living planet symposium | BONN 23–27 May 2022

TAKING THE PULSE OF OUR PLANET FROM SPACE

BIODIVERSITY – Status of a new hyperspectral space mission

S. Jacquemoud and the BIODIVERSITY Science Team

B6.01.1 National EO satellite missions – Thursday – 26.05.2022

BIODIVERSITY – Status of a new hyperspectral space mission

Briottet X.[1], Adeline K.[1], Bajjouk T.[2], Carrère V.[3], Chami M.[4], Constans Y.[1], Dupiau A.[1,5], Dumont M.[6], Doz S.[1], Fabre S.[1], Féret J.B.[7], Foucher P.Y[1]., Gomez C.[8], Herbin H.[9], Jacquemoud S.[5], Lang M.[10], Le Bris A.[11], Le Dantec V.[12], Loyer S.[13], Marion R.[14], Minghelli A.[15], Miraglio T.[1], Sheeren D.[10], Szymanski B.[16], Verpoorter C.[17], Romand F.[18], Desjardins C.[19], Rodat D.[19], Cheul B.[19]

1: ONERA DOTA, Université Fédérale de Toulouse, 31400 Toulouse, France
2: Ifremer, DYNECO, LEBCO, 29280 Plouzané, France
3: Université de Nantes, Laboratoire de Planétologie et Géosciences, UMR 6112, 44322 Nantes Cedex 3, France
4: LATMOS, Sorbonne Université, UMR 8190, OCA de Nice, 06304 Nice Cedex 4, France
5: Université Paris Cité, Institut de Physique du Globe de Paris, CNRS, 75005 Paris, France
6: Université Grenoble Alpes, Université de Toulouse, Météo-France, CNRS, CNRM, Centre d'Études de la Neige, 38000 Grenoble, France
7: UMR TETIS (INRAE, CNRS, CIRAD, AgroParisTech), Université de Montpellier, 34093 Montpellier, France
8: IRD, Department of Civil Engineering, Indian Institute of Science Bangalore, 560012 India
9: LOA, UMR 8518, Université de Lille, 59655 Villeneuve d'Ascq Cedex, France
10: Université de Toulouse, INRAE, UMR DYNAFOR, 31326 Castanet-Tolosan, France
11: LASTIG, Université Gustave Eiffel, ENSG, IGN, 94160 Saint Mandé, France
12: CESBIO, UMR 5126 (CNES, CNRS, INRAE, IRD, Université Toulouse 3), 31400 Toulouse, France
13: SHOM, 29200 Brest, France
14: CEA/DAM/DIF, 91297 Arpajon, France
15: Université de Toulon, CNRS, SeaTech, LIS laboratory, UMR 7020, 83041 Toulon, France
16: DGA, 60, Boulevard du Général Martial Valin, 75509 Paris Cedex 15, France
17: Université Littoral Côte d'Opale, Université de Lille, LOG UMR CNRS 8187, 62930 Wimereux, France
18: ACRI-ST, 06904 Sophia-Antipolis, France
19: CNES, 18 Avenue Edouard Belin, 31400 Toulouse, France

