MicroCarb :
L’essai solaire en Test Vide Thermique

Présentation COMET-OOE – 25/06/2024

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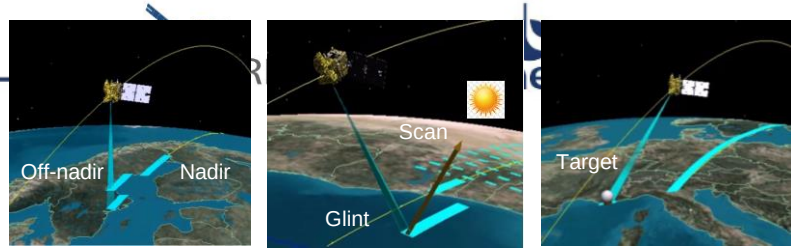
(Responsable Performances Mission)

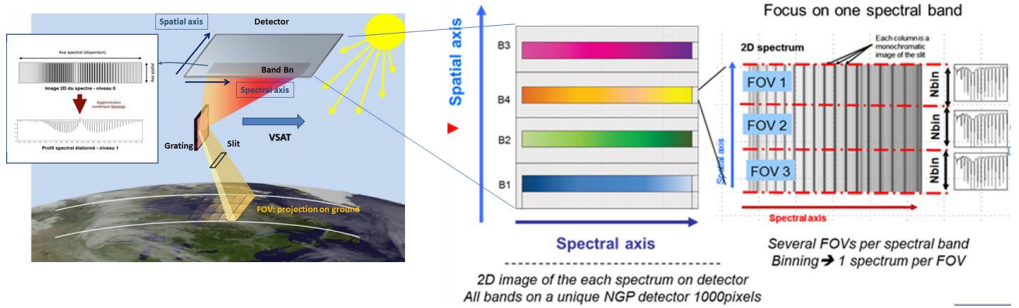
On behalf of the performance team

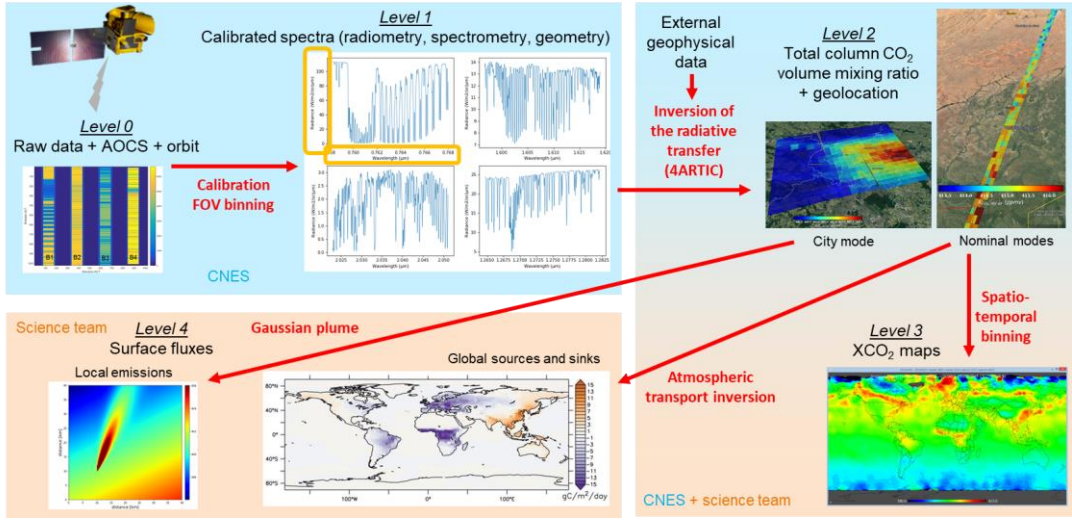
The MicroCarb CO2 mission at a glance

- Objectives
  - Natural CO2 fluxes at global scale
  - Demonstrator for CO2 anthropogenic emissions
- **Main product: CO2 column integrated concentration**
  - **Rqmt for random error < 0.5 ppm (G) , < 1.5ppm (T)**
  - **Rqmt for regional bias < 0.1 ppm (G), < 0.2 ppm (T)**
- Orbit
  - Polar sun-synchronous, alt 649 km, LTAN 22h30
  - Cycle 25 days, sub-cycle 7 days, ± 200km ACT mirror

  ➔ Any target can be observed once a week
- Observations modes
  - Science: Nadir, scan, glint, city, region
  - Calibration: Shutter, Sun, Lamp, Cold Space, Limb
  - Validation: Fixed-Target, Off-nadir target
- Instrument
  - Compact instrument (80 kg, 60W) on micro-satellite
  - Passive grating spectrometer in 4 NIR / SWIR bands
    - CO2 1.61 µm & 2.05 µm, O2 0.76 µm & 1.27 µm
    - High resolving power 25000, high SNR
    - 3 ACT footprints 4.5x9 km²
  - Embedded imager (red band resolution 140m)
- **XCO2 retrieval : 4ARTIC**
  - **Full physics, optimal estimation, GEISA, LIDORT**

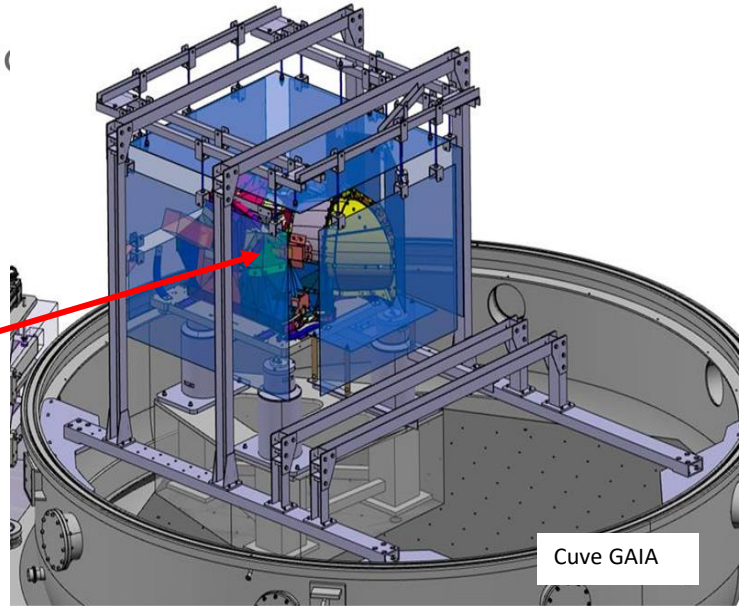


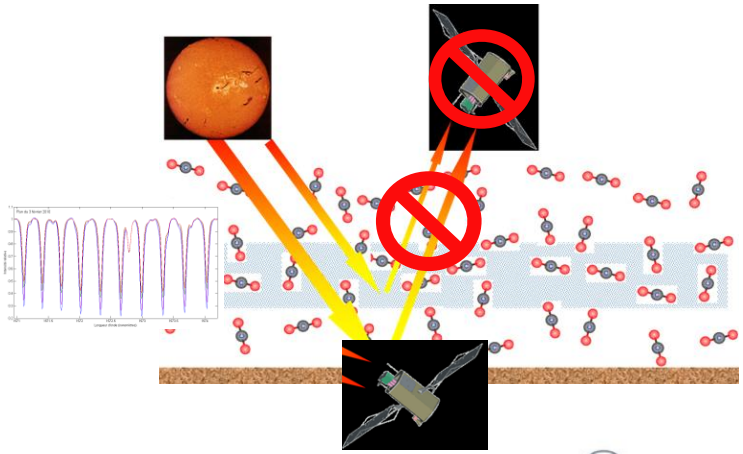




Instrument Ground Calibration by Airbus

- **TVAC tests from September 28th to November 24th**
- **The Thermal VACuum test reproduces the space conditions in and around the instrument**
  - ➔ The instrument reaches its flight performances
- **Objectives of the TVAC calibration**
  - Test the optical impact of vacuum and thermal conditions
  - Check the instrument performances
  - Get the ground calibration coefficients
- **OGSE (Optical Sources)**
  - Lasers and white lamps (and darks)
  - Collimated or not
  - Optical patterns : field effets, fast temporal changes
- **Solar Test**
  - CNES wanted to add natural atmospheric scenes before flight
  - To look at atmospheric absorptions (sun = source)
  - Gas cell cannot reproduce the same spectrum shapes
  - Very few atmospheric missions perform such a test!





