What new processes and features can be detected in ports, estuaries and inland waters?

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1. CSIR; 2. UCT; 3. CyanoLakes

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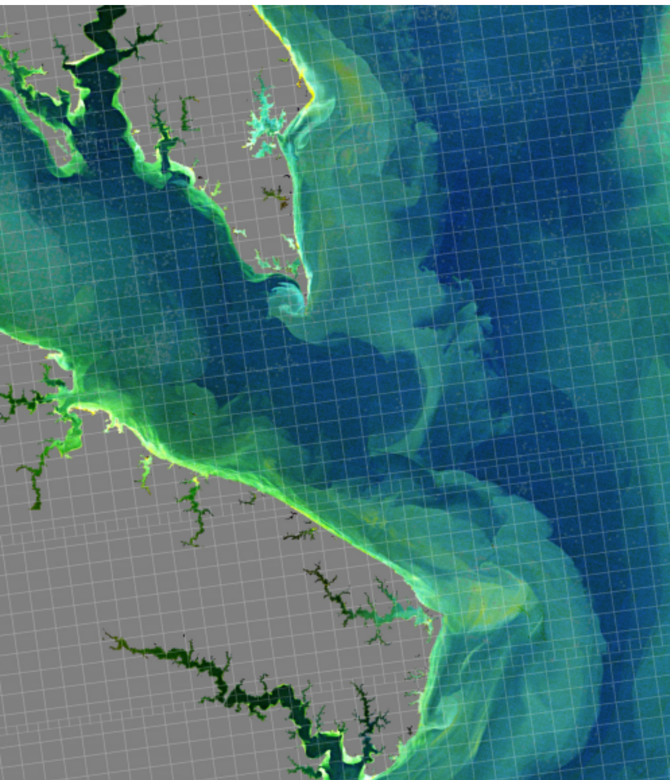
IOCS 2015, San Francisco




Images courtesy: Franz et al 2015, Oberholster (unpublished)

High Resolution Water Colour Sensors: Emerging Opportunities…

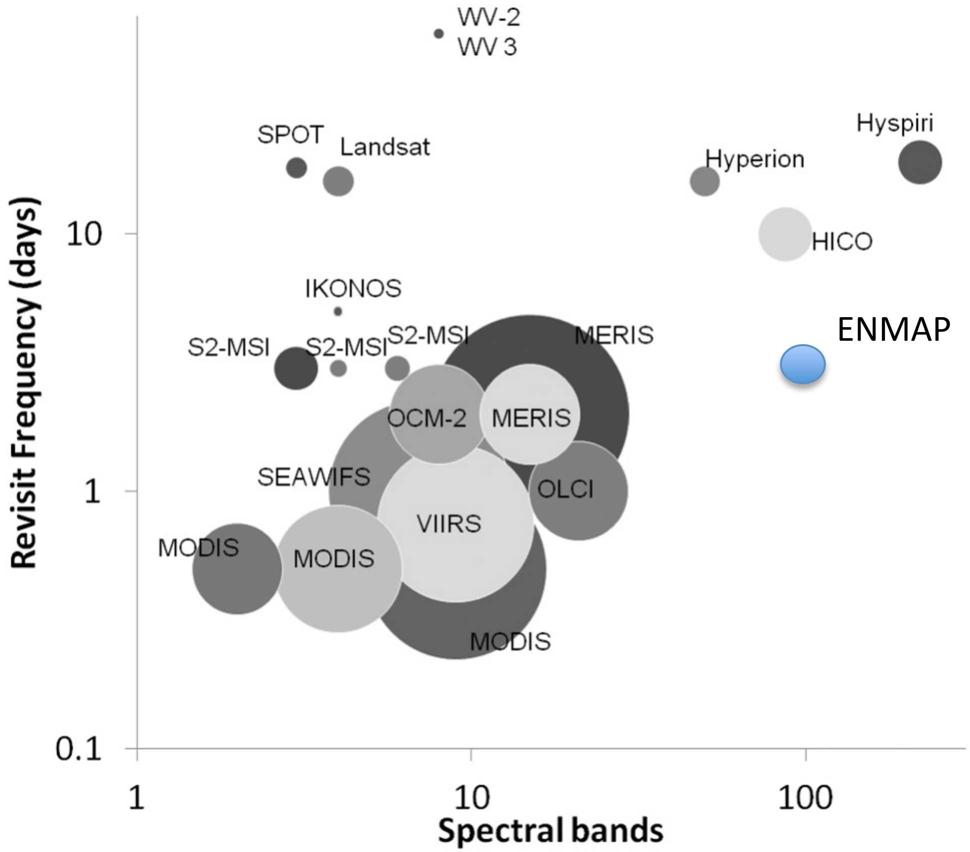


Fig. 5. The spectral (x-axis), temporal (y-axis), and spatial (size of the bubble) characteristics of satellite sensors commonly used for freshwater ecosystem measurements. Note: sensors that provide different spatial resolutions are plotted separately, and sensors with overlapping resolution characteristics are slightly jittered for graphing purposes.

Hestir, E.L., et al., Measuring freshwater aquatic ecosystems: The need for a hyperspectral global mapping satellite mission, Remote Sensing of Environment (2015), http://dx.doi.org/10.1016/j.rse.2015.05.023

High Resolution Sensors: What are the trade offs?

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Spatial and temporal resolution

- High enough temporal resolution for operational/ ecological application (with cloud consideration)?
- What is the highest value spatial resolution trade off?

Radiometric and spectral resolution

- Sufficiently high SNR & dynamic range for water
- Sufficient spectral signal for disambiguation of major constituents

Free & systematic acquisition

Commercial sensors such as WV-3 etc undoubtedly of great value but largest community benefit from Landsat -8 and Sentinel 2 as primary free sensors in next 5 years

Community processor including AC

Very important enabler from both science and community perspective

A Global Set of User Requirements for EO derived Water Quality?

WATER QUALITY INFORMATION	WATER QUALITY VARIABLE
Primary production and eutrophication status	CHL
	CPC
	CPE
	Surface algal blooms
Aquatic carbon content, carbon fluxes	CDOM
Erosion, re-suspension and deposition	TSM (ΣCHL+NAP)
Light climate information related to the combined effects of algae, CDOM and suspended matter	K_d
	Transparency
	Turbidity
Ecological condition	Emergent macrophytes
	Submerged macrophytes

CHL=chlorophyll; CPC=cyano-phycocyanin; CPE=cyano-phycoerythrin, CDOM=coloured dissolved organic matter; TSM-total suspended matter; NAP=non-algal particulate matter; K_d=vertical attenuation of light

Australia

Evaluating the Feasibility of Systematic Inland Water Quality Monitoring with Satellite Remote Sensing
Dekker & Hestir ,CSIRO, 2012

FRESHMON Products:

* Total Suspended Matter (TSM), Turbidity (TUR)
* Secchi Depth (SD), Z90
* Chlorophyll-a (CHL)
* Colored Dissolved organic matter (CDM)
* Organic Absorbers (SOA)
* Water depth (OWD)
* Macrophyte mapping

Europe

FRESHMON: Water Framework Directive downstream services for inland water monitoring

Product	Temporal Scale	Spatial Scale	Confidence
Algal biomass chlorophyll-a for inland and coastal waters	Sub-weekly to multi-annual	<100m	Minimum = gross binary status indicator Ideal = 30% error
Cyanobacteria occurrence for inland waters	Sub-weekly to multi-annual	<100m	Minimum = binary flag identifier for cyano presence
Water clarity (Secchi disk depth & Total Suspended Solids)	Sub-weekly to multi-annual	<100m	Minimum = gross binary status indicator Ideal = 30% error
Invasive macrophyte coverage	Monthly to multi-annual	20 – 100m	Minimum = areal error < 5 pixels^2

South Africa

Summary of key user needs for water quality products, driven primarily by the National Eutrophication Monitoring Programme (NEMP) of the the South African Department of Water Affairs.

