# CORATHYP
# CORrection ATmosphérique de données HYPerspectrales

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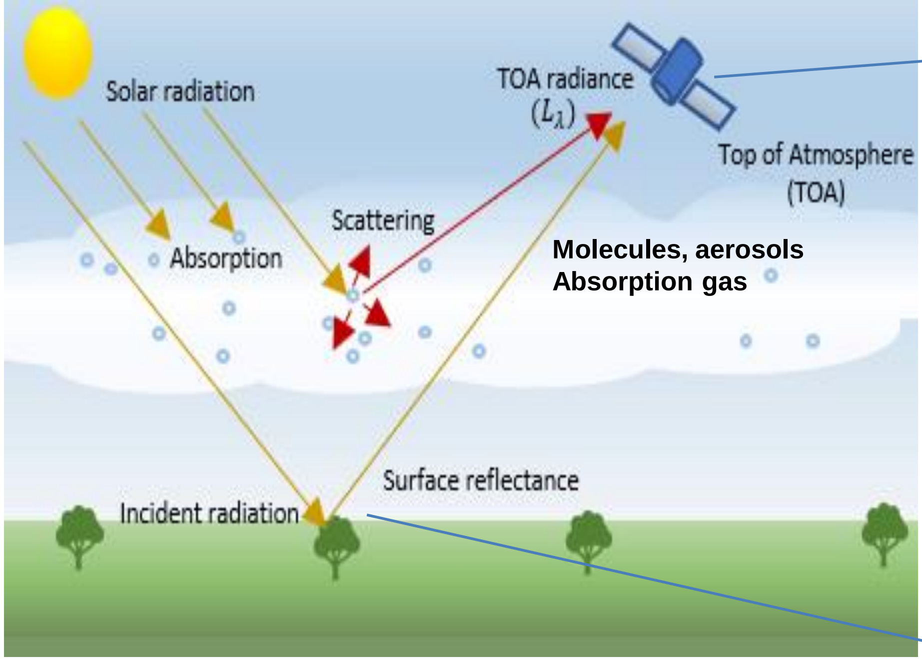
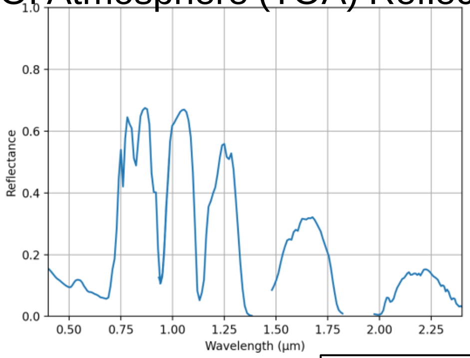
# THEORICAL BACKGROUND : ATMOSPHERIC CORRECTION



