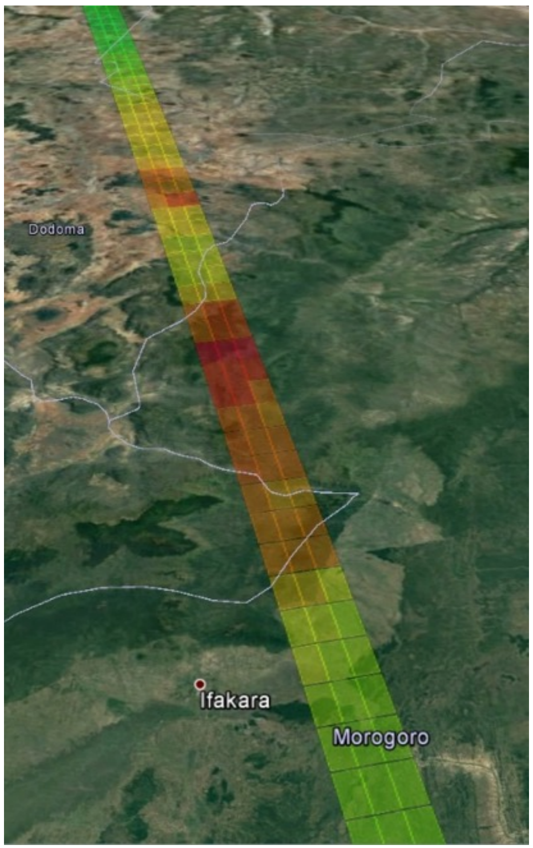

THE MICROCARB L1 & L2 PRODUCTS

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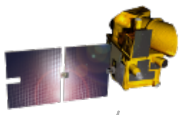
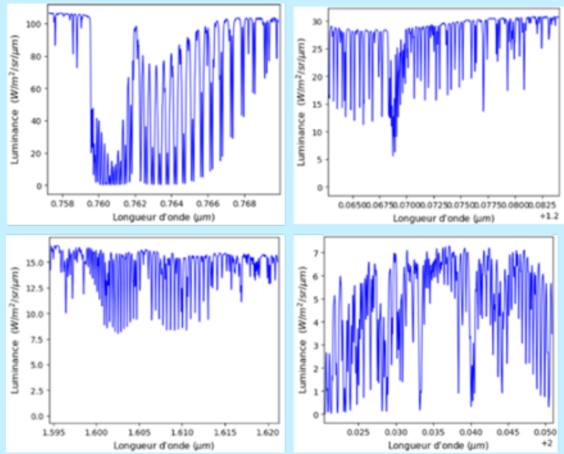
1 - Centre National d'Etudes Spatiales – Toulouse - France
2 - Laboratoire des Sciences du Climat et de l'Environnement – France



THE MICROCARB PRODUCTS

Level 0
= raw data

Calibration, binning



Level 1 = calibrated spectra
(+ images, geometry…)

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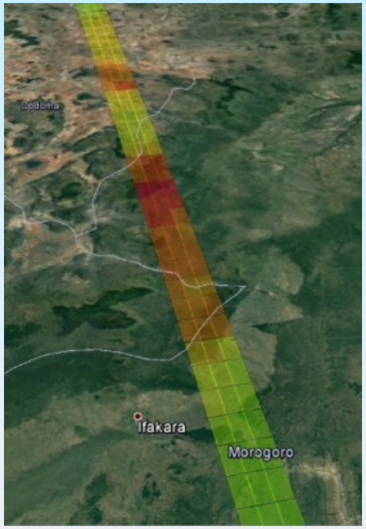
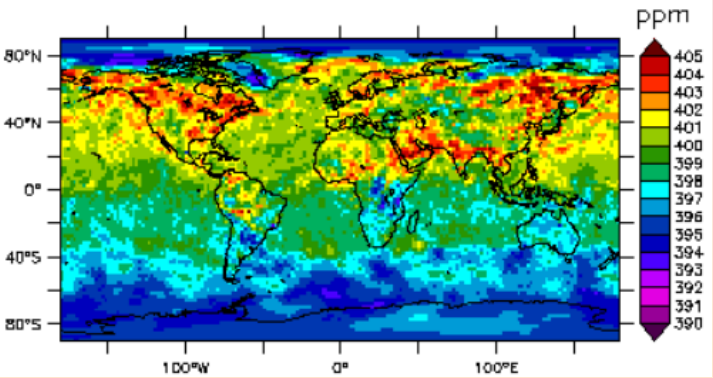
CNES + labs

