NOVELTIS

Innovating to protect our World's Life

ITSC-21 , Darmstadt, Germany, November 29th-December 5th, 2017 session 2a Radiative Transfer

The 4A/OP model: from NIR to TIR, new developments for time computing gain and validation results within the frame of international space missions

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Context of Development

- 4A = **A**utomatized **A**tmospheric **A**bsorption **A**tlas
  - Fast and accurate line-by-line RTM developed and validated at **LMD**
  - Scott et Chédin (1981), Tournier *et al.* (1995)., Chéruy *et al.* (Jacobians, 1995)

http://ara.abct.lmd.polytechnique.fr/

- 4AOP: cooperation between **LMD**, **CNES** and **NOVELTIS**
  - with the support of the CNES, NOVELTIS has created an **Operational** version of this code called **4A/OP**, co-developed with the LMD
  - This code is regularly updated and improved by the LMD, NOVELTIS and CNES.

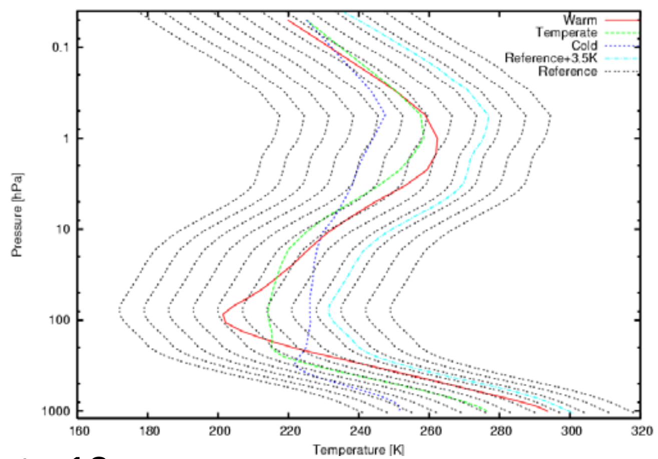
- Use of 4AOP :
  - by several research groups (70 groups in the world since 15 years)
  - **reference** RT code for CNES missions such as **IASI** and **IASI-NG**, **MicroCarb** and **Merlin**
  - Can be integrated in **operational processing chains** including inverse problems processing

- Annual follow-up committee with LMD, CNES and NOVELTIS

General presentation

- 4A :
  - Pioneer **radiative transfer model** to bypass LBL processing time by calculating once and for all a set compressed look-up-tables (LUT) of monochromatic optical depths, layer-by-layer and for each individual absorbing gas.
  - Fast computation of **jacobians, transmittances** and **radiances** with the same precision of a classic monochromatic line by line algorithm from **NIR to LWIR** wavelengths at high spectral resolution (nominal 5.10-4 cm-1)
- Atlas:
  - Based on latest version of **GEISA-15** database:

    up to **53** atmospheric molecular species
  - **12** temperature profiles (7K distant);
  - **44** pressure levels between surface and top of the atmosphere 0,0026 hPa;
  - Nominal Atlases Processing intervals (API) for each gas is 15 cm-1:
    - several matrices compressed in wave numbers / layer / temperature.



- User simulation:
  - $\sigma(T)$= interpolation between $\sigma(np)$ and $\sigma(np+1)$, np=1 to 12
  - $\sigma_{\rho} = \sigma_{\rho ref} * \rho / \rho_{ref}$
  - If pressure levels are differents from the atlases, interpolation in pressure

General presentation

2a 2.02 (E. Bernard et al)

TIR, NIR, SWIR
[600 – 13300] cm^{-1}
[0.75 - 16] µm

2a 2.01 (R. Armante et al)

Main features

wavenumber / wavelength input handling

Zenith, nadir or limb observations

Spherical atmosphere

Continua
H_2O, O_2, N_2

Spectroscopic features in the Atlas
Isotopes (H_2O/HDO, CH_4/CH_3D)
O_2/CO_2 Line-Mixing and water vapor broadening
Pressure-shift (H_2O, CO_2, N_2O, CH_4)

