NASA EPSCoR
Research Performance Final Report (RPPR)
Seed Award

I. Collaborating Organizations

A. Academic Collaborators *(do not include names of minors)*

Name	Academic Affiliation	RID Project Role	Nearest person month worked	Contribution to Project	Funding Support
Yin Bao	University of Delaware	PI	1	PI Bao administered the project, designed and implemented a stereo machine vision system at the research site, and advised a graduate student to manage the data and conduct research.	PI's startup funds
Rodrigo Vargas	University of Delaware	Co-PI	0	Co-PI Vargas maintained the instrumentation at the research site and provided PhenoCam and carbon flux data for this research.	N/A
Puranjit Singh	University of Delaware	Graduate Student	9	Mr. Singh managed the stereo image collection and conducted machine learning	This grant and PI's startup funds

				research for predicting gross primary productivity of the salt marsh using imagery data.	

B. NASA Collaborators

Name	Title	NASA Center	Nature of the Collaboration

C. Industry Collaborators

Name	Title	Industry/Company Name	Nature of the Collaboration

D. New non-EPSCoR grants

Funding Entity	Award Name	Value of New Grant

E. Other Organizations Involved as Partners

Organization	Nature of the Partnership	Benefit of the Partnership
The St. Jones Reserve of the Delaware National Estuarine Research Reserve	In-kind support	Supports electrical power and wireless communication for the deployed instruments.

II. 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)
08/14/2025	Singh, P., Bao, Y., Vargas, R. (2025). Improving machine vision systems for monitoring ecosystem phenology using vision foundation models in salt marsh. *2025 ASABE Annual International Meeting*, July 13-16, Toronto, Ontario, Canada.
10/24/2025	Singh, P., Bao, Y., Vargas, R. (2025). Improving machine vision systems for monitoring ecosystem phenology using vision foundation models in salt marsh. 2025 Delaware Data Science Symposium, October 24, Newark, Delaware, USA. (Statewide EPSCoR Best Poster Award)

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)

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

Issued	

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.**

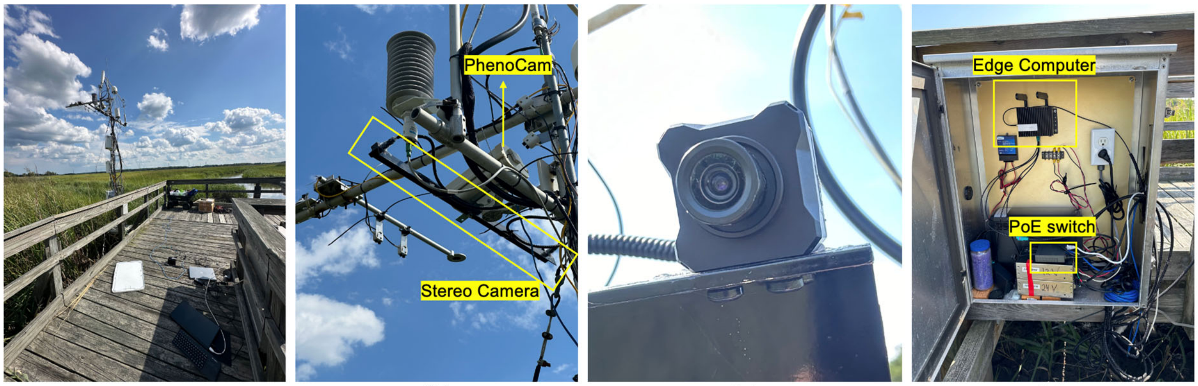
Accomplishments title	Short Description of accomplishments
A stereo imaging system for salt marsh monitoring	**We have developed and deployed a long-range binocular stereo imaging system for salt marsh monitoring.**
Daily RGB-D imagery of salt marsh	**We have collected daily red-green-blue-depth images of the salt marsh at the St. Jones Reserve since mid-October, 2024.**
Manuscript in preparation	**A manuscript is in preparation for submission to *Agricultural and Forest Meteorology* and will be included as one chapter in Puranjit Singh's dissertation. The datasets, models and source code will be released on GitHub in conjunction with the publication.**

III. Changes/Problems

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

During the first half of the project period, we have established a long-term stereo machine vision system on top of the existing salt marsh ecosystem monitoring tower at the St. Jones Reserve (Dover, DE). We also encountered several challenges that delayed our planned data acquisition schedule for two months.

