

AI FOR ENVIRONMENT @ CNES

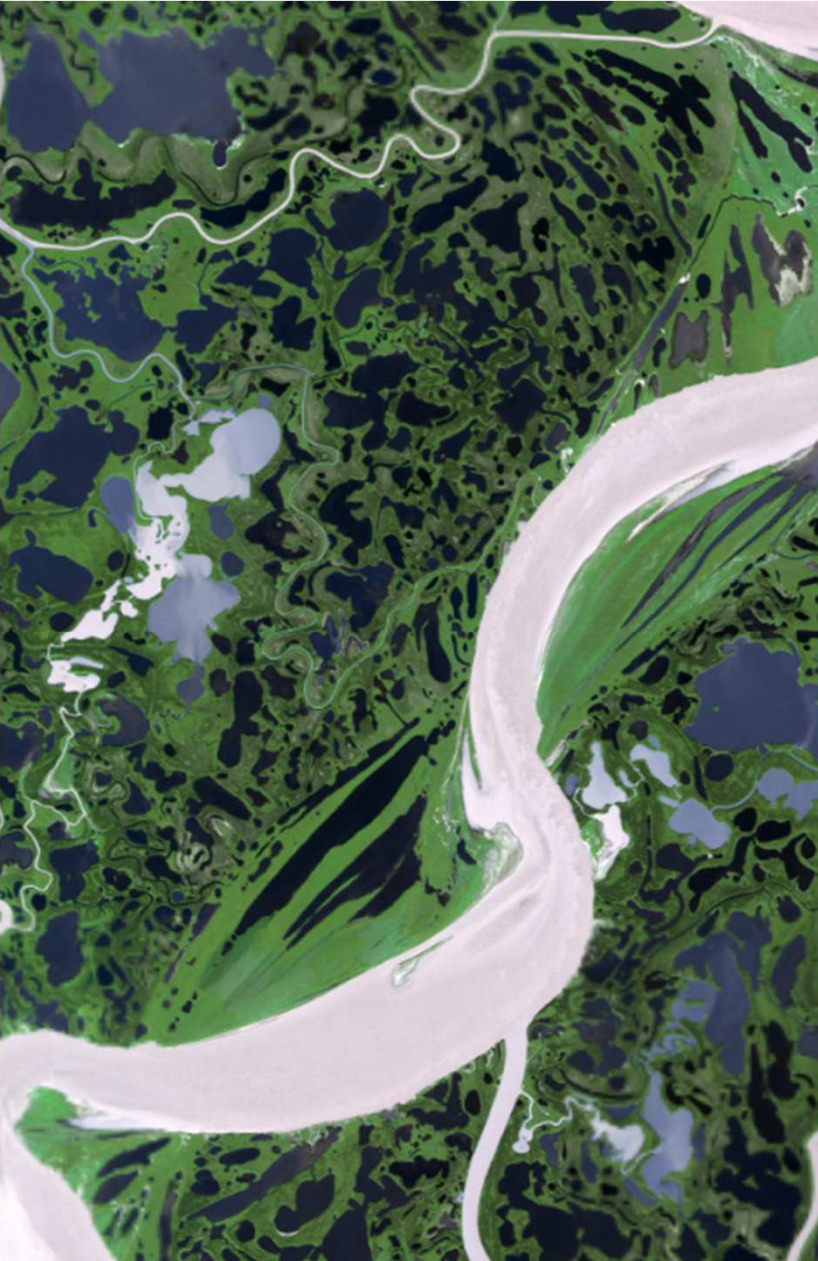
ONGOING & FUTURE CHALLENGES

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ANITI Days, Toulouse



SUMMARY

- CNES role: the French Space Agency
- AI for Environment: motivations (Data, Uses)
- General approach for integrating AI in CNES activities
- Some realizations
- Upcoming challenges for CNES, ANITI and the whole community

CNES & EARTH OBSERVATION

- The French Space **programmatic Agency**
- The French **technical expertise Center** for Space: engineering & science
- Among CNES strategic priorities:
 - Supporting & promoting scientific excellence: **Understanding of the Earth System**
 - Competitiveness of the Space ecosystem: promoting the uptake of Satellite data, fostering new applications, feeding the digital industry with **innovative data, algorithms, models**
- Among actors within the Environment theme (*geoscience - Earth observation*)
 - Data Terra - national Earth System research infrastructure
 - Toulouse & ANITI → OMP; including CNES teams in CESBIO, LEGOS, GRGS...
 - CNES technical teams: Data Campus Department
- CNES/Founder Partner of ANITI
 - Environment: CNES support to RELEO & PILearnWater Chairs; AI roadmap interactions.



Défense
& Dual



Science



Institutionnels
civils



Acteurs
privés



AI FOR ENVIRONMENT: USES

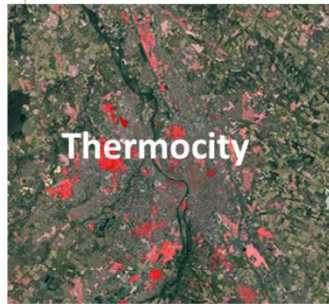
- Scientific hot topics: **water cycle, carbon cycle & greenhouse gases, vegetation cycle, geodesy), climate, weather prediction**



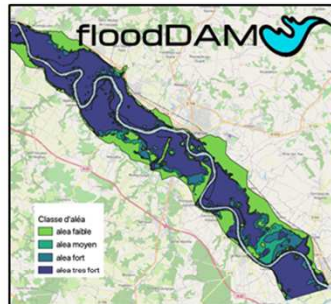
- Applications:



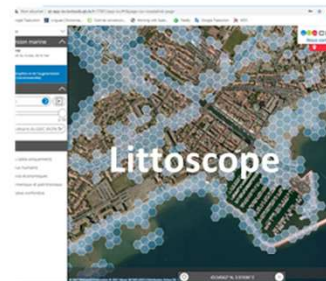
Gestion de l'eau	Aménagement du territoire	Alimentation (agriculture, élevage, pêche)	Prévention des risques et gestion des catastrophes	Météorologie	Environnement, Patrimoine, Climat et Biodiversité	Education
Santé	Renseignement et Défense	Energies et Matières premières	Développement International et aide humanitaire	Transports, BTP et Infrastructures	Finance, Assurance, Tourisme, ...	