Wide variety of surface:
Snyder, IREMIS, personal surface albedo,
BRDF models (via VLIDORT)

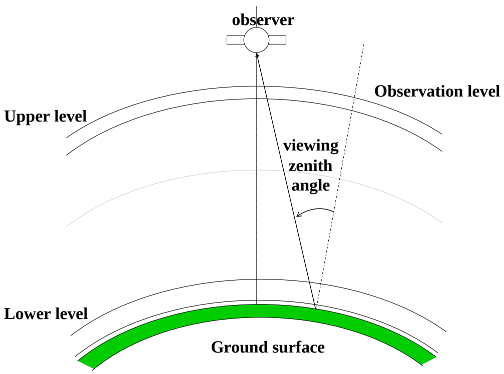
Solar contribution:
Any available solar spectrum, including Doppler shift of solar lines

Scattering: molecule + aerosol/cirrus profiles

→ 4A coupled with DISORT, LIDORT, VLIDORT
→ Jacobian calculation
→ Polarization (VLIDORT)

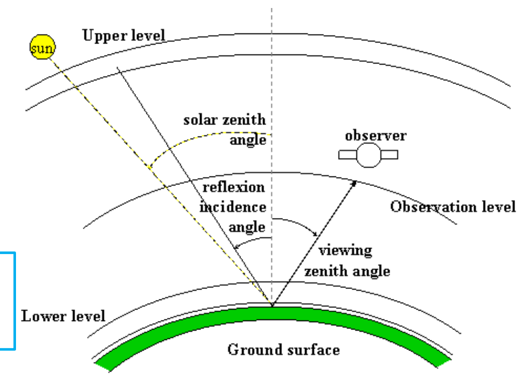
General presentation

- Viewing and geometric configuration:
  - 2 types of MODE: EARTH VIEW / LIMB
  - 4 types of VIEWING GEOMETRY