The stereo camera consists of two ZED X One cameras (Stereolabs, CA, USA) with a baseline of 0.82 m between the two cameras. An aluminum L shape extrusion was used to mount the two cameras and prevent bending due to the long baseline. The two cameras were connected to an edge computer (ZED Box, Stereolabs, CA, USA) using 5m GMSL2 cables. With this baseline, stereo camera can allow for a maximum measurement distance of 370 m. Then the stereo camera needs to be calibrated using a checkerboard pattern to obtain the intrinsic and extrinsic camera parameters using the ZED software development kit (SDK). Due to the unusually long baseline, a large checkerboard pattern (0.9×1.2m) had to be used for the two cameras to capture the pattern at the same time at a close distance (3m) in the lab. Many attempts were made to satisfy the various spatial coverage and viewing angle requirements to complete the calibration process. On August 13, the stereo camera system was installed onto the tower with the same viewing angle as the PhenoCam, which was used to monitor the greenness of the salt marsh. The major components of the system are shown in Figure 1. To make the system weatherproof, silicone sealant was used to seal the camera cable connectors and screws on the camera housings. In addition, cable looms were used to protect the camera cables. While the camera system operates at the time of the initial installation, additional time was needed to purchase and install a Power-over-Ethernet (PoE) switch to power the stereo camera system and provide internet access via the cellular modem on the tower. Then a remote desktop was established to access the edge computer from campus.



(a) (b) (c) (d)

Figure 1. (a) Ecosystem monitoring tower at the St. Jones Reserve. (b) Custom stereo camera installed onto the PhenoCam with the same viewing angle. (c) Left Zed X One camera on the stereo camera rig. (d) Edge computer and PoE switch in the power supply box.

Several days after the stereo camera system started collecting images, we noticed that the images were blurry during sunny days (Fig. 2a). The blurred images are not usable for stereo matching and depth image generation. Therefore, we uninstalled the camera system and found moisture in the lenses. Because lenses cannot be removed due to a permanent seal, we heated up the camera under halogen lamps for a week to completely remove the moisture in the lenses. Then we fabricated acrylic enclosures for the two cameras, placed moisture absorbing silica in the enclosure, and sealed the enclosures with silicone sealant (Fig. 2c). Although the moisture issue was resolved, some lighting artifacts showed up in the images due to reflection from other instruments on the tower. Then we used sealant to cover all sides of the enclosure except the front side to minimize the issue (Fig. 2b). Quality daily stereo images around noon were collected starting in mid-October, which is approximately at the middle of the senescent phase.

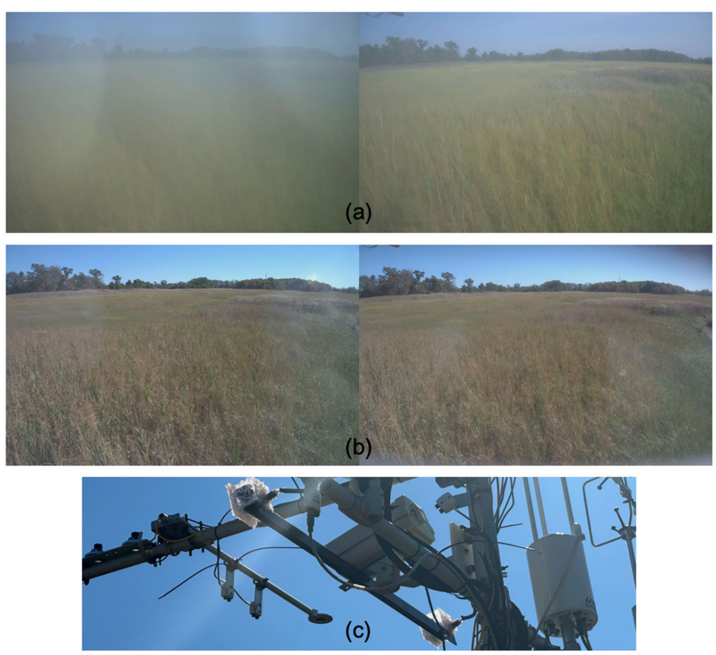


Figure 2. (a) Blurred stereo images due to moisture in the lenses. (b) Clear stereo images after installing weatherproof enclosures. (c) Enclosed stereo cameras.

