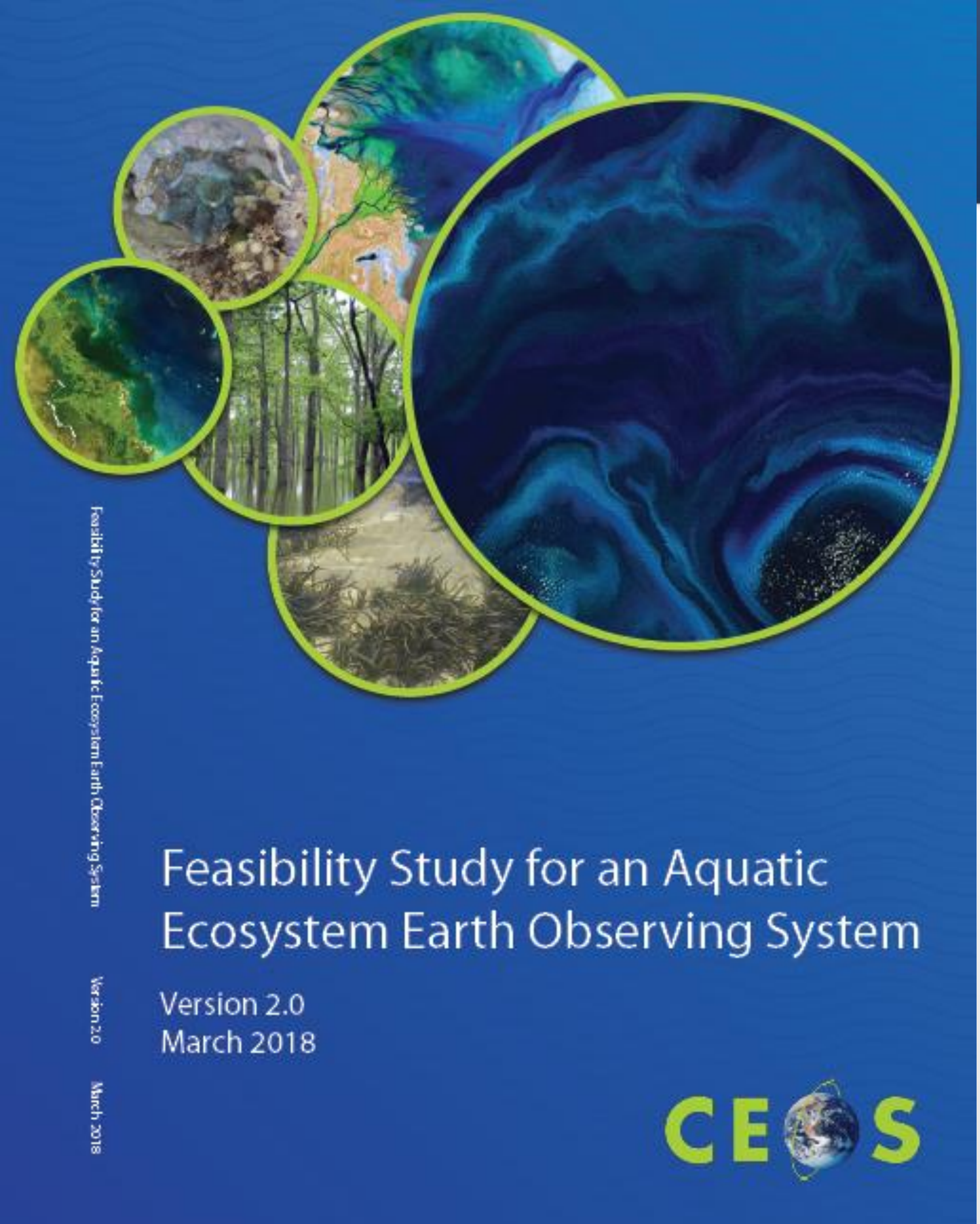
