MicroCarb status and XCO2 validation needs

TCCON / COCCON annual meeting – 12/06/2023

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LSCE : François-Marie Bréon (PI)

LERMA : Yao Té, Pascal Jeseck

Outline

- MicroCarb mission summary and status
- Current works with TCCON and EM27/SUN
- Cal/Val plan
- Cal/Val needs towards TCCON and COCCON

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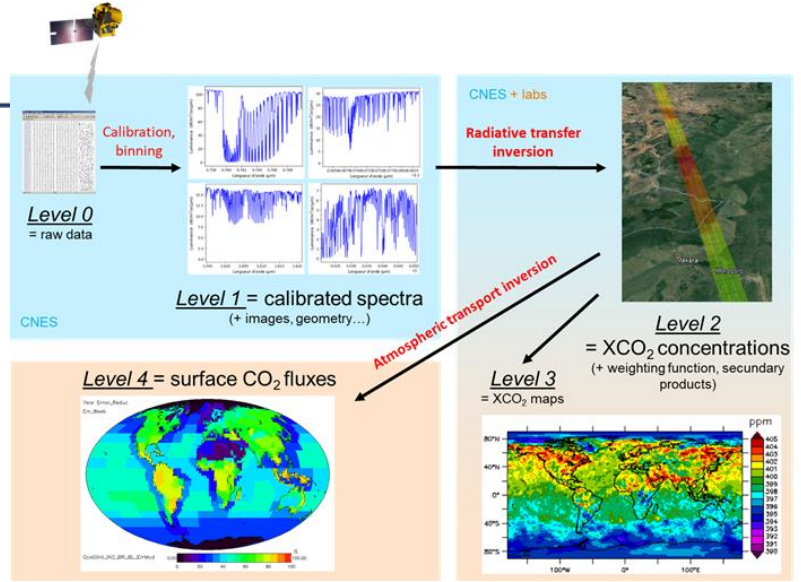
Mission overview

- **Measurement of CO2 column integrated concentration**
  - **Accuracy requirements on XCO2**
    - Random error < 0.5 ppm (G) , < 1.5ppm (T)
    - Regional bias < 0.1 ppm (G), < 0.2 ppm (T) (~1000km, ~1week)
- **Dedicated to the natural fluxes of CO2 at global scale**
  - **Also a mapping mode for anthropogenic emissions**
- **Orbit : Sun-synchronous, 22h30 LTAN, 649 km elevation**
- **Compact instrument (80 kg, 60W) on-board a dedicated microsatellite**
- **Satellite is integrated and under testing, system ready for launch by end 2023**
  - **Development delayed by 3 years due to detector issues**
  - **Actual launch date between mid 2024 and mid 2025 (depending on Vega-C)**
- **Life duration: 5 years**



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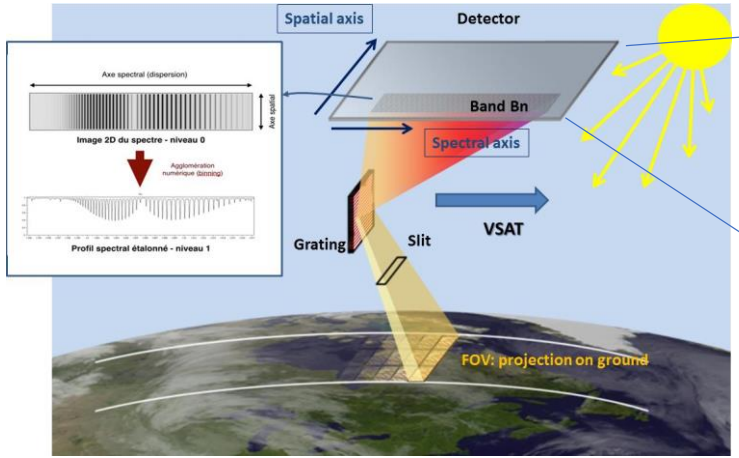
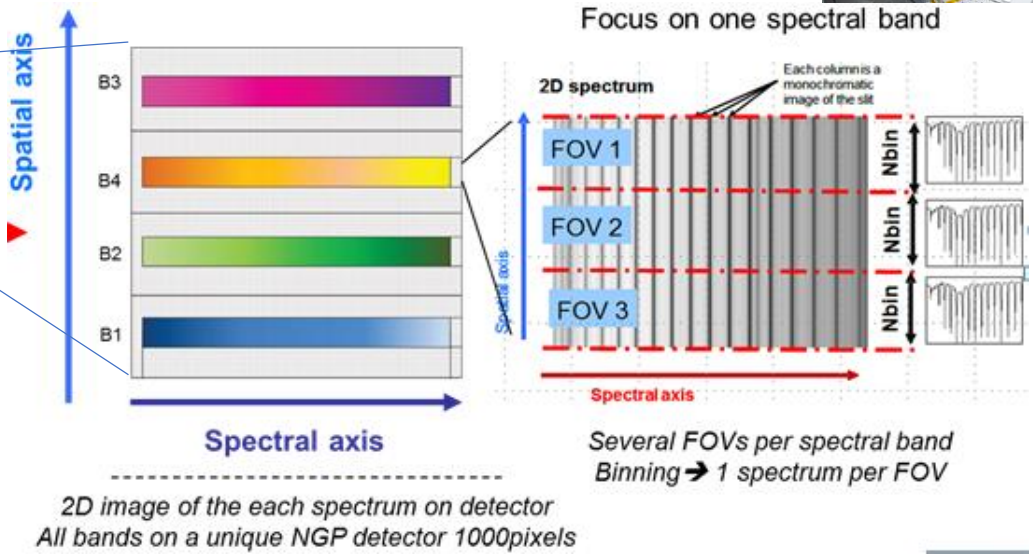
Instrument overview





