Development of Unmanned Marine Observation Vehicles to Contribute to Forecasting and Monitoring of Typhoon Artificial Control

R&D Item

1. Development of Virtual Mooring (VM) Technology for Stormy Environments

Progress until FY2024

1. Outline of the project

We develop virtual mooring (VM) drone (VMD); sailboat-type uncrewed maritime surface vehicle (USV) that can operate around the center of typhoons and continuously obtain atmosphere-ocean data along their movement based on technologies that enable autonomous navigation and VM driven by winds and ocean currents.

By 2023, we completed to design VM functions and sailboat-type hull, and then conducted tank and coastal sea tests. Finally, we carried open ocean test over the east of the Philippines using the research vessel *Mirai* . We verified hull control via satellite communication, and offshore navigation. In 2024, we conducted the final open ocean test to assess weather resistance under typhoon-level stormy conditions in western North Pacific/ Bering Sea.

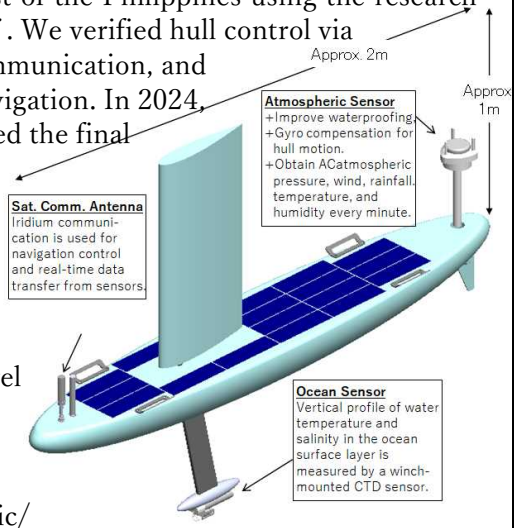

Fig. 1 Overview of the VM drone prototype. Specifications are subject to change by improvement through the project.

2. Outcome so far

1. In the initial fiscal year (2022), we developed VMD prototype #1 based on various test results from the VM drone Prototype 0, including tank tests. Repeated coastal trials led to improvements in hull structure and control software, enhancing navigation performance.
2. In the following year (2023), prototype #2 was developed and deployed in a short-term open ocean test over the east of the Philippines during *R/V Mirai*' tropical Northwest Pacific cruise (June–July), a typhoon generation area. We confirmed hull control via satellite communication, navigation performance, and data transmission. However, due to consistently fair weather during the test period, performance under strong wind and wave conditions could not be assessed.

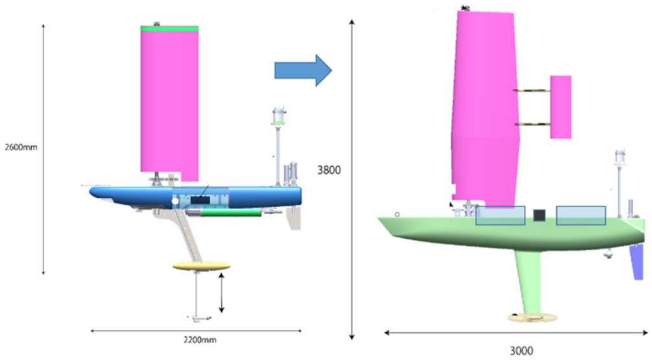

Fig. 2 Comparison of VM drone prototypes—#2 (left) and #3 (right). Improvements in weather resistance and navigation performance were made, and #3 was deployed in the final (2024) open ocean test in the western North Pacific/Bering Sea under stormy condition using *R/V Mirai* cruise

3. In the final fiscal year (2024), prototype #3, featuring an improved weather-resistant design and enhanced navigation performance, was tested during the R/V Mirai western North Pacific/ Bering Sea cruise (October–November) to verify its weather resistance in typhoon-level storm conditions (wind speed > 17 m/s). It demonstrated sufficient hull control and navigation performance, even when tilting sideways up to a rolling angle of 70 degrees.

Fig. 3 VM drone prototype No. 3, deployed during *R/V Mirai* western North Pacific/Bering Sea cruise for weather resistance test under typhoon-level stormy conditions.

3. Future plans

One of the future development challenges is ensuring long-term operation in the vicinity of typhoons. To achieve this, open ocean tests based on autonomous return (recovery) from coastal areas like Okinawa are essential. We will continue part of the development through the K Program.

