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TAKING THE PULSE OF OUR PLANET FROM SPACE

EUMETSAT ECMWF EUSPA

Requirements and design considerations for edge applications on EO missions

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Presentation Outline

CRAFT PROSPECT

- Why Deploy AI at the Edge for EO Missions?
- Challenges in Deploying AI at the Edge
- **Case Study: Wildfire Response**
- Future Work

Why Deploy AI at the Edge for EO Missions?

Problem	Benefit of AI at the Edge
Large data volumes leading to bottleneck in downlink	**Data product sizes can be reduced** to alleviate bottleneck; **high-value data can be identified on-board and prioritised** in downlink queue
Large data volumes obfuscating high-value data	**Data products can be tagged with rich content** such as features, value, status and changes, **enabling faster lookup** on ground or separate downlink channels
Raw data must be pre-processed on ground before dissemination to users	**Pre-processing can be performed on-board** while waiting for ground station pass, **eliminating equivalent latencies** on ground
Operational responses to features of interest in payload data are very high latency (space-ground-space)	**On-board information extraction enables near-real-time decision making** and responsive tasking, **closing operational feedback loop** on-board
Sensor degradation with time	**Anomaly detection can identify defects** from nominal conditions and trigger **automated calibration, validation and adaptive optics**

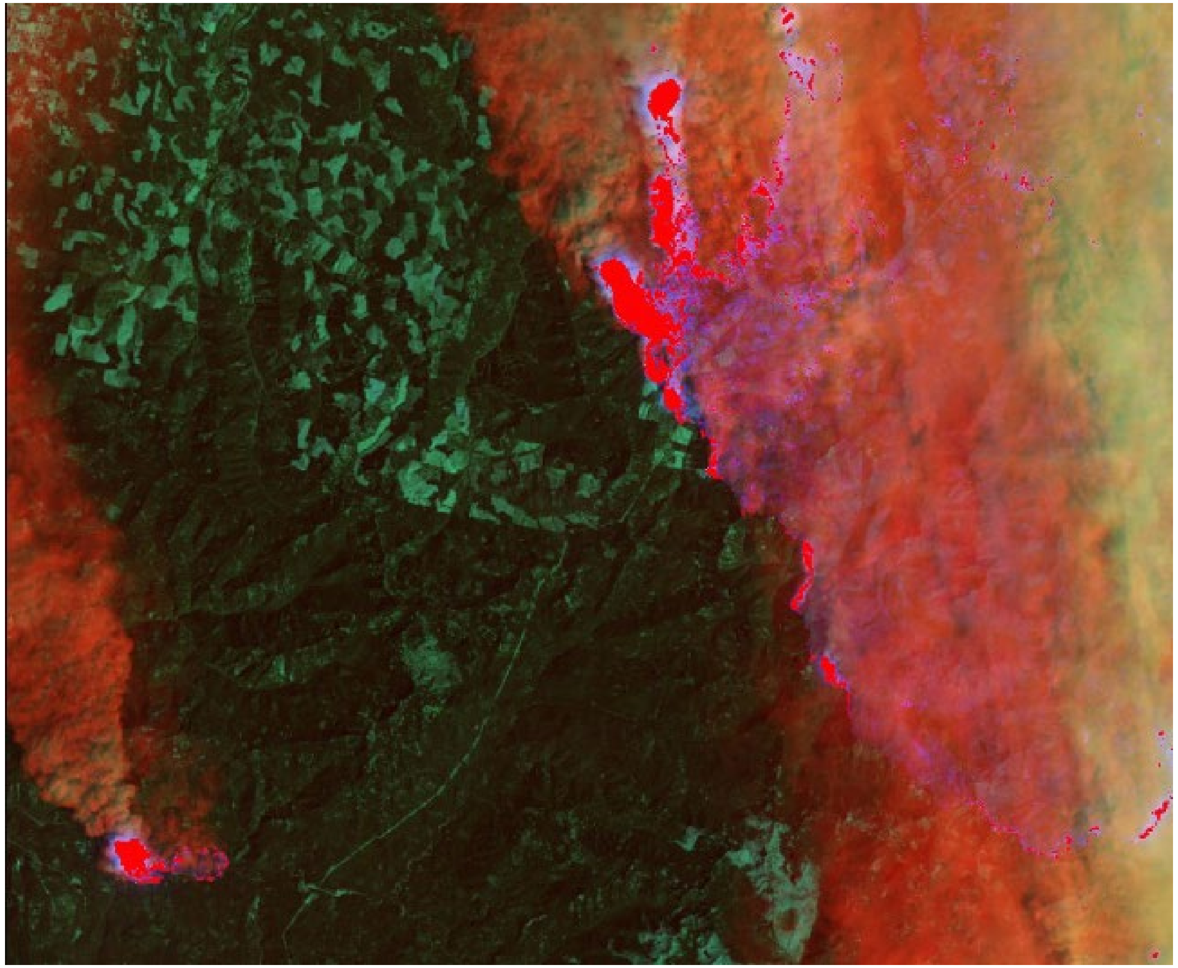
Challenges in Deploying AI at the Edge

Challenge	Solution
Fault-tolerance of AI, especially in mission-critical applications	Hardware and/or software redundancy, FDIR
Balancing latency, accuracy and power requirements	Optimise models for embedded processing using available tools
Trust that outputs and decisions are accurate and truthful, will not harm life or mission assets	Assurance during development and testing, verification in real-time (e.g. autonomy supervisor)
Risk of data loss when autonomously processing and prioritising data	Focus on lossless techniques, e.g. data prioritisation, compression. Minimise risk of loss through software assurance

