Interagency Workshop on Societal Applications of Satellite Data for Ocean Health and Fisheries

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Introduction

In addition to the crucial role the ocean plays in regulating Earth's climate, a healthy ocean benefits people as a source of food and livelihood. However, industrialized society is taxing ocean life through increased pollution, warming, changing chemistry, and over-fishing, which all threaten food, economic, and human security. Identifying and tracking marine biological indicators and their response to multiple stressors can guide sustainable management and conservation efforts.

From the vantage point of space, Earth observation by satellites allow for global ocean monitoring in the present and offer even greater potential for the future. Ocean-color sensors measure light reflecting off the water, yielding valuable ecological information such as the concentration of chlorophyll and detrital material, both indicative of the state of ocean biology and its overall health. Satellite remote sensing of ocean color is challenging because it requires a cloud-free view and the subtraction of contributions from the intervening atmosphere. Furthermore, the ocean is dynamic and constantly changing, in a way that is more similar to weather systems in the atmosphere than vegetation on land, which has a slower rate of change.

To initiate a discussion on the opportunities and challenges of Earth observation for the ocean sector, NASA and the World Resources Institute (WRI) organized a one-day, interactive workshop that focused on current and future uses of ocean satellite data products to support decision making in the context of ocean health, fisheries, and human security. The workshop took place on November 2, 2017, at WRI Headquarters in Washington, DC. The meeting was also live-streamed via *Adobe Connect*. More than 150 local and remote participants came from a wide range of communities, including satellite data providers, current and potential new data users from diverse domestic and international governmental agencies, nongovernmental organizations, and private businesses. The attendees represented a variety of backgrounds including research, resource management, policy, national security, public health, education, and the fishing industry. Also in attendance at the workshop was **Paul Doremus**, the Chief Operating Officer of the National Oceanic and Atmospheric Administration's (NOAA) Fisheries and Acting Assistant Secretary for Conservation and Management.

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The workshop began with a series of overview presentations to introduce its goals and provide background on existing and emerging satellite data products. These presentations addressed agency programs and priorities for satellite applications. Four panel discussions were followed by a closing keynote address from **Paul Woods** [Global Fishing Watch (GFW)—*Chief Technology Offficer*] on GFW, a software package used for fishing vessel tracking. Several presentations during the meeting highlighted applications of GFW. The four panels engaged workshop participants in discussions on the themes of ocean health in the context of climate change, fisheries and ecosystem health, links between fisheries and human security, and resources and tools for accessing ocean satellite data products. To facilitate interaction between participants, the agenda budgeted time for formal discussion throughout the meeting and also provided ample opportunity for informal discussion and networking between participants during coffee breaks and lunch. A summary of meeting highlights follows. The full agenda, all presentations, and recordings are available from the workshop website at *http://www.wri.org/events/2017/11/nasa-wri-ocean-health-and-fisheries-applications-workshop*.

Introductions and Overview

Stephanie Uz [NASA's Goddard Space Flight Center (GSFC)—*Applied Sciences Manager*] opened the meeting by welcoming participants and outlining the day's agenda that was planned by NASA and WRI, working closely with NOAA—the agency responsible for fisheries management. The goals of the workshop were to introduce diverse members of the ocean sector to the latest ocean science and satellite data products that could aid their decisions, and to discuss end-user needs. A series of invited short presentations relevant to ocean health and fisheries were intended to highlight specific, relevant datasets and other existing and emerging products and tools, and to start a dialogue between data providers and data users on activities and needs across the ocean sector to increase the practical exploitation (application) of satellite data products. She concluded with three overarching questions for participants to consider throughout the workshop:

- Are you using satellite data right now? If so, how? If not, would you like to use it and how?
- Where do you see big data or product gaps?
- What are some barriers to data access?

The goals of the workshop were to introduce diverse members of the ocean sector to the latest ocean science and satellite data products that could aid their decisions, and to discuss end-user needs.

Jeremy Werdell [GSFC—*PACE*[1] *Project Scientist*] presented a brief explanation of satellite ocean color. Spaceborne radiometers measure the spectral distribution of light leaving the ocean surface from which the constituents influencing its color can be inferred, including information useful for fisheries management. Answering complex and emerging questions about changes at the base of the ocean food web requires knowledge about the types of phytoplankton that are present, and how they change with time. Werdell outlined the scientific justification to shift from current radiometric measurements (e.g., MODIS and VIIRS,[2] which measure at a series of discrete wavelengths) to spectroscopic ones [e.g., the Ocean Color Instrument (OCI) currently being designed for PACE, which will measure a continuous series of wavelengths]. Werdell ended with some comments designed to help demystify the acquisition, use, and analysis of satellite ocean color data products.

Woody Turner [NASA Headquarters (HQ)—*Program Manager for Ecological Forecasting*] introduced NASA as an organization that uses space-based satellites for basic and applied science activities, noting that increasingly novel uses of such data are just beginning to be explored. Turner outlined NASA's Applied Sciences Program within the Earth Science Division. He detailed three active Ecological Forecasting projects related to fisheries management, the detection and prediction of harmful algal blooms, and forecasting the beaching of high accumulations of *Sargassum*, a genus of brown macroalgae (seaweed). He introduced the Marine Biodiversity Observation Network (MBON) of the Group on Earth Observations Biodiversity Observation Network (GEO BON), which seeks to improve coordination of biodiversity data in the U.S., the Western Hemisphere, and ultimately the world. He concluded by mentioning the Applied Sciences Program's Early Adopters activity to generate simulated data for upcoming satellite missions before launch and the omnibus Research Opportunities in Space and Earth Sciences (ROSES) solicitation, through which NASA's basic and applied Earth Science programs solicit proposals for funding of projects across a wide range of disciplines.

