# The SOS-ABS radiative transfer code

## A Successive Orders of Scattering code including gas absorption

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# AGENDA

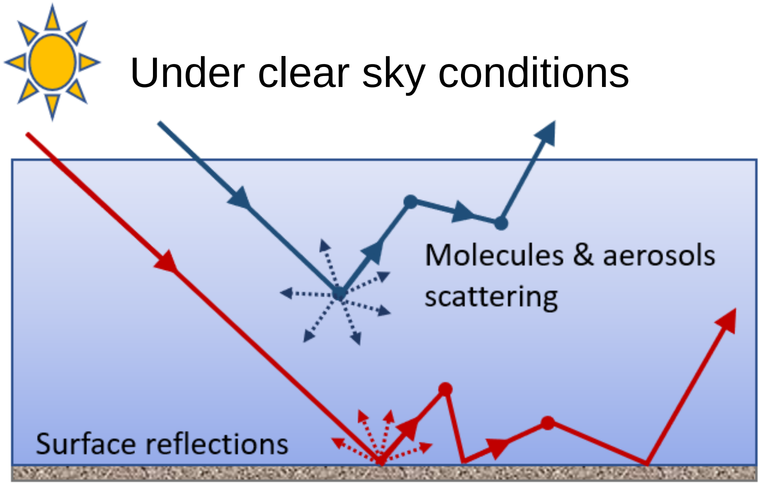
- 1) Brief history
- 2) Main features
  - Aerosols
  - Gaz
  - Surface
- 3) How it works
  - The successive orders approach
  - Adaptation for gas simulations
- 4) Validation
- 5) On-going activities and outlook

GROUP

# HISTORY OF THE SOS CODE

# HISTORY OF THE SOS RT CODE

- SOS code
  - 1D, plan parallel RT code
  - Successive Orders of Scattering method
  - Polarized radiance of the {Earth surface – atmosphere} system
  - Reflective part of the spectrum (0.4 – 4 µm)
  - Mono-spectral simulations




- SOS-ABS code
  - SOS method coupled with the gaseous ABSorption
  - Spectral resolution: 1, 5 or 10 $cm^{-1}$

Fortran
Python binding

- Heritage of the OS code from the LOA laboratory

# HISTORY OF THE SOS RT CODE

1974 OS code implemented in LOA laboratory

1989 Sun-glint added — Deuzé J.L, M. Herman, and R. Santer, « Fourier series expansion of the transfer equation in the atmosphere-ocean system », *J. Quant. Spectrosc. Radiat. Transfer*, vol. 41, no. 6, pp. 483-494, 1989.

2005 CNES decided to ensure the long-term future of the code
→ Redesigning the code and adding new functions

2007 New reference paper — Lenoble J., M. Herman, J.L. Deuzé, B. Lafrance, R. Santer, D. Tanré, « A successive order or scattering code for solving the vector equation of transfer in the earth's atmosphere with aerosols », *J. Quant. Spectrosc. Radiat. Transfer*, vol. 107, pp. 479-507, 2007.

2012 First tests with LOA for including gaseous absorptions

Few test versions of SOS-ABS for CNES studies

2019 SOS v6.2 (without gaseous absorption) on-line : public release / GPL v3 open source licence https://github.com/CNES/RadiativeTransferCode-SOS

2023 Soon release of the SOS-ABS v5 to users

# SOS-ABS CODE FEATURES

# FEATURES: RAYLEIGH SCATTERING

- Molecular optical thickness
  - From user's value
  - calculated by the code $\tau_m = \frac{P}{P_0} \times \left(\frac{84{,}35}{\lambda^4} + \frac{-1{,}225}{\lambda^5} + \frac{1{,}4}{\lambda^6}\right) \times 10^{-4}$

