

Multi-Asset New Observing Systems Flight Demonstration

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New Approaches to Observation: NASA's NOS and ESA's ϕ -Lab

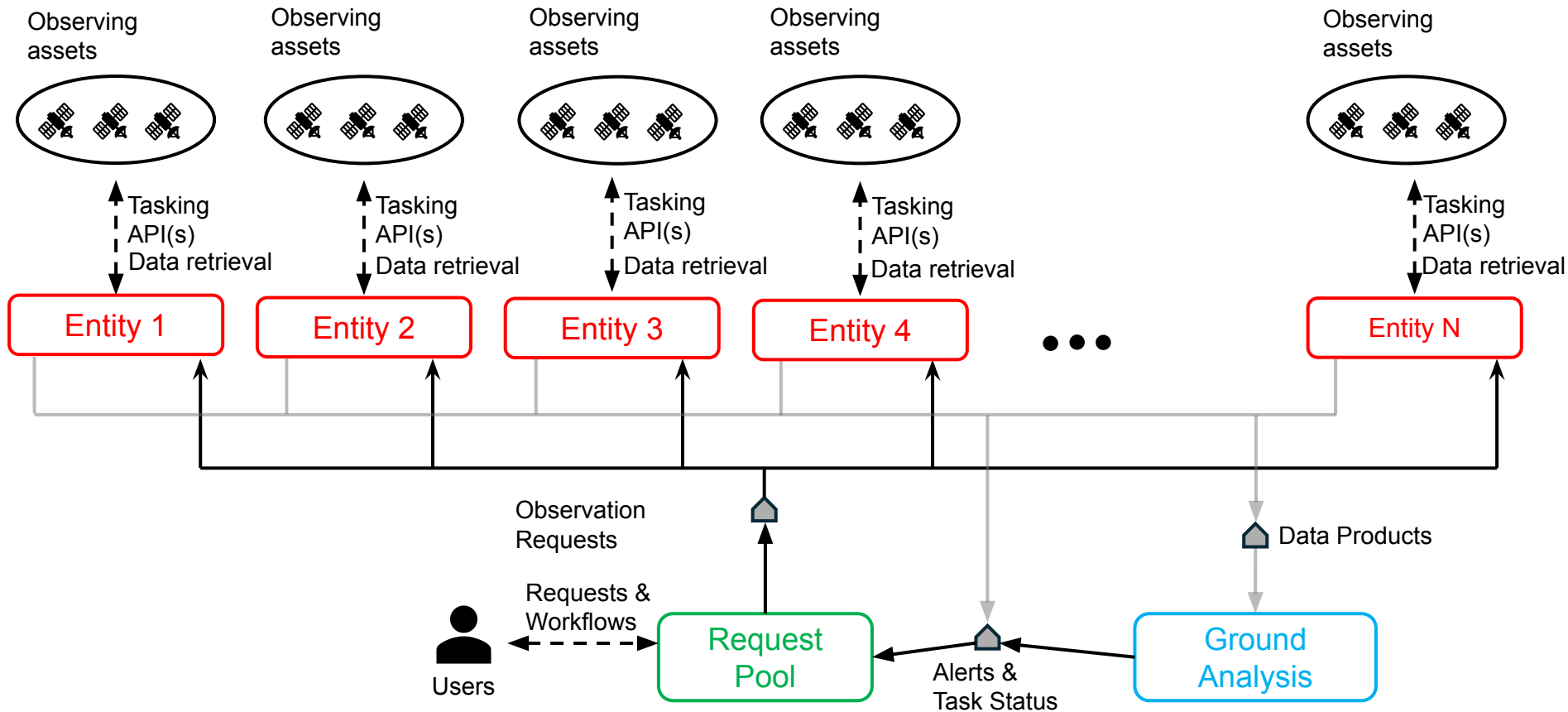
- NASA New Observing Systems (see [Lemoigne 2020])
 - Multiple collaborative sensor nodes producing measurements integrated from multiple vantage points and in multiple dimensions (spatial, spectral, temporal, radiometric)
 - Provide a dynamic and more complete picture of physical processes or natural phenomena
- ESA's ϕ -Lab (See [ESA ϕ -Lab])
 - “accelerating the future of Earth observation exploiting transformational innovation” including artificial intelligence

