SCIENTIFIC AND TECHNICAL INSIGHT INTO MICROCARB

International Working Group on Green House Gazes Monitoring from Space
IWGGMS-12

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OUTLINE

- SCIENTIFIC TOOLS
- REQUIREMENTS AND PERFORMANCES

Scientific numerical tools

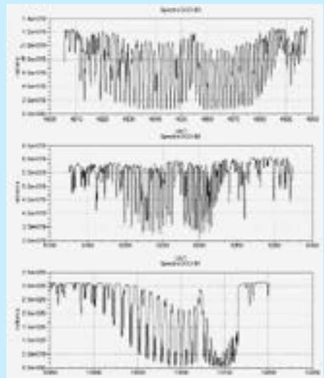
Instrumental design + defects

CNES

Instrument simulator

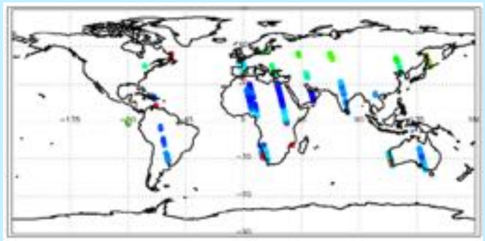
Atmospheric spectra at infinite resolution

4AOP



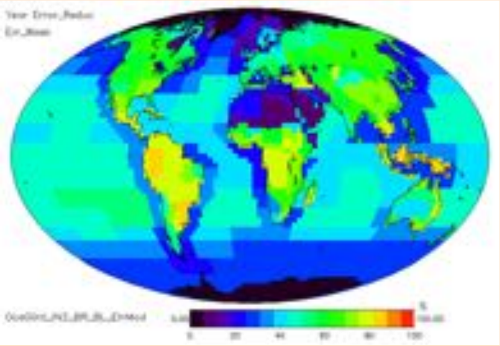
Level 1 = calibrated spectra
+ performances

4ARTIC



Level 2
= CO_2 Volume mixing ratio
+ performances

SIMGES



Level 4
= CO_2 surface fluxes
+ performances

LSCE

MicroCarb has a complete simulation chain:

- Derivation of MRD, SRD and IRD requirement documents
- Performances assessment at each level
- Enables quick and efficient feed-back

→ Use for instrumental design

→ Preparation for ground segment

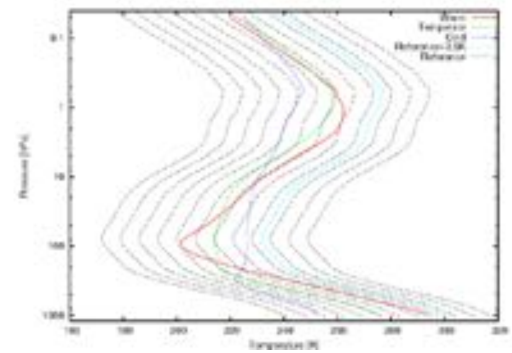
L1 RADIATIVE TRANSFER CODE “4AOP”

- Developed by LMD & NOVELTIS, operated by CNES for MicroCarb
- Computes radiance spectra and jacobians

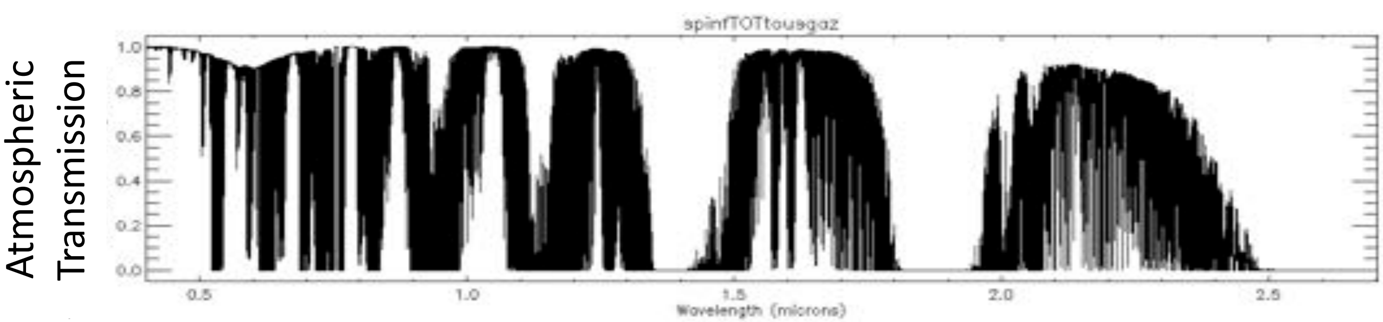
- LUT for cross sections (atlas), built from the GEISA database
- Diffusion (Rayleigh, aerosols): DISORT, LIDORT, VLIDORT