URBAN THERMOGRAPHY



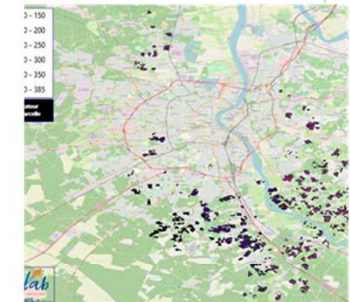
FLOODING HAZARDS



COASTAL FLOODING HAZARDS



OBJECT DETECTION

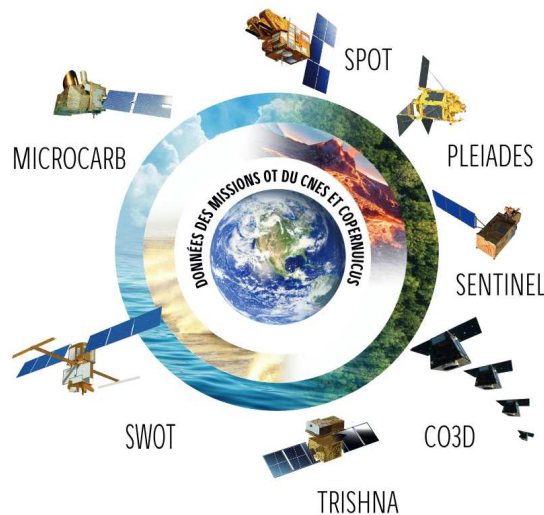


AGRICULTURAL IMPACT OF FIRES

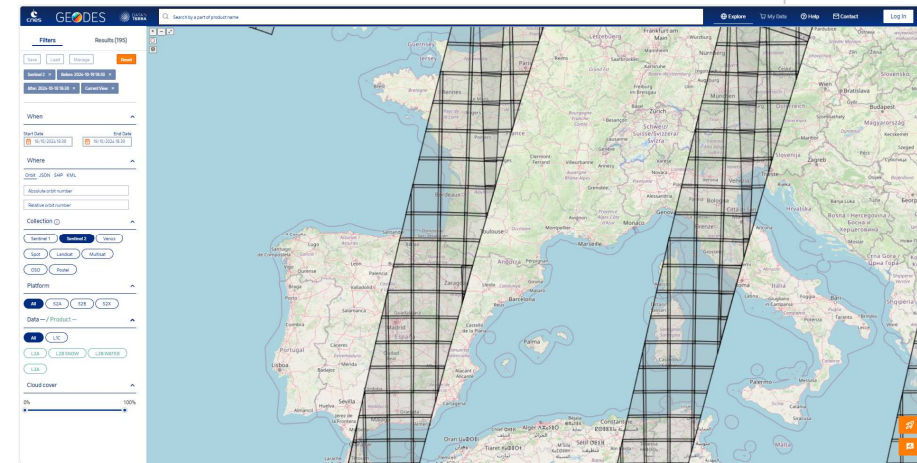


AI FOR ENVIRONMENT: SPECIFIC EO FEATURES

- Our EO Datasets
 - **Multi-modality:** altimetry, radiometry, SAR, optical imaging / multi-spectral, hyperspectral, infrared, 3D...
 - **Multi-temporal:** long-term past observations, *irregular* revisit
 - **Global coverage:** variety of landscapes, acquisition conditions(atmosphere, viewing angle...)
 - **High dimension & volumetry**