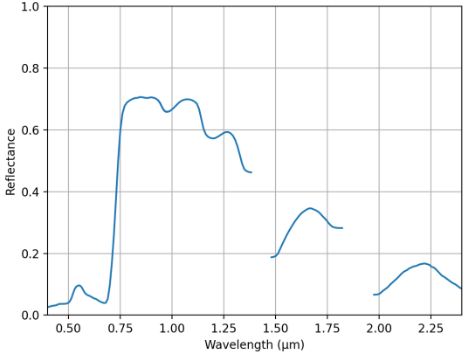

Top Of Atmosphere (TOA) Reflectance




Removing atmospheric effects

Needs knowledge of atmospheric composition

Bottom Of Atmosphere (BOA) Reflectance

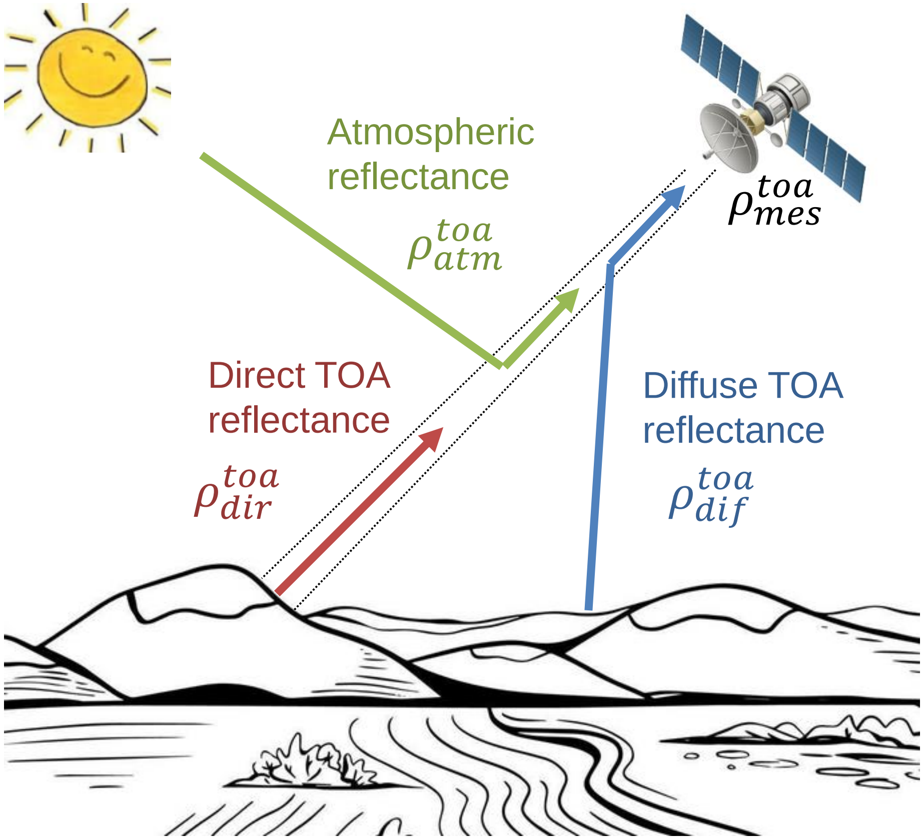


# CORATHYP GOALS

- **Atmospheric correction of hyperspectral satellite images over lands**
  - Background : recent (PRISMA, EnMap) and future sensors (CHIME, French mission…)
- **Based on state of the art**
  - Bibliography for multi & hyperspectral, airborne and satellite
- **Exploit high spectral resolution**
  - Estimation of gas and aerosols from the image
- **Adaptability to any sensor**
  - Dedicated to all hyperspectral sensors (but available also for multispectral)
- **Modular code** :
  - Step by step processing (select features to correct adjacency, absorption, slopes..)
  - Best algorithms selection (test various approaches)
  - Standalone modules for atmospheric characterization (Usable outside of CORATHYP)

# PHYSICS MODEL DESCRIPTION & SOLVING

# INCOMING SIGNAL AT SATELLITE LEVEL

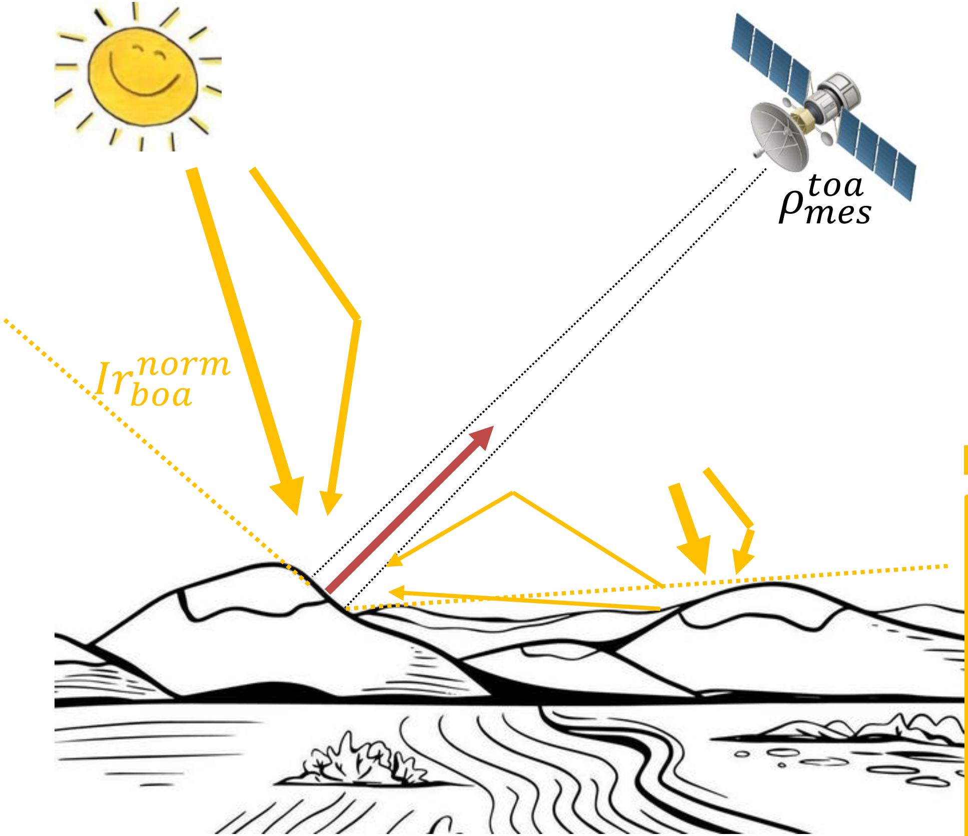



Considering a target pixel, the signal measured by a satellite sensor $\rho_{mes}^{toa}$ depends on :