Paul DiGiacomo [NOAA's Center for Satellite Applications and Research—*Chief of Satellite Oceanography and Climatology Division*] described many types of NOAA ocean observations and their societal applications. He clarified that Earth observing satellites cannot monitor fish populations directly from space, but do so indirectly by looking

[1] PACE stands for Plankton, Aerosol, Cloud, ocean Ecosystem, a next-generation ocean color satellite currently in mission design, with launch planned for 2022.

[2] MODIS stands for Moderate Resolution Imaging Spectroradiometer, which flies on NASA's Terra and Aqua platform; VIIRS stands for Visible–Infrared Imaging Radiometer Suite, which flies on the Suomi National Polar-orbiting Platform (NPP) and the recently launched Joint Polar Satellite System-1 (JPSS-1).

at the environmental conditions of ecosystems. NOAA is both a provider and user of satellite data for *environmental intelligence* in support of its long-term goals. Legislation mandates that NOAA prioritize ecological forecasting of harmful algal blooms, hypoxia, pathogens, and habitat. Priorities are developed based upon stakeholder needs, NOAA capacity, and national significance. As capacity develops and expands, decision support forecasts improve and increase their effectiveness. For example, because so many endangered species are migratory, the goal is to use a dynamic approach, predicting species locations in near-real time (e.g., using Whale Watch,[3] Turtle Watch,[4] EcoCast—see **Figure 1**) to inform fishers to reduce *bycatch* (i.e., catching animals other than the target species), and redirect ship traffic or naval exercises away from marine sanctuaries. DiGiacomo mentioned other NOAA programs, informed by NOAA's diverse observation network (ships, aircraft, buoys, gliders, floats, satellites) and assets from other partners (NASA, National Science Foundation, U.S. Environmental Protection Agency, individual states, and academic institutions).

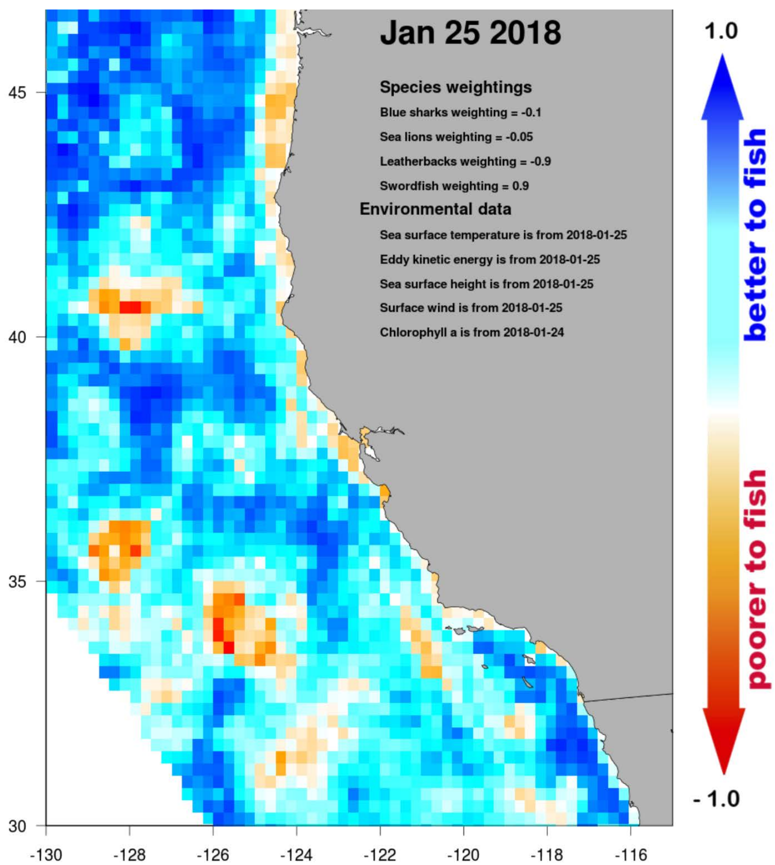

Figure 1: EcoCast is a NASA-funded dynamic management project that synthesizes satellite data with *in situ* observations in near-real time to give fishers and managers the ecosystem assessment tools they need to maximize productive catch while minimizing nontarget (unwanted) bycatch. The scale reflects areas that are better to fish (blue scale) and worse to fish (red scale). The EcoCast predictive map integrates multiple dynamic species distribution models that account for distribution of catch (swordfish) and bycatch (leatherback sea turtle, blue sharks, marine mammals). It builds upon the capabilities of WhaleWatch and TurtleWatch, mentioned in the text. **Image credit:** Hazen *et al.*, NOAA Fisheries/Southwest Fisheries Science Center

Christa Peters–Lidard [GSFC—*Deputy Director for Hydrosphere, Biosphere, and Geophysics Laboratory*] described NASA's Earth observations and applications programs. She showed several current examples of data relevant to the ocean including: maps created by the Global Precipitation Measurement (GPM) mission and Integrated Multi-satellitE Retrievals for GPM (IMERG); Landsat coastal water quality maps; and ocean color products derived from a variety of previous and current sensors, and modeled phytoplankton. She also touched upon several upcoming missions of interest: Ice, Clouds, and Land-Elevation Satellite-2 (ICESat-2); Surface Water and Ocean Topography (SWOT); and PACE. Peters–Lidard discussed NASA's Capacity Building Program, which seeks to engage current and future decision makers in a spectrum of

[3] WhaleWatch is a NASA-funded project coordinated by NOAA Fisheries' West Coast Region to help reduce human impacts on whales by providing near-real-time information on where they occur and hence where whales may be most at risk from threats, such as ship strikes, entanglements, and loud underwater sounds.

