EQSATCONDR

Equatorial Satellite Constellation De-risking

GSTP Element 1 "Develop": Assessments to Prepare and De-Risk Technology Developments

Final Presentation
16/12/2022

Agenda

1. Introduction
2. Technical Activity Overview
3. Proposed Concept
4. Development Plan
5. Evaluation of the EO Service
6. Evaluation of the HTS Communications Service
7. Evaluation of the Dual Service
8. Future Steps

1 INTRODUCTION

Introduction

Project Framework

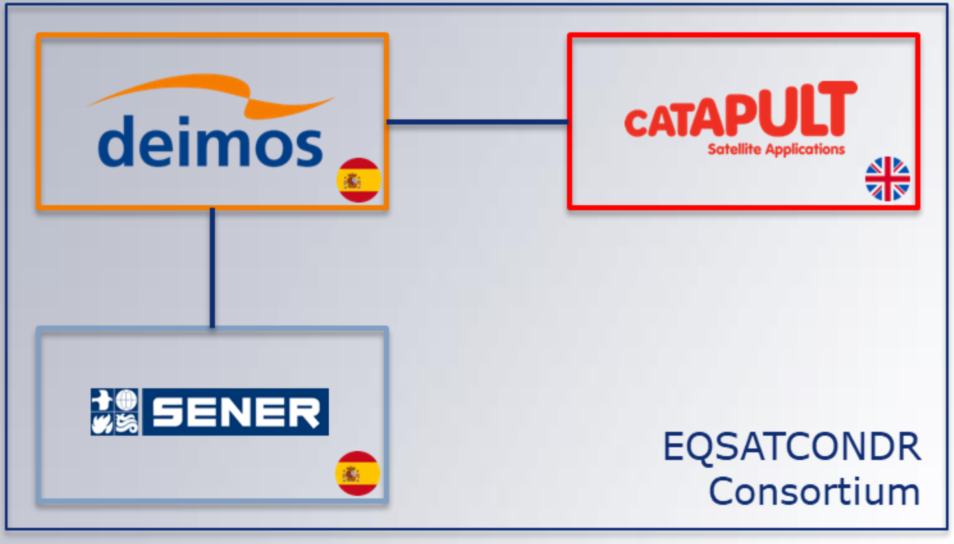
- The project **"Equatorial Satellite Constellation Derisking - EQSATCONDR"** has been developed in the framework of a **General Support Technology Programme (GSTP)**
  - GSTP Element 1 "Develop": Assessments to Prepare and De-Risk Technology Developments (G617-241TA)
  - ESA Contract No. 4000135220/21/NL/GLC/va

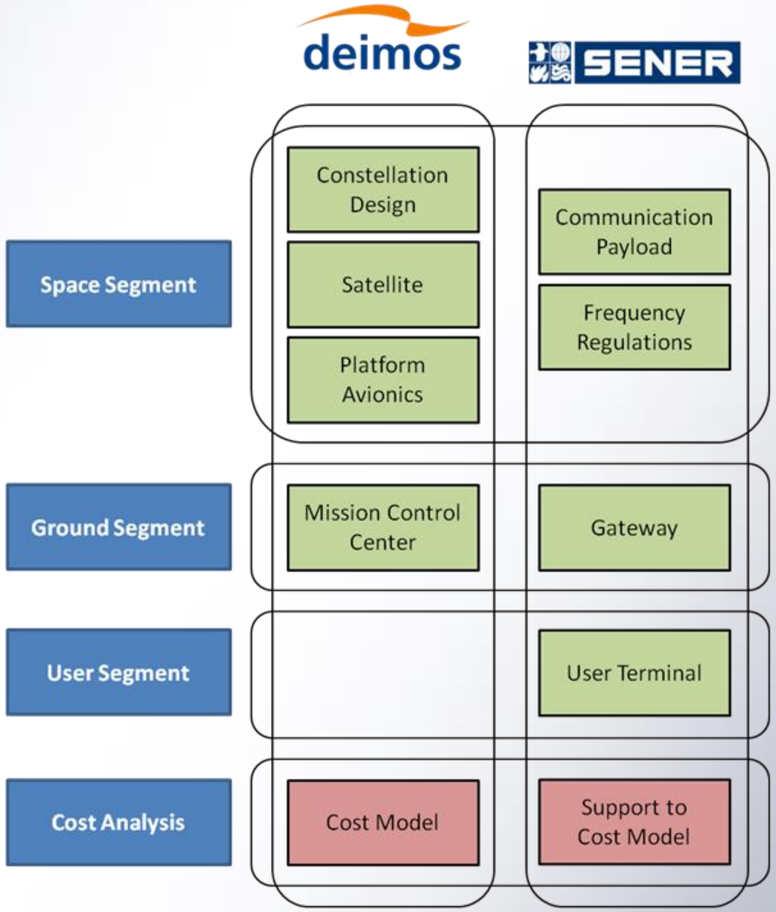
- **The main goal of this GSTP is to evaluate the potential added value and to address critical issues of potential development activities**
- The results are intended to be used to help orient and adapt the follow-on development activity with respect to various aspects (i.e., technical, implementation, cost…)

Introduction

Consortium

- **DEIMOS Engineering and Systems** S.L.U. (Spain), as Prime Contractor
- SENER, through **SENER TAFS** S.A.U. as subcontractor
- **Catapult** UK, as consultant, supporting the definition of the overall HTS concept and service





2 TECHNICAL ACTIVITY OVERVIEW

Objective of the Technical Activity

- The objective of the activity was to assess and demonstrate the business and technical feasibility of a **dual-service** mission of **high-throughput satellite (HTS)** telecommunications and **Earth observation** (remote sensing) services over the **equatorial region**
  - **Equatorial LEO constellation of homogenous small-satellites**

- **New and disruptive service concept** → *Necessary to assess the technical feasibility and performance of the proposed concept, as well as demonstrate its business viability from a use-case perspective*

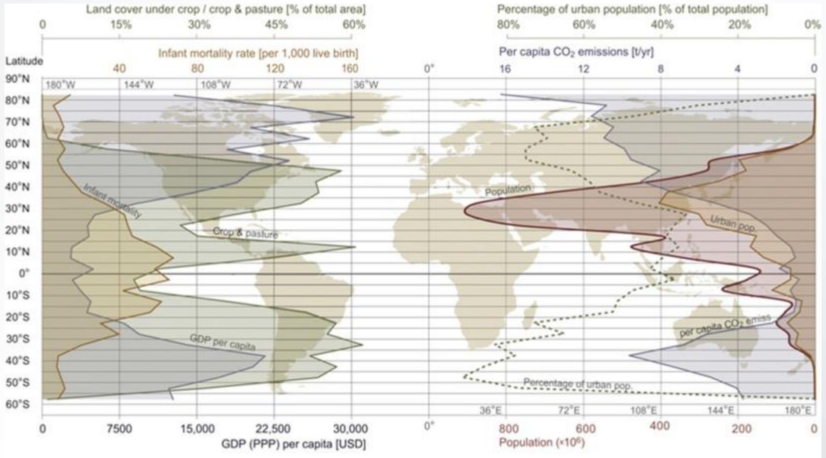
- The de-risk activity has been focused on the critical aspects of the dual-service constellation and satellite, to remove the principal risks:
  - system concept and architecture definition, including payloads and their accommodation
  - preliminary business case
  - development schedule
  - combined dual-service quality

The feasibility of the proposed service has been proven by simulation campaigns and analysis. This will further facilitate the impact of this concept and service, so as to establish a basis for investment in the satellite and constellation development.

Motivation of the Activity

Important trend in the space market is the use of LEO constellations to provide satellite-based services

- Drastically **reduce the latency of transmission of the state-of-the-art GEO telecommunication satellites** by using lower orbits (LEO)
- Propose an **alternative and more affordable system architecture** that reduces the size of GEO satellites and the number of satellites of LEO mega-constellations by serving the Equatorial region
- Target a service of a very large customer base and regions with limited connectivity by focusing on the Equatorial band
- Provide very low revisit times for Earth observation application over regions that are covered less frequently with polar and SSO orbits

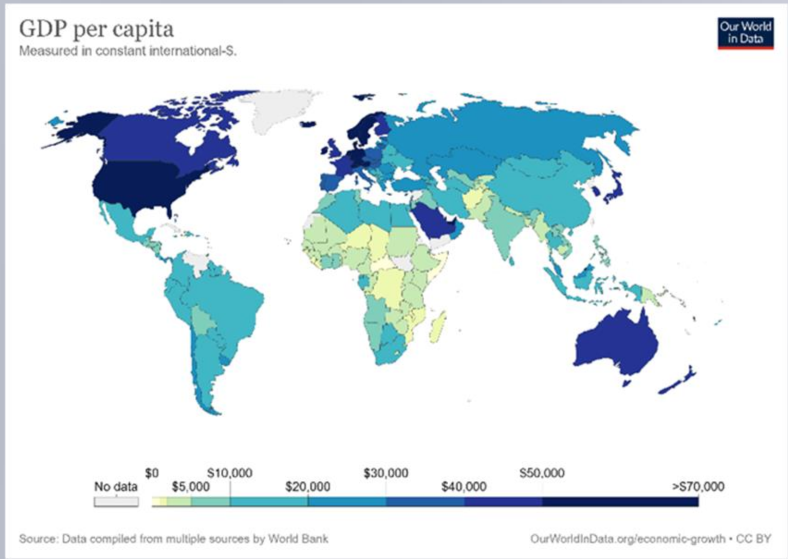


Distribution of population and economic indicator versus latitude

Exploit benefits of combining different space applications (telecommunication and Earth Observation) into one platform

Motivation of the Activity

Challenges of Communications in Equatorial Regions



National GDP per Capita

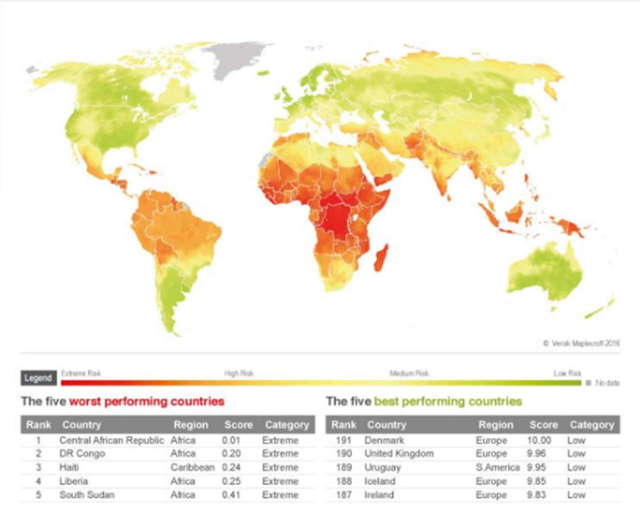
- Remote and inaccessible locations
- Poor infrastructure such as communications, transport, power supply
- Unequally distributed populations in the equatorial region with small sparse remote populations but with ten cities on the equator with a population greater than one million
- Expanding to 20 degrees north and south of the equator, the region takes in some of the fastest growing cities
- Gross Domestic Product (GDP) in the tropical regions is low and satellite communications are beyond the reach of most businesses and individuals.
- Some of the poorest countries in the world are in equatorial regions, yet some of the fastest growing economies

The market demands for services of wide bandwidth in regions where conventional networks are not fully deployed. This provides communication services to regions with limited connectivity

Motivation of the Activity

A constellation for the equatorial region would provide a key service for many of the world's underdeveloped and vulnerable nations

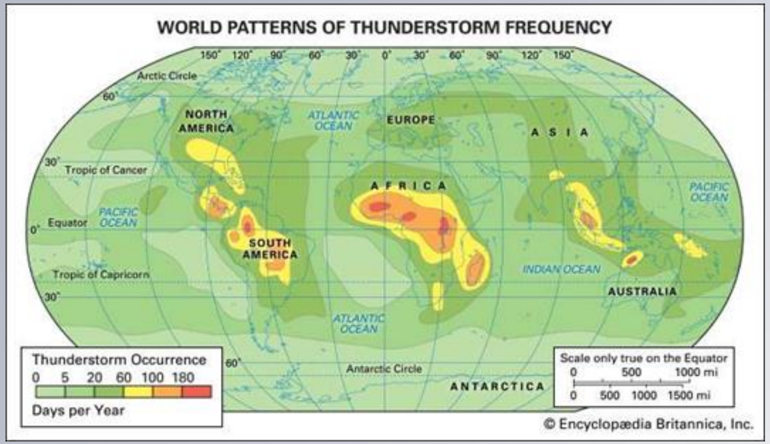
- Regions heavily affected by metrological events
- Tropical rainforests, which are in a band around the equator (±25º latitude), are experiencing high levels of forest loss caused mainly by illegal rainforest deforestation
- Support United Nations Sustainable Development Goals and other international organizations have (e.g., the World Meteorological Organization (WMO) for meteorological services)



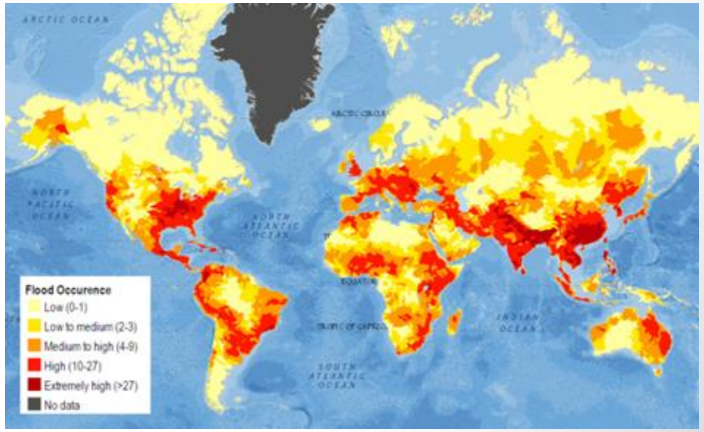
Rank	Country	Region	Score	Category
1	Central African Republic	Africa	0.01	Extreme
2	DR Congo	Africa	0.20	Extreme
3	Haiti	Caribbean	0.24	Extreme
4	Liberia	Africa	0.25	Extreme
5	South Sudan	Africa	0.41	Extreme

Rank	Country	Region	Score	Category
191	Denmark	Europe	10.00	Low
190	United Kingdom	Europe	9.96	Low
189	Uruguay	S.America	9.95	Low
188	Iceland	Europe	9.85	Low
187	Ireland	Europe	9.83	Low

