SEER

U.S. OFFSHORE WIND
SYNTHESIS OF ENVIRONMENTAL
EFFECTS RESEARCH

OFFSHORE ENVIRONMENTAL MONITORING WITH PLATFORM-MOUNTED SENSORS

MARCH 2026

BACKGROUND

Collecting observations of environmental conditions and marine life can help scientists understand how the offshore environment is changing and how animals use the ocean and respond to offshore energy infrastructure. Observing animals in offshore locations is difficult because of extreme environmental conditions, high costs of deployment, and logistical challenges associated with installation and maintenance. Finding opportunities to integrate environmental monitoring sensors onto existing offshore systems and platforms can allow for more data collection at lower cost.

New types of remote environmental sensors are being developed to observe seabirds, whales, and other marine life, opening opportunities to advance our scientific understanding of the marine environment and how animals respond to human infrastructure. Sensors can be deployed to measure interactions between the atmosphere and ocean; detect the presence of sensitive, threatened, or elusive species; observe behavior of individual animals; and collect information on many other phenomena. Environmental monitoring sensors have a range of requirements. For example, some sensors measure acoustic properties to listen for animals, others need range of sight to observe thermal or visual signatures, and others sample the chemical composition of water or air. Sensors range in size from small components that can be added to a circuit board to 100-pound systems that need to be mounted on a stable platform.

