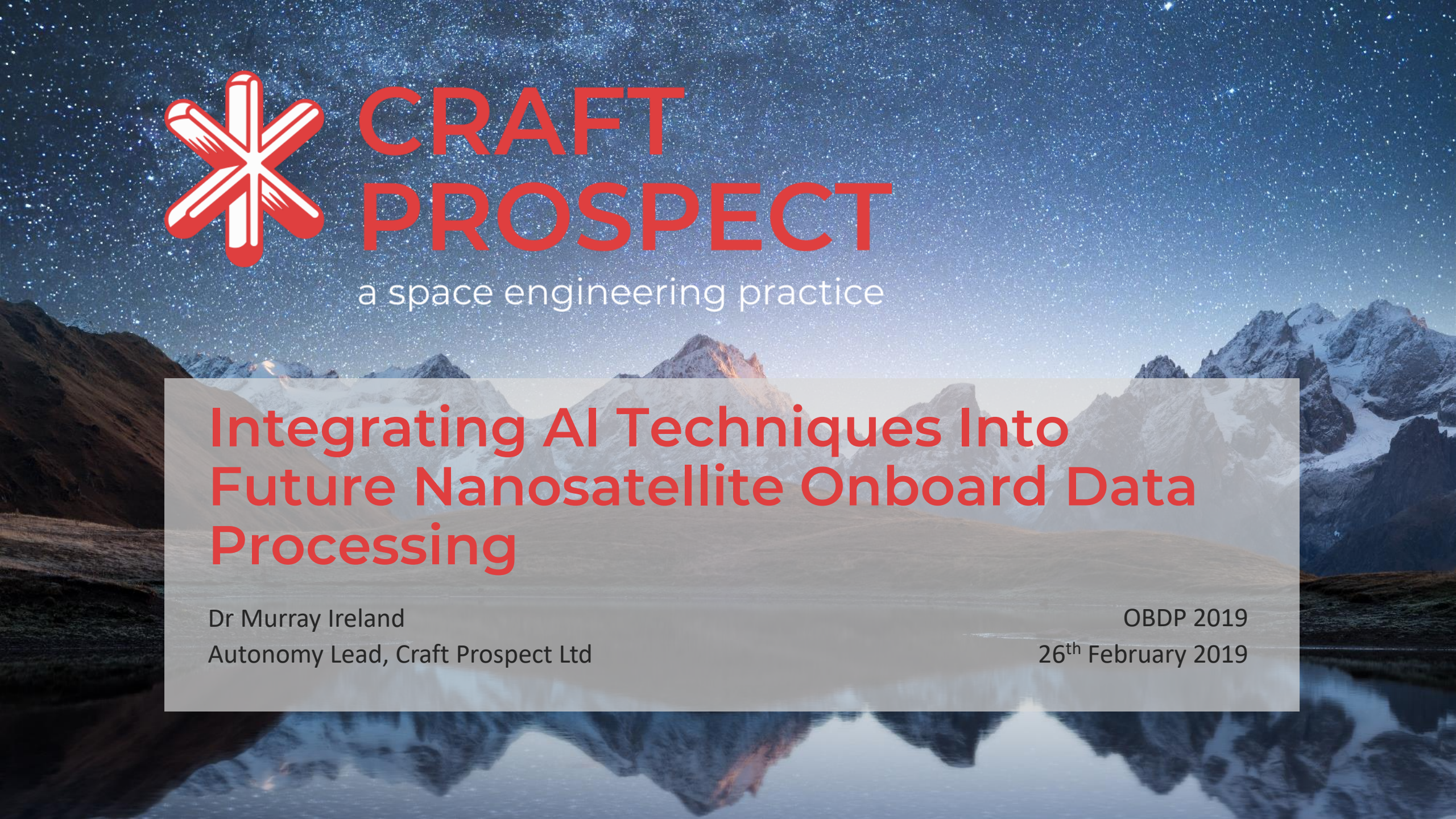

Integrating AI Techniques Into Future Nanosatellite Onboard Data Processing

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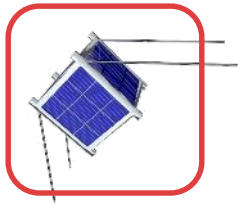
Autonomy Lead, Craft Prospect Ltd

OBDP 2019
26th February 2019

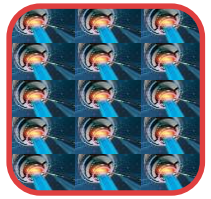
Contents

Craft Prospect Today



Mission & System Engineering

Enabling Technologies & Services



Novel Mission Applications

Products
e.g. Forwards Looking Imager

MISSION CONSULTANCY

RESPONSIVE OPERATIONS

Revenue

Enables

KEY AUGMENTATION SERVICE

Throughout all, investing in the development of systems engineering and processes

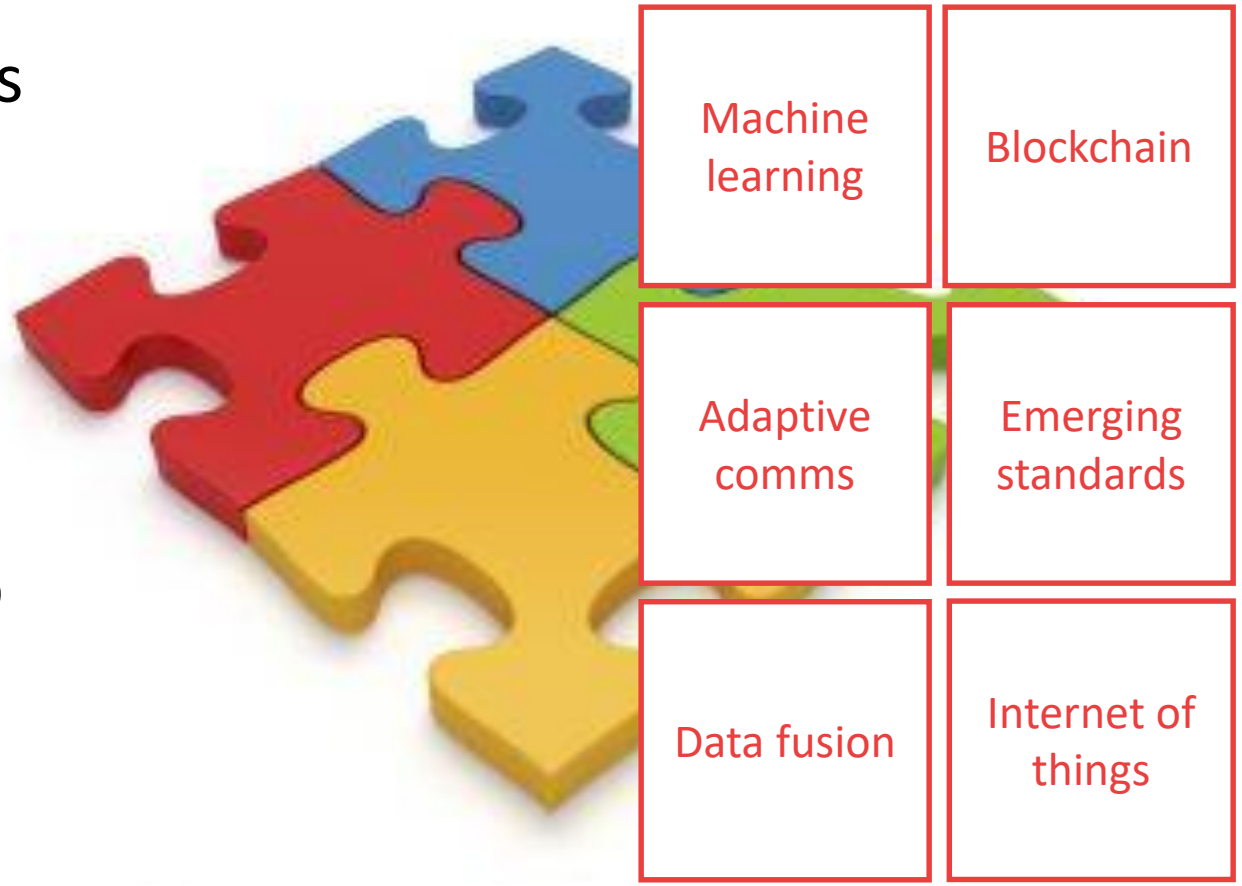
Opportunity

- Growth in demand for real-time actionable data from space
- Resource-constrained small satellites dominating manifests
- Intensive applications like space video and IoT communications
- Need to manage complex networked concept of operations
- Existing operation paradigms are outdated
- Rapidly-evolving consumer-drive autonomy market

→ Develop common product components to enable more responsive operations

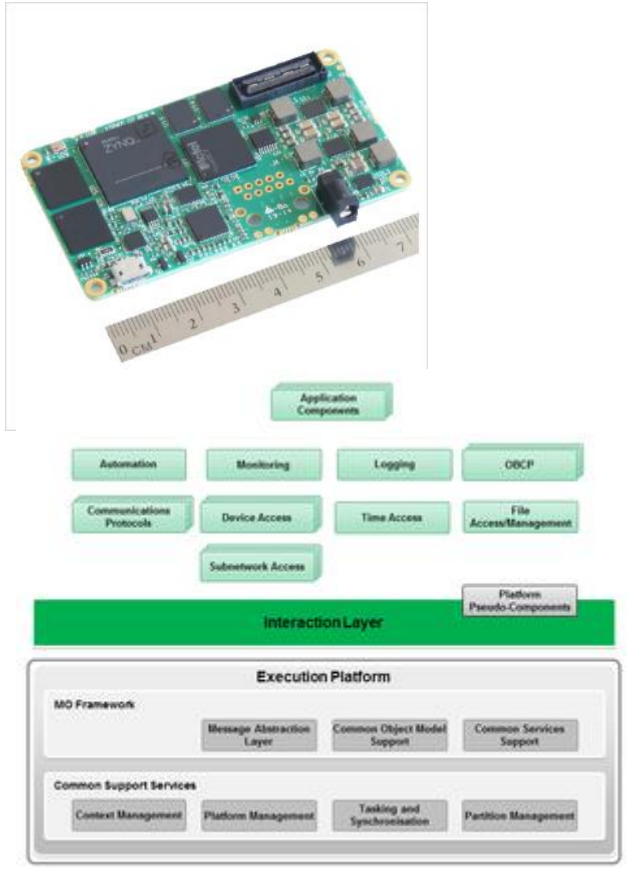
What is Responsive Operations?