Spatial Resolution: Trade Offs from an Inland Perspective

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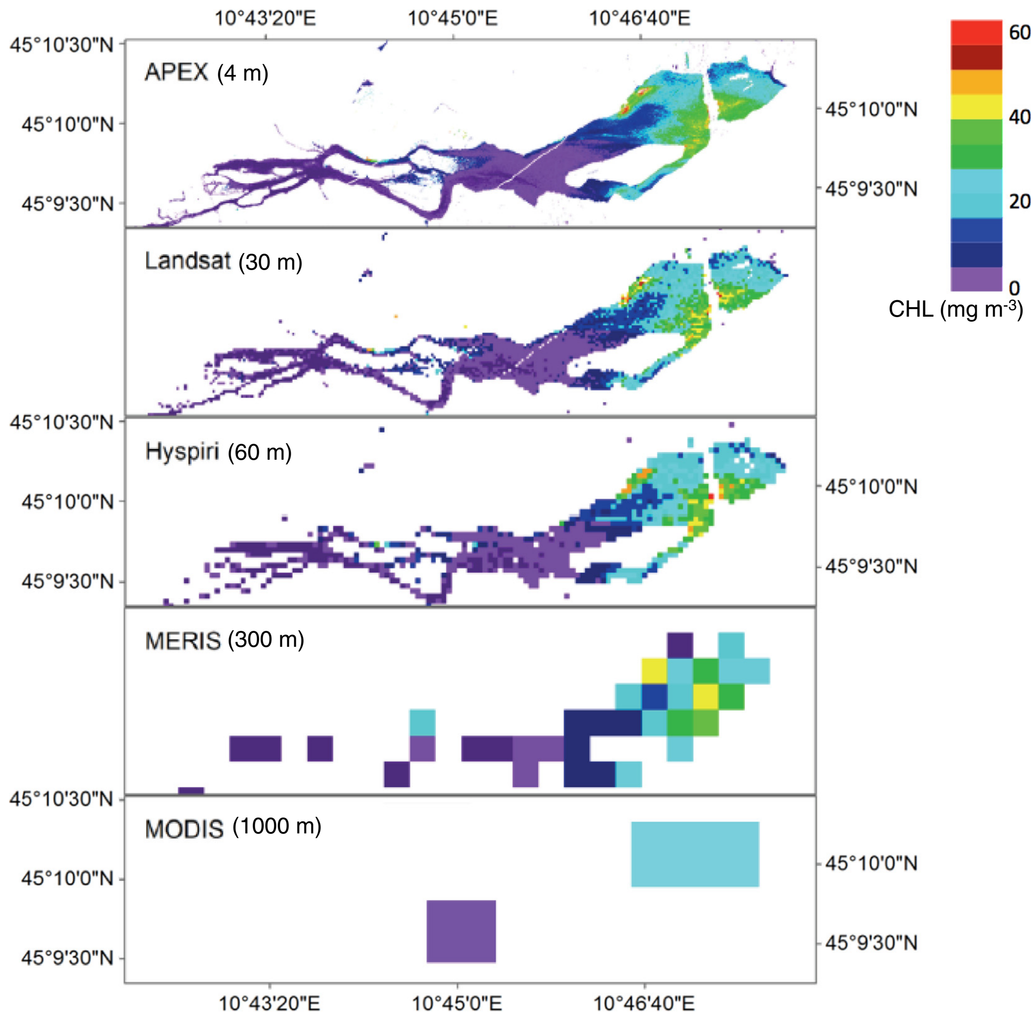

Fig. 9. CHL concentration in Upper Mantua Lake from the APEX airborne imaging spectrometer (top), and re-sampled to different sensor spatial resolutions. Color scale ranges from purple to red for CHL ranging from 0 to 60 mg m^{-3}. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Hestir, E.L., et al., Measuring freshwater aquatic ecosystems: The need for a hyperspectral global mapping satellite mission, Remote Sensing of Environment (2015), http://dx.doi.org/10.1016/j.rse.2015.05.023

Spatial Resolution: Trade Offs from an Inland Perspective

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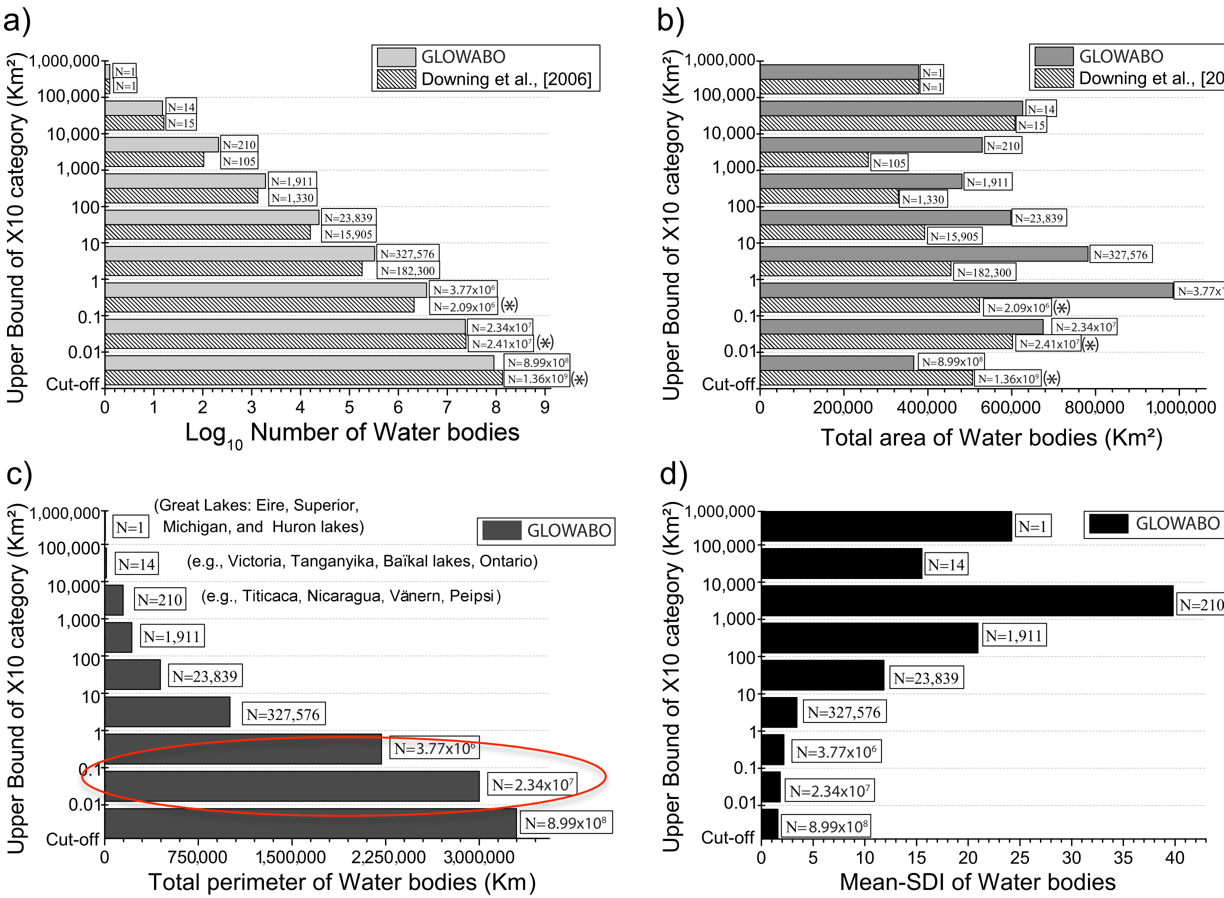


Figure 2. The (a) number, (b) total area, (c) total perimeter, and (d) mean SDI of water bodies of the GLOWABO (excluding the Caspian Sea). Numbers on *y* axis are the lower/upper boundary of decadal size classes. GWEM results are shown with grey bars while dashed bars are number as reported from *Downing et al.* [2006] and used here for comparison (excluding the Caspian Sea). Note that for the smaller-size category that GWEM data are ranged between 0.01 and 0.002 km^2 were recalculated using the statistical extrapolation approach detailed by *Downing et al.* [2006]. Below 10 km^2 (asterisk), data are extrapolated from canonical data set (GLWD, *Lehner and Döll* [2004]) using the power law abundance-size relationship.