Radiative transfer inversion



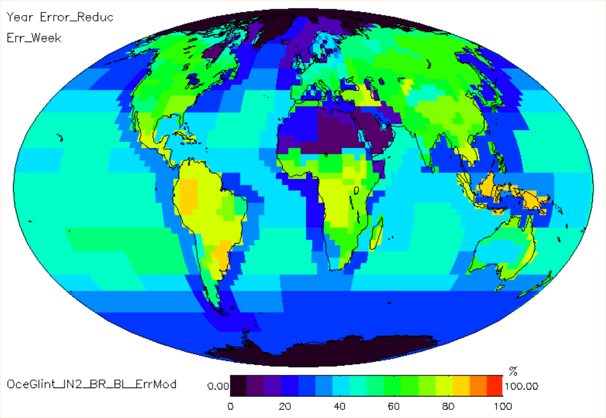
Level 2
= XCO_2 concentrations
(+ weighting function, secundary products)

Level 3
= XCO_2 maps



Atmospheric transport inversion

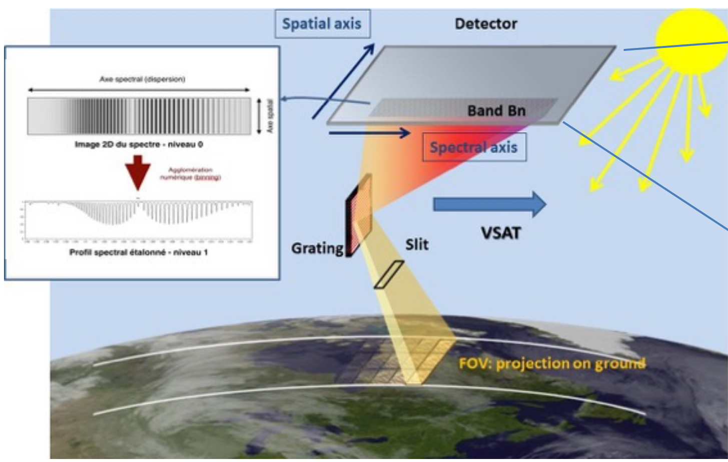
Level 4 = surface CO_2 fluxes



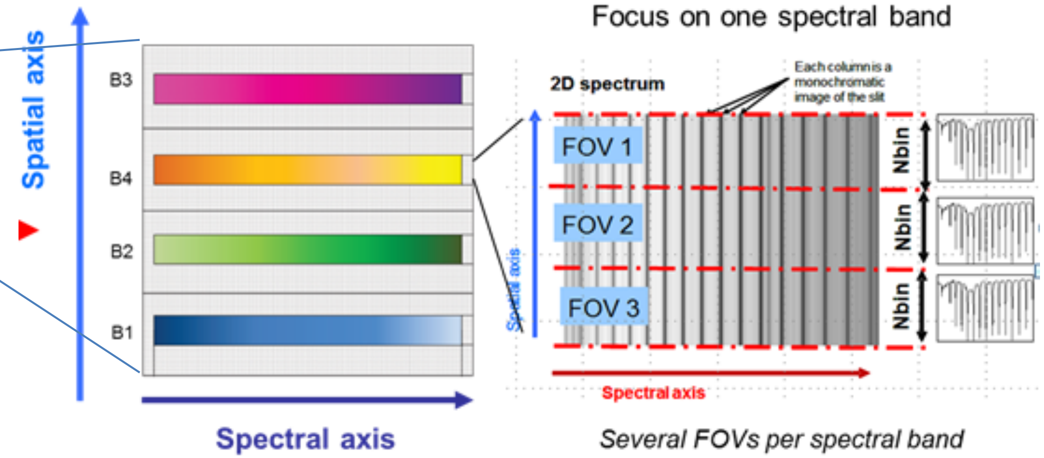
Labs

THE MICROCARB INSTRUMENT

- Instantaneous slit projection : 0.64 km x 13.5km, split in 3 IFOV ACT
- Temporal integration of 1.3s : 3 footprints (FOV) of 4.5 km * 9 km ~40 km2
- 4 spectral bands : 0.76 µm O2, 1.61 µm CO2, 2.03 CO2 & new 1.27 µm O2
- Only 1 telescope, 1 spectrometer, 1 grating, 1 detector

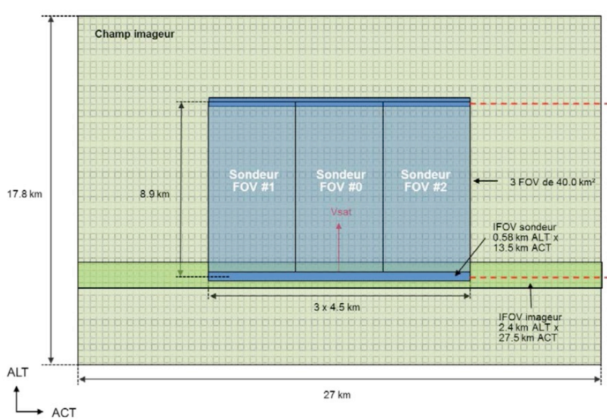


Focus on one spectral band



Several FOVs per spectral band
Binning → 1 spectrum per FOV

2D image of the each spectrum on detector
All bands on a unique NGP detector 1000pixels



