IOCS 2019
BREAK OUT WORKSHOP 3

HIGH-SPATIAL RESOLUTION CAPABILITIES

- ARNOLD DEKKER, MARIA TZORTZIOU, NIMA PAHLEVAN, JOE ORTIZ, CHUANMIN HU, ZHONG-PING LEE, ERIC HOCHBERG

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HIGH-SPATIAL RESOLUTION CAPABILITIES

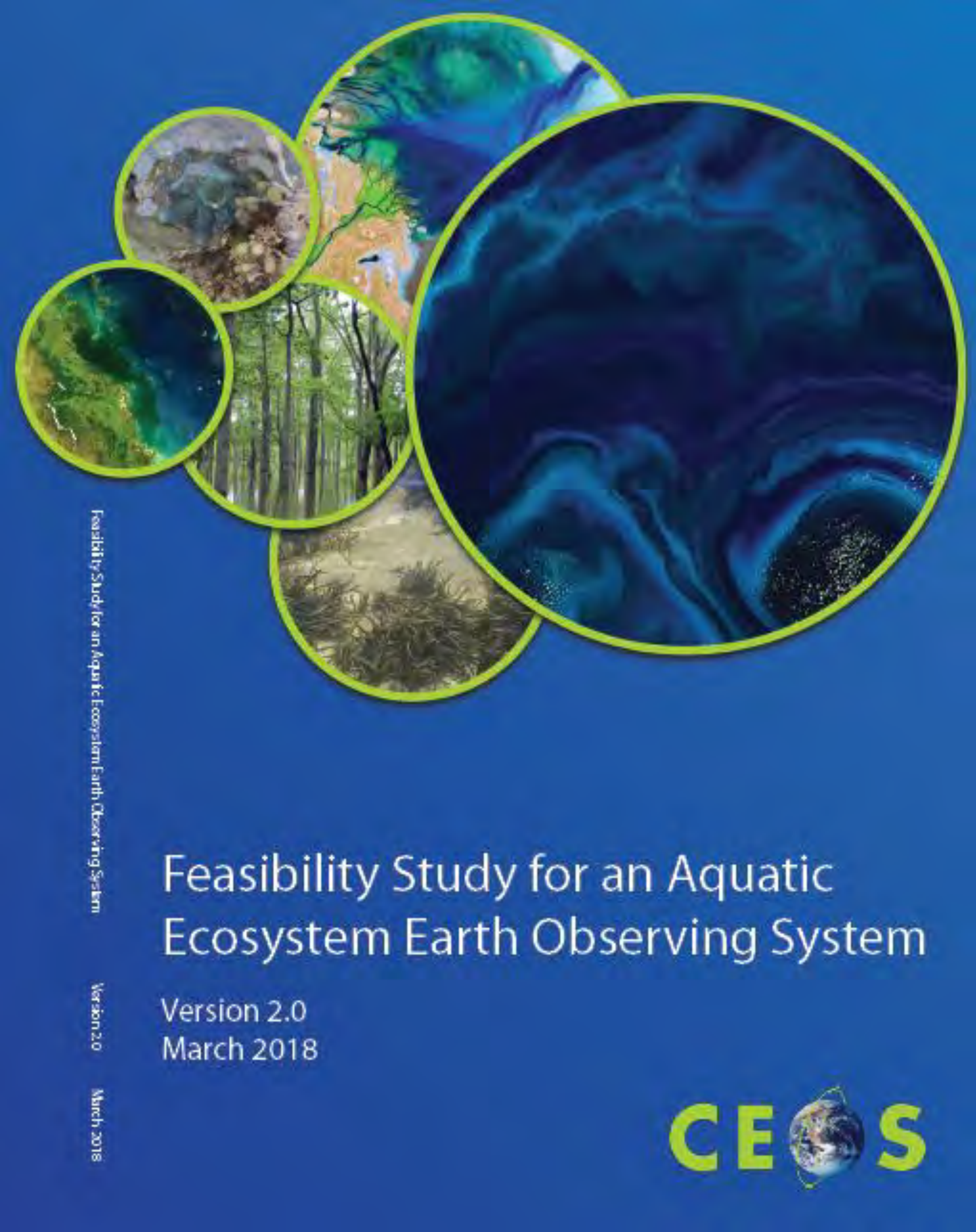
DO WE HAVE (NEED?) A CONSISTENT DEFINITION OF LOW-MEDIUM-HIGH-VERY HIGH SPATIAL RESOLUTION?

DATA EXISTS FROM 3 MM TO 1000000 MM (=1 KM)

3 MM: IN SITU DIGITAL HYPERSPECTRAL CAMERA; 3CM: DRONES

10 CM: AIRBORNE DIGITAL CAMERA

1.2 M WORLDVIEW 3 ETC…….., 5 M RAPIDEYE, ETC….10 M S-2, 30 M LANDSAT, 250 TO 300 M S-3 & GCOM-C SGLI ETC.



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……….

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

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

- 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***

The CEOS Teams that wrote or supported the report

Lead: CSIRO - Arnold Dekker; Coordinator: DLR - Nicole Pinnel

Members:

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DLR	Peter Gege, Harald Krawczyk, Bingfried Pflug, Birgit Gerasch (Germany)
VITO	Sindy Sterckx (Belgium)
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CSA	Martin Bergeron & Maycira Costa (Canada)
USGS	Thomas Cecere (USA)
WaterInsight	Steef Peters (Netherlands)
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CSIRO	Hannelie Botha & Antonio Robles-Kelly (Australia)

Supporting sponsors:

(NSO)	Mark Loos & Joost Carpaaij (Netherlands)
(EC)	Astrid-Christine Koch & Catharina Bamps (European Commission)

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

These are interrelated!!!