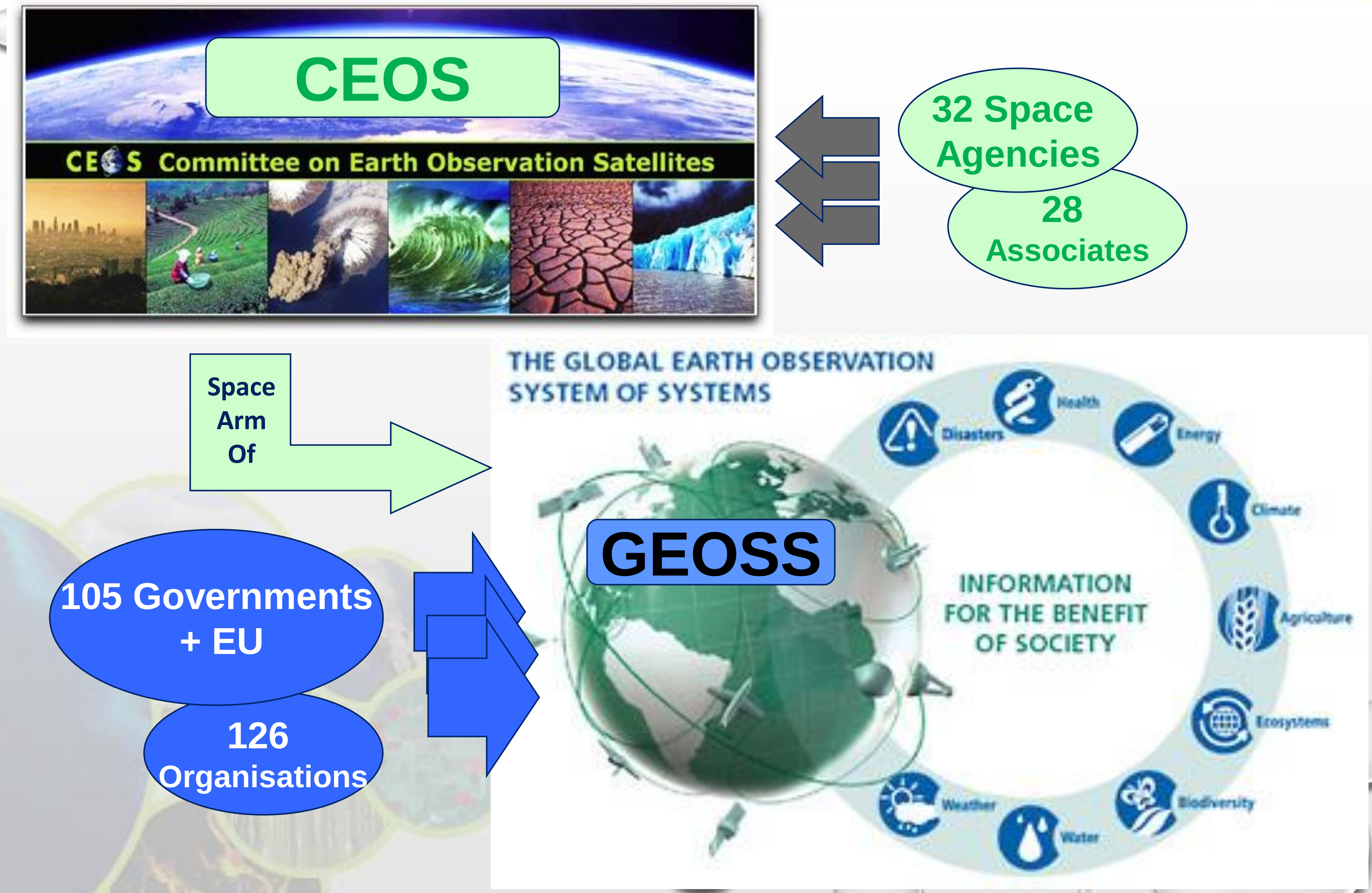