- Passive grating spectrometer in VNIR and SWIR
- Compact instrument: 1 telescope, 1 spectrometer, 1 detector for 4 spectral bands
- Integration time 1.3s
- Swath 13.5km, 3 FOV ~4.5x9 km^2, every 1.4s
- 1-axis across track pointing mirror (+/- 200km)
- Embedded imager (red band, 110mx140m)

Spectral Performances	B1 (O_2)	B4 (O_2)	B2 (CO_2)	B3 (CO_2)
Central Wavelength (nm)	763.5	1273.4	1607.9	2037.1
Bandwidth (nm)	10.5	17.6	22.1	28,1
Mean Spectral resolution (λ/Δλ)	25 500	25 900	25 800	25 900
SNR @ Lmean (per channel)	285	378	344	177

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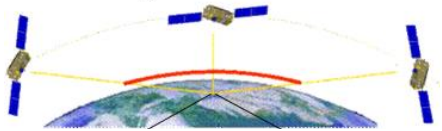
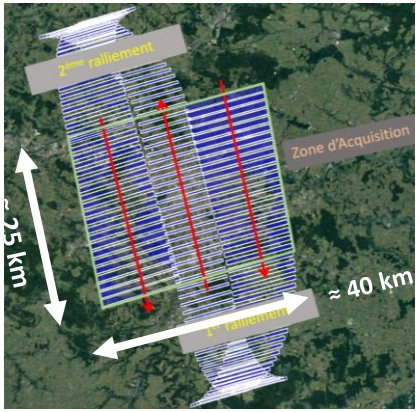
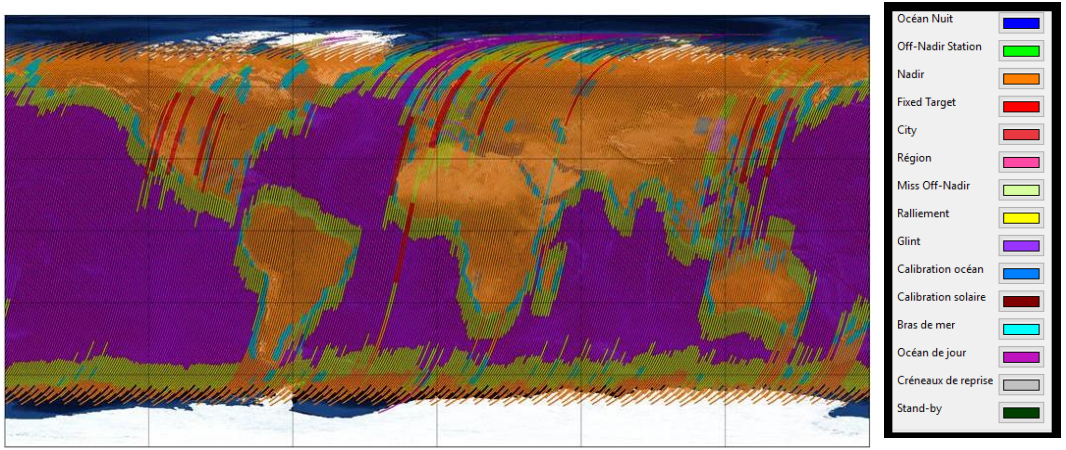
Operating modes

- **Science nominal modes**
  - Nadir (lands)
  - Glint (ocean)
  - Scan (lands) using mirror
- **Probatory modes**
  - City
  - Region
- **Calibration modes**
  - Sun, lamp, shutter, cold space, moon, ground laser, limb…
- **L2 validation modes**
  - Fixed-Target
  - Offnadir target

Fixed-Target (~OCO-2)	Off-nadir target	City
 Target Mode observes surface zenith angles between ±75° 		



Example of a mission plan

1 cycle = 368 orbits = 25 days

Using the pointing mirror, we can observe each location at least 1 every week

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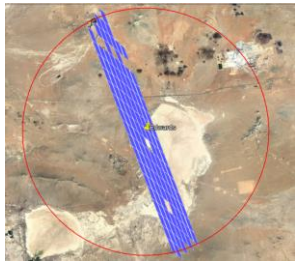
4ARTIC retrievals on OCO-2 spectra over TCCON stations

- **4ARTIC has been applied to OCO-2 spectra (in polarized mode), and compared to XCO2 from TCCON**

- 4ARTIC is an optimal estimation based code (Rodgers, 2000)
- Profiles or scaling factors retrieval scheme

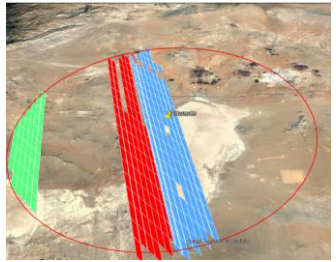
- Only nadir modes considered
- 3 ways to spatio-temporal binning (20km, 1h)
- Use of OCO-2 met priors, then ECMWF priors

