U. S. Department of Commerce

National Oceanic and Atmospheric Administration (NOAA)

The Value of Geostationary Ocean Color

NOAA Technical Report

Title Page Figure: Red-tide bloom on August 22, 2018 from Copernicus Sentinel-3. Blooms cause widespread fishkills and respiratory irritation in beachgoers along Florida's Gulf Coast.

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About this Report

This Report is the internal NOAA submission to the XORWG and designed to inform the first decision points on instrument selection within GeoXO.

Included in our submission to GeoXO is the IOCCG Report 12 (IOCCG, 2012). Together, the two Reports form a Value Assessment for an Ocean Color Instrument within the GeoXO Constellation – an examination of the science (IOCCG-12) and the connections to NOAA Missions (this Report).

Overview - Why Geostationary Ocean Color now?

The hourly images from geostationary ocean color represent a leap in oceanographic capability for the United States. Populations of valuable sustainable fisheries and protected resources once covered by clouds will be revealed. Gap-free time series of algal concentration, type, and growth will improve the performance of all ocean color products.

Imagine near-real time information about ocean ecosystems, similar to what Americans receive in the form of weather forecasts.

Cloud cover is an issue over our most valuable fisheries, protected species populations, and coastal communities. Hourly images from geostationary ocean color can mitigate the effect of cloud cover over these areas.

The United States Commercial and Recreational Fisheries was valued at $244.1 billion in sales and supported 1.74 million jobs (National Marine Fisheries Service, 2020). Scientific advice from NOAA, including information about ocean and ecosystem conditions, supports management decisions. Improvements to this scientific advice from geostationary ocean color can impact economics of the commercial and recreational fisheries of the United States.

The ability to improve daily imagery often obscured by clouds will improve estimates of the flux and movement of phytoplankton biomass and other critical water quality parameters (e.g., sediment, water clarity, water quality, CDOM) which are important to aquaculture operations in the U.S., in addition to state monitoring programs.

The Economic Exclusive Zone (EEZ) of the U.S. is nearly 3.4 million square nautical miles. Geostationary ocean color provides a synoptic view of our EEZ that is impossible to achieve from ships.

The road to geostationary ocean color at NOAA is smoothly paved. 36,000 km above Earth sits GOCI on COMS and GOCI II on GEO-KOMPSAT-2A. NASA has plans for the GLIMR instrument over the Gulf of Mexico.

When NOAA launches this instrument, our science teams will be ready, having worked with these data streams in testbeds and established new workflows.

NOAA has established prediction systems for Dynamic Ocean Management that protect whales, and help avoid bycatch. These prediction systems are ready for the hourly images from geostationary ocean color instruments.

Coastal communities and fisheries will benefit from increases in performance of Harmful Algal Bloom (HAB) Forecasts from geostationary ocean color that include more geographical detail, more frequent updates, and refined determination of harmful algal species. More frequent imagery within a day will improve tracking of HABs, especially during cloudy conditions, and provide more information regarding the amount of algae vertically distributed in the water column.

The determination of Phytoplankton Functional Types from a geostationary ocean color instrument will support new indicators of ecosystem production, refine estimates of the overall fisheries yield, and advance HAB forecasting.

The Remarkable Attributes of Geostationary Ocean Color

Multi-spectral marine reflectance from the visible to near-infrared measured by ocean color instruments can be used to derive products such as:

- Chlorophyll concentration
- Phytoplankton functional groups
- Phytoplankton fluorescence
- Net primary production
- Atmospheric aerosols
- Water clarity (depth attenuation, turbidity, total suspended matter)
- Colored dissolved organic matter (CDOM)

An ocean color instrument in geostationary orbit provides a powerful capability to NOAA and the United States. Unlike existing polar orbiting satellites with ocean color instruments, which visit an area of ocean once per day, geostationary satellites with ocean color instruments would have an hourly temporal resolution throughout the day. This capability unlocks the potential to discern daily changes in ocean biology and rapid coastal ocean dynamics. Data collection over the same ocean area during the day provides the ability to create images free from clouds.

The inclusion of hyperspectral sensors and optics to achieve 300 m spatial resolution elevates the performance of all of the above. Current ocean color algorithms in coastal regions are extremely inadequate for water clarity/quality applications, as input to ecosystem and fishery production models. Our best algorithms today will benefit from the abilities derived from hyperspectral sensors – estimating additional algal pigments, performing better atmospheric correction, and differentiating suspended material from algal cells. With better spatial resolution comes better imaging of ocean features and the ability to approach the coast and work in bays and estuarine environments.

The combined attributes of instrument and spacecraft (i.e., hourly temporal resolution, hyperspectral radiometry, 300m spatial resolution) leads to (a) more accurate and timely forecasts and scientific advice from NOAA to federal, state, and local agencies about rapidly emerging coastal hazards such as harmful algal blooms; and (b) better predictions and scientific advice for decision making about valuable sustainable fisheries and protected resources.

Methods – Approaching an Assessment of Value

This Report strives to describe the benefits of Geostationary Ocean Color as it relates to NOAA mission objectives. More specifically, this refers to the benefits gained in forecasts, predictions, indices, assessments, and scientific advice NOAA provides to its stakeholders. At the core of this expression of value is the relationship between NOAA mission objectives and how this instrument can improve NOAA's performance when meeting those objectives and be of more value to our stakeholders.

An element of the assessment of value is the extent to which many of these satellite data streams and products impact an operating area that is the sum of the U.S. EEZ and the coastal extent of the U.S., including the Great Lakes. One quality of the oceans is its inaccessibility, and satellite observations provide both focused and synoptic views of great expanses of this realm.

Coastal Hazards: Harmful Algal Bloom and other Ecological Forecasting efforts

The Harmful Algal Bloom and Hypoxia Research and Control Amendments Act of 2004 (HABHRCA 2004, Public Law 108–456) and 2014 (HABHRCA 2014, Public Law 113–124) reaffirmed and expanded the mandate for NOAA to advance the scientific understanding and ability to detect, monitor, assess, and predict HAB and hypoxia events. Congress most recently reauthorized HABHRCA through the National Integrated Drought Information System (HABHRCA 2017, Public Law 115-423). NOAA provides operational HAB forecasts for Lake Erie and the Gulf of Mexico. The Lake Erie forecast provides current extent and 5-day outlook of cyanobacterial bloom trajectory and concentration, including 3D models, to support public drinking water managers and the fishing and tourism industries. NOAA also monitors conditions daily and issues forecasts for red tide blooms in the Gulf of Mexico and East Coast of Florida in support of the tourism industry and public health.