[4] TurtleWatch is a formerly NASA-funded tool that provides up-to-date information about the thermal habitat of loggerhead sea turtles in the Pacific Ocean, north of the Hawaiian Islands.

activities both in the U.S. and in developing countries, to improve access to NASA Earth science and data that cover a range of societal applications.

By working with Bloomberg to serve water risk data, WRI is able to reach 320,000 investors, helping to inform investments in water intensive sectors, such as power and agriculture.

Janet Ranganathan [WRI—*Vice President for Science and Research*] described WRI as a global nonprofit research institute that advances evidence-based approaches for more sustainable management of the planet. WRI is an avid user of NASA and NOAA Earth science data—but only uses a fraction of what could be used. She noted that "we are drowning in Earth science data" but it is not yet reaching all those who could use it to make more sustainable decisions. Such utility comes from WRI's Aqueduct open data platform, which provides globally consistent, sub-basin level data on water risk (i.e., quantity, quality, demand, future projections). By working with Bloomberg to serve water risk data, WRI is able to reach 320,000 investors, helping to inform investments in water intensive sectors, such as power and agriculture. Ranganathan concluded with a preview WRI's Resource Watch (*http://www.vizzuality.com/projects/resource-watch*), a free, interactive, open data platform for collaboration and action that will empower people with the information they need to more sustainably manage the world's resources. Resource Watch is scheduled to launch on April 11, 2018.

Discussion Summary

The discussion focused both on getting satellite data easily into the hands of nontraditional users and also sharing examples of how to use the data. **Mitchell "Mitch" Roffer** [Roffer's Ocean Fishing Forecasting Service (ROFFS), Inc.] had recently returned from Tanzania, where he said they have access to the data but lack the experience and ability to use it. People need on-line resources on how to use the data, so that they don't have to travel. (The fourth panel discussion on page 17 elaborates on specific resources and tools to help anyone access the data.) **Amita Mehta** [GSFC] commented that NASA's Applied Remote Sensing Training (ARSET) offers thematic online training for very local end users around the world. ARSET trains people from a variety of backgrounds—from government employees to farmers and fishers, including dam operators in small African countries. ARSET shares NASA and NOAA data and teaches people how to apply satellite data to themes such as water resources, air quality, ecological forecasting, and disaster management.

Carlos Del Castillo [GSFC—*Chief of Ocean Ecology Laboratory*] acknowledged that data producing organizations have a lot of data and amazing tools—but they are not necessarily intuitive to nonspecialists. Thus, tools need to be tested and evaluated before launch to prevent situations where tools are only understood by the people who made them. **Janet Ranganathan** agreed, noting that currently the largest fraction of funding goes into the production of data, and that additional funds need to be made available for the applications of the data. Coordination with development agencies and foundations could create more coherence.

Woody Turner reminded people about SERVIR,[5] a NASA capacity-building project in coordination with the U.S. Agency for International Development (USAID), to provide satellite-based solutions to address particular challenges. SERVIR applies Earth observations to support decision making in developing countries. Although it hasn't yet done much with fisheries applications, the project could be so encouraged. A discussion followed concerning the emphasis on training and experience with these international programs at the government level and the need to connect with true end-users (e.g., fishermen). The private sector and academia also need to engage in the discussion. The consensus was that there is much more to be done in this area. In this vein, the Canadian Space Agency started the Societal Applications in Fisheries and Aquaculture using Remotely Sensed Imagery (SAFARI) to connect users, particularly in India. Data providing agencies agreed that they have a long way to go to make a substantive impact at the user level.

[5] SERVIR is not an acronym. It is a Spanish word that means "to serve."

Panel 1: Ocean Health in the Context of Climate Change

Stephanie Uz [GSFC] moderated this panel, which focused on the big picture of how satellite data and other products indicate the ways in which the ocean is changing and how that impacts ocean biology. In addition to satellite data, assimilating data from many sources refines understanding of the role of ocean life within the Earth system, and improves our ability to predict and prepare for changes.

Steven Pawson [GSFC, Global Modeling and Assimilation Office (GMAO)] explained how NASA observations are used to constrain the physical state of the ocean in the Goddard Earth Observing System (GEOS) model for seasonal-to-decadal analysis and prediction and a subseasonal-to-seasonal model for monthly forecasts. He explained that GMAO is upgrading to a new model and compared their respective outputs. Pawson also discussed a more recent effort to constrain the biological state of the ocean using NASA's Ocean Biology Model, described its components, and showed some initial chlorophyll forecasting results in the Tropical Pacific.

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Scott Doney [University of Virginia—*Professor of Environmental Change*] stated that climate change and other human impacts are directly affecting ocean life and health. New data analysis tools are emerging—such as seascapes (*http://www.marinebon.org/seascapes.html*), which provide a dynamic approach for identifying and monitoring marine habitats. Borrowed from the world of "big data," they provide a combination of satellite and *in situ* observations to offer a powerful approach for monitoring ocean ecosystem health, addressing ocean conservation challenges, and detecting ongoing changes that arise from natural variability and human impacts.