Recent Developments in Commercial Low Earth Orbit (LEO)

1. proliferation of Low Earth Orbiting (LEO) platforms to improve temporal and spatial coverage and reduce cost of observation services;
2. edge computing (including “AI processors”) to immediately process acquired data into knowledge;
3. improved software environments onboard spacecraft – flight of common distributions of Linux as to "spacecraft virtual machines" in which software is deployed as a container with access to well defined spacecraft interfaces and even tested in the cloud on Virtual Machines; and
4. satellite communications link to enable 24/7 low data rate on demand communications to and from the ground to enable both (a) rapid dissemination of observed events or features and (b) rapid tasking from the ground.

New Capabilities Enabled

1. onboard analysis of acquired data, leveraging available onboard edge compute;
2. onboard rapid self-response, leveraging the knowledge generated from the onboard analysis to direct/reconfigure sensors on the same platform;
3. rapid notification of the ground or other assets, leveraging the knowledge from onboard analysis and 24/7 satellite communications link;
4. rapid cross-tasking of other assets, wherein insights derived on one spacecraft are used to drive tasking of another spacecraft; and
5. multi-agent systems technology to orchestrate user defined workflows across both flight and ground and also across multiple spacecraft operated by different providers.

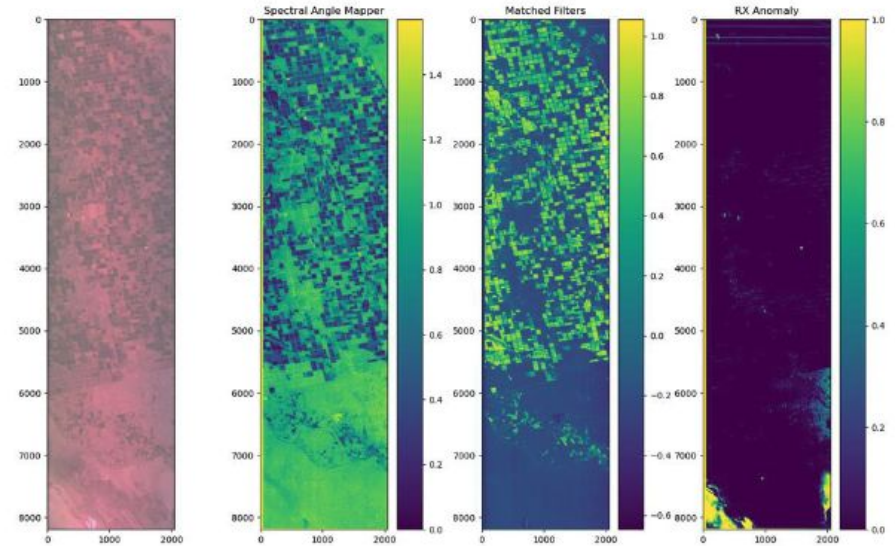


Federated Service-oriented Architecture

Onboard Analysis

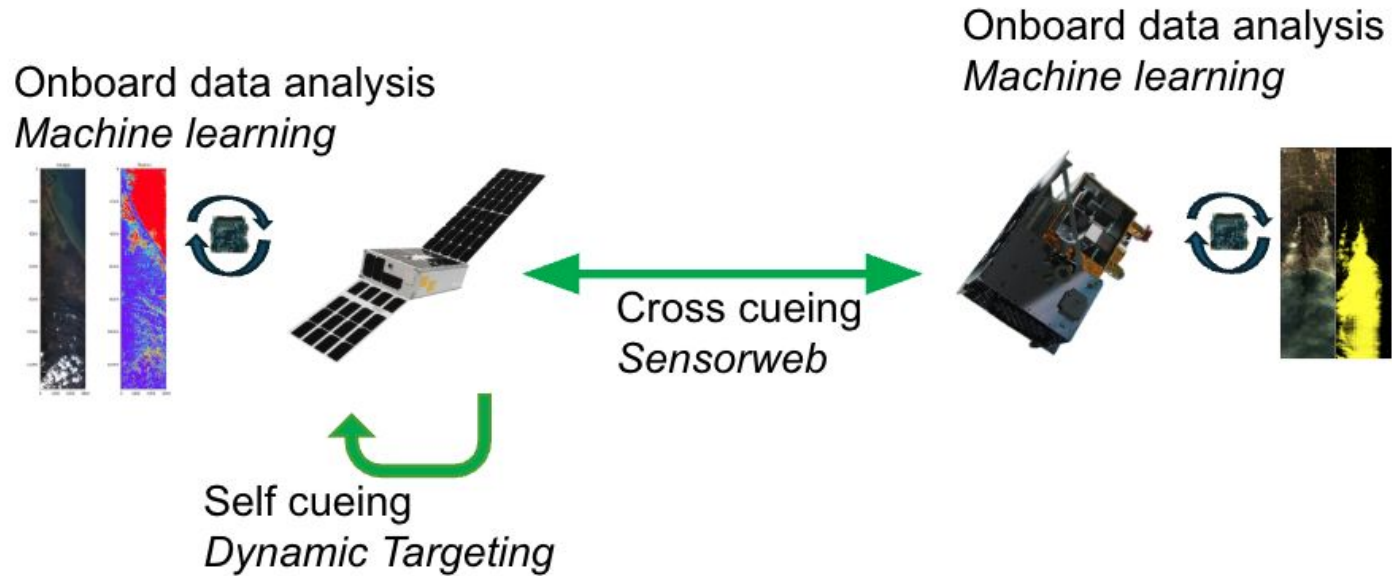
YAM-6 Vegetation Spectral Algorithms

1. **Onboard Analysis** includes deep learning and spectral analysis onboard processing algorithms for a range of science applications [4].
2. While flying off-line learned classifiers has significant (2004) heritage [5,6], dramatic improvements in edge computing mean that much more sophisticated onboard analysis is now possible [4].
3. For example, hyperspectral unmixing onboard ASE/EO-1 took hours to execute [7], now with dedicated AI/CNN hardware, CNN inference can be performed in 10s of seconds or faster.
4. Deep learning applications include [4]: cloud screening, surface water extent (flooding/hydrology), algal bloom/ocean color, and land use. Thermal analysis for detection of volcanic activity and wildfires is also an important application although without a higher wavelength (e.g. VSWIR or TIR) such analysis is susceptible to red-edge confusion [8].
5. Spectral signature detection approaches [4] include spectral angle mapper, matched filters, and spectral unmixing both using deep learning / CNN hardware and traditional means such as Sequential Maximum Angle Convex Cone (SMACC). Spectral anomaly detection schemes include Reed-Xiaoli.

