End-user driven optimization of the SWIR spectral sampling for a future hyperspectral sensor using end-to-end simulations

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

1: ONERA DOTA, Université Fédérale de Toulouse, 31400 Toulouse, France
2: Ifremer, DYNECO, LEBCO, 29280 Plouzané, France
3: LATMOS, Sorbonne Université, UMR 8190, OCA de Nice, 06304 Nice Cedex 4, France
4: Université de Paris, Institut Physique du Globe de Paris, CNRS, 75005 Paris, France
5 : Univ. Grenoble Alpes, Université de Toulouse, Météo-France, CNRS, CNRM, Centre d'Études de la Neige, 38000 Grenoble, France
6: UMR TETIS (INRAE, CNRS, CIRAD, AgroParisTech), Université de Montpellier, 34093 Montpellier, France
7: IRD, Department of Civil Engineering, Indian Institute of Science Bangalore, 560012 India
8: LOA UMR 8518 Université de Lille, 59655 Villeneuve d'Ascq Cedex
9: CESBIO - UMR 5126 (CNES, CNRS, INRAe, IRD, Université Toulouse 3), 31400 Toulouse, France
10: LASTIG, Univ. Gustave Eiffel, ENSG, IGN, 94160 Saint Mandé, France
11: CEA/DAM/DIF, F-91297 Arpajon, France- France
12: Université de Toulon, CNRS, SeaTech, LIS laboratory, UMR 7020, 83041 Toulon, France
13: Université de Toulouse, INRAE, UMR DYNAFOR, 31326 Castanet-Tolosan, France
14: DGA, 60, Boulevard du Général Martial Valin 75509 PARIS Cedex 15, France
15: Université Littoral Côte d'Opale, Université de Lille, LOG UMR CNRS 8187, 62 930 Wimereux, France
16: CNES, 31400, Toulouse, France
17: Université de Nantes, Laboratoire de Planétologie et Géodynamique, UMR 6112, 44322 Nantes Cedex 3, France
18: ACRI-ST, 06904 Sophia-Antipolis, France
19: SHOM, 29200 BREST, France

Context

Project needs:

- Use a single SWIR detector for cost savings and HSI design complexity reduction
- ➢ How to reduce the number of SWIR bands compared to the initial 10-nm sampling strategy?

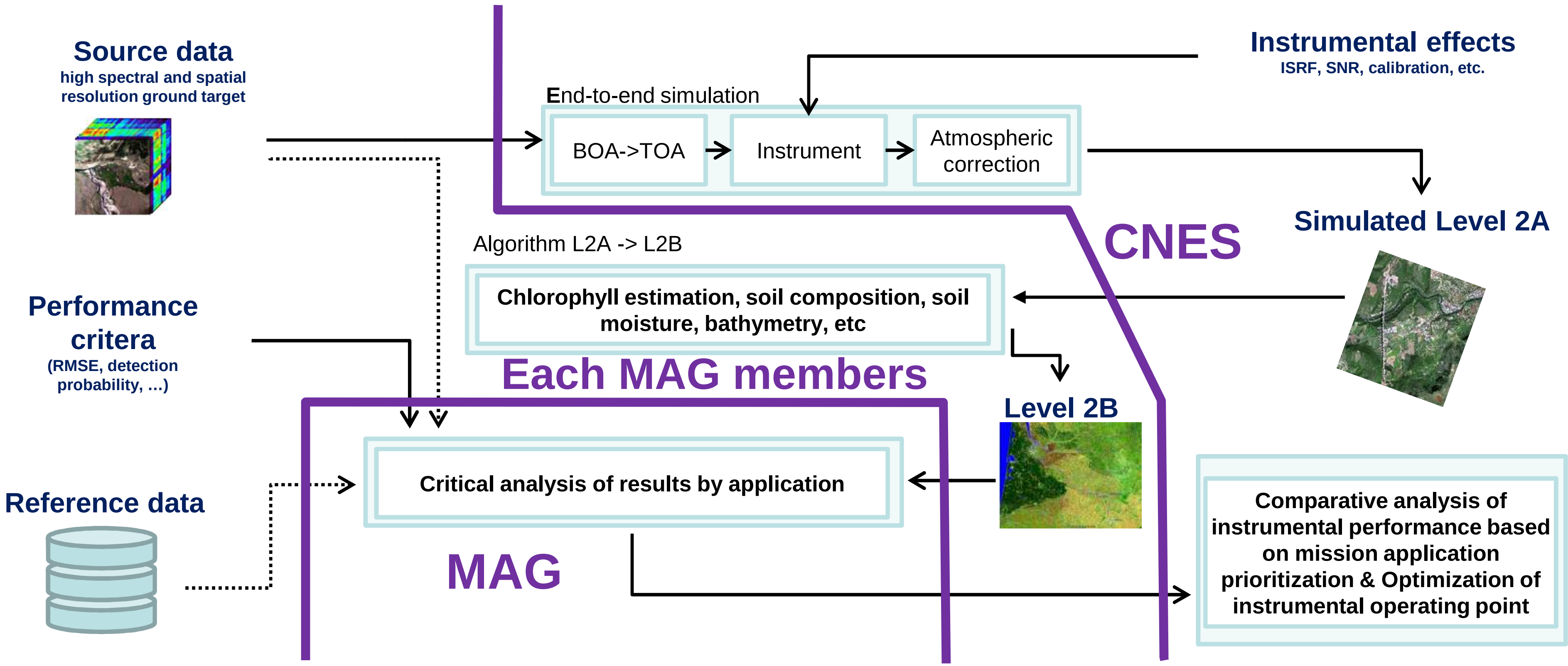
Several options to reduce the number of spectral bands in the SWIR:

- Remove spectral range intervals, increase spectral sampling, increase spectral resolution

MAG study goal was to recommend a spectral sampling strategy in the SWIR taking into account SNR and image quality suitable for different applications:

- Geosciences: mineralogy, soil moisture content
- Natural Vegetation: tree species classification, mediterranean forest EBV (Chl_{ab}, Car, LMA, EWT) at tree level
- Coastal and continental waters: bathymetry, bottom classification of shallow water, classification of coastal habitats
- Urban area: urban land cover
- Industrial site: aerosols (PM1), methane, carbon dioxide
- Cryosphere: specific surface area, black carbon rate
- Atmosphere: water vapor, carbon dioxide and aerosol

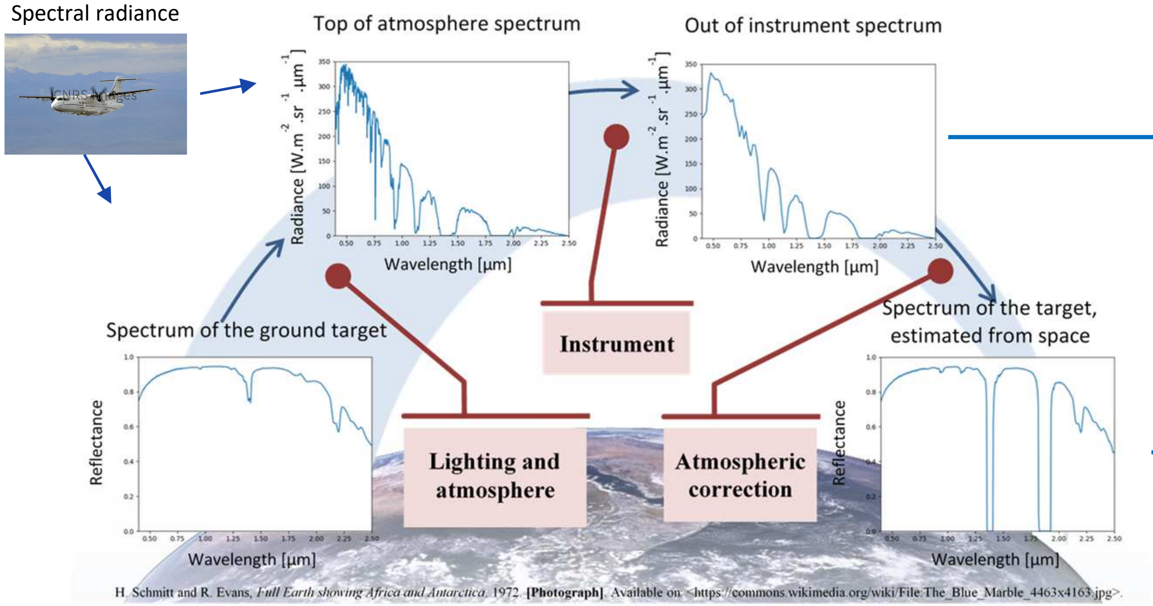
Mission Advisory Group: Work breakdown - 2022 activity