Mark Eakin [NOAA's Coral Reef Watch] discussed coral bleaching, and gave an overview of Coral Reef Watch's satellite-based products, as introduced in Paul DiGiacomo's earlier presentation. Coral Reef Watch products use data from both polar-orbiting and geosynchronous satellites. This tool gives managers the ability to predict coral bleaching, such as that which occurred between 2014 and 2017—the longest, most widespread, and likely, the most damaging thermal stress event ever. He ended by mentioning the recent film *Chasing Coral* (*http://www.chasingcoral.com*), which documents the state of coral reefs around the world and explored how they are vanishing at an unprecedented rate.

Panel 1 Discussion Summary

The main themes of the discussion with all participants included the importance of refining predictive capabilities through the assimilation of additional datasets. These include satellite data from the European Space Agency (ESA) and Japan Aerospace Exploration Agency (JAXA), and getting data developers into the field to interact with end-users to share resources and understand practical requirements. In an era of shrinking budgets, there is a need for more of this to be done online.

Mark Eakin discussed the hands-on workshops for resource managers, conducted annually with each U.S. Coral Reef jurisdiction in partnership with several international partners (e.g., SERVIR and the World Bank). Earlier funding for these activities has now largely disappeared, and there is a consequent need to put training and feedback tools online.

There was focused discussion on the impact that Hurricanes Irma and Maria had on coral reefs around the Virgin Islands and Puerto Rico. According to Eakin, damage assessments are still ongoing, limited by logistical limitations (e.g., fuel for boats). Reports from the Florida Keys indicate the extent of damage was not as bad as feared there, but was worse in the southern Keys compared to the northern Keys. NASA is currently funding a project to include more satellite data to predict coral reef disease in the Pacific.

There was a general discussion about resource constraints. **Scott Doney** noted that the American Association for the Advancement of Science provides a robust analysis of administration and congressional budgets. The current administration has proposed cuts for NASA Earth Science—including the PACE mission; similar cuts were proposed for NOAA. Several websites have detailed analyses of budget proposals.

Charlie Iceland [WRI] asked about the extent to which ESA and JAXA support monitoring of ocean temperature, acidification, and other parameters and whether agencies share resources. Several speakers offered that international collaboration is common and ongoing, thereby optimizing use of limited funding and other resources.

Panel 2: Fisheries and Ecosystem Health

Cara Wilson [NOAA Fisheries] moderated the fisheries and ecosystem health panel, which focused on the use of science and technology to improve local resilience and support decisions for sustainable fisheries. The focus was on the need to develop actionable information that takes advantage of the repeated, synoptic view afforded by satellites to improve health and safety, while minimizing waste and environmental impacts.

Camrin Braun [Massachusetts Institute of Technology/Woods Hole Oceanographic Institution] discussed the new paradigm for fisheries management. Traditionally, managers used a *static, catch-limited* approach for a given oceanic area, which ignores processes that operate on a variety of scales. Conversely, *dynamic* management incorporates changes in space and time in response to the shifting nature of the ocean and its species, and considers biological, oceanographic, and socioeconomic factors. He discussed oceanographic factors that impact fish habitats and how fish interact with ocean eddies. Improvements include observations at increasingly smaller scales. Planned NASA missions like PACE and SWOT will make measurements at finer spectral and spatial scales, respectively, to augment *in situ* data.

"As with every model I use such as weather and wind and swell, I watch them to see how it applies to my local conditions, and then I determine my own degree of accuracy and apply them to making decisions about how I manage the farm. When a domoic acid event occurs, I comb [through] the models to see how it relates to my situation."

—**Bernard Friedman**, Santa Barbara Mariculture Company, Santa Barbara, CA

Mitchell "Mitch" Roffer explained how his company uses satellite data to produce a value-added fish forecast product. He focused on ROFFS work with fisheries and aquaculture, beginning with satellite data, and giving examples of how they tailor specific products to meet their customers' needs, with the goal of sustaining and increasing what Roffer referred to as *catchability*. Roffer noted that optimal satellite products would be hourly, cloud-free, microwave sea surface temperature (SST) data, multispectral ocean color data at 250-m (~820-ft) spatial resolution, and global positioning system (GPS) data. He noted that his customers need data in real time, and such data are not always available.

Shelly Tomlinson [NOAA Ocean Services] addressed using satellites to forecast harmful algae blooms (HABs), which are associated with several human health and animal illnesses. While satellite imagery alone cannot distinguish a HAB from non-harmful algae—and is not useful for all species—it can be a useful tool when combined with other ecological data. Several algorithms have been developed to detect HABs using data from ocean color sensors (VIIRS, MODIS, and OLCI[6]). While this is an international problem, her specific examples focused on the U.S. She then proceeded to show four places where satellites are being used for HAB forecasting and monitoring: in the Gulf of Mexico, over Lake Erie, in California's coastal waters, and in the U.S. Pacific Northwest. Tomlinson also included a slide with personal testimonials from shellfish growers (e.g., see quote from Bernard Friedman on this page), fishermen, and marine mammal rescue centers (e.g., see quote from Richard Evans on page 19) about how they use this information.

Bernard Friedman [Santa Barbara Mariculture Company] described his experience as an aquaculture farmer who operates a 25-acre open-ocean shellfish farm one mile off the coast of Santa Barbara, CA, with annual production of about 100,000 pounds of mussels. Offshore shellfish farming has massive potential to provide healthy protein at a much less environmental cost than any other form of farming on this planet. His mussels provide a local source of seafood since their phytoplankton food source continuously and naturally renews itself. He stated that the meat quality found inside the shellfish is a direct indicator of ecosystem health: When the meat turns toxic, as it did during the El Niño of 2015-16, he would like to know in advance of the onset of harmful conditions—but often he does not.[7]

[6] OLCI stands for Ocean and Land Colour Instrument and flies on ESA's Copernicus Sentinel-3 mission.