Climate Change Vulnerability Index 2017



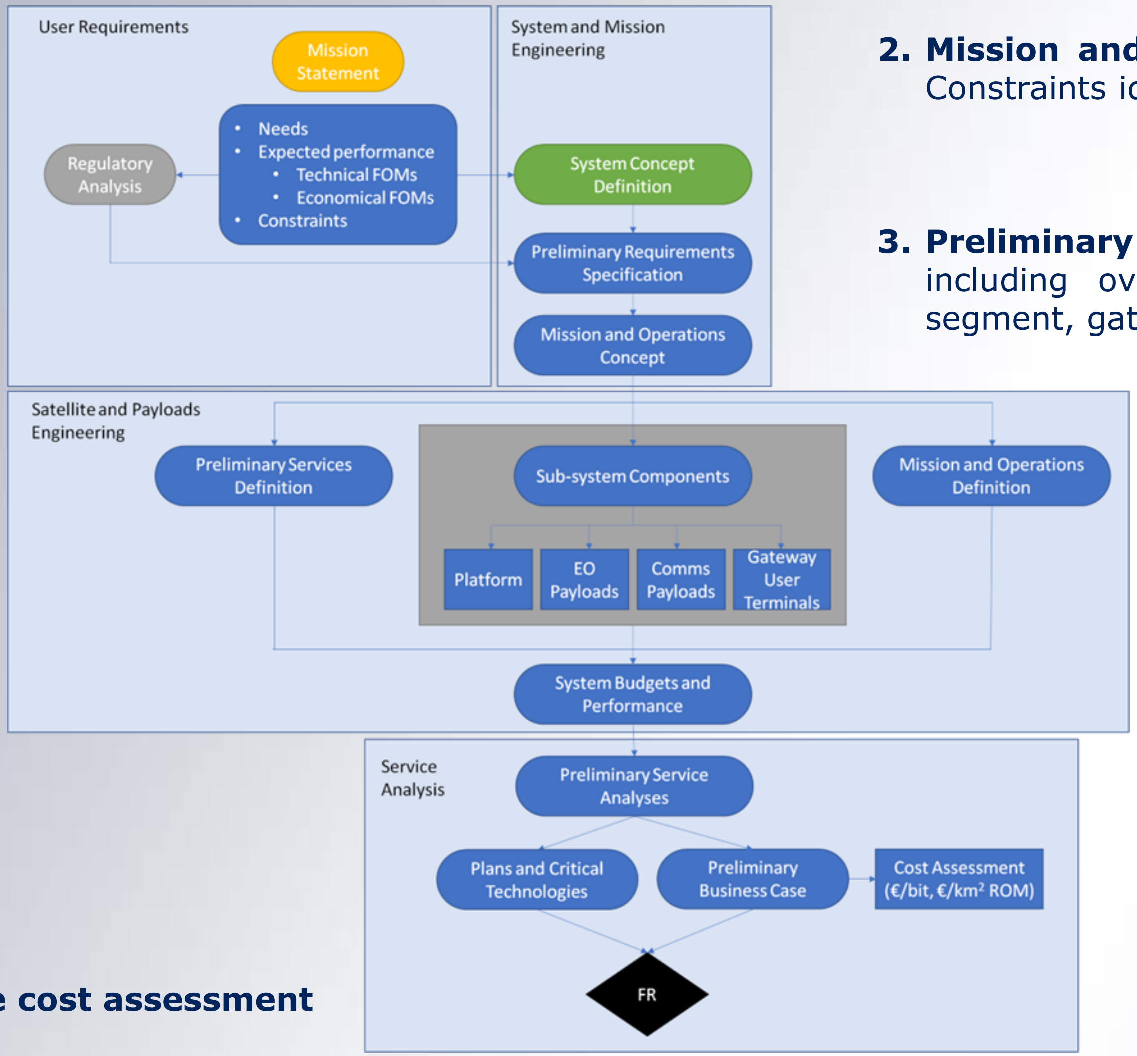
World distribution of extreme weather (thunderstorms)



World distribution of flood disasters

Work Logic

1. Analysis of the **end-user requirements** and understanding of the needs



2. **Mission and System requirements** definition. Constraints identification

3. **Preliminary System Concept Definition**, including overall mission architecture, ground segment, gateway, user terminals, launch, etc.

4. **Definition of the Satellite Architecture**, focusing on the platform and both payloads (EO and HTS Comms)

5. Preliminary **analysis** of the dual service **expected performances**

6. **Identification of the critical technologies** requiring further study / development. **Definition of development plan and roadmaps** for future activities

7. **Total service cost assessment**

3 PROPOSED CONCEPT

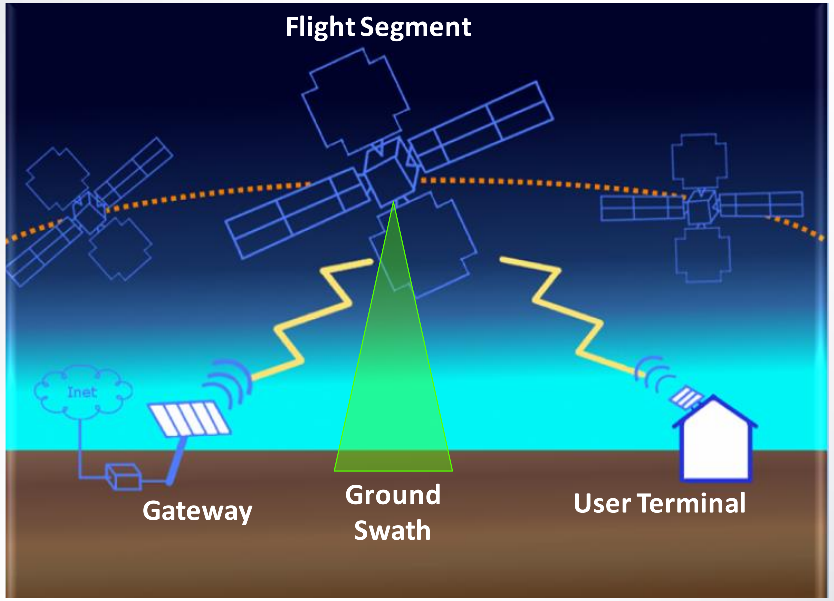
Concept Proposed

Space segment

- Constellation of small satellites
  - Small satellite platform
    - HTS communication payload
    - EO payload
    - Avionics

Ground segment

- Gateway station with antennas and modems
- User terminals with antennas and modems
- Mission control center



EQSATCONDR concept of an equatorial constellation of small satellites offering dual HTS communications and Earth Observation services

Orbit and Mission Architecture

Four different constellation altitudes were analyzed: 1500km, 1100km, 800km and 500km

Swath width / footprint and resolution / GSD

R: The payload shall have a GSD not greater than 500 m (G) / 1 km (T)

R: The payload shall provide a swath on ground of at least 100 km (G) / 40 km (T)

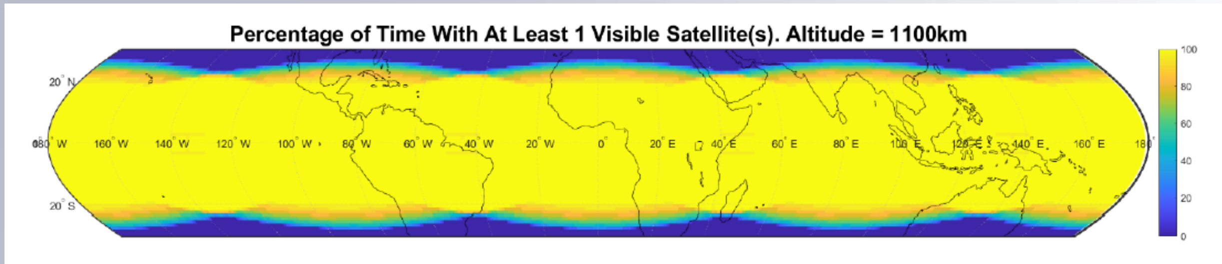
Ground Station Visibility

R: The mission shall serve the land areas in the Equatorial region in the ±30º (G) / ±20º (T) latitude band for the communication service

R: The mission shall provide observations over land areas in the ±25º (G) / ±20º (T) latitude band region

R: The mission shall guarantee a revisit time of 60 min (T) and 30 min (G)

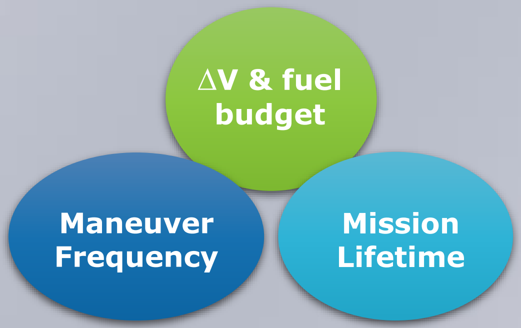
The goal was also to reduce the number of launches required!



Visibility map for a 4×15 orbital configuration with an inclination of 15° at 1100km

- ✓ **Total number of satellites had to reach 60, giving 4 orbits of 15 satellites at a 15° inclination**
- ✓ With this architecture, the entire region up to approximately 20º either side of the equator is covered 100% of the time

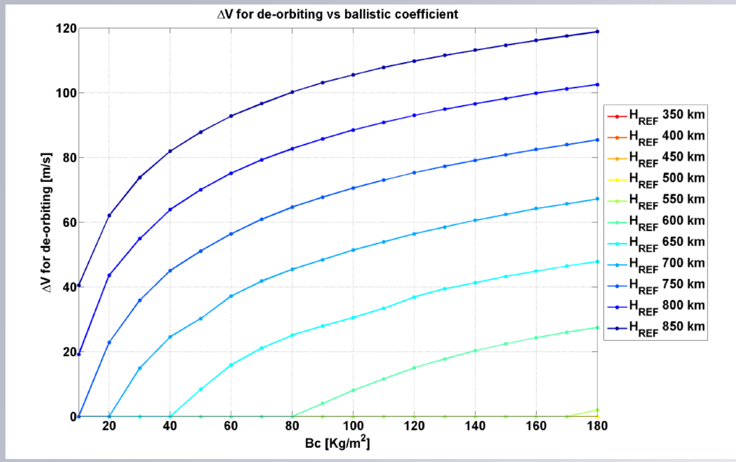
Orbit and Mission Architecture



- **Injection errors correction & Constellation deployment phasing**
  - Orbit altitude slightly influences the delta-V required, lowering it for higher altitudes.

- **Orbit maintenance**
  - × For low altitudes close to 500 km, the frequency of maneuvers and the corresponding delta-V for orbit maintenance is too demanding
  - ✓ Increasing the altitude to 800 km reduces the number of maneuvers for orbit maintenance to just one during the entire mission lifetime

- **Collision avoidance**
  - ✓ Provision for 2 collision avoidance maneuvers per year shall be taken for altitudes lower than 700 km or higher than 1000 km
  - × For altitudes between 700 km and 1000 km a provision of 6 collision avoidance maneuvers per year shall be taken



ΔV required for uncontrolled re-entry

- **End-of-life disposal to comply with ESA requirements on space debris mitigation**
  - ✓ Only for orbits below 550km altitude, a controlled re-entry could be performed without maneuvers
  - × For orbits above 750 km, the re-entry requires a maneuver for all the ballistic coefficients analysed

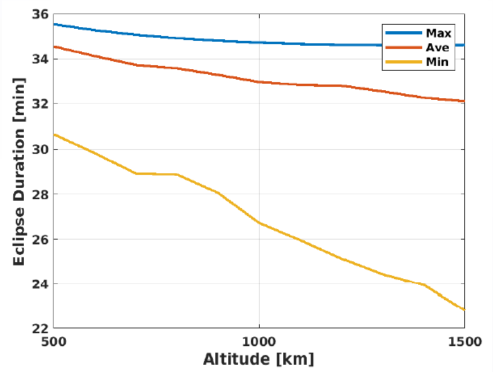
Orbit and Mission Architecture

Eclipse Analysis

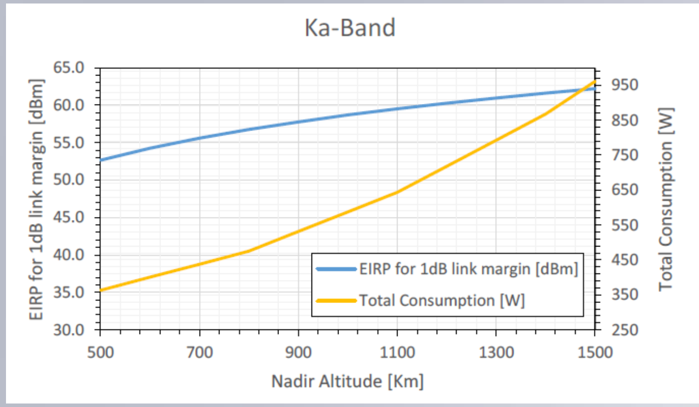
Key parameter for the design of the power and thermal spacecraft subsystems

Parametric analysis performed to evaluate the variation of the eclipse duration with altitude

✓ **Lower altitudes calls for longer eclipse duration, while higher altitudes cause shorter eclipse duration**



Eclipse duration statistical variation as function of orbit altitude for 20º orbit inclination



Payload power budget variation as function of orbit altitude in Ka-band

Link Budget

The transmission power requirement per channel is proportional to the square of the satellite altitude, while the number of available channels per satellite is inversely proportional to the satellite altitude.

✓ **The choice of a low altitude leads to both an increase in communication capacity and a reduction in power requirements per satellite.**

Latency

R: The mission shall guarantee system latency no greater than 100 ms

- **Lower altitudes will lead to lower system latency, but this value is fulfilled selecting a LEO orbit, disregarding the specific altitude.**

Orbit and Mission Architecture

Extreme altitudes were discarded:

500 km

- need of too many satellites and orbital planes
- frequent altitude maintenance manoeuvres impacting mission operations

1500 km

- higher power required from the COMMS payload
- worsening in launcher capacity
- increasement in de-orbit delta-V required

The selection should focus on intermediate altitudes:

- Higher altitudes will ask for higher power needed by the payload, which is already a very critical point
- 1200 km altitude should be discarded because of the presence of OneWeb satellites

In terms of latitudes…

- To cover +/-30º latitude band too many satellites and orbital planes would be needed
- From a market analysis point of view a latitude band of +/-20º is still interesting, not reducing significantly the number of possible users of the proposed service

Selected Orbit and Mission Architecture:

60 satellites placed in 4 orbital planes at 1100 km altitude and 15º inclination guaranteeing continuous coverage in the ±20º latitude band.

Launch Strategy

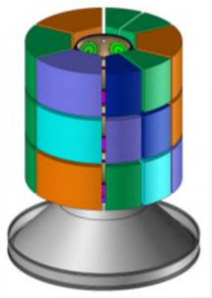
Possible launchers assessed: Vega-C & Vega-E, Falcon-9, Ariane 6

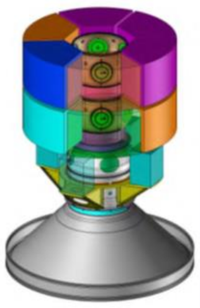
✓ **Ariane-6**

- Rideshare launch service solution on Ariane 62 and Ariane 64 for small satellites
- Stack with small S/C aggregated on one or several MLS carrying systems:
  - HUB: offers 6 ports, each being able to accommodate in radial direction a spacecraft of 350 kg mass
  - ASAP-A6: it provides up to 4 external platforms for spacecraft of 300 kg
- Payloads can be injected into different orbits for instance to initiate plane changes or orbit raising manoeuvres
- **Ariane 62** performance estimation for EQSATCONDR orbit: **9000 kg**
- **Ariane 64** performance estimation for EQSATCONDR orbit: **19750 kg**

EQSATCONDR Satellites are compliant with Ariane 6 MSL HUB carrying system but not with ASAP-A6 (mass out of range)

Ariane 6 MLS carrying system with 3 HUB



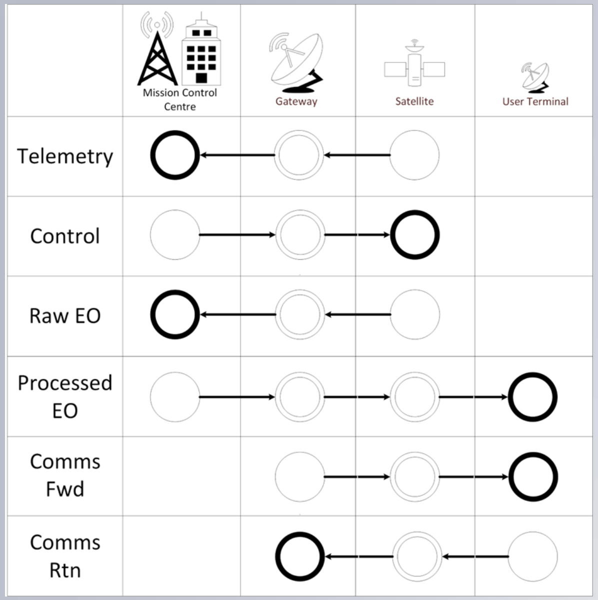


Ariane 6 MLS carrying system with 1 ASAP-A6 + 2 HUB

Ariane 62 is selected as baseline launcher for the baseline deployment strategy of 4 dedicated launches

Concept Architecture

- Architecture considers the following parts:
  - Space segment (bent-pipe type communications payload)
  - Ground segment (VSAT gateway)
  - User Segment (User Terminals)
  - Mission Control Centre (MCC)
- Multiple beams from each satellite cover different areas and can intersect when handover occurs

