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Article

Lessons learned from the NOAA CoastWatch Ocean Satellite Course Developed for Integrating Oceanographic Satellite Data into Operational Use

Cara Wilson [1*] and Dale Robinson [2]

[1]Node Manager, CoastWatch-West Coast Node, NOAA/SWFSC/ERD, 99 Pacific Street, Suite 255A, Monterey, CA USA 93940; cara.wilson@noaa.gov
[2]Operations Manager, CoastWatch-West Coast Node, Institute of Marine Sciences, University of California, Santa Cruz, Santa Cruz, CA 95064, USA.
* Correspondence: cara.wilson@noaa.gov

Abstract: Data from environmental satellites are underutilized in many branches of operational oceanography. Several challenges exist for potential users of satellite data that may impede or preclude employing satellite products in their work. Users outside of the satellite community often encounter difficulty in discovering the types of satellite measurements that are available, and determining which satellite products are best for operational activities. In addition, the large choice of satellite data providers, each with their own data access protocols and formats, can make data access confusing and inefficient. NOAA's CoastWatch Program is designed to be a Value Added Provider, whose mission is to help make satellite data easier for users to access. With this objective the West Coast Node of CoastWatch developed the NOAA Ocean Satellite Course, which introduces scientists and resource managers to ocean satellite products, and provides them tools to facilitate data access when using ArcGIS or R software. These tools leverage upon the data services provided by ERDDAP, a data distribution system designed to make data access easier for both humans and machines. The course has been offered annually since 2006, and over 350 participants have taken it. Results of post-course surveys are analyzed to measure course effectiveness. Lessons learned from conducting these courses are summarized.

Keywords: Remote Sensing, Satellites, NOAA, CoastWatch, Oceanography, Training, Education, Operational Oceanography, ERDDAP, Value Added Provider

1. Introduction

The inclusion of satellite data into operational applications has often lagged behind its use in research applications [1]. The first meteorological satellites were launched in 1960's [2], but it took a decade before data from satellites were routinely used operationally and several more decades before satellite data were used in numerical weather prediction [1]. Similarly, ocean satellite data have been readily available for decades (Table 1), yet these data resources are still underutilized in many branches of operational oceanography [3,4]. However, satellite data can provide important environmental data to operational oceanographic applications, given its global spatial scale and the decades of data that are now available [5]. Additionally, satellites are expensive national investments, and the data from them should be utilized to their maximum benefit. In the National Marine Fisheries Service (NMFS), of the National Oceanographic and Atmospheric Administration (NOAA), operational management activities that could benefit from satellite data include stock assessment, habitat classification and conservation efforts. However, the scientists and managers responsible for these activities are typically not experts in acquiring and processing satellite data, which can lead to obstacles in them integrating satellite products in their work [3].

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Table 1. List of oceanographic satellite measurements and the start of their continuous time series of data.

Measurement	Since
Sea ice	1978
Sea Surface Temperature	1981
Sea Surface Height	1992
Ocean Color (Chlorophyll)	1997
Precipitation	1997
Surface Vector Winds	1999
Salinity	2011

Incorporating ocean satellite products into operational use requires a minimum of three steps: data discovery, access, and utilization, and there can be barriers associated with each one. Data discovery is the process of determining what data are available and if they are useful for an application. This process typically involves a web search to find products and product documentation. Understanding the documentation and determining if a product is useful for an application might involve locating additional web resources and talking with satellite data subject matter experts. This step can be the most time consuming, considering the array of satellite products that are available. For example, the Group for High Resolution Sea Surface Temperature (GHRSST) catalog lists over 80 disparate sea surface temperature datasets [6]. After locating desirable products, a user must gain access to the data. Satellite products can be downloaded from a multitude of data providers including NOAA, National Aeronautics and Space Agency (NASA), Jet Propulsion Laboratory (JPL), European Space Agency (ESA), European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). These organizations may or may not require a registration step, and the data access can be via direct download of data files via FTP and HTTP, or through online data servers (e.g. THREDDS, OpenDAP [7]), each with its own protocols to search, subset, and download data. Utilizing the data might require a different set of software packages, scripts, and libraries to extract the data in a usable form since the data files can be in variety of file formats, including GRIB, HDF, netCDF or older binary and text formats.

NOAA's CoastWatch Program (https://coastwatch.noaa.gov) is designed to address the issues outlined above, as its mission is to provide easier access to global and regional satellite products [8]. The program is structured with a central node, that makes and distributes satellite products, and six regional nodes that develop products and provide services tailored to the needs of their local users. The regional nodes do much more than just distribute data; by offering tiered levels of assistance to users they act as value added providers. In addition to providing access to data they develop tools and tutorials, provide training and hands-on assistance, find or create products in response to users' needs and work directly with users on projects. The West Coast Node (WCN, https://coastwatch.pfeg.noaa.gov) is housed at the Southwest Fisheries Science Center (SWFSC) and caters primarily to the needs of NMFS scientists. The WCN works closely with the data group at the SWFSC Environmental Research Division (ERD) that hosts the WCN/ERD ERDDAP server.

developed the NOAA Ocean Satellite Course [9] to increase the awareness and utilization of satellite data by fisheries scientists and managers. The course has been offered and refined annually for over a decade. In this paper we describe the course content and structure, present results of post-course surveys designed to measure course effectiveness and review the course impacts on operational oceanography. We also describe efforts to extend the reach of the course both nationally and internationally, and discuss lessons learned over the almost one and a half decades the course has been offered.

