R&D item

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

Progress until FY2023

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.

In the first year (2022), we designed VM function and sailboat, built prototypes (#0 and #1) and tested them in full-scale tank and coastal waters in Japan to confirm hull strength, sail control, and navigation performance. In the current year (2023), we built protype #2 and conducted the first short-term open ocean test off the east coast of Philippines during R/V *Mirai* tropical ocean cruise to confirm sail control, satellite communication and navigation performance in the open ocean.

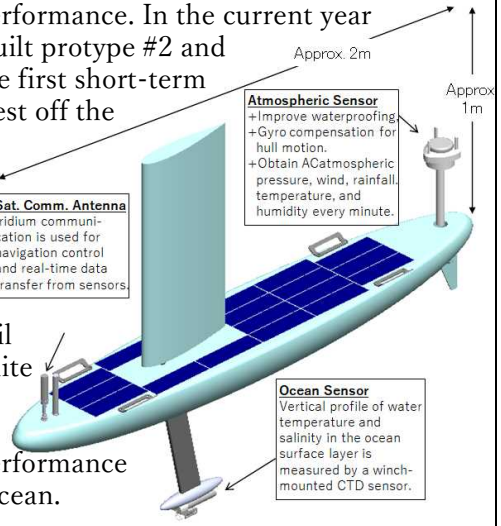

Fig. 1 Overview of the VM drone prototype. Specifications are subject to change by improvement through the project.

2. Outcome so far

1. Based on various test results in 2022, we built prototype #2 to improve hull structure, control software, and navigation performance and then tested it in coastal waters in Japan.
2. After several tests in coastal waters in Japan, we conducted the first short-term open ocean test off the east coast of Philippines in Summer (June-July) 2023 during R/V *Mirai* tropical ocean cruise to examine ship control, navigation performance, and satellite communication for data acquisition.
3. Because we encountered difficulty in ship control which must be due to malfunction with gyros and GPS, we continue to fix problems after the cruise.

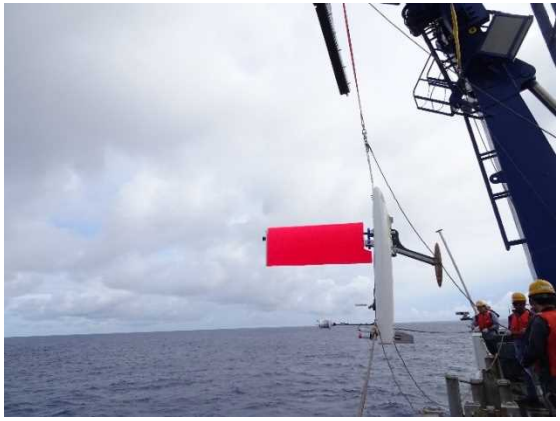

Fig. 2 Deployment of VMD prototype #2 from the A-frame crane (blue structure on the right side of the photo) on the aft deck of R/V *Mirai* during its tropical ocean cruise in the east of Philippines. Before the open ocean test, the hull structure, navigation equipment, satellite communications, and observation sensors are carefully inspected.

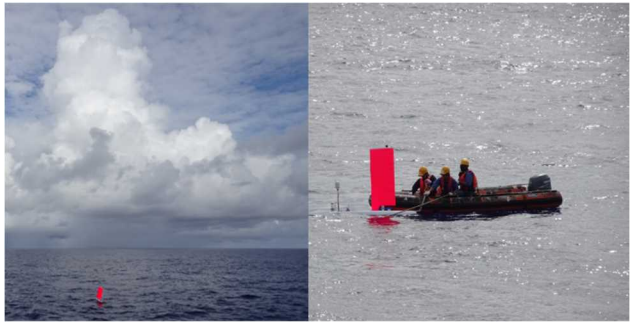

Fig. 3 VMD prototype #2 sailing under developing cumulonimbus clouds off the east coast of Philippines during R/V *Mirai* tropical ocean cruise (left). During the open ocean tests, the prototype #2 controlled from R/V *Mirai* via satellite communications, and simultaneously received both navigation and observation data. After completion of the open ocean test, prototype #2 was towed to vicinity of R/V *Mirai* by observation technicians aboard a Zodiac boat (right) and lifted onto the aft deck by the A-frame crane (Fig. 2), where it was serviced for the next test.