Objectifs de l'essai solaire

Les performances mission sont très délicates à atteindre

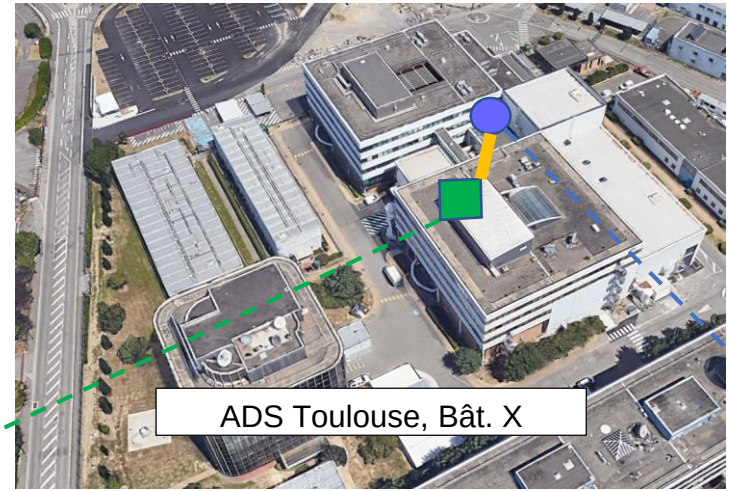
- **Attendus de l'essai**
  - Vérification indépendante de certaines performances instrumentales par leur impact au L1 et au L2
  - Amélioration de l'algorithme L1 ➔ L2 pour la spectroscopie, l'impact des variations de P,T,AOD,SZA
  - Traçabilité du XCO2 MicroCarb au Système International
  - Création de données de références pour comparaison avec mesures vol
  - Test des chaines de traitements L1 et L2 avant vol sur données réelles
  - Préparation des méthodes de cal/val

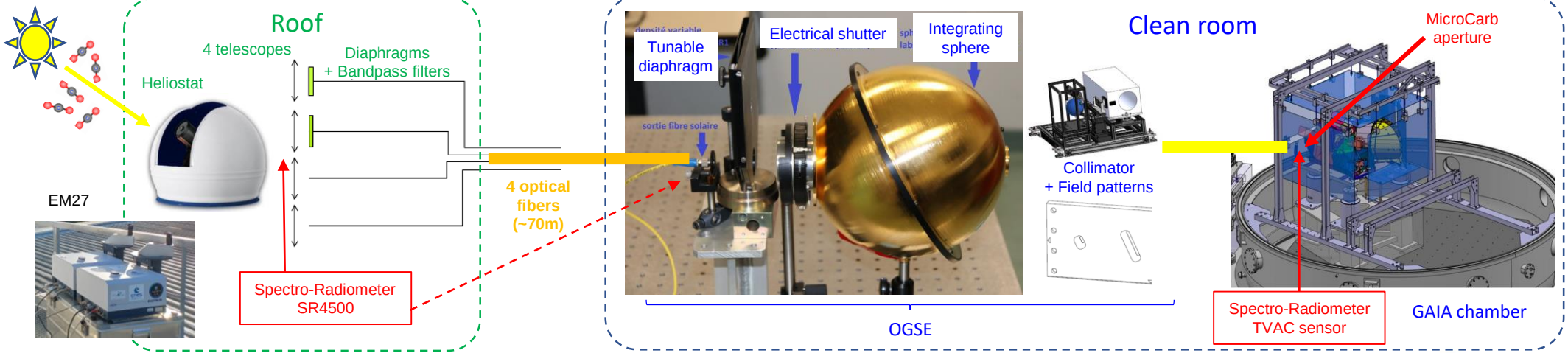
- **Avantages par rapport aux activités du TVAC instrument**
  - Observation des défauts instrument sur les spectres types de la mission
  - Observation des défauts instrument sur le XCO2, avec une mise en évidence parfois plus facile en raison du caractère cumulatif au L1 (e. g. même défaut dans tous les fonds de raies)
  - Activités de validation du XCO2 et du transfert radiatif

- **Avantages par rapport à la cal/val**
  - La scène observée est très bien connue grâce à des mesures exogènes
  - La lente variabilité atmosphérique permet de moyenner et de supprimer le bruit
  - La diffusion atmosphérique y a un impact négligeable sur le XCO2
  - Les perturbations de scène introduits par les OGSE sont très bien connus
  - L'instrument lui-même est très bien connu grâce aux caractérisations ADS en TVAC faites en même temps (avant vol)

« Solar test » setup

TVAC test oct – nov 2022



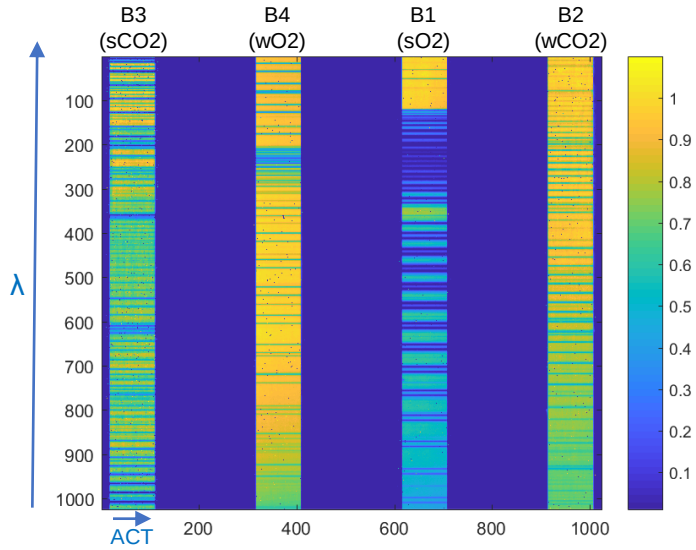


Parallel observations

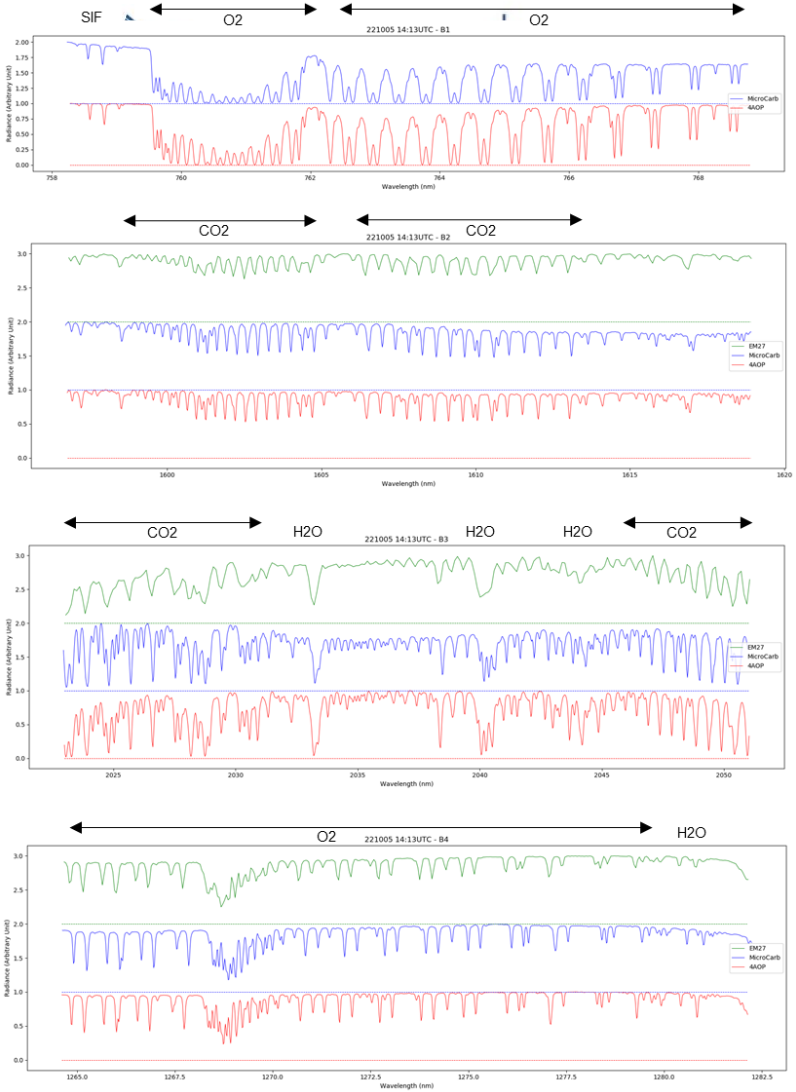
- **During these first tests, we deployed remote measurements (EM27 and AERONET = CIMEL)**

MicroCarb 1st atmospheric observation!