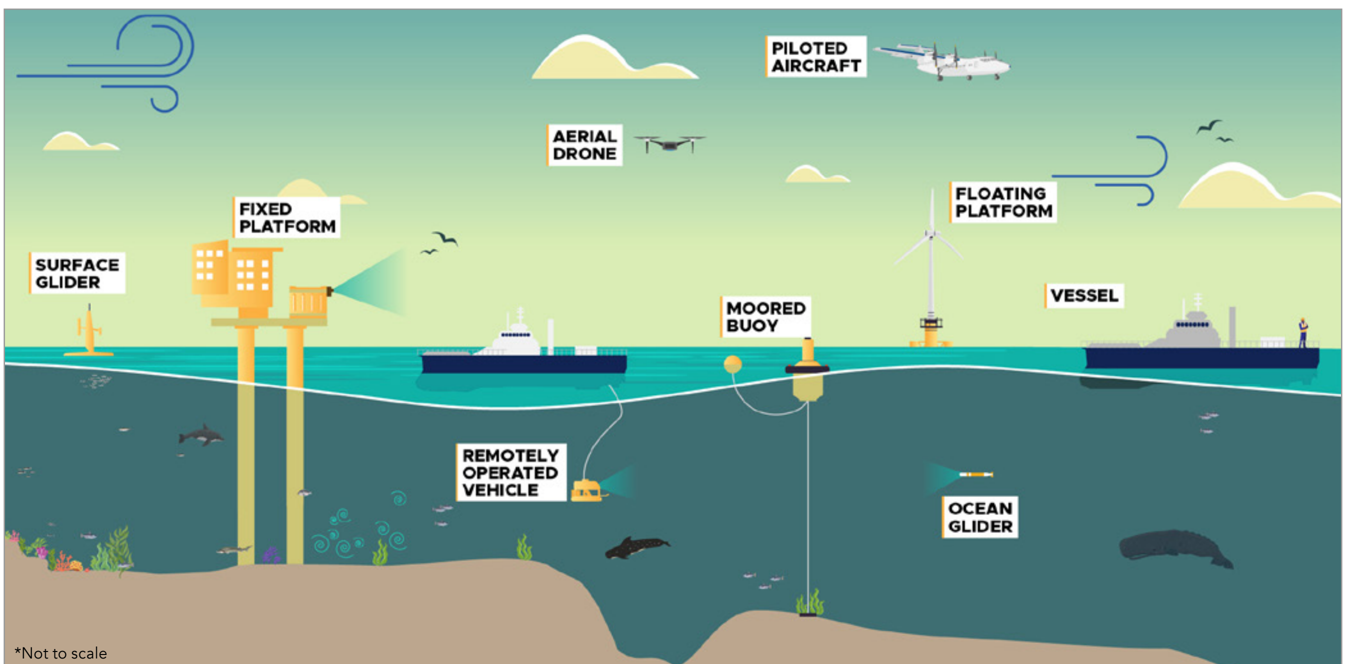


Figure 1. Different types of offshore infrastructure, as shown here, can be used as platforms for environmental monitoring sensors below water, at the surface, or above water. *Illustration by Stephanie King, Pacific Northwest National Laboratory (PNNL)*

Because of the variety of instruments that can be used for remote marine observations (Figures 1 and 2), there is no one-size-fits-all deployment platform. The characteristics, functions, and needs of the sensor must be considered when integrating the sensor with a suitable platform. Some considerations include the sensor's power draw, communication protocol, size, and required field of view.

This research brief describes the primary considerations for selecting an appropriate platform for existing or novel offshore environmental sensors. It is designed to support early decision-making and planning for offshore data collection campaigns and includes descriptions of different platform types and important integration questions to consider throughout the sensor design and/or platform selection process.

PLATFORMS FROM SMALL TO LARGE

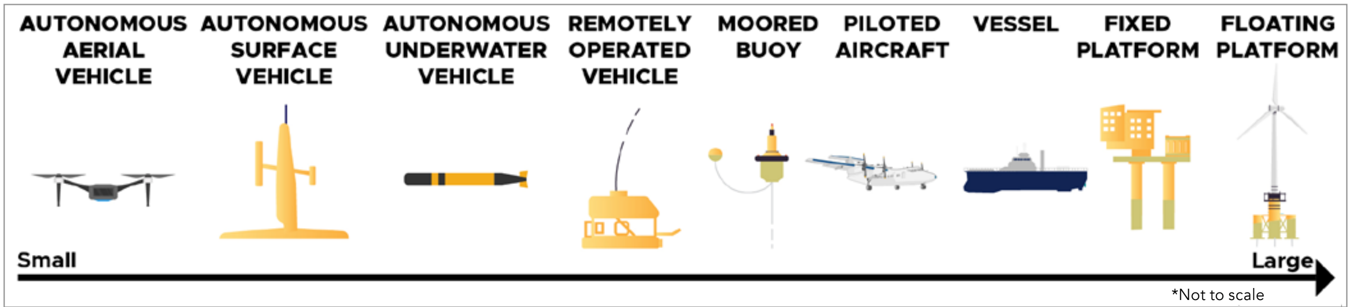


Figure 2. Diverse platform sizes and designs create opportunities for the integration of different types of sensors. The illustrated platforms are ordered generally (but not strictly) from the smallest platforms (left), which can be less than 1 meter (m), to the largest platforms (right), which can be greater than 100 m (graphics not to scale). *Illustration by Stephanie King, PNNL*

Autonomous aerial vehicles (AAVs), or drones, operate without an onboard pilot. Sizes range from very small, consumer-grade (138-millimeter) AAVs to large-scale industrial or military-grade (14.5-m) AAVs. AAVs cover large areas in a short amount of time and can reach places that are risky or inaccessible to humans. AAVs can collect environmental and biological data (e.g., imaging and acoustic recordings) over large areas but are limited to collecting data above water. Operational regulations may limit air space availability and use. Payload capacity (i.e., the number and type of sensors that can be added) is a function of size and weight as well as battery life or fuel capacity, which affects flight time and range. AAVs can be limited by flight time and distance (if line-of-sight is required) or affected by adverse weather conditions. The cost to integrate sensors into AAVs is comparable to the cost of purchase, which ranges from hundreds to thousands of dollars for consumer drones and up to hundreds of thousands of dollars for industrial drones.

