No single mission can do everything


DSCOVR
SOHO
ACE
COMS
FY-2
FY-2
HIMAWARI-8
INSAT-3D
ELECTRO-L
KALPANA
METEOSAT-7
METEOSAT-10
GOES - WEST
GOES - 14
GOES - EAST
140.7° E
128.2° E
105° E
90° E
86.5° E
82° E
78° E
74° E
57° E
0°
180° W
135° W
105° W
90° W
75° W
NOAA-15/18/19
SENTINEL-1
SENTINEL-2
SENTINEL-3
METEOR
DMSP-F14-18
COSMIC
SUOMI NPP
A-TRAIN CONSTELLATION
METOP
FY-3
GCOM
JASON -2/3
GPM
USA
JAPAN
SOUTH KOREA
INDIA
CHINA
FRANCE
RUSSIA
NOAA
EUMETSAT
EUROPEAN COMMISSION
NATIONAL SPACE ORGANIZATION (NSPO)
EUROPEAN SPACE AGENCY
GEOSTATIONARY ORBIT
NEAR-POLAR ORBIT
LAGRANGE POINT 1

Combined High-Spatial/High-Temporal Resolution Capabilities

Maria Tzortziou, Arnold Dekker, Nima Pahlevan, Joe Ortiz, Chuanmin Hu, ZhongPing Lee, Eric Hochberg, Joe Salisbury, Antonio Mannino, Wonkook Kim, Jacques Stum

- **What applications** can be better achieved by combining high-temporal and high-frequency data?
- Can high-temporal and high-spatial resolution observations **be fused** into a single product?
- Attention to what common attributes help promote interoperability of high-temporal or high-spatial resolution remote sensing products and **what are common end-user objectives and requirements**?

EPA – Spatial Resolution Requirements for Satellite Imagery Application

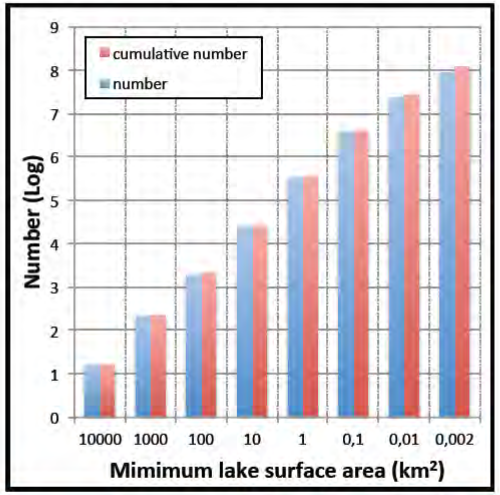
Application	Satellite Product	Requirements	Citation
HABs detection, quantification, and prediction in lakes, reservoirs, estuaries and coastal waters	Chl-a, c and phy HAB pig		
Aquatic invasive species in lakes, reservoirs, estuaries and coastal waters	Phytopl function specific aquatic		
Water clarity for optically shallow and optically deep waters	Kd, Kpa		

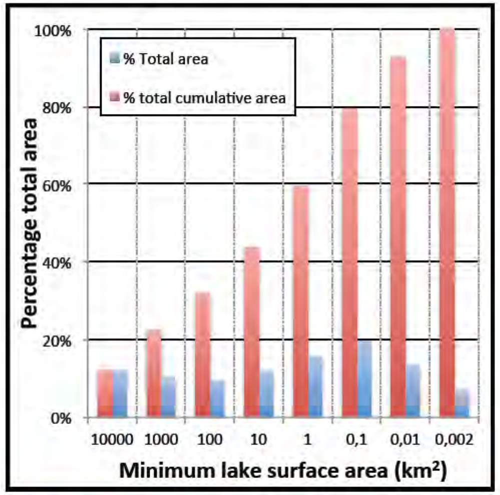
EPA National Lakes Assessment; National Coastal Condition Assessment: Chlorophyll-a, turbidity, CDOM, light attenuation for water quality monitoring and assessment		**Spatial:** 30 m GSD (local) for lakes and reservoirs **Spatial:** <200m GSD (local) for estuaries Spatial: 500m GSD (local) for coastal waters	Keith et al. 2014. IJRS. 35(9): 2927-2962. Mishra et al. 2014. GIScience and Remote Sensing. 15(2): 175
Oil Spill monitoring in rivers, lakes estuaries and coastal waters			
Nutrients and co-pollutants on aquatic resources (also see hypoxia and land use change applications)			
Hypoxia (also see nutrients and co pollutants)			

Land use and land cover change impacts to water quality (also see nutrients and co-pollutants)	IOPs, chl-a, Kd, CDOM, etc	**Spatial:** 30 m GSD (local) for lakes and reservoirs **Spatial:** <200m GSD (local) for estuaries **Spatial:** 500m GSD (local) for coastal waters **Temporal:** 3 hrs **Coverage** (Width from coast to ocean): Minimum distance: 5.5 km (3 nmi) Maximum distance: 22 km (12 nmi) **Field of Regard for Retrievals:** 50°N to 14°N; 160°W to 60°W	Le et al. L&O: 60(3): 920-933 Lunetta et al. IJRS: 30(13): 3291-3314
Coral reefs	Kd, Kpar, NTU, chl-a, etc	**Spatial:** 30-250 m GSD (local) for coral reefs **Examples:** Florida Keys National Marine Sanctuary, Puerto Rico, and Hawaii **Temporal:** Daily	Barnes et al. 2013. RSE. 140: 519-532. Barnes et al. 2013. RSE. 134: 377-391. Zhao et al. 2013. RSE. 131: 38-50.
Estuarine acidification	CDOM, DOC, etc	**Spatial:** <200m GSD (local) for estuaries **Temporal:** 3 hrs **Coverage:** US estuaries	Kelly et al. 2011. Science. 332 1036-1037. Safe & Sustainable Water Resources, Strategic Research Action Plan 2016-2019
Effulent detection	Visible/true color imagery, ocean color products	***Spatial:** 5-10m GSD (local) for rivers **Spatial:** 30 m GSD (local) for lakes and reservoirs **Spatial:** <200m GSD (local) for estuaries **Spatial:** 500m GSD (local) for coastal waters **Temporal:** <0.5 hrs **Coverage** (Width from coast to ocean): Minimum distance: 5.5 km (3 nmi) Maximum distance: 22 km (12 nmi) **Field of Regard for Retrievals:** 50°N to 14°N; 160°W to 60°W	USEPA Document #832-F-99-051
Benthic habitat monitoring	Seagrass extent	**Spatial:** 1-10m GSD (local) for estuaries **Temporal:** daily **Coverage:** US estuaries and coastal waters	Williams et al. 2003. Environmental Monitoring & Assessment 81: 383-392 Clinton et al. 2007. USEPA 600/R-07/062

Agency	Applications	Satellite products	Spatial requirements	Temporal requirements
NOAA	Habitat assessment, fisheries management, water quality, HABS, ecological forecasting, pollution monitoring, coral health, acidification	Chlorophyll, Rrs(λ), abs(λ), HABs, K_{490}, K_{PAR}	100m – 4km	3hrs - daily
EPA	Sustainable coastal resources; air, climate and energy research; healthy and sustainable coastal communities	Chlorophyll, Rrs(λ), abs(λ), abs(cdom, phy, det), HABs, SPM, K_{490}, K_{PAR} and more	<250m to 500m	0.5 – 3hrs
EPA	Pathogen detection, indicators, modeling	Turbidity, salinity proxies, etc	<250m to 500m	1 – 3hrs
EPA	Oil Spill monitoring in rivers, lakes, estuaries and coastal waters	Visible/true color imagery	<250m to 500m	0.5-1 hr
US Navy	Surface currents, instrument assessments, bathymetry, visibility, coastal oceanography, navigation	Chlorophyll, Rrs(λ), abs(λ), abs(cdom, phy, det), bbp(λ), HABs, SPM, K_{490}, K_{PAR} currents, etc.	250m – 1km	1hr - daily
U.S. Army Corps of Engineers	Coastal & Inland Water Quality Monitoring and Forecasting (including HAB detection and monitoring), Nearshore Benthic Habitat Mapping to Support Coastal Operations and Planning	Chl-a, phycocyanin, CDOM, turbidity, CDOM, green laser reflectance, hyperspectral Rrs, bottom type characterization, habitat change detection	5 to 50 m	daily (WQ), monthly-seasonal (mapping)

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.

Application of satellite Imagery to monitor Oils Spills

- For operational purposes, **1 km resolution would only be useful for large events** such as the Deepwater Horizon or Valdez.
- For the small (more frequent spills), improved spatial resolution would be needed to increase the number of spills that could be detected. Sensors operating in **wide swath mode with a spatial resolution of 50–150 m** were found to be sufficient and allow covering large ocean areas efficiently *("Oil spill detection by satellite remote sensing" by Brekke and Solberg, 2005).*

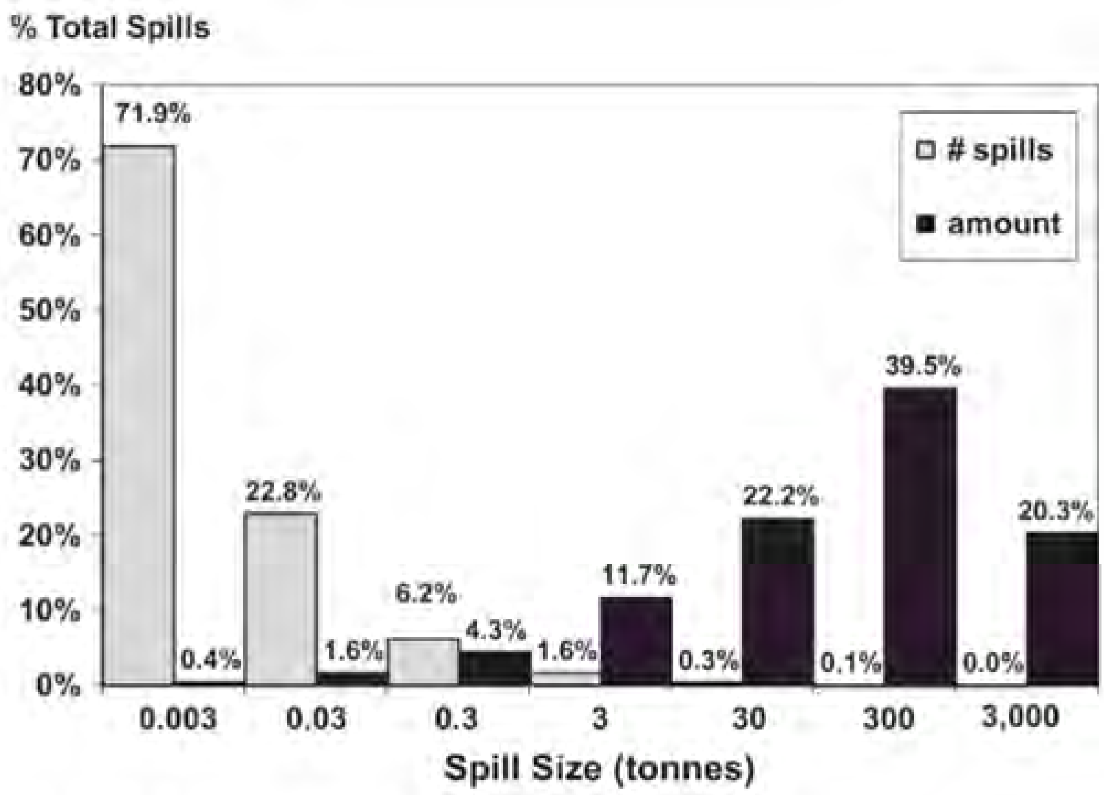
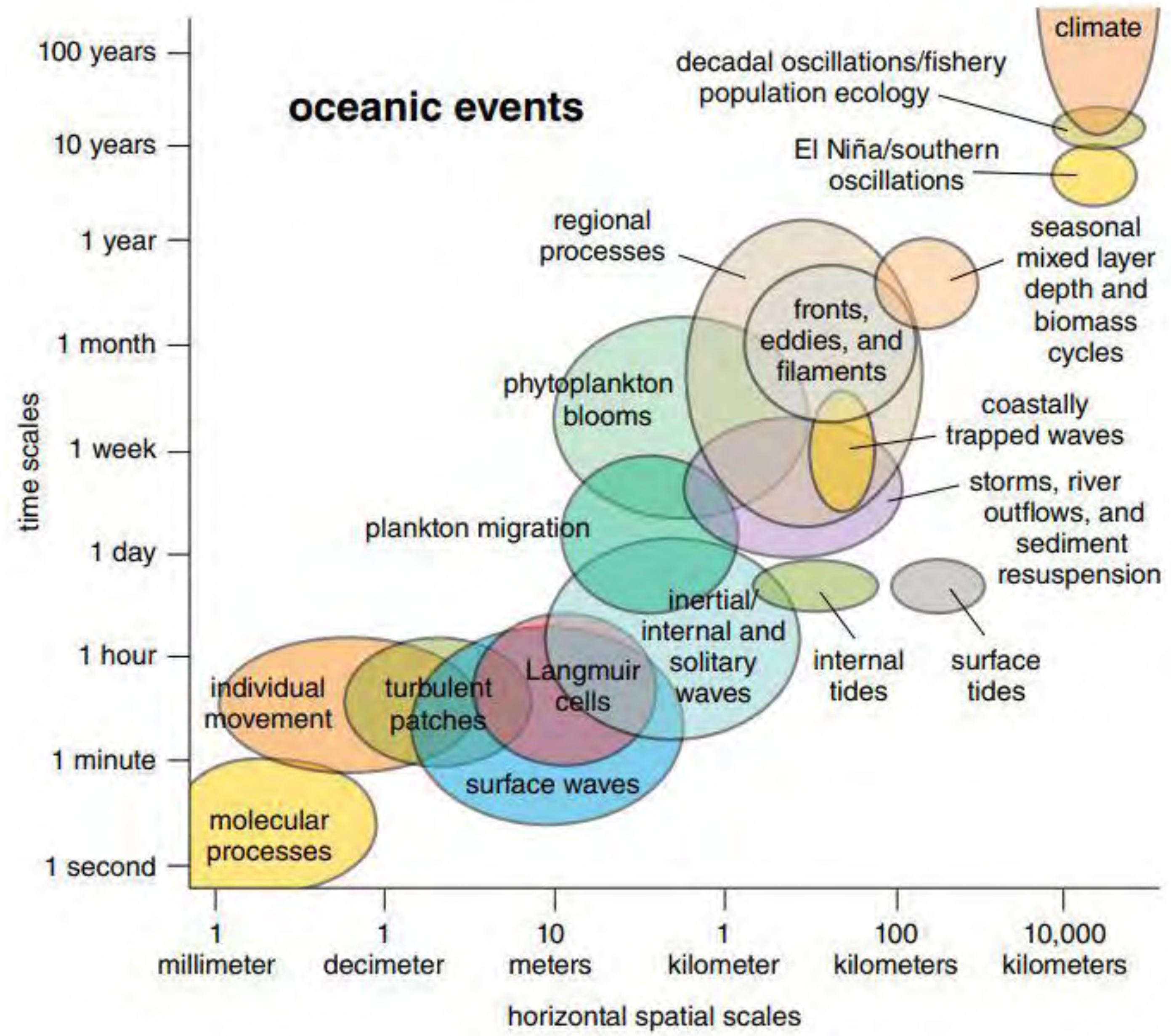


FIGURE 2.1 Size classes of U.S. marine oil spills, 1990–1999 (ERC data).

