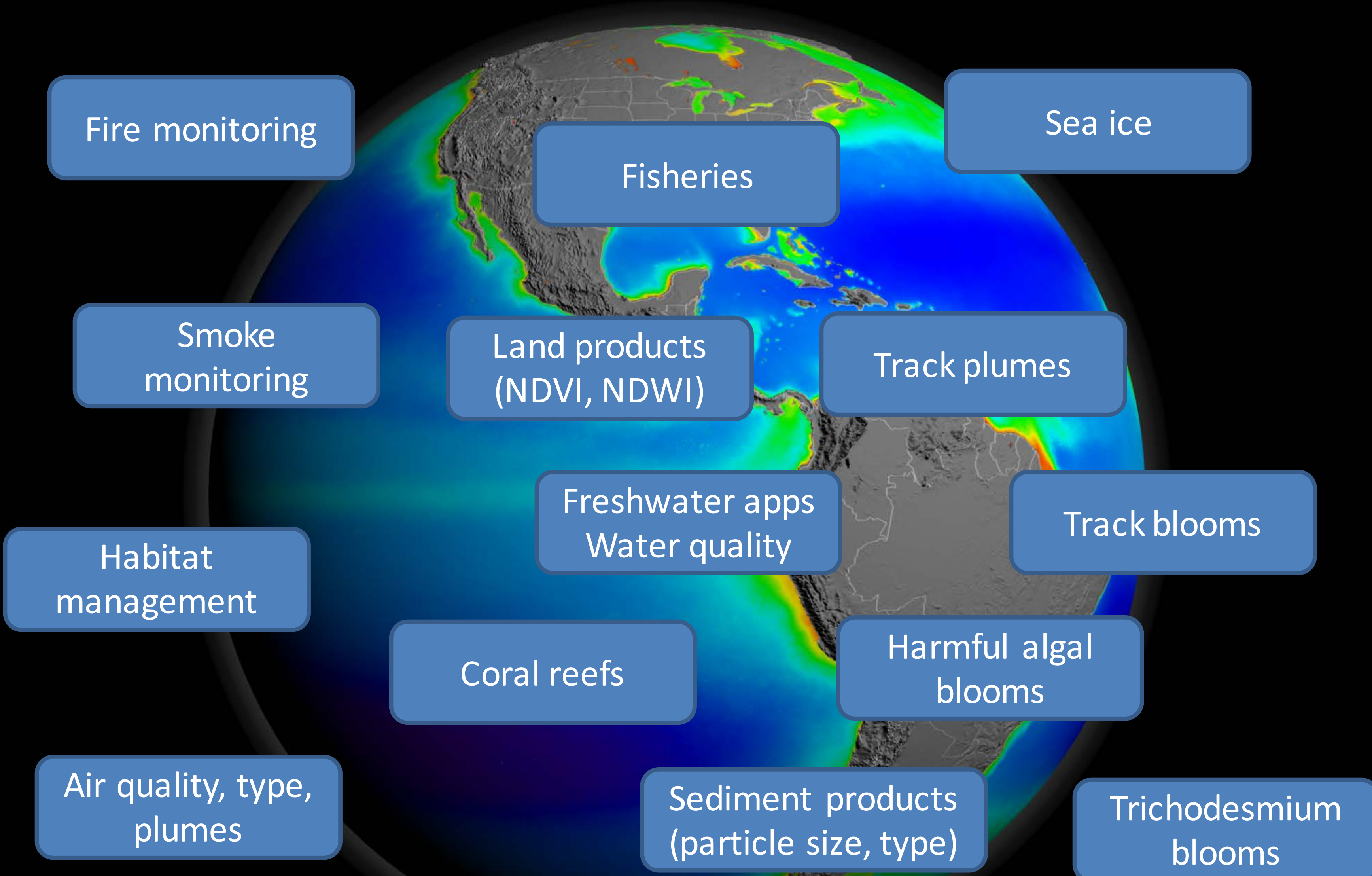


PACE: How can we do our Science in a way that will maximize its utility

Maria Tzortziou (CCNY/GSFC)

Ali Omar (NASA/LARC), Woody Turner (NASA HQs)

Why ?

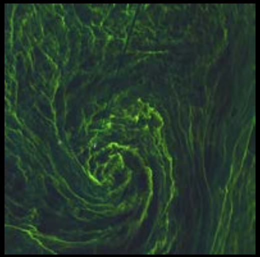
2007 report *Earth Science and Applications from Space: National Imperatives for the Next Decade* (commonly referred to as the Decadal Survey) specifically calls for: 'societal needs help to guide scientific priorities more effectively and that emerging scientific knowledge is actively applied to obtain societal benefits'

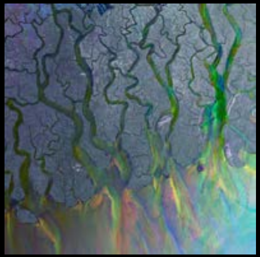
Supply — *Supply of knowledge & information*

Demand — *Need to use this information/knowledge*









Objective #1:

Link, early in the mission development process, the PACE products to specific applications questions, so to that **PACE products become relevant/useful to an as wide user community as possible.**

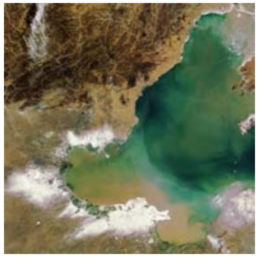
Objective #2:

*Assess and **achieve consensus recommendations within the Science Team on the spectrum of applications we can address with PACE** measurements and retrieval approaches.*

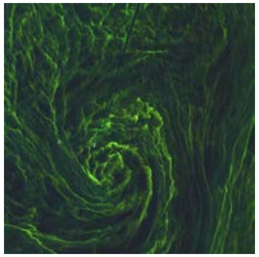
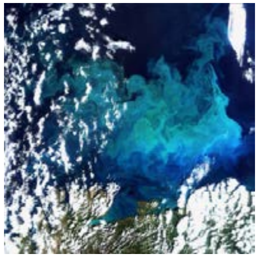
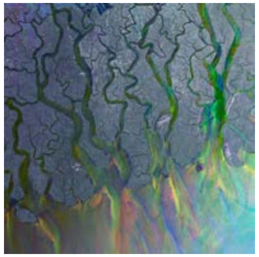
Objective #3:

Identify **measurement requirements and accuracy needs** for specific application concepts.

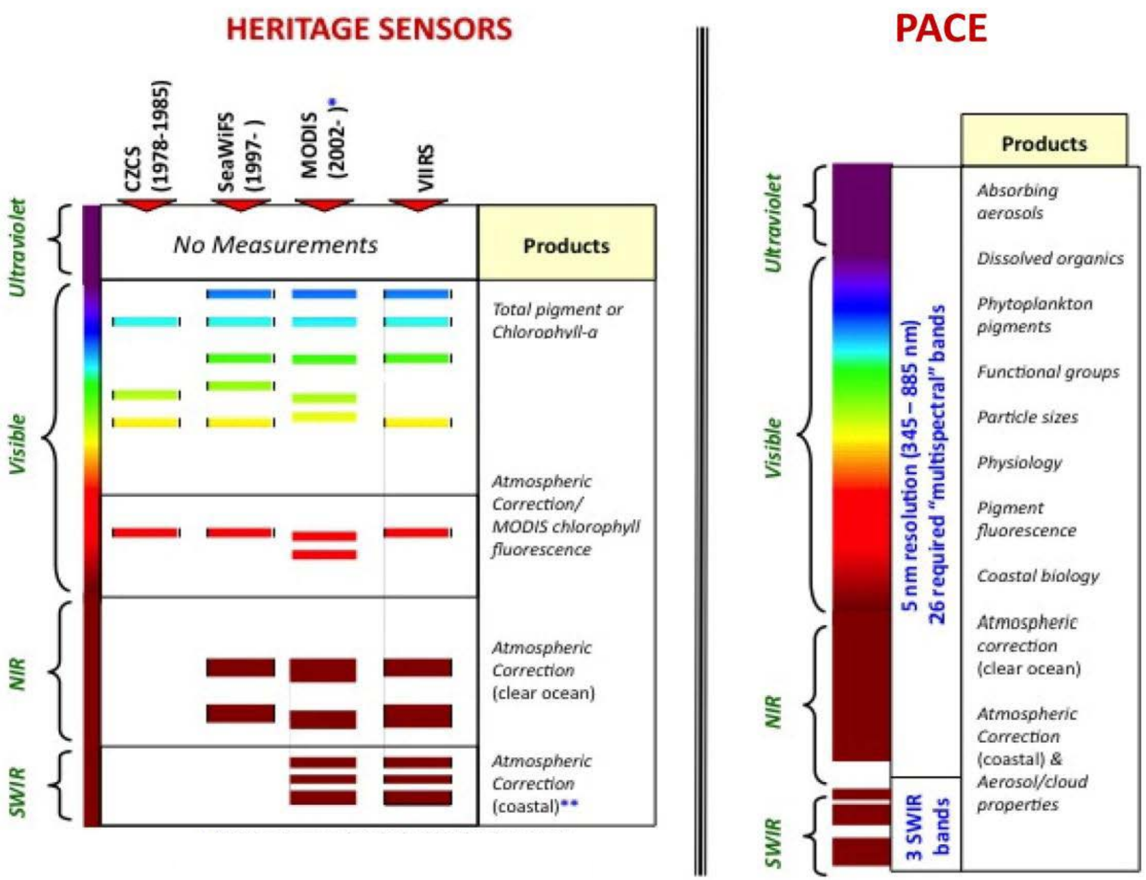
NOAA Habitats	NRL	GoM Fishery Mgmt Council	NOAA Fisheries	US Navy	NOAA Weather
US Army Corps of Engineers	Fed. Aviation	BOEM	EPA Air Quality	EPA Water Quality	NOAA Coasts





PACE: A Climate Initiative Mission with Enhanced Capabilities



PACE advanced capabilities :

- **hyper-spectral** data
- **extended spectral** range (UV-SWIR)
- **2-day global coverage**
- **higher signal-to-noise**
- Multiple observations at **high lat**
- key observations of **aerosols/clouds**
- enhanced **atmospheric correction**

ENHANCED SCIENCE & APPLICATIONS
ocean, atmosphere, land

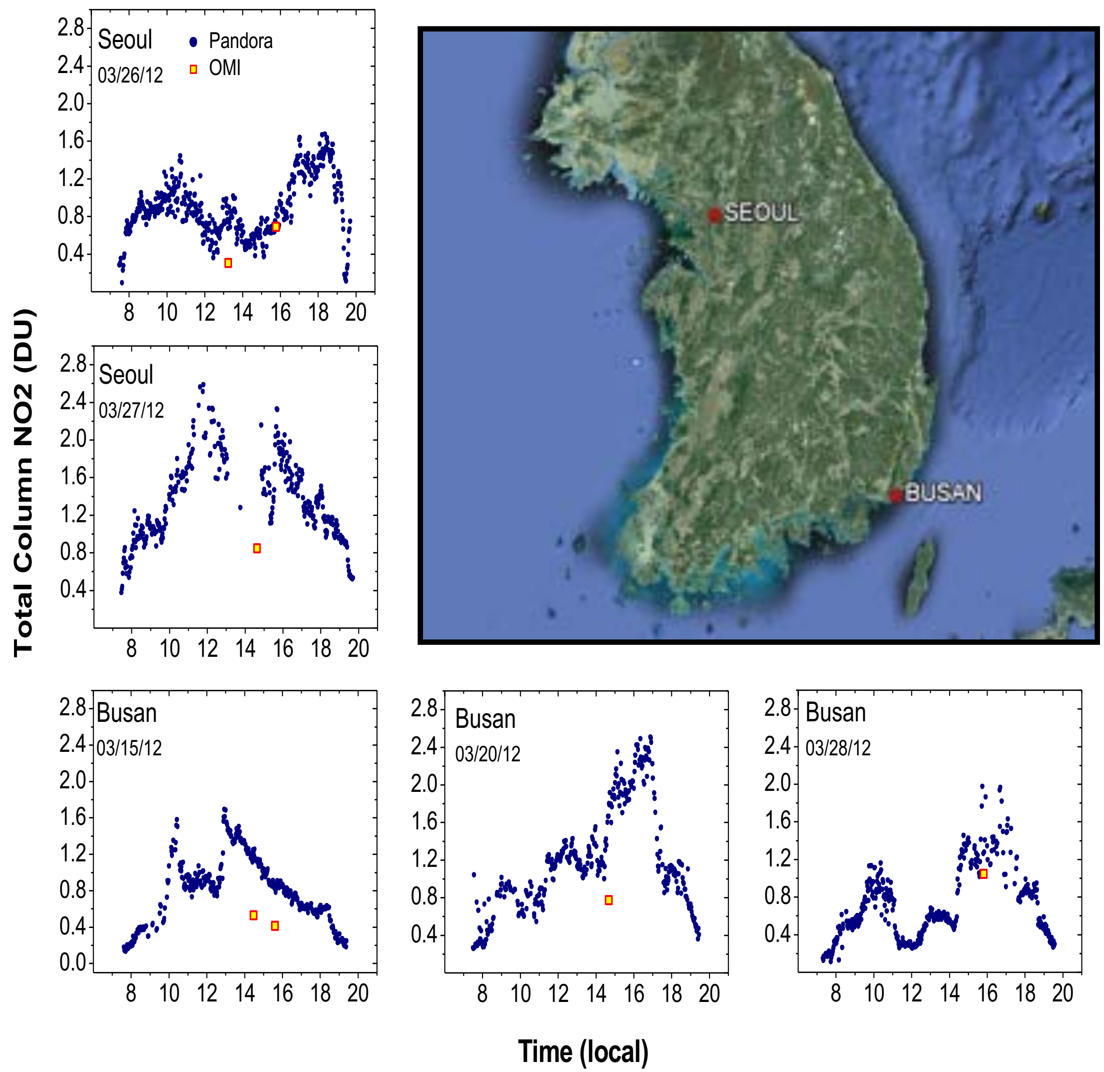
PACE: A Climate Initiative Mission with Enhanced Capabilities

