Beyond PACE

Ocean Color - Measurement requirements of coastal & applications research

Maria Tzortziou
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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)
**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 aerosolization), to economic impacts (e.g., loss of tourism and seafood sales).

**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 conditions and societal impacts.
Ocean Color Measurement Requirements needed to further improve coastal & applications research (in addition to appropriate radiometric sensitivity):

- Improved spectral resolution, >16 bands/hyper-spectral due to optical complexity of coastal areas
- Improved spectral range: UV-NIR-SWIR, thermal imagery
- Improved spatial resolution, < 500 m due to spatio-temporal scales of physical & biogeochemical processes in coastal areas
- Improved temporal resolution, > 1 image per day
Beyond PACE: Future measurement requirements of coastal and applications research

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

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

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).

- 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
Coastal SCIENCE and RESEARCH objectives

• 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, eddies, fronts
  - dispersion of sediments, nutrients, carbon, pollutants
  - phytoplankton bloom dynamics
• Address interdisciplinary “Earth System Science” questions:
  - exchanges & feedbacks at land‐sea interface
  - exchanges & interactions at the ocean‐atmosphere interface
• Quantify biological and biogeochemical rate process measurements:
  - primary productivity
  - net community production
  - photochemical oxidation
• Integrate high resolution observations and new products with models to improve predictions of impacts of current/future pressures

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
Beyond PACE: Coastal areas are highly dynamic environments.

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)

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

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.
Beyond PACE: Coastal areas are highly dynamics environments

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.)
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.
Beyond PACE: Coastal areas are highly dynamic environments

**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 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
Beyond PACE: Coastal areas are highly dynamic environments.
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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)
**Beyond PACE: Future measurement requirements of coastal and applications research**

**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**

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<thead>
<tr>
<th>Spectral Range</th>
<th>Visible - SWIR</th>
<th>Thermal IR</th>
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<tbody>
<tr>
<td>380 to 2500 nm</td>
<td>3.98, 7.35, 8.28, 9.07, 10.53, 11.33, and 12.05 μm</td>
<td></td>
</tr>
<tr>
<td>Spectral Bandwidth</td>
<td>10 nm, uniform over range</td>
<td>0.084, 0.32, 0.34, 0.35, 0.36, 0.54, 0.54, and 0.52 μm</td>
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<tr>
<td>Swath Width</td>
<td>145 km</td>
<td>600 km</td>
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<tr>
<td>Spatial Resolution</td>
<td>60 m (Depth &lt; 50m)</td>
<td>60 m (Depth &lt; 50m)</td>
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<tr>
<td></td>
<td>1 km (Depth &gt; 50m)</td>
<td>1 km (Depth &gt; 50m)</td>
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<td>Orbit</td>
<td>Polar Ascending</td>
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<td>Equatorial Crossing</td>
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<tr>
<td>Equatorial Revisit</td>
<td>19 days</td>
<td>5 days</td>
</tr>
<tr>
<td>Rapid Response</td>
<td>3 days</td>
<td>3 days</td>
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**Coral reefs**

AVIRIS 2005 — Kaneohe Bay, Hawaii

**Sargassum spp. (GoM)**

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

**Trichodesmium mats (GoM)**

**Oil spill (GoM)**
Beyond PACE: RECOMMENDATIONS for Ocean Color / Optical remote sensing

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".


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 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 (IOC/CG, 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 (Carter 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

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

Bring on the global constellation of geostationary ocean colour sensors.....
Beyond PACE: Future measurement requirements of coastal and applications research

**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.

- 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.
Four Measurement Requirements:

- Improved spectral resolution, >16 bands/hyper-spectral
- Improved spectral range: UV-NIR-SWIR
- Improved spatial resolution, < 500 m
- Improved temporal resolution, > 1 image per day

due to optical complexity of coastal areas

due to spatio-temporal scales of physical & biogeochemical processes in coastal areas
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, but NOT in combination)
- Improved temporal resolution, > 1 image per day (beyond PACE)

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 applications 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.