- Correction for prior and averaging kernel not applied here



Nearest OCO-2 footprint vs TCCON

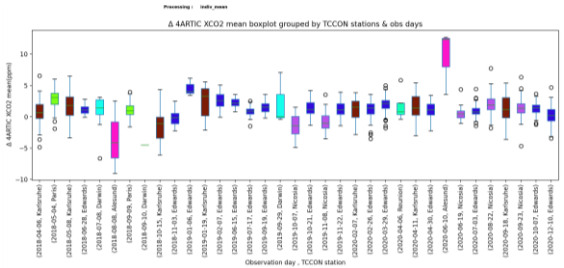
Each OCO-2 footprint vs TCCON



Average of OCO-2 footprint vs TCCON

		Inversion a priori ECMWF					
		Inversion SA : inversion profil			Inversion SA : Scaling factor		
		count	mean	std	count	mean	std
indiv_all	XCO2_4ARTIC-TCCON	818	1,59	1,452	887	1,596	1,377
	XCO2_ACOS-TCCON	818	1,972	1,299	887	1,968	1,292
	XCO2_4ARTIC-ACOS	818	0,383	1,337	887	0,373	1,285
area_mean_raw	XCO2_4ARTIC-TCCON	13	1,623	0,73	13	1,538	0,469
	XCO2_ACOS-TCCON	13	1,871	0,747	13	1,845	0,75
	XCO2_4ARTIC-ACOS	13	0,248	0,814	13	0,307	0,599

➔ Same order of magnitude as ACOS raw, but still to improve!
➔ Errors not correlated to ACOS



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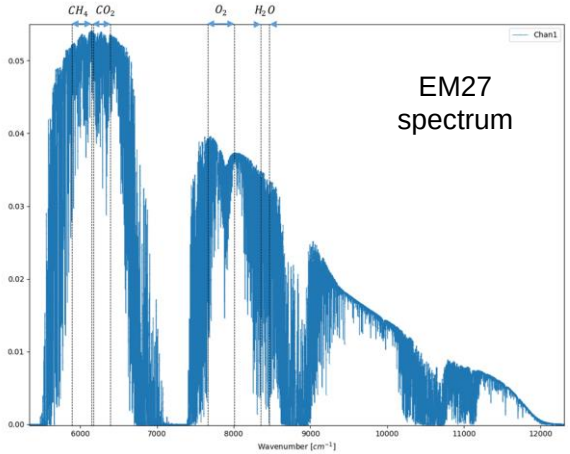
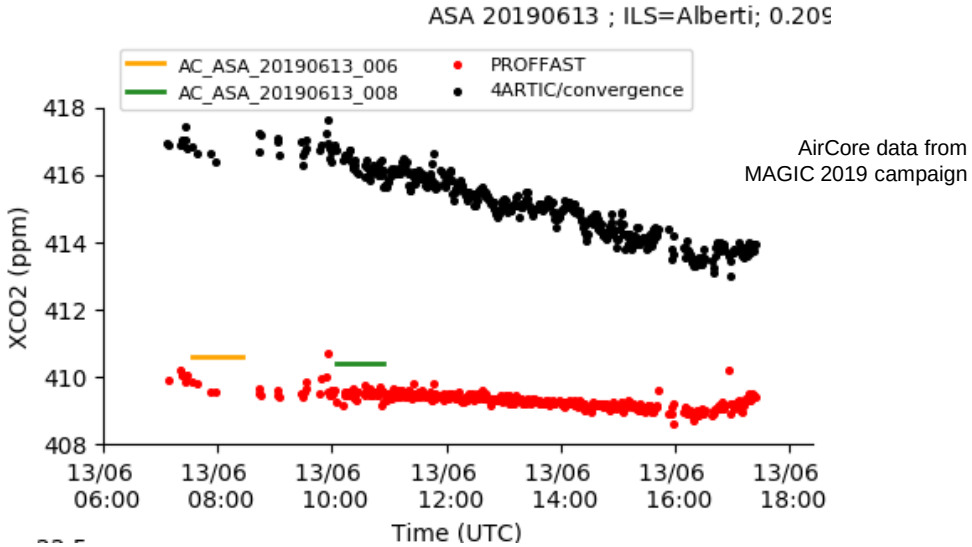
4ARTIC retrievals on EM27 spectra

- **CNES has been owning an EM27/SUN since 2018**
- **4ARTIC has been applied to EM27 spectra, in up-looking configuration**
- **Cross-validation of 4ARTIC and PROFFAST**





Known issues in our processing, to be solved quickly:

- ILS knowledge
- Spectral shift
- Radiometric preprocessing (taken from PROFFAST)
- Radiometric absolute calibration

Very preliminary results

- 4ARTIC exhibits larger random noise (continuum fitting and spectral shift)
- 4ARTIC is biased vs PROFFAST
- Unlike PROFFAST, 4ARTIC is not empirically corrected

