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RSS-Hydro, S.à r.l.-S

Conventional EO Satellites vs. CubeSats
-
FLD, AI flood detection onboard NanoSATs

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-
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Content:

Part 1: Conventional EO Satellites vs. CubeSats

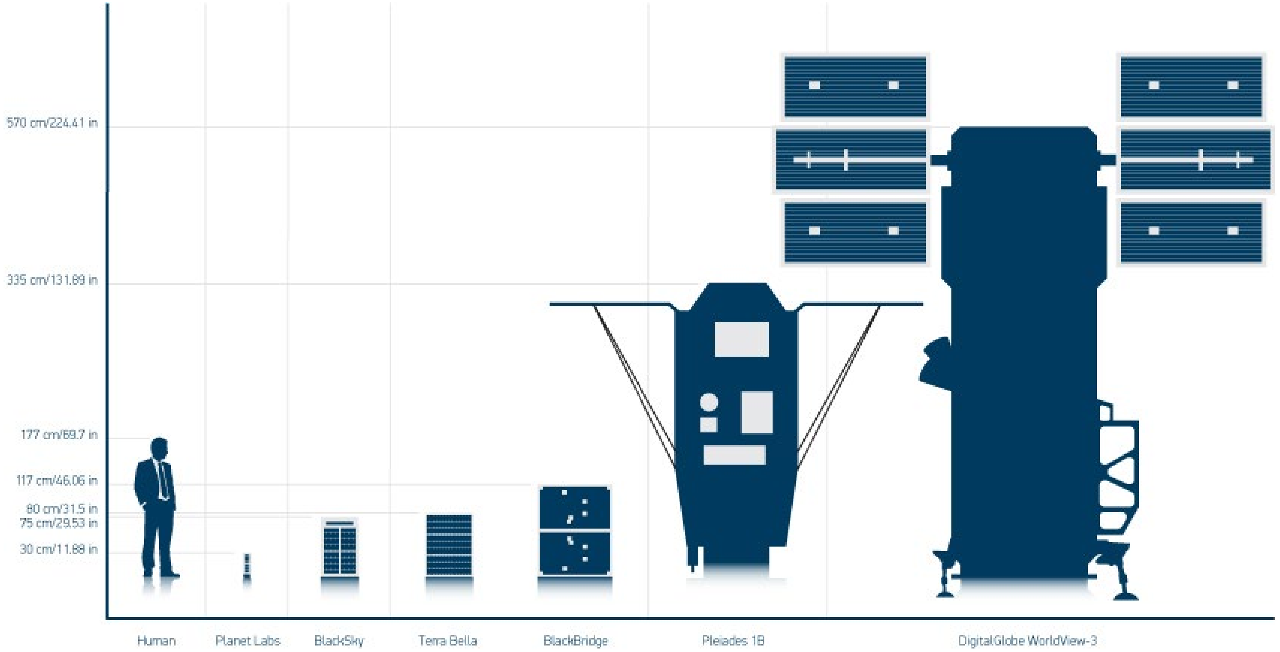
- a light hearted Overview
- Optical EO from LEO
- Basic Principles of Optical Spaceborne Imaging

Part 2: FDL-Europe - Disaster Prevention, Progress and Response (Floods)

- Flood Detection On Low Cost Orbital Hardware – Story and approach
- World Floods data set
- End to End machine learning approach
- Optimisation for deployment onboard the Satellite

Summary and Outlook

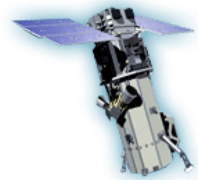
Conventional EO Satellites vs. CubeSats

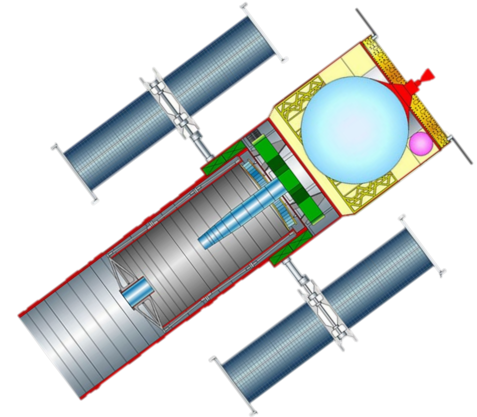


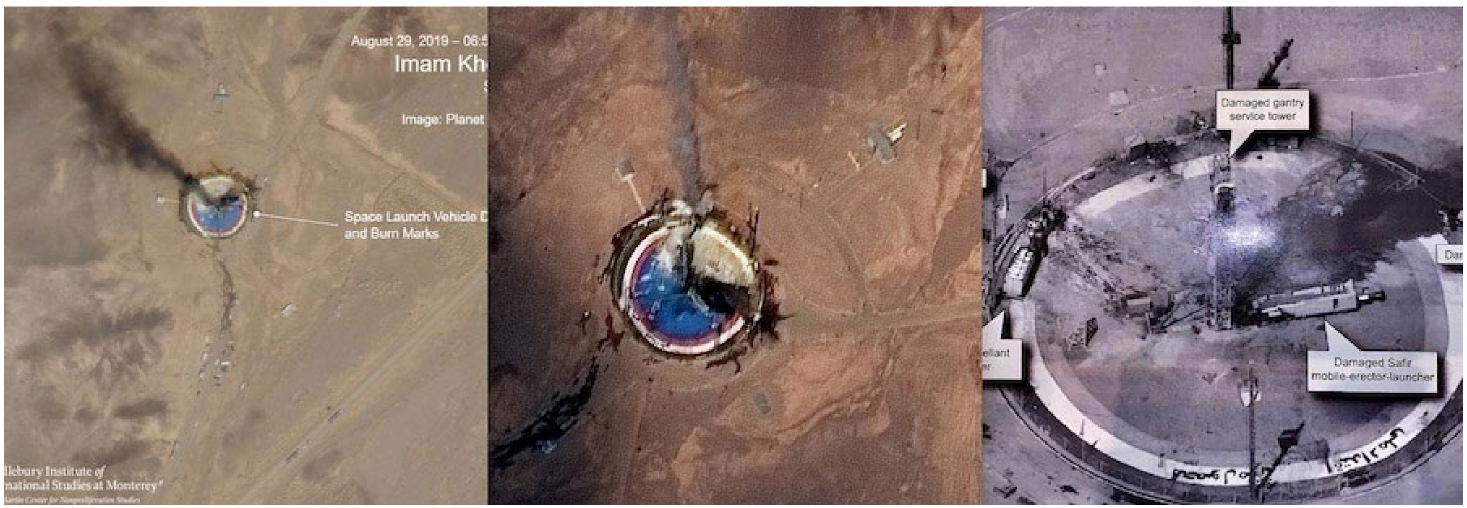
Credit: Digital Globe 12/2016

…so where are the differences?

Pictures from Space





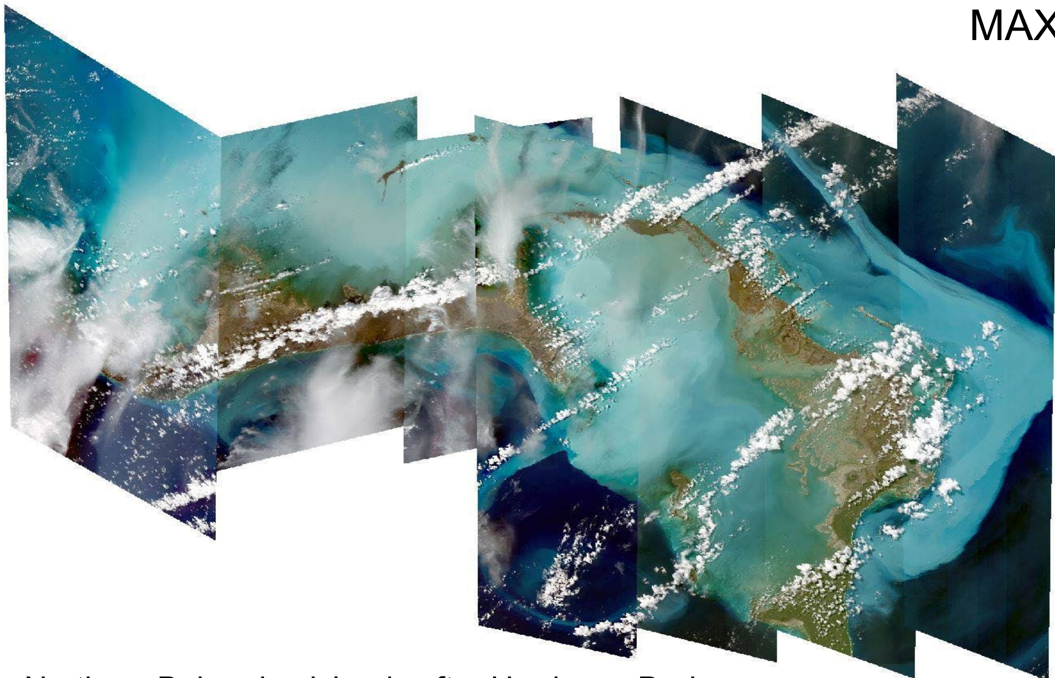


Spaceflight now 30/08/2019, Images of Semnan launch site Credit: Planet, Maxar and @realDonaldTrump

- Left: captured by Planet approx. 3m resolution (Dove, RapidEye or Skysat)
- Centre: Maxar/Digital Globe WorldView2 Satellite approx. 0.3m resolution
- Right: US intelligence image https://twitter.com/realDonaldTrump/status/1167493371973255170
  suspected KH11 type satellite (USA-244)

Very High-resolution Images by WorldView

MAXAR



Northern Bahamian islands after Hurricane Dorian

WorldView 2 Satellite

- Multispectral images captured from a single orbit
- 29,900 km2 in 7 separate scenes