Factors that might increase or decrease the applications value of a mission (from PACE Mission Applications Reviews: July 2015 and December 2015)

- Inclusion of a **polarimeter**
- **Increased spatial resolution** (better than 500 m at nadir)
- **Low latency**
- **High spectral resolution 400-440 nm** for NO2 retrievals

High spectral resolution for coastal applications: accurate atmospheric correction

- Total column **NO2: high and highly variable in coastal regions close to coastal megacities**, affecting coastal ocean color
- Ancillary observations from AQ sensors may not be suitable for correction (coarse resolution/overpass timing).
- **High spectral resolution** in the PACE OCI would allow for retrievals of NO2 for accurate atmospheric correction



Tzortziou et al 2014 JGR Oceans

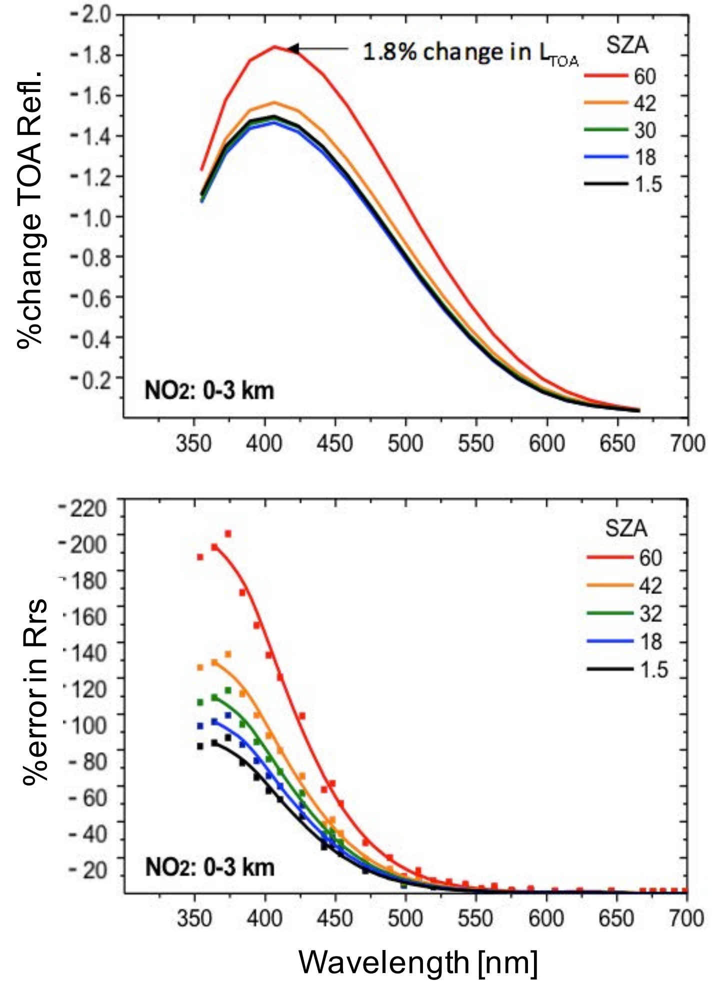
High spectral resolution for coastal applications: accurate atmospheric correction

- Total column **NO_2: high and highly variable in coastal regions close to coastal megacities**, affecting coastal ocean color
- Ancillary observations from AQ sensors may not be suitable for correction (coarse resolution/overpass timing).
- **High spectral resolution** in the PACE OCI would allow for retrievals of NO_2 for accurate atmospheric correction

→ **Risk-reduction activities for PACE Instruments:** KORUS-OC campaign (May-June 2016): An 18-22 day oceanographic campaign coordinated with KORUS-AQ.

Tzortziou's team: measurements for improved atmospheric correction of Coastal OC retrievals.

Sensitivity to 1DU NO2



Tzortziou et al 2014 JGR Oceans

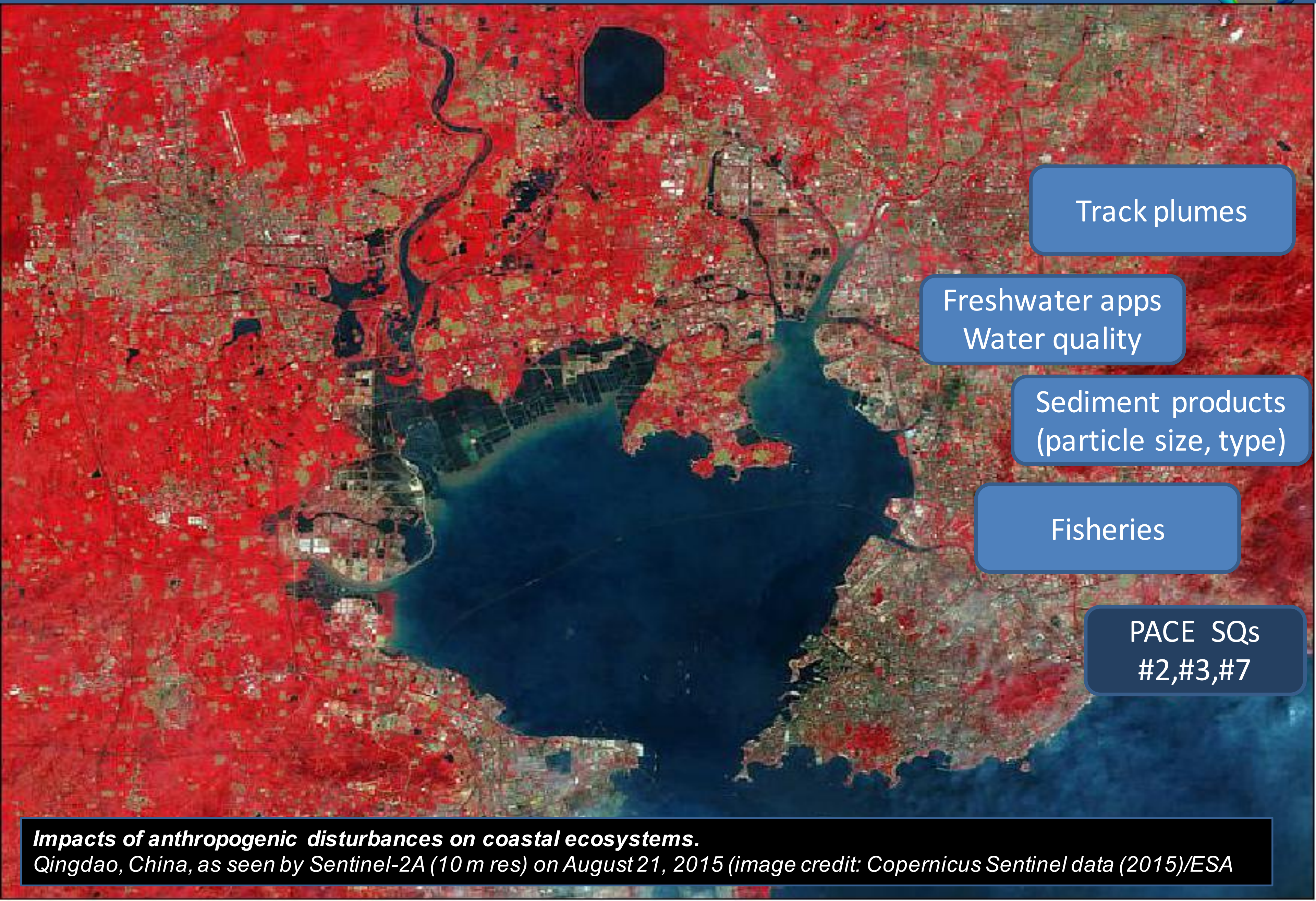
High quality, high spatial resolution information

Q1: What is the value of 500 m vs 1 km?

Q2: What is the value of 50-100 m?

PACE Science & Applications

PACE Science Team Meeting
January 20-22 2016, CA



Impacts of anthropogenic disturbances on coastal ecosystems.
Qingdao, China, as seen by Sentinel-2A (10 m res) on August 21, 2015 (image credit: Copernicus Sentinel data (2015)/ESA

