Summer School Alpbach 2016

Satellite Observations of the Global Water Cycle

July 12-21, Alpbach/Tyrol - Austria

Water quality assessment of coastal areas, rivers and lakes

TEAM RED

Serena Annibali, Matthias Biber, Mary Borderies, Antonio Cabacos, Sabrina Esch, Loris Franchi, Magnus Johan Isaksen, Filip Jaromczyk, David Jelem, Anna Larsson, Jere Mäkinen, Nina-Elisabeth Nemec, Indrek Sünter, Daniel Vech

Team Tutors: Günter Kargl (Engineering), Matthias Drusch (Science)

FFG esa INTERNATIONAL SPACE SCIENCE INSTITUTE Hallerstrasse 6 • CH-3012 Bern • Switzerland AUSTROSPACE

Water Quality

Good Environmental Status of water, if:

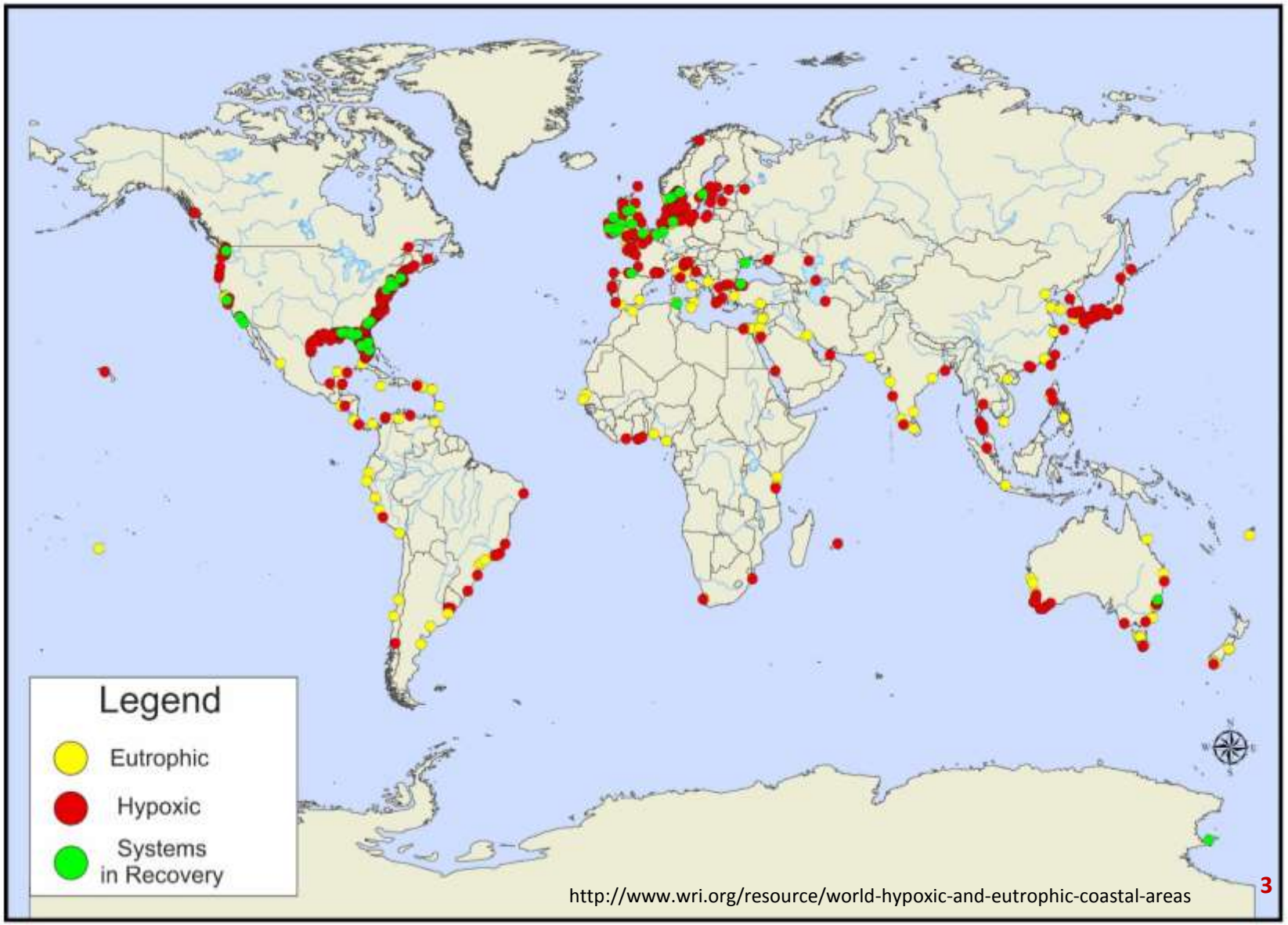
- Eutrophication is minimised
- Alteration of hydrographical conditions does not affect the ecosystem
- Concentrations of contaminants give no effects

http://ec.europa.eu/environment/marine/good-environmental-status/index_en.htm

"A variety of acute and chronic hazards facing the world ocean will impact ocean biology and water color. These changes include sediment plumes, altered food webs, harmful algal blooms, changing acidity, and alterations of benthic habitats."

Dierssen, 2010

Eutrophic & Hypoxic Areas (In-Situu)

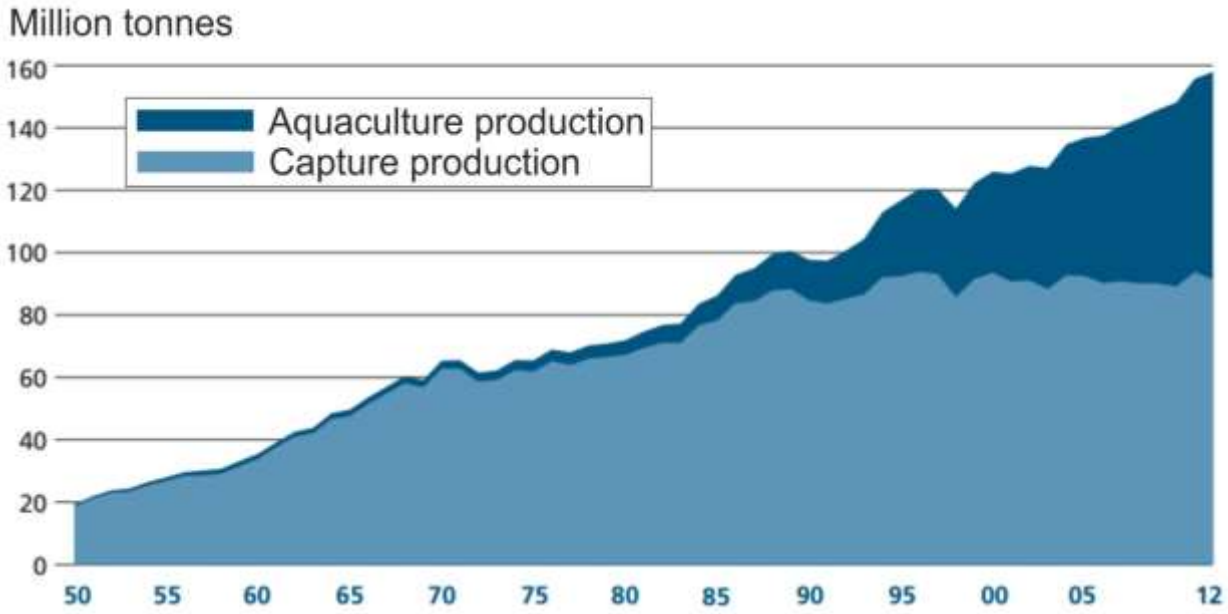


http://www.wri.org/resource/world-hypoxic-and-eutrophic-coastal-areas

Socio-Economic Need

- Half the world's populations lives within 60 km of the sea (UNEP[1])
- Fishery and aquaculture ensure livelihood of 10-12 % of the world's population (FAO[2])

World capture fisheries and aquaculture production



- Coastal and maritime tourism in Europe employs over 3.2 M people and generates a total of 183 B €

1 United Nations Environmental Programme 2 Food and Agricultural Organisation

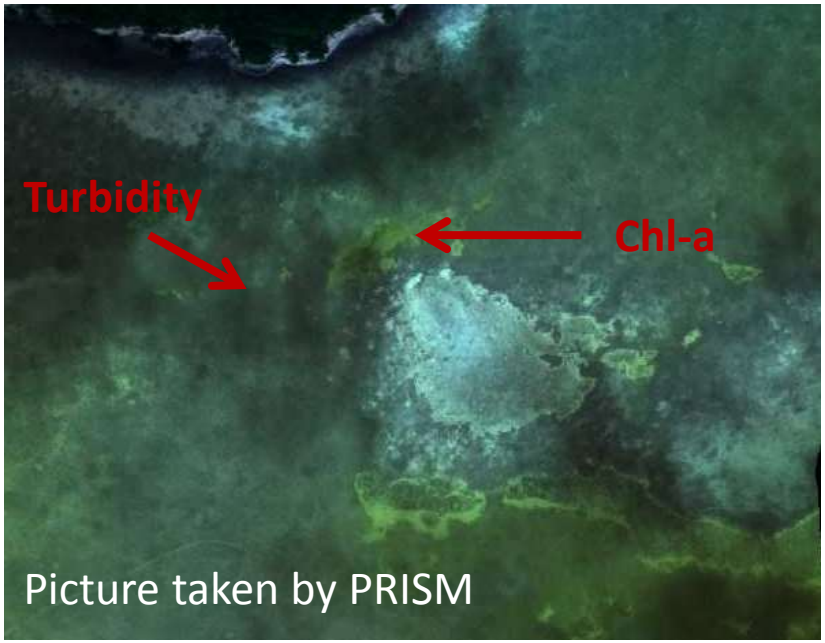
Science Objectives

Provide measurements for:

1. improved retrieval of **water quality indicators** from spectral radiances
2. a better **process-understanding** of turbulent mixing in coastal regions
3. analysing the **nutrient transport** (i.e. nitrate) from land into rivers, lakes and coastal waters
4. the development of **prototype monitoring** systems of coastal waters, rivers and lakes (i.e. algae blooms)

Observables

1. **Turbidity [NTU]**
2. **Chlorophyll-a concentration [mg/m^2]**
3. **Coloured dissolved organic matter (CDOM) [1/m]**
4. **Sea surface temperature (SST) [K]**



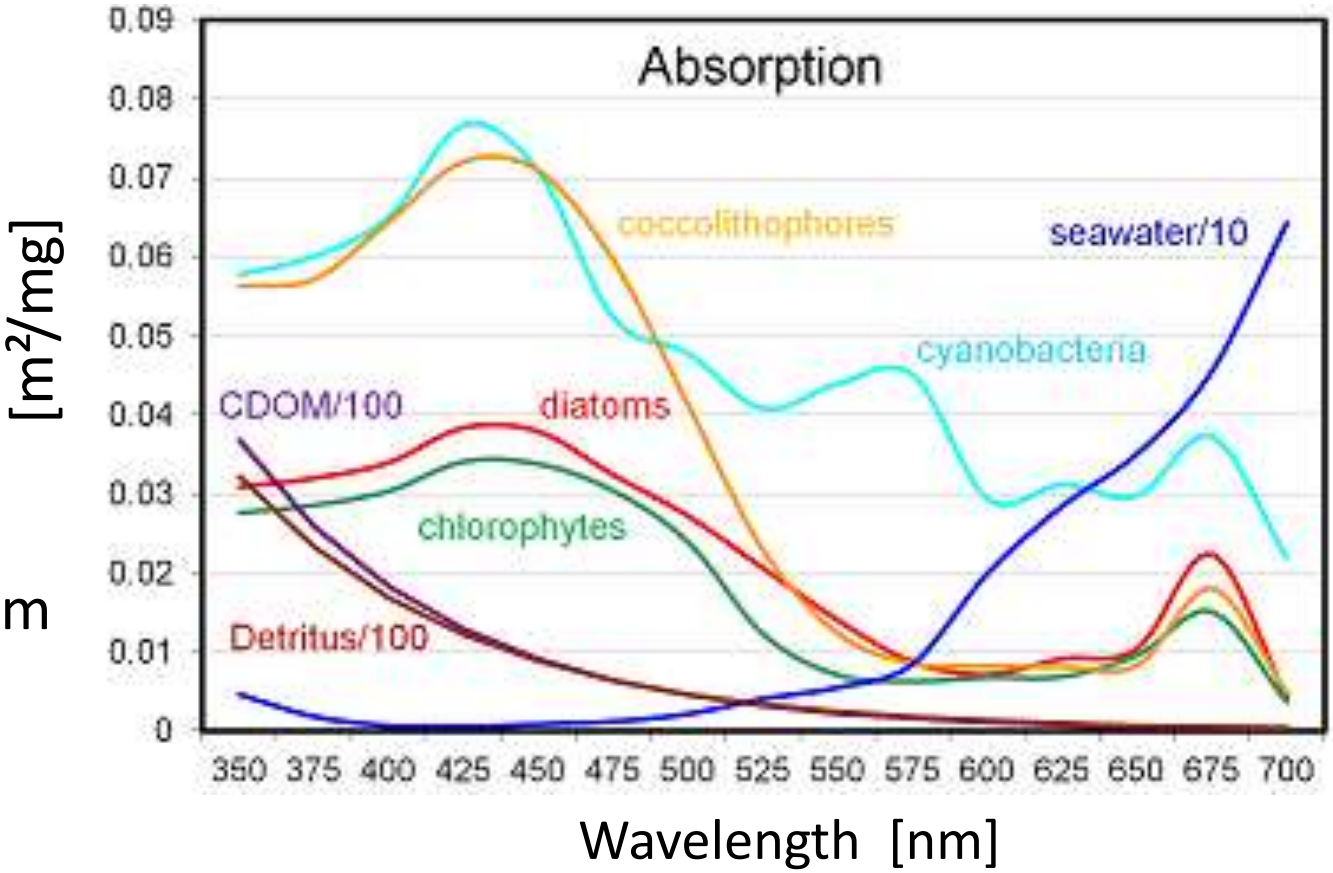
Scientific Requirements

Observables and Accuracy Requirements (Sentinel-3)

	Unit	Range	Accuracy
Turbidity	NTU	0.001 - 0.1	5 %
Chl-a	mg/m^2	0.001 -150	10-70 %
CDOM	1/m	0.01 - 2	10-70 %
SST	K	-	0.1 K

Spectral Signatures - CDOM & Chl-a

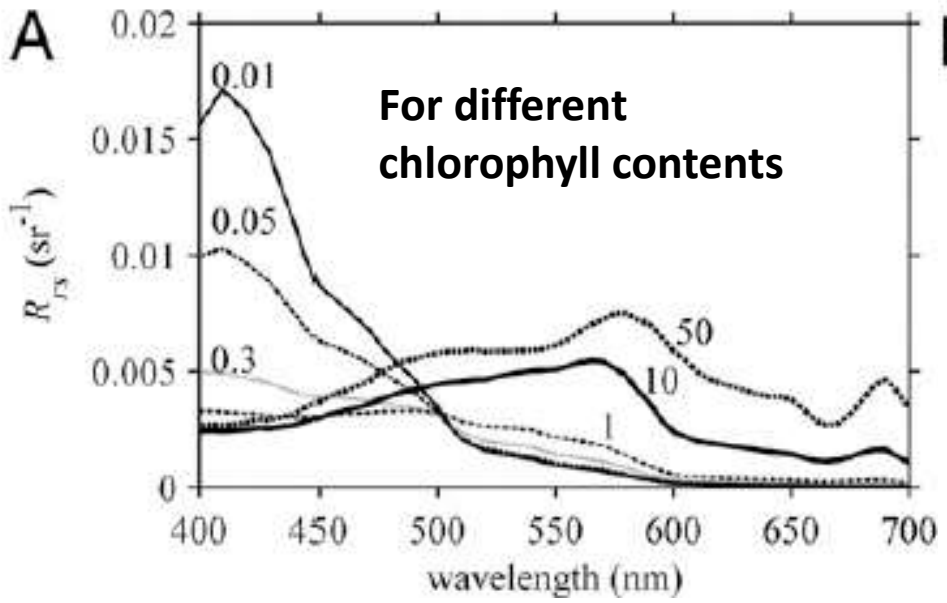
Requirement 1:
Spectral range from 350 – 880 nm



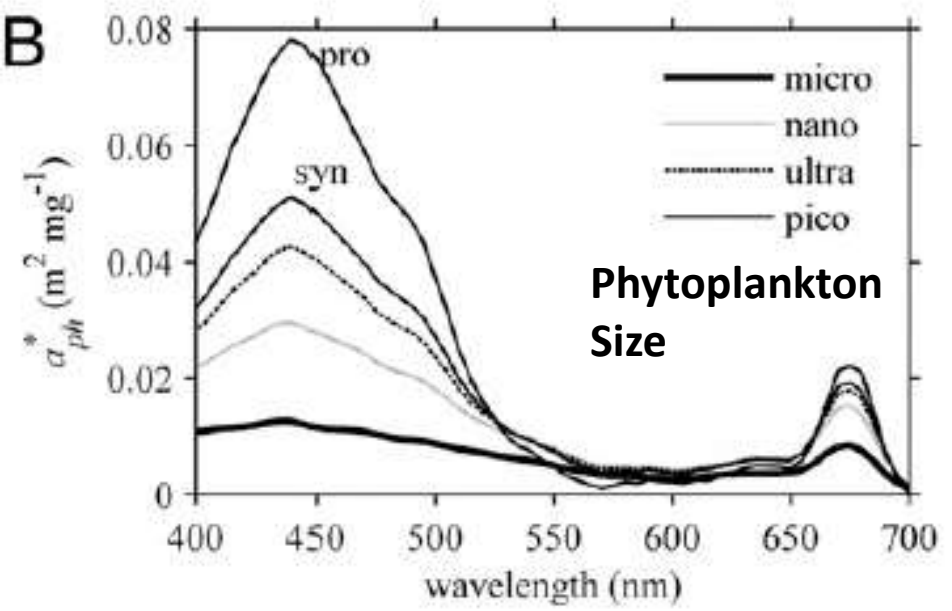
http://gmao.gsfc.nasa.gov/research/oceanbiology/description.php

Spectral Signatures of Chlorophyll

Reflectance



Normalized Chl Absorption



New observation systems / instruments are needed (Dierssen, 2010):

- **Additional spectral channels** for better assessment of Chl-a and phytoplankton and their various ecological and biogeochemical roles.
- **High-resolution spectral information** between 430 and 500 nm to differentiate distinct absorption features of diatoms and cyanobacteria.