- Geolocational accuracy
- Sunglint avoidance
- Polarisation sensitivity

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

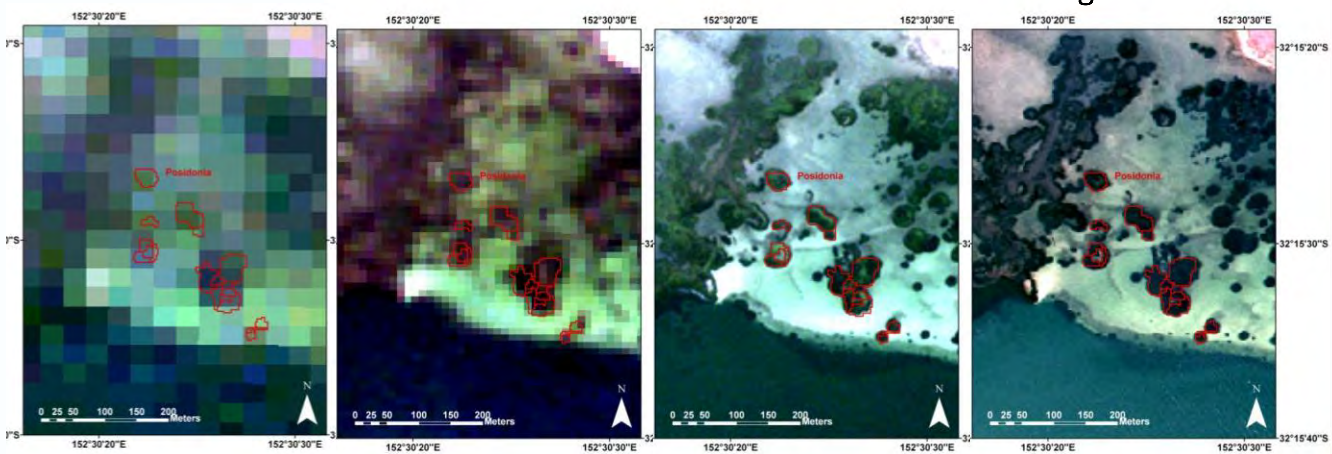
(Example is Posidonia seagrass beds under 1 m of water in a coastal lagoon)

Low cost
Coarse detail

→

Higher cost
Fine detail

Landsat TM5 20 September 2008	ALOS/(S-2) 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. Assumption that this is appropriate for macrophytes, seagrass, macro-algae and coral reefs As well…….is this correct???

Table 6.2.

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	
$\geq 10\ km^2$	1054 m	44	25,976	Focus of current and future OC sensors
$\geq 1\ km^2$	333 m	60	353,552	
$\geq 0.1\ km^2$	105 m	80	4,123,552	HICO
$\geq 0.01\ km^2$	33 m	90	27,523,552	Focus of this study
$\geq 0.002\ km^2$	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%	
≥ 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 [nm]	FWHM [nm]	Water quality and benthic characterisation related application	
+/-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

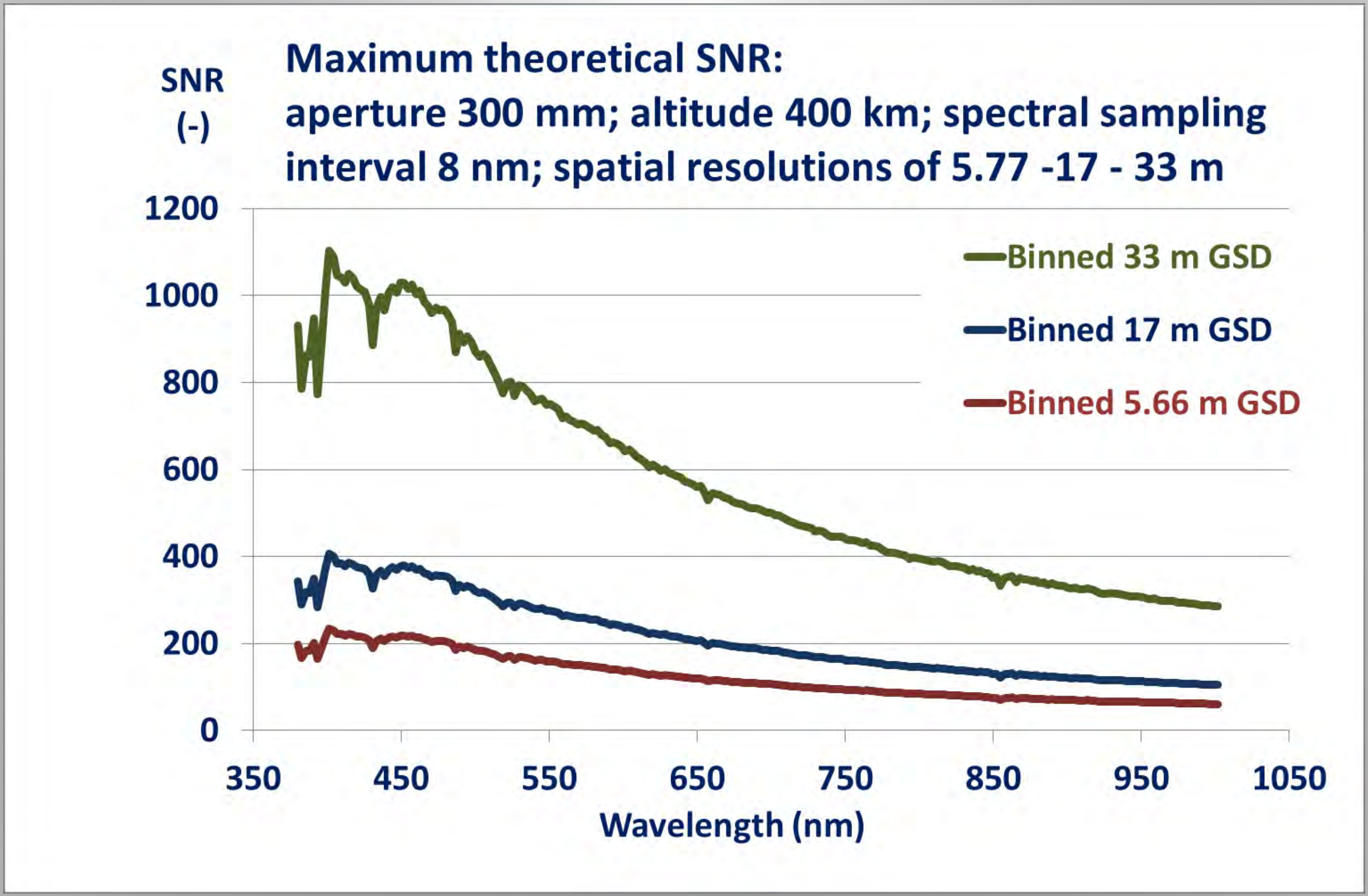
		reference band PFT (Wolanin et al., 2016)	
565	5 to 8	CPE in vivo absorption maximum and possibly fluorescence (Dierssen et al., 2015)	12
+/-583	5 to 8	CPE and CPC reference band; chlorophylls a,b and c (Johnsen et al., 1994); CPE fluorescence (Dierssen et al., 2015)	13
+/-594	5 to 8	PFT (Wolanin et 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 [nm]	FWHM [nm]	Atmospheric characterisation and air-water interface effect removal bands	
+/- 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