- Validated by LMD with TCCON and GOSAT

- Recent and on-going developments for 4AOP:
  - Now works from NIR to TIR, extension to UV/VIS
  - Optimisation of the code (interfaces, parallelisation)
  - Diffusion acceleration
  - Photosynthesis fluorescence



Atlas temperature discretisation (black) and user temperature profile examples



L1 -> L2 INVERSION TOOL « 4ARTIC »

THALES

- Prototyped and operated by CNES, developed by Thalès Service, scientific support from LSCE & LMD
- 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 (L2) → x; Jacobian matrix → K

- Based on Rodgers 2000: optimal estimation with gaussian probability functions
  - Fast performance estimation mode:

A posteriori covariance matrix
➔ **XCO2 random error** (ppmv) , column integrated

$$\hat{S} = (K^T S_\varepsilon^{-1} K + S_a^{-1})^{-1}$$

Jacobian matrix ← Spectral performances

Noise covariance matrix ← Radiometric performances

State vector a priori covariance matrix

Bias transport by gain matrix G
➔XCO2 **bias** (ppmv), column integrated

$$b_x = G b_y$$

$$G = \hat{S} K^T S_\varepsilon^{-1} = \frac{\partial \hat{x}}{\partial y}$$

  - Retrieval mode: by iterations, from a priori xa:

$$x_{i+1} = x_a + \left(S_a^{-1} + K_i^T S_\varepsilon^{-1} K_i\right)^{-1} K_i^T S_\varepsilon^{-1} \left[\left(y - F(x_i)\right) + K_i\left(x_i - x_a\right)\right]$$

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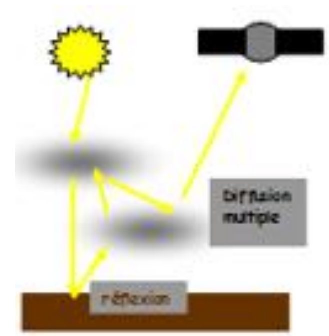
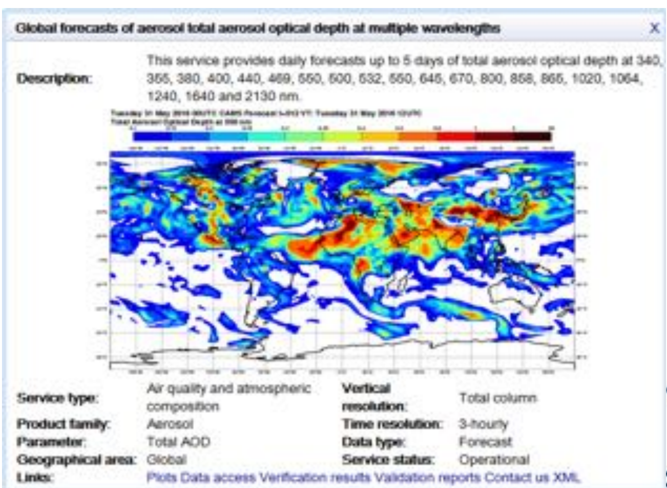
L1 -> L2 INVERSION TOOL « 4ARTIC »

- State vector:
  - 19 vertical levels of CO_2 and H_2O + Psurf + albedo (& slope) per band (+ fluorescence)
  - Retrieval may include estimation of instrumental unknowns: radiometric offset, shift / width of ISRF