Adapted by Tom Dunne from an illustration by Tommy Dickey

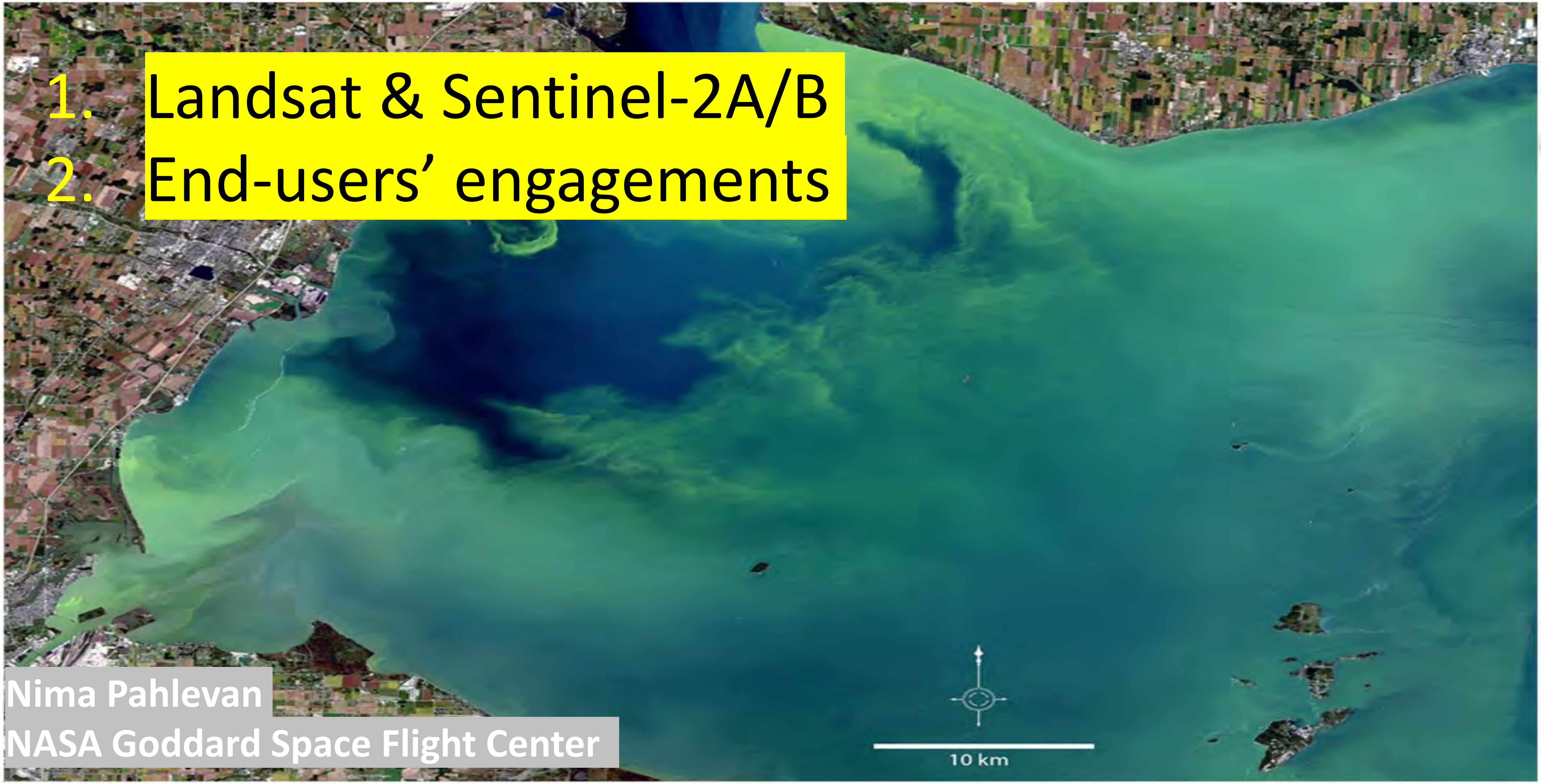


Combined High-Spatial/High-Temporal Resolution Capabilities

Toward a Satellite-Based Monitoring System for Water Quality

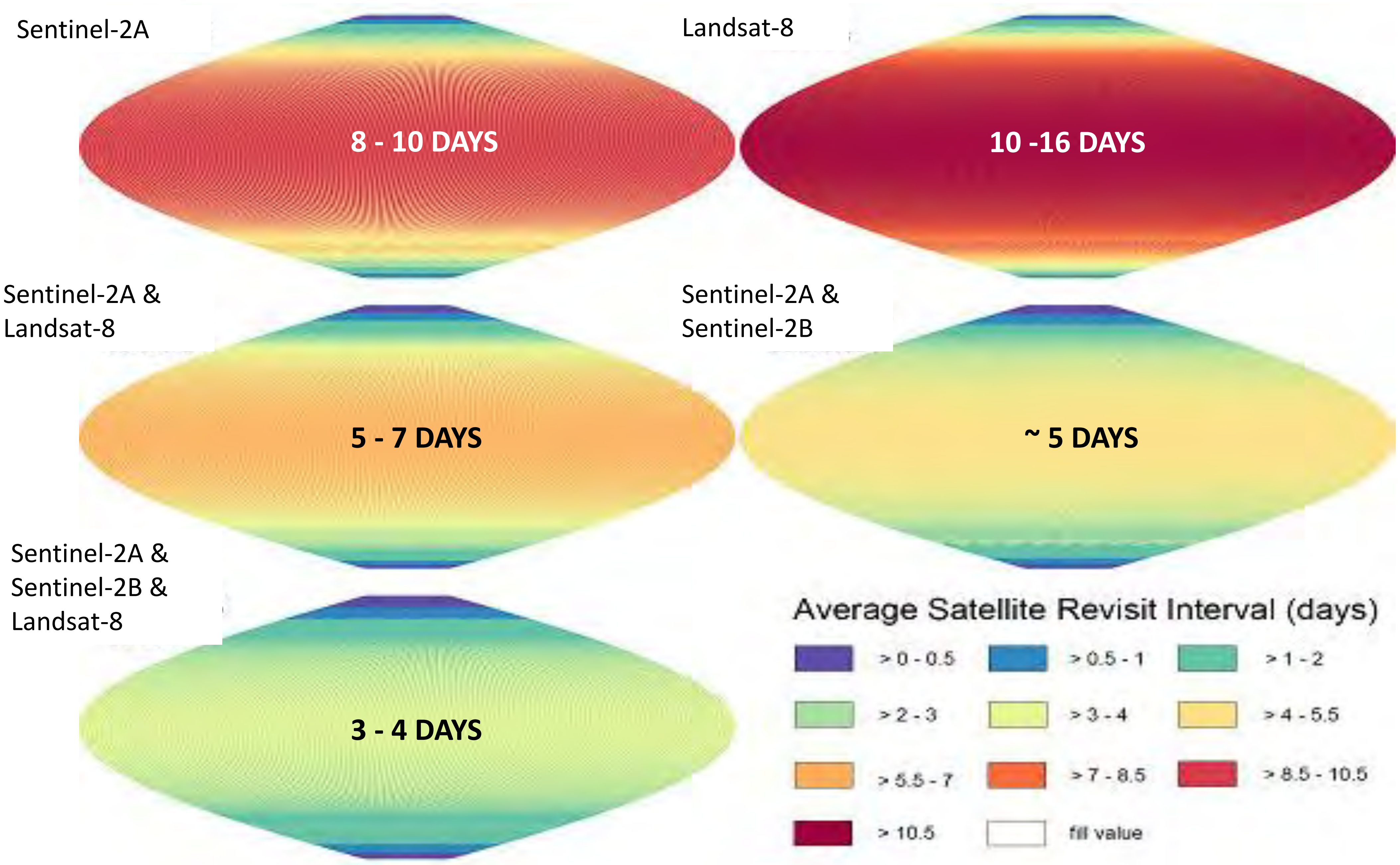
Nima Pahlevan

1. Landsat & Sentinel-2A/B
2. End-users’ engagements



Nima Pahlevan
NASA Goddard Space Flight Center

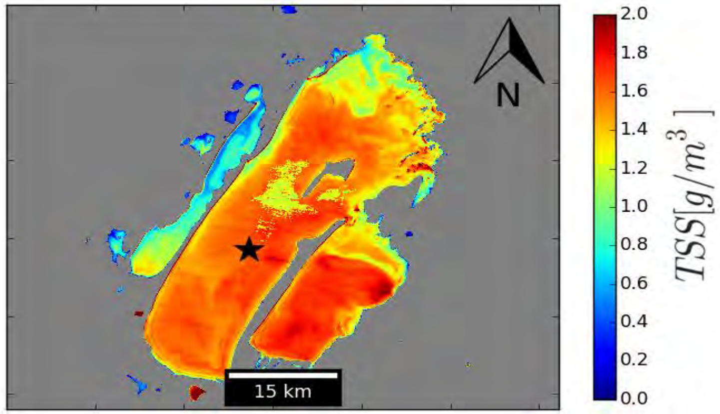
A hazardous algal bloom containing the toxin microcystis covered large portions of western Lake Erie in September 2017. Swirls of algae can be seen south of Detroit River’s mouth in this natural-color Landsat 8 image. Credit: USGS EROS

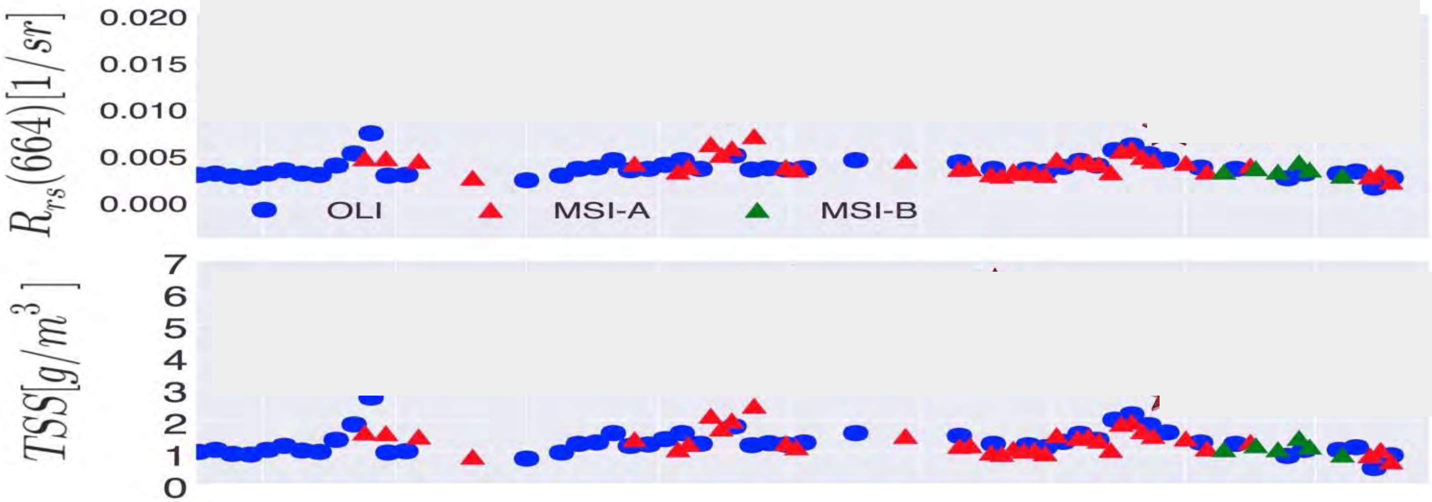


Li, J.; Roy, D.P. A Global Analysis of Sentinel-2A, Sentinel-2B and Landsat-8 Data Revisit Intervals and Implications for Terrestrial Monitoring. *Remote Sens.* **2017**, *9*, 902.