2. NOAA Ocean Satellite Course

The NOAA Ocean Satellite Course was initially offered in 2006 by the WCN of the NOAA CoastWatch program. Since that time, the course has been held annually, primarily on the US West Coast. The goal of the course is to provide participants the knowledge and tools they require to

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incorporate off-the-shelf satellite data products into their operational activities, without delving too much into the details of how the products are made. This distinction differentiates the NOAA Ocean Satellite Course from other well-established satellite remote sensing courses that cover such topics as ocean optics, atmospheric corrections, ocean color algorithms, and image analysis (e.g. http://www.geo.cornell.edu/ocean/satellite/). EUMETSAT, Europe's operational satellite agency, has been offering courses in marine training that are similar to the NOAA course since 2017 [10].

The primary target audiences for the NOAA course are scientists and managers within the NOAA line offices of NMFS and the National Ocean Service (NOS) who are involved in operational activities but are not currently using satellite data in their work. Course attendance has generally been between 20 to 30 participants per year and of the over 350 total participants (Figure 1), approximately 75% have been NOAA employees and affiliates (Figure 2). The course is offered at no cost to participants, thereby reducing financial barriers and drawing participants who might be uncertain about whether a tuition fee is a justifiable cost. Although the course was conducted by the regional WCN, it was attended by participants across the country.

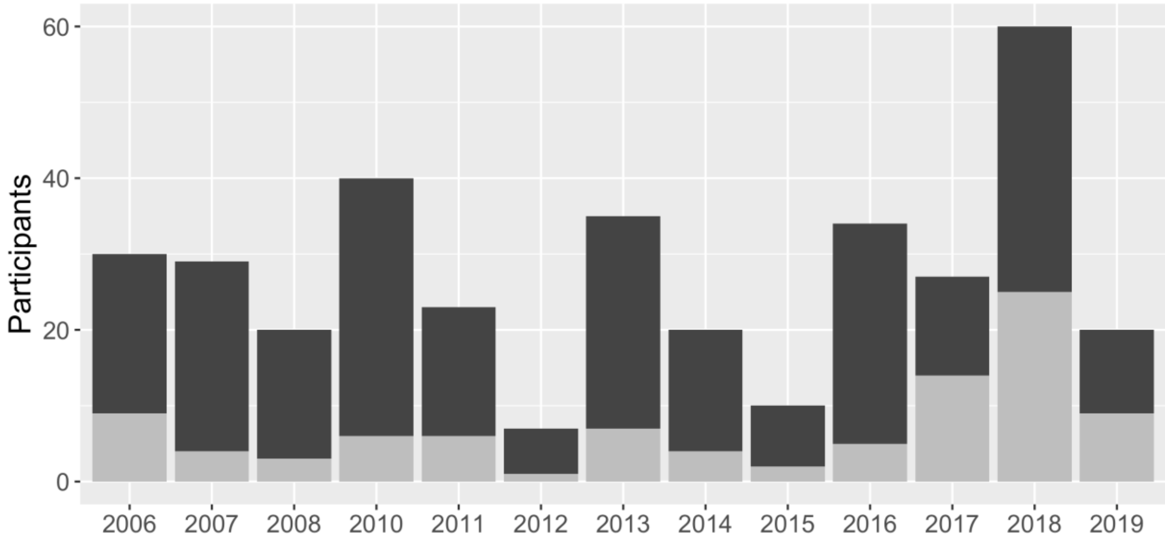

Figure 1. The number of participants in the NOAA satellite course since 2006 (black), and the number of survey responses received back from each year's participants (gray).

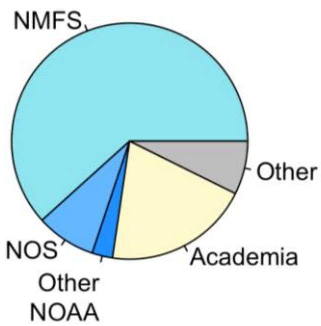

Figure 2. Affiliations of the 355 participants who have taken the NOAA Satellite Course since 2006.

Our approach has been to choose the analytical tools used in the course based on the skill-set and software preference of the participants. Most participants have software packages with which they normally carry out their analytical tasks. During the course beginnings, ArcGIS [11] and Matlab [12] were the most commonly used software packages (Figure 3). Over the years, there has been a steady increase in the use of R [13], and currently R and ArcGIS are the two most commonly used packages. In 2017 Python [14] started appearing as a software used by some participants, but it is not

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widely used by course participants. Python [14] and R [13] are both available under open source licensing, which is advantageous to operational users without the resources to buy expensive software licenses. By teaching in alignment with the software already being used by the participants, we leverage preexisting skills sets and avoid the challenge of introducing unfamiliar software. As a result, the hands-on portion of the course can focus on techniques to bring satellite data into the software packages and convert the data into a format that is usable to the participant. The participants can typically take over from that point and apply the data to their projects. In effect, the course becomes an exercise in capacity building, developed on established capabilities, that can be taken back to the workplace and integrated into an existing operational workflow.

