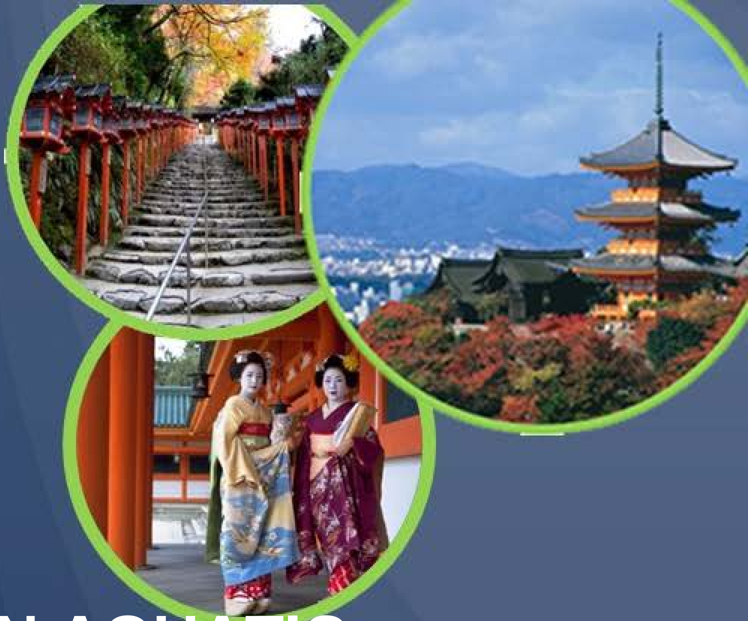
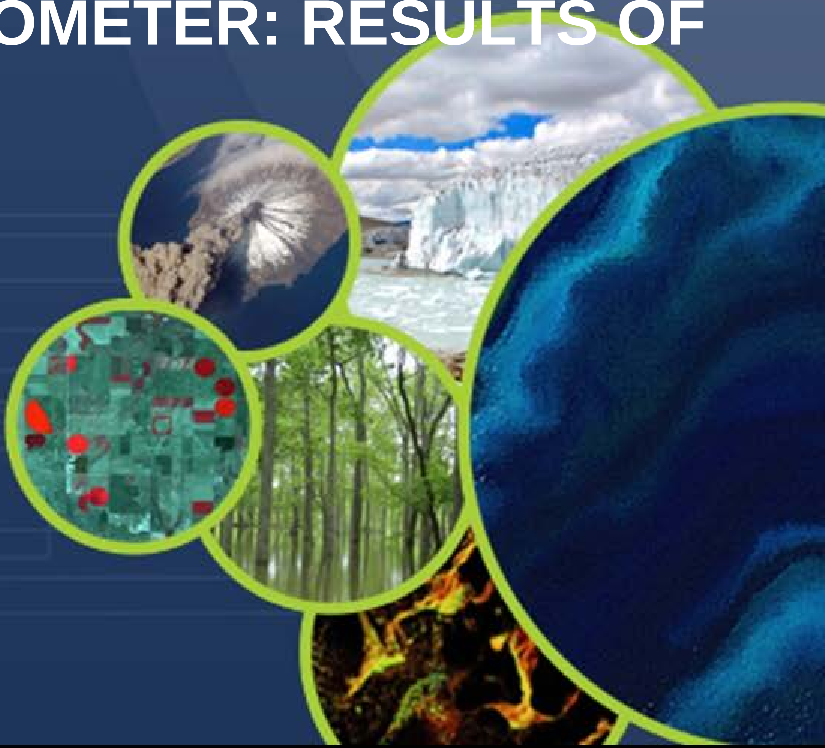
CEOS
Committee on Earth Observation Satellites



DESIGN CONSIDERATIONS FOR AN AQUATIC ECOSYSTEM IMAGING SPECTROMETER: RESULTS OF A CEOS FEASIBILITY STUDY



Ad-Hoc Working Group CEOS

Presented by A.G. Dekker CSIRO

IAC, Adelaide, 25-29 September 2017

Scope of the Feasibility Study Imaging Spectrometer for (non-Ocean) Aquatic Ecosystems

