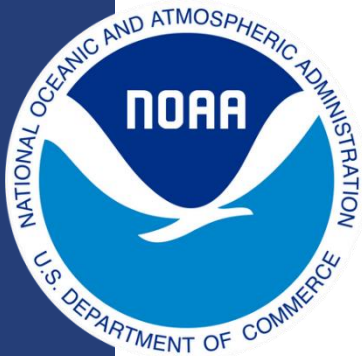




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Report for Dedicated JPSS VIIRS Ocean Color Calibration/Validation Cruise: Florida Coastal Oceans in May-June 2024

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US DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service
Center for Satellite Applications and Research
College Park, MD
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Preface

The Ocean Color Science Team at the NOAA Center for Satellite Applications and Research (STAR) is dedicated to the “end-to-end” production of high-quality, fit-for-purpose, remotely sensed ocean color products that are required and expected by all NOAA line offices as well as by external users, including state-level and regional users. The team has coordinated the ocean color calibration and validation (Cal/Val) field campaign since 2014 with an annual dedicated cruise over open oceans and coastal regions. The overarching goal of the Cal/Val campaign is to collect in situ ocean radiometric and bio-optical data that can be utilized for the assessment of satellite data uncertainty and calibration of the satellite data to achieve high data quality from satellite-derived ocean color products. The Cal/Val field campaigns have been receiving support from the Joint Polar Satellite System (JPSS), the Office of Marine and Aviation Operations (OMAO), and the STAR management. To date, nine cruises have been conducted, which cover the U.S. east, west, and south coastal waters and the Hawaiian waters. The in situ Cal/Val efforts are proven essential for maintaining the integrity of NOAA’s satellite ocean color data products, which undergo calibration changes in orbit, and for extending the applicability of synoptic water quality data products.

The 2024 cruise marked the ninth field Cal/Val expedition (the first one was in 2014). The specific objective was to take in situ ocean color measurements from ship-borne platforms in the southeast coastal waters of the United States. The matchup data, together with previous data collections, are used to validate the Visible Infrared Imaging Radiometer Suite (VIIRS) observations from the Suomi National Polar-orbiting Partnership (SNPP), NOAA-20, and NOAA-21 satellites, which are the primary sources for NOAA operational remotely sensed ocean color data products. In addition, in situ ocean property data can also be used for evaluation and validation of ocean color products derived from other satellites, including the Ocean and Land Colour Instruments (OLCI) onboard the Sentinel-3A and Sentinel-3B satellites, and the Second-Generation Global Imager (SGLI) on the Global Change Observation Mission-Climate (GCOM-C) satellite. Following prior successful practices, we invited external collaborators, who are experts in satellite ocean color remote sensing, to participate in the field campaign. During the cruise, the participants were able to take measurements of a range of ocean optical and bio-optical properties simultaneously with the NOAA team. In this report, we summarize the field campaign and the accomplishments of each participating team, with a focus on the data collected during the cruise. All in situ data will be assembled by the NOAA Ocean Color Science Team for an in-depth intercomparison and post-analysis.

Through the NOAA mission of science, service, and stewardship, we strive to provide ocean satellite data products that improve our understanding of the global ocean and inland water optical, biological, and biogeochemical properties, which support research and applications to benefit society.

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Abstract

The ninth VIIRS ocean color Cal/Val field campaign was carried out in May-June 2024 aboard the NOAA Ship *Nancy Foster*. The cruise visited 38 stations, while traversing about 2,000 km around the Florida coast. Multiple optical and bio-optical instruments were successfully deployed from the ship to measure oceanic and atmospheric quantities essential for the calibration and validation of VIIRS satellites. Data on various apparent optical properties (AOPs) and inherent optical properties (IOPs) were retrieved. Seawater samples were also collected for water constituent analysis, including phytoplankton biomass and phytoplankton types. Collectively, this field campaign generated the largest number of shipborne measurements than any previous cruise of this project. This document reports the field efforts and achievements by individual participating teams. The preliminary results suggest that the cruise goal has been achieved. Data synthesis and comparison are being conducted by the STAR Ocean Color Science Team.

1. Introduction

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Satellite ocean color observations are essential for environmental monitoring and prediction. The NOAA satellite division currently operates three polar-orbiting VIIRS ocean color instruments. The first one is operational aboard the SNPP satellite (2012–present) (Goldberg et al., 2013). It crosses the equator at 1:30 pm local solar time (daytime ascending node). The NOAA-20 (2017–present) and NOAA-21 (2022–present) satellites carry the second and third VIIRS instruments, respectively. The SNPP, NOAA-20, and NOAA-21 fly in the same nominal orbital plane, separated by a time difference of approximately 25 minutes from one another. The JPSS VIIRS constellation provides three visits each day with close-to-seamless global coverage.

The radiance emerging beneath the water surface, a.k.a. water-leaving radiance ($L_w(\lambda)$, $\text{mW cm}^{-2} \mu\text{m}^{-1} \text{sr}^{-1}$), carries fundamental information on water constituents and is the key spectral data expected from satellite observations. Satellites directly measure the total radiance ($L_t(\lambda)$) exiting both oceans and atmosphere. A procedure known as atmospheric correction (AC) is needed to estimate path radiances contributed by different sources, such as aerosols, gases, and water surface reflection, and subsequently remove them from the total (Gordon and Wang, 1994; International Ocean-Color Coordinating Group, 2010; Wang, 2007). Inevitably, the imperfect AC model introduces uncertainties or errors, which will propagate to the desired water-leaving radiance data. In particular, $L_w(\lambda)$ only accounts for a small fraction (typically a few percent in blue bands for open oceans) of the total radiance sensed by satellite sensors, with the majority being atmospheric in origin. Small errors in atmospheric correction can translate into large errors in the resulting normalized water-leaving radiance ($nL_w(\lambda)$) data products. To account for this problem, vicarious calibration (VC) is required to ensure the satellite $L_w(\lambda)$ data quality (Wang and Jiang, 2025; Wang et al., 2016; Werdell et al., 2007; Zibordi et al., 2025; Zibordi et al., 2015). The VC is usually implemented with coefficients determined from high-quality in situ measurements at the Marine Optical Buoy (MOBY) (Clark et al., 2002; Perez et al., 2022). The AC and VC uncertainties will impact the final estimation of $nL_w(\lambda)$ and remote sensing reflectance ($R_{rs}(\lambda)$, sr^{-1}) data products.

Many water bio-optical properties have been generated from satellite $nL_w(\lambda)$ or $R_{rs}(\lambda)$ observations. As a primary indicator of water quality and ecosystem productivity, chlorophyll-a concentration (Chl-a, mg m^{-3}) can measure the amount of green photosynthetic pigments in phytoplankton. This historical quantity is currently being estimated from a polynomial model of the $R_{rs}(\lambda)$ ratios at blue and green bands for coastal oceans and an exponential model of the ocean color-index (OCI) for clear oceanic waters (Hu et al., 2012; Wang and Son, 2016). The water IOPs, such as particle backscattering coefficient ($b_{bp}(\lambda)$), light absorption coefficient due to phytoplankton ($a_{ph}(\lambda)$), and light absorption coefficient due to colored detrital matter ($a_{dg}(\lambda)$, including colored dissolved organic matter (CDOM) and detritus), are estimated with semi-analytical algorithms (Lee et al., 2002; Shi and Wang, 2019). Several satellite ocean color data products have emerged and been evaluated by the NOAA Ocean Color Science Team. For example, the suspended particulate matter (SPM, mg L^{-1}) quantifies the dry weight of total particulates in global waters (Wei et al., 2021). SPM data are important for water quality monitoring, coastline erosion, and land-ocean

interaction studies. Another recent product describes the global water transparency or Secchi depth (Z_{SD} , m), which is based on the new transparency model development (Lee et al., 2016; Wei et al., 2025). Many other data sets are or can be created from satellite $R_{rs}(\lambda)$ measurements, such as particulate organic carbon (POC), particulate inorganic carbon (PIC), net primary production (NPP), and phytoplankton functional types (PFTs). Such ocean color derivations are not only subjected to uncertainties of the bio-optical models but also impacted by $R_{rs}(\lambda)$ uncertainties or errors.

With the support of the JPSS program and STAR management, the NOAA Ocean Color Science Team has been leading the field campaigns to collect in situ measurements in both the U.S. east and west coastal waters, the northern Gulf of America, and Hawaii. The NOAA OMAO allocated ship time (NF-24-05) for the ninth cruise with the NOAA Ship *Nancy Foster* (Hull number R352) from late May to early June 2024. The overall goal of the NF-24-05 expedition is to provide the best ocean color validation measurements for the ocean color satellites operationally run by NOAA investigators. Another goal is to ascertain validation measurement uncertainties through inter-calibration and intercomparison among Cal/Val team members. A third goal is to optically characterize different oceanic properties to better relate to satellite data and for algorithm development. All of these activities will contribute to the ability of NOAA to provide ocean color satellite data that meets mission requirements.

The NOAA scientists and investigators, teamed up with researchers from U.S. universities and other U.S. federal agencies, conducted a successful voyage traversing the southeast coastal waters. During the campaign, a comprehensive data set of in situ radiometric and bio-optical properties was obtained for satellite data calibration and validation, including measurement intercomparison and algorithm recalibration. In the following sections, we report the planning and execution of the field campaign (Section 2), as well as accomplishments and contributions of each individual team (Section 3 to Section 9). As the shipborne observations expand from in-water to above-water deployments, as well as water sampling and analysis, the reported results are largely preliminary and do not represent the final data analyses. Interested readers should reach the individual teams for more information on data processing, analyses, and findings.

2. Field Campaign and Execution

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2.1. Region of Investigation

The campaign was set to measure in situ ocean color spectra and water bio-optical properties in the West Florida Shelf (WFS), Straits of Florida (SoF), and the South Atlantic Bight (SAB) (Figure 1).

The WFS is a wide carbonate ramp that extends hundreds of kilometers from the Florida coast to the steep continental slopes near the 1000-m isobaths. Much of the shelf is nutrient-poor but maintains high biological productivity and active fisheries, including frequent occurrences of the harmful algal bloom of *Karenia brevis* (Weisberg and Liu, 2025). The ocean circulation generally determines the material properties of both land and ocean origins. The northeasterly trade winds are dominant for most of the year (spring, fall, and winter), favoring upwelling events on the shelf. Southwesterly winds are often prevalent during May-August. In general, the strongest wind stress is observed in fall and winter (Liu and Weisberg, 2012), which can churn up bottom sediments and whiten the water color with elevated water turbidity. As a result, the water-column bio-optical properties on the shelf exhibit strong seasonality (Figure 2). In summer, the coastal waters are often characterized by low Chl-a, deep water transparency or Secchi depth, low SPM, and bluer water classes.

The Straits of Florida is situated between the Florida Keys and Cuba, and between southeastern Florida and the Bahamas. It features the Florida Current from the Gulf Loop Current. As the origin of the northward-bound Gulf Stream, the Florida Current flows swiftly at speeds ranging from 1.0 to 2.5 m s⁻¹ (or 2 to 5 kt). Time series observations indicate remarkably steady current speeds (Volkov and Smith, 2024). Submesoscale and mesoscale eddies frequently occur in this narrow channel, especially during summer, leading to localized bio-optical anomalies (Zhang et al., 2019). Overall, the channel waters are relatively poorer in nutrients, with further elevated water transparency or decreased Chl-a and SPM concentrations. Seasonal variability is common in the primary water bio-optical properties (Figure 2).

Our survey in the SAB was primarily focused on the Atlantic continental shelf and slopes off Florida, Georgia, and South Carolina. The strong Gulf Stream current flows northward along the shelf slope and modulates water exchanges between coastal and open oceans, which are further related to bottom Ekman layers and to upwelling and downwelling associated with cyclonic frontal eddies that move along the stream between wave-like meander crests (Andres et al., 2023; Gomez et al., 2026). Figure 2 summarizes the seasonal variability of several bio-optical properties in this region.

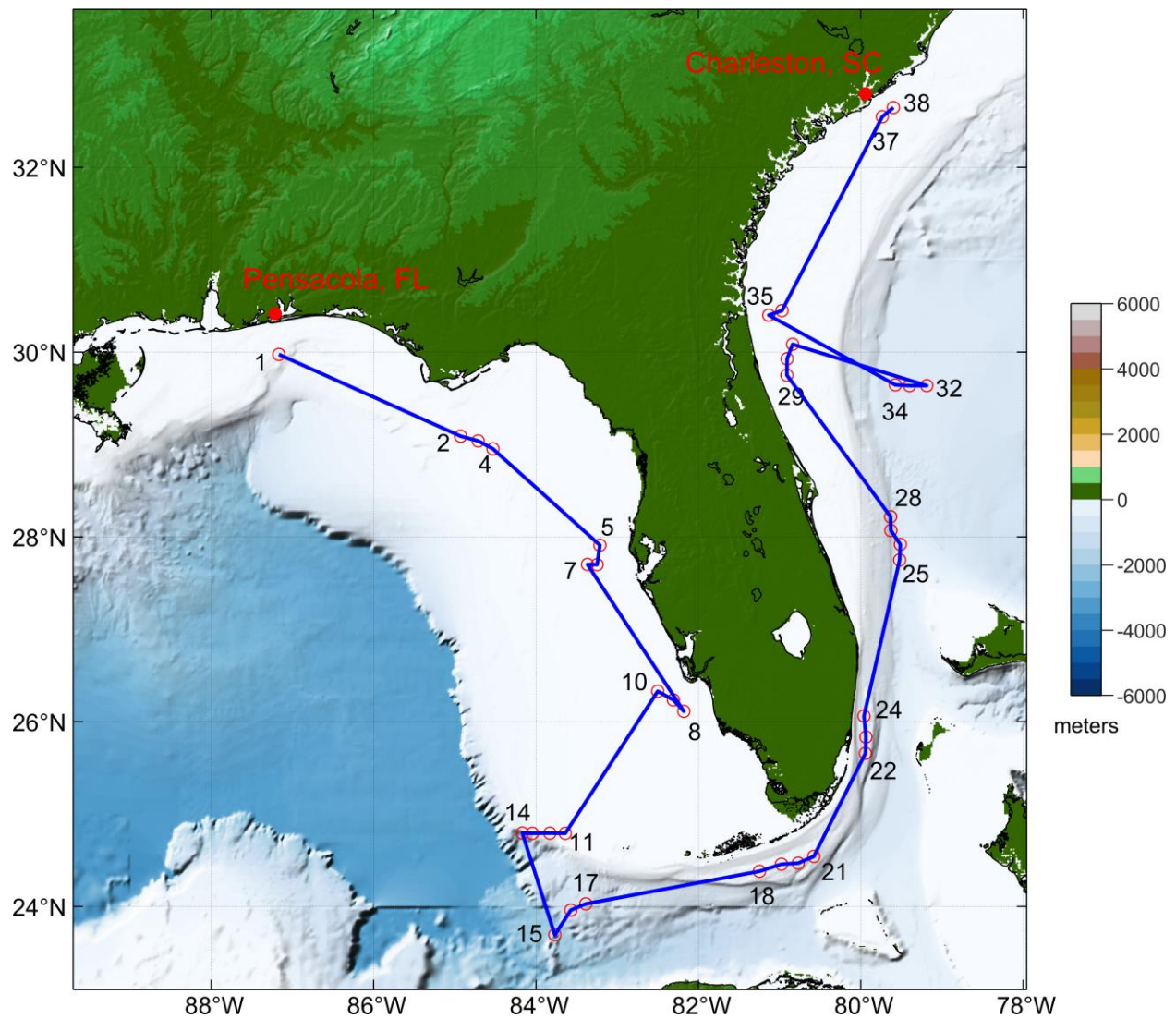


Figure 1. Study area and sampling stations for the VIIRS Cal/Val field campaign (NF-24-05) in May-June 2024. Thirty-eight stations are noted in open circles, while the ship tracks are indicated in solid lines (in blue). The station numbers are labeled selectively to demonstrate the sampling sequences during the cruise.

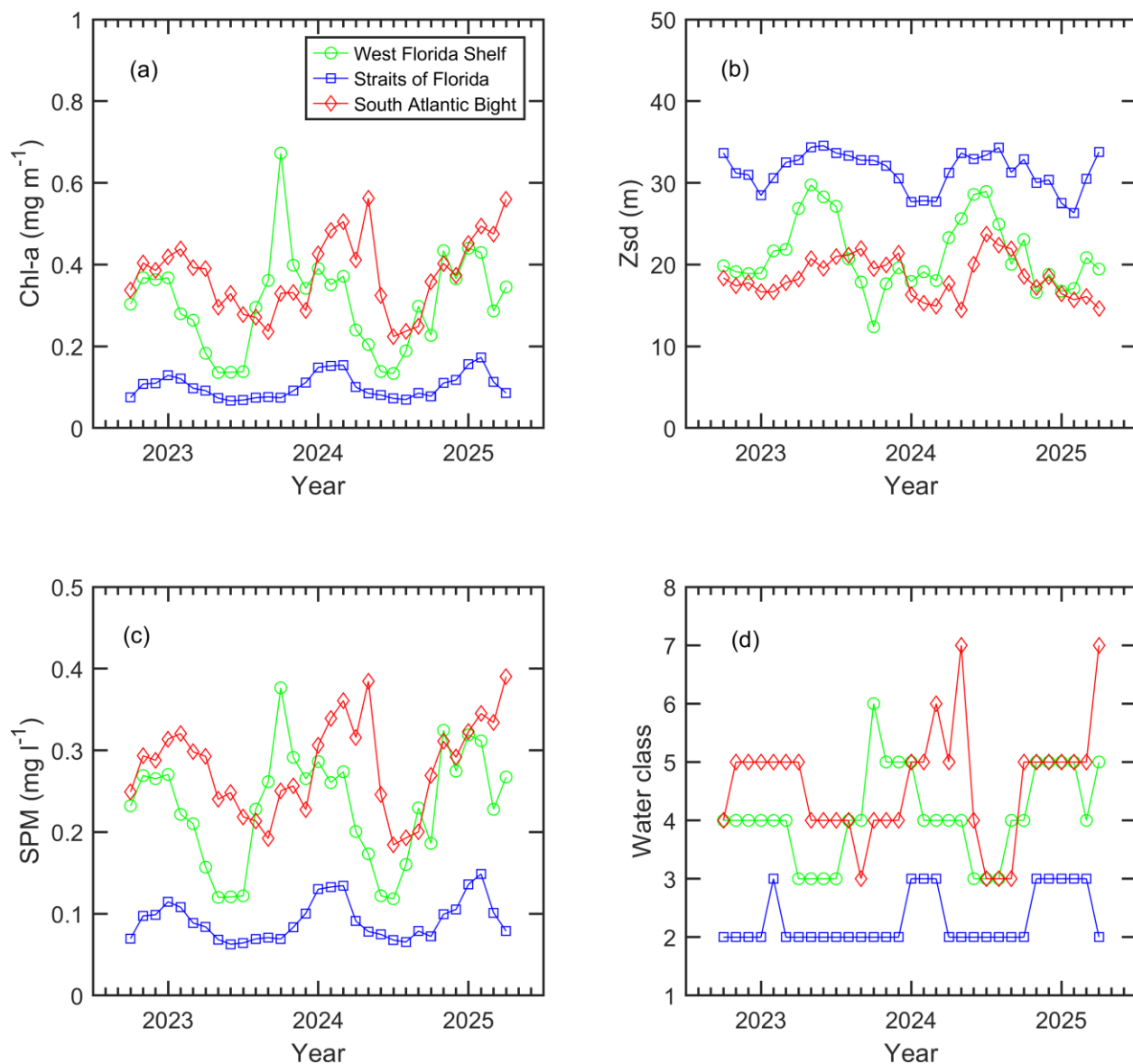


Figure 2. Regional water bio-optical properties estimated from the NOAA satellite data products (VIIRS-SNPP, monthly 2.3-km data).

2.2. Research Vessel

The NOAA Ship *Nancy Foster* was chosen to conduct the VIIRS ocean color Cal/Val campaign for the convenience of operability and capability (Figure 3). *Nancy Foster* is homeported in Charleston, South Carolina. It primarily supports fish habitat and population studies, seafloor mapping surveys, oceanographic studies, and maritime heritage surveys along the U.S. Atlantic and Gulf coasts and the Caribbean Sea. As one of the most operationally diverse platforms in the NOAA fleet, it is equipped with single-beam and multibeam echo sounders for seabed mapping, an echo sounder system for fish stock assessment, and an Acoustic Doppler Current Profiler

(ADCP) for ocean current monitoring. It is capable of measuring water temperature and salinity with a thermosalinograph. This ship features two winches and two deck cranes, along with an aft A-Frame and a port-side A-Frame. Besides, spacious wet and dry laboratories as well as high-performance computers are available for water sample processing, data acquisition, and data storage and analysis. These conditions allow the scientific party to deploy optical and bio-optical instruments and the conductivity, temperature, and depth (CTD) rosette and to conduct seawater flow-through measurements.



Figure 3. NOAA Ship *Nancy Foster* (Hull #R352). Photo credit: NOAA.

2.3. Participants and Tasks

Seven teams took part in the 2024 Cal/Val field campaign. A total of 14 researchers from U.S. federal agencies and universities, including two graduate students, were closely involved in the efforts (see Table 1 and Figure 4).

The NOAA team included three investigators, whose primary goal was to retrieve hyperspectral water AOP and IOP data with water-column profiling instruments (Table 2). In particular, Michael Ondrusek took the duty as the chief scientist and coordinated cruise planning and execution. Eric Stengel and Charles Kovach provided assistance in many cruise-related activities, including logistical support.

Sherwin Ladner was the principal investigator (PI) from the Naval Research Laboratory (NRL) at the Stennis Space Center, Mississippi. The objective of the NRL team was to measure the AOP data with both a floating radiometric package and handheld radiometers simultaneously with the

NOAA and other teams, and also to collect surface water IOP data with a flow-through system following the ship tracks (also see Table 2).

The City College of New York (CCNY) field team (PI: Alex Gilerson) had two researchers, Eder Herrera and Ahmed El-Habashi (Dr. El-Habashi was then officially affiliated with NRL). The team's task was to deploy hyperspectral cameras for surface reflectance and polarization measurements and to record seawater fluorescence for the estimation of chlorophyll-a concentration (Table 2).

Table 1. Participants and tasks in the VIIRS Cal/Val 2024 cruise.

Name (Last, First)	Title	Primary Affiliation	Tasks	Onboard
Ondrusek, Michael	Chief Scientist	NOAA	AOPs and IOPs; Chief Scientist	Yes
Stengel, Eric	Researcher	NOAA	AOPs and IOPs	Yes
Kovach, Charles	Researcher	NOAA	AOPs and IOPs	Yes
Ladner, Sherwin	Researcher	NRL	AOPs and IOPs	Yes
El-Habashi, Ahmed	Researcher	NRL	AOPs	Yes
Herrera, Eder	Researcher	CCNY	AOPs	Yes
Nemeth, Brad	Grad student	USF	Water sampling and AOPs	Yes
Goes, Joaquim [†]	Researcher	LDEO	Fluorescence	No
Bailess, Alex	Grad student	OSU	AOPs	Yes
Chaves, Joaquín E.	Researcher	NASA	AOPs	Yes
Freeman, Scott	Researcher	NASA	AOPs	Yes
Allen, Kelsey	Researcher	NASA	Water sampling	Yes
Smith, Harrison	Researcher	NASA	AOPs and IOPs	Yes
Strohm, Vanessa R. [‡]	Researcher	NASA	Water sampling	No

[†] Set up and tested instruments before ship's departure

[‡] Set up and tested instruments before ship's departure

Brad Nemeth was a graduate student from the College of Marine Science at the University of South Florida (USF) team (PI: Chuanmin Hu). The primary objective was to collect and filter seawater samples for in-lab hyperspectral light absorption estimation. It was also planned for the team to take simultaneous measurements of water AOPs (Table 2).

The Oregon State University (OSU) team (PI: Nick Tufillaro) was represented by Alex Bailess, who was then a graduate student. During the cruise, Bailess was to deploy a profiling radiometer for water AOP observations, together with other teams. He was also tasked with making concurrent surface irradiance measurements for an instrument intercomparison study (Table 2).

The NASA Goddard Space Flight Center (GSFC) team (PI: Antonio Mannino) sent four research scientists (Joaquín Chavez, Scott Freeman, Kelsey Allen, and Harrison Smith) aboard *Nancy*

Foster to conduct optical observations and water sampling, filtering, and analyses. Vanessa Strohm participated in pre-cruise setups and post-cruise data analyses.

The Lamont-Doherty Earth Observatory (LDEO) at Columbia University) team (PI: Joaquim Goes) managed to set up instruments for automatic seawater sampling and analyses throughout the cruise. Charles Kovach and others offered help in running instruments. Goes himself did not stay aboard for the cruise.



Figure 4. Participants of the 2024 campaign posed for a team photo at the end of the cruise (from left to right: Ahmed El-Habashi, Eder Herrera, ship crew, Joaquín Chavez, Michael Ondrusek, Kelsey Allen, Brad Nemeth, Alex Bailess, Harrison Smith, Sherwin Ladner, Scott Freeman, Charles Kovach, Eric Stengel, and ship crew).

Table 2. Participating teams and measured quantities, instruments, and operating methods for the 2024 Cal/Val cruise.

Team	Measurands	Instruments	Operating methods
NOAA	$R_{rs}(\lambda)$, $K_d(\lambda)$	HyperPro-II (2 sets)	Water-column profiling
	AOT	Microtops II sunphotometer	Handheld
	$a(\lambda)$, $c(\lambda)$	Hyperspectral absorption and attenuation meter (AC-S)	Water-column profiling
	$b_b(\lambda)$	Backscattering meter (BB3)	Water-column profiling
	$R_{rs}(\lambda)$	Spectra Vista Corp (SVC) radiometer	Handheld
NRL	$R_{rs}(\lambda)$	1). Analytical Spectral Devices (ASD) radiometer	Handheld
		2). Spectral Evolution (SEI) Radiometer	Handheld
		3). Tethered spectral radiometer buoy (TSRB)	Tethered and floating
	$a(\lambda)$, $c(\lambda)$	Hyperspectral absorption and attenuation meter (AC-S)	Flow-through
CCNY	$b_b(\lambda)$	Backscattering meter (BB3)	Flow-through
	$R_{rs}(\lambda)$	GER 1500 radiometer	Handheld
	Stokes vector, waves	Hyperspectral polarization camera system	Ship-mounted
	AOT	Microtops II sunphotometer	Handheld
USF	Chl-a	Turner Designs Trilogy fluorometer	Rosette water sampling, lab testing
	$a_p(\lambda)$, $a_g(\lambda)$, $a_{ph}(\lambda)$	Perkin-Elmer Lambda 850+ spectrometer	Rosette water sampling, lab testing
	$R_{rs}(\lambda)$	SVC radiometer	Handheld
OSU	$R_{rs}(\lambda)$	HyperPro-II	Water-column profiling
		Open-source spectral sensors	Ship-mounted
LDEO	PFTs	Aquatic Laser Fluorescence Analyzer (ALFA)	Flow-through
	Fluorescence	Fluorescence Induction and Relaxation (FIRE) fluorometer	Flow-through
NASA	$R_{rs}(\lambda)$	Dynamic Above-water Radiance and Irradiance Collector	Ship-mounted
	POC	Elementar Vario Isotope Select	Rosette water sampling, lab testing
	DOC	Shimadzu TOC-L carbon analyzer	Rosette water sampling, lab testing
	SPM	Microbalance	Rosette water sampling, lab testing
	PFTs	Imaging FlowCytobot (IFCB)	Flow-through
		FlowCam	Rosette water sampling, lab testing
	$a_g(\lambda)$	Cary 100 UV-Visible Scanning Spectrophotometer	Rosette water sampling, lab testing

2.4. Cruise Track, Shipborne Observations, and Operation

The cruise track with discrete stations is outlined in Figure 1, where the ship departed on May 20 out of Pensacola, Florida, and arrived in Charleston, South Carolina, on June 1. The stations were spaced to meet our daily travel limitations and still meet our destination timeframe. The plan also had to stipulate that the ship arrives in Jacksonville, Florida, on May 31 for refueling. There is only time for one station the first day out of port for a check-out station and potentially on the morning of the last day, depending on the time the ship needs to dock. Every other typical day, three stations are planned. To achieve an optimal satellite measurement matchup, the clearest skies and calmest seas are sought. For each station, as the ship progressed along the cruise track, three stations were occupied, with the timing centered around the VIIRS overpass, which primarily occurred between 1200 and 1430 hours. At each station, profilers and above-water measurements were conducted simultaneously; a floating instrument was deployed off the stern, and a rosette and IOP package were deployed off the side J-frame. The order of the sampling was arranged so the radiance validation measurements were closest to the satellite overpasses. The first station was occupied from 0900 to 1100 hours, with the Rosette and IOP packages deployed first, then the TSRB floater, then the profilers and above-water measurements. The second station was selected based on optimal sky conditions, with generally at least 10 NM between stations to ensure there is no overlap when matching up in situ data to 5×5 pixel averages in the satellite data. As NOAA ships generally have a maximum cruising speed of 10 kt, the second station was scheduled for 1200 to 1400 hours, depending on satellite overpass time, with J-frame sampling first, then floaters, then profilers and above-water radiometers. The ship would then steam another 10 NM for the third station scheduled between 1500 and 1700 hours. On several days, the first three stations finished early, and a fourth station was added.

Snapshots show the above-water radiometric measurements (Figure 5), in-water radiometric measurements and IOP measurements (Figure 6), and seawater collection, preprocessing, and measurements (Figure 7). More detailed descriptions of the instrument deployments, data processing, and results are given by individual teams (from Section 3 to Section 9).

Above-water measurements

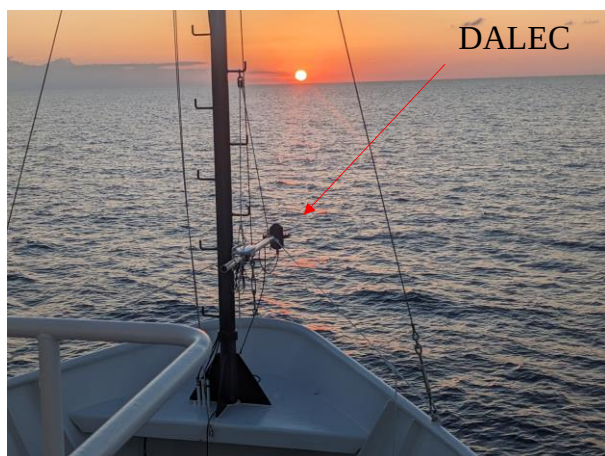
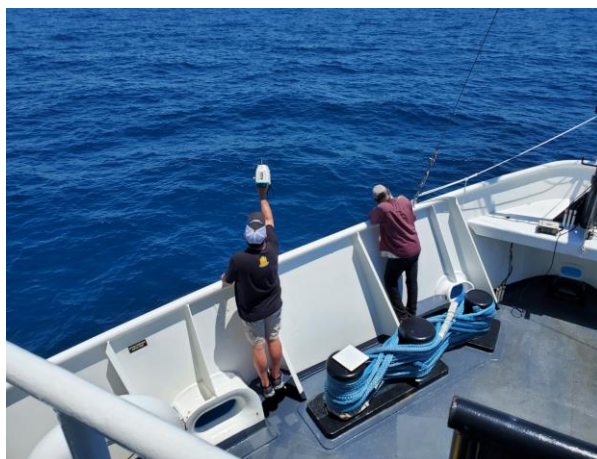


Figure 5. Above-water radiometric measurements conducted from the foredeck and upper deck of *Nancy Foster* (Clockwise from top-left: handheld radiometers measuring total radiance from the water surface; handheld radiometers measuring sky radiance; mounted DALEC radiometric system; mounted hyperspectral polarization camera systems).

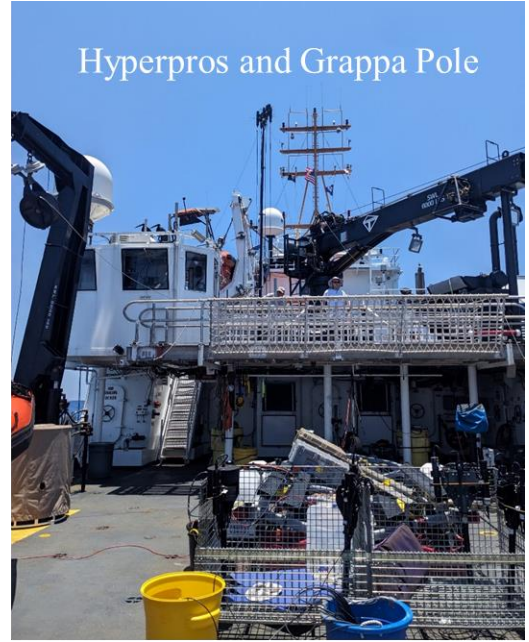


Figure 6. Deployment of in-water optical packages from the afterdeck of *Nancy Foster* (clockwise from top-left: three profiling HyperPro-II radiometers and one TSRB system, HyperPro-II radiometers in foreground and the Grappa pole installed with surface irradiance sensors in the background, a HyperPro and IOP control station, and a scene of simultaneous deployments of multiple HyperPro-II instruments).

