Building Capacity in Ocean Remote Sensing with the NOAA CoastWatch Satellite Course

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***Abstract*—Identifying and using satellite data products appropriate for a given application can be challenging for users outside of the satellite community. As a result, ocean satellite data are underutilized in both research and operational oceanography. The goal of the NOAA CoastWatch satellite course is to build capacity in using satellite data within NOAA and beyond by providing background knowledge, tools, tutorials and hands-on help on individual projects to course participants. In 2020, the course was transitioned to the online environment, allowing a wider range of users outside of NOAA and the USA to attend. The course, associated resources and impacts are described, as well as recent changes and future plans. An example Python script is also provided to illustrate a typical case study and solution leveraging the ERDDAP data server to simplify data access.**

Keywords—satellite data, satellite oceanography, training, capacity building, CoastWatch, ERDDAP

I. Introduction

CoastWatch (https://coastwatch.noaa.gov) is a program of the National Oceanic and Atmospheric Administration (NOAA) that provides environmental satellite products to help understand, manage and protect ocean and coastal resources. The program was established in 1987 in response to harmful algal bloom events that occurred in U.S. coastal waters [4]. The severe impact of these events on marine resources prompted federal and state officials to explore additional data sources for monitoring coastal waters, in particular sea surface temperature (SST) data acquired from satellite sensors. At that time the latency between acquiring raw sensor data and releasing the processed SST data product was too long to adequately monitor rapidly developing algal blooms. CoastWatch was created to meet that operational user need for near real-time satellite data, and the program has continued to evolve during the past three decades to meet the changing needs of operational users.

Today CoastWatch distributes a suite of environmental satellite data products (e.g. sea surface temperature, ocean color, altimetry, sea surface salinity, ocean surface winds) as both near real-time and as high-quality retrospective datasets. Its organizational structure includes a central office collocated with the NOAA's National Environmental Satellite, Data and Information Service (NESDIS)

(Fig. 1)

As part of its mission, CoastWatch works to increase the use of satellite data products to ensure that these valuable resources are not underutilized. A step in achieving this goal is to build capacity among user groups who are less familiar with using satellite observations, but who could benefit from including satellite observations in their research and management activities. In order to build capacity, CoastWatch has developed an ocean satellite data training course with the objective of providing participants with the knowledge and tools they require to incorporate satellite data products into their ocean applications [2]. The course was developed and initially offered in 2006 by the West Coast Node of the CoastWatch program which is collocated with the Southwest Fisheries Science Center in the NOAA National Marine Fisheries Service (NMFS). It has been expanded since that time, and is now offered by all of the CoastWatch nodes in multiple locations throughout the U.S.

To date, 519 people have attended the course. Of these, 64% were NOAA staff, and 25% were affiliated with universities. Within NOAA, staff from all NOAA line offices have participated in the course, with 68% of NOAA participants coming from NMFS.

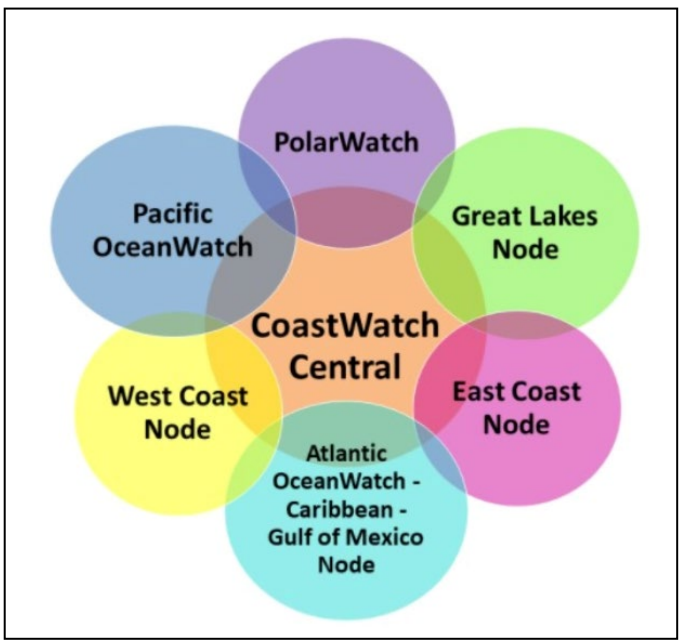

Fig. 1. The structure of the NOAA CoastWatch program includes a central operations office and a distribution of regional nodes across the United States.