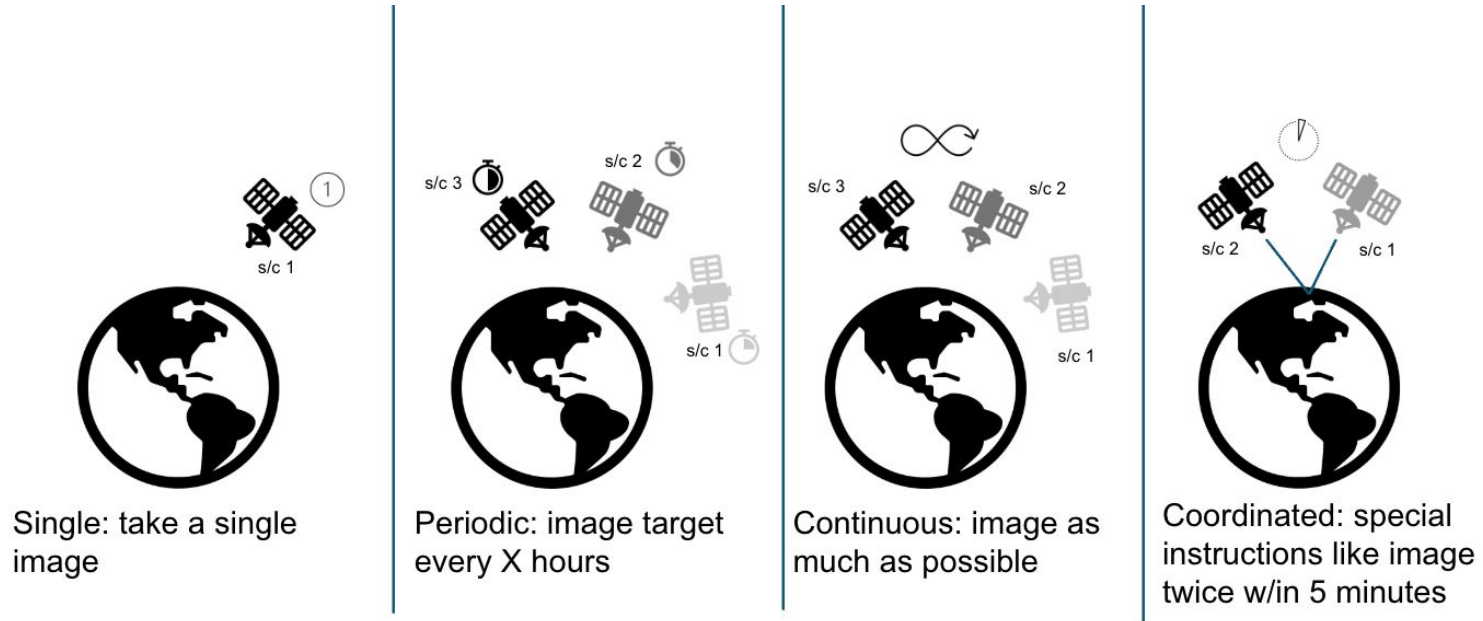


Examples of potential onboard analysis enabled by space edge computing. Shown is imagery acquired by the Loft YAM-6 spacecraft (visible mapping of imagery at left) with spectral analysis algorithms from left to right: Spectral Angle Mapper (vegetation signature), Matched Filters (vegetation signature), and Reed-Xiaoli Anomaly Products.