117 million lakes > 0.002 km^2 covering 3.7% of Earth's non-glaciated land area.

If our ultimate aim is a global freshwater earth observation system covering as many water bodies as possible there would be approximately:

±27 million lakes > 0.01 km^2, e.g. possibly amenable to sensors at a Sentinel 2/Landsat 8 type ground resolution (20-30 m);

>300,000 lakes > 1 km^2, e.g. possibly amenable to sensors at a Sentinel 3 type ground resolution (300 m);

A global inventory of lakes based on high-resolution satellite imagery (2014). Verpoorter, Kutser, Seekell, and Tranvik

High Resolution Sensors: Need for High Quality Radiometry

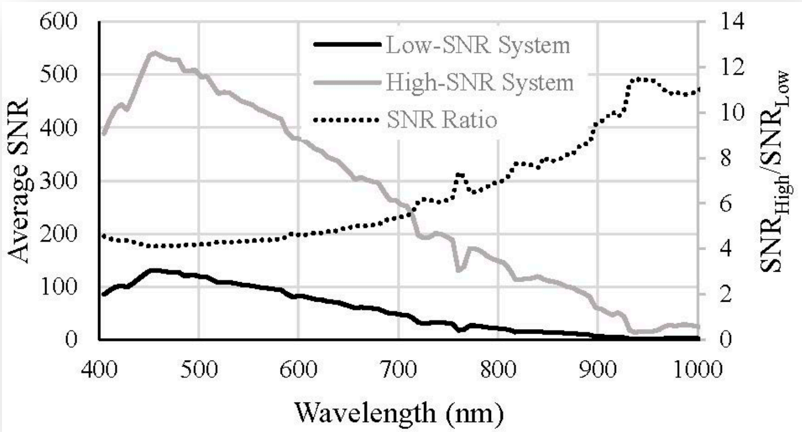


Figure 2. The average SNR calculated from the at-sensor radiances (of all 490 images) for the low- and high-SNR systems. The ratio of the average SNR for the high-SNR system to that for the low-SNR system is plotted on the secondary axis.

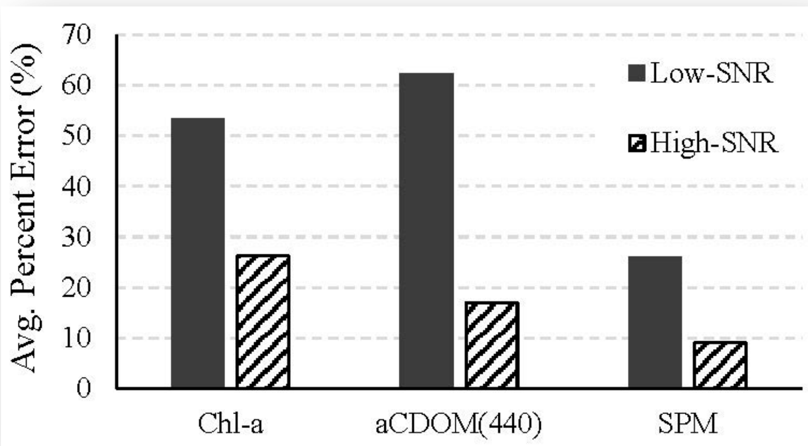


Figure 9. The average percent errors for the low- and high-SNR systems in the concentrations of chl-*a* and SPM and $a_{CDOM}(440)$ retrieved from the 20 atmospherically corrected noisy images using the non-linear least squares error minimization approach

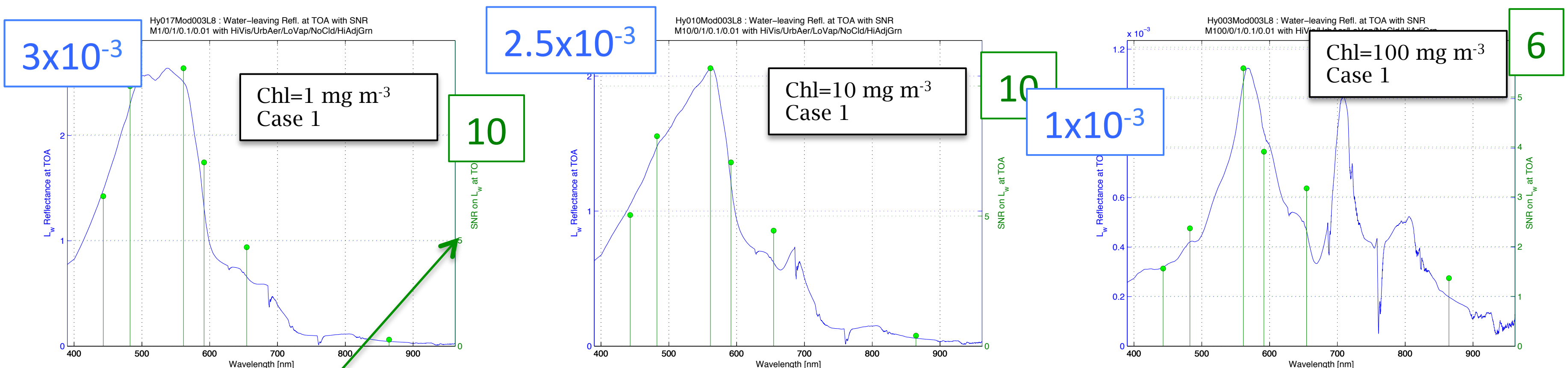
Moses, W.J.; Bowles, J.H.; Corson, M.R. Expected Improvements in the Quantitative Remote Sensing of Optically Complex Waters with the Use of an Optically Fast Hyperspectral Spectrometer—A Modeling Study. Sensors 2015, 15, 6152-6173.

Mission Requirements: Landsat 8 SNR Considerations

Landsat 8 bands are not optimally located but the data are free and it offers a 30 m ground resolution with nominal SNR values of 200 – 350 in the visible….

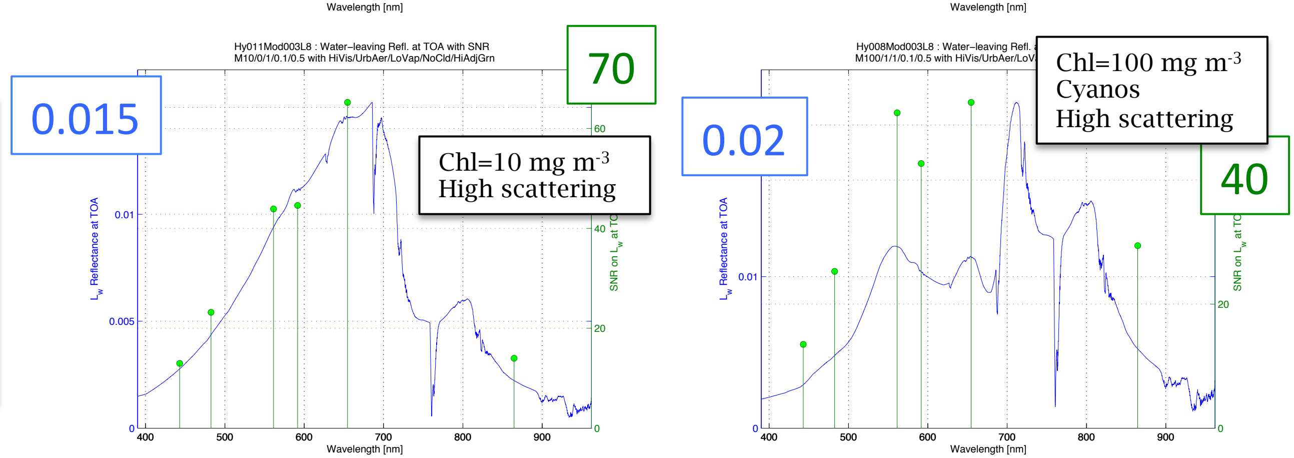
It appears that there may be a need to spatially bin pixels for darker Case 1 type waters where signals approach the NEΔL values….