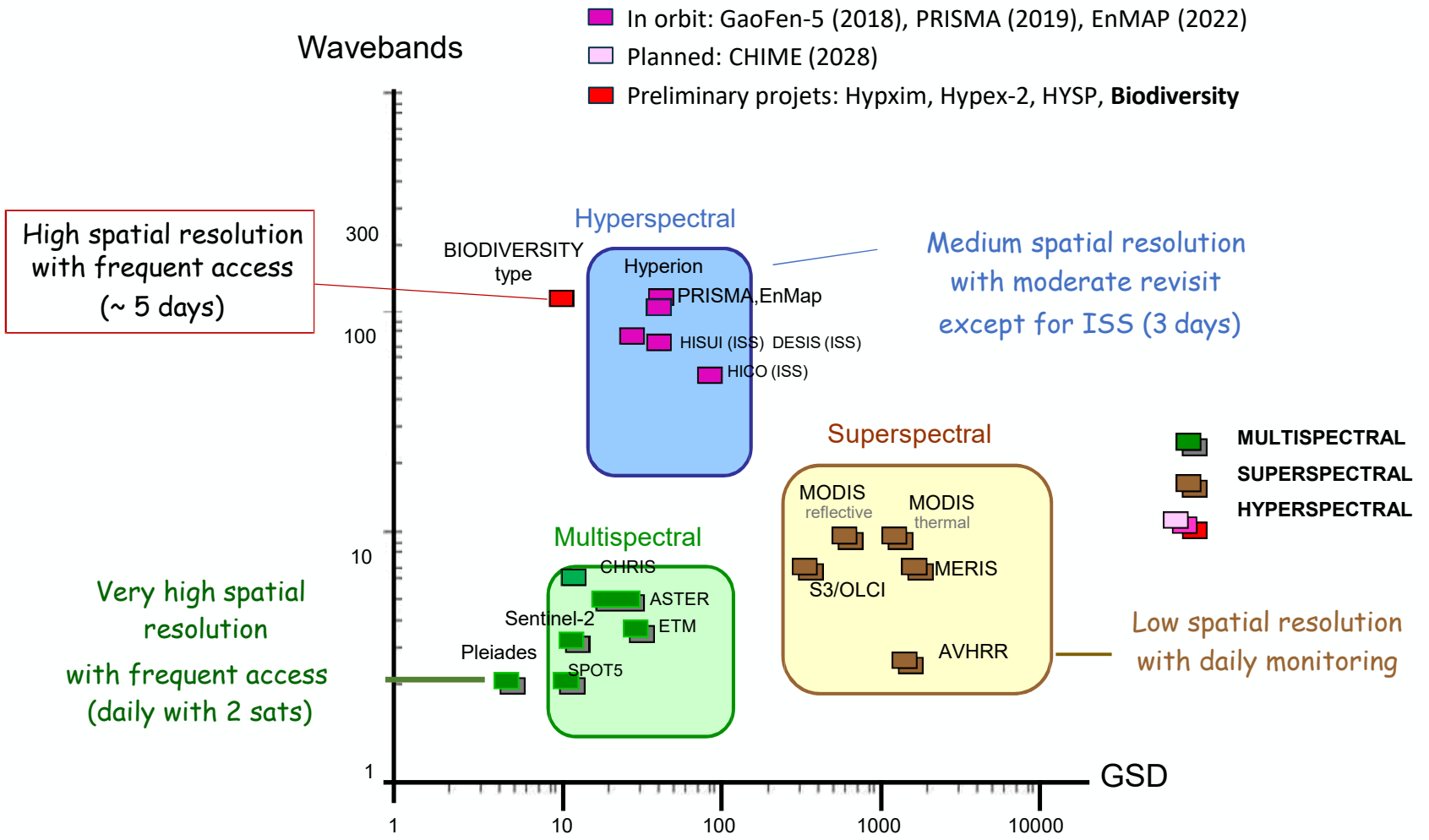
Context (1/3)

Several hyperspectral space missions are already in operation (Hyperion/2000, Gaofen 5/2018, DESIS/2018, PRISMA/2019, HISUI/2019, EnMap/2022), most of them have a ground sample distance (GSD) of 30 m with high radiometric quality. At this GSD, the performance of some applications is reduced due to mixed or insufficient pixels to characterize a particular scene.

→ There is therefore a real need to complete this fleet with a new hyperspectral image sensor with a better spatial resolution.

For many years, French scientific teams supported by CNES/DGA have been working on the specifications of a new sensor under several names HYPXIM-CNES, HYPEX-ESA, HYSP-CNES, BIODIVERSITY-CNES.

Context (2/3)


In orbit: GaoFen-5 (2018), PRISMA (2019), EnMAP (2022)
Planned: CHIME (2028)
Preliminary projets: Hypxim, Hypex-2, HYSP, Biodiversity
Wavebands
High spatial resolution with frequent access (~ 5 days)
Hyperspectral
BIODIVERSITY type
Hyperion
PRISMA,EnMap
HISUI (ISS)
DESIS (ISS)
HICO (ISS)
Medium spatial resolution with moderate revisit except for ISS (3 days)
Superspectral
MODIS reflective
MODIS thermal
MERIS
S3/OLCI
AVHRR
Low spatial resolution with daily monitoring
Multispectral
CHRIS
ASTER
ETM
Sentinel-2
Pleiades
SPOT5
Very high spatial resolution with frequent access (daily with 2 sats)
MULTISPECTRAL
SUPERSPECTRAL
HYPERSPECTRAL
300
100
10
1
GSD
1
10
100
1000
10000