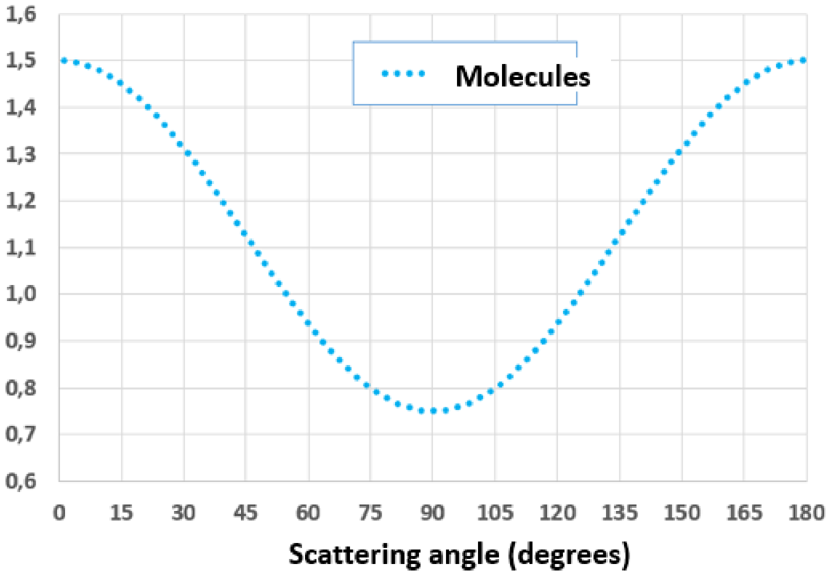
- Phase function
  - moderated by the depolarization factor

