DATA [SATELLITE]

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Synopsis

Global monitoring services require reliable, systematically acquired, calibrated, global data sources and processing systems…

Taking a holistic approach to DATA would include at least the following elements:

requirements and specifications of satellite data, collection, delivery, processing, archiving, standards, quality, midstream products, downstream products.

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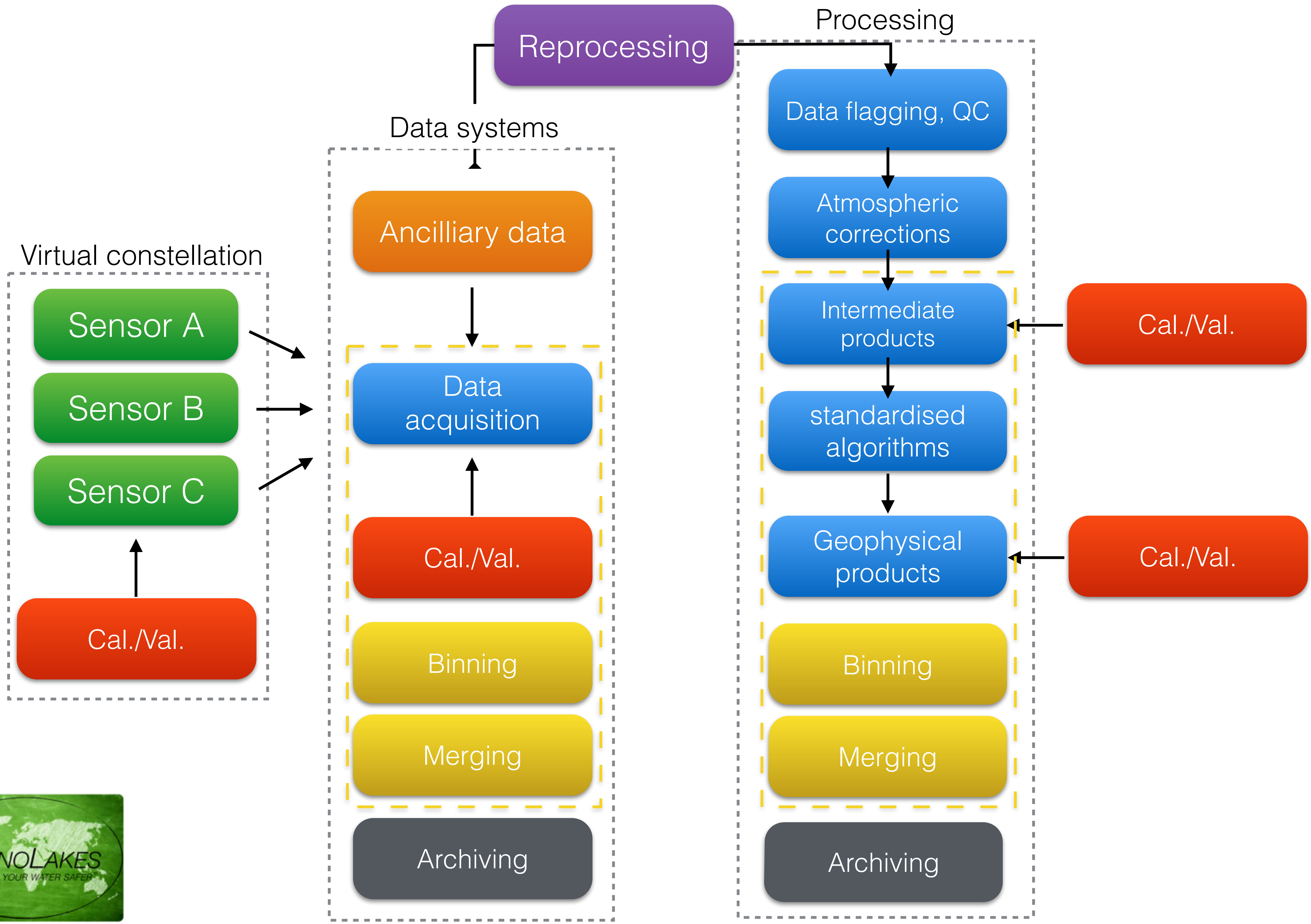
Key system components of a global water quality monitoring service



Key Questions

- Can requirements of Ocean-Colour missions meet inland and near-coastal minimum requirements?
- How divergent/synergistic are inland versus OC requirements?
- Can *vegetation* missions meet inland and near-coastal *minimum requirements*?
- What do we mean by ‘global’?