TRADE-OFF RESOLUTIONS

Higher spatial resolution = lower radiometric resolution=less depth penetration



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 and bathymetry**

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.

Sensor gaps: these are only EO sensors that meet requirements, *Note: Updated from 2018 report due to launch of DESIS and PRISMA –See report for analysis of all EO sensors –*

(blue)	**Meets baseline requirements**
(green)	**Meets threshold requirements**
(yellow)	**Suitable for some applications - but does not meet one or more requirements**
(orange)	**Commercial data costs**
(grey)	**Unsuitable**

Data currency	Sensor functional type	Sensor Functional Type (= Optical and Nearby Infrared)	Spatial Resolution (= Pixel size)	Spectral bands (water-relevant SNR spectral range (360—1000 nm)		Revisit frequency cycle (once every x days)	Raw Data Cost per km^2 [USD]	Launch Date	End Date
Future	Hyper-spectral Satellite	EnMap	30 m	90		Programmable (once per 4 days)	Free RD	2020	
Current		PRISMA	20 m spectral– 2.5 m B&W	66		25 days/pointing-7 days	Free RD	Q1 2019	
Future		SBG (FKA:HyspIRI)	30	60		16	Free	2022	
Future	Hyper-spectral Int.Space Station	HISUI	20 * 30 m pixels	60		orbit between 51 degrees North and South resulting in a 3 to 5 days cadence	Free RD	Q4 2019	
Current	Hyper-spectral Int.Space Station	DESIS	30 m	235		orbit between 51 degrees North and South resulting in a 3 to 5 days cadence	Commercial	2018	

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…)-see next discussion slides

http://ceos.org/document_management/Publications/Feasibility-Study-for-an-Aquatic-Ecosystem-EOS-v.2-hi-res_05April2018.pdf

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SHORT DISCUSSION STARTERS

- KEVIN TURPIE (BY ARNOLD DEKKER): NASA DECADAL PLAN 2017 SURFACE BIOLOGY GEOLOGY MISSION (INCL. ALGAL BLOOMS)
- ZHONG-PING LEE: INTRO TO SPATIAL
- ERIC HOCHBERG: CORAL REEFS 2 TO 30 M PIXELS: DOES IT MATTER?
- CHUANMIN HU: FROM MODIS TO S-2 : WHAT DO WE GAIN AND LOSE?
- JOE ORTIZ: ADVANCED ALGORITHMS & SPATIAL STATS

"Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space,"
National Academies of Science, Engineering and Medicine, 2017 (Second Decadal Survey)
One of the Priority Missions:

Surface Biology and Geology (SBG) Study

K. Turpie *kturpie@umbc.edu*

Decadal Survey (DS) – The US National Research Counsel Committee on Earth Science and Applications from Space advised NASA regarding the development of remote sensing assets into the coming decade.

Designated Observables – The **DS** pointed to the development of assets for five broad areas of observation, one of which was referred to as Surface Biology and Geology (**SBG**).

SBG Objectives – Combined visible to shortwave infrared imaging spectroscopy and multispectral or hyperspectral thermal infrared imagery to study terrestrial and **aquatic ecosystems and biodiversity,** geology, volcanoes, the water cycle, and applied sciences topics relevant to many societal benefit areas. **SBG** will look at global and event-driven processes and change.

SBG Architecture Study – NASA has initiated a 3-year mission architecture study, which has three teams to look at **Candidate Architecture Formulations**, **Research and Applications (R&A)**, and **Cost Analysis**. A **Mission Concept Review (MCR)** is targeted for late 2021.

Approach – The **SBG Study** will look at many observing architectures, utilizing concepts from the **HyspIRI** precursor study and new ideas and advances with instrument technologies. Candidate architectures will include small-sat and medium class concepts, and industry and foreign partnerships.

Working Groups – The **R&A team** has 4 working groups (**Algorithms**, **Calibration and Validation**, **Applications**, and **Modeling**) leveraging community input. The **Aquatic Study Group** (**ASG**, formerly of **HyspIRI**) also continues to provide input.

Workshop – NASA is also holding an invitation-only, **SBG Community Workshop** (11-14 June 2019) to update user communities on the current **SBG** study plan and to get community feedback.