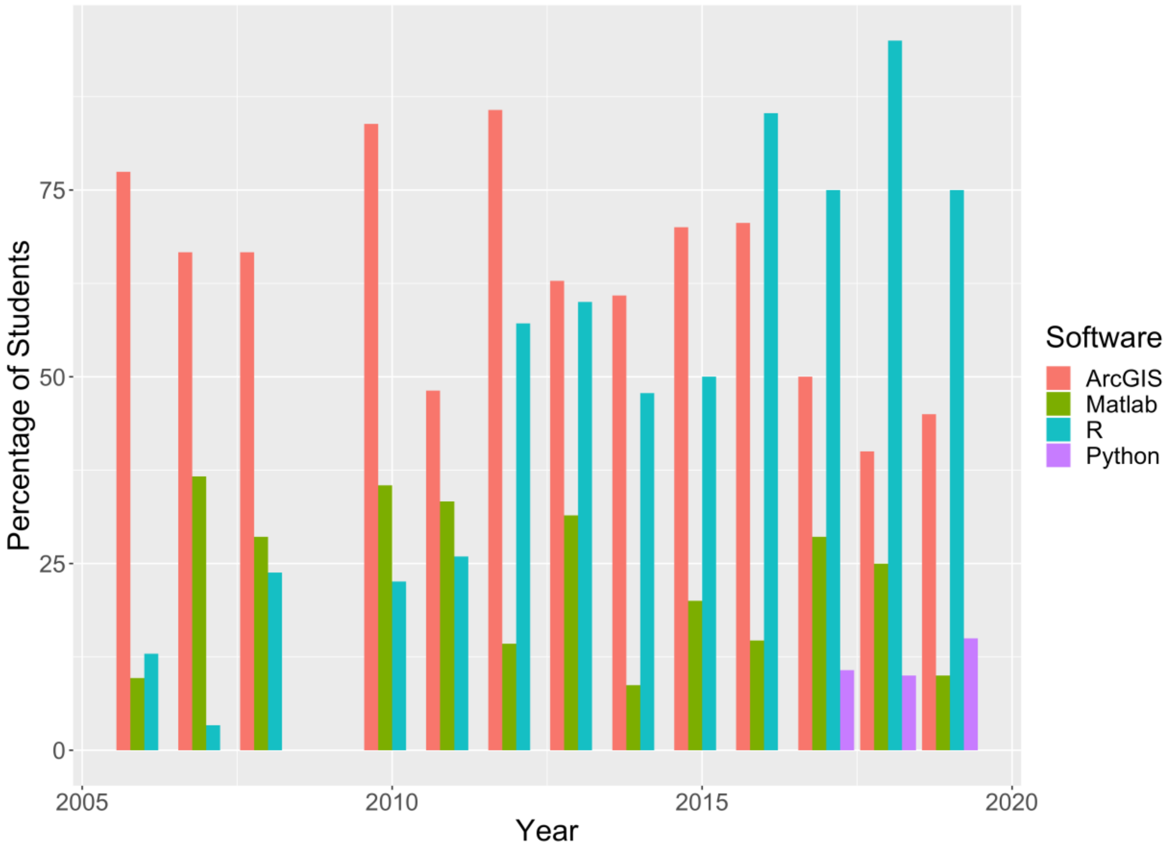

Figure 3. Software utilization of course participants. Since many participants use more than one software package the percentages for a given year will exceed 100%.

2.1. Pre-course activities

An important component contributing to the success of the course is advanced preparation by the students and the instructors, which is facilitated by setting up a registration process several months before the scheduled course dates. Students are required to submit an online registration form that requests, in addition to contact information and affiliation, information about their familiarity with satellite data, the satellite products that are of interest to them, the computer software packages they wish to use, and a brief description of the project they are interested in working on during the workshop periods of the course. Instructors use the information to adjust the course content to match the level of experience and the interests of course participants.

About four to six weeks prior to the course, students receive a welcome email from course organizers providing logistical information. Specifications for the software packages are also included to ensure that the versions installed on the students' laptops are compatible with the course tools. This software information is particularly important to NOAA employees and affiliates who require the assistance of an IT specialist with administration access to add or update software on their laptop computers. Within the same welcome email are links to test scripts, for use prior to the course

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to ensure that the software is working properly, as well as links to course materials that allow students to review the materials in advance.

2.2. Course format

The course is conducted over three days and has three main components: 1) lectures that provide participants with a basic knowledge of satellite remote sensing; 2) live demonstrations of tools developed to facilitate the use of satellite data; and 3) a hands-on workshop applying satellite data to a work-related project of the participants choosing. On the first day, lectures center around how satellite measurements are made and the types of measurements that are available. These lectures are not intended to provide detailed information about how satellite products are made (e.g. atmospheric corrections, radiative transfer models, etc.), but rather to give students sufficient background to select the best products for their applications. The first day also includes introductions to the tools used in the course to help them bring satellite data into their analysis software of choice. To improve retention of introductory material and reduce presentation fatigue, lectures are interspersed with hands-on demonstrations of the course tools. During the first half of the second day, instruction on using the course tools begins in earnest. Students are walked through the steps of satellite data discovery, download, and visualization in a series of exercises that are based on common oceanographic applications, such as generating a timeseries of satellite data within a user-defined area. For the final day and a half of the course, students apply the tools and information from the course to a project of their choosing, with instructors providing guidance and troubleshooting problems.

2.3. Data Access Tools

The course employs three data access tools: ERDDAP, a data server developed by NOAA's ERD; the rerddapXtracto package for accessing ERDDAP through R; and the Environmental Data Connector, a plug-in module for accessing ERDDAP through ArcGIS. Each of these tools in outlined in more detail below.

2.3.1. ERDDAP

The ERDDAP data server [15] is the primary source of satellite data products for the course. ERDDAP provides a simple, consistent way to download data, allowing the sub-setting of data both temporally and spatially, and providing over 30 common data, metadata, and image formats for downloading data. ERDDAP provides both a graphical interface, to visualize and manually download selected data, and a RESTful URL [16], where a data request is completely defined in a single URL. The RESTful URL allows users to bring selected satellite data directly into their analysis software. Behind the scenes, an additional benefit is that a single ERDDAP can serve as a conduit to access datasets housed on other servers (ERDDAP, THREDDS, SOS…), thereby providing a single location and access protocol for datasets made available by multiple data providers. ERDDAP is used by over 80 institutions world-wide to serve satellite and other environmental data. For the course, we used the ERDDAP co-operated by CoastWatch WCN and the ERD of NOAA's SWFC, which serves over 1,400 satellite datasets [15]. After completing the course students can continue to use the WCN/ERD ERDDAP as a rich source of satellite data for future projects. The demonstration on how to use ERDDAP that was developed for this course is on the WCN website [17] and on GitHub [18].