- Signal coming directly from the pixel
- Signal coming from the whole scene through scattering
- Signal scattered by atmosphere without interaction with surface

$$\rho_{mes}^{toa} = \rho_{dir}^{toa} + \rho_{dif}^{toa} + \rho_{atm}^{toa}$$

# BOA REFLECTANCE INVERSION FROM DIRECT TOA REFLECTANCE




Surface reflectance $\rho_{boa}$ is extracted from direct TOA reflectance :

$$\rho_{boa} = \frac{\rho_{mes}^{toa} - \rho_{atm}^{toa} - \rho_{dif}^{toa}}{Ir_{boa}^{norm} \times T_{dir}^{\uparrow}}$$

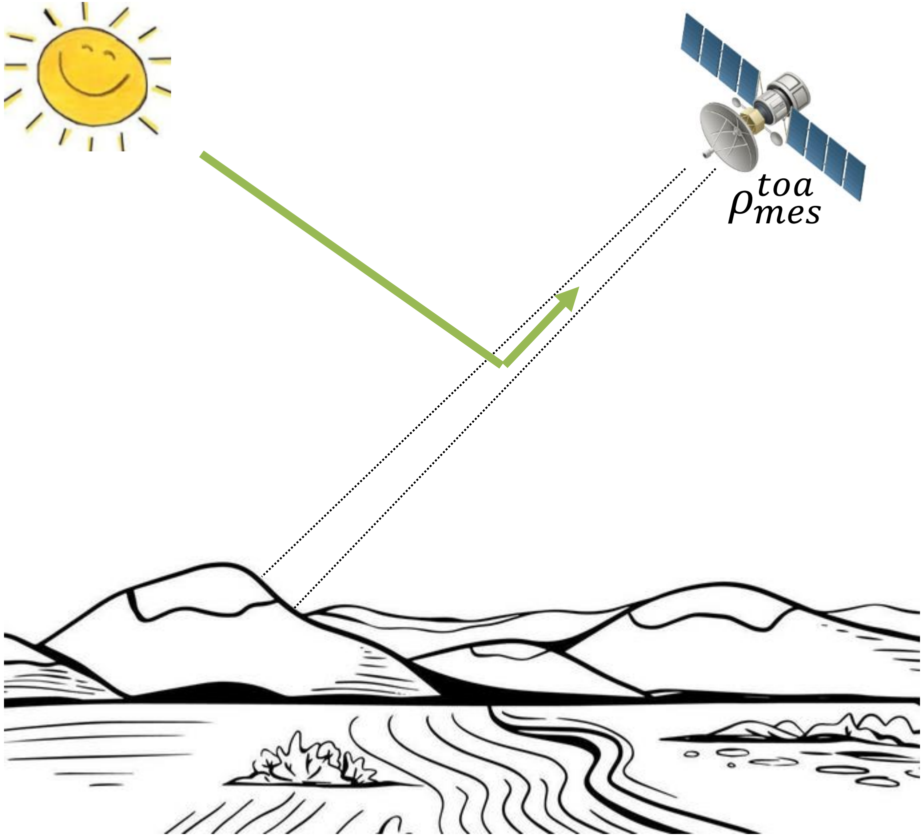
Normalized BOA Irradiance depends on :

- Atmospheric composition
- Pixel altitude & slope
- Neighbourhood reflectances & relief
- Sun Zenith Angle

Upward Direct transmittance depends on:

- Atmospheric composition
- Pixel altitude
- Viewing Zenith Angle

# ATMOSPHERIC TOA REFLECTANCE

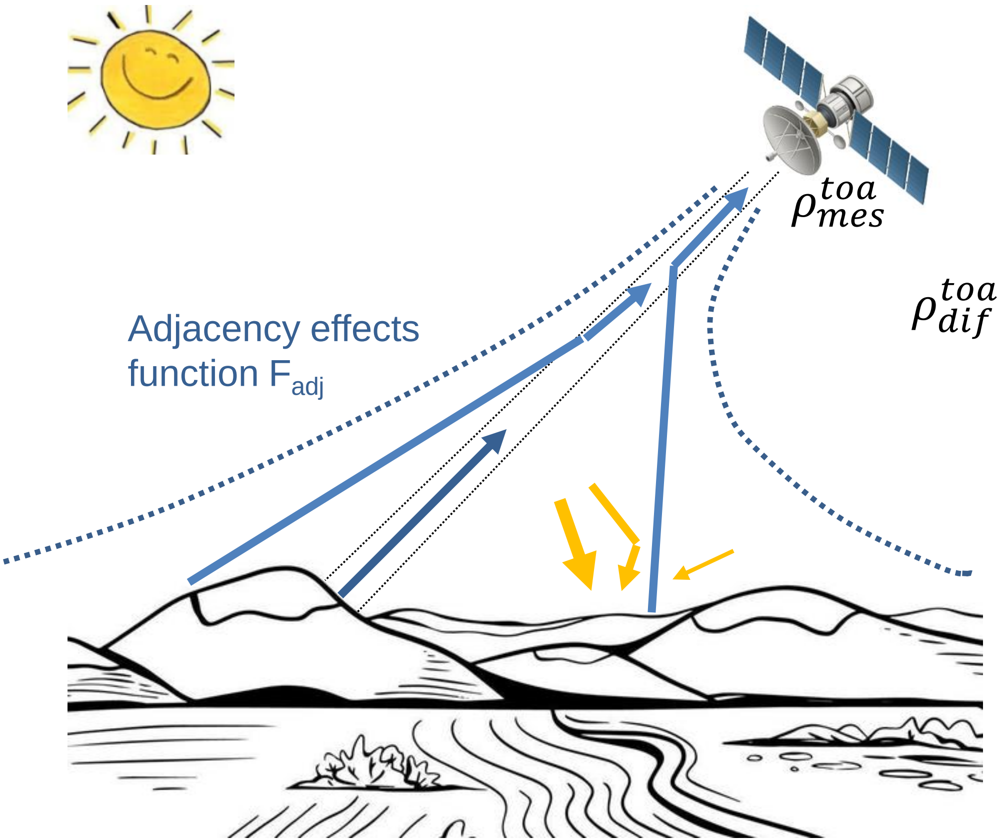



Atmospheric reflectance depends on :

- Atmospheric composition
- Pixel altitude
- Sun Zenith Angle
- View Zenith Angle

Easy to calculate with a Radiative Transfer code

# DIFFUSE TOA REFLECTANCE




Needs knowledge of incident irradiance and surface reflectances of **the whole measured scene** :

$$\rho_{dif}^{toa} = T_{dif}^{\uparrow} \times \iint_M E_{boa}^{norm}(M)\rho_{boa}(M)F_{adj}(M)dS$$

Weighting function determining the contribution of each pixel to upward diffuse beam. Depends on :

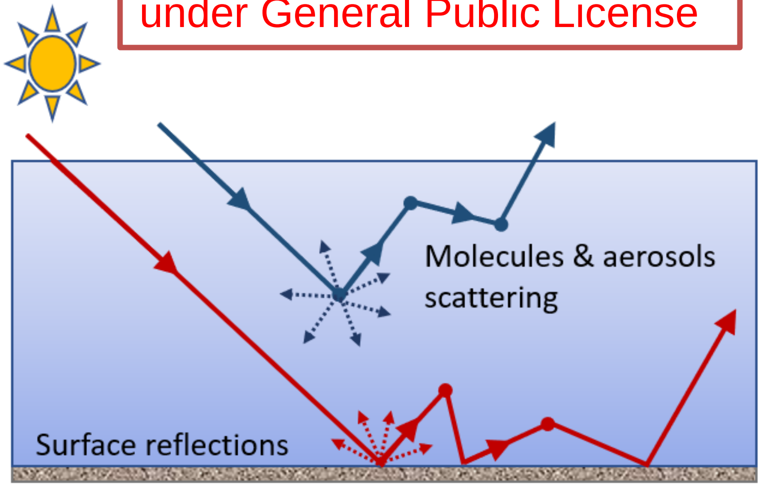
- Atmospheric composition
- Topography
- Viewing angles

# RADIATIVE TRANSFER

# SOS-ABS RADIATIVE TRANSFER 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 (0.364 – 4 $\mu$m)
- Under clear sky conditions

SOS-ABS Soon available under General Public License




› SOS-ABS code
- SOS method coupled with the gaseous ABSorption

Fortran
Python binding

› Heritage of the OS code from the LOA laboratory

# SOS-ABS MAIN FEATURES (FOR CORATHYP)

## Aerosols

**Literature Models** :

- WMO (continental, urban, maritime and combination of models)
- Shettle & Fenn (continental, urban and maritime)

