II. Accomplishments:

A. What are the major goals of this research infrastructure development project?

Major Goals

The major goals of this project are to advance the scientific understanding, validation, and application of ocean-profiling LiDAR (High Spectral Resolution LiDAR; HSRL) systems for observing subsurface ocean structure, biodiversity, and carbon cycling, while simultaneously strengthening research capacity through collaboration with NASA Langley Research Center (LaRC). Ocean-profiling LiDAR has been identified as a high-priority capability in NASA Earth Science planning documents due to its unique ability to penetrate the ocean surface and provide vertically resolved measurements of particulate backscatter and optical properties that are critical for understanding ocean ecology and the global carbon cycle. Within this context, the project has two primary scientific objectives. First, it seeks to validate and interpret the vertical structure of HSRL in-water retrievals by linking LiDAR backscatter signals to key biological components of the marine ecosystem, including phytoplankton, zooplankton, and fish. Second, it aims to understand the physical oceanographic processes that drive horizontal variability in HSRL signals, with a particular focus on the role of Lagrangian coherent structures (LCS) in shaping plankton patchiness in dynamic marine environments.

Approach

To achieve these goals, the project employs a multi-faceted technical approach that integrates airborne remote sensing, in situ observations, and advanced data analysis. A central component of the methodology is the coordinated deployment of NASA airborne HSRL systems with the University of Delaware's autonomous underwater glider "Orris," which is uniquely equipped with optical, acoustic, and environmental sensors designed to validate LiDAR measurements. For **Objective 1**, in situ datasets collected by Orris including radiometric measurements, optical backscatter, chlorophyll fluorescence, and acoustic backscatter are used to directly compare and evaluate HSRL-derived estimates of diffuse attenuation and particulate scattering. These comparisons are critical for determining the accuracy of LiDAR retrievals and for identifying the contributions of different biological scatterers to the observed signal. Additional enhancements to the platform, including the integration of a shadowgraph imaging system, will allow for high-resolution classification of plankton taxa using machine learning approaches, thereby improving interpretation of LiDAR signals in terms of ecosystem composition.

Objective 2 focuses on understanding the horizontal structure of LiDAR signals by analyzing along-track variability in HSRL backscatter data in the context of ocean circulation processes. This effort leverages historical NASA airborne LiDAR datasets collected during multiple field campaigns (2015–2022) over the Mid-Atlantic Bight, combined with high-resolution, data-assimilative ocean circulation models (ROMS/DOPPIO). Lagrangian coherent structures are computed using particle tracking and finite-time Lyapunov exponent (FTLE) analyses to identify regions of convergence and divergence in ocean flow. These features are then compared to spatial patterns in HSRL backscatter to test the hypothesis that small-scale variability in LiDAR signals reflects physical aggregation processes that drive plankton patchiness. This approach provides a novel framework for linking biological patterns observed by LiDAR to underlying physical dynamics in the ocean.

The project is structured around several key activities with associated milestones. **Activity 1a** involves analysis of in situ and airborne data collected during the NASA PACE-PAX campaign in September 2024, during which the Orris glider was successfully deployed in the Southern California Bight and coordinated with multiple HSRL-2 overflights. This dataset has been collected and is currently undergoing processing and analysis. **Activity 1b** will involve a planned field deployment in Bermuda during the NASA NightBLUE campaign in September 2025, where Orris was to be equipped with enhanced instrumentation, including a shadowgraph imaging system, to collect vertically resolved biological and optical data in a contrasting low-productivity ocean environment. **Activity 2** involves retrospective analysis of historical HSRL-1 datasets and associated ocean model outputs to investigate horizontal variability and LCS-driven processes. Milestones associated with these activities include completion of initial data processing, integration of in situ and LiDAR datasets, implementation of classification and modeling approaches, and synthesis of results across study regions.