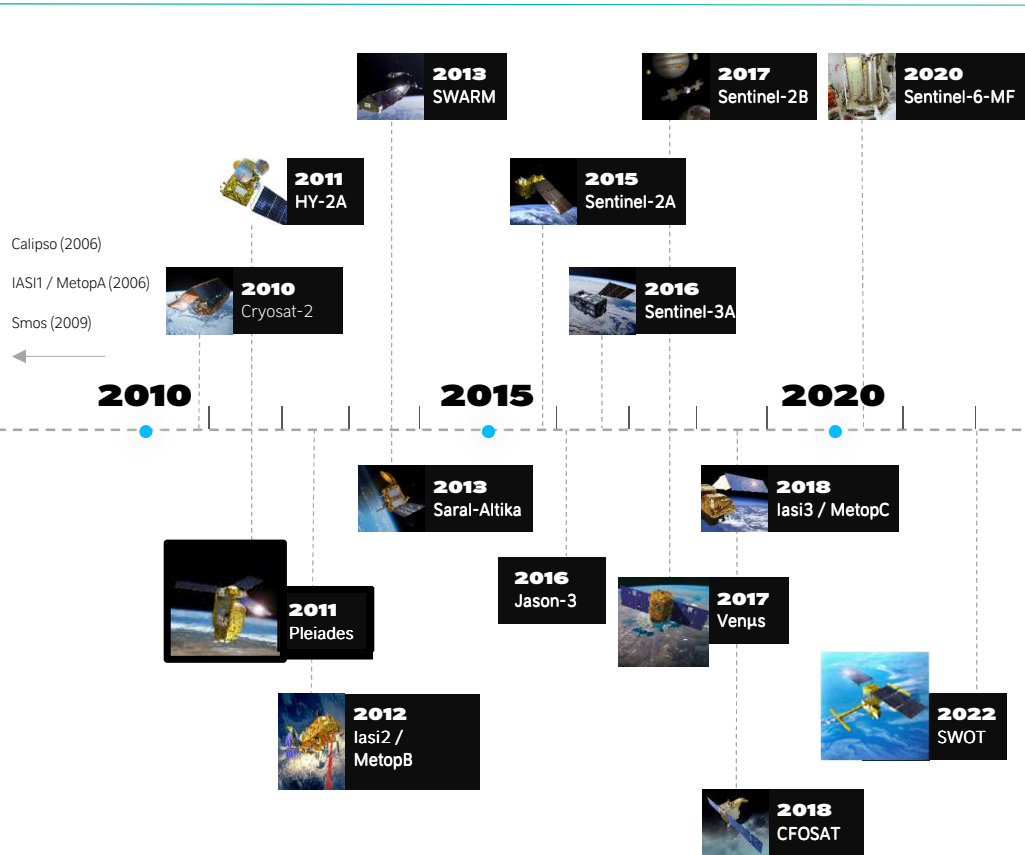


GEODES

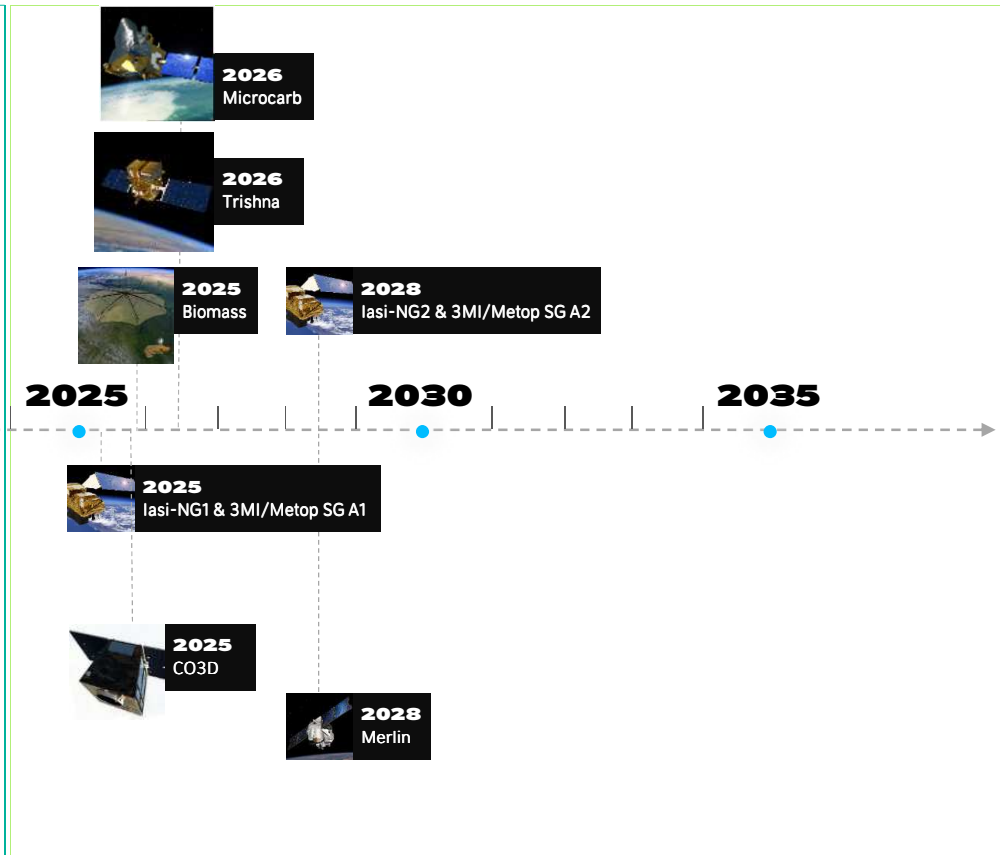


CNES EARTH OBSERVATION SATELLITES

PROGRAMMES IN OPERATION



PROGRAMMES IN DEVELOPMENT



GROUNDBREAKING EO DATA: SWOT EXAMPLE

- Surface Water Ocean Topography. Joint CNES-NASA mission
- **Swath (image) altimetry**
- Data available at <https://hydroweb.next.theia-land.fr/>

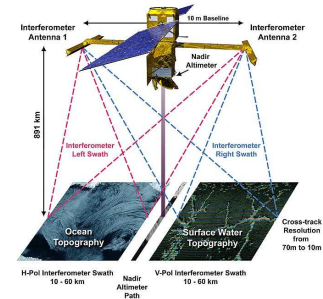
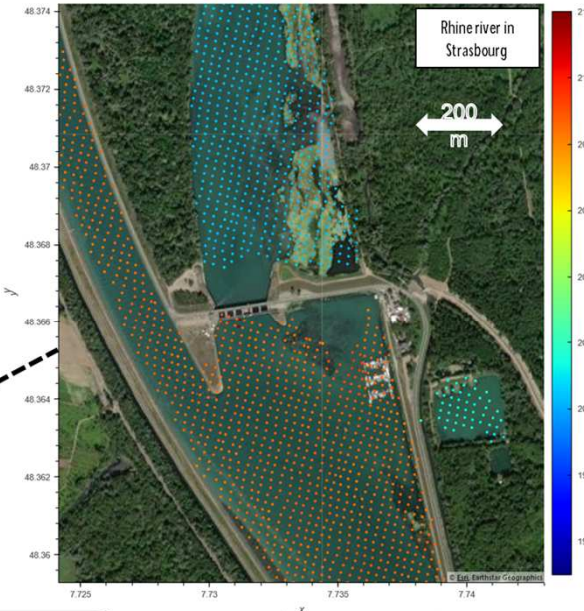
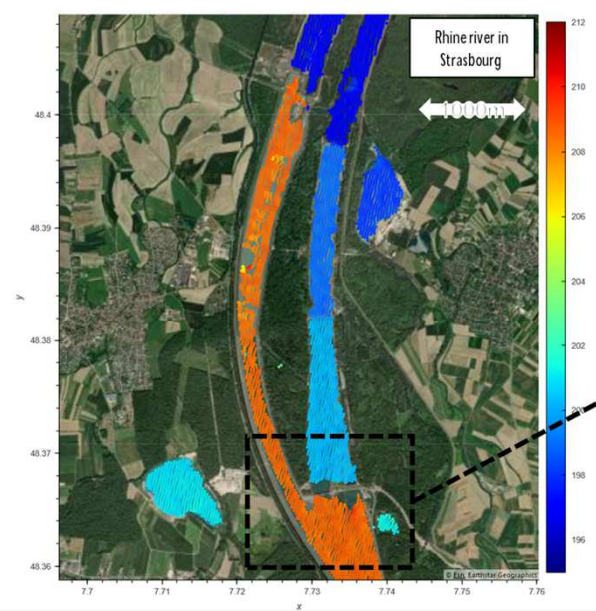


