# 4A/OP : A fast and accurate operational forward radiative transfer model for the TIR and the SWIR

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## 4A/OP Operational release for 4A (Automatized Atmospheric Absorption Atlas)

4A, stands for **A**utomatized **A**tmospheric **A**bsorption **A**tlas is a fast and accurate line-by-line radiative transfer model developed and validated at LMD 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. 4A/OP is a user-friendly software for various scientific applications, co-developed with the LMD and easily distributed to registered users. This version is regularly updated and improved by the LMD, NOVELTIS and CNES.
The 4A/OP software is used by several research groups and can be integrated in operational processing chains including inverse problems processing. In particular, 4A/OP has been chosen as reference RT code for CNES missions (IASI, Microcarb).

## 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].

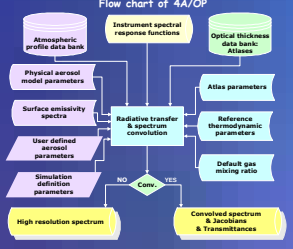
**· Atlases**

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:

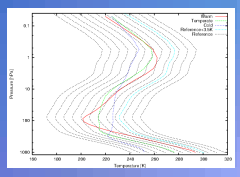
- ✓ for up to 53 atmospheric molecular species from the latest version of GEISA-11 database (reference mixing ratio profiles);
- ✓ for 12 nominal atmospheres (12 temperature profiles 7K distant);
- ✓ for a set of 44 pressure levels between surface and top of the atmosphere;
- ✓ for a 5 $10^{-4}$ $cm^{-1}$ 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

Flow chart of 4A/OP




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



**· 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

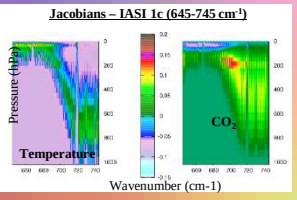
The computation is performed in a **spherical atmosphere**, at a user defined observation level for **zenith**, **nadir** or **limb** observations.

4A computes the radiance spectrum in a user-defined spectral domain in the **infrared region**; the usual domain is between 600 and 13,000 $cm^{-1}$. 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).

**· 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.

**Jacobians – IASI 1c (645-745 $cm^{-1}$)**



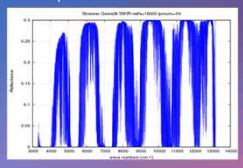

## Extension to the SWIR domain

**· Main features**

- ✓ **Rayleigh** scattering
- ✓ Any available **solar spectrum**
- ✓ **Doppler shift** of solar lines
- ✓ $CO_2$ line-mixing and $CO_2$ line broadening by $H_2O$
- ✓ $O_2$ **Line-mixing** effects + CIA contribution in $O_2$ A-band
- ✓ Scattering module: DISORT, LIDORT or VLIDORT (including **jacobian** calculation)
- ✓ **Polarization** with VLIDORT
- ✓ **BRDF** introduction (via LIDORT or VLIDORT)

**· Current use**

- ✓ Microcarb : preliminary design studies (CNES)
- ✓ Microcarb : chosen by the PI as reference code
- ✓ Merlin : Validation of the spectroscopy ($CH_4$)
- ✓ GOSAT retrievals /spectral calibration



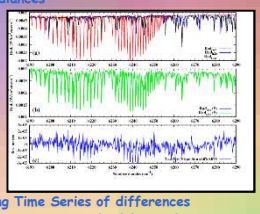
Reflectance spectrum between 13500 and 3000 $cm^{-1}$ (from 0.74 to 3 µm)

## 4A/OP validation at LMD

**· In the SWIR** : Validation of 4A/OP through the analysis of differences between simulated (4A/OP) and observed (TCCON and GOSAT) Radiances

- ✓ Instruments : TCCON sites (Parkfalls, Lamont, Lauder, Orléans, …) and TANSO-FTS instrument (GOSAT)
- ✓ Collocations between TCCON sites and GOSAT spectra
- ✓ GOSAT spectrally and radiatively calibrated by NOVELTIS and available on the Ether web site (http:www.pole-ether.fr)