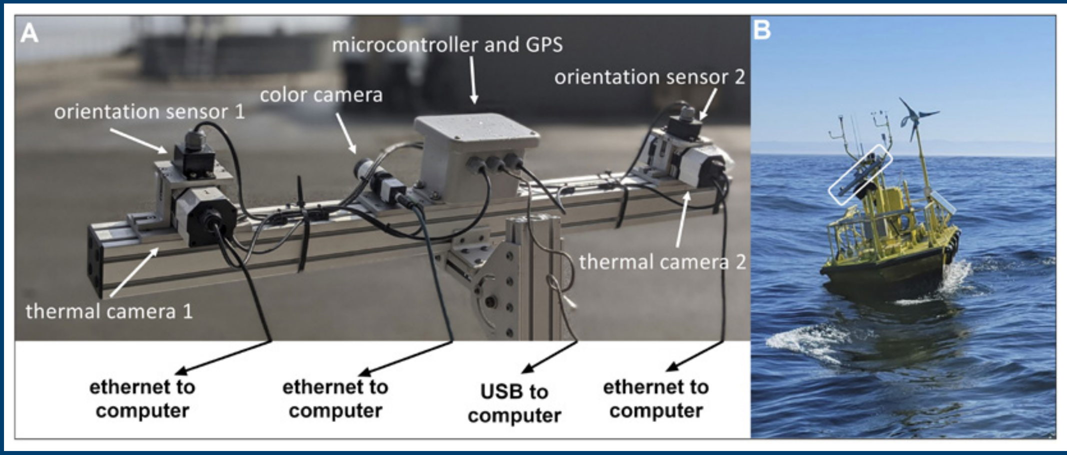
Autonomous surface vehicles (ASVs) operate along the sea surface with external features for power and communication. They can be operated by remote control or pre-programmed to move along a linear path or set of waypoints. Surface gliders are powered by solar, wave, or wind energy or by energy stored in batteries or fuel, allowing for long-term sampling over large distances (hundreds to thousands of kilometers). They can operate in harsh and remote environments, are fast and highly maneuverable, and can collect data above and below the surface. However, surface noise (e.g., sea spray, sound from waves, light scatter) may limit the use or capability of some sensors. Sizes range from small (<1 m) to large (>20 m). ASVs can use satellite links to transmit data in near real time, but most systems cannot support high data transfer rates. Similarly, costs for integrating sensors into ASVs can vary widely from relatively low cost to a comparable cost for purchasing the ASV, which can range from thousands of dollars up to one million dollars.

Autonomous underwater vehicles (AUVs) operate below the sea surface and use propellers, thrusters, or variable buoyancy to move vertically and wings to move horizontally. AUVs can have relatively large spatial coverage (>10,000 kilometers) and temporal coverage (>3 months), but their range and duration are limited by the power capacity of their batteries. They are relatively quiet and generate little flow noise or self-noise during maneuvers (e.g., inflating/deflating the buoyancy pump), but they are slow-moving, with a typical pace of 0.5 to 1.0 knots. Payload capacity can be limited by the size of the AUV, which can range from small (<0.25 m) to extra-large (>2 m). The cost for integrating sensors into AUVs is comparable to the cost of purchase, ranging from thousands to hundreds of thousands of dollars. AUVs can transmit data using satellite links while at the surface, and while some can recharge at offshore docking stations, they typically must return to shore or the support vessel for recharge and data offload.

Remotely operated vehicles (ROVs) are unoccupied underwater vehicles that are connected by a tether, which allows them to be operated by crew at the ocean surface. ROVs typically require a deployment vessel and winch for operation. In some cases, hybrid ROVs can be temporarily disconnected to operate autonomously. ROVs can weigh between 3 and 20 kilograms (kg) for smaller vehicles up to nearly 5,000 kg for larger heavy-duty systems. ROVs can cost tens of thousands to hundreds of thousands of dollars. Because of the expertise required to operate ROVs and their size limitations and limited availability, the costs for integrating sensors into an ROV might range from thousands to tens of thousands of dollars. Complex environments and tether length can restrict movement while pressure resistance can limit depth. Adverse weather can impact surface operations and remote piloting requires specialized training.