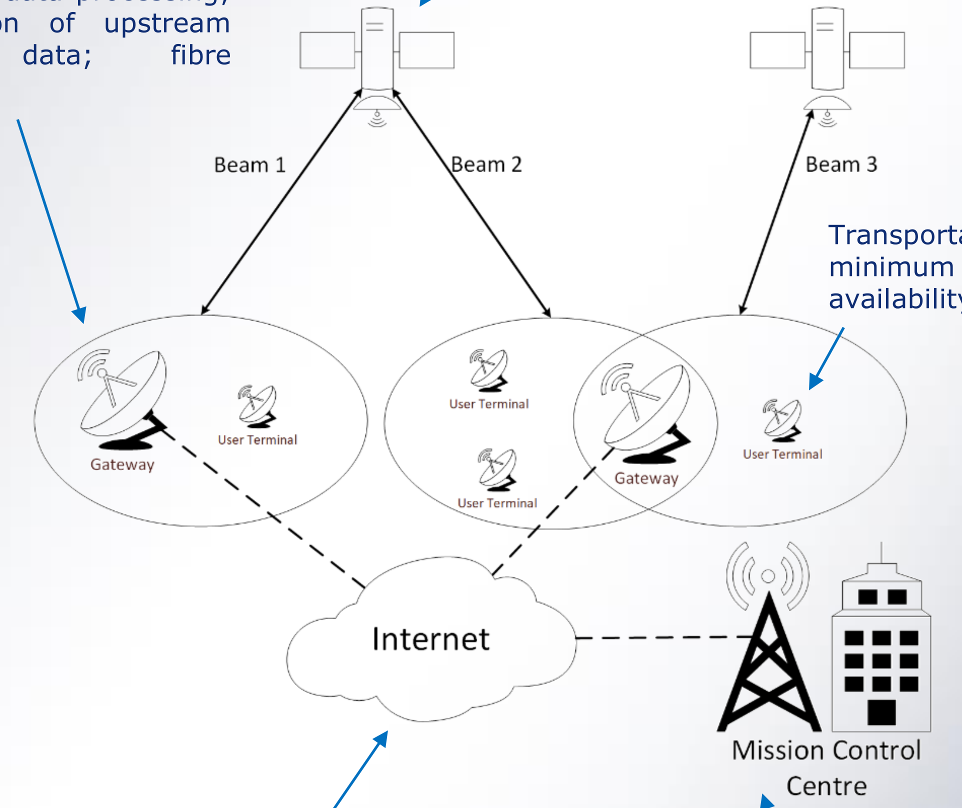


Antennas shall have unobstructed view of the sky to maintain communication with satellites passing over the gateway's region

Different packets originate & terminate in different locations

Capture EO data; bent pipe comms payload

Simple EO data processing; transmission of upstream comms data; fibre connection



Transportable; minimum guaranteed availability & data rate

Data routed through the internet between gateways and the MCC

Command & Control; collation of data over time; database of EO & user details

Concept of Operations

Launch and Early Orbit Phase (LEOP)

- The baseline launcher selected is the Ariane 62
- Nominal orbit acquisition, including counteract of launcher injection errors
- LEOP is assumed to last approximately 1 week

Commissioning Phase

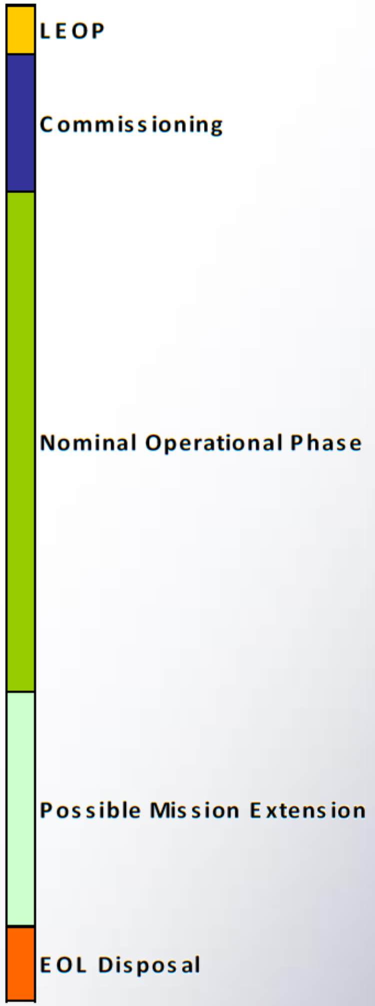
- To verify and calibrate the core system elements and functionalities
- Phasing sequence for the EQSATCONDR satellite constellation deployment
- Targeted to 6 months

Nominal Operational Phase

- Nominal data products are acquired by the satellite and the communications service is provided
- Satellite nominal operations
- 7-years nominal lifetime of the satellite
- Possible extension if resource availability and satellite health allow for it (TBC)

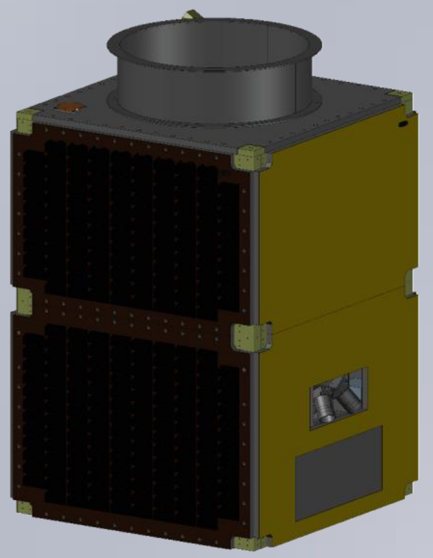
EOL Disposal Phase

- Compliant with ESA requirements. Safe uncontrolled decay shall be guaranteed within 25 years.
- Satellite’s passivation
- EOL phase is expected to last at most 3 months and ends with the satellite being de-activated



Small Satellite Platform

Small platform proposed for EQSAT mission



mini4EO satellite

- Total dry mass < 300 kg
- Payload allowable mass 55 kg
- 400W peak generation
- 200W average generation
- 0.9 x 0.9 x 1.55 m

mini4EO satellite

- Rebrand of the Sat4EO+ Satellite (EO minisatellite providing VHR products)
- Currently under development by DEIMOS
  - PDR Status + Critical Technologies on CDR

Substitution of main EO Payload by main COMS payload and secondary EO payload implied major design changes and/or redistribution of the COTS of the platform

Characteristics of EQSATCONDR Payloads

Parameter	Value
Comms Payload Mass	< 30kg
Comms Payload Power(2)	@50 users <1700W **@8 users ~402W**
Comms Payload Volume	< 1 x 1 x 0.5m
EO Payload Mass	~ 1,7 kg
EO Payload Power(1)	~ 12 W
EO Payload Volume	0.1 x 0.1 x 0.2 m (2U)

(1) Duty cycle of the EO PL is estimated as a 15%

(2) Duty cycle of the COMMS PL is estimated as an 80% according to the region of activity. COMMS PL should be OFF only when passing above the Pacific Ocean.

8 simultaneous users are considered the baseline for this study

- Bottom-up approach, considering the capability of the platform in terms of power generation and power dissipation

Small Satellite Platform

Mass Budget

Subsystem	W. w/eqpt margin [kg]
Structure	110.2
Thermal	5.5
COMMS	3.0
EPS	67.9
AOCS	14.8
Propulsion	13.0
CDHS	8.0
Payload(s)	27.3
HARNESS (5% of the nominal S/C dry mass)	12.5

Total S/C Dry Mass	262.2
Total S/C Dry Mass w/ System Margin (20%)	314.6
Total S/C Wet Mass w/ System Margin (20%)	319.4

Delta-V Budget

The analysis encompasses the following orbit manoeuvres and main contributions:

- Injection errors correction.
- Constellation deployment and phasing.
- Orbit maintenance.
- Collision avoidance.
- End-of-life disposal to comply with ESA requirements on space debris mitigation.

Orbit Reference Altitude [km]	1100
Nominal Orbit Acquisition (IP & OOP)	
Injection Error Correction (IP & OOP) ΔV [m/s]	12.6
Constellation Phasing (IP) ΔV [m/s]	5.8
Orbit Maintenance (IP & OOP)	
In-Plane Control ΔV (IP) [m/s]	0.0
Collision Avoidance (IP)	
Collision Avoidance ΔV [m/s]	2.0
EOL Disposal (IP)	
Controlled Re-Entry ΔV (no margin) [m/s]	179.4
Total Budget	
Total ΔV (no margin) [m/s]	**199.8**

The overall ΔV budget is computed by summing all the contributions outlined above and following the ESA guidelines for ΔV and fuel budget computation

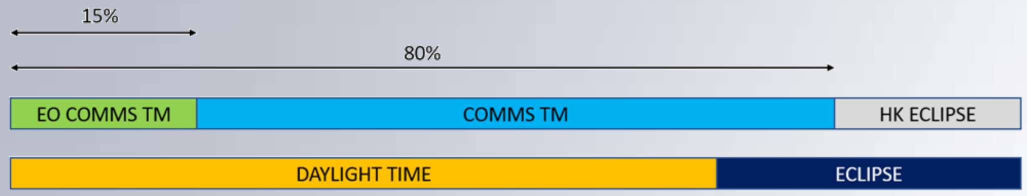
Small Satellite Platform

Power Budget

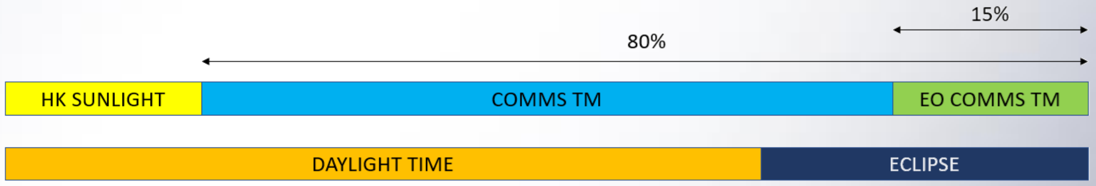
Subsystem	HK Sunlight	HK Eclipse	Detumbling Mode	EO	Pointing	COMMS TM	Starting COMMS	EO COMMS TM	Firing	Safety Mode
Thermal	0.00	36.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
COMMS	2.10	2.10	2.10	2.10	2.10	12.60	2.10	2.10	2.10	2.10
EPS	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50
AOCS	55.51	55.17	141.94	55.87	222.78	55.83	55.83	55.87	80.12	32.83
Propulsion	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	378.00	0.00
CDHS	26.25	26.25	26.25	68.25	26.25	26.25	26.25	42.00	26.25	26.25
Payload(s)	5.00	5.00	0.00	17.00	5.00	402.55	201.28	414.55	5.00	0.00
Total Power Consumption before EPS efficiency [W]	**99.34**	**135.00**	**186.78**	**159.71**	**272.62**	**513.71**	**301.94**	**531.01**	**507.95**	**77.66**
Total Power Consumption [W] (*)	**139.42**	**189.48**	**262.15**	**224.15**	**382.62**	**721.00**	**423.77**	**745.28**	**712.92**	**108.99**

(*) Total power consumption calculated considering equipment margins. Also considering a 95 % battery charging regulator efficiency, a 90% PCDU efficiency and a 20% system margin

Considering the demanding duty cycle of the payload(s), two worst-case scenarios were analyzed to size the EPS:

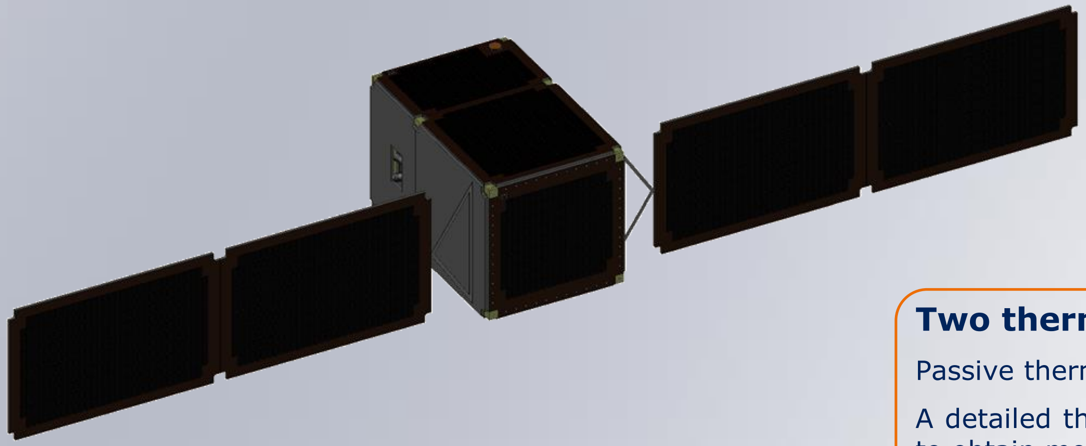


Schematic WCS CONOPS - No sun pointing



Schematic WCS CONOPS - All payloads' duty cycle in eclipse

Small Satellite Platform



Double steerable solar panels

The SC will have to be Nadir-pointed for a significant part of each orbit

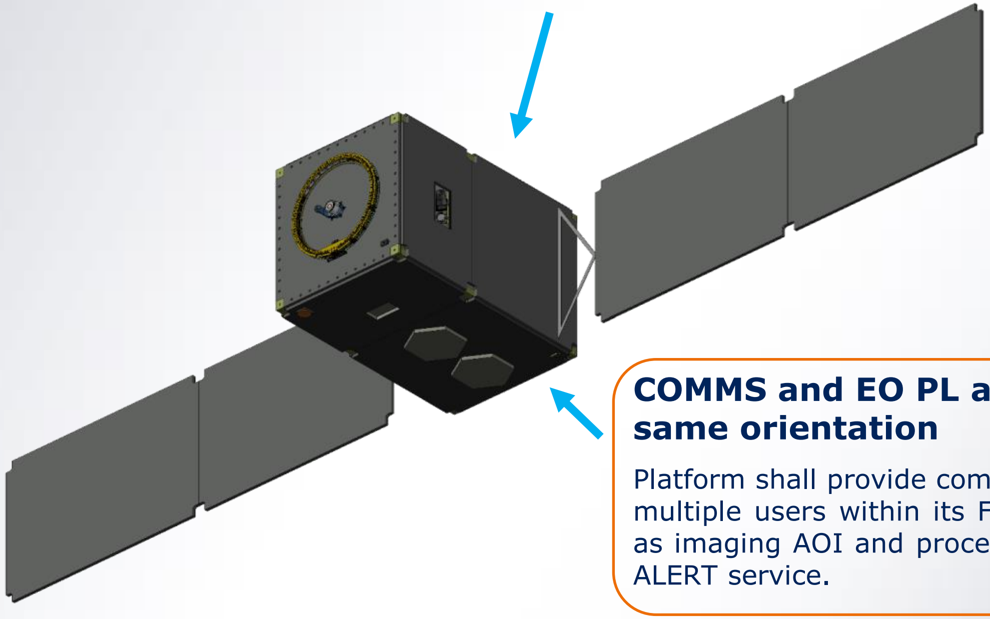
Power generation capabilities are significantly increased by the degree of freedom added by the steerable mechanism

Two thermal radiators located on the side panels

Passive thermal control / Silver FEP coating (or similar)

A detailed thermal analysis (including modelling of heat pipes) is needed to obtain more accurate dissipation capacities of the platform

Dimensions	1 x 1 x 1.55 m
Dry mass (w. 20% margin)	~316 kg
Wet mass	~321 kg



Launch Approach

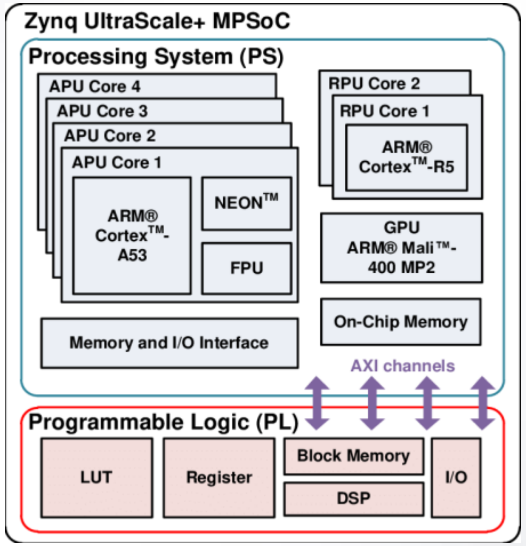
Mass and volume are compliant with Ariane 6 MLS HUB

4 launches are envisaged, each one carrying 15 satellites belonging to the same orbital plane

COMMS and EO PL allocated with the same orientation

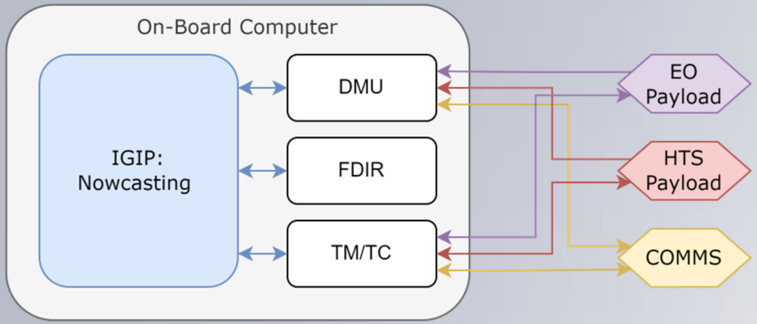
Platform shall provide communication services to multiple users within its FOV, at the same time as imaging AOI and processing data for the EO-ALERT service.