Requirement 2: Spectral Resolution

Wavelength [nm]	Bandwidth [nm]	Application
360	20	CDOM
410	3	CDOM
412	3	CDOM, Turbidity
443	3	Chlorophyll, CDOM, Turbidity
488	20	Turbidity
540	20	Turbidity
645	3	Chlorophyll
667	3	CDOM, Turbidity
670	3	Chlorophyll
676	3	Chlorophyll / Turbidity
748	20	Turbidity
868	20	Turbidity

+ 3 additional spectral bands for atmospheric correction

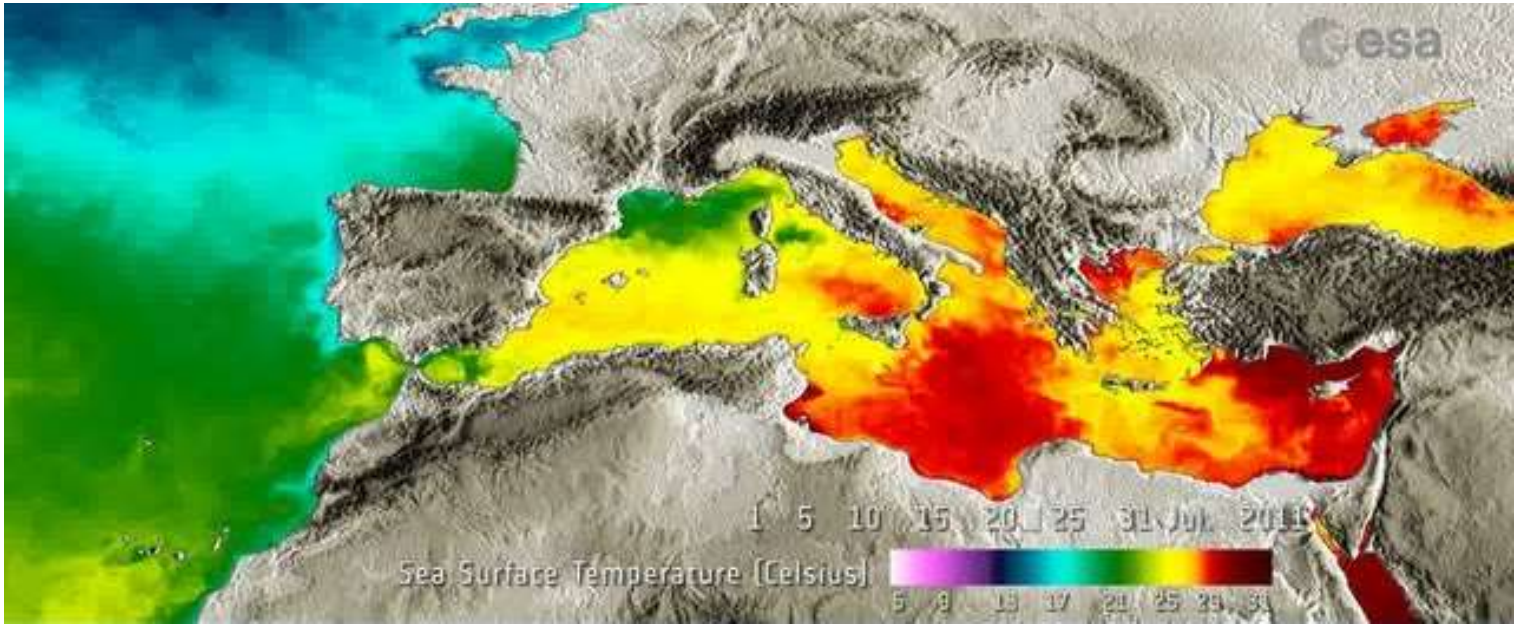
Sea Surface Temperature (SST)

- Satellite measurements of SST and chlorophyll *a* can be used to estimate sea surface nitrate
- The procedure relies on empirical relationships between shipboard measurements of nitrate and its predictor variables, SST and chlorophyll *a* in surface waters.
- From empirical studies results that the largest source of error in the estimation of nitrate can be related to errors in satellite estimate of SST and chlorophyll *a* (Goes, 1999).

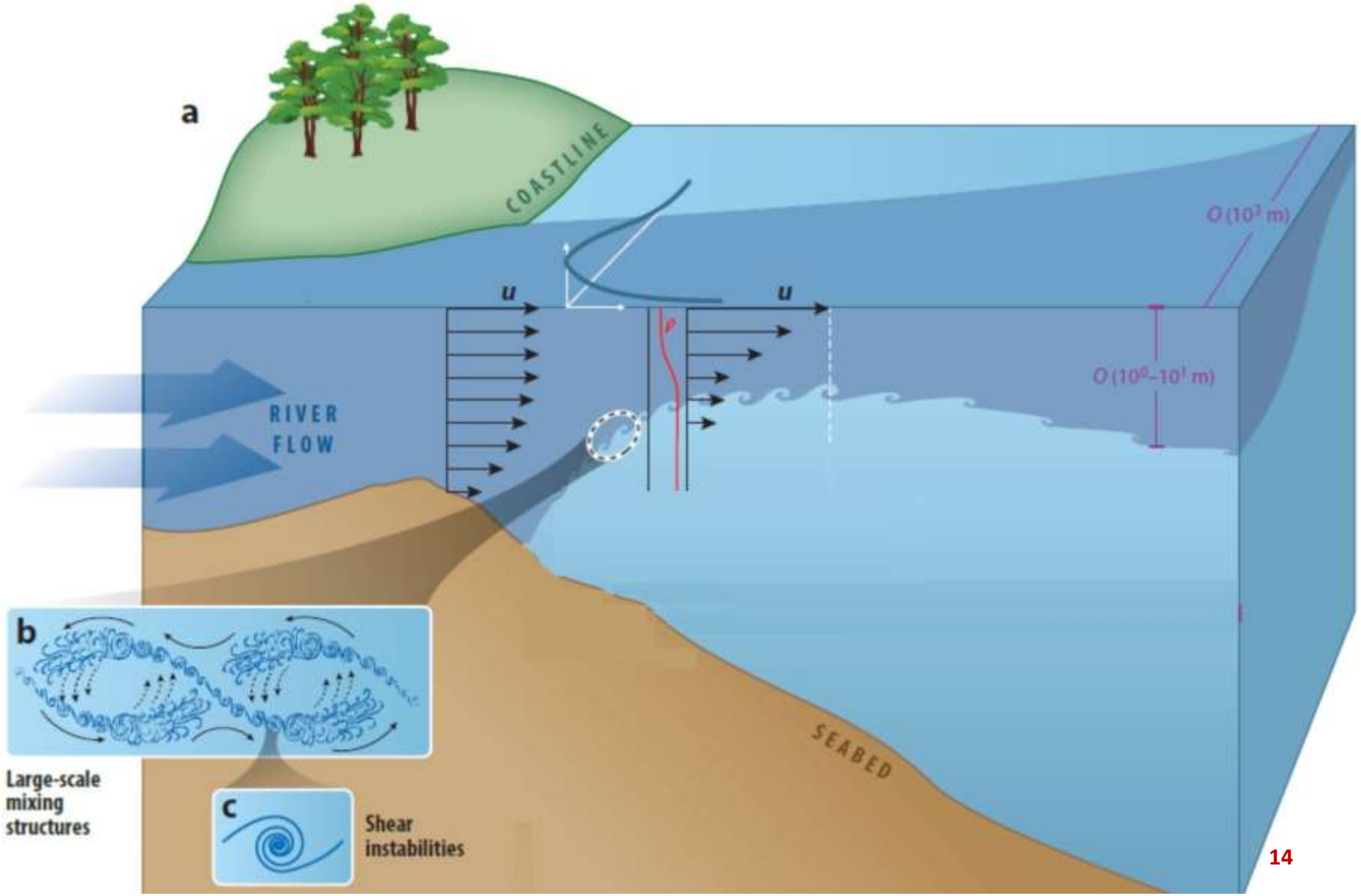
Goes, Joaquim I., et al. "A method for estimating sea surface nitrate concentrations from remotely sensed SST and chlorophyll aa case study for the north Pacific Ocean using OCTS/ADEOS data." IEEE Transactions on Geoscience and Remote Sensing 37.3 (1999): 1633-1644.

Requirement 3: SST

- High spatial resolution SST measured with 0.1 K of accuracy.



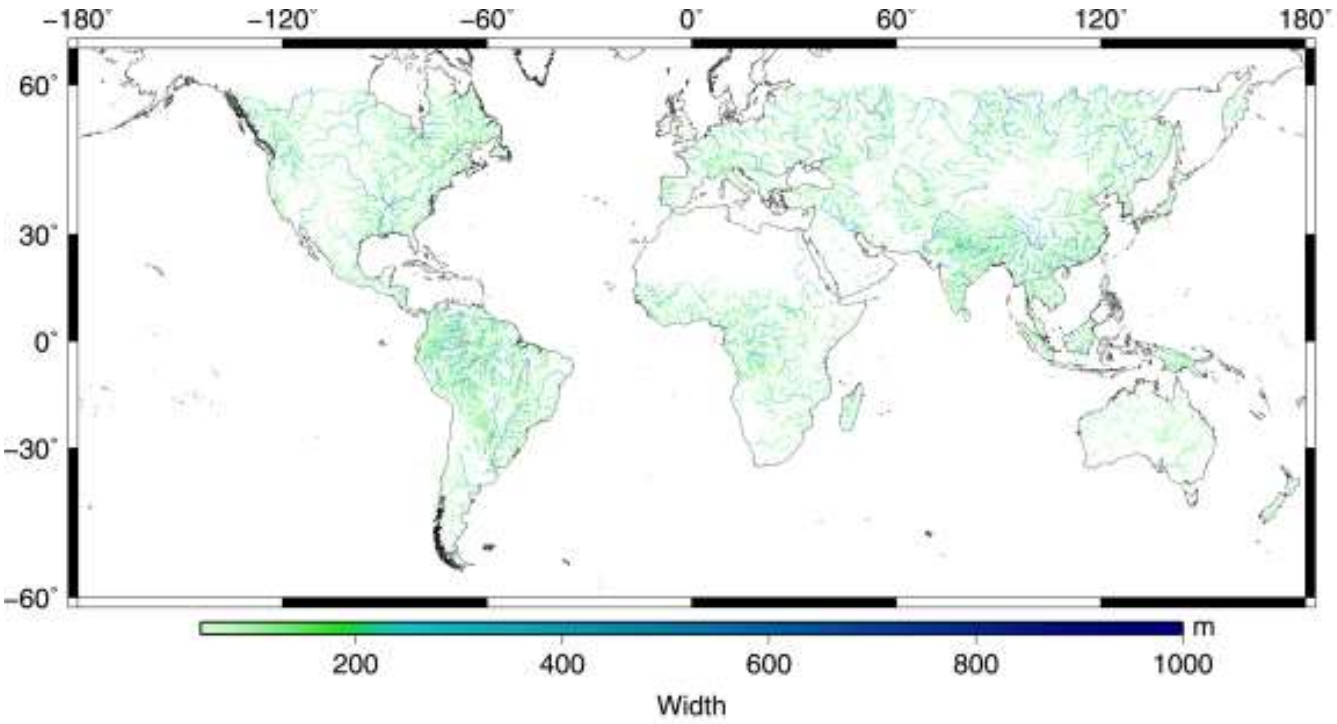
Turbulent Mixing



Requirement 4: Spatial Resolution

Spatial Resolution:
< 25 m

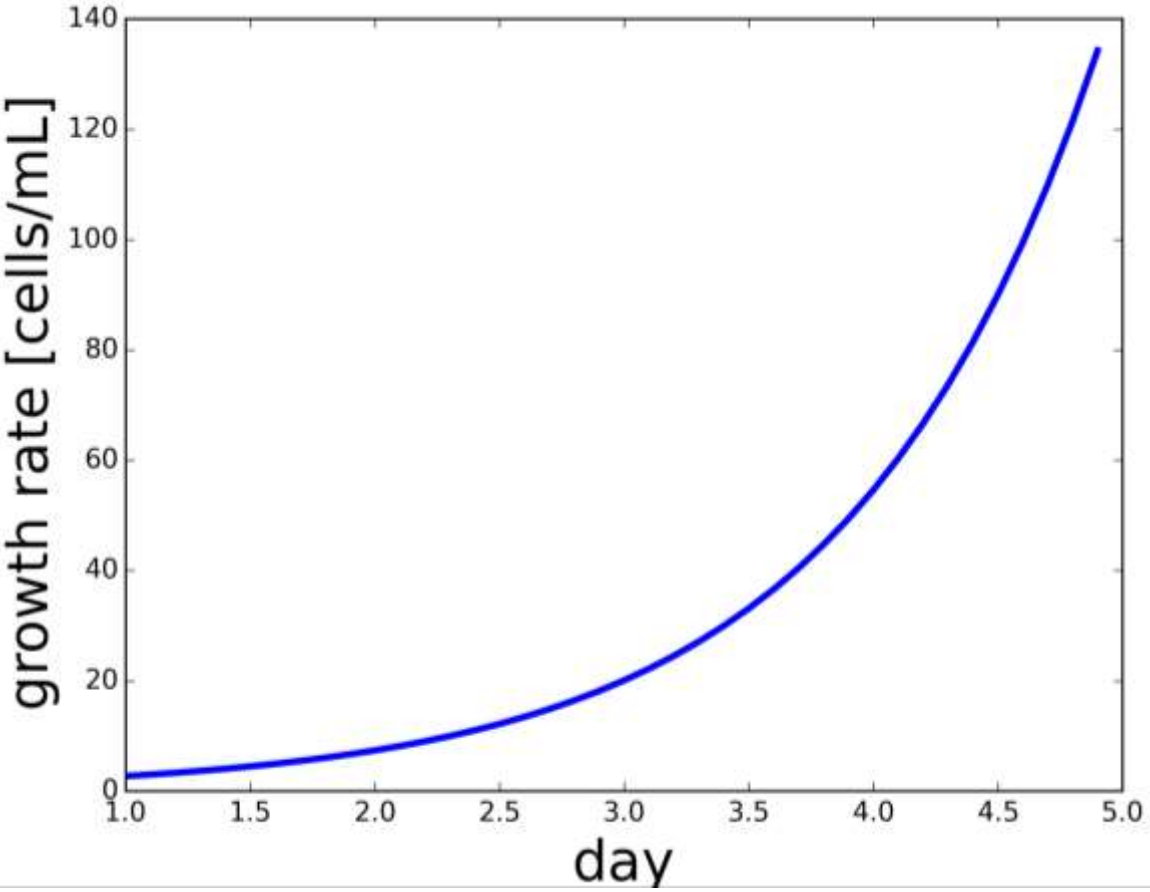
A simple global river bankfull width and depth database



Water Resources Research Volume 49, Issue 10, pages 7164-7168, 24 OCT 2013 DOI: 10.1002/wrcr.20440
http://onlinelibrary.wiley.com/doi/10.1002/wrcr.20440/full#wrcr20440-fig-0002

Requirement 5: Temporal Resolution

Exponential rate of algae growth

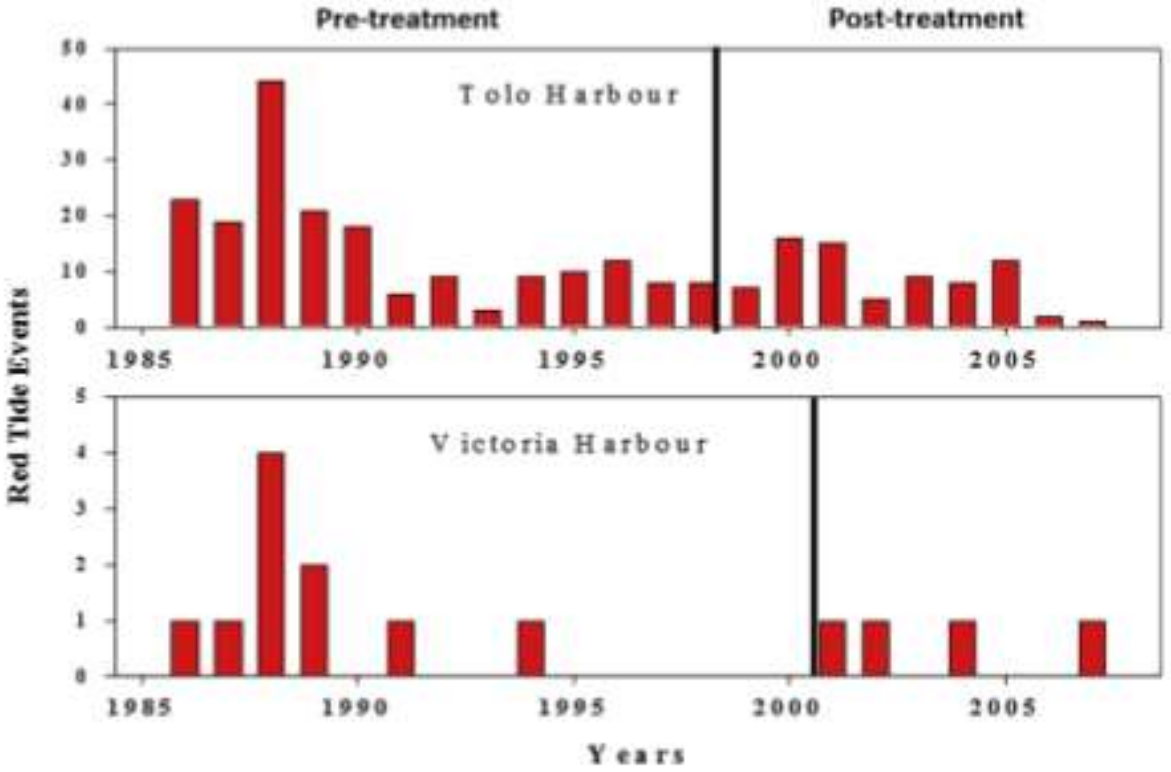


Changes in Chl-a and turbidity need a revisit time of less than 3 days.