- Shift in the concept of operations paradigm
- (Near) real-time actionable delivery
- Onboard autonomy and decision making
- Bypassing the human in the loop
- Retasking assets on-the-fly
- Networks of networks: sensing, processing, delivering

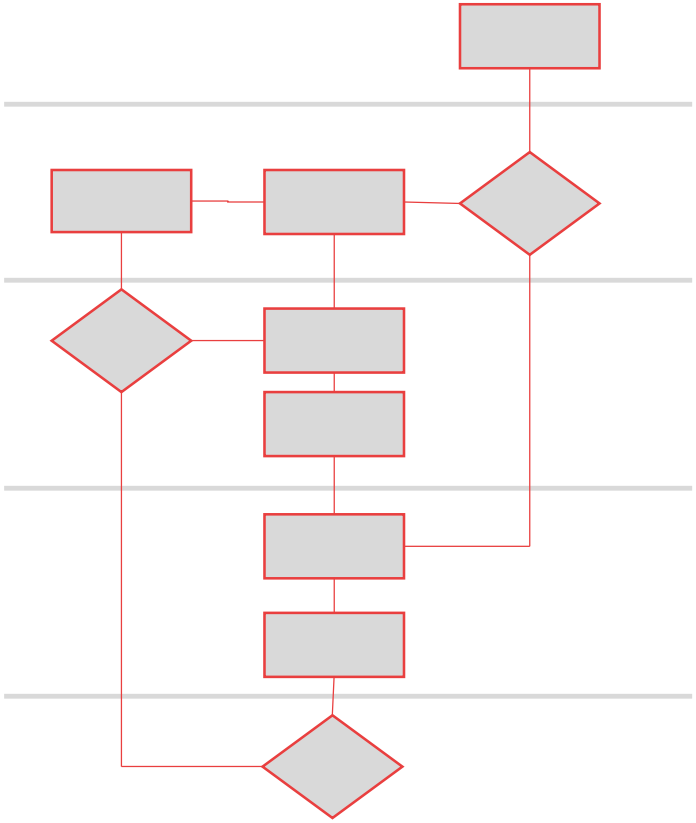


Framework Needs

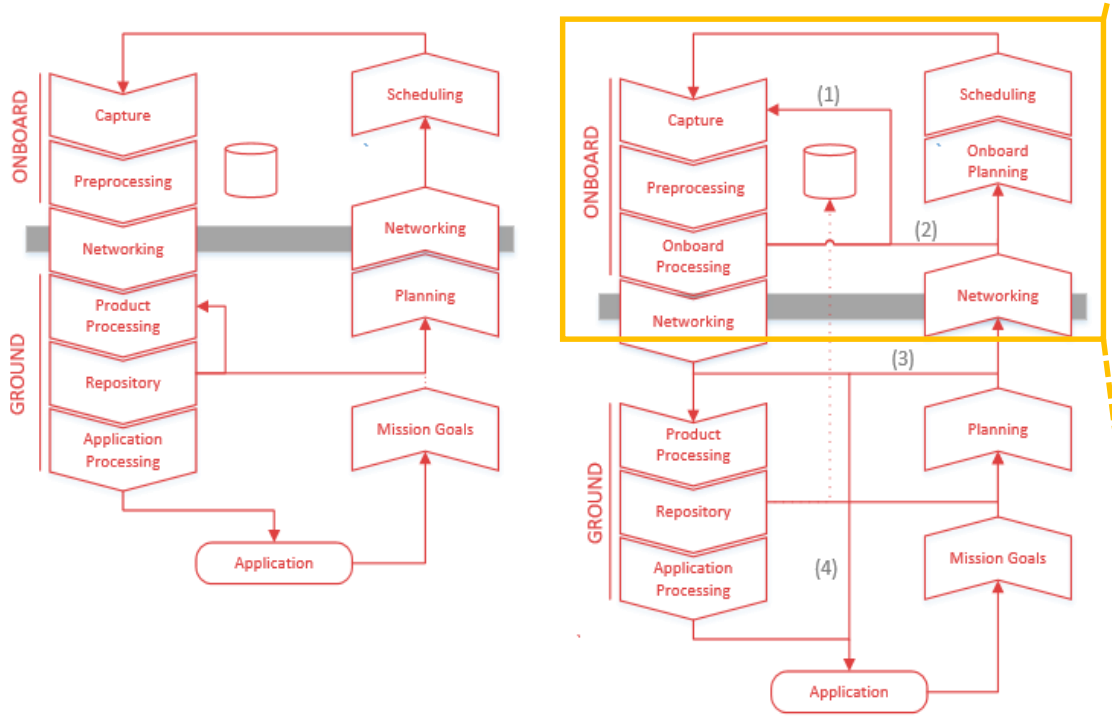
Align to/extends existing approaches



Interfaces to existing software/hardware



Allows robust fault detection, isolation and recovery



Current → Future

Monitoring & Control *
- Event Log
- (Critical) Monitor
- Event-Action

Planning & Scheduling *
- Resource Forecasting
- Goal Planning
- Scheduling

Autonomy Manager
- Autonomy Supervisor

Flight Dynamics *
- Orbit Model

Onboard Control Procedures *
- Scripting

Data Source
- Instrument