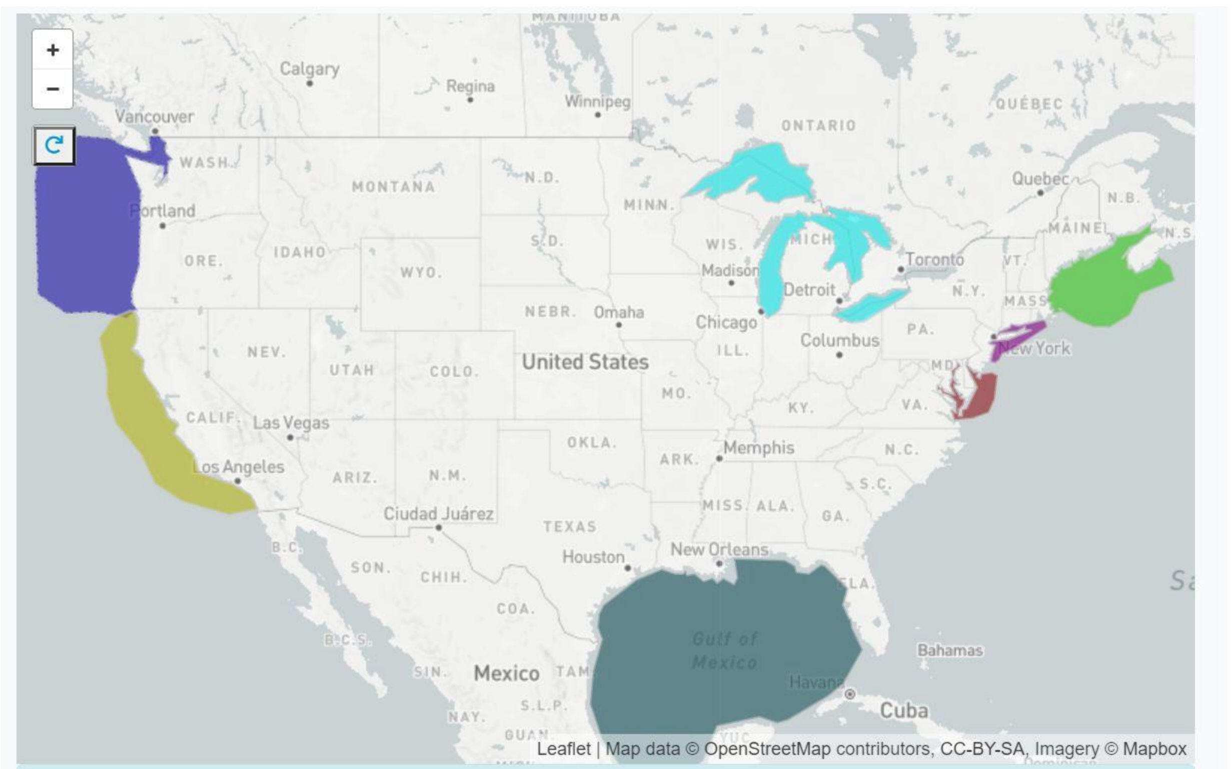

Figure 1. NOAA’s Ecological Forecasting “ hot spots” around the nation, focusing forecasts available related to harmful algal blooms coastal pathogens and hypoxia (from: https://oceanservice.noaa.gov/ecoforecasting/#hotspots)

In addition, ecological forecasts are running in ‘demonstration’ mode. These are validated forecast products run routinely and are in various stages of transition to operations. More information is provided on the Ecological Forecasting website: https://oceanservice.noaa.gov/ecoforecasting/. HAB forecasts in demonstration mode are listed below, and Table 1 includes a more comprehensive list of other NOAA ecological forecasts which could benefit from GEO (e.g., pathogens, hypoxia), including estimated annual operating cost.

- Pacific Northwest HAB Bulletin System: Forecasts the areal extent, cell concentration, toxicity, and geographic location of HABs to inform shellfish harvest management (timing openings) by state and tribal managers.

- California Harmful Algae Risk Mapping: Forecasts the location and movement of HABs and their toxins to guide shellfish harvest and marine mammal protection by state and federal managers.

- Gulf of Maine Seasonal HAB Forecast: Forecasts the severity (magnitude) of the *Alexandrium* bloom for state shellfish harvest managers and aquaculture industry.

- Lake Erie Seasonal Forecast: Forecasts the severity of cyanobacterial bloom for public drinking water and land managers, and federal partners (e.g. EPA).

- Gulf of Maine Forecast: Forecasts HAB cell presence for shellfish harvest for state managers and aquaculture.

- Gulf of Mexico Red Tide Respiratory Forecast: Shows where the blooms are and where they are going on a finer scale so individuals and public health managers may make more informed decisions about which beaches to visit or avoid to safeguard their health.

It is estimated that the acute health effects associated with marine pathogens and HAB toxins costs almost $1 B/year. Improved ecological forecasts improve mitigation and decision making, reducing the impacts and costs of events and longer-term changing conditions by both providing sufficient time for mitigation and predicting when conditions will return to normal (e.g. allowing shellfish closures to be lifted as quickly and safely as possible).

State fisheries, state health departments, water treatment managers, local commerce and tourist industries, and recreational and commercial fisheries and shellfisheries are increasingly demanding ecological forecasting services they can use to protect their resources, residents, and jobs from hazards and changing conditions that are becoming more frequent, larger, more toxic, and more complex. Multiple federal agencies (e.g. FDA, CDC, and NASA) also rely on NOAA science and forecasts to fulfill their missions.

NOAA annually invests more than $8M in ecological forecasting, not including larger corporate investments in supporting infrastructure (e.g., NOS hydrodynamic models, OAR global climate models, NWS high performance computing, and web hosting platforms). A representative sample is shown below.

Table 1. A representative sample of current ecological forecasts which could benefit from GeoXO with annual operating costs.

Product Name	**Use and Intended Stakeholder**
Lake Erie HAB Forecast	Current extent and 5-day outlook of cyanobacterial bloom trajectory & concentration/ public drinking water managers, fishing industry, tourism industry. Includes 3D model.
National *Vibrio parahaemolyticus* Shellfish Guidance *(demonstration)*	Support shellfish harvest practices to protect the public from illness/aquaculture industry and national stakeholders (Interstate Seafood Sanitation Conference). The tools posted here.
Gulf of Mexico Hypoxia Forecasting System *(operational)*	Seasonal forecast for hypoxia and setting nutrient management targets/land management, Gulf of Mexico Hypoxia Task Force, NOAA, EPA, and State members of the HTF

California Harmful Algae Risk Mapping *(demonstration)*	shellfish harvest, marine mammal protection/state and federal managers
Chesapeake Bay *Vibrio vulnificus* Guidance *(operational)*	Protection of public health from waterborne exposure/health officials, public
Lake Erie Seasonal HAB Forecast *(demonstration)*	Forecast severity (magnitude over peak month) of cyanobacterial bloom/ public drinking water and land managers, federal partners (EPA)
Chesapeake Bay Hypoxia Forecast and Annual Report Card *(operational)*	Nowcast and short term forecast of hypoxic water to aid natural resource managers, academia and the commercial and recreational fishing industry. Includes a striped bass habitat suitability index and metrics of ocean acidification.
Gulf of Maine Seasonal HAB Forecast *(demonstration)*	forecast of severity (magnitude) of the Alexandrium bloom/state shellfish harvest managers and aquaculture industry
Gulf of Maine HAB Forecast *(in development)*	predicting HAB cell presence for shellfish harvest/state managers and aquaculture
Coral Reef Watch Bleaching Forecast *(operational)*	Four month bleaching outlook/multiple including international, Coral Reef Conservation Program, and more
Karenia brevis Red Tide Improvement - Gulf of Mexico *(demonstration)*	Beach hazards-respiratory illness from HAB toxins/state and local managers, public