Moored buoys are held vertically in the water column via a line or chain attached to an anchor at the seabed. Surface buoys have a platform at the surface while subsurface buoys remain below the surface and may also be mounted to the seafloor. Buoys come in a variety of shapes (e.g., spherical, cylindrical, discus) and sizes (less than 1 m to tens of meters), with costs ranging from one thousand to hundreds of thousands of dollars. Buoys are usually temporary, and—depending on their size—risk biofouling or becoming lost. Moored buoys provide a platform for long-term deployment; however, subsurface buoys or attached monitoring sensors may require release mechanisms for recovery and would not be ideal for short-term monitoring. Moored surface buoys provide an opportunity for cabled data transfer to shore or transmission using satellite links, but transmission can be limited by data transfer rates. Some buoys can provide power to operate sensors. Because of space and access limitations, costs for integrating sensors into a moored buoy are likely to range from thousands to hundreds of thousands of dollars.

Integration Example: Observing Birds and Bats With Thermal Cameras on a Buoy



ThermalTracker-3D (Matzner et al. 2020) is a monitoring technology developed by scientists at Pacific Northwest National Laboratory (PNNL) that uses two thermal cameras to automatically identify the movement of birds and bats, day or night and in any weather condition. ThermalTracker-3D converts a sequence of video frames into a single image that contains an entire flight track, including direction of travel, flight heights, flight speed, and animal wingspan and body length. ThermalTracker-3D can be integrated with offshore platforms such as buoys, substations, or turbines and is suitable for long-term, continuous monitoring, including from airplanes and autonomous aerial vehicles. Schneider et al. (2024) deployed the stereo camera system for a full year in 2021 on a wind-profiling lidar buoy off Humboldt Bay, California, and successfully identified 3D trajectories for 1,407 birds moving between 10 and 500 m from the device. To install ThermalTracker-3D on the buoy, a stabilization system was used to counteract the motion induced from waves. The ThermalTracker-3D was connected to the buoy's onboard data acquisition and communication system to allow remote configuration and data transmission to shore through a satellite link. One important lesson from the deployment was that systems mounted offshore should be fully marinized (designed for use in a marine environment) for long-term performance. Although the stabilization system degraded in the harsh marine environment and failed after 3 months, the camera and computer components performed well throughout the offshore deployment, including surviving a 50-foot wave. *Figure from Schneider et al. (2024)*

Piloted aircraft allow for versatile data collection over large areas that might be otherwise inaccessible from the water. Piloted aircraft range in size from 2.8 to 14.5 m in length and can weigh 300–14,000 kg. Larger aircraft can carry multiple sensors and heavier payloads. However, operations are subject to Federal Aviation Administration regulations and can be limited by weather conditions. Each aircraft has its own limits in altitude, speed, and operational time depending on fuel reserves and distance from the nearest landing strip. There can be large costs involved in chartering aircraft, including time waiting for appropriate weather conditions and the cost of fuel, which likely range from thousands to hundreds of thousands of dollars. High operational costs, even when smaller aircraft are used, often make it prohibitive to use piloted aircraft for smaller projects.

Vessels used for platform construction, maintenance, research and monitoring, and support (e.g., transporting equipment to/from offshore installations, cable-laying, anchor handling, tug and dive support, crew transfer or accommodation, lifeboats, and rescue and evacuation standby) span from relatively small (<25 m) to large (150 m) sizes. Larger vessels can accommodate many sensors in a range of sizes, and with early coordination in the planning process, offshore service vessels may be available as a sampling platform. Vessels of opportunity with predictable routes can provide low-cost, reliable options for collecting data. However, unless the vessel has a consistent fixed schedule, their availability and course may be unreliable, especially for consistent monitoring. While some sensors can be attached easily to a vessel, if modifications to the sensor or vessel are needed or increase the vessel's operating costs (e.g., to maintain a specific speed or route for data collection), costs for integrating sensors could potentially span thousands to hundreds of thousands of dollars. However, deploying sensors on preplanned trips or on smaller, low-cost vessels may substantially lower integration costs.