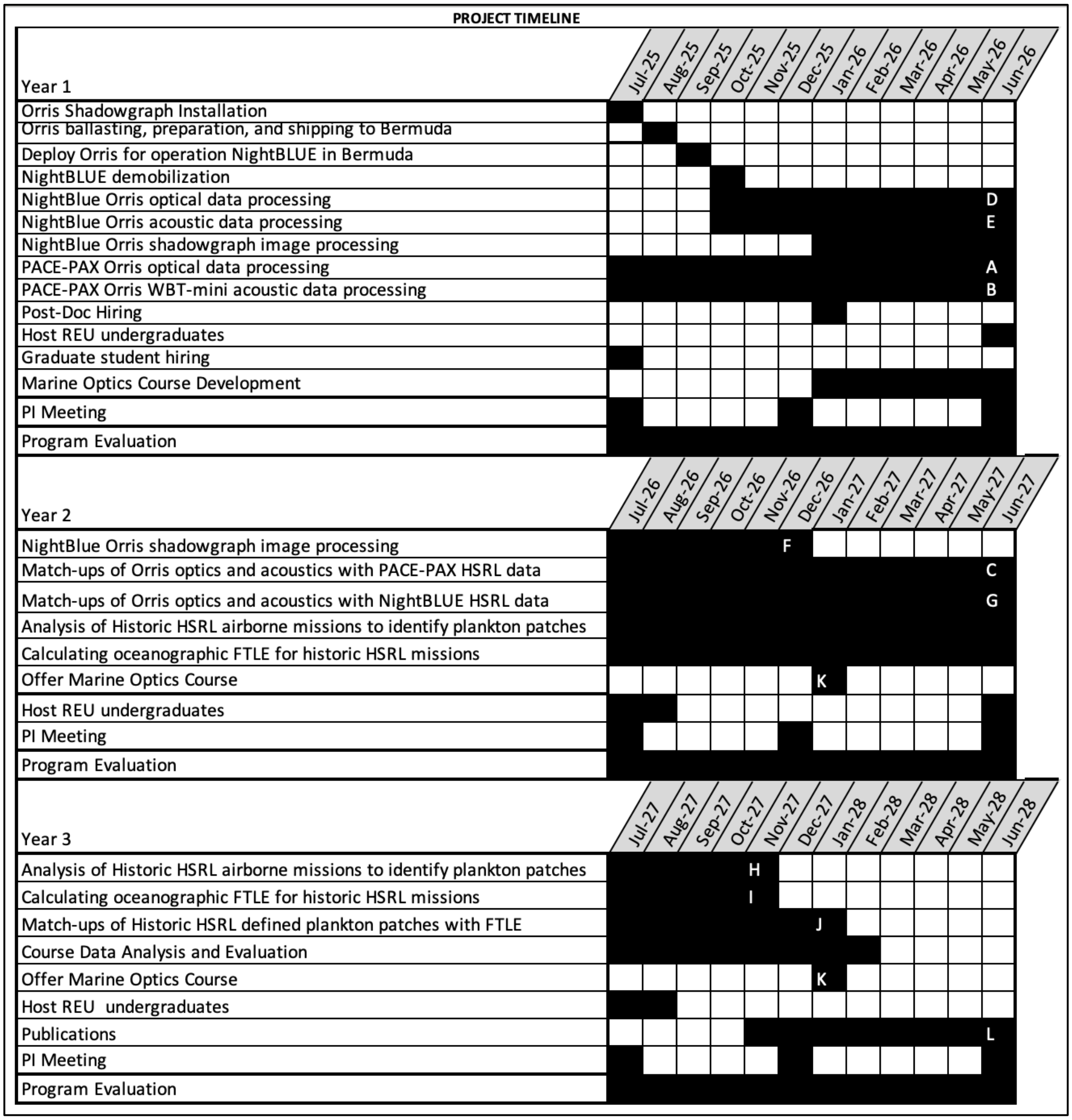
Milestone and Target Dates

In Y1 of this project we expect to complete the following

1. Install shadowgraph on the Orris Glider: Complete
2. Ballast and ship Orris to Bermuda for deployment: Complete
3. Deploy Orris for operation NightBlue with NASA HSRL-2 overflights: Complete
4. Demobilize Night Blue: Complete
5. NightBlue Orris optical processing: Complete
6. NightBlue Orris WBT-mini acoustic data processing: 20% Complete
7. NightBlue Orris shadowgraph image processing: Incomplete
8. PACE-PAX Orris optical data processing: Complete
9. PACE-PAX Orris WBT-mini acoustic data processing: 50% Complete
10. Post-Doc Hiring: Complete
11. Host REU undergraduates: Incomplete
12. Graduate student hiring: Complete
13. Marine Optics Course Development: 10% Complete
14. PI Meetings: Complete
15. Program Evaluation: 15% Complete

A detailed timeline of these, and other goals are in Table 1.