3. Future plans

We will build the final prototype #3 based on the test results in 2023 and test it at open ocean again during R/V *Mirai* cruise in 2024 to confirm ship control, navigation performance, and satellite communication as the final examination. The test was originally planned to be conducted at the tropical ocean in the summer season as same as that in 2023, but we will change the test schedule to *Mirai* Bering Sea cruise in autumn (October-November) because stormy conditions such as strong winds and high waves are expected, which is much suitable for the final test focusing on the weather resistance performance of the VMD.

R&D item

2. Development of Atmosphere-Ocean Sensors for Stormy Environments

Progress until FY2023

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 the first year (2002), atmospheric sensors were waterproofed and then tested in laboratory, water tank, and coastal waters by using VMD prototype #0 and #1. In the current year (2023), we conducted the first short-term open ocean test off the east coast of Philippines during R/V *Mirai* tropical ocean cruise to confirm waterproofing and accuracy of atmospheric sensor installed on #2 as well as oceanographic sensor.

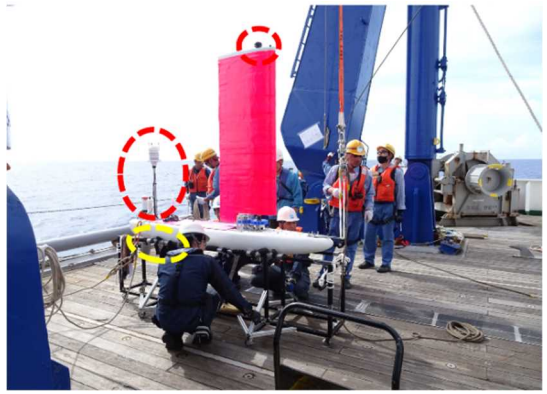

Fig. 1 Refurbished atmospheric and oceanographic sensor (red and yellow dashed circles, respectively) installed with VMD prototype #2 during R/V Mirai tropical ocean cruise. Tose sensors and satellite communication are carefully inspected before deploying the prototype into the ocean.

2. Outcome so far

1. Continuing from previous year, we improved waterproof performance of atmospheric sensor and correction method for hull motion by repeated tests in coastal waters as well as oceanographic sensor (no winch, so far) installed on prototype #2.
2. We made short-term open ocean test off the east coast of Philippines, where is main location of typhoon generation season, during R/V *Mirai* tropical ocean cruise in summer (June-July).
3. Atmospheric and oceanographic data from sensors installed on prototype #2 were obtained successfully, and validated with true values of *Mirai's* observation data. We confirmed that those data were sufficiently accurate though it is limited in relatively calm condition of weak winds (< 10 m/s) and low significant wave heights (about 1 m).

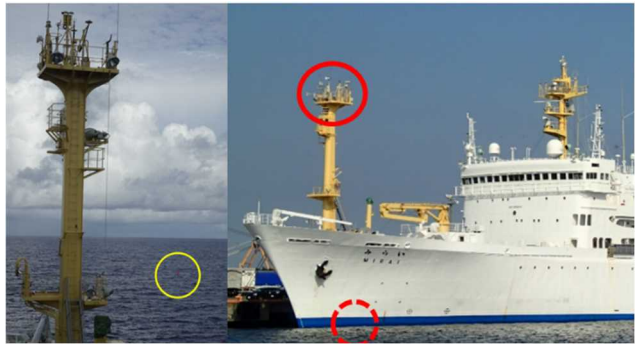

Fig. 2 Locations of meteorological sensors named SOAR (sea surface altitude: 23 m, red solid circle) and surface seawater analyzer (water depth: 5 m) (dashed red circle) equipped with R/V *Mirai* (right). Overall view of the foremast (left) and a distant view of VMD prototype #2 (solid yellow circle)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