R&D Item

2. Development of Atmosphere-Ocean Sensors for Stormy Environments

Progress until FY2024

1. Outline of the project

We develop atmosphere-ocean sensors outfitted on virtual mooring drones (VMDs) which provide sufficient accuracy even in stormy environment with large hull motion caused by strong wind and high waves around the center of typhoons and waterproofness enough to withstand temporary submergence and heavy rainfall.

In 2022, atmospheric sensors were waterproofed and then tested in laboratory, water tank, and coastal waters by using VMD prototype #0 and #1. And then, we conducted a short-term open ocean test off the east coast of Philippines during 2023

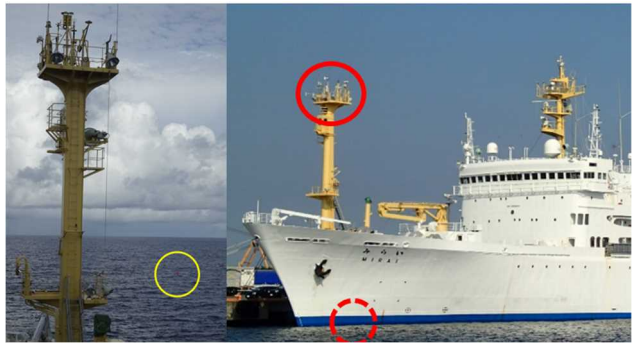

Fig. 1 Locations of meteorological sensors named SOAR (sea surface altitude: 23 m, red solid circle) and surface seawater analyzer (water depth: 5 m) (dashed red circle) equipped with R/V *Mirai* (right). Overall view of the foremast (left) and a distant view of VMD prototype #2 (solid yellow circle) undergoing open ocean test.

R/V Mirai tropical ocean cruise to confirm waterproofing and accuracy of sensors installed on prototype #2. In 2024, we conducted the final open ocean test to assess weather resistance under typhoon-level stormy conditions in western North Pacific/Bering Sea in October-November.

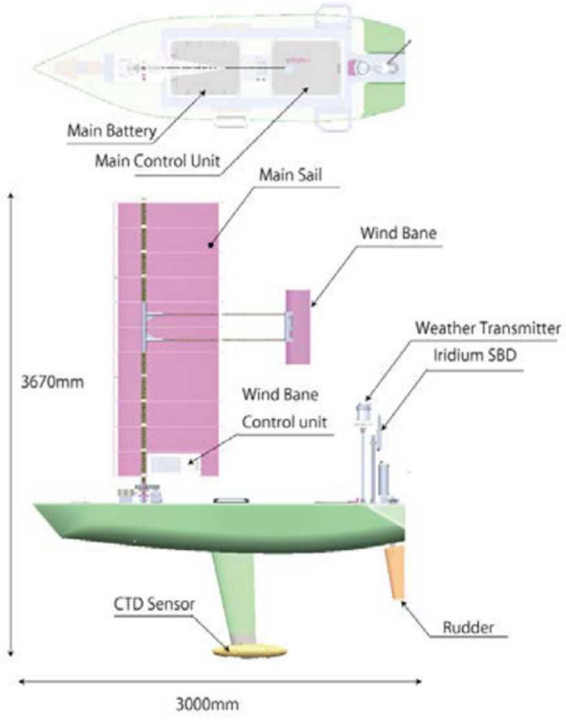

Fig. 2 Atmospheric and oceanic sensor array installed on VM drone prototype #3. Enhancements include a CTD winch for ocean surface layer observations, improved motion stabilization due to a larger hull, and reinforced batteries for increased data transmission density, enhancing real-time monitoring capabilities around the center of typhoons.

2. Outcome so far

1. Atmospheric and oceanic observation sensors were installed on VMD prototype #1 for repeated tests in water tank and coastal waters in 2022, leading to improvements in waterproofing and motion correction methods.
2. Based on previous test results, upgraded sensors were installed on prototype #2 in 2023 for the first open ocean test east of the Philippines during *Mirai'* tropical Northwest Pacific cruise (June–July), most typhoon generation area. Despite relatively calm conditions, comparison with *Mirai's* reference data confirmed sufficiently accurate observations.
3. In 2024, further enhanced sensors were installed on prototype #3 to demonstrate weather resistance in typhoon-level stormy conditions (wind speed > 17 m/s). The final open ocean test was conducted during *Mirai* autumn cruise (October–November) in the western North Pacific/Bering Sea, where extreme stormy conditions were most likely. Even under strong winds and waves causing a rolling angle of up to 70 degrees, the system successfully collected observation data with high accuracy.

3. Future plans

One of the future development challenges is ensuring long-term operation in the vicinity of typhoons. To achieve this, offshore tests based on autonomous return (recovery) from coastal areas like Okinawa are essential. We will continue part of the development through the K Program.

