The Potential of High-Fidelity Spatial, Spectral, Temporal, and Radiometric Sensors to Advance Aquatic Remote Sensing Beyond Chlorophyll

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NASA SARP Participants
(Kim Dawid, Tyler Dawson, Emma Accorsi, David Westerberry)
<table>
<thead>
<tr>
<th>TARGETED OBSERVABLE</th>
<th>SCIENCE/APPLICATIONS SUMMARY</th>
<th>CANDIDATE MEASUREMENT APPROACH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerosols</td>
<td>Aerosol properties, aerosol vertical profiles, and cloud properties to understand their direct and indirect effects on climate and air quality</td>
<td>Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform</td>
</tr>
<tr>
<td>Clouds, Convection, &amp; Precipitation</td>
<td>Coupled cloud-precipitation state and dynamics for monitoring global hydrological cycle and understanding contributing processes</td>
<td>Radar(s), with multi-frequency passive microwave and sub-mm radiometer</td>
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<tr>
<td>Mass Change</td>
<td>Large-scale Earth dynamics measured by the changing mass distribution within and between the Earth’s atmosphere, oceans, ground water, and ice sheets</td>
<td>Spacecraft ranging measurement of gravity anomaly</td>
</tr>
<tr>
<td>Surface Biology &amp; Geology</td>
<td>Earth surface geology and biology, ground/water temperature, snow reflectivity, active energy processes, vegetation traits and algal biomass</td>
<td>Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR</td>
</tr>
<tr>
<td>Surface Deformation &amp; Change</td>
<td>Earth surface dynamics from earthquakes and landslides to ice sheets and permafrost</td>
<td>Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction</td>
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<tr>
<td>Greenhouse Gases</td>
<td>CO₂ and methane fluxes and trends, global and regional with quantification of point sources and identification of source types</td>
<td>Multispectral short wave IR and thermal IR sounders; or lidar**</td>
</tr>
<tr>
<td>Ice Elevation</td>
<td>Global ice characterization including elevation change of land ice to assess sea level contributions and freeboard height of sea ice to assess sea ice/ocean/atmosphere interaction</td>
<td>Lidar**</td>
</tr>
<tr>
<td>Ocean Surface Winds &amp; Currents</td>
<td>Coincident high-accuracy currents and vector winds to assess air-sea momentum exchange and to infer upwelling, upper ocean mixing, and sea-ice drift.</td>
<td>Radar scatterometer</td>
</tr>
</tbody>
</table>

“Thriving on our Changing Planet”

Ecosystem Change

Surface Biology & Geology

“…and algal biomass”

NO! Don’t stop there!

Decadal Survey 2017
What do Managers Need from Optical Remote Sensing in Aquatic Ecosystems?

- Status, Condition and Trend & Anomalies:
  - **Status (survey, classify and map)**
    - **what is where? (=99% of current remote sensing effort)**
      - (is it absent when it should be present) or
      - (is it present when it should be absent?)
  - **Condition:**
    - is it healthy?, is it stable?
    - is it stressed?
  - **Trend:**
    - Is it getting worse or is it improving?
      - Remote Sensing can do hind casting and now casting
      - Model data fusion and data assimilation needed for forecasting
  - **Anomalies:**
    - Normal (to be expected) or exceptional (indicating exceptional change from before? E.g. climate change indication?)

Courtesy of Arnold Dekker
<table>
<thead>
<tr>
<th>EBV class</th>
<th>EBV</th>
<th>Wetland vegetation</th>
<th>Benthic communities</th>
<th>Coral</th>
<th>Phytoplankton</th>
<th>Pelagic organisms</th>
<th>Habitat type</th>
</tr>
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<tbody>
<tr>
<td>Genetic composition</td>
<td>Population genetic diversity</td>
<td>Mangrove/salt marsh</td>
<td>Seagrass</td>
<td>Macroalgae</td>
<td>Coral</td>
<td>Phytoplankton</td>
<td>HAB</td>
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<tr>
<td>Species populations</td>
<td>Distribution</td>
<td>Abundance</td>
<td>Size/vertical distribution</td>
<td>Pigments</td>
<td>Phenology</td>
<td>Taxonomic diversity</td>
<td>NA</td>
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<tr>
<td>Species traits</td>
<td>Ecosystem structure</td>
<td>Functional type</td>
<td>Fragmentation/heterogeneity</td>
<td>Ecosystem function</td>
<td>Net primary production</td>
<td>Net ecosystem production</td>
<td>NA</td>
</tr>
</tbody>
</table>

