4A/OP: A fast and accurate operational forward radiative transfer model: spectroscopic features & application to IASI and IASI-NG solar bands

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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**.
It is a particularly efficient tool 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, easily and freely distributed to registered users. This code 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 such as **IASI**, **MicroCarb** or **IASI-NG**.

What is 4A/OP?

4A allows the fast computation of the transmittances and the radiances with the same precision of a classic line-by-line algorithm from NIR to LWIR wavelengths at high spectral resolution. The 4A calculation relies in particular on a multi-dimensional interpolation using a pre-built optical thickness database called "Atlases" [1].

The Atlases are built for up to 53 atmospheric molecular species, 12 nominal atmospheres, 44 pressure levels, for a $5x10^{-4}$ cm^{-1} nominal spectral step (compressed in wave numbers / layer / temperature). 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

4A interpolates in the Atlases to get the optical thickness profile for any given atmospheric condition. 4A returns the high spectral resolution spectra (nominal spectral resolution: 5.10-4 cm^{-1}) or the convolved spectra with various types of instrument functions and provides jacobians on user-defined layers.

• MAIN FEATURES

✓ **Spherical atmosphere**

✓ **Zenith**, **nadir** or **limb** observations

✓ Usual **spectral domain**: [600 – 13300] cm^{-1}

✓ **Wide variety of surface**: numerous typical spectral **emissivities**, surface **albedo**, multiple **BRDF/BPDF** models (via VLIDORT)

✓ **Solar contribution**: any available solar spectrum, including **Doppler shift** of solar lines

✓ **Scattering**: by **molecule** (Rayleigh) and **aerosols/cirrus** (coupled with DISORT, LIDORT, VLIDORT), including jacobian calculation

✓ **Polarization** with VLIDORT

• SOFTWARE PACKAGE FEATURES

The current operational version **4AOP2012v1.0 (03/2012) includes:**

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

• SOFTWARE FEATURES

GUI: create a basic input file by selecting values with buttons, pull-down menus, and text fields.

Portable: 4A/OP runs on any platform with several Fortran 90 compilers (PGI, intel, GNU) and has been tested on Sun and Linux PC.

Running time: 4A/OP is **100 times faster** than a classical "line by line" for an equivalent precision.

• SUCCESS STORY

• TIR domain

✓**IASI:** RT model for level 1 Cal/Val

✓**IASI:** Metop-A & Metop-B: level 1 operational processing at CNES (Technical Expertise Center) for the monitoring of the IASI data

• SWIR domain

✓**MicroCarb:** preliminary design studies (CNES)

✓**MicroCarb:** chosen by the PI as reference code

✓**Merlin:** Validation of the spectroscopy (CH_4)

✓**GOSAT:** retrievals /spectral calibration

• Cal/Val activities for Metop-A & B

✓Spectral calibration for IASI/A and inter-calibration of IASI/A & IASI/B

✓Daily collocations (clear scenes) with ECMWF analyses

✓Statistics (Calc-Obs.) on 4 months in 2013 as a function of: time, viewing angle, wavenumber…

Main conclusions for the inter-calibration campaign:

✓ [645- 2760 cm^{-1}]:
➔IASI/A-IASI/B < 0.1 K

✓ For all viewing angles:
➔ IASI/A – IASI/B < 0.15 K

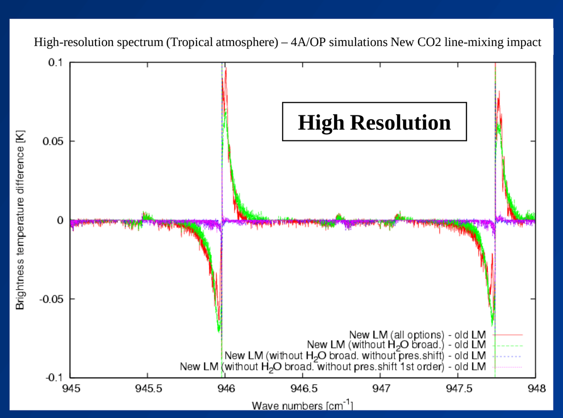
Spectroscopic features

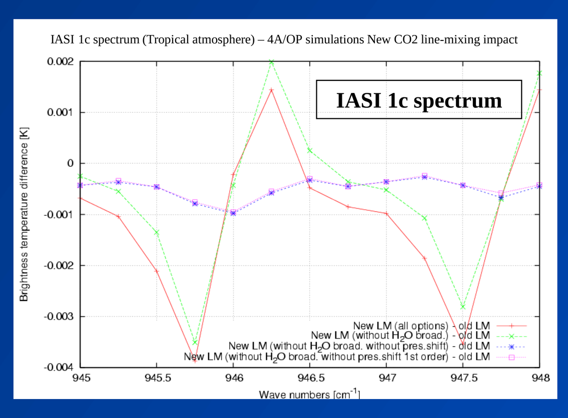
The 4A/OP software includes the up-to-date physics from the most advanced spectroscopic characteristic of the main molecules in the TIR and SWIR spectral domains.

CO2 LINE-MIXING

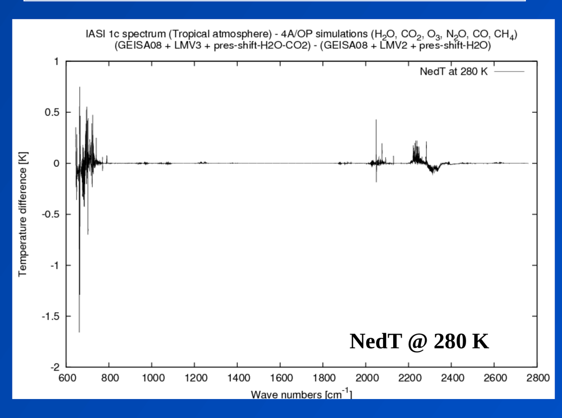
✓ ***Complete matrix formulation for the calculation of the absorption coefficient: from Lamouroux et al., 2010***
✓ ***Spectroscopic parameters from HITRAN 2008 completed with database of CDSD-296 (Tashkun et al., 2006) and CDSD-1000 (Tashkun et al., 2003)***
✓ ***Includes the pressure-shift for each CO2 line: from the empirical formulation developed by Hartmann (2009)***
✓ ***Foreign-broadening by H_2O: from Sung et al., 2009***

Impact of the new line-mixing including PS and H_2O broadening





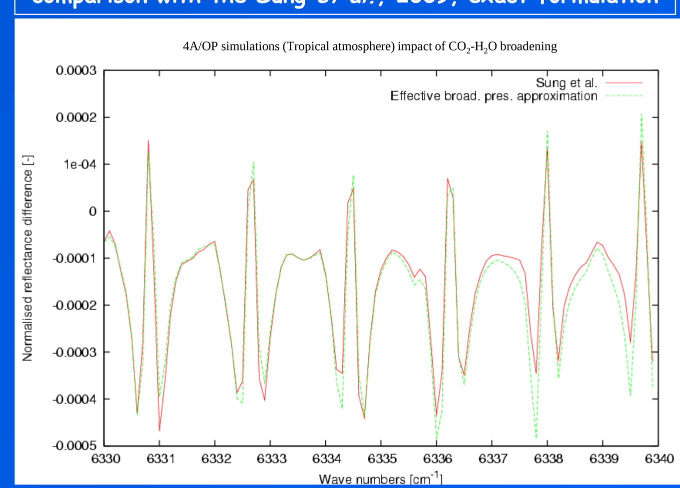
IASI 1c spectrum: H_2O, O_3, N_2O, CO, CH_4
Difference between new LM and old LM