Agmin Newsletter No.225

Requirement 6: Lifetime

- Observe inter- and intraannual variability in water quality



Lifetime of more than 3 years

Davidson, K. et al. (2014): Anthropogenic nutrients and harmful algae in coastal waters. In: Journal of Environmental Management 146.

Key Observation Requirements

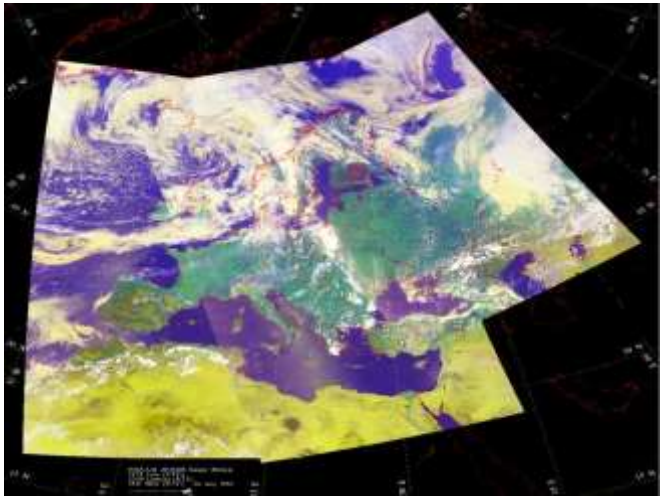
- Requirement 1: Spectral range from 350 – 868 nm
- Requirement 2: Sufficient number of spectral bands at high spectral resolution
- Requirement 3: SST measured with 0.1 K of accuracy
- Requirement 4: Spatial resolution of < 25 m
- Requirement 5: Temporal resolution of < 3 days
- Requirement 6: Lifetime of more than 3 years

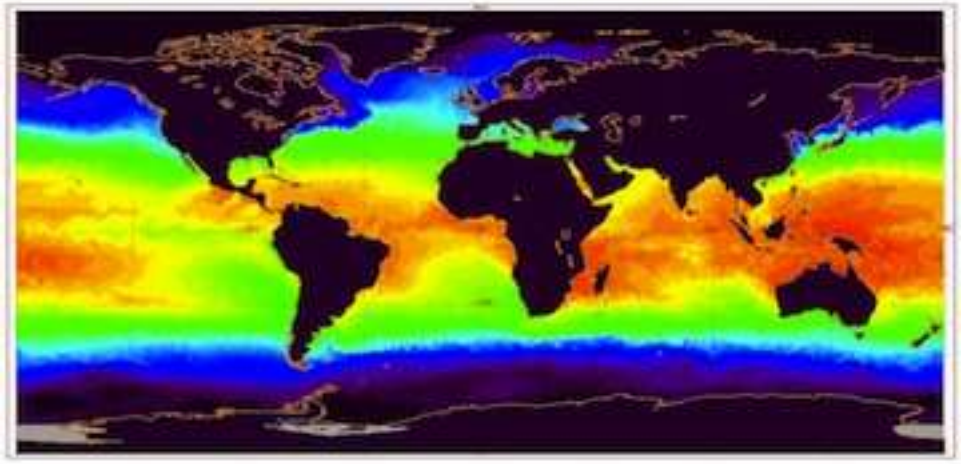
Instrumentation

Instrument Requirements

1. Spectral range of 350 – 950 nm.
2. Spectral resolution of 3 – 20 nm (depending on the band).
3. Ground swath of 350 km from 500 km altitude.
4. Ground resolution of 20 m from nadir.
5. Shutter to protect the instrument from direct sunlight in tumbling, commissioning phases of the mission.
6. Temperature accuracy of 0.1 K.
7. Baffle to limit stray light.
8. Pointing accuracy of 0.003 deg.
9. Knowledge of 0.001 deg.
10. Nadir pointing.

Radiometer for Accurate SST





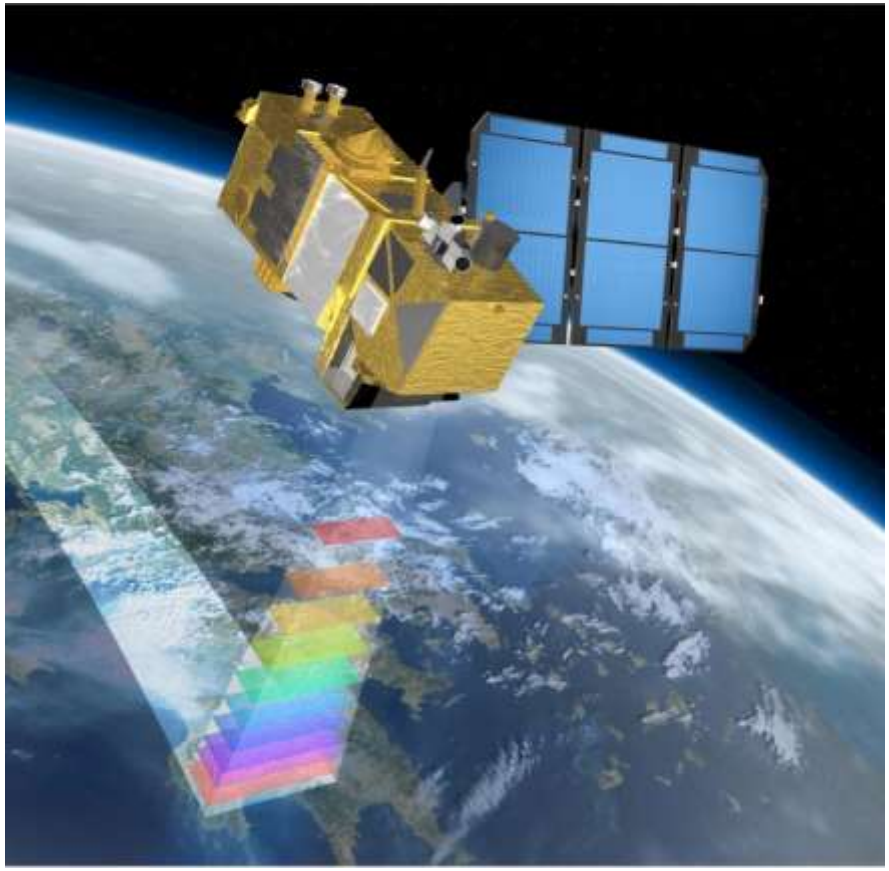
Radiometer for Accurate SST

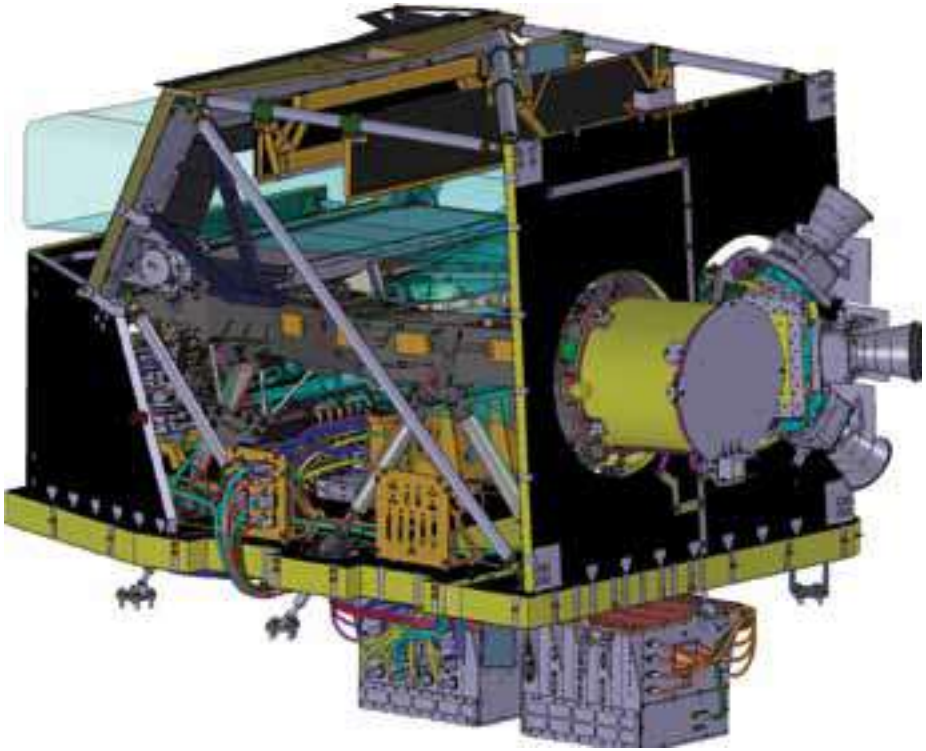
- Based on the six channel Advanced Very High Resolution Radiometer (AVHRR/3).

Centre Wavelength (nm)	Band width (nm)	Resolution (km)	S/N @ 0.5% albedo	NEΔT (Noise equivalent temperature difference)
630	100	1.1	>9:1	-
862	275	1.1	>9:1	-
1670	60	1.1	>20:1	-
3740	380	1.1	-	50 mK
11000	1000	1.1	-	50 mK
12000	1000	1.1	-	50 mK

- Thermal infrared detectors cooled by passive radiant cooler.

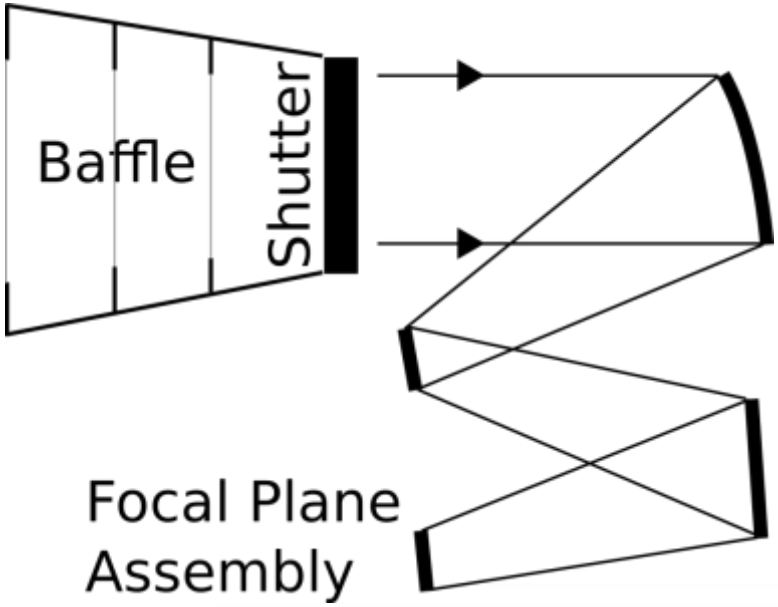
Multi-Spectral Imager





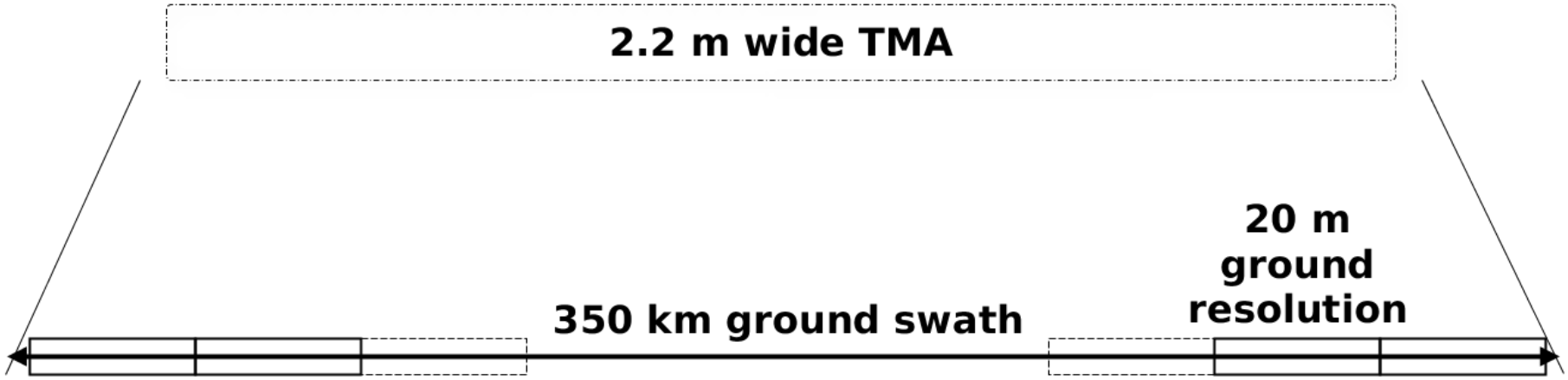
Sentinel-2 MSI

Multi-Spectral Imager



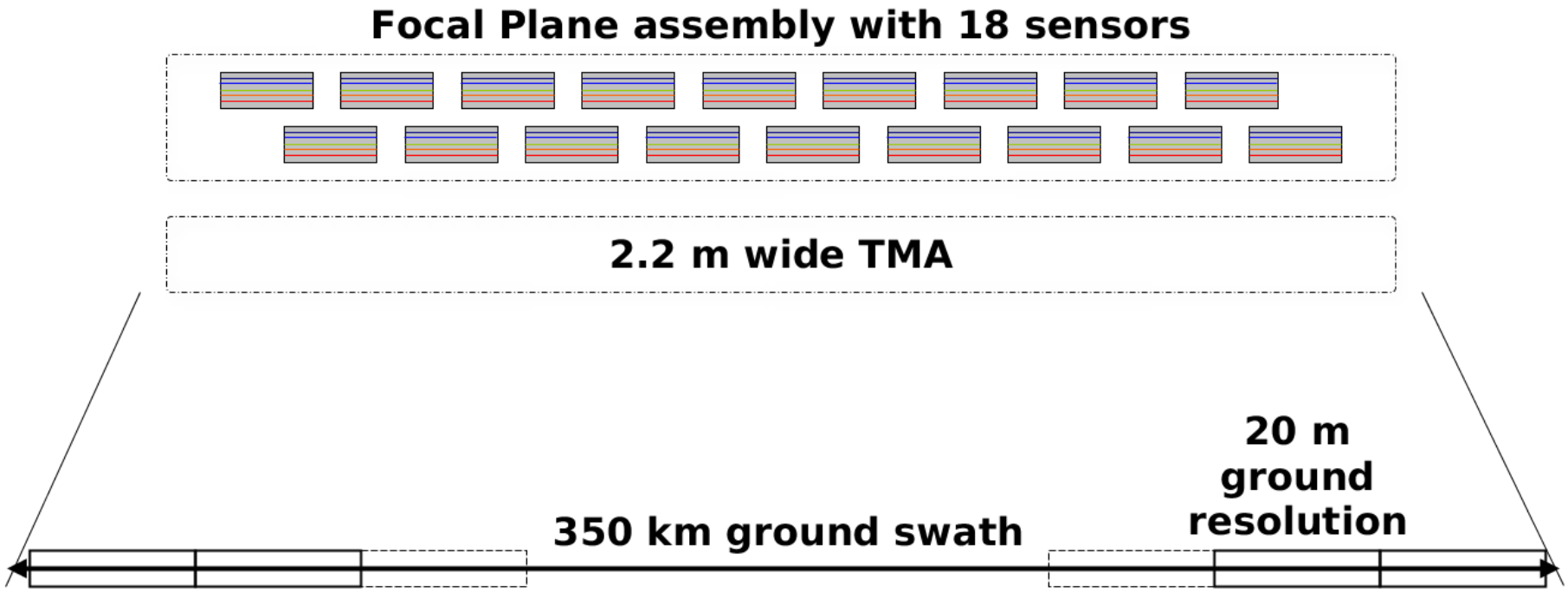
Reflective Three-Mirror Anastigmat telescope