Current Distillation of Desired SBG Capabilities

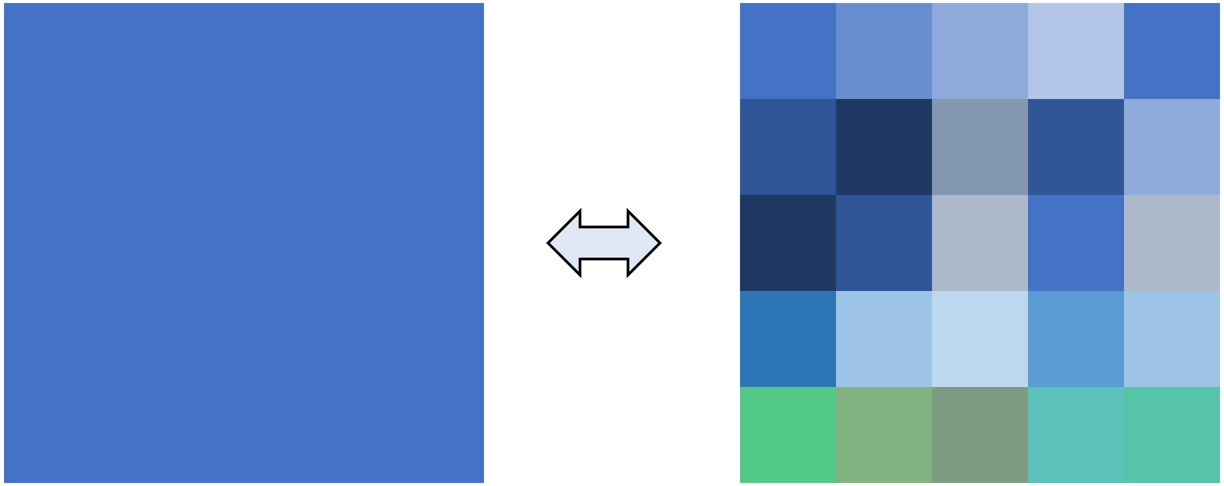
VSWIR	
Spectral Range	0.4 to 2.5 μm
Spectral Resolution	10 nm
SNR	VNIR: 400 SWIR: 250
GSD	30-45 m
Revisit	16 days
Coverage	Global
Local time for acquisition	From 10:30 am to 1:30 pm

TIR	
Spectral Range	8 to 12 μm; 3-5 μm for Fires
Spectral Bands	Multiple (>2)
SNR	>200
GSD	60-100 m
Revisit	Weekly
Coverage	Global
Local time for acquisition	Can vary

Zhong-Ping Lee:
Science with high temporal resolution

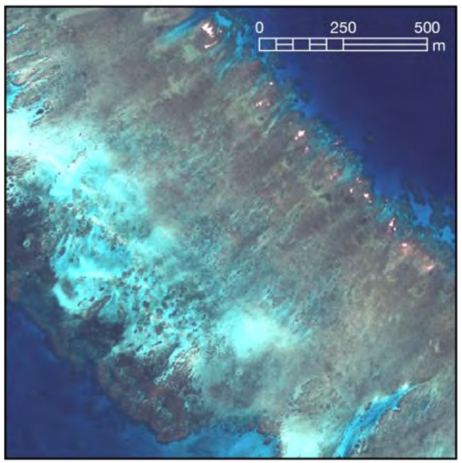
“True” phytoplankton dynamics, rather than advections or movements of water parcels

Impact of reduced spatial resolution

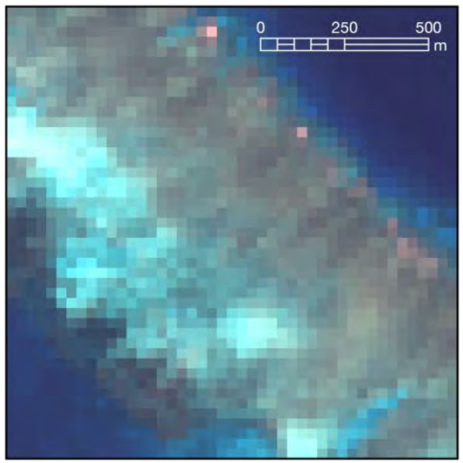


(Lee et al. 2012b)

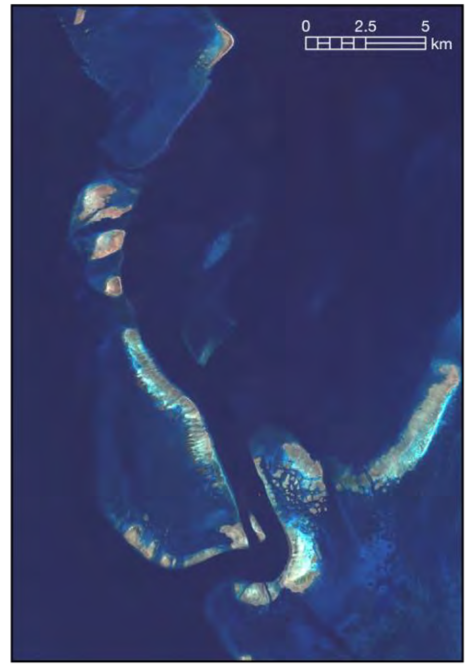
Eric Hochberg
: Spatial Resolution Considerations for Coral Reef Study