- Instrument Manager

Networking
- Comms Stack
- Comms Manager

Data Processing
- Realtime Process
- Offline Process

Archiving *
- Product Summary
- Data Manager
- Data Store

Deployment *
- Component Explorer

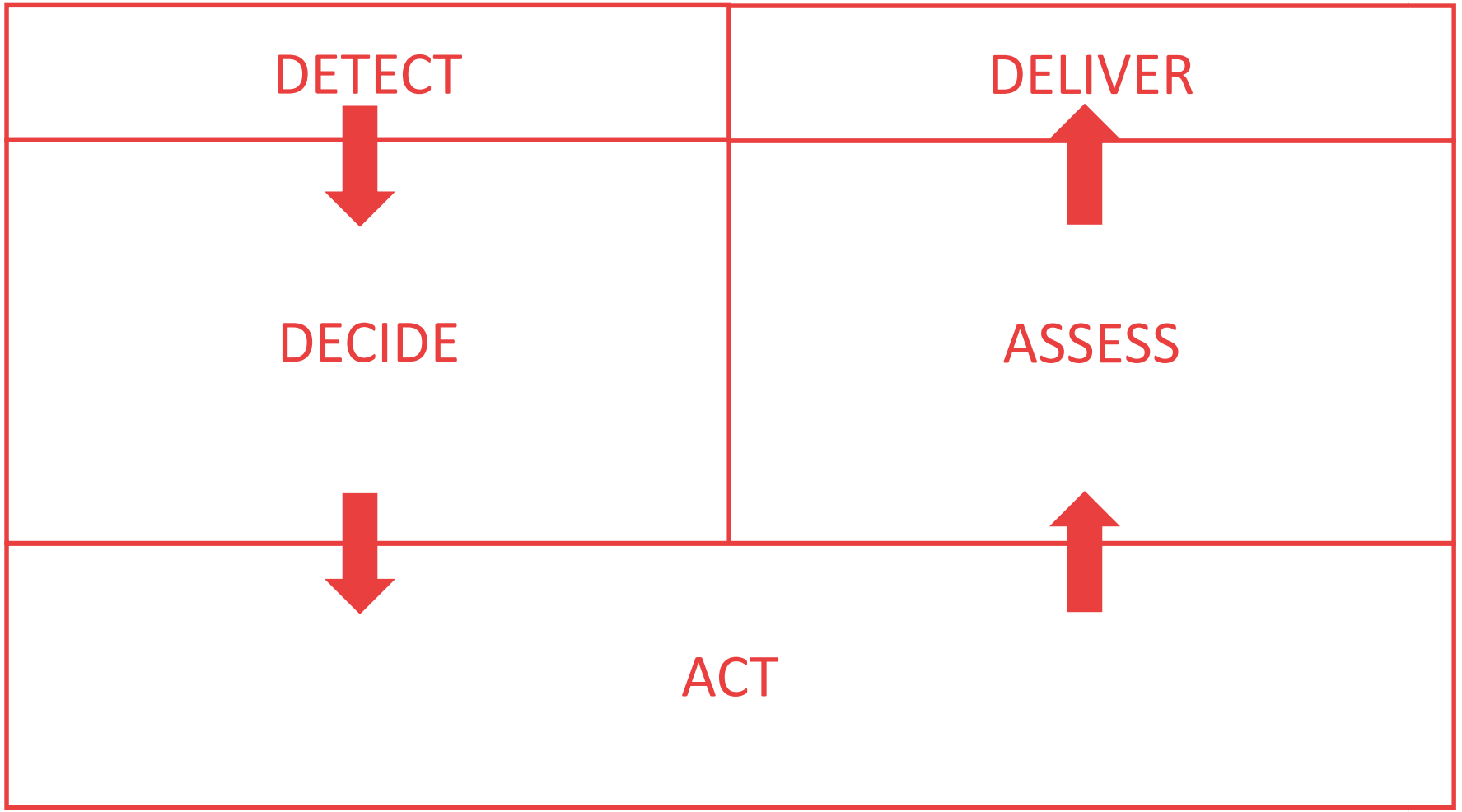
bright ascension

Defined in this work

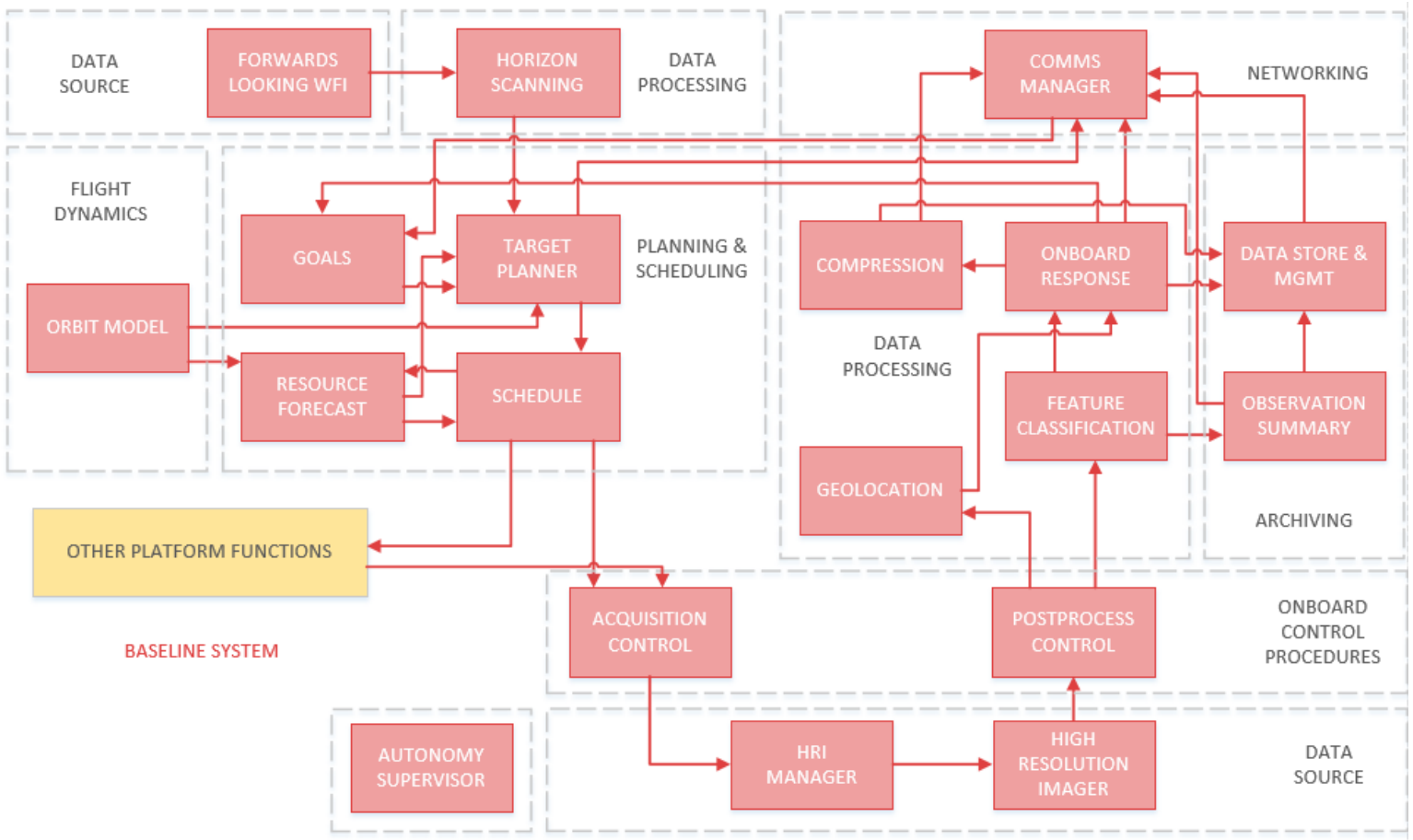
Gen1 current or planned

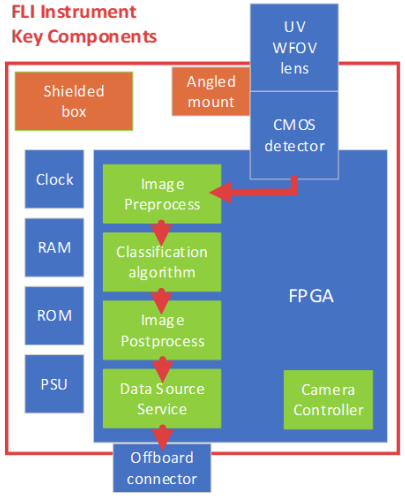
* defined MO service exists

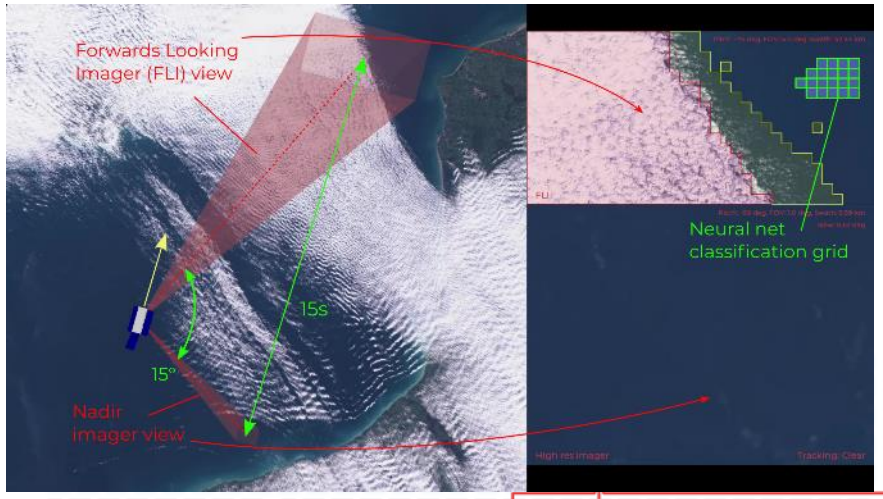
Reference Onboard Architecture

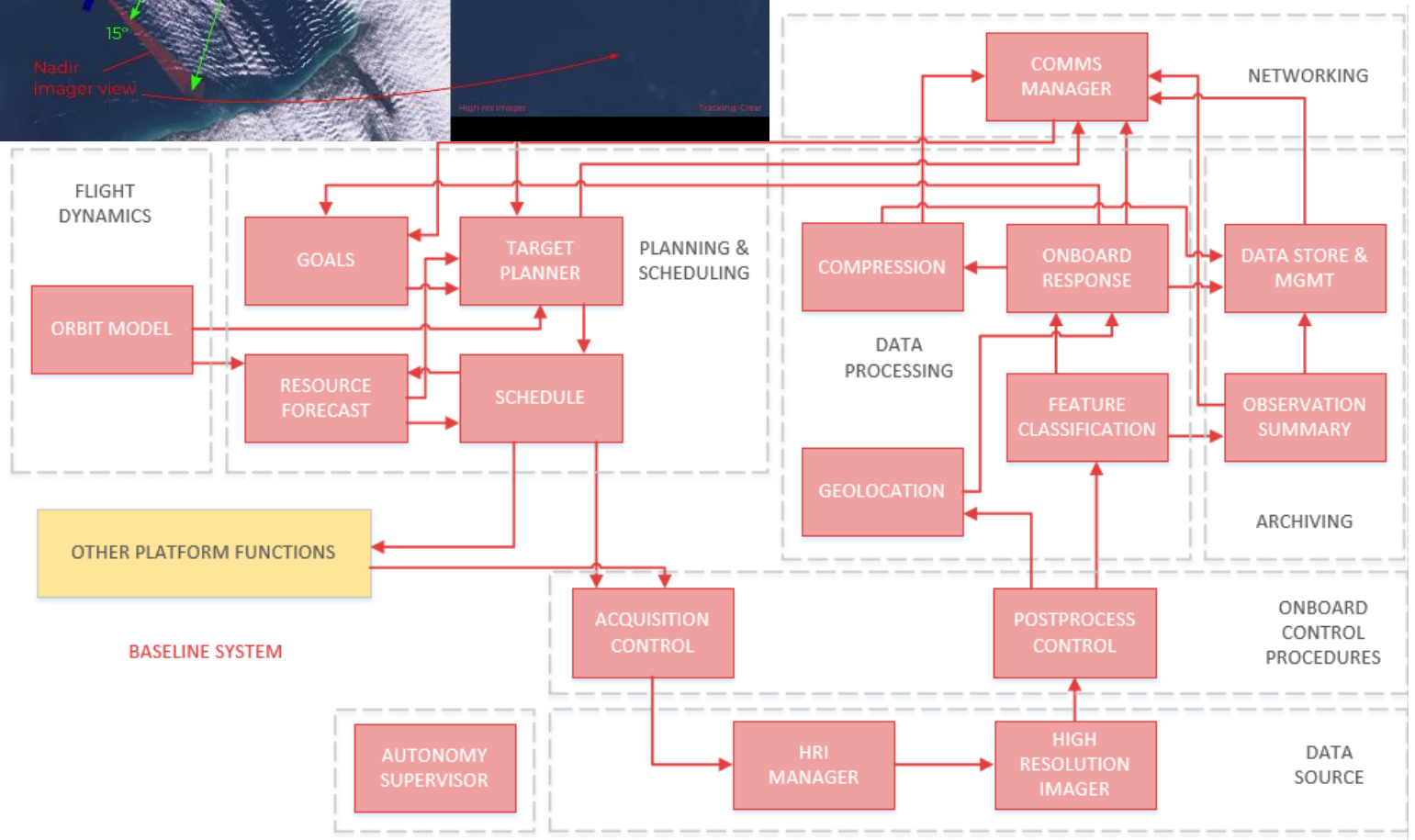


Reference Onboard Architecture




FLI Instrument
Key Components
UV
WFOV
lens
Shielded
box
Angled
mount
CMOS
detector
Clock
RAM
ROM
PSU
Image
Preprocess
Classification
algorithm
Image
Postprocess
Data Source
Service
FPGA
Camera
Controller
Offboard
connector