Avionics for on-board processing



The selected avionics is the **Zynq UltraScale +**

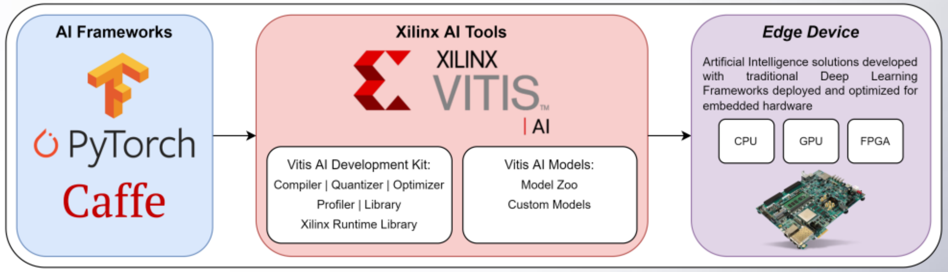
- **Multiprocessor system on a chip (MPSoC) that integrates CPUs, RPUs, a GPU and an FPGA**
- **High flexibility to integrate different processing algorithms with hardware acceleration**
- Hardware tested in space in similar applications as in the EOAlert project
- Multiple companies offer both rad-hard and rad-tolerant COTS hardware



Avionics high-level architecture diagram

- Architecture of the system composed by the HTS payload, the EO Payload, the OBC and the communication's system
- The Image Processing Subsystem (IPS) will manage alone the payloads, the processing for EO and HTS, and communications.

- Complexity of the AI algorithms is linked to the avionics hardware
  - A software solution based in AI for this project would include neural networks that need specific hardware to maximize performance.
- To facilitate deployment of AI-based solutions, the processing hardware needs compatibility with deep learning frameworks that facilitate the development and testing of the software.



AI Deployment on Xilinx SoCs

HTS Communications Payload

Signal Analysis – Frequency Band

Trade-off between different frequency bands to be used by EQSATCONDR: Ku, Ka, Q/V

Ka-Band

- Commonly used for LEO satellite constellations
- Significantly affected by atmospheric attenuation but is still manageable with good availability even in equatorial regions
- Highly congested

Q/V Band

- Relatively unutilized, so the regulatory issues are less restrictive
- Higher bandwidth and data rates to be used
- High degree of rain fade present for these frequencies in the equatorial region

Spectrum availability was assessed for both fixed and mobile satellite services in the Ku, Ka and Q/V bands (ITU Regulation)

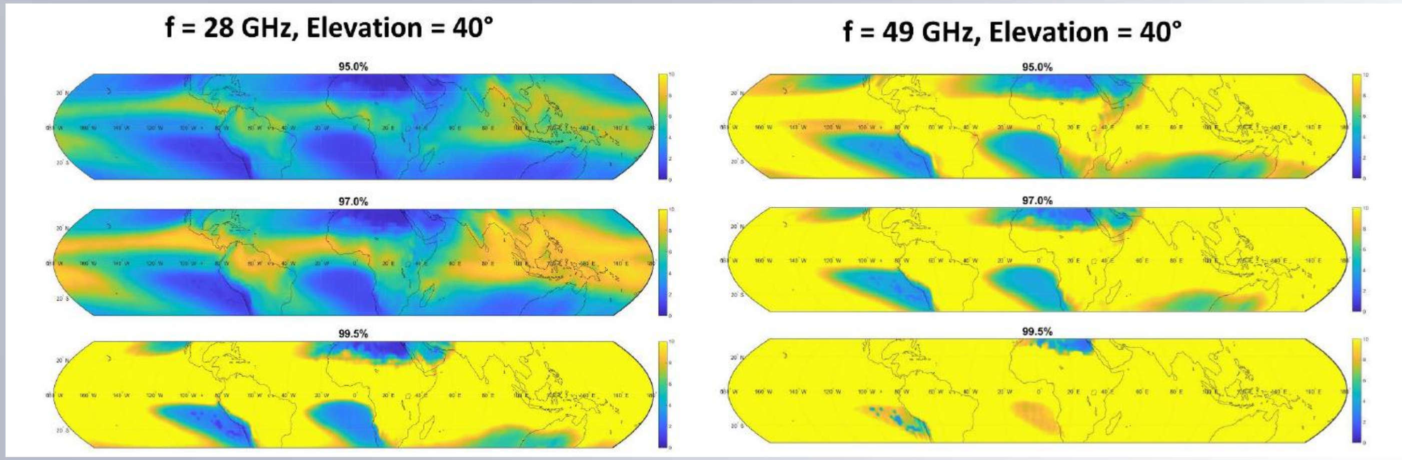
ITU considers to types of protection mechanisms:

- Coordination between services (GSO and non-GSO) where frequency overlap occurs (in both directions of transmission).
- Hard Limits. Effective Power Flux Density (EPFD) limits to protect GSO stations from other non-GSO services.

HTS Communications Payload

Connection Availability

R: Connection availability shall be above 99% for minimum guaranteed user bit rate of 10Mbps



Rain Fade Maps from Ka Frequency Band (left) to V Frequency Band (right) for 95%, 97% and 99.5% Availability

Selection of the frequency band

High frequencies, like the Ka-bands and the Q/V bands, are affected by signal attenuation due to heavy rain

Atmospheric attenuation analysis was carried out to assess the areas in which rain fade is at an unacceptable level for the link availability required (threshold set at 10 dB)

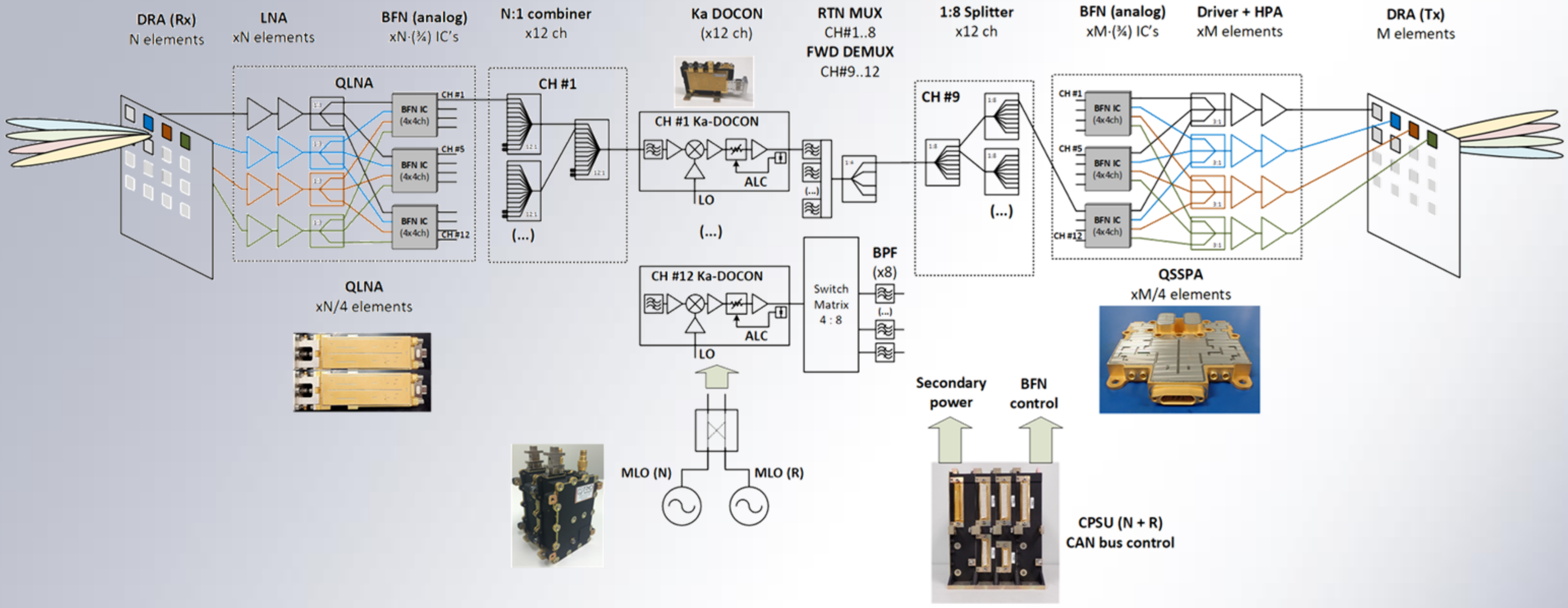
Balance the higher bandwidth and data rates achievable in the higher bands with the better atmospheric propagation of the lower ones.

→ ***Ka Band as baseline for the EQSATCONDR HTS Comms Service***

HTS Communications Payload

Comms Payload Concept

- **Tx/Rx Active phase arrays** with **BFN analog ASIC** (COTS) to minimize consumption
- **Transparent payload**



HTS Communications Payload

Service Capacity & Datarate

Rain conditions:

Channel Bandwidth = 10MHz

Modulation = QPSK 3/4

Datarate = 10.62 Mbps

Capacity (8 users per satellite) > 80Mbps

No Rain conditions:

Channel Bandwidth = 70MHz

Modulation = 8PSK 3/4

Datarate = 111.4 Mbps

Capacity (8 users per satellite) > 800Mbps

HTS Communications Payload

Latency

- **Satellite payload** is transparent and its contribution to latency is **<0.1ms**
- **RF propagation time** (uplink + downlink) ranges from **7.33ms to 10.25ms**
- **Main delay** comes from **video encoding (55ms) / decoding (15ms)** in case of streaming
- **Using the proper coding (HEVC, etc) and terminal / gateway hardware, latencies below 100ms are achievable**

HTS Communications Payload

Link Budget Analysis

- Two link budgets have been performed to assess both user and gateway ground terminal characteristics at Ka-Band. EIRP levels at gateway links are sized to the number of users.

- The following assumptions are also considered:
  - Orbit altitude set to 1100km.
  - Minimum data rate of 10Mbps => Payload designed for **70MHz**
  - 1dB link margin at 99% availability.
  - 18dB of losses due to rain
  - Maximum user antenna size 1m.
  - Maximum gateway antenna size 4.6m.
  - 26.5dBi satellite phased array antenna.

- Payload requirements for this link budget:
  - Minimum **8 beams**, goal 32 beams
  - **G/T > 0.4dB/K**
  - **EIRP** (1 channel):
    - User Link > **60.2dBm**
    - Gateway Link > **47.2dBm (1 channel)**

PARAMETER	USER TERMINAL	GATEWAY (32 Users)
Antenna Size (m)	1.0	4.6
EIRP (dBm)	80	95
EIRP (dBW)	50	65
G/T (dB/K)	16.8	29.8
HPA Power (dBm)	35	36

HTS Communications Payload

Link Budget Analysis

	Gateway Up-Link		
	Up-Link Frequency	30.00	GHz
GW Tx	**HPA Power**	**22**	**dBm**
GW Tx	Tx Power	21	dBm
GW Tx	**Tx Antenna Gain**	**59.00**	**dBi**
GW Tx	**EIRP (single beam)**	**80.00**	**dBm**
	Distance	1100.00	Km
	Atmospheric losses	-18	dB
	Free Space Loss	-182.82	dB
SAT Rx	**Rx Antenna Gain**	**26.60**	**dBi**
SAT Rx	Rx Noise Figure	3	dB
SAT Rx	Rx Bandwidth	10	MHz
SAT Rx	**G/T**	**0.43**	**dB/K**
SAT Rx	**Rx Signal Power**	**-95.22**	**dBm**
	Rx Noise Power	**-103.43**	**dBm**
	Up-Link C/N	**8.22**	**dB**
	QPSK 3/4 C/N minimum	4.03	dB
	Tx implementation losses	-1.5	dB
	Rx implementation losses	-1	dB
	Required C/N	**6.53**	**dB**
	Link margin	**1.69**	**dB**
	Data rate	**10.62**	**Mbps**

	User Down-Link		
	Down-Link Frequency	20.20	GHz
SAT Tx	**HPA Power**	**34.6**	**dBm**
SAT Tx	Tx Power	33.6	dBm
SAT Tx	**Tx Antenna Gain**	**26.60**	**dBi**
SAT Tx	**EIRP**	**60.20**	**dBm**
	Distance	1100.00	Km
	Atmospheric losses	-18	dB
	Free Space Loss	-179.38	dB
UT Rx	**Rx Antenna Gain**	**43.00**	**dBi**
UT Rx	Rx Noise Figure	3	dB
UT Rx	Rx Bandwidth	10	MHz
UT Rx	**G/T**	**16.83**	**dB/K**
UT Rx	**Rx Signal Power**	**-95.18**	**dBm**
	Rx Noise Power	**-103.43**	**dBm**
	Down-Link C/N	**8.25**	**dB**
	QPSK 3/4 C/N minimum	4.03	dB
	Tx implementation losses	-1.5	dB
	Rx implementation losses	-1	dB
	Required C/N	**6.53**	**dB**
	Link margin	**1.72**	**dB**
	Data rate	**10.62**	**Mbps**

Payload EIRP

Payload G/T

HTS Communications Payload

deimos SENER

Power Budget (Digital vs Analog BFN)

- **Analog BFN** has a significant reduction in power consumption

Analog BFN selected

Downlink

		Digital BFN	Analog BFN	Analog BFN
		Full load	Full load	Half load
		8 beams	8 user beams	4 user beams
		4 GW beams	4 GW beams	2 GW beams
		Ka band	Ka band	Ka band
Antenna gain	dB	5	5	5
Tx Losses	dB	-0.5	-0.5	-0.5
Number of Tx elements		64	64	64
Beam gain	dB	23.06	23.06	23.06
HPA power	W	0.79	0.79	0.39
Beams		8.4	8.4	52.5
Power per beam	W	5.98	5.98	0.48
Power per beam	dBW	7.77	7.77	-3.20
EIRP	dBm	60.33	60.33	49.36
Total RF power	W	50.27	50.27	25.13321338
HPA efficiency		32%	32%	24%
HPA consumption (1 element)	W	2.45	2.45	1.64
MPA consumption	W	0.28	0.28	0.28
MPA + HPA total consumption	W	**175.2**	**175.2**	**122.8**
ADAR3000 consumption	W	0.38	0.38	0.38
D/A consumption	W	1.5	0	0
UPCON consumption	W	0	0	0
Tx DAC+UPCON total consumption	W	**30.0**	**18.1**	**18.1**
MRO + LO	W	2.5	2.5	2.5
Digital processor consumption	W	70	2	2
Sec. Power consumption (total)	W	**277.7**	**197.8**	**145.4**
Tx heat dissipation	W	**227.4**	**147.5**	**120.3**

Uplink

		Digital BFN	Analog BFN	Analog BFN
		Full load	Full load	Half load
		8 beams	8 user beams	4 user beams
		4 GW beams	4 GW beams	2 GW beams
		Ka band	Ka band	Ka band
Antenna gain	dB	5	5	5
Rx Losses	dB	-0.5	-0.5	-0.5
LNA NF	dB	2.1	2.1	2.1
Antenna Temperature	K	40	40	40
Number of Rx elements		100	100	100
G/T	dB/K	1.07	1.07	1.07
LNA consumption	W	0.85	0.55	0.6
ADAR3001 consumption	W	0.373	0.373	0.373
A/D consumption	W	1.4	0	0
DOCON consumption	W	0	2.13	2.13
Rx total consumption	W	**129.3**	**108.6**	**100.8**
Rx heat dissipation	W	**129.3**	**108.6**	**100.8**