- Embedded imager
  - Includes the spectrometer FOV
  - Resolution 110m x 140m
  - 1 spectral band 550 – 700 nm
  - Useful for cloud detection and geolocation

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L1A SPECTROMETER PRODUCTS (1/2)

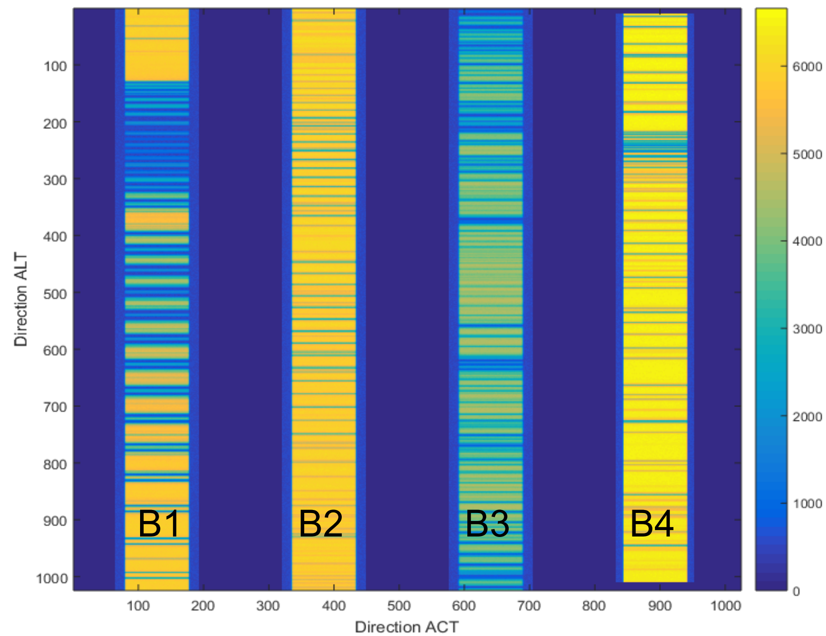
Calibrated data at detector level (pixels)

- All L0 matrix pixels are downloaded
- L1A neither delivered nor archived (too large)

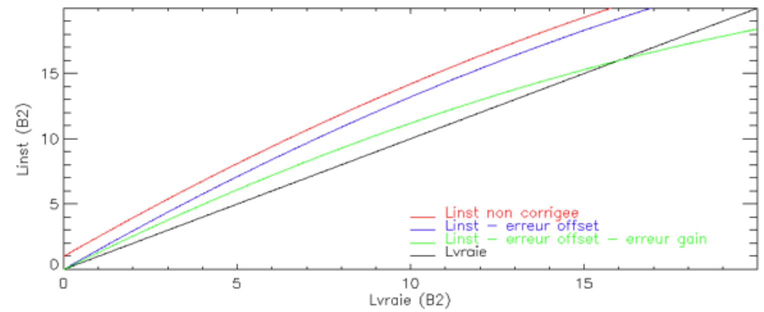
- Radiometric calibration:

$$L1A = A * gij * f_{NL}(L0 - dark)$$

  - Dark removal
    (daily measurements of the shutter)
  - Non-linearity correction f_{NL}
    (from ground characterization)
  - Relative gains gij correction
    (from monthly lamp measurements)
  - Absolute gain A
    (from monthly solar acquisitions)
  - 2D correction for straylight
  - 2D spike detection



Spectral bands at detector level



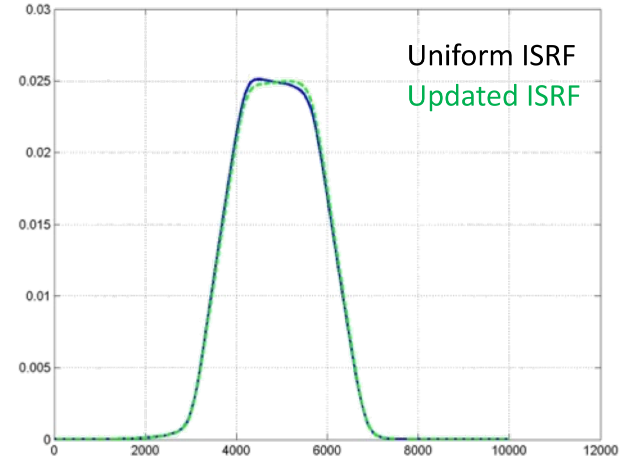
Radiometric curve for each pixel

L1A SPECTROMETER PRODUCTS (2/2)

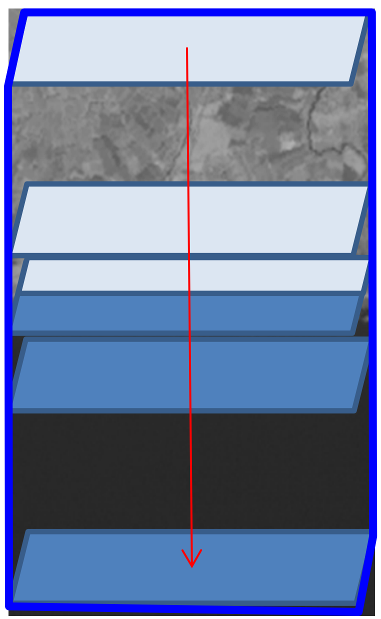
- Spectral calibration:
  - Dispersion law