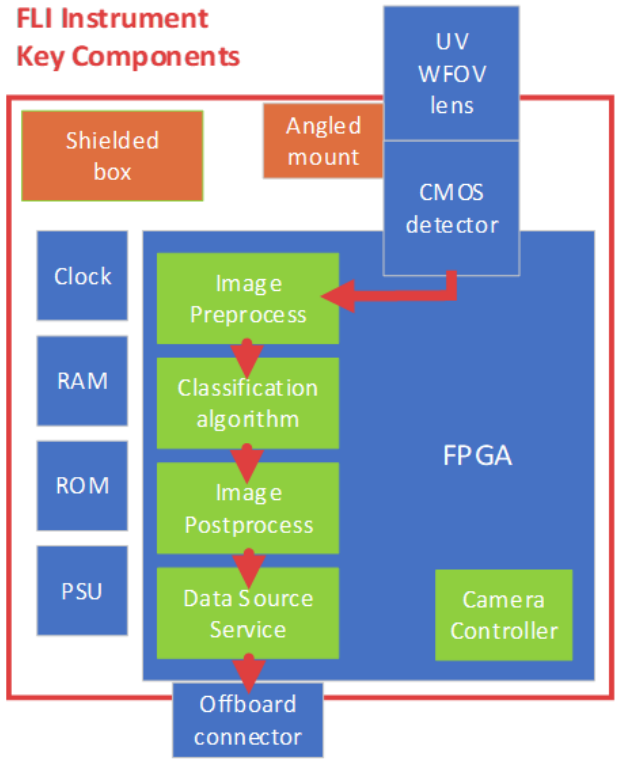

Forwards Looking
Imager (FLI) view
15s
15°
Nadir
imager view
Neural net
classification grid

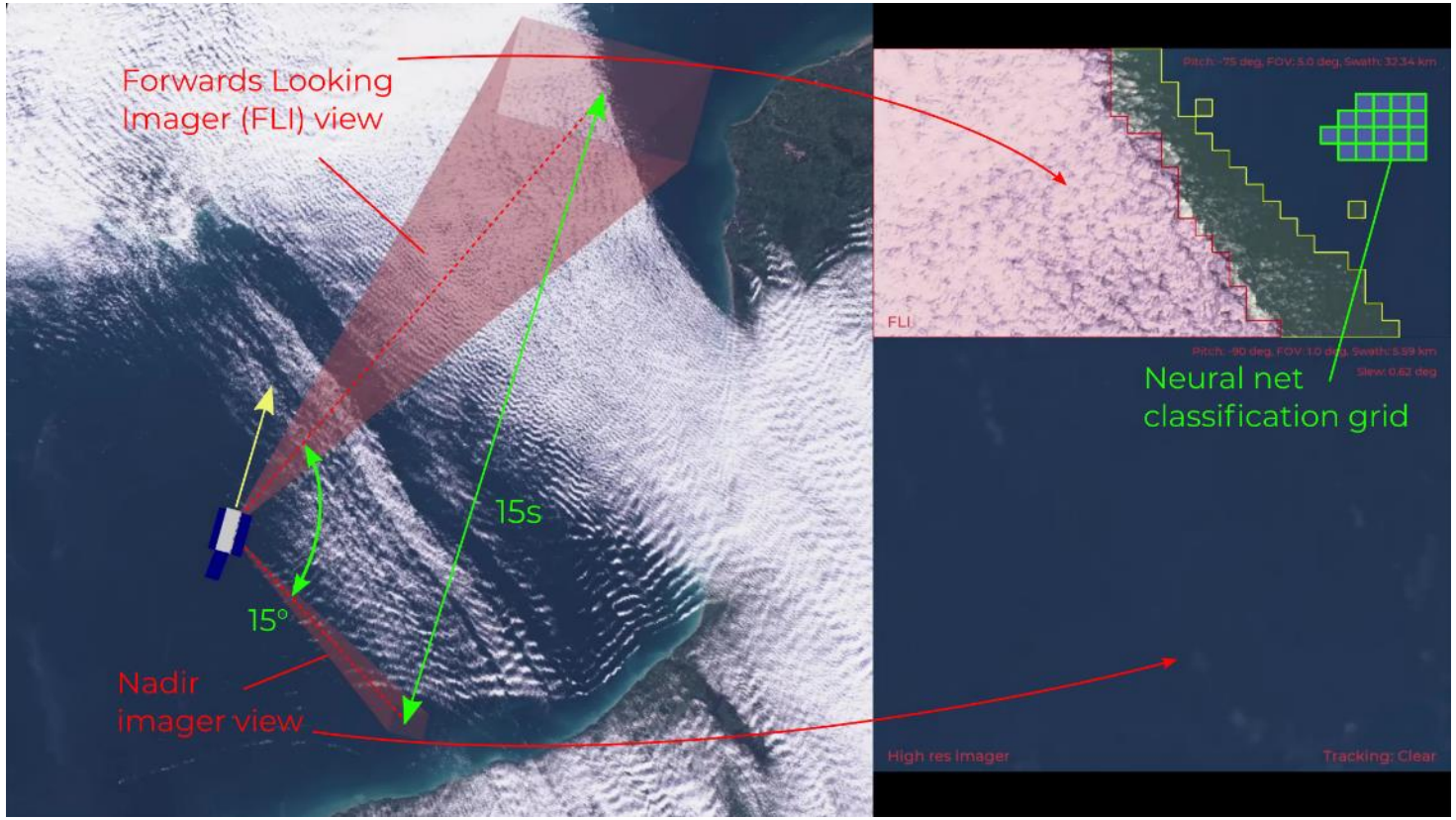

COMMS
MANAGER
NETWORKING
FLIGHT
DYNAMICS
GOALS
TARGET
PLANNER
PLANNING &
SCHEDULING
COMPRESSION
ONBOARD
RESPONSE
DATA STORE &
MGMT
ORBIT MODEL
DATA
PROCESSING
RESOURCE
FORECAST
SCHEDULE
FEATURE
CLASSIFICATION
OBSERVATION
SUMMARY
GEOLOCATION
ARCHIVING
OTHER PLATFORM FUNCTIONS
ACQUISITION
CONTROL
POSTPROCESS
CONTROL
ONBOARD
CONTROL
PROCEDURES
BASELINE SYSTEM
AUTONOMY
SUPERVISOR
HRI
MANAGER
HIGH
RESOLUTION
IMAGER
DATA
SOURCE

Framework Applications

- Optimisation
- Responsive tasking
- Fleet management
- Edge computing
- Intelligent FDIR
- Enable service capability
  - Space ledger
  - Quantum key distribution

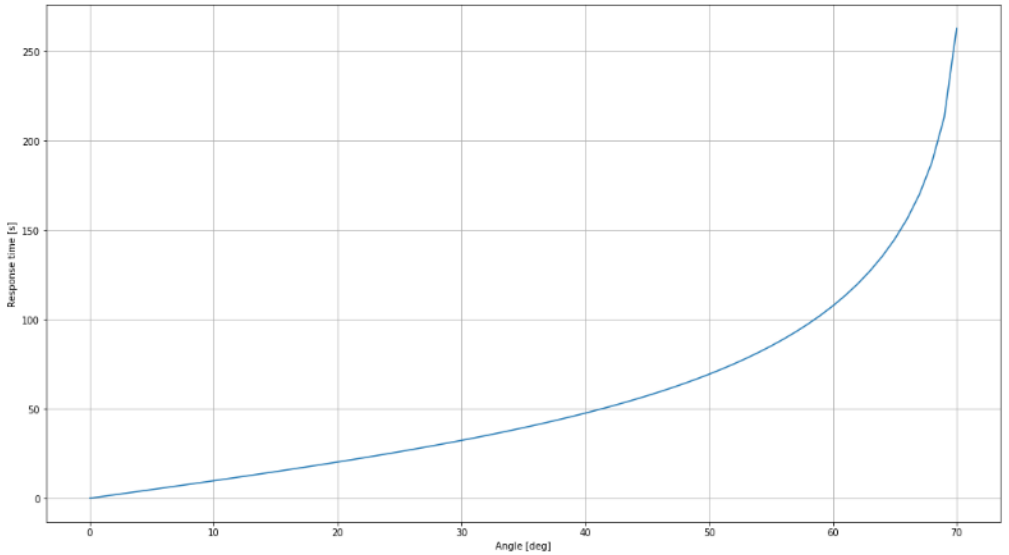
Detect: Forwards Looking Imager

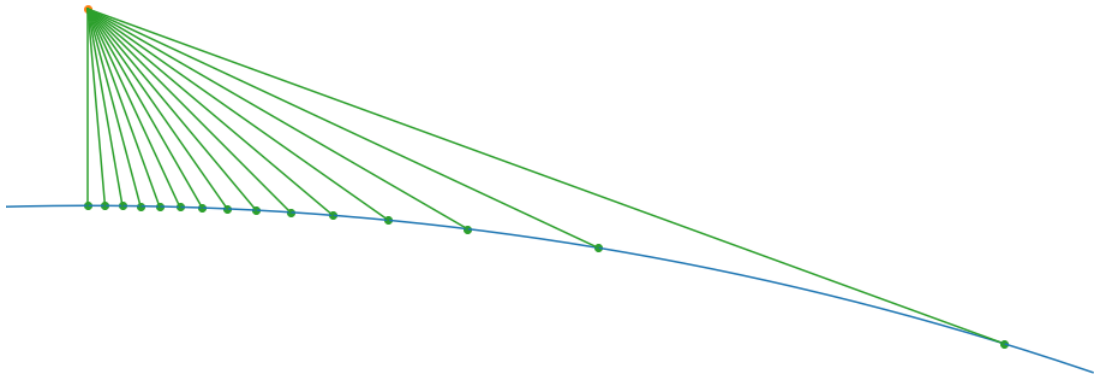




Forwards Looking Imager

- FLI looks ahead of satellite to capture upcoming cloud cover
- Larger angle from nadir:
  - ✓ More time to respond
  - ✗ More distortion and parallax
- Configurable:
  - Angle can be varied to suit application
  - Imager/lens can be swapped