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Data sources

Key requirements for satellite data sources meeting a global water quality monitoring service:

- Meets ***minimum* requirements** in term spectral, radiometric resolution satisfactory for product generation
- **Coverage** - systematic global (land+coastal oceans)
- **Frequency** - enough to resolve weekly-scale changes in dynamic lentic systems (2/3 day minimum)
- **Timeliness** - data delivery in near real-time (min. 12 hour timeliness, goal 3 hours) to meet demanding apps.
- **Accessibility** - readily accessible, public license (free)
- **Calibration** (absolute, on-board, lunar, vicarious) linked to data quality standards
- **Validation** of derivative products to meet data quality standards
- **Standardisation of data/product formats** to facilitate data merging
- **Standardisation of data binning** procedures (L3 product generation)
- **Multiple sensors/missions needed** for frequent global coverage (constellations) - 3 satellites can provide 60% ocean coverage in four days (IOCCG, 2007).
- **Science traceability** matrix method linking problems to products to data sources (IOCCG, 2012)

Possible game changers: Sentinel-2, PACE, Geostationary, VHR Constellations

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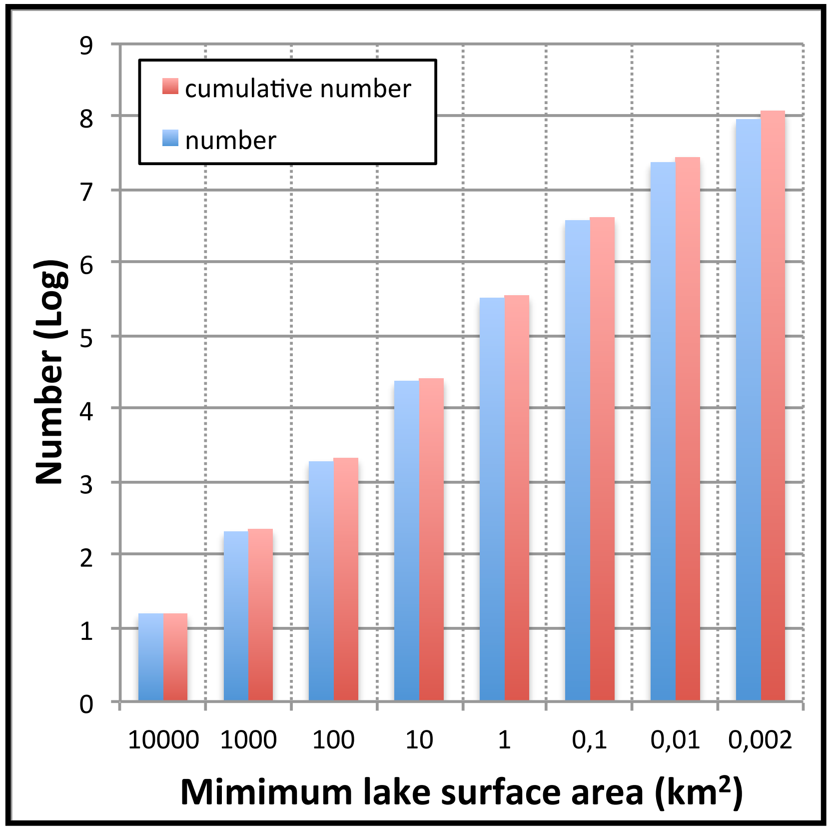
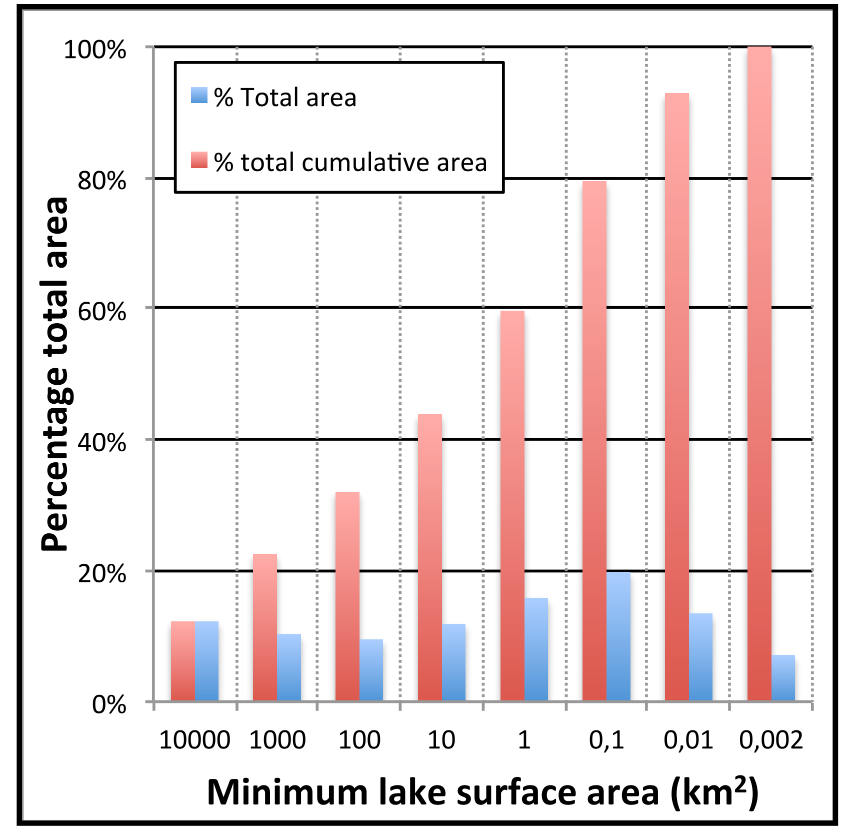
Potential data sources