$$P_{mol}(\Omega) = 1 + f \times \left[\frac{3.\,cos^2(\Omega) - 1}{4}\right]$$

$$\approx \frac{3}{4} \times \left[1 + cos^2(\Omega)\right]$$

f = 2(1- δ )/(2+ δ )
δ depolarisation factor

| | |
|---|---|
| δ | 0.0279 |
| *f* | 0.9587 |



# FEATURES : AEROSOLS

**Aerosols**

**Predefined models**

- WMO
- Shettle & Fenn

**Mono-modal models**

- Log-Normal Distribution
- Junge's law

**Bimodal models**

**User's phase function**

Non-spherical particles

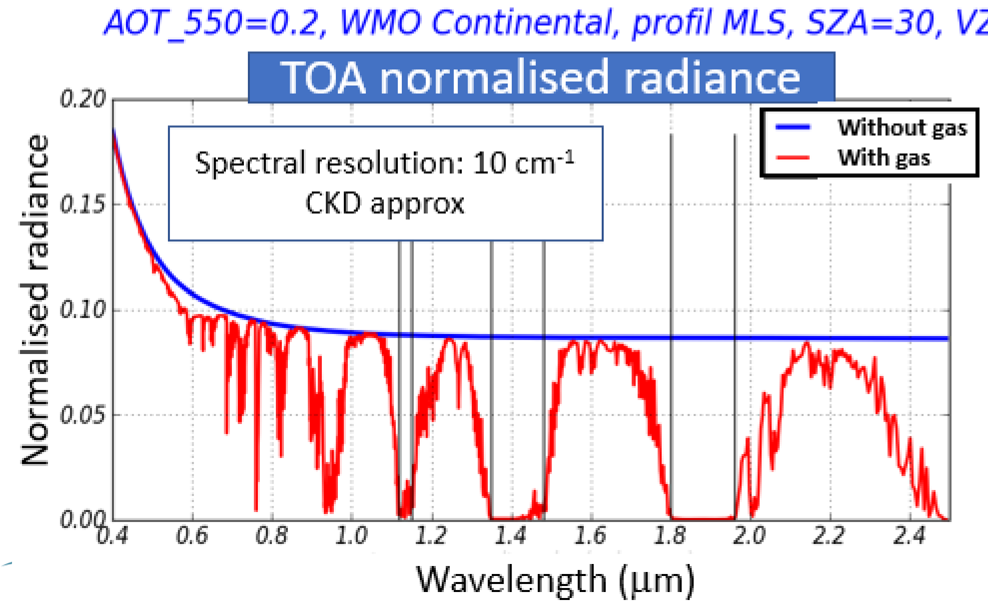
**Multi-modes models**

CAMS data

- LND
- Junge's law
- Mixture by mixing ratios to the total AOT

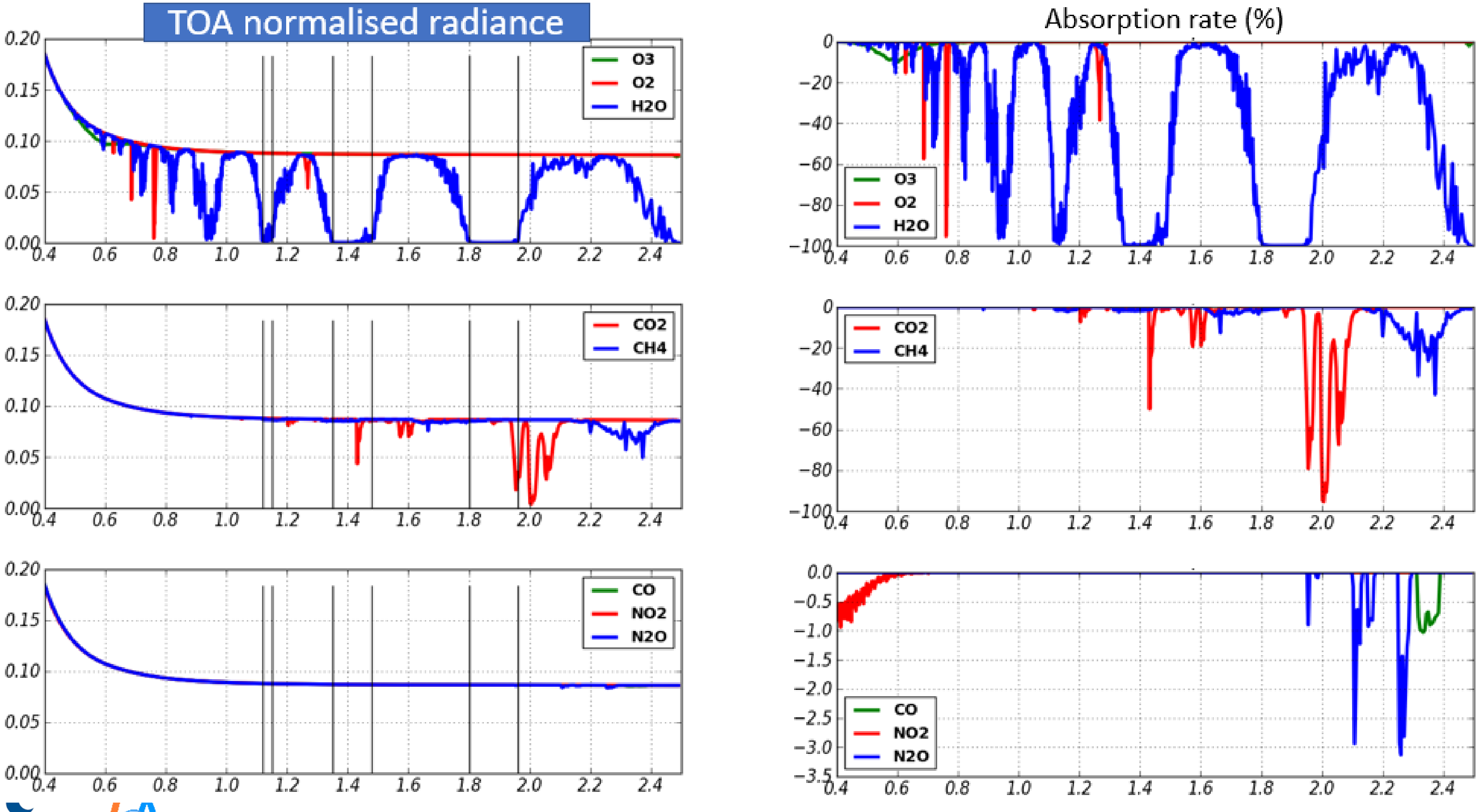
# FEATURES : GAS

- Main gases impacting the reflective part of the spectrum
  - Ozone ($O_3$)
  - Water vapor ($H_2O$)
  - Dioxygen ($O_2$)
  - Carbon dioxide ($CO_2$)
  - Methane ($CH_4$)
  - Nitrous oxide ($N_2O$)
  - Nitrogen dioxide ($NO_2$)
  - Carbon monoxide (CO)




- Spectral resolution: 1, 5 or 10 $cm^{-1}$
- 0.4 to 4.0 µm (→ 0.36 to 4.0 µm)
- Predefined profiles or user profile