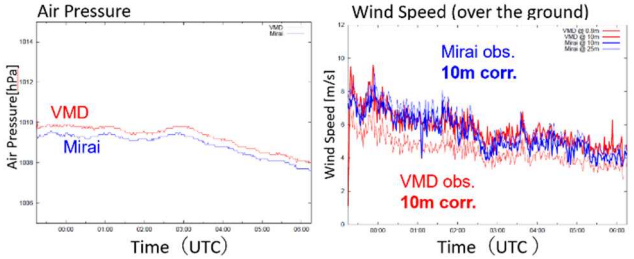

Fig. 3 Comparison of atmospheric observation data obtained by VMD prototype #2 (VMD, red line) and *Mirai* (blue line) (left: air pressure, right: wind speed, July 15, 2023). Air pressure and wind speed are corrected to the sea level and 10 m height, respectively. Both air pressures show almost identical variation and have bias of approx. 0.5hPa. Wind speeds are in agreement with each other within 1 m/s accuracy, but the error trend differs greatly depending on period by period, and its cause is under investigation.

3. Future plans

Based on test results in 2023, we will further improve atmospheric sensor and equip ocean sensor with a winch, and test them at open ocean again during R/V *Mirai* cruise in 2024. The test was originally planned to be conducted at the tropical ocean in the summer season as same as that in 2023, but we will change the test schedule to *Mirai* Bering Sea cruise in autumn (October-November) because stormy conditions such as strong winds and high waves are expected, which is much suitable for the final test focusing on the weather resistance performance of the observation sensors.

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

R&D item

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

Progress until FY2023

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* (Fig. 1) tropical ocean cruises in 2023 and 2024 to validate hull control, navigation, communication, and accuracy of atmosphere-ocean sensors in stormy condition with strong wind and high waves.

In the current year (2023), we successfully conducted the first short-term open ocean test of VMD prototype #2 off the east coast of Philippines during R/V *Mirai* cruise. In addition, we submitted marine scientific research (MSR) application for the final open ocean test in 2024 after international coordination with relevant countries in advance.

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. We conducted the first short-term open ocean test of VMD prototype #3 off the east coast of Philippines in Summer (June-July) 2023 during R/V *Mirai* tropical ocean cruise (Fig. 2) to examine ship control, navigation, sensor accuracy, and satellite communication, etc. (Fig. 3).
2. We established safety procedures on the deck of R/V *Mirai* and ocean, including deployment and retrieval prototype #3 during the test period, and coordinated with research safety committee of the representative institution in advance. As a result, we completed the test without any loss, damage, or accidents.
3. We submitted MSR application, which is required to obtain consent from coastal states if we plan activities in waters under the jurisdiction of foreign state, to MEXT (and then, MOFA) for the final open ocean test in 2024 after international coordination with relevant countries concerning the test in advance.

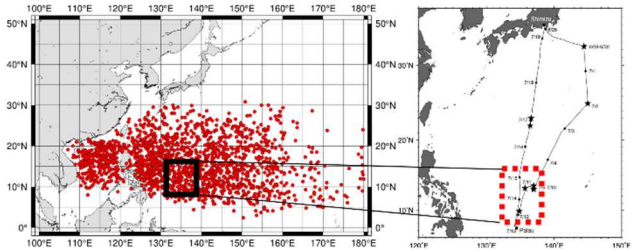

Fig. 2 Climatology of typhoon occurrence locations (red dots), 1951-2021, based on Digital Typhoon*1 (left). Track of R/V *Mirai* topical ocean cruise in 2023 (MR23-05 Leg.1) and stationary points for open ocean test of VMD prototype #2 off the east coast of Philippines (right).

*1 http://agora.ex.nii.ac.jp/digital-typhoon/reference/birthplace.html.ja

Fig. 3 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.

3. Future plans

We will conduct the final open ocean test again during R/V *Mirai* cruise in 2024 with VMD prototype #3 to examine ship control, navigation, satellite communication, and sensor accuracy. The test was originally planned to be conducted at the tropical ocean in the summer season as same as that in 2023, but we will change the test schedule to *Mirai* Bering Sea cruise in autumn (October-November) because stormy conditions such as strong winds and high waves are expected, which is much suitable for the final test focusing on the weather resistance performance.