**Legend**
- Unproven
- Demonstrated limited cases
- Routine use
- Habitat model required

**Phytoplankton Food Quality Index PFTs to Identify HABs**

Optically similar genera are functionally different (toxic vs. non-toxic, type of toxins, etc)

Aphanizomenon flos-aquae

Microcystis spp.
Predicting Toxic Blooms

Kudela et al. 2015, Remote Sens. Env.
Scaling to Regional Analyses

https://cchab.sfei.org/
Scaling to Regional Analyses

Above threshold for all of 2017 (and 2018)

30-day window, June 2, 2017

Threshold for concern

https://cchab.sfei.org/
Lake Elsinore CA, June 2, 2017

AVIRIS + MASTER → L8 OLI + S3A/OLCI → Toxin Index

Reported Toxins: <1.5 ppb
Lake Elsinore CA, June 28, 2017

Reported Toxins: >10,000 ppb

NASA SARP DC-10
In the US, if the bloom coverage per county increases by 1%, the estimated number of deaths per year will increase by about 440.
Phytoplankton Food Quality Index

**PHYD OTax (PFT algorithm)**

- Each PFT assigned a nutritional value
- Values based on evolutionary traits
- Good correspondence between microscopy, HPLC, and PHYD OTax for PFTs
San Francisco Bay Salt Ponds: 2013

RED: Dinoflagellate
GREEN: Chlorophyte
BLUE: Cyanobacteria

Tyler Dawson
Sherry Palacios
HyspIRI Data
San Francisco Bay Salt Ponds: 2014

RED: Dinoflagellate
GREEN: Chlorophyte
BLUE: Cyanobacteria

Tyler Dawson
Sherry Palacios
HyspIRI Data
San Francisco Bay Salt Ponds: 2015

RED: Dinoflagellate
GREEN: Chlorophyte
BLUE: Cyanobacteria

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Sherry Palacios
HyspIRI Data
San Francisco Bay Salt Ponds: 2016

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BLUE: Cyanobacteria

Tyler Dawson
Sherry Palacios
HyspIRI Data
San Pablo Bay, 2015

RED: Dinoflagellate
GREEN: Cyanos
BLUE: Chlorophyte
AVIRIS & Microscopy Track the Drought

Plankton Food Quality Index (0-1)

Year


EDDI Drought Index

0 0.6 0.65 0.7 0.75 1 1.5 2 2.5

HyspIRI 2016: R=Dinoflagellate, G=Cyano, B=Cryptophyte

HyspIRI 2016: R=Dinoflagellate, G=Cyano, B=Cryptophyte

Progression of California Drought in 2014

January 1, 2014

May 13, 2014
Calibration/Validation Requires Measurements at Appropriate Scales!

Airborne to In-water Matchup

Multiple In-Water vs. Hydrolight Matchups

Red Tide conditions, Monterey Bay, CA
At-Sensor Radiance \( \text{W m}^{-2} \text{sr}^{-1} \text{nm}^{-1} \)

- **Wavelength [nm]**
  - 400
  - 500
  - 600
  - 700

**Data Collection**

- HyspIRI, 31 Oct 2013

**Unconstrained Atmospheric Correction**

- At-Sensor Radiance \( \text{W m}^{-2} \text{sr}^{-1} \text{nm}^{-1} \)

**Standard L2 \( R_{rs} \)**

- ATREM
- Tafkaa

**C-AERO/C-OPS Calibration**

- \( R_{rs} \) (\text{sr}^{-1})

**Refined Correction**

- HyperPro
- ATREM+

A=Diatoms  B= Dinoflagellates  C=Chlorophyll
Algal Biomass is routinely limited to bulk pigments

PFTs (PHYDOTax), FQI, Physiology provides more useful information

50m GSD 380-800 nm @10nm Dedicated Atmos. Corr. Return rate of ~5-15 d Robust cal/cal program
Thank You

Collaborators:
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