II. Course Goals and Audience

Satellite data provide valuable observations for operational and research applications, by providing high spatial coverage of consistent observations. Decades of satellite observations are now available for the main ocean parameters of interest to oceanographers, marine biologists and resource managers. However, most staff from NOAA line offices are outside of the satellite community and, therefore, are not familiar with using satellite data. The abundance of ocean satellite data products and data access protocols available from NOAA and partner institutions can be overwhelming and make it challenging for novice and even experienced users to identify and use the most appropriate product for their application. These challenges can prevent users from integrating satellite data into their applications, despite the benefits [3].

The CoastWatch satellite course helps to bridge that gap in knowledge and to build capacity by specifically tailoring training courses to the needs of course participants. The courses are offered free of charge and focus primarily on increasing capacity within NOAA. However, interested parties from outside of NOAA are encouraged to attend as resources allow.

III. Course Structure

Course materials are delivered as a series of lectures and tutorials. The lectures are designed to give students the background to select the best satellite products for their projects, but do not contain detailed information about how satellite products are made (e.g., atmospheric corrections, radiative transfer models). The lecture materials cover the basics of remote sensing, sea surface temperature, ocean color, altimetry, sea surface salinity, ocean surface winds, applications of satellite data, and how to choose a data product.

The tutorials introduce the tools and techniques used in the course to help bring satellite data into R, Python, MATLAB and ArcGIS analysis software. The tutorials leverage the features of the ERDDAP data server [1, 5], which provides a simple, consistent way to temporally and spatially subset datasets and download data in multiple formats. Students learn how to access and download data, make maps and time-series, match animal and vessel tracks with satellite data, create virtual buoys, and extract data from within an irregular boundary. In addition, a set of tutorials has been developed specifically for the polar regions to address reprojecting data into local map projections and obtaining areal sea ice coverage.

Historically, the course has been offered in person over three to four days. Beginning in 2020, following stay-at-home orders, all training materials were redesigned for online delivery. A "flipped classroom" approach [6] was chosen for the online format, where students learn new material on their own and at their own pace using online course materials and work on problem-solving during live class time. The lectures are available as pre-recorded presentations, and all tutorials and example scripts are available on GitBook and GitHub. Interactive learning takes place via instructor-facilitated asynchronous forum discussions and live office hours for group discussions and individual assistance.

IV. Tailoring of Classes

Important to the success of the course is properly targeting course content to the needs of participants and to their familiarity with satellite data. Prior to the course start date, students complete an online questionnaire that includes a brief description of the project they are interested in working on during the course, plus their preferred analytical software programs and satellite products of interest. Instructors use this information to adjust the course content to match the level of experience and the interests of course participants.

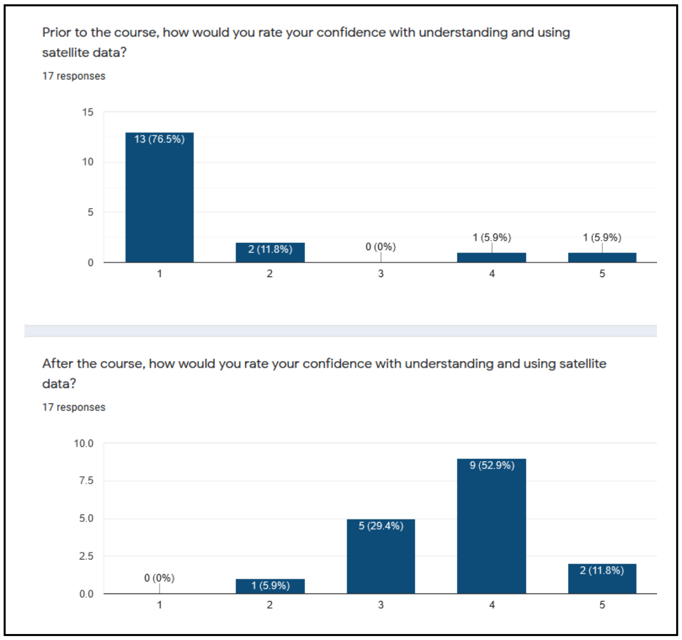

Fig. 2. Satellite Data Familiarity of Course Participants. Participants' self-evaluation of their familiarity with satellite data before (top) and after (bottom) taking the 2020 satellite course.

Using a modular approach, topics can be included or excluded depending on the desired length of the class. The length of recent virtual classes has ranged from a half-day to a full week. Tutorials and example scripts can be adjusted to match the software preferences of participants. Additionally, based on topics of interest identified in the pre-course survey, guest lectures have been organized to highlight topics or products that may not yet be covered by existing materials and to connect participants to key data producers and subject matter experts across NOAA line offices.