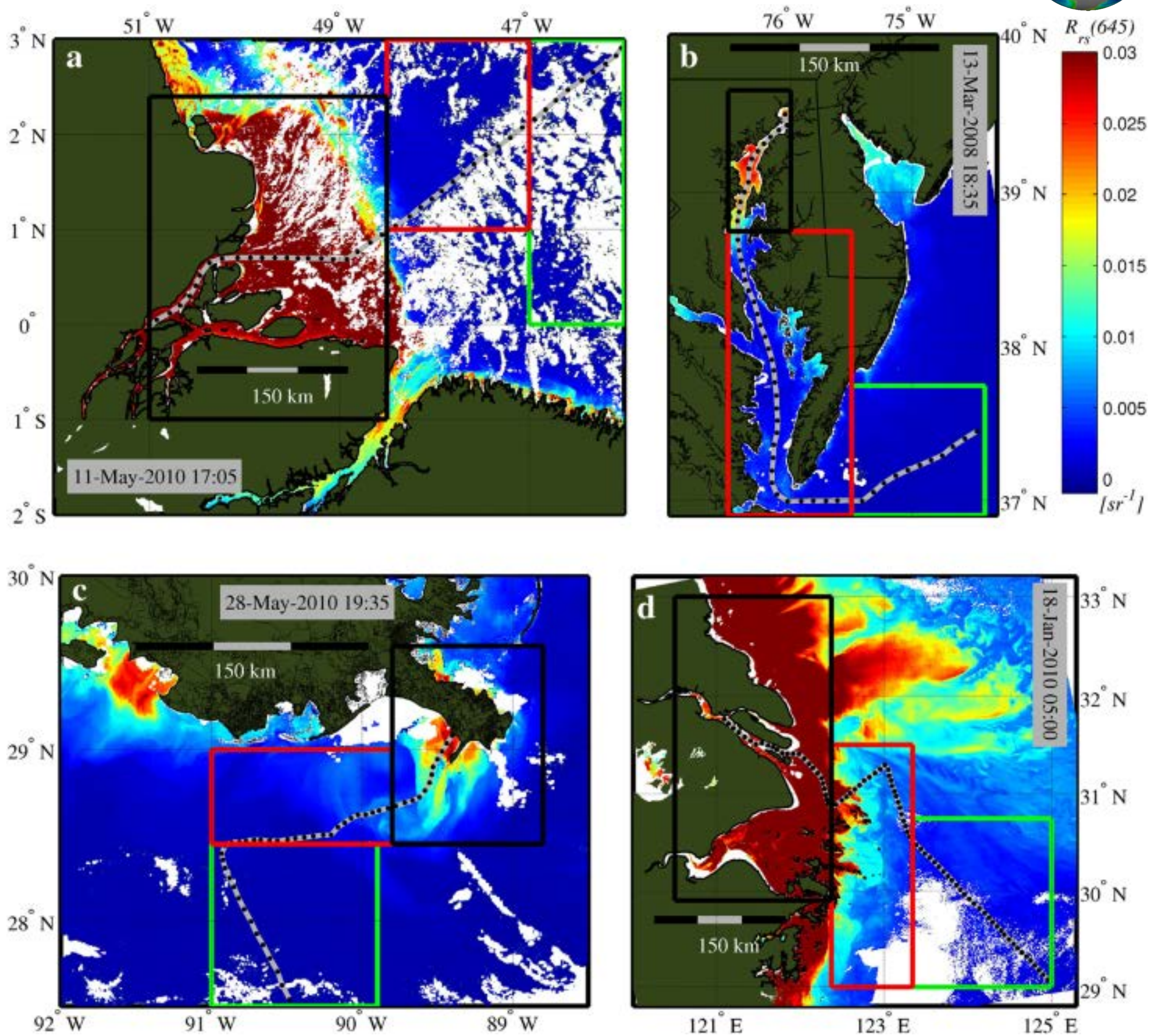
Aurin et al., 2013 had measurements in

(a) Amazon River,

(b) Chesapeake Bay,

(c) Mississippi River,

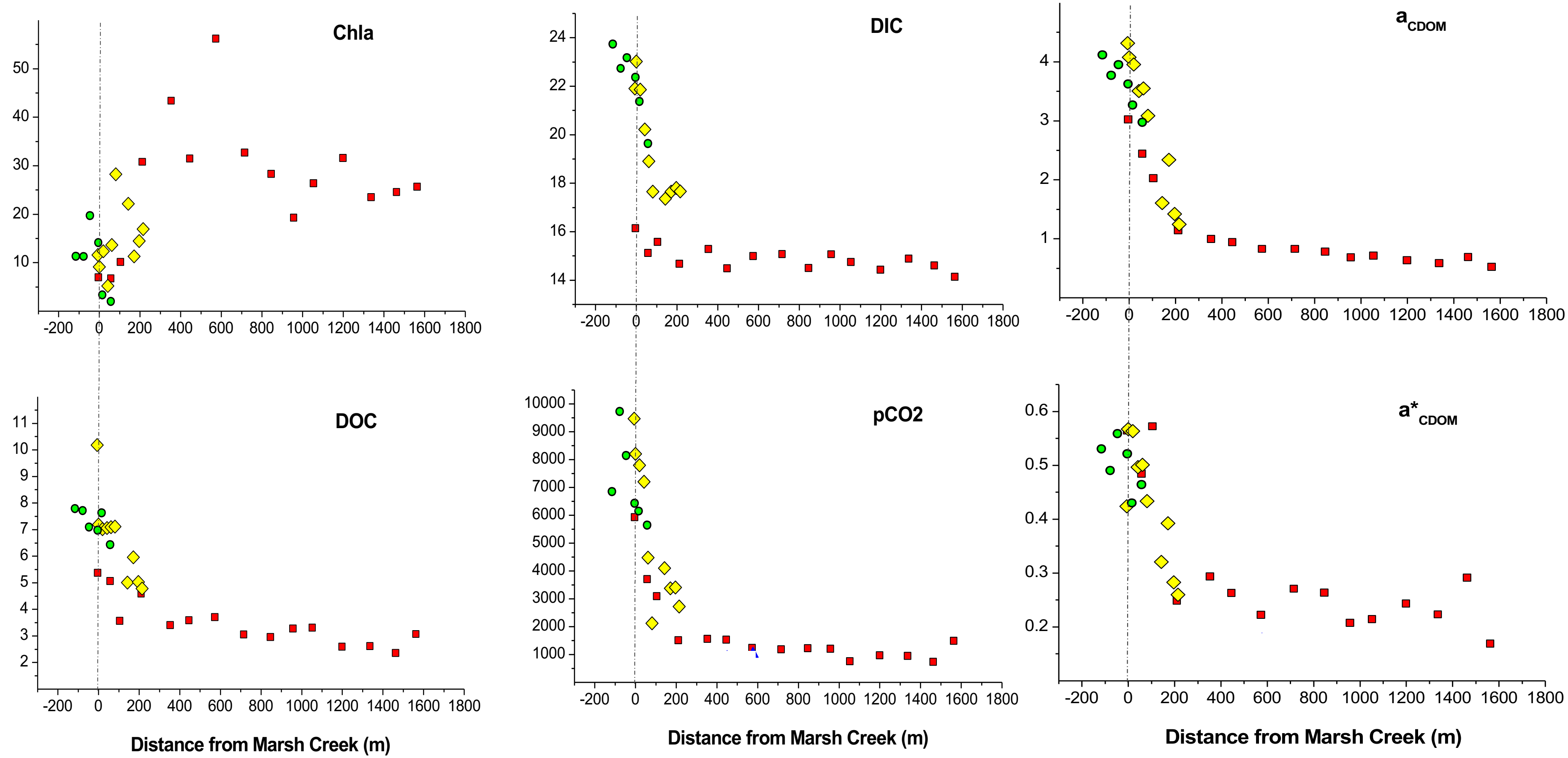
(d) Yangtze River



Spatial resolution better than 500m is required to resolve spatial heterogeneity in ocean color and suspended materials in **river plumes**.

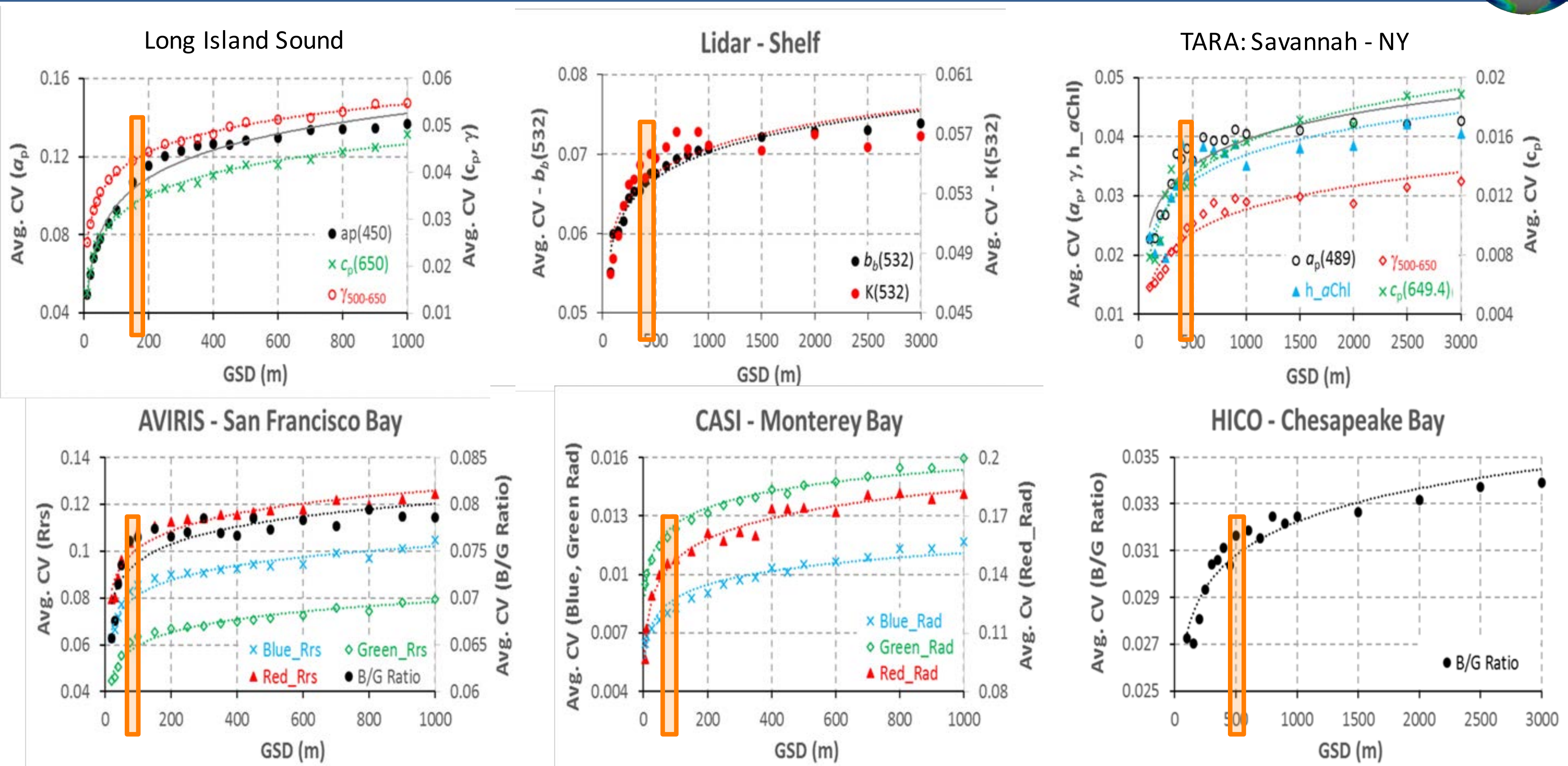
1-km resolution is adequate in the open ocean.

Aurin et al., 2013



- **Strongest gradients (> factor of 5) in Chla, DIC, DOC CDOM, and pCO2 within the first 200 m from marsh.**
- **Strong gradients (factor of 2) in carbon within the first 500 m from marsh.**
- **Spatial resolution better than 500 m is needed** to resolve exchanges of dissolved organic C and N at the land-estuarine interface associated with tidal exchanges of organic matter

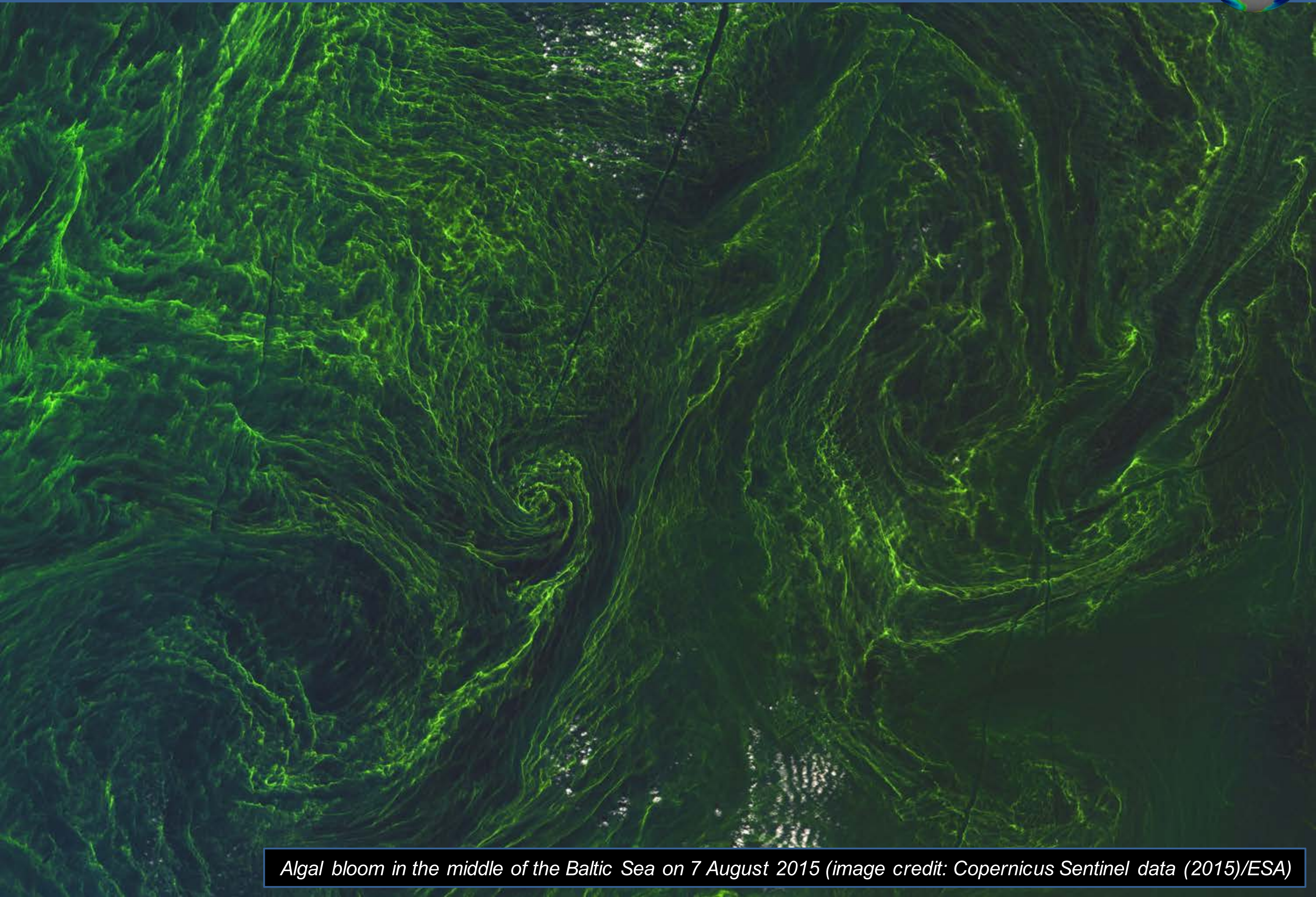
Tzortziou et al., 2011



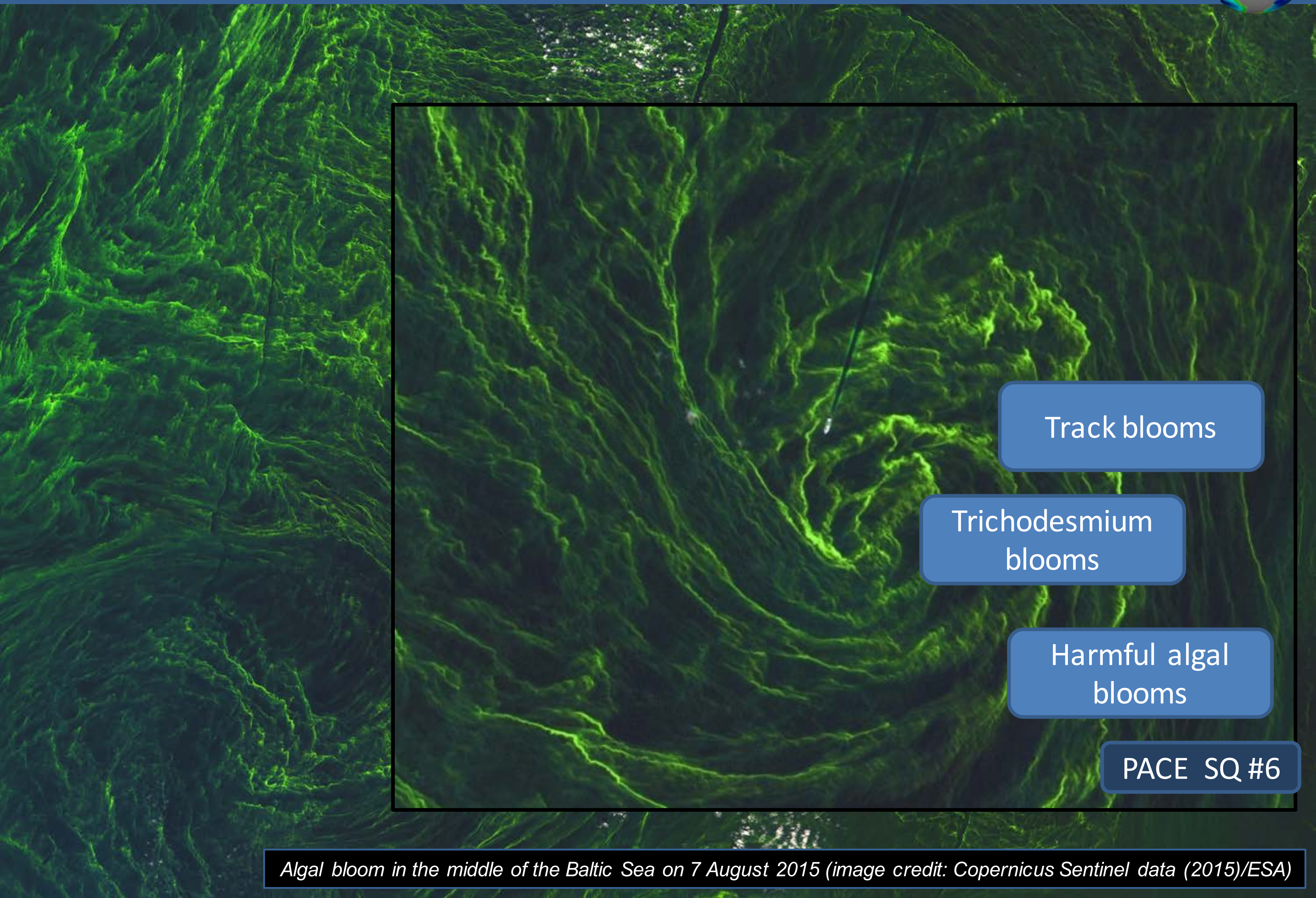
- **Inflection points in the relationship between the average sub-pixel variation and GSD indicate thresholds where decreasing GSD would yield a significant increase in spatial information.**
- **Flat portions of the curves to the right of inflection points suggest that GSD (Ground Sample Distance) related changes in spatial information will be small.**

For near-coast waters, inflection points occur at GSD of between 100 m and 200 m while for off-shore waters inflection points tend to occur at larger scales, GSD ≈ 500 m.