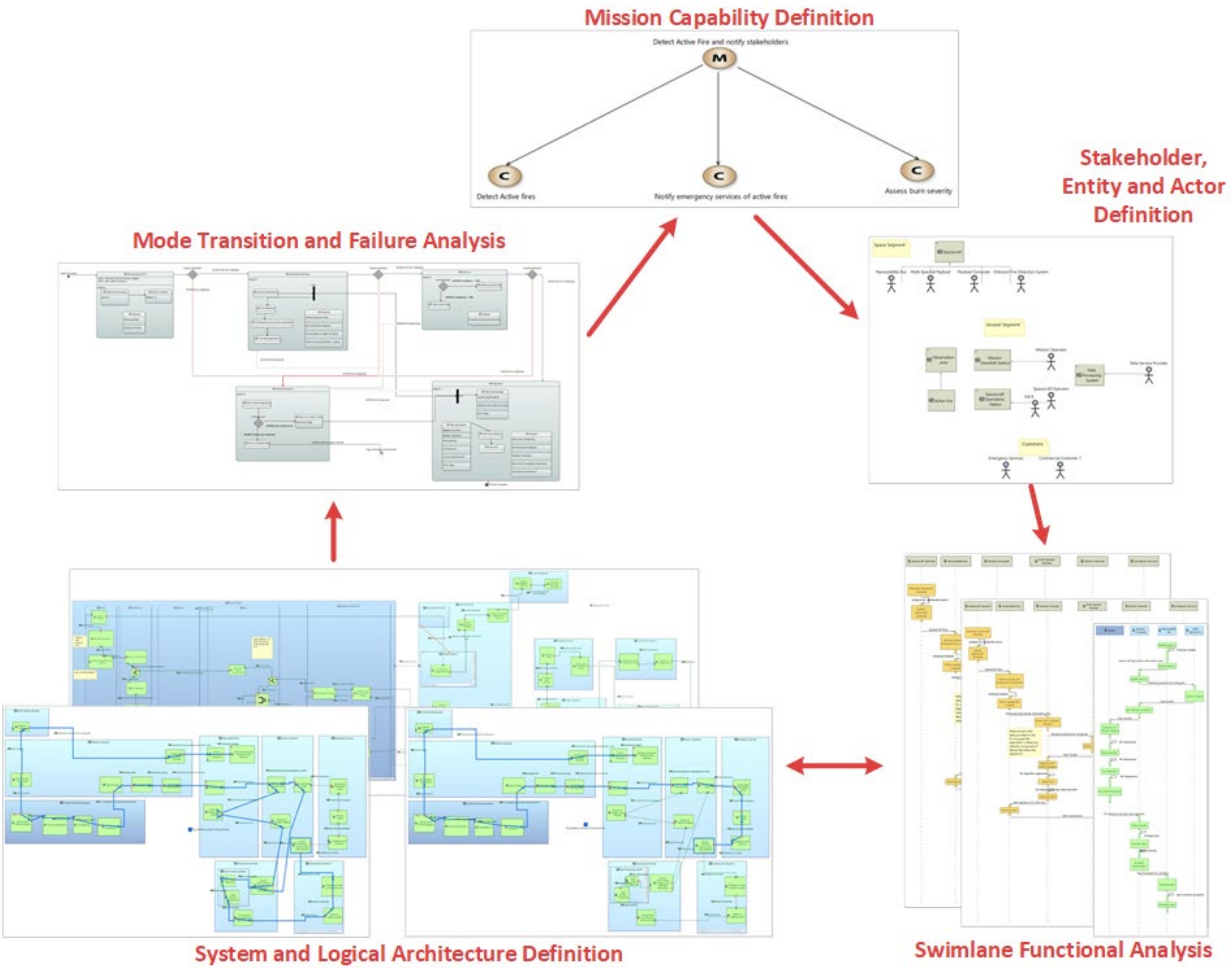
Case Study: Wildfire Response

Case Study Outline

- MBSE for System Design
- System Requirements
- Defining AI Component Requirements
- Assurance
- Processing Results
- Mission Results



Model Based Systems Engineering for System Design



- Critical to analyse functional behaviour and architecture for a successful mission
- Multiple behavioural chains associated with each mission segment are capable of being visualised, highlighting the recurring system components
- Traceability, iteration and multiple viewpoints are key benefits to ensure no failure modes or requirements are missed and to communicate requirements to multiple stakeholders and engineering disciplines

System Requirements

Requirement	Rationale
The Emergency Response Service shall determine the location of a visible active fire within 200 m of its true location.	NASA FIRMS currently has an accuracy of ~200 m. The response can be augmented with ground units or aircraft to localise the fire more accurately.
The Emergency Response Service shall inform emergency services of a visible active fire with 3 hours of it starting.	NASA FIRMS can provide active fire alerts within 3 hours of *in-orbit observation*, not considering when the fire *started.* A 3-hour start-to-response latency is a significant improvement in most cases.
The Emergency Response Service shall positively identify 95% of all visible active fires acquired by the satellite instrument within the area of interest.	Failing to notify of a visible active fire can lead to loss of life, assets and infrastructure and so must be minimised.
The Emergency Response Service shall falsely indicate visible active fires in the area of interest as less than 52 instances per month.	Notification of a false active fire can lead to wasted time and resources and so must be minimised. An absolute value is chosen based on FIRMS false positives over 2020.

