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Design and Development of a Low-Cost Autonomous Buoy for Seawater Quality Monitoring and Climate Change Adaptation in the Seto Inland Sea

○Zachary WILLIAMS, Manuel SOTO CALVO, Han Soo LEE, Jae-Soon JEONG, Morhaf ALJBER, Nobuhito MORI

This study presents the design, development, and deployment of BOB (Biophysical Ocean Buoy), a low-cost, solar-powered autonomous buoy aimed at monitoring seawater quality and supporting climate change adaptation in the Seto Inland Sea. The buoy collects real-time data on key parameters such as temperature, salinity, and pollutant dispersion, providing valuable insights into marine ecosystem dynamics.

The Seto Inland Sea, an economically and ecologically vital region in Japan is subject to severe challenges due to climate change. Marine ecosystems along with coastal communities are threatened through rising sea temperatures, ocean acidification and changes in salinity. Understanding hydrographic dynamics and monitoring seawater quality in this area are crucial for developing effective risk projections and adaptation strategies.

This study aims to design, develop and deploy BOB (Biophysical Ocean Buoy), a low-cost, solar-powered autonomous drifting buoy, to collect real-time data on seawater parameters and provide insights into pollutant dispersal and biological phenomena in the Seto Inland Sea.

The buoy features a modular architecture prioritizing cost-efficiency, ease of assembly and scalability. The hull of the buoy is constructed from stainless steel weather-resistant casing with an acrylic dome to ensure buoyancy and durability in harsh marine environments. The structure of the buoy is broken down into three main sections: power system, communications system and the sensors and probes. The power system consists of a rechargeable battery combined with solar cells and a charge controller to ensure continuous operation under variable weather conditions while simultaneously optimizing the energy use of the system. The Iridium satellite system is used as the communications module to secure constant and reliable transmission of data packets in real time even in remote marine areas.

Cost-effective, laboratory and research-grade sensors are employed in the construction of the buoy to ensure accurate data. A temperature sensor is used to measure the sea surface temperature at approximately 30cm below the sea surface. Real-time geographic positioning is also measured from the iridium satellite in combination with a module utilizing global navigation satellite systems (GNSS) ensuring the accuracy of the location is 2.0m Circular Error Probable (CEP). Seawater parameters such as salinity, electrical conductivity and total dissolved solids (TDS) are measured using an electrical conductivity probe.

An optimized power management protocol is employed by the buoy to minimize energy consumption and maximize operational duration. The rechargeable battery is sized along with the solar cells to ensure there is a positive energy balance assuming a certain number of sunlight hours. The solar charging maintained battery levels even in low sunlight conditions, and deployment potential was extended by efficient sensor operation and data transmission intervals. A process involving duty cycling is employed to ensure that sensors only operate during data collection intervals and enter a sleep mode or completely power off. Data packets are compressed and sent at regular intervals to minimize satellite communication time. The satellite modem is also configured so that the time it takes to attempt to transmit the data is limited to ensure that poor weather conditions do not undermine the energy saving methods implemented.

BOB was deployed in the Seto Inland Sea for two different trials: in late May and mid-December in 2024 in effort to capture seasonal variations in seawater quality. The deployment site was carefully chosen to ensure there were diverse environmental conditions including areas affected by pollutant inflows and varying current patterns due to tide, wind and waves.

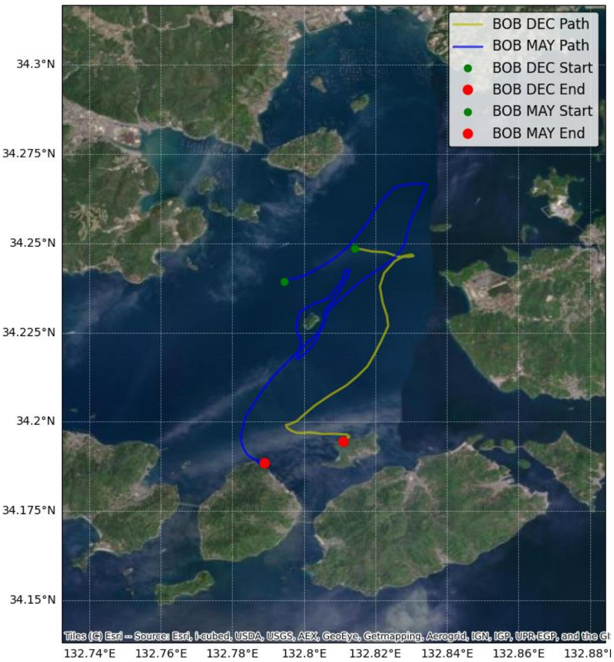

Figure 1. Track of buoy in the Seto Inland Sea for deployment in May and December 2024

The buoy showed effective operation under varying weather conditions including cloudy and rainy days. The tracks of BOB for both May and December were similar as shown in Figure 1. The buoy was deployed in the morning on both occasions and the paths showed change to northerly then southerly direction which is based on changed in the direction of the currents which is seen to occur every 5-6 hours.

High resolution data on temperature and salinity revelead clear spatial and temporal variations reflection some seasonal change in hydrographic dynamics. Figure 2 shows the temperature variation throughout the deployment period for the buoy during the first deployment in May. The highest recorded temperature value was in the afternoon hours and it peaked at 19°C,

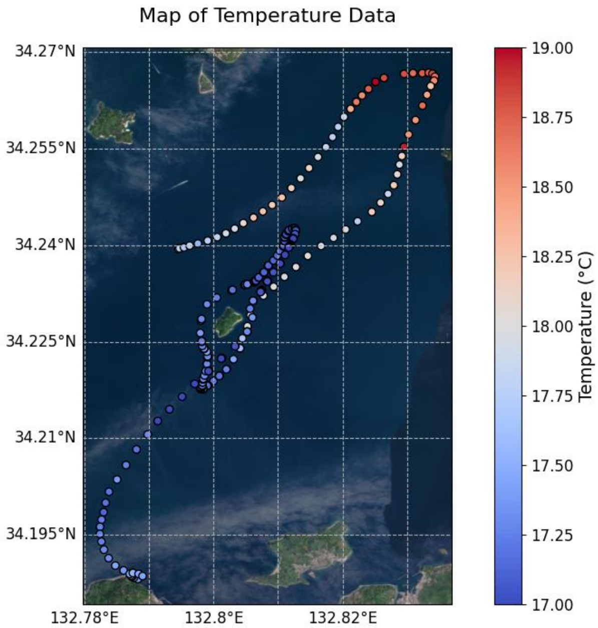

Figure 2. Variation of temperature measured by the buoy in the Seto Inland Sea for the May 2024 deployment

Drift patterns captured by the location data provided valuable insights into polluatant dispersion and potential biomass movement.

This study highlights BOB as a scalable, low-cost solution for monitoring seawater quality and tracking particles, bridging the gap between research and practical climate adaptation measures. Future work includes prolonged deployments to validate long-term performance, integration of additional sensors for expanded data collection and application in other coastal regions to address climate adaptation challenges.