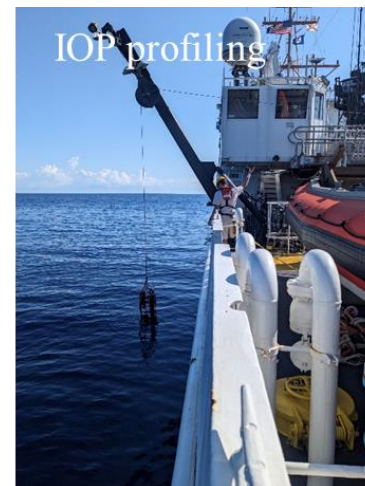


Figure 7. Water sample processing and measurements aboard *Nancy Foster* (from top-left clockwise: USF water filtration station, NASA enclosed filtration station, deployment of IOP package, flow-through phytoplankton measurement station, and flow-through water IOP measurement).

Table 3. Shipborne measurements at 38 discrete stations. The tick marks indicate that the teams were able to deploy their instruments. Refer to individual teams for specific measurements.

Date	Sta.	Lat	Long	NOAA	NRL	CCNY	USF	LDEO	OSU	NASA
5/20/2024	1	29.975	-87.167	✓	✓	✓	✓	✓	✓	✓
	2	29.090	-84.928	✓	✓	✓	✓	✓	✓	✓
5/21/2024	3	29.039	-84.712	✓	✓	✓	✓	✓	✓	✓
	4	28.953	-84.530	✓	✓	✓	✓	✓	✓	✓
	5	27.910	-83.213	✓	✓	✓	✓	✓	✓	✓
5/22/2024	6	27.699	-83.248	✓	✓	✓	✓	✓	✓	✓
	7	27.702	-83.367	✓	✓	✓	✓	✓	✓	✓
	8	26.112	-82.180	✓	✓	✓	✓	✓	✓	✓
5/23/2024	9	26.235	-82.308	✓	✓	✓	✓	✓	✓	✓
	10	26.329	-82.501	✓	✓	✓	✓	✓	✓	✓
	11	24.791	-83.640	✓	✓	✓	✓	✓	✓	✓
5/24/2024	12	24.793	-83.830	✓	✓	✓	✓	✓	✓	✓
	13	24.792	-84.045	✓	✓	✓	✓	✓	✓	✓
	14	24.794	-84.169	✓	✗	✓	✗	✓	✓	
	15	23.692	-83.768	✓	✓	✓	✓	✓	✓	✓
5/25/2024	16	23.960	-83.571	✓	✓	✓	✓	✓	✓	✓
	17	24.028	-83.387	✓	✓	✓	✓	✓	✓	✓

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Date	Sta.	Lat	Long	NOAA	NRL	CCNY	USF	LDEO	OSU	NASA
5/26/2024	18	24.380	-81.248	✓	✓	✓	✓	✓	✓	✓
	19	24.457	-80.977	✓	✓	✓	✓	✓	✓	✓
	20	24.469	-80.771	✓	✓	✓	✓	✓	✓	✓
	21	24.542	-80.578	✓	✗	✓	✗	✓	✓	✓
5/27/2024	22	25.657	-79.943	✓	✓	✓	✓	✓	✓	✓
	23	25.834	-79.936	✓	✓	✓	✓	✓	✓	✓
	24	26.061	-79.961	✓	✓	✓	✓	✓	✓	✓
5/28/2024	25	27.750	-79.522	✓	✓	✓	✓	✓	✓	✓
	26	27.919	-79.513	✓	✓	✓	✓	✓	✓	✓
	27	28.068	-79.630	✓	✓	✓	✓	✓	✓	✓
	28	28.218	-79.633	✓	✗	✓	✗	✓	✓	
5/29/2024	29	29.751	-80.911	✓	✓	✓	✓	✓	✓	✓
	30	29.927	-80.908	✓	✓	✓	✓	✓	✓	✓
	31	30.085	-80.840	✓	✓	✓	✓	✓	✓	✓
5/30/2024	32	29.637	-79.187	✓	✓	✓	✓	✓	✓	✓
	33	29.637	-79.400	✓	✓	✓	✓	✓	✓	✓
	34	29.645	-79.575	✓	✓	✓	✓	✓	✓	✓
5/31/2024	35	30.400	-81.134	✓	✓	✓	✓	✓	✓	✓
	36	30.449	-80.971	✓	✓	✓	✓	✓	✓	
6/1/2024	37	32.548	-79.735	✓	✓	✓	✓	✓	✓	✓
	38	32.647	-79.599	✓	✓	✗	✓	✗	✓	✓

3. Measurements of Hyperspectral AOPs and IOPs Using Profiling Instruments (NOAA Team)

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NOAA scientists were responsible for all aspects of cruise logistics as the chief scientist and primary liaisons between the science party and the NOAA Ship *Nancy Foster* (e.g., Section 2). This included securing ship time through the NOAA OMAO and developing and submitting project instructions. The project instructions are a cruise plan that outlines all science operations and ship requirements and requires approval from NOAA STAR management, OMAO, and the NOAA Ship *Nancy Foster* before the project. As the liaison between the science party and OMAO, the NOAA team ensured that all required medical and personnel forms were submitted to OMAO. NOAA transported all NOAA and NASA scientific equipment by truck from Maryland to Pensacola, FL, and then from Charleston, SC back to Maryland after the cruise. During the cruise, the chief scientist was responsible for planning ship trajectories, station locations, sampling sequence, and communications with the ship. In the following, we report the in situ data collection effort and preliminary results.

3.1. Deployment of Multiple Radiometric Profilers

As already mentioned, the objective for the VIIRS Cal/Val cruise is to validate VIIRS and other ocean color satellite products. The most important product and primary validation objective for the NOAA group is to validate $R_{rs}(\lambda)$ that the satellite measures, as all other secondary products are derived from and dependent on these measurements. As in past Cal/Val cruise analyses, two to four profilers are deployed simultaneously off the stern. The replication allows for checking measurement uncertainty to ensure reliable validation results. The profilers have a downward-looking radiance sensor (for upwelling radiance, $L_u(\lambda)$) and an upward-looking irradiance sensor (for downwelling plane irradiance, $E_d(\lambda)$). Each system has an above-water irradiance sensor (for surface irradiance, $E_s(\lambda)$) mounted on a telescoping pole (Grappa Pole, Figure 6) to raise the sensor above the ship's infrastructure to avoid shadowing from the ship. During this project, the team had five profiling instruments for measuring $R_{rs}(\lambda)$. NOAA had two Seabird HyperPro II Profilers (Serial numbers #86 and #222), USF had one, and OSU had one. The Seabird HyperPro II sensors are hyperspectral with a 10 nm bandwidth measured every 3 nm. NASA had a Biospherical compact optical profiling system (C-OPS), which has 19 bands. The profilers were deployed by hand across the stern, one on each quarter and one or two between the A-Frame (Figure 6). During the deployment, the ship maintained bare steerageway with the sun off the port quarter. This enabled the team members making above-water measurements on the bow to conduct measurements 90 to 135 degrees from the sun during the profile cast. All profilers had the radiance sensors mounted towards the port to avoid shadowing from the instrument. The profilers were allowed to drift at least 20 m behind the ship to avoid ship shadowing. Then slack was given in the line, which allowed the profilers to sink vertically through the water column to 15 m at a descent rate of 0.1 to 0.3 m s⁻¹. Once all the profilers reached the desired depth, the lines were pulled in

slowly to allow the profilers to kite to the surface while maintaining distance from the ship. The instruments continuously logged during multiple profiles, and after 3 to 5 profiles were conducted, the logging was stopped. This is one cast, then 2 to 4 more casts were usually conducted per station. Measurements are only valid under consistent light levels, ideally with no clouds in front of the sun.

3.2. Deployment of Handheld Radiometers

NOAA/STAR deployed a SVC 512i above-water handheld spectroradiometer during the cruise. The HR-512i covers a spectral range of 350 nm to 1050 nm with a 3 nm spectral resolution and an 8-degree field of view (FOV). Above-water validation measurements were conducted on the bow simultaneously with the other team members (see Section 4) while the floaters and profilers were deployed. The method of Mueller et al. (2003) was utilized with an NRL Spectralon® white plaque with a nominal reflectance of 0.99. The water and plaque measurements were conducted at an angle of 40° to 45° from the nadir and an azimuth angle to the sun of 90° to 135°. The sky was measured at a 40° to 45° zenith angle and at an azimuth angle to the sun of 90° to 135°. Aerosol optical thickness (AOT) was measured using a Microtops sunphotometer. The data are delivered for processing to NASA as part of the Aerosol Robotic Network (AERONET) program.

3.3. Calibration of radiometers

Pre-cruise calibrations were conducted in the NOAA College Park Calibration Lab on May 10, 2024, on the NOAA HyperPro, the NRL TSRB, and the USF HyperPro Sensors. Post-cruise calibrations were conducted on June 24, 2024. No significant differences were observed between the pre- and post-cruise calibrations. Radiance sensors were calibrated with a National Institute of Standards and Technology (NIST)-traceable Optronic Laboratories OL-455 integrating sphere. Irradiance sensors were calibrated with a NIST-traceable FEL 1000 W standard irradiance lamp. The post-cruise calibration-generated calibration files were used to process the HyperPro data.

3.4. IOP Profiles

Inherent optical properties were measured at each station by lowering a package by cable down to 100 m. The package contained an ac-s (WET Labs, Inc.), a BB9 (WET Labs, Inc.), and a Seabird CTD. All data were collected and stored using a DH4 data handler (WET Labs, Inc.). The system was deployed at each station; however, an error occurred with the DH4, and all stored IOP profile data were lost.

3.5. Daily Observations of Water AOPs

On day one (May 20, 2024), the ship departed later in the morning, and only one station, a.k.a. the check-out station, was occupied about 15 NM south of Pensacola (Figure 8), where nearshore conditions (Chl-a concentrations of 0.4 mg m⁻³), clear skies, and calm seas were observed. For

AOP profilers, NOAA #222, OSU and USF HyperPros, as well as the NASA C-OPS, were deployed. The USF HyperPro was not working, and the shutter on the NOAA E_d sensor (#233) also was not working.

On day 2 (May 21, 2024), Stations 2, 3, and 4 were occupied to the east, just south of Apalachicola Bay (Figure 9). These stations were centered further offshore than Station 1, with the estimated Chl-a concentrations averaging around 0.12 mg m^{-3} . Again, clear sky and sun conditions were encountered. For Station 2, the E_d sensor from the USF profiler (#290) was used on the NOAA #86 profiler. C-OPS had problems on Stations 3 and 4 and was replaced with the NOAA HyperPro #222. For the remainder of the cruise, NOAA #86 with the USF #290 E_d sensor, NOAA #222, and the OSU HyperPros were deployed at each station.

On May 22, the cruise track required the ship to progress south, and Stations 5, 6, and 7 were occupied approximately 20 NM west of Clearwater, FL (Figure 10). The VIIRS Chl-a concentrations ranged from 0.26 mg m^{-3} at Station 5 to 0.11 mg m^{-3} further south at Station 7. Clear skies and calm seas were encountered for all three stations, and good matchups were observed between the NASA Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) and VIIRS satellites and the HyperPro data for the first three days.

On Day 4, May 23, the transect took us south looking for clear skies (Figure 11). During the morning, stations were occupied just offshore of Naples, FL. The area was cloudy during the first stations, 8 and 9. Profiles were executed either under overcast conditions or during windows when the sun was visible through cloud breaks. Station 9 was located 10 NM northwest of Station 8 while trying to get away from the cloud line. Station 10 was 10 NM north of Station 9 and outside of the clouds.

On May 24, the fifth day, the ship headed southwest, directly west of the Florida Keys, where clear skies and calm seas were encountered (Figure 12). Station 12 was 10 NM west of Station 11 and Station 13 was 10 NM west of Station 12. A fourth station was added 5 NM west of Station 13 where only profilers were run. These were all blue water stations near the edge of the Loop Current with the VIIRS Chl-a concentrations averaging around 0.093 mg m^{-3} . Despite near-perfect conditions, HyperPro values were consistently higher than PACE at wavelengths below 500 nm.

Overnight on the morning of May 25, the PACE satellite went into safe mode and therefore there were no PACE matchups again until May 31. During the night, the ship transected southeast to occupy Station 15 just north of the Cuban International Waters. Stations 16 and 17 were occupied north of that location (Figure 13). Conditions were favorable with no clouds, low winds (8 kt), and Chl-a concentrations ranging from 0.088 mg m^{-3} at Station 15 to 0.091 mg m^{-3} at Station 17, which was near the Loop Current. There was good agreement between VIIRS and spectrally weighted values from the HyperPro. Overnight on May 25, it was necessary to start moving east to stay on schedule to make Jacksonville by May 31. Four stations (18, 19, 20, and 21) were sampled moving east following the Keys to the north (Figure 14). Again, conditions were optimal for validation with 100% clear skies and 4 kt winds. The VIIRS Chl-a concentrations ranged from 0.09 to 0.125 mg m^{-3} . NOAA-20 and NOAA-21 matched HyperPro values well, while SNPP was near the glint zone and was consistently low. Only HyperPros were occupied during Station 21.

On the eighth day, three stations (22, 23, and 24) were occupied directly off Miami in the Gulf Stream (Figure 15). PACE was still in safe mode, and NOAA-20 was in the glint. Despite the rapidly moving Gulf Stream moving the stations north, conditions were perfect with clear skies and no wind. Chlorophyll-a concentrations were below 0.1 mg m^{-3} . Good matchups were observed

between the HyperPro, SNPP, and NOAA-20. The May-28 stations were occupied just off the coast near Cape Canaveral (Figure 16). Selecting locations was tricky as cloud coverage was over 60% and moving. There was one matchup for NOAA-20 at Station 25, but it was cloudy for the rest of the stations. NOAA-21 and SNPP had better coverage. PACE was still in Standby Mode. Cloud conditions were much more favorable on May 29. On this 10th day of the cruise, three stations (29, 30, and 31) were occupied directly offshore of St. Augustine, FL (Figure 17). There was still no PACE data; however, good matchups were observed with the three VIIRS sensors and the HyperPro. The VIIRS chlorophyll-a concentrations ranged from 0.29 mg m⁻³ at Station 29 to 0.22 mg m⁻³ at Station 31.

On May 30, three stations were moved offshore to avoid predicted clouds nearshore, and the ship had to stay within range to go into Jacksonville for fueling on May 31. Environmental conditions remained favorable, despite slightly elevated wind speeds (10–15 kt) and low chlorophyll-a concentrations (0.04–0.08 mg m⁻³). Observations from NOAA-20, SNPP, and the HyperPro showed strong agreement, whereas NOAA-21 exhibited noticeable divergence (Figure 18). The PACE satellite came back online on May 30 but not at our sampling location. As scheduled, the ship had to go into port in Jacksonville, FL for refueling on the morning of May 31. The ship did not depart the dock until 1300 hours and therefore, only two stations could be sampled near shore directly east of Jacksonville (Figure 19). The PACE satellite was operational again and agreed well with the HyperPro, NOAA-20, and NOAA-21 data. The VIIRS Chl-a concentrations ranged from 0.18 to 0.21 mg m⁻³. On the last sampling day of the cruise on June 1, the region we had to sample in the proximity of Charleston was completely clouded in, and no matchups were obtained (Figure 20).

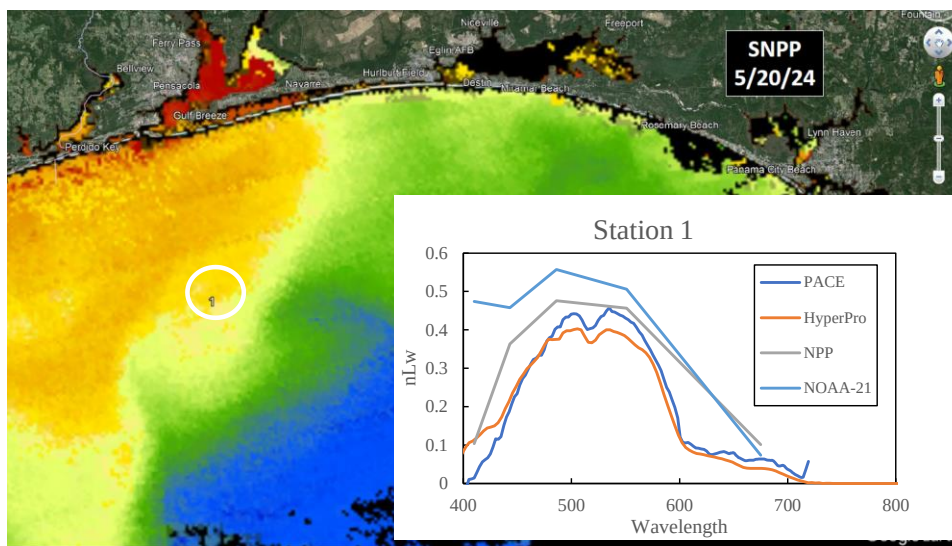


Figure 8. Satellite and in situ $nL_w(\lambda)$ spectra measured at the Checkout station (Station 1) on May 20, 2024. The background image is the chlorophyll-a concentration derived from SNPP.

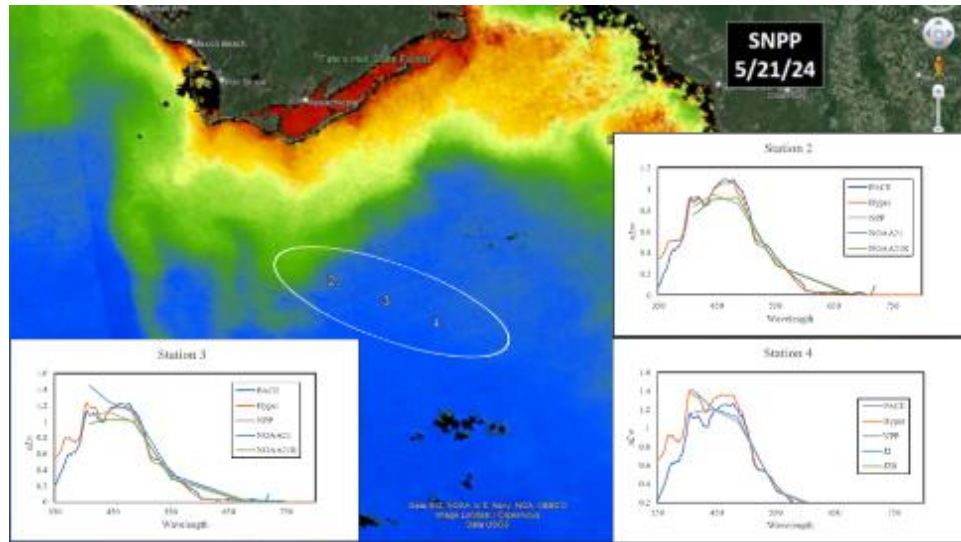


Figure 9. Satellite and in situ $nL_w(\lambda)$ spectra measured at three stations on May 21, 2024.

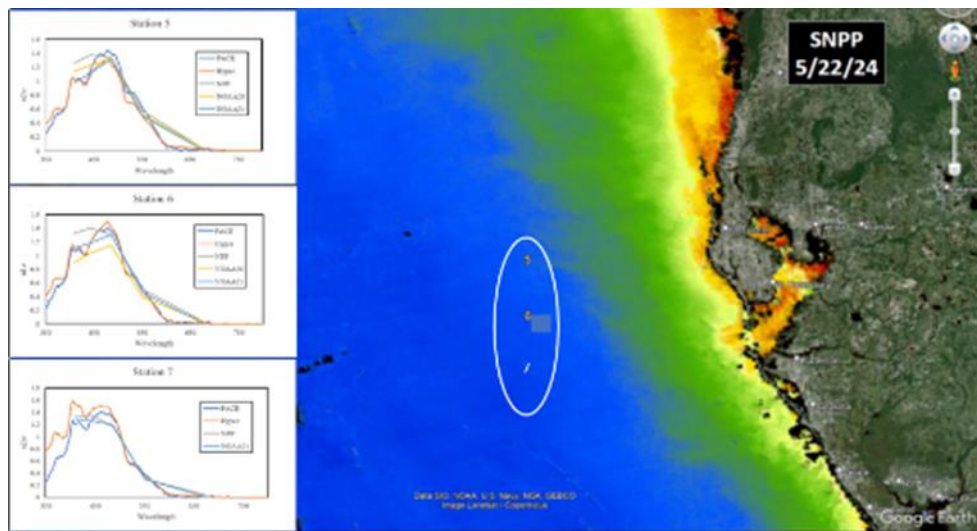


Figure 10. Satellite and in situ $nL_w(\lambda)$ spectra measured at Stations 5, 6, and 7 on May 22, 2024.

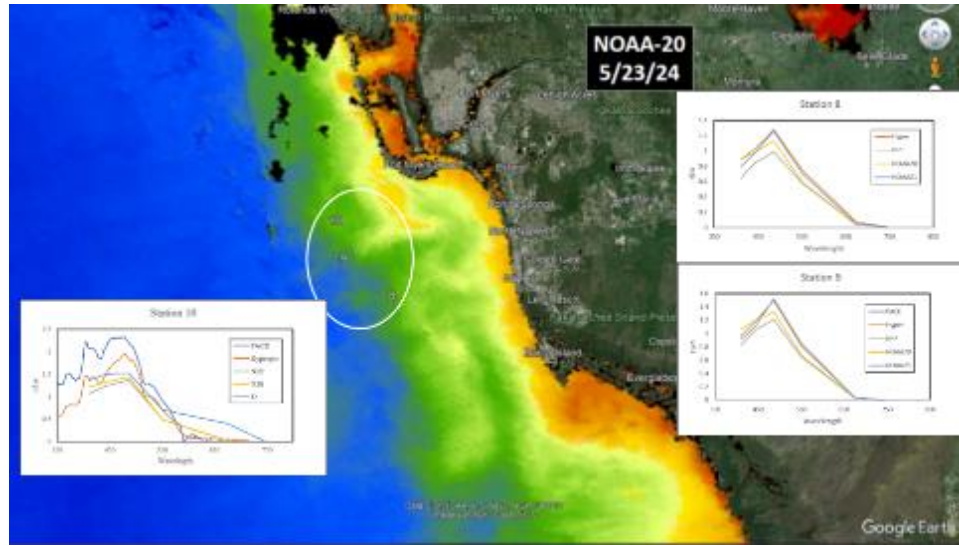


Figure 11. Satellite and in situ $nL_w(\lambda)$ spectra measured at Stations 8, 9, and 10 on May 23, 2024. HyperPro data for Stations 8 and 9 are spectrally weighted to VIIRS bands for consistency.

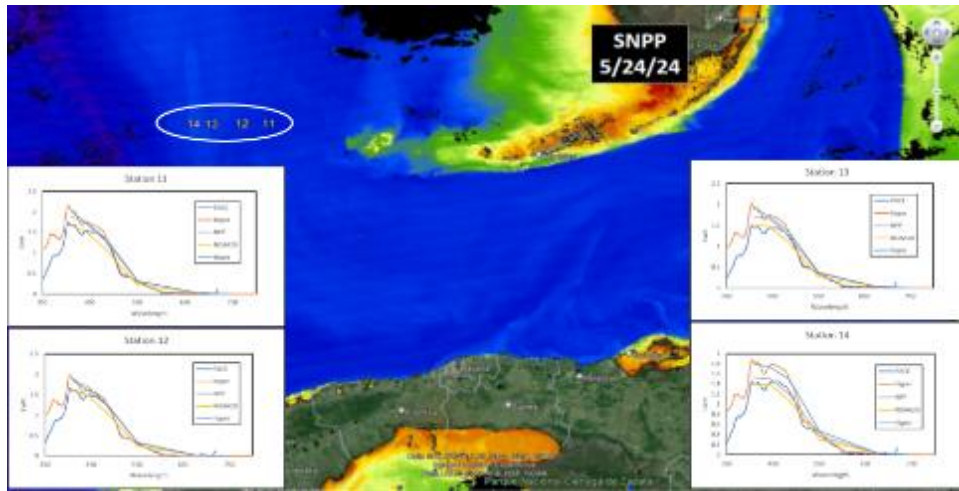


Figure 12. Satellite and in situ $nL_w(\lambda)$ spectra measured at Stations 11–14 on May 24, 2024.

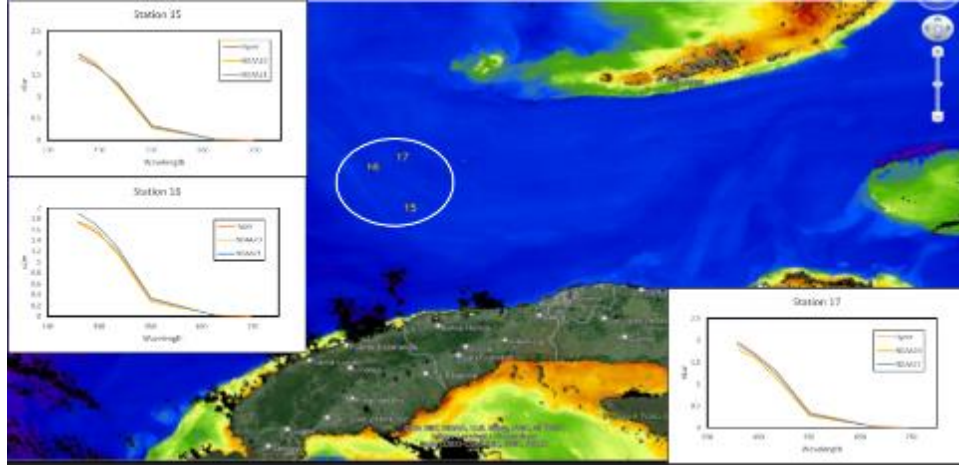


Figure 13. Satellite and in situ $nL_w(\lambda)$ spectra measured at Stations 15–17 on May 25, 2024. NOAA-20 image overlaid with May 25, 2024 stations with VIIRS matchups only, as PACE went into safe mode overnight. Station 15 was just north of Cuban waters, so Stations 16 and 17 had to be occupied further to the north. HyperPro values were spectrally weighted to VIIRS bands since PACE values were not measured.

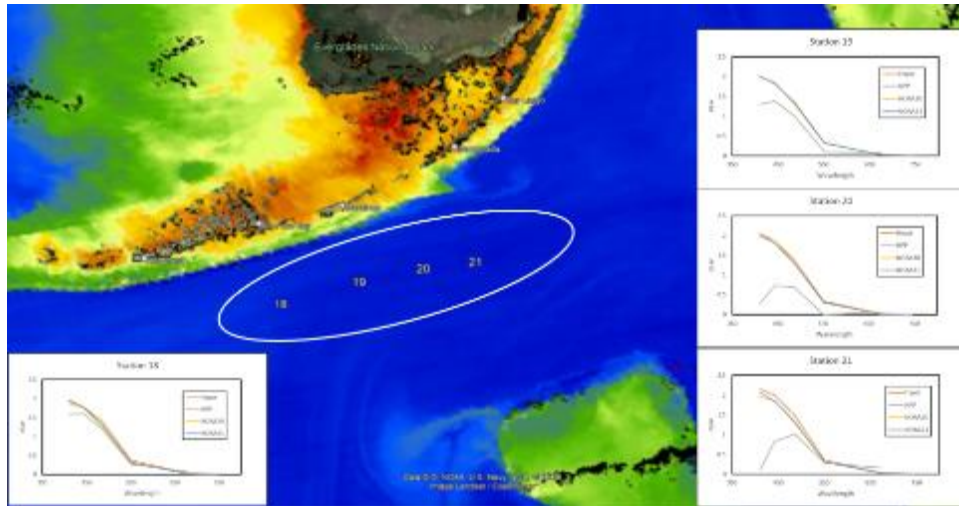


Figure 14. Satellite and in situ $nL_w(\lambda)$ spectra measured at Stations 18–21 on May 26, 2024. Occupied four stations just south of the Florida Keys while transecting east. PACE is still in safe mode. HyperPro values were spectrally weighted to VIIRS bands since PACE values were not measured.

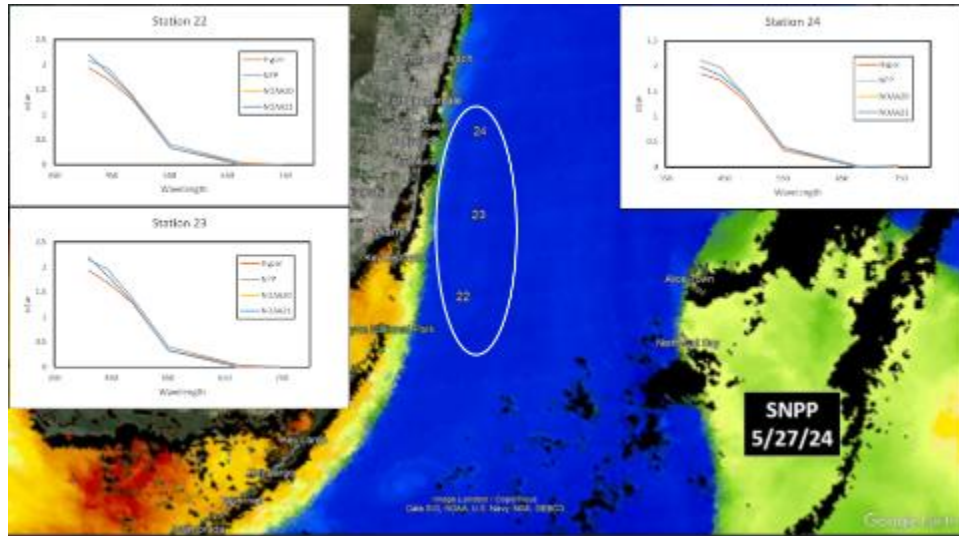


Figure 15. Satellite and in situ $nL_w(\lambda)$ spectra measured at Stations 22–24 on May 27, 2024. These stations are located directly off the coast of Miami, FL. HyperPro values are spectrally weighted to VIIRS bands since PACE values were not measured.

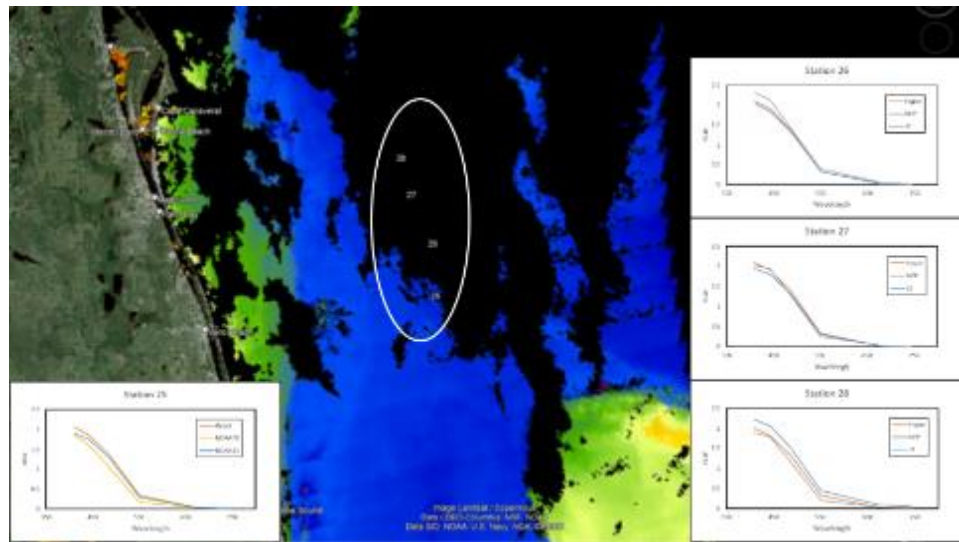


Figure 16. Satellite and in situ $nL_w(\lambda)$ spectra measured at Stations 25–28 on May 28, 2024. Four stations just off Cape Canaveral. NOAA-20 mostly in the clouds. SNPP and NOAA-21 in and out of clouds. HyperPro values spectrally weighted to VIIRS bands since PACE values were not measured.

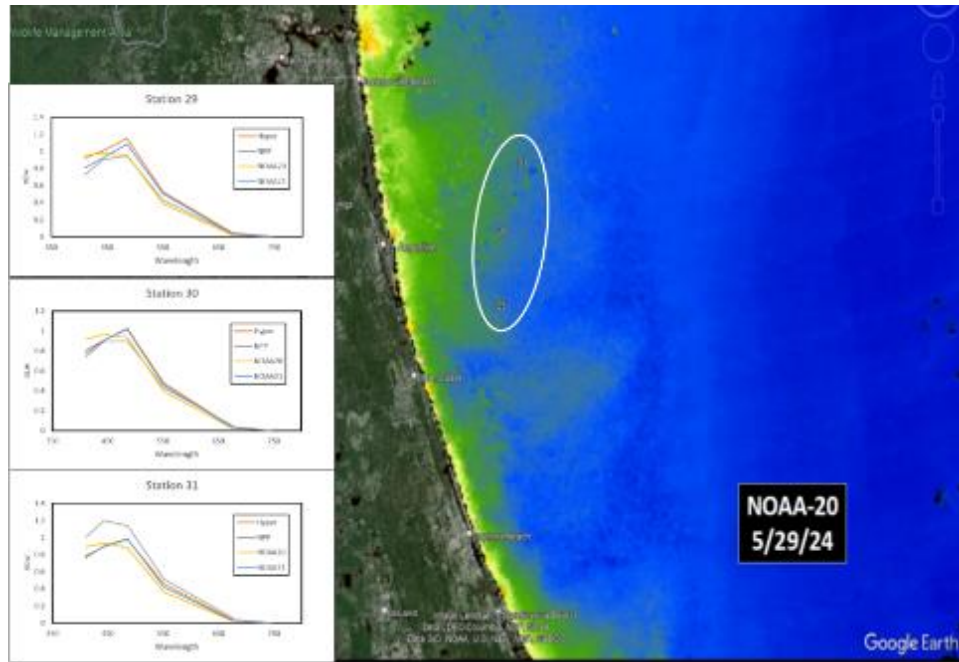


Figure 17. Satellite and in situ $nL_w(\lambda)$ spectra measured at Stations 29–30, May 29, 2024. All VIIRS values match HyperPro well except SNPP at Station 31. HyperPro values are spectrally weighted to VIIRS bands since PACE values were not measured.