There are (a lot of) terrestrial, ocean and atmospheric sensors….. but none specifically for where ~60% of global population lives and ~60 Trillion U$ of GDP is produced……….

CEOS and GEOSS Relationship



Scope of the Feasibility Study For an Aquatic Ecosystem Earth Observing Sensor

- One of the GEO Water Strategy recommendations (2015) to CEOS was : a feasibility assessment to determine **the benefits and technological difficulties of designing a hyperspectral satellite mission focused on inland water quality measurements**:
- The GEO AquaWatch community proposed to extend the scope to: **(i) a dedicated imaging spectrometer or (ii) augmenting designs of planned spaceborne sensors for terrestrial and ocean colour, to allow improved inland, near coastal waters, benthic and shallow water bathymetry applications**.
- CEOS agencies also requested : augmenting designs of spaceborne sensors for terrestrial and ocean colour applications as **a cost-effective pathway to addressing the same science and societal benefit applications**
- Focus is on a **global mapping mission**

Scope of the Feasibility Study For an Aquatic Ecosystem Earth Observing ~~Sensor~~

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Scope of the Feasibility Study for an Aquatic Ecosystem
Earth Observing System

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The CEOS Teams that wrote or supported the report

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(EC)	Astrid-Christine Koch & Catharina Bamps (European Commission)

Table of Contents:

Feasibility Study for an Aquatic Ecosystem Earth Observation System

Available from: http://ceos.org/about-ceos/publications-2/

From science and applications requirements to design specifications for an EO sensor

Measurement requirement (B= Baseline, T=Threshold)

- **Levels/ranges of the desired aquatic ecosystem variable (e.g. concentration, spatial cover etc.)**

- **Temporal resolution**
- **Spatial resolution**
- **Spectral resolution**
- **Radiometric resolution**

- **Geolocational accuracy**
- **Sunglint avoidance**
- **Polarisation sensitivity**

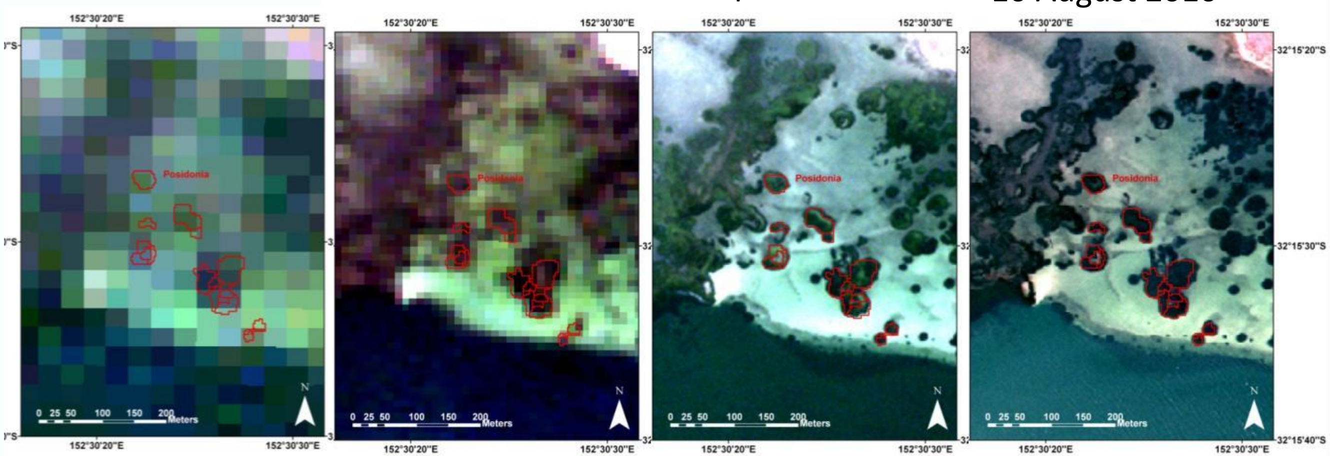
Effects of spatial resolution on feature discrimination: Question: which most suitable for a global mapping mission?

(Example is Posidonia seagrass beds under a 1 m of water in coastal lagoon)

Low cost
Coarse detail

Higher cost
Fine detail

	Landsat TM5 20 September 2008	ALOS 5 January 2007	QuickBird-2 20 September 2008	WorldView-2 10 August 2010



Spatial resolution:	**30m**	**10m**	**2.6m**	**1.6m**
Spectral Bands:	**4 VIS/NIR, 2 SWIR, 1 ThIR**	**4 VIS/NIR**	**4 VIS/NIR**	**8 VIS/NIR**

Spatial resolution for inland waters is a key driver for specifications

Ground sampling distance requirements showing resolvable size class and total cumulative number and area coverage of the world's lakes (based on assumptions using Verpoorter et al. (2014) dataset). (Courtesy E.L. Hestir & Mark Matthews)

Size Class	Required GSD*	% Total Area	Total number	
≥ 10 km^2	1054 m	44	25,976	Focus of current and future OC sensors
≥ 1 km^2	333 m	60	353,552	
≥ 0.1 km^2	105 m	80	4,123,552	
≥ 0.01 km^2	33 m	90	27,523,552	Focus of this study
≥ 0.002 km^2	15 m	100	117,423,552	

*Calculated using a box of 3 x 3 pixels sufficient to resolve the specified lake size

Ground sampling distance requirements showing the resolvable river width class and cumulative number of total river reaches of the world's rivers from Pavelsky et al. (2012) dataset.