[7] Learn more about Friedman's personal connection to satellite data in "Using Scientific Muscle to Grow Safer Mussels," posted on *The Earth Observatory—https://earthobservatory.nasa.gov/IOTD/view.php?id=91595*.

Panel 2 Discussion Summary

Monitoring ocean biology and ecosystem health from space is complicated by the intervening clouds and the fact that everything moves and changes. **Woody Turner** pointed out that the trade-offs between spatial, temporal, and spectral resolution is the key to what can be resolved. A future geostationary ocean color sensor (e.g., the proposed GEO CAPE[8] mission), combined with current satellite capabilities and improved models, would radically enhance our ability to derive actionable information about submesoscale, transient biological features. The 2017 Decadal Survey is setting priorities for missions in the next decade.[9]

The group discussed differences between the needs of aquaculture and those of the wild fishing fleet. **Bernard Friedman** said that policies lag offshore shellfish farming[10] practices, referring to offshore shellfish as the "canary in the coalmine," since they respond to various stressors before harmful levels of demoic acid (a neurotoxin found in algae) can be detected by other means, and enter into policy discussions. He would like advanced information about the types of plankton at his farm and when they turn toxic. **Shelly Tomlinson** pointed out that ecological modeling is a new domain, not as mature as dynamical models, and currently being assessed and refined.

Mitch Roffer described how forecasting wild fish stocks has economic impacts for ROFFS customers, who use them for strategic planning of their fishing fleet assets. In Tanzania, he recently used satellite data to help identify new fishing areas so that they could stop overfishing historical fishing sites and develop a properly managed, sustainable fishery. While spatiotemporal satellite data and models are useful for developing such broad plans, neither are yet reliable at the operational scale (i.e., submesoscale, hourly).

Camrin Braun emphasized the challenges posed by satellite data latency and infrequency, as weather fronts are in motion and a satellite image that is hours old can show a location hundreds of miles away from a current location. Some end-users expressed annoyance that agencies take a long time to quality-control data prior to sharing it, while many operational users do not require precise values, and actually prefer relative amounts (e.g., chlorophyll concentrations), but would prefer faster, near-real-time experimental products. Something that combines the speed, direction, and magnitude of a front would be useful, although preferred habitats are species specific. **Paul DiGiacomo** mentioned the importance of blending geostationary and polar products to fill gaps and create a truly operational product—not yet available for ocean color. As noted earlier, GEO-CAPE is proposed, but will not occur within the next five years.

[8] GEO CAPE stands for Geostationary Coastal and Air Pollution Events, and was one of the missions proposed in the 2007 Earth Science Decadal Survey—*https://www.nap.edu/catalog/11820/earth-science-and-applications-from-space-national-imperatives-for-the*.

[9] The second Earth Science Decadal Survey was released January 5, 2018. It is called *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observations* (2018), and is now available online at *https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth*.

[10] In 2016 NOAA published the nation's first regulatory program for offshore aquaculture in federal waters, intended to expand opportunities for marine aquaculture and meet the growing demand for sustainable local seafood.

Panel 3: Links Between Fisheries and Human Security

Charlie Iceland [WRI] moderated this panel, which focused on organizations that use ocean satellite data and products to inform decisions that assist society and human security. Quickly getting actionable Earth-observation information into easily usable tools is key to supporting tactical intervention.

Johanna Polsenberg [Conservation International] shared the Ocean Health Index (OHI, *http://www.oceanhealthindex.org*). The OHI is a mechanism for marine ecosystem-based management, defined in an easy-to-use global metric that can be used to monitor progress over time. This index was created to capture the human-ocean coupled system; distill it into easy-to-understand metrics; incorporate sustainability into all indicators; monitor progress and track through time; and motivate actions to improve ocean health. Thus far, limited satellite data have been applied, and used to monitor various phenomena—e.g., sea ice, mangroves, SST, ultraviolet radiation, and sea-level rise. Polsenberg discussed the 10 comprehensive goals of OHI and the core process to score them, and challenged participants to think about global or regional satellite data that could be applied.

Beth Lowell [Oceana] introduced her organization, which is dedicated to international ocean conservation, and using satellite data to protect the ocean, with a focus on responsible fisheries management. Oceana's motto is: *"Save the oceans, feed the world."* She then described how illegal, unreported, and unregulated (IUU) fishing and seafood fraud are issues that undermine responsible fisheries management, and that sea-based traceability—while difficult—helps track seafood through the complex seafood supply chain. She also gave a preview of Global Fishing Watch (GFW),[11] an online, free platform that incorporates real-time commercial fishing activity data into useful maps, developed in coordination with scientists, data providers, and resource managers. Oceana has a team of analysts that use the maps in combination with other data to produce reports and to support campaigns to improve fisheries management around the world—see **Figure 2**. Recent projects include identifying hotspots of transshipping activity and discovering unlawful fishing activity typically just outside countries' exclusive economic zones, in order to stop it. Lowell explained that governments are recognizing the importance of publically sharing fisheries data to fight illegal fishing, e.g. Indonesia now publishes its data in GFW. Oceana and GFW are working with more governments to secure additional vessel tracking data.

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[11] See **Paul Woods**' keynote address on page 19 to learn more about Global Fishing Watch.