- Field of view: 38.58°
- Focal length: 18.75 cm
- Lens diameter: 50 cm

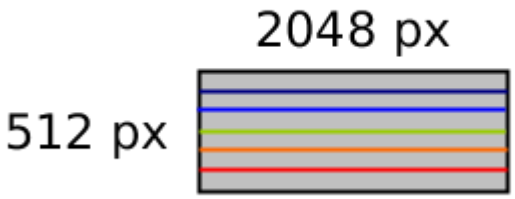


Multi-Spectral Imager

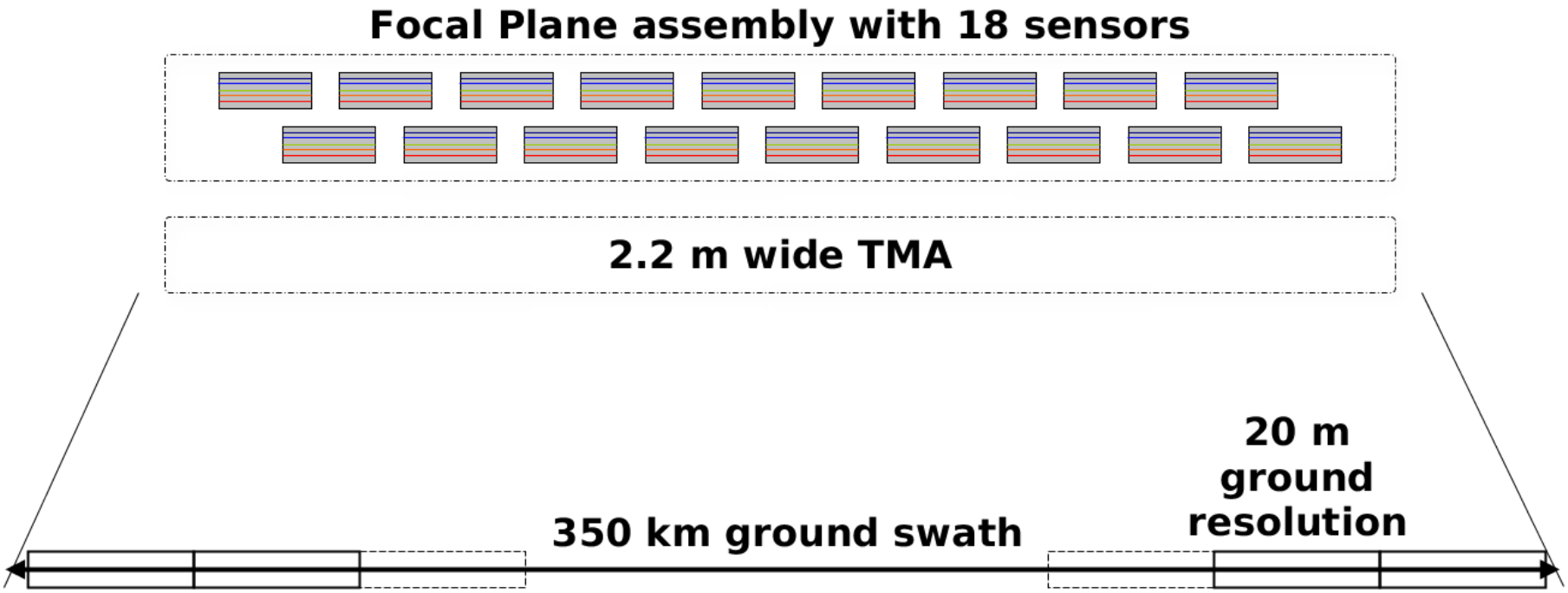
$$\frac{350\ \text{km}}{20\ \text{m}} = 17500\ \frac{\text{pixels}}{\text{swath}} \qquad \frac{17500\ \text{pixels}}{2048\ \text{pixels}} \approx 9\ \text{sensors}$$



Multi-Spectral Imager



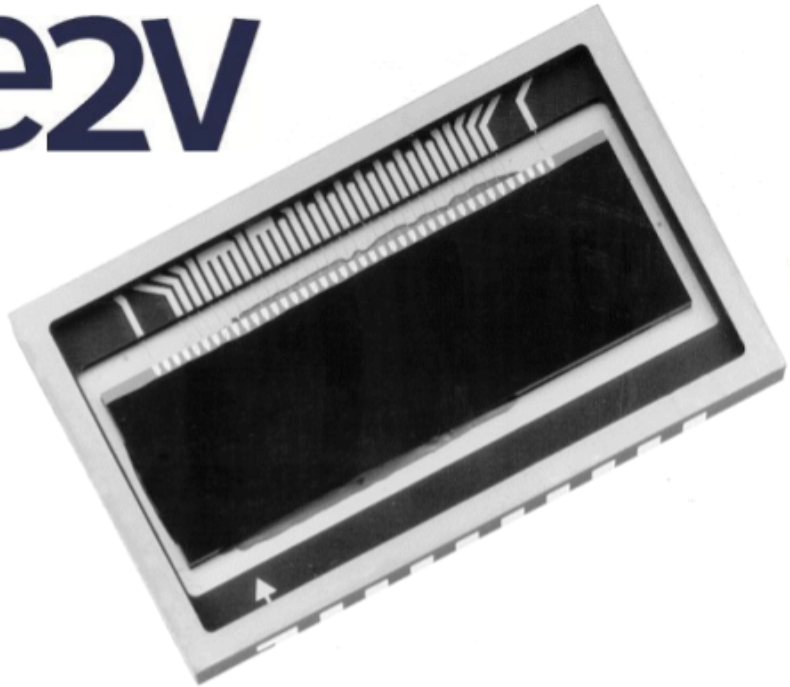
Each sensor with 15 narrow bandpass filters



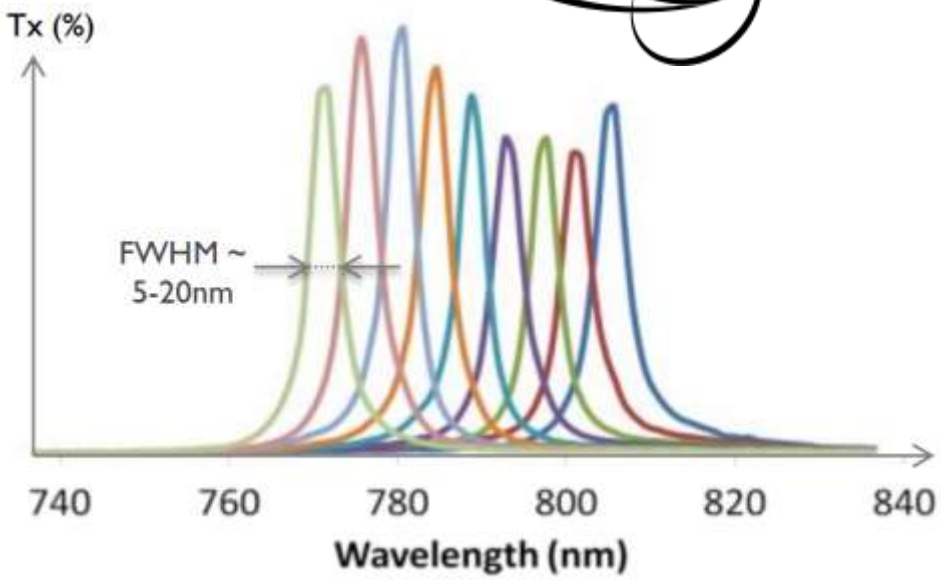
Sensors and Filters

CCD42-10 Back Illuminated
High Performance AIMO CCD Sensor

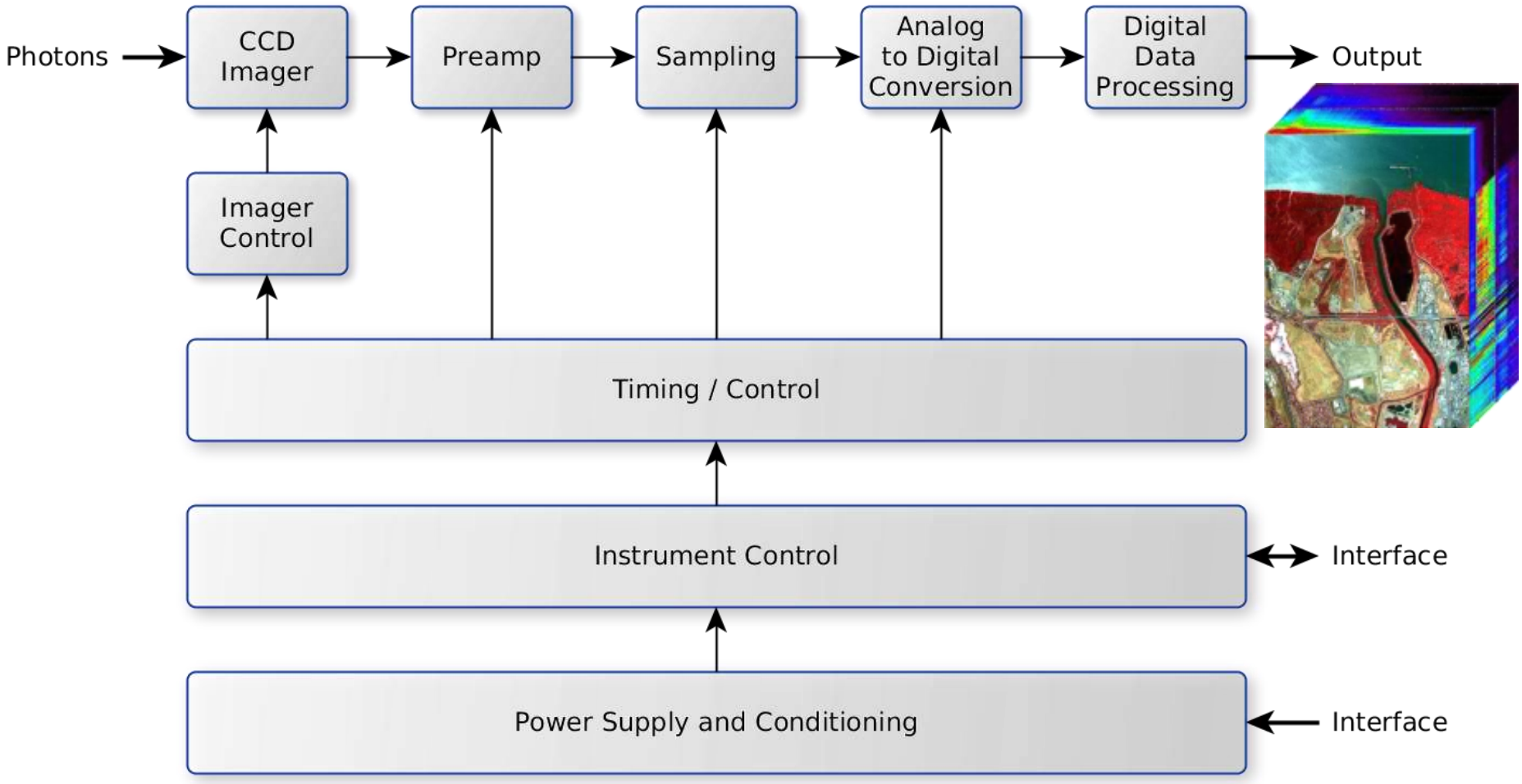
e2v



imec



Multi-Spectral Imager



Instrument Specifications

Band number	Central wavelength (nm)	Bandwidth (nm)	Signal-To-Noise Ratio
1 (CDOM)	360	20	573
2 (CDOM)	410	3	400
3 (CDOM, turbidity)	412	3	316
4 (chlorophyll, CDOM)	443	3	504
5 (turbidity)	488	20	2192
6 (turbidity)	540	20	2406
7 (chlorophyll)	645	3	721
8 (CDOM, turbidity)	667	3	735
9 (chlorophyll)	670	3	738
10 (chlorophyll, turbidity)	676	3	738
11 (turbidity)	748	20	2214
12 (reference)	764	4	653
13 (reference)	767	3	490
14 (turbidity)	868	20	1933
15 (reference)	940	20	631

Development Challenges

- **Instrument design changes**
  - Increase focal length to 18.75 cm.
  - Resize optics from 12 to 18 sensors on the focal-plane-array.
    - Instrument length is increased from 1.47 to 2.2 m.
  - Spectral filters with ~3 nm bandwidth.

- **Impact on the project**
  - Cost
  - Schedule
  - Lower TRL

Instrument Data Rates

	Max. data rate	Max data per orbit
Spectral imager	880 Mbps	77 GB*
Thermal imager	1.9 Mbps	114 MB
Total	882 Mbps	77 GB

* Assuming the worst-case coastline of 5000 km per orbit.

	Value	Unit	Comments
Size of a raw image	864	KB	18 sensors with 2048 x 256 pixels
Size of a reduced image	324	KB	Lossless
Maximum exposure time	2.88	ms	Estimated from ground resolution
Raw data rate	2347	Mbps	Data to be processed by the instrument data handling system
Reduced data rate	901	Mbps	
Data per pass	77	GB	Assuming worst-case coastal line of 5000 km.

Space Segment

S/C Requirements

System	
Payload mass:	410 kg (total)
Payload power:	427 W
Spectral imager size:	2.2x0.93x0.62 m^3
Thermal imager size:	0.80x0.36x0.29 m^3
Payload data stream of	1 Gbit/s
Storage requirements:	4 Tbit
Operational temperature:	-40° +/-10° drift
ADCS pointing accuracy	0.002°

Orbit

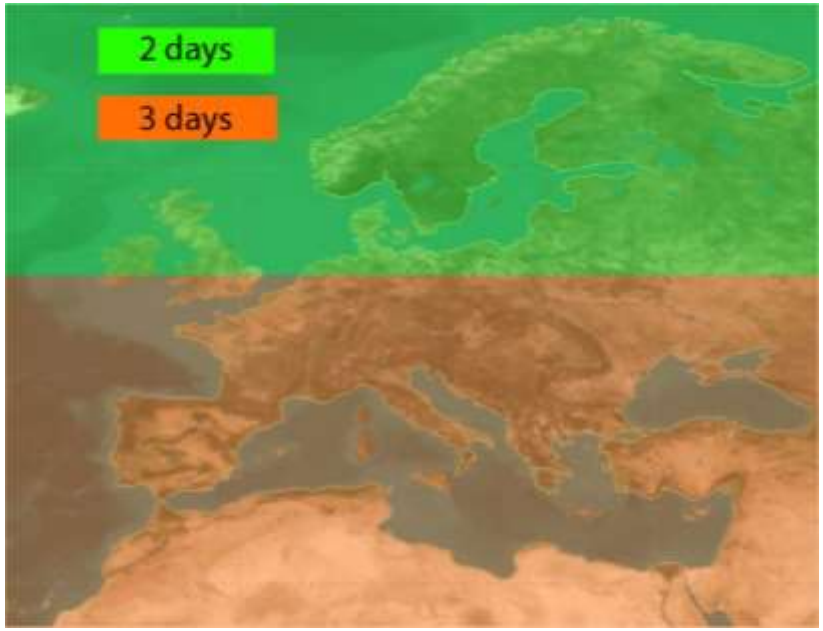
- 2nd S/C as baseline

- 511 km altitude, SSO 12:00
- 95 minutes orbital period
- 140° true anomaly shift between the satellites
- Two days revisit time above 50°
- Three days revisit time below 50°

- 2nd S/C launched one year later
- Overlap of 4 years

- De-orbit time of 14 years

Revisit time at different latitudes

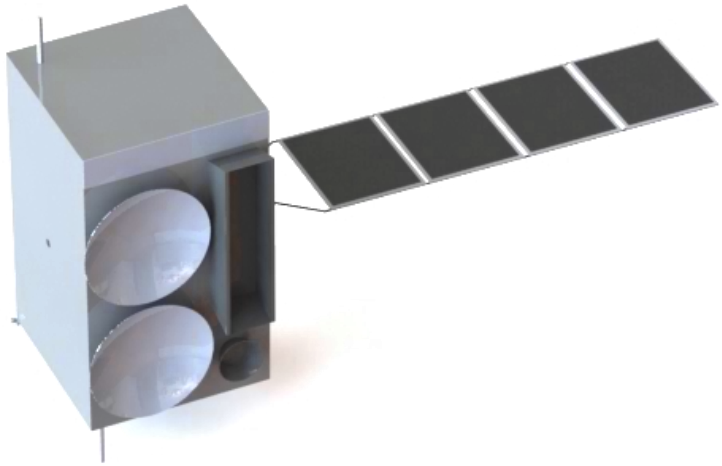


Spacecraft Configuration

- Airbus Astrobus L (Sentinel)

CoastSat

- Telescope
- 7 m^2 solar panels
- 8x1N hydrazine thruster
- 2 parabolic dish antennas for X-band downlink
- 2 S-band patch antennas TT&C



Launcher – Soyuz

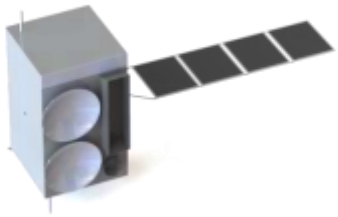
- 2 satellites with 2 Soyuz launches
- Soyuz capacity to 500 km SSO > 4600 kg
- The fairing size limits us to 1 satellite/launch