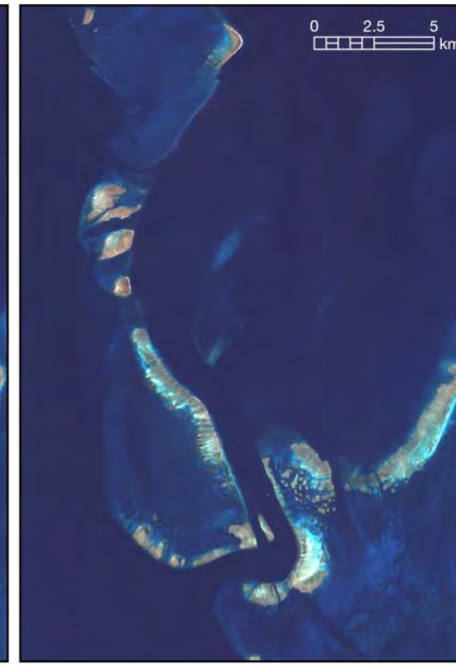
2 m pixels



30 m pixels



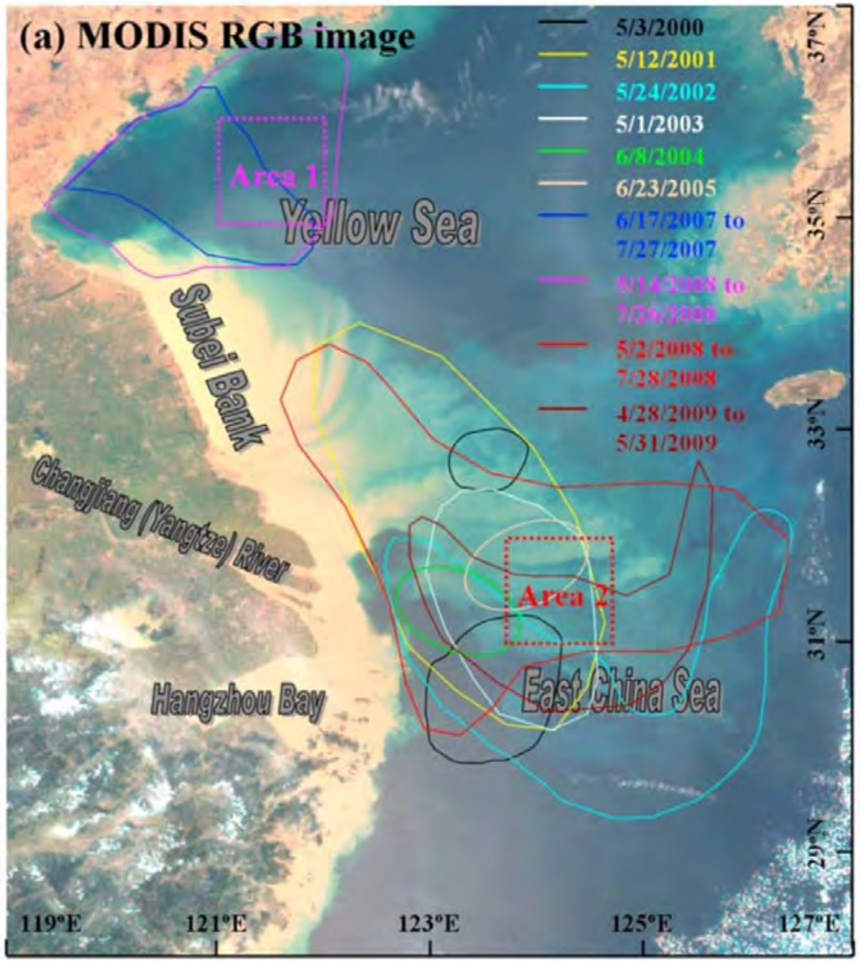
2 m pixels



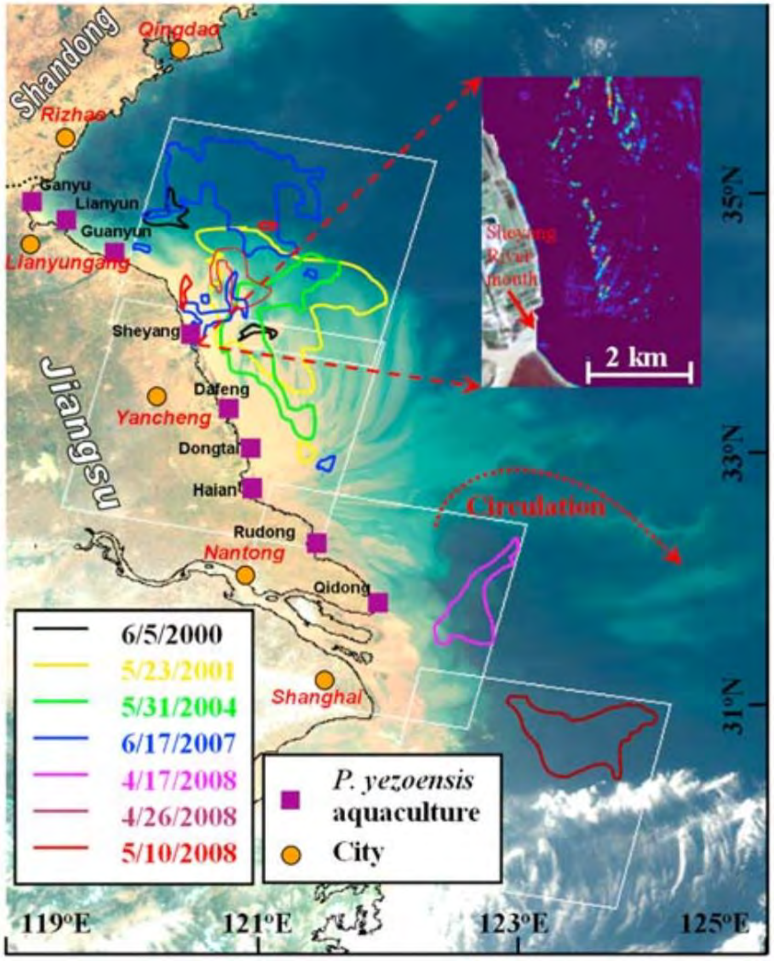
30 m pixels

Chuanmin Hu: High-resolution RS: What do we again and lose?