Camrin Braun (middle) tags a shark to track its movement in the North Atlantic. In his presentation [see page 14], Braun mentioned that one of the challenges of fisheries management is that a single shark can cover lots of ground in relatively short time, as evidenced in Figure 2—by Oceana in which shark tracks are superimposed on a Global Fishing Watch map. **Photo credit**: Tane Sinclair-Taylor/ MIT-WHOI

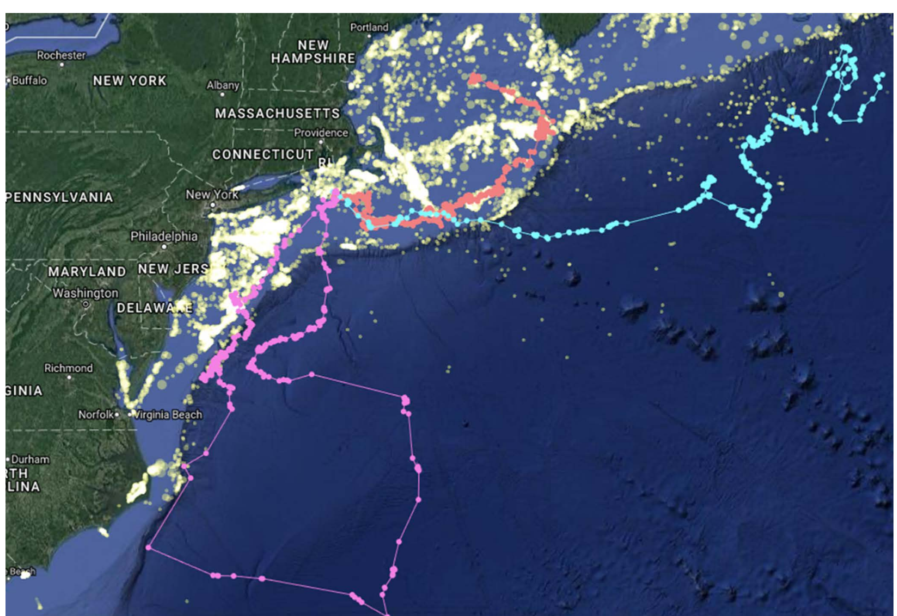

Figure 2: Example of a blue shark case study and a Global Fishing Watch workspace showing the interactions between three tagged shark tracks (red, blue, and pink dotted lines) and commercial fishing activity (white dots) in the Northwest Atlantic during June - September 2016. **Image credit**: Beth Lowell/Oceana

Christoph Aubrecht [European Space Agency/World Bank] noted that the wealth of the global ocean is conservatively estimated at $1.5 trillion U.S. dollars annually, and that almost 15% of the world's population depends on fisheries or aquaculture for livelihood. Unfortunately, in recent years, the health of the ocean has declined, leading to food insecurity and instability. In response, the World Bank promotes a *blue economy*—a sustainable ocean economy where economic activity is in balance with ocean health. Aubrecht described the *Earth Observations for Sustainable Development* (EO4SD) initiative with the development banks, that includes using EO in support of fisheries and aquaculture management. The main challenges include fast delivery of actionable satellite information and the reliability of the analytics. Persistence is an issue for tactical support and is being addressed through new, small satellites. The main concern is how to put these tools into the appropriate hands with a long-term sustainable framework.

Panel 3 Discussion Summary

The main themes of the discussion were about building capacity around the United Nations Sustainable Development Goals (UN SDGs), especially Goal 14: Conserve and sustainably use the oceans, seas, and marine resources. In particular, **Joanna Polsenberg** and others noted that it can be challenging for developing governments to handle big data, making it challenging for them to integrate products into their decision-support process and strengthen their ability to enforce regulations.

GFW is a success story in that regard: Use of the tool by developing countries has doubled, enabling them to better protect their territorial waters since most productive fishing areas are within the exclusive economic zone of countries. **Beth Lowell** said Oceana sees fisheries starting to recover once countries enforce scientifically-based catch limits, protect habitats where fish spawn, and reduce bycatch. The World Bank has also had success reaching local communities and has strong capacity-building programs via developmental banks to address local problems.

A discussion about how African nations make use of satellite data pointed to several areas of significant concern that workshop participants from Africa bought to the group's attention. **Christoph Aubrecht** asked with whom data providers should engage to increase capacity-supporting resource management and noted that the World Bank had a project in the western Indian Ocean dealing with oil spills related to piracy that successfully used synthetic aperture radar (SAR) imagery to identify and catch oil slick offenders and stop them.

Paul DiGiacomo described ongoing discussions with the Committee for Earth Observation Satellites (CEOS) and the challenge presented by SDG targets being socioeconomic, while data collected by Earth Observation providers are more statistically based. Workshops engaging stakeholders hope to explore practical scenarios to bridge this gap (e.g., GEO Blue Planet workshop in January).[12]

[12] The workshop is called *Implementing and Monitoring the Sustainable Development Goals in the Caribbean: The Role of the Ocean*, January 17-19, 2018, in St. Vincent and the Grenadines in the Caribbean. To learn more, see *http://www.gstss.org/2018_Ocean_SDGs*.

Panel 4: Resources and Tools for Using Ocean Satellite Data Products

Paul DiGiacomo moderated this panel on the satellite data products available for different levels of user engagement, from detailed scientific analysis to quick looks at global imagery. Before introducing the presentations on what users need and how to get appropriate tools and data to them, DiGiacomo specifically mentioned two relevant international efforts from the Group on Earth Observations (GEO): the Blue Planet network initiative, and AquaWatch, a water-quality information resource.

The challenge is in getting these data into the hands of interested nonscientists and training them to use them—a chasm between research and applications.

Carlos Del Castillo began by showing data from the Sea-viewing Wide Field-of-View Sensor (SeaWiFS) that shows the planet "breathing." He then gave some historical perspective, reminding participants of the humble beginnings of ocean color satellite data acquisition, and the contrast today, where there are many sensors, many satellites, and many different users from a variety of backgrounds. The challenge is in getting these data into the hands of interested nonscientists and training them to use them—a chasm between research and applications. NASA's ARSET has archived several excellent ocean color webinars useful for this purpose: see *https://arset.gsfc.nasa.gov/sdgs#SDG14* to learn more.

Jim Acker [GSFC, Earth Sciences Data and Information Services Center] endorsed Jeremy Werdell's introduction to ocean color and recommended his own book on the subject for those with a deeper interest in the history of ocean color.[13] He then gave overviews of three different analysis tools: Worldview (*https://worldview.earthdata.nasa.gov*), NASA Earth Observations, or NEO (*https://neo.sci.gsfc.nasa.gov*), and Giovanni (*https://giovanni.gsfc.nasa.gov/giovanni*). He contrasted each tool by using them to examine the seasonal Amazon River outflow plume. Worldview is primarily designed to provide near-real-time daily (or finer temporal resolution) data in layers that are easy to combine for data analysis. NEO gives 50 satellite datasets and is a useful tool for comparing up to three images or times. Acker demonstrated NEO's Data Probe and Transect capabilities. Giovanni contains both satellite and model output data, with several different visualization and analysis capabilities. One noteworthy capability of Giovanni is creating time series; another is creating a difference map between two output files (with Panoply). All of these NASA tools are available for viewing and analyzing remotely sensed data on-the-fly without having to download software.

CoastWatch offers tools and tutorials for searching, downloading, analyzing, and imaging satellite data that enable easy access and use, including by nonexperts.

Veronica Lance [NOAA—*CoastWatch/OceanWatch Program Scientist*] showed how NOAA CoastWatch/OceanWatch (*coastwatch.noaa.gov*),[14] provides fit-for-purpose global and regional, near-real-time, and science-quality time-series satellite data products. They are derived from NOAA and non-NOAA satellites for multiple environmental parameters. Global and regional satellite data products are converted into actionable information through assimilation with other data and models, and used to understand, manage, and protect ocean and coastal resources. CoastWatch offers tools and tutorials for searching, downloading, analyzing, and imaging satellite data that enable easy access and use, including by nonexperts.

[13] Learn more about what led Acker to write *The Color of the Atmosphere With the Ocean Below: A History of NASA's Ocean Color Missions* at *https://earthobservatory.nasa.gov/blogs/earthmatters/2015/09/28/some-insight-on-the-color-of-the-ocean*.

[14] NOAA CoastWatch/OceanWatch central office is in College Park, MD, with several nodes distributed geographically and among NOAA line offices such as Fisheries Service, Ocean Service, and Oceanic and Atmospheric Research.

Panel 4 Discussion Summary

We are data rich, but often information poor.

One focus of the discussion on resources and tools for using ocean satellite data products was on building value-added products and making sure they're useful to end-users. Returning to a topic raised in the Panel 2 discussion, having fast access to lower resolution than research-grade data products would have significant utility for appropriate groups, and intermediary arrangements through organizations such as WRI can help to bridge this divide. Applied Sciences projects that are funded through NASA require an evaluation of the usefulness of the product and includes a benefit analysis to business and other operations.

Related to this is the paradox of building trust in information content quality while also conveying data uncertainties. Again, users frequently need a less-complicated answer than the highly scrubbed data provide.

As noted by an earlier group, a key discussion addressed building capacity by sharing assets and training people to find and use available resources, including online tutorials—especially important for developing countries. As reported earlier, the divide between sophisticated and unsophisticated users is a wide one as regards data access, availability, and manipulation. On the topic of scattered resources, **Jim Acker** said there are some websites that consolidate them; however, the agencies need to be mindful of customer demand for "one-stop-shopping." In support of raising awareness about satellite assets and training opportunities, **Veronica Lance** suggested that getting stories out to the public about how data are used is an effective way to spark ideas.

There was a question about whether NOAA provides a routine dataset on ocean acidity. A group at NOAA develops such a product that goes into Coral Reef Watch; however, this is not yet monitored by satellites nor routinely served, although **Veronica Lance** said they are working on algorithms to do this.

When asked about how to appropriately cite data, **Jim Acker** responded that there are instructions for this on each dataset's landing page. **Carlos Del Castillo** pointed out that users need to be aware that agencies serve out each other's data which can lead to credit confusion, e.g., NASA data might incorrectly be credited to NOAA. **Veronica Lance** mentioned that metadata helps with this by including the history of a dataset.

All-Panel Discussion Summary

At the conclusion of the fourth panel, the panelists from all four panels gathered to synthesize concepts raised throughout the day. The main point of discussion was the extent to which end-user needs are guiding product and mission development. Commercial businesses use needs analyses to assess and guide product development. **Mitch Roffer** asked whether anyone has done this, to which **Mark Eakin** and **Shelly Tomlinson** replied that NOAA has done this for Coral Reef Watch and HAB forecasting, and **Steven Pawson** replied that NASA GMAO also does to some extent. **Mark Eakin** qualified that people need to see example products first to give them a concept of what's possible, before they can give feedback on how well the product can serve their needs.

Carlos Del Castillo mentioned the best mechanism for users to get exactly what they need is by establishing a true partnership with an academic research organization during a NASA Applied Sciences Program funding call, especially where funding is the limiting factor. NASA's Early Adopters Program is another way to gauge user needs early in mission design and development process, in which users test synthetic data prior to launch—not just for PACE, but for all future missions. Engineering trade-offs made in concert with end-user needs can lead to more-efficient use of available resources, as was done by ESA in conducting a needs assessment prior to the Copernicus mission. **Christoph Aubrecht** added that international collaboration can also help with funding constraints. For example, NASA and ESA work together on joint campaigns as well as on the upcoming ESA Biomass Mission, planned to launch in 2021.

On the subject of whether user needs are identified through top-down mechanisms (i.e. data in search of users), **Christoph Aubrecht** shared that ESA strategically engages leadership teams at development banks that are developing goals and ESA advises on how Earth observations can help address these long-term goals. **Carlos Del Castillo** contrasted this with the practice at NASA, where Applied Science proposals have traditionally been led by scientists rather than end-users. **Woody Turner** responded that this is changing and that end-users are now writing proposals.

As to how users could learn about and access the plethora of available resources, **Steven Pawson** noted that products are probably underutilized due to lack of awareness. **Beth Lowell** reiterated that there are a lot of freely available, great data resources online, but that it's not always obvious where to find what one needs.

Keynote Presentation

Paul Woods [GFW—*Chief Technology Officer*] discussed traffic in the South China Sea and pointed out that many vessels actively try to avoid detection. He noted that the global economy loses $83 billion annually to illegal fishing, overfishing, and poor fisheries management. In response to this daunting problem, Oceana, Skytruth, and Google conceived and created GFW and publically launched it in 2014. Woods described how GFW has used the Automatic Identification System (AIS) to identify ~60,000 vessels since 2012. This tool was developed to jumpstart a discussion about how to track vessels—successfully. Woods went on to describe how satellite data are applied to GFW to identify vessel type. This is important because vessels lie about their AIS identification. GFW uses machine learning to recognize patterns, allowing them to distinguish fishing vessels from non-fishing vessels, and then distinguish the types of fishing vessels, e.g., trawl, longline, or purse seine. The system was launched at the Our Ocean Conference in 2016, and already has users from 189 countries, with 32,500 registered users and 5,000 core users. Woods summarized many of the applications of GFW and its research program, and showed an example of combining Sentinel-1 satellite radar data with AIS data in Google Earth Engine to improve the ability to identify nonbroadcasting vessels—the so-called "dark fleet."

"As the medical director of a southern California marine mammal rehabilitation center, I am always in need of current data concerning domoic acid blooms in southern California waters. We have been using these pictorial data to keep abreast of the seasonal trends in domoic blooms that impact marine mammals in southern California waters. For the first time in 20 years we are able to verify domoic acid blooms in a timely fashion, that could result in moderate to severe pathologies and deaths in marine mammals in Orange County waters. This is a classic example of 'forewarned is forearmed.'…."

—Richard Evans,
The Pacific Marine Mammal Center, Laguna Beach, CA

With more capabilities coming online, this is an exciting time for remote sensing. The flipside is that with increasing amounts of data available, there is an ever-increasing need to distill key information from those data and get that information to end-users.

Keynote Presentation Discussion Summary

Participants discussed the challenges of enforcing IUU regulations and whether additional assets might be integrated. **Paul Woods** suggested that suborbital assets (i.e., unpiloted aerial vehicles) could help. High-resolution images by private companies (e.g., Digital Globe) were also discussed, but there are many challenges to using these data with any frequency, and it is not fast to get an image this way. New SAR constellations will increase temporal frequency. The consensus was that the problem requires a multilayered approach: GFW can help with the big picture of the IUU problem but needs people on the water too. Additionally, sometimes the problem is not with getting the information, but moving it to the right organizations, such as law enforcement. High costs associated with targeted scenes is another area of concern. End-users with demonstrable needs must keep asking cognizant agencies and companies for these sorts of data. **Mitch Roffer** asked whether NOAA uses GFW data to study fishing effort over time, but **Paul Woods** responded that GFW gets more engagement outside of the U.S. on that issue.

With more capabilities coming online, this is an exciting time for remote sensing. The flipside is that with increasing amounts of data available, there is an ever-increasing need to distill key information from those data and get that information to end-users.

Conclusion

Stephanie Uz and **Janet Ranganathan** wrapped up the meeting with a few closing remarks and an opportunity for some final input from the participants. Both of them emphasized the need to continue the dialogue between satellite data providers and users in order to tailor products to user needs, along with intermediaries who build customizable tools for a broad target audience, offer training opportunities, and promote success stories about people already applying the data. NASA and NOAA will also coordinate efforts with other groups undertaking similar efforts, such as GEO Blue Planet.

Paul DiGiacomo noted that success stories are a useful way to connect new users, and offered the opportunity for Blue Planet to work with NASA, NOAA, and WRI in sharing stories and case studies (e.g., the Aquawatch report on water-quality-monitoring case studies). He reiterated the importance of capacity building through training and end-user engagement. **Janet Ranganathan** reminded everyone about putting information in an accessible format where the users are, as WRI plans to do with Resource Watch (launching April 2018), combined with stories that include partners sharing data-use examples.

Future discussions and trainings will address needs identified during the workshop. ■