Image radar de Toulouse par le satellite SWOT



For reference, this box would be a Sentinel-3 SAR footprint in the left panel (0.3x7km)

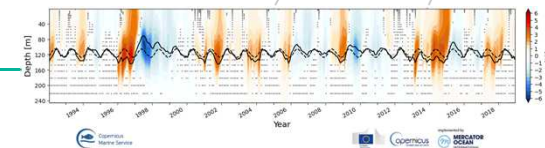
GENERAL APPROACH FOR INTEGRATING AI

- **AI already in action** for many operational tasks in EO, e.g. in satellite image processing:
 - Downstream EO Data platforms: Advanced scientific products, applications
 - Ground segments: e.g. within 3D extraction pipeline steps
- **AI as a tool - not an end**
 - Machine / Deep Learning to overcome bottlenecks in performance, automation, generalisation...
 - Applied mathematics / signal processing competences (e.g. *structured phenomena, uncertainty estimation...*) + understanding of the problem's physics & application issues
- **Field realities:** AI implementation in real-world applications often still requires a significant attention/effort
- **Data Shift & Non-observable parameters issues**



GENERAL APPROACH FOR INTEGRATING AI

- **AI already in action** for many operational tasks in EO, e.g. in satellite image processing:
- **AI as a tool - not an end**
- **Field realities:** AI implementation in real-world applications often still requires a significant attention/effort
 - The problem must be well defined! Non-ambiguity between classes...
 - Data preparation (Application-Ready Data, « AI-ready data »): heterogeneous datasets **registration...**
 - (Semi-)Supervised methods: scarcity of specific **labelled EO Datasets / labeling tools**
 - Rare objects/conditions: need for data augmentation (GenAI ?), continual learning...
 - ➔ At the start, AI model engineering performance gains are masked by data preparation issues
- **Data Shift & Non-observable parameters issues**
 - Example in oceanography (*provided by CLS, N. Verbrugge*): subsurface ocean temperature evolution
 - impact of global warming on ML training/test datasets (long-term series)
 - data fusion (in situ...); EO mostly captures surface information (height, T°) → possible compensation between (new) physical subsurface processes, weaker observability



SOME REALISATIONS

- Super-resolution
- Land cover dynamics
- Uncertainty-aware change detection
- NeRF & implicit representations
- AI4GEO: VHR data (few open labeled datasets), 3D

Nord de l'Espagne, 08.08.2020, bandes B5, B6, B7 zoomées à 5m par zoom bicubique



Nord de l'Espagne, 08.08.2020, bandes B5, B6, B7 zoomées à 5m par super-résolution



SCIENTIFIC PRODUCTS

- Example : Land cover mapping / geophysical variables
- (Semi-)supervised or unsupervised methods, regression...
- Example: Random Forests on Sentinel data; Dieback of tree species, Water bodies...