Sensor	Agency	Satellite	Availability	Swath	GSD	Bands	No.
Future/current OC							
OLCI	***ESA***	***Sentinel-3***	***Oct 2015***	***1270 km***	***300 m***	***21***	***3***
MODIS	NASA	Aqua/Terra	1999-current	2330 km	250 m	2	2
VIIRS	NOAA	NPP	2011-current	3000 km	370 m	5	2+
MERSI	CMA	FY-3	2008-current	2900 km	250 m	4	3+
SGLI	JAXA	GCOM-C		1150 km	250 m	11	
Retrospective							
MERIS	ESA	Envisat	2002-2012	1150 km	300 m	15	1
Hyperspectral/Supplementary							
HICO	NASA	Intl. Space.	2009-2014	50 km	**100 m**	124	1
HSI	DLR	EnMap	2017+	30 km	30 m	242	
VSWIR	NASA	HyspIRI	2020+	145 km	60 m	200	
HRV sensors							
TM,ALI	NASA	Landsat	1970 +	185 km	30 m	4	4+
MSI	***ESA***	***Sentinel-2***	***2015+***	***290 km***	***60 m***	***13***	***2***
MSI	DLR	RapidEye	2009	78 km	6.5 m	5	5
Cubesats	**PlanetLabs**	**Dove**	**2015+**	**Global daily**	**5 m+**	**3**	**flock**
Geostationary							
GOCI-II	KARI	GeoKompsat	2019		250 m	13	
	NASA	***GEO-CAPE***	***>2022***		***250 m***	***155***	

Spatial resolution requirements





Lake size	Required GSD*	% Total Area	Total Number
≥ 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**
≥ 0.002 km^2	15 m	100	**117,423,552**

- GSD less than 30 m likely too high
- GSD of 100 m likely sufficient for 80% surface area of world lakes
- Sheer number of lakes means GSD < 100 m prohibitive without pre-selection criterion (but desirable for regional implementations)
- Rivers currently excluded.

Data from Verpoorter at al. (2014) * calculated for a box of nine pixels

Verpoorter, C., Kutser, T., Seekell, D. a., & Tranvik, L. J. (2014). A Global Inventory of Lakes Based on High-Resolution Satellite Imagery. Geophysical Research Letters.

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Generalised sensor product/specifications matrix

Sensor	HRV (Land/Veg)	Multi (OC)	Hyper (Exp.)
Water Quality Indicators	Turbidity	Turbidity	Turbidity
	Z_{sd}	Z_{sd}	Z_{sd}
	TSM	TSM	TSM
	a_{CDOM}	a_{CDOM}	a_{CDOM}
	Chlorophyll-a	Chlorophyll-a	Chlorophyll-a
	Cyanobacteria	Cyanobacteria	Cyanobacteria
	Accessory pigments	Accessory pigments	Accessory pigments
	Type diagnostics	Type diagnostics	Type diagnostics
GSD	High (< 30 m)	Low (> 250 m)	Med (30-100 m)
Revisit	Low	High	Low
Swath	Medium	Wide	Narrow
Data volume	High	Med	Highest
Sensor cost	Low	Med	Highest
Constellation size	5	3	10
SNR	Often Low	Highest	Medium
Calibration	Often poor	Mostly sufficient	Often uncharacterised
Timeliness	Often poor	Mostly sufficient	Order
Access	Various	Mostly available	Various
Coverage	Land	Land & Oceans	Targetted