R&D Item

3. Test operation under stormy environment in the tropical northwestern Pacific Ocean

Progress until FY2024

1. Outline of the project

We conduct open ocean tests of virtual mooring drone (VMD) prototypes in the tropical Northwest Pacific Ocean, a region where many typhoons are generated and develop, during R/V *Mirai* cruises to validate hull control, navigation, communication, and accuracy of atmosphere-ocean sensors in stormy condition with strong wind and high waves.

In 2024, to verify weather resistance of VMD in typhoon-level stormy conditions, *Mirai* western North Pacific/Bering Sea cruise was selected, where extreme wind and wave conditions were more likely. International coordination for maritime research and safety measures such as deck operation procedures were prepared, ensuring a secure open ocean test under stormy conditions.

Fig. 1 R/V *Mirai* used for open-ocean tests of prototypes. A-frame crane on the aft deck (blue dashed circle) and other equipment used for deployment and retrieval of the VM drone prototypes. C-band radar (yellow dashed circle) and various atmosphere-ocean sensors equipped with the vessel are used to validate data obtained by the prototypes.

2. Outcome so far

1. In 2023, VMD prototype #2 underwent its first short-term open ocean test east of the Philippines, a key typhoon generation area, during *R/V Mirai* tropical Northwest Pacific cruise (June–July).
2. International coordination was conducted with relevant countries before submitting Marine Scientific Research (MSR) application through the Ministry of Foreign Affairs. Comprehensive safety measures were prepared, including deck operation procedures for deployment and recovery of VMD, ensuring a safe test without losing the prototype.
3. To verify the weather resistance of the further improved VMD prototype #3, the final open ocean test was conducted in 2024 during *R/V Mirai* western North Pacific/Bering Sea cruise (MR24-07 Leg 1, October–November), where typhoon-level strong wind and wave conditions were expected. As in the previous year, thorough appropriate preparation and stringent safety measures ensured a successful test without any incidents.

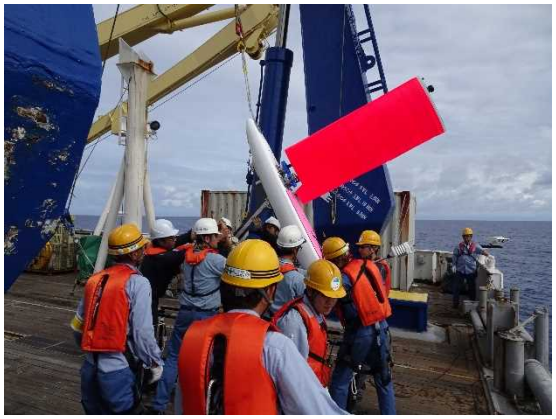

Fig. 2 Deployment of VMD prototype #2 from aft deck to the ocean surface during R/V *Mirai* tropical ocean cruise). After this, it is lifted by blue A-frame crane (Fig. 1) seen on both sides of the photo, and the crane arm is swung out to sea from the aft deck to safely and slowly land on the water.

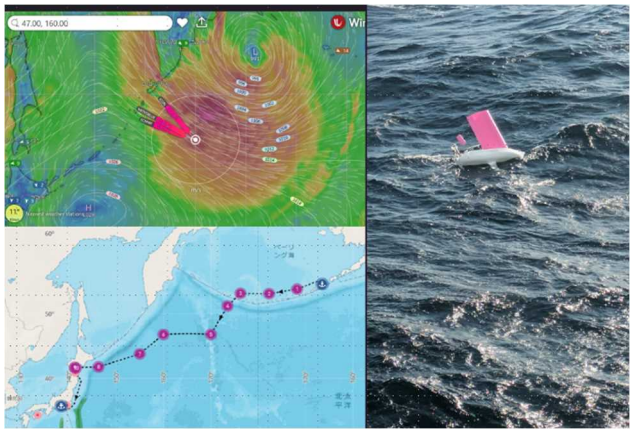

Fig. 3 *R/V Miriai*' 2024 western North Pacific/Bering Sea cruise (MR24-07 Leg 1) used for the final open ocean test (bottom left), wind conditions near the test area (top left), and VMD prototype #3 undergoing testing in strong winds with a rolling angle of up to 70° (right).

3. Future plans

One of the future development challenges is ensuring long-term operation in the vicinity of typhoons. To achieve this, open ocean tests based on autonomous return (recovery) from coastal areas like Okinawa are essential. We will continue part of the development through the K Program.