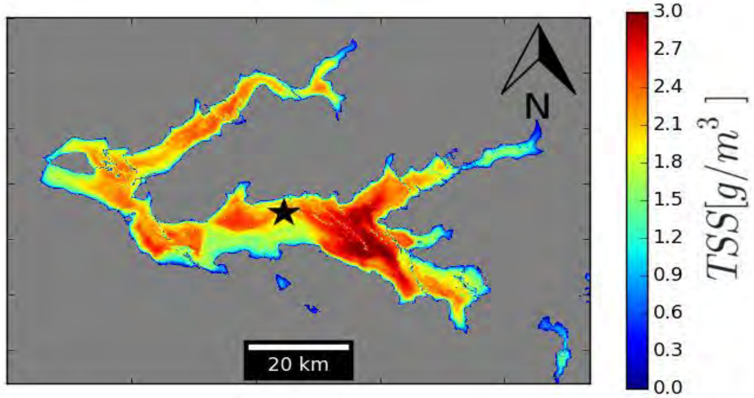
Example time-series applications

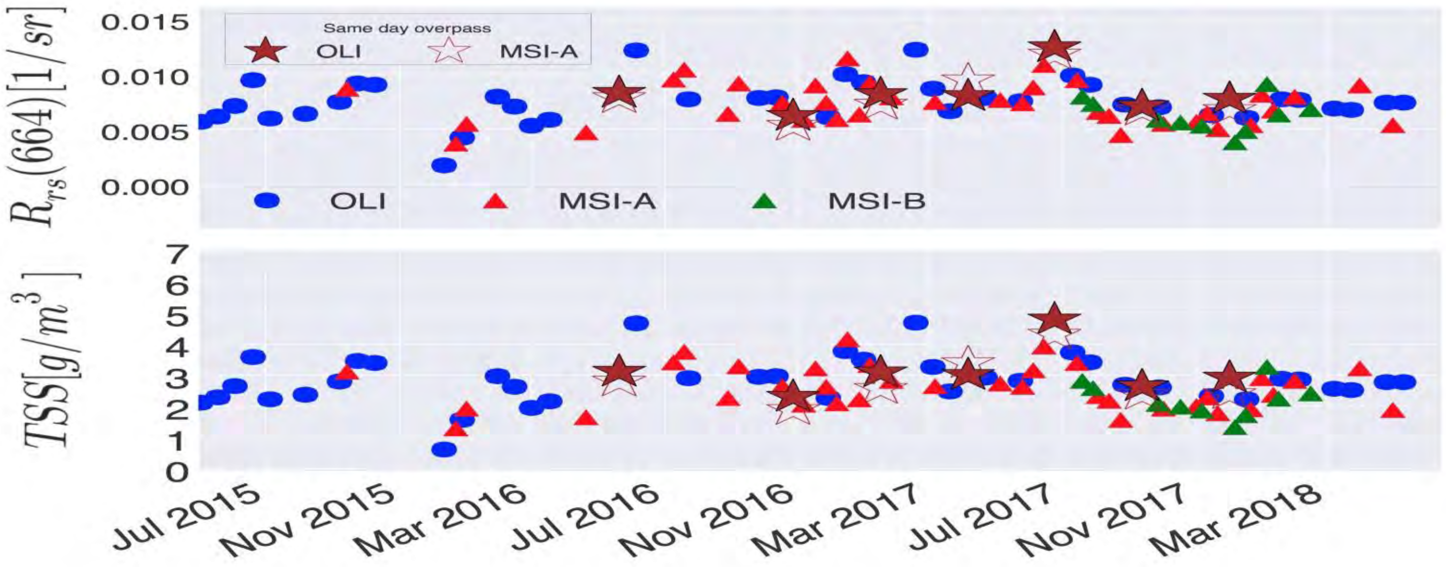
Lake Bangweulu, July 23rd 2016



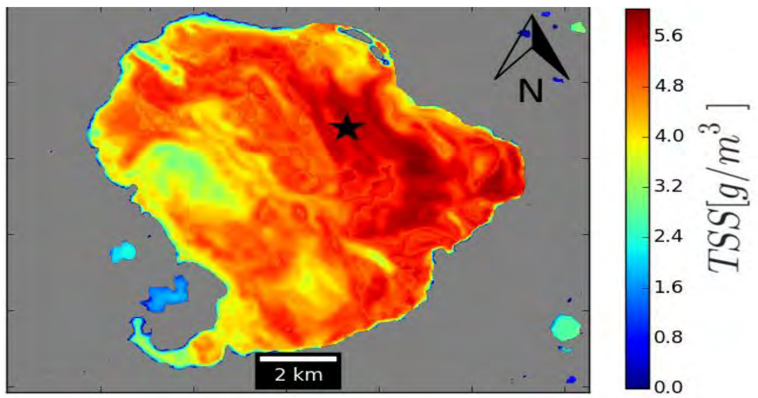


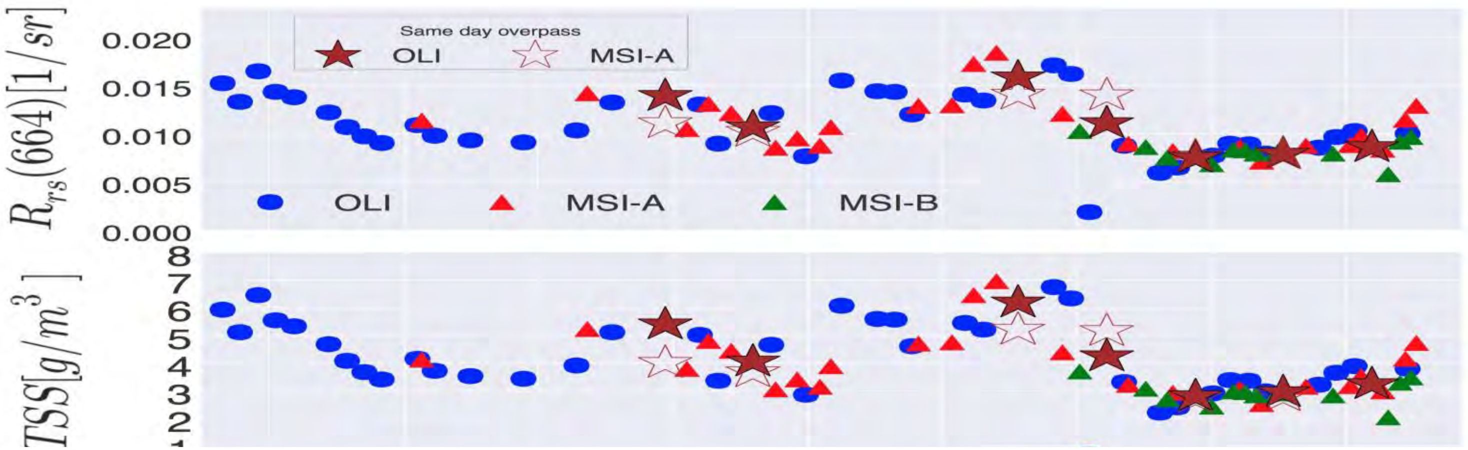
Lake Kyoga, January 23rd 2016



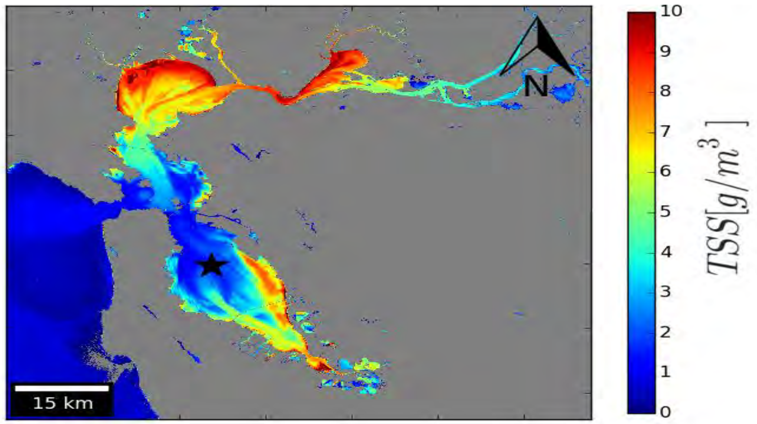


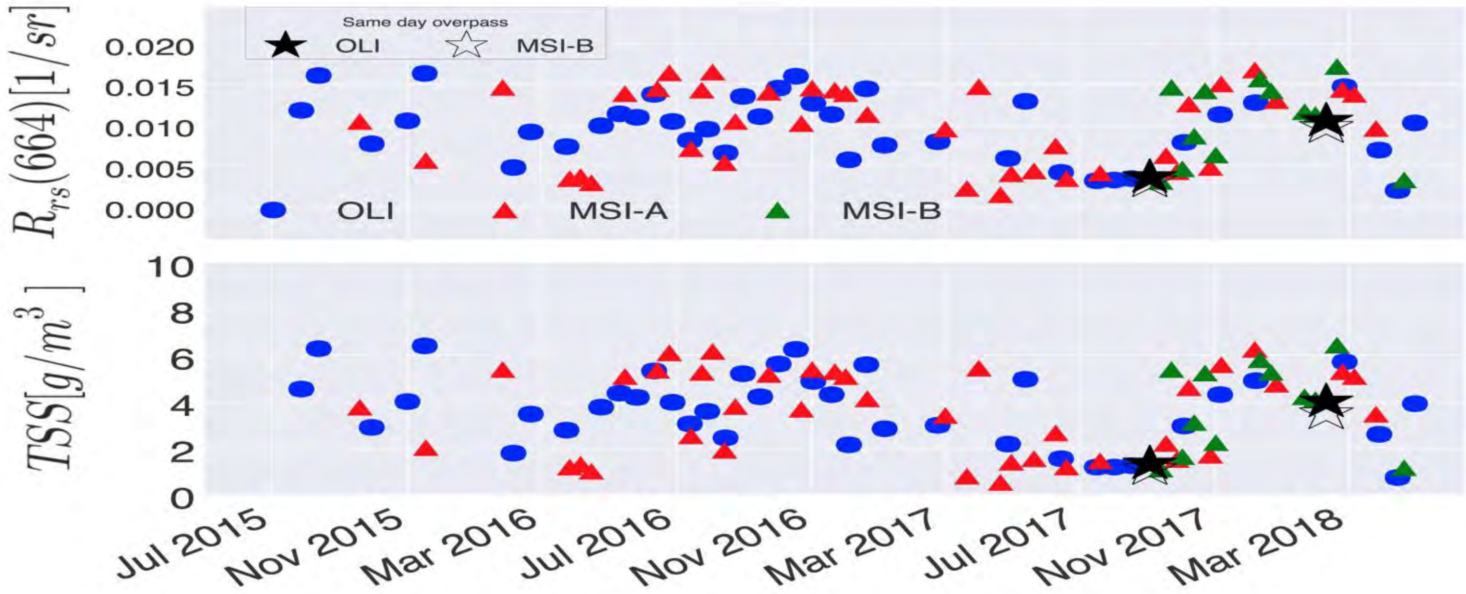
Apopka Lake, April 7th 2017





San Francisco Bay, June 14th 2017





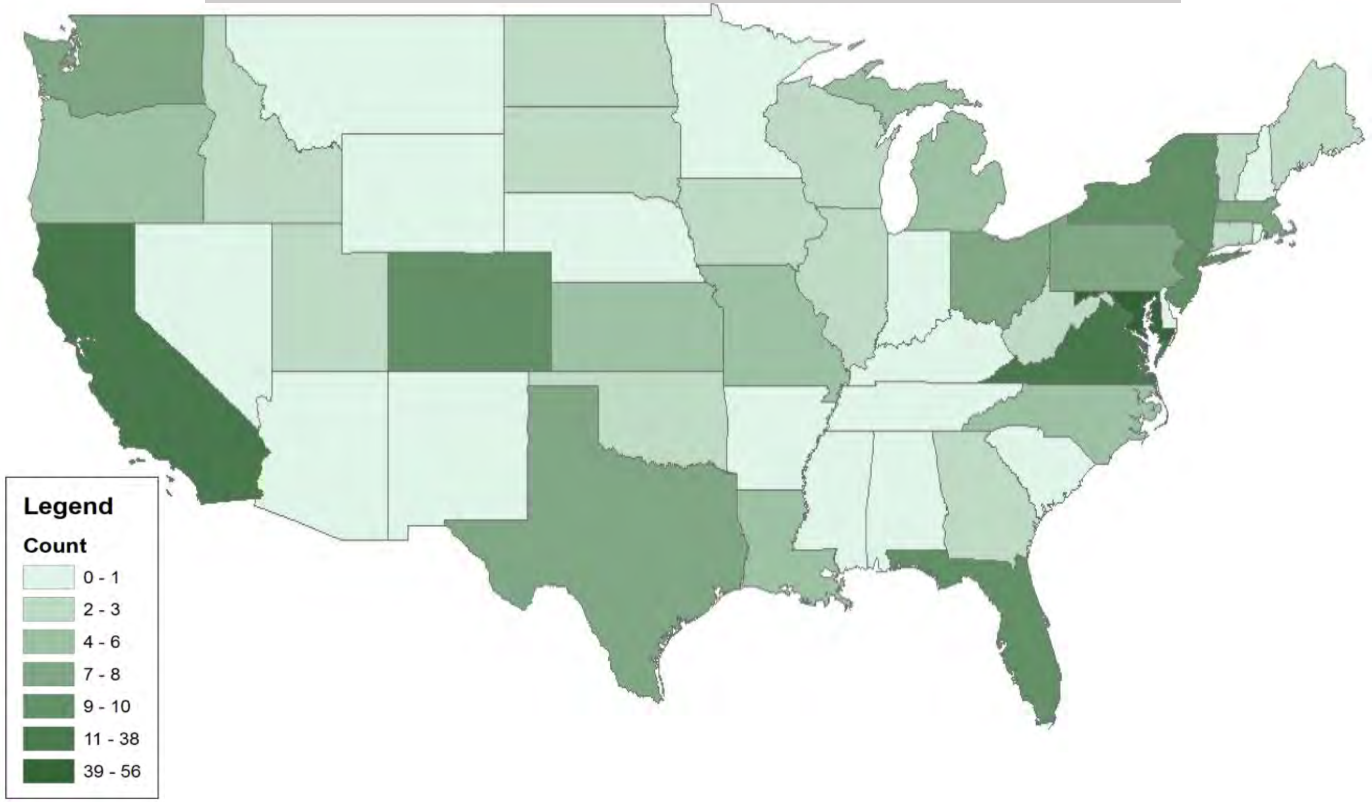
1. Landsat & Sentinel-2A/B
2. End-users’ engagements

A hazardous algal bloom containing the toxin microcystis covered large portions of western Lake Erie in September 2017. Swirls of algae can be seen south of Detroit River’s mouth in this natural-color Landsat 8 image. Credit: USGS EROS

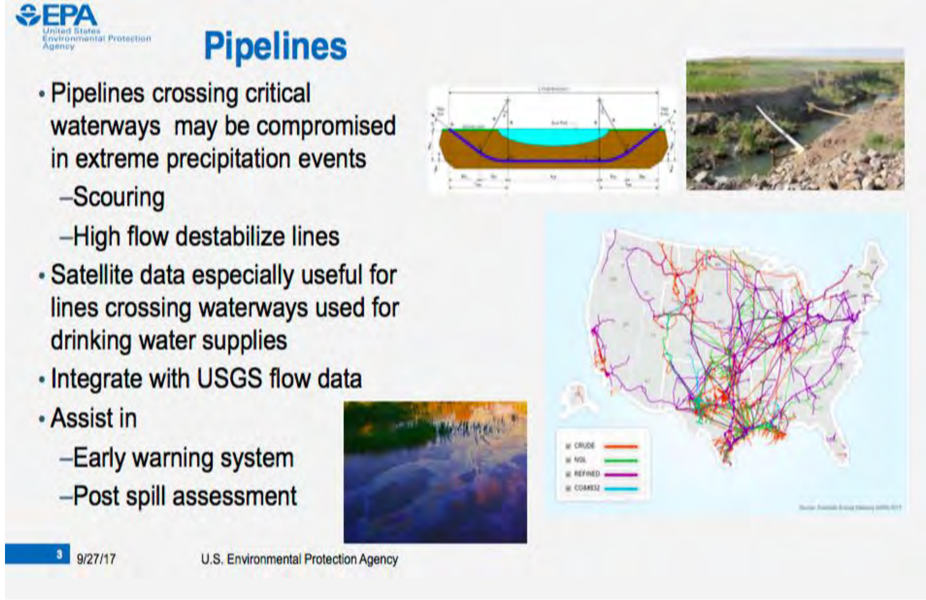
NASA's end-user workshop (Sep 2017)

- Promote **analysis-ready Landsat/Sentinel-2 data** for water quality monitoring
- Understand end-users' needs and requirements
- Attendees: Water authorities, decision-makers, ecologists, private sector, academicians

Distribution of Participants (n ~ 350)




Water Quality Issues in the
Grand Lake Watershed
Grand Lake, Oklahoma. June-July 2011
Grand Lake, Oklahoma. June-July 2011
Marion Lake, Kansas. May 2004


EPA
United States Environmental Protection Agency
Pipelines
• Pipelines crossing critical waterways may be compromised in extreme precipitation events
–Scouring
–High flow destabilize lines
• Satellite data especially useful for lines crossing waterways used for drinking water supplies
• Integrate with USGS flow data
• Assist in
–Early warning system
–Post spill assessment
3
9/27/17
U.S. Environmental Protection Agency


Fall Creek Reservoir
May 01, 2016 Landsat 8
Decision:
To sample or not.
Data courtesy of the U.S. Geological Survey,
image processing by U.S. Army Corps of Engineers, Portland District


Shellfish farming

NASA's Applied Sciences and SDG 6 monitoring

- Since 2017
- Introduce EO-based water quality monitoring
- Engage countries in validating EO products

Latin America (Bogota, Colombia)

Colombia, Peru, Venezuela, Bolivia, Panama, Costa Rica , Ecuador

Africa/Asia (Bellagio, Italy)

Zambia, Senegal, Uganda, Egypt, Mongolia, Colombia

OBSERVATIONS

APPLICATION AREA	SPATIAL	SPECTRAL	TEMPORAL
SHELLFISH FARMS	• Farm planning/site identification • Proximity to shorelines	• Harmful algae bloom identification and mitigation • Ability to distinguish specific algae species • Reliable chlorophyll-a products	Timely products for growth predictions and risk mitigations Diurnal variability of HABs (e.g., Cochlodinium)
DRINKING WATER SUPPLY RECREASIONAL WATERS	30-m may be inadequate (e.g., 62% of U.S. reservoirs can be monitored with 30-m GSD (Clark et. al. 2017)	• HAB detection • HAB quantification/identification • Illegal discharge	Major data gaps in cloudy regions (e.g., Colombia, Senegal)
AQUATIC INVASIVE VEGETATION (AIV)	30-m may be adequate	Separate out IAVs from intensive algal blooms	
PIPELINE LIKEAGE	Narrow streams: < 30m	Detect anomalous features	When it occurs (i.e., disaster response)

OBSERVATIONS

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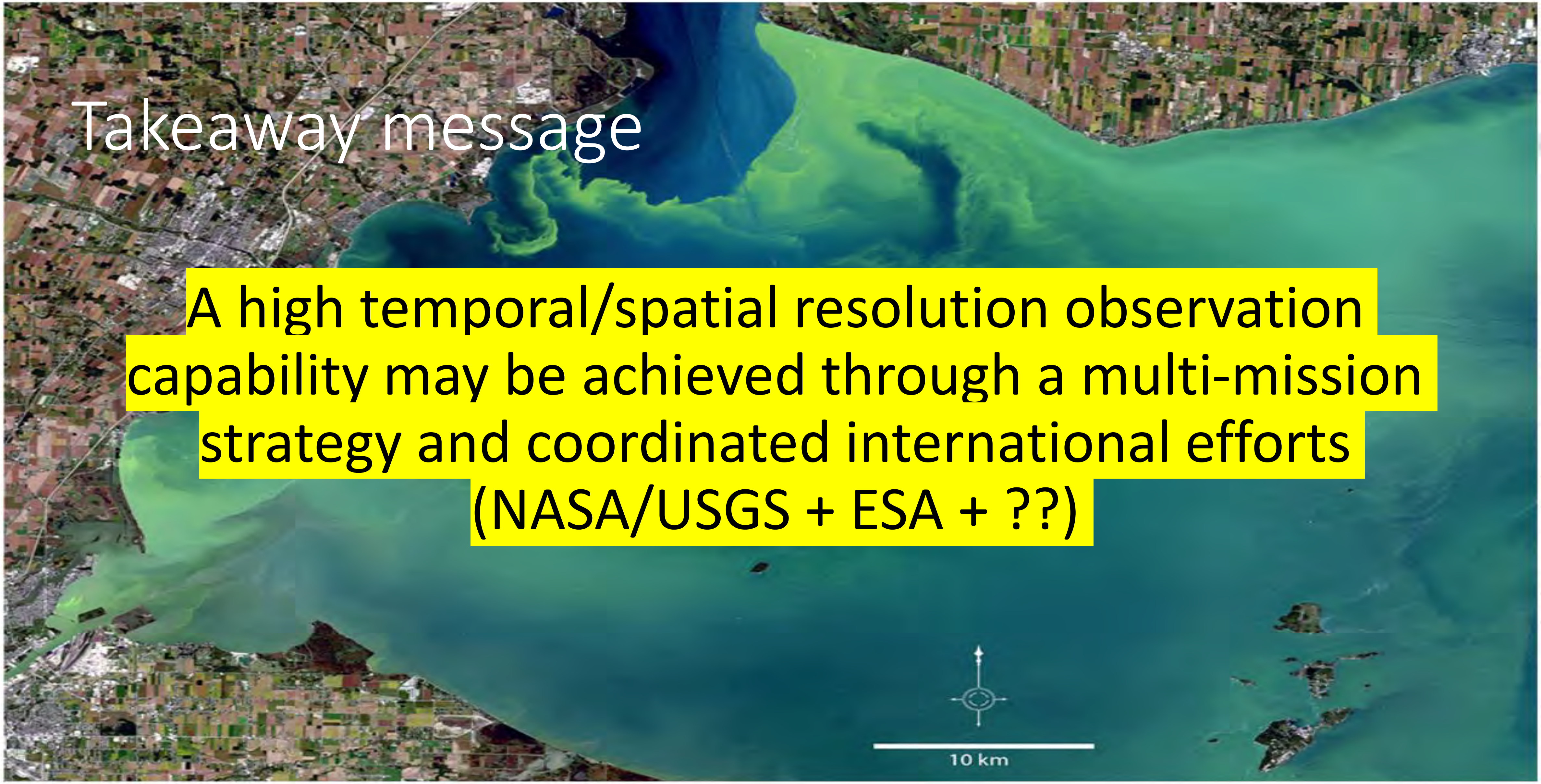
Takeaway message

A high temporal/spatial resolution observation capability may be achieved through a multi-mission strategy and coordinated international efforts (NASA/USGS + ESA + ??)