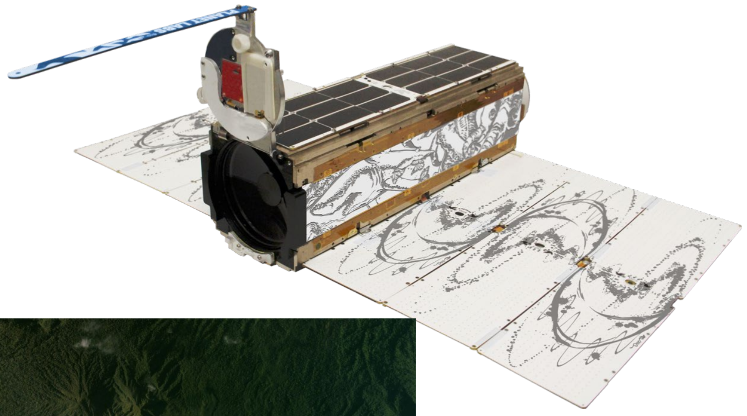
- Highly agile: body-pointing range of ±40º correspondent to 1355km FOR cross-track
- Pointing accuracy <500 m at image start and stop
- Large 2.2 TB on-board storage;
- Imagery is downlinked in X-band at 800 Mbit/s
- Theoretical 1.1 day revisit time

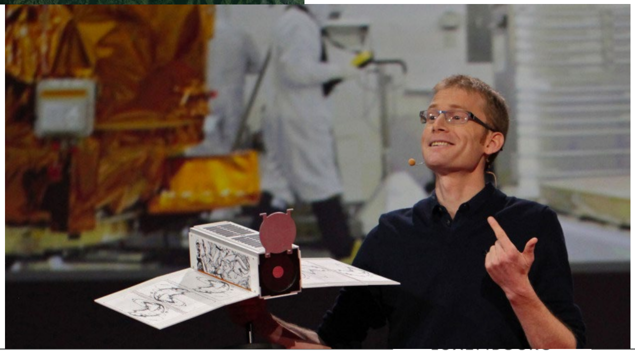
High-resolution Optical Images from CubeSats

Table 2
Preliminary assessment of the feasibility of Cubesat-based missions carrying different remote sensing technologies.

Technology	Feasibility assessment (feasible/problematic/ infeasible)	Justification
Atmospheric chemistry instruments	Problematic	Low sensitivity in SWIR-MIR because of limited cooling capability
Atmospheric temperature and humidity sounders	Feasible	e.g., GNSS radio occultation, hyperspectral millimeter-wave sounding
Cloud profile and rain radars	Infeasible	Dimensions, power
Earth radiation budget radiometers	Feasible	[63]
Gravity instruments	Feasible	[64]
High resolution optical imagers	Infeasible	Not enough resolution-swath, because limited space for optics and detectors
Imaging microwave radars	Infeasible	Limited power
Imaging multi-spectral radiometers (vis/IR)	Problematic	Limited imaging capability
Imaging multi-spectral radiometers (passive microwave)	Problematic	Limited imaging capability
Lidars	Infeasible	Limited power
Lightning imagers	Feasible	[30]
Magnetic field instruments	Feasible	[65]
Multiple direction/polarization radiometers	Problematic	Limited dimensions for receiver electronics
Ocean color instruments	Feasible	[4]
Precision orbit	Feasible	[66]
Radar altimeters	Infeasible	Dimensions
Scatterometers	Infeasible	Dimensions

Selva, D., Krejci, D., 2012. A survey and assessment of the capabilities of Cubesats for Earth observation. Acta Astronaut. 74, 50–68. https://doi.org/10.1016/j.actaastro.2011.12.014



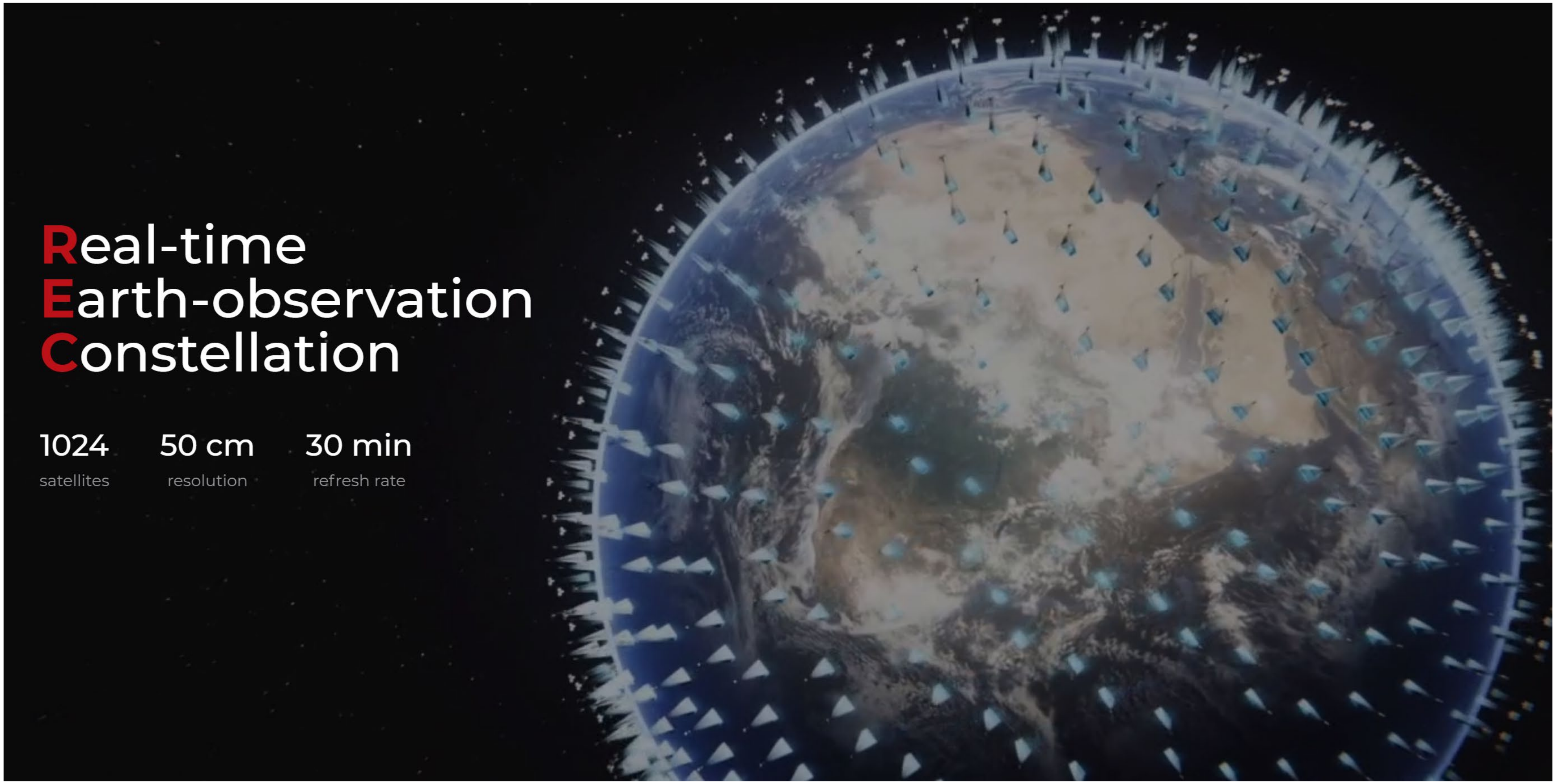


Comparison

Planet, Planetscope
3.6m GSD, MS

WorldView 2,
approx. 2m, MS

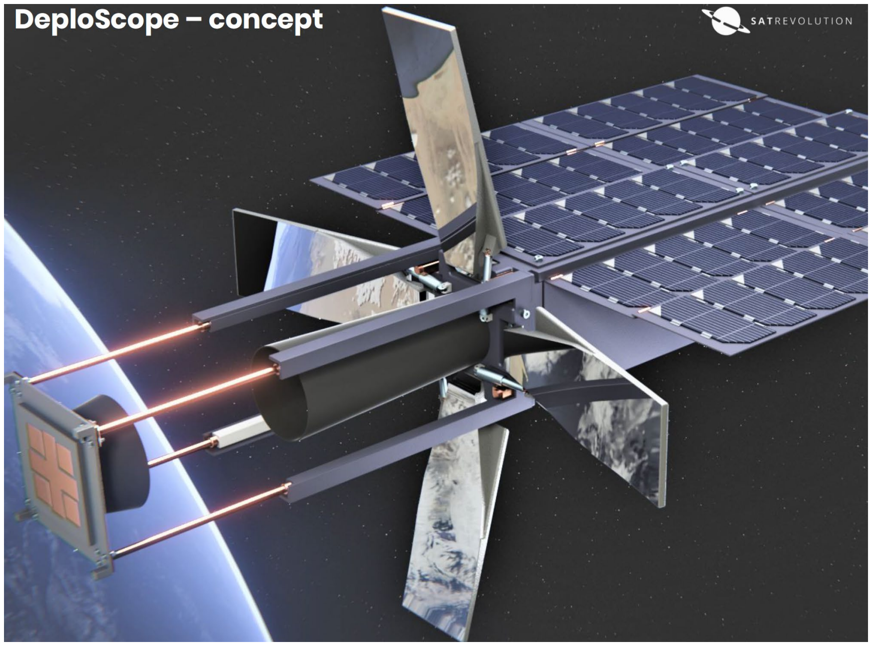
Satellite Revolution (?!)



Reference: https://satrevolution.com/rec/

Poźniak, Tomasz, 2019. Earth observation by utilizing nanosatellite constellation. Presented at the 11th European CubeSat Symposium, Luxembourg. https://www.cubesatsymposium.eu/

Satellite Revolution (?!)