Context (3/3)

BIODIVERSITY is composed of two instruments:

HSI camera: 10 m GSD, spectral range from 0.4 to 2.4 µm

PAN camera: 4 m GSD, one broadband

The objective of this presentation is to specify the spectral resolution, SNR, and image quality suitable for different applications:

- Geosciences: mineralogy, soil moisture content
- Natural vegetation: tree species classification, Essential Biodiversity Variables (pigments, LMA, EWT) at tree level
- Coastal and continental waters: bathymetry, shallow water bottom classification, coastal habitat classification
- Urban areas: urban land cover
- Industrial sites: aerosols (PM1), methane, carbon dioxide
- Cryosphere: single scattering albedo, black carbon
- Atmosphere: water vapor, carbon dioxide and aerosols

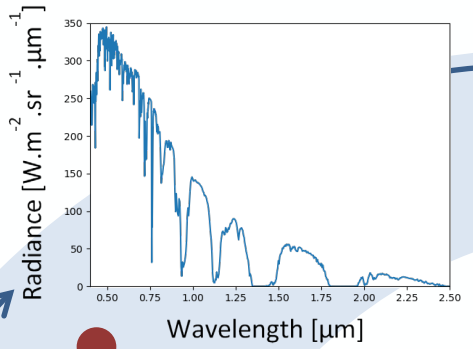
Method: image simulations

22 images + 3 spectral libraries

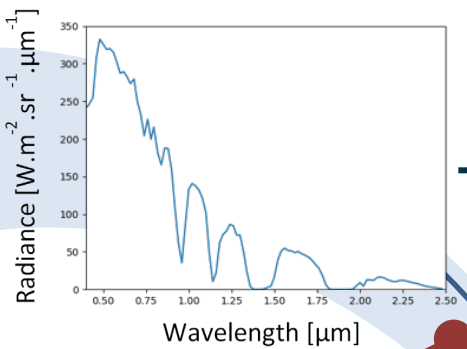
All data sets have been processed with the same E2E chain

Spectral radiance

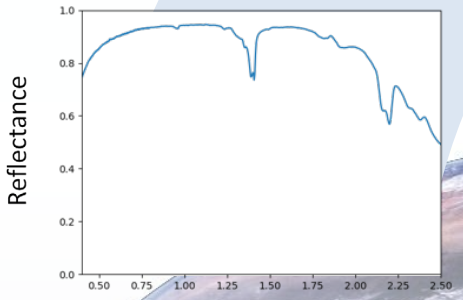
Top of atmosphere spectrum



Out of instrument spectrum



Spectrum of the ground target

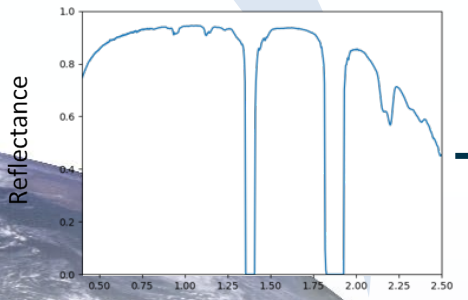


Instrument

Lighting and atmosphere

Atmospheric correction

Spectrum of the target, estimated from space



<u>Two outputs before processing</u>

Industrial plants, urban areas, atmosphere

Natural vegetation, coastal and inland waters, cryosphere

H. Schmitt and R. Evans, *Full Earth showing Africa and Antarctica*. 1972. **[Photograph]**. Available on: <https://commons.wikimedia.org/wiki/File:The_Blue_Marble_4463x4163.jpg>.

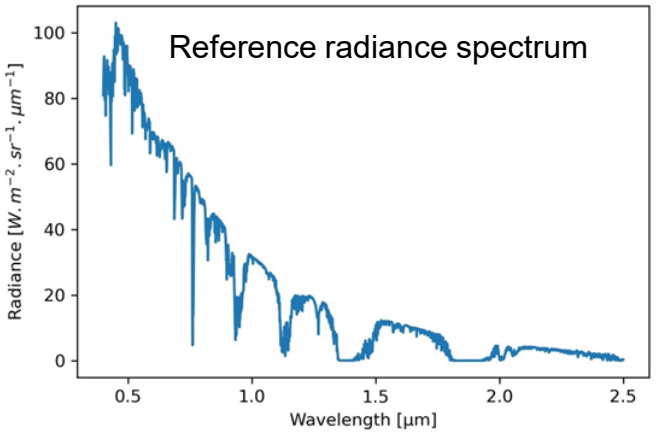
Method: instrument (1/2)