Table 1: Detailed project timeline including field campaigns, processing, course, and program evaluations. Milestone completions are indicated by letters referenced in section



B. What was accomplished under these goals?

Upon the news of funding of this project, we immediately started working on the integration of the Wassoc Shadowgraph with Teledyne Webb Research. Unfortunately, due to unforeseen setbacks there was not enough time to complete the integration before our shipping deadline to Bermuda for project NightBlue. So, we decided to postpone the shadowgraph installation, and instead coordinate with the RV Atlantic Explorer to collect zooplankton samples near the glider during deployment and NASA overflights. These zooplankton collections are a substitute for the zooplankton images the Shadowgraph would have collected during the NightBlue mission. This collaboration was also beneficial for the scientists (Dr. Amy Maas and Dr. Leo Bercial) who are on the NASA PACE Science team. They positioned their ship near the glider, and under the NightBlue HSRL-2 overflights to augment their sampling.

We deployed Orris on September 5, 2025 off of Bermuda. We started with some nearshore transects for night-time overflights of the HSRL-2. We later moved the glider offshore to meet up with the RV Atlantic Explorer for combined day-night operations. The glider was recovered September 26, 2025. The glider was demobilized and shipped back to UD. Zooplankton samples from the RV Atlantic Explorer were preserved and shipped back to UD for imaging.

Specific Objectives

Glider Orris was successfully deployed and recovered for project NightBlue. During this deployment we had 20+ overflights during the day and night of the HSRL-2. We also had two days, and 5 coordinated HSRL-2 overflights of co-located glider and RV Atlantic explorer. This was a significant improvement of overflights from compared to PACE-PAX (2 overflights).

Both the PACE-PAX and NightBlue optical data from Orris are fully processed and ready to be uploaded to public databases. Acoustic datasets for both PACE-PAX and NightBlue are still in process but expected to be completed by June 2026. Our attempts to use public tools did not work, so we have purchased a license to use Echoview, which will significantly speed up the process.

We hired a post-doctoral researcher (George Cutter) who is an expert in marine active acoustics in March of 2026. He is currently focusing on processing the acoustic (Wbt-mini) data sets from PACE-PAX and NightBlue. We also identified a Graduate Student to work on this project.

Preserved zooplankton samples from the RV Atlantic Explorer are beginning to be imaged by a Zooscan system to produce images of dominant taxa during the NightBlue deployment.

After the deployment, we restarted the engineering and integration of the Shadowgraph into the glider. This was completed in April 2026. We are planning an additional glider mission in June 2026 to collect data with the shadowgraph off the coast of Delaware. There is a possibility that NASA will be able to do overflights.

We expect REU students to be active in the lab, working on this project June-August, 2026.

We have started to design the optics course, and plan to offer a semester long course in Spring 2027.

Significant Results

Objective 1

Optical data important for understanding the HSRL-2 system has been processed for the PACE-PAX and NightBlue (Figure 1). Figure 1 shows in-situ particulate backscatter (bbp), which is the main signal that is detected by the HSRL-2 system in the Santa Barbara Channel (PACE-PAX), and in Bermuda (NightBlue). Importantly, these two systems are optically distinct. The

Santa Barbara channel has a high particulate backscatter from 0-25 m depth due to its nutrient rich system, allowing phytoplankton to accumulate. Below 25 m depths, particulate backscatter is likely due to sinking phytoplankton (carbon export) and zooplankton, which are key components for this project. We also have fully processed irradiance data to compute diffuse attenuation coefficients for comparison with HSRL-2. We have also completed depth resolved glider-HSRL-2 match ups (Figure 2). These match-ups are the first ever for comparing in-situ Bbp for the HSRL-2. These initial results have been presented at the Ocean Sciences Meeting in Glasgow in February 2026, and at PACE-PAX Science team meetings.

We continue to make progress on processing the acoustic data from both PACE-PAX and NightBlue (Figure 3). Early efforts to do this processing with free, online tools proved difficult. We have recently resorted to using the commercial software, EchoView. Our post-doc (George Cutter, PhD) will be taking the lead in analyzing both the continuous wave, and frequency modulated data. We also have started imaging the zooplankton collected by the RV Atlantic Explorer (Figure 4) as a substitute for the lack of a shadowgraph on the NightBlue Mission.