A hazardous algal bloom containing the toxin microcystis covered large portions of western Lake Erie in September 2017. Swirls of algae can be seen south of Detroit River's mouth in this natural-color Landsat 8 image. Credit: USGS EROS

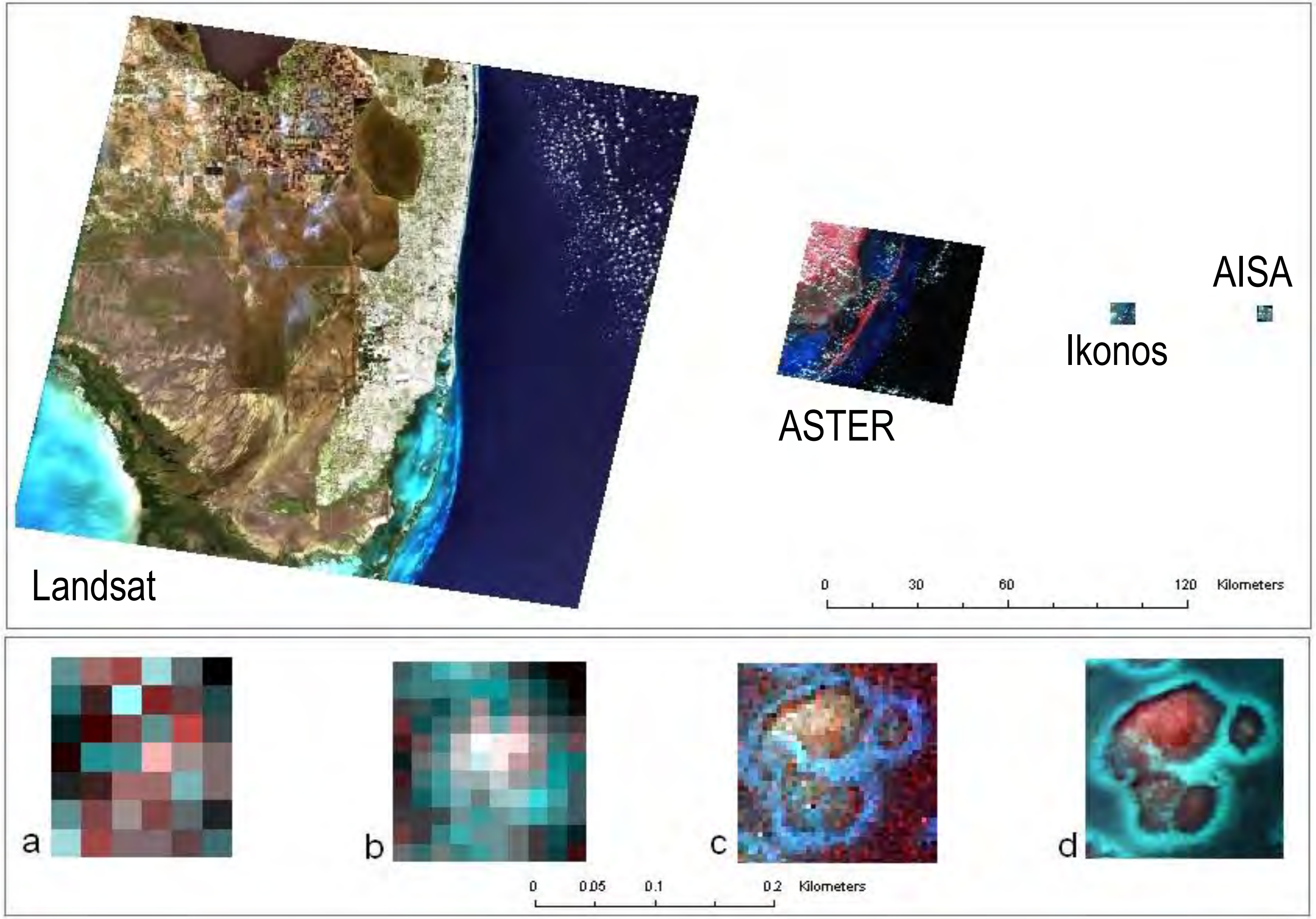
Combined High-Spatial/High-Temporal Resolution Capabilities

Opportunities and challenges in high-res data

Chuanmin Hu

Opportunities and challenges in high-res data

What trade space is optimal between resolution and coverage?



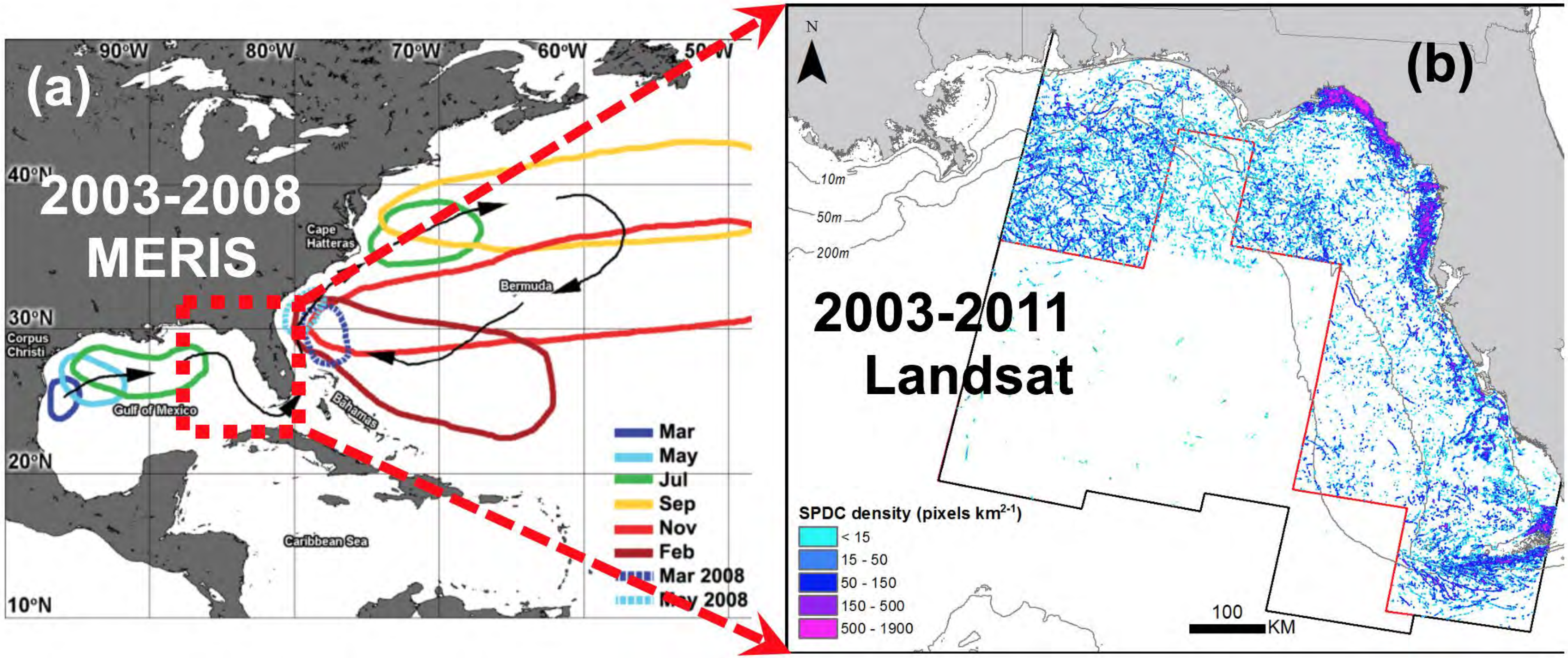
Credit: Damaris Torres-Pulliza

Opportunities and challenges in high-res data

High-res data may fill information gap

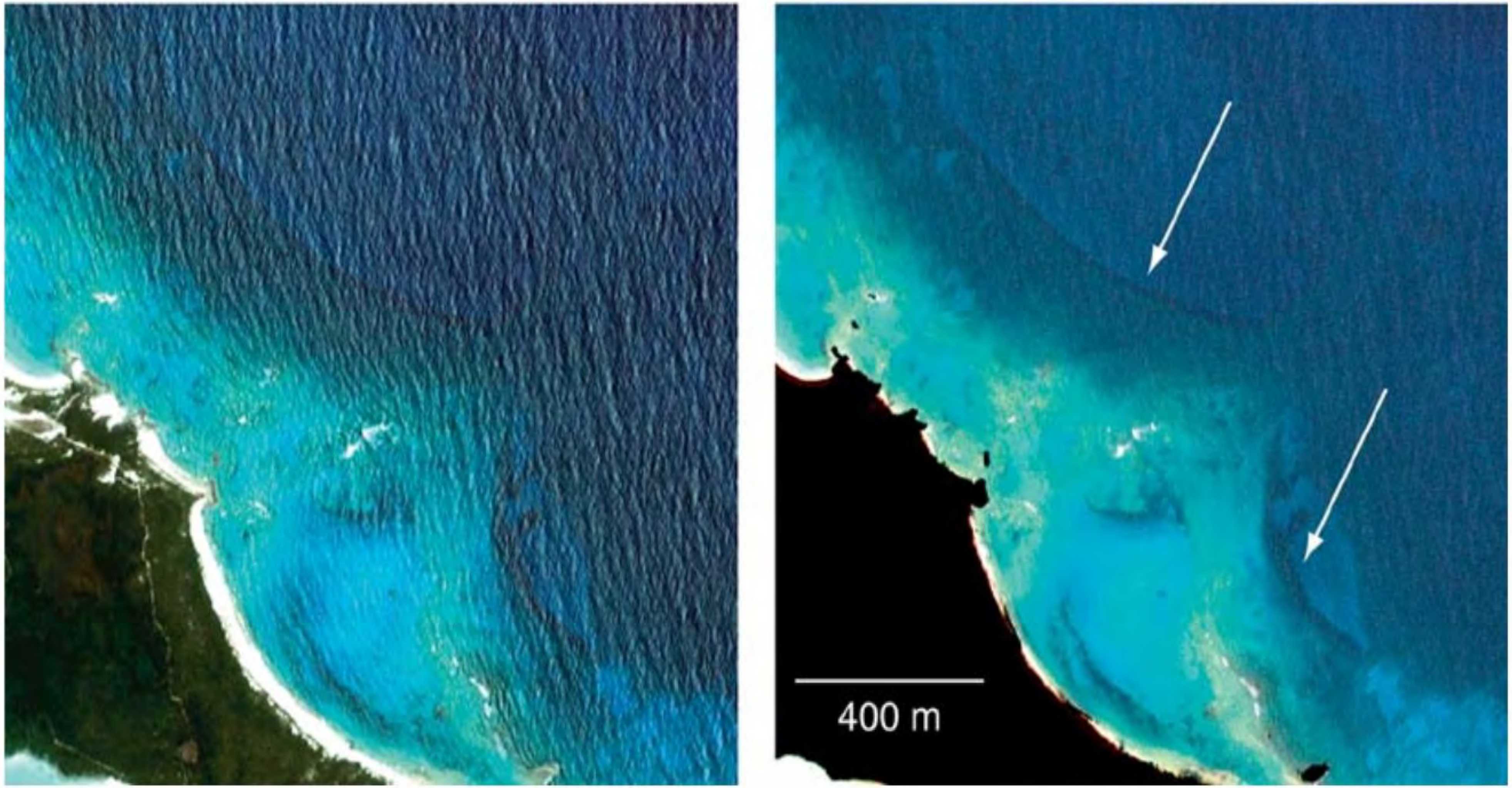
MERIS-based results show virtually no floating algae in the eastern Gulf of Mexico (Gower et al., 2011)

Landsat-based results show lots of floating algae in the eastern Gulf of Mexico (Hardy et al., 2017)



Opportunities and challenges in high-res data

Challenge in correcting glint features due to surface waves

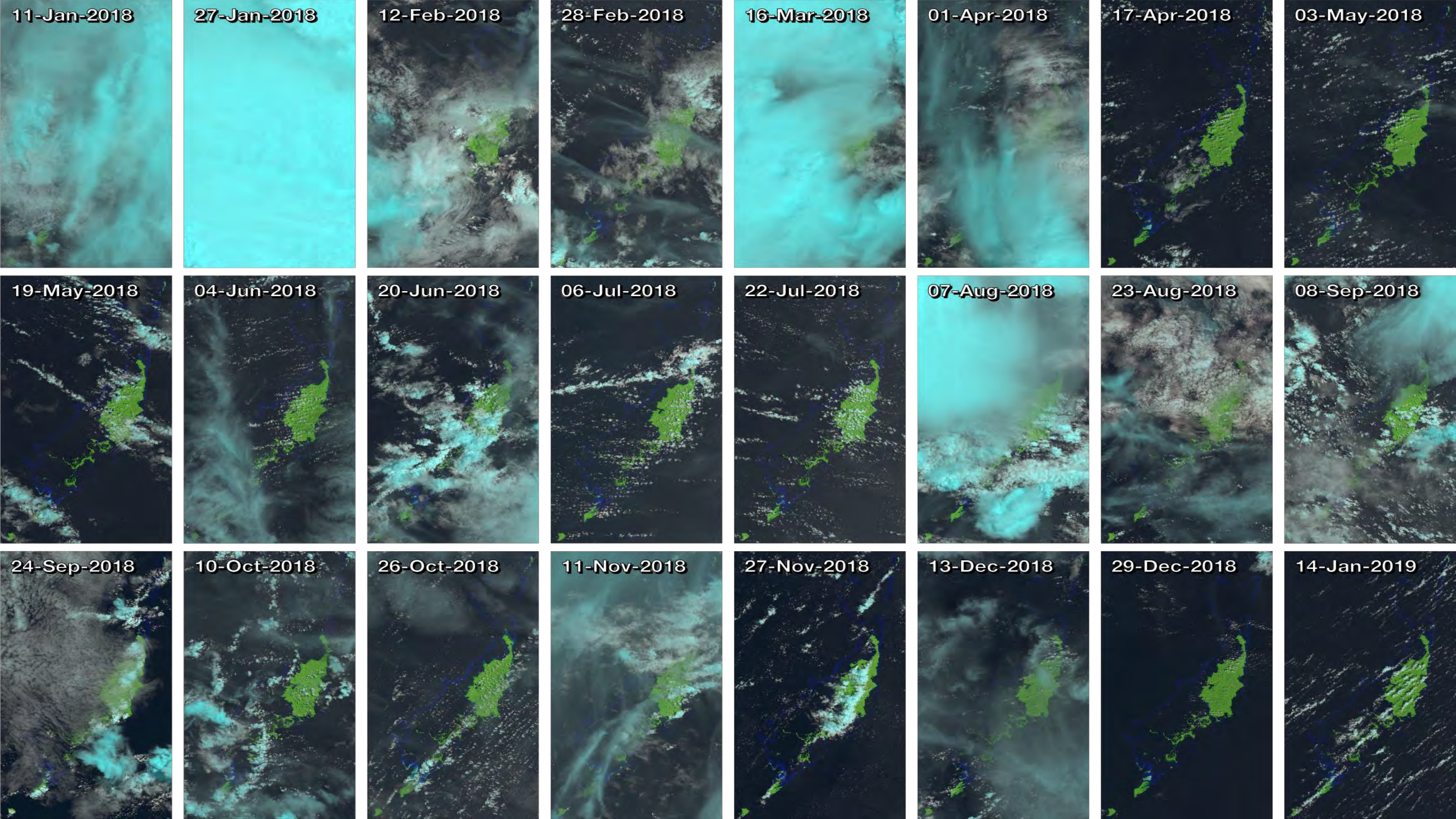


IKONOS image showing sky glint patterns due to surface waves
From Hochberg et al. (2003, IEEE TGRS)

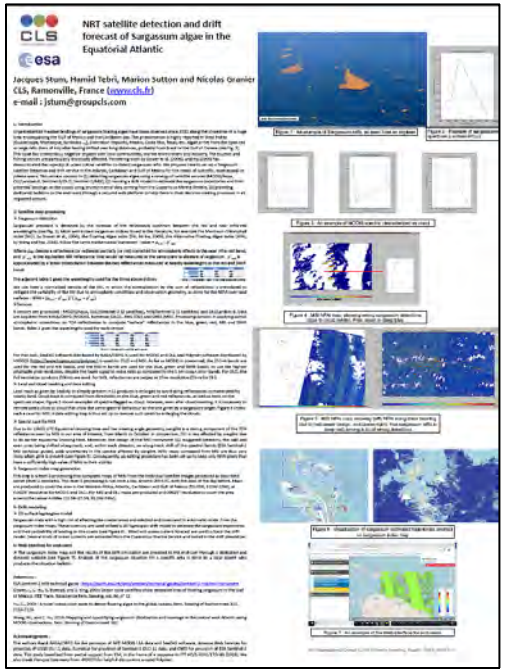
Combined High-Spatial/High-Temporal Resolution Capabilities

Temporal Resolution Considerations for Coral Reef Study

Eric Hochberg


11-Jan-2018
27-Jan-2018
12-Feb-2018
28-Feb-2018
16-Mar-2018
01-Apr-2018
17-Apr-2018
03-May-2018
19-May-2018
04-Jun-2018
20-Jun-2018
06-Jul-2018
22-Jul-2018
07-Aug-2018
23-Aug-2018
08-Sep-2018
24-Sep-2018
10-Oct-2018
26-Oct-2018
11-Nov-2018
27-Nov-2018
13-Dec-2018
29-Dec-2018
14-Jan-2019

Combined High-Spatial/High-Temporal Resolution Capabilities


NRT satellite detection and drift forecast of Sargassum algae in the Equatorial Atlantic
Jacques Stum, Hamid Tebri, Marion Sutton and Nicolas Granier
CLS, Ramonville, France (www.cls.fr)
e-mail : jstum@groupcls.com

NRT satellite detection and drift forecast of Sargassum algae in the Equatorial Atlantic

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CLS, Ramonville, France (www.cls.fr)
e-mail : jstum@groupcls.com

Figure 1 : An example of Sargassum rafts, as seen from an airplane

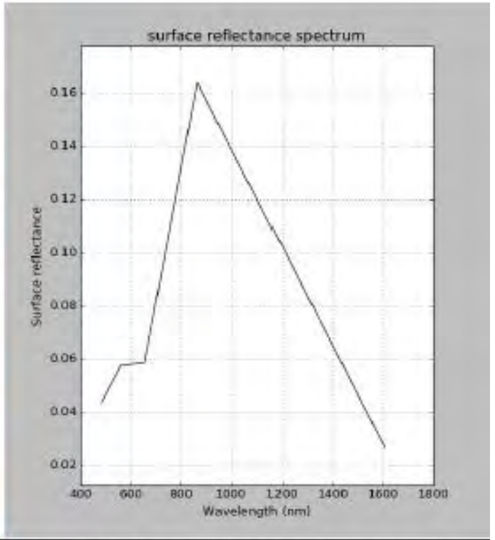


Figure 2 : Example of sargassum spectrum (Landsat-8/OLI)