NB: Currently For 4ARTIC Xair is not retrieved but read from PTU Psurf

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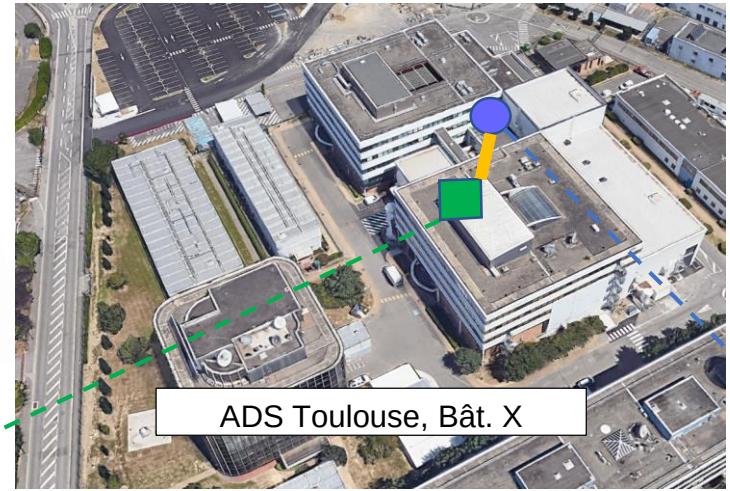
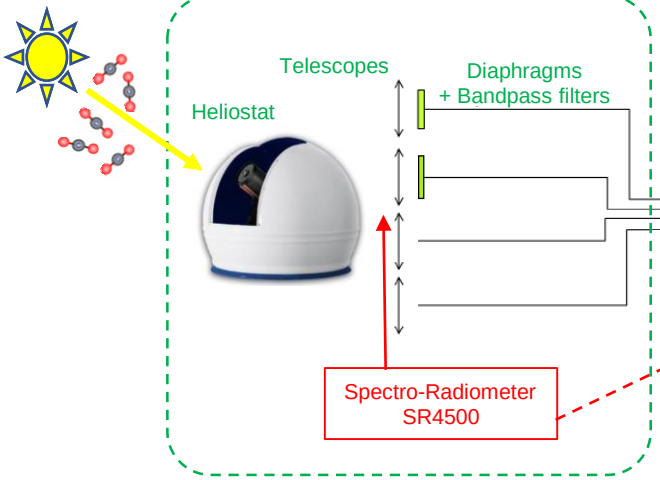
The MicroCarb TVAC « Solar test »

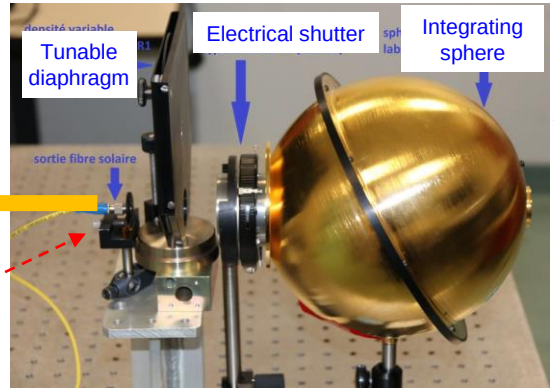


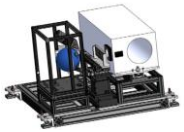
- Up-looking pre-launch observation during TVAC
- Oct – Nov 2022
- Airbus setup based on telescope + optical fiber

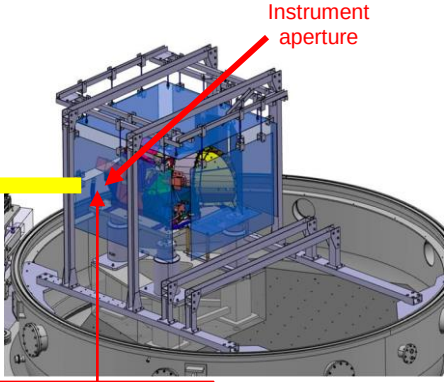
Roof



Clean room







OGSE

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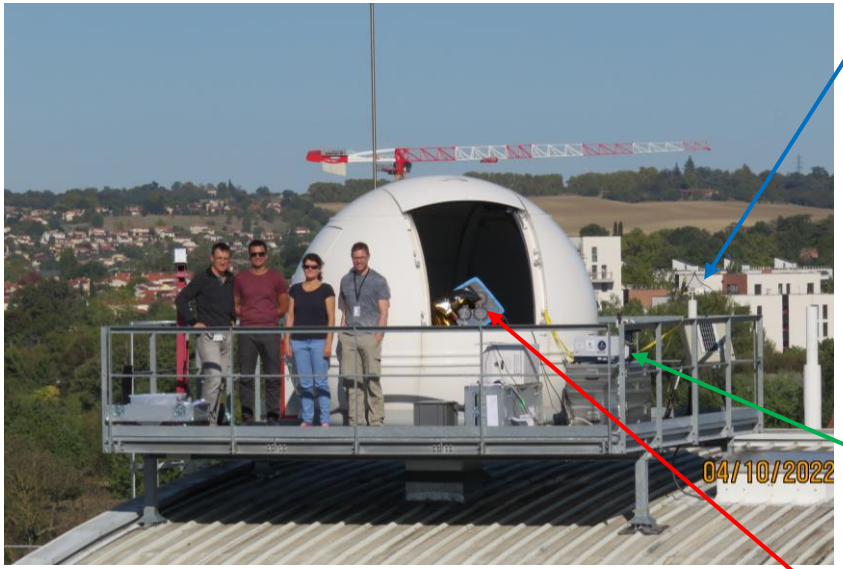
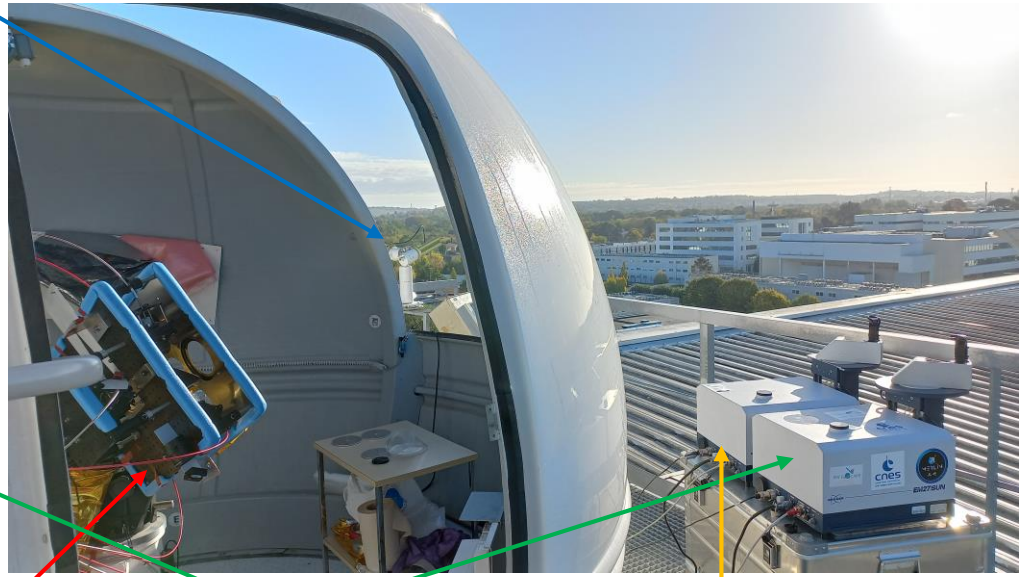
Simultaneous observations

