

# AI-DRIVEN ONBOARD SATELLITE PROCESSING: A PARADIGM SHIFT IN EARTH OBSERVATION

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**Abstract.** *The surge of Earth Observation (EO) satellites has resulted in unprecedented data volumes, frequently exceeding the downlink and processing capabilities of ground stations. Traditional workflows—capture, downlink, process—are considered inefficient for time-critical applications such as disaster response, maritime surveillance, and climate monitoring. In this context, AI-driven onboard satellite processing is explored, where artificial intelligence (AI) and GPU/AI accelerator hardware (e.g., NVIDIA Jetson, Intel Myriad) are deployed directly on satellites to enable real-time, in-orbit analytics.*

*Building on missions such as ESA's PhiSat-1 (2020, Myriad-2 VPU), PhiSat-2 (2024, Intel Movidius VPU) and Orbital Sidekick (2021, Jetson TX2), concrete demonstrations of onboard AI for cloud filtering, anomaly detection, hyperspectral leak monitoring, and object recognition are analyzed. Results have shown up to a 95% reduction in downlink data volume and millisecond-scale inference times, demonstrating that onboard computing significantly enhances satellite efficiency. The role of parallel computing architectures (GPUs, VPUs, FPGAs) is further examined, performance benchmarks are discussed, and future directions for autonomous, adaptive, and swarm-enabled satellite constellations are forecast. Findings highlight that shifting computation from ground to orbit fundamentally changes EO economics, enabling a proactive, responsive, and intelligent space infrastructure.*

**Keywords:** *satellite processing, onboard AI, GPUs, Intel Myriad, NVIDIA Jetson, parallel computing, Earth observation, remote sensing, autonomous satellites*

## 1. Introduction

EO satellites are critical for monitoring deforestation, food security, disaster relief, and climate change. Yet, they face three bottlenecks:

1. Downlink congestion – limited bandwidth cannot handle terabytes/day.
2. Latency – delays reduce value in time-sensitive crises.
3. Energy inefficiency – transmitting raw data consumes significant onboard power.

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The rise of compact accelerators (Jetson, Myriad, FPGA-based AI cores) enables a paradigm shift: processing at the edge in space. Instead of sending all data, satellites can now send insights. This short paper unifies research on onboard AI models and hardware, highlighting the synergy of deep learning + parallel computing.

## 2. AI Models for Onboard Processing

Key onboard AI applications include:

1. Image Segmentation & Classification
  - *PhiSat-1 (ESA, 2020)*: CNN for cloud filtering on Intel Myriad-2 → reduced irrelevant data by 30–40% [1].
  - *PhiSat-2 (ESA, 2023)*: Advanced Myriad VPU, handling larger datasets and adaptive learning [2].
2. Object Detection
  - *D-Orbit ION SCV Dauntless David (2022)*: NVIDIA GPUs for real-time ship detection → data downlink reduced by >90% [3].
3. Anomaly Detection
  - *Satellopic-IBM CubeSat (2021)*: AI flagged unusual vegetation dynamics, aiding agriculture monitoring [4].
4. Hyperspectral Leak Detection
  - *Orbital Sidekick (2021)*: Jetson TX2 classified methane leaks from hyperspectral data in orbit, providing instant alerts to oil & gas stakeholders [5]. For the current, operational GHOSst constellation, the primary processor is the NVIDIA Jetson AGX Xavier.

These models demonstrate how in-orbit inference can turn satellites from passive sensors into active decision-makers.

## 3. Parallel Computing and Hardware Architectures

### 3.1 GPUs (e.g., NVIDIA Jetson)

- Thousands of CUDA cores optimized for matrix multiplications.
- Used in CubeSats for real-time detection, offering 10–20× faster inference than CPUs.

### 3.2 VPUs (Intel Movidius Myriad)

- Ultra-low-power, tailored for space constraints.
- Myriad-2 ran PhiSat-1’s AI model with <2W power.
- Myriad-X offers 10× higher TOPS/Watt efficiency, making it attractive for CubeSats.

### 3.3 FPGAs and ASICs

- Provide reconfigurable AI inference, robust against radiation.
- Increasing adoption in DARPA Blackjack and ESA OPS-SAT missions.

Benefits of Parallel Architectures

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- Low latency inference (ms–s).
- Adaptive operations: onboard AI can re-task sensors.
- Bandwidth optimization: up to 95% less downlink volume.

#### 4. Case Studies and Achieved Results

- PhiSat-1 (2020, ESA): Cloud masking CNN, reduced useless data by ~30%.
- PhiSat-2 (2024, ESA): Extended AI applications (scene classification, adaptive onboard learning).
- D-Orbit ION (2022): Real-time maritime detection → 90%+ data reduction.
- Satellogic–IBM (2021): Agricultural anomaly detection with edge AI.
- Orbital Sidekick (2021): Hyperspectral methane monitoring with Jetson AGX Xavier.

These missions validate that onboard AI is no longer experimental—it is operational.

#### 5. Future Prospects

1. Autonomous Constellations – intelligent swarms capable of collaborative sensing.
2. Adaptive AI Models – on-orbit retraining to adapt to new environments.
3. Fusion Processing – SAR + hyperspectral + optical onboard integration.
4. Neuromorphic & Quantum AI chips in orbit – ultra-low-power, next-generation computing.
5. Integration with Ground AI – hybrid cloud-space ecosystems for global decision pipelines.

#### 6. Conclusion

AI-driven onboard satellite processing marks a paradigm shift in EO. With GPUs (Jetson), VPUs (Myriad), and future neuromorphic chips, satellites are becoming autonomous analysts rather than passive imagers. Demonstrations from PhiSat-1/2, D-Orbit ION, and Orbital Sidekick prove reductions in latency, bandwidth, and cost, while boosting responsiveness. The trajectory is clear: in the coming decade, all EO missions will embed AI at the edge, creating real-time, adaptive, and intelligent monitoring systems for Earth’s most pressing challenges.

#### References

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