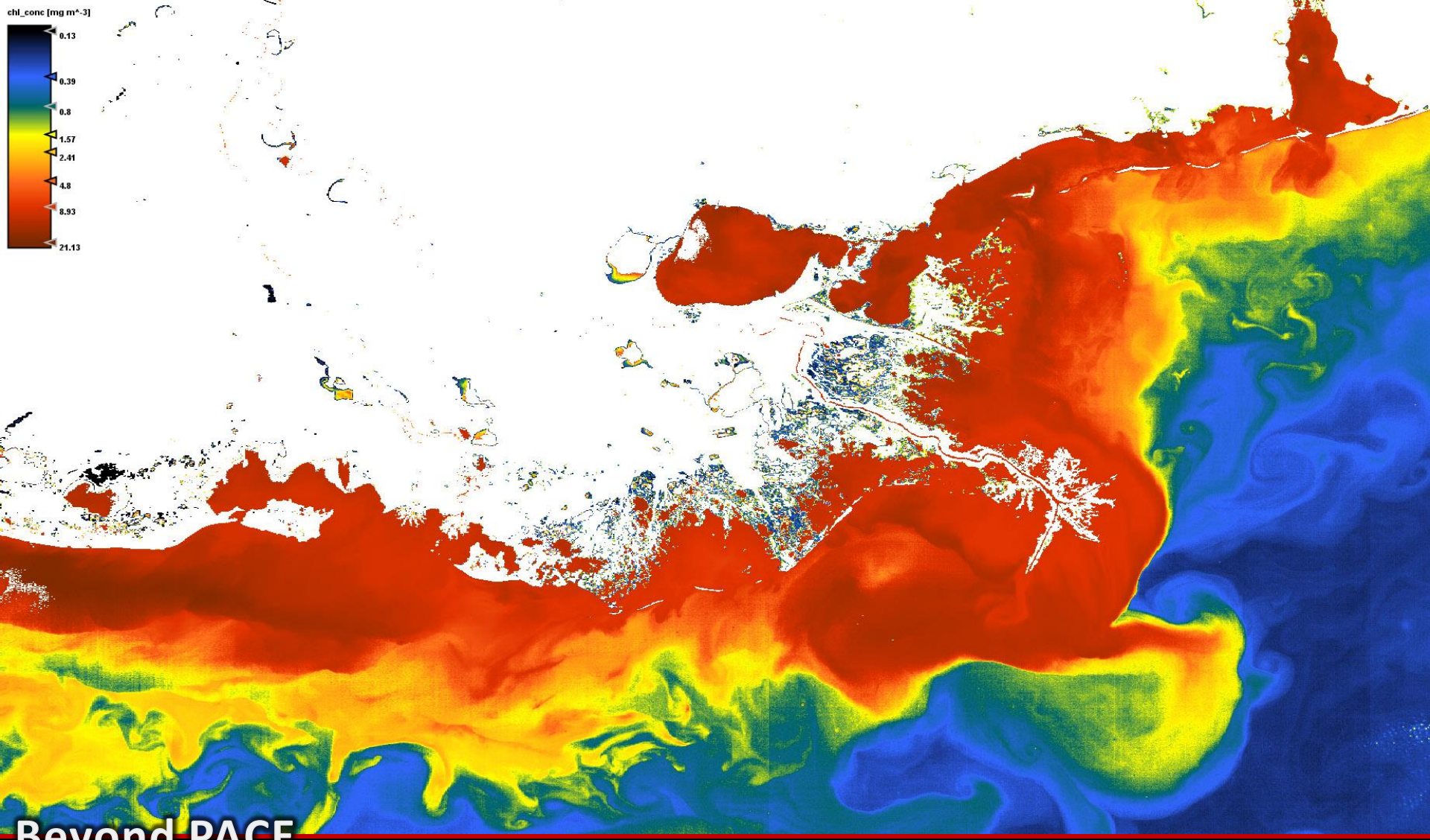
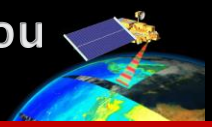


Beyond PACE

Ocean Color -Measurement requirements of coastal & applications research

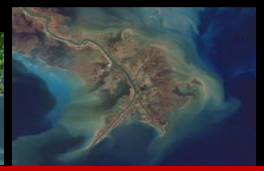
Maria Tzortziou
martz@umd.edu



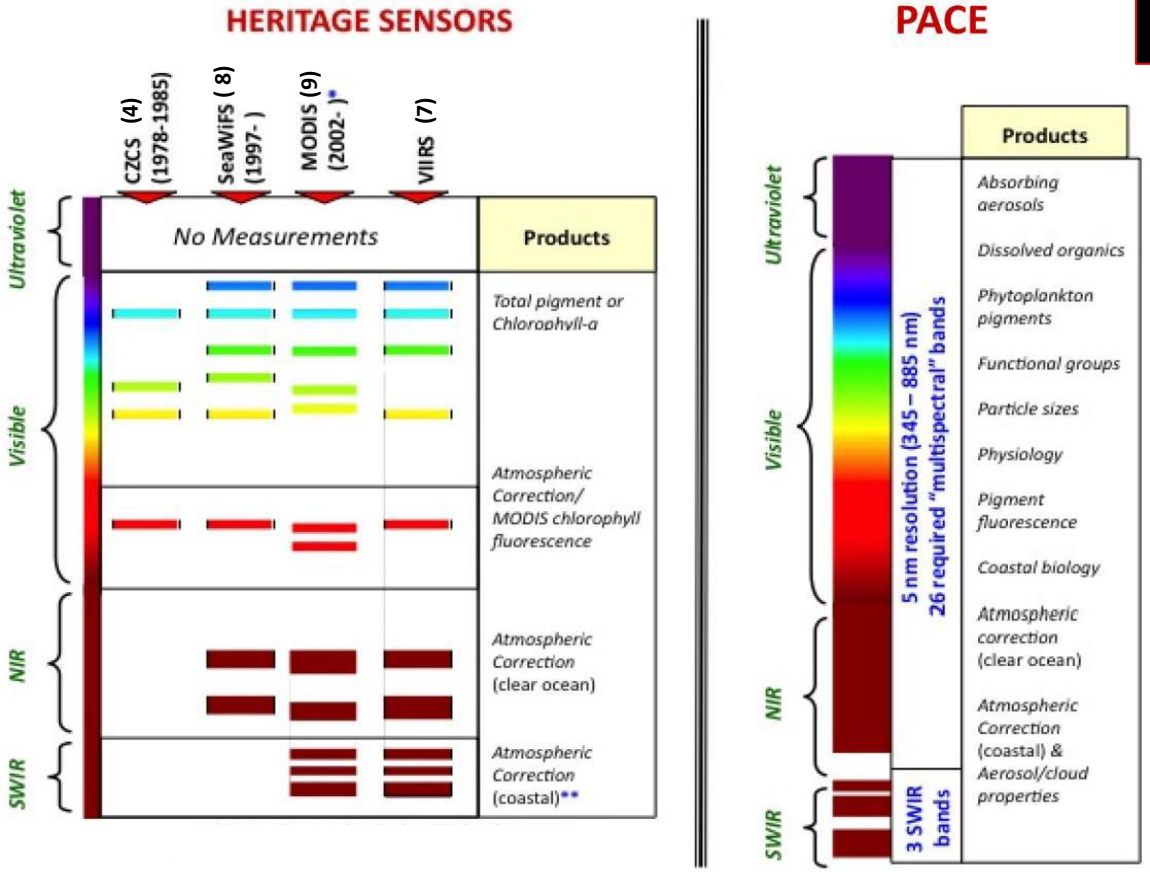








PACE: A Climate Initiative Mission with Enhanced Capabilities



* 2-day **global** coverage
* multiple daily observations at high latitudes

PACE advanced capabilities :

- **hyper-spectral** data
- **extended spectral** range (UV-SWIR)
- **higher spatial** resolution in inland (lakes), estuarine, coastal waters (250-500m?)
- key observations of **aerosols/clouds**
- **higher signal-to-noise**
- continual **community access** to data in near real time.
- development and implementation of **applications** (ocean/ atmosphere/terrestrial)

→ Improved **spectral range and spectral resolution** for PACE, will result in more, and higher quality, products relevant to **coastal ocean science & applications**, and **atmosphere science & applications** (polarimeter TBD).
→ Improved **spatial resolution and enhanced atmospheric correction** will extend retrievals to inland/estuarine and coastal waters.

(*from PACE STD Report, 2012, available on PACE website*)

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.