- We can offer space for smaller satellites heading for SSO

Mission Overview

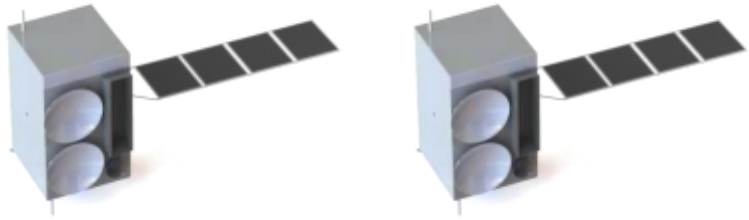
Phase I

- Single space segment
- Proof of concept
- Complimentary to coarse EO data



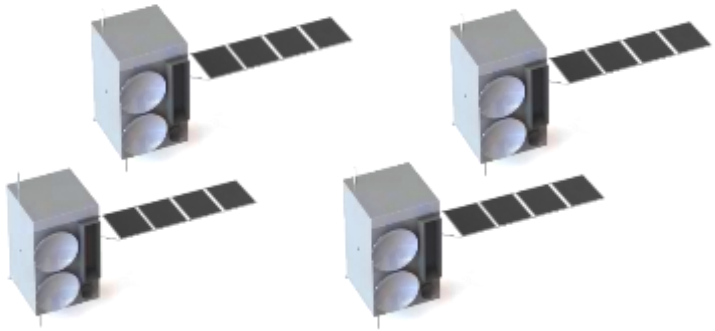
Phase II

- 1 year later launch of S/C 2
- Both segments operational
- Scientific objectives fulfilled



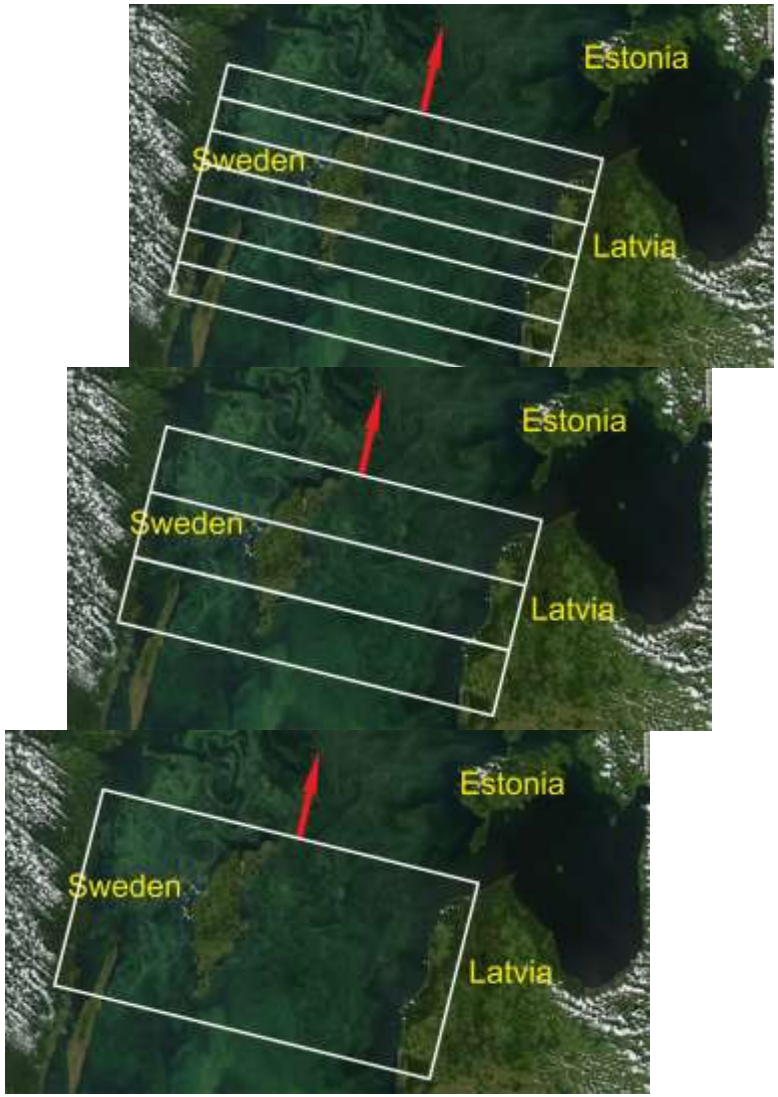
Phase III

- Optional (not part of original mission)
- Expansion of the CoastSat constellation into a continuous monitoring service



Operational Mode

- Out of EEZ (370 km) – no data collection
- From EEZ to 10 x typical river width (TRW, 150 km for Amazon) – 500x500 m^2 spatial resolution
- From TRW to 100 m off coast (OC) – 50x50 m^2 spatial resolution
- From OC to 10 km inlands – 20x20 m^2 spatial resolution
- Reduces data collection by a factor of 10 compared to maximal spatial resolution

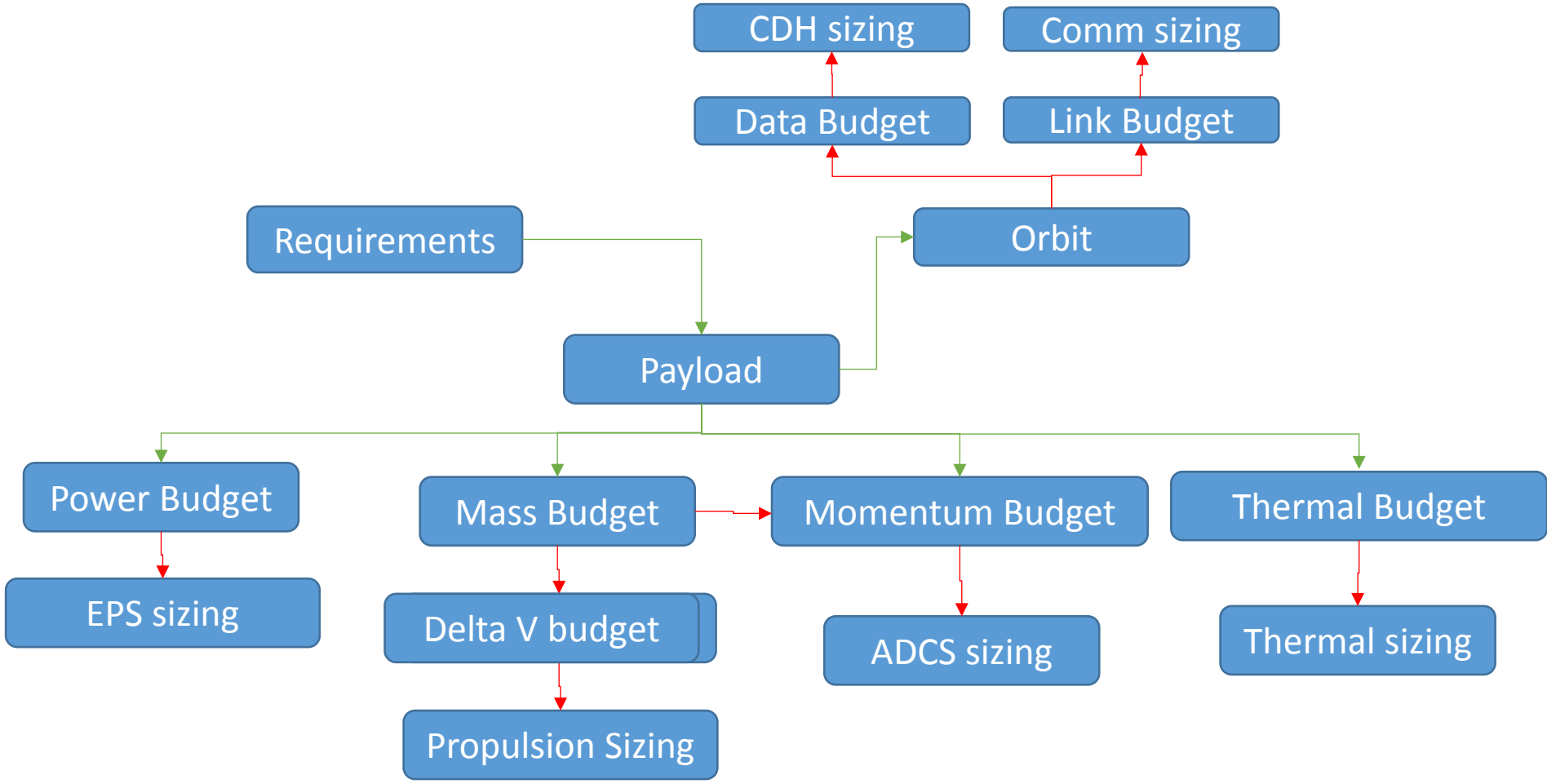


Additional Operational Modes

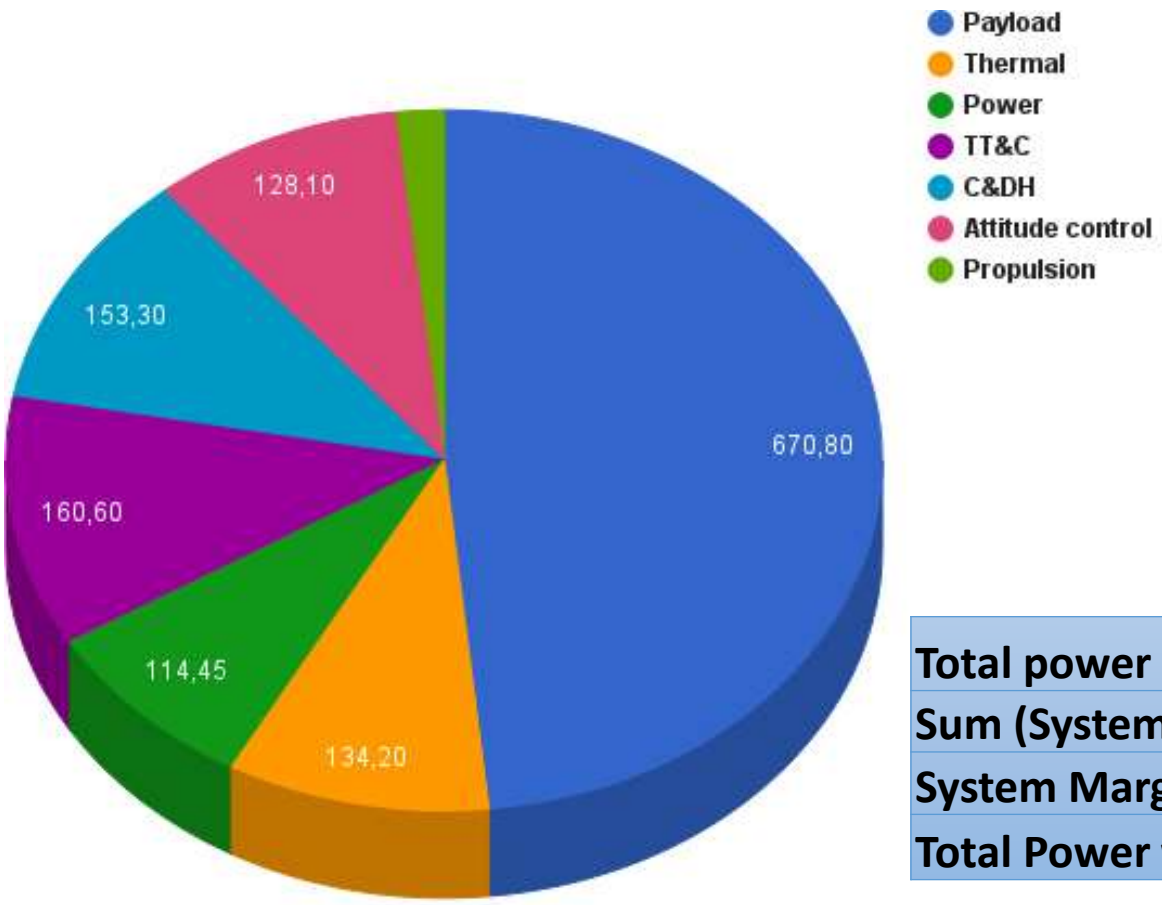
- Although not designed for it, CoastSat can be used for monitoring:
  - Volcano eruptions
  - Forest fires
  - Hurricanes
  - etc.
- The spatial resolution is high enough to cover roughly 5% of all the lakes/ponds in the areas of interest

Satellite Design

Methodology for System Design



Power Budget



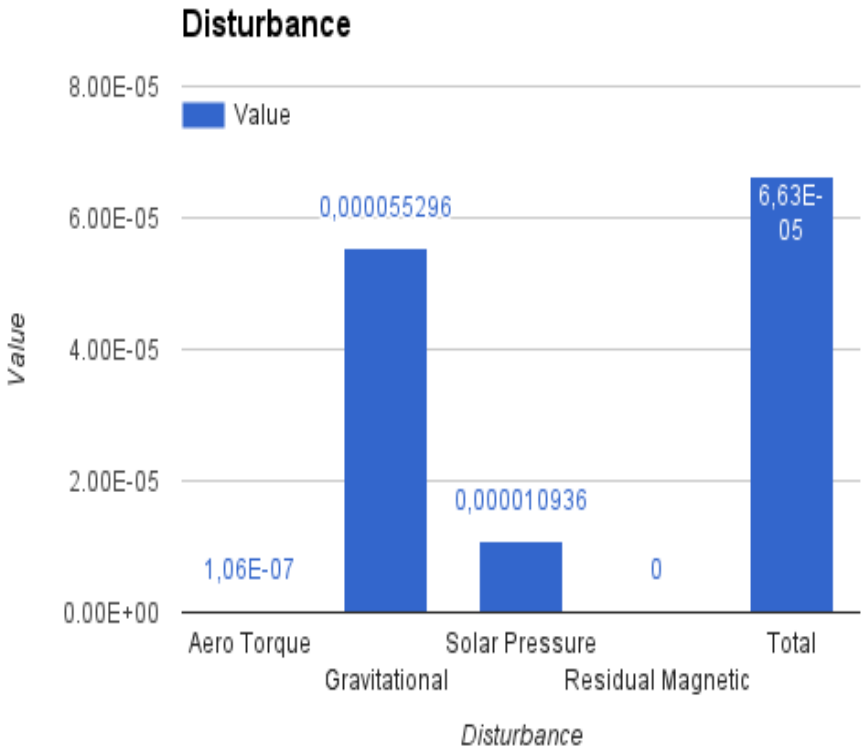
Total power	1215
Sum (System Power)	1228
System Margin	20%
Total Power w Margin[W]	1473

EPS Architecture

- Multijunction Ga/AS Solar Array:
  - Area = 7 m^2
  - Mass = 34 Kg
  - 1 degree of freedom gimbal to sun tracking capability:
  - Range of rotation: 360º
  - Power consumption: 3W
  - Dimensions(mm): Ø 157 x h 160
  - Mass: 3.5 kg
- PCDU
  - Peak Power Tracking to solar Array
  - Regulated Bus
  - Mass: 22,5 kg
  - Volume: 605*300*212 (mm)
  - Power: 1.5 KW @regulated 28V

Momentum Budget

Requirements	
Pointing accuracy [deg]	0,003
Knowledge[deg]	0,001
•Three axis satabilized zero momentum	
•Nadir Pointing	



Reaction Wheel	
Torque[Nm]	0,0124
Momentum [Nms]	0,2358

Thrusters		Force[N]
Torque	3	1,27
Momentum	0	
Moment Arm	2	
Number of Thruster	8	
Pulse time	2	
Momentum for RW desaturation	0,06	0,3
Total Thruster	3	1,3

Magnetic Torquers	
Dipole moment (A.m2)	6
Earth Magnetic Field: worst case	0,000046
Torque provided (Nm)	2,76E-04

Delta-V Budget

Lifetime: 5 years

Maneuver	Delta-v [m/s] / year	Delta-v [m/s] / lifetime
Altitude maintenance	5	25
Momentum wheels unloading	3	15
ADCS	10	50
Phasing	8.5	8.5
Overall	18/26.5	98

Propulsion Architecture

8 Airbus DS 1N thruster

- Mass: 290 gr
- Specific Impulse, Nominal: 220 s

Airbus EPDM - BLADDER TANK BT 01/0 Plus feeding system

- Mass: 8.5 kg
- Tank Net Volume: 59 litres
- Max. Propellant Volume: 39 litres

Thermal Budget

System	Temperature		
Spacecraft	240	+/- 15	K
Multi spectral camera focal plane	233	+/-10	K
Thermal camera (build in cooling system)	105	+/- 0.001	K

Maximum power dissipation on spacecraft	599	599	W
Minimum power dissipation on spacecraft	200	200	W
Solar energy absorbed		8549,1	W
Albedo energy absorbed		2190,1	W
IR energy absorbed		1706,4	W

TCS Architecture

Thermal Passive Control

- Material for spacecraft's face turned towards the sun silver coated Teflon blanket with a coating of indium-tin oxide
- Material for spacecraft's face turned towards the space black-Kapton blanket

Heaters and Radiators:

Radiator area to accommodate s/c power dissipation	1,3	m^2
Minimum temperature for given radiator area	-32	deg, C
Required heater power (during eclipse)	106	W