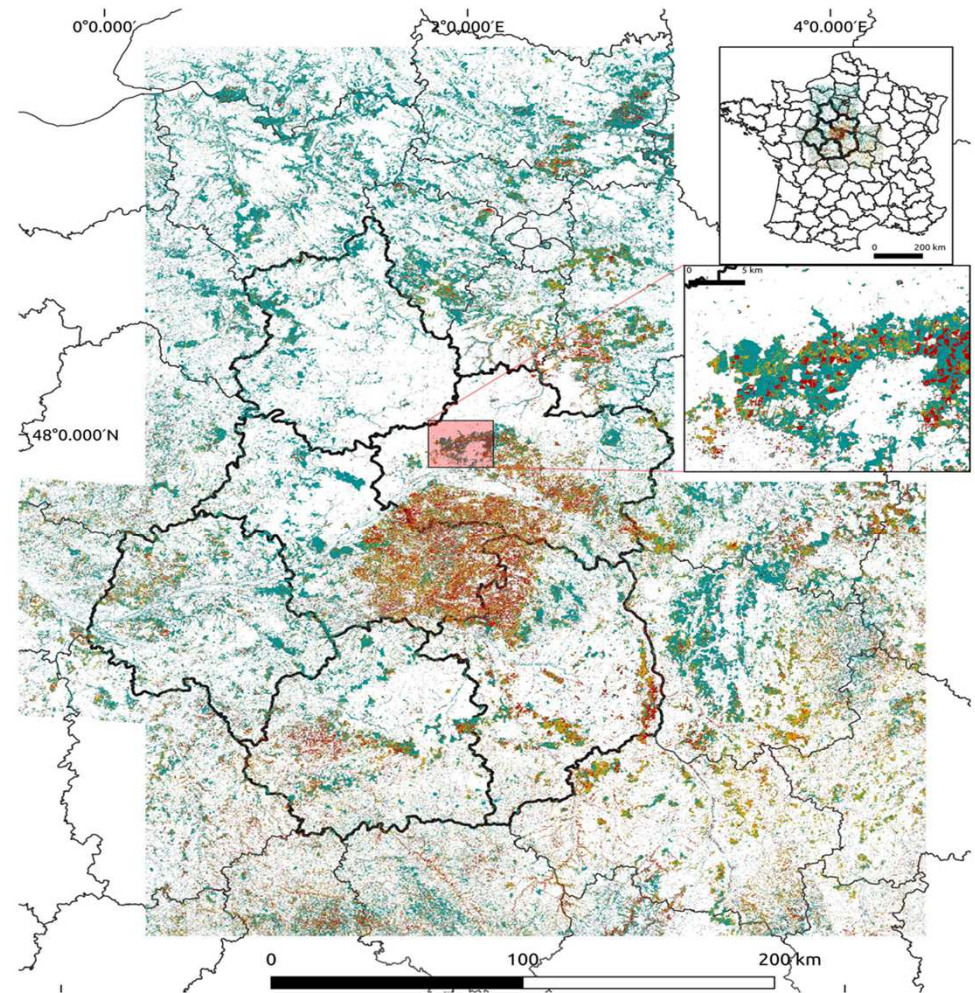
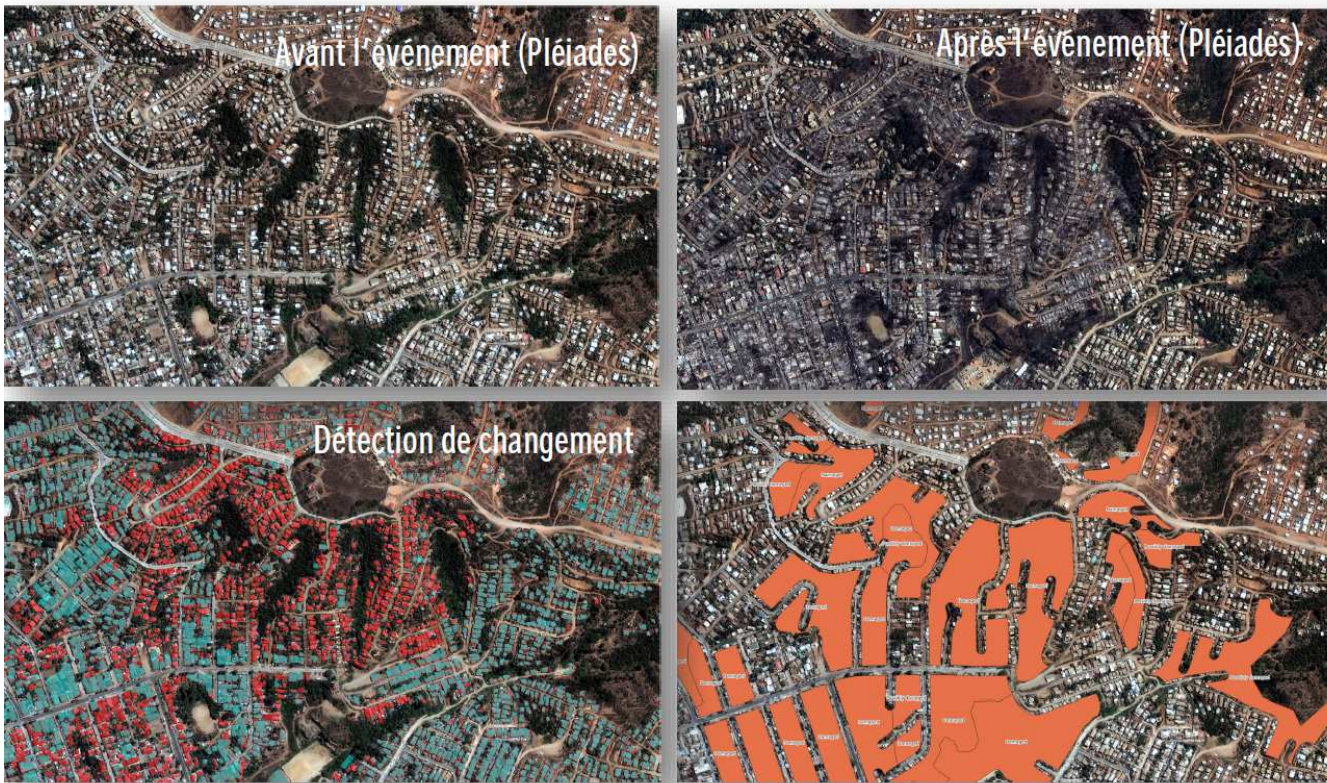


Figure 4: Final map production for the year 2022. Healthy, declining and very declining pixels are in cyan, orange and red, respectively. The deciduous tree OSO land cover map is used.