Fixed platforms are large structures attached to the seabed in shallow and moderately deep waters (<60 m). Because they are permanent, they are more robust against environmental conditions, offer opportunities for long-term data collection, and can support integrated monitoring systems above or below the ocean surface. Fixed platforms, such as monopiles and jacket foundations, are typically used to support offshore wind turbines, electrical substations, oil and gas rigs, and meteorological equipment. Fixed platforms may be cabled, which may allow for power flow to integrated monitoring systems or allow for cabled data transfer to shore. Data transfer for above-water monitoring may also use satellite links, with limited data transfer rates. Issues may arise with data access if the data collected are archival or if the sensors require frequent battery or hard drive replacement. Because of the complexity of accessing platforms or coordinating the integration of sensors into fixed commercial offshore platforms (e.g., safety, labor, logistics considerations), which may require modifications to the sensors and platform, the costs can span hundreds of thousands to millions of dollars.

Fixed Platform Example: Measuring Open Ocean Wind and Waves

Woods Hole Oceanographic Institution's (WHOI) Air-Sea Interaction Tower (ASIT) is 3 km south of Martha's Vineyard, Massachusetts, and has been operating since 2003 as part of the Martha's Vineyard Coastal Observatory. The cabled, fixed platform sits at a water depth of 15 m, extends 23 m above sea level, has 19 ports that provide 6 kilowatts of power, and has a fiber optic cable that allows for high-speed data transfer in real time. A suite of atmospheric and oceanographic sensors hosted by WHOI are available online (https://mvco.whoi.edu). Instrumentation may be added or removed by WHOI or partners depending on the changing needs of the projects supporting the work, such as the addition of biological monitoring equipment in 2024. Data collected by the ASIT are being used by researchers around the United States to advance understanding of atmospheric processes and improve weather forecasting models. *© Woods Hole Oceanographic Institution. This work is reproduced and distributed with the permission of the Woods Hole Oceanographic Institution.*

Floating platforms, such as spar-buoy, semisubmersible, and tension-leg platforms, are designed to float and are anchored into the seabed with mooring lines, typically in deeper waters (>60 m and up to 2,000 m in some cases) where fixed platforms are not feasible. Floating platforms include combinations of flotation and mooring lines stabilized by chains, anchors, tension legs/tethers, ropes, and cables. Because they are mobile, they provide flexibility for exploratory operations or for use in deep-water areas. However, they are more susceptible to environmental forces. Floating platforms may be cabled, allowing power flow to integrated monitoring systems for cabled data transfer to shore. Data transfer for above-water monitoring may also use satellite links, with limited data transfer rates. Issues may arise if data collection needs to remain at one location over a long-term period, if the data are archival, or if the sensors require frequent battery or hard drive replacement. Similar to fixed platforms, the complexity of accessing floating commercial offshore platforms and coordinating sensor integration can cost hundreds of thousands to millions of dollars, especially if the sensor or platform requires modification.

INTEGRATION CONSIDERATIONS

When planning offshore monitoring campaigns, it is crucial to evaluate platform options and constraints during the sensor specification or design phase, as small choices in components could affect the selection of deployment options in the future. Several questions need to be answered early in the sensor design process so that instruments are developed with the characteristics of the end goal in mind. This may include planning the sensor integration during the design and building phase of the platforms themselves (if possible), as this is often easier than integrating sensors after construction. A list of questions that should be evaluated throughout the sensor design and/or platform selection process are listed in Table 1. General platform capabilities are characterized in Table 2.