- Aerosol retrieval baseline:
  - Developed by Vanessa Sherlock & NOVELTIS (CNES funding)
  - Simplified explicite scheme based on 3 parameters [$\ln(AOD(\sigma_0))$, k, z_{aero}] retrieved in the state vector
  - $AOD(\sigma) = AOD(\sigma_0)(\sigma/\sigma_0)^k$
  - Gaussian vertical distribution (from Butz) with mean altitude z_{aero}
  - NB: other algorithms also under study



- Dedicated on-going study to test 4ARTIC with the OCO-2 L1B dataset
  - Comparison to TCCON, to L2 OCO-2
  - A priori state from OCO-2 data, and from external data:
    - Psurf, H_2O and T profiles from ECMWF
    - Aerosol AOT at different wavelength from CAMS
    - Altimetry from SRTM



L2 -> L4 SIMULATOR « SIMGES »

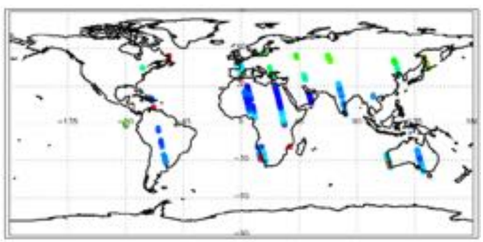
LABORATOIRE DES SCIENCES DU CLIMAT & DE L'ENVIRONNEMENT

NOVELTIS

- Developed and operated by LSCE / NOVELTIS, funded by CNES
- Based on the inversion of a transport model including surface sinks and sources

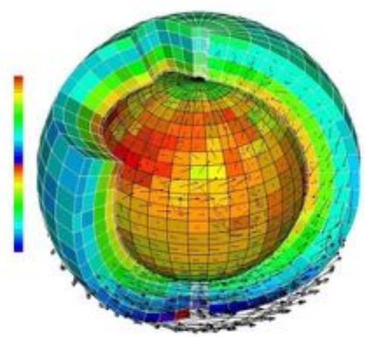
$$\partial/\partial t \ (\rho \mathbf{C}) = -\nabla \cdot (\rho \mathbf{C} \mathbf{V}) \quad \mathbf{Sc}$$

Concentrations de CO2



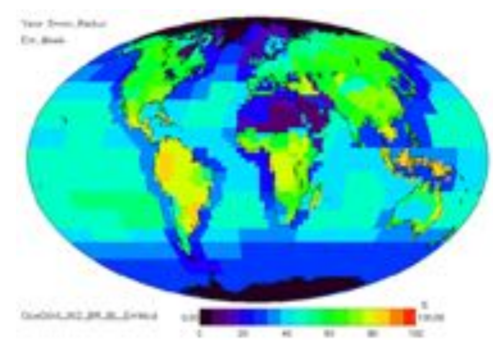
CO2 VMR from MicroCarb and other sources (sat, ground)

Modèle de transport Atmosphérique (LMDZ)



Resolution 3.75° x 2.5° (418kmx280km) x19z x 6h

Sources/puits de CO2 modélisés par région



500x500 km² regions
Week temporal scale

- Flux and performances by optimal estimation
- Provides sensitivity studies:
  - Impact of L2 performance (random error and biases)
  - Scan mode
  - Size & number of FOVs
  - Vertical sensitivity of CO2 VMR