UNCERTAINTY-AWARE CHANGE DETECTION FOR HAZARD RESPONSE



Input image



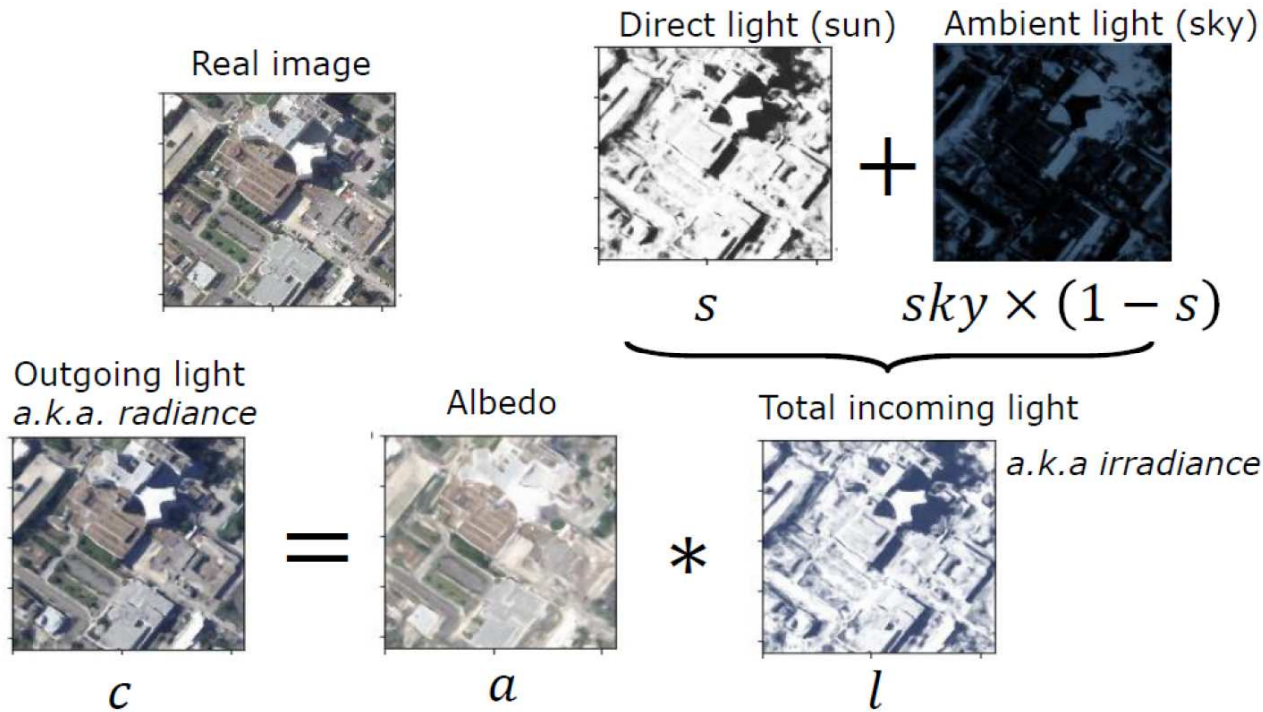
Semantic Segmentation



Uncertainty Estimation

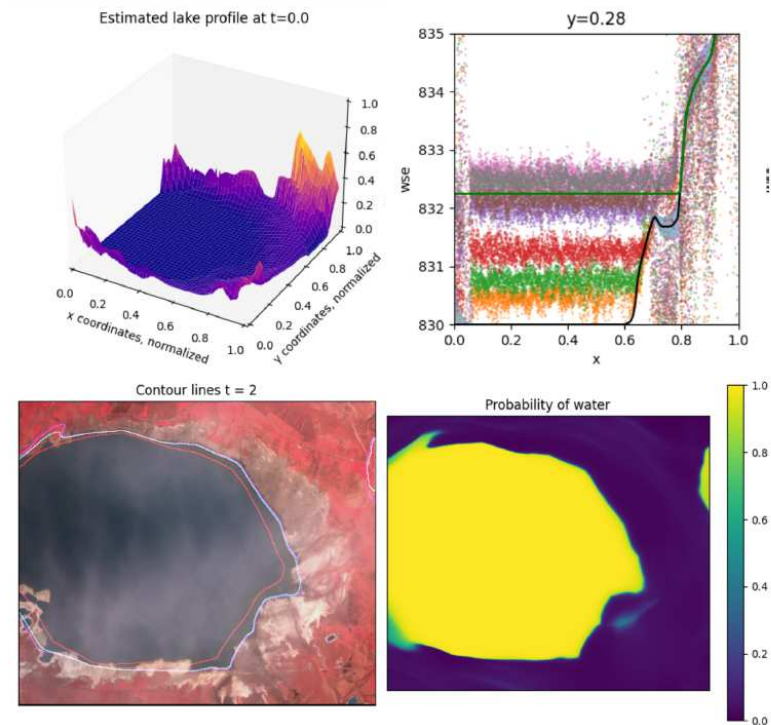
IMPLICIT NEURAL REPRESENTATIONS

- Neural Radiance Fields (NeRF) for EO 3D representation