**Mono-modal or Bi-modal :**

- Log normal Distribution (LND) or Junge Law

**Mixture of mono-modal particles :**

- CAMS compatible

**User-defined IOP :**

- Allows non-spherical particles

## Gas Absorption

**Absorption features :**

- Modelling according to the Correlated K-Distribution method
- Absorbing gases : $H_2O$, $O_3$, $CO_2$, $O_2$, CO, $CH_4$, $N_2O$, $NO_2$
- Default or User profiles
- Ability to fix amount of $H_2O$, $O_2$ (Psurf) $O_3$, $CO_2$, $CH_4$

**Spectral features :**

- Range : 0.364 µm to 4.0 µm
- Resolution: 1 $cm^{-1}$, 5 $cm^{-1}$, 10 $cm^{-1}$

**Calculation modes :**

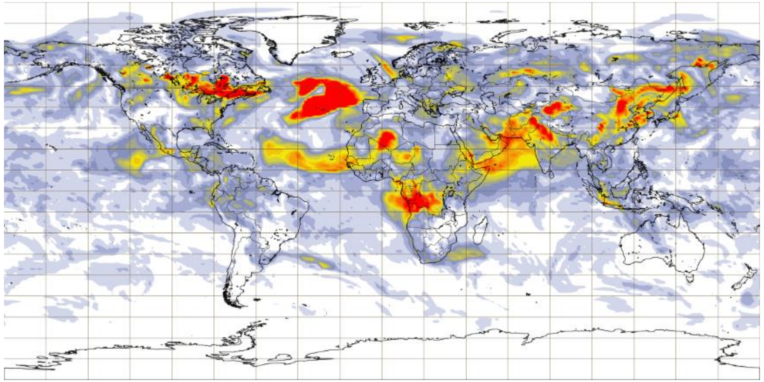
- Fine and Simplified

# ATMOSPHERIC CHARACTERIZATION

# ATMOSPHERIC COMPOSITION CONFIGURATION

## › CAMS aerosol Model (1)

- Aerosol mixture of 7 particule types :
  - SeaSalt, Dust, Organic matter, Sulfates, Black Carbon, Ammonium, Nitrates
  - LND distribution of each particule:
  - Inherent Optical Properties (IOP) dependant to Relative Humidity (5 particules)
- Extraction of particule mixture ratios from CAMS Re-Analysis



## › ECMWF

- Relative Humidity
- Surface pressure at image center (on-going)
- Ozone content at image center (on-going)

## › Retrievals from Image

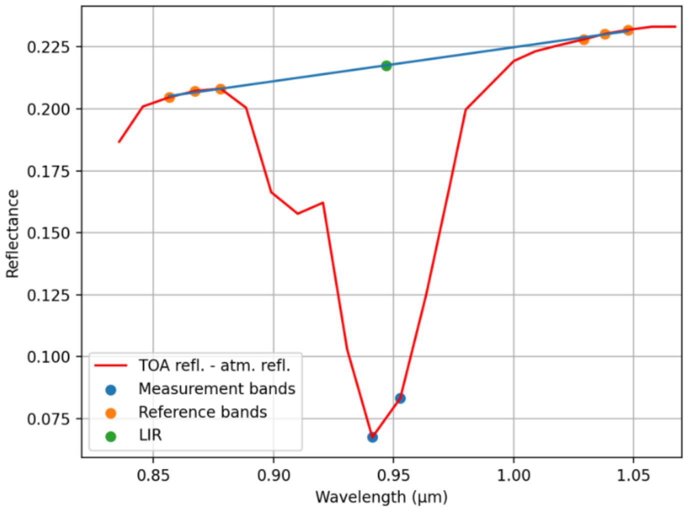
- AOT (mean Image value)
- Water vapour content (pixel value)

(1) B.Rouquié, O.Hagolle, F.M.Bréon, O.Boucher, C.Desjardins, S.Rémy, « Using Copernicus Atmosphere Monitoring Service Products to Constrain the Aerosol Type in Atmospheric Correction Processor MAJA », Remote sensing November 2017

# WATER VAPOUR CONTENT RETRIEVAL : APDA ALGORITHM (1)

## › Algorithm Basis :

- Image processing
  - Remove atmospheric reflectance from TOA reflectance
  - Calculation of Mean TOA reflectance in absorption band
  - Estimation of TOA reflectance without absorption through interpolation
  - Calculation of APDA ratio
- Comparison with APDA Look Up Tables




$$APDA = \frac{\overline{\rho_m - \rho_{atm}^m}}{Interpol\left(\rho_{ref}^i - \rho_{atm}^i, \lambda_m\right)}$$