Even though we had the setback of not having the shadowgraph on the NightBlue mission as planned, we have now completed the integration, and plan to run an additional glider mission off the coast of Delaware in June 2026 to understand the relationship between the shadowgraph images, and the acoustics.

Objective 2

Nothing to Report

C. As a NASA EPSCoR research infrastructure development project, what opportunities for development has the project provided to the University and the jurisdiction's competitive research capabilities as a whole?

We brought 3 graduate students to Bermuda to gain the skills of operating this specialized slocum glider. They were trained in glider ballasting, piloting, programming, deployment and recovery. These students were also trained on specific techniques for sensor calibration. Once back in Delaware, the students were trained on glider data processing and plotting. One student also participated in the integration and testing of the Shadowgraph instrument at Teledyne Webb Research in Falmouth MA. The student learned how to integrate, operation and understand the shadowgraph images.

D. How have the opportunities and/or results been disseminated to communities of interest?

Initial results from our PACE PAX and NightBlue deployment were presented at a poster at the Ocean Sciences Meeting in Glasgow, Scotland in February 2026.

We have also jointly presented our results to the PACE-PAX team virtually in May 2026 with our collaborators from NASA Langley.

E. What do you plan to do during the next reporting period to accomplish the goals and

objectives?

We will launch a new Glider mission in DE for Year 2

III. Products:

A. List Journal publications – Please only list papers that have been published. **Please do not remove the table; or alter columns, add additional rows as required.**

Date Published	Published Paper (APA format)

B. List Conference Papers – Please only list papers that are included in conference proceeding. **Please do not remove the table; or alter columns, add additional rows as required.**

Conference Date	Conference Paper (APA format)

C. List Conference Presentation – Please list conference presentation. **Please do not remove the table; or alter columns, add additional rows as required.**

Conference Date	Presentation Topic (APA format)
February, 2026	Yuleny Gomez Rodriguez[1], Brian Collister[2], Johnathan W Hair[2], Chris A Hostetler[2], Taylor Shingler[2] and Matthew J Oliver[1], (1)University of Delaware, College of Earth Ocean and Environment, Newark, United States, (2)NASA Langley Research Center, Hampton, VA, United States, Comparison of Glider and Airborne LiDAR Estimates of Particulate Backscatter and Diffuse Attenuation Profiles in the Santa Barbara Channel. Ocean Sciences Meeting, February 2026, Glasgow, Scotland

D. List Books and/or other Publications – Please include explanations, help us to learn about your accomplishments. **Please do not remove the table; or alter columns, add additional rows as required.**

Date	Explanations (APA format -Book, Newspaper Op-Ed, …)

E. List talk/presentation/event/outreach activity – Please include explanations, help us to learn about your accomplishments. **Please do not remove the table; or alter columns, add additional rows as required.**

Date	List talk/presentation/event/outreach activity (APA format if applicable)
May, 2026	Matthew J. Oliver[1] Jonathan H. Cohen[1] Yuleny Rodriguez Gomez[1] Rebecca Walsh[1] Rachel Lazzaro[1], George Cutter[1] Brian Collister[2], Johnathan Hair[2], Chris Hostetler[2], Taylor Shingler [1]University of Delaware [2]NASA LARC. PACE-PAX Glider Update

F. List of new or updated Website(s) or other Internet site(s). **Please do not remove the table; or alter columns, add additional rows as required.**

URL	Short description of purpose of site

G. Technology/Technique – **Please do not remove the table; or alter columns, add additional rows as required.**

Technology/Technique	Short description of technologies or techniques

H. List patent – Please include Patent Number/Patent Title/ Patent Abstract (or link to it). **Please do not remove the table; or alter columns, add additional rows as required.**

Date Patent Issued	Patent Number/Patent Title/ Patent Abstract (or link to it)

I. List Inventions – Please include Invention Title, List of Inventor(s) and Description. **Please do not remove the table; or alter columns, add additional rows as required.**

Invention Title	List Inventor(s)	Invention Description

J. List Licenses – Please include license issued, Invention Title, List of Inventor(s) and Description. **Please do not remove the table; or alter columns, add additional rows as required.**

Date License Issued	License Assignees	License Title

K. List New/Revised Courses – Please include new/revised courses. **Please do not remove the table; or alter columns, add additional rows as required.**

