An onboard processing module for hyperspectral imaging missions

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NTNU, 06.09.2017

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The HyperScout mission

cosine | measurement systems

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vito

esa

TU Delft

The HyperScout mission

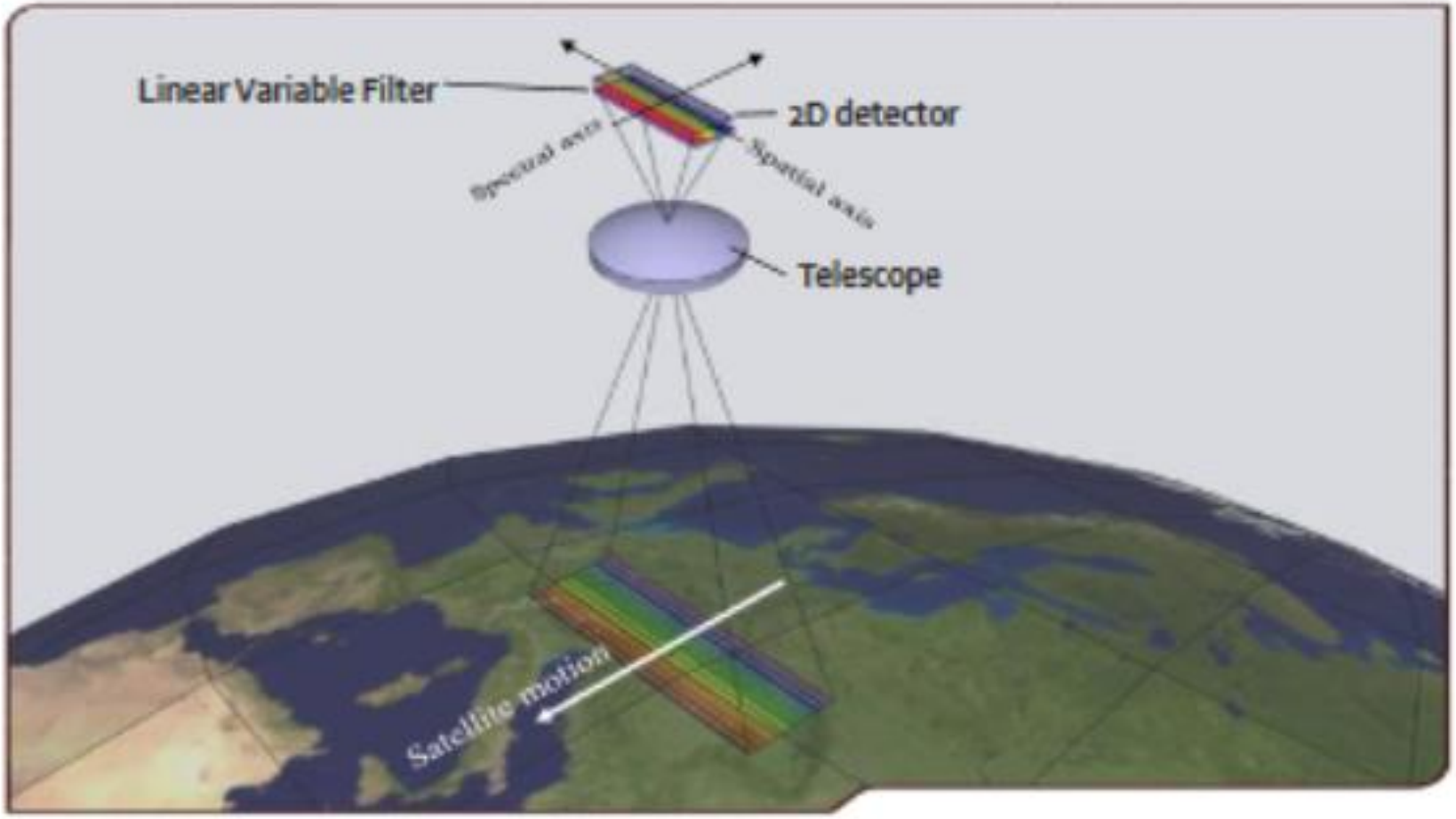
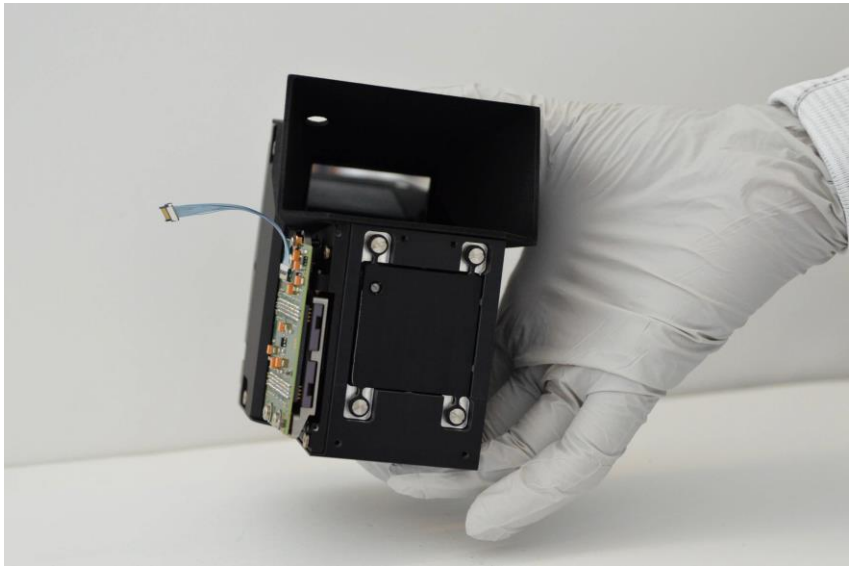


Image courtesy VITO.

The HyperScout mission

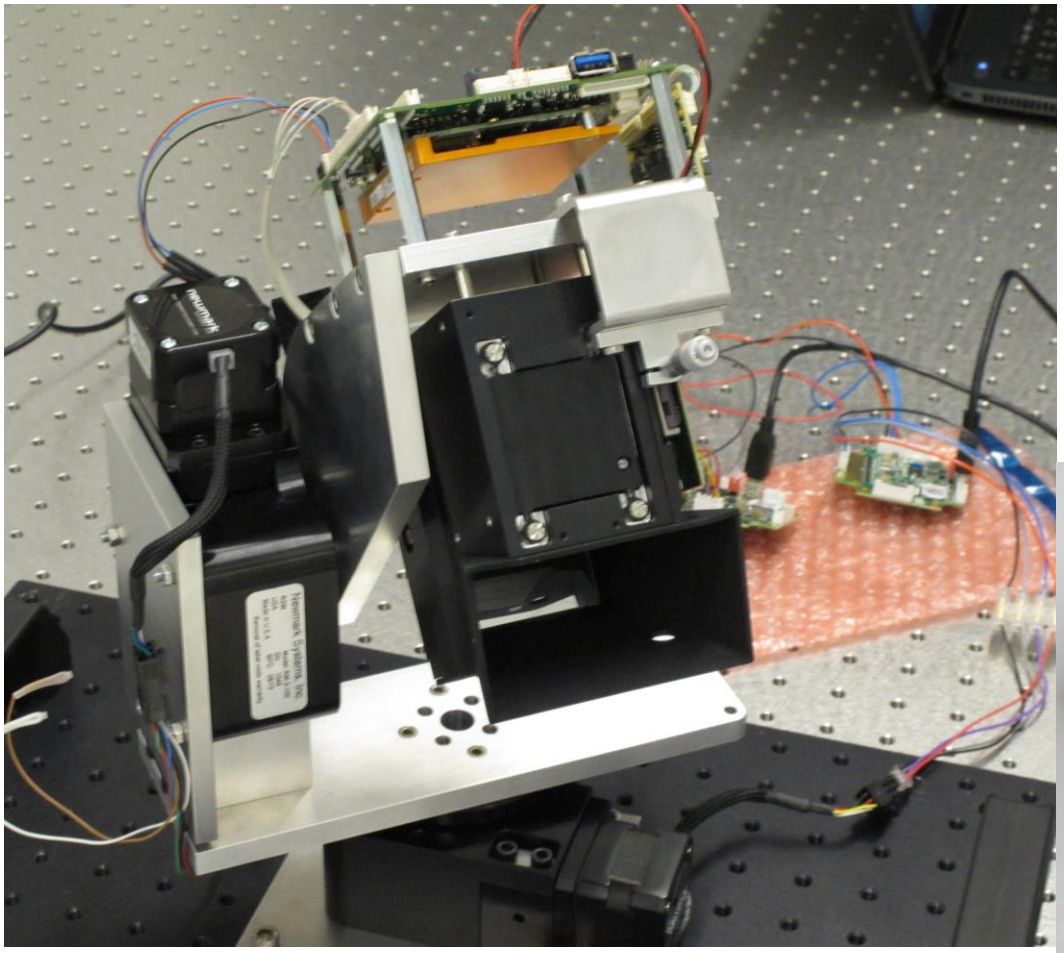
"Miniaturized hyperspectral imager with its own brain"

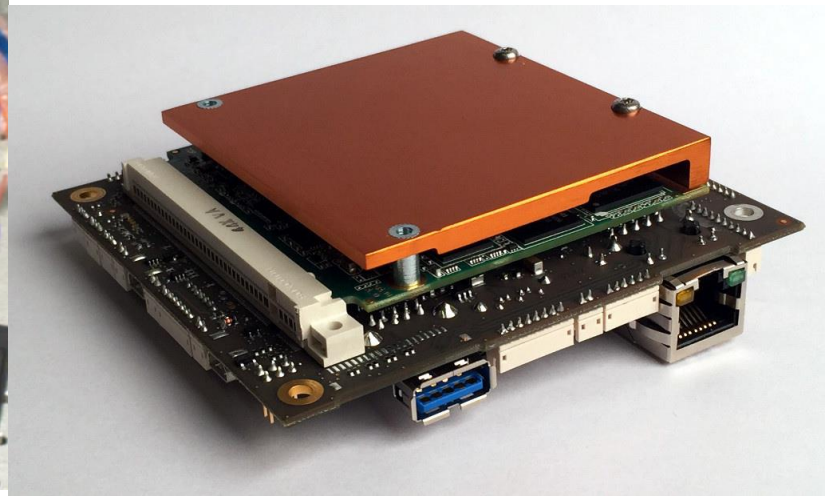
- Resolution: 3052 x 1836 px
- FOV: 23°x 16°
- Swath @540 km: 220 x 152 km
- Mass: 1.1 kg
- Volume: 1 U compatible
- Spectral range: 400-1000 nm
- Spectral resolution: 14 nm
- Spectral bands: 50
- Launch: 1 febr 2018



- Onboard processing:
  - Data volumes from instrument is ~1 terabyte per orbit.
  - Downlink capacity only ~1-2 Mbps on the CubeSat platform.
  - Solution: Process the data onboard and extract high-level information of interest.