(1) D.Schläpfer, C.C.Borel, J.Keller, K.I.Iten, “Atmospheric pre-corrected differential absorption techniques to retrieve columnar water vapor: application to AVIRIS data”, Remote Sensing of Environment, Vol 65, p 353-366, 1998

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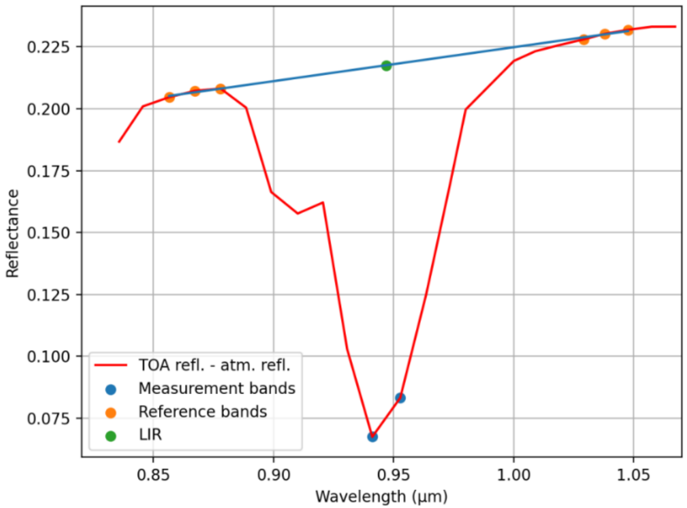


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\+ Independant of surface (theory)
Largely used algorithm

− Lack of reliability on low surface reflectances

(1) D.Schläpfer, C.C.Borel, J.Keller, K.I.Iten, “Atmospheric pre-corrected differential absorption techniques to retrieve columnar water vapor: application to AVIRIS data”, Remote Sensing of Environment, Vol 65, p 353-366, 1998

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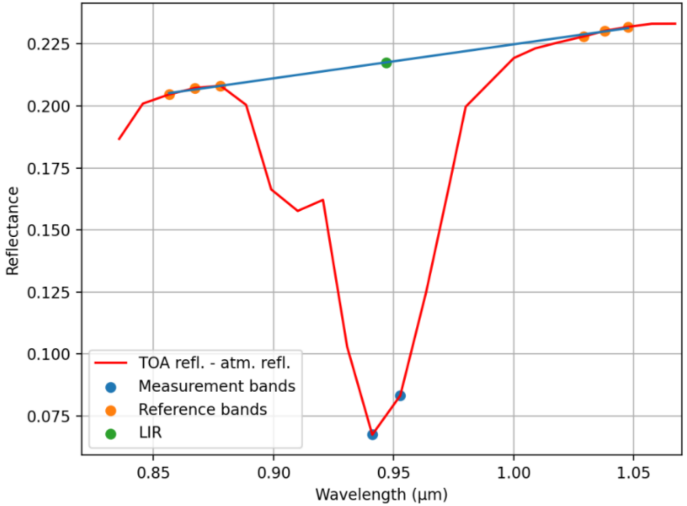


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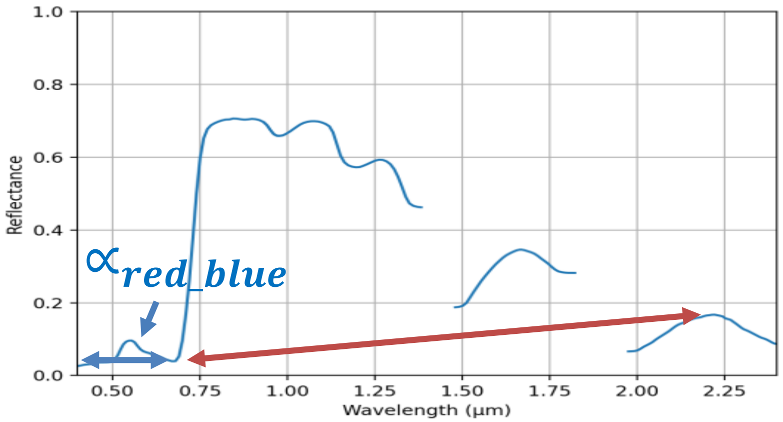
**Improvement in progress for low surface reflectance pixels**

(1) D.Schläpfer, C.C.Borel, J.Keller, K.I.Iten, "Atmospheric pre-corrected differential absorption techniques to retrieve columnar water vapor: application to AVIRIS data", Remote Sensing of Environment, Vol 65, p 353-366, 1998

