the analysis of differences between simulated (4A/OP) and observed Brightness Temperatures (< deltas >): the biases and standard deviations are systematically investigated in order to unambiguously identify the source of the discrepancies: natural (e.g. seasonal cycle,), spectroscopic, instrumental, thermodynamical, ...

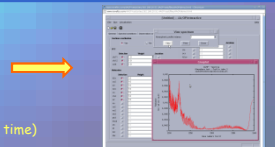


- Instruments: IASI (all channels) but also AIRS, IIR, Seviri, MODIS, TOVS, ATOVs, ...
- Collocations (300km, 3 hours) of clear satellite observations with ARSA (Analyzed Radio Soundings Archive <http://ara.abct.lmd.polytechnique.fr>)
- Monthly statistics from, so far, July 2007 to October 2011: approximately 90 items per month for sea, night, tropical atmospheres

Bias "calc-obs" for all of the 8461 channels of IASI between July 2007 and October 2011. Talk Armante et al. Friday 23, 17:00

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.



Running 4A/OP

4A/OP runs on any platform with several Fortran 90 compilers (gfort90, f90, ifort, gfortran/g95) and has been tested on Sun and Linux PC.

Run time examples (CPU time)

Machine	IASI spectrum alone	IASI spectrum + 4 Jacobians
Linux Xeon Bipro 3.4 GHz (32bits - Fedora)	about 35 s	about 2.5 min
Linux Xeon 7 proc. 3GHz (64bits - Debian)	about 21 s	

References

- [1] Scott, N.A. and A. Chedin, 1981: A fast line-by-line method for atmospheric absorption computations: The Automated 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., 2011: The 2009 edition of the GEISA spectroscopic database : J. Quant. Spectrosc. Radiat. Transfer, 112, 2395-2445.
- [4] L. Chaumat, C. Standfuss, B. Tournier, E. Bernard, R. Armante and N.A. Scott, 2012: 4A/OP Reference Documentation, NOV-3049-NT-1178-v4.3, NOVELTIS, LMD/CNRS, CNES, 315 pp.

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