UP

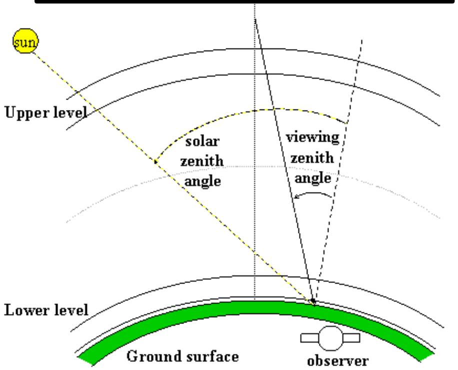
DOWNUP



Surface: emissivity or bi-directional reflectance

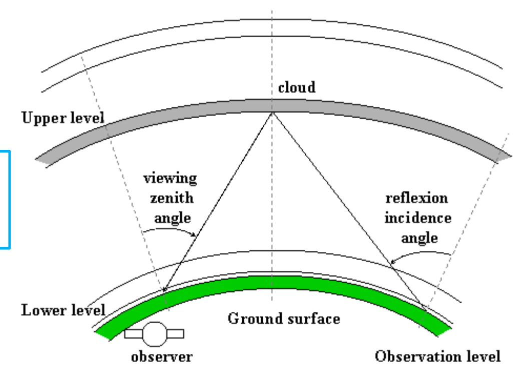
Earth View

User can define zenithal and azimuthal solar angles

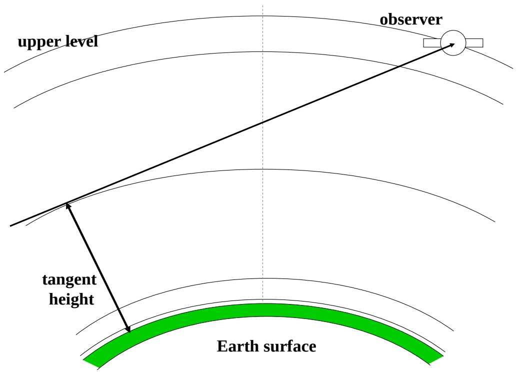


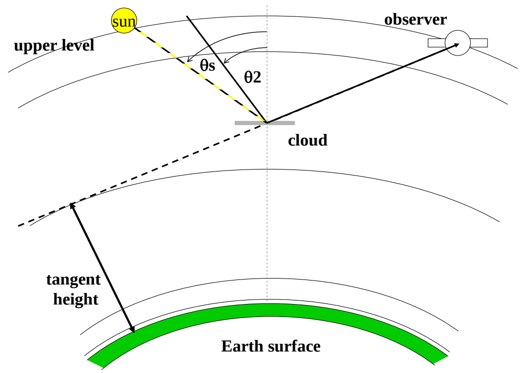
DOWN

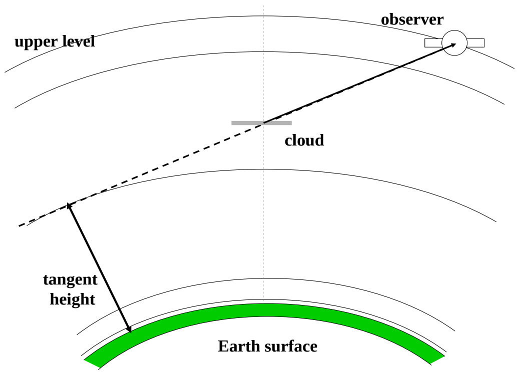
UPDOWN



General presentation





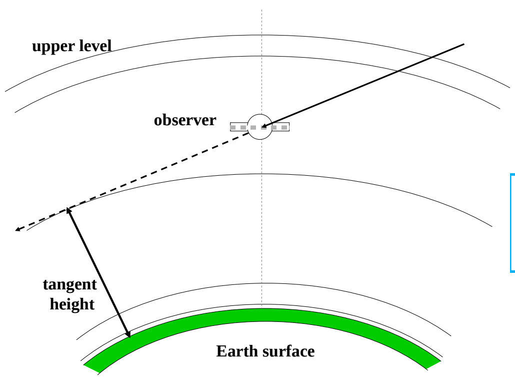


Cloud simulation

DOWNUP

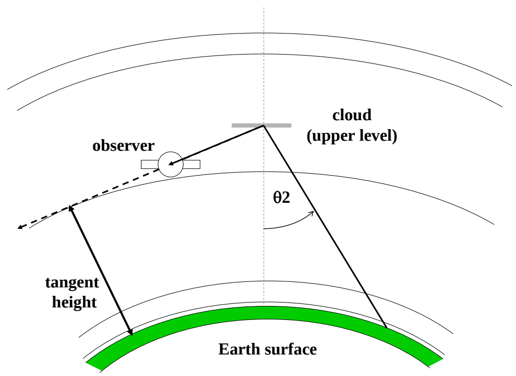
UP

LIMB



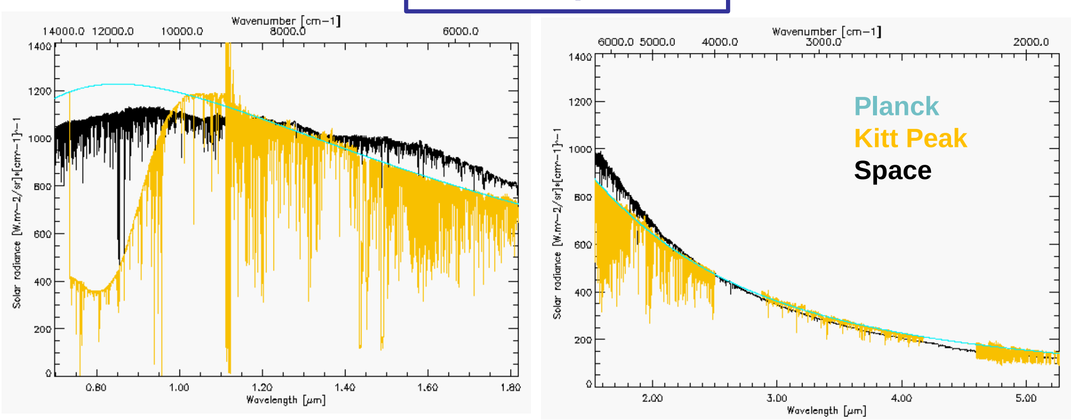
DOWN

UPDOWN

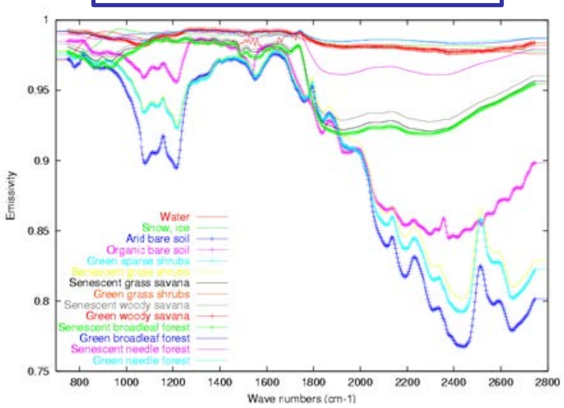


- 4A/OP Inputs:
  - **Atlases** : as many as absorbing gases in a given spectral interval, layer-by-layer optical depths computed at a nominal spectral resolution: 5.10^{-4} cm^{-1})