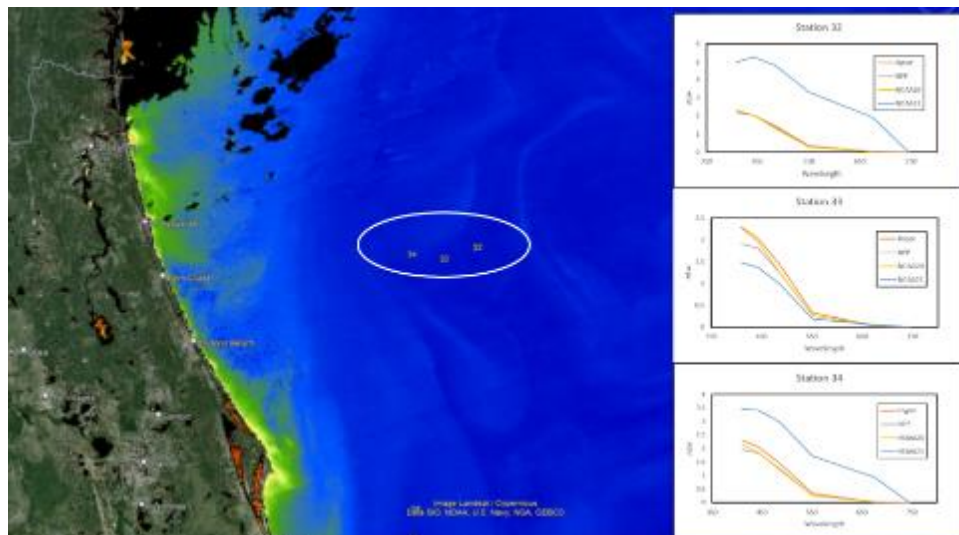


Figure 18. Satellite and in situ $nL_w(\lambda)$ spectra measured at Stations 32–34 on May 30, 2024. Good matchups between SNPP, NOAA-20, and the HyperPro. HyperPro values are spectrally weighted to VIIRS bands since PACE values were not measured.

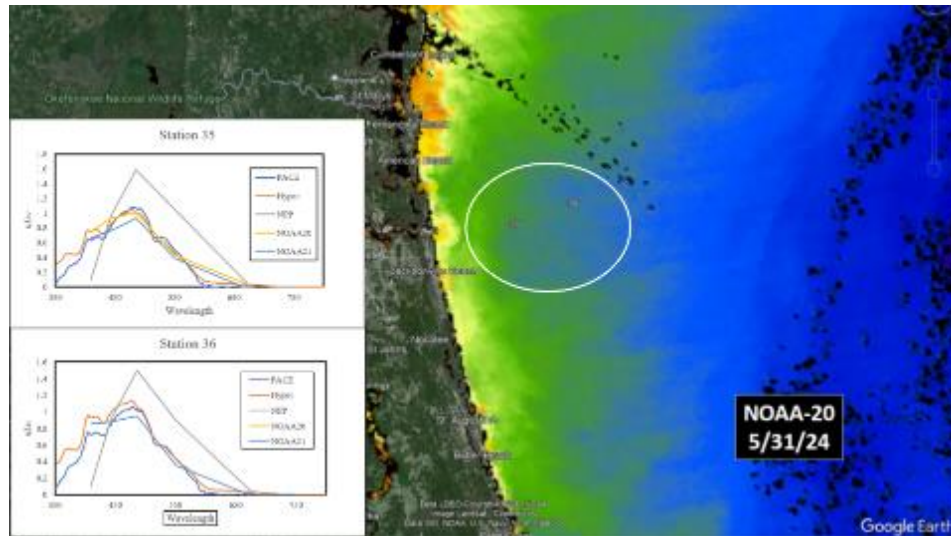


Figure 19. Satellite and in situ $nL_w(\lambda)$ spectra measured at Stations 35–36 on May 31, 2024. The morning was spent refueling the ship in Jacksonville, FL, and therefore there was only time for two nearshore stations later in the afternoon. The PACE satellite was back online with good agreement with the HyperPro, NOAA-20, and NOAA-21.

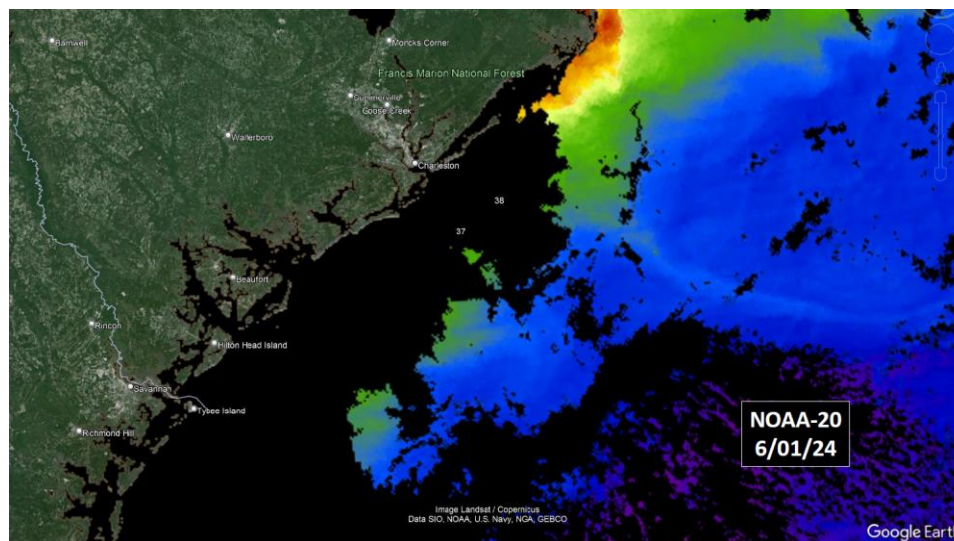


Figure 20. NOAA-20 image for the last sampling day of the trip. The region was completely cloudy, and no matchups were obtained.

4. Measurements of Hyperspectral Reflectance and IOPs using Surface Methods (NRL Team)

Sherwin Ladner

Naval Research Laboratory, Stennis Space Center, Mississippi

NRL collected above-water $R_{rs}(\lambda)$ measurements at 35 of the 38 stations from May 20 through June 01, 2024, using two handheld hyperspectral radiometers and a TSRB system. NRL also collected continuous underway hyperspectral IOPs using the ship's seawater flow-through system along the cruise track. Note that the stations were adaptively planned and selected based on predicted (<https://www.windy.com/>) weather forecasts and clear sky conditions to increase the probability of obtaining satellite matchups. NRL provided individual daily near-real-time Google Earth (KMZ) chlorophyll-a images for VIIRS sensors (SNPP and NOAA-20) in near real-time to assist in planning the next day's station locations and to determine if daily stations collected yielded valid sensor matchups (Figure 21).

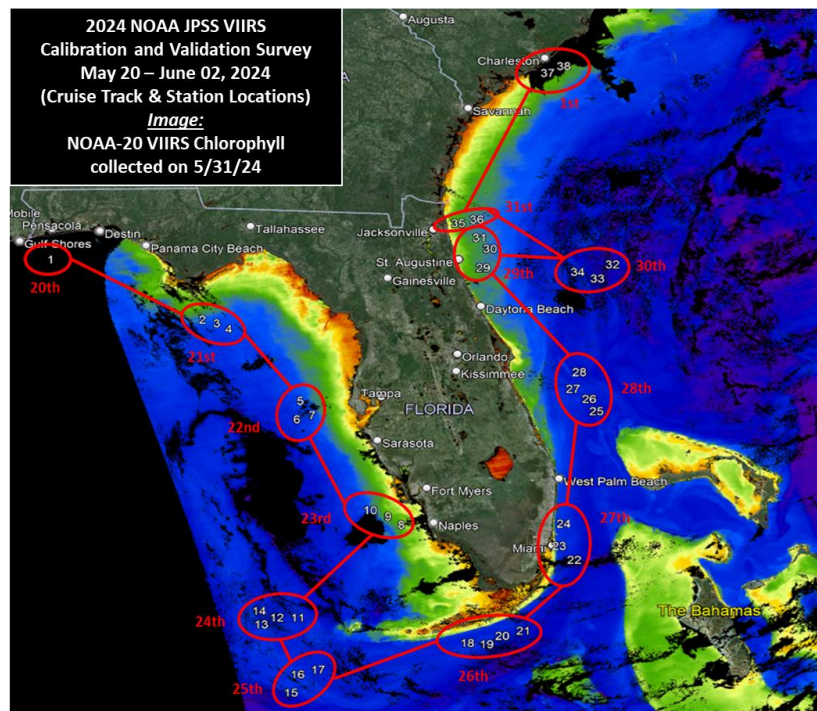


Figure 21. NOAA-20 VIIRS Chlorophyll-a image captured on May 31, 2024, illustrating the 38 station locations (white numbers). Red circles indicate each day's sampling locations from May 20 through June 01, 2024. NRL's Automated Processing System v24 (APS) processed the individual daily images.

4.1. Above-water and In-water Radiometry Measurements

Above-water remote sensing reflectance measurements were taken using an ASD FieldSpec Handheld-2 hyperspectral spectroradiometer and a SEI PSR-1100F hyperspectral spectroradiometer. Each spectroradiometer was calibrated for spectral radiance using NIST-traceable standards by the respective manufacturers. The bow location was selected to reduce the amount of contamination from the ship's structure during the collection of the calibrated reference plaque and the water's surface. The ship was positioned so measurements could be taken at a 90–135° azimuth angle from the sun. Above-water measurements were taken coincident with the in-water (HyperPro) $R_{rs}(\lambda)$ measurements/profiles.

Above-water measurements were acquired using the ASD and SEI hyperspectral spectroradiometers at 35 of the 38 stations covered. All above-water measurements were made using the NRL white 99% reflectivity (white) 10-inch plaque during the standard sky, water, and reference plaque sequence for deriving the above-water $R_{rs}(\lambda)$. The white plaque has a known bidirectional reflectance distribution function (BRDF) surface and is used to normalize the uncalibrated irradiance measurements for $E_s(\lambda)$. Above-water measurements may vary due to instrument type and calibration, warm-up time, shadowing of the plaques, variable light field, etc.

The above-water measurement activities took place on the bow of the ship. At the start of each station, the reference plaque was placed on the bow's bollard posts (Figure 22). The plaque was occasionally partially obscured from the full hemisphere by the ship's bridge, participants, cloud cover, and the bow rail at low sun angles (early morning and late afternoon). The magnitude of this bias will depend on how much of the diffuse component is blocked. The ship was oriented to reduce these impacts. Optimal and non-variable light conditions were sought for the sky, water, and reference measurements for the complete sequence. NRL recorded station metadata (time, latitude, longitude, instrument base filenames, spectra target assignments and number of scans, ocean parameters from ship's flow-through, physical water characteristics, meteorology, etc.) on handwritten log sheets during each station and later compiled into an Excel spreadsheet. Other personnel took photographs of the sky and water surface conditions and the participants in action. All groups in attendance attempted to make concurrent measurements using multiple above-water spectroradiometers (ASD, SEI, and SVC) coincident with the profiling radiometer deployments.

NRL deployed an in-water Satlantic/Seabird HyperPro-II radiometer system in a floating mode using a collar, or TSRB (Figure 22). The floating system (s/n 138) was equipped with a downward-looking OCR radiance sensor (s/n 311) and an upward-pointing OCI irradiance sensor (s/n 375). Downwelling surface irradiance was measured with an $E_s(\lambda)$ sensor (s/n 376) mounted atop a grappa pole on deck containing $E_s(\lambda)$ sensors for all deployed HyperPro sensors. It also measured ancillary parameters, including water depth, temperature, and instrument tilt. The NRL floater was deployed shortly after the HyperPro-II profiling instruments (Figure 22), and logging occurred for 5-10 minutes based on tilt angles and sky conditions. During deployment, the raw data were continuously logged. Data were processed by NOAA STAR (Mike Ondrusek) using the Satlantic/SeaBird Prosoft software version 8.1.5.



Figure 22. Pictures illustrate the above-water collection using the Spectral Evolution and ASD (top 2 pictures). The bottom picture illustrates the TSRB deployment.

The NRL ASD instrument was configured to average 5 spectra per scan and save five spectral scans for each of the 3 targets (sky, reference, and water). The SEI is designed to collect one spectrum at a time and must be triggered for each individual scan (10 scans per target). During each station, five consecutive radiometric spectra with dark measurements subtracted were taken of each of the following targets: 1) sky, 2) NRL white plaque, and 3) water for the ASD. The same sequence was collected for the SEI with 10 radiometric spectra per target. For both the ASD and SEI instruments, an 8-degree fore optic was attached; integration time was optimized for each target prior to collection (i.e., the integration time of the sensor was changed based on the relative brightness of the target, and new dark counts were taken to correct for instrument noise). The sensor zenith angles for the θ_p , θ_{sfc} , and θ_{sky} measurements were 40° , 40° , and 40° , respectively. The relative azimuth angle of the sensor to the sun ranged from 90° to 135° depending on visual surface contamination (sea foam, glint, bubble, shadows, etc.). The post-processing of the ASD and SEI above-water data collected by NRL was performed using codes developed by NRL for the 35 stations collected, and $R_{rs}(\lambda)$ was computed using the NRL white plaque using the same

collection protocols for both instruments to look at inter-sensor differences. The NRL software corrected the $R_{rs}(\lambda)$ using a NIR baseline-subtraction protocol and the calculation of the surface reflectance correction ρ , based on the solar azimuth and wind speed calculation (Mobley, 2015). This approach is a substantial improvement over using a constant ρ of 0.021 to minimize the reflected sunlight contribution.

The ASD spectroradiometer measures light at 1.0 nm sampling over the 325 nm to 1075 nm spectral range. The SEI spectroradiometer measures light at 1.0 nm sampling over the 320 nm to 1100 nm spectral range. Processing follows the equation:

$$R_{rs}(\lambda) = (L_t(\lambda) - L_{sky}(\lambda)\rho(\theta))/(\pi L_p(\lambda)/refl) \quad (1)$$

where:

- $L_t(\lambda)$ is the measured signal from the water and includes both $L_w(\lambda)$ and reflected skylight;
- $L_{sky}(\lambda)$ is the measured sky radiance;
- $L_p(\lambda)$ is the average measured signal from the white Spectralon® plaque;
- $refl$ is the reflectivity of the plaque (approximately 99% white; actual measured spectral values are used in the calculation); and
- The Fresnel reflectance $\rho(\theta)$ is expressed as a function of viewing angles.

The value of $\rho(\theta)$ is dependent on wind speed and direction, detector FOV, and sky radiance distribution. Only in the case of a level sea surface and a uniform sky radiance distribution does $\rho(\theta)$ equal the average of the Fresnel reflectance over the detector FOV. For our measurement angles under nominal sky and wind conditions, we pull $\rho(\theta)$ from the table of Mobley (2015).

The computed $R_{rs}(\lambda)$ is assumed to be “black” at about 750 nm due to water absorption. If not zero, then it is assumed that $L_{sky}(\lambda)$ was not estimated correctly. Following the “quick and easy” algorithm (Carder and Steward, 1985), it is further assumed that any error in the skylight reflection term is white (not wavelength dependent) and one may simply subtract the computed $R_{rs}(750)$ from the entire spectrum. In practice, this may lead to negative reflectance values $R_{rs}(\lambda)$ near 750 nm. Therefore, the processing subtracts the smallest $R_{rs}(\lambda)$ in the range from 700 nm to 800 nm.

A preliminary comparison of the NRL in situ $R_{rs}(\lambda)$ data with the corresponding NOAA observations is given in Figure 23 and Figure 24. Further, the comparisons in Figure 25, Figure 26, and Figure 27 have included satellite matchups.

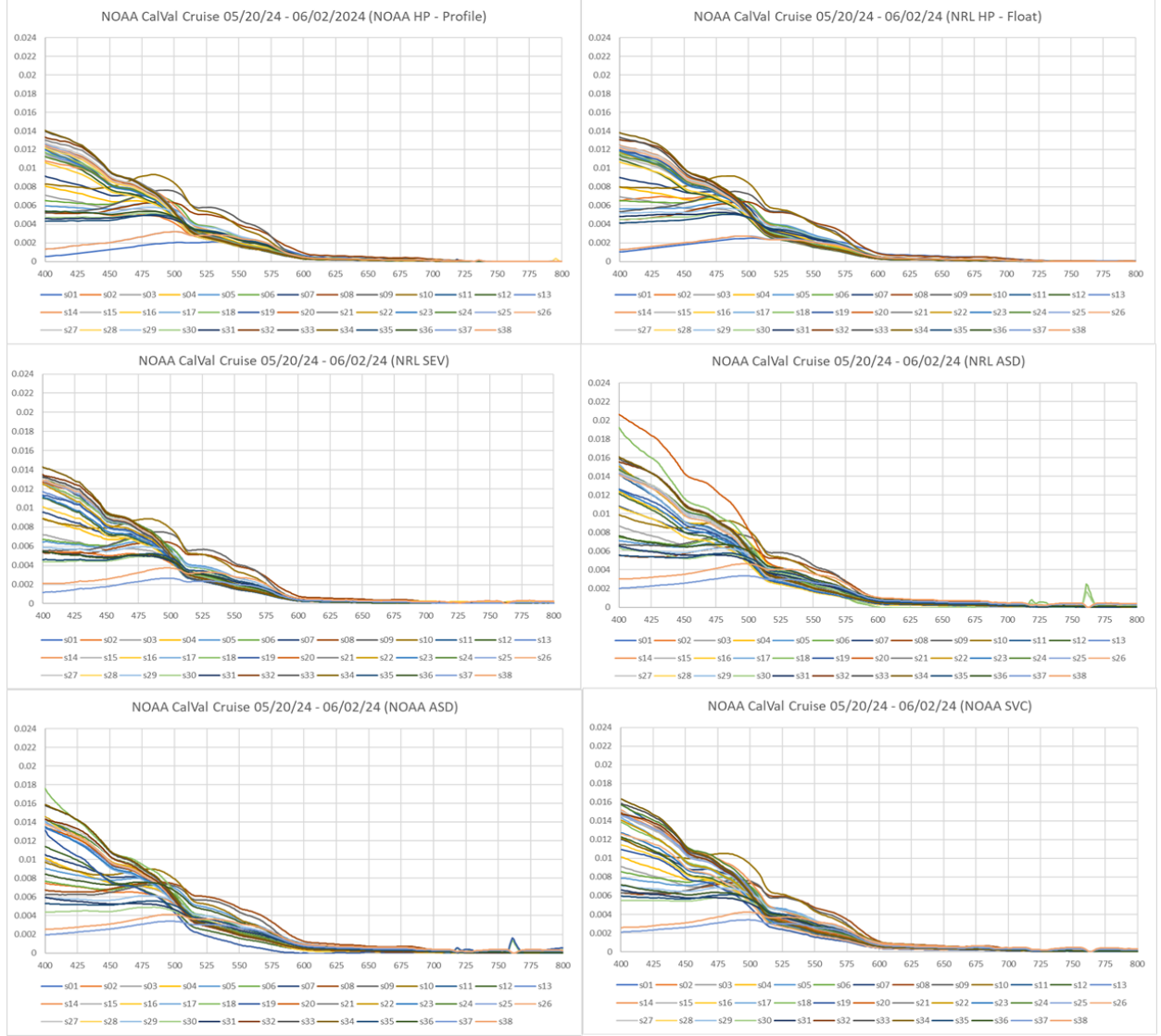


Figure 23. Overview of in situ $R_{rs}(\lambda)$ measurements collected by the NOAA and NRL instruments.

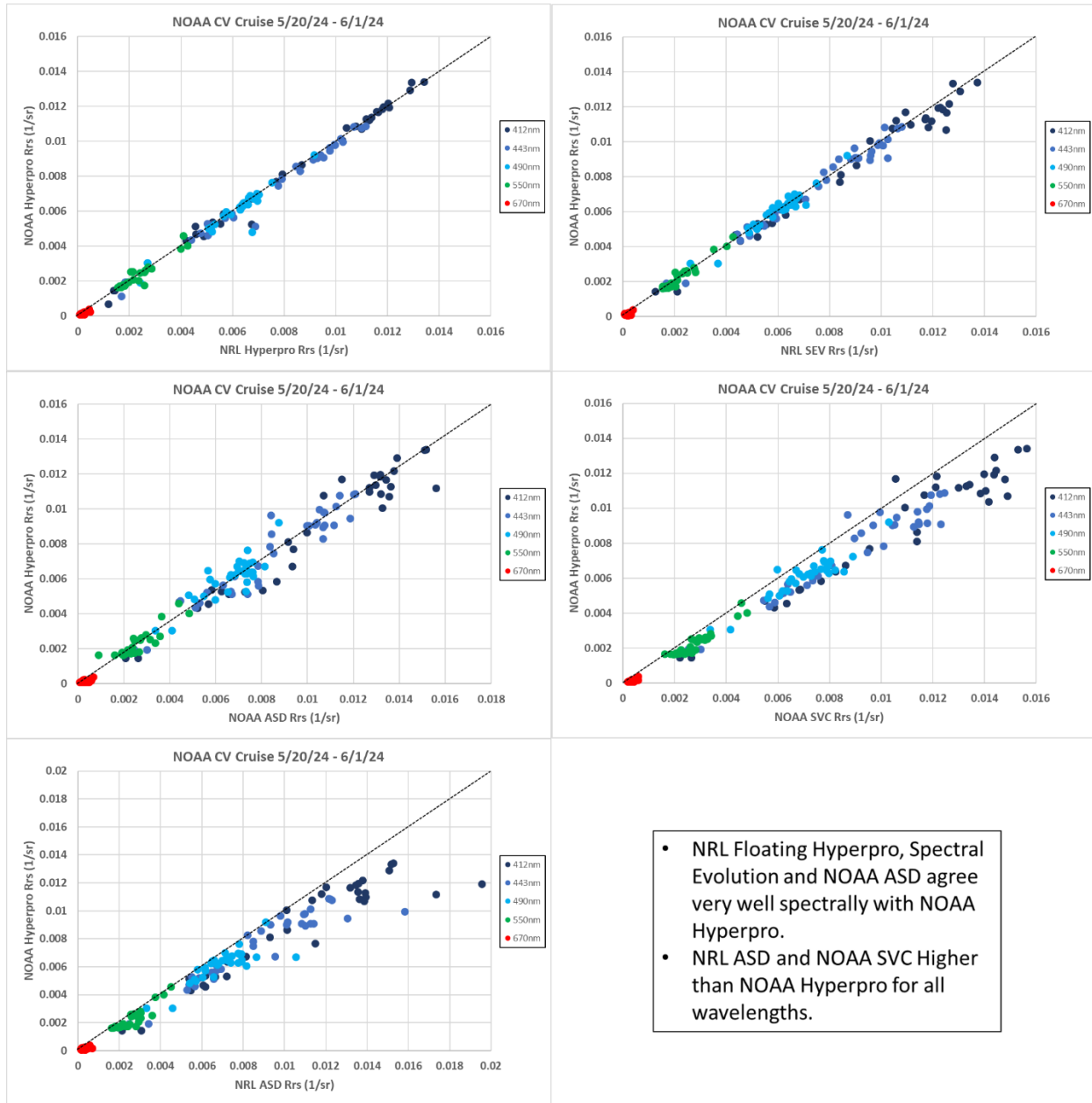


Figure 24. Comparison of $R_{rs}(\lambda)$ measurements between NOAA's profiling HyperPro (y-axis for all plots) and NRL's $R_{rs}(\lambda)$ measurements from various radiometers.

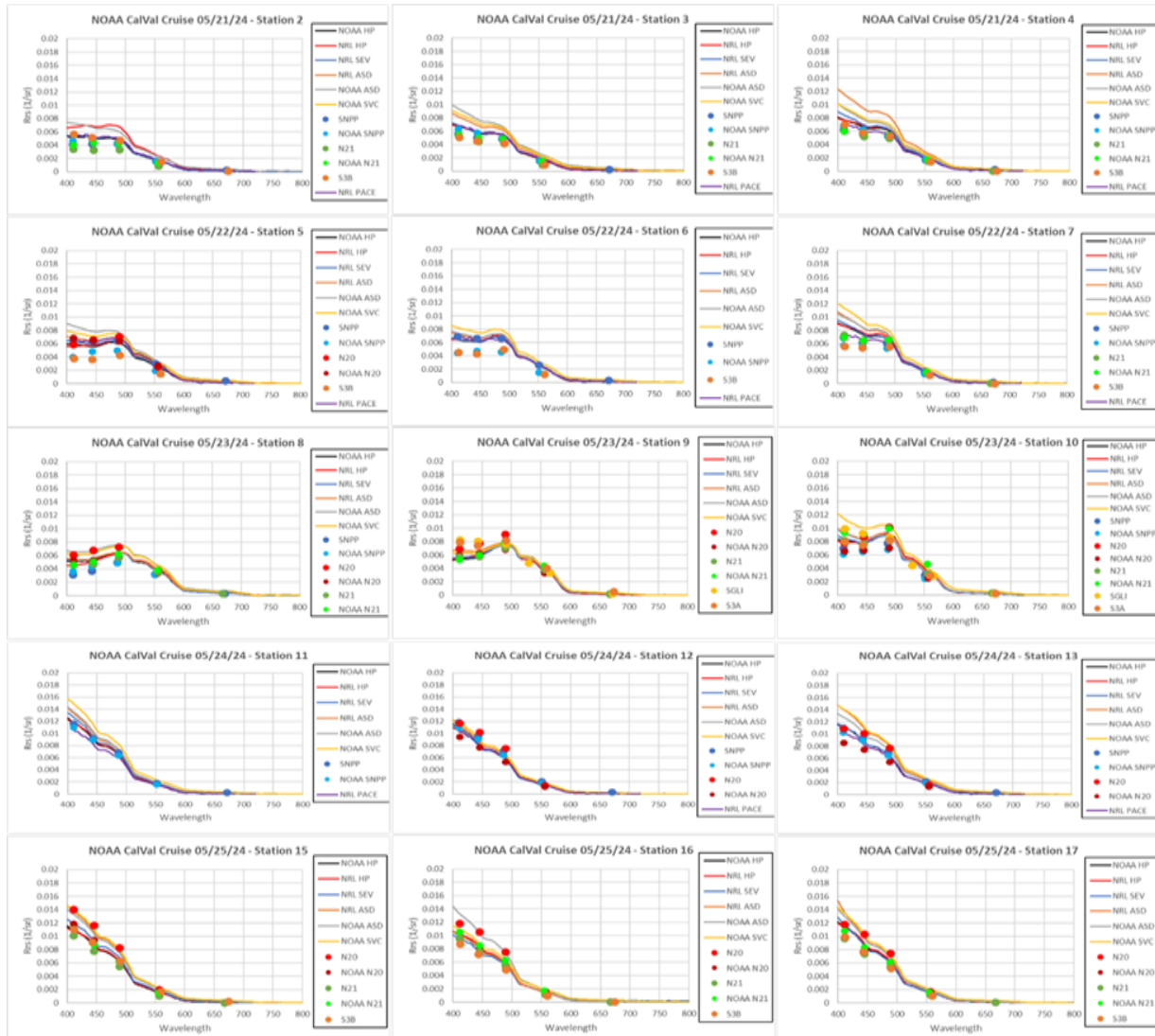


Figure 25. Part 1. Spectral matchups at each station between the NOAA profiling HyperPro (black line), NRL floating HyperPro (red line), NRL SEV (blue line), NRL ASD (orange line), NOAA ASD (grey line), NOAA SVC (yellow line), NRL-processed SNPP VIIRS (blue circle), NOAA processed SNPP (cyan circle), NRL-processed NOAA-20 (red circle), NOAA-processed NOAA-20 (maroon circle), NRL-processed NOAA-21 (dark green circle), NOAA-processed NOAA-21 (light green circle), NRL-processed Sentinel-3A/B (orange circle) and NRL-processed PACE-OCI (purple line). Some satellite matchups are missing due to cloud or glint contamination or an AC failure.