No	Parameter	Value
1	Spectral range	VNIR – achromat
2	GSD (Ground Sample Distance)	1,1 m @350 km
3	Sensor size	8,5x7,1 mm
4	Pixel size	3,45x3,45 um
5	Focal length	1100 mm
6	f#	f/6,1
7	FoV (Field of View)	±0,288°
8	MTF (Modulation Transfer Function)	7% - 15,6% @93 lp/mm
9	Strehl ratio	0,8
10	Mass	>360 g (optics only)
11	Dimensions – stowed position	100x100x175 mm
12	Dimensions – deployed position	180x180x175 mm
13	Optical surface tolerances	P-V<1 μm; RMS: 1 fringe @632,8 nm; focal length tolerance: 0,02%
14	Acceptable deployment error	7 μm
15	Thickness of optical elements	3,5-6 mm
16	Materials TBD	Aluminium, SiC, Zerodur, Invar

Current stage

Phase 1
Q3 2019
- DeploScope's early design & NanoBus in orbit demonstration (as Światowid's base in mid July)

Phase 2
Q3 2021
- ScopeSat prototype in orbit demonstration

Phase 3
Q4 2022
- 16 ScopeSats in orbit – 16 h revisit time
- First constellation's iteration
- **Starting the satellite factory project**

Phase 4
Q4 2023
- 66 ScopeSats in orbit – 4 h revisit time
- Second constellation's iteration

Phase 5
Q2 2026
- 1024 ScopeSats in orbit – 30 min revisit
- Final constellation's iteration

Earth observation from LEO

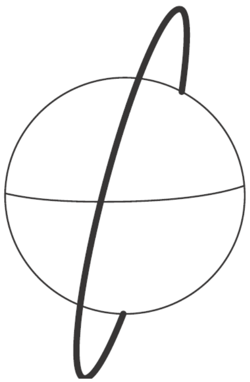
‘The Risky Rush for Mega Constellations’

The European Space Agency recently was forced to maneuver its Aeolus satellite to avoid a potential collision with one of SpaceX's Starlink satellites. Credit: ESA and ATG medialab

Experts are alarmed by plans to launch tens of thousands of revolutionary satellites in coming years

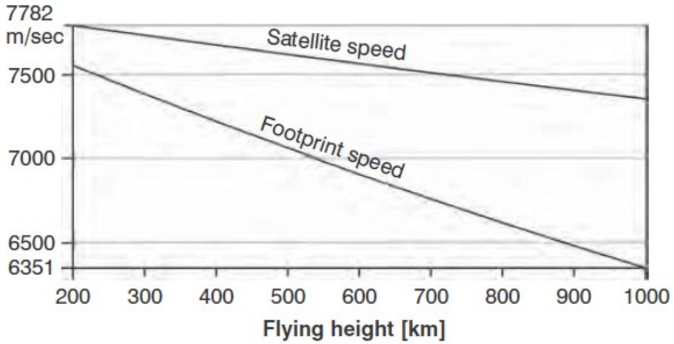
O'Callaghan, Jonathan, 2019. The Risky Rush for Mega Constellations. Scientific American
https://www.scientificamerican.com/article/the-risky-rush-for-mega-constellations/

Earth observation from LEO



- Sun-synchronous, near-polar orbit with 98° inclination
  - most common orbit for optical EO satellites
  - orbit period approx. 90 min at 700-800km

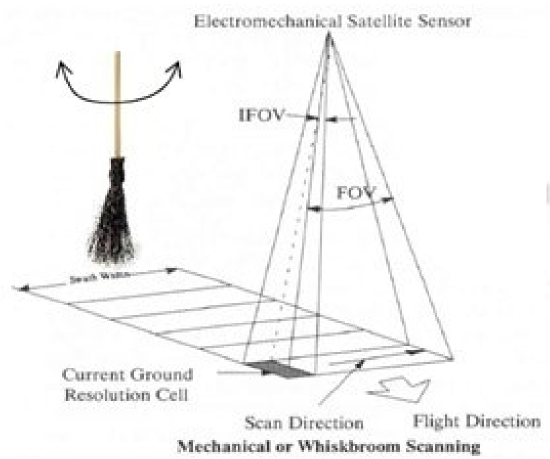
- Satellite Speed as a function of flying height in a 'circular' orbit:
  - Approx. 7 km/s for EO satellites
  - t_{dwell} (1m GSD) ~ 0.14msec
  - $t_{int} < t_{dwell}$

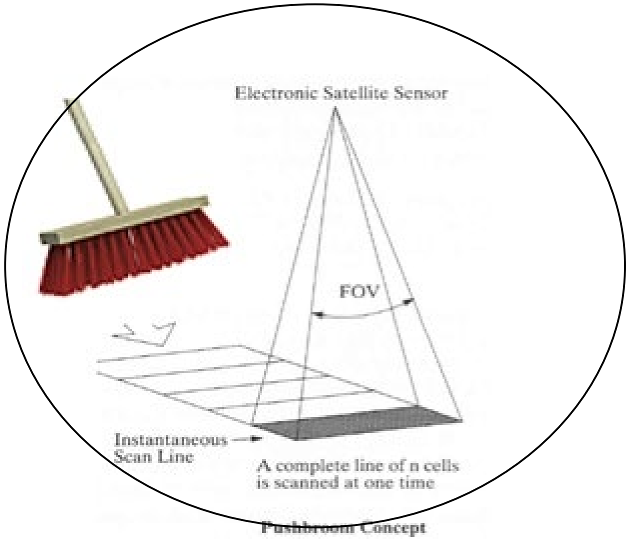


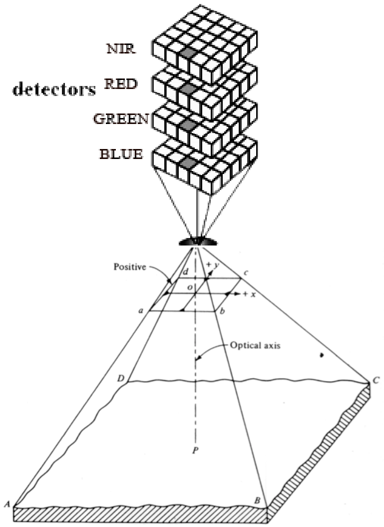
- Example Ikonos2 (typical for EO satellites)
  - Inclination: 98.1°
  - Period: 97 min
  - Equatorial crossing: 10:30 am solar time
  - Altitude: 681km

Satellite speed: 7.613 km/s
Footprint speed: 6.878 km/s

Principles of Imaging Sensors





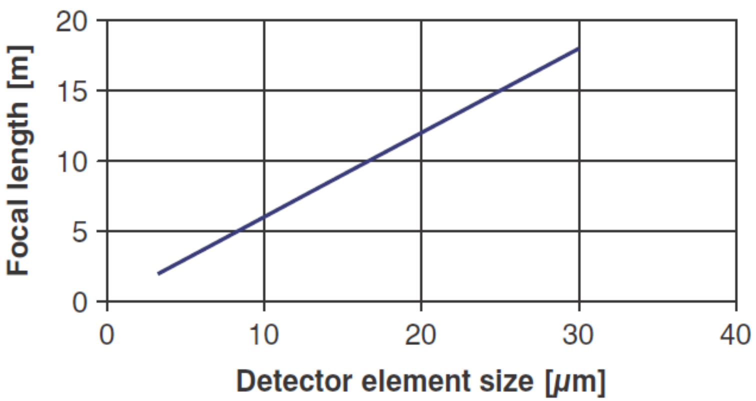


Staring, frame Geometry

Relationship between detector element, focal length, orbit height and GSD:

$$f = \frac{H_{Orbit}}{GSD} \cdot x$$

The figure shows the relationship between required focal length and detector size for a orbit altitude of 600km at 1m GSD.



Requirements for Spaceborne Imaging Systems:

- Spatial resolutions and quality:

$$MTF_{SR} = MTF_{Optics} \,.\, MTF_{D} \,.\, MTF_{PS}$$

- Radiometric aspects:
  - Higher resolution means smaller amounts of energy from smaller ground pixels
  - ***Time related*** factor: dwell time (t_{dwell}) and ***geometry related*** factor (IFOV)
  - E.g. the reduction of 10m to 1m GSD reduce the amount of energy at the detector by approx. 1000.

- Pointing accuracy:
  - Start and stop pointing: < 500m
  - Geolocation accuracy: 6.5m

  Common specification for high-resolutions EO systems

- Platform stability:

$$MTF_{PS} = MTF_{LM} \,.\, MTF_{J} \,.\, MTF_{sin}$$

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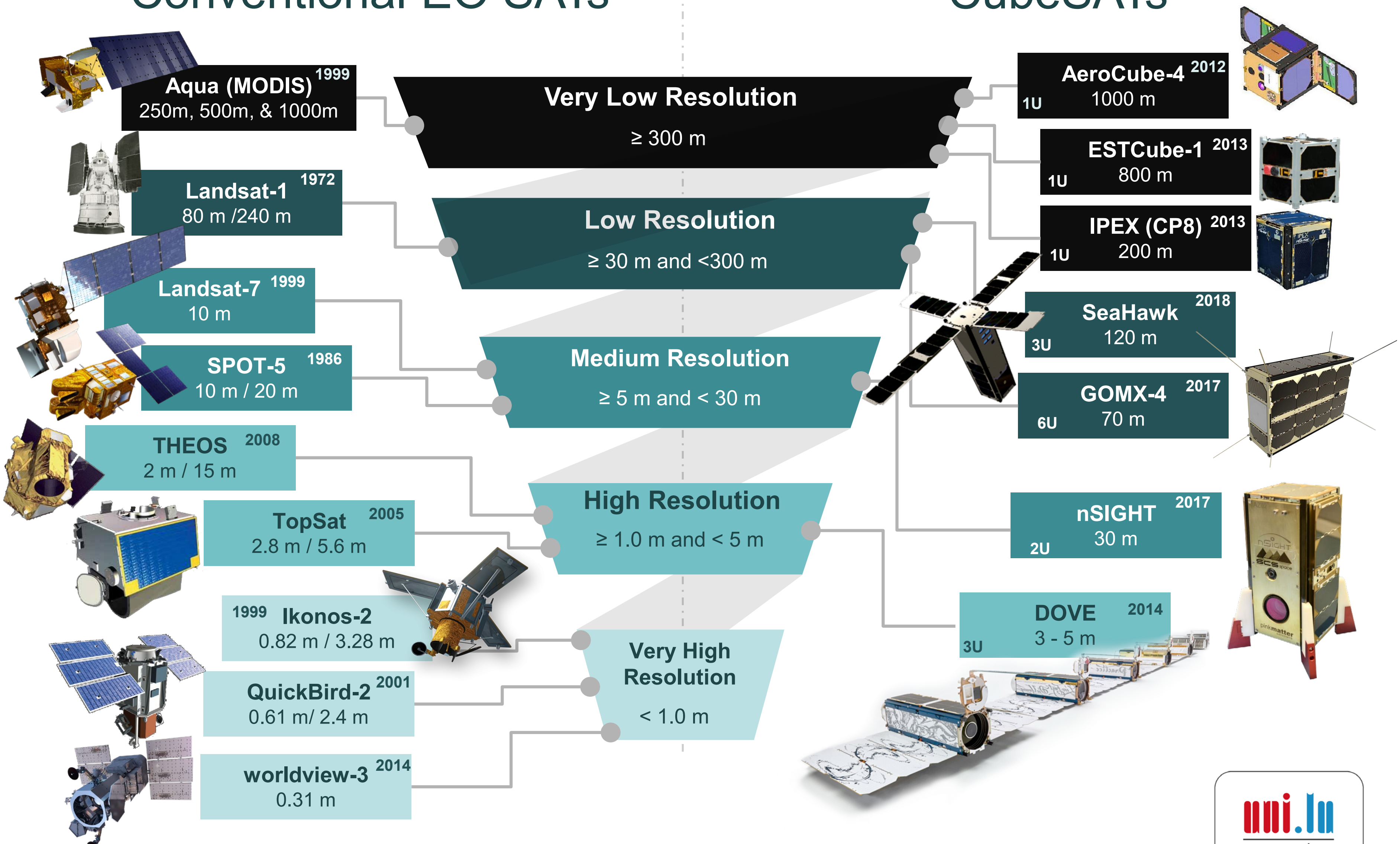
Conventional EO SATs

