



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



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## Abstract

4A is a fast and accurate line-by-line radiative transfer model developed and validated at LMD (Laboratoire de Meteorologie Dynamique) for the computation of transmittances, radiances and Jacobians, particularly efficient in terms of accuracy and computation time. Within this frame, and with the support of the CNES (the French Space Agency), NOVELTIS has created an "operational" version of this code called 4A/OP for distribution to registered users. This version is regularly updated and improved by the LMD, NOVELTIS and CNES. This software is used by several research groups and can be integrated in operational processing chains including inverse problems processing. 4A/OP has the official support of CNES for radiative transfer applications in the infrared, and recently in the Short Wave InfraRed (SWIR). In particular, 4A/OP was selected by CNES as the official radiative transfer model for IASI level 1 Cal/Val and level 1 operational processing for MetOp-A and MetOp-B. Moreover, 4A-SWIR was selected as the reference code for Microcarb mission and is also used for the GOSAT retrievals and spectral calibration. A new version of the software is ready for distribution. After a description of 4A/OP, additional and updated capabilities (spectroscopy, scattering ...) as well as a validation status using IASI level 1 observations are presented.

## 4A/OP Operational release for 4A

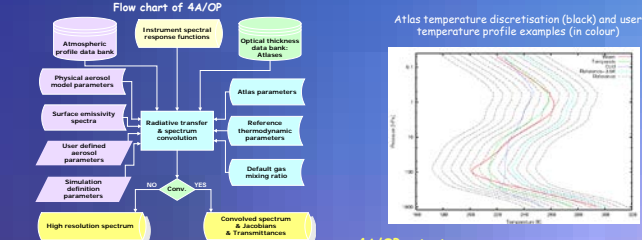
4A stands for Automated Atmospheric Absorption Atlas.  
4A is a fast and accurate line-by-line radiative transfer model particularly efficient in the infrared region of the spectrum.  
4A/OP is a user-friendly software for various scientific applications, co-developed by LMD (Laboratoire de Météorologie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

## 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 from the latest version of GEISA-11 database (reference mixing ratio profiles);
  - ✓ for 12 nominal atmospheres (12 temperature profiles 7 K distant);
  - ✓ for a set of 44 pressure levels between surface and top of the atmosphere;
  - ✓ for a  $5 \cdot 10^{-4} \text{ cm}^{-1}$  nominal spectral step;
  - ✓ separation into  $15 \text{ cm}^{-1}$  blocks for each gas: several matrices compressed in wavenumber / 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.ipl.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

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 3000  $\text{cm}^{-1}$ . 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).

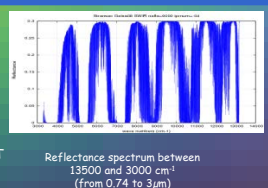
## Software features

- **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 (g90, f90, ifort, gfortran/g95) and has been tested on Sun and Linux PC.
- **Run time examples (CPU time)**

Machine	IASI spectrum alone	IASI spectrum with 4 Jacobians
Linux Xeon Bipro 3.4 GHz (32bits - Fedora)	about 35 s	about 2.5 min
Linux Xeon 7 proc. 3.6GHz (64bits - Debian)	about 21 s	about 2 min

## Extension to SWIR domain

- **Main features**
  - ✓ Rayleigh scattering
  - ✓ Any available solar spectrum
  - ✓ Doppler shift of solar lines
  - ✓  $\text{CO}_2$  line-mixing and  $\text{CO}_2$  line broadening by  $\text{H}_2\text{O}$
  - ✓  $\text{O}_2$  Line-mixing effects + CIA contribution in  $\text{O}_2\text{-A}$ -band
  - ✓ Scattering module: DISORT, LIDORT or VLIDORT (including Jacobian calculation)
  - ✓ Polarization with VLIDORT
  - ✓ BRDF introduction (via LIDORT or VLIDORT)



- **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 reference code for Microcarb mission
  - ✓ Validation of the spectroscopy for Merlin mission ( $\text{CH}_4$ )
  - ✓ 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
  - $\text{CH}_4$  Line-mixing
- ✓ **Technical developments**
  - Speed up in scattering case
  - Graphical user interface to include SWIR features

## 4A/OP enhancement

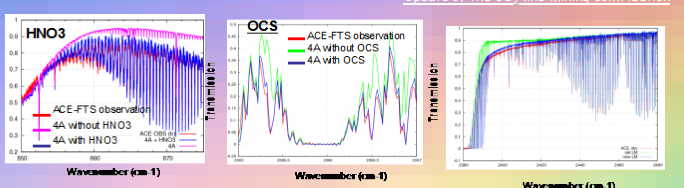
NOVELTIS is in charge of the industrialization and the distribution of 4A, in accordance with a convention signed between CNES, LMD/CNRS and NOVELTIS. The 4A/OP software is a version of the 4A code for distribution to registered users. Current version : 4AOP2012v1.0 (03/2012)

- 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  $\text{CO}_2$  line-mixing
    - ✓ New GEISA 2011 spectroscopy
    - ✓ Pressure shift for  $\text{H}_2\text{O}$ ,  $\text{CO}_2$  and  $\text{N}_2\text{O}$
    - ✓ Update reference gas mixing ratio profile
    - ✓ Improved TIPS' formulation
  - Update and improved the GUI

## 4A/OP validation at LMD

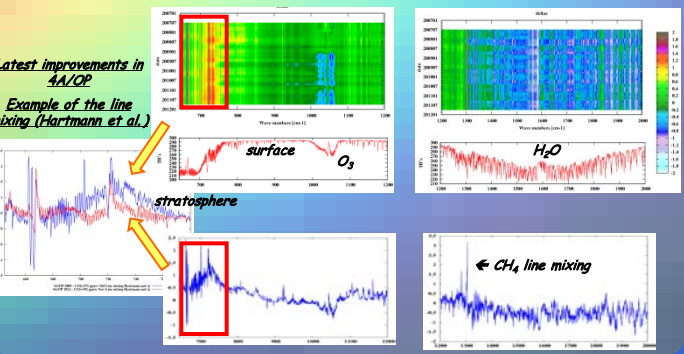
No "minor" constituents in limb-viewing! Due to very long optical paths, number of molecules may impact the radiative transfer in a non-negligible way ( $\text{NO}$ ,  $\text{SO}_2$ ,  $\text{NO}_2$ ,  $\text{HNO}_3$ ,  $\text{HF}$ ,  $\text{HCL}$ ,  $\text{OCS}$ ,  $\text{HCN}$ ).



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 (« deltas »).**
- Instruments : IASI/AMSU-A/MHS (all channels)
- Collocations (300 km, 3 hours) of clear (\*\*\*) satellite observations with the Analyzed RadioSounding Archive (ARSA, <http://abct.lmd.polytechnique.fr>)
- Monthly statistics from : approximately 80 items per month for sea, night, tropical atmospheres

## IASI bias (2007/07 → 2011/12) for all the channels of B1 and B2



## 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., 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, 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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