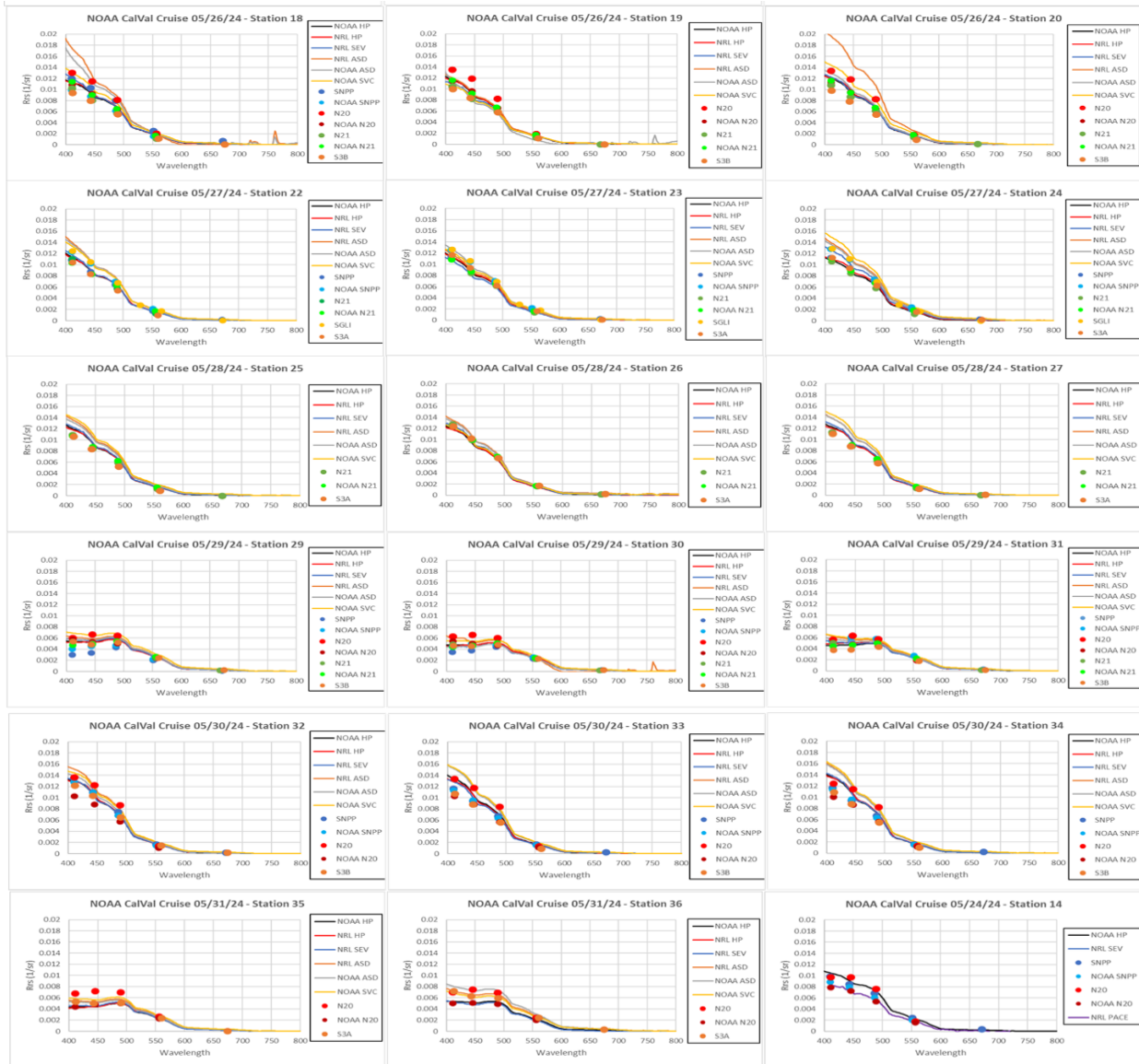
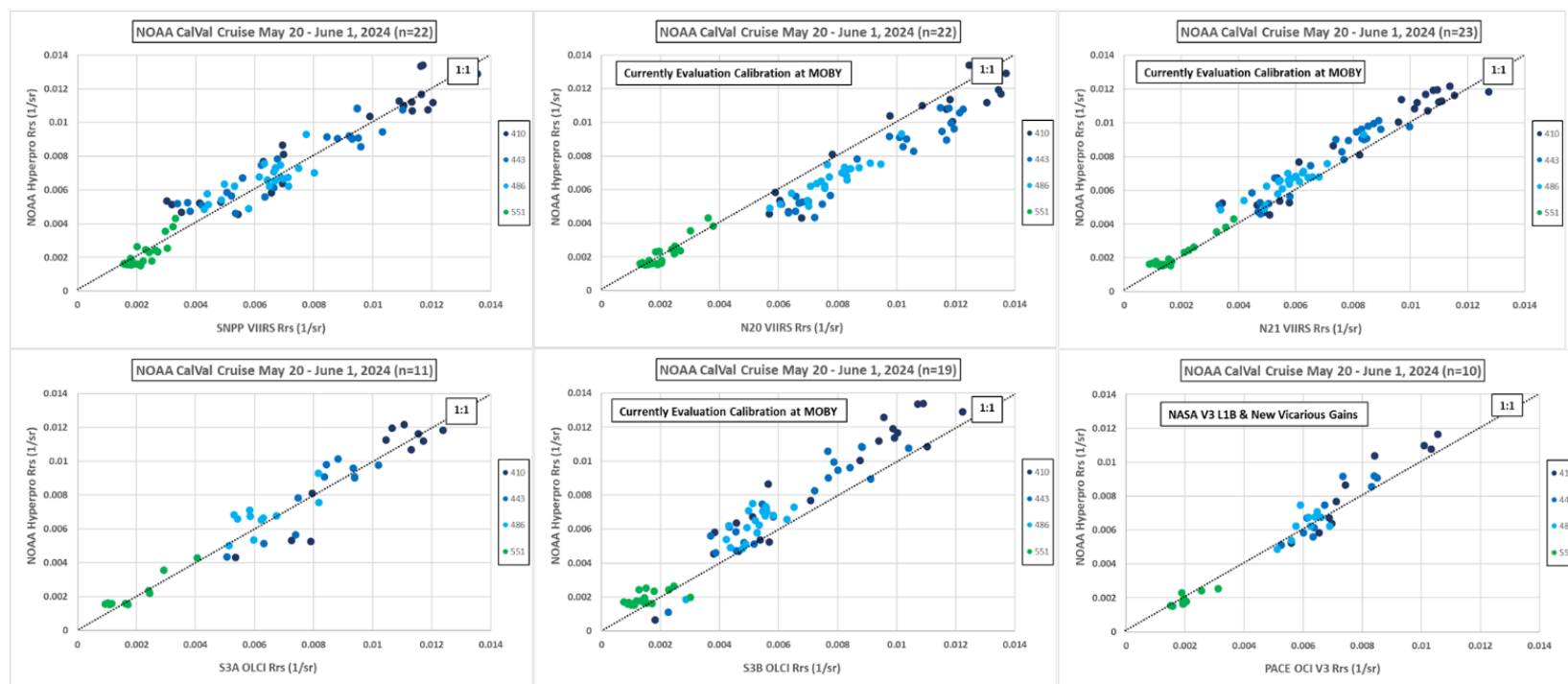
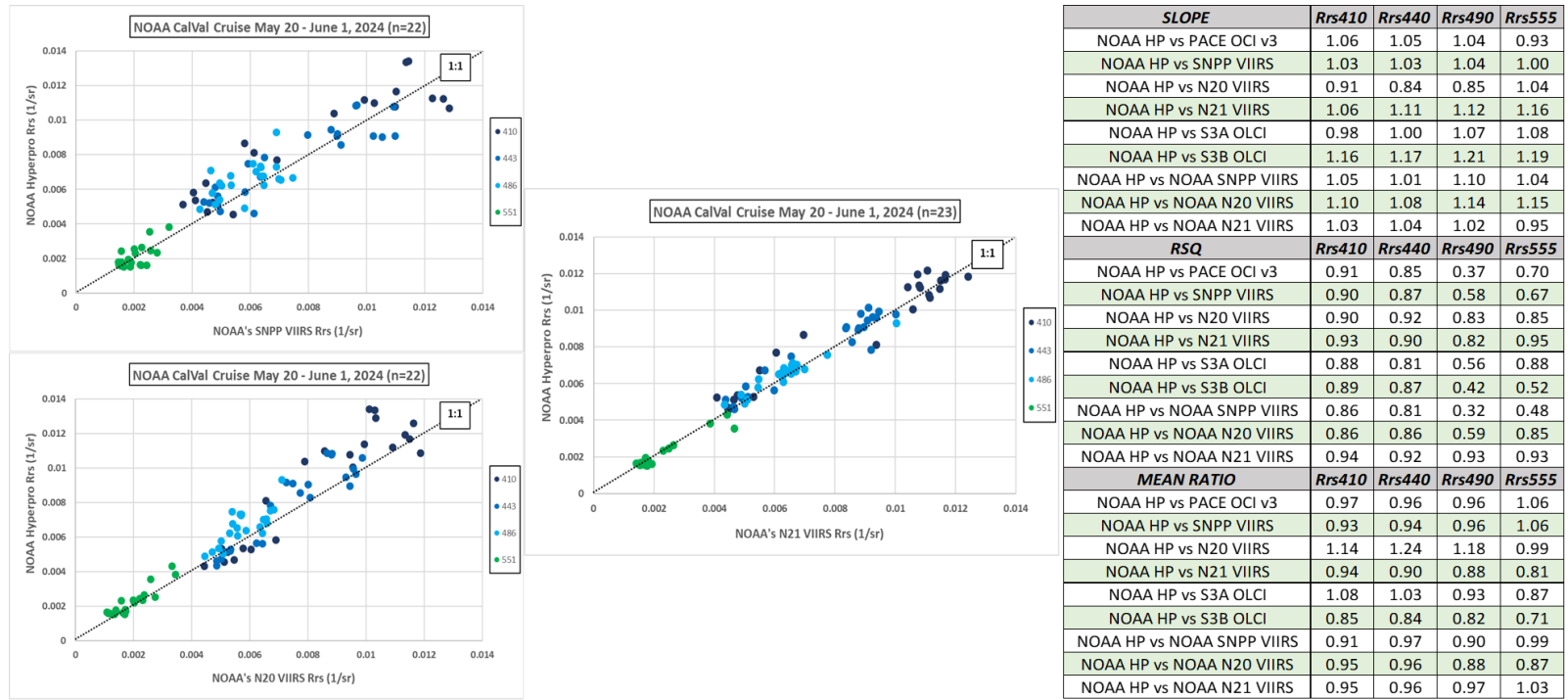


Figure 25. Part 2. Spectral matchups at each station between the NOAA profiling HyperPro (black line), NRL floating HyperPro (red line), NRL SEV (blue line), NRL ASD (orange line), NOAA ASD (grey line), NOAA SVC (yellow line), NRL-processed SNPP VIIRS (blue circle), NOAA processed SNPP (cyan circle), NRL-processed NOAA-20 (red circle), NOAA-processed NOAA-20 (maroon circle), NRL-processed NOAA-21 (dark green circle), NOAA-processed NOAA-21 (light green circle), NRL-processed Sentinel-3A/B (orange circle) and NRL-processed PACE-OCI (purple line). Some satellite matchups are missing due to cloud or glint contamination or an AC failure.



NRL APS matchups show good agreement. N20 is overestimating and S3B is underestimating spectral Rrs.

Figure 26. First row: $R_{rs}(\lambda)$ matchups between NOAA's profiling HyperPro (y-axis) and NRL-processed SNPP VIIRS, N20 VIIRS, and N21 VIIRS (x-axis); bottom row: the same matchups but for NRL-processed Sentinel-3A OLCI, Sentinel-3B OLCI, and PACE OCI for 4 visible wavelengths (410 nm, 443 nm, 486 nm, and 551 nm). NRL-processed ocean color satellites' $R_{rs}(\lambda)$ data show good agreement with the NOAA HyperPro.



NOAA MSL12 VIIRS Rrs matchups show good agreement with insitu.

Figure 27. $R_{rs}(\lambda)$ data matchups between NOAA's profiling HyperPro (y-axis) and NOAA-processed SNPP VIIRS (x-axis, top left), N20 VIIRS (x-axis, bottom left), and N21 VIIRS (x-axis, middle) for 4 visible wavelengths (410 nm, 443 nm, 486 nm, and 551 nm). The panel on the right details the statistics (slope, r-squared, and mean ratio) for each satellite to HyperPro matchups.

4.2. Continuous Underway Flow-through Measurements of IOPs

IOP flow-through measurements were collected to address specific objectives as follows, but will be used for other analyses as well:

- Characterize the spatial variability of IOPs ($a_t(\lambda)$, $a_p(\lambda)$, $b(\lambda)$ converted to $b_b(\lambda)$, $c(\lambda)$) along the cruise track and how the variability impacts the uncertainty of in situ measurements at each station, along with sub-pixel variability.
- Evaluate the vertical optical changes within one optical depth (penetration depth of satellite observations) in coastal and offshore waters. The flow-through data at a source depth of 3 m can be different from observed satellite values. Vertical IOP profiles can be used to evaluate the vertical changes and the effect on surface IOP validation.
- Determine the $a_t(\lambda)$ and $c(\lambda)$ properties at specific wavelengths to validate the IOPs derived from the ocean color satellites.
- Determine the optical water mass characteristics using spectral scattering and absorption to identify the response of ocean color.
- Define coastal/shelf frontal boundaries, ocean processes, and water mass types.

IOPs were collected continuously along the cruise track using a flow-through seawater system on the NOAA Ship *Nancy Foster*, designed, set up, and operated by NRL (Sherwin Ladner). The system integrated an unfiltered SeaBird hyperspectral ac-s instrument for total absorption and beam attenuation, a SeaBird BB3 backscattering meter operating at three channels (440, 532, and 650 nm), and the vessel's global positioning system (GPS) and Thermo-Salinograph/CTD connected to the ship's seawater flow-through system, where the water intake was located at approximately 3 m below the ocean surface. The instrument data were recorded using a DH4 data logger. The ac-s was placed in a temperature-controlled water bath (PVC tube) to dissipate the instrument's heat and stabilize instrument temperature (Figure 28).

The ship's flow-through system data streams included position, time, date, heading, water temperature, and salinity. Temperature and salinity are required for the standard processing protocol corrections during the post-processing of the ac-s data. The DH4 host software (WLHOST) was used to combine and store all these data inputs and allowed a WetView display capability in real-time to monitor the ac-s data to ensure the instruments were operating correctly and producing reliable and consistent data. The data sample rate of the ac-s meters was 4 Hz. Output data files from the DH4 were saved hourly and timestamped for the entire cruise track (Figure 29).

The ac-s sensor was cleaned and calibrated by Sherwin Ladner and Brandon Acker (NRL) at the end of the cruise. Calibration of the ac-s instrument included running Nanopure™ water through the instrument using a gravity feed. This clean water calibration was done before and after cleaning the absorption and scattering tubes. The BB3 instrument was also calibrated at the end of the cruise by placing black electrical tape over the sensors for 5 minutes to get a dark reading for post-processing corrections.

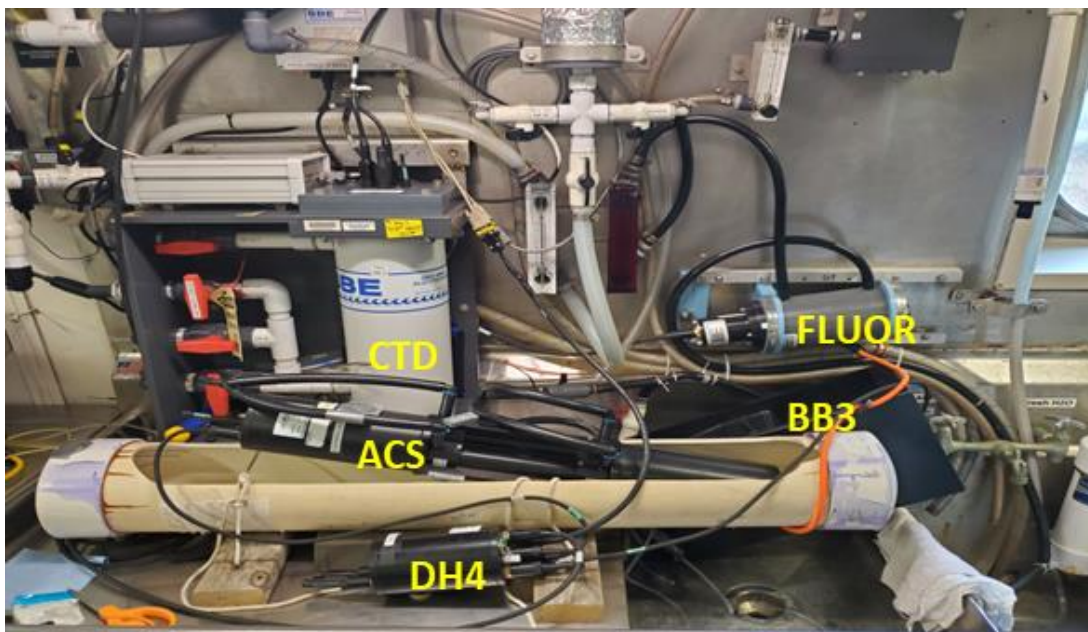


Figure 28. The NRL IOP continuous flow-through wet lab setup on the NOAA Ship *Nancy Foster*, which included a hyperspectral ac-s instrument (non-filtered), BB3 sensor, and access to the ship's GPS and Thermo-Salinograph (CTD). The instrument data were recorded using a DH4 data logger. The ac-s instrument was placed inside a PVC tube water bath to maintain a constant temperature during operation and was calibrated with Nanopure™ water before and after the cruise. The BB3 instrument was placed inside a flow cell. Both the PVC tube and the BB3 flow cells were designed specifically for those instruments.

The hyperspectral ac-s instrument measured $c(\lambda)$ and $a(\lambda)$ from 400 nm to 743 nm at approximately 4.0 nm spacing, and the BB3 instrument returns total volume scattering function (β), volume scattering function of particles (β_p), $b_{bp}(\lambda)$, and $b_b(\lambda)$ at 3 channels (440 nm, 532 nm, and 650nm). Concurrent flow-through measurements of time, latitude, longitude, temperature, and salinity from a thermosalinograph (CTD) will be used for correction of the ac-s $a(\lambda)$. Correctly addressing the thermal, salinity, and scattering ($c-a$) corrections that must be applied is important (Röttgers et al., 2013; WET Labs Inc., 2013). All the flow-through instruments collected through the DH4 were time-merged using the Archive Processing program (WAP), and hourly output archive files were generated. Hourly WAP archive files were then combined to create daily files. The daily WAP archive files were binned to 1-minute time bins to reduce the amount of data for spreadsheet import and analysis. The standard order of the post-processing protocol used (WET Labs Inc., 2013):

- Detrending if sensor drift over time was encountered.
- Apply temperature and salinity corrections to ac-s $a_t(\lambda)$ data using the coincident ship thermo-salinograph temperature and salinity data.
- Temperature-corrected pure water calibration data for $a_t(\lambda)$ and $c_t(\lambda)$.
- Subtract the pure water calibration data from the in situ data.
- Remove spikes in data due to bubbles, etc., using a σ filter and then interpolate.
- Apply scattering corrections to total absorption $a_t(\lambda)$ according to Röttgers et al. (2013).

- Add spectral pure-water absorption coefficients (Pope and Fry, 1997) to measured $a_{t-w}(\lambda)$ to yield $a_t(\lambda)$.
- Compute spectral scattering $b(\lambda) = c_t(\lambda) - a_t(\lambda)$.

A preliminary in situ IOP data comparison is given in Figure 30. The in situ data are further compared with satellite matchup data in Figure 31.

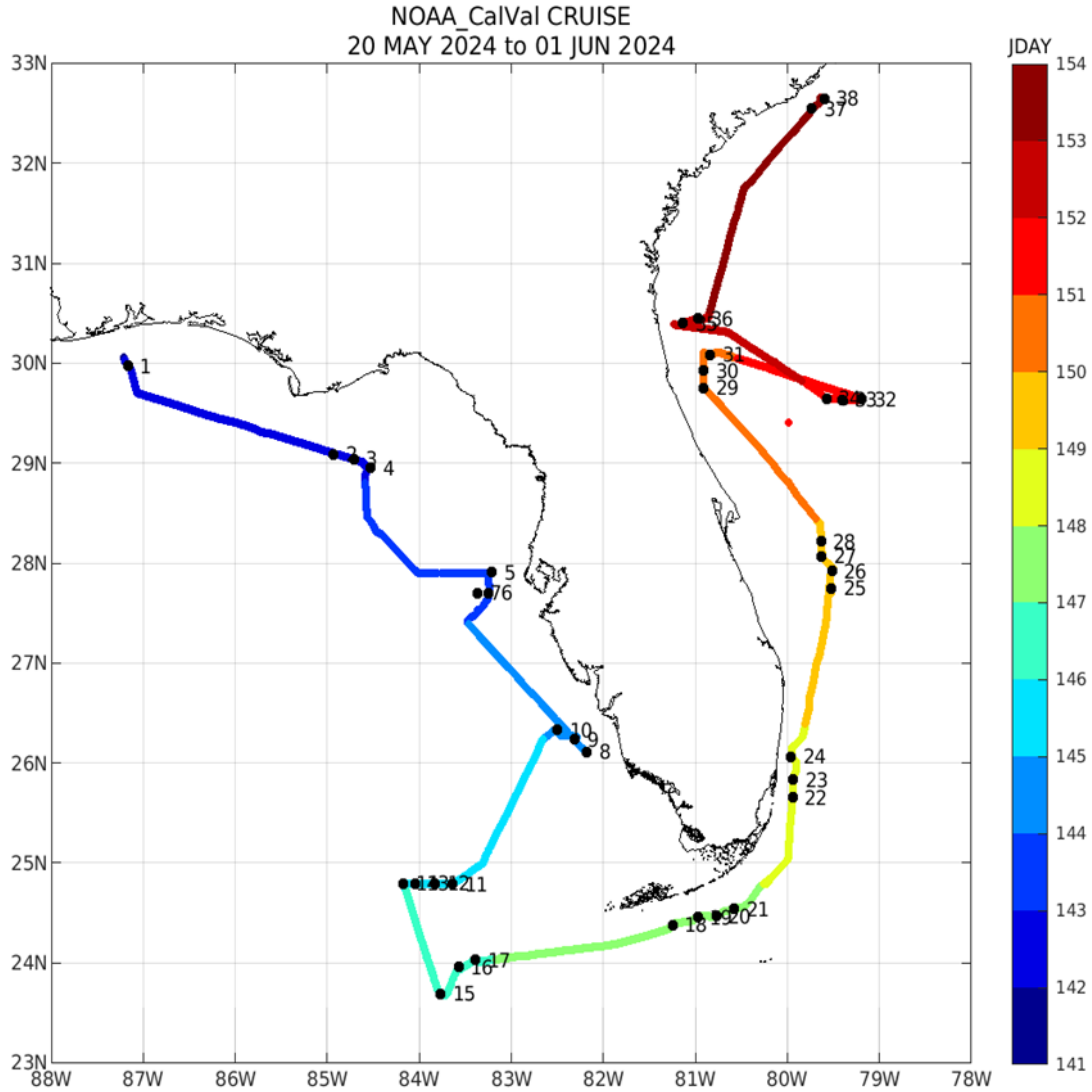
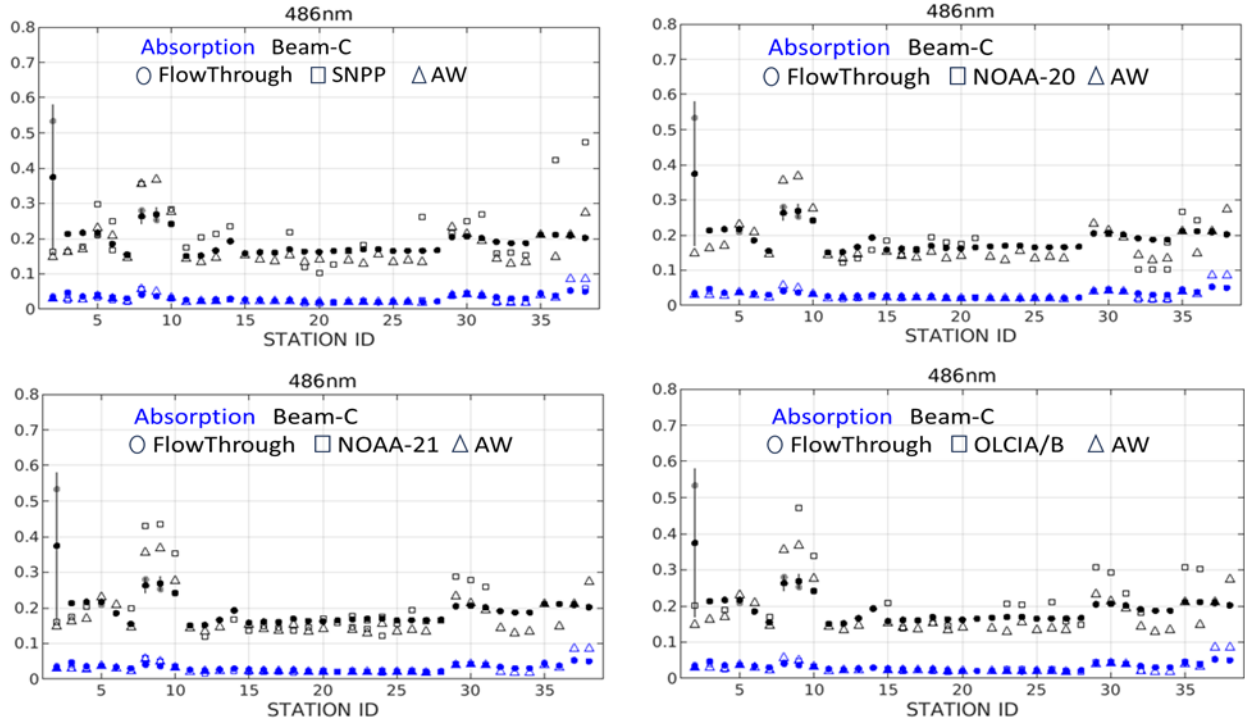


Figure 29. Illustration of the 38 station locations (black circles/numbers) covered aboard the NOAA Ship *Nancy Foster* departing Pensacola, Florida, and finishing up in Charleston, South Carolina. The line represents the cruise track from May 20 through June 01, 2024. The color palette represents the Julian Day and shows the coverage and sampled stations for each day of the cruise.



- FT = mean & standard deviation (Station GMT $\pm$ 30 minutes)
- AW = QAA IOP Algorithm applied to NRL Spectral Evolution Rrs.
- Good agreement between FT and Satellite IOPs.
- Higher variability near coast.

Figure 30. Satellite (open squares) and flow-through IOP (filled circles) matchups for total absorption (blue) and beam attenuation (black) at 486 nm for each station (x-axis) are shown for all plots. The Spectral Evolution hyperspectral $R_{rs}(\lambda)$ (AW – open triangles) was input into the same IOP model (QAA) used in the satellite processing. The plots represent in situ IOP matchups with SNPP VIIRS (top left), NOAA-20 VIIRS (top right), NOAA-21 VIIRS (bottom left), and Sentinel-3A/B OLCI (bottom right) for each station. The standard deviation for the satellite extractions ($\pm$ 30 minutes from the station above water measurements) is also shown on plots but is only visible for nearshore stations. Note good agreement between in situ and satellite IOPs. Higher variability occurs near the coast.

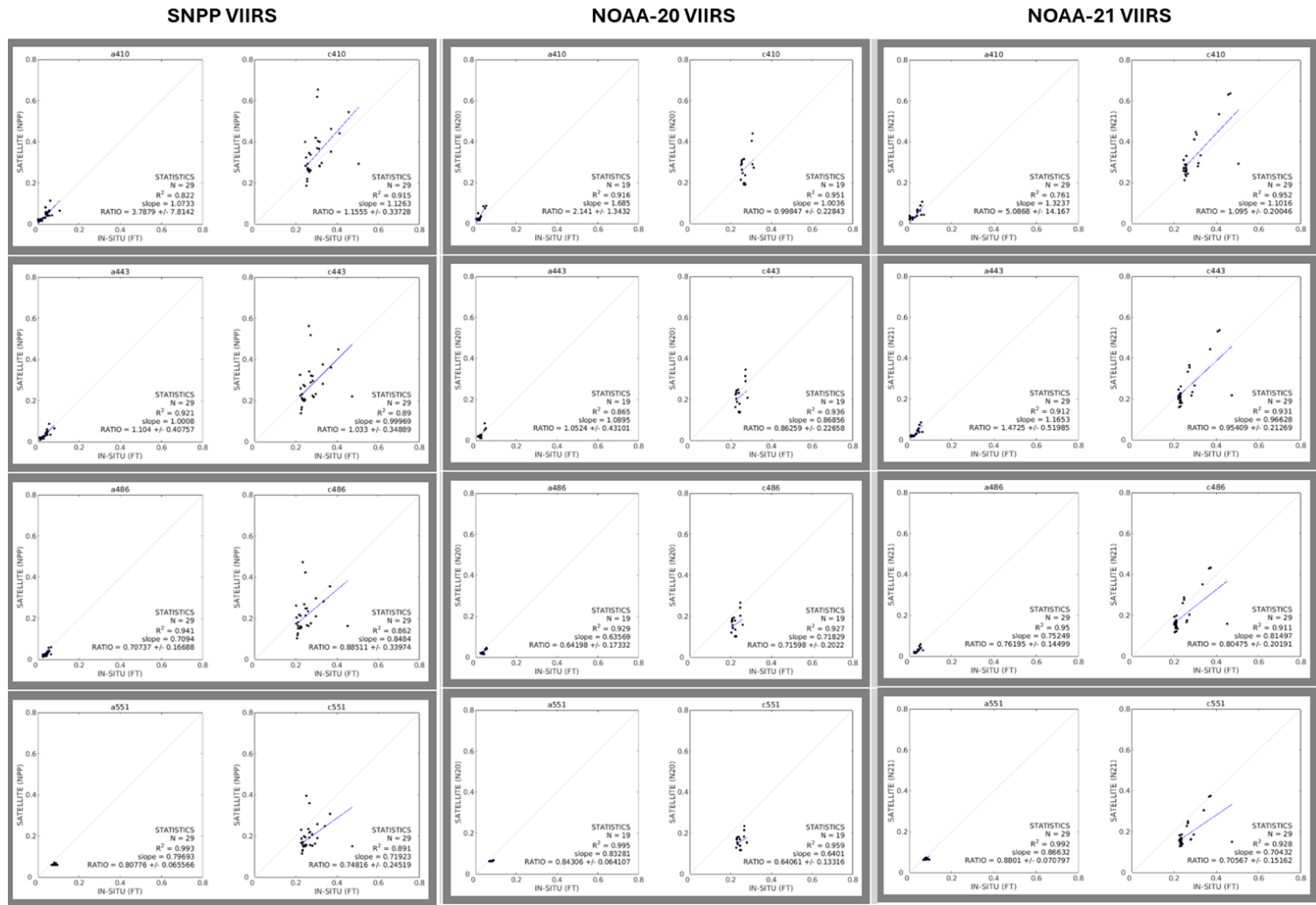


Figure 31. Satellite and in situ flow-through IOP matchups for SNPP (left), NOAA-20 (middle), and NOAA-21 (right) VIIRS total absorption (left column) and beam attenuation (right column) at 410 nm, 443 nm, 486 nm, and 551 nm for all valid station locations. The number of valid stations (N) and statistics including R^2 , slope, and ratio are located at the bottom right of each plot.

5. Measurements of Reflectance, Polarization and Fluorescence (CCNY Team)

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The main instrument of the CCNY group used for above-water observations in the validation process was GER (Spectra Vista Corporation, NY). Measurements were also made with the hyperspectral polarimetric imaging system, which included a snapshot hyperspectral imager ULTRIS X20 (Cubert Hyperspectral, Germany) and a polarization camera M2450 (Teledyne DALSA, Canada). In addition, AOT was measured by a Microtops II sunphotometer (Solar Light, PA) at 5 wavelengths: 380, 500, 675, 870, and 1020 nm. A Custom Laser Analytical Spectroscopic System (CLASS) (analog of the ALFA instrument) was used to measure Chl-a concentration together with the concentrations of other pigments on the way in the flow-through mode.

5.1. Handheld Spectroradiometer

The GER 1500, Field Portable Spectroradiometer, is a hand-held spectroradiometer designed to provide fast spectral measurements covering the UV, Visible, and NIR wavelengths from 350 to 1050 nm at 3 nm full-width half-maximum (FWHM) resolution. It uses a diffraction grating with a silicon diode array that has 512 discrete detectors and provides the capacity to read 512 spectral bands. Subsequent download and analysis are done using a personal computer with a standard RS232 serial port and the GER 1500 licensed operating software. The GER 1500 is equipped and operated with a standard lens with 4° nominal FOV for above-water observations. The GER 1500 spectral radiometer calculates $R_{rs}(\lambda)$ by sequentially measuring total sea-surface radiance $L_t(\lambda)$, sky radiance $L_{sky}(\lambda)$, and downwelling plaque radiance $L_p(\lambda)$.

The instrument underwent radiometric and wavelength calibration in the optics mode (with the lens) at NRL-DC in April 2024. Main details of the data processing follow the Mobley (1999) approach and are available in cruise report #4 (Ondrusek et al., 2019).

5.2. Hyperspectral Polarimetric Imaging System

The system (Figure 32) included a snapshot hyperspectral imager with a manually rotatable polarizer and a polarization camera, with a filter wheel that contained color filters. The system was operated by two laptop computers.

The hyperspectral imager has a unique capability of simultaneously recording data from 410×410 pixels, FOV = 35°, in the hyperspectral mode for each pixel with 164 bands in the range of 350-1000 nm. It is used for measurements of radiance at various viewing and azimuth angles in the FOV and estimation of radiance uncertainties in the hyperspectral mode.

The polarization camera is equipped with a Sony image polarization sensor with $2464 \text{ (H)} \times 2056 \text{ (V)}$ pixels, where each 2×2 pixel area consists of four subpixels that are equipped with polarizers oriented at 0° , 90° , 45° , and -45° , respectively, which was integrated by Teledyne DALSA into the M2450 camera and calibrated at CCNY. In our implementation, it is coupled with a lens and a motorized filter wheel (Finger Lakes Instrumentation, NY) containing five narrow band-pass filters (AVR Optics, NY) with rectangular transmission spectra at the following center wavelengths (bandwidths): 442 (42), 494 (41), 550 (32), 655 (40), and 684 (24) nm, plus an open aperture for panchromatic observations. The camera and lens provide a rectangular FOV ($\text{HFOV} \times \text{VFOV} = 29.2^\circ \times 38.4^\circ$) similar to the FOV of the imager. Typical integration time was 2 ms for water measurements, 0.7 ms for sky measurements, and 0.05 ms for white plaque measurements. Videos of the water surface were acquired with a typical frame rate of about 30-40 frames/second and 8-bit digitization; standalone images were acquired with 8- and 12-bit digitization. The user interface provided by the manufacturer was integrated with the filter wheel interface to allow for automatic acquisition of videos and images of polarization components. These images and videos were then reprocessed to get images and videos of Stokes vector components, the Degree of Linear Polarization (DoLP) and angle of linear polarization (AoLP), which are further used in the analysis (Malinowski et al., 2024a).

Polarimetric measurements provide important information in the characterization of ocean wave slopes and analysis of their variability in different open ocean and coastal areas as a function of wind speed in comparison with the Cox-Munk model (Cox and Munk, 1954), which is a part of the atmospheric correction model.

5.3. CLASS System

The CLASS instrument is a compact laser fluorometer that provides fluorescence measurements of chromophoric organic matter (COM), chlorophyll, and phycobiliprotein pigments from the deconvolution of the fluorescence spectra resulting from the excitation of the water in the sample cuvette by the laser light at the blue (405 nm) and green (520 nm) wavelengths. For Chl-a measurements, the instrument was calibrated using fluorometric Chl-a measurements in previous cruises. Post-cruise calibration was performed against NASA high-performance liquid chromatography (HPLC) data from water samples collected at the stations.

In addition to the validation of the VIIRS and OLCI sensors, the focus in this cruise was also on the validation of the PACE OCI instrument.



Figure 32. Snapshot hyperspectral imager with polarization camera on the ship.

5.4. Preliminary Results

Examples of comparison of measurements by GER and OC satellites for four stations are shown in Figure 33. GER spectra were adjusted to have $R_{rs}(750) = 0 \text{ sr}^{-1}$.

Examples of imager data from two stations are shown in Figure 34. The standard deviation spectra are typical for windy conditions with some glint at Station 26 and lower wind at Station 31. Standard deviation spectra characterize the $L_t(\lambda)$ and $R_{rs}(\lambda)$ uncertainty measurements in the hyperspectral mode (Malinowski et al., 2024b).

Examples of measured Stokes vector parameters I, Q, and U with Q/I and U/I in the normalized form and the DoLP measured by the polarization camera are shown in Figure 35 for two stations: Station 5 in coastal waters and Station 11 in open ocean waters. The DoLP mostly follows the water absorption spectrum: higher values in the blue and red in coastal waters and increasing towards red in the open ocean waters. These data will be used for the validation of data from the PACE polarimeters.