Defining AI Component Requirements

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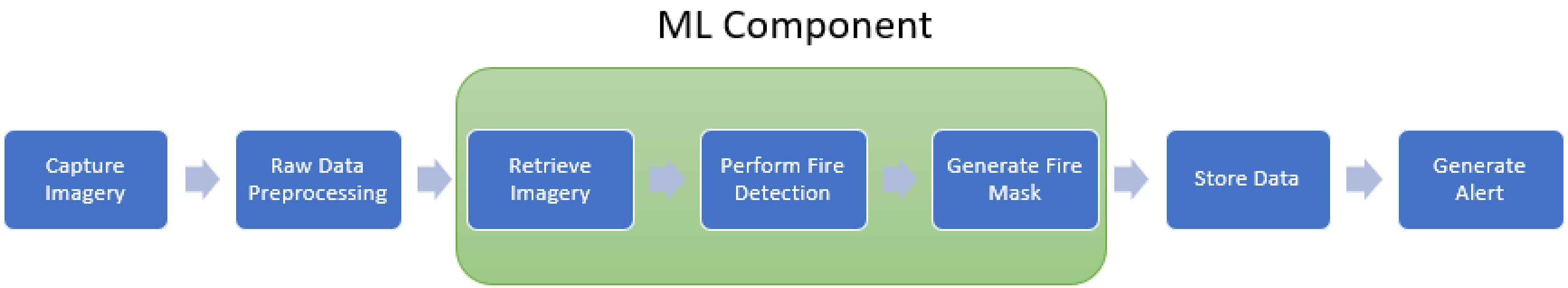
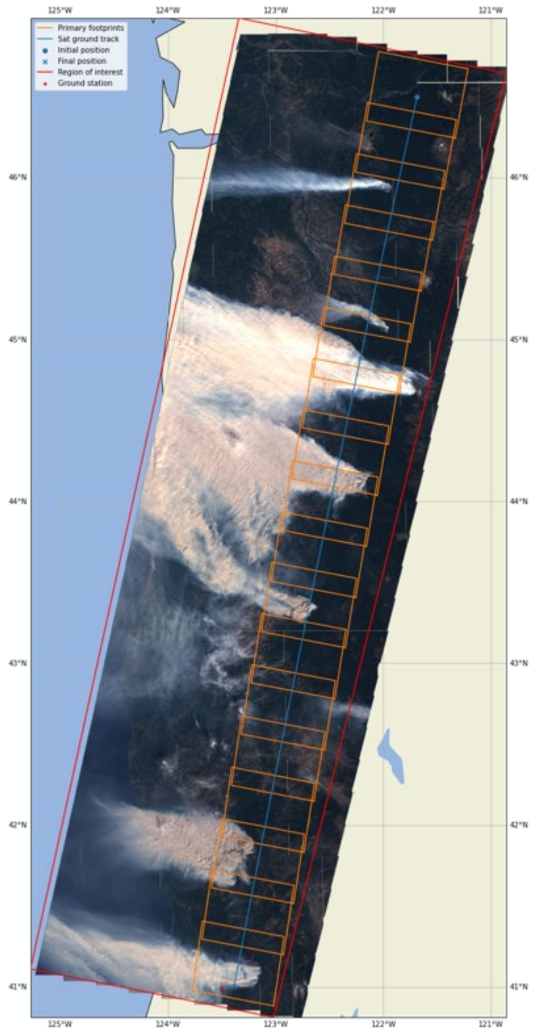
System Interfaces



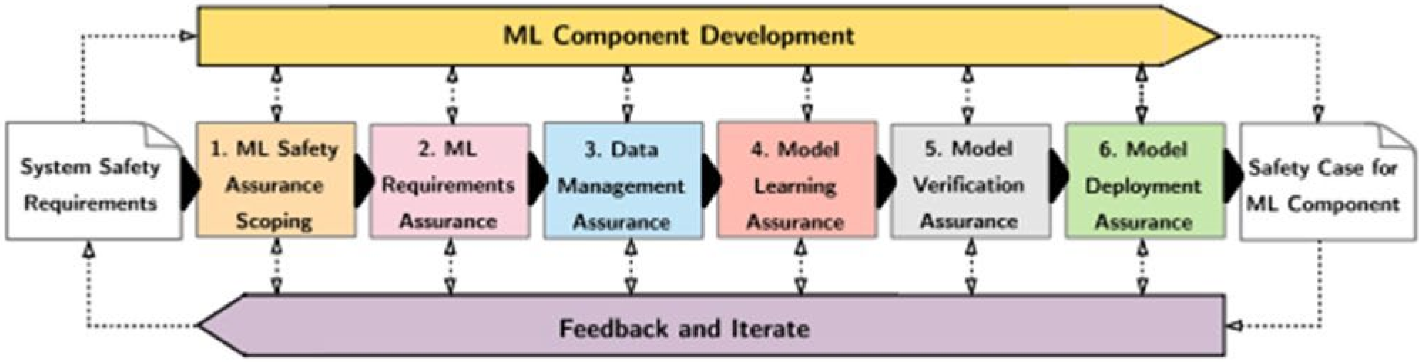
Operational Environment

- A CubeSat constellation in sun-synchronous low-Earth orbit.
- Sensor data is captured by a multispectral instrument (MSI) with properties equivalent to Landsat-8 OLI.
- The MSI generates a frame every 5 seconds, ensuring contiguous captures.
- The region of interest is Oregon, USA.