- EM27 (CNES & LERMA) and CIMEL (AERONET)
- AirCore launch
- Simultaneous observations by OCO-2, OCO-3, GOSAT & GOSAT-2





CIMEL

EM27 LERMA

EM27 CNES

MicroCarb heliostat

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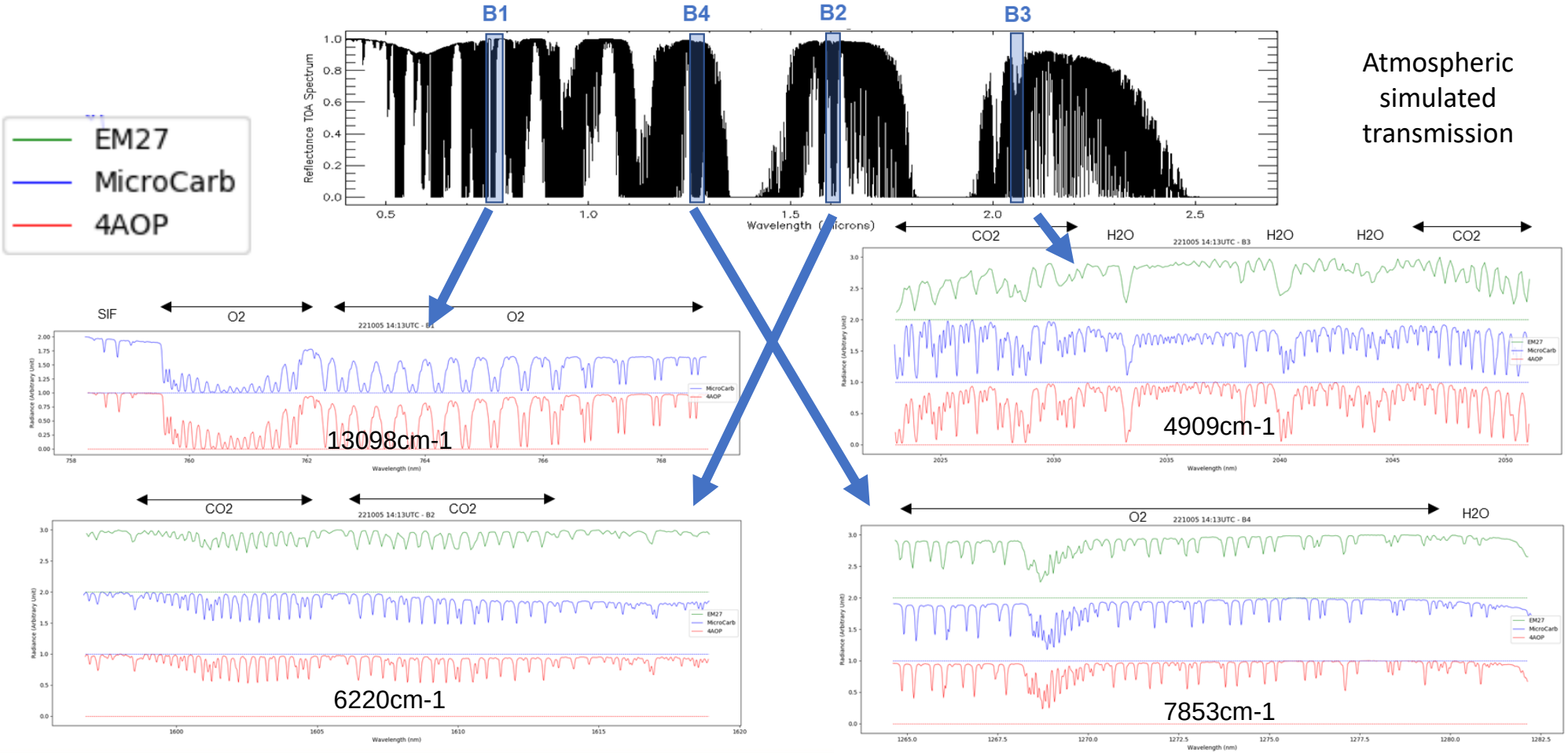
MicroCarb first atmospheric light! (5 oct 2022)