The Chl-a distribution along the cruise track from the CLASS instrument is shown in Figure 36, with mostly Chl-a below 0.5 mg m^{-3} around the coast and higher Chl-a at the beginning of the cruise.

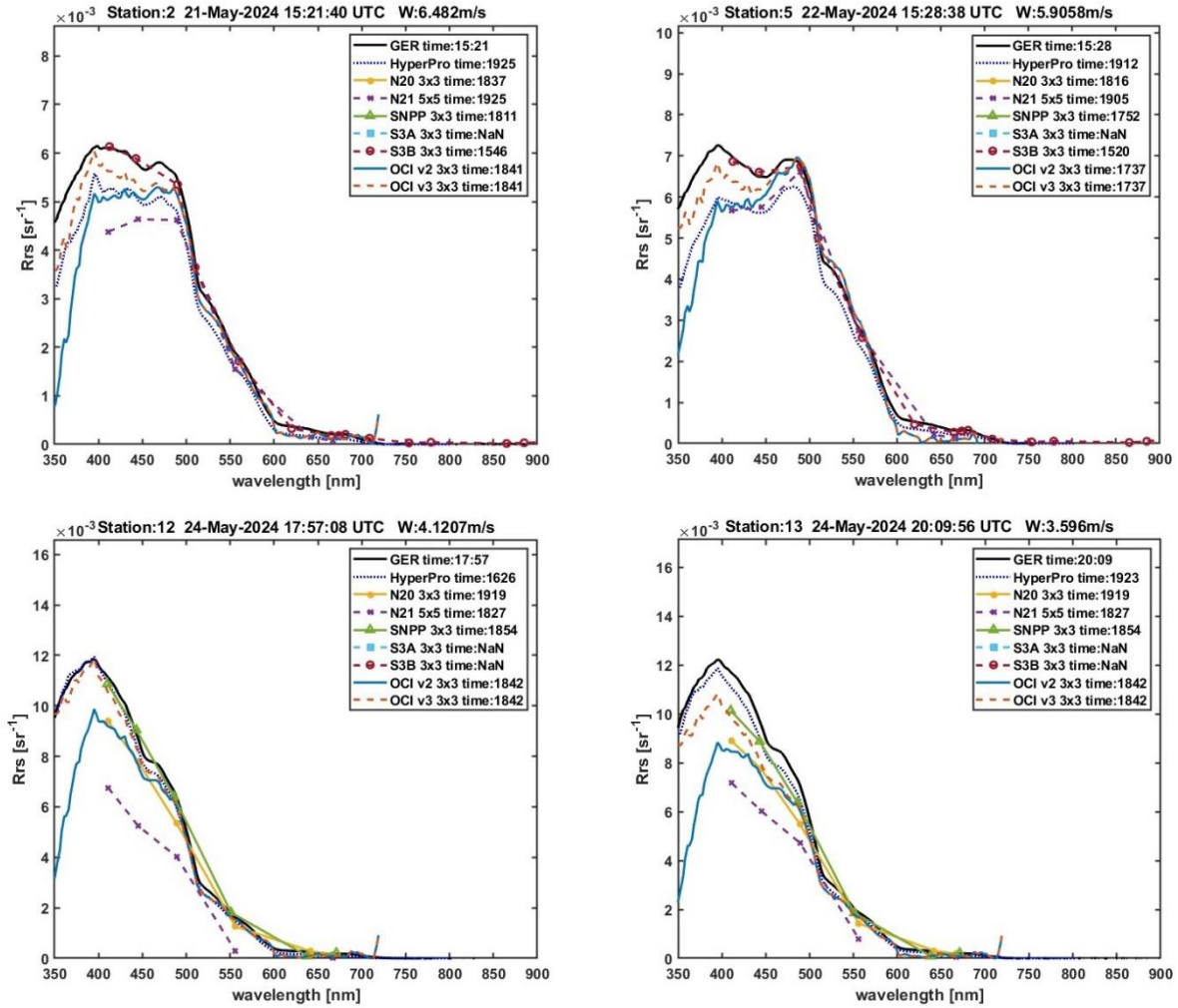


Figure 33. Comparison of measured spectra by GER and satellite data for four stations: coastal waters (1st row: Station 2 and Station 5), open ocean waters (2nd row: Station 12 and Station 13). There are also spectra from the HyperPro measurements by Mike Ondrusek.

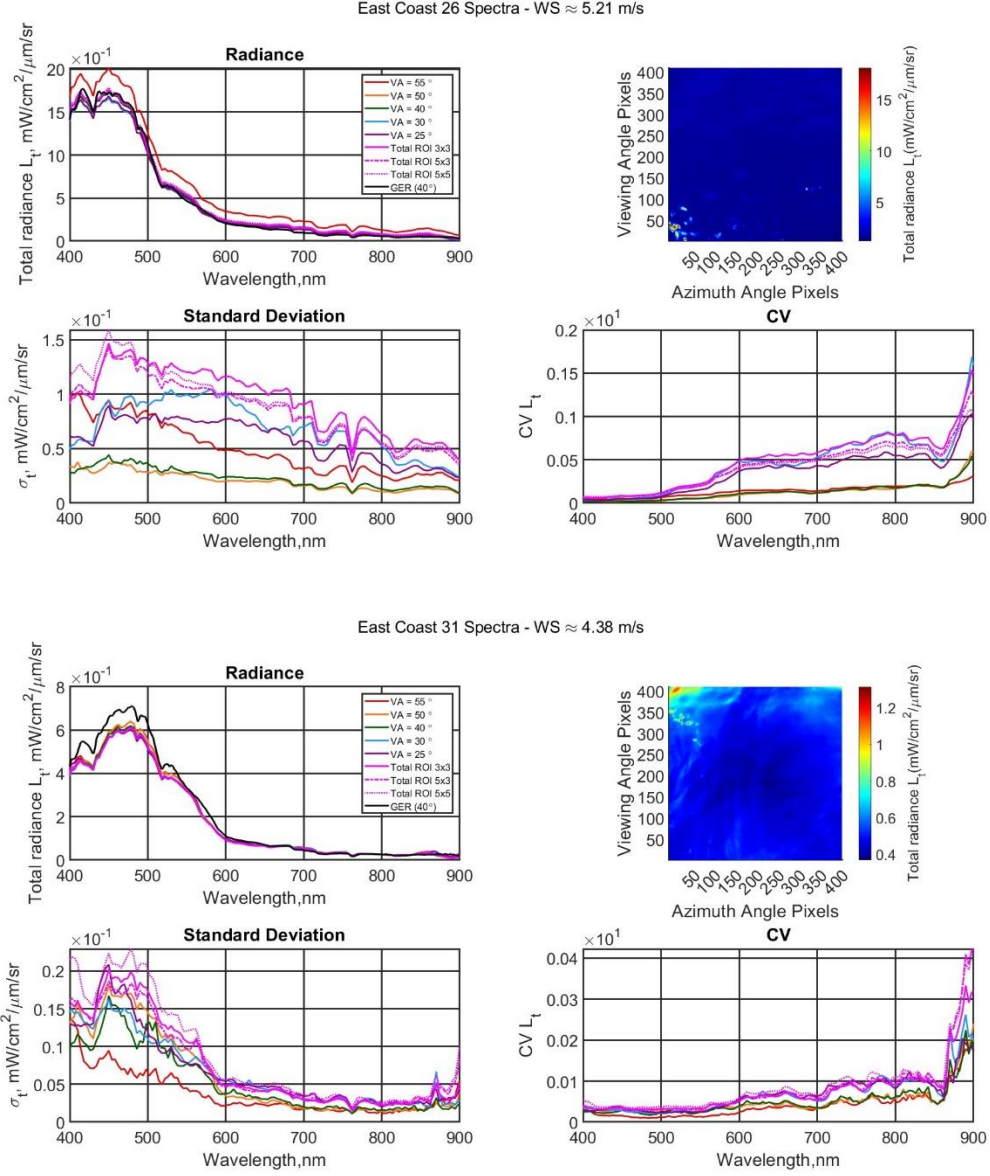


Figure 34. Data from the hyperspectral imager: above-water spectral radiances at viewing angles 25–55° compared with GER spectra (top left), radiance uncertainties (bottom left), radiance at 402 nm distribution in the FOV (top right), coefficient of variation (CV) (bottom right). Station 26 in open ocean waters, Station 31 in coastal waters.

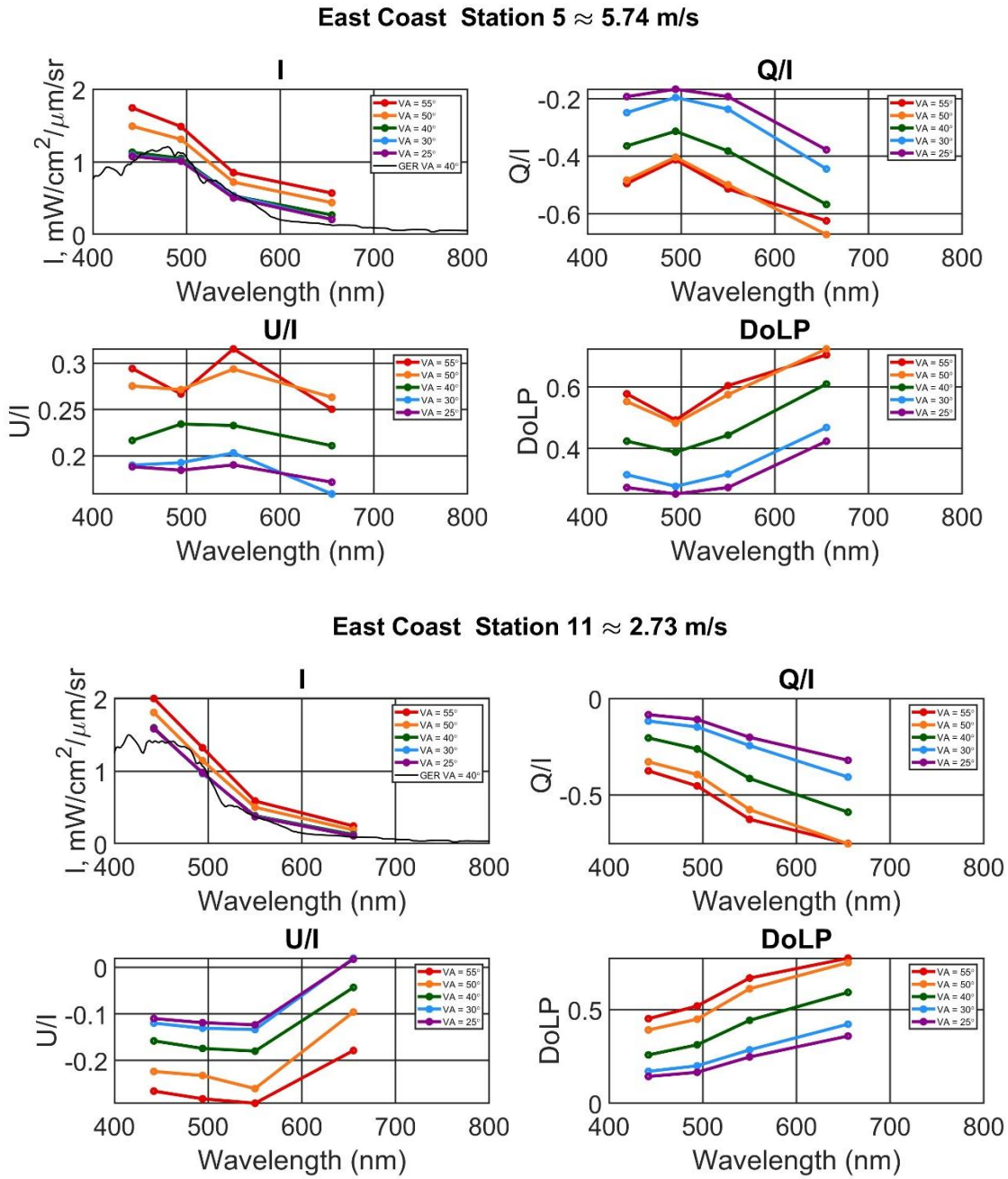


Figure 35. Example of measurements of I, Q/I, U/I and the DoLP by the polarization camera at Station 5 (1st and 2nd rows) and Station 11 (3rd and 4th rows).

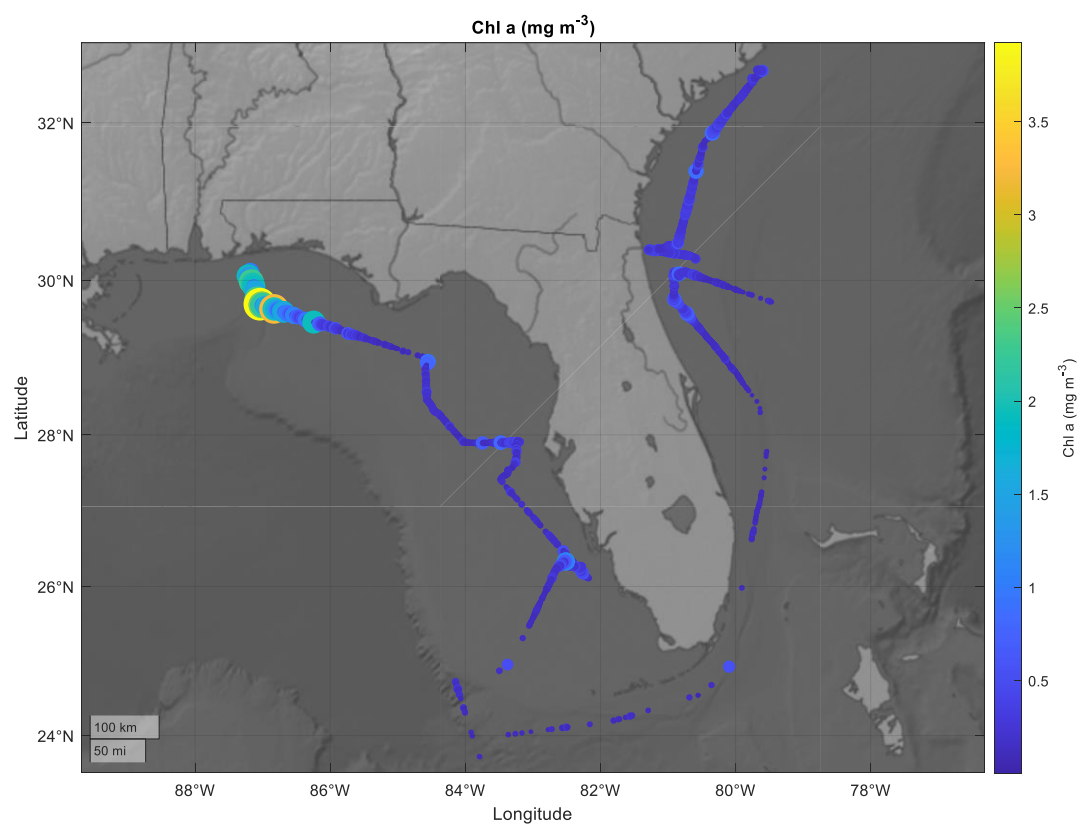


Figure 36. Chl-a distribution along the cruise track from the CLASS instrument.

6. Measurements of Spectral Absorption Coefficient and Reflectance (USF Team)

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University of South Florida, St. Petersburg, Florida

The goal of the USF effort on the 2024 VIIRS Cal/Val cruise was to measure bio-optical properties of surface waters for evaluations of VIIRS and other satellite measurements. These include the spectral absorption of particulate and dissolved materials, as well as fluorometric chlorophyll-a concentration, in near-surface water samples. Additionally, measurements for $R_{rs}(\lambda)$ estimation were made using above-water radiometry and in-water HyperPro-II profiling of the near-surface waters.

6.1. Spectral Absorption and Chlorophyll-a Concentration

Water samples were collected within 5 m of the surface at 31 stations using *Nancy Foster*'s CTD rosette, and from the ship's flowing seawater system at 5 stations (Table 4). These samples were filtered through a glass fiber filter (Whatman GF/F), and a portion of the filtrate was further filtered through a 0.2 μm nylon membrane filter. The GF/F filters were stored in liquid nitrogen and transferred to a -80°C freezer upon return to shore. The 0.2 μm filtrates were stored at $0-4^\circ\text{C}$. These samples were subsequently examined using a Perkin-Elmer Lambda 850+ spectrometer over a spectral range of ~ 300 to 800 nm at 1 nm intervals. The filtrate was used for the determination of the CDOM absorption, $a_g(\lambda)$. Measurement of the spectral absorption of filter pads determined the particulate absorption, $a_p(\lambda)$. Additional processing of the filter pads allowed for the separation of $a_p(\lambda)$ into a pigmented fraction attributed to phytoplankton, $a_{ph}(\lambda)$, and a detrital fraction, $a_d(\lambda)$ (Kishino et al., 1985). This extraction of the particulate pigments also allowed fluorometric determination of Chl-a (Welschmeyer, 1994) using a Turner Designs Trilogy fluorometer. These Chl-a and CDOM absorption at 400 nm are shown in Table 4, and the spatial distribution of the samples is shown in Figure 37.

Chl-a from all collected water samples ranged from 0.03 to 0.64 mg m^{-3} and averaged $\sim 0.14\text{ mg m}^{-3}$. CDOM absorption at 400 nm ranged from 0.011 to 0.365 m^{-1} , with a mean of 0.048 m^{-1} . Figure 38 shows the particulate and CDOM absorption spectra derived from the water samples, which provide information about the materials present in the water samples.

6.2. Above-water Remote Sensing Reflectance

Above-water $R_{rs}(\lambda)$ measurements were collected at 33 stations using a SVC HR-512i spectroradiometer, which has a spectral range from $<350\text{ nm}$ to $>850\text{ nm}$ with $<3.5\text{ nm}$ resolution. The USF HR-512i failed near Station 22, so NOAA's HR-512i was used after Station 25. The $R_{rs}(\lambda)$ was derived from multiple radiance measurements of the water's surface, the sky, and a white-reference reflectance plaque (Carder and Steward, 1985; Mueller et al., 2003). The measurements were taken from a location near the ship's bow. The solar zenith angle, wind speed,

and instrument viewing angles were used to determine a correction factor for reflected skylight (Mobley, 1999). The HR-512i was used with a 4° FOV fore-optic lens, and the nominal measurements were made at an azimuth angle of 90° relative to the sun. The target viewing angles for the sea-surface and sky (θ_w & θ_s) were about 40° from nadir and zenith, respectively. The viewing angle was recorded by the HR-512i for each measurement, and $R_{rs}(\lambda)$ was computed for each measurement sequence using both the instrument and nominal viewing angles. The derived $R_{rs}(\lambda)$ for all the stations are shown in Figure 39.

6.3. In-water Radiometry

Early in the cruise, the USF HyperPro-II system experienced power and communication cable failures. To maintain continuity in the multi-profiler radiometric deployments at each station, a backup NOAA HyperPro-II system was substituted for the remainder of the campaign.

Table 4. Sampling time, depth, Chl-a, and $a_g(400)$ for water samples collected during the 2024 VIIRS Cal/Val cruise. Stations marked with * indicate water samples collected from the ship's flow-through system.

Time (UTC)	Station ID	Sample depth (m)	Chl-a (mg m ⁻³)	$a_g(400)$ (m ⁻¹)
5/20/24 21:24	1	1.5	0.444	0.3647
5/21/24 15:00	2	3*	0.121	0.0389
5/21/24 18:29	3	1.8	0.125	0.0326
5/21/24 21:45	4	1.8	0.116	0.0265
5/22/24 14:08	5	1.8	0.250	0.0542
5/22/24 17:30	6	1.8	0.175	0.0275
5/22/24 20:57	7	1.8	0.085	0.0173
5/23/24 14:26	8	1.8	0.640	0.0651
5/23/24 18:47	9	1.8	0.481	0.0602
5/23/24 21:48	10	1.4	0.245	0.0347
5/24/24 14:20	11	1.8	0.080	0.0169
5/24/24 16:41	12	1.8	0.077	0.0198

Continued next page:

Table 4. (Continued) Sampling time, depth, Chl-a, and $a_g(400)$ for water samples collected during the 2024 VIIRS Cal/Val cruise. Stations marked with * indicate water samples collected from the ship's flow-through system.

Time (UTC)	Station ID	Sample depth (m)	Chl-a (mg m^{-3})	$a_g(400)$ (m^{-1})
5/24/24 21:00	13	1.8	0.050	0.0215
5/24/24 22:40	14	3*	0.106	0.0239
5/25/24 14:35	15	1.8	0.085	0.0350
5/25/24 18:41	16	1.8	0.067	0.0217
5/25/24 21:37	17	1.8	0.080	0.0185
5/26/24 13:16	18	1.8	0.074	0.0222
5/26/24 16:51	19	1.8	0.047	0.0125
5/26/24 20:02	20	1.8	0.051	0.0155
5/27/24 14:37	22	1.8	0.080	0.0114
5/27/24 17:11	23	1.8	0.052	0.0167
5/27/24 21:26	24	1.8	0.037	0.0190
5/28/24 14:16	25	1.8	0.045	0.0127
5/28/24 17:26	26	1.8	0.033	0.0131
5/28/24 20:31	27	1.8	0.062	0.0189
5/29/24 14:23	29	1.8	0.211	0.0462
5/29/24 17:20	30	5	0.218	0.0575
5/29/24 21:39	31	5	0.191	0.0519
5/30/24 14:15	32	1.8	0.060	0.0260
5/30/24 17:46	33	1.8	0.046	0.0242
5/30/24 21:50	34	1.8	0.040	0.0183
5/31/24 20:09	35	3*	0.208	0.0426
5/31/24 21:15	36	3*	0.162	0.0381
6/1/24 17:33	37	1.8	0.175	0.1947
6/1/24 21:33	38	3*	0.176	0.2071

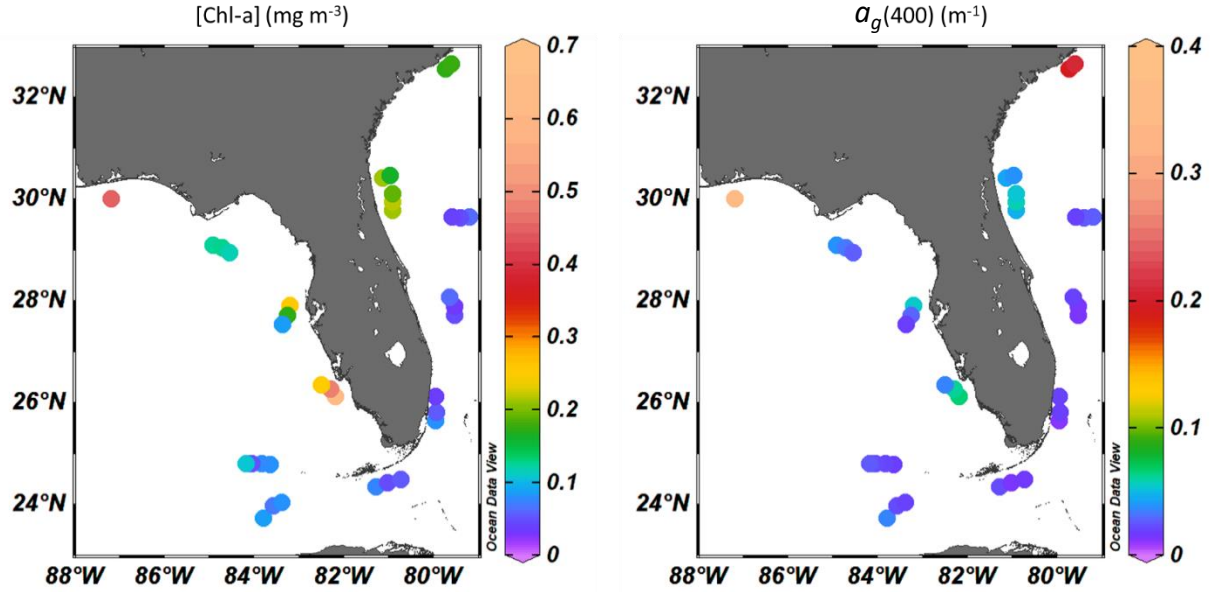


Figure 37. Distribution of water sample measurements, with symbols indicating Chl-a values in the map on the left, and $a_g(400)$ in the map on the right.

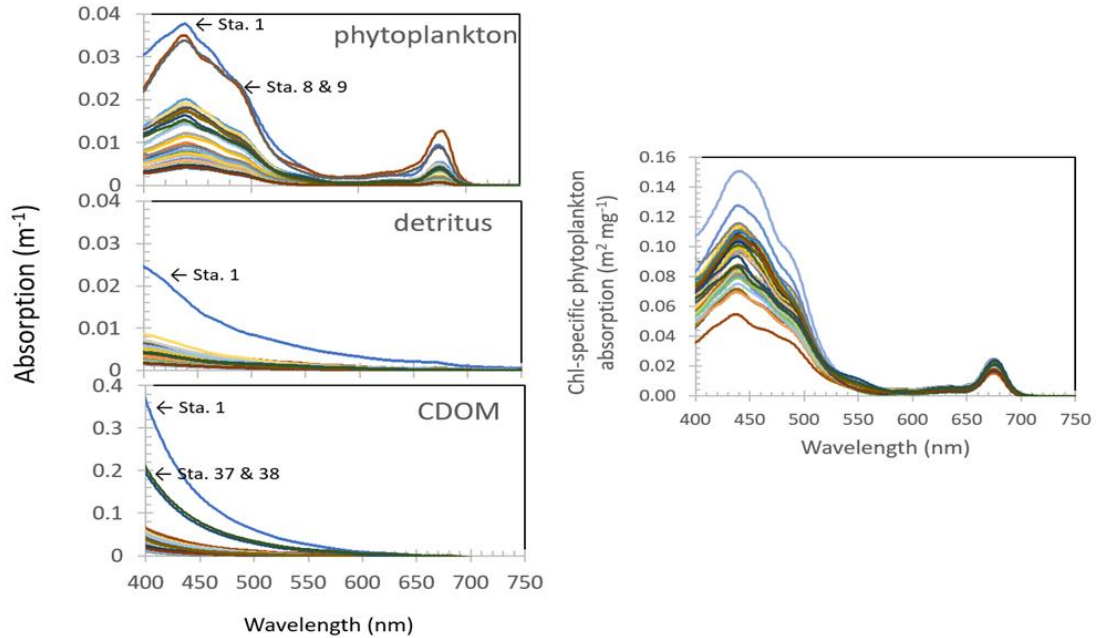


Figure 38. Spectral light absorption coefficients for phytoplankton pigments (top-left), non-pigmented particulate matter (i.e., detritus, center-left), chromophoric dissolved organic matter (bottom-left), and the chlorophyll-specific phytoplankton absorption ($a_{ph}^*(\lambda)$, right panel). The locations of selected stations (1, 8, 9, 37, and 38) are shown in Figure 37.

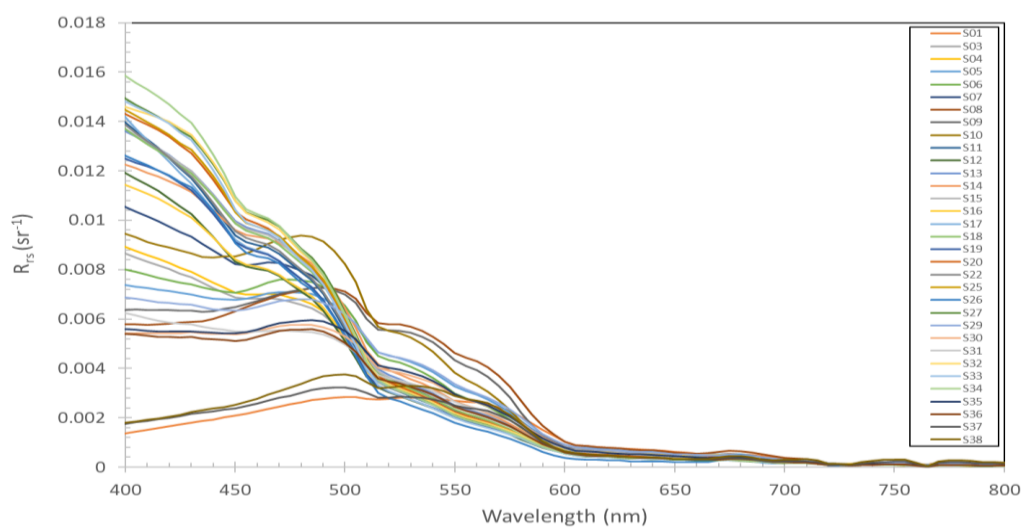


Figure 39. $R_{rs}(\lambda)$ for each station, derived from above-water HR-512i measurements collected with the USF sampling sequence.

7. Measurements of Hyperspectral AOPs and Surface Irradiance (OSU Team)

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The OSU team deployed a hyperspectral in-water profiler and a suite of newly developed open-source multispectral radiometers during the cruise, with two-fold objectives: 1) to derive water-leaving radiances and reflectances from the in situ profiler for product validation and calibration of VIIRS ocean color observations, and 2) to test the new open-source radiometers and compare the results of these cost-effective downwelling irradiance sensors with the leading industry standard, the HyperOCR.

7.1. Radiometric Measurements with a HyperPro

OSU operated a set of hyperspectral ocean color sensors attached to a Satlantic/SeaBird Scientific (SBS) HyperPro-II in the free-fall profiler configuration. Both commercial (SBS HyperOCR) and open-source (ARON) downwelling irradiance sensors were mounted on a Grappa pole to mitigate stray light contamination from the vessel. An upwelling radiance sensor and a downwelling irradiance sensor were mounted directly onto the HyperPro-II system in the standard configuration to derive $L_w(\lambda)$, $nL_w(\lambda)$, and $R_{rs}(\lambda)$.

The HyperPro-II is deployed overboard and kited at a minimum distance of 20 m from the hull (allowed to drift) so that the shadow of the ship and reflected light from the vessel do not interfere with the optical measurements. We also ensure that the E_d sensor of the HyperPro-II is facing the sun to avoid self-shadowing during deployment. Weights were installed in the ‘nose cone’ of the HyperPro and adjusted depending on the density of the seawater to allow a ‘slow drop’ profile ($\sim 0.3 \text{ m s}^{-1}$ or less).

Data were collected using Satlantic’s SatView and Nils Haentjen’s Inlinino (Haëntjens and Boss, 2020)(see <https://github.com/OceanOptics/Inlinino>). Inlinino provides a more user-friendly interface than Satlantic’s SatView and has regular updates. Post-processing was performed with Satlantic’s ProSoft version 8.1.4 using protocols outlined by Jasmine Nahorniak (aquahue.net) and Mike Ondrusek. The equations used by ProSoft to derive the above-water products are listed below.

$$R_L(0^+, \lambda) = \frac{L_w(0^+, \lambda)}{E_d(0^+, \lambda)}$$

where $E_d(0^+, \lambda)$ denotes downwelling spectral irradiance measured just above the surface (i.e., $E_s(\lambda)$) or extrapolated through the surface. For $E_s(\lambda)$, the median of the time series data is taken for each wavelength. $L_w(0^+, \lambda)$ denotes upwelling spectral radiance propagated through the surface.

$$L_{wn} = L_w(\lambda) \frac{F_o(\lambda)}{E_s(\lambda)}$$

where $F_o(\lambda)$ is the mean extraterrestrial solar irradiance, and $L_w(0^+, \lambda)$ is the upwelling radiance propagated through the surface $Z(0^+)$ using the following

$$L_w(0^+, \lambda) = L_u(0^-, \lambda) \frac{1 - \rho(\lambda, \theta)}{n_w^2(\lambda)}$$

where the Fresnel reflectance index of seawater $\rho(\lambda, \theta)$ is defaulted to 0.021, and $n_w(\lambda)$ is the Fresnel refractive index of seawater (Default value 1.345).

All remote sensing reflectances derived from the HyperPro profiles are shown below (Figure 40). Apparent visible wavelengths (AVWs) were added following the derivations in Vandermeulen et al. (2020). These AVWs aid in the assessment of optical water type; values closer to 440 nm reflect pure, clear, oceanic waters, while values closer to 500 nm represent turbid, sediment-, or phytoplankton-laden regimes.