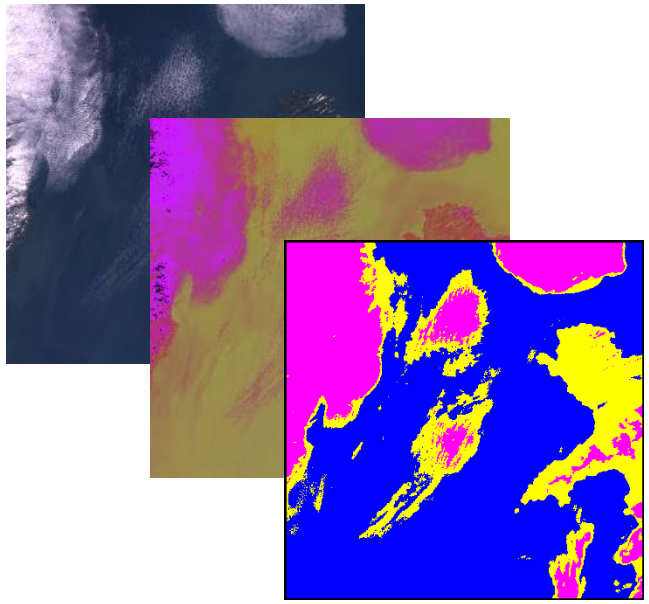




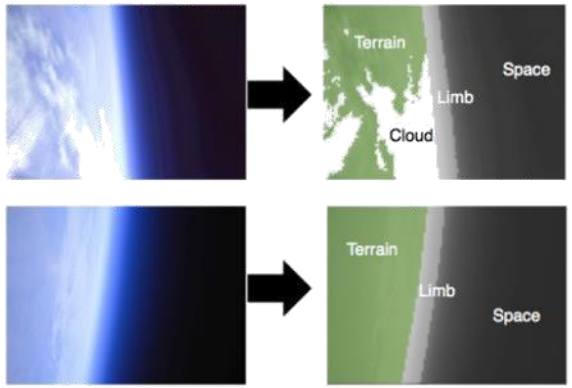
FLI Applications

- Enables responsive operations
- Target prioritisation & payload pointing
- Resource management
- Downlink management
- Constellation task reassignment
- Real-time bulletins for customers

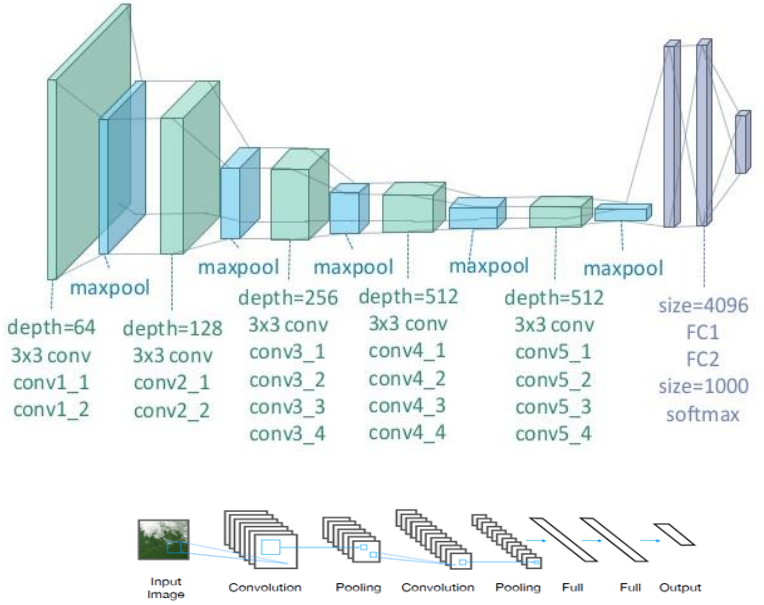
FLI Algorithm



Fmask



TextureCam

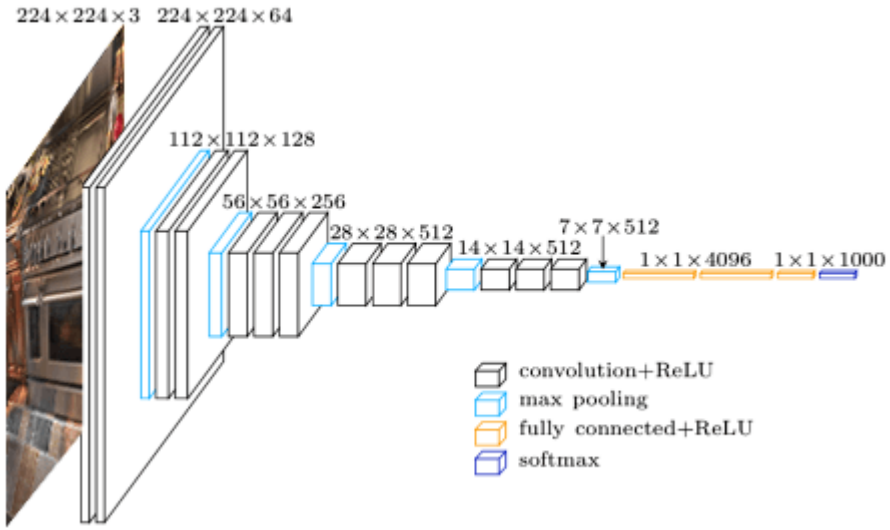


Deep learning

Increasing applicability across domains

Deep Learning

- Applied transfer learning to existing CNN
- Trained using:
  - open-source dataset (initially)
  - in-house dataset (updates)
- Ground-based network for verification
- Lighter network optimised and deployed on FPGA SoC



partly_cloudy
urban
woodland

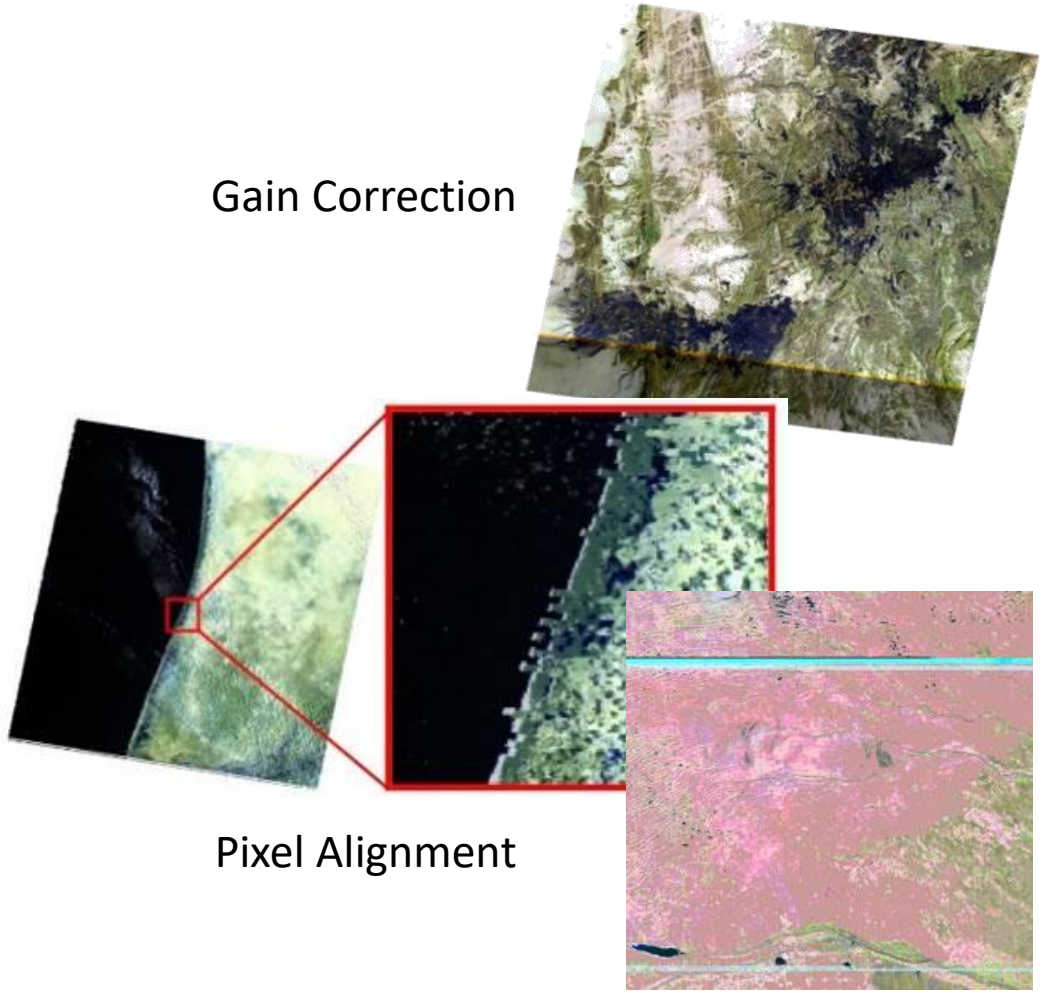
clear
river
woodland

cloudy

Implementation Challenges

- Power and processing constraints
- Access to applicable Level 0 training data
- Ground reference points
- Incorporating anomalies
- Onboard systems interfacing
- Meeting operational regulations
- Demonstrating mission assurance
- Parallax error due to forwards looking