Ackleson, Moses, & Miller



Algal bloom in the middle of the Baltic Sea on 7 August 2015 (image credit: Copernicus Sentinel data (2015)/ESA)



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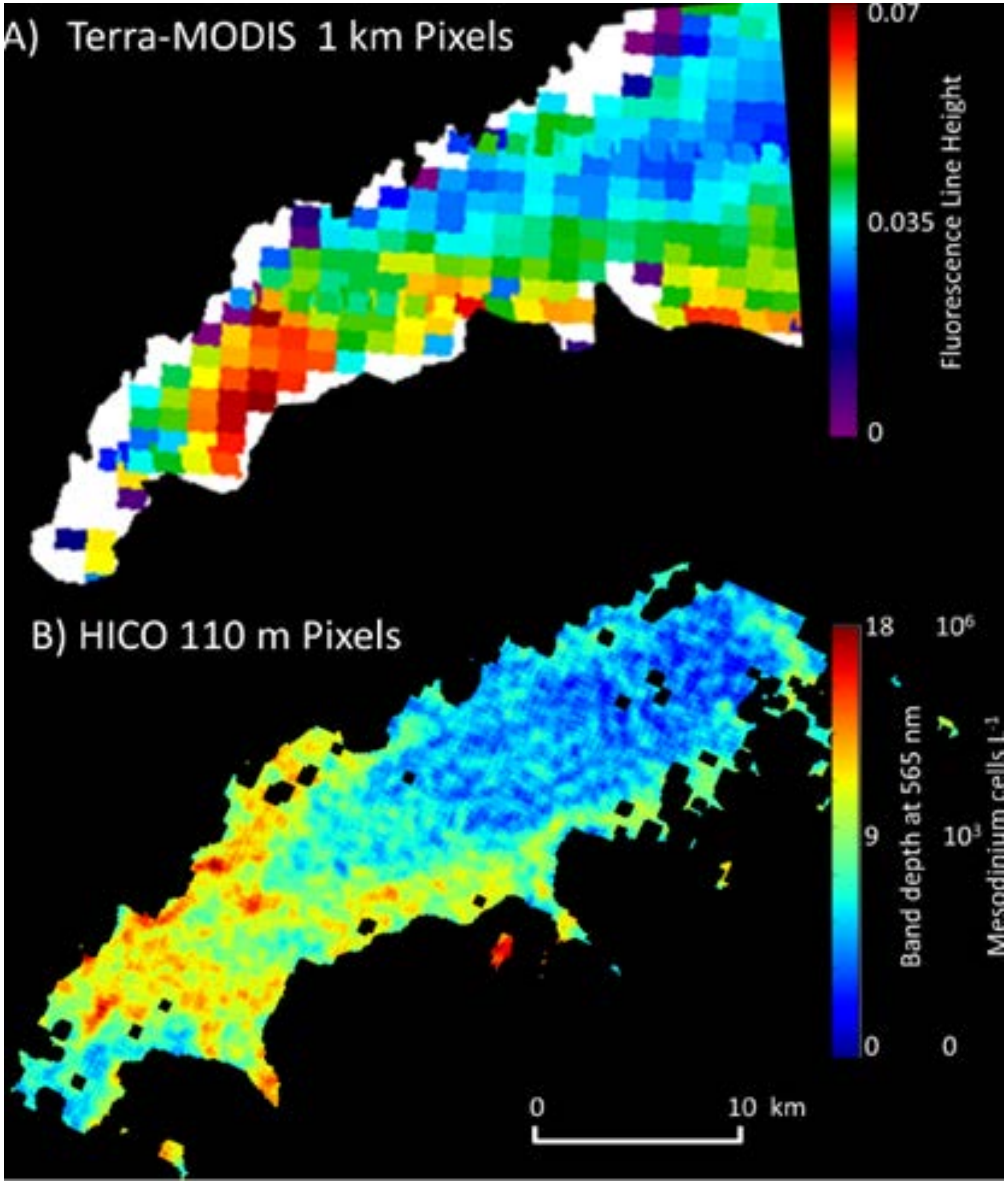


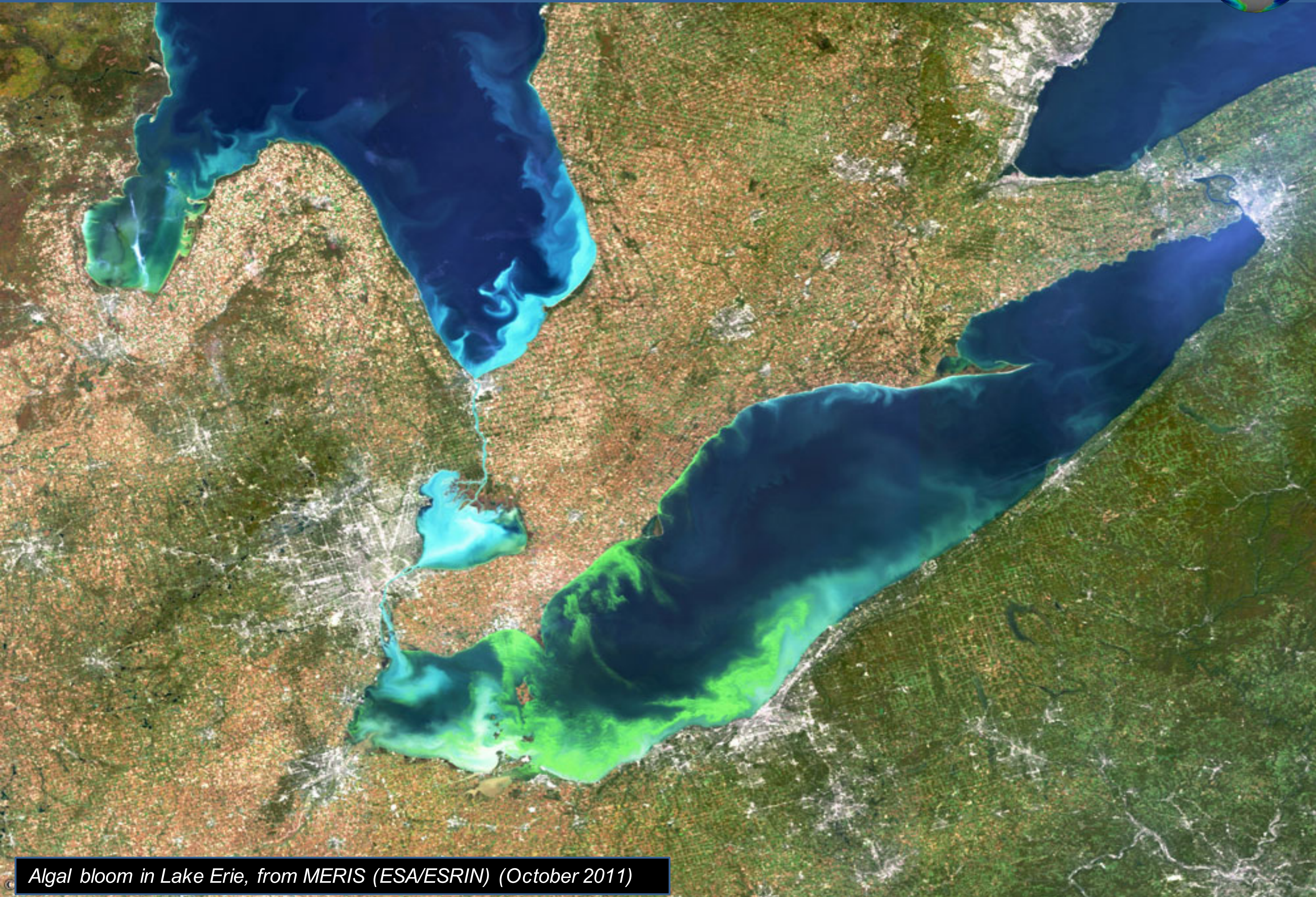
Dense and patchy near-surface blooms of *Mesodinium rubrum* in the western Long Island Sound (Dierssen et al 2015)

Combination of:

→ **high spectral** and
→ **high spatial resolution (e.g., HICO 100m)**

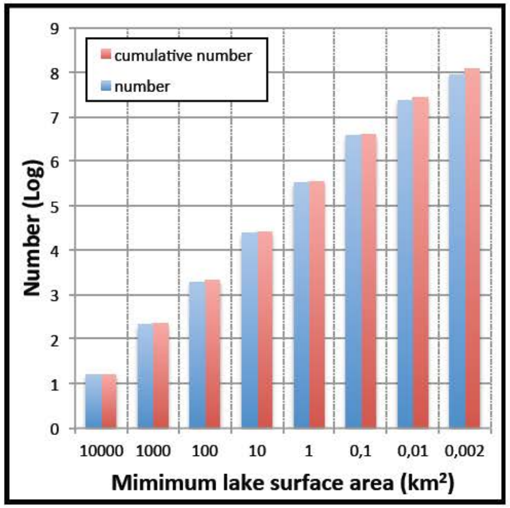
is particularly powerful for capturing harmful or non-harmful algal bloom dynamics.

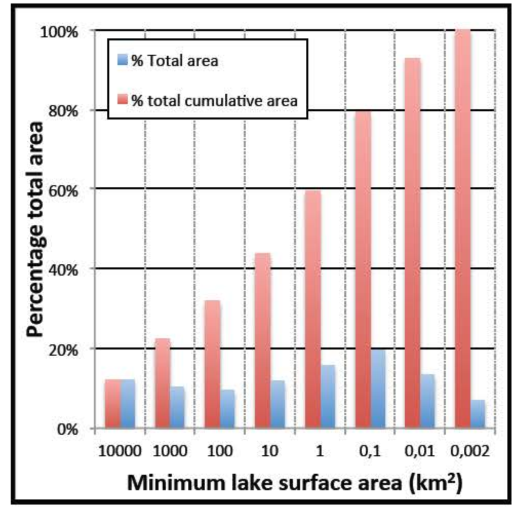
"Compared with the 1-km MODIS image, the ***higher spatial resolution (110 m) of the HICO image revealed intense small patches*** *of yellow fluorescing Mesodinium in WLIS"*



Algal bloom in Lake Erie, from MERIS (ESA/ESRIN) (October 2011)