# FEATURES : GAS



# FEATURES : BRDF / BPDF

› Land
- Lambertian surface
- BRDF Roujean model
- BPDF :
  - Rondeaux model
  - Bréon model
  - Maignan model

$$R_p^{Rondeaux}(\theta_S, \theta_V) = \frac{Fp(\alpha_I, n)}{4(\mu_S + \mu_V)}$$

Incidence angle: $\alpha_I$; Refractive index: $n$; $\mu = \cos\theta$

$$R_p^{Bréon}(\theta_S, \theta_V) = \frac{Fp(\alpha_I, n)}{4\mu_S\mu_V}$$

$$R_p^{Maignan}(\theta_S, \theta_V) = \frac{C \exp(-\tan(\alpha_I)) \exp(-\nu) F_p(\alpha_I, n)}{4(\mu_S + \mu_V)}$$

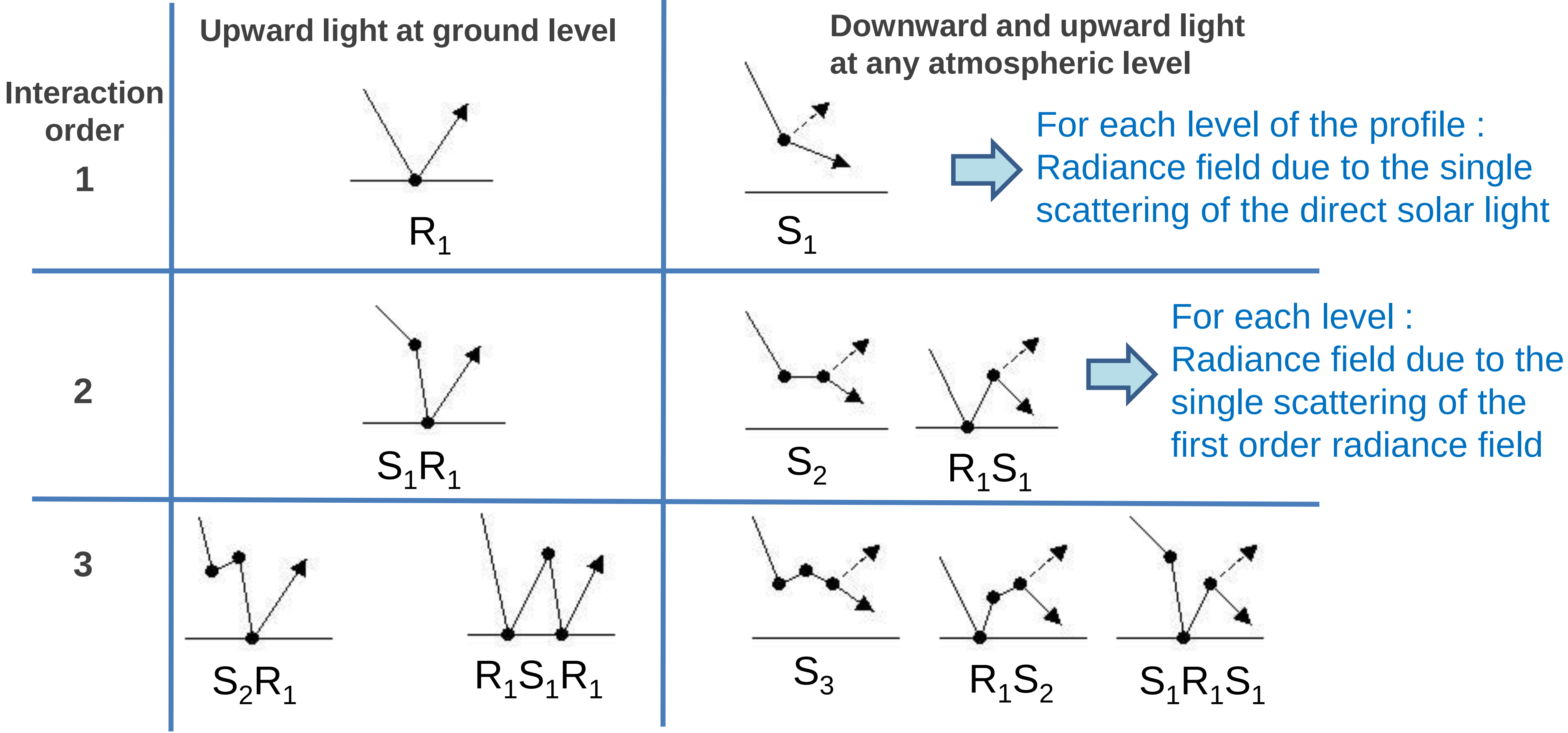
$\nu$ = NDVI
C = ponderation coef

› Ocean
- Fresnel reflexion on flat sea
- Rugged sea surface → Sun glint (Cox & Munk model)

CS GROUP

# SOS-ABS MODEL

# SOS-ABS : A SUCCESSIVE ORDERS OF SCATTERING MODEL



# SOS-ABS MODEL

- Modelling the gas absorption
  - Coupling effect of scattering and absorption
  - Gas transmission calculated from CKD (Correlated K-Distribution) method

Lacis and Oinas, 1991

For a given gas *g*

$$T_{\Delta\nu}(u_g) = \sum_{i=1}^{NE} exp(-m.k_i^g.u_g) \times \Delta g_i^g$$

Gas amount in the layer (part. / cm$^2$) [$u_g$]

CKD coefficient for the exponential i of the gas (cm$^2$ / part.) [$k_i^g$]

Term for order i of the distribution function [$\Delta g_i^g$]

$$\text{air mass } m = \frac{1}{cos\theta_s} + \frac{1}{cos\theta_v}$$

$k_i^g$ and $\Delta g_i^g$ calculated by a Line-By-Line code (LBLRTM)
→ provided by HYGEOS for SOS-ABS

# SOS-ABS MODEL

› Modelling the gas absorption