  - **ISRF:** any type of instrument (radiometer, spectrometer, FTS, etc)
  - **Atmospheres at user defined levels**
  - **Emissivities: constant** & **spectral** emissivities (Snyder *et al.*, 1998) & **IREMIS** emissivities (Borbas *et al.*, 2008)
  - **Aerosol model:** from **OPAC** (aerosol, cirrus) or user's model
  - **Sun spectrum:** high spectral resolution (Fraunhoffer lines coupling with the terrestrial atmosphere): **space** spectrum, **Kitt Peak** and **TOON** spectra, **Planck**

Solar spectra



Snyder emissivities

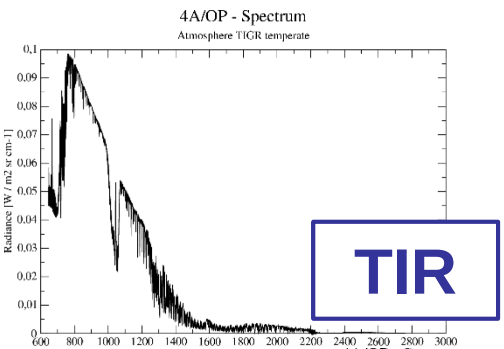


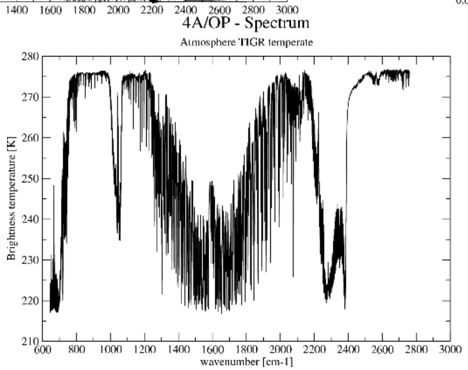
- 4A/OP Outputs:

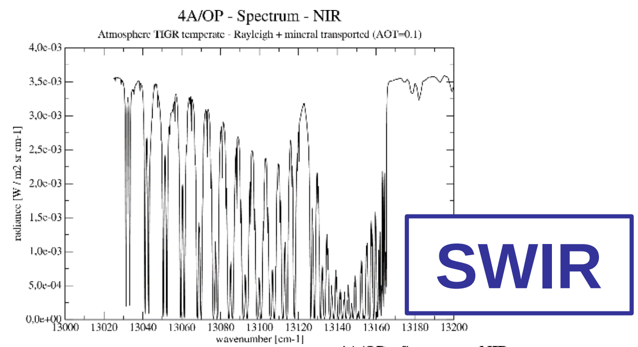
At High/infinite spectral resolution (5 10^{-4} cm-1) or Convolved with any type of ISRFs