Band Number	µm	Resolution
1	0.433–0.453	30 m
2	0.450–0.515	30 m
3	0.525–0.600	30 m
4	0.630–0.680	30 m
5	0.845–0.885	30 m
6	1.560–1.660	30 m
7	2.100–2.300	30 m
8	0.500–0.680	15 m
9	1.360–1.390	30 m
10	10.6-11.2	100 m
11	11.5-12.5	100 m



Realised SNR < 5 at most wavelengths for Case 1 type waters

NB: SNR defined here as noise in L_w at TOA rather than more conventional noise in total L_{TOA}



Landsat 8 Application Examples – SeaDAS Approach

Very promising L8 processing chain in SeaDAS with vicarious calibration, dark pixel type AC correction and application of OC3 variant in-water algorithm. Repeat cycle, glint and adjacency flagged as issues to consider…

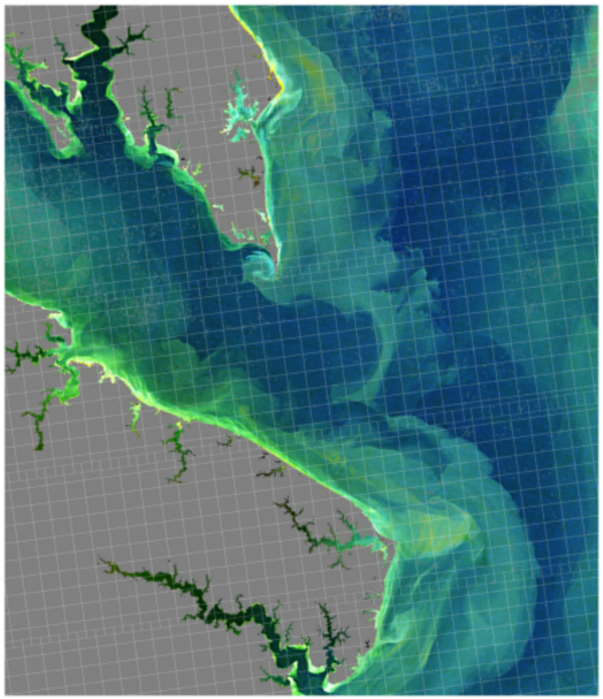


Fig. 5 Three-band water-leaving reflectance composite image from OLI at the location where the Potomac River enters Chesapeake Bay. MODIS Aqua scan pixel boundaries for the same date are overlaid to demonstrate the subpixel variability revealed by the higher spatial resolution of OLI.

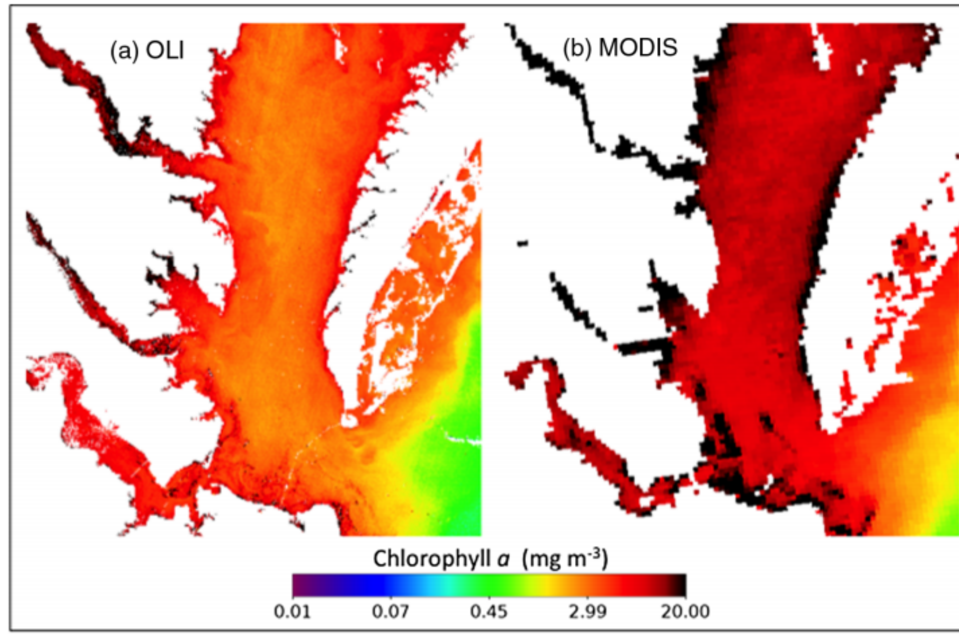


Fig. 3 Images of chlorophyll *a* concentration retrieved from OLI and MODIS Aqua over Chesapeake Bay on September 5, 2013. The MODIS data were collected on the same day, about 3 h later. The chlorophyll *a* concentration was retrieved using standard NASA ocean color processing in SeaDAS.

B.A Franz, S.W. Bailey, N. Kuring, and P.J. Werdell, "Ocean color measurements with the Operational Land Imager on Landsat-8: implementation and evaluation in SeaDAS", Journal of Applied Remote Sensing 9, doi: 10.1117/I.JRS.9.096070 (2015).