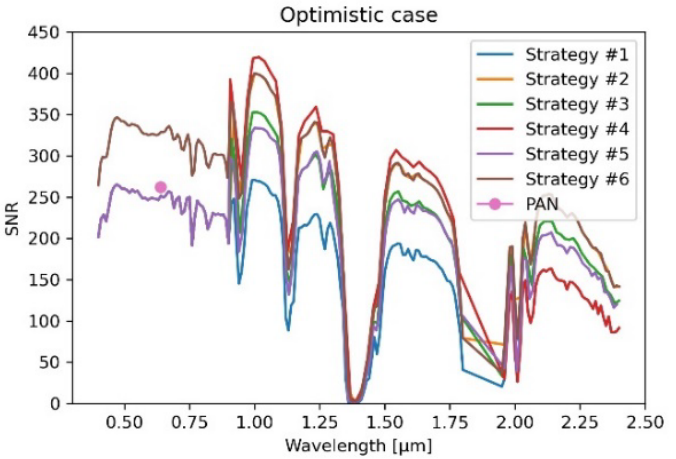
- **6** spectral sampling strategies

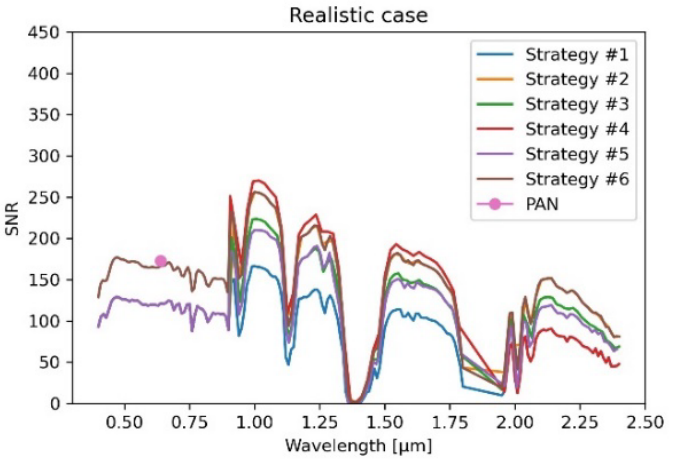
Strategy	VNIR (400 – 900 nm)			SWIR (900 – 1850 nm / 1950 – 2400 nm)		
	Spectral sampling [nm]	Spectral width [nm]	Number of channels	Spectral sampling [nm]	Spectral width [nm]	Number of channels
#1	10	10	51	10	10	136
#2	10	10	51	20	20	68
#3	10	10	51	16	16	85
#4	10	10	51	22 for $\lambda \leq 1{,}95$ 10 for $\lambda > 2{,}05$	22 for $\lambda \leq 1{,}95$ 10 for $\lambda > 2{,}05$	86
#5	10	10	51	12	Linear increase from ~14 nm to ~17 nm over [0,9 – 1,3], [1,3 – 1,8] and [1,95 – 2,4]	112
#6	8	16	63	10	20	136

Method: instrument (2/2)

- **2** signal-to-noise ratios (SNR): Optimistic [100-400] @Lref + Realistic [50-250] @Lref

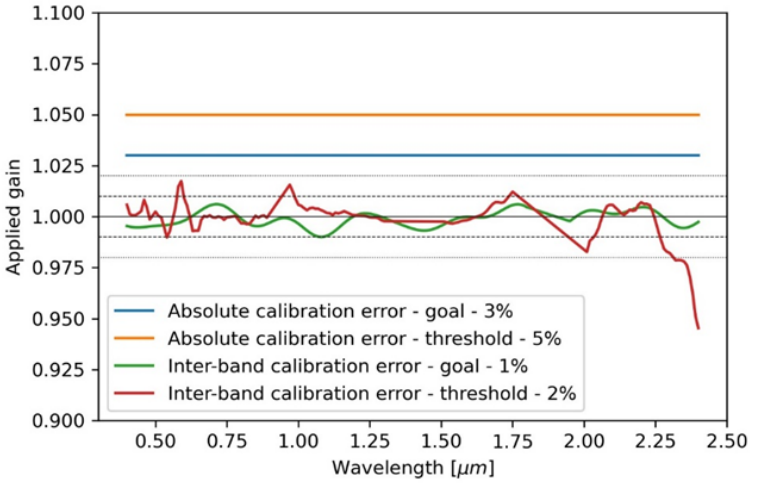






- **2** calibration performances:
  Target: 3% absolute / 1% interband
  Threshold: 5% absolute / 2% interband