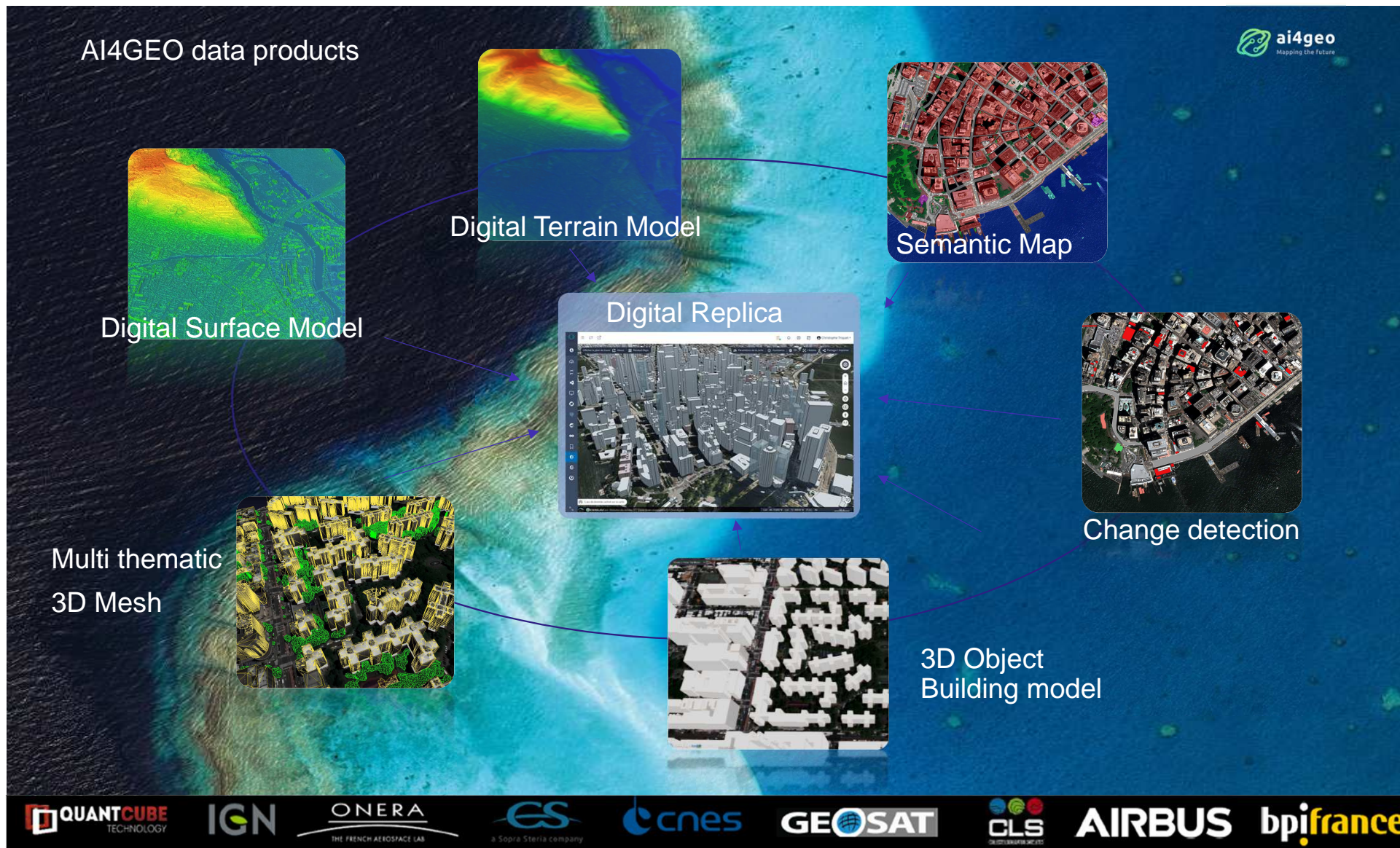


Estimation implicite de lacs – Stage CNES

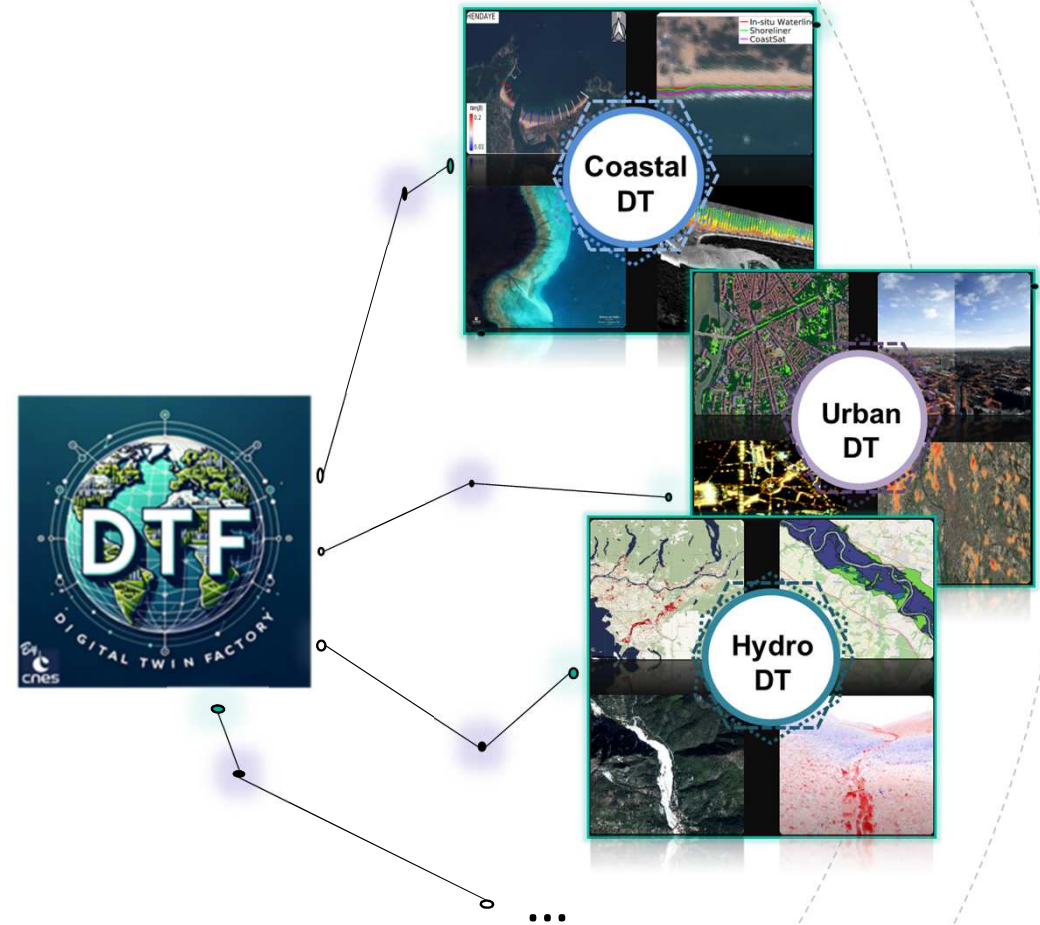
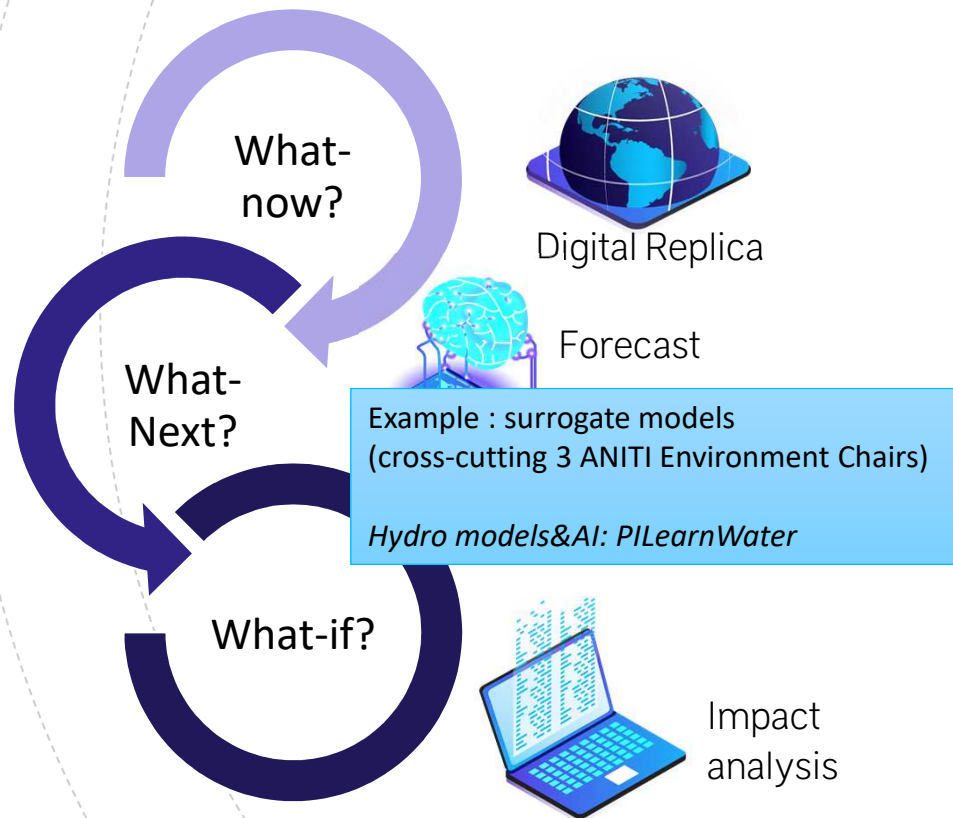
Modèle implicite des lacs dérivés du nuage de points SWOT.
 Bathymétrie 2.5D et de la **variation** de hauteur d'eau dans le temps.