Temporal? Is 2-day revisit enough?

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

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

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	Pro M Perf
What is the air quality	The Environmental Protection Agency	Observations of AOD at spatial	Public Health and Air	Environmental	Aerosol Optical	AOD wit zonta m
	assessment of sustainability and					retrievals
How are the productivity and biodiversity of coastal ecosystems changing, and how do these changes	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	chl-a, K_{PAR} , K_{490} Spatial: 1 km Temporal: daily Coverage: Global Latency: 12 hours	Ecologial Forecasting	NOAA [Paul DiGiacomo, Cara Wilson NOAA]	chl-a, K_{PAR} , K_{490}	0.5 hour direct br nm res. Spatial r km2 (±1 angles a

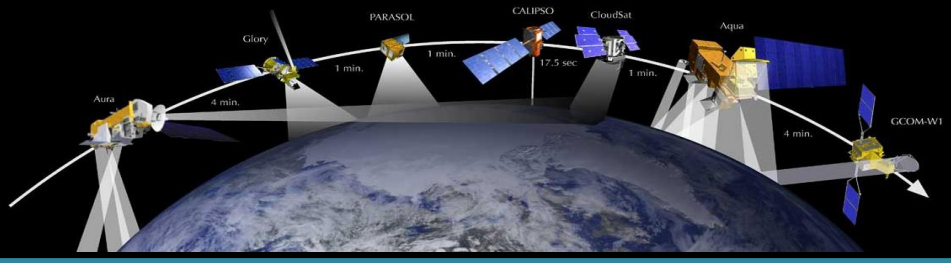
Ocean Color Measurement Requirements needed to further improve coastal & applications research (in addition to appropriate radiometric sensitivity):

→ Improved spectral resolution, >16 bands/hyper-spectral
→ Improved spectral range: UV-NIR-SWIR, thermal imagery

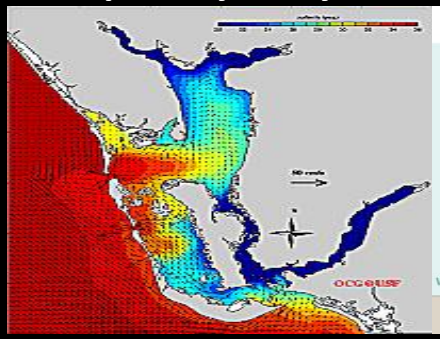
} due to optical complexity of coastal areas

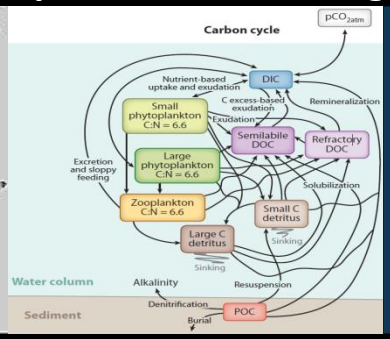
→ Improved spatial resolution, < 500 m
→ Improved temporal resolution, > 1 image per day

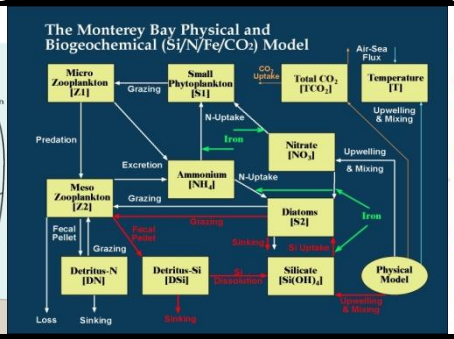
} due to spatio-temporal scales of physical & biogeochemical processes in coastal areas

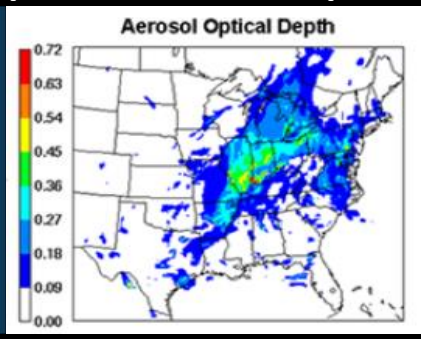


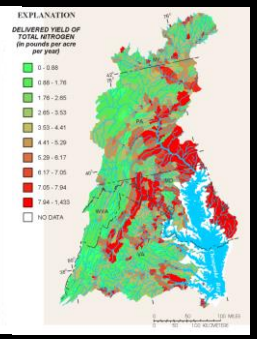
Coupled hydrodynamic-photochemical-biogeochemical models / coupled ocean-atmosphere-land models











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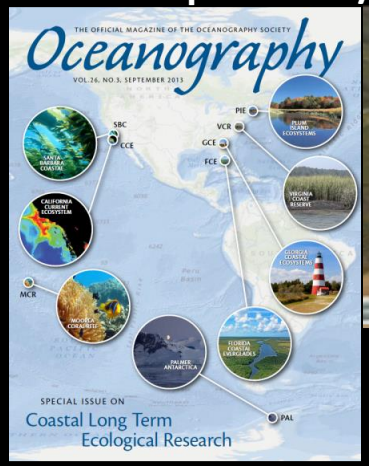
Coastal Ocean Observatories:
Various platforms/instruments, Continuous, interdisciplinary, free/easy data access, relevant to society



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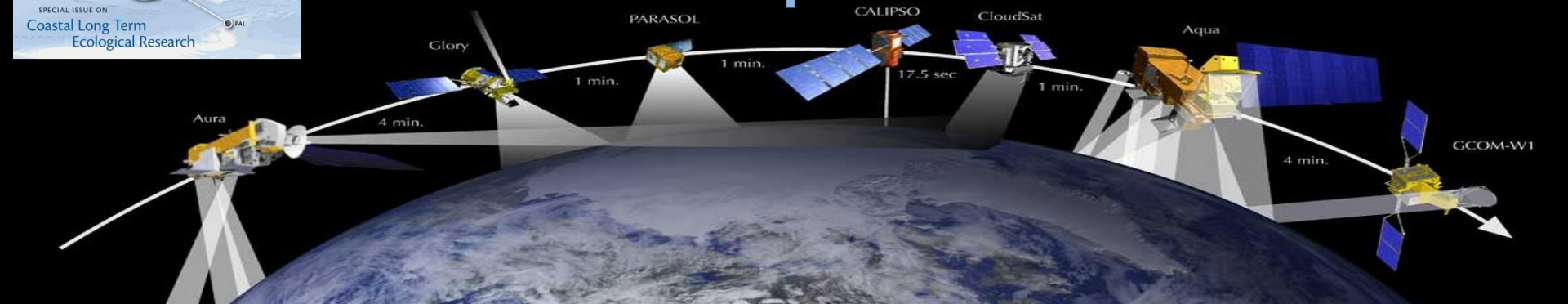
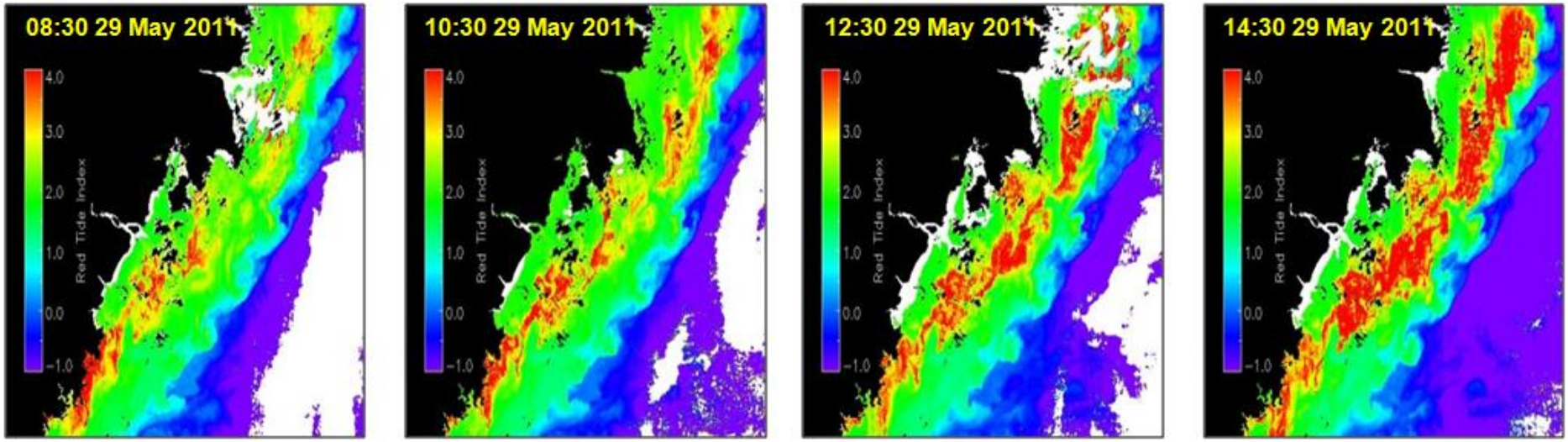


Harmful algal bloom along the East China's coast



GOCI-observed diurnal changes of a harmful algal bloom of *Prorocentrum donghaiense* along the East China's coast. From Lou and Hu (2014).