⇒ 6 × 2 × 2 = 24 simulations



Results: spectral sampling

Most of the applications tested are not dependent on the spectral strategy except for

Geosciences: mineralogy

Minerals tested: kaolinite, calcite, gypsum, alunite, hematite, goethite, rare earth element

Best strategies #1 and #4, acceptable strategies #5 and #6

Bathymetry: strategy #6 non recommended

Industrial plants:

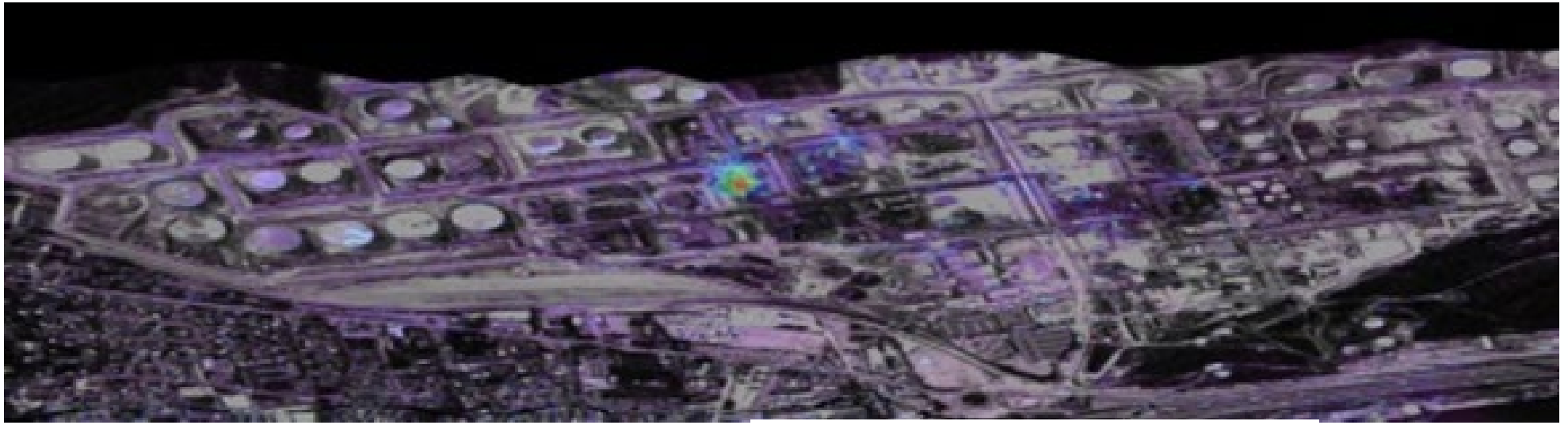
Aerosols: strategy #6 non recommended if unknown aerosol model

Gas: strategy #5 unable to detect CH_4 (< 1500 ppm.m) and CO_2 (< 150 000 ppm.m) accurately