$$\varepsilon = 1 - \frac{\sigma(post)}{\sigma(prior)}$$

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OUTLINE

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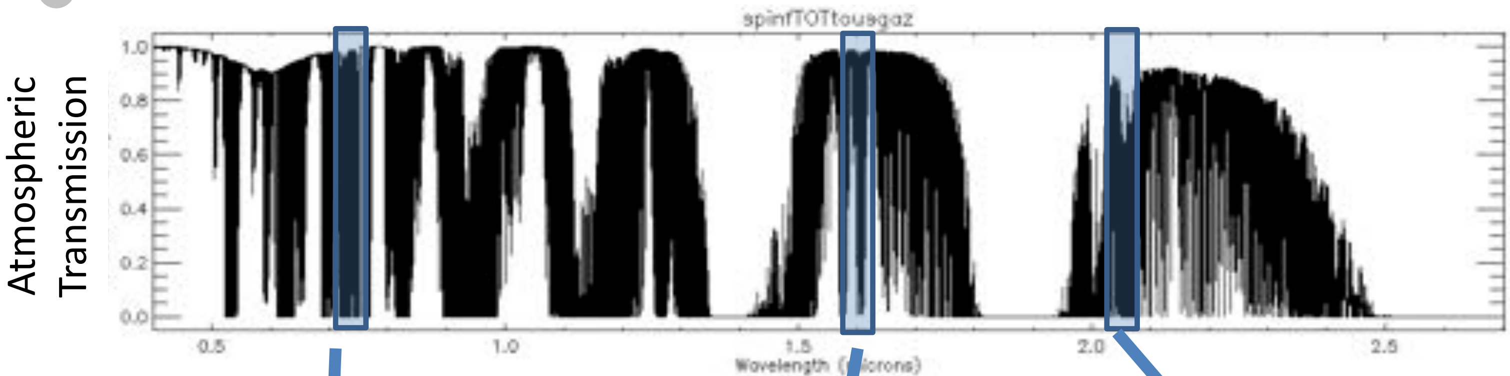
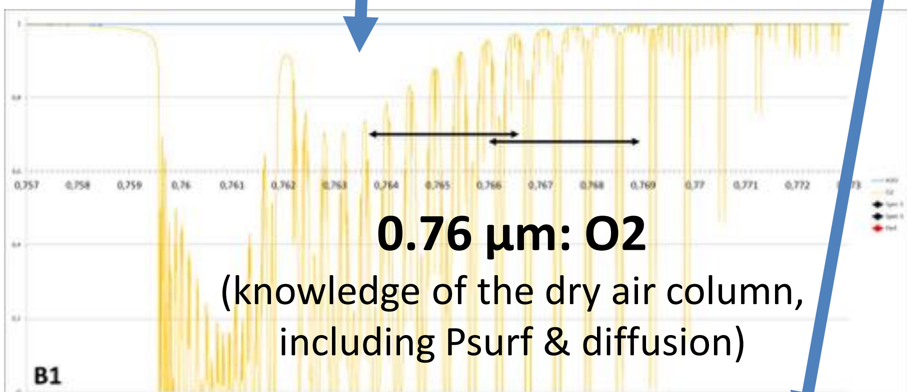
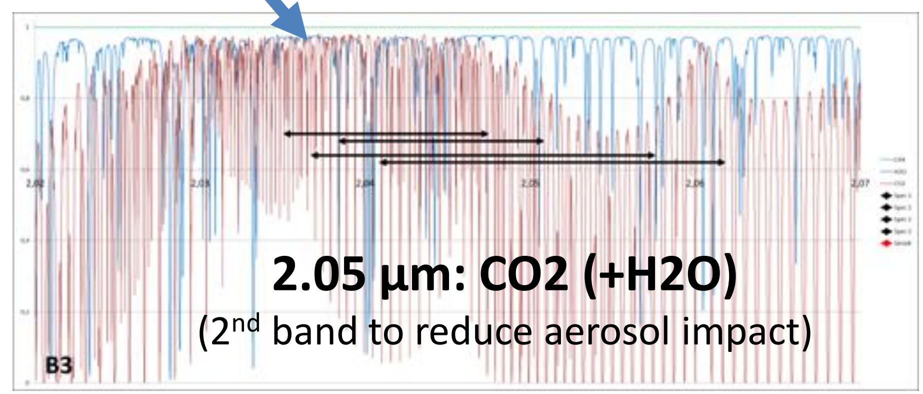
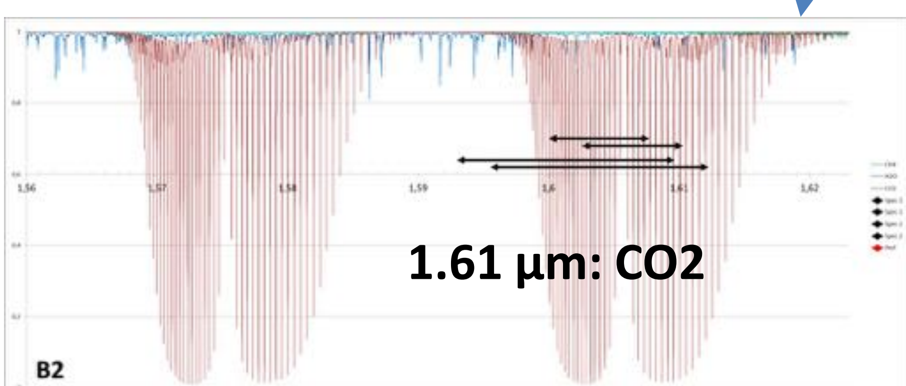
MICROCARB NOMINAL SPECTRAL BANDS