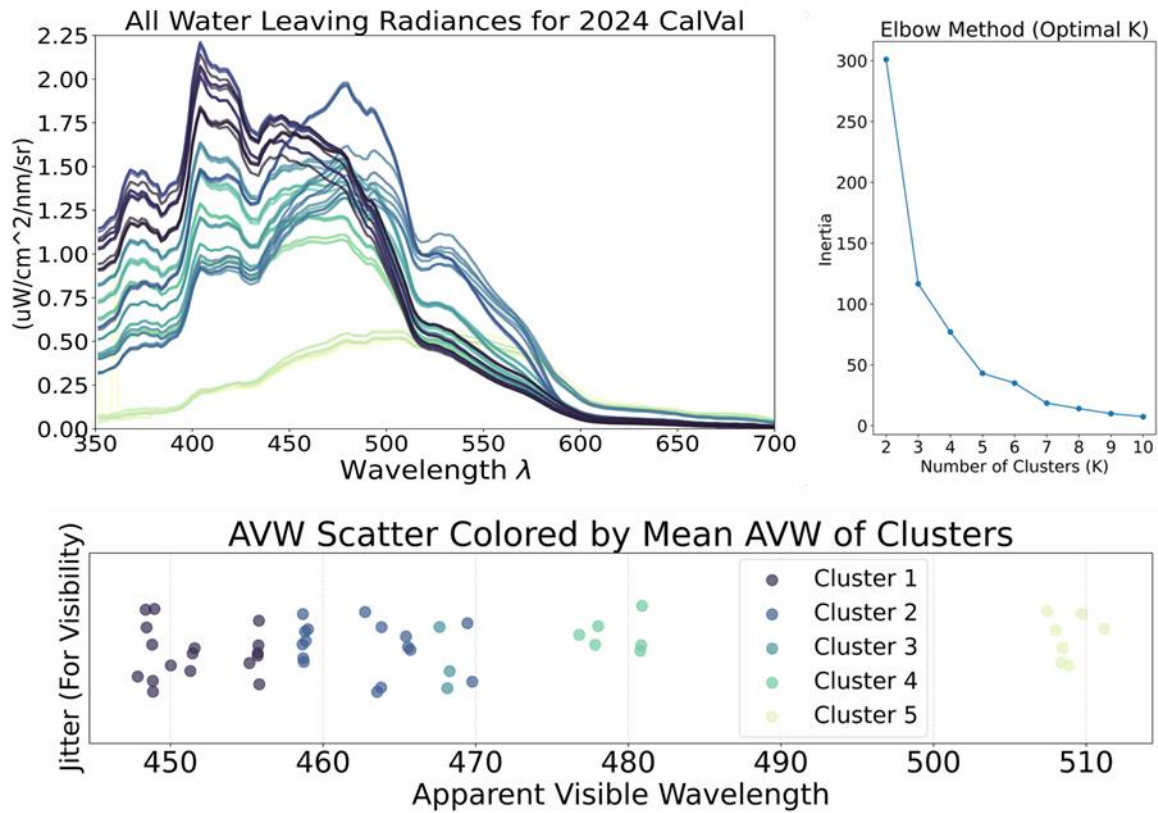


Figure 40. Example of all water-leaving radiance derived from HyperPro throughout the cruise (upper left) and the apparent visible wavelengths (lower panel). The spectra are colored based on optical water types, which were binned using an elbow method (upper right) from the Python library scikit-learn, including a k-means clustering of the spectra.

7.2. Measurements from Open-Source Sensors

Open-source tools provide accessible and cost-efficient alternatives for oceanographic instrumentation. The high cost of oceanographic instrumentation from industry is often a large barrier for scientists, particularly those outside of the United States. Open-source tools can often provide similar data quality to their industrial counterparts at a fraction of the cost. Here, we trade the high spectral resolution of the HyperOCR (~130 spectral channels) for an open-source sensor, the AMS731 (10 spectral channels), that can be easily assembled and deployed for less than one-hundredth the cost of its commercial counterpart. Triplicate copies of these open-source irradiance sensors were brought on this cruise and mounted on the Grappa pole along with their commercial counterparts, which included three HyperOCRs and a Biospherical irradiance sensor (Figure 41).



Figure 41. Open Source spectral sensors (3D-printed housings with die-cut PTFE cosine correctors) are marked with an orange star. They are mounted directly adjacent to HyperOCRs and a Biospherical irradiance sensor.

Sensors were constructed of a 3D-printed Acrylonitrile Butadiene Styrene (ABS) housing with a CNC-milled polytetrafluoroethylene (PTFE) cosine corrector. A 10-channel photodiode (AMS7341) was laid beneath the fore optics, with unique channels (wavelengths/colors of light) created by annealing small filters over independent sections of a photodiode. The 10-channel photodiodes were connected to an Arduino MKR Zero microcontroller, which was powered by an internal 3.7V Lithium Polymer (LiPo) battery. We chose the Arduino MKR Zero for easy data logging using the onboard microSD port. We programmed the microcontrollers to optimize the gain and integration times of the AMS7341 based on the ambient light conditions. Code can be found in a public repository (<https://github.com/abailless/ARON/blob/main/MySAS.ino>).

We allowed the open-source and HyperOCR sensors to log data continuously for two and a half days and then began the matchup process. First, we binned the data by minute to remove small-scale swell and wave effects on the data. This was done by taking a 1-minute moving window after first removing any outliers from the data (if $SD > 5$). For the data closest to the satellite overpass time (within one hour), we filtered for only the highest values in the minute-binned window. We chose the highest values after outliers were removed because near solar noon these data correspond to when the irradiance sensors are pointed directly up at the sun - instead of the median or mean, which correspond to data during some level of pitch and roll from the ship at these times. This can be seen in Figure 42.

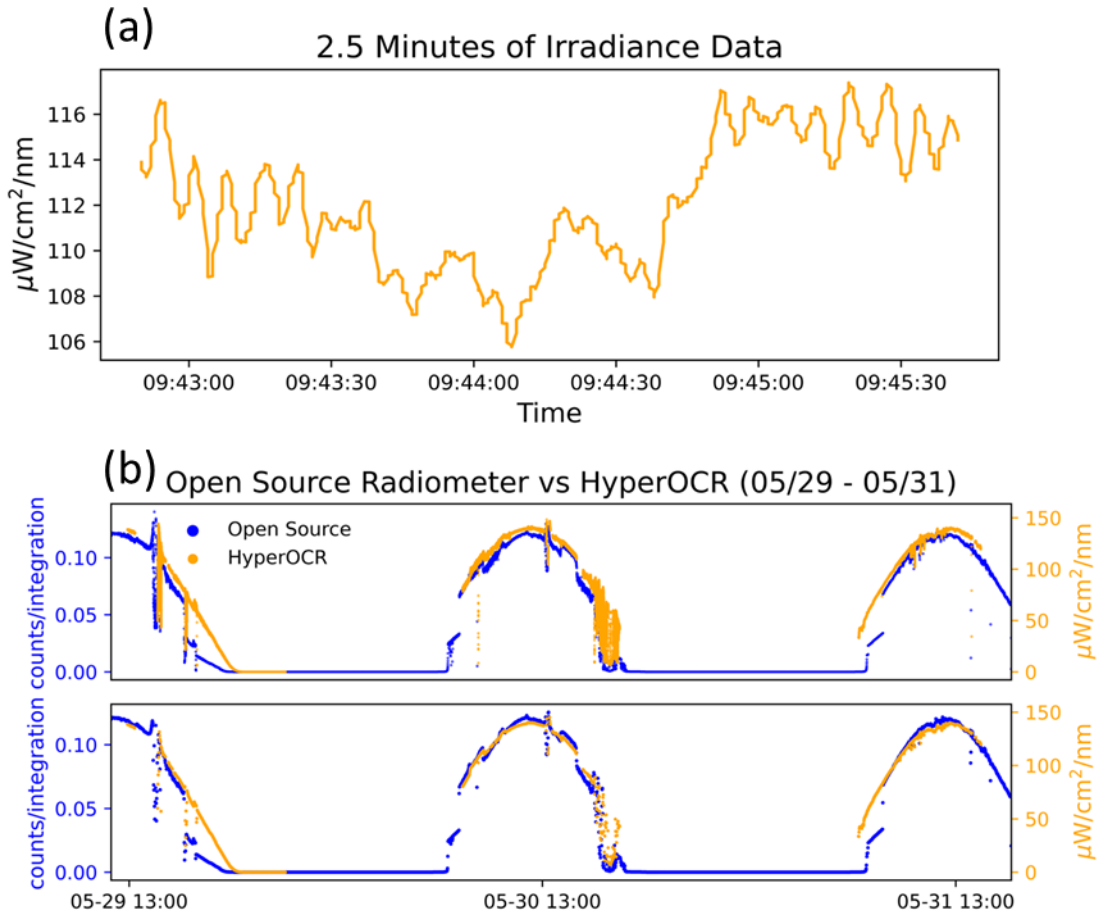


Figure 42. (a) Effect of swell and waves on *Nancy Foster* and its impact on the irradiance data; (b) Raw and minute-binned data from the uncalibrated open-source radiometer and HyperOCR sensors for two and a half days. Open-source sensor data is in counts/integration time, while the HyperOCR is in microwatts per square centimeter per nanometer.

The next set, after the time dimension was synced between the sensors, was to synchronize the spectral dimension. While we could simply match the center wavelengths of our open-source multispectral sensor to the HyperOCR, the optimal way to do this is to integrate over the entire spectral response function of each wavelength, rather than just one point. We obtained the full width at half maximum (FWHM) for the response functions of each wavelength and modeled a series of Gaussians to more accurately convert the hyperspectral spectra of the HyperOCR into the multispectral spectrum observed by the open-source sensors. This Gaussian decomposition can be seen in Figure 43, and its match over all measured spectra can be seen in Figure 44. We recognize that the HyperOCRs have their own spectral response functions that should be accounted for, but these are less significant (smaller FWHM) than those for the open-source sensors.

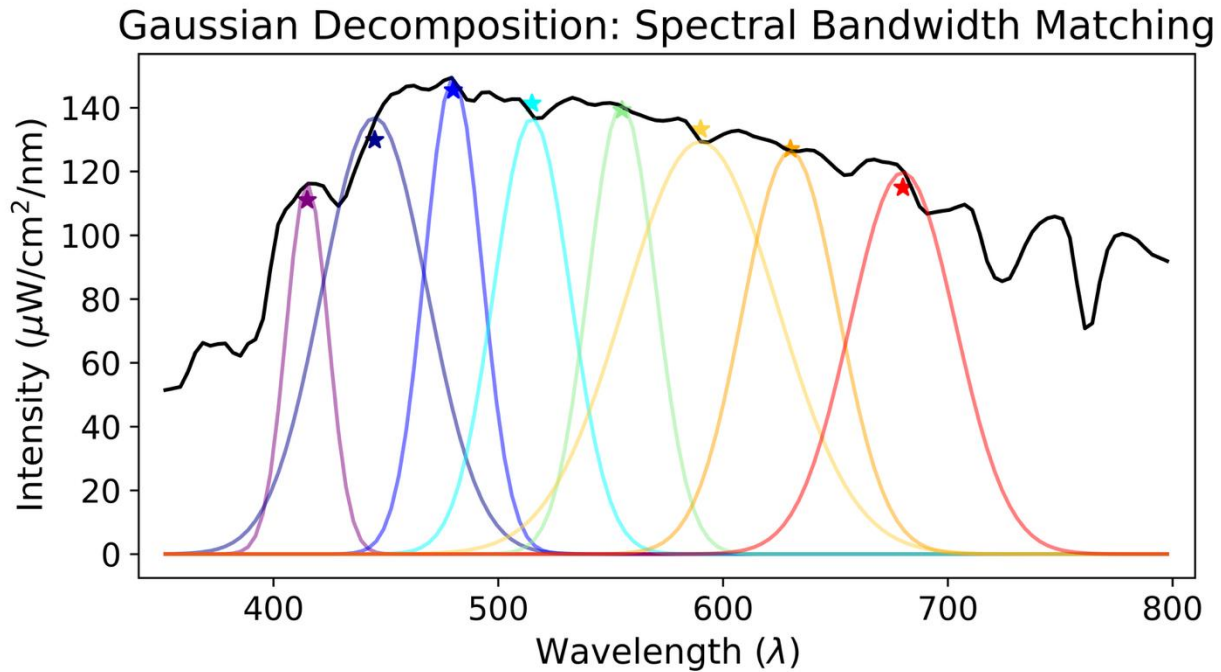


Figure 43. Spectral response functions of the open-source radiometers (colored by center wavelength) mapped to the measured hyperspectral irradiance of the sun and sky. The stars represent the ‘true’ value used to compare the HyperOCR to the open-source sensors, as they are integrated by their relative Gaussian weight to the measured irradiance reference spectra (black).

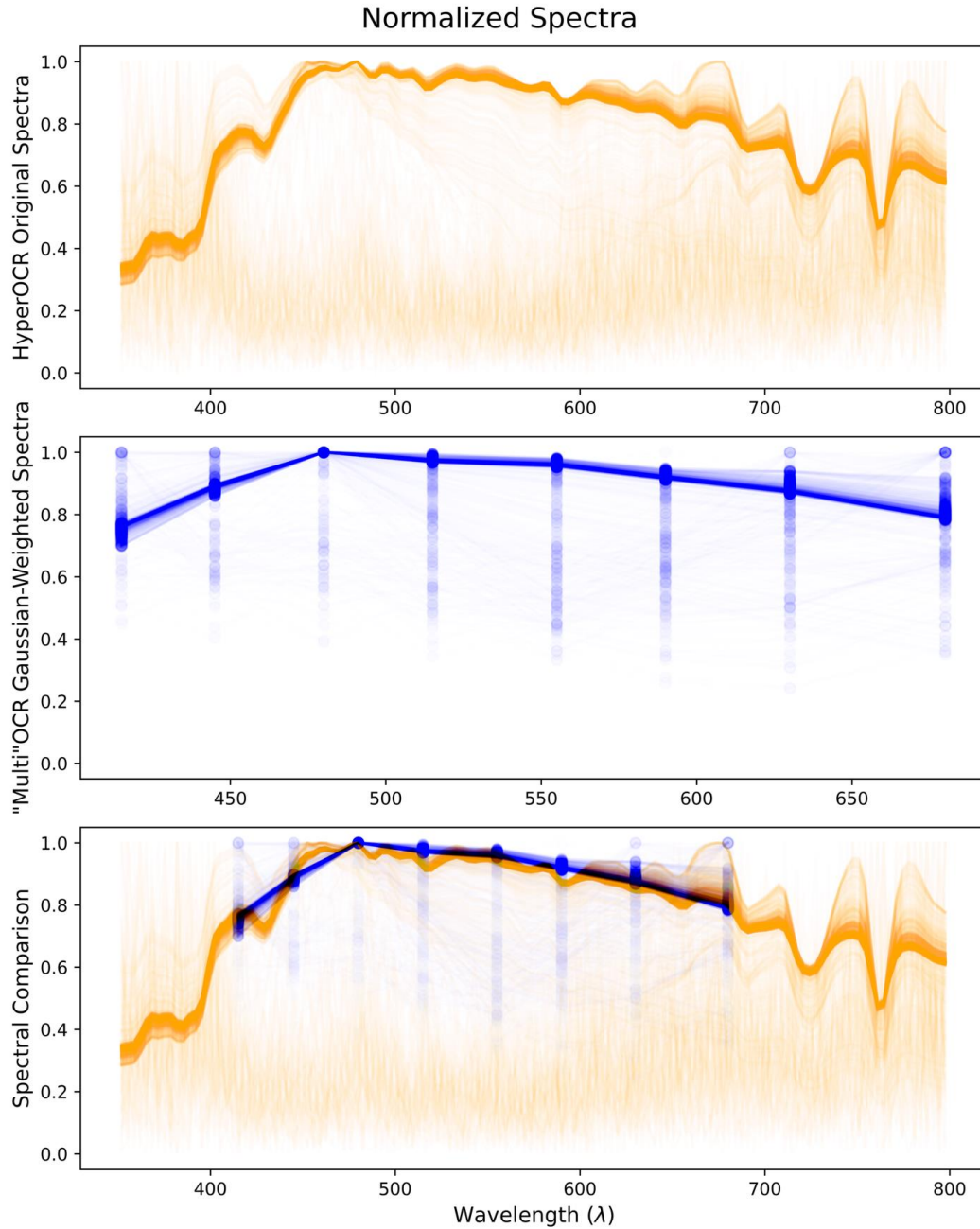


Figure 44. All hyperspectral irradiance measurements made during the two-and-a-half-day window are shown in the top plot. Spectra are plotted semi-transparently and normalized by their maximum value (to 1). Darker lines show significant and consistent ‘modes’ of spectral shapes. Notice the light orange noisy spectra at the bottom of the first plot (between 0.0 and 0.4) – these are the data collected at night and are below the detection limit for the instrument – it is just noise. The second plot shows all the multispectral data derived from the plot above using the Gaussian weighting function from Figure 43. They are overlaid with one another in the last plot of this figure.

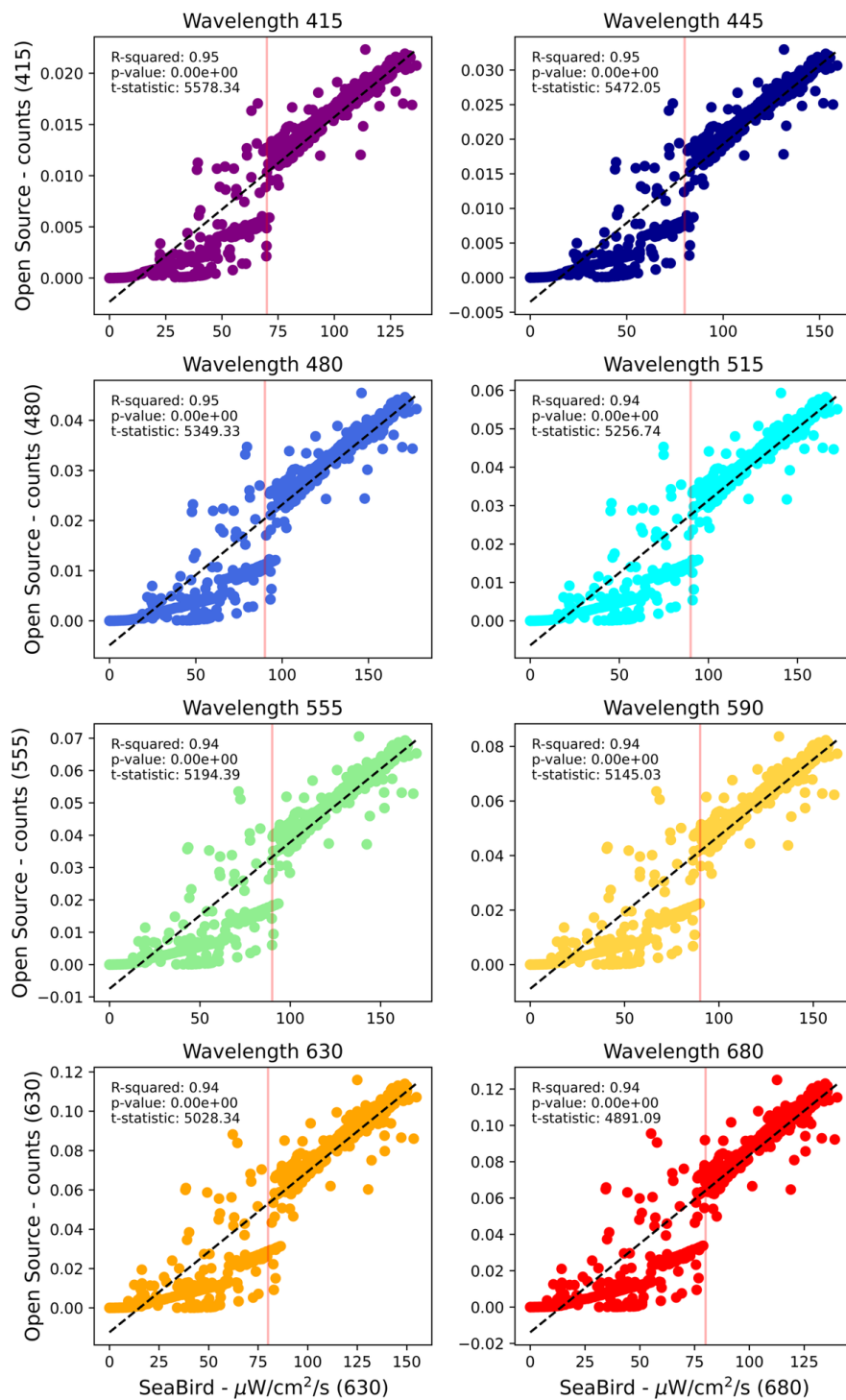


Figure 45. Linearity between the open-source sensors (y-axis: counts) and HyperOCR (x-axis: microwatts per centimeter squared per second). The red vertical line denotes a solar zenith angle of 45°.

Once the sensors were aligned in both time and spectral dimensions, we next examined the linearity of response. Matchups between all visible wavelengths for the sensors are shown in Figure 45. Note the high degree of linearity and strong R^2 values (0.94–0.95) between these sensors across nearly all irradiance values. However, there is a delineation in the matchup data between 70–90 $\mu\text{W}/\text{cm}^2/\text{s}$, which corresponds to a solar zenith angle of around 50° at the time and latitude where the data was collected (marked with a red line in Figure 45). We believe this step-function delinearity is a result of the height of the light-shield around the cosine corrector, which shadows part of the PTFE cosine corrector at mid to high solar zenith angles. Future iterations of the 3D-printed chassis will lower the height of this outer shielding and should resolve this issue. For this cruise, the delinearity at higher solar zenith angles was not detrimental for the majority of our measurements. This is because for calibration and validation of satellite products, we are ideally looking to collect data when the solar zenith angle is as close to 0° as possible; values between 0° and 30° are suitable, while values between 30° and 60° are occasionally acceptable in optimal atmospheric and oceanic conditions.

7.3. Summary

Reflectances and water-leaving radiances were derived for all stations using data from the hyperspectral in-water profiler. We found that throughout the course of this two-week cruise we encountered roughly 5 optical water types, from clear open-ocean regimes to turbid Case-2 waters of high complexity.

Data were presented from an open-source irradiance sensor that is under development at OSU. Future developments for these open-source sensors include: measurement of field of view (cosine response) to derive cosine corrector effectiveness, thermal responsivity, and an improved user-interfacing software. However, the initial matchup data between these new multispectral sensors and the industry standard is exciting. These new sensors provide a cost-effective alternative to their commercial counterparts, with initial matchups at the 0.94–0.95 R^2 level. As for cost, these open-source sensors are two orders of magnitude more affordable than their commercial counterparts.

While the open-source sensors lack the spectral resolution of the HyperOCRs, Tan et al. (2024) detail a multivariate linear model to accurately model the downwelling irradiance spectrum at a hyperspectral resolution using just four in situ spectral channels.

These results demonstrate that low-cost, open-source sensors can deliver scientifically robust measurements while lowering barriers to participation in oceanographic research. The strong agreement with commercial radiometers highlights their potential as reliable, scalable alternatives for optical oceanography. With continued refinement, these systems will broaden access to high-quality optical data, strengthen collaborative calibration and validation efforts, and expand our ability to monitor diverse marine environments in support of future satellite ocean color missions.

8. Measurements of Key Water Components and Hyperspectral Reflectance (NASA Team)

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8.1. Introduction and Campaign Overview

Conducted in May and June 2024 by NOAA/STAR, with participation from the NASA/GSFC Ocean Ecology Laboratory (OEL) Field Support Group (FSG), the Dedicated JPSS VIIRS Ocean Color Calibration/Validation Cruise was a successful and well-timed field campaign. Departing from Pensacola, Florida on May 20th and concluding in Charleston, South Carolina on June 1, 2024, the campaign traversed a wide array of aquatic environments. The route included the optically complex waters of the Gulf and the Florida Strait, as well as the coastal and shelf domains of the South Atlantic Bight. This specific cruise track encompassed a wide dynamic range of optical water types. Spanning from highly productive coastal margins to clear open-ocean regimes, the transect yielded a robust in situ dataset for the validation of satellite ocean color products.

While primarily designed to support the ongoing Cal/Val of the JPSS VIIRS sensors, the temporal alignment of this campaign provided an invaluable opportunity: early on-orbit validation for NASA's PACE mission. Occurring just a few months after the successful launch of PACE in February 2024, this cruise captured critical in situ sea-truth data during the mission's early operational phase. High-quality field measurements acquired during this window were essential for assessing initial sensor performance, refining early data processing algorithms, and establishing baseline uncertainties for PACE's novel data products. Unfortunately, the PACE observatory experienced an anomaly and entered a safehold state during the campaign. Consequently, no science data were collected by the orbiter between ~22:40Z on May 24 and 18:32Z on May 30, which limited the number of possible satellite-to-in situ matchups during this field deployment.

Despite this setback, the campaign executed a comprehensive sampling strategy. The FSG collected a full suite of radiometric and optical measurements relevant to ocean color, paired with extensive biogeochemical sampling to fulfill the Cal/Val requirements of both VIIRS and PACE. Notably, this cruise marked the inaugural field deployment of two new major NASA OEL systems. From above the surface, continuous hyperspectral radiometry was acquired using the newly integrated DALEC to derive in situ $R_{rs}(\lambda)$. Also, this campaign marked the inaugural field deployment of the OEL Imaging FlowCytobot (IFCB, McLane Research Laboratories, Falmouth, MA) acquired in 2023. The IFCB is an automated imaging flow cytometer that uses laser-triggered fluorescence to continuously photograph suspended marine particles and phytoplankton cells. In water, high-resolution vertical profiles of IOPs were conducted at 36 stations using the FSG's integrated optics package, which featured an ac-s spectrophotometer, a BB9 backscattering sensor, and a SBE 49 CTD, to characterize the water column's spectral absorption, attenuation, and backscattering.

To achieve optical closure and validate satellite algorithms, these optical measurements were coupled with biogeochemical and taxonomic sampling. The biogeochemical suite included determinations of phytoplankton pigments via HPLC, POC, PIC, SPM, $a_p(\lambda)$, and $a_g(\lambda)$. Furthermore, phytoplankton community structure was resolved across all size classes: discrete flow cytometry (FCM) quantified picoplankton populations (e.g., *Synechococcus* and picoeukaryotes), while the continuous underway IFCB captured and classified the larger nano- and microplankton functional groups.

By measuring this comprehensive suite of radiometric, optical, biogeochemical, and taxonomic data across a broad dynamic range of water types, the 2024 campaign provided a valuable dataset. Ultimately, these integrated observations contribute critical ground-truth data for the initial validation of the NASA PACE mission and the continued calibration of JPSS VIIRS.

8.2. In-Water Profiling of Inherent Optical Properties Package

To complement the discrete biogeochemical and taxonomic measurements, high-resolution vertical profiles of IOPs were acquired at 36 stations. These profiles were conducted using the FSG integrated IOP package, which is designed to comprehensively characterize the water column's spectral absorption, attenuation, and backscattering properties. The core of the optical suite featured a SeaBird Scientific (formerly WET Labs) ac-s in situ spectrophotometer. This instrument measured hyperspectral absorption and beam attenuation across approximately 80 wavelengths spanning the visible to near-infrared spectrum (400–750 nm), allowing for the high-resolution derivation of total spectral scattering.

Co-deployed on the profiling frame was a nine-wavelength BB9 sensor to quantify spectral backscattering. A SeaBird SBE 49 FastCAT CTD continuously recorded conductivity, temperature, and pressure alongside the optical data.

8.3. Above-Water Radiometry: DALEC System

The DALEC instrument (Brando et al. (2016), Figure 46) is an autonomous, ship-mounted radiometric system operated continuously while underway to acquire hyperspectral measurements of downwelling hemispherical irradiance, total upwelling surface radiance, and sky radiance. To mitigate optical contamination from sun glint and ship shadow, the DALEC utilizes an automated sensor mount that dynamically adjusts its viewing azimuth and zenith angles relative to both the solar position and the vessel's heading.

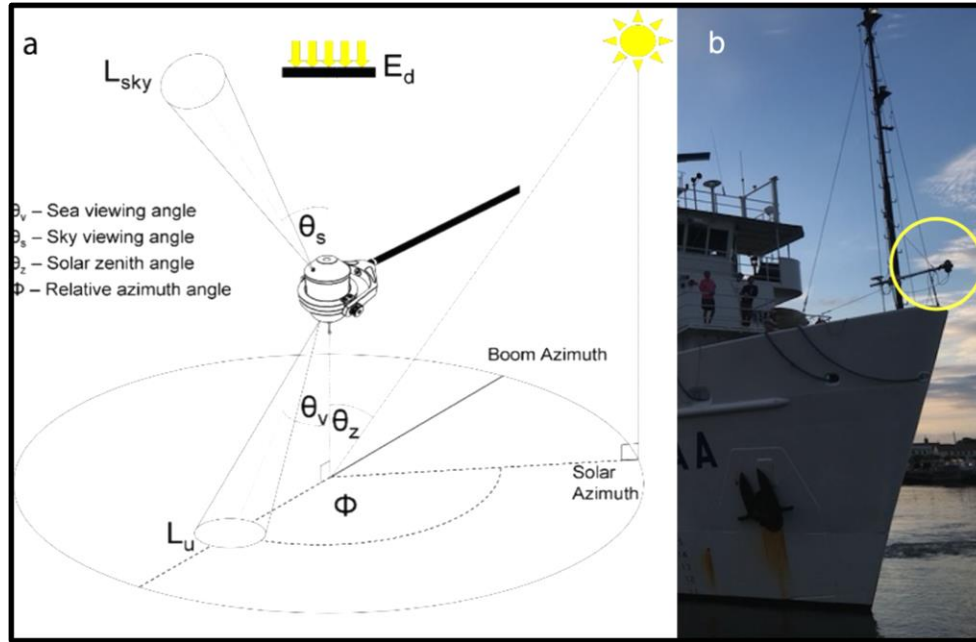


Figure 46. DALEC system and deployment configuration. (a) Technical schematic of DALEC sensor head showing the three radiometric channels (L_u , L_{sky} , E_d) and motorized azimuth mount with passive gimbal stabilization. (b) DALEC bow-mount installation on the NOAA Ship *Nancy Foster* during the JPSS VIIRS ocean color Cal/Val field campaign, showing the forward-projecting aluminum pole and sensor positioning approximately 10 m above the sea surface. Schematic source: Brando et al. (2016).

8.4. Baseline Biogeochemistry and Phytoplankton Community Structure

To establish the baseline phytoplankton biomass across the campaign domain, surface total chlorophyll-a and 25 other phytoplankton pigments were measured using HPLC at 34 discrete stations. Overall, the sampled waters reflected predominantly oligotrophic to mesotrophic conditions. Surface chlorophyll-a concentrations ranged from a minimum of 0.046 to a maximum of 0.396 mg m^{-3} , with a median of 0.105 mg m^{-3} . The highest concentrations were observed at the nearshore coastal stations within the Gulf, peaking off the coast of the Ft. Myers and Sanibel Island region (Figure 47). In contrast, the lowest biomass concentrations were recorded as the vessel transited through the clear, oligotrophic waters of the Florida Strait and into the South Atlantic Bight.

While the long-term MODIS-Aqua May climatology (2003–2025; Figure 48) encompasses a much broader maximum concentration range (0.060 to 1.404 mg m^{-3} , median: 0.093 mg m^{-3}), spatial matchups ($N = 34$) between the two datasets demonstrated excellent agreement in the clearer, oligotrophic waters (i.e., $< 10^{-1} \text{ mg m}^{-3}$). The primary divergence occurred at the higher end of the range in productive coastal zones where the in situ concentrations fell below the region's average (Figure 47). Nevertheless, the overall spatial correlation suggests that the campaign successfully captured the region's biogeochemical gradients.

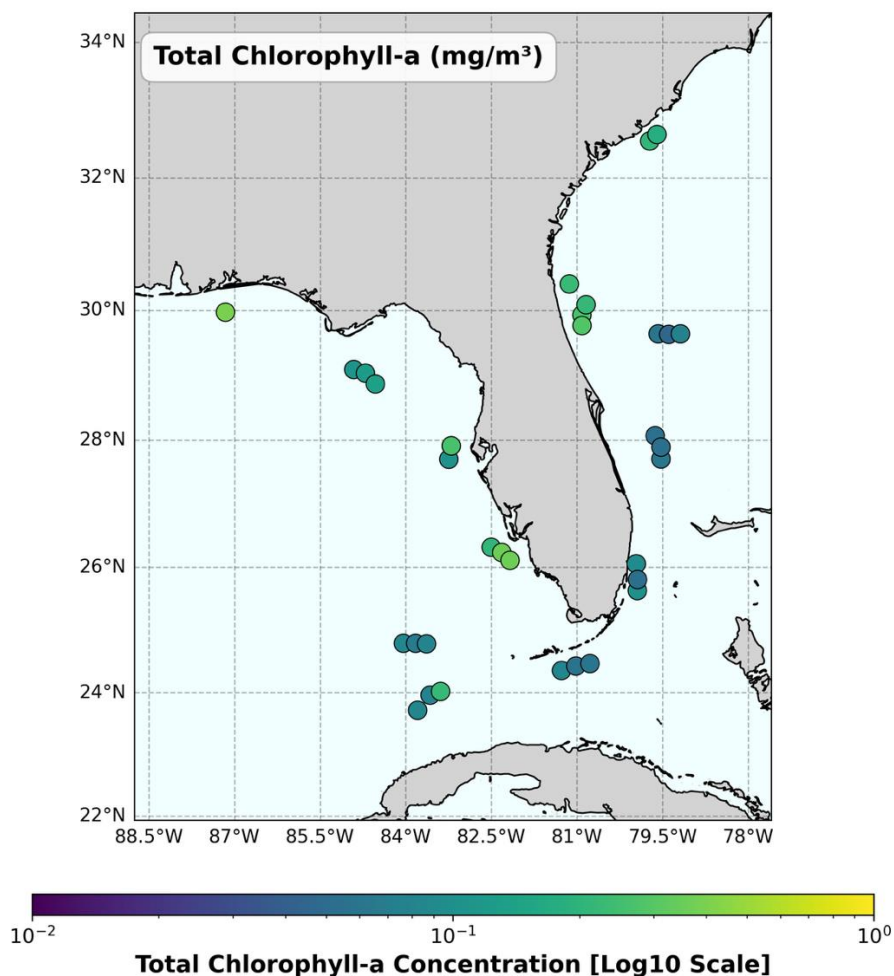


Figure 47. Total chlorophyll-a concentrations at 34 stations along the 2024 JPSS VIIRS ocean color Cal/Val field campaign cruise track.