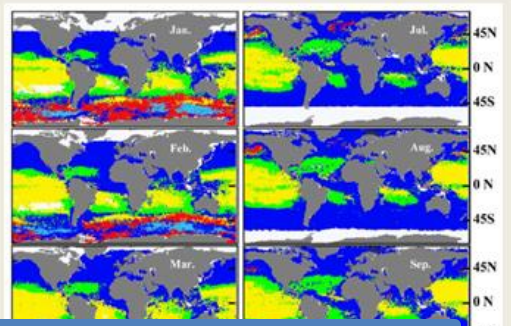
Oceans/Inland Waters | **Water Resources** | **Disasters** | **Ecological Forecasting** | **Climate**

- Water Quality Indicators/ Ecosystem Health
- Sediment transport (navigation)
- Post-storm Assessments (e.g., flood detection)
- Detection and tracking of hazards, including oil spills and HABs
- Improve assimilation of satellite data into operational models to (i) assess/improve management of coastal resources , and (ii) improve forecasting/predictions. Predictions at :
  - short term scales: necessary for managers to prepare for, and respond to events
  - longer scales: to enable strategic planning/to prevent, estimate impacts, mitigate impacts of events

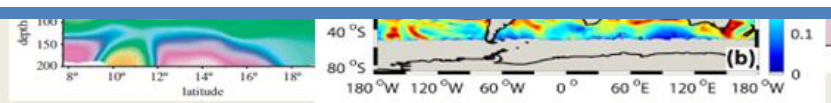
- Improve **separation of dominant optically active constituents** (CDOM, NAP, Chla): still a major challenge
- Estimate **particle abundance, size distribution , characteristics**
- **Resolve / quantify different phytoplankton pigments, key groups (functional/HABS)** and their optical properties
- **Observe/understand short-term changes, evolution of processes, transformation pathways**
  - biological pump
  - tidal dynamics,
  - dispersion of se
  - phytoplankton
- **Address interdisciplinary "**
  - exchanges & fee
  - exchanges & int
- Quantify **bi**
  -
  -
  -
- Integrate hi
current/futu

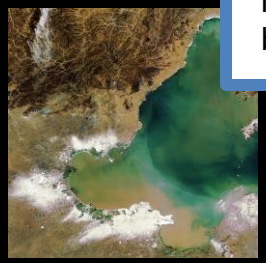
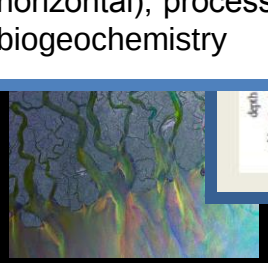
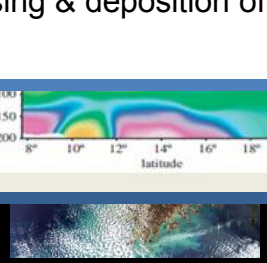
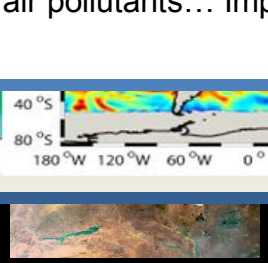
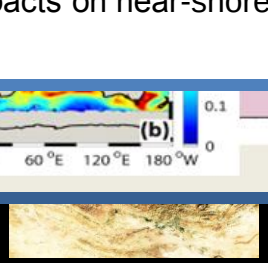
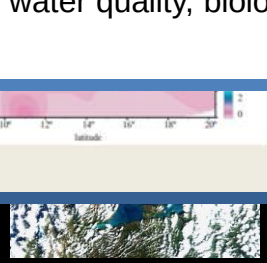
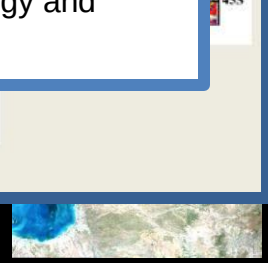
GEO-CAPE Interdisciplinary Science Group
(Co-Leads: Carolyn Jordan, Maria Tzortziou, Laura Iraci)

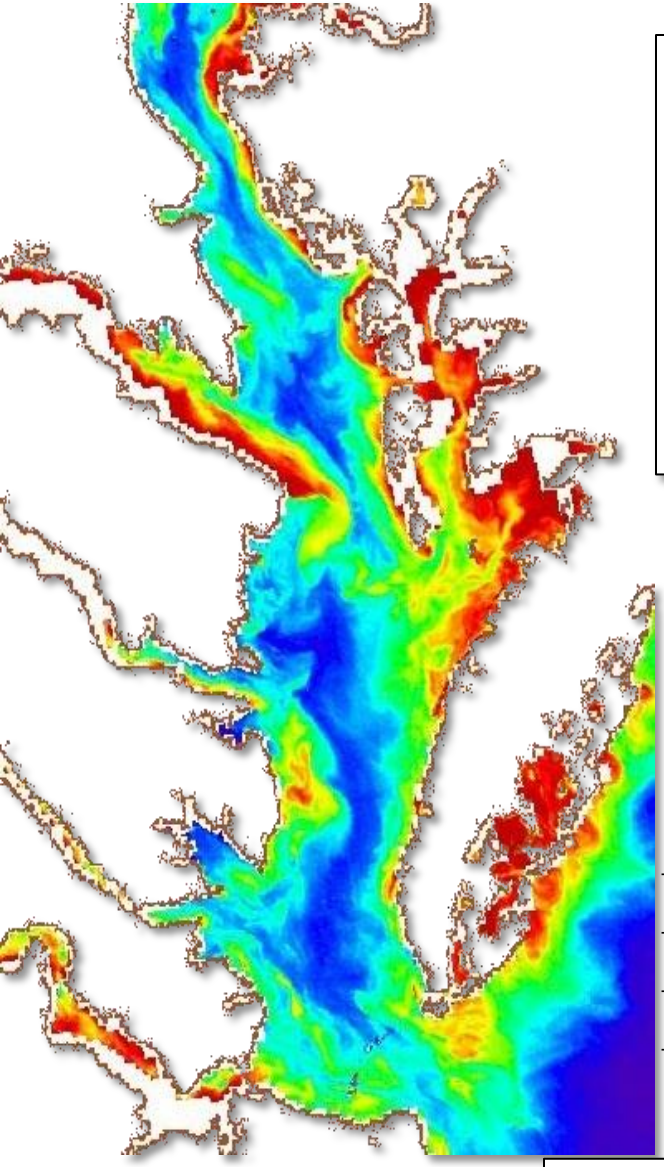
1) Influences of clouds, aerosols, meteorology on coastal waters and vice versa
2) Bidirectional fluxes of chemical constituents between the atmosphere and coastal waters
3) Impacts of anthropogenic activities on coastal ocean biogeochemical cycles



- Evaluate the spatial and temporal patterns in atmospheric variability and what this variability represents in terms of uncertainties in ocean color data products
- Apply results from ocean and air-quality measurements to examine optical closure in the ocean-atmosphere system
- Assess the role of estuarine & coastal systems a net source/sink for certain aerosols and trace gases.
- Integrate results with air-quality model simulations, to study effects of meteorological processes at the land-ocean interface (e.g. land-sea breeze circulations) on transport (vertical and horizontal), processing & deposition of air pollutants… Impacts on near-shore water quality, biology and biogeochemistry