CubeSATs



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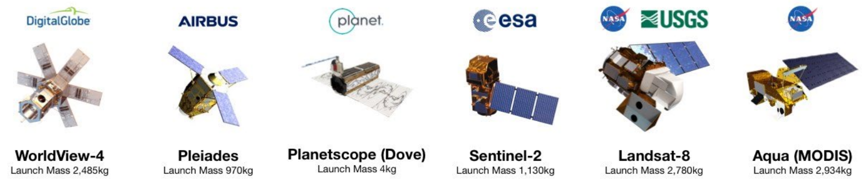
Evolution of Optical EO Satellites:



Launch Date	Organisation	Mission		Orbit	GSD	Sensor(s)	Pointing capability/Agility
1972 - 2013	NASA	Landsat	Landsat 1-3	907 to 915 km, 99˚	80m	Multi spectral Scanner (MSS)	Up to 10.3º off nadi
			Landsat 4-5	705 km, 98.2˚	30m	Thematic Mapper (TM)	
			Landsat 7		30m	Enhanced Thematic Mapper Plus (ETM+) 8-band whiskbroom scanning radiometer	Up to 7.5º off nadir
			Landsat 8		30m	Operational Land Imager (OLI) similar spectral bands to the ETM+	Up to 7.5º off nadir
1998-03-24	CNES (Centre national d'études spatiales)	Spot 1- 4		832 km, 98.8˚	10 PAN / 20 MS	High-Resolution Visible and Infrared sensor (HRV IR)	± 27˚
1999-09-24	Space Imaging/ GeoEye Inc.	Ikonos-2		681 to 709 km, 98.1˚	1 m PAN (0.82 m at nadir), 4 m MS (3.2 m at nadir)	Kodak Optical Sensor Assembly (OSA) Pushbroom detector	±30º
1999-12-18	NASA	Terra	ASTER	705 km	15 m VNIR 30 m SWIR 90 m TIR 15 m Stereo	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) 14 bands	0˚ / 27˚
2002-05-04			MODIS	705 km	250 m (bands 1–2) 500 m (bands 3–7) 1000 m (bands 8–36)	Moderate Resolution Imaging Spectroradiometer (MODIS) Medium-resolution, multi-spectral, cross-track scanning radiometer 36 spectral bands	
2001-10-18	DigitalGlobe Inc	QuickBird-2		450 km, 97.2˚	0.61 m (PAN) and at 2.4 m (MS)	Ball Global Imaging System 2000 (BGIS 2000) Pushbroom array	±30º
2002-05-04	CNES (Centre national d'études spatiales)	Spot-5		832 km, 98.7˚	5m (single) 3.5m (double) PAN / 10m MS	High Resolution Geometric (HRG) High Resolution Stereo (HRS)	± 27˚ HRG ± 20˚ HRS
2008-08-29	RapidEye/Planet	RapidEye		630 km, 98˚	6.5 m	Jena-Optronik RapidEye Earth Imaging System (REIS) Multispectral pushbroom sensor 5 spectral bands	±20˚
2013-11-21	Skybox/Terra Bella/Planet	SkySat		600 km, 97.8˚	90 cm PAN / 2.0 m MS	CMOS frame detectors (30f/s video from space)	
2014-08-13	DigitalGlobe Inc/MAXAR	WorldView-3		617 km	0.31 m PAN 1.24 m MS 3.7 m SWIR	Panchromatic, 8 Multispectral and 8 SWIR bands	±40º (nominal in any direction)
2015-06-23	ESA and EU (European Commission - Copernicus)	Sentinel-2 (a, b)		786 km, 98.5˚	10 m: (VNIR) B2, B3, B4, B8 (4 bands) 20 m: B5, B6, B7, B8a, B11, B12 (6 bands) 60 m: B1, B9, B10 (3 bands)	Multispectral Imager (MSI) 13 bands VNIR + SWIR	

information: eo Portal Directory

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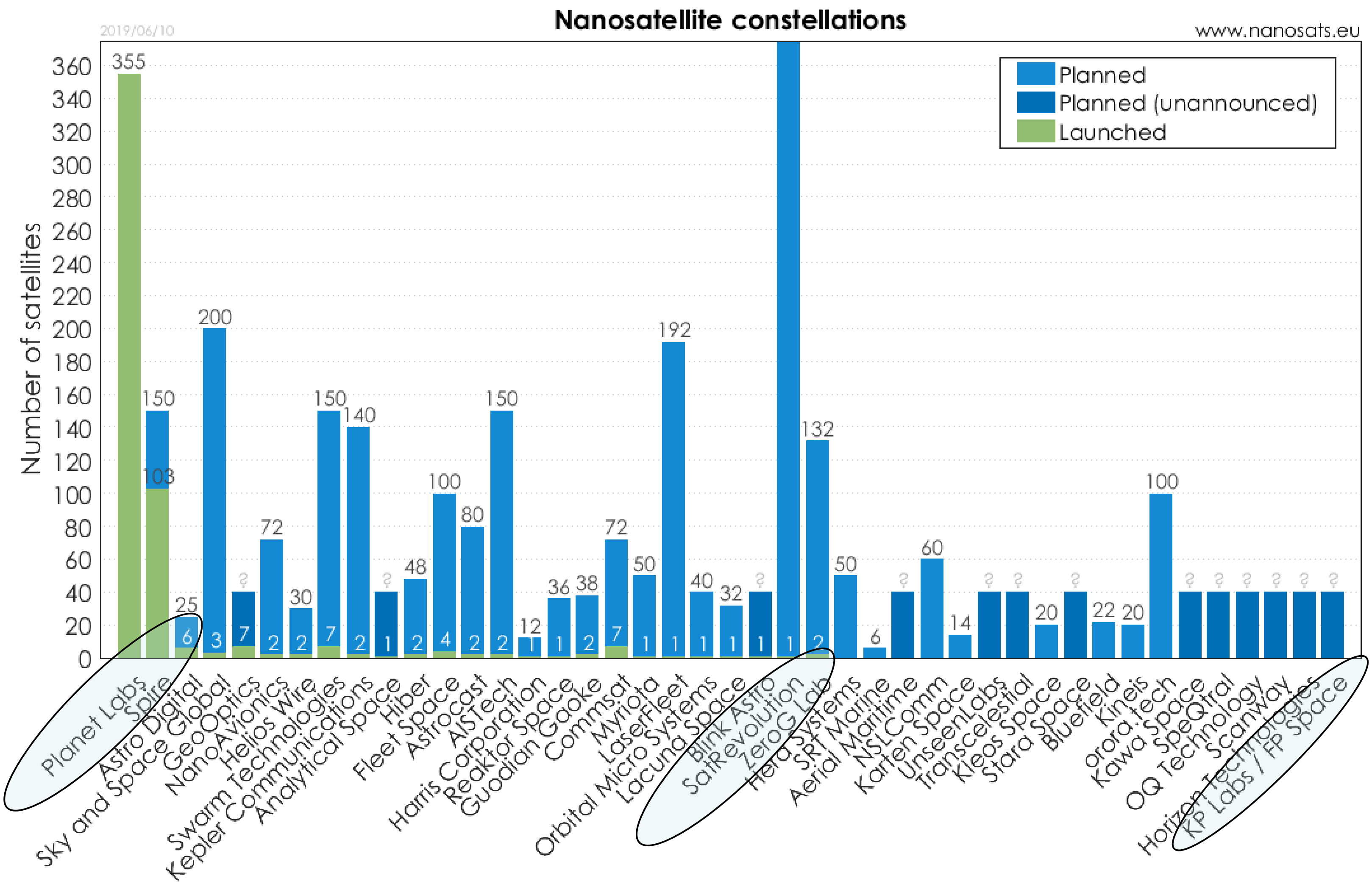
Some Planned and Launched CubeSat Missions