2.3.2 rerddapXtracto package for R

A common task in fisheries science is to extract satellite data along a set of latitude, longitude, and time coordinates representing the track of an animal fitted with a location tag (Figure 4) or a ship's station locations, a task which requires some degree of programming skill. To simplify this task the rerddapXtracto R package was developed specifically for course participants to perform this data extraction on any gridded dataset on any ERDDAP for a user supplied set of latitude, longitude, and time coordinates [19]. In addition, satellite data can be extracted for an irregularly shaped area such as a marine sanctuary or a fishery management area. Students are provided with a set of premade

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scripts that demonstrate the use of the functions in the R rerddapXtracto package [19]. This documentation is also available on the WCN website [20] and on GitHub [21].

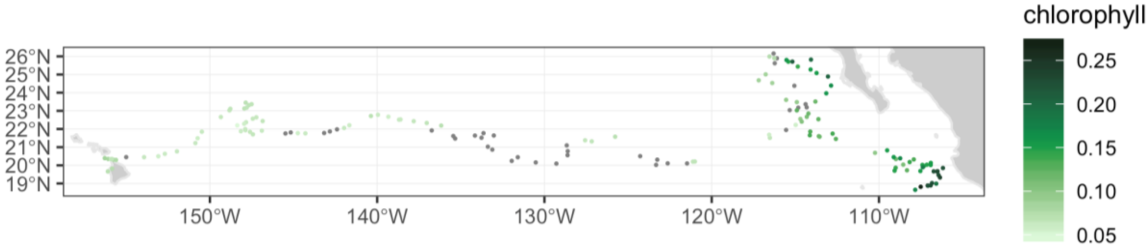

Figure 4. Output graphic from an R script which matches up locations from a tagged fish with satellite chlorophyll data.

2.3.3 Environmental Data Connector (EDC) for ArcGIS

Many fisheries and marine resource managers use ArcGIS [11], which traditionally has not also been easy to import satellite data into. To mitigate this issue, we contracted Applied Science Associates (now RPS Group) in 2008 to develop the Environmental Data Connector (EDC) [22]. The EDC is a plug-in module developed for use with ArcGIS that provides a GUI-interface for accessing datasets served on ERDDAP or THREDDS servers. With the EDC, datasets can be subset spatially and temporally, and then imported directly into ArcGIS. Maintaining the EDC has been difficult; it has required funding to update it periodically to retain compatibility with new releases of ArcGIS. However, the current version of ArcGIS has an improved capacity to import 3-dimensional (x, y and time) data from a netCDF file, prompting our current strategy of moving away from the EDC in favor of integrating the tools inherent to ArcGIS into our training materials.

2.4. Datasets

The datasets used for the course are primarily off-the-shelf satellite products, which are on regular spatial grids (level-3 and level-4 products). Whenever possible, we make available near real-time versions of each product, which have lower quality control but are available with low latency, and delayed release (science quality) versions that are binned into daily, weekly and monthly averaged composites. Other products included in the course are those that blend multiple sensors into a dataset, thereby providing improved spatial coverage and often extending the temporal coverage back a decade or longer [6,23]. This mix of products supports many of the fisheries management activities carried out by NMFS. Stock assessment, habitat classification and conservation efforts require long-term satellite records of the highest possible quality on decadal timescales, in order to accurately detect trends and anomalies that might be influencing the populations living marine resources (LMRs). In contrast, some fishery management needs, such as optimizing ship surveys in real-time and driving models in the emerging field of dynamic ocean management [9, 10,11], require recent and near-real-time satellite data.

2.5. Student Projects

Students are expected to have a project in mind to work on during the second half of the course. This expectation is key aspect of the course satellite course, in that it facilitates employing some of the core tenets the problem-based learning (PBL) to our instructional design. Students apply the knowledge and tools introduced during the lectures and demonstrations to a problem of their choosing, drawing on the expertise of fellow students, with the instructor supporting, guiding, and monitoring the learning process. The learning is linked to a larger, authentic task or problem, i.e. the student project, that the students have ownership of and it is an authentic task, all key components of PBL [24]. Ideally, the students will leave the course with the confidence to address satellite based-applications, while also expanding their understanding of ocean satellite data.

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2.6. Post-course activities

At the conclusion of the course, students are requested to complete an evaluation survey to document their experiences and to determine which aspects of the course worked well and which could be improved. That information is used in the continual process of fine-tuning the course to optimize its effectiveness. The students are also requested to turn in a summary slide that describes how they applied their newly acquired satellite data skills to their course project or future projects. The slides are useful for designing new tools to address common tasks for future participants and to demonstrate to NOAA management the utility of operational satellite products.

2.7. Extending our reach

Until recently, the NOAA Satellite Courses offered by WCN have been held almost exclusively on the US West Coast, in either Corvallis, OR (2006-2013) or Seattle, WA (2014-2017). As a consequence, participation has been biased towards those residing regionally or those who could secure travel funds to attend. This situation was mitigated beginning in 2017, when WCN began working with personnel from other CoastWatch regional nodes to develop versions of the course to be held in other regions of the US. The operations manager of the Central Pacific OceanWatch Node audited the 2017 NOAA Satellite Course held in Seattle to gain experience with the materials and format, and then conducted a similar course in Hawaii in the Fall of 2018. The East Coast Node (ECN) held their inaugural course in Narragansett, RI in August 2018. The ECN collaborated with the lead instructors from the WCN in organizing the course, and the WCN instructors travelled to Narragansett to assist with the course. ECN will conduct their next course in College Park, MD in 2019. The WCN conducted its 2019 NOAA Satellite Course in March at the Alaska Fisheries Science Center’s (AFSC) Auke Bay Laboratory in Juneau, AK, per their request. A significant number of AFSC scientists had never been able to attend the course in Seattle as its timing, held in late August, conflicted with their operational field work. In addition, a collaboration between WCN and the Atlantic Node is planned for 2020 to offer a course in Puerto Rico.