Data & Link Budget

Data generation	Typical accumulation per day	Data generation (raw data)
Example: Baltic sea	4613 s	1 Gbit/s
Example : Mediterranean sea	4248 s	1 Gbit/s
High data rate requires on board data processing, geolocation based pre-selection		

Ground station	Access time per day	Data rate	Max. amount per day
Svalbard	6191 s	300 Mbit/s (X-band)	1.86 Tbit
Kiruna	5078 s	100 Mbit/s (X-band)	0.5 Tbit
Total daily transfer limited to 2.36 Tbit per day; dual channel transmission of data			

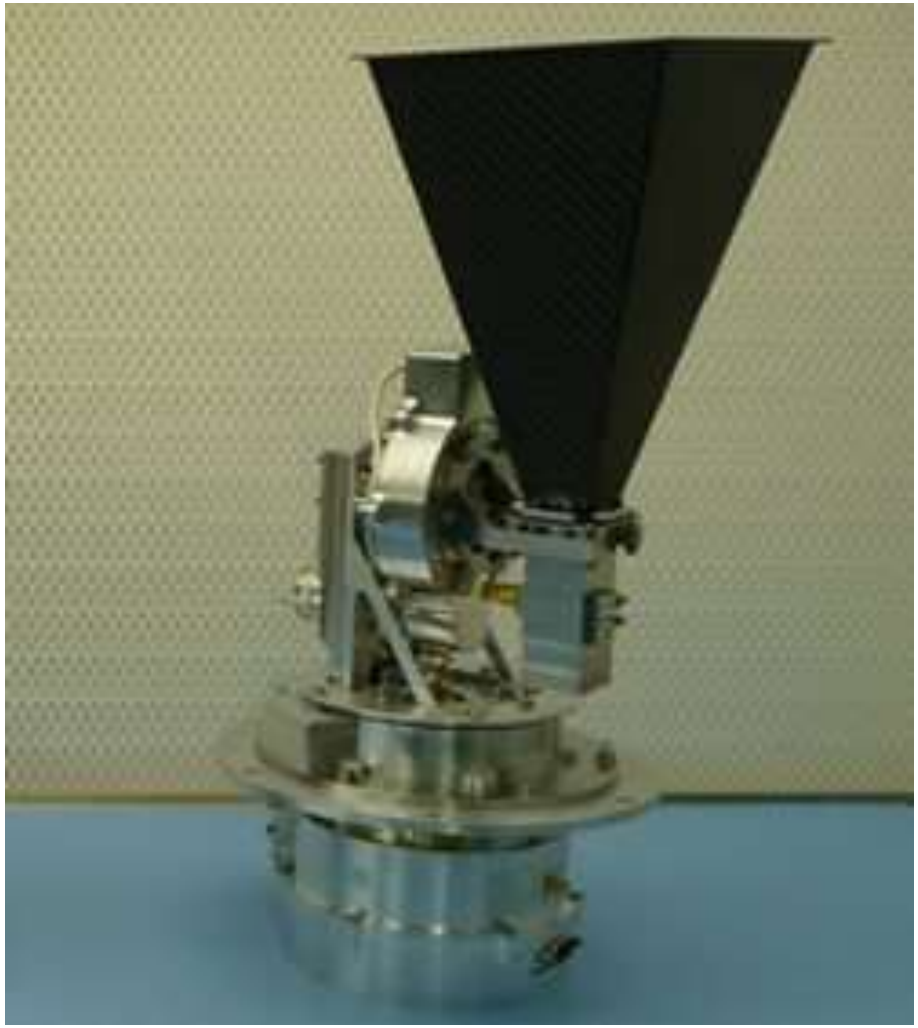
Communication Architecture

2 SSTL X-band antenna

- Power consumption: 3.9 W
- Mass: 3.25 kg
- Azimuth range: ± 270 deg
- Elevation range: ± 80 deg
- Tracking range: ≤ 20 deg/s
- Pointing accuracy: ≤ 0.25 deg

S/C commanding:

- SSTL X-band transmitter XTx400 for the downlink of payload telemetry
- SSTL S-band receiver for TT&C uplink
- SSTL S-band patch antenna
- S-band transmitter for downlink



CDH Architecture

SSR - Solid State Recorders for space applications

- Mass: 8-20 kg
- Width : 250 mm
- Height: 250mm
- Lenght: 300-600 mm
- Power: 10-100 W
- Specs : Up to 3 Tbit capacity
  Up to 20 Gbps input data rate

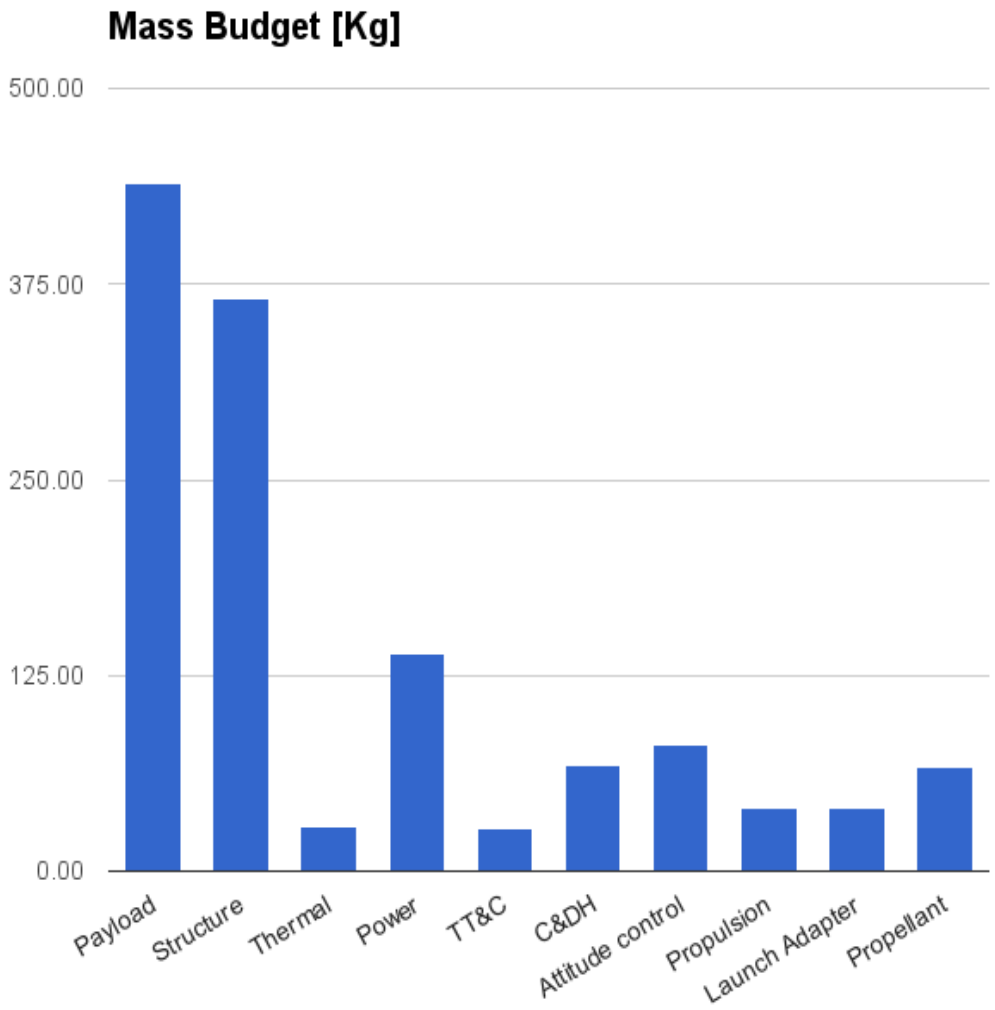
Payload data handler, SparcV8

- Mass: 5,5 kg
- Volume: 272*284*112 mm3
- Power: 8W
- Operating speed: 80 MHz

Other instrumentation:

- SSTL flight computer
- SSTL HSDR for buffering image data
- SSTL MMU for telemetry storage

Mass Budget



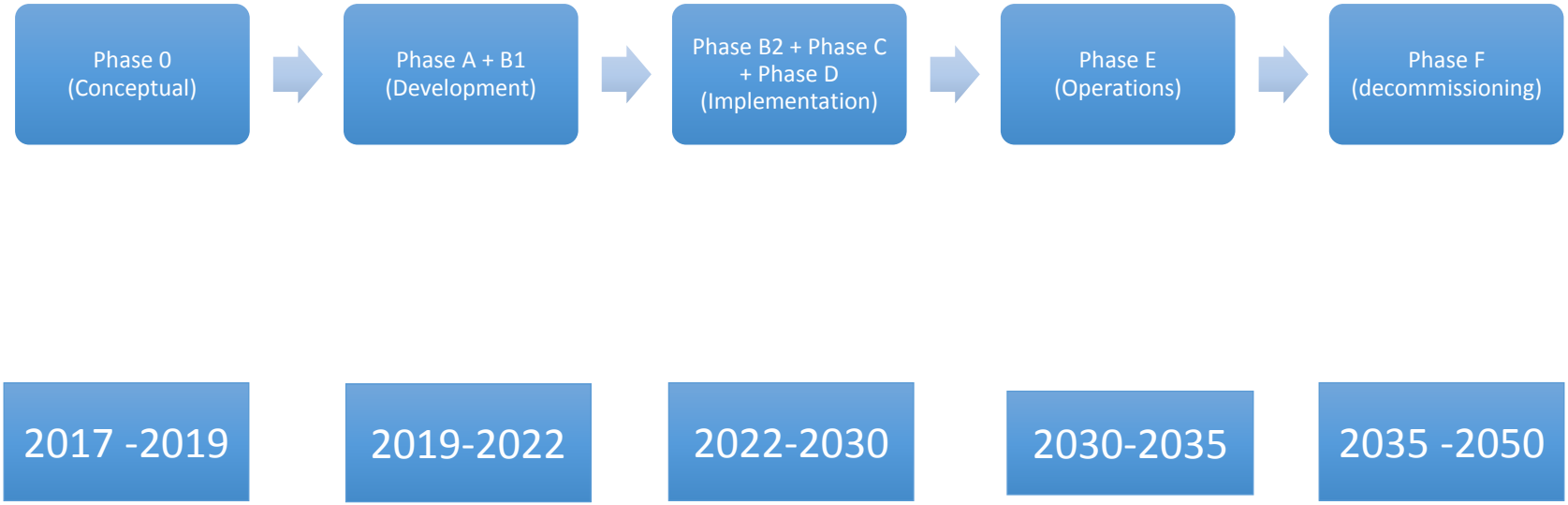
Dry Mass	1287
Sum (System Mass)	1211
System Margin	20%
Total Mass With Margin [kg]	1453

Risk Analysis

Description of risk	Likelyhood	Severity	Rating	Project impact
Launch failure	improbable	catastrophic	5	Space segment
Loss of one space segment	remote	significant	8	Revisit time
Delay in instrument development	remote	moderate	6	Cost increase Schedule delay
Orbit & ADCS cannot meet requirements	occasional	moderate	9	Lower spatial resolution

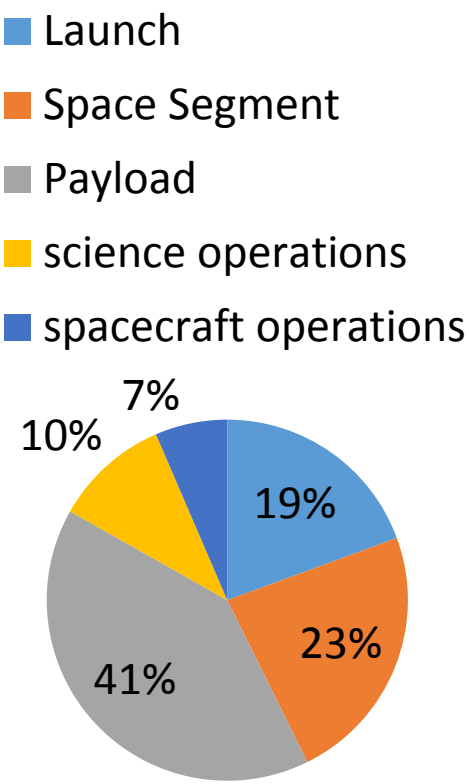
Programatics

Timeline


Phase 0
(Conceptual)
Phase A + B1
(Development)
Phase B2 + Phase C
+ Phase D
(Implementation)
Phase E
(Operations)
Phase F
(decommissioning)
2017 -2019
2019-2022
2022-2030
2030-2035
2035 -2050

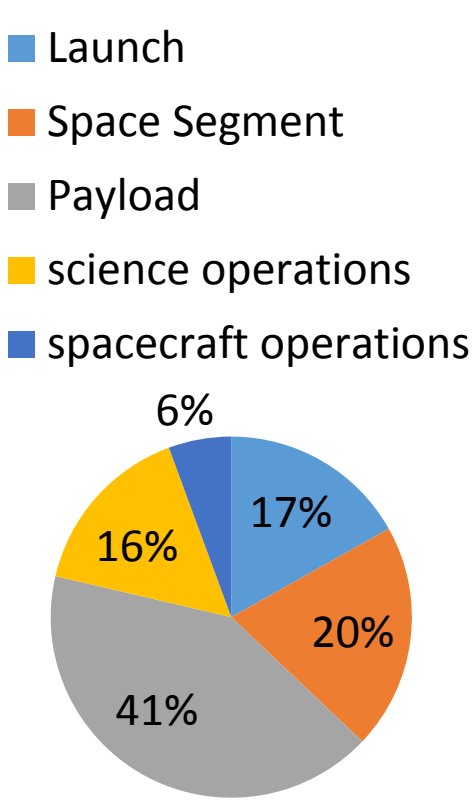
Cost Estimate

Baseline: 2 Satellites



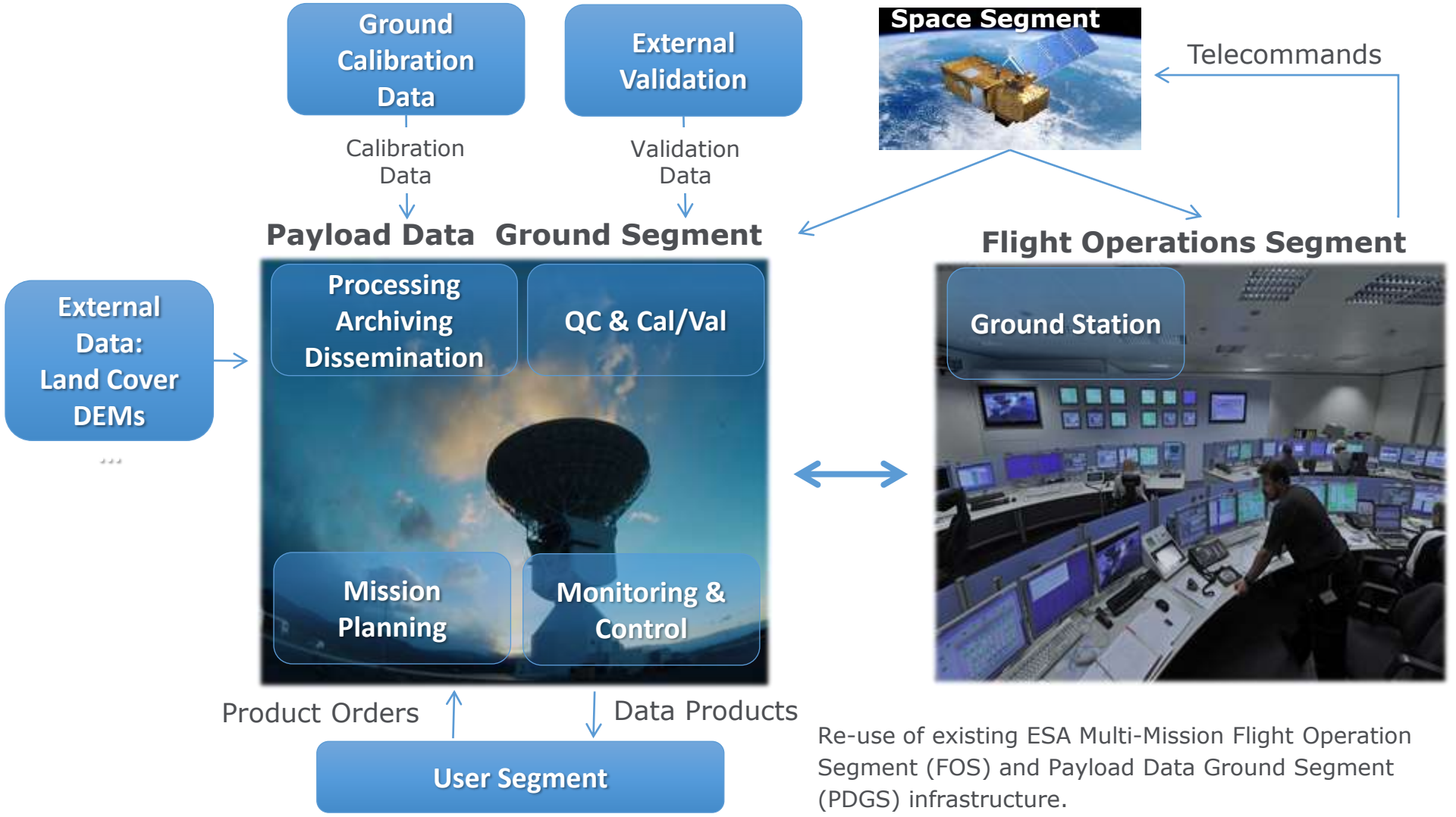
773 M €

Descoping: 1 Satellite



455 M €

Ground Segment



Re-use of existing ESA Multi-Mission Flight Operation Segment (FOS) and Payload Data Ground Segment (PDGS) infrastructure.