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CubeSat Missions

	Launch Date	Organisation	Mission	Orbit	GSD	Sensor(s)	Resolution	Agility and Positioning
3U	2014 - 20XX	Planet Labs	**Dove (Flock-xx xx)**	400, 500, 600 (most are 500km)	3 - 5m	?		
3U	2015-12-16	Microspace Rapid Pte Ltd.	**Athenoxat-1**	540 km, 15 deg	Global view resolution: 1km Wide Angle resolution: 50m to 300m Narrow Beam Resolution: 1m to 20m	?	f/2 to f/10 Optics speed 2.5 deg narrow beam aperture Visible/IR, multiband, hyperspectral Spectrum up to 30Hz Video Refresh	ACS air-coil magnetorquers primarily for stabilization ADS sensors: coarse sun sensors, magnetometer & gyroscopes CDH & ADCS software including Nadir vector determination & payloads drivers
3U	2016-09-26	UK Space Agency	**ALSAT-Nano**	680 km, 98.2 deg, SSO		XCAM C3D2 (CMOS)	1200 x 1080 pixels Focal length: 45 cm	
3U	2018-12-03	University of North Carolina Wilmington	**SeaHawk**	580 km, 97.8 deg	120 m	push-broom design, with 4 linear array CCDs, each containing 3 rows of detectors	1800x 6000 pixels 8 bands deep	
6U	2017-08-14	NASA Jet Propulsion Laboratory	**ASTERIA**	400 km, 51.6 deg, ISS	30 m	Fairchild CIS2521 (CMOS)	2592 pixels x 2192 pixels Focal length: 85 mm Aperture diameter: 60.7 mm (f/1.4) Pixel size 6.5 µm x 6.5 µm Plate scale: 15.8 arcseconds per pixel Field of view: 11.2° x 9.6°	
6U	2018-02-02	GomSpace	**GOMX-4**	500 km	70 m	HyperScout camera from Cosine for hyperspectral images	4096 x 1850 pixels Spectral range: 400 - 1000 nm Spectral resolution: 15 nm Dynamic range: 12 bit SNR: 50-100	
6U	2019-09-05	ESA	**Phi-Sat-1**	450-550 km	VNIR 75 / TIR 390 (590km)	HyperScout-2, two spectral channels, each with 2D sensors operating in pushbroom mode.	FoV: VNIR 31 x 16 / TIR 31 x 16 Swath: VNIR 310 x 150 / TIR 310 x 150 Spectral bands: VNIR 45 / TIR 4 Spectral range [µm]VNIR 0.4 – 1.0 TIR 8.0 - 14	
6U	2022-12-31	KP Labs (FP Space)	**intuition-1**	?	?	hyperspectral instrument	Spectral resolution in the range of visible and near-infrared light The band is divided into 150 channels	

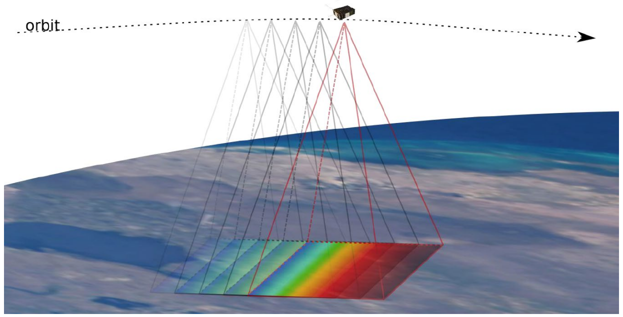
Example: GomX4 - Technology Demonstrator

GOMX-4A camera (GomSpaceNanoCam):

Sjælland(DK)

Credit: GomSpace and Cosine; MarcoEsposito

GOMX-4B Hyperspectral Imager Hyperscout I by Cosine :



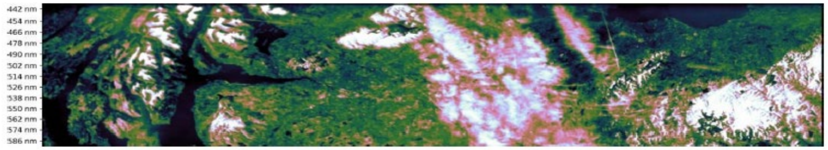


Figure 6: First light of HyperScout. False colour single image of the Scottish landscape between Glasgow and Edinburgh. Image acquired on the 20th of March 2018

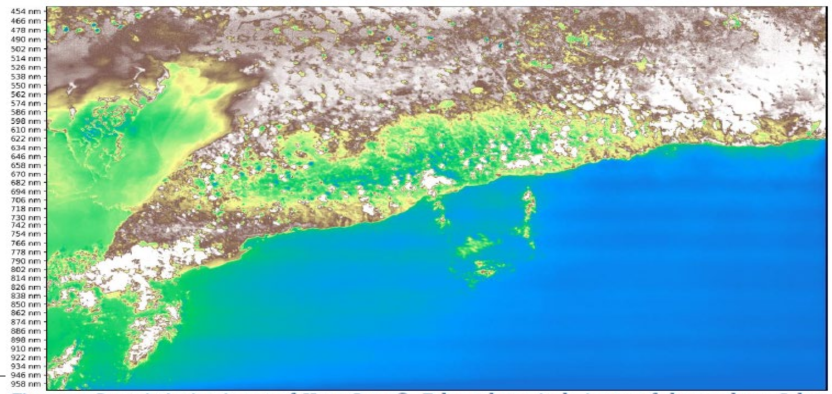


Figure 7: Commissioning image of HyperScout®. False colour single image of the southern Cuban coastline. Image acquired on the 26th of March 2018

Hyperscout applications

Disasters:

- Volcano and wild fire
- Flooding
- Monitoring geo hazards

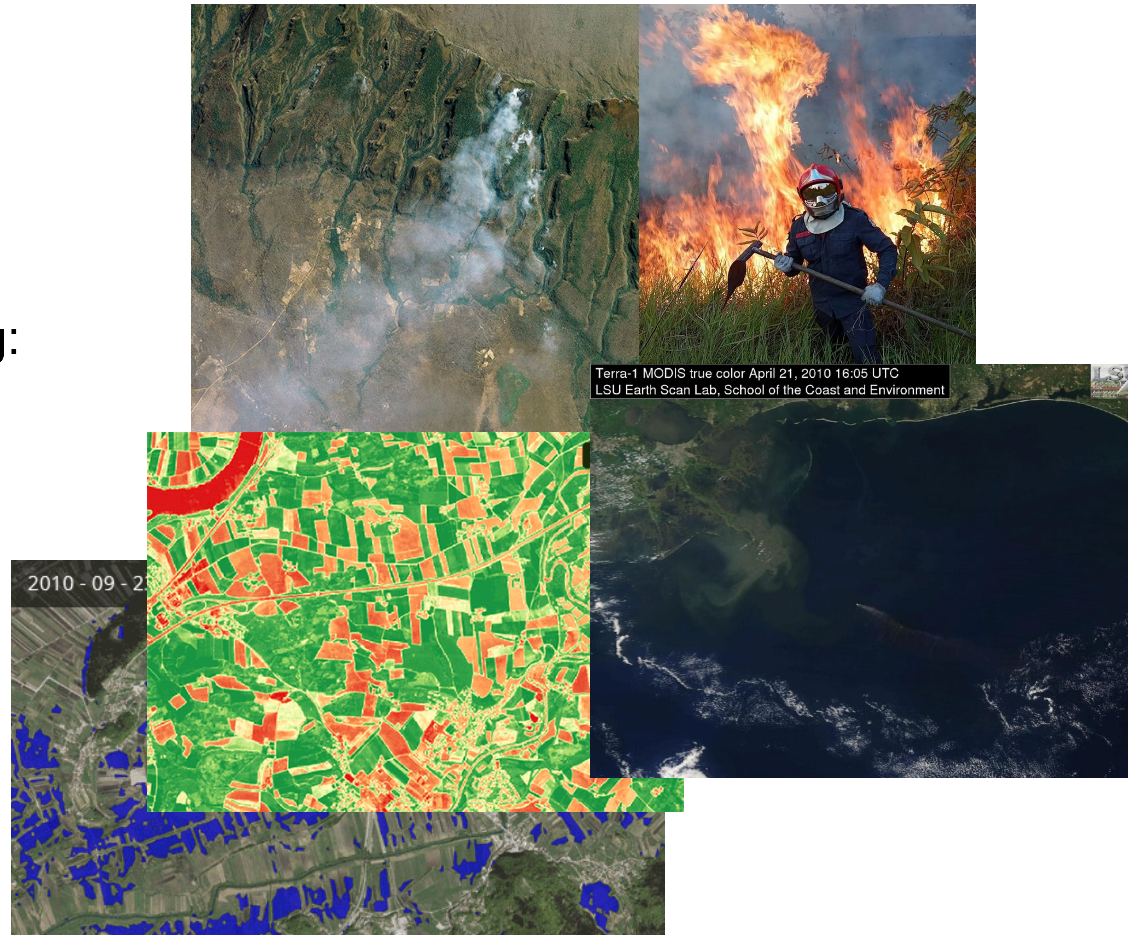
Environmental Monitoring:

- Water quality
- Pollution, oil spills etc.

Farming and agriculture:

- Crop monitoring
- Forest monitoring

Mapping



Sentinel-hub

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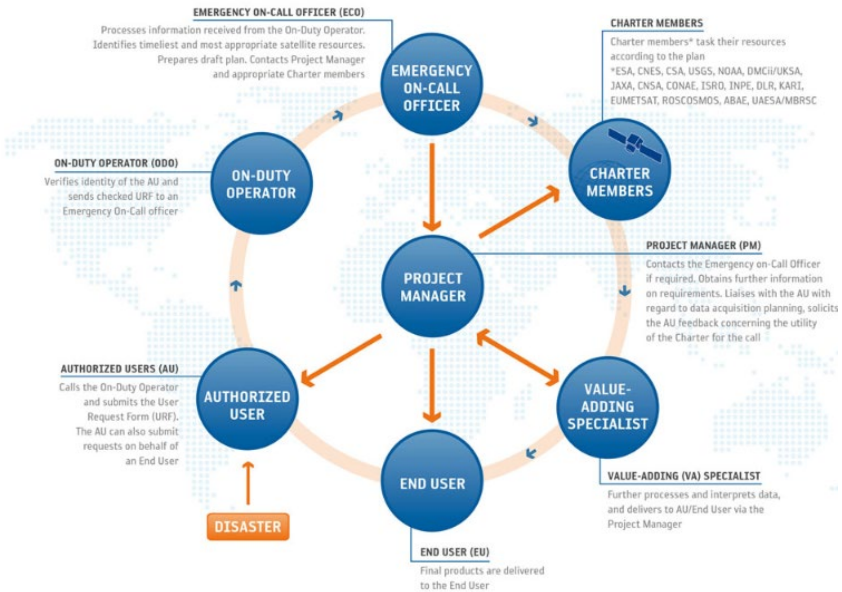
Part 2: FDL-Europe Flood detection

Flood detection and monitoring from Orbit

How can we reduce the time from disaster to data?