Spatial resolution requirements





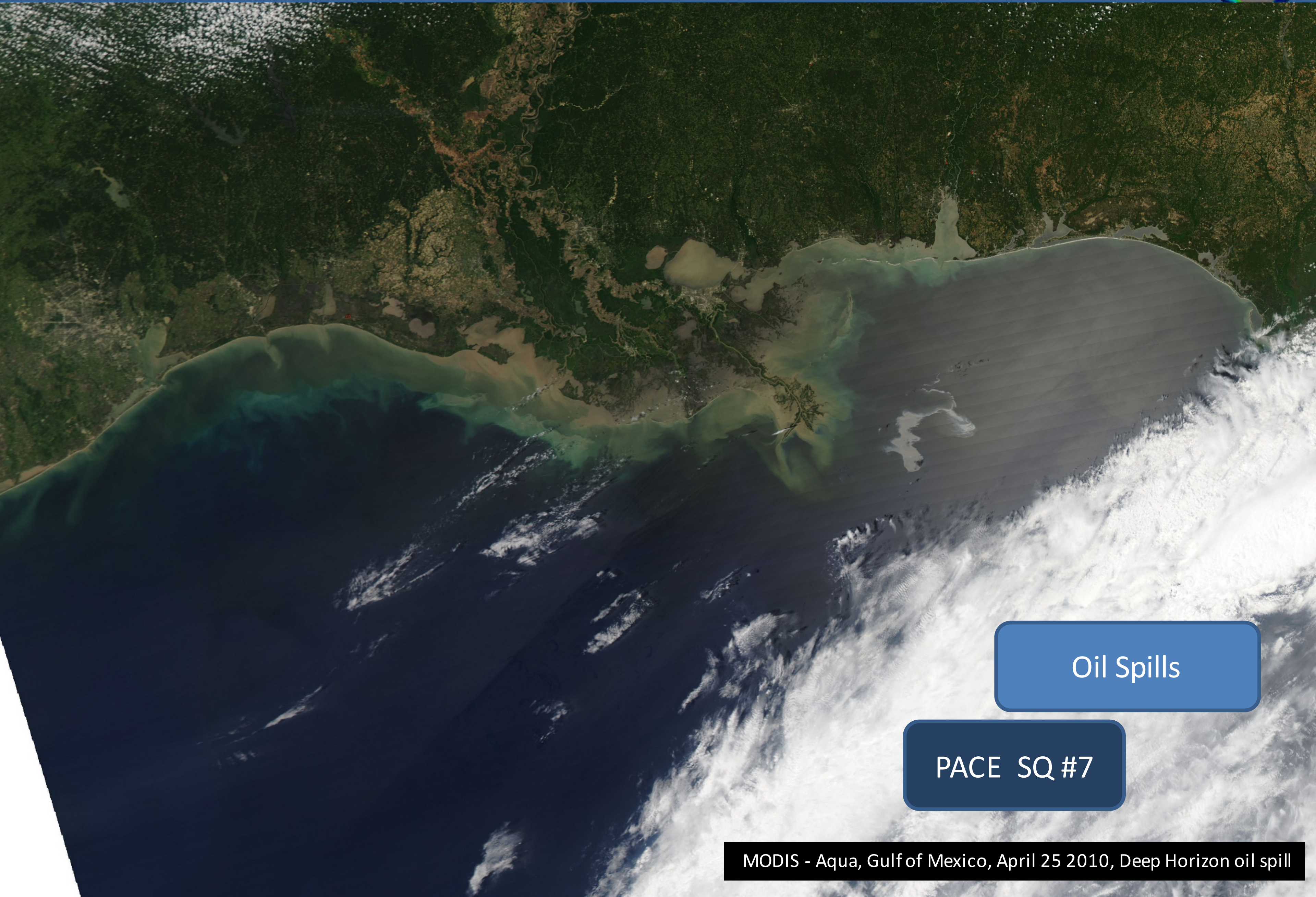
Lake size	Required GSD*	% Total Area	Total Number
≥ 1 km^2	333 m	60	353,552
≥ 0.1 km^2	**105 m**	80	4,123,552
≥ 0.01 km^2	33 m	90	**27,523,552**
≥ 0.002 km^2	15 m	100	**117,423,552**

- 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.

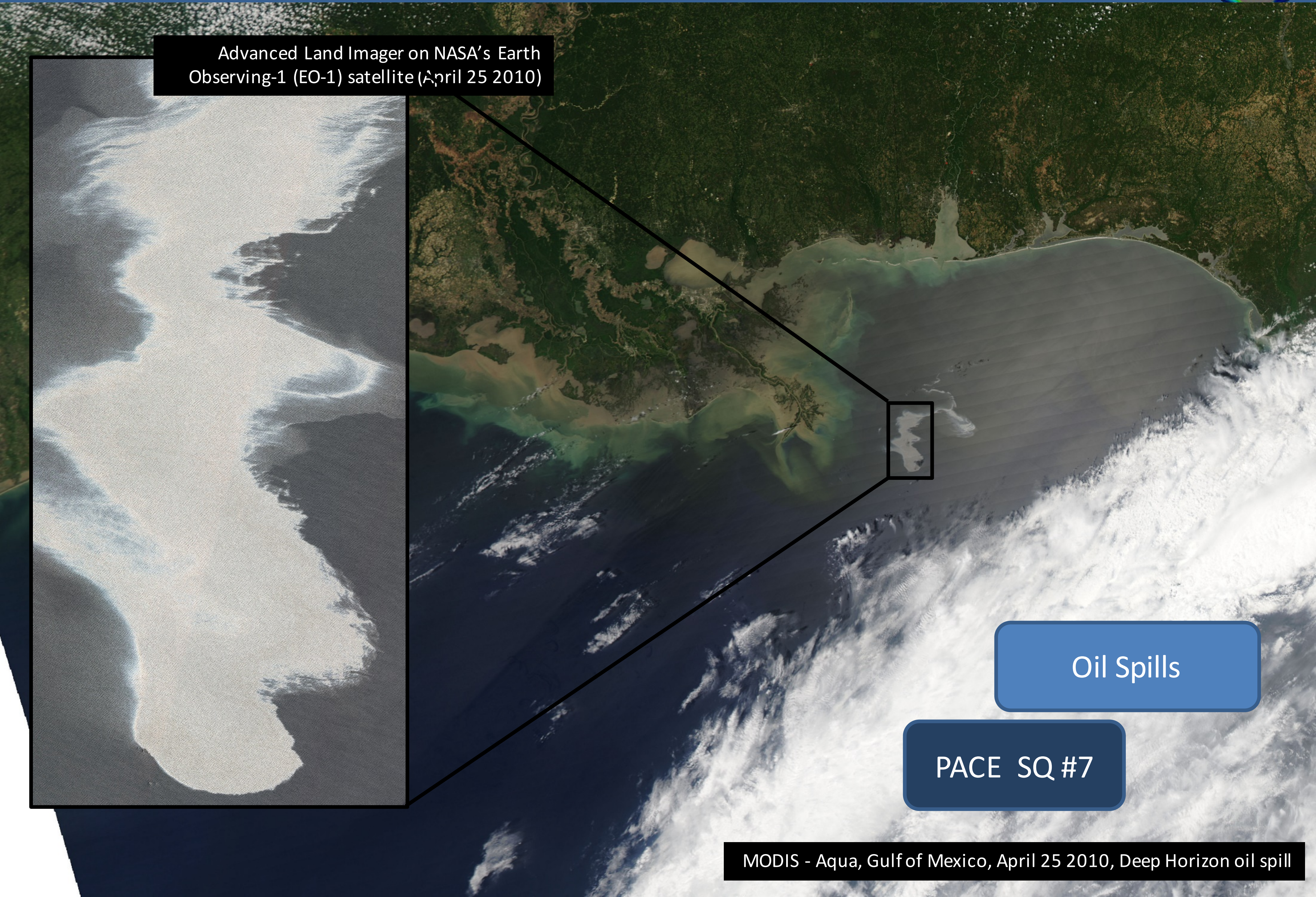
Data from Verpoorter at al. (2014)   * calculated for a box of nine pixels

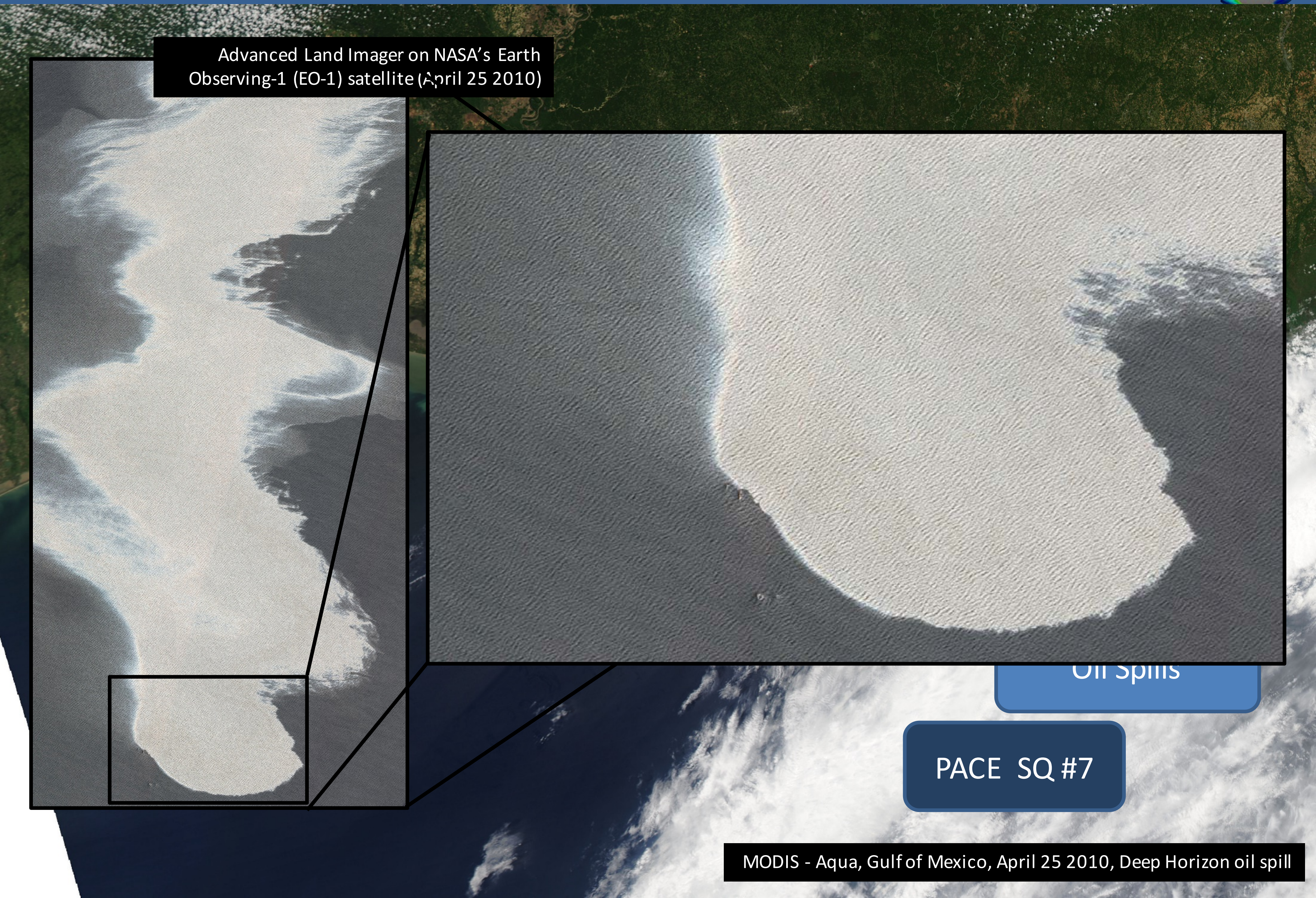
Verpoorter, C., Kutser, T., Seekell, D. a., & Tranvik, L. J. (2014). A Global Inventory of Lakes Based on High-Resolution Satellite Imagery. Geophysical Research Letters.

by Mark Mattthews (CyanoLakes)



MODIS - Aqua, Gulf of Mexico, April 25 2010, Deep Horizon oil spill


Advanced Land Imager on NASA's Earth Observing-1 (EO-1) satellite (April 25 2010)
Oil Spills
PACE SQ #7
MODIS - Aqua, Gulf of Mexico, April 25 2010, Deep Horizon oil spill


Advanced Land Imager on NASA's Earth Observing-1 (EO-1) satellite (April 25 2010)
PACE SQ #7
MODIS - Aqua, Gulf of Mexico, April 25 2010, Deep Horizon oil spill

EPA – 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).*

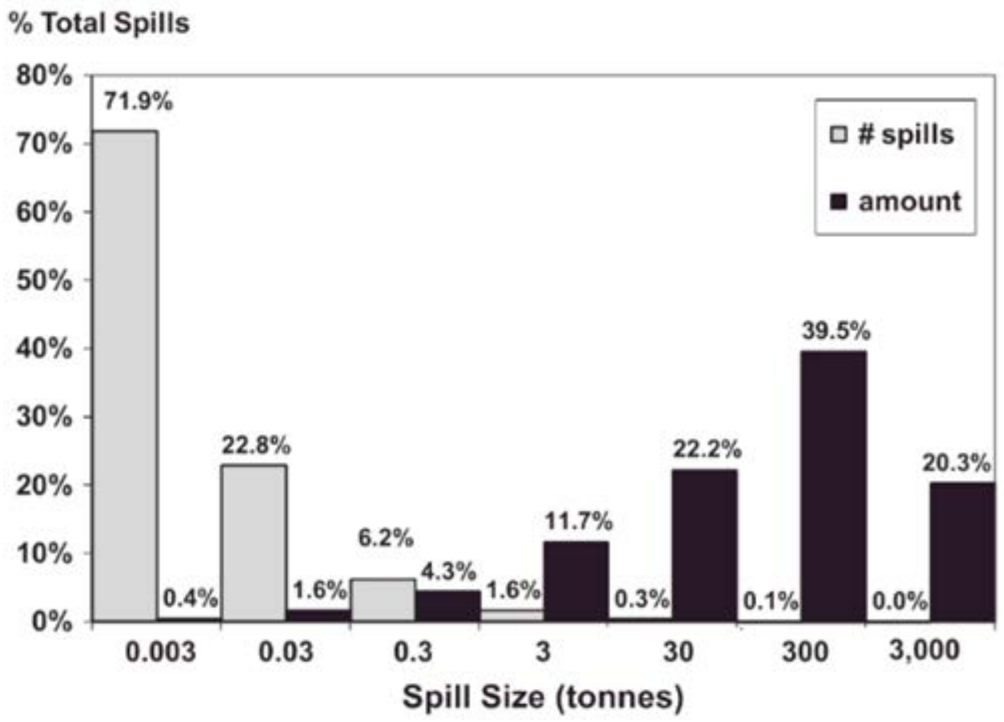


FIGURE 2.1 Size classes of U.S. marine oil spills, 1990–1999 (ERC data).