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Prognosis

High Resolution Visible sensors aimed at vegetation/land cover
Products and quality sub-optimal, GSD meets or likely *exceeds* requirements, high data volumes, many sensors required, land coverage, *poor timeliness*, variable availability. Binning data to improve SNR.
Multispectral sensors aimed at ocean colour applications
Allows most products to be derived with good quality, GSD on threshold or unsatisfied, global coverage, open data access, meets timeliness.
Hyperspectral Experimental Sensors
Enables goal products but quality not assured, GSD potentially optimal, data volume prohibitive, coverage limited - many sensors needed.

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First guess at *minimum* requirements

Requirement	Goal Spec.	Threshold. Spec.	Sensors
Spectral bands	21+ VNIR	15 VNIR	OLCI, Hyper
GSD	100 m	300 m	OLCI, HICO
Revisit (in constellation)	2/3 days	4/5 days	OLCI, Sentinel-2
Coverage	Land & Coastal Seas	Land	OLCI
Timeliness	3 hour	12 hour	OLCI

Can minimum requirements be met using virtual constellation of current sensors?

Likely YES, with concerted co-ordination activities.

Product generation

Requirements for generally accepted, standardised, globally calibrated and validated product generation:

- the need for an adequate, generally accepted approach to deal with the **atmosphere** (e.g., adoption of generally accepted atmospheric correction for complex waters)
- Identification and use of **intermediate products**, e.g. bottom-of-Rayleigh.
- **Algorithms** which are standardised, globally applicable, quantitative, validated, globally/regionally calibrated, proven, reliable, accepted.
- **Data merging** to take advantage of diverse data sources
- Strategy for **reprocessing** - i.e. L0 archives and product processing chains.
- **Data binning** L3 product generation (e.g. weekly/monthly composites etc.)

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Algorithms

"The time is right for an internationally coordinated effort to develop a global inland water quality product, as inland water quality algorithms are maturing." Malthus et al. (2012)

- Where are we when it comes to generalised, globally applicable and accepted algorithms? *Making some progress but lots of work still to be done…*

- *What are the 'low hanging fruit'?*

"Given these considerations, coordinated development for global algorithm application should be focused on ***MERIS/OLCI*** *initially." Malthus et al. (2012)*

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Malthus, T. J., Hestir, E. L., Dekker, A. G., & Brando, V. E. (2012). The case for a global inland water quality product. In IEEE International Geoscience and Remote Sensing Symposium, 2012 (pp. 5234–5237).

Current cal./val. initiatives

- Some publications moving towards this direction (e.g., Dogliotti et al. for TSM)
- **ESA Diversity II** ATBD (Brockmann Consult) - assessment of algorithms, and validation with matchups using an in situ dataset collected from water quality monitoring programmes from 50 lakes across the globe.
- **NERC Globolakes** (U. Stirling, Andrew Tyler) - ongoing - algorithm inter-comparison exercise and validation.
- Globolakes **Limnades** in situ database for inland waters - includes optical and geophysical data.
- Ocean Colour bio-optical databases could supplement these, e.g., MERMAID, etc.