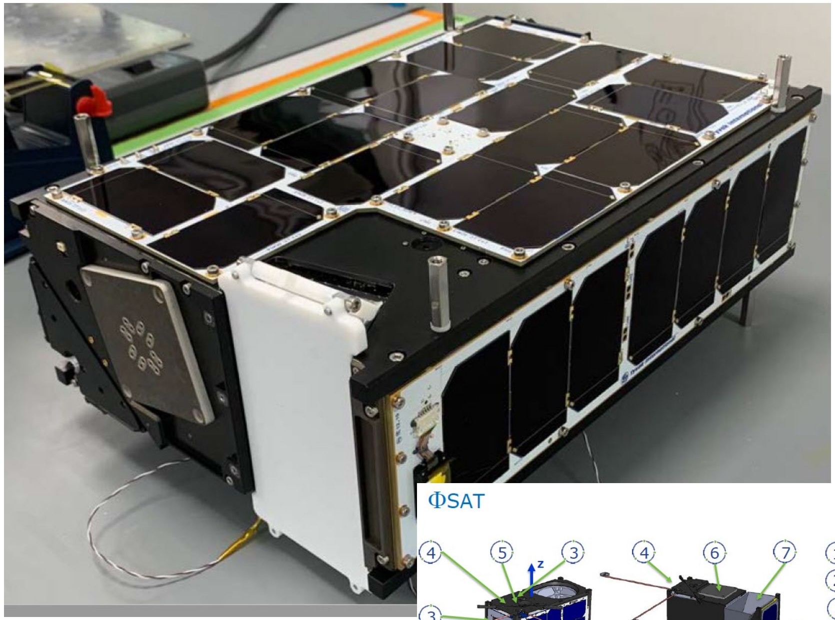
- Time for supply of data can be hours, on average 2 days: International “Space and Major Disasters” Charter

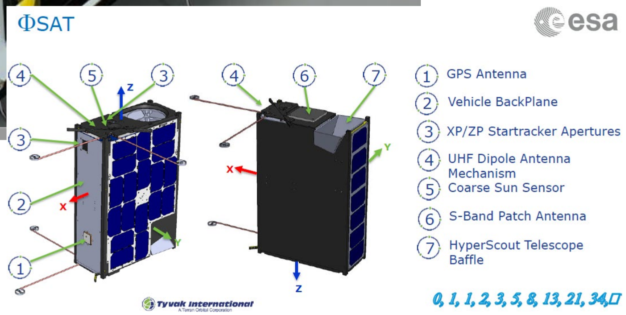
- How do we get data to the ground more quickly?
- How can we accelerate/automate the image analysis process?

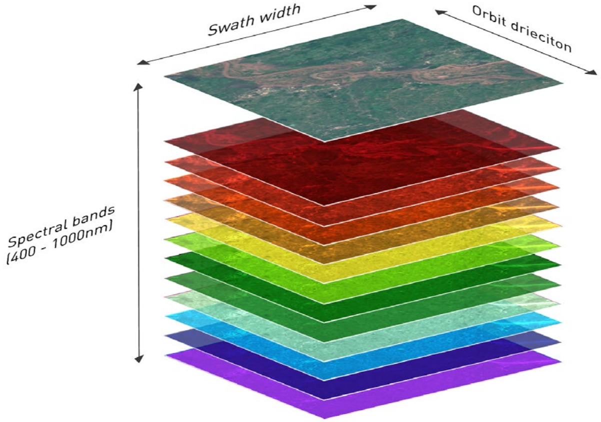


PhiSAT-1 On-board Processing

- FSSCat/PhiSat-1 technology demonstrator twin sat mission;
- Hyperspectral Sensor: Cosine Hyperscout II

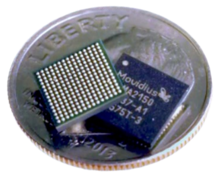


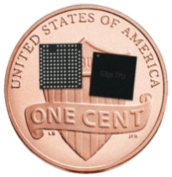


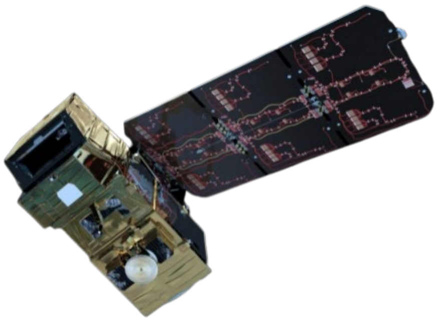


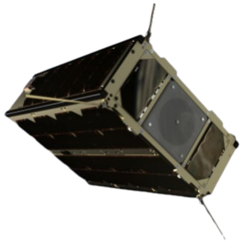
Example: PhiSAT-1

- Limited downlink capabilities
- AI processing on-board









560 Mbps

ESA Maspalomas, Spain

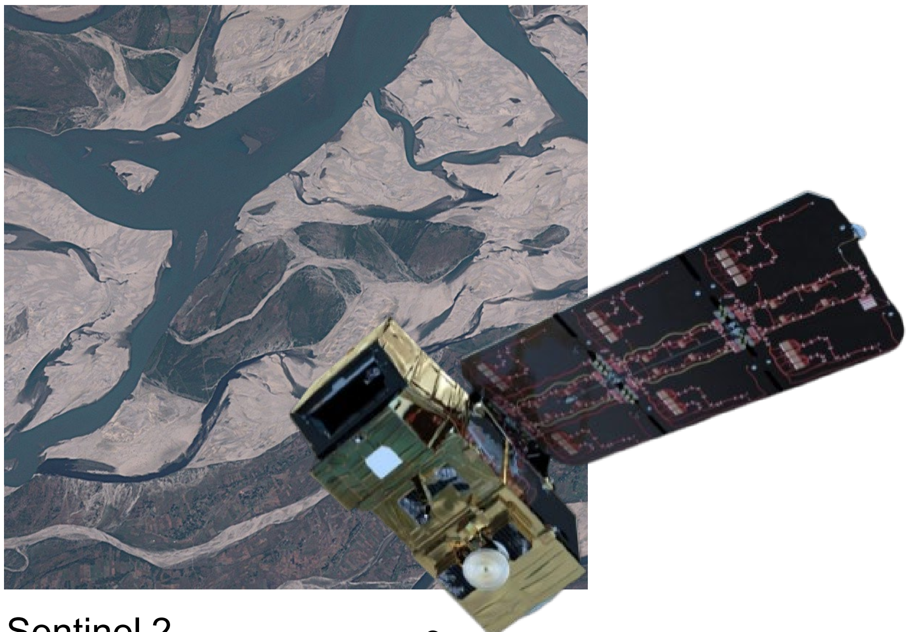
< 1Mbps

COTS ground station (ISIS)

Example: PhiSAT-1

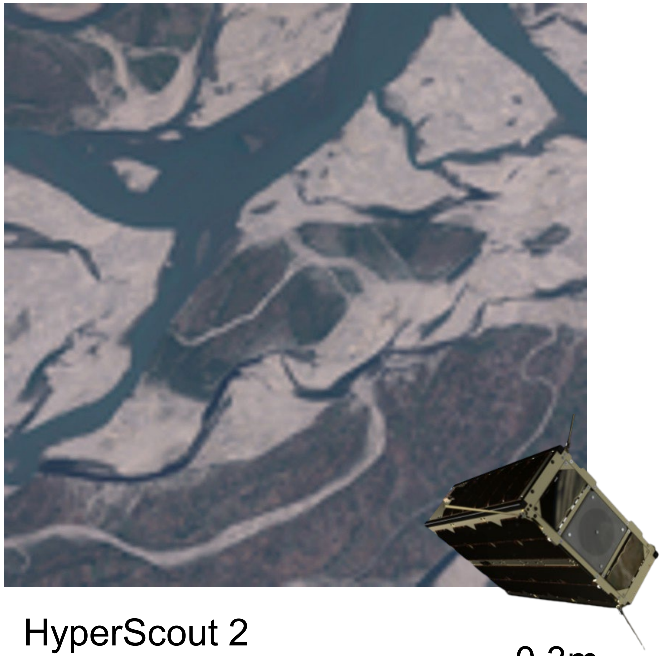
Difference in Image Quality

- Geometric, spectral, radiometric resolution,
- S/N ratio, motion blur etc.



Sentinel 2
(10m resolution)

3m



HyperScout 2
(70m resolution,
simulated)

0.3m

Antti Lipponen (Twitter @anttilip)