The HyperScout mission





The GOMX-4B satellite

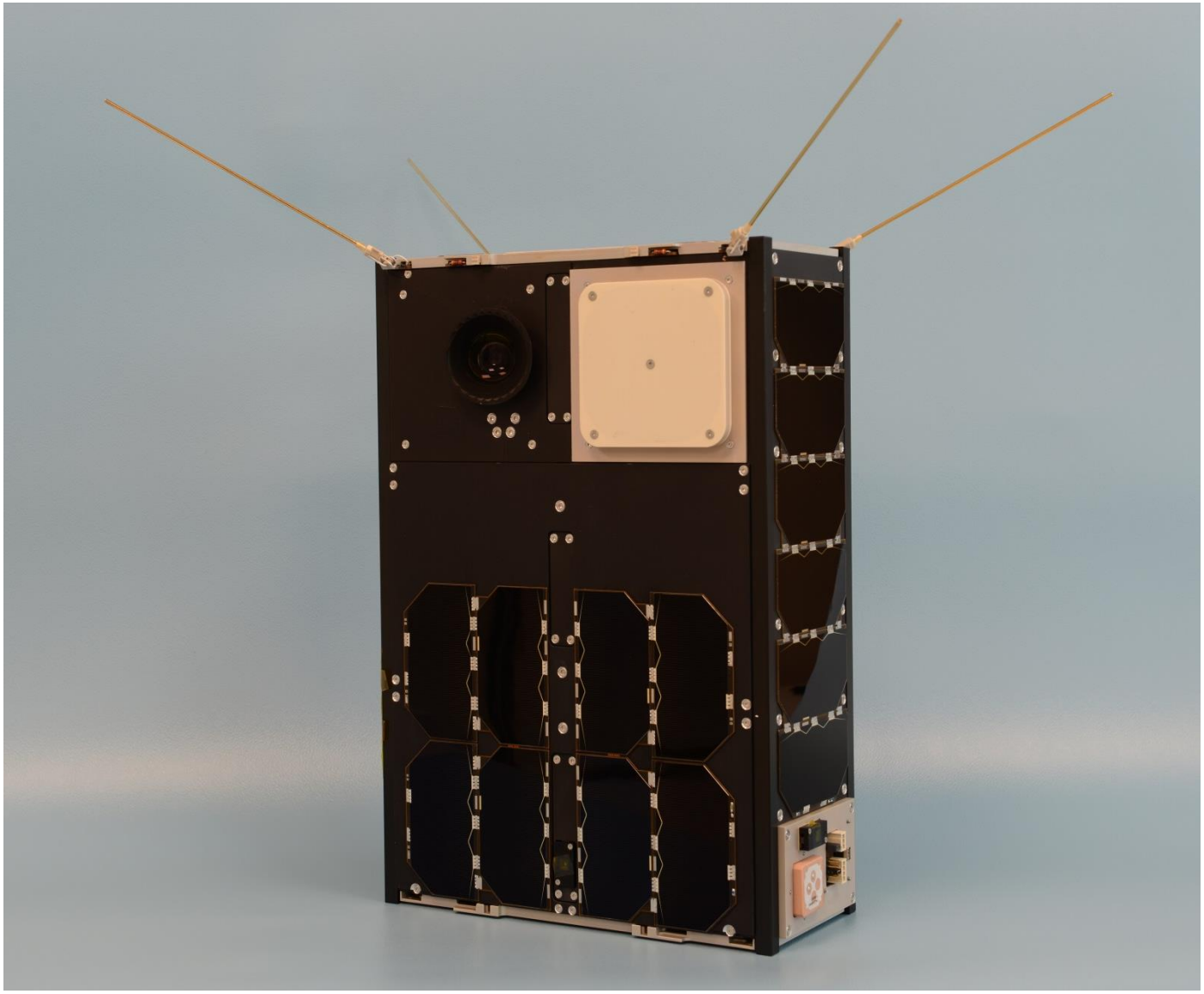
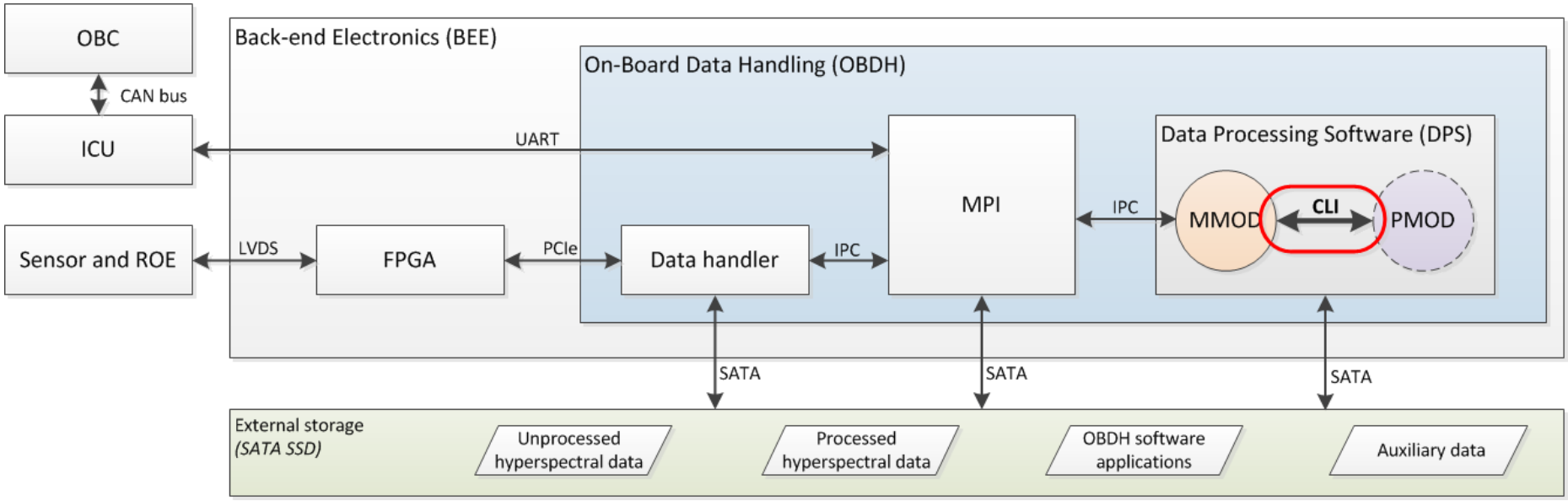
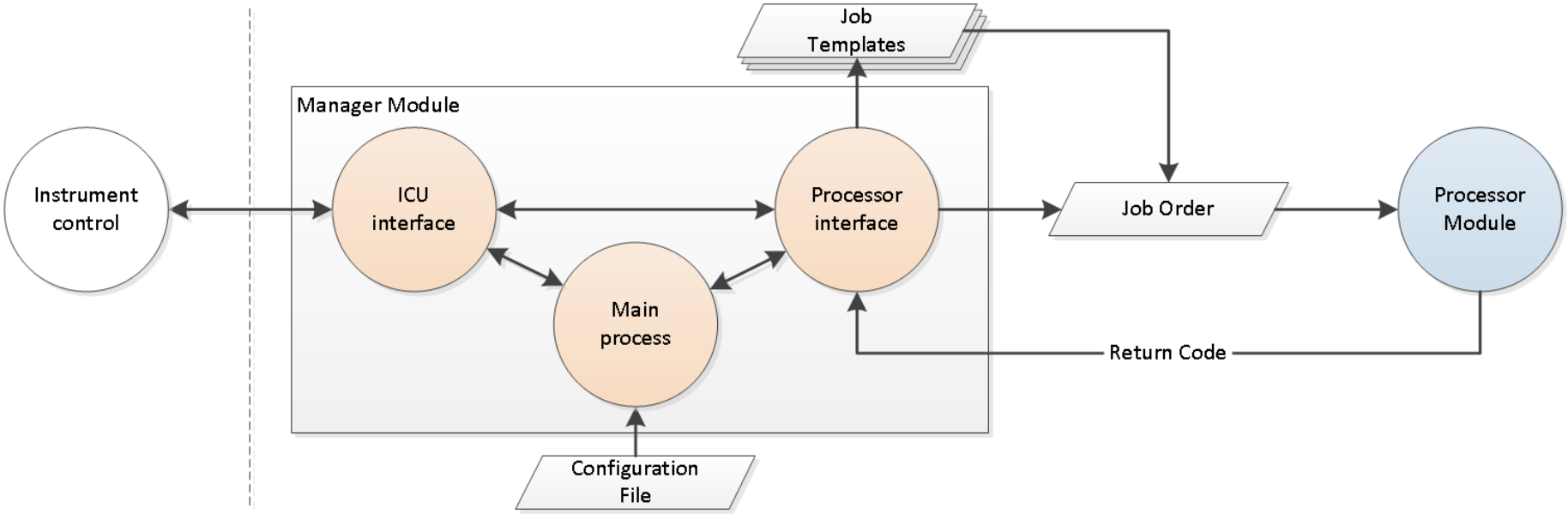


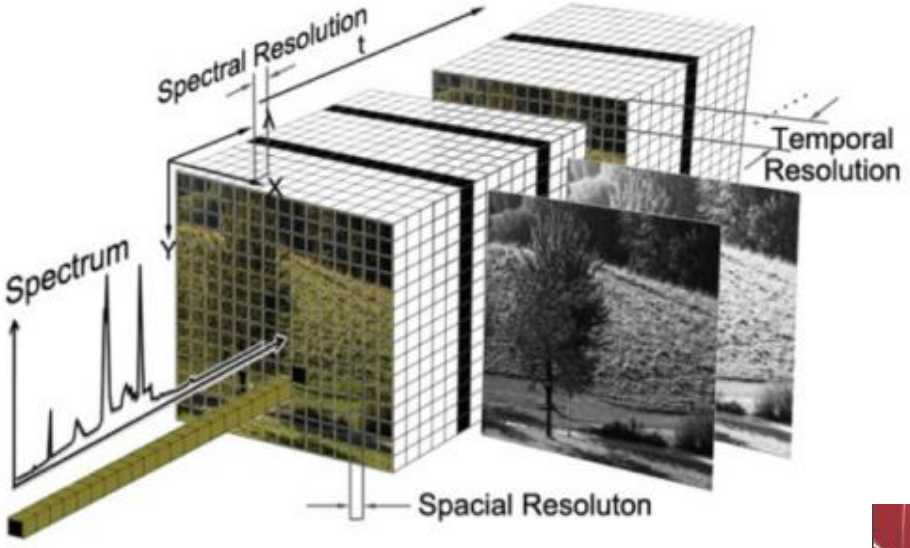
Image courtesy GomSpace.