# AEROSOL RETRIEVAL : MAJA DDV ALGORITHM

**Assumption** : constant spectral relationship into **Dark Dense Vegetation** BOA reflectance spectra




- Reflectance in the Red band is proportional to the SWIR band
- Reflectance in the Blue band is proportional to the Red band

**Red-Blue relation is more reliable (2)**

## MAJA algorithm (1)

**For 1/3 image pixel (subsampled image) :**

- Extract Neighbourhood and identify DDV pixels
- For a selection of AOT values :
  - Atmospheric correction in Red and Blue bands on DDV pixels
  - Quadratic difference on Blue band

$$err^2_{MS}(i) = \left(\rho^{blue}_{boa} - \propto_{red\_blue} \times \rho^{red}_{boa}\right)^2$$

- Cost function calculation as a function of AOT

$$cost(aot) = \sum_i W^2(i) \times err^2_{MS}(i)$$

- Minimize Cost function to retrieve AOT


(1) O.Hagolle et al, “MAJA ATBD”, 2017
(2) O.Hagolle et al, ” A Multi-Temporal and Multi-Spectral Method to Estimate Aerosol Optical Thickness over Land, for the Atmospheric Correction of FormoSat-2, LandSat, VENµS and Sentinel-2 Images ”, Remote sensing March 2015


CS GROUP

# VALIDATION

# VALIDATION APPROACH

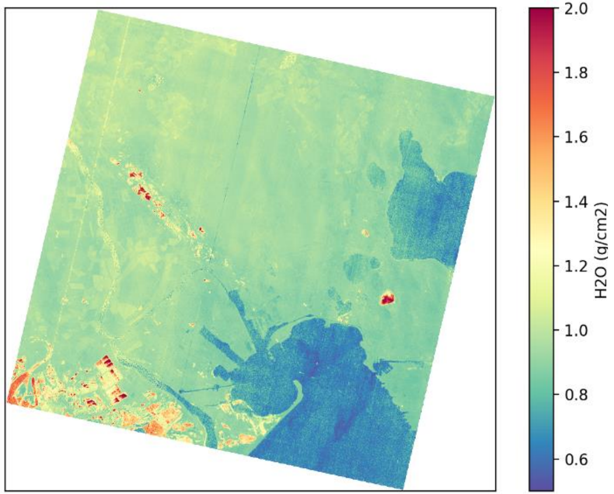
- **SOS-ABS Synthetic Images (done)**
  - Analysis of atmospheric composition
    - AOT, Surface pressure, $H_2O$ retrieval
  - Analysis of surface reflectance retrieval (flat and homogeneous terrain)
- **PRISMA processing (in progress)**
  - Comparison with surface reflectance from **PRISMA L2** products
  - Comparison with **La Crau** in-situ measurements :
    - AOT, $H_2O$ and Surface reflectance
  - Comparison with **AERONET** data :
    - AOT, $H_2O$
- **SENTINEL2 processing (on-going)**
  - Comparison with **MAJA** L2 processor :
    - $H_2O$, AOT and Surface reflectances (topography)
  - Comparison with **AERONET** data :
    - $H_2O$ and AOT

La Crau site

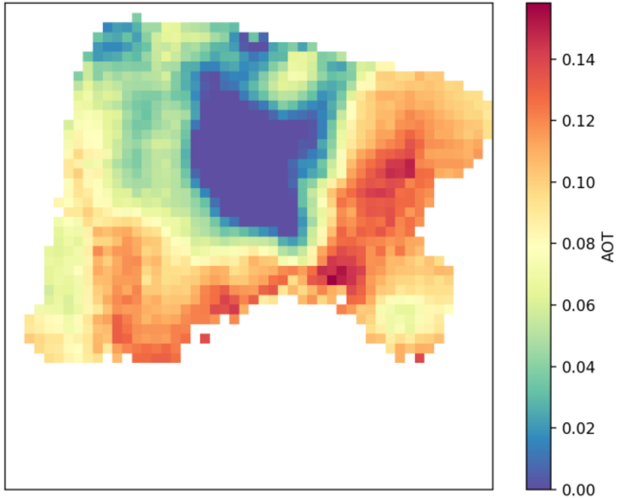
# PRISMA PROCESSING : FIRST RESULTS ON LA CRAU