- **The 5/10/2022 debug session gave the opportunity to acquire the MicroCarb first atmospheric spectra!**
  - Instrument not yet in nominal conditions
  - Preliminary radiometric and spectral calibration
  - Averaging of 104 obs (~140s)
- **We are very happy to see how well our measurement fit with 4AOP simulations, and EM27 measurements**



L1A normalized raw data



L1B (vertically shifted for lisibility)

Plan for a typical day for MicroCarb measurements

An ideal 1 day timeline…

- Nominal measurements (« base ») every ~30min
- 5 optical perturbation on slowly varying SZA
  - Non-linearity : diaphragm change
  - Remanence : quick shutter
  - ISRF : several ALT mask positions
  - Straylight : several ACT mask positions
  - Non-linearity : Tint variation
- Nadir land (« Egalisés ») & Ocean glint (« Full ») radiance switchs
- Airglow at dusk
- Regular darks and lamp
- Plan for 1 full day, 1 backup day + 1 debug session

Slot	Horaire cible de début (heure locale)	Elévation solaire (°)	Flux	Expérience	Conf Instrument et OGSE	Fen. MVP	Fen. MPI	Nb FS	Tempo. préalable (min)	Durée (min)	Priorité (1= haute 3 = basse)
1	7:29	-5.8	Egalisés	Dark		rem	rem	400		9.18	1
2	7:38	-3.9	Egalisés	Dark		vol	vol	400	1	10.18	1
3	7:48	-1.8	Egalisés	Gij		vol	vol	400	1	10.18	1
4	**7:59**	**0.0**	Egalisés	Attente élévation solaire						30.64	3
5	8:29	5.1	Egalisés	Base	L=Lmoy	vol	vol	400	0	9.18	3
6	8:38	6.7	Egalisés	Test	0.3, 0.65, 1, 2.5, 4, 8 Lmoy					30.00	2
7	9:08	11.9	Egalisés	Base	L=Lmoy	vol	vol	400	0	9.18	2
8	9:18	13.4	Pose obturateur	Dark		vol	vol	100	0	2.30	1
9	9:20	13.8		Attente fin de manoeuvre						7.70	3
10	**9:28**	**15.1**	Egalisés	Base	L=Lmoy	vol	vol	400	0	9.18	1
11	9:37	16.6	Egalisés	REM	L=0.3Lmoy, 25 cycles 10-10	rem	tem	500	2	13.48	1
12	9:50	18.8	Egalisés	REM	L=0.3Lmoy, 25 cycles 10-10	rem	tem	500	0	11.48	2
13	10:02	20.6	Egalisés	REM	L=Lmoy, 25 cycles 10-10	rem	tem	500	2	13.48	1
14	10:15	22.7	Egalisés	REM	L=Lmoy, 25 cycles 10-10	rem	tem	500	0	11.48	2
15	10:27	24.5	Egalisés	Base	L=Lmoy	vol	vol	400	1	10.18	1
16	10:37	25.9	Egalisés	REM	L=4Lmoy, 25 cycles 10-10	rem	tem	500	2	13.48	1
17	10:50	27.9	Egalisés	REM	L=4Lmoy, 25 cycles 10-10	rem	tem	500	0	11.48	2
18	11:02	29.4	Bascule héliostat + Dépose obturateur	Dark		rem	tem	100	0	2.30	1
19	11:04	29.7		Dark		vol	vol	100	2	4.30	1
20	11:08	30.3		Attente fin de manoeuvre						3.41	3
21	11:12	30.7	Egalisés	Base	L=Lmoy	vol	vol	400	0	9.18	1
22	11:21	31.9	Egalisés	NL	L=8Lmoy	vol	vol	50	2	3.15	1
23	11:24	32.2	Egalisés	NL	L=4Lmoy	vol	vol	50	2	3.15	1
24	11:27	32.6	Egalisés	NL	L=2.5Lmoy	vol	vol	50	2	3.15	1
25	11:30	33.0	Egalisés	NL	L=0.65Lmoy	vol	vol	470	2	12.79	1
26	11:43	34.4	Egalisés	Base	L=Lmoy	vol	vol	400	2	11.18	1
27	11:54	35.6	Egalisés	NL	L=0.3Lmoy	vol	vol	545	2	14.51	1
28	12:09	36.9	Egalisés	NL	L=0.3Lmoy	vol	vol	545	0	12.51	1
29	12:21	38.0	Egalisés	NL	L=0.3Lmoy	vol	vol	545	0	12.51	1
30	12:34	38.9	Egalisés	NL	L=0.3Lmoy	vol	vol	545	0	12.51	2
31	12:46	39.7	Egalisés	Base	L=Lmoy	vol	vol	400	2	11.18	1
32	12:58	40.2	Egalisés	NL Tint	L=Lmoy, Tint=2Tintnom	vol	vol	100	1	3.30	3
33	13:01	40.4	Egalisés	NL Tint	L=Lmoy, Tint=0.3Tintnom	vol	vol	545	1	13.51	3
34	13:14	40.9	Chgmt conf	Dark	Tint=0.3Tintnom	vol	vol	100	0	2.30	3
35	13:17	40.9		Dark	Tint=2Tintnom	vol	vol	100	1	3.30	3
36	13:20	41.0		Dark		vol	vol	100	1	3.30	1
37	13:23	41.1		Attente fin de manoeuvre						6.11	3
38	13:29	41.2	Full	NL	L=8Lmoy	vol	vol	50	2	3.15	1
39	13:32	41.2	Full	NL	L=4Lmoy	vol	vol	50	2	3.15	1
40	13:36	41.2	Full	Base	L=Lmoy	vol	vol	400	2	11.18	1
41	13:47	41.2	Full	NL	L=0.3Lmoy	vol	vol	545	2	14.51	1
42	14:01	41.0	Full	NL	L=0.3Lmoy	vol	vol	545	0	12.51	1
43	14:14	40.7	Full	NL	L=0.3Lmoy	vol	vol	545	0	12.51	2
44	14:26	40.2	Full	NL	L=0.3Lmoy	vol	vol	545	0	12.51	2
45	14:39	39.5	Full	Base	L=Lmoy	vol	vol	400	2	11.18	1
46	14:50	38.8	Chgmt conf (opt)	Dark		vol	vol	100	0	2.30	1
47	14:52	38.7		Dark		vol	spa	100	2	4.30	2
48	14:57	38.4		Attente fin de manoeuvre						8.41	3
49	15:05	37.7	Egalisés	Base	L=Lmoy	vol	vol	400	0	9.18	2
50	15:14	37.0	Egalisés	NU-ALT	L=4Lmoy; ¼ D, ¾ L	vol	spa	400	1	10.18	1
51	15:24	36.0	Egalisés	NU-ALT	L=4Lmoy; ½ D, ½ L	vol	spa	100	1	3.30	1
52	15:28	35.7	Egalisés	NU-ALT	L=4Lmoy; ¼ D, ¾ L	vol	spa	50	1	2.15	1
53	15:30	35.5	Egalisés	NU-ALT	L=4Lmoy; 100% L	vol	spa	50	0	1.15	1
54	15:31	35.3	Egalisés	NU-ALT	L=4Lmoy; ¾ L, ¼ D	vol	spa	50	0	1.15	2
55	15:32	35.2	Egalisés	NU-ALT	L=4Lmoy; ½ L, ½ D	vol	spa	100	1	3.30	1
56	15:35	34.9	Egalisés	NU-ALT	L=4Lmoy; ¼ L, ¾ D	vol	spa	400	1	10.18	2
57	15:46	33.8	Egalisés	Base	L=Lmoy	vol	vol	400	2	11.18	1
58	15:57	32.5	Egalisés	NU-ACT	L=4Lmoy; 0/6	vol	spa	100	0	2.30	1
59	15:59	32.2	Egalisés	NU-ACT	L=4Lmoy; 0/6	vol	spa	100	0	2.30	1
60	16:01	31.9	Egalisés	NU-ACT	L=4Lmoy; 1/6	vol	spa	100	0	2.30	1
61	16:04	31.7	Egalisés	NU-ACT	L=4Lmoy; 1/6	vol	spa	100	0	2.30	1
62	16:06	31.4	Egalisés	NU-ACT	L=4Lmoy; 2/6	vol	spa	100	0	2.30	2
63	16:08	31.1	Egalisés	NU-ACT	L=4Lmoy; 2/6	vol	spa	100	0	2.30	2
64	16:11	30.8	Egalisés	NU-ACT	L=4Lmoy; 3/6	vol	spa	100	0	2.30	1
65	16:13	30.5	Egalisés	NU-ACT	L=4Lmoy; 3/6	vol	spa	100	0	2.30	1
66	16:15	30.2	Egalisés	NU-ACT	L=4Lmoy; 4/6	vol	spa	100	0	2.30	2
67	16:17	29.9	Egalisés	NU-ACT	L=4Lmoy; 4/6	vol	spa	100	0	2.30	2
68	16:20	29.6	Egalisés	NU-ACT	L=4Lmoy; 5/6	vol	spa	100	0	2.30	1
69	16:22	29.3	Egalisés	NU-ACT	L=4Lmoy; 5/6	vol	spa	100	0	2.30	1
70	16:24	29.0	Egalisés	NU-ACT	L=4Lmoy; 6/6	vol	spa	100	0	2.30	2
71	16:27	28.7	Egalisés	NU-ACT	L=4Lmoy; 6/6	vol	spa	100	0	2.30	2
72	16:29	28.4	Egalisés	Base	L=Lmoy	vol	vol	400	1	10.18	1
73	16:39	27.0	Chgmt conf (opt) + Pose obturateur	Dark		vol	vol	100	0	2.30	1
74	16:41	26.6		Dark		vol	spa	100	1	3.30	1
75	16:45	26.2		Dark		rem	tem	100	1	3.30	1
76	16:48	25.7		Attente fin de manoeuvre						6.11	3
77	16:54	24.8	Full	Base	L=Lmoy	vol	vol	400	0	9.18	1
78	17:03	23.4	Full	REM	L=Lmoy, 25 cycles 10-10	rem	tem	500	2	13.48	1
79	17:17	21.3	Full	REM	L=0.3Lmoy, 25 cycles 10-10	rem	tem	500	2	13.48	1
80	17:30	19.2	Full	REM	L=0.3Lmoy, 25 cycles 10-10	rem	tem	500	0	11.48	2
81	17:42	17.3	Full	REM	L=4Lmoy, 25 cycles 10-10	rem	tem	500	2	13.48	1
82	17:55	15.1	Full	Dark		rem	rem	100	0	2.30	2
83	**17:57**	**14.7**	Full	Base	L=Lmoy	vol	vol	400	0	9.18	1
84	18:07	13.2	Full	Dark		vol	vol	100	0	2.30	2
85	18:09	12.8	Full	Base	L=Lmoy	vol	vol	400	0	9.18	3
86	18:18	11.2	Full	Base	L=Lmoy	vol	vol	400	0	9.18	1
87	18:27	9.7	Full	Base	L=Lmoy	vol	vol	400	0	9.18	3
88	18:37	8.1	Full	Base	L=Lmoy	vol	vol	400	0	9.18	2
89	18:46	6.5	Full	Base	L=Lmoy	vol	vol	400	0	9.18	3
90	18:55	4.9	Full	Base	L=Lmoy	vol	vol	400	0	9.18	3
91	19:04	3.3	Full	Base	L=Lmoy	vol	vol	400	0	9.18	3
92	19:13	1.8	Full	Dark		vol	vol	400	0	9.18	1
93	19:22	0.4	Full	Gij		vol	vol	400	0	9.18	1
94	19:32	-1.2	Full	Attente coucher du soleil						9.19	3
95	**19:30**	-0.7	Full	Airglow		vol	vol	2571		59.01	2
96	20:29	-12.2		Fin		vol	vol			0.00	