AMLAS: Assurance of Machine Learning for use in Autonomous Systems

- Assurance artefacts are generated throughout component development
- Datasets are evaluated against requirements
- Model is evaluated against requirements during testing, verification and deployment (SIL simulation testing)
- Stages of development are reiterated where AI model accuracy and robustness may be improved
- Artefacts such as datasets and requirements are independently validated



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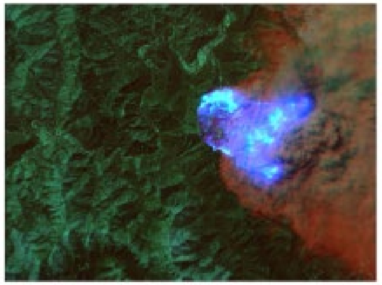
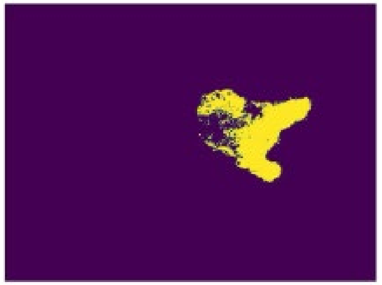
Processing Results

Data Products:

- Level-1: Full, unbiased MS data to enable ground-based V&V and re-training, and secondary ground applications
- Level-3: Georeferenced pixel fire masks extracted from L1 products enabling precise geolocation of fires to 30m
- Level-4: Extremely lightweight wildfire text alerts, supported by low-resolution annotated thumbnails



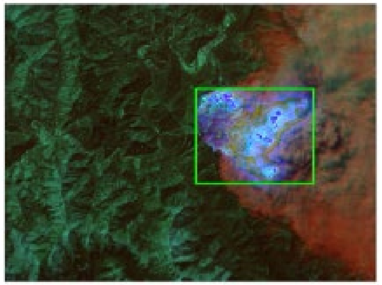
a) Level-1 false colour image.



b) Level-3 fire mask.

```
FIRES DETECTED
LARGE fire:
    Time 20200908-065847.184
    Location (123.4094°S, 41.8675°E)
    Area 40.08 sq km
```

c) Level-4 alert message.

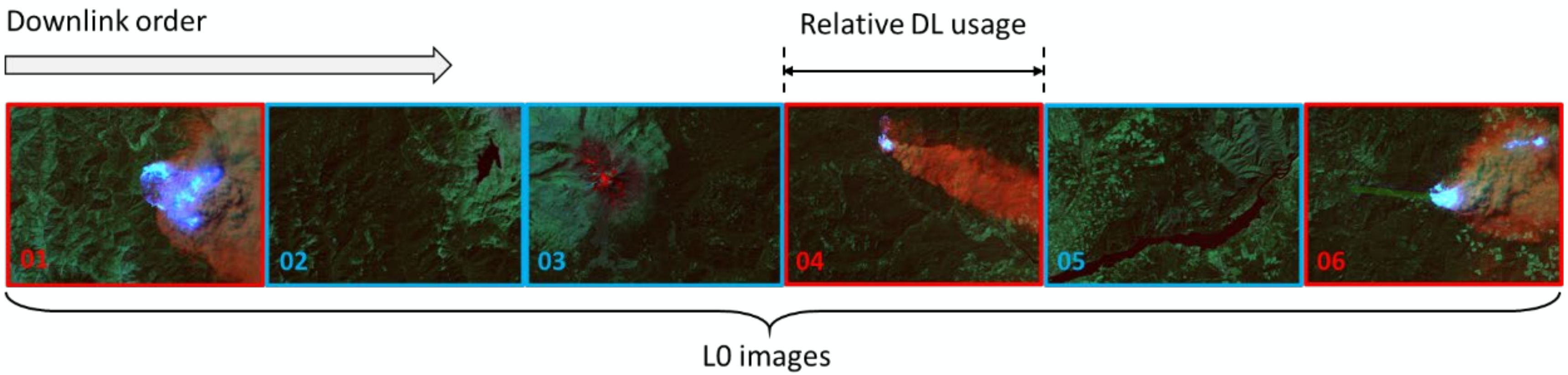


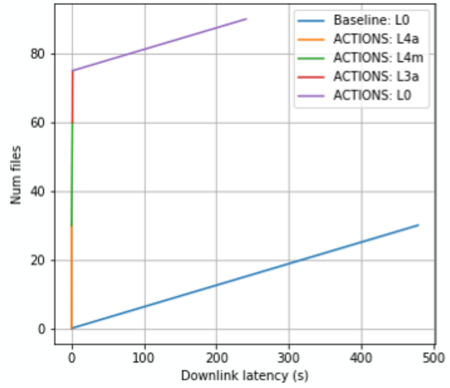
d) Level-4 verification thumbnail.