Lake Erie Hypoxia Hydrodynamic/DO Coupled Model *(operational)*	Real time nowcast/forecast for monitoring of hypoxic zone in Great Lakes, Lake Erie/water resource and land management, coastal communities drinking water plants, state and provincial fisheries managers, Ohio EPA, federal partners (EPA)
Puget Sound *Vibrio* forecast *(demonstration)*	Predicting pathogen presence for shellfish harvest/state managers and aquaculture
Pacific Northwest HAB Bulletin System *(demonstration)*	Timing shellfish harvest for public protection from HAB toxins/state and tribal managers
Experimental Biophysical Nowcast in Lake Michigan (demonstration)	Estimates the transport of river inputs by currents in Lake Michigan

Multiple images per day provide a means to refine estimates of bloom extent and total bloom biomass – the intensity of the bloom - by understanding the daily changes in algal position in the water column. Many coastal HAB species are dinoflagellates, which means they have a flagella and the capability to swim within the water column. In addition, several species of toxic cyanobacteria which plague our freshwater systems, have gas vacuoles which allow them to sink and float. Both of these mechanisms allow these organisms to respond to changes in light, temperature and nutrient availability throughout the day. Ocean color remote sensing is only able to resolve features in the surface of the water column, which in general is about a secchi depth. Therefore, as these HAB species swim or float up and down the water column, current polar orbital imagers could underestimate the total biomass of a bloom when cells are subsurface. However, having the capability for multiple scenes throughout the day improves our ability to estimate total HAB biomass, important to guiding public health officials, water treatment, fisheries and aquaculture activities, and coastal managers. Having multiple images delivered with higher spatial resolution would better resolve which specific coastal areas and fishery stocks may be affected by the bloom, and improve the ability to track HABs movement both vertically and horizontally throughout the day. With hourly images providing the ability to deliver cloud-free imagery, a more data-dense and accurate forecast is possible with minimal observation gaps.

Today, many state monitoring *in situ* sampling programs are guided by these Harmful Algal Bloom Forecast systems. Current operational algorithms rely on fluorescence, chl *a* and the spectral characteristics of individual algal types to monitor blooms. Some differences in optical signatures due to the absorption and backscattering properties of the algal population can assist in separating out phytoplankton groups, however current capabilities cannot identify harmful from non-harmful species or detect toxins without field samples and taxonomic identification. Often state monitoring programs are limited in the number of samples and frequency at which they are able to collect, limiting their ability to estimate the extent of a HAB or validation of satellite estimates. With the improvement in spectral resolution hyperspectral imagery provides, NOAA would have the ability to improve upon the information regarding phytoplankton functional type (information about the algal composition of the bloom) to provide better information on the type of algae present and the extent of toxic algal conditions. Our hopeis that it may be possible to understand the composition of algal blooms through hyperspectral imagery.

The value of improved performance of HAB forecasts due to geostationary ocean color may be manifested as additional spatial and temporal details for each HAB event. The case of softshell clam in Maine illustrates this potential benefit (Trainer, 2020; Figure below). The economic impact of fishery closure due to a HAB event is decreased by 75% when a closure lasts just one week rather than one month – a savings of ~$1.3M from this single softshell fishery in Maine valued at $7.7M in 2018 (National Marine Fisheries Service, 2018a). In the same scenario, when the area of closure is considered, a reduction in economic impact of nearly 50% is realized when the area of closure changes by 25% - a savings of approximately ~$1.7M. We expect similar benefits to be seen across the coast and in many fisheries. This example illustrates that fishery impacts of HABs are sensitive to the area closed and the time closed. These two quantities are influenced by the spatial and temporal resolutions of geostationary ocean color. That is, a more detailed image of HAB events more often may provide information for more precise closures in space and time across the fishery sector.

NMFS and NOS produce and supply HAB Forecasts and Ecological Forecasts in fulfillment of the Harmful Algal Bloom and Hypoxia Reduction and Control Acts of 2014 and the Magnuson-Stevens Sustainable Fisheries Act.

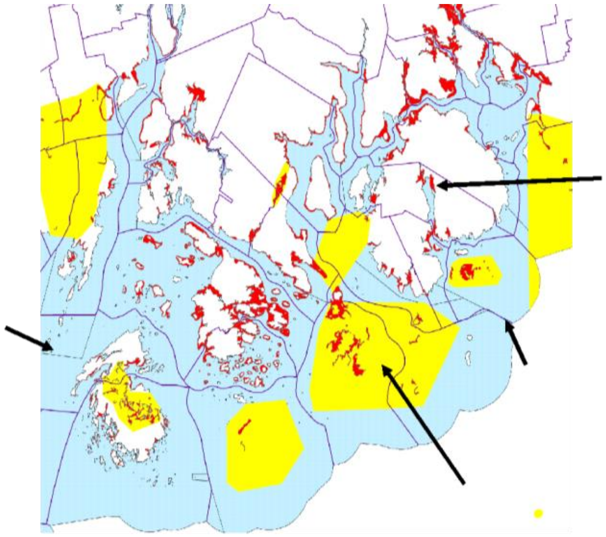

Figure 2: Softshell clam production areas (red) and areas closed (yellow) due to red tide illustrate the spatial scale of HAB events. (From: Hoagland et al. 2013, in: Trainer, 2020)

Coastal Hazards: Coastal Monitoring of water clarity and quality

The use of geostationary satellite imagery for ocean color provides a number of beneficial applications for coastal monitoring of water clarity and quality. Whether identifying and tracking algal blooms, understanding coastal ecosystems and developing ecosystem models, or assessing the impact of more frequent extreme events resulting from climate change, bay-level scientists and managers agree on the benefits from having this data stream. Short-term events, such as aquaculture-adjacent algal blooms, are dynamic in nature and would greatly benefit from the frequent imagery provided from the geostationary satellite as would assessing impacts due to storms and high precipitation events. For example, the NOAA Chesapeake Bay Office identified that, for Chesapeake Bay restoration and monitoring efforts, the most beneficial applications, economic benefits, and resolution requirements are below and could be extrapolated to other coastal areas:

Applications of ocean color in Chesapeake Bay

- Chlorophyll
  - Useful in the tracking and identification of algal blooms, which can aid shellfish aquaculture activities avoid toxic blooms and low dissolved oxygen events. Early warning allows for mitigation to protect shellfish stocks and ensure public health safety.
  - Vital for understanding primary production, food webs, and coastal ecosystem dynamics
  - Tracking of chlorophyll, through ocean color, shows promise for evaluating water quality standards attainment (reduction of nutrients and sediment) for the Chesapeake Bay Watershed Total Maximum Daily Load (TMDL). (Chlorophyll imagery is currently used in attainment evaluations for water quality in the Gulf of Mexico/Florida)
- Turbidity
  - Assessing the impacts of extreme events (e.g., Tracking sediment plumes resulting from high precipitation events which are predicted to increase in frequency with climate change)

○ Understanding fish habitat condition especially during critical times such as spawning