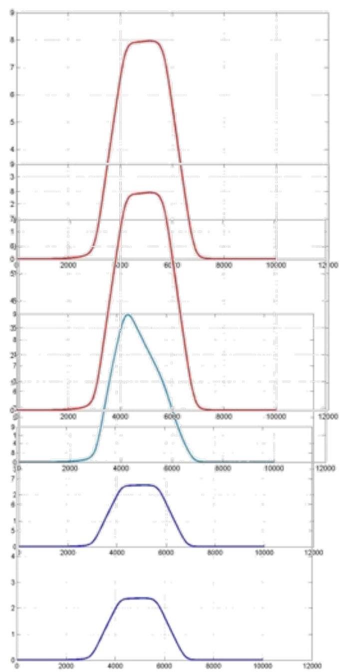
    (from monthly solar acquisition and correction for Satellite Doppler)
  - ISRF at pixel level

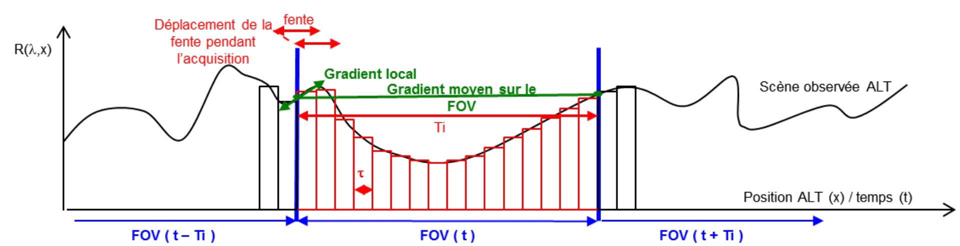
  ➔ Combination of ground characterization with the information on ALT non-uniformity from intermediate readings (14 readings of the detector during integration time for a few continuum channels)