In addition to training the NOAA operational workforce, engaging an international workforce is an important element in increasing use of satellite data in oceanography. Towards this end, the WCN manager has been the lead instructor in the tutorial sessions offered by the Pan Ocean Remote Sensing Conference (PORSEC) in Indonesia (2014), Brazil (2016) and South Korea (2018), incorporating elements of the NOAA Satellite Training Course. The tutorials attracted an international group of advanced undergraduate students, graduate students and young professionals who wanted to expand their expertise in using ocean satellite products.

3 Measuring course effectiveness

3.1 Post-course feedback

The participants feedback collected after each course has provided valuable qualitative information about the participants' experiences in the course. The students have consistently commented on the effectiveness of the hands-on training and advantages of having the one-on-one assistance of the instructors to help them get their project started.

More quantitative metrics data were collected from courses held from 2013 to 2017 when the course was funded by the JPSS program as a means to increase the awareness and usage of ocean color satellite data from the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument on the Suomi NPP satellite. Participants were asked about their familiarity with VIIRS before the course and if they planned to use it in the future. The results of the survey clearly demonstrated an increased awareness of VIIRS data by class participants and an intent to use the data in the future (Figure 5). Prior to taking the course, only 19% of respondents were aware of the existence of VIIRS data and less that 2% had used the data. After having the opportunity to learn about and use VIIRS data in the course, most respondents indicated that they either planned to use (80%) or might use (16%) VIIRS data in their future work. Those not planning to use VIIRS data, or who were unsure, primarily cited

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the lack of a long timeseries for VIIRS data (the sensor became operational in 2012) or that the VIIRS data did not cover their time period of interest.

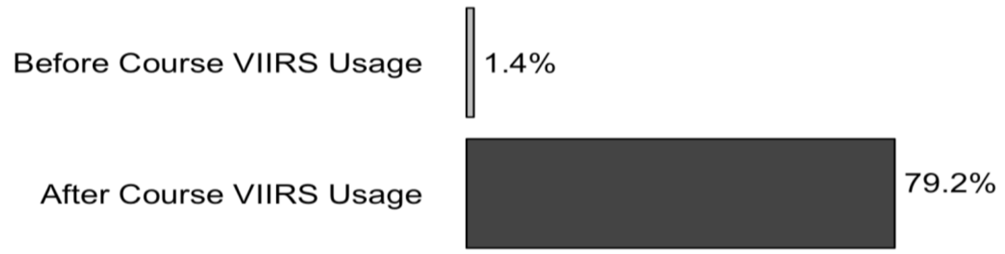

Figure 5. Before course usage of VIIRS satellite data (light gray) and after course usage of VIIRS satellite data (dark gray) from participants who took the course 2013-2017. 65 evaluations were received from the total of 126 participants, a response rate of 52%.

3.2 Long-term effectiveness

To evaluate the long-term effectiveness of the course, past participants of the NOAA Satellite Course were surveyed in February 2019. Of the 355 total participants, 293 were located and sent surveys and 96 responded, a response rate of 33%. Respondents could remain anonymous. 75% of respondents identified as working for the federal government. Participants were asked to assess their current satellite usage and compare it to their usage prior to taking the course (Figure 6). The most dramatic change was reported for the percentage of respondents not using satellite data. Before the course 41% of participants were not using satellite data. After the course only 14% reported not using satellite data. An increase in satellite data use was reported for all other categories (some, moderate, and extensive use) after taking the course, with the percentage of respondents reporting a moderate usage of satellite data doubling from 13% prior to the course to 26% after the course. Overall these data indicate that participation the satellite course has been effective at increasing the usage of satellite data, especially in the federal government sector.

3.3 Operational Outcomes

Ultimately, the best means for measuring the extent to which the NOAA Satellite Course has impacted the incorporation ocean satellite data into operational oceanography is to document how course graduates have applied the satellite data to their management activities. As part of the February 2019 survey, past course participants where asked for specific examples of how they have used satellite data in their work. Richards (class of 2006) used satellite data to identify factors influencing early life survival of shrimp [25]. Bjorkstedt (class of 2006) used sea surface temperature and chlorophyll data to provide oceanographic context for Marine Protected Areas (MPAs) along the California Coast [26]. Quinlan (class of 2013) assessed the impact of the Deep Water Horizon oil spill on marine fish [27]. Danner (class of 2007) developed a model to forecast stream temperatures that are important to salmon [28,29]. Runchie and Muhling (both class of 2017) used satellite data to describe the environmental characteristics of bluefin tuna catch in the California Current [30]. Post-course collaboration between course instructors and participants has resulted in the development of habitat models [31,32], and the use of satellite chlorophyll measurements to assess the potential influence of harmful algal blooms on the decade-long increase in Southern Right Whale mortality [33].

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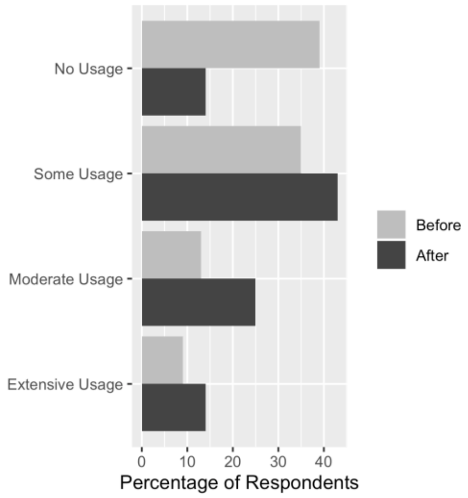

Figure 6. Participant's self-evaluation of their satellite data usage before taking the satellite course (light gray) and after taking the satellite course (dark gray). Data are from a poll sent out to all participants who had taken the course between 2006-2019. 96 responses were received from 293 surveys sent out, a response rate of 33%.