CO_2 – H_2O FOREIGN BROADENING

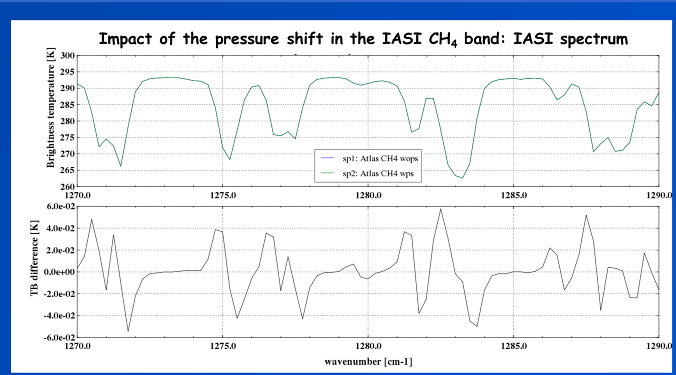
✓ Very important impact on the spectra regarding the high requirements on the CO_2 mission
✓ Complex to directly include in the atlas: fixed profile of H_2O and no linear dependence with H_2O profile
✓ Approximation that allows the calculation in 4A: take into account the H_2O user profile
✓ "***Effective broadening pressure approximation***": determination of an effective pressure (P_{EFF}) depending on the H_2O content (X_{H2O}): $P_{EFF} = P(1+0.835\ X_{H2O})$ with P = the real pressure
✓ Get the CO_2 optical thickness at P_{EFF} in the Atlases
✓ Impact of this approximation compared to the exact formulation (Sung *et al.*, 2009): example in the UVNS bands (see figure): relative error of 5/10000 : 2nd order
✓ Approximation developed and validated for the SWIR spectral domain
✓ Need consolidation in the TIR region: work in progress

"Effective broadening pressure approximation" at 1.6 µm: comparison with the Sung *et al.*, 2009, exact formulation



Pressure Shift

✓ ***Take into account of the PS for H_2O, CO_2, N_2O and CH_4: included in the Atlases***
✓ ***Spectroscopic coefficients from GEISA are used***



Distinguishing HDO from its H_2O main isotope in the 4A/OP radiative transfer modelling from the GEISA-2015 spectroscopic database

✓Statement: Important biases observed (figure b) in the "calc-obs" chain developed at LMD in the region 2500-2760 cm^{-1} which have been attributed to HDO lines (figure c).

✓ Introduction of HDO as an independent molecule in the radiative transfer modelling of 4A/OP from data in GEISA database in order to possibly use different concentration profiles for H_2O and HDO

✓ Validation made at LMD: "calc-obs" considerably improved (figure d)

"calc-obs" between 4A/OP and IASI observation time and space collocated with radiosoundings from the ARSA database

a) IASI observation

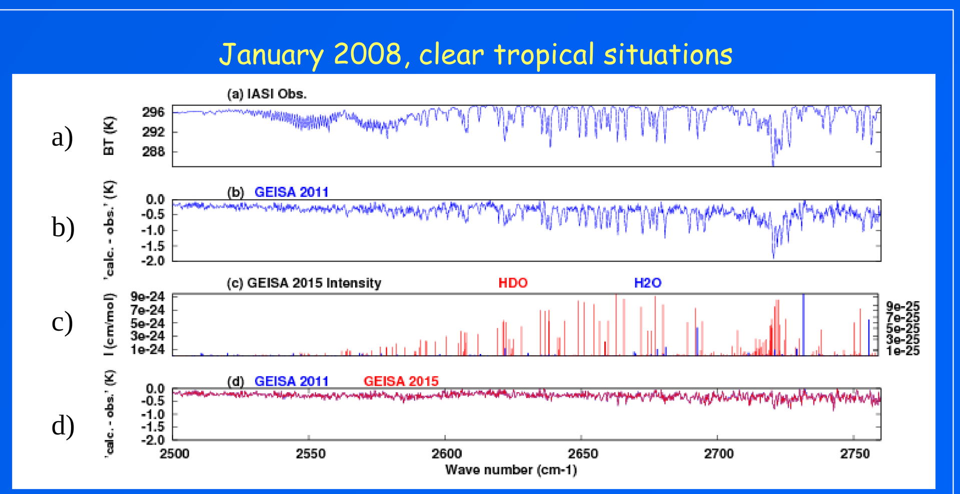
b) « **calc-obs** » with the **same concentration** profile for H_2O and HDO

c) H_2O and HDO line intensities

d) « **calc-obs** » with a **different concentration** profile for HDO and H_2O (taken from Schneider *et al.*, AMT, 2010)

➔ More details in ***Armante et al.*** (2016, submitted) at Special Issue of J. Mos. Spectr. on « Spectroscopic databases »

January 2008, clear tropical situations



Solar Band Application (1)

Polarization study from IASI-NG measurements

OBJECTIVES

✓ Analysis of **atmospheric polarization signal at high spectral resolution** of IASI-NG measurements (Thermal infrared domain) from 4A/OP simulated IASI-NG polarized spectra based on a climatological aerosol distribution (GADS database)
✓ Establish **recommendations** for the IASI-NG instrument design