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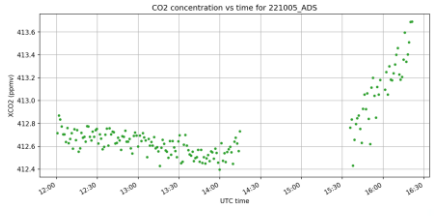
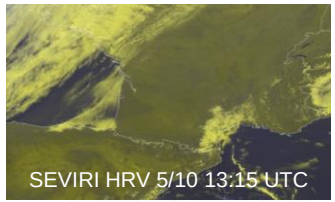
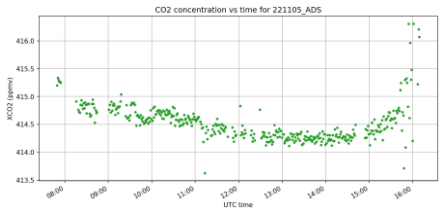
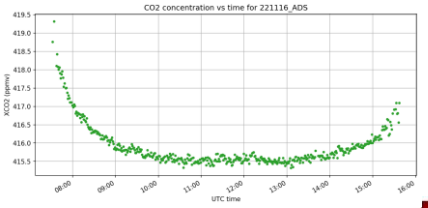
Satellite XCO2 measurements

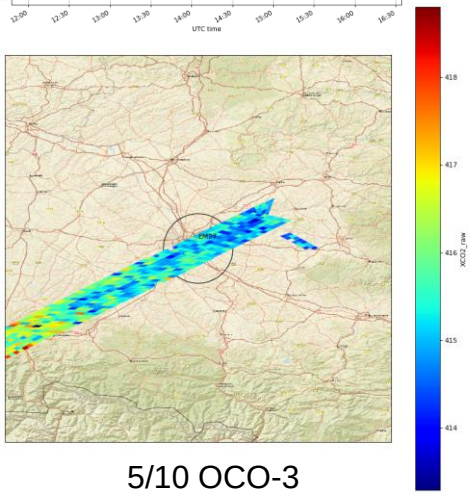
- 4 overpasses gave an L2 (+ potential 2 others GOSAT-2)
- To be compared soon with MicroCarb L2



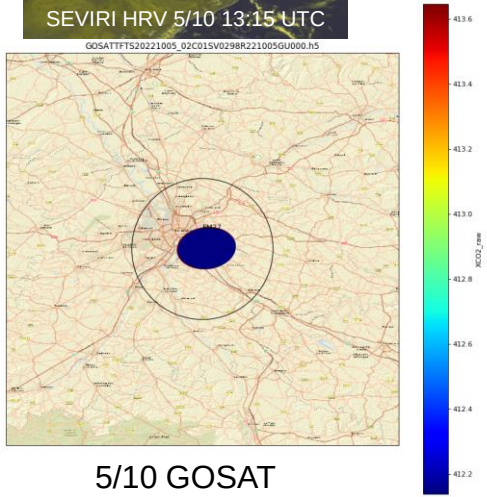




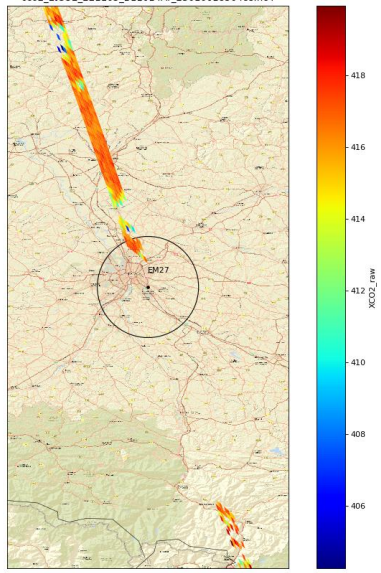




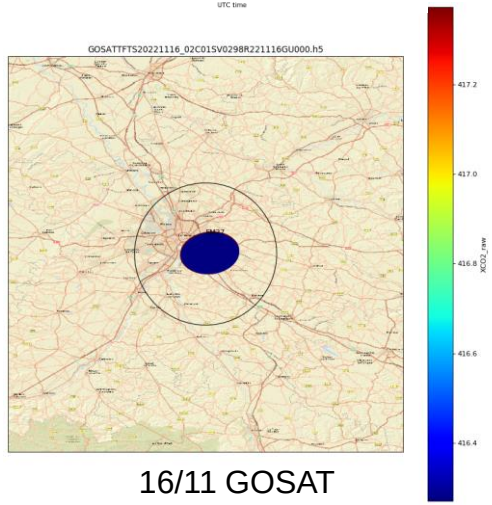
5/10 OCO-3



5/10 GOSAT



5/11 OCO-2



16/11 GOSAT

Date	SAT	Nb points EM27	EM27 moy (ppm)	EM27 std (ppm)	Nb points SAT	Distance moy (km)	Distance std (km)	SAT raw moy (ppm)	SAT raw std (ppm)	SAT BC moy (ppm)	SAT BC std (ppm)	SAT raw – EM27	SAT BC – EM27	SAT (BC – raw)
05/10/2022	OCO-3	34	412.69	0.07	666	10.898	5.05	413.46	0.71	415.16	0.48	0.77	2.47	1.70
05/10/2022	GOSAT	57	412.59	0.08	2	0.882	0.039	412.89	0.79	412.89	0.75	0.31	0.31	0.00
05/11/2022	OCO-2	56	414.28	0.10	21	16.317	2.382	416.04	0.93	416.55	1.19	1.75	2.27	0.51
16/11/2022	GOSAT	54	415.56	0.09	2	0.915	0.023	417.29	0.38	416.82	0.55	1.73	1.26	-0.47

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MicroCarb other science activities of interest to TCCON / COCCON

- **Part of the French ground-based FTS consortium**
  - CNES, LERMA, LSCE, GSMA, LOA, LMD
  - 1 TCCON, 4 EM27, CHRIS
  - Coordinated by Yao Té and Caroline Bès
  - Works on inter-comparison, EM27 and PROFFAST understanding and tuning to improve our confidence in the measurements

  ➔ See dedicated poster by Yao Té, and talk at next IWGGMS by Yao Té

- **Participation and support to the MAGIC campaigns (5 campaigns each year since 2018)**