Data Products Based on CEOS Conventions

Level 1

- Top-Of-Atmosphere radiances in sensor geometry [W/m2 sr]
- Same but in cartographic geometry [W/m2 sr]

Level 2

- Bottom of the atmosphere reflectance in cartographic geometry [W/m2 sr]
- SST [°C]

Level 3

- CHL-A [mg/m3]
- Nitrate [mg/m3] (prototype, regional)
- CDOM [mg/m3]
- Additional products from data assimilation

CEOS = Committee on Earth Observation Satellites

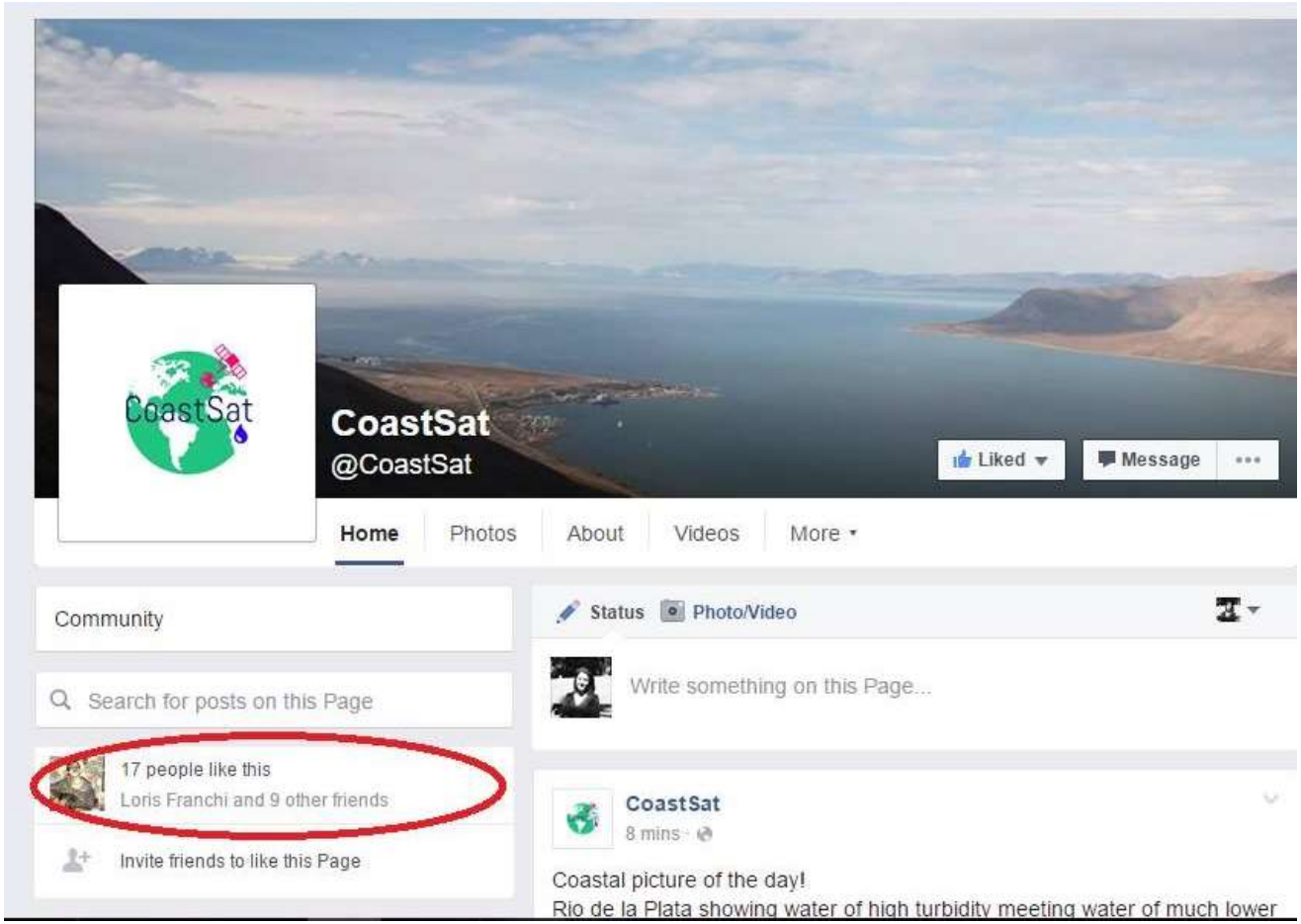
Calibration / Validation Activities

- Provide measurement protocols for the partnerships
- Establishing a dedicated network to validate our products (Argos floats, measurement campaigns...)
- Data assimilation / Comparison against models

Public Outreach & Educational Activities

- **Online Forums** to support scientific use of data
- User **Symposium COAST** every 2 years to exchange state-of-art research
- **Attract students to science**: field visits, mesaurement days, science camps, distributing in-situ measurement kits.
- **Social media** channels like Twitter, Facebook, Instagram
- **Alert Service**

Follow CoastSat!



Future Work

Traceability of L2 (geophysical parameters) to L1 (radiance) product requirements

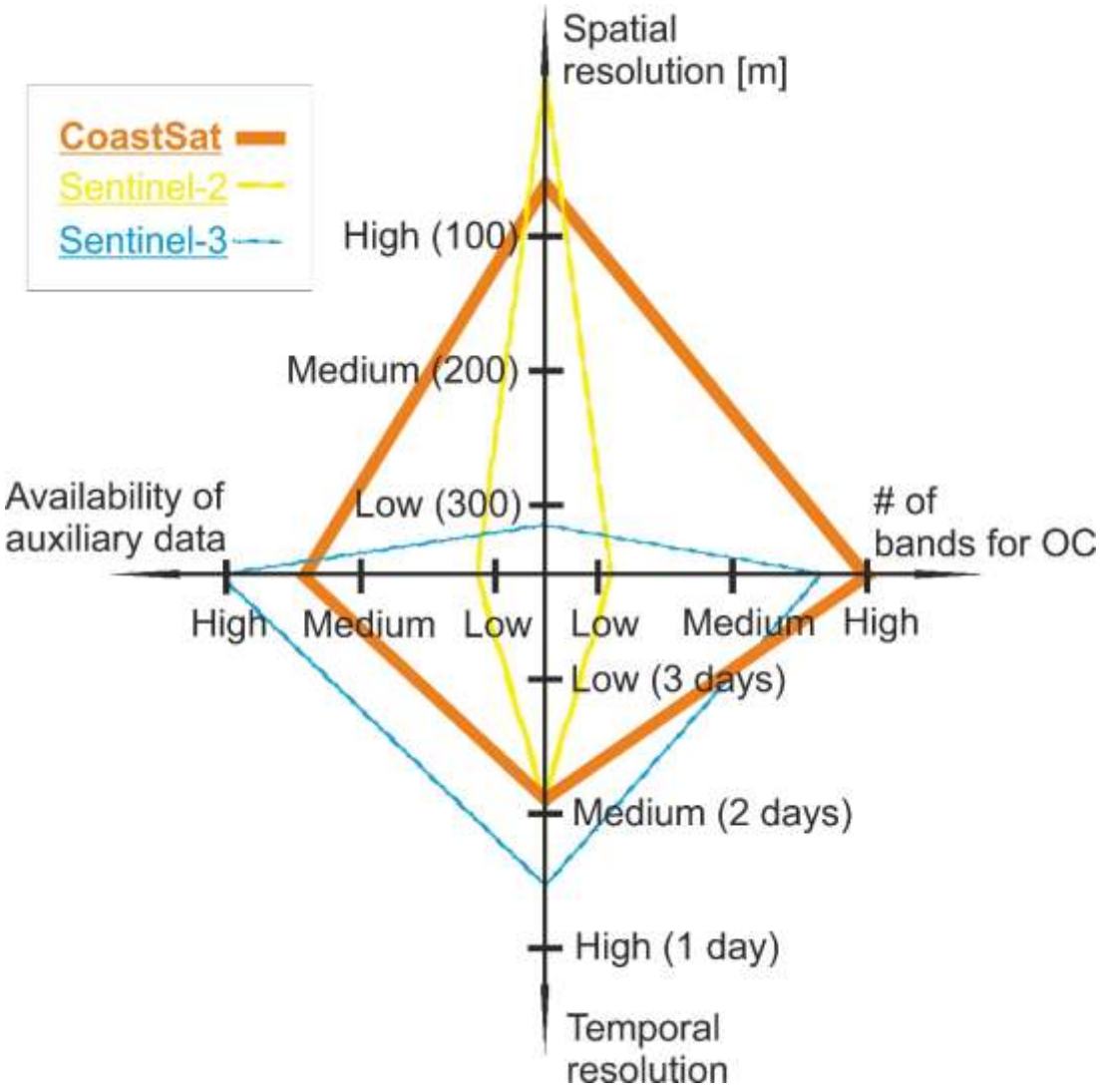
- Radiative transfer calculations / atmospheric correction
- Stray light effects
- Polarization
- Spectral sampling intervals
- SNR and instrument requirements at L1B

Optimized instrument design

- Reduced aperture (roughness / straylight sensitivity
- Reduced size and mass
- Maintaining spectral coverage and resolution

Optimized choice of platform.

Comparison With Recent Missions



CoastSat will help at

Process-understanding	• Improve the understanding of turbulent processes in coastal areas
Global ocean model forecast	• Validation of forecasts from 3D global ocean models • Data assimilation to improve the initial state
Informing local authorities	• Install prototype-monitoring systems of coastal waters, rivers and lakes

Keep the Oceans Clean!

Back up slides

Traceability Matrix

Science Requirements	Measurements Requirements (bandwidth, spatial resolution, revisit time, exposure time)	Instruments	Instrument requirements	Mission Requirements (e.g. Orbit/life time)	Data Products
PR1: Measure chlorophyll-a concentration	Spatial resolution 5 - 10 km with a revisit time of 24h - 2d, wavelengths required 443, 645, 670/676 nm	High resolution spectrometer, including a NIR or ideally a SWIR band for atmospheric correction	Minimum color depth: 10-bit.	3-5 years would be required to follow the change of seasons	Measured radiance of the various wavelengths, which is then converted into chlorophyll-a concentraction (mg/l) based on existing methods and in situ data
SR2: Measure coloured dissolved organic matter (CDOM)	revisit time of 24 h - 2 d, wavelengths required 350, 410/412, 443, 667 nm. Little temporal variation (even over multi-year periods) within sites (Brezonik et al. 2015)		Minimum color depth: 10-bit.	3-5 years would be required to follow the change of seasons	Measured absorption is converted into CDOM concentration based on existing methods and in situ data
OR3: Measure turbidity	Need to correct for clouds and land has to be removed from data before final processing. Sunlight correction is also necessary to convert data to NTU units. 100x100km2 spatial resolution with 1 month revisit time to improve the measurement frequency of Ocean Health Index (OHI) of one year	High resolution spectrometer, possibly an IR camera (also used to measure SST) to resolve clouds (to be removed from the data). Wavelength is based on MODIS instrument specification. Spectral resolution is based on Sentinel-3 OLCI	Dynamic range: 0.001 - 0.1. Minimum color depth: 10-bit.	3-5 years would already be good enough to contribute for annual trending of local turbidity	Spectral intensity data can be converted to Nephelometric Turbidity Units, NTU, by EoMap algorithm plus in-situ measurements
OR4: Measure sea surface temperature (SST)	At least monthly temporal resolution to cover seasonal effects. Data from Landsat8 used to measure the SST and turbidity of river plumes (V. E. Brando, et al, 2015) Spatial resolution: 30m Revisit time: 16 days	Thermal infrared instrument (TI) Advantages: - good resolution and accuracy - tested in other missions Weaknesses: - obscured by clouds - requires atmospheric correction Passive microwave instrument (PM) Advantages: - Clouds are mostly transparent - Relatively insensitive to atmospheric effects Weaknesses: - Poorer resolution and accuracy - Sensitive to surface roughness and precipitation Good to combine both	Required resolution: 0.2 K		Measured brightness temperature is converted into actual temperature based on existing methods

Complementarity of other missions

Better global coverage
in space and time

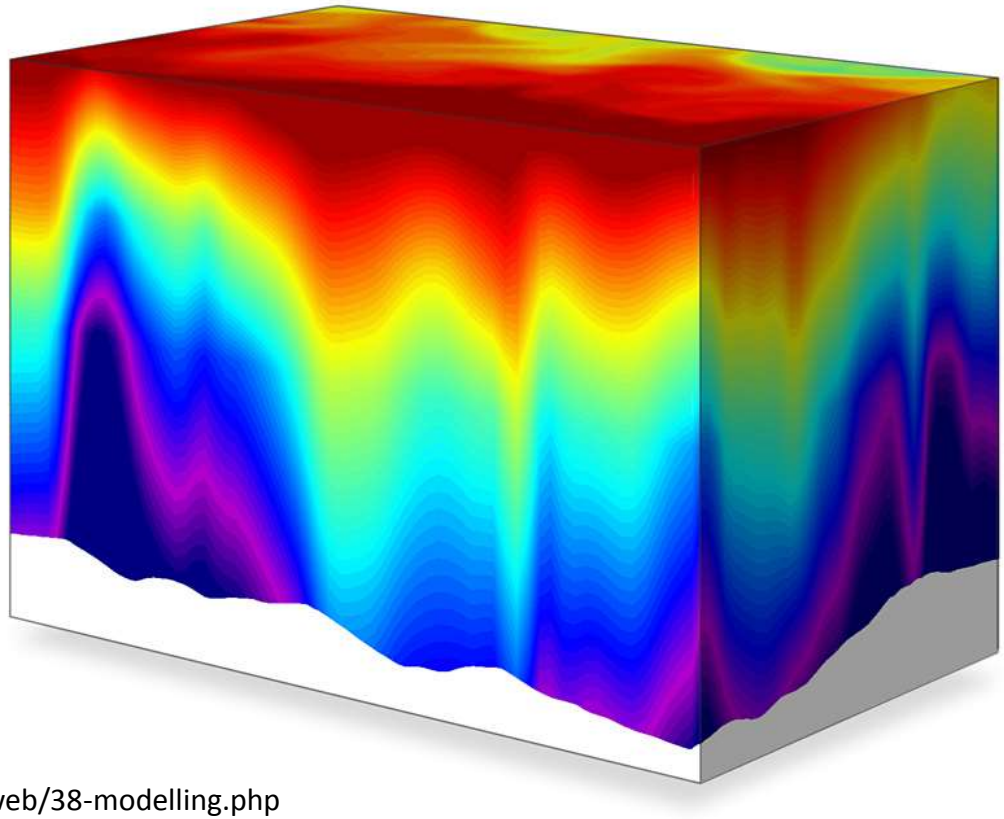
Impact on Data assimilation in:

- Regional and local ocean model
- Ecosystem model

SMOS - Sentinel 2
Credit: ESA

From the Surface and Down / DA

- Required for data assimilation into 3D ocean models in order to derive estimates for sub-surface layers (Gregg, 2008)



http://marine.copernicus.eu/web/38-modelling.php

Scientific Impacts

- Ecosystem, biochemical, and hydrological models need a better **spatial** and **temporal** coverage for:

1. Model validation

2. Data assimilation

3. Improving growth model

ADCS Architecture

GNSS Navigation

- Mass : 1.7kg
- Power @28V: 10 W
- Unit dimensions : 300 mm x 180 mm x 45 mm

3 Axis star tracker

- Mass (kg): DPU: <1.2 ; 30º baffle CHU: 1.4
- Power: 16 – 50 V unregulated DPU: 6.5W;CHU: 0.5W
- Dimensions
  - DPU: 155 x 210 x 56
  - 30º baffle ;
  - CHU: Ø147 x 283 (H)
- Relative accuracy: X/Y < 3 arcsec (1σ)
  Z < 25 arcsec (1σ)