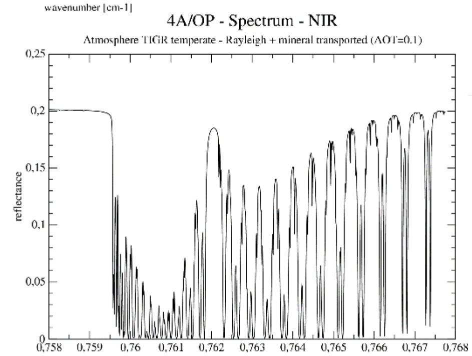
- Spectra
- Transmittances
- Jacobians

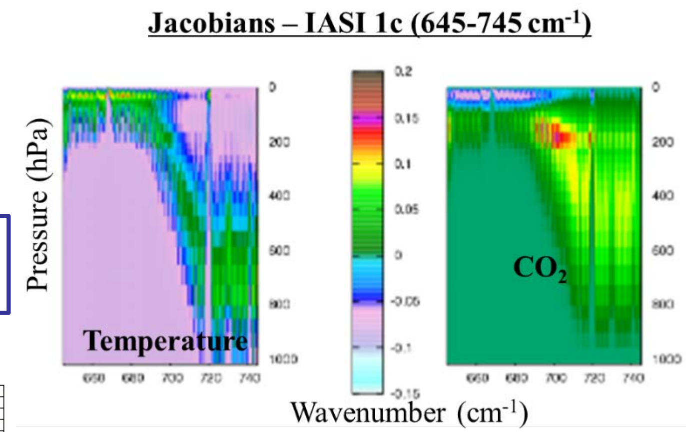
  w.r.t. : Temperature, gas mixing ratio, emissivity, surface temperature, surface pressure, Aerosol Optical Thicknesses