Quantitative metrics data are collected to gauge the effectiveness of each course and to modify future courses to be more effective. Participants are asked in pre- and post-course surveys about their familiarity with satellite data, their comfort level in using satellite data in work projects, and the likelihood that they would use satellite data in future projects. The results indicate participants feel more confident in their knowledge and understanding of satellite data and are more likely to integrate satellite products in their research after attending the course (Fig. 2 and 3).

V. Student Projects

A hands-on workshop is also included in the course, in which participants apply the skills and tools they have learned to a work-related project. Students are encouraged to come to the class with a project of their own choosing. Working on a personal project of interest ensures participants take ownership of the learning process and reinforces specific components learned in the course that will enable them to advance their research. Students edit and troubleshoot example scripts during the class with the help of instructors and leave the class with ready-to-use workflows for their specific applications.

The course concludes with "lightning talks", where each participant briefly presents their project and the progress they have made during the course. The lightning talks session is often attended by the CoastWatch program manager and other CoastWatch staff as the presentations often help identify data gaps and user requests, and highlight how datasets are used in practice.

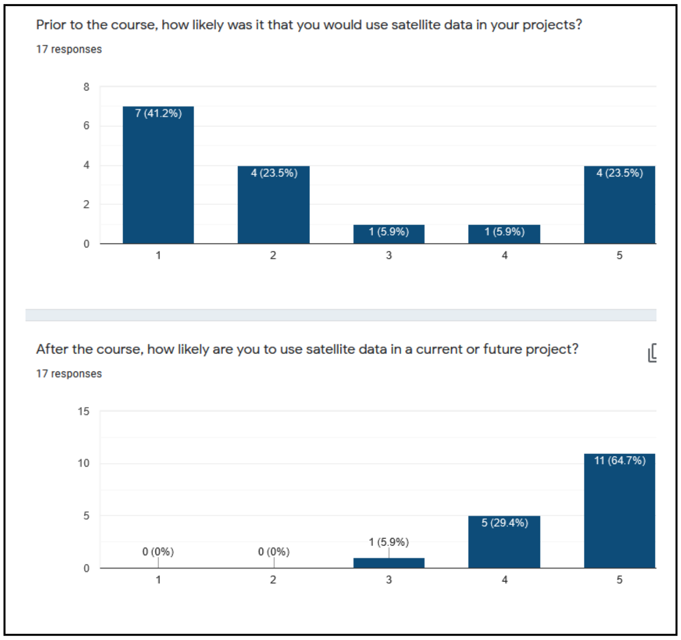

Fig. 3. Satellite Data Usage by Course Participants. Participants' self-evaluation of their satellite data usage before (top) and after (bottom) taking the 2020 satellite course.

This process facilitates a user engagement feedback loop where users can communicate their needs and requirements to CoastWatch staff who are then able to relay those to NESDIS science teams. For instance, NMFS staff who participated in the course identified their need for long time-series of ecological observations. NESDIS scientists are now working to develop long-term sensor-agnostic super-collated or blended SST products to address this need.

VI. New Audiences and Modules

One benefit of the virtual format is that researchers outside of NOAA, both domestic and international, are able to participate in the classes. For instance, one recent course included international participants from several research institutions in Bangladesh, Uruguay, Antigua and Barbuda, and Australia. As interest builds in new audiences, CoastWatch staff are working to design additional resources. A module on water quality is in the works to address the needs of users involved in aquaculture. Another module about harmful algal blooms will also be developed in the near future.

VII. Additional Resources

All online resources can be accessed freely at the following links: https://coastwatch.gitbook.io/satellite-course/
https://dale-robinson.gitbook.io/coastwatch-satellite-course-may-2021/tutorials/python-tutorial

Inquiries, questions or data requests can be addressed to:
Coastwatch.info@noaa.gov