For a mixture of n gas species

$$T_{\Delta\nu}(u_1, u_2, \ldots, u_n) = \sum_{i_1=1}^{NE_1} \sum_{i_2=1}^{NE_2} \cdots \sum_{i_n=1}^{NE_n} \left[ \sum_{g=1}^{n} exp\left(-m.k_{i_g}^{g}.u_g\right) \right] \times \Delta g_{i_1}^{1} \times \Delta g_{i_2}^{g} \times \cdots \times \Delta g_{i_n}^{g}$$

$NE_g$ : number of exponentials for the gas g

$i_g$ : exponential number

$$T_{\Delta\nu}(u_1, u_2, \ldots, u_n) = \exp(-m.\delta_{\Delta\nu}^{abs})$$

⇒ $\delta_{\Delta\nu}^{abs}$ Absorption optical thickness over the spectral range $\Delta\upsilon$

⇓

$L_{\Delta\nu}(\delta_{\Delta\nu}^{abs})$ : Radiance

*Approximation*

Approximate calculation mode option of SOS-ABS

Fine calculation mode option of SOS-ABS

› Finer radiance calculation

$$L_{\Delta\nu} = \sum_{i_1=1}^{NE_1} \sum_{i_2=1}^{NE_2} \dots \sum_{i_n=1}^{NE_n} \left[ L_{\Delta\nu}\left(\delta_{i_g}^{g}\right) \right] \times \Delta g_{i_1}^{1} \times \Delta g_{i_2}^{g} \times \cdots \times \Delta g_{i_n}^{g}$$

$L_{\Delta\nu}\left(\delta_{i_g}^{g}\right)$ : Radiance calculated for the optical thickness of each expansion term

The exponential $i_g$ corresponds to the transmission $exp\left(-m.k_{i_g}^{g}.u_g\right)$

for which the optical thickness is $\delta_{i_g}^{g} = k_{i_g}^{g}.u_g$

# SOS-ABS VALIDATION

› Comparison to ARTDECO simulations

- DOAD RT code :
  - Adding doubling method
  - Polarisation
  - Gas absorption

- Use of same CKD coefficients
- Same IOP (Rayleigh, aerosols)