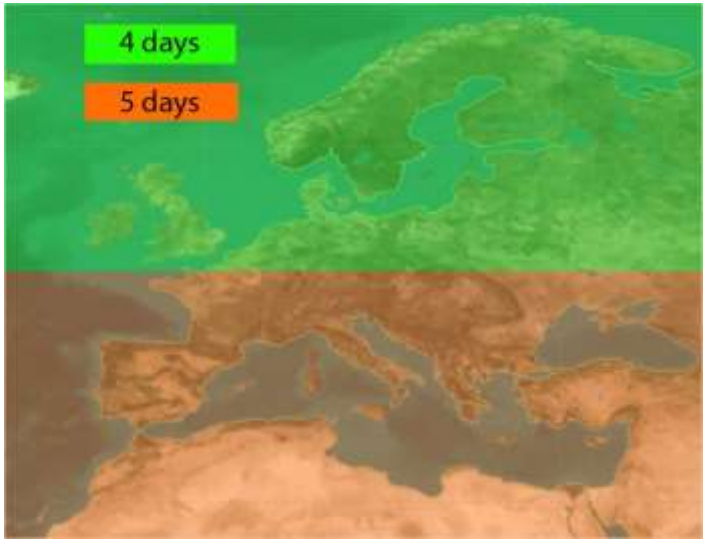
Traceability Matrix

Science Requirements	Measurements Requirements (bandwidth, spatial resolution, revisit time, exposure time)	Instruments	Instrument requirements	Mission Requirements (e.g. Orbit/life time)	Data Products
PR1: Measure chlorophyll-a concentration	Spatial resolution 5 - 10 km with a revisit time of 24h - 2d, wavelengths required 443, 645, 670/676 nm	High resolution spectrometer, including a NIR or ideally a SWIR band for atmospheric correction	Minimum color depth: 10-bit.	3-5 years would be required to follow the change of seasons	Measured radiance of the various wavelengths, which is then converted into chlorophyll-a concentraction (mg/l) based on existing methods and in situ data
SR2: Measure coloured dissolved organic matter (CDOM)	revisit time of 24 h - 2 d, wavelengths required 350, 410/412, 443, 667 nm. Little temporal variation (even over multi-year periods) within sites (Brezonik et al. 2015)		Minimum color depth: 10-bit.	3-5 years would be required to follow the change of seasons	Measured absorption is converted into CDOM concentration based on existing methods and in situ data
OR3: Measure turbidity	Need to correct for clouds and land has to be removed from data before final processing. Sunlight correction is also necessary to convert data to NTU units. 100x100km2 spatial resolution with 1 month revisit time to improve the measurement frequency of Ocean Health Index (OHI) of one year	High resolution spectrometer, possibly an IR camera (also used to measure SST) to resolve clouds (to be removed from the data). Wavelength is based on MODIS instrument specification. Spectral resolution is based on Sentinel-3 OLCI	Dynamic range: 0.001 - 0.1. Minimum color depth: 10-bit.	3-5 years would already be good enough to contribute for annual trending of local turbidity	Spectral intensity data can be converted to Nephelometric Turbidity Units, NTU, by EoMap algorithm plus in-situ measurements
OR4: Measure sea surface temperature (SST)	At least monthly temporal resolution to cover seasonal effects. Data from Landsat8 used to measure the SST and turbidity of river plumes (V. E. Brando, et al, 2015) Spatial resolution: 30m Revisit time: 16 days	Thermal infrared instrument (TI) Advantages: - good resolution and accuracy - tested in other missions Weaknesses: - obscured by clouds - requires atmospheric correction Passive microwave instrument (PM) Advantages: - Clouds are mostly transparent - Relatively insensitive to atmospheric effects Weaknesses: - Poorer resolution and accuracy - Sensitive to surface roughness and precipitation Good to combine both	Required resolution: 0.2 K		Measured brightness temperature is converted into actual temperature based on existing methods

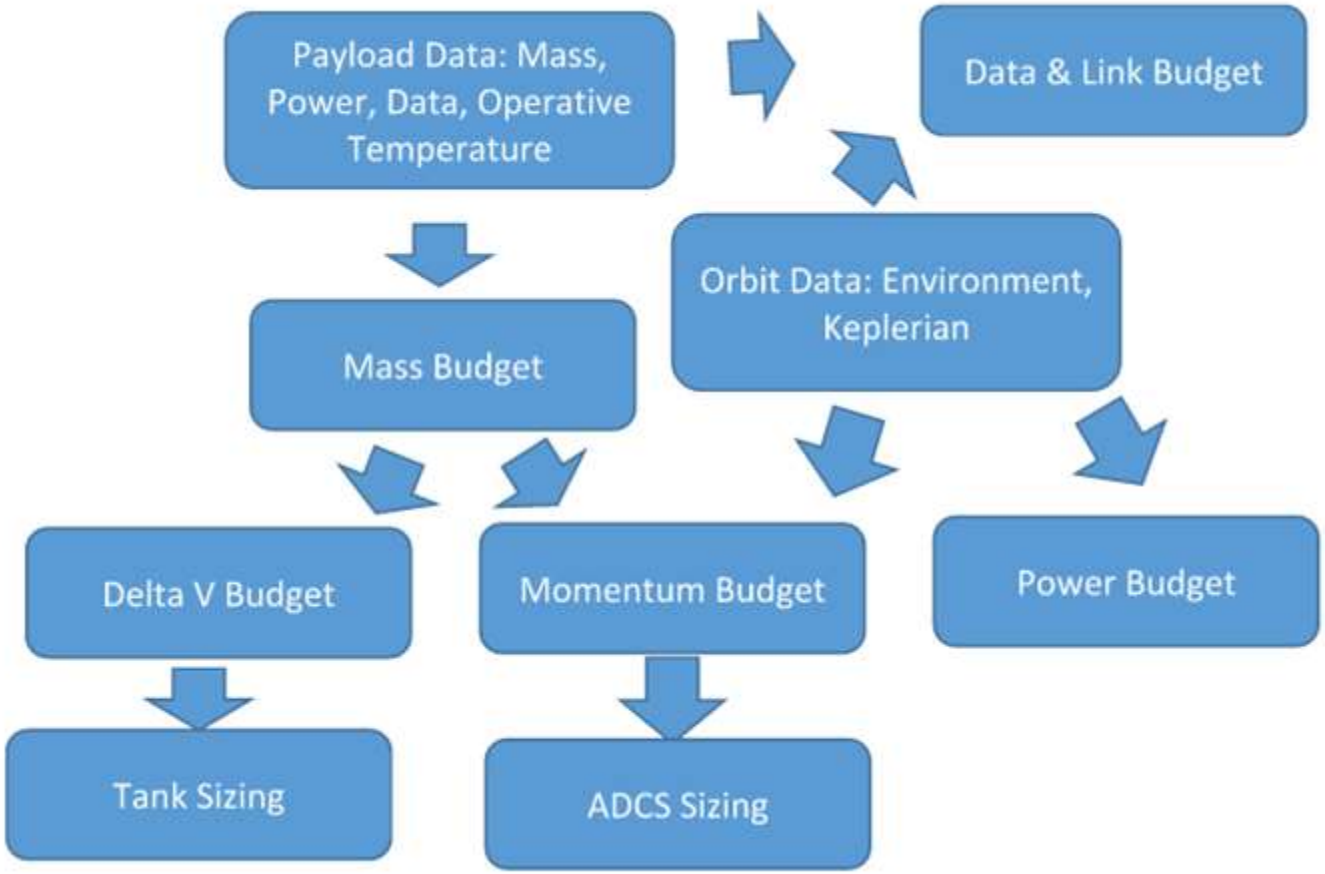
Orbit: Single satellite

- 511 km altitude, SSO
- 95 minutes orbital period
- Two days revisit time above 47°
- Three days revisit time below 47°

Revisit time at different latitudes



Methodology for system design



Propulsion system

- Main engine: Hydrazine, 22N Monopropellant
- ADCS: 8 x hydrazine 2N
- Pressure fed, simple blowdown system
- S/C dry mass: 1387 kg
- S/C wet mass: 1468 kg
- Propellant mass: 74 kg

Delta-V Budget

Lifetime: 5 years

Maneuver	Delta-v [m/s] / year	Delta-v [m/s] / lifetime
Altitude maintenance	5	25
Momentum wheels unloading	3	15
ADCS	10	50
Phasing	8.5	8.5
Overall	18/26.5	98

Link Budget (2 Satellites)

Ground station/ Area	Svalbard	Kiruna	Baltic Sea	Mediterranean Sea
Overflight time per day	6191	5078	9226 (4613 in sunlight)	8496 (4248 in sunlight)
Data rate	300 Mbit/s (X-band)	100 Mbit/s (X-band)	1 Gbit/s	1 Gbit/s
Max. amount per day	1.86 Tbit	0.5 Tbit	4.6 Tbit	4 Tbit

Onboard data preprocessing is required to only map coastal areas

Power budget

Element	Power [%]	Power [W]	Margin [%]	Power w/ margin [W]
Payload	46%	559	20%	670,80
Structure	0%	0	5%	0,00
Thermal	10%	122	10%	134,20
Power	9%	109	5%	114,45
TT&C	12%	146	10%	160,60
Command & Data Handling	12%	146	5%	153,30
Attitude control	10%	122	5%	128,10
Propulsion	2%	24	5%	25,20

Power budget

Sum (System Power)	1228
System Margin	20%
Total Power w Margin[W]	1473,6
Bus Power	669

- **Triple-junction ga/as solar cells 10 m^2**
- **Li-on Battery 127 Ah @EOL with**
- **UnRegulated Bus**

Mass Budget

Element	Break Down	Mass [Kg]		Mass w/ margin [kg]
Payload	31%	399	10%	438,90
Structure	27%	348	5%	365,40
Thermal	2%	26	10%	28,60
Power	21%	132	5%	138,60
TT&C	2%	26	5%	27,30
C&DH	5%	64	5%	67,20
Attitude control	6%	77	5%	80,85
Propulsion	3%	39	5%	40,95
Launch Adapter	3%	39	5%	40,95
Propellant	8%	74	10%	81,40

Mass Budget

Sum (System Mass)	1224
System Margin	20%
Total Mass w Margin[Kg]	1468,8
Dry Mass w Margin[Kg]	1.387,40
Bus Mass (No structure)	364

- Linear Dimension 3m
- Body Area 6 m^

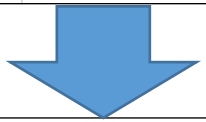
Momentum Budget

- From orbital Environment to Momentum Budget

Aero Torque	1,06E-07
Gravitational	0,000055296
Solar Pressure	0,000010936
Total	6,63E-05
Margin	20%

ADCS Sizing

Requirements	
Pointing accuracy	0,003
Knowledge	0,001



Reaction Wheel	**Torque[Nm]**	0,0124	
	Momentum [Nms]	0,2358	
			Force
Thrusters	**Torque**	4	2,36
	Momentum	0	
	Moment Arm	1,5	
	Number of Thruster	8	
	Pulse time	2	
	Momentum for RW desaturation	0,0786	0,0524
	Total Thruster	4	2,4124
Magnetic Torquers	**Dipole moment (A.m2)**	6	
	B_worst case	0,000046	
	Torque provided (Nm)	2,76E-04	

ADCS Sizing

Element	Model
4 Reaction Wheel	W18E
3 Magnetic Torquers	MTR-5
2 Star Tracker	Rigel L
3 Magnetometer	SSTL magnetometer
3 Fiber Optical Gyro	ASTRIX® 200
1 GPS / Galileo	SGR-ReSI

ADCS Architecture (Safe Mode)

Magnetometer

- Mass:190 gr
- Volume: 36*90*130 (mm)
- Power supply: Supply ± 12 V ; Consumption <300mW
- Sensitivity: ± 10 nT
- Range: ± 60 µT

3 Magnetic Torquers

- Magnetic torque: ± 5 Am² per Coil
- Mass: 500 gr
- Volume: 66*252*39 (mm)
- Power: 0,5W @ 5V p/ coil

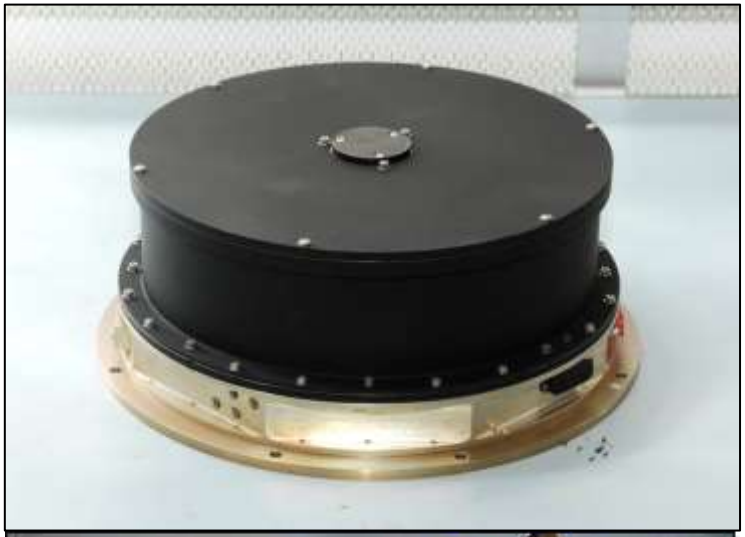
ADCS Architecture

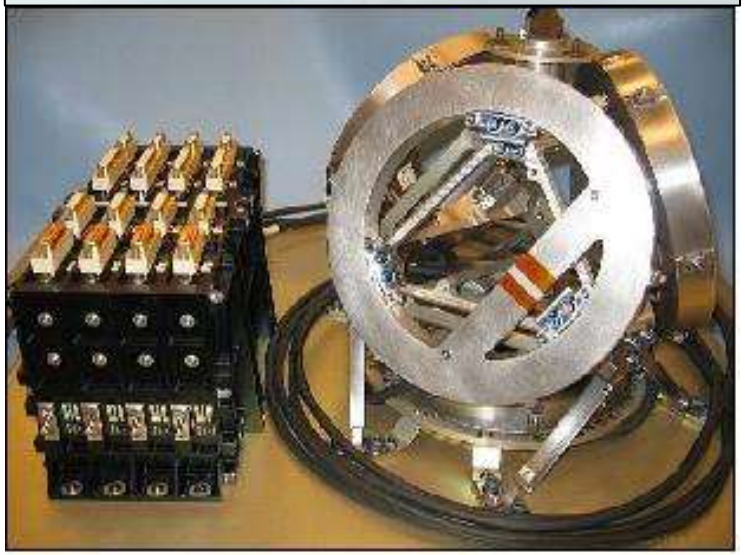
4 Reaction wheels (Tetrahedron congifuration)

- Redundancy
- Mass(Kg): 2.3
- Speed range max operational [RPM]: 4000
- Max gross torque [Nm]: 0.248

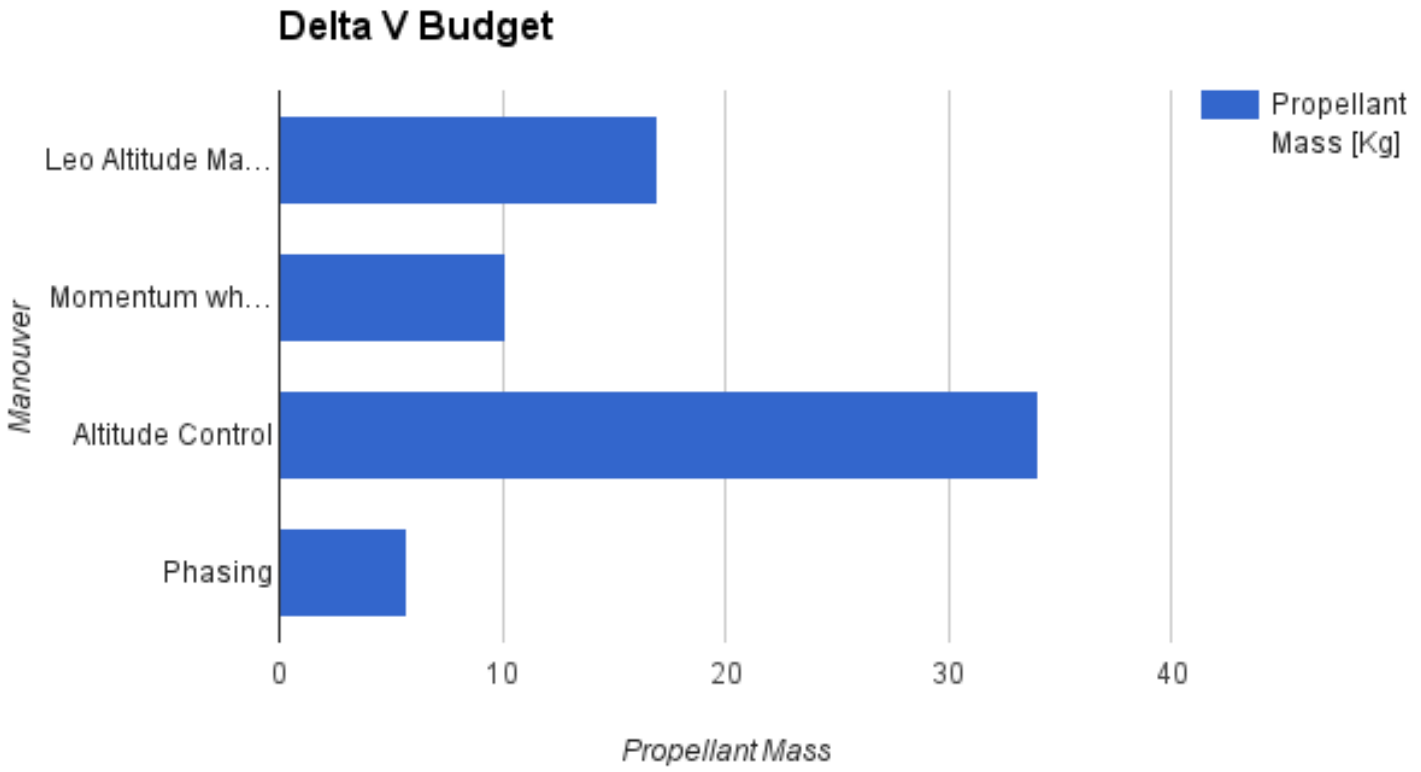
3 Axis Laser Gyro

- Mass :12,7 kg
- Volume:
- GEU 295x150x145 mm^3
- Power : 5.5 W





Delta V Budget



Total Propellant Mass [Kg]	**58**	100% margin for attitude control
Total Mass + Margin [Kg]	**64**	10 % margin for the total value
Volume[m³]	**0,074**	