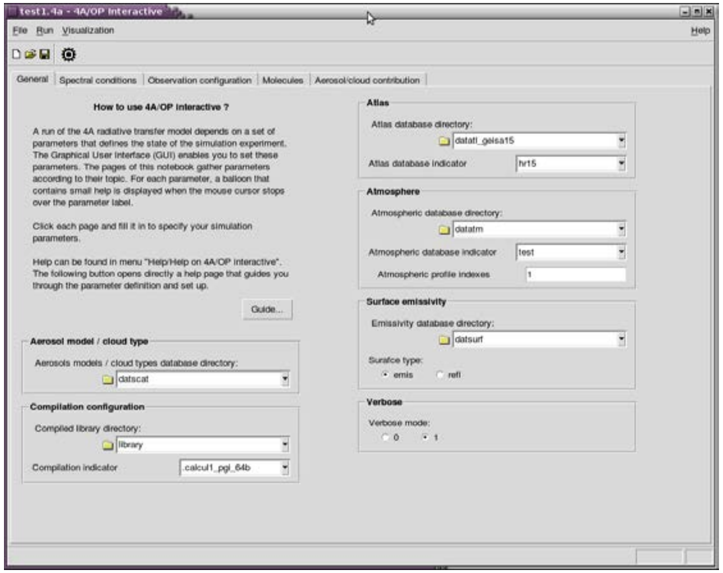






General presentation

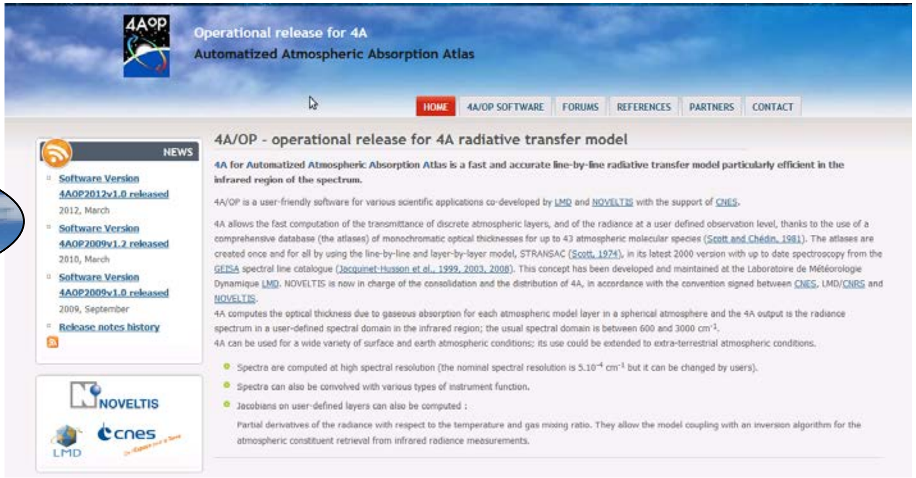
GUI



Quick User manual
Advanced User manual

Web site

http://4aop.noveltis.com



Performance

- Time computing performance

	TIR No scattering			SWIR Rayleigh + Aerosol		
Machine	**TIR ∞ Spectrum**	**IASI spectrum** *(ISRF's width of 32 cm^{-1})*	**IASI spectrum + 4 jacobians**	**SWIR ∞ O_2 (0.76 μm) Spectrum**	**SWIR Microcarb O_2 (0.76 μm) spectrum**	**SWIR Microcarb O_2 (0.76 μm) spectrum + 5 jacobians**
Linux Centos 6.5 2.4Ghz (64bits - 32Go)	≈ 60 s Get binary : 24 s + Binary to ASCII: 36 s	≈ 34 s	≈ 200 s	≈ 112 s	≈ 112 s	≈ 13 min

- The computation time is a function of the number of levels, the number of implied molecular species, the spectral resolution and the width of the instrumental function for the convolution case

- Taking into account the scattering may considerably increase up to 15 times (depending on spectral regions) the computing time with respect to 4A/OP without scattering
  - ➢ A way to attenuate this slowing down: perform a contraction of the optical thicknesses by degrading the calculation spectral sampling step