3.4 A Case Study – The Path towards Integrating Satellite Data into Stock Assessment

A training course can have wide ranging impacts on operational oceanography, both directly, by helping with individual research or management applications, and indirectly by informing planning and infrastructure decisions at organizations charged with operational activities. For example, Kalei Shotwell, of the Alaska Fisheries Science Center (AFSC), participated in the inaugural 2006 NOAA Ocean Satellite Course. Based on the training she received, she subsequently used satellite data to identify factors influencing Alaska sablefish recruitment [34], and initiated a process for automatic integration of satellite data into the Ecosystem-Socioeconomic Profile (ESP) of the Sablefish Stock Assessment in 2017 [35]. She has continued to be a strong supporter and advocate for the satellite course, collaborating with the WCN to host the 2019 satellite course at the AFSC Auke Bay Laboratory. Recently she has collaborated with WCN to develop a specialized webpage that will provide time-series of environmental satellite data for the different fishery management regions in Alaska. Ultimately, data from the webpage will be used to inform annual stock assessment reports. She has also initiated the development of an ERDDAP at AFSC with the help of staff from CoastWatch WCN to house ecosystem data that may ultimately feed the ESPs and can be easily incorporated into the annual stock assessment and fishery evaluation reports [36].

4. Lessons learned

Over the thirteen years of conducting the NOAA Ocean Satellite Course, valuable insights have been gained about how to effectively train end-users to incorporate ocean satellite data into their operational activities. These lessons learn are based on the observations of instructors, advice from instructional professionals, and, most importantly, direct and indirect input from participants. These lessons can be grouped into several broad categories summarized below.

4.1 Teach with the software used by course participants

Operational end-users typically employ a set of analytical tools that they have already integrated into the workflows for their operational task. Using these same analytical tools in the course, with which participants are already familiar, instead of imposing a new and unfamiliar set of tools improves the effectiveness of the course in the following ways. First, course time is spent on techniques to acquire and process satellite data rather than teaching a new software program. Second, the need to install and pay a new software license is avoided. Finally, the skills and techniques participants learn in the course can be immediately applied to existing workflows. Currently the

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NOAA course focuses on accessing data with either ArcGIS or R (Figure 3). Materials developed for the course demonstrating the use of the rerddapXtracto package for R [19] are now available on the WCN website [21] and on GitHub [20].

4.2 One-stop shopping for data

Providing participants with a single online location to access the data they need gives them a consistent way to obtain data without having to deal with multiple formats and access protocols. During the course, this allows participants to quickly start to use satellite data. An added benefit is that participants can return to the same location for additional satellite data needs and introduce colleagues to data source. For our courses, we use data providers that maintain a large ocean satellite catalog that is distributed via an ERDDAP data server [15]. Materials demonstrating the use of ERDDAP that were developed for the course are now available on the WCN website [17] and on GitHub [18].

It is important that the data catalog contains datasets that are appropriate for the operational applications the course participants are working on. For example, fisheries management applications, such as determining ecological tends or characterizing fish habitats, require science quality datasets that go back decades. Typically, daily satellite observations are too frequent for these long-term studies, requiring weekly or monthly versions of the dataset, and often an anomaly product is required to evaluate changes in environmental conditions. In addition, most end-users are interested in a satellite product type, like chlorophyll or sea surface temperature, and are less concerned with which sensor or satellite collected the data. Therefore, products like the MUR sea surface temperature [37] and the ESA's OC-CCI products [23] that merge together data from multiple sensors and platforms to create long timeseries are extremely valuable for fisheries applications. Near real-time data are also needed for optimizing ship surveys in real-time and developing models in the emerging field of dynamic ocean management [9, 10,11].

4.3 Student Projects and Slides

NOAA NESDIS has financially supported some of the training courses. To justify the expenditure and to ensure that funding is in place to continue and improve the course, the agency requires documentation of course outcomes. In addition, as course designers we benefit from documentation of our users' satellite needs and the applications for which they employ satellite data. To address these needs, we ask each student for a single summary slide of the project they worked on during the course that describes the project objectives and how the skills they learn in the course will help them apply satellite data to achieve the objectives. In addition to satisfying our programmatic needs for documentation, the slides are a useful resource for showing new students what can be done with satellite data.

4.4 Rotate course locations

When the students bring their own laptops and use their own software, it allows courses to be held almost anywhere, freed from the restraint of needing a computer room with all the required software. Roaming courses, offered in a variety of geographic locations, allow broader participation when there are limited travel funds available to attend the course. In addition, targeting different locations helps to avoid saturating the market for a satellite course in one area and allows instructors to localize the content of the course to address different regional needs.

4.5 Learning goes both ways

These courses provide a valuable opportunity for course instructors to understand both the types of satellite products operational end-users need, and their specific applications. This information helps instructors to develop more effective course materials and improve on the data access tools used in the course. For example, both the EDC and the rerddapXtracto R package were developed specifically to address user needs, including feedback from course participants and

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funding for some of the development came to in order to support the course. Conducting the course also helps to identify gaps in the existing suite of satellite products. Communicating these data needs back to NOAA's data providers allows them to better address user needs. In addition, because participants are proficient in the software packages used for the course, they often develop creative scripts to accomplish operational tasks that they are willing to share with the instructors and other course participant which expands the tool set offered to future participants.