OBDH

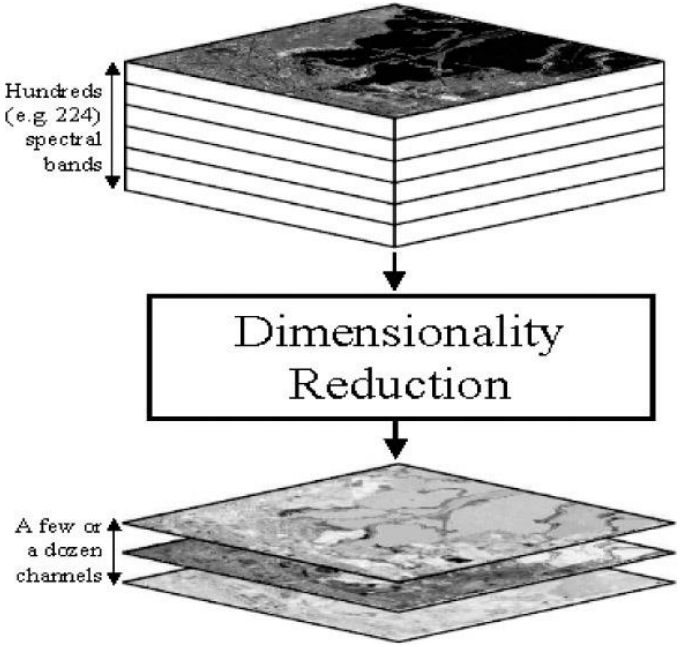

OBC
CAN bus
ICU
Sensor and ROE
Back-end Electronics (BEE)
On-Board Data Handling (OBDH)
UART
LVDS
FPGA
PCIe
Data handler
IPC
MPI
IPC
Data Processing Software (DPS)
MMOD
CLI
PMOD
SATA
SATA
SATA
External storage
(SATA SSD)
Unprocessed hyperspectral data
Processed hyperspectral data
OBDH software applications
Auxiliary data

Manager Module

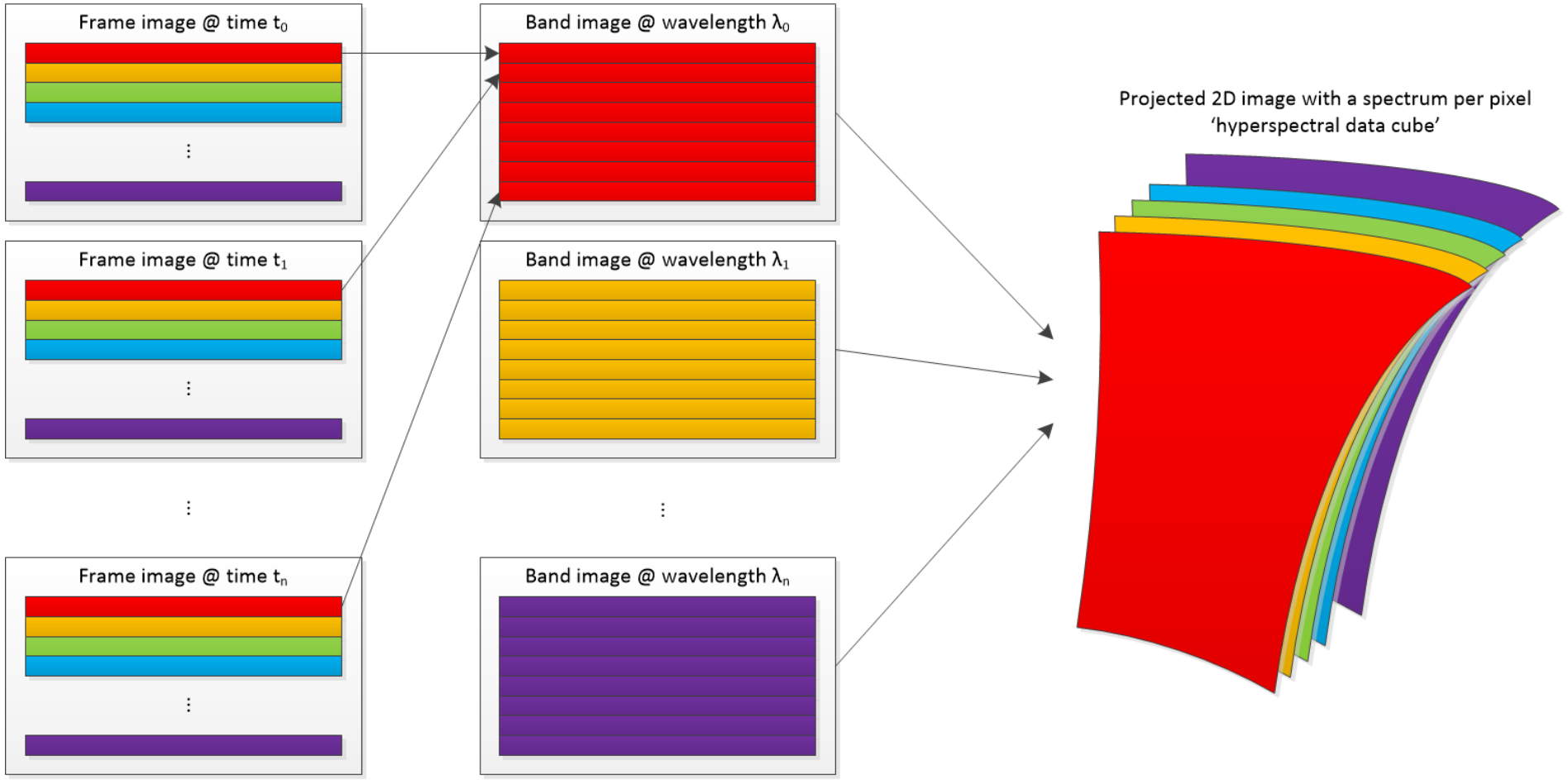




High-level image analysis, computer vision and applications



L0-L2a processing



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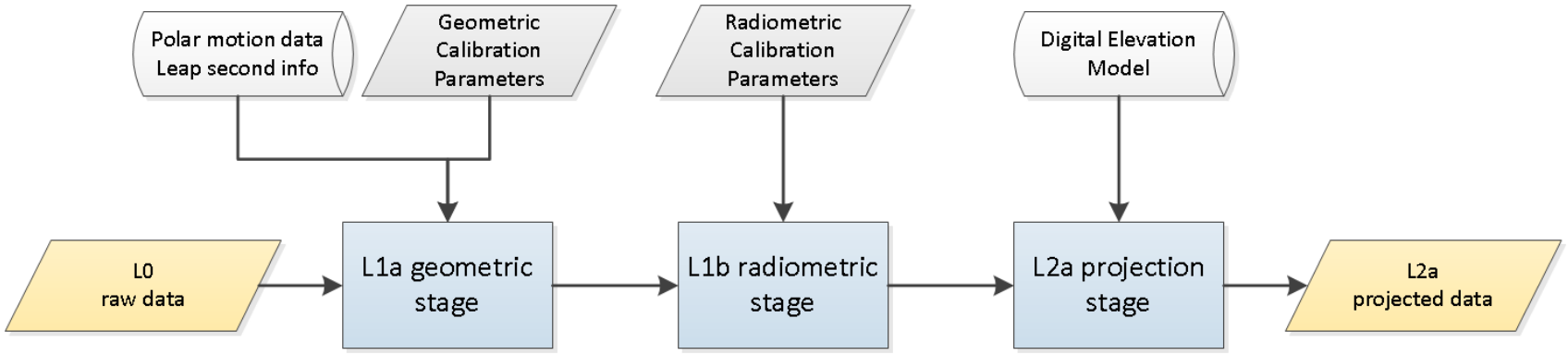
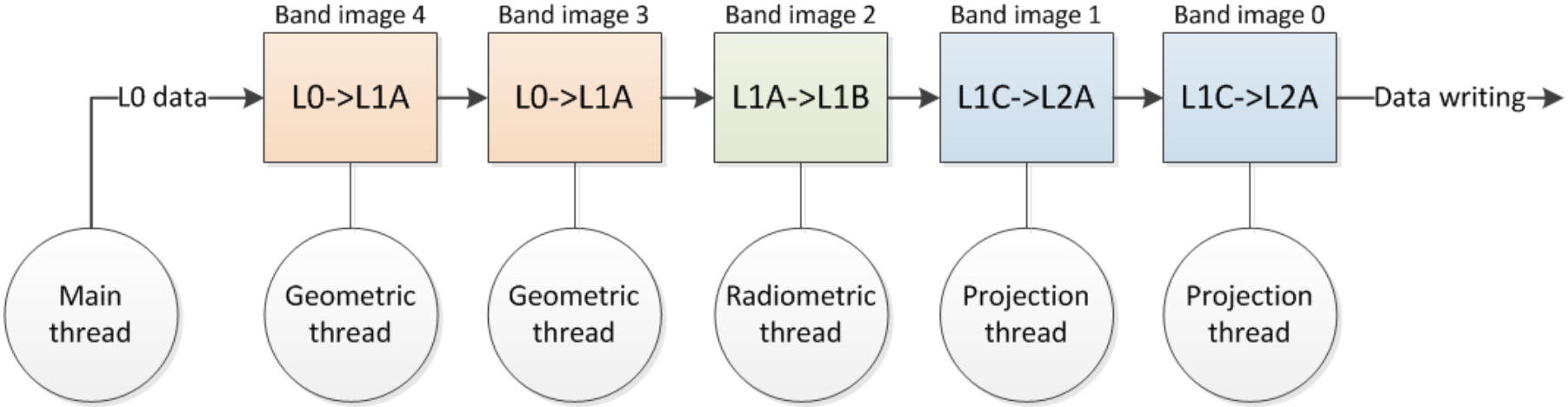
L0-L2a processing





L0-L2a processing

Processing times for a simulated acquisition

- 140 frame images @ 3052x1836 px as input.
- Generates full L2a data cube with 45 bands.
- All processing is applied on a band-image level – data reshaping stage (L1c) can be skipped.
- Highly configurable: Processing time depends on desired quality.

Data level	Processing step	Processing time (low quality)	Processing time (high quality)
L1a	Geometric calculations	1 min 16 sec	1 min 31 sec
L1b	Radiometric corrections	1 min 36 sec	1 min 37 sec
L1c*	Data reshaping	-	-
L2a	Projection and resampling	1 min 57 sec	6 min 17 sec