PRISMA Image :
RGB Surface reflectance

CORATHYP H2O map
APDA using 1.1 µm H2O band




CORATHYP AOT map
MAJA inheritated DDV algorithm

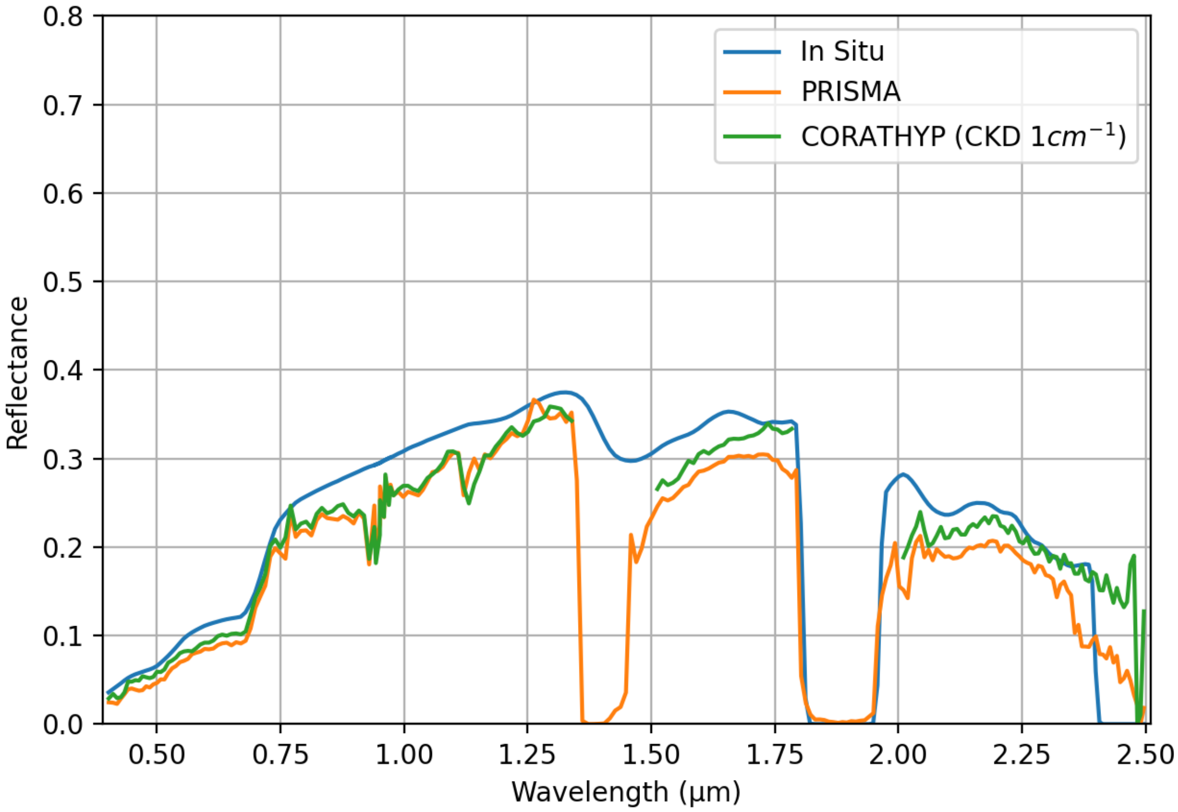



Data from La Crau
H2O : NCEP source
AOT : CIMEL

| H2O (g/cm2) | AOT |
|---|---|
| 0.95 | 0.103 |

# PRISMA PROCESSING : FIRST RESULTS ON LA CRAU

Comparison of CORATHYP retrieved reflectance with in-situ measurements and PRISMA L2 product



# ON-GOING PROGRESS AND OUTLOOK

# PROGRESS AND OUTLOOKS

## › In progress :

- Improve $H_2O$ retrieval
- Initialize atmosphere composition with ECMWF data
  - Ozone & Mean sea level Pressure

## › On-going Validation :

- Processing of SENTINEL2 and PRISMA
- Comparison with Atmospheric Correction codes (MAJA, PRISMA)
- Comparison with in-situ measurements (La Crau, AERONET)

## › Potential evolutions in the future :

- Psurf, $O_3$, $CO_2$ & $CH_4$ retrievals
  - SODA algorithm (1) shows encouraging results on synthetic data. Need to be evaluated on real data
- Improve MAJA DDV algorithm with new spectral bands
- Cloud detection
  - Using $O_2$ band ?

(1) Rodger A, "SODA: A new method of in-scene atmospheric water vapor estimation and post-flight spectral recalibration for hyperspectral sensors Application to the HyMap sensor at two locations", Remote sensing of environment, 2011.

# THANK YOU ! ANY QUESTION ?