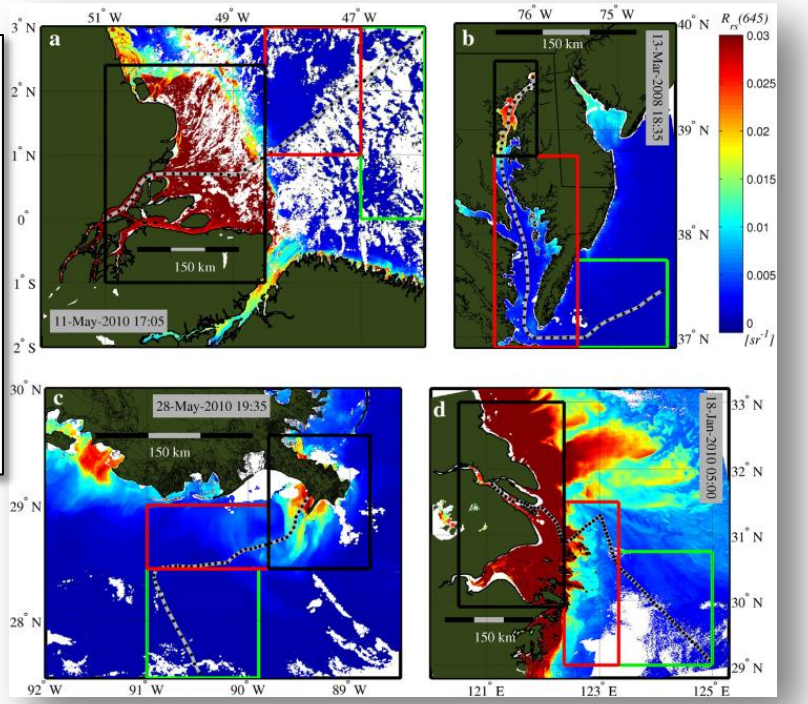


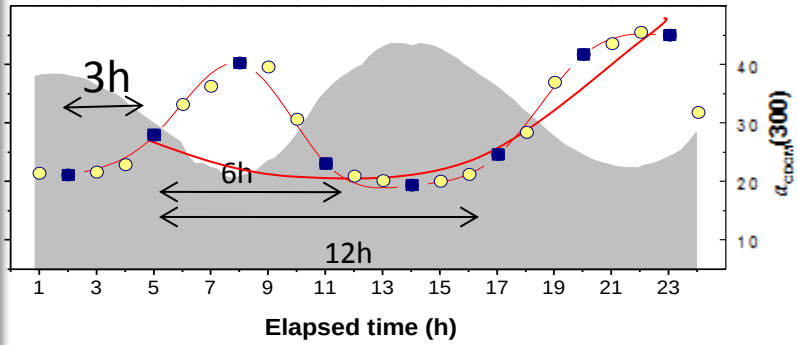


MODIS-Aqua:
Lw(645),250-m
(Franz et al. 2006).

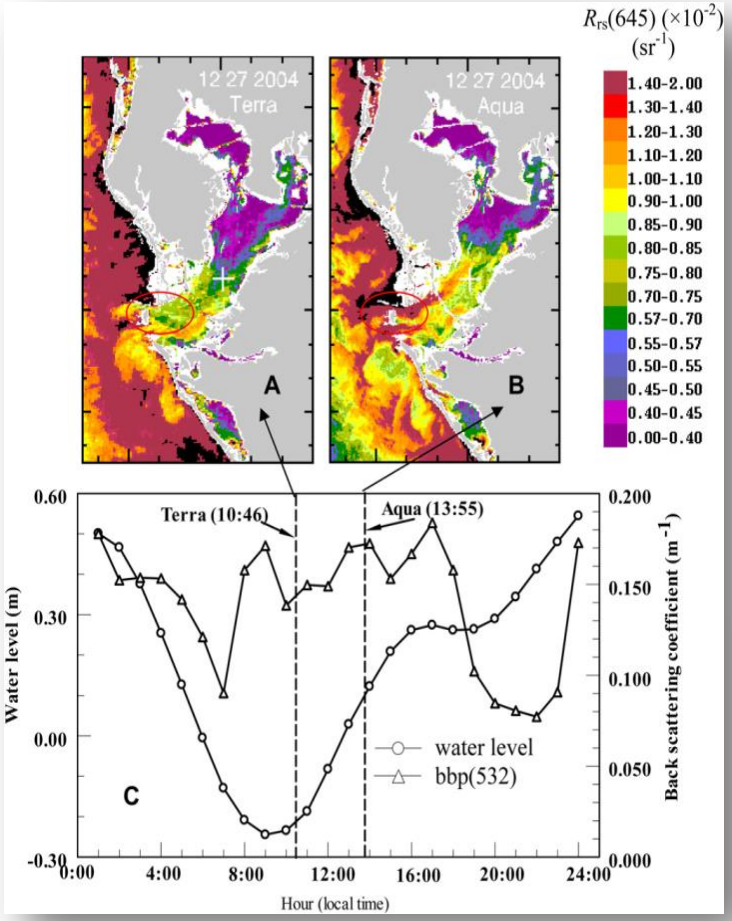
Spatial resolution < 500m is required to resolve spatial heterogeneity in ocean color and suspended materials in **river plumes**. **1-km resolution is adequate in the open ocean**.
(a) Amazon River,
(b) Chesapeake Bay,
(c) Mississippi River,
(d) Yangtze River.
(Aurin et al., 2013)



Wetipquin wetlands

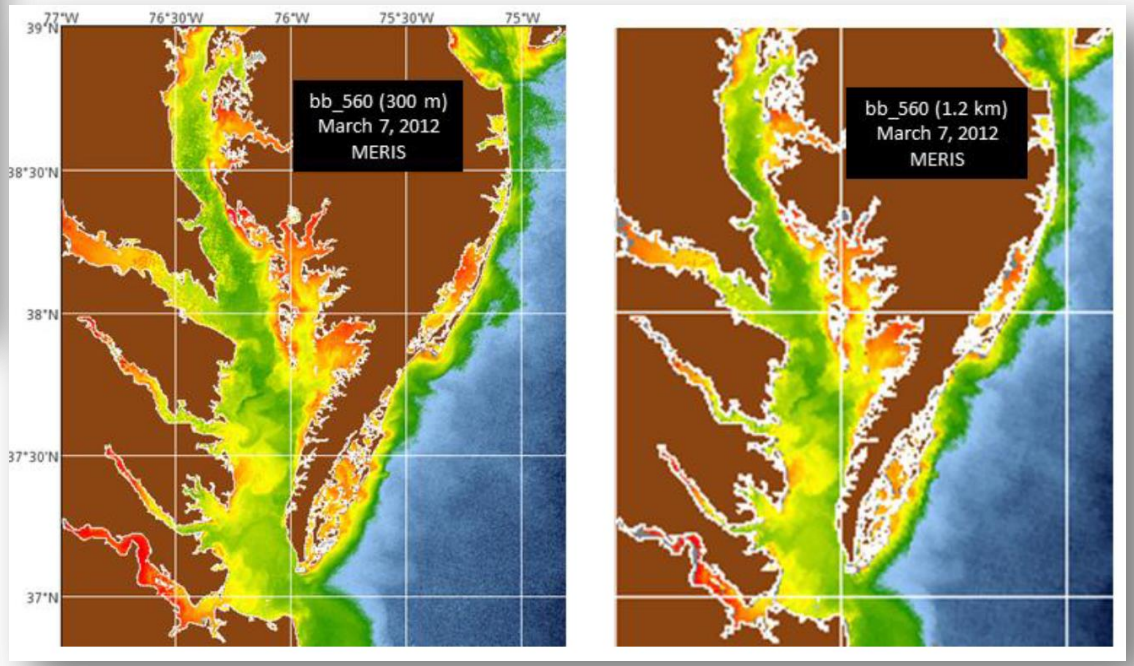


Tzortziou et al. (2012) had hourly measurements of wetland-ocean exchanges of CDOM, DOC, DIC, and Chla. **Temporal resolution better than 3-hr, and spatial resolution < 500m** are required to resolve temporal and spatial patterns at the land-ocean interface.