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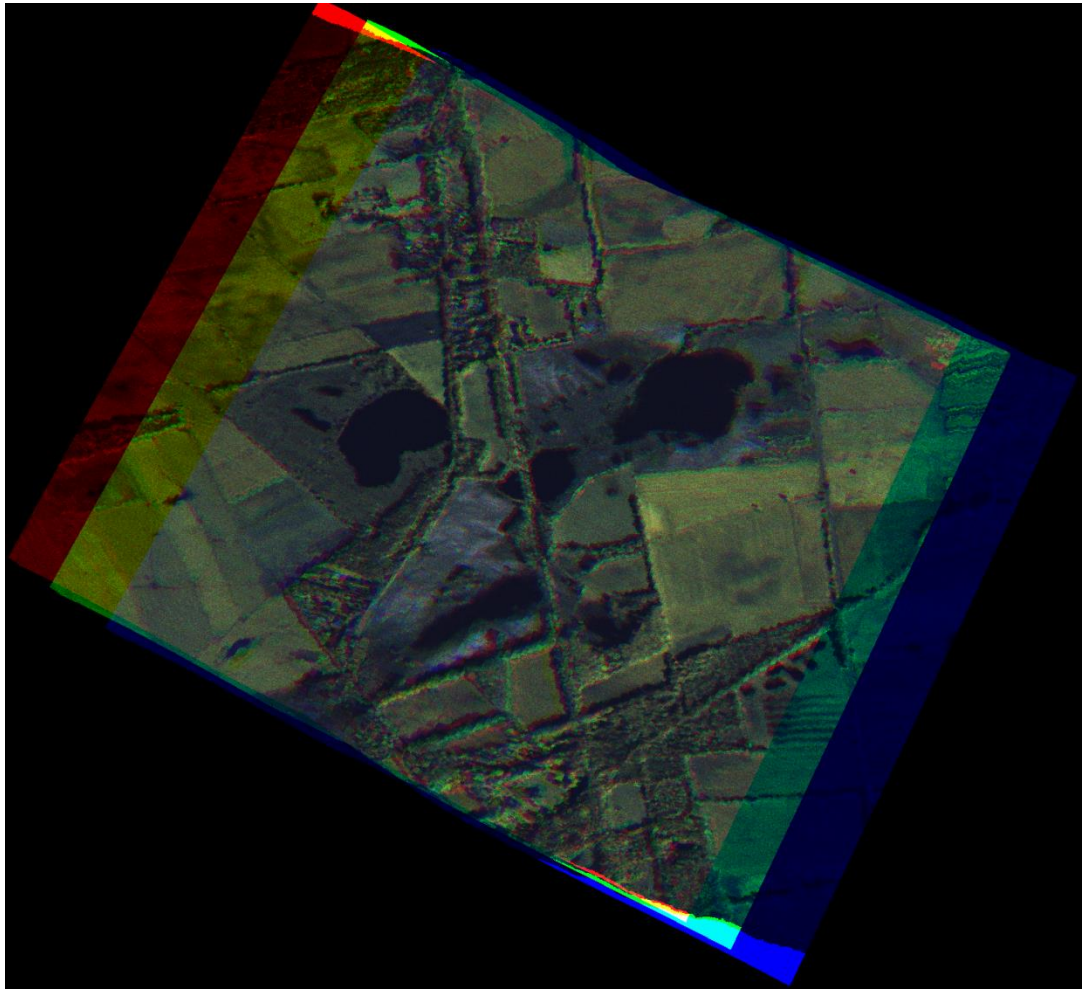
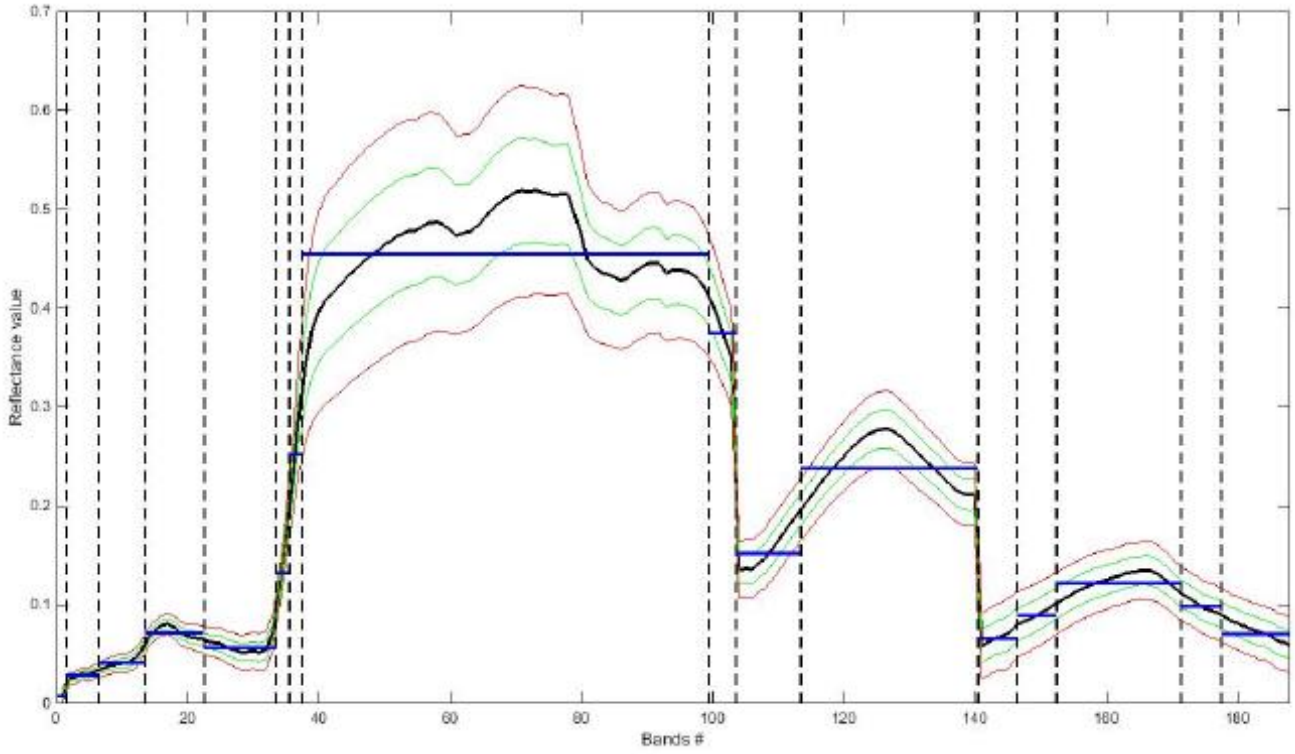
L0-L2a processing



Dimensionality reduction

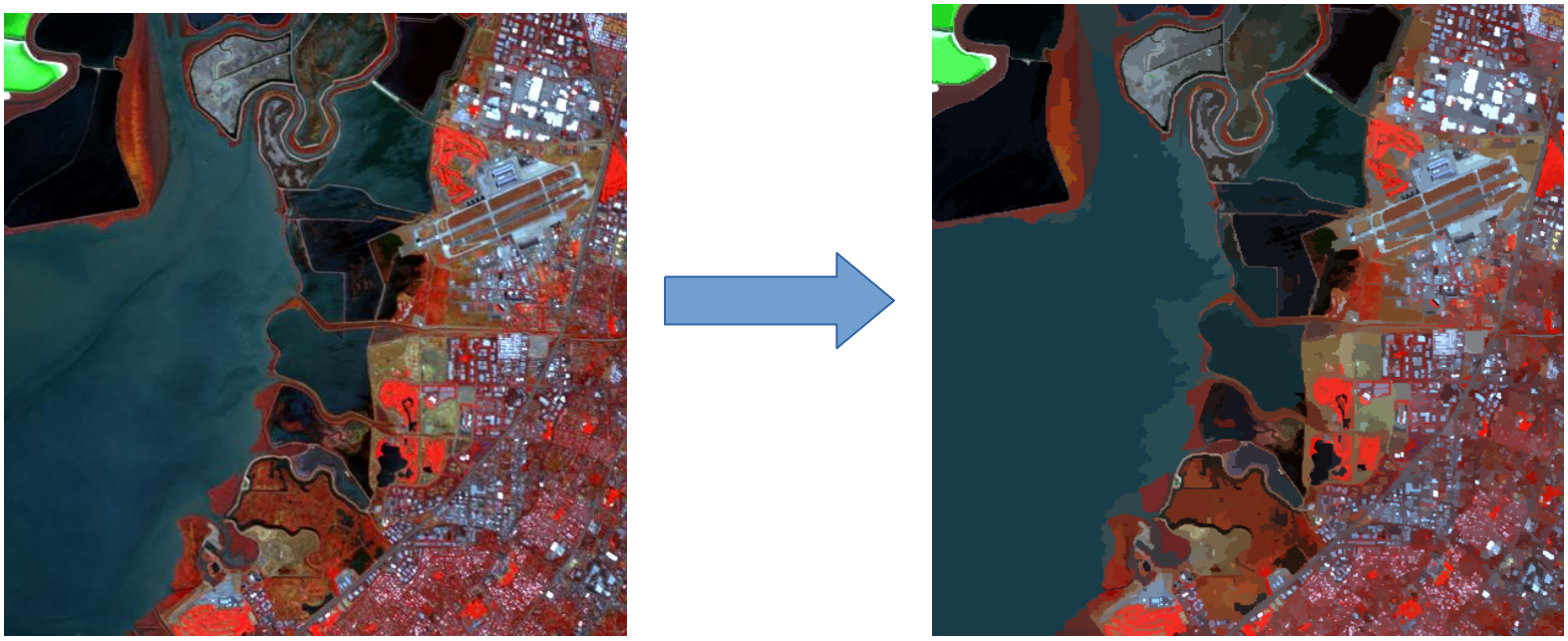
- In both spectral and spatial domain.
- Either as preprocessing step or as stand-alone products.



Spectral Region Splitting (SRS)

Dimensionality reduction

- In both spectral and spatial domain.
- Either as preprocessing step or as stand-alone products.



Hyperspectral image segmentation

From onboard processing to onboard intelligence

- In order to truly interpret a scene intelligently it is necessary to transform pixel values into contextual information.
- Two applications identified as particularly useful for the HyperScout mission:
  - Cloud detection
  - Land-cover classification
- Cloud detection provides a way to filter out unwanted parts of images.
- Land-cover classification acts as a basis for mapping applications and change detection.

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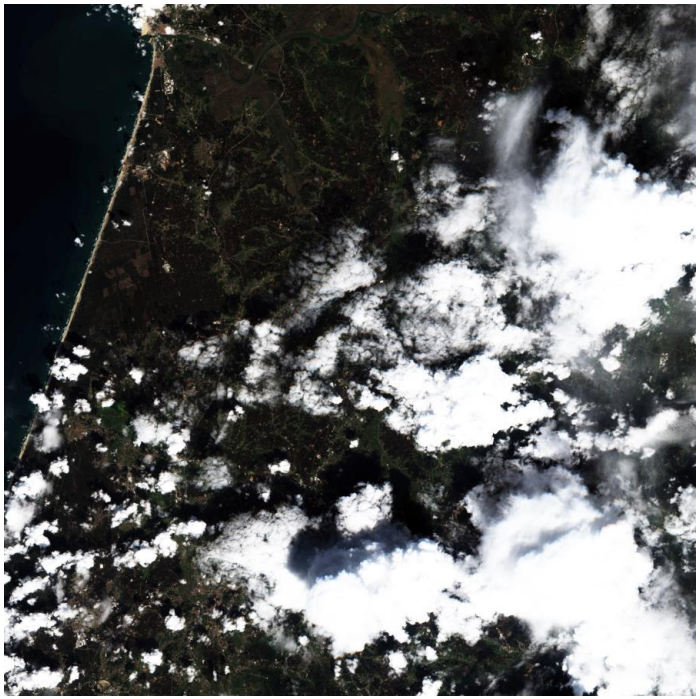
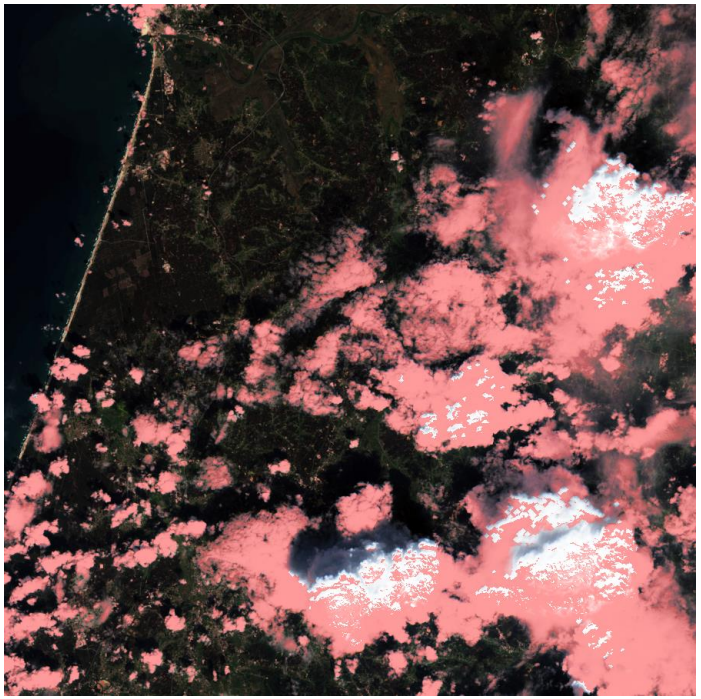
Cloud detection

- Sentinel-2 data for development; official cloud mask as reference.
- Pixel-based classifiers may result in a high number of false positives and false negatives.
- Clouds vary in intensity, pattern and composition.
- Goal: Object-based cloud detection, identify coherent areas of cloudy and clear-sky conditions.