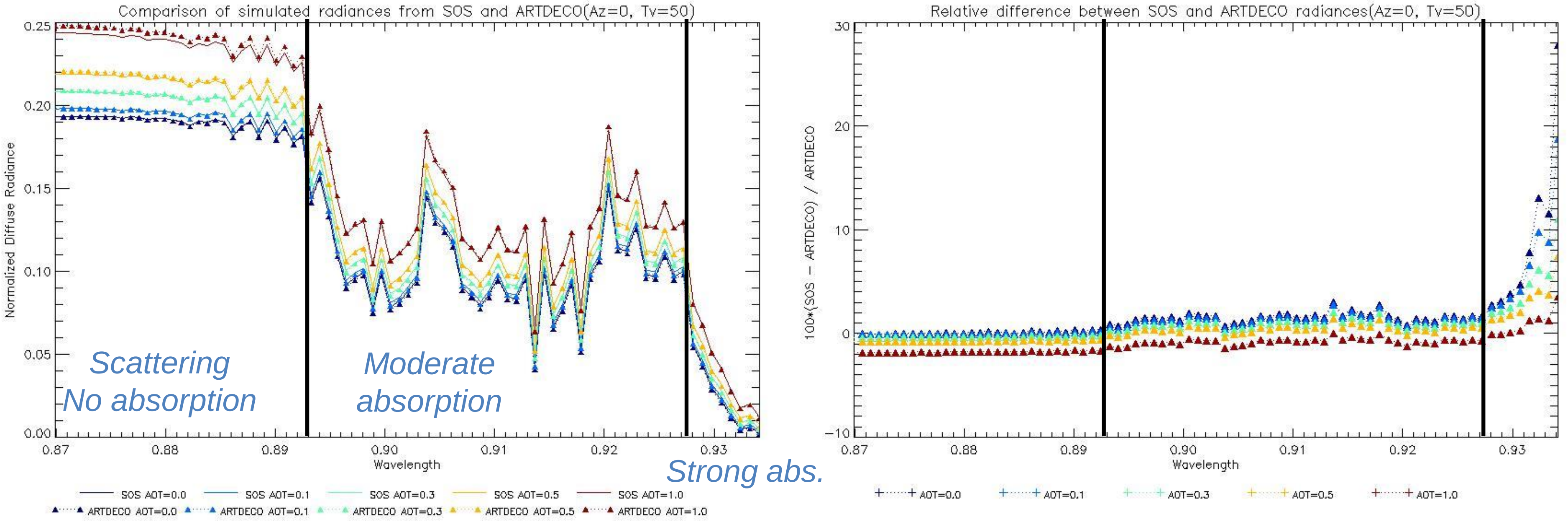
- Set of scenarios
  - Spectral ranges :
    - $O_3$ centred on 550 nm
    - $O_2$ centred on 760 nm
    - $H_2O$ centred on 910 nm
  - AOT : 0 to 1 (0.0, 0.1, 0.3, 0.5, 1.0)
  - Viewing angle VZA = 0°, 30°, 50°, 70° (SZA = 50°)

*ARTDECO*
*Atmospheric Radiative Transfer Database for Earth Climate Observation*

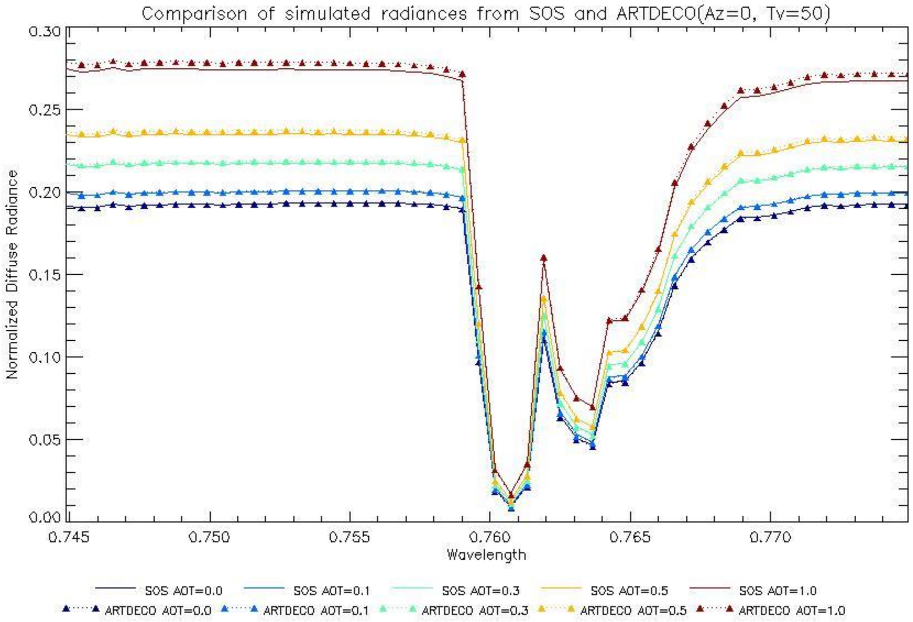
https://www.icare.univ-lille.fr/artdeco/