Studying ocean biodiversity, habitats, and how they are affected by human impacts and climate change
Deep blue Red Sea reefs captured with Sentinel-2A on June 28, 2015 (image credit: Copernicus Sentinel data (2015)/ESA)

Analyses of coral reefs using high spatial- resolution **(30-m or better)** data span a broad scale of applications, including:

→ design and evaluation of Marine Protected Areas (MPAs)
→ study of ecosystem associations, (e.g., coral reefs with seagrass beds and mangroves),
→ investigations of the ecology of coral reefs and the organisms that live in them (e.g., fish).

(Monitoring Coral Reefs from Space, Oceanography 2010)

Habitat Mapping

Coral reefs

PACE SQs
#2,#5,#7

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, cyanobacteria and phycocyanin, other HAB pigments	**Spatial:** 30 m GSD (local) for lakes and reservoirs **Spatial**: <200m GSD (local) for estuaries **Spatial**: 500m GSD (local) for coastal waters	Lunetta et al. 2015. RSE. 157: 24-34.
Aquatic invasive species in lakes, reservoirs, estuaries and coastal waters	Phytoplankton functional groups, specific species, aquatic plants, etc	**Spatial:** 30 m GSD (local) for lakes and reservoirs **Spatial:** <200m GSD (local) for estuaries **Spatial:** 500m GSD (local) for coastal waters	Great Lakes Restoration Initiative http://www.greatlakesrestoration.us/actionplan/pdfs/glri-action-plan-2.pdf Great Lakes Water Quality Agreement http://binational.net/wp-content/uploads/2014/05/1094_Canada-USA-GLWQA-_e.pdf
Water clarity for optically shallow and optically deep waters	Kd, Kpar, NTU	**Spatial:** 30 m GSD (local) for lakes and reservoirs **Spatial**: <200m GSD (local) for estuaries **Spatial**: 500m GSD (local) for coastal waters	*Barnes et al. 2013. RSE. 140: 519-532.* *Barnes et al. 2013. RSE. 134: 377-391.* *Zhao et al. 2013. RSE. 131: 38-50.*
EPA National Lakes Assessment; National Coastal Condition Assessment: Chlorophyll-a, turbidity, CDOM, light attenuation for water quality monitoring and assessment	Chl-a, turbidity, CDOM, light attenuation (Kd), secchi depth	**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): 175-198. Schaeffer et al. 2015. IJRS. 36(8): 2219-2237. NLA Quality Assurance Plan: http://water.epa.gov/type/lakes/lakessurvey_index.cfm NCCA Quality Assurance Plan: http://water.epa.gov/type/oceb/assessmonitor/ncca.cfm
Oil Spill monitoring in rivers, lakes, estuaries and coastal waters	Visible/true color imagery	***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	Draft Oil Spill Research Strategy, ORD, EPA, Washington DC January 12, 2011 http://1.usa.gov/1Jru4HQ ICCOPR Oil Pollution Research R&T Plan FY15-21
Nutrients and co-pollutants on aquatic resources (also see hypoxia and land use change applications)	Chl-a, turbidity, CDOM, light attenuation (Kd), secchi depth, eutrophication index, HABs	**Spatial**: 30 m GSD (local) for lakes and reservoirs **Spatial**: <200m GSD (local) for estuaries **Spatial**: 500m GSD (local) for coastal waters	Nitrogen & Co-pollutants Cross-cutting Research Roadmap Schaeffer et al. 2012. ES&Technology. 46:916-922. Schaeffer et al. 2013. JARS. 7: 073544-1. Total Maximum Daily Loads: Citizen's guide to the Chesapeake Bay TMDL http://ian.umces.edu/pdfs/ian_newsletter_314.pdf
Hypoxia (also see nutrients and co-pollutants)	IOPs, chl-a, Kd, PAR, etc	**Spatial**: 250-500m GSD (local) for Gulf of Mexico	Le et al. JGR-Oceans 119(11): 7449-7462. Schaeffer et al. RSE 115: 3748-3757

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, cyanobacteria and phycocyanin, other HAB pigments	**Spatial:** 30 m GSD (local) for lakes and reservoirs **Spatial**: <200m GSD (local) for estuaries **Spatial**: 500m GSD (local) for coastal waters	Lunetta et al. 2015. RSE. 157: 24-34.
Aquatic invasive species in lakes, reservoirs, estuaries and coastal waters	Phytoplankton functional groups, specific species, aquatic plants, etc	**Spatial:** 30 m GSD (local) for lakes and reservoirs **Spatial:** <200m GSD (local) for estuaries **Spatial:** 500m GSD (local) for coastal waters	Great Lakes Restoration Initiative http://www.greatlakesrestoration.us/actionplan/pdfs/glri-action-plan-2.pdf Great Lakes Water Quality Agreement http://binational.net/wp-content/uploads/2014/05/1094_Canada-USA-GLWQA-_e.pdf
Water clarity for optically shallow and optically deep waters	Kd, Kpar, NTU	**Spatial:** 30 m GSD (local) for lakes and reservoirs **Spatial**: <200m GSD (local) for estuaries **Spatial**: 500m GSD (local) for coastal waters	*Barnes et al. 2013. RSE. 140: 519-532.* *Barnes et al. 2013. RSE. 134: 377-391.* *Zhao et al. 2013. RSE. 131: 38-50.*

Land use and land cover change impacts to water qualilty (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	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	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	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	USEPA Document #832-F-99-051
Benthic habitat monitoring	Seagrass extent	**Spatial:** 1-10m GSD (local) for estuaries	Williams et al. 2003. Environmental Monitoring & Assessment 81: 383-392 Clinton et al. 2007. USEPA 600/R-07/062
Pathogen detection, indicators, modeling	Turbidity, salinity proxies, etc	**Spatial:** 30 m GSD (local) for lakes and reservoirs **Spatial:** <200m GSD (local) for estuaries **Spatial:** 500m GSD (local) for coastal waters	Arnone and Walling. 2007. Journal of Water and Health. 5: 149-162. EPA. Recreational water quality criteria. 820-F-12-058

High quality, <u>high spatial resolution</u> information

Q1: What is the value of 500 m vs 1 km?

<u>Required</u> to study coastal processes, ecosystems, resources at the <u>land-ocean interface.</u>

For example,

→ capture the **factor of 2 change in carbon** components at land-estuary interface

→ apply satellite data to monitor processes in **coastal waters/integrate into models (HAB detection/identification, invasive species, water clarity, hypoxia, pathogen indicators)**

→ track **river plumes, sediments**

Q2: What is the value of 50-100 m?

To study open ocean, coastal, estuarine and inland processes, hazards, disasters: finer scales, <u>more</u> 'frequent' events, stronger gradients.

For example:

→ Capture the **more than a factor of 5 change in carbon** components at land-estuary interface

→ **Estuarine water quality, HABs** in <u>most</u> estuaries (not just the few largest)

→ For **inland applications**, in most (80% total area) of lakes

→ **Oils spills**, to capture the <u>more frequent</u> events

→ **Habitat mapping/monitoring**, **coral reefs,** design/evaluation of **marine protected areas**

Relevant to SQs #2,3,5,6,7. For example:

SQ#3 in PACE STM: ***What are the material exchanges between land & ocean? How do they influence coastal ecosystems and biogeochemistry?***

LATENCY

Q1: Do we need low latency from a polar-orbit sensor (1-2 day global coverage?)

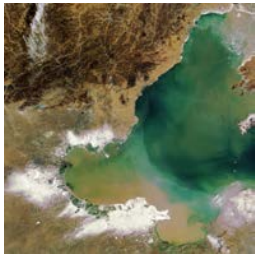
For applications of ocean color data to **emergency management and response to hazards/disasters**.

For **operational data assimilation**, forecasting/nowcasting, improved data latency (how quickly this information can be assimilated into the model after the measurement is made) will improve the capability to respond to a specific event.

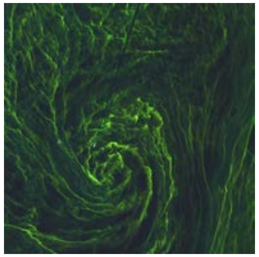
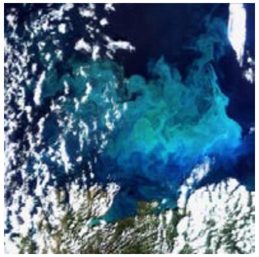
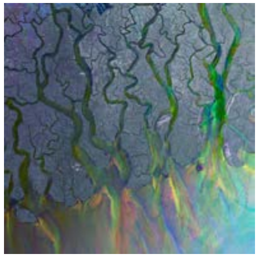
<u>Polar Orbit Satellites:</u>

MODIS: has had direct broadcast capability since 2000. MODIS Direct Broadcast Software,Support Forum;, etc
Rapid Response / LANCE (Land, Atmosphere Near-real-time Capability for EOS) has been providing global swath imagery from MODIS since 2001, to make imagery available in less than 3 hours

VIIRS-JPSS: "Latency is a critical component to the operational management of an incident. Therefore, it is crucial that **remotely sensed data is made available to the decision makers on the ground as quickly as possible"** (JPSS Science Seminar Annual Digest). (0.5-3 hrs latency; 1 hr for real time monitoring)





LATENCY

Q2: Do we need PACE ocean color products in under 3 hours? Do we need direct broadcast?

→ **Improved latency / direct broadcast will open the door to new applications not currently explored**

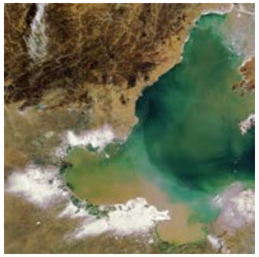
→ **For some applications we know we do**

- **Oil spill monitoring**:

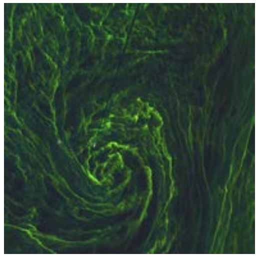
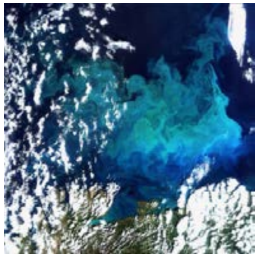
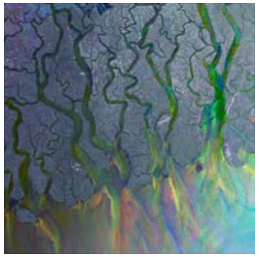
NOAA users highlighted the need for <u>improved data latency (0.5-1hr)</u> to be able to assimilate satellite observations into operational models, track oil spills and provide warnings/alert the community.

NRC, 2011 *Assessing Requirements for Sustained Ocean Color Research and Operations:* During spill events, "decision makers need access to imagery <u>within two hours of data collection</u>"

EPA: During the Deep Water Horizon response, <u>30 minute turn around</u> was desired





LATENCY

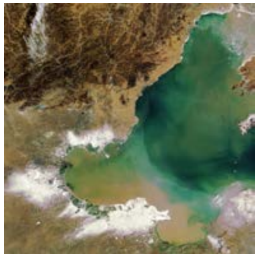
Q2: Do we need PACE ocean color products in under 3 hours? Do we need direct broadcast?

- **HABs and Fisheries**

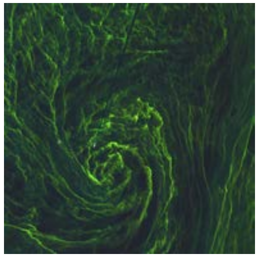
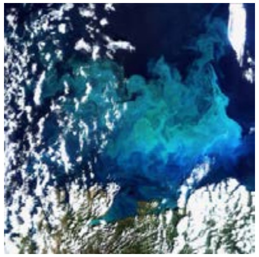
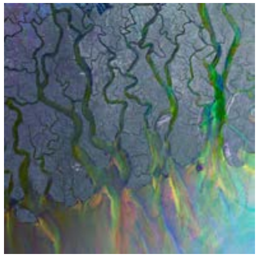
Report from "Ocean Satellite Data: Requests from the Fishery and Aquaculture Community" (funded by NASA, hosted by Oregon State University)

The workshop was designed to brainstorm possible future ocean satellite sensors and data products that will benefit the fisheries and aquaculture communities and associated research. **Twenty-one U.S. and international participants from various fields associated with fisheries and aquaculture attended**

"The longer the delay, the less valuable the data becomes. Ideally, the latency should be no longer than 40 minutes."