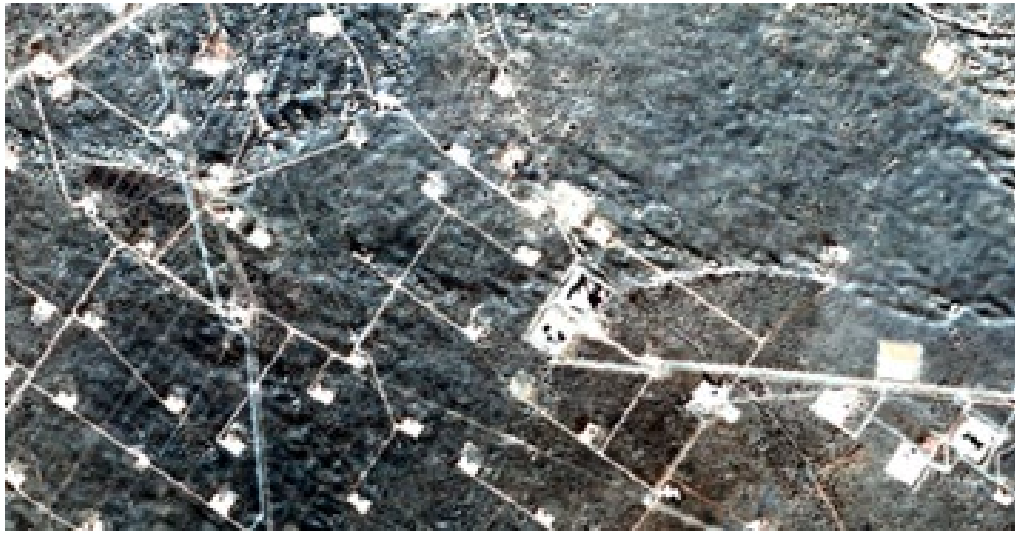
Atmosphere: strategy #2 non recommended for H_2O and CO_2

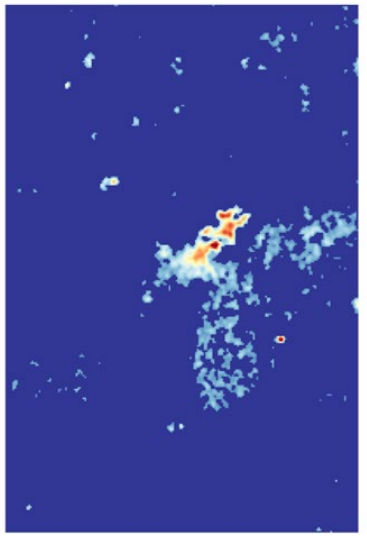
	VNIR		SWIR	
	Sampling	Width	Sampling	Width
#1	10	10	10	10
#2	10	10	20	20
#3	10	10	16	16
#4	10	10	variable	variable
#5	10	10	12	variable
#6	8	16	10	20

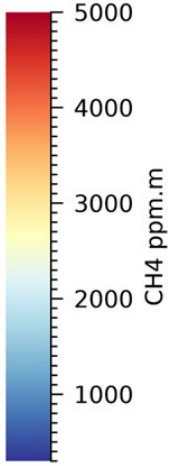
Results: spectral sampling



Fos sur Mer (France)
CO_2
@HYSPEX







Carlsbad (NM, USA)
CH_4 Leak
@AVIRIS

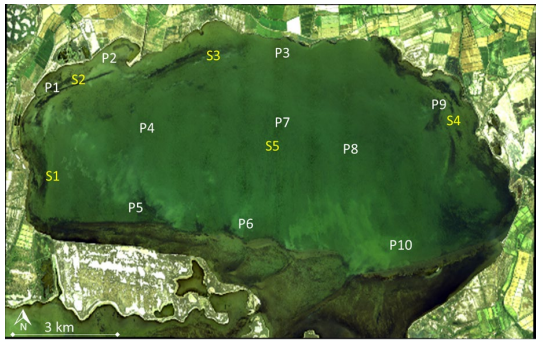
Results: signal-to-noise ratio

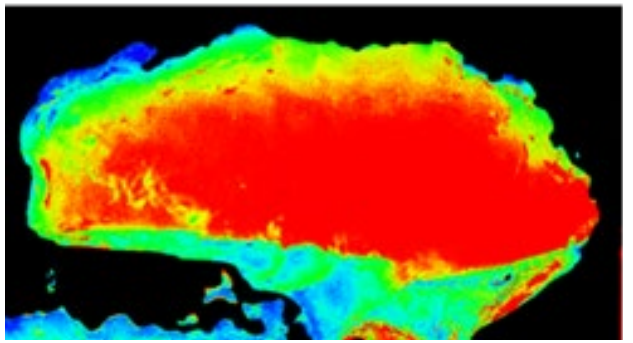
Optimistic [100-400] @Lref + Realistic [50-250] @Lref

A weak degradation of the estimation is observed from optimistic down to realistic, but most of the applications tested have little or not dependence on SNR except for