Course Number	Course Name/Title	Offering Institution

L. Others: List Databases, Physical collections, Audio or video products, Software or NetWare, Models, Instruments or equipment, Data & Research Material (e.g., cell lines, DNA probes, animal models) related to your EPSCoR research. **Please do not remove the table; or alter columns, add additional rows as required.**

Accomplishments title	Short Description of accomplishments

IV. Participants & Other Collaborating Organizations:

A. University Research Team Members (do not include names of minors). **Please do not remove the table; or alter columns, add additional rows as required.**

Name	Project Role	Nearest person month worked	Contribution to Project	Funding Support
Matthew Oliver	PI	1	Co-Science/ Project Lead	UD
Jonathan Cohen	PI	1	Co-Science/ Project Lead	UD
George Cutter	Postdoctoral Researcher	5	Expert in marine active acoustics	UD
Amy Slocum	Non-Technical Staff	1	Evaluation and assessment	NSF EPSCoR/ State of DE/UD

B. NASA Collaborators. **Please do not remove the table; or alter columns, add additional rows as required.**

Name	Title	NASA Center	Nature of the Collaboration
Chris Hostetler	Scientist	Langley	Planning
John Hair	Scientist	Langley	Planning/Field Operations
Brian Collister	Scientist	Langley	Data Processing
Taylor Shingler	Scientist	Langley	Field Operations

C. Industry Collaborators. **Please do not remove the table; or alter columns, add additional rows as required.**

Name	Title	Industry/Company Name	Nature of the Collaboration

D. New non-EPSCoR grants. **Please do not remove the table; or alter columns, add additional rows**

as required.

Funding Entity	Award Name	Value of New Grant

E. Other Organizations Involved as Partners. **Please do not remove the table; or alter the columns, add additional rows as required.**

Organization	Nature of the Collaboration	Benefit of Collaboration	Additional Information
ASU-BIOS/PACE Science Team	Data Collection	Addition of RV Atlantic Explorer to Project NightBlue	The Atlantic Explorer collected zooplankton near the glider during Project NightBlue

V. Changes/Problems

A. Changes in approach and reasons for change.

We could not get the shadowgraph integrated into the glider in time for project NightBlue in Bermuda.

B. Actual or anticipated problems or delays and actions or plans to resolve them.

We instead collaborated with two NASA PACE Science Team members at Bermuda Institute of Ocean Science (BIOS) to collect zooplankton near the glider. Their team benefited from the acoustics on the glider, and the NASA HSRL-2 overflights

C. Changes that have a significant impact on expenditures.

Our post-doc hire (George Cutter) is permanently remote in Maine, also and EPSCoR state. This will slightly change our travel budgets.

D. Significant changes in use or care of human subjects, vertebrate animals, and/or biohazards.

None

E. Change of primary performance site location from that originally proposed.

We adding the pelagic ocean off of Delaware (Mid-Atlantic Bight) as an additional location for science data collection so that we can collect shadowgraph data.

VI. Impact: Stimuli article, attach a high-resolution photo and a one line caption. Obtain permission to publish photo from any recognizable person. ***Do not*** *include photos of minors.*

AUTONOMOUS UNDERWATER GLIDERS ENHANCE MARINE OBSERVATIONS: Advancing Oceanographic Retrievals and Interpretation for NASA Airborne LiDAR Systems. Article by Riley Bell; Photo courtesy of Matthew Oliver. April 27, 2026.

Dr. Matthew Oliver, Patricia and Charles Robertson Distinguished Professor of Marine Science and Policy, and Co-PI Jonathan Cohen, Professor of Marine Science and Policy, at the University of Delaware share a deep fascination with the ocean. In a recent project, they made transformative headway in the area of oceanographic observation by utilizing autonomous underwater gliders. Oceans are vast and difficult to measure at large scales; satellite technologies, particularly NASA's airborne High Spectral Resolution LiDAR (HRSL-2) systems, use lasers to observe the ocean's surface and interior, but they cannot provide a complete picture. After the underwater gliders collect measurements, the limits of using airborne systems alone can be offset by combining atmospheric and in situ observations, extending LiDAR's capability to more reliably map the oceans. Coordinated field campaigns and iterative analysis over the project's course also enhanced the algorithms used to extract key variables from the data, such as optical properties and biological structures. The project strengthened the links among airborne data, in situ measurements, and satellite missions like NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE). It also improved understanding of ocean ecosystems, biogeochemical processes, and water quality, leading to better satellite validation and predictive models. In the long term, these water-penetrating LiDAR systems will be the cornerstone of ocean sensing and surpass current satellite observations.