○ Measuring light attenuation at Submerged Aquatic Vegetation (SAV) beds

○ Improving ecological models and forecasts

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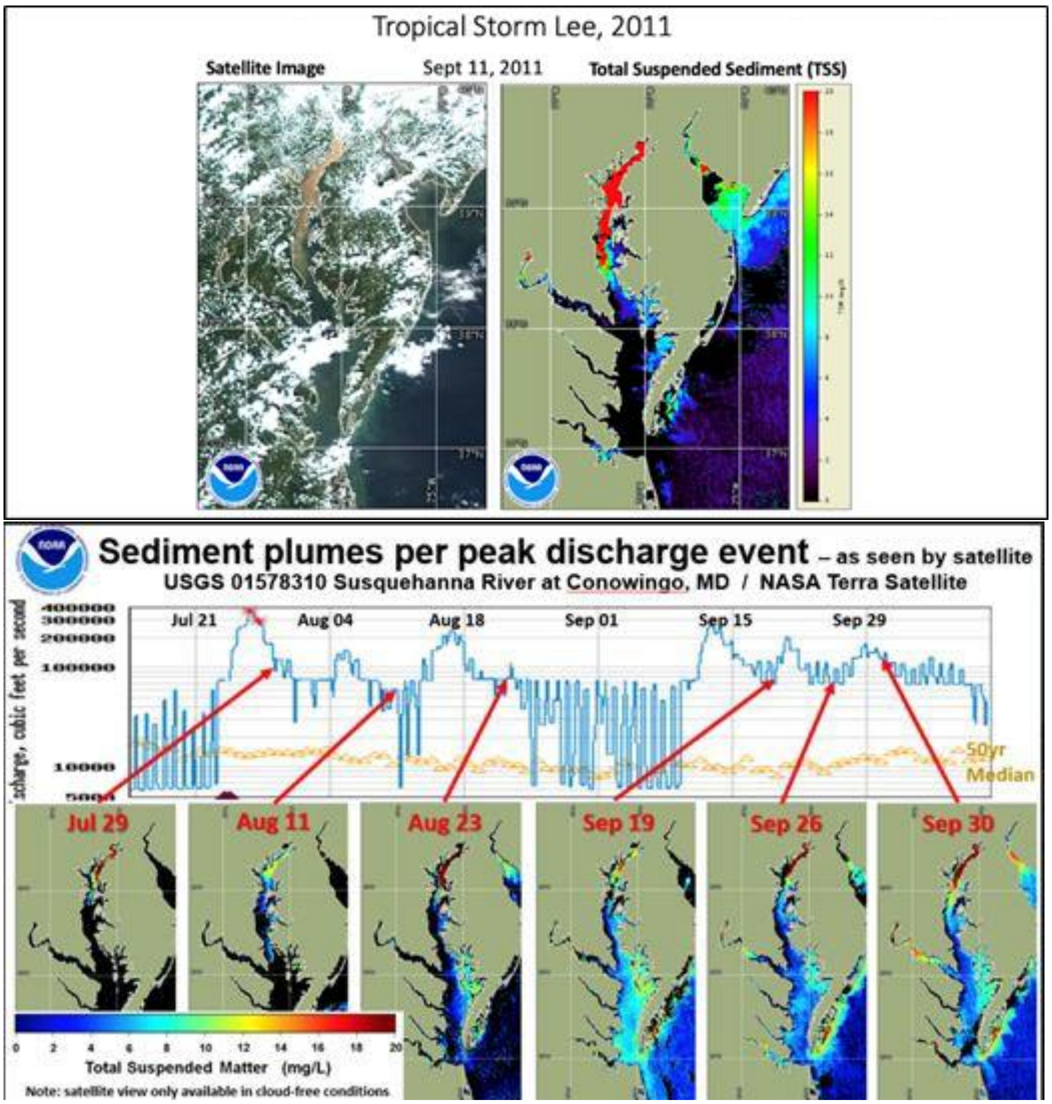

Figure 3: Current LEO satellites provide important information on sediment (Total Suspended Sediment and Total Suspended Matter) images during high discharge events following severe storms, as demonstrated by Tropical Storm Lee in September 2011. Cloudy conditions (noted in black pixels) obscure estimates of the extent of these events.

Using the Chesapeake as an example, the economic value of Chesapeake Bay commercial fisheries, which are informed by satellite data products is shown below. It is important to note that this is only addressed as a subset of species and does not include multi-million dollar efforts by EPA and states to improve Bay watershed water quality.

- Aquaculture
  - Maryland: contributes $9 million a year to the economy, with a 25% growth rate since 2012 (van Senten et al., 2020)
  - Virginia: $53 million a year in farm gate value (Hudson, 2019)
- **Striped Bass MD/VA (2016) - $12,070,000** (National Marine Fisheries Service, 2018b)
  - Maryland $ 7,102,000
  - Virginia $ 4,968,000
- **Blue Crab - $101,539,000** (National Marine Fisheries Service, 2018b)
  - Maryland $ 60,677,000
  - Virginia $ 40,862,000

Resolution requirements

- Current ocean color imagery resolution is too coarse for many coastal applications. Examining smaller tributaries, river mouths, and vital economic areas require a finer resolution
- Full benefits of geostationary coastal imagery would be met if resolution was improved to 100m.

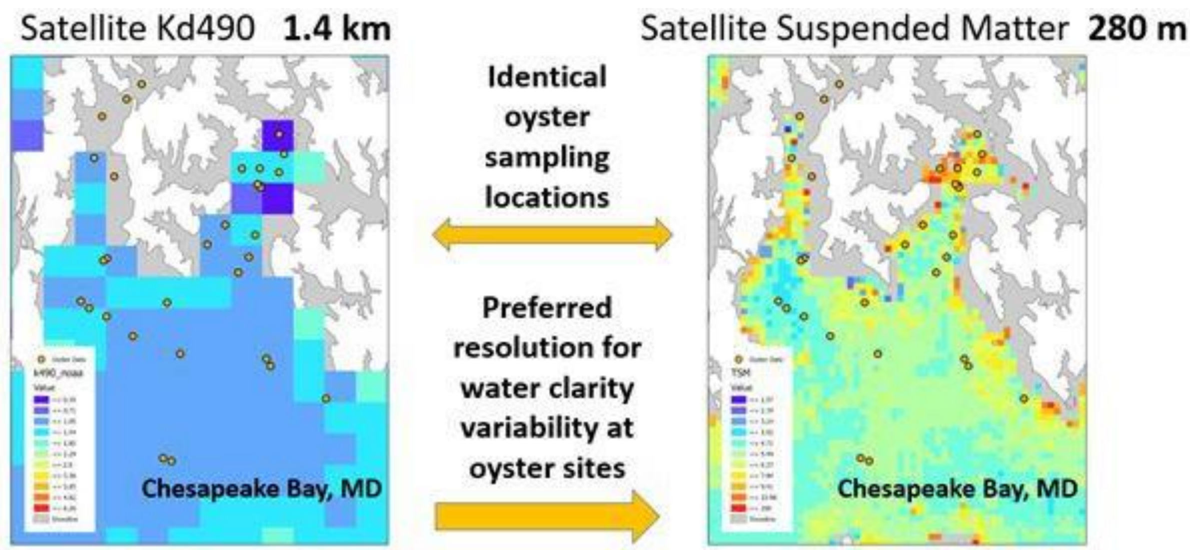

Figure 4: The increase in spatial resolution to approximately 300 m resolution provides better resolution in the tributaries within Chesapeake Bay where most important oyster aquaculture sites are located.