Approach

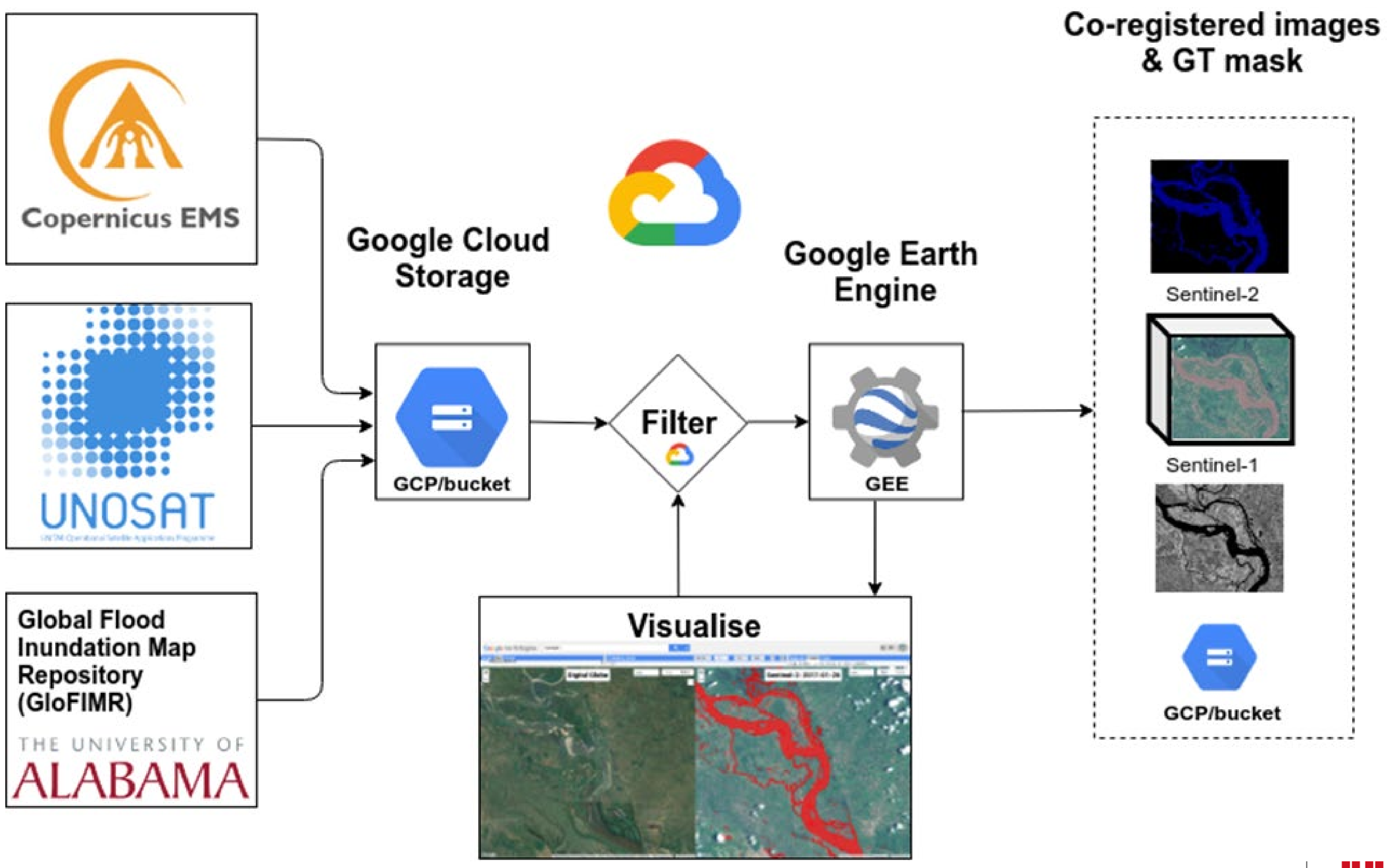
1. Dataset of global flood events and Sentinel 2 images
2. End to End machine learning models based on simulated imagery (degraded Sentinel 2 images)
3. Convert and test models on simulated images from ΦSat-1 representative hardware (Intel Neural Compute Stick) prior to launch and deployment

Floods training data
- Combination of currently existing data bases
- Verification

ML Flood detector
- Based on simulated training data
- Features:
  - Clouds
  - Flood water
- Model architecture

Optimisation for Satellite
- Sensor
- Onboard compute

WORLDFLOODS Dataset

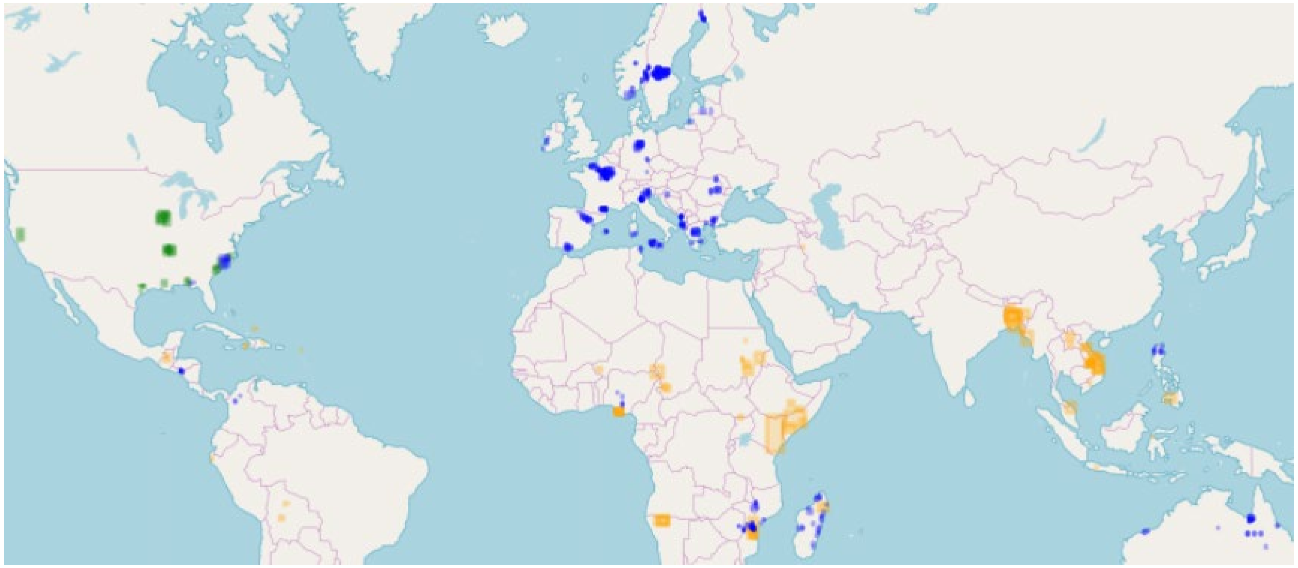


WORLDFLOODS Dataset

- 150 floods
- 618 flood maps

235,000 patches
(256x256 px)

- 303 GB



■ Unosat (127) ■ GloFIMR (37) ■ Copernicus EMS (454)

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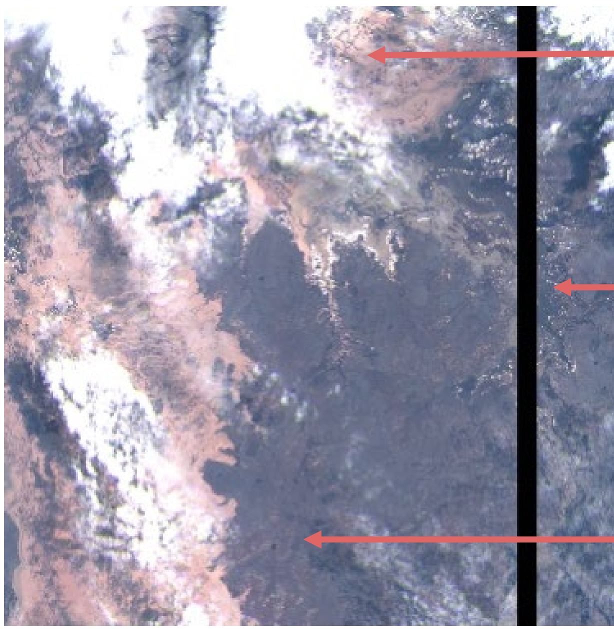
WORLDFLOODS Dataset