Method: IHS images simulation

Inputs: 22 images + 3 spectral libraries
All the applications were processed with the same EtoE chain

Two possible inputs
(depending on the application)



<u>Two outputs before processing</u>

Industrial plant, urban area, atmosphere

Natural vegetation, coastal and inland waters, cryosphere

Method: instrument

IHS Instrument operating points:

- **6** spectral sampling strategies:

Strategy	VNIR [400 – 900]		SWIR]900 – 1 800] ∪ [1 950 – 2 400]	
	Spectral step [nm]	Spectral width [nm]	Spectral step [nm]	Spectral width [nm]
#1	10	10	10	10
#2	10	10	20	20
#3	10	10	16	16
#4	10	10	22 for $\lambda \leq$ 1,95 10 for $\lambda >$ 2,05	22 for $\lambda \leq$ 1,95 10 for $\lambda >$ 2,05
#5	10	10	12	Linear increase: from ~ 14 nm to ~17 nm over [0,9 – 1,3], [1,3 – 1,8] and [1,95 – 2,4].
#6	8	16	10	20

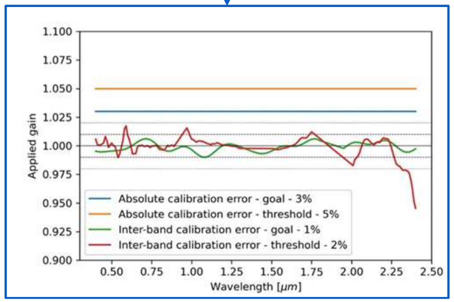
24 simulations

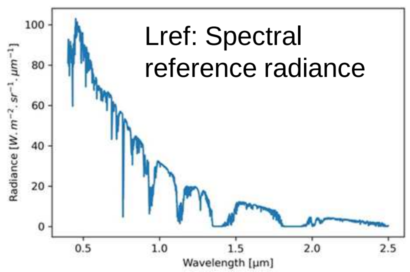
- **2** SNR:

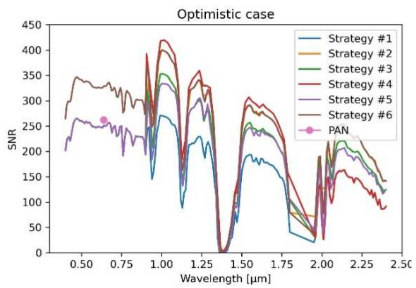
<u>Realistic</u>: [50, 250] @Lref
<u>Optimistic</u>: [100, 400] @Lref

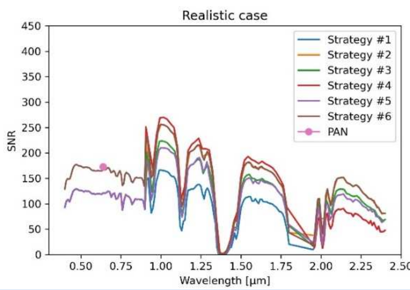
- **2** calibration performances:

<u>Target:</u> 3% absolute / 1 % interband
<u>Threshold:</u> 5% absolute / 2 % interband