Table 1. Questions and Considerations Relevant to Platform Selection

Access

- *Will physical access to the platform be necessary during deployment?*
- *If so, how often is access necessary and for how long?*
- *Can the data and sensor configurations be remotely accessed and/or modified?*

Attachment

- *Is there adequate space on the platform?*
- *Are customized attachment mechanisms required?*
- *Is the sensor enclosure designed for expected environmental conditions of the mounting location?*
- *Does the sensor need to be stabilized?*
- *Do multiple sensors or platforms need to be deployed to make the desired measurement?*

Coordination and Safety

- *Are there safety concerns for deployment, maintenance, and retrieval?*
- *Does sensor integration, deployment, and data retrieval require coordination with the platform owner?*

Cost

- *Does installation require expensive infrastructure customization, development, or modification?*
- *Do the deployment, recovery, and/or maintenance costs fit within budget?*

Data Management

- *Do the data need to be processed and analyzed automatically?*
- *Do the data need to be delivered in real time or near real time?*
- *Are there data security issues if data are remotely accessed/transmitted?*

Data Quality

- *Will the structure cause field of view or light interference?*
- *Will structure operations add unwanted noise?*
- *Will environmental conditions affect data collection?*

Power

- *What are the electrical power requirements for the sensor's peak and average demand?*
- *If power is necessary, is a backup power source available?*
- *What is the operating duty cycle of the sensor?*
- *Does the platform's power source meet the sensors power demand?*

Table 2. Capabilities of Different Platforms*

	Deploy Duration	Integration Cost	Platform Size	Potential Space	Motion	Power	Sampling Interface
AAV	Short	Low – Mid	Small – Medium	Less	Controllable	Low	Below
ASV	Short	Low – Mid	Small – Large	Less	Responsive	Low – Mid	Above/At/ Below
AUV	Short	Low – Mid	Small – Medium	Less	Controllable	Low	At/Below
ROV	Short	Mid – High	Small – Medium	Less	Controllable	Low	Below
Buoy	Mid – Long	Mid – High	Small – Large	Less	Responsive	Low – High	Above/At/ Below
Vessels	Short – Mid	Mid	Small – Large	More	Responsive	Low – High	Above/At/ Below
Piloted Aircraft	Short	Mid – High	Medium – Large	More	Responsive	Mid – High	Above
Fixed Platform	Long	High	Small – Large	More	Fixed	Low – High	Above/At/ Below
Floating Platform	Long	High	Small – Large	More	Responsive	Low – High	Above/At/ Below

*Deployment lengths are defined as short (days to weeks), mid (months), and long (1+ year); integration costs are defined as low (hundreds of dollars), mid (thousands of dollars), to high (hundreds of thousands to millions of dollars); platform size is defined as small (meters), medium (tens of meters), and large (hundreds of meters); potential space is defined as less (centimeters to meter) and more (meters); motion is defined as controllable (sensor position can be controlled), responsive (sensor position responds to wave/air motion), and fixed (platform position is stable relative to water motion); and power is defined as low (watts), mid (hundreds of watts), and high (up to a kilowatt or more). Sampling interface refers to the environments the sensors can sample (i.e., above the water/air, at the waterline/air-sea interface, or below the water/underwater).

NEXT STEPS AND CONSIDERATIONS

Once an appropriate platform for offshore monitoring is identified, the next step in planning a data collection campaign is to determine who to contact and when. Early planning and communication are crucial for researchers who wish to deploy an environmental observation or monitoring system. Connecting the platform manufacturers or operators with the technology developers in the early planning stages is also a critical step. All parties should discuss the scope and timeline of the monitoring systems and the platform, including costs, timing, space and power requirements, maintenance, and data access/offload requirements. This may require agreements on the prioritization and timing of tasks as they relate to monitoring versus operation to optimize monitoring that can not only benefit the scientific community but support regulatory compliance.

Additional Resources and Further Reading

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