The FSG collected a comprehensive suite of biogeochemical, bio-optical, and taxonomic measurements to characterize the optically active components relevant to ocean color validation (Table 5). Sampling for carbon pools and inherent optical properties was conducted at a targeted subset of mid-day stations aimed at the satellite overpasses. Additionally, to validate phytoplankton community structure and corroborate pigment-based taxonomy, discrete samples were collected at 24 stations for laboratory flow cytometry and FlowCam analysis, which directly complement the continuous underway IFCB observations.

This deployment was particularly timely and critical for the early validation of the PACE mission. Unlike legacy multi-spectral sensors, PACE's hyperspectral Ocean Color Instrument (OCI) was specifically designed to move beyond legacy products and optically resolve distinct PFTs and taxonomic groups from space. To validate these algorithms, high-resolution taxonomic data are required.

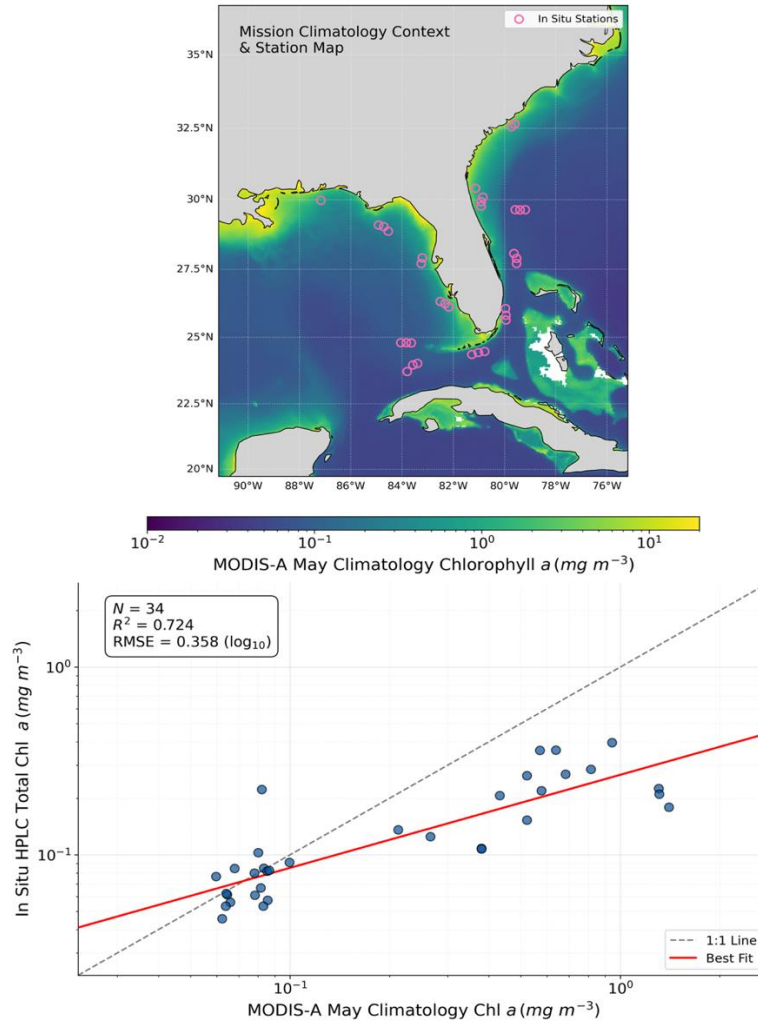


Figure 48. Comparison of in situ HPLC total Chlorophyll a against historical MODIS-Aqua May climatology (2003–2025). The top panel shows the MODIS-A climatology (mg m^{-3}) with the sampling locations mapped. The bottom panel shows the matchups between the climatology and the in situ observations.

Operating continuously on the vessel's flow-through seawater system, the IFCB provided a stream of automated, image-based data, capturing spatial shifts in the abundance and community composition of major phytoplankton groups across the cruise track to directly support PACE PFT validation efforts.

The distribution of the IFCB image data classifications (Figure 49) revealed distinct regional shifts in both absolute abundance and relative community composition. Overall, dinoflagellates dominated the microplankton fraction, particularly throughout the Gulf portion of the transect.

Table 5. Summary of in situ biogeochemical parameters collected by the NASA Field Support Group (FSG) during the May–June 2024 Dedicated JPSS VIIRS Ocean Color Calibration/Validation Cruise.

Parameter	Symbol	Description & Analytical Method	Total Samples	Unique Stations
Phytoplankton Pigments	ppig	High-Performance Liquid Chromatography (HPLC) for phytoplankton pigment determination.	99	34
Particulate Organic Carbon	poc	Particulate organic matter. (<i>Note: excludes 36 filtrate blanks</i>)	36	12
Particulate Absorption	a _p	Spectral absorption by phytoplankton collected on filter pads.	36	12
Total Suspended Matter	tsm	Gravimetric determination on 47 mm GF/F filters.	47	12
Particulate Inorganic Carbon	pic	Measured by laboratory coulometry.	32	10
Dissolved Organic Carbon	doc	Dissolved organic carbon analysis.	36	12
Chromophoric Dissolved Organic Matter	cdom	Spectral absorption by CDOM (a_g, λ).	12	12
Lugol's Phytoplankton	lug	Samples preserved in Lugol's stain for FlowCam (Yokogawa) determination of phytoplankton type/abundance; complements in situ IFCB.	38	24
Flow Cytometry	fcyt	Samples preserved with glutaraldehyde for laboratory flow cytometry analysis.	38	24

Distinct biomass hotspots were observed in the nearshore waters upon departing port and further south off the coast of Ft. Myers and Sanibel Island. The community structure within these coastal hotspots was characterized by a relative dominance of dinoflagellates, which is of particular ecological interest given this specific region's well-documented susceptibility to endemic dinoflagellate-driven harmful algal blooms (HABs).

As the campaign transited through the Florida Keys and into the Florida Strait, the community structure shifted with diatoms increasing in relative proportion, becoming co-dominant or locally dominant over dinoflagellates. As the campaign transitioned into the South/Mid-Atlantic portion of the cruise, the community reverted to one predominantly dinoflagellate-dominated, albeit at substantially lower absolute cellular abundances compared to the dense hotspots observed in the Gulf.

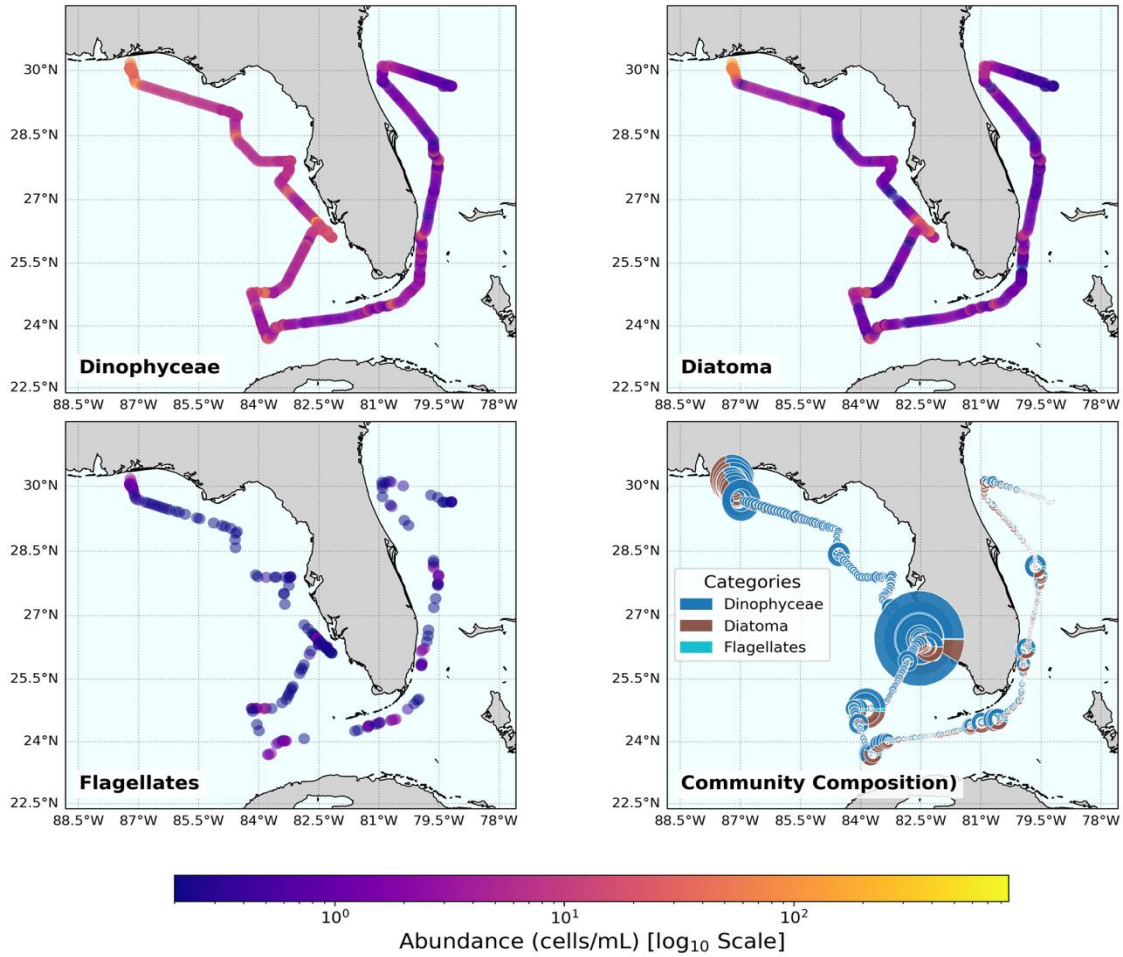


Figure 49. Spatial distribution and community composition of dominant phytoplankton groups derived from continuous underway IFCB observations. The first three panels display the absolute abundance (cells ml^{-1} , $\log_{10}$ color scale) of the top automatically classified taxonomic categories across the cruise track, utilizing a shared color scale to highlight geographic shifts in population density. The bottom-right panel summarizes the relative community structure at each location using localized ring plots. Within each ring, colors indicate the relative proportion of the major groups, while the overall diameter of the ring is scaled proportionally to the square root of the total combined abundance, highlighting localized biomass hotspots.

To complement the microplankton observations from the IFCB, discrete flow cytometry (FCM) was utilized to quantify the nano- and picoplankton fractions of the community. Mapping of these smaller size classes (Figure 50) revealed a distinct regional succession that mirrored the dynamic shifts seen in the larger taxa. Within the Gulf, picoeukaryotes clearly dominated the absolute cell counts of the small-size fraction. As the cruise transitioned out of the Gulf, passing through the Florida Strait and into the proximity of the Bahamian Archipelago, the dominance of picoeukaryotes noticeably waned. Moving further north into the South Atlantic Bight, the picoplankton community underwent another distinct shift, with *Synechococcus* emerging as the overwhelmingly dominant contributor to total FCM cell counts in the Atlantic waters.

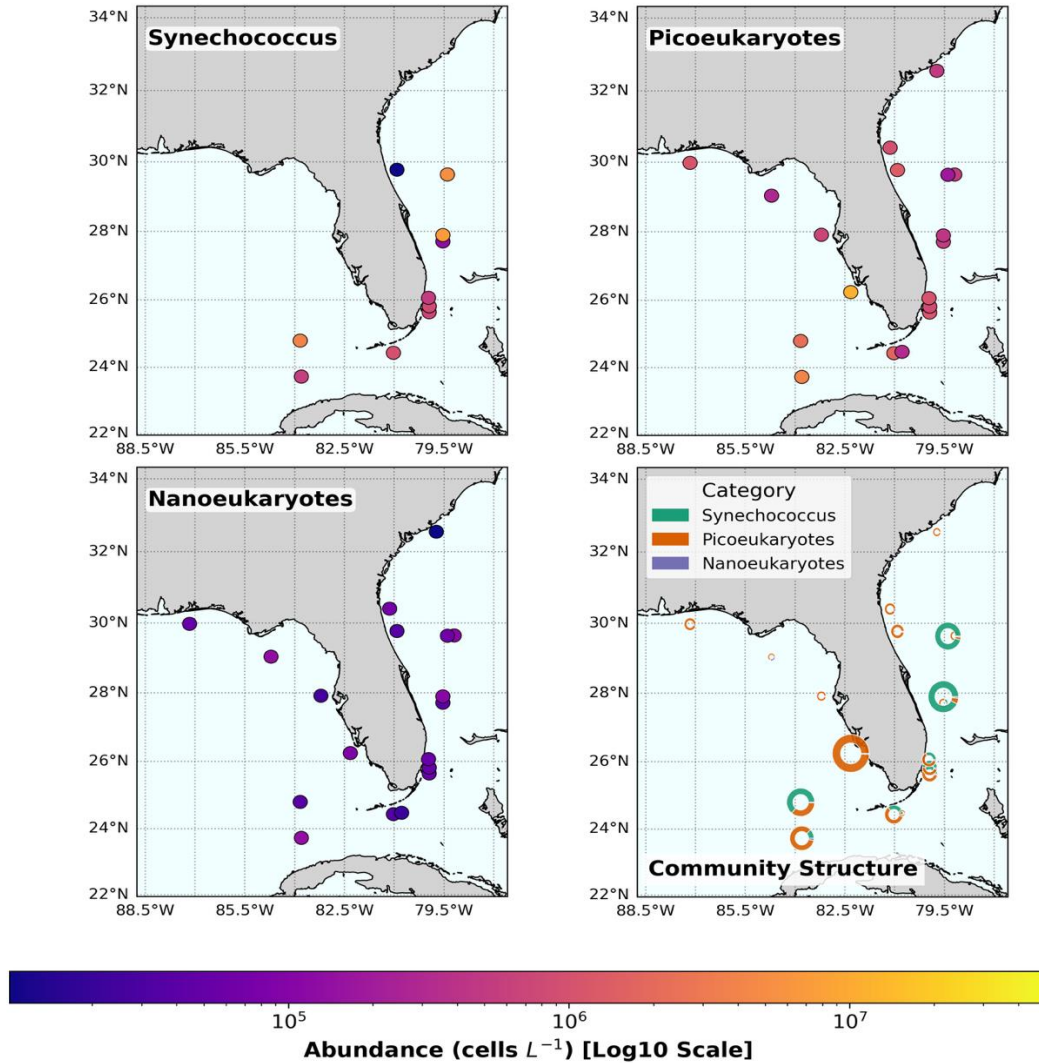


Figure 50. Surface distribution and community structure of picoplankton and nanoplankton measured via flow cytometry (FCM). The first three panels depict the log₁₀-scaled absolute abundance (cells L^{-1}) of *Synechococcus*, picoeukaryotes, and nanoeukaryotes. The bottom-right panel summarizes community composition through localized ring plots, where internal colors denote relative structural proportion and the overall ring diameter is scaled to the square root of the total FCM cellular abundance.

Phytoplankton community size structure, estimated from diagnostic HPLC pigment concentrations following the approach of Uitz et al. (2006), revealed that picoplankton constituted the overwhelmingly dominant fraction across the majority of the cruise track (Figure 51). This picoplankton dominance was geographically widespread, being particularly pronounced in deeper, offshore waters as well as throughout the entirety of the Atlantic portion of the sampling domain.

In contrast, the microplankton fraction only achieved dominance in highly localized coastal areas, specifically at the nearshore stations at the very beginning of the campaign and again coinciding with the previously noted biomass hotspots off the coast of Ft. Myers and Sanibel Island.

The spatial distributions of the biogeochemical parameters: POC, SPM, and DOC, closely mirrored the observed trends in the plankton populations (Figure 52). Generally, higher concentrations of all three parameters were recorded throughout the Gulf, with distinct regional maxima off the coast of the Ft. Myers and Sanibel Island region. This localized peak in particulate and dissolved carbon correlates with the dinoflagellate biomass hotspots previously identified with the IFCB. As the campaign transitioned into the more oligotrophic waters of the Florida Strait and continued northward into the South Atlantic Bight, concentrations of POC, SPM, and DOC decreased, reflecting the overall reduction in biological productivity and the shifting trophic state of the region.

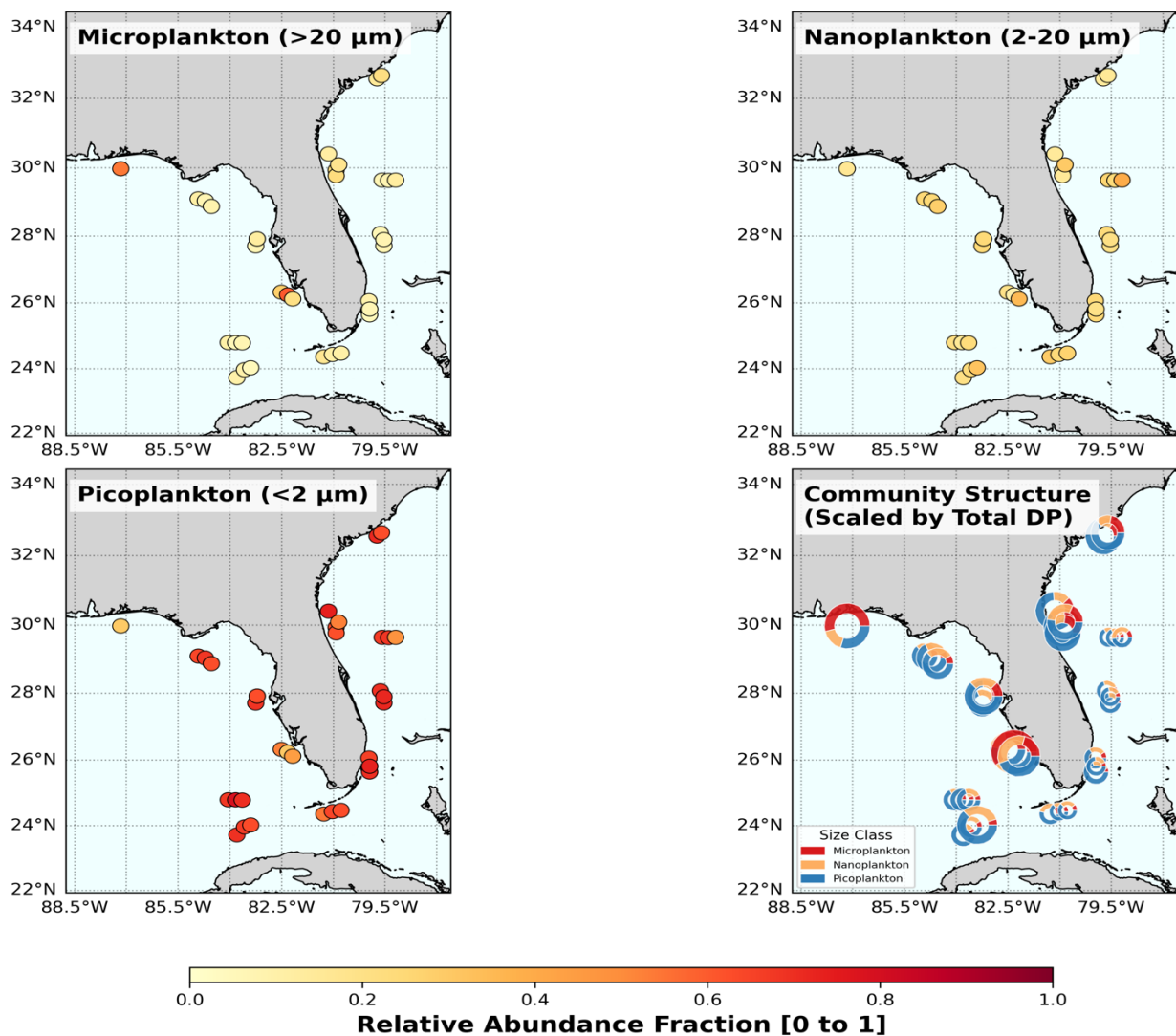


Figure 51. Calculated phytoplankton size-fractionated community structure across 34 stations sampled during the May–June 2024 Dedicated JPSS VIIRS Ocean Color Calibration/Validation Cruise. Ring plots show the relative contribution of microplankton (>20 μm, red), nanoplankton (2–20 μm, orange), and picoplankton (<2 μm, blue) estimated from HPLC diagnostic pigments following Uitz et al. (2006).

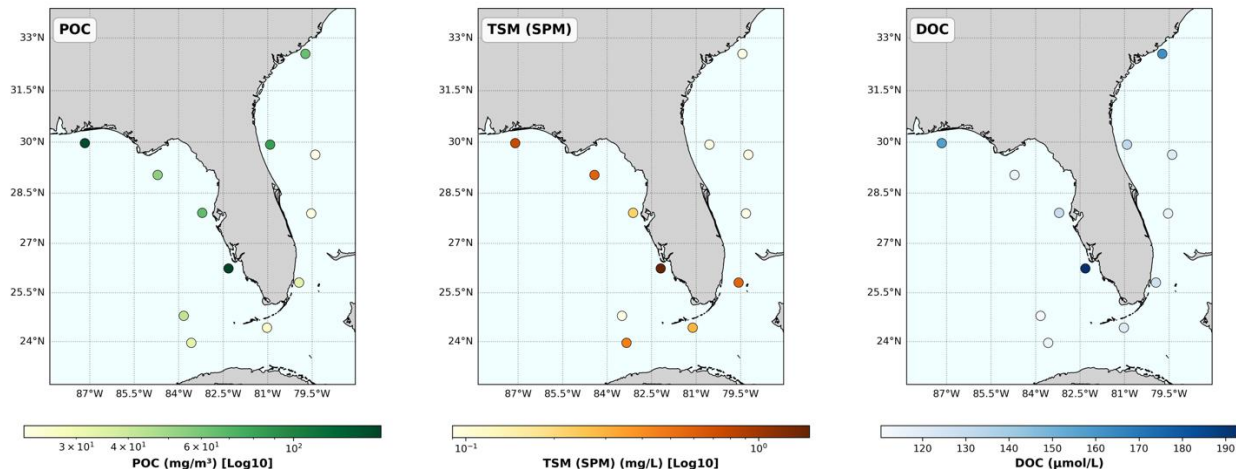


Figure 52. Surface concentrations of particulate organic carbon (POC), suspended particulate matter (SPM), and dissolved organic carbon (DOC) during the JPSS VIIRS ocean color Cal/Val 2024 field campaign.

Consistent with the distributions of plankton biomass and bulk carbon pools, spectral absorption by CDOM exhibited a similar spatial distribution. Surface absorption at 400 nm was generally higher within the Gulf, with a pronounced maximum co-occurring in the Ft. Myers and Sanibel Island region (Figure 53). However, despite these localized coastal peaks, the overall magnitude of CDOM absorption in the visible remained relatively low throughout the entire campaign, with surface values remaining below 0.1 m^{-1} (Figure 54). This suggests that while CDOM clearly tracked the regional shifts in productivity and biomass, the sampled waters were not heavily dominated by highly absorbing terrestrial or humic inputs. It should be noted that discrete particulate absorption samples are currently pending analysis; consequently, a comprehensive optical absorption budget and associated optical closure exercises cannot be executed at this time.

Integrating data from diagnostic HPLC pigments, continuous optical imaging (IFCB), and discrete FCM yields a multi-scale perspective of the phytoplankton community across the campaign's region. Because the optical resolution of the IFCB ($\sim 3.4 \text{ } \mu\text{m}/\text{pixels}$), like all standard light microscopy, limits the detection of cells in the pico- and smaller plankton sizes, relying on imaging alone would yield an incomplete taxonomic picture. Pigment-based size fraction estimates and flow cytometry bridged this observational gap, establishing that picoplankton formed the prevailing size class across the majority of the cruise track, particularly in deeper offshore waters and throughout the Atlantic side of the study area. FCM data helped delineate this assemblage, pointing toward an apparent spatial shift across the campaign; within the specific stations sampled, picoeukaryotes tended to represent the more abundant picoplankton fraction in the Gulf, while relative counts of *Synechococcus* became notably higher in the Atlantic waters.

Distinct microplankton blooms punctuated the coastal Gulf regions. Here, the IFCB captured intense, dinoflagellate-dominated biomass hotspots, most notably off the coast of Ft. Myers and Sanibel Island. This microplankton peak correlated with localized maxima in bulk carbon stocks (POC, DOC) and optical (CDOM) signatures. As the transect moved southward through the Florida Keys and Strait, the sparse microplankton fraction captured by the IFCB briefly shifted toward diatom co-dominance before the community settled back into the oligotrophic, *Synechococcus*-dominated state of the South Atlantic Bight. This multi-instrument synthesis

resolved individual size-class limitations to capture regional ecological shifts, providing essential in situ data for validating PACE PFT algorithms.

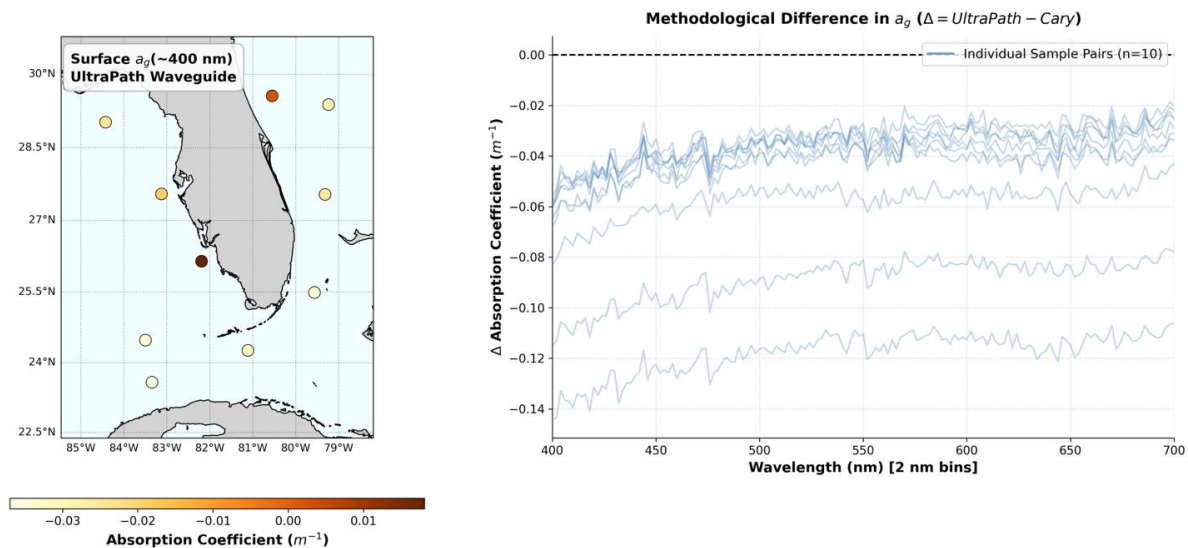


Figure 53. Left. Light absorption by CDOM at 400 nm for surface samples collected during the 2024 JPSS VIIRS Ocean Color Cal/Val campaign measured with an UltraPath high-performance, modular liquid-core waveguide spectrophotometer (World Precision Instruments, Sarasota, FL). Right. Difference in CDOM absorption as measured by the UltraPath minus that measured on a Cary 100 benchtop spectrophotometer (see Figure 54).

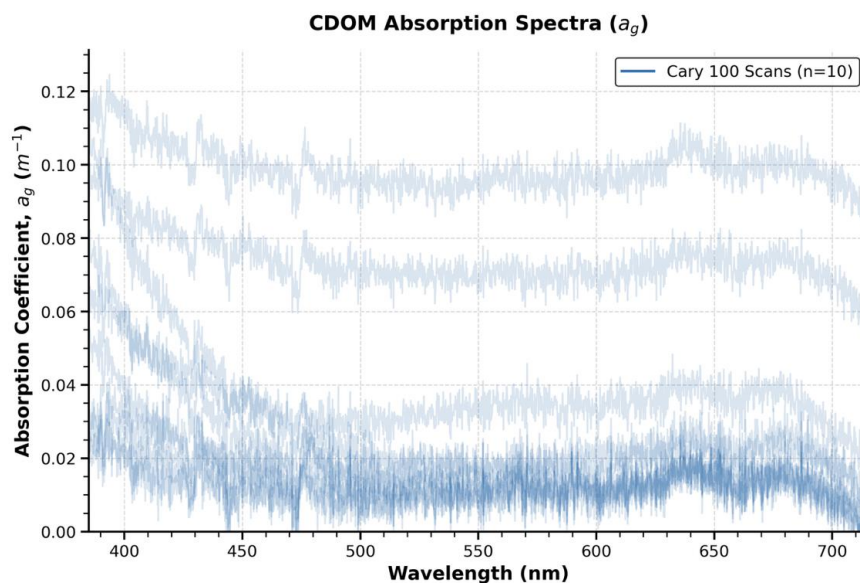


Figure 54. Spectral absorption by CDOM in the visible wavelength range (~400–700 nm), measured using a Cary 100 benchtop spectrophotometer from surface samples collected during the 2024 JPSS VIIRS Ocean Color Cal/Val campaign.

8.5. Satellite Context and PACE-OCI Coverage

Taking place shortly after the launch of NASA's PACE observatory, this cruise provided one of the earliest dedicated opportunities for in-water validation of the hyperspectral OCI. By combining an extensive suite of bio-optical measurements with taxonomic resolution, most notably through deployment of the OEL IFCB, the campaign yielded the multi-scale in situ dataset for validating the retrieval of PFTs by PACE. Building upon this established in situ baseline, the following section details the concurrent remote sensing context and orbital satellite coverage over the sampling domain.

To evaluate the availability of concurrent remote sensing observations, Figure 55 shows the spatial and temporal distribution of PACE-OCI Level-2 granules intersecting the in situ sampling stations. In total, 18 individual orbital overpasses were successfully acquired during the campaign window from May 20 to June 1. The spatial footprints of these granules provided coverage over the sampling stations during the initial and final phases of the deployment. However, as illustrated by the temporal axis (Figure 55, bottom panel), a significant data gap occurred mid-campaign. Between May 25 and May 29, the PACE spacecraft entered a documented safhold mode. This anomaly necessitated the temporary cessation of all orbiter science operations, resulting in a complete halt of OCI data collection during those five days. Consequently, while robust satellite matchups are available for the margins of the cruise, in situ stations sampled during this specific window lack corresponding PACE observations (Table 6).

Of the 18 PACE-OCI overpasses above, at least five distinct ones yielded high-quality matchup potential, where concurrent in situ stations (± 4 hours) successfully aligned with valid, cloud-free satellite pixels (Figure 56). These potential matchups are geographically distributed across the targeted region, capturing stations located in both the optically complex, nearshore coastal environments and in clearer, offshore waters. Securing matchups across a broad spatial range is necessary for satellite validation. Because PACE's OCI retrieves advanced data products (e.g., PFTs) across varied optical regimes, reference data must span from productive coastal waters to oligotrophic offshore environments to accurately evaluate algorithms across their operational limit.