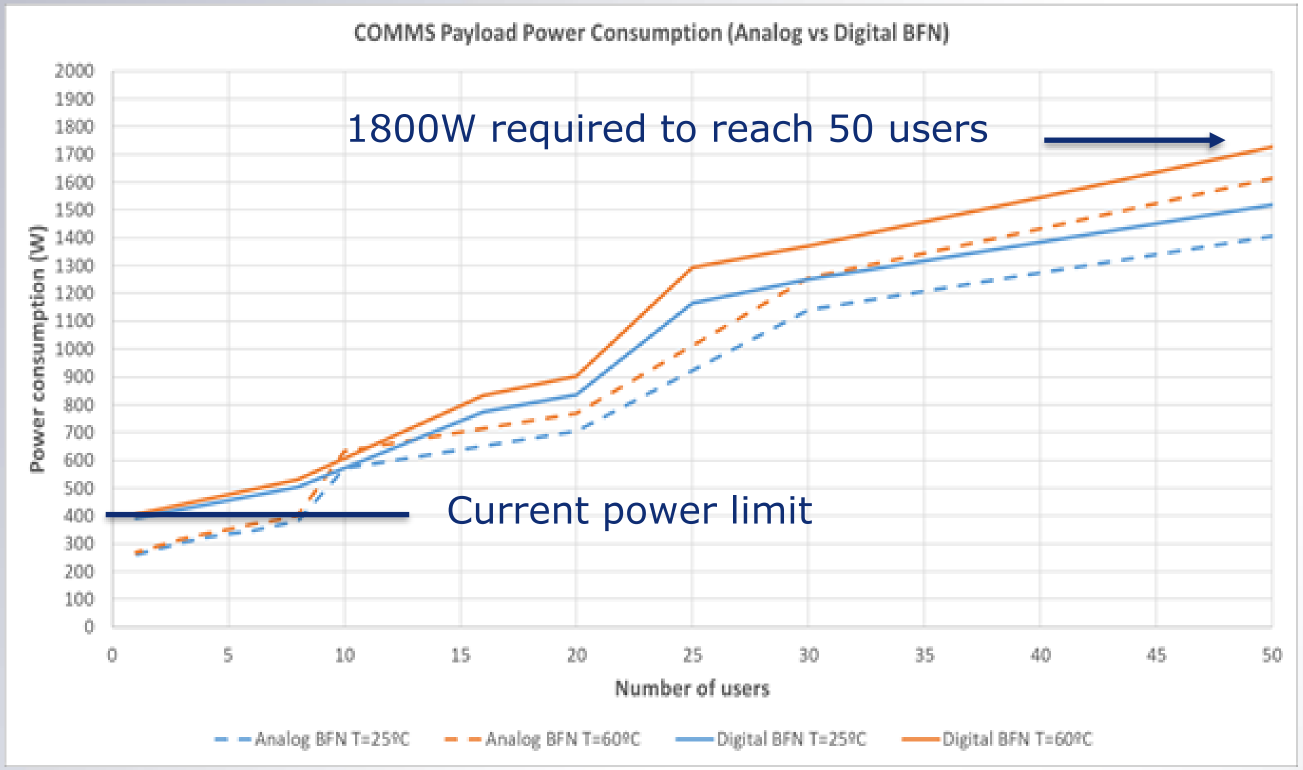
Payload

TOTAL Payload consumption	W	**407.0**	**306.4**	**246.2**
Margin	%	*10%*	*10%*	*10%*
DC/DC efficiency	%	*89%*	*89%*	*89%*
Primary Power consumption (total)		**503.1**	**378.7**	**304.3**
TOTAL heat dissipation	W	**452.8**	**328.4**	**279.2**

HTS Communications Payload

Future improvements / recommendations

- Evaluate the use of **commercial / COTS components** to reduce space segment cost
- **Satellite capacity** is **limited** by the **available power** in the platform. To increase comms capacity (and revenue) additional power would be required:



Gateway and user terminals

Ka-Band ground station from Envistacom LLC

GATEWAY

- 3 parabolic antennas to allow simultaneous communication with three in view satellites
- Antenna aperture is 3.5m to 5m
- Adequate satellite tracking suitable for LEO orbits
- Minimum EIRP level required should be greater than 65dBW
- Considering 5dB backoff, a 12W High Power Amplifier (HPA) shall be used
- LNB Noise Figure below 2dB
- Overall RF systems consumption below 600W

Each antenna will require approximately 18m of clearance in all directions and an absence of obstructions so that they are able to communicate with passing satellites as effectively as possible

USER TERMINAL

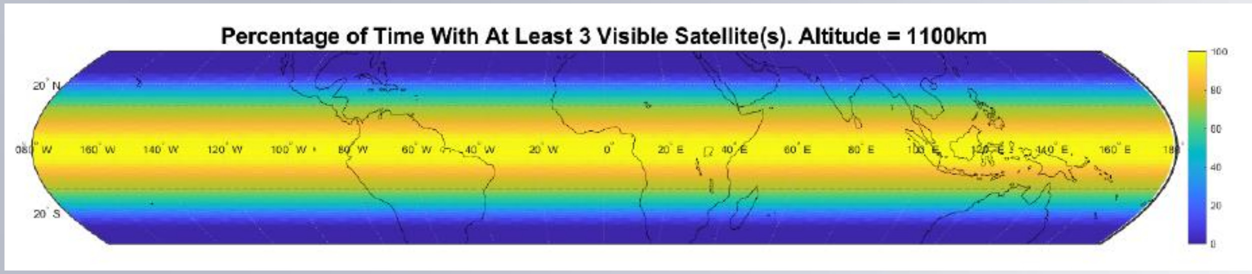
- Small aperture parabolic dish (<=1m aperture)
- Possibility to be accommodated on a mobile platform
- Minimum EIRP level required for a single user is 50dBW
- Considering 5dB backoff, a 10W power amplifier shall be used
- LNB Noise Figure below 2dB
- Overall RF systems consumption below 150W

Ka-Band phased array antenna (left), parabolic antenna (right) for maritime applications

Ground Segment Visibility Analysis

Gateways Visibility Analysis

- Each gateway shall be capable of communicating with up to three satellites at once and acquiring a communication link down to 20° elevation



Three satellite visibility map for a 4x15 orbital configuration at 1100km

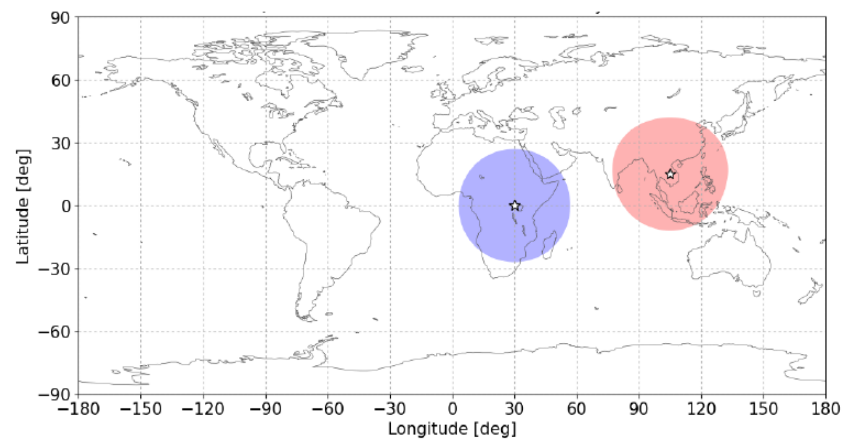
✓ The region within which gateways could be sensibly placed extends to +/-13º latitudes north and south to maximize visibility while minimize rain fade

Ground Stations Visibility Analysis

- Raw data can be downloaded with less stringent requirements to ground stations and contacts with ground stations is needed also to download telemetry and upload commands
- Looking at the Equatorial ground station, no blind orbits are present, meaning that it can guarantee one contact per orbit, with a maximum gap between contacts of 1.7 hours. <u>This is beneficial both for the data management and data latency</u>

User Terminal Visibility Analysis

- For the delivery of HTS communication service, at least one satellite must always be visible to the UT



Visibility areas for the baseline orbit of the Equatorial (purple) and low latitude (red) GSs, with a minimum elevation constraint of 5 deg

Earth Observation Payload

Parameters Evaluated for EO Payload Selection

- The payload shall be able to provide the service of EO **extreme weather nowcasting**.
- The payload shall be able to observe frequencies in the Infrared (IR) section of the Electromagnetic Spectrum (EM), multispectral and hyperspectral.
  - From H2020 project EO-ALERT heritage, the bands extracted as reference are: 6.2 µm, 7.3 µm, 8.7 µm, 10.8 µm, 23 µm. These bands belong to the Long-Wavelength Infrared (**LWIR**) range, this implies the need of a specific infrared detecting equipment which is called a **microbolometer**.
- Visible (**VIS**) and Near Infrared (**NIR**) bands are still desirable.
- **Commercially available imagers** are preferred, that is, Commercial off-the-shelf (COTS) products with high TRL.
- Reduction of mass, power, volume, GSD @1100 km and cost.
- The payload shall comply with the **EO service requirements** and the **EO payload requirements** identified

Camera	Provider	Spectral Bands	GSD	Swath
HyperScout-2	**COSINE**	**50-bands (nominal) VNIR 3-bands TIR**	**@450km channel 1: 75m channel 2: 490m**	**@450km 310 x 150 km**
MultiScape 100 & 200	SIMERA	7 bands VNIR	4.75 m @500km	19.4 km @500km
DragonEye Imager	Dragonfly Aerospace	PAN + 6-bands MS	@500km PAN 1.4 m MS 2.8 m	22 km @500km
HyperEye		148 spectral bands from 470nm to 900nm	275 m @500km	570 km @500km
SIRC-EO	MDA Space and Robotics	8-12 µm	250 m @500km	
ECAM-IR1	Malin Space Science Systems	8-12 µm (LWIR)	N/A (wo. optics)	N/A (wo. optics)

→ **EO payload selected as the baseline for the EQSATCONDR constellation**

HyperScout-2 (Cosine)

Earth Observation Payload

deimos SENER

HyperScout-2

Channel 1: VIS/NIR — **Channel 2: TIR**

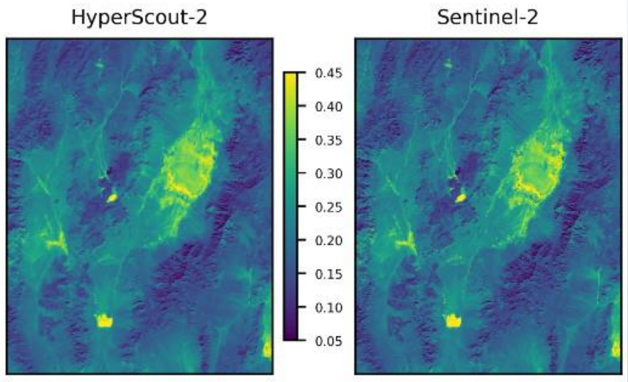
Field of View	31º x 16º
Focal length	41.25 mm
F-number	f/4
Pixel size	5.5 μm
ACT pixels	4096 px
Spectral range	450-950 nm
N spectral bands	50 nominal; up to 120 in boost mode
Spectral resolution	16 nm
Nominal data throughput	45.5 MB/s
GSD @500km	67 m
Swath @500km	280 km
Data volumen single swath	2300 MB raw; 750 MB compressed

Field of View	31º x 16º
Focal length	25.78 mm
F-number	f/2.5
Pixel size	17 μm
N Pixels	840 x 700 px
Spectral range	8-14 μm
N spectral bands	3
Spectral bandwidth	B1: 8-14 μm; B2: 10.05-11.24 μm; B3: 11.40-12.50 μm
Nominal data throughput	45.5 MB/s
GSD @500km	330 m
Swath @500km	280 km
Data volumen single swath	250 MB raw; 80 MB compressed

Other Features:

- ❑ HW for data processing, VNIR onboard processing, TIR on board processing (in development), onboard data manipulation.
- ❑ Flight Heritage → High TRL

Memories	64 GB / 128 GB
Interfaces	Data & TM/TC: RS422; Power: 12 V
Mass	1.8 kg
Volume	1.8 L
Power	11 W Peak

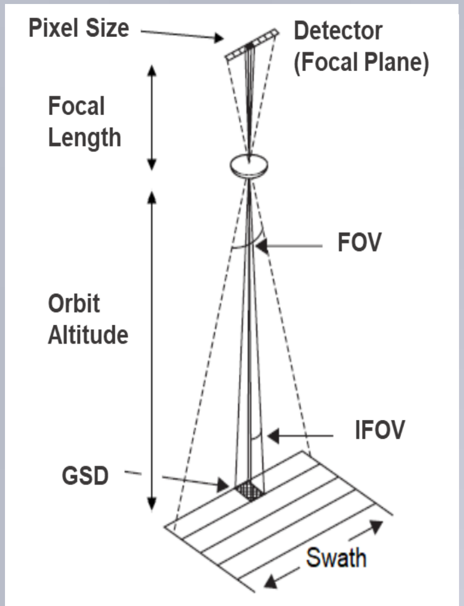


Source: HyperScout-2 datasheet

(https://www.cosine.nl/cases/hyperscout-2/)

Earth Observation Payload

Resolution



Relation between GSD, h, pixel size and focal length

$$\frac{h}{GSD} = \frac{f}{d_{pixel}}$$

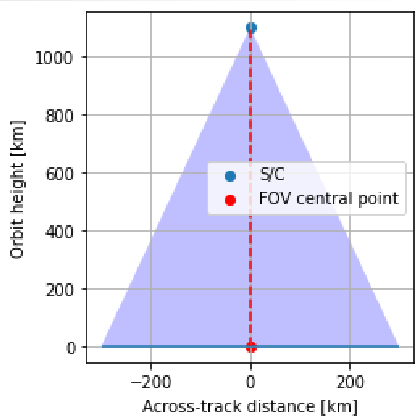
HyperScout-2

Channel 1: VIS/NIR

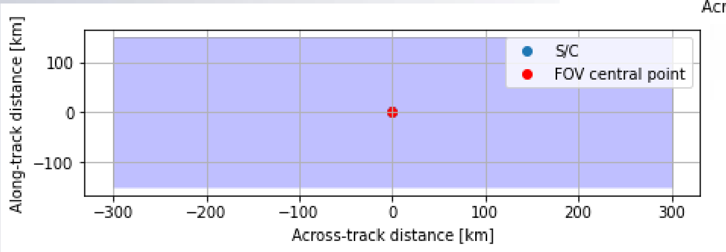
GSD @1100km	147 m
Swath @1100km	600 km

Channel 2: TIR

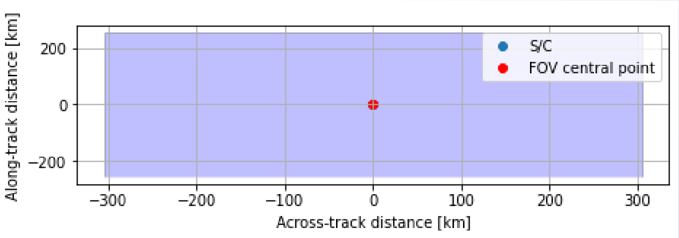
GSD @1100km	725 m
Swath @1100km	609 km



EO P/L FOV and ACT swath at EQSATCONDR orbit height with nadir-pointing (VNIR and TIR channels)



EO P/L footprint with nadir-pointing (VNIR)



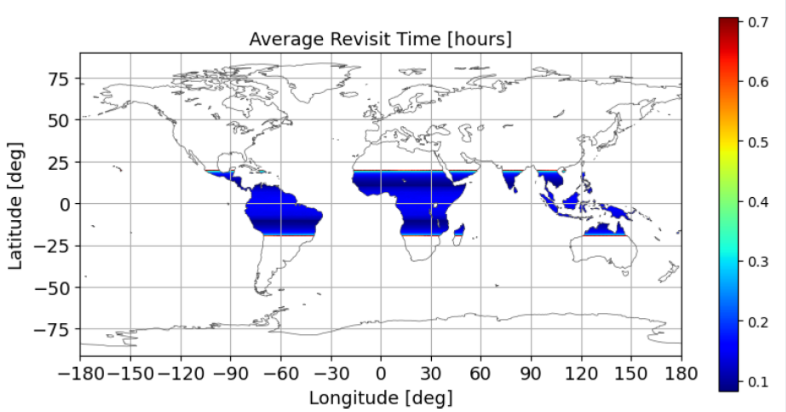
EO P/L footprint with nadir-pointing (TIR)

- Resolutions **not competitive with VHR and MR EO Markets**
- EQSATCONDR will compete against **GEO satellites**

Earth Observation Payload

Coverage, Revisit Time and Duty Cycle

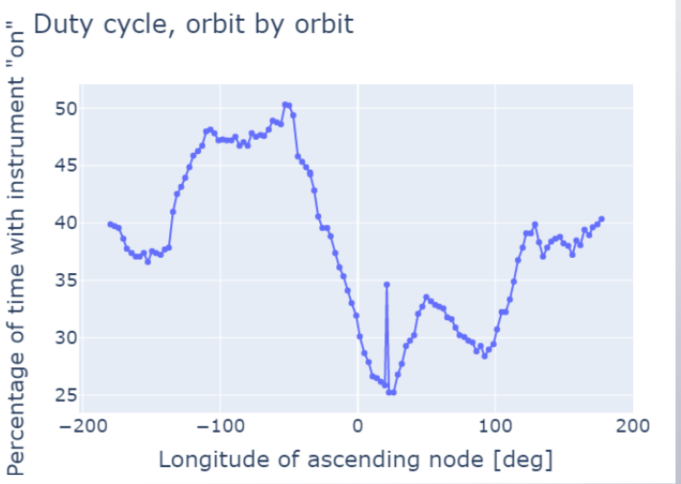
- Given the selected orbit and corresponding coverage band of the comms service, the threshold value of **±20º latitude band is considered for the Earth Observation service**.
  - Payload Field of Regard (FoR) of ±25º is required to cover up to 20º latitude. This FoR can be achieved either by the instrument Field of View, or by platform agility.