Integrated difference between uniform and non-uniform ISRF: 2.2%

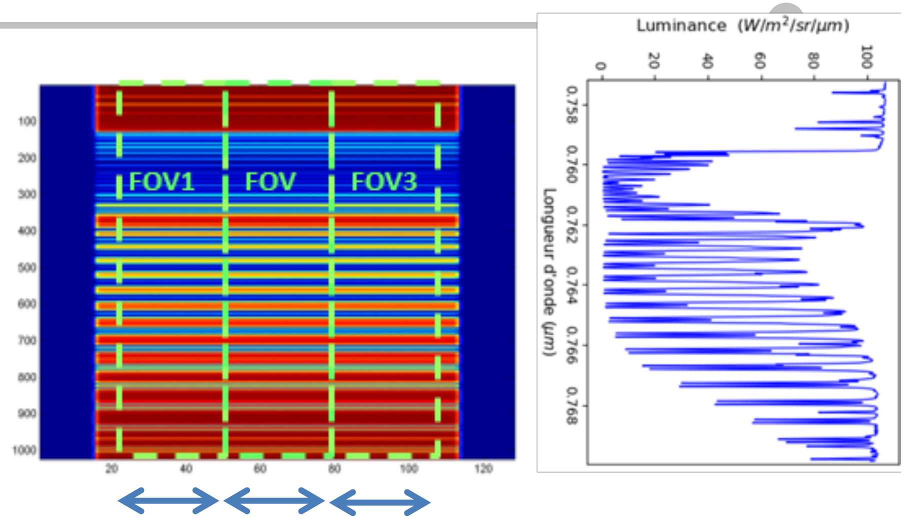






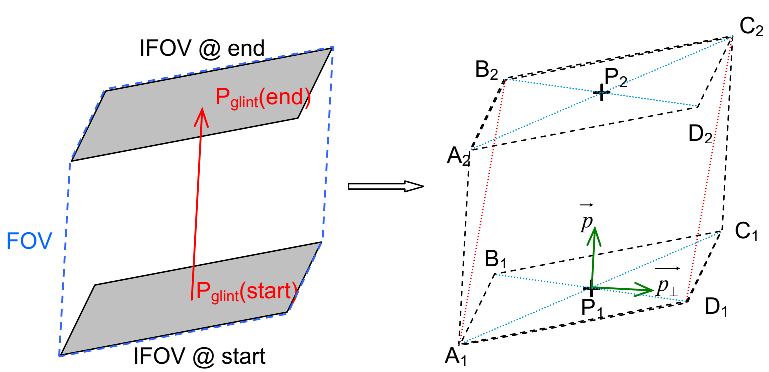
L1B SPECTROMETER PRODUCTS

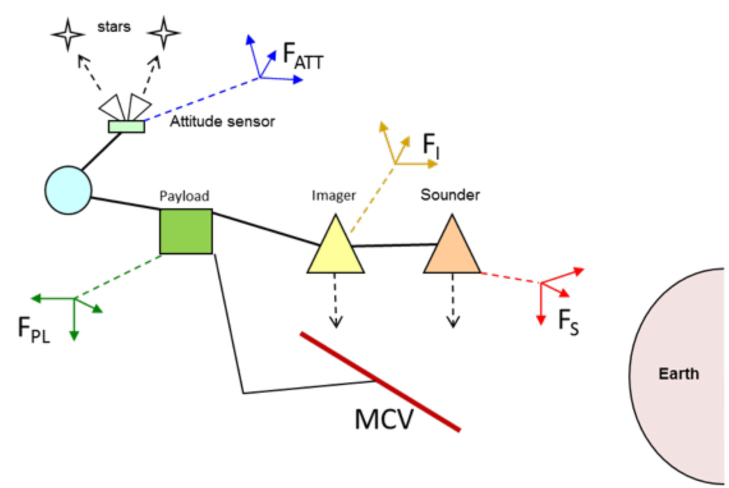
Calibrated spectra at FOV (after binning)



- Binning in 3 FOV
  - Correction for potential smile and keystone
  - Binning of pixels in 3 FOV (29 pixels / FOV)
  - Binning of ISRFs in 3 FOV (29 ISRF / FOV)
  - ➔ An updated ISRF is given for each channel of each FOV

- Geometric model of FOV
  - Coordinates of each vertex of each IFOV + center
  - FOV spatial spread function
  - Uses orbitography and attitude





L1C SPECTROMETER PRODUCTS

Calibrated spectra for each FOV including corrections from geophysical data

- L1C processing (experimental) to reach the best L1 performance so as to reduce L2 regional biases
  - ✦ Geolocation refinement by correlation of the imager with Sentinel 2
    ➔ Increase the quality of surface pressure and albedo priors
  - ✦ Creation of a 4AOP polarized theoretical spectrum
    - » Same priors as L2
  - ✦ Correction of dispersion law by correlation with the theoretical spectrum
    ➔ Corrects any instrumental spectral defect, rather than in the L2 processor
  - ✦ Correction of residual instrumental polarization with the theoretical spectrum and the Mueller matrix of the instrument projected in the same frame
    - » MicroCarb has a low polarization rate (Glint: 0.2%, Nadir : <1%) thanks to a scrambler
    - » This rate is still high enough to induce regional biases
    - » Most part of the natural polarization is known : Rayleigh, glint ➔ easy to correct

  ➔ This methodology reduces the L2 ground segment sizing by avoiding polarized computations with iterations

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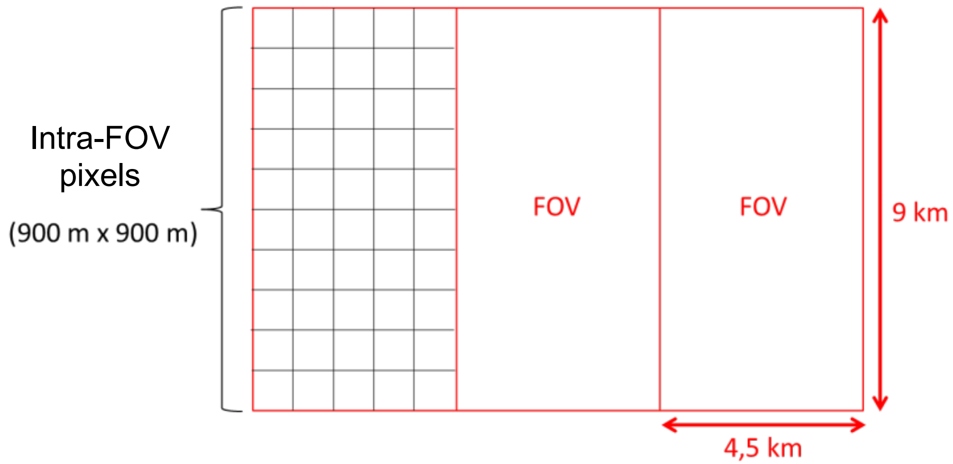
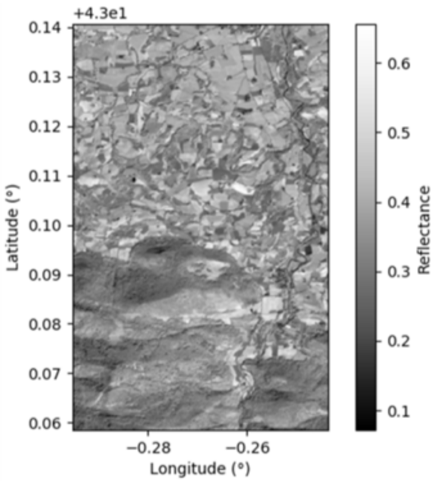
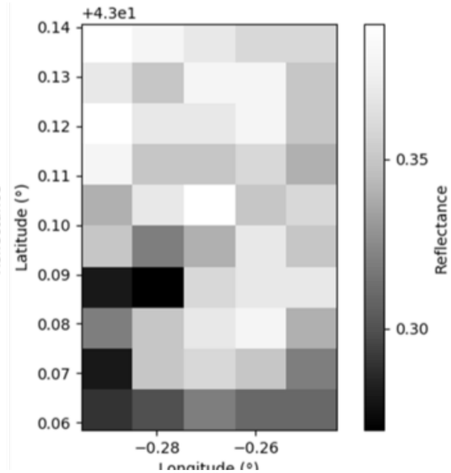
L1C SPECTROMETER PRODUCTS