See better and track better



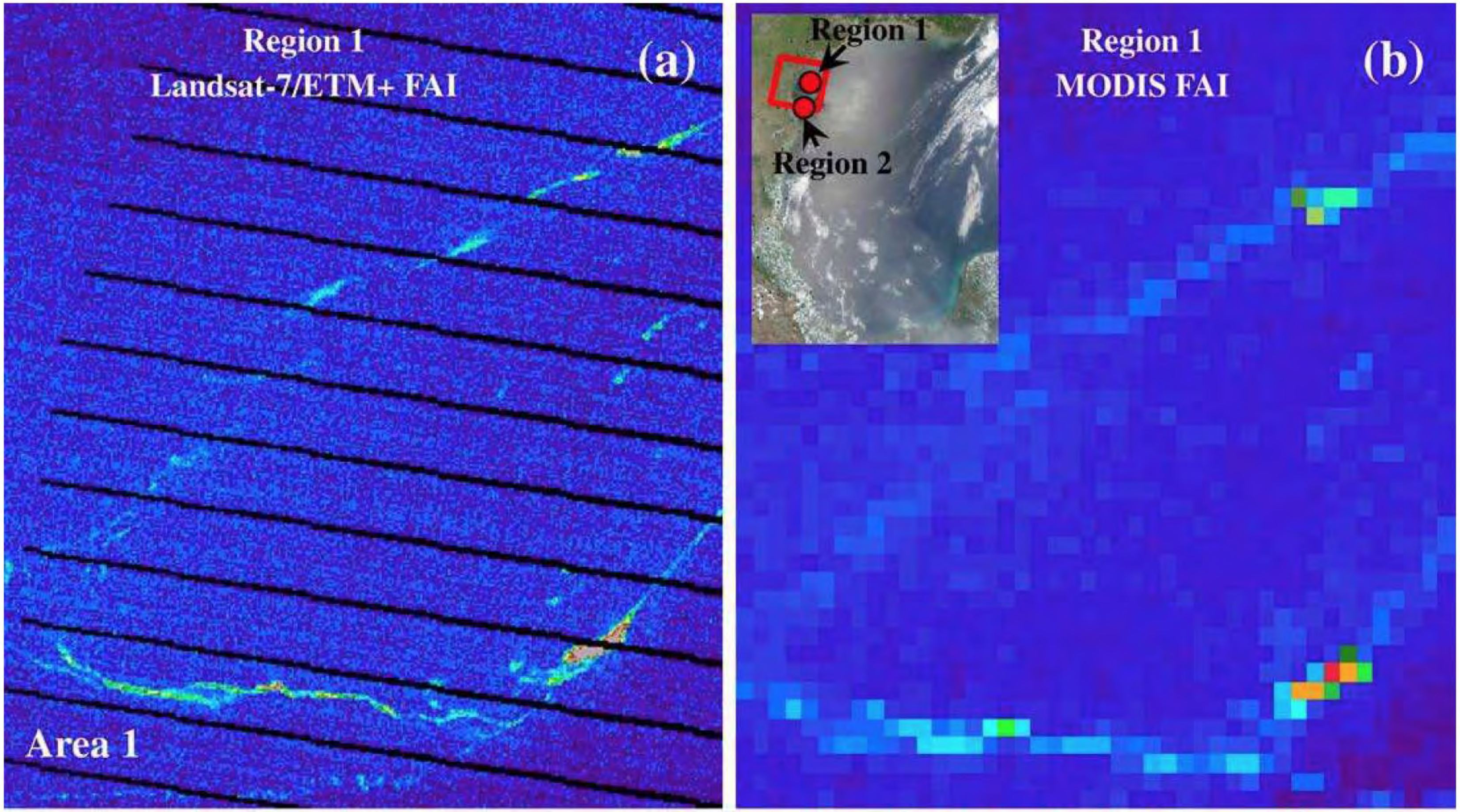
MODIS only detects large algae slicks in offshore waters



Landsat extends to coastal regions, thus tracking algae origin

High-resolution RS: What do we again and lose?

See better and track better

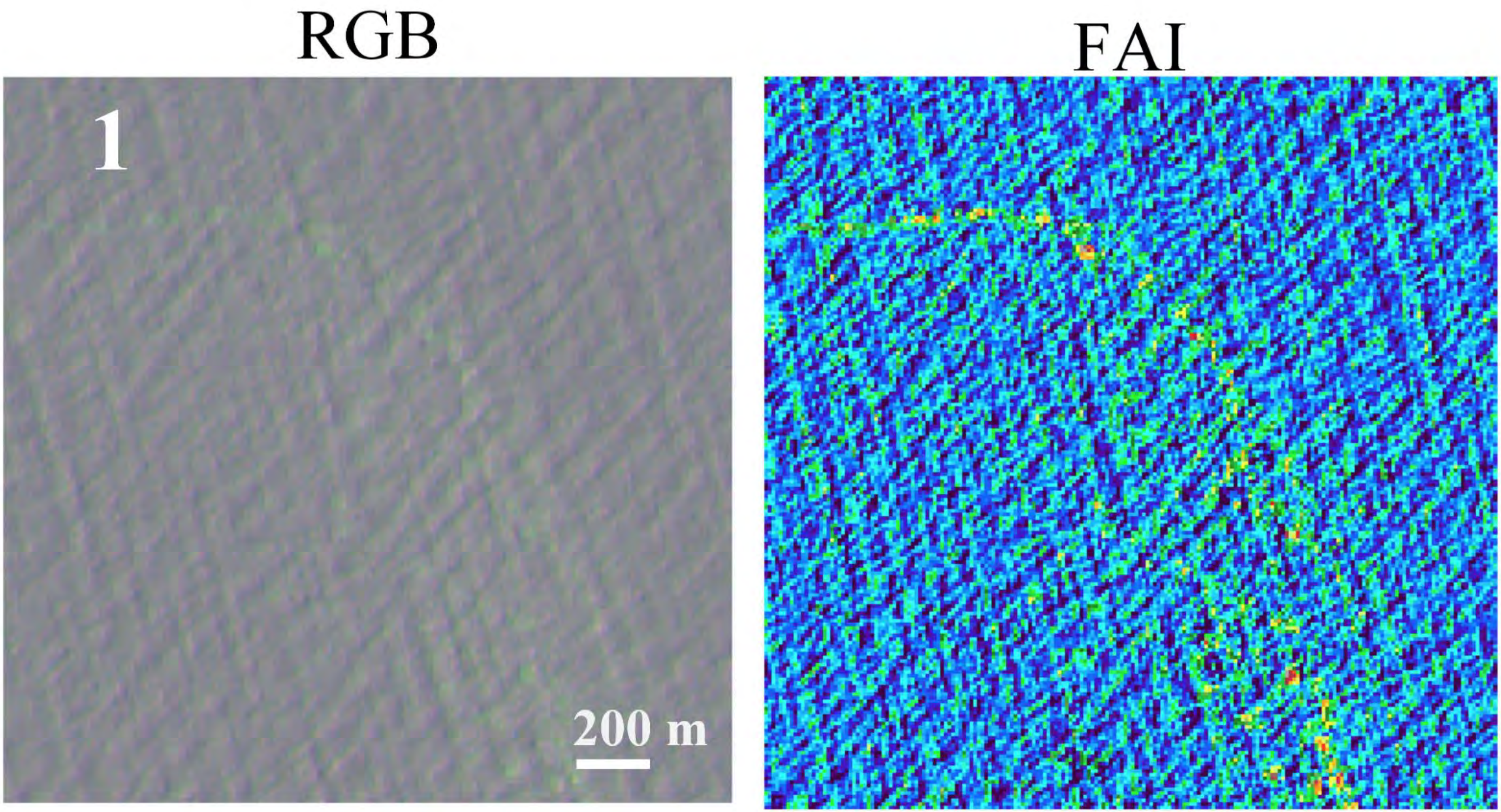


Landsat detects fine features

MODIS (250-m) detects smeared features or no feature

High-resolution RS: What do we again and lose?