- CNES & LMD studies (V. Sherlock) have confirmed the importance of each of the 3 « classic » bands for the CO_2 estimation in aerosol-loaded atmospheres

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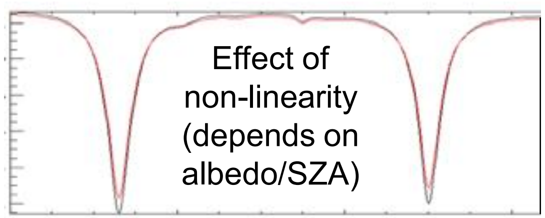
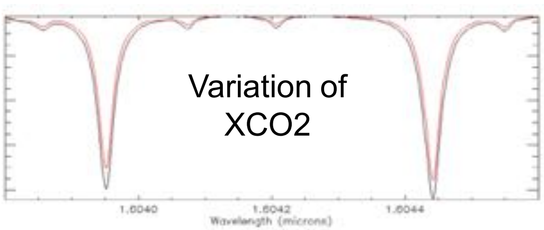
INSTRUMENTAL REQUIREMENTS

- Main contributor to XCO2 random error: SNR, band width, spectral resolution
  - A min value is specified for each
  - An empirical L2 function let industry determine the actual triplet (function created from a large set of 4ARTIC simulations)

Parameter	Value
Wavelength	0.76 µm, 1.61 µm, 2.06 µm
Band widths	30 to 90 cm^{-1}
Resolution (l/Dl)	25 000
SNR	200 to 500 (all bands)
FOV size	3 FOV x 4.5 km x 9 km

- Instrumental artifacts:
  - ✦ If direct impact at L1: equivalent pseudo-noise >1000 (G), >500 (T)
  - ✦ If impact at L2: Pseudo-noise & global bias < 0.4ppmv,
    Regional bias < 0.1ppmv(G), < 0.2ppmv (T)





Direct impact at L1	Direct impact at L2
Channel-to-channel calibration residual (0.3%)	Absolute calibration residual (2-4%)
Gaussian shape (potential resampling)	Band-to-band calibration residual (1.5-3%)
Spectral shift	Pointing precision and stability
Channel-to-channel coregistration	A posteriori geolocation (300m)
ISRF knowledge (0.5-1%)	Band-to-band coregistration
Non-linearity knowledge (0.3-0.5%)	
Instrumental polarization residual (0.1-0.25%)	

ISRF knowledge, Non-linearity knowledge, Instrumental polarization residual → Strong potential regional bias

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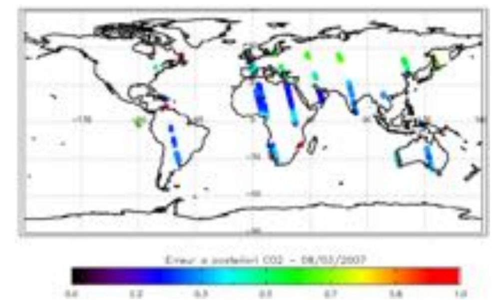
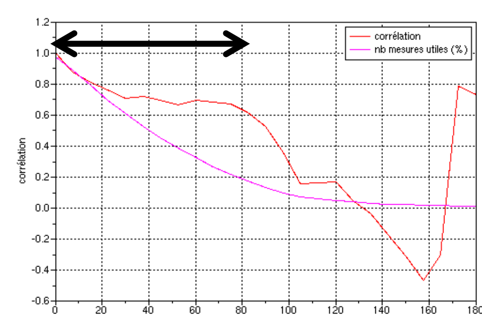
PERFORMANCE BUDGET