Fisheries: Timing of the Spring Bloom

Fishery Management Councils and state and local agencies receive information from NOAA about the status of ecosystems throughout the U.S. EEZ. Within these Ecosystem Status Reports, indicators of the timing of the onset of the spring phytoplankton blooms are communicated to decision makers. The timing of the spring bloom can be related to the hatching time of certain marine species (fish, shrimp) and the synchrony of these two indicators may be used to predict the future growth of a population.

Cloud-covered images are common in some marine ecosystems and can cause inaccuracies in the detection of the onset of the spring bloom - we cannot make a good prediction. The temporal resolution of Geostationary Ocean Color can deliver cloud-free images and increase the performance of indicators of the timing of the spring bloom. Further, the precise location and intensity of the bloom can result in more accurate indicators.

The benefits in the indicator described above result in the decision maker's ability to better understand the future state of fisheries, to make decisions that allow fisheries to operate at levels that better balance fishery operations with sustainment of populations. These indicators allow a diagnostic as ocean conditions surrounding our valuable ecosystems change. If the timing of when species hatch deviates too far from the spring bloom, populations may suffer. If indicators suggest poor survivability, decision makers or industry may make adjustments to compensate - prepare for smaller catches, adjust the timing of trips.

NOAA delivers this information in support of fulfillment of mandates under the Magnuson-Stevens Sustainable Fisheries Act, and the NMFS Policy on Ecosystem-Based Fisheries Management.

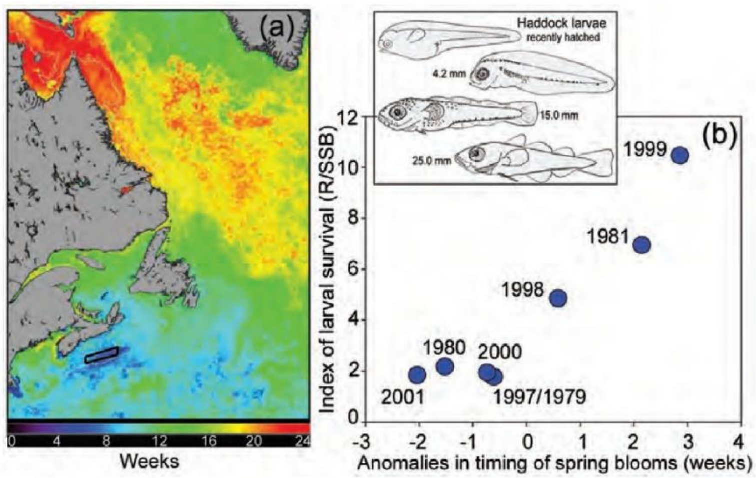

Figure 5: Image of the spring bloom in Labrador (left), and the relationship between larval fishsurvival and the timing of the spring bloom (right). Image from IOCCG (2008).

Fisheries: Protected Resources – Whale Watch

Whale Watch is a NMFS Prediction System used to protect the Blue Whale population off the west coast of the U.S. Driven by a model that identifies suitable habitat for Blue Whales, it highlights areas for fishing operations to avoid, preventing bycatch or contact with this protected species. A clear challenge to the operation of this warning system is the need to composite 8 days of polar ocean color imagery in order to obtain a sufficiently cloud-free image of ocean color to drive the core model of the forecast, the habitat likelihood model.

Prediction systems like these dynamic ocean management tools are built to be updated in near-real time. Incorporation of geostationary ocean color input into the Whale Watch system would provide more than one image per day and eliminate gaps in the warning maps that exist in cloudy polar images, thus increasing the utility of the information. Similarly, the higher spatial resolution of nearly 300m would make the maps more precise, allowing a more detailed view for operators.

NOAA produces prediction systems and forecasts like these in support of fulfillment of the Magnuson-Stevens Sustainable Fisheries Act, the Marine Mammal Protection Act, and the Endangered Species Act.

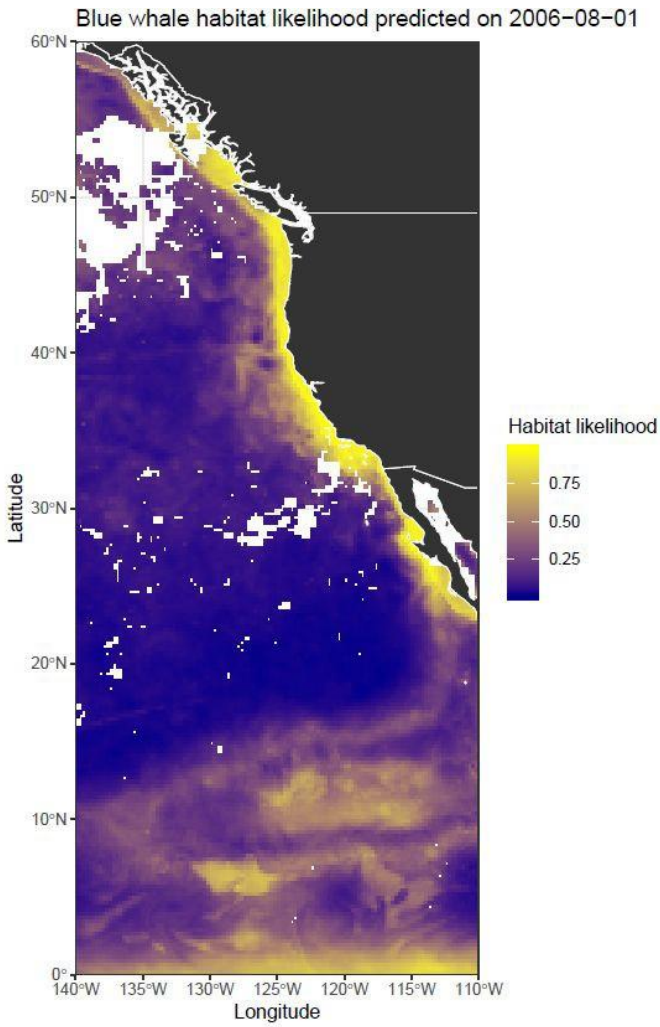

Figure 6: Habitat likelihood map from WhaleWatch on August 1, 2006. The white areas are gapsfrom lack of data. Yellow tones indicate the likelihood of encountering a blue whale. Image From: Elliott Hazen, SWFSC, NMFS. https://www.fisheries.noaa.gov/west-coast/marine-mammal-protection/whalewatch

Ocean Color Linkages to Fishery Stock Assessment

NMFS produces over 400 fishery stock assessments that are used as scientific advice to Fishery Management Councils. Within the stock assessment process, a certain level of natural mortality is modeled at a constant rate. However, extreme mortality events from harmful algal blooms, hypoxic events, or other epizootics upset this assumption of mortality and present major challenges to the assessment of marine animals. As most management for fish stocks is based upon catch quotas obtained from projections, it is necessary to incorporate the likelihood of an episodic event occurring into the management advice. Without knowledge of these events, our predictions can be inaccurate, and decisions on economic welfare of the industry and communities might be flawed.

The red tide severity from a suite of available field collected observations and satellite remote sensing information has been incorporated into the stock assessment for gag and red grouper off Florida. This includes the satellite-based Harmful Algal Bloom forecast from NOAA NOS.