Gain Correction

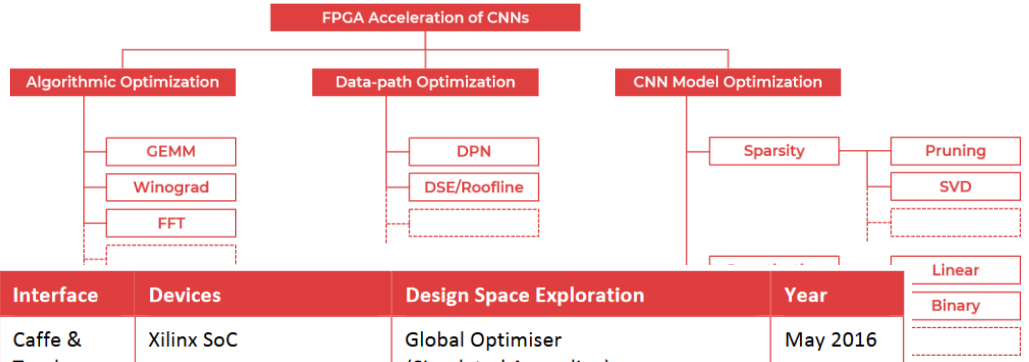


Pixel Alignment

Sun Glint

Enabling Strategies

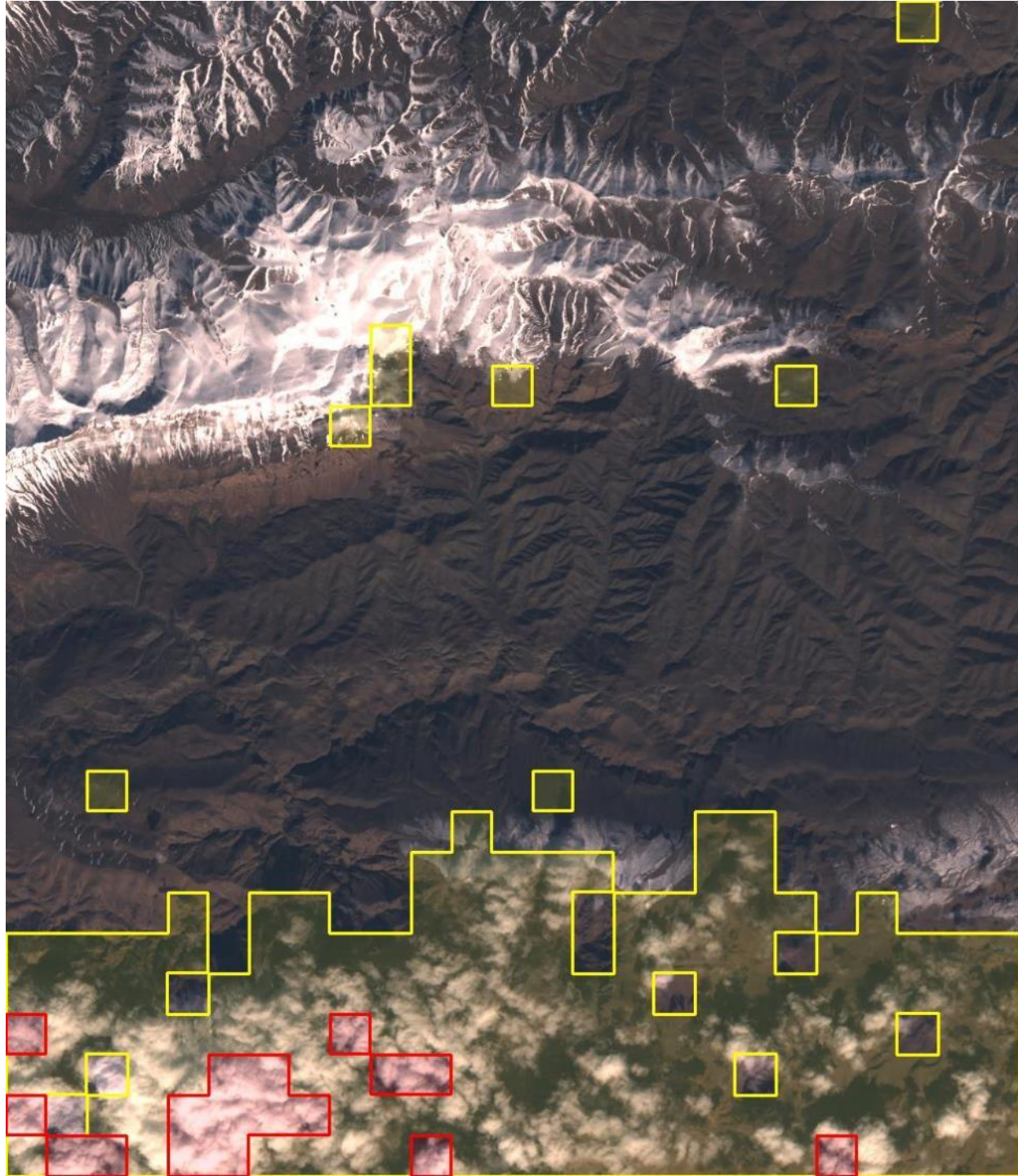
- Target FPGA with known flight heritage
- Tools to enable rapid synthesis from high level languages to embedded
- Evaluation of optimisation pipelines and approaches
- Adapted existing open source libraries for image processing and deep learning
- Simplification of the convolutional neural network
- Creating a system-in-the-loop test including distortions and anomalies



Name	Interface	Devices	Design Space Exploration	Year
fpgaConvNet	Caffe & Torch	Xilinx SoC	Global Optimiser (Simulated Annealing)	May 2016
DeepBurning	Caffe	Xilinx SoC	Heuristic	Jun 2016
Angel-Eye	Caffe	Xilinx SoC	Heuristic with Analytical Model	Jul 2016
ALAMO	Caffe	Intel SoC & Standalone	Heuristic	Aug 2016
Haddoc2	Caffe	Xilinx & Intel Standalone	Deterministic	Sep 2016
DnnWeaver	Caffe	Xilinx & Intel	Custom Search Algorithm	Oct 2016
Caffeine	Caffe	Xilinx Standalone	Exhaustive over Roofline Model	Nov 2016
AutoCodeGen	Proprietary	Xilinx Standalone	Heuristic with Analytical Model	Dec 2016
FINN	Theano	Xilinx SoC & Standalone	Heuristic	Feb 2017
FP-DNN	TensorFlow	Intel Standalone	Algorithmic	May 2017
Snowflake	Torch	Xilinx SoC	Heuristic	May 2017
SysArrayAccel	C	Intel Standalone	Exhaustive over Analytical Model	Jun 2017
FFTCodeGen	Proprietary	Intel HARP	Roofline and Analytical Models	Dec 2017