River Reach Size Class (width)	Required GSD*	Total number of reaches	Percent of total reaches	
1.5 km	500	2,877	< 0.1%	
≥ 1 km	333	8,483	<1%	
≥ 0.5 km	167	35,420	1%	Focus of current and future OC sensors
≥ 0.1 km	33	382,466	12%	Focus of this study
≥ 0.05 km	17	766,303	24%	Focus of this study
≥ 0.01 km	3	2,576,452	81%	

*Calculated using a box of 3 x 1 pixels sufficient to resolve the width of the river reach

Summary spectral bands & resolution from: (i) multiple types of simulations, (2) spectral pigment features (from phytoplankton, macrophytes and other benthos), and algorithm requirements

Centre	FWHM	Water quality and benthic characterisation related application	
[nm]	[nm]		
+/-380	15	CDOM (Mannino et al., 2014) ; NAP; PFT (Wolanin et al., 2016); mycosporin-like amino acids (Dupuoy et al., (2008)	1
+/-412	5 to 8	CDOM (Mannino et al., 2014); PFT (Wolanin et al., 2016)	2
+/-425	5 to 8	CDOM ; Blue Chl-a absorption reference band ; NAP; PFT (Wolanin et al., 2016)	3
+/-440	5 to 8	CDOM (Mannino et al., 2014); Blue Chl-a absorption maximum; PFT (Wolanin et al., 2016)	4
467	5 to 8	Band required to separate Pheaocystis from diatoms (Astoreca et al., 2009); Blue Chl-a absorption band reference band; Accessory pigments	5
+/-475	5 to 8	Accessory pigments ; Blue Chl-a absorption band reference band ; PFT (Wolanin et al., 2016), NAP;	6
+/-490	5 to 8	Blue Chl band-ratio algorithm; PFT (Wolanin et al., 2016), Accessory pigments	7
+/-510	5 to 8	Blue Chl band-ratio algorithm ; NAP ;	8
+/-532	5 to 8	PFT & carotenoids (Wolanin et al., 2016); NAP	9
+/-542	5 to 8	NAP	10
555	5 to 8	NAP (as most algal pigments absorptions are low); Cyanophycoerythrin reference band PFT (Wolanin et al., 2016)	11
565	5 to 8	CPE in vivo absorption maximum and possibly fluorescence (Dierssen et al., 2015)	12

		reference band PFT (Wolanin et al., 2016)	
565	5 to 8	CPE in vivo absorption maximum and possibly fluorescence (Dierssen et al., 2015)	12
+/-583	5 to 8	CPE and CPC reference band; chlorophylls a,b and c (Johnsen et al., 1994); CPE fluorescence (Dierssen et al., 2015)	13
+/-594	5 to 8	PFT (Wolanin et al., 2016)	14
+/-615	5 to 8	CPC in vivo absorption maximum (Hunter et al., 2010) -avoiding chlorophyll- c	15
624	5 to 8	CPC in vivo absorption maximum (Dekker, 1993; Simis 2007), suspended sediment, PFT(Wolanin et al., 2016); chlorophyll c (Johnsen et al., 1994)	16
631	5 to 8	PFT (Wolanin et al., 2016)	17
+/-640	5 to 8	NAP, CPC reference band	18
649	5 to 8	Chl-b in vivo absorption maximum (Johnsen et al., 1994)	19
665	5 to 8	FLH baseline (Gower et al., 1999; Gilerson et al., 2008)	20
676	5 to 8	Red Chl-a in vivo absorption maximum (Johnsen et al., 1994)	21
683	5	Chlorophyll fluorescence (FLH) band (Gower et al., 1999; Gilerson et al., 2008)	22
+/-700	5 to 8	HABs detection; NAP in highly turbid water; reference band for 2 or 3 band Chl-a algorithms	23
+/-710	5 to 8	FLH baseline (Gower et al., 2005); HABs detection; NAP in highly turbid water; reference band for 2 or 3 band Chl-a algorithms	24
+/-748	15	NAP in highly turbid water (Ruddick et al., 2006) ; FLH baseline band (Gilerson et al., 2008)	25
+/-775	15	NAP in highly turbid water (Ruddick et al., 2006);	26

Recommended spectral bands for atmospheric correction purposes as well as Non Algal Particulate matter concentration estimation.