Sentinel-2 RGB image

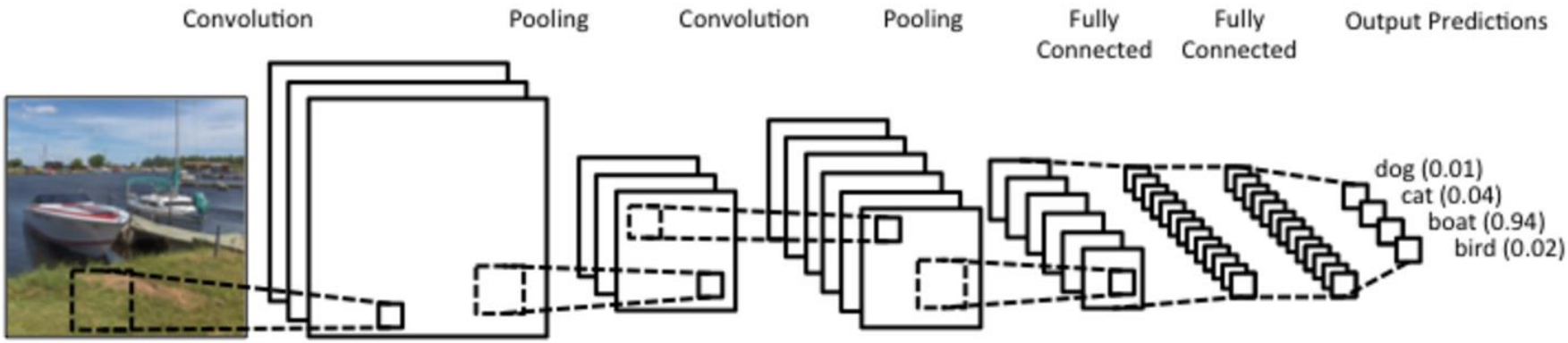


Sentinel-2 cloud mask

Cloud detection

Convolutional Neural Network (CNN)

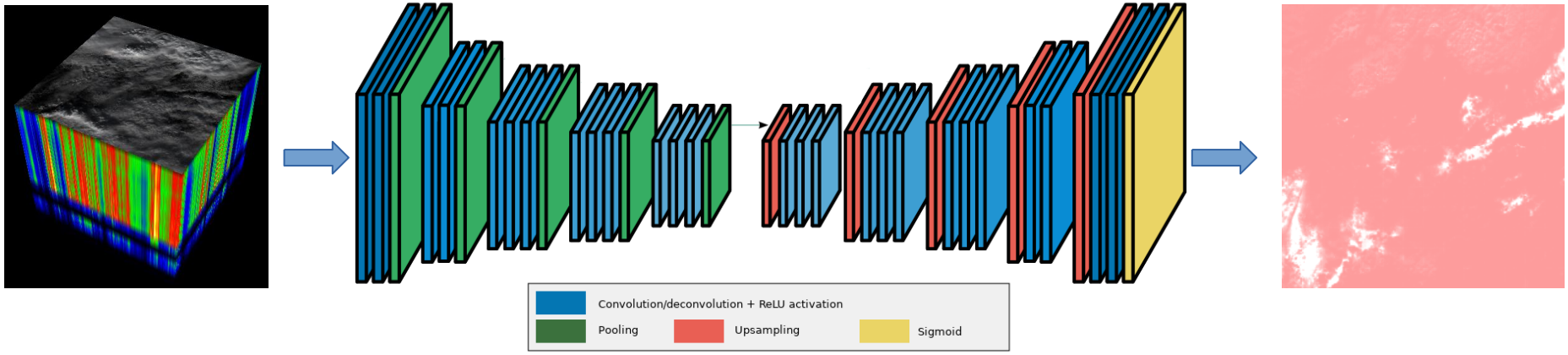
- Machine learning technique.
- “Sees” a neighbourhood of pixels.
- Learns high-level abstractions through a series of convolutions.
- Sate-of-the-art in several computer vision problems.
- Complex and black-box model – hard to observe.
- A high number of parameters to learn – requires large amounts of training data.



Cloud detection

- Customly defined CNN model.
- To obtain a cloud *mask:* include a set of *deconvolutional* layers.
- Sigmoidal activation function on final layer yields values in range [0,1].
- Window size: 128x128 px.

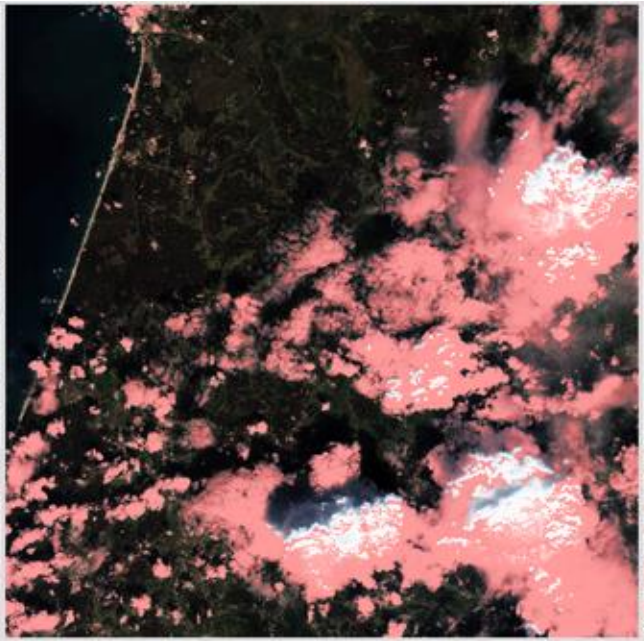
- Training data: ~60 Sentinel-2 scenes with manually corrected cloud masks.
  - Mirror and rotate each sample 90, 180 and 270 degrees -> 8x samples.
  - Split into 20/80% for validation/training.



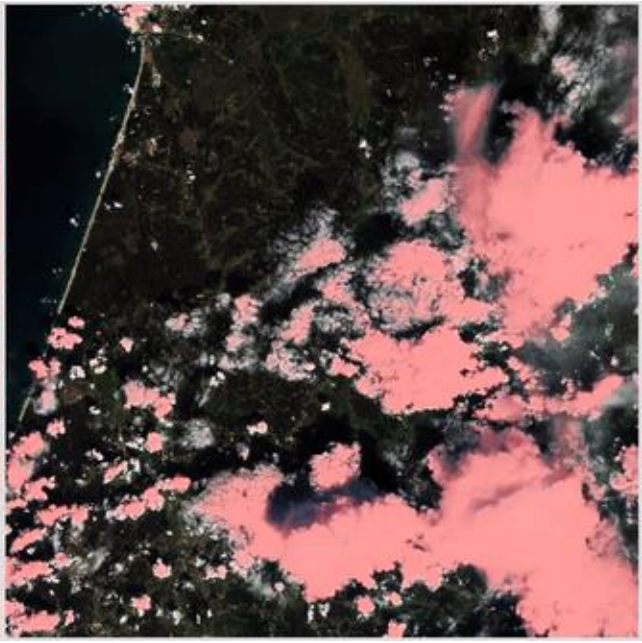
Schematic and topology of the CNN model

Cloud detection

Sentinel-2 RGB image



Sentinel-2 cloud mask



CNN mask

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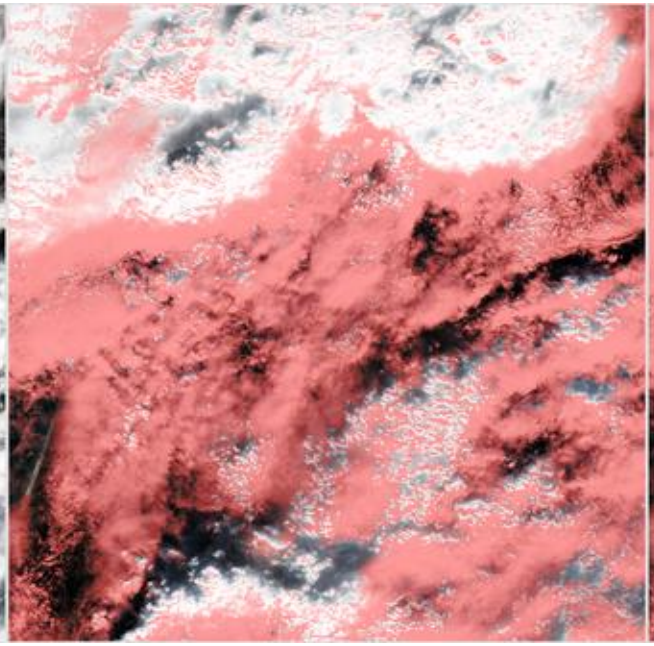
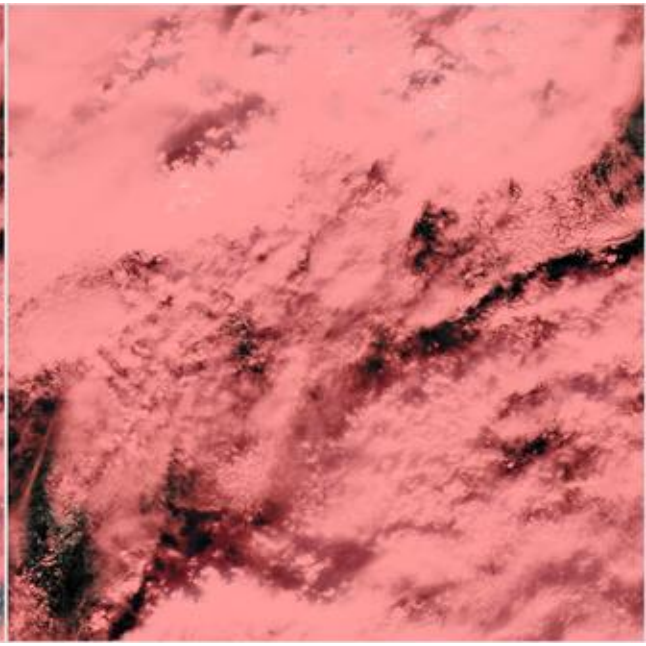
Cloud detection