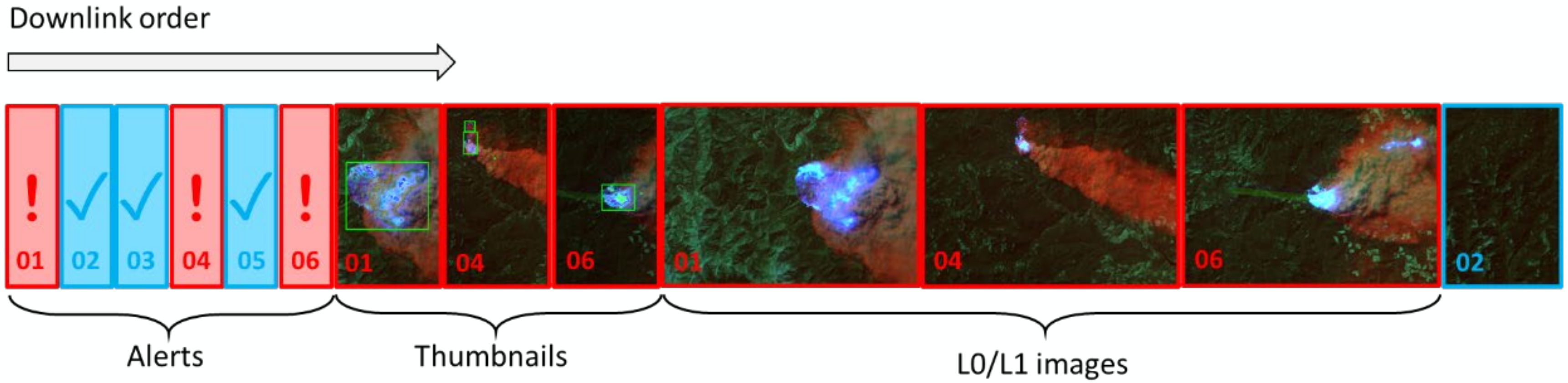
Metric	Value	Notes
Model accuracy – MeanIoU	93%	Good result for pixel-based inference
Model accuracy – true positive	100%	Very good result against labelled test dataset
Model accuracy – true negative	99.2%	
Model throughput (FPS)	0.3	Sufficient to meet real-time processing requirements
Model throughput (QPS)	413.5	
Model throughput (PPS)	952,680	
Fire masking component latency	3.57 s	
Information latency	4.84 s	

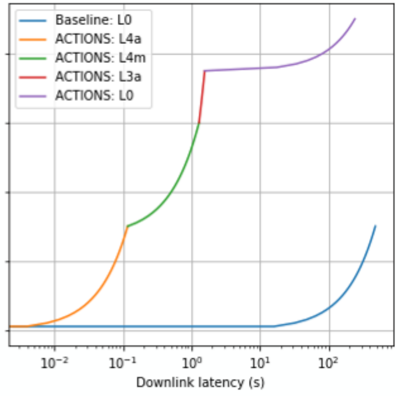
Mission Results

Intelligent Queuing of Payload Data





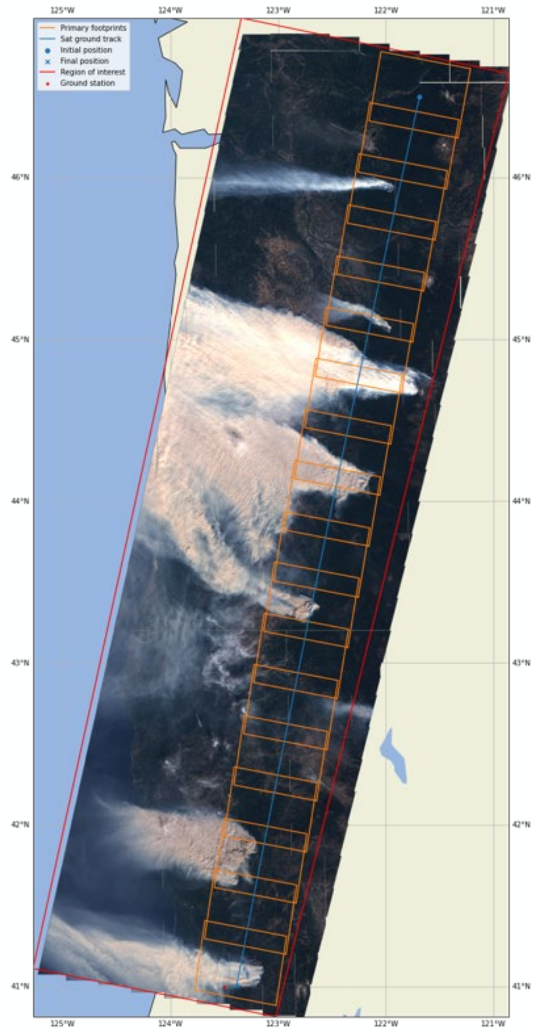




Mission Results

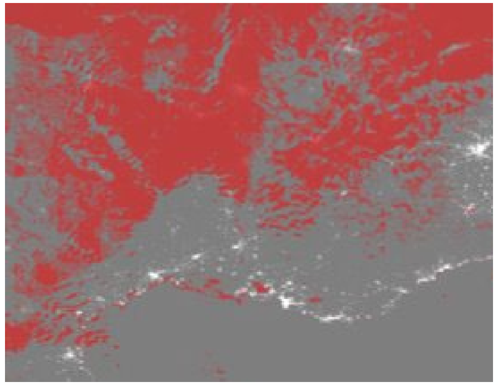
Requirements Compliance

Requirement	Compliant	Evidence
The Emergency Response Service shall determine the location of a visible active fire within 200 m of its true location.	Yes	30 m resolution available in fire mask, geolocation accuracy sub-50 m for test
The Emergency Response Service shall inform emergency services of a visible active fire with 3 hours of it starting	Yes	Requirement met with 188 satellites and single ground station, using intelligent downlink queue. Smaller constellation size possible if aiming to match FIRMS latency only (12 hours).
The Emergency Response Service shall positively identify 95% of all visible active fires acquired by the satellite instrument within the area of interest	Yes	False negatives calculated at 0.76%, yielding 98.24% true positives
The Emergency Response Service shall falsely indicate visible active fires in the area of interest as less than 52 instances per month	Partial	Depending on threshold in validation approach, false positives in simulation tests are either 53 (moderate threshold) or zero (low threshold)



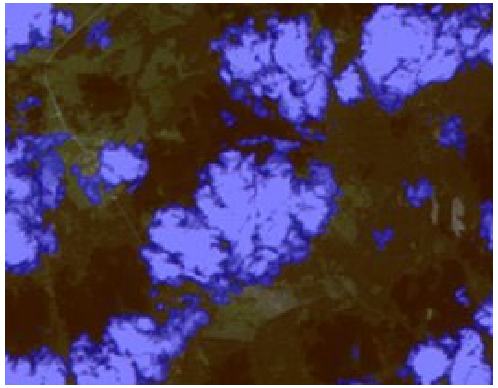
Future Work

Working with partners in industry and academia to deliver **responsive** and **trusted** operations which will advance a new generation of commercial applications and scientific discovery to benefit our **Living Planet**.



Development Work

- InCubed: On-board data processing (with SSTL and University of Surrey)
- ARTES: Mission-critical autonomy (for satcom missions)



In-Orbit Demonstrations:

- ROKS: Night-time cloud detection (CPL, 2023)
- KAUST-SAT: Day-time cloud masking (Unibap/Simera Sense, 2023)
- InCubed: Planned for 2024-2025

Thank you

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