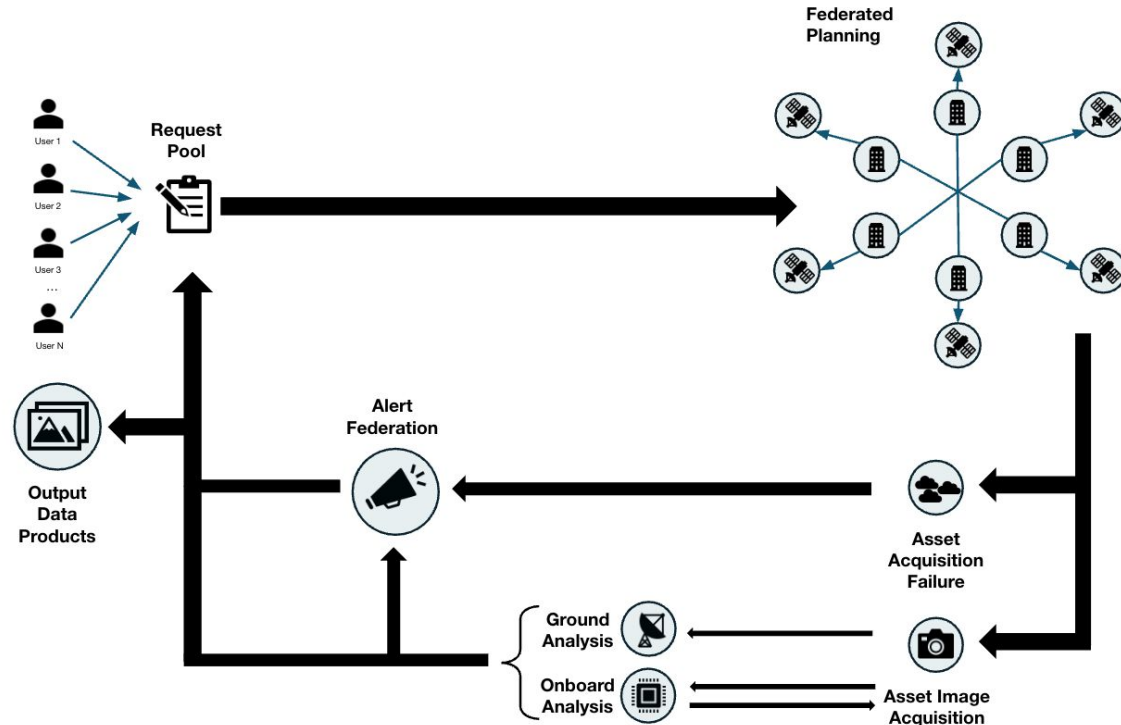
Onboard Analysis enables self and cross-cue-ing



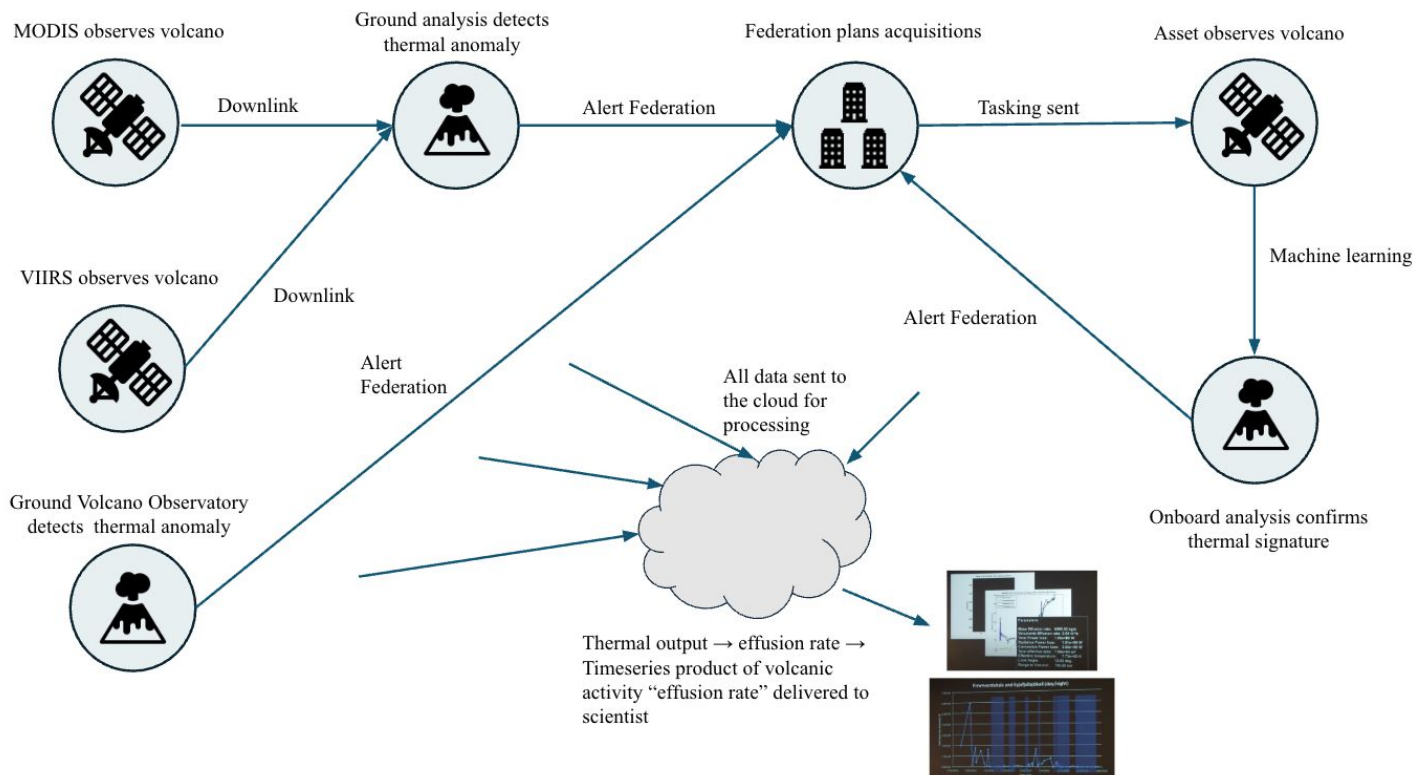
Autonomous Scheduling enables automatic fulfillment of aggregate requests:



Federated scheduling hides distributed control of assets from user

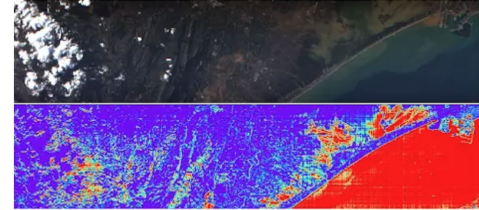


Federated, Automated Scheduling can implement workflows for users

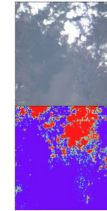


Early Steps of Execution are already complete

- Flights of JPL onboard data analysis on CogniSAT-6
 - 36+ executions of data analysis models
 - Deep CNN: (thermal, cloud, surface water extent) x 2 models
 - 90+ executions of spectral Algorithms: (cloud, surface water extent, vegetation, minerals) x 3 models + anomaly detector
- Working engineering challenges in meeting rapid 40 second timeline for image analysis and slewing.
- Anticipated flights in May 2025.

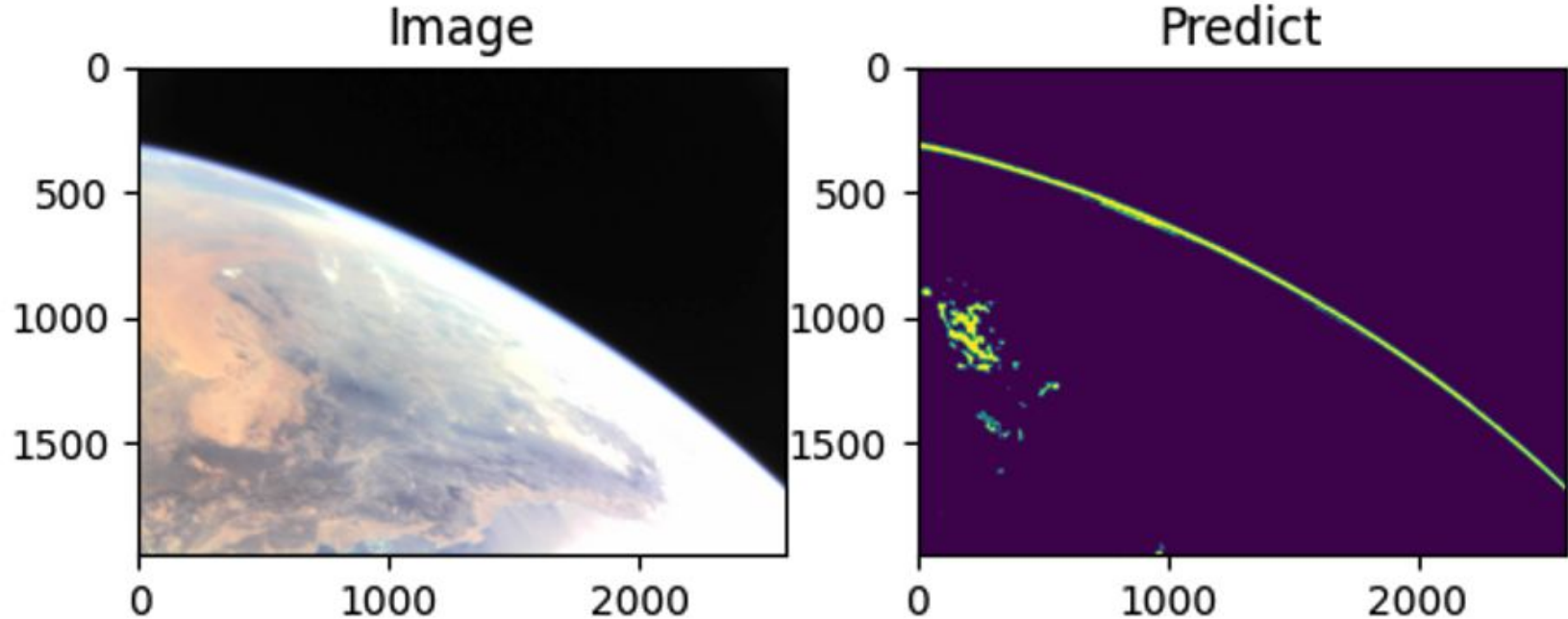


(a) Valencia, Spain, 11/02/2024. At top is a color mapping of the scene acquired by the spacecraft. At bottom is the segmentation obtained onboard for surface water extent with red indicating water and purple indicating non-water. *Image at top is from CogniSAT-6/HAMMER, 2024, Ubotica. All rights reserved.*



(b). Ulsan, South Korea, 10/27/2024. At top is a color mapping of the scene acquired by the spacecraft. At bottom is the segmentation obtained onboard for cloud detection with red indicating clouds and purple indicating non-clouds. *Image at top is from CogniSAT-6/HAMMER, 2024, Ubotica. All rights reserved.*

Onboard Spectral Analysis - Flown