- The CEOS response to (GEOSS) Water Strategy recommendations was endorsed by CEOS at the 2015 CEOS Plenary.
- This study addresses original recommendation C.10 : A feasibility assessment to determine **the benefits and technological difficulties of designing a hyperspectral satellite mission focused on water quality measurements**:
- The GEO AquaWatch community proposed to extend the scope to: **(i) a dedicated imaging spectrometer or (ii) augmenting designs of spaceborne sensors for terrestrial and ocean colour, to allow improved inland, near coastal waters, benthic and shallow water bathymetry applications**.
- Augmenting designs of spaceborne sensors for terrestrial and ocean colour applications could be **a cost-effective pathway to addressing the same science and societal benefit applications**
- Focus is on a **global mapping mission**

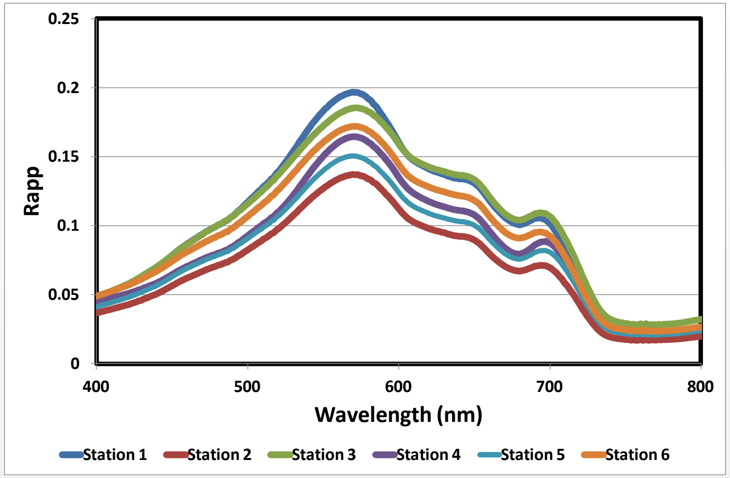
Scope of the Feasibility Study
Imaging Spectrometer for Aquatic Ecosystems

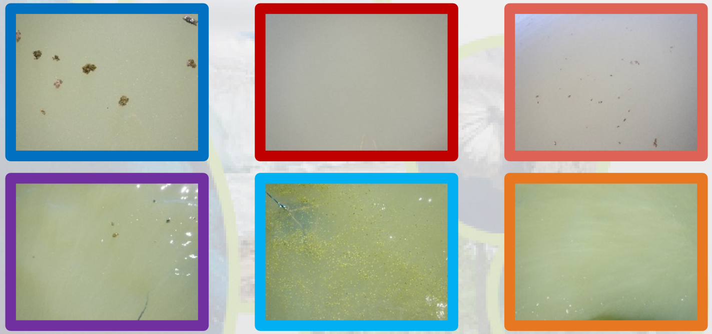
Three activities defined in this feasibility study:

1. An assessment of the benefits and technological difficulties of designing a global satellite mission focused on inland, estuarine, deltaic and near coastal waters - as well as mapping macrophytes, macro-algae, seagrasses and coral reefs and shallow water bathymetry- at significantly higher spatial resolution than 250m.
2. To examine threshold and baseline observation requirements for sensors suitable for aquatic ecosystems to inform CEOS Agencies
3. That the GEO Water community define inland and near-coastal water quality and benthic habitat essential variables, including an assessment of relative priority, linked to defined economic, social and environmental benefits. This information would be of great value in informing investment decisions.

Inland waters: not so simple: land-water boundaries; lakes at -140 to 4500 m altitude