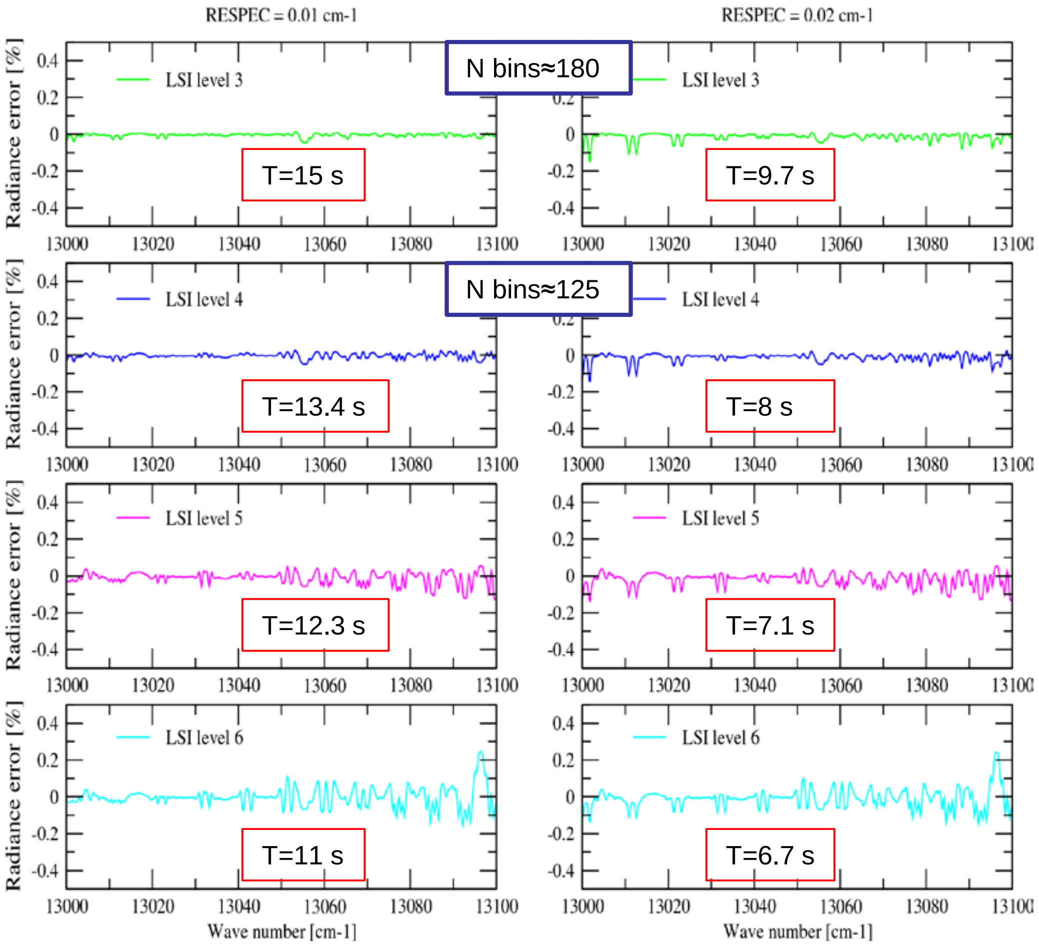
Fast scattering

- 4A + LIDORT : time computing saving development
  - **Assessment on time computing**: from few minutes to 1 hour depending on the spectral resolution and spectral range.
  - **Goal**: decrease critically the time computing in scattering simulation BUT keep a good radiometric precision.
  - **Selection** of a generic method, already experienced/validated in NIR-SWIR domain: Low Stream Interpolation (**LSI**) method [O'Dell, 2010]
  - Based on the **spectral high redundancy** of the signal over reduced spectral domain
  - Principle: based on several fast computations steps
    - Applied for a given spectral band
    - Dynamic classification of gaseous optical thickness on a small number of bins (selected with double-k distribution method)
    - Scattering computation with low-precision (2-STREAMS) calculation on all spectral band samples
    - Scattering computation with low-precision (2-STREAMS) calculation on bins
    - Scattering computation with high-precision (16-STREAMS) calculation on bins
    - Derivation of the 2-STREAMS error w.r.t. 16-STREAMS computation on bins
    - Interpolation of the 2-STREAMS error on all spectral band samples
    - Correction of the (2-STREAMS) calculation by the interpolated 2-STREAMS error
  - Applied for radiance and Jacobians computations

Fast scattering

- Results
  - Implementation in 4A:
    - One flag to activate/deactivate
    - One parameter (*level_fast* = 1 -> 6) for speed level that controls the number of bins
  - Band O2 @ 0.76 µm & CO2 @ 1.6 µm:
    - Gain factor of ~60
    - Accuracy loss < 0.1%
  - Band CO2 @ 2.1 µm:
    - Accuracy loss ≈ 0.5%
    - Needs improvements of the performance
  - LSI method not much sensitive to the geophysical parameters
  - Jacobians are well reconstructed
  - Validation on the complete NIR-SWIR spectral domain

Example of the performance study of the LSI method
B1 Microcarb
2 values of spectral sampling step (RESPEC)
4 speed levels (3, 4, 5, 6)



Fast scattering

- In progress:
  - 4A + VLIDORT: including polarization

- Future:
  - Need some improvements (better assessment of molecular OT vertical dependency)
  - More validation for Jacobians
  - TIR spectral domain examination and validation

Parallelization

- Development for a 4A-parallelized version
  - Need for a massive radiative transfer calculation with 4A for the OSSE IASI-NG...
  - ➔ 4A in sequential mode not adapted
  - Development of a parallelized version of 4A
    - Open-MP API
    - Gain from 4 to 5 on a 6 CPU requested
    - Difference with 4A