February 2024 Reed-Xiaoli Anomaly Detection from ION SCV 004 (D-Orbit, Skyserve.ai)
(left) color image (Imagery D-Orbit All Rights Reserved.) (right) anomaly score where yellow = high anomaly

Related Work

- Sensorweb
 - Volcano [Chien et al. 2020 JAIS]
 - Flooding [Chien et al. 2019 JAIS]
 - Commercial Volcano + Flooding [Kangaslahti et al. 2023 JAIS]
- Cloud avoidance using lookahead visible sensor
TANSO-FTS2 GOSAT2 [Suto et al. AMT 2021]
- Onboard Analysis and ML on ASE/EO-1 2004-2017 [Chien et al. 2005]
- Early flights on CogniSAT-6 [Chien et al. 2024 IGARSS, Zillberstein et al. 2025 FSW]

Next Steps

- Flight of Dynamic Targeting for cloud avoidance on CogniSAT-6 in May 2025; Deployment of Dynamic Targeting to spacecraft with dedicated lookahead sensor; Deployment of Dynamic Targeting for Science Missions
- Deployment of onboard planning element of FAME
- Deployment of multi-agent, federated scheduling (incl. workflows)
- Extension of FAME demonstration to 50 platforms for 1+ years of operations
- Widespread deployment of multi-agent, federated scheduling for science mission(s)

Conclusions

- Proliferated LEO + Edge Compute + ISL = Opportunity
- Capabilities
 - Self-tasking, Cross-tasking
 - Federated scheduling of workflows
- In implementation for 1 year demonstration in 2026-2027



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