Sentinel-2 RGB image

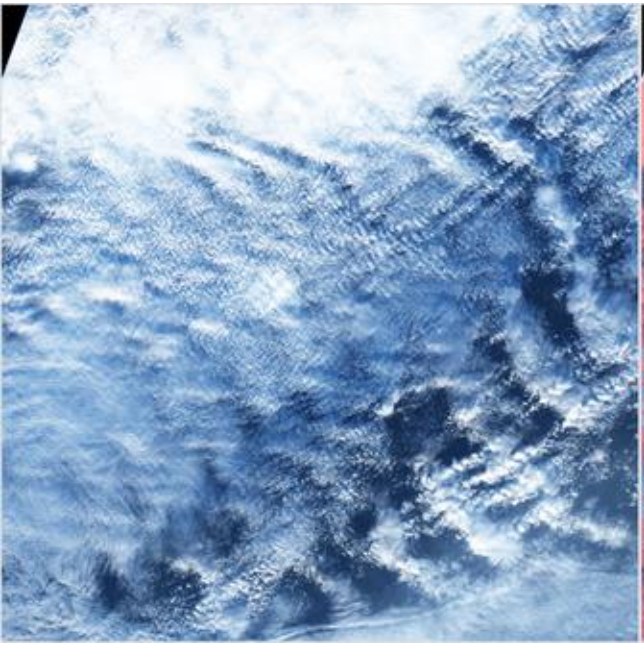


Sentinel-2 cloud mask

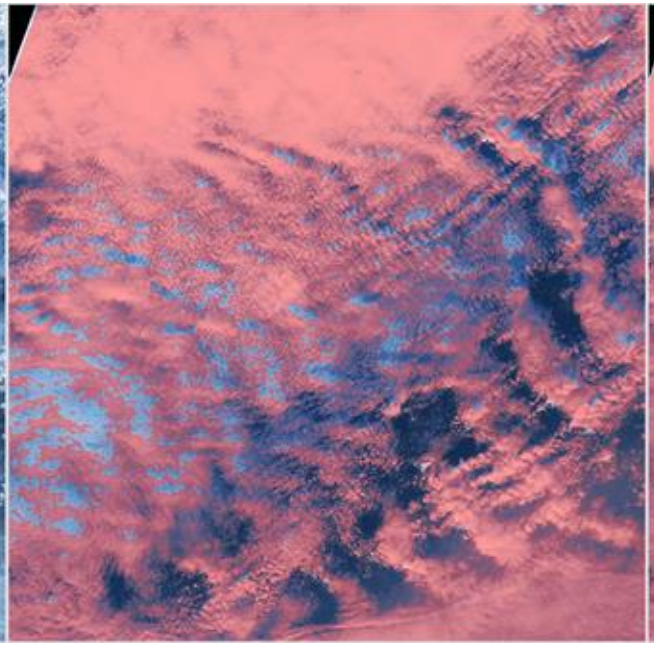


CNN mask

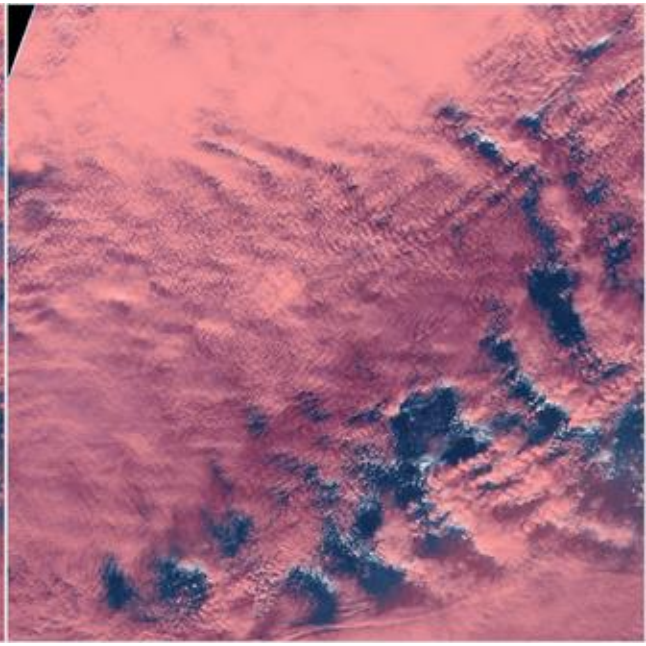
Cloud detection



Sentinel-2 RGB image



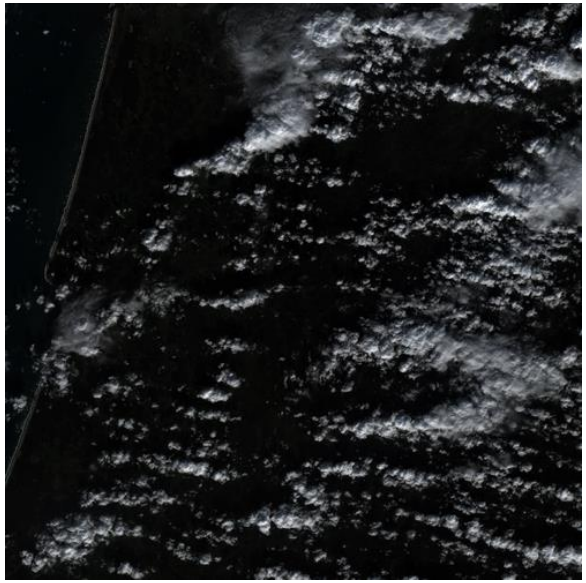
Sentinel-2 cloud mask



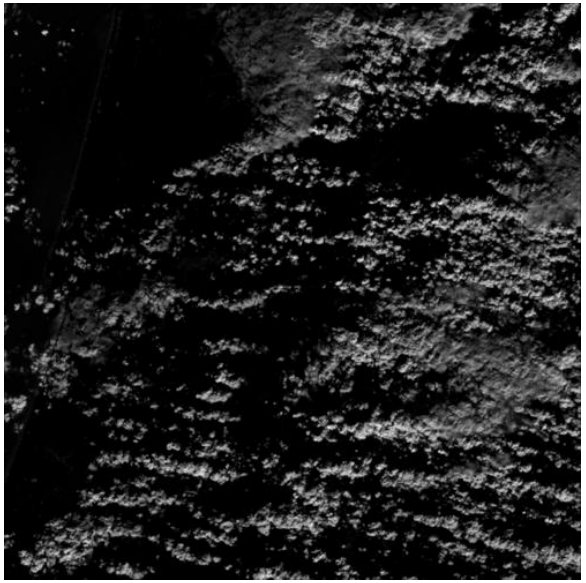
CNN mask

Cloud detection: Future work

- Improve quality and quantity of labelled training data for cloud detection CNN by automatically deducing cloud masks based on large time series over the same area.
- With training data of sufficient quality, introduce more fine-grained cloud detection: Detect cloud type and cloud shadows.



Sentinel-2 image



Cloud mask deduced from time series

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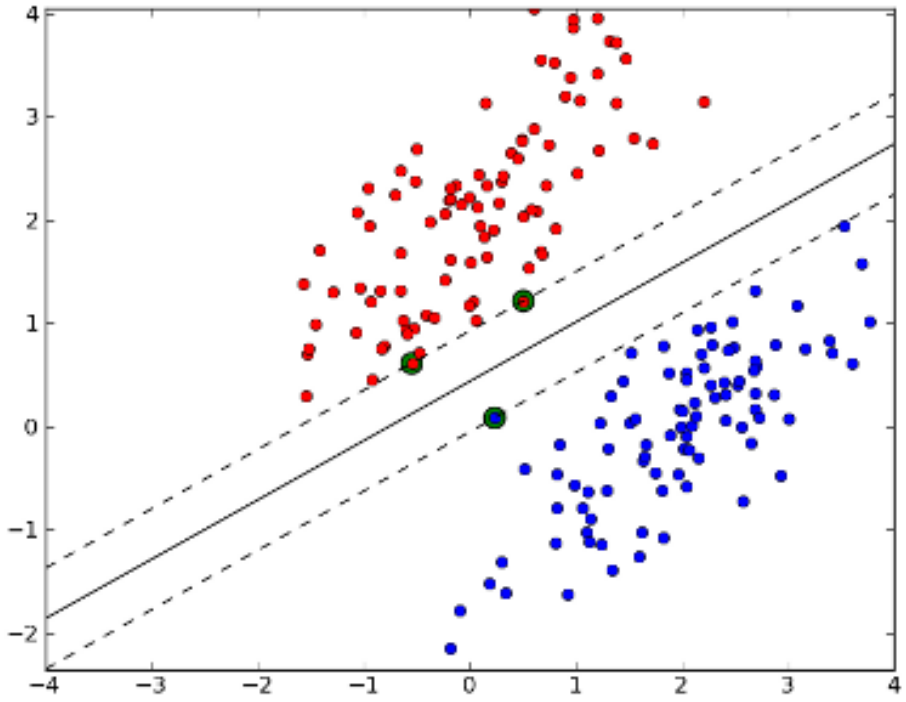
Land-cover classification

Support Vector Machines (SVM)

- Well-known and proven machine learning technique.
- Defines separating hyperplanes in the input feature space.
- Great performance even with low amounts of training data.
- Robust and observable model.