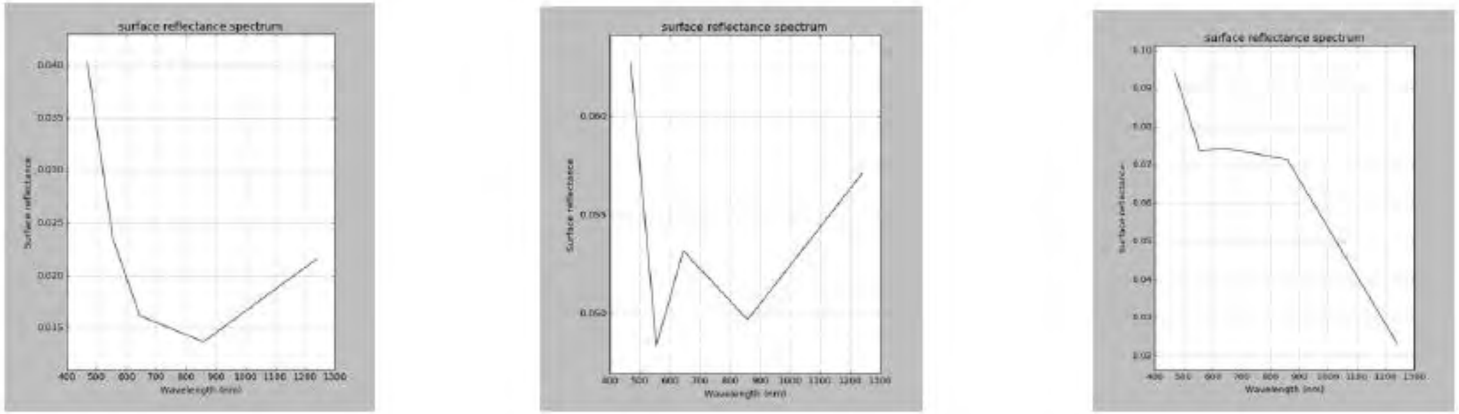


Figure 3 : An example of MODIS spectra, characterized as cloud

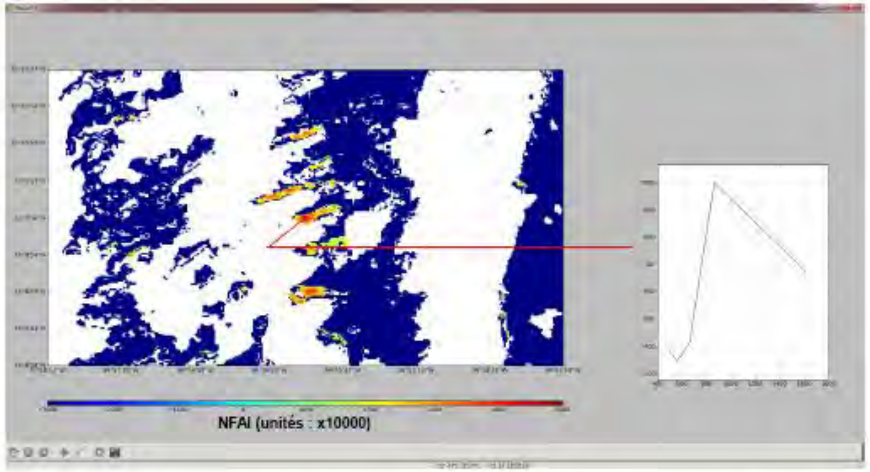


Figure 4 : MSI NFAI map, showing wrong sargassum detections close to cloud (white). Free ocean in deep blue.

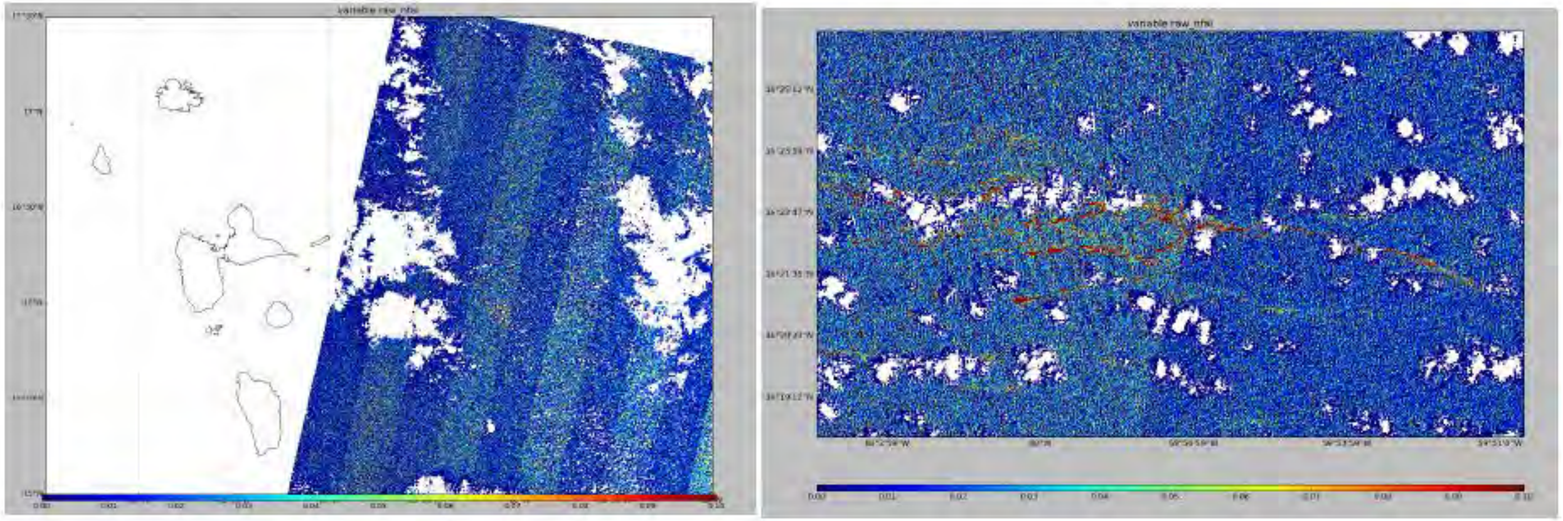


Figure 5 : MSI NFAI map, showing (left) NFAI along-track banding due to instrument design, and (zoom right), true sargassum rafts in deep red) among a lot of wrong detections

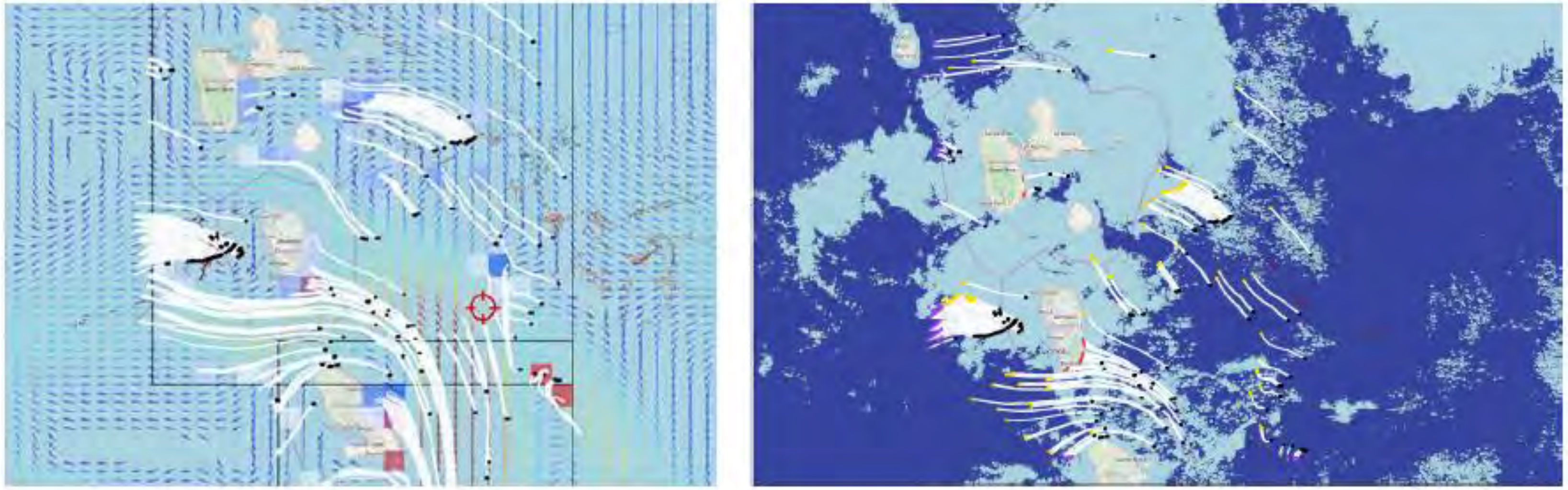


Figure 6 : Visualization of sargassum estimated trajectories overlaid on sargassum index map

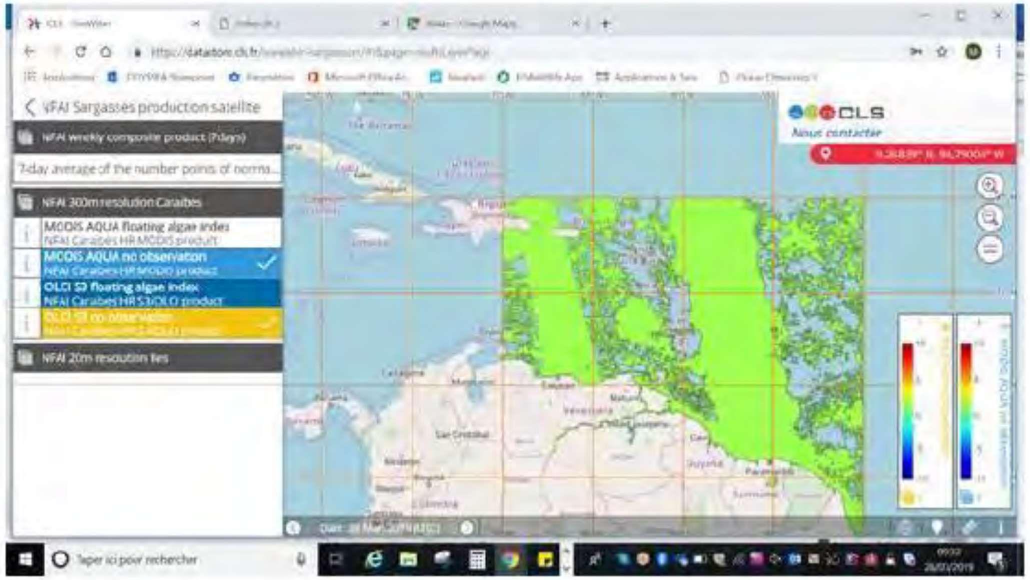
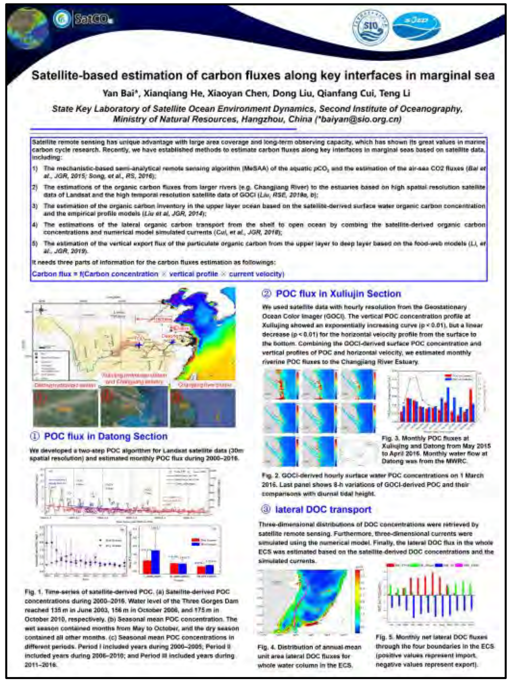


Figure 7 : An example of the Web interface for end-users

Combined High-Spatial/High-Temporal Resolution Capabilities



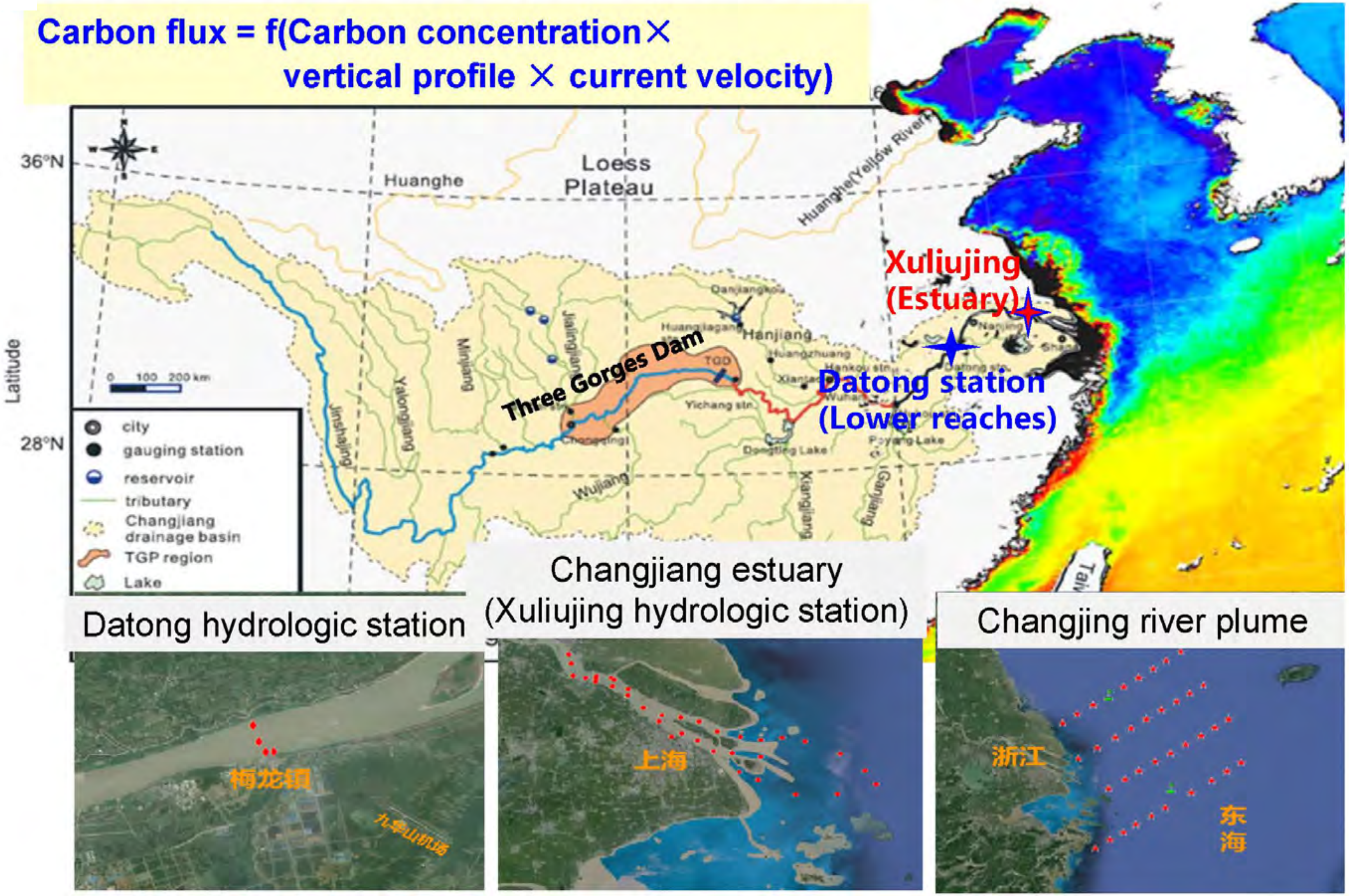
Estimation of terrestrial carbon fluxes based on high spatial/temporal resolution satellite monitoring

Yan Bai*, Xianqiang He, Xiaoyan Chen,
Dong Liu, Qianfang Cui, Teng Li, Zhihong Wang

State Key Laboratory of Satellite Ocean Environment Dynamics (SOED), Second Institute of Oceanography (SIO), Ministry of Natural Resources (MNR), China

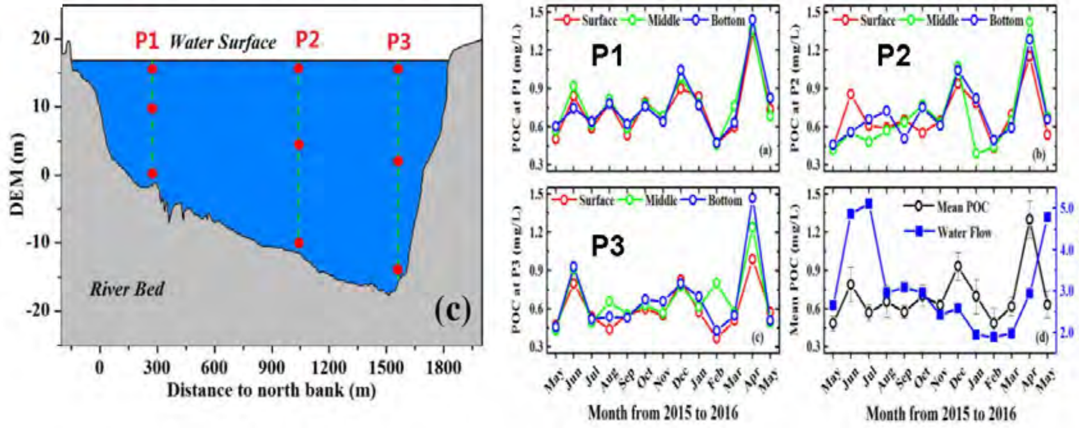
Satellite estimation of carbon fluxes at lower reaches hydrologic station & estuary: Changjiang River

Carbon flux = f(Carbon concentration × vertical profile × current velocity)