centre	FWHM	Atmospheric characterisation and air-water interface effect removal bands	
[nm]	[nm]		
+/- 360	8	To constrain the SWIR-based aerosol model over turbid waters	1
+/- 368	8	To constrain the SWIR-based aerosol model over turbid waters	2
+/-412	8	NO2	
+/-520	8	Aerosol retrieval	3
+/-575	8	Chappuis band for O3 absorption(Gorshelev et al.(2014)	4
+/-605	8	Chappuis band for O3 absorption (Gorshelev et al.(2014)	5
+/-620	8	Aerosol retrieval	
+/-709	8	Aerosol retrieval	
+/-740	8	Sun glint removal	
+/- 761	3	Sun glint removal	6
+/-775	16	Aerosol retrieval; water vapour reference band	7
+/-820	16	Water vapour absorption	8
+/-865	16	Aerosol retrieval; water vapour reference band; sunglint removal; (Dogliotti et al., 2015)	9
+/-940	16	Water vapour absorption	10
+/-1020	16	water vapour reference band	11
+/-1050	16	water vapour reference band	12
+/-1130	16	Water vapour absorption	13
+/-1135	16	Water vapour reference band	14
+/- 1380	16	Cirrus clouds	15

Temporal resolution requirements

1. **Within hours such as algal blooms, flood events with associated influxes of high nutrient, high coloured dissolved organic matter and suspended sediment loads into reservoirs, estuaries or coastal seas or with tidal or wind driven events.**
2. **Within days such as pollution events, dredging effects etc.**
3. **Within weeks such as coral bleaching events (Healthy coloured coral -> bleached coral -> dead coral or recovered coral).**
4. **Seasonally to yearly to longer term such as successions of phytoplankton functional types or emergence, florescence and decay of macrophytes.**
5. **For bathymetry???...............**