Our original hypothesis was that depth image-derived canopy structure features can improve the modeling of ecosystem productivity. However, we found weak correlation between these image features and gross primary productivity (GPP) of the Salt Marsh ecosystem. We believe that the depth images were not able to capture fine canopy structure details due to the insufficient spatial resolution of the image resolution and the far distance of the scene. The resulting 3D point cloud shows a smooth surface across the landscape. Therefore, we shifted our focus onto recent advancement in Vision Foundation Models, particularly the DINO models released by Meta AI. DINO can provide high-quality feature embeddings and excel at several down-stream computer vision tasks including image segmentation, image retrieval, and monocular depth image estimation. This suggests that DINO can extract features of both color and 3D structure in the image. We used the DINO feature embeddings as inputs and screen >40 machine learning (ML) models for predicting GPP. This approach achieved high prediction accuracy as shown in Table 1. In contrast, using engineered features from the depth image (generated by DepthAnythingV2) produced poor prediction accuracy.

Table 1. Performance metrics of ML models trained on features extracted from three vision foundation models for GPP prediction.

Vision Foundation model	Best performing ML model	Hyperparameters	MAE	RMSE	R^2
DINOv2	HistGradient Boosting Regressor	min_samples_leaf = 20 max_iter = 100 learning_rate = 0.1	0.96	1.28	0.91
DINOv3	Bayesian Ridge Regressor	max_iter = 300 tol = 0.001 fit_intercept = True	0.75	1.01	0.94
DepthAnythingV2	ExtraTree Regressor	n_estimator = 120 random_state = 0 min_samples_leaf = 1	2.59	3.28	0.44

A no-cost extension was granted to extend the project until February 28, 2026, because we had difficulty recruiting a new graduate student for this project. To address this, one of his PI Bao's current PhD student Puranjit Singh who has other commitment was asked to assist with the project. As a result, this work will be one chapter of Puranjit Singh's dissertation. Co-PI Rodrigo Vargas moved to another institute in Summer 2025. PI Bao took over the operation and maintenance of the entire instrumentation at the research site.

B. Changes that have a significant impact on expenditures

N/A

IV. Impact

Include article and photo w/caption (see instructions). Obtain permission to publish photo from any recognizable person via NASA Media Release Form. Do not include photos of minors.

Coastal Sentinels: Using AI to Map the Carbon Pulse of America's Salt Marshes

Along the fringes of our coastlines, salt marshes perform a silent, high-stakes miracle. These "blue carbon" ecosystems sequester carbon dioxide at rates up to ten times faster than mature tropical forests. Yet, for decades, we have struggled to measure exactly how much carbon they capture across vast, shifting landscapes. Traditional monitoring tools like a flux tower are expensive and difficult to maintain. This research is transforming how we track this natural infrastructure by turning simple webcams into advanced scientific sensors. By pairing a fixed-position camera "PhenoCam" that capture daily snapshots of the landscape with the latest Vision Foundation Models, our team has achieved a breakthrough in ecological monitoring. This AI doesn't just "see" the marsh; it interprets the complex visual patterns of plant health and seasonal change to predict Gross Primary Production (GPP), the total amount of carbon the ecosystem "breathes in". The results are striking: the most advanced models can now predict carbon fixation with 94% accuracy. This technology offers a scalable, cost-effective way to verify the success of federally funded coastal restoration projects. Instead of relying on expensive, labor-intensive field teams for every acre, we can now use intelligent, automated software to monitor our environmental assets in real-time.

Figure 3. Stereo camera installation on a salt marsh monitoring tower at the St. Jones Reserve.