- Actual performance budget
  - 4ARTIC transfers each L1 performance at L2 as pseudo-noise ($\hat{S}$) or bias (b_x)
    - We can conclude on the acceptance of potential non-conformities
  - A complete performance budget at L2 will be performed
    - Noise and pseudo-noise (random error) : summed at variance level
    - Regional biases : We have to characterize their spatial correlation



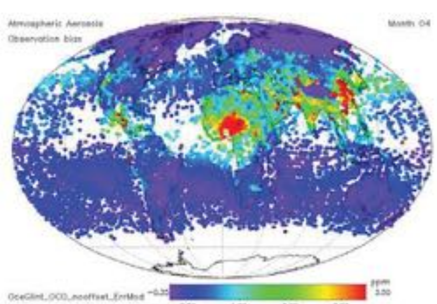
Bias pattern for an instrumental artifact

- End-to-end orbital simulations at L2 with 4ARTIC
  - Give the regional pattern of instrumental defects
  - Characterize the geophysical biases (aerosols, air mass, albedo, Psurf, etc.)

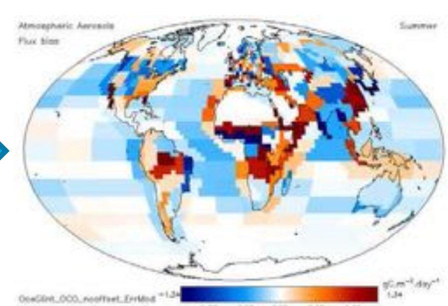


Spatial correlation of the bias

- Impact of the L2 random errors and biases on L4 with SIMGES



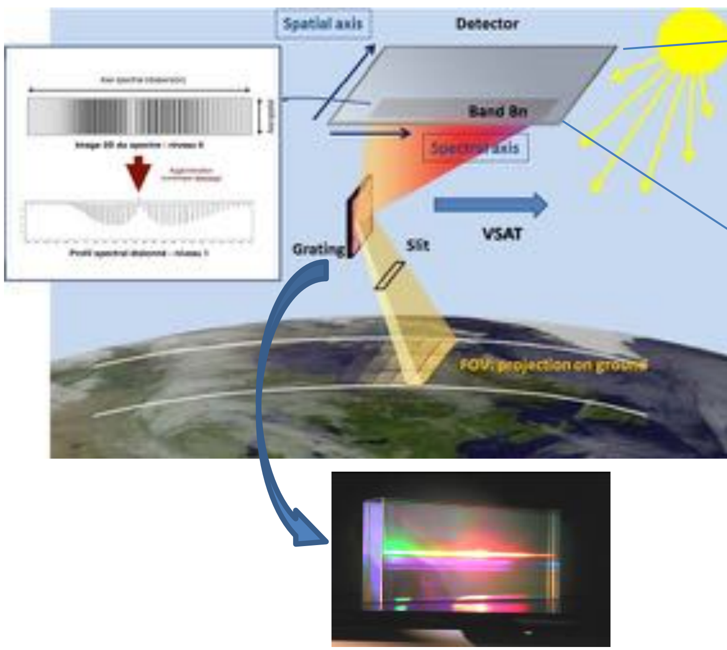
Theoretical aerosol L2 bias

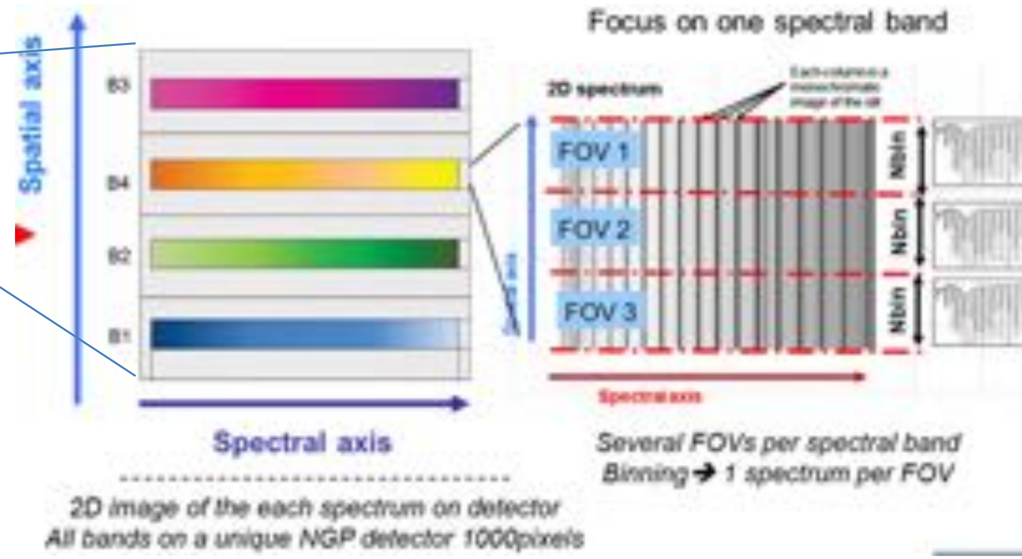


Induced L4 biases

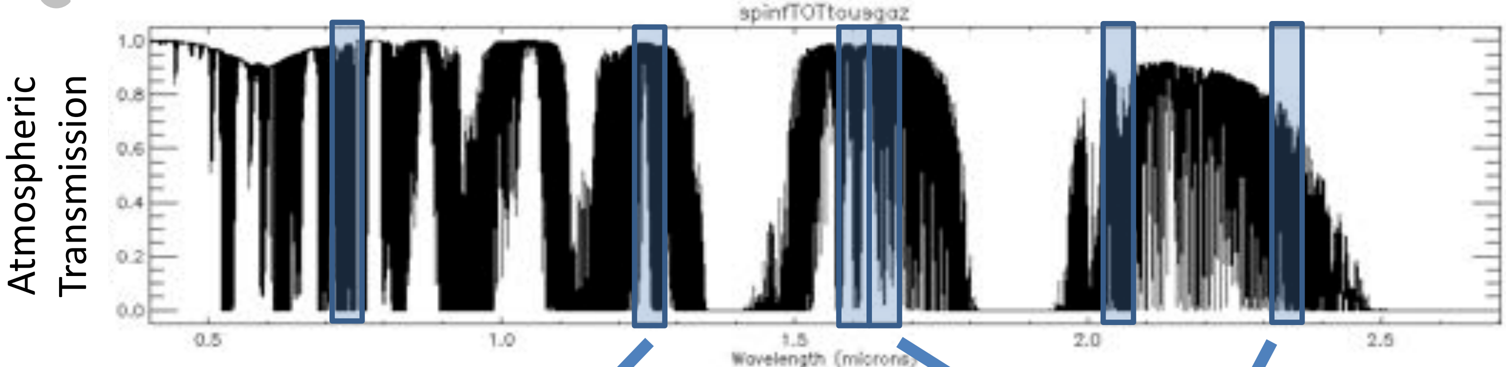
INSTRUMENTAL DESIGN

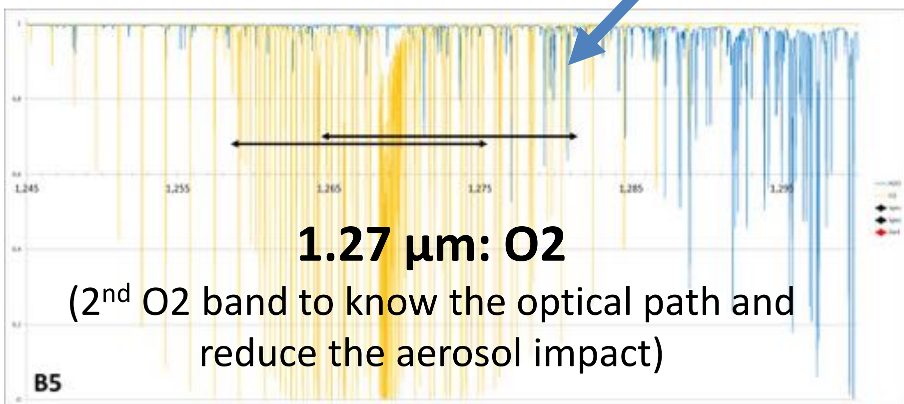
- The instrumental design has evolved to be more compact
- On going instrument detailed definition and performance budget
- We now have 3 FOV (swath 13.5km), each ~40 km2
- New: all spectral bands now acquired on a unique NGP detector
  ➔ Possibility to add new spectral bands (1 or 2 additional bands)