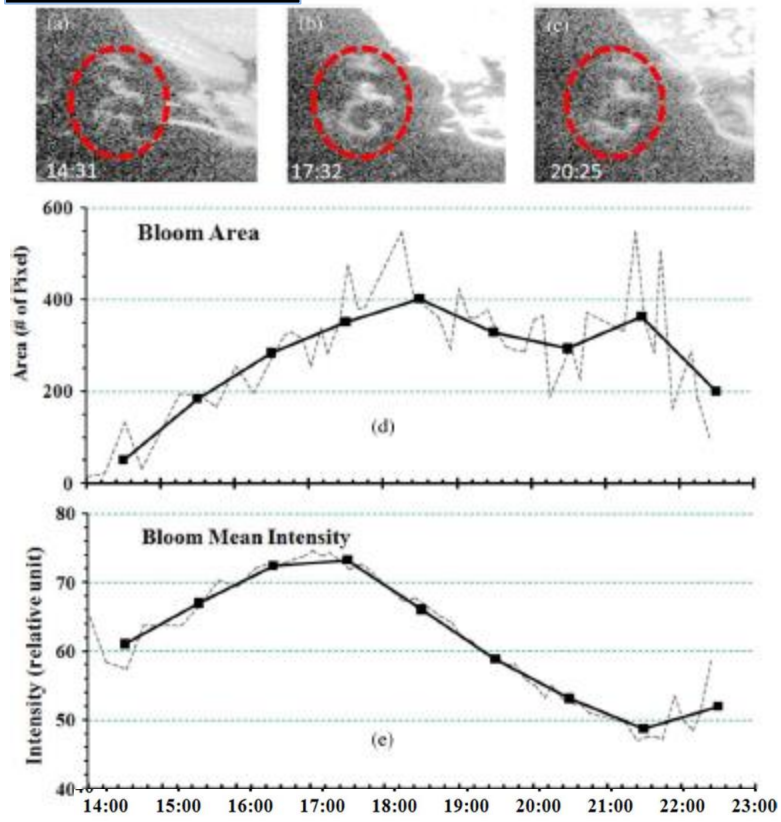


Chen et al. (2010) found **high-frequency changes in both phytoplankton and suspended sediments** driven by **tidal and subtidal currents,** in Tampa Bay.

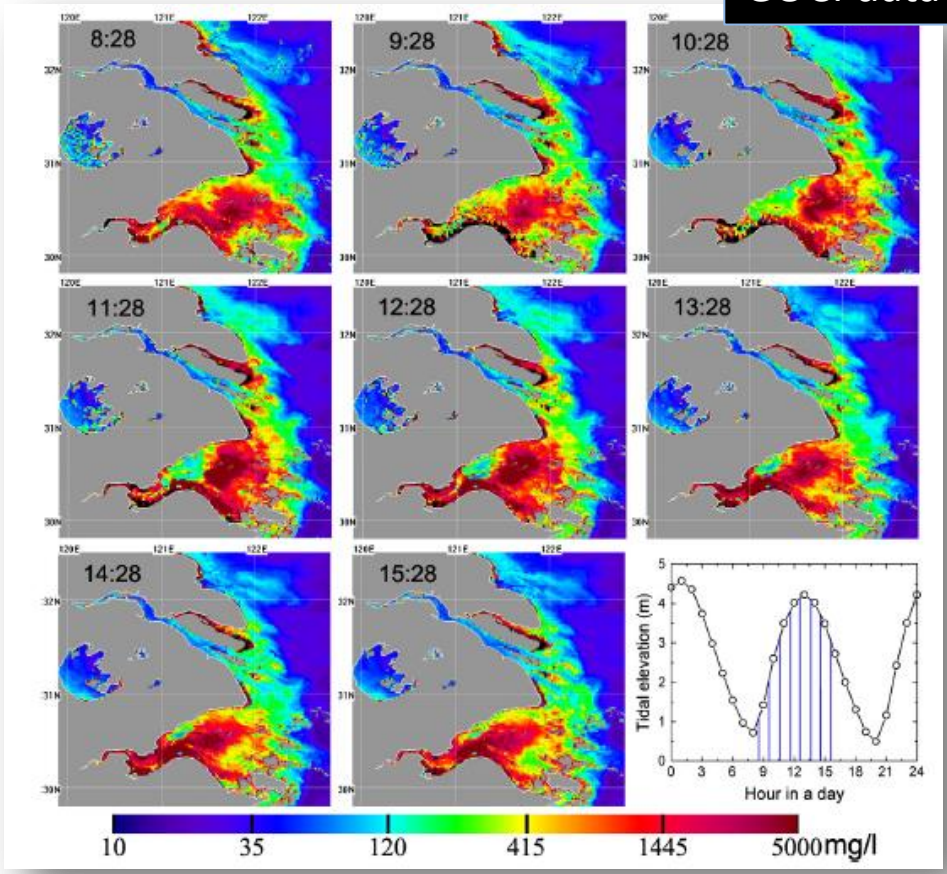
MERIS images of the Chesapeake Bay collected March 7, 2012.
LEFT: **300 m resolution** total backscattering coefficient at 560 nm (bb 560 nm). RIGHT: **1.2 km resolution** bb 560 product.
(from PACE SDT Report. Image courtesy of Robert Arnone, Naval Research Laboratory.)



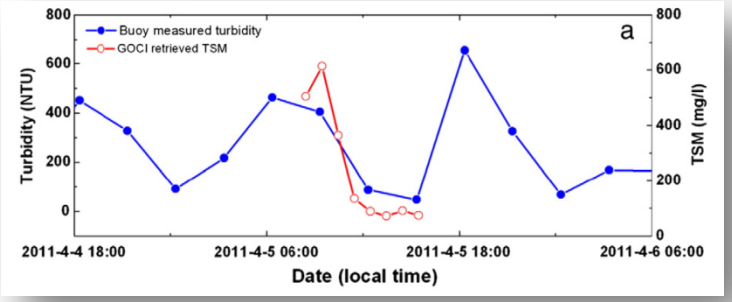
GOES Imager



GOCI data



Using geostationary data from GOES, Hu and Feng (2014) were able to capture the strong **diurnal changes of a *Trichodesmium bloom*** in the Gulf of Mexico, due possibly to a combined effect of physical aggregation and phytoplankton migration. **The bloom area increased by eightfold, and the mean bloom intensity increased by ~22%, within 4 hours.**



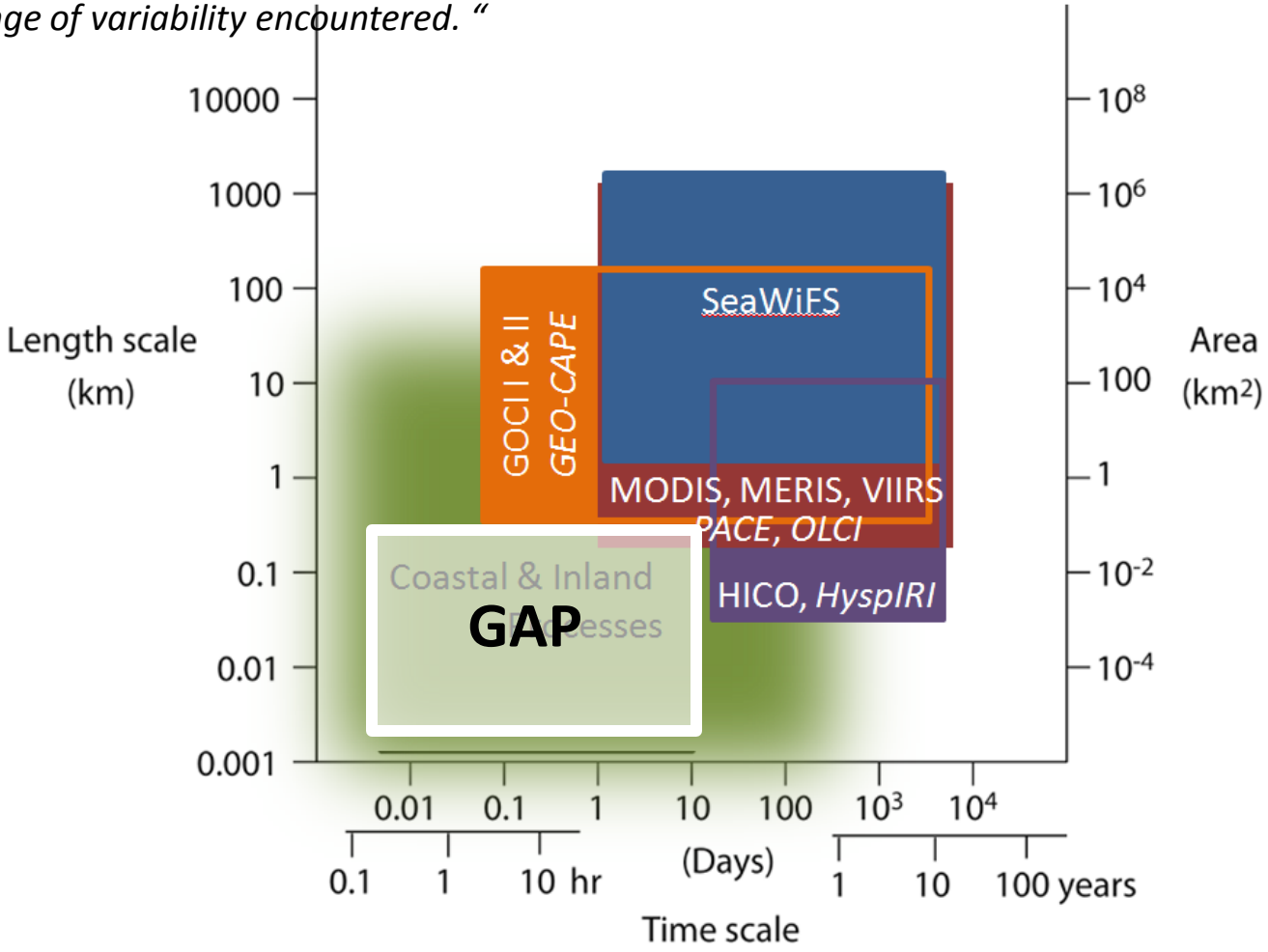
He et al (2013), looked at the **hourly changes in TSM in the Hangzhou Bay** retrieved by GOCI on 5 April 2011.