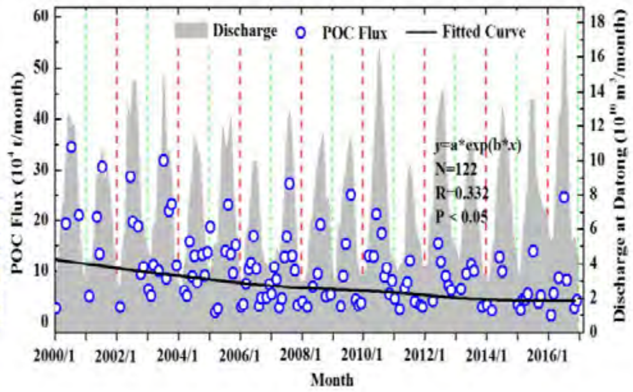


(1) Estimation of particulate organic carbon flux at lower reaches Datong hydrologic station through different stages of the Three Gorges Dam by using high spatial resolution satellite observation *(Liu, Bai*, et al., RSE, 2019a)*

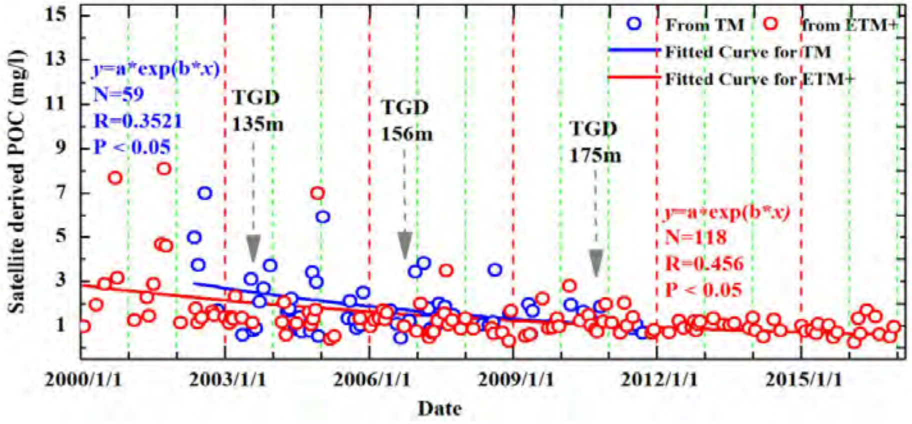
POC concentration was spatially consistent



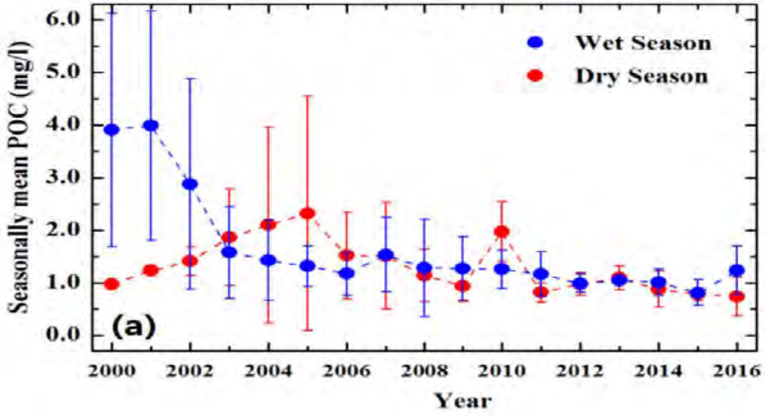
monthly POC fluxes (2000-2016)



POC(Landsat-5 TM and Landsat-7, 30m)

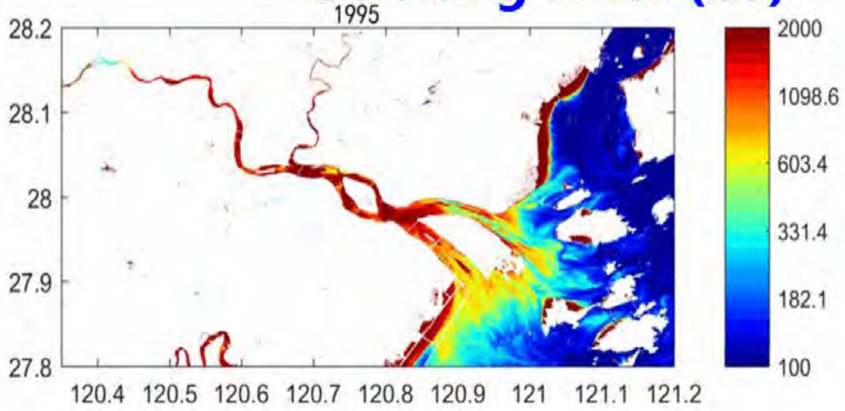


Seasonal POC concentration

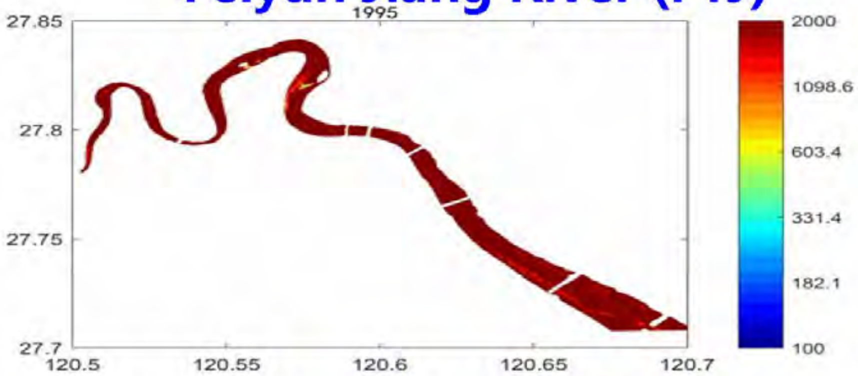


Example: Time series of Lansat-TM derived TSM concentration in small rivers (Wang, et al., unpublished data)

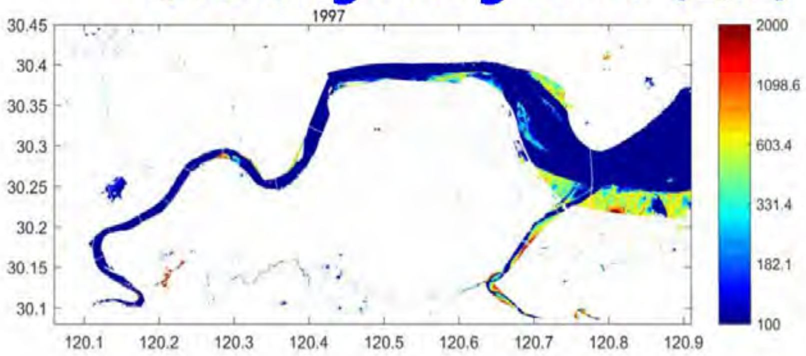
Ou Jiang River (OJ)



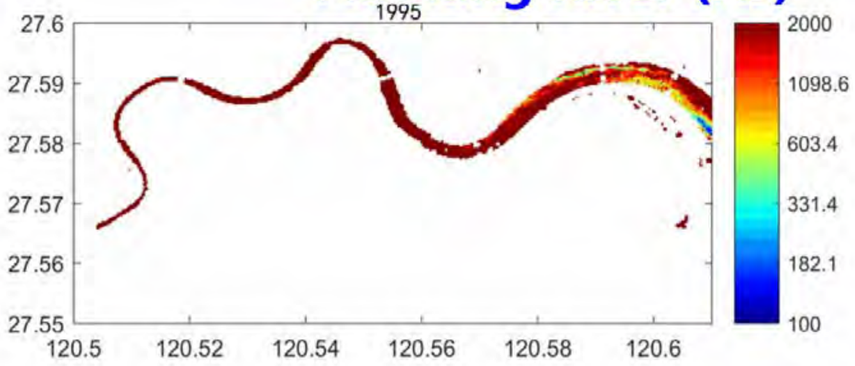
Feiyun Jiang River (FYJ)



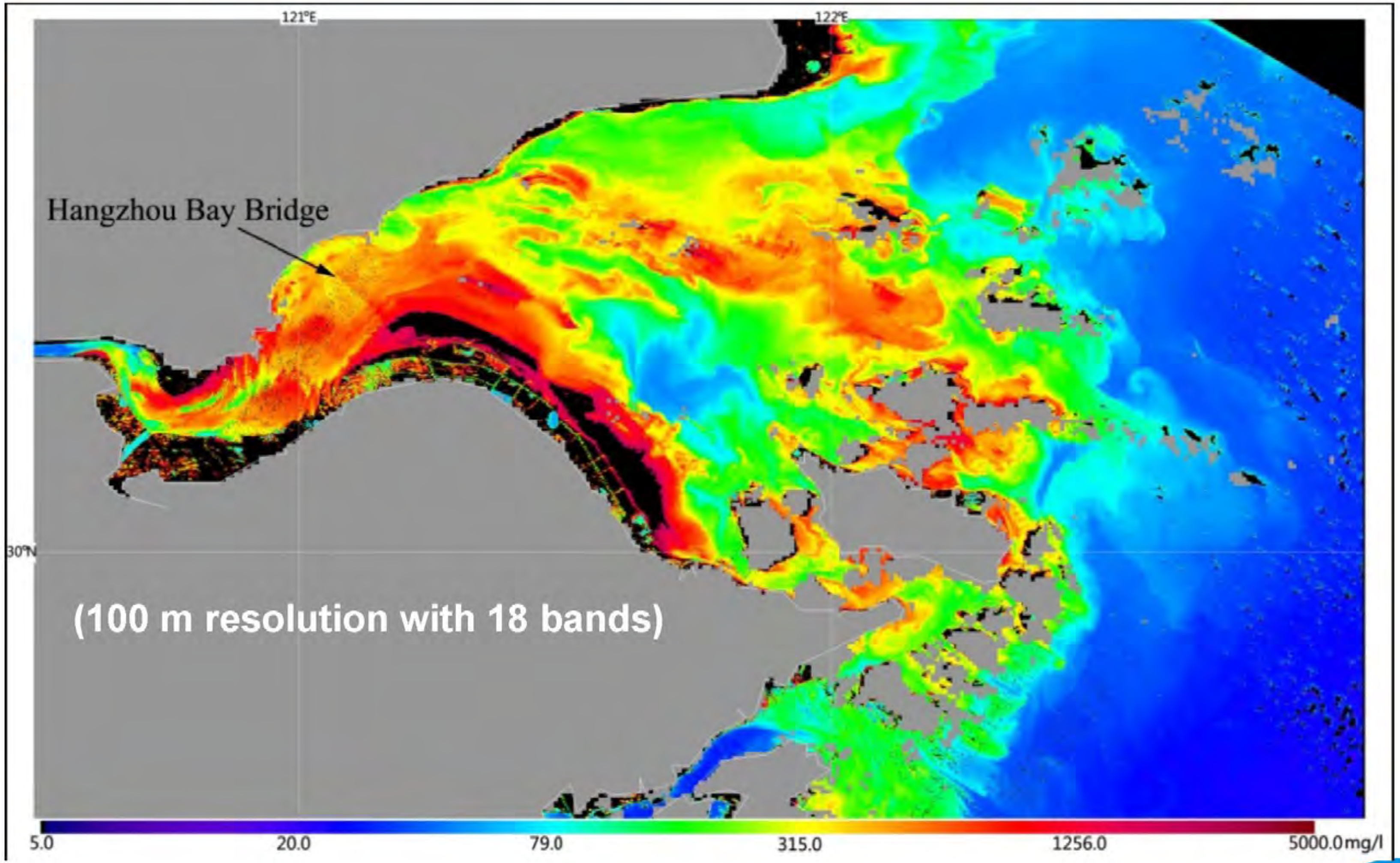
Qiantang Jiang River (QTJ)



Ao Jiang River (AJ)

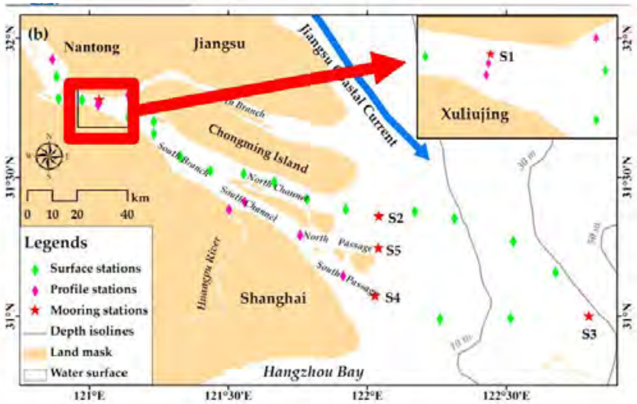


Example: satellite observation of the TSM dynamic in the Hangzhou Bay by the "Tiangong-2" Space Lab (*He et al., OE, 2017*)



Ocean Satellite SOED

(2) Estimation of POC flux from Changjiang River to the estuary by high temporal resolution satellite observation from GOCI *(Liu, Bai*, et al., RSE, 2019b)*



$$[\text{POC Flux}] = \int_0^1 \text{POC}(x) \times \text{D}(x)dx$$

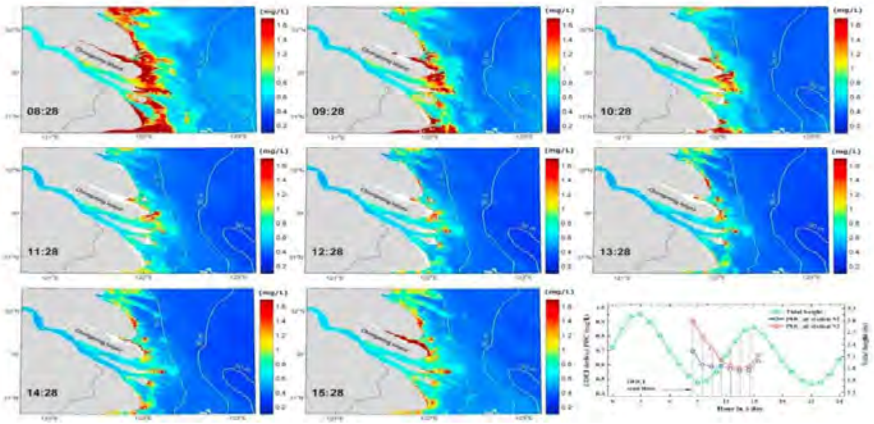
1) Vertical profile of POC (exponentially increasing curve)

$$\text{POC}(x) = (2.21 \times \text{POC1-0.59}) \times e^{-0.79x} + 0.26,\ p < 0.01$$

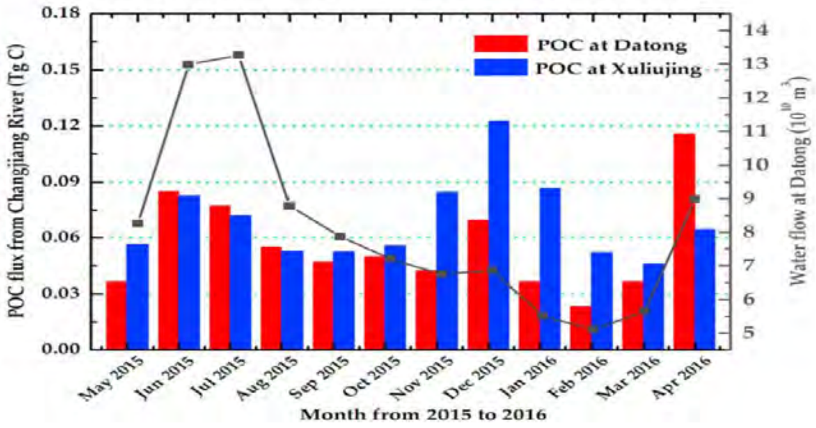
2) vertical distribution of daily water flow(linear decrease)

$$\text{D}(x) = \text{D1} \times (0.27 \times x + 0.73),\ p < 0.01$$

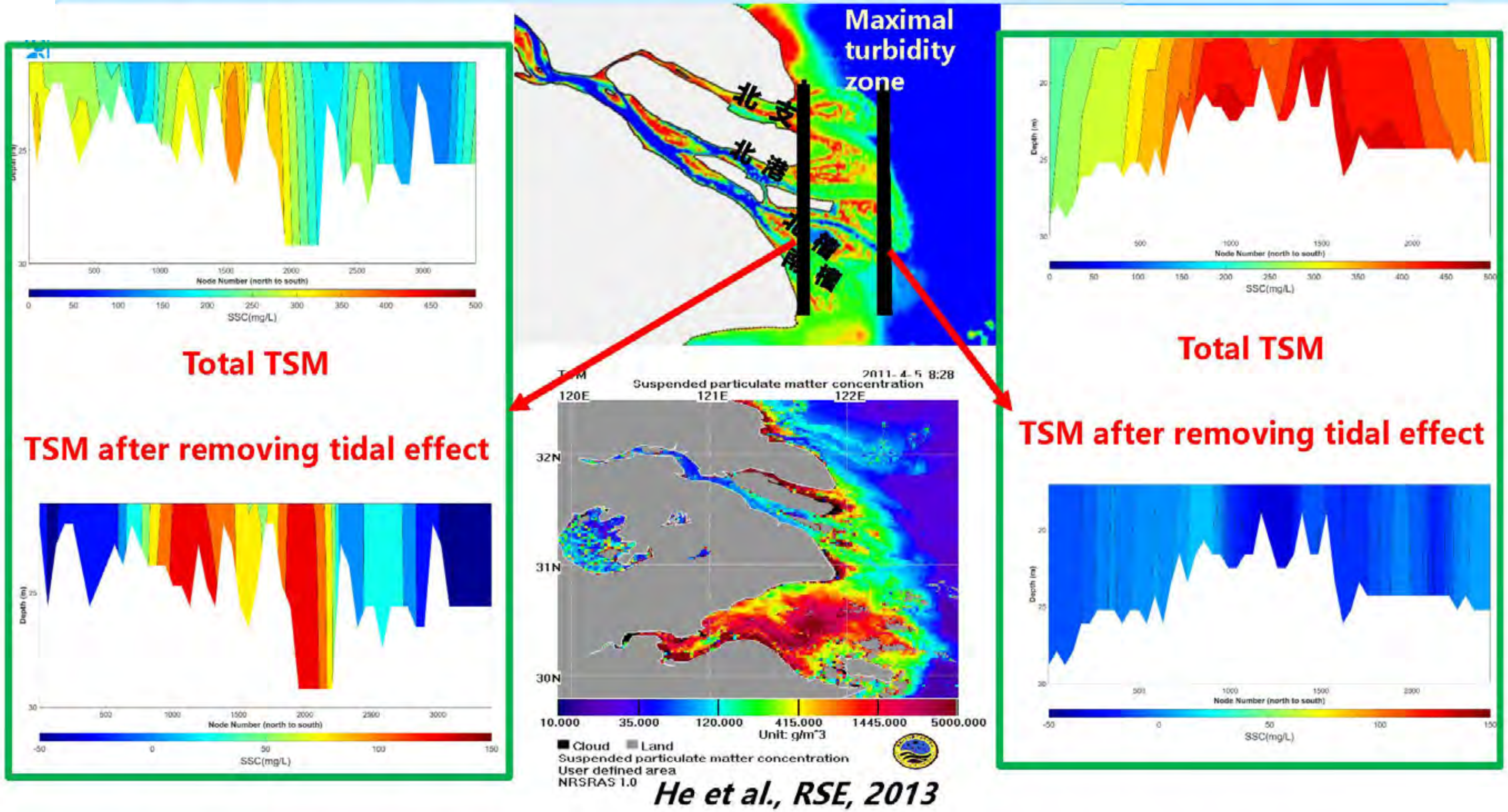
Hourly surface GOCI-derived POC Concentrations (500m) on 1 March 2016.