Bathymetry

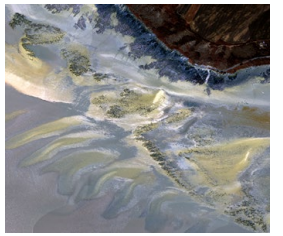
Camargue (France) @HYSPEX

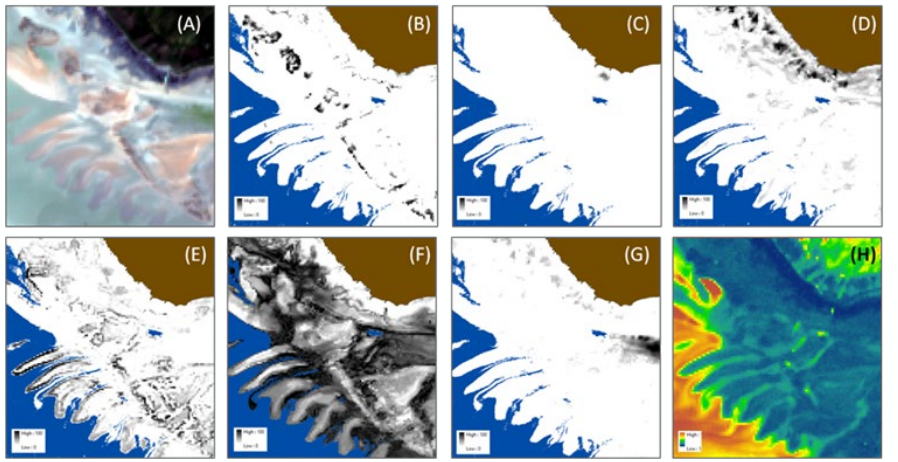




Shallow water classification

Champeaux (France) @HYSPEX





(A) Image using unmixing
(B) Biogenic reef
(C) Macroalgae
(D) Rock
(E) Sand
(F) Mud
(G) Microphyto-benthos
(H) RMSE

Results: calibration performance

Target 3% absolute / 1% interband + Threshold 5% absolute / 2% interband

Most of the applications tested have little or not dependence on calibration performance except for

Bathymetry: Not fullfiled for Threshold

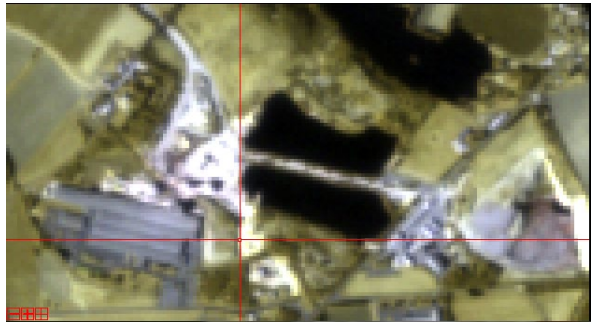
Cryosphere: Black Carbon not estimated with Threshold

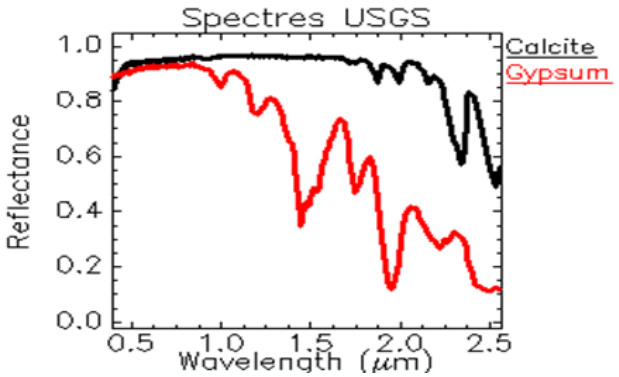
Results: calibration performance

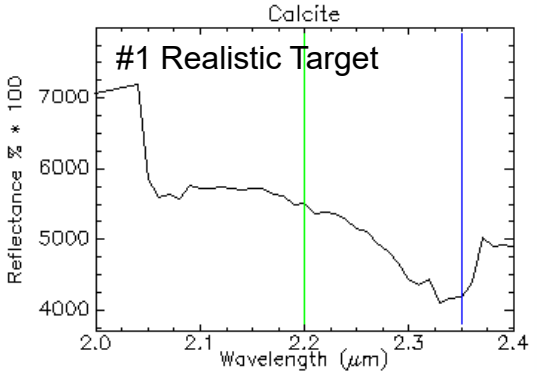
Target 3% absolute / 1% interband + Threshold 5% absolute / 2% interband