Summary of collected data

- **… Which had to be adapted to reality!**
  - Availability of the instrument
  (slots inserted amongst instrument characterizations
  - Fiber lower performances

- Clouds
- Winds < 60km/h
- Day duration
- Operation mistakes

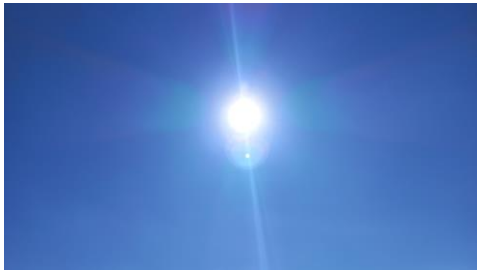
			Geophysical conditions								Optical disturbances					Ground-based parallel				In situ parallel	Satellites			
Date	Hours (LT)	MicroCarb duration	Sky	Solar elev. (°)	P (hPa)	T (°C)	U (%)	MicroCarb (Tdet, FOD) & setup	Nominal obs ("bases")	Airglow	Flux	Temporal	ALT non-uniform	ACT non-uniform	Tint change	EM27 CNES	EM27 LERMA	CIMEL CNES	CHRIS	AirCore ASA	OCO-2	OCO-3	GOSAT	GOSAT-2
04-oct	9h30 - 17h40	0h			1001-1002	20-33	25-60	Off (setup debug only)													Nadir	Target		Target
05-oct	14h13 - 16h18	2h		31	1002-1003	24-28	44-55	160K, 0mA	Few cases			Only for 1 flux				pb suntracker						Target	Target	
31-oct	12h31 – 13h24	1h		28 to 31	993-994	25-27	41-46	165K, 1mA	Few cases								No operator				Glint			
01-nov	12h13 – 12h36	30min		31	1003-1004	19-29	60-30	165K, 1mA. Setup power failure	Few cases														Target	Target
02-nov	15h37 – 15h56	30min (over 2h)		10 to 25	1001-1003	20-30	25-50	165K, 1mA	Only a few cases			Only for 1 flux					No operator							Target
05-nov	8h04-18h00	7h (over 10h)		5 to 31	1001 - 1004	10-16	50-80	165K, 1mA. Morning lost for setup debug.	Many cases	1h	Uncomplete, varying SZA		Setup problem								Nadir			
07-nov	10h26 - 14h28	4h		19 to 30	995 - 999	17-20	40-60	165K, 1mA	Few cases		Uncomplete		Uncomplete				No operator						Target	Target
10-nov	12h42 – 16h02	3h		5 to 27	1006	15-17	60-68	165K, 1mA	Few cases		Too short, varying SZA	Only for 1 flux, varying SZA	12 positions, short	3 positions, short									Target	
16-nov	8h30 – 16h30	8h		7 to 27	983 - 988	10-20	50-90	165K, 1.8mA	Many cases, regular		Stable SZA, 11 fluxes	7 fluxes, many cycles		1 position, long	3 values					Long recovery, ~40km from ADS, air leak			Target	

8 opportunities, ~26h of data, ~38000FS, >100 000 spectra! But ~half will be screened for clouds

Sky

- **Difficult to manage in November!!**
- **The clear sky sessions were rare, forcing us to attempt in degraded conditions**

5/10



31/10

1/11

2/11

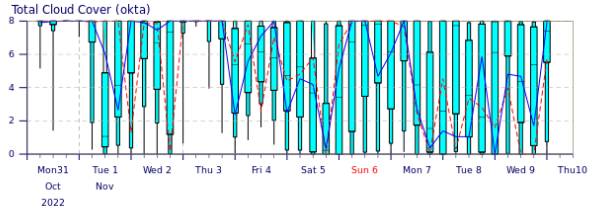
5/11

7/11

10/11

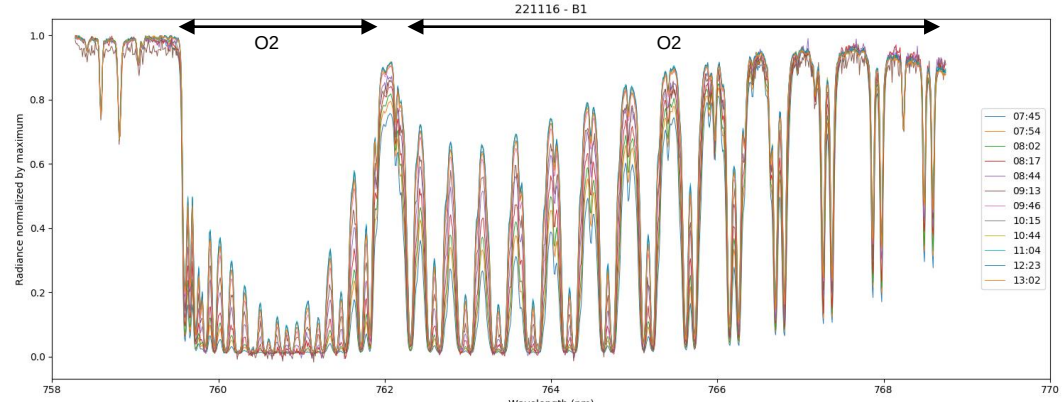
16/11

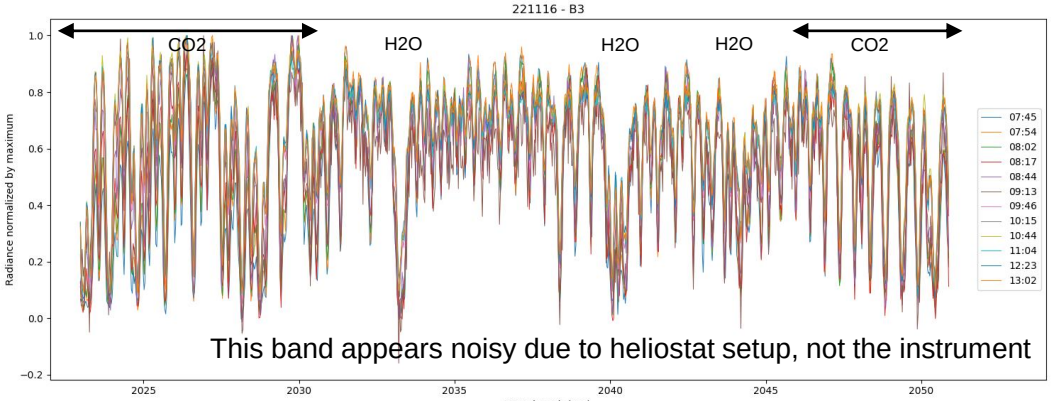
- **The weather forecast was often with low confidence**
- **The common weather forecast sites often ignore the cirrus**
- **We had a weather forecaster but not during 22/10 – 6/11**