DIGITAL REPLICA / AUTOMATIC PROCESSING - AI4GEO

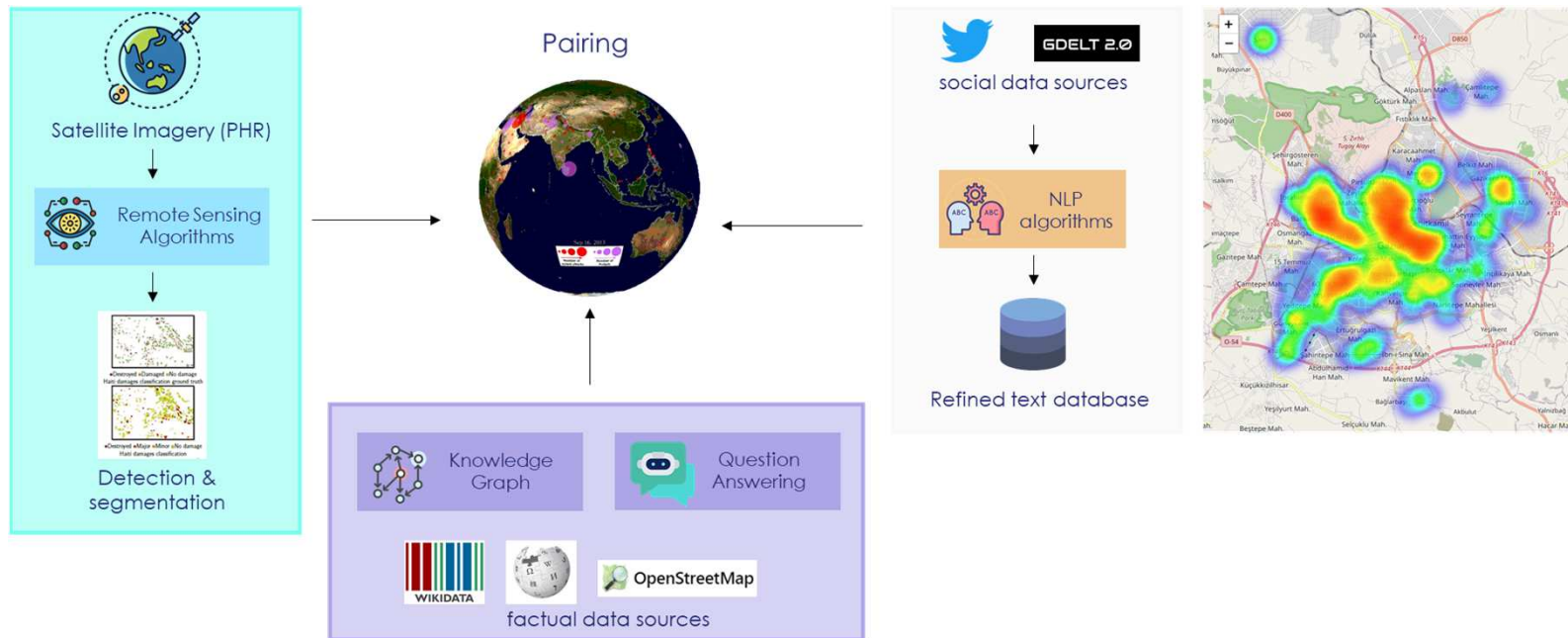


GEOSPATIAL DIGITAL TWINS



AUGMENTED IMAGERY / VISUAL QUESTION ANSWERING / LLM

- Example : R&D CNES - Thales SN



- LLM & VQA :
 - New way of user interaction with models / with EO Data
 - integration in ChatGPT, Planetary Computer... sovereignty challenges

OTHER UPCOMING SCIENTIFIC CHALLENGES IN EO

- **Integrating physics in ML models** → see *RELEO Chair* presentation
- **Frugality** :
 - in Labeled Datasets
 - in computing resources → **Edge computing in EO** / reactivity, selectivity
- Facilitating AI integration in applicative pipelines → **towards EO Foundation Models**
 - valorisation of national EO Datasets: 3D, VHR, Infrared, (swath) altimetry...
 - *attention paid to frugality in such context!*
- **Massive data fusion, data flow**
 - New methods, attention paid to quality & uncertainties
 - Data sharing: EO Data Platforms. *Tools sharing (e.g. upcoming **PLUTO**)*
- **AI Ethics** → e.g. Visual Question Answering
- **Explicability**, consistency, interpretability...
 - + *Critical systems, safety of life: many challenges in space applications in general*
→ *autonomous space operations...*
- **Need for more researchers in AI for EO!**