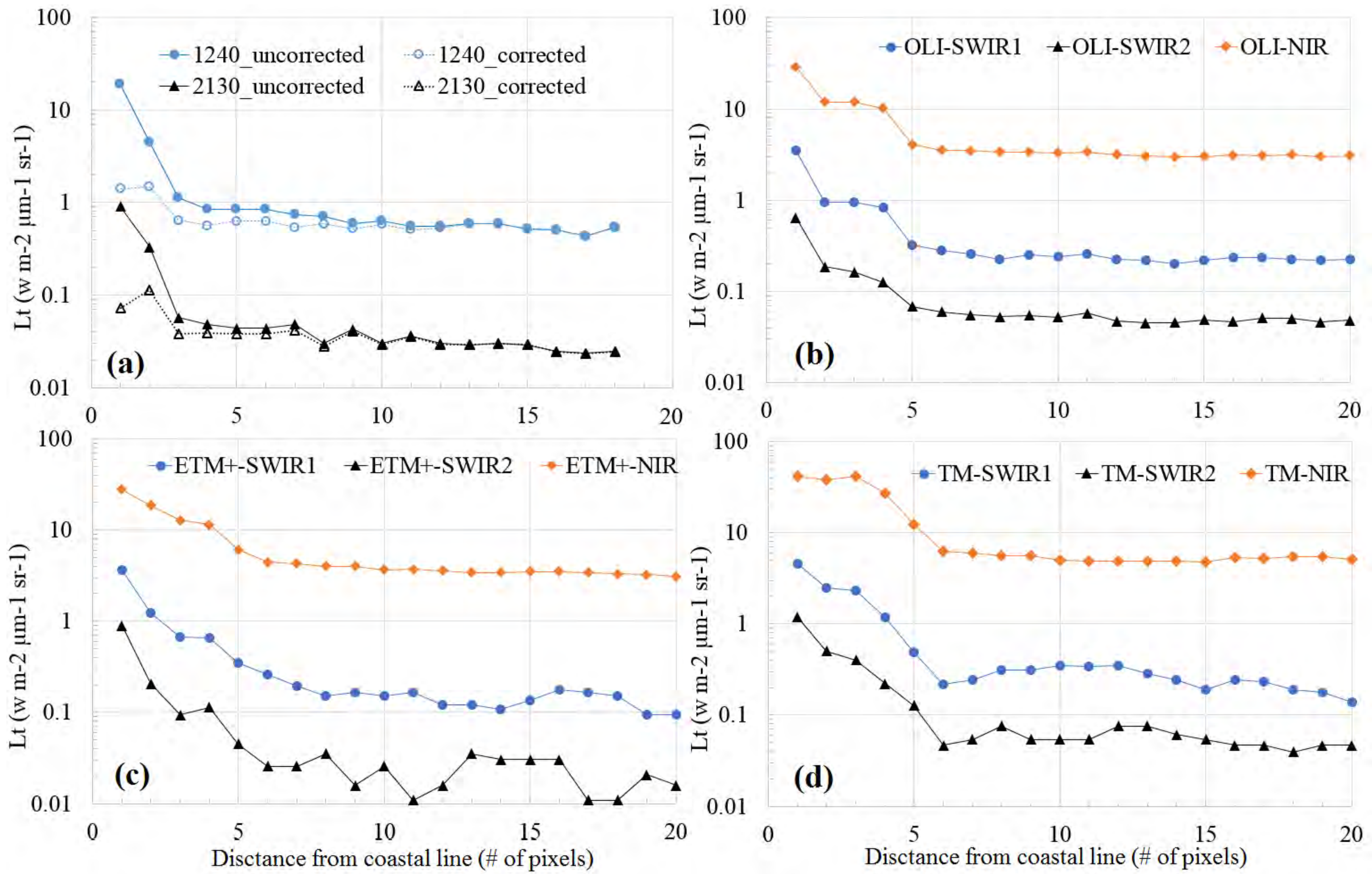
At MSI 10-m resolution, a lot of unwanted "noise"



How do we extract algae features, not noise?

High-resolution RS: What do we again and lose?

How close can we get to land?



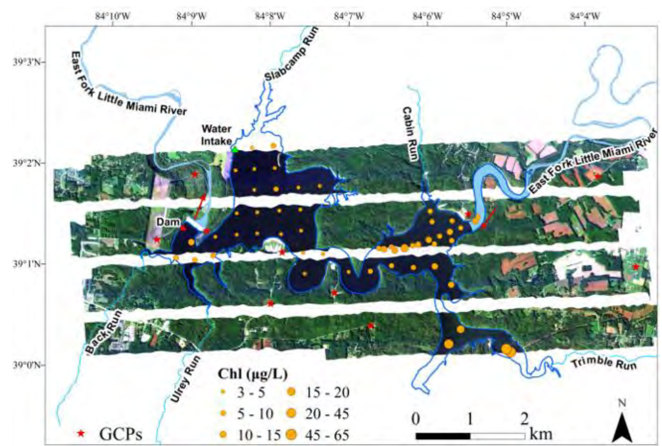
It appears that adjacency effect on Lt is only a few pixels instead of a few kilometers. It's counter intuitive, but good news for inland water applications (from Feng and Hu 2017)