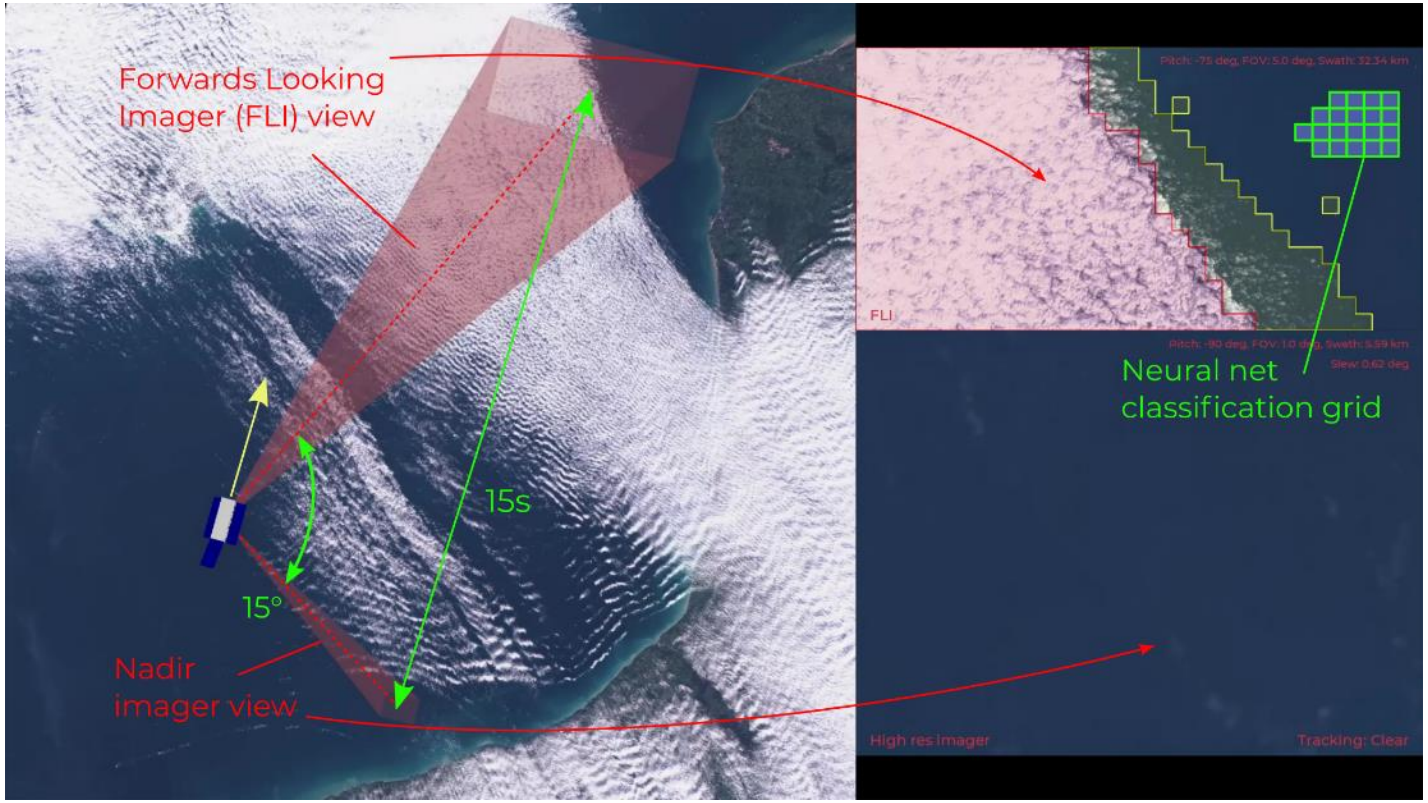
Test Case:
Cloud Detection

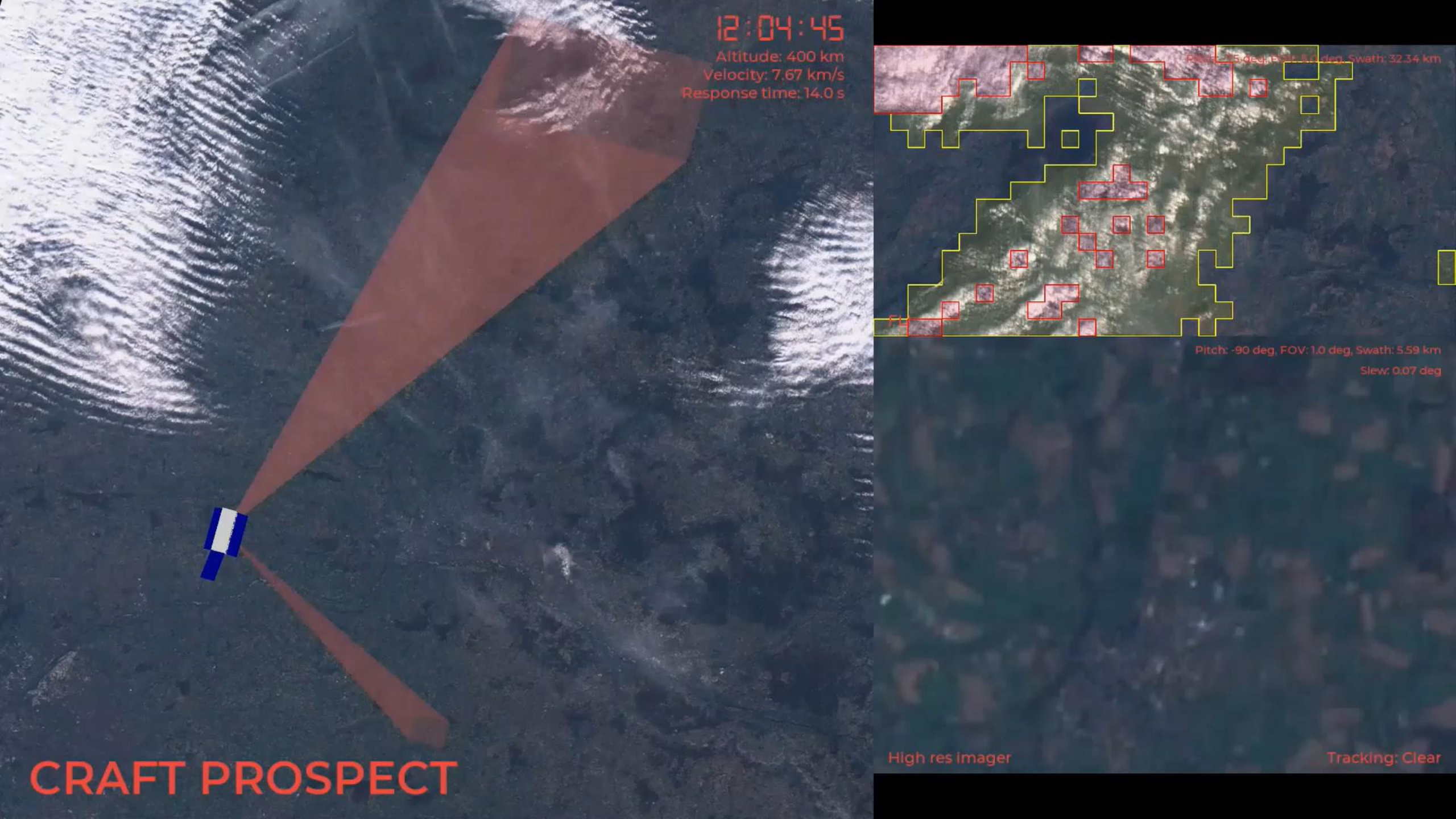
- Image split into tiles
- Cloud detection payload classifies each segment with single label:
  - Clear (no colour)
  - Partly cloudy (yellow)
  - Cloudy (red)
- Cloud cover knowledge allows payloads and EO sensors to target clear regions



Test Case: Cloud Detection

- Example parameters:
  - Network trained on 1 km^2 tiles
  - FLI footprint = 32.3 x 16.7 km
    = 34 x 17 image tiles ~1 km^2
- Requirements:
  - Capture every ~2 s for unbroken coverage
  - Network must classify 578 images + pre-/post-processing in < 2 s
  - Areal rate: 270 km^2/s




12:04:45
Altitude: 400 km
Velocity: 7.67 km/s
Response time: 14.0 s
Pitch: -90 deg, FOV: 1.0 deg, Swath: 5.59 km
Slew: 0.07 deg
High res imager
Tracking: Clear
CRAFT PROSPECT

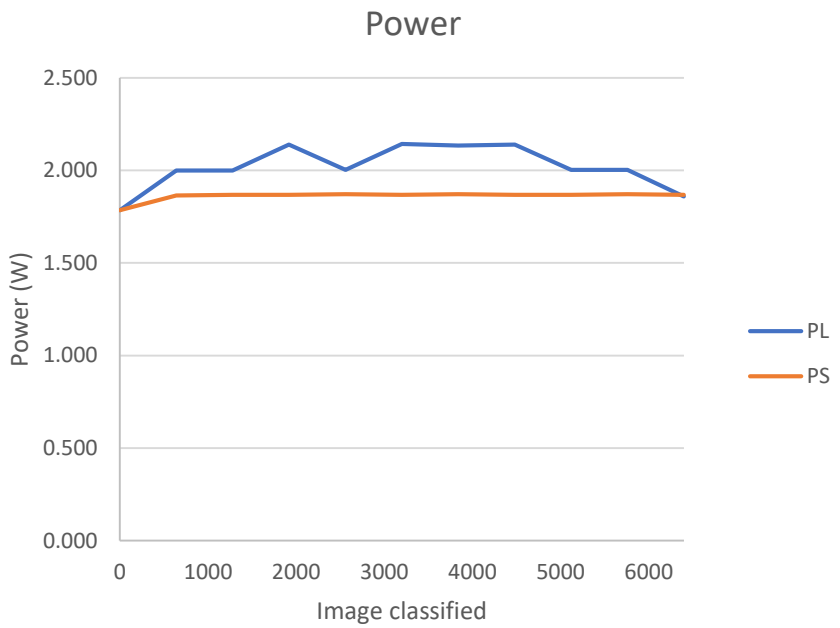
Metrics

Platform/model	Image rate	Accuracy[2]	Power[3]
FLI cloud detection network (PL)	337.7 im/s	97%	0.23 W
FLI cloud detection network (PS)	1.21 im/s	97%	0.06 W
Cloud detection network on VPU[1]	17.7 im/s	97%	0.75 W

[1]Network of similar depth to FLI network

[2]Using identical training and test sets

[3]Over idle

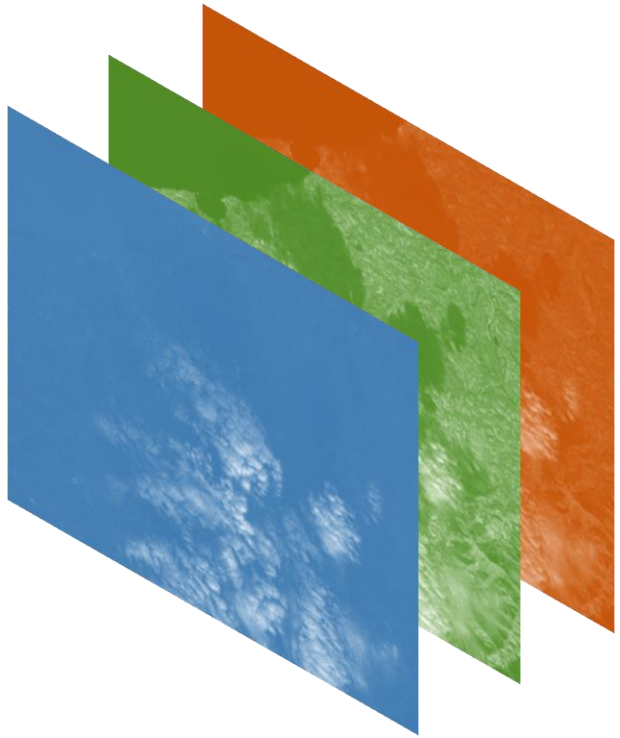


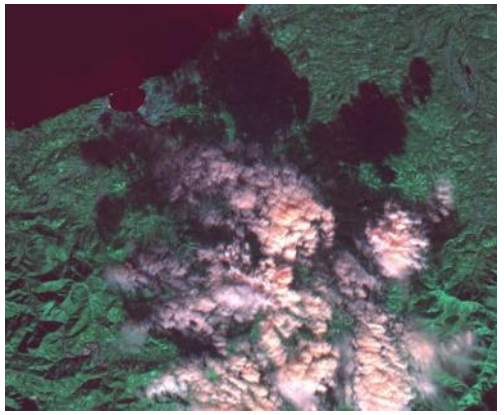
Product

- Engineering models of the FLI MVP now available
- Delivered to first customers for third party performance benchmarking and interface testing
- FPGA-based (2W), but extendable with Myriad VPUs for additional low-power neural networks
- Integrates with HIL simulation for testing
- Reconfigurable for real-time ops
  - Tile-size, sensor input, resamples, field of view, responsive time
  - Network updates
- Internal or external camera sources
- DEMO AVAILABLE AT OBDP

ESA Work on MSI

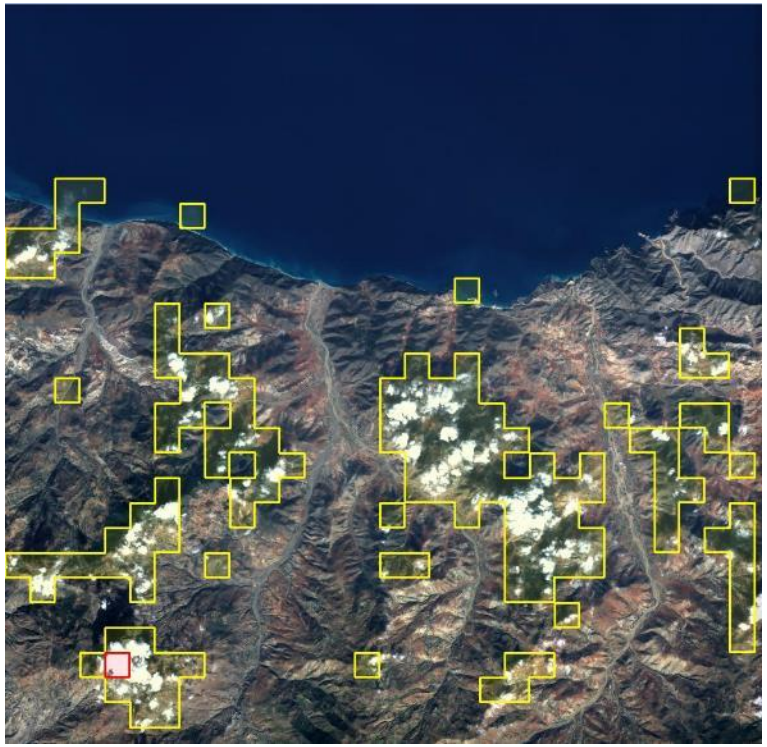
- Transfer learning:
  - Movidius Neural Compute Stick
  - Sentinel-2 MSI imagery
- Preliminary work: 3-band combinations
  - RGB
  - Visible + near-infrared channels
- Future plan: Extend to N-band networks