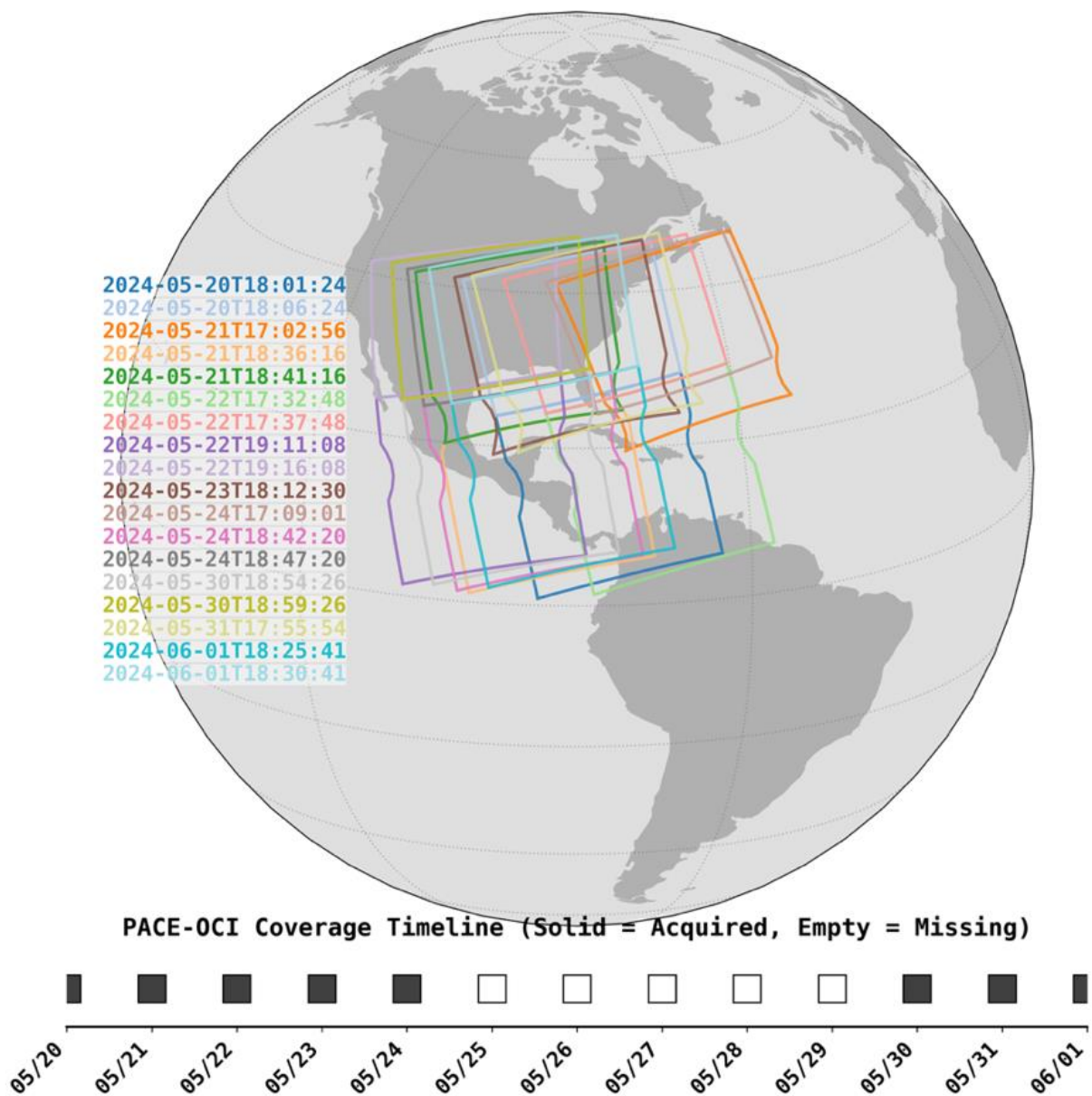


Figure 55. Spatial and temporal coverage of PACE-OCI Level-2 granules intersecting the cruise domain during the May–June 2024 validation campaign. Each swath edge is color-coded, with the corresponding UTC acquisition timestamp listed chronologically along the left margin. A daily timeline spans the duration of the field campaign. Solid markers indicate days with successful PACE-OCI acquisitions. Empty markers (May 25–29) represent a temporary gap in orbital coverage resulting from a spacecraft safhold event, during which no science data were collected.

Table 6: Summary of PACE-OCI Level-2 granules utilized for regional coverage mapping and matchup analysis.

Status	Date	Time (UTC)	PACE Granule Prefix
Acquired	May 20, 2024	18:01:24	20240520T180124.L2
Acquired		18:06:24	20240520T180624.L2
Acquired	May 21, 2024	17:02:56	20240521T170256.L2
Acquired		18:36:16	20240521T183616.L2
Acquired		18:41:16	20240521T184116.L2
Acquired	May 22, 2024	17:32:48	20240522T173248.L2
Acquired		17:37:48	20240522T173748.L2
Acquired		19:11:08	20240522T191108.L2
Acquired		19:16:08	20240522T191608.L2
Acquired	May 23, 2024	18:12:30	20240523T181230.L2
Acquired	May 24, 2024	17:09:01	20240524T170901.L2
Acquired		18:42:20	20240524T184220.L2
Acquired		18:47:20	20240524T184720.L2
Spacecraft Safehold	May 25–29, 2024	N/A	No Science Data
Acquired	May 30, 2024	18:54:26	20240530T185426.L2
Acquired		18:59:26	20240530T185926.L2
Acquired	May 31, 2024	17:55:54	20240531T175554.L2
Acquired	Jun 01, 2024	18:25:41	20240601T182541.L2
Acquired		18:30:41	20240601T183041.L2



Figure 56. Evaluation of PACE-OCI Level-2 spatial coverage and in situ matchup potential. Panels display valid water pixels (grey), flagged/invalid pixels (red), and concurrent (± 4 hours) in situ stations (cyan circles). Text indicators denote the successful presence ($\checkmark$) or absence ($\times$) of at least one valid spatial match-up for each orbital overpass.

9. Underway Characterization of Phytoplankton Biomass, Community Structure, and Photophysiology Using ALFA and FIRE (LDEO Team)

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9.1. Underway CLS/ALFA Measurements of Phytoplankton Biomass and Community Composition

Phytoplankton pigment biomass and broad community composition were characterized using the CLS, also known as the Aquatic Laser Fluorescence Analyzer (ALFA). ALFA is an active laser-fluorescence instrument that measures the spectral emission of naturally occurring fluorescent constituents following laser excitation. Spectral deconvolution separates overlapping fluorescence bands attributable to Chl-a, CDOM, and several phycoerythrin forms associated with major pigment-defined phytoplankton groups. The system therefore provides high-frequency estimates of total chlorophyll fluorescence together with relative fluorescence signatures of blue-water cyanobacteria, green-water cyanobacteria, and cryptophytes (Chekalyuk et al., 2014; Chekalyuk and Hafez, 2008).

These group-specific signals are based on diagnostic pigment fluorescence rather than direct taxonomic identification. They are therefore best interpreted as indicators of pigment-defined ecological groups, not as species-specific cell abundances. Their ecological interpretation is strengthened when evaluated with HPLC pigments, microscopy, imaging, flow cytometry, and hydrographic observations.

ALFA was operated continuously in underway flow-through mode, receiving near-surface seawater from the ship's seawater supply. This configuration yielded high-spatial-resolution measurements of phytoplankton biomass and pigment-group variability along the cruise track and allowed sharp transitions between coastal, shelf, and oceanic water masses to be resolved. The ALFA measurements presented here should be considered preliminary. A portion of the record from the earlier part of the cruise requires additional quality control and validation for instrument stability, calibration consistency, and possible flow-through artifacts. Chlorophyll-a fluorescence will also be evaluated against independent discrete pigment measurements where available. Consequently, unusually high or rapidly changing signals in the early cruise record are not interpreted quantitatively here; the discussion below emphasizes the more robust large-scale spatial patterns.

9.1.1. Chlorophyll-a

ALFA derives Chl-a from its characteristic red fluorescence emission near 680 nm. Because Chl-a is common to essentially all oxygenic phytoplankton, it provides a useful first-order index of total photosynthetic pigment biomass. Fluorescence-derived Chl-a should not be equated directly with phytoplankton carbon biomass, because cellular chlorophyll content and fluorescence yield vary with taxonomy, nutrient status, irradiance history, and non-photochemical energy dissipation. When calibrated against extracted chlorophyll or HPLC pigment measurements, however, laser-induced chlorophyll fluorescence provides an effective high-resolution measure of spatial changes in phytoplankton biomass (Chekalyuk et al., 2014; Chekalyuk and Hafez, 2008). The preliminary distribution shows comparatively elevated Chl-a in the northern Gulf of Mexico shelf waters and generally lower values over much of the central and eastern Gulf, through the Florida Straits, and along the western Atlantic track. This broad decline from shelf-influenced to offshore waters is consistent with reduced nutrient supply and stronger stratification in oligotrophic oceanic waters, although local enhancements likely reflect fronts, shelf-break exchange, eddies, and other processes that intermittently increase nutrient availability or concentrate phytoplankton.

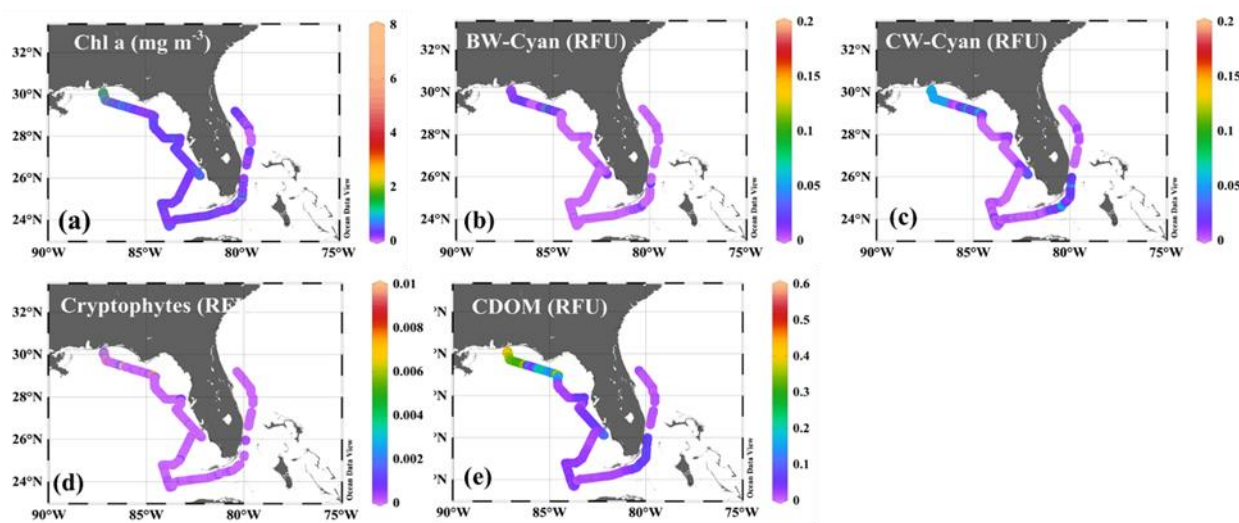


Figure 57. Underway ALFA measurements of phytoplankton biomass and pigment-defined community structure. Spatial distributions of (a) Chl-a; (b) blue-water cyanobacteria (BW-Cyan); (c) green-water cyanobacteria (GW-Cyan); (d) Cryptophytes; and (e) CDOM fluorescence

9.1.2. Blue-water cyanobacteria

The blue-water cyanobacteria signal corresponds to the ALFA PE-1 spectral component, with fluorescence centered near 565 nm. It is associated primarily with phycoerythrin-rich cyanobacteria having relatively high phycoerythrin-to-phycoerythrobilin (PUB/PEB) ratios, a pigment configuration that increases absorption of blue light and is common in optically clear oceanic waters. Oceanic *Synechococcus* populations frequently contribute to this signal, although PE-1 should be treated as a pigment-defined group rather than a unique taxonomic marker (Chekalyuk and Hafez, 2008; Goes et al., 2014). Blue-water cyanobacterial fluorescence was generally low across much of the cruise track, with spatially coherent enhancements in portions of

the northern Gulf and a smaller increase near the Florida Keys/Florida Straits transition. Such variability is consistent with changes in water-mass history, nutrient supply, and underwater spectral quality. Importantly, cyanobacteria can constitute a substantial fraction of the community even when bulk Chl-a is low, so PE-1 variability provides information on community composition that is not evident from total chlorophyll alone.

9.1.3. *Green-water cyanobacteria*

The green-water cyanobacteria signal corresponds to the PE-2 component, centered near 578 nm, and is associated with cyanobacteria possessing phycoerythrin with relatively lower PUB/PEB ratios. This pigment configuration is better suited to greener light fields and is commonly associated with coastal, shelf, and mesohaline waters where CDOM and suspended particles preferentially attenuate blue wavelengths (Chekalyuk and Hafez, 2008). Previous ALFA studies have linked this component to coastal *Synechococcus*-type assemblages, although PE-2, like PE-1, remains a spectral ecological category rather than a species-level identification.

Green-water cyanobacterial fluorescence was enhanced over portions of the northern Gulf shelf and declined markedly toward more oceanic waters. A second localized enhancement occurred near southern Florida and the Florida Keys. The contrast between PE-1 and PE-2 distributions indicates that cyanobacterial community structure changed along the transect, likely in response to differences in water-mass origin, optical environment, nutrient regime, and mixing. Coastal and shelf waters generally contain more CDOM and particles and often receive greater nutrient inputs, whereas offshore waters are typically clearer, more strongly stratified, and nutrient-depleted; these gradients can favor different pigment strategies and cyanobacterial assemblages.

9.1.4. *Cryptophytes*

Cryptophytes are detected from the PE-3 fluorescence component centered near approximately 590 nm. These eukaryotic phytoplankton possess distinctive phycoerythrin-containing light-harvesting complexes, and the PE-3 signal has been shown to track cryptophyte occurrence and to covary with diagnostic pigments such as alloxanthin (Chekalyuk et al., 2014; Chekalyuk and Hafez, 2008).

Cryptophyte fluorescence was generally low over much of the offshore transect but showed localized enhancements, with the strongest apparent signals occurring in portions of the northern Gulf where Chl-a and coastal influence were also greater. Lower values characterized much of the central Gulf, Florida Straits, and western Atlantic, with smaller localized features near southern Florida. This pattern is consistent with the tendency of cryptophytes to be more prominent in nutrient-influenced coastal and transitional waters than in strongly oligotrophic open-ocean environments.

Because PE-3 is a relative fluorescence signal, its magnitude depends not only on cell abundance but also on cellular pigment content and fluorescence yield. It should therefore be interpreted as a relative indicator of cryptophyte-type phycoerythrin until comparison with HPLC pigments and direct cell observations is completed.

Overall, the underway ALFA measurements reveal substantial spatial structure in both total phytoplankton pigment biomass and pigment-defined community composition. The broad pattern is a transition from comparatively higher-biomass, more coastally influenced waters in the northern Gulf toward predominantly low-biomass conditions through the central and eastern Gulf, Florida Straits, and western Atlantic. Superimposed on this biomass gradient are distinct changes in the relative fluorescence signatures of blue-water cyanobacteria, green-water cyanobacteria, and cryptophytes.

In several regions, Chl-a remains low while the relative contributions of cyanobacterial pigment types change appreciably. This decoupling is ecologically important because it indicates community reorganization without a large change in total phytoplankton biomass. Once the early-cruise record has been fully quality controlled, joint interpretation of ALFA with FIRE, hydrography, nutrients, CDOM, HPLC pigments, and microscopic or imaging observations should help distinguish changes driven primarily by water-mass structure and resource availability from those associated with physiological acclimation or shifts in community composition.

9.2. Underway FIRE Measurements of Phytoplankton Photophysiology

Phytoplankton photosynthetic physiology was characterized continuously during the cruise using a Fluorescence Induction and Relaxation (FIRE) fluorometer. FIRE is an active chlorophyll-a fluorescence technique that probes the functional state of Photosystem II (PSII) using rapid sequences of excitation flashlets. During the induction sequence, PSII reaction centers are progressively closed as the primary quinone electron acceptor, Q_A , is reduced, producing a rise in fluorescence from minimum fluorescence (F_0) toward maximum fluorescence (F_m). The subsequent relaxation sequence follows the reopening of PSII reaction centers as Q_A is reoxidized. Together, these measurements provide complementary information on PSII photochemical efficiency, functional light-harvesting capacity, energetic connectivity among PSII units, and acceptor-side electron-transfer kinetics (Gorbunov and Falkowski, 2005; Gorbunov and Falkowski, 2021; Kolber et al., 1998).

Because FIRE characterizes photosynthetic function rather than biomass alone, it provides a sensitive means of resolving changes in phytoplankton physiological state across hydrographic gradients. FIRE responses can reflect photoacclimation, nutrient availability, photoinhibition, temperature, taxonomic composition, and other environmental controls; accordingly, individual parameters are interpreted most robustly in combination rather than as unique indicators of a single stressor (Falkowski et al., 2004; Suggett et al., 2009).

During the cruise, the FIRE fluorometer was operated exclusively in underway flow-through mode, receiving near-surface seawater from the ship's continuous seawater supply. This configuration provided high-frequency measurements along the cruise track and resolved photophysiological transitions at spatial scales finer than could be achieved using discrete CTD stations alone. Five FIRE-derived parameters are considered here: F_v/F_m (where $F_v = F_m - F_0$), the functional absorption cross-section of PSII (σ_{PSII}), the PSII connectivity parameter (p), and the fast and intermediate fluorescence-relaxation time constants (τ_1 and τ_2).

F_v/F_m quantifies the efficiency with which excitation energy absorbed by PSII can be used for photochemistry. In fully dark-acclimated phytoplankton, F_v/F_m represents the maximum quantum yield of PSII photochemistry and is widely used as an indicator of photosynthetic competency

(Falkowski et al., 2004; Kolber et al., 1998). For continuously sampled underway water, however, measurements may retain effects of recent light history and non-photochemical quenching; F_v/F_m is therefore interpreted here as an index of PSII photochemical efficiency under the measurement conditions rather than as a unique measure of nutrient stress or cellular “health.” Taxonomic composition and photoacclimation can also contribute substantially to natural variability in F_v/F_m (Gorbunov and Falkowski, 2021; Suggett et al., 2009).

The cruise measurements show F_v/F_m values of approximately 0.30–0.55, with coherent spatial variability along the transect. Such variability indicates changes in PSII photochemical performance among the sampled water masses, but its cause cannot be assigned from F_v/F_m alone. Interpretation therefore requires comparison with σPSII , p , relaxation kinetics, hydrography, nutrients, and community-composition measurements.

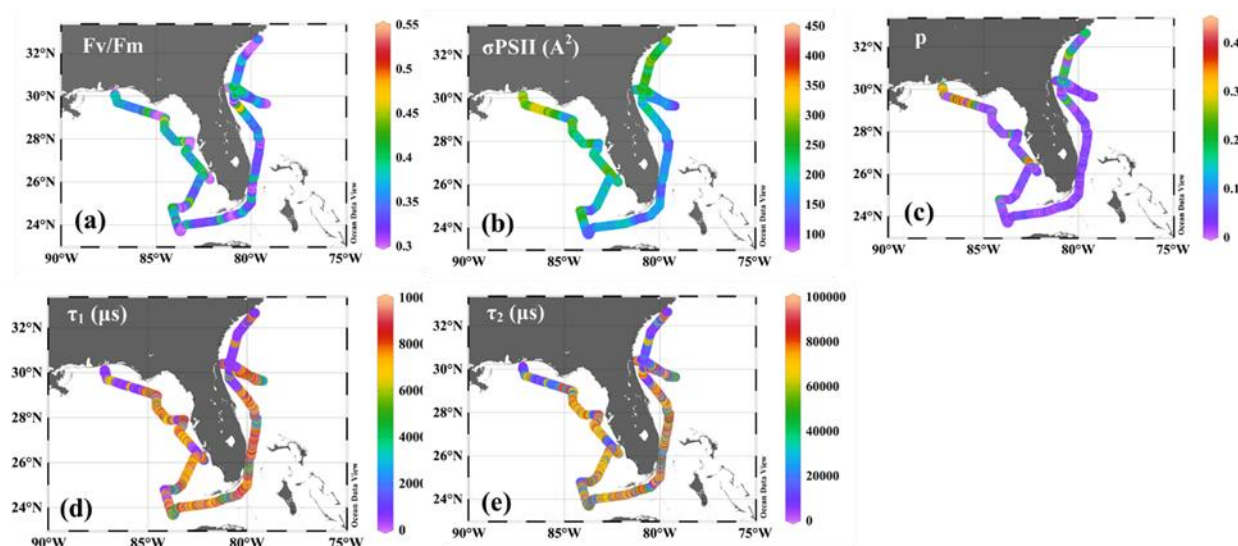


Figure 58. Spatial distributions of five Photosystem II (PSII) photophysiological parameters measured continuously along the cruise track using the Fluorescence Induction and Relaxation (FIRE) fluorometer: (a) F_v/F_m , (b) σPSII , (c) p , (d) τ_1 , and (e) τ_2 .

9.2.1. Functional absorption cross-section of PSII

The functional absorption cross-section of PSII or σPSII describes the effective cross-sectional area over which absorbed photons can drive charge separation at a PSII reaction center. It is derived from the kinetics of fluorescence induction during the single-turnover excitation sequence and reflects both the optical properties of the PSII antenna and the efficiency with which excitation energy is delivered to photochemistry. Thus, σPSII is a functional, rather than purely optical, measure of PSII light-harvesting capacity.

Across the cruise track, σPSII ranged from approximately 70 to 450 $\text{\AA}^2$, with higher values occurring in discrete regions rather than following a simple latitudinal gradient. Values were generally lower along the eastern Florida shelf, higher along the western shelf, and highest in portions of the northern Gulf of Mexico. Variability in σPSII can arise from changes in pigment composition, antenna organization, taxonomic composition, nutrient status, and photoacclimation

to the prevailing light field. The coherent spatial pattern therefore likely reflects a combination of water-mass transitions and associated changes in phytoplankton community structure and light-harvesting strategy.

9.2.2. Energetic connectivity among PSII reaction centers

The connectivity parameter p describes the degree to which excitation energy can migrate among neighboring PSII units. Values approaching zero indicate relatively independent reaction centers, whereas higher values indicate greater energetic coupling, allowing excitation arriving at a closed center to be transferred to a neighboring open center (Kolber et al., 1998). During the cruise, p ranged from near zero to approximately 0.4, with some of the strongest connectivity observed in the northern Gulf of Mexico and generally lower values through much of the Florida Straits and western Atlantic. These patterns are consistent with spatial changes in the functional organization of the photosynthetic apparatus and may reflect both taxonomic differences and physiological acclimation.

9.2.3. Kinetics of Q_A^- reoxidation and PSII electron transfer

The relaxation phase of the FIRE measurement provides mechanistically distinct information on acceptor-side electron transfer. Following the single-turnover excitation sequence, Q_A is reduced to Q_A^- as electrons are transferred downstream toward Q_B and the plastoquinone pool, Q_A is reoxidized, PSII reaction centers reopen, and fluorescence declines. Because this relaxation is kinetically heterogeneous, FIRE resolves it into multiple components. The τ_1 and τ_2 terms represent fast and intermediate components of Q_A^- reoxidation in active PSII centers and are influenced by the redox and occupancy state of downstream electron acceptors (Gorbunov and Falkowski, 2021; Kolber et al., 1998).

Shorter relaxation times indicate more rapid Q_A^- reoxidation and reopening of PSII reaction centers, whereas longer time constants indicate slower acceptor-side electron transfer. The underway measurements show substantial spatial variability, with τ_1 extending to approximately 10,000 μ s and τ_2 to approximately 100,000 μ s. The broadly coherent geographical structure of both parameters suggests organized changes in PSII electron-transfer kinetics across the sampled hydrographic regimes rather than random variability in a single fitted parameter.

9.3. Cruise-Scale Interpretation

Taken together, the five FIRE parameters reveal a strongly structured photophysiological landscape across the Gulf of Mexico, Florida Straits, and western North Atlantic. F_v/F_m reflects PSII photochemical efficiency, σ_{PSII} describes functional light-harvesting capacity, p reflects energetic coupling among PSII units, and τ_1 and τ_2 characterize the kinetics of PSII reopening following charge separation. These parameters need not vary in parallel because each describes a different component of photosynthetic function.

The observed patterns are therefore best interpreted as evidence of spatial changes in phytoplankton community composition, photoacclimation, and electron-transfer physiology associated with contrasting water masses and environmental conditions. In particular, shelf-to-ocean transitions can alter nutrient supply, underwater spectral quality, mixed-layer light exposure, and community composition, all of which can influence FRe-derived parameters. Attribution to any single mechanism will require integration with nutrients, temperature, salinity, pigment composition, optical properties, and phytoplankton community observations. The principal value of the underway FRe record is its ability to resolve these physiological transitions continuously across fronts and water-mass boundaries, complementing discrete station measurements and providing a high-resolution context for interpreting satellite and in situ bio-optical observations.

10. Concluding Remarks

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The NOAA/STAR Ocean Color Science Team completed the annual VIIRS Cal/Val cruise (NF-24-05) from May 20 to June 1, 2024, aboard the NOAA Ship *Nancy Foster*. The cruise set off from Pensacola, Florida, and ended in Charleston, South Carolina. During the expedition, the field team successfully deployed instruments from the ship and collected water samples in the West Florida Shelf, the Straits of Florida, and the South Atlantic Bight. A variety of important quantities were recovered from 38 stations, including hyperspectral remote sensing reflectance, diffuse attenuation coefficient, light absorption coefficient, light backscattering coefficient, Stokes matrix, aerosol optical depth, phytoplankton pigments and types, suspended particulate matter, and/or particulate organic carbon. In addition, several groups were able to continuously measure seawater along ship tracks for bio-optical quantities such as light absorption coefficient (Section 4), dominant phytoplankton groups (Section 8), and phytoplankton biomass and pigment-defined community structure (Section 9) throughout the cruise.

Direct validation of the VIIRS satellite performance was achieved through simultaneous measurements of water-leaving radiance by participating teams. In particular, favorable weather was encountered during the cruise, with mainly calm seas and clear skies, which are optimal for satellite and in situ matchup comparison. Preliminary results revealed high data quality of satellite $nL_w(\lambda)$ products from SNPP, NOAA-20, and NOAA-21 (Section 3). Derived ocean color products were evaluated using measured in situ water bio-optical properties. These concurrent measurements of water-leaving radiances and derived products enable the tuning and refinement of existing ocean color algorithms, while offering a framework to assess uncertainties across in situ methods. While some raw data undergo post-processing, this field campaign has successfully reached its goal: to provide high-quality in situ optical measurements for the VIIRS ocean color calibration and validation. Furthermore, because all in situ optical measurements are hyperspectral, this field campaign provided some of the earliest evaluation data for the PACE mission.

The 2024 field campaign marked the ninth dedicated VIIRS ocean color Cal/Val cruise. It traversed over 1,000 NM (~2,000 km) of coastal waters and covered more stations than any previous cruise of this project (Figure 59). Up to this point, the Ocean Color Science Team has obtained high-quality in situ optical measurements at a total of 230 stations, a valuable dataset for the assessment of the NOAA VIIRS satellite data products. As part of this ongoing effort, a subsequent campaign to measure in situ ocean color data over the southwest U.S. coastal waters was conducted in 2025; the corresponding cruise report will be drafted in 2027.

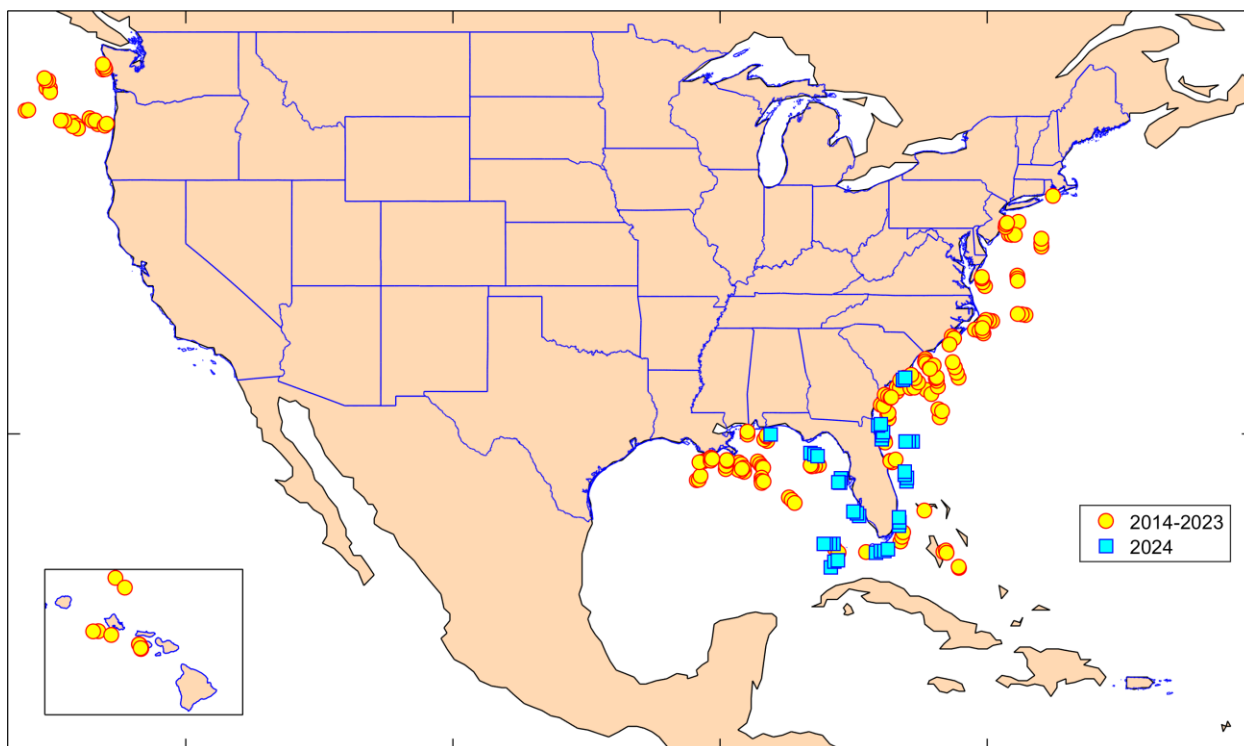


Figure 59. Stations for shipborne in situ optical observations during the NOAA VIIRS Cal/Val field campaigns (2014–2024).

Acknowledgments

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Appendices: Symbols, Abbreviations, and Acronyms

Table A1. List of symbols and descriptions

Symbol	Description	Units
a	Light absorption coefficient	m^{-1}
a_d	Light absorption coefficient by detrital matter	m^{-1}
a_g	Light absorption coefficient by CDOM	m^{-1}
a_p	Light absorption coefficient by particles	m^{-1}
a_{pg}	Light absorption coefficient by CDOM and detritus	m^{-1}
a_{ph}	Light absorption coefficient by phytoplankton	m^{-1}
a_{ph}^*	Chlorophyll-specific phytoplankton absorption coefficient	$\text{m}^2 \text{mg}^{-1}$
b	(total) Light scattering coefficient	m^{-1}
b_b	Backscattering coefficient of particles	m^{-1}
β	Volume scattering function	$\text{m}^{-1} \text{sr}^{-1}$
E_d	Downwelling irradiance	$\text{mW cm}^{-2} \mu\text{m}^{-1}$
E_s	Downwelling irradiance just above the water surface	$\text{mW cm}^{-2} \mu\text{m}^{-1}$
K_d	Diffuse attenuation coefficient for downwelling irradiance	m^{-1}
L_{surf}	Total radiance from the water surface	$\text{mW cm}^{-2} \mu\text{m}^{-1} \text{sr}^{-1}$
L_{sky}	Radiance of sky	$\text{mW cm}^{-2} \mu\text{m}^{-1} \text{sr}^{-1}$
L_u	Upwelling radiance	$\text{mW cm}^{-2} \mu\text{m}^{-1} \text{sr}^{-1}$
$L_u(0^-, \lambda)$	Spectral upwelling radiance just below the water surface	$\text{mW cm}^{-2} \mu\text{m}^{-1} \text{sr}^{-1}$
L_w	Water-leaving radiance	$\text{mW cm}^{-2} \mu\text{m}^{-1} \text{sr}^{-1}$
nL_w	Normalized water-leaving radiance	$\text{mW cm}^{-2} \mu\text{m}^{-1} \text{sr}^{-1}$
R_{rs}	Remote sensing reflectance	sr^{-1}
W_s	Wind speed	m/s
λ	Wavelength	nm
φ	Relative azimuth of the sensor to the sun	deg
ρ	Fresnel reflectance factor of seawater	
θ	Zenith Angle	deg
θ_s	Solar-zenith Angle	deg

Table A2. List of abbreviations and acronyms

Name	Description
AC	Atmospheric correction
ADCP	Acoustic Doppler Current Profiler
AERONET	Aerosol Robotic Network
ALFA	Aquatic Laser Fluorescence Analyzer
AoLP	Angle of Linear Polarization
AOP	Apparent optical property
AOT	Aerosol optical thickness
ASD	Analytical Spectral Devices
AVW	Apparent visible wavelength
BRDF	Bidirectional reflectance distribution function
Cal/Val	Calibration and Validation
CCNY	City College of New York
CDOM	Colored dissolved organic material
Chl-a	Chlorophyll-a concentration (mg m^{-3})
C-OPS	Compact-Optical Profiling System
DALEC	Dynamic Above-water Radiance and Irradiance Collector
DoLP	Degree of linear polarization
EDR	Environmental Data Record
FIRe	Fluorescence Induction and Relaxation
FOV	Field of view
FWHM	Full width at half maximum
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
HPLC	High-Performance Liquid Chromatography
IFCB	Imaging FlowCytobot
IFOV	Instantaneous field of view
TSRB	Tethered spectral radiometric buoy
IOP	Inherent optical property
JPSS	Joint Polar Satellite System
LDEO	Lamont-Doherty Earth Observatory at Columbia University

Table A3. A continuation of Table A2

Name	Description
MSL12	Multi-Sensor Level-1 to Level-2
NESDIS	National Environmental Satellite, Data, and Information Service
NIR	Near-infrared
NIST	National Institute of Standards and Technology
NRL	Naval Research Laboratory
NOAA	National Oceanic and Atmospheric Administration
OC	Ocean Color
OCI	Ocean color instrument
OLCI	Ocean and Land Colour Instrument
OMAO	Office of Marine and Aviation Operations
OSU	Oregon State University
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
PAR	Photosynthetically available radiation (400–700 nm)
PFT	Phytoplankton Functional Type
SAB	South Atlantic Bight
SEI	Spectral Evolution, Inc.
SGLI	Second Generation Global Imager
SNPP	Suomi National Polar-orbiting Partnership
SoF	Straits of Florida
SPM	Suspended Particulate Matter
SST	Sea surface temperature
STAR	Center for Satellite Applications and Research
SVC	Spectra Vista Corporation
SWIR	Shortwave infrared
USF	University of South Florida
UV	Ultraviolet
VIIRS	Visible Infrared Imaging Radiometer Suite
WFS	West Florida Shelf