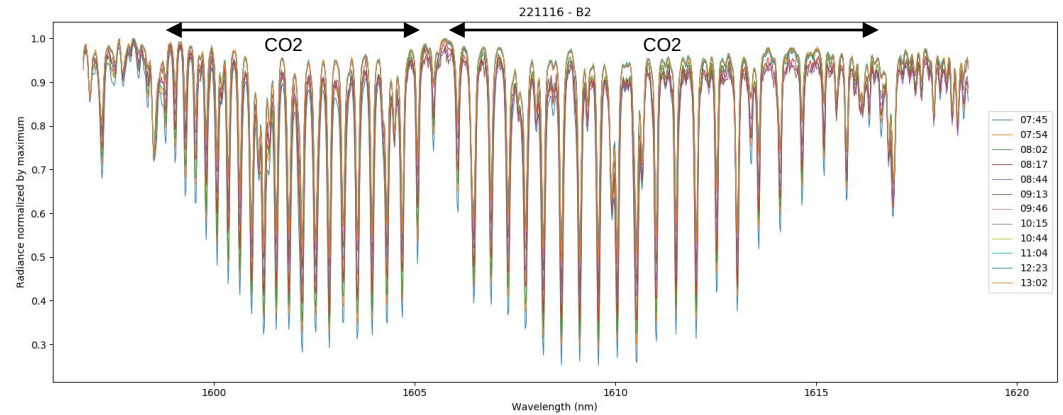


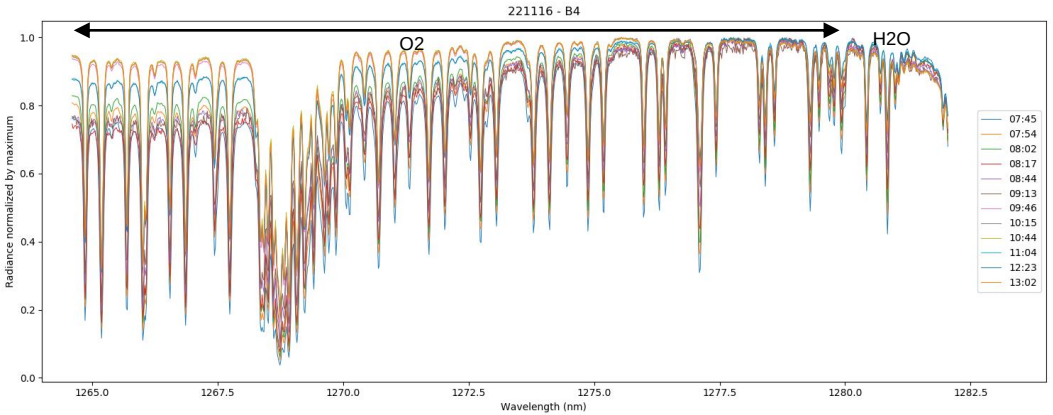
Preliminary analysis of varying SZA

- Line depth increases with air mass : consistent with expected
- Impact of temperature, pressure, humidity, clouds will be assessed



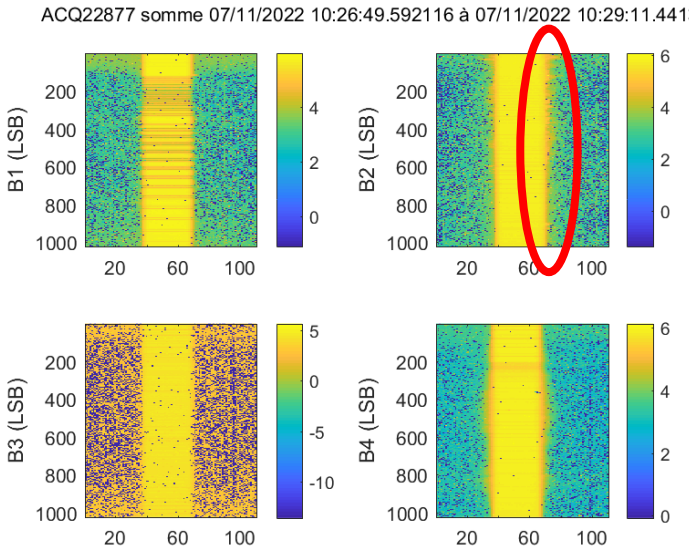




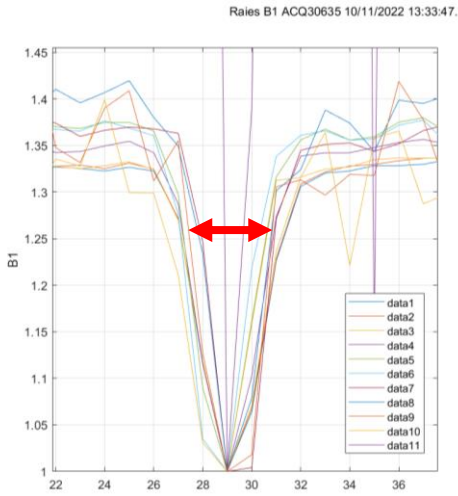


Preliminary analysis of optical perturbations

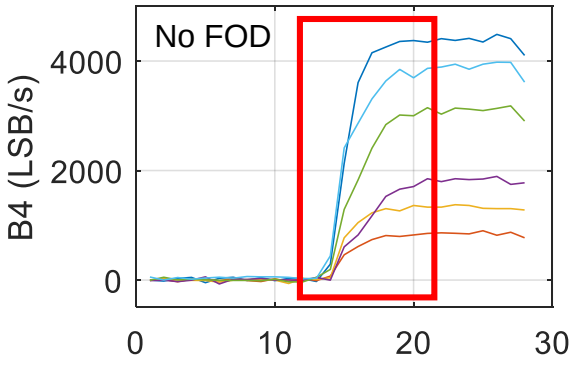
- **Straylight from ACT non uniform scene**

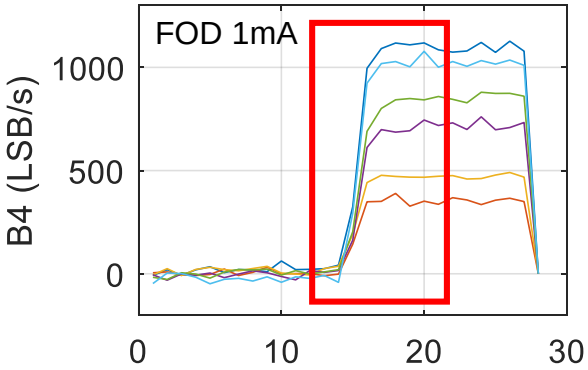


- **ISRF from ALT non uniform scene (variable width of a same solar line)**

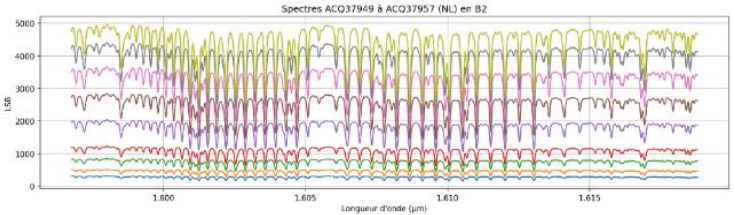


- **Remanence from fast shutter**
  (trapping on B4 for continuum & lines)