Good agreement between GOCI-TSM and turbidity from buoy.

Spatial and Temporal Resolution

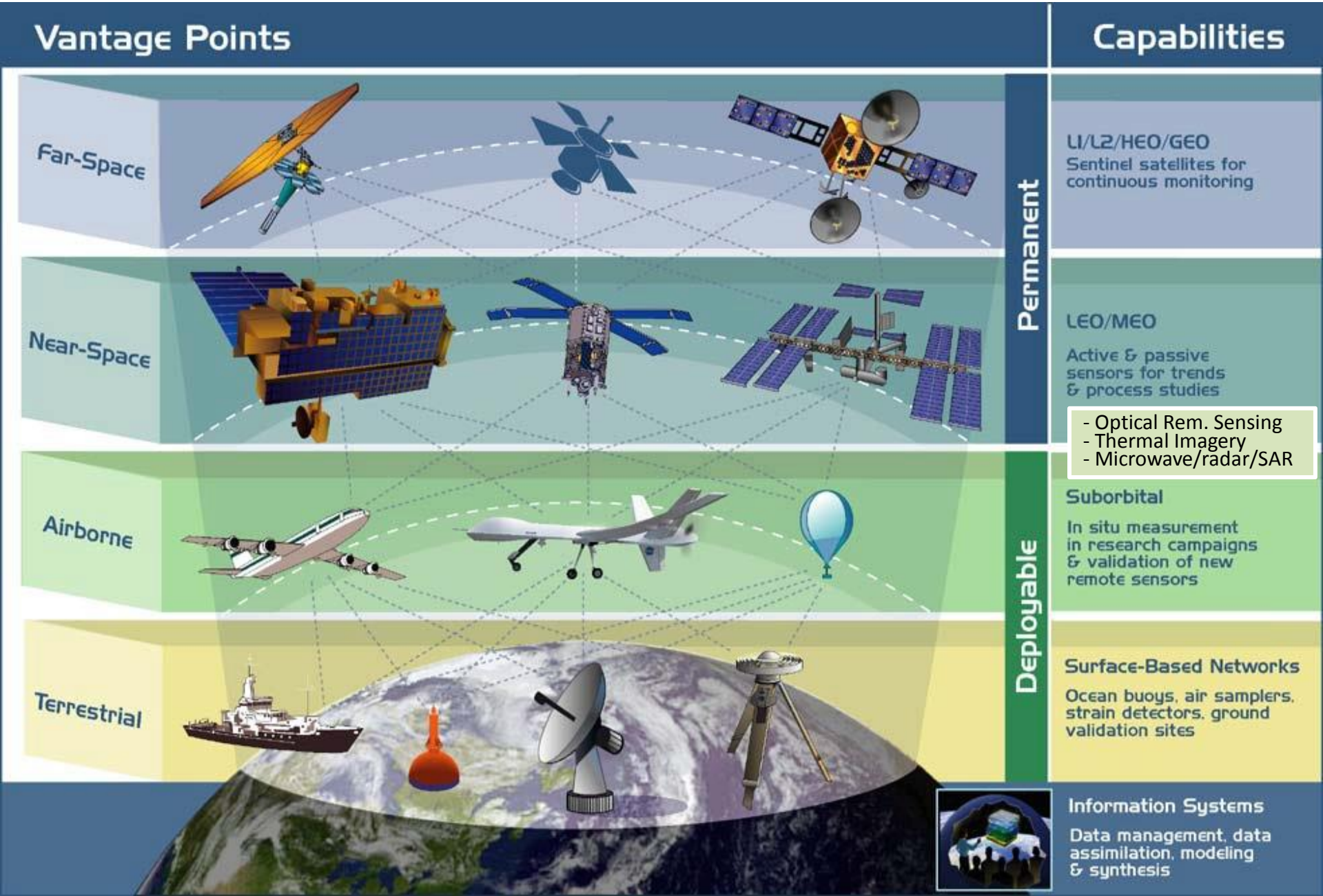
" • Significant overlap with current & future satellite sensors.

• Satellite platforms cannot fully capture all scales of temporal and spatial variability in coastal waters. Aircraft sensors and continual in situ observational platforms (observatories) are needed to fully capture of the range of variability encountered. "



from Mouw et al., Remote Sens. Environ, In revision

Synthesis of 2012 Workshop for Remote Sensing of Coastal and Inland Waters


Vantage Points
Capabilities
Far-Space
Near-Space
Airborne
Terrestrial
Permanent
Deployable
L1/L2/HEO/GEO
Sentinel satellites for continuous monitoring
LEO/MEO
Active & passive sensors for trends & process studies
- Optical Rem. Sensing
- Thermal Imagery
- Microwave/radar/SAR
Suborbital
In situ measurement in research campaigns & validation of new remote sensors
Surface-Based Networks
Ocean buoys, air samplers, strain detectors, ground validation sites
Information Systems
Data management, data assimilation, modeling & synthesis

Spatial and Temporal Resolution

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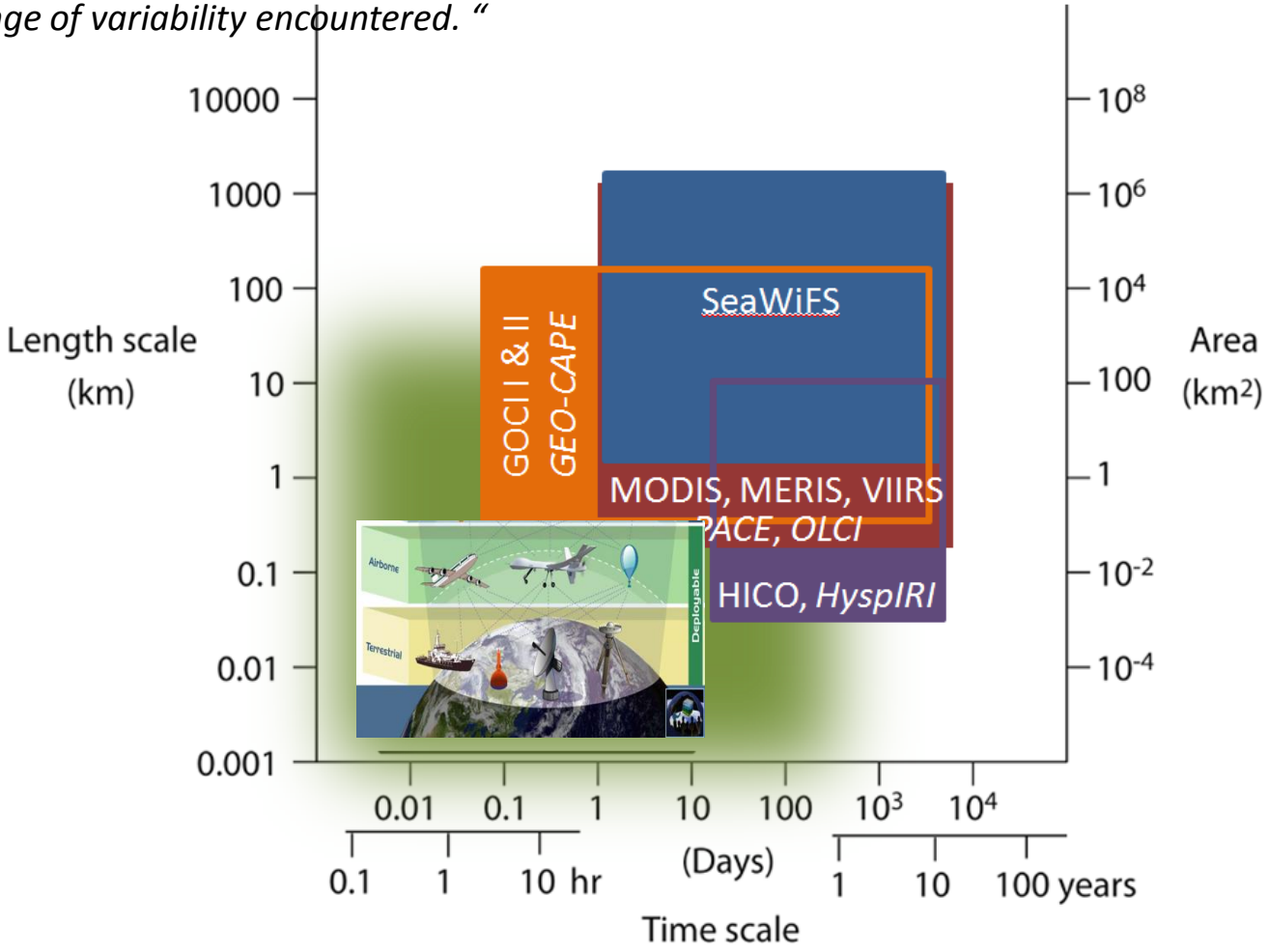