Results: spectral sampling

Strategy	VNIR [400 – 900]		SWIR]900 – 1 800] ∪ [1 950 – 2 400]	
	Spectral step [nm]	Spectral width [nm]	Spectral step [nm]	Spectral width [nm]
#1	10	10	10	10
#2	10	10	20	20
#3	10	10	16	16
#4	10	10	22 for λ ≤ 1,95 10 for λ > 2,05	22 for λ ≤ 1,95 10 for λ > 2,05
#5	10	10	12	Linear increase: from ~14 nm to ~17 nm over [0,9 – 1,3], [1,3 – 1,8] and [1,95 – 2,4].
#6	8	16	10	20

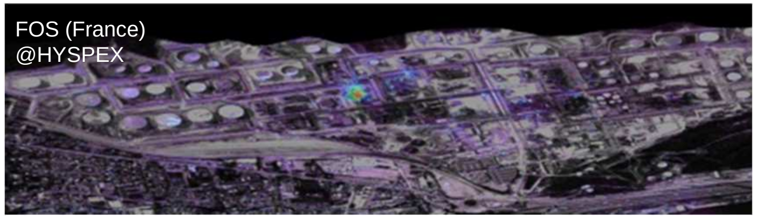
Most of the applications tested are not dependent on the spectral strategy except for

Geosciences: Mineralogy

Tested minerals : kaolinite, calcite, Gypsum, Alunite, Hématite, Géolithe, Rare Earth Element (REE)

- Best strategies: #1, 4, acceptable strategies: #5, 6

Bathymetry: #6 non recommended



Industrial Plants:

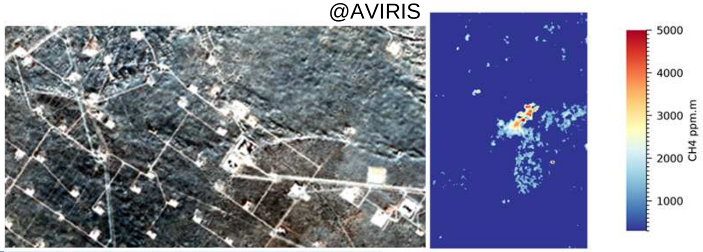
Aerosols (PM1): Foucher et al., 2019, Calassou et al., 2020

- If aerosol model not known: only the realistic-Threshold, strategy #6 is acceptable

Gas (détection and quantification of methane, carbon dioxide) Nesme et al., 2021

- Realistic #5 does not able to detect methane
- (with an accuracy < 1500 ppm.m)
- and carbon dioxide (< 150 000ppm.m)

Carlsbad, New Mexico (USA)
Methane Leak
@AVIRIS

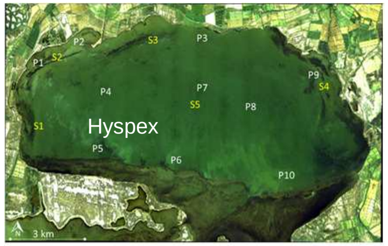


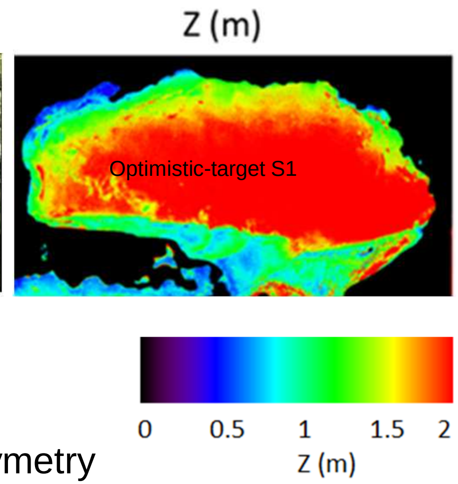
Atmosphere : Gas (H_2O, CO_2) #2 non recommended,
Aerosols: do not depend on the spectral strategy

Results: SNR (realistic (SNR@Lref between 50 and 250) and optimistic (SNR@Lref between 100 and 400))

A weak degradation of the estimation is observed from optimistic down to realistic, but most of the applications tested have little or no dependence on SNR except for:

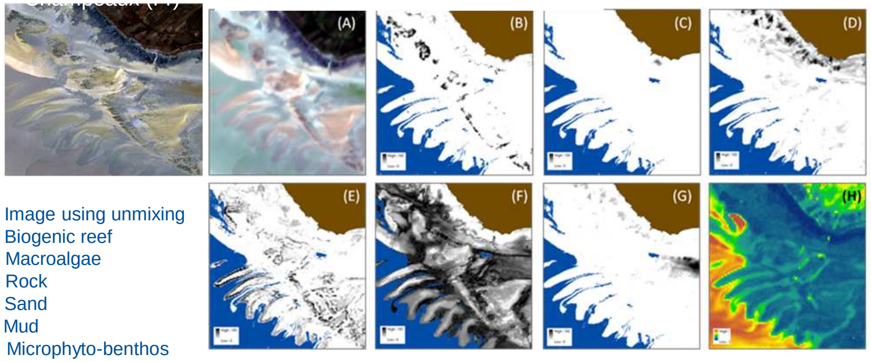
Camargue (France)





Bathymetry

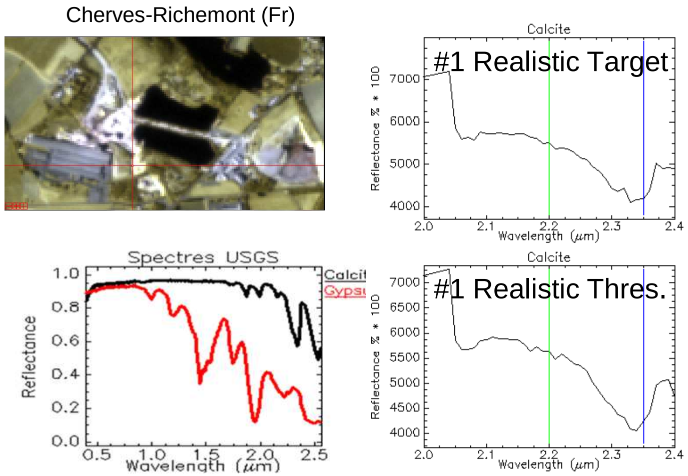
Abundance maps @HYSPEX



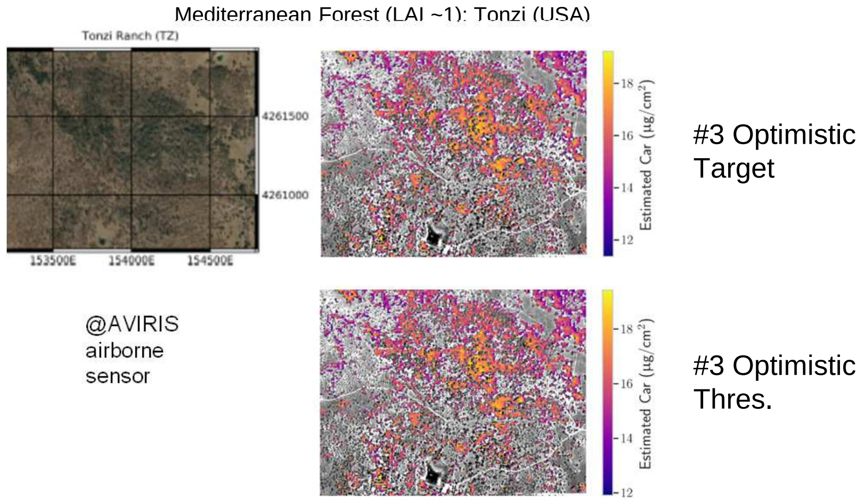
(A) Image using unmixing
(B) Biogenic reef
(C) Macroalgae
(D) Rock
(E) Sand
(F) Mud
(G) Microphyto-benthos
(H) RMSE

Shallow water classification

Results: Calibration (Target (3% absolute / 1 % interband) and threshold (5 % absolute / 2 % interband))



Calcite detection



Car quantification of *Quercus Douglasii*

A small but non-significant performances loss is observed from target calibration (3 % absolute / 1 % interband) to threshold target (5% / 2%) except for:

Bathymetry: Not fullfiled for Threshold

Cryosphere: Black Carbon rate not estimated with Threshold

Conclusion (1/1)

- 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
- Applications whose methods are based on the use of the global signature have no sampling dependency -> 16/20 nm spectral sampling is sufficient: Soil Moisture Content, Tree species classification, Forest EBV, Bathymetry, Bottom Classification of shallow water, classification of coastal habitats, urban land cover, snow/Ice characterization, spectral 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, Gas of industrial Plant or of atmosphere
- Generally, a performance loss is observed from target calibration (3 % absolute / 1 % interband) to threshold target (5% / 2%)
- Some applications depend on SNR: bathymetry, bottom classification of shallow water, classification of coastal habitats

Conclusion (1/2)

- A large French scientific community is involved to optimize the design of the instrument
- The MAG members made the recommendation on the compatibility of each proposed instrumental configuration for each application needs.
- From these results, CNES is studying the best trade-off to design the future HSI sensor to fulfill the mission objectives.
- Article is under review

Table 48: Synthesis (where k.a. means if the estimation is done with a prior knowing the type of aerosol and not k.a. if it is not known). The color code is as follow: □ indicates the best performances close to the objective, □ indicates a small degradation of the performances but remain acceptable performances close to the objective, □ indicates the performances remain acceptable, □ indicates the performances are of the same order of the acceptable uncertainty, □ indicates the performances cannot be obtained.

	Optimistic		Realistic	
Thematic	Target	Threshold	Target	Threshold
		Spectral feature		
Mineralogy	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6
Gas of Industrial Plant: ΔCH_4 (ppm.m)	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6
Gas of Industrial Plant: ΔCO_2 (150000 ppm.m)	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6
Atmosphere Gas H_2O	1, 2, 3, 4, 5, 6	Not tested	Not tested	1, 2, 3, 4, 5, 6
Atmosphere Gas CO_2	1, 2, 3, 4, 5, 6	Not tested	Not tested	1, 2, 3, 4, 5, 6
		Spectral continuum		
Soil Moisture Content	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6
Tree Species Classification	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6
Forest EBV	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6
Bathymetry	1, 2, 3, 4, 5, 6		1, 2, 3, 4, 5, 6	
Bottom Classification of Shallow Water	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	
Classification of Coastal habitats (without Fusion)	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6
Urban Land Cover	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6
Aerosols of Industrial Plant: aerosol model known PM1	80µg/cm²: 1, 2, 3, 4, 5, 6	80µg/cm²: 1, 2, 3, 4, 5, 6	150µg/cm²: 1, 2, 3, 4, 5, 6	150µg/cm²: 1, 2, 3, 4, 5, 6
Aerosols of Industrial Plant: aerosol model not known PM1	150µg/cm²: 1, 2, 3, 4, 5, 6	150µg/cm²: 1, 2, 3, 4, 5, 6		
Cryosphere Spec. Surf. area	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6
Equivalent Black Carbon content	1, 2, 3, 4, 5, 6		1, 2, 3, 4, 5, 6	
Atmosphere Aerosol with revisit or auxiliary	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6	1, 2, 3, 4, 5, 6

From HSI MAG report – HPS-NT-SY-014-CNES – 28/06/2022

LATMOS

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

ONERA
THE FRENCH AEROSPACE LAB

LPG

ACRI IN

CNRM

DGA

cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES

SHOM
L'océan en référence

SeaTech
ÉCOLE D'INGÉNIEURS

INRAE
science for people, life & earth

IGN
INSTITUT NATIONAL DE L'INFORMATION GÉOGRAPHIQUE ET FORESTIÈRE

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

Ifremer

IRD
Institut de Recherche pour le Développement
FRANCE

CESBIO

IPGP
INSTITUT DE PHYSIQUE DU GLOBE DE PARIS

TERRITOIRE ENVIRONNEMENT TELEDETECTION INFORMATION SPATIALE
tetis

LA

cea

ulco
Université
Littoral Côte d'Opale