State-of-the-art / candidate algorithms for standardisation

Name	WQ Variable	Method	Input	Quantitative	Validated scope	Error (%)	Compatibility	Availability	Ref
Single-band Semi-analytical	TURB	semi-analytical	Rrs	YES	Regional	12%-22%	All	No	Dogliotti et al. 2015
C2R/CC	TURB	NN	Rrs/TOAR	Yes	Global		MERIS	BEAM	(Doerffer and Schiller, 2008;
Secchi 4-band	zsd	(B3 - B10)/(B6-B10)	Rrs	YES	Local		MERIS	No	Haermae et al., 2001
C2R/CC	Kd, z90	NN	Rrs/TOAR	Yes	Global		MERIS	BEAM	(Doerffer and Schiller, 2008; Doerffer et al, 2012)
Single-band Semi-analytical	TSM	semi-analytical	Rrs	YES	Regional	12%-22%	All	No	Dogliotti et al. 2015
3-band TSM	TSM			YES	Regional		MERIS, Hyper		(Koponen et al., 2007)
Maximum Peak Heigh (MPH)	Chl	Empirical, switching	BRR or TOAR	YES	Global	30%-50%	MERIS, Hyper	BEAM	Matthews et al. (2012)
FUB	Chl	NN	TOAR	YES	Global		Various		Schroeder et al. 2007
FUB	acdom	NN	TOAR	YES	Global		Various		Schroeder et al. 2007
Decoding index	acdom	empirical	Rrs	YES	Regional		Multi/hyper	No	Gitelson et al. (1993)
Maximum Peak Heigh (MPH)	Cyano	spectral index	BRR or TOAR	NO	Global		Multi, Hyper	BEAM	Matthews & Odermatt (2015)
PC SA	PC	semi-analytical	Rrs	YES	Regional		Hyper, Multi	No	Simis et al. 2007
CI-multi	Cells	empirical	BRR	YES	Regional		Multi	No	Lunetta et al. 2014
SLH, AMI	Type	spectral index	TOAR, Rrs	NO	Local		Hyper	No	Kudela et al., 2015
Optical water type classif.	Type	fuzzy	Rrs	NO	-		MERIS	BEAM	Moore et al. (2014)

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State-of-the-art / candidate algorithms for standardisation

Name	WQ Variable	Method	Input	Quantitative	Validated scope	Error (%)	Compatibility	Availability	Ref
(advanced) Linear Matrix Inversion (a-LMI)	chl, tsm, cdom	linear matrix inversion	BOAR	YES	Regional	unquantified	Rrs	No	Giardino et al. (2007), Brando et al. (2012)
Modular inversion Processor (MIP)	chl, tsm, cdom	Downhill Simplex non-linear optimization	BOAR	YES	?	unquantified	Rrs	No	Heege & Fischer (2004), Odermatt et al. (2008)
Hydropt	chl, tsm, cdom	Levenberg Marquardt non-linear optimization	BOAR	YES	Regional	unquantified	Rrs	No	Van Der Woerd et al. (2008)
Great Lakes Regional algorithm	chl, tsm, cdom	Levenberg Marquardt non-linear optimization	BOAR	YES	Regional	unquantified	Rrs	No	Shuchman et al. (2006), (Pozdnyakov et al. 2005)

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Co-ordination (WQ virtual constellation)

"a set of ***space*** *and* ***ground segment*** *capabilities operating together in a coordinated manner, in effect a virtual system that overlaps in coverage in order to meet a combined and* ***common*** *set of Earth Observation* ***requirements****."*

- Need for a Water Quality Virtual Constellation, á la CEOS OCR-VC, which brings together diverse data sources and missions towards one onjective

- **Space segments,** i.e., sensors, need to be short listed, or commissioned, which meet the *minimum* requirements

- **Ground segments** - data processing systems and intermediate product generation schemes should be co-ordinated and *standardised* as far as possible

- **Combined and common set of requirements -** these need to be clearly defined and include global coverage, spatial resolution, frequency, latency etc.

- **Can we piggy back on OCR-VC and INSITU-OCR activities?**

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Challenges (items for discussion)

- **How do we co-ordinate acquisition and processing of diverse data sources?**
  - Task: Establish WQ virtual constellation to identify suitable data sources and develop a strategy to acquire, process and archive these data.
- **How do we implement global data processing, production and archiving?**
  - Task: identify suitable data processing hubs and funding models.
- **How do we identify and perform global calibration and validation of quantitative standardised algorithms?**
  - Task: motion for an “inland water quality algorithm standardisation and global calibration” exercise.
- **How do we deal with the atmosphere?**
  - Task: Identify and adopt a generally accepted atmospheric correction technique and/or intermediate products.
- **How do we develop a strategy for merging and binning complimentary data from various sources?**
  - Task: Define requirements and strategy for merged/binned products.
- **How do we ensure future satellite missions meet the minimum requirements for water quality in inland / near coastal waters?**
  - Task: Identify requirements for meeting the needs of inland waters $>1km^2$ and $<1km^2$.

Reference docs

IOCCG,1998. Minimum requirements for an operational ocean-colour sensor for the open ocean. Report No. 1.

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IOCCG. 2007. Ocean-Colour Data Merging. Report No. 6.

IOCCG. 2012. Mission Requirements for Future Ocean-Colour Sensors. Report No. 13.

Dekker, A. G., & Hestir, E. L. (2012). Evaluating the Feasibility of Systematic Inland Water Quality Monitoring with Satellite Remote Sensing, CSIRO.