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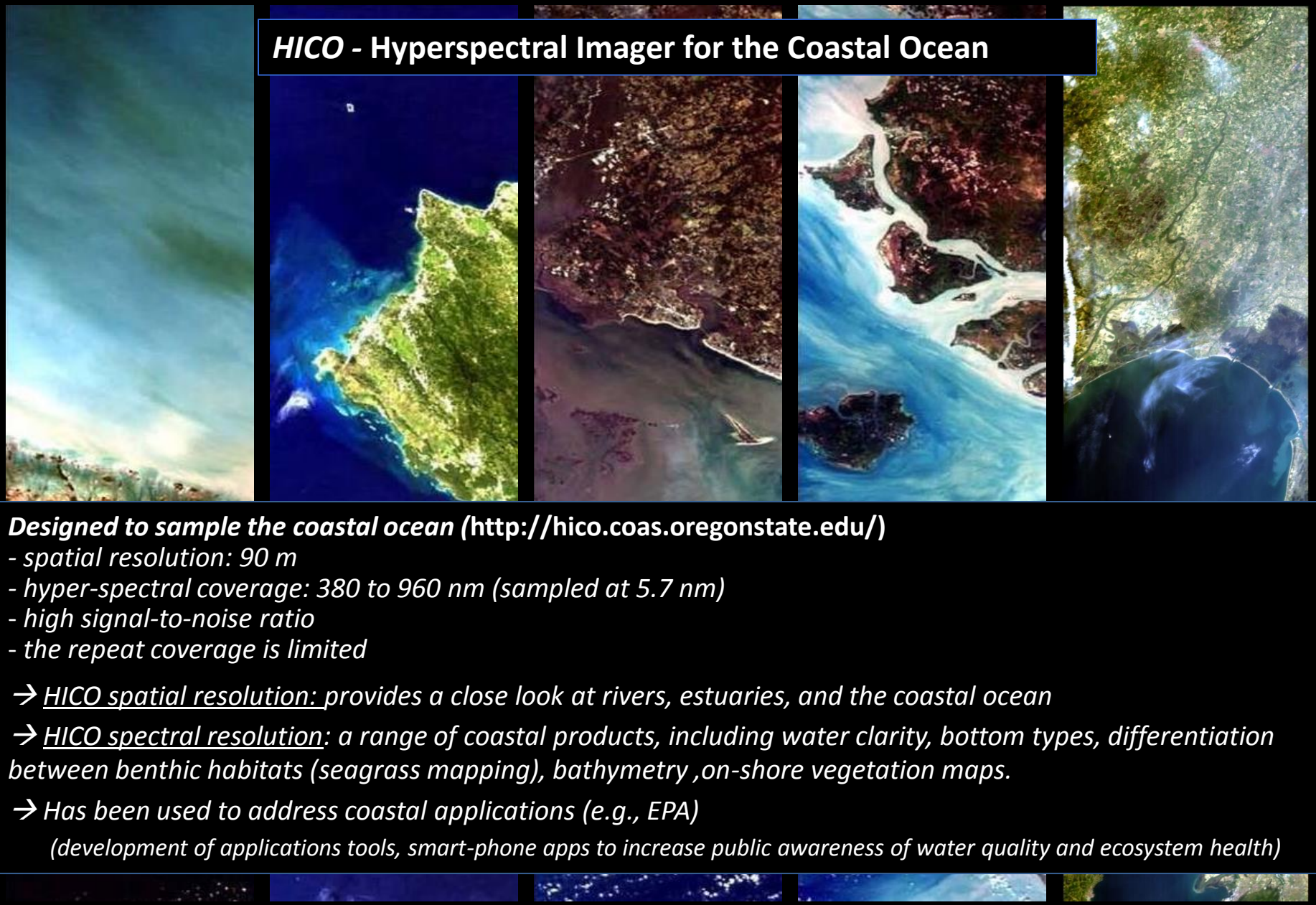


HICO - Hyperspectral Imager for the Coastal Ocean

***Designed to sample the coastal ocean* (http://hico.coas.oregonstate.edu/)**

- spatial resolution: 90 m
- hyper-spectral coverage: 380 to 960 nm (sampled at 5.7 nm)
- high signal-to-noise ratio
- the repeat coverage is limited

→ *HICO spatial resolution: provides a close look at rivers, estuaries, and the coastal ocean*

→ *HICO spectral resolution: a range of coastal products, including water clarity, bottom types, differentiation between benthic habitats (seagrass mapping), bathymetry ,on-shore vegetation maps.*

→ *Has been used to address coastal applications (e.g., EPA)*

(development of applications tools, smart-phone apps to increase public awareness of water quality and ecosystem health)

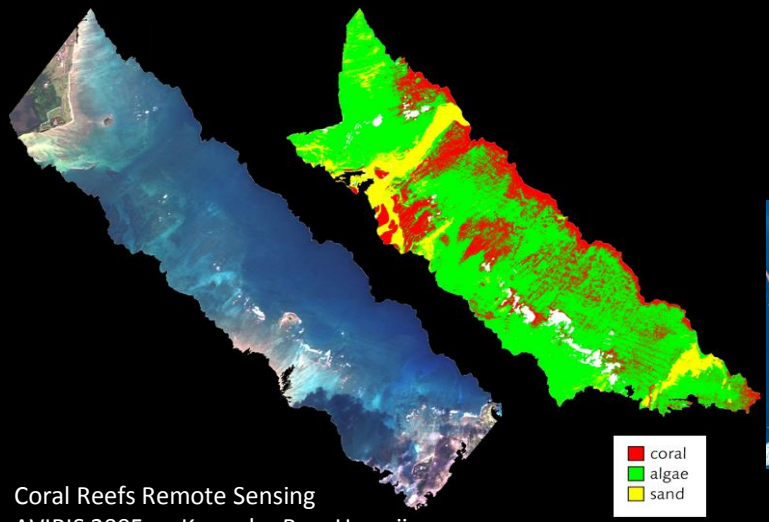
NASA – Future Decadal Survey Mission: Hyperspectral Infrared Imager (HyspIRI)

Hyperspectral at 60 m resolution (depth < 50m)

Improved capabilities in six major areas:
- wetlands (delineation and type)
- shoreline processes (land/water/ice geomorphology)
- water surface features classification
- water column retrievals
- bathymetry
- benthic cover types (classification and mapping)

(the HyspIRI White Paper, under review by the HyspIRI Aquatic Studies Group)

HyspIRI	Visible -SWIR	Thermal IR
Spectral Range	380 to 2500 nm	3.98, 7.35, 8.28, 9.07,10.53, 11.33, and 12.05 µm
Spectral Bandwidth	10 nm, uniform over range	0.084, 0.32, 0.34, 0.35,0.36, 0.54, 0.54, and 0.52 µm
Swath Width	145 km	600 km
Spatial Resolution	60 m (Depth < 50m) 1 km (Depth > 50m)	60 m (Depth < 50m) 1 km (Depth > 50m)
Orbit	Polar Ascending	Polar Ascending
Equatorial Crossing	11:00 a.m.	11:00 a.m.
Equatorial Revisit	19 days	5 days
Rapid Response	3 days	3 days



Coral Reefs Remote Sensing
AVIRIS 2005 — Kaneohe Bay, Hawaii

***Sargassum spp.* (GoM)**

***Ulva prolifera* bloom (off Qingdao, China)**

***Trichodesmium* mats (GoM)**

Oil spill (GoM)

Previous Decadal Survey – National Research Council (NRC)

Committee on Assessing Requirements for Sustained Ocean Color Research and Operations – NRC, 2011

Gap Analysis - needed resources for RS of coastal and inland waters
(*Colleen Mouw et al, In Revision, Remote Send Environm*).