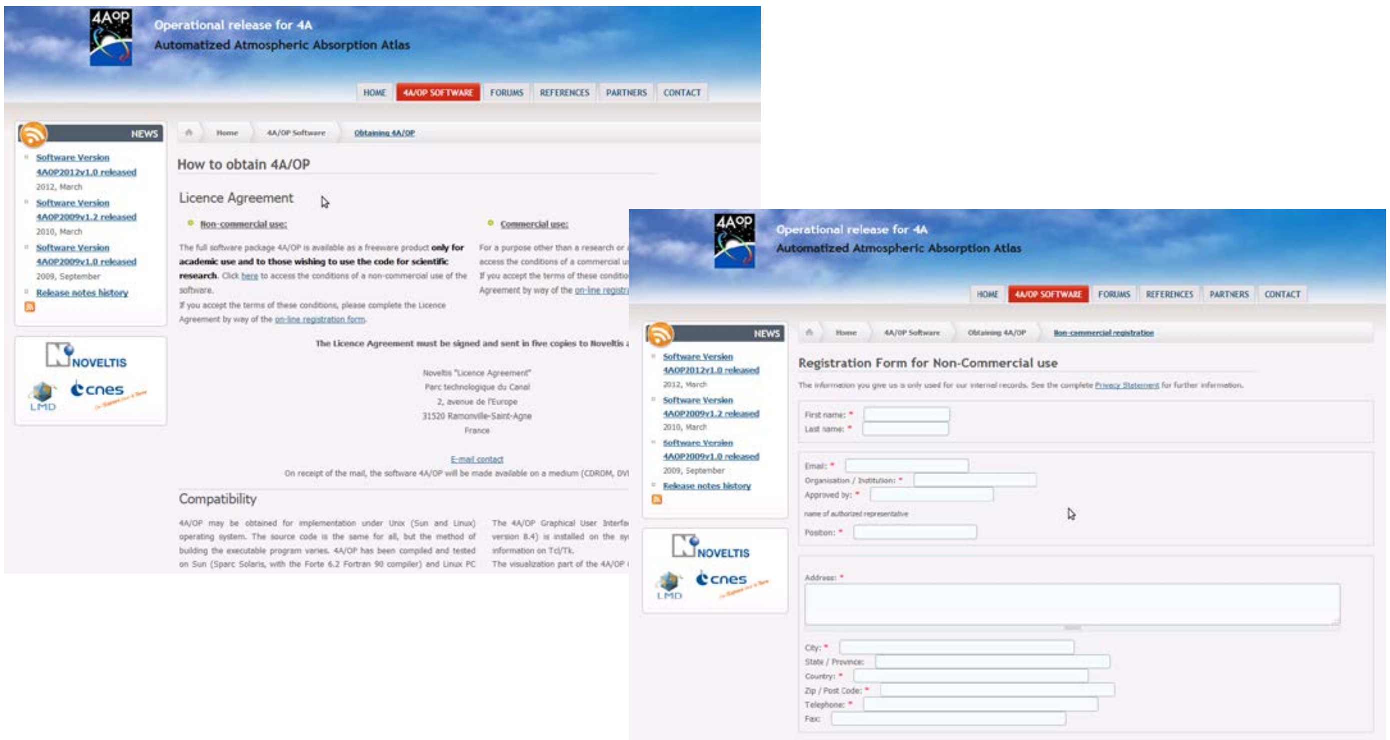
	4A	4A – parallel
Scattering	√	x
Atmospheric profile	On the fly	Ahead (memory storage)
Atlas	On the fly	Ahead (memory storage)

- Performance

2311 TIGR profiles	TIR No scattering IASI spectrum		TIR No scattering IASI spectrum + Jacobians	
Machine	**4A**	**4A parallel**	**4A**	**4A parallel**
Linux Centos 6.5 2.4Ghz (64bits - 32Go)	21h 30m	5h 5m - Read Atlas: 960 s	128h 23m	23h

Distribution (current)

- On-line registration form http://4aop.noveltis.com
- So far 4A/OP distributed for IR domain applications
- 70 groups in the world get 4A/OP since 2003



- 4A/OP is distributed since 10 years under a commercial/non-commercial license

Distribution (future)

- 4A/OP will be soon delivered under a **GNU LGPL license** covering **NIR-SWIR-TIR** spectral domain

- 4A/OP will be accessible by **downloading via website**

- The user will be given access to:
  - The 4A/OP software
  - The atlas

- The users will be able to **select** spectral domains adjusted to their own applications and get the corresponding **ATLASES**

- The user can register via our website to benefit from support, be informed on new releases and receive the newsletter