Landsat 8 Application Examples – LUT based algorithms

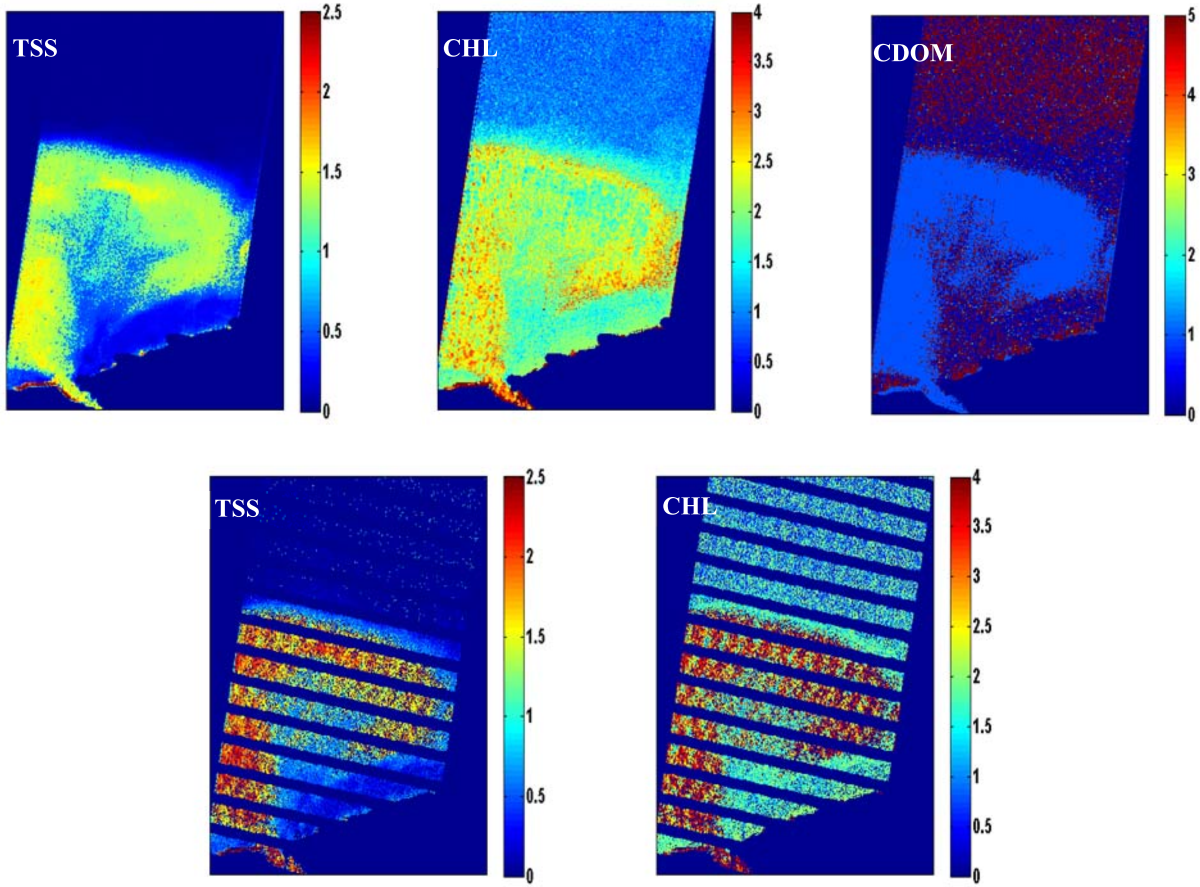


Figure 5. Water constituent maps obtained from the smoothed SR products derived from the simulated OLI (upper row) and L7. The maps from left to right denote TSS, CHL, and CDOM absorption. The low variability of CDOM absorption as well as CHL maps are noticeable.

Nima Pahlevan John R. Schott, Investigating The Potential Of The Operational Land Imager (Oli) For Monitoring Case Ii Waters Using A Look-up-table Approach, Pecora 18-Forty Years of Earth Observation...Understanding a Changing World November 14-17, 2011, Herndon, Virginia

Landsat 8 Application Examples – AC approaches & TSS

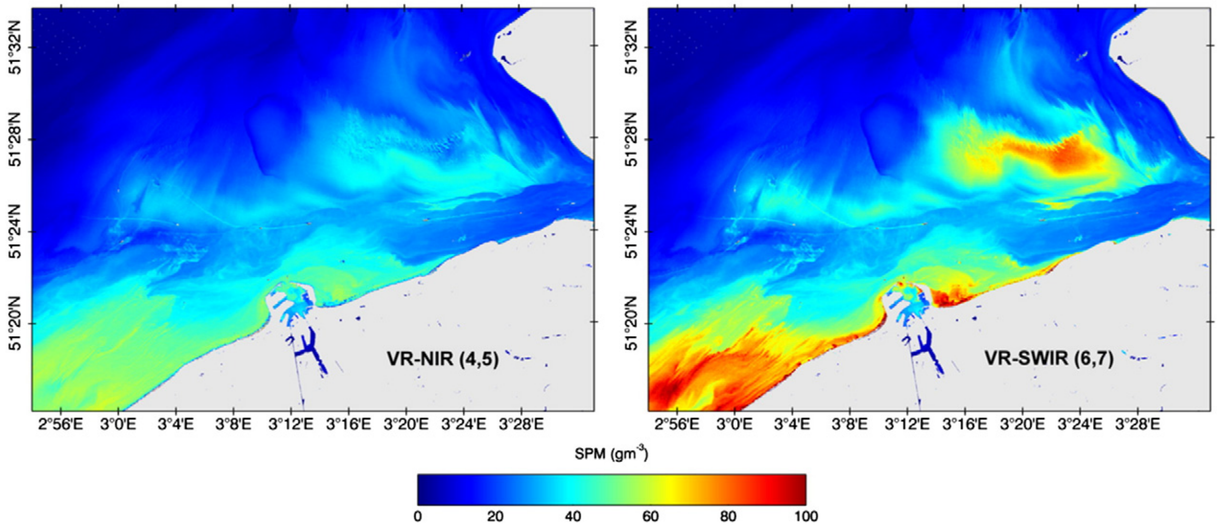


Fig. 3. OLI-derived suspended particulate matter concentration (SPM) over Belgian coastal waters (2014-03-16, scene LC81990242014075LGN00) processed using the VR-NIR 4,5 (left) and VR-SWIR 6,7 (right) methods.

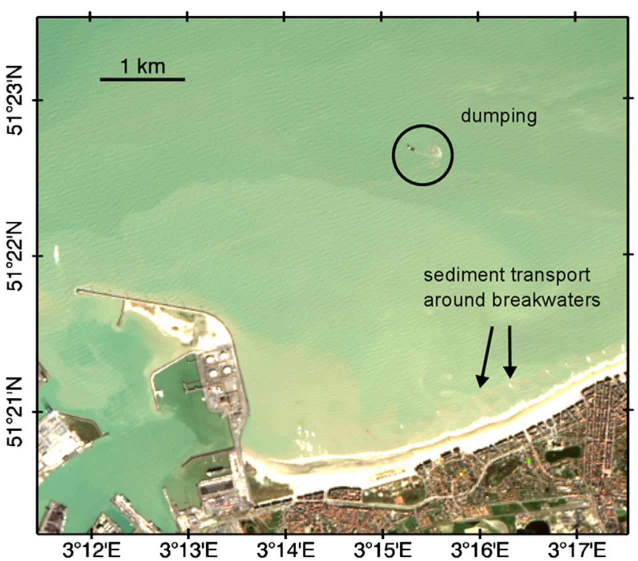


Fig. 2. Crop of Fig. 1 showing the dumping of dredged material at a designated site. Surface gravity waves can be seen at this resolution.