4.6 Room for Improvement

The NOAA Satellite Course was developed by satellite oceanographers with limited professional training in education techniques or theory. In the future, we intend to incorporate input from professional educators to improve the course lecture materials. In addition, an effective evaluation process is important for improving the course and assessing course effectiveness. Our evaluations process has focused on asking about satellite data usage, which has provided valuable insight for improving the course. However, additional insights could have been gained by ask participants to assess their pre and post confidence levels on specific aspects covered in a training [38]. For our future training courses, we plan on incorporating this improved survey design, which would specifically ask about each of the different components of the course: knowledge about satellite datasets, experience with accessing data, background using analysis software (e.g. R, ArcGIS).

5. Summary

The NOAA Satellite Course is a short class, only three days long, that has been offered for over a decade with minimal resources. Since 2006 over 350 scientists and marine resource managers have taken this course, with about 75% of them working for NOAA/NMFS or NOAA/NOS in an operational capacity. Students are shown how to access gridded (level-3 and level-4) satellite data served on an ERDDAP server [15] which provides the ability to download data in over 40 different graphical and data formats. Students are given tools to facilitate their access to satellite data from ERDDAP from either ArcGIS [11] or R [13], which lead to greater uptake in satellite usage, as they are not required to learn a new software program. Materials developed for the course demonstrating the use of ERDDAP and the rerddapXtracto package for R [19] are now available on the WCN website [17,21] and on GitHub [21][18]. Results from post-course surveys for all participants (2006-2019) were analyzed which confirmed that there was an increase in satellite usage by course participants. The overall satellite usage (some + moderate + extensive) of respondents increased from 61% prior to the course to 86% after taking the course (Figure 6) .

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References

1. National Research Council. *From Research to Operations in Weather Satellites and Numerical Weather Prediction: Crossing the Valley of Death*; National Academies Press: Washington, DC, 2000; p 182.

Peer-reviewed version available at *ISPRS Int. J. Geo-Inf.* **2019**, *8*, 354; doi:10.3390/ijgi8080354

2. Hill, J. *Weather from Above*; Smithsonian: Washington, DC, 1991.
3. Wilson, C. The rocky road from research to operations for satellite ocean color data in fisheries management. *ICES Journal of Marine Science* **2011**, *68*, doi:10.1093/icesjms/fsq1168.
4. Miloslavich, P.; Seeyave, S.; Muller-Karger, F.; Bax, N.; Ali, E.; Delgado, C.; Evers-King, H.; Loveday, B.; Lutz, V.; Newton, J., et al. Challenges for global ocean observation: the need for increased human capacity. *Journal of Operational Oceanography* **2018**, 10.1080/1755876x.2018.1526463, 1-20, doi:10.1080/1755876x.2018.1526463.
5. IOCCG. *Why Ocean Colour? The Societal Benefits of Ocean-Colour Technology*; Platt, T., Hoepffner, N., Stuart, V., Brown, C.W., Eds.; Reports of the International Ocean Colour Coordinating Group, No. 7: Dartmouth, Canada, 2008; pp. 141.
6. Group for High Resolution Sea Surface Temperature (GHRSST). Available online: https://www.ghrsst.org (accessed on March 25, 2019).
7. Signell, R.P.; Carniel, S.; Chiggiato, J.; Janekovic, I.; Pullen, J.; Sherwood, C.R. Collaboration tools and techniques for large model datasets. *J. Mar. Sys.* **2008**, *69*, 154-161, doi:10.1016/j.jmarsys.2007.02.013.
8. NOAA CoastWatch Program. NOAA CoastWatch/OceanWatch. Available online: https://coastwatch.noaa.gov/cw/about-coastwatch.html (accessed on June 24, 2019).
9. NOAA Satellite Course, CoastWatch West Coast Regional Node. Available online: https://coastwatch.pfeg.noaa.gov/courses/satellite_course.html (accessed on March 25, 2019).
10. Evers-King, H. (Plymouth Marine Laboratory, Plymouth, UK), personal communication, 2019.
11. ESRI *ArcGIS Desktop: Release 10*, Environmental Systems Research Institute: Redlands, CA, https://www.esri.com, 2019.
12. The MathWorks Inc. *MATLAB and Statistics Toolbox*, Natick, Massachusetts, United States, https://www.mathworks.com, 2019.
13. R Core Team *R: A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing: Vienna, Austria, https://www.R-project.org, 2019.
14. Python Core Team *Python: A dynamic, open source programming language* Python Software Foundation, https://www.python.org/: 2019.
15. Simons, R.A. ERDDAP, NOAA Southwest Fisheries Scinece Center Monterey, CA: NOAA/NMFS/SWFSC/ERD. Available online: http://coastwatch.pfeg.noaa.gov/erddap (accessed on Feb 21, 2019).
16. Vaqqas, M. RESTful Web Services: A Tutorial. Available online: http://www.drdobbs.com/web-development/restful-web-services-a-tutorial/240169069 (accessed on April 24, 2019).
17. Wilson, C.; Robinson, D. An introduction to using ERDDAP. Available online: https://coastwatch.pfeg.noaa.gov/projects/erddap/ (accessed on June 25, 2019).
18. Wilson, C.; Robinson, D. An introduction to using ERDDAP. Available online: https://github.com/dhr-sc/erddap_basics (accessed on June 25, 2019).
19. Mendelssohn, R. *rerddapXtracto: Extracts Environmental Data from 'ERDDAP' Web Services. R package version 0.3.5. https://CRAN.R-project.org/package=rerddapXtracto*, 2019.
20. Wilson, C.; Robinson, D. R exercises for the NOAA satellite course. Available online: https://coastwatch.pfeg.noaa.gov/projects/r/ (accessed on June 25, 2019).
21. Wilson, C.; Robinson, D. R exercises for the NOAA satellite course. Available online: https://github.com/dhr-sc/text_book (accessed on June 25, 2019).
22. RPS Group. Environmental Data Connecter (EDC), version 1.3.5. Available online: https://www.pfeg.noaa.gov/products/EDC/ (accessed on March 25, 2019).