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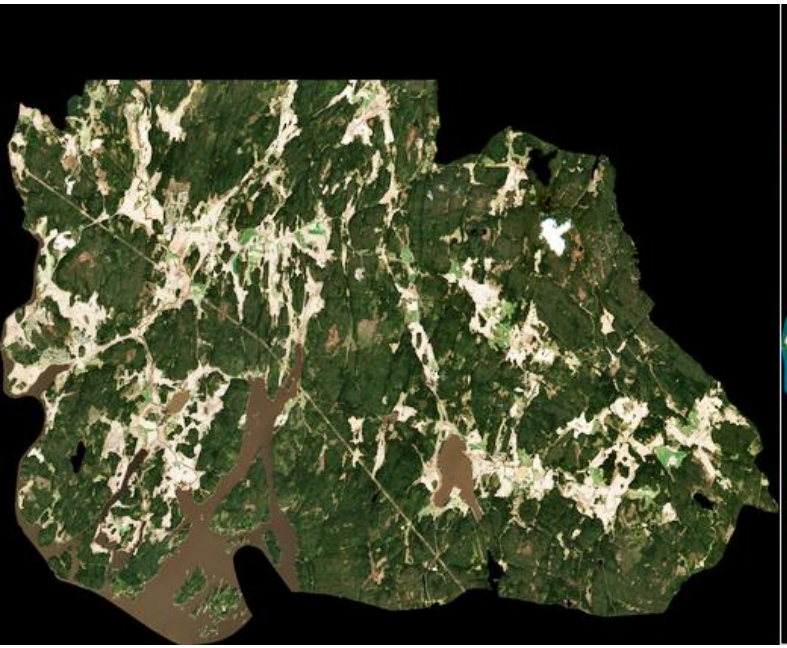
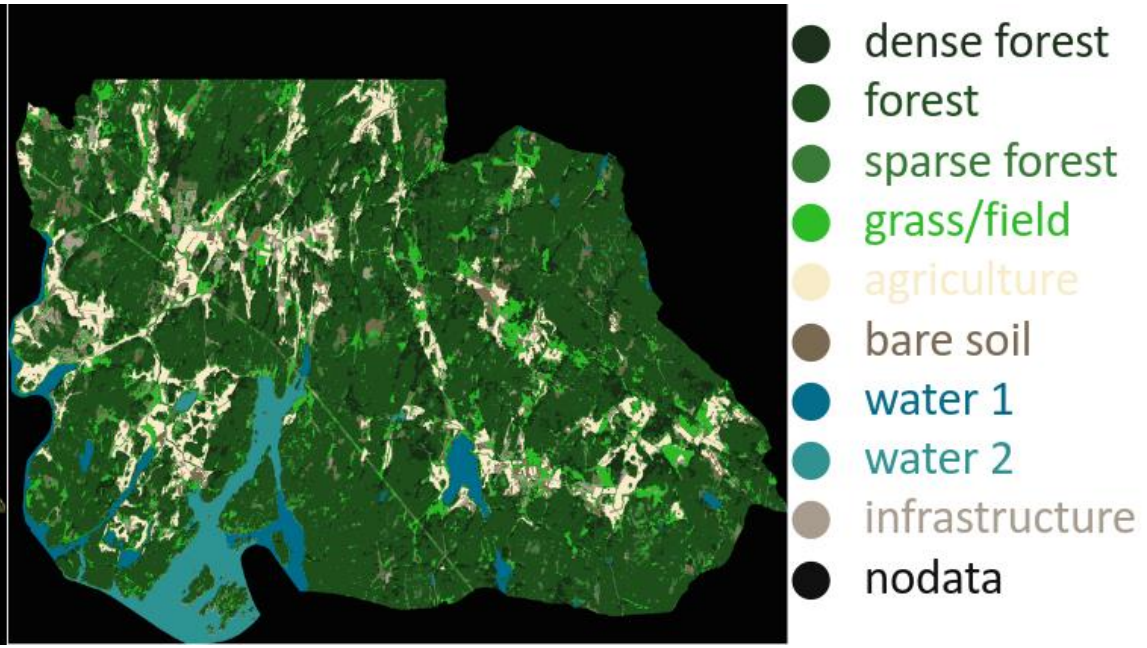
Land-cover classification

Success rate: 94-95%

- Measured against a set of manually classified test scenes.





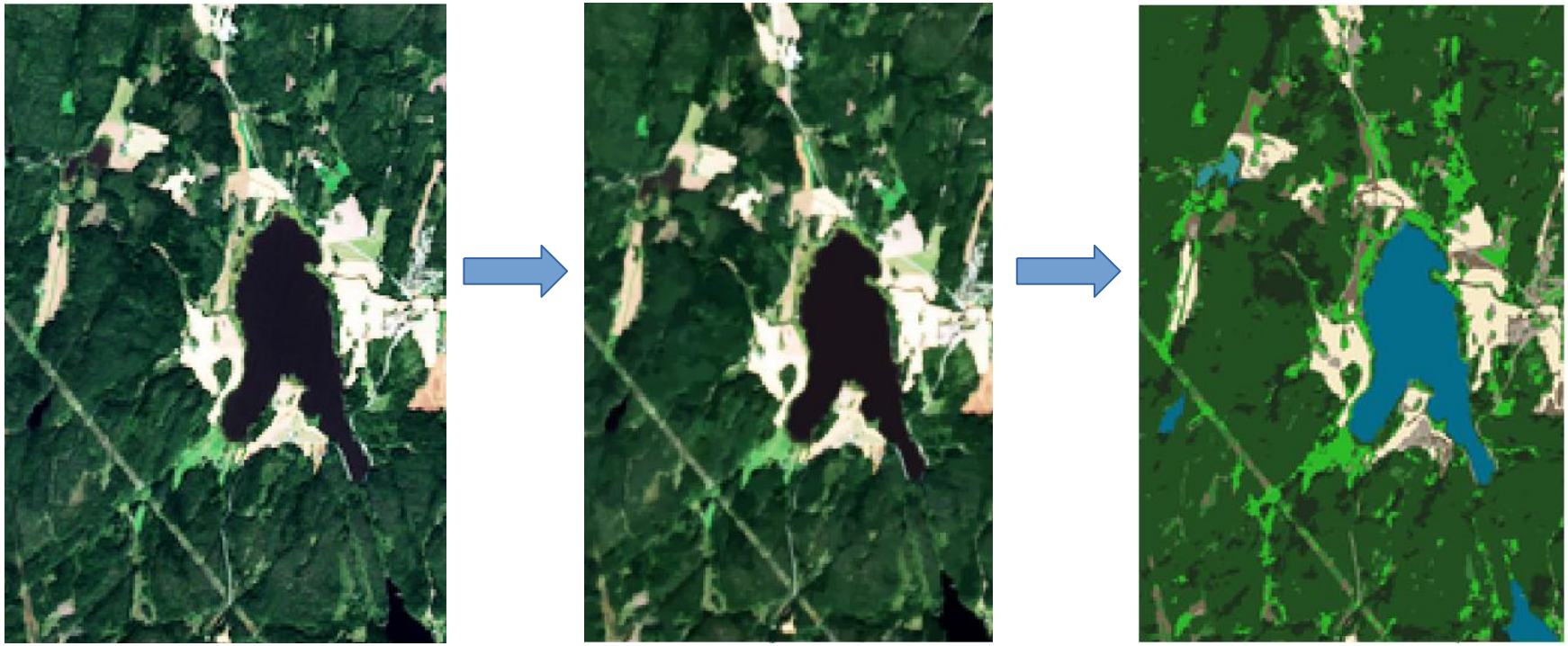
Sentinel-2 RGB image

Land-cover map classified by SVM

Land-cover classification

Designed to operate on segmented images:

- Lower spread in feature space → larger margin for the support vector.
- Smoother land-cover map.



Original image | Segmented image | Land-cover map

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Land-cover classification

Designed to operate on segmented images:

- Lower spread in feature space → larger margin for the support vector.
- Smoother land-cover map.

With segmentation

Without segmentation

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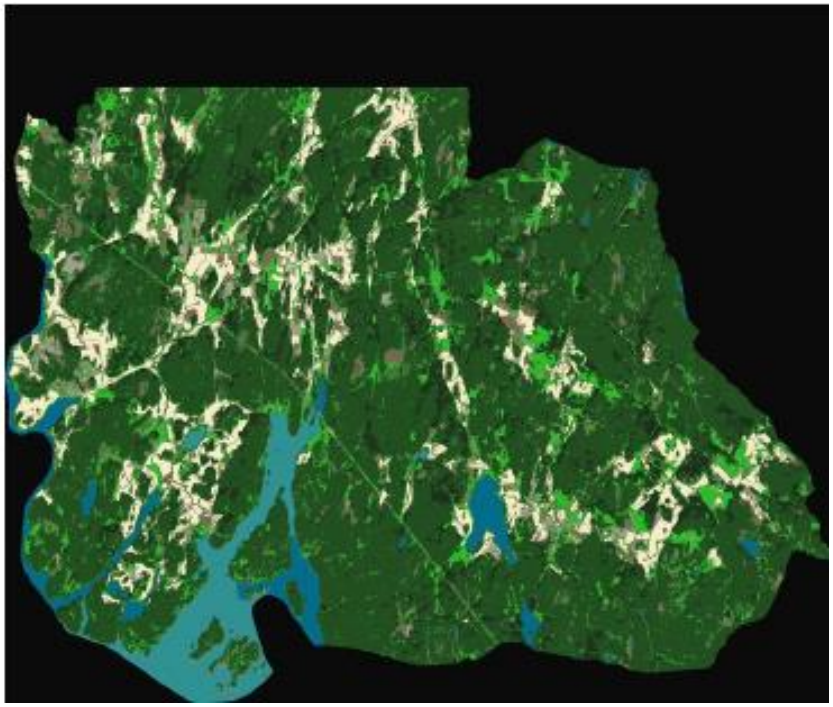
Change detection

Once the context of the scene is captured, it is trivial to query images, extract information of interest and detect transition in class.
Demo: Detection of clearcutted forest.

8 May 2016



5 September 2016

Change detection

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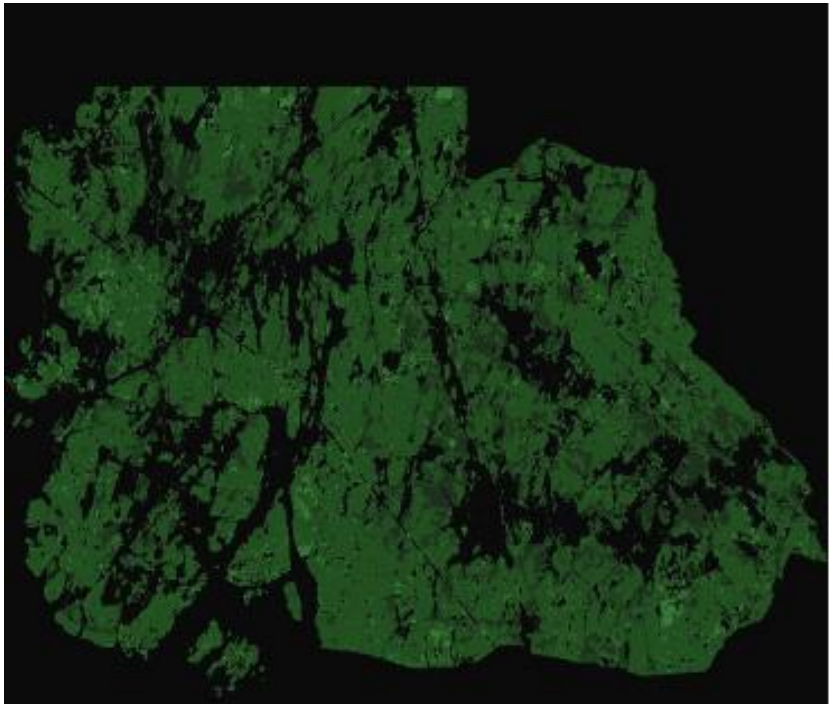