FINER SPATIAL RESOLUTION = LESS PHOTONS
FINER SPECTRAL RESOLUTION = LESS PHOTONS

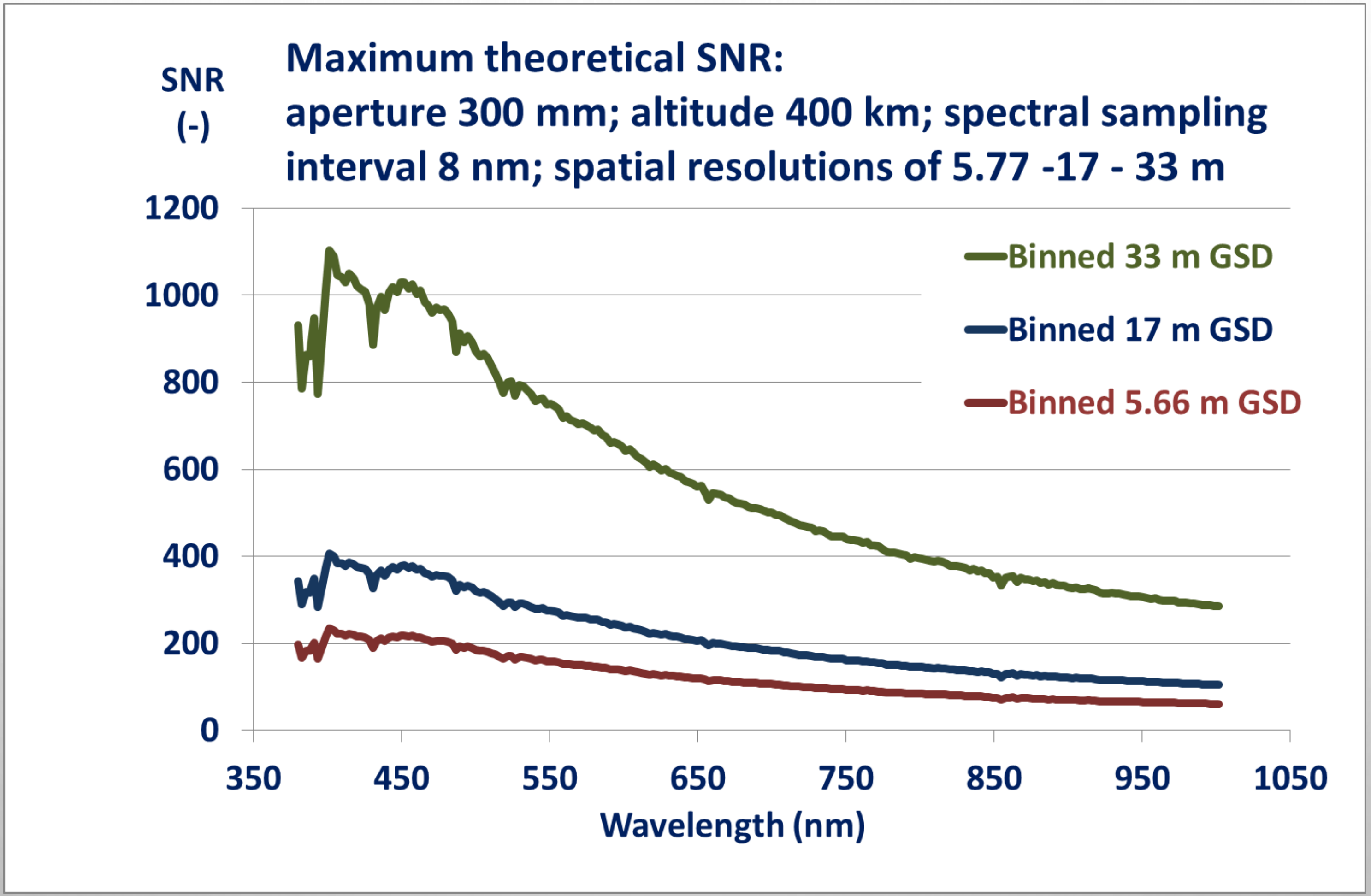
LESS PHOTONS MEANS REDUCED RADIOMETRIC RESOLUTION=> LESS DEPTH INTERVALS

- Finer spatial resolution = lower radiometric resolution= less depth penetration but improved identification of smaller benthic features and less water column concentration composition discrimination
- Coarser spatial resolution = higher radiometric resolution=deeper depth penetration but reduced identification of smaller benthic features and improved water column concentration composition discrimination.
- Finer spectral resolution=> higher depth penetration although counteracted by lower radiometric resolution=> lower depth penetration but improved benthic cover and water column concentration composition discrimination.
- Coarser spectral resolution=> higher radiometric resolution => better depth penetration but counteracted by less depth penetration due to broader spectral bands and less detailed benthic cover and water column concentration composition discrimination

e.g. Worldview-3 : high spatial , coarse spectral (~50 nm wide bands)=> medium radiometric resolution

TRADE-OFF RESOLUTIONS

Higher spatial resolution = lower radiometric resolution=less depth penetration



Sat Dek pty ltd & CSIRO

CEOS Report : “Feasibility Study for an Aquatic Ecosystem Earth Observation System: Summary

1. Spectral and spatial resolution are the core sensor priorities

- Spectral
  - ~26 bands in the 380-780 nm wavelength range for retrieving the aquatic ecosystem variables
  - ~15 spectral bands between 360-380 nm and 780-1400 nm for removing atmospheric and air-water interface effects.
  - These requirements are very close to defining an imaging spectrometer with spectral bands between 360 and 1000 nm (suitable for Si based detectors), possibly augmented by a SWIR imaging spectrometer.
- Spatial-
  - ~17 m pixels resolves ~25% of river reaches globally
  - ~33 m pixels resolves the vast majority of water bodies (lakes, reservoirs, lagoons, estuaries etc.) large than 0.2 ha
  - Still maintains radiometric sensitivity

2. Radiometric resolution and range and temporal resolution need to be as high as is technologically and financially possible.
3. A high temporal resolution could be obtained by a constellation of Earth observing sensors e.g. in a various low earth orbits augmented by high spatial resolution geostationary sensors.

What other non-aquatic applications would benefit from a sensor with these specifications???

- Agriculture?
- Forestry?
- Vegetation (e.g. invasive species, anomalies, stress)
- Minerals?
- Soils?
- Urban?
- Mining and mine site rehabilitation?
- …..
- …..

Increased overlap with non-aquatic applications would increase possibility of the proposed EO sensor system being funded.

! Feedback welcome!

Important to get feedback now:

CEOS Freshwater from Space workshop 13-15 November 2018 in Delft The Netherlands: 40 invited experts across water quality, water quantity, soil moisture, ground water, evaporation/evapotranspiration, precipitation and cross-cutting experts to provide guidance to CEOS agencies for future sensor programmes.

Should a system of EO satellites for aquatic ecosystems all have the same specifications or should we aim for a mix (multi-spectral, hyperspectral, fine to medium spatial resolution? etc…) : use DESIS as Pilot Study!

Please Provide Feedback! & See Poster

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