- Computation of Intra-FOV Pixels (PIF)
  - Using the intermediate readings and the 29 ACT pixels / FOV in ~200 channels (continuum + lines), we can build sub-FOV maps of some geophysical parameters
  - Albedo in 4 bands (+ imager)
  - Ice, vegetation (NDVI)
  - Thick clouds (see next slides)





True albedo

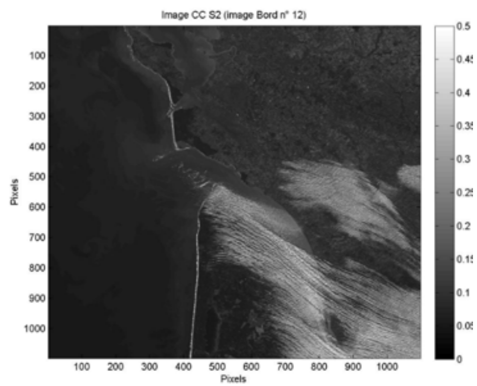


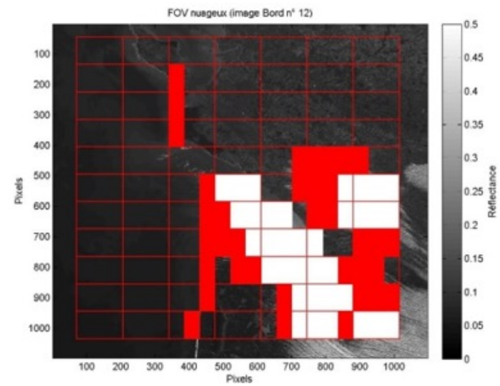
MicroCarb Sub-FOV albedo

L1C EMBEDDED CLOUD DETECTION

- 1st filter for thick cloud detection : very rough
  - Threshold on the radiometry of the imager (mean reflectance of MODIS + margin)

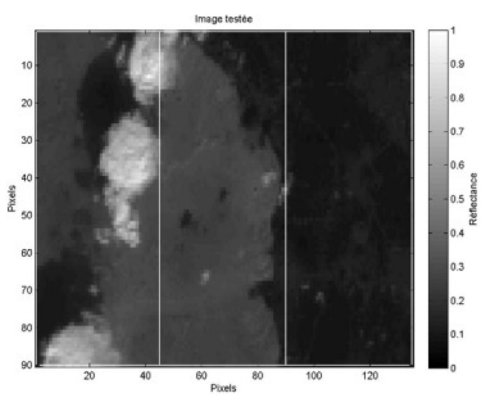
MicroCarb image to analyze



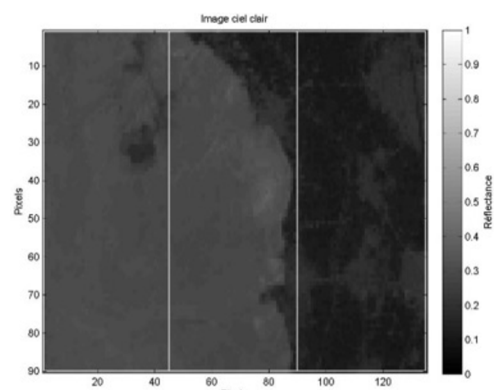


Thresholding

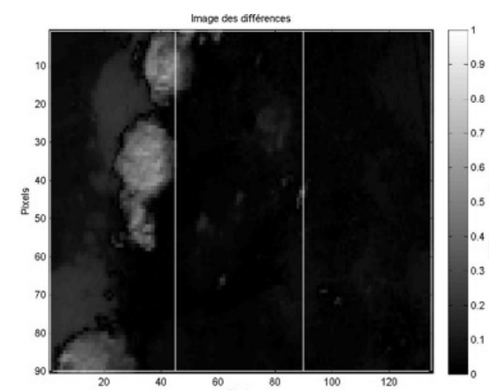
- 2nd filter for thick cloud detection
  - Pixel to pixel comparison of the imager with a clear sky S2 image climatology