*On the right : 4A/OP - GOSAT radiances around the Parkfalls TCCON site : a) individual CO2, H2o and solar contributions; b) total radiance; c) mean 4A/OP-GOSAT radiances*



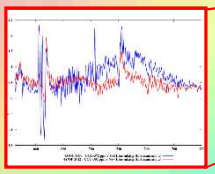
**· In the TIR** : Validation of 4A/OP through the analysis of Long Time Series of differences between simulated (4A/OP) and observed (IASI, AIRS, ) Brightness Temperatures (« deltacs »),

- ✓ Instruments : IASI - AIRS (all channels)
- ✓ Collocations (100km, 3 hours) of clear satellite observations with the Analyzed RadioSoundings Archive (ARSA, http:abct.lmd.polytechnique.fr)
- ✓ Monthly statistics : approximately 80 items per month for sea, night, tropical atmospheres

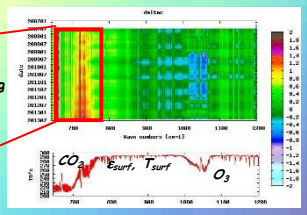
**IASI bias (2007/07 ➔ 2013/06) for all channels of the B1**

*Latest improvements in 4A/OP*

*Example of the $CO_2$ line mixing (Hartmann et al)*



**· P,Q,R Line Mixing**
✓Version 2
✓Version 3




## 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 plaform with several Fortran 90 compilers (pgf90, f90, ifort, gfortran) and has been tested on Sun and Linux PC.

4A/OP is 100 times faster than a classical "line by line" for an equivalent precision

**· Run time examples** (CPU time)

| Machine | IASI spectrum alone | IASI spectrum + 4 Jacobians |
|---|---|---|
| NOVELTIS: Linux Xeon Bipro 5150 (2 core) 2.66 GHz (64bits - CentOS 6.5 ) | about 16 s | about 2.7 min |
| ClimServ : Linux AMD Opteron Bipro (8 core) 2.5GHz (64bits - Scientific 6.6) | about 20 s | about 1.46 min |

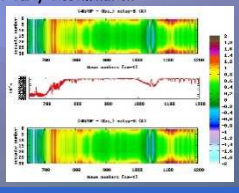
## Use of 4A/OP in the CAL/VAL activities of MetOpA-MetOpB

**4A/OP has been used : (i) in the CNES spectral calibration of IASI/A; (ii) in the intercalibration of IASI A and B (collaboration CNES/LMD) starting during the early dissemination**

- ✓ Instruments : IASI onboard Metop-A **and** Metop-B
- ✓ Daily collocations of clear IASI/A and IASI/B with analyses of the ECMWF
- ✓ Statistics (4A/OP-Obs.) from 24th January to 6th June of 2013 as a function of : time, viewing angle, wavenumber, …)

**Main conclusion obtained for the intercalibration campaign** :

- ✓From 645 to 2760 $cm^{-1}$, the differences IASI/A-IASI/B is < 0.1 K
- ✓For all viewing angles, the differences IASI-A - IASI-B is < 0.15 K



## 4A/OP enhancement

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://4aop.noveltis.com/ 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

Latest developments in the TIR :

- Scattering for cloud (cirrus…) contribution
- New atlases of absorption optical thicknesses:

- ✓ Improvement of CO2 line-mixing
- ✓ New GEISA 2011 spectroscopy
- ✓ Pressure shift for $H_2O$, $CO_2$ and $N_2O$
- ✓ Update reference gas mixing ratio profile
- ✓ Improved TIPS' formulation

## In progress …

- ✓ Next steps
  - ➢ GNU GPL license / On-line download
  - ➢ Migration of 4A-SWIR into operational version
- ✓ Scientific developments
  - ➢ Further validation with real measurements
  - ➢ NETL
  - ➢ Introduction of $CH_4$ Line-mixing and updates of $CO_2$ (TIR) and $O_2$ (SWIR) line mixing
- ✓ Technical developments
  - ➢ Speed up in scattering case
  - ➢ Graphical user interface to include SWIR features
- ✓ Spectral extension
  - ➢ Extension to visible and UV domains

## 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, 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.