Challenges

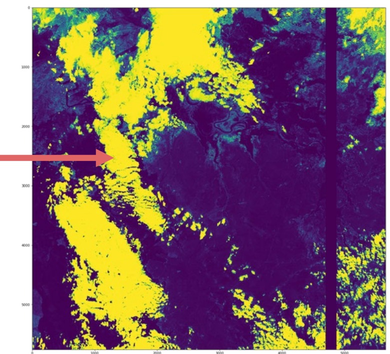


Clouds

Artifacts

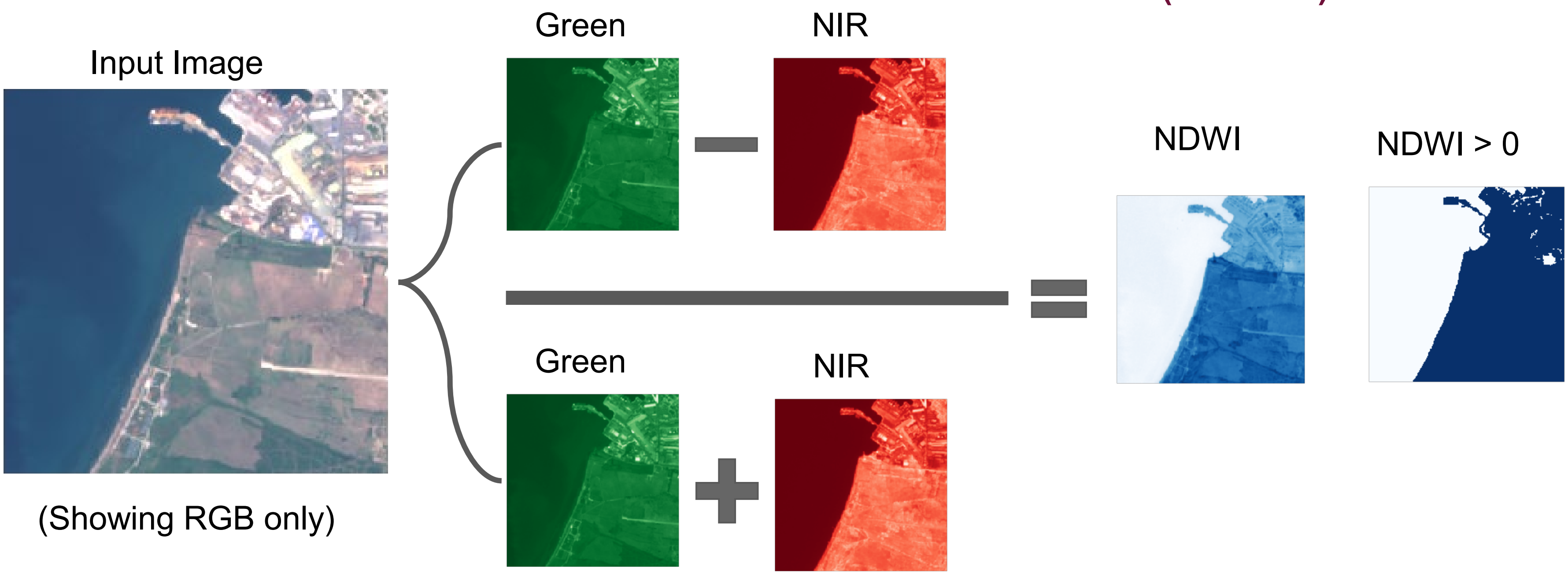
Image, label noise

s2_cloudless github.com/sentinel-hub/sentinel2-cloud-detector



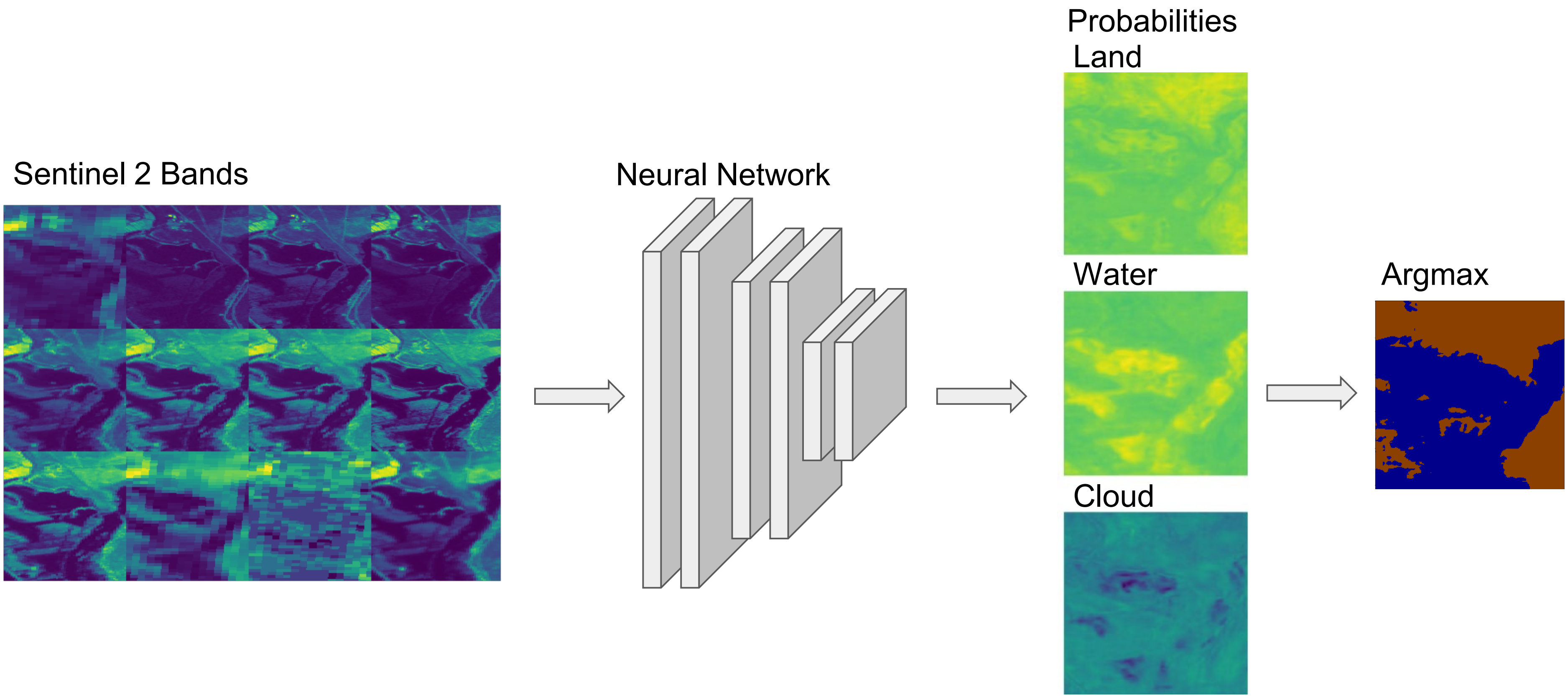
Type	%pixels
Clouds	45.9%
Land	43.7%
Invalid	7.5%
Water/Flood	**2.85%**

Baseline: Normalised Difference Water Index (NDWI)



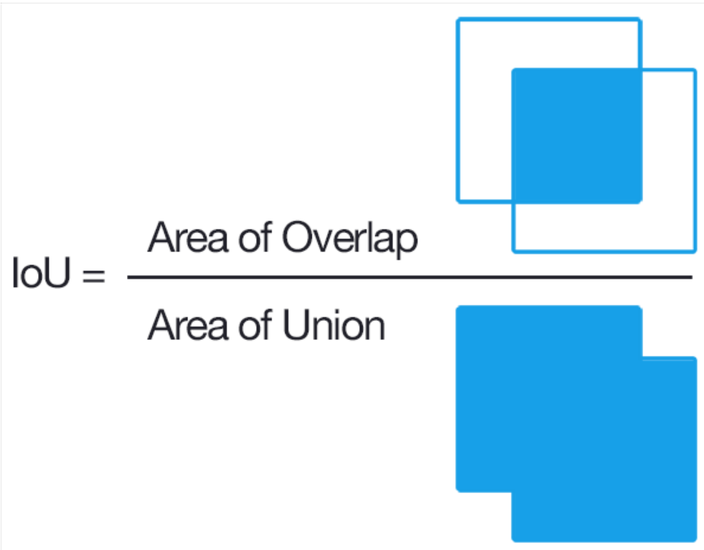
Sentinel 2 RGB | Ground truth | NDWI

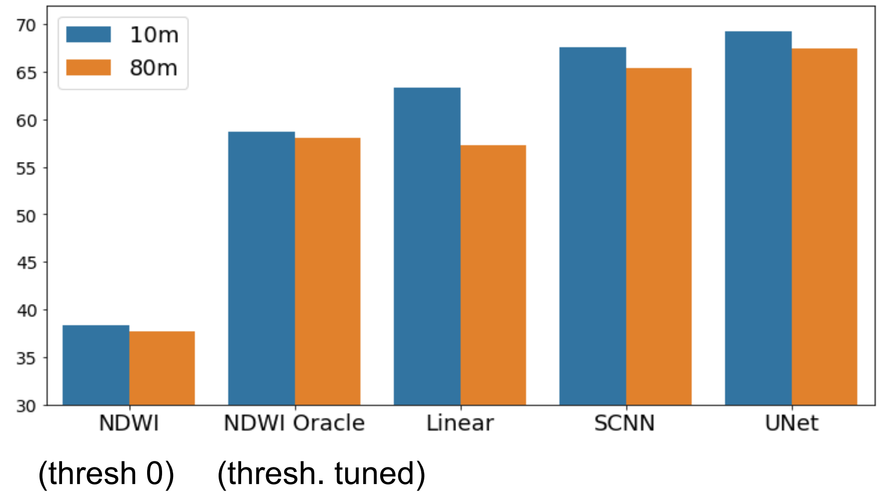
Model architecture: fully convolutional neural networks



End to End machine learning approach

Evaluation





We experiment with training on both raw (10m/pixel) and degraded (80m/pixel) images

	IoU		Recall	
	10m	80m	10m	80m
NDWI (thresh 0)	38.37	37.47	43.7	43.13
NDWI (thresh. tuned)	58.63	58.09	93.26	97.72
Linear	63.34	57.25	96.24	95.24
SCNN	67.54	65.42	**97.43**	**97.03**
UNet	**69.25**	**67.51**	97.34	96.56

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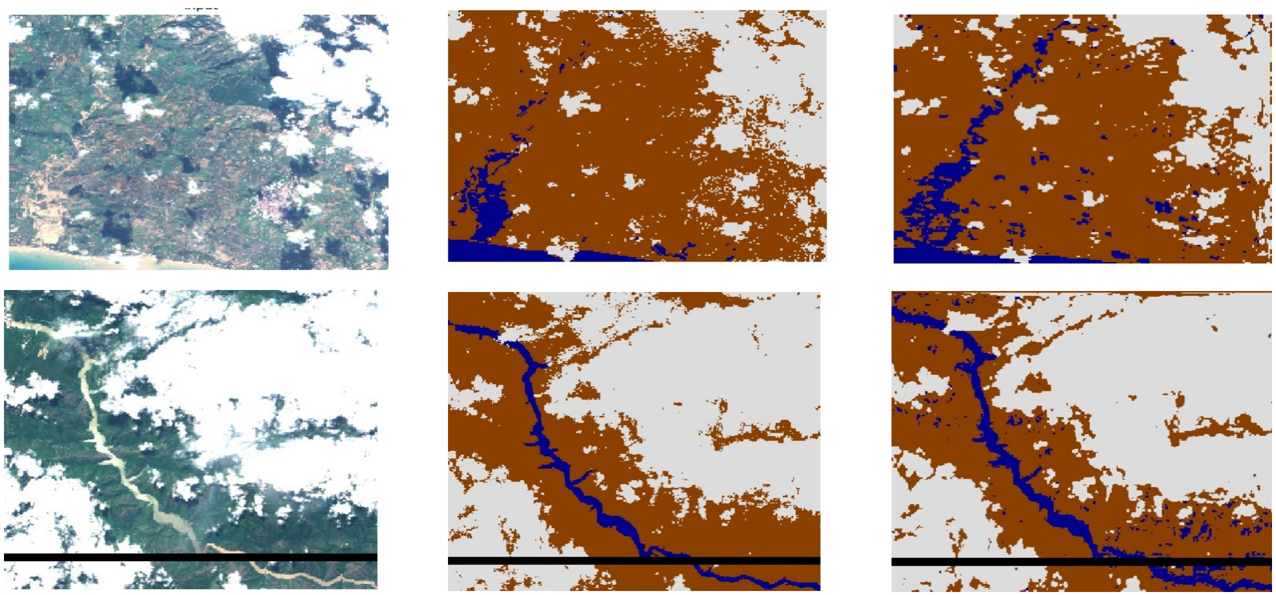
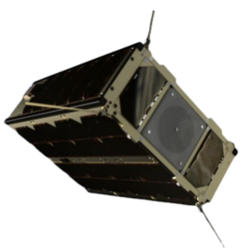
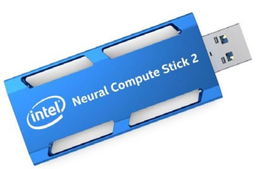
Simulation on Satellite hardware

Optimisation: ‘lean’ deep learning algorithm to be deployed directly on the satellite

- Performance drop < 1%
- Deep learning NN: Model size < 0.5 MB
- 12MP image mapped in < 1 minute







Outlook

- Image resolution quality of conventional EO Satellites will remain superior for the foreseeable future
- CubeSat technology will mature rapidly; technology demonstrators will soon become operational systems
- AI on small CubeSats satellites is expected to be a game changer (for some applications)
  - We hope that our Flood detector will be tested onboard Small or Nano satellites in the future

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Thanks for listening!

RSS-Hydro, S.à r.l.-S

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Low Earth Orbits (LEO)

- Revisit time:
  - is a function of swath width, spacecraft agility/pointability and the number of space crafts
  - Often called ‘temporal resolution’