8 May 2016
"All types of forest"

5 September 2016
"Bare soil"

Change detection

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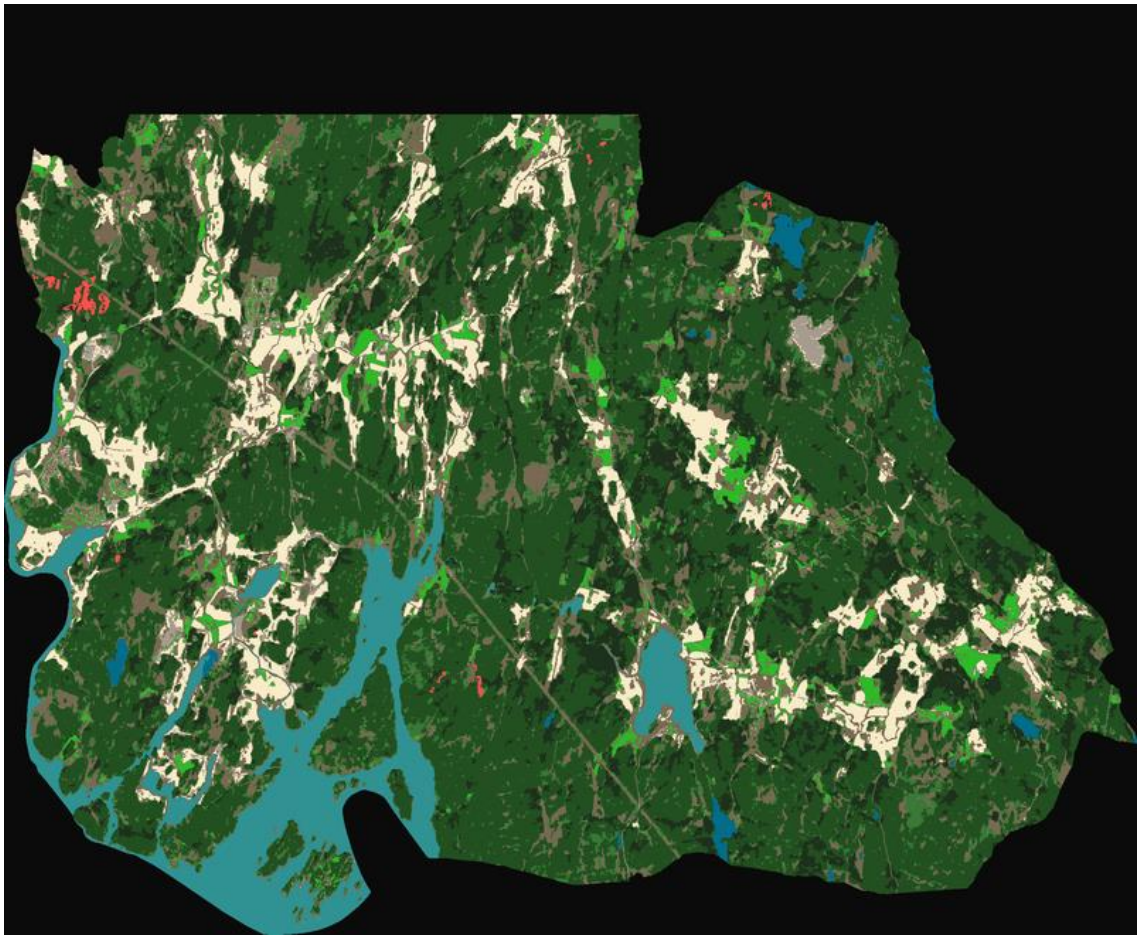
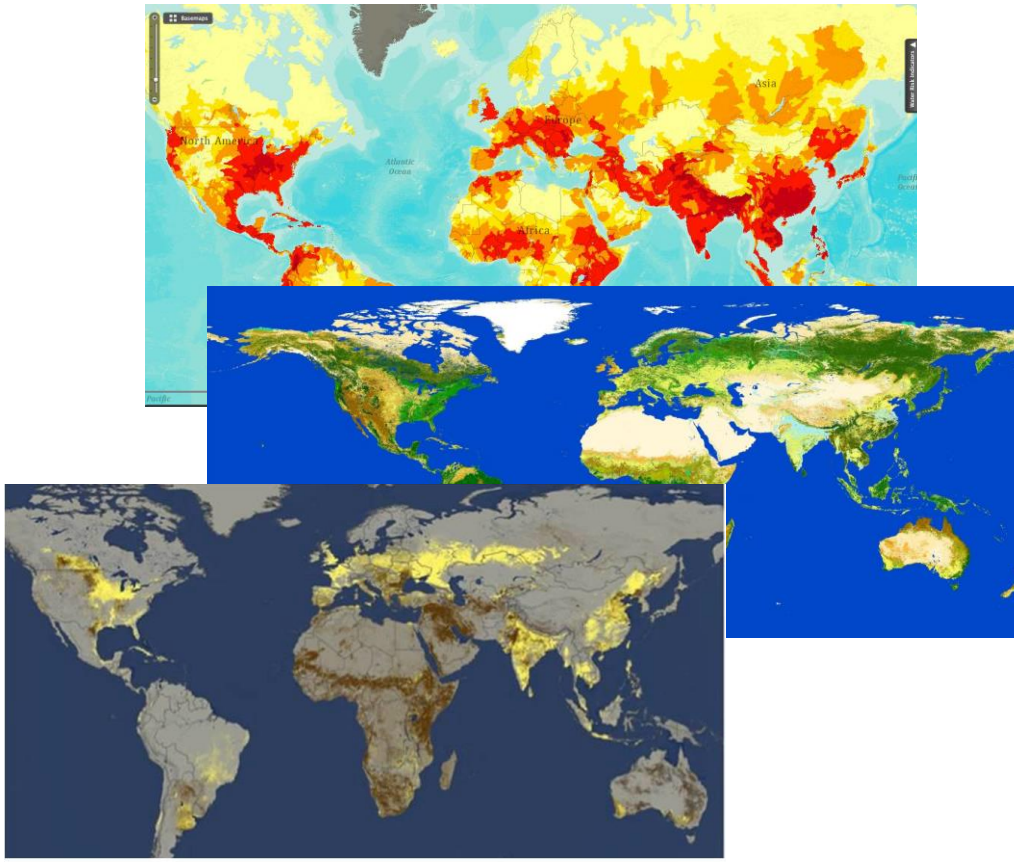
Demo: Detection of clearcutted forest.



Spectral indices

With cloud detection and land-cover classification, applications based on spectral indices can be constrained to operate on valid areas.

- Flood monitoring
- Crop water requirements
- Vegetation health
- Drought
- Urbanisation
- Fire hazard
- Burned areas
- +++



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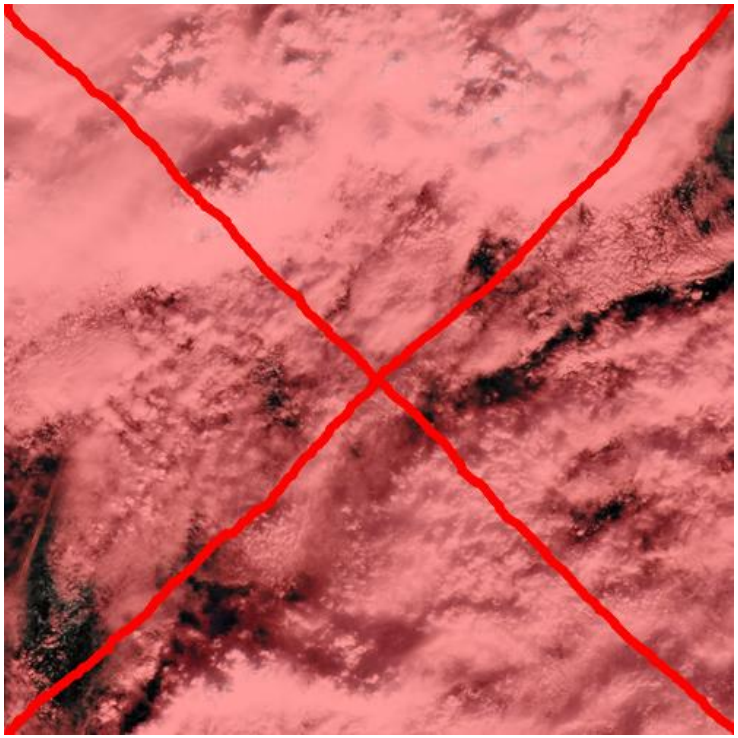
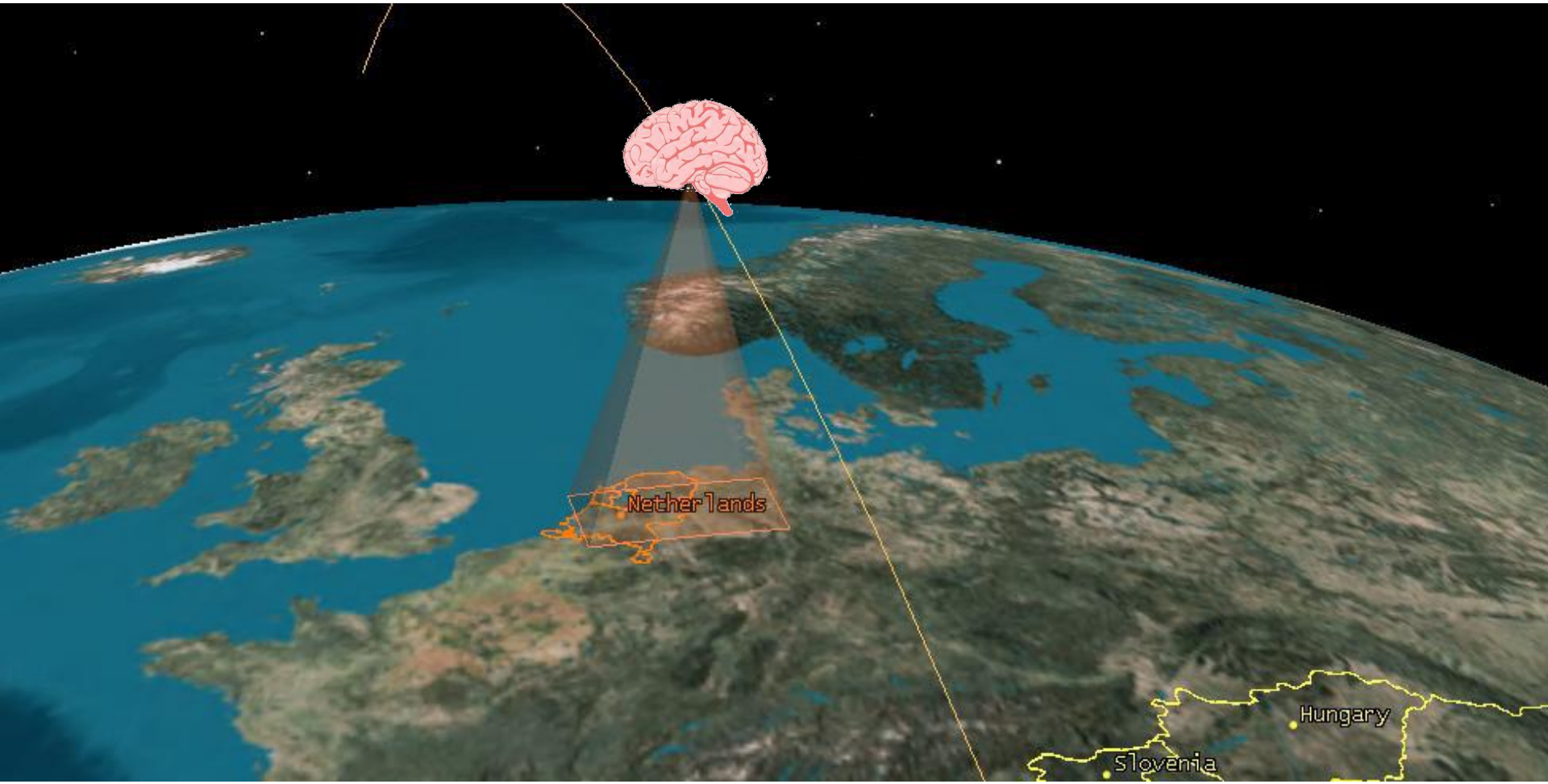
Downlink prioritization

Discard fully clouded images or identify clear-sky regions.



Thank you



http://hyperscout.nl

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