  ➔ See dedicated talk at new IWGGMS by Cyril Crevoisier

- **Science activities related to MicroCarb level 2 algorithm**
  - Spectroscopy updates for O2 at 1.27µm by LiPhy and LMD
    - Mondelain et al. 2018, Konefal et al. 2019, Tran et al. 2020, Kassi et al. 2021, Tran et al. 2021)
  - Solar spectrum updates by LATMOS
    - Meftah M. (2022). SOLAR-HRS: High-resolution extraterrestrial solar Reference Spectra for disk-integrated, disk-center, and intermediate cases

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MicroCarb cal/val planning

- **T0: launch (between mid 2024 and mid 2025)**
- **T0 > T0 + 1 month: early operations, in orbit functional verification**
- **T0 + 1 month > T0 + 6 months: cal/val phase 1**
  - L1 calibration, start of L2 processing
- **T0 + 6 months > T0 + 12 months: cal/val phase 2**
  - L2 tuning and validation
- **T0 + 12 months: routine start, public release**
  - Validation and algorithm activities go on

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MicroCarb L2 CalVal : Objectives

- **XCO2 error characterization and mitigation**
  - Our current L2 performance budget shows many contributor to XCO2 error (random error and regional biases)
  - Find the bias dependencies (SZA, albedo, Position on Orbit, etc.) and discriminate mission artifacts from real signal
  - Needs to average random error to emphasize biases
  - L1 & L2 algorithms update and possibly L2 empirical debiasing

  ➔ We mostly need massive and varied statistics of XCO2 error w.r.t. a truth, which can be achieved only with permanent networks

  ➔ We will also make a few very accurate atmospheric characterizations by campaign

- **XCO2 traceability to WMO standart (global bias)**

- **Validate secondary science products : aerosols, SIF, airglow, Psurf, XH2O, clouds**

Performance Item	CO2 random error (ppm)		CO2 regional bias
	1sig	Max	1sig
L1 radiometry			
Radiometric noise (SNR)	0.59	1.20	
Absolute gain residual			0.32
Band to band gain residual			0.25
Channel to channel gain residual			0.04
Dark signal residual			0.24
Dark signal channel to channel residual			0.03
Non-linearity residual			0.09
Instrumental polarization residual			0.15
Straylight	0.25	0.25	
Detector persistence	0.19	0.30	0.10
L1 spectrometry			
Spectral shift			0.35
Limited knowledge of the ISRF (uniform scenes)	0.07	0.07	0.32
Limited knowledge of the ISRF (heterogenous sce	0.10	0.10	
L1 geometry			
Limited knowledge of geolocation			
Intra-band misregistration	0.14	0.14	
Inter-band misregistration	0.25	0.25	
Limited knowledge of VZA	0.20	0.20	0.20
Inter band differential VZA	0.15	0.15	0.15
FOV spread function shape			
Limited knowledge of the FOV spread function			
L2 processing			
Limited a priori knowledge of CO2			0.01
Limited knowledge of weather analysis and DEM	0.25	0.5	
Spectroscopy misknowledge			0.30
Impact of aerosols (incl. apriori)			0.70
Limited knowledge of the solar spectrum			
Unscreened clouds	0.20	0.20	0.10
Impact of 1.27 µm airglow	0.22	0.22	
Impact of 0.76 µm vegetation fluorescence			0.03
Impact of 4AOP calculation accuracy			0.20
Approximation of gain matrix formalism (added)			0.30
Mission Requirement (ppm)	**0.5 - 1.5**		**0.1 - 0.2**
Random error budget (ppm)	**0.87**	**1.45**	
Regional bias budget (ppm)			**1.39**

Q1 2022 budget, without calval and bias correction

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L2 calval strategy with external truths : 3 scales

- **Massive operational comparisons : cal/val 1 & 2 & routine**
  - To ground networks : TCCON, automated EM27, AERONET
  - To models (all data) : CAMS analysis (NRT) and optimized-fluxes (delayed)
  - To other satellites (SNOs) : OCO-x, GOSAT-x, CALIPSO, Sentinels, etc.

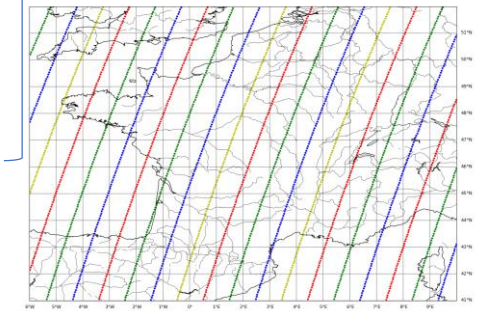
- CNES TEC will implement the operational comparisons

- **Casual measurements : high frequency in cal/val 2 + routine**
  - Each instrument : EM27, AirCore, AMULSE, aerosols, is invited to be deployed under MicroCarb overpasses as often as possible
  - NB: Mission pointing plan will be automatically released by AERIS

- **Campaigns : ~ cal/val 2 (summer)**
  - MAGIC 2025 dedicated to MicroCarb cal/val, in France
  - CO2 instruments : EM27, AirCores, AMULSE, CHRIS, SAFIRE, TCCON?
  - Aerosol instruments : AERONET, ground lidar, in situ profile (LOAC)?