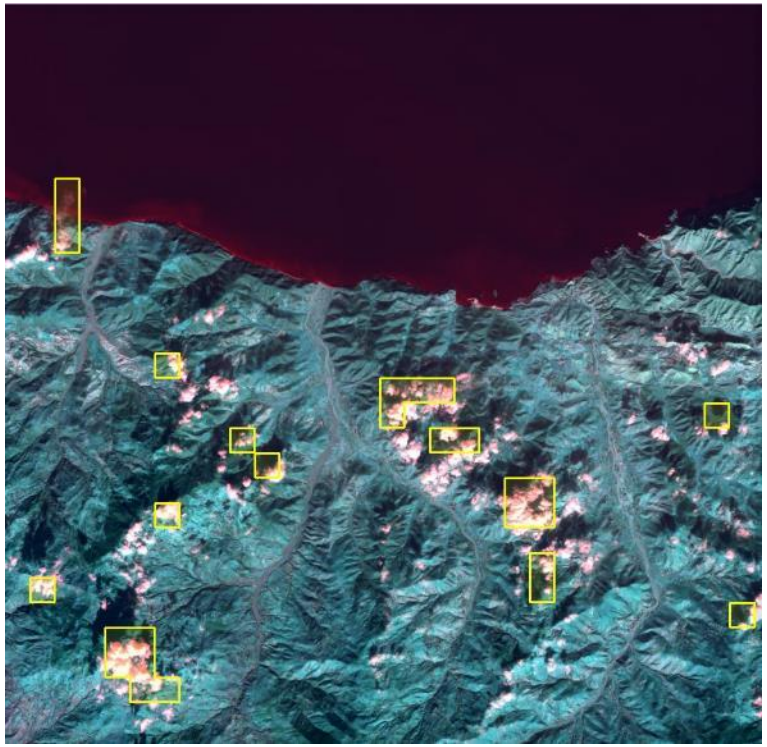


MSI Classification

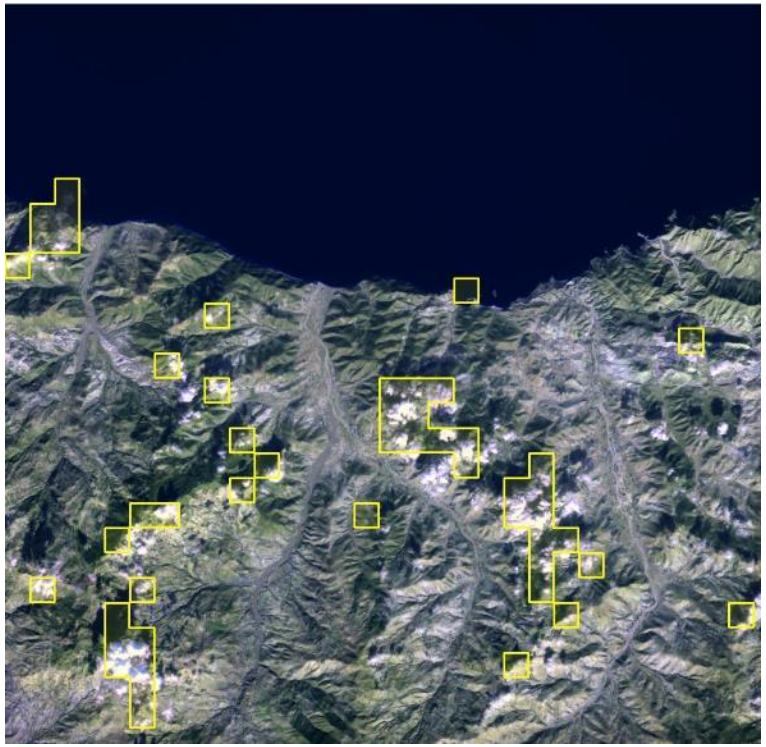
True colour



SWIR

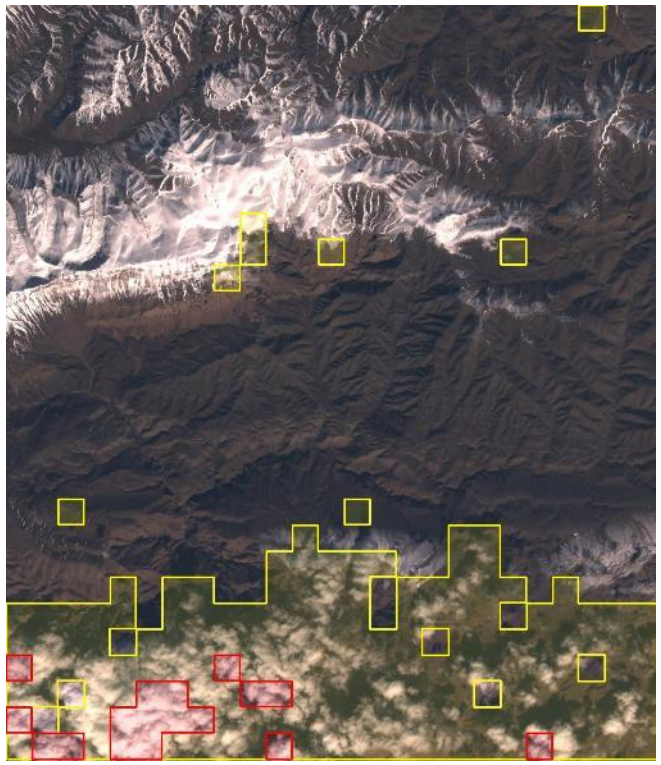


False colour (urban)

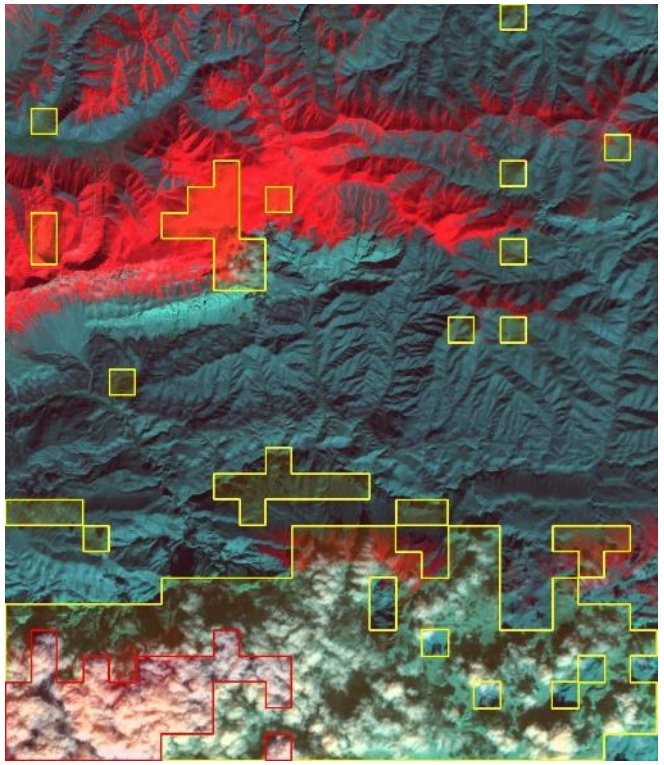


MSI Classification

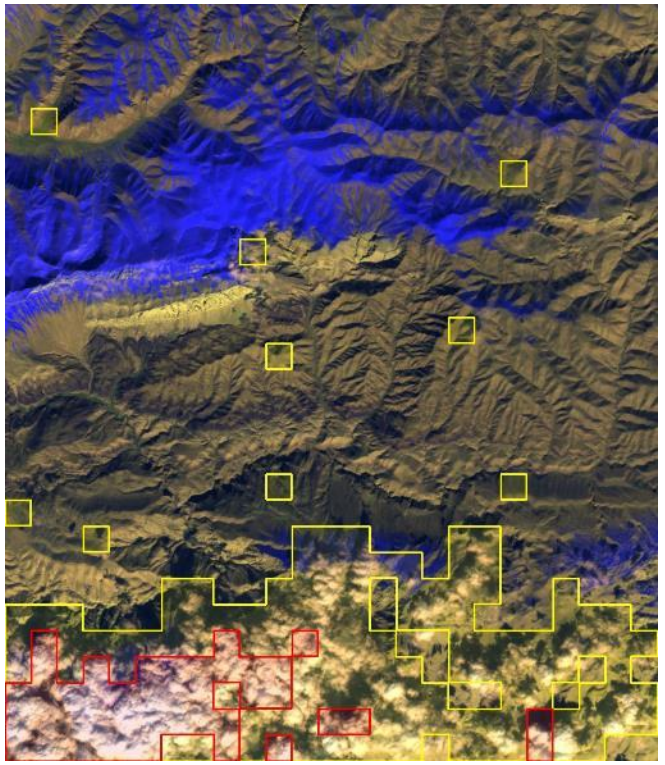
True colour



SWIR



False colour (urban)



Closing Remarks

- Working with partners to develop autonomy framework and payload computer which will incorporate FLI and other enabling technologies
- FLI is designed to be:
  - Fast
  - Low power
  - Reconfigurable
  - Supporting of 3rd party sensors
  - The first step in CubeSat autonomy

Acknowledgements

UK SPACE AGENCY

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esa European Space Agency

MANCHESTER 1824 The University of Manchester

UCL

bright ascension

CATAPULT Satellite Applications

GSI Global Surface Intelligence

"Onboard Data Autonomy for Next Generation of EO Nanosatellites"

Higgs Centre for Innovation Science & Technology Facilities Council

Scottish Centre of Excellence in Satellite Applications

University of Glasgow

Thanks

Questions are welcome


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