Q. Vanhellemont, K. Ruddick,
Remote Sensing of Environment
161 (2015) 89–106

Landsat 8 Application Examples – Cyanobacterial Detection

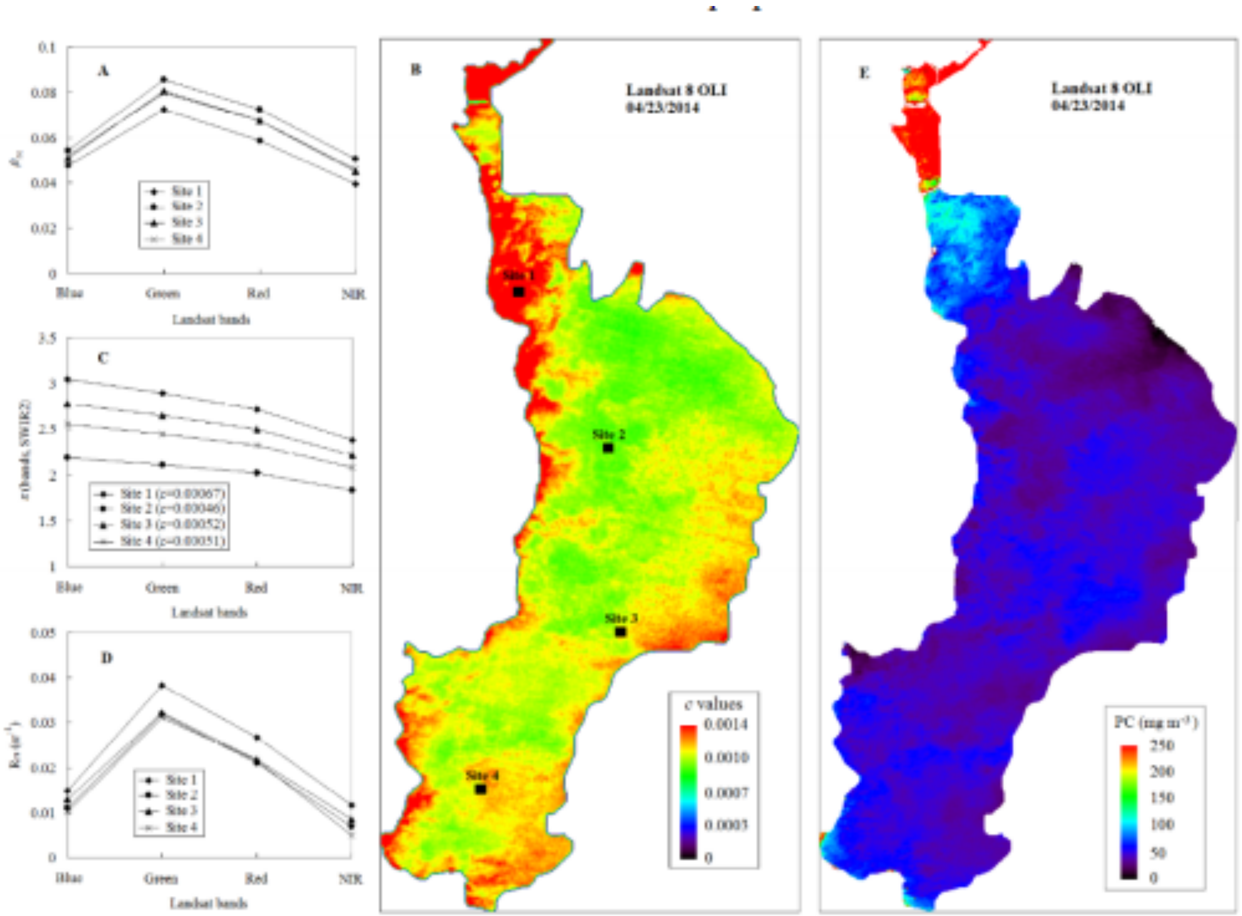


Fig. 8. Atmosphere and water properties derived from Landsat 8 OLI data collected on 23 April 2014.

Deyong Sun, Chuanmin Hu, Zhongfeng Qiu, and Kun Shi, "Estimating phycocyanin pigment concentration in productive inland waters using Landsat measurements: A case study in Lake Dianchi," Opt. Express 23, 3055-3074 (2015)

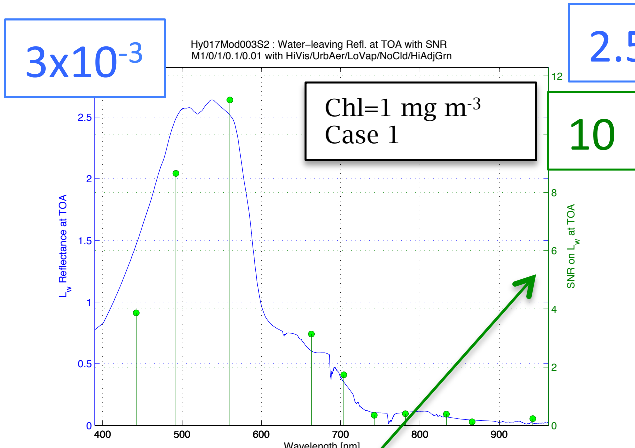
Mission Requirements: Sentinel 2/MSI SNR Considerations

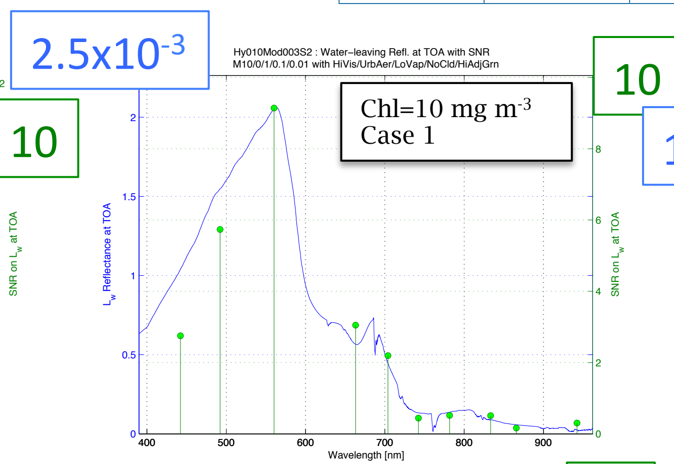
Sentinel 2 offers well placed bands and innovative spatial resolution (10 – 60m), but there are concerns about the radiometric sensitivity with nominal SNR values of ± 90 – 170 at native resolution…

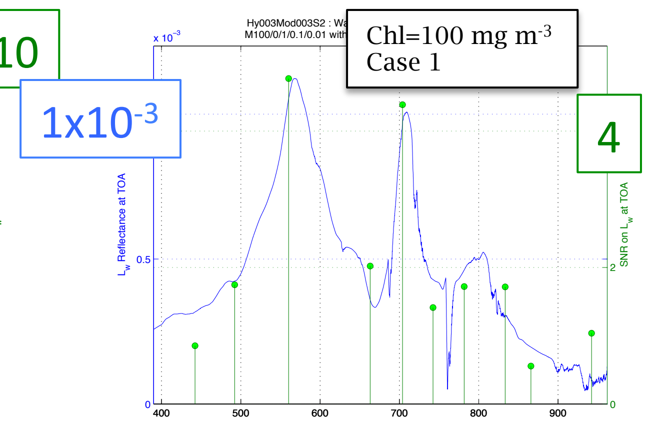
It appears that there will be a need to spatially bin pixels for darker Case 1 type waters where signals approach the NEΔL values….

Table 6.1. Spectral bands and signal-to-noise ratio requirements for the Sentinel-2 mission.

Band number	Central wavelength (nm)	Bandwidth (nm)	Spatial resolution (m)	L_{ref} ($W\,m^{-2}\,sr^{-1}\,\mu m^{-1}$)	SNR @ L_{ref}
1	443	20	60	129	129
2	490	65	10	128	154
3	560	35	10	128	168
4	665	30	10	108	142
5	705	15	20	74.5	117
6	740	15	20	68	89
7	783	20	20	67	105
8	842	115	10	103	174
8b	865	20	20	52.5	72
9	945	20	60	9	114
10	1380	30	60	6	50
11	1610	90	20	4	100
12	2190	180	20	1.5	100