Monthly POC fluxes at Xuliujing and Datong from May 2015 to April 2016.



(3) Combing GOCI-derived POC concentration and FVCOM-simulated current to estimate POC flux to the shelf



Based on model simulation and GOCI-derived POC, POC flux to the shelf is smaller that of that at estuary by deposition.

(4) Estimating dissolved organic carbon inventories in the East China Sea using remote-sensing data*(Liu, Bai*, et al., JGR, 2014)*

$$OC_{reservior} = \int_{0}^{z_{eu}} OC_{surf} * f(z, L)\,dz$$

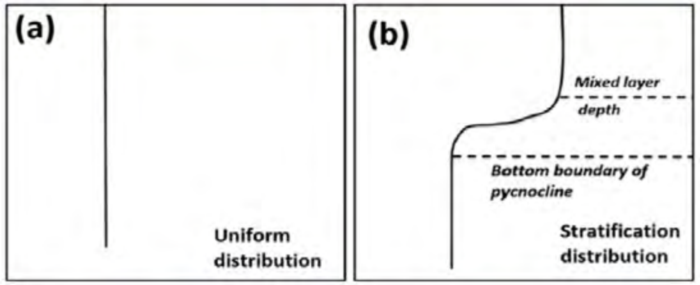
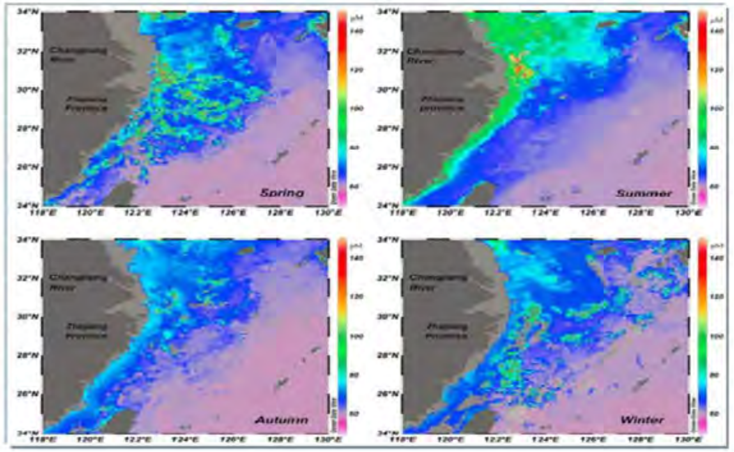
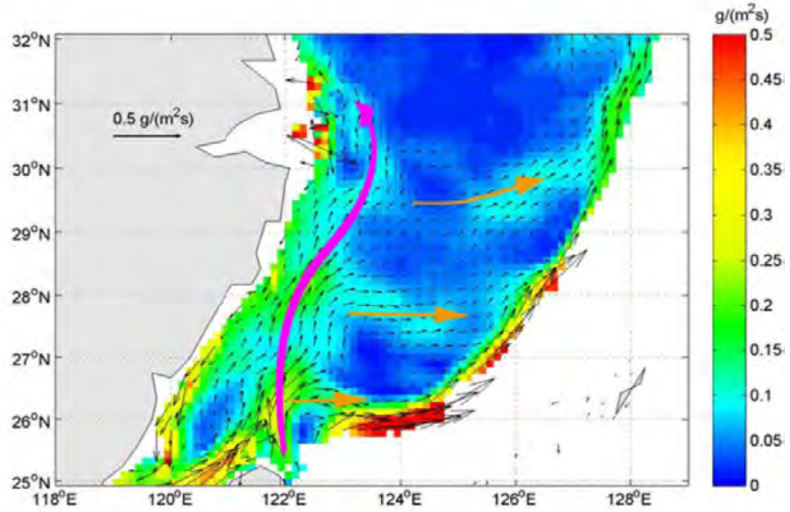
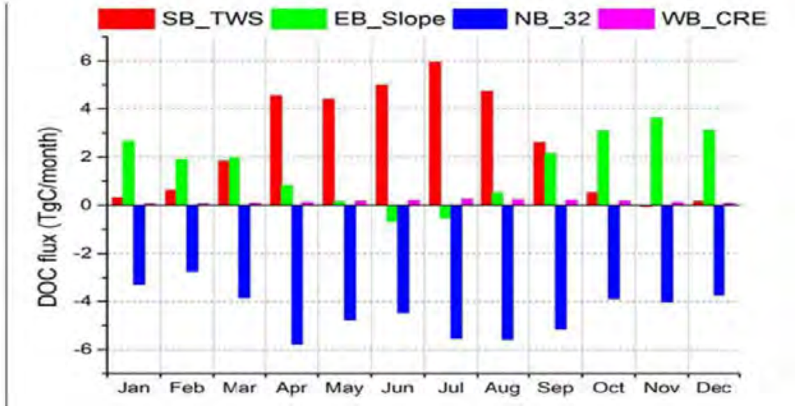


Figure 6. Two simplified models of the vertical DOC profile: (a) a uniform model and (b) a stratification model.



(5) Estimation of lateral DOC transport in marginal sea based on remote sensing and numerical simulation*(Cui, He*, et al., JGR, 2018)*





Thank you for your attention!

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SatCO2 is also a Platform to Connect Scientists and End-Users to Enrich the Products.

Combined High-Spatial/High-Temporal Resolution Capabilities

Hyperspectral Application of Derivative Spectroscopy

Joe Ortiz

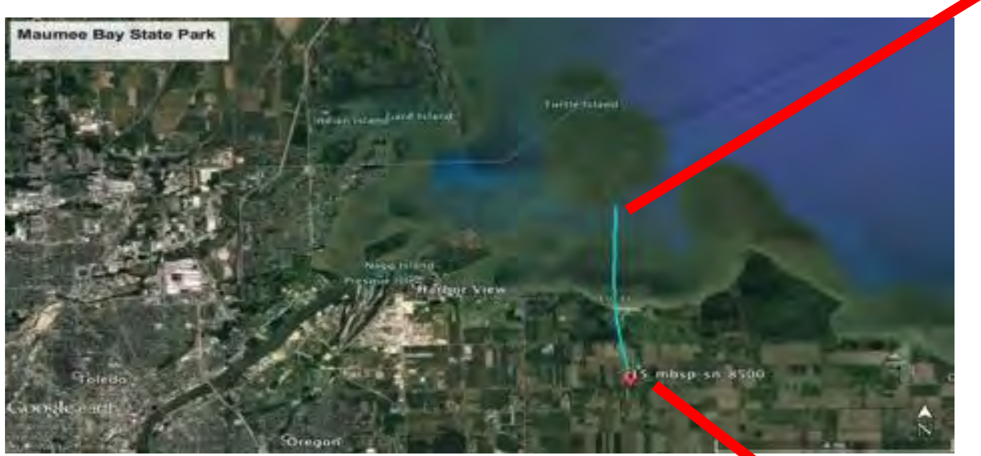
Hyperspectral Application of Derivative Spectroscopy

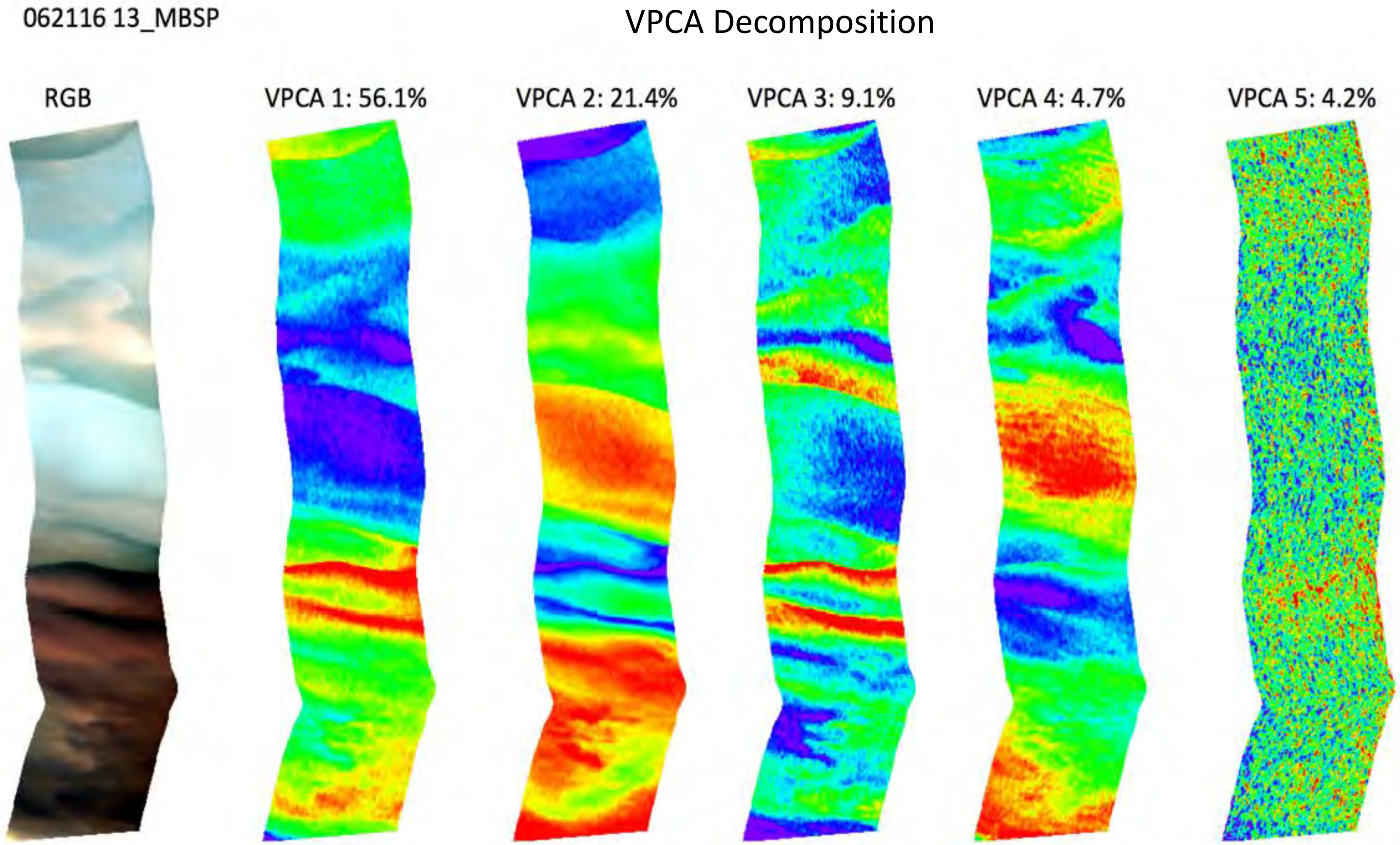
KENT STATE UNIVERSITY

<u>NASA HSI2 (Hyperspectral Imager 2)</u>

North of Maumee Bay State Park

June 21, 2016, Swath 13

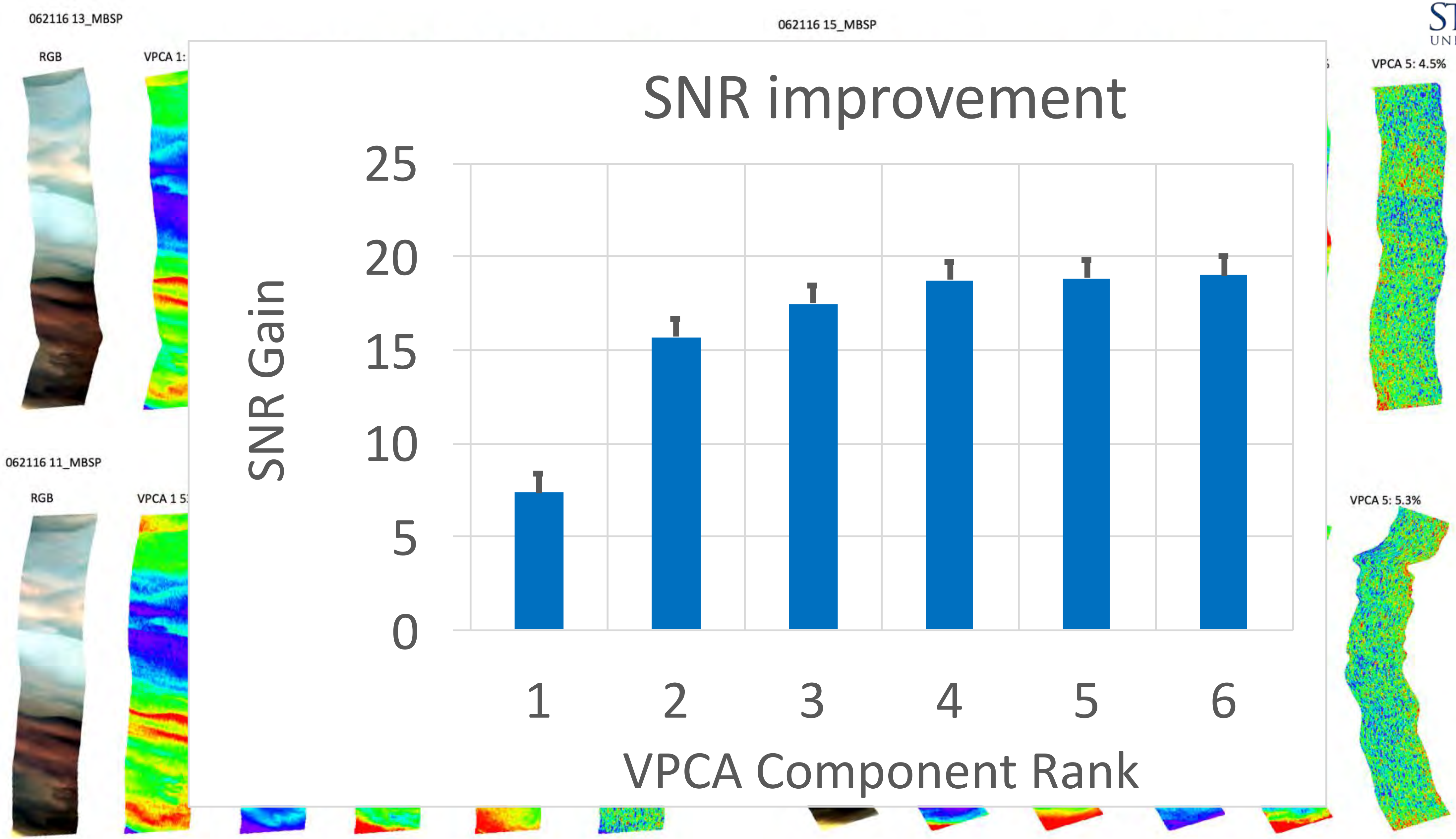




Original Image (RGB)