To learn more about the UD's Ocean Exploration, Remote Sensing and Biogeography Laboratory (ORB Lab), which Dr. Oliver leads, visit https://sites.udel.edu/ceoe-moliver/

PHOTO CAPTION: An autonomous glider is prepared to take in situ underwater measurements.

Project Evaluation:
The Advancing Oceanographic Retrievals and Interpretation for NASA airborne LiDAR systems project funded by NASA EPSCoR involves the University of Delaware and a collaboration with NASA Langley Research Center (LaRC). Evaluation of the project supports effective management by providing feedback on progress and implementation to project PIs. The evaluation used quantitative methods to assess project activities and a strategic implementation plan to track activities goals and milestones (See Appendix 1).

To evaluate the interaction with NASA Langley, we focused on 1) Participation and Engagement, 2) Quality of the Interaction, 3) Outputs and Deliverables, and 4) Impact.

Participation and Engagement were high throughout the project. Teams maintained daily communication during Project Night Blue to coordinate HSRL-2 overflights with glider operations, including real-time alignment of flight paths, sampling strategies, and environmental conditions such as weather and sea state. Beyond intensive field periods, communication has remained consistent, with interactions occurring several times per week and monthly meetings to review and iterate on technical results.

Quality of Interaction was evidenced by highly coordinated and iterative decision-making processes. Daily debriefs during field operations enabled adaptive planning and integration of airborne and in situ observations. The collaboration extended effectively beyond the core teams, including coordination with the NASA PACE Science Team and joint sampling efforts with the R/V *Atlantic Explorer*, which significantly enhanced data quality and scientific value to all participants.

Outputs and Deliverables include multiple high-visibility scientific presentations and contributions to ongoing publications. Results from the PACE-PAX and Night Blue campaigns were co-presented by NASA Langley and University of Delaware personnel (Led by UD Grad Student) at the Ocean Sciences Meeting in February 2026 (Glasgow, Scotland), followed by additional joint presentations in March 2026. Furthermore, the team has been invited to contribute figures to an upcoming NASA publication, reflecting the scientific relevance and quality of the work.

Impact of the collaboration is already evident and continues to grow. The success of coordinated airborne and in situ observations has led to planned additional deployments in June 2026, aimed at enhancing understanding of coupled acoustic and optical signals through integration of the delayed shadowgraph sensor. This momentum also supports potential future deployments and overflights in 2027 in the Mediterranean, in collaboration with NASA and the ESA. The work has attracted broader NASA interest, including visits from NASA Goddard Space Flight Center scientists to the University of Delaware to explore promising results and future opportunities. These developments indicate both scientific impact and the strengthening of inter-institutional partnerships.

Overall, the collaboration has been highly successful, characterized by sustained engagement, effective interdisciplinary coordination, strong scientific outputs, and clear momentum toward future joint initiatives. The project is on target in meeting its stated goals and has expanded opportunities to enhance collaborations and increase research capacity in Delaware and the nation.