MicroCarb Image to analyze



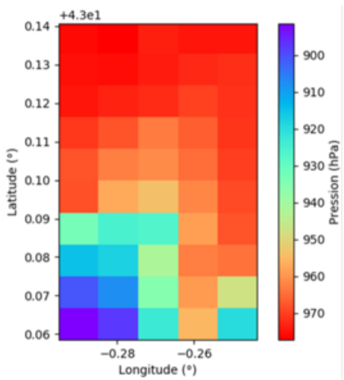
S2 clear sky image



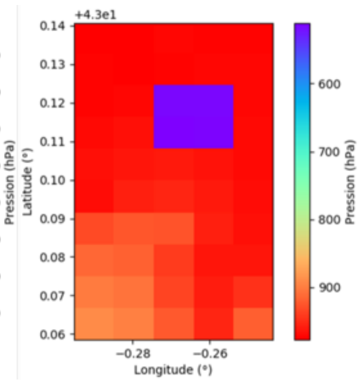
Difference

L1C CLOUD DETECTION : FINAL INDEX

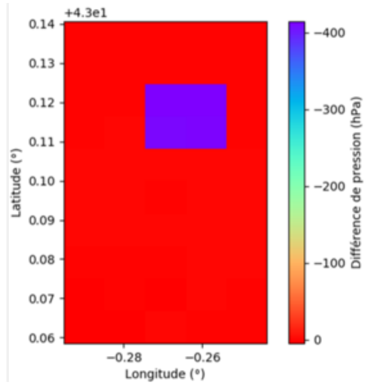
- Comparison of prior and estimated surface pressure at FOV level (high SNR)
- Cloud intra-FOV maps. For each PIF:
  - Estimation of surface pressure from a few O2 lines @ 0.76µm (with Rayleigh but no aerosols)
  - Computation of prior surface pressure from ECMWF + Digital Elevation Model)
  - Difference between both enlights clouds (even with the PIF low SNR)



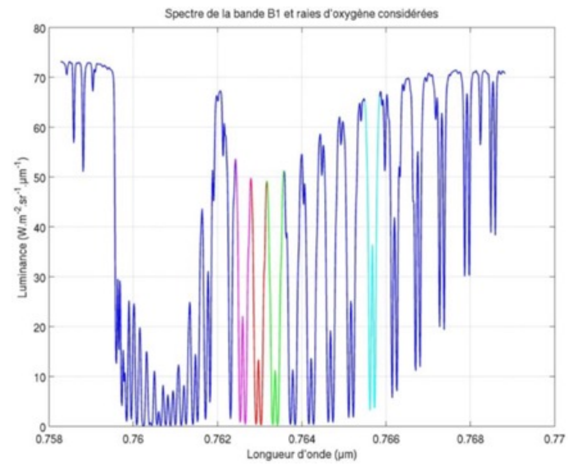
Clear sky Psurf



Psurf including a cloud



Difference



O2 absorption lines of multi-reading used for Psurf retrieval

- Same work may be done with H2O lines @ 2.04 µm (under evaluation)
  - More sensitive close to the surface
- Albedo intra-FOV maps
  - Difference between MicroCarb and S2 albedo enlights clouds

➔ All this information is combined to provide a cloud contamination index

L2 PRE-FILTER

- The beginning of mission will focus on the easiest scenes, and progressively increase the situations
- The filter have to be refined

- Pre-filtering :
  - Remove SZA > 75°
  - Remove lower SNRs / seas
  - Remove highly heterogeneous scenes
  - Remove thick cloud contaminated scenes
  - Remove aerosol loaded scenes (AOD>0.3) from CAMS index

L1 -> L2 INVERSION TOOL : 4ARTIC

- Inversion of the radiance spectra to retrieve the geophysical state

$$y = f(x) + \varepsilon \approx Kx + \varepsilon \text{ with } K = \frac{\partial y}{\partial x}$$

Measured spectrum (L1) → y; Geophysical state vector (L2) → x; Jacobian matrix → K

- Based on Rodgers 2000: optimal estimation with gaussian probability functions
  - Iterations for non-linearity : $x_{i+1} = x_a + \left(S_a^{-1} + K_i^T S_\varepsilon^{-1} K_i\right)^{-1} K_i^T S_\varepsilon^{-1}\left[\left(y - F(x_i)\right) + K_i\left(x_i - x_a\right)\right]$

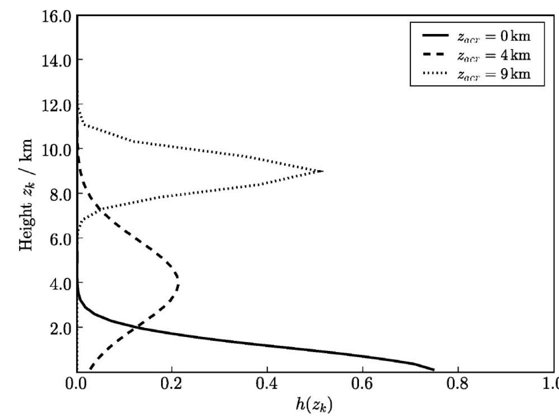
    State vector a priori covariance matrix → S_a; Noise covariance matrix → S_ε; Prior state vector → x_a
  - Gauss-Newton or Levenberg-Marquardt
  - Stop criteria based on slight evolution of chi2 & slight evolution of state vector