- **Non linearity from tunable diaphragm**
  - See next slides



L2 estimation attempts : first results

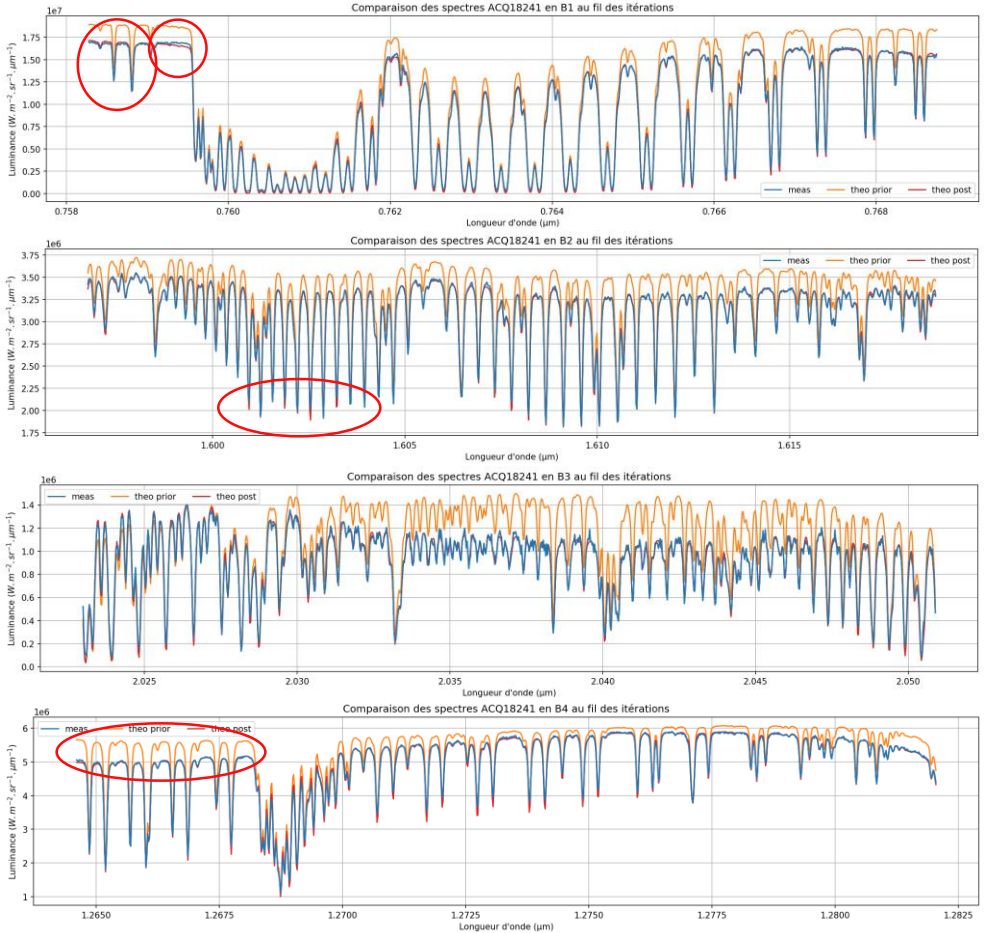
- **The L1 calibration is not completed, but we already started L2 retrievals**

- **Here we rely mostly on CNES preliminary spectrum calibration**
  - Radiometric absolute calibration (including setup) done by comparison with 4AOP
  - No correction for non-linearity

- **Working on measurements 5/11/2022, 12:42 UTC**
  - We compared the XCO2 MicroCarb from 4ARTIC with respect to the XCO2 from EM27 (truth)
  - The difference is > several ppm

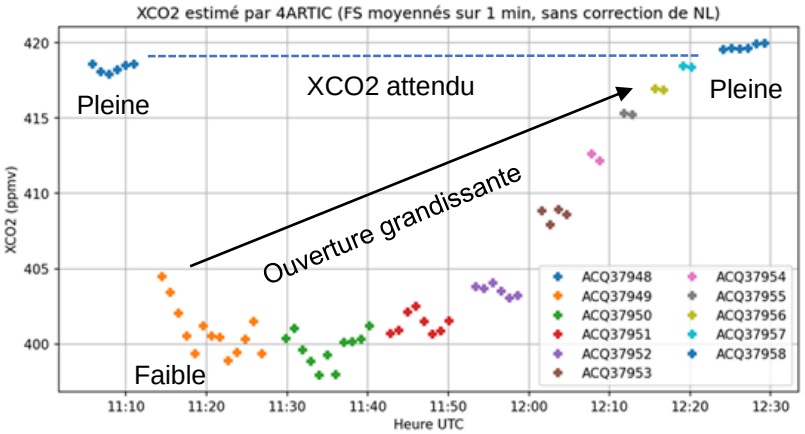
  As expected, we see the strong impact of an uncomplete L1 calibration

  - Some unexpected spectral residuals, that will help to characterize the instrument



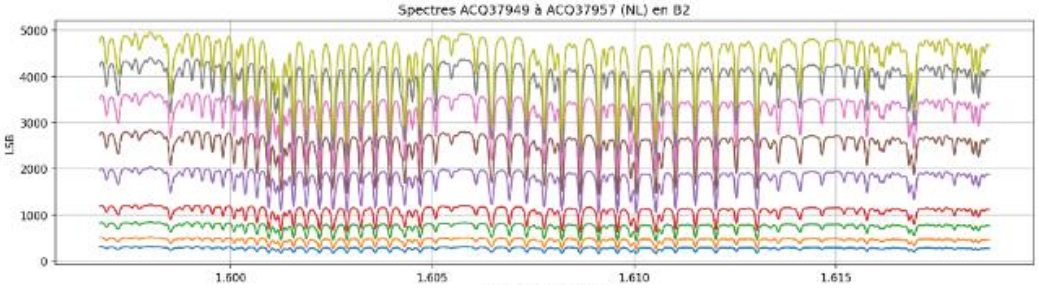
Impact de la non-linéarité (non-corrigée)

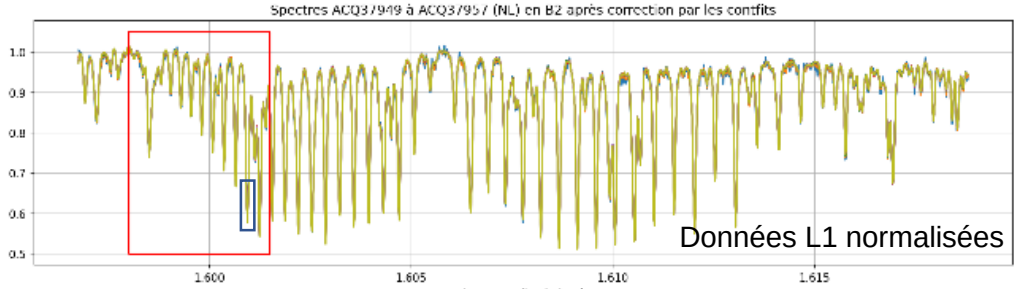
- **Observations d'une même atmosphère (durée 1h20) avec différentes ouvertures de diaphragme**
- **Impact L1 : variation de profondeur de raie**
  - Même après correction de l'effet SZA
- **Impact L2 : variation du niveau XCO2**
- **Test des différents jeux de correction de NL en cours**

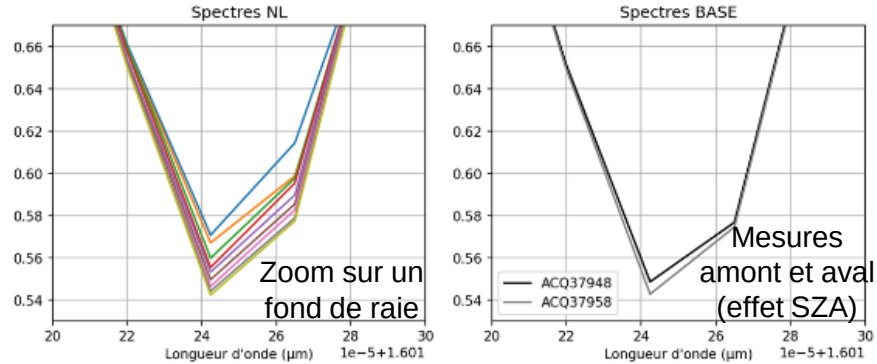


XCO2 de l'essai solaire sans correction de NL

Données L1



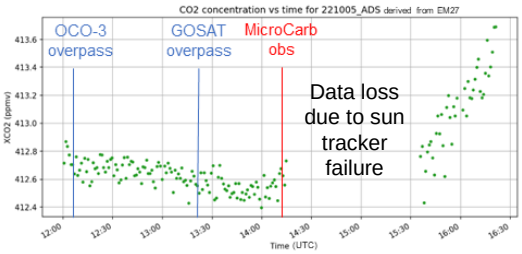




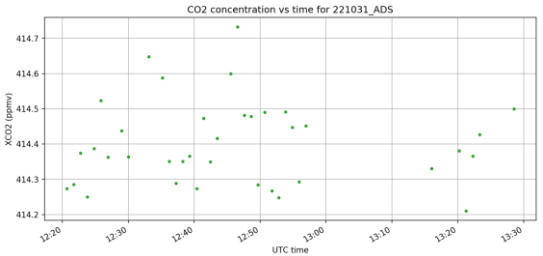
EM27 XCO2 measurements

- Will be used as the XCO2 truth to reach with MicroCarb L2
- Quality still under discussion
- Angular artifacts or natural variations?