Average revisit time map for the EQSATCONDR constellation

- Except for a very tiny band around 20º where the revisit time is around 45 min, **the average revisit time is below 15 minutes**

✓ System fully compliant with the 30 min goal requirement



Duty cycle over land areas for the EQSATCONDR orbit

- Real operational duty cycle will be defined by the actual users of the service and their operational needs

✓ **An average duty cycle of 15% was considered for the EO service**

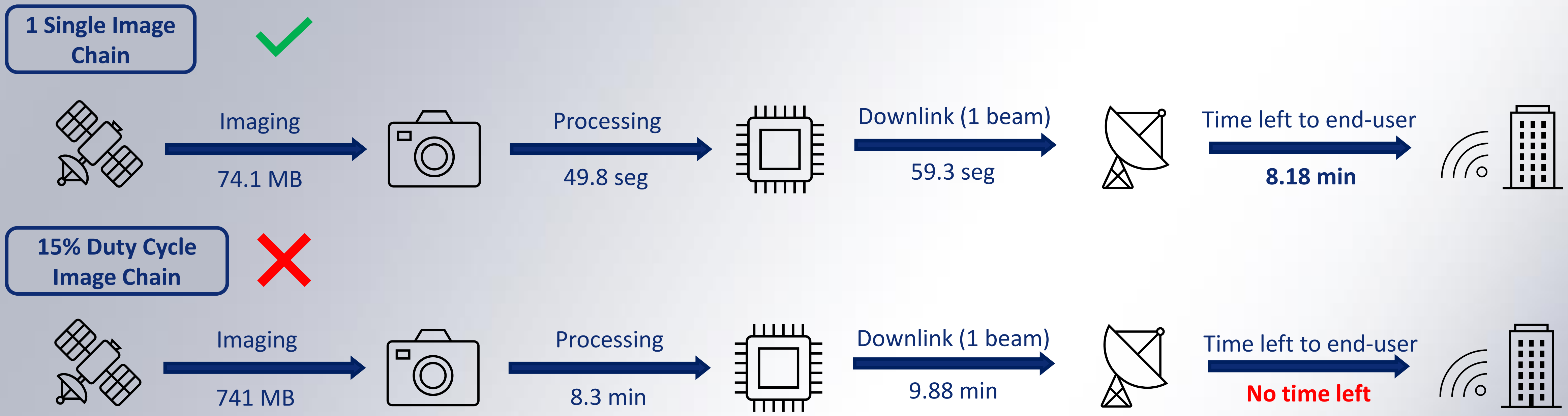
Earth Observation Payload

Latency

R: EO product shall be available to users in real time

R: The system shall be able to process the data on-board with a latency less than 5 min and a goal latency less than 1 min.

R: The end-to-end data latency from data acquisition to user delivery should be below 10 minutes



4 DEVELOPMENT PLAN

Key Technologies and TRL Status

Small Satellite Platform (TRL 3)

- An existing DEIMOS platform design (**mini4EO**) will be exploited and adapted to the needs of the dual service
  - Following the initial **SAT4EO** System Engineering and Technology Prototype (SAT4EO GSTP) study, the program has been continued thanks to the further DEIMOS internal investment in the SAT4EO+ platform, which is complemented by institutional support. Important to remark the Critical Elements development (SAT4EO-CE Incubed) supported by ESA
  - **Sat4EO+ PDR** held in Q4 2022. For the AOCS subsystem, under the scope of **SAT4EO-CE, CDR** held in Q4 2022.

HTS Communications Payload (TRL 5-6)

- COMMS payload is based on existing units (converters, filters, CPSU) and main RF blocks (LNA and SSPA) that come from existing units but need to be packaged to meet antenna dimensions.
- Analog BFN is based on Analog Devices BFN integrated circuit that has been qualified for new space as plastic COTS.

Earth Observation Payload (TRL 7)

- EO payload selected, HyperScout®2, is based on available COTS units with flight heritage (TRL 9).
- However, this camera is developed (and thus qualified) to fly in LEO around 500 km. For the EQSATCONDR project, changes are not necessary in the design, but at least delta qualification is necessary to assess the feasibility within the new environment

Avionics for on-board EO processing (TRL 7)

- The selected avionics for OB processing have varying TRLs in the range 7 to 9, depending on the technology employed.
- No design modifications have been identified for the use of this equipment in the EQSAT mission, but at least delta qualification is necessary to assess the feasibility within the new environment.

On-board EO processing algorithms

- DEIMOS brings an on-board processing and AI-based mission and system concept from mid-TRL activities such as EO-ALERT (H2020, TRL 5 late-2020) and SWANS (TRL 4).

Small Satellite for dual-service (TRL = 1)

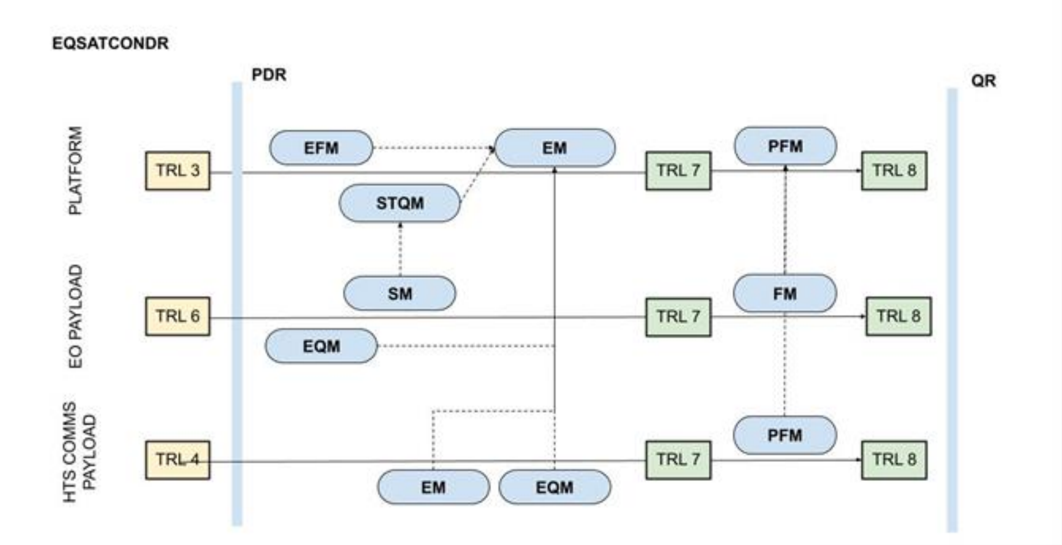
- Innovative and new concept for the LEO Equatorial dual HTS telecommunications (telecom) and Earth observation (remote sensing) service
- During the de-risk activity, this concept has been matured to reach a TRL 2.

Preliminary Development Plan

Master Schedule

Milestone	Description	Date
KO	Phase 0 Kick-Off	T0
PRR	Preliminary Requirements Review	T0 + 6
SRR	System Requirement Review (End of Phase B1)	T0 + 12
PDR	Preliminary Design Review (End of Phase B2)	T0 + 18
CDR	Critical Design Review (End of Phase C)	T0 + 30
QR	Qualification Review	T0 + 57
AR	Acceptance Review	T0 + 58
ORR	Operational Readiness Review (End of Phase D)	T0 + 59

Model Philosophy



EQSARCONDR Development Plan

Constellation Production

- 4 satellites per month is envisaged with the aim of deploying the full constellation in less than two years
- Deimos current capabilities allow to integrate two mini-satellites per month
- Internal investment to enlarge both the infrastructure and the personnel for constellations' integrations

5 EVALUATION OF THE EO SERVICE

Evaluation of the EO Service

Applications of Interest

HyperScout-2

Channel 1: VIS/NIR

Spectral range	450-950 nm

- 10 overlapping bands with Sentinel-2 (B1, B2, B3, B4, B5, B6, B7, B8, B8a, B9) → **182/261 S2 calculable indices**
- **Crop water management**
- **Flood detection**
- **Change detection of land use**
- **Vegetation monitoring**
- …

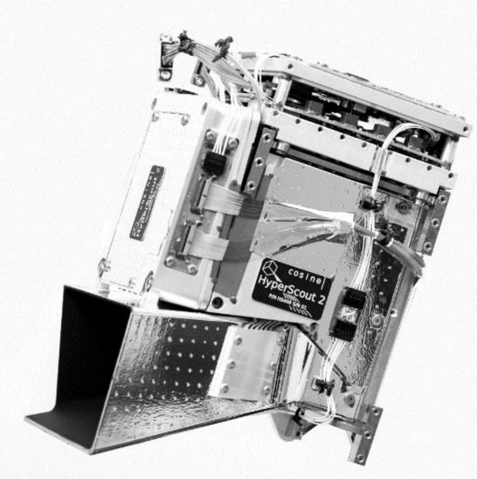
Channel 2: TIR

Spectral range	8-14 μm

- **Land Surface Temperature (LST):**
  - Fire hazard monitoring
  - Urban Heat Island
  - Agriculture: warnings of frost & planting time optimization
- **Sea Surface Temperature (SST)**
- **Soil moisture measurements**

Other

- No SWIR band → No cloud masking and other applications
- HyperScout-2 focuses on IA EO Market → Extra applications
- Algorithms to cover other satellites bands



HyperScout-2 EO P/L

Evaluation of the EO Service

Applications of Interest

- **50 potential use cases** identified within **13 different application segments** (based on EUSPA segmentation[1])
- Potentially more cases feasible if military applications are considered
- Detailed applications to be explored at a later stage

Agriculture
- Carbon content assessment
- Environmental impact monitoring
- Biomass & vegetation monitoring
- Pastureland management
- Climate & weather services

Emergency management
- Early warning
- Human displacement monitoring
- Post-event analysis
- Preparedness
- Rapid mapping

Forestry
- Biomass monitoring
- Deforestation/degradation monitoring
- Forest inventory monitoring
- Forest vegetation health monitoring
- Illegal logging monitoring
- Forest exploitation certification

Biodiversity
- Ecosystems monitoring

Fisheries
- Fish stock detection

Environmental monitoring
- Environmental auditing
- Environmental resources management
- Impact studies and ESG

Climate services
- Climate change mitigation and adaptation
- EO-based climate modelling

Energy & raw materials
- Environmental impact assessment
- Illegal mining monitoring
- Renewable energy assessment
- Risk assessment for energy assets

Insurance & finance
- Risk assessment & modelling
- Event footprint
- Index production

Infrastructure
- Environmental impact assessment
- Monitoring of impact of human activities on infrastructure
- Vulnerability analysis

Aviation & drones
- Particulate Matter Monitoring
- Aircraft Maintenance and Operation Optimization
- Hazardous weather id.

Maritime
- Marine pollution monitoring
- Ship route optimization
- Metocean (meteorology over oceans)

Urban development
- Air quality monitoring
- Light pollution
- Urban heat islands
- Informal dwellings

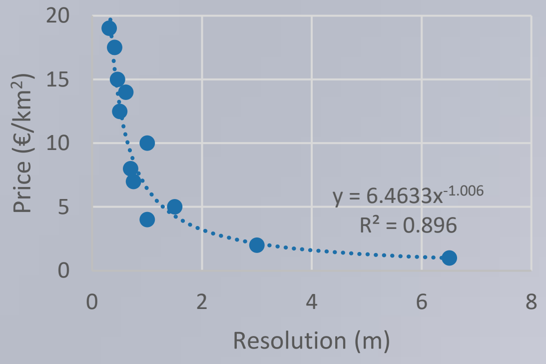
1 Source: EUSPA EO & GNSS Market Report, 2022

Evaluation of the EO Service

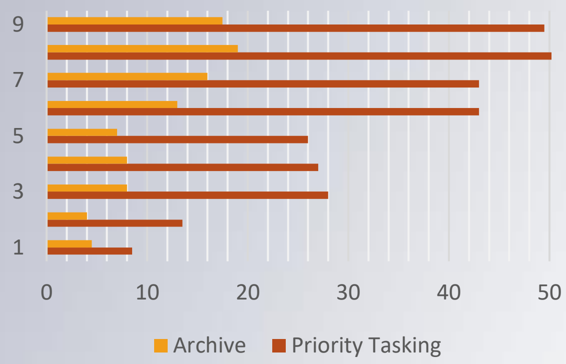
Pricing Options

Pay per image (€/km²)

- Price point based on **extrapolation from commercial imagery** data considering resolution (low) and very low latency
- Two price points: archival data & low latency data (equivalent to priority tasking, 3.08x higher price on average)



Effect of resolution on pricing (Source: Up42[1])



Effect of timeliness on pricing (Source: Up42[2])

Potential pricing for EQSATCONDR data: €14B/year value creation

Instrument channel	Resolution (GSD)	Expected pricing (archive)	Expected pricing (low latency)
VNIR	147 m	0.04 €/km²	0.13 €/km²
TIR	725 m	0.01 €/km²	0.03 €/km²

Subscription model (€/year)

- Unlikely model for comm'l customers: prefer pay per image
- **Preferred model for institutional customers**: position as cheap way to access better-than-GEO EO capabilities (e.g., Meteosat-like)
- Potential price point **based on value of competing GEO systems**

Program	Agency	Budget (EUR million)	Included in budget	Duration (years)	Value per year (EUR million)
Meteosat NextGen	Eumetsat	1,300	3 satellites, launch, ground segment, operations	12	108.3
GOES-R (16-19)	NOAA	11,000	4 satellites, launch, ground segment, operations	20	550
Himawari 8-9	Japan Meteo Agency	370	2 satellites, launch	15	25
Chollian 2A/B	KARI	510	2 satellites, launch	10	51

- If priced as "low cost service", need to be below Himawari cost
- **Potential range of prices: EUR 5-25 million / year**
- Feasibility of prices to be evaluated with customer interactions in later studies