Joe Ortiz
NASA HSI2 based Multivariate approaches to Chl a estimation (U. Cincinnati, U. Alabama)-

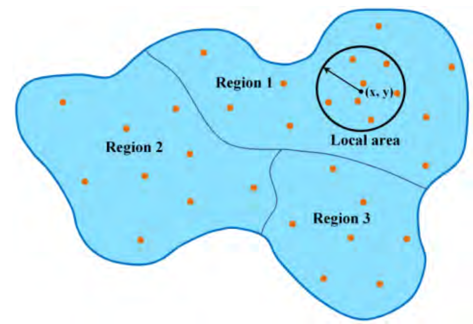
- 2 slide summary
- 1-3m resolution Hyperspectral NASA HSI2 data from Harsha Lake
- Work by Min Xu, and Hongxing Liu, et al. presenting two approaches to high spatial resolution modeling of Chl a
  - Geographically adaptive modeling
  - Multivariate ensemble modeling

Geographically adaptive models for *Chl-a* estimation

- HSI2 data of Harsha Lake, Oct 5, 2015
- Calibrate empirical algorithms for different regions or local areas of the image
- Significantly improve the *Chl-a* estimation accuracy by 33-47% compared with the best traditional empirical method (global model).



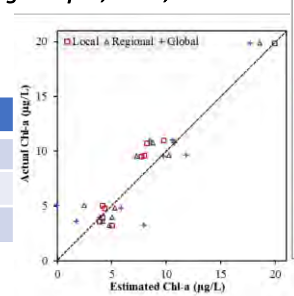
Harsha Lake, in situ data, and GCPs overlaid on HSI2 image stripes, Oct 5, 2015

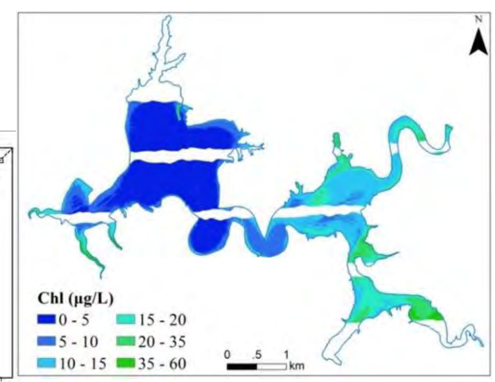


Regionally and locally adaptive models

Models performance evaluated by 10 checking points

RMSE	0-8μg/L	8-16μg/L	16-20μg/L	Overall	*r*
Global	3.22	1.48	2.75	2.48	0.882
Regional	1.49	1.61	1.91	1.65	0.950
Local	0.94	1.52	1.71	1.31	0.970





Chl-a distribution by locally adaptive models

Xu et al., *IEEE Tran. Geosci. Remote Sensing,* 2019

Multi-model ensemble for *Chl-a* retrieval

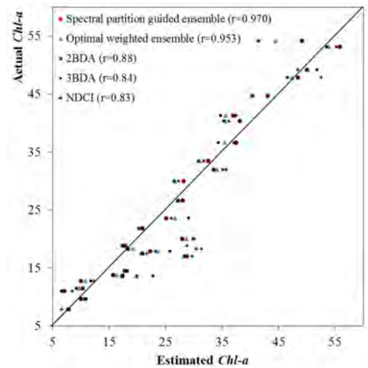
- Sentinel-2A satellite data of Harsha Lake, Oct 7, 2016
- The optimally weighted ensemble and a spectral partition guided ensemble method
- Spectral space partition rules built by the Classification and Regression Tree method
- Considerably better prediction ability of the ensemble than that of all individual empirical algorithms in the ensemble.

Optimally weighted ensemble method (OWEM):

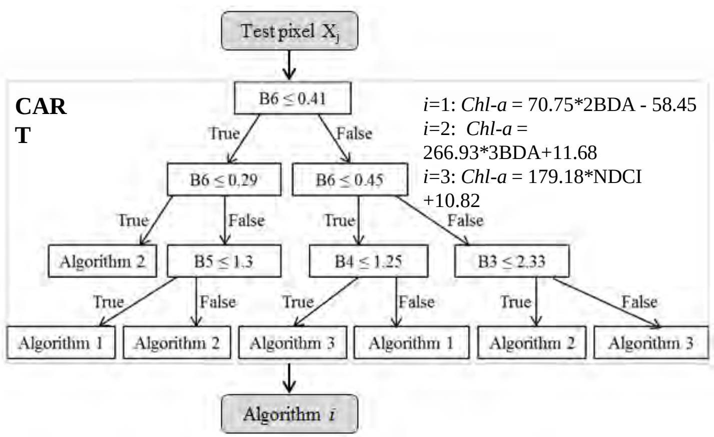
Chl-a = **<u>0.48</u>***(70.75*2BDA-58.45) + **<u>0.32</u>***(266.93*3BDA+11.68) + **<u>0.20</u>***(179.18*NDCI+10.82)

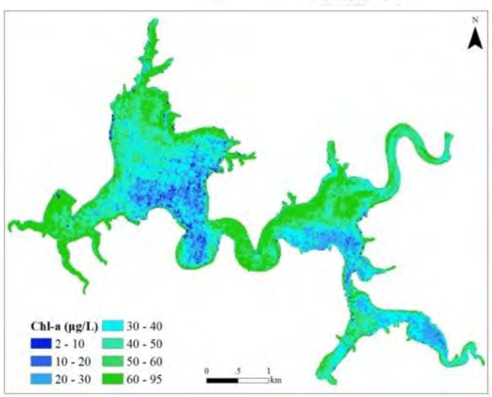
Models' performance

Methods	*r*	RMSE (μg/L)
NDCI	0.83	4.70
3BDA	0.84	4.57
2BDA	0.88	4.50
OWEM	0.95	4.07
SSPGSM	0.97	3.57



Spectral space partition guided selection method (SSPGSM):





Chl-a distribution by spectral partition guided ensemble

Xu et al., *IEEE Tran. Geosci. Remote Sensing,* 2019

Over to you for DISCUSSION!!!!