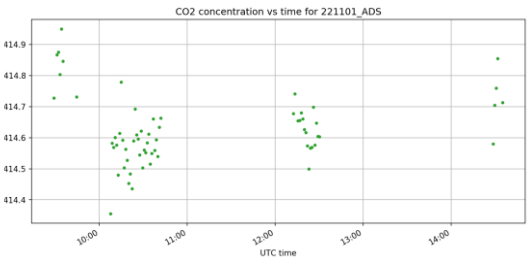
5/10



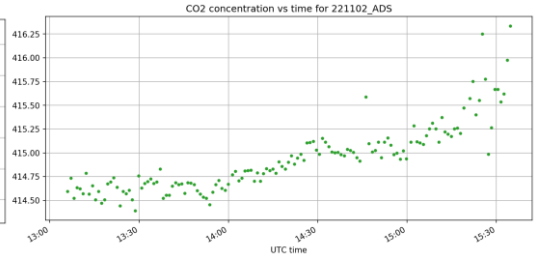
31/10

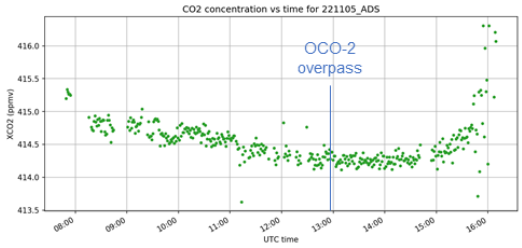


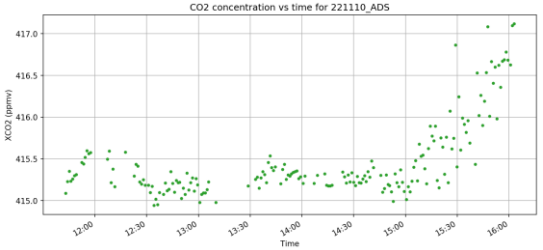
1/11

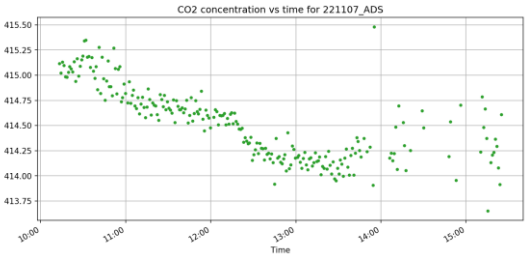


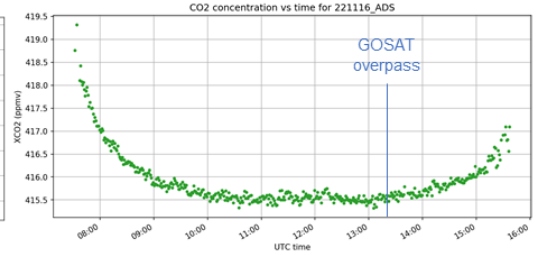
2/11











5/11

7/11

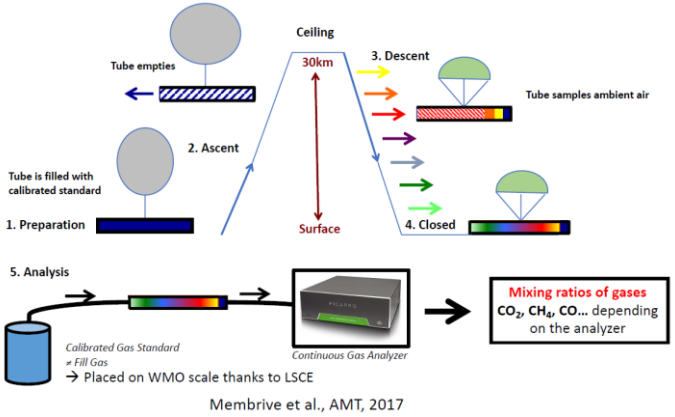
10/11

16/11

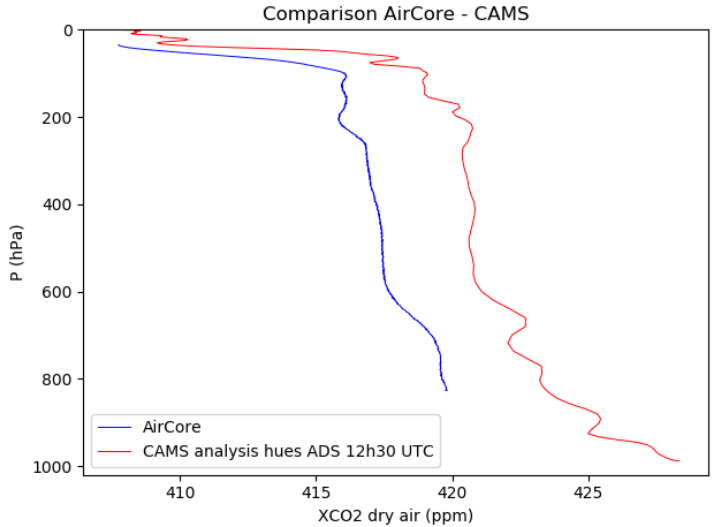
Processed at CNES with PROFFAST

AirCore launch at Aire sur l'Adour

- **AirCore is an atmospheric vertical sampler under BLD**
- **Should be used as a XCO2 truth and indication for vertical profile**

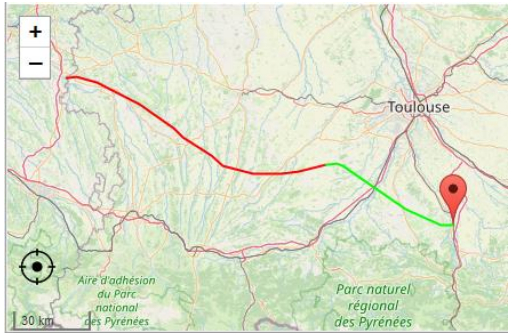


Membrive et al., AMT, 2017



AirCore data processing done by LMD

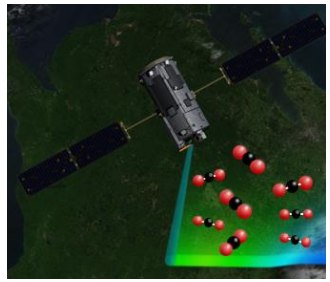
- **ASA managed to launch one AirCore on 16/11/2022**
  - Long recovery time (8h >> 3h requirement) ➔ Loss of vertical resolution
  - AirCore shutter not closed at landing ➔ Loss of the profile bottom (20%, in the least known part)

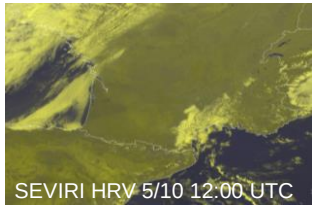


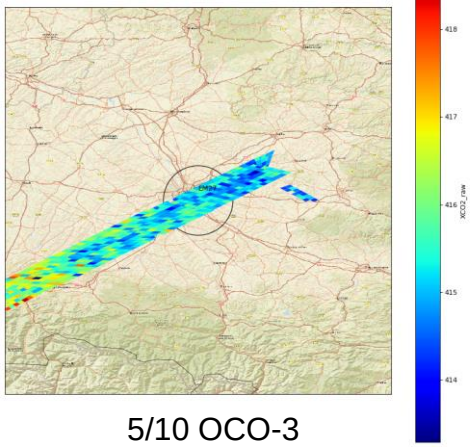
Launch, recovery and Picarro analysis done by CNES balloon division

Satellite XCO2 measurements

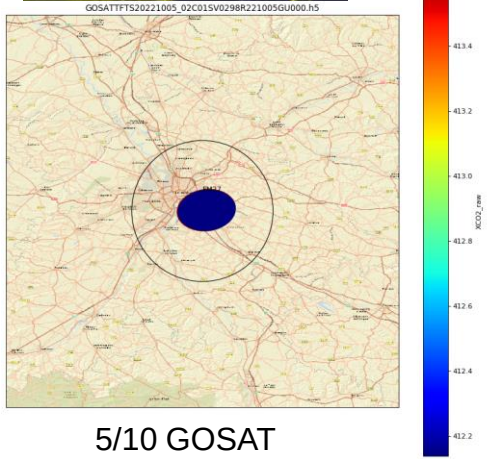
- 4 overpasses gave a L2 (+ potential 2 others GOSAT-2)
- To be compared soon with MicroCarb L2