Geostationary ocean color is valuable because it provides a higher level of spatial and temporal detail about the bloom. This added detail about the bloom increases the accuracy of the index in the stock assessment model that determines the increased level of mortality (losses of fishes) the red and gag grouper stocks may experience. Which specific area of the ocean is affected? When will this event end? This all translates into a much better advice as to how to better prepare the fishery for this impact (larger or smaller impact). Simply stated, there is a need to know if a stock is going to be harmed by a harmful algal bloom and to what degree *prior* to making catch decisions.

NMFS performs stock assessments as part of the fulfillment of the Magnuson-Stevens Sustainable Fisheries Act. Find more information on the red tide impacts on grouper at: http://sedarweb.org/docs/wpapers/S61_WP_06_red_tide_mortality_index.pdf

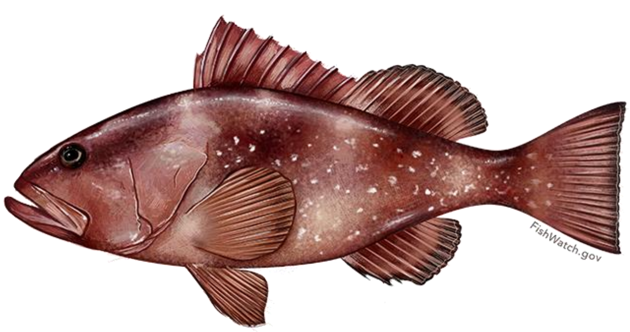

Figure 7: The red grouper (*Epinephelus morio)* fishery has a stock assessment with built-in triggers for Harmful Algal Blooms that elevates NOAA's scientific advice. Image From: https://www.fishwatch.gov/profiles/red-grouper

Fisheries: Detecting the Biological Enhancement of Cyclonic Eddies in the Pacific

Northeasterly trade winds and island topography encourages generation of eddies on the leeward side of the Hawaiian Islands. These eddies cause upwelling of nutrients into the euphotic zone (surface layer with sufficient light to support photosynthesis.) This “eddy pumping” and enhanced biological processes resulting from the upwelling nutrients can greatly influence the ecosystem surrounding the Hawaiian Islands. This biological enhancement can result in an increase in production in the $119M fishery of the Hawaiian Islands (National Marine Fisheries Service, 2020). This equates to potentially more trips by industry that are informed to be more successful, avoiding wasted trips that miss the area of enhancement.

Due to cloud cover common in this area, polar orbiters do not produce useful data fields. Polar orbiting satellites provide images about every 2 days that could be blocked by clouds. SST from geostationary orbit provides a capability to image these eddies during the formation and throughout the life of the eddy, however, no companion or coincident ocean color measurements are made from geostationary orbit for these waters. This could lead to a lack of certainty about the biological effect that is influential to this ecosystem.

The overall value of geostationary ocean color is in the capability to directly determine the biological influence of cyclonic eddies near Hawaii. With the use of existing geostationary SST to detect them, this becomes a near-real time prediction of increased productivity in this region - an economic benefit to a large fishery.

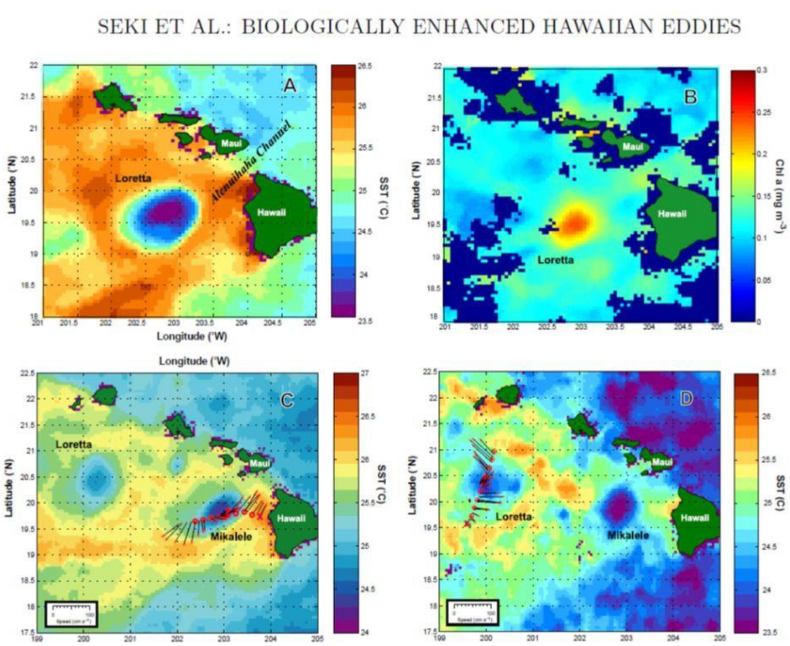

Figure 8: Cyclonic eddies on the leeward side of the Hawaiian Islands (left panels and bottom right) are detectable by geostationary SST, but the biological enhancement cannot be detected without composite images from polar orbiting satellites (top right). Image from Seki et al., 2002.

Fisheries: Predicting Big Eye Tuna Abundance in the Pacific

Big Eye Tuna is a $100M fishery in the Pacific (National Marine Fisheries Service, 2018a) and represents almost half of U.S. tuna landings (National Marine Fisheries Service, 2018b, Woodworth-Jefcoats and Wren, 2020). A relationship between the phytoplankton population estimated by satellite-derived chlorophyll and the catch per unit effort provides the ability to predict the expected catch. This ability to forecast the catch rate of Big Eye Tuna is valuable to the fishing industry for planning purposes – to modulate the number of trips made as the catch limit is approached, and to coordinate efforts when the limit is not yet in sight. All of this translates to large economic sums. The translation is the amount saved by optimizing these trips across large fishing areas.

The prediction system described above is limited by cloud covered ocean color imagery, an important component of the analysis. These gaps lead to composite images, areas with little information, and a decreased prediction skill.

Improvements in ocean color gained from geostationary ocean color include a mitigation of cloud cover via multiple images per day. This, along with the increase in spatial and spectral resolution will improve the performance of the prediction of tuna catch for this area of the Pacific. The value of these improvements is likely to be represented by some portion of the gains from industry response to tuna catch rate.

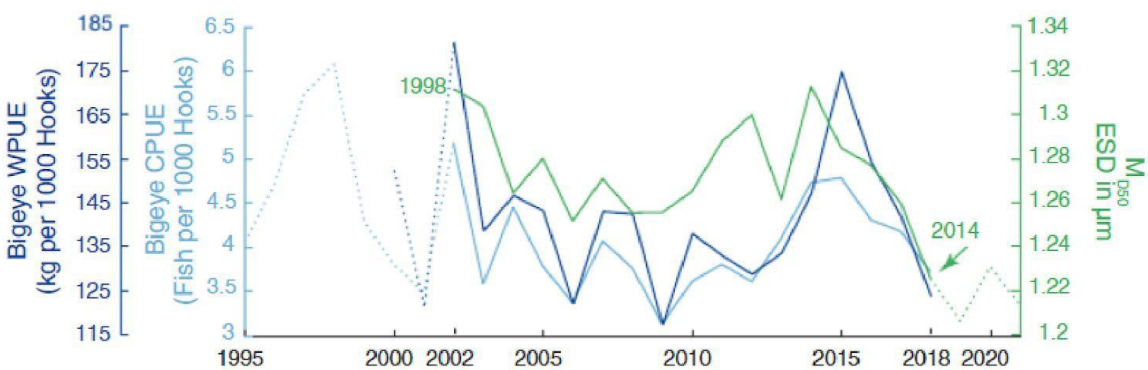

Figure 9: Catch per unit effort and weight per unit effort (left) and cell mass of phytoplankton calculated from satellite ocean color and lagged (right) for Bigeye tuna as a function of year. Image From: Woodworth-Jefcoats and Wren (2020).