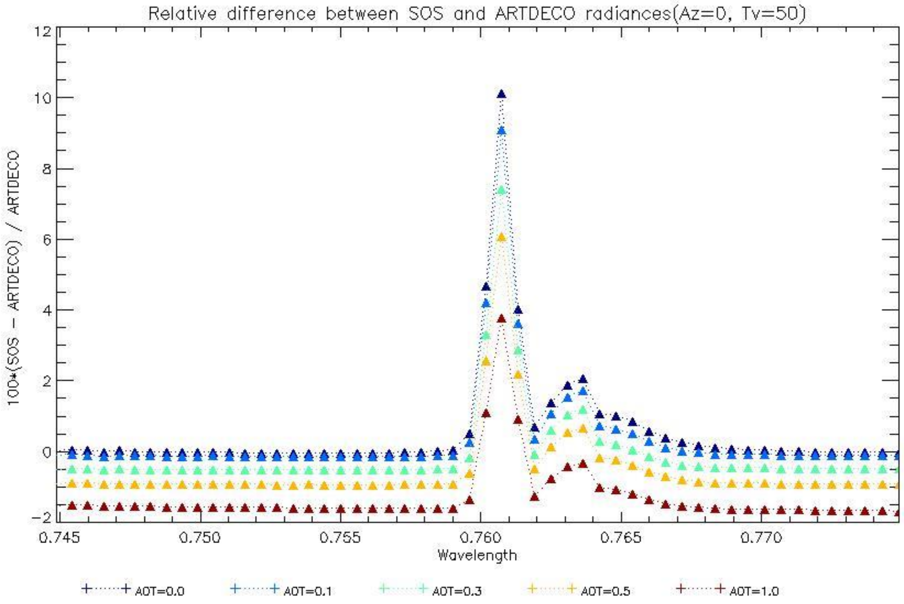
# VALIDATION

## $H_2O$ band test



## $O_2$ band test


Comparison of simulated radiances from SOS and ARTDECO(Az=0, Tv=50)
Normalized Diffuse Radiance
Wavelength
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.745
0.750
0.755
0.760
0.765
0.770
SOS AOT=0.0
SOS AOT=0.1
SOS AOT=0.3
SOS AOT=0.5
SOS AOT=1.0
ARTDECO AOT=0.0
ARTDECO AOT=0.1
ARTDECO AOT=0.3
ARTDECO AOT=0.5
ARTDECO AOT=1.0


Relative difference between SOS and ARTDECO radiances(Az=0, Tv=50)
100*(SOS – ARTDECO) / ARTDECO
Wavelength
12
10
8
6
4
2
0
-2
0.745
0.750
0.755
0.760
0.765
0.770
AOT=0.0
AOT=0.1
AOT=0.3
AOT=0.5
AOT=1.0

# ON-GOING PROGRESS AND OUTLOOK

# ON-GOING ACTIVITIES / OUTLOOK

- Improvements
  - Update of CKD coefficients
    - Finer estimate
    - Better H2O model including a concentration dependence
    - UV extension (360 nm)
  - Increase the number of models for calculating molecular optical thickness
  - Improve simulations in case of fine scattering OT vs. absorption OT (RAMI4ATM benefit)
- New validation exercise with ARTDECO
- Publication in preparation
- Release this summer → GPL v3 open source licence
  https://github.com/CNES/RadiativeTransferCode-SOS

THANK YOU !