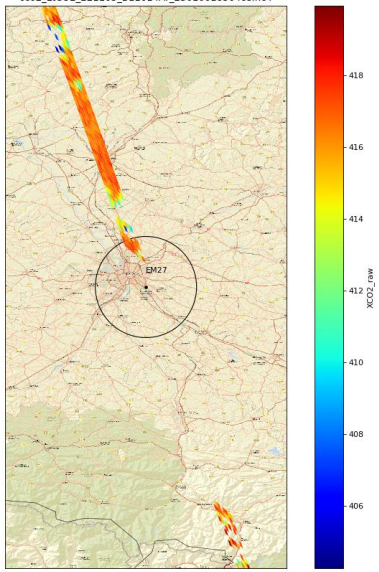




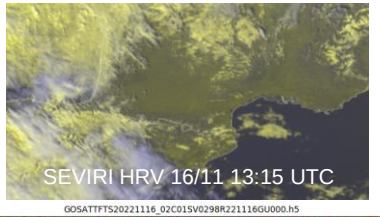
5/10 OCO-3

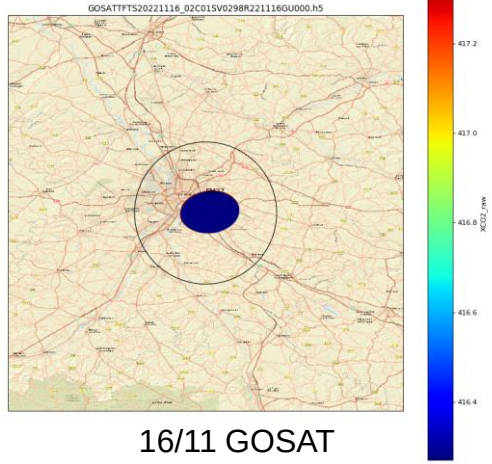


5/10 GOSAT



5/11 OCO-2

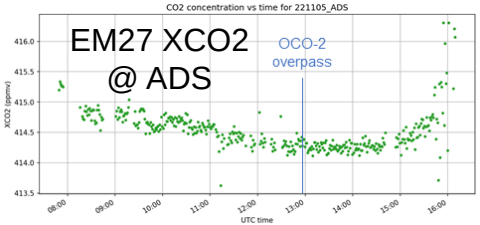


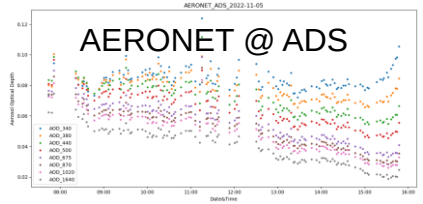


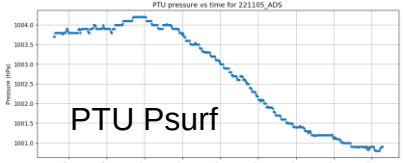
16/11 GOSAT

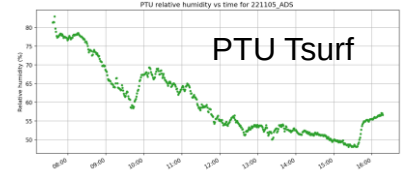
Date	SAT	Nb points EM27	EM27 moy (ppm)	EM27 std (ppm)	Nb points SAT	Distance moy (km)	Distance std (km)	SAT raw moy (ppm)	SAT raw std (ppm)	SAT BC moy (ppm)	SAT BC std (ppm)	SAT raw – EM27	SAT BC – EM27	SAT (BC – raw)
05/10/2022	OCO-3	34	412.69	0.07	666	10.898	5.05	413.46	0.71	415.16	0.48	0.77	2.47	1.70
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

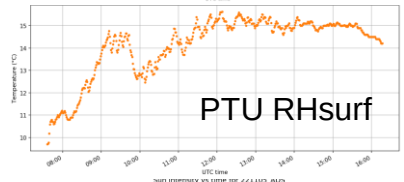
Simultaneous observations to characterize the atmosphere

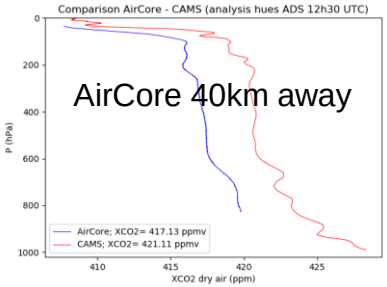


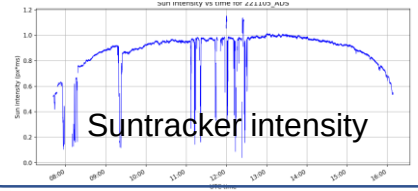




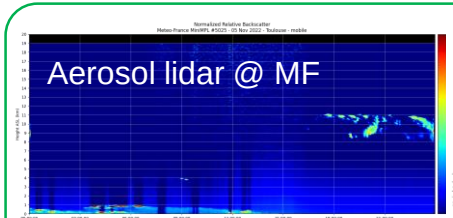


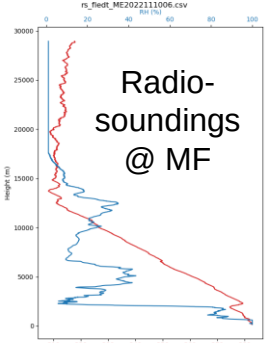


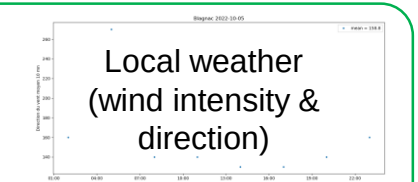


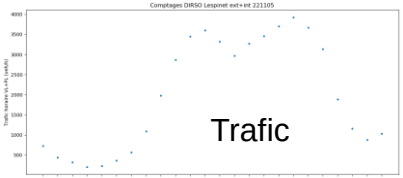


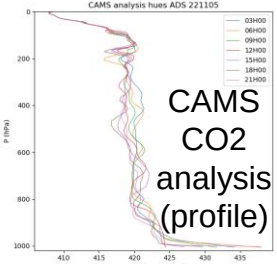
Measurements for MicroCarb
(@ Airbus + AirCore)

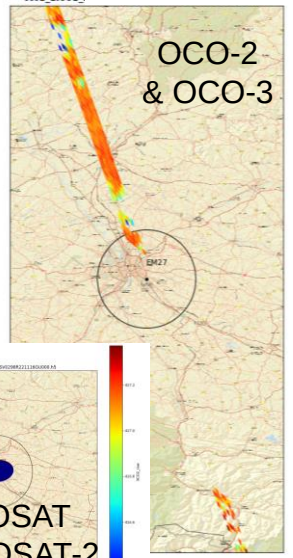


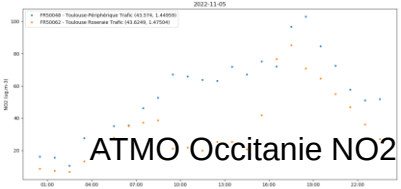


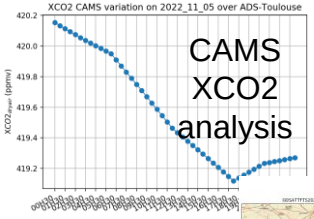


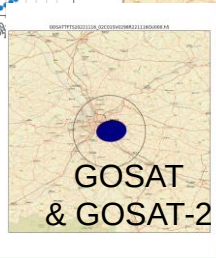


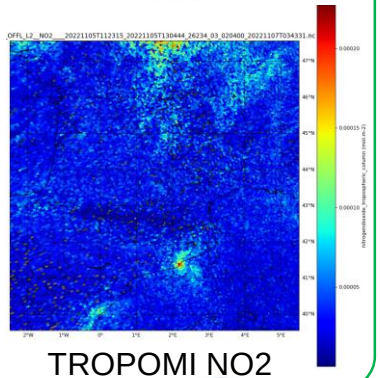












Other local,
sat and
model data

Achievements of the solar test

- **Successes**
  - We got a large dataset (larger than expected), with a variety of geophysical conditions (P,T,U,SZA,clouds)
  - First results are very encouraging (spectral shape)
  - All OGSE perturbations done, in ~stable conditions
  - Solar measurements used for instrument characterization
  - Many external measurements done : EM27, CIMEL + MF
  - 4 successful satellite overpasses

- **Mixed results**
  - Incomplete acceptance test of the setup : low transmission in B3, the highest radiances could not be explored
  - No reliable radiometric calibration of the setup (SR4500 gave spurious results)
  - Many clouds to screen
  - No solar elevation > 31°

- **Failures**
  - No reliable in situ profiling, which precludes to get a profile truth
    - Originally, ASA AirCore was a backup and was not fully secured (manpower, availability, criticity)
    - Balloon with AMULSE planned for launch at ENSIACET, but AMULSE not available (conflict with MAGIC campaign)
    - Aircraft SAFIRE measurements not available (not compatible with moving TVAC calendar)

➔ **This test is globally a large success, with missing in situ measurements and low signal in B3**
➔ **Very good training for cal/val!**

Next steps for exploitation

Once screened for clouds, fully calibrated at L1, first L2 processed:

- **Continue the study the impact of sun path OGSE perturbations at L1**
  - Compare spectra without and with the perturbation
  - Compare to results of TVAC characterisation and to models
- **Study the impact of optical perturbations at L2**
  - Compare XCO2 without and with the perturbation
- **Update processor parameters**
- **Study the impact of geophysical conditions (SZA, P, T, U, cirrus) at L2**
- **Compare to parallel measurements**
- **Retrieve XCO2 with 4ARTIC on satellite spectra and EM27 spectra**
- **Format data for release**

➔ **This requires several months**

Acknowledgements

CNES warmly thanks all partners involved in this experiment!

- **Airbus Defence and Space**
- **The MicroCarb Science Team**
- **The CNES balloon department**
- **The OCO-2&3 and GOSAT1&2 science teams**