NOAA User Latency Requests

- **NOAA operational Line Offices have provided true latency values for their respective critical products (focusing on the near-real time requirements)**

30 minutes — Weather Service

NWS:
ATMS
- SDR
- TDR

CrIS SDR
VIIRS Imagery EDR (Alaska Region)

60 minutes — Search And Rescue Satellite Aided Tracking

NESDIS:
SARSAT Data

80 minutes — Ocean Service

NWS:
VIIRS SDR
AMSR-2 SDR

NESDIS:
ADCS Data

NOS:
VIIRS Imagery EDR

120 minutes — Fisheries

NMFS:
VIIRS Ocean Color/Chlorophyll

12 hours – During Event

24 hours – Normal Monitoring

NOS:
VIIRS
- Ocean Color/Chlorophyll
- Sea Surface Temperature
- Aerosol Optical Thickness

AMSR-2 Sea Surface Temperature

NMFS:
ADCS Data
VIIRS
- SDR
- Aerosol Optical Thickness

Sea Surface Temperature
OMPS SDR
CERES SDR
AMSR-2 Sea Surface Temperature

Any latency requests less than total system latency for JPSS (103 minutes) are captured as objective latencies for each respective product

http://www.goes-r.gov/downloads/2013-PG-OCONUS/06-19/Goldberg_Overview-Algorithms-PG.pdf

Applications Traceability Matrix

(with input/requirements from user community representatives, e.g., NOAA, EPA, USGS, FAA)

Application Question	Application Concept	Application Measurement Requirements	Applied Sciences Category	Potential Host Agency	Mission Data Product	Projected Mission Performance	ARL	Ancillary Measurements
What is the air quality forecast of particulate matter (PM) predicted from PACE measurements of the aerosol optical depth (AOD) in regions where there are no direct	The Environmental Protection Agency produces a daily air quality index which comprises both the ozone and particulate matter concentrations. In regions where there are no direct measurements of PM, satellite measurements of AOD can be used to estimate PM.	Observations of AOD at spatial resolutions of less than 1 km and latencies of less than 1 hour	Public Health and Air Quality	Environmental Protection Agency [James Szykman - EPA]	Aerosol Optical Depth	AOD within ± 0.02 at a horizontal resolution of 250 m	3	Aerosol vertical distributions Surface PM concentrations at a few locations
Volcanoes: What is the volcanic ash concentration during and after a volcanic eruption? Is there an impact on air quality as a result of a volcanic material deposited in coastal/populated regions?	Can we quantify this concentration using measurements collected to support PACE atmospheric corrections in coastal regions? Can we provide useful data to enable prudent aviation volcanic ash hazard mitigation policy and advisories?	Observations of AOD at spatial resolutions of less than 1 km and latencies of less than 1 hour	Disaster Mitigation Health and Air Quality	Federal Aviation Administration (FAA), US EPA, NOAA, International Civil Aviation Organization, Volcanic Ash Advisory Centers [Shobha Kondragunta- NOAA]	Aerosol Optical Depth	AOD within ± 0.02 at a horizontal resolution of 250 m	3	Aerosol vertical distributions Sulfur dioxide concentrations
How do exchanges across the lan-ocean interface influence carbon and nutrient loadings, water quality, and ecosystem dynamics in coastal waters?	The EPA Safe and Sustainable Water Resources Research Program (SSWR) aims at developing core indicators of water resource integrity and sustainability as well as indicators of key drivers and pressures across a range of spatial and temporal scales for use in integrated assessments. Integration of satellite observations with field measurements and modeling tools is needed to demonstrate assessment of sustainability and integrity of water	Observations of Chla, Kd (water quality indicators) at: Spatial resolution (GSD local): Estuaries: ≤250m Coastal Waters: ≤500m Coverage needed (Width from coast to ocean): Minimum distance: 5.5 km Maximum distance: 22 km Latency 0.5-12 hours	Water Resources Oceans, Coasts, Great Lakes - Ecosystems and Human Health	Environmental Protection Agency [Blake Schaeffer, EPA]	chl-a, K_{PAR}, K_{490}	0.5 hour data latency, direct broadcast of 5 nm res. data Spatial resolution of 1 km2 (±10%) at all angles across track Along-track spatial resolution of 250 m x 250 m to <1 km2 for inland, estuarine, coastal, and shelf area retrievals for all bands	3	Aerosols (spectral shape, vertical distribution), NO2, O3 concentrations for atmospheric correction
How are the productivity and biodiversity of coastal ecosystems changing, and how do these changes relate to natural and anthropogenic forcing, including local to regional impacts of climate variability?	Assimilation of PACE satellite-derived optics and biogeochemical variables into operational seasonal-interannual models (Global Ocean Data Assimilation System / Coupled Forecast System (CFS); Real-Time Ocean Forecast System, RTOFS) for improving model skills and forecasting capabilities.	chl-a, K_{PAR}, K_{490} Spatial: 1 km Temporal: daily Coverage: Global Latency: 12 hours	Ecolgial Forecasting	NOAA [Paul DiGiacomo, Cara Wilson NOAA]	chl-a, K_{PAR}, K_{490}	0.5 hour data latency, direct broadcast of 5 nm res. data Spatial resolution of 1 km2 (±10%) at all angles across track Along-track spatial resolution of 250 m x 250 m to <1 km2 for inland, estuarine, coastal, and shelf area retrievals for all bands or a subset of bands	3	Aerosols (spectral shape, vertical distribution), NO2, O3 concentrations for atmospheric correction
Oil Spill monitoring, response	NOAA's subsurface oil monitoring program uses various modeling and observational approaches (airborne, shipborne, ground-based, space-based measurements) to track oil spills: where the oil is going on the surface and under the sea, and what the consequences are to coastal communities, wildlife and the marine environment (e.g. Deepwater Horizon/BP Oil Spill).	Visible/true color imagery Spatial: < 300 m GSD (local) Temporal: 1 hr Coverage: coastal waters <185 km (<100 nmi); 50°N-10°N, 160°W-60°W Uncertainty: n/a Latency: 0.5-1 hour	Disasters Water Resourcces	NOAA [Paul DiGiacomo, Cara Wilson NOAA]	Visible/true color imagery	0.5 hour data latency, direct broadcast of 5 nm res. data Spatial resolution of 1 km2 (±10%) at all angles across track Along-track spatial resolution of 250 m x 250 m to <1 km2 for inland, estuarine, coastal, and shelf area retrievals for all bands	3	Aerosols (spectral shape, vertical distribution), NO2, O3 concentrations for atmospheric correction

Justification for ARL 3: Proof of Application Concept (Viability Established) Feasibility studies to assess the potential viability of and provide a proof-of-concept for the application have been conducted.

White Papers – PACE Applications

PACE MISSION APPLICATIONS – AIR QUALITY

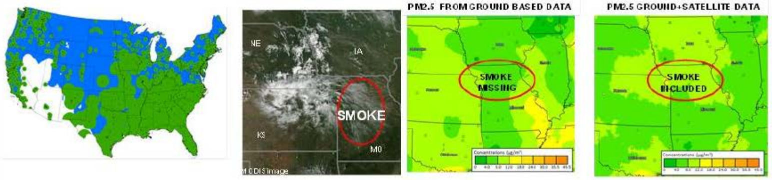


Figure 1. Ground monitors (denoted by small dots) for measuring the concentration of particulate material (PM). Without satellite data, the area of coverage would be limited only to the areas shaded green. The MODIS Satellite data is used to fill most of the gaps (but not all). The next columns show MODIS image of a typical air quality situation resulting from fires, the nominal solution (PM2.5 from ground based data), and NASA's contribution (PM2.5 from Ground + Satellite Data). In the nominal solution because the ground monitors in this region are very few, the interpolated PM2.5 data shows relatively good Air Quality (AQI of 0 – 4). The addition of satellite data shows that the Air Quality as a result of the fires is poorer at AQI = 4-8.0. Satellite data has real value in producing an Air Quality Index that actually protects the public from harm. If the satellite data were not there, there would be no indication of this poorer air quality (Images courtesy of the AirNow Group).

Application Question/Issue

What is the air quality forecast of particulate matter concentration (PM, an indication of the extent of air pollution) predicted from *satellite* measurements of the aerosol optical depth (AOD) in regions where there are no *ground* measurements of PM? Figure 1 is an illustration of such an application.

Who Cares and Why?

In regions where there are no ground measurements of PM, the EPA and thus the public has no indication of the extent of air pollution, a situation that has deleterious public health implications. Satellite measurements of AOD can be used to estimate PM in such areas. The Environmental Protection Agency (EPA) produces a daily air quality index (AQI) which comprises both the ozone and particulate matter concentrations. The latest surveys show 75 -80% of the public are aware of AQI and 50% report taking action based on the AQI.

Needed Measurement(s)

The accuracy of the daily (and forecast) AQI depends on the spatial resolution, latency and accuracy of the satellite-observed AOD and the validity of the relationship between column AOD and surface PM. To meet the needs of the public, the satellite measurements of AOD must be produced at spatial resolutions of less than 1 km at a latency not exceeding 1 hour and at an accuracy of ±0.05. The predicted PM using the column AOD and auxiliary measurements must be within ± (1 $\mu g/m^3$+42%)

The NASA Response

Based on current estimates, the PACE mission will produce AOD at an accuracy of ± 0.02 at a horizontal resolution of 250-500 m. It is expected that the latency of the broadcast PACE data will be at least as good as the Land Atmosphere Near Real-Time Capability for EOS (LANCE, http://lance-modis.eosdis.nasa.gov/data_products/) MODIS AOD products currently available in less than 90 minutes for the Level 2 10 km Swath AOD. Additional capabilities such as ground-based lidars, sondes or models of trajectories (e.g., HYSPLIT http://ready.arl.noaa.gov/HYSPLIT.php), and chemical transport models are required to identify elevated layers. This is because PACE will measure whole column AOD and the air quality concern is only the layer closest to the surface. The availability of a PACE Polarimeter will significantly reduce reliance on ground- based measurements and enhance accuracy of the predicted PM.

Comments? Thoughts?

For additional information about PACE mission applications or this particular application, please contact Ali H. Omar at ali.h.omar@nasa.gov

PACE/HyspIRI COMPLEMENTARY MISSION APPLICATIONS:
Improving Hazard Assessment and Aviation Safety

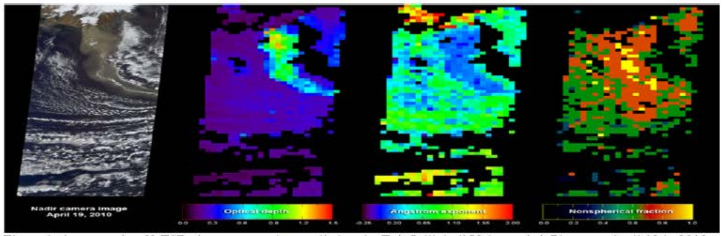


Figure 1. An example of MISR air mass mapping applied to the Eyjafjalljökull Volcano Ash Plume on April 19th, 2010. The four panels show successive information content (true color, optical depth, size, and sphericity) obtained from retrievals using multi-spectral, multi-angle MISR data (courtesy of Ralph Kahn and the MISR Team). This is similar to the information content of the multi-angle multi-spectral polarimeter planned for PACE.

Application Question/Issue

Aviation operations can be significantly impacted by volcanic ash as evident from the recent Eyjafjallajökull volcano in Iceland (April 2010). Knowledge of the location, amount, and evolution of the volcanic plume and its ash content will enable timely and accurate hazard assessment/avoidance and enhance aviation safety after volcanic eruptions.

Who Cares and Why?

Volcanic plumes consist of Sulfur Dioxide (SO_2) and volcanic ash which is predominantly composed of silicates with a melting point (~1100°C) far below typical turbine engine full thrust temperatures of ~ 1400°C. Aircraft flight through high concentrations of volcanic ash will fuse molten silicate on to turbine blades and guide vanes leading to transient flame out, and possibly engine failure. According the International Civil Aviation Organization (ICAO) Journal Issue 1 (2013), more than 100,000 commercial flights were cancelled during the Eyjafjallajökull's 2010 volcanic eruption and over $5 billion in global GDP was lost due to what eventually became the largest shut-down of European air traffic since World War II.

Needed Measurements

An ICAO task force recommended the use of satellite-based observations to guarantee safety while avoiding the unnecessary closure of immense portions of airspace. The closure of air space during the 2010 eruption of Eyjafallajökull was based on forecasts rather than satellite observations of ash. Satellite measurements will help to initialize and/or validate such forecasts. Measurements of volcanic plumes, plume height, ash and SO_2 concentrations, and the ability to discriminate between clouds of volcanic ash and meteorological (water/ice) clouds are needed. Some of these measurements are needed both day and night for the development of advisories directly or as inputs to model simulations from which such advisories will be developed.

The NASA Response

Measurements, similar to the information content of Figure 1 above, that would identify the ash particle size and concentration (from a **Multi-angle Multi-spectral Polarimeter on PACE**), and the ability to discriminate between water/ice clouds and volcanic plumes (from **HyspIRI**) would form **a complementary data** set and provide the relevant Volcanic Ash Advisory Centers (VAACs) **sufficient actionable information** for hazard avoidance during volcanic eruptions. The Eyjafjallajökull plume was observed by many satellite sensors including OMI, MISR, MODIS, SEVIRI, ASTER, AIRS, and CALIPSO. The MODIS instruments (in low earth orbit on the Terra and Aqua satellites) and the SEVIRI instrument (on METEOSAT in geostationary orbit) tracked the geographic transport of the ash plume and estimated its height and ash particle size. HyspIRI TIR measurements will provide us with similar capabilities. The MISR instrument on the Terra satellite, provided critical information that allowed mapping the height of distinct plumes over the North Atlantic. Multi-angle aerosol measurements on board PACE would enable plume heights to be derived in a manner similar to those employed using MISR. Additionally polarization measurements aboard PACE would enable separation of volcanic ash from sulfate aerosols. The ability to obtain these data results in direct societal benefit.

Comments? Thoughts?

For additional information about PACE mission applications or this particular application, please contact Ali H. Omar at ali.h.omar@nasa.gov

White Papers – PACE Applications

PACE MISSION APPLICATIONS - Harmful Algal Blooms

Upper Left: Harmful Algal Blooms kill fish, contaminate seafood and pollute our waters (Photo from NOAA/IOOS). Lower Left: Warning sign for cyanobacteria (Image Credit: J. Graham, USGS). Right: Satellite image of Lake Erie, showing the extent of the 2011 harmful algal bloom (the most severe in decades). Credit: MERIS/NASA; processed by NOAA/NOS/NCCOS.