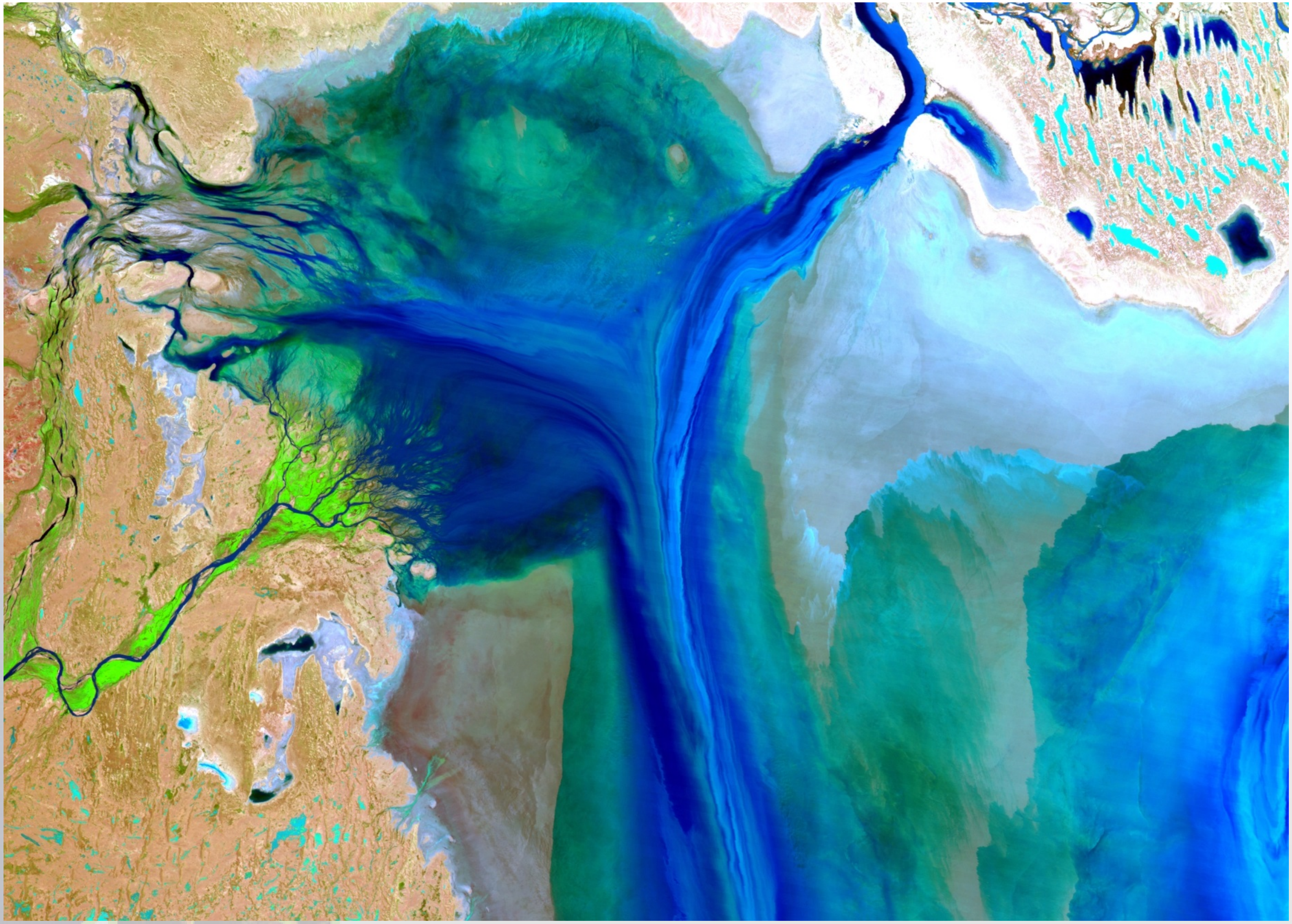
- Reflectance





CSIRO

Salt lakes- not so simple (Lake Eyre- Australia after floods)



Seagrass and intertidal: not so simple:

Simulation results Rrs (normalized) for a range of inland to coastal water types

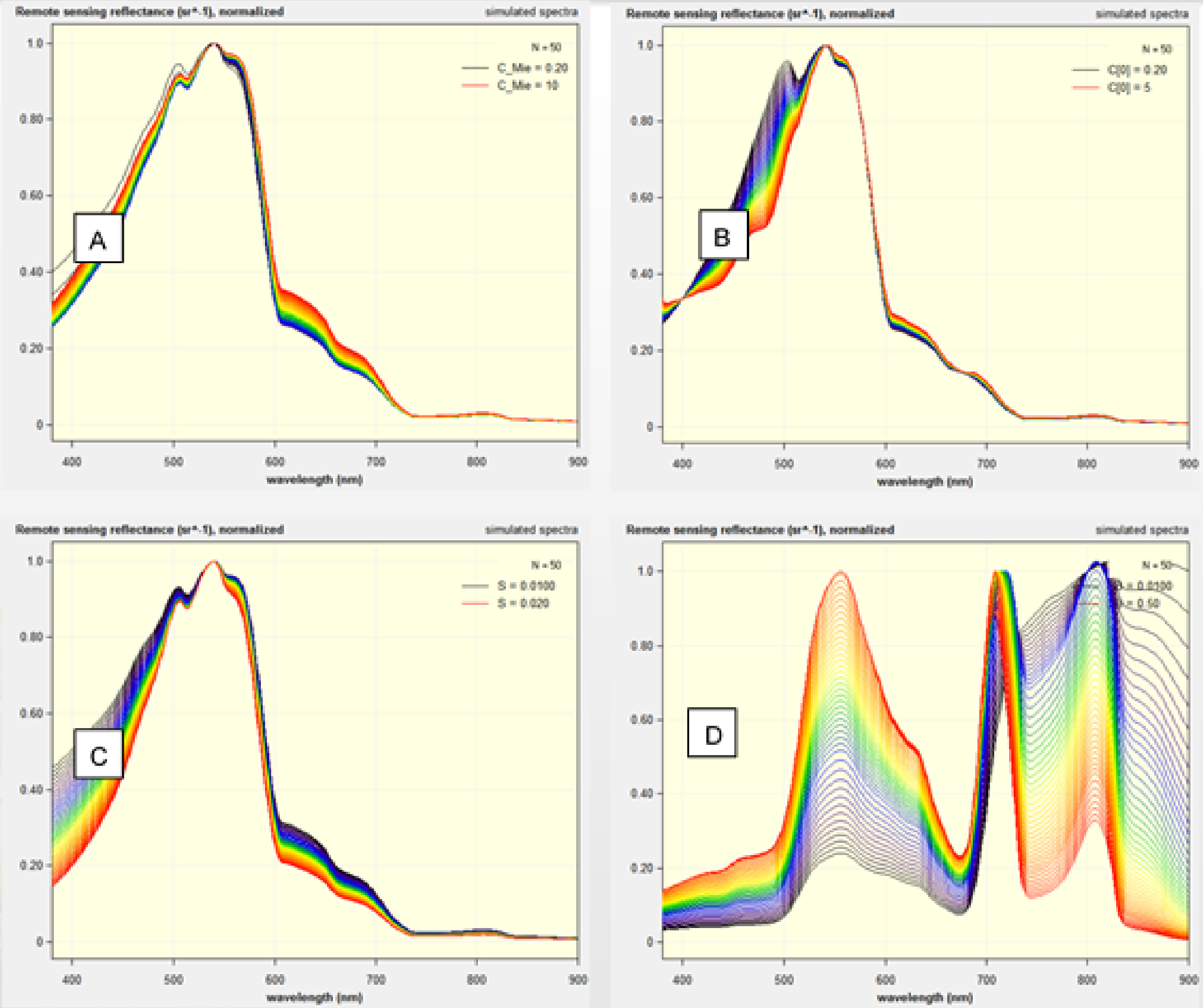
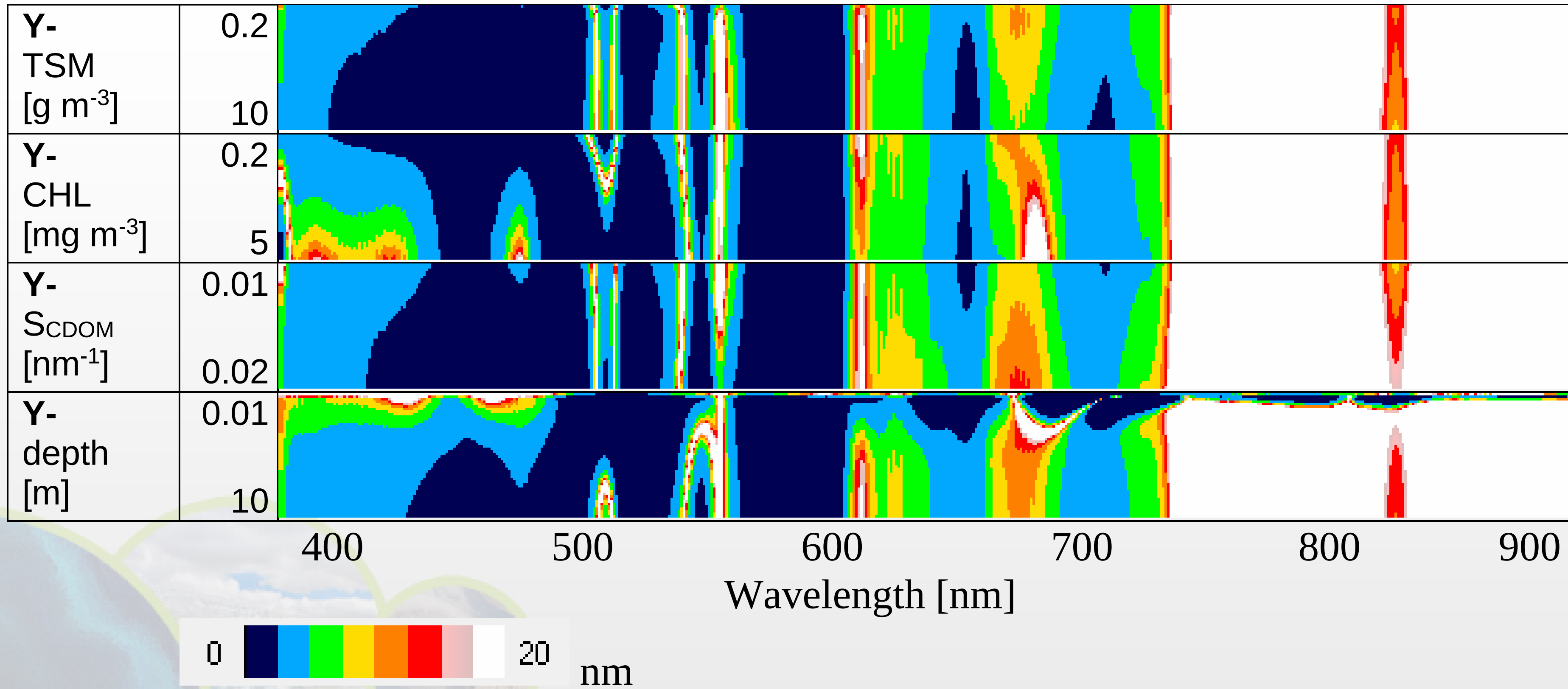