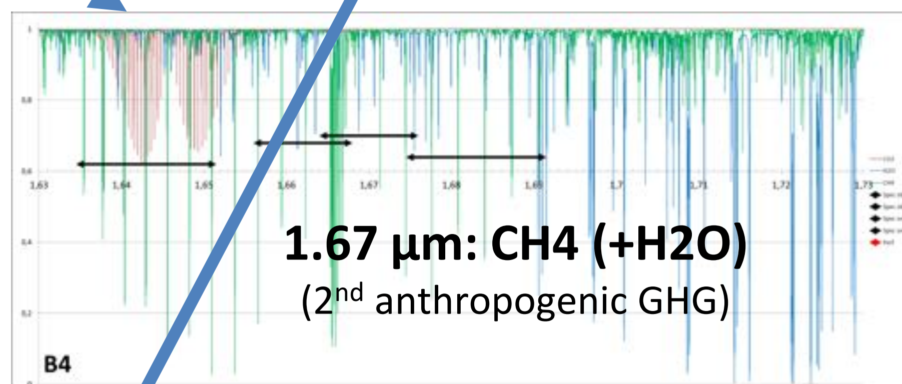


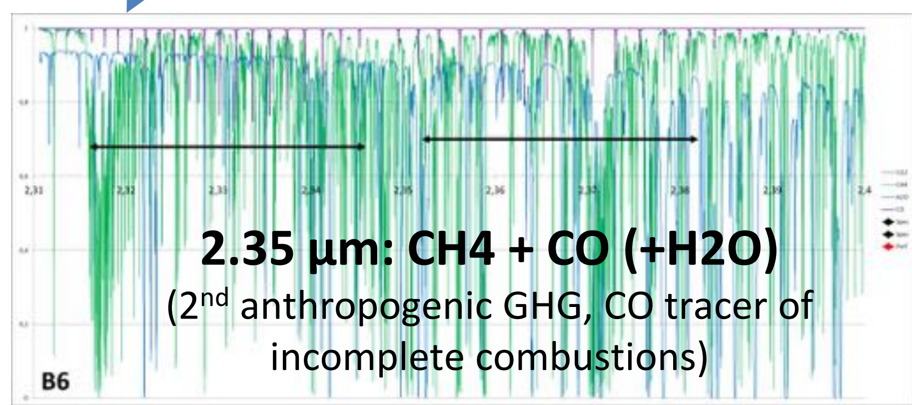


MICROCARB POTENTIAL ADDITIONAL BANDS









- O_2 in B1&B5 may help to reduce aerosol impact (but airglow emission ➔ LATMOS study optimistic)
- Potential new species: CH_4, CO
- CH_4 in B4&B6 may help to reduce aerosol impact

➔ The final choice will be a trade off with instrument capabilities and scientific interest

➔ See dedicated poster 53 by Jouglet et al.

CONCLUSIONS

- The MicroCarb project has a complete set of numerical tools (4AOP, instrument simulator, 4ARTIC, SIMGES) to link L1, L2 and L4, and transfer requirements and performances

- CNES is able to operate the complete chain to master the mission overall performances

- These tools are used to:
  - Specify and adjust the design of the instrument
  - Design the ground segment
  - Provide a complete performance budget

- With the coming performances of the new instrumental concept, end-to-end simulations are planned to consolidate the performance budget on realistic orbits