VIII. Example Script using Python and ERDDAP

The following Python example demonstrates how to leverage the ERDDAP data services to generate satellite data match-ups to in-situ observations locations. In this example, a value of SST is extracted for each daily location along a turtle track.

```
# Anaconda 3, with Python 3.6.4
# Load the required Python packages
import pandas as pd
import numpy as np
import urllib.request
import xarray as xr
import netCDF4 as nc
import time
from matplotlib import pyplot as plt
from matplotlib.colors import LinearSegmentedColormap,BoundaryNorm,Normalize
from mpl_toolkits.basemap import Basemap
from datetime import date,datetime
np.warnings.filterwarnings('ignore')

# Read turtle track data from a CSV file:
# (the CSV file can be downloaded here: https://oceanwatch.pifsc.noaa.gov/files/25317_05.dat)
df = pd.read_csv('25317_05.dat')


# Extract SST data from ERDDAP
# ERDDAP base URL:
url = ["https:", "",
       "oceanwatch.pifsc.noaa.gov",
       "erddap", "griddap",
       "CRW_sst_v1_0.csv?analysed_sst"]
SST = '/'.join(url)

# load longitude and latitude
lon=df.mean_lon
lat=df.mean_lat

# Convert to ERDDAP date: 2010-12-15
dates=[]
for i in range(len(df.month)):
    dt = date(df.year[i],
         df.month[i],
```

```
         df.day[i]).strftime(
                             '%Y-%m-%d'
                             )
    dates.append(dt)

# Extract a value of SST for each date/location
# by building an ERDDAP URL with
# dataset, date, lon, lat
col_names = [
             "date",
             "matched_lat",
             "matched_lon",
             "matched_sst"
             ]
tot = pd.DataFrame(columns=col_names)

# For loop for building the URL
for i in range(len(dates)):
    print(i,len(dates))
    url_parts = [
                 SST, "[(",
                 str(dates[i]), "):1:(",
                  str(dates[i]), ")][(",
                    str(lat[i]), "):1:(",
                  str(lat[i]), ")][(",
                  str(lon[i]), "):1:(",
                  str(lon[i]), ")]"
                  ]
    url = ''.join(url_parts)
    new = pd.read_csv(url,skiprows=1)
    new.columns = col_names
    tot = tot.append(new,
             ignore_index=True)

# Plotting on a map:
# Set up color scale
jet = ["blue", "#007FFF", "cyan",
       "#7FFF7F", "yellow", "#FF7F00",
       "red", "#7F0000"
       ]

levs = np.arange(14, 26.5, 0.05)
```

```
cm = LinearSegmentedColormap.from_list('my_jet', jet, N=len(levs))

# Set up bounding box zoom and map bounds
bbox = [120 ,255, 15, 55]
plt.figure(figsize=(10,10))

# Define the projection, scale,
# map corners, and resolution
m = Basemap(projection='merc',
            llcrnrlat=bbox[2],
            urcrnrlat=bbox[3],
            llcrnrlon=bbox[0],
            urcrnrlon=bbox[1],
            lat_ts=10,resolution='l')

# Draw coastlines
# Fill continents and water with color
m.drawcoastlines()
m.fillcontinents(color='gray')
m.drawmeridians(np.arange(bbox[0],
                bbox[1], 10),
                labels=[0,0,0,1]
                )


m.drawparallels(np.arange(bbox[2]+5,
                bbox[3], 10),
                labels=[1,0,0,0]
                )

# build and plot coordinates onto map
x,y = m(list(df.mean_lon),list(df.mean_lat))
m.scatter(x, y, c=tot.matched_sst, cmap=cm)

# Special markers to show start and end locations
m.plot(x[0], y[0], marker='v', color='r')
m.plot(x[-1], y[-1], marker='^', color='g')

# format color scale:
levs2 = np.arange(14,26.5,1)
cbar = m.colorbar(fraction=0.022,
                  ticks=levs2,
```

```
                    label='SST (ºC)'
                    )

plt.title("Turtle #25317")
plt.show()
```

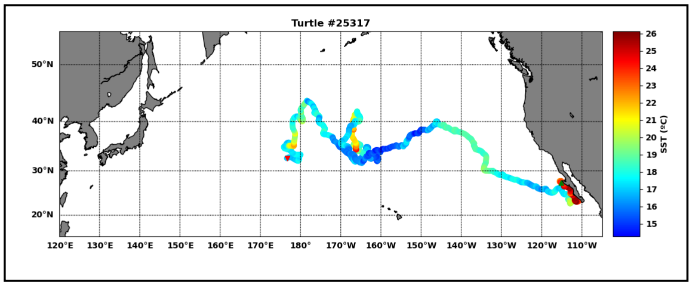

Fig. 4. Turtle track color-coded by SST value.

This and other Python and R scripts are available on the CoastWatch course Gitbook pages:
https://coastwatch.gitbook.io/satellite-course/tutorials/python-tutorial
https://coastwatch.gitbook.io/satellite-course/tutorials/r-tutorial

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