Figure 1: Normalized remote sensing reflectance for (A) TSM range 0.2 - 10 mg/l, (B) CHL range 0.2 – 5 µg/l, (C) S_{CDOM} range 0.010 – 0.020 nm^{-1}, (D) depth range 0.01 – 0.5 m.

Spectral resolution (in 2.5 nm steps) required to resolve change at low to high variable concentration (standard OAC scenario-optically shallow water)



Trade-off between spatial, spectral and radiometric resolution

The priority in specifications for an aquatic ecosystem imaging spectrometer (or many multi-bands sensor is from 1 to 4:

1. Spatial resolution (as not getting a pure aquatic pixel avoids any measurement at all)
2. Spectral resolution (to discriminate between all the variables)
3. Radiometric resolution: should be as high as possible given priorities 1 and 2
4. Temporal resolution (varies from once a season to hourly intervals) can be solved by LEO+GEO and /or constellations of LEO's

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

center	FWHM	Water Quality and Benthic Characterisation Related Application	
[nm]	[nm]		
+/-380	15	CDOM ; NAP; PFT	1
+/-412	5 to 8	CDOM ; PFT	2
+/-425	5 to 8	CDOM ; Blue Chl-a absorption reference band ; NAP; PFT	3
+/-440	5 to 8	CDOM ; Blue Chl-a absorption maximum; PFT	4
467	5 to 8	Pheaocystis/ diatoms ; Blue Chl-a ; Accessory pigments	5
+/-475	5 to 8	Accessory pigments ; Blue Chl-a absorption band reference; PFT, NAP;	6
+/-490	5 to 8	Blue Chl band-ratio algorithm; PFT;Accessory pigments	7
+/-510	5 to 8	Blue Chl band-ratio algorithm ; NAP ;	8
+/-532	5 to 8	PFT & carotenoids; NAP	9
+/-542	5 to 8	NAP	10
555	5 to 8	NAP; Cyanophycoerythrin reference band; PFT	11
565	5 to 8	CPE in vivo absorption maximum and possibly fluorescence	12
+/-583	5 to 8	CPE and CPC reference band; chlorophylls a,b and c; CPE fluorescence	13