Application Question/Issue: ***How can we better understand the causes and impacts (economic, cultural, environmental, human health) of Harmful Algal Blooms (HABs), and how can we improve monitoring and forecasting of the location and extent of HABs using ocean observations from space?***

Who Cares and Why?

Coastal HAB events have been estimated to result in economic impacts in the United States of at least $82 million each year. The impacts of HABs range from environmental (e.g., alteration of marine habitats and impacts on marine organisms including endangered species), to human health (e.g., illness or even death through shellfish consumption, asthma attacks through inhalation of airborne HAB toxins), to socio-economic and cultural (e.g., commercial fisheries, tourism, recreation).

NOAA, USGS, EPA (e.g., Gulf of Mexico Program), and other state environmental agencies and local health departments are interested in improved monitoring and understanding of HAB events. Among the main goals of these end-users is to provide coastal communities with advance warning, so they can adequately plan and deal with the adverse environmental and health effects associated with a harmful bloom.

Needed Measurements

Improved monitoring and forecasting of HABs requires satellite observations of sea-surface-temperature (SST), chlorophyll-a (Chla) and HAB pigments. To meet the needs of the user communities, satellite measurements (daily images) must be produced at spatial resolutions of approx. 300 m, with a spatial coverage that includes coastal waters (<100 nautical miles from the coast), signal-to-noise ratio (SNR) of 1000, uncertainty of 30% and range of 0.5-400 ug/L. Extended spectral coverage in the near infrared and shortwave infrared regions would be particularly helpful.

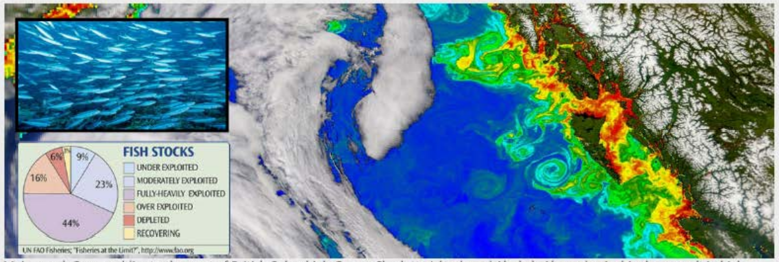
The NASA Response

The high (5-nm) spectral resolution measurements from PACE will allow regional algorithms to be developed for identifying and quantifying specific phytoplankton groups, thus allowing identification of HABs and tracking their evolution and variability over seasonal to interannual time scales. This information will lead to a highly sought-after understanding of environmental factors governing HAB appearance and demise. The recommended PACE ocean color data latency (0.5 hour data latency), extended spectral range from the ultraviolet (~350nm) to short-wave infrared (SWIR; 2130nm), spatial coverage (global), and spatial resolution of 250 m x 250 m to <1 km^2 in inland, estuarine, coastal and shelf waters, will meet the majority of users needs for improved space-based HAB retrievals. The combination of high quality PACE ocean color imagery with ancillary observations from various platforms, including other (current and planned, domestic and international) satellite sensors, aircraft measurements, ground-based and marine observation networks, will allow us to vastly improve monitoring and forecasting of the location and extent of HABs.

Comments? Thoughts?

For additional information about PACE mission applications or this particular application, please contact Maria Tzortziou at: *maria.a.tzortziou@nasa.gov*

PACE MISSION APPLICATIONS - Marine ecosystem resources: Fisheries



Main panel: Ocean eddies to the west of British Columbia's Queen Charlotte Islands and Alaska's Alexander Archipelago result in high biological activity in the ocean (Image Credit: SeaWiFS Ocean Color image; SeaWiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE). Upper Inner panel: Fisheries (Photo Credit: ESA, id 289871). Lower inner panel: ~70% of the major marine fish stocks are either depleted, overexploited or being fished at their biological limit (Credit: UN FAO fisheries, http://www.fao.org)

Application Question/Issue: ***How can we improve monitoring of our global ocean resources and their habitat, as needed for implementing ecosystem-based management approaches for productive and sustainable fisheries, safe sources of seafood, the recovery and conservation of protected resources, and healthy ecosystems?***

Who Cares and Why?

The international trade in coastal and marine fisheries contributes $70 billion annually to the US economy (NOAA's State of the Coast). Yet, according to the Food and Agriculture Organization of the United Nations (FAO), 70 per cent of the world's fish stocks for which assessment information is available are reported as fully exploited or overexploited and, thus, require effective and precautionary management.

A wide range of users from the private and public sectors, including NOAA Fisheries, regional Fishery Management Councils, local health departments, global conservation organizations (e.g., WWF), and private fish forecasting companies, are interested in assimilation of earth-observation data into fisheries research and management. Among their major goals is providing services for productive, healthy and sustainable fisheries, assessing the status of fish stocks, ensuring compliance with fisheries regulations, and supporting conservation of protected species.

Needed Measurements

Improved monitoring and forecasting of our global ocean resources and their habitat requires global-scale satellite observations of sea surface temperature (SST), sea surface height (SSH), surface vector winds, and ocean color (e.g., chlorophyll-a, diffuse attenuation coefficient, ocean reflectance, phytoplankton pigments). To meet the needs of the user communities (e.g., NOAA Fisheries), satellite imagery must be at a global scale, medium to high spatial resolution (i.e., 100 m to 4 km at nadir), every 3hrs to daily. Hyperspectral ocean color capability is critical for quantifying phytoplankton biomass and pigments, assessing key phytoplankton groups, and estimating net primary productivity.

The NASA Response

With advanced global remote sensing capabilities (2-day global coverage, extended spectral range, climate-quality hyperspectral observations, high signal-to-noise ratio, reduction in instrument artifacts, and better instrument performance tracking compared to heritage sensors), the PACE ocean color sensor will help refine measurements of primary productivity in coastal and open ocean environments, of phytoplankton pigments and biological communities, and of ecosystem structure needed to help improve the way we use our global ocean resources.

An important application of satellite ocean color imagery is the mapping of ecological boundaries often through delineation of mesoscale ocean features, such as fronts, upwelling currents, gyres and eddies. These mesoscale features cross major sections of our oceans and influence nutrient availability, primary production, distribution and abundance of fish, including commercial species and also protected species such as whales, sea turtles, and salmon. As our planet changes, PACE will provide a unique capability to observe how the spawning habitats of different species of organisms change, and where ecological conditions make life possible for these species as they adjust their range and life cycles. Combined with ancillary data on ocean physical properties, PACE ocean color observations will help us to better understand essential fish habitats and the productivity dynamics of the phytoplankton that forms the base of the global ocean food web.

Comments? Thoughts?

For additional information about PACE mission applications or this particular application, please contact Maria Tzortziou at: *maria.a.tzortziou@nasa.gov*

White Papers – PACE Applications

PACE MISSION APPLICATIONS - Harmful Algal Blooms

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The NASA Response

The high (5-nm) spectral resolution measurements from PACE will allow regional algorithms to be developed for identifying and quantifying specific phytoplankton groups, thus allowing identification of HABs and tracking their evolution and variability over seasonal to interannual time scales. This information will lead to a

PACE

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NOAA, USGS, EPA (e.g. Gulf of Mexico Program), and other state environmental agencies and local health departments are interested in improved monitoring and understanding of HAB events. Among the main goals of these end-users is to provide coastal communities with advance warning, so they can adequately plan and deal with the adverse environmental and health effects associated with a harmful bloom.

Needed Measurements

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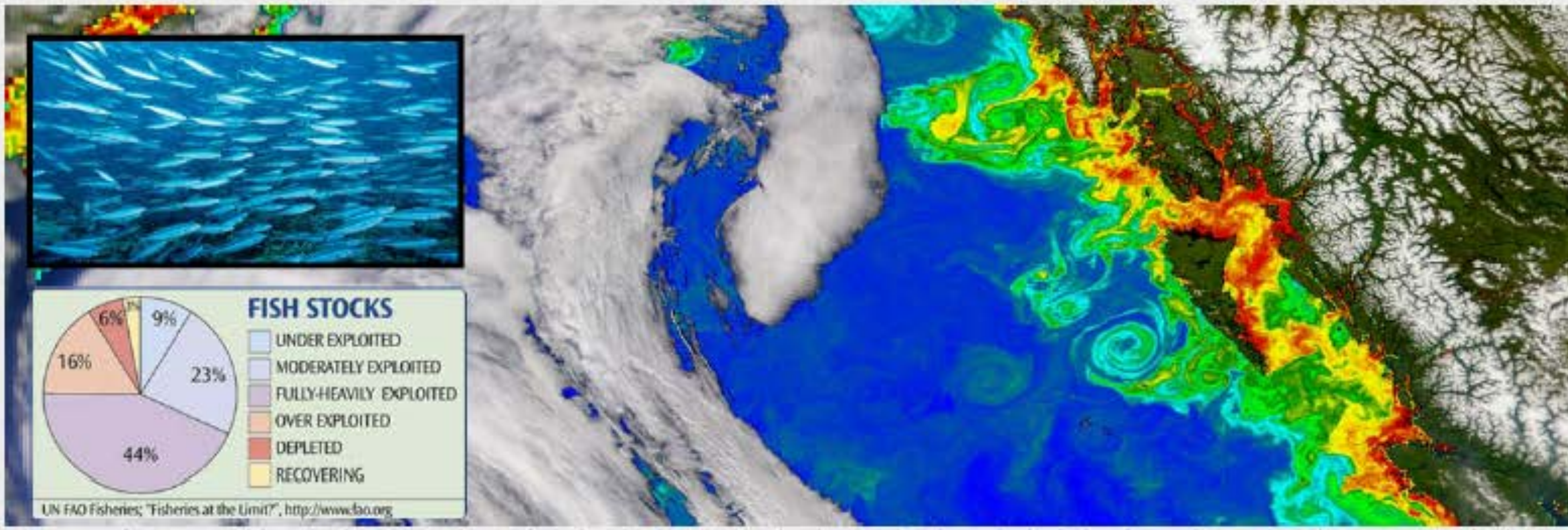
Comments? Thoughts?

The PACE website is designed to reach out and engage the community of practice, accept and process feedback and queries, support interactive workshops and disseminate user tutorials and other pertinent information. Please, provide comments and thoughts at **http://decadal.gsfc.nasa.gov/pace.html**

White Papers – PACE Applications

PACE MISSION APPLICATIONS - Marine ecosystem resources: Fisheries



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Who Cares and Why?

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The NASA Response

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Improved monitoring and forecasting of our global ocean resources and their habitat requires global-scale satellite observations of sea surface temperature (SST), sea surface height (SSH), surface vector winds, and ocean color (e.g., chlorophyll-a, diffuse attenuation coefficient, ocean reflectance, phytoplankton pigments). To meet the needs of the user communities (e.g., NOAA Fisheries), satellite imagery must be at a global scale, medium to high spatial resolution (i.e., 100 m to 4 km at nadir), every 3hrs to daily. Hyperspectral ocean color capability is critical for quantifying phytoplankton biomass and pigments, assessing key phytoplankton groups, and estimating net primary productivity.

The NASA Response

With advanced global remote sensing capabilities (2-day global coverage, extended spectral range, climate-quality hyperspectral observations, high signal-to-noise ratio, reduction in instrument artifacts, and better instrument performance tracking compared to heritage sensors), the PACE ocean color sensor will help refine measurements of primary productivity in coastal and open ocean environments, of phytoplankton pigments and biological communities, and of ecosystem structure needed to help improve the way we use our global ocean resources.

An important application of satellite ocean color imagery is the mapping of ecological boundaries often through delineation of mesoscale ocean features, such as fronts, upwelling currents, gyres and eddies. These mesoscale features cross major sections of our oceans and influence nutrient availability, primary production, distribution and abundance of fish, including commercial species and also protected species such as whales, sea turtles, and salmon. As our planet changes, PACE will provide a unique capability to observe how the spawning habitats of different species of organisms change, and where ecological conditions make life possible for these species as they adjust their range and life cycles. Combined with ancillary data on ocean physical properties, PACE ocean color observations will help us to better understand essential fish habitats and the productivity dynamics of the phytoplankton that forms the base of the global ocean food web.

Comments? Thoughts?

For additional information about PACE mission applications or this particular application, please contact Maria Tzortziou at: *maria.a.tzortziou@nasa.gov*

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Application Question/Issue: *How can we improve monitoring of our global ocean resources and their habitat, as needed for implementing ecosystem-based management approaches for productive and sustainable fisheries, safe sources of seafood, the recovery and conservation of protected resources, and healthy ecosystems?*

Who Cares and Why?

The international trade in coastal and marine fisheries contributes $70 billion annually to the US economy (NOAA's State of the Coast). Yet, according to the Food and Agriculture Organization of the United Nations (FAO), 70 per cent of the world's fish stocks for which assessment information is available are reported as fully exploited or

observation data into fisheries research and management. Among their major goals is providing services for productive, healthy and sustainable fisheries, assessing the status of fish stocks, ensuring compliance with fisheries regulations, and supporting conservation of protected species.

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Comments? Thoughts?

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Next priorities:

- Water Quality and Human Health
- Habitats (both at 1-km and, potentially, 500, 100, 50 m resolution)

→ Development of **cross mission activities** to establish connections between the PACE/ACE missions and other NASA missions.

PHyG (<u>P</u>ACE, <u>Hy</u>spIRI, <u>G</u>EOCAPE) group: Jeremy, Emmanuel, Kevin, Antonio, Maria

No mission can do everything

Maximize return on investment