METHOD

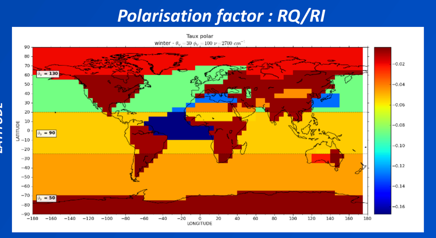
✓ **Qualitative sensitivity analysis** : definition of typical and extreme observation cases
✓ **Statistical analysis** : definition of an ensemble of typical IASI-NG atmospheric scenes based on realistic aerosol distributions set-up using GADS
➔ **696 surface/atmospheric scenarios**
✓ Calculation of the 2 polarization components (I, Q) and the polarization rate (Q/I) using 4A/OP + VLIDORT
✓ **Radiometric analysis** : definition of an "equivalent polarization pseudo-noise" due to atmospheric polarization : $NeDT = \Delta L / (\partial L/\partial T)_{TREF}$ with $\Delta L = \sqrt{[RI - (RI^2+RQ^2)]}$
➔ comparison to the IASI-NG radiometric noise specifications: definition of a flag → UPPER or LOWER the IASI-NG radiometric noise

RESULTS

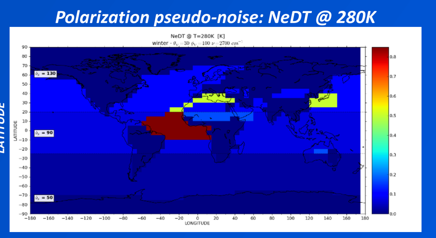
✓ 99.5% of the scenarios are lower than the IASI-NG radiometric noise specification
✓ 3 scenarios over 174 in IASI-NG spectral band B4 show a "polarization pseudo-noise" greater than the IASI-NG radiometric noise: illumination and observation geometries are close to an aerosol backscattering situation (*characterized by θ_V=30° and 45°, φ_V=100°, aerosol profile includes MITR*)
✓ 4% of the scenarios in spectral band B4 have a relative error < 50%

Parameters:
θ_V=30°
φ_V=100°
θ_S=35°
φ_V=50, 90, 130°
B4: 2700 cm^{-1}
GADS: winter aerosol profiles

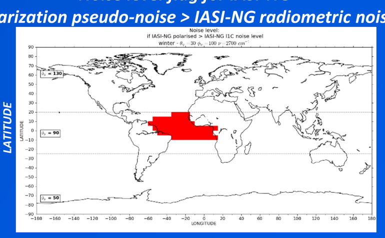
Polarisation factor : RQ/RI



Polarization pseudo-noise: NeDT @ 280K



Noise level flag for IASI-NG
Polarization pseudo-noise > IASI-NG radiometric noise



CONCLUSIONS

✓ From a climatological point of view, IASI-NG is mostly not affected by aerosol polarization
✓ Critical geometrical/geophysical parameters : anti-solar direction, backscattering situation, mineral transported aerosol
✓ Future work : Extension of the geophysical scenarios to cirrus clouds and polarizing surfaces (BPDF)

Solar Band Application (2)

The BRDF effect in the IASI solar band B3

Statement:

GSICS, 2013: the calibration error between GOES-14 and IASI in the band 3 where the solar influence is not negligible is probably due to the BRDF effect (X. Wu *et al.*, 2009)

Objectives:

Show how to improve the simulations in the MWIR by taking into account the directional effect of the incident solar radiation reflection at the surface considering a BRDF

Method:

✓ Implementation of a BRDF model in the 4A/OP software
✓ Cox and Munk model: glitter simulation
✓ Comparison between the simulation and the observation

Preliminary results:

✓ Qualitative validation: simulation of a IASI orbit and comparison to the measurements on some spectra (approximation of the atmosphere and surface states by considering standard values)
✓ Improvements of ≈20K of the difference Simulation-Measurement

Future:

✓ Quantitative validation by the "calc-obs" at the LMD
✓ Official implementation in the 4A/OP software

References

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[5] IASI-NG: sensibilité des spectres atmosphériques à la polarisation TIR: étude 2, Rapport final NOV-FE-0277-NT-001_version2