- Radiative transfer (K & spectra) computed with 4AOP
  - Pre-computed LUT of cross-sections, spectroscopy from GEISA
  - Diffusion from LIDORT, accelerated with Low-Stream Interpolation (O'Dell 2011)
  - Our RT speed has still to improve (not at the state of the art)
  - → Diffusion with SOS under progress

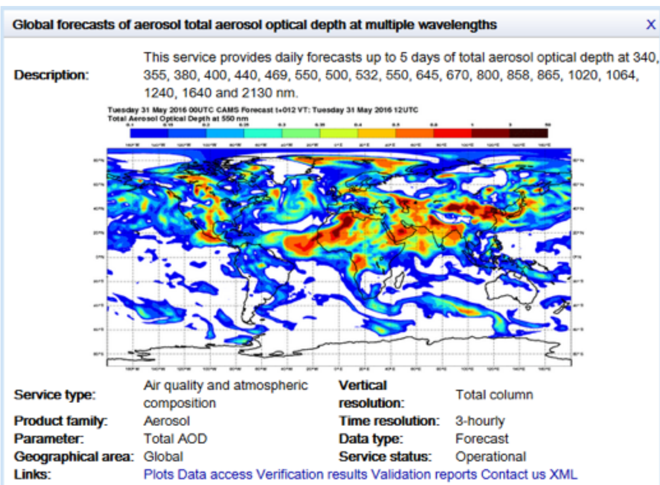
4ARTIC MAIN HYPOTHESIS

- State vector:
  - 19 layers of CO_2 and H_2O + Psurf + albedo (& slope) per band, fluorescence, airglow, aerosols
    - ➔ These will be delivered as primary or secundary products
  - May include the retrieval of instrumental unknowns (radiometric offset, spectral shift)

- Aerosol / thin clouds retrieval baseline:
  - 3 parameters retrieved in the state vector [AOD(σ_0), k, z_{aero}]
  - Angström coefficient : $AOD(\sigma) = AOD(\sigma_0)(\sigma/\sigma_0)^k$
  - Gaussian vertical distribution with mean altitude z_{aero}, decreasing width with z_{aero} (Butz et al. 2009)
  - ➔ Retrieval eased by the 1.27 µm O_2 band
  - Single Scattering Albedo = 1
  - Henyey-Greenstein phase function with g=0.8



- Priors:
  - Psurf, H_2O and T profiles from ECMWF
  - Aerosol AOT at different wavelengths, vertical profiles and aerosol main type from CAMS
  - Altimetry from Planet Observer
  - CO_2 from CAMS
  - Albedo from Sentinel 2 L2 synthesis
  - Airglow from LATMOS climatology



INVERSION OF OCO-2 L1B WITH 4ARTIC

4ARTIC is currently tested with the OCO-2 L1B B9

- Most favorable conditions:
  - Work with TARGET data over TCCON
  - Clear sky, same prior and a priori covariances as OCO-2, no aerosol retrieval

- Statistics on 2400 spectra (courtesy of Leslie David, LSCE) :

	XCO2 (ppm)	Psurf (hPa)	XH2O (ppm)
4ARTIC - TCCON	-0.67 +/- 2.03 (0.51%)	1.42 +/- 4.43 (0.45%)	-33.03 +/- 153.27 (6.19%)
ACOS (raw) - TCCON	-2.23 +/- 1.80 (0.45%)	-0.43 +/- 3.23 (0.33%)	112.74 +/- 182.37 (7.37%)

  - Overall biases are low
  - Overall standard deviation of the same order of magnitude as ACOS

- Continued work:
  - Understanding of residuals
  - Aerosol loaded scenes
  - Glint observations
  - Own priors, application of some L1 processings

CONCLUSIONS

- MicroCarb main innovations :
  - ISRF knowledge in heterogeneous scenes
  - L1C with refined geolocation, spectral law and polarization impact
  - Intra-FOV information (a few channels) gives access to albedo, ice, NDVI, clouds
  - Cloud detection: based on imager and intra-FOV pixels
  - 1.27 µm band : better assessment of the aerosols (Angström coefficient), less sensitive to spectroscopy errors, same vertical sensitivity to aerosols as wCO_2 + sCO_2

- A complete chain of processing for L1 & L2 (& L3) is now specified
  - Most critical parts are prototyped
  - Testing under going for 4ARTIC, to come for other parts
  - Ground segment development starts next september

- Format of products : as similar as possible to OCO-2

  ➔ To ease the use of the MicroCarb data by the community

- A SIF product will also be computed by a pre-processor provided by UoL (Hartmut Boesch & Dongxu Yang)

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