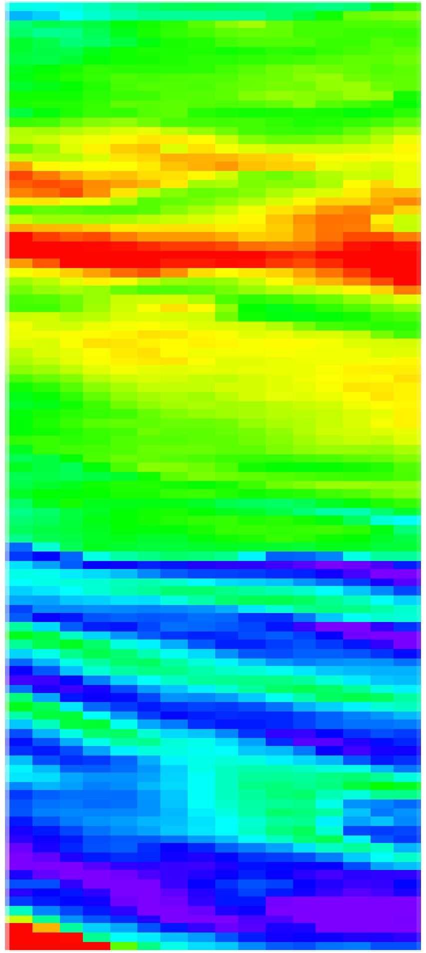
Initial SNR 1000:1

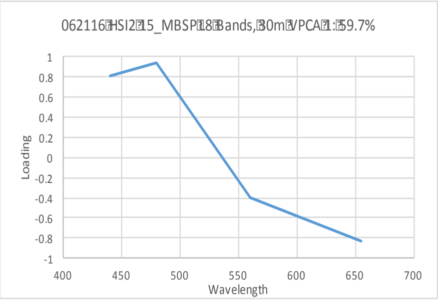
After: Ortiz *et al.* JGLR, 2019



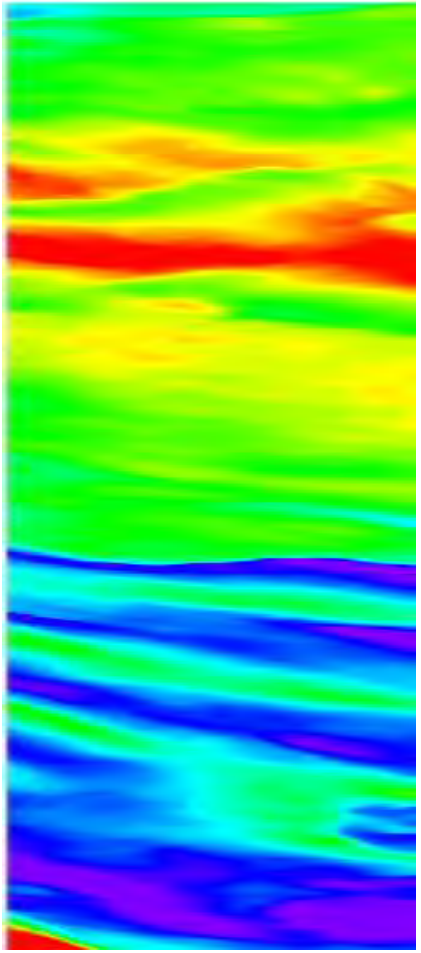
After: Ortiz *et al.* JGLR, 2019

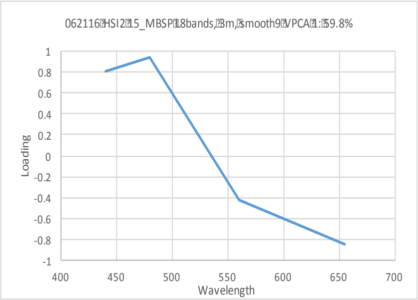
VPCA 1 Simulated L8 bands, 30m



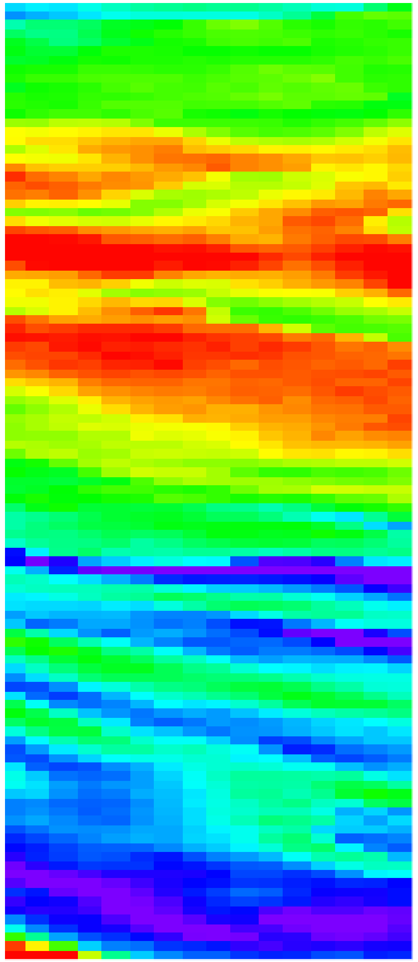


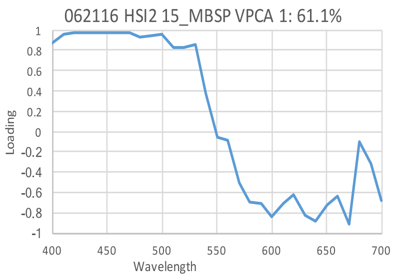
VPCA 1 Simulated L8 bands, 3m, Smooth 9x9



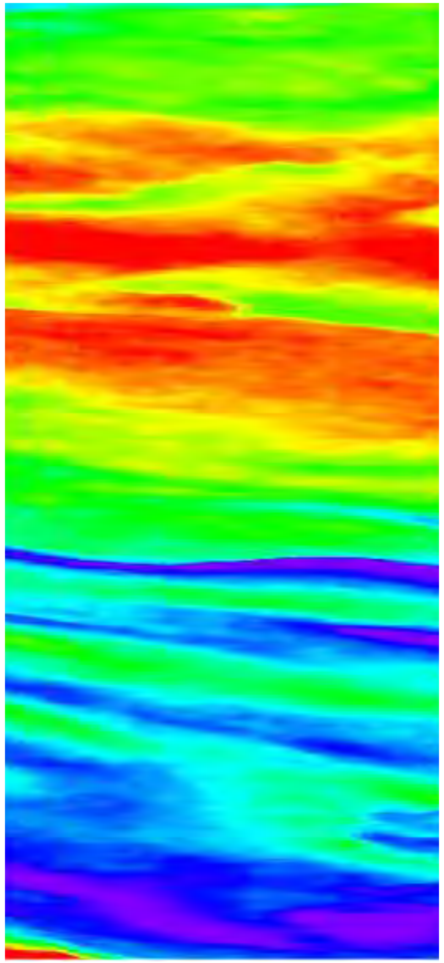


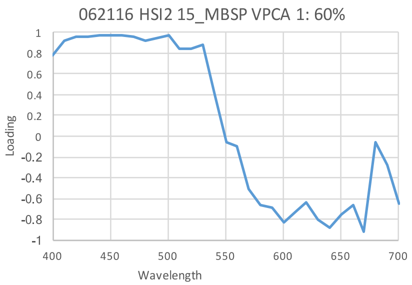
VPCA -1 HSI2 10nm, 30 m





VPCA1 HSI2 10nm, 3 m, Smooth 9x9





Composition:
Illite,
diatoms and
phycoerythrin
(R=0.94)

N

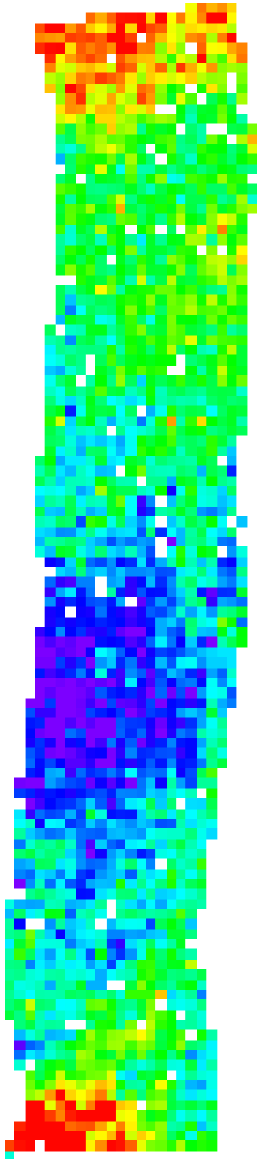
Ortiz et al., (HyspIRI 2017; jortiz@kent.edu)

Actual L8 Image Decomposition

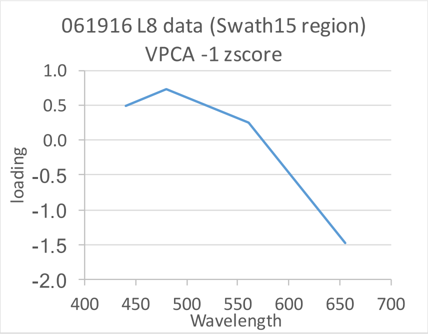
061916 L8 (surface reflectance product), swath15 subset: VPCA decomposition

RGB

061916 L8 swath 15 subset VPCA -1

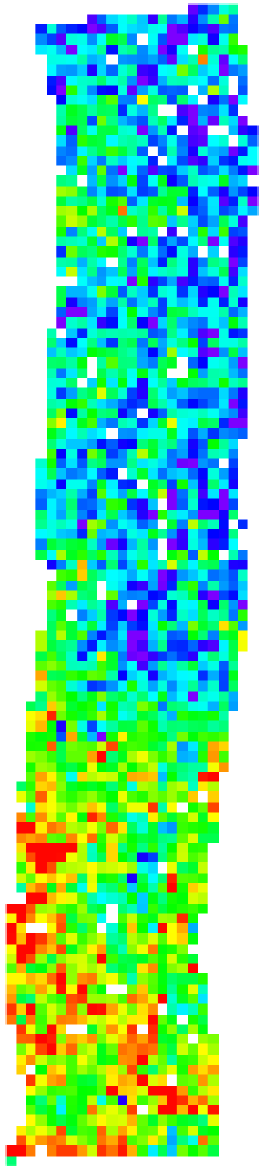


Composition:
Diatoms
(R=0.996)

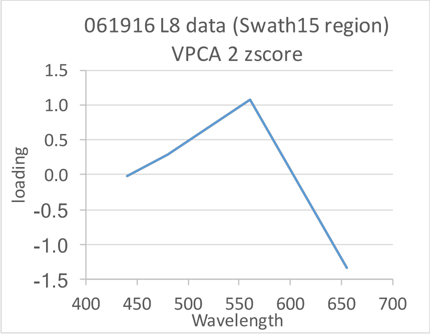


↑N

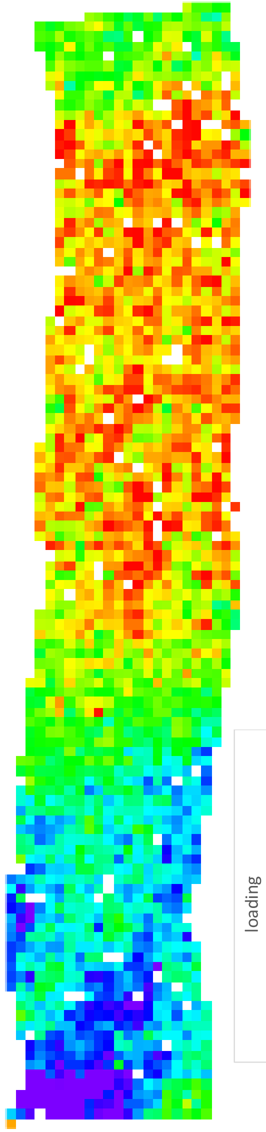
061916 L8 swath 15 subset VPCA 2



Composition:
Phycocyanin
(R=0.993)

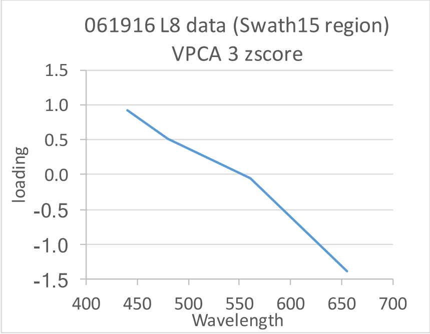


061916 L8 swath 15 subset VPCA 3



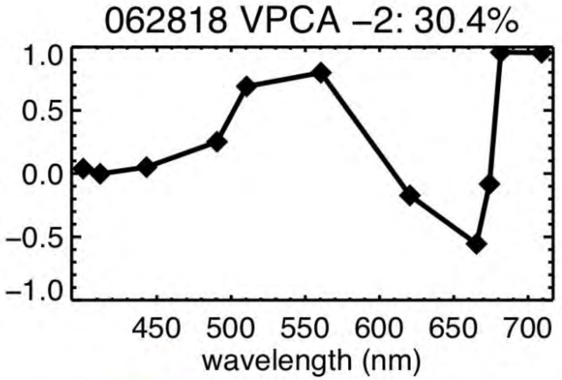
KENT STATE UNIVERSITY

Composition:
Chl a &
carotenoids
(R=0.996)

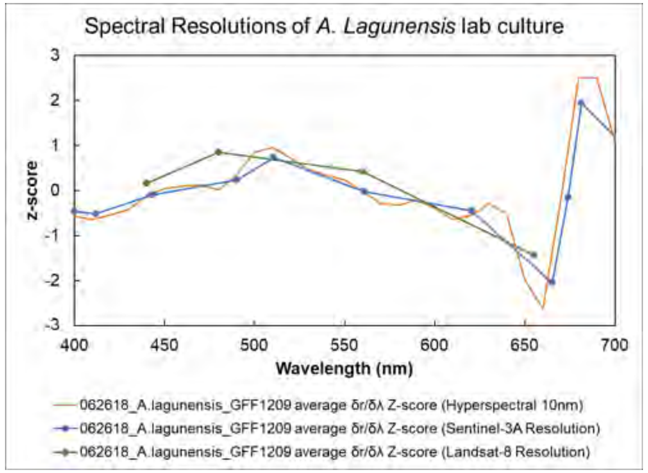


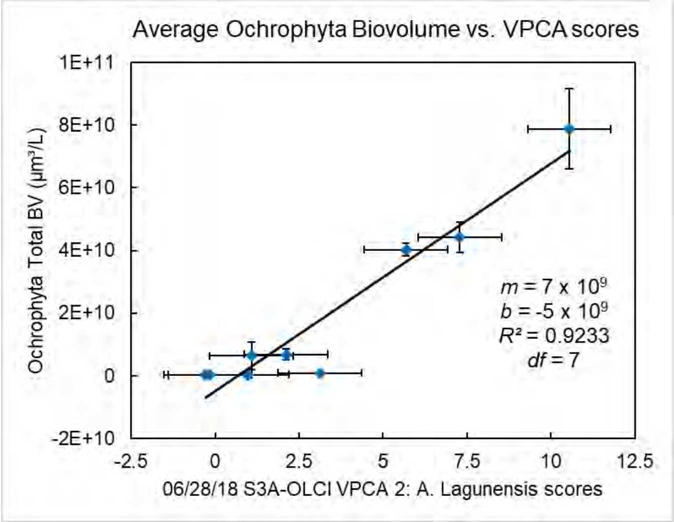
Ortiz et al., (HyspIRI 2017; jortiz@kent.edu)

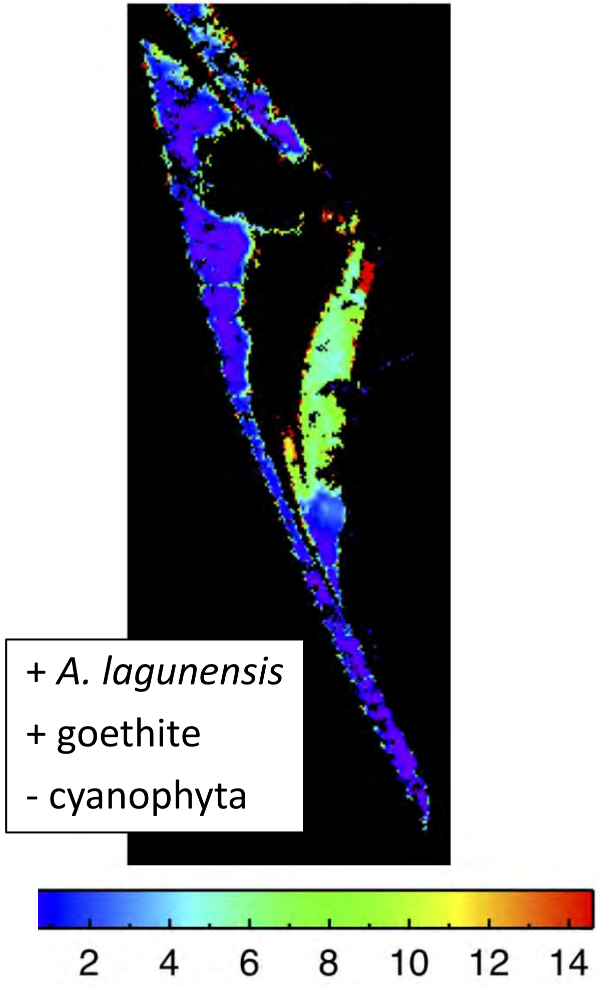
Indian River Lagoon Brown Tide
A. lagunensis from Sentinel-3A



- KSU VPCA spectral decomposition identifies Brown Tide in IRL, Florida
- Spectral signature for *A. lagunesis* in spectral library matches spectral signal extracted from Landsat 8 OLI, Sentinel-3A OLCI
- Landsat 8 OLI, Sentinel-3A OLCI spatial patterns match known Brown tide in Mosquito Creek, IRL
- Cell count concentration for Ochrophyta match pixels values extracted from Sentinel-3A OLCI (R^2= 0.92)







Taylor Judice, Kent State Univ., 2019; Funding: HW Hoover Foundation