1 Includes pricing from WorldView 2-4, GeoEye 1, Pleiades 1A/1B, Quickbird, Kompsat 3/3A, Deimos 2, IKONOS, Kompsat 2, Spot 6/7, PlanetScope, and RapidEye
2 Includes pricing from WorldView 2-4, GeoEye 1, Pleiades 1A/1B, Kompsat 3/3A, Deimos 2, Kompsat 2, Spot 6/7, and TripleSat

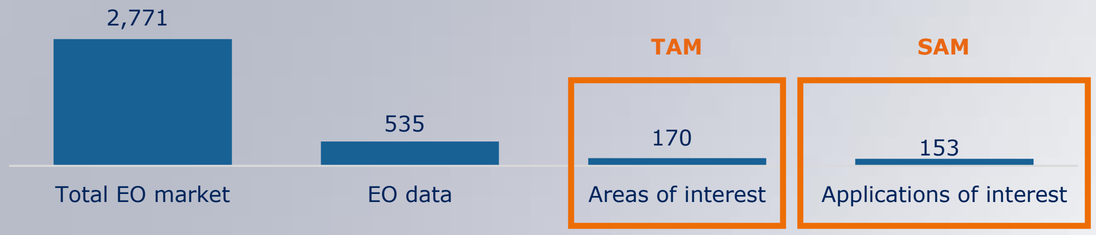
Evaluation of the EO Service

Market Assessment

Commercial

- Definition: **EO data market in areas of interest** (TAM) and **applications of interest** (SAM)
- Top-down estimate based on EUSPA data, assume constant growth (5.5% CAGR, same source)

Estimated commercial EO market 2021 (EUR million)



Institutional

- Bottom-up estimate based on total potential customers (countries) and potential pricing (see range in previous slide)
- 119 countries in areas of interest: 42 micronations (e.g., islands), **77 potential targets**
- Assume same growth as for Commercial market
- Assume total and serviceable markets coincide

Price per year (EUR million)	Total addressable market (EUR million)	
5	385	→ Used as baseline
25	1,925	→ Potential upside

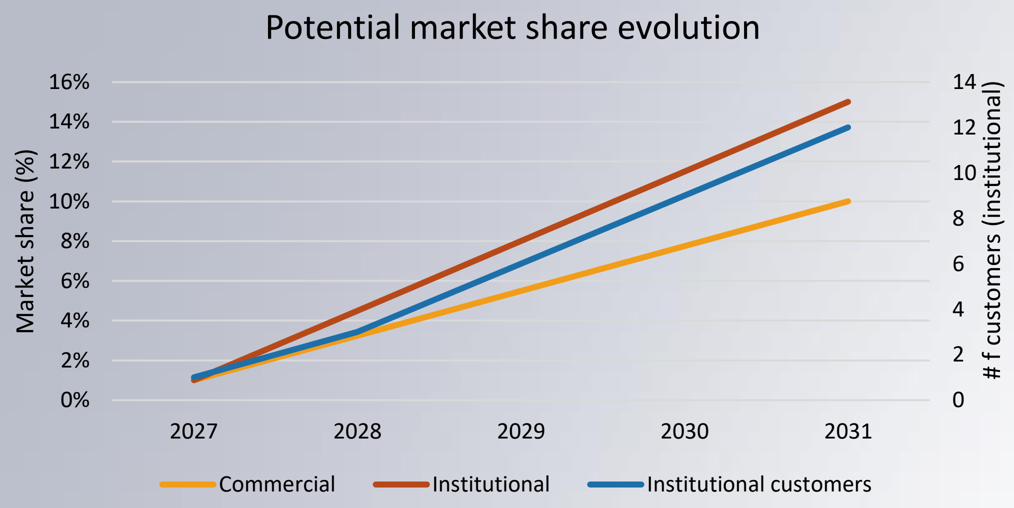
Market opportunity for EQSATCONDR EO service

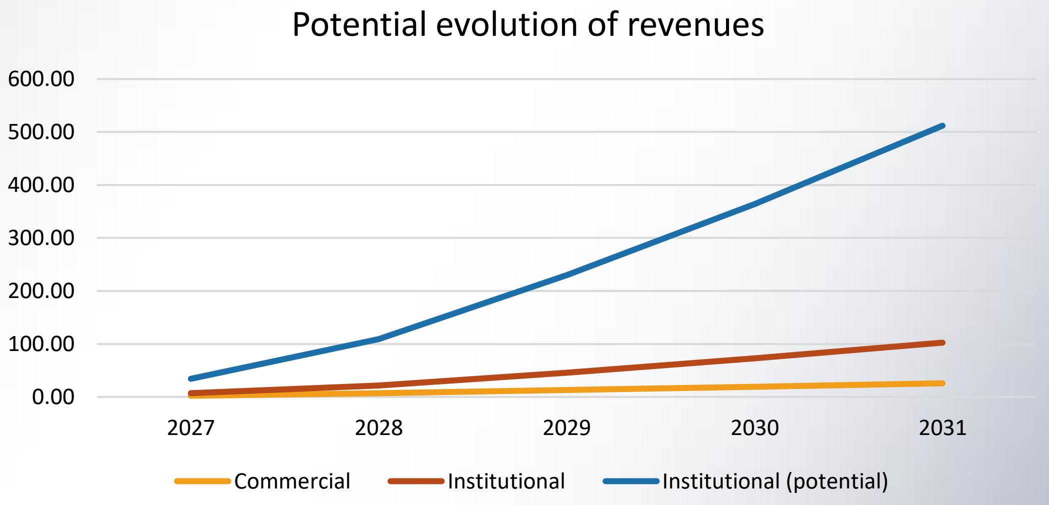
	2021, EUR million		2031, EUR million	
	TAM	SAM	TAM	SAM
Commercial	170	152	290	260
Institutional	385 – 1,925	385 – 1,925	657 – 3,284	657 – 3,284
Total	**555 – 2,095**	**538 – 2,078**	**947 – 3,574**	**917 – 3,544**

Evaluation of the EO Service

Revenue Potential

- Revenue potential **depends strongly on capacity to capture customers and institutional pricing**
- Reasonable assumptions can provide an order of magnitude estimate: need to be validated at later design phases
- Basic assumptions:
    - Lifetime: 7 years, start in 2027
    - Market share targets: 10% for commercial, 15% for institutional (12 customer countries), 1% at start
- Cumulative revenue potential: EUR 0.3-1.3 billion





6 EVALUATION OF THE HTS COMMUNICATIONS SERVICE

Evaluation of the HTS COMMS Service

Applications of Interest

Avoid

❌ **Niche markets** that are the targets of major LEO constellations such as Starlink and OneWeb broadband services → They focus on larger use cases such as home broadband or maritime shipping

Focus on

✔ **Energy, Mining, Transport and Civil Engineering sectors** who have a strong commercial requirement for low-cost connectivity solutions in remote areas of the tropics.

- Medium to long-term installations such as civil engineering works or open-cast mining which require data connectivity
- Short-medium term weather forecasts and warnings of rain and lightning to plan their activities

✔ Take advantage of the GS architecture and resources to act as a **reliable** and **near-real time** communication **channel for downloading the EO products**, reducing the data timeliness (latency).

? Other **potential applications** such as IoT/condition monitoring data, maritime shipping, road tolling, remote heavy equipment operators… → Considered for the market estimation but not in the business case due to saturation of the system.

Evaluation of the HTS COMMS Service

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Pricing Options

- **Growing investment in localised prediction systems by commercial weather forecast and advisory services.**
- The Emergen report estimates that over 44% of the €1.74bn weather alert investment will be in the Asia Pacific region.

Report by Emergen Research "Weather Alert and Warning Systems Market 2021"

ACTIVITY	Market size	Notes
Global Storm Alert Services	€1,740,000,000	Emergen report 2021
Tropical Region Weather Alert	€87,000,000	Estimated 5% of global
Government/Institutional Weather Alert	€65,200,000	Assumed 75% of total
Commercial Weather Alert market	€21,750,000	Assumed 25% of total

Supplier	Service	Mbps (download) Or usage	Pricing (monthly)	Location
Eutelsat	Domestic BB	22	$41.00	UK
Eutelsat	Domestic BB	37	$62.00	UK
Eutelsat	Domestic BB	75	£96.00	UK
Iridium	Voice & Text 150 Mins/Month	Data packet 340 Bytes	$109.99	Global
Inmarsat	Fleet BB 75MB	Usage 75MB per month	$309.00	Global
Inmarsat	Fleet BB 1024 MB	Usage 1024MB per month	$1,516.00	Global
SpaceX Starlink	Domestic BB	90-200	$99.00	USA
SWARM	150 LEO satellites for IOT	IoT service (e.g., water monitoring)	$5.00	Global
Orbcomm	ORBCOMM IOT	Data and tracking	$33-$90	Global but mainly mid latitudes
Globalstar	Commercial IoT	Data and tracking	$18-$35	80% of globe. Equatorial Gaps

Pricing for the HTS service is estimated based on price and capability of competing services

Total Serviceable Market for the HTS service →

Pricing (EUR/month)	Yearly revenues (EUR)
35	201,600
55	316,800
75	432,000
100	576,000

The service would be able to capture less than 1% of the total Tropical Region Weather Alert market.

7 EVALUATION OF THE DUAL SERVICE

ROM Cost Estimate

Total System

- Total Satellite
  - Payloads (Communications & Earth Observation)
  - Platform
- Launch
- Total Ground Segment
  - Gateways
  - User Terminal
  - Control Centre
- Operations and Maintenance

Approach for the constellation deployment:

- First unit (PFM), covering the non-recurring cost
- 59 units (FMs), as recurrent ones

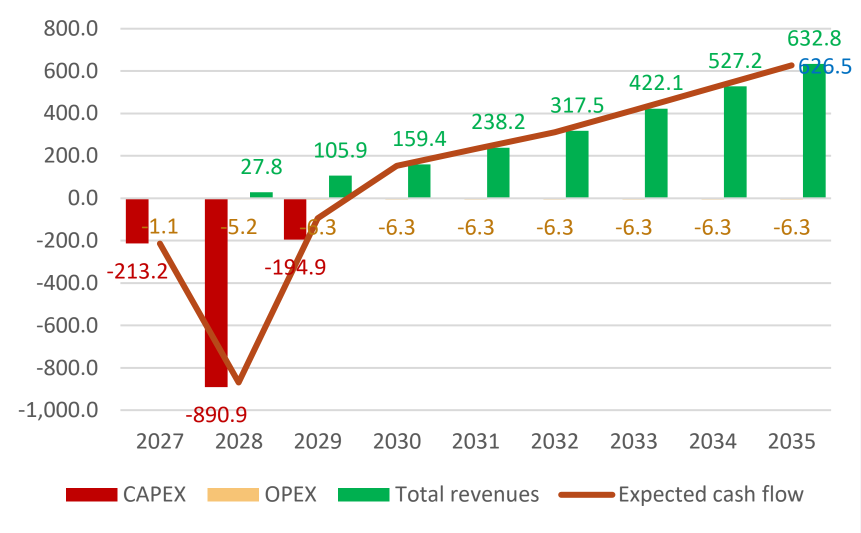
SATELLITE	First Unit Cost (ROM) [M€]	Recurrent Cost (ROM) [M€]
Platform (mini4EO)	14.5	8.0
EO Payload	0.5	0.4
HTS Payload	10.3	6.1
TOTAL	**25.3**	**14.5**

TOTAL SYSTEM	Cost per Unit	Units	Total Cost [M€]
Satellite	First Unit: 25.3 M€/satellite Recurrent Units: 14.5 M€/satellite	60 satellites (1NRC + 59RC)	881
Mission Control Centre	5 M€	-	5
User Terminals	0.1 M€/user terminal	480 (60 satellites serving 8 user beams at time)	48
Gateways – Fixed Cost	2 M€/gateway	30 gateways	60
Gateways – Variable Cost	0.11 M€/year·gateway	8 years * 30 gateways (Gateways development)	26
Launch & Insurance	75 M€/launch	4 launches of 15 satellites	300
Operations & Maintenance	3 M€/year	7 years	21
		TOTAL	**1341**

Evaluation of the Dual Service

Service	Baseline	Upside
EO	586.4	2,426.4
HTS	1.6	4.6
Total	588.0	2,431.0
HTS share of total	0.3%	0.2%

Revenue potential for the combined HTS and EO services (EUR million)



Financial projection (EUR million). Upside case

System would only recoup the total investment in the upside scenario

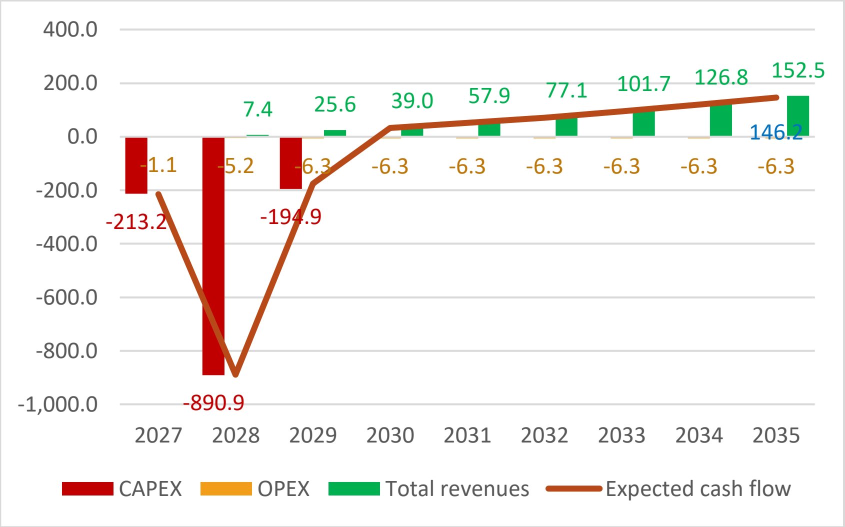
- Total cumulative cash flow through the system's lifetime would be positive in the last year of operations, reaching EUR 1081.50 million of total profits.
- In the baseline case though, total cumulative cash flow at system lifetime would still be EUR -761.50 million.

NPV of the EQSATCONDR system in its current configuration is negative for the baseline case, but positive for the upside case

The system is not feasible in its current configuration from a business point of view

Scenario	NPV (EUR million)
Baseline	-799.8
Upside	+162.3

Net Present Value of the EQSATCONDR system



Financial projection (EUR million). Baseline case

Conclusions

EQSATCONDR service has been evaluated to be **technically feasible**, although **not feasible from a business point of view**

- The revenue potential is too low to recover the investment required to deploy the system.

The contribution of the HTS service to the revenues is negligible while significantly driving the cost of the satellites

- EUR 6.1 million payload costs, ~42% of total recurrent satellite costs
- Additionally driving requirements on power, orbital configuration, operations, etc., which further increase costs.
- Even if the initial 50 expected users per platform were reached, the improvement would be negligible on the total revenue at the end of the mission

For the EO service, the institutional market has been found as the ideal target for EQSATCONDR

- Assumed that, at the end of the lifetime, a 10% market share is reached in the commercial market, and a 15% market share is reached in the institutional market
- Significant effort should be done for early customer engagement

To improve the financial profitability of the service…

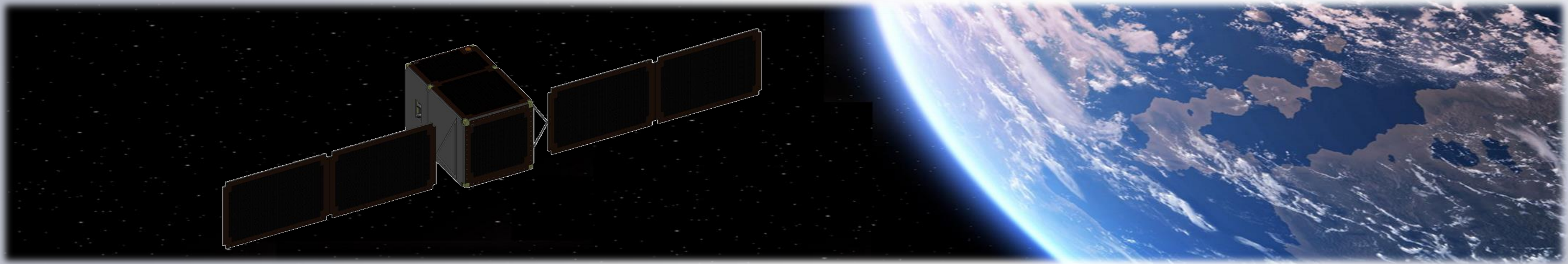
- Evaluate alternative launchers to reduce launch costs
- Use gateways as a service (GaaS)
- Identify alternative user terminals
- Eliminate the HTS communications service

8 FUTURE STEPS

Open Points for future phases

A list of open points has been identified since their detail was out of the scope of a de-risking activity…

- mini4EO platform lifetime is 7 years (COTS selection). However, the first batch is expected to operate with an extended lifetime up to 8 years → **lifetime of the P/F & P/L units would require an assessment with the supplier.**
- Study the **impact of having only half of the constellation available during the first year of operations.**
- Link budgets presented for the EQSAT concept show **margins lower than the 3dB as per ESA margins policy for Phase 0 studies.**
- **Storage needs** for the constellation units was preliminarily addressed but requires further analysis.
- A **Spare Philosophy** needs to be addressed.
- A consolidated list of **Long Lead Items (LLIs)** has to be included.
- A formal RFQ/RFI process shall be initiated with the **EO P/L provider** Cosine.
- An **assessment on the full constellation schedule** is required.