Fisheries: Ecosystem Modeling – Near-Real Time Models Support Council Decisions and theSablefish Stock Assessment

A state-of-the-art biophysical ocean model is used to provide fisheries-relevant data and derived products to end-users, specifically the Pacific Fisheries Management Council (PFMC) and the NMFS West Coast Regional Office (WCRO). Model-based predictions of species distributions are used for living marine resource management under seasonal forecasting and climate change scenarios. Such models support operational products at multiple temporal scales (near real-time, seasonal forecasts and long-term projections).

The California Current Integrated Ecosystem Assessment (IEA) and various Ecosystem Status Reports synthesize environmental data to provide NOAA, the PFMC, and other stakeholders with periodic assessments of the ecosystem state. In support of its ecosystem-based management processes, the PFMC has requested that NMFS provide an annual state-of-the-ecosystem report at its March meetings. These reports contain an array of environmental and ecological indices designed to summarize ocean/climate conditions and fisheries impacts in a way that is useful to fishery managers. An important contribution would be near-real-time estimates of phytoplankton biomass, primary productivity, and other biogeochemical conditions derived from ocean color. Imagery of high spatial resolution and capable of delivering high temporal resolution could improve the quality of the time series information.

Sablefish is a lucrative groundfish species harvested along the US west coast with a value of $110.4M and a harvest of 38.7 million pounds (National Marine Fisheries Service, 2018a). Historical west coast sablefish recruitment estimates have been developed based on our existing physical ocean models and are presented to the PFMC. The physical oceanographic data in these models serve as proxies for biogeochemical conditions. These models are likely to be aided considerably by inclusion of food supply metrics (i.e., phytoplankton from ocean color), which will be explicitly observed by a geostationary ocean color instrument.

The high spatiotemporal and spectral resolution will deliver data fields of phytoplankton community structure that can allow models to better simulate the prey field and resultant impacts on populations of commercial fish species. By improving estimates of climate-driven changes in fish stocks, NMFS may be better equipped to achieve its mission.

Integrated Ecosystem Assessments include work done under the NMFS Policy for Ecosystem Based Fisheries Management and the Magnuson-Stevens Sustainable Fisheries Act. Work on sablefish is done in fulfillment of the Magnuson-Stevens Sustainable Fisheries Act. Find more about the Integrated Ecosystem Assessment for the California Current at: https://www.integratedecosystemassessment.noaa.gov/regions/california-current

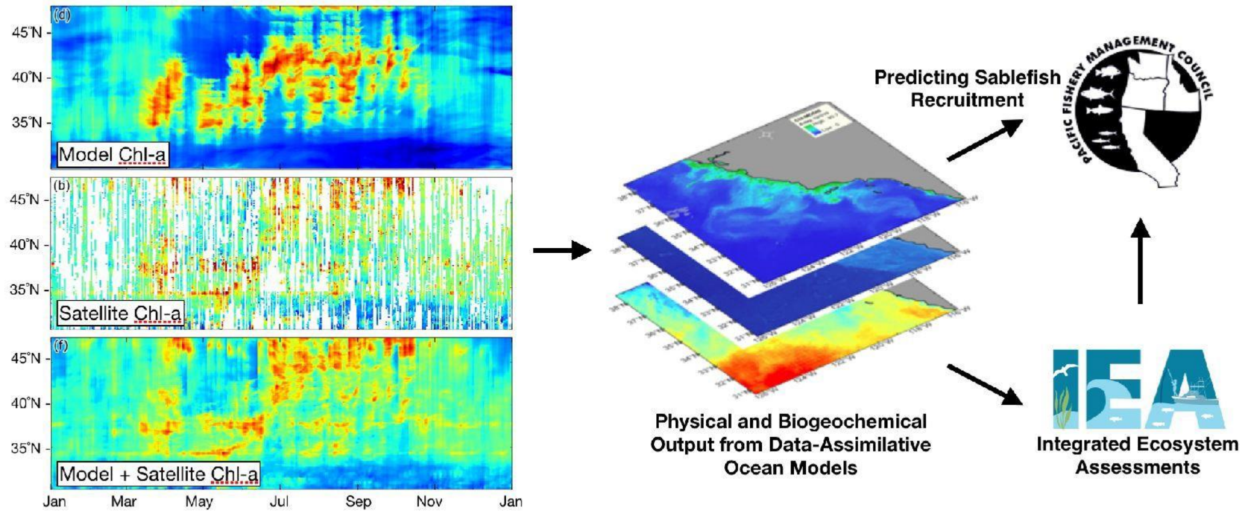

Figure 10: Schematic of modeling results with satellite chlorophyll a data and the development ofmodel output for physical and biogeochemical fields that are used in Sablefish recruitment predictions and the IEA for the California Current. NMFS SWFSC.

Fisheries: Phytoplankton Functional Types / Phytoplankton Size Class

Ocean data across the entire U.S. EEZ is being collected to monitor changing ocean conditions and the impact of these changes on the size and type of phytoplankton (algae) to help better define the base of the marine food web. These shifts affect life in the oceans, including valuable fisheries, protected species, and coastal communities. To achieve mission objectives across the country, there is a need for accurate, timely, and fit for purpose Phytoplankton Functional Type (PFT) and Phytoplankton Size Class (PSC) products derived from satellite ocean color measurements. Products like PFT and PSC are made possible by hyperspectral ocean color imagery.

Since different phytoplankton have different ecological roles, there are multiple phytoplankton types in the coupled ocean-biogeochemical models for species like sardine and anchovy. These physical-biogeochemical models rely on satellite data to constrain them so they provide a better estimate of the ocean state. Compared to using chlorophyll alone, adding satellite data on phytoplankton functional type can reduce the uncertainty in these models, making for better predictions. In addition, PFT and PSC products can document the shift of species in the ocean and potentially predict the impact on the food chain – ultimately leading to information about fishery production and protected species populations.

This work is replicated now across the 3.4 million square nautical miles of the United States Exclusive Economic Zone and is an operational cog that connects physics to fisheries. Modern understanding of energy pathways in the oceans, fueled by knowledge of phytoplankton type, now include a direct grazing and a microbial loop pathway with robust network models of energy flow throughout the marine food web. This new understanding allows better interpretation of observations and more accurate forecasts of future productivity.

Work on PFT and PSC is done in fulfillment of the NMFS Policy for Ecosystem Based Fishery Management and the Magnuson-Stevens Sustainable Fisheries Act.