+/-594	5 to 8	PFT	14
+/-615	5 to 8	CPC in vivo absorption maximum -avoiding chlorophyll- c	15
624	5 to 8	CPC in vivo absorption maximum, suspended sediment, PFT; chlorophyll c	16
631	5 to 8	PFT	17
+/-640	5 to 8	NAP, CPC reference band	18
649	5 to 8	Chl-b in vivo absorption maximum	19
665	5 to 8	FLH baseline	20
676	5 to 8	Red Chl-a in vivo absorption maximum	21
683	5	Chlorophyll fluorescence (FLH) band	22
+/-700	5 to 8	HABs detection; NAP; reference band for 2 or 3 band Chl-a algorithms	23
+/-710	5 to 8	FLH baseline; HABs detection; NAP; reference band Chl-a algorithms	24
+/-748	15	NAP in highly turbid water	25
+/- 775	15	NAP in highly turbid water	26

Note that for the algal pigment absorption maxima we have included reference bands for the 3 band pigment absorption and fluorescence line height approaches. Physics based spectral inversion methods do not need these pigment reference bands. When the band center has a +/- sign it means that the wavelength center is not critical and may vary by about 5 nm.

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

+/- 730	**Sun and sky glint/NAP/atmospheric correction**
+/- 740	**Sun and sky glint/NAP/atmospheric correction**
+/- 750	**Sun and sky glint/NAP/atmospheric correction**
+/- 770	**Sun and sky glint/NAP/atmospheric correction**
+/- 865	**Atmospheric correction**
***1240* or 1238**	**Atmospheric correction (*MODIS* or VIIRS)**
***1640* or 1600**	**Atmospheric correction(*MODIS* or VIIRS)**
***2130* or 2257**	**Atmospheric correction (M*ODIS* or VIIRS)**

Spatial & spectral resolution requirements

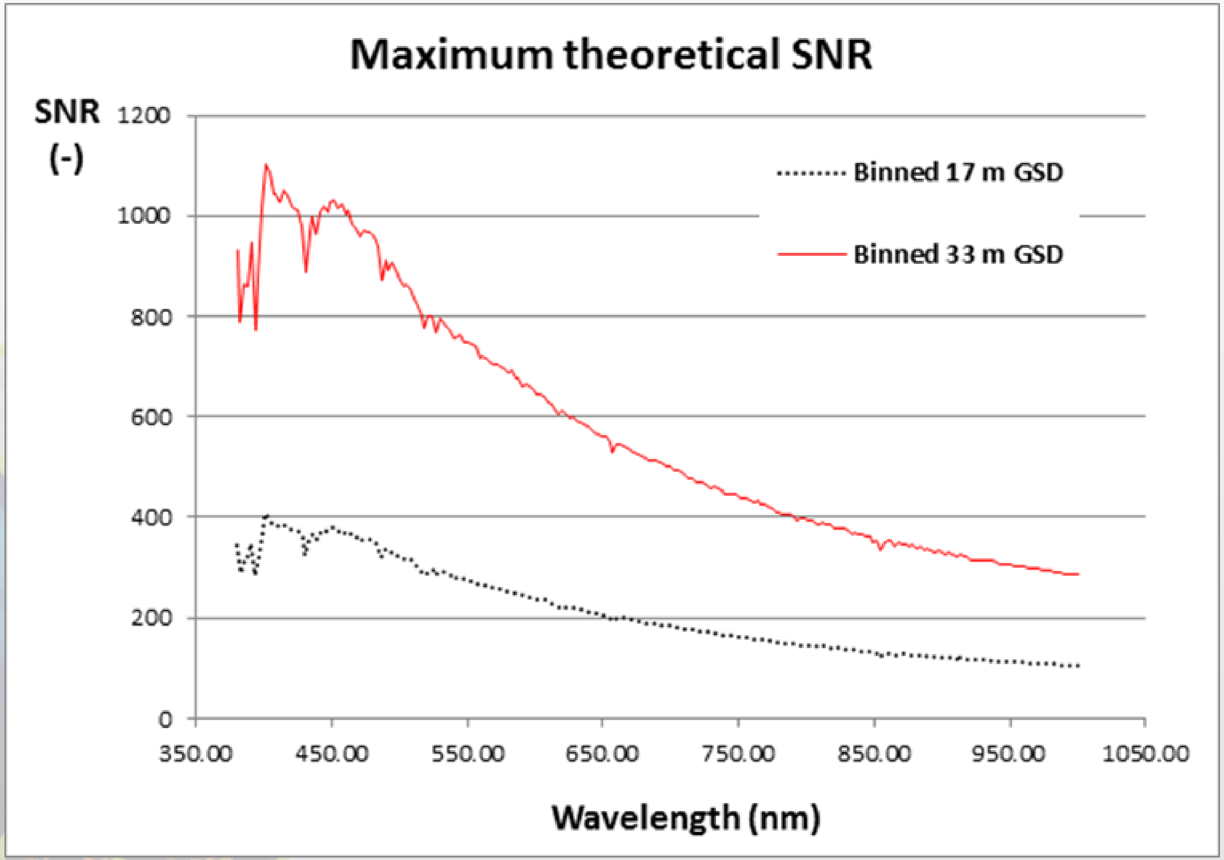
The minimum spatial resolution requirement for inland water bodies can be categorized for large lakes and for smaller water bodies:

- **A GSD of 300 m can observe the majority of the world's lake surface area (but is a small fraction of the total number of lakes)**
- **The Sentinel-3 series of satellites has 22 spectral bands, high SNR and a GSD of 300m and is thus adequate for large lakes.**
- **A sensor with a minimum GSD of 15-17 m would enable observations for ~25% of global river reaches and 90 to 100% of lakes 0.2 ha or larger.**
- **The focus should be around 5 to 8 nm spectral intervals and a GSD of about 17 m, whilst a GSD of 30 m could be a compromise between costs and S:N (= close to experimental sensor ENMAP Specs)**

A simulation of achievable radiometric resolution within constraints of spectral and spatial resolution in terms of SNR (By M. Bergeron CSA)

Raw Ground Sampling Area of 5.66 and 11 m binned (3 bins) to 17 and 33 m;

- Raw Spectral Sensing Interval of 2.66 nm binned (3 bins) to 8 nm;
- Assumes typical TOA radiance at 42 degrees SZA from Zia Ahmad (2012);
- a 30 cm aperture for the fore optics.



CEOS Report
“Feasibility Study Imaging Spectrometer”:

Society needs detection, assessment and monitoring of aquatic ecosystems :

UN SDG’s 6, 14 and 15 contain aquatic ecosystem variables specifically.

Coral reefs, seagrasses, macro-algae, macrophytes (freshwater) could all possibly be measured with a fixed set of multispectral bands for each separate application

However…..

- When measuring optically active water constituents over large ranges (optically deep water case) and needing to measure the substratum/benthic spectra through a water column (optical shallow water case), there is not one specific multispectral band set that will be able to do it all- **strong indication imaging spectrometry will be required**.

On the other hand …..

- By augmenting planned **land sensors spectrally** or **ocean sensors spatially**, cost-effective solutions for observing aquatic ecosystems could be achieved.

Suggestions for improvements appreciated

Arnold Dekker: Honorary Science Fellow - CSIRO, Australia

Director SatDek(*Satellite based Discovery of Environmental Knowledge*
Honorary Professor - Australian National University
Adjunct Professor - University of Queensland
arnoldgdekker@gmail.com Mob: +61 (0) 419411338

And thanks to all who contributed:, **Peter Gege, Nicole Pinnel, Xavier Briottet, Steef W.M. Peters, Sindy Sterkx, Kevin Turpie, Claudia Giardino, Elisabeth Botha, Maycira Costa, Martin Bergeron, Nima Pahlevan, Thomas Heege, Andy Court and Vittorio E. Brando**