PERTEO Project

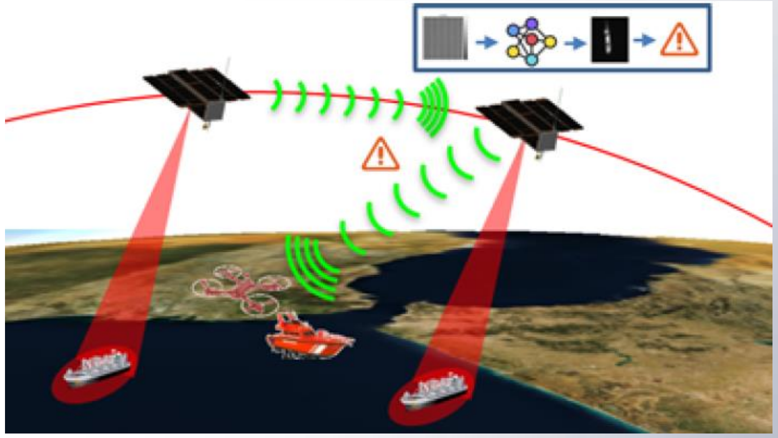
PERTEO: Persistent Real-Time Earth Observation for Responsive Disaster Management

Origin

- **TARGET:** ESA Open Space Innovation Platform (OSIP) for the ESA Initial Support for Innovation.
- ***ESA** identified as one of the accelerators the need for **"rapid and resilient crisis response"** and as one of the solution elements it is highlighted "timely collection, dissemination and transformation of the relevant data relies on **in-orbit processing and an intelligent, fast and secure interconnected space network** to ensure the safety and prosperity of citizens and builds resilience to climate change. Space should enable European governments and emergency services to respond to natural disasters, by providing timely and accurate high-resolution images...".*

Main Objectives

- To define and analyse the feasibility and performance of a Persistent Responsive Real-Time Earth Observation small satellite constellation mission (PERTEO) to **support disaster management** and therefore become an **essential service** to **save lives** and **combat climate change.**
- This mission would provide a global democratic service to support disaster management, in both the **pre-disaster (mitigation, preparedness) and post-disaster (response) phases**, and would dramatically improve satellite-based Disaster Management services Space applications and thus allow nations to manage more effectively emergency and crisis situations.



PERTEO Project

Motivation of the Activity

- **Current satellite-based Disaster management services are neither persistent nor highly responsive**

Motivation

System responsiveness ↔ **Persistence of the service**

Lead-time and latency

Availability and revisit time

Edge-computing for on-demand applications (ML/AI)
&
Global persistent communications

PERTEO Project

Motivation of the Activity

- The PERTEO mission would provide a semi-autonomous heterogenous constellation (**Persistency**), providing a highly responsive (**Real-time** tasking and product delivery) service.
    - The design of the constellation includes **three types of sensing acquisition**: **SAR, Hyperspectral and VHR** combining their capabilities to achieve almost real-time due to their in-orbit distances.
    - **Six platforms** are considered in **each** orbit organized in pairs mounting the same instrument.
    - Solution is **responsive**: **Real-time** (<1 min, down to seconds) is achieved in first observation product.
    - **Persistency** is achieved with a **low revisit time** (<1 hour any payload; < 3 hours any specific payload choice)

- A **persistent comms link**, e.g., GEO-relay or ISL, enables **software defined real-time changes in the satellite tasking**, in the **satellite application configuration** (i.e., AI app change), and enables **real-time global product delivery**.
    - The order of the observations from the payloads depends on the product and service
    - **In most cases the SAR leads the constellation processing logic, followed by the Hyperspectral or the VHR**
    - The event inferred by the leading platform will direct the acquisition of the platform coming behind.

PERTEO Project

Mission Design

- Constellation of **48 satellites** placed in 8 orbital planes
- Sun Synchronous Orbit (SSO) at 500 km and inclination of 97.4º
- Revisit time over the Equator below 1.2 hours and 1 hour over Europe (assuming an instrument FOV of +/- 30º)

Use Cases:

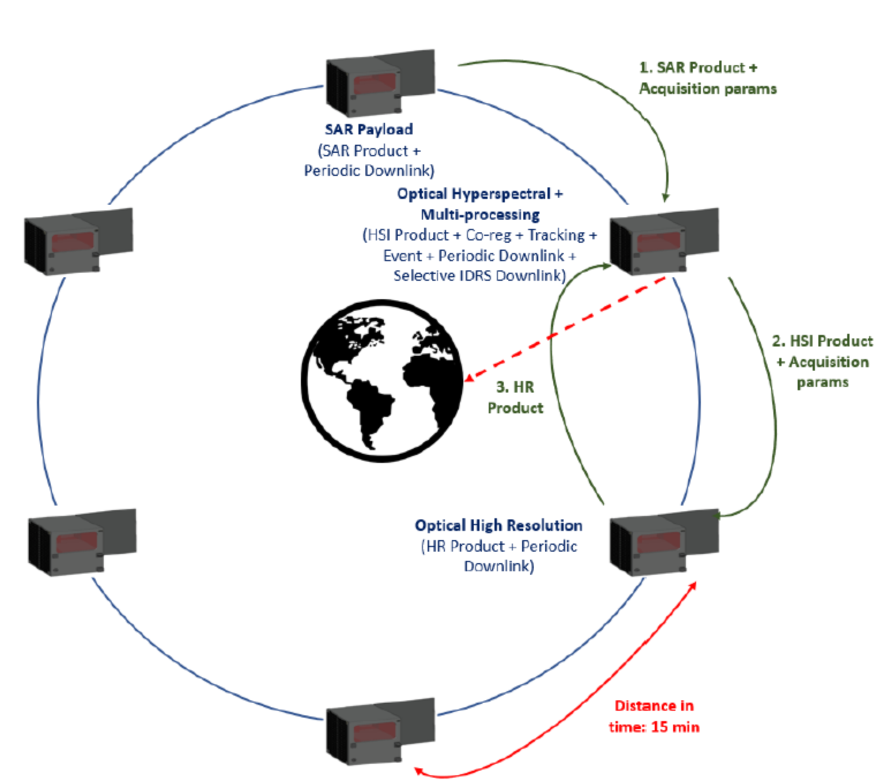
1. Floods
2. Air pollution
3. Ship detection
4. Fire
5. Storm

Backup:

6. Oil spill
7. Earthquake

Payloads to be embarked:

- Synthetic Aperture Radar (SAR)
- Optical (Hyperspectral and High Resolution)
- Data Processing Unit (DPU)

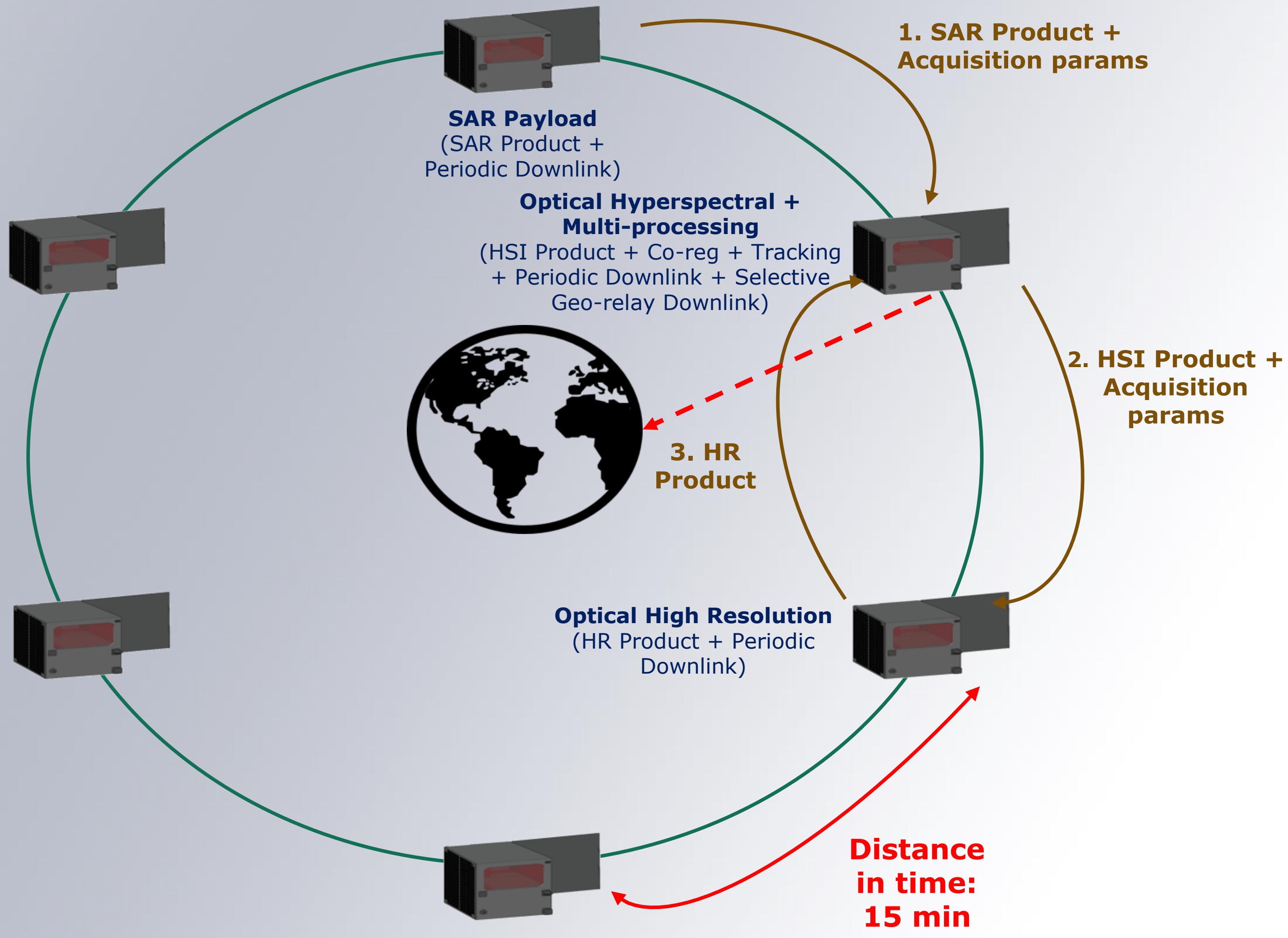


Earth Observation and satellite-based communications to provide a global democratic service to support disaster management

- **Heterogenous constellation of small satellites**
- mini4EO Lite platform (DEIMOS)

PERTEO Project

CONOPS



Downlink Comms

X-Band => Periodic imaging product downlink

- Ground
  - Relevant products based on AI events + Custom AI data
- Inter-Satellite
  - Acquisition params
    - LOS
    - GPS
    - Payload
    - OBC
  - Event products
    - SAR
    - HSI
    - HR

On-board processing

- Tasking
  - Countries affected
  - Areas affected
    - Agriculture
    - Housing
    - Critical infrastructure
    - Cultural heritage
    - Education
    - Other
- Products
  - Geo-location
  - Imaging
  - AI inference
  - Tracking
  - Event

PERTEO Project

Project Achievements

- The satellites in the constellation are software defined, in real-time, thus providing an **on-demand reconfigurable** mission implementation for multiple applications (ML/AI) provision.
    - The feasibility of DL on a Leopard DPU has been proved, and the enhancement of Versal increasing the number of DPUs available will allow on-demand reconfiguration and parallel processing according to its HW resources.

- The **miniaturisation of VHR payloads** and the upcoming **deployment of IoT networks** and capabilities will meet the improvement in disaster management services (**Pre and post**).
    - The capabilities of a VHR payload has been explored and the pre, monitoring and post scenarios have been defined for the selected use cases.

PERTEO Project

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Project Achievements

Use case / sensing / processing fields

		AI imagery input			Validation (ground)
		SAR	Hyper	HR	
Ship	AI field	Ship detection		Ship Classification	AIS
	Latency	(< 1 min +) ~30 min + < 1 min ~ < 31 min			
Storm	AI field	Wind-Speed / Change detection	Convective cell segmentation		Pluviometry + RADAR
	Latency	(< 1 min +) ~15 min + < 1 min ~ < 16 min			
Flood	AI field	Flood-mask	Flood-mask		IoT (Water level)
	Latency	(< 1 min +) ~15 min + < 1 min ~ < 16 min			
Air quality	AI field	Wind-Speed	AQI		IoT (AQI)
	Latency	(< 1 min +) ~15 min + < 1 min ~ < 16 min			
Fire	AI field		Wildfire detection	Hot-spot detection	IoT (Temperature)
	Latency	(< 1 min +) ~15 min + < 1 min ~ < 16 min			

PERTEO Project

PERTEO vs. EQSATCONDR

Similarities

- **Instruments:** both constellations have **EO P/Ls** and require a **persistent**, **near-real time communications system** to downlink the data products.
- **Applications of interest:** support weather alerts, disaster management… taking advantage of the near-real time connectivity (IDRS in PERTEO/HTS + Gateways in EQSATCONDR).
- **Satellites:** both projects have their platforms based on small satellites <~300 kg with a new space approach.
- **De-risking:** both projects have studied the technical and business feasibility of a constellation with the previous points

Differences

- **Coverage:** PERTEO is focused on global and European coverage while EQSATCONDR is aimed at the equatorial region.
- **Mission Analysis:** PERTEO is 48 satellites placed in 8 LEO orbital planes, SSO orbits at 500 km w/ 97.4º inc. EQSATCONDR is 60 satellites placed in 4 orbital planes at 1100 km w/ 15º inc.
- **Project focus:** PERTEO was more focused on the processing chain while EQSATCONDR put more emphasis on the platform capabilities.

PERTEO Project

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PERTEO vs. EQSATCONDR

Why should the projects be unified and continue?

1. **Similarities:** both projects have resemblance in terms of **instruments, applications of interest, satellites approach…**
2. **Differences:** even though there are disparities, some are complementary, and a future study can benefit from it (e.g., PERTEO focusing on the processing chain while EQSAT focusing on the platform)
3. Having a constellation capable of providing weather alerts for **disaster management** with a **persistent/near-real time responsiveness** will make the constellation a strategic asset for Europe.
4. **The use cases of a unified project could definitely improve** ESA's Copernicus Programme (e.g., Emergency Service, Land Monitoring Service, Security Service…); add value to some **Directorate-Generals (DGs) of the European Commission (EC)** (e.g., DG AGRI, DG ENV, DG EFIS…); and other **member states** or even the **scientific community** could benefit from it.

What DES propose?

Phase A / Phase B1 project:

- To prepare a proposal with alternatives/future studies and include it as part of ESA, EC Horizon 2023-24, EUSPA…
- The de-risking has been already performed → Focus on **unifying the strong points** of each constellation
- To perform a detailed technical and business analysis (including programmatic) and increase the TRL of the unified concept.

Thanks for
your attention!