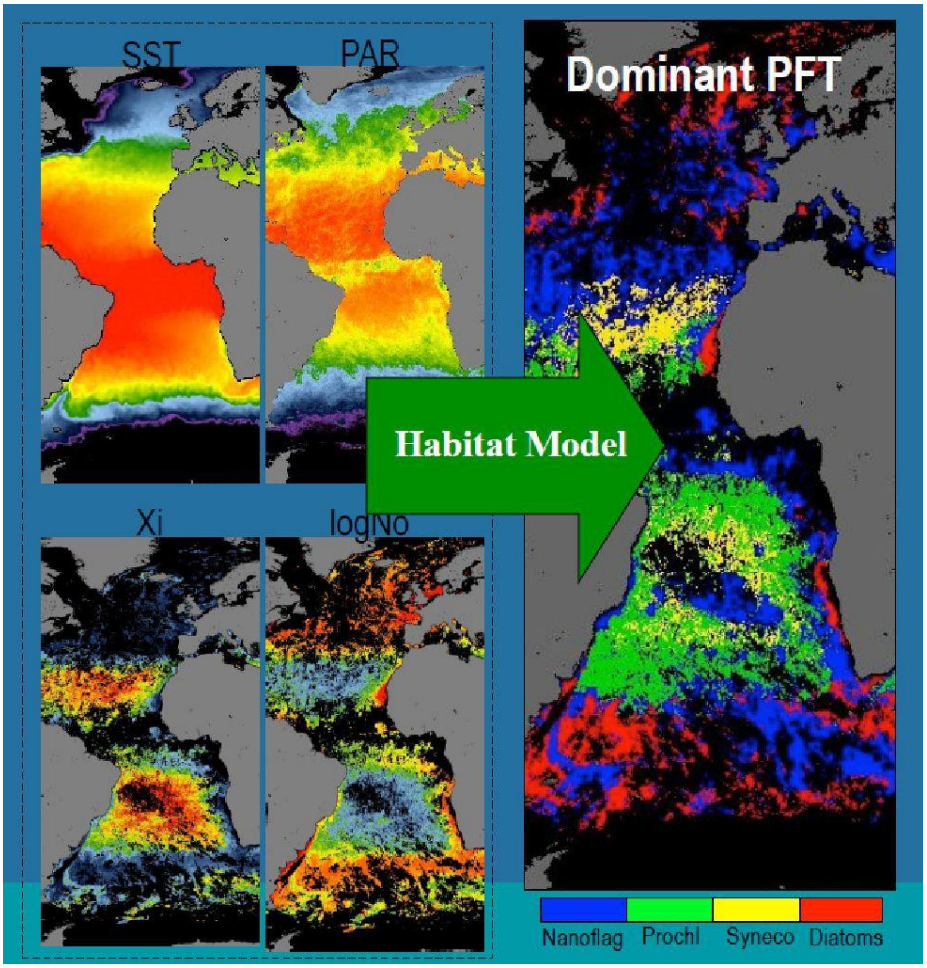

Figure 11: Assembly of a Phytoplankton Functional Type map for the Atlantic that distinguishes between four types of phytoplankton (right panel). Image from the IOCCG International Ocean Colour Science Meeting 2015: https://iocs.ioccg.org/iocs-2015-meeting/

Fisheries and Coastal: Coral Reef Monitoring

Characteristics of geostationary ocean color (chl a), turbidity (Kd490), and sea surface temperature over the spatial extent of the U.S. tropical Pacific (Hawaiian Island Archipelago, Marianas Islands Archipelago, Pacific Remote Islands, American Samoa) provide essential data products for assessing drivers resilience of coral reefs across time and space for stakeholders such as NMFS scientists and jurisdictional resource management agencies, and help fulfill our mandate from Coral Reef Conservation Act of 2000 (CRCA 2000) that includes monitoring and assessing the sustainable use and long-term conservation of coral reefs and coral reef ecosystems. Improving spatial resolution (500m) as well as temporal resolution (hourly) will increase the utility of these satellite-derived parameters in our analyses - ultimately improving our understanding of determinant of ecological change on coral reefs.

Specifically, in the nearshore, an ocean color product from a geostationary satellite could offer the temporal resolution to monitor sediment discharge on reefs after storms or algal blooms in response to anthropogenic nutrient pulses. Offshore, this means that we could also get improved spatial coverage for estimating ocean acidification effects, and avoid the reliance on monthly estimatesand thereby reducing data gaps.

In the southeast U.S., improved spatial resolution of satellite products that can document coral bleaching patterns (and forecasts) would be used to better plan surveys and experiments as well as help inform coral restoration planning. Additionally, the light intensity of ocean color imagery can be used to determine benthic habitat of sand, seagrass, and, when combined with high-resolution bathymetric data, can determine live or dead coral reefs. Increasing the temporal resolution improves the chance of getting useful imagery.

NMFS efforts on coral reefs are in fulfillment of the Coral Reef Conservation Act of 2000. Find more details about Coral Reef Watch at: https://coralreefwatch.noaa.gov/

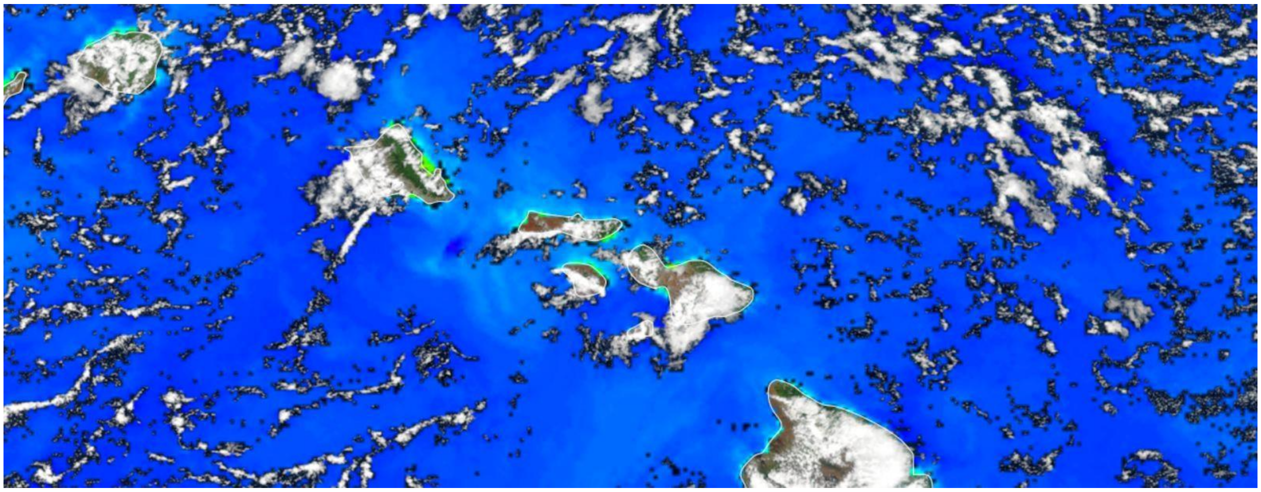

Figure 12: An ocean color image of the Hawaiian Islands illustrated the high level of cloud covertypical in this part of the Pacific Ocean. NOAA can see only ⅕ of the coral reefs it is tasked tomonitor with this level of cloud cover. The coral reefs of the Hawaiian Islands were valued at $33.57B, making each management decision about runoff, harmful algal blooms, and bleaching a valuable one (Bishop et al., 2011). Image from Mark Eakin, NOAA.

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END OF REPORT