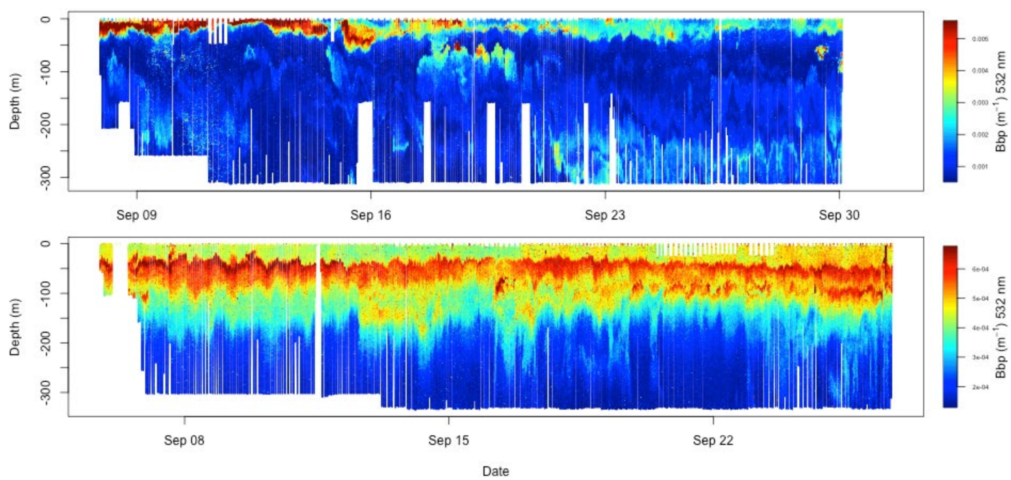


Figure 1: Particulate backscatter (Bbp m^{-1}) at 532 nm is the primary optical parameter needed to characterize the NASA HSRL-2. Here we show processed Bbp measured with the glider Orris during PACE-PAX in the Santa Barbara Channel in 2024 (top) and during NightBlue in Bermuda in 2025 (bottom). The glider dove to ~300 m depth. Bbp during PACE-PAX is about an order of magnitude hire than during NightBlue. This reflects the underlying productivity of the system.

Figure 2: **(Left)** Pooled model-2 regression for four HSRL-2/glider overflights (2 PACE-PAX, 2 NightBlue flights). PACE-PAX are coastal, Case-2 waters while NightBlue are open ocean, Case-1 waters. Match-ups are done at a 2-km spatial and 3-hr temporal scale. NightBlue values are much lower and are in good agreement in the upper 30m. As match-ups get deeper, there is more disagreement. PACE-PAX values are much higher, showing a big difference between flyover 1 (circles) and flyover 2 (triangles). Satellite data suggest flyover 2 was near a sharp optical gradient, which may explain the discrepancy. **(Right)** Waterfall plots for the overflights in the left figure. NightBlue has excellent agreement in the upper 30 meters. Glider values are slightly higher in PACE-PAX. The second over flight in PACE-PAX was near a strong spatial optical gradient.

Figure 3: Acoustic returns from the 200 kHz transducer during PACE-PAX. Higher values indicate more acoustic scatterers (zooplankton). We are making progress on processing this data, but it is not et complete. The bar on top represents day/night (yellow/black). The acoustic pattern strongly suggests a strong diel vertical migration of zooplankton, which will likely interact with the HSRL-2 signal.

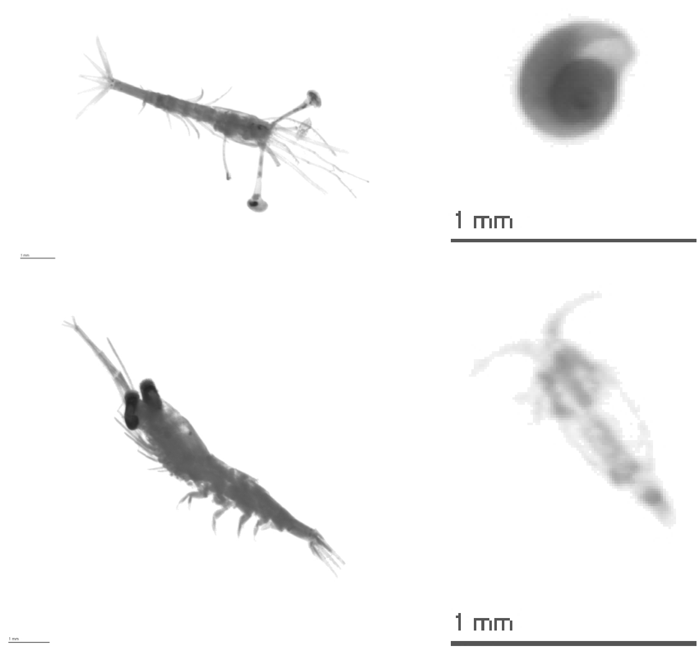


Figure 4: Examples of various zooplankton captured aboard the RV Atlantic Explorer next to the glider, and imaged at the University of Delaware during project NightBlue. Top left is a decapod shrimp, top right is a pteropod, bottom left is a krill, and bottom right is a copepod. Note the difference in scale bars for each image. We will continue to analyze and classify these images to understand the make-up of acoustic scatterers, and how they impact the glider and HSRL-2 particulate backscatter signals.