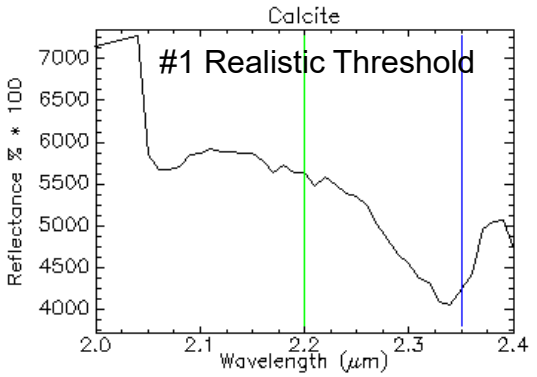
Calcite detection

Cherves-Richemont (France) @HYSPEX



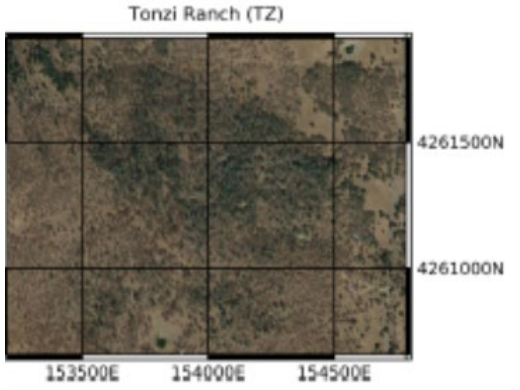


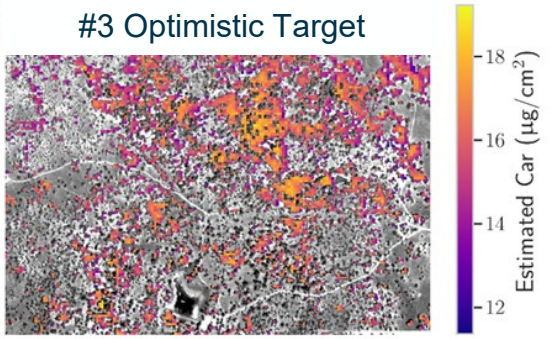


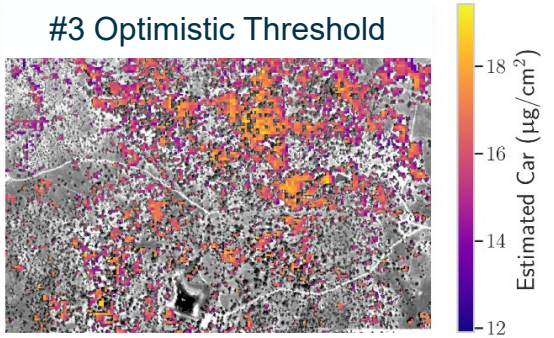


Chlorophyll estimation for *Quercus douglasii*

Tonzi (CA, USA) (LAI~1) @AVIRIS







Conclusion (1/2)

- CNES is working on a hyperspectral mission (0.4-2.4 µm, 10 m GSD) with a PAN camera (4 m GSD) → Phase A (feasibility) will end in 2022
- A large french scientific community is involved to optimize the design of the instrument
- All the products simulated in this exercise use the same end-to-end chain, with the same instrumentation parameters, making it easy to compare different applications
- This work is based on 24 (instrument configurations) × 25 (22 images + 3 spectral libraries) = 600 samples with different spectral sampling / SNR / calibration performance
- Some applications depend on SNR (bathymetry, shallow water bottom classification, coastal habitat classification)
- A slight loss in performance is observed between the Target calibration and the Threshold calibration

Conclusion (2/2)

- Applications whose methods are based on the use of the global spectral signature have no sampling dependency → 16-20 nm spectral sampling is sufficient (soil moisture content, tree species classification, essential biodiversity variables, bathymetry, shallow water bottom classification, coastal habitats classification, urban land cover, snow/ice characterization, aerosol optical thickness, except for aerosol of industrial plant)
- Applications whose methods are based on the use of specific absorption bands depend on the spectral resolution → 10 nm spectral sampling is recommended (mineralogy, industrial plant or atmospheric gas)

Based on these results, CNES is studying the best compromise to design the future hyperspectral sensor to meet the objectives of the priority applications

Questions: xavier.briottet@onera.fr