Earth and Planetary Sciences » Oceanography and Atmospheric Sciences » "Topics in Oceanography"

ICES Journal of Marine Science (2011), 68(4), 677–686. doi:10.1093/icesjms/fsq168

The rocky road from research to operations for satellite ocean-colour data in fishery management

Cara Wilson*

Environmental Research Division, NOAA Southwest Fisheries Science Center, 1352 Lighthouse Ave., Pacific Grove, CA 93950, USA

...

educating participants about the availability, access, and use of satellite data, providers obtain a better understanding of user needs and requirements. Some examples of this are given below.

Better data accessibility

Courses conducted by NOAA were designed to help participants work with satellite data using ArcGIS, software familiar to many fishery scientists. Because importing satellite data into ArcGIS can be cumbersome, particularly for lengthy time-series, a new ArcGIS extension (Environmental Data Connector, EDC) now

coastal water types.

Coastal zones are extremely dynamic relative to the open ocean, so greater spatial and temporal resolution is needed to resolve their features, e.g. 30–300 m, multiple looks per day (IOCCG, 2000). These spatial and temporal scales are unachievable simultaneously with polar-orbiting satellites. Airborne sensors deliver high spatial resolution, with fewer atmospheric correction issues, but provide only a single snapshot in time (Carder *et al.*, 1993; Davis *et al.*, 2002; Filippi *et al.*, 2006). Geostationary satellites are the best option for high temporal resolution, which has been demonstrated with SST data (Maturi *et al.*, 2008). The first ocean-colour sensor

Keynote Address: 2013 International Ocean Colour Science Meeting

Issues related to ocean colour in coastal zones and inland waters

Stewart Bernard, Tim Moore, Stefan Simis, Lisl Robertson, Hayley Evers-King, Mark Matthews, and Mark Dowell

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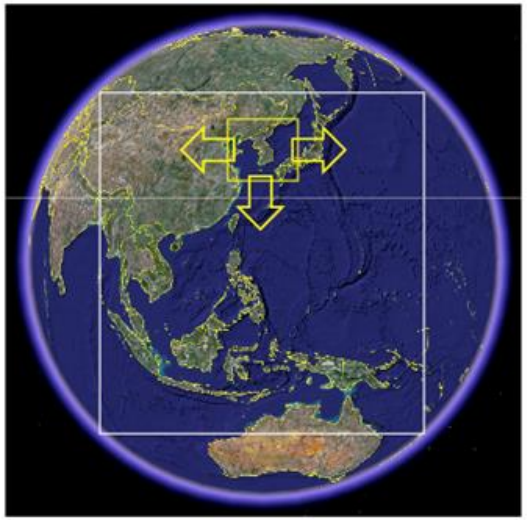
Summary: Suggested Ways Forward for Coastal and Inland Ocean Colour Applications

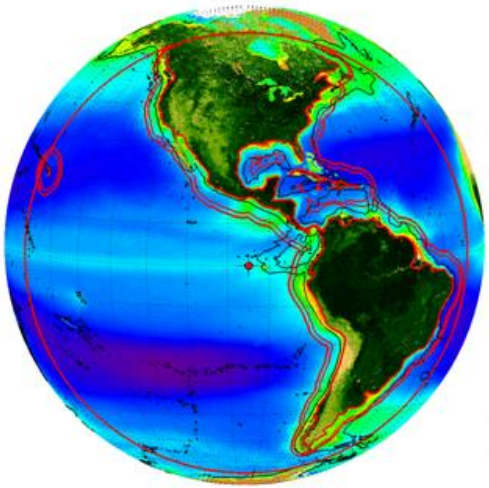
Bring on the global constellation of geostationary ocean colour sensors…..

Constellation of Geo Ocean Color Missions

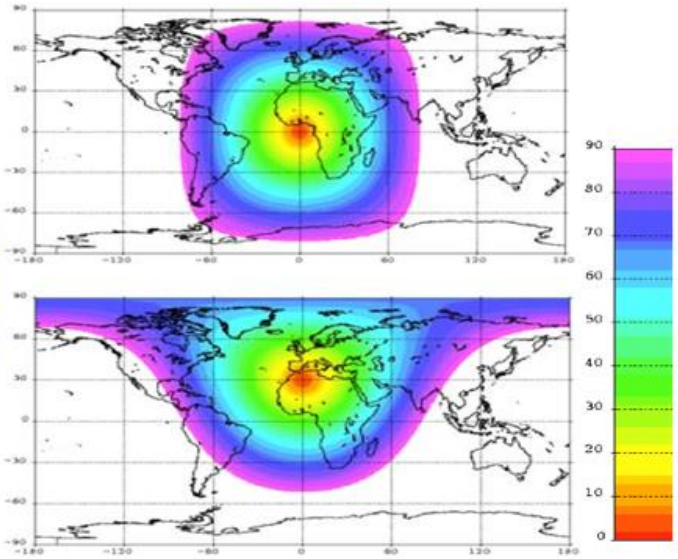
- Diurnal variability of coastal processes and hazards observable from Geo.
- Several other nations are planning Geo ocean color missions: Korea (operational follow-on), Europe and India.



GOCI-II: 2018



GEO-CAPE



HOCI or OCAPI

- Harmonization through constellation promotes consistent global assessment of coastal ecosystems and carbon fluxes.
- Synergies with PACE: improve global productivity measurements, on-orbit cross-calibration, joint cal/val activities, etc.

Detection and tracking of red tides in coastal waters

Coastal Phytoplankton Dynamics

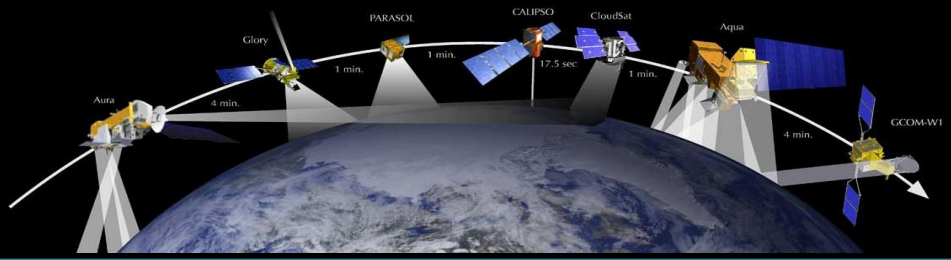
Four Measurement Requirements :

→ Improved spectral resolution, >16 bands/hyper-spectral
→ Improved spectral range: UV-NIR-SWIR

due to optical complexity of coastal areas

→ Improved spatial resolution, < 500 m
→ Improved temporal resolution, > 1 image per day

due to spatio-temporal scales of physical & biogeochemical processes in coastal areas



BEYOND PACE: SUMMARY

- PACE will provide unique capabilities compared to previous NASA OC sensors, resulting in unique opportunities for coastal and applications research.

- To improve coastal and applications research, we need:
  - → Improved spectral resolution, >16 bands/hyper-spectral (PACE will have)
  - → Improved spectral range, UV-NIR-SWIR (PACE will have)
  - → Improved spatial resolution, < 500 m (PACE may have, <u>but NOT in combination</u>)
  - → Improved temporal resolution, > 1 image per day (<u>beyond PACE</u>)

- Recommendations from the Science & Applications Communities, we need:
  - → A multi-sensor approach (high-resolution polar orbit and geo, constellation of geo)
  - → Investment on geostationary
  - → Combination with passive/active RS, optical RS, thermal, radar SAR, aircraft sensors, EV-Is
  - → Improved algorithms that use the improved capabilities of future sensors
  - → Improved in-situ/field observations , updated protocols, coordinated networks, data access
  - → Improved coupled physical-ecosystem models , coupled terrestrial-ocean-atmosphere models.
  - → coordination with the international community

- To address **<u>applications</u>** we need:
  - → improved latency requirements
  - → more studies to quantify the impact of applications requirements on measurement/mission characteristics & minimize risks related to overall mission cost and data quality
  - → more interactions with the USER community: feedback, outreach & training.