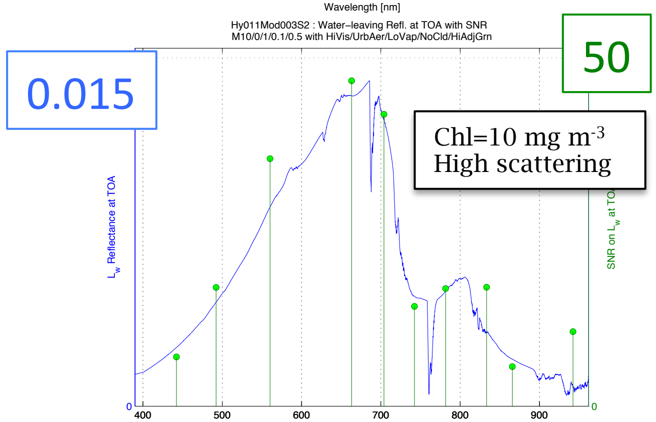


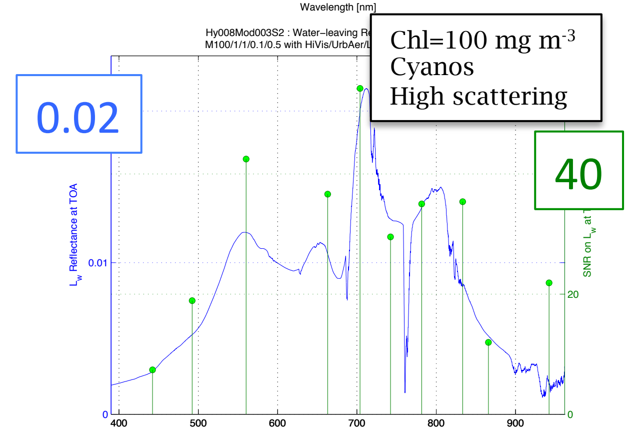




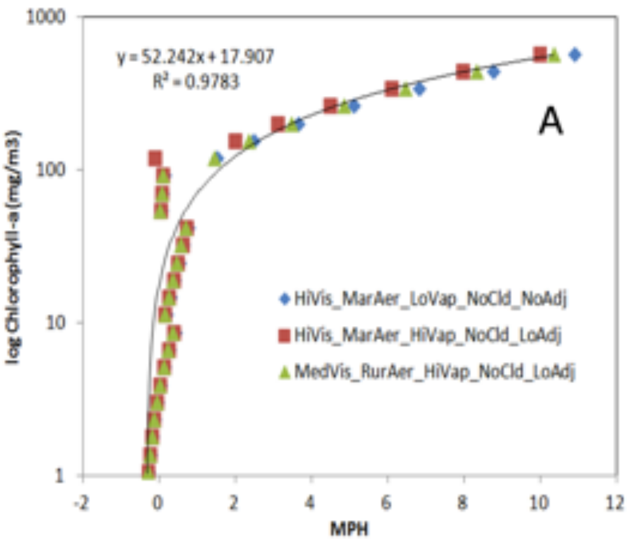
Realised SNR < 5 at most wavelengths for Case 1 type waters

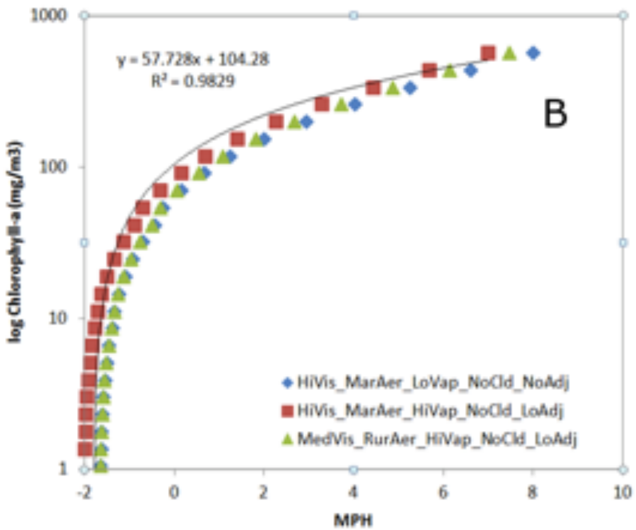
NB: SNR defined here as noise in L_w at TOA rather than more conventional noise in total L_{TOA}

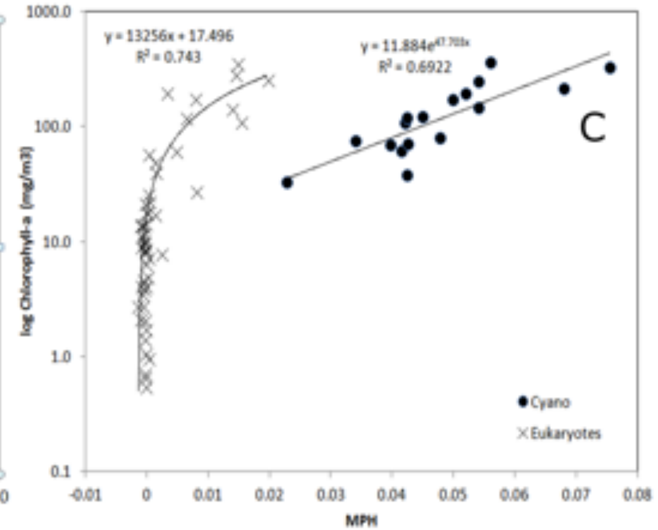




Simulated first order performance example Maximum Peak Height algorithm for Sentinel 2 & 3







Preliminary performance of MPH algorithm for OLCI bands from modelled TOA – as expected looks good for Case 1 waters & highlights overly simplistic modelling….

Preliminary performance of MPH algorithm for MSI bands (665, 705, 865 nm) from modelled TOA. Looks very promising and width of 665 nm band appears not to be an issue…

Preliminary performance of MPH algorithm for MSI bands (665, 705, 865 nm) from MERIS averaging. Looks very promising, will need dynamic scaling flags in absence of 620 nm band

Worldview 2 Example – The Possibilities of Commercial Sensors

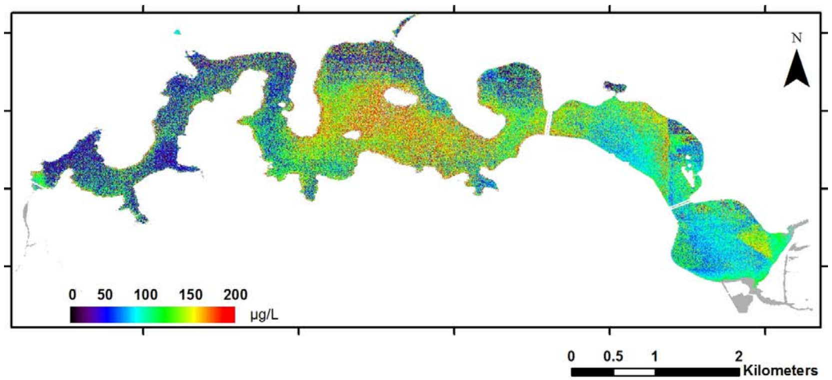


Figure 4-21 Chlorophyll concentration in Lake Burley Griffin from a Worldview-2 image 17 March 2010

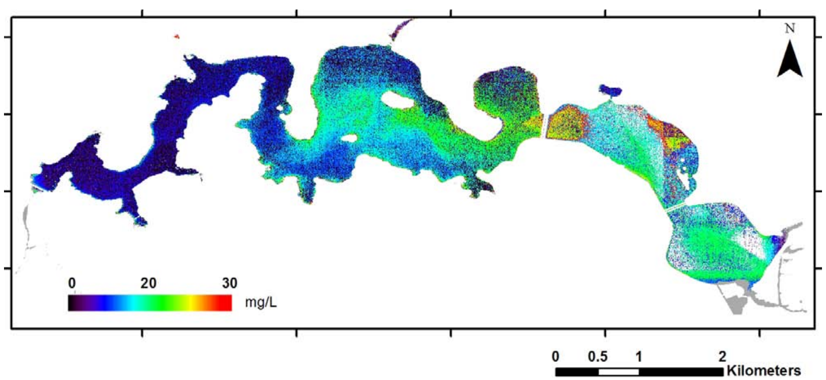


Figure 4-22 Non-algal particulate concentration in Lake Burley Griffin from a Worldview-2 image 17 March 2010

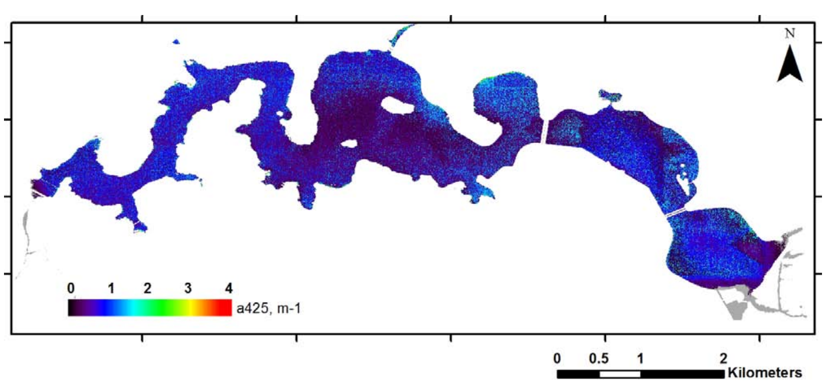


Figure 4-23 Coloured dissolved organic matter in Lake Burley Griffin from a Worldview-2 image 17 March 2010