- All labs (Fr + Int) are invited to contribute to measurements and analysis
- CNES will support and participate

Week 1, 2, 3, 4
(25day cycle)
Revisit every week with pointing mirror



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Interaction plan elaboration

- **A short document was circulated a few years ago to TCCON Pis**

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TCCON – MicroCarb interface

By the MicroCarb project team, February 2020

The scope of this document is to present the MicroCarb mission and a proposal for the interface between the MicroCarb operations and the TCCON stations for the target observations. We do not mention scientific cooperation here but this deserves dedicated discussions as it is likely to be of mutual interest.

1. MicroCarb mission

The continuous increase of greenhouse gas concentrations in the atmosphere due to human activities since the beginning of the industrial age is clearly identified as the main cause of the recent climate change. Among these gases, carbon dioxide is the one with the most important contribution. The CO2 atmospheric concentration results from complex exchanges (sources and sinks) between the main carbon reservoirs (ocean, soils, vegetation and the atmosphere). A continuous monitoring is necessary to improve the understanding of these processes and analyse their seasonal and long term variations. A space system provides the opportunity of a global coverage as well as a unique reference for the different measurements.

MicroCarb will measure the CO2 atmospheric concentration (XCO2, product level 2) at global level and map the sources and the sinks (product level 4), from a low earth orbit, with the level of performances required to reduce the current uncertainty on the major CO2 fluxes. It is the first project at European level dedicated to this objective, and is intended to be launched at the end of 2021 for a 5 years lifetime.

- **Several discussions with Yao Té & Pascal Jeseck**

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MicroCarb – TCCON (+ COCCON) routine interactions

- **Operating modes above stations**
  - Fixed-target modes bring many data at each overpass, but rarely (large cost for the mission availablity)
  - ➔ Numerous in cal/val, decrease in routine
  - Offnadir-target modes bring few data at each overpass, but often (no cost for the mission availability)
  - ➔ As often as possible (cal/val and routine)
  - The opportunities are ~the same for the two modes

- **We propose to adopt a similar warning e-mail scheme as OCO-2 to the TCCON / EM27 PIs**
  - **Every week, CNES sends an "information email" for opportunities in next 2 weeks**
    - Defines the opportunities within [D+2 ; D+15] (2 weeks)
    - Sent only to the PIs whose station offers at least one opportunity, to invite to update status
  - **Every day, operation team sends a "confirmation email" for actual observation on D+1**
    - Sent only to the PI whose TCCON station offered at least one opportunity on (D+1)
    - Selection made on station operational status, weather forecasts, and mission planning criteria
    - Sent at 12.00 UTC on D day at the latest, covering opportunities of (D+1) day
  - **After a confirmed observation, operation team sends a "feedback email"** (new)
    - MicroCarb data OK / NOK up to level 2, acquisition mode, orbit number

➔ **Do you agree with this way of interacting?**

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Operational needs towards the TCCON and COCCON networks

- **During cal/val, we need short-time delivery of TCCON L2 data (and COCCON)**
  - 1 year delay is too large, between 2 and 4 weeks would be great
  - Getting the NRT only with a few stations would be already great. Some criteria:
    - Possibility of prompt data delivery
    - Availability / reliability
    - Uniformity of area around the station (reflectance, altitude, XCO2)
    - Variety of scenes
    - XCO2 quality (if available)

➔ **Can we easily achieve this NRT need within at last a few stations?**

- **Even if the TCCON data are freely delivered, we are aware of the network need for support**
  - Support to current stations? European stations? ➔ Acknowledgement, agreements with relevant agencies, NRT observation funding?
  - Support to validate stations? ➔ Use French facilities (SAFIRE aircrafts, AirCore)
  - Build new TCCON or COCCON stations to improve the atm. representivity? ➔ French Guyana?

➔ **How can we support?**

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Scientific needs towards the TCCON and COCCON networks

- **Document the accuracy so as to derive a validation budget**
  - Each instrument accuracy (MicroCarb, TCCON, COCCON)
    - Precision, trueness (absolute and stability), traceability to WMO
    - Vertical sensitivity, horizontal representativity
    - Impact of conditions
  - Satellite vs ground-based inter-comparison methodology accuracy
    - Between several instances of a same instrument (e.g. TCCON, EM27)
    - Between instruments (e.g. EM27 vs AirCore)
    - Between instruments and MicroCarb

➔How many MicroCarb footprints should we average?
➔Can we reach a 0.1 – 0.2 ppm bias detection?
➔Can we dedicate an EM27/SUN as a transfer standart?

- **Discuss the L2 inter-comparison results**

- **Use the Level 1 spectra for spectroscopic improvements**

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Discussions have started for long, but nothing formalized

- **Some TCCON stations are represented in the MicroCarb Science Group**
  - Paris (supported by CNES funding), Harwell

- **Discussions were initiated with Debra Wunch for TCCON a few years ago**
- **Discussions also with KIT for EM27/SUN and PROFFAST**

- **Some agency-level contacts have been initiated (Japan, Canada, CEOS)**
- **Discussions are on-going with CO2M (EUMETSAT) for common support to Eur stations**
  - Ground-based measurements side meeting at next IWGGMS
- **CNES wrote acknowledgment letters the importance of European stations**

- **The MicroCarb team plans to contact each TCCON PI by e-mail to start a relationship (within the next weeks)**
- **We can start by formal and informal discussions up to Wednesday morning ☺**

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Conclusions

- **MicroCarb prepares to XCO2 validation activities, in particular with TCCON and EM27/SUN**

- **TCCON and EM27 data will be the main validation sources in cal/val (near-real time) and routine for massive statistics**

- **Several raised points:**
  - Interactions for operations
  - Interactions for accuracy
  - How to support the network

- **We look forward to collaborate!**
- **We can start by discussions up to Wednesday morning ☺**

MicroCarb CNES operation team


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