Peer-reviewed version available at *ISPRS Int. J. Geo-Inf.* **2019**, *8*, 354; doi:10.3390/ijgi8080354

23. Sathyendranath, S.; Grant, M.; Brewin, R.J.W.; Brockmann, C.; Brotas, V.; Chuprin, A.; Doerffer, R.; Dowell, M.; Farman, A.; Groom, S., et al. ESA Ocean Colour Climate Change Initiative (Ocean_Colour_cci). 3.1 ed.; Analysis, C.f.E.D., Ed. 2018; http://dx.doi.org/10.5285/9c334fbe6d424a708cf3c4cf0c6a53f5.
24. Savery, J.R.; Duffy, T.M. *Problem Based Learning: An instructional model and its constructivist framework*; CRLT Technical Report No. 16-01; Center for Research on Learning and Technology, Indiana University: 2001; p 17.
25. Richards, R.A.; O'Reilly, J.E.; Hyde, K.J.W. Use of satellite data to identify critical periods for early life survival of northern shrimp in the Gulf of Maine. *Fish. Oceanogr.* **2016**, *25*, 306-319, doi:10.1111/fog.12153.
26. Bjorkstedt, E.P.; García-Reyes, M.; Losekoot, M.; Sydeman, W.; Largier, J.; Tissot, B. *Oceanographic context for baseline characterization and future evaluation of MPAs along California's North Coast.* ; 2017; p 89.
27. Quinlan, J.; Keller, C.; Hanisko, D.; McManus, M.; Kunzleman, J.; Foley, D.; Trinanes, J.; Christman, M. Deep Water Horizon Technical Report: Examining the Scope of Spill Impacts to Early Stage Fishes in the US Economic Exclusion Zone. **2015**, 10.13140/RG.2.1.3328.3288, doi:10.13140/RG.2.1.3328.3288.
28. Central Valley Temperature Mapping and Prediction. Available online: https://oceanview.pfeg.noaa.gov/CVTEMP/ (accessed on March 25, 2019).
29. Danner, E.M.; Melton, F.; Pike, A.; Hashimoto, H.; Michaelis, A.; Rajagopalan, B.; Caldwell, J. River Temperature Forecasting: a Coupled-Modeling Framework for Management of River Habitat. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* **2012**, *5*.
30. Runcie, R.M.; Muhling, B.; Hazen, E.L.; Bograd, S.J.; Garfield, T.; DiNardo, G. Environmental associations of Pacific bluefin tuna (*Thunnus orientalis*) catch in the California Current system. *Fish. Oceanogr.* **2018**, *00*, 1-17, doi:10.1111/fog.12418.
31. Becker, E.A.; Forney, K.A.; Foley, D.G.; Smith, R.C.; Moore, T.J.; Barlow, J. Predicting seasonal density patterns of California cetaceans based on habitat models. *Endangered Species Research* **2014**, *23*, 1-22, doi:10.3354/esr00548.
32. Becker, E.A.; Foley, D.G.; Forney, K.A.; Barlow, J.; Redfern, J.V.; Gentemann, C.L. Forecasting cetacean abundance patterns to enhance management decisions. *Endangered Species Research* **2012**, *16*, 97-112, doi:10.3354/esr00390.
33. Wilson, C.; Sastre, A.V.; Hoffmeyer, M.; Rowntree, V.J.; Fire, S.E.; Santinelli, N.H.; Ovejero, S.D.; D'Agostino, V.; Marón, C.F.; Doucette, G.J., et al. Southern right whale (Eubalaena australis) calf mortality at Península Valdés, Argentina: Are harmful algal blooms to blame? *Mar Mammal Sci* **2016**, *32*, 423-451, doi:10.1111/mms.12263.
34. Shotwell, S.K.; Hanselman, D.H.; Belkin, I.M. Toward biophysical synergy: investigating advection along the Polar Front to identify factors influencing Alaska sablefish recruitment. *Deep-Sea Res., II* **2014**, *107*, 40-53, doi:http://dx.doi.org/10.1016/j.dsr2.2012.08.024.
35. Shotwell, S.K.; Fissel, B.; Hanselman, D.H. Ecosystem-Socioeconomic Profile of the Sablefish stock in Alaska In Assessment of the Sablefish stock in Alaska, Hanselman, D.H., Rodgveller, C.J., Lunsford, C.R., Fenske, K.H. In *Stock assessment and fishery evaluation report for the groundfish resources of the Gulf of Alaska and Bering Sea Aleutian Islands*, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501, 2017.
36. Shotwell, S.K. (AFSC Auke Bay Laboratory, Juneau, AK), personal communication, 2019.
37. MUR SST. Available online: https://mur.jpl.nasa.gov (accessed on Feb 21, 2019).

Peer-reviewed version available at *ISPRS Int. J. Geo-Inf.* **2019**, *8*, 354; doi:10.3390/ijgi8080354

38. Sufi, S.; Nenadic, A.; Silva, R.; Duckles, B.; Simera, I.; de Beyer, J.A.; Struthers, C.; Nurmikko-Fuller, T.; Bellis, L.; Miah, W., et al. Ten simple rules for measuring the impact of workshops. *PLoS Comput Biol* **2018**, *14*, e1006191, doi:10.1371/journal.pcbi.1006191.