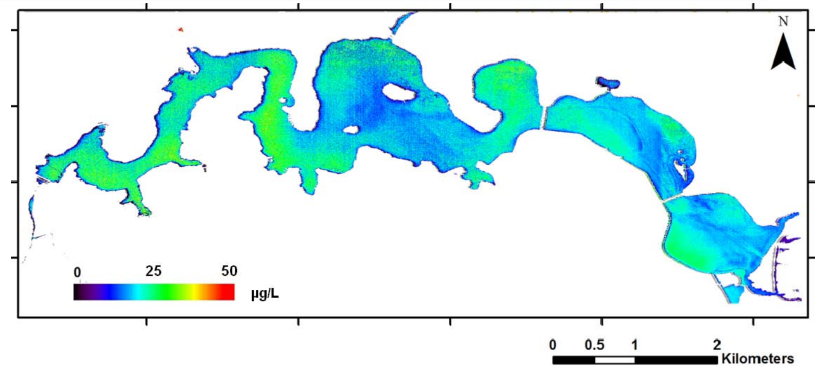


Figure 4-24 cyano-phycocyanin concentration in Lake Burley Griffin from a Worldview-2 image 17 March 2010

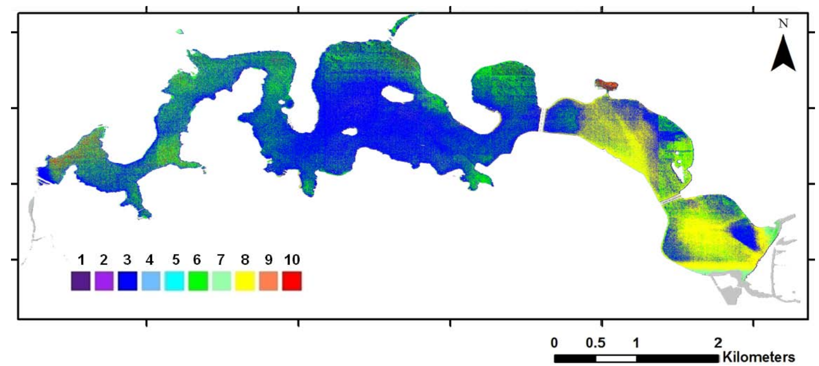
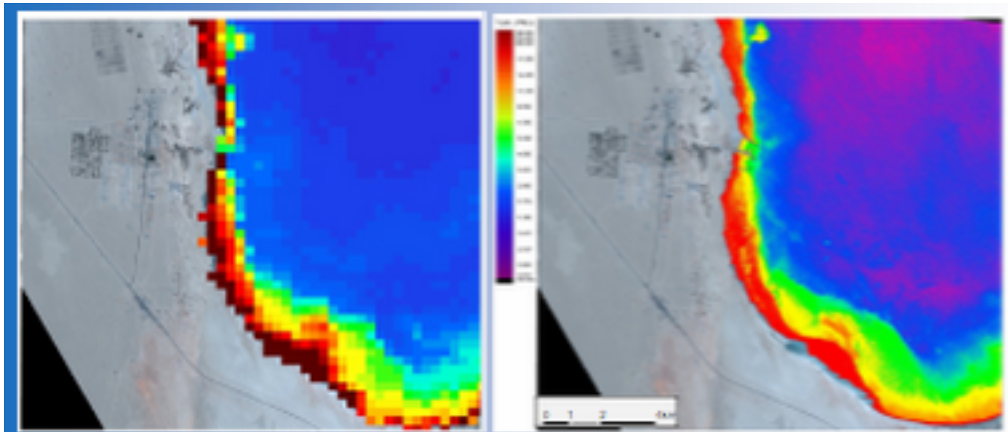


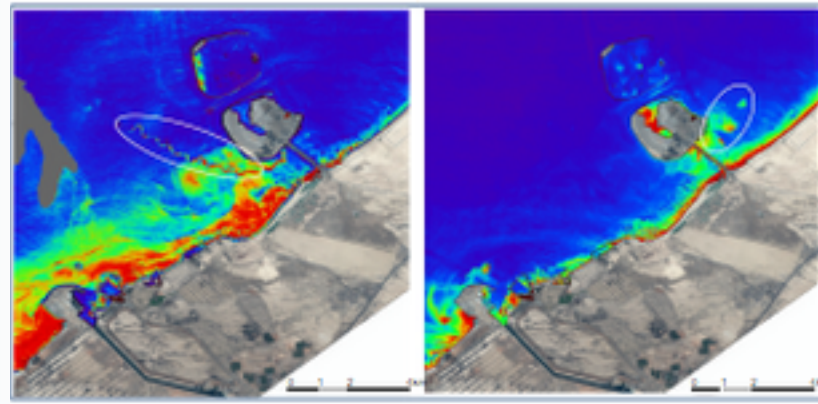
Figure 4-25 Water types (1-10) in Lake Burley Griffin from a Worldview-2 image 17 March 2010

Dekker, A.G. & Hestir, E. L. 2012. Evaluating the Feasibility of Systematic Inland Water Quality Monitoring with Satellite Remote Sensing, CSIRO: Water for a Healthy Country National Research Flagship

Pleiades Example – The Possibilities of Commercial Sensors

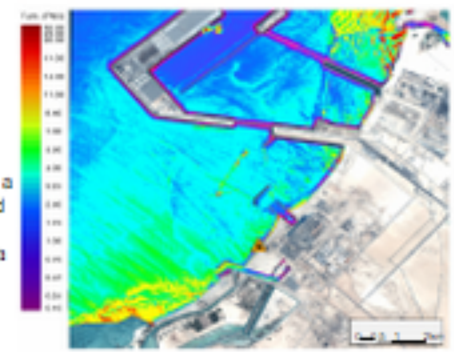


Turbidity maps from MERIS FR and Pléiades (calibrated).
Left: Turbidity map of the MERIS image (05/03/2012) superimposed on the True Color land from the Pléiades image dated 06/03/2012. The spatial resolution of the MERIS Turbidity map is 300m.
Right: Turbidity map at 2m resolution, obtained applying the calibrated "mean" algorithm on the Pléiades image dated 06/03/2012, superimposed on True Color land from the same image



Zoom of VHR TSM maps near Abu Dhabi. VHR resolution maps allows to see much more particular in the proximity of the coast.
Left: Particular of the TSM map from a Pléiades scene acquired the 14/11/2012.
Right: Particular of the TSM map from a Pléiades scene acquired the 07/02/2013.

VHR Turbidity map near a Desalination Plant.
Particular of the Turbidity from a Pléiades images (2m) acquired the 07/02/2013, near the desalination plant of AlTaweela (yellow triangle).



Turbidity from Pléiades in the coasts of United Arab Emirates

Giulio Ceriola (2), Dimitrios Sykas (1), Stelios Bollanos (1), Gordon Campbell (3)

- Planetek Hellas ebe, (Greece) (bollanos@planetek.it)
- Planetek Italia S.r.l, Bari (Italy)
- European Space Agency – ESA

What new processes and features can be detected in ports, estuaries and inland waters?

Summary:

- Landsat 8 offers high quality radiometry at 30 m resolution, community processing tools, and demonstration of validated products for Chl a, TSS, CDOM and cyanobacteria. Revisit time may present problems for operational/ecological applications, and limited spectral resolution may hamper constituent disambiguation across wide ranges of water types.

- Sentinel 2 will offer good spectral coverage, and 5 day revisit time in full constellation but is likely to require spatial binning to 60m to offer sufficient SNR for aquatic applications. Range of products such as Chl a, TSS, CDOM and cyanobacteria across wide range of water types should be feasible with appropriate AC, SNR etc evaluation. Community processing tools required.

- Emerging AC tools such as SeaDAS modules and ACOLITE are vital components and Sentinel 2 options need to be demonstrated….

- Demonstrated ability to exploit commercial